

Early greek astronomy

IV The Pythagoreans and later pre-Socratics  
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EARLY GREEK ASTRONOMY TO ARISTOTLE

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ASPECTS OF GREEK AND  
ROMAN LIFE

*General Editor: Professor H. H. Scullard*

EARLY GREEK  
ASTRONOMY  
to Aristotle

D. R. Dicks



THAMES AND HUDSON



## CHAPTER IV

THE PYTHAGOREANS AND  
LATER PRE-SOCRATICS

AS WE HAVE ALREADY SEEN, the concepts of periodicity, sphericity, and circular motion as applied to the universe as a whole are already present in the work of Heraclitus, Parmenides, Empedocles, and Anaxagoras; but astronomical thought is still in the pre-scientific stage, and the idea of the celestial sphere is still far from being worked out in detail. The nearest approach in the Pre-Socratic period to an astronomical scheme which might possibly have taken the place of the concept of the celestial sphere is in the system attributed to the later Pythagoreans of the last half of the fifth century. Now it has been said (Guthrie, vol. i, p. 146) that 'The history of Pythagoreanism is perhaps the most controversial subject in all Greek philosophy', and 'No one can claim even to have plumbed what a modern scholar has despondently called "the bottomless pit" of research on the Pythagoreans'. Here we are concerned only with the role of the Pythagoreans in the history of astronomy; but even to elucidate this some attention must be paid to the difficulties peculiar to any discussion of Pythagorean beliefs.

Put very briefly, the main problem is to try to distinguish the teachings and discoveries of Pythagoras himself from those of his successors in the school which he founded, and which continued as a recognized body of doctrines some two hundred years after his death – and to differentiate between these successors. The problem is complicated by several factors: (a) Pythagoras himself, who founded the Pythagorean brotherhood in the latter part of the sixth century BC at Croton in south Italy, left no writings; (b) it was a religious and mystical association or sect, as well as a philosophical school, which had strict rules of secrecy concerning its teachings; (c) there was a strong tendency for later writers to

attribute as many discoveries as possible to the Master, who rapidly became an almost superhuman figure – unhistorical legends about him were already circulating in Aristotle's time; (d) the original brotherhood, which had by this time set up branches in many towns of Magna Graecia, was forcibly disbanded in the middle of the fifth century, and its members dispersed throughout Greece carrying their teachings with them; and finally (e) the sources which purport to tell us most about the movement, namely the so-called Lives of Pythagoras by Porphyry and Iamblichus (Neo-Platonists of the third and fourth centuries AD), at best go back to fourth-century BC accounts which were already uncritical in character (as just mentioned), and at worst are patent amalgams of Pythagorean, Orphic, and Neo-Platonic doctrines. In fact, as in the case of Thales, the tertiary sources are utterly unreliable for Pythagoras himself.

Of the secondary sources, Herodotus mentions the Pythagoreans once (ii, 81) and Pythagoras once (iv, 95), both times in connection with the doctrine of transmigration and the immortality of the soul. Plato, who was undoubtedly greatly influenced by Pythagorean teaching, and not least in his astronomical ideas (as we shall see later), yet names Pythagoras only once (*Rep.* x, 600b, where he contrasts him favourably with Homer for setting a good example for his followers to emulate), and the Pythagoreans once (*Rep.* vii, 530d, where Socrates draws attention to the importance attached by the Pythagoreans to the sister sciences of astronomy and harmonics – see pp. 108f.). Aristotle, in the extant works, makes only two incidental references to Pythagoras, one of which occurs in a passage where the text is disputed (*Met.* A 5, 986a30), and neither of which gives any information about him. (The other passage is *Rhet.* 1398b14, where the name occurs in a sentence illustrative of inductive reasoning.) On the other hand, Aristotle frequently mentions the Pythagoreans, whom he sometimes designates as οἱ καλούμενοι Πυθαγόρειοι, 'those called Pythagoreans', and he is, in fact, our most reliable authority for their scientific teachings. He wrote a work *Περὶ τῶν Πυθαγορείων* which has, unfortunately, not come down to us.

From the state of the evidence, then, it would appear to be a



hopeless task at this distance of time to try to apportion various doctrines to individual Pythagoreans, when even Aristotle was not in a position to do so. He knew that different opinions were current among these philosophers, but he was apparently unable to connect them with particular names, and has to be content with saying 'some of the Pythagoreans think this . . . while others think that . . .' – whereas in dealing with the other Pre-Socratics he nearly always attributes specific doctrines to individual thinkers by name. Attempts by modern scholars to differentiate between what they suppose to be the views of Pythagoras himself and those of his pupils cannot therefore rest on any firm basis and should be discounted. In particular, Heath's ideas on the state of astronomical knowledge in Pythagoras' time (sixth century BC) are far too sanguine. He says (*Arist.*, p. 51),

It appears probable, therefore, that the theory of Pythagoras himself was that the universe, the earth, and the other heavenly bodies are spherical in shape, that the earth is at rest in the centre, that the sphere of the fixed stars has a daily rotation from east to west about an axis passing through the centre of the earth, and that the planets have an independent movement of their own in a sense opposite to that of the daily rotation, i.e. from west to east.

As we have seen, there is no good evidence for such advanced knowledge in this early period, and historically this picture is completely anachronistic (on this see further my articles on Thales and Anaximander). The best that we can do is to follow Aristotle's example, and examine the astronomical knowledge which there is reasonably good evidence that the Pythagorean school in general possessed, bearing in mind that most of it must be referred to the latter part of the fifth century BC.

The great novelty that the Pythagoreans introduced into Greek philosophical thought as a whole was their insistence on the importance of number. Number was for them the ἀρχή that the Ionian philosophers sought. Numbers were the basic stuff (ὕλη) out of which the whole universe developed – numbers, in some way which Aristotle was never able to fathom, and which he

evidently and with good justification regards as extremely perverse (*cf. Met. A* 8, 989b29ff. and *N* 6, 1092b26ff. = *DK* 58 B22 and B27), conceived of as actual physical entities occupying spatial extension, not intellectual abstractions; and numerical relationships constituted the governing principles of the entire cosmos. This is not the place to go into the details or speculate on the origin of this remarkable doctrine. Perhaps the discoveries (traditionally ascribed to Pythagoras himself) of the chief musical intervals, the octave, fourth, and fifth, expressed as the numerical ratios 2:1, 4:3, 3:2, of the fact that the first four integers add up to 10 (called by the Pythagoreans the 'tetractys' and regarded as a sacred symbol), and that the diagonal of a square is incommensurable with its side (the famous 'theorem of Pythagoras'<sup>74</sup>), all contributed to their belief that numbers formed the fundamental elements of the universe – but this belongs properly to the history of mathematics.

In astronomy the Pythagoreans also introduced a startling innovation. This was to displace the earth from the central position in the cosmos which it seems to have occupied in the astronomical ideas of most of the Pre-Socratics, and to regard it as another celestial body moving in a circle, like the sun, moon, and stars, round a central fire which provided the motive power for the whole universe and was variously called the watch or the tower or the throne of Zeus, or the hearth of the universe. Aristotle tells us (*De Caelo* ii, 13, 293a23 = *DK* 58 B37; *cf. also* Simplicius *ad loc.*) that, as well as the earth, the Pythagorean scheme postulated a counter-earth (ἀντίχθων) which also moved round the central fire, closer to it than the earth, but always invisible to us because we live on the hemisphere facing away from the counter-earth.<sup>75</sup> Aristotle's account does not mention the planets by name; we are merely told that the Pythagoreans regarded the earth as 'one of the stars' (ἐν τῶν ἀστέρων), but ἀστρον is a general word (as indeed is ἀστήρ) which can be applied indifferently to the fixed stars, the planets, the sun, and the moon. A tertiary source (Aëtius, *DK* 44 A16 and 17) fills in some details and specifically attributes the scheme to Philolaus, a Pythagorean of the latter half of the fifth century BC.



Under Philolaus (DK 44) DK lists nineteen passages (B1–B19) as definite fragments of a work *Περὶ φύσεως*.<sup>76</sup> Unfortunately, the genuineness of these is disputed (KR, p. 311, will have none of them; Guthrie, vol. i, p. 331, is far less convinced they are false), but anyway only one fragment (B7) is apparently connected with this astronomical scheme, and all *that* says is that in the middle of the sphere is what is named the hearth (ἐν τῷ μέσῳ τῆς σφαίρας ἔστι καλεῖται). According to Aëtius (DK 44 A16 and 17), in the middle was the central fire, next came the counter-earth, then the earth, then the moon, then the sun, then the five planets, and finally the outer sphere of the universe which carried the fixed stars. It is noteworthy that the order of the individual planets is not specified, nor are they actually named; in fact, the Greek names for Saturn, Jupiter, and Mars, i.e. the stars of Cronus, Zeus, and Ares respectively, appear only in the *Epinomis* (987c) of the extant texts before Aristotle,<sup>77</sup> although Plato in the *Timaeus* (as we shall see) mentions the Morning Star (Venus) and Mercury, and knows that the planets are five in number (38c–d). If we assume that the order of the planets was that generally accepted in later Greek astronomy (which is the order of their sidereal periods and of their distances from the sun), then the complete Philolaic scheme will have been (starting from the outside, τὸ περιέχον) fixed stars, Saturn, Jupiter, Mars, Venus, Mercury, sun, moon, earth, counter-earth, central fire – making ten bodies in all (counting the fixed star sphere as one) moving in circles round the fiery centre.

The postulate of the counter-earth is a puzzling feature of the system. In one place (*Met.* A 5, 986a3f. = DK 58 B4) Aristotle suggests that the only reason for it is to bring the total number of celestial orbits up to ten, which was the sacred number of the Pythagoreans, the visible orbits being only nine, i.e. fixed stars, five planets, sun, moon, and earth. In another passage (*De Caelo* ii, 13, 293b21f.) he mentions the view held by ‘some’ that there were other bodies, invisible to us, also encircling the middle (φέρεσθαι περὶ τὸ μέσον), which were supposed to explain why lunar eclipses are more frequent than solar – an idea, as we have seen, already attributed to Anaxagoras. It has been suggested that

the counter-earth might have performed the same function in the Philolaic scheme. This, however, is impossible, since the orbit of the moon is outside the earth’s, while that of the counter-earth is inside it (i.e. nearest the central fire). The other bodies mentioned by Aristotle were presumably envisaged as having their orbits between those of the moon and the earth if they were to produce more frequent lunar eclipses, but the counter-earth itself could not have had this effect.<sup>78</sup> Simplicius, in his commentary on the above passage of the *De Caelo*, says that the Pythagoreans called the moon ἀντίχθων and also a ‘heavenly earth’ (αἰθερίαν γῆν). There is nothing intrinsically improbable here (*pace* Guthrie, vol. i, p. 291); both moon and counter-earth encircle the central fire, one on either side of the earth, so that either could be described in some sense as ἀντί, ‘over against’, ‘counter to’ the earth.<sup>79</sup> In the same passage Simplicius informs us that ‘those who are familiar with the more genuine doctrine call fire in the centre the creative force which from the centre gives life to the whole earth and warms again that part of it which has grown cold’.<sup>80</sup> The only difference between this and Aristotle’s version is that the latter speaks of the central fire without mentioning its ‘creative force’ and its effect on the earth – presumably, knowledge of this constitutes the ‘more genuine’ doctrine. Perhaps a more cogent reason for the postulate of the counter-earth was to account for the fact that we never see the central fire, and to exclude the possibility that some daring explorer might go round to the other side of the earth and wonder why he still could not see the fiery centre, which, as consisting of divine fire that provided the generative force for the whole cosmos, might be expected to be a spectacular sight. Assume the existence of a body like the counter-earth which moves with our earth at the same speed in an orbit between us and the central fire,<sup>81</sup> and at least you have a specious reason for our never seeing it.

Aristotle says specifically that according to the Pythagoreans ‘the earth being one of the stars and carried in a circle round the centre makes (ποιεῖν) night and day’ (*De Caelo* 293a22–3), and this is duly confirmed by Simplicius who adds that night and day depend on the position of the earth relative to the sun. Exactly



how is not explained, but the assumption that the earth was supposed to take 24 hours to circle the centre, the moon  $29\frac{1}{2}$  days, and the sun a year would suffice to account very roughly for some of the main phenomena of the heavens as seen from the earth. Day would be produced when the inhabited part was facing the sun on the same side of the central fire, and night when it had moved round  $180^\circ$  to the other side of the centre. This is presumably what Simplicius means when he goes on to say (p. 512, 16–17) that night results from the earth's coming into the cone of its shadow: since we live only on one hemisphere, night is produced when the other hemisphere faces towards the sun and casts its shadow over our side. The phases of the moon would be approximately accounted for: in Fig. 9, position (a) would be near new moon and (b) and (c) near full moon, but in between the latter positions (when the moon was on the line joining sun, earth, counter-earth, and central fire) it would seem that for a terrestrial observer it must disappear briefly and then reappear. Again every month there would have to be a solar eclipse, and days and nights would have to be of equal length always all over the world.

Aëtius says that Philolaus regarded the sun as glassy (*ύαλοειδής*), 'receiving the reflection of the fire in the cosmos, and filtering both light and warmth through to us, so that in a certain sense there are twin suns, the fiery one in the heaven (*ἐν τῷ οὐρανῷ*) and the fiery one by reflection from it' (DK 44 A19). Unfortunately, it is not clear which fire is meant here, for Philolaus seems to have envisaged two sources of fire, the outermost surrounding fiery sphere (this originally Heraclitan idea was, according to the doxographers, common to several later Pre-Socratics) and the central fire (DK 44 A16); anyway, it is difficult to see how a reflected sun really helps matters.

Another minor difficulty (of which Heath makes much, *Arist.*, pp. 101f.) is that, according to Aristotle and the tertiary sources, in the Pythagorean scheme there were ten bodies moving in ten orbits round the central fire; but if the daily rotation of the heavens is to be accounted for by the earth's moving round the central fire, there is no need to postulate any motion of the fixed star sphere, so that there would have been only nine circular motions,

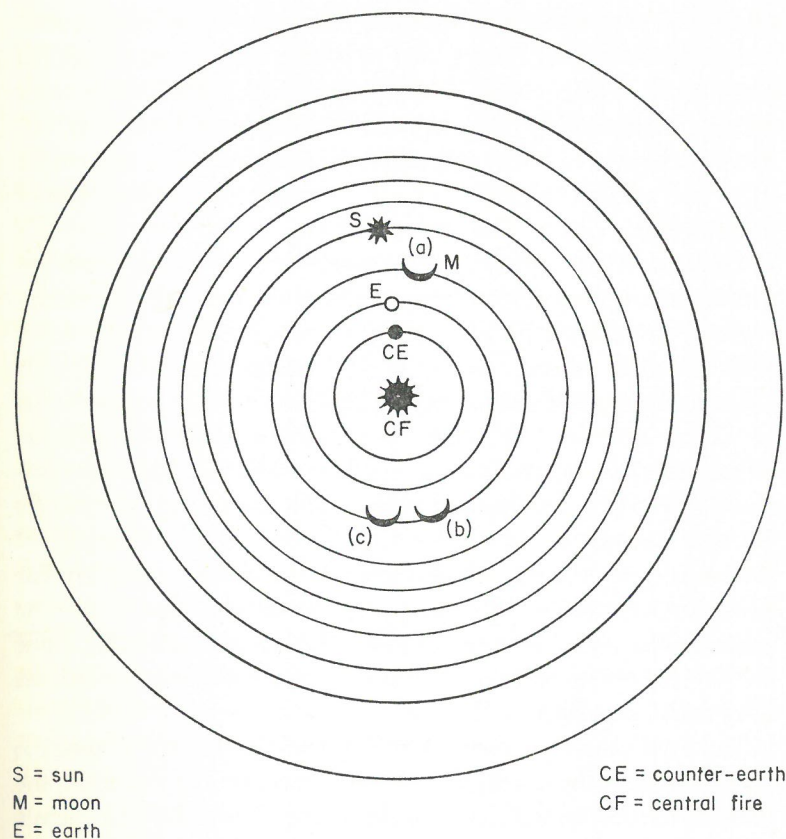


Fig. 9. Schematic representation of the Philolaic system

contrary to what all our sources affirm. To resolve this discrepancy it has been suggested that the sphere of the fixed stars was, indeed, endowed with a very slow revolution, and that this must have been intended to represent the phenomenon of the precession of the equinoxes (see pp. 15f.). However, to suppose that astronomical theory or observational technique had reached such a level in Philolaus' time that the effects of precession (about  $50''$  of arc a year for stars on the ecliptic) would be noticed, is quite out of the



question, and it is now certain that it was Hipparchus in the second century BC who made this discovery. The inventors of the counter-earth and the central fire (neither of which has any observational basis) could well have assumed a very slow rotation of the outer sphere, which could anyway not be disproved,<sup>82</sup> and which would bring the total number of revolutions up to ten and would fit in well with their preconceived notions on the construction of the universe.

The whole scheme is a good example of the type of presumptive theorizing that characterizes much of the astronomical thinking of the Pre-Socratics; it is very much a product of the study and bears little relation to the facts of actual observation (e.g. it takes no account of the latitudinal and longitudinal variations of the planetary bodies). Van der Waerden's belief that the scheme, which he describes as 'eine so raffiniert ausgedachten astronomische System', must belong to a stage in astronomical thought after the *Timaeus*, i.e. not before c. 360 BC, is wholly untenable.<sup>83</sup> Rather is it just the sort of scheme with which Plato was familiar from his knowledge of Pythagorean doctrines, and which he unsuccessfully tried to reconcile with the slightly later concept of the celestial sphere and the spherical earth at the centre (see below, Chapter V, especially p. 149).

The fatal objection to it (as so far described in the sources) is that it apparently envisages the orbits of the earth and all the heavenly bodies round the central fire as being in the same plane, whereas, of course, to correspond with observed phenomena, the plane of the orbits of sun, moon, and planets should be inclined to that of the earth. There is only one mention of inclined orbits in our sources and that is by Aëtius (*DK* 44 A21) where he states, 'Some say that the earth is at rest; but Philolaus the Pythagorean says that it is carried in a circle round the fire on a slanting circle in a similar fashion to the sun and moon' (κύκλω περιφέρεισθαι περὶ τὸ πῦρ κατὰ κύκλον λοξὸν ὁμοιοτρόπως ἥλιω καὶ σελήνῃ). As it stands, and if the whole sentence is to be attributed to Philolaus, this can hardly mean anything other than that *all three* bodies, earth, sun, and moon, move in an inclined orbit. Yet this would not produce the required results. It is possible that the last four

words are not Philolaus', but added by Aëtius or his source, and this apparently is how Heath takes it when he says, 'The earth revolves round the central fire in the same sense as the sun and moon (that is from west to east), but its orbit is obliquely inclined; that is to say, the earth moves in the plane of the *equator*, the sun and the moon in the plane of the zodiac circle. It would no doubt be in this way that Philolaus would explain the seasons.'<sup>84</sup> Clearly, this entails reading a great deal more into the evidence than is in fact there. 'Ὁ λοξὸς κύκλος' was in later Greek astronomy a normal expression for the ecliptic; it seems more than probable that Aëtius (or his source), knowing this, added it to the astronomical knowledge attributed to Philolaus simply to make the latter's views sound more plausible.<sup>85</sup> It is noteworthy that in the longer passage of Aëtius that describes the complete scheme (*DK* 44 A16), and in Aristotle's and Simplicius' account, there is no mention at all of inclined orbits, and it would seem very questionable to accept the unsupported statement of a tertiary source such as Aëtius in a case like this.

Very little astronomical sense is apparent in another feature of the Pythagorean scheme, the famous 'harmony of the spheres'. According to Aristotle (*De Caelo* ii, 9, 290b12f. = *DK* 58 B35), an absurd and extravagant opinion (his own words) was held by the Pythagoreans, to the effect that, with so many huge celestial bodies whirling at such great speeds round the centre, it was impossible that no noise should be generated by their motions, but each body must produce a different tone according to its distance from the centre, so that the whole system created a 'harmony'. An ingenious explanation was given of the awkward fact that no one ever hears this harmony, namely that everyone, from the moment of birth, has this sound as a constant background and therefore does not consciously hear it, since there is no absolute silence to contrast with it. This poetic fancy (presumably suggested by the discovery of the ratios governing the chief musical intervals – see above) was taken up by Plato in the myth of Er in *Republic* x (see p. 111), and further elaborated by later writers who invented all sorts of musical schemes supposed to represent the proportionate distances of the heavenly bodies – Heath (*Arist.*, pp. 105f.) treats of these at



some length. Nevertheless it has no significance for mathematical astronomy, however much it gripped the imagination of later ages, except in so far as to demonstrate once more how prone the Pythagoreans were to subordinate the facts of natural phenomena to their philosophical and mystical predilections.

Despite the many drawbacks of the Pythagorean scheme, it also displays several features which permanently influenced Greek astronomical thought. It emphasized the circular motions of the heavenly bodies round a common central point; the concept was already prominent in Empedocles' ideas, but the Philolaic system went a step further by actually postulating an imaginary centre of rotation, and this was destined to be a key concept in the later development of the epicyclic and eccentric theories. It differentiated between the planets and the other celestial objects, and there is no good evidence that this distinction (traditionally, but improbably, credited to Pythagoras himself) was made by any of the earlier Pre-Socratics except Anaxagoras. Above all, it accustomed men to thinking in terms of the sphere as what one might call the typical astronomical shape, not only for the universe as a whole (this had been generally accepted since Parmenides), but more particularly as the shape of the earth itself. After the fifth century BC no Greek writer of any repute (with the exception of the atomists, Leucippus and Democritus, who held somewhat reactionary views on astronomy – see below) conceived of the earth as anything other than a globe. In Socrates' youth the shape of the earth was still a debatable matter (*cf.* p. 94), but the great authority of Plato, who certainly believed in a spherical earth (see p. 98) and who did much to make Pythagorean astronomical notions respectable, was sufficient to put the matter beyond doubt. Aristotle accepts the sphericity beyond any question (*De Caelo* ii, 14, 297a8ff.) and dismisses the proponents of a flat or drum-shaped earth in a few sentences (*ibid.* 294a).

That the Pythagoreans *did* regard the earth as a sphere is certain. In a curious chapter of the *De Caelo* where Aristotle is discussing which is 'upper' and 'lower' and which is 'left' and 'right' in the universe (ii, 2), he takes the (to us) unnatural view that the invisible (i.e. south) pole is the upper one, and those

living there are in the upper hemisphere and on the right, while we (i.e. the inhabitants of the northern hemisphere) are in the lower hemisphere and on the left, 'contrary to what the Pythagoreans say; for they make us the upper ones in the right-hand part, and those at the south pole the lower ones in the left-hand part' (285b25–7). However odd the argumentation appears to us,<sup>86</sup> it is at least clear that the Pythagoreans considered the earth as spherical. This is confirmed by one of the reasons that Aristotle reports for the Pythagorean view that the earth and the counter-earth move round the centre: he says (293b25–30) that they considered that it made no difference to the observed phenomena, since, even on the assumption that the earth (not the central fire) was at the centre of the universe, we ourselves anyway lived half a diameter of the earth away from its centre. Thus the sphericity is again assumed, although the truth of the Pythagorean argument entails ignoring completely the different effects of parallax in the two cases, a procedure which Heath justifiably describes as 'a somewhat extreme case of making the phenomena fit a preconceived hypothesis' (*Arist.*, p. 100).

Another very influential tenet of Pythagorean thought was their insistence on the divine nature of the celestial bodies. This also received the sanction of Plato and Aristotle, became orthodox doctrine which was accepted even by the mathematical astronomers (see the introduction to Ptolemy's *Almagest*, ed. Heiberg, pp. 6, 23; 7, 20ff.), and provided the fundamental basis for astrology. There is little doubt that the idea of the divinity of the planets, at any rate, came originally from Babylonia, where an astral religion is attested as early as the second millennium BC.<sup>87</sup>

According to the tertiary sources, two individual Pythagoreans from Syracuse, Hicetas and Ecphantus (*DK* 50 and 51), introduced a modification of the Philolaic system by postulating a central earth rotating on its own axis from west to east, thus accounting for the daily movement of the heavens. Cicero (*Acad. Prior.* ii, 39, 123), ostensibly quoting Theophrastus, would have us believe that Hicetas regarded the earth as the only moving body in a universe where the sun, moon, and stars were all stationary. This, if true, would demonstrate an unbelievably imperfect knowledge



of astronomy on Hicetas' part, since it would argue that he completely ignored the proper motions of the planetary bodies in the zodiac. However the tertiary evidence is very meagre, and even the actual existence of these two Pythagoreans has been doubted (*cf.* Guthrie, vol. i, p. 323).

As to other astronomical knowledge attributed to the Pythagoreans, Aëtius reports that Philolaus regarded the moon as like the earth, but with animals and plants fifteen times the size of terrestrial ones and a day fifteen times as long (*DK* 44 A20); this is obviously an inference from the length of a month. Diogenes Laertius says that they knew that the moon was illuminated by the sun (*DK* 58 B1a), which is probable enough as it was certainly known by Anaxagoras; on the other hand, according to Aëtius (*DK* 58 B36), some of the later Pythagoreans still thought of the moon's waxing and waning as caused by its own flame – which indicates little awareness of the true nature of lunar phenomena. From the concept of the spherical universe and the spherical earth, it would seem but a small step to the acceptance of the idea that all the celestial bodies are spherical; but there is no good evidence that the Pythagoreans actually took this step. Heath (*Arist.*, p. 115) cites Aëtius for the statement that the Pythagoreans regarded the sun as spherical (οἱ Πυθαγόρειοι σφαίροειδῆ τὸν ἥλιον, *Aët.* ii, 22, 5 = *Dox. Gr.*, p. 352); but this comes from Stobaeus' *Eclogae* (compiled about AD 500), is unsupported by any other source,<sup>88</sup> and cannot be regarded as reliable testimony for Pythagorean beliefs. In fact, immediately above this passage, Aëtius says that Alcmaeon (a Pythagorean of the early-fifth century BC) believed that the sun was flat (πλάτυν εἶναι τὸν ἥλιον, *DK* 24 A4). The same Alcmaeon, in agreement with 'certain of the mathematicians' is also credited by Aëtius (*loc. cit.*) with knowing that the planets have a movement from west to east. This is the movement along the zodiac in the opposite direction to the daily rotation of the heavens, and could be roughly accounted for on the Philolaic system by assuming different speeds of rotation for each planet round the central fire (that is if the considerable deviations in latitude of the planets is ignored, as also their retrograde movements and stationary points); but whether

knowledge of this double motion can be attributed to such an early figure as Alcmaeon is extremely doubtful. Aëtius also mentions (*DK* 58 B37c) three Pythagorean theories about the Milky Way: some thought that it was the track of a burnt-out star which had fallen from its proper place; others that it was the original course of the sun (presumably made visible by a sort of residual after-glow!); and others that it was the reflection of the rays of the sun in the heaven, just as the rainbow is its reflection in the clouds. Finally, we are told that they called the Pleiades the 'lyre of the Muses' and the planets the 'hounds of Persephone' (*DK* 58 c2).

Despite their insistence on the importance of number, we have practically no information about how the Pythagoreans applied numbers in their astronomical thinking. The sources tell us nothing, for example, about the periods allotted to the revolutions of the celestial bodies in the Philolaic scheme; it is true that later commentators indulge in much speculation about the different intervals and notes that they suppose to have comprised the harmony of the spheres, but they are not forthcoming about any actual parameters. Presumably the very fact that the scheme envisaged the revolutions of the different bodies as occurring in a particular order shows that some attention must have been paid to observed phenomena, and some quantitative information about solar, lunar, and planetary movements must have been utilized.

The only concrete evidence we have in this connection is a statement by Censorinus, a Roman grammarian of the third century AD who wrote a work, *De Die Natali*, containing a certain amount of calendaric information (not always accurate), that Philolaus the Pythagorean made a 'Great Year' consist of 59 years, including 21 intercalary months, and an ordinary year of  $364\frac{1}{2}$  days (*op. cit.* 18, 8). A 'Great Year' was a period after which sun, moon, and planets were supposed to occupy exactly the same positions again as at the beginning;<sup>89</sup> but it came to be regarded as a common multiple of solar and lunar periods only for calendaric purposes (see below), and this is the sense in which Censorinus uses the expression – he gives several figures for this period as put forward by various authorities (*op. cit.* 18, 5ff.). On the basis of



this attribution to Philolaus, the Italian scholar Schiaparelli<sup>90</sup> sets out a list of planetary periods (duly reproduced by Heath, *Arist.*, p. 102, note 2) which he compares with the modern figures, claiming that they show an extraordinarily close correspondence. It is important to realize that there is no evidence whatsoever that these figures were known to Philolaus; they are obtained merely by dividing the 21,505½ days of his Great Year by the nearest whole number of revolutions which each planet makes during that period according to modern knowledge, but counting Venus, Mercury, and the sun all together as completing one revolution in 364½ days. This foisting on an ancient scientist of knowledge based on modern data is a common feature of many present-day treatments of ancient astronomy, and one that it is continually necessary to guard against.

Another Pythagorean, Archytas, a contemporary and friend of Plato, and a mathematician of note who used a three-dimensional construction to solve the famous problem of doubling the cube,<sup>91</sup> provides some evidence of a general kind that mathematical techniques were to some extent applied to natural phenomena; he says (*DK* 47 B1), 'the mathematicians transmitted to us clear means of discerning (διὰ γινωσκῖν) about the speed of the stars and risings and settings, and about geometry and numbers and sphaeric [i.e. the geometry of the sphere with particular reference to astronomical problems] and not least about music.' This is the Archytas whom Horace apostrophizes as 'measurer of earth and sea and sand without number' and as one who has 'scaled the airy dwellings and traversed the round heavens with a mind that was after all to die'.<sup>92</sup> The concept of the spherical earth must soon have provoked attempts to estimate its size, and it is possible that a figure of 400,000 stades for the circumference, which Aristotle (*De Caelo* ii, 14, 298a15-17) attributes to 'some of the mathematicians', may have derived from Archytas (although it might equally well have come from Eudoxus - see below); and Horace's last two lines might refer to astronomical investigations by Archytas. He is also said (by Eudemos, *DK* 47 A24) to have asked the percipient question whether, if he stood on the outermost edge of the universe, i.e. the sphere of the fixed stars, he would be able

to extend his arm and stick outwards; the natural affirmative answer would entail acceptance of a boundless universe.

Archelaus, a pupil of Anaxagoras, seems to have held much the same astronomical opinions as his master, but to have introduced a few variations. According to the tertiary sources, both regarded the stars as fiery masses, with the earth lying motionless at the centre of the cosmos, and the heavens tilted towards the south; but Archelaus apparently considered the earth not as a flat disc, but as a disc with a raised edge and a hollow middle part. This, he thought, explained why the sun does not rise and set at the same time in all regions, as it ought to do if the earth were level (ὁμαλή - *DK* 60 A4 = Hippol., *Ref.* i, 9, 4). Presumably the idea was that the sun would appear to rise and set at different times behind the raised outer rim according to the position of the inhabitants on the slopes of the hollow part; again this is a recognizable attempt to accommodate theory to the facts of observation (*cf.* p. 59). We are also told (*DK* 60 A1 and A4) that he regarded the sun as the largest of the celestial bodies, the moon as the next largest, while the others (not specified) were of various sizes.

Another philosopher who followed Anaxagorean notions was Diogenes of Apollonia (*flor.* c. 430 BC). For him, the ἀρχή was air, which he considered to be divine, eternal, immortal, and the guiding principle of the whole universe. From air, by the different combinations of its characteristics, i.e. temperature, moistness or dryness, rarefaction and condensation, and motion, were produced all the phenomena of the visible world. Warm air is the mark of intelligence, the amount of it contained in a particular organism determining its character. Pure divine air was fiery, and there were innumerable gradations of warmth down to inanimate objects which contain no warm air (fragments 5, 7, and 8 and the tertiary evidence *DK* 64 A5, 6 and 7). Much of this (amusingly satirized in Aristophanes' *Clouds* 225f.; 264; 828f.) recalls what the tertiary sources assert of Anaximenes. He also regarded air as the ἀρχή, and it is presumably recollection of this that caused part of the doxographical tradition to make the absurd assertion that Diogenes was actually a pupil of Anaximenes (*DK* 64 A1).



The scanty fragments of his work remaining give us no details about his astronomical ideas, for which we have to trust the tertiary sources. According to these he regarded the earth as 'round' (στρογγύλη), supported by air in the centre of the cosmos (*ibid.*). Unfortunately, στρογγύλος (like its English equivalent) is ambiguous in meaning;<sup>93</sup> it may mean 'round' like a ball (synonymous with σφαιροειδής, 'spherical'), or 'round' like a dish, or simply 'curved' (see *LSJ s.v.*). Here, since Simplicius tells us (*DK* 64 A5) that Diogenes followed Anaxagoras' views in many respects, the word can hardly mean 'spherical', but refers to a disc-shaped earth (*cf.* Guthrie, vol. ii, p. 372 note 1); he is also coupled with Anaxagoras in thinking that the cosmos was tilted towards the south (Aëtius, *DK* 59 A67). The stars, the sun, and the moon he regarded as consisting of red-hot pumice-stone (κισηροειδῆ), through the pores of which came rays from the aether. This sounds very odd, particularly for the moon, which Anaxagoras knew shone by reflected sunlight, and it is likely that the source, Aëtius (*DK* 64 A12–14), has his facts muddled – he even says that Diogenes considered that the sun was extinguished by cold acting in opposition to the heat! Another obvious borrowing from Anaxagoras is the notion that, as well as the visible stars, invisible stones are also carried round the earth like the one that fell at Aegospotami (A12). This refers to the fall of a large meteorite in 467 BC, which caused a considerable sensation and which was supposed to have been predicted by Anaxagoras (*cf.* *DK* 59 A11 and 12). To him we must also trace the idea that the drawing up of moisture by the sun's heat from the regions round the earth produces winds and the turnings of sun and moon; the remaining moisture forms the sea which will gradually become dried up (A17). The same process was used to explain the annual flooding of the Nile in summer, the sun drawing water from the sea and releasing it into the river (A18).

From what we know of the opinions of Empedocles, Anaxagoras, Archelaus, and Diogenes (and it must be remembered that we are largely dependent on the tertiary sources for them), it would seem that there was a common store of astronomical ideas in the second half of the fifth century BC which was drawn on by all the

thinkers of the period.<sup>94</sup> Certainly, the atomists, Leucippus and Democritus, whom we come to next, drew on it. This is not the place to give a detailed account of the atomic theory developed by them, modified later by Epicurus, and expounded with missionary zeal by Lucretius in his *De Rerum Natura*. Suffice it to say that, according to this theory, matter consists of the conglomeration of many, small, invisible (and indivisible), homogeneous particles, which originally were scattered in infinite numbers throughout the void, differing from each other only in size and shape (some being round, some hooked, some triangular, and so on). By the action of the primeval vortex (δίνη), vaguely described as having been set in motion by necessity (δι' ἀνάγκην), the atoms came together, like shapes being attracted to like, to form first a sort of spherical membrane or caul (σύστημα σφαιροειδές . . . οἶον ὑμένα). As this whirled round, the finer atoms (e.g. of fire) went out towards the surrounding void and formed the celestial objects, while the coarser ones collected towards the centre and formed the earth and all its contents. This process goes on continuously throughout the limitless void, local conglomerations of atoms coming together to form countless worlds which grow, flourish, and then dissolve into their constituent atoms again (Diog. Laert. ix, 30ff. = *DK* 67 A1; Aëtius, A24).

Of the two proponents of atomism, Leucippus was the older, and his work, the 'Great World-System' (μέγας διάκοσμος), is generally dated to between 440 and 430 BC; Democritus was about ten years younger than Socrates (born in 469) and long outlived him. In the sources they are generally mentioned together when the basic principles of the system are being described, but their astronomical views are reported as showing considerable differences, and so here they are treated separately.

According to Diogenes Laertius (ix, 33), Leucippus said that the circle of the sun was the outermost, that of the moon the nearest to the earth, and those of the other celestial bodies (not specified) were in between. The earth is described as 'riding (or being carried) in a whirl round the centre' (τὴν γῆν ὀχεῖσθαι περὶ τὸ μέσον δινουμένην – ix, 30), a description which at first sight seems to show strong affinities with the Pythagorean moving earth.



However this is so foreign to what we know of the rest of atomist astronomy that it seems certain that Diogenes' account is confused here: he knew that the whole cosmos was supposed to have been formed by the action of the δίνη and carelessly uses the verb δινέω in connection with the earth as though the process was still going on. Other ideas attributed to Leucippus by Diogenes are that the earth is 'drum-shaped' (τυμπανώδης – cf. Aëtius, *DK* 67 A26), i.e. shaped like a tambourine, that the stars are made red-hot by the speed of their revolution, as is also the sun which is made more fiery by the stars, and that the moon receives only a small portion of fire. Then follows a passage where solar and lunar eclipses are apparently explained by the tilting of the earth towards the south, the northern part being always snowy, very cold, and frozen (ix, 33). The bizarreness, not to say incomprehensibility, of this 'explanation' has led most scholars to assume a lacuna in the text, because although the tilting might be adapted to explain differences in the seasons and the lengths of day and night (as had already been suggested by Anaxagoras, who makes the cosmos, not the earth, tilt – see above, p. 59), it is difficult to see how it can be made to account for eclipses. On the other hand, it is obvious that Leucippus' astronomical ideas were remarkably primitive for his time, and it may well be that he failed to understand the reasoning behind the theory of tilting. Diogenes ends his account by saying that, according to Leucippus, the sun is seldom eclipsed, while this is constantly (συνεχές) happening to the moon because their circles are unequal. Aëtius adds very little; he says that both Leucippus and Democritus considered the cosmos as spherical (*DK* 67 A22), and gives as a further reason for the tilting of the earth the porousness or rarity (ἀραιότης) of its southern regions (A27) – presumably the picture was of a top-heavy earth weighed down by snow and ice in the north and out of balance with the dry, warm, and light south.

Democritus' astronomical views are much more sophisticated than his predecessor's and show a greater willingness to pay attention to the facts of observation, but on the theoretical side he made no advances and his ideas are an amalgam of those of Anaxagoras and his pupils. In particular, he seems to have

rejected or ignored the theoretical advances made by the Pythagoreans and taken up by Plato, e.g. the concept of the spherical earth. It was, perhaps, Plato's consciousness of the defects of Democritus' astronomical views that gave rise to the story, reported by Diogenes Laertius on the authority of Aristoxenus, that Plato wanted to burn all Democritus' books he could get hold of, but was dissuaded from this by two Pythagoreans (Diog. Laert. ix, 40).

Once again we have to rely on secondary and tertiary sources for the details of Democritus' astronomical beliefs, since of the nearly three hundred passages listed by *DK* as B fragments only half a dozen have any relevance at all to astronomy. Thus B5b, B11r, and B13, which can hardly count as actual fragments of Democritus' writings and might well have been included among the A references, are quotations of titles only, namely Περὶ τῶν πλανήτων (*On the Planets*), Μέγας ἐνιαυτὸς ἢ Ἀστρονομίη (the *Great Year* or the *Astronomy*) – also referred to as Ἀστρολογία and Περὶ ἀστρονομίας – and Παράπηγμα (*Calendar*). Fragment B14 is a collection of data from the last-named, mostly taken from the calendar attached to Geminus' *Isagoge* and Ptolemy's *Phaseis* (on these see pp. 84f.). Fragment B15 is concerned with the shape of the inhabited world and is a very dubious fragment anyway (see below). Fragment B25 informs us that Democritus regarded ambrosia as the vapours by which the sun is nourished.<sup>95</sup> To judge by the list of over sixty titles attributed to him by Diogenes Laertius on the authority of Thrasyllus (an Alexandrian astrologer of the late-first century BC), Democritus' intellectual interests extended over a wide range, and it is a great pity that not a single one of his writings has come down to us complete.

In astronomy, he corrected Leucippus' erroneous view of the order of the celestial bodies and stated that the moon was closest to the earth (which he regarded as having been formed before the stars). Then came the sun, and then the planets (unspecified) which have not all the same height (i.e. distance from the earth) – this is according to Hippolytus (*DK* 68 A40). Aëtius says that he put the fixed stars first (reckoning inwards from the surrounding void), then the planets (again unspecified), then the sun, then



Φωσφόρος (i.e. Venus), and then the moon. The fixed stars he regarded as stones (presumably fiery) and the sun as a red-hot stone (A85-7). On the other hand, Seneca (*Nat. Quaest.* vii, 3, 2) asserts that Democritus suspected that there were several stars which were not fixed, but he did not enumerate them by name because the courses of the five planets were not yet understood.<sup>96</sup> If this were true, and it may very well be, granted Democritus' apparent rejection or ignorance of Pythagorean astronomical ideas (despite a misguided attempt by part of the doxographical tradition to connect him with both Pythagoras himself and Philolaus – cf. Diog. Laert. ix, 38), then it is difficult to see what he could have put into a work entitled *On the Planets*.

Sun and moon he regarded as composed of smooth and round atoms, λείων καὶ περιφερῶν ὄγκων (ix, 44); περιφερής describes spherical atoms which are the constituents alike of fire and the soul substance and νοῦς 'mind', which he equated with the divine (Aëtius, A74, νοῦν τὸν θεὸν ἐν πυρὶ σφαιροειδεῖ: A135 = Theophrastus, *De Sensu* 68, τοῦ θερμοῦ τὸ σχῆμα σφαιροειδές). Aristotle, who wrote a book on Democritus (cf. Simplicius, A37), tells us that he regarded the sphere as the most mobile shape (A101 = *De Anima* i, 2, 405a11). Originally, sun and moon were not fiery, being made of the same type of atoms as constituted the earth, but later, in the process that led to the enlarging of the sun's circle, fire was cut off in it (A39). This view did not prevent Democritus from realizing that the moon shines by light from the sun (Plutarch, A89a).

Despite his avowed dislike of Anaxagoras, whom he accused of plagiarizing old ideas about the sun and moon (B5), many of Democritus' own astronomical ideas, as reported in our sources, are identical with those of Anaxagoras. Thus both believed that the moon was like the earth in having mountains and glens and plains (DK 59 A77 and 68 A90), and both gave the same explanation of the Milky Way (68 A91) and of comets (68 A92); both regarded the earth as flat, but Democritus followed Archelaus in supposing that it was disc-shaped and hollow in the middle (A94). Water collected in the hollow parts, and local excess accumulations of water caused the land mass to shift and so produced

earthquakes (A97). This passage comes from Aristotle, who, as we have seen (p. 46), connects Democritus with Anaximenes and Anaxagoras in believing the earth to cover the air beneath it like a lid. The earth was tilted towards the south not, as Leucippus had thought, because its northern parts were heavier, but because the southern part through an over-abundance of natural produce and growth outweighs the virgin north (τὰ βόρεια ἄκρατα); either Aëtius' account is faulty (A96) or Democritus had very confused ideas of the Anaxagorean notion of tilting, since the passage actually talks about the 'greater weakness of the southern part of the surrounding (air)', διὰ τὸ ἀσθενέστερον εἶναι τὸ μεσημβρινὸν τοῦ περιέχοντος, which makes very little sense here.

In the beginning the earth moved about (πλάζεσθαι) because of its smallness and lightness, but as it grew denser and heavier it remained stationary (A95). According to Agathemerus (B15), compiler of a small and very bad geographical treatise of uncertain date but undoubtedly post-second century AD, Democritus thought that the inhabited part of the earth (ἡ οἰκουμένη) was not round (στρογγύλος again), as the ancients believed, with Greece in the centre and Delphi in the middle of Greece. This was the traditional picture, descended from the Homeric concept of the all-encircling Ocean stream, and already criticized by Herodotus (iv, 36). Democritus, on the other hand, maintained that it was oblong (προμήκης), its length (i.e. west to east) being half as long again as its breadth (north to south). The same source informs us that Democritus wrote a Γῆς περίοδος, 'Circuit of the Earth', and a Περὶ πλοῦς, literally a 'sailing round', that is a navigational account; but neither of these titles occurs in the list given by Diogenes Laertius (A33). Agathemerus is a poor authority, and it is surprising that Diels should classify the passage as a B fragment.

Finally, Lucretius tells us (*De Rerum Natura* v, 621f. = A88) that Democritus believed that the sphere of the fixed stars revolved with the greatest velocity, while the sun and moon, being nearer the earth, were less affected by the 'revolution of the heavens' (*caeli turbo*) and therefore moved more slowly, the moon being the slowest of all; hence the sun was overtaken by the zodiacal signs in a year and the moon in a month, but to our eyes it seemed as



though the latter moved faster. This is an idea that is implicitly criticized by Plato in the *Laws* (see below, p. 139; cf. Aristotle, *De Caelo* ii, 10). It is evidently an attempt to account for the different speeds of revolution of sun and moon relative to the fixed stars from west to east, but it manifestly confuses the diurnal revolution of the whole heaven in the plane of the equator with the movements of the sun and moon in the plane of the ecliptic. If it were merely a question of relative speeds, all the revolutions would be in the same plane. Alexander of Aphrodisias, a third-century AD commentator on Aristotle, attributes to the Pythagoreans the idea that the celestial bodies which are furthest away move with greater speed than those closer to the earth (*in Met.* A 5); but this cannot be true of the Philolaic system, in which (as we have seen) the earth itself was a moving body and the sphere of the fixed stars was either motionless or was endowed with a very slow movement.

In the last decades of the fifth century BC, the Hesiodic type of observational material mentioned above (p. 60) began to be correlated with current astronomical ideas, and one of the first results was the emergence of the 'paraepgmata' or astronomical calendars. These were a kind of almanac engraved originally on stone or wooden tablets, giving astronomical and meteorological phenomena for all the days of the month. Each day was originally represented by a hole at the side of that part of the engraved text which gave the prognostication for that particular day, and into the hole a movable peg was inserted; next day the peg was inserted into the next hole and so on (hence the name, from παραπήγνυμι, 'fix beside'). Fragments of four stone paraepgmata from Miletus and elsewhere, the earliest of which dates from the second century BC (thus comparatively late in the development of Greek astronomy), have actually been found.<sup>97</sup> The information given was of the type: 'Day 6: the Pleiades set in the morning; it is winter and rainy' or 'Day 26: summer solstice; Orion rises in the morning; a south wind blows'; and apparently from the first such data were also written up as separate texts.<sup>98</sup>

It is from two extant examples of these, the calendar attached to Geminus' *Isagoge*<sup>99</sup> and Ptolemy's *Phaseis*,<sup>100</sup> that we derive

most of our information about them.<sup>101</sup> Both these calendars were compiled at a time when mathematical astronomy had already reached a high level of proficiency, and so they cannot be regarded as typical of the earliest examples; in fact, they contain meteorological and astronomical data<sup>102</sup> deriving from many different observers in different localities. Thus the calendar attached to Geminus' work uses as sources Democritus (the earliest authority cited, which confirms the title, Παράπηγμα, attributed to him – see p. 81), Euctemon, Meton, Eudoxus, and Callippus. Ptolemy (about three hundred years later) adds ἐπισημασίαι from the Egyptians (who observed παρ' ἡμῶν, i.e. in Alexandria – exactly who these were is not clear), Hipparchus, Julius Caesar, Dositheus, Metrodorus, Philippus, and Conon. Ptolemy, of course, was aware that the data connected with the various days of the year depended on the latitude of the observer (cf. pp. 14f.), and he gives (*Phas.*, p. 67 ed. Heib.) the places where the observers made their observations. This fact was apparently not appreciated by the general public who presumably used the paraepgmata as calendaric guides for the business of everyday life.

Thus we find a body of material that soon became traditional in character and was copied and recopied indiscriminately by compilers and popularizers who never made any observations themselves and ignored the discrepancies arising from the different regions to which the data were applicable. One result of this can be seen in the rustic calendar set out in ch. 25–31 of Book xviii of Pliny's *Naturalis Historia* (first century AD), where he complains of the different dates he finds given for the same phenomena in various authorities, and demonstrates his own scientific incompetence in dealing with the material.

Obviously, to be any use at all such data must be attached to a fixed calendaric scheme based on the solar year, and here a well-known difficulty obtrudes itself. The most natural means of dividing the year into convenient periods longer than single days and nights is by the lunar (synodic) month – the time that elapses between one phase of the moon and the next recurrence of that phase. The Babylonian calendar, for example, like the early



Jewish calendar and the official Mahommedan calendar to this day, was at all times a lunar calendar; a new month began with the first visible appearance of the crescent of the new moon (hence the importance attached to being able to predict this and the elaborate computational schemes for this purpose).<sup>103</sup> Moreover, the moon plays a very important role in the religious practices of most peoples, in that the occurrence of religious festivals is largely regulated by its phases (the date of Easter, for example). Nilsson has shown that most Greek festivals took place at or near full moon (*Primitive Time-Reckoning*, p. 343), and that all the Greek names for months (which vary from city to city, each having its own particular calendar) are connected with religious festivals.<sup>104</sup>

Unfortunately, the lunar month is incommensurable with the solar year: no convenient whole number of months makes up exactly one year. The lunar month is a little more than  $29\frac{1}{2}$  days; 12 of these amount to 354 days and 13 to 384 days, whereas the sun takes very nearly  $365\frac{1}{4}$  days to complete one full cycle. Thus a purely lunar-based calendar is very soon going to become greatly out of step with the sun. A festival supposed to be held at full moon in mid-summer would in the course of years be taking place in the autumn, winter, or spring. In fact, the Mahommedan year of 12 lunar months is about 11 days out by the sun each year, and every date in this calendar goes the complete round of the seasons every 33 years.

Now this is all very well for the followers of Mahomet, but it would not do for the Greeks. One of the characteristics of both Greek and Roman religion is the insistence on exact ritual; the gods were displeased if the rites were not carried out in exactly the fashion laid down, and this, of course, included having them on the same day or days each year. Geminus, *Isagoge* ch. 8, the *locus classicus* for Greek calendaric cycles, is very clear on this point. There is also the obvious absurdity in holding, say, a harvest thanksgiving festival at a time when the corn had not even been planted. So the Greeks expended considerable thought in establishing a luni-solar year, in which the months and days are measured by the phases of the moon but which still keeps in step with the sun. The problem then is to find an extended period which is a

common multiple of the lunar and solar cycles, and to intercalate months as necessary during any one period.

According to Geminus (*loc. cit.*), the earliest such intercalation cycle was one of 8 years, the 'octaëteris', since 8 solar years of 365 days are roughly equal to 99 lunar months of  $29\frac{1}{2}$  days. However his description of how this evolved is unsatisfactory (see below, pp. 188–89) and there is considerable doubt concerning the origin of this cycle. Censorinus (*De Die Nat.* 18, 5) tells us that it was usually ascribed to Eudoxus, but that other names were also connected with it, including that of Cleostratus of Tenedos. This latter is a shadowy figure of the second half of the sixth century BC, mentioned less than a dozen times in the tertiary sources (see DK 6) and supposed to have written on astronomy. The scholiast on Euripides, *Rhesus* 528 quotes two of his hexameters (Diels supplies a third, DK 6 B1), and it is possible that he wrote a poem in the Hesiodic manner giving some information about the constellations then known; but it is wholly impossible that he introduced the zodiacal signs and understood the concept of the ecliptic, as Pliny tries to make out, since this does not appear until the end of the fifth century BC;<sup>105</sup> and attempts to build up Cleostratus as a key figure in early Greek astronomy<sup>106</sup> are certainly misconceived.

The first well-attested intercalation cycle is connected with the names of two Athenian astronomers, Meton and Euctemon, who flourished about 430 BC and, according to Ptolemy (*Phas.*, p. 67, 2), made observations at Athens, in the Cyclades, in Macedonia, and in Thrace. In the *Almagest* (iii, 1) they are cited for observations of the summer solstice, including one on 27 June 432 BC, which, despite their inaccuracy by the standards of later astronomy (emphasized by both Hipparchus and Ptolemy – modern calculations show that the solstice actually occurred about  $1\frac{1}{2}$  days later), were nevertheless used as confirmation of the figure that Hipparchus decided on for the length of the year and that Ptolemy also accepts (viz.  $365\frac{1}{4}$  days less  $\frac{1}{300}$  of a day). Meton suggested a period of 19 years, called after him the Metonic cycle, to bring the lunar month into correlation with the solar year. This cycle contained 235 lunar months (7 of which were



intercalary) and 6,940 days, and, according to Geminus,<sup>107</sup> 110 of the months were 'hollow', i.e. of 29 days each, and 125 'full', i.e. of 30 days each. This would give a mean lunar month less than two minutes too long and a solar year of  $365\frac{5}{9}$  days, about 30 minutes too long.<sup>108</sup>

Meton and Euctemon are frequently cited in the *paraepgmata*, and are the earliest names connected with the observations of equinoxes as well as solstices. Moreover, according to a second-century BC papyrus fragment known as the *Ars Eudoxi*,<sup>109</sup> Euctemon gave the lengths of the astronomical seasons starting from the summer solstice as 90, 90, 92, and 93 days respectively (the modern figures to the nearest whole day are 92, 89, 90, and 94), which shows that he was aware of the non-uniformity of the sun's course round the earth. Now, recognition of the equinoxes and of the inequality of the seasons implies a comparatively sophisticated stage in astronomical thought, and presupposes at least some knowledge of the concept of the celestial sphere and a spherical earth – see my article in *JHS* 86, 1966. Thus the Pythagorean ideas were now beginning to bear fruit when applied to the observational material that was available, and it would seem that a much clearer picture was being obtained of at least the sun's course, with the solstices and equinoxes marking the four seasons of the solar year.

An essential part of this picture is the concept of the sun's circuit of the heavens marked by its passage through the zodiacal constellations in a plane *inclined* to that of the equator. As we have seen, this was not part of the Philolaic scheme. The invention of the ecliptic as the sun's oblique path is attributed by Eudemus to Oinopides of Chios (*DK* 41, 7), who we are told was a little younger than Anaxagoras (*ibid.* 1), and who is mentioned in the pseudo-Platonic dialogue *Amatores* (132a–b) in connection with drawings of inclined circles; he, too, seems to have been a Pythagorean. No actual figure for the obliquity of the ecliptic is ascribed to Oinopides, but he may have known the rough estimate of  $24^\circ$  (see below, pp. 157–58). According to Censorinus (*De Die Nat.* 19, 2) Oinopides made the length of the year  $365\frac{2}{3}$  days, while Aelian and Aëtius ascribe to him a Great Year of

59 years (*DK* 41, 9). It is possible, as Tannery suggests,<sup>110</sup> that, starting with the figures of  $29\frac{1}{2}$  days for the lunar month and 365 days for the solar year, Oinopides realized that the smallest whole number of years to contain a whole number of lunar months would be 59 ( $2 \times 29\frac{1}{2}$ ), containing 730 ( $2 \times 365$ ) months which would be equivalent to 21,557 days, and this divided by 59 would give  $365\frac{2}{3}$  days.

Equinoxes and solstices and other *paraepgma* data are also mentioned in the medical treatises of the Hippocratic corpus, especially the works entitled *On Airs, Waters, Places* and *On Diet*.<sup>111</sup> These treatises are notoriously difficult to date,<sup>112</sup> but certainly none of them can be earlier than 425 BC.

Hence all the evidence points to the conclusion that the last decades of the fifth century BC saw the real beginning of mathematical astronomy in Greece, although the celestial sphere as a fully developed concept does not appear until the fourth century. It seems certain that calendaric problems provided the initial impetus for this development. There is ample evidence that in the fifth century the Athenian civil calendar was in a state of confusion. Aristophanes in the *Clouds* (610ff.) makes the moon complain that the Athenians were not arranging the days properly in accordance with its phases (*cf. Peace* 406). Thucydides (v, 20) explains that time-reckoning by the tenure of office of state magistrates (this was the normal official method, e.g. an event would be dated in such-and-such a year of so-and-so's archonship) was bound to be inaccurate (it would anyway only be readily intelligible to a reader in one city, since each city had its own magistrate list and calendar), and the only safe method was by counting summers and winters. This would be with the help of a *paraepgma*. He also uses the astronomical phenomena listed in the *paraepgmata*, such as the solstices (vii, 16; viii, 39) and the rising of Arcturus (ii, 78) for dating specific events. It must be realized that astronomically based cycles, such as the Metonic cycle, were only used in scientific texts, while in the ordinary civil calendar of each state no systematic scheme of intercalation was apparently in use, but intercalation depended on the vagaries of officialdom.<sup>113</sup>

The new astronomical ideas naturally did not immediately



win full acceptance, and many of the old, crude notions of the early Pre-Socratics lingered on into the fourth century and even later, to judge from the sources. Antiphon (the sophist of the second half of the fifth century, not the orator), who was no mean mathematician,<sup>114</sup> is said to have believed that the moon shone by its own light, but that the concealed part round it was dimmed by the proximity of the sun, since the stronger fire dims the lesser one, which happens also with the other stars (*DK* 87 B27). He also thought (B26) that the sun's fire fed on the damp air round the earth and that its risings and settings were caused by the recurrent failure of its burning owing to the opposing effect of moisture; and he is coupled with Alcmaeon and Heraclitus in supposing that the moon was bowl-shaped (*σκαφοειδής*), and that eclipses were caused by the turnings and inclinations of its bowl (B28) – all three of these 'b' fragments (in Diels' classification) come from Aëtius. Metrodorus of Chios, one of Democritus' disciples, apparently still believed that night and day were caused by the alternate extinguishing and rekindling of fiery vapour in the sun, that this also produced eclipses, and that the sun created the stars out of 'radiant water' (*λαμπροῦ ὕδατος*, *DK* 70 A4). Aëtius connects him with Anaximander and Crates (*flor.* second century BC) in putting the sun as the highest of the celestial bodies, then the moon, and below these the fixed stars (which were illuminated by the sun) and the planets (*DK* 12 A18; *cf.* 70 A9). The same source tells us that according to both Thales and Metrodorus the moon was illuminated by the sun (70 A12 – the coupling together of these names is patently absurd), and that Metrodorus explained the Milky Way as the sun's circle. Hecataeus of Teos or its colony Abdera is joined with Heraclitus by Aëtius in allegedly stating that the sun is an 'intelligent, ignited mass from the sea' (*ἡναμματοειδὲν τὸ ἐκ θαλάττης*, *DK* 73 B9); Hecataeus is dated to the end of the fourth century BC.

The sophists in general did not profess a specialist knowledge of astronomy – their forte was to teach people how to 'get on in life' by inculcating the arts of rhetoric and argumentation and the handling of affairs. However Hippias, a sophist who was specially disliked by Plato, is portrayed as claiming a profound knowledge

of the stars and celestial matters (*Hipp. Maj.* 285b), and certainly seems to have been an accomplished mathematician.<sup>115</sup> Unfortunately, there is no evidence as to what his astronomical ideas were. According to the pseudo-Plutarchian *Lives of Ten Orators*, the funeral monument of Isocrates, who died in 338 BC, depicted Gorgias, one of the older sophists (*c.* 485–375 BC), as looking at an astronomical sphere (*εἰς σφαῖραν ἀστρολογικὴν βλέποντα* – *DK* 82 A17); but this is probably no more than artistic convention, since a globe was a recognized decorative feature.<sup>116</sup> There is no evidence in the extant fragments of Gorgias or in the tertiary sources<sup>117</sup> that he paid any particular attention to astronomy.



- DK H. Diels, *Die Fragmente der Vorsokratiker*, 6th ed., revised by W. Kranz, 1951-52
- Dox. Gr. H. Diels, *Doxographi Graeci*, 1879
- EGP J. Burnet, *Early Greek Philosophy*, 4th ed., 1930
- GFH D. R. Dicks, *Geographical Fragments of Hipparchus*, 1960
- Guthrie, *Hist. of Greek Philos.* W. K. C. Guthrie, *History of Greek Philosophy*, 1962-
- Harv. Theol. Rev. *Harvard Theological Review*
- Heath, *Arist.* T. L. Heath, *Aristarchus of Samos*, 1913
- Heath, *Greek Astron.* T. L. Heath, *Greek Astronomy*, 1932
- Heath, *Hist. of Greek Maths.* T. L. Heath, *History of Greek Mathematics*, 2 vols., 1921
- J. Hist. Id. *Journal of the History of Ideas*
- JHS *Journal of Hellenic Studies*
- Journ. Amer. Orient. Soc. *Journal of the American Oriental Society*
- Journ. Brit. Astron. Assoc. *Journal of the British Astronomical Association*
- Journ. Cuneif. Stud. *Journal of Cuneiform Studies*
- JNES *Journal of Near Eastern Studies*
- JRS *Journal of Roman Studies*
- KR G. S. Kirk and J. E. Raven, *The Pre-Socratic Philosophers*, 1960
- L'Antiq. Class. *L'Antiquité Classique*
- LSJ H. G. Liddell and G. S. Scott, *A Greek-English Lexicon*, 9th ed., revised by H. S. Jones
- MNRAS *Monthly Notices of the Royal Astronomical Society*
- Neugebauer, *ACT* O. Neugebauer, *Astronomical Cuneiform Texts*, 3 vols., 1955
- Neugebauer, *Ex. Sci.* O. Neugebauer, *The Exact Sciences in Antiquity*, 2nd ed., 1957
- OCT *Oxford Classical Texts*
- Philol. Untersuch. *Philologische Untersuchungen*
- Philos. *Philosophy*
- Phron. *Phronesis*
- Proc. Amer. Philos. Soc. *Proceedings of the American Philosophical Society*
- RE Pauly-Wissowa, *Real-Encyclopädie der classischen Altertumswissenschaft*
- Rhein. Mus. *Rheinisches Museum für Philologie*
- Ross, *Arist. Met.* W. D. Ross, *Aristotle's Metaphysics*, 2 vols., 1924
- Ross, *Arist. Phys.* W. D. Ross, *Aristotle's Physics*, 1936
- Van der Waerden, *Anf.* B. L. van der Waerden, *Die Anfänge der Astronomie*, 1956

- 1 Part of the material in this chapter has been adapted from my article in *Bull. Inst. of Class. Stud.* No. 11, London, 1964, pp. 43ff.
- 2 Hence a description of the type of instrument used in later Greek astronomy, e.g. by Hipparchus and Ptolemy, has been postponed to the second volume—meanwhile, see *Journ. Brit. Astron. Assoc.* 64, 1954, pp. 72-85
- 3 Much of this may be found in the elementary handbooks of astronomy written by Geminus in the first century BC (*Isagoge in Phainomena*, ed. Manitius, Teubner, 1898) and by Cleomedes in the first century AD (*Cyclica Theoria*, ed. Ziegler, Teubner, 1891)
- 4 E.g. by Autolycus of Pitane in his *On Risings and Settings*, ed. Hultsch, Teubner, 1885, the earliest extant Greek astronomical treatise, dating from the last decades of the fourth century BC
- 5 Adapted from O. Schmidt's paper on Autolycus in *Den 11. skandinaviske matematikerkongress*, Trondheim, 1949, pp. 204-05
- 6 Ptol., *Geogr.* i, 7, 4
- 7 Cf. Fig. 13, (p. 222) a diagrammatic representation of the terrestrial sphere with a parallel of latitude  $\phi$  at which the plane of the observer's horizon is HH. Note that the latitude is given by the angle  $\phi$  which by elementary geometry is the same as the height of the north celestial pole above the horizon, but not directly by the angle  $\alpha$ , which is the angle that the equatorial plane makes with the horizon and is, in fact, the 'co-latitude' =  $90^\circ - \phi$
- 8 This is the ratio accepted by Hipparchus for Athens (*Comm. in Arat.* i, 3, 6), and gives a latitude about  $1^\circ$  too low – see p. 154
- 9 A ratio given by Eudoxus – see p. 154
- 10 On ancient trigonometry, see especially Heath, *Hist. of Greek Maths.*, vol. ii, pp. 257-60, 265-73, 276-86
- 11 See GFH, pp. 159; 162-63
- 12 See a news story in *The Times* of 14 April 1965, headed 'Error Found in Moon's Orbit'
- 13 Cf. O. Neugebauer, *The Exact Sciences in Antiquity*, 2nd ed., 1957, p. 99, 'Mythological concepts which involve the heavens, deification of Sun, Moon, or Venus cannot be called astronomy if one is not willing to count as hydrodynamics the existence of belief in a storm deity or the personification of a river. Also the denomination of conspicuous stars or constellations does not constitute an astronomical science'
- 14 See A. Pannekoek, *Hist. of Astron.*, English trans., 1961, ch. 7; Neugebauer, *op. cit.*, ch. 4
- 15 Cf. GFH, p. 14. The idea that astrology is an early, bastard form of astronomy is based on no good evidence at all—cf. Neugebauer, *op. cit.*, p. 168
- 16 Plato's recommendation in the *Laws* of the public worship of sun, moon, and stars (821 c-d) was never put into practice
- 17 See *Hermes* 91, 1963, pp. 60ff.







much this is pure coincidence or whether it represents a vestigial memory of an eclipse enshrined in the epic tradition, it is impossible to say. One would, perhaps, have thought that such a rare and impressive phenomenon as a total solar eclipse, if it had actually been experienced, would have merited more than such a brief allusion.

- According to Plutarch (*De Fac. in Orb. Lun.* 931e) solar eclipses were mentioned by Mimnermus and Archilochus (both of the seventh century BC), Stesichorus (seventh – sixth century) and Pindar (sixth – fifth century) as well as by Cydias (early-fifth century). Of these only the two mentioned by Archilochus (fr. 74 *Anth. Lyr. Gr.*, ed. Diehl) and Pindar (*Paean* ix, 1–5, fr. 44, Bowra) can be identified with any certainty, the former as the eclipse of 6 April –647 (Jacoby's doubts about this in *CQ* 35, 1941, pp. 97–8 are unnecessary), and the latter that of 30 April –462, being the largest visible at Thebes in Pindar's time (cf. J. K. Fotheringham, 'A Solution of Ancient Eclipses of the Sun', *MNRAS* 81, 1921, pp. 104ff.; 107; 109).
- 24 As Finley points out (*World of Odysseus*, 1956, pp. 151–52), all that Helios can do when Odysseus' men kill his cattle (*Od.* xii) is to rush off and complain to Zeus.
- 25 Cf. *Il.* viii, 541, where a particular day is described as 'bringing evil' for the Greeks, and *Od.* i, 283, where rumour 'brings news' for men.
- 26 Normally in the literary sources, unless the context clearly indicates otherwise, as it does at 567, 'rising' (ἐπιτολή, distinguished from the daily rising which is ἀνατολή – cf. Geminus, *Isag.* 13) and 'setting' (δύσις) refer to the heliacal rising and cosmical setting, both phenomena occurring before sunrise – cf. p. 13.
- 27 The standard works in this field are P. V. Neugebauer, *Tafeln zur astronomische Chronologie*, 1912–25, and *Astron. Chron.*, 1929; the astronomical data in F. K. Ginzel, *Handbuch der math. und techn. Chron.*, 3 Bd., Leipzig, 1906–14 (photo-lith. repr. 1958) are based on Neugebauer's tables, but Ginzel also gives additional tables listing useful data not tabulated by Neugebauer; U. Baehr, *Tafeln zur Behandlung chron. Probleme*, 1955 (Veröffentlichungen des Astron. Rechen-Institut zu Heidelberg, Nr. 3) repeats some of Neugebauer's tables using more recently worked values for the different constants.
- 28 E.g. in the 'parapegma' texts, see pp. 84f.
- 29 Cf. M. P. Nilsson, *Primitive Time-Reckoning*, 1920, pp. 40–1; 49; 56; 64; 89; 115f.; 129f.; Aratus, *Phain.* 264f. and schol. *ad loc.*
- 30 Cf. 586–88, 'Women are most wanton and men most feeble when Sirius parches the head and knees, and the skin is dry because of the heat'; similarly at *Scut. Her.* 397. As in *Il.* xxii, 30–1, it is highly improbable that the figurative language used here implies a belief that the stars actually affected conditions on earth – cf. above, p. 95.
- 31 W. Kubitschek, *Grundriss der antiken Zeitrechnung* (in Müller's *Hdbk. d.*

- Alert.*), 1928, p. 109, fixes it at 28 Dec. for latitude 38°N. about 800 BC.
- 32 Well explained by A. W. Mair in an addendum, entitled 'The Farmer's Year in Hesiod' (especially pp. 130; 142), to his translation of Hesiod's poems (Oxford, 1908).
- 33 As is stated by the scholiast on Aratus, *Phain.* 254 – cf. 172 – and alleged extracts from which are given in Pseudo-Eratosthenes, *Catast.* fr. 1 and 32 (ed. Robert, Berlin, 1878; cf. Maass, *Philol. Untersuch.*, Heft 6, 1883, pp. 3–55); cf. Diod. Sic. iv, 85; Plato, *Epin.* 990a; Callim. *Ep.* 27.
- 34 Cf. my article 'Solstices, Equinoxes, and the Pre-Socratics', *JHS* 86, 1966.
- 35 W. K. C. Guthrie, *History of Greek Philosophy*, vol. ii, 1965, p. 345.
- 36 First ed. 1903; 5th ed. 1934–37 revised and re-edited by W. Kranz in three vols. and reprinted several times since.
- 37 E.g. in *Metaphysics* A – although there is little doubt that his historical notices of earlier doctrines are sometimes coloured by his own preconceptions; cf. H. Cherniss, *Aristotle's Criticism of Pre-Socratic Philosophy*, 1935.
- 38 Cf. *CQ* 9, 1959, pp. 294–309, especially 298.
- 39 Anthologies of the collected 'opinions' (δόξαι – also ἀρέσκοντα, Latinized as *placita*) of earlier thinkers were best-sellers in late antiquity.
- 40 Cf. also Heath, *Arist.*, pp. 2f.
- 41 Cf. *JHS* 86, 1966, pp. 29f.
- 42 G. S. Kirk and J. E. Raven, *The Pre-Socratic Philosophers*, 1960, p. 7 – hereafter referred to as *KR*.
- 43 Cf. Aristophanes, *Clouds* 180; *Birds* 1009; Plato, *Theaet.* 174a.
- 44 Both these theorems are attributed to Thales on the authority of Eudemus (Proclus, *Comm. in Eucl.* i, ed. Friedlein, pp. 299, 1; 352, 14). For Thales bringing geometry into Greece from Egypt, see the 'Eudemian summary' in Proclus (*op. cit.*, p. 65, 7; Wehrli, *Die Schule des Arist.*, Heft 8 – Eudemos von Rhodos, fr. 133).
- 45 Which would require, as well as an accurate knowledge of solar and lunar cycles and the moon's deviations in latitude from the ecliptic, an understanding of the concept of geographical latitude in order to be able to predict the totality of the eclipse in a given region. Such an advanced level of knowledge was not even reached by Babylonian astronomy of the Seleucid period (the last three centuries BC), much less that of the sixth century BC.
- 46 Cf. the creation myths of the ancient Egyptians and Babylonians and of *Genesis* (*KR*, ch. 1, especially pp. 33f.). Recent speculation has attributed a similar type of cosmogony, with the personified figures of Πόρος and Τέκμων (apparently 'Contrivance' and 'Differentiation') to the seventh-century BC Spartan poet, Alcman – see M. L. West, *CQ* 13, 1963, pp. 154–56, and *CQ* 17, 1967, pp. 1–15.
- 47 The same word is used by Socrates (*Phaedo* 109a2) of the heavens (οὐρανός) in a similar context – see p. 95.



- 48 Cf. the waters of the firmament in *Genesis* 1  
 49 See especially C. H. Kahn, *Anaximander and the Origins of Greek Cosmology*, Columbia Univ. Press, 1960, *passim*  
 50 Compare the accounts of Anaximander's supposed 'system' given by Heath, *Arist.*, 1913, ch. 4; J. S. Morrison, *JHS* 75, 1955, pp. 62-3; KR, pp. 134-37; Kahn, *op. cit.*, pp. 87ff.; Guthrie, vol. i, pp. 93-9; O'Brien, *CQ* 61, 1967, pp. 423ff.  
 51 It is very improbable that the planets were yet differentiated (cf. *JHS* 86, 1966, p. 30), and, if they were not, occultations of stars by them would presumably not be noticed, so that Anaximander's alleged order of the celestial bodies might not seem so crass; but occultations of stars by the moon are relatively frequent and more easily observable  
 52 Strangely, no modern booster of the Pre-Socratics as 'super-scientists' has, to my knowledge, seized on this as 'convincing evidence' for their understanding of the principle of the hovercraft. . . . No doubt this will come in time - we have already had it suggested that Wegener's theory of continental drift was anticipated by Thales' earth floating on water! (K. R. Popper, 'Back to the Pre-Socratics', *Proceedings of the Aristotelian Society*, Oct. 1958, p. 3). For a sensible rebuttal of such fancies see G. S. Kirk, 'Popper on Science and the Pre-Socratics', *Mind* 69, 1960, p. 328  
 53 The dates of the Pre-Socratics are largely guesswork, although some guesses are more informed than others  
 54 This type of contradiction is frequent in the tertiary sources, and serves to demonstrate why they are so untrustworthy as independent evidence  
 55 Heath (*Arist.*, p. 42-3) also compares another passage in Aëtius (ii, 23, 1 = *DK* 13 A15), which speaks of 'the stars making their turnings by being thrust off course' by wind (ἐξωθούμενα τὰ ἄστρα τὰς τροπὰς ποιεῖσθαι). This is another notion that we shall meet again in connection with later Pre-Socratics  
 56 *DK* 21 A32; A33; A37-41; A45  
 57 His is the famous dictum πάντα ῥεῖ (cf. Plato, *Theaet.* 181a), and the remark that you cannot step into the same river twice (*DK* 22 B31)  
 58 His is the first extant use of the actual word κόσμος in its philosophical sense of 'world-order', i.e. practically equivalent to 'universe' - cf. J. Kerschensteiner, *Kosmos*, Munich, 1962 (Zetemata, Heft 30)  
 59 J. H. Morrison in *JHS* 75, 1955, accepting every scrap of evidence from whatever source, has attempted a reconstruction which is based on attributions to both Anaximander and Parmenides of astronomical knowledge (e.g. of the ecliptic) which it is highly improbable that they possessed (see my article in *JHS* 86, 1966)  
 60 This from Strabo via Posidonius, A44a - it is, of course, completely wrong, as the theory of zones is a gross anachronism for Parmenides' time: cf. my *GFH*, pp. 23-6  
 61 ἀλλότριον φῶς, properly 'a light belonging to someone or something

- else' - the phrase is evidently a pun on the Homeric ἀλλότριος φῶς, 'a foreign man', *Il.* v, 214; *Od.* xviii, 219  
 62 Cf. fr. 115, 11, αἰθέρος . . . δῖναις and the αἰθέριος δῖνος of Aristophanes, *Clouds* 380  
 63 ἀλισθείς - not necessarily 'globulated', as some translators have it  
 64 Unfortunately, the text of Plutarch, *De Fac. in Orb. Lun.* 929c (which provides the fragment) is uncertain; for the MS ἀπεσκεύασε δὲ οἱ αὐγὰς, ἔστε αἶαν καθύπερθεν, Diels conjectured ἀπεστέγασεν . . . ἔστ' ἂν ἔη καθύπερθεν, followed by KR who translate (p. 334), 'But she kept off the sun's rays, so long as it was passing over above her, and cast a shadow over as much of the earth as was the breadth of the pale-faced moon' (cf. Guthrie, vol. ii, p. 197). Yet the verb ἀποστεγάζω, here translated 'kept off', is used again in fr. 100, 14 where KR translate it 'uncover' (the meaning given by *LSJ*, s.v.), which is also how Diels translates his own conjecture (*DK*, vol. i, p. 330, 'Der Mond deckte ihr (der Sonne) die Strahlen ab'). Cherniss (*Moralia*, vol. xii, Loeb, *ad loc.*) retains the MS reading, but prints ἀπεσκεύασεν for ἀπεσκεύασε, and translates, 'His beams she put to flight . . . From heaven above as far as to the earth, Whereof such breadth as had the bright-eyed moon She cast in shade'  
 65 Compare the famous clepsydra simile in B100 (also from Aristotle - *De Resp.* 7, 473b9), designed to illustrate the corporeality of air by the behaviour of water in a double-ended vessel when one end is blocked up. This is *not*, as sometimes claimed (e.g. by Burnet, *Early Greek Philosophy*, p. 27), an instance of the use of the experimental method in ancient science - see KR, p. 342; Guthrie, vol. ii, pp. 225-26  
 66 Unless Aristotle misunderstood the point of Empedocles' analogy. For a discussion of various views on this passage, see Guthrie, vol. ii, p. 198-99  
 67 J. Longrigg in *CQ* 15, 1965, has an ingenious notion that this idea might well have been 'derived from his observation of the formation of salt under the action of the sun's heat'! (p. 251)  
 68 Aristotle obviously had a similar feeling when he contrasts the sobriety of Anaxagoras' views with the random opinions of his predecessors (*Met.* A 984b17)  
 69 Cf. Xenophon (*Mem.* iv, 7), who makes Socrates assert that Anaxagoras must have been out of his mind (παρεφρόνησεν) to have said such things, and makes him refute them by some painfully naive arguments  
 70 The scientific ideas that Aristophanes pokes fun at and attributes to Socrates and his 'thinking-shop' in the *Clouds*, are mainly those of Anaxagoras  
 71 His word for the primal movement is περιχώρησις, 'rotation', instead of δίνη  
 72 Diog. Laert. ii, 12 (cf. Diod. Sic. xii, 39). Plutarch (*Per.* 32) connects Anaxagoras' impeachment with a decree proposed by one Diopeithes, c. 431 BC, and aimed at 'those who do not believe in the gods or who teach doctrines about celestial matters'. This, together with Plutarch's



exaggerated description of the hostility of the Athenian public to new astronomical ideas (*Nic.* 23 – see my forthcoming review in *CR* of T. W. Africa's *Science and the State in Greece and Rome*, 1968) has led some scholars (e.g. J. B. Bury, *CAH*, vol. v, p. 383) to suppose that the study of astronomy was officially forbidden at Athens during the latter part of the fifth-century BC. Nothing could be further from the truth. As we shall see, this was the time when Greek mathematical astronomy had its beginnings, with the collation and codification of astronomical and meteorological phenomena in the 'parapegmata', the diffusion of Pythagorean ideas on the sphericity of the earth and the circular orbits of celestial bodies, the discovery of the obliquity of the ecliptic by Oinopides, and the activities of Meton and Euctemon in measuring solstices and equinoxes and improving the calendar.

The circumstances of Anaxagoras' impeachment are by no means clear – see the discussions by Taylor (*CQ* 11, 1917, pp. 81–7), Davison (*CQ* n.s. 3, 1953, pp. 42–5), and Guthrie (vol. ii, pp. 322–23); but it seems most likely that it was really Pericles who was being attacked through his old master, Anaxagoras. As a former Persian subject, Anaxagoras also came under suspicion of 'medism'. The fact that he advocated unorthodox opinions about the celestial bodies may have helped the prosecution, but it is highly improbable that this alone would have been sufficient to condemn him – just as a similar charge did not suffice in the case of Socrates, who was condemned mainly because of his anti-democratic connections and sentiments

- 73 Cf. K. R. Popper, 'Back to the Pre-Socratics', *Proceedings of the Aristotelian Society*, Oct. 1958, p. 3, '... but most of them [the ideas of the Pre-Socratics], and the best of them, have nothing to do with observation'. Kirk notes the 'superficial glance which was all that many Pre-Socratics seem to have considered necessary' (*Mind* 69, 1960, p. 329)
- 74 The mathematical relationship expressed by which is now known to have been familiar to the Babylonian mathematicians at least a thousand years before Pythagoras
- 75 This, as Heath points out (*Arist.*, p. 99), entails one complete rotation of the earth on its axis as it completes one circuit of the central fire
- 76 This, however, is a stock title which the doxographers attribute to practically every single Pre-Socratic – cf. *KR*, p. 101
- 77 On the nomenclature of the planets see F. Cumont, 'Les noms des planètes et l'astrolatrie chez les Grecs', *L'Antiq. Class.* 4, 1935, pp. 5–43
- 78 Unless, indeed, the moon was supposed to reflect the light of the central fire and not that of the sun. Apparently, some Pythagoreans realized that the moon shone by reflected sunlight (*Diog. Laert.* viii, 27), but others still spoke of its own fire being kindled, spreading to the state of full moon, and then being gradually extinguished (*Aëtius*, *DK* 58 B36)
- 79 Cf. the use of the word ἀνατρέπειν in a geographical sense – *GFH*, p. 125

- 80 The Greek is οἱ δὲ γνησιώτερον αὐτῶν μετασχόντες πῦρ μὲν ἐν τῷ μέσῳ λέγουσι τὴν δημιουργικὴν δύναμιν τὴν ἐκ μέσου πᾶσαν τὴν γῆν ζωογονοῦσαν καὶ τὸ ἀπεψυγμένον αὐτῆς ἀναθαλοῦσαν. Surprisingly, this has been interpreted as referring to another brand of Pythagoreanism which believed in a fiery core at the centre of the earth, itself situated in the middle of the universe – as though the words ἐν τῷ μέσῳ and ἐκ μέσου referred to the earth's centre and not the centre of the cosmos (*H. Richardson*, *CQ* 20, 1926, pp. 118–21; *Guthrie*, vol. i, pp. 290f.). Not only does the context show this interpretation to be impossible, but there is no good evidence for the idea of a fiery core to the earth in Pythagorean thought. Guthrie can only point to a similar idea in Empedocles and assume that this might have formed part of early Pythagoreanism, and the single piece of evidence for a geocentric universe in this school (which entirely contradicts what we are told by Aristotle who, after all, did write a book on the Pythagoreans) is the muddled account of Diogenes Laertius (viii, 25 *ad fin.*), ostensibly reporting Alexander Polyhistor, which does not mention the Philolaic scheme at all, but attributes a 'spherical cosmos possessing soul and intellect and surrounding the central earth that is also spherical and inhabited all round' to 'Pythagorean writings'. There is obvious confusion with Stoic ideas here
- 81 This is implicit in Simplicius' words, (pp. 511–12 ed. Heiberg, ἡ δὲ ἀντίχθων κινουμένη περὶ τὸ μέσον καὶ ἐπομένη τῇ γῇ ταύτῃ οὐχ ὀρᾷται ὑφ' ἡμῶν διὰ τὸ ἐπιπροσθεῖν ἡμῖν αἰεὶ τὸ τῆς γῆς σῶμα)
- 82 As Dreyer sensibly remarks (*Hist. of Astron.*, Dover reprint, 1953, p. 48), it would require an observer at the centre of motion itself to differentiate between a motionless outer heaven and an earth revolving in exactly twenty-four hours, and a slowly rotating outer heaven with an earth revolving in a slightly shorter period
- 83 B. L. Van der Waerden, *Die Astronomie der Pythagoreer*, Amsterdam, 1951, p. 54. The book gives a totally misleading idea of its subject matter, and is based largely on what the author thinks Pythagorean astronomy ought to have been; thus, to explain the Philolaic system Van der Waerden makes up his own 'einzige Lösung' (p. 60) according to which the order of the orbits from the centre is sun, Mercury, Venus, earth (with moon encircling it), Mars, Jupiter, and Saturn – an order for which, needless to say, there is not a shred of evidence and which contradicts the little we are told about the scheme
- 84 *Arist.*, p. 100 – but his translation of the passage '... that it revolves round the fire in an oblique circle in the same way as the sun and moon' (p. 97) does not square with such an interpretation (which Dreyer also seems to accept – *op. cit.*, p. 45). As far back as 1810, A. Boeckh evidently took the same view (*Gesammelte Kleine Schriften*, Bd. 3, Leipzig, 1866, pp. 266; 276f.)
- 85 This is obviously the motivation of Boeckh, Heath, Dreyer, and Van der



- Waerden as well; but it is surely not justifiable in the face of the bulk of the evidence
- 86 Cf. Guthrie, *Aristotle On the Heavens*, Loeb, 1960, pp. 136–37
- 87 Cf. Van der Waerden, *Anfänge der Astronomie*, 1966, pp. 49–50. On the influence of Babylonian astronomy on Greek, see above, pp. 163ff.
- 88 Hence Diels omits it from *DK* 58 – cf. *Dox. Gr.*, Prolegomena, p. 69
- 89 Cf. *Timaeus* 39d
- 90 *I precursori di Copernico nell'antichità*, Milan, 1873, p. 8
- 91 Heath, *Hist. of Greek Maths.*, vol. i, pp. 246–49
- 92 *Odes* i, 28, 1–6
- 93 Hence the unnecessary doubts that have been raised as to whether Plato regarded the earth as spherical; but Socrates in the *Phaedo* opposes στρογγύλος το πλάτους, 'flat' (97d – see above, p. 94), which is the word specifically connected with the Anaxagorean disc-shaped earth (see p. 58), and so in this case there is nothing to prevent στρογγύλος meaning 'spherical' – and the rest of Plato's astronomical passages undoubtedly imply a spherical earth (see p. 98)
- 94 Or, perhaps more accurately, there was a common stock of astronomical notions ascribed to earlier thinkers from which all tertiary sources draw
- 95 The notion that the celestial bodies are nourished by exhalations from the earth (probably on the analogy of burnt offerings to the gods) is attributed by Aëtius to both Heraclitus and Philolaus (*DK* 22 A11; 44 A18)
- 96 sed nec numerum illarum posuit nec nomina, nondum comprehensis quinque siderum cursibus
- 97 See A. Rehm's article in *RE*, Bd. 18 (4), 1949, col. 1299f. H. Diels (*Antike Technik*, 3rd edition, 1924, Tafel 1, pp. 6–7) gives an illustration of one fragment
- 98 See the detailed study by Rehm, 'Parapegmastudien', *Abhandl. d. Bayerischen Akad. d. Wiss.*, phil.-hist. Abt., neue Folge, Heft 19, 1941, pp. 5ff.
- 99 Ed. Manitius, Teubner, 1898, pp. 210–33; Manitius shows that the calendar actually belongs to a period about one hundred years earlier than the main text which is dated to c.70 BC
- 100 Ed. Heiberg, vol. ii, 1907, *Claudii Ptolemaei Opera Astronomica Minora*, Teubner, pp. 1–67
- 101 Other Greek calendars are published in *Sitz.-Berichte Akad. Heidelb.*, phil.-hist. Kl. I (1910), II (1911), IIIA (1913) – this contains a conjectural restoration by Rehm of Euctemon's parapegma (on whom see below) – IV (1914), and V (1920)
- 102 ἐπισημασίαι, 'signs or indications of weather' – ἐπισημαίνειν is used of marking a change in the weather; cf. Rehm's article 'Episemasiai' in *RE*, Suppl. Bd. 7, 1940, cols. 175–98
- 103 O. Neugebauer, *The Exact Sciences in Antiquity*, 2nd ed., 1957, ch. 5
- 104 M. P. Nilsson, *Primitive Time-Reckoning*, p. 343; *Die Entstehung . . . griech. Kal.*, 1962, pp. 31f.; 56

- 105 Pliny, *Nat. Hist.* ii, 31 – on this see *JHS* 86, 1966, pp. 26–7; 30
- 106 E.g. J. K. Fotheringham, in *JHS* 39, 1919, pp. 164–84; refuted in detail by E. J. Webb in *JHS* 41, 1921, pp. 70–85; Fotheringham's reply in *JHS* 45, 1925, pp. 78f., based on incorrect ideas of early Babylonian astronomy (including the so-called Babylonian 'saros' – on which see Neugebauer, *Ex. Sci.*, pp. 141–42), is not convincing
- 107 *Isag.* ch. 8 – Geminus connects Euctemon but not Meton with this cycle (§ 50), but Meton's share in the discovery is amply attested by other sources (cf. Heath, *Arist.*, p. 293) and it is possible that his name may have dropped out of the text – see Manitius *ad loc.*
- 108 This figure is expressly mentioned by Hipparchus as the estimate of Meton and Euctemon – *Almag.* iii, 1, p. 207, 9 ed. Heiberg
- 109 Ed. F. Blass, 1887 – it is not, of course, by Eudoxus himself, but may be a student's exercise based partly on Eudoxan data, but containing many errors and with later material added
- 110 Quoted by Heath, *Arist.*, p. 132
- 111 See the calendar compiled by W. H. S. Jones (Loeb *Hippocrates*, vol. i, pp. 67–8)
- 112 Cf. R. Joly, *Hippocrate: Du Régime*, Budé, 1967, pp. xiv–xvi
- 113 On the whole subject see B. L. van der Waerden in *JHS* 80, 1960, pp. 168–80; W. K. Pritchett in *Historia*, Bd. 13, Heft 1, 1964, pp. 21–36
- 114 He suggested a method of squaring the circle by successively inscribing regular polygons with double the number of sides of the previous one – see Heath, *Hist. of Greek Maths.*, vol. i, p. 222
- 115 Heath, *Hist. of Greek Maths.*, vol. i, pp. 23; 225
- 116 Cf. A. Schlachter, *Der Globus*, ed. F. Gisinger, 1927 (Stoicheia, Heft 8), pp. 174f. The author's attribution of knowledge of the celestial sphere and advanced astronomical ideas to Anaximander and Parmenides should be disregarded
- 117 With the single exception that a fifth-century AD writer on rhetoric, Sopater, attributes to him the opinion that the sun is a molten lump (*DK* 82 B31)
- 118 E.g. A. E. Taylor (*A Commentary on Plato's Timaeus*, Oxford, 1928) was firmly convinced that the whole world-system expounded in that dialogue was not Platonic at all, but fifth-century Pythagorean – a 'Taylorian heresy' that has been sufficiently refuted by F. M. Cornford in *Plato's Cosmology*, 1937, pp. ix. On the other hand, the extent to which what are generally regarded as typically 'Platonic' doctrines (e.g. the theory of Ideas, the immortality of the soul, and the recollection of knowledge) are the creations of Socrates or of Plato himself remains a question which is as insoluble as ever (cf. C. J. de Vogel, *Phronesis* 1, 1955, pp. 26–35)
- 119 Thus the description of the spindle of Necessity with its eight whorls (*Rep.* x, 616b–617b) forms part of the myth of Er which is avowedly only a tale (cf. the beginning, 614b, εἰς ποτε . . . and the end, 621b, καὶ οὕτως, ὃ



Γλαύκων, μῦθος ἐσώθη . . .), and the whole of Timaeus' account of the genesis of the universe (including, therefore, the astronomical section, *Tim.* 36b–40d) is no more than a 'likely tale' with which mere mortals must be satisfied (*id.* 29d)

- 120 One is irresistibly reminded of Fitzgerald's Omar Khayyam,

*Myself when young did eagerly frequent  
Doctor and Saint, and heard great argument  
About it and about: but evermore  
Came out by the same door where in I went*

(Stanza 27)

- 121 Because both Simmias and Cebes had consorted with the Pythagorean Philolaus (61d6–7), Simmias' assent has been used as evidence (somewhat illogically) for a non-Philolaic, presumably early, version of Pythagorean cosmology, in which the spherical earth and not the central fire (note 80) was placed at the centre of the universe (*cf.* Burnet, *EGP*, p. 297 note 3). This is at complete variance with what Aristotle tells us about Pythagorean doctrines, as is also the only other evidence for this belief, namely, the garbled account of Diogenes Laertius (Diels, *Vorsokr.* p. 58 B1a6); when it comes to choosing between the latter and Aristotle, there is little doubt as to which to follow. Moreover, Simmias' assent need only refer to the statement that the earth needs no support, which is equally apposite for the planetary earth in the Philolaic system itself; the conditional form in which Socrates states the central position and circularity of the earth (despite the fact that there can be little doubt that this is Plato's own view – see below) may have been purposely chosen so as to command Simmias' assent to the proposition that the earth needs nothing to support it. Socrates might have thought, 'I know that you, as a Pythagorean, do not agree that the earth is at the centre of the universe, but grant me for the sake of argument that it is, then you will certainly agree that it needs no support, won't you?', and Simmias, of course, does

- 122 This is probably a reference to the dodecahedron, which can be constructed from twelve regular pentagons; its volume approaches closely that of the circumscribed sphere, and if the pieces are made of flexible material stitched together (as here) and filled out, a sphere would result – see Burnet *ad loc.* In the *Timaeus* (55d–56b) four of the five regular solids are appropriated to the four elements (earth = cube, fire = pyramid or tetrahedron, air = octahedron, and water = icosahedron), but the fifth, the dodecahedron, which cannot be constructed from Plato's basic right-angled triangles, is merely stated somewhat vaguely to be used by the god 'for the whole' (ἐπὶ τὸ πᾶν, 55c) – very possibly with this passage of the *Phaedo* in mind. It is highly improbable that any allusion to the twelve signs of the zodiac is intended, which is an entirely different concept, and still less likely that an astronomical system of mapping the sky into twelve zones

is referred to, for which there is no evidence at all (see Cornford, *Plato's Cosmology*, 1937, p. 219)

- 123 J. A. Stewart, *The Myths of Plato*, ed. G. R. Levy, 1960, p. 119  
124 The situation is similar in modern science fiction; it is the writers who operate on a plausible basis of modern scientific concepts (of course, imaginatively employed and extended) who succeed best in this genre  
125 Aristotle, characteristically, fails to realize this, and subjects Plato's fanciful picture of the earth's subterranean waters (111d–112e) to a solemn, scientific criticism (*Meteor.* ii, 2, 355b32ff.); *cf.* also Friedlander, *Plato*, vol. i (English trans. 1958), p. 267  
126 No ancient commentator ever had any doubts as to this, but some modern scholars have exercised their ingenuity in manufacturing them; e.g. T. G. Rosemeyer, *CQ* 6, 1956, pp. 193–97, and *Phronesis* 4, 1959, pp. 71–2; J. S. Morrison, *Phron.* 4, 1959, pp. 101–19  
127 Presumably, this implies indirect observation of the sun's image on a liquid surface, not direct observation through, e.g., a liquid-filled flask, since the words φάντασμα and εἰκὼν would hardly be appropriate for the latter method. Since Socrates is still talking about the time when he was a young man, unless Plato is here committing an anachronism (which is by no means improbable), this would seem to indicate that the observation of eclipses was a well-known procedure in the middle of the fifth-century BC  
128 J. Adam, *The Republic of Plato*, 2nd ed., vol. ii, p. 67  
129 For which see the monumental bibliography compiled by H. Cherniss in *Lustrum* 4–5, 1959–60  
130 Some of the more perceptive treatments of this and other topics in Platonic philosophy are to be found in the collection of articles entitled *Studies in Plato's Metaphysics*, ed. R. E. Allen, 1965  
131 *Met.* A 6, especially 987b14ff.; for the other passages imputing this doctrine to Plato, see W. D. Ross, *Aristotle's Metaphysics*, vol. i, 1924, p. 166 *ad loc.*  
132 *Cf.* A. Wedberg, *Plato's Philosophy of Mathematics*, 1955, who upholds Aristotle's interpretation; for weighty arguments against it, see H. Cherniss, *Aristotle's Criticism of Plato and the Academy*, vol. i, 1944, pp. 226f.; 244; 289f. and notes  
133 *Cf.* Wedberg, *op. cit.*, p. 32, 'Between extreme nominalism, which denies the existence of any abstract entities, and an extreme realism, which accepts more or less wholesale all significant expressions as designating entities (abstract if not concrete), there is an entire spectrum of possible positions . . . Plato did never clearly define where along this spectrum he took his stand'  
134 Socrates is somewhat unfair here; there is no reason why Glaucon's remark should be taken absolutely literally – he might himself have been thinking of astronomy in a metaphysical way – particularly in view of Socrates' own phrases earlier where he speaks of 'leading the soul upwards'



- (ἀνὰ πῶι ἄγει τὴν ψυχὴν, 525d) and 'making it see the Idea of Good' τὸ ποιεῖν κατιδεῖν τὴν τοῦ ἀγαθοῦ ἰδέαν, 526e)
- 135 There is an obvious allusion to the comic caricature of 'Socratic science' in Aristophanes *Clouds* 188ff.; cf. Plato *Apol.* 19c
- 136 E.g. H. S. Williams, *Hist. of Sci.*, 5 vols., 1904-10, vol. i, pp. 180ff. (Plato's point of view 'essentially non-scientific'); W. C. D. Dampier-Whetham, *Hist. of Sci.*, 1929, p. 28 (Plato's science 'fantastic . . . he roundly condemned experiment'); F. K. Richtmyer, *Introd. to Mod. Phys.*, 2nd ed., 1934, p. 9; C. Singer, *Short Hist. of Sci.*, repr., 1943, pp. 34f. (but Singer does see some redeeming features in Plato, especially for mathematics and astronomy); B. Russell, *Hist. of West. Philos.*, 1945, p. 165 (the *Timaeus* is 'silly'); J. Jeans, *The Growth of Physical Sci.*, 1947, pp. 47ff. (Plato, a 'major disaster' for physics); J. O. Thomson, *Hist. of Anc. Geogr.*, 1948, p. 101; B. Farrington, *Greek Sci.*, Pelican, 1953, p. 120
- 137 E.g. J. Adam, *The Republic of Plato*, 2nd ed., 1965, Appendices I and II to Book vii
- 138 The translation is my own but obviously owes much to other versions, of which P. Shorey's (in the Loeb *Plato*) probably comes closest to it. The Greek text (about which there are no serious ms doubts) is as follows (529c-d): ταῦτα μὲν τὰ ἐν τῷ οὐρανῷ ποικίλματα, ἐπεὶ περ ἐν ὁρατῷ πεποικιλται, κάλλιστα μὲν ἡγεῖσθαι καὶ ἀκριβέστατα τῶν τοιούτων ἔχειν, τῶν δὲ ἀληθινῶν πολὺ ἐνδεῖν, ἃς τὸ δὴ τάχος καὶ ἡ οὐσα βραδυτῆς ἐν τῷ ἀληθινῷ ἀριθμῷ καὶ πᾶσι τοῖς ἀληθεῖσι σχήμασι φοράς τε πρὸς ἄλληλα φέρεται καὶ τὰ ἐνόντα φέρει. The infinitive ἡγεῖσθαι depends on δεῖν understood from Glaucon's question; τῶν ἀληθινῶν I take to mean the true realities compared and contrasted with τῶν τοιούτων which are the things of the visible world; ἃς . . . φοράς is adverbial accusative serving to define both πολὺ ἐνδεῖν and φέρεται, and τὰ ἐνόντα must, in my view, mean the actual celestial bodies which are carried round in the orbits that Plato hypostatizes as 'real speed' and 'real slowness'. For other interpretations of this passage, see Adam, App. X to Book vii
- 139 προβλήμασιν ἄρα, ἣν δ' ἐγώ, χρώμενοι ὥσπερ γεωμετρίαν οὕτω καὶ ἀστρονομίαν μέτιμεν, τὰ δ' ἐν τῷ οὐρανῷ ἐάσομεν – note the last word; Plato does not use here the phrase χαίρειν ἔαν, 'to renounce' or 'dismiss altogether' (frequent elsewhere in Plato, e.g. *Phaedo* 63e; *Prot.* 348a; *Phileb.* 59b), as he might well have done had he meant to imply that observation could be dispensed with entirely, but the simple verb meaning 'to let be' or 'leave on one side', evidently for the time being while the astronomer concentrates on the mathematical side of his subject
- 140 Many interpreters of the Line have been led astray by a failure to appreciate the twofold purpose of the simile, and, by trying to force Plato's thought into a rigidly consistent scheme, have rendered it a good deal more obscure. For an eminently sensible treatment of the Line, see J. L. Stocks, *CQ* 5, 1911, 73-88 (p. 76, 'The Line is not a progression'; p. 78, 'Thus mathe-

- mathematics becomes, what Plato in his theory of education requires it to be, the stimulus to philosophy'); cf. F. M. Cornford, *Mind* 41, 1932, pp. 37-52 and 173-190 ('The distinction of objects [in the Line] is a matter of expediency in teaching')
- 141 As E. Dönt well remarks, it is not the observable phenomena of the heavens that Plato regards as unchanging and eternal, but 'unwandelbar sind nur die Gesetze, die dem Wunderbau des Himmels zugrundeliegen' ('Platons Spätphilosophie und die Akademie', *Österreichische Akademie der Wissenschaften, Sitzungsberichte*, phil.-hist. Klasse, Bd. 251, Abh. 3, Wien, 1967, p. 65)
- 142 Cf. the similarly hyperbolic statement that the man out of the Cave will be able to 'look on the actual sun itself' (516b – quoted above)
- 143 Well represented by Neugebauer (*Ex. Sci.*, 2nd ed., p. 152): 'His advice to the astronomers to replace observations by speculation would have destroyed one of the most important contributions of the Greeks to the exact sciences'
- 144 His standpoint in this respect is consonant with his hostility to the views of Democritus, who composed a 'parapegma' or at least made observations for one (see above)
- 145 There is no evidence anywhere in the extant works of Plato that he ever conceived of anything other than the earth as lying at the centre of the universe; nor does Aristotle attribute any such notion to him. The well-known story found in two passages of Plutarch (*Quaest. Plat.* viii, 1 and *Numa* 11 – the former by hearsay, φασί, but the latter allegedly on the authority of Theophrastus) that, towards the end of his life, Plato repented of having given the earth this central position, which should be occupied by something better, may safely be dismissed as a speculative piece of gossip or a misunderstanding of the sources.
- 146 This, of course, is not the first time this has been pointed out – cf. A. N. Whitehead, *The Concept of Nature*, 1920, p. 18 ('Plato's guesses read much more fantastically than Aristotle's systematic analysis; but in some ways they are more valuable. The main outline of his ideas is comparable with that of modern science'); *Sci. and the Modern World*, 1926, pp. 42-3; P. Shorey, 'Platonism and the History of Science', *Proc. Amer. Philos. Soc.* 66, 1927, pp. 159-82; A. Rey, *La sci. dans l'antiq.*, 6 vols., 1930-48, vol. iii, 282ff.; G. C. Field, 'Plato and Natural Sci.' *Philos.* 8, 1933, pp. 131-41; A. Momigliano (reviewing Farrington's *Sci. and Polit. in the Anc. World*, 1939) in *JRS* 31, 1941, pp. 149ff.; J. E. Boodin, 'The discovery of form', *J. Hist. Id.* 4, 1943, p. 191 (' . . . Platonic intuition of form and measurement everywhere'); W. Heisenberg, *Philos. Probs. of Nucl. Sci.*, trans. F. C. Hayes, 1952, pp. 33f. (Plato's stress on mathematical laws of nature underlying natural phenomena); p. 57; and on the whole subject, G. E. R. Lloyd, 'Plato as a Natural Scientist', *JHS* 88, 1968, pp. 78-92
- 147 Plato seems here to have taken over the semi-mystical Pythagorean



- conception of numbers as the basic 'stuff' out of which the universe is composed (see pp. 64f.). There is obviously less justification in the case of harmonics for a purely theoretical treatment than in astronomy, and it would seem that Plato in this instance allowed himself to be unduly influenced by Pythagorean notions, in the interests of emphasizing his cherished conviction that mathematical harmony underlies the whole phenomenal world – cf. the number mysticism of *Rep.* viii, 546b–c, the notorious 'Platonic number', which has nothing to do with astronomy
- 148 Taking ἀνωθεν with καθορᾶν (cf. 616d, κύκλους ἄνωθεν τὰ χεῖλη φαίνοντας and *Phaedo* 110b, εἰ τις ἄνωθεν θεῶτο) – others take it with τεταμένον 'stretched from above' (cf. Adam, *ad loc.*)
- 149 Adams translates περιφοράς as 'revolving spheres', which is misleading as there is no mention of spheres in the description at all; περιφορά means the particular form of movement appropriate to a circle, i.e. revolution or rotation (cf. Arist., *De Anima*. i, 3, 13, νοῦ μὲν γὰρ κίνησις νόησις, κύκλου δὲ περιφορά)
- 150 Cornford's picture of a 'nest of hemispherical bowls' (*Plato's Cosmology*, p. 75; *The Republic of Plato*, p. 350) is an unwarranted inference from the actual Greek text which mentions neither spheres nor hemispheres. We are told simply that the whorls fit inside each other καθάπερ οἱ κάδοι οἱ εἰς ἀλλήλους ἀρμόττοντες. Now the κάδος in shape is generally taken to resemble the amphora, having two handles and a neck narrower than its belly (cf. Amyx in *Hesperia* 27, 1958, pp. 186–90); this, of course, makes it impossible for such κάδοι to fit into one another. It seems likely that here Plato is using κάδος in its other sense of a measure of volume (see *LSJ s.v.*); two such standard measures, in the form of bronze cylinders, one fitting inside the other, have actually been found and are dated to c.400 BC (*The Athenian Agora*, vol. x, 1964, Pl. 14, DM 42 and 43). The notion of hemispherical bowls is in any case excluded by the description of the outer whorl as being 'hollow and scooped out all through' (κοίλῳ καὶ ἐξεγλυμμένῳ διαμπερές) and the spindle's shaft as being 'driven right through' (διαμπερὲς ἐληλάσθαι); rather, we should think of thick, cylindrical discs, fitting closely inside each other, but each able to rotate round the shaft. It is possible that Plato conceived of the discs as tapering slightly, so that the whole shape would be that of a truncated cone; Strabo uses the word σπόνδυλος to describe that segment of the terrestrial globe lying between the equator and the Arctic Circle (*Str.* ii, 5, 6, C 113)
- 151 Both interpretations go back to the ancient commentators: the former to Proclus (*in Remp.* ii, p. 130, 4 ed. Kroll), upheld by A. Boeckh, *Kleine Schriften*, 1866, vol. iii, pp. 298ff., and recently revived by J. S. Morrison in *JHS* 75, 1955, pp. 66–7 (who does not mention Boeckh); and the latter to Theon of Smyrna (*Ad Leg. Plat. Util.*, p. 143 ed. Hiller), preferred by Adam (vol. ii, pp. 446–47)
- 152 διὰ παντὸς τοῦ οὐρανοῦ καὶ γῆς τεταμένον – Boeckh (duly followed by

- Morrison) unconvincingly takes διὰ here in the sense of 'over', despite the clear parallel in *Tim.* 40b τὸν διὰ παντὸς πόλον τεταμένον (cf. Adam, vol. II, App. VI, p. 471)
- 153 οἷον τὰ ὑποζώματα τῶν τριήρων – again there is doubt as to the meaning; the reference might be to ropes passed horizontally round a ship from stem to stern, or to ropes going under the keel and up the sides in a vertical plane, both types serving to strengthen the hull (see Adam *ad loc.*)
- 154 Cf. Adam *ad loc.*; Cornford, *Tim.*, p. 88 and *Rep.*, p. 354; Heath, *Greek Astron.*, p. 48; Shorey in the Loeb *Rep.* translates 'with returns upon itself', which is hardly illuminating
- 155 If Zeus is the sphere of the fixed stars, are we to imagine the other gods as standing and being carried round on his back?
- 156 R. Hackforth, *Plato's Phaedrus*, 1952, pp. 72–3; but the reason he gives (p. 74, '... it seems an insuperable objection that the planets of Greek astronomy did not have hosts of satellites') is irrelevant – there is no question of planetary satellites, but of a multiplicity of gods and daemons which is well attested for Plato (cf. *Polit.* 272e; *Tim.* 40d; 41a; *Rep.* 617e; 620d; *Laws* 899b; *Epin.* 948d)
- 157 Cf. J. Bidez, *Eos ou Platon et l'Orient*, 1945, ch. 8
- 158 Both Sophocles and Euripides equate Hestia with the earth – Soph. fr. 615 (Pearson, vol. ii); Eur. fr. 938 (Nauck); cf. *Tim.* Loc. 97d; *Plut.*, *De Primo Frigido* 954f.
- 159 The extant work (itself a paraphrase of Plato's *Timaeus*) that goes under his name is a first-century AD forgery
- 160 Cf. the two articles by G. Vlastos in *Studies in Plato's Metaphysics*, ed. R. E. Allen, 1965, ch. 18, where most of the pertinent literature is cited
- 161 For which see Cornford's admirable commentary, pp. 59–72
- 162 In this famous phrase, it is a mistake to stress μῦθον at the expense of εἰκότα – the notion of 'likeness' or 'plausibility' is emphasized in 29c (cf. Cornford, pp. 30ff.). It must be remembered that in Platonic doctrine it is axiomatic that there can be no true knowledge of sensible phenomena; anyone can make up an implausible account of the genesis of the universe (cf. Hesiod's *Theogony* and the creation myths of the Egyptians and the Babylonians), but it is the business of the philosopher to give the most likely account consistent with his insight into the nature of real knowledge (cf. *Tim.* 53d)
- 163 He even goes so far as to assert (p. 74), 'Plato probably had it before him as he wrote'!
- 164 Properly speaking, an armillary sphere is a representation, by means of circular rings mounted on a stand, of the main circles of the celestial sphere (equator, tropics, zodiac, horizon, solstitial and equinoctial colures) with the earth globe at the centre; it does not show the planetary orbits or the fixed stars, except in so far as the constellations of the zodiac may be marked on the band that represents it. An astrolabe is essentially a



- sighting instrument used to determine the position of the sun or moon and the risings and settings of the more prominent fixed stars relative to a particular horizon (cf. my *GFH*, pp. 195–99). An orrery is a more complicated device that imitates the actual movements of the heavenly bodies round the earth by mechanical means (cf. R. T. Gunther, *Early Science in Oxford*, vol. ii, 1923, pp. 267f.)
- 165 Gunther, *op cit.*, pp. 264ff. with illustrations
- 166 For ancient astronomical instruments in general, see my paper in *Journ. Brit. Astron. Assoc.*, 64, 1954, pp. 77–85
- 167 Cf. Heath, *Arist.*, pp. 162–63
- 168 Cf. Cornford (p. 103) quoting Aristotle, *Phys.* iv, 223b; for some criticisms of Cornford's remarks, see Vlastos in *Studies in Plato's Metaphysics*, pp. 409f.
- 169 Burnet's text reads εἰς [τόν] τάχει μὲν ἰσόδρομον ἡλίῳ κύκλον ἰόντας, τὴν δ' ἐναντίαν εἰληχότας αὐτῷ δύναμιν. τόν is the unanimous reading of all the best mss as well as Proclus and Stobaeus (and is retained by Hermann in the Teubner text and Rivaud in the Budé text), but its retention involves the attribution to Plato of the notion that the sun, Mercury, and Venus all move on one and the same circle, which is undoubtedly wrong in the present context and for Platonic astronomy in general; hence Burnet brackets it. Cornford (p. 105 note 2) suggests that τόν may have been read on the mistaken supposition that Plato believed that Mercury and Venus revolved round the sun (the theory attributed to Heracleides of Pontus – see p. 219), in which case all three bodies would have one main orbit. There is, however, another reading, τοῦς, which is given in the 'vulgate' and by a later hand in Y, and printed by Stallbaum and Bury (the latter in the Loeb *Timaeus*), and which gives the same sense as the omission of τόν – Taylor, (*Tim.*, p. 196), though rejecting τοῦς, rightly construes 'εἰς (κύκλου) ἰόντας ἰσόδρομον ἡλίῳ κύκλον, κύκλον being an accusative of the internal object after ἰόντας
- 170 Cf. Heath, *Arist.*, pp. 166ff.; Heath himself leaves the matter open
- 171 But see my explanation of this phrase, p. 112
- 172 Contrast this with the statement on pp. 86–7, 'We can now see why the changes in the relative positions of the planets are not ascribed merely to differences of speed, though that would be a possible way of representing the facts' (my italics)
- 173 Cornford rightly emphasizes (pp. 92–3; 109) that Plato is not writing a treatise on astronomy, but a myth of creation
- 174 This was generally accepted by the Greek astronomers; Ptolemy takes it for granted, and makes the mean, daily longitudinal movement of Venus and Mercury exactly the same as that of the mean sun (*Almag.* ix, 3 and 4). In Eudoxus' system also the same assumption is made, and Plato may well have derived his knowledge of the phenomenon from this source
- 175 Both Cicero (*Tim.* 25) and Chalcidius (*Tim.* 36d, p. 28 ed. Waszink) translate thus

- 176 And could readily be paralleled by similar instances in the comments of ancient and modern scholars unversed in scientific language – e.g. (*si parva licet . . .*) Guthrie (vol. i, p. 94), in discussing Anaximander's alleged astronomical system, actually speaks of a 'spherical plane'!!
- 177 This is the explanation favoured by Proclus (*in Tim.* 221e–f) after rejecting various others
- 178 Taken with laborious seriousness by Adam (vol. ii, App. I, pp. 264–312); but cf. Shorey's remarks (Loeb *Rep.*, vol. ii, Introd., p. xlv)
- 179 It is difficult to imagine what is meant by *all eight* orbits – i.e. including apparently the revolution of the Same, in terms of which all the others are measured, 39d6 – completing their courses together
- 180 *In Tim.* 276d *ad fin.* – followed by Heath (*Arist.*, p. 174) and Cornford (p. 119)
- 181 γῆν δὲ τροφὸν μὲν ἡμετέραν, εἰλλομένην δὲ περὶ τὸν διὰ παντὸς πόλον τεταμένον, φύλακα καὶ δημιουργὸν νυκτός τε καὶ ἡμέρας ἐμνησάτο, πρῶτην καὶ πρεσβυτάτην θεῶν ὅσοι ἐντὸς οὐρανοῦ γεγόνασιν. This seems to be the soundest text. Burnet (*OCT*) reads . . . ἰλλομένην δὲ τὴν περὶ τὸν . . . and notes in his apparatus criticus 'b8 ἰλλομένην FPr. Aristoteles Plut.: εἰλλομένην A: εἰλλομένην P CI τὴν AP: om. FYPlut.' K. Burdach, however, in an article that deserves to be better known ('Die Lehre des Platonischen Timaios (40b) von der kosmischen Stellung der Erde', *Neue Jahrb. f. d. klass. Altertum* 49, 1922, pp. 254–78), after a careful and exhaustive survey of the various instances, shows that the form with εἰ is to be preferred here, and that the two word-families in εἰλ- and ἰλ- which originally had separate meanings (the former indicating 'press, crowd together' and the latter 'roll, wind, turn') became confused in Hellenistic times not only in spelling (both εἰ for ἰ and its converse being common in Alexandrine recensions), but also in meaning, so that in this case little weight can be attached to readings transmitted through literary sources; in particular, he shows that the notion that ἰλλω is an older and more genuine form of εἰλλω is entirely wrong. The retention of τὴν in Burnet's text is indefensible, as Cornford points out (p. 120 note); it is not mentioned by any of the ancient commentators who quote the passage and is found in two mss only
- 182 In both passages, the words translated 'coils and moves' are the same, ἔλκεσθαι καὶ κινεῖσθαι (which is the consensus of all modern editors), but the mss also transmit the forms εἰλεῖσθαι, εἰλεῖσθαι, εἰλλεσθαι. Burnet's choice of ἰλλομένην at *Tim.* 40b–c is evidently influenced by these two passages in the *De Caelo*
- 183 Cf. H. Cherniss, *Aristotle's Criticism of Plato and the Academy*, 1944, Appendix VIII, pp. 557–58 – the whole of this Appendix is a valuable discussion of Aristotle's criticism with special reference to astronomical ideas
- 184 This is apparently Heath's final conclusion, *op. cit.*, p. 178



- 185 Cornford confuses his own argument by asserting, 'The effect is that in relation to absolute space she [the earth] stands still, while in relation to the other makers of day and night, the fixed stars, she rotates once every twenty-four hours in the reverse sense' (p. 131) – cf. p. 121, where he remarks more logically that 'the Earth must stand still, relatively to the diurnal revolution of the stars'
- 186 Cornford's citation (p. 130 note 3) of *Epinomis* 983b–c as evidence for a moving earth is misconceived because, as Cherniss points out (*op cit.*, pp. 556–57) ὅτιν τε καὶ οὐρανόν here 'is merely a solemn expression for "the whole material universe", the specific subject being the stars (including sun and moon) which carry out their revolutions in years, months, and days'
- 187 The weakness of which is demonstrated by the unconvincing nature of the scanty evidence adduced in support of it – e.g. when Timaeus Locrus describes the earth as ἐν μέσῳ ἰδρυμένα (97d), Cornford is constrained to remark 'a word which does not exclude motion' (p. 121 note 2) – Proclus knew better (*in Tim.* 281e). It is also difficult to reconcile a rotating earth with Cornford's own simile of the moving staircase (see above), which would seem to require the assumption of an absolutely stationary earth; it is noteworthy that he makes no attempt to explain this
- 188 Or, apparently, to Cornford – but Duhem (*Système du monde*, vol. ii, 1913, p. 88) read the sentence in this way
- 189 Cf. T. H. Martin (*Études sur le Timée*, vol. ii, pp. 88f.) who as long ago as 1841 gave what is essentially the correct interpretation
- 190 Cf. Proclus, *in Tim.* 281b *ad fin.*, τῷ οὐρανῷ δύνανται ἔχουσά πως ἀντίρροπον, and, for night and day, 282c; Plut., *Quaest. Plat.* viii, 3, 1006e–f
- 191 *In Tim.* 281e *ad fin.*: 'Let Heraclides of Pontus . . . hold this opinion [viz. that the earth rotates], since he moves the earth in a circle; but Plato keeps it unmoved'
- 192 *In De Caelo*, p. 519, 9–11; cf. 444, 34ff.; 541, 28ff.
- 193 40d – whether we read ἄνευ διόψεως τούτων αὐτῶν μιμημάτων . . . with most of the MSS, or ἄνευ δι' ὅψεως . . . with Burnet (OCT) and Rivaud (Budé text), the sense is clearly that mere description of the phenomena without 'imitations' of the movements is insufficient for a proper understanding of them. However, as we have seen (pp. 120–21), such 'imitations' are not to be thought of as complicated models like the planetaria or orreries envisaged by Cornford, or the astrolabe mentioned by Proclus (*in Tim.* 248b); rather what is meant is a simple celestial globe that by its rotation can demonstrate risings and settings, or diagrams of the planetary movements such as Eudoxus must have used in constructing his system – μιμήματα can include drawing (cf. *Epin.* 975d)
- 194 40c, χορείας . . . καὶ παραβολὰς ἀλλήλων – Proclus (*in Tim.* 248c) correctly explains παραβολὰς as 'comings together' in longitude, i.e. as applied to stars which rise or set simultaneously

- 195 The word is ἐπανακυκλήσεις. If my interpretation (above, p. 112) is correct, this means literally 'additional circlings', backwards in this case, i.e. retrograde movements of the planets in contrast to προχωρήσεις, 'progressions', forward motion along the zodiac; this is in accord with Proclus, who read ἀνακυκλήσεις and προχωρήσεις (284a–c), but paraphrased by ὑποποδισμούς, 'retrogradations', and προποδισμούς, 'advances' (cf. *Hypotyp.* vii, 4). Cornford (p. 135), who notes that Heath's 'returnings of their orbits upon themselves' is unsatisfactory and himself translates 'counter-revolutions', nonetheless agrees that retrograde motion is meant (cf. above, pp. 132f.)
- 196 Apparently, even at this date, the identity of the Morning and Evening Stars with the single planet Venus was not generally recognized among non-scientists, despite the fact that, according to the doxographers, Parmenides had already pointed this out (see p. 51). The mention of the sun as also 'wandering' may perhaps refer to Eudoxus' (erroneous) belief that it exhibited deviations from the ecliptic in latitude (on this, see below); but, as so often in Plato, the text here is doubtful (cf. England's note *ad loc.*) and the meaning may be 'the sun and the moon do what we all know they do'
- 197 Cf. Heath's critical discussion of such views (*Arist.* pp. 182ff.)
- 198 As Taylor holds (*Plato: The Laws*, trans. A. E. Taylor, 1960, p. 210 note)
- 199 As suggested by Taylor (*Plato: The Man and his Work*, p. 486 note)
- 200 This is not to say that Plato *knew* the complete Eudoxan system, for which there is no evidence in Platonic astronomy; 'hints' of such knowledge found by Ross (*Aristotle's Physics*, 1936, p. 95) and Guthrie (Loeb *De Caelo*, pp. xix–xx, footnote) are chimerical – cf. Lasserre, *Die Fragmente des Eudoxos von Knidos*, 1966, pp. 181–82
- 201 On this concept, see Guthrie, *Hist. of Greek Philos.*, vol. ii, pp. 163–64; cf. 414ff.
- 202 E.g. by Nicomachus (c. AD 100), *Arith.* i, 3, 5, ed. Hoche, Teubner, 1866
- 203 The single exception of any note (Diogenes Laertius' remark (iii, 1, 37) that 'some' attribute the *Epinomis* to Philippus of Opus is hardly good evidence for denying its Platonic authorship) is Proclus, who complains that it is 'full of spurious, mystical matter and betrays a foolish and senile mind' (*in Remp.* ii, p. 134, 5f. ed. Kroll), and who, according to the *Prolegomena in Platonis Philosophiam* ascribed to Olympiodorus (Hermann, *Platonis Dialogi*, Teubner, vol. vi, p. 218), put forward two very unconvincing arguments (one of which hinges on an astronomical point – see below) purporting to show that Plato could not have written the dialogue – on these arguments see E. des Places (*Epinomis*, Budé ed., 1956, p. 102)
- 204 For which see J. Harward, *The Epinomis of Plato*, 1928, pp. 26–58, and the edition of Des Places cited above, note 203, where most of the relevant literature is mentioned; cf. the latest editor F. Novotny, *Platonis Epinomis*, Prague, 1960. E. Dönt (see above, p. 235 note 141 – cf. also



Wiener Studien 78, 1965, p. 54) accepts it unquestioningly as a work written by Philippus of Opus – a position that few modern scholars would defend

- 205 *Gnomon* 25, 1953, pp. 371–75
- 206 Reviewing Novotny's ed. in *AJPh* 83, 1962, pp. 313–17
- 207 *Plato: the Man and his Work*, p. 498 note 1
- 208 Cf. *Timaeus* 47a–b for the same thought. At 47a5 Burnet (*OCT*, followed by Cornford) reads after ἐνιαυτῶν περίοδοι the words καὶ ἡμεραί καὶ τροπαί from one MS (F) although they are omitted by the two other best MSS (A and Y), and consequently by Hermann (and before him Stallbaum) in the Teubner text. Cicero (*Tim.*, ed. F. Pini, 1965, § 52) translates the Greek by 'annorumque conversiones' and evidently did not have equinoxes and solstices in his text; Chalcidius (§ 47, p. 44 ed. Waszink) has 'annorumque obitus et anfractus', which also suggests that he read ἐνιαυτῶν περίοδοι alone, without the addition of F's words (cf. his commentary, *op. cit.*, p. 156). In fact, the words καὶ ἡμεραί καὶ τροπαί, which add nothing essential to the sense, would seem to be an otiose gloss incorporated into the text of F
- 209 The sentiments here are very similar to those expressed in *Laws* 966–67 (sec p. 141)
- 210 We should very much like to know what these 'proofs' were. Guesses about the size of the sun go back as far as Heraclitus, who thought it was only a foot wide (see p. 48), whereas Anaxagoras stated it was bigger than the Peloponnese (p. 58), and Archelaus that it was the largest of the celestial bodies (p. 77); but these are evidently no more than guesses. Later astronomers, as we shall see, used measurements of the earth's shadow at lunar eclipses to estimate the relative sizes and distances of sun, moon, and earth, and such methods may well have been known to Eudoxus who, according to Archimedes (*Arenarius*, p. 7 ed. Dijksterhuis) proved that the sun's diameter is nine times that of the moon. In all probability, then, it is to Eudoxus' 'proofs' that Plato refers
- 211 Much of this has already been said in *Laws* x – see above
- 212 The position of aether (αἰθήρ) here has been held to constitute an argument against the genuineness of the *Epinomis* (Cherniss in *Gnomon* 25, 1953, p. 372), on the ground that in this dialogue 'the ether is situated between fire and air', and 'since the regular solid which the *Epinomis* assigns to ether could still be only the dodecahedron and since the faces of this figure cannot be constructed out of Plato's two elementary triangles, the location of such a fifth body between fire and air would prevent the mutual interchange and transmutation of their corpuscles and so would disrupt the rationale of the "stereometric atomism" of the *Timaeus*'. The reference here is to *Tim.* 53c–57c where Plato gives his views as to how the basic elements combine to form different substances (see above, p. 232 note 122); according to Xenocrates (one of his pupils), Plato in the *Epinomis* intended

the dodecahedron to be the figure representing the fifth element, aether (Xenocrates fr. 53, Heinze). However, Cherniss' argument is invalidated by the simple fact that the aether, as an element, is not situated between fire and air in the *Epinomis*. It is true that at 984b6 we find αἰθέρα μὲν γὰρ μετὰ τὸ πῦρ θῶμεν, but this does not refer to the order of the elements, but to the order of the living beings whose main constituents are the elements; this is made absolutely clear by the preceding lines, νῦν οὖν δὴ περὶ θεῶν ἐγχειρῶμεν . . . τὰ δύο κατιδόντες ζῶα ὁρατὰ ἡμῖν, ἃ φαμεν τὸ μὲν ἀθάνατον, τὸ δὲ γήινον ἅπαν θνητὸν γεγενῆσθαι, τὰ τρία τὰ μέσα τῶν πέντε τὰ μετὰξὺ τούτων . . . πειραθῆναι λέγειν. The divine beings whose main constituent is aether are the first of the three classes intervening between the star gods and terrestrial life, but there is no reason to suppose that Plato intended this to be the actual order of the elements in the sense that Cherniss intends, nor that Plato or any of his readers would have found this statement inconsistent with the doctrine of the *Timaeus*; rather, it would seem logical to assign to two invisible classes of being, intermediate between the visible types, the appropriate invisible elements, aether and air, the former of which has already been postulated as the purest type of air in the *Phaedo* (109b; 111b) and *Timaeus* (58d). In any case, μετὰ at 984b6 may very well indicate not a spatial relationship, but a temporal one in the genesis of the universe, or an order of rank or importance; cf. 984c7, δεῦτερα δὲ καὶ τρίτα καὶ τέταρτα καὶ πέμπτα ἀπὸ θεῶν τῶν φανερῶν ἀρξάμενα γενέσεως εἰς ἡμᾶς τοὺς ἀνθρώπους ἀποτελεῦσθαι, and 984d. It does not necessarily follow that, because Plato chose to make aether the primary constituent of the second class in his hierarchy of living beings, this must reflect his conception of the physical order of the elements. Still less is it safe to assume (nor does Cherniss assume) that there is any spatial significance in the verbal order in which they are mentioned in the later dialogues; in the *Epinomis* itself (981c) they appear in the order fire, water, air, earth, aether; in the *Laws* (889b and 891c) the order is fire, water, earth, air; in the *Timaeus* the apparent order (to judge from 53c and 55d) is fire, earth, water, air – but in 53e we have one clear reference to spatial order when we are told that earth and fire are the extremes with the others (not actually named here) in between. Moreover, Cherniss' objection rests on the assumption that the dodecahedron is the regular solid to be assigned to the element aether; but there is nothing in the *Epinomis* to warrant this assumption, and Cherniss himself rightly remarks that this is probably Xenocrates' own 'attempt to read Aristotelian doctrine back into the *Timaeus*' (*loc. cit.*, note 4). The train of thought in the *Epinomis* is simply different from that in the *Timaeus*; in the former Plato is not concerned with the elements and their configuration out of 'atomic' triangles, nor with the interaction and transformation of elemental substances, but with a hierarchy of living organisms and their relationships to each other and to mankind – he is, in fact, operating on a different plane



- of imagination, and to demand a rigid correspondence in every detail between two such planes is to try to force a mechanical consistency on an intellect which has as many facets as there are stars in the heavens. The addition of aether as a fifth element in the *Epinomis* is certainly a novel development in Plato's thought (perhaps not entirely unheralded in the *Timaeus* – cf. Cornford, pp. 220–21, on 55c–d), but there is no justification for treating it as an argument against the genuineness of the dialogue
- 213 For a comparison of the demonology outlined here with that found in other Platonic dialogues (especially the *Symposium* and the *Phaedrus*) see the comments of Harward, Des Places, and Novotny *ad loc.*
- 214 On the other hand, there is plenty of imaginative fantasy to be found in the other Platonic dialogues, and in some ways (e.g. the importance of religious beliefs and of astronomy as an educational discipline) the *Epinomis* merely carries to a logical extreme tendencies and opinions already apparent in his earlier work. The senility of which Proclus complains (see above) may be more apparent than real, and although Plato was an old man when he wrote the dialogue, it would be presumptuous to decide that the new directions in which his thoughts were turning were unworthy of Platonic philosophy as a whole
- 215 A. Bouché-Leclercq, *L'astrologie grecque*, Paris, 1899, pp. 24, note 1 and *ff.*; 28f.; 75f.
- 216 Cf. M. P. Nilsson in *Harv. Theol. Rev.* 33, 1940, pp. 1–8, who points out that there were no indigenous cults of the heavenly bodies in early Greek history (Helios and Selene being merely gods of mythology), and that Plato was the first to insist on the divinity of the visible stars and suggest that they should be worshipped with full rites
- 217 Cf. my *GFH.*, pp. 12f. (where in footnote 4, for 'Kramer' read 'Cramer')
- 218 Cf. J. Bidez, *Eos ou Platon et l'Orient*, 1945. Bidez does not accept the Platonic authorship of the *Epinomis*
- 219 For the different types of astrology, see my article 'Astrology and astronomy in Horace', *Hermes* 91, 1963, pp. 67f.
- 220 The best MSS give (986b)  $\mu\iota\alpha\ \delta\epsilon\ \tau\omega\upsilon\upsilon\ \pi\lambda\alpha\upsilon\eta\tau\omega\upsilon\ \alpha\sigma\tau\rho\omega\upsilon$  which is impossible since the sense demands that the reference here must be to the fixed stars, the planets being designated as  $\pi\acute{\epsilon}\nu\tau\epsilon\ \delta\epsilon\ \xi\tau\epsilon\rho\alpha\iota$  – hence Burnet (*OCT*) brackets  $\pi\lambda\alpha\upsilon\eta\tau\omega\upsilon$  and Hermann (Teubner) reads  $\alpha\pi\lambda\alpha\upsilon\omega\upsilon$ , but it is difficult to see why this easy reading should have been changed to  $\pi\lambda\alpha\upsilon\eta\tau\omega\upsilon$ . Des Places (Budé) prints  $\pi\acute{\alpha}\nu\tau\omega\upsilon$  which has some MS support, and Novotny (*ad loc.*) is inclined to accept this reading
- 221 On planetary names see especially F. Cumont, 'Les noms des planètes et l'astrolatrie chez les Grecs', *L'Antiq. Class.* 4, 1935, pp. 5–43
- 222 Cf. Neugebauer, *Ex. Sci.*, pp. 80ff. It seems that the Egyptians could recognize some thirty-six constellations and stars (only two of which, Sirius and Orion, can be certainly identified with those familiar to us), later known as 'decans' (so called because they were supposed to rise above

- the horizon at intervals of 10 days), which were used as a crude type of astronomical calendar; and they were interested in the heliacal rising of the bright star Sirius because it happened to coincide for some centuries with the annual flooding of the Nile, the main event in the life of the country. Apart from these few observational data there are no traces of any real astronomical concepts or of any underlying mathematical theory in old Egyptian texts. The Egyptian calendar, however, consisting of 12 months of 30 days each plus 5 additional days at the end of the year, became the standard astronomical time-scale used by the Greek astronomers (and still by Copernicus in the sixteenth century), and the Egyptian division of day and of night into twelve parts each also became standard practice – see below
- 223 This refers to the annual motion of the planets among the stars which takes place from west to east (opposite to the direction of the daily rotation of the heavens), and is therefore towards the right if one contemplates a conventional drawing or model of the celestial sphere with the north pole at the top (cf. Fig. 4, p. 18). Proclus (see above, note 203) tries to use this passage as an argument against the genuineness of the *Epinomis* by pointing to the apparent contradiction to the statement in the *Timaeus* that the revolution of the Same (i.e. the diurnal movement) is towards the right; but his argument is misconceived (in that he fails to appreciate the different viewpoints of the two passages – see pp. 121f.), and anyway this statement the *Epinomis* is consistent with *Laws* 760d where motion to the right is stated to be eastwards ( $\tau\omicron\ \delta'\ \epsilon\pi\iota\ \delta\epsilon\ \xi\iota\alpha\ \gamma\iota\gamma\nu\epsilon\sigma\theta\omega\ \tau\omicron\ \pi\rho\delta\varsigma\ \xi\omega$ )
- 224 Burnet (*OCT*), followed by Harward, actually inserts  $\omicron\upsilon\kappa$ , for which there is no MS authority at all, before  $\alpha\gamma\omega\upsilon$ . Des Places, followed by Novotny, points out that this is unnecessary since the same sense can be obtained without the insertion of  $\omicron\upsilon\kappa$  – he translates 'pourrait avoir l'air d'entraîner les autres, du moins aux yeux des gens mal informés de ces questions'
- 225 This explanation was first suggested by Heath (*Arist.*, p. 185) and approved by Cornford (pp. 91–2). In his later (and slighter) book (*Greek Astronomy*, 1932, pp. xliii and 61–2) Heath seems to have accepted the other interpretation
- 226 The order given here is the order of the synodic periods, and also probably reflects the type of data found in Babylonian sources; the moon was the most important object of study for the Babylonian astronomers because their calendar was at all periods a strictly lunar one, the solstices were also tabulated, and tables are extant dealing with observations of Venus from the second millennium BC. If Plato had been speaking as a Greek professional astronomer, he would surely have placed the sun as the first of the seven orbits to be studied, in view of its fundamental importance as providing the basic time unit (the tropical year) and the basic line of reference (the ecliptic) in astronomical calculations



- 227 A saying which Aristotle (*De Anima* 411a18) attributes to Thales – probably wrongly, cf. CQ 9, 1959, pp. 296–97
- 228 The geographical fragments have been edited by F. Gisinger, *Die Erdbeschreibung des Eudoxos von Knidos* (Stoicheia, Heft 6), 1921. The only collection of all the fragments is the recent edition (with commentary) by F. Lasserre, *Die Fragmente des Eudoxos von Knidos*, De Gruyter, Berlin, 1966; Lasserre's arrangement of the material leaves much to be desired as regards clarity, and his commentary is unilluminating for astronomical detail, but at least we now have all the relevant sources for Eudoxus (and much that is dubiously relevant) between the covers of one book
- 229 *Op. cit.*, pp. 5–6
- 230 G. de Santillana, 'Eudoxus and Plato', *Isis* 32, 1949, pp. 248–62; cf. Lasserre, pp. 137–42
- 231 In 365 according to De Santillana, or 360 according to F. W. F. von Bissing in *Forschungen und Fortschritte* 25, 1949, p. 225f.
- 232 E.g. Diog. Laert. viii, 87; Plutarch, *Marcell.* xiv, 11
- 233 Which we have on the excellent authority of Aristotle himself, *Nic. Eth.* i, 12, 1101b27f. and x, 2, 1172b9. In the latter passage Aristotle remarks on the temperance of Eudoxus' own character (διαφερόντως γὰρ ἔδδκει σώφρων εἶναι), which was not at all pleasure-loving, in spite of his philosophical opinions
- 234 E. Frank, 'Die Begründung der math. Naturwissenschaft durch Eudoxos' in *Wissen, Wollen, Glauben*, ed. L. Edelstein, 1955, pp. 134–57, especially 145–50
- 235 Apparently based solely on the undisputed fact that Eudoxus did at some period visit Sicily – cf. Aelian, *Var. Hist.* vii, 17; Ptolemy, *Phaseis*, p. 67 ed. Heiberg, where he is stated to have made 'weather observations' (ἐπισημασται – see above, p. 85) in Asia, Sicily, and Italy
- 236 He was responsible for the redrafting of the theory of proportion, as set out and used in Euclid Books v and vi, to make it applicable to all magnitudes whether commensurable or incommensurable, and also for propounding the so-called 'method of exhaustion' for determining the areas and volumes of various curvilinear figures by 'exhausting' or using them up (δραπανῶν) by inscribing polygons the areas of which were known – cf. Heath, *History of Greek Maths.* vol. i, pp. 322ff.; O. Becker, 'Eudoxos-Studien I–V' in *Quellen und Studien zur Geschichte der Math., Astron. und Physik*, Abt. B, Bd. 2, 1933, pp. 311–33 and 369–87; Bd. 3, 1936, pp. 236–44; 370–88; 389–410. Becker's attempt to construct a pre-Eudoxan general theory of proportion is criticized by Heath, *Maths. in Aristotle*, 1949, pp. 81–3
- 237 In *Arati et Eudoxi Phaenomena commentariorum libri tres*, ed. Manitius, Teubner, 1894 – hereafter cited as *Comm. in Arat.*
- 238 This is more accurate than saying that the poem is simply a versification of Eudoxus, as I did on p. 1 of *GFH*

- 239 It needed proof because apparently many authorities doubted it, διὰ τὸ διστάζεσθαι παρὰ τοῖς πολλοῖς, i, 2, 1
- 240 For the calculation of latitude from the longest day, see Chapter I, pp. 19ff. The obliquity of the ecliptic in Eudoxus' time was 23°44' (see my *GFH*, p. 168), and this is the value I have used in the present calculations
- 241 Lasserre argues confidently for this (pp. 181ff.), to the extent of assigning fragments to the two works even when Hipparchus does not specify them by title (e.g. fr. 52 and 53) – on the assumption that the *Enoptron* contained better observations and 'stylistic improvements' (p. 192, *comment. ad loc.*)
- 242 5:3 gives 15 hours and 12:7 gives 15 hours 9 minutes; differences in the lengths of the day at the summer solstice were the means of differentiating latitudes north of the equator commonly used by pre-Hipparchian geographers – cf. *GFH*, pp. 159; 163
- 243 I.e. the great circles intersecting at the poles and passing through the solstitial and equinoctial points respectively of the ecliptic – called κόλουροι, i.e. 'curtailed', because their lower segments are cut off from view by the horizon (cf. Geminus, *Isag.* 5, 49)
- 244 Using such phrases as συμφώνως τοῖς φαινόμενοις or συνεγγίζει τῷ φαινόμενῳ (τῇ ἀληθείᾳ)
- 245 One might perhaps in these cases suspect textual corruption in the mss of Eudoxus' works that Hipparchus used
- 246 In fact, Eudoxus was more correct here than Hipparchus; according to Baehr's tables, the declination of Canopus ( $\alpha$  Carinae) in the former's time was  $-52.8^\circ$  and in the latter's  $-52.7^\circ$ , so that it would be near the limit of visibility at latitude  $37^\circ$  and invisible at the true latitude of Athens,  $38^\circ$ , but in both cases it would (just) be visible at Rhodes (cf. Geminus, *Isag.* 3, 15 and Manitius' note *ad loc.*)
- 247 These are probably  $\kappa\lambda$  Draconis and  $\varsigma$  Urs. Min., the latter being a fourth magnitude star listed by Ptolemy among the ἀμύρρωτοι of Ursa Minor, i.e. those not counted in the actual constellation figure (*Synt.* ii, 38, 12 ed. Heib.)
- 248 On the role these played in ancient astronomy, see Chapter I, p. 19
- 249 Cf. ii, 1, 1 and especially ii, 1, 26, καὶ ὁ Εὐδόξος δέ, ᾧ κατακολούθηκεν ὁ Ἀρατος, τὸν αὐτὸν τρόπον ὑποτίθεται ἐν ταῖς συνανατολαῖς τὰς ἀρχὰς τῶν ζώδιων ἐπὶ τῆς ἀνατολῆς – this evidently refers to a separate work of Eudoxus entitled *Simultaneous Risings* (Συνανατολαί) also apparently used by Aratus (cf. i, 4, 19 and i, 5, 15). Curiously, Lasserre ignores the evidence for such a work, although he is ready to attribute to Eudoxus another treatise with the improbable title *On Solar Occultations* (Περὶ ἀφανισμῶν ἡλιακῶν – *LSJ* s.v. ἀφανισμός also give this attribution) on very slender evidence (pp. 212–13)
- 250 See *JHS* 86, 1966, pp. 27–8 for the development of this usage
- 251 Stars not assigned letters by Bayer are usually designated by their numbers in Flamsteed's British Catalogue published in 1725



- 252 Cicero (*De Rep.* i, 22) quotes Gallus (a Roman astronomical writer of the second century BC) on Eudoxus' globe, *eandem illam sphaeram solidam astris quae caelo inhaererent esse descriptam*, and expressly contrasts this early type of solid globe with the *sphaera Archimedis*, which imitated the movements of sun, moon, and planets, and therefore was much more than a simple globe. Gallus is no great authority, it is true, since in the same passage he attributes the making of the first globe to Thales. . . .
- 253 Lasserre's contention (p. 191) that Eudoxus did not use a globe because the terms 'right' and 'left' are inappropriate for its surface is ill-conceived; one can perfectly well speak of 'the right' and 'the left' of figures on a globe (as the Greeks did), regardless of whether the directions are the same for the observer. Thus it makes no difference whether the figures are drawn as seen from the inside (as on celestial globes with the observer supposed to be at the centre), or as they actually appear in the sky relative to the right and left hand of the observer (as on many star maps); the left arm or the right foot or the head of the figure will in both cases denote the same stars. This was well understood by the Greek astronomers (cf. *Comm. in Arat.* i, 4, 9-11, where Hipparchus commends Aratus for attempting to give precision to his descriptions of figures by using the terms 'left' and 'right'); it is only modern commentators who have introduced confusion here. Where there was any likelihood of ambiguity, stars were described as lying further west, east, south, or north as the case might be.
- 254 E. J. Webb, *The Names of the Stars*, 1952 (published posthumously) – see especially ch. 3-5 and cf. his remark on p. 63, 'If we look at the stars as they appear in the sky [a thing that very few scholars do, as Webb rightly complains] . . . we shall perceive in many cases . . . obvious reasons for names which have been quite obscured by the artificial figures, constructed often long ages after the names themselves had become traditional'.
- 255 Cf. the information collected by M. P. Nilsson, *Primitive Time-Reckoning*, Lund, 1920.
- 256 Theoretically, the vacant space should correspond to the 'antarctic' circle, i.e. the limit of the stars never visible at that time and place, its centre should mark the position of the south pole (because, owing to the effect of precession – see above, pp. 15f. this pole has shifted its position among the stars), and its radius the latitude of the constellation-makers.
- 257 E. W. Maunder, *The Astronomy of the Bible*, 2nd ed., 1908, pp. 157-59.
- 258 R. H. Allen, *Star Names and their Meanings*, 1899, pp. 14-15.
- 259 Ptolemy says specifically that he himself has not always used the same shapes for the constellations as his predecessors, just as they did not always use the same as the astronomers before them, but made alterations in the interests of a more convenient arrangement, and he gives an example from Hipparchus (*Synt.* vii, 3, ed. Heib. vol. ii, p. 37, 11ff.). Modern astronomers from Bayer onwards have made further changes, until in 1930 by international agreement the present constellation boundaries were standardized.

- 260 M. W. Ovenden, 'The Origin of the Constellations', *Philosophical Journal* 3(1), 1966, pp. 1-18. Ovenden seeks to demonstrate that the constellations were designed by the Minoans mainly as navigational aids round about 2,800 BC  $\pm$  300 years at latitude  $36^{\circ}$ N.  $\pm$   $1\frac{1}{2}^{\circ}$  and longitude  $26\frac{3}{4}^{\circ}$ E. – he has even found a suitable island in the Dodecanese for their observatory, the island of Stampalia (locally known as Astropalia 'which has an obvious astronomical "ring" about it')! Some of the arguments he uses are remarkably circular; in trying to prove (pp. 5-6) that certain constellations were arranged symmetrically with respect to the celestial north pole of that epoch, he uses a statistical method based on the hypothesis that they were so arranged as 'a band of the sky equidistant from the celestial pole' (and what? Ovenden does not say, but presumably means the equator). It is to be hoped that the 'results' of this fascinating paper will not be taken seriously; apart from the fallacious argumentation and fanciful speculation it contains, its whole thesis is vitiated by the totally unfounded assumption of the advanced astronomical knowledge possessed by the constellation-makers so-called – see below.
- 261 *JHS* 86, 1966, p. 29.
- 262 For the difficulties inherent in the concept of equinoxes, as opposed to solstices which are easily observable phenomena requiring no astronomical theory for their perception, see my article in *JHS* quoted above.
- 263 Often made with the help of an instrument known as a 'precession globe', i.e. a celestial globe the poles of which are adjustable in circles round the ecliptic poles to take into account the shift in position (about  $1^{\circ}$  in 72 years) of the celestial poles owing to the effect of precession – see above. Even with this aid, such comparisons are of very doubtful validity, since we know neither the exact boundaries of the ancient constellations, nor the latitude of the original observations, nor the standard of accuracy involved; the latter especially, one suspects, is commonly overestimated by modern commentators.
- 264 Robert Brown, *Researches into the Origin of the Primitive Constellations of the Greeks, Phoenicians and Babylonians*, 2 vols., 1899, 1900, p. 15 – a highly misleading work, packed with erroneous and outdated material. Only marginally less misleading is W. Hartner's article, 'The Earliest History of the Constellations in the Near East and the Motif of the Lion-Bull Combat', *JNES* 24, 1965, pp. 1-16, which, based on totally inadmissible premisses, attributes sophisticated astronomical concepts to the Sumerians of the fourth millennium! Equally misguided are the attempts made to impute complicated astronomical motives to the builders of ancient monuments such as Stonehenge (e.g. by G. S. Hawkins in *Vistas in Astronomy*, vol. x, 1968, pp. 45-88); such fantasies are reminiscent of the 'pyramid literature' (on which see Neugebauer, *Ex. Sci.*, p. 96) – and equally valueless, despite the modern trappings of computer calculations with which they are invested.



- 265 R. Böker, 'Die Entstehung der Sternsphäre Arats', *Berichte über die Verhandlungen der sächsischen Akademie der Wissenschaften zu Leipzig* 99, 1952, pp. 3-68. Böker finds fault with Hipparchus' criticism of Eudoxus-Aratus because it is based on the supposition that the data were valid for Greece and that the colures were drawn through the beginning of the signs (p. 5); he completely ignores Hipparchus' own discussion of the latitude appropriate to the observations (*Comm. in Arat.* i, 3, 5-12), and his emphasis on the different placing of the solstitial and equinoctial points by Eudoxus and Aratus (ii, 1, 15ff.; 20ff.; 2, 5-6), which shows that he was fully alive to the difficulties of assessing the older material fairly. Böker's lack of historical sense is demonstrated by his reference to Aratus' astronomical source as 'Pseudo-Eudoxos' (duly castigated by Ludwig in *RE*, s.v. Aratos, Suppl. Bd. 10, 1965), his belief that the Greek constellations go back no further than the sixth century BC (thus apparently ignoring those mentioned in Homer and Hesiod - see above), his supposition that Eudoxus used the 360° division of the circle (in flat contradiction to the available evidence - see above), and his reference (p. 105 of a 'Nachtrag' to a German translation of Aratus by A. Schott - *Das Worte der Antike* VI, München, 1958 - where Böker repeats much of the nonsense in his earlier paper) to Anaximander's famous sixth-century BC workshop in Miletus where he busied himself with all possible astronomical and meteorological instruments (!). Moreover, Böker's supposedly scientific treatment of the Aratean data is basically unsound since he does not take into consideration the conditions and limitations of the original observational material (cf. Ludwig, *loc. cit.*), and anyway a close examination shows that out of the twelve Aratean passages he discusses in pp. 19-29, only three agree fully with the results obtained by his methods. Unfortunately, the erroneous conclusions he arrives at (that the Aratean sphere is valid only for the epoch -  $1,000 \pm 30-40$  years at a latitude between  $32^{\circ}30'$  and  $33^{\circ}40'$ , with the colures marked at the end of  $15^{\circ}$  of the relevant signs, and with the position of the zero point of the zodiac at about  $26^{\circ}$  of the ecliptic of AD 1900 - p. 8) have been accepted by Van der Waerden in his latest work, *Die Anfänge der Astronomie* (= *Erwachende Wissenschaft* II), Noordhoff, Groningen, 1966 - on which see further below
- 266 In the period between Hipparchus and Eudoxus the north celestial pole would have shifted westwards some  $3^{\circ}$ , thus altering the positions of the stars relative to the circles of the celestial sphere
- 267 On a very rough count, there are twenty-three such instances in Book I of the *Commentary* - admittedly, the disagreements are more than twice as numerous, but then its main purpose is to criticize and correct
- 268 This passage alone is enough to refute a large part of Ovenden's thesis, since he makes much play with alleged differences in the respective 'zones of avoidance' of the Eudoxan-Aratean and the Hipparchian spheres (*op. cit.*, pp. 9-10)

- 269 Cf. Neugebauer, *Ex. Sci.*, pp. 103ff.
- 270 'Babylonian' is used as a convenient generic term for the distinctive culture of the Tigris and Euphrates valleys, which was dominated at different times by Akkadians, Kassites, Assyrians, Persians, and finally Macedonians and Greeks in the Seleucid period
- 271 Cf. the omen series of texts collectively known as 'Enuma Anu Enlil' discussed by E. F. Weidner in *Archiv für Orientforschung* 14, 1942 and 17, 1954
- 272 Cf. Van der Waerden, *Anf.*, pp. 56ff.
- 273 All authorities agree that these 'ways' are bands of a certain width (variously estimated) parallel to the equator, and not lines delimiting zones as in the Greek concept of 'arctic' and 'antarctic' circles - cf. C. Bezold, A. Kopff and F. Boll, 'Zenit- und Aequatorialgestirne am babylonischen Fixsternhimmel', *Sitzber. d. Heidelb. Akad. d. Wiss., phil.-hist. Kl., Abh.* 11, 1913, pp. 3-59; E. F. Weidner, 'Ein babylonisches Kompendium der Himmelskunde', *Amer. Journ. Sem. Lang. and Lit.* 40, 1924, pp. 186-208, and 'Der Tierkreis und die Wege am Himmel', *Arch. f. Orientf.* 7(4), 1931, pp. 170ff.; J. Schaumberger, 3. *Ergänzungshefte zur Sternkunde und Sterndienst in Babel*, Kugler, 1935, pp. 321ff.
- 274 Rome, 1950 = Teil 4, Bd. 2 of the *Sumerisches Lexikon*, ed. P. A. Deimel
- 275 Particularly striking is the fact that the Babylonians designated the 'horn' (i.e. the claws) of the Scorpion as ZI.BA.AN.NA/zibanîtu, meaning 'Balance, Scales' (Gössmann, p. 72), just as the Greek astronomers differentiated the Claws (Χηλαί, Latin *Chelae*) from the rest of the constellation and later called them the Balance (Ζυγός, Latin *Libra*) - the latter name seems to be post-Hipparchian, for in the *Comm. in Arat.* Χηλαί is consistently used except in one passage (iii, 1, 5), which Manitius regards as spurious on other grounds as well (p. 303, note 41). Ptolemy (*Synt.* viii, 1, *ad init.*) uses, Χηλαί for the *figure*, but Ζυγός for the *sign* - cf. Bouché-Leclercq, p. 141
- 276 Van der Waerden, *Anf.*, pp. 67-8
- 277 *Op. cit.*, pp. 256-57; but Van der Waerden himself admits that this does not hold for Aries, Cancer, and Aquarius, and his arguments for Virgo (cf. Webb, *The Names of the Stars*, p. 33, 'the assumption that, because the Greek Virgin carries a Corn-Ear in her hand, the Babylonian Corn-Ear must have been carried in the hand of a Virgin, though apparently taken for granted by all Assyriologists, is of course ridiculous'), Sagittarius, and Capricornus are extremely flimsy, depending largely in the last two cases on representations of the figures in the Dendera zodiac, which since it dates from the Roman period in Egypt, is hardly convincing evidence
- 278 This is against the view supported by Webb (see above, pp. 159-60) that certain names (including the Triangle) are obviously appropriate for certain star-groups; Van der Waerden (p. 68) specifically comments on the likeness of these particular stars to a plough!
- 279 Cf. Van der Waerden, p. 68 and diagram p. 66



- 280 The Seleucid era began in 312 BC; after this there is a long series of texts (the latest being dated to AD 75) which show Babylonian mathematical astronomy at its highest level of development – see O. Neugebauer, *Astronomical Cuneiform Texts*, 3 vols., 1955. There is no doubt at all, as we shall see, that the results obtained and (to some extent) the methods used by the Babylonians during this period were known to the Greek astronomers from at least the time of Hipparchus (second century BC) onwards. The disputed questions are when and how these results and methods were transmitted to Greece, and what influence the earlier stages of Babylonian astronomy had on its Greek counterpart, and again when and how this influence was exerted
- 281 Aristophanes fr. 163, πόλος τὸδ' ἐστίν; εἴτα πόστην ἥλιος τέτραπται; Even here it is not altogether impossible for πόλος to have the same meaning as in *Birds* 179f., namely 'region of the sky'
- 282 In which case it would be similar to the 'scaphe' (σκάφη) mentioned by Cleomedes (*Cycl. Theor.* i, 10, 54f.) as being used by Eratosthenes for his famous measurement of the earth. Vitruvius in his chapter on sun-dials (ix, 8) speaks of 'a hemisphere hollowed out of a square' (*hemicyclium excavatum ex quadrato*) which was supposed to have been invented by Berossus (on whom see note 306, below); but this must have been a later type because he describes it as 'cut away to suit the latitude' (*ad enclimaque succisum*), and this presupposes greater theoretical knowledge than either Berossus or Eratosthenes could have possessed – see CQ n.s. 5, 1955, pp. 248f. Vitruvius goes on to say that the invention of the 'scaphe or hemisphere' was attributed to Aristarchus
- 283 For common misconceptions concerning the use of sun-dials in antiquity, see *JHS* 86, 1966, p. 29
- 284 Cf. Diels, *Antike Technik*, 3rd ed., 1924, pp. 162–63
- 285 Cf. Neugebauer, *Proc. Amer. Philos. Soc.* 107, 1963, p. 533
- 286 Cf. Weidner, *Amer. Journ. Sem. Lang. and Lit.* 40, 1924, pp. 198f.; Neugebauer, *Isis* 37, 1947, pp. 37–43; Van der Waerden, *Anf.*, pp. 80–1
- 287 Neugebauer, *Ex. Sci.*, pp. 81; 85–6. Van der Waerden claims (*op. cit.*, p. 88) that the division of day and night into twelve equal periods each is attested by the numbers on an ivory prism of the Assyrian period (thus before 630 BC); but his interpretation of this text (following Fotheringham in *The Observatory*, No. 703, 1932, p. 338) is far from secure, and on his own admission the meaning of half of it remains unknown
- 288 To explain the frequent Greek references to Egyptian astronomical observations, Van der Waerden suggests that in the period from 630 to 480 BC (during part of which Egypt came under Babylonian rule) Babylonian astronomical ideas strongly influenced the local Egyptian astronomy, to the extent of causing a resurgence of observational activity, and that this was how Eudoxus came to profit from his stay in Egypt (*Anf.*, pp. 130f.). The evidence for such a supposition is extremely thin,

- and consists (apart from inferences drawn from Greek literary sources) of a single Demotic text, written in the first century AD but apparently based on an original of the late-sixth or early-fifth century BC, which contains a number of eclipse omens arranged by the months in which they take place, groups of three months being assigned to four separate terrestrial regions, and also a concordance of Egyptian and Babylonian names for the months. However, since the contents of the text obviously belong to the pre-scientific stage of astronomy and there is no mention of the planets or the fixed stars, Van der Waerden is forced to assume a later blooming of Egyptian observational astronomy (*op. cit.*, p. 133), for which, needless to say, there is no evidence at all
- 289 See Bouché-Leclercq, *L'astrol. grecque*, p. 93, note 2
- 290 In the Philolaic system and perhaps by Democritus – see pp. 65f.; 82
- 291 See the Venus tablets of Ammizaduga in the astrological omen series 'Enuma Anu Enlil' – Van der Waerden, *Anf.*, pp. 34ff.
- 292 Published in *Late Babylonian Astronomical and Related Texts*, 1955, (Brown University Studies 18), by A. J. Sachs as facsimiles of the original copies made by Pinches and Strassmaier – no translations are given
- 293 Van der Waerden, *Anf.*, p. 105
- 294 See the standard work by O. Neugebauer, *Astronomical Cuneiform Texts*, 3 vols. 1955, where all the Seleucid material is dealt with
- 295 Cf. Van der Waerden, *Anf.*, p. 166
- 296 *ACT*, vol. ii, p. 280
- 297 Cf. Neugebauer, *Proc. Amer. Philos. Soc.* 98, 1954, p. 64: 'But there is no trace of any definition of the vernal point as the intersection of ecliptic and equator (which nowhere appears in Babylonian astronomy)'
- 298 Cf. Van der Waerden, *Anf.*, pp. 104–05
- 299 *ACT*, vol. ii, p. 281
- 300 Neugebauer, *Journ. Cuneif. Stud.* 2, 1948, pp. 209ff.
- 301 Neugebauer, *Journ. Amer. Orient. Soc.* 70, 1950, pp. 1–8; cf. Van der Waerden, *Anf.*, pp. 115–16
- 302 Van der Waerden, *Arch. f. Orientf.* 16, 1953, p. 223
- 303 A. Sachs, *Journ. Cuneif. Stud.* 2, 1948, pp. 289–90; Van der Waerden, *loc. cit.*, p. 222, note 25
- 304 Fotheringham remarks that this puts Ptolemy in a better position than any modern astronomer as regards the length of observation series available to him (*The Observatory*, No. 51, 1928, pp. 312–13)
- 305 On this see especially Neugebauer, *Proc. Amer. Philos. Soc.* 107, 1963, pp. 534–35
- 306 The Babylonian priest Berossus (or Berossos), who founded a school in the island of Cos and wrote in Greek a history of his own country (see the fragments edited by P. Schnabel, *Berossos und die bab.-hell. Lit.*, Leipzig, 1923), is often cast in the role of intermediary between Babylonian and Greek science (cf. Neugebauer, *Ex. Sci.*, p. 157). Unfortunately, the



- extant fragments do not bear this out, and what little astronomy they contain (e.g. fr. 16-26 on the phases of the moon) bears no relation to contemporary Babylonian lunar theory (Neugebauer, *Proc. Amer. Philos. Soc.* 107, 1963, p. 529). Berosus dedicated his *Babyloniaca* to Antiochus I (281-261 BC) and is thus, anyway, too late for Eudoxus
- 307 *Proc. Amer. Philos. Soc.* 107, 1963, pp. 529ff.
- 308 Neugebauer, *Ex. Sci.*, pp. 102; 140. Van der Waerden thinks differently - see below
- 309 Cf. *ACT*, vol. i, p. 11, 'All that can be said with safety at present is that the methods for computing lunar and planetary ephemerides were in existence c. 250 BC. Their previous history is unknown to me'
- 310 *Journ. Cuneif. Stud.* 6, 1952, pp. 54ff. It should be noted that Sachs' treatment depends on the *assumption* 'that the planetary data refer to signs of the zodiac, not constellations' (p. 55)
- 311 Even Van der Waerden admits that there is no trace of the zodiac as such in these texts - *Anf.*, p. 77 (see also below)
- 312 Chiefly in his book *Die Anfänge der Astronomie* (= *Erwachende Wissenschaft II*), Noordhoff, Groningen, 1966, which sums up the results of his earlier papers on the subject
- 313 *Op. cit.*, pp. 171-72; 201-03
- 314 See *JHS* 86, 1966, p. 29
- 315 On which see above, p. 43 and *CQ* 9, 1959, pp. 294ff.
- 316 See his highly misleading account of Pythagorean astronomy in *Die Astronomie der Pythagoreer*, Amsterdam, 1951
- 317 To the examples mentioned above, add his unquestioning acceptance of Böker's untenable theory that the Eudoxan-Aranean sphere is only accurate for a date about -1,000 BC (see above, p. 162 and note 265)
- 318 According to the *Ars Eudoxi* (see above, p. 88, note 109), Eudoxus estimated the number of days from the autumnal equinox to the winter solstice as 92 and from the winter solstice to the vernal equinox as 91; but unfortunately the papyrus is defective with regard to his estimates of the other two astronomical seasons (cols. 22-3). Since it is certain that in the Eudoxan solar theory the sun's longitudinal motion is assumed to be uniform (see above, p. 181), Heath is probably right in supposing that Eudoxus made the lengths of the seasons 91 days each, with an additional day for autumn to make the total up to 365 (Heath, *Arist.*, p. 200), thus making no use of the discovery by Meton and Euctemon of the inequality of the seasons (see below, p. 88)
- 319 E. F. Weidner, *Arch. f. Orientf.* 7(4), 1931, p. 171; O. Neugebauer, *Isis* 37, 1947, p. 38
- 320 Kugler, *Sternkunde u. Sterndienst in Babel*, vol. i, 1907, p. 13; vol. ii, 1909-10, pp. 77-8; cf. Neugebauer, *Ex. Sci.*, p. 169
- 321 Cf. T. W. Africa, *Science and the State in Greece and Rome*, 1968, p. 37: 'Hamstrung by the dogma that celestial motion was perfect and circular,

- Greek astronomers expended great ingenuity to reconcile the erratic behavior of the planets with their presumed circular motion'
- 322 Proclus in his *Comment. in Euclid.* i expressly draws attention to the fact that several of the theorems were included because of their usefulness in astronomy (pp. 268-69 ed. Friedlein). The earliest extant Greek mathematical treatise, Autolycus' *On the Moving Sphere*, dated to the last decades of the fourth century BC, already contains propositions relating to the sphere which are merely stated without proof, and were therefore presumably taken from a still earlier textbook on 'sphaeric' which contained the proofs - cf. Heath, *Hist. of Greek Maths.*, vol. i, pp. 349-50
- 323 Neugebauer, *Ex. Sci.*, p. 110
- 324 Delambre, for example, in his still indispensable *Histoire de l'astronomie ancienne*, 2 vols., 1817, nowhere mentions the planetary scheme, and only deals with Eudoxus' other astronomical work in the course of a chapter on Aratus (tom. i, ch. 4, pp. 61-74), although he has a brief section (tom. i, pp. 301-10) on Simplicius' in *De Caelo*. Delambre evidently did not know of Eudoxus' mathematical work, since he says (p. 131), '... rien ne prouve qu'il fût géomètre'
- 325 L. Ideler, *Abh. d. Berlin. Akad.*, hist.-phil. Kl., 1828, pp. 189-212, and 1830, pp. 49-88; E. F. Apelt, *Abh. d. Fries'schen Schule*, Heft 2, Leipzig, 1849; T. H. Martin, *Mém. de l'Acad. des Inscript. et Belles-Lettres*, tom. 30, pt. 1, 1881, pp. 153-302; G. V. Schiaparelli, 'Le sfere omocentriche di Eudosso, di Callippo e di Aristotele', *Pubblic. del R. Osserv. di Brera in Milano* 9, 1875 - German trans. by W. Horn, *Abh. z. Gesch. d. Math.*, Heft 1, Leipzig, 1877, pp. 101-98. Martin states (pp. 160-61) that his own work was completed before Schiaparelli's, and that the reading of the latter's description has not caused him to make any changes in his own views, which, as we shall see, differ from Schiaparelli's in one important respect
- 326 J. L. E. Dreyer, *A History of Astronomy from Thales to Kepler*, Dover repr., 1953, pp. 89-103; T. L. Heath, *Aristarchus of Samos*, pp. 193-211
- 327 In describing the rest of Eudoxus' system, it will henceforth be taken for granted that each sphere is affected by the rotations of the spheres enveloping it; for economy of words only the individual rotations will be mentioned
- 328 Simplic., p. 495,4 ed. Heib., ἐγκεκλιμένους πρὸς τὸν διὰ μέσων τῶν ζῳδίων τοσοῦτον, ὅσον ἡ πλείστη κατὰ πλάτος τῇ σελήνῃ παραχώρησις γίγνεται . . . τὴν τρίτην δὲ [ὑπέθετο] διὰ τὸ μὴ ἐν τοῖς αὐτοῖς τοῦ ζῳδιακοῦ σημείοις βορειοτάτην τε καὶ νοτιωτάτην φαίνεσθαι γινόμενῃν, ἀλλὰ μεταπίπτειν τὰ τοιαῦτα σημεία τῶν ζῳδίων αἰεὶ ἐπὶ τὰ προηγούμενα
- 329 τὴν μετάπτωσιν παντάπασιν ὀλίγην γίνεσθαι καθ' ἕκαστον μῆνα, p. 495, 14
- 330 In fact, its changes in *declination* (from the equator) are much greater than its changes in *latitude*, but Eudoxus probably failed to distinguish between the two - cf. Martin, *op. cit.*, p. 217



- 331 Martin (pp. 214–15) suggests the sidereal or tropical month of about 27½ days, but there is no evidence and little likelihood that this was known to Eudoxus
- 332 Whatever speed was assigned to the third sphere (and conjecture is fruitless) could easily have been compensated by increasing slightly the speed of the second sphere
- 333 E.g. W. D. Ross, *Aristotle's Metaphysics*, vol. ii, 1924, pp. 385ff.
- 334 The nodes are the two diametrically opposite points where the mean lunar orbit intersects the ecliptic
- 335 Who clearly indicates in *Met.* A 8, 1073b26–7 that the second sphere for all the planets and the sun and moon represents their direct (eastwards) motion along the ecliptic
- 336 Namely, the slow rotation of the poles of the lunar orbit round the poles of the ecliptic. The only evidence adduced for Eudoxus' knowledge of this period is a remark by Ptolemy that the eclipse period of 223 lunations was known 'roughly' to 'the still older astronomers' (ὁλοσχερέστερον μὲν οὖν οἱ ἔτι παλαιότεροι . . . ἔγγιστα ἑώρων μῆνας μὲν ἀποτελουμένους σκῆ, *Almag.* iv, 2, p. 270, 1ff. ed. Heib.), and since he counts Hipparchus as παλαιός (iii, 1, p. 191, 17f.), παλαιότερος is taken as referring to Eudoxus. This is very tenuous, and anyway the context makes it clear that οἱ ἔτι παλαιότεροι here refers to the Babylonian astronomers (οἱ Χαλδαῖκοι – *op. cit.*, p. 270, 20), whose results Hipparchus discussed
- 337 Cf. Delambre, tom. i, pp. 73; 122; 125
- 338 Martin realized this clearly (*op. cit.*, especially pp. 216–21) and his treatment of the Eudoxan system is sensible apart from a tendency to accept data derived from the *Ars Eudoxi* as genuinely Eudoxan when there is no proof of this; Lasserre also notes the uncritical assumption of a mistake on the part of Simplicius (*Die Fragmente des Eudoxos von Knidos*, 1966, p. 202), but gives no discussion of the issues involved
- 339 This is so on both Schiaparelli's and Simplicius' interpretations
- 340 Εὐδόξῳ τοῖνυν καὶ τοῖς πρὸ αὐτοῦ τρεῖς ὁ ἥλιος ἐδόκει κινεῖσθαι κινήσεις, p. 493, 11f.
- 341 Theon Smyrn., pp. 135 ed. Hiller (apparently from Adrastus – *cf.* p. 129); 173; 194; Pliny, *Nat. Hist.* ii, 67; Alex. Aphrod., in *Met.* 8, p. 703 ed. Hayduck; Chalcid., *Comm. in Tim.* 77, p. 125 ed. Waszink; Mart. Cap. viii, 849 (287 G), p. 315 ed. Eyssenhardt; also 863 (293 G), p. 322 ed. Eyssenhardt
- 342 The mathematical details are best studied in Schiaparelli or Heath (who also gives a modern solution, using analytic geometry, by N. Herz); *cf.* also Neugebauer, *Scripta Math.* 19, 1953, pp. 226–29
- 343 Since the figure is described on the surface of a sphere, Schiaparelli calls it (somewhat misleadingly) a 'spherical lemniscate'
- 344 *Comm. in Eucl. i*, ed. Friedlein, Teubner, pp. 127, 1; 128, 5
- 345 The ancient astronomers regularly assumed that the sidereal periods of

- Mercury and Venus were the same as the sun's, i.e. 1 year (see note 174), because these planets are never seen far from it. In fact, this assumption results from the very large parallax effects caused by the earth's rotation in the case of the inferior planets, whereas for the superior planets (at their much greater distances from the sun) such effects are far less noticeable. On the geocentric hypothesis one is bound to give Mercury and Venus sidereal periods equal to that of the sun, and no valid comparison with the true values (on the heliocentric system) can be made
- 346 The *Ars Eudoxi* actually gives the figure of 116 days for the synodic period of Mercury (col. 5, p. 16 ed. Blass), but there is no knowing whether this was in fact derived from Eudoxus or a later source
- 347 It should be emphasized that, in this part of his reconstruction, Schiaparelli is demonstrating his own ingenuity rather than that of Eudoxus (as Martin points out – *op. cit.*, p. 225 note 1). There is no evidence that Eudoxus used the figures given by Schiaparelli and, to judge from the inaccuracy of much of the rest of his astronomical work, it would seem highly improbable that he knew the correct values
- 348 The logic of this last assertion is questionable, since in fact the maximum latitudes are approximately  $2\frac{1}{2}^\circ$  for Saturn and  $1\frac{1}{2}^\circ$  for Jupiter
- 349 If indeed he assumed any as regards the inclinations and the dimensions of the 'hippopedes'. It is by no means impossible that he contented himself with showing the theoretical possibility of explaining retrograde motion and stationary points by means of the 'hippopedes', without actually assigning any parameters to the systems apart from the sidereal and synodic periods
- 350 Cf. Dreyer, pp. 380ff.
- 351 It does not seem that Eudoxus regarded his sets of spheres as anything other than mathematical abstractions; there is no evidence that he speculated on the material of which they were comprised or the connection between them or the power that moved them. As we shall see, Aristotle was concerned with all these things. According to Archimedes (*Aren.* 9, ed. Heib., vol. ii, p. 220) Eudoxus supposed the sun's diameter to be nine times that of the moon; how he arrived at this figure we do not know – in reality the ratio is about 400:1
- 352 καὶ δοκεῖ μάλιστα πάντων αὐτῇ ἡ περίοδος τοῖς φαινόμενοις συμφωνεῖν, *loc. cit. ad fin.*
- 353 On the 'parapegmata', see above, pp. 84f.
- 354 Latitudinal zones on the terrestrial sphere in which, for practical purposes, such data as the length of the longest day, the ratios of the gnomon to its shadow at stated times, and the appearance of the night sky remained the same for all observers in the same 'clima' – see on the development of this concept CQ 5, 1955, pp. 248ff.; CQ 6, 1956, pp. 243ff.; GFH, pp. 154ff.
- 355 Vitruvius (ix, 8) says in connection with sun-dials that Eudoxus (or, according to some sources, Apollonius) invented the 'spider' (*arachne*).



- What this was is not certain, but it is not unlikely that Eudoxus investigated the shadows cast by a gnomon, and the lines and circles marking these may have suggested the term (*cf.* Diels, *Antike Technik*, 3rd ed., 1924, pp. 160–61 and diagram on p. 163). Later, the movable disc (representing the ecliptic) of the planispheric astrolabe was called the ‘spider’ (*GFH*, pp. 197; 201), but Eudoxus certainly did not know this instrument
- 356 Ptolemy says (*Phas.*, p. 67, 5 ed. Heib.) that Callippus made observations in the Hellespont
- 357 Sosigenes (a Peripatetic philosopher of the second century AD – not the astronomer of the same name who helped Julius Caesar reform the calendar; Simplicius makes it clear that Sosigenes derived most of his information from Eudemus’ *History of Astronomy*, on which *cf.* CQ 9, 1959, pp. 301f.) *ap.* Simplic. p. 504, 17, οὐ μὴν αἶ γε τῶν περὶ Εὐδοξον σφζουσιν τὰ φαινόμενα, οὐχ ὅπως τὰ ὕστερον καταληφθέντα, ἀλλ’ οὐδὲ τὰ πρότερον γνωσθέντα καὶ ὑπ’ αὐτῶν ἐκείνων πιστευθέντα
- 358 *Loc. cit.* 36–7, τὰ φαινόμενα εἰ μέλλει τις ἀποδώσειν – a perfectly regular and straightforward use of ἀποδίδωμι in the sense of ‘account for’, ‘explain’ (see *LSJ s.v.*). Unfortunately, Sosigenes (followed by all later commentators) preferred the far less accurate, if more picturesque, phrase τὰ φαινόμενα σφζειν, i.e. ‘to preserve (agreement with) the facts of observation’. Kranz (*Rhein. Mus.* 100, 1957, p. 128) is wrong in supposing that the phrase was first used by Heracleides Ponticus, a pupil of Plato; the passage he quotes from Simplicius in support of this is clearly an *indirect* quotation and describes Heracleides’ views in Simplicius’ own words – in *De Caelo* ii, 13 p. 519 ed. Heib., ἐν τῷ κέντρῳ δὲ οὖσαν τὴν γῆν καὶ κύκλῳ κινουμένην, τὸν δὲ οὐρανὸν ἡρεμοῦντα ‘Ἡρακλείδης ὁ Ποντικὸς ὑποθέμενος σφζειν ὥρετο τὰ φαινόμενα. Sosigenes’ phrase, in its literal English translation of ‘to save (preserve) the appearances’ with all the ambiguities inherent in the expression, has led to the misleading idea that the Greek astronomers were concerned mainly with distorting the results of observation to make them fit into preconceived, theoretical schemes. The whole history of Greek astronomy, which shows a steady development from the naiveties of the Pre-Socratics, through the Pythagoreans and Plato, to the system of Eudoxus, and finally to the Hipparchian-Ptolemaic system of epicycles and eccentrics, demonstrates how false this idea is; at each stage, as new and more accurate observations were accumulated, older theories were dropped in favour of newer ones which seemed to provide a more complete explanation of astronomical facts
- 359 p. 497, 17 ed. Heib.
- 360 Cols. 22–3; these values are a considerable improvement on those of Euctemon (*cf.* p. 88) and, compared with the true figures for 330 BC, are less than half a day out – *cf.* Schiaparelli, p. 46
- 361 The mathematical details are given by Schiaparelli (*op. cit.*), whom Heath (*Arist.*, pp. 213–16) follows closely. It must again be emphasized (*cf.* note

- 347) that the values assumed by Schiaparelli are entirely conjectural, as indeed is the mode of operation of the additional spheres, since we have no information on these points from the ancient sources
- 362 Geminus, *Isag.* 8, 58–60; *cf.* p. 189 above
- 363 As explicitly stated by Hipparchus *ap.* Ptol., *Almag.* iii, 1, p. 207, 11 ed. Heib.
- 364 E.g. *Almag.* iii, 1; iv, 10; v, 3; vi, 5; vii, 3, *et al.*
- 365 *Cf.* Van der Waerden, *JHS*, 80, 1960, p. 170; Ginzel, *RE*, Bd. 10(2), 1919, col. 1663
- 366 Ed. W. K. C. Guthrie, Loeb, repr. 1960; P. Moraux, Budé, 1965
- 367 *De Caelo* ii, 10, 291a29–32, περὶ δὲ τῆς τάξεως αὐτῶν [τῶν ἄστρον], ὃν μὲν τρόπον ἕκαστον κεῖται (*v.l.* κινεῖται) τῷ τὰ μὲν εἶναι πρότερα τὰ δ’ ὕστερα, καὶ πῶς ἔχει πρὸς ἀλλήλα τοῖς ἀποστήμασιν, ἐκ τῶν περὶ ἀστρολογίαν θεωρεῖσθω: *cf.* 291b10 and *Met.* A 8, 1073b3–6
- 368 W. D. Ross, *Aristotle’s Physics*, 1936, *Introd.*, pp. xv–xviii
- 369 W. D. Ross, *Aristotle’s Metaphysics*, 1924, *Introd.*, pp. xxiv–xxix
- 370 *Op. cit.*, pp. xxix note 1; 382; 384. It is fair to point out that the difference in styles has also been given the opposite interpretation, i.e. that the fuller style is *earlier* than the more concise one (e.g. by F. Blass in *Rhein. Mus.* 30, 1875, pp. 481–505). P. Merlan (*Traditio* 4, 1946, pp. 1–30), on the other hand, sees 1074a31–38 as an essential part of the argument of this chapter, which he finds ‘logically and satisfactorily organized’ (*op. cit.*, p. 14)
- 371 *Cf.* Moraux, *Introd.*, pp. lxiv–lxv; cxxivff.
- 372 Thus various attempts have been made to trace specifically Aristotelian doctrines, such as those of the fifth element and the Unmoved Mover, back to the lost, early dialogue *De Philosophia* (of which we have fragments, ed. V. Rose, Teubner, pp. 24–40), and to discover a line of development between this (presumed to be still strongly under Platonic influence) and Aristotle’s later ideas; but the very divergent conclusions reached by different scholars (for references, see Moraux, pp. li–lv) do not inspire much confidence
- 373 Except Aristarchus and Seleucus, who undoubtedly put forward at least tentatively a heliocentric hypothesis – see Heath, *Arist.*, pp. 301ff.
- 374 For the astronomical opinions of many of the Pre-Socratics, Aristotle’s is the only evidence that can be considered to any degree reliable – see above, Chapter III
- 375 In the whole work, Aristotle records only one detailed astronomical observation (that of an occultation of Mars by the moon, ii, 12, 292a3–6, τὴν γὰρ σελήνην ἑωράκαμεν – hence presumably observed by Aristotle himself – διχότομον μὲν οὖσαν, ὑπελθοῦσαν δὲ τῶν ἀστέρων τὸν τοῦ Ἄρεος, κ.τ.λ.), and this is neither dated by him (modern calculations show that it was probably the occultation of 4 May 357 BC – *cf.* Guthrie *ad loc.*, Loeb, p. 205) nor reported in the form that a practising astronomer would use (compare the manner in which similar occultations by the moon of



the Pleiades are reported by Ptolemy from Timocharis, 283 BC, and Agrippa, AD 92, in *Almag.* vii, 3, ed. Heib., vol. ii, p. 25, 15f. and p. 27, 1f.). Aristotle adds that similar observations have been made by the Egyptians and the Babylonians (see above, p. 167)

376 Cf. *Met.* Δ 8, 1073b9–10, πλείους γὰρ ἕκαστον φέρεται μιᾶς τῶν πλανωμένων ἄστρον. I follow Cherniss' interpretation (*Aristotle's Criticism of Plato and the Academy*, 1944, App. VIII, pp. 547f.) which is surely correct. Aristotle has at the back of his mind those like Heracleides Ponticus who were able to account for the daily risings and settings by postulating a rotating earth and a fixed outer sphere, but he insists that this is not sufficient, since any planetary body must have more than one individual motion; but, if the earth is given the requisite number of motions, then other phenomena will be produced which are contrary to the facts of observation. This seems preferable to assuming (with Heath, *Arist.*, p. 241, and Guthrie, *op. cit.*, pp. 242–43) that Aristotle was unaware of the alternative explanation of the daily revolution (a highly improbable assumption, since Heracleides was also a pupil of Plato), and was referring only to a double motion of the earth, one component of which he infers must be in the plane of the ecliptic

377 See above, pp. 136f.

378 On τροπαί, see p. 116

379 κυρτός, 297b28; cf. *Meteor.* ii, 7, 365a32, ὡς οὐσης [τῆς γῆς] κυρτῆς καὶ σφαίροειδοῦς – strictly, this proves only the curvature of the earth's surface, but taken in conjunction with the other arguments it serves as proof of the sphericity

380 The examples he gives, that stars seen in Egypt and Cyprus are invisible further north and that those continuously visible in the north are seen, further south, to rise and set (298a3–6), are almost certainly taken from Eudoxus – cf. p. 155

381 The figures cited by Guthrie (Loeb, pp. 254–55) from Prantl are completely and inexplicably wrong (except the last one), and it is incredible that they should continue to be repeated (e.g. by J. H. Randall, *Aristotle*, p. 160, note 21). For the conversion of stades into miles, the best assumption is to take 8.72 stades as equivalent to 1 English mile or (which gives roughly the same result) 10 stades as equivalent to 1 geographical or nautical mile (= 1.152 Eng. miles) – on the value of the stade, see GFH, pp. 42–6

382 *De Caelo* ii, 11, 291b13, ἡ δὲ φύσις οὐδὲν ἀλόγως οὐδὲ μᾶττην ποιεῖ: cf. ii, 8, 289b25; 290a31. This is the keynote of all Aristotle's natural philosophy – he is a teleologist

383 It is difficult to imagine what gave rise to this curious notion, which (as far as I know) does not appear in any other ancient source. Simplicius in his commentary (pp. 454–56 ed. Heib.) is obviously (and not surprisingly) unhappy about Aristotle's arguments in the whole of this section; he quotes the passage in the *Timaeus*, and refers approvingly to Ptolemy's opinion

that the stars *do* rotate since it is in their nature to do so (*Hypoth. Planet.* ii, p. 131, 9f. ed. Heib., vol. ii, *Claud. Ptol. Op. astron. min.* – this second book of the *Planetary Hypotheses* is extant only in an Arabic translation of which Heiberg gives a German version by L. Nix) – but he throws no further light on any actual observations of this alleged phenomenon

384 This is not stated explicitly, but seems a necessary inference from his previous words, since he is evidently using ἄστρον as a general term to denote *all* the celestial bodies – cf. 290a14–15, μόνος δὲ δοκεῖ τῶν ἄστρον ὁ ἥλιος . . . Heath (*Arist.*, p. 235) attempts a defence of Aristotle which carries little conviction

385 This is an essential presupposition for the theory of unmoved movers (see below), and Aristotle takes great pains in arguing against the proponents of a plurality of worlds, the Atomists

386 αἰθήρ, which he derives from αἰεῖν, 'always running' (cf. Plato, *Crat.* 410b), because it is in continual motion, criticizing Anaxagoras' use of the term to denote fire (*De Caelo* i, 3, 270b22–5; cf. *Meteor.* i, 3, 339b22). Yet in *Phys.* iv, 4, 212b21 Aristotle himself uses it as a synonym for πῦρ. For αἰθήρ in Homer, see above p. 30

387 1074a7–8, τούτων δὲ μόνας οὐ δεῖ ἀνελιχθῆναι ἐν αἷς τὸ κατωτάτω τεταγμένον φέρεται. Actually, as Sosigenes notes (*ap. Simpl.*, p. 503, 28), without discussing the point, the moon also requires counteracting spheres; for Aristotle's own explanation in the *Meteorologica* of such phenomena as comets, shooting stars, and the Milky Way (on which see below) envisages the outer layer of the sublunary sphere as being carried round in the same way as the fixed stars – so that there is the same need for the motions of the moon's individual spheres to be cancelled out as in the cases of the other planetary bodies (cf. Heath, *Arist.*, p. 219)

388 1074a12–14, εἰ δὲ τῇ σελήνῃ τε καὶ τῷ ἡλίῳ μὴ προστιθείη τις ἄς εἴπομεν κινήσεις, αἱ πᾶσαι σφαῖραι ἔσονται ἑπτά τε καὶ τεσσαράκοντα

389 1074a3, εἰς τὸ αὐτὸ ἀποκαθιστάσας τῇ θέσει. Sosigenes spells this out – speaking of the last of Saturn's counteracting spheres, he says (*ap. Simpl.*, p. 502, 17) στραφῆσεται οὖν οὕτως ὁμοίως κινουμένη τῇ ἀπλανεῖ, οὐ μέντοι καὶ τὴν τάξιν ἔξει τῆς ἀπλανοῦς, περὶ ἄλλους στρεφομένη πόλους καὶ οὐ τοὺς τῆς ἀπλανοῦς – cf. p. 498, 5–7

390 The same error vitiates the results of an ingenious paper by N. R. Hanson, 'On Counting Aristotle's Spheres', *Scientia*, 98, 1963, pp. 223–32, who tries to prove that a 55-sphere system cannot work, but that 'The required observations can be generated either within a system of 49 spheres, or within one comprising 61 spheres – the latter being preferable from an "Aristotelian" point of view' (p. 223); later he suggests that either 50 or 54 or 62 or 66 spheres would suffice (p. 232)! Hanson agrees that '55 spheres is all right [*sic*] if only we assume that each new α [the first sphere in each set] *absolutely* has the motion of the fixed stars' (p. 229), but he regards this as incompatible with Aristotle's 'unified mechanically-articulated



cosmology'. Yet this assumption *does* according to all our evidence underlie Eudoxus' original scheme (cf. *Met.*  $\Lambda$  8, 1073b18–19, ὦν τὴν μὲν πρῶτην τὴν τῶν ἀπλανῶν ἄστρον εἶναι) and Hanson rightly points out that 'Aristotle is explicit in adapting [*sic*] *en bloc* Eudoxus' technique for his own cosmology' (p. 226). His ideas about the connections postulated between the spheres by Aristotle go well beyond what we are entitled to infer from Aristotle's words, and the whole paper (which out-Aristotles Aristotle) seems an excellent example of the dangers of forcing a spurious scientific rigidity on the modes of ancient astronomical thought. However, Hanson is probably more correct than he realizes in saying (p. 229) that, if 55 spheres are insisted upon, 'Aristotle's entire cosmology becomes a childish re-scaling of the Eudoxan calculation technique' – although 'childish' seems unnecessarily harsh

- 391 287a5–11, especially the last sentence, ὥστε σφαίροειδὴς ἂν εἴη πᾶσα· πάντα γὰρ ἄπτεται καὶ συνεχῇ ἐστὶ ταῖς σφαίραις
- 392 οὐρανός in all three of the senses which Aristotle defines in *De Caelo* i, 9, 278b8ff. (namely, the outer circumference of the world, the celestial regions, and the whole universe) is conceived of as 'body' (σῶμα); cf. ii, 3, 286a10–12
- 393 ii, 12, 293a6–8, ἐν πολλαῖς γὰρ σφαίραις ἡ τελευταία σφαῖρα ἐνδεδεμένη φέρεται, ἐκάστη δὲ σφαῖρα σῶμα τι τυγχάνει ὄν
- 394 See *De Gen. et Corr.* ii, 10, 336a31ff., διὸ καὶ οὐχ ἡ πρώτη φορὰ αἰτία ἐστὶ γενέσεως καὶ φθορᾶς, ἀλλ' ἡ κατὰ τὸν λοξὸν κύκλον, and the whole of this chapter; also *Meteor.* i, 9, 346b21–4; ii, 4, 361a12–14; cf. *Met.*  $\Lambda$  5, 1071a13, . . . ὥσπερ ἀνθρώπου αἵτιον τὰ τε στοιχεῖα . . . καὶ παρὰ ταῦτα ὁ ἥλιος καὶ ὁ λοξὸς κύκλος, where Ross' note (p. 365) to the effect that it was Hipparchus who first called the ecliptic ὁ ἐκλειπτικός is wrong – the latter term is not found until Achilles Tatius in the third century AD (its appearance in Cleomedes, *Cycl. Theor.* ii, 5, p. 206, 26 ed. Ziegler, is an interpolation), whereas Hipparchus and Ptolemy always use the phrases ὁ λοξὸς κύκλος or ὁ διὰ μέσων τῶν ζῳδίων κύκλος (as does Aristotle himself – see above and  $\Lambda$  8, 1073b19), restricting ἐκλειπτικός to the meaning 'pertaining to eclipses'
- 395 ἐλάττους γὰρ ἥλιος καὶ σελήνη κινεῖνται κινήσεις ἡ τῶν πλανωμένων ἄστρον ἔνια, 291b35
- 396 *Phys.* vii, 2, 243a32–4, where the mover is said to be ἄμα the moved and ἄμα is defined as 'nothing being in between them' (ὅτι οὐδὲν ἐστὶν αὐτῶν μεταξύ) – a similar definition of ἄμα is given in v, 3, 226b21; cf. viii, 1, 242b59–63
- 397 258b10–11, ἀνάγκη εἶναι τι αἰδίων ὁ πρῶτον κινεῖ, εἴτε ἔν εἴτε πλείω. Later Aristotle says that it is better to envisage only one unmoved first mover, on the principle of the economy of hypotheses (259a6–13); but, as we shall see, he has to abandon this position with regard to the movers of the planetary spheres
- 398 As Ross explains (*Arist. Phys.*, pp. 727–28), 'the sphere may be regarded

as produced by uniform expansion from the centre, or by uniform contraction from the circumference'

- 399 Ross (*Arist. Met.*, p. cxxxiv) says, 'This, however, is an incautious expression which should not be pressed. Aristotle's genuine view undoubtedly is that the prime mover is not in space', and he cites in support *De Caelo* 279a18. Yet this passage does not altogether bear out Ross' opinion. Aristotle is explaining (279a6ff.) that there cannot be any bodily mass outside the heavens, for the world (ὁ πᾶς κόσμος) is made up of all the available matter (ὕλη) and there is only one world; 'outside the heaven, there is neither place nor void nor time (οὐδὲ τόπος οὐδὲ κένον οὐδὲ χρόνος ἐστὶν ἔξω τοῦ οὐρανοῦ) . . . and therefore neither are the things there born in place (διόπερ οὐτ' ἐν τόπῳ τὰ κεῖ πέφυκεν), nor does time make them grow old, nor is there any change at all in any of the things that are posited to lie beyond the outermost revolution (τῶν ὑπὲρ τὴν ἔξωτάτω τεταγμένων φορᾶν), but changeless and unaffected they continue to lead the best and most self-sufficient life throughout all eternity' – and Aristotle goes on to stress the ideas of immortality and divinity which men have always connected with the notion of eternity. Thus there *are* at least conceptual entities ἔξω τοῦ οὐρανοῦ – and what better place could there be for the notional first mover or movers? Cf. W. Theiler in *JHS* 77 (1), 1957, pp. 127–31, who cites two passages in Sextus Empiricus (*Hyp.* iii, 218 and *Adv. Math.* x, 33) for Aristotle's view of god πέρας τοῦ οὐρανοῦ. There is no need at all to assume 'an incautious expression' on Aristotle's part. In fact, the eternity of the whole heaven (including all time and infinity) is described in this passage of the *De Caelo* in terms that recall those applied later to the prime mover (it is 'deathless and divine' and the source of existence and life for all other things, 279a28–30; cf. *Met.*  $\Lambda$  7, 1072b14 and 28–30); the reason why the latter is not actually mentioned by name here is presumably because Aristotle had not yet elaborated this concept (cf. Cherniss, *Arist. Crit. Pl. and Acad.*, App. X, p. 588). P. Merlan in *Apeiron*, Monash University, Australia, 1, 1966, pp. 3–13, has an interesting analysis of this passage; his main thesis, that Aristotle's theology is basically polytheistic, is probably correct; less convincing is his insistence that Aristotle's views on the fifth element and the unmoved mover or movers are self-contradictory – on this apparent contradiction, see further above, p. 213
- 400 1071b20, ἔτι τοίνυν ταύτας δεῖ τὰς οὐσίας εἶναι ἀνευ ὕλης· αἰδίου γὰρ δεῖ, εἴπερ γε καὶ ἄλλο τι αἰδίων. ἐνέργειαι ἄρα – note the plural, which anticipates the prime movers of the planetary spheres mentioned later; hence the plural ἐνέργειαι (found in two MSS) seems better than the singular of the Oxford text (cf. Merlan, *loc. cit.*, p. 11 note 1)
- 401 κινεῖ δὲ ὡς ἐρώμενον, 1072b3. For both desire (ἔρεξις) and thinking (νόησις) are types of movement in Aristotle's view (cf. 1072a30, νοῦς δὲ ὑπὸ τοῦ νοητοῦ κινεῖται), as is explained in *De Anima* iii, 10



402 1072b26-30; cf. *Nic. Eth.* x, 8, 1178b21-2

403 It is difficult to see how to reconcile this statement with the ἀνεκίττουσαι σφαῖραι

404 This is the very puzzling passage 1074a31-8 (see above, p. 195). One may agree with Merlan (*Traditio* 4, 1946, p. 13) that Aristotle is arguing against views such as those attributed to Heraclides Ponticus (Aët. ii, 13, 15; *Dox. Gr.*, p. 343), that every star was a world by itself, with its own earth and air; but why does he, immediately after stressing the plurality of prime movers (and since these are 55 or 47 in number, how is it that they do not partake of matter by Aristotle's own reasoning?), relapse into speaking of 'the first unmoved mover' (τὸ πρῶτον κινουὺν ἀκίνητον ὄν, a37) as if it were the only one? A possible explanation perhaps (which I have not seen suggested elsewhere) is that Aristotle regarded the prime mover of the outer heaven as a *primum inter paria*; there is only one basic principle of celestial movement (ἀρχή) for our one, unique universe, but this principle manifests itself in a number of independent prime movers of which the first (activating the sphere of the fixed stars) is commonly used as the exemplar, since the daily revolution of the heavens from east to west is the only revolution common to all the celestial bodies. Such an explanation (which cannot here be developed in detail) might serve to account for the emphasis that Aristotle lays (both here and in *De Caelo* i, 8 and 9 - see above, p. 199) on the idea of one world only; more than one world would entail more than one set of unmoved movers, and more than one principle of circular motion would be utterly incompatible with his whole philosophical system

405 1074a38-b14, esp. b2, θεοί τέ εἰσιν οὗτοι καὶ περιέχει τὸ θεῖον τὴν ὅλην φύσιν and b9, ὅτι θεοὺς φέροντο τὰς πρώτας οὐσίας εἶναι, θείως ἂν εἰρῇσθαι νομίσειεν. If we regard a31-38 as a long parenthesis (see above, p. 195), the antecedent of οὗτοι will be the divine celestial bodies mentioned in a30; but even if we do not so regard it, the lack of a specifically expressed antecedent need not prevent its referring to the prime movers which have been the subject of discussion (Merlan - *op. cit.*, p. 14 - thinks of a gesture towards the heavens when the passage was read aloud). It seems likely that by τῶν ἀρχαίων καὶ παμπάλαιων (b1) and τῶν πρώτων (b14) Aristotle means the ancient Egyptians and Babylonians (cf. *De Caelo* ii, 12, 292a7-9), who undoubtedly had an astral religion from very early times; but there is no evidence for star gods in early Greek belief

406 This and the last two books (iii and iv) of *De Caelo* deal with the four elements, their mutual transformations, and the general principles of the processes of generation and decay - cf. H. D. P. Lee, *Meteorologica*, Loeb, 1952, p. x

407 This occurrence was known to Anaxagoras, who is even supposed to have predicted it (*DK* 59 A11 and 12; *Diog. Laert.* ii, 10), but this is simply a picturesque inference derived from his well-known views of the celestial

bodies as fiery stones (see above, pp. 58f. and Heath, *Arist.*, p. 246 note 1)

408 This comet is mentioned three times by Aristotle (343b1; b18; 344b34), always with the epithet 'great' (ὁ μέγας). It is possible that it was an appearance of what is now known as Halley's comet, which in its 76- or 75-year period would have been due to appear about 370 BC

409 This is a common phenomenon in naked-eye observation, and its precise description by Aristotle confirms that he himself had experience of it. The star in question is either δ or ε Canis maioris

410 If this is what is referred to in *Meteor.* i, 5 as Ideler, Heath, and Lee assume; E. W. Webster (in the Oxford translation, vol. iii, 1931, *ad loc.*) thinks rather of 'phenomena of cloud coloration' - cf. Lee, p. 36. The aurora is rarely seen except in extreme northern or southern latitudes round the earth's north or south magnetic poles

411 And therefore rises and sets with the heavens - hence the moon also should have been endowed with counteracting spheres (see note 387)

412 See pp. 29f. for this concept in Homer

413 Aristotle's 'explanation' is even less convincing than usual. He seems to regard the Milky Way as that part of the sphere of the fixed stars which contains the greatest number of bright stars (346a17ff. - hence presumably the appellation 'greatest circle'); but the fixed stars form the outermost sphere of the whole universe, and it is difficult to see how this can be regarded as in close enough contact with the outer stratum of the sublunary region to ignite it. Perhaps he would invoke the concept of the counteracting planetary spheres (see above) to meet this point. It is interesting that the text refers to a diagram (ὀπογραφή) and a globe (σφαῖρα) on which stars might be marked (346a32f.) - no doubt as visual aids to accompany the lecture (cf. Lee, p. 67 note b)

414 See pp. 84ff.

415 ὁ διὰ παντὸς φανερός (κύκλος), 362b2 - but this, as Aristotle must have known (cf. *De Caelo* ii, 14, 297b31f.), properly refers to the limit of the circumpolar stars at a particular latitude, which changes with the observer's locality. Poseidonius and Strabo rightly criticize Aristotle for defining a zone by a variable circle (Str. C 95 - see *GfH*, p. 166). The same confusion is apparent in the chapter on winds (ii, 6), where in the circular diagram based on the eight commonly used reference points (namely, summer and winter sunset and sunrise, equinoctial sunset and sunrise, and the north and south poles - see Lee, p. 187), a chord connecting the points where two northerly winds blow is described as 'nearly corresponding to the wholly visible circle, but not accurately' (ἡ δὲ τοῦ ΙΚ διάμετρος βούλεται μὲν κατὰ τὸν διὰ παντὸς εἶναι φαινόμενον, οὐκ ἀκριβοῦς δέ)

416 This is because of his insistence that motion must start from the right, therefore east must be the right-hand side, and the motion of the heavens must be from right to left. However, when we face south (as in the northern hemisphere we must in order to face the sun), the motion of the heavens



is clearly from our left (east) to our right (west), on the normal supposition that we are standing up with our heads in the direction of the visible north pole; but this does not accord with the right's being the start of the motion – hence we have to suppose that our feet are towards the north pole and our head towards the south, which is therefore the upper pole. This whole chapter shows Aristotle at his least convincing in an astronomical context. Wicksteed (Loeb *Physics*, pp. lxii–lxiii) has a good note on this passage, and correctly points out that in terrestrial maps east is on the right, but in celestial maps (e.g. *Norton's Star Atlas*) east is on the left. For Pythagorean views on the supremacy of the right and Plato's connection of this with the east, see above p. 121

- 417 From what we are told of Aristotle's relations with Callippus, *Met.* A 8 can hardly have been written before 330 BC and probably later – see pp. 190 and 194
- 418 E.g. *Met.* A 9, 992a32; cf. his sharp criticism in *De Caelo* iii, 7 of Plato's elemental triangles as described in the *Timaeus* – see Solmsen, *Arist. Syst. Phys. World*, 1960, pp. 259f.
- 419 Cf. Merlan in *Traditio* 4, 1946, p. 5, who draws attention to the tripartite classification mentioned in *Phys.* ii, 7, 198a29, whereof astronomy belongs to the second part which is concerned with 'things that are in motion but are indestructible'
- 420 See p. 199; cf. *Met.* A 8, 1050b22, where Aristotle assures us that there is no need to fear that the heavens will become tired!
- 421 E.g. ii, 6, 288a27–b7; 288b22–30; iv, 3, 311a9–12; cf. i, 8, 277b9–12 and Guthrie *ad loc.*
- 422 The controversy has centred on *De Caelo* i, 9, 279a33–b3; ii, 1, 284a18–b4; ii, 3, 286a10–12; iii, 2, 300b18–22; iv, 2, 309b17–24 – all these passages have been thought to be inconsistent with the concept of a prime mover – as well as on the passages mentioned above. Cherniss (*loc. cit.*) cites most of the relevant literature; cf. Moraux, p. xliii–xlv
- 423 For the stars do not vary their distances from each other – 288b10–12; cf. 289a5–7
- 424 287a23–4, ἡ τοῦ οὐρανοῦ φορὰ . . . μόνῃ συνεχῆς καὶ ὁμαλῆς καὶ αἰδίου
- 425 ἀνωμαλία . . . ἀνωμαλίαν: μεταβάλλοι . . . μεταβάλλει; ἀδυναμία . . . ἀδύνατον (288a26; 288b5; 288b21)
- 426 As Cherniss points out, *op. cit.*, App. X, pp. 581–82; cf. Moraux, p. xlv
- 427 Cf. *Met.* Θ 8, 1050b21, οὐκ ἔστι κατὰ δύνανμιν κινούμενον ἀλλ' ἢ ποθὲν ποί
- 428 287b27–8, ἀνάγκη γὰρ καὶ τοῦτο ἢ ἀρχὴν εἶναι ἢ εἶναι αὐτοῦ ἀρχήν
- 429 The passages cited by Ross (*Met.* A 4, 1070b34; 7, 1072b13; 10, 1076a4) are simply general expressions of the universal influence of the prime mover of the outer heaven to which, in a sense, everything in the celestial regions is subject, since it is the cause of all risings and settings. As mentioned above (note 404), Aristotle seems to use this as an exemplar or typical prime mover

- 430 The question cannot be argued in detail here, but cf. the views of Merlan cited above, note 399
- 431 Cf. Moraux, p. xlii and lxxxviii and the authorities referred to in his notes
- 432 This itself is incompatible with the description in ii, 4 (see above, p. 203) – air has no business to be in the celestial regions at all, and the only planetary spheres immediately beneath which there is air are those of the moon (cf. *Meteor.* i, 3 and 4; above, pp. 199; 203)
- 433 This is part of his argument against the Pythagorean 'harmony of the spheres'
- 434 291b2, ἕκαστον γὰρ ἀντιφέρεται τῷ οὐρανῷ κατὰ τὸν αὐτοῦ κύκλον – this, of course, refers to motion along the zodiac in the opposite direction (i.e. west to east) to the daily rotation
- 435 Thus Saturn has the longest sidereal period (about 29½ years) and the moon the shortest (about 27½ days)
- 436 Cf. Moraux, p. cii, 'Les théories proprement astronomiques du *De Caelo* ne paraissent ni très claires ni très cohérentes'; cf. pp. cxxv–cxxvi
- 437 E.g. *De Caelo* ii, 3, 286a4–7; 5, 287b31–288a2; 12, 291b25–8; 292a14–18; *Met.* A 8, 1073b13–17
- 438 Hence, of course, the comparative success of the Greeks in the two fields, mathematics and astronomy, which make least use of the controlled experiment
- 439 And Ptolemy was just as convinced of the divine nature of the heavens and the celestial bodies as ever Plato and Aristotle were (cf. *Almag.* i, 1, p. 6, 23 ed. Heib., and the famous epigram in the *Palatine Anthology*, ix, 577)
- 440 *Summa Theol.* i, 50, 3–4; cf. P. Duhem, *Le système du monde*, tom. v, 1917, p. 539ff.
- 441 See P. Wicksteed, *The Reactions between Dogma and Philosophy*, 1920, pp. 33f.
- 442 In reality, we know nothing for certain of how Eudoxus or Callippus made their observations. It is a reasonable assumption that they made use of celestial globes and the gnomon, but we can only guess at the type of sighting instrument they employed, if indeed they used any – it is remarkable what can be achieved by simply using the fingers of the outstretched arm to gauge the relative positions of celestial objects
- 443 Author of two extant treatises, *On the Moving Sphere* and *On Risings and Settings*, which (with Euclid's *Phainomena*) are the earliest mathematically based works on astronomy that have come down to us – but there is no actual mention of the theory of concentric spheres in these works