ALEXANDER JONES

Later Greek and Byzantine Astronomy

During much of the thirteen centuries of Greek-speaking culture that intervened between the career of Claudius Ptolemaeus (Ptolemy) and the fall of Constantinople to the Turks in 1453, astronomy was a highly prized discipline. It became, however, a received science, one to be mastered, explicated, exploited, but scarcely to be tested or augmented. During the twilight of antiquity older writings were gradually lost and rival methods faded from use, until Ptolemy's models and tables became almost synonymous with astronomy. The Byzantine Greeks never quite forgot how to use the tables to predict the celestial phenomena, and their reconquest of the theoretical expanses of the *Almagest* after AD 1300 was among the intellectual highlights of the Middle Ages, preparing for the developments of the European Renaissance. From Byzantium the Islamic world too drew its knowledge of Ptolemaic astronomy; and in return Byzantine scholars studied and translated Arabic works. Their attempts to absorb this 'new astronomy' and confront it with their own Ptolemaic heritage make up one of the most interesting parts of the vast astronomical literature lying, largely unpublished and even unread, in numerous manuscripts.

Late antiquity

Ptolemy's principal astronomical works, the *Almagest*, *Handy Tables* and *Planetary Hypotheses*, appeared in succession during the decades following AD 150. What was the contemporary state of Greek astronomical practice, and what sort of reception did Ptolemy's writings obtain? Using contemporary documents recovered by archaeology, supplemented by clues from the ancient astrological literature, we can begin to answer these questions. And because of the special conditions of climate and culture that favoured the survival of numerous papyrus texts there, we are best informed about the astronomy of provincial Roman Egypt.

The more than 100 astronomical papyri currently known – most of them as yet unpublished – are predominantly numerical tables and texts concerned with the practical task of determining the positions of the heavenly bodies at specific dates. These were the papers of astrologers, whose activity is also witnessed by numerous papyrus horoscopes and fragments of astrological treatises. Temples belonging to the partially Hellenised Egyptian local cults provided one of the venues where horoscopes were computed and cast; but many astrologers were probably independent professionals. Although most of the papyri are written in Greek, Demotic Egyptian texts and tables occur as late as the second century of our era. Aside from the language and script, there is no important difference between the Demotic and Greek documents, so that the astronomy they record can best be described as 'Graeco-Egyptian'.

Unlike its Mesopotamian counterpart, Graeco-Egyptian astronomy had no observational component, except as reflected in the works of 'scientific' astronomers such as Ptolemy; and these theoretical works are almost wholly absent from the papyri. The conventions used in the papyri are fairly uniform: positions of heavenly bodies are given in sidereal ecliptic co-ordinates (longitudes are in degrees within zodiacal signs), and the fractional parts of numbers are expressed sexagesimally, a convention obviously adopted from Babylonian astronomy. The dates are sometimes in the civil ('Alexandrian') calendar established by Augustus; this had 12 months of 30 days each and 5 'epagomenal' days not belonging to any month at the end of the year, with a sixth epagomenal day every 4 years. The older Egyptian calendar, with the same 12 months but invariably five epagomenals (see p. 35), also survived in astronomical tables because of the convenience of computing with uniform years of 365 days. The Roman (Julian) calendar appears infrequently as early as the reign of Augustus, becoming more common in ephemerides from the fourth century AD and later.

The methods by which the Graeco-Egyptian astrologers computed the configuration of the heavens divide into two groups: versions of Ptolemy's tables, and representatives of an older astronomical tradition, largely arithmetical in character, that descends at no great remove from the mathematical astronomy of the Babylonian cuneiform texts (Fig. 32). In the non-Ptolemaic methods one began by tabulating the dates and longitudes of a succession of characteristic moments in the anomalistic cycles of a heavenly body, e.g. summer solstices or the first appearances of Mercury as morning star. The progress in time and longitude from one epoch to the next was found by simple arithmetical rules which, at least for the five planets, can sometimes be traced back half a millennium in Babylonian tablets. One then established how the body in question had moved between the preceding epoch and any given date either by linear interpolation between epoch positions or by looking up the progress in a table (or 'template') that set out a standard pattern of day-to-day motion during the anomalistic period. The templates, which seem to have been a specifically Greek innovation, were also usually computed according to straightforward arithmetical rules, e.g. keeping the speed constant or having it increase or decrease by constant differences.

Ptolemy's tables follow an essentially different structure reflecting the kinematic models compounded of circular motions that he deduces in the *Almagest*. The uniform,

32 A fragment of a late third-century AD papyrus almanac in codex format, excavated at Oxyrhynchus in Egypt. The planetary positions, pertaining to the reign of the Roman emperor Elagabalus (AD 218–22), were in part computed by methods known to us from Babylonian tablets five centuries older. (Egypt Exploration Society, P. Oxy. 3299)

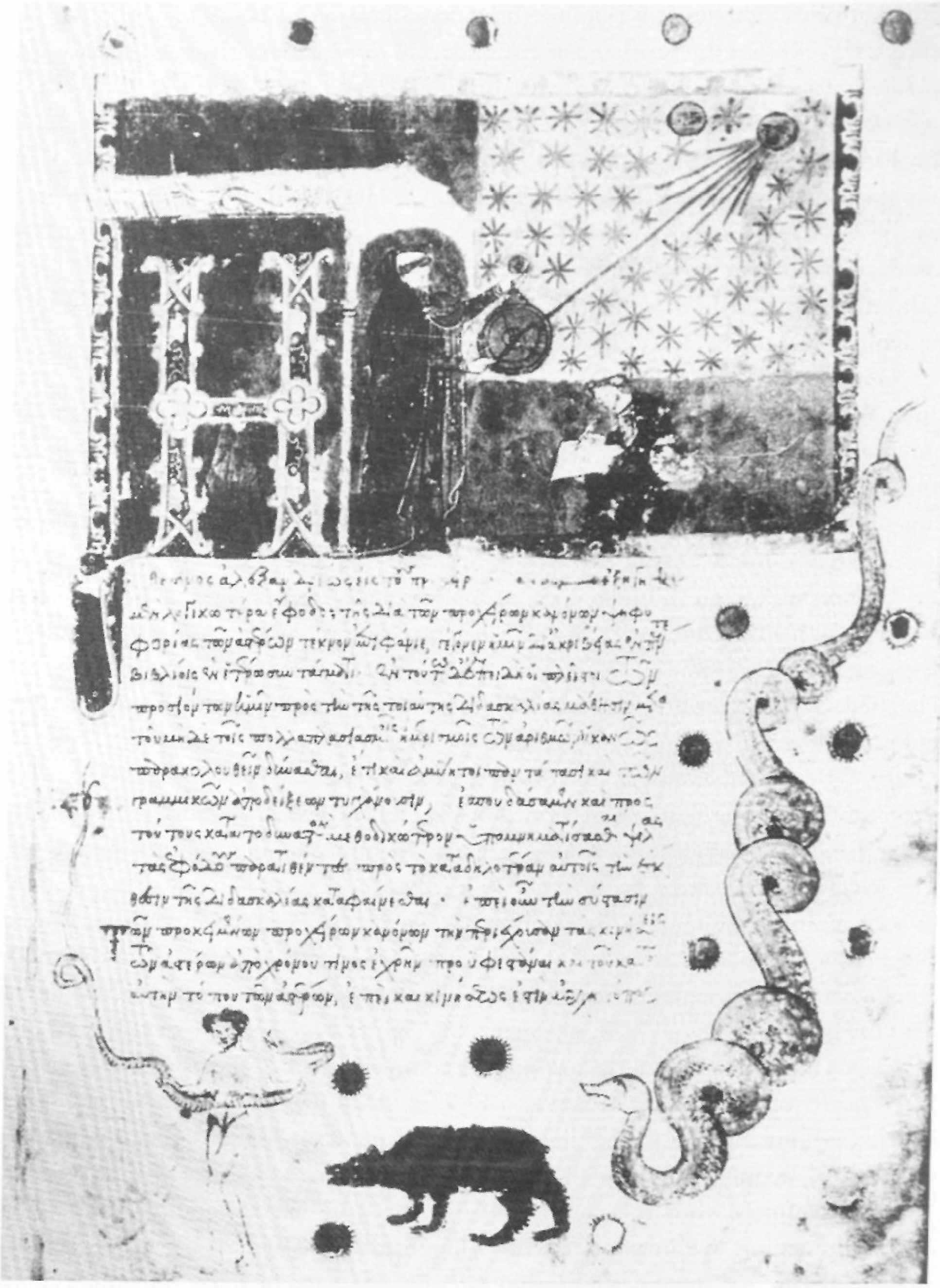
or 'mean', motions are tabulated as a linear function of time since a single epoch date in the remote past; complex trigonometrical tables ('equation tables') are then used to find the longitude and latitude of the body as a function of the mean motions. It was not the original tables embedded in the theoretical exposition of the *Almagest* that achieved wide circulation, but rather the *Handy Tables*, which Ptolemy had adapted for more convenient use. Fragments of several manuscripts of the *Handy Tables* survive on papyrus, some as old as the early third century AD; and almanacs from about this date were often computed using the *Handy Tables*. We also have examples of tables that were modified in various ways from Ptolemy's. On the other hand, Egypt has so far yielded no tables independent of Ptolemy that use the analysis of planetary motion into mean motion and equation tables.

Ptolemy's tables came into common use quickly, but did not immediately drive the Babylonian-style arithmetical methods into oblivion. As late as the middle of the fourth century AD both approaches to astronomical computation are found side by side. This is hardly surprising, since the *Handy Tables* were not only more accurate and theoretically sophisticated than the older techniques, but also much more difficult to use. Vestiges of the Mesopotamian heritage lived on into the Middle Ages in the perpetual almanacs, tables that presented the longitudes of the planets at intervals of 5 or 10 days for a Babylonian Goal Year period ranging from 8 years (for Venus) to 83 years (Jupiter), after which the cycle could be repeated.

The astronomical literature of late antiquity that has come down to us through medieval manuscript copies is dominated by commentaries of one sort or another on Ptolemy's works. On the one hand, a great demand existed for instruction manuals for the *Handy Tables*, which Ptolemy's own curt preface did not satisfy. On the other, the *Almagest* found its way into the curriculum of academic mathematical education, as a sequel to the reading of Euclid's *Elements* and the treatises on spherical astronomy by Autolycus and Theodosius. The earliest known commentary on Ptolemy's tables is an anonymous fragment dating from about AD 203, barely a generation after Ptolemy himself, that rather ineptly discusses the lunar tables of the *Handy Tables* and their relation to the *Almagest*. The third century, a period of political and social instability throughout the Roman empire, has left us little else of an astronomical nature.

During the fourth century AD, by contrast, mathematical and astronomical education flourished in Alexandria at the hands of the pedagogues Pappus and Theon of Alexandria. Pappus, who is deservedly better known for his mathematical *Collection*, also composed a long commentary on the *Almagest* about AD 320, of which parts concerning Ptolemy's lunar and eclipse theory survive. Pappus still had access to some of the older literature that is lost to us – he was well informed about Hipparchus's measurements of the distances of the sun and moon, for example – but for the most part he was content to clarify and fill out Ptolemy's mathematical expositions, and there is no allusion to developments after Ptolemy. The better preserved commentary on the *Almagest* by Theon, dating from the 360s, exceeds in bulk the work it explicates. It is more thorough and carefully written than Pappus's, but even poorer in material of historical interest. Among Theon's other works are a lucid manual to the *Handy Tables* (Fig. 33), and a larger treatise that attempts to show how Ptolemy derived the *Handy Tables* from the tables of the *Almagest* – a difficult undertaking in which Theon acquits himself surprisingly well. The manual is noteworthy for giving the earliest account of the supposed 'trepidation' or oscillation in longitude of the equinoctial points, a concept that survived in Islamic and European solar theory as late as Copernicus (see pp. 149, 153 and 185). Of other commentaries by Serapion, Arcadius and Theon's fabled daughter Hypatia, we know next to nothing.

On a higher plane than the voluminous commentaries of Theon and Pappus is the *Hypotyposis* (or *Outline of the Astronomical Models*) by the Neoplatonist philosopher Proclus, who was active during the mid fifth century AD at Athens. Proclus wished to describe briefly and non-technically the problems, hypotheses and methods of astronomy, which he equated with the contents of the *Almagest*, and his book is one of the best introductions to that work. His descriptions of some of Ptolemy's observational instruments go into more detail than the *Almagest* does, and he knew something about the theory (first set out in a part of Ptolemy's *Planetary Hypotheses* that now exists only in Arabic translation) of models composed of nested spheres for the sun, moon and planets. Proclus rejects Ptolemy's theory of precession, ostensibly on observational grounds, but perhaps also influenced by the lingering preference of the astrologers for



33 An illustrated manuscript of the *Handy Tables* with Theon's manual, copied in 1358. The picture depicts an astronomer holding what is presumably meant to be an astrolabe, with a seated assistant to his right. The figures surrounding the text represent (from left to right) Ophiuchus, one of the Bears, and Draco. (Biblioteca Ambrosiana, Milan, MS H57 Sup., f. 1r) using sidereal longitudes. He also chastises the astronomers for believing in the physical reality of their models, and maintains a strictly 'instrumentalist' interpretation of Ptolemy's astronomical models as computational devices that have no physical validity.

Given the seemingly total neglect of observational and theoretical astronomy in the 300 years following Ptolemy, it comes as a surprise to encounter in the prefatory matter to some medieval copies of the *Almagest* a list of seven observations made between AD 475 and 510 at Athens and Alexandria. The observers were the brothers Heliodorus and Ammonius and a third man who may have been their uncle Georgius, all Neo-platonists intellectually allied to Proclus. The observations were naked-eye sightings in which the moon or a planet either occulted or passed close to another planet or a fixed star. The only instrument mentioned is the plane astrolabe, which was used to convert equinoctial to seasonal hours. What was the purpose of these observations? Some are compared with positions computed from the *Handy Tables*, but it is difficult to discern in them any systematic effort to check the tables' accuracy.

The plane astrolabe, whose history up to this point is mired in obscurity, emerges about the time of Theon in its normal medieval form combining a stereographic projection of the celestial sphere on one face with a sighting instrument on the other. No ancient specimens survive, but we do possess technical treatises on the astrolabe and its applications by John Philoponus (a pupil of Ammonius, early sixth century AD) and, in Syriac, Severus Sebokht (seventh century); both appear to be reworkings of a lost book by Theon.

Byzantine astronomy

The transition between the periods labelled 'antiquity' and 'Byzantium' may be very crudely characterised as astronomy's passage from one intellectual centre in Alexandria to another in Constantinople, and from a pagan to a Christian milieu. More detailed inspection of course tends to obscure these neat distinctions. Hypatia's murder at the hands of a Christian mob in AD 415 was perhaps no more typical of intellectual conditions in Alexandria than the fact that her Christian pupil Synesius of Cyrene was able to reconcile a dilettantish interest in the pagan sciences with political and ecclesiastical activities, finally becoming bishop of Ptolemais in AD 410. And a century and a half later, the pagan Neoplatonist philosopher Olympiodorus could deliver lectures on astrology, the text of which survives, to an Alexandrian audience that must have been overwhelmingly Christian.

In the meantime Constantinople, although the imperial seat since AD 330 and the site of a 'university' (that is, a school with several endowed teaching positions) since AD 425, was not notable for its astronomers until the time of Emperor Heraclius (AD 610–41), when Olympiodorus's pupil Stephanus of Alexandria came to the city, supposedly at the emperor's summons. Very little is actually known about Stephanus's activity as astronomer and astrologer, except that he is alleged to have cast Heraclius's horoscope.

Heraclius himself appears as the author of a prolix manual of instructions for the *Handy Tables*, modelled on Theon's shorter commentary and adapted for use at the latitude of Constantinople; modern scholars, doubting an emperor's competence in the subject, have presumed that the book must have been ghost-written by Stephanus.

This first establishment of a tradition of technical astronomy in the capital was short-lived. The century and a half between the reign of Heraclius and the beginning of the ninth century has left us negligible traces of astronomical writings, a silence that may be partly the effect of the iconoclastic religious movement of the eighth century and its hostility to scientific and intellectual institutions. Elsewhere in the Greek-speaking empire, however, one finds scattered traces of manuscripts and of practitioners who maintained the ability to read and use them. Not only was the survival in outlying districts of astronomy, even if it was at a modest level, crucial for the revivification of studies in Greek during the ninth century and after, but its role in transmitting Greek astronomy into other cultures should not be forgotten. Thus parts of the *Handy Tables*, with instructions compiled from Theon and other sources, were translated into Latin in the sixth century at Rome; and at the other geographical extremity the astrologers Stephanus and Theophilus of Edessa, rather shadowy figures of the late eighth century, served as points of contact between Greek and Islamic astrology.

In the course of the next century, the intense interest in Greek scientific writings on the part of Arabic scholars must have depleted the stock of old manuscripts still in Byzantine hands; and of such copies as survived from antiquity, often in the form of papyrus rolls, many were damaged or fragile. Fortunately the ninth century also inaugurated a period during which the remains of ancient literature were sought out and recopied in durable parchment codices. The beginnings of this process are often associated by modern historians with Leo the Mathematician, a scholar whose scientific attainments are alleged to have inspired Caliph al-Ma'mūn (see p. 161) to invite Leo to Baghdad about 830. According to the tale, Leo refused, but managed to obtain a teaching position at the church of the Forty Saints in Constantinople, and in time appointment to the archbishopric of Thessalonica. The overthrow of iconoclasm brought an end to Leo's tenure, but he eventually re-emerged as head of another school under imperial patronage in the Magnaura Palace, living at least until 869. Leo's personal library is known to have included manuscripts of mathematical authors (Archimedes, Apollonius), at least one astrological collection, and perhaps the *Almagest*; and although none of his copies survive, their importance for the survival of these texts cannot be doubted. More questionable is Leo's ability to interpret these highly technical works, for his own surviving writings are meagre and unimpressive.

Among the surviving Greek manuscripts from the time of Leo and shortly after, copies of scientific works are remarkably prominent – an emphatic contrast to the obscure place these writings have held in modern Classical studies since the eighteenth century. The astronomical manuscripts include four of the *Almagest* (some incorporating minor writings of Ptolemy), another four of the *Handy Tables*, two containing commentaries by Theon and Pappus, and one with the writers on spherical astronomy. These codices were written by skilled professional calligraphers, usually employing the new Greek minuscule script, and the cost of both the parchment and the scribe was high. The versions of the texts that they contain are often important for modern editors because they are closer to the authors than other manuscript copies and exhibit few attempts to correct or improve upon the text as received. But this same paucity of corrections by scribe or owner also suggests that, for all their splendour, these manuscripts were more for display than for study. Original writings from the ninth and tenth centuries, whether in the margins of the extant contemporary codices or in later copies, are pitiful and scarce. One concludes that practical understanding of astronomy was sustained by few besides the astrologers, whose working copies of the old texts were presumably more perishable than the bibliophiles' treasures that have come down to us, but whose existence is revealed by the odd horoscope or anecdote.

The eleventh century brings a reversal of this situation: almost no surviving contemporary manuscripts, but renewed activity in scholarship, attested by later and, alas! very unsatisfactory copies. The earliest of these texts, a long marginal note to the *Handy Tables* originally written about 1032, already shows that Byzantine astronomy was now embarked on a new course. For the unknown author mentions various parameters of the sun's motion that differ from Ptolemy's values, parameters that were in fact measured by the astronomers of al-Ma'mūn at Damascus in the first half of the ninth century, and he also discusses astronomical tables of a certain 'Alim' who can be identified as the tenth-century astronomer Ibn al-Aʿlam (see pp. 153 and 163). In the latter case, at least, we are dealing with an actual translation of Arabic tables into Greek, which, though not now extant, was still available in the twelfth century; we are told moreover that the Greek version of Ibn al-Aʿlam's tables utilised the Byzantine (Julian) calendar.

Further acquaintance with the works of the ninth-century Arabic astronomers is revealed by an anonymous manual, mostly assembled in the 1060s, that gives instructions and examples of astronomical computations such as the components of a horoscope and the characteristics of eclipses, by methods that are wholly non-Ptolemaic. The text refers to the tables of Ḥabash al-Ḥāsib (see pp. 151 and 155), whereas the long section concerning solar eclipses proves to be a competent Greek translation of the original instructions of al- Khwārizmī's *zīj* (see pp. 148 and 151), followed by a worked example using the eclipse of 20 May 1072. The author actually observed this eclipse, using an astrolabe to sight the solar altitudes (cf. Fig. 34). A more chaotic collection of astronomical chapters and tables, dating from the twelfth century, mentions further Arabic astronomical authorities. It contains a brief handbook on the astrolabe, 'compiled from various methods taken from a Saracen book', employing transliterations of Arabic technical vocabulary. These texts are manifestly the fragmentary remains of a larger

34 The only surviving Byzantine astrolabe, this instrument is signed by one Sergius, a 'Persian', and dated July 1062. It is thus contemporary with the earliest Arabic influences on Byzantine astronomy. IC no. 2 (Civici Musei d'Arte e di Storia, Brescia)

transmission of Islamic astronomy into the Byzantine world, although it is not necessary to assume that Greek translations existed of every Arabic author named; some of the information was doubtless second hand, and some tables may have been consulted directly in the Arabic. Of the scholars participating in this transmission of the eleventh and twelfth centuries, only one, the polymath Symeon Seth (late eleventh century) is known by name. The chronicler Anna Comnena, who had much experience of astrologers at her father Alexius I Comnenus's court, was satisfied of Seth's competence by his predicting the death of the Norman Robert Guiscard in 1085. His knowledge of Arabic astronomy may have been at a less technical level than that of the anonymous texts, and might perhaps be connected with a sojourn in Egypt, where he had observed a solar eclipse in 1058.

The Islamic tables that were now becoming accessible in Byzantium did not differ profoundly in arrangement, notation, or purpose from Ptolemy's tables, on which, after all, the Arabic *zījes* had to a great degree been modelled. We have already seen that the Greek writers were aware of differences between the old and new tables in some of the numerical parameters, e.g. the mean motions of the sun, moon and planets and the rate of precession. Other tables, such as the star catalogues and the lists of co-ordinates of principal cities, were presumably more up to date in the Arabic works; it was from such a source, rather than observation, that the eleventh-century astronomers first corrected Ptolemy's erroneous latitude for Constantinople. And the indirect influence of Indian astronomy was felt in the introduction of sine tables and in features of al-Khwārizmī's methods of eclipse prediction that had little resemblance to Ptolemy.

To judge from the career of Seth, and from the largely astrological contents of the later manuscripts that preserve the anonymous manuals, the astronomical writings of the eleventh and twelfth centuries were still the work of practising astrologers. The great men of letters of this time, such as Psellus and Eustathius, at best betray knowledge of the rudiments of astronomy; nor do we find prominent figures of church and state writing on the science, as their counterparts were to do during the Palaeologan period. That fine manuscripts of astronomical classics were nevertheless esteemed – if not actually read – by the mighty is suggested by the emperor Manuel I Comnenus's choice of a tenth-century copy of the *Almagest* as a gift to the Sicilian king William I about 1158.

The sack of Constantinople by the Venetians and their allies in the Fourth Crusade (1204) was a cultural as well as a political disaster for the Byzantine Empire, and astronomy seems to have experienced a hiatus that lasted through the 57-year interval during which the seat of the empire was displaced to Nicaea, and indeed until the reign of Andronicus II Palaeologus (1282–1328). The recovery, when it came, was fast and vigorous. Manuscripts were produced in great numbers, and the many surviving copies of astronomical works, old and new, that date from the late thirteenth and fourteenth centuries prove to have been scholars' books, written in often crabbed hands on paper rather than parchment, but bristling with corrections and annotations.

One of the new lines of astronomical scholarship begins with Theodorus Metochites (1270–1332), minister of Emperor Andronicus II and a scholar of wide interests. In 1314, when he was forty-three, Metochites began to study astronomy with the help of Manuel Bryennius, and he eventually produced a vast treatise, entitled *Elements of Astronomy*, that constituted the first significant Greek attempt to master the theoretical and mathematical content of Ptolemaic astronomy since the time of Theon. Metochites has nothing to say about Arabic contributions, and elsewhere asserts that Ptolemy had left nothing for his posterity to discover in this field.

Metochites's pupil Nicophorus Gregoras inherited his master's hard-won grasp of Ptolemy, and exploited it by predicting the solar eclipse of 16 July 1330. He undertook this most difficult of computations not merely as a scientific exercise, but as a sally in his bitter polemic with the Calabrian monk Barlaam of Seminara. Barlaam, however, rose to the challenge by using Ptolemy's tables to predict the solar eclipses of 14 May 1333 and 3 March 1337. It is not known whether either Gregoras or his adversary, for whom mathematical astronomy was only a minor issue in their wide-ranging dispute on religious and other questions, bothered to observe the eclipses. Gregoras's other works include two handbooks on the astrolabe; and he suggested a revision of the calendar based on a value for the length of the tropical year more accurate than Ptolemy's. Although Gregoras claims to have established this parameter by observation, it is actually equivalent to a value for the rate of precession of 1° in 66 years which the Byzantine astronomers of the eleventh century had already learned of from Arabic sources.

But at the same time as Metochites was reviving the Ptolemaic tradition, more recent astronomical texts were passing into Greek from Persia. In contrast to the Arabo-Byzantine contacts of the eleventh and twelfth centuries, the new transmission took the form of translations or adaptations of complete *zījes* (see pp. 150–55), including the *Zīj al-Sanjarī* of al-Khāzinī (*c.* 1120) and the *Zīj al-ʿAlaʾī* of al-Fahhad (*c.* 1150). Some or all of these versions are almost certainly to be attributed to one Chioniades. According to the account of George Chrysococces a generation later, Chioniades had studied the mathematical sciences and medicine at Constantinople but, in order to master astronomy, found it necessary to travel to Trebizond and beyond to Persia, whence he brought back various treatises that he translated into Greek.

The translations that have come down to us date from about the years 1295–1302, and display a progressing grasp of Persian and Arabic and of the technical vocabulary of astronomy. We have two manuscripts containing these works that are nearly contemporary with the translations. For reasons that are not yet clear, however, the Persian tables seem to have attracted little attention in Constantinople until a generation later, when several copies were made. It was in the 1340s as well that Chrysococces, who had learned astronomy from a pupil of Chioniades, produced the *Persian Syntaxis*, a set of tables originally translated by Chioniades, with new instructions by Chrysococces himself. Nearly twenty copies of this work survive. The central tables for computing the longitudes of the heavenly bodies in the *Persian Syntaxis* derive from the *Zīj-i Īlkhānī* of Naṣīr al-Dīn al-Ṭusī (*c.* 1270). This is not the only evidence of Byzantine familiarity with the quite recent work of al-Ṭusī and the Maragha astronomers (see pp. 150, 151 and 164), for among the 'Chioniades' materials dating to the beginning of the century is a short illustrated text that sets out al-Ṭusī's innovative model for the moon.

But documents of such theoretical interest were not typical productions of the astronomers of the fourteenth and fifteenth centuries, who remained preoccupied with the adaptation and manipulation of a bewildering profusion of tables. Chrysococces's tables reappear in slightly modified form as the topic of the last part of the *Astronomical Tribiblos* (*c.* 1352) of Theodorus Meliteniotes, who, among other lofty ecclesiastical functions, directed the patriarchal school at Constantinople; the first two parts of this unusual 'synthesis' of astronomical traditions comprise a manual for the astrolabe and a commentary on Ptolemy's tables. Unusually, Meliteniotes vehemently deprecates the astrological concerns that had been prominent in Chrysococces's work, as in most of the sets of tables of this period. About the same date, Cyprus emerged as a centre for up-to-date methods, producing another revision of the tables of the *Persian Syntaxis* and a translation from Latin of the *Toledan Tables*. Byzantium was by now drawing as much from the West as from the East in its appetite for tables; and it is not surprising to find Greek adaptations of Hebrew works (by way of Latin) in the fifteenth century.

The Turkish capture of Constantinople in 1453 seems to have been accompanied by less violence and destruction than the Venetian sack two and a half centuries earlier.

But the blow it inflicted on Byzantine astronomy proved fatal, because the flow of Greek scholars and Greek manuscripts to Italy and other parts of western Europe, both before and after the final defeat, drained the Greek world of the resources necessary for yet another scientific revival. Nearly every astronomical manuscript that we now possess was in the West by the sixteenth century, brought over by refugees such as Cardinal Bessarion and Isidore of Kiev, or by Western humanists visiting the East in search of literary treasures. European scholars made uneven use of this inheritance, neglecting almost entirely the Persian tables and the other Islamic materials (although it has been suggested that Copernicus somehow learned of the Maragha models for the moon and planets, which recur in his works, from the Byzantine manuscripts). The Renaissance's greatest debt to Byzantium in astronomy was ironically for its most conservative aspect, the preservation of good texts of the writings of antiquity, especially the *Almagest* and its commentators, which helped to prepare the ground for Regiomontanus and Copernicus.

The course of medieval Greek astronomy was shaped by several forces. The retrospective, antiquarian character of Byzantine secular culture was only imperfectly counteracted by intercourse with the Islamic world and the western Mediterranean until the very latest period. Moreover, astronomical tables were the indispensible ancillary to astronomy, and mastery of the most difficult varieties of prediction (eclipses) and of the geometrical principles underlying the tables proved a scholar's intellectual prowess; but the reputed perfection of Ptolemy's works left little role for observation or new theoretical speculation. And finally, the vicissitudes of politics and religion periodically subjected learning to long interruptions, which were particularly disastrous for a highly technical science dependent for its continuity on competent instruction. One is astonished, not so much that later Byzantine astronomy was an astronomy of manuscripts and computations, but that, being such, it could flourish so vigorously.

Bibliography

Neugebauer, O. 1975. *A History of Ancient Mathematical Astronomy*. 3 vols. Berlin, Heidelberg and New York: Springer-Verlag.

Pingree, D. 1964. Gregory Chioniades and Palaeologan Astronomy. *Dumbarton Oaks Papers* 18, 133–60.

Tihon, A. 1981. L'astronomie byzantine (du v^e au xv^e siècle). *Byzantion* 51, 603–24.

Tihon, A. 1983–. *Corpus des Astronomes Byzantins*. (Editions and translations of Byzantine astronomical writings, in progress.) Amsterdam.

Tihon, A. 1990. Tables islamiques à Byzance. *Byzantion* 60, 401–25.

Tihon, A. 1993. L'astronomie à Byzance à l'époque iconoclaste (viii^e–ix^e siècles). In *Science in Western and Eastern Civilization in Carolingian Times*. Basel.

Wilson, N.G. 1983. *Scholars of Byzantium*. London: Duckworth.