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This issue has been made possible with the support of Hublot, the Swiss watch brand which has created a timepiece containing all the functions of the Antikythera Mechanism, as they had been published by the Antikythera Mechanism Research Project up to 2008. Since then, Hublot has been involved in the active support of many aspects of the Antikythera research and public understanding, and its R&D department is developing technologies that will assist the archaeological research (and noticeably, the "Bubblot" submarine drone). The company was the main sponsor of the exhibitions in Paris and Beijing in 2011, funded the Antikythera shipwreck exhibition in 2012 at the National Archaeological Museum in Athens, and designed the new Mechanism showcase in collaboration with the Museum. Since 2015, Hublot is supporting the "Return to Antikythera" underwater expedition, which aims to bring back more artifacts from the wreck, and perhaps some missing fragments from the Mechanism that would add to the texts within this publication. We, editors of Almagest, wish to express our thanks to Hublot for their support to this thematic issue. thanks to Hublot for their support to this thematic issue.

Almagest

1
General Preface to the Inscriptions

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Abstract

This is the prefatory paper to a series which presents the surviving text inscriptions on the Antikythera Mechanism. The structure of the mechanism and the history of the reading of the inscriptions are briefly reviewed. The methods used by the Antikythera Mechanism Research Project to image the inscriptions —computed tomography and polynomial textual mapping— are outlined. The layout of the inscriptions is described, and the dimensions of the mechanism deduced to allow the space available for inscriptions to be estimated. General conventions and notations are provided for the presentation of the inscriptions.

1.1 Introduction

The Antikythera Mechanism was a geared device displaying chronological cycles of the Sun and Moon, and motions and phenomena of the heavenly bodies, made somewhere in the Hellenistic world in or before the early 1st century BC[1] Its mechanical components and display facings were made of bronze alloys, while the casing was wooden.[2] Such devices are mentioned in a number of classical sources, sometimes under the figurative name *sphairai* (Latin *sphaerae*) since they functioned as a representation of the cosmic sphere.[3] More recent designation has been as a "planetarium" and a "calendar computer," and while neither expression is entirely adequate by itself, the two taken together provide a good description of the Mechanism's functions. The fragments of the Antikythera Mechanism (Fig. 1.1) were recovered just over a century ago by sponge divers from the wreck of a Greco-Roman ship that sank, probably not long after 70 BC, off Antikythera, a small island between Crete and the Peloponnese.[4] They have been preserved, ever since their discovery, in the National Archeological Museum in Athens. Through the work of many people, most notably Albert Rehm, Derek de Solla Price, Allan Bromley, Michael Wright, and researchers belonging to and collaborating with the Antikythera Mechanism Research Project (AMRP), we currently have fairly secure understanding of a substantial portion of the inner workings as well as the outer displays of the Mechanism.

References to other papers in this series take the form IAM followed by the paper number and, where relevant, section number. Figures are designated by the paper number followed by the figure number (e.g. Fig. 1.1), and there are ten supplementary illustrations designated S1 etc.

1 See Freeth *et al.* 2006 for work up to that date, and continuing bibliography at http://www.antikythera-mechanism.gr/bibliography.

2 Wright 2011, 7-10.

3 See Edmunds 2012, 2014, Jones 2016, Price 1974. "Calendar computer" is Price's final designation (in the subtitle of Price 1974); "planetarium" was proposed by Rehm 1905, 27.

4 For an account of the salvage of the wreck see Throckmorton 1970, 113-168 and Tsipopoulou, Antoniou, & Massouridi 2012.

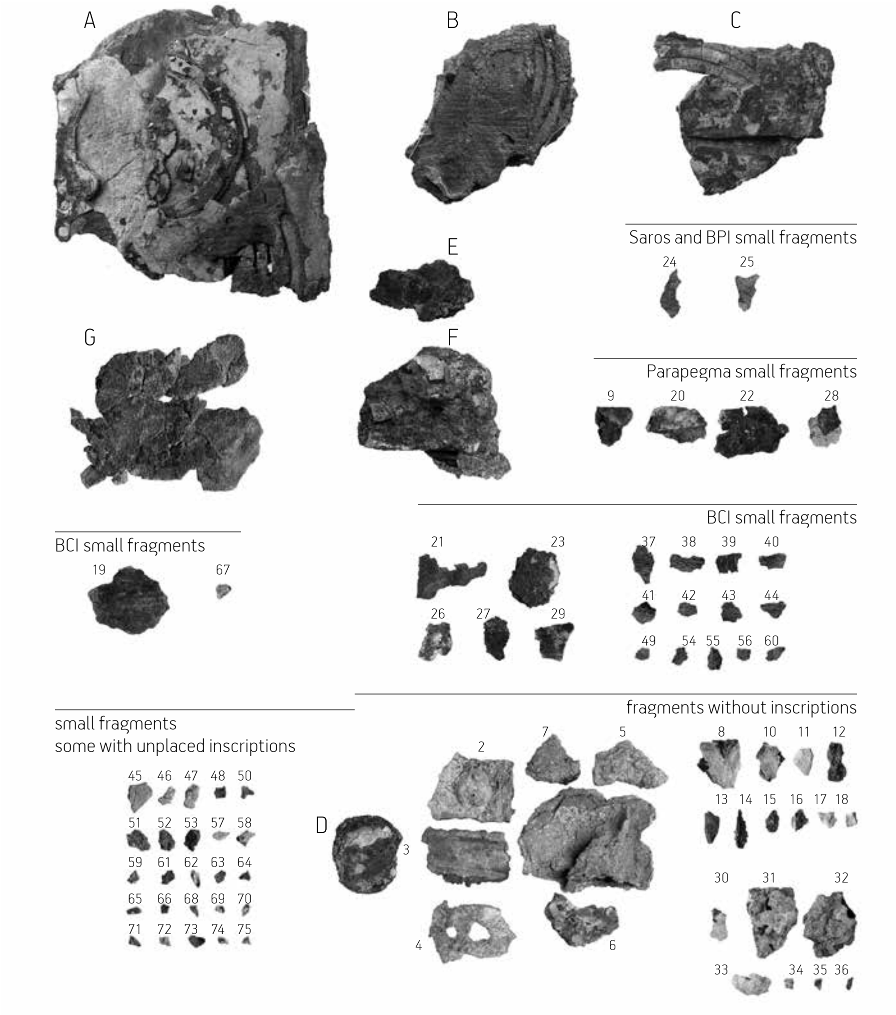


Figure 1.1: *The 82 known fragments of the Antikythera Mechanism (Images: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)*

Its exterior was box-shaped, roughly 330 mm tall, 180 mm wide, and something more than 80 mm from front to back. There has been some disagreement about the structure of its casing, but we believe the physical evidence and other considerations support the description we give here.[5] Fig. 1.2 gives an impression of the exterior (front and back) of the Mechanism, emphasizing the bronze plates which carry the inscriptions.

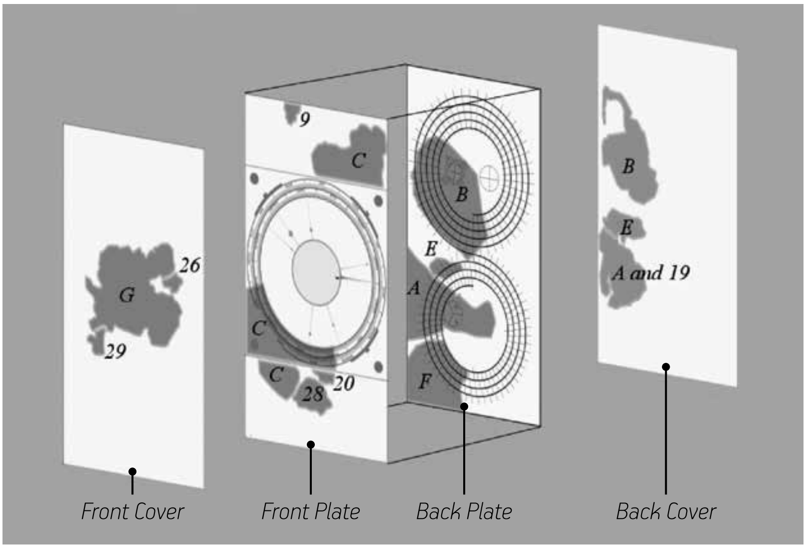


Figure 1.2: *Reconstructed schematic of the front and back plates and covers of the Antikythera Mechanism, omitting the back dial pointers. The view is from the front, assuming transparency through the Mechanism. The letters and numbers indicate the approximate*

5 Price deduced the basic two-face structure of the Mechanism in 1958, having discovered how Fragments A and B fitted together and, less exactly, their original spatial relationship to Fragment C (Price 1959, 62-63). Previous attempts at reconstruction relied on speculation and on erroneous ideas about the fragments' original configuration. Price's 1959 drawing of the reconstructed Mechanism (Price 1959, 62) shows only the inner casing, so that the Back Plate projects some way above and below the casing; subsequently (Price 1974, 17) he proposed a boxlike structure with outer casing enclosing a smaller inner frame for the gears. Recent reconstructions have mostly resembled Price's second design (though not in all details), but M.T. Wright's models, following his interpretation of the remains of the casing visible in early photographs as well as the surviving physical evidence, are more like Price's earlier conception, with the approximately square casing for the gearwork stepped out at its back into a shallow wooden frame that encloses and backs the Back Plate (Wright 2011, 11-12 and fig. 1.1 on p. 1 and 1.2 on p. 4). Reasons for believing that the Mechanism's front face had the same dimensions as its back face are presented in *IAM* 3.

original positions of the surviving fragments
The Mechanism was accompanied by two metal plates that may have functioned as front and back covers that would have been removed to expose the Mechanism's displays. A knob or crank to drive the device projected from the box's right side as seen from the front. The front face was divided vertically into three plates: a square central plate, and above and below it two rectangular plates. Most of the square plate was taken up by a circular dial with multiple pointers radiating from the center to a pair of concentric graduated scale rings, while the rectangular plates had no dials. The rear face, on the other hand, was a single metal plate bearing several dials, with one pointer to each dial. The basic principle of the Mechanism's operation was that the rotary input on the side, probably driven by hand, represented the progress of time — approximately $4\frac{2}{3}$ rotations of the input giving one rotation (representing a solar year) of the Mechanism's largest gear. The pointers revolved around the dials on the front and back faces to show diverse chronological cycles related to the Sun, Moon and the concurrent motions of the heavenly bodies through the zodiac.

The viewer would have also seen Greek texts inscribed on and around the dials as well as on the detached cover plates. These inscriptions were written in tiny capital letters (letter height ranging from about 1.2 mm to about 3.0 mm), similar in style to those used in the Hellenistic period for inscriptions on stone. During the first years following the discovery of the fragments in 1902, the inscriptions attracted as much attention as the mechanical features, for it was hoped not only that their contents would explain the nature of the Mechanism, but also that study of the style of lettering would furnish a dating of the Antikythera shipwreck. Current dating by the epigraphy suggests that it is characteristic of the second half of the second century BC but does not exclude a date as early as say 200 BC or as late as the wreck date**.** Ceramics and coins found in the wreck establish a far more precise date for the shipwreck (and hence at least a *terminus ante quem* for the Mechanism) than paleographical analysis of the Mechanism's inscriptions can offer.[6] But the inscriptions have proved crucial for understanding of the function of the Mechanism: in the first instance by establishing that it was connected with astronomy; subsequently by yielding several key words and numbers that complemented and filled gaps in the physical evidence for reconstructing the gearing; and most recently by clarifying the astronomical and cultural meaning of the data that the Mechanism's dials displayed.

At the outset formidable obstacles stood in the way of reading the inscriptions. What

6 Ceramics: Weinberg et al. 1965, Kavvadias 2012. Coins: Yalouris 1990, Oikonomidou 2001, Tselekas 2012. The current consensus places the wreck around 70-50 BC; datable Pergamene tetradrachm coins set a *terminus post quem* of 76 BC, while the ceramics appear to be characteristic of dates ranging from the 80s through the 50s. On the paleography of the Mechanism's inscriptions see *IAM* 2.3-2.4**.**

survives is a shattered and crushed fraction of the original whole, and all the longer inscriptions are more than half missing, an irreparable loss. Pressure and impacts displaced components and bent and distorted surfaces that once were flat. Centuries of immersion in seawater caused the bronze plates to be corroded to the point that little or no free metal remains, and their surfaces came to be caked over with layers of a hardened mixture of corrosion materials and sedimentary matter. Adjacent components stuck together, concealing inscribed surfaces.

The first efforts to read the texts, made within days of the discovery within the Museum, were limited to a few words and word fragments that happened to be on the outside of pieces that were in more or less the condition that they had come out of the sea. At that time and for many decades after, the only prospect for recovering more text was through physical alteration of the fragments aimed at undoing the sea's work by separating fused components and cleaning off the accreted matter. Such conservation work was carried with noteworthy success in about 1905 and again in 1953. However, large parts of the inscriptions could not be transcribed either on account of surface damage or because they were hidden inside the fragments.

Earlier published and unpublished readings of the texts were superseded by a set of transcriptions published by Price in 1974.[7] Price, whose own knowledge of Greek was slight, obtained the collaboration of the epigrapher George Stamires during his visit to the National Archeological Museum in 1958, and the texts that appear in his monograph are primarily Stamires's work with occasional interventions by Price himself. On the whole this collection represented a considerable advance on anything that had appeared before, with respect to both the quantity of text read and the accuracy of the readings. Nevertheless Price conceded that there were only two of the longer inscriptions of which one could "read and understand more than a scattered word or two".[8]

The research program on the Mechanism begun by A. Bromley and M.T. Wright in the late 1980s and subsequently continued by Wright alone was primarily devoted to study of the physical and mechanical features of the fragments.[9] As well as autopsy, Bromley and Wright carried out together with H. Mangou of the Museum's Department of Physical and

7 Price 1974, 18 and 46-51. For a detailed review of transcriptions preceding the present series of papers, see *IAM* 2.2.

8 Price 1974, 48-49.

9 Wright 2005, 13 n. 10 reports that he and Bromley made limited efforts to read the inscriptions but invited the collaboration of an epigrapher; this epigrapher's work seems not to have been completed.

Chemical Research a series of radiographs of the fragments in 1990.[10] Like the radiographs that H. Karakalos had prepared for Price in 1971-1972,[11] these were made for the sake of revealing the internal mechanical structure of the fragments. To obtain information about the relative depth of components within fragments, stereographic radiography and linear motion tomography (LMT) were employed. As applied to the Mechanism's fragments, LMT involved radiating a fragment while the fragment and the film were moved continuously in such a way that the parts of the fragment lying in a plane appeared in sharp focus in the radiograph while other planes were blurred. Wright, Bromley, and Magou found that the tomographic images were capable of capturing traces of inscriptions both on exposed surfaces and on surfaces embedded within the fragments.[12] Although they were unable to read any of the embedded lines of text, they expressed confidence that, with refined technique, LMT could be applied successfully to the inscriptions.

In 2005 the Antikythera Mechanism Research Project in collaboration with the National Archeological Museum investigated the 82 currently known fragments of the Mechanism with high resolution photography, reflectance imaging (Polynomial Texture Mapping, or PTM) carried out by a team from Hewlett-Packard Corp.,[13] and microfocus X-ray computed tomography (CT) by X-Tek Systems Ltd. (now part of Nikon Metrology).[14] The data and images obtained by these nondestructive techniques greatly enhanced the legibility of the exposed inscriptions, and made it possible for the first time to read writing on surfaces embedded inside fragments. The first publication arising from this project, in 2006, included provisional texts, much more extensive than those of Stamires and Price, of several of the inscriptions.[15] A second paper in 2008 was devoted to the inscriptions on the Mechanism's back dials, only a small part of which had been read by Stamires and Price.[16] Revised and expanded texts of some of the inscriptions, based on the AMRP data, have since appeared in other publications.[17]

The series of papers that the present article introduces contain revised editions and in-depth studies of all the Mechanism's inscriptions. Some (the Front Dial Inscriptions and Parapegma Inscription) have not been revisited in print since Price's 1974 *Gears from the Greeks*; the new editions significantly augment Price's texts with parts of the inscriptions that have

10 Wright, Bromley, and Mangou 1995, Mangou 2012.
11 Price 1974, 12-13.
12 Wright, Bromley, and Mangou 1995, 542.
13 http://www.hpl.hp.com/research/ptm.
14 http://www.xtekxray.com/applications/antikythera.html.
15 Freeth et al. 2006, Supplementary Information 5-14.
16 Freeth, Jones, Steele, & Bitsakis 2008.
17 See *IAM* 2.2.

become visible or legible for the first time through X-ray CT, which has the ability to isolate text in "slices" through the fragments and has contributed several thousand additional text characters. The surviving parts of three other extensive inscriptions, the Back Plate Inscription, the Front Cover Inscription, and the Back Cover Inscription, were transcribed in 2006, but prolonged study of the CT and PTM data gathered in 2005 has led to substantial progress in recovering continuous and intelligible texts for them. The transcriptions in the present series of papers are based almost exclusively on computer-assisted visualization derived from the data produced in 2005. Use of these techniques has made it possible to see the remains of the inscriptions with much greater clarity on a computer screen than can be attained through autopsy or conventional photography. Where inscribed surfaces have been lost or degraded since 1902, however, older photographs and transcriptions have occasionally proved useful as primary evidence for the readings.

The 2006 AMRP paper's discussion and texts of the inscriptions were described as a work-in-progress, with the promise of a more definitive publication in due course, of which the present series is the fulfillment. This prefatory paper appears under the names of nearly all the authors of the 2006 paper (who constituted the original AMRP) along with researchers who joined in the inscriptions research since 2006. This recognizes the fundamental contribution of the collaborators from the National Archeological Museum, Hewlett-Packard, X-Tek, and the original academic team in obtaining the data and the provisional readings on which the new editions and analysis of the inscriptions are built. The remaining papers are authored by the researchers who, studying the relevant inscriptions since 2006, are responsible for the editions, translations, and new interpretations. Mike Edmunds has acted as the independent coordinating editor for the series, and does not claim to have contributed directly to the detailed reading or decipherment of the inscription texts.[18]

18 The plan for the present publication of the inscriptions by the AMRP was agreed in June 2012. One of the original members, Dr. Tony Freeth, subsequently withdrew from that agreement in October 2012 and has published related material independently elsewhere (Freeth 2014). See also the acknowledgements in the present paper.

1.2 Reading the Inscriptions with CT and PTM Imaging

X-ray Computed Tomography (CT) creates a high-resolution 3D density map of a sample. The "density" is not quite material density, although it follows the material density closely, but it more closely follows the electron density, as it is the electrons in the sample which absorb the X-rays. Chemical differences are therefore also shown, with higher atomic number elements like iron, tungsten and gold appearing much denser than, say, aluminum or silicon.

A CT scan builds this 3D density map from a large number of X-ray images, or radiographs, from many different angles, collected as the sample is rotated very slowly on a turntable. In each radiograph the intensity, or grey value, is reduced by the amount and density of material along the line of travel of the X-rays. If the X-ray source is small then the sample can be placed close to the source to create a magnified image on the detector. In this way small details in the sample can be seen in the images. After the scan finishes, the radiographs are reconstructed into a 3D volume which contains 3D pixels, or "voxels" whose grey level represents the X-ray density at that position, the density and path length effects having been separated.

Penetrating large fragments of corroded bronze while still maintaining high resolution require special measures. First the X-rays need enough energy to be able to penetrate a long distance of dense material. Secondly the size of the emission point of X-rays needs to be kept small so that magnified images of the sample remain sharp. The X-ray source used to inspect the fragments of the Mechanism was powerful enough to penetrate 50 mm of solid steel and yet still see details down to 25 microns (0.025 mm). The resolution of the CT scans of the Mechanism's fragments ranged from 40 to 100 microns.[19]

The CT volume is analysed either by rendering it as a 3D object which the user can turn, move, clip and change the lighting on, or by extracting 2D grayscale slice images from the volume at any orientation and position. Since the acquisition geometry is very well known, the size of the voxels is also known to great precision allowing accurate measurements to be taken from the data.

The primary means of visualizing the contents of the CT volumes of the Mechanism's fragments was the software VGStudio MAX (by Volume Graphics). This software enables one to choose any axial direction through the volume and generate two-dimensional grayscale images of planar slices perpendicular to that axis. For examining an inscribed

19 A few brief details of the imaging and computing were given in Edmunds and Freeth 2011, while Ramsey 2012 discusses the CT more fully and includes a non-technical account of the method.

surface, one normally will use an axis perpendicular to the desired region of the surface, adjusting the level of the slice so that it cuts through the engraved traces or the accretion layer that preserve a negative impression of the engraving. The inscribed surfaces are seldom exactly planar, and the clarity of the letters varies unpredictably with the slicing level so that one sometimes gets best results with a "deep" slice near the level of the bottoms of the engraved grooves, sometimes with a slice closer to the plate's surface. Hence one typically sees only a small patch of an inscription clearly at a time, and to read it in entirety requires continual manual adjustments of the settings.

VGStudio Max can also export an "image stack" consisting of many two-dimensional grayscale image files corresponding to a set of uniformly spaced slices perpendicular to a chosen axis. Such a stack can then be viewed as a multilayered image in Photoshop or imported into other CT visualization software such as Osirix.[20] Using Photoshop one can make a manual tracing of the letters visible in the various layers, and by means of careful masking one can also generate a composite image from the most legible parts of different layers, simulating a nonplanar slice that bends with the inscribed surface. Experience shows that a combination of approaches is most productive, with Photoshop providing the most convenient means of reading the bulk of an inscription and preparing publishable images of large regions, while the CT visualization software provides greater control and clarity for the more difficult regions.

CT is the only means of reading letters on surfaces embedded within fragments.[21] It is also highly effective when one is dealing with exposed surfaces that are superficially corroded, since the letter outlines are generally much clearer in slices made deeper within the material. In general it is the technique on which we have relied most. For inscriptions on highly distorted exterior surfaces, however, and for a few fragments whose CT volumes have unsatisfactory clarity, the PTM technique is often preferable.

PTM, or Polynomial Texture Mapping, is currently the primary example of a class of techniques known as "Reflectance Transformation Imaging" or RTI.[22] This method involves photographing an object multiple times, each with a unique lighting direction, but keeping the relative position of the camera and subject fixed. This procedure samples the "reflectance function" of points on the surface of the object, specifically, how the

20 http://www.osirix-viewer.com.

21 The potential of tomographic imaging to reveal embedded inscriptions was first remarked by Wright, Bromley, & Mangou 1995, 542.

22 Malzbender, Gelb, & Wolters 2001; www.hpl.hp.com/research/ptm/ri.html; culturalheritageimaging.org/Technologies/RTI. The PTM data files of the Mechanism may be found at: http://www.hpl.hp.com/research/ptm/antikythera_mechanism/index.html.

color and intensity of those points vary with incoming illumination angle. Once acquired, low order mathematical models are fit to the reflectance functions independently for each pixel, allowing computer software to render the object surface at arbitrary lighting conditions in real time.

In addition, optical reflectance properties of the acquired surface can be transformed to provide renderings simulating material variations. For example, once the predominantly dull, diffuse reflectance of the Antikythera Mechanism fragments is acquired in this manner, it can be transformed to reflectance properties associated with shiny, specular surfaces such as obsidian or metal, allowing greatly improved perception of surface shape. Since these renderings can also be produced in real time, the user is free to vary lighting direction interactively to investigate specific regions of surface shape under these new material properties. This specific surface enhancement method is entitled *specular enhancement*. Other enhancement method variations can also be performed. For example, the technique of *diffuse gain* simply increases the second derivative, or curvature, of the reflectance function in lighting space, keeping the estimate of the surface normal (orientation) fixed. This causes surface appearance to be more sensitive to variations in lighting direction, a useful transformation not available in the physical world. Once again the investigator is free to vary lighting direction interactively in real time, greatly assisting in the perception of surface shape.

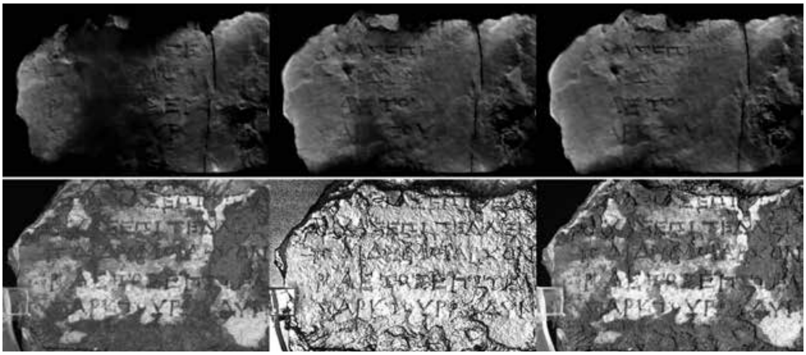


Figure 1.3: *Part of the Parapegma Inscription on Fragment C-1. Top, left to right, three CT "slices" at progressively lower levels relative to the surface of the inscribed plate. Bottom, left to right, PTM visualizations with simulated conventional illumination, specular enhancement, and diffuse gain (Images: Antikythera Mechanism Research Project)*

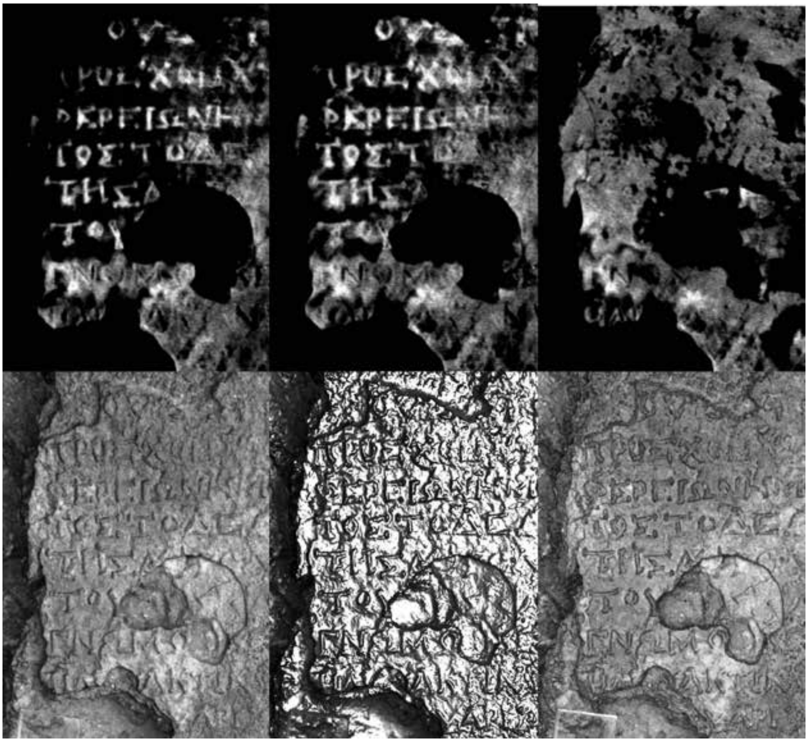


Figure 1.4: *Part of the offsets of the Back Cover Inscription on Fragment B-1. Top: CT "slices" as in Fig. 1.3 top. Bottom: PTM visualizations as in Fig. 1.3 bottom (Images: Antikythera Mechanism Research Project)*

Reading an inscription through PTM is an experience closer to that of traditional epigraphy than using CT, since it involves viewing a simulation of a three dimensional surface under light rather than ghostly outlines of letters in a slice through the material. Letter forms can look surprisingly different in CT, especially if the slice is near the level of the base of the grooves; markings arising from accidental causes can look deceptively like deliberate engraving; and parts of letters may be invisible at any slicing level on account of shallow engraving or surface corrosion. Prolonged practice and relying on more than one pair of eyes are the best protection against misreadings, especially those originating from wishful thinking.

1.3 Nomenclature of the Fragments

The letters A-G and numbers 1-75 used to identify the individual fragments are shown with the fragments in Fig. 1.1.[23] P. Rediadis and I. N. Svoronos introduced the designations A, B, C, and D for the four fragments known by early 1903, and assigned the numbers 1 and 2 to the two faces of each fragment.[24] Except for Fragment E, which was so designated in articles by M. T. Wright in 1997 and the early 2000s,[25] the remaining fragments did not receive a systematic nomenclature until 2005, when M. Zafeiropoulou, cataloguing in the Museum's bronzes storeroom the 79 currently identified fragments that were not on public display, extended the capital letter designations to F and G, and gave numbers from 1 through 75 to the remaining smaller fragments.[26] In the course of the 2005 AMRP data-gathering, the faces of Fragments E, F, G, and 1 through 75 were more or less arbitrarily assigned numbers 1 and 2 for the sake of standard reference. In the present series of papers we will employ the notation (e.g.) 43-2 to designate face 2 of fragment 43.

23 See also: http://www.antikythera-mechanism.gr/data/fragments.

24 Svoronos 1903a and 1903b.

25 Wright and Bromley 1997, Wright 2004, 9, and 2005, 10. Zafeiropoulou gave the same designation to E in 2005.

26 Zafeiropoulou 2012.

1.4 Layout of the Mechanism: Displays and Inscriptions

The identification of four distinct major inscriptions in addition to the various sets of dial scale inscriptions is chiefly due to Price.[27] Since the remains of these inscriptions exist in six of the "major" fragments (designated by letters) and more than twenty small fragments (designated by numbers), and range from just a few characters to extensive runs of partial lines of text, criteria are needed for identifying the inscriptions to which each belonged. These are:

i. Size of lettering and line spacing. As Price pointed out, the major inscriptions are each characterized by a fairly uniform average letter height (measured from the baseline to the top level of most letters) and line spacing (measured from baseline to baseline).[28] This criterion has broad applicability, even with very small fragments.
ii. Characteristic vocabulary. Three of the major inscriptions exhibit largely formulaic verbal patterns that repeat distinctive words and phrases, so that even one partially preserved characteristic word may suffice to identify a fragment's provenance.
iii. Matching of inscribed plate and offset fragments. Three of the major inscriptions survive partly through fragments of the original inscribed plates and partly through fragments of a layer of accretion that preserved mirror-reversed offsets of the lettering. Corresponding regions of plate and offset may be identified by even a few legible letters or parts of letters appearing (aside from mirror-reversal) in exactly the same configuration.[29] Since the lettering on one or the other of a pair of matched fragments may be damaged or obliterated, the existence of offsets can greatly enhance our ability to reconstitute the text. Additionally, some offsets preserve text where the original plate has not survived, or partly overlap two plate fragments, thus establishing their relative positions.
iv. Matching of fragments with photographs. Small fragments that were separated from the major fragments since their discovery in 1902 can sometimes be visually matched with parts of the major fragments in early photographs.

Referring to Figure 1.2, we outline of the Mechanism's displays and inscriptions as they are currently known:

27 Price 1974, 46-51.

28 Price 1974, 47-48.

29 Price 1974, 47, identified the match between Fragment 19 and offsets on Fragment A-2, and integrated the transcriptions from the two witnesses.

1. On the central square plate (Dial Plate) of the Mechanism's front face (*IAM* 3)

Most of the square plate was occupied by a large circular dial surrounded by two graduated scale rings. The Greek names of the signs of the zodiac were inscribed on the inner Zodiac Scale and the Greek names for Egyptian months on the outer Egyptian Calendar Scale, which was manually moveable to accommodate the gradual shift of the Egyptian calendar year relative to the seasons. Pointers revolving around the dial represented the motions around the zodiac of the Sun, the Moon, and the five planets known in antiquity, as well as the date in the Egyptian calendar year.[30] Short texts (single words and letters) were inscribed on the dial rings. The remains of these texts, collectively designated *Front Dial Inscriptions*, are all in Fragment C.

2. On two rectangular plates (Parapegma Plates) above and below the front Dial Plate (*IAM* 3)

These plates were inscribed with the *Parapegma Inscription*, comprising a list of first and last visibilities of stars, which linked to index letters on the Zodiac Scale. During or after the shipwreck they became displaced and ended up lodged between the Front Cover Plate and the Mechanism's front face. The remains of the Parapegma Inscription are in Fragment C and several small fragments (9, 20, 22, and 28).

3. On the dials of the Mechanism's back face (Back Plate) (*IAM* 4)

The largest features of the back face were two large dials, each consisting of a spiral groove, which was originally tracked by the end of a variable-radius pointer-follower. The spiral-shaped strip of plate running along the exterior of the successive turns of the groove was a scale engraved with radial lines dividing it into cells. The upper spiral (Metonic Dial) represented a 19 year Metonic lunisolar cycle of 235 lunar months, and its cells were inscribed with the local names of months and the numbers of years within the cycle. Immediately inside the innermost turn of the groove, numbers were inscribed representing a repeating cycle of 29-day and 30-day lunar months. Within the circular space inside the spiral, a small circular dial (Games Dial) had a pointer revolving once every four years; this dial was inscribed on the inside with the ordinal numbers of the cycle's years, and on the outside with the names of Greek athletic competitions that were held at two-year and four-year intervals. Inside the Metonic Dial to the left, it is conjectured that there was another subsidiary dial (Callippic Dial), showing the 76 years of the Callippic calendar.

The lower spiral dial (Saros Dial) represented a 223 lunar month Saros eclipse cycle.

30 The inscriptional evidence for planetary pointers is discussed in *IAM* 5 and 6.

Some of its cells at five-month or six-month intervals were inscribed with highly abbreviated inscriptions ("glyphs") indicating the possibility that a solar eclipse or a lunar eclipse (or both) could occur at the new or full Moon during the current month. There was also a small circular dial (Exeligmos Dial) in the space inside the spiral, which showed the triple Saros or Exeligmos cycle, with a pointer revolving once every 669 lunar months. This dial was inscribed with numbers involved in the adjustment of the time of day predicted (on the glyphs) for occurrence of the eclipse.

The inscriptions of all the foregoing dial scales are collectively designated *Back Dial Inscriptions*. Those of the upper dials are preserved in Fragment B, the remainder in Fragments A, E, F, 24, and 25.

4. Around the dials of the Back Plate (*IAM* 4)

An extended text (the *Back Plate Inscription*, BPI) was inscribed in the spaces of the back face surrounding the two spiral dials; remains of it are in Fragments A, E, F, 24, and 25. It gives further information about groups of eclipses, referred to by index letters in the glyphs.

5. On the Front Cover Plate (*IAM* 6)

A long text, the *Front Cover Inscription* (FCI), was inscribed on the Front Cover Plate. Its remains, which were attached to Fragment C as it was discovered in 1902, now comprise Fragment G and numerous small fragments (21, 23, 26, 27, 29, 37–44, 49, 54-56, and 60). The text describes the synodic cycles of motion of the five planets relative to the Sun and around the zodiac.

6. On the Back Cover Plate (*IAM* 5)

A long text, the *Back Cover Inscription* (BCI), was inscribed on the back cover plate. It comprises a description of the dials and other features of the Mechanism's front and back faces. Its remains are in Fragments A, B, E, 19, and 67.

7. On interior components and unplaced small fragments

A few isolated letters or numerals are found on components of the Mechanism that would not normally have been exposed to view. These were likely part-identifiers for the benefit of the builder or operator of the Mechanism.[31] These include the following:

31 Price 1974, 20.

On A-2, near the top, an offset letter previously read as H (eta), but probably to be viewed sideways and read as Ξ (xi, numerical value 60) in the form of that letter that has a vertical stroke crossing the three horizontals (Ɨ).[32]

On C-2, near the center of the cylindrical cap feature and again on the lunar phase apparatus about halfway between the remains of the contrate and of the Moon ball, T (tau, numerical value 300).[33]

Inside Fragment D, inscribed on both the single gear preserved in this fragment and on a disk riveted to this gear, ME (mu ..., numerical value 45).[34]

Additionally, there remain a few tiny fragments in the range 45-75 bearing bits of inscription whose provenance has not been identified. These are not included in the present series of papers.

The inscriptions served several distinct functions. The dial inscriptions gave the positions of the pointers immediate meaning, in terms of astronomy and systems of time-reckoning. The pointer positions predicted recurring astronomical and terrestrial events, e.g. eclipses, planetary positions and athletic competitions. Back Plate Inscription and Parapegma Inscription augment the information on astronomical phenomena predicted by the dial displays. The Front Cover Inscription is a more general description of the behavior of the planets displayed by pointers on the front dial, while the Back Cover Inscription helps the viewer to identify the meaning of the displays on both faces of the Mechanism.

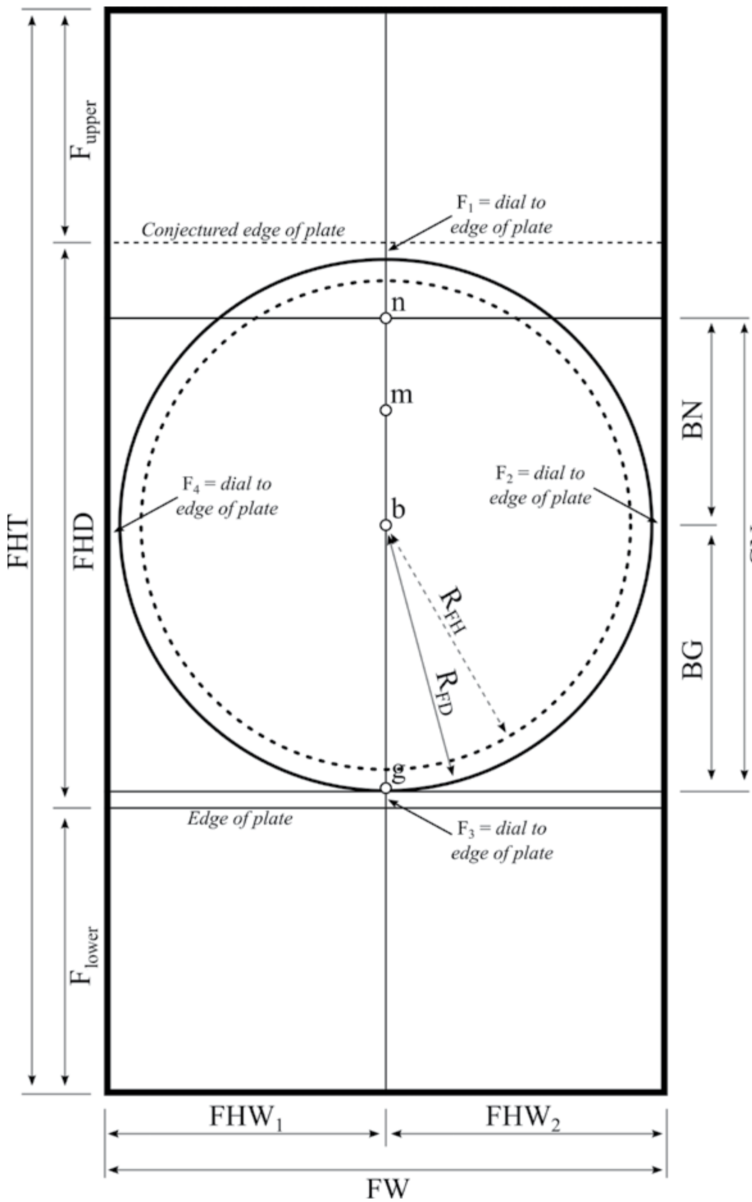
32 The letter was described, fairly precisely, by Rediadis in Svoronos 1903a, 45 (= Svoronos 1903b, 45). Identified as eta by Price 1974, 20.

33 Rediadis in Svoronos 1903a, 47 (= Svoronos 1903b, 46); Wright 2006, 326 figure 8.

34 Freeth & Jones 2012, section 3.6.2.

1.5 The Dimensions of the Antikythera Mechanism

To determine the space available for inscriptions, we combine various measurements to estimate the dimensions of the front and back faces of Mechanism. The nomenclature of the features and distances is given in Fig. 1.5.



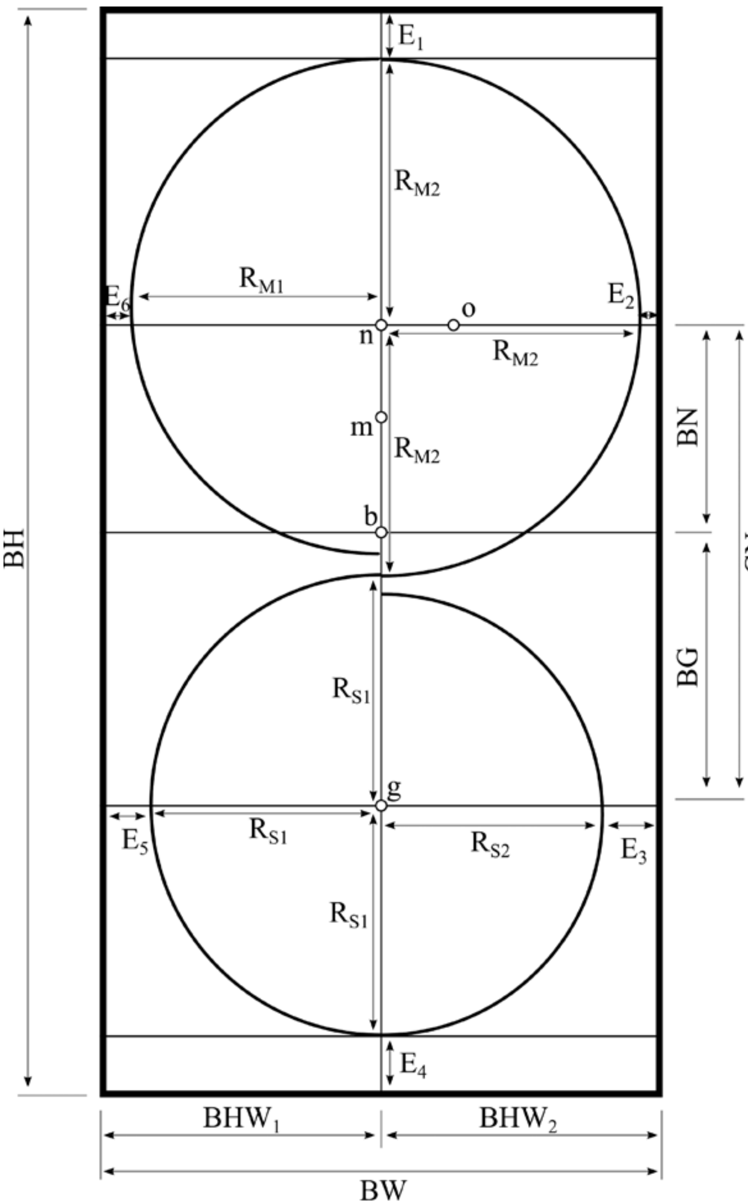


Figure 1.5: *Diagrams for determining the dimensions of the Mechanism's front and back plates*

(1) BG: The distance between the main front dial pointer axis b and the lower back (Saros) dial pointer axis g

Measurement of g to b is possible visually on the rear of fragment A using a calibrated digital photographic image, 02 A-2 4000 (the nomenclature is a series number followed by the fragment and face designation followed by the image's linear pixel size, i.e. 4000 indicates a 4000x4000 pixel image) . The result for BG is 79.5 mm, which agrees exactly with measurement on Price's (1974) Fig. 29, although it is slightly different from the 78 mm he quotes on p. 15, near the foot of the right-hand column. We adopt BG = 79.5 mm.

(2) BN: The distance between the main front dial pointer axis b and the upper back (Metonic) dial pointer axis n

Measurement of b to gear train axis m is possible visually on images of the rear of fragment A as above. The result is 47 mm. The distance between axes m and n (missing from fragment A) can be estimated by the radii of gears from the table of gear sizes in Freeth *et al.* 2006, Supplementary Information. Gear m2 has radius 4 mm, and we assume that the conjectured gear n1 has the same radius (14 mm) as the gear f1 which has the same tooth count. Thus total distance b to n is 47 + 4 + 14 = 65 mm, which agrees exactly with measurement on Price 1974, Fig. 29. We adopt BN = 65 mm.

(3) GN: The distance between the upper back (Metonic) dial pointer axis n and the lower back (Saros) dial pointer axis g

A direct estimate of the inter-axial distance GN is given by adding BG + BN = 79.5 + 65 = 144.5 mm, with an estimated error of ±2 mm. An independent measurement of 143.4 mm has been given by Anastasiou, Seiradakis, Carman, & Efstathiou 2014, although they adopt 150.3 mm for manufacturing a physical model.

We can also make an alternative estimate via o-n and o-g by noting that axes o and n are at the same level vertically. Their distance apart can be estimated on a radiograph (013 B 150 keV; the nomenclature is a series number followed by the fragment designation and the energy of the X-ray source), and setting a scale by assuming the central radii of the Metonic dial slots (see below). Setting the centre of the dial by the circular hole through which the axis passes, the distance o-n is 24 ± 0.5 mm. The measured inner and outer tooth radii of gear o1 (from Freeth *et al*. 2006, Supplementary Information) are 12.2 mm and 13.3 mm respectively, while we expect the corresponding radii of the missing n1 to be 12.5 mm and 13.1 mm by analogy with the existing gear i2 which has the same number (53) of teeth. Adding one inner to one outer radius to mesh gives o-n as 25.5 ± 0.3 mm.

So a reasonable estimate for o-n is 25.0 ± 1 mm. For o-g, a 3D surface model of A2, made from photos by photogrammetry, and calibrated according to radius of e3 = 52.4 mm, gives a distance between the visible centres of g and o as 149.6 mm. But there is also a front-to-back distance between the planes containing the visible centres of g and o, which is estimated (roughly) to be about 14 mm, and this would correct the true in-plane measurement of o-g to $\sqrt{149.6^2-14^2}$ = 148.9 mm. Combining with o-n gives GN = $\sqrt{148.9^2-25^2}$ = 146.8 mm.
We adopt 145.5 ± 2 mm for GN.

(4) Radius of the Metonic dial slots

The structure of the back dials as spiral slots constructed from semicircles was first identified by Wright 2004, and further investigated by Anastasiou, Seiradakis, Carman, & Efstathiou 2014. Price 1974, 15 gives measurements of some of the slots. We have fitted circles to the fragment B visual image 10 B2 4000 and also to an X-ray image (13 B 1500kV). Least-squares fitted circles to the edges of the right-hand slots (as viewed from the back, and requiring that they share a common centre) give the results in the second column of Table 1, with an estimated error of ±1 mm. Estimate can also be made, to about ±2 mm, from Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 9, and (for comparison with previous work) by fitting circles to the reconstruction of the dial in Freeth, Jones, Steele, & Bitsakis 2008, Fig. 15. We use the nomenclature R_{M1}, R_{M3}, R_{M5}, R_{M7}, R_{M9} for the left-hand semicircles' radii (in decreasing size order) and R_{M2}, R_{M4}, R_{M6}, R_{M8}, R_{M10} for the right-hand semicircles.

Our fitting of circles shows that the center of the *right-hand* semi-circle is indeed the axis n, in agreement with Anastasiou, Seiradakis, Carman, & Efstathiou 2014, who call this the "pointer axis."

Table 1.1: *Estimates of the right-hand Metonic Dial slot radii in mm (to center of slot)*

Slot	*Measured radius*	*Adopted radius*
R_{M2}	74	73
R_{M4}	65	65
R_{M6}	58	58
R_{M8}	51	51
R_{M10}	43.3	43

Table 1.2: *Comparison of estimates of the largest left-hand Metonic Dial slot radius in mm*

Slot R_{M2}	This paper: from visual image	Price 1974	This paper: measured from reconstruction in Freeth, Jones, Steele, & Bitsakis 2008, Fig. 15	This paper: from X-ray image	From Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 9
Centre	75	74			
Outer side			73	74.9	76.6
Inner side				73.5	75.5

Our Table 1.1 X-ray measurements of the slot radii imply a regular spacing of 7.5 ± 0.5 mm. This estimate excludes the measured R_{M2}, which appears anomalously large for an assumed regularity of spacing, and—as there may be some mechanical distortion—we have decided to correct this R_{M2} downwards by 1 mm. We adopt R_{M2} = 73 ± 1.5 mm as the central radius of the largest right-hand Metonic slot. The central radius of the largest *left-hand* slot is therefore expected to be 7.5/2 = 3.75 mm less than that of the right-hand slot, giving R_{M1} = 69 ± 1.5 mm.

To summarize, we adopt R_{M1} = 69 ± 1.5 mm, R_{M2} = 73 ± 1.5 mm as the central radii of the largest part of Metonic Dial slot. Slot widths are approximately 1.5 mm. A half-slot width *s* (0.75 mm) must be added to each central slot radius to convert to the outer slot radius.

(5) Radius of the Saros dial slots

This is rather more problematic than for the Metonic dial, since in the visual images the scales appear somewhat distorted (presumably through damage), as was noted by Price 1984, 15, and some distortion is also visible in the CT. We confirm that the axis g is the centre of the semi-circles on the *left-hand* side of the dial (as viewed from the back), as also found by Anastasiou, Seiradakis, Carman, & Efstathiou 2014. We adopt the nomenclature R_{S1}, R_{S3}, R_{S5}, R_{S7} for the left-hand semicircles' radii (in decreasing size order) and R_{S2}, R_{S4}, R_{S6}, R_{S8} for the right-hand semicircles.

Using a stacked CT X-ray image, we have least-squares fitted circles to edges of the slots on the right-hand side of the dial, requiring they share a common center, to an accuracy of about ±2 mm. The results for the largest right-hand slot R_{S2} are given in Table 1.3. Price does not give an estimate of the outer slot, although his inner and outer radii for the sides of the third slot inwards S6 at 52.3 mm and 54.4 mm agree well, within expected errors, with our measurements of 51.9 mm and 53.4 mm.

Table 1.3: *Estimates of the largest right-hand Saros Slot radius in mm*

Slot R_{S2}	This paper: from X-ray image	From Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 10
Outer side	69.8	70.9-72.8
Inner side	68.1	69.7

Our X-ray measurements give the following radii for the outer and inner radii of the right-hand side slots: 69.8, 68.1 for S2; 61.5, 59.9 for S4; 53.4, 51.9 for S6; thus giving centre slot radii of R_{S2} = 69, R_{S4} = 60.7, R_{S6} = 52.7, and an average inter-slot distance of 8.2 mm. The corresponding value from Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 10 is rather uncertain, but of order 9-10 mm. We adopt 8.2 ± 0.5 mm. The radius of the largest *left-hand* slot is therefore expected to be 8.2/2 = 4.1 mm more than that of the right-hand slot, giving R_{S1} =73 ± 2 mm. Anastasiou's value would be around 76 mm, and a measurement from the Figure 25 reconstruction of Freeth, Jones, Steele, & Bitsakis 2008, Fig. 25 gives 71 mm.

To summarise, we adopt R_{S1} =73 ± 2 mm and R_{S2} = 69 ± 2 mm as the central radii of the largest part of the Saros Dial slot. Slot widths are approximately 1.5 mm. A half-slot width *s* (0.75 mm) must be added to each central slot radius to convert to the outer slot radius.

(6) Other Back Plate distances

Measurement on both visual and CT images yields E3 = 15.5 mm as the distance from the outer slot center to the right-hand edge of the back plate. The plate's right-hand-side "half width" $BHW_2 = R_{S2} + s + E3 = 69 + 0.75 + 15.5 = 85$ mm. On the CT the distance from the outer spiral slot edge to bottom of plate is E4 = 12 mm.

(7) Front Dial outer radius

We have used CT images of fragment C, which is the lower left-hand corner (as viewed from the front) of the front dial, to least-squares fit circles to the dial annuli and the ring of 365 holes. The radius of the ring of holes is R_{FH} = 74.0 mm, with an error of ±3 mm estimated from experimenting with fitting the ring in segments. The measured distance between ring of holes and the outer edge of the dial is 7 mm. This gives an estimated radius for the dial of R_{FD} = 81 ± 3 mm, which we adopt. The fitted outer radius of the front dial is 80.5, in excellent agreement. Price estimates 77.2 mm. It is also possible from the CT to estimate the (quite small) distance F_3 between the edge of the outer dial and the bottom edge of the front dial plate, giving F_3 = 1.5 mm.

(8) Back and Front Plate Widths and Heights

We adopt the nomenclature BW, BH for the Back Plate's width and height, FW for the Front Plate's width, FHD for the height of the front Dial Plate containing the dial, and FHT for the total height of the complete Front Plate assembly comprising the Dial Plate and the two Parapegma Plates. If we assume that the plates are rectangular, then:

$$
\begin{aligned}
BW &= BHW_1 + BHW_2 \\
&= E_5 + R_{S1} + s + R_{S2} + s + E_3 \\
&= E_6 + R_{M1} + s + R_{M2} + s + E_2 \\
FW &= FHW_1 + FHW_2 \\
&= F_4 + 2\,R_{FD} + F_2 \\
BH &= E_1 + R_{M2} + s + GN + R_{S1} + s + E_4 \\
FHD &= F_1 + 2\,R_{FD} + F_3 \\
FHT &= F_{upper} + FHD + F_{lower}
\end{aligned}
$$

where F_{upper} and F_{lower} are the heights of the spaces available for the Parapegma Plates above and below the Dial Plate. Filling in the adopted values gives:

$$
\begin{aligned}
BW &= E_5 + 73 + 0.75 + 69 + 0.75 + E_2 \\
&= E_6 + 69 + 0.75 + 73 + 0.75 + 15.5 \\
FW &= FHW_1 + FHW_2 \\
&= F_4 + 162 + F_2 \\
BH &= E_1 + 73 + 0.75 + 144.5 + 73 + 0.75 + 12 \\
&= 304 + E_1 \\
FHD &= F_1 + 162 + 1.5 \\
&= F_1 + 163.5 \\
FHT &= F_{upper} + FHD + F_{lower}
\end{aligned}
$$

The difference between the outer radii of the upper and lower spirals on the back poses the question of whether the vertical line through the pointer axes was *centred* front and back. On the assumption that it was, then $BHW_1 = BHW_2$ and:

$$
\begin{aligned}
BW/2 &= E_6 + R_{M1} + s \\
&= R_{M2} + s + E_2
\end{aligned}
$$

giving

$$E_6 = 4 + E_2$$

and

$$
\begin{aligned}
BW &= 147.5 + 2\,E_2 \\
BW/2 &= E_5 + R_{S1} + s \\
&= R_{S2} + s + E_3
\end{aligned}
$$

giving

$E_5 \quad = E_3 - 4$

$\quad\quad = 11.5$

and

$BW \quad = 138 + 1.5 + 2\ E_3$

$\quad\quad = 170.5$

Combining this with the previous result gives

$E_2 \quad = 11.5$

$E_6 \quad = 15.5$

Rounding, we have BW = 171, with an error of ±3 mm. If centred, then $F_2 = F_4$, so

$FW \quad = 162 + 2\ F_2$

If, and only if, front and back are of equal width, then $170.5 = 162 + 2F_2$ and $F_2 = F_4 = 4$. F_2 and F_4 are rather larger than the measured value of $F_3 = 1.5$ mm, the distance of the bottom of the front dial from the plate edge, but there is no reason (other than neatness) that the top and side spacings should be the same. Hence reasonable estimates for FW lie in the range to 167 to 174 mm, or perhaps 165 to 176 mm when all estimation errors are taken fully into account, with a preferred value around 170.5 mm.

If, and only if, the heights, top and bottom about the axis b, of the back dial are the same as the front dial, then

$BN + R_{M2} + s + E_1 \quad = R_{FD} + F_1 + F_{upper}$

$BG + R_{S1} + s + E_4 \quad = R_{FD} + F_3 + F_{lower}$

Assuming initially that $F_1 = F_3 = 1.5$ mm, then FHD = 165. Hence

$BN + R_{M2} + s + E_1 \quad = 65 + 73 + 0.75 + E_1$

$\quad\quad = 81 + 1.5 + F_{upper}$

so that

$F_{upper} \quad = 56 + E_1$ mm

Again,

$BG + R_{S1} + s + E_4 \quad = 79.5 + 73 + 0.75 + 12$

$\quad\quad = 81 + 1.5 + F_{lower}$

so that

$F_{lower} \quad = 83$ mm.

The minimum value of E_1 can be estimated as the width of the scale (7.5 mm, see discussion above of the Metonic dial slots) plus, say, 1.5 mm (cf. F_3), giving E_{1min} = 9 mm. If E_1 is symmetric with E_4, then E_1= 12 mm. The corresponding values are BH = FHT = 313 mm to 316 mm, and F_{upper} = 65 mm to 68 mm, with estimated errors around ±3 mm. There is no obvious constraint on an upper value for E_1, so these values could be larger.

(9) The "best estimates"

Front and Back plate heights: FHT = BH = 313 mm to 316 mm

Plate widths: FW = BW = 171 mm
Parapegma plates: height available for top plate 65 mm to 68 mm;
height available for lower plate 83 mm; width 171 mm.

Compounded measurement errors on these numerical values are estimated to be of order ±3 mm. If the condition that front and back plates are of identical size were relaxed, then the space available for the Parapegma plates could change; in particular the space could be slightly narrower, but not below 162 mm.

(10) Did the slots of the spiral dials intersect?

The central radius of the largest slot of the Metonic dial is estimated as 73 mm, and the central radius of the largest slot of the Saros dial is also estimated as 73 mm, so their sum is 146 ± 3 mm. Our adopted distance between their axes is estimated as 145.5 ±2 mm. Within the errors, the slots would indeed intersect—although since the slot width is of order 1.5 mm, the errors could allow that their ends did not quite meet. The dial plate might have been slightly mechanically stronger if the slots were not continuous, but there could have been an advantage for a continuous slot in that that driving the pointer-followers a bit too far in the forward-time direction would not stress the mechanism.

Freeth, Jones, Steele, & Bitsakis 2008, Fig. 2 have an interaxial distance ng of 150 mm (cf. our value 144.5), with the sum of the radii of the Metonic and Saros slots as 73 + 71 = 144 mm (cf. our value 146), allowing a distance of 6 mm for a scale between the (un-connected) slots. Their construction is neat, but the required sizes—particularly the interaxial distance—seem to stretch the error levels on our adopted measurements rather far.

1.6 Conventions for the editions

For most of the Mechanism's inscriptions, the editions in this series of papers are the first to employ the full Leiden conventions standard for epigraphical texts[35] and to provide detailed epigraphical apparatus. We use the following notations:

[αβγ]	lost text, editorially restored.[36]
α̣β̣γ̣	unclear letter traces, ambiguous outside their context.
. .	unclear letter traces, insufficient for restoration.
ΑΒΓ	clear but unconstruable letters.
nn	lost numerals.
v	*vacat* (vacant space).
- 14 -	estimated space for 14 lost letters.
—— —— ——	broken top or bottom.

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Enquiries via www.antikytheramechanism.gr/contact/.

35 Van Groningen 1932.

36 In the translations, partially preserved words are bracketed entire if the surviving letters are insufficient to determine the word, and left entirely unbracketed if restorations are certain.

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2
Historical Background and General Observations

Almagest

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Abstract
This paper presents a detailed account of the history of the fragments of the Antikythera Mechanism preserved in the National Archeological Museum, Athens, with particular attention to previous transcriptions and paleographical appraisals of the inscriptions in the fragments. The paper concludes with general observations about the technique and paleography of the inscriptions.

2.1 Modern history of the fragments

The initial discovery and first interpretations of fragments of the Antikythera Mechanism were reported on a day-to-day basis in several Athenian newspapers (Table 2.1).[1] These reports appear generally to have been published the day after they were written or, in the case of evening newspapers, sometimes on the same day. Notwithstanding a few obscurities and inconsistencies, they allow us to reconstruct the story of those days in some detail.

YEAR	MORNING				EVENING		UNKNOWN	
	To Asty	*Skrip*	*Embros*	*Akropolis*	*Neon Asty*	*Estia*	*Eleutheros Typos*	*Sphaira*
1901/7/24	1?	1?						
1902/5/21	1	1						
1902/5/22		1			1	1		1
1902/5/23	1	1		1	2	1		
1902/5/24	1					1	1	
1902/5/25		1	1		1			
1902/5/29	1							
1902/5/30	2							
1902/5/31	2							
1902/6/1				1				
1902/6/4	1							
1902/6/23	1							
1902/6/24	1							
1902/12/13	1							
1902/12/14	1							
1902/12/18	1							

Table 2.1: *Articles in Greek newspapers relating to the discovery of the Antikythera Mechanism's fragments*

1 Partial lists of the reports in Svoronos 1903a, 15-17, note 1 (from second column of p. 15) translated into German = Sovronos 1903b, 15-17, note 1 (from second column of p. 15); Price 1974, 9-10; Fragkou 2010a, 28-35, translated into English = Fragkou 2010b, 27-33. Scans of many newspapers of the time are currently accessible through the websites of the Library of the Parliament of Greece, http://catalog.parliament.gr, and the Greek National Library, http://efimeris.nlg.gr/ns/main.html. Additionally, the database "Archaeological events in Greek press (1832-1932)" of the Aristotle University of Thessaloniki (http://invenio.lib.auth.gr) contains transcriptions of numerous articles relating to the Antikythera wreck and the Mechanism. Some articles are reproduced in Fragkou 2010a, 65-71 = Fragkou 2010b, 62-67, and in Nikoli 2012, 16-87. Among those cited below, Νέον Ἄστυ and Ἑστία were evening newspapers. The available collections of the newspapers have occasional gaps, and I may have overlooked some pertinent articles.

The newspapers credit the discovery of the fragments in the National Archaeological Museum to Spyridon Stais (1859-1932), a representative of the island of Kythera in the Greek parliament who had served from May 27, 1900 to November 25, 1901 (Julian calendar)[2] as Minister of Education in the government of Georgios Theotokis. Stais was not an archeologist; he had studied mathematics and physics and taught mathematics in schools before his political career.[3] As minister, however, he had negotiated the Greek government's support of the salvage of the Antikythera wreck in 1900-1901, and continuing interest in the outcome of this project suffices to explain his visit to the Museum, apparently on Saturday, May 18, 1902 (but possibly on Monday, May 20), together with his wife and sister-in-law, a Miss Vouya.[4] Stais was shown a room where unidentified bronze fragments from the wreck were stored in the hope that they might yield pieces of the so-called "Youth of Antikythera" statue, and among them he noticed two or three objects, described in the reports as "slabs" or "plates" (πλάκες), on the surfaces of which one could see toothed gears and an inscription in mirrored writing. The fragment bearing the gears must have been the one now called Fragment A, while the one with the mirror inscription was surely the present Fragment B.[5] Little or nothing of this inscription was read on that day.

Descriptions of the fragments in less ephemeral and more scholarly Greek publications

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2 The Julian calendar was employed in Greece until 1923. Dates cited here from Greek sources before 1923 are therefore Julian unless otherwise indicated. Their Gregorian equivalents are thirteen days later; e.g. June 1 (Julian) is June 14 (Gregorian).

3 Biography in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 22, 269-270. The contemporary reports are consistent in their identification of the discoverer, typically qualified as "the former Minister of Education" or the like.

4 The first and most circumstantial reports are in *Σκρίπ* no. 2428, May 21, 1902, p. 4 ("Σπουδαία ἀνακάλυψις διὰ τὰς ἀρχαιοτήτας τῶν Κυθήρων"), and *Τὸ Ἄστυ* no. 4139, May 21, 1902, p. 1 ("Σπουδαία ἀνακάλυψις ἐν τῷ Ἐθνικῷ Ἀρχειολογικῷ Μουσείῳ"). In both, the discovery is said to have occurred "yesterday" (i.e. Monday, May 20), and "the day before yesterday" in a report published on May 22 ("Δύο ἐνεπίγραφα τεμάχια ἀπὸ τὰ Ἀντικύθηρα", *Νέον Ἄστυ* no. 162, 2). On the other hand, *Ἑστία* year 9 no. 82, May 22, 1902, p. 4 ("Ἡ πλὰξ τοῦ Μουσείου μας") and *Τὸ Ἄστυ* no. 4141, May 23, 1902, p. 1 ("Ἡ ἐνεπίγραφος πλὰξ τῶν Ἀντικυθήρων") date the discovery to "last Saturday" (i.e. May 18), which may reflect a correction of the information provided to the first reporters.

5 Fragment A is the only one bearing a complex of gears matching the descriptions in the reports in *Σκρίπ* and *Τὸ Ἄστυ*. Parts of the mirror-writing inscription are found on both Fragments A and B, but the part on A was almost entirely concealed by other material as late as 1903, and no one except Rehm seems to have been aware of its existence at this time, or indeed until the time of Price and Stamires in the 1950s. According to the report in *Τὸ Ἄστυ* Stais discovered *three* fragments (while *Σκρίπ* is vague about the number). If correct, these would presumably have been A, B, and C; but this is hard to reconcile with the subsequent report (see immediately below) that a third fragment, apparently C, was found only on May 21.

from 1902 through 1910 (after which the Mechanism fell into neglect for almost two decades) did not mention the circumstances under which they came to notice. Later accounts introduced elements of confusion that continue to infect the secondary literature on the Mechanism. Ioannis Theofanidis (1877-1939),[6] who studied the Mechanism in the 1920s and 1930s, was probably relying on recollections (his own or that of people he consulted) when he wrote in the late 1920s that "the then [*sic*] minister of education, Mr. Sp. Stais [...] by complete chance saw it cast down outside the door of the Archaeological Museum, among many other fragments found there, where the useless bits were put that had been separated from the works of art while they were being cleaned".[7] Price, on the other hand, got the right setting but the wrong protagonist when he wrote in 1959 that "Valerios Stais, an archaeologist at the National Museum, [recognized the fragments of a mechanism while] examining some calcified lumps of corroded bronze that had been set aside as possible pieces of broken statuary".[8] Throckmorton subsequently repeated this story with the additional false details that Valerios Stais was a young man and Spyridon's nephew;[9] they were in fact first cousins, and Valerios (1857-1923) was about 45 years old (two years older than Spyridon) and the director of the Museum. Price's 1974 account of the discovery, based on a selection of newspaper reports from May 23, 1902 onwards, was in most respects correct.[10] Nevertheless, Valerios Stais continues to receive spurious credit for first noticing the fragments.[11]

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6 Biography in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 12, 542 and suppl. 3, 78.

7 Theofanidis [1927-1930], "97" [correct pagination: 89] with note 3. More recent assertions (e.g. Marchant 2008, 37) that the unassigned fragments from the wreck among which the Mechanism was discovered were stored in the open air appear on the face of it implausible. Theofanidis dates Stais's discovery to just a few days after the fragments had been recovered from the wreck site; in reality the interval must have been the better part of a year.

8 Price 1959, 61. Despite the slip, his version shows that he must already have had access to some newspaper accounts.

9 Throckmorton 1970, 153. Biographies of Valerios Stais in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 22, 269; Oikonomos 1922; Petrocheilos 1992. Valerios Stais's father Nikolaos and Spyridon's father Emmanuel (1817-1895) were sons of Valerios Stais, representative of Kythera in the 1817 Assembly of the Ionian Islands established under Maitland's British administration (information courtesy of Marina Papadimitriou).

10 Price 1974, 9. Price's history of the events of 1900-1905 is not quite free of errors. Not realizing that the Greek calendar of the time was the Julian, Price assigned incorrect weekdays to the newspaper issues and dated the Saturday when Stais was reported to have made the discovery as May 17, one day too early. He also followed Throckmorton in identifying Spyridon Stais as a "prominent archaeologist" (p. 8), and makes him the author of Valerios Stais's 1905 monograph on the wreck (p. 11) — in fact by 1974 Price seems to have forgotten that Valerios existed!

11 Marchant 2008, 37-38, offers a new variation, according to which an "unnamed

Price expressed surprise that "such exciting pieces" could have gone unnoticed for so many months until Spyridon Stais's chance visit to the Museum.[12] In fact it is highly probable that they *were* noticed immediately upon their having been brought out of the sea. Valerios Stais wrote in 1905 that the Mechanism was recovered "around the end of the period of salvage of the antiquities of Antikythera," which would mean the summer of 1901.[13] By this stage it appears that the divers were attempting a systematic clearing of all the antiquities, now chiefly smaller and more mundane objects that they were able to reach.[14] On July 24, two newspapers reported a telegram received by the Ministry of Education from the work site. *Τὸ Ἄστυ* —in general the most thorough and reliable of the Athenian newspapers in its archeological coverage— stated that:[15]

> "a single inscribed slab [πλὰξ] was found, the letters on which, however, could not be copied. Besides this were found vases, fragments of statues, and other ancient objects".

Σκρίπ reported the finding of a "marble slab bearing a difficult-to-read inscription".[16] No inscription on stone has been identified among the objects from the Antikythera wreck in the Museum; the only things that could be described as an inscribed "slab" (as in fact they were, repeatedly, in the newspapers in 1902) were the fragments of the Mechanism.[17] It seems likely that the reporter for *Σκρίπ* simply assumed that an inscribed slab *ought* to be marble!

museum worker noticed the significance of the decaying, fractured lump" and notified Valerios about it. In case any doubt lingers concerning the identity of the discoverer, we have Valerios's own testimony ("Αἱ ἀρχαιότητες τῶν Ἀντικυθήρων", *Τὸ Ἄστυ* no. 4343, December 13, 1902, 1-2) that they were found by "the former minister, Mr. Stais."

12 Price 1974, 9.

13 Stais 1905, 18. The salvage was terminated on September 30, 1901 (Svoronos 1903a, 15 = 1903b, 14); a letter of Stais to Kavvadias dated November 24 of an unstated year, adduced by Petrakos 1991 as evidence of a revival of the campaign in November, 1901, actually must date to a later, now largely forgotten unsuccessful attempt to revisit the wreck site in the winter of 1905-1906 that was extensively reported in the Athenian newspapers of the time.

14 Throckmorton 1970, 151, supported by newspaper reports listing the objects found. In particular *Τὸ Ἄστυ* no. 3835, July 13, 1901, summarizes a report to Spyridon Stais from his representative at the site, according to which the divers were working slowly but systematically to recover all objects down to a depth 1 meter below the surface of the sea bottom and as far down as 35-40 fathoms (64-73 meters), the limit of their diving range.

15 *Τὸ Ἄστυ* no. 3846, July 24, 1901, p. 2.

16 *Σκρίπ* no. 2132 [misprinted 2142], July 24, 1901, p. 2.

17 I am indebted to John Seiradakis and Magdalini Nikoli for directing me to the newspaper articles from July 24, 1901.

In connection with these contemporary reports, it deserves mention that Theofanidis also wrote of a "first" discovery of the Mechanism preceding Stais's.[18] The discoverer, according to Theofanidis, was his fellow naval officer, Perikis Rediadis (1875-1938),[19] who at the time held the rank of sublieutenant (ἀνθυποπλοίαρχος) and was assigned to the troopship *Mykali*, the vessel that was put into service on several occasions during the period of salvage transporting antiquities from Antikythera to Athens and carrying archeologists and representatives of the Ministry of Education back and forth.[20] According to Theofanidis, the Mechanism was so encrusted with marine accretions that the petty officer who was loading the antiquities on the deck of the *Mykali* nearly tossed it overboard as worthless, but was prevented from doing so by Rediadis, who had noticed a piece of metal projecting from a broken face of it. Theofanidis must have heard this story directly from Rediadis, and it may have undergone some distortion in the quarter century since the events it describes.[21] Rediadis was later to publish several articles on the Mechanism, and none of them mention this incident.[22] In any case, it could not have occurred on the date shortly before July 24 when the Mechanism seems to have been brought to the surface, because the *Mykali* was not at Antikythera at that time, and only arrived there at the beginning of August with Spyridon Stais aboard, to collect the salvaged objects that had accumulated over the summer. This assemblage, including the Mechanism, arrived at Piraeus to be taken to the Museum on August 3.[23]

Taking into consideration, with all due caution, the newspaper reports from July 24, 1901,

18 Theofanidis [1927-1930], 83 with note 6.

19 Biography in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 21, 84, and [Anonymous] [1939?].

20 According to Svoronos (1903a, 44 note 2 = 1903b, 43 note 1), Rediadis went to Antikythera five times on board the *Mykali*.

21 Theofanidis commits errors that reveal that he did not extensively consult contemporary published sources; thus he writes that the wreck was salvaged by sponge divers from Kalymnos in 1902, getting both the island and the year wrong.

22 *Τὸ Ἄστυ* no. 4171, June 23, 1902, p. 2 and no. 4172, June 24, 1902, p. 2; "Ὁ ἐξ Ἀντικυθήρων ἀστρολάβος", in Svoronos 1903a, 44-52 (= "Der Astrolabos von Antikythera," in Svoronos 1903b, 43-51); Rediadis 1903; Rediadis 1910.

23 Among the objects that arrived in Athens with Stais on August 3, the one that got the most attention was a well preserved bronze statuette of a youth missing its right arm (now National Archaeological Museum X 13399, with the arm restored from the 1974 Cousteau excavations, X 18960); see *Ἑστία* year 8 no. 149, August 3, 1901, p. 3, *Τὸ Ἄστυ* no. 3857, August 4, 1901, p. 1, *Νεολόγος* no. 1430, August 4, 1901, p. 1, *Καιροί* no. 4510, June 23, 1901, p. 2, and *Ἐμπρὸς* no. 1712, August 4, 1901, p. 2. The discovery of the statuette had been reported already by telegram six weeks earlier (*Ἐμπρός* no. 1670, June 23, 1901, p. 2, and *Ἀκρόπολις* no. 6938, June 23, 1901, p. 3), which shows that this was the first delivery of finds from Antikythera since the beginning of the summer. Oddly, the majority of the newspaper reports identify the lost arm as the *left* one.

Theofanidis's story, and the general character of the salvage operations during the summer of 1901, there is good reason to believe that the separate fragments A, B, and C (and possibly also D, E, and F which were found in the Museum subsequently) came into being through the breaking up of a single "slab" after it had come out of the sea, as Price hypothesized.[24] Such a composite would have borne on one face the hard-to-read mirror-writing inscription that Stais later noticed on Fragment B, while the other face would have been almost entirely featureless except perhaps for some illegible traces of direct inscription that Rediadis later reported on Fragment C.[25] The gears and other mechanical elements that were so conspicuous on Fragments A and C in 1902 would have been concealed inside the composite slab. It is difficult to believe that these mechanical elements would have escaped notice in the summer of 1901 if they had been exposed. Price supposed that the gradual drying out of the object could have caused stresses that led to its fragmentation, but given the fragility of the calcified materials that compose the present fragments, one could just as well suppose that it broke apart as a result of a casual impact.

Let us return to the story of the fragments immediately following Stais's visit to the Museum. On Tuesday, May 21, several archeologists including Gavriel Vyzantinos (1868-1910),[26] an Ephor (i.e. superintendent) of Antiquities who had been involved in the salvage of the wreck, inspected the fragments, and a further fragment —presumably the present Fragment C— equal in size to the smaller of the other two —presumably B— was reportedly found.[27] Vyzantinos informed reporters of a few letters that had been read on the fragments; these can be identified as parts of a direct-writing inscription on Fragment A and of the mirror-writing inscription on Fragment B.[28] On Wednesday, Adolf Wilhelm (1864-1950),

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24 Price 1974, 10. On the other hand, Theofanidis ([1927-1930], "97" [correct pagination: 89] with note 3) alleges, we do not know on what authority, that the sponge divers who salvaged the wreck deliberately shattered unidentified objects to determine whether they were antiquities or mere "fossils."

25 Svoronos 1903b, 46. The illegible letters mentioned by Rediadis were probably part of the inscription on the present Fragment G, which was separated from C after 1903.

26 Vyzantinos was the assistant of the General (i.e. chief) Ephor of Antiquities, P. Kavvadias, cf. Petrakos 2011, 20, where he is characterized as "undistinguished and [...] without accomplishment". Biographical information about Vyzantinos is scarce. He was appointed Ephor in 1898, having previously been director of the National Lyceum (*Τὸ Ἄστυ* no. 2883, November 22, 1898, p. 2), briefly succeded Kavvadias as General Ephor in 1910, but died (by suicide) in that year (Petrakos 2013, v. 1, 256-257). He had supervised the earlier stages of the salvage at Antikythera in late 1900 and early 1901, and wrote a valuable short account of them (Vyzantinos 1901a, translated into English: Vyzantinos 1901b).

27 "Αἱ χαλκαὶ πλάκες τῶν Ἀντικυθήρων", *Νέον Ἄστυ* no. 163, May 23, 1902, p. 2.

28 "Αἱ ἀρχαιότητες τῶν Ἀντικυθήρων", *Σκρίπ* no. 2429, May 22, 1902, p. 3; "Δύο ἐνεπίγραφα τεμάχια ἀπὸ τὰ Ἀντικύθηρα", *Νέον Ἄστυ* no. 162, May 22, 1902, p. 2.

an epigrapher and the secretary of the Austrian Institute in Athens, and the numismatist Ioannis Svoronos (1863-1922)[29] spent several hours attempting to read and estimate the date of the mirror-writing inscription on Fragment B.[30] On Thursday, Konstantinos Rados (1862-1931, a naval historian),[31] Valerios Stais, Panagiotis Kastriotis (1859-1931, another Ephor of Antiquities), and Wilhelm inspected the fragments.[32] Photographs were made on May 28.[33] On June 23, the newspaper *Τὸ Ἄστυ* published an article by Rediadis containing the first detailed description of the fragments, which leaves no doubt that the only fragments known at this stage were the present Fragments A, B, and C.[34]

The last issue of the 1902 volume of the journal *Ἐφημερὶς Ἀρχαιολογική*, published on February 15, 1903, contains a long anonymous report of the finds from the Antikythera wreck. It includes a rather cursory description of the fragments (not even specifying how many there were), but stating that, at the date of writing, they had undergone no conservation ("it still remains as it was removed from the sea").[35] A photograph shows the face of Fragment B bearing the mirror-writing inscription.

About June 1903, the first fascicle (plates and text) of volume 1 of Svoronos' illustrated

29 Biography in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 22, 605.

30 "Δύο ἐνεπίγραφα τεμάχια ἀπὸ τὰ Ἀντικύθηρα", *Νέον Ἄστυ* no. 162, May 22, 1902, p. 2; "Ἡ πλὰξ τοῦ μουσείου μας", Ἑστία year 9 no. 83, May 22, 1902, p. 4; "Ἡ χάλκινη πλὰξ τῶν Ἀντικυθήρων", *Σκρίπ* no. 2430, May 23, 1902, p. 2; "Ἡ ἐνεπίγραφος πλὰξ τῶν Ἀντικυθήρων", *Τὸ Ἄστυ* no. 4141, May 23, 1902, p. 1; "Αἱ χαλκαὶ πλάκες τῶν Ἀντικυθήρων" (a very circumstantial report) and "Τὸ ἀστρολάβον τῶν Ἀντικυθήρων", *Νέον Ἄστυ* no. 163, May 23, 1902, p. 2.

31 Biography in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 21, 23.

32 "Τὸ περίεργον εὕρημα τῶν Ἀντικυθήρων", *Τὸ Ἄστυ* no. 4142, May 24, 1902, p. 1; "Αἱ χαλκαὶ πλάκες τῶν Ἀντικυθήρων", *Νέον Ἄστυ* no. 165, May 25, 1902, pp. 1-2.

33 "Τὸ ἀνεξήγητον μηχάνημα τῶν Ἀντικυθήρων", *Τὸ Ἄστυ* no. 4147, May 29, 1902, p. 1. It is not known whether the photographs subsequently published in [Anonymous] 1902 and Svoronos 1903a/1903b were from this session.

34 "Ὁ ἀστρολάβος τῶν Ἀντικυθήρων", *Τὸ Ἄστυ* no. 4171, June 23, 1902, p. 2. A continuation of this article, under the same headline, appeared in no. 4172, June 24, 1902, p. 2.

35 [Anonymous] 1902; the description of the Mechanism is cols. 170-172 with the photograph as text figure 14 on cols. 165-166. Svoronos (1903a, 16 = 1903b, 16) tells us that the article was a collaboration of several of the leading Greek archeologists of the time, Valerios Stais, Christos Tsoundas (1857-1934), and Konstantinos Kourouniotis (1872-1945), under the direction of Panagis Kavvadias (1850-1928). Kavvadias was also the source of information for one of the earliest published mentions of the Mechanism in a language other than Greek, Vicars 1903, 562. (Its discovery in the Museum had already been briefly reported in the London newspaper, *The Standard*, Saturday, June 7, 1902, p. 7 — the corresponding Julian calendar date in Greece was May 25).

survey of the Museum's antiquities, devoted to the Antikythera wreck, was published in Greek, with a German translation appearing soon after; this work incorporates a section by Rediadis on the Mechanism's fragments.[36] Rediadis describes four fragments, designated for the first time by the letters A, B, C, D (Fragment D is mentioned here for the first time), and Plate X presents photographs of both faces of all four fragments (specimens for A-2 and C-1 in supplementary Figs. S6 and S9), with a larger reproduction of B-1, the mirror-writing face of Fragment B, on Plate IX (supplementary Fig. S8).[37] This photograph is not the same as the one in *Ἐφημερὶς Ἀρχαιολογική*, but the condition of the fragment is indistinguishable. Rediadis speaks of the extremely fragile state of the fragments, so that they break "on the application of the slightest force that the hand of the conservator can apply to it", which perhaps is an indication that conservation had begun — though if so, it had certainly not progressed very far, if we may judge by the photographs and by the very limited amount of inscriptional text reported by Rediadis on the authority of Svoronos and Wilhelm.

The conservation had been entrusted to the chemist Othon Rousopoulos (1855-1922),[38] who was responsible also for the conservation of other bronze artifacts in the Museum at that time.[39] There were two elements involved in the conservation of the Mechanism's fragments:

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36 Svoronos 1903a, 44-52, and 1903b, 43-51. The chronology of these publications (self-described not as a catalogue but as a series of plates with explanatory text) has been a matter of confusion in scholarship on the Mechanism since Price's time. The title pages of both the Greek and German editions of the Antikythera fascicle bear the date 1903. An announcement of the Greek edition in the biweekly periodical *Παναθήναια*, issue of June 30, 1903, 573-574, confirms that this edition was published by the middle of 1903, while the German edition was advertised on the back pages of the *Mitteilungen des Kaiserlichen deutschen archäologischen Instituts, Athenische Abteilung* 28 (1903), published soon after February 24, 1904. The relative order of publication of the two editions is indicated by an error in the account of the inscriptions of the Mechanism's fragments in the Greek edition (p. 46, an inscription said to be on Fragment C that is in fact on Fragment A) that is corrected in the German. The title page provided for the text section of the German edition when volume 1 was completed bears the date 1908, and many bound copies lack the original 1903 title page; the title page of the Greek edition of the completed volume 1 has no date.

37 The principal fragments were never designated in print by Greek letters, as stated in Wright 2006, 322.

38 Biography in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* and *Μέγα Ἑλληνικὸν Βιογραφικὸν Λεξικὸν* 1, 85-103.

39 The fragments were placed for safekeeping in a glass cabinet and assigned to Rousopoulos immediately after they were photographed on May 28, 1902 ("Τὸ ἀνεξήγητον μηχάνημα τῶν Ἀντικυθήρων", *Τὸ Ἄστυ* no. 4147, May 29, 1902, p. 1), and it was expected that the work would begin within a few days ("Ἀρχαιολογικά," *Τὸ Ἄστυ* no. 4153, June 4, 1902, p. 2.). In fact, in the light of the remarks in the *Ἐφημερὶς Ἀρχαιολογική* report it appears

removal of extraneous matter and corrosion products from the surfaces to restore them to a semblance of their ancient appearance (καθαρισμός, *Reinigung*, literally "cleaning"), and separation of components that had become fused together. Since separation exposed new surfaces for cleaning, the process was iterative. In a presentation to the International Archeological Congress at Athens on March 29, 1905, Rousopoulos described his preferred technique for cleaning bronzes as a reduction by means of zinc and hydrochloric acid.[40] But since this was not applicable in the case of objects such as the Mechanism's fragments that were corroded to the point that little or no free metal survived, he reports that he subjected them instead to a treatment with potassium cyanide, a reagent widely used in the conservation of metal artifacts at that time.[41] He speaks of the "difficulty and riskiness of the delicate task" of cleaning the Mechanism, "a real test of patience and endurance". Once cleaned, the fragments were protected by an application of Zapon lacquer.

The challenge that Rousopoulos faced in the case of the Mechanism was to remove obscuring layers of accreted matter mixed with corrosion products without also mutilating or destroying "original" surfaces that were themselves by now composed of corrosion products. In this he appears to have been largely successful. Some loss of surface detail would, however, have been unavoidable in any treatment by reduction, the more so as the treatment was prolonged. The indistinctness of the lettering on some of the inscribed fragments in their present condition is probably due in part to this chemical cleaning, and in part to bits of the inscribed surface coming off with the accretion layers when they were separated.

The state of Fragments A, B, C, and D in October 1905 is documented by a set of photographs made by Georg Karo (1872-1963), the second director of the Athenian branch of the German Archeological Institute, for the philologist and epigrapher Albert Rehm (1871-1949) in that month.[42] (Supplementary Fig. S10 reproduces Karo's photograph of C-1.) Another set made,

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that the work was delayed for many months, perhaps because Rousopoulos was occupied with other work in the Museum, perhaps also because of fears such as those expressed by Svoronos ("Τὸ ἀστρολάβον τῶν Ἀντικυθήρων," *Νέον Ἄστυ* no. 163, May 23, 1902, p. 2) that the fragments might be destroyed in the process of cleaning.

40 Rousopoulos 1905.

41 Rousopoulos provides little detail. "Finkener's method" of cleaning antique bronzes, as described in Rathgen 1898, 108-120 = Rathgen 1905, 125-139, was an electrolytic process in which the object was immersed in a bath of potassium cyanide. Rathgen, however, recommends this method only for objects in which a good core of free metal survives, which was not the case with the Mechanism's fragments. Some surfaces of the fragments, e.g. the back face of Fragment C, show little evidence of cleaning in the early photographs, suggesting that Rousopoulos applied chemical cleaning only to certain areas of interest.

42 The set of prints that Karo sent to Rehm is preserved in Bayerische Staatsbibliothek Rehmiana III/9. Karo's letter accompanying the photographs, dated, October 14, 1905, is in

reportedly, in 1918 shows fragments A, B, and C practically unchanged since 1905 (fragment D does not appear in this set), so we may conclude that Rousopoulos's conservation had come to a halt about the end of 1905.[43] (Supplementary Fig. S7, of A-2, is from this set.) The number of fragments had grown by this time through the separation of fused pieces of material. One such new fragment, a piece of inscribed plate now known as Fragment 19, was removed from Fragment A (leaving behind mirror-image impressions), and a photograph and transcription of it were published by Valerios Stais early in 1905 in a pamphlet on the finds from the Antikythera wreck.[44] Fragments 19 and 67 (a smaller piece of the same inscribed plate, also removed from A) are also shown in one of Karo's photographs. Transcriptions of text from other pieces detached from Fragments A and C, mostly identifiable among the present fragments, appear in Rehm's notes and in Theofanidis's publications.[45]

Rehmiana IV D. Biography of Rehm: Haffter 1950.

43 Rehm's prints of this set are also in Rehmiana III/9; they can be distinguished from Karo's by the different rulers that were photographed with the fragments. There was apparently no photograph of Fragment D in the new set. We tentatively identify them with a set mentioned by Price (1974, 11) whose negatives, bearing the date "IX 13/18", were preserved in the National Archeological Museum in his time, though unfortunately they cannot now be located. We base this identification on Price's statement (p. 12) that two photographs of Fragments A and C in Zinner 1943, which are from Rehm's prints, belong to the 1918 set. Since, however, Price mistakenly says that photographs from the 1918 set had previously appeared in Gunther 1932 (which actually reproduces part of Plate X of Svoronos 1903a/1903b) and Zinner 1931 (which has no photographs at all), caution is in order. Moreover, comparison of the 1905 set and the presumed 1918 set does not fully bear out Price's remark that the 1918 photographs "show extra detail revealed after a new cleaning"; some of the later set are indeed sharper than their 1905 counterparts but others are poorer if not entirely spoiled by overexposure, and there is no sign of intervening conservation work. The most noticeable difference in the fragments between the two sets is that some bits of material had broken off the rear face of Fragment A by the second set. Price had photographs of Rehm's full set of prints (negative strip in the Adler Planetarium collection), and in Price 1974, 23-26 he reproduced photographs of A-1 and C-1 from the Karo set and of A-2 and C-2 from the 1918 set.

44 Stais 1905, 18-23. The monograph is announced as a "new book" in the April 1905 issue of *Παναθήναια*, p. 64. Stais, incidentally, speaks of the conservation of the Mechanism's fragments as being still in progress, and expresses the expectation that more fused pieces of plate would be removed in due course.

45 Rehm's transcriptions of some of the detached fragments are in his 1906 *Notizbuch* in Rehmiana III/7; a copy (in another hand) of a somewhat more extensive version is in the file of Price's notes on the Mechanism's inscriptions at the Adler Planetarium. See also Theofanidis [1927-1930], "98"-"99" [correct pagination: 90-91]; 1934a, 144; and 1934b, 151.

Some of the fragments (probably A, B, and C) were on public display from at least as early as 1907 to just before the Second World War in the Rotunda of the Museum among other bronze artifacts from the Antikythera wreck (cases 237-244).[46] Ioannis Theofanidis studied them in the late 1920s and early 1930s, and his frustratingly inexact descriptions and line drawings, published in 1927 and 1934, are the only known evidence for their state at this period.[47] During the Second World War the fragments were in underground storage along with the rest of the Museum's collections.[48] In 1953 Ioannis Bakoulis, the head technician of the Museum, carried out a new course of conservation on them, which likely involved both chemical cleaning and physical removal of accretion layers.[49]

The condition of Fragments A, B, and C after the 1953 conservation is documented in photographs provided by the Museum that year to Derek de Solla Price, which he published several times between 1956 and 1974.[50] Compared to their 1905/1918 states, all three fragments have undergone visible alterations, some of which appear to be the result of accidental breakages (likely incurred during the wartime storage) rather than deliberate interventions by the conservator. Photographs taken by or for Price during his 1958 sojourn at the Museum show not only Fragments A, B, and C but also many other fragments; most of the larger ones among them can be identified among the present fragments by their shapes although the photographs are unfortunately not sharp enough to show much detail.[51] Some

46 Stais 1907, 301-302 (= Stais 1910, 357); Baedeker 1908, 88; Theofanidis [1927-1930] "97" [correct pagination: 89]; Karo 1937, 133.

47 Theofanidis [1927-1930]; Theofanidis 1934a and 1934b.

48 Responding in a letter dated July 14, 1944 (Rehmiana IV A) to an application from Rehm to obtain casts of the fragments, Walther Wrede (1893-1990), first director of the German Archeological Institute in Athens, notified Rehm that all the Museum's antiquities including the Mechanism had been inaccessibly stored in underground locations since 1940. The Mechanism had probably been deposited, with the ceramics and other small objects, in wooden crates in the basement of the new wing of the Museum (Petrakos 1994, 87-90).

49 The new conservation is mentioned in "ΤΟ ΑΡΧΑΙΟΝ ΩΡΟΛΟΓΙΟΝ ΑΣΤΡΟΝΟΜΙΑΣ, ΜΙΑ ΑΝΑΚΟΙΝΩΣΙΣ ΤΟΥ ΑΡΧΑΙΟΛΟΓΙΚΟΥ ΜΟΥΣΕΙΟΥ", *Ἐλευθερία*, Sunday, January 11, 1959, p. 11. A previous article by Athena Kalogeropoulou in the same newspaper, "ΟΙ ΑΡΧΑΙΟΙ ΕΓΝΩΡΙΖΑΝ ΟΛΑ ΤΑ ΜΥΣΤΙΚΑ ΤΗΣ ΝΑΥΣΙΠΛΟΪΑΣ," *Ἐλευθερία*, Friday, January 9, 1959, p. 3, states that the fragments had not yet been installed in the new exhibits of the Museum by the beginning of 1959.

50 Price 1974, 12. The photographs are reproduced there on pp. 23-26, figs. 12, 15, 17a, 17c, 18a, and 19a.

51 Price's photograph collection is kept at the Adler Planetarium. Price worked on the fragments at the Museum in 1958, 1961, and 1972 (Price 1974, 12-13), but the first of these visits appears to have been the occasion of the great part of his physical examination of the fragments, including his collaboration with George Stamires on the inscriptions. The

of these fragments, like Fragment 19, are known to have been separated from A, B, or C during Rousopoulos's conservation. Of particular importance among this group is Fragment G (Supplementary Fig. S5), an inscribed plate fragment assembled from numerous pieces that had been separated from C-1. Others among the "new" fragments certainly broke off or were removed from the principal fragments after 1918. The flat boxes (some of them are cigar boxes) in which the fragments were stored may be seen, including a box containing crumb-sized bits which appears no longer to exist.[52]

Fragment D, which had apparently gone missing after 1905, was found again around 1972-1974.[53] Another substantial fragment not previously known, now called E, was discovered by Petros Kalligas in 1976 in the Museum's basement pottery storeroom (Y15), along with fragments of pottery, glass, and other small objects from the Antikythera wreck, and transferred to the bronzes storeroom.[54] In advance of the 2005 data-gathering of the Antikythera Mechanism Research Project, the inventory of known fragments was brought up to 82, including another major new discovery (Fragment F). [55] E and F were not formerly parts of one or other of the four fragments known in 1903, as documented in the photographs published in that year. Among the smaller fragments now designated by numbers 1 through 75, Fragments 19 through 30 and 39 through 44 are mostly identifiable in Price's 1958 photographs and appear to have been separated from one or another of the four "original" fragments (in particular A and C), while at least some of the rest may, like E and F, have lurked for decades among unidentified materials from the salvage of the wreck.

photographs in question can be dated to this visit by the use of one of them as the cover image on the June 1959 issue of *Scientific American* in which Price 1959 appeared. Oddly, Price 1974, 47 speaks of the existence of only "some fifteen small fragments, most of them being scraps of inscribed plate…", though his photographs show many more than that. We note here that a pair of negatives showing both sides of Fragments A, B, and C, photographed by Emile Séraf is now in the collection of the Athens Department of the Deutsches Archäologisches Institut; these cannot be precisely dated but show the fragments in approximately the same state as Price's photographs, while being of distinctly higher quality.

52 This box was the source of the samples used for the metallurgical analyses made shortly after Price's 1958 visit, which are reported in Price 1974, 63-66; see also below, section 2.4. The fragments were still stored in the cigar boxes when they were seen by Arthur C. Clarke in 1965 (Clarke 1975, 115 = Clarke 1977, 190; Clarke 2001).

53 Price 1974, 13.

54 Personal communication from Mary Zafeiropoulou.

55 The discovery of Fragment F and several small fragments not known to Price in the Museum's bronze storeroom is due to Mary Zafeiropoulou, who also assigned the now standard letters and numbers to all the fragments beyond A-E; see Zafeiropoulou 2012a and 2012b, 11.

Despite Price's dangerous wish, expressed in *Gears from the Greeks*, that the fragments should be subjected to yet another round of cleaning and separation,[56] the principal fragments, A, B, and C have not experienced much alteration since 1955, and scarcely at all since 1990, in which year they were photographed by M. T. Wright.[57] (Supplementary Figs. S1 - S4 show the inscription-bearing faces of A, B, and C as they were in 2005.) According to former conservators of the Museum, Fragments A, B, C, D, and G as well as some of the smaller inscribed fragments have been conserved from time to time when it was considered necessary.[58] The most notable changes visible between 1955 and 1990 are, on Fragment A, the reattachment of a small piece that had broken off it between 1918 and 1955, and on Fragment C, the reattachment of another small piece that had broken off between 1953 and 1958.[59]

56 Price 1974, 47. Two decades earlier, before he had seen the fragments in person though apparently after Bakoulis's work, Price applied unsuccessfully to the Greek government to have them sent to the British Museum for conservation, as he reports, somewhat intemperately, in Price 1956, 33 n. 18.

57 Personal communication. Wright's photographs of Fragments A, B, and C (both sides) are reproduced in Wright 2007 (as well as, variously, in several of his other papers).

58 Personal communication from Mary Zafeiropoulou.

59 The reattachment of the piece from Fragment A appears to have occurred between 1971-1972 (the date of Karakalos's radiographs, which do not show the piece) and 1980 (the date of the television series *Arthur C. Clarke's Mysterious World*, episode 3 of which featured Price's work on the Mechanism including a brief view of Fragment A in which the piece is just visible). The bit broken off the bottom of Fragment C can be seen lying next to the rest of the fragment in some of Price's unpublished photographs from 1958. This damage had happened since the photographs made for Price in 1953, and it seems to have been repaired during Price's visit. The fragments in their present condition show signs of having suffered other breakages that were probably repaired immediately. Researchers have repeatedly remarked on the ease with which the fragments' chalk-like material breaks or crumbles with handling; see for example Rediadis's remarks quoted above, Theofanidis [1927-1930], "97" [correct pagination: 89]; Price 1974, 46; Bromley 1990, 643; and Marchant 2008, 179-181.

2.2 Previous transcriptions

Before the 2005 data gathering, the only means of reading the Mechanism's inscriptions was autopsy, with only small assistance from conventional photography.[60] Conventional radiographs did not show inscribed letters at all; the linear tomography of Wright, Bromley, and Magou was just sensitive enough to reveal some letters concealed within Fragment C but not clear enough to enable them to be read.[61] CT and PTM imaging have now effectively superseded direct inspection. Earlier published and unpublished transcriptions nevertheless continue to be useful as evidence for the history of the fragments and potentially as witnesses of text that has been lost or become less legible as a consequence of accidental damage and essential conservation work. We here list the transcriptions up to the 1970s that we are aware of. A detailed survey of earlier transcriptions of the individual inscriptions will be provided in each of the remaining papers in the present series.

Transcriptions in newspapers, 1902: *Σκρίπ* May 22, *Νέον Ἄστυ* May 22 and 23, *Ἑστία* May 22, *Τὸ Ἄστυ* May 23 and 24, *Ἐλεύθερος Τύπος* May 24
Back Plate Inscription (A) and Back Cover Inscription (B), readings communicated to reporters by Vyzantinos (?), Wilhelm, and Svoronos.

Svoronos 1903a, 46/1903b, 45-46
Back Plate Inscription (A) and Back Cover Inscription (B), credited to Svoronos with contributions by Wilhelm.

Stais 1905, 22
Back Cover Inscription (19).

Rehm 1905, 18-21
Parapegma Inscription (C), and supplements to the 1903 Svoronos and 1905 Stais transcriptions of the Back Cover Inscription (B, 19).

Rehm 1906a, 86-87
Front Dial Inscriptions (C), Front Cover Inscriptions (various small fragments, some of which are now parts of G).[62]

60 Most of the photographs that Rehm and Price worked with are unsatisfactory for reading the inscriptions, and the photographs that appeared in publications up to and including Price 1974 are generally illegible.

61 Wright, Bromley, & Magou 1995, 542.

62 We suspect that Rehm made other transcriptions that have not yet been located. The copies of small fragments in the "Notizbuch" are labelled with Greek letters running from iota through sigma, implying that there were eight previous texts. The Back Cover Inscription on B,

Rehm 1906b, 3

Parapegma Inscription (C).

Rados 1910, 10-11 and 34

Back Plate Inscription (A) and Back Cover Inscription (B) reproduced from Svoronos 1903a, Back Cover Inscription (19) reproduced, with a typographic error, from Stais 1905, and Front Dial Inscriptions (C) from Karo's report of Rehm's researches.

Theofanidis [1927-1930], "98"-"99" [correct pagination: 90-91]

Front Cover Inscription (small fragment, now part of G), Parapegma Inscription (C), Back Dial Inscriptions (24), Back Plate Inscription (A, 24), and Back Cover Inscription (B, 19), in part credited to Vasileios Leonardos.[63]

Theofanidis 1934a, 141-146

Repeats transcriptions from Theofanidis [1927-1930].

Price 1959, 64-65

Front Dial Inscriptions (C), Parapegma Inscription (C), Back Dial Inscriptions (A, B). Price credits the transcriptions to the epigrapher George Stamires.

Price 1974, 18 and 46-51

Front Cover Inscription (G), Front Dial Inscriptions (C), Parapegma Inscription (C, 20, 22, 28), Back Plate Inscription (A), Back Cover Inscription (A, B, 19). Again Price attributes the transcriptions, at least in large part, to Stamires.[64]

the Back Plate Inscription on A, the Back Cover Inscription on 19, the Parapegma Inscription on C, and the month name on C would account for five, and it is plausible that Rehm also noticed the Back Cover Inscription on A which is not mentioned in published scholarship before Theofanidis [1927-1930] "98" [correct pagination: 90], who mentions "a multitude of pressed-on letters absolutely incapable of being read". The isolated letters "T" on Fragment C and "H" (actually the four-stroke form of xi, "Ξ", read sideways) on Fragment A, mentioned by Rediadis in Svoronos 1903a, 45-47 and 1903b, 45-46, would complete the tally.

63 For Leonardos see note 69 below.

64 Stamires left academic life in 1961 after his appointment as a research assistant to B.D. Meritt at the Institute for Advanced Study, Princeton, came to an end, so it is doubtful whether his collaboration with Price continued long after 1958. Price had definitely lost all contact with Stamires by 1973 (letter of Price to B.D. Meritt, October 3, 1973, Meritt papers, American Philosophical Society). Price's file of notes and transcriptions of the inscriptions, preserved at the Adler Planetarium Chicago, contains pages in more than one hand, but it is not clear whether any of them were written by Stamires.

Price, unpublished file of transcriptions and notes at Adler Planetarium

In addition to preliminary versions of the transcriptions published in Price 1974, these undated notes include some of the inscribed small fragments that were not included in that work.

Antikythera Mechanism Research Project: Freeth et al. 2006, Supplementary Information 5 and 8-10

Front Cover Inscription (G), Back Dial Inscriptions (A, B, E, F, 24), Back Plate Inscription (A, E, F), Back Cover Inscription (A, B, E, 19).

Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes [revised 2011], 10-11, 19-20, 25-28, and 40

Back Dial Inscriptions (A, B, E, F, 24).

Zafeiropoulou 2012a, 245

Front Cover Inscription (G), credited to A. Tselikas.

Freeth & Jones 2012, Section 2.3.2 and Fig. 4

Back Cover Inscription (i 16-26), transcription, and Parapegma and Front Dial Inscriptions, transcription incorporating some restored text, uncredited but based on preliminary work towards the editions in the papers IAM 3 and IAM 5 of the present series.

Freeth 2014, Supplementary note S2 with Figs. S5 and S13

Back Plate Inscription, transcription by C. Crowther with T. Freeth, and Saros Dial Inscriptions by T. Freeth.

2.3 Previous paleographic appraisals

The first scholars to examine the inscriptions were at least as interested in dating them according to their letter forms as in reading them. A date of manufacture for the Mechanism would establish a *terminus post quem* for the date of the shipwreck, which was a subject of vigorous debate in 1902. When Vyzantinos spoke to reporters on May 21 after an initial examination of the just-discovered fragments (*Σκρίπ* and *Νέον Ἄστυ*, May 22), he said that the antiquities from the shipwreck belonged to the interval between 150 B.C. and A.D. 200, a cautious assessment that probably reflected the views of most of the Greek archeologists who had studied the materials.[65] For months, however, Svoronos had been vocally maintaining that the wreck dated from the time of Constantine, that is, the 4th century A.D.[66] Hence when Wilhelm visited the Museum on May 22 at the archeologists' invitation to examine the inscriptions, it is not surprising that Svoronos chose to be present and to involve himself. The earlier reports from that day have Wilhelm making a preliminary statement giving his opinion that the writing dated to the 1st century B.C.; but later that day Svoronos spoke to the reporters at greater length, saying that the letter forms were characteristic of the second or 1st century B.C., but that the serifs pointed to a later date, as late as the 2nd or 3rd century A.D.[67] It is hard to resist a suspicion that Svoronos, whose epigraphical experience was chiefly with coins, allowed his judgment to be biased by his conviction that the wreck was from the late Roman Empire. In any case both Wilhelm and Svoronos were basing their datings on fewer than fifty mirror-image letters of the Back Cover Inscription that they were able to make out on Fragment B. [68]

The situation had scarcely changed by the end of 1902. In response to Svoronos's repeated

65 The report in *Νέον Ἄστυ* on the same day has Vyzantinos assigning this date range specifically to the Mechanism, but this was probably not an attempt at paleographical assessment but rather an inference from the archeological context.

66 See e.g. his address reported in *Τὸ Ἄστυ* 3869, August 16, 1901, p. 2.

67 According to *Τὸ Ἄστυ*, May 23, Svoronos said that the serifs implied a first or second century AD date, while *Νέον Ἄστυ*, May 23, reports him as saying that the date could be as late as the third century.

68 Wilhelm's involvement seems to have been slight following his first inspection of Fragments A and B on May 22, 1902. A week after his visit, a report "Τὸ ἀνεξήγητον μηχάνημα τῶν Ἀντικυθήρων", *Τὸ Ἄστυ*, no. 4147, May 29, 1902, p. 1 states that once the fragments had been cleaned, the reading of the inscriptions would be entrusted to the "expert epigrapher" Vasileios Leonardos (1857-1930), the director of the Epigraphic Museum, calling him "the only Ephor of Antiquities competent for this". After this assertion of territoriality, Leonardos vanishes from the story of the Mechanism until the 1920s, when he read at least one of the inscriptions for Theofanidis (Theofanidis [1927-1930], "99" [correct pagination: 91]). Biography of Leonardos in *Μεγάλη Ἑλληνικὴ Ἐγκυκλοπαίδεια* 15, 937-938.

public airings of his theories concerning the wreck (in addition to the late dating, Svoronos maintained that the ship was heading from Argos to Constantinople when it sank), Valerios Stais published a lengthy rebuttal in *Τὸ Ἄστυ*, December 13 and 14. In the first instalment he asserts that the letter forms of the Mechanism's inscriptions, being typical of the third and second centuries BC, would be difficult to date later than the 1st century B.C., and "*impossible*, completely impossible" (his emphasis) to assign to the 4th century A.D. The anonymous article on the wreck in the 1902 volume of *Ἐφημερὶς Ἀρχαιολογικὴ* uses almost identical words to state that the writing would be difficult to date later than the middle of the 1st century B.C.[69]

Thus Svoronos was more or less on his own in opposition to the leading Greek archeologists on both the broad question of the provenance and date of the wreck and on the dating of the Mechanism. Despite its appearance of being an official publication of the wreck and the salvaged antiquities, his 1903 monograph is really a "minority report". Here, embedded in Rediadis's section on the Mechanism, we find Svoronos asserting that the inscriptions could be dated paleographically as late as the time of the emperors Maximus and Gordian (A.D. 235-244).

Up to this point all the appraisals had been based on the rather meager readings that had been obtained from the mirror-text Back Cover Inscription on Fragment B and a handful of letters —no entire words— of the Back Plate Inscription on A, before either fragment had been subjected to cleaning and separation of accreted layers of plate. One outcome of Rousopoulos's work was the removal of Fragment 19, the largest surviving piece of the original plate bearing the Back Cover Inscription, from Fragment A. The inscribed face of Fragment 19 was in much better condition than any part of the inscriptions that had been seen hitherto, and in 1905 Stais based on it the first detailed discussion of the letter forms and their dating, though his concern remained to establish a Hellenistic date and rule out a late Roman one rather than to try to narrow down the dating within the Hellenistic period. Thus he notes the use of isosceles A with horizontal middle hasta, the rectilinear E and Σ, and the forms of Π and Ω, all of which, he says, argue for a date within the last three centuries BC.

In his first unpublished essay on the Mechanism, written in late 1905, Rehm does not discuss the paleography in detail, but expresses his comfort with an Augustan (i.e. late 1st century B.C.) date for the letter forms.[70] This dating was influenced, however, by an extra-paleographical consideration, namely Rehm's belief that the Egyptian month name that he read on Fragment C's exposed dial pertained to the reformed Egyptian calendar, introduced during the reign of Augustus. Rehm did not know that this calendar dial was a removable ring designed to be adjustable in position relative to the solar year, from which

69 [Anonymous] 1902, 172. For the authors of this article see note 35 above.

70 Rehm 1905, 30.

it follows that the *unreformed* calendar was intended. (No conclusions can be drawn from this concerning the Mechanism's date since the unreformed calendar continued to be used for astronomical calculations long after it ceased to be the civil calendar in Egypt.)[71] In his second essay, from late 1906, Rehm characterizes the writing as typical of the first century BC, singling out the tendency of the top and bottom hastae of sigma to be not quite parallel and that of the right vertical hasta of pi to be shorter than the left hasta.[72] In the margin Rehm added the argument from the Egyptian month for a *terminus post quem*, this time giving the specific year 26 B.C. as the inaugural year of the reformed Egyptian calendar.

Rados assigns the writing to the 1st century B.C., citing Stais's monograph, though in fact Stais had only given that century as the latest possible.[73]

Theofanidis writes, with reference to the Back Plate Inscription on Fragment A and the Parapegma Inscription on C, that the style of letter forms is characteristic of the 2nd century B.C.[74] Since this is an estimate different from any that had appeared in print earlier, we suppose that he got it from Leonardos, who he says read the Parapegma Inscription for him.

Although Price was assisted by Stamires for the reading of the inscriptions, he resorted for their paleographical dating to B.D. Meritt, whose appraisal was made from photographs. According to Price's 1959 summary, Meritt judged the writing as belonging to the 1st century

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71 We comment here on Price's often cited dating of the Mechanism to about 82 B.C. (Price 1959, 65), later revised to about 87 B.C. (Price 1974, 19). Price derived this dating by a circuitous argument from a "fiducial mark" that he discovered on the frame plate of Fragment C just outside the calendar dial, and that he supposed to indicate an epoch alignment for the beginning of an Egyptian calendar month. The presence of a crack running along the mark has raised doubts about whether it is a deliberate engraving (Bromley 1990, 651-652). If it does mark an epoch position for the ring, it stands to reason that the mark signifies an epoch alignment of a solar longitude of approximately Libra 18° with the *beginning* of the Egyptian year (Thoth 1), not the beginning of the calendar's second month (Phaophi 1) as required for Price's dating. This would have been valid close to the end of the 3rd century B.C., say around 210 B.C. (For a similar argument see Carman & Evans 2014, 760-763.) Such an epoch would provide us with a *terminus post quem* for the date of the Mechanism's manufacture.

72 Rehm 1906b, 8. Lippold 1923, 250 n. 6, quotes a private communication from Rehm to the same effect: "Die Schrift —das einzige Datierungsmittel— setze ich ins 1. Jahrh. v. Chr.… also frühestens Zeit des Posidonios. *Nach* Chr. Geb. herunterzugehen wird man auch keinen Anlaß haben". Rehm seems by this time to have abandoned, or forgotten, his inference of a post-30 B.C. date from the Egyptian month name, though he had previously communicated it to Georg Karo, through whom it appeared in print; see Leroux 1913, 102, and Karo 1948, 181.

73 Rados 1910, 24.

74 Theofanidis [1927-1930] "98"-"99" (correct pagination: 90-91).

B.C.; it "could hardly be older than 100 B.C. nor younger than the time of Christ".[75] In 1974 Price reported Meritt's view slightly differently, and with some detail:

> "The letter forms are, in the opinion of Professor Benjamin Meritt, characteristic of the first century B.C., or more loosely, of Augustan times. For example, the left vertical of Π is much longer than the right; the vertical strokes of M and the horizontal ones of Σ are not parallel. There are tiny serifs at the end of each stroke".

With access to the imaging of the inscriptions made possible by the 2005 data-gathering, H. Kritzas has concluded that the possible date range for the inscriptions is:[76]

> "the second half of the 2nd Century BC and the beginning of the 1st Century BC, with an uncertainty of about one generation (50 years). Dates around 150 BC to 100 BC are a plausible range".

Characteristics of attested forms of twelve letters, which Kritzas associates with various typical date ranges, are adduced to support this dating.[77] Subsequently, C. Crowther has offered several qualifications of Kritzas's comments on individual letter forms, and given as a general assessment that the possible range for the Mechanism's inscriptions extends from the late third century through the early 1st century B.C., "with a preference for the earlier half of this period".[78] And most recently, P. Iversen considers that the letter forms allow for a dating anywhere from slightly before 200 BC to slightly after A.D. 50.[79]

Among the various people who have offered paleographical datings of the inscriptions, Wilhelm, Leonardos, Meritt, Kritzas, Crowther, and Iversen all qualify as experienced and competent epigraphers, and Rehm, though early in his epigraphical career, had already acquired considerable experience from his work as epigrapher for the German excavations in Asia Minor; on the other hand, we may discount Svoronos, whose outlier opinion was evidently neither expert nor unbiased. Every estimate except Svoronos's has fallen within a range from the late 3rd century B.C. to the 1st century A.D. (with the later part of this range now discounted because we know that the Mechanism cannot be later than the shipwreck), but when it comes to determining tighter bounds, there is no consensus.

That there should be divergences among datings by experts is no cause for surprise, since letter forms are a reliable basis for dating inscriptions only when the inscription has a

75 Price 1959, 61.
76 Freeth et al. 2006, Supplementary Information 7.
77 See also Hannah 2008, 31 for endorsement of Kritzas's dating.
78 Quoted in Freeth 2014, Supplementary Note S2.
79 Iversen (forthcoming).

known provenance and can be compared to numerous other datable inscriptions from the same place, conditions that are not satisfied for the Antikythera Mechanism; in general, in the words of A.G. Woodhead, "this criterion [*scil.* letter forms], so often used as a first resort, is much better left as a final refuge; its evidence is far less precise and secure than is popularly supposed".[80] Additionally, we are dealing with inscriptions made in the style of Hellenistic inscriptions on stone, but on a different medium, with different tools, and at a much smaller size than the typical range of contemporary stone inscriptions.[81] Hence while their paleography establishes with high probability that they were inscribed at some point between the late 3rd century B.C. and the date of the wreck, we cannot appeal to the letter forms to narrow this interval.

80 Woodhead 1967, 62; see also McLean 2002, 42-45; Tracy 2009; Iversen (forthcoming). Tracy gives examples of datings that have proved to be many decades in error; see also Tracy 2000, 71, for an instance in which two separately published fragments of inscription, one of them exactly dated by its contents to 191 B.C. and the other paleographically dated to c. 280 B.C., proved to be adjoining pieces of the same inscription.

81 For example, letter heights in Attic decrees are typically 5-9 mm (Tracy 1970, 324 n. 26), while inventories and leases can have letter heights around 3-4 mm (McLean 2002, 43). By contrast the largest lettering of the Mechanism, in the Parapegma Inscription, keeps within the range 2.3-3.0 mm, and the smallest lettering, on the dials, is barely taller than 1 mm.

2.4 General observations on the inscriptions

Although we conventionally speak of the Antikythera Mechanism as having consisted of bronze and wood, there is some question about the precise composition of the alloy or alloys employed, in particular with respect to the inscribed plates. In 1910 Rediadis asserted that the mechanical components of the Mechanism were made of copper (ἐκ χάλκου), citing an analysis by the chemist A.K. Dambergis, which was, however, of other antiquities from the Antikythera wreck, not the Mechanism.[82] Price obtained chemical and spectrographic analyses of small samples from the previously mentioned box of crumb-sized bits that was stored with the Mechanism's fragments in 1958; it is likely that the contents of this box were chiefly bits broken off the inscribed plates and the accretion layers. These analyses indicated a composition of copper with a small amount (1–10%) of tin but no other metals in significant quantity.[83] On the other hand, recent nondestructive (surface) chemical analyses of small inscription fragments conducted by P. Mitropoulos in the Electronic Microscopy and Microanalysis facilities of the Department of Geology and Geoenvironment, University of Athens, found, in addition to an alloy comprising 85% copper and 15% tin, two other pewter-like alloys in which tin was the predominant component, with smaller amounts of copper and lead.[84] Plate having these latter compositions would have been very soft, so suitable for engraving though not for components requiring rigidity.[85]

The lettering appears to have been engraved using a burin, a tool with a sharp, hard metal point at one end and a rounded handle at the other which is pushed by the engraver's hand.[86] Unlike a tracer or chisel, which is hammered into the plate to make grooves, a burin forms grooves by removing metal, not displacing it; CT cross sections of the Mechanism's lettering show no ridges alongside the grooves (Fig. 2.1).[87]

82 Rediadis 1910, 164; Dambergis 1906.

83 Price 1974, 63-66, giving reports by E.R. Caley (chemical analysis) and C.S. Smith (spectrographic analysis). Caley remarks on the absence of lead as a likely indicator of a date of manufacture earlier than the 1st century B.C. However, the presence of lead in bronzes in the later Hellenistic period was largely motivated by its enhancement of the casting properties of the alloy, whereas leaded bronze is less suited to cold working; hence unleaded bronze continued to be used for objects fashioned from sheet bronze (Craddock 1977, 111 and 115).

84 Zafeiropoulou 2012a, 243.

85 Wright 2011, 8-9.

86 M.T. Wright, by personal communication.

87 Maryon 1949, 115-118.

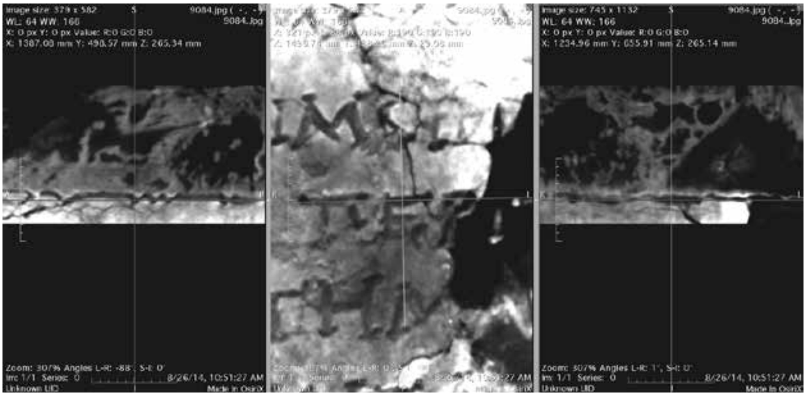

Figure 2.1: *CT views of engraved lettering in Fragment E. (left) Vertical cross section in a plane perpendicular to the plate. (center) Cross section parallel to the plate and near its surface. (right) Horizontal cross section in a plane perpendicular to the plate. This part of the plate has a layer of accreted matter against it, whose surface follows the outlines of the engraving*
(Images: Antikythera Mechanism Research Project)

The inscriptions, when viewed directly, give an impression of neatness and regularity, which is largely due to their tiny size (Fig. 2.2). Under magnification, the sizes, line and letter spacing, and shapes of the letters prove to be rather irregular, though the engraver has clearly worked hard to imitate the appearance of serifed lettering on stone (Fig. 2.3). Correct syllabic word division has been respected at line-ends. There is no punctuation, and numerals as a rule are not marked as such by an overstroke (an exception in the Back Cover Inscription, II.3) but are usually preceded and followed by modest *vacats*. *Vacats* also occasionally separate words, following no obvious principle.

Figure 2.2: *Fragment 19, a piece of the Back Cover Inscription plate, at actual size, image from PTM ak1a with specular enhancement*
(Image: Antikythera Mechanism Research Project)

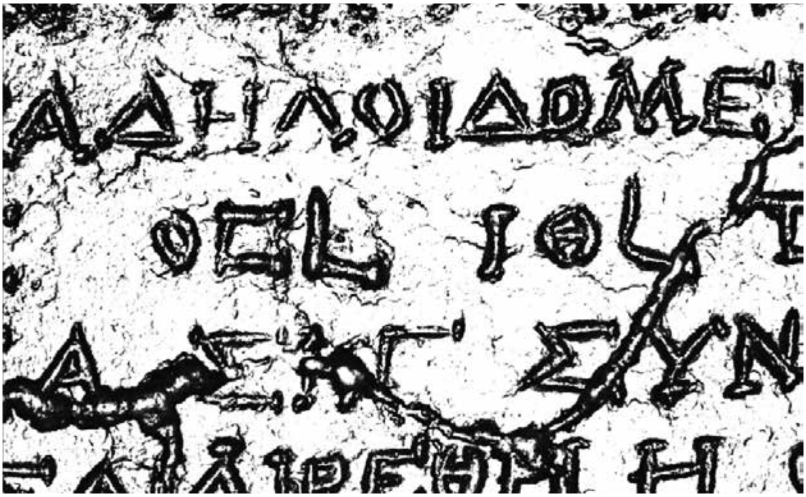

Figure 2.3: *Detail of Fragment 19, image from PTM ak1a with specular enhancement* (Images: Antikythera Mechanism Research Project)

The variable state of preservation of the inscriptions is an impediment to comparing the lettering from one part of the Mechanism to another. We have good specimens of the Parapegma Inscription on Fragment C-1, and of the Back Cover Inscription on Fragment 19 and inside Fragment E (viewable only by CT). The best specimens of the Back Plate Inscription are in Fragment F (viewable by CT) in addition to some well preserved letters on Fragment A-2. For the most part, the remains of the Front Cover Inscription are badly corroded, and probably the best specimen of its lettering is in the offsets on Fragment 21. Of the inscriptions on the dial scales, those on the front dial are mostly rather unclear, those of the upper back dials very badly preserved indeed, but there are some good specimens of the eclipse glyphs on the Saros Dial. Some differences in the general look of the lettering are apparent, in particular a tendency for verticals in parts of the Front Cover Inscription and the Back Plate Inscription to slope slightly, in contrast to the greater uprightness seen elsewhere. Such diversity is perhaps not enough in itself to imply that more than one engraver was at work.

Letter forms can be variable, even within a single inscription. The slightly diverging top and bottom strokes of the sigmas have been remarked on for their bearing on the paleographical dating; but one also frequently finds sigmas with parallel top and bottom strokes (e.g. both forms in Fig. 2.3, Back Cover Inscription II.20). Omicron is sometimes small and elevated above the baseline, sometimes a larger loop occupying the full normal letter height. The middle "vee" strokes of mu sometimes touch at the baseline, sometimes above it, and the slope of the first and last strokes from the vertical is also variable. These may be accidental variations arising from the handling of the engraving tool in making very small letters. There are also some instances of truly distinct letter forms:

– In the Back Cover Inscription, theta is always a narrow oval with a cross stroke;

in the other inscriptions, it is always a near-circular loop with a central dot. This consistent distinction of forms would be hard to explain unless the Back Cover Inscription was engraved by a different person from the other inscriptions.

– In the Front Cover Inscription, xi occurs in two forms, either with three horizontal strokes (Ξ) or with three horizontals crossed centrally by a vertical stroke (Ɨ). The four-stroke version seems to have been used in this inscription specially for numerals, and it also occurs among the index letters on the Zodiac Scale.
– The normal form of omega has a large loop open at the bottom (Ω); but in the Back Plate Inscription (line 4) there is a likely instance of the W-shaped cursive omega (ω).

Numerals are in the Ionian (alphabetic) notation; there are no instances of fractions. The symbol representing 6 (often wrongly called "stigma", though actually a form of digamma) comprises three straight strokes like an E without its middle stroke. A special symbol employed as an index letter in the Back Plate Inscription (line 29) may be a modified alpha standing for 1000. The L-shaped symbol for ἔτος ("year") occurs in the scale inscriptions of the Metonic and Games Dials as well as in the Back Cover Inscription (II.19, where its resolution is -ετηρίς, "period of years"). The symbol for ὥρα ("hour"), comprising a cursive omega crossed by a vertically elongated rho, occurs in the eclipse glyphs of the Saros Dial.

Definite or probable instances of errors committed by the engraver include the following:

– Parapegma Inscription: PP2 col. iii line 5 ἐπιτέλλει should have been the second last word
– Back Plate Inscription: 8 the line was initially begun too far to the left (corrected); 10 θραικίαν for θραικίας; 14-15 μεγάλην for μεγάλαι; 18 the index letter sigma should have been first; overstrokes seem to have been omitted over some letters in the index letter lines
– Back Cover Inscription: I.19 Ἀφροδίτη for Ἀφροδίτης; II.3 ὅλη for ὅληι; II.5 στημάτιον for στημάτια (corrected)

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3

The Front Dial and Parapegma Inscriptions

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Abstract

The dial at the center of the front face of the Antikythera Mechanism was surrounded by two scales, one representing the zodiac, the other the Egyptian calendar year. The Zodiac Scale was inscribed with the names of the zodiacal signs as well as series of index letters in alphabetic order, while the Egyptian Calendar Scale was inscribed with the Greek names of the Egyptian months. In addition, two rectangular plates, the remains of which survived displaced from their original positions, bore an inscription, called the Parapegma Inscription, comprising an alphabetically indexed list of annually repeating astronomical events relating to the Sun and to fixed stars. This paper gives transcriptions and translations of the inscriptions on the dial scales and the Parapegma Inscription, and deduces the original structure, layout, and location of the Parapegma Inscription. A provisional astronomical analysis of the data in the Parapegma Inscription and tentative restorations of some of its damaged and missing lines are also provided.

3.1 Introduction

The front face of the Antikythera Mechanism bore a single circular dial that occupied most of the area of a square plate, the Dial Plate (Fig. 3.1). The dial had multiple pointers radiating from its center to represent the longitudes of the Sun, Moon, and the five planets known in Antiquity.[1] Surrounding the dial were two concentric graduated scale rings. The outer Egyptian Calendar Scale was divided into twelve sectors, each containing thirty subdivisions, and one smaller sector containing five subdivisions, representing the 365 days of the Egyptian calendar year. Each sector was inscribed with the Greek name of an Egyptian month, running clockwise. The inner Zodiac Scale was divided into twelve sectors, each containing thirty subdivisions, representing the twelve zodiacal signs and the 360 degrees of the zodiac.[2] Each sector of the Zodiac Scale was inscribed with the name of a zodiacal sign, running clockwise in order of increasing longitude, and with small letters, running clockwise in alphabetic order, placed outside and immediately clockwise of the graduation marks corresponding to various degrees in the zodiacal signs. These "index letters" linked the associated degrees to lines of an inscription, called the Parapegma Inscription, that was inscribed on two rectagular Parapegma Plates, which we name PP1 and PP2.

1 Paper 5 in this series - IAM 5.5; Freeth & Jones 2012, section 2.3; previously conjectured by Wright 2002.

2 The sectors of the Zodiac Scale are not exactly equal, as shown by Evans, Carman, & Thorndike 2010, who argue that this was an intentional feature making it possible to display the Sun's true longitude with the same pointer that indicated the Egyptian calendar date. Other reconstructions since Wright 2002b have hypothesized separate pointers for the true Sun and mean Sun (though Wright presciently remarked that this was necessary "on the assumption that both Zodiac and calendar rings were equally divided").

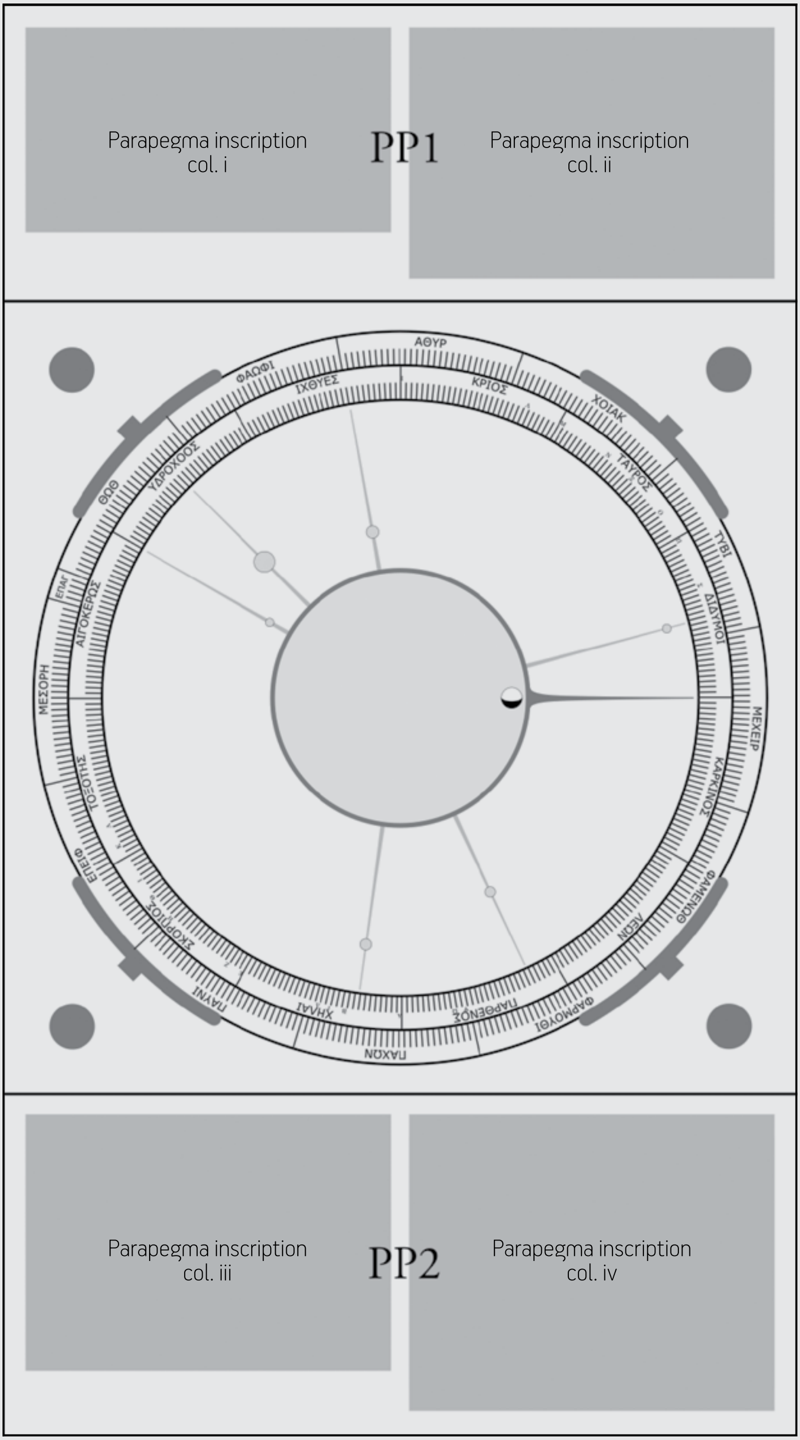

Figure 3.1: *Reconstruction of the Antikythera Mechanism's front face*

The Parapegma Inscription comprised a list of solstices, equinoxes, entries of the Sun into the zodiacal signs, and first and last appearances of stars and constellations before dawn and after dusk. Thus whenever the pointer on the front dial representing the position of the Sun in the zodiac pointed at a degree division bearing an index letter, the viewer could look up the corresponding line of the Parapegma Inscription and read off a prediction of a solar or stellar event predicted for the date in question. We will show in this paper that the Parapegma Plates also formed part of the Mechanism's front face, above and below the Dial Plate, as originally proposed by Price, so that it would have been easy to consult the inscription while watching the dial.[3]

The present edition of the Front Dial Inscriptions and Parapegma Inscription takes advantage of the Polynomial Texture Mapping (PTM) and Microfocus X-Ray Computed Tomography (CT) imaging of the fragments that was carried out in 2005 by the Antikythera Mechanism Research Project in collaboration with the National Archeological Museum.[4] CT has made it possible to read text hidden beneath layers of accreted matter or on surfaces embedded within fragments, for example on portions of the dial scales that are concealed behind PP1 (Fig. 3.2). CT and PTM imaging are both helpful in detecting and reading text on exposed but damaged surfaces. The part of the Parapegma Inscription that we reconstruct as PP1 col. i was entirely unknown to its previous transcribers, Rehm, Price and Stamires. The fragments of plate bearing the text that we assign to the two columns of PP2 were known to Price and Stamires, but many letters that were either invisible or illegible to them can now be read accurately through CT. Even PP1 col. ii, which is on a fully exposed plate, has been augmented with letters that were missed by all previous transcribers from Rehm onwards. Complementing the new imaging technologies, a 1905 photograph has enabled us to locate two of the small fragments as pieces broken off PP2 and to verify the reading of a lost part of PP1 col. ii, for which we were previously dependent on Price's adaptation of Rehm's unpublished transcriptions.

3 Price 1974, 16-17 with Fig. 7.

4 IAM 1.2.

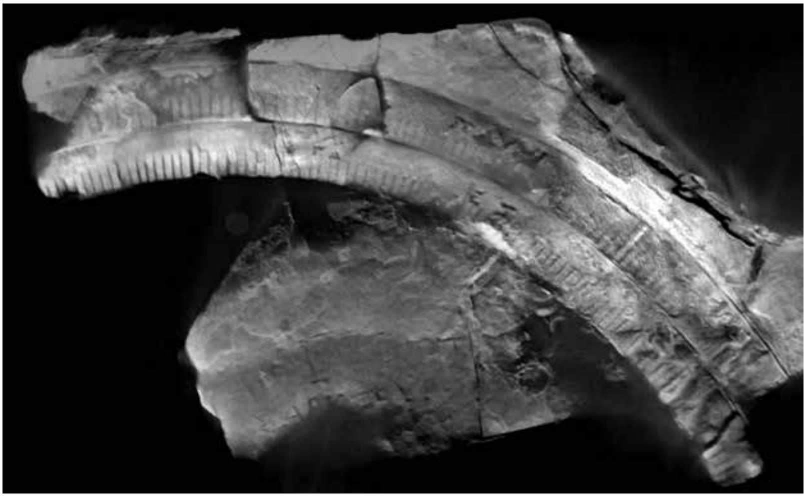

Figure 3.2: *Fragment C, CT composite image of the inscriptions of the Zodiac Scale and Egyptian Calendar Scale*
(*Image: Antikythera Mechanism Research Project)*

With more of the Parapegma Inscription at our disposal, we have learned a great deal about its structure. Rehm and Price recognized that the inscription contains chronologically ordered statements of the first and last morning and evening appearances of certain stars and constellations. It also turns out to contain statements of the solstices and equinoxes and of the Sun's entry into the twelve thirty-degree zodiacal signs. The number of listed events was 42, nearly twice as many as the 24 that Price had guessed. Price's conjecture that the inscription occupied two plates above and below the dial, in columns of text occupying half the width of each plate, was correct, as can be shown both from the logic of the inscription's arrangement and from physical evidence, although his hypothetical placements of the surviving fragments were not.[5] Each of the four columns of the inscription comprised the events falling within one of the four astronomical seasons demarcated by the solstices and equinoxes, and its location on the plates positioned it nearest to the corresponding quadrant of the dial. We have also confirmed another of Price's conjectures, that the dial was oriented such that the graduation marking the beginning of the zodiacal sign Aries and the vernal equinox was at the top. We thus obtain a clearer and more secure reconstruction of the appearance of the Mechanism's front face than has previously been possible.

5 See Price 1974, 17, fig. 7, for his hypothetical layout, according to which the parapegma began in the right half of the upper plate, and continued through two columns on the lower plate, so that the text on C-1, our PP1 col. ii, is the *left* column of his lower plate.

3.2 Fragments preserving parts of the Front Dial and Parapegma Inscriptions

The preserved Front Dial Inscriptions are entirely in Fragment C, while parts of the Parapegma Inscription are in C and the four small fragments 9, 20, 22, and 28.

The dimensions of Fragment C (Fig. S3 and S4) are approximately 106 mm (width) by 96 mm (height) by 22 mm (thickness). It consists of three originally separate major components that fused together during the long immersion of the Mechanism. These are, listed from back (C-2) to front (C-1):

(1) The Moon Casing, a circular disk or boss of diameter 65 mm having a shallow cylindrical wall (1 mm thickness) projecting outwards 7 mm from the disc where not broken away, the whole resembling the lid of a jar. There are numerous mechanical details that need not be described here.[6] This was the casing, with a surviving fragment of the assembly, of a display of the spherical Moon making its revolution around the Earth while exhibiting its cycle of phases. We are not concerned with the Moon Casing in the present paper.

(2) Part of the front face of the Mechanism, the principal element of which was the Dial Plate, a nearly square plate approximately 165 mm height by 171 mm width, with a circular cutout of diameter approximately 132 mm, and a ring-shaped sink, about half the depth of the plate, having outer diameter about 162 mm and inner diameter about 146 mm. One corner of the Dial Plate, amounting to a little less than a quarter of the whole, survives.

The ring-shaped surface between the inner circumference of the sink and the circumference of the cutout was engraved with the Zodiac Scale. This scale, about a fifth of which survives, was graduated by radial lines into twelve sectors labelled with the names of the signs of the zodiac (letter height averaging about 1.8 mm), and each sector was subdivided by shorter radial lines (about 3 mm long) into 30 individual degrees, some of them labelled with letters of the Greek alphabet (letter height averaging about 1.2 mm).[7] The sink, which was normally concealed, was drilled through with 365 small holes, of diameter about 0.7-0.8

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6 For details see Wright 2006, where the purpose of this component was brilliantly explained for the first time, and Carman & Di Cocco 2016.

7 A shallow circular groove runs around the dial along the exterior ends of the short graduation strokes on both the Zodiac and Egyptian Calendar Scales. Perhaps these were guidelines to help the engraver keep the strokes equal in length.

mm, at approximately equal spacing around the ring.[8]

The sink was occupied by a removable ring, the Egyptian Calendar Ring, whose thickness was approximately equal to the sink's depth so that its exposed front face was flush with the Dial Plate. This face was engraved with the Egyptian Calendar Scale, graduated into sectors corresponding to the twelve 30-day months and the five additional "epagomenal" days of the Egyptian calendar year, with smaller graduations marking the single days; again about a fifth of this scale survives. The Greek names of the Egyptian months were inscribed in the pertinent sectors (letter height averaging about 1.8 mm). Somewhere on the back face of the ring there must have once existed a peg placed so that it could be fitted in any of the 365 holes in the zodiac ring, allowing any desired alignment of the Egyptian year with the zodiacal signs.[9] It was thus a moveable calendar ring for the "wandering" year of the Egyptian calendar. The exposed front faces of the Dial Plate, the Egyptian Calendar Ring, and the Zodiac Ring were all more or less flush.

The surviving corner of the Dial Plate is perforated by a small rectangular hole, though which passes a cylindrical shaft joining a circular thumb button on the Dial Plate's front to a flat bolt on the back (Fig. 3.3). The bolt ran through a bearing riveted to the plate's back along its edge (only one supporting block of the bearing flanking the bolt survives), so that by means of the thumb button it could be slid back and forth a few millimeters. With the button at its furthest position from the plate's edge, the bolt's end would be approximately flush with the edge. This was evidently a catch by which the Dial Plate could be held in position or removed to expose the gearwork behind; there were probably such catches in all four corners of the plate.[10]

8 The outer circumference of the sink appears to be cut right through the Dial Plate so that the part comprising the sink and the Zodiac Scale constitutes a separate element from the outer part of the Dial Plate. This may have been a consequence of imperfect workmanship in making the sink (M. T. Wright, by personal communication). The parts of the plate were held together by a thin backing ring and a curious channel-shaped feature that ran along the back of the scales. There are also remains of what may have been a second, smaller backing ring adhering to the back of the zodiac scale, suggesting that there once existed a further plate element filling in the circular cutout and providing a “background” for the revolving pointers.

9 If there had been more than one peg, irregularities in the positions of the pegholes might have made it difficult to install the ring in some orientations.

10 Wright 2011, 12. In Fragment F there is a broken corner of a plate furnished with a very similar sliding catch. The catch is in better condition than the one in C, and the bearing is intact. The identification of this corner as part of the Back Cover Plate (Freeth & Jones

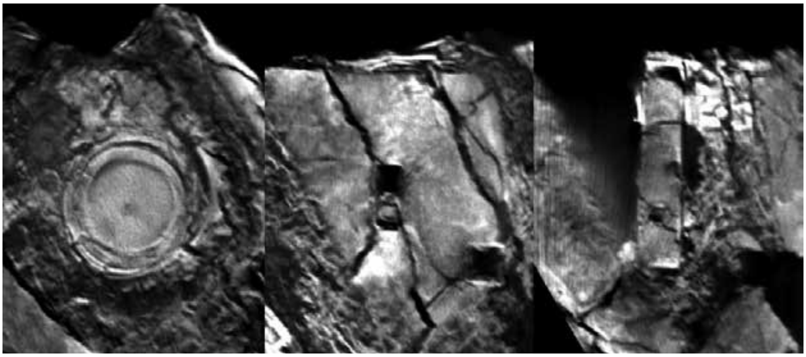

Figure 3.3: *Fragment C, CT slices through the thumb button (left), hole in Dial Plate (center), and bolt of the sliding catch (right, with remains of the mounting of the bearing to the bolt's right, near the upper edge)*
(Images: Antikythera Mechanism Research Project)

The original orientation of the surviving part of the Dial Plate, relative to the Mechanism as a whole, is partially determined by the two surviving straight edges of the plate, which are respectively perpendicular and parallel to a radius running from the center point of the scales through the graduation on the Zodiac Scale marking the beginning of the zodiacal sign Libra. The names and letters inscribed on the dials do not establish which of the four possible orientations is correct, since they run around the rings, perpendicular to whatever radius passes through them.[11]

(3) The Parapegma Plates, two plates inscribed with text on one face. Both are fragments broken on most sides, so that their original extent is not immediately obvious, but one of them has part of a straight lower edge, and the other has part of a straight upper edge preserved. These edges are exactly parallel to the lines of inscribed text. The larger fragment, which we will call PP1, is pressed against parts of the Moon Casing and the Dial Plate and its scales, and it is significantly buckled, especially where it lies on top of the thumb button. Its inscribed text faces forwards, and is oriented such that the beginning of Libra on the Zodiac Scale is upward. Its lower edge is preserved.

2012, 1.4.1) is not at all a certainty since the fragment is uninscribed and is stuck on F with the face bearing the thumb button facing inwards, against the Back Plate, so its position has obviously been disturbed. The possibility that it was actually another corner of the front Dial Plate that broke off and fell through to the rear of the Mechanism cannot be excluded.

11 Decisive physical evidence, such as matching fracture marks, seems to be lacking that would demonstrate whether (and if so, in what way) Fragment C was originally joined directly to Fragment A. Price (1974, 12 and 47) believed that he had confirmed such a fit in 1961, but his claim has been contradicted by Wright 2006, 323.

Riveted to the back of PP1 and along the right surviving end of this edge is a bearing (Fig. 3.4) that appears to have been like the less well preserved bearing of the catch on the Dial Plate. There is no evidence of any component mounted on PP1 that would have passed through this bearing. The other fragment, PP2, is pressed against the Moon Casing, and its inscribed side faces backwards (and thus is partly concealed by the Moon Case), again oriented so that the beginning of Libra is upward. Near the left extremity of its straight edge (with respect to the inscribed side), and very close to the edge itself, the plate is perforated by a small drilled hole, apparently filled by a nail or rivet that continues through a thin vestige of a more or less rectangular feature that was mounted on the back (uninscribed) face of the plate (Fig. 3.5).

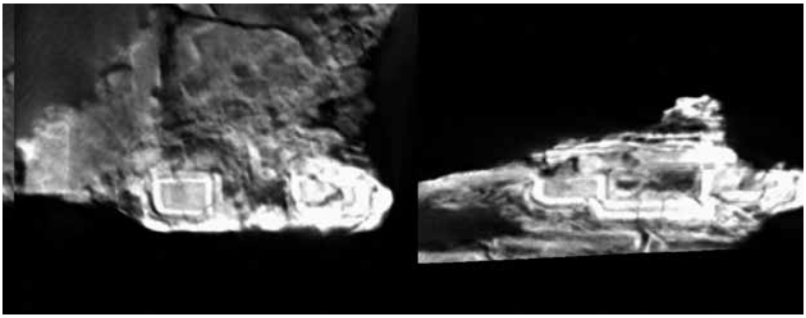

Figure 3.4: *CT slices through the bearing on PP1 in Fragment C: (left) parallel to the plate and through the feet of the bearing; (right) perpendicular to the plate (Images: Antikythera Mechanism Research Project)*

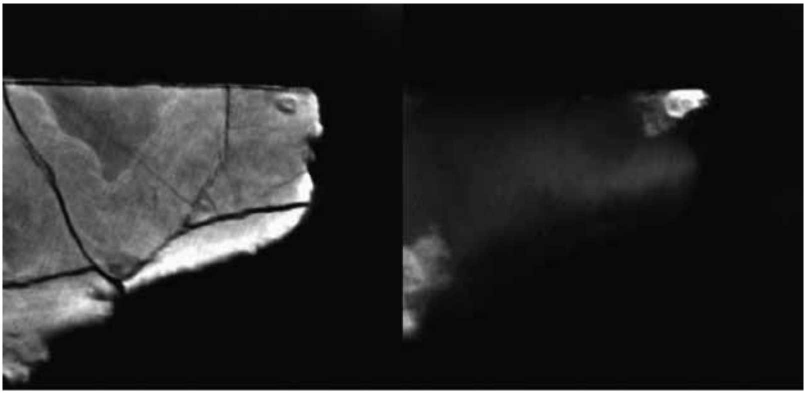

Figure 3.5: *Nail or rivet near the edge of PP2 in Fragment C: (left) CT slice through the plate; (right) CT slice slightly behind the rear (uninscribed) face of the plate (Images: Antikythera Mechanism Research Project)*

In PP1, parts of nine lines of a column of the Parapegma are preserved, with a baseline-to-baseline spacing of about 5.1 mm, along with a vestige of a single line of another column. PP2 preserves parts of four lines of a column of the inscription, with baseline-to-baseline spacing about 5.6 mm. The normal letter height on both plates ranges from about 2.5 mm to about 3.0 mm. The average letter spacing (from left side to left side) is about 3.0 mm, again with considerable variation from line to line.

Later in this paper (section 3.9) we will show, as Price suspected, that the radius through the beginning of Aries on the Zodiac Dial Scale pointed straight upwards, and the radius through the beginning of Libra straight down. This is not, however, something that one can deduce by simply looking at the fragment. As it is normally portrayed in photographs and drawings, and as it has been mounted in the Museum for many years, the radius through the beginning of Libra points upwards, because with this orientation all the inscribed texts visible on the dials and plates are more or less right way up.

The three components of Fragment C described above are stuck together in a manner that obviously does not reflect their original positions in the original Mechanism. Besides facing in opposite directions, the texts inscribed on the two parapegma plates are not exactly horizontal, as defined by the radii perpendicular to the radius through the beginning of Libra. PP1 is tilted about 6° counterclockwise from horizontal, and PP2 is tilted clockwise about 4°. The Moon Casing was originally at the center of the dials, with its periphery concentric with them; but in its present position it is displaced so far off center that part of it is directly behind, and stuck to, the back of the dial scales. All these elements must have shifted in position and orientation during or after the shipwreck.

Photographs allow us to trace the history of Fragment C in reverse order from its present state, which has not significantly altered since 1953.[12] For Fragment C in its previous state, the most substantial evidence we have is the pair of Karo's 1905 photographs showing C-1 (supplementary Fig. S10) and C-2, and the 1918 photograph of C-2.[13] These show that both parapegma plates were much more extensively preserved than they are now.[14] The

12 Photographs from Price's 1958 visit to the Museum, in the Adler Planetarium collection, show Fragment C with a small piece broken off of PP2 (as it was in the 1953 photographs and in its present condition). This damage seems to have been repaired at the time, and has no significance for our investigations.

13 The 1918 photograph of C-1 is spoiled by bad exposure and lighting, at least in Rehm's print. See also Theofanidis [1927-1930], "99" [correct pagination: 91] and 1934, 144 for rather crude line drawings of C-2 that appear to confirm that the fragment still had the 1905-1918 outline, as well as a transcription by Leonardos that includes some text that was no longer on Fragment C after the breakage.

14 The breakage must have been accidental, and probably occurred during the emergency

back faces of the parapegma plates on C-2 were covered with a layer of accretion, so that the inscription that is now easily made out on the small remaining exposed surface of PP2 was invisible. This surface was probably cleaned during the 1953 conservation.

For the 1903 state, we depend on the photographs in Svoronos's volume on the Antikythera wreck of C-1 (Fig. S9) and C-2, and Rediadis's verbal description in the same volume. C-2 shows even more accretion material than in the post-1905 state, but apparently no other distinct features. C-1, on the other hand, has layers of material almost entirely covering the surfaces that were exposed in 1905. These layers were carefully removed in the c. 1905 conservation work.

During his 1958 visit, Price saw Fragment G, a fairly extensive piece of inscribed plate assembled from many smaller pieces — in his notes, he calls it the "jigsaw fragment". Probably through study of the early photographs, he realized that G had originally been the great part of the layer of material in the 1903 photograph of C-1 that concealed the parapegma plates. Though he says little about Fragment G in his 1959 *Scientific American* article, he alludes to it as the "front door" of the Mechanism, and a schematic diagram of his reconstruction of the original relative positions of the major fragments shows that he had established that, when it was part of C, G's inscription —the Front Cover Inscription[15]— was facing forwards like the inscription on PP1, but was oriented the other way up.[16] In 1974 he presented this hypothesis explicitly if rather circumspectly.[17] Close inspection of the 1903 photograph confirms that Price had the relationship of G and C exactly right.

Relying on the criteria of lettering size, line spacing, and characteristic vocabulary,[18] we can identify four small fragments as having belonged to the Parapegma Inscription (Fig. 3.6). Three of these were already identified as such by Stamires and Price.[19]

wartime storage (IAM 2.1).

15 See IAM 6.

16 Price 1959, 65 and diagram on 62-63. This diagram (as well as a photograph in the Adler Planetarium collection from 1958 showing Price examining the fragments) shows a slightly larger Fragment G than now exists, incorporating the present Fragment 29 at its bottom left.

17 Price 1974, 21-22 with figure 10. The statement on p. 47 that Fragment G was assembled from pieces removed from Fragment *B* is presumably a typographical error.

18 See IAM 1.4.

19 Price 1974, 46, fig. 35.

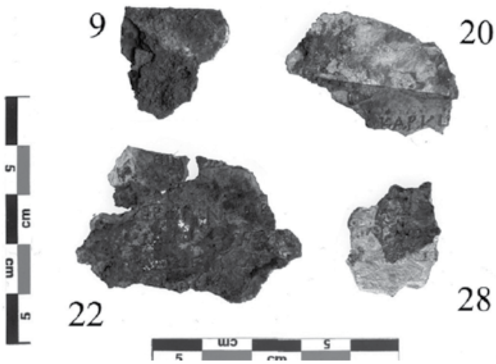

Figure 3.6: *Fragments 9, 20, 22, and 28*
(Images: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

Fragment 9. Width 21 mm, height 23 mm. A piece of plate with parts of four lines of inscription (letter height about 2.3 mm, baseline-to-baseline about 4.7 mm), almost entirely concealed by a layer of other material; slightly above the top line is a straight edge parallel to the text, which must have been the original top edge of the plate. Fragment 9 does not appear in any photographs before 2005, and is not mentioned in *Gears from the Greeks*.

Fragment 20. Width 36 mm, height 27 mm. The fragment is composed of two pieces of plate that slightly overlap. One of these, which bears part of one line of inscription (letter height about 2.5 mm), has a straight upper edge running parallel to the text; this would have been the original edge of the plate. Between the left margin of the text and this edge, a small circular hole is drilled through the plate, and a small object having a rectangular cross-section is lodged in the hole, seemingly the remains of a peg or rivet. The edge of the other plate that overlies this edge at a slight angle (about 10°) is also straight and thus an original edge. In the transcription of the parapegma inscription in *Gears from the Greeks* this is fragment (ii).

Fragment 22. Width 47 mm, height 32 mm. A piece of plate, preserving no original edges, with parts of six lines of inscription (letter height about 2.5 mm, baseline-to-baseline about 5.3 mm). This is Price's fragment (v).

Fragment 28. Width 20 mm, height 25 mm. A piece of plate, preserving no original edges, with parts of four lines of inscription (letter height about 2.3 mm, baseline-to-baseline about 5.3 mm). This is Price's fragment (iv), but Price and Stamires evidently had difficulty making out the text, and their attempt at a transcription has the fragment oriented the wrong way up.

3.3 Previous transcriptions

During his visits to the Museum in 1905 and 1906, Rehm transcribed PP1 col. ii, as well as the single word, Παχών, on the Egyptian Calendar Scale.[20] His reading of Παχών was reported in print in a monograph on the Mechanism by K. Rados, but the transcription of the Parapegma Inscription remained in manuscript, and in fact Rehm never referred to it in any of his substantial later publications on parapegmata.[21] Meanwhile in the 1920s the epigrapher Vasileios Leonardos read part of the parapegma text —not very accurately— for Ioannis Theofanidis, who included it in his encyclopedia article on the voyages of St. Paul with a terse interpretation of the text as instructions for determining the season of the year.[22]

In 1958, Price and Stamires transcribed the texts that they could make out on what was left of the plate and the dials, and Price published a drawing of Fragment C with these transcriptions the following year.[23] Price also discovered that the lines of the Parapegma Inscription were keyed to graduations on the dial by means of a series of alphabetically ordered index letters. Subsequently he gained access to Rehm's papers, and the transcriptions that he included in his 1974 *Gears from the Greeks* incorporate Rehm's readings from the parts of Fragment C that had broken off.[24] In this work Price also drew attention for the first time to the survival of other bits of parapegma text visible on the back face of the other plate stuck to the front dial on Fragment C as well as on three small fragments. As we have already noted, he conjectured that the Parapegma Inscription was laid out in a two-column format on two rectangular plates that were originally situated above and below the front dial, and he attempted a tentative and partial reconstruction of the parapegma text.

20 The extant transcriptions of the Parapegma Inscription are Rehm 1905, 21 and Rehm 1906b, 3. Both must have been copied from manuscript transcriptions that have not been located. Price 1974, 46 incorporates readings from Rehm's 1906 version, a handwritten copy of which (not quite identical to the one in Rehm 1906b) is in the file of Price's transcriptions at the Adler Planetarium, Chicago. The Παχών reading is first reported, with the first letter indicated as illegible, in Rehm 1905, 19, and with all letters shown as clear in Rehm 1906a, 86.

21 Rados 1910, 34. Rados learned of the reading from a lecture that Karo gave at the Deutsches Archäologisches Institut in Athens on December 6, 1906 about the Antikythera wreck, in which he presented part of Rehm's unpublished research on the Mechanism (Rados 1910, 1, note 1); see IAM 2.1.

22 Theofanidis [1927-1930] "99" [correct pagination: 91]. The text is reproduced in Theofanidis 1934a, 144, where it is described as "une instruction pour les levers et couchers des astres du Zodiaque".

23 Price 1959, 65.

24 Price 1974, 18 (dial inscriptions), 46, and 49 (parapegma).

The provisional new texts of inscriptions on the Mechanism published in 2006 did not include the Front Dial and Parapegma Inscriptions.[25] A partial restoration of these inscriptions based on a preliminary version of the texts published here was incorporated in T. Freeth's digital reconstruction of the Mechanism's front face as published in 2012.[26]

25 Freeth et al. 2006.

26 Freeth & Jones 2012, Fig. 4. Dr. Freeth participated in discussions with the present authors concerning the Parapegma Inscription during 2008-2012, and we gratefully acknowledge his responses to proposed readings and provision of CT images.

3.4 Transcription and translation

In sections 3.7 and 3.8 we will show that Fragments 20 and 22 can be exactly placed as parts of PP2 that were still on Fragment C in its post-1905 state, and that Fragment 9 was originally a piece from the top of PP2, to the left of what remained of PP2 on the post-1905 state of C. Our transcription assumes these placements. On the other hand it remains uncertain where Fragment 28 belonged (see 3.11), so we present its text as an unplaced fragment. More generally we adopt a cautious and minimal approach to restoring the Parapegma Inscription's text; more extensive restorations dependent on hypothetical elements are offered in sections 3.9-3.11.

The transcriptions are based on the 2005 CT, PTM, and photographs, and on the 1905 photograph of C-1 (supplementary Fig. S10). Letters that are extant or legible only in the 1905 photograph are underlined.[27] For the Parapegma Inscription, the notations x+1 etc. (z+1 etc. for Fragment 28) are used to number lines when it is not visually evident how many lines preceded the top line of a surviving sequence. The fragments preserving parts of each line of the Parapegma Inscription are indicated in parentheses to the left of the text.

Names of zodiacal signs on the Zodiac Scale

1. Extending from left edge to the 19th graduation of the leftmost (Virgo) sector (counting clockwise from the presumed longer graduation marking the beginning of this sector, which we count as the 1st graduation):
   [Παρθ]ένος
   Virgo

2. Extending from the 9th to the 17th graduation of the next (Libra) sector:
   Χηλαί
   Libra

3. Extending from the 9th to the 20th graduation of the next (Scorpio) sector:
   Σκ̣ορπ̣ίος
   Scorpio
   κ̣: entire letter visible but faint | ι̣: indistinct

27 Karo's 1905 photograph of C-1 is the only known photograph to show legibly the part of PP1 col. ii that was subsequently lost to breakage, as well as the small region of the calendar dial exposed in Fragment C's post-1905 state. This area of the dial, with its month-name inscription, is still extant but was in better condition in 1905 than it is now. Other photographs from before 2005 show no details of the inscriptions that cannot be seen at least as well by means of CT or PTM.

4. Extending from the 10th graduation of the next (Sagittarius) sector to the right edge:

Τοξ[ότης]

Sagittarius

Index letters on the Zodiac Scale

Virgo sector (preserved from its 15th graduation on, but surface damaged to the left of the 19th graduation):[28]

To the right of the 19th graduation: Ψ̣

To the right of the 21st graduation: Ω

The index letters in this sector were read from PTM ak32a; they cannot be seen in CT. | Ψ̣: lower portion of a vertical with a broad serif.

Libra sector:

To the right of the 1st graduation: Α

To the right of the 11th graduation: Β

To the right of the 14th graduation: Γ

To the right of the 16th graduation: Δ

Scorpio sector:

To the right of the 1st graduation: Ε

To the right of the 4th graduation: Ζ

To the right of the 17th graduation: Η

To the right of the 22nd graduation: Θ

Sagittarius sector:

To the right of the 1st graduation: Ι

To the right of the 3rd graduation: Κ̣

To the right of the 7th graduation: Λ

Κ̣: entire letter visible but faint

28 Price 1959, 65, reports no index letters in this sector, but Price 1974, 18, reports "with great uncertainty" Ω to the right of the 18th graduation (counting clockwise from the extrapolated 1st graduation as defined above). We suspect that he interpreted the remains of the psi that we report above as the lower right portion of this supposed omega.

Names of Egyptian months on the Egyptian Calendar Scale

1. Extending from the 7th through the 18th graduation of the leftmost (Pachon) sector (counting clockwise from the presumed longer graduation marking the beginning of this sector, which we count as the 1st graduation):
Παχ̣ών
Pachon

Indistinct traces of x are visible in the 2005 photograph and PTM (ak32a); the letter is clear in the Karo photograph.

2. Extending from the 10th through the 19th graduation of the next (Payni) sector:
Παῦνι
Payni

3. Extending from the 10th through the 21st graduation of the next (Epeiph) sector:
Ἐπείφ
Epeiph

Parapegma Inscription
PP1

col. i.

(9) *top margin 2.5 mm.*
1 [Αἰγοκέρως ἄρχ]ε̣ται ἀνα[τέλλειν.]
2 [*v* τροπαὶ χει]μ̣εριναί[ί. Α]
3 [–7– ἐπιτέλ]λ̣ει *v* ἑσ̣[πέριος/περία. *nn*]
4 [–13–]. Ε. [
3-4 lines lost

(C) x+1 [ ] ΙΑ
— — —

(9) 1 [Capricorn] begins to rise.
2 Winter [solstice. 1]
3 [ ] rises in the evening. [*nn]*
4 [ ]...[
3-4 lines lost

(C) x+1 [ ] 11
— — —

1 Ε̣: serifed top and bottom horizontals, apparently some spread towards right, notch along edge about halfway between the two horizontals; either Ε or Σ
2 Μ̣: apparent upper right end of ascending oblique, meeting a straight vertical (inclining slightly counterclockwise of true vertical) near the top; the bottom of the vertical not preserved | Ι̣²: serif and very top of vertical
3 Λ̣: lower portion of descending oblique along edge with serif at bottom; N appears to be excluded since there is no trace of the right vertical | *v*: one letter | Σ̣: trace of upper left corner along edge
4 ̣¹: top of serifed(?) vertical along edge | ̣²: notch along edge at top height, belonging to a serif or gently descending oblique
x+1: this line vertically half-way between col. ii lines x+6 and x+7, and ending immediately to the left of the beginnings of those lines

col. ii.

— — —

(C) x+1 [Κ *v* –12–] ̣ Ι ἑσ̣[π]ερ̣[ί]α̣[*nn*]
x+2 <u>Λ</u> *v* <u>Ὑάδ̣</u>[ες δύον]ται ἑσ̣περίαι̣. *v* ΚΑ
x+3 <u>Μ</u> *v* <u>Ταῦρ̣ο̣ς̣ ἄρ̣χ̣ε̣τ</u>αι ἀνατέλλειν. Α
x+4 [Ν *v*] <u>Λύ̣ρα</u> ἐ[πιτ]<u>έ̣λ̣λ̣ε̣</u>[ι] ἑσπερία. *v* ΙΑ
x+5 Ξ̣ *v* Πλειὰς ἐπι[τ]έλλει ἑῴ̣α̣. *v* ΙΖ̣
x+6 Ο *v* Ὑὰς ἐπιτέλλει v ἑώια. *v* Κ̣Ε
x+7 Π *v* Δίδυμοι ἄρχονται ἐπιτέλλε̣ι̣ν̣. [Α]
x+8 Ρ *v* Ἀετὸς ἐπιτέλλει ἑσπέριο[ς. *nn*]
x+9 Σ *v* Ἀρκτοῦρος δύνει *v* ἑῷ̣ιος. *v* Ι̣
bottom margin 7 mm.

— — —

x+1 [Κ] in the evening. [*nn*]
x+2 Λ Hyades set in the evening. 24
x+3 Μ Taurus begins to rise. 1
x+4 [Ν] Lyra rises in the evening. 11
x+5 Ξ Pleiad rises in the morning. 17
x+6 Ο Hyad rises in the morning. 25
x+7 Π Gemini begin to rise. [1]
x+8 Ρ Aquila rises in the evening. [*nn*]
x+9 Σ Arcturus sets in the morning. 10

All lines *v*¹ (following index letter): average about 2 mm.
x+1 ̣ : serifed right ends of horizontals at top and baseline level, apparently diverging slightly, and a horizontal or mark just above half height, either Ε̣ or Σ| σ̣: lower left corner and indistinct trace of upper left corner | ρ: very bottom of vertical and serif, faint | *v*²: half a letter
x+2 δ: lower part of descending oblique visible in Karo photograph; Rehm also reads δ | σπ: very indistinct, but π is clear in Karo photograph | ι̣³: only top of vertical with serif,

faint | v^2: one letter

x+3 ι̣^{2}: indistinct, along break

x+4 v^2: two letters

x+5 Ξ̣: most bottom stroke with serif at right end; right portion of middle stroke | ι̣^{4}: serifed top of vertical stroke | α̣^{2}: lower part of serifed ascending oblique stroke | v^2: width of one to two letters | Ζ̣: top and bottom serifed horizontal strokes, straddling a crack; vertical stroke would coincide with crack

x+6 v^2: one letter | v^3: width of four letters | Κ̣: serifed vertical, faint traces of left ends of both oblique strokes, close to following Ε

x+7 ι̣ν̣: indistinct traces

x+8 v^2: width of one letter | Ε̣: very faint but complete

x+9 v^2: half a letter | ι̣^{2}: indistinct traces | v^3: width of three letters | Ι̣: vertical stroke serifed at both ends, surface damaged to the right

PP2

col. iii.

(C+22) top margin 7.5 mm

[Α *v* Χηλ]αὶ ἄρχονται ἐπιτ̣[έ]λ[λ]ειν.
[*v* ἰσημ]ερ̣ί̣α̣ φθ̣ινοπ̣ω̣ρι̣νή. *v* Α
[Β *v* –5– ἐπι]τέλλουσιν [ἑ]σ̣π̣έριοι. ΙΑ
[Γ *v* –6– ἐπιτ]ελλε[ι ἑσ]περία. ΙΔ
(22) [Δ *v* –14– ἐπι]τ̣έλ̣λει. ΙϹ
[Ε *v* Σκορπίος ἄρχεται ἐπιτέλ]λ̣ειν. Α̣
— — —

(C+22) [Α] Claws (i.e. Libra) begin to rise.
[ ] Autumnal equinox. 1
[Β] rise in the evening. 11
[Γ] rises in the evening. 14
(22) [Δ] rises [in the morning/evening.] 16
[Ε Scorpio begins] to rise. 1
— — —

1 τ̣^{2}: left portion of horizontal, and serifed bottom of vertical

2 ρ̣ι̣α̣: complete but blurry | θ̣: indistinct traces | π̣: right end of horizontal and short right vertical | ω̣: complete but blurry | ι̣^{4}: top of serifed vertical | v^2: width of one letter

3 σ̣^{2}: bottom left corner | π̣^{2}: bottom of right vertical

5 τ̣^{2}: horizontal along edge

6 [ἐπιτέλ]λ̣ειν: or [ἀνατέλ]λ̣ειν | 6 λ̣^{2}: apex along edge | Α̣: top parts of ascending and descending obliques

col. iv.

(22+20) *top margin 7.2 mm*
1 Μ *ν* Καρκί[νος ἄρχεται ἐπιτέλλειν.]
(22) 2 [τροπαὶ θεριναί. Α]
3 Ν *ν* Ὠρί̣[ων ἐπιτέλλει ἐῷιος. *nn*]
4 Ξ *ν* Κ̣ύων̣ [ἐπιτέλλει ἐῷιος. *nn*]
5 Ο *ν* Ἀετ[ὸς δύνει ἐῷιος. *nn*]
6 Π̣ *ν* Λ̣[έων ἄρχεται ἐπιτέλλειν. Α]
— — —

(22+20) 1 Μ Cancer [begins to rise.]
(22) 2 [Summer solstice. 1]
3 Ν Orion [rises in the morning. *nn*]
4 Ξ Sirius [rises in the morning. *nn*]
5 Ο Aquila [sets in the morning. *nn*]
6 Π Leo [begins to rise. 1]
— — —

All lines *v*[1] (following index letters): average about 2.5 mm
1 [ἐπιτέλλειν]: or [ἀνατέλλειν]
2 ν̣ή: the surface of the plate bearing the writing is twisted about 30° counterclockwise from horizontal
3 ι̣[1]: bottom serif of vertical stroke
4 Κ̣: descending oblique with serif | ν̣: left vertical with serif
6 Π̣: horizontal | Λ̣: ascending oblique with bottom serif, and top of descending oblique | [ἐπιτέλλειν]: or [ἀνατέλλειν].

Unplaced fragment (Fragment 28).

— — —
(28) z+1 [ ] Κ̣[*n?*]
z+2 [–*n*– ἄρχεται ἐπιτ]ε̣λλειν. [Α]
z+3 [–*n*+6– ἑσπέ]ριος. *ν* Ι̣C
z+4 [–*n*+6– ἑσπε]ρία̣. *ν* Κ[*n?*]
z+5 [–*n*+11–]Ε̣ ̣ ̣[ ]
— — —

— — —
(28) z+1 [ ] 2[*n?*]
z+2 [begins] to rise. [1]
z+3 [ ] in the evening. 16
z+4 [ ] in the evening. 2[*n?*]
z+5 [ ] ... [ ]
— — —

z+1 Ḳ: apparently a descending oblique with serif, and faint lower portion of vertical, but it is not certain that these are not accidental marks
z+2 ε̣[3]: trace of bottom horizontal along edge
z+3 *v*: two letters. Ị: top of a serifed vertical
z+4 ά̣: lower end of ascending oblique with serif | *v*: three letters
z+5: The original surface of the plate has been stripped away in the region around this entire line, and the traces are very shallow and faint. | Ẹ: top of vertical, whole of serifed top horizontal, right ends of middle horizontal, and right end of serifed bottom horizontal, all rather faint | . . : very uncertain traces

3.5 Parapegmata

The term "parapegma" is used in both ancient texts and modern scholarship with two distinct though overlapping meanings.[29] On the one hand any Greco-Roman artefact furnished with a series of peg-holes standing for units of time, especially days, composing a repeating cycle can be called a parapegma; the holes are typically accompanied by inscriptions or pictorial elements associating the stages of the cycle with something else, for example the deities associated with the seven days of the planetary week. The ancient Greek word *parapêgma,* meaning *"beside-pegging,"* must have originally referred to this kind of object. On the other hand, a text written on any medium that lays out in chronological order an annually repeating cycle of days associated with events and phenomena, among which dates of first and last visibility of stars and constellations (referred collectively as *phaseis*, "appearances," or as *phaseis* and *krypseis*, "disappearances") figure prominently, is a parapegma. What connects the two uses of the word is a category of public inscription, specimens of which dating from the second or early first centuries BC have been found at Miletos, that used a series of peg-holes to represent the days in a solar year, with inscriptions next to many of the holes describing astral and other events associated with the corresponding days.[30] The Parapegma Inscription of the Mechanism is a parapegma in the second sense.

One of the best preserved and most characteristic parapegmata is a text, probably composed during the Hellenistic period (certainly not before the late third century BC), that is appended to the end of Geminos's *Introduction to the Phenomena* (mid first century BC) in the medieval manuscript tradition; whether Geminos was responsible for its presence there is an open question, but it is conventionally referred to as the Geminos Parapegma.[31]

29 Parapegmata of both kinds are surveyed and catalogued in Lehoux 2007.

30 Fragments of two parapegma inscriptions were found during the German excavations at Miletos in 1902-1903. One of them, probably laid out in a format of one column for each zodiacal month (notwithstanding Rehm's objection, Rehm 1904, 753), is represented by IMilet. inv. 456A, 456D, and 456N. 456C, which contains a dedication by Epikrates son of Pylon and an introductory text with different but similar letter forms, and traces of peg holes along the right side, probably also belongs to this parapegma. Epikrates son of Pylon is also known from the dedication of his statue base, *IMilet.* 331, and, according to a likely restoration of his name in *IMilet.* 107, he held the honorary office of stephanephoros in a year that must have fallen within the gap between 184/183 BC and 89/88 BC in the preserved lists of Milesian stephanephoroi (he was not stephanephoros *in* 89/88 BC as stated by Lehoux 2005, 134). The other Milesian parapegma inscription, laid out in a format of two zodiacal months per column, is represented by 456B. The inscriptions were published in Diels & Rehm 1904 and Rehm 1904, and again more conservatively in Lehoux 2005.

31 Complete translation in Evans & Berggren 2006, 231-240.

We shall frequently have occasion to refer to this text. It describes recurring events in a solar year beginning with the Summer Solstice and divided into twelve parts or "zodiacal months," each beginning with the Sun's entry into a new zodiacal sign. Within each zodiacal month, events are assigned to day numbers counted from the Sun's entry as "day 1." The section for Taurus is a typical specimen:

> The Sun traverses Taurus in 32 days.
>
> On the 1st day, according to Eudoxos, Orion sets acronychally; rains. According to Kallippos Aries finishes rising; rains, often also hail.
> On the 2nd day, according to Euktemon, Sirius is hidden; and hail occurs; on the same day Lyra rises. According to Eudoxos, Sirius sets acronychally; and rain occurs. According to Kallippos, the tail of Taurus rises; southerly winds.
> On the 7th day, according to Eudoxos, rain occurs.
> On the 8th day, according to Euktemon, Capella rises in the morning; fair weather; it rains with southerly water.
> On the 9th, according to Eudoxos, Capella rises in the morning.
> On the 11th, according to Eudoxos, Scorpius begins to set in the morning; and rain occurs.
> On the 13th, according to Euktemon, the Pleias rises; beginning of summer; and weather-change. According to Kallippos, the head of Taurus rises; weather-change.
> On the 21st, according to Eudoxos, the whole of Scorpius sets in the morning.
> On the 22nd, according to Eudoxos, the Pleiades rise; and weather-change.
> On the 31st, according to Euktemon, Aquila rises in the evening.
> On the 32nd, according to Euktemon, Arcturus sets in the evening; weather-change. According to Kallippos, Taurus finishes rising. According to Euktemon, the Hyades rise in the morning; weather-change.

The visibility events associated with asterisms (stars, star clusters, and constellations) in the Geminos Parapegma and other documents of its kind are consequences of the fact that all stars rise and set a few minutes earlier every day than the day before. Four kinds of visibility events are recognized:

> Morning rising: the first occasion when the asterism can be seen close to the eastern horizon before sunrise, after an interval of some days on which the asterism could not be seen at that time.[32]

32 Geminos 13.9, ed. Manitius 148, defines the morning rising as "when (the star) rises enough in advance (of the Sun) so that the star has escaped the Sun's rays and its rising can be beheld."

Evening setting: the last occasion when the asterism can be seen close to the western horizon after sunset, or perhaps the following day, when the asterism can no longer be seen; the verb *kryptesthai* ("to disappear") is sometimes employed instead of *dynein/dynesthai* ("to set").[33] In ancient texts, e.g. in the line quoted above for the first day in the zodiacal month of Taurus, this event is sometimes designated "acronychal setting," meaning setting at nightfall.

Evening rising: the last occasion when the asterism can be seen rising at the eastern horizon after sunset, or perhaps the following day, when it is already above the horizon when first sighted.[34] This event is also called "acronychal rising" both in ancient texts and modern terminology.

Morning setting: the first occasion when the asterism can be seen setting below the western horizon before sunrise, following days on which the asterism is still above the horizon at dawn.[35] In modern terminology (but not in ancient parapegmata) this event is sometimes called "cosmic rising".

Very occasionally, a parapegma will also record dates when a star becomes "conspicuous" (*phaneros*) a few days after its morning visibility. For constellations, distinct dates may be specified for when the constellation is considered to be visible for the first or last time in its entirety, when it begins to be visible or invisible, or when specified stars within it are visible for the first or last time. Some parapegmata, including the Geminos Parapegma but apparently not the Mechanism's inscription, intermittently leave out the indication of whether it is a morning or evening event.

The Geminos Parapegma exhibits features that are frequently encountered in other parapegmata, though as it happens, *not* in the Mechanism's Parapegma Inscription:

33 Geminos 13.18, ed. Manitius 152: "when some star is beheld setting after the Sun after sunset" (presumably for the last time). According to Geminos's definitions, the evening events are symmetric with their morning counterparts, that is, the morning rising and evening setting have the asterism visible close to the horizon respectively for the first and last time, while the morning setting and evening rising have the asterism seen crossing the horizon respectively for the first and last time. Since the evening events are defined as the last evening when a certain criterion is met, an observer would have to wait one more night to confirm that either evening event has taken place.

34 Geminos 13.13, ed. Manitius 150: "when (the asterism) first is beheld as having escaped the rays of the Sun after sunset."

35 Geminos 13.16, ed. Manitius 152: "when the star is seen setting for the last time before the rising of the Sun."

statements of weather changes, and attributions of both the astral and meteorological statements to specific authorities, mostly the well known Greek astronomers Euktemon, Eudoxos, and Kallippos. (In Lehoux's nomenclature, a parapegma containing weather phenomena is "astrometeorological," and one that cites authorities is "attributive".) The Greek parapegma tradition regularly omitted a kind of information that might seem essential: the geographical locations for which the statements are supposed to be valid. Only the parapegma that Ptolemy published in his *Phaseis*, which is an effort at reform of the genre, provides geographical data.[36] Also characteristic is the lack of clear definition for the asterisms in the visibility statements: constellations, including some large ones such as Orion, and clusters such as the Pleiades, are more commonly cited than single stars, and we are usually not told the criteria for determining when such an object is visible in whole or part.[37] (Again, Ptolemy breaks with tradition by restricting consideration to individual bright stars.)

The reason for inscribing a parapegma on the Mechanism, the derivation of its contents, and its relation to other surviving parapegmata are questions beyond the scope of the present paper. It is worth remarking, however, on the centrality of parapegmata in the history of Greek astronomy. If the very frequent citations of Euktemon and Eudoxos in the extant parapegmata are authentic, Greek astronomers were compiling the kinds of statement recorded in parapegmata as far back as the fifth century BC, while the format as a serial list of days in an annual cycle is attested already around 300 BC in the Greek papyrus *P. Hibeh* 1.27.[38] While mathematical modeling of the motions of the heavenly bodies acquired greater importance in the astronomy of late Hellenistic and Imperial times, we nevertheless find the great second century BC astronomer Hipparchos among the authorities for parapegma data, and Ptolemy as the author of an extant parapegma. The tradition was still alive in late antiquity.

36 Heiberg 1907, 66-67.

37 Occasionally a specific part (i.e. star) of a constellation is indicated, e.g. "the shoulder of Orion rises," in contrast to the less specific "Orion begins to rise" or "Orion rises entire."

38 *P. Hibeh* 1.27 (published in Grenfell & Hunt 1906) has unusual features in its use of the Egyptian calendar and its inclusion of religious festivals and calculated lengths of daylight, perhaps reflecting its Greco-Egyptian provenance as much as its early date. Since the Egyptian calendar year had a constant length of 365 days, the dates associated with astronomical statements in the papyrus would have rapidly lost their validity. The *word* "parapegma" first occurs in another papyrus dating from the second century BC, *P. Ryl.* 4.589 (published in Hunt *et al.* 1911-1952, vol. 4), though the surviving part contains a schematic lunisolar calendar but no astral and meteorological statements. Geminos is the earliest extant author who employs the word in the sense in which we use it.

3.6 The Parapegma Inscription: PP1 col. ii

The parapegma text was physically laid out in several distinct sections whose states of preservation vary considerably. We shall begin with the text on C-1, which is conspicuous in the fragment's present condition and much of which is easily legible (Figs S3 and 3.7); still more of it was preserved in Rehm's time. Our transcription differs from its predecessors in several minor details and one that is more significant: previous transcriptions did not take note of the presence of numerals at the ends of some lines. We will explain the meaning of these numerals when we come to the inscription on PP2 (section 3.7). We believe that almost every line of the inscription originally ended with such a numeral, and have indicated their expected places in the transcription and translation (where we employ "*nn*" for an undetermined numeral) even when no trace is visible. Because of the extreme distortion and damaged surface of the rightmost part of the plate, only the numeral at the end of line 2 is easily seen in a conventional photograph or by direct inspection. We only noticed the numerals here because our study of PP2 had led us to expect them. The previous transcriptions also did not record two very conspicuous letters IA at the left edge of the present fragment, at a height intermediate between lines 6 and 7, and having slightly smaller letter height than the main body of the inscription. These letters must have belonged to another column of the inscription to the left of the one under consideration. We will refer to this previously unrecognized left column as col. i and the better preserved right column as col. ii.

Figure 3.7: *Fragment C, CT composite image of the Parapegma Inscription on PP1 (Image: Antikythera Mechanism Research Project)*

The text of col. ii consists of a series of simple sentences, each preceded by a letter of the Greek alphabet and followed by a numeral. As Rehm already noted, the letters, as they were preserved in his time, ran in alphabetic order from lambda through sigma. The first partially preserved line would originally have had the letter kappa, so that the extant text should have been preceded somewhere by a further nine statements, labelled alpha through iota. The statement labelled sigma is near the bottom edge of the plate, which is clearly an original edge since it is straight and parallel to the lines of text. If there were further statements labelled tau and so forth, they would have had to be inscribed somewhere else.

Six of the preserved statements, and probably a seventh in the less well preserved line x+1, follow the fixed pattern *N V A,* where *N* is the name of an asterism (star, constellation, or star cluster) standing as the subject of the sentence, *V* is the appropriate present indicative form of a verb meaning "rises" (ἐπιτέλλω) or "sets" (δύνω or δύομαι), and *A* is an adjective, modifying *N*, meaning "in the morning" or "in the evening." Rehm recognized that these were statements characteristic of a Greek parapegma and signifying the annually recurring event when the asterism makes its first visible rising or setting either just before sunrise or just after sunset. The listed events are in more or less correct chronological order and fall within the interval between Vernal Equinox and Summer Solstice. The asterisms in this section of the Parapegma Inscription, as well as those in the one other fragment (Fragment 22) that preserves asterism names, all belong to the set of asterisms associated in the Greek parapegma tradition with Euktemon and Eudoxos among other authorities (see section 13). This set comprises fifteen asterisms, many though not all of them characterized by very bright stars; it almost certainly antedates the introduction of the zodiac into Greek astronomy, and Scorpius is the only zodiacal constellation that figures in it.

The statements in lines x+3 and x+7 follow a different pattern *N V I,* where *N* is the name of a constellation standing as subject, *V* is the appropriate present indicative form of the verb ἄρχομαι, meaning "begins," and I is the infinitive of a verb meaning "to rise" (ἐπιτέλλειν or ἀνατέλλειν, apparently used synonymously). No adjective follows, but for these events to fall into correct chronological sequence with the other listed astral events, these statements must refer to the morning. This special treatment appears to be conferred only on constellations belonging to the zodiac. Two possible interpretations of these lines will have to be considered. On the one hand they may refer to the actual constellations Aries, Taurus, etc., in which case the events in question would probably be the dates when the first stars of these constellations were supposed to make their first visible risings. Alternatively, they may refer to the zodiacal *signs*, the 30° sectors of the ecliptic (such as are marked on the Zodiac Dial Scale) named for the constellations that were roughly aligned with them; in this case, since the signs are not visible objects, the events must be the *ideal* morning risings of the beginnings of the signs, i.e. the dates when the Sun enters each sign so that the first (westernmost) point of the sign crosses the eastern horizon precisely at sunrise. In this case, these lines would mark the beginnings of zodiacal months. As Rehm noted, the Geminos Parapegma contains similarly worded statements attributed to Kallippos, and these definitely refer to the zodiacal constellations, not to the signs.[39]

As we have already remarked, parapegmata are extant in the form of publicly displayed inscriptions on stone, and in these the single days of the solar year are represented by drilled holes that were evidently meant to hold a movable peg indicating the current day. If a hole had a statement inscribed beside it, that statement described the astral or meteorological events associated with that day, while days that had no associated events were represented by holes unaccompanied by text. Parapegmata in manuscript form typically numbered the days within subdivisions of the year, e.g. within the twelve zodiacal months or the months of a non-lunar calendar such as the Egyptian or Roman calendar; in such texts only the days having associated events were listed, according to the day number in the zodiacal or calendar month. Rehm supposed that the index letters of the parapegma inscription corresponded to matching letters inscribed on a dial scale distinct from the Calendar Dial Scale that he had seen on C-1, and that the function of the letters was to indicate the date of each astral event.[40] His conjecture turned out to be essentially correct: when Price saw Fragment C in its present state, with part of the Zodiac Dial Scale exposed, he discovered that it bore the irregularly spaced index letters that we have transcribed above, and realized that they were the counterparts of the index letters in the parapegma inscription. The Calendar Dial Scale, meanwhile, turned out to be movable with respect to the Zodiac Dial Scale, reflecting the shifting relationship of the 365-day Egyptian year to the natural seasons. Thus the astral events were associated with degrees of the Sun's longitudinal motion through the zodiac, not with time units.

Price noticed an anomaly in the distribution of the astral events apparently implied by the index letters:[41]

> "I feel that… the phenomena fall too thickly in the first part of the alphabet, but there are too few of them for the available letters in the second part… there is some mismatch or misplacement that I cannot understand… the problem seems to be unresolvable with this little evidence."

The part of the parapegma in the preserved part of PP1 col. i comprises nine phenomena, all falling between the Vernal Equinox and the Summer Solstice. Since the first of the nine was lettered kappa, one would expect there to have been nine phenomena in

39 Rehm 1905, 21, pencilled addition in bottom margin: "Speziell kallippische Phase!"

40 Rehm 1905, 19-22. Rehm mistakenly identified this second scale as the scale of what we now know as the Saros Dial, partly preserved on A-2.

41 Price 1974, 49.

the lost preceding part of the list, lettered from alpha through iota. But Price had found alpha through epsilon on the Zodiac Dial Scale, distributed over the interval from the first degree mark of Libra to the first degree mark of Scorpio, that is, over about thirty days starting about the Autumnal equinox. That would leave just four phenomena to be distributed over an interval of about 150 days from the point where the Zodiac Dial Scale could no longer be seen to the Vernal Equinoctial Point about the beginning of Aries, a much lower density of phenomena than in the preserved stretches. Six letters of the Greek alphabet, tau through omega, were left for the remaining quarter year, from about the Summer Solstice to about the Autumnal Equinox, which seemed acceptable, but they would have had to be inscribed somewhere else since the sigma line on PP1 was clearly at the bottom of the plate.[42]

42 In *Gears from the Greeks* Price assumes that the Parapegma Inscription comprised a single, complete, run through the 24 letters of the Greek alphabet. Unpublished notes in Price's file of notes on the Mechanism's inscriptions, now at the Adler Planetarium, show that at some stage he had contemplated the possibility that there were multiple alphabetic sequences.

3.7 PP2 cols. iii and iv

The straight top edge of the part of PP2 that is extant on Fragment C is clearly the original edge of the plate. Price and Stamires produced the first transcription of the parapegma text inscribed on its back face, but it was necessarily limited to the two parts of lines visible on the small exposed portion. With the aid of CT we can read the entire surviving text on this piece of plate, comprising parts of four lines starting slightly below the edge and running parallel to it (Fig. 3.8, left).

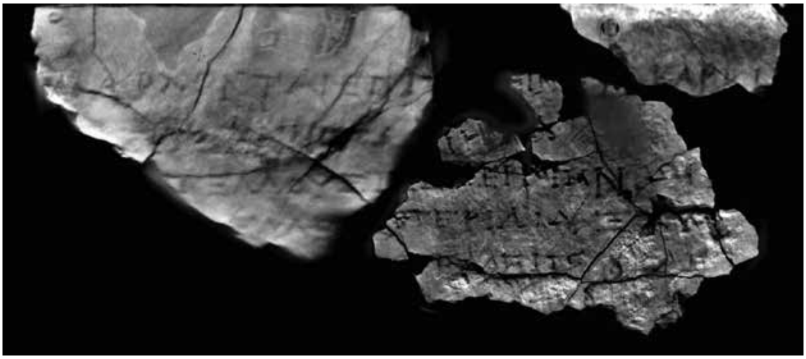

Figure 3.8: *CT composite image of the Parapegma Inscription on PP2 comprising (from left to right) Fragments C, 22, and 20*
(Images: Antikythera Mechanism Research Project)

Fragment 20's composition from two slightly oblique and slightly overlapping pieces of plate suggests that it preserves bits of both PP1 and PP2 from the post-1905 state of Fragment C, around the place where the edges of the two plates met and crossed; we have confirmed this through careful comparison of surface features of Fragment 20 (on the back face with respect to the inscription) with the Karo photograph of C-1 (supplementary Fig. S10) in this region.[43] Surface features of the back face of Fragment 22 are easily matched with the lower left corner of PP2 in Karo's photograph.

Hence we can read or restore a substantial part of the top five lines of PP2, with slight traces of a sixth line (Fig. 3.8). One structural feature becomes immediately obvious: the parapegma text on this plate was laid out in two columns, the left one of which we will refer to as col. iii and the right one as col. iv. We have the ends of the top lines of col. iii, and the beginnings of the lines of col. iv. In both columns, the top line gives one of the zodiacal sign statements,

43 Price 1974, 46 indicates a guess that Fragment 20 belonged to PP2, but thought that it came from the upper edge of the plate to the *left* (as one would view the inscribed face) of the part surviving on C-2.

and there is something anomalous about the second line: no index letter or visible text in col. iv, and a reference to the Autumnal Equinox in col. iii. Putting together the information that we have, we can plausibly hypothesize that the dates when the four signs Aries, Cancer, Libra, and Capricorn were stated to "begin to rise" were also marked, in an *indented* second line, as the equinoxes and solstices. This leads us to several conclusions:

- The "begins to rise" statements must refer to the zodiacal signs, not the zodiacal constellations, since the irregular intervals between the first morning risings of the constellations would not coincide with the solstices and equinoxes. This is confirmed by the fact that on the Zodiac Dial Scale, there are index letters next to the initial graduation of the three signs Libra, Scorpio, and Sagittarius whose beginnings are preserved; in the corresponding part of the Parapegma Inscription these would have been "begins to rise" statements.

- The solstitial and equinoctial points are considered to be placed at the beginnings of their zodiacal signs, as in other Greek parapegmata and astronomical authors (e.g. Ptolemy), rather than say at 8° or 10° into the signs, as in Greco-Roman sources influenced in this respect by Babylonian mathematical astronomy.

- A statement "N begins to rise" is equivalent to statements of the form "the Sun in N" found in other parapegmata, marking the beginning of a zodiacal month.

- The complete parapegma inscription was laid out in four sections corresponding to the quarters of the year beginning with the solstices and equinoxes. Each quarter comprised three zodiacal months.

- The last sign of PP2 col. iv is Virgo. About half this sign is extant on the Zodiac Dial Scale, on which two index letters psi and omega can be read. Hence this column's events were lettered from mu through omega, making a total of thirteen events and fourteen lines.

- The first sign of PP2 col. iii is Libra, the sign whose beginning is the autumnal equinoctial point. Hence this part of the inscription too corresponds to an extant part of the Zodiac Dial Scale, and the index letters of col. iii can be restored from the letters on the dial as running from alpha at least as far as lambda, totalling eleven events and twelve lines.

- One can presume at least two missing lines in PP1 col. ii above the present line x+1, for "Aries begins to rise" and "Vernal Equinox." The index letter of this event was not later in the alphabet than iota. Thus the three consecutive astronomical seasons spring, summer, and autumn were respectively on PP1 col. ii, PP2 col. iv, and PP2 col. iii. The section beginning with Capricorn and the Winter Solstice remains to be accounted for.

We turn now to the numerals, written in slightly smaller letters after the ends of the statements in col. iii. Here we are lucky, since lines 1-2 have been identified as signifying the Sun's entry into Libra, so that the entire col. iii corresponds to a preserved portion of the Zodiac Dial Scale, where we have index letters marking phenomena at the 1st, 11th, 14th, and 16th division marks of Libra and the 1st division mark of Scorpio — exactly matching the numerals in the parapegma inscription. This observation leads to a choice of two interpretations of the numerals in the inscription:

- The numerals could simply be the numbers of the graduations on the Zodiac Dial Scale where the index numbers were inscribed. They would thus represent the Sun's longitude in degrees within the currently occupied zodiacal sign, counting the first degree in the sign, what we would call 0° or perhaps more accurately the interval from 0° up to 1°, as "degree 1." Such numerals would be a redundant tabulation of information that could also be read from the dial.

- The numerals could be day numbers counted from the first day of the current zodiacal month, like the day numbers in the Geminos Parapegma. Since the Sun always spends 30±2 days in a zodiacal sign, the day numbers of phenomena would differ from the degree numbers by at most 2 by the end of a month, and towards the beginnings of any month they would be equal. Libra would likely have been allotted 30 days, so that the degree and day numbers for that sign would be the same through the whole month.

Since the evidence does not allow us to decide whether the numerals mean degrees or days, we will refer to them as day/degree numerals.

As mentioned above, numerals were not previously noticed at the ends of the statements in PP1 col. ii, but notwithstanding the poor condition of the right extremity of the plate (partly the effect of a pronounced warp caused by pressure or impact), a few can be made out. We presume that a day/degree numeral followed every statement in the parapegma, except that in the case of the double statements at the solstices and equinoxes, the numeral 1 (alpha) appeared only at the end of the second line as in PP2 col. iii lines 1-2.

On the basis of the match of the index letters on the Zodiac Dial Scale with the phenomena in PP2 col. iii we restore the index letters in this part of the inscription as alpha through epsilon. The preserved index letters of col. iv, mu through pi, duplicate part of the sequence in PP1 col. ii. There must, therefore, have been more than one alphabetic sequence. There is nothing surprising in this, since the parts of the parapegma that we have considered so far assign three or four events to each zodiacal sign. If this density was roughly maintained through all twelve signs, we may expect that the total number of events was something around the high thirties or forties, enough to require two partial or complete runs through the Greek alphabet.

3.8 PP1 col. i

We have drawn attention above to the presence of two very clear letters inscribed just against the present left edge of PP1, about halfway in height between col. ii lines x+6 (indexed omicron) and x+7 (pi). From their appearance and position, it appears practically certain that these letters, IA, represent a day/degree number 11 at the end of a parapegma statement, all that remains on the present Fragment C of a column of statements to the left of col. ii. Since the parts of the parapegma pertaining to the seasons beginning with the vernal equinox, summer solstice, and autumnal equinox are already accounted for, this col. i must have contained the season beginning with the winter solstice. We designate the line of col. i to which the surviving numeral belongs as line x+1.

We can see no trace of this left column of parapegma inscription on the Karo 1905 photograph of C-1. The appearance of the left quarter or so of PP1 in the Karo photograph is difficult to interpret, and no other photograph from this period showing PP1 from a different angle has so far been found, except for the badly exposed print of the 1918 photograph in Rehm's collection. In Karo's photograph, the region to the immediate left of lines 2-4 of the preserved column shows a rough surface that could be an accretion layer, and to the left and lower left of this is a region that appears to be perfectly smooth except for an apparently engraved straight line that runs nearly parallel to the more or less straight edge of the plate; this edge forms about a 60° angle with the lower edge of the plate. This smooth region appears somehow to be distinct from the visibly inscribed part of the plate, and we suspect that either the original surface of the plate here had been stripped away or that some layer of material was lying on top of it, perhaps another displaced fragment of plate. The illumination of the photograph is unhelpful at this end of the plate, so that even the IA that we know was there cannot be made out.

Fragment 9 (Fig. 3.9) is part of the top lines of the missing column, preserving the Sun's entry into Capricorn and winter solstice followed by two stellar events.[44] The fragment was not part of PP1 in its post-1905 state. Lines 1-2 of PP1 col. i would have been approximately aligned with the lost top two lines of col. ii, which contained the statement of the Sun's entry into Aries and the Vernal Equinox. Hence Fragment 9 line 3, in its lowest possible position, would have been roughly aligned with line 1 of col. ii, and to allow room for the

44 Fragment 9 cannot be a piece of PP2 col. iv extending the top lines still preserved in Fragment C. Aside from the traces at the left edge of line 2 which are not consistent with the event of this line being the *summer* solstice (see note to line 2), the margin between the upper edge of the plate and the top of line 1 is much smaller than the upper margin in the PP2 fragments.

restored end of Fragment 9 line 1, it has to have been entirely to the left of the edge of PP1 as it was in 1905. It is a near certainty that Fragment 9 was not stored together with the known Mechanism fragments in Price's time.

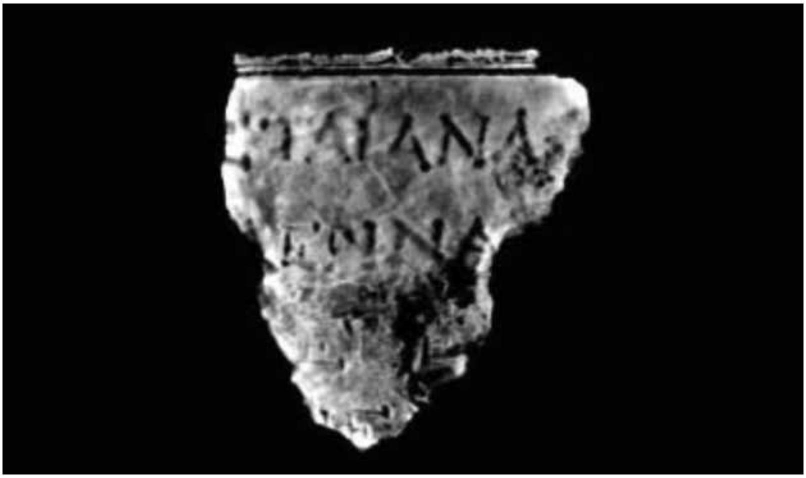

Figure 3.9: *CT composite image of Fragment 9*
(Image: Antikythera Mechanism Research Project)

If col. ii line x+1 immediately followed the lost lines for the entry into Aries and the equinox, then col. ii lines x+6 and x+7 would have been the eighth and ninth lines of this column, and col. i line x+1, of which the day/degree numeral 11 is extant about halfway between col. ii lines x+6 and x+7, would almost certainly have been either the eighth or the ninth line of col. i, depending on whether the line spacing of the column was slightly looser or slightly tighter than that of col. ii. The spacing of the four extant lines in Fragment 9 is in fact significantly greater than the average in col. ii, so it is more likely that col. i line x+1 was the eighth line. In any case, col. i has to have contained statements of at least seven events with distinct index letters.

3.9 The layout of the Parapegma Inscription

If PP1 col. ii contained no events between the Vernal Equinox and the event of line x+1, the index letter corresponding to the Vernal Equinox was iota; otherwise it would have been an earlier letter of the alphabet. PP2 col. iii's events certainly accounted for a series of index letters from alpha through lambda, all of which are visible on the corresponding part of the Zodiac Dial Scale. PP2 col. iv had events with index letters beginning with mu and extending to omega (index letter preserved on the Zodiac Scale). We can thus provisionally summarize the contents of the four columns of parapegma text as follows:

PP1 col. i	PP1 col. ii
Capricorn – Pisces	Aries – Gemini
index letters: at least eight	iota (or earlier) – sigma
≥ 9 lines	≥ 11 lines
PP2 col. iii	PP2 col. iv
Libra – Sagittarius	Cancer – Virgo
alpha – lambda (or later)	mu – omega
≥ 12 lines	14 lines

In PP1, the right column follows immediately after the left in the order of the Sun's motion through the zodiac, but in the PP2 the left column follows the right. Arranged as above, with PP1 above PP2, the four columns run clockwise, whereas if PP2 is put at the top, the columns run counterclockwise. Since the Zodiac Dial Scale, like all the known dials of the Mechanism except the four-year Games Dial of the back face, run clockwise, it makes sense for the inscription, in its original mounting on the Mechanism, to have occupied the parts of the front face above and below the dial as Price conjectured in 1974, with PP1 as the top part and PP2 as the bottom part. In this way, each of the four columns would give information pertaining to the Sun's movement through the nearest quadrant of the Zodiac Dial Scale. As a corollary, the Zodiac Dial Scale would have to have been oriented so that the beginning of Aries was at the top, as Price guessed in 1974.[45]

Fig. 3.10 shows the approximate locations of the surviving parts of the Parapegma Plates according to this hypothesis. What clinches the argument is the bearing mounted behind the

45 Price 1959, 62-63, right figure, shows outlines of Fragments G and C oriented so that the beginning of Cancer (the Summer Solstice) would have been at the top. It is not known what considerations led him to put the beginning of Aries at the top in 1974, though if we take him at his word (Price 1974, 13), he believed that he had confirmed in 1961 the correct physical join between Fragments C and A which would have determined the orientation.

right end of PP1's bottom edge in Fragment C, which turns out to be approximately where the bolt of the presumed upper right sliding catch of the Dial Plate would have projected when in the engaged position.[46] The rivet hole and vestigial feature on PP2 in Fragment C are suitably positioned to be the remains of another bearing which would have received the bolt of the lower left sliding catch of the Dial Plate—which is in fact the extant one! It is thus apparent that the Parapegma Plates were riveted to the wooden frame housing the gearwork by rivets like the one in Fragment 20 (which was at the exact midpoint of PP2's upper edge), while the Dial Plate, when in place, was attached to the Parapegma Plates by the sliding bolts. The projection of the bearings attached to the Parapegma Plates beyond the plates' edge (Fig. 3.4) would have prevented the Dial Plate from falling into the gearwork when it was disengaged.

The approximate dimensions of the original plates can be determined from the known position of the dial, which was centered slightly higher than the geometrical center of the Mechanism's front and back faces. We can estimate the usable height of the upper plate, PP1, as about 65-68 mm, and that of the lower plate, PP2, as about 83 mm.[47] Taking into account the extant margins at the bottom of PP1 and at the top of PP2, this would mean that the columns of PP1 probably could not have contained more than twelve lines, while those of PP2 could have contained fifteen or possibly even sixteen lines. This is consistent with what we previously deduced about the numbers of lines in each column, and confirms that PP1 was indeed at the top.

The alphabetic sequences of index letters obviously cannot have followed the clockwise structure of the inscription's contents. The events in PP2 col. iv follow directly after those of PP1 col. ii in their annual cycle, but the index letters jump back from sigma to mu. Moreover, while the other columns would not seem to have listed more than thirteen events at most, PP1 col. i would have to have had to contain something like twenty events to account for the end of the alphabet begun in PP2 col. iii plus the beginning of the alphabet continued in PP1 col. ii.

46 Precise measurements cannot be obtained for the distance of the bearing from PP1's right edge or for that of the extant sliding catch from the corresponding edge of the Dial Plate because both plates are badly fractured and distorted in those regions.

47 See IAM 1.5.

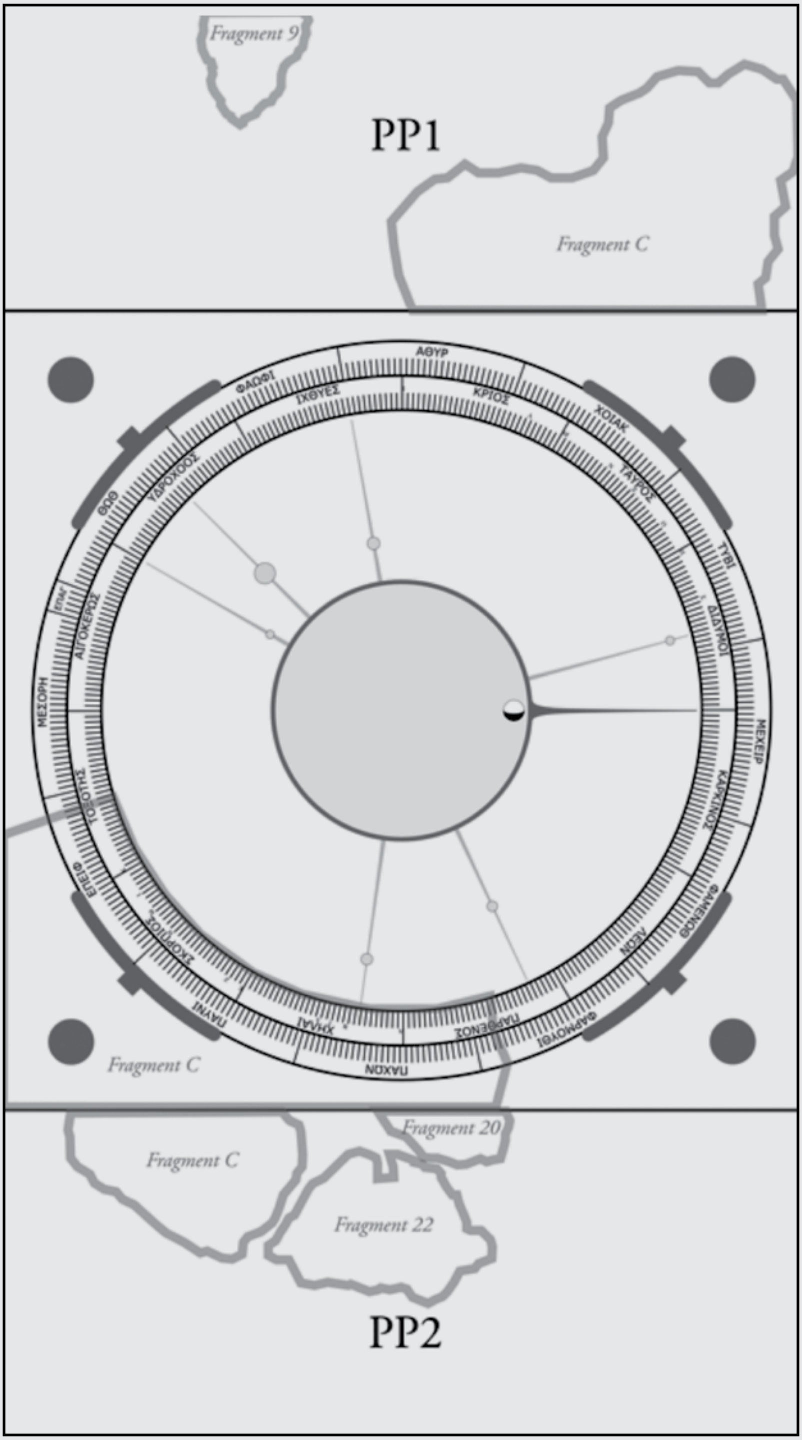

Figure 3.10: *Known original locations of the surviving fragments of the front face*

A satisfying resolution of the index letter sequences has been proposed by T. Freeth, who has portrayed it in a conjectural reconstruction of the Mechanism's front face.[48] The reconstruction can be deduced as follows. One may reasonably assume, first of all, that the sequences of index letters of PP1 col. ii and PP2 col. iv, which begin in the middle of the alphabet, were each continuations of sequences in one of the other pair of columns. It is known that PP2 col. iii began with alpha and included iota, so it cannot have been the first part of the same sequence as PP1 col. ii which also had an event indexed with iota. The alternative is for PP2 col. iii to lead into PP2 col. iv, that is, lettering the events on this plate according to the normal "reading" order for a text in columns, that is, from left to right. One would thus infer that there were no more stellar events listed in col. iii following the event indexed lambda at the 7th degree of Sagittarius. Complementarily, PP1 col. i leads into PP1 col. ii in both the astronomical and the "reading" order, so col. i began with alpha. In each plate of the inscription, one would have seen a single continuous alphabetic sequence, which comprised a complete alphabet in PP2 but an incomplete one in PP1. On the dial, the sequence would have been continuous within each quadrant, but there would have been discontinuities in the sequence of letters at the beginnings of Cancer, Libra, and Capricorn.

Accepting Freeth's hypothesis, we can revisit the reconstruction of PP1 col. i and the questions of how many events it listed and how many lines there were between lines 1-4 in Fragment 9 and line x+1 in Fragment C. Let us consider the possibilities for reconstructing the two columns systematically:

> (1) The only lost lines from the top of col. ii were the two that contained the Sun's entry into Aries and the Vernal Equinox, with the index letter iota. In this case, the IA remaining from col. i is in a position intermediate between the original eighth and ninth lines of col. ii, so that the line that ended with the IA must have been either the eighth or the ninth line of col. i.
>
> > (1a) If it was the eighth line, it contained the seventh event in the column, and had index letter eta. Then there must have been a ninth line and an eighth event ending the left column, with index theta, to obtain continuity with the right column's index letters.
> >
> > (1b) If it was the ninth line, it contained the eighth event, had index letter theta, and was the last line and event of col. i.
>
> (2) There were at least three lines, and at least two events, lost from the top of col.

48 Freeth & Jones 2012, Fig. 4; the text of the Parapegma Inscription as shown there reflects a provisional transcription of the fragments and differs in some details from the edition presented here.

ii. Thus the index letter of the top line of col. ii was either theta or a letter earlier in the alphabet than theta. In this case the line of col. i to which the IA belonged would have been at least the ninth line and eighth event of the column, and so would have been indexed with theta or a letter later in the alphabet than theta. Since this overlaps with the lettering of col. ii, we can dismiss this possibility.

Thus we can confirm that col. i had 9 lines and listed 8 events, indexed alpha through theta. On logical grounds we do not have a way of knowing whether the line ending in IA was the eighth line indexed as eta or the ninth line indexed as theta, but the wide line spacing in Fragment 9 argues for this line having been the eighth. PP1 col. ii contained ten (iota through sigma); PP2 col. i contained eleven (alpha through lambda); and PP2 col. ii contained thirteen (mu through omega).

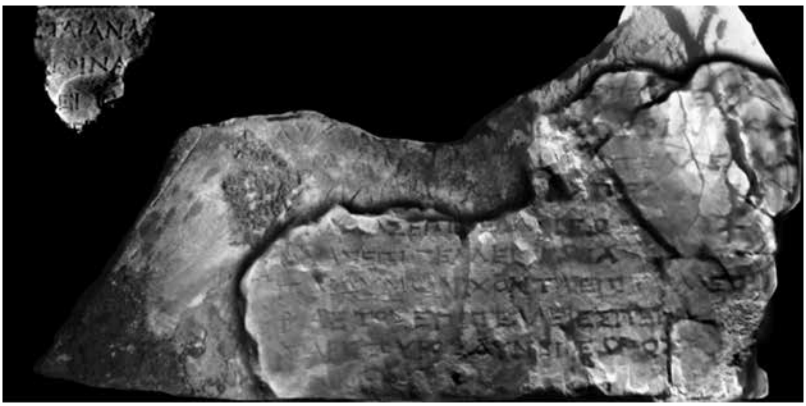

Figure 3.11: *Combined image of PP1, incorporating CT composite images of Fragments 9 (upper left) and C (lower right) superimposed on the 1905 photograph of C (Image: Antikythera Mechanism Research Project)*

We can thus offer a provisional reconstruction of PP1 as follows (Fig. 3.11):

col. i

(9)	1	[Α *v*	Αἰγοκέρως ἄρχ]εται ἀνα[τέλλειν.]	
	2	[*v*	τροπαὶ χει]μ̣εριναῖ[ί. A]	
	3	[Β *v*	–7–	ἐπιτέλ]λ̣ει *v* ἑσ̣[πέριος/περία. *nn*]
	4	[Γ *v*	–13–	]̣ Ε̣ [
(lost)	5	[Δ *v*	*lost*	..]
	6	[Ε *v*	*lost*	..]
	7	[Ζ *v*	*lost*	..]
(C)	8	[Η *v*	*lost*	] ΙΑ
(lost)	9	[Θ *v*	*lost*	..]

or			
	8	[Η *v*	*lost* ..]
(C)	9	[Θ *v*	*lost*] ΙΑ

col. ii

(lost)	1	[Ι *v*	Κριὸς ἄρχεται ἐπιτέλλειν.]
	2	[*v*	ἰσημερία ἐαρινή. Α]
(C)	3	[Κ *v*	–12–]̣ Ι ἑσ̣[π]ερ̣[ί]α̣[*nn*]
	4	Λ *v*	Ὑάδ̣[ες δύον]ται ἑσ̣περίαι̣. *v* ΚΑ
	5	Μ *v*	Ταῦρ̣ο̣ς̣ ἄ̣ρχ̣ε̣ται ἀνατέλλειν. Α
	6	[Ν *v*]	Λύ̣ρα ἐ[πιτ]έ̣λ̣λ̣ε̣[ι] ἑσπερία. *v* ΙΑ
	7	Ξ *v*	Πλειὰς ἐπι[τ]έλλει ἑῷι̣[ο]ς. *v* ΙΖ̣
	8	Ο *v*	Ὑὰς ἐπιτέλλει *v* ἑώια. *v* Κ̣Ε
	9	Π *v*	Δίδυμοι ἄρχονται ἐπιτέλλει̣ν̣. [Α]
	10	Ρ *v*	Ἀετὸς ἐπιτέλλει ἑσπέριο[ς. *nn*]
	11	Σ *v*	Ἀρκτοῦρος δύνει *v* ἑῷι̣ος. *v* Ι̣

Two of the missing lines in col. i would have contained the Sun's entries into Aquarius and Pisces.

At this point we have arrived at definitive totals for the events and lines in each column:

PP1 col. i Capricorn – Pisces alpha – theta (five stellar events) 9 lines	PP1 col. ii Aries – Gemini iota – sigma (seven stellar events) 11 lines
PP2 col. iii Libra – Sagittarius alpha – lambda (eight stellar events) 12 lines	PP2 col. iv Cancer – Virgo mu – omega (ten stellar events) 14 lines

3.10 Tentative identifications of missing asterism names

The names of seven asterisms are preserved in the Parapegma Inscription: Sirius, Arcturus, Pleiades, Hyades, Lyra, Aquila, and Orion. As already noted, these are all found among the set of fifteen asterisms that served as a standard repertoire for the majority of parapegmata, starting with the citations of Euktemon and Eudoxos in the Geminos Parapegma and other sources (see section 13). It is a reasonable hypothesis that this repertoire provided all the asterisms of the Parapegma Inscription. Each asterism has four annually recurring visibility events, and in the case of Orion and Scorpius the parapegma tradition also sometimes distinguished between the dates when the asterism begins to rise or set and when its entirety is considered to rise or set, making a total of 68 potential events in a "complete" parapegma. In practice no extant parapegma or set of parapegma data attributed to an individual authority is complete in this sense. The citations of Euktemon in the Geminos Parapegma, for example, amount to only forty events, with another five or so being attested in other sources. Some events seem to have held little interest across the tradition; for example settings of Vindemiatrix and risings of Sagitta are seldom listed. The Mechanism's parapegma, with thirty stellar events, would have been selective even by the tradition's standards.

In several partially preserved lines of the Parapegma Inscription, the name of the asterism is lost but we have some clues to its identity, such as the grammatical number and gender of the name and its approximate length, in addition to the rough date when it was supposed to occur. As a guide to the events that would be plausible candidates for listing within a date range, we have constructed a "model" parapegma (section 13) based on a modern theory for estimating visibility dates. It must be kept in mind, however, that modern visibility models reproduce ancient visibility reports only within very broad tolerances (see section 14); the differences between dates in our model parapegma, for example, and dates of the same events ascribed to Euktemon or Eudoxos exhibit standard deviations of around 10 days. We have also used several other ancient parapegmata and parapegma-like texts as guides to the ranges of dates that the ancient tradition allowed for ancient events.[49]

PP1 col. i

3 [Κύων *v* ἐπιτέλ]λ̣ει *v* ἑσ̣[πέριος. *nn*]
3 [Sirius ri]ses in the eve[ning. *nn*]

The only evening rising that takes place while the Sun is in or near Capricorn is that of Sirius. Sirius's evening rising is surprisingly rarely listed in parapegmata, though the Geminos

49 Most of the texts are conveniently collected in Wachsmuth 1897 and Lehoux 2007.

Parapegma cites Eudoxos for its occurring on the zodiacal date Sagittarius 16, which is about twenty days too early. The available space would suggest a longer asterism name. However, the presence of an otherwise unexplained *vacat* after ἐπιτέλλει might reflect an effort to stretch out a short line of text for better appearance (cf. the *vacat* in the short col. ii line x+6), in which case another *vacat* can be hypothesized after the name.

PP1 col. ii

x+1 [Κ *v* Πλειάδες δύνου]σ̣ι ἑσ̣[π]ερ̣[ί]α̣ [ι. *nn*]
x+1 [Κ *v* Pleiades se]t in the evening. [*nn*]

There is a very strong expectation that a parapegma would list the evening setting of the Pleiades, which would occur while the Sun is in Aries. Moreover, the preserved ΑΙ at the left edge requires a plural subject, ruling out other events that fall within this zodiacal month, and the restoration given above fits the available space (estimated 12 letters) well. For alternation between plural and singular forms of the asterism name, compare lines x+2 and x+6.

PP2 col. iii

3 [Β *v* Ἔριφοι ἐπι]τέλλουσιν [ἑ]εσ̣π̣έριοι. ΙΑ
4 [Γ *v* Πλειὰς ἐπιτ]έλλε[ι ἑσ]περία. ΙΔ
5 [Δ *v* Στέφανος ἑῷιος ἐπι]τ̣έλ̣λει. ΙϚ
3 [Β *v* Haedi] rise in the evening. 11
4 [Γ *v* Pleias] rises in the evening. 14
5 [Δ *v* Corona] rises [in the morning]. 16

The surviving text of these lines shows that the listed events for Libra were the evening rising of an asterism with a plural name, probably masculine,[50] then an evening rising of a feminine singular asterism, and thirdly a rising of a singular asterism of indeterminate gender. (Line 5 is the only instance of a stellar event having no indication of morning or evening following the verb; the horizontal spacing relative to the preceding lines

50 It is worth considering the possibility that ἑσπέριος was employed in this line as an adjective of two terminations, modifying a feminine plural asterism. Only two asterisms other than Haedi have plural names among the ones used regularly in parapegmata: the Pleiades and Hyades. Πλειάδες is definitely too long to be squeezed into the available space, which is determined by Χηλαί in line 1. Ὑάδες would fit, but the evening rising of the Hyades (effectively Aldebaran) takes place about twenty days later than the 11th day or degree in Libra; the dates ascribed to Euktemon and Eudoxos are indeed early too in comparison to modern computation, but not *this* early. There is also no credible candidate for a feminine singular asterism having an evening date soon after the evening rising of the Hyades.

suggests that the expected adjective preceded the verb rather than being omitted.) From the day/degree numerals and the Zodiac Dial Scale inscriptions we know that these events fell around the middle of the zodiacal month and that the next stellar event was at Scorpio 4°.

The only masculine plural asterism in the standard Parapegma repertoire is Haedi (ἔριφοι). Our calculations estimate the evening rising of Haedi as occurring while the Sun is in Virgo or (for very southerly latitudes) just entering Libra, but the parapegma tradition inclines to later dates. The Geminos Parapegma states that it falls on Libra day 3 according to Euktemon. Columella (11.2.66) has a listing of the event on September 27, i.e. day 2-4 counted from the Sun's entry into Libra on the autumnal equinox (which he places on the three days September 24-26), and this is consistent with the Euktemon date in the Geminos Parapegma. However, Columella (11.2.73) also lists the same event on October 6, i.e. day 11-13 in Libra. Comparably late dates are given in the Aëtios Parapegma (October 7, ed. Wachsmuth 291), in Lydos, *De Mensibus* (October 6 according to Demokritos, ed. Wünsch 163), and in the Clodius Tuscus Parapegma (October 4, 8, and 9, ed. Wachsmuth 149). We consider the identification of the asterism of line 3 as Haedi to be highly probable.

The feminine name of the asterism of line 4, unless there was a *vacat*, should have been about one letter's width wider than the presumed ἔριφοι of line 3. This was probably Πλειάς, the singular form of the Pleiades attested in PP1 col. ii line x+5. The evening rising of the Pleiades, an event unlikely to be skipped in a parapegma, is listed in the Geminos Parapegma for Libra day 5 according to Euktemon and day 8 according to Eudoxos, both being slightly later than our calculated dates. Closer to line 4's day/degree number 14 are the listings in Pliny (October 10 according to Caesar, 18.74.313), Columella (October 10, 11.2.74), and Clodius Tuscus (October 9 and 12, in addition to several earlier dates, ed. Wachsmuth 146-149).

The event of line 5 occurring at day/degree 16 is most likely the morning rising of Corona Borealis; the date comes too soon after the evening rising of the Pleiades for the evening rising of the Hyades. Again the dates in the Geminos Parapegma are earlier, Libra 7 according to Euktemon and 10 according to Eudoxos. On the other hand, Pliny (18.74.313) gives October 8 specifically for Alphekka according to Caesar and October 15 for the constellation as a whole, Columella (11.2.73-74) gives October 8 and 13-14, and Clodius Tuscus gives October 8, 11, and 13 (along with other earlier dates, ed. Wachsmuth 149).

We know from the Zodiac Dial that there were three stellar events in the zodiacal month of Scorpio, at the 4th, 17th, and 22nd degrees, and two in Sagittarius, at the 3rd and 7th degrees. The corresponding day numbers would have been the same as the degrees in these zodiacal months, or at most differing by one. Since the model parapegma lists well over five stellar events for these signs, any identifications of the events that were listed on the Mechanism would be exceedingly speculative in the absence of further clues.

PP2 col. iv

13 [Ψ *v* Αἶξ ἐπιτέλλει ἑσπερία. ΙΘ]
14 [Ω *v* Ἀρκτοῦρος ἐπιτέλλει ἑῷιος. ΚΑ]
13 [Ψ *v* Capella rises in the evening. 19]
14 [Ω *v* Arcturus rises in the morning. 21]

The morning rising of Arcturus, a few days before the autumnal equinox, was perhaps the single most important and widely recognized stellar event of the year for the Greeks, so that it is hard to believe that the event indexed as omega at the 21st degree of Virgo was anything else. The best candidate for the event indexed psi, at the 19th degree, is the evening rising of Capella.

3.11 Fragment 28

We now turn to the one remaining fragment of the Parapegma Inscription, Fragment 28, that we have not accounted for (Fig. 3.12). Parts towards the ends of five consecutive lines are preserved, but the preserved information is extremely limited:

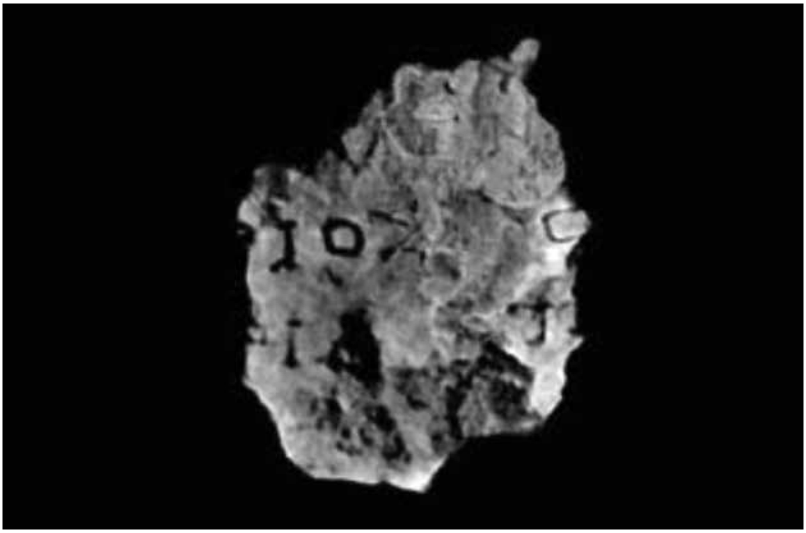

Figure 3.12: *CT composite image of Fragment 28*
(Image: Antikythera Mechanism Research Project)

> line z+1: possibly a stellar event whose numeral indicating the degree or day within the relevant zodiacal sign is in the twenties, but the reading is not certain.
> line z+2: the Sun's entry into a zodiacal sign that does not correspond to a solstice or equinox since the next line is a stellar event.
> line z+3: a stellar appearance or disappearance in the evening, with numeral 16.
> line z+4: appearance or disappearance in the evening of an asterism whose gender is feminine, with numeral in the twenties.
> line z+5: indeterminate because of severe surface damage.

This fragment obviously did not come from anywhere in PP1 col. ii, and the zodiacal sign entered in line z+2 cannot be Capricorn, Cancer, or Libra. We can also rule out Scorpio and Sagittarius in the latter column, because the day/degree numerals preserved in Fragment 28 lines z+3 and z+4 do not even nearly match the preserved locations of the first two index letters in the Scorpio and Sagittarius sectors of the Zodiac Dial Scale.

There was at most one line below PP1 col. i line x+1, so if Fragment 28 was part of this column, it must have been partly or entirely above line x+1. Moreover, the Sun's entry into Pisces would have had to come between Fragment 28 line z+4 and col. i line x+1, since the day/degree number 11 in col. i line x+1 is less than the day/degree numbers in Fragment 28 lines z+3 and z+4. Thus the only possible placement for Fragment 28 in PP1 col. i would be such that Fragment 28 line z+2 is the Sun's entry into Aquarius.

We have thus narrowed down the possible identifications of the zodiacal sign entered in line z+2 to Aquarius, Leo, or Virgo. The listed events immediately following this entry were two evening risings or settings, the second of which was of a feminine singular asterism. No feminine asterism has an evening event during or sufficiently near the zodiacal month of Leo, so we are left with Aquarius and Virgo.

For Aquarius, the only candidate for the feminine asterism is Lyra. Our calculations place Lyra's evening setting late in the zodiacal month of Capricorn or early in that of Aquarius. In the Geminos Parapegma it falls on Aquarius day 3 according to Euktemon and day 11 according to Eudoxos; other parapegmatic sources give a wide range of dates, among which the latest are February 6 (approximately Aquarius 16) in Clodius Tuscus (ed. Wachsmuth 122) and February 7 (approximately Aquarius 17) in Pliny (*Naturalis Historia* 18.235, ed. Wachsmuth 324). The necessary restoration, Λύρα δύεται, at ten letters is very short for the estimated 14-letter gap (the somewhat more common verb δύνει would make it still shorter). There also exists one just acceptable candidate for the event of line z+3: the evening setting of Delphinus. By our calculations, this should have occurred around the middle of Capricorn, while in the Geminos Parapegma it falls on Capricorn day 27 according to Euktemon, and Aquarius day 4 according to Eudoxos; the latest date given in the parapegma literature seems to be January 28 (approximately Aquarius 7) in the Aëtios Parapegma (ed. Wachsmuth 293).

Since PP1 col. i contained a total of five stellar events, including one in Capricorn on line 3 and one in Pisces on line x+1, with the two events on z+3 and z+4 hypothetically assigned to Aquarius, the remaining event could have belonged to Capricorn on line 4, Aquarius on line z+5, or Pisces on line x+0 or x+2, so that we could not assign absolute line numbers to the lines of Fragment 28 or to x+1 on Fragment C. The proposed restoration of Fragment 28 would be as follows:

(28) z+1 [̣ *v*] Κ̣[*n*?]
z+2 [̣ *v* Ὑδροχόος ἄρχεται ἐπιτ]έ̣λλειν. [Α]
z+3 [̣ *v* Δελφὶς δύεται ἑσπέ]ριος. *v* Ι̣C
z+4 [̣ *v* Λύρα δύεται ἑσπε]ρία̣. *v* Κ[*n*?]
z+5 [–*n*+11–]Ε̣ ̣ ̣ [ ]

(28) z+1 [ ] 2[*n*?]
z+2 [Aquarius begins] to rise. [1]
z+3 [Delphinus sets] in the evening. 16
z+4 [Lyra sets] in the evening. 2[*n*?]
z+5 [ ] ... [ ]

We now turn to Virgo. In this sign, Capella is the only possibility for the feminine asterism in line z+4. Our calculations estimate that its evening rising could fall anywhere within the zodiacal month of Virgo, with the date varying considerably according to latitude. In the Geminos Parapegma it falls on Virgo day 20 according to Euktemon, and Libra day 4 according to Eudoxos. The restoration Αἶξ ἐπιτέλλει, at 12 letters, would need a bit of stretching to fit the 14-letter gap, but this could have been done with small *vacats* or just slightly wider letter spacing, or line z+2 might have been more tightly spaced than usual.

An evening event that could plausibly have preceded the evening rising of Capella in Virgo's zodiacal month is the evening setting of Vindemiatrix. By our calculations this would occur within a few days of the 12th day of Virgo. But the restoration Προτρυγητὴρ δύνει (or still worse, δύεται) seems too long for the space, unless the rare variant Τρυγητήρ or Τρυγητής was used. Moreover, it would be unexpected to have Vindemiatrix represented in the parapegma by its evening setting rather than its morning rising, a few days later, which was traditionally the harbinger of the vintage as the star's Greek and Latin names signify; the only attestation of the evening setting in the parapegma literature seems to be in the Geminos Parapegma, Leo day 18 according to Dositheos, a surprisingly early date.

The only other stellar event we can suggest for z+3 is the evening rising of Pegasus; Ἵππος ἐπιτέλλει is a good fit to the available space. The model parapegma, which in general appears to yield dates for this large constellation that are not as close as one would wish to the dates in ancient parapegmata, predicts dates for the evening rising late in the zodiacal month of Cancer or early in that of Leo, and the Geminos parapegma cites Euktemon for Leo day 17.[51] On the other hand, the two dates offered by the Clodius Tuscus Parapegma (ed. Wachsmuth 145-146) are September 6 (approximately Virgo 11) and 14 (approximately Virgo 19), both comfortably within the zodiacal month of Virgo, and Lydos *De Mensibus* (ed. Wünsch 160) also gives September 6 with Eudoxos as authority. (This event is not among the Eudoxos data in the Geminos Parapegma.)

On the zodiac dial, stellar events are marked at the 19th and 21st degrees of Virgo. These cannot be reconciled with the day/degree numerals in lines z+3 and z+4 unless these numerals are to be interpreted as day numbers counted from the Sun's entry into the zodiacal sign, and in this case the zodiacal month of Virgo would have had to be assumed to be 31 days long rather than 30 (its length according to the Geminos Parapegma). The restoration would thus be as follows:

51 Pliny 18.74.309 gives August 12 according to "the Athenians," which would closely match the Euktemon date.

(28) 10 [Υ *v*] Ḳ [n?]
11 [Φ *v* Παρθένος ἄρχεται ἐπιτ]ẹ́λλειν. [Α]
12 [Χ *v* Ἵππος ἐπιτέλλει ἑσπέ]ριος. *v* Ị̣C
13 [Ψ *v* Αἶξ ἐπιτέλλει ἑσπε]ρίạ . *v* Κ
14 [Ω *v* Ἀρκτοῦρος ἐπιτέλλει] ẹ̔ ῷ̣ ị [ος. ΚΒ]

(28) 10 [Υ *v*] 2[*n*?]
11 [Φ *v* Virgo begins] to rise. [1]
12 [Χ *v* Pegasus rises] in the evening. *n* 16
13 [Ψ *v* Capella rises] in the evening. *n* 20
14 [Ω *v* Arcturus rises] in the morning. [22]

3.12 Astronomical assessment

A recent astronomical assessment of the Parapegma Inscription was based on the contents in PP1 col. ii as transcribed by Rehm and Price-Stamires, that is, lines x+2 through x+9 without knowledge of the degree/date numerals.[52] In other words, the only available information was the order of six stellar phenomena relative to each other and to the two preserved dates of sign entry. For purposes of analysis, the authors computed dates of the stellar phenomena by modern theory for 150 BC and for a range of latitudes from 25° to 45°, making almost identical assumptions to ours about which stars constitute each asterism for purposes of visibility, but applying a different model for stellar visibility.[53] For any pair of stellar events listed as occurring consecutively in the Parapegma Inscription, a "sequence error" was defined as 0 if the order of events agreed with modern computation for a given latitude, and otherwise as the positive number of days separating dates of the two events as computed by the modern visibility model. "Zodiac errors" were similarly computed between all the stellar events and the dates of sign entry. The sum of sequence errors or of zodiac errors for a particular latitude was taken as a measure of the fit of the Parapegma Inscription's contents to that latitude.

The conclusion of this study was that the contents of PP1 col. ii lines x+2 to x+9 fit best latitudes between 33.3° and 37.0°. Similar tests of sequence and zodiac errors applied to the Euktemon and Eudoxos data in the Geminos Parapegma found larger inaccuracies than for the Mechanism data, especially in the case of the Eudoxos data which includes several large outliers that strongly affect the calculated errors.

The discovery of the date/degree numbers in the Parapegma Inscription offers an opportunity for a more precise assessment of the recorded phenomena. Complete numerals are preserved for five stellar events in PP1 col. ii in the zodiacal months Aries, Taurus, and Gemini, in all of which the identity of the asterism and phenomenon is certain. A further three numerals of events in Libra are preserved in PP2 col. i, and we consider our restorations of the lost asterism names to be probable enough to use these events since the descriptions of the events are otherwise at least partly preserved. The identifications of the eight asterisms and phenomena whose degree numbers in Virgo, Scorpio, and Sagittarius are marked by index letters on the zodiac dial seem to us to be too uncertain to use. We thus have taken into consideration a smaller data set consisting of just the five events in PP1 col. ii, and a larger set that also includes the three events in PP2 col. i.

52 Anastasiou et al. 2013.

53 See Appendix 1 (section 13) for our identifications of asterisms with individual stars; the only divergence is that Anastasiou *et al.* use an aggregate apparent magnitude and mean position for the Pleiades. The visibility models are discussed in Appendix 2 (section 14).

Zodiacal dates for each asterism were calculated by modern theory for 100 BC by the method described in Appendix 2. The degree/date numbers of the Mechanism's inscription and the degree numbers associated with the Scorpio events were treated as zodiacal dates, using the lengths of zodiacal months in the Geminos Parapegma. In the following table, we give the latitude yielding the closest fit to the Mechanism data (as defined in Appendix 2), the mean difference (Mechanism minus modern theory), and standard deviation. Fig. 3.13 shows how the standard deviation varies with the latitude used for the modern theory calculations.

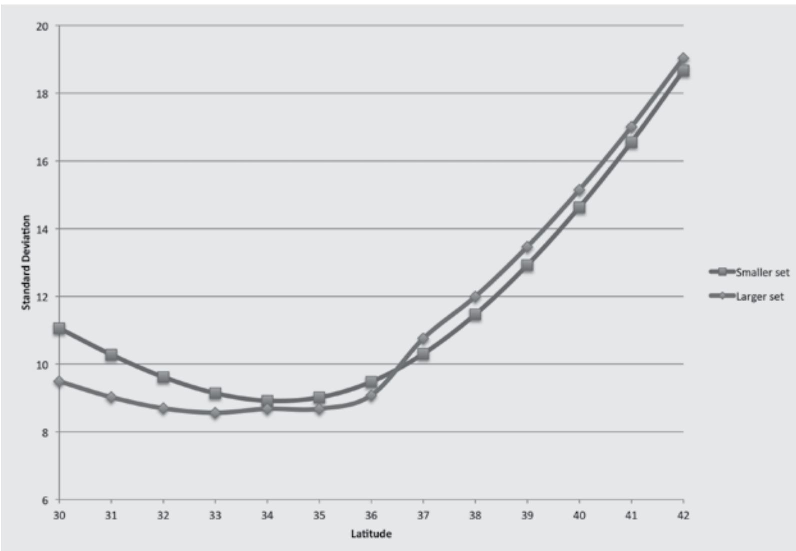

Figure 3.13:. *Fit of the Parapegma Inscription data to modern theory calculations according to latitude*

	Latitude	Mean difference	Standard deviation	Number of events
Smaller set	34° 13′	–3.1 d	8.9 d	5
Larger set	33° 4′	–0.6 d	8.6 d	8

The results are broadly consistent among the data sets and consistent with the results obtained by Anastasiou *et al.* In Appendix 2 we show indications that best fits to our visibility model may underestimate latitudes by about a degree and a half. Correcting for this would bring the estimated latitude for the data in the Parapegma Inscription to about 35°, which suggests that its contents were based, directly or indirectly, on observations made at a mid-Mediterranean locality such as Rhodes or, at furthest north, southern Greece. Egypt (roughly 31° or less) is much less likely, and Epirus (around 41°) more or less out of the question. The small mean difference found for the larger set could mean either that the inscription was based on recent observations or that, in adapting older data, the stellar phenomena were aligned with zodiacal dates in a manner that would conceal the precessional shift. The standard deviations for the best fit latitudes are in the same range as we have found for the Euktemon and Eudoxos data in the Geminos Parapegma; the number of dates preserved in the Parapegma Inscription is too small to allow a meaningful appraisal of whether its dates are on the whole more or less accurate than the Euktemon and Eudoxos dates.

3.13 Appendix 1. Model Parapegma

The fifteen asterisms for which the parapegma tradition transmits statements of risings and settings attributed to Euktemon are as follows:

Greek name	*Translation*	*Modern name*
Ἀετός	Eagle	Aquila
Αἴξ	Goat	Capella
Ἀρκτοῦρος	Bear-guard	Arcturus
Δελφίς	Dolphin	Delphinus
Ἔριφοι	Kids	Haedi
Ἵππος	Horse	Pegasus
Κύων	Dog	Sirius
Λύρα	Lyre	Lyra
Ὀϊστός	Arrow	Sagitta
Πλειάδες, Πλειάς	Pleiades, Pleiad	Pleiades
Προτρυγητήρ	Vintage-bringer	Vindemiatrix
Σκορπίος	Scorpion	Scorpius
Στέφανος	Crown	Corona Borealis
Ὑάδες, Ὑάς	Hyades, Hyad	Hyades
Ὠρίων	Orion	Orion

The majority of subsequent authorities and texts in the ancient parapegma tradition used these asterisms either exclusively or with very few additions. The parapegma presented in this appendix gives zodiacal day numbers for all four visibility events for the asterisms of Euktemon, computed by the software Alcyone Planetary, Lunar and Stellar Visibility version 3.1.0 (PLSV), which employs an implementation of the "classical" visibility model of Schoch (see Appendix 2). Julian calendar dates of the events were determined for 100 BC and for three latitudes: 31° (approximately valid e.g. for Lower Egypt and Alexandria), 36° (e.g. Rhodes and generally mid-Mediterranean latitudes), and 41° (e.g. Epirus and Rome). For individual stars Sirius (α CMa), Arcturus (α Boo), Capella (α Aur), and Vindemiatrix (ε Vir), the visibility dates can be determined directly. For the other asterisms, the following criteria were adopted:

- Small constellations and clusters (Lyra, Aquila, Corona Borealis, Pleiades, Hyades, Haedi, Sagitta, Delphinus): the asterism is considered to rise or set (in the sense of Parapegma phenomena) when its brightest star rises or sets.
  - Pleiades: Alcyone (η Tau)
  - Hyades: Aldebaran (α Tau)[54]
  - Lyra: Vega (α Lyr)
  - Aquila: Altair (α Aql)

- Corona Borealis: Alphekka (α CrB)
- Haedi: η Aur
- Delphinus: Rotanev (β Del)
- Sagitta: γ Sge[55]

- Large constellations (Orion, Scorpius, Pegasus): the asterism is considered to begin to rise or set when the first of certain designated bright stars rise or set, and it is considered to rise or set entire when all the designated stars have risen or set.
  - Orion (large constellation): Rigel (β Ori), Betelgeuse (α Ori), Bellatrix (γ Ori), Saiph (κ Ori)
  - Scorpius: Acrab (β Sco), Shaula (λ Sco)
  - Pegasus: Scheat (β Peg), Markab (α Peg), Algenib (γ Peg), and Alpheratz (α And)[56]

54 Aldebaran was considered by Greek astronomers to be part of the Hyades; see e.g. Ptolemy, *Almagest* 7.5, ed. Heiberg 2.88.

55 Sagitta, a small constellation consisting of only dim stars, is problematic in the parapegma tradition. Only setting dates for Sagitta were recorded (Columella 11.2.21 assigns its evening rising to February 22, but this is obviously an error for the evening setting), and in most sources the dates are extremely late. The evening setting, according to the PLSV model, should take place in early January (January 2 for latitude 31°, January 10 for 41° in 100 BC). However, the date attributed to Euktemon in the Geminos Parapegma (the constellation's name is missing in the Greek text, but can be restored from the medieval Latin version) was the 22nd of the zodiacal month of Aquarius, which would be about the middle of February, and other parapegma statements in Columella (11.2.21, making the correction just mentioned) and the Aëtios Parapegma (ed. Wachsmuth 293) and Clodius Tuscus Parapegma (three dates, ed. Wachsmuth 123-124) have dates in the range February 18-27. These greatly outnumber the attestations of dates close to the expected ones in the Clodius Tuscus Parapegma (January 13, ed. Wachsmuth 119), and Pliny 18.64.234 (January 5 specifically for Egypt). The PLSV model predicts Sagitta's morning setting in mid August (August 8 for 31°, August 18 for 41° in 100 BC). The Euktemon date in the Geminos Parapegma is the 10th day in Virgo, about September 5, which is Pliny's date for Attica (18.74.310), while the Quintilius Parapegma (ed. Wachsmuth 294), Pliny again (for Assyria, 18.74.309), the Aëtios Parapegma (ed. Wachsmuth 291), and the Clodius Tuscus Parapegma (ed. Wachsmuth 145) have dates ranging from August 25 to September 4. Anastasiou *et al.* 2013, A8 (online version only) explain the discrepancy between the Euktemon dates for Sagitta and those predicted by their visibility model as due to the dimness of γ Sge; but this will not do for the huge lag of the attested dates for evening setting after the expected dates since by the attested dates the constellation is well below the ideal horizon at sunset.

56 Alpheratz was considered to be common to Andromeda and Pegasus; see Ptolemy, *Almagest*, 7.5, ed. Heiberg 2.76. Pegasus is a very large constellation, making the identification

The Julian calendar dates were then converted to zodiacal day numbers using the dates of the Sun's entry into the zodiacal signs computed for 100 BC by the JPL Horizons ephemeris.[57]

Even for individual stars, modern models of stellar visibility are based on a slender empirical base, and one should assume that our computed zodiacal dates are only rough approximations of the dates when the risings and settings would have been observed by an ancient observer with reasonably good eyesight, a clear horizon, and favorable atmospheric conditions. Closely spaced groups of stars would probably have had a greater effective visibility than the brightest single star among them; in particular, our model surely underestimates the visibility of the Pleiades (apparent magnitude 1.6 in contrast to Alcyone's magnitude of 2.9). For the larger constellations, we have the added uncertainty concerning which stars any particular parapegmatist would have considered essential for stating that the constellation was partially or completely visible.

We have also given stellar dates attributed to Euktemon and Eudoxos in the Geminos Parapegma, supplemented for Euktemon by a few dates that can be estimated by combining information from the Geminos parapegma with the parapegma in the manuscript *Vind. phil. gr.* 108 ff. 282v-283r (V) and the Miletos parapegma fragment IMilet. inv. 456A (M).[58] For a comparison of these dates with the those generated by the PLSV model, see Appendix 2.

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of the "essential stars" particularly difficult; we have selected the four brightest stars, which form the quadrangle that represented the horse's torso.

57 http://ssd.jpl.nasa.gov. We used tropical longitudes since that is ostensibly the frame of reference of parapegmata that count days from a solstice or equinox.

58 The Vienna text, which gives unattributed intervals in days between consecutive stellar risings and settings rather than absolute day numbers in a chronological framework, is edited in Rehm 1913, 14-26; for its close relation to the Euktemon data in the Geminos Parapegma see pp. 12-13 and Hannah 2002. IMilet. inv. 456A was originally published in Diels & Rehm 1904, with a more cautious reedition in Lehoux 2005. (The dates of stellar phenomena given as applicable to Attica in Pliny 18 are also mostly equivalents of Euktemon dates expressed in the Roman calendar.) The intervals between stellar phenomena reported for Euktemon in the various sources exhibit frequent small variations (and occasional larger ones), probably because Euktemon's dates were adapted in different ways to the zodiacal frameworks of later parapegmata.

ASTERISM	*EVENT*	*31°*	*36°*	*41°*	*EUKTEMON*	*EUDOXOS*
Pleiades	ES	♈ 17	♈ 17	♈ 17	♈ 10	♈ 13
Scorpius begins	ER	♈ 21	♈ 21	♈ 20	♓ 29[59]	
Orion begins	ES	♈ 29	♈ 26	♈ 23		♈ 13
Hyades	ES	♈ 28	♈ 27	♈ 26	♈ 23	♈ 21
Lyra	ER	♉ 5	♈ 28	♈ 19	♉ 2	♈ 27
Capella	MR	♉ 6	♈ 28	♈ 15	♉ 8	♉ 9
Vindemiatrix	MS	♈ 29	♉ 7	♉ 20		♈ 13
Orion	ES	♉ 13	♉ 11	♉ 8	V: ?[60]	♉ 1
Sirius	ES	♉ 20	♉ 14	♉ 11	♉ 2	♉ 2
Haedi	ES	♉ 12	♉ 14	♉ 16		
Haedi	MR	♉ 21	♉ 18	♉ 14		
Scorpius	ER	♉ 19	♉ 20	♉ 22		
Sagitta	ER	♉ 30	♉ 24	♉ 19		
Pleiades	MR	♉ 22	♉ 25	♉ 29	♉ 13	♉ 22
Capella	ES	♉ 22	♉ 26	♉ 30	VM: ♉ 27[61]	
Scorpius begins	MS	♉ 28	♉ 27	♉ 25		♉ 11
Aquila	ER	♊ 3	♉ 31	♉ 26	♉ 31	♊ 7
Scorpius	MS	♉ 29	♉ 31	♊ 4		♉ 21
Delphinus	ER	♊ 8	♊ 3	♉ 30		♊ 18
Arcturus	MS	♉ 31	♊ 9	♊ 22	♉ 32	♊ 13
Hyades	MR	♊ 5	♊ 9	♊ 14	♉ 32	♊ 5
Orion begins	MR	♊ 27	♋ 1	♋ 7	♊ 24[62]	♊ 24
Corona	MS	♊ 31	♋ 10	♋ 21		♌ 10[63]
Orion	MR	♋ 14	♋ 19	♋ 26	♋ 13	♋ 11
Pegasus	ER	♌ 3	♋ 28	♋ 21	♌ 17	
Sirius	MR	♋ 23	♋ 30	♌ 3	♋ 27[64]	♋ 27
Aquila	MS	♌ 1	♌ 5	♌ 9	♋ 28	♌ 5
Sagitta	MS	♌ 13	♌ 18	♌ 23	♍ 10	
Lyra	MS	♌ 13	♌ 21	♌ 30	♌ 17	♌ 22
Delphinus	MS	♌ 17	♌ 21	♌ 25		♌ 18
Vindemiatrix	ES	♍ 10	♍ 12	♍ 14		
Capella	ER	♍ 30	♍ 17	♌ 28	♍ 20	♎ 4
Haedi	ER	♎ 1	♍ 21	♍ 5	♎ 3	
Vindemiatrix	MR	♍ 24	♍ 22	♍ 21	♍ 10	

ASTERISM	***EVENT***	***31°***	***36°***	***41°***	***EUKTEMON***	***EUDOXOS***
Arcturus	MR	♎ 1	♍ 28	♍ 25	♍ 10[65]	♍ 19
Pleiades	ER	♎ 3	♍ 30	♍ 24	♎ 5	♎ 8
Pegasus	MS	♎ 1	♎ 4	♎ 7		
Scorpius begins	ES	♎ 12	♎ 9	♍ 29		♎ 12
Scorpius	ES	♎ 17	♎ 10	♎ 5		♎ 17
Corona	MR	♎ 19	♎ 14	♎ 9	♎ 7	♎ 10[66]
Hyades	ER	♏ 1	♎ 29	♎ 28	V: ♎ 20[67]	♎ 22
Arcturus	ES	♎ 27	♏ 6	♏ 15	♏ 5	♏ 8
Pleiades	MS	♏ 15	♏ 16	♏ 17	♏ 15	♏ 19
Orion begins	MS	♏ 20	♏ 17	♏ 15	♏ 15	♏ 19
Lyra	MR	♏ 26	♏ 19	♏ 11	♏ 10	♏ 21
Scorpius begins	MR	♏ 19	♏ 19	♏ 19		♏ 18
Hyades	MS	♏ 21	♏ 20	♏ 20	♏ 27	♏ 29
Orion begins	ER	♏ 22	♏ 24	♏ 26		♏ 12
Sirius	MS	♐ 7	♏ 31	♏ 29	♐ 7	♐ 12
Corona	ES	♏ 25	♐ 3	♐ 12		♑ 9[68]
Orion	MS	♐ 5	♐ 4	♐ 2	V: ?[69]	♐ 8
Orion	ER	♐ 10	♐ 14	♐ 18		
Haedi	MS	♐ 11	♐ 14	♐ 19		
Scorpius	MR	♐ 14	♐ 17	♐ 20	♐ 10[70]	♐ 21
Capella	MS	♐ 13	♐ 18	♐ 24	♐ 19	♐ 23
Aquila	MR	♐ 28	♐ 25	♐ 22	♐ 15	♐ 26
Sagitta	MR	♑ 1	♐ 27	♐ 23		
Sirius	ER	♑ 3	♑ 8	♑ 11		♐ 16
Aquila	ES	♑ 5	♑ 8	♑ 11	♑ 7	♑ 18[71]
Delphinus	MR	♑ 13	♑ 10	♑ 7	♑ 2	♑ 12[72]
Sagitta	ES	♑ 10	♑ 14	♑ 18	♒ 25[73]	
Delphinus	ES	♑ 14	♑ 16	♑ 19	♑ 27	♒ 4
Lyra	ES	♑ 19	♑ 27	♒ 5	♒ 3	♒ 11
Vindemiatrix	ER	♒ 24	♒ 22	♒ 20	♓ 12	
Arcturus	ER	♓ 10	♓ 6	♓ 2	♓ 12	♓ 4
Pegasus	ES	♓ 5	♓ 7	♓ 10	V: ♒ 25[74]	
Pegasus	MR	♓ 17	♓ 17	♓ 17	♓ 14	
Corona	ER	♓ 23	♓ 17	♓ 11		♓ 21

59 "The first stars of Scorpius set."

60 In V the evening rising of Orion is listed after the evening setting of the Hyades but as 14 days before the evening setting of Sirius, which is only 10 days after the evening setting of the Hyades. The numeral must be corrupt.

61 IMilet. inv. 456A col. ii lists for what are probably the last seven days of Taurus the following events: (1) an evening event according to Euktemon; (2) no event; (3) the evening setting of Capella according to an authority whose name is lost, Philippos, and the Egyptians; (4) the evening setting of Capella according to Kalaneus of the Indians; (5) no event; (6) the evening rising of Aquila according to Euktemon, (7) the morning setting of Arcturus according to Euktemon and the evening rising of Aquila according to Philippos. V lists the "setting of Capricorn" following 18 days after the morning rising of the Pleiades and five days before the evening rising of Aquila. Αἰγόκερω ("of Capricorn") must be a corruption of Αἰγός ("of Capella"). The Geminos Parapegma has, for Taurus day 25, "Aquila (Ἀετός) sets in the evening," which is manifestly an error, and Manitius plausibly conjectured that the constellation name here was again a corruption of Capella (Αἴξ).

62 "Orion's shoulder rises."

63 This date is clearly an error, though a statement in the Clodius Tuscus Parapegma (ed. Wachsmuth 142) that the setting takes place on August 5, which would be approximately the same date as Leo day 10, shows that it was present in the tradition at an early date.

64 A second entry at ♌ 3: "Sirius conspicuous."

65 A second entry at ♍ 20: "Arcturus conspicuous."

66 Constellation name restored by Manitius.

67 "From rising of Corona to rising of Hyades, 13 days. From rising of Hyades to setting of Arcturus, 16 days."

68 Like the Eudoxos date of Corona's morning setting, this is clearly an error, though the Clodius Tuscus Parapegma (ed. Wachsmuth 117) and Lydos, *De Mensibus* (ed. Wünsch 73) give an approximately equivalent date, January 1.

69 "From setting of Pleiades to setting of Orion entire, 3 days." This would put the rising of Orion at about ♏ 15, which is implausibly early. The next event listed in V is the morning setting ofSirius, so the date for Orion's morning setting should be before ♐ 7.

70 "The sting of Scorpius rises."

71 Names of Eudoxos and constellation restored by Manitius.

73 Constellation name restored by Wachsmuth on the basis of the Latin version. Manitius conjectures Pegasus. V gives both the setting of Sagitta and the *rising* of Pegasus on the same day, while it has the *setting* of Pegasus 16 days later and 12 days before the vernal equinox ("From setting of Sagitta and rising of Pegasus to <rising> of Vindemiatrix and Arcturus and setting of Pegasus, 16 days"). Obviously the two events for Pegasus have been erroneously interchanged. Note that the Geminos parapegma puts Euktemon's date for the evening rising of Pegasus two days after the evening risings of Vindemiatrix and Arcturus.

74 See preceding note.

3.14 Appendix 2. Modelling stellar visibility phenomena

Whether or not a star is visible close to the time when it crosses the horizon at rising or setting depends on astronomical, geographical, atmospheric, and meteorological conditions in addition to the visual acuity, sensitivity, and observational experience of the individual observer. If the visibility of a constellation is in question, one must also take into account which star or set of stars are considered to constitute the constellation's essential parts.

The astronomical factors are reducible to the star's apparent magnitude and the apparent positions of the star and the Sun relative to the horizon. These can be modelled accurately for a particular latitude and chronological period by modern theory, except that we are unlikely to know the outline of an ancient observer's horizon. Hence we can determine the exact dates when a star crosses the eastern or western *ideal* horizon simultaneously with the Sun. It is not possible, however, to model with exactitude the number of days after an ideal morning rising or setting a star will have be visible or be seen setting for the first time by a typical observer, or how many days before an ideal evening setting or rising a star will be visible or be seen rising for the last time, and there does not even exist a satisfactory body of empirical data on the basis of which one could say how accurate the existing visibility models are.

According to the classical "*arcus visionis*" approach to modelling visibility of heavenly bodies, which goes back to Ptolemy, the primary criterion for visibility is whether the difference in altitude (or depression) between the apparent positions of the body and the Sun is greater than a certain arc (the *arcus visionis*) which is dependent on both the magnitude of the body and the difference in azimuth between its rising or setting points and those of the Sun around the date of the visibility phenomenon.[75] In general, the larger the *arcus visionis,* the further the date of the visibility phenomenon is from the ideal phenomenon. The azimuthal factor can be treated in a simplified way, by assigning to a given stellar magnitude two arcus visionis values, one of which applies to the phenomena in which the Sun and star are both rising or both setting (i.e. morning rising and evening setting), while a smaller value applies to the phenomena in which one body rises while the other sets (evening rising and morning setting). Alternatively, one can attempt to model a vari-

75 In the simplest form, the test is applied to the moment when the apparent altitude of the body is zero. However, the outline of the true horizon can advance or delay the moment of sunrise or sunset relative to the rising or setting of the body; and moreover because of atmospheric extinction it is unlikely that a star will be visible right at the horizon. These effects can be compensated by setting a "critical altitude" that the body must exceed in order to be visible.

able arcus visionis dependent on both the azimuth difference and the magnitude; such a model ought to provide a better representation of the visibility conditions for stars that are not close to the ecliptic. In any case, values for *arcus visionis* should be empirically calibrated, but there is a dearth of reliable data for doing this.[76]

An alternative approach, developed by Anastasiou *et al.,* seeks to determine criteria for stellar visibility from "first principles".[77] They first model the brightness of an arbitrary point of the sky as a function of the point's altitude, the Sun's depression below the horizon, and the azimuthal distance between the point and the Sun, on the basis of empirical measurements published by Nawar and by Koomen et al.[78] This is then combined with Tousey and Koomen's table estimating the minimum magnitude for a star to have a 98% probability of visibility as a function of the brightness of the immediately surrounding sky.[79]

For the present paper we have used the Alcyone Software freeware program Planetary, Lunar, and Stellar Visibility version 3.1.0 (henceforth PLSV). This program uses an *arcus visionis* model for stellar visibility, with *arcus visionis* (h) determined as a function of apparent magnitude ($\boldsymbol{m}$) according to the following default relations derived by Swerdlow and Lange from Schoch's estimates *of arcus visionis* for the superior planets:[80]

$$h_{\mathrm{MR,ES}} = 10.5° + 1.4°m$$

$$h_{\mathrm{MS,ER}} = 8.9° + 1.1°m$$

The critical altitude for visibility was set at 0°, that is, it was assumed that in the absence of solar glare a star would be visible when at the altitude of the (ideal) horizon. A zero critical altitude is certainly not correct, and the *arcus visionis* relations depend on empirical data of uncertain quality. Although the software allows these parameters to be modified, we have retained the defaults since we do not have a basis for determining more appropriate values. For the principal stars used in ancient parapegmata, the values of *arcus visionis* yielded by the formulas given above fall in the range of 7°-16°.

Anastasiou *et al.* report dates of six phenomena involving four individual stars and the

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76 See the discussion of these problems (by N. M. Swerdlow and R. Lange) "Sources of Computations and Cautions concerning Accuracy" at http://www.alcyone.de/plsv/documentation/index.html.

77 Anastasiou et al. 2013, A1-A4 (in the online version).

78 Nawar 1983; Koomen et al. 1952.

79 Tousey & Koomen 1953.

80 Schoch 1927.

Pleiades, computed by their method for 150 BC and for a range of latitudes, from which we have selected those for latitudes 31°, 36° and 41°, and in addition two further phenomena of Vega computed for the same year and the latitude of Athens.[81] The mean difference of their dates over those we compute for the same year and latitude by means of PLSV is approximately +1.5 days, with a standard deviation of approximately 3.8 days. While the number of dates compared is not sufficient to obtain a precise measure of how closely the two methods agree, let alone to diagnose their divergences, the agreement validates the usefulness of either method as a provisional standard for evaluating ancient parapegmata.

For Mediterranean latitudes the daily change in the altitude difference between the Sun and a star can be as little as around half a degree per day or as great as nearly a degree per day. If we suppose that two observers in the same period and locality are not likely to have reported a visibility phenomenon for the same star on dates having the altitudinal difference between star and Sun varying by more than say 5° between the two observations, we can conclude that discrepancies larger than ten days between dates in the ancient sources cannot be explained entirely in terms of visual acuity, local atmospheric conditions, or the defectiveness of the modern visibility model. We may hope by a similar argument that PLSV will not normally yield dates for the risings and settings of an individual star differing by more than ten days from the dates when a competent ancient observer would report the same events, presuming that the modern model is applied to the correct star, latitude, and chronological period.

Precession, and to a lesser degree, stellar proper motion, lead to changes in the dates of visibility phenomena relative to each other and to the solstices and equinoxes, but over the three or four centuries from the beginnings of the parapegma tradition to the date of the Mechanism's manufacture these changes are small. In the three centuries between 400 BC and 100 BC, the dates of stellar phenomena should shift on average about 1.8 days later in the Julian calendar, and about 4.2 days later relative to the solstices and equinoxes, with a standard deviation of a little over one day in either case, so that the relative dates of the phenomena are fairly stable.[82] From a sufficiently large body of zodiacal dates of

81 The dates computed for Aldebaran ES and MR, Vega ER, Pleiades MR, Altair ER, and Arcturus MS are reported in a graph, Anastasiou et al. 2013, 176, Fig. 2; those of Vega MR and ES for the latitude of Alexandria are on pp. A2-A3 in the appendices (in the online version). The Pleiades were assigned a location and a magnitude based on an aggregate of the ten brightest stars in the cluster (p. 185 note 16), whereas we have used Alcyone to stand for the cluster.

82 For the stars used in our calculations of the model parapegma, the average shifts from 400 BC to 100 BC were approximately 1.2 days later in the Julian calendar, and 3.6 days later relative to the solstices and equinoxes, with standard deviation approximately

stellar phenomena, one ought to be able to obtain a very rough estimate of when the observations were made, though an error of one day in the ancient determination of the solstices and equinoxes would throw the estimate off by about seventy years. The long term changes in the relative dates of the phenomena are probably too slow to be usable for dating parapegmatic observations or calculations.

Latitude, on the other hand, has a pronounced effect on the dates of stellar visibility phenomena. In general, for a Mediterranean range of latitudes, the date of a particular visibility phenomenon of a particular star will either tend to fall progressively earlier or progressively later with increasing latitude. The typical shift in date over the range 31°-41° is well over ten days, with no bias favoring a tendency to earlier or later dates with more northerly latitudes. Some events exhibit little or no shift of date; for example the setting dates (both morning and evening) of the Pleiades and Aldebaran shift by no more than two days over the ten degree latitudinal spread. At the other extreme, the settings of Arcturus and Alphekka, the risings of Capella, and all the phenomena of Vega all shift by fifteen or more (up to thirty-three for Capella's evening rising).

In principle, then, it should be possible to estimate the latitude for which a sufficiently large set of parapegma data was observed or computed. We can use as a test Ptolemy's *Phaseis,* which contains dates of phenomena of thirty bright stars that Ptolemy computed, according to the information he provides, from the coordinates and magnitudes in his star catalogue (*Almagest* 7-8) according to an *arcus visionis* model for a series of five latitudes corresponding to longest days ranging from 13.5 hours to 15.5 hours at half hour intervals.[83] As a subset of these data, we selected Ptolemy's dates for eleven stars,[84] for the latitudes having longest day 14 hours (30° 22′ according to Ptolemy, Almagest 2.6), 14.5 hours (36°), and 15 hours (40° 56′). The latitudes for which the PLSV model yields the best fit[85] are as follows:

1.2 days. These are slightly smaller shifts than the expected values (derived from the differences between the sidereal, Julian, and tropical years) because of uneven distribution of the stars in question.

83 Ptolemy appears to have used a model in which *arcus visionis* varied linearly as a function of azimuthal distance; see Graßhoff 1993.

84 Capella, Vega, Arcturus, Aldebaran, Sirius, Alphekka, Altair, Betelgeuse, Rigel, Bellatrix, and Alpheratz.

85 The date of a particular phenomenon corresponding to a given latitude was modelled as a least squares fit of a quadratic function to the dates calculated by PLSV for seven latitudes ranging from 28.5° to 43.5° at 2.5° intervals. We define "best fit" for the latitude as the latitude for which the standard deviation of differences between attested and PLSV dates is minimum, disregarding the mean difference, so that the result will not be affected

Longest day	Latitude (Ptolemy)[86]	Latitude (PLSV fit)	Mean difference[87]	Standard deviation	Number of dates
14 h	30° 22′	28° 58′	+3.4 d	3.0 d	43
14.5 h	36°	34° 36′	+3.3 d	3.2 d	41
15 h	40° 56′	39° 33′	+3.2 d	3.1 d	42

The PLSV model differentiates between the three sets of data remarkably well, with the estimated latitudes increasing from one set to the next by differences that are practically identical to the differences between the latitudes that Ptolemy ostensibly computed them from; but the estimated latitudes are consistently about a degree and a half too small. It is not clear whether this results from a bias in Ptolemy's method of calculation or in the PLSV model. In Fig. 3.14 the standard deviation is plotted for each data set as a function of the latitude for which PLSV dates are computed, showing that the quality of fit is quite sensitive.

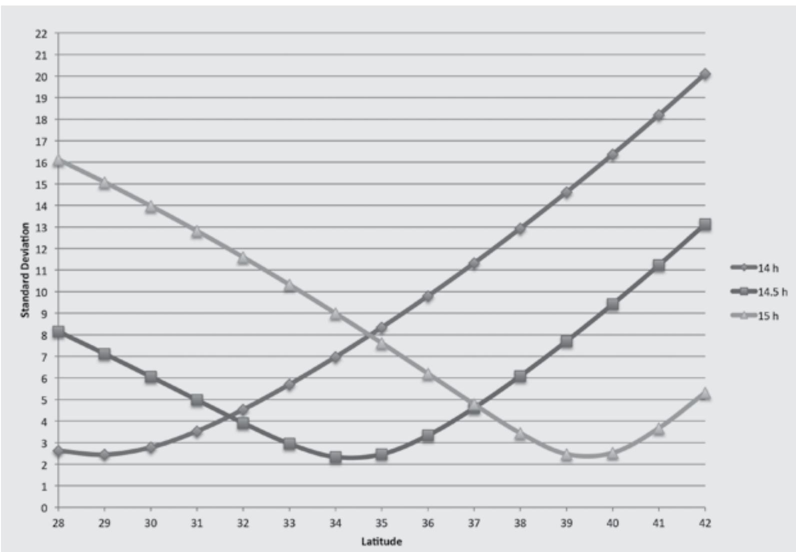

Fig. 3.14: *Fit of Ptolemy's data to modern theory calculations according to latitude*

by any systematic shift due to errors in the dates of the solstices and equinoxes assumed in the ancient sources.

86 From *Almagest* 2.6.

87 Dates relative to the summer solstice in 100 BC obtained from the PLSV model were subtracted from Ptolemy's dates relative to the date he assigns to the summer solstice (Epeiph 1 in the reformed Egyptian calendar).

Ptolemy's dates of phenomena relative to the summer solstice as he determined it average about 3.3 days later than the dates computed by the PLSV model for 100 BC relative to the summer solstice in that year. Assuming a precessional shift in dates of one day in seventy years, this would situate Ptolemy's calculations around AD 132, which on the face of it compares rather well with his epoch of AD 137 for his star catalogue (*Almagest* 7.4). The agreement is, however, to some extent coincidental, because Ptolemy's assumed solstices and equinoxes for his own time were about a day too late, so that his dates of the phenomena relative to his summer solstice average about a day less then relative to the true solstice. This might suggest that the PLSV dates are also about one day too early (we recall that they also averaged about 1.5 days earlier than dates computed by Anastasiou *et al.*).

We have also found latitudes that yield best fits for the zodiacal dates ascribed to Euktemon in the Geminos Parapegma (supplemented by other sources) and to Eudoxos in the Geminos Parapegma, as well as the Egyptian calendar dates in *PHibeh* 1.27 converted to zodiacal dates relative to the summer solstice date recorded in the papyrus.[88] For each collection of dates, we have estimated the latitude twice: (i) using all the attested phenomena according to the identifications of asterisms with specific stars in Appendix 1 except for a few extreme outliers, and (ii) limiting consideration to asterisms that can safely be equated, so far as visibility is concerned, with single bright stars: Sirius, Arcturus, Capella, Lyra (Vega), Aquila (Altair), and Hyades (Aldebaran). The results are as follows:

	Full set[89]				Single bright stars			
	Latitude	Mean difference	Standard Deviation	Number	Latitude	Mean difference	Standard Deviation	Number
Euktemon	33° 48′	–3.0 d	8.9 d	41	35° 13′	–3.1 d	7.2 d	24
Eudoxos	33° 41′	–1.0 d	9.1 d	47	35° 4′	+0.5 d	8.6 d	25
PHibeh 1.27	33° 59′	+3.0 d	9.0 d	22	35° 57′	+2.5 d	9.2 d	13

88 For *PHibeh* 1.27 we consider Pharmouthi 22, which is the third of the four consecutive days on which the longest day is stated to be in effect, to be the summer solstice, rather than Pharmouthi 24, which is the date on which the papyrus refers explicitly to the solstice but which is no longer assigned the maximum length of day. It is clear that the solstices and equinoxes of the papyrus were meant to be spread out as evenly as possible, with three 91 day intervals and one 92 day interval, while length of day is made to increase or decrease between extreme values of 10 and 14 hours by 1/45 hour per day, requiring five additional days of maximum or minimum length to be placed around the two solstices.

89 Omitting Euktemon's phenomena for Sagitta, Eudoxos's morning and evening settings of Corona, and *PHibeh* 1.27's phenomenon for Vindemiatrix.

Fig. 3.15 shows how the standard deviations vary when we compute the dates according to the PLSV model for a range of latitudes from 30° to 42°. It is clear that reducing the data set to the securely identifiable single bright stars makes the quality of the fit more sensitive in the lower range of latitudes, but all the sets show similar rapidly increasing trends in the higher latitudes, making it quite improbable that any of the three sources was based on observations or calculations for a latitude as far north as, say, 39°. If the fits to the single bright stars can be relied on and the PLSV model is not biased, all three sources would appear to reflect conditions around the latitude range 34°-37°. Correcting for the possible bias we found from the Ptolemy data, the range could shift northward to 35.5°-38.5°. From the little information we have concerning the localities where Euktemon and Eudoxos worked, this seems about right. Ptolemy asserts, we do not know on what authority, that Euktemon observed in Athens, the Cyclades, Macedonia, and Thrace, and Eudoxos in Asia (Minor), Sicily, and Italy, so that he considers their data to be valid for latitudes where the longest day is between 14.5 and 15 hours, i.e. between 36° and 40° 56′ (*Phaseis,* ed. Heiberg 66-67).[90] Hipparchos (ed. Manitius 28) concludes that Eudoxos's description of the system of constellations in his *Phaenomena* was written to fit the latitude of "Hellas," at 37°, and though the *Phaenomena* did not, to our knowledge, contain parapegmatic data, it is plausible that Eudoxos would have intended his dates of stellar phenomena to be applicable to the same approximate latitude. In any case Euktemon and Eudoxos are not likely to have compiled parapegma data at or for a latitude south of Rhodes, at 36°. As for *PHibeh* 1.27, it appears practically certain that the dates of phenomena in this papyrus originated in a source composed at a latitude much further north than Egypt.[91]

90 Ptolemy is speaking here of Euktemon's and Eudoxos's records of weather phenomena, but presumably the same would apply to their stellar phenomena.

91 Hibeh (el-Hiba) is in the Fayum, latitude 28° 46′, while the introduction of the text in the papyrus alleges that its teaching originated with a man from Sais in the Delta, Latitude 30° 58′.

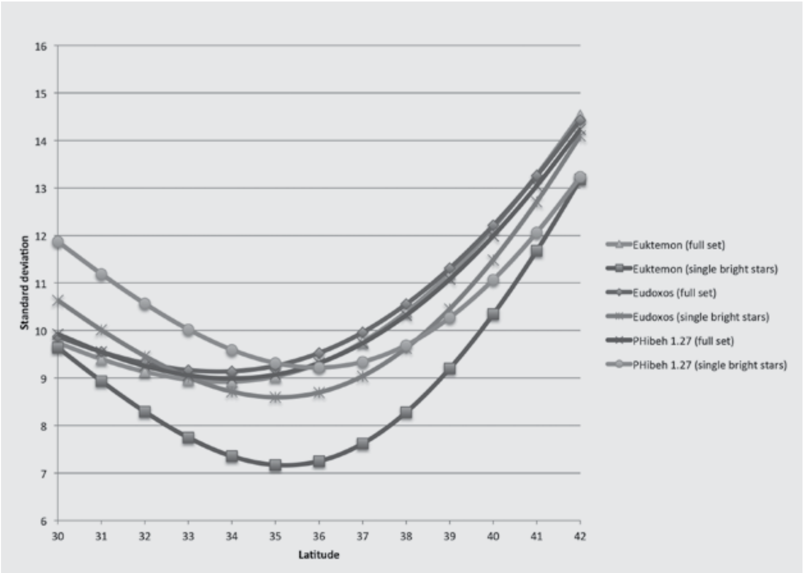

Figure 3.15: *Fit of parapegma data from the Geminos Parapegma and PHibeh 1.27 to modern theory calculations according to latitude*

The Euktemon dates average about 3 days earlier than those obtained from the PLSV model for 100 BC; if the PLSV dates are tending to be about a day too early as the comparison with the Anastasiou et al. model and Ptolemy's data suggest, the lead would increase to about four days. Euktemon's *floruit* is estimated as second half of the fifth century BC from the fact that Ptolemy (*Almagest* 3.1) associates him with Meton of Athens in the observation of the summer solstice of 432 BC, so the expected lead would be about 4.7 days if the Euktemon dates were relative to solstices or equinoxes that were accurate for his time.[92]

Since Eudoxos was active in the first half of the fourth century BC, it is at first glance surprising that the Eudoxos dates in the Geminos Parapegma have a very small average difference relative to the PLSV model, which is even positive if we consider only the bright individual stars. However, this seems to be at least in part a consequence of the way that the Eudoxos dates were incorporated into the Geminos Parapegma. While the Euktemon dates appear to have been incorporated on the assumption that Euktemon's solstices

92 Bowen & Goldstein 1988 argue that this was likely not a true observation of the date of the solstice; but for dating Euktemon's activity the question is immaterial. If the Egyptian calendar equivalent that was established in antiquity for the Athenian date of the Meton-Euktemon solstice was correct, which is unfortunately not certain, the true solstice was about a day later than the recorded date.

and equinoxes coincided with the first days of the relevant zodiacal months according to the Geminos Parapegma's own temporal framework (this is explicitly stated for the two equinoxes and the winter solstice), the Parapegma includes statements that Capricorn day 4 was the winter solstice according to Eudoxos and, 91 days later, that Aries day 6 was the vernal equinox. If, as seems likely, Eudoxos's solstices and equinoxes were supposed to be separated by near-equal intervals of 91 or (in one case) 92 days approximating equal quarters of the year, his summer solstice would have fallen on the Parapegma's Cancer day 2 or 3, and his autumnal equinox would have fallen on the Parapegma's day 1 or 2. This means that, depending on the season of the year, a Eudoxos date in the Parapegma can be as much as five days earlier relative to the immediately preceding solstice or equinox according to Eudoxos than relative to the Parapegma's own solstice or equinox. It is not clear what was the compilator's rationale for aligning the Eudoxos solstices and equinoxes with his own dates; perhaps he chose to equate the Eudoxos autumnal equinox with his own. An optimal alignment would likely have had the Eudoxos solstices and equinoxes falling two to four days earlier.

PHibeh 1.27 can be dated to before about 240 BC on grounds of archeological context and a dated document written on its back.[93] The positive mean differences, taken naively, would indicate a date around the late first century AD As was the case for the Eudoxos data, the solstices and equinoxes in the papyrus are at near-equal intervals of 91 and 92 days, this cannot by itself account for the large discrepancy since we are not now dealing with a case of data transferred from a zodiacal framework with equally spaced solstices and equinoxes to another framework with them unequally spaced. It seems, rather, that the stellar dates and the solstices and equinoxes have been incorporated in the papyrus's Egyptian calendar framework, likely from disparate sources, in an inconsistent way. The Egyptian calendar's steady shifting one day backwards every four years relative to astronomical phenomena may be the underlying cause, if the stellar dates were converted from some other chronological system to the Egyptian calendar according to appropriate equivalences for the time in question, and then combined with a set of Egyptian calendar dates for the solstices and equinoxes that had been approximately valid some decades earlier. The papyrus's equinoxes and solstices would have most nearly coincided with correct dates around 306 BC plus or minus a few years, so the conversion of the stellar phenomena would best fit a date around the end of the first quarter of the third century.

As the foregoing examples show, extracting estimates of the date and locality of origin of parapegma data from comparison with the PLSV model or other modern visibility models is not a simple matter. Calibration of the modern models is one problem: we have indications that the PLSV model may be resulting in systematic errors in estimated latitudes

93 Grenfell & Hunt 1906, 138-139.

(making them too far south) and dates (making them too late). But the chief difficulties arise from uncertainty in the alignment of the solstice and equinox dates assumed in the ancient sets of parapegmatic data with the astronomically correct dates and from the fact that probably none of our data sets represents a direct and "clean" record of original observations or calculations preserved in its original chronological framework. Evidence from the comparison with the modern model has to be considered in conjunction with whatever other information we have about the history of the data sets, and its testimony is clearest when negative; for example our analyses above render very doubtful the assumptions of *PHibeh* 1.27's editors that it was based on astronomical observations made in Egypt around 300 BC[94]

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94 J.G. Smyly in Grenfell & Hunt 1906, 140.

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6

The Front Cover Inscription

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Abstract

The bronze plate known as the "Front Cover" of the Antikythera Mechanism had inscriptions on its outside face. This paper describes the reconstruction of the surviving parts of this text from the Mechanism's fragments, giving transcriptions and translations. The texts give data on synodic cycles for the five planets, and it may be conjectured that lost lines described the behaviour of the Sun and Moon. The data strongly support the idea that planetary motions were displayed on the front face of the Mechanism using simple epicyclic or eccentric models. Previously unattested long and accurate period relations are given for Venus and Saturn, which are favourable for geared representation and probably of Greek, rather than Babylonian, origin.

6.1 Introduction

Whereas during much or all of the time that it was immersed in the sea the Mechanism's back face was partly covered by an inscribed plate (the Back Cover Plate),[1] the front face was covered by *two* layers of inscribed plate. Fragment C, in its "original" 1902 state, comprised these two layers fused to parts of the front face (the dial plate and the casing of the Moon's phase display). Immediately superimposed on the front face were the two Parapegma plates, displaced from their proper locations above and below the dial plate and oriented in what seems to be a random manner.[2] The Parapegma plates were themselves overlaid by the plate that we conventionally call the Front Cover Plate, though we cannot be certain that it really was meant to serve as a cover or that the position in which it was found reflects where it was meant to be when the Mechanism was intact. On its outside face, the Front Cover Plate bore an inscription, oriented upright with respect to the Mechanism's top and bottom. Like the Back Cover Plate, the Front Cover Plate accumulated a hard layer of accretion over its inscribed face that retained mirror-reversed offsets of the inscription. Patches of the accretion layer subsequently became detached from the corresponding surfaces of the plate and became fused again in somewhat shifted positions.

As part of the c. 1905 conservation work, the accretion layer and the Front Cover Plate were painstakingly removed from Fragment C in many small pieces, and most of the pieces of the Front Cover were later reassembled as the present Fragment G. Besides G, two smaller pieces of the plate exist as separate fragments; and additionally we have many small fragments of the accretion layer bearing offsets, most but not all of which overlap with extant parts of the Front Cover. (Also some bits of the accretion layer remain on the surface of G.) In all we have a vertical extent of a little over 110 mm preserving parts of 43 consecutive lines of the inscription, and there were certainly more lines at the beginning and likely also more at the end. Supposing that the plate was truly a cover, it could have held about sixty lines of text if its height matched that of the front dial plate, and double that if it protected the entire front face. The aggregate width of the surviving plate is about 115 mm. If, as seems probable, the plate was originally about the same width as the Mechanism's faces (i.e. just over 170 mm), the average line would have contained about 70 letters. We can thus estimate that the complete inscription contained well over three hundred words, and likely on the order of five hundred to a thousand words.

The surviving portion of the inscription consists of descriptions of the cycles of apparent motion (*synodic cycles*) of the five planets through the zodiac. Each planet is discussed individually in a passage of eight to twelve lines, in the order Mercury, Venus, Mars, Jupiter, Saturn. (The planets' pointers were described in the same order in the Back Cover

1 *IAM* 5.1.

2 *IAM* 3.1-2.

Inscription, with the Sun inserted between Venus and Mars.)[3] The first part of each planet's section states a long time interval that is supposed to contain exact whole numbers of synodic cycles, periods of the planet's revolution around the zodiac, and solar years, followed by the approximate length of a single synodic cycle in days. The remainder of the section breaks down the synodic cycle into intervals of specified durations in days, characterized by whether the planet is moving eastward or westward in the zodiac and towards or away from the Sun.

Texts providing such information about planetary synodic cycles are attested in both Greek and Babylonian astronomy. For a close parallel, comprising five sections giving breakdowns of each planet's synodic cycle into stages of specific durations, we have to wait until late antiquity. The text in question is transmitted in various Byzantine astrological manuscripts, some of which ascribe it to Heliodoros, the brother of the sixth century AD Neoplatonist philosopher Ammonios; it is based in a rather haphazard way on Ptolemy's astronomical models and tables, but debases Ptolemy by treating each planet's synodic cycle as a constant period subdivided into constant stages.[4] In the planetary theories of both Babylonian and Roman-period Greek astronomy the synodic cycles were modelled as variable and dependent on the planet's position in the zodiac. It is probably significant that the only instances currently known of texts on cuneiform tablets or Greco-Egyptian papyri that prescribe a nonvarying subdivision of a planet's synodic cycles pertain to Venus, the planet with the least pronounced zodiacal anomaly.[5]

The Front Cover Inscription is not simply an astronomical text, but an astronomical text accompanying an astronomical mechanism. The reader of such a text in such a setting would receive it not only as a description of astronomical reality but at the same time as a description of the behavior of the device: the theoretical assumptions built into it as well as the phenomena that it simulated. The Front Cover Inscription and the Back Cover Inscription thus have complementary roles as "captions" for the Mechanism, with the Back Cover Inscription giving the viewer a guide to the meaning of the many exterior features, and the Front Cover Inscription directing the viewer's attention to the astronomical "facts" that these features displayed when the Mechanism was in operation. Since there is no reason why the text should have been limited to describing the behavior of the planets (or, if we prefer, the behavior of the planetary pointers on the front dial), we may conjecture that lost lines were devoted to the phenomena of the Sun and Moon as represented by the gearwork.

3 *IAM* 5.5, note to I 18.

4 Neugebauer 1958.

5 Babylonian cuneiform tablet BM 33552, in Britton & Walker 1991; Greek papyrus *POxy astron.* 4135 in Jones 1999, 1.81-84 and 2.10-13.

Just as the Back Cover Inscription supplies the modern investigator with information about aspects of the Mechanism's exterior that cannot be reconstructed from the physical remains, the Front Cover Inscription provides us with clues to the lost planetary gearwork as well as some measure of the understanding of planetary motion that the designers of the Mechanism possessed. In this last respect it is especially valuable, despite its many lacunae, because we have extremely few documents from the Hellenistic period that present any aspect of planetary theory beyond an elementary level.

6.2 Fragments preserving parts of the Front Cover Inscription

Three fragments are parts of the original inscribed plate of the Front Cover Inscription. In addition, we have many identified fragments of the accretion layer bearing offsets of the inscription. With the exception of Fragments 42 and 51, the original relative locations of all the fragments are known (Figs 6.1-6.2).[6]

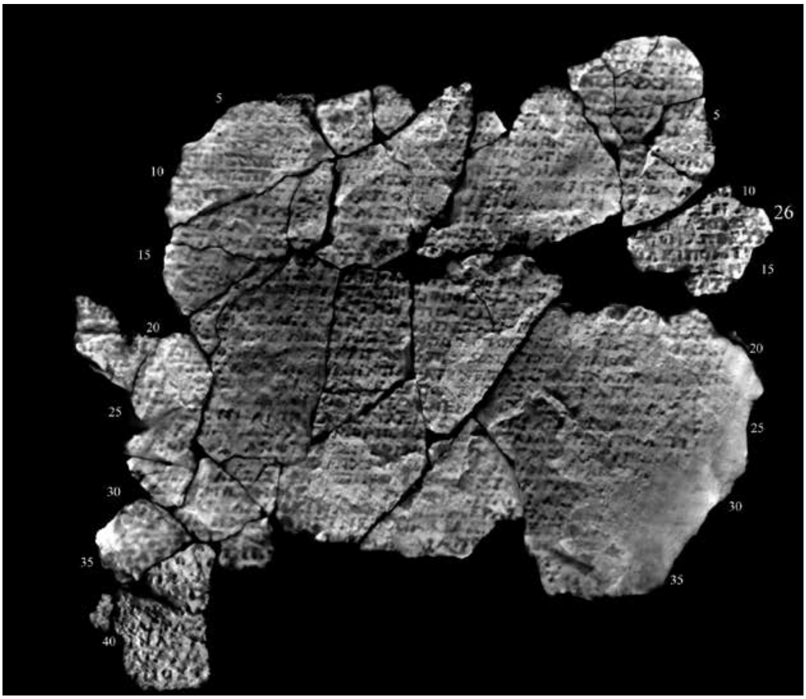

Figure 6.1: *CT composite image of the plate fragments of the Front Cover Inscription (Image: Antikythera Mechanism Research Project)*

6 The locations on G of offset fragments 23, 37-41, 43-44, and the fragments with numbers above 45 were found by A. Jones; T. Freeth found the location of 27, while Jones and Freeth independently located 21. Freeth conjectured the locations of 26 and 29 in relation to G before they were established by study of the text and the photographic evidence for 29 mentioned in the next note. Most of these juxtapositions of fragments were shown visually in a video animation prepared by Images First Ltd. which was displayed as part of the National Archaeological Museum's temporary exhibition, "The Antikythera Shipwreck: The Ship, The Treasures, the Mechanism" (April 5, 2012-June 29, 2014).

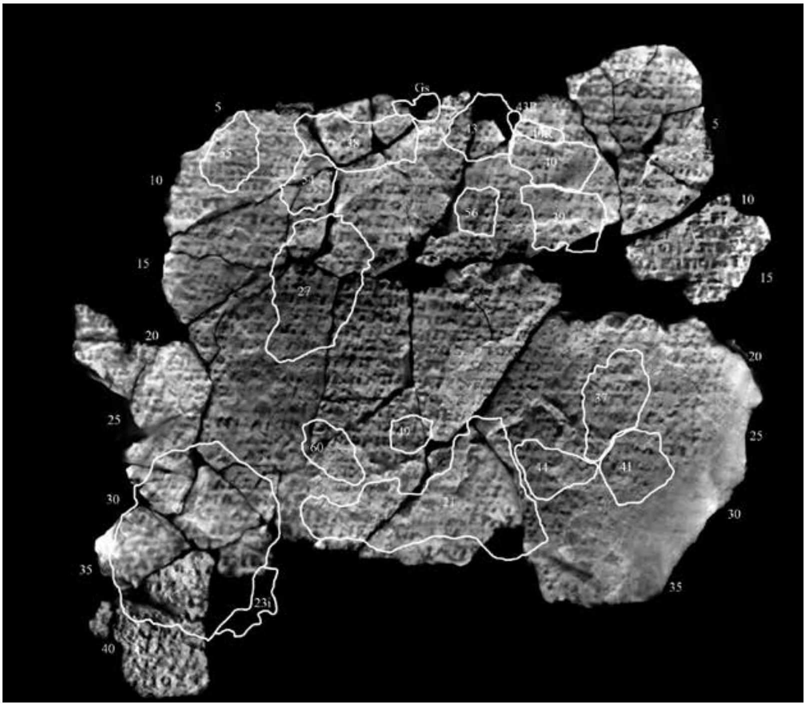

Figure 6.2: *Locations of offset fragments of the Front Cover Inscription. For notations with appended letters see the introduction to the apparatus in section 6.4*
(Image: Antikythera Mechanism Research Project)

Fragments of the Front Cover Plate

Fragment G (supplementary Fig. S5), 115 mm (width) by 94 mm (height), containing parts of thirty-six text lines (1-36, though the remains of 36 are just illegible traces). This fragment, our principal witness for the Front Cover Inscription, was assembled by museum technicians from about twenty pieces of plate, the largest of which, constituting its lower right portion, is approximately 48 mm by 51 mm. Most of the pieces bear visible writing, though some patches are concealed behind a thin layer of accretion. The engraving is everywhere shallow and blurred owing to corrosion and perhaps also early chemical cleaning, and even in CT images the legibility varies from mediocre to poor. The surface towards the lower right edge tapers to complete smoothness. The continuity of text as established in the present transcription confirms that the pieces have been fitted together correctly.

The average baseline-to-baseline spacing in G is approximately 2.6 mm as measured between the baselines of lines 2 and 36. Typical letter height is about 2.0 mm. The average letter width, from left edge to left edge of consecutive letters, is approximately 2.2 mm, though from line to line the average can deviate by as much as roughly 10% from this value. Thus while the letter heights and horizontal spacing of the Front Cover Inscription are about the same as those of the Back Cover Inscription, the line spacing is considerably tighter than the Back Cover Inscription's 3.5 mm baseline-to-baseline.[7]

Fragment 26 (Fig. 6.3, left), 26 mm by 20 mm, containing parts of seven text lines (10-16).

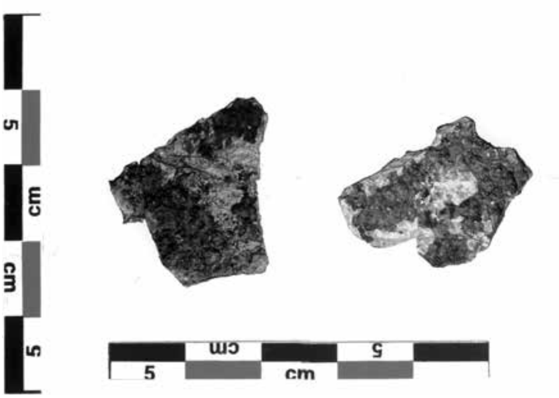

Figure 6.3: *Fragments 26 (left) and 29 (right)*
(Images: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

Fragment 29 (Fig. 6.3, right), 23 mm by 23 mm, containing parts of ten text lines (lines 34-43, the last of which is just illegible traces). In some of Price's photographs taken during his visit to the National Archeological Museum in 1958, Fragment 29 is visible as an attached part of G, joining the present bottom edge at its left end.[8] The correctness of this join is confirmed by Fragment 23's offsets, which overlap parts of both 29 and G. Continuity of text establishes that Fragment 26 belongs in the large inlet of the right side of G. The configuration of the three plate fragments is shown in Fig. 6.1.

Fragments of the accretion layer containing offsets of the inscription

We list below the offset fragments with their approximate dimensions and the line numbers of the text lines that they partially preserve. Figs. 6.4-6.7 show photographs and PTM

7 *IAM* 5.2.

8 Adler Planetarium collection, color negative in Envelope 2, showing all fragments in the cardboard boxes; black-and-white photograph in Price family collection showing Price measuring Fragment A with G and other fragments visible on his work table. A black-and-white photograph of G in Adler Folder 1, reproduced as Price 1974, 50, fig. 40, shows the fragment missing not only Fragment 29 but also two small bits that are at present attached immediately to the left and right of where 29 was. Black-and-white negatives in Adler Negative Roll 2 show G in its present state together with several small fragments. Unfortunately we do not know the relative chronology of the various photographs.

images of these fragments, and Fig. 6.2 shows their original locations in relation to the plate fragments where these are known.

21: 45 mm by 26 mm, 9 lines (25-33).
23: 28 mm by 35 mm, 13 lines (27-39).
27: 18 mm by 25 mm, 9 lines (13-21).
37: 23 mm by 38 mm, 7 lines (20-26).
38: 36 mm by 18 mm, 3 lines (6-8).
39: 27 mm by 20 mm, 4 lines (10-13).
40: 28 mm by 16 mm, 4 lines (6-9).
41: 23 mm by 23 mm, 5 lines (25-29).
42: 20 mm by 14 mm, 3 lines (not placed).
43: 22 mm by 21 mm, 5 lines (4-8).
44: 26 mm by 17 mm, 4 lines (26-29).
49: 09 mm by 08 mm, 3 lines (25-27).
51: 13 mm by 14 mm, 5 lines (not placed).
54: 10 mm by 12 mm, 4 lines (8-11).
55: 10 mm by 14 mm, 5 lines (6-10).
56: 07 mm by 09 mm, 3 lines (10-12).
60: 10 mm by 11 mm, 3 lines (25-27).

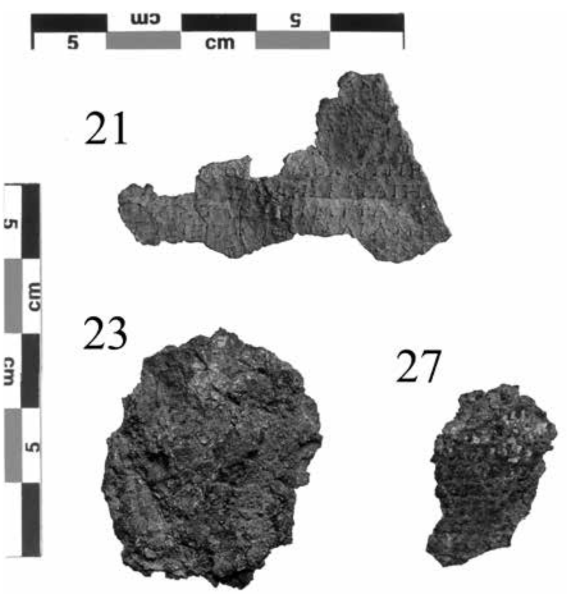

Figure 6.4: *Fragments 21, 23, and 27, mirror-reflected*
(Images: National Archaeological Museum of Athens (K. Xenikakis), copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

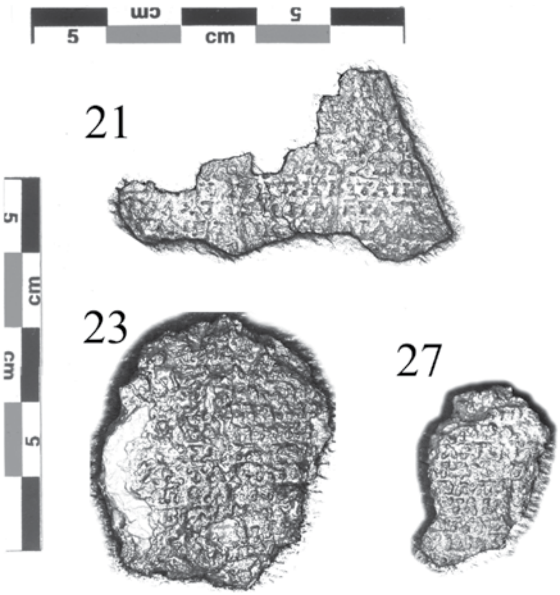

Figure 6.5: *Mirror-reflected PTM images of Fragments 21, 23, and 27 with specular enhancement (Image: Antikythera Mechanism Research Project)*

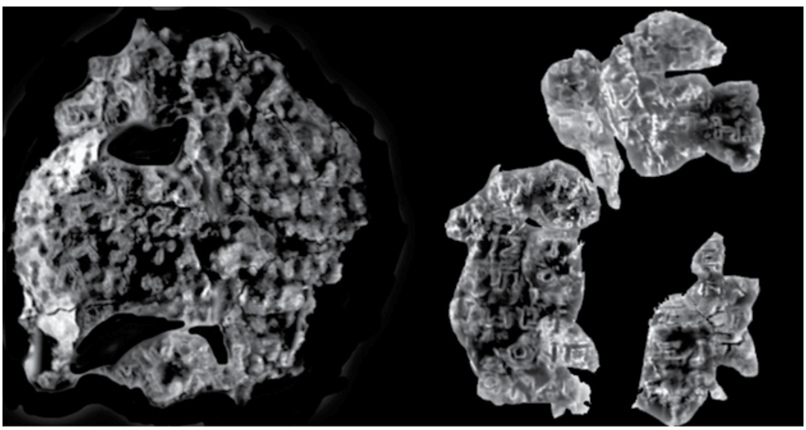

Figure 6.6: *Fragment 23, CT composite images of offsets on surface (left) and flakes in interior (right)*
(Image: Antikythera Mechanism Research Project)

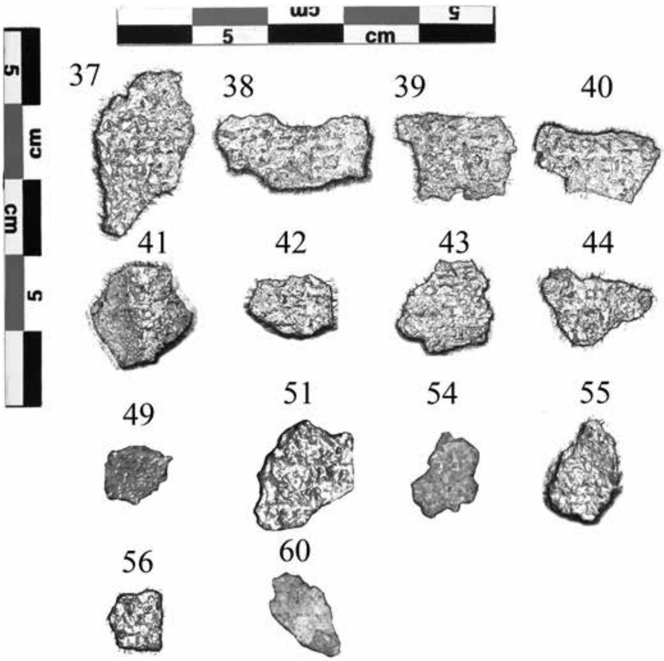

Figure 6.7: *Mirror-reversed PTM images of small offset fragments with specular enhancement (Image: Antikythera Mechanism Research Project)*

Most of the offset fragments are thin plates, but 23 and 27 are comparatively thick, and their interiors contain jumbled flakes of accretion including some that bear offsets legible in CT. The interior offsets in 23 are particularly helpful for reconstituting the inscription (Fig. 6.6). All the offset fragments are presumed to have been separated from Fragment C during the conservation work of c. 1905. The 1903 published photograph of C-1 (supplementary Fig. S9) shows only the Front Cover plate and the layer of accretion, featureless and indistinguishable from each other. Rediadis reported that C-1 bore "traces of an illegible (forwards-running) inscription", and it is possible that a region indicated by the letter "b" in the photograph was where these letters could be seen.[9]

9 This is according to the German language edition, Svoronos 1903b, 46. In the Greek edition, Svoronos 1903a, 46, Rediadis mistakenly asserted that C-1 bore the part of the Back Plate Inscription that Svoronos had in fact transcribed from A-2. The letters on Plate 10 were intended to mark features discussed in Rediadis's text, but there is no reference to "b". The region marked by "b" corresponds to the upper right corner of the present Fragment G, where the lettering is comparatively clearly preserved.

By the time that Rehm saw C-1 in September, 1905, the Front Cover plate and accretion layer had been entirely removed (supplementary Fig. S10).[10] The first record of the Front Cover Inscription fragments as separate entities is Rehm's notebook of 1906.[11] On the pages numbered 86 and 87 of this notebook (Fig. 6.8), Rehm drew the outlines and what he could make out of the text of ten small fragments, labelled with the Greek letters ι through σ.[12] A transcript of Rehm's copies, without the Greek letter identifiers, also exists among Price's manuscript notes on the inscriptions (Fig. 6.9), and this includes three more fragments which, for continuity, we designate τ through φ.[13] Rehm's copies are interesting as showing that Fragment G had not yet been assembled from the pieces that had been separated from C. His ι, ο, and ξ are easily recognized as three of the larger pieces now in G. Among the offset fragments that Rehm copied, κ is the present 41 joined to the bottom half (only!) of 37; λ is 40, but some letters copied by Rehm have since broken off; μ is 43, but again some letters have since broken off; ν is a piece of 21; σ is 44; τ is probably 23; υ is another piece of 21; and φ is 27.[14] It thus appears that some joining of small offset fragments, as well as minor breakage, took place between 1906 and 1958, when Price saw the fragments in essentially the form that they have now (except for the detachment of 29 from G).[15]

10 Rehm 1905, 17-18.

11 Rehm 1906a.

12 Rehm must therefore have previously made a collection of eight inscription fragments labelled α through θ, which is not known to survive. These likely included the inscriptions on Fragments A-2 (Back Plate Inscription), B-1 (Back Cover Inscription offsets), and 19 (Back Cover Inscription) previously published by Svoronos and Stais, the Egyptian calendar month and the Parapegma Inscription that Rehm had found on C-1 in 1905, and perhaps also the Back Cover Inscription offsets on A-2 and the isolated inscribed letters on A-2 and C-2.

13 Price collection at the Adler Planetarium. This sheet must have duplicated a set of Rehm's notes different from the 1906 notebook.

14 Rehm's π is 25 (offsets of the Back Plate Inscription); we have not been able to identify ρ.

15 Theofanidis's transcription of text read on "certain oxidized fragments of inscribed plates" (Theofanidis [1927-1930], "99" [correct pagination 91]) is from the part of G that Rehm copied as his fragment omicron, but it is not possible to tell whether it was still a separate fragment in the 1920s. It seems improbable that a conservator would have known how to fit the pieces of G together at a date so remote from when they were separated from C.

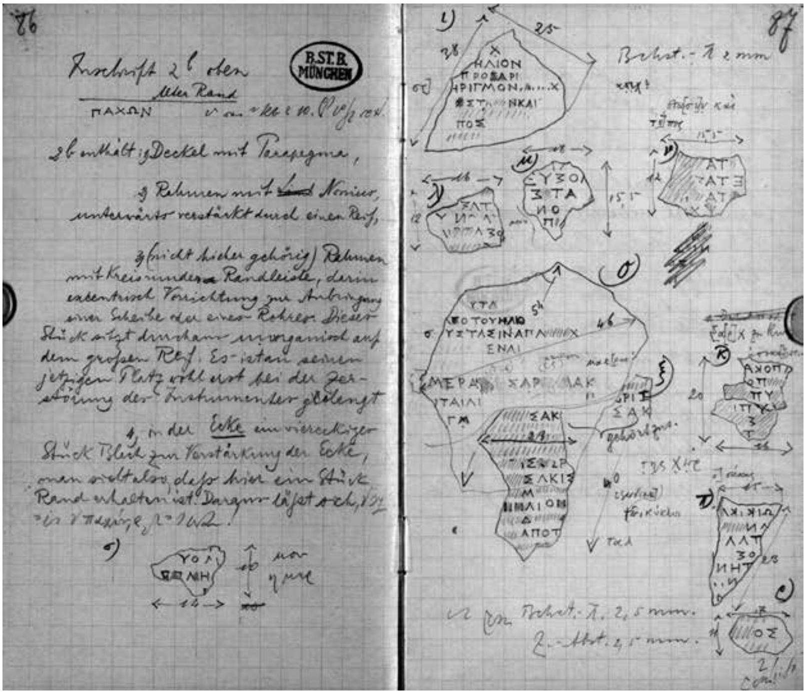

Figure 6.8: *Pages from Rehm's 1906 notebook with copies of small inscription fragments (Bayerische Staatsbibliothek)*

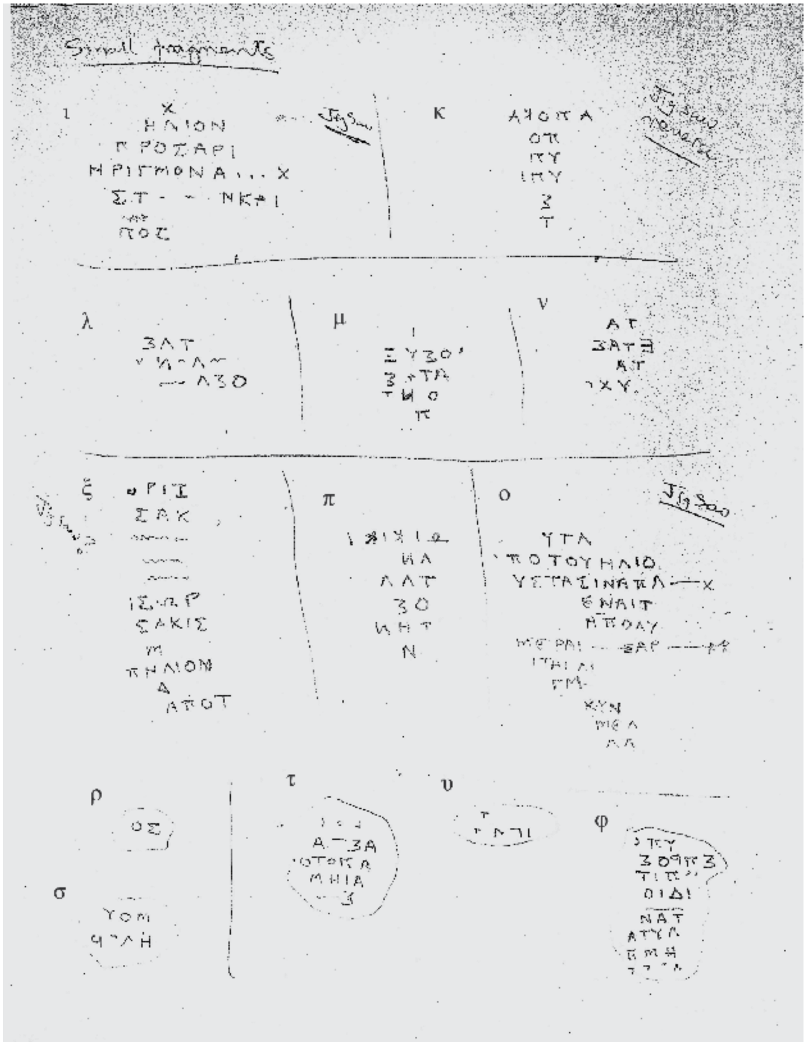

Figure 6.9: *Price's transcription of Rehm's small inscription copies (Adler Planetarium)*

6.3 Previous transcriptions and study of the Front Cover Inscription

Rehm's copies of fragments of the Front Cover Inscription plate and offsets, preserved in his 1906 notebook and in a transcription among Price's papers, have been referred to above in section 2. The first published transcription of any part of the inscription appeared in Theofanidis's encyclopedia article on the voyages of St. Paul; it comprises a few letters and traces from lines 21-31.[16] Price gave disjointed readings (fewer than two hundred letters, few complete words) from the more legible parts of thirty lines of G in *Gears from the Greeks*, as well as six lines from Fragment 21.[17]

The 2006 AMRP paper presented a far more extensive provisional text of Fragment G, comprising nearly a thousand letters read from CT.[18] A revised and extended text by A. Tselikas was reported by M. Zafeiropoulou in 2012.[19]

16 Theofanidis [1927-1930], "99" [correct pagination 91]. The first five lines are reprinted in Theofanidis 1934, 146.

17 Price 1974, 49, Fig. 38 and 48, Fig. 37. The caption of the latter figure seems to imply that Price thought that Fragment 21 belonged to the Back Plate Inscription.

18 Freeth et al. 2006, Supplementary Information, 8.

19 Zapheiropoulou 2012, 245.

6.4 Transcription and translation

The text presented here combines readings from fragments G, 26, and 29 of the Front Cover Plate, read from CT, readings from the offset fragments 21, 23, 27, 37-44, 49, 51, 54-56, and 60, read from both CT and PTMs, and occasional readings from Rehm's 1906 copies of lost portions of offset fragments. The apparatus reports details of the contributions of the individual fragments.

Text

1 ὑπολει]π̣όμενος [
2 μεγίσ]τ̣ο̣υ̣ ἀποστήμ[ατος
3] ̣ο̣ν ἐξ ἀρχῆς Π̣[
4]Σ̣[̣ ̣] ̣ ̣ ε̣ἱ̣ς̣ δὲ [τ]ὰ̣ ἑπόμενα. v ὁ δὲ Φώ̣[σφορος
5] ζῳ̣ι̣δ̣[ί]ου, ἐν δὲ ἴσοις v υξβ̣L v ἀποκαταστ̣άσ[εις
6]ΥΣ υξβ, ἑ̣κάστην δ᾽ ἀποκατάστασιν ἐν ἡμέρ̣αις φ̣[πδ
7] ̣ΝΑΣ. κ̣α̣ὶ̣ ἀ̣π̣ὸ̣ μὲν [τ]ῆ̣ς πρὸς τὸν Ἥλιον συν̣ό̣δου̣ ὑ̣πολε[ίπεται
8]Ν̣ ἀπόστημα ἐν ἡμέραις σκδ̣. προσάγει δὲ πρὸς τὸν Ἥλ[ιον
9 παρ]α̣γίνεται ἐπὶ τὸν [ἑ]σπεριν̣ὸν στηριγμὸν, ἀπ̣έχ̣ω̣ν ἀπὸ τ̣ο[ῦ Ἡλίου
10 πρ]οσάγει πρὸς τὸν Ἥ̣λιον ἐκ̣ προηγήσεων καὶ σύνοδον Α ̣Ω ̣[
11] ἐπὶ τὸ μέγιστο̣ν ἀπόστη̣μ̣α ἐν ἄλλαις ἡμέραις v ξη v ̣ ̣[
12 στηριγ]μὸν ̣Σ̣ προηγο̣ύμενος, ἀ̣ποστὰς δ᾽ ἀπ[ὸ τ]ο̣ῦ̣ Ἡλίου ̣Μ̣[
13] ἡ̣μ̣έ̣ρ̣αις μ̣θ̣ ὑπολ̣ειπό̣μ̣ενος ἐπὶ τὸ μέγισ̣τ̣[ον ἑ]ῷιον ἀπόστη[μα
14 ἀπο]στήματος̣ προσά[γ]ε̣[ι] πρὸς τ̣ὸ̣[ν Ἥλιον ὑπ]ολειπόμεν[ος
15]Χ̣ΗΣΤ ̣Σ ̣Ο ̣ ̣Α̣ΕΠΙΤΕ ̣[-7-] ̣Α̣ ̣Σ̣Π[̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣]Π̣Ο̣ΣΤ̣ ̣ ̣ΣΙΝ ̣[
16]Σ̣Τ̣Α̣ΤΑΙΣ̣ ̣Β̣ΙΩΝΤ̣Α̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣ ̣[-12-]ΤΑΣ ̣[
17 ἑ]κ̣ά̣στην̣ δ̣᾽ ἀποκατάστασιν ἐν ἡμέραις μικ[ρῶι ἐλάσσοσι
18] ̣Σ ̣ ̣ ἄ̣ρχεται δ̣έ τὴν ὑ̣πόλειψιν ̣ ̣Ν ̣Μ̣ ̣ ̣Σ ἀπέχω̣[ν ἀπὸ τοῦ
19] ἑσπ[ερινοῦ] στηριγμοῦ, καὶ ὑπολείπεται μέχρι τῆς ἑῴιας στά[σεως
20] ̣ ̣[̣ ̣] ̣ ̣αι̣ς τμθ v ἡμέραις σύ̣νοδο̣ν ποι̣ε̣ῖται τῶι Ἡλ̣ί̣ω̣ι̣ ΜΑΣΗ̣[
21]αις τμθ̣ ἐπὶ τ̣ὸν ἑ̣ῷ̣ι̣ο̣ν σ̣τ̣ηριγμὸ̣ν ἀ̣πέχων ἀ̣πὸ τοῦ Ἡλίου ὡς ̣ ̣ ̣ ̣ ̣[
22]πβ̣ v καὶ̣ ἐπὶ τὴ̣ν ἑσπερι̣νὴν παραγ̣ίνεται στάσιν ἀπέχω̣ν ἀπὸ [τοῦ
23] δ̣ὲ ἡ̣μ̣έ̣ρ̣α̣ς̣ η πάλιν ̣ ̣ ̣Ε̣ ̣ὑ̣πολεί̣π̣εσθ̣αι̣. ἐν δὲ ΤΩ ̣ ̣ ̣Α̣[
24]ΝΕ ̣ ̣ ̣ ̣ στάσι̣ν. ὁ δὲ Φ̣α̣έθω̣ν ἐν v ̣ ̣ ̣ ̣ ̣ ἀποκαταστ̣ά̣σ̣[εις
25] ἑκάστη̣ν̣ δ᾽ ἀπ̣οκατάστασιν ἐ̣ν̣ ἡμέραις μικρῶ̣ι̣ ἐλάσσ[οσι
26] ̣ ̣ ̣ καὶ δω̣δεκατη̣μόριον Ω̣[̣] ἄ̣ρχεται δὲ τὴν ὑπόλε̣ι̣ψ̣ιν̣ [
27] ̣Δ̣ΙΟΝ[̣] ̣Ζ v ἀπὸ τοῦ ἑσπερινοῦ̣ στηριγμοῦ καὶ ὑπολείπ̣[εται
28] ̣ ̣ ̣ ̣ ̣ ̣ ̣ΕΤΩΝ̣ ἕ̣ω̣ς ἐν χρό̣ν̣ω̣ι̣ τ̣αῖς v ρλθ ἡμέραις σύνοδ̣[ον
29] τ̣αῖς ἄλλαις ρλθ̣ v ἐπὶ τὸν ἑ̣ῷιον στηριγμό̣ν, ἀπέχ[ων ἀπὸ τοῦ Ἡλίου
30] ̣ μείνας ἡμέρας v η v προηγεῖται ἡμέρας [
31] ̣ ̣ ̣ ̣ ̣ καὶ πάλι μείνας τὰς η ἡμέρας, πάλι̣ν̣ Α̣Ρ[
32] ̣ τῶν v ρδ v ἡμέραν, γίνεται κατὰ διάμετρο̣ν [
33 ἀποκα]ταστάσεις ἐν μ̣[̣ ̣ ̣] ̣ ̣[̣] υ̣μβ v διαπο̣ρευθε̣ὶ̣ς τ̣ὸ̣ν̣ [
34 ἀποκ]ατάστασιν ἐν [-9-] ̣ ̣ ̣ ̣ [-5-] ̣ ̣ ̣ [̣] ̣ ̣ ̣
35 τὴ]ν ὑπόλει̣ψ[ι]ν Π[-17-]ΤΟΝ ̣[
36 ὑπολε]ίπεται μέχρ[ι -19-] ̣ ̣[
37] σ̣[ύ]ν̣[ο]δον πο̣ιεῖτ[αι
38 στ]η̣ριγμ̣ὸν ἀπ̣[έχ]ω[ν
39] ἡμέρας [
40 με]ίνας v η [
41] κ̣ατὰ διάμ̣[ετρον
42] ̣ποστ[
43] ̣ ̣ ̣ ̣ [

Unplaced fragment (Fragment 42)

1] ̣ [̣] Α[
2]Ο̣Γ̣ΙΣΤ[
3]ΞΔ *v* Κ[

Unplaced fragment (Fragment 51)

1]Ν̣ ̣ [
2]ΝΤ̣ΚΔ̣[
3]μεί̣ν̣α[ς
4 στηρ]ιγμο̣ ̣ [
5 ἡμ]έρ̣αις [

Apparatus

To indicate which letters are preserved on the various fragments of the inscribed plate (G, 26, and 27) and the accretion layer (all other fragments), the readings of each line from each fragment are reported separately below, with the fragment identified in the second column. “Gs” refers to displaced flakes of inscription adhering to G; “40R” and “43R” are letters of Fragments 40 and 43 read by Rehm in 1906 but no longer extant, and “23i” and “27i” are letters embedded inside Fragments 23 and 27.

1 G ὑπολει]π̣όμενος [

π̣: right vertical with serif, right end of horizontal along edge

2 G μεγίσ]τ̣ο̣υ̣ ἀποστήμ[ατος

τ̣: bottom of vertical along edge | ο̣: lower half of loop | υ̣: vertical, possibly a bit of the vee along edge

3 G] ̣ο̣ν ἐξ ἀρχῆς Π̣[

 ̣: serifed bottom of vertical? | ο̣: complete but malformed, with straight right side | Π̣: left vertical, bending left at bottom, and left part of horizontal

4 G]Σ̣[̣ ̣ ̣ ̣]Ε̣Ι̣Σ̣[-3-] ̣ ἐπόμενα. *v* ὁ δὲ Φώ̣[

Σ̣[1]: complete but blurry | Ε̣: traces at baseline, middle, and top height along edge, sigma not excluded | Ι̣: vertical with serif at top; superimposed, an apparent narrow loop, too narrow for phi, seems to be surface damage | Σ̣[2]: entire but distorted | ̣: trace near baseline along edge | *v* half letter | ω̣: left horizontal with serif, lower left part of loop along edge

Gs] ̣ ̣[

 ̣ ̣: bottom of vertical, slightly sloping to right at top, possibly met near bottom by descending diagonal from its left; to the right of this, bottom of a vertical with bend (serif?) to right at baseline

43]Σ̣ΔΕ[

Σ̣: right end of lower horizontal, sloping downwards to right, with serif

5 G] ζ̣ω̣ι̣δ̣[ί]ου, ε[ν] δ̣ὲ ισο[-4-]β̣L *v* ἀποκατασ̣τάσ[

ζω̣ι̣δι indistinct and distorted, near edge | δ̣: lower right corner of letter, indistinct | σ̣: serifed right end of lower horizontal and slight trace of right end of upper horizontal

Gs]ΕΝΔ[

43]Σ̣ΟΙΣ *v* Υ[

Σ̣: bottom half, indistinct | *v* half letter

43R] ̣Ο< ̣>ΣΥΞ[

 ̣: bottom of steeply sloping ascending diagonal at edge Rehm | < ̣>: Rehm leaves no space for a letter between Ο and Σ

6 G]ΥΣ υ̅ξ̅β̅, ἑ̣κάστην δ᾽ἀποκατάστασιν ἐν ἡμέρ̣αις φ̅ [

ε̣: indistinct, along break | ρ̣: trace at top level along break

38] ἑ̣κάστ̣ην̣ δ᾽[

ε̣: indistinct | τ̣: serifed vertical | ν̣: indistinct

43]ΟΚΑΤΑΣ[

40R]ΤΑ̣Σ[

Α̣: Λ Rehm

40]Τ̣[

Τ̣: serifed bottom of vertical

7 G] ̣ΝΑ̣Σ̣. κ̣α̣ὶ̣ ἀ̣πὸ̣ μὲν [τ]ῆ̣ς πρὸς τὸν Ἥλιον συνό̣δου̣ ὑ̣πολε[

 ̣: trace near baseline | Α̣Σ̣ κ̣α̣ι̣: indistinct | α̣: apical letter | ο̣: trace of upper right of loop along break | η̣: right vertical | ο̣: top left part of loop along edge | υ̣: bottom of vertical | υ̣: indistinct

55]ΝΑΣ[

38 ἀ]πὸ μὲ̣ν τ̣ῆ̣ς̣ [

ε̣: top and bottom horizontals | τ̣η̣ς̣: indistinct

43]ΣΤΟΝΗ̣[

Η̣: left half of letter

40]Ἥ̣λιον συν̣[

η̣: right half of letter | ν̣: left vertical

8 G]Ν̣ ἀπόστημα ἐν ἡμέραις σ̅κ̅ [̣]. προσάγει δὲ πρὸς τὸν Ἥλ[ιον

Ν̣: bottom of left vertical and bottoms of diagonal and right vertical meeting

55]ΠΟΣΤ[

54]ΑΕΝ̣[

Ν̣: serifed bottom of left vertical

38 ἐ]ν̣ ἡμέρ̣α̣ι̣[ς

ν̣: serifed right vertical | ρ̣α̣: indistinct | ι̣: serifed top of vertical

43]Δ̣[

Δ̣: top of apical letter

43R]Δ̣ *v* Π[

Δ̣: descending diagonal along edge Rehm

40]οσαγει δε[

9 G] ̣γίνεται ἐπὶ τὸν [ἑ]σπεριν̣ὸν στηριγμόν, ἀπέ̣χω̣ν ἀπὸ τ̣ο[

̣ : blurry, perhaps α | ν̣: indistinct | ε̣: indistinct | ω̣: left half of letter | τ̣: indistinct, along break

55]INET[

54] τὸν [

40]ΝΑ̣Π̣Ε̣ [

Α̣Π̣Ε̣: indistinct

10 G πρ]οσάγει πρὸς τὸν [Ἥ]λιον ἐκ̣ προηγήσε ̣ν̣ καὶ σύνοδον Α ̣ [

κ̣: blurry | ̣ : indistinct traces | ν̣: complete but distorted | ̣ : trace at top level along edge

55]Α̣ΓΕ ̣ [

Α̣: faint, along edge | ̣ : serifed top of vertical along edge

54]ΣΤΟΝΗ̣[

Η̣: vertical, serifed at top and bottom

56]Η̣Σ[

Η̣: bottom half of letter

26]Ω̣[

̣ : trace at top level along edge

39]ΩΝΚΑ̣Ι̣ΣΥ̣[

11 G] ἐπὶ τὸ μέγιστο̣ν ἀπόστη̣μ̣α ἐν ἄλλ̣αις ἡμέραις [

ο̣: left side of loop along break | η̣: faint | μ̣: right half of letter | λ̣: faint, indistinct

26]Σ̣ *ν* ξ̅η̅*ν* ̣ ̣ [

Σ̣: right part of bottom horizontal | *ν* less than half a letter | *ν* half a letter | ̣ ̣ : apical letter (alpha?) but instead of horizontal stroke, a gently ascending diagonal from bottom left to middle of right descending diagonal; to the right, unclear traces, possibly bottoms of two verticals

54]ΙΣ̣ [

Σ̣: left half of letter

56]ΑΕ[

39]ΛΑΙΣΗ[

12 G στηριγ]μὸν ̣ Σ̣ προηγο̣ύμενος, ἀ̣ποστὰς δ' ἀπ[ὸ

̣ : indeterminate traces | Σ̣: top and bottom horizontals, speck in center, epsilon or xi not excluded | ο̣: right side of loop along break | α̣: trace at baseline along break

26]ο̣ῦ̣ Ἡλίου ̣ Μ̣ [

ο̣υ̣: bottoms of letters, blurry | ̣ ̣ : confused and distorted traces, resembling messy epsilon | Μ̣: distorted

56]Α̣ΠΟ̣[

Α̣: trace at baseline along edge | Ο̣: left side of loop

39] ̣ ̣ ̣ Δ̣ [

̣ ̣ ̣ : blurry, indeterminate traces | Δ̣: apical letter

13 G] ἡ̣μ̣έ̣ρ̣α̣ις μ̣̅θ̣̅ ὑ̣πο̣λ̣ειπό̣μ̣ενος ἐπὶ τὸ μέγισ̣[τον

η̣μ̣ε̣ρ̣α̣: blurry and distorted | μ̣: leftmost and rightmost strokes, sloping; middle of letter is indistinct, straddling break | θ̣: large, somewhat angular loop | υ̣: right ascending diagonal (?) along break | ο̣: top of loop along break | λ̣: top of apical letter | ο̣: faint loop along edge | μ̣: left vertical and left descending diagonal | σ̣: trace at top level along edge

26 ἐ]ῶιον ἀπόστη[μα
27]ΥΠΟ[
39] . . . . Σ̣Τ̣[

. . . . : blurry, indeterminate traces | Σ̣Τ̣: faint

14 G ἀπο]στήματος π[ρ]οσά̣ [γ]ε[ι] πρὸς τ̣ὸ̣[ν

α̣: left ascending diagonal and top of right descending diagonal of apical letter | τ̣: horizontal | ο̣: trace at top level

26 ὑπ]ολειπόμεν[ος
27]προσα[

15 G]Χ̣ΗΣΤ . Σ . Ο̣ . . Ε̣ΠΙΤΕ . [- 7 -] . Α̣ . Σ̣Π[

Χ̣: ascending and descending diagonals clear; left half of letter blurry, kappa also possible | . : indistinct traces on break | . : top of vertical (?), perhaps iota | Ο̣: top half of small loop | . : traces at top level directly above trace at baseline, and, to right, trace of right (?) end of serifed descending (?) diagonal at baseline, and further to right, descending diagonal | . : apical letter or vertical meeting descending diagonal at top level | . : indistinct | Α̣: distorted, doubtful | . : indistinct | Σ̣: distorted

26]Π̣Ο̣ΣΤ̣ . . ΣΙΝ . [

Π̣: right end of horizontal and top of right vertical | Ο̣: top of loop | Τ̣: horizontal, missing right end, and top of vertical | . . : blurry, indeterminate traces | . : trace at top level along edge

27]ΑΕΠΙΤΕ[

16 G]Σ̣Τ̣Α̣ΤΑΙΣ̣ . . Β̣ΙΩΝ̣Τ̣Α . . . . [

Σ̣[1]: top and bottom horizontals, spreading towards right, but distorted epsilon is possible | Τ̣Α̣: complete but blurry | Σ̣[2]: blurry, near break, xi possible | . : traces resembling a sloppy eta but apparently lying low relative to baseline | Β̣: complete, near break, but traces of both loops might not be deliberate, and rho or delta are possible | Ν̣: diagonal and serifed right vertical | Τ̣: left end of horizontal and vertical, along break | . . . . : blurry and indistinct traces

26]ΤΑΣ . [

. : trace at top height along edge

27]ΙΩΝΤ̣Α̣[

Τ̣Α̣: faint and uncertain

17 G ἐ]κ̣ά̣στην̣ δ̣᾽ἀποκατάστασιν ἐν ἡμέραις μικ[ρῶι

κ̣: faint, indistinct traces | α̣[1]: blurred | ν̣: distorted | δ̣: top of apical letter and faint trace of bottom right corner |

27]ΟΚΑΤΑ[

18 G] . Σ . . ἄρχεται δ̣έ τὴν ὑ̣πόλειψιν . . Ν . Μ̣ . . Σ ἀπέχω̣[ν

.[1]: indistinct trace near edge | . .[1]: indistinct traces near edge | δ̣: apical letter, straddling break | υ̣: slight traces of tops of diagonals, straddling break | . .[2]: resembling distorted epsilon, with middle horizontal too high, followed by indistinct trace along edge | .[2]: indistinct trace | Μ̣: presumed right half of letter faint and indistinct | . .[3]: blurry traces | ω̣: horizontal at baseline, along edge

27]ΕΤΑΙΔ[

19 G] ἑσπ[ερινοῦ] στηριγμοῦ, καὶ ὑπολείπεται μέχρι τῆς ἑῴας στά[σεως

27]Μ̣Ο̣Υ̣ΚΑ[

Μ̣: right half of letter | Ο̣: traces of left and right sides of loop | Υ̣: tops of diagonals and vertical

20 G̣ ̣ ̣[̣ ̣] ̣ ̣αι̣ς τ̅μ̅θ̅ ν ἡμέραις σύ̣νοδο̣ν ποι̣ε̣ῖται τῶι Ἡλ̣ί̣ω̣ι̣ ΜΑΣΗ̣[

̣ ̣[1]: indeterminate traces along edge | ̣ ̣[2]: bottoms of two verticals | ι̣[1]: blurry | υ̣: faint | ο̣: distorted | ι̣[2]: lower part of vertical | λ̣: left ascending diagonal and serif of right descending diagonal | ι[3]: blurry | ω̣: left half of letter, faint | ι̣[4]: fat and blurry | Η̣: faint but distinct

27] ̣ ν ΗΜΕ[

̣: indeterminate trace at edge

27i]ΜΕ[̣] ̣[

̣: serif at baseline

37]Η̣Λ̣[

Η̣Λ̣: complete but indistinct

21 G]αις τ̅μ̅θ̣̅ ἐπὶ τ̣ὸν ἑ̣ῷ̣ι̣ο̣ν στ̣ηριγμὸν̣ ἀ̣πέχων ἀ̣πὸ τοῦ Ἡλίου ̣ς̣ ̣ ̣ ̣ ̣[

θ̣̅: faint and blurry | τ̣[1]: horizontal and top part of vertical, near breaks | εωιο: faint, indistinct traces | τ̣[2]: horizontal, and small trace of vertical along break | ν̣: trace of left vertical near break | α̣[1]: indistinct | α̣[2]: faint left diagonal along break, and bottom tip of right diagonal | ̣: indistinct | ̣ ̣ ̣ ̣ ̣: faint and indistinct traces

27i]ΗΡ[

37]Λ̣ΙΟΥΩΣ̣[

Λ̣: faint | Σ̣: bottom left corner

22 G] π̅β̣̅ ν καὶ̣ ἐπὶ τὴ̣ν̣ ἑ̣σπερι̣νὴν παραγέ̣νεται στάσιν ἀπέχω̣ν ἀπὸ [

β̣: small loop with a blurry extension above | ι̣: blurry | η̣ν̣ε̣: blurry | ι̣: trace of vertical along break | ι̣: badly formed or blurred, appearing like a very narrow epsilon | ω̣: blurry

37]ΝΑΠΕΧ[

23 G] δ̣ὲ ἡ̣μ̣έ̣ρ̣α̣ς η̣̅ πάλιν̣ ̣ ̣Ε̣ ̣ ὑ̣πολεί̣π̣εσθ̣αι̣ . ἐν δ̣ὲ ΤΩ̣ ̣ ̣ ̣Α̣[

δ̣: apical letter | ἡ̣μ̣έ̣ρ̣α̣: very faint | ̣ ̣: faint, indeterminate traces | η̣̅: faint | ̣ ̣ ̣: apical letter (?); to the right of this, apparently the left half of nu or mu, and further right, faint indeterminate traces | Ε̣: vertical and top and middle horizontals | ̣: small trace at top height along break | υ̣: blurry, near break | ι̣: blurry | π̣: small traces straddling break | θ̣: indeterminate traces | ι̣: top part of vertical | δ̣: apical letter | Ω̣: left half of letter and faint right horizontal | ̣ ̣ ̣: traces of three verticals with two faint horizontal or slightly descending diagonal strokes joining them at mid height; to the right of this, seemingly Ƶ | Α̣: sloppy, with apparent superfluous stroke crossing end of right descending diagonal

37]ΝΔΕΤΩ[

24 G]ΝΕ ̣ ̣ ̣ ̣ στάσι̣ν. ὁ δὲ Φ̣α̣έθω̣ν ἐν ν ̣ ̣ ̣ ̣ ̣ ἀποκαταστ̣ά̣σ̣[εις

̣ ̣ ̣ ̣: indeterminate traces | ι̣: blurry and faint | φ̣: loop along break | α̣: apical letter staddling break | ω̣: blurry, straddling break | ν: one letter | ̣: faint traces near a break, suggestive of omega | ̣ ̣ ̣ ̣ ̣: leftmost, faint traces near a break, suggestive of omega; then a coarsely damaged letter, apparently chi or sigma; then traces resembling a sloppy mu; then a vertical with either three horizontals or two loops to its right, i.e. epsilon or beta;

then traces suggestive of mu or chi, faint towards the top | τ̣α̣σ̣: faint, indeterminate traces

37]ΑΠΟΚΑ[

25 G] ἑκάστη̣ν̣ δ᾽ἀπο̣κατάστασιν ἐν̣ ἡμέραις μικρῶι̣ ἐλάσσ[οσι

η̣: both vertical strokes, between which blurry traces more suggestive of nu | ν̣: blurry | ο̣: blurry | ν̣: trace of top of left vertical and trace of bottom of right vertical straddling break | ι̣: blurry

60]Κ̣Α[

Κ̣: bottom half of vertical with serif, descending diagonal, and trace of left end of ascending diagonal along edge |

49]ΣΙΝ[

21]ΗΜΕ̣[

Ε̣: vertical along edge

37] ̣Ι̣ΚΡΩ[

 ̣: trace at baseline along edge | Ι̣: indistinct

41]Ω̣Ι̣Ε[

Ω̣: serifed right horizontal along baseline | Ι̣: serifed bottom of vertical

26 G] ̣ ̣ ̣ καὶ δω̣δεκατη̣μόριον Ω̣[̣] ἄ̣ρχεται δὲ τὴν ὑπόλε̣ι̣ψ̣ιν̣ [

 ̣ ̣ ̣: indeterminate traces | ω̣[1]: faint and indistinct | Ω̣[2]: faint and angular | α̣: traces of apex and bottoms of both diagonals straddling break | ε̣ι̣: faint | ψ̣: indistinct | ν̣: left (?) vertical

60]ΤΗΜ[

49]Ν̣Ω̣[

Ν̣: right vertical with serif, faint trace of diagonal | Ω̣: left half, indistinct

21]Α̣ΡΧΕΤ[

Α̣: trace at baseline along edge

44]Ι̣ ̣[

Ι̣: serifed bottom of vertical ̣: trace at baseline along edge

37]Ν̣ ̣[

Ν̣: indistinct | ̣: trace of descending diagonal at top level

41]ΥΠΟΛ[

27 G] ̣Δ̣ΙΟΝ[̣] ̣Ζ *v* ἀπὸ τοῦ ἑσπερινοῦ̣ σ̣τηριγμοῦ καὶ ὑπολείπ̣[εται

 ̣[1]: indeterminate traces | Δ̣: blurry | ̣[2]: indeterminate traces | *v*: one letter | υ̣σ̣: blurry | π̣: left vertical

23i]Ζ *v* Α[

v: one letter

60]ΥΕΣ[

49]Ν[

21] στηριγ̣ [

γ̣: vertical along edge

44]ΓΜΟΥΚΑ[

41]Ι̣ ὑ̣πολε̣ [

Ι̣: vertical along edge, indistinct | ε̣: indistinct

28 G] ̣ ̣ ̣ ̣ ̣ ̣ ̣ΕΤΩΝ̣ ἕ̣ω̣ς ἐν χρό̣ν̣ωι̣ τ̣αῖς *v* $\overline{ρλθ}$ ἡ̣μέραις σύν[ο]δ̣[ον

. . . . : faint and indistinct traces | Ṇ: blurry, straddling break | ẹω̣: blurry, straddling breaks | ọ: blurred | ṿ: complete but distorted | ṭ: vertical, faint horizontal | *v*: half a letter | η̣: distorted

21]ΑΙΣ *v* ρλθ [

v: half a letter

44]ΗΜΕΡΑ̣ [

Α̣: top of ascending diagonal along edge

41]ΣΣΥΝΟ[

29 G] τα̣ῖς ἄλλαις ρλθ̣ *v* ἐπὶ τὸν ἑ̣ῶ̣ιον στηριγμόṿ, ἀπέχ̣ [ων

α̣: indistinct | *v*[1]: one letter | θ̣: faint loop | *v*[2]: one letter | ẹ: upper right corner along break | ι̣: distorted, indistinct | ṿ: left vertical; remainder blurry | χ̣: faint

23]Σ ἄλλαις [

23i]ΙΣ ἄλλαις [

21 ἐ]π̣ὶ̣ τὸν ἑ̣ῶιον στηρ[

π̣: right vertical, curving rightwards at bottom | ι̣: indistinct | ẹ: horizontal at baseline along edge

44]ΙΓΜ̣ [

Μ̣: sharp vertex at top level along edge

41]ΠΕ. [

.: top of descending diagonal at top level along edge

30 G]. μεί̣̣νας ἡμέρας *v* η̣ *v* προη̣γεῖται ἡμέρας [

.: indistinct and faint | ει̣̣: indistinct traces near break | | η̣[1]: blurry | η̣[2]: blurry, traces in middle resembling nu

23] μ̣ε̣ί̣ν̣α̣ς Η[

μ̣ε̣ι̣ν̣α̣ indistinct

23i μ]είνα̣ς̣ ΗΜ̣ [

α̣: faint | ς̣: right end of top horizontal | Μ̣: left vertical and top of descending diagonal

21 ἡμ]ἑ̣ρ̣α̣ς̣ *v* η *v* προηγεῖται ἡμ̣[

ẹ: serifed right end of bottom horizontal along edge | ρ̣: serifed bottom of vertical | α̣: serifed letter, indistinct | ς̣: horizontal at baseline, bending downwards towards right, with serif at right end | *v*[1]: one letter | *v*[2]: one letter | μ̣: trace at baseline along edge

31 G]. . κ̣αὶ πάλι μείνας τα̣ς η̣ ἡμέρας, πάλι̣ṿ Α̣Ρ[

. .: faint, indistinct traces | κ̣: blurry, straddling break | α̣: indistinct, straddling break | *v*[1]: half a letter | η̣: blurry | *v*[2]: half a letter | ι̣ṿΑ̣: faint

23]. . . . . καὶ̣ π̣άλι Μ[

. . . . .: indistinct | ι̣: indistinct | π̣: right half of letter

23i]Κ̣[.]Ι[. . .]ΙΜ[

Κ̣: bottom half of letter

21 μ]είνας τὰς *v* η *v* ἡμέρας ΠΑ[

v[1]: half a letter | *v*[2]: half a letter

32 G]. Ν *v* ρδ *v* ἡμέραν, γίνεται κατὰ δι[άμ]ετρο̣ν [

.: faint traces | *v*[1]: half a letter | *v*[2]: one letter | ọ: indistinct

23] ̣ τῶν̣ *v* ρ̅δ̅ ν ἡμέρα̣ [

̣: vertical along edge | ν̣: indistinct | α̣: left and right diagonals

23i]N *v* ΡΔ[

v: half a letter

21] γίνεται κατὰ διάμετ̣[ρον

τ̣: faint

33 G ἀποκα]τ̣α̣στάσ[ε]ις ̣ ̣ ̣[̣ ̣ ̣] ̣ ̣[̣] υ̣̅μ̅β̅ *v* διαπο̣[ρευ]θε̣ὶς τ̣ὸ̣ν̣ [

τ̣α̣: faint | ̣ ̣ ̣: blurry, indeterminate traces | ̣ ̣: indeterminate top of letter, then top of serifed vertical | υ̣: vee, possible trace of vertical along break | *v*: one letter | ο̣: left and upper parts of loop | ι̣: trace of top of vertical | τ̣ο̣ν̣: faint

23 ἀποκα]ταστάσεις ἐν μ̣ [

μ̣: vertical, sloping to right, with serif or short descending diagonal stroke meeting it at top level, along edge

23i]ΣΤΑΣΕ[

21] ̣Β[-6-]ΡΕΥΘ[

̣: sharp apex at top height along edge

34 G ἀποκ]α̣τάστ̣[ασ]ιν ἐν [-17-] ̣ ̣ ̣ ̣[

α̣: faint, indeterminate traces | τ̣: trace at top level along edge | ̣ ̣ ̣ ̣: indeterminate traces along edge | ̣ ̣ ̣[1]: traces at baseline and top height along edge; to the right of this, a vertical, then the bottom of an ascending diagonal | ̣ ̣ ̣[2]: faint, indeterminate traces

29]Τ̣Α[

Τ̣: trace at baseline

23 ἀποκ]ατάστασιν ἐ̣ν̣ [

ε̣: blurry | ν̣: vertical along edge

23i]ΣΤΑ̣[̣ ̣ ̣]Ε[

Α̣: serifed lower part of ascending diagonal

35 G]Ν̣Υ̣[-18-]ΤΟΝ̣[

Ν̣Υ̣: top halves of letters | ̣: vertical

29]ΠΟΛ ̣[

̣: blurry trace along edge

23]Ν̣ ὑπολε ̣ ̣[

23i]ΥΠΟΛ[̣ ̣] ̣[̣]ΝΠ[

̣: serifed bottom of vertical, slightly below baseline

36 G] ̣ ̣[

̣ ̣: indeterminate traces of tops of letters along edge

29]ΠΕΤΑ[

23]Π̣Ε̣Τ̣ΑΙΜ[

Π̣Ε̣Τ̣: indistinct | Μ̣: indistinct vertical, sloping slightly to right

23i]ΙΠΕΤ[̣ ̣ ̣]ΕΧΡ[

37 29] σ̣[υ]ν̣[ο]δο̣ν π[

σ̣: right end of bottom horizontal | ν̣: bottoms of both verticals | δ̣: trace of right descending diagonal along edge | ο̣: obscured by extraneous marks

23]δ̣ον πο̣ιε[

ο̣: indistinct

23i]ΔΟΝ ̣ [̣ ̣ ̣]ΕΙΤ[

̣ : vertical

38 29 στ]η̣ριγ̣μ̣ὸν ἀπ̣[έχων

η̣: indistinct vertical | γ̣: indistinct vertical | μ̣: one sharp apex | π̣: left vertical and left end of horizontal

23]Ο̣Ν̣Α̣[

ο̣ν̣α̣: doubtful traces of tops of letters

23i]ΟΝΑ[̣ ̣ ̣]Ω[

39 29] ἡμέρας [

23i]ς̣ [

ς̣: serifed right end of top horizontal

40 29 με]ίνας ν π̄ [

41 29] κ̣ατὰ διάμ̣[ετρον

κ̣: traces at baseline and top level along edge | μ̣: trace at baseline

42 29] ̣ποστ[

̣ : vertical stroke leaning slightly rightward at top (an accidental feature?), also faint trace as of an apical letter superimposed

43 29] ̣ ̣ ̣ ̣ [

̣ ̣ ̣ ̣ : indeterminate traces of tops of letters

Unplaced Fragment 42

1 ̣ : faint apparent lower part of vertical with serif, and to the right of this, a descending diagonal with large serif, possibly kappa | 2 Ο̣: apparent right arc and speck of lower left of small elevated loop | Γ̣: complete, but epsilon cannot be ruled out

Unplaced Fragment 51

1 Ν̣: verticals certain, blurry trace at mid height between them, possibly Η̣ | ̣ : indistinct trace
2 Τ̣: apparently complete in CT, but the PTM suggests Σ̣ | Δ̣: left half of the letter, with apparent horizontal stroke at baseline
3 ι̣: indistinct trace
4 μ̣ο̣: very indistinct traces
5 ε̣: small, unidentifiable trace | ς̣: traces of left ends of horizontals at top height and baseline

Translation

1] regressing [
2 greatest] elongation [
3] the initial… [
4]… in the following direction. Pho[sphoros
5] zodiacal sign (?), in equal 4[6]2 years, restitutions… [
6]… 462, and each restitution in 5[84] days [
7]… And after the conjunction with the Sun it regresses [
8 greatest] elongation in 224 days. It approaches the Sun [
9] it arrives at the evening station, being distant from the [Sun
10] it approaches the Sun by way of advances, and… conjunction [
11] to the greatest elongation in another 68 days… [
12 morning] station… advancing. Standing away from the Sun…[
13] in 49 (?) days regressing to the greatest morning elongation [
14 greatest] elongation it approaches the Sun regressing [
15]… [
16]… [
17] each restitution in a little less than […] days [
18]… It begins the regression… being distant [from the Sun
19] evening station, and it regresses as far as the morning stopping [
20] … 349 days it makes a conjunction with the Sun… [
21] 349 [days] to the morning station, being distant from the Sun… [
22] 82 and it comes to the evening stopping, being distant from [the Sun
23]… 8 (?) days, again… to regress. In… [
24]… stopping. Phaethon [makes…] restitutions [
25] each restitution in a little less than […] days [
26]… and a twelfth part… It begins the regression [
27]… […]7 from the evening station and regresses [
28]… in a time interval, 139 days, conjunction… [
29] in another 139 [days] to the morning station, being distant [from the Sun
30]… after pausing for 8 days it advances for […] days [
31]… and again after pausing for the 8 days it again begins (?) [
32]… day of the 104 it comes to be diametrically opposite [
33] restitutions in 442… having traversed the [
34 each] restitution in…[
35] the regression…
36] it regresses as far as far as… [
37] it makes a conjunction [
38] station, being distant [from the Sun
39] days [
40] after pausing 8 [days
41] diametrically opposite [
42]… [
43]… [

6.5 Commentary

Synodic cycles, period relations, and terminology

A planet's synodic cycle is the periodic cycle of its apparent longitudinal motion relative to the Sun as observed from the Earth. From the point of view of ancient astronomy, we can distinguish three kinds of events, or "phases" that repeat in a fixed order in a planet's synodic cycle. Considering the planet's elongation from the Sun, the delimiting moments are the conjunctions, oppositions (only possible for the superior planets Mars, Jupiter, and Saturn), greatest elongations (only possible for the inferior planets Mercury and Venus), and first and last visibility. Secondly, the stationary points delimit the intervals of a planet's motion in the directions of increasing longitude ("direct" in modern terminology) and decreasing longitude (modern "retrograde"). The sequence of phases other than first and last visibility is as follows:

Superior planets	*Inferior planets*
Conjunction	Superior conjunction
Morning station	Greatest evening elongation
Opposition	Evening station
Evening station	Inferior conjunction
Conjunction	Morning station
	Greatest morning elongation
	Superior conjunction

First visibility occurs shortly after conjunction, and last visibility shortly before conjunction; however, in the case of Mercury the morning station may take place before first visibility and the evening station after last visibility.

Because the orbits of the Earth and the other planets are eccentric, neither the time intervals between successive phases nor the durations of complete synodic cycles (from any phase to the recurrence of the same phase) are constant. In both Babylonian and Greek mathematical astronomy, a common means of expressing the long-term behavior of the planets' synodic cycles was a period relation of the following form:

Π synodic cycles = Y years = Z revolutions of the planet around the ecliptic

which implies that after a constant period of Y years, the planet will return simultaneously to its original longitude and to its original configuration relative to the Sun.[20] For an inferior planet, Y and Z are equal, whereas for a superior planet $Y = \Pi + Z$. The mean synodic period is thus:

20 Neugebauer 1975, 1.388-390.

$p = Y / \Pi$

which can be expressed in days by multiplying the quotient by the assumed length of the year.[21]

The Front Cover Inscription employs terminology for the synodic cycles and their phases that is mostly well known from Greek astronomical texts. In our translation we have used literal renderings rather than interpretations according to modern terminology. In particular we have respected the Greek conventions according to which longitudinal motion in the direction of the daily revolution of the heavens, i.e. westward, is characterized as forward motion and eastward motion is backward, which are the reverse of the modern nomenclature of "direct" and "retrograde." The following list sets out the technical terms, their literal meanings as given in the translation, and the modern interpretations. Those marked with an asterisk are unusual as technical terms.

Pertaining to synodic phases
ἀποκατάστασις = "restitution" = synodic cycle (*literally* restitution)
σύνοδος = conjunction
κατὰ διάμετρον = "diametrically opposite" = opposition
μέγιστον (ἑῷον/ἑσπερινὸν) ἀπόστημα = greatest (morning/evening) elongation
ἑῷος/ἑσπερινὸς στηριγμός = morning/evening station
ἑῴα/ἑσπερινὴ στάσις* = "morning/evening stopping" = station

Pertaining to longitudinal motion
ὑπολείπεται = "regresses" = increases in longitude
ὑπολειπόμενος = "regressing" = increasing in longitude
ὑπόλειψις = "regression" = direct movement

είς τὰ ἑπόμενα = "in the following direction" = eastwards

προηγεῖται= "advances" = decreases in longitude
προηγούμενος = "advancing" = decreasing in longitude
προήγησις= "advance" = retrograde movement

Pertaining to motion relative to the Sun
προσάγει* = "approaches" = decreases in elongation
ἀπέχων* = "being distant" = having elongation
ἀποστάς* = "standing away" = having elongation

21 In Babylonian and earlier Greek astronomy, no distinction was made between sidereal and tropical years. The Callippic intercalation cycle implies a year of exactly $365\frac{1}{4}$ days.

Models for synodic cycles

Babylonian mathematical astronomy employed arithmetical algorithms to model the intervals of time and longitudinal motion between successive phases.[22] These algorithms were derived from empirical data without assumption of an underlying geometrical model for the planet's motion. While Babylonian-style models were known and practiced in the Greek-speaking world, at least from the first century AD onwards,[23] the "main stream" of Greek planetary theory that culminated in Ptolemy assumed geometrical models based on a combination of two circular motions, one of a center (*C*) revolving around the Earth (*O*), the other of the planet (*P*) revolving around this moving center (Figs. 6.10-6.11). In the simplest form, such a model has the Earth at the geometrical center of the circular path of *C*, while *C* is invariably the geometrical center of the path of *P*, and both revolutions are performed at a uniform angular velocity relative to their centers. If the radius of *P*'s path is less than that of *C*'s path, then *P*'s path, which does not enclose the Earth, is called an "epicycle", and *C*'s path is called the "deferent." If, however, *P*'s path encloses the Earth, it is called an "eccenter". Since the resulting motion of *P* relative to *O* is the sum of two uniformly revolving vectors, any simple epicyclic model is observationally equivalent to a simple eccentric model with the radii and associated rates of revolution exchanged, and *vice versa*.

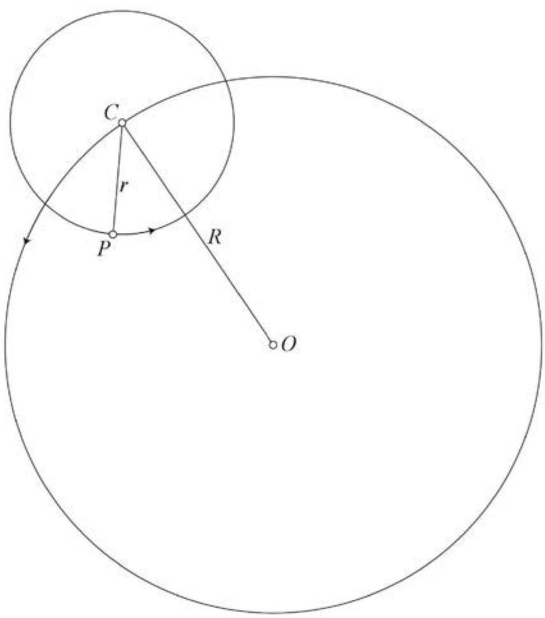

Figure 6.10: *Simple epicyclic model for a planet*

22 Neugebauer 1955, 2.279-315.

23 Jones 1998.

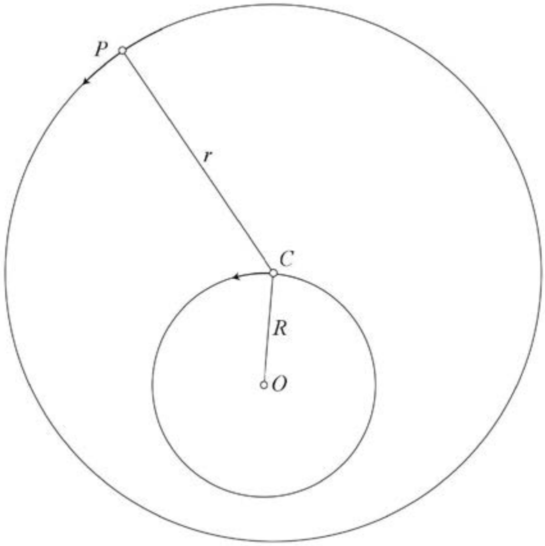

Figure 6.11: *Simple eccentric model for a planet*

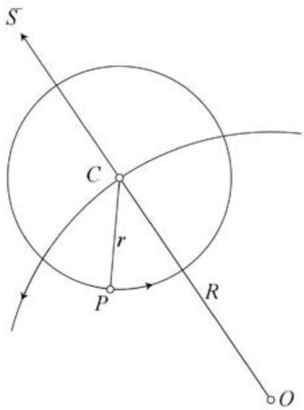

Figure 6.12: *Epicyclic model for an inferior planet*

In the following discussion we will employ epicyclic models. An epicyclic model for an inferior planet must satisfy the condition in the period relation that $Y = Z$, as well as the stronger constraint that the planet has one greatest elongation in either direction of the Sun in each synodic cycle. This requires that radius *OC* is aligned with the mean Sun ($\overline{S}$) so that its period of revolution is one year, while the period of revolution of *P* around *C*, relative to the geocentric radius *OC*, is the mean synodic period p (Fig. 6.12). On the other hand, for a superior planet the rate of revolution of *C* around *O* is independent of the mean Sun, but the constraint that opposition always occurs between the morning and evening stations means that radius *CP* must always be parallel to the direction of the mean Sun $O\overline{S}$ (Fig. 6.13). Hence the period of revolution of *P* around *C*, relative to radius *OC*, or in other words the mean synodic period p, is:

$p = 360°/\overline{v}_p = 360°/(\overline{v}_s - \overline{v}_c)$

where $\overline{v}_s$ is the rate of revolution of the mean Sun, $\overline{v}_c$ is the rate of rotation of *OC*, and $\overline{v}_p$ is the rate of rotation of *CP* relative to *OC*. In all epicyclic models for a planet, to obtain satisfactory representation of the retrogradations it must be assumed that the planet revolves in the same sense around its epicycle as the epicycle revolves around the Earth, so that retrogradations occur when the planet is nearest to the Earth.

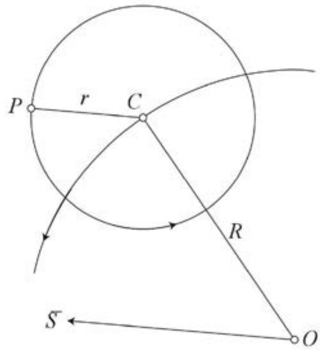

Figure 6.13: *Epicyclic model for a superior planet*

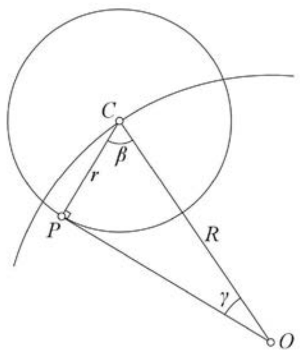

Figure 6.14: *Greatest elongation of an inferior planet*

According to the epicyclic model, the time interval between superior and inferior conjunction of an inferior planet or between conjunction and opposition of a superior planet is obviously $p / 2$. The time interval between the conjunctions and the greatest elongations of an inferior planet, as well as the actual arcs of maximum elongation, can easily be derived by trigonometry from the period relation and the assumed ratio of the epicycle's radius (r) to the deferent's radius (R). In Fig. 6.14 we have for the maximum arc of elongation, $\Delta\lambda_{GE}$:

$\Delta\lambda_{GE} = \gamma = \arcsin(r / R)$

while the time interval between inferior conjunction and greatest elongation is:

$t_{GE} = (\beta / 360°)\, p = (\arccos (r / R) / 360°)\, p$

Conversely, these relations allow one to derive r / R from a given maximum arc or time interval.

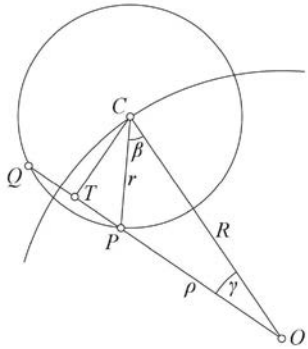

Figure 6.15: *Apollonios's theorem determining the stationary points of a planet*

For the stations, Ptolemy (*Almagest* 12.1) provides a theorem that he says was demonstrated by Apollonios of Perge among others; it is usually inferred that Apollonios discovered it.[24] In Fig. 6.15, the planet *P* is at its station; line *OP* is produced to meet the epicycle again at *Q*, and *PQ* is bisected at *T*. Apollonios's theorem states:

$$OP / PT = \overline{v}_p / \overline{v}_c$$

where, as before, $\overline{v}_p$ is the rate of revolution of the planet around the epicycle relative to radius *OC* and $\overline{v}_c$ is the rate of revolution of *C* around *O*. From this it follows that we can calculate the time interval between the planet's inferior conjunction or opposition and its station thus:

$$t_{STN} = (\beta / 360°)\, p$$

where:

$$\beta = \arcsin[(\rho + \overline{v}_p / \overline{v}_c) / R] - \arcsin[(\overline{v}_p / \overline{v}_c)] / r)$$

$$\rho = \sqrt{[(R^2 - r^2)\, (\overline{v}_p / \overline{v}_c) / (2 + \overline{v}_p / \overline{v}_c)]}$$

For the inferior planets, the elongation from the Sun at station, $\Delta\lambda_{STN}$, is:

$$\Delta\lambda_{STN} = \gamma = 90° - \arcsin[(\rho + \overline{v}_p / \overline{v}_c) / R]$$

24 Neugebauer 1975, 1.191-193.

For the superior planets, however:

$$\Delta\lambda_{STN} = 180° - \beta - \gamma = 90° + \arcsin[(\overline{v}_p / \overline{v}_c) / r]$$

Though considerably more complicated than the calculations for greatest elongation, the derivation of t_{STN} was carried out for all the planets by Ptolemy (*Almagest* 12.2-6), so it was in principle within reach of any diligent astronomer who had the necessary trigonometrical resources. Such resources existed from Hipparchos's time if not earlier.[25]

For reference, we have calculated t_{STN} and $\Delta\lambda_{STN}$ for all planets and t_{GE} and $\Delta\lambda_{GE}$ for the inferior planets, assuming Ptolemy's value for *r* (top row) as well as a range of values surrounding Ptolemy's value; in all cases, *R* = 60 following Ptolemy's convention. To obtain the times between the respective phases and superior conjunction (inferior planets) or conjunction (superior planets), one subtracts the tabulated times from *p* / 2.

Mercury (*p* ≈ 115.88d)

r	t_{STN}	$\Delta\lambda_{STN}$	t_{GE}	$\Delta\lambda_{GE}$
22.5	11.24	17.23°	21.88	22.02°
19	9.58	12.23°	23.03	18.46°
20	10.20	13.73°	22.70	19.47°
21	10.69	15.17°	22.38	20.49°
22	11.08	16.55°	22.05	21.51°
23	11.39	17.89°	21.71	22.54°
24	11.63	19.21°	21.38	23.58°
25	11.82	20.51°	21.04	24.62°

Venus (*p* ≈ 583.92d)

r	t_{STN}	$\Delta\lambda_{STN}$	t_{GE}	$\Delta\lambda_{GE}$
$43\frac{1}{6}$	20.90	28.24°	71.35	46.01°
40	16.61	19.02°	78.16	41.81°
41	18.41	22.17°	76.06	43.10°
42	19.75	25.06°	73.92	44.43°
43	20.76	27.80°	71.72	45.78°
44	21.48	30.42°	69.48	47.17°
45	21.97	32.97°	67.17	48.59°
46	22.26	35.47°	64.79	50.06°

25 Van Brummelen 2009, 34-68.

Mars ($p \approx 779.94$d)

r	t_{STN}	$\Delta\lambda_{STN}$
39.5	36.50	135.87°
36	30.34	146.83°
37	32.69	143.27°
38	34.52	140.09°
39	35.93	137.22°
40	36.98	134.58°
41	37.75	132.13°
42	38.25	129.83°
43	38.51	127.66°
44	38.56	125.59°
45	38.42	123.62°

Jupiter ($p \approx 398.88$d)

r	t_{STN}	$\Delta\lambda_{STN}$
11.5	60.25	115.68°
10	57.25	120.04°
10.5	58.41	118.43°
11	59.41	116.98°
11.5	60.25	115.68°
12	60.97	114.49°
12.5	61.57	113.40°
13	62.09	112.41°

Saturn ($p \approx 378.09$d)

r	t_{STN}	$\Delta\lambda_{STN}$
$6\frac{5}{6}$	69.86	107.24°
6	68.10	109.76°
6.25	68.70	108.93°
6.5	69.24	108.17°
6.75	69.71	107.47°
7	70.13	106.81°
7.25	70.50	106.21°
7.5	70.83	105.65°

A simple epicyclic (or eccentric) model for a planet obviously generates constant and invariable synodic cycles with respect to conjunctions, oppositions, stations, and greatest elongations.[26] (Visibility phases are effected by the varying angle between the ecliptic and the horizon as well as meteorological conditions.) Modifying the model by displacing the Earth (now *T*) from the center *O* of the deferent (Fig. 6.16) results in varying synodic cycles while maintaining the long-term period relation. With a suitable eccentricity, such an eccenter-and-epicycle model can reproduce reasonably well the variations in the time intervals as well as the planet's total longitudinal progress from one occurrence to the next of the same phase. However, an eccenter-and-epicycle model calibrated to fit the overall durations and longitudinal progresses of the synodic periods will give a poor representation of the planet's apparent velocity when, according to the model, it is nearest to the Earth, and as a result it models the retrogradations poorly, conspicuously so in the case of Mars. This defect can be remedied quite effectively by introducing an "equant"

26 For the effects of adding eccentricity and equant to an epicyclic planetary model as discussed in this paragraph see Evans 1984.

point *E*, distinct from *O* and such that *E* and *T* are equidistant from *O* in opposite directions (Fig. 6.17); the equant functions as the center of uniform revolution of *C*, i.e. the radius *EC* has a uniform rate of revolution.

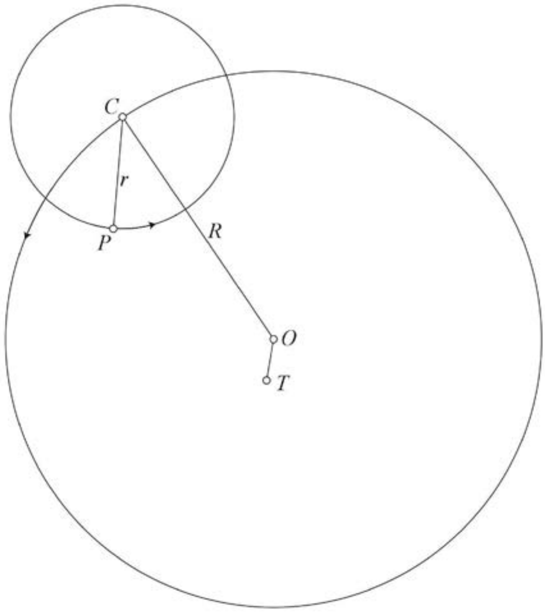

Figure 6.16: *Eccenter-and-epicycle model for a planet*

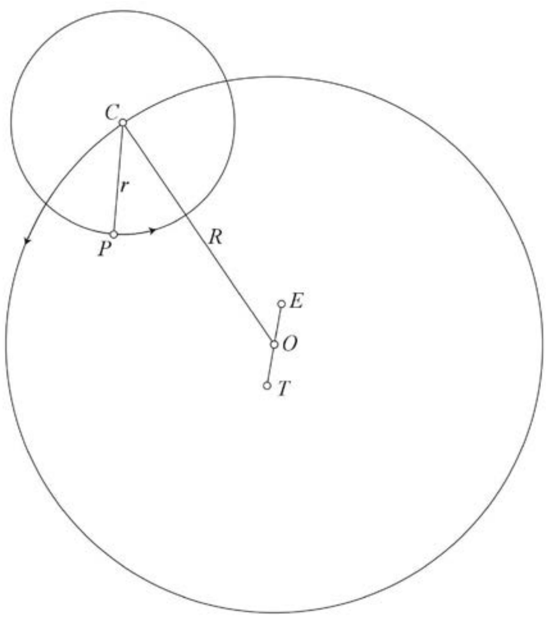

Figure 6.17: *Equant model for a planet*

The association of the theorem on stations with Apollonios is strong evidence that either simple epicyclic or simple eccentric modelling had been applied to the planets by the early 2nd century BC[27] Another passage in Ptolemy's *Almagest* (9.2) asserts that Hipparchos wrote a work in which he criticized the mathematical astronomers up to his time for working with geometrical models that did not allow for variation in the synodic cycles; this would imply that only simple models were current around the third quarter of the second century. Pliny the Elder (died AD 79) gives a confused account of planetary theory (*Hist. Nat.* 2.56-80) which contains our earliest evidence for models incorporating an eccentricity to explain synodic variations. Finally we arrive at Ptolemy, who employs equant models and is usually supposed to have introduced them, though this has been questioned.[28]

Implications for the Mechanism

The idea that the Mechanism had some kind of planetary display goes back to the earliest investigations of the fragments. Various suggestions have been offered as to the nature and level of astronomical sophistication of the display:

Display of planets' mean motion in longitude. This would be a mechanically straightforward translation of the input drive by way of gear trains into uniform rates of longitudinal motion appropriate for each planet according to a suitable period relation; the natural place for the display would be the central front dial, with pointers standing for each of the planets along with the Sun and Moon. Aside from the period relation, a display of mean motion would not embody any specific planetary model. Rehm's unpublished reconstructions seem to be of this kind,[29] and it seems that Price supposed that a display of planetary longitudes, if there was one, would show mean motions only.[30] As Neugebauer pointed out, the mean motions of the inferior planets coincide with the mean Sun, so that it is hard to see how they could have had separate pointers.[31]

27 For arguments for an early second century date for Apollonios see Toomer 1970; Evans & Carman 2014 show that the evidence could also be compatible with a late third century date. We are not persuaded by Goldstein 2009 that Ptolemy's testimony and its implications for Apollonios's knowledge of epicyclic or eccentric models should be disregarded. As Toomer (1984, 556, note 3) points out, however, Ptolemy does not assert that Apollonios operated with both kinds of model and was conversant with their interchangeability, contrary to Neugebauer 1959.

28 Duke 2005.

29 Diagrams of hypothetical mechanism in Rehm 1906a, 92-93 and Rehm 1906b, drawings accompanying pp. 16 and 18.

30 Price 1974, 59-60.

31 Neugebauer 1975, 652, note 7.

Chronological display of planets' synodic cycles. Gear trains could also translate the input motion into displayed revolutions of synodic cycles. A single revolution of a pointer could represent a complete synodic cycle, and graduations and inscriptions around the dial could mark the dates of the synodic phases. Such a display could only represent a model according to which the synodic cycles are constant and unvarying; the subdivision of the cycle could be derived from a simple epicyclic or eccentric model, an arithmetical scheme, or unmediated empirical evidence. One of Price's vague expressions about planetary displays seem to be along these lines.[32] A reconstruction involving five subsidiary dials on the Mechanism's front face, one for each planet's cycle, has been offered by Evans, Carman, and Thorndike.[33]

Display of planets' motion in longitude according to a model assuming an invariable synodic cycle. This is the assumption underlying reconstructions of planetary displays by Wright, Edmunds and Morgan, Freeth and Jones, and Carman and Evans (in a proposal distinct from the one cited in the preceding paragraph), and apparently also Theofanidis's reconstruction.[34] Again, the front dial is the obvious place for a set of planetary pointers. All the reconstructions of this kind known to us employ devices involving pins mounted on gears and riding in hinged slots to effect an anomalistic motion; these are translatable into theoretical models of the simple epicyclic or eccentric type, though the kinematic equivalence is not always immediately obvious.

Display of planets' motion in longitude according to a model assuming varying synodic cycles. Wright has also suggested that a display embodying an eccenter-and-epicycle model could also be achieved within the constraints of the Mechanism's known features,[35] and one of his physical models incorporates a working reconstruction of the display for Mars assuming an eccentric deferent.[36]

It has been argued elsewhere that the Back Cover Inscription's description of the Mechanism's front face establishes beyond plausible doubt that there was in fact a display involving all five planets known in antiquity, and further, that the display consisted of a system of pointers on the central dial to indicate the planets' longitudes along the Zodiac Dial.[37] As we have written above, we believe that the only reasonable interpretation of the Front

32 Price 1959, 65.

33 Evans, Carman, & Thorndike 2010, 22-24.

34 Theofanidis 1934; Edmunds & Morgan 2000; Wright 2002; Freeth & Jones 2012; Carman, Thorndike, & Evans 2012.

35 Wright 2009.

36 Personal communication (June 4, 2014). This is the second model referred to in Wright 2013, 9 note 4.

37 See IAM 5.5, following Freeth & Jones 2012.

Cover Inscription is as a delineation of astronomical "facts" displayed by the Mechanism in action. On this basis we can rule out the notion that only mean motions of the planets were displayed, since the inscription carefully describes stages of forward and backward motion for each planet as well as Venus's varying speed relative to the Sun. On the other hand there is no indication that the synodic cycles or their constituent stages were variable in duration; specific numbers of days are allotted to each stage, and near the beginning of each planet's section was an explicit statement that each synodic cycle contained a stated number of days. A compelling case thus emerges for the third type of display in our list, one kinematically equivalent to a system of simple epicyclic (or eccentric) models.

A different point of divergence among recent discussions of the Mechanism's planetary display concerns the underlying period relations. Several proposals have favored relations equating fairly small numbers of years and synodic cycles, such as the Babylonian "Goal Year" periods which all are shorter than a century, both because short periods could be represented by simpler systems of gears having plausible tooth counts, and because the evidence for Greek knowledge of long and accurate planetary periods, such as were assumed in Babylonian mathematical astronomy, is slender before the first century AD.[38] By contrast, Wright has constructed his conjectural working models of the Mechanism's planetary display using very long period relations that maintain a long-term accuracy of about a degree's error in 500 years or better.[39] Such a period relation, to be viable as gearwork, must contain numbers of years and synodic cycles that can be reduced to factors small enough to be possible as tooth counts or factors of tooth counts; its mechanical representation then becomes a gear train involving multiple pairs of engaged gears.[40] Wright has given one motivation for using these accurate period relations as his desire to show the physical practicability of a planetary display representing the high end of the knowledge that can plausibly be ascribed to astronomers at the time of the Mechanism's manufacture, but he also has maintained that it is not merely possible but indeed probable that the designer would have known and sought to mechanize planetary periods comparable to those of the Babylonian mathematical models.

No complete statement of a period relation is preserved in the Front Cover Inscription, but fortunately it is sufficient to have just one of the constituent numbers in order to reconstruct the equation since the ratios of the terms are approximately known. In line 6, within the formula setting out the period relation for Venus, the number 462 is well preserved, and in line 42, within the corresponding formula for Saturn, we have the num-

38 Edmunds & Morgan 2000, 6.13-15; Freeth 2002, 47-52; Freeth & Jones 2012, 3.3.1.
39 Wright 2013. Evans, Carman, & Thorndike 2010, 24-31, also propose gear trains approximating Babylonian long period relations.
40 Wright 2013.

ber 442.[41] As we will show below, these are the numbers of years in long, accurate, and previously unattested period relations for their respective planets. The fact that the terms of both relations are suitably factorable for representation through gears adds weight to the argument that they were included in the inscription as statements of the theory built into the Mechanism, not as ideal periods that the Mechanism merely approximated. The implication that the Mechanism used compound gear trains to obtain the desired periodicities of at least two of the planets may have implications for whether specific devices for producing the anomalies would have been mechanically viable, but this is a question beyond the scope of the present paper.

A third question that the Front Cover Inscription casts light on is the relation between the design of the Mechanism and Babylonian astronomy. It has often been remarked that the lunisolar gearwork is entirely founded on two period relations that were attested in Babylonian astronomy earlier than their appearance in a Greek context: the "Metonic" equation of 19 solar years with 235 lunar months, and the "Saros" cycle equating 223 lunar months, 239 periods of lunar anomaly, and 242 periods of lunar latitude. Discussions of the assumed planetary period relations that the Mechanism might have represented either exactly or approximately have therefore tended to look to either the shorter and less precise Babylonian Goal Year periods or the long periods of Babylonian mathematical astronomy.[42] Now of the two period relations that can be recovered from the Front Cover Inscription, the 462-year relation for Venus could be a practicable approximation of the unfactorable Babylonian 1151-year relation, but the 442-year relation for Saturn cannot be accounted for in this way because the Babylonian 265-year relation is already practicable with gears as well as being shorter than the 442-year relation. We infer that, for the planets, the designers of the Mechanism drew on otherwise unknown research in the Greek tradition that was either independent of the Babylonians or, perhaps more likely, built on their foundations.

The descriptions of the planets' synodic cycles also tend to distance the Mechanism from Babylonian planetary theory. In Babylonian astronomy, the most prominent synodic phases are the first and last appearances, which seem not to have been mentioned at all in the Front Cover Inscription. On the other hand, the Babylonians did not include greatest elongations of the inferior planets or conjunctions of any planet among the predicted or observed phases, while sunset ("acronychal") risings of the superior planets, rather than their true oppositions, were recognized as significant phases. The Front Cover Inscription, on the contrary, takes a severely geometrical approach to the defining the key stages of the synodic cycles.

41 Lines 16 and 24 contained parts of the formulas for Mars and Jupiter respectively, but we are unable to read any numerals because of the damaged condition of these lines.

42 See the articles cited in notes 38 and 39 above.

Concordance of parallel passages.

The paragraphs for all three superior planets used almost exactly the same verbal framework for describing their periodicities and synodic phenomena; a similar parallelism probably also held between the paragraphs for the two inferior planets, though our evidence is slighter since little of the paragraph for Mercury survives. The following tables facilitate comparison of the corresponding passages.

Inferior planets

	Mercury	*Venus*
Planet named	—	4
Period relation	—	5-6
Synodic period in days	—	6
Superior conjunction	—	7
Greatest evening elongation	—	8
Evening station	—	9
Inferior conjunction	—	10
Greatest morning elongation	—	11
Morning station	—	12
Greatest morning elongation (again)	1-2	13-14

Superior planets

	Mars	*Jupiter*	*Saturn*
Planet named	?	24	?
Period relation	?	24	33
Synodic period	17	25	34
Evening station	18-19	26-27	35-36
Conjunction	20	28	37
Morning station	21	29-30	38-39
Evening station (again)	22-23	31	40
Opposition	?	32	41

Line-by-line commentary.

Lines 1-4: Mercury

Little can be made of these lines, which must belong to the description of the last stages of Mercury's synodic cycle. Lines 1 and 2 apparently correspond to the occurrences of ὑπολειπόμενος and [μεγίστου ἀπο]στήματος in lines 13 and 14, which respectively describe the planet's direct motion while increasing in elongation from the Sun leading to the greatest morning elongation, and the motion, still direct but now decreasing in elongation, following that event.

Lines 4-16: Venus

4-6. Name, period relation, and synodic period

Venus is identified by its descriptive name Phosphoros (line 4). The only other legible naming of a planet, in line 24, gives only the descriptive name, and it is likely that this was the practice throughout the text. By way of contrast, both descriptive and theophoric names are given in the Back Cover Inscription.[43]

The number 462 which appears in lines 5 and 6 identifies the period relation for Venus as:

462 years = 289 synodic periods = 462 revolutions of the ecliptic

This relation is not attested in any other known source from antiquity. The ratio 462 : 289 factorizes as (2 x 3 x 7 x 11) : (17 x 17), so it can be represented by a gear train with reasonable tooth counts, e.g. (66 : 51) x (63 : 51). It is also the first continued-fraction convergent of the ratio 1151 : 720 which defines the period relation for Venus in Babylonian mathematical astronomy. Since 1151 is prime, the Babylonian period relation could not be represented by a practicable gear train. Hence it is possible that the 462 : 289 ratio was adopted for the Mechanism as a best approximation of the Babylonian ratio, without the need to presume independent empirical input.

Venus's synodic period is approximately 583.92 days; from the 462-year period relation and a $365^1/4$ day year one would obtain 583.89. The period as recorded in line 6 of our text was probably just 584 days; only the first digit is preserved.

Synodic phases

The cycle set out in the text apparently began with superior conjunction, since line 7 has the planet increasing in longitude after conjunction. The next phase reached is the greatest evening elongation (line 8). This is stated to be 224 days after superior conjunction (line 8).[44] If this number was obtained by accurate trigonometrical calculation from the theoretical model, it would correspond to an epicycle radius of approximately $44^2/_3$ such that the deferent's radius is 60, which in turn could have been derived from an assumed 48° for the arc of Venus's greatest elongation, a parameter that is attested in several ancient sources.[45]

After the greatest elongation, the planet approaches the Sun (line 8) while continuing

43 Cf. BCI lines I 19 and 23, in *IAM* 5.4.

44 The traces of the numeral are also compatible with 221, but 224 appears to be the correct reading since the intervals from superior conjunction to greatest elongation and from greatest elongation to inferior conjunction should add up to half the synodic period.

45 Neugebauer 1975, 2.804.

to increase in longitude. After an interval not preserved in the text, but which ought to have been about 50 days, Venus reaches its evening station (line 9). The text appears to have specified Venus's elongation from the Sun, which should have been about 32° in the direction of increasing longitude. Following station, Venus continues to approach the Sun while now moving retrograde until inferior conjunction (line 10).

At this point the text took a step backward chronologically, stating the interval from the greatest evening elongation to the inferior conjunction, 68 days (presumably in the gap between lines 10 and 11), and the corresponding interval of 68 days from inferior conjunction to the greatest morning elongation (line 11). Then it breaks down the latter interval into a first part in which the planet moves retrograde to its morning station (line 12, again with a lost indication of the elongation from the Sun at station) and a second part, lasting 49 days if the numeral is correctly read, in which the planet moves direct to its greatest morning elongation (line 13). 46 days from morning station to greatest elongation, and thus 22 days from inferior conjunction to the station, would be in better agreement with the epicycle radius of $44^2/_3$ obtained above.

The final stage of the cycle is the direct motion from greatest morning elongation, with the planet approaching the Sun (line 14), concluding with superior conjunction.

Lines 15-16 are in wretched condition and practically unreadable. It is not clear where the section concerning Venus ended and that concerning Mars began.

Notes on specific passages:
5. The reading ζωιδ[ί]ου is highly uncertain, and we do not see how an allusion to a zodiacal sign would fit in here.

The point of ἴσοις ("equal") is not clear, unless it anticipates the fact that the number of Venus's revolutions around the ecliptic given in line 6 is the same as the number of years.

6. The word at the beginning of the line might have been κύκλους, "circles" or "circuits."

10. The word following συνόδου at the line's end might have been a specification of which kind of conjunction takes place; but neither ἀπώτερον ("further") nor ἀνώτερον ("higher") would be expected for inferior conjunction.

11. ἄλλαις ("another") presumably because an interval of 68 days was previously specified in a lost part of the text for the time from greatest evening elongation to inferior conjunction.

Lines 16-24: Mars
Period relation and synodic period. Mars's period relation ought to have been set out in the line preceding the statement of its synodic period (line 17), but we have not succeeded

in making sense of the traces in line 16. The synodic period is approximately 779.94 days, which the text probably expressed as "a little less than 780 days."

Synodic phases
The starting phase of the text's synodic cycle is not entirely clear from the surviving text, but on analogy with the paragraphs for Jupiter and Saturn, we believe it was the evening station, following opposition. Line 18 indicates a beginning of direct motion, which should mean the evening station, while line 19 refers to the entire interval of the planet's direct motion from the evening station until the morning station. Lines 20-21 breaks this interval into two equal parts of 349 days from evening station to conjunction and from conjunction to morning station. As in the case of Venus, the elongations at the stations were given, but unfortunately the numbers are lost.

In line 22, the interval of 82 days must be from morning station to evening station since:

2 x 349 days + 82 days = 780 days

82 days is in fact longer than the time of retrogradation that would be obtained from any chosen epicycle radius for Mars; the maximum possible is about 77 days, corresponding to an implausibly large radius of about $43^1/_2$, while an accurate epicycle radius would give a retrograde time of about 73 days. It is possible that the discrepancy resulted from assuming an interval of several days of zero velocity at the stations, as the text prescribes for Jupiter and Saturn; however, in the section for Jupiter the stated duration of the retrogradation does *not* include the days of no motion.

Line 23 shows that Mars's stations were described as effectively lasting several days, like those of Jupiter (30-31) and Saturn (39-40). It seems likely that the duration of the stations were assumed to be 8 days for all three superior planets, though the reading of the numeral in the present line is not certain.

The remaining part of the section for Mars (lines 23-24) is too broken to interpret; one would expect a reference to the planet's opposition at the midpoint of its retrogradation (cf. 32 and 41).

Lines 24-32: Jupiter
Period relation and synodic period. The number of years of the period relation was likely written in an illegible part of line 24. The synodic period is approximately 398.88 days, so the continuation of line 25 must have given 399.

Synodic phases
Lines 26-29 correspond closely to lines 18-21 in the description of Mars's synodic cycle: the interval of direct motion from evening to morning station is specified, and then broken into two equal intervals of 139 days from evening station to conjunction and from

conjunction to morning station. This is, within a day, the length of the intervals between the conjunction and the stations calculated from Ptolemy's epicycle radius of $11\frac{1}{2}$.

According to lines 30-31, the planet stands still for 8 days at either station. The number 104 in line 32 must be the duration of the entire retrogradation, not counting the eight-day pauses, since:

2 x 139 + 2 x 8 + 104 = 398

though it is not clear how the text accounted for the total's shortfall of just under a day relative to the synodic period. The opposition falls at the midpoint of the 104-day interval.

Notes on specific passages:
26. δωδεκατημόριον ("twelfth part") is likely to have the sense of "30° interval" here, and possibly refers to the amount that Jupiter progresses in longitude in one synodic period (the mean is actually a little over 33°).

28. ἐν χρόνῳ ("in a time interval") is awkward here, but no alternative reading suggests itself.

Lines 32-43: Saturn.
Period relation and synodic period. Line 33 gives the number of years in the following period relation for Saturn:

442 years = 427 synodic periods = 15 revolutions of the ecliptic

Like that for Venus, this relation is not attested in any other known ancient source. The ratio 442 : 427 factorizes as (2 x 13 x 17) : (7 x 61), so it can be expressed as a plausible gear train, e.g. (68 : 61) x (52 : 56). In this case, the period relation cannot be accounted for as simply an approximation of the Babylonian period relation

265 years = 256 synodic periods = 9 revolutions of the ecliptic

since the Babylonian relation is both shorter and suitably factorable for gearwork.

Line 34 is all that remains of the statement of the synodic period. Combining the ratio from the 265-year period relation with a $365\frac{1}{4}$ day year would yield approximately 378.09 days, in agreement with the planet's actual synodic period.

Synodic phases
Little remains of the treatment of Saturn's synodic phases. The correspondence of wording in lines 35-41 with parts of 26-32 shows that the basic pattern was the same as for Jupiter. The only numerical parameter preserved is an 8-day interval of effective immobility at

Saturn's evening station (line 40).

Lines 42-43 are too poorly preserved to make any sense of. Since line 41 corresponded to line 32, which is the last line concerning Jupiter, we suspect that the text went on to discuss material other than the planets' synodic cycles.

Unplaced fragment 42
Our reading of line 2 is based on identifications of each letter's traces that would be most plausible if taken in isolation, but it does not fit the known vocabulary of the inscription. If we reject the reading of the first letter, it might preserve part of [με]γίστ[ον ἀπόστημα], "greatest elongation"; if so, the planet in question is either Mercury or Venus. If we suppose the second letter to be an epsilon, one could restore [Πυρ]όεις, "Fiery one," i.e. Mars, in which case line 3 would be part of the statements of Mars's period relation and synodic period. Line 3 seems to give us a numeral, either 64 or a number terminating in 64. We have not succeeded in finding a plausible identification of this number among the quantities that are likely to have appeared in the inscription's text.

Unplaced fragment 51
Lines 3-5 appear to contain vocabulary referring to a planet's apparent pause at a station, the (following?) station, and an interval of days between stages of the synodic cycle. Line 2 might contain a numeral (324 or 224).

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Almagest

5
The Back Cover Inscription

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Abstract
This paper presents an edition with translation and commentary of an extended text that was inscribed on a plate (or conceivably a pair of plates) that lay against the rear face of the Antikythera Mechanism while it was under the sea. This plate, which may have functioned as a protective cover, is extant only in small fragments, but more of its text was preserved as offsets on a layer of accreted matter that built up against it. The text was a systematic description of the dials, pointers, and other external features of the Mechanism, beginning with the front face and continuing with the rear face. The best preserved passages include descriptions of features on lost parts of the Mechanism: a display of pointers bearing small spheres representing the Sun and planets on the front dial, and a dial on the upper back face representing a 76-year "Kallippic" calendrical cycle.

5.1 Introduction

During a long interval of the Mechanism's immersion in the sea, an inscribed bronze plate (or conceivably a pair of plates) about two millimeters thick lay against the Mechanism's rear, with the inscribed side facing inwards and oriented right way up with respect to the Mechanism. The plate was not flush with the Mechanism's back plate, in part at least because the pointers of the back dials held them apart. Through the action of the seawater, a film of hard accretion of variable thickness, but generally less than a millimeter in depth, built up against the inscribed face, so that its surface was a negative copy of the plate's surface, with the inscription's engraved lettering reproduced as slightly raised, mirror-reversed offsets.[1] Eventually the inscribed plate fragmented, and by the time that the Mechanism's fragments were salvaged, most of the plate had fallen off, leaving much of the accretion layer still attached to the fragments together with some patches of the plate itself. Remains of the offsets and original plate are found in the present Fragments A, B, and E, as well as Fragments 19 and 67, which are pieces of the plate separated from A in 1905.

The physical relation of the plate to the Mechanism when it was intact is uncertain. Price supposed that, in addition to bearing the inscription, it served as a hinged "door" protecting the back face when the Mechanism was not in use.[2] Assuming that its remains were found in roughly their original locations, the text would have been visible to a spectator only when the door was open. Since, however, no evidence of hinges has been identified, we follow more recent investigators in speaking of the plate as the "Back Cover," and so its inscription is formally called the "Back Cover Inscription". The truth is that we do not know whether the plate was intended as a protective cover rather than a detached sheet meant to be deployed in some other way, which either was intentionally stored against the back face for safer transport or accidentally got that position during or after the shipwreck.[3]

In all, parts of fifty-five lines of text are preserved. It can be inferred that the text was written in a single wide column (averaging around 75 letters to a line), running along practically the full breadth of a plate having about the same width as the Mechanism's faces, since a

1 The initial explanation of the mirror-reversed lettering seen on Fragment B when it was discovered in 1902 was that one was seeing the back of an engraved plate; see for example Rediadis in Svoronos 1903a, 46 = Svoronos 1903b, 45. Theofanidis [1927-1930], "98" (correct pagination 90) seems to have been the first to give the correct explanation in print.

2 Price 1955, 65, and Fig. on 62-63; Price 1974, 21-22 (where a "diptych" arrangement with two hinged doors is suggested). The "door" nomenclature was retained in Freeth et al. 2006, 587, and Freeth, Jones, Steele, & Bitsakis 2008, supplementary notes 7.

3 See section 3 for discussion of a plate fragment with a sliding catch in Fragment F, which, if it came from what we are calling the Back Cover, would confirm that it was indeed a removable cover.

layout in two or more columns would not accommodate the minimum of words required to obtain continuity of sense between some of the consecutive preserved parts of lines. The surviving text comes from towards the beginnings (left ends) of the lines, with many line beginnings either preserved or reconstructible.[4]

The offset layer on Fragment B-1 (Fig. S2) shows very clearly both the left margin of the text and the physical left edge of the Back Cover, which was very close to the margin and very nearly parallel to the sides of the Back Plate. If we extrapolate this edge downwards, using the known original configuration of Fragments B and A, we find that the line would have fallen about a centimeter to the right of the left margin of the text preserved in A-2 (and E), which also inclines slightly clockwise relative to the edge of the Back Plate (Fig. 5.1). In other words, looking at A-2, we see the lines of offset text as not exactly horizontal but inclining slightly upwards to the right.[5] The margin of the plate on B-1 and that of the plate on A-2 and E were respectively about 30 mm and 20 mm to the right of the back plate's edge (i.e. to this edge's left when we are looking at the mirror-reversed offsets on the fragments). Hence at the time that the offsets were formed, the Back Cover was split in two parts, either through a fracture or because it originally comprised two separate plates, and both parts were in somewhat different laterally shifted positions relative to the Mechanism's frame.

4 In this discussion we use "left" and "right" in relation to the text as it appeared on the inscribed plate. The directions are reversed on the preserved offsets.

5 Aside from considerations of physical appearance, the margins can be identified by their consistently lining up with beginnings of words or syllables according to the standard Greek conventions for line breaks.

Figure 5.1: *Mirror-reversed image of B-1 superimposed on A-2 in its approximate original position, with the left margins of the Back Cover Inscription shown as white lines (Image: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)*

The total preserved height is about 200 mm, and it is not clear how much text preceded or followed the extant lines. A plate coextensive with the Mechanism's faces could potentially have held about ninety lines of text, or on the order of twelve hundred words. This would be the equivalent of four or five pages in a typical modern edition of an ancient Greek prose text. At a minimum, the text was about two-thirds of that length.

The recognition of the Back Cover Inscription as a distinct entity was due to Price, following upon his discovery of how Fragments A and B fitted together. The part of the inscription preserved in offsets on B had been remarked, and a few letters successfully read, at the time that the Mechanism was first noticed in the Museum in May, 1902, but to the early investigators it was not clear, for example, that the mirrored text on B-1 and the normally oriented text visible on A-2 —actually part of the Back Plate Inscription— did not come from a single inscription. The natural presumption was that a text accompanying a mechanical instrument ought to contain an explanation of how to operate the instrument; and as bit by bit more of the inscription was read, with terminology showing up relating to both astronomical objects and mechanical elements, the label "instruction manual" persisted. We can now see, however, that this characterization is not quite exact though it comes close to the truth. The text, so far as it survives, does not contain instructions for operating the Mechanism (except perhaps in part II.5-16), but it systematically *describes* the visible components of the Mechanism. Its relation to the Mechanism was like that of a caption to a drawing or picture, addressed to the viewer rather than to the operator, and explaining the meaning of what he or she was seeing.

The part of the inscription surviving on Fragment B appears to have concerned the Mechanism's front face, and its better preserved lines appear to be inventorying features in a more or less radial order from the center of the front dial outwards. The part in A, E, 19, and 67 relates to the rear face, describing in turn the upper spiral dial, the subsidiary dials enclosed within the spiral, the lower spiral dial, and the subsidiary dial enclosed in it. Since the division between the accounts of the two faces apparently coincided with the discontinuity in the lateral shift of the text's left margin, the possibility arises that the inscription comprised two detached plates that were meant to be deployed or mounted so that one could read the plate concerning each face while looking at that face. For example, the intention might have been that the Mechanism would be mounted on a plinth at a suitable height for convenient operating and viewing, with the explanatory plaques fixed to the front and back of the plinth.

The principle of furnishing a publicly displayed scientific object with an explanatory "caption" inscription can be paralleled in several Greek inscriptions that accompanied sundials, for example the following inscription (since lost) copied by Cyriacus of Ancona in 1444 in Samo-

thraki from one face of a marble pedestal in the form of a triangular pyramidal frustrum:[6] «τοῦ γνώμονος ἡ | [σκι]ὰ ἐπιοῦσα ἐπὶ τὰ|ς γραμμὰς ση|μαίνει τὰς ὥρας | τοῦ ἐνιαυτοῦ καὶ | τῆς ἡμέρας. | Τροπῶν θερινῶν | πρώτη, ἰσημεριῶν ἡ μέση, | [χει]μερι[ν]ῶν ἡ ἐσχάτη».
("When the shadow of the gnomon reaches the lines, it indicates the seasons of the year and the hours of the day. The first (line) is for the summer solstice, the middle one is for the equinoxes, the last one is for the winter (solstice)").

The sundial captions are obviously much briefer than the Back Cover Inscription, because the objects that they explained were, from the viewer's perspective, much simpler. More comparable in scale to the Back Cover Inscription are the captions (ὑπογραφαί) that Ptolemy provides in *Geography* 7.5, 7.7, and 8.3-28 to accompany his maps of the known world and its regions.[7] For example, the caption for the world map (7.5), which runs to nearly a thousand words, inventories the three continents, the seas and unknown lands that border them, and the largest bays and islands, as well as specifying the known world's limiting parallels and meridians and its north-south and east-west dimensions.

While part of the interest of the Back Cover Inscription for us is the light it casts on how the Mechanism's makers imagined that people would experience it and what they would need to know in order to appreciate it, the text also contributes to our knowledge of the Mechanism's appearance and functions. At early stages in the study of the fragments, when little had yet been deduced from the physical evidence, readings from the inscription, though limited to disconnected words and phrases, were instrumental in establishing that the Mechanism was an astronomical device. The serendipitous occurrence of numerals representing 19 years, 76 years, and 223 (lunar months) on Fragment 19 pointed researchers to the crucial role of the Metonic period and the Saros cycle in determining all the functions relating to the Sun and Moon. In the present, more advanced state of reconstruction of the Mechanism, the part describing the back face serves mostly to reinforce the understanding of the back dials and their pointers that we can obtain in the first instance from the substantial parts that survive of them and of the gears that drove them — though it is only from the inscription that we learn that there were two subsidiary dials inside the upper spiral dial but just one inside the lower spiral. The part describing the front face, on

6 Gibbs 1976, 394, no. 8008, following the restoration of the text in Wilhelm 1937 (we reject the emendation of ἰσημεριῶν to ἰσημερινῶν in the 8th line); for Cyriacus's drawing, see Bodnar & Mitchell 1976, 79 and 88. Other examples, incompletely preserved, include inscriptions from Amastris (Gibbs 1976, 392, no. 8001), Oropos (Schaldach 2004, 442, inscribed on the sundial itself), and Alexandria (Breccia, Alexandria Mus. No. 185, for which see Jones 2014, 178-181). The Alexandrian inscription runs to more than a hundred words, and was probably much longer when complete.

7 Berggren & Jones 2000, 4, 108-111, 117, and 121-122.

the other hand, gives its clearest testimony precisely where the physical evidence is most defective, namely with respect to the way that the Mechanism displayed the motions of the planets.

5.2 Fragments preserving parts of the Back Cover Inscription

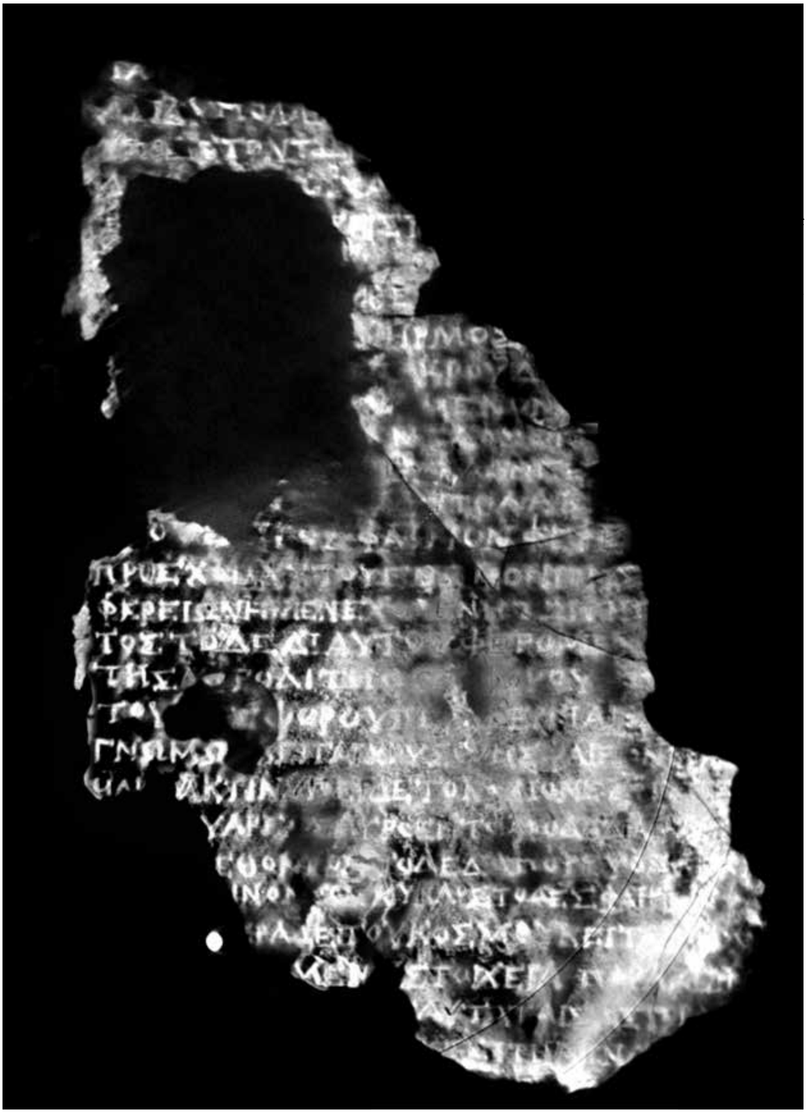

Figure 5.2: *CT composite image of the Back Cover Inscription preserved in Fragment B (Image: Antikythera Mechanism Research Project)*

Comparison with the early photographs shows that the accretion layer on B-1 has not significantly altered since 1902 (supplementary Fig. S8); in particular, there have been no losses to breakage. Much less of the inscription can be made out in the early photographs, chiefly along the right edge (i.e. the beginnings of the text lines). It appears that B-1 was left more or less untouched in the 1905 conservation, but was subsequently cleaned of superficial material concealing the offsets, probably during the 1953 conservation.

The greater portion of Part II survived in a similar manner, as an accretion layer lying over the Back Plate on Fragment A-2, with smaller pieces of the Back Cover plate still adhering to the accretion layer. The earliest photograph (supplementary Fig. S6), published in 1903, shows A-2 in this state. The photograph is not as clear as one would wish, but seems to show the accretion layer as having a more or less rectilinear right edge about 20 mm to the left of the right extremity of the fragment, with the rest of its outline irregular; the layer's dimensions were apparently about 50 x 85 mm. No letters can be made out, and it is not possible to discern which regions of the accretion layer were covered by fragments of the Back Cover plate.

The 1905 photograph of A-2 shows the state following the 1905 conservation work, part of which consisted of separating the surviving bits of the Back Cover plate, i.e. the present Fragments 19 and 67.[8] The accretion layer appears almost as extensive as in the 1903 photograph, but about a centimeter (or less) seems to have disappeared off the lower edge. The surface apparently had not been cleaned, and no lettering can be seen, though this is in part due to the relatively poor quality of the photograph. Rehm wrote *Patinaabklatsch* ("patina-offsets") along the lower edge on his print of the photograph, which shows that he had seen mirrored letters there, and understood how they had formed. In the 1918 photograph (supplementary Fig. S7), the accretion layer appears unaltered from the 1905 state except that a small region at the lower left had now broken off, but the much sharper image shows some lettering.

By the 1950s, the accretion layer had suffered more damage; more or less the lower half of the area visible in the 1918 photograph was no longer on A-2. Most of this material seems to have been entirely lost, but a piece about 25 x 20 mm survived as a detached fragment, visible in some of Price's 1958 photographs. It has since been rejoined to A, though not exactly in its original location (which can be determined from the 1918 photograph) because a bit of the Back Plate that provides the linkage is gone. The surface of what remained of the accretion layer (Figs 5.3 and supplementary S1) was cleaned, probably in the 1953 conservation work, so that much more of the mirrored text became legible. There are, however, significant regions whose surface is abraded to the point that the letters are illegible or entirely obliterated.

8 Fragment 67, slightly larger than it is now, appears in one of 1905 Karo photographs alongside Fragments 19 and D.

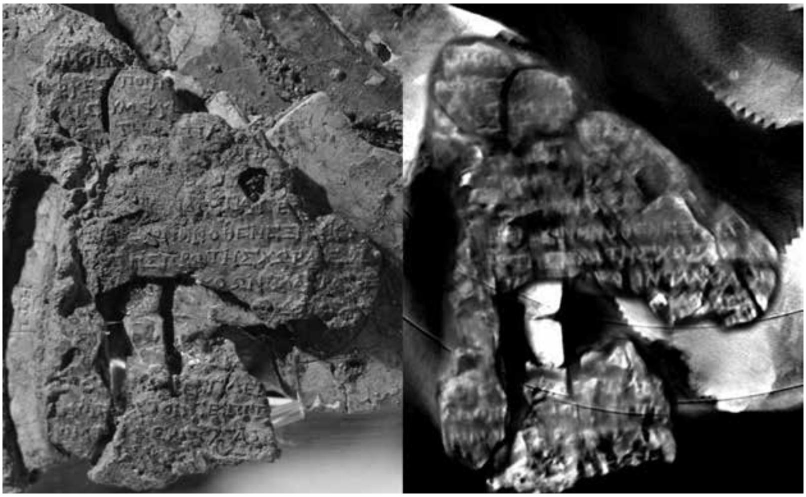

Figure 5.3: *The Back Cover Inscription preserved on A-2: (left) mirror-reversed photograph, (right) CT composite image*
(Images: photo Niels Bos; CT Antikythera Mechanism Research Project)

Fragment 19 (Fig. 5.4, left) is an oval piece of the Back Cover plate, about 50 x 40 mm. Most of its surface is in excellent condition; the preserved text partly coincides with surviving offsets on A-2, but some of the corresponding offsets were lost in the pre-1950s damage. Fragment 67 (Fig. 5.4, right), another piece of the Back Cover, is about 10 x 10 mm, and matches an extant region of the offsets.

Figure 5.4: *Fragments 19 (left) and 67 (right)*
(Images: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

Fragment E has an irregular region, about 40 x 60 mm, of the offset layer, some of which is covered by pieces of the Back Cover plate (Fig. 5.5)

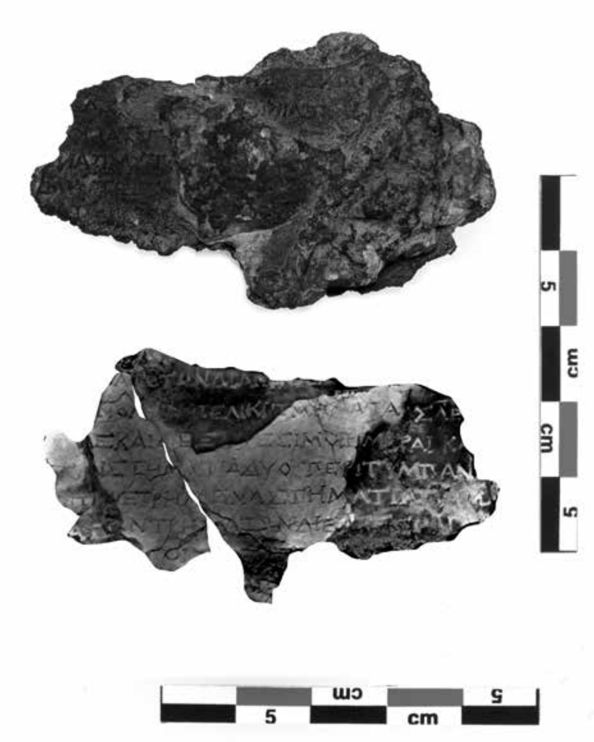

Figure 5.5: *The Back Cover Inscription in Fragment E: (top) mirror-reversed photograph, (bottom) CT composite image*
(*Images: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund; Antikythera Mechanism Research Project)*

Fig. 5.6 shows the parts of the Back Cover Inscription preserved on Fragments E, 19, and 67, overlaid on the surviving offsets of A-2 and the 1918 photograph (both mirror-reversed).

Figure 5.6: *Composite image superimposing photographs of Fragments 19 and 67 and CT composite of E on photograph of the surviving inscription on A-2 on the 1918 photograph of A-2 (Images: Antkythera Mechanism Research Project; Niels Bos; Bayerische Staatsbibliothek, Rehmiana III 9)*

Fragment F contains a small piece from the corner of a rectangular plate with a sliding catch similar to the catch on the Front Plate preserved in Fragment C. It has been suggested that this was a piece of the Back Cover plate, but it bears no inscription and may well have belonged to a different component of the Mechanism, possibly even the Front Plate itself.[9]

On Fragment B the line spacing of the text averages approximately 3.5 mm baseline to baseline (measured on CT from I.3 to I.26), and the typical letter height is about 2.0 mm though with considerable variation. In the preserved parts of I.16-25 the average letter width including space between letters is approximately 2.2 mm, but the average for individual lines ranges from about 1.9 mm to about 2.6 mm. Assuming a usable plate width of about 165 mm, complete lines would have averaged about 75±10 letters per line. Fragment 19 averages a slightly larger line spacing of 3.7mm baseline to baseline (measured from photograph from II.14-23); the letter heights and average widths (measured in II.16-18) are consistent with those from B. The remains on the other fragments are insufficient for precise measurements of the lettering, but consistent with those from B.

9 See IAM 3.2.

5.3 Previous transcriptions and study of the Back Cover Inscription

Wilhelm's and Svoronos's readings of a few words from the offsets on B were announced in the Athens newspapers soon after the discovery of the fragments in May 1902 and consensus settled on two points: that the text consisted of instructions for the instrument's use, and that the presence of references to the Sun and (probably) Venus established the instrument as astronomical. The first formal transcription, however, was in Rediadis's 1903 report on the Mechanism; it is credited to Svoronos with contributions from Wilhelm.[10] In terms of the number of letters read, it was an advance on the version given in the newspapers the previous year, but scarcely in terms of understanding of the text since hardly any new recognizable and meaningful words had emerged. A transcription of similar extent, though diverging in the reading of some of the letters, was published by Theofanidis; it was probably the work of Leonidas, whom Theofanidis elsewhere credits with assisting him with the inscriptions.[11]

Valerios Stais gave the first transcription of the recently separated Fragment 19 in his 1905 monograph on the Antikythera wreck.[12] Again probably relying on Leonidas, Theofanidis subsequently published a more accurate text.[13] Theofanidis also mentioned the presence of offsets on Fragment A, apparently being the first scholar to do so in print, but did not attempt to transcribe them.[14]

The Stamires-Price transcription in *Gears from the Greeks* represents a major advance, made possible by the 1953 conservation which had greatly enhanced the legibility of the offsets on A-2 and B-1, and Price's determination that those on B-1 had originally been more or less directly above those on A-2.[15] The transcription of Part II is a composite of readings from A and 19, together with a few unattributed readings that likely came from a manuscript transcription (which cannot now be located) of A, presumably by Rehm, made when the offsets were better preserved.[16] Price had little to say in general about the contents of the

10 Svoronos 1903a, 46 = Svoronos 1903b, 45-46. The transcription is reproduced by Rados 1910, 10.

11 Theofanidis [1927-1930], "98" (correct pagination 90), and 1934a, 143. The acknowledgement of Leonidas's assistance is at Theofanidis [1927-1930], "99" (correct pagination 91), note 1.

12 Stais 1905, 22, note 1; reproduced in Rados 1910, 11.

13 Theofanidis [1927-1930], "99" (correct pagination 91), and 1934a, 144.

14 Theofanidis [1927-1930], "98" (correct pagination 90): "σωρεία πεπιεσμένων γραμμάτων ἀπολύτως ἀνεπιδέκτων ἀναγνώσεως."

15 Price 1974, 47.

16 The presumed "Rehm" readings appear in the beginnings of the last several lines, with

Back Cover Inscription, but he remarks about the lines in Part II that were best preserved (largely through Fragment 19) that "on the whole it seems that this text is concerned, as indeed it should be, with explaining the dials and pointer readings on the pair of back dials...," a statement that we are glad to be in a position to confirm.[17]

A provisional transcription of the Back Cover Inscription was presented in the supplementary materials of the Antikythera Mechanism Research Project's 2006 paper.[18] While retaining many readings from the Stamires-Price transcription, this text added letters read for the first time on Fragments B and A by means of CT, and incorporated the text from E which had not been previously transcribed.

Most recently, Freeth and Jones published in 2012 a discussion of the Back Cover Inscription together with a text of several lines from Part I revised by Jones[19], though some readings have since been corrected.

the bottom two corresponding to an area of the offsets that is visible in the 1918 photograph but no longer exists. The handwritten drafts of the Stamires-Price transcriptions in the Adler Planetarium collection show Part II in two states, before and after these readings were incorporated.

17 Price 1974, 50.

18 Freeth et al. 2006, supplementary information 8-9.

19 Freeth & Jones 2012, 2.3.1-2.3.2.

5.4 Transcription and translation

The Back Cover Inscription as we have it is divided into two series of consecutive lines, respectively preserved in Fragment B alone and in the group of fragments A, E, 19, and 67. Reconstructing the original relative positions of A, B, and E suggests that the last line in B, represented by only a few doubtful traces of tops of letters, ought to have been the line immediately preceding the first line in E, which is also represented by just a few letters. However, very small adjustment in the positioning of the fragments would create enough room for a lost intervening line or perhaps make the last line in B the same as the first in E.[20] The question of continuity is further complicated by the shift and twist noted above of the lower lines of the inscription relative to the upper lines. We therefore designate the two parts as I and II respectively, counting the lines in each part from 1. For the sake of concordance with earlier transcriptions, we note the following equivalences: our I.2 is AMRP (2006) line 1 and Price (1974) line 1; our II.2 is AMRP line 28; and our II.8 is AMRP line 34 and Price line 30.

Part I was read primarily from CT of Fragment B supplemented by PTMs ak35a, ak36a, and ak37a. Part II was read from CT (E and 19); PTMs ak1a (19), ak47a (A), ak49a (A), and ak61a (67); digital photographs kindly provided by Niels Bos (A), and the 1918 (?) photograph of A2. Letters visible in the 1918 photograph but no longer preserved are underlined.

Part I, text.

1   ̣ ̣[
2   ταύτην δ[
3   δεῖ δ᾽ ὑπολαβ̣[εῖν
4   ὑπὸ δὲ τὸν τω ̣[
5   δ ̣[-6-]οικα[
6   ε[-9-]ηι σπ̣[
7   [-10-] π̣ροσ̣[
8   ο̣[-10-]μ̣θε ̣[
9   ̣[-10-]ν ἡρμοσ[
10   [-11-] ἐ̣π᾽ ἄκρου δ[
11   [-11-] ̣ωσμένων ̣[
12   [-12-]ε̣ μέλαν οτ ̣[
13   [-11-] ̣ ̣ ̣ ̣ ̣ ̣λ̣ω̣ν γεγ[
14   [-10-] ̣ε ̣ δ ᾽ὑπολαβεῖ[ν
15   [̣ ̣]οθ̣ε ̣ ̣ τὸ σφαιρίον φερε ̣[
16   προέχον αὐτοῦ γνωμόνιον σ[

20 In the transcription in Freeth et al. 2006, supplementary information 8-9, I.29 is equated with II.2. We believe this is definitely too tight a relative placement of the two parts.

17 φερειῶν ἡ μὲν ἐχομένη τῶι τῆς [
18 τος, τὸ δὲ δι ᾿αὑτοῦ φερόμεν[ον
19 τῆς Ἀφροδίτη<ς> Φωσφόρου ̣ ̣ ̣[
20 τοῦ [Φω]σφόρου περιφέρειαν ̣[
21 γνώμω[̣] κεῖται χρυσοῦν σφαιρίον ̣ ̣[
22 Ἡλί̣[ου] ἀκτίν,᾿ ὑπὲρ δὲ τὸν Ἥλιόν ἐστιν κυ[
23 [-3- το]ῦ Ἄρεως Πυρόεντος, τὸ δὲ διαπορε[υόμενον
24 [Διὸς Φα]έθοντος, τὸ δὲ διαπορευόμενον̣ [
25 [νου Φα]ίνοντ̣ος κύκλος, τὸ δὲ σφαιρίον φλ̣[
26 [-7-]ε̣ρα δ̣ὲ τοῦ κόσμου κεῖται ̣ ̣ ̣[
27 [-10-]μεν[̣] στοιχεῖα παρακείμ[ενα
28 [-12-] ̣αυτα ταῖς ἀσπιδ̣[ίσκαις
29 [-12-] π̣ρ̣οειρημένα̣[
30 [-16-]α̣σ̣π̣[̣ ̣] ̣[

Part I, apparatus

1 ̣ ̣: along edge, bottom of serifed vertical somewhat to right of margin, with trace of descending diagonal meeting the vertical just above the serif from the left side (perhaps ν); to the right of this, two small traces at baseline level, not serifed.
3 β̣: small trace of lower left corner of letter
4 δ̣: horizontal stroke at baseline level | ̣: serifed bottom of vertical stroke extending slightly below baseline
5 ̣: small trace at top level along edge
6 π̣: vertical with serif at bottom, part of horizontal projecting slightly left of vertical
7 π̣: right part of horizontal at top level, top part of left vertical, short serifed right vertical | σ̣: left half of letter with corners at top and bottom
8 ο̣: left side of loop | μ̣: right half of vee and right vertical serifed at bottom | ̣: small traces at edge at top and baseline level, e.g. σ or χ
9 ̣: small trace at top level along edge
10 ε̣: indistinct traces of right ends of top and bottom horizontals
11 ̣[1]: indistinct traces at edge, conceivably right part of vee and right vertical of μ | ̣[3]: trace at baseline level, possibly lower left corner of σ
12 ε̣: top and bottom horizontals and part of vertical visible in PTM ak35a | ̣: indistinct traces, possibly a vertical serifed at bottom
13 first letters extremely indistinct, conceivably ̣ ̣ ̣κ̣υ̣κ̣λ̣ω̣ν
14 ̣[1]: indistinct | ε̣: bottom half of letter with middle horizontal, faint | ̣[2]: indistinct
15 θ̣: bottom half of letter, rather angular and with the right ascending stroke projecting slightly below baseline (a deformed υ cannot be ruled out) | ̣ ̣: indeterminate traces along edge, and traces of serifed right ends of horizontals at top and baseline level along edge | ̣: trace at top level, e.g. τ or σ
19 ̣ ̣ ̣: extremely indistinct; conceivably ̣σ̣ ̣
20 ̣: trace along edge of vertical or loop

21 ̣ ̣: serifed bottom of vertical, somewhat to right of ν, followed by lower left portion of loop(?)
22 ι̣: serifed top of vertical
24 ν̣: left vertical stroke
25 τ̣: right half of letter | λ̣: apical letter, no horizontal visible
26 ε̣: traces of serifed right ends of horizontals (?) at top and baseline level along edge | δ̣: lower right corner of letter | ̣ ̣ ̣: very indistinct traces
28 ̣: trace at edge at top level | δ̣: top of apex
29 π̣: top right corner of letter | ρ̣: loop | α̣: top of apex
30 α̣: top of apex | σ̣: top horizontal and left extremity of descending diagonal | π̣: horizontal stroke at top level with slight traces of two verticals | ̣: horizontal stroke at top level?

Part I, translation

1 ...
2 this ...
3 One should understand...
4 Below the...
5 ...
6 ...
7 ...
8 ...

9 ... fitted(?)...
10 ... at the tip...
11 ...
12 ... black...
13 ...
14 ... one should understand...
15 ... the little sphere travels...
16 ... little pointer projecting from it...
17 arcs, the one next to the... of the...
18 Stilbon(?), and the... travelling through it
19 of Aphrodite Phosphoros...
20 the arc of Phosphoros...
21 on the pointer lies a golden little sphere...
22 ray of the Sun, above the Sun is the circle(?)...
23 of Ares Pyroeis, and the... making its way through...
24 of [Zeus] Phaethon, and the... making its way through...
25 circle of [Kronos] Phainon, and the little sphere...
26 ... of the cosmos lies...
27 ... letters situated beside...
28 ... the little disks...

29 … aforesaid…

30 … disk(s)(?) …

Part II, text

1 [-4-] ̣λοσ̣[

2 [-4-] ἀπὸ τῶν διαιρέ̣σε̣[ων

3 [̣ ̣ ἐ]ν ὅλη<ι> τῆι ἕλικι τμήματα *v* σ̅λ̅ε [

4 ΤΑΙ δὲ καὶ αἱ ἐξαιρεσιμοὶ ἡμέραι κα̣[

5 [ἔ]χον στημάτια δύο *v* περὶ τυμπάνι̣[ον

6 [τ]ὰ̣ προειρημένα στημάτια τρημα̣[

7 [δι]ὰ τῶν τρήματων διέλκεσθαι ̣ ̣[

8 ὁμοίως τοῖς πρω ̣[ ] ̣ ̣ ̣[

9 φυὲς ποιησ̣[̣ ̣] τ̣υ̣μπ[

10 καὶ συμφυὲ[ς

11 [̣]α̣ στημά̣τια̣ [

12 [-7-]σ̣[̣ ̣]α̣γ̣ε̣σ̣[

13 [-2-]ρ̣ο̣υ̣ ̣ ̣θ̣ο̣δ̣ου[̣]η[

14 [-4-] τ̣ὴν ἐ̣ναντίαν *v* ε̣ [

15 [̣ ̣ ̣] π̣ερόνην ὅθεν ἐξηλκύσ̣[θη

16 [̣ ̣ ̣] τ̣ῆς πρώτης χώρας *v* μ[

17 [γνω]μόνια δύο *v* ὧν τὰ ἄκρα φέ̣[ρεται

18 [̣ ̣] τέσσαρα, δηλοῖ δ᾽ ὁ μὲν τὴ[ν

19 ̣ς τ̣ὴ̣ν τῆς *v* οςL *v* ιθL *v* του[

20 μ̣ος ε̣ἰ̣ς ἴσα *v* σκγ *v* συν τεσ[

21 τ̣ε ̣α̣ ̣ ̣ος διαιρέθη <ι> *v* ἡ *v* ὅλη [

22 μ̣ο̣ν[̣ ̣ ̣ ̣]οι ἐγλειπτικοὶ χρ̣[

23 ὁμο[ίω]ς̣ τοῖς ἐπὶ τῆς ε[

24 <u>ἄκρο</u>ν̣ φέρεται κ[̣] ̣ ̣[

25 ̣ ̣ ̣μ̣εντ ̣υ̣π̣[

Part II, apparatus

Lines 1-7 are preserved in E.

1 ̣: apparently complete but gritty traces of ε or (less likely) σ | σ̣: bottom left corner

2 ε̣[1]: bottom stroke with serif, and trace of bottom end of vertical | ε̣[2]: bottom stroke with serif, and trace of bottom end of vertical | ̣: trace at baseline

3 *v*: one letter

4 α̣: left ends of ascending diagonal and horizontal, no serif visible

5 αδ: corr. from ον | *v*: 1/2 letter | ι̣: trace at baseline

6 ̣: trace at top level | α̣: trace at baseline

7 ̣ ̣: top of serifed apex and, to its right, trace at top level

Lines 8-9 are preserved in A and E

8 A ομοιω[

E [ ]ως τοις πρω ̣[ ] ̣ ̣ ̣[

ϛ̣: serifed right ends of top and bottom strokes | ̣: horizontal at top level with serifs at both ends

9 A φυες ποιησ̣[

possibly a trace of μ (tops of apices) to left of φ | σ̣: traces of top and bottom left corners along edge

E [ ] ̣ ̣μπ[

̣ ̣: horizontal at top level with serifs (?) at both ends, and to the right of this, serifed top of descending diagonal

Lines 10-13 are preserved in A

11 α̣: faint | α̣: indistinct

12 σ̣[1]: faint | α̣: apical letter, faint | γ̣: complete, rather narrow | ε̣: indistinct, distorted | σ̣: bottom left corner

13 ρ̣ο̣υ̣: complete but indistinct | ̣ ̣: indistinct traces, the rightmost part of which resembles the right half of pi | θ̣ο̣: indistinct | δ̣: apical letter with apparent horizontal at baseline, but lambda canot be ruled out

Lines 14-15 are preserved in A, 19, and 67

14 A [-5-] ̣ναντιαν *v* ε̣[

̣[1]: possibly top half of ε | ̣[2]: trace of descending diagonal at top level, possibly χ

67 [ ] τ̣ην ε[

τ̣: vertical with bottom serif, right part of horizontal with serif

19 [ ] ̣τ̣ιαν *v* ε̣[

̣[1]: bottom of vertical (?) along edge | *v*: 1 letter | ̣[2]: ascending diagonal starting from baseline

15 A [-4-]ερονην οθεν εξηλκυσ̣[

σ̣: trace at baseline level along edge

67 [ ] ̣ερ[

̣: trace of horizontal or serif at top height

19 [ ] ̣ν οθεν εξηλ̣[

̣[1]: vertical with serif at bottom | ̣[2]: small trace at baseline

Lines 16-23 are preserved in A and 19. Some letters legible in the 1918 photograph of A2 are now lost or illegible

16 A [̣ ̣ ̣] τ̣ης πρωτης χωρας *v* μ[

τ̣: faint

19 [ ]η̣ς πρωτης χωρας *v* μ[

η̣: serifed bottom of right vertical and small trace of horizontal | *v*: half a letter

17 A [-3-] ̣[-4-]υο ων τα ακρα φερ[

̣: sharp apex

19 [ ]μονια δυο *v* ων τα ακρα φε̣[

v: half a letter | ε̣: bottom of vertical with tiny traces of horizontals at baseline and mid level

18 A [-10-] ̣ [̣ ̣]ι δ ο μ̣ ̣ ̣ [

 ̣: serifed top of vertical | μ̣: top half of letter | ̣ ̣: indistinct traces

19 [ ]α̣ τεσσαρα δηλοι δ ο μεν τη[

α̣: descending diagonal of apexed letter

19 A ̣στ̣[

 ̣: apparently, right ends of a stroke ascending slightly at top height and descending slightly at baseline | τ̣: left end of serifed horizontal at top level, vertical serifed at bottom along edge

19 [ ] ̣ν της *v* ος∟ *v* ιθ∟ *v* του[

 ̣: serifed top of vertical at top level | v^1: one and a half letters | v^2: one letter | v^3: one letter

20 A μ̣ο̣ [

μ̣: left ascending stroke with bottom serif clear, remainder of letter faint in depressed area of surface | ̣: traces at top level (?) and baseline along edge

A_{1918} [̣]ος ε̣ι̣ς [

19 [ ] ε̣ι̣ς̣ ισα *v* σκγ *v* συν τεσ[

ε̣ι̣: faint | v^1: one letter | v^2: half a letter | ς̣: top and bottom horizontals with serifs, small trace of meeting of diagonals, ε not excluded

21 A τ̣ε̣ [

A_{1918} ̣ε̣ ̣ ̣ ̣ ̣ο̣ς̣[

19 [ ]α̣ ̣ ̣ος διαιρεθη *v* η *v* ολη [

v^1 and v^2: half a letter

22 A μ̣ο̣ν[ ] εγλει[

A_{1918} μ̣ο̣ν̣[

19]οι εγλειπτικοι χρ̣[

ρ̣: faint

23 A ομο[ιω]ς τοις επι τ̣[

19 [ ] ε̣πι της ε[

ε̣: top horizontal and top part of vertical

24 A [-4-] ̣ φερεται κ[

A_{1918} ακρον φ̣ερ̣ετ̣αι̣ [

19 [ ] ̣ ̣[

 ̣ ̣: tops of two apices

Line 25 is preserved in A. Some letters legible in the 1918 photograph of A2 are now lost

25 A [̣ ̣ ̣]μ̣εντ̣υ̣π̣[

μ̣: right vertical, slightly sloping, with bottom serif

 ̣[1]: indistinct | υ̣: vee with serifs | π̣: horizontal and top parts of verticals

A_{1918} ̣ ̣ ̣μ̣ε ̣ ̣ ̣[

 ̣ ̣ ̣: indistinct | μ-: entire letter, indistinct

Part II, translation

1 …
2 … from the divisions…
3 … in the entire spiral 235 sectors…
4 … and the omitted days…
5 having two bearings around a disk…
6 the aforesaid bearings, perforations…
7 to be pulled through the perforations…
8 similarly to the first(?)…
9 cause to be attached… disk(?)…
10 and attached…
11 bearings…
12 …
13 …
14 … the opposite…
15 … pin from whence it was pulled out…
16 … the first space…
17 two pointers whose tips travel…
18 … four… one of them indicates the…
19 … the 19-year period of the 76-year period…
20 … into 223 equal (parts?) with four(?)…
21 … the whole has been divided…
22 … times(?) of eclipses…
23 similarly to the… on the…
24 tip travels…
25 …

5.5 Commentary

Our commentary interprets the Back Cover Inscription as a systematic, feature-by-feature description of the Mechanism's exterior. The item-by-item concordance between Part II and the Mechanism's back face as we know it from the surviving pieces of the back plate and the reconstructed gearwork is compelling evidence for this interpretation. That Part I relates in a similar manner to the front face can be inferred from lines I.21-22, which obviously refer to a pointer display of the Sun's motion, since the existence of such a pointer on the front dial is implied by index letters on the zodiac dial, which correlate solar longitudes to stellar visibility phenomena in the Parapegma Inscription.

The sequence of lines I.19-25 within which the passage on the solar pointer occurs name, in order, the planet Venus, the Sun, and the planets Mars, Jupiter, and Saturn. One naturally expects mention of the remaining planet known in antiquity, Mercury. The planets are obviously listed in order of increasing presumed distance from the Earth in a geocentric cosmology. Several variant orders are known from Greco-Roman sources; they invariably place the Moon nearest to the Earth, and Mars, Jupiter, and Saturn in that order outward from the Sun, with the fixed stars furthest of all; where there was room for variation was in the relative order of Venus and Mercury and whether they were both nearer or further than the Sun.[21] The sequence of the inscription would have to be either Moon-Mercury-Venus-Sun or Moon-Venus-Mercury-Sun. Since each planet evidently took up a full line or more of the inscription, there appears to be insufficient space for Mercury between the passages referring to Venus and the Sun (or following the passage concerning the Sun, for that matter). Hence we believe the order was the same as Ptolemy preferred, Moon-Mercury-Venus-Sun, and in fact the termination of the name for Mercury may be preserved at the beginning of I.18. (The planets appear in the same order —omitting the Sun— in the Front Cover Inscription.) The description of the display for the Moon, which fortunately we know a fair bit about from the physical remains, would have occupied the poorly preserved upper lines of part I.

It is a reasonable hypothesis that the inscription made the same kind of statement about each of the planets, though the verbal parallelism was not absolute. Taking into account the surviving stretches of text together with the known constraint that a line of text would have contained something in the neighborhood of 75 letters, we can reconstruct the form of statement as a version of the following:

21 The evidence for the various orderings is collected by Neugebauer 1975, 2.690-693; Ptolemy discusses some of the issues in *Almagest* 9.1 and in the part of *Planetary Hypotheses* Book 1 surviving only in Arabic (Goldstein 1967, 6-7). The astronomical Keskintos inscription from Rhodes, IG XII,1 913 (Jones 2006a and 2006b), which has sometimes been cited in connection with the Mechanism, had the order Venus-Mercury-Mars-Jupiter-Saturn.

Above the circle of *planet X* is the circle of *planet Y*, and the little sphere that travels through it is *Z* [probably a color].

A series of such statements amounts to a description of a diagram of the geocentric system as a set of concentric circles or circular rings representing an onion-like cosmology of nested planetary spheres—actually spherical shells—within which the actual planets may be portrayed as small circles or spots. Such cosmological images are well known from Renaissance art, [22] but they have an ancient pedigree that can be traced through numerous medieval manuscript illustrations even if no original example is known to have survived from antiquity. Fig. 5.7 is a translated redrawing of a simple diagram from a collection of scholia on Ptolemy's *Handy Tables* in the ninth century manuscript Florence *Laur. plut*. 28.01, f. 176v.[23] Fig. 5.8, redrawn and translated from the c. AD 1100 manuscript Florence *Laur. plut*. 9.28 f. 96r, is a similar diagram from the sixth century traveller Kosmas Indikopleustes's *Christian Topography* representing the "pagan cosmology" (as distinct from Kosmas's flat-Earth cosmology).[24] As these examples show, representations of the geocentric cosmology typically did not attempt to represent the distances of the heavenly bodies to scale, but just the relative order of distances of their "spheres" as a succession of bands of more or less equal breadth. The zodiac usually encloses the system, both as a synecdoche for the sphere of the fixed stars and as the apparent path travelled by the heavenly bodies. Kosmas' diagram also gives a concordance of the zodiacal signs with the Egyptian and Roman calendar months approximately coinciding with the Sun's traversal of each sign.[25]

22 See Giusto de' Menabuoi's fresco "The Creation of the World" (c. 1376) in the Baptistery of the Cathedral of Padua, and Giovanni di Paolo's "The Creation of the World and the Expulsion from Paradise" (1445), Lehman Collection, Metropolitan Museum of Art, accession number 1975.1.31 (reproduced in Freeth & Jones 2012, Fig. 2).

23 We have omitted labels referring to the solstices and the autumnal equinox and identifying the horizontal and vertical lines as colures.

24 Images of the original manuscripts may be viewed at the Biblioteca Medicea Laurenziana's website, http://teca.bmlonline.it (by search for "plut.28.01" and "plut.09.28").

25 The numerals following the names of the Egyptian months are just the ordinal numbers of the months counting from the vernal equinox.

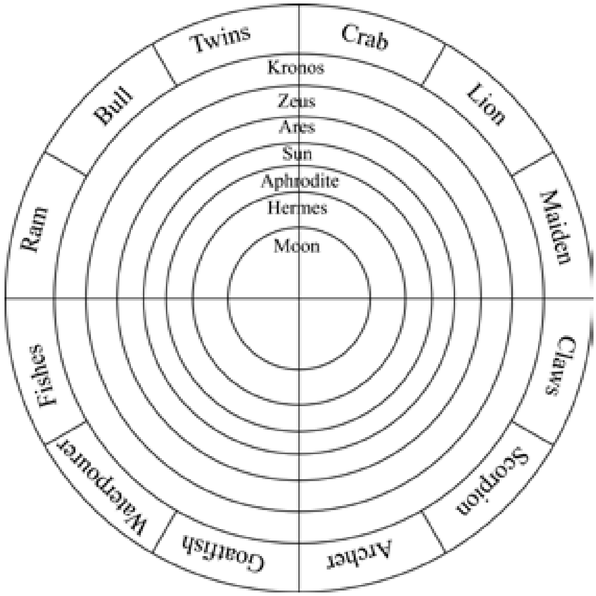

Figure 5.7: *Redrawing of cosmological diagram from* Laur. plut. *28.01, f. 176v*.

Figure 5.8: *Redrawing of cosmological diagram from* Laur. plut. *9.28, f. 96r*

Our contention is that the front dial of the Mechanism, as delineated in the Back Cover Inscription, was a mobile version of a geocentric cosmological diagram, in which the Sun and planets were represented by small spherical symbols mounted on revolving pointers radiating from the dial's center (Fig. 3.1).[26] These spheres would have been set at successively increasing distances from the center, with the one for Mercury innermost and that for Saturn outermost. Right at the center, of course, was the revolving casing for the Moon, which displayed the Moon's phases through its own little sphere, in this instance not mounted on a pointer but seen through an orifice in the casing. The Earth might have been represented as a circular feature on the casing; the zodiac scale, engraved with the names of the zodiacal signs and the index letters linking to constellations, stood for the fixed stars, and the calendar scale provided the concordance with the Egyptian months.

Part I: description of the Mechanism's front face

3. The phrase δεῖ δ᾽ὑπολαβεῖν ("one should understand") recurs (probably) at I.14. It probably introduced an injunction to the reader to interpret a particular feature of the front face in a certain astronomical way.

9. Possible completions are ἡρμόσθαι, "to have been fitted", or a form of the corresponding participle. We suppose this is likely to refer to a component fitted in a mechanical sense to some other component.

10. There is too little context to allow one to guess what component's extremity is referred to.

12. The mention of the color black probably was part of a description of the revolving Moon phase ball, which is presumed to have been half black, half white.[27] We conjecture therefore that a section of the text beginning somewhere before I.12 and ending at about I.16 was devoted to the apparatus in the center of the front dial that displayed the Moon's longitudinal motion as well as its phases.

14. Cf. I.3.

15. This "little sphere" is likely again the Moon phase ball.

16. αὐτοῦ ("it") probably refers to the cylindrical casing of the Moon phase display, and the pointer would be that for the lunar longitude, projecting from the rim of the casing close to the phase ball.[28]

17. As already conjectured by Svoronos (1903a, 46 = 1903b, 46), the completion of the first word is obviously περιφερειῶν, "circular arcs" or "circumferences", meaning a partial or complete circular line. We suggest restoring the contination as ἡ μὲν ἐχομένη τῷ τῆς Σελήνης κύκλῳ, "the (arc) next to the Moon's circle" (or some equivalent noun). We interpret the putative "Moon's circle" as the outline of the phase display casing, serving as an image representing the sphere of the Moon in a geocentric cosmology, and the "next" arc would therefore be a circular outline representing the sphere of the planet closest to the Earth after the Moon. It is not clear whether there was actually a plate behind the planetary pointers engraved

26 For a previous argument to this effect see Freeth & Jones 2012, 2.3.2. Wright 2012, 287 has also suggested that there were planetary pointers bearing small spheres ("globules").

27 Wright 2006, 319 and 327.

28 Wright 2006, 328.

with concentric circles for the planets' cosmological spheres, or their visualization was left to the viewer's imagination.

18. We conjecture that the first letters are the final syllable of Στίλβοντος, Stilbon or "Gleamer", the Hellenistic descriptive name of the planet Mercury (otherwise known by the theophoric name ὁ τοῦ Ἑρμοῦ ἀστήρ, "the star of Hermes"). The descriptive names of the remaining four planets (Phosphoros/Lightbearer = Venus, Pyroeis/Fiery = Mars, Phaethon/Radiant = Jupiter, Phainon/Shiner = Saturn) appear in I.19-20 and 23-25, in combination with the theophoric names, as frequently occurs in late Hellenistic and Roman period astronomical and astrological texts.[29] A reconstruction bridging the gap between I.17 and I.18 could be on the following lines: ἡ μὲν ἐχομένη τῷ τῆς Σελήνης κύκλῳ περιφέρεια κύκλος ἐστὶν τοῦ Ἑρμοῦ Στίλβοντος, "the arc next to the Moon's circle is the circle of Hermes Stilbon".

We conjecture that the noun following φερόμενον was σφαιρίον, "little sphere," as in I.21 and 25, and that this was a small spherical attachment on the planet's longitudinal pointer. On analogy with I.22, the statements about these spheres may have specified their colors, so that the viewer would easily be able to distinguish the pointers belonging to the heavenly bodies.

The rest of this line probably was something like ὑπὲρ δὲ τὴν τοῦ Στίλβοντος περιφέρειάν ἐστιν κύκλος, "Above the arc of Stilbon is the circle" (cf. I.22).

19. The engraver definitely omitted the last letter of Ἀφροδίτη by mistake; there is no space for an effaced letter, and also no visible evidence of a correction of the error. For other errors see II.3, 5 (apparatus), and 21.

On analogy with I.18 and 23-25, the illegible letters following Φωσφόρου were probably τοδ, introducing the specification of the little sphere for Venus.

20. We conjecture that the words preceding this line were ὑπὲρ δὲ τήν, "above the," and that the line continued by introducing the Sun's circle.

21. Unless there was an orthographical mistake such as γνώμωνι for γνώμονι, one has to restore the nominative γνώμων, but then the syntax of this line is hard to reconstruct. The phrasing does not seem to parallel that for the planets very closely, perhaps because the way that the Sun was portrayed on the dial was in some way distinctive.

22. Mention of an ἀκτίς ("ray" or "brightness") of the Sun is enigmatic. Did this allude to a decorative feature? Or perhaps in some way an attachment to the pointer represented the zone of proximity to the Sun within which a planet would not be visible.

ὑπέρ ("above"), we suggest, was to be understood in the figurative cosmological sense,

29 On the two systems of names see Cumont 1935. Whether or not Cumont was right in arguing that the descriptive names were invented in the Hellenistic period as a "scientific" replacement for the theophoric expressions, both were in use side by side as early as the 1st century BC (cf. Geminos, *Introduction to the Phenomena* 1).

that is, further from the center of the dial, to be interpreted as further from the Earth in the geocentric system.

The last preserved letters suggest κύκλος, "circle," used as an alternative to περιφέρεια, "arc". Judging by the space available on this line, more was said about this before its associated planet, Mars, was named in the next line.

23. Following a previously published conjecture,[30] we tentatively restore the remainder of the line as follows: τὸ δὲ διαπορευόμενον αὐτοῦ σφαιρίον πυρρόν (?). ὑπὲρ δὲ Πυρόεντά ἐστιν κύκλος τοῦ, "and the little sphere making its way through it is fire-red (?). Above Pyroeis is the circle of...".

24. We tentatively restore: τὸ δὲ διαπορευόμενον αὐτοῦ σφαιρίον... ὑπὲρ δὲ Φαέθοντός ἐστιν ὁ τοῦ Κρο-, "and the little sphere making its way through it is.... Above Phaethon is the circle of Kronos....".

26. We suppose that the "cosmos" refers to the region of the front dial occupied by the little spheres and pointers for the heavenly bodies.

27. The "letters" are surely the alphabetic index letters on the zodiac scale that key solar longitudes to predicted visibility phenomena of constellations in the Parapegma Inscription.

28. It is not clear what is meant by ἀσπιδίσκαι, "disks" or "bosses." In Heron, *Dioptra* 5-6 the word applies to disk-shaped visual targets used in land surveying. One possibility here is that they are the circular buttons in the four corners of the front dial plate, by which the sliding catches holding the plate in place were engaged or disengaged.

Part II: description of the Mechanism's back face

2. Lines II.2-16 apparently concern the upper spiral ("Metonic") dial of the back face.[31] This is an exceptionally prolix treatment of a single dial, apparently motivated by the unusual format and the complexity of the pointer-follower. The inscriptions are described first (II.2-4), then the pointer and its operation.

The διαιρέσεις ("divisions") mentioned in this line were probably the radial division strokes dividing the scale of the spiral into cells for the calendar months.

3. The number 235 is determined by the Metonic relation 235 lunar months = 19 solar years, and the remains of the dial on Fragment B suffice to confirm that there were indeed 235 cells.[32] Note the omitted iota adscript (cf. II.21) and the short horizontal stroke over the numeral, the only definite instance in the Mechanism's inscriptions of this generally common way of indicating a cardinal numeral.

4. The "omitted" days were the day numbers in specified calendar months of the Metonic cycle that were to be skipped over so that an appropriate number of months would have

30 Freeth & Jones 2012, 2.3.2.

31 Wright 2005.

32 Wright 2005, 10.

twenty-nine days instead of thirty. These numbers were inscribed inside the innermost turn of the spiral slot.[33] ἐξαιρέσιμος was a technical term for such skipped days, found elsewhere only in Geminus, *Introduction to the Phenomena* 8 (where a scheme for their distribution in a Metonic cycle similar but not identical to that of the Mechanism is prescribed) and in pseudo-Aristotle, *Oeconomica* 1351b15, an anecdote about the fourth century BC mercenary leader Memnon of Rhodes. Memnon is said to have deducted the equivalent of six days' pay *per annum* from his soldiers' wages on the pretext that they did not have to do any work on these "omitted" days.

5. Lines II.5-7 describe the apparatus by which the pointer-follower was mounted at the axial center of the spiral dial. Attached to the axle was a circular disk (τυμπάνιον — in mechanical texts the same word, when qualified with ὀδοντωτόν, "toothed," means "gear") riding just over the surface of the Back Plate. Two upright bearings (στημάτια) were attached in diametrically opposite positions near the perimeter of the disk, and the shaft of the pointer-follower passed freely through rectangular perforations (τρήματα) in the bearings. Remains of this mounting surviving in Fragment B were identified by Magdalini Anastasiou.[34]

The engraver initially inscribed the singular στημάτιον, "bearing", and then, before going further, corrected by engraving alpha superimposed on the omicron and the delta of δύο on the nu. This *currente calamo* error and correction is interesting as showing that the text was not first written on the plate in paint or scratched wax but engraved immediately from a separate exemplar.

9. συμφυές, "fused" or "attached," is the conventional vocabulary for mechanical components attached to other components so that they have no freedom of independent movement. It is not clear what is spoken of in this way in this and the following line.

14. Despite the miserable condition of the preceding lines, it appears that this passage describes how the pointer-follower traces the spiral groove from its innermost extremity to its outermost (perhaps this is what is "opposite" here).

15. The pointer-follower as currently understood had three elements that could have been described as a "pin" (περόνη): the projection that rode in the spiral slot; a horizontal, sharp-ended pin that sticks out from the pointer's end; and a larger rod that held together the components of the bearing.[35] It is not clear which one is meant here; the text seems to be describing an operation connected with the resetting of the pointer-follower to the beginning of its spiral, in which the pin in question was temporarily removed from its setting and then replaced, seemingly a linch-pin whose removal would facilitate the lifting of the pointer out of the slot.

16. Possibly the first cell of the Metonic spiral scale.

17. This passage (II.17-19) proves that there were in fact two subsidiary dials within the

33 Freeth, Jones, Steele, & Bitsakis 2008, 614-615.

34 Anastasiou 2014, 42-46; Anastasiou, Seiradakis, Carman, & Efstathiou. 2014, 3-5.

35 Anastasiou, Seiradakis, Carman, & Efstathiou 2014, 3-5.

Metonic spiral, one of which is the extant "games" dial whose pointer revolves once in four years' motion, while the other, now entirely lost, had a pointer revolving once in 76 years' motion.[36] Both were divided into four equal sectors (II.18), respectively counting years in the four-year cycle and Metonic 19-year periods in the 76-year Callippic cycle.

18. The subject of δηλοῖ is probably κύκλος, "circle," i.e. "dial." The text can be tentatively restored as follows: δηλοῖ δ 'ὁ μὲν τὴν τῆς (τετραετηρίδος) (ἔτος), "one of (the dials) shows the year of the four-year cycle". On analogy with the next line, τετραετηρίδοs and ἔτος would probably have been abbreviated as δL and L.

19. One has to presume ὁ δὲ ("while the other") towards the end of the preceding line. The abbreviations οςL and ιθL must be interpreted respectively as ἑκκαιεβδομηκονταετηρίδος and ἐννεακαιδεκαετηρίδα, a flexible reading of the L symbol for ἔτος, "year", not attested elsewhere.

20. The text has now turned to the lower spiral dial, with its 223 divisions for the lunar months in a Saros cycle.

21. It is not clear what division is referred to here, since the division of the spiral scale into 223 cells has apparently been dealt with in the preceding line.

22. This line, unfortunately not well preserved, must be describing the "glyphs" or abbreviated predictions of solar and lunar eclipse possibilities in cells of the Saros scale. The restoration χρόνοι, "times", is tempting.

23. Likely to be restored ὁμοίως τοῖς ἐπὶ τῆς ἑτέρας ἕλικος, "similarly to the… on the other spiral", a phrase that may indicate that the same apparatus for the pointer-follower was here too.

24. Paralleling II.17, the text was probably γνωμόνιον οὗ τὸ ἄκρον φέρεται, "a little pointer whose tip travels". This must refer to the lower subsidiary dial tracking the *exeligmos* (triple Saros) cycle, and the singular noun shows that there was in fact only one subsidiary dial here.

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36 Wright 2005, 10-11 proposed that the extant subsidiary dial on Fragment B was a Callippic cycle dial. Freeth, Jones, Steele, & Bitsakis 2008, supplementary notes 19-23 identified the extant dial as displaying a four-year cycle, but conjectured that there was also a Callippic cycle dial on the lost left side of the Metonic dial's center.

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4

The Back Dial and Back Plate Inscriptions

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Abstract
The rear face of the Mechanism consisted of a rectangular "Back Plate" dominated by two large spiral dials. The upper five-turn Metonic Dial represented a 235-lunar-month calendrical cycle while the lower four-turn Saros Dial represented a 223-lunar-month eclipse prediction cycle. A subsidiary quadrant "Games" dial was situated inside the Metonic Dial, and a subsidiary three-sector Exeligmos Dial inside the Saros Dial. Preserved text inscribed around the dials (from the lower right quarter of the plate), probably representing about a quarter of the original inscription, provided further information associated with the predictions of eclipses. This paper describes the reconstruction from the Mechanism's fragments of the surviving parts of the text on the plate and its dials, giving transcriptions and translations. The Metonic Dial inscriptions imply a calendrical scheme similar to that described by Geminos. It was intended to be a version of the calendar of Corinth as it was practiced either at Corinth itself or in some locality of Epirus. The Games dial shows six competitions, four Panhellenic (Olympics, Pythian, Isthmian, and Nemean) plus Naa (Dodona) and very probably Halieia (Rhodes). On the Saros dial there were probably originally about 50 or 51 month cells with a lunar and/or solar eclipse prediction, each carrying a "glyph" and an index letter. Predicted

eclipse times (in equinoctial hours) on the glyphs were calculated as times of true syzygy according to solar and lunar models that both involved anomaly, with the simple Exeligmos dial extending the predictions over three or more Saros cycles. We are reluctant to base a firm construction date on interpretation of the eclipse cycles. The additional information referred to by index letters from the Saros dial was grouped into paragraphs; that for lunar eclipse prediction probably ran down one side of the plate, and that for solar eclipse prediction down the other. Statements about direction may imply a meteorological aspect by referring to predictions of winds attending the eclipses. Five references to colour and size at eclipse are the only Greco-Roman source known to us that suggests prediction of eclipse colors, and might conceivably be linked with astrology.

4.1 Introduction

The rear face of the Mechanism consisted of the so-called Back Plate, a rectangular plate, approximately 316 mm tall by 171 mm wide, dominated by two large spiral dials (Fig. 4.1).[1] The upper Metonic Dial represented a 235-lunar-month calendrical cycle while the lower Saros Dial represented a 223-lunar-month eclipse cycle.[2] Each spiral was defined by a slot cut through the back plate, approximating an Archimedean spiral by means of alternating semicircular arcs, and winding clockwise from the inner to the outer end of the slot, making five complete turns for the Metonic Dial and four complete turns for the Saros Dial. Although there is some uncertainty, it appears that the two outer ends either coincided —so that there was a single continuous slot for both spirals— or came close to doing so.[3] The inner end of each spiral was about halfway between the spiral's geometrical center and the center point of the Back Plate. The scales of the dials ran continuously along the outside of the slot, taking up the entire winding strip of metal between the successive turns and finally running once around the outermost turn. Where the scales came closest to the edges of the Back Plate, they left only small margins. There would have been some overlap of the scale areas of the two spirals near the centre.

Two series of inscriptions belong to the Metonic Dial. (i) The scale of the dial was divided by radial lines into 235 cells subtending approximately equal arcs, representing single synodic months. Every cell contained an inscription, consisting of either just a month name or an ordinal year number followed by a month name. (ii) Immediately inside the innermost turn of the slot, numerals were inscribed at intervals of two or occasionally three cells. When the Mechanism was set to display the chronological and astronomical situation for

1 Freeth, Jones, Steele, and Bitsakis 2008, building on earlier contributions, in particular Price 1959 and 1974, Wright 2004 and 2005, and Freeth et al. 2006. For the estimated dimensions see IAM 1.5.

2 The names used here for the parts of the Mechanism are modern, and reflect modern nomenclature for elements of ancient astronomy. "Metonic" is the modern designation of a period comprising 235 synodic months and (approximately) 19 solar years, as well as of calendrical cycles based on this period. Greek writers attributed it to Meton of Athens (fl. 432 B.C.) though it was known earlier in Mesopotamia and served as the basis of regulation of the Babylonian calendar from about 500 B.C. on (Britton 2007). In Greek texts it is called ἐννεακαιδεκαετηρίς ("19-year period") or ἐνιαυτὸς Μέτωνος ("year of Meton"). "Saros" is the modern name for a 223 synodic month eclipse period also known to the Babylonians (who called it, with convenient inexactitude, "18 years") and the Greeks (who called it περιοδικός, "periodic," according to Ptolemy, *Almagest* 4.2). Greek sources use the name Σάρος for different chronological intervals of allegedly Babylonian origin, and it was Halley who mistakenly associated it with the 223 synodic month period; see Neugebauer 1957, 141-142.

3 IAM 1.5.

a particular date, the cell indicated by the pointer-follower of the Metonic Dial gave the current year and month in the calendar cycle.[4] If this cell lined up radially with a numeral inscribed along the inner rim of the slot, this meant that the month had twenty-nine days instead of the "normal" thirty, with the day number corresponding to the numeral skipped over in the count of days.

The Games Dial was a small subsidiary dial situated in the right half of the space at the center of the Metonic Dial;[5] its circle was divided by two engraved diameters into four approximately equal quadrants. It too has two series of inscriptions (iii): inside each quadrant is an ordinal year number, while outside the perimeter of each quadrant are names of athletic competitions. The pointer of this dial would have shown the position of the current calendar year in a repeating four-year cycle, as well as competitions taking place in that year. (A second subsidiary dial, the Callippic Dial, is conjectured to have occupied the left half of the central space.)[6]

The Saros Dial's scale was divided by radial lines into 223 cells subtending approximately equal arcs, again representing synodic months. Only one series of inscriptions accompanied this dial: (iv) in some of the cells of the scale, highly abbreviated texts (named "glyphs" in recent scholarship)[7] indicated the possibility that a lunar or solar eclipse might occur in the corresponding months, as well as a time of day or night for the eclipse. About one-quarter of the cells had such a glyph, while the remainder were left vacant. The subsidiary Exeligmos Dial, situated in the right half of the space at the center of the Saros Dial, was divided radially into three approximately equal sectors (v): two of the sectors contain numerals, while the third seems to have been left vacant. When this dial's pointer indicated one of the numerals, that number of hours was to be added to the times given in the glyphs.

The space left around the two spirals consisted of four roughly triangular spaces at the corners and two larger, again roughly triangular, spaces halfway down the two sides of the plate. The only remains of the plate outside the dials, preserved in Fragments A, E, and F,

4 For the structure of the pointer-followers of the spiral dials see Anastasiou, Seiradakis, Carman, and Efstathiou 2014, 3-7, and IAM 5.5, commentary to lines II 5-15.

5 It should be noted that Price 1974, 44 conjectured that the main upper dial (which is in fact the Metonic Dial) might be a four-year dial.

6 Wright 2005, 11 conjectured that the extant subsidiary dial (the Games Dial) inside the Metonic Dial was a Callippic Dial. A preserved passage of the Back Cover Inscription (II 17-19) referring to the Metonic and Callippic periods makes the former existence of a Callippic Dial probable, and in Freeth, Jones, Steele, and Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 23 it was hypothesized to have occupied a position to the left of the Metonic Dial's center.

7 The term was introduced in Freeth et al. 2006, 589 and Supplementary Information 5

come from its lower right quarter, wrapping around the right half of the eclipse spiral, and accounting for about half of the larger triangular area in the right center and most of the smaller area in the lower right. In all three fragments, the plate outside the Saros Dial is inscribed with parts of a single text (vi), the "Back Plate Inscription". It seems likely that other parts of this inscription occupied all six triangular spaces outside the dials; if so, we have about a quarter of the original text. This text provided further information in connection with the predictions of eclipses on the Saros Dial.

This paper contains new, critical editions and translations of all the inscriptions on the Mechanism's rear face. For the inscriptions of the upper dials (the Metonic and Games Dials) we have not seen a need to provide extensive commentaries, but we summarize the principal findings of the 2008 paper and draw attention to a few developments in our understanding of these inscriptions since 2008.[8] We offer a more extensive treatment of the Saros Dial and Back Plate Inscriptions, based on findings that we obtained between 2007 and 2012 in the process of preparing our editions. Two recently published papers report and develop some of these findings (which were communicated to their authors);[9] however, we believe it will be useful to present our analyses and arguments more or less as they stood in 2012, making the necessary adjustments to take into account more recent revisions in the texts of the inscriptions, and referring to the more recent publications for a few salient additions or corrections.

8 Anastasiou, Seiradakis, Carman, and Efstathiou 2014; Iversen 2011, 2013a, 2013b, and 2015. Paul Iversen's work on the Metonic and Games Dials (in part in collaboration with John D. Morgan) will be reported in greater depth in Iversen (forthcoming, a) and Iversen (forthcoming, b).

9 Carman & Evans 2014 (see in particular pp. 697 note 2 and 765); Freeth 2014 (see below, note 34).

4.2 Location and layout of the Back Dial and Back Plate Inscriptions

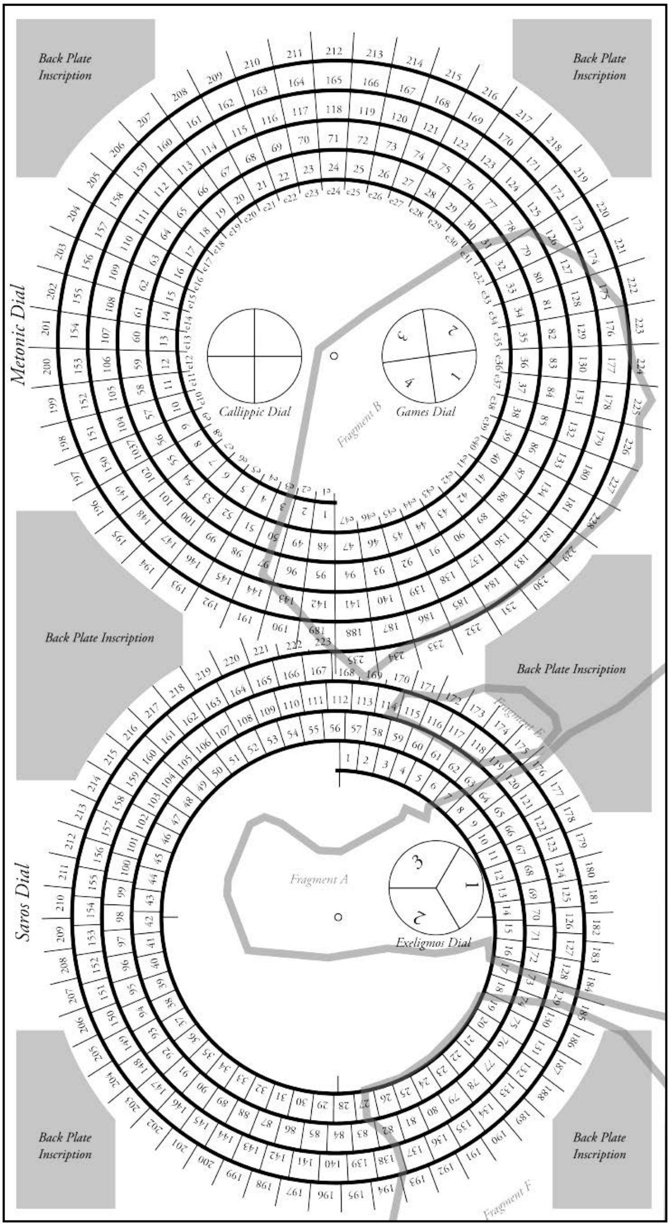

Figure 4.1: *Reconstruction of the back face of the Mechanism, with scale cells and sectors numbered for reference. Regions of the plate surviving in the major fragments are approximately indicated by dark gray outlines*

The surviving parts of the Mechanism's back face are divided among four of the major fragments, which were originally contiguous but had broken apart by 1902 when Fragments A and B were discovered in the Museum.[10] Fragment B preserves part of the upper half of the back face, while parts of the lower half are present in Fragments A, E, and F. In addition, we have two small fragments (24 and 25) of accretion material that formerly adhered to the lower back face, preserving mirror-reversed imprints.

Fragment B (see supplementary Fig. S2), the second largest fragment of the Mechanism, has dimensions 111 mm (height), 98 mm (width), 20 mm (thickness). B-1 preserves about a third of the spiral scales of the Metonic Dial and about a third of the space inside the spiral, including the entire Games Dial. On B-2 are the remains of a bridge radially crossing the turns of the spiral, which was there to provide them with support and stability, and a single gear that directly drove the pointer of the Games Dial. A layer of accretion material bearing the mirror-reversed impressions of the Back Cover Inscription overlays about three-quarters of B-1; a small bit of the Back Cover plate itself is also present. A substantial portion of the pointer of the spiral is lodged in the space between the accretion layer and the Back Plate.

Part of the Metonic Dial scales that is not behind the accretion layer is now exposed but has undergone much surface damage. In photographs from 1902-1918, this region was wholly concealed behind a layer of patina. This material was probably removed during the conservation work of 1953. In addition to providing the only means of reading the dial inscriptions in Fragment B that are not now exposed, CT has also proved more effective than PTMs for the exposed area (Fig. 4.2).

10 The original configuration of Fragments A and B was deduced by Price in 1958 (Price 1959, 62-64) and, as he later reports, confirmed in 1961, apparently by fitting the fragments together physically (Price 1974, 47). Bromley and Wright established the correct placement of Fragment E around 1990, and Wright has published a photograph taken at that time showing A, B, and E fitted together in their approximate relative positions (Wright 2004, 9, Fig. 10, and Wright 2005, 10, Fig. 5). Fragment F's location immediately below Fragment A was established by Freeth et al. 2006, 589, Fig. 4. Conservation carried out around 1905 and 1953 removed material from the surfaces of fragments A and B, so that little if any of the original contact surfaces survive.

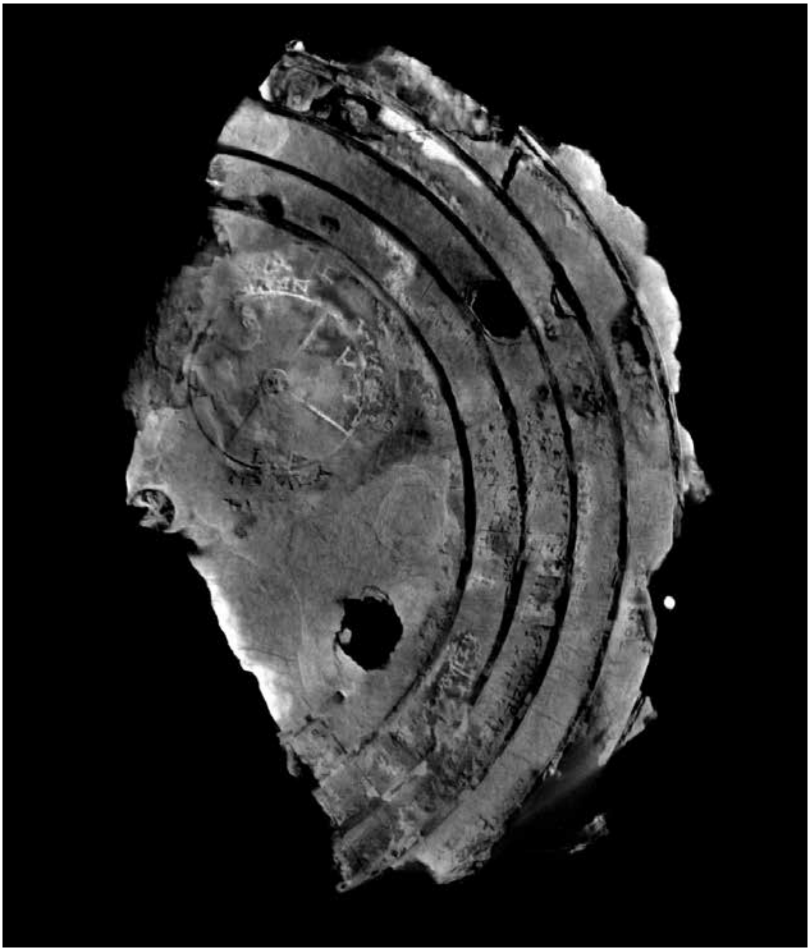

Figure 4.2 : *Fragment B, CT composite image*
(Image: Antikythera Mechanism Research Project)

Fragment A (supplementary Fig. S1), the largest surviving piece of the Mechanism, has dimensions 174 mm (height), 164 mm (width), 55 mm (thickness). It preserves a major portion of the gearwork that led by various complex trains from the rotary input on one of the Mechanism's sides to those outputs on the front and back faces relating to solar and lunar motion, chronological systems, and eclipse prediction. A-2 also retains part of the lower half of the Back Plate itself, including parts of the Saros Dial and the entire Exeligmos Dial. Overlaying part of the Back Plate is an accretion layer of corrosion products bearing mirror-reflected offsets of the Back Cover Inscription. This layer conceals parts of the dials. The entire inscribed area of the Back Plate outside the Saros Dial is exposed, though parts are obscured or obliterated by surface damage. We have depended primarily on PTMs and photographs for the exposed inscriptions on Fragment A, and on CT for the inscriptions concealed behind the accretion layer.

Fragment E (Fig. 4.3), 37 mm height, 61 mm width, 14 mm thickness) consists of three layers of material. The lowest layer comprises part of the Saros Dial and the surrounding area of the Back Plate. Next, and entirely covering this, is part of the layer of accreted material bearing the offsets of the Back Cover Inscription. Topmost, though partly broken away so as to expose the offsets on the accretion layer, is part of the Back Cover itself. Fragment E was originally attached to the rear face of Fragment A, but had already become separated when the Mechanism was discovered in 1902. It lay unrecognized in the Museum's store until 1976, when it was found by the museum's curator of bronzes, Petros Kalligas, who sent photographs of it to Price on April 4.[11] The inscriptions on the Back Plate in E can only be seen in CT.

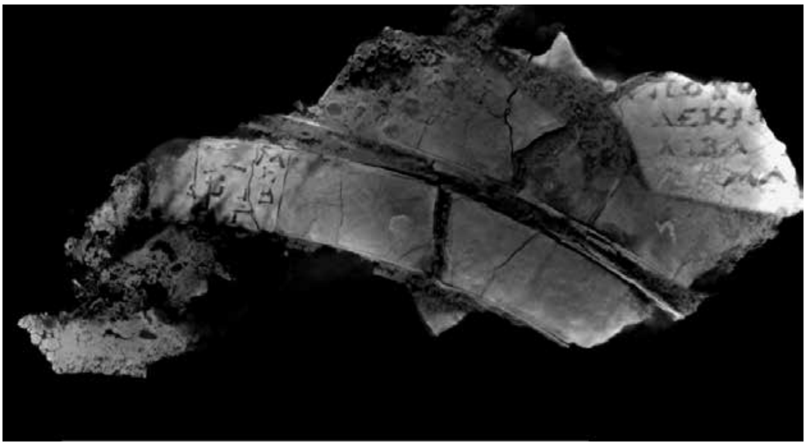

Figure 4.3 : *Fragment E, CT composite image*
(Image: Antikythera Mechanism Research Project)

Fragment F (Fig. 4.4), 80 mm height, 94 mm width, 35 mm thickness) preserves another part of the Saros Dial and the surrounding Back Plate, both of which are entirely concealed by a layer of patina. Adhering to part of the inscribed face is a small piece from the corner of a metal plate with a sliding catch similar to the one preserved in Fragment C.[12] Part of the Mechanism's containing frame is also present. Fragment F was originally situated immediately below Fragment A, to which it would have been rather precariously attached, but it had broken off before the 1902 discovery and was not identified in the Museum's

11 The Price-Kalligas correspondence (comprising three letters from Kalligas and two from Price, 1976-1978) is preserved at the Adler Planetarium, Chicago. Price mistakenly thought that Fragment E adjoined the top of Fragment B, at the top of the original Mechanism. The first published description of Fragment E is in Wright 2005, 9; Wright determined its correct original location.

12 See IAM 3.2.

store until it was discovered by M. Zafeiropoulou in April, 2005.[13] The inscriptions are only visible by way of CT.

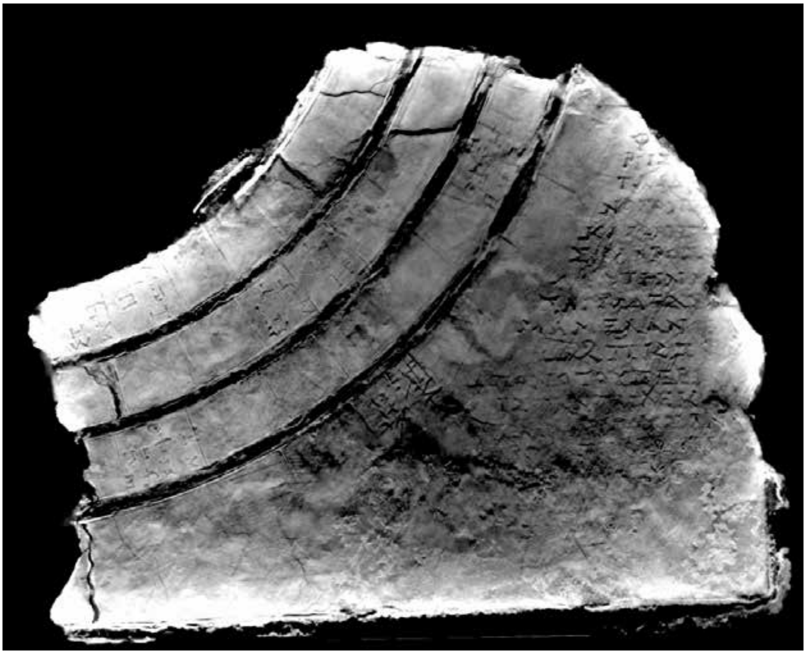

Figure 4.4 : *Fragment F, CT composite image*
(Image: Antikythera Mechanism Research Project)

13 Zafeiropoulou 2006, 830-831.

Two small platelike fragments, numbered 24 (29 mm height, 13 mm width) and 25 (21 mm height, 19 mm width), are part of a layer of accreted matter that originally lay against the Back Plate on A (Fig. 4.5). They preserve mirror-reversed "offset" impressions of parts of the Back Plate Inscription and the scale inscriptions of the Saros Dial, and in addition a bit of the surface of the Back Plate itself adheres to Fragment 25.

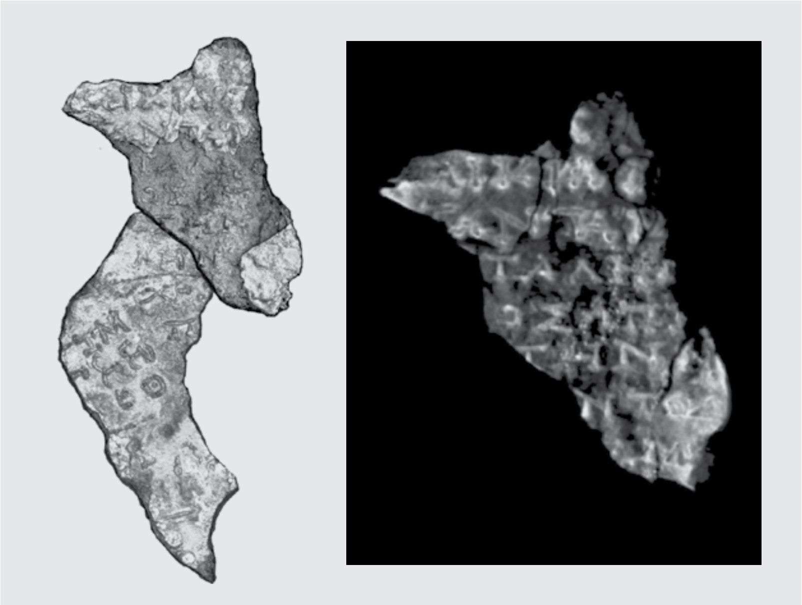

Figure 4.5: *(Left) Fragments 24 and 25, image from PTM ak2a and ak2b with diffuse gain; (right) Fragment 25, CT composite image*
(Images: Antikythera Mechanism Research Project)

4.3 Previous transcriptions and study of the Back Plate Inscription

Fragment A was one of the original two or three fragments to be accidentally discovered at the National Archeological Museum on May 18 or 20 (Julian), 1902.[14] In the condition in which it was found, only the top six or so lines of the Back Plate Inscription were exposed, while the remainder (as well as the Saros Dial scales) were hidden behind a layer of accreted matter, as can be seen in the photograph of A-2 in Svoronos's 1903 publication of the wreck.[15] When a group of archeologists including Gavriel Vyzantinos examined Fragment A on May 21 with the aid of a lens, only a few letters, including the unrecognizable word fragments INON (in the present line 3) and ΤΩΝ (likely a misreading of TAN in the present line 5) could be read, as reported in two Athens newspapers, *Σκρίπ* and *Νέον Ἄστυ* on May 22.[16] Attention soon shifted decisively to the mirror-writing inscription on B-1, which was seen to contain identifiable vocabulary relating to astronomy, and no further readings from A-2 were reported until Periklis Rediadis's report on the Mechanism incorporated in Svoronos's book. In its Greek edition, a few letters on five lines, credited to Svoronos and corresponding to lines 1-3 and 5-6 of the present lineation, are erroneously said to be inscribed on C-1.[17] The German edition has the identical transcription, but assigns it to its correct place on A-2.[18] The longest stretch of letters that Svoronos thought he was able to read was the sequence IKOMA in line 2, of which only the first two letters are correct, and not one complete word could be guessed at.

The layer covering the rest of the inscription was separated from A-2 during the conservation work of around 1905; two pieces of this layer survive, the present Fragments 24 and 25, which bear mirror-writing impressions of parts of the Back Plate Inscription and the Saros Dial scale inscriptions that exactly match the engraved text on A. A photograph of A-2 taken by Georg Karo for Albert Rehm in October, 1905, though none too clear, shows the entire inscribed area as it is now preserved.[19] A later photograph in Rehm's collection, believed to date from 1918, catches more detail, and hints that parts of the inscription were slightly more legible then than they are now. During his visits to Athens in 1905 and 1906 Rehm must have seen more of the inscription than Svoronos had, but if he made a fuller transcription if it, it has not come to light.

14 See IAM 2.1 for the history of discovery and conservation of the fragments.

15 Svoronos 1903a and 1903b, plate 10.

16 "Αἱ ἀρχαιότητες τῶν Ἀντικυθήρων," *Σκρίπ* no. 2429, May 22, 1902: 3; "Δύο ἐνεπίγραφα τεμάχια ἀπὸ τὰ Ἀντικύθηρα", *Νέον Ἄστυ* no. 162, May 22, 1902: 2.

17 Svoronos 1903a, 46.

18 Svoronos 1903b, 45.

19 Bayerische Staatsbibliothek, Rehmiana III/9.

Ioannis Theofanidis published transcriptions of parts of lines 12-18 in his encyclopedia article on the voyages of St. Paul and in his 1934 paper on the Mechanism, and he made the happy guess that ΩTHN in line 14 was the end of the wind name Ἀπηλιώτην, signifying either the East Wind or the direction due east.[20] Although his restorations of other bits of words in these lines as wind names have turned out to be false, such names do occur intermittently in the rest of the inscription. Theofanidis believed that the plate bearing the inscription was extraneous to the Mechanism and merely stuck on it, and that it was a remnant of a circular diagram showing the directions of the rising and setting points of stars on the horizon as an aid to navigation; under the influence of this hypothesis, his drawings misrepresent the lines of text as fanning out from a center point rather than running along parallel lines.

Fragment 24 was known to Theofanidis, who gave a transcription of it in his encyclopedia article.[21] Surprisingly, he did not recognize that it matched part of the inscription on A-2, the transcription of which was given immediately above.

In 1958 Derek de Solla Price and George Stamires studied the Mechanism's fragments (which had undergone another round of conservation in 1953); the transcription of the Back Plate Inscription that Price published in 1974 was presumably based on Stamires's work, since Price did not have sufficient knowledge of Greek to read or interpret the more extended inscriptions.[22] This was a more comprehensive transcription than any that had preceded it, with parts of lines 1-6 and 10-18 represented; roughly three quarters of the letters agree with the readings offered in the present paper. Stamires and Price were able to verify Theofanidis's Ἀπηλιώτην by reading several letters of the beginning of the word on line 13; but this was the only complete word that they correctly read or restored. While dismissing Theofanidis's other restorations of wind names, Price introduced a new false restoration, Ἰάπυγος, "West-northwest Wind," in lines 16-17.[23] He confessed his inability to explain the purpose of the direction references.

20 Theofanidis [1927-1930], "98" [correct pagination: 90] and 1934, 145. In the former article, "99" [correct pagination: 91] he repeats Svoronos's transcription of lines 1-3 and 5-6, saying these lines were formerly on a layer of material on Fragment C that had been removed to expose the parapegma inscription. Thus he was relying on Svoronos 1903a and unaware of the correction in Svoronos 1903b; but it is strange that he did not notice that these lines are actually on Fragment A, right above the ones that he himself transcribed. In the 1934 paper he makes no mention of the upper lines.

21 Theofanidis [1927-1930], "98" [correct pagination: 90]. It does not appear to be mentioned in Theofanidis 1934.

22 Price 1974, 48 and 50-51.

23 The file of Price's notes on the inscriptions kept at the Adler Planetarium, Chicago strongly suggests that Price introduced this restoration at a late stage, probably after his collaboration with Stamires had ceased.

In his 1959 *Scientific American* article, Price provided drawings of the portions of the Back Plate on B-1 and A-2.[24] The drawing of B-1 shows the cells of the Metonic Dial scale, with attempts to transcribe a few letters in eight of the cells. The circular outline of the Games Dial and its quadrant divisions is also shown, though it lies entirely behind the accretion layer with the Back Cover Inscription offsets; Price must have managed to see it by looking obliquely into the narrow gap between the Back Plate and the accretion layer.[25] The only indication he gives of inscribed text on the Games Dial is a sigma near the bottom of its lower left quadrant, which does not seem to correspond to any of the actual inscriptions.[26] On A-2 Price's drawing shows the cells of the Saros Dial, with incomplete but fairly good copies of the glyphs in cells 125, 178, and 184, and in the text of the article he correctly identifies the notations signifying Sun, Moon, and numbered hours.[27] He also shows the subsidiary Exeligmos Dial with the eta inscribed in its lower left sector, though the sector divisions are not drawn. Surprisingly, the corresponding figure in *Gears from the Greeks* shows fewer cell inscriptions on the Metonic dial, while the transcriptions of the three cells of the Saros Dial with glyphs are different from their 1959 versions and on the whole less accurate.[28]

On one page of his manuscript notes on the Mechanism's inscriptions Price drew a copy of Fragment 24 and noted its correspondence to the inscription on A, but in *Gears from the Greeks* he did not mention Fragment 24 at all. Price's 1958 photographs of the Mechanism's fragments show both 24 and 25, but he does not appear to have taken any special notice of 25.[29]

The paper on the Mechanism published in 2006 by the Antikythera Mechanism Research Project (AMRP) includes as part of its supplementary material a new provisional text of the Back Plate Inscription.[30] For the part preserved on A-2, this text follows Stamires-Price fairly closely, though adding a small number of new letters and correctly reverting in line 3 to the 1902-1903 reading INON (Stamires and Price apparently thought they saw HΛION, "Sun," with the lambda and iota fused). Moreover, through study of CT volumes, the AMRP

24 Price 1959, 64.

25 See also Wright 2005, 11, who reports being able to see only the upper left part of the circle with parts of two of the radii, as well as traces of dial inscriptions visible in tomographic images.

26 The sigma also appears in the drawing of B-1 in Price 1974, 17, Fig. 7. In the 1959 drawing the Games Dial is shown as a pair of concentric circles, whereas the 1974 drawing correctly shows only one circle.

27 Price 1959, 64-65.

28 Price 1974, 17, Fig. 7.

29 Price's collection of photographs relating to the Mechanism as well as his file of notes on the inscriptions are at the Adler Planetarium, Chicago.

30 Freeth et al. 2006, Supplementary Information 9-10.

researchers were able to add readings from inside Fragment E, which yielded earlier portions of lines 5-8 (though due to a slight misalignment of the fragments they were erroneously assigned to lines 4-7), and Fragment F, which yielded an entirely new run of thirteen lines of the inscription some distance below the part preserved in A. Over the entire inscription, about five letters out of six read in 2006 agree with our readings.

The AMRP researchers correctly read and recognized two new wind names in addition to retaining Theofanidis's correct Ἀπηλιώτην and Price's incorrect Ἰάπυγος, namely Λίβα, "West Wind," in Fragment E, line 6, and Νότον/Νότου, "South Wind," in Fragment F, lines 5 and 12. Unclear CT images misled them into reading two place names, Φάρος, "Pharos" (Fragment F, line 7) and Ἰσπανίας, "Spain" (Fragment F, line 13). Pointing out that the solar eclipses are highly dependent on geographical location, and that ancient eclipse observations often took note of wind directions during the eclipse —and perhaps also tacitly reasoning from the location of the inscription next to the eclipse spiral — the researchers suggested that the inscription had something to do with eclipses.

The 2006 paper also included provisional transcriptions of sixteen glyphs of the Saros Dial scale, relying on CT for those in Fragments E, F, and the parts of A hidden behind the accretion layer.[31] These were the first published transcriptions to show the index letters, though their function was not yet understood. The AMRP researchers were the first to identify the glyphs as indications that eclipses of the Sun or Moon could occur in the months corresponding to the inscribed cells, and they conjectured (unaware that Price had partially anticipated them) that the glyphs also gave a prediction of the time of eclipse in seasonal hours.

In 2008 a group of researchers associated with the AMRP published a second paper devoted to the Back Dial Inscriptions.[32] The revised transcriptions of the Saros Dial glyphs now extended to eighteen cells, and the numerals of the Exeligmos Dial were described and explained as time corrections for the predicted eclipse times. The index letters were explained for the first time, and on their basis a revised conjectural reconstruction of the distribution of glyphs was presented. This paper also provided the first transcriptions of the Metonic Dial and Games Dial inscriptions (aside from the few letters that Price copied). The calendar of the Metonic Dial scale was identified as that of Corinth, and a conjectural restoration of the entire calendrical scale was offered.

Meanwhile in 2007, Yanis Bitsakis and Emmanouel Georgoudakis (then of the Cultural Foundation of the National Bank of Greece, Center for History and Palaeography), who had undertaken a revision of the reading of the Back Plate Inscription, discovered in the part of

31 Freeth *et al.* 2006, 589, Fig. 4 and Supplementary Information 5. In this paper the Saros Dial's spiral was incorrectly reconstructed with its beginning and end at the bottom.
32 Freeth, Jones, Steele, & Bitsakis 2008.

the inscription in Fragment F terminology relating to colors, and on the basis of this as well as the expressions previously read relating to directions, Bitsakis identified the inscription as an eclipse description text. Comparing their readings with his own (from PTM) of the inscription on Fragment A, Alexander Jones established that the inscription comprised a series of paragraphs with repetitive structure, and conjectured that these paragraphs were linked to groups of the eclipse predictions in the Saros Dial scale by means of sets of index letters. Bitsakis and Jones produced an augmented and substantially improved transcription of the entire Back Plate Inscription in 2009. This transcription and the findings concerning the contents and structure of the inscription provided the foundations for the treatment of the Saros Dial and Back Plate Inscriptions in the present paper, which was drafted in 2012.

An extensive study of the eclipse predictions of the Mechanism was published by Tony Freeth in 2014.[33] This paper included revised copies of the glyphs as well as a transcription of the Back Plate Inscription. The latter was prepared by Charles Crowther (Centre for the Study of Ancient Documents, Oxford) on the basis of images and tracings provided to him by Freeth.[34]

33 Freeth 2014.

34 Freeth 2014, Note S2. Dr. Freeth had been provided by Bitsakis and Jones with their transcriptions and translations of the Back Plate Inscription in 2009 and 2012; the 2012 version differs in only minor details from Dr. Crowther's transcription and translation, made in November 2013 (according to personal communication from Dr. Crowther). In addition to its original contributions to the subject, Freeth 2014 presents several research findings relating to the Mechanism's eclipse inscriptions that had been communicated to Dr. Freeth by Bitsakis and Jones between 2009 and 2012. These include the fundamental identification of the Back Plate Inscription as eclipse descriptions organized in structurally repetitive paragraphs with statements about colors and changing directions, the correct alignment of the partial lines in Fragments E and A, the correlation of the paragraphs with the Saros Dial glyphs through groups of index letters, the reference of all the surviving paragraphs to solar eclipses, the probable division of the complete inscription into two halves pertaining respectively to lunar and solar eclipses, and the fact that all eclipses grouped together in each paragraph had the Moon within fixed zones of elongation from one of the lunar nodes. Further findings relating to the Saros Dial glyphs communicated to Dr. Freeth in 2012 include demonstrations that the eclipse times in the glyphs probably indicate the times of true syzygy, that the intervals between such times can be approximately modelled as the sum of periodic solar and lunar components, and that the Saros Dial was normed so that the Moon was close to apogee at its first Full Moon, aligning the dial with the presumed marks for the Full Moon Cycle inscribed inside the Saros Dial. Freeth 2014 makes no mention of either Bitsakis or Jones except as authors of published works.

4.4 Transcriptions and translations

i. Inscriptions in the cells of the Metonic Dial

All remains of the Metonic Dial are in Fragment B, and have been read from CT. For discussion, see section 5.

Transcription and translation

Cell		
1	(ἔτος) α ´ | Φ̣[οινι-] | κ̣αῖος̣	Year 1 Phoinikaios
2	Κρα- | νε̣ῖ- | ος̣	Kraneios
3	Λ[ανο-] | τ̣[ρόπι-] | [ος]	Lanotropios
31	[Δωδ]ε- | [κα-] | [τεύ]ς	Dodekateus
32	Εὔ- | κλει- | ος	Eukleios
33	Ἀρτε- | μίσι- | ος	Artemisios
34	Ψ̣υ̣- | δ̣ρ̣ε- | [ύ]ς̣	Psydreus
35	*no legible text*	[Gameilios]
36	Ἀγρι- | άνι- | ο̣ς	Agrianios
37	Π̣ά̣- | [να]- | μος	Panamos
38	Ἀπελ- | λαῖος̣	Apellaios
39	(ἔτος) δ ´ | Φ̣[οι]ν[ι-] | [καῖ]ο̣ς	Year 4 Phoinikaios
40	Κ̣ρ̣α- | ν̣ε[ῖ-] | ο̣ς	Kraneios
41	Λ̣ανο- | τρό- | πιος	Lanotropios
42	Μαχα- | νεύς	Machaneus
43	Δωδε- | κα- | τεύς	Dodekateus
44	Εὔ- | κ̣λ̣ει- | ος̣	Eukleios
45	Ἀρτε- | μίσι- | ος	Artemisios
46	Ψυ- | δρεύς	Psydreus
47	Γαμε[ί]- | λιος̣	Gameilios
48	Ἀγρι- | άνιος	Agrianios
49	Πάνα- | μος	Panamos
79	Μαχα- | νεύς	Machaneus
80	Δωδε- | κ̣α̣τ̣ε- | ύ̣ς̣	Dodekateus
81	Εὔ- | κλε̣[ι-] | ος	Eukleios
82	Ἀ̣ρ̣τ̣ε- | μ̣[ίσι-] | ος	Artemisios
83	*no text visible*	[Psydreus]
84	[ ] | [ ] | ος	[Gameili]os
85	*no text visible*	[Agrianios]
86	Π̣ά̣ν̣α̣- | μ̣[ο]ς̣	Panamos

87	Ἀ̣π̣ελ- | λαῖος	Apellaios
88	(ἔτος) η ´ | Φοινι- | καῖο̣ς̣	Year 8 Phoinikaios
89	Κρα- | νεῖ- | ος	Kraneios
90	Λ̣α̣ν̣ο- | τρ̣[ό]πι- | ος	Lanotropios
91	Μαχα- | νεύς	Machaneus
92	Δωδε- | κατε- | ύς	Dodekateus
93	Εὔ- | κλει- | ο̣ς	Eukleios
94	Ἀρτε- | μίσι- | ος	Artemisios
95	Ψυ- | δρεύς	Psydreus
96	Γαμεί- | λιος	Gameilios
97	Ἀγ̣[ρι-] | άν[ιος]	Agrianios

127	Λα[νο-] | [τ]ρ̣ό̣[πι-] | ο[ς]	Lanotropios
128	Μ[α]χα- | [νεύς]	Machaneus
129	Μα̣χα- | νε̣ύ̣ς	Machaneus
130	Δω̣[δε-] | κα[τ]ε̣- | ύ̣[ς]	Dodekateus
131	Ε̣ὔ̣- | κλει- | ος	Eukleios
132	Ἀρ̣[τε-] | μίσι- | [ο]ς̣	Artemisios
133	[Ψυ-] | δρεύς	Psydreus
134	[Γα]μ[εί-] | λ̣ι̣ος	Gameilios
135	Ἀγρι- | άνιος	Agrianios
136	Πάνα- | μος	Panamos
137	Ἀπελ- | λαῖος	Apellaios
138	(ἔτος) ιβ ´ | Φοινι- | καῖος	Year 12 Phoinikaios
139	Κρα̣ν̣ε̣[ῖ-] | ος	Kraneios
140	Λ̣α̣ν̣ο̣- | [τρόπιος]	Lanotropios
141	Μαχα- | ν̣ε̣ύς	Machaneus
142	Δωδε- | κατεύς	Dodekateus
143	Ε[ὔ-] | κ̣λ̣[ειος]	Eukleios

174	*no text visible*	[Apellaios]
175	[(ἔτος) ι]ε ´ | Φ̣[οι]ν̣ι̣- | καῖος	Year 15 Phoinikaios
176	Κρα- | νε̣ῖο̣ς	Kraneios
177	[Λα]ν̣ο̣ | [τρό]π̣[ι-] | [ος]	Lanotropios
178	Μαχα- | νεύ̣ς̣	Machaneus
179	Δωδ̣ε̣- | κ̣α̣τ̣ε̣ύ̣ς	Dodekateus
180	Εὔ̣- | κ̣λ̣ειος	Eukleios
181	Ἀρτε- | μίσιος	Artemisios
182	Ψ̣υ- | [δρ]εύς	Psydreus
183	Γαμεί- | λιος	Gameilios
184	Ἀ[γριά-] | νιος	Agrianios
185	[Πά]να- | μος	Panamos

186	Ἀπελ- | λαῖος	Apellaios
187	(ἔτος) ι̣ς̣ | [Φοινι-] | κ̣[αῖος]	Year 16 Phoinikaios
188	Κ̣ρ̣α̣- | [νεῖος]	Kraneios
189	Λαν̣[ο-] | τρ̣όπι- | [ο]ς	Lanotropios
225	[ ] | ος	[Kranei]os
226	[Λανοτρό-] | π̣ι̣ο̣ς	Lanotropios
227	[Μ]α̣[χα-] | νεύς	Machaneus
234	[Πά-] | [ναμ]ος	Panamos
235	Ἀπελ- | λαι̣̃ο̣ς	Apellaios

Apparatus

1 (ἔτος): L (likewise 39, 88, 138, 187) | Φ̣: faint and indistinct | κ̣: bottom half of letter, indistinct | ς̣: letter straddles division line between cells 1 and 2 | 2 ε̣: faint and distorted | ς̣: indistinct | 3 τ̣: faint | 34 Ψ̣υ̣: faint | δ̣ρ̣: faint | ς̣: faint | 36 ο̣: indistinct | 37 Π̣α̣: indistinct | 39 Φ̣: faint | ο̣: faint | 40 Κ̣ρ̣: faint | ν̣: faint | ο̣: faint | 41 Λ̣: indistinct | 44 κ̣λ̣: faint | ς̣: indistinct | 47 ς̣: indistinct | 80 κ̣α̣τ̣: faint | υ̣ς̣: faint | 81 ε̣: horizontal stroke at baseline | 82 Α̣ρ̣τ̣: indistinct | μ̣: bottom half of letter | 86 Π̣α̣ν̣α̣: indistinct | μ̣[ο]ς̣: indistinct | 87 Α̣π̣: faint | 88 ο̣ς̣: indistinct | 90 Λ̣α̣ν̣: indistinct | ρ̣: indistinct | ο̣: indistinct | 93 ο̣: indistinct | 97 γ̣: complete, along edge | 127 ρ̣ο̣: indistinct | 129 α̣: indistinct | ε̣υ̣: indistinct | 130 ω̣: indistinct | ε̣: indistinct | υ̣: indistinct | 131 Ε̣υ̣ indistinct | 132 ρ̣: bottom of vertical | ς̣: indistinct, along bottom edge of cell | 134 λ̣ι̣: very faint | 139 α̣ν̣ε̣: faint | 140 Λ̣α̣ν̣ο̣ very faint | 141 ν̣ε̣: indistinct | 143 κ̣λ̣: faint and indistinct | 175 Φ̣: faint | ν̣ι̣: indistinct | 176 ι̣ο̣ς indistinct | 177 ν̣ο̣: top parts of letters | π̣: indistinct | 178 υ̣ς̣: indistinct | 179 δ̣ε̣: indistinct | κ̣α̣τ̣ε̣υ̣: indistinct | 180 υ̣: indistinct | κ̣λ̣: indistinct | 182 Ψ̣: right half of letter | 187 ι̣: indistinct | ς̣: left and top of symbol | κ̣: indistinct | 188 Κ̣ρ̣α̣: indistinct | 189 ν̣: lower half of letter | ρ̣: indistinct | 226 π̣: faint | ι̣ο̣: indistinct | 227 α̣: indistinct | 235 ι̣ο̣: indistinct

ii. Inscriptions adjacent to the innermost turn of the Metonic Dial

The remains of these inscriptions are in Fragment B, and were read from CT. For discussion, see section 4.5.

Transcription and translation
Cell

e1	α´	1st
e33	β̣´	2nd
e35	ς´	6th
e37	ια´	11th

e39	ιε´	15th
e41	ιθ´	19th
e43	κγ´	23rd
e45	κζ´	27th

Apparatus
e33 β̣: very faint

iii. Inscriptions of the Games Dial

The dial survives complete in Fragment B, and has been read from CT. For discussion, see section 4.5.

Transcription and translation

Sector	*Location*		
1	interior	(ἔτος) α´.	Year 1
	exterior	Ἴσθμια | Ὀλύμπ̣ι̣α̣	Isthmians | Olympics
2	interior	(ἔτος) β´.	Year 2
	exterior	Νέμε̣α̣ | Νᾶα	Nemeans | Naa
3	interior	(ἔτος) γ´.	Year 3
	exterior	Ἴσ[θ]μ̣ια | Π̣ύθ̣ια	Isthmians | Pythians
4	interior	(ἔτος) δ´.	Year 4
	exterior	Νέμεα | Ἁ̣λ̣ιεῖα	Nemeans | Halieia

Apparatus
1 interior (ἔτος): L (likewise 2, 3, 4) | exterior π̣ι̣α̣: indistinct | 2 exterior ε̣α̣: indistinct | 3 exterior μ̣: indistinct | Π̣: right half of letter, indistinct | ι̣: indistinct | 4 exterior Ἁ̣: right descending diagonal stroke | ι̣: indistinct

iv. Inscriptions in the cells of the Saros Dial

The inscriptions ("glyphs") in cells 61, 114, 119 (except for the last letter of its second line) and 172 are preserved in Fragment E and were read from CT. Those in cells 20, 25, 26, 78, 79, 131, 137, and 190 are in Fragment F and were read from CT. The remaining preserved glyphs are in Fragment A. The glyph in cell 13 was read from CT and from a photograph by Emile Seraf (see the "comments on readings" below). Those in cells 8, 67, 72, 119 (last letter of line 2), and 120 were read from CT, and those in cells 125, 178, and 184 from the PTMs. For the interpretation of the glyphs, see section 4.7 below.

Transcription

Cell	
8	Σ̣ .̣	.̣ .̣ .̣	Β
13	Η	ὤρ(α̣) α ʹ.	Γ
20	Σ [ ]	ὤρ(α̣) ς ʹ.	Ε
25	Η	ὤρ(α̣) ς ʹ.	Ζ
26	Σ ἡμ(έρας)	ὤρ(α̣) ζ ʹ.	Η̣
61	Σ [ ]	[ ]	[Ο]
67	Σ [ ]	ὤ̣ρ̣(α̣) η ʹ	Π
72	Η ν̣υ̣(κτὸς)	ὤ̣ρ̣(α̣) .̣ ʹ.	Ρ
78	Η	ὤρ(α̣) α ʹ.	Τ
79	Σ ἡμ(έρας)	ὤρ(α̣) ι ʹ.	Υ
114	Σ ἡμ(έρας)	ὤρ(α̣) ιβ ʹ.	Γ̅
119	Η νυ(κτὸς)	ὤρ(α̣) ιβ ʹ.	Δ̅
120	Σ ἡμ(έρας)	ὤρ(α̣) .̣ ʹ.	Ε̣̅
125	Σ ἡμ̣(έρας) ὤ̣ρ̣(α̣) η ʹ.	Η ὤρ(α̣) γ ʹ.	Ζ̅
131	Σ ὤρ(α̣) β ʹ.	Η νυ(κτὸς) ὤρ(α̣) θ ʹ.	Η̅
137	Σ ἡμ(έρας) ὤρ(α̣) ε ʹ.	Η ὤρ(α̣) ιβ ʹ.	Θ̅
172	Σ ὤρ(α̣) ς ʹ.	Η ὤρ(α̣) ιβ ʹ.	Π̅
178	Σ ὤρ(α̣) θ ʹ.	Η ὤρ(α̣) θ ʹ.	Ρ̅
184	Σ ἡμ(έρας) ὤρ(α̣) δ ʹ.	Η̣ ὤρ(α̣) α ʹ.	Σ̣̅
190	Σ ἡμ(έρας)	ὤρ(α̣) θ ʹ.	Τ̅

Translation

Cell	
8	Moon, ... Β
13	Sun, 1st hour. Γ
20	Moon, [ ] 6th hour. Ε
25	Sun, 6th hour. Ζ
26	Moon, 7th hour of day. Η
61	Moon, ... [Ο]
67	Moon, [ ] 8th hour. Π
72	Sun, ... hour of night. Ρ
78	Sun, 1st(?) hour of day. Τ
79	Moon, 10th hour of day. Υ
114	Moon, 12th hour of day. Γ̅
119	Sun, 12th hour of night. Δ̅
120	Moon, ... hour of day. Ε̅

125 Moon, 8th hour of day. Sun, 3rd hour of day. Ζ̅
131 Moon, 2nd hour. Sun, 9th hour of night. Η̅
137 Moon, 5th hour of day. Sun, 12th hour. Θ̅

172 Moon, 6th hour. Sun, 12th hour. Π̅
178 Moon, 9th hour. Sun, 9th hour. Ρ̅
184 Moon, 4th hour of day. Sun, 1st hour. Σ̅
190 Moon, 9th hour of day. Τ̅

Apparatus

Throughout these inscriptions, ἡμέρας is represented by a mu suspended directly above an eta; νυκτός is represented by an upsilon suspended above a nu; and ὥρᾳ is represented by the digraph ϕ.

8 Σ̣ left side blurry, followed by indistinct traces to its right and on the following line | 20 right of Σ, possibly a small raised mu to the right of the sigma but no visible trace of an eta below it | 26 Ḥ: indistinct, scarcely visible trace | 67 η̣ blurry | 72 ̣: apparently the left half of epsilon or beta, the remainder distorted and indistinct | 78 an apparent mark to the left of alpha is probably not a letter | 120 ̣: extremely faint and indistinct traces | 125 η² is written to the right of the division between cells 125 and 126

Comments on readings

8: This glyph has not previously been reported. All plausible reconstructions of the distribution of glyphs require a glyph in this cell, either for just a lunar eclipse possibility or for both lunar and solar eclipse possibilities (see below, section 7). Hence the sigma at the beginning of the top line, though blurred in the CT, is assured. The index letter beta in the third line is also in agreement with all reconstructions. CT volume A6, which gives the best images for this cell, appears to show at least two indistinct letters or symbols to the right of the sigma and at least two letters or symbols in the second line, though the traces become increasingly faint in both lines towards the right. These observations favor identifying the glyph as both lunar and solar.

13: The glyph of this cell survives but has been partially obscured, probably as a consequence of the joining to it of a small fragment consisting of part of this turn of the spiral scale and a portion of the accretion layer bearing offsets of the Back Cover Inscription. This fragment had broken off Fragment A before Price's time and was reattached in the 1970s. No significant part of cell 14, which ought to have been inscribed with a glyph according to all reconstructed schemes, survives. The cell that now adjoins cell 13 is in fact cell 15, so that the reattached fragment is not quite in its proper position, as can be confirmed by comparing the inscription offsets with photographs from the early 20th century, when the accretion layer in this region of Fragment A was intact. The glyph of cell 13 has previously been transcribed on the basis of the CT volumes, in which the hour numeral is visible as an apical letter, leaving it uncertain whether it is an alpha (1) or delta (4).[35] Our reading of cell 13 with a definite alpha is based on the very clear appearance of the glyph in an undated photograph (1950s to 1970s), one of a pair showing both sides of Fragments A, B, and C, taken by the archeological photographer Emile Seraf.[36]

20: A small mark is visible in CT to the right and above the sigma in the first line, close to a crack.[37] Although this could be reconciled with part of the raised mu of the abbreviation of ἡμέρας, there is no trace of an eta below; we conclude that this is an accidental feature rather than engraved lettering.

61: This glyph was not previously reported. Unfortunately, all that remains of it is the sigma at the beginning of the first line, whose presence was predicted by all plausible reconstructions of the glyph distribution.

67: This glyph was previously reported from extremely indistinct images, on the basis of which sigma at the beginning of the first line and pi as index letter were reported in agreement with all plausible reconstructions.[38] In both CT volumes A5 and A6, traces of the sigma are visible though the letter could probably not be recognized if it was not expected; however, at the beginning of the second line traces can be seen identifiable as the top part of the symbol for ὥρᾳ, followed by a faint but distinct eta. The index letter pi is also distinct.

72: The hour numeral was previously reported as an eta, based on traces interpreted as the left vertical and left part of the mid-height horizontal strokes of that letter.[39] Closer examination of the cell in CT volume A5 (which provides clearer images for this region than A6) shows a vertical with what appear to be strokes going out from it to the right at top, mid height, and baseline; depending on the plane selected for viewing, the strokes either appear to continue horizontally rightwards as in an epsilon or to meet in indistinct loops as in beta. There is space for, but no clear trace of, an iota immediately preceding this letter. Hence beta (2), epsilon (5), or iota-beta (12) are credible readings.

35 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 25; Freeth 2014, Fig. S13 and Note S4, 2.

36 The negative of this photograph was acquired with the rest of Seraf's collection by the Athens department of the Deutsches Archäologisches Institut, whom we thank for providing a scan.

37 We were alerted to this by C. Carman (personal communication).

38 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26; Freeth 2014, Fig. S13.

39 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26.

78: The second line was previously reported as a ὥρα̣ symbol (malformed on its right side) followed by a tiny raised νυκτός abbreviation and the numeral alpha (1).[40] This reading violates the normal syntax of the glyphs, according to which an indication of day or night, if present, precedes the ὥρα̣ symbol. In fact what was interpreted as the left vertical of the nu of νυ(κτός) is actually the right end of the ὥρα̣ symbol, *not* malformed, and we take the remaining mark between this symbol and the alpha to be an accidental feature.[41]

119: The cell is mostly preserved in Fragment E, but its rightmost portion is in A. Previously, only images and readings from the portion in E have been reported.[42] Since the hour numeral as preserved in E is an iota close by the break, it was assumed that the numeral could have been simply iota (10) or iota followed by alpha (11) or by beta (12). The last of these possibilities is proved correct by a beta in the appropriate position clearly visible in CT volume A5.

120: All that can be seen of the hour numeral is a faint and doubtful vertical stroke in volume A6, which would be consistent with any numeral except alpha (1), delta (4), or theta (9). The 2008 publication gave an "uncertain" reading of eta (8) in a rather low position; we consider this to be a phantom reading.[43] More recently, iota-beta (12) has been offered as "very uncertain."[44]

125: The hour numeral in the first line was read as eta (8) in the 2008 publication.[45] More recently beta (2) has been proposed on the basis of a blurry CT image.[46] We consider the eta to be certain on the basis of PTM ak48a and CT volume A6, both of which show the letter complete with all serifs.

172: In the 2008 publication the hour numeral in the first line was incorrectly read as epsilon (5).[47]

40 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26.

41 Similarly Freeth 2014, Note S4, 2.

42 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26; Freeth 2014, Fig. S13 and Note S4, 2.

43 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 26; the reading is judged "highly dubious" by Freeth 2014, Note S4, 2.

44 Freeth 2014, Fig. S13 and Note S4, 2.

45 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 27.

46 Freeth 2014, Fig. S13 and Note S4, 2.

47 Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 27; corrected in Freeth 2014, Fig. S13 and Note S4, 2.

v. Inscriptions of the Exeligmos Dial

The dial survives nearly complete in Fragment A; sector 2 was read from PTM, sector 3 from CT. For the interpretation of the inscribed numerals, see section 8 below.

Text and translation.

Sector		
2	η	8
3	ις	16

vi. Back Plate Inscription

The preserved text of lines 1-18 of the Back Plate Inscription, except for the leftmost portions of 5-8, are in Fragment A. Fragment 25 duplicates parts of lines 9-16 of the Back Plate Inscription (and actually has a bit of the surface of the Back Plate itself adhering to it at lines 15-16), while Fragment 24 duplicates parts of lines 14-17. The inscriptions in E preserve the beginnings of lines 5-8. The inscriptions in F preserve lines 19-36. It is unlikely that there existed any lines of the Back Plate Inscription lost in the interval between line 18 (in A) and line 19 (in F), where the right rim of the Saros Dial comes very close to the right edge of the plate. Much of this interval is present on A, and bears no detectable writing.

The mean baseline-to-baseline spacing of the Back Plate Inscription in Fragments A and F is approximately 3.0 mm. The average letter height is about 1.6 mm in Fragment A as measured from a photograph, but about 2.0 mm in Fragment F as measured from CT images. The interlinear space thus averages about 1.4 mm in Fragment A and about 1.0 mm in Fragment F. Average horizontal letter spacing, from the leftmost point of one letter to the leftmost point of the next is about 2.1 mm in both fragments, though with considerable (roughly ±15%) variation from line to line.

Text and translation

0	[ἀπὸ περιίσταν-]	[From... and they veer]
1	[ται δὲ καὶ κατα]λ̣ή̣γο[υσι]	[about and] end up
2	[πρὸς . . . . . . μ]ικραί. τ̣[ὸ δὲ]	[towards.... S]mall. The
3	[χρῶμα . . . . . .] ̣ινον. *v*	[color] *uncertain*.
4	[ ]Ω̣ *v*	[ ]Ω(?)
5	ἀ̣πὸ βο[ρείου], π̣ε̣ρ̣ι̣ίσ̣ταντ[αι]	From *boreas*, and they veer about
6	δὲ κα̣ὶ [κατ]αλήγου̣σι πρ[ὸς]	and end up towards
7	λίβα. *v* μ̣[έ]σαι. τ[ὸ] δὲ χρῶ̣-	*lips*. [Inter]mediate. The co-
8	{μα}μα μ̣έλαν. *v*	lor black.
9	Α̣ *v* Ν *v* ̣ *v* Β̣ *v* Φ̣	A(?) N ... B(?) Φ(?)
10	ἀ̣πὸ θ̣ραικίαν, πε̣[ρι-]	From *thrakias*, and they veer
11	ίστανται δ̣[ὲ καὶ]	about and

12	καταλήγ̣ο̣[υσι]	end up
13	πρὸς ἀπηλι-	towards *apêli-*
14	ώτην. μ[εγά-]	*ôtês*. Large(?).
15	λην. τὸ δὲ̣	The
16	χρῶμα	color
17	πυρ̣[ρόν.]	fiery red.
18	ΖΘ̣̅Σ ̣ Χ̣	ΖΘ̅(?)Σ…Χ(?)
19	ἀπ̣[ὸ ζε-]	From *ze-*
20	φύ̣[ρου, πε-]	*phyros*, and they
21	ριίστ̣[αν-]	veer
22	ται δὲ [πρὸς]	about towards
23	νότον κ[αὶ]	*notos* and
24	καταλήγου̣-	end
25	σιν πρὸς ἀ[πη-]	up towards *apêli-*
26	λιώτην. μέ̣-	*ôtês*. Inter-
27	σαι. τὸ δὲ χρῶ̣-	mediate. The co-
28	μα μέλαν. *v*	lor black.
29	̣Λ̣Ξ̣(*symbol*)Π̅ΚΖΦ	̣Λ̣Ξ̣(symbol)Π̅ΚΖΦ
30	ἀπὸ νότου, περι-	From *notos*, and they veer
31	ίστανται δὲ κα̣ὶ	about and
32	καταλήγουσιν	end up
33	πρὸς ἀπηλιώτην.	towards *apêliôtês*.
34	μ̣ι̣κ̣ραί. τὸ δὲ χρῶμα̣	Small(?). The color
35	μέλαν. *v*	black.
36	*v* Τ *v* Η̅ *v* Θ *v* Ρ̅ *v* Ψ̣	Τ Η̅ Θ Ρ̅ Ψ(?)

Apparatus

1 λ̣η̣γ̣: left ascending diagonal and top part of descending diagonal of apical letter, then a serifed bottom of right vertical, then a vertical with bottom serif, meeting horizontal at top height that extends very slightly to the left and farther to the right | 2 τ̣: serifed left part of horizontal and serifed bottom part of vertical | 3 ̣: trace at baseline along edge | 4 Ω̣: right half of large, very wide loop, with small gap at the top | 5 In ecthesis | α̣: bottom end of descending diagonal | π̣ε̣ρ̣ι̣: indistinct traces | σ̣: indistinct | 6 ι̣: vertical with serif at bottom, along edge | υ̣: indistinct | 7 *v*: one letter | μ̣: trace at baseline along edge | ω̣: left half of letter, indistinct | 8 {μα}: faint, presumably effaced | μ̣: complete but indistinct | 9 Α̣: apical letter with faint horizontal cross-stroke at mid height | ̣: apparent ascending and descending strokes of apical letter | Β̣: small loop between mid and top height, traces below indistinct, to the right near baseline an indentation resembling the serifed right extremity of omega (possibly an accidental feature) | Φ̣: complete but distorted by damaged surface | 10 In ecthesis | α̣: faint apical letter | *l.* θραικίας | θ̣: indistinct | ε̣: vertical, indistinct | 11 δ̣: indistinct | 12 ο̣: left side of small loop, indistinct | 15 ε̣: indistinct | 17 ρ̣: indistinct | 18 Θ̣̅: most of a large loop well preserved (a large omicron cannot be ruled out), bar over letter | ̣: indistinct nar-

row letter (iota or rho), pitted surface, possibly a trace of a bar over the letter | Χ̣: complete but indistinct | 19 In ecthesis | π̣: left vertical (?), faint and indistinct | 20 υ̣: left descending diagonal and vertical with serif at bottom | 21 τ̣: trace at top level along edge | 24 υ̣: small, doubtful trace at top height along edge | 26 ε̣: indistinct traces at baseline along edge | 27 ω̣: indistinct, missing top of loop | 29 ̣: apical letter | Λ̣: faint | Ξ̣: apparently form with vertical cross-stroke, bottom horizontal with serifs, clear traces of bottom end of vertical and left end of top horizontal, faint traces of shorter middle horizontal | Μ̣: a faint trace of ascending diagonal with serif at bottom, possible faint traces to right | 30 In ecthesis | 31 ̣ι: faint | 34 ̣ι̣κ̣ρ: indistinct traces, with a break running through the presumed rho; (μ)έ̣σ̣(αι) cannot be ruled out | α̣: faint | 36 *v*$^{1-5}$: space for 1-2 letters | Ψ̣: faint and doubtful |

Comments on readings

1: Crowther[48] reports ̣Ι̣ΤΟ. The horizontal stroke of the second letter extends, so far as we can tell, only a little way to the left of the vertical, but further to the right than would be normal for tau; we believe gamma is the strongly preferable reading. What remains of the first letter is a vertical serifed at top and bottom with the edge of the surviving engraved surface immediately to its left. The combination of readings in lines 1-3, with a possible καταλήγουσιν in 1, a highly probable μικραί in 2, and a termination possible for a color adjective followed by vacant space in 3, provide a strong case for restoring lines 0-4 as a regularly structured paragraph of the inscription followed by a line of index letters, rather than the "introductory" section hesitantly suggested by Crowther.[49]

4: We believe this ought to be a line of index letters, but the one letter or symbol partially surviving is hard to identify. We agree with Crowther's observation that the loop appears to be too broad for omicron, and as he notes, it also has a slight gap at the top. A semblance of a vertical stroke descending from the loop is actually the edge of the break, though this could in principle have followed the right edge of an engraved stroke had there been one there. Phi is unlikely both because of the gap and because there is no trace of a serif where the descending vertical should have ended. This leaves as the only plausible candidate the cursive (open-topped) form of omega.

7: We are confident of μέσαι. Crowther reads [̣ ̣]Ω̣Ε̣ΑΙ on the basis of CT, but raises the possibility that the supposed epsilon is actually a sigma so that (disregarding the doubtful omega) [μέ]σ̣αι would be possible. We see the entire sigma in PTM ak50a. The vacant space to the right

48 Crowther's transcription is the right part of Freeth 2014, 9, Fig. 8, supplemented by his epigraphic notes at Note S2, 2-3. Crowther's notes say nothing about the index letter lines 9, 18, 29, and 36, whereas their readings are discussed in detail by Freeth 2014, Fig. S6, so it would appear that these lines in Crowther's transcription are largely Freeth's readings and restorations.

49 Freeth 2014, S2, 2.

of λίβα accounts for the fact noted by Crowther that μέσαι would be shorter than the lacuna.

8: The engraver inscribed the beginning of line 5, the first line of this paragraph, in ecthesis (i.e. hanging indentation) as he did for the other paragraphs, and then continued with lines 6-8 having a straight left margin. After writing μα in this position, which brought the text right to the outer rim of the Saros Dial scale, he seems to have effaced the strokes and begun the line again immediately to the right of them.

9: Crowther reports ΝΛ̣̅Β̣Φ̣̅.[50] Freeth describes the last of these letters as "convincing" while indicating that the barred lambda and beta are only apparent if one is expecting to find these letters.[51] In PTM ak50a and CT volume A6 we see a likely alpha to the left of nu, the two sloping strokes of the presumed lambda (but no clear trace of a bar above), a plausible beta (or conceivably omega), and a convincing phi (with no visible bar).

10: The ungrammatical reading ἀπὸ θραικίαν is not in doubt. On Fragment A the alpha of -αν is damaged at the top while only the bottom of the left and right sides of nu survive, but Fragment 25 has clear offsets of both letters. Crowther reports θραικί[ου] π̣ε̣ρ̣ι̣-, but to the right of the epsilon the plate's surface has been lost to a depth probably greater than the engraving reached, and we can see no further traces.

11: Crowther reports δ̣ὲ̣ κ̣[αὶ], but again to the right of the delta the plate's surface is gone.

14: The traces of the mu, visible only in Fragment 25, support Crowther's restoration [μεγά-]|λην, "large." In the corresponding parts of the other passages we have adjectives indicating size in feminine nominative plural. We suspect that the accusative singular here is a copying error, likely through assimilation to the preceding ἀπηλιώτην.

18: Crowther reports ΖΘ̅Σ̣̅Ρ̣Χ̣. Freeth, however, indicates that no bar is visible over the theta, so the bar in the transcription is presumably conjectural.[52] In fact a bar *is* clearly visible in PTM ak49a, whereas we can see none on the damaged surface over the sigma. Freeth characterizes the identification of the letter reported as rho as "very likely" in contrast to the sigma and chi for which he merely claims consistency with the data.[53] On the basis of PTM ak49a we would say that sigma is certain and chi highly probable, but for the letter in between we can only see rough indentations in the surface and no definite remains of engraving. This letter, however, must have been narrow, either rho or iota.

50 In Crowther's transcription, index letters without bars are indicated by a subscript 1, and those with bars by a subscript 2.

51 Freeth 2014, Fig. S6.

52 Freeth 2014, Fig. S6 and tracings in Fig. 8.

53 Freeth 2014, Fig. S6.

19: The faint but complete alpha and small (uncertain) trace of pi survive in Fragment F only because the line was engraved in ecthesis; Crowther does not report them (though in his epigraphic notes he indicates "possible compatible traces of the left foot of alpha"), and the accompanying tracing shows them restored too far to the right.

22: Crowther assumes a *vacat* following δὲ, and comments that νότον in line 23 has to be understood adverbially as if it were νοτόνδε. There would have been enough room at the end of 22, however, for the expected preposition πρός as we restore the line.

29: In our transcription and translation, "(symbol)" stands for a symbol, very clear in the CT, consisting of an ascending and a descending stroke meeting at about half height, like a broad, low lambda, with the left ascending stroke continuing upwards and curving in an arc leftwards so that the top half of the symbol resembles that of a 2; following a suggestion of Gregg Schwendner,[54] we believe this was the numeral for 1000 (drawn as a notional alpha modified by a hooked stroke), though here functioning as a symbol supplementing the letters of the Greek alphabet. Crowther reports the entire line as (symbol)Π̅ΚΖ̅Φ. Freeth states (in agreement with our observations) that there is no trace of a bar over the zeta, so that the bar in the transcription is an editorial supplement.[55] Freeth does not mention any traces to the left of the barred pi. In fact, to the left of the pi, three further engraved letters are present, the first (approximately aligned with the beginning of line 28) apparently an apical letter, i.e. alpha, delta, or lambda, with no visible bar, the second a probable lambda, and the third a probable xi of the old form with a vertical crossing the middles of the three horizontal strokes (as also found in the Front Cover Inscription where xi is a numeral).

34: Crowther reports μικράν̣. The right portion of line 34 is very indistinct in the CT, and while the mu and alpha are sufficiently clear, the letters between them are a jumble of disconnected and blurry marks. A vertical to the immediate right of the mu is probable, but one cannot be sure of a single other stroke until one gets to the alpha. The structure of the inscription's paragraphs leads us to expect either μέσαι, "intermediate," or μικραί, "small." To our eyes, the hints offered by the CT slightly favor ικρ over εσ, but either would fit the space and could be reconciled with the traces. Of the final letter, all that can be made out with certainty is a slightly sloping vertical, serifed at the bottom and, apparently, at the top, though in Freeth's tracing this is interpreted as the top of the descending diagonal of nu. Very indistinct marks to the right of this vertical could be interpreted as parts of a second vertical, but this would be so close to the vertical of the following tau that the tau's horizontal

54 By comment posted at http://www.currentepigraphy.org/2009/03/18/peculiar-symbol-in-hellenistic-inscription/. In Greek papyri the numeral 1000 is sometimes written almost identically to the symbol in our inscription; see for example *PLond* 1.24 line 8 (Seider 1967, plate 9). We know of no other epigraphic example.

55 Freeth 2014, Fig. S6.

would have to be curtailed on its left side, as indeed it is shown in Freeth's tracing. We are confident that the letter is iota, followed by a properly formed tau of which the leftmost extremity is indistinct in the CT.

36: Crowther reports $\overline{\underset{.}{\Psi}}$ following P, and Freeth's tracing shows this letter about as far to the right of the rho as the other letters in this line are spaced apart. The supposed letter is described by Freeth as "hard to read, though definitely plausible".[56] In the CT we see a faint serifed, slightly sloping vertical, and possible but very slight traces of a V-shaped stroke crossing it.

56 Freeth 2014, Fig. S6.

4.5 Discussion of the Metonic and Games Dial Inscriptions

As noted above, the Metonic Dial scale's cells are inscribed with a repeating cycle of twelve month names (Table 4.1). Although very few of the cells are completely legible, the repetitions of month names guarantee that the foregoing spellings are all correct. Where necessary, the names were split into two or three lines within a cell according to proper division of syllables (note the division -ε|ύς reflecting a vestigial digamma).

Table 4.1: *The inscribed texts of the Metonic Dial*

(ἔτος) *n* Φοινικαῖος	Year *n* Phoinikaios
Κρανεῖος	Kraneios
Λανοτρόπιος	Lanotropios
Μαχανεύς	Machaneus
Δωδεκατεύς	Dodekateus
Εὔκλειος	Eukleios
Ἀρτεμίσιος	Artemisios
Ψυδρεύς	Psydreus
Γαμείλιος	Gameilios
Ἀγριάνιος	Agrianios
Πάναμος	Panamos
Ἀπελλαῖος	Apellaios

There were nineteen repetitions of the annual cycle covering the 235 cells of the scale, so that seven intercalary months must have been inserted somewhere in agreement with the requirements imposed by the Metonic cycle relation:

235 months = 19 calendar years = 19 x 12 months + 7 intercalary months

The legible cell sequences include a single instance of an intercalary month, a repeated Machaneus (the fourth month) in year 11.[57] It can be inferred from the surviving sequences that two intercalary months must have occurred within years 1-3 of the cycle, one within years 4-7, one within years 8-10, one within years 12-14, and one in years 16-19. This is not sufficient information to determine which years other than year 11 were intercalary. However, if a pattern distributing the intercalary years as evenly as possible as assumed, the sequence of ordinary (O) and intercalary (I) years must have been:

57 The cells in question had not been read in the 2008 edition, in which the calendar cycle was reconstructed *exempli gratia* on the assumption that the intercalated month was always the sixth, Eukleios.

I 0 0 I 0 0 I 0 0 I 0 I 0 0 I 0 0 I 0

This is the cyclic permutation of the sequence of optimally spread intercalations such that the beginning of year 1 falls earliest of the whole cycle relative to the solar year, e.g. relative to a solstice or equinox. We are confident that this is the correct sequence for the dial.

If the intercalary months were distributed with maximum evenness *in terms of months*, they would have occurred at intervals of 33 or 34 months, and this is contradicted by the absence of intercalations in cells 95-96 and 229-230. Hence either Machaneus was always the intercalary month, or more than one calendar month was occasionally duplicated but not following a pattern of even distribution. The data are consistent with repetitions of Machaneus in all intercalary years, but the confirmation of this hypothesis is not strong.[58]

The numerals in certain of the cells e1-e47 around the inner rim of the Metonic Dial indicate day numbers to be skipped over in the count from 1 through 30 in all months radially aligned with the inscribed cell. For example, the numeral 2 in cell e33 means that there is to be no day number 6 in Artemisios in year 3 (cell 33), in Dodekateus in year 7 (cell 80), in Lanotropios in year 11 (cell 127), and so forth. The scheme must have distributed 22 skipped days over 47 months in accordance with the Metonic relation:

235 months = 5 x 47 months = 6940 days = 5 x (47 x 30 days – 22) days

The legible inscriptions are consistent with the following scheme, which maximizes the evenness of distribution of skipped days (at intervals of 64 or 65 days) and of 29-day and 30-day months (Table 4.2).

Table 4.2: *Reconstructed scheme of skipped days of the Metonic Dial*

cells	*day*	*cells*	*day*
1, 48, 95,142, 189	1	24, 71,118,165, 212	16
3, 50, 97,144, 191	5	26, 73,120,167, 214	20
5, 52, 99,146, 193	9	28, 75,122,169, 216	24
7, 54,101,148, 195	13	30, 77,124,171, 218	28
9, 56,103,150, 197	17	33, 80,127,174, 221	2
11, 58,105,152, 199	21	35, 82,129,176, 223	6
13, 60,107,154, 201	26	37, 84,131,178, 225	11
15, 62,109,156, 203	30	39, 86,133,180, 227	15
18, 65,112,159, 206	4	41, 88,135,182, 229	19
20, 67,114,161, 208	8	43, 90,137,184, 231	23
22, 69,116,163, 210	12	45, 92,139,186, 233	27

58 Anastasiou, Seiradakis, Carman, and Efstathiou 2014, Supplementary Appendix A.

Geminos, *Introduction to the Phenomena* chapter 8, describes a similar scheme in which days are to be skipped over (ἐξαιρέσιμοι) at intervals of 64 days throughout a Metonic or Callippic cycle. The word ἐξαιρέσιμος, which occurs also in the Mechanism's Back Cover Inscription (I 4),[59] had the technical sense of a day to be omitted from a calendar month to maintain correct astronomical alignment of the calendar, as is clear from Cicero, *In Verr.* 1.2.129:

"It is the custom of the Sicilians and the other Greeks, because they want their days and months to be in agreement with the behavior of the Sun and Moon, from time to time, if there was a discrepancy, to remove some single day or at most two days from a month, which they call *exairesimoi*; likewise from time to time they make a month longer by one day or two days".[60]

Cicero apparently describes a more haphazard practice than the schemes of Geminos and the Mechanism, which would never deduct more than two days from a month or add days to a month.[61]

The Back Cover Inscription (II 17-19) alludes to the 76-year Callippic period relation in terms that strongly suggest that a subsidiary dial, no longer extant, displayed the number of the current Metonic cycle within a 76-year cycle.[62] The Callippic period relation, being based on a quadrupling of the Metonic cycle, does not alter the ratio of months to years or require any change to the distribution of intercalary months, but it does change the ratio of days to months and years:

76 years = 940 months = 27759 days = 4 x 6940 days – 1 day

Hence if the designer of the Mechanism held the Callippic period relation to be accurate, it must have been intended that one further day was skipped over in every fourth Metonic cycle. The extant inscriptions give no hint of which day was to be omitted.

The identification of the specific calendar of the Metonic Dial inscriptions depends on matching its month names and their sequence with evidence for local calendars, chiefly attested

59 IAM 5.4.

60 "Est consuetudo Siculorum ceterorumque Graecorum, quod suos dies mensisque congruere uolunt cum solis lunaeque ratione, ut non numquam, si quid discrepet, eximant unum aliquem diem aut summum biduum ex mense, quos illi exaeresimos dies nominant; item non numquam uno die longiorem mensem faciunt aut biduo".

61 The only other instance of ἐξαιρέσιμος in this calendrical sense is pseudo-Aristotle, *Economics* 1351b15, recounting an anecdotal instance of a frugal general deducting a portion of soldiers' pay proportional to the number of skipped calendar days.

62 IAM 5.4.

in inscriptions. Inscriptional evidence from two geographical regions shows a significantly high rate of matching with the Mechanism's months. On the one hand a set of Hellenistic inscriptions from Tauromenion in Sicily provides an almost complete set of the month names of the local calendar and their sequence, which was as follows, starting with the month that began the year at Tauromenion (Table 4.3)[63]

Table 4.3: *The calendar of Tauromenion*

Ἀρτεμίτιος[64]	*Artemitios*
Διονύσιος	Dionysios
Ἑλώρειος[65]	Heloreios
Δαμάτριος	Damatrios
Πάναμος	*Panamos*
Ἀπελλαῖος[66]	*Apellaios*
Ἰτώνιος	Itonios
Καρνεῖος	*Karneios*
Λανοτρόπιος[67]	*Lanotropios*
Ἀπολλώνιος	Apollonios
Δυωδεκατεύς	*Dyodekateus*
Εὔκλειος	*Eukleios*

The seven italicized month names are in exact or near-exact agreement with the corresponding ones of the Mechanism's calendar, if we align the first month of the Mechanism's year, Phoinikaios, with the seventh of the Tauromenian calendar, Itonios. Hence it appears that both calendars descended from a common ancestor, but that at least one of them had undergone a process of substitution of new names for some of the months.

On the other hand, inscriptions from several localities in northwest Greece attest to month names that exactly or nearly match those of the Mechanism, though these give little hard evidence for the order of the months. The places in question were either colonies of Corinth in Epirus or members of the Epirotic League, and it appears highly probable that their calen-

63 For Artemitios as the first month of the Tauromenian year, see Battistoni 2011, 183.

64 The termination -ίτιος, lost from the Tauromenian inscriptional evidence, can be restored from parallels in related Sicilian calendars (Iversen 2015).

65 For this reading see Iversen 2015.

66 In IG XIV 429 we have an instance of Ἀπελλαῖος δεύτερος, i.e. an intercalary Apellaios following the normal one.

67 Battistoni 2011, 182 shows that the end of this name should probably be restored in agreement with the Mechanism's spelling.

dars were variants of the calendar of Corinth, for which unfortunately the direct evidence is slender. By 2007 Pierre Cabanes had identified the thirteen month names as belonging to the putative calendar of Corinth as attested in Epirus (Table 4.4).[68]

Table 4.4: *Month names identified by Cabanes as belonging to the calendar of Corinth, listed in his conjectural sequence*

Ἀρτεμίσιος/Ἀρτεμίτιος	*Artemisios/Artemitios*
Ψυδρεύς	*Psydreus*
Ἀγριάνιος	*Agrianios*
Φοινικαῖος	*Phoinikaios*
Ἁλιοτρόπιος	Haliotropios
Δάτυιος	Datyios
Κρανεῖος	*Kraneios*
Πάναμος	*Panamos*
Ἀπελλαῖος	*Apellaios*
Γαμίλιος	*Gamilios*
Μαχανεύς	*Machaneus*
Δευδεκατεύς	*Deudekateus*
Εὔκλειος	*Eukleios*

The degree of coincidence between the calendar in Epirus and the Mechanism's calendar is in fact still greater than appears from the ten matching names italicized in the above list. Datyios, attested in a single inscription from Dodona, probably does not belong to this calendar, and in fact may not even be a month name.[69] Eliminating Datyios makes room in the expected set of twelve month names for Deudekateus (also attested as Δυωδέκατος, Dyodekatos), which Cabanes supposed to be a name specifically for an intercalated month inserted in the twelfth place in an intercalary year; moreover, one inscription, IG IX,1 694, implies as a sequence of consecutive months Machaneus, Dyodekatos, Eukleios, Artemitios in agreement with the Mechanism's order. "Haliotropios," which supposedly signifies a month approximately coinciding with a solstice, turns out to be an editorial phantom misread or conjectured in inscriptions that variously appear to have had either Ἀλοτρόπιος, Alotropios, or Λανοτρόπιος, Lanotropios, the month name attested on the Mechanism and in Tauromenion.[70]

68 Cabanes 2007. A few inscriptions are dated with a month simply named ἐμβόλιμος, "intercalary."

69 Iversen 2013a.

70 Iversen 2013a. We concur with Iversen's disagreement with Cabanes's more recent effort to differentiate the calendar of Corinth (for which he adheres to his previous reconstruction) from that of the Mechanism, Cabanes 2011.

In the 2008 edition of the Metonic Dial inscriptions, it was suggested that the partial match of the months at Tauromenion to those in Epirus could be explained through the fact that Tauromenion had been refounded by Syracuse in the early fourth century BC as a colony of mercenaries. The calendar of Syracuse, like that of its founder, Corinth, is extremely poorly documented, but the authors of the 2008 edition hypothesized that Syracuse had substantially the same calendar as Epirus, and that the substitution of several different month names had occurred in connection with the adoption of a variation of Syracuse's calendar at Tauromenion. However, Paul Iversen has demonstrated that at least one month in use in Syracuse was different from those attested in Epirus and on the Mechanism, and that it is far more probable that the calendar of Tauromenion is simply the calendar of Syracuse.[71] We conclude, in agreement with Iversen, that the calendar of the Mechanism was intended to be a version of the calendar of Corinth as it was practiced either at Corinth itself or in some locality of Epirus.

The Games Dial's four quadrants bear inscriptions both inside and outside the circular outline of the dial. Inside the quadrants, in counterclockwise order, are inscribed year numbers from 1 through 4. Outside each quadrant, two lines of inscription give the names of two athletic festivals. It is noteworthy that this dial, the only one on the Mechanism for which the prevailing sense of motion of the pointer going forward in time was counterclockwise, is also the only one whose dial inscriptions are oriented with the tops of the letters towards the center; that is, on all the dials, the direction in which the inscriptions would have been read indicated the "forward in time" direction.

The names of six competitions appear in these inscriptions. Four of them are those of the Panhellenic Games: the penteteric Olympics (in year 1) and Pythians (in year 3), and the trieteric Isthmians (in years 1 and 3) and Nemeans (in years 2 and 4).[72] The arrangement of these competitions shows that the years indicated by the dial were not those of the calendar of Olympia or of Athens according to which the standard chronological Olympiad cycle was reckoned. In the Olympiad cycle, the Nemean games, which took place in the summer, and the Isthmians, which took place in the following spring, were assigned to the same years, since the beginning of the calendar years of Olympia and Athens both fell in early summer. The years of the Games Dial must have begun at some other time of year. It seems probable that they were intended to be the same as the years of the Metonic Dial, though for mechanical reasons what the Games Dial actually displayed were solar years of uniform length

71 Iversen 2013a. Full documentation of Iversen's contributions to the understanding of the Mechanism's calendar and its relations to the various local calendars discussed here will appear in Iversen (forthcoming, a) and (forthcoming, b).

72 "Penteteric" competitions were held every four years, "trieteric" competitions every two years. The Greek terms literally mean "every five years" and "every three years," reflecting the ancient practice of inclusive counting.

rather than lunisolar calendar years which could be either twelve or thirteen months long. The lines demarcating the quadrants are inclined about 8° counterclockwise from horizontal and vertical. In the 2008 study it was conjectured that, when the Mechanism was set to a date coinciding with the beginning of the first year of its Callippic cycle, the pointers of the Metonic and Games Dials would have been parallel, pointing straight down.[73] (This could also have been true of the pointer of the presumed Callippic Dial.) If so, the division lines of the Games Dial would have been approximately aligned with the latest possible beginnings of the Metonic Dial's calendar years. Iversen has persuasively argued that the Corinthian year began in the late summer, and conjectured that the division lines were intended to mark an astral phenomenon that was used to regulate the calendar on the assumption that it always fell within Phoinikaios; this event would most probably have been either the autumnal equinox or the morning rising of Arcturus.[74]

The second competition named in the Dial inscription for year 2 is the Naa, which took place at Dodona. An inscription from Dodona gives Apellaios as the month in which the Naa were held.[75] Year 4 too has a second competition whose name was not read in the 2008 edition but has since been identified with strong probability as the Halieia of Rhodes.[76] The order in which the two competitions are listed for each year of the cycle could reflect the order in which they were actually held in those years (assuming that the Halieia followed the Nemeans) or simply that the designer chose to list the trieteric games before the penteteric ones.

73 Freeth, Jones, Steele & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 21.
74 Iversen (forthcoming a).
75 Cabanes 1976, 586, text 71, reprinted by Cabanes 1988, 58. The festival is also sometimes written Νάϊα, but Νᾶα is the form found in local inscriptions.
76 Iversen 2013b and (forthcoming b), and cf. Iversen 2011 and 2013; Zafeiropoulou 2012, 247.

4.6 The Saros

The foundation of the Mechanism's eclipse predictions is the Saros, a period comprising 223 synodic months while approximating integer numbers of four other periodicities that play a role in eclipse phenomena:[77]

223 synodic months ≈ 238.992 periods of lunar anomaly
≈ 241.999 periods of lunar latitude
≈ 18.030 periods of solar anomaly
≈ 18.029 tropical years
≈ 6585.322 days

Hence if two syzygies are separated by 223 synodic months, the interval between them in days is close to constant (because of the near integer numbers of lunar and solar anomalistic periods), and the Moon will return to approximately the same elongation from the same node, while also being at approximately the same distance from the Earth. If the earlier of the two syzygies had a lunar eclipse, these circumstances suffice to ensure that the later one will almost always have a lunar eclipse of roughly the same duration, magnitude, and directions of obscuration as reckoned with respect to the ecliptic; the directions as reckoned with respect to the celestial equator will also be preserved, though less accurately because of the comparatively large error of the Saros as a period of tropical years. For any terrestrial place of observation, the local times of the second eclipse's beginning, middle, and end will be roughly 8 equinoctial hours later than those of the first eclipse. Thus it is possible for both eclipses to fall within the nighttime and so to be in principle observable, but in many cases an observable eclipse will be followed after a Saros by an unobservable, diurnal one. A triple Saros, called an Exeligmos (ἐξελιγμός, "turn of a wheel," a name cited by Geminus 18 and Ptolemy, *Almagest* 4.2), will normally bring a recurrence of lunar eclipses having approximately the same characteristics and approximately the same local times, though the cumulative effect of the not-quite-integer numbers of the various periods in three successive Saros cycles will result in some degradation in the repetition of the characteristics.

During a Saros, the Sun passes each lunar node 19 times, so that there will be 38 conjunctions and 38 oppositions when the Moon is closer to a node than at the preceding and following syzygies of the same kind. A lunar eclipse can only occur at such an opposition, and—with exceptions observable only at extreme terrestrial latitudes—a solar eclipse can only occur at such a conjunction. These syzygies are thus known as lunar and solar eclipse possibilities ("EPs"). The 38 EPs of a single kind (lunar or solar) are spaced at intervals of six months, with five intervals of five months interspersed among them, so that a Saros

77 For a discussion of the Saros as an eclipse cycle, with particular bearing on Mesopotamian eclipse prediction, see Steele 2000a, esp. 422-424 and 431-432.

contains three series of eight EPs and two series of seven EPs separated by six month intervals, in a cyclic permutation of 8-7-8-7-8. These intervals reflect the fact that five and six synodic months are close to but respectively less than and greater than an integer and a half periods of latitude:

5 mean synodic months ≈ 5.43 periods of latitude
6 mean synodic months ≈ 6.51 periods of latitude

The EPs of each kind strictly alternate between the two nodes, with the signed lunar elongation from the nearer node increasing in a six-month interval and decreasing in a five-month interval. Since in the course of any of the groups of EPs at six-month intervals the Moon approaches the node from behind and then recedes from it in advance, lunar eclipses tend to have greater magnitudes around the middle of the series, and the EPs flanking the five-month intervals may not be accompanied by umbral lunar eclipses. Solar eclipses behave less regularly because of the parallactic component in the Moon's apparent latitude as observed from a particular locality, but the conditions for eclipses are also more favorable towards the middle of each group of solar EPs.

The 38 solar EPs occur half a month away from the 38 lunar EPs. Because of the phase difference of half a synodic month between conjunctions and oppositions, in a group of seven or eight lunar EPs separated by six-month intervals, the solar EPs will follow immediately after the lunar EPs for the first half of the group, and immediately precede them for the last half of the group. In other words, in a group of eight lunar EPs, the first four will be followed by their solar counterparts and the last four will be preceded; and in a group of seven lunar EPs, the first three will be followed and the last three preceded by solar EPs, while the middle one may go either way depending on the precise alignment of the group with the nodes. Thus the groups of seven or eight solar EPs at six-month intervals are symmetrically out of phase with the groups of lunar EPs, with the five-month intervals between solar EPs falling in the middle of the lunar EP groups.

Seven six-month intervals followed by a five-month interval amount to 47 months, a sort of "poor man's Saros" that returns the Moon to just over the same elongation from the same node though not to the same stage in the lunar and solar anomalistic periods:

47 mean synodic months ≈ 51.004 periods of latitude

Thus lunar eclipses occurring at the *n*th EP in an eight-EP group and in the following group will be similar in their characteristics, though not as similar as lunar eclipses separated by a Saros. On the other hand, six six-month intervals followed by a five-month interval, amounting to 41 months, bring the Moon to just short of the same elongation from the opposite node:

41 mean synodic months ≈ 44.493 periods of latitude

Thus lunar eclipses occurring in the *n*th EP of a seven-EP group and in the following group will have similar magnitudes and durations, but the directions of obscuration are not preserved: if the Moon is obscured from its north side in one eclipse, it will be obscured from the south side in the other, and *vice versa*.

As we have already remarked, solar eclipses are highly contingent on the effects of parallax because the conditions for a solar eclipse depend on the apparent position of the Moon as seen from a point on the Earth's surface, and this can differ from the position as seen (notionally) from the Earth's center by an amount on the order of a degree, i.e. twice the Sun's apparent diameter. Both the magnitude and the timing of a solar eclipse are extremely sensitive to differences in parallax such as arise from the imprecisions of the Saros period relation. Consequently, the pattern of solar eclipses observable in a particular locality during one Saros will not be repeated in subsequent Saros cycles.[78] The Saros only allows one to predict which conjunctions are solar EPs, which even when diurnal may or may not be accompanied by observable eclipses, and to predict the approximate time of true conjunction, which might be taken as a very crude approximation of the time of mid-eclipse if an eclipse occurs.

78 An important difference between the treatment of solar eclipse prediction in ancient and modern astronomy is that, instead of investigating the path travelled by the shadow on the Earth's surface, ancient predictive methods sought to forecast the circumstances of the eclipse as observed from a specific locality.

4.7 The eclipse glyphs and their distribution

In the Antikythera Mechanism, eclipses were not displayed or predicted through a mechanical modelling of the relative configurations of the Earth, Moon, and Sun, comparable to the visual display of lunar phases by means of a rotating black-and-white ball on its front face.[79] Rather, eclipses were predicted schematically, by means of a dial representing an ostensibly repeating Saros cycle of EPs, which was established somehow prior to the construction of the Mechanism.[80] In this respect they were treated in the same way as the dates of first and last visibility of fixed stars: the conditions of stellar visibility were not mechanically modelled, but an annually repeating cycle of the phenomena, derived from observations or from a model of stellar visibility, was represented on the front Zodiac Dial.[81]

Roughly a third of the Saros Dial is preserved in Fragments A, E, and F. Its unusual spiral structure was essentially the same as that of the Metonic Dial situated directly above it;[82] in both cases the object appears to have been to enable a clear display of the current stage of a cycle lasting more than two hundred months, allowing sufficient space for each month on the dial's scale to inscribe a short text. As we have seen, the Saros Dial had a spiral slot of four turns perforating the Back Plate. A revolving pointer-follower tracked this groove clockwise from beginning (inside) to end (outside) as the Mechanism's input drive was cranked forward a number of turns corresponding to 223 synodic months as displayed, for example, by the motions of the solar and lunar pointers on the Zodiac Dial.[83] The spiral scale running along the outside of the groove was divided into 223 divisions or "cells" standing for the 223 months of the Saros. The months were evidently considered to begin with the first visibility of the new Moon, so that opposition would correspond to a position of the pointer close to the middle of a cell, and conjunction to a position close to its end.

Cells corresponding to months containing either a solar EP or a lunar EP or both were inscribed with a highly abbreviated text or "glyph"; the other cells were left vacant.[84] All 38 lunar EPs appear to have been inscribed, whereas some of the solar EPs were omitted.

79 For the Moon phase display see Wright 2006.

80 Freeth et al. 2006, 589.

81 Price 1974, 18; IAM 3.

82 The spiral structure of the back dials was deduced by Wright 2005.

83 Freeth et al. 2006, 589 with Fig. 3.

84 Our discussion of the distribution and contents of the glyphs follows Freeth et al. 2006, 589 (with Fig. 4) and Supplementary Information 5 and Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 24-41.

The following are examples of the three kinds of glyph that a cell could contain:

lunar EP	*solar EP*	*lunar and solar EPs*
Σ $\overset{M}{H}$	H	Σ ϕ θ
ϕ H	ϕ ς	H ϕ θ
E Z	$\overline{P}$	

In the lunar EP glyph, the initial sigma identifies the EP as lunar (Σελήνη, "Moon," or perhaps σεληνιακή, "lunar"). The eta-mu monogram indicates a diurnal EP (ἡμέρας, "of day"); in the case of a nocturnal one (the "normal" situation for a lunar eclipse) it would be simply omitted.[85] The omega-rho monogram stands for ὥρᾳ, "at hour",[86] and the eta is the numeral 8, for the eighth hour. Lastly, epsilon is an index letter labelling the inscribed cell. The solar EP glyph begins with eta (Ἥλιος, "Sun," or ἡλιακή, "solar"), then the hour monogram and the numeral 6 (digamma), for the sixth hour. In this instance the EP is diurnal, the "normal" situation for a solar eclipse; if it was nocturnal, the hour monogram would be preceded by a nu-upsilon monogram (νυκτός, "of night"). Zeta is the index letter. The third example of a glyph contains a lunar EP (ninth hour of night) followed by a solar EP (ninth hour of day), and the index letter rho with a bar over it.

Every cell containing an EP or EPs had an index letter, and as the third example shows, a cell bore only a single index letter even if it contained two EPs. This will be an important consideration when we come to investigate the structure of the text to which the index letters refer, since it implies that the text must have been arranged in such a way that no ambiguity arose about whether the indexed text referred to a lunar or a solar EP. The inscribed cells were indexed in alphabetic order, running twice through the complete 24-letter standard Greek alphabet, and apparently through two or three further letters or symbols, making probably 50 or 51 indexed glyphs in all. The index letters of the second alphabet were distinguished from those of the first by bearing a horizontal stroke above the letter.[87]

85 Similar abbreviations by suspension of ἡμέρας and νυκτὸς in seasonal hour indications occur in astronomical papyri of the Roman period, e.g. the ephemeris *POxy astron.* 4179 from A.D. 348, for which see Jones 1999, 2.188-191.

86 This symbol is common in papyrus horoscopes and other astronomical papyri from the 2nd century AD onwards, e.g. *PFouad* 6, a horoscope for someone born in AD 125 (Neugebauer & van Hoesen 1959, 38-39). The earliest instance known to us, other than those on the Saros Dial, is a birthdate in AD 88 inscribed in horoscopic format, from Tremithos, Cyprus (Mitford 1961, 118-119).

87 Contrary to Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended 2012) 28, we are now convinced that the entire second alphabet was marked with bars above the letters (though some cannot now be discerned), as reported in Steele 2011, 464.

Since the 2008 publication of the glyphs detectable through surface imaging and CT in the surviving parts of the Saros Dial scale, two further glyphs have been detected. One occupies cell 8, which was reliably predicted to contain either a lunar or a lunar plus solar glyph, and unfortunately the glyph is not legible enough to determine which kind it was with certainty. The other is in cell 61, where a lunar glyph was predicted. Hence no further information has been obtained about the complete scheme of glyphs. In the 2008 publication, a model was also proposed for reconstructing the complete scheme in agreement with the attested glyphs, the principal challenge being to find a criterion for the omitted solar EPs that accounts for the attested glyphs, vacant cells, and index letters. This was not a unique solution,[88] and in the following we prefer to limit ourselves to certain assumptions about the scheme's structure that we consider to be very plausible:

(1) There was a complete set of lunar EPs in an 8-7-8-7-8 pattern.[89] Two alignments of the 8-7-8-7-8 pattern are possible consistent with the attested lunar glyphs. In one alignment the first EP of the first group of 8 was in cell 172, while in the other the first EP of the first group was in cell 37. The only difference between these distributions is that, starting with cell 172, we obtain a lunar EP in cell 214, but if we start with cell 37, the EP moves to cell 213. (The 2008 reconstruction started with cell 172.)

(2) The solar EPs were an incomplete but nearly complete subset of an 8-7-8-7-8 pattern.[90]

88 In Freeth, Jones, Steele, & Bitsakis 2008, Supplementary Notes (amended 2012) 32 it was asserted that only one alignment of the 8-7-8-7-8 groups for the lunar EPs was consistent with the preserved readings. We are grateful to Christián Carman for pointing out to us that a second solution is possible.

89 Every surviving cell that ought to contain a lunar EP if the set was complete does in fact contain one. The evidence would be consistent with having some lunar EPs (in lost cells) omitted, but some of these would have to be in the middle of the lunar EP groups, where eclipses of larger magnitudes are expected. We consider the omission of such EPs to be highly unlikely.

90 Seven 8-7-8-7-8 patterns are consistent with the attested solar glyphs, with the first set of 8 starting respectively at cell 60, 148, 13, 101, 189, 54, or 142, listed in increasing order of the total number of solar EPs that must be assumed skipped in cells preceding lunar EPs. (The existence of seven solutions was established by Christián Carman.) The first three of this list conform to the symmetry rule set out above if the lunar 8-7-8-7-8 began with cell 37, and the first two conform if the lunar pattern began with cell 172. Freeth 2014, Note S3, 2 proposes a model according to which the solar EPs are supposedly a subset of an 8-8-8-7-7 pattern, but the actual pattern resulting after the omissions (Freeth 2014, 5 Fig. 4) turns out to be almost identical to the reconstruction we present below in Table 4.6 which is based on an 8-7-8-7-8 sequence for both solar and lunar EPs, with the lunar sequence starting with cell 172. The only divergence is in cell 149, for which Freeth's re-

The distribution of the complete set of solar EPs, including the omitted ones, was out of phase with the lunar EPs in such a way that in a group of 8 lunar EPs at six-month intervals, the first four have solar EPs in the same cell and the last four have them in the preceding cell, while in a group of 7, the first three have solar EPs in the same cell and the last three have them in the preceding cell (leaving the middle EP undetermined by this symmetry rule).

(3) The omitted solar EPs were spread fairly evenly among the five groups composing the Saros.[91] This implies that the total number of glyphs was either 50 or 51, that is, there were either two or three additional letters or symbols following the two complete alphabets of index letters.

On this basis, we obtain the reconstruction presented in Table 4.5. In the table, an asterisk indicates an omitted solar EP or a vacant cell with no index letter, a slash means "or," and surviving glyphs or vacant cells are enclosed in boxes. Double horizontal strokes show the five-month intervals on the hypothesis that the first group of the 8-7-8-7-8 pattern begins with cell 172, and a broken horizontal stroke shows the slightly earlier placement of one five-month interval on the hypothesis that the first group begins with cell 37. The choice between these hypotheses only affects the glyphs and their index letter possibilities in cells 202-214; the glyphs and possible index letters resulting from starting in cell 37 are in parentheses.

construction posits a solar EP as well as the lunar EP. Neither this cell nor the solar eclipse paragraph of the Back Plate Inscription that would have referred to it if it contained a solar EP is extant. (Freeth's diagrams illustrating his reconstruction of the Saros Dial, e.g. p. 5, Fig. 4, also show the non-extant cell 143 as containing both a lunar and solar EP, but this appears to be an oversight since his Fig. S9, representing the derivation of his scheme of EPs, indicates that a solar EP is excluded in this cell.)

91 We further believe that the omitted solar EPs were probably all either adjacent to one of the five-month gaps or one EP away from a five-month gap, since the EPs in the middles of the groups often do correspond to observable solar eclipses. We do not use this hypothesis in the following analysis; if it is correct, the 8-7-8-7-8 pattern of solar EPs must have started with cell 60 since otherwise the omitted EP in cell 113 would be the third in its group.

Table 4.5: *Provisional reconstruction of the glyph distribution of the Saros Dial*

Cell	*EP*	*index*
2	ΣΗ/Σ*	Α
8	ΣΗ/Σ*	Β
13	Η	Γ
14	Σ	Δ
19	*	*
20	Σ	Ε
25	Η	Ζ
26	Σ	Η
31	Η	Θ
32	Σ	Ι
- - - - - -		
37	ΣΗ/Σ*	Κ
43	ΣΗ/Σ*	Λ
49	ΣΗ/Σ*	Μ
55	ΣΗ/Σ*	Ν
60	Η/*	*/Ξ
61	Σ	Ξ/Ο
66	Η/*	*/Ο
67	Σ	Π
72	Η	Ρ
73	Σ	Σ
78	Η	Τ
79	Σ	Υ
- - - - - -		
84	ΣΗ/Σ*	Φ
90	ΣΗ/Σ*	Χ
96	ΣΗ/Σ*	Ψ
102	ΣΗ/Σ*	Ω
107	Η	$\overline{A}$
108	Σ	$\overline{B}$
113	*	*
114	Σ	$\overline{\Gamma}$
119	Η	$\overline{\Delta}$
120	Σ	$\overline{E}$
- - - - - -		
125	ΣΗ	$\overline{Z}$
131	ΣΗ	$\overline{H}$
137	ΣΗ	$\overline{\Theta}$
143	ΣΗ/Σ*	$\overline{I}$
148	Η/*	*/$\overline{K}$
149	Σ	$\overline{K}$/$\overline{\Lambda}$
154	Η/*	*/$\overline{\Lambda}$/$\overline{M}$
155	Σ	$\overline{\Lambda}$/$\overline{M}$/$\overline{N}$
160	Η/*	*/$\overline{M}$/$\overline{N}$
161	Σ	$\overline{N}$/$\overline{\Xi}$
166	Η/*	*/$\overline{\Xi}$
167	Σ	$\overline{O}$
- - - - - -		
172	ΣΗ	$\overline{\Pi}$
178	ΣΗ	$\overline{P}$
184	ΣΗ	$\overline{\Sigma}$
190	Σ*	$\overline{T}$
195	Η/*	*/$\overline{\Upsilon}$
196	Σ	$\overline{\Upsilon}$/$\overline{\Phi}$
201	Η/*	*/$\overline{\Phi}$/$\overline{X}$
202	Σ	$\overline{\Phi}$/$\overline{X}$/$\overline{\Psi}$ ($\overline{X}$/$\overline{\Psi}$)
207	Η/*	*/$\overline{X}$/$\overline{\Psi}$/$\overline{\Omega}$ (*/$\overline{\Psi}$/$\overline{\Omega}$)
208	Σ	$\overline{\Psi}$/$\overline{\Omega}$/symbol ($\overline{\Omega}$/symbol)
- - - - - -		
213	Η/*(ΣΗ)	*/$\overline{\Omega}$/symbol (symbol)
214	Σ (no glyph)	symbol (no glyph)
- - - - - -		
219	ΣΗ	symbol

4.8 The times in the glyphs

In the 2008 publication, the precise meaning of the times recorded in the glyphs as well as their method of computation remained unsolved problems. A reconsideration of the evidence, including revised readings of a few times in the glyphs, suggests that at least a partial solution is possible. In our efforts to analyse these times, as in our examination of the Back Plate Inscription later in this paper, we adopt the broad principle that the designers of the Mechanism possessed a level of understanding of the astronomy of the Sun and Moon such that a competent astronomer of the time, say Hipparchos, would not have rejected their *theoretical* treatment of eclipses as grossly incompetent, whatever imprecisions there may have been in the execution. The mechanism for lunar anomaly seems ample justification for this confidence.

The time statements in the glyphs represent an abbreviated form of the conventional Greek formula for a time expressed in seasonal hours of day or night, "at hour *n* of day/night", where *n* is always a whole number from 1 through 12. In principle, "hour *n* of day" means a time within the interval between $(n-1)D/12$ and $nD/12$ counted from the moment of sunrise, where *D* is the duration of day from sunrise to sunset expressed in any constant time units, since the duration of one seasonal hour of day is defined as $D/12$. "Hour *n* of night" has the corresponding meaning in terms of the duration of night from sunset to sunrise. Two considerations, however, make it very unlikely that the times in the glyphs have precisely this meaning.

First, the Saros period is in excess of a whole number of years by more than ten days. Because of this, the lengths of daytime and nighttime will be significantly different for the dates of two eclipse possibilities separated by a Saros. This means that the time units would not remain constant for any particular glyph.

Secondly, because the Saros was not close to a whole number of days long, a time correction would be needed when forecasting any time associated with an eclipse on the basis of an eclipse one Saros back. The assumed overrun was one-third of a day, so that a triple Saros, called an Exeligmos, would make a whole number of days. The numerals 8 and 16 inscribed in two of the three sectors of the Exeligmos Dial are the numbers of hours to be added to the times in the glyphs for the second and third Saros of each Exeligmos cycle.[92] Hence they must be understood as equinoctial hours if they are to be applicable day and night throughout the year. The glyph times are thus in all probability *idealized* seasonal hours, reckoned as if there was no annual variation in the lengths of day and night, and so counted in *equinoctial* hours from 6 A.M. and 6 P.M. This convention is exactly paralleled in Greek lunar tables and

92 Freeth, Jones, Steele, & Bitsakis 2008, 615, Fig. 2 caption.

astronomical ephemerides from Roman Egypt.[93]

The division lines of the Exeligmos Dial are aligned so that the division marking the beginning of the third Saros of the Exeligmos (16 hours correction) radiates approximately horizontally to the left of the dial's center, and thus the division marking the beginning of the first Saros (0 hours correction) is approximately 30° clockwise of pointing straight upwards. We will return to this nonintuitive alignment at the end of this section.

Since the times are expressed in a consistent manner throughout the dial, it is only reasonable to assume that they should refer to the same stage of an eclipse or eclipse possibility in all the statements, whether they refer to lunar or solar EPs. This consideration limits us to just one candidate, the moment of syzygy. In a complete set of 38 lunar EPs in a Saros, some of the EPs will necessarily not be accompanied by umbral eclipses, so it would not be meaningful to give, say, a time for the beginning of obscuration. In the case of solar EPs, the situation is more extreme: because of the effects of parallax, the Saros does not enable one to make forecasts of the times or durations or even of the mere occurrence of solar eclipses visible in one geographical region on the basis of past eclipses. Hence unless the Saros Dial reflects a level of ignorance of the nature and behavior of solar eclipses that we would be reluctant to impute to a competent Hellenistic astronomer, the only meaningful times that could be associated with solar EPs in a repeating Saros cycle are the moments of syzygy.

We thus have a strong expectation simply from their mode of expression and their presence on the Saros Dial that the glyph times represent moments of syzygy counted in equinoctial hours from 6 A.M. for "day" or 6 P.M. for "night." It is easily established that the time interval between any pair of these times is not consistently the number of intervening lunar months (always an integer or an integer plus a half) times the length of a mean synodic month, so that the times must be of *true* syzygy, taking some account of the varying apparent speeds of the Sun and Moon.

In the kinematic approach to astronomy embodied by Ptolemy's *Almagest*, the time of true syzygy must be computed by an iterative process, taking the mean syzygy as a first approximation and repeatedly adjusting the time by the computed elongation of the Moon from the Sun divided by the estimated speed of the Moon relative to the Sun. A surprisingly good approximation can be obtained more directly by modelling the difference between the time of true and mean syzygy as the sum of two periodically varying components, one having as its period the anomalistic month and the other the solar year. In the Babylonian System A and System B lunar theories, time of true syzygy is calculated by algorithms equivalent to this kind of model, employing arithmetical functions to represent the periodic lunar and solar components.

93 Jones 1997, 27-29; Jones 1999, 1.14-15, 1.180, 1.187, 1.205.

We can illustrate this using the 446 syzygies within an arbitrary Saros cycle computed by modern theory. In Fig. 4.6 we plot (hollow markers) the difference between the times of true and mean syzygy (modulo 12 hours to simulate a situation in which times but not dates are given) against the stage of the anomalistic month. Obviously the predominant component of the time difference is a sinusoidally varying element dependent on lunar anomaly and having an amplitude of roughly 10 hours, while the values spread within a range of about ±5 hours of this component. The gray curve models this component as a scaled sine function with amplitude 9.7 hours.

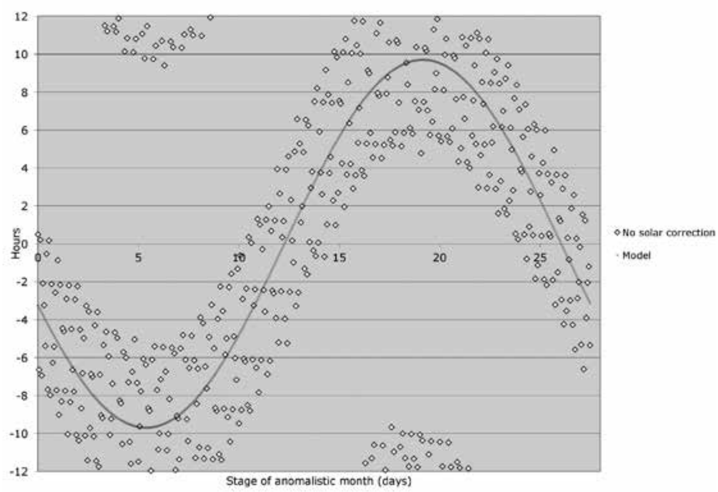

Figure 4.6: *Time of true syzygy minus time of mean syzygy plotted against stage of the anomalistic month, for syzygies of one Saros cycle computed by modern theory*

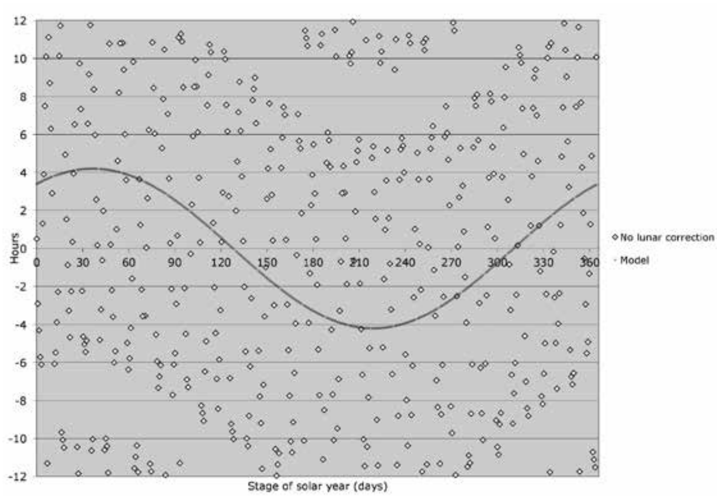

Figure 4.7: *Time of true syzygy minus time of mean syzygy plotted against stage of the solar year, for syzygies of one Saros cycle computed by modern theory*

In Fig. 4.7 we plot the same time differences (hollow markers) against the stage of the solar year, revealing that the values spread within a ±10 hour range around a component dependent on solar anomaly and with amplitude about 4 hours. If we correct the time difference by our sine-function model for the lunar component (Fig. 4.8), the residues (solid markers) cluster within roughly ±1 hour of a scaled sine function (gray line) having amplitude 4.2 hours. The solid markers in Fig. 4.9 similarly show how the data plotted in Fig. 4.6 are affected by correcting the time differences by the model for the solar component.

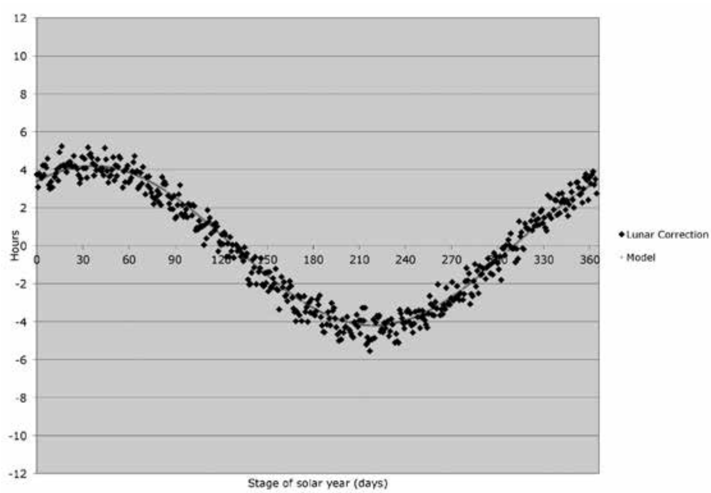

Figure 4.8: *Data from Figure 4.7 corrected by the sinusoidal lunar model of Figure 4.6*

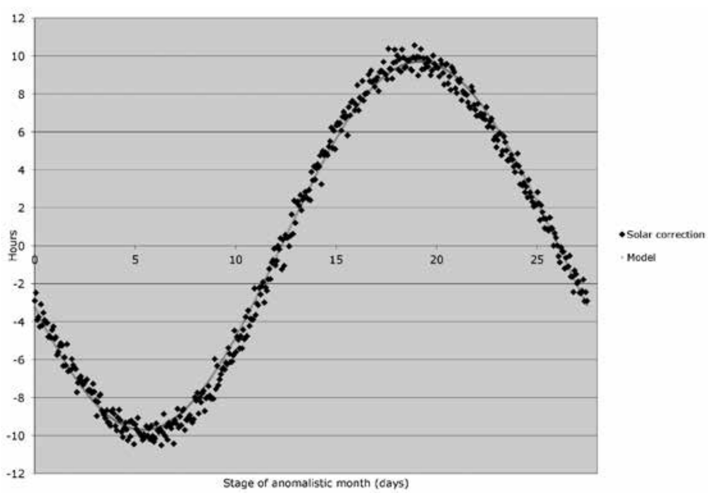

Figure 4.9: *Data from Figure 4.6 corrected by the sinusoidal solar model of Figure 4.7*

We now turn to the 22 reasonably secure times from the glyphs.[94] Since we do not have complete dates, but only times of day or night, we must estimate the alignment of the times relative to the times of mean syzygy. We have done this by assigning an arbitrary time of mean syzygy to any one of the syzygies, which determines the times of all the remaining mean syzygies in the Saros cycle, and adjusting the chosen time to see if a more or less symmetrical pattern of time differences can be obtained that could make sense as a sinusoidally varying lunar component blurred by a smaller solar component or other elements. We obtained the best results by assigning to the opposition of cell 1 a mean time of syzygy at 3 P.M.

Fig. 4.10 shows the differences between the times in the glyphs and our estimated times of mean syzygy plotted against the stage of the anomalistic month, where we have arbitrarily set the opposition of cell 1's month as day 0. Seventeen of the data points conform reasonably well, say within ±5 hours, to a sinusoidal model of appropriate amplitude, while five (corresponding to the lunar EPs of cells 125, 172, and 184 and the solar EPs of cells 13 and 119) do not. We believe that this is satisfactory confirmation that we are dealing with times of true syzygy computed by a method reflecting the influence of lunar anomaly, though a rate of one grossly discrepant value in five is unsettling.

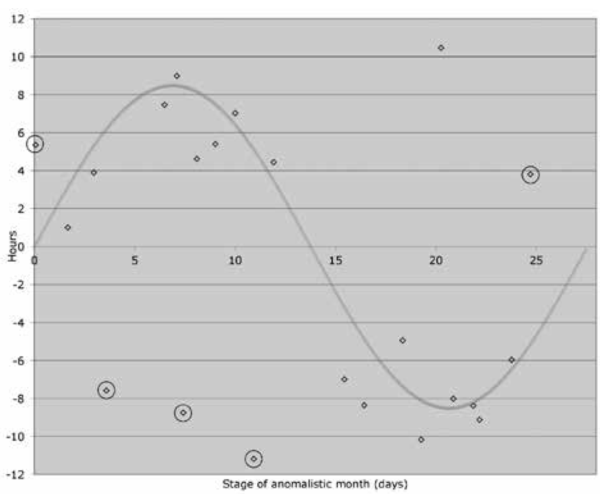

Figure 4.10: *Glyph time minus normed mean syzygy plotted against stage of the anomalistic month*

It deserves note that the lunar component appears to be near zero and increasing for the stage of the anomalistic month that we have defined as day 0. This implies that the Moon was close to its apogee at the opposition of cell 1. The Saros Dial is believed to have been calibrated to show the stage of the so-called Full-Moon Cycle, the beat period of the anom-

94 We assume that cell 20 did not indicate a diurnal hour.

alistic and synodic months, by means of four fiducial marks at 90° intervals immediately inside the dial and aligned so that the first of the marks was at cell 1; one of these marks survives.[95] Taken together, these considerations suggest that the Mechanism's Saros cycle may have been chosen so that cell 1's opposition was exactly at the lunar apogee. This would explain why the EPs do not start in cell 1.

We now plot in Fig. 4.11 the time differences corrected by our sinusoidal model against the stage of the solar year. The data points corresponding to the grossly discrepant time differences found in Fig. 4.9, circled in the present graph, should probably be disregarded. What remains shows less sign of a component dependent on solar anomaly than one might expect.

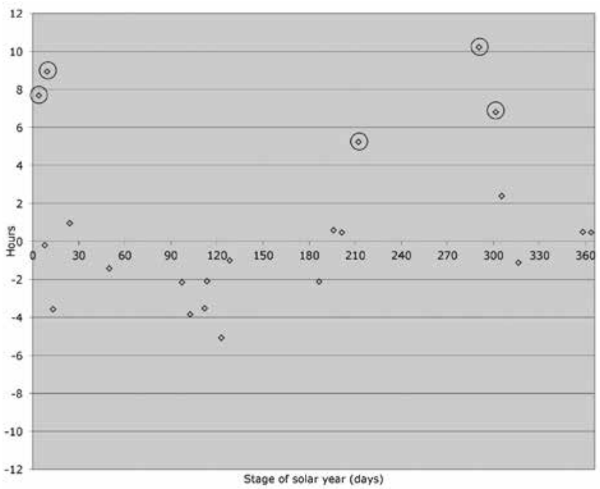

Figure 4.11: *Glyph time minus normed mean syzygy, corrected by lunar model from Fig. 4.10, plotted against stage of the solar year*

Our initial inference from the foregoing investigations was that the times in the glyphs were computed as times of true syzygy with a solar model that assumed either a small anomaly or none at all (i.e. effectively conjunctions and oppositions of the true Moon with the mean Sun) and that the calculations were comparatively sloppy to account for the remaining noise after the sinusoidal lunar correction was applied. However, in 2013 Christián Carman and James Evans, with whom we had shared our provisional conclusions, demonstrated that the glyph times could be successfully approximated, with significantly smaller errors than we found, by combining an optimized lunar model based on the assumption that lunar velocity behaves as a Babylonian-style linear zigzag function with an optimized solar model based

95 Freeth, Jones, Steele, and Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 39-40.

on the assumption that solar equation behaves as a linear zigzag function.[96]

Without recapitulating their more sophisticated analysis, we can confirm their deduction of a solar anomaly component. In Fig. 4.12 we reproduce the data of Fig. 4.11 together with a hypothetical sinusoidal solar component with amplitude ±3 hours, normed so that cell 1's opposition coincides with solar apogee, which appears to fit the data from the glyphs, aside from the outliers already identified, reasonably well. Fig. 4.13 shows the original data from Fig. 4.10 corrected by subtracting the sinusoidal solar component, plotted against the stage of the anomalistic month. The improvement of the fit to the hypothetical lunar component is obvious.

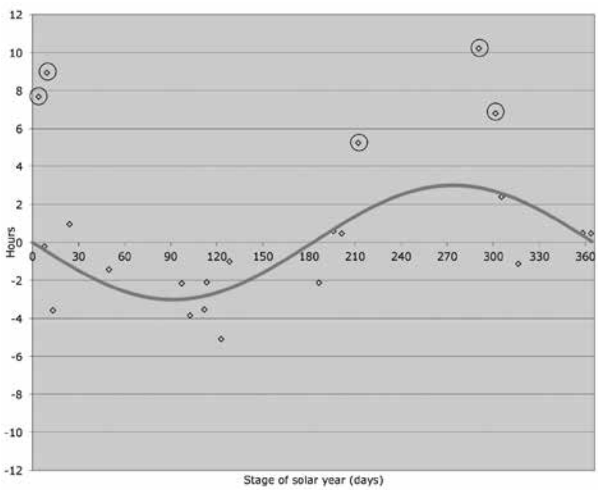

Figure 4.12: *Data from Figure 4.11 compared with a hypothetical sinusoidal solar component*

We conclude, then, that the times in the glyphs were calculated as times of true syzygy according to solar and lunar models that both involved anomaly. Carman, Evans, and Freeth suggest that these models were based on arithmetical functions rather than a trigonometrical representation of geometrical models.[97] The cycle of predictions on the Saros Dial was apparently normed such that at the opposition of its first month (cell 1) the Moon was assumed to be at its apogee.

96 Carman & Evans 2013; the research was subsequently published as Carman & Evans 2014. Freeth 2014, Note S4 similarly models the glyph times using Babylonian-style arithmetical functions, representing the time from one syzygy to the next as the sum of a zigzag function for the lunar component plus a zigzag function for the solar component, which is closer to the methods known from Babylonian astronomy.

97 We abstain here from appraising the merits of the specific models proposed in Carman & Evans 2014 and in Freeth 2014.

Carman and Evans have systematically deduced that this opposition was probably meant to be that of May 12, 205 BC, so that the epoch of the Saros Dial would have been the New Moon of April 29, 205 BC.[98] We note, that if we accept both the April 29, 205 BC epoch date and Iversen's conjecture that the epoch of the Mechanism's Callippic cycles was four lunar months later, August 23, 205 BC,[99] then when the Mechanism was set to the latter date, not only would the pointers of the calendrical upper dials have been parallel, pointing straight down, but also the pointers of the Saros and Exeligmos Dials would have been very nearly parallel, pointing about 30° clockwise of straight up. This seems likely to be the explanation why the Exeligmos Dial was normed so that its pointer had this orientation at the beginning of each cycle. It would be beyond the scope of the present paper to discuss at greater length the question of how these epoch dates relate to that of the construction of the Mechanism, beyond the obvious point that at a minimum it provides us with a *terminus post quem*.

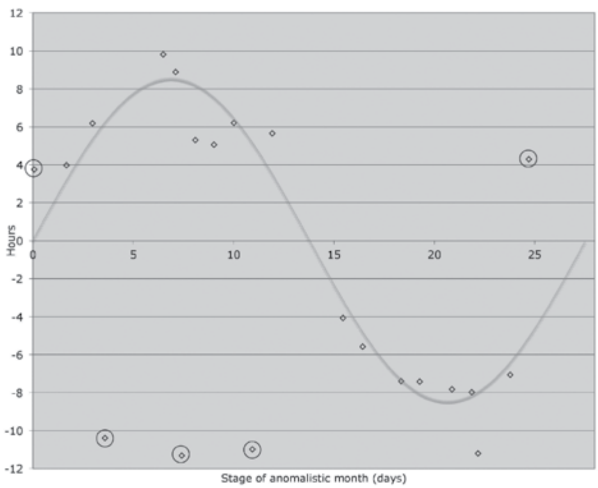

Figure 4.13: *Data from Figure 4.10 corrected by subtracting the solar component of Figure 4.12*

98 Freeth 2014, 11 and Note S5 arrives at the identical epoch date by methods that he asserts (Note S5, 2) are "entirely different" from those of Carman and Evans (citing Carman & Evans 2013), though many of the same considerations are taken into account.
99 Iversen (forthcoming, a).

4.9 Overview of the Back Plate Inscription

The Back Plate Inscription consists of a series of rigidly patterned sections or paragraphs, each comprising three parts. The first part is a sentence asserting that some unstated plural subject starts (present tense) from a certain direction, "veers about" —in one instance, "veers about towards" a certain direction— and "ends up towards" a certain direction. The terms used to specify directions are the names of winds such as *boreas* and *apêliôtês*, which were conventionally employed to designate directions on the horizon according to various "windrose" schemes. This sentence about directions is followed by a stand-alone adjective (nominative plural, feminine).[100] The last part is a statement that "the color is" a certain hue. Following each paragraph is a single line consisting of a series of alphabetic letters (and at least one nonalphabetic symbol) that do not spell out recognizable words, with horizontal bars over some of the letters.

These letters with and without bars immediately suggest a connection with the index letters of the Saros Dial. To understand the function of the index letters, it is helpful to consider the other place on the Mechanism where such index letters are found.[101] The Zodiac Dial at the center of the front face had a graduated scale representing the twelve zodiacal signs and 360 degrees of the ecliptic. Certain degree marks are labelled with letters, running in alphabetic order. These letters associated their degrees with letter-indexed lines in an inscription elsewhere on the front face listing annually repeating astronomical phenomena, namely the first and last morning and evening visibilities of stars and constellations, solstices and equinoxes, and the Sun's entry into zodiacal signs. When a revolving pointer representing the Sun's longitude on the central dial indicated a labelled degree, the corresponding phenomenon in the indexed inscription was predicted. The index letters of the Saros Dial surely had an analogous function, linking the glyphs to a text, inscribed somewhere else on the Mechanism, that gave fuller information about the predicted eclipses. We may identify the Back Plate Inscription as this text, and the lines of letters alternating with the paragraphs as the index letters that link the preceding paragraphs to the corresponding glyphs. Thus it appears that the predictions in a single paragraph were applicable to several eclipses in the Saros cycle.

Taking Fragment A (some of whose lines are supplemented by Fragment E) and Fragment F together, we appear to have a continuous run of five paragraphs and their associated index letter lines, concluding near the bottom of the Back Plate. We can infer that the index lines belong with the paragraphs that precede them because the final index line (36) is close enough to the lower edge of the plate so that there would be no room for further text. The

100 In one instance, lines 14-15, we appear to have an accusative singular feminine adjective; we think this is a textual error.

101 Price 1974, 18; IAM 3. For the principle of alphabetical indexing, and parallels on some Greek sundials, see Steele 2011, 461-465.

smaller triangular spaces at the four corners of the Back Plate had room for just two paragraphs each, while the two larger spaces at the middles of the plate's right and left sides had room for four. Thus the inscription potentially comprised sixteen paragraphs. One might guess provisionally that paragraphs referring to lunar EPs ran down one side of the plate, and paragraphs referring to solar EPs down the other;[102] such an arrangement would explain why nothing in the surviving part of the inscription seems to identify which kind of eclipses the paragraphs relate to, and why a single index letter was considered as an unambiguous reference for both a lunar and a solar EP when both fell within the same month. We shall see later on, however, that the solar EP paragraphs would not have required all the space available along the right side of the plate.

102 Freeth 2014, 7-8, proposes an arrangement with the lunar paragraphs on the two sides of the Metonic Dial and the solar ones on the two sides of the Saros Dial. However, the first preserved paragraph straddles the line of division between the upper and lower halves of the Back Plate, so the arrangement we propose here appears preferable.

4.10 The groups of index letters[103]

Three index lines are partly preserved on Fragment A, but because of surface damage many of the letters are uncertain. The two index lines in Fragment F, however, are largely legible, and it is with these that we begin our attempt to recover the principle according to which the EPs were grouped. In line 29, we have the letters Λ, Κ, Ζ, and Φ with no visible bar over them, $\overline{\Pi}$ and (uncertainly) Ξ, and a symbol that resembles a notation for the numeral 1000 found in Greek papyri. In line 36, we have Τ and Θ with no visible bar, and $\overline{\mathrm{H}}$ and $\overline{\mathrm{P}}$ with bars. In comparing these letters with the reconstructed Saros Dial scheme (Table 4.5), we need to keep in mind that a bar over a letter may simply have been engraved too slightly to be detectable in the CT. Nevertheless we initially take the readings at face value.

Three securely read barred letters ($\overline{\mathrm{H}}$, $\overline{\Pi}$, $\overline{\mathrm{P}}$) are associated with cells that contained both lunar and solar glyphs. Of the securely read letters with no visible bar, two (Κ, Φ) are also associated with cells containing both lunar and solar glyphs; Λ has a cell that could have had both kinds or just lunar; but the other three (Ζ, Θ, Τ) are associated with cells containing only solar glyphs. It is unlikely that all three of these were really barred letters whose bars are escaping detection, so we can conclude that the part of the inscription that we possess was not entirely concerned with lunar EPs, whereas it may have been entirely concerned with solar EPs.

Now three letters in line 29, Κ, Φ, and $\overline{\Pi}$, turn out to be associated with cells 37, 84, and 172, which contain not only solar EPs but also the first lunar EPs of three of the five groups of seven or eight lunar EPs at six-month intervals. The remaining two of these lunar groups begin with cell 125, which is indexed with $\overline{\mathrm{Z}}$, and either cell 219 or cell 213, which was indexed with one of the undetermined additional letters or symbols that followed the second complete alphabet. When we further observe that a securely read, definitely unbarred Ζ has already appeared in line 18 of the inscription, the conclusion seems inescapable that the Ζ in line 29 was actually supposed to be barred —a scribal error seems likely here rather than a defect of the CT— while the special symbol was one of the additional notations following the complete alphabets. Thus all five cells containing the first lunar EPs of the 8-7-8-7-8 groups were indicated in line 29.

This is a very important result, because it implies that the elongation of the Moon from the node was in some way involved in the groupings of EPs in the inscription. If it is lunar EPs that these five letters in line 29 are referring to, then the Moon was near the maximum negative elongation from the node that is possible for an EP, whereas if the line refers to solar EPs,

103 Some findings in this section confirm conjectures explored, with generally inconclusive results, by T. Freeth in collaboration with some of the present authors (Steele, Jones, and Bitsakis) in 2009. See also Freeth 2014, Notes S2 and S3.

then the Moon had a very small elongation, in the immediate vicinity of the node; either way, we can speak of a comparatively narrow zone of nodal elongation that accounts for most, perhaps all, of the EPs in line 29. The EPs in this group were not, however, all at the same node, since the intervals between them form a cycle of 47-41-47-41-47 synodic months, and as we have seen, an interval of 41 months brings about a change of node.

Turning to the group of index letters in line 36, we observe that one pair among them, $\overline{\text{H}}$ and $\overline{\text{P}}$, designated a pair of cells (131 and 178) that contain both lunar and solar glyphs and that come immediately after cells 125 and 172 whose index letters are in line 29. The other pair, Θ and T, designated cells 31 and 78, which contain only solar glyphs and which, in the sequence of solar EPs, come immediately *before* cells 37 and 84 whose index letters are again in line 29. The fact that the two groups are related in this way leads us to two conclusions: first, that all the letters in both groups probably refer to the solar EPs in the corresponding cells, and secondly, that line 36's group contained solar EPs falling with two small zones of nodal elongation flanking the zone of nodal elongation associated with line 29.

To develop this idea, we calculated nodal elongations for all 38 solar EPs in the Saros cycle, neglecting the effects of solar and lunar anomaly, and hypothetically assigning to the EP of cell 125 a small positive nodal elongation so that the EPs are distributed according to the pattern derived above in which the first lunar EP of the 8-7-8-7-8 cycle is that of cell 172. Fig. 4.14 plots the recomputed nodal elongations, and shows by horizontal lines hypothetical boundaries for a 5° wide zone of nodal elongation (from –1° to +4°, between the solid lines) which takes in most of the identified EPs of line 29 and two 2.5° wide zones (from –3.5° to –1° and from +4° to +6.5°, between the broken and solid lines) which take in most of the EPs of line 36.[104] The graph shows that the EPs of both cells 213 and 219 fall within the central zone; one of these presumably was indexed with the special nonalphabetic symbol in line 29. On the other hand, it cannot be the case that the inscription's groups comprised *all* solar EPs falling within a particular zone as shown in this graph, since by that criterion cell 43's index letter (Λ) ought to be in line 36, rather than line 29.

104 In the graph, double letters AA, BB stand for additional symbols used after the completion of the second alphabetic sequence.

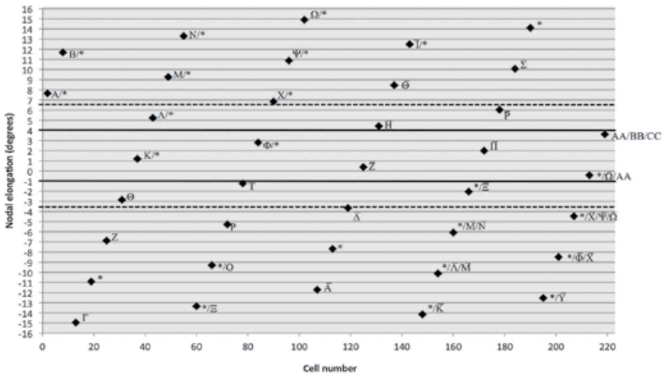

Figure 4.14: *Schematic calculation of nodal elongations of the solar EPs. Asterisks indicate definite or possible omission of a solar glyph according to the reconstructed glyph distribution*

Bringing line 18's index letters into consideration helps to bring out a pattern. This line begins with Z, a probable $\overline{\Theta}$, and Σ. Like the Z in line 29, the Σ in line 18 ought to have a bar though we cannot see it. For it cannot be an accident that we have the following pattern for sets of three consecutive cells:

line 18	*line 36*	*line 29*
Z (cell 25, solar)	Θ (cell 31, solar)	K (cell 37, solar)
$\overline{\Theta}$ (cell 137, lunar-solar)	$\overline{\text{H}}$ (cell 131, lunar-solar)	$\overline{\text{Z}}$ (cell 126, lunar-solar)
$\overline{\Sigma}$ (cell 184, lunar-solar)	$\overline{\text{P}}$ (cell 178, lunar-solar)	$\overline{\Pi}$ (cell 172, lunar-solar)

It appears that, in the progression from the group of line 29 to that of line 36 and then to that of line 18, we are picking successively earlier solar EPs in some series, but successively later ones in others. Hence we may predict that line 18 ought also to contain the index letter P (cell 72, preceding T in line 36), and this is consistent with the space for and doubtful traces of an indeterminate but narrow letter (thus likely I or P) between Σ and the uncertain X.

Summing up, a partial condition for inclusion in a group appears to have been that the Moon's nodal elongation fell within one of two ranges of values symmetrically situated with respect to the range of line 29's group; three series of solar EPs use the ranges on one side of the "central" range, and two series use the ranges on the other side. However, our analysis has not revealed the rationale for the order in which the groups were presented in the inscription, or for the order of the index letters within each group. We can partially confirm the three groups that we have so far discussed as follows, with barring of some letters supplementing what is visible in the images:

(line 29) (symbol)-219 $\overline{\Pi}$-172 K-37 $\overline{\text{Z}}$-125 Φ-84
(line 36) T-78 $\overline{\text{H}}$-131 Θ-31 $\overline{\text{P}}$-178
(line 18) Z-25 $\overline{\Theta}$-137 $\overline{\Sigma}$-184 P-72

This is as far as we had succeeded in understanding the index letter groupings by 2012.

A significant advance has been made subsequently by Freeth, by demonstrating that nodal elongation is not the *immediate* criterion for inclusion in a group, but rather the lunar latitude, which, though functionally dependent on nodal elongation, depends for its sign on both the sign of the elongation and whether the nearby node is the ascending or descending node.[105] In addition to clarifying the principles of inclusion or exclusion of EPs in the groups of the inscription, this hypothesis also satisfactorily explains the order of the index letters in each group. In the following, we adopt this hypothesis in carrying forward our own line of analysis of the data. Our results confirm Freeth's proposal while also showing that his detailed reconstruction of the scheme of EP groupings and their rationale requires amendment.

The hypothetical zones of nodal elongation drawn in Fig. 4.13, which we chose so as to reproduce as well as possible the allotment of index letters in lines 29 and 36 of the inscription, are not symmetrical with respect to positive and negative elongation. Hence if we wish to preserve the grouping while replacing nodal elongation with lunar latitude as the measure, we have to introduce a small negative shift in the assumed elongations. Fig. 4.15 shows the lunar latitudes for the EPs, using elongations reduced by 1.5° from the values assumed in Fig. 4.13, an amount chosen by trial and error. We have drawn horizontal lines as before to demarcate zones (now of lunar latitude) grouping together the index letters in lines 9, 18, 29, and 36. The match of these zones to the evidence of the inscription is now excellent, both in terms of which index letters fall in each group and in terms of the order of the letters, which approximately corresponds to order of decreasing latitude.[106]

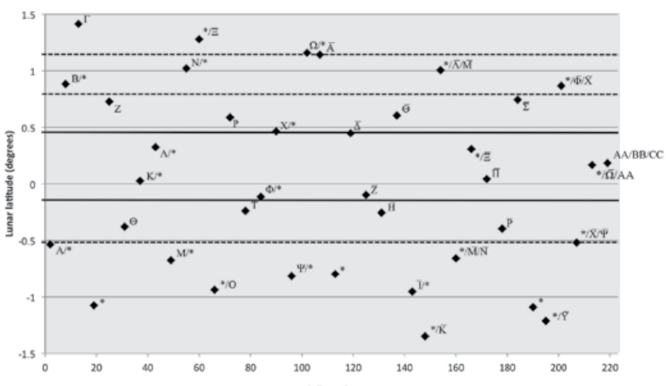

Figure 4.15: *Schematic calculation of lunar latitudes of the solar EPs. Asterisks indicate definite or possible omission of a solar glyph according to the reconstructed glyph distribution*

105 Freeth 2014, Notes S2 and S3.

106 Small discrepancies in the order of letters may be attributed to uncertainties about precisely how the nodal elongations and latitudes were computed.

Freeth noted that the inscription paragraphs to which lines 9, 18, 29, and 36 belong correspond to solar EPs for which the lunar latitude is respectively farther north, north, close to zero, and south. Not being aware of the first three index letters in line 29, however, he conjectured a paragraph with EPs with a range of northerly latitude intermediate between the ranges of lines 18 and 29, placing this in the lost lower left corner of the Back Plate. We can now see that the EPs indexed Λ (cell 43) and $\overline{\Xi}$ (cell 166, restoring a bar over the letter) were part of the line 29 group, which must therefore have extended further north of the ecliptic than it did south. The first index letter of line 29 must have been $\overline{\Delta}$ (again, the bar cannot be seen in the CT), and this establishes an approximate upper bound for the line 29 group's latitudes since the EP labelled X (cell 90), which had close to the same latitude, is confirmed for the line 18 group.

Revising Freeth's reconstruction of the inscription, we propose that the solar EPs were all described in a series of five paragraphs running down the right side of the Back Plate, with the paragraphs as well as the individual EPs within each paragraph ordered from most northerly to most southerly lunar latitude. The paragraph of line 36 was the last one, and in fact all EPs below the southern boundary of line 36's zone in Fig. 4.14 could have had no solar glyph according to our reconstructed distribution. This confirms the hypothesis proposed in the 2008 publication that the omission of solar EPs from the full set of 38 was intended to reflect the effect of parallax, which for an observer in the northern hemisphere makes the Moon's apparent latitude more southerly than its true latitude (calculated as if seen from the center of the Earth).[107]

The exclusion of the EPs with lunar latitude more southerly than the boundary of line 36's zone means that there would have been just 27 solar EPs with glyphs. The complete set of paragraphs for the solar EPs clearly required less than half the available space around the dials on the Back Plate, so we raise the possibility that the paragraphs for the 38 lunar EPs were more detailed and took up all the spaces along the left side as well as the space in the top right corner.

We are now in a position to narrow down the possibilities for reconstructing the glyph distribution of the Saros Dial and the index lines of the Back Plate Inscription's solar paragraphs. We take as principles (1) that all solar EPs that fell within the five more northerly zones in Fig. 4.14 had solar glyphs indexing to the appropriate paragraphs of the inscription (this allows us some restorations and resolutions of unclear letters),**[108]** and (2) that all solar EPs

107 Freeth, Jones, Steele, & Bitsakis 2008, 616.

108 Lost index line corresponding to northernmost zone restored as Γ Ξ Ω. Line 9 restored as $\overline{\mathrm{A}}$ N $\overline{\Lambda}$ B $\overline{\Phi}$. Line 18 restored as Z $\overline{\Theta}$ $\overline{\Sigma}$ P X (though $\overline{\Sigma}$ should properly be in either first or second place). Line 29 restored as $\overline{\Delta}$ Λ $\overline{\Xi}$ (symbol) $\overline{\Pi}$ K $\overline{\mathrm{Z}}$ Φ. Line 36 requires no restorations: T $\overline{\mathrm{H}}$ Θ $\overline{\mathrm{P}}$ $\overline{\Psi}$.

that fell in the southernmost zone did not have solar glyphs. The first of these principles gives us the following restorations of the index lines of the inscription:

4? Γ Ξ Ω
9 $\overline{\mathrm{A}}$ N $\overline{\Lambda}$ B $\overline{\Phi}$
18 Z $\overline{\Theta}$ $\overline{\Sigma}$ P X
29 $\overline{\Delta}$ Λ $\overline{\Xi}$ (symbol) $\overline{\Pi}$ K $\overline{\mathrm{Z}}$ Φ
36 T $\overline{\mathrm{H}}$ Θ $\overline{\mathrm{P}}$ $\overline{\Psi}$

The paragraph for the most northerly solar EPs ought to have been the one represented by the very damaged lines 1-4 if the solar paragraphs were all together and in appropriate order from north to south; that there *was* a paragraph for these EPs is certain since the extant solar glyph in cell 13 (Γ) belongs in it. We suggest that the clear but fragmentary trace of a single letter in line 4 was the right half of omega in its cursive (open-topped) form.[109] The barred sigma in line 18 should, as Freeth already noted, be the first index letter in the line; we agree with him that this is probably a copying error.[110]

The principles turn out to eliminate all uncertainties in the Saros Dial's glyph sequence except for whether the second last lunar EP was in cell 213 or 214 (Table 4.6). If the lunar 8-7-8-7-8 sequence began with cell 172, cell 213 was a solar-lunar glyph, cell 214 was vacant, and only cells 213 and 219 were indexed by nonalphabetic symbols; if the sequence began with cell 37, cell 213 was solar, 214 lunar, and the three cells 213, 214, and 219 had nonalphabetic symbols. Thirdly, according to our reconstruction both cells 213 and 219 ought to be referenced in line 29, one after the other in the list. Since there is only one nonalphabetic symbol in this line, we think it is possible that the same symbol served for both cells.

109 The cursive omega is not attested elsewhere in the Mechanism's inscriptions as a letter in its own right, but the symbol for ὥρα in the glyphs is based on this form.
110 Freeth 2014, Note S3, 3.

Table 4.6: *Revised glyph sequence reconstruction for the Saros Dial*

Cell	*EP*	*index*
2	Σ*	Α
8	ΣΗ	Β
13	Η	Γ
14	Σ	Δ
19	*	*
20	Σ	Ε
25	Η	Ζ
26	Σ	Η
31	Η	Θ
32	Σ	Ι
37	ΣΗ	Κ
43	ΣΗ	Λ
49	Σ*	Μ
55	ΣΗ	Ν
60	Η	Ξ
61	Σ	Ο
66	*	*
67	Σ	Π
72	Η	Ρ
73	Σ	Σ
78	Η	Τ
79	Σ	Υ
84	ΣΗ	Φ
90	ΣΗ	Χ
96	Σ*	Ψ
102	ΣΗ	Ω
107	Η	$\overline{\mathrm{A}}$
108	Σ	$\overline{\mathrm{B}}$
113	*	*
114	Σ	$\overline{\Gamma}$
119	Η	$\overline{\Delta}$
120	Σ	$\overline{\mathrm{E}}$
125	ΣΗ	$\overline{\mathrm{Z}}$
131	ΣΗ	$\overline{\mathrm{H}}$
137	ΣΗ	$\overline{\Theta}$

Cell	*EP*	*index*
143	Σ*	$\overline{\mathrm{I}}$
148	*	*
149	Σ	$\overline{\mathrm{K}}$
154	Η	$\overline{\Lambda}$
155	Σ	$\overline{\mathrm{M}}$
160	*	*
161	Σ	$\overline{\mathrm{N}}$
166	Η	$\overline{\Xi}$
167	Σ	$\overline{\mathrm{O}}$
172	ΣΗ	$\overline{\Pi}$
178	ΣΗ	$\overline{\mathrm{P}}$
184	ΣΗ	$\overline{\Sigma}$
190	Σ*	$\overline{\mathrm{T}}$
195	*	*
196	Σ	$\overline{\Upsilon}$
201	Η	$\overline{\Phi}$
202	Σ	$\overline{\mathrm{X}}$
207	Η	$\overline{\Psi}$
208	Σ	$\overline{\Omega}$
213	Η (ΣΗ)	symbol
214	Σ	symbol
	(no glyph)	(no glyph)
219	ΣΗ	symbol

4.11 The direction statements

What would the information in the paragraphs have meant in relation to eclipses? To anyone familiar with the treatment of eclipses in ancient Near Eastern and Greco-Roman astronomy and astrology, the statements about directions will suggest two possible meanings: either the directions from which the lunar or solar disk appears to be obscured at the various stages of the eclipse, or the changing directions of actual winds blowing during the eclipse. The adjectives and adjectival phrases seem to be a qualitative indication of the eclipse magnitude. Lastly, the colors would be descriptive of the appearance of the lunar or solar disk during the eclipse. We will explore these interpretations at greater length below.

From a modern point of view, no natural connection is to be expected between the occurrence of an eclipse and the blowing of winds in a locality where it is observable, except for the marginally verified phenomenon of winds induced by total solar eclipses.[111] Nevertheless there was a strong tradition in Mesopotamian and Greek astronomy, astrology, and meteorology regarding "eclipse winds" as observable and significant phenomena. The tablets of lunar eclipse omens in the Babylonian series *Enūma Anu Enlil* (composed before the 7th century BC) contain many omen texts in which the directions from which the lunar disk is obscured at the beginning and end of the eclipse, or the direction of the wind blowing during the eclipse, or both are factors in the "if" clause of the omen.[112] Babylonian eclipse observations from the first millennium BC also regularly include reports of the directions of obscuration at the eclipse's beginning and end as well as the wind direction prevailing during the eclipse (occasionally it is noted that the wind direction was different at the beginning and end of the eclipse).[113] We have no evidence that Babylonian astronomers made predictions of directions of obscurations or wind directions during eclipses.[114]

The Greeks definitely believed that wind directions were to some degree predictable. Many of the annually recurring weather phenomena recorded in *parapêgmata* in relation to stellar first and last visibilities, solstices, and equinoxes were specific directional winds. Nor did this presumed annual cycle preclude other intermittent weather signs predicting winds; non-annual phenomena, both meteorological and astral, could also act as weather signs. Shooting stars, for example, were signs predicting winds blowing from the quarter to which they were seen

111 For the apparent reality of the solar "eclipse wind" see Gray & Harrison 2013.

112 Rochberg-Halton 1988, 51-55 and 57-60. Interestingly, the solar eclipse omens do not incorporate winds or directions of obscuration in their "if" clauses (Francesca Rochberg by personal communication).

113 Huber & De Meis 2004; Gautschy 2012.

114 Cuneiform texts survive containing schemes for predicting weather through correlation with planetary periods, but they make no reference to specific wind directions or eclipses; see Hunger 1976.

heading;[115] if the northern or southern stars of Cancer called *Aselli* (ὄνοι, γ and δ Cnc) become invisible, it is a sign respectively for the north or south wind;[116] ebb tide signified a north wind and flood tide a south wind;[117] frequent flashes of lightning in one part of the sky signified wind from that direction.[118] Ptolemy attributes to both the planets and the zodiacal signs a power to set particular winds in motion.[119] The unknown author of the book on weather signs conventionally attributed to Theophrastos mentions that weather changes are correlated with the Moon's phases,[120] and that a gap observed in a halo around the Moon or Sun indicated the onset of a wind from the quarter corresponding to the orientation of the gap.[121]

A connection between eclipses and winds is mentioned by Aristotle, *Meteorologica* 367b25-32, where it is asserted that an onset of wind occurs *before* a lunar eclipse (at sunset for a midnight eclipse, at midnight for a dawn eclipse).[122] Otherwise we know of no instances in Greco-Roman sources of either specific predictions of winds, and particularly of wind *directions*, during eclipses, or methods of making such predictions, though we shall presently see that Ptolemy was probably aware of the existence of such methods. The astrologer Hephaistion of Thebes (c. A.D. 400) attributes to the "Egyptians of old" a doctrine that the direction from which the wind blows at the onset of an eclipse indicates the country that will be adversely affected by it, whereas the direction at the end of the eclipse indicates the country that will be favorably affected; thus a *change* of wind direction was considered normal during an eclipse.[123] Hephaistion's "Egyptians" were almost certainly Greco-Egyptian astrological authorities dating from the Hellenistic period, so they are not very remote chronologically or culturally from the builders of the Antikythera Mechanism.[124]

The verb in the Back Plate Inscription translated as "to veer," περιίστασθαι, is not especially common, and a search of ancient Greek literature by means of the *Thesaurus Linguae Graecae* fails to turn up any passage in which the verb is used in connection with eclipse phenomena. There are, however, instances of its use in connection with shifting wind directions,**[125]** in-

115 [Aristotle], *Problemata* 26.23; Pseudo-Theophrastos, *De Signis* 37; Ptolemy, *Tetrabiblos* 2.14.10 (Hübner).

116 Ptolemy, *Tetrabiblos* 2.14.9 (Hübner) —possibly an interpolated sentence— and Hephaistion, *Apotelesmatica* 1.3 (Pingree 33).

117 Pseudo-Theophrastos, *De Signis* 29.

118 Pseudo-Theophrastos, *De Signis* 32.

119 Ptolemy, *Tetrabiblos* 2.13.4 (Hübner).

120 Pseudo-Theophrastos, *De Signis* 5-8.

121 Pseudo-Theophrastos, *De Signis* 31.

122 A close parallel to this passage is in [Aristotle], *Problemata* 26.18.

123 Hephaistion, *Apotelesmatica* 1.21.

124 Pingree 1974.

125 For others, see [Aristotle], *Problemata* 26.31 (943b29) and 26.56 (947a3).

cluding a striking parallel to the formula of our inscription in Aristotle, *Meteorologica* 365a6:

"οἱ δ ᾽ἐτησίαι περιίστανται τοῖς μὲν περὶ δυσμὰς οἰκοῦσιν ἐκ τῶν ἀπαρκτίων εἰς θρασκίας καὶ ἀργέστας καὶ ζεφύρους... τοῖς δὲ πρὸς ἕω περιίστανται μέχρι τοῦ ἀπηλιώτου".
("For people who live in the west, the Etesian winds veer from *aparktias* to *thraskias* and *argestês* and *zephyros*... while for those who live in the east, they veer to *apêliôtês*".)

Aristotle's use of this construction enables us to dismiss an objection that has been raised against interpreting the inscription's wind-directions as references to actual winds, namely that the horizon directions associated with Greek wind names were (as in English) the directions *from which* the winds blow, so that the preposition πρός, "towards," would never be used with a wind-direction name to mean the wind bearing that name.[126] One would indeed never write that a wind blows πρὸς ἀπηλιώτην, "towards *apêliôtês*" meaning towards the east, since the wind that blows in that direction is called *zephyros*, the *west* wind. But it does make sense in Greek, as in English, to write that the wind direction shifts from south to east (ἀπὸ νότου πρὸς ἀπηλιώτην, or using Aristotle's equivalent expressions, εἰς ἀπηλιώτην or μέχρι ἀπηλιώτου) meaning that what was initially a south wind (blowing north) has become an east wind (blowing west).

However, before hastening to the conclusion that the vocabulary of our inscription was associated with winds but not with eclipse obscurations, we ought to take note of *POxy. astron.* 4137, a first century AD Greek papyrus fragment from Oxyrhynchus that, like most literary and "paraliterary" papyri, is not at present in the *Thesaurus Linguae Graecae*.[127] This preserves part of a canon of predictions of lunar eclipses dating to the mid first century AD, the only such text in Greek that we currently possess. The predicted data include the date of the eclipse, its magnitude and duration, the directions of obscuration (προσνεύσεις, "inclinations") at the beginning, middle, and end of the eclipse, and the Moon's position relative to a fixed star. The directions of obscuration of the partial lunar eclipse of December 10/11, AD 56 are described thus in lines 4-9:

"ἡ μὲν ο[ὖν πρόσν(ευσις) πρώτου] ἐγλ(ελοιπότος) ἔσται μεταξὺ μ̣[εσημβρίας καὶ] ἀνατολ(ῆς)· περιστήσε[ι δὲ πλεῖστον] ἐγλελοιπὸς πρόσν̣(ευσιν) [ὡς πρὸς μεσημβ(ρίαν)]· ἔσχατον δ ᾽ἀναπ[ληρούμενον ὡς] μεταξὺ μεσημ(βρίας) καὶ δ̣[ύσεως.]"
("The [inclination of the beginning] of obscuration will be between s[outh and] east; at [greatest] obscuration it will cause the inclination to veer [towards the south]; at final cle[aring] towards south and w[est.]")

Although some uncertainty may adhere to the exact wording of the gaps between the preserved part-lines, it is certain that the incomplete word περιστησε in line 6 is either περιστήσεται, the future tense of περιίστασθαι, "it will veer" or (as restored here), περιστήσει, the future

126 Papathanassiou 2010, 546.
127 Jones 1999, 1.87-94, and 2.16-17.

of the verb's transitive form, "it will cause to veer" with the direction of obscuration being either the subject or the direct object.

The terminology of "inclinations" found in this papyrus is only intelligible to us because Ptolemy explains it in *Almagest* 6.11, where as part of the subject of eclipse theory and prediction he provides a mathematical treatment of "inclinations," interpreted as meaning the point on the horizon intersected by the great circle passing through the centers of the lunar disk and the Earth's shadow (for lunar eclipses) or the centers of the solar and lunar disks (for solar eclipses). He remarks that the reason for determining these directions is that they are regarded as having a certain "signification" (ἐπισημασία), a term that had the technical meaning of a "weather-prediction sign" or a change in the weather associated with such a sign.[128] Although Ptolemy offers no details, it is tempting to conjecture that some correlation was presumed to exist between the directions of obscuration and the wind directions at the various stages of the eclipse. Such a scheme would explain why the Hephaistion's "Egyptian" scheme involves interpreting wind directions at both the start and the finish of an eclipse.

Thus we cannot decide simply on the basis of the wording of the "directions" sentences in the Back Plate Inscription whether their predictions refer to directions of obscuration or to winds. *Prima facie* the interpretation as directions of obscuration seems to be favored by the fact that these directions are an objectively valid, "astronomical" consequence of the conditions giving rise to an eclipse, whereas forecasts of wind directions would imply a physical (or even divinatory) framework that is otherwise not explicit in what we know of the Mechanism's displays and functions; for although parapegmata were instruments of weather prediction, the Mechanism's Parapegma Inscription did not contain explicit statements of weather changes but only the astronomical phenomena on which such predictions could have been based. But these considerations that weigh on the side of obscuration directions will count for nothing unless the specific content of the statements as well as the index letters associated with them turn out to make sense in terms of the actual characteristics of a series of eclipses occurring in the course of a Saros cycle.

As a first step in testing the hypothesis that the sentences refer to obscuration directions, we consider the meaning of the directional terms in the inscription. In technical contexts Greek wind names were associated with "windroses," that is, systems of either eight or twelve equally distributed horizontal directions.[129] Though several variations on windroses are attested in Greco-Roman sources, it is probable that the one assumed in the Back Plate Inscription was close to one of the following reconstructions (the twelvefold one being essentially the windrose ascribed to the Hellenistic geographer Timosthenes) (Fig. 4.16).[130]

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128 Neugebauer 1975, 1.141-142; Lehoux 2004.

129 Rehm 1916.

130 As Crowther (Freeth 2014, Note S2, 2) points out, the presence of θραικίας among

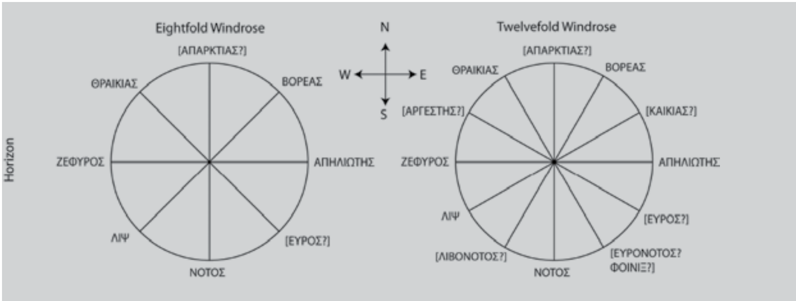

Figure 4.16: *Reconstructed eight-direction and twelve-direction windroses for the directions attested in the Back Plate Inscription*

Of course if one is applying such a scheme to the solar or lunar disk as seen from below, the diagrams have to be mirror-reversed (Fig. 4.17).

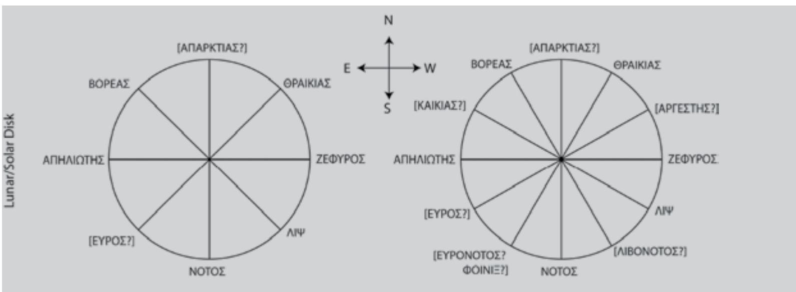

Figure 4.17: *Reconstructed windroses oriented for celestial directions*

Now if we number the preserved paragraphs of the inscription 1 through 5, the directions of the statement in paragraph 1 are both lost, while the remainder would map on the windroses as shown in Fig. 4.18.

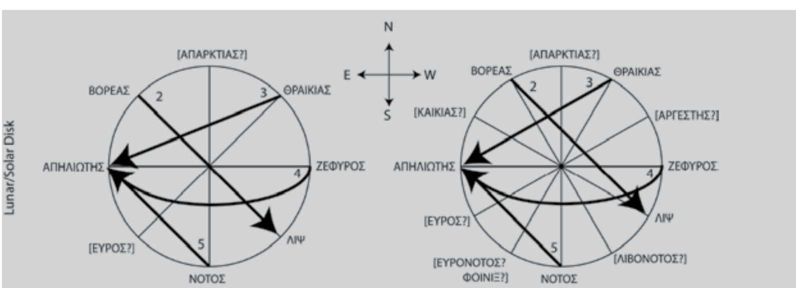

Figure 4.18: *The shifts of direction in the Back Plate Inscription*

the wind directions in the inscription favors a twelve-direction windrose since attested eight-direction systems did not include this wind.

The diagrams incidentally explain why an intermediate direction is specified in paragraph 4 only: whereas in most cases —all cases for the twelve-direction system— one may presume that the "veering" sweeps out the shorter arc around the circle, here the starting and finishing directions are diametrically opposite so that the sense of the shift has to be explicitly stated.

A basic rule is that the obscuration in lunar eclipses tends westward, but eastward in solar eclipses. Hence paragraphs 3-5 would refer to solar eclipses, but paragraph 2 would have to refer to lunar eclipses. Aside from being in conflict with our analysis of the index letter groups, this is troubling for two reasons. First, in an inscription encompassing both lunar and solar eclipses, one would expect the two kinds to be dealt with in separate sections, whereas here we seem to have both kinds treated in what, according to its position on the plate, would seem to be the last quarter of the inscription. And more seriously, solar eclipses do not repeat their directions of obscuration after 223 months — as we have already remarked with respect to eclipse times, the Saros is only meaningful as a period of repetition for solar eclipse *possibilities*, not actual solar eclipses visible from a particular region of the Earth because of the effects of parallax. Predictions of directions of obscuration for solar eclipses based on a repeating Saros cycle could only refer to a highly idealized model in which the effect of parallax is ignored or grossly simplified and the diameter of the lunar disk considerably exaggerated. Such predictions would have scarcely any relation to actual eclipses observable in any locality.

If, notwithstanding these difficulties, the paragraphs are describing the shifting directions of obscuration of eclipses, one would have to conclude that they cannot be in an ecliptic frame of reference, that is, east and west are not reckoned as parallel to the ecliptic. Since the Moon is always close to one of its nodes at an eclipse, the obscuration always crosses the eclipsed body in a direction inclined approximately 5° from the ecliptic, whereas our diagrams would imply much more deviant paths. The ecliptic frame of reference is the only one that preserves directions of obscuration in the long term through a series of eclipses —properly, just lunar eclipses!— at Saros intervals, because the relative orientation of the Sun and Moon would not stay the same relative to the celestial equator or the observer's horizon. Since the Saros exceeds 18 solar years by just about 11 days, however, the configuration would not change by much in an equatorial frame of reference after a single Saros. One might contemplate the possibility that the directions in the text are reckoned such that east and west are parallel to the celestial equator, and that the predictions were at best valid for a run of a few Saros cycles around the epoch for which they were calibrated. For eclipses occurring close to the equinoxes and at the right node, the path of obscuration deviates from the equator by almost 30°, perhaps enough to make a predicted course "from *notos* to *apêliôtês*" or "from *boreas* to *lips*" credible. Ptolemy's hypersophisticated "inclinations" projected by great circles upon the horizon are out of the question.

Moreover, we cannot reconcile the groupings of letters in the index lines, as we have reconstructed them, with any rational prediction of obscuration directions according to even an idealized, parallax-free eclipse theory. The trend of the obscuration, at least in an ecliptic frame of reference, should be northward for all eclipses having the Moon near the ascending node, and southward for all eclipses having it near the descending node. We have seen, however, that solar EPs near opposite nodes are grouped together in the inscription's paragraphs.[131]

We may sum up as follows. (1) Any competent Hellenistic astronomer would have known that it does not make astronomical sense to offer predictions of obscuration paths of solar eclipses following a Saros cycle, yet if the statements in the inscription are about obscuration paths, the surviving ones are for solar eclipses. (2) To the extent that a Saros cycle is a suitable framework for predicting obscuration paths —i.e. for lunar eclipses— it works best if the frame of reference is the ecliptic, because the Saros is not close enough to an integer number of solar years to preserve paths relative to the equator over more than one or two cycles, while the configurations relative to the horizon are not preserved at all. Yet the pairs of directions in some of the paragraphs of the inscriptions deviate too far from due east-west orientation to be obscuration paths in an ecliptic frame of reference. (3) The cells indicated by the index letter groups would not have corresponded to eclipses with similar obscuration paths.

Taking into consideration the level of astronomical knowledge reflected in the mechanical design of the Mechanism, it is difficult to believe that the astronomer-mathematician responsible for the scientific content of its inscriptions would have bungled the prediction of obscuration paths so badly. We are therefore led to prefer the alternative interpretation of the statements in the inscription as predictions of winds attending the eclipses. While of course a correlation between nodal elongations at eclipses (or EPs) and changes of wind direction does not really exist, ancient meteorological theories made such a correlation perfectly reasonable.[132]

131 Freeth 2014, Note S2, 4-6 attempts, unconvincingly in our view, to maintain that the predictions of the inscription are of eclipse obscurations. In this context he does not mention the fact that the prediction associated with the EPs in line 9 gives an impossible direction for solar eclipses.

132 Montelle 2011, 152 draws attention to how Hellenistic astrological authors mutated the Mesopotamian practice of treating directions of eclipse obscurations as data for interpreting eclipse omens into one using wind directions, and suggests that this tendency may have been motivated by the fact that directions of obscuration do not have a very wide range of variation, limiting their prognostic usefulness.

4.12 Sizes and colors

The paragraphs of the inscriptions may be summarized as follows:

Paragraph	*Directions*	*Size*	*Color*
1 (lines 0-4)	?	small	?
2 (lines 5-9)	NNE to WSW	intermediate	black
3 (lines 10-18)	NNW to E	large?	red
4 (lines 19-29)	W *via* S to E	intermediate	black
5 (lines 30-36)	S to E	small?	black

The directions, as already noted, do not reveal any obvious pattern. The sizes, however, show, if the readings for the third and fifth paragraphs are correct, a symmetrical progression from small to large to small again.[133] The unstated subject to which these characteristics are attributed is grammatically feminine plural, so ἐκλείψεις ("eclipses") is possible but "winds" (ἄνεμοι) is not. While it is tempting to think of magnitudes or durations of obscuration, once again we run into the problem that the Saros does not bring about repetitions of these aspects of solar eclipses because they are strongly affected by parallax.[134] We suppose that they may be understood as a qualitative "upper bound" for both magnitudes and durations.

The readiest interpretation of the color predictions is that they refer to the appearance of the Sun's disk during the eclipse. For the third color in paragraph 1, possibilities that we can think of that have the surviving -ινον termination include πράσινον ("light green"), σκοτεινόν ("dark"), and κόκκινον ("scarlet"). In the other paragraphs, the colors seem to correlate with the size predictions in that the "large" eclipses are assigned red and the "medium" and southerly "small" eclipses are assigned black.

Babylonian lunar eclipse omen texts frequently cite the color of the eclipsed luminary as an element in the protases ("if" clauses), and this, like eclipse winds, passed into the treatment of eclipses in Hellenistic astrology.[135] Hephaistion (1.21) tells us that his "Egyptians of old" assigned various dire consequences to total eclipses —he does not discriminate between lunar and solar— according as the color is "black" (μέλαν), "red" (ἐρυθρόν), "whitish" (ὑπόλευκον), "violet" (ἰοειδές), or "golden" (χρυσοειδές).[136] Ptolemy (*Tetrabiblos* 2.10 Hübner) does not

133 This was noticed by Freeth 2014, Note S2, 6, though he assumes a six paragraph reconstruction with another "large" paragraph between our numbers 3 and 4.

134 Freeth 2014, Note S2, 6 interprets them as magnitudes.

135 Rochberg-Halton 1988, 55-57. Francesca Rochberg informs us by personal communication that colors are less prominent in the Babylonian solar eclipse omens, though the color of the Sun's light (e.g. "red" or "cool") is sometimes a factor in the omen.

136 In 1.23 Hephaistion gives σκοτεινόν as one of the possible colors of Sirius at its first

restrict the relevance of colors to total eclipses, and in fact he attributes the same significance not only to the color of the luminary itself but to that of nearby optical phenomena such as rods and halos. His colors include "black" (μέλαν), "greenish yellow" (ὑπόχλωρον), "white" (λευκόν), "ruddy" (ὑπόκιρρος), "yellow" (ξανθόν), and "variegated" (ποικίλον).

Outside of the Back Plate Inscription, we are not aware of any Greco-Roman source that offers predictions of eclipse colors or indeed states that such colors are predictable. It is conceivable that certain schemes found in Indian astronomical texts for predicting changing colors through the course of an eclipse derive from Greek astronomy.[137] Much more relevant to our inscription, however, are medieval Arabic and Hebrew tables that predict colors of both solar and lunar eclipses as a function of nodal elongation, that is, a criterion closely related to the one determining the EP groups in our inscription.[138] The color schemes tend to run from black at the nodes themselves through reddish, yellowish, and grayish hues as the absolute elongation increases, in other words a similar pattern to the one apparent in our inscription. Goldstein offers remarks that have equal bearing to the color predictions in our inscription:[139]

"From a modern point of view, there should not be a table for colors of solar eclipses; for lunar eclipses, the modern theory bears little relationship to the medieval table… Although the entries in the medieval tables do not conform to modern data, this tradition may well have affected the perception of reality by those who accepted it".

Following Pingree, Goldstein conjectures that the earliest tables for predicting eclipse colors were in the *zij* of al-Khwarizmi (c. A.D. 830) and that the doctrine had an Indian origin. It now appears plausible that the ultimate source was Greek, and if there was an Indian intermediary, it was different from the known Indian schemes that prescribe changing colors to different stages of an eclipse.

morning appearance.

137 Montelle 2011, 219 and 241-242.

138 Goldstein 2005.

139 Goldstein 2005, 12; Pingree 1976, 166.

4.13 General remarks on the inscriptions of the Mechanism's back face

The layout of the back face of the Antikythera Mechanism seems to have been designed to give immediate visual impact to a parallelism between the information displayed in its top and bottom halves: each spiral represents an astronomically meaningful cycle of comparable length comprising whole numbers of synodic months, in one case equated to a whole number of solar years, and in the other, to whole numbers of anomalistic and dracontic months. If the conjectural Callippic Dial was present, then a second parallelism subsisted between subsidiary dials within each spiral representing the smallest multiple of the spiral's cycles that contained a whole number of days; and the Games Dial too is a representation of the smallest multiple of *solar years* comprising a whole number of days.

The inscriptions, on the other hand, add quite contrasting overlays of meaning to each half. The Metonic Spiral translates a purely astronomical relation between mean lunar and solar longitudinal periods into a calendar, and moreover a regional calendar that had no distinctive role in Greek astronomy (as the Athenian and Egyptian calendars did) and that would not have been well known outside the specific localities where it was in use at the time that the Mechanism was made. Geminos's chapter "On Months" (*Introduction to the Phenomena* 8) is illuminating here for its treatment of calendars as human inventions based on astronomical facts but fundamentally determined by the requirements set by the societies that use them. Again, the inscriptions of the Games Dial refer to athletic competitions, that is, *social* phenomena that had four-year and two-year periodicities unconnected with astronomy; for example, the fact that a competition was held at Olympia every four years had nothing to do with the 365 1/4 day solar year.

The inscriptions of the lower dials, on the other hand, relate them not to social but to natural phenomena, namely eclipses. The decision to represent the Saros cycle as, above all, a cycle of eclipse possibilities was not as obvious as it might at first appear.[140] Among the three ancient Greco-Roman writers on astronomy who discuss the Saros or the Exeligmos, it is only the encyclopedist Pliny the Elder (*Naturalis Historia* 2.56) who explicitly characterizes the Saros as an eclipse period, whereas Geminos (*Introduction to the Phenomena* 18) and

140 We do not know of another Greco-Roman text or artefact that definitely employs a subdivision of the Saros into a fixed arrangement of eclipse possibilities at 6-month and 5-month intervals, though the principle was likely applied in a first century BC canon of predicted lunar eclipses fragmentarily preserved in a Demotic Egyptian papyrus (Steele 2000b, 89). An anonymous third-century AD commentator on Ptolemy (Jones 1990, 22-23) and Plutarch, *De facie in orbe lunae* 20, 933 E both discuss such a distribution with the more accurate 5458-month lunar anomalistic period of the Babylonian System B lunar theory, which was known to Hipparchus.

Ptolemy (*Almagest* 4.2) speak of the Saros and Exeligmos as periods of synodic months that approximately comprise whole numbers of anomalistic and draconitic months, in other words, theoretically meaningful period relations for the Moon's motion rather than periods of lunisolar phenomena. In designing the Mechanism's gearwork, its inventors exploited the Ptolemy-Geminos interpretation of the Saros as the basis for reproducing lunar anomaly, but the exterior makes only a slight gesture towards this theoretical side of the Saros in the form of the unlabelled fiducial marks inscribed along the inner rim of the Saros Dial that apparently indicate the Full Moon cycle.[141]

The fact that every cell of the Saros Dial that contains a glyph has an index letter implies that the complete Back Plate Inscription contained information supplementing both lunar and solar eclipse possibilities; however, we have only a little over half of the text from the lower right side of the plate, which, as we have seen, appears to have been devoted entirely to solar eclipse possibilities. Whether the descriptions of lunar eclipses had the same format and contents as the solar paragraphs, and whether they were likewise grouped solely according to the criterion of lunar latitude without taking into account which node the Moon was near have to remain open questions.

Knowing, as they surely did, that the Saros could not predict whether a solar eclipse possibility would be accompanied by an observable eclipse, let alone its duration and magnitude, the designers could simply have left the predictions of solar eclipse possibilities as bare statements with at most a time of syzygy. Instead, they appear to have offered predictions of optical or meteorological circumstances that they expected would accompany a solar eclipse *if* an eclipse occurred at an eclipse possibility. The correspondences between these predictions and the eclipse phenomena invoked in the astrological literature are surely not accidental. We see it as an indication that the Mechanism was fashioned to represent and simulate a Hellenistic cosmology in which astronomy, meteorology, and astral divination were intertwined.

141 Freeth, Jones, Steele, and Bitsakis 2008, Supplementary Notes (amended June 2, 2011) 39-40.

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Almagest

Supplementary Illustrations

Figure S1. Fragment A-2. Offset remains of the Back Cover Inscription covers part of the lower right. Remains of the Back Plate Inscription and Saros Dial scale are exposed in the extreme right center, and part of the Exeligmos Dial at the bottom, slightly right of center (Image: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

5
cm

Figure S2. Fragment B-1. Offset remains of the Back Cover Inscription cover the left two-thirds, with a small fragment of the Back Cover plate adhering at the extreme lower left. Parts of the Metonic Dial scale inscriptions are exposed to the right (Image: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

Figure S3. Fragment C-1. Parts of the Zodiac Scale (inner ring) and Egyptian Calendar Scale (outer ring) are exposed at the top and lower right. Covering them are parts of Parapegma Plate 1 (PP1, top) with a portion of the Parapegma Inscription exposed and of Parapegma Plate 2 (PP2, bottom)
(Image: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sportσ/Archaeological Receipts Fund)

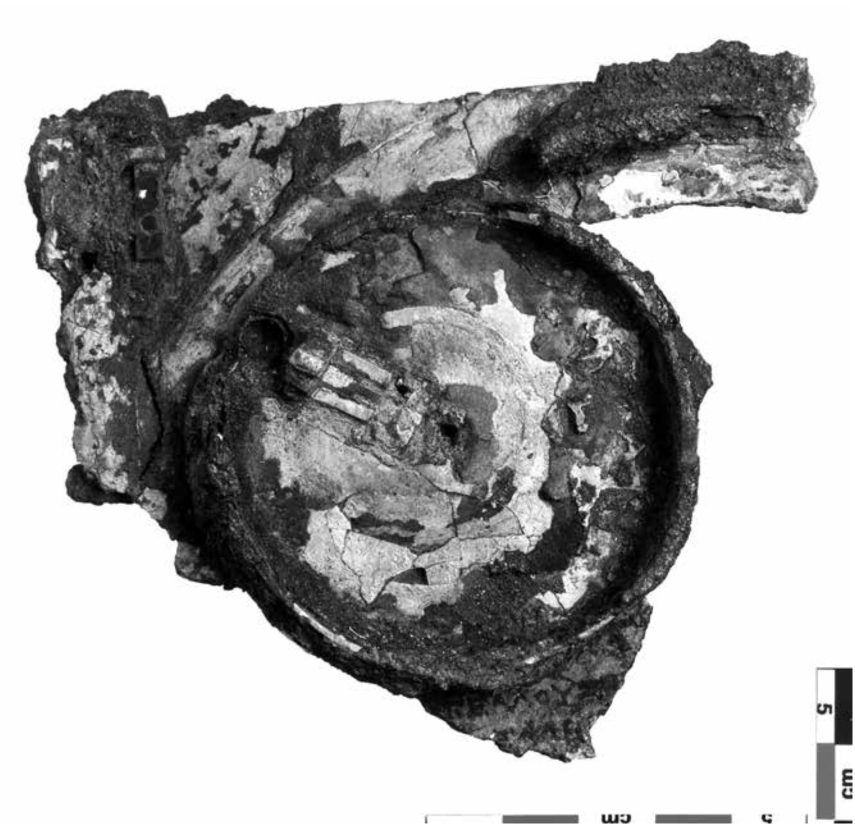

Figure S4. Fragment C-2. Part of Parapegma Plate 2 with a portion of the Parapegma Inscription is exposed at the bottom. The large circular feature is the apparatus for the Moon phase display, seen from what would have been the Mechanism's interior (Image: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

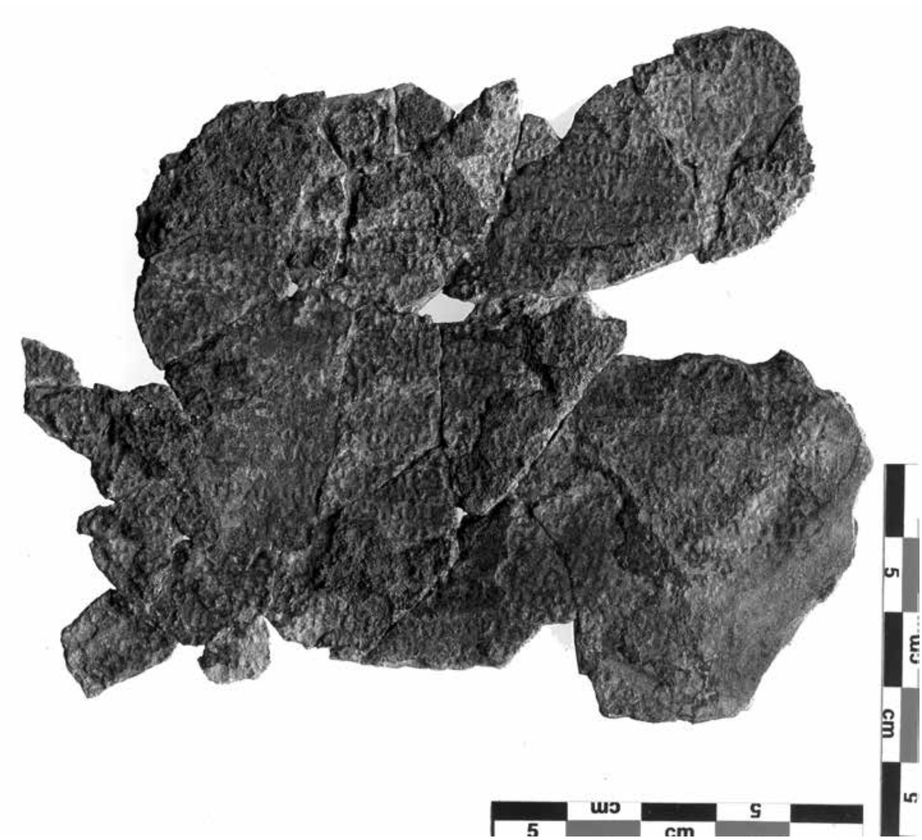

Figure S5. Fragment G, bearing part of the Front Cover Inscription (Image: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright: Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)

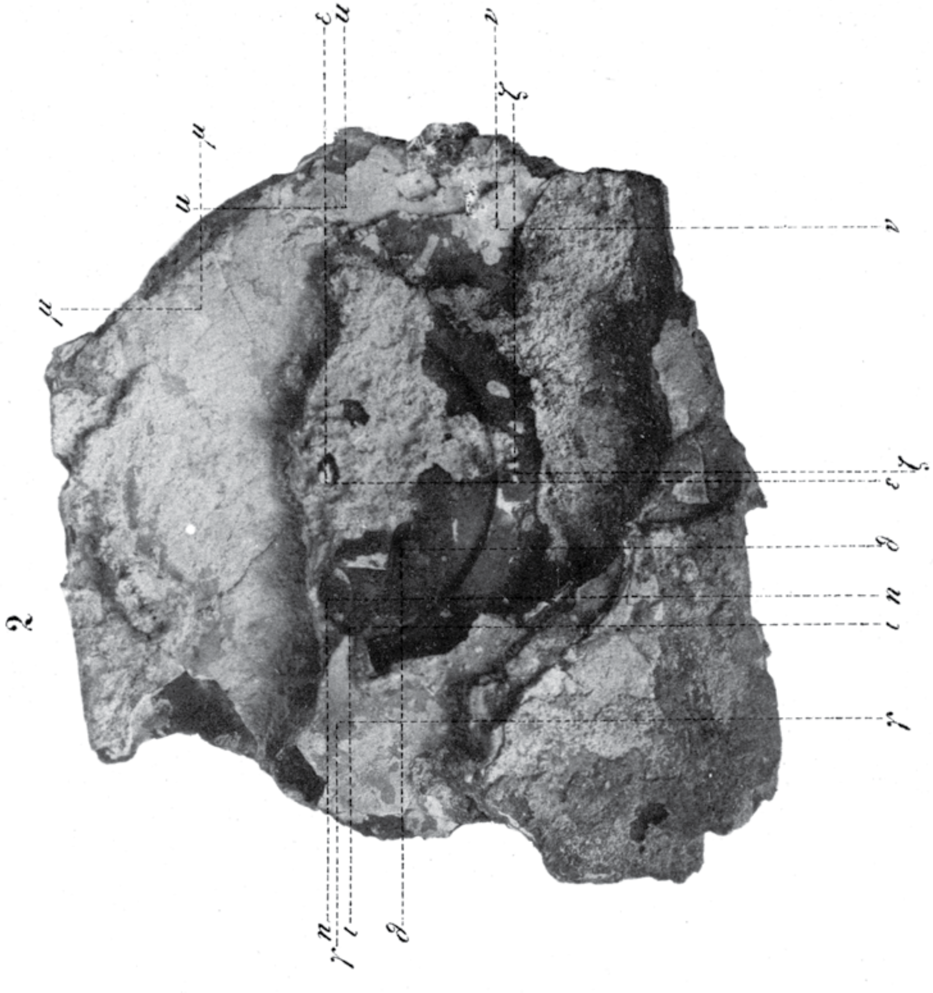

Figure S6. Fragment A-2 in 1902-1903, before conservation. Less of the Back Plate Inscription was exposed at the extreme right center than at present, and none of the Saros Dial and Exeligmos Dial inscriptions could be seen. Part of the Back Cover plate (incorporating the present Fragments 19 and 67), with the inscribed face inwards, was still attached in the lower right, concealing the offset remains of the Back Cover Inscription that are now exposed (Image: Svoronos 1903a/1903b, Plate X)

Figure S7. Fragment A-2 in 1918 (?), after the c. 1905 conservation, which involved the separation of Fragments 19 and 67. The Back Plate Inscription and a part of the Saros Dial scale were exposed in the extreme right, as at present. The offset remains of the Back Cover Inscription were more extensive than at present. The Exeligmos Dial was still concealed under patina
(Image: Bayerische Staatsbibliothek, Rehmiana III 9)

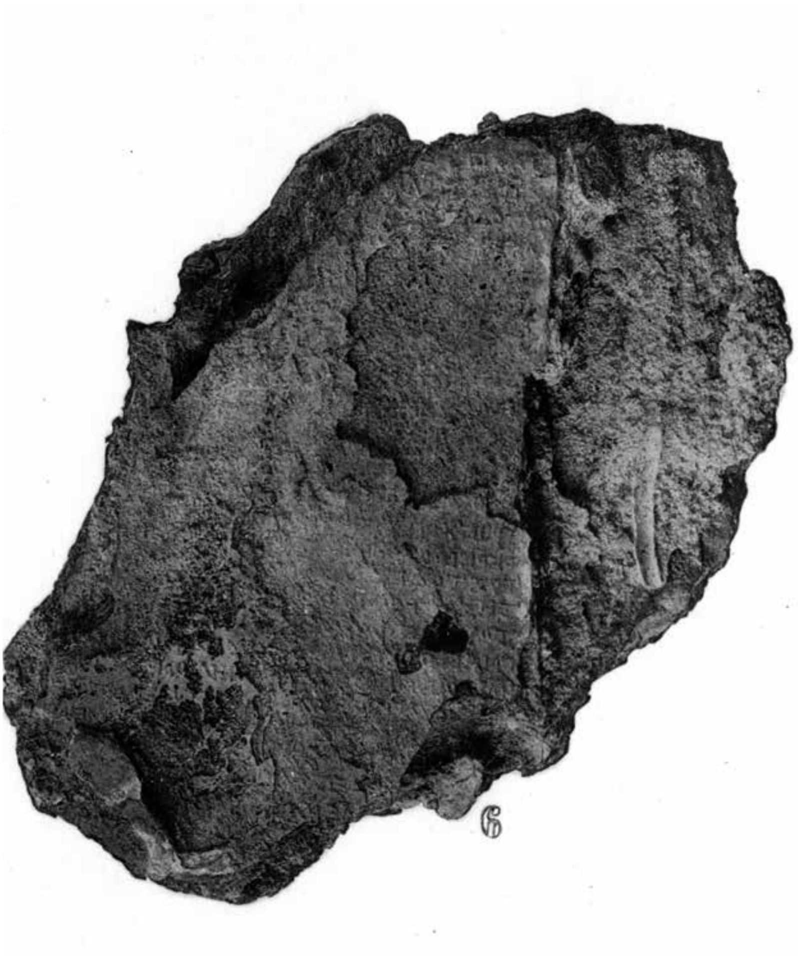

Figure S8. Fragment B-1 in 1902-1903, before the c. 1905 conservation. The remains of the Back Cover offsets and plate were essentially indistinguishable from their present state, though parts of the offsets are more legible now following removal of patina in 1953. The Metonic Dial inscriptions on the right were entirely concealed by accreted material, which was removed in 1905.
Image: (Svoronos 1903a/1903b, Plate IX)

Figure S9. Fragment C-1 in 1902-1903, before the c. 1905 conservation. The Zodiac and Egyptian Calendar scales were entirely concealed behind parts of the Front Cover plate (incorporating the present Fragments G, 26, and 29), which in turn was mostly concealed behind accreted material (incorporating numerous present small fragments bearing offsets). The letters b probably indicate a place where some of the Front Cover Inscription could be seen by autopsy, though it is not visible in the photograph (Image: Svoronos 1903a/1903b, Plate X)

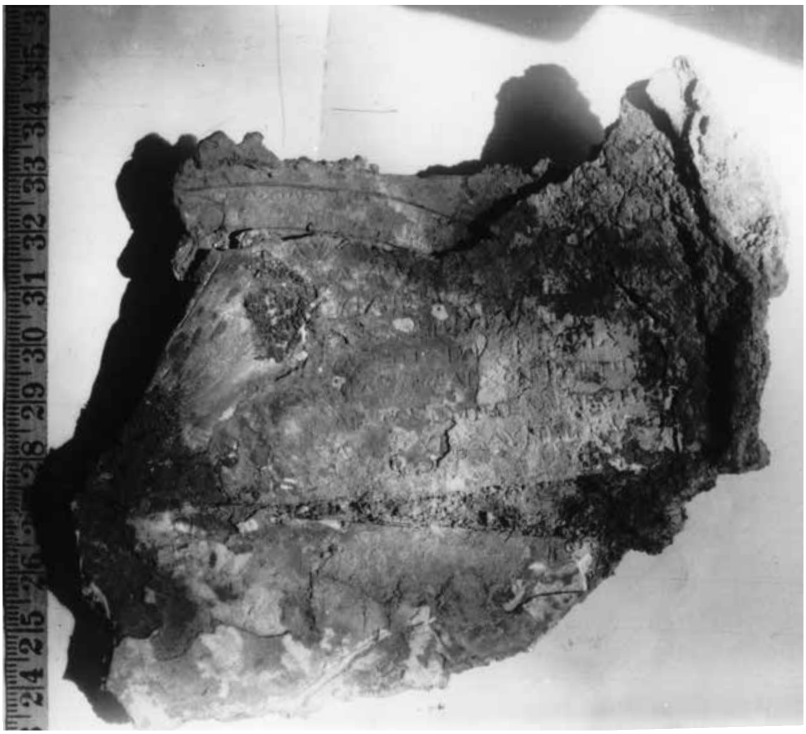

Figure S10. Fragment C-1 in 1905, after the c. 1905 conservation, involving the removal of Fragments G, 26, 29, and the offset fragments of the Front Cover Inscription. Part of the Egyptian Calendar scale was exposed, but the Zodiac Scale was still entirely concealed. Parapegma Plates 1 and 2 were now exposed, and were more extensively preserved than at present. The exposed portion of the Parapegma Inscription on PP1 was mostly if not entirely legible. The 1905 photograph of C-2 shows the inward-oriented inscribed face of PP2 —at that time incorporating the present Fragments 20 and 22— as entirely hidden behind patina (Image: Bayerische Staatsbibliothek, Rehmiana III 9)