SAVING THE APPEARANCES

'Saving the appearances', *σώζειν τὰ φαινόμενα*, is a slogan that, in its time, stood or was made to stand for many different methodological positions in many different branches of ancient natural science.[1] It is not my aim, in this paper, to attempt to tackle the subject as a whole.[2] I shall concentrate on just one inquiry, astronomy. Nor, with astronomy, can I do justice to all the complexities of what was certainly one of the central methodological issues, if not *the* central issue, in the history of ancient theoretical astronomy. I have a quite limited aim, to examine the foundations, and test the applicability, of a widespread and influential line of interpretation of ancient Greek astronomy according to which it was essentially, or at least predominantly, what we may call 'instrumentalist'[3] in character—that is, broadly speaking, that Greek astronomical theories were devices or fictions put forward purely for the sake of calculations with no claims to correspond with physical reality.

Thus Duhem, one of the chief proponents of the line of interpretation in question, distinguished two views of the status of astronomical hypotheses as follows:

> On peut, en effet, regarder les hypothèses de l'Astronomie comme de simples fictions mathématiques que le géomètre combine afin de rendre les mouvements célestes accessibles à ses calculs; on peut y voir aussi la description de corps concrets, de mouvements réellement accomplis. Dans le premier cas, une seule condition est imposée à ces hypothèses, celle de *sauver les apparences*; dans le second cas, la liberté de celui qui les imagine se trouve beaucoup plus étroitement limitée; s'il est, en effet, l'adepte d'une philosophie qui prétende connaître quelque chose de la céleste essence, il lui faudra metter ses hypothèses d'accord avec les enseignements de cette philosophie.[4]

Although he recognized some exceptions, the most notable of which was Aristotle, Duhem ranged the major Greek astronomers and commentators on the status of astronomy under the former head. Their hypotheses were 'pure conceptions'. It was not a question of their being true, or even probable ('vraisemblable')—and he glosses 'true' by 'in conformity with the nature of things'.[5] Their aim was simply

[1] This paper stems from a question originally put to me by my colleague, Dr. N. Jardine, Lecturer in the History and Philosophy of Science at the University of Cambridge, to whom my warmest thanks are due not only for raising the problem but also for many illuminating discussions both of the philosophical issue and of aspects of the historical questions treated here. I am also most grateful for the comments made on an earlier draft of this paper at a seminar at the Institute for Classical Studies, London, and especially for those of Mr. M. F. Burnyeat, Professor A. C. Lloyd, Dr. R. Sorabji, and Professor G. Vlastos.

[2] Apart from the work of Duhem (1908), the chief general discussion is that of Mittelstrass (1962). (The bibliography at the end of the article provides details of these and other works that will also be referred to by author's name and date of publication.)

[3] 'Instrumentalism' is defined by Hesse (1967), p.407, as follows: 'Instrumentalists assume that theories have the status of instruments, tools, or calculating devices in relation to observation statements. In this view it is assumed that theories can be used to relate and systematize observation statements and to derive some sets of observation statements (predictions) from other sets (data); but no question of the truth or reference of the theories themselves arises.'

[4] Duhem (1908), p.281. Cf. Doland and Maschler (1969), p.28.

[5] e.g. Duhem (1908), pp.120, 284.

and solely to 'save the appearances', interpreted by Duhem as meaning that they should furnish conclusions that correspond with the observations.[6] It was possible for several different hypotheses to save the same appearances: in that case it was not a question of choosing between them on the grounds of correspondence with physical reality, but merely on the grounds of mathematical simplicity. With some modifications and developments, Duhem saw the same fundamental methodological debate running through the whole of Western science down to Galileo, and indeed on through to his own day. The tradition of the principal Greek theorists, including Geminus, Ptolemy, Proclus, and Simplicius, continues through Maimonides, Aquinas, Jean de Jandum, down to Osiander, Ursus, and Bellarmin.[7] Against them were ranged the realists, Alpetragius, the Averroists, and so on down to Kepler and Galileo. Nor does Duhem leave us in any doubt about his own position, which is that the former view is correct: 'en dépit de Képler et de Galilée, nous croyons aujourd'hui, avec Osiander et Bellarmin, que les hypothèses de la Physique ne sont que des artifices mathématiques destinés à *sauver les phénomènes.*'[8]

In the course of assessing the evidential basis of this interpretation of the main stream of Greek astronomy I shall have occasion to question the way in which the alternatives are presented by Duhem. But before turning to the evidence it is as well to point out that the 'instrumentalist' line has some formidable supporters. Even before Duhem had developed his interpretation at length in his articles in *Annales de philosophie chrétienne*, Dreyer had written that, by the time of Ptolemy, 'it had . . . become a recognized fact, that the epicyclic theory was merely a means of calculating the apparent places of the planets without pretending to represent the true system of the world', and again that 'it appears from many statements, not only of Ptolemy himself, but also of his commentators, that they merely considered the numerous circles as a convenient means of calculating the positions of the planets.'[9] In his *The Physical World of Late Antiquity*, Sambursky wrote of Proclus, at least, that 'he takes a decidedly positivistic view and rejects the idea that any reality can be attributed to Ptolemy's spheres or segments of spheres.'[10] Finally there is a particularly clear statement of a Duhemian line, with an explicit acknowledgement to Duhem, in Wasserstein's article 'Greek Scientific Thought'. From Plato's time, he wrote,

> geometrical methods and procedures become predominant. By this I do not mean only that astronomical models are now conceived as geometrical constructions; I mean something quite different; namely that like the geometer or arithmetician the astronomer now starts from axioms or postulates, or whatever you like to call them, and then deduces a system from them. The important point here is this: the geometer is not concerned with the truth

[6] e.g. Duhem (1908), p.135.

[7] Duhem claimed Copernicus too for this tradition in so far as he commented (Duhem (1908), p.374): 'Copernic a essayé l'hypothèse du mouvement de la Terre à titre de supposition purement fictive'. Yet he went on to note, and to blame Copernicus for, certain realist assumptions: 'il a voulu faire davantage . . . il a voulu prouver la vérité de cette hypothèse . . .'

[8] Duhem (1908), p.592, cf. pp.484, 587 ff.

[9] Dreyer (1906), pp.196 and 201.

[10] Sambursky (1962), p.146. Cf. also Dijksterhuis (1961), p.67: 'Among later Greek philosophers Proclus is clearly in agreement with the standpoint taken by Ptolemy in the *Almagest*: the motions into which the single planetary motion observed is resolved are mere mathematical fictions, which exist nowhere but in the mind of the astronomer carrying out the resolution; . . . the only object pursued in framing an astronomical theory is that of making it possible to calculate the celestial phenomena.'

of his initial axioms, just as the logician is not concerned with the truth of his initial premisses—both are concerned only with the *validity* of the conclusions that are derived *deductively* from their axioms or premisses . . . Similarly in Greek astronomy the aim was *not*, at least not always, the discovery of a theory that corresponded with fact, with physical truth, with physical reality. Σῴζειν τὰ φαινόμενα is not that, at least it is not always that, in the dominant strand of the astronomical tradition, even as represented by Ptolemy, and before him by Hipparchus, by Eudoxus, and indeed, as we shall see, by Plato.[11]

After this negative statement of what one strand of Greek astronomy was not, Wasserstein went on to define it positively as follows: 'The Greek astronomer in formulating his astronomical theories does not make any statements about physical nature at all. His theories are purely geometrical fictions. That means that to save the appearances became a purely mathematical task, it was an exercise in geometry, no more, but, of course, also no less.'[12]

Now the instrumentalists present a variety of ancient texts in support of their view, but the key witness is undoubtedly Proclus. Duhem's view of Proclus' position is clear:

Tout l'effort de Proclus va à établir que les mouvements hypothétiques en des excentriques et des épicycles qui, par leur composition, reproduisent le mouvement des astres errants sont de pures abstractions.[13]

Les combinaisons de mouvements proposées par les astronomes étant de pures conceptions, dénuées de toute réalité, elles n'ont pas à être justifiées à l'aide des principes de la Physique; elles doivent seulement être disposées de telle sorte que les apparences soient sauvées.[14]

[He sums up] Les artifices géométriques qui nous servent d'hypothèses pour sauver les mouvements apparents des astres ne sont ni vrais, ni vraisemblables. Ce sont de pures conceptions que l'on ne saurait réaliser sans formuler des absurdités.[15]

Duhem's discussion of Proclus is liberally interspersed with translations, even the occasional Greek phrase, from, especially, the *Hypotyposis*, and, writing in 1908, he based himself on Halma's edition of 1820[16] (Manitius's Teubner came out in 1909). The most important passages come in the final chapter of the *Hypotyposis*, where both Halma's Greek and his French translation are extraordinarily defective.[17] Thus Duhem's first quotation from Proclus runs: 'les astronomes qui ont présupposé l'uniformité des mouvements des corps célestes ignoraient que l'essence de ces mouvements est, au contraire, l'irrégularité.'[18] But the Greek is: τὰς κινήσεις τῶν οὐρανίων ὁμαλὰς ἀποφῆναι προθυμηθέντες οἱ περὶ ἀστρονομίαν δεινοὶ ἔλαθον ἑαυτοὺς αὐτὴν τὴν οὐσίαν αὐτῶν ἀνώμαλον καὶ παθῶν ἀνάπλεων ἀποφήναντες,[19] i.e. 'those who are clever at astronomy,

[11] Wasserstein (1962), p.54. (The italics are Wasserstein's.)

[12] Wasserstein (1962), p.57. He had just quoted the preface to Copernicus' *De Revolutionibus* ('the task of the astronomer consists in the careful collection of observations of heavenly movements. Since, however, no reasoning can help him to attain to the true causes of these movements, he conceives and imagines any sort of hypothesis by means of which these movements can be geometrically calculated both for the past and for the future. It is not necessary that these hypotheses be *true*; it is not even necessary that they be *likely*; it suffices that they lead to a calculation that accords with the observations') where he noted 'suggestive echoes of older doctrines or rather shades of older attitudes.'

[13] Duhem (1908), p.132.

[14] Duhem (1908), p.133.

[15] Duhem (1908), p.135.

[16] As the footnote (Duhem (1908), p.132 n.1) indicates.

[17] Thus apart from the many incoherences that Halma's Greek text contains, his translation completely omits the passage from ει δε και (*sic*) (Halma (1820), p.151, col.1 line 12) to και διακρισεις (*sic*) (line 21) in the Greek.

[18] Duhem (1908), p.132.

[19] *Hyp.* 236, 12–15, Manitius, Halma (1820), pp.150–1.

who were eager to show that the movements of the heavenly bodies are regular, tended, without realizing it, to show that their substance itself is irregular and full of modifications.' Here Duhem drastically misrepresents Proclus' position. He implies that Proclus' *own* view is that the movements of the heavenly bodies are essentially irregular, and indeed full of *πάθη*: the astronomers did not realize this and tried to show that those movements are regular. But it is clear that what Proclus is in fact doing is criticizing the astronomers for producing theories that *conflict* with the assumption of the regularity of the movements of the heavenly bodies.[20]

At this point it is not Halma's Greek text that is the source of the problem. Although printed without accents and smooth breathings, his Greek is the same as Manitius's. One suspects, however, that Duhem followed Halma's French translation, where we find: 'que les astronomes . . . qui ont présupposé que les mouvements des corps célestes étoient uniformes, ignoroient que leur essence est l'irrégularité et la variation', that is precisely the same misrepresentation of *ἔλαθον* as in Duhem.[21]

That should already put one on one's guard. But worse is to follow. Proclus goes on to mention two different ways of construing the epicycles and the eccentrics that the astronomers postulated. Manitius's text (*Hyp.* 236, 15 ff.) may be translated: 'For what are we to say about the eccentrics they go on about and the epicycles? [Are we to say] that they are merely contrivances [objects of thought] or that they also have existence in their spheres in which they are fixed?'[22]

He then goes on to consider each of these two possibilities and to raise difficulties about both, that is at *Hyp.* 236.18 ff. and 236.25 ff. 'For if [one is to say] that they are only contrived, they have unwittingly gone over from physical bodies to mathematical concepts and given the causes of physical movements from things that do not exist in nature.'[23] This first difficulty is then followed by a second (*Hyp.* 236, 22 ff.) where he attacks the idea of putting these objects of thought in motion.[24]

[20] Even though Proclus allows the movements of the planets to be complex, he insists that they are orderly, cf. further below, pp.208 ff. and n.41. It is striking that in his later *Système du monde* Duhem gave a more accurate translation of this passage ('ils ne se sont pas aperçu qu'ils déclaraient, [par là], que l'essence même de ces corps célestes était privée d'uniformité et douée de toutes sortes de passivités', Duhem (1954), i.104), but in no way modified his general interpretation of Proclus. Wasserstein, who translated the passage correctly although he omitted the important *καὶ παθῶν ἀνάπλεων*, also took it that Proclus himself held the movements of the heavenly bodies to be irregular and indeed that this text showed that 'he is willing to regard not only circularity but even uniformity as expendable assumptions' (Wasserstein (1962), p.56).

[21] Halma (1820), pp.150–1. The one point of variation is that Halma's 'leur' (p.151, col. 2 line 3) might refer to either 'mouvements' or—more likely—'corps célestes', whereas Duhem opts definitely for the former ('l'essence de ces mouvements'). It seems more likely, however, that it is the heavenly bodies (*τῶν οὐρανίων*) rather than their movements whose substance (*οὐσίαν*) is said to be irregular and full of modifications.

[22] *τοὺς γὰρ ἐκκέντρους οὓς θρυλοῦσι καὶ τοὺς ἐπικύκλους τί φῶμεν; ἆρα ἐπινοεῖσθαι μόνον ἢ καὶ ὑπόστασιν ἔχειν ἐν ταῖς σφαίραις αὐτῶν, ἐν αἷς ἐνδέδενται;*

[23] *εἰ μὲν γὰρ ἐπινοεῖσθαι μόνον, λελήθασιν ἀπὸ τῶν φυσικῶν σωμάτων εἰς μαθηματικὰς ἐπινοίας μεταστάντες καὶ ἐκ τῶν οὐκ ὄντων ἐν τῇ φύσει τὰς τῶν φυσικῶν κινήσεων αἰτίας ἀποδιδόντες.*

[24] *οὐ γάρ, ἐπειδὴ ταῖς ἐπινοίαις ἡμῶν κινοῦνται, διὰ τοῦτο οἱ ἐπ' αὐτῶν νοούμενοι ἀστέρες κατὰ ἀλήθειαν ἀνωμάλως κινοῦνται*, 'for it is not the case that since they are moved according to our thoughts, for that reason the stars that are imagined on them truly move irregularly'. What is being denied here is not the reason (the

Proclus then continues by considering the second alternative, the view that the epicycles and eccentrics actually exist in the spheres in which they are fixed, and here his objection is that the epicycles and eccentrics destroy the *συνέχειαν*—continuity or connection—of the spheres: the circles and the spheres are moved separately; 'nor do they move these [the circles] in the same way as each other, but in opposite directions';[25] and they 'confound their relative distances, if sometimes they [the circles] are brought together and are in a single plane, but sometimes are separated and cut each other. Thus there will be all kinds of divisions and foldings-up and separations of the heavenly bodies.'

Although many points of detail are obscure, the overall structure of the argument of this passage seems clear enough. Proclus mentions two possible ways of taking epicycles and eccentrics and raises objections against *both*. Where precisely that leaves Proclus himself is a question I shall postpone for the moment, because I want to consider how Duhem—and Halma—took the passage. At this point Duhem was, to some extent at least, critical of what he found in Halma. Thus he disagrees with Halma's reading *ἐκ τῶν οἰκούντων ἐν τῇ φύσει* and suggests that a negative has dropped out: *οὐκ οἰκούντων*.[26] Moreover he distinguishes the two theses that Proclus considers much more clearly than Halma's translation does. Halma seems to have taken his *αρα* (*sic*) on p.151, col. 1 line 3 as inferential, not as an interrogative. At least he translated: 'il faut donc les concevoir comme simplement fictifs et idéaux, ou comme attachés à des sphères.' While Duhem keeps 'simplement fictifs et idéaux', he sets out the alternatives more clearly: 'ou bien . . . ou bien . . .'[27] Yet the important point is that in the sequel both Duhem and Halma imply that *Proclus opts for* the instrumentalist alternative. After mentioning the two possibilities very sketchily in the passage just quoted, Halma proceeds: 'car puisqu' ils ne doivent être que des conceptions.'[28] Similarly Duhem went on: 'ceux qui le prétendent "oublient que ces cercles sont seulement dans la pensée".'[29] Where they both agree, and both misrepresent the Greek, is in this: both take as an assertion what is, in the Greek, the protasis of a conditional, where the apodosis sets out an objection to the view contained in that protasis. Both represent Proclus coming down firmly for the instrumentalist option,[30] whereas in fact Proclus raises objections against that view just as much as against the alternative, according to which the epicycles and eccentrics were held to exist in the spheres in which they are fixed.

That much should be clear. But it might be thought that although Duhem (misled, perhaps, to some extent, by Halma) has misrepresented Proclus' argument

stars truly move irregularly, but not for the reason given) but (as in Manitius's translation) the conclusion—they do not truly move irregularly at all.

[25] Thus the moon and sun move on their epicycles in a sense opposite to that of the epicycles on their deferents. Each of the planets, however, moves on its epicycle in the same sense as that of the epicycle on its deferent (cf. Proclus, *Hyp.* 154, 27 ff.).

[26] Duhem (1908), p.133 n.1 on Halma (1820), p.151, col.1 lines 7 f. Yet Grynaeus's edition of 1540 already has the negative and indeed provides the same text as that in Manitius: *ἐκ τῶν οὐκ ὄντων ἐν τῇ φύσει* (Grynaeus (1540), p.81).

[27] 'Ou bien ces cercles sont simplement fictifs et idéaux; ou bien ils ont une existence réelle au sein des sphères des astres . . .', Duhem (1908), pp.132–3.

[28] Halma (1820), p.151 col.2 lines 7 f. Proclus' criticism of the astronomers then becomes that they attribute material properties to mathematical conceptions!

[29] Duhem (1908), p.133. He fudges the criticism of the astronomers that follows: 'ils font des échanges entre des corps naturels et des conceptions mathématiques.'

[30] The structure of the argument, with the two alternatives set out with *εἰ μὲν* and *εἰ δὲ*, is, of course, much obscured in Halma's text.

at certain points in the final chapter of the *Hypotyposis*, the main burden of his interpretation of Proclus' position is, nevertheless, one with which we must agree. For this question we have to discuss what precisely Proclus' position was, and unfortunately one can scarcely say his position was *precise*. To understand his point of view in the *Hypotyposis* it is necessary first to consider what he says at the outset of the work, where he explains its purpose:

> The great Plato, my friend, expects the true philosopher at least to say goodbye to the senses and the whole of wandering substance and to transfer astronomy above the heavens and to study there slowness-itself and speed-itself in true number. But you seem to me to lead us down from those contemplations to these periods in the heavens and to the observations of those clever at astronomy and to the hypotheses they devised from these, [hypotheses] which Aristarchuses and Hipparchuses and Ptolemies and such-like people are used to babbling about. For you desire indeed to hear also the doctrines of these men, in your eagerness to leave, so far as possible, nothing uninvestigated of what has been discovered by the ancients in the inquiry into the universe.[31]

He goes on to explain that he had promised to work on this 'in his own fashion' when he had some free time, and that now that he has, he is fulfilling that promise: 'Closing my eyes, for the time being, to those exhortations of Plato and to the expositions themselves of the heavenly movements both of the fixed stars and of the planets which he persuaded us to give the first rank to, I shall proceed to tell you the "absolute" truth as believed on the basis of long and endless arguments by those who love to gaze at the heavenly bodies.'[32]

Proclus thus opens his work with an explicit disclaimer. He cannot here do astronomy in the way that he believes Plato to recommend in the *Republic*, 'transferring astronomy above the heavens' and there studying 'slowness-itself' and 'speed-itself' in 'true number'. What the *Hypotyposis* contains is quite different, because he is led down from such (purely abstract) contemplations to such matters as the periods in the heavens and the observations of the astronomers. As a good Platonist—as he conceives—Proclus often mentions the inexactness of sensible objects.[33] Yet that does not deter him from giving a quite lengthy account of astronomy in the *Hypotyposis*, including not only a full, if in parts inaccurate, statement of current astronomical theories, but also a surprisingly detailed description of the main astronomical instruments and how to use and construct them.[34] He begins with a statement of the ten main problems, such as, for example, the variations in the apparent speeds of the sun,

[31] Πλάτων μὲν ὁ μέγας, ὦ ἑταῖρε, τόνγε ὡς ἀληθῶς φιλόσοφον ἀξιοῖ τὰς αἰσθήσεις χαίρειν ἀφέντα καὶ τὴν πλανωμένην ἅπασαν οὐσίαν οὐρανοῦ τε ὑπεραστρονομεῖν κἀκεῖ τὴν αὐτοβραδυτῆτα καὶ τὸ αὐτοτάχος ἐν τῷ ἀληθινῷ ἀριθμῷ σκοπεῖν. σὺ δέ μοι φαίνῃ κατάγειν ἡμᾶς ἀπ' ἐκείνων τῶν θεαμάτων εἰς τὰς ἐν οὐρανῷ ταύτας περιόδους καὶ τὰς τῶν δεινῶν περὶ ἀστρονομίαν τηρήσεις καὶ τὰς ἐκ τούτων αὐτοῖς μεμηχανημένας ὑποθέσεις, ἃς Ἀρίσταρχοί τε καὶ Ἵππαρχοι καὶ Πτολεμαῖοι καὶ τοιοῦτοί τινες διαθρυλεῖν εἰώθασι. ποθεῖς γὰρ δὴ καὶ τὰς τούτων ἐπιβολὰς ἀκοῦσαι μηδὲν ἀδιερεύνητον κατὰ δύναμιν ἀπολιπεῖν τῶν τοῖς παλαιοῖς ἐξηυπορημένων ἐν τῇ θεωρίᾳ τῶν ὅλων προθυμούμενος (*Hyp.* 2, 1–13). The opening sentence is, of course, an allusion to Plato, *Republic* 529 d.

[32] μύσας ἐν τῷ παρόντι πρὸς τὰς τοῦ Πλάτωνος ἐκείνας παρακελεύσεις καὶ αὐτὰς τὰς περὶ τῶν οὐρανίων κινήσεων τῶν τε ἀπλανῶν καὶ τῶν πλανωμένων ὑφηγήσεις, ἃς ἐκεῖνος ἡμᾶς πρεσβεύειν ἀνέπεισεν, ἔρχομαί σοι λέξων αὐτὴν καθ' ἑαυτὴν τὴν διὰ μακρῶν καὶ ἀπεράντων ἐφόδων πεπεισμένην τοῖς φιλοθεάμοσι τῶν οὐρανίων ἀλήθειαν (*Hyp.* 4, 1–7). The reference to the φιλοθεάμονες (an allusion to *Republic* V) shows that the expression αὐτὴν καθ' ἑαυτὴν τὴν . . . ἀλήθειαν is ironic.

[33] e.g. *In Ti.* i.351 20 ff.

[34] See especially *Hyp.* ch. 3, 42,5–54,12, cf. 4, 128,6–130,26 and ch. 6, 198,15–212,6, and cf. 72,20 ff., 110,3 ff., 120,15 ff.

moon, and planets,[35] and he introduces this by saying that he will first identify the phenomena that caused astronomers to inquire into their causes:

> They correctly hypothesized that the movements of the heavenly bodies must be circular and orderly, even if the circular movement is not the same in all of them, nor unmixed with what is not such [i.e. not circular], yet this too is assuredly orderly. For being borne always in the same way and according to a single formula and in one absolutely self-consistent order would, I suppose, best befit the most divine of visible things, especially for those who postulate that all these things are borne round according to reason. For reason is always the provider of order in all the things of which it has charge. Clinging to this notion, as to a safe stern-cable, they appear with reason already to be vexed at this apparent disorder, seeking which hypotheses would show them that the periods in those circles are accomplished rationally instead of irrationally, and that they are determined by numbers that befit each one instead of being borne round indeterminately and in a disorderly fashion.[36]

Once the problematic phenomena have been set out, the bulk of the *Hypotyposis* consists of a detailed analysis of each of these in turn. In the final chapter he first of all recapitulates the problems and gives their suggested solutions and then ends with the passage Duhem made so much of. It is worth noting, first, that the doubts raised in that passage do not relate to everything that has gone before. The chief question Proclus poses concerns the status of the *epicycles* and *eccentrics*. But not all his discussions of the problematic phenomena depend directly on those hypotheses.[37] More important, it would be wrong to assume that the doubts he expresses about the status of the epicycles and eccentrics apply also to the doctrine that there are *heavenly spheres*—for example a sphere of the fixed stars.[38] Finally his doubts about epicycles and eccentrics are the more understandable when we reflect that—unlike many other late commentators—Proclus knows very well that they are not in Plato.[39]

[35] *Hyp.* 6,12–16,16.

[36] τοῦτο μὲν ὀρθῶς ὑποθέμενοι τὸ τὰς κινήσεις τῶν θείων σωμάτων ἐγκυκλίους δεῖν καὶ τεταγμένας ὑπάρχειν, εἰ καὶ τὸ ἐγκύκλιον οὐ τὸ αὐτὸ ἐν πᾶσιν ἐκείνοις, οὐδὲ ἄμικτον πρὸς τὸ μὴ τοιοῦτον, ἀλλ' οὖν καὶ τοῦτο πάντως τεταγμένον. τὸ γὰρ ἀεὶ ὡσαύτως καὶ καθ' ἕνα λόγον φέρεσθαι καὶ μίαν τάξιν αὐτὴν καθ' ἑαυτὴν ὁμολογοῦσαν πρέποι ἄν που τοῖς θειοτάτοις τῶν φανερῶν μάλιστα τοῖς κατὰ νοῦν ἐκεῖνα πάντα περιάγεσθαι τιθεμένοις· νοῦς γὰρ ἀεὶ τάξεως χορηγός ἐστιν ἅπασιν, οἷς ἂν ἐπιστατῇ. ταύτης δὲ ὥσπερ ἀσφαλοῦς πείσματος ἐξεχόμενοι τῆς ὑπονοίας [καὶ] εἰκότως ἤδη δυσχεραίνειν φαίνονται πρὸς τὴν φαινομένην ταύτην ἀταξίαν [καὶ] ζητοῦντες, τίνες ὑποθέσεις αὐτοῖς ἀντὶ μὲν ἀλόγων κατὰ λόγον ἐπιτελουμένας τὰς περιόδους ἀποφήναιεν <ἐπὶ> τῶν κύκλων ἐκείνων, ἀντὶ δὲ ἀορίστως καὶ ἀτάκτως φερομένων ὡρισμένας ἀριθμοῖς τοῖς προσήκουσιν ἑκάστοις (*Hyp.* 4, 15–6, 5). Note especially ὀρθῶς at 4,15.

[37] Thus in one instance (that of the precession of the equinoxes) he resolves the problem simply by denying that the phenomenon occurs (*Hyp.* 136, 4 ff., 234, 7 ff.).

[38] Thus in *In Ti.* he follows Plato in postulating a system based on spheres of the Same and of the Other (to account for the daily movement of the heavens and the longitudinal movement of each planet on the ecliptic respectively), e.g. *In Ti.* iii.73. 27 ff., 123.20 ff., 146.1 ff., 148.1 ff.: the substance of which the stars and their spheres are composed is discussed at *In Ti.* iii.128, 14 ff. (cf. below p.211 and n.51), cf. e.g. 96.6 f. where he says that the spheres 'fill up' the whole of the heavens. Cf. also the references, at *Hyp.* 236, 18 and 238, 1, to the spheres in which the epicycles or eccentrics are fixed, in his account of the difficulties facing those hypotheses.

[39] This is clear from e.g. *In Ti.* iii.56.31 ff., 76.28 f., 96.19 ff. and *In R.* ii.214, 6 ff., 227.23 ff. At *In Ti.* iii.146.14 ff., especially, epicycles and eccentrics are again criticized as involving *either* little circles that move in a direction opposite to that of the spheres on which they are located (which will destroy the continuity of the spheres or introduce into the heavenly bodies circles belonging to another nature, φύσις) *or* movement round different centres, and

Although Proclus evidently has his over-all, and as he believes Platonic, quarrel with any kind of 'phenomenal' astronomy, he certainly does not object to all phenomenal astronomical hypotheses equally. Thus he shows no signs of wavering on the question of the earth being at rest in the centre of the heavens.[40] Nor, despite Duhem and Wasserstein, can there be any doubt about his endorsing the view that the observed courses of the heavenly bodies must, so far as possible, be explained in terms of *circular* and *orderly* movements.[41] The problem was, of course, to account for the evident complexity of the movements of the planets, sun, and moon. His dilemma is acute: he knows there is no Platonic authority for eccentrics and epicycles, yet how can the complex movements of the planets, sun, and moon be explained without them? In one mood he reiterates the Platonic thesis that sensible objects are unstable, adding a contrast between human beings—who must be content with approximations to the truth—and the gods—who alone grasp the truth itself.[42] Then again, in his accounts of Plato's astronomy, especially, he certainly acknowledges that the movements of the planets, sun, and moon are, to some extent at least, irregular. In *In Ti.* iii.56, 31 ff., for example,[43] he interprets Plato in the *Republic* to be saying that while the fixed stars are both regular and orderly, and sublunary things are both irregular and disorderly, the planets are intermediate between them, irregular but orderly, and in that work he attributes the complexity (ποικιλία) of the planet's motions to their souls.[44] Yet Proclus sometimes appears to want more

Proclus objects to the latter on the dynamical grounds that it 'does away with the common axiom of the physicists', namely that every simple movement is either round the centre of the universe or to or from that centre.

[40] See e.g. *Hyp.* 28, 7 ff. and 21 ff., *In Ti.* iii.137.6 ff.

[41] This is clear from *Hyp.* 4.15 ff. (quoted above, n. 36). Elsewhere in *Hyp.* he says that the assumption of the regularity of the movement of the heavenly bodies is the ἀρχή of the whole of astronomy (28.15–20), that it is accepted by all astronomers that the heavenly bodies move in an orderly fashion since they are 'far from mortal troubles' (18.17–25—note the first person plural at 18.22—cf. 26.7 ff.), and that the astronomers claimed to give an account of the phenomena that is in accord with the 'incontrovertible assumptions concerning the heavenly bodies' that they all move regularly, and that their irregularity is apparent and not true, the result of the combination of their various movements (146.4 ff.). Again in his accounts of Plato's astronomy Proclus assumes the orderliness (τάξις) of the movements of all the heavenly bodies (e.g. *In Ti.* iii.55. 11 f., 57.2 f., 90.22 ff., 96.21 ff., 127.7 ff., 146.2, 147.12, *In R.* ii 230.22 ff., 231.3 ff.: at *In Ti.* iii.117.19 f. he says it is μὴ θέμις to consider their souls to be irrational); at *In Ti.* iii.56.12 ff. he asserts that not only the fixed stars, but also the planets have a *single, regular* (ὁμαλός) unceasing movement, even though he later qualifies this by introducing an element of irregularity in their movements (see below, nn.43 and 44); and he criticizes astronomical hypotheses on the grounds that they are 'far removed from the *simplicity* of divine things' (*In Ti.* iii. 56.29) although the 'simplicity' of the planets includes multiplicty (πλῆθος) (*In Ti.* iii.127.9 ff.).

[42] e.g. *In Ti.* i.352.5 ff., 28 ff., 353.22 ff. Yet at *In Ti.* iii.122.10 ff. he insists that the heavenly region is as immaterial as it is possible for any sensible object to be—that is, that it is free from any unstable, ἀνέδρασος, matter, cf. 122.18 ff.—and that it is free from the accidental.

[43] Cf. also *In Ti.* iii.67.2 ff. (the movements of the planets are regular ἑαυταῖς, but irregular πρὸς ἀλλήλας), 79.12 ff., 96.21 ff., 147.9 ff., cf. *In R.* ii.230.15–22, 234.26–235.3.

[44] e.g. *In Ti.* iii.147.2 ff. The planets undergo a complex of movements, (a) in longitude (κατὰ μῆκος), (b) in latitude (κατὰ πλάτος), (c) in 'anomaly' (κατὰ βάθος, the motion in anomaly, being represented by an epicycle, produces variations in the distance of the planet from the earth, i.e. 'in depth') and (d) axial rotation. The resultant movement of (a), (b), and (c) is spiral—a mean between purely circular, and rectilinear, movement. See e.g. *In Ti.* iii.76.30 ff., 78.29 ff., 95.34 ff., 128.8 ff., 148.5 ff., *In R.* ii.232.24 ff., 233.16 ff.

than that—to want a determinate and detailed account of their movements.[45] In that mood, even though he is critical of epicycles and eccentrics, he comes close to accommodating himself to them in certain passages. There are, then, I suggest, certain vacillations in the line that Proclus adopts in the texts in which he comes closest to confronting the problem directly.

This can be seen by juxtaposing some of the passages in question. Take first the continuation of a text from the first chapter of the *Hypotyposis* to which I have already referred.

> I shall proceed [he has just said] to tell you the 'absolute' truth as believed on the basis of long and endless arguments by those who love to gaze at the heavenly bodies. Nor shall I be able to restrain, here, my usual testing of opinions, though I shall use it sparingly, since I believe the refutation of the hypotheses will be obvious to you from their very exposition—the hypotheses in which they unfold, with pride, the whole of the theory which they propose.[46]

That looks like a straightforward and outright condemnation, as also may *In Ti.* iii.56, 28 ff.; for instance, where he says: 'Nor do these hypotheses [particularly epicycles and eccentrics] have any probability, but some are far removed from the simplicity of divine things, and others, fabricated by more recent astronomers, suppose the motion of the heavenly bodies to be as if driven by a machine.' Yet we may contrast with this the conciliatory tone of the beginning of chapter 7 of the *Hypotyposis* (212.9 ff.): 'Since we said in the introduction from what [starting-points] especially those who love to gaze at such things have been led to investigate these things, come now, in each case, let us bring forward the resolutions of these [difficulties] from these hypotheses, approving [*ἐγκρίνοντες*] some of what they say, but rejecting [or testing, *βασανίζοντες*] other parts.' Even in the concluding section of the chapter (238.21 ff.) he criticizes the astronomers for, among other things, not stating *ὅσα δυνατὸν προσευπορῆσαι*, those things that it is possible to grasp, the problems that can be resolved, and at the very end of the chapter he again appears to hedge his bets in the final sentence of the work: 'Yet one must know this much, that among all the hypotheses these are the simplest and most fitting for heavenly bodies, and that they have been contrived to discover the manner of the movements of the stars that are really moved as they appear, so that the measure of what is in them may be grasped.'[47] Finally, in *In Ti.* too he says at one point[48] that epicycles and eccentrics are not in vain, since they enable one to resolve complex movements into simple ones.

There are, then, certain unresolved tensions in Proclus' position. There is evidence, in both *Hyp.* and *In Ti.*, of his desire for a simple account, not just of

[45] Cf. the demand at *Hyp.* 238.13 ff. to know the causes of the planes and distances, 'I mean the true causes, such that when the soul saw them especially it might cease all its travail.'

[46] *Hyp.* 4.5–12. The text continues from that quoted above, n.32: *οὐδὲ ἐνταῦθα μὲν ἐπέχειν δυνάμενος τὴν εἰωθυῖαν ἐμοὶ τῶν δογμάτων βάσανον, σπανίᾳ δὲ ὅμως αὐτῇ χρώμενος, ἐπεὶ καὶ σοὶ καταφανῆ πέπεισμαι δι' αὐτῶν ἔσεσθαι τῶν λεγομένων τὸν τῶν ὑποθέσεων ἔλεγχον, ἐφ' αἷς ἐκεῖνοι καλλωπιζόμενοι πᾶσαν ἐξελίττουσι τὴν προκειμένην αὐτοῖς θεωρίαν.*

[47] *Hyp.* 238.22 ff. *πλὴν τοσοῦτον ἰστέον, ὅτι πασῶν τῶν ὑποθέσεων αἱ ἁπλούστεραι καὶ οἰκειότεραι θείοις σώμασιν αὗταί εἰσι, καὶ ὅτι ἐπινενόηνται πρὸς εὕρεσιν τοῦ τρόπου τῶν κινήσεων τῶν ἀστέρων κατ' ἀλήθειαν οὕτω κινουμένων, ὥσπερ καὶ φαίνονται, ἵνα γένηται καταληπτὸν τὸ μέτρον τῶν ἐν αὐτοῖς.*

[48] *In Ti.* iii.148.23 ff. At *In Ti.* iii.65.26 ff., too, his own solution to the problem of the sun's movement appears to incorporate the epicyclic hypothesis. Cf. also *In R.* ii.233.21 ff.

the movement of the fixed stars, but also of those of the planets, sun, and moon.[49] Moreover he knows, or at least the end of the *Hypotyposis* suggests that he knows, that the *simplest* hypotheses are eccentrics and epicycles.[50] Yet there are problems, not just the lack of Plato's authority, but also the question we began with, are they mere contrivances or do they have real existence? *Both* present difficulties. But when he sets out those difficulties, it is not that he intends this as a *reductio* argument, but rather as a genuine statement of ἀπορίαι. We should now reconsider the nature of the difficulties he specified. Against the assumption that the epicycles and eccentrics are real he argues by pointing to complications (such as that the continuity of the spheres is destroyed) that are themselves realist (p.206 above). But if the epicycles and eccentrics are simply objects of thought, then one has unwittingly slipped over into mathematics and one cannot account for physical motions by appealing to things that do not exist in nature. Now why should Proclus be dissatisfied with that solution? Surely the chief problem, on that way of taking the epicycles and eccentrics, is simply that *a merely instrumentalist account will not do.* So whilst he argues against the realist way of taking these hypotheses on realist assumptions, he argues against the instrumentalist way of taking them *also* on realist assumptions. Nor is that surprising when we reflect that in *In Ti.* too his standpoint is a realist one when he discusses, for example, what the stars and the spheres in which they are carried round are made of and concludes that both consist of a special kind of fire.[51]

Duhem's interpretation of Proclus, I conclude, is open to criticism on three grounds. First he speaks quite generally of Proclus' view on astronomical hypotheses. But what is at issue in the key passage at the end of *Hyp.* ch. 7 is not the status of astronomical hypotheses in general, but only that of epicycles and eccentrics. Elsewhere, Proclus shows no inclination to consider as mere objects of thought such assumptions as that the earth is at rest or that the movement of the heavenly bodies is, in general, circular and orderly. Secondly, as far as the particular text discussing epicycles and eccentrics is concerned, Duhem represents Proclus opting for the instrumentalist view, when in fact he criticizes both that and the realist alternative. Thirdly, the assumptions at work in both cases in that text turn out to be realist ones.[52]

II

Now Proclus is not exactly one of the leading lights in the history of Greek astronomical theory: rather he is a moderately intelligent summarizer and critic

[49] e.g. the reference to the simplicity of divine things at *In Ti.* iii.56.29 and 127.9 ff., and that to a single regular movement at 56.12 (see n.41 above). At *Hyp.* 18.2 ff. the Pythagorean preference for the simplest hypotheses, on the grounds that they are more fitting for divine bodies, is endorsed by Proclus himself and in that work he distinguishes between the eccentric and the epicyclic hypothesis on the grounds of simplicity at 76.17 ff. and 148.18.

[50] Cf. also *Hyp.* 198.6 ff. where he says he has given an outline account of the hypotheses of those who appear to have furthered (κατωρθωκέναι) the inquiry concerning the heavenly bodies most.

[51] *In Ti.* iii.128.14 ff., 28 ff., cf. also 113.20 ff., 114.15 ff.

[52] Thus his fundamental complaint against epicycles and eccentrics is not that they do not provide a means of calculating the positions of the heavenly bodies ('save the phenomena' in Duhem's understanding of that phrase)—on the contrary, to judge from, for example, *In Ti.* iii.148.23 ff., he is prepared to use them in that capacity. Rather it is that these models do not yield—what Proclus ultimately demands—a consistent physical account.

of received views. Yet he does at least state and discuss a distinction between the view that epicycles and eccentrics are mere objects of thought and the view that they have real existence in the spheres in which they are fixed, and that is rare enough, indeed quite exceptional, in ancient texts of whatever period.[53] The other writers whom Duhem and others cite yield no passage in which the general contrast between 'instrumentalist' and 'realist' astronomy is debated. There are, of course, discussions of, for example, the distinction between φυσική and μαθηματική beginning with Aristotle's in *Physics* B ch. 2, which itself provided the starting-point for other analyses, and Duhem, for one, certainly took these texts to be relevant to the issue and indeed to provide evidence to support his general view. Once again, however, we may have doubts.

The chief text is the famous passage in Simplicius, *In Ph.* 291.21 ff., where he quotes Alexander who in turn quotes Geminus' summary of Posidonius' *Meteorologica.* Duhem, who quotes the text at length, hails it as the most exact ancient Greek definition of the roles of the astronomer and the physicist, and he takes the distinction between those two to be one between two independent, autonomous, and unconnected inquiries. His view of how that distinction was interpreted by the Greeks comes out very clearly in a passage where he summarizes the Greek achievement before turning to consider Arabic astronomy:

> Leur génie logique et métaphysique s'était appliqué . . . à l'examen des compositions de mouvements imaginées par les astronomes; après quelques hésitations, il s'était refusé à regarder les excentriques et les épicycles comme des corps doués, au sein des cieux, d'une existence réelle; il n'avait voulu y voir que des fictions de géomètres, propres à soumettre au calcul les phénomènes célestes; pourvu que ces calculs s'accordassent avec les observations, pourvu que les hypothèses permissent de sauver les apparences, le but visé par l'astronome était atteint; les hypothèses étaient utiles; seul le physicien eût été en droit de dire si elles étaient ou non conformes à la réalité; mais, dans la plupart des cas, les principes qu'il pouvait affirmer étaient trop généraux, trop peu détaillés pour l'autoriser à prononcer un tel jugement.[54]

The astronomer, therefore, on this reading, is not merely distinct from the physicist, he is not concerned with physical problems at all. Provided the hypotheses allowed the appearances to be saved, his job was done. The subjunctive used as a conditional in Duhem's penultimate sentence ('eût été en droit': only the physicist *would have had* the right) is especially remarkable, as also is Duhem's conclusion that in the majority of cases the physicists' principles were too general to authorize him to pronounce such a judgement.

But if we turn to the passage in Geminus or to that in Aristotle (on which Simplicius was commenting at that point), the contrast drawn between astronomy and physics is, in certain respects, crucially different from Duhem's version. In Aristotle, as is well known, the mathematician differs from the physicist in that he deals with surfaces, volumes, and so on in abstraction from physical objects. Optics, harmonics, and astronomy are introduced as 'the more physical of the μαθήματα': whereas geometry investigates physical lines but not *qua* physical, optics investigates mathematical lines but not *qua* mathematical, but *qua* physical. By implication astronomy does the same. When Aristotle first raises the question of whether astronomy is or is not a part of physics, he says it is absurd if the physicist should be supposed to know what the sun and moon are,

[53] That is, in the context of astronomy. The notion of things that exist merely as objects of thought had, of course, long been familiar in other, philosophical, contexts, notably in debates on the nature of forms.

[54] Duhem (1908), p.277.

but not to know any of their essential attributes, and he remarks that in point of fact those who write on nature do discuss such questions as the shape of the moon and sun and whether the earth and the cosmos are spherical.[55]

The upshot of this passage in Aristotle is that astronomy *ἐπαμφοτερίζει*: it is one of the more physical branches of mathematics, and some of its subject-matter is dealt with also by the physicist. Geminus' position, in the passage quoted by Simplicius, is similar, though he is concerned more directly with the relationship between astronomy (not mathematics in general) and physics. It is the job of physics to deal with the *οὐσία* of the heaven and the stars, their *δύναμις* and quality, their coming-to-be and destruction: it is even in a position to prove facts about their size, shape, and arrangement. Astronomy, on the other hand, 'does not try to speak about any such kind of thing. It proves the arrangement of the heavenly bodies by declaring that the heaven is truly a cosmos. It speaks about the shapes and sizes and distances of the earth, sun, and moon, about eclipses and conjunctions of stars, and about the quality and quantity of their movements . . . It needs, accordingly, arithmetic and geometry.'[56] Geminus proceeds to give instances of the same point proved both by the astronomer and by the physicst (that the sun is of great size, and that the earth is spherical—Aristotle's example). The two approaches will differ, the physicist arguing from the *οὐσία* and the *δύναμις*, the astronomer from the properties of figures and magnitudes. When he proves facts from external properties, the astronomer is not qualified to judge of the cause, as when, for instance, he declares the earth or the stars to be spherical. 'Sometimes he does not even seek to grasp the cause' (*In Ph.* 292.12 f.), as when he speaks about eclipses. 'At other times he inquires by means of hypothesis, and exhibits certain ways, by the assumption of which the phenomena will be saved'—and the examples given are eccentrics and epicycles. Then: 'it will be necessary to go into in how many ways it is possible for these appearances to be accomplished so that the theory concerning the wandering stars may fit the explanation of causes according to the possible method.'[57] After mentioning the views of a 'certain Heraclides' to the effect that the earth moves in a certain way (a famous crux which fortunately does not concern us here), Geminus says that it is not the business of the astronomer to know which bodies naturally rest and which move, but he introduces hypotheses . . . and considers from what hypotheses the appearances in the heaven will follow. But he must take his *ἀρχαί* (starting-points or principles) from the physicist, namely that the movements of the stars are simple and regular and ordered.[58]

Here too, then, as in Aristotle, the same problem, such as the shape of the earth, can sometimes be dealt with by both the astronomer and the physicist: the distinction will be between the kinds of argument they use. Geminus further tells us (1) that in some cases the astronomer does not even seek to grasp the cause, (2) it is his business to say in how many ways it is possible to save the phenomena, (3) it is *not* his business to know which bodies naturally move and which are naturally at rest, but (4) he must take his starting-points or principles

[55] Aristotle, *Ph.* 193 ^{b} 22–194 ^{a} 12.

[56] Simplicius, *In Ph.* 291.26 ff.

[57] Simplicius, *In Ph.* 292.18–20. *δεήσει τε ἐπεξελθεῖν, καθ' ὅσους δυνατὸν τρόπους ταῦτα ἀποτελεῖσθαι τὰ φαινόμενα, ὥστε ἐοικέναι τῇ κατὰ τὸν ἐνδεχόμενον τρόπον αἰτιολογίᾳ τὴν περὶ τῶν πλανωμένων ἄστρων πραγματείαν.*

[58] Simplicius, *In Ph.* 292.26 f. *ληπτέον δὲ αὐτῷ ἀρχὰς παρὰ τοῦ φυσικοῦ, ἁπλᾶς εἶναι καὶ ὁμαλὰς καὶ τεταγμένας κινήσεις τῶν ἄστρων . . .*

from the physicist. (1), (2), and (3) enable one not merely to distinguish between, but to contrast, astronomy and physics. So far as these statements go, Duhem's view might seem to be the one we should prefer. Yet the introduction of the fourth point makes a crucial difference.[59] (2) certainly says that the astronomer should consider in how many different ways the phenomena can be saved: but (4) subordinates astronomy to physics in this respect, that the astronomer has to take his ἀρχαί from physics, for example the principle that the movements of the stars are simple, regular, and ordered. Geminus, following Aristotle, distinguishes, even contrasts, astronomy and physics: but he does *not* say it is legitimate to do astronomy *divorced from* physics. On the contrary, Geminus' position is clearly that astronomy *presupposes* physics. The problem here is not that Duhem mistranslates the Greek. He writes, quite correctly, 'c'est du physicien qu'il tient ses principes.'[60] It is rather that he ignores the point in question in his discussion. Where Duhem argues that Greek astronomy was concerned purely with the mathematics of their problems, to the exclusion of physics, it is clear that Geminus links that mathematical study to physical assumptions. Nor are there grounds, in the Geminus passage at least, for the subjunctive used as a conditional ('eût été en droit') in which Duhem implies that Greek physicists were not, in general, in a position to provide what they saw as sound and adequate principles on which astronomy could be based.

Two of the main authorities cited by Duhem, Proclus, and Geminus, turn out to be frail supports indeed, and the same goes for our source for Geminus, Simplicius himself. Like his contemporary, Philoponus,[61] Simplicius points out critically that the astronomers have not demonstrated their hypotheses and he knows that the same phenomena were sometimes explained by different hypotheses.[62] But that is not to make him an instrumentalist. What he considers (in Duhem's terms) as 'fictitious' or 'not real' are simply the irregularities of the movements of the sun, moon, and planets. The contrast is between those irregularities—which are merely *apparent*—and the *true* circular, orderly, and regular motions in terms of which (as Plato had suggested)[63] those irregularities are to be explained.[64] Simplicius' realist assumptions come out often enough in his discussion of astronomical problems, for example in his reference to the problem of the void left between the spheres in his account of the difficulties that the eccentric hypothesis faces,[65] in his own discussion of what is in between

[59] Cf. also the reference to the heavens being a true κόσμος at Simpl. *In Ph.* 291.27 f.

[60] Duhem (1908), p.122 lines 35 f.

[61] Philoponus, *De Opificio Mundi* iii ch. 3, 114.24 ff. At iii ch. 4, 117.21 ff. he implies that the astronomers attempted to give a physical account of the phenomena.

[62] Simplicius, *In Cael.* 488.25 ff., 492.25 ff. But at 32.29 ff. he dissents from Philoponus to say it is no cause for reproach (ἔγκλημα) that the astronomers save the same appearances by different hypotheses. Cf. further below, pp.217 f., on Ptolemy and Hipparchus.

[63] Simplicius is, of course, our chief evidence for this, e.g. *In Cael.* 488.19 ff., citing Sosigenes, who himself may have been following Eudemus.

[64] e.g. *In Cael.* 422.3 ff., 427.10 ff. Even in 488.10 ff. when Simplicius says that the 'true account' not only does not accept stations, retrogradations, and so on (even if they appear thus) but also 'does not admit the hypotheses' (eccentrics, epicycles, and reacting spheres) 'as being such', what he has in mind is Plato's stipulation that the motions of the sun, moon, and planets should be interpreted as *simple* (ἁπλᾶς, *In Cael.* 488.13, cf. μίαν ἀεὶ κύκλῳ, Plato, *Laws* 822 a, a passage to which Simplicius goes on to refer, *In Cael.* 489.5 ff.): he recognizes, however, that astronomers had had to be content interpreting the motions of the sun, moon, and planets in terms of regular, uniform, and circular movements (488.14 ff.).

[65] *In Cael.* 510.15 ff.

the stars,[66] and in his recognition that one hypothesis might be preferred to another on the grounds that it postulates fewer heavenly bodies.[67] Finally his lengthy comments on Aristotle's doctrine of the fifth element presuppose that both the stars and the spheres to which they are attached are corporeal entities, σώματα, consisting of a substance whose special property it is to move in a circle.[68]

But if the principal commentators cannot be said to support Duhem's overall thesis, it is now time to turn to his interpretation of the positions of the main astronomical theorists themselves. Of course the chief problem that confronts us is that although we have our Ptolemy, we have none of Apollonius' astronomy and very little of Hipparchus and Aristarchus. We have Aristotle's *De Caelo* and *Metaphysics* Λ ch. 8, but not Eudoxus or Callippus. So we are bound to admit that much remains indeterminate in this question. Yet if we can begin where the evidence is solid, we have, at least, our Ptolemy.

No one can doubt that the second book of the *Planetary Hypotheses* with its tambourines or segments of spheres on which the planets are carried is attempting a realist account,[69] that is an account of the actual arrangement of physical objects in the heavens. But given that Halma only edited and translated the section of book I that is extant in Greek, and that a section of what is extant only in Arabic was omitted from Nix's German translation,[70] it might be thought that Duhem had some excuse for representing Ptolemy as an instrumentalist in his articles in 1908. But the situation is more complicated. For one thing Duhem seems to ascribe several physical assumptions to Ptolemy. He began his discussion: 'Ptolémée attribue à chacun des astres errants un orbe d'une certaine épaisseur, contigue aux orbes de l'astre qui le précède et de l'astre qui le suit. Entre les deux surfaces sphériques, concentriques au Monde, qui délimitent son orbe, la planète se meut . . .'[71], and this is strange. He cited *Syntaxis* ix ch. 1 as his authority for this, but that chapter concerns merely the order and relative distances of the planets, and says nothing about the nature and disposition of their spheres, let alone about two spherical surfaces which delimit the orbit of the planet and between which it moves.[72] Yet whatever the source of Duhem's remark, the idea that Ptolemy's astronomy presupposes physical considerations is played down in the sequel. Duhem concentrates, rather, on such texts as *Syntaxis* xiii ch. 2 and iii ch.4, interpreting these as support for his general thesis about Greek astronomy,[73] and indeed a modern Duhemian might still want to argue that Ptolemy was a sound instrumentalist in the *Syntaxis* even though he mistakenly adopted a naïve realist position in the *Planetary Hypotheses.* But to

[66] *In Cael.* 461.17 ff., cf. also 443.27 ff., 451.10 ff.

[67] *In Cael.* 509.16 ff.

[68] *In Cael.* 435.12–438.26, cf. 428.26 ff., 448.6 ff., 455.29 ff., 477.5 ff., 509.30 ff.

[69] See especially ch. 6, 117.8 ff.

[70] Nix (1907). The complete Arabic text has subsequently been edited, and the missing section of book i translated, by Goldstein (1967).

[71] Duhem (1908), p.129.

[72] He later correctly noted, however, that Ptolemy refers to the homogeneity and transparency of the medium of the heavenly region in *Syntaxis* xiii ch. 2, ii.533.1–10; Duhem (1908), pp.130 f.

[73] e.g. 'il faut bien se garder de croire que ces constructions mécaniques aient, dans le Ciel, la moindre réalité' (Duhem (1908), p.131). Here as elsewhere it is not clear whether by 'constructions mécaniques' Duhem means the astronomical hypotheses, or actual scale models. On the previous page he ascribes to Ptolemy the view that it is folly to try to represent the movements of the heavenly bodies in mechanical devices made of *wood* or *metal*: yet in *Syntaxis* xiii ch. 2 the devices (ἐπιτεχνήματα) that Ptolemy says may be found troublesome are simply the astronomical hypotheses themselves.

that one must say that although most of the *Syntaxis* is undoubtedly taken up with solving purely mathematical problems, the whole discussion is set very firmly in the framework of certain physical assumptions. The two chief instances are (1) the use of physical arguments, relating to αἰθήρ, in the proof of the sphericity of the heavens in i ch.3,[74] and (2) the fact that the two main arguments in i ch. 7 for the absolute immobility of the earth are both physical, namely the doctrine of natural places and the absence of observed centrifugal effects on the earth's surface.[75]

What has impressed modern commentators is the problem that arises from the values that Ptolemy adopts for the diameter of the epicycle and deferent of the moon, values from which it follows that the apparent angular diameter of the moon should vary by about a factor of 2, when the observed variation is much smaller.[76] But the conclusion drawn from this by Dreyer, for example, when he says that 'it had now become a recognized fact, that the epicyclic theory was merely a means of calculating the apparent places of the planets without pretending to represent the true system of the world',[77] is simply *not* drawn by Ptolemy himself. He merely passes over the problem in silence. Even in xiii ch.2, when he asks us not to be dismayed by the complexity of the hypotheses that he has to use, his standpoint is not one of indifference to the question of whether his devices represent the 'true system'. Why, one might ask, should he worry over purely mathematical complexity? One might suggest that the source of his concern is, in part at least, the implications of those complexities when translated into physical terms. Certainly the justification that he offers for the hypotheses he adopts is one that appeals to the difference between the substance of the heavens and the sublunary region. At *Syntaxis* xiii ch.2, ii.532.14 ff., he says:

> It is not fitting to compare human things with divine ones,[78] nor to form beliefs concerning such great things from examples that are so unlike them. For what could be more unlike than those things that are eternal and unchanging and those that are never unchanging, or those that can be hindered by anything and those that cannot be hindered even by themselves? . . . For provided each of the appearances is saved as a consequence of the hypotheses, why should it still seem strange to anyone that such complications can come about in the movements of the heavenly bodies, when their nature is such as to offer no hindrance, but is exactly fitted to yield and give way to the natural movements of each of them (even if the movements happen to be contrary) so that they can all penetrate and shine through absolutely all the fluid media.

Thus he does not defend his hypotheses *solely* on the grounds that they save the phenomena: rather he adduces physical arguments from the nature of the sub-

[74] The argument is that the heavens are composed of the finest and most homogeneous element, αἰθήρ: since the surfaces of homogeneous bodies will themselves be homogeneous, and the most homogeneous solid figure is the sphere, we may suppose that the αἰθήρ is spherical, *Syntaxis* i ch. 3, i.13.21 ff.

[75] *Syntaxis* i ch. 7, i.21.14 ff., 24.14 ff.

[76] Indeed the actual values he assigns to the least and greatest distances of the moon in the *Planetary Hypotheses* (i part 2, ch. 3, Goldstein (1967), p.7, cf. *Syntaxis* v chs. 13–18) are 33 earth radii and 64 earth radii respectively, ignoring fractions. Cf. e.g. Neugebauer (1957), pp.195 f., and Copernicus, *De Revolutionibus* iv ch. 2.

[77] Dreyer (1906), p.196.

[78] The importance of Ptolemy's reference to the *divinity* of the objects studied by astronomy should not be underestimated. The famous epigram ascribed to him (*Anth. Pal.*, ix.577) suggests, if genuine, a more than merely conventionally religious element in the spirit with which he conducted his investigations and *Syntaxis* i ch. 1, i.7.17 ff., clearly states that contemplation of the good order and proportion of divine things promotes good order in the soul.

stance of the heavenly region (which is eternal, unchanging, homogeneous, and transparent) to support the possibility of the types of motion he proposes.[79] Here too, then, the influence of his underlying realist assumptions is apparent.

Apart from xiii ch.2, the other main passage in the *Syntaxis* that Duhem took instrumentally is iii ch.4, where Ptolemy observes, in connection with his theory of the sun in particular, that the appearances may be saved on either an epicyclic or an eccentric hypothesis. The recognition of the equivalence of these two models is, indeed, represented by Duhem as good evidence that all that ancient astronomers were concerned with was the mathematics of the problem, not the physics. That conclusion is, however, premature. What Ptolemy actually says, after noting that both models can be used to account for the appearances in relation to the sun, is that the eccentric hypothesis is to be preferred because 'it is simpler and effected by one, not two movements.'[80] That is not as clear as it might be, since the 'simplicity' in question might be either mathematical or physical or both. The issue would have been settled if Ptolemy had said either that the eccentric is superior merely because it is easier to calculate with, or that it is preferable because it requires fewer heavenly bodies.[81] But the reference to one, not two movements would appear to be compatible with either type of concern, and if that is the case, one should hesitate before concluding that Ptolemy has in mind mathematical considerations *alone*. That is, no doubt, to some extent a matter of debate. But the fundamental point remains that to represent Ptolemy in general as interested purely in the mathematics of his problems cannot be right given first the appeal to physical arguments in i chs. 3 and 7 of the *Syntaxis* and second the straightforwardly realist account offered in the second book of the *Planetary Hypotheses*.[82]

But Ptolemy aside, how did other ancient astronomers react to the equivalence of the epicyclic and eccentric hypotheses, a feature which—as is now generally agreed[83]—was probably known and demonstrated by Apollonius himself? So far as Apollonius' own position goes, we simply have no evidence at all. But Duhem used a passage in Theon of Smyrna to suggest that Hipparchus' response, at least, contributed to the divorce of mathematics from physics in Greek astronomy. The information we have from Theon is meagre enough. First in ch.26 he says: 'Hipparchus says that it is worthy of mathematical[84] attention to see the reason why the same results appear to follow from such widely differing hypotheses, that of the eccentric circles, and that of the concentric, epicyclic ones.'[85] Then in ch.34, when, following Adrastus, he has shown that each of the two hypotheses can be represented as the *per accidens* consequence of the other, he goes on:

> Seeing this, Hipparchus praised the epicyclic hypothesis as being his own, saying that it is more plausible that all the heavenly bodies should lie symmetrically with regard to the centre of the universe and be joined together similarly. Yet since he was not sufficiently supplied from physics, not even he recognized exactly which of the planetary motions is according to nature and thus a true motion, and which is accidental and [only] apparent.[86]

[79] I am grateful to Professor G. J. Toomer for having emphasized this point to me.

[80] *Syntaxis* iii ch. 4, i.232.14–17. *εὐλογώτερον δ' ἂν εἴη περιαφθῆναι τῇ κατ' ἐκκεντρότητα ὑποθέσει ἁπλουστέρᾳ οὔσῃ καὶ ὑπὸ μιᾶς, οὐχὶ δὲ ὑπὸ δύο κινήσεων, συντελουμένῃ*. Cf. Duhem (1908), pp.131 f.

[81] Cf. Simplicius, *In Cael.* 509.16 ff., noted above, n. 67.

[82] Although as noted above, p.215, Duhem began by noting some interest in physical principles on Ptolemy's part, he subsequently represents Ptolemy as a pure instrumentalist, e.g. (1908), p.284.

[83] See e.g. Neugebauer (1959), pp.5–21.

[84] *μαθηματικῆς*: a term which does not, of course, necessarily mean 'mathematical' as opposed to 'physical'.

[85] *Expositio rerum mathematicarum* 166.6 ff., cf. also ch. 32, 185.17.

[86] *Exp. rer. math.* 188.15 ff. *ὅπερ καὶ συνιδὼν ὁ Ἵππαρχος ἐπαινεῖ τὴν κατ'*

Duhem, whose translations here were, in the main, accurate enough,[87] drew some drastic conclusions from the latter passage: 'En prouvant que deux hypothèses distinctes pouvaient s'accorder *par accident* et sauver également toutes les apparences du mouvement solaire, Hipparque a grandement contribué à délimiter exactement la portée des théories astronomiques.' That 'delimitation' becomes clear in the outcome, where, referring now to Theon, Duhem wrote: 'Ces propositions mettent en évidence, selon lui, l'impossibilité où se trouve l'astronome de découvrir l'hypothèse vraie, celle qui est conforme à la nature des choses.'

One may first object that the passage that Duhem goes on to quote as giving Theon's view on the subject is in fact one of his frequent quotations from Adrastus.[88] It was Adrastus who thought that the disagreement among the mathematicians was shown up as absurd because both hypotheses save the phenomena. Yet Theon himself did not believe that to be the end of the matter. On the contrary chapters 32 ff. are devoted to establishing that there is *one* correct account. Although he recognizes that the two hypotheses are mathematically equivalent, one account is the true natural, *κατὰ φύσιν*, one, the other merely *per accidens*, *κατὰ συμβεβηκός*. The natural account turns out to be one in which the epicycle is interpreted as a great circle on a solid sphere, this solid sphere being imagined as carried round within two hollow spheres.[89] It is only possible to say, as Duhem says, that Theon believed that the astronomer cannot discover the true hypothesis, by quoting a passage from Theon's preliminary aporetic discussion, before he came to give his own solution. Moreover Theon is not only a naïve realist himself, but he also represents Greek astronomy as a whole as founded on physics. This comes out clearly in a passage not mentioned by Duhem in which Theon contrasts Babylonian and Egyptian astronomy with Greek in just this respect: the former were merely arithmetical and geometrical, but incomplete because lacking *φυσιολογία*, while the Greeks included the latter.[90] Finally at the end of the treatise Theon quotes Dercyllides to the effect that in astronomy certain principles must first be agreed, and these principles turn out to include not merely the assumption that the cosmos is orderly, but also which bodies are in movement and which at rest.[91]

But then what about Hipparchus? Here Theon may well be a very unreliable witness: we must bear in mind that he attributes to Hipparchus a preference for the epicyclic hypothesis which is precisely the hypothesis that he, Theon, prefers. But so far as what Theon says goes, the reason he gives for Hipparchus' prefer-

ἐπίκυκλον ὑπόθεσιν ὡς οὖσαν ἑαυτοῦ, πιθανώτερον εἶναι λέγων πρὸς τὸ τοῦ κόσμου μέσον πάντα τὰ οὐράνια ἰσορρόπως κεῖσθαι καὶ ὁμοίως συναρηρότα· οὐδὲ αὐτὸς μέντοι, διὰ τὸ μὴ ἐφωδιάσθαι ἀπὸ φυσιολογίας, σύνοιδεν ἀκριβῶς, τίς ἡ κατὰ φύσιν καὶ κατὰ ταῦτα ἀληθὴς φορὰ τῶν πλανωμένων καὶ τίς ἡ κατὰ συμβεβηκὸς καὶ φαινομένη.

[87] Duhem (1908), pp.119 f. (Theon's expression *διὰ τὸ μὴ ἐφωδιάσθαι ἀπὸ φυσιολογίας*, 188.19 f., would seem to mean 'because he was not sufficiently supplied from physics', i.e. with data or principles or both, rather than Duhem's vague 'ne connaissant pas suffisamment la Physique').

[88] See *φησί* at *Exp. rer. math.* 154.12; cf. the reference to Adrastus at 151.20.

[89] See especially *Exp. rer. math.* 181.12 ff., 186.12 ff. Cf. also the rejection of eccentrics as being remote from what is 'according to nature' and rather 'per accidens' in ch. 34, 188.13–15.

[90] *Exp. rer. math.* 177.9–178.2, especially 177.20 ff: *πάντες μὲν* (i.e. the Babylonians, Chaldaeans and Egyptians) *ἄνευ φυσιολογίας ἀτελεῖς ποιούμενοι τὰς μεθόδους, δέον ἅμα καὶ φυσικῶς περὶ τούτων ἐπισκοπεῖν· ὅπερ οἱ παρὰ τοῖς Ἕλλησιν ἀστρολογήσαντες ἐπειρῶντο ποιεῖν . . .*

[91] *Exp. rer. math.* 199.14 ff., 200.7 ff.

ence is general and cosmological, not purely mathematical. He does not say that Hipparchus chose epicycles because they are mathematically simpler—more convenient for the purposes of calculation—but rather that he did so because 'it is more plausible that all the heavenly bodies should lie symmetrically with regard to the centre of the universe and be joined together similarly.'[92] The point appears to be that whereas in the case of an individual planet the eccentric hypothesis may save the phenomena, the system as a whole requires several different eccentrics, that is several different centres of motion, while on the epicyclic hypothesis, on the other hand, the concentric deferents have a single centre. The latter is clearly more easily squared with Aristotle's physical principle according to which movement must be either to, from, or round the centre of the universe,[93] and if that was Hipparchus' point, or one of them, then it would indeed be mistaken to represent him as a pure instrumentalist.

Finally we must comment very briefly on the fourth-century-B.C. evidence used by Duhem. Here the contrast between Eudoxus and Callippus on the one hand, and Aristotle on the other, is usually represented as one between a kinematic, and a dynamical, theory,[94] and indeed Aristotle's introduction of retroactive spheres is to be explained in terms of an attempt to account for the transmission of movement from the outermost sphere to the sublunary region. Yet while we can be confident that Aristotle made that much of an attempt at a dynamical theory, the fact that our evidence for Eudoxus and Callippus is limited to their kinematic theories does not of itself prove that they had no dynamical theories at all. It is as well to recognize that we simply have no reliable information on that point,[95] only at best a questionable argument from silence.[96] Nor do we have any *evidence* concerning their views on the status of the homocentric spheres they postulated, though we may of course advance certain conjectures on that question.

III

It is now time to take stock of our conclusions, and I must first repeat, with the strongest possible emphasis, that for many of the most important figures in the history of Greek astronomy we are simply not in a position to pronounce definitely on their views either on the status of the various hypotheses they used, or on the more general question of the nature of astronomy and its relation to physics. Where we do have some evidence, however, whether from practising astronomers or from the major commentators, it often contradicts the line of interpretation advocated so forcefully by Duhem and thereafter echoed by others. So far from the majority of those texts supporting the thesis that Greek astronomers were, in general, not concerned with the truth of their hypotheses and with whether they conformed to the nature of things, those texts tend to provide evidence against that thesis. In the methodological statements of

[92] *Exp. rer. math.* 188.17 ff., quoted above p.217 and n. 86.

[93] Cf. Proclus' reference to this 'common axiom of the physicists', *In Ti.* iii.146.21 ff., above, n. 39.

[94] I should certainly now wish to qualify too conventional statements of my own to that effect; Lloyd (1970), p.92.

[95] It is noteworthy that Simplicius refers to the concentric spheres model (common to Eudoxus, Callippus, and Aristotle) as the hypothesis of the *reacting* spheres, e.g. *In Cael.* 32.16 ff., 488.9, 493.4 ff.

[96] Wright (1973–4), pp.165 ff. has indeed recently argued that certain features of Eudoxus' system reveal his concern for the physics of his problems and that his interest was far from being purely geometrical.

Geminus, Theon, and Proclus, and in the actual practice of Ptolemy, we find support for the opposing point of view, that so far from being indifferent to physics the astronomer must take his starting-points from the physicist, starting-points which include not only the general Platonic assumption that the movements of the heavenly bodies are regular, uniform, and circular, but also assumptions or theories concerning which bodies are at rest and which in movement, mentioned among the ἀρχαί by Theon and explicitly discussed in the first book of Ptolemy's *Syntaxis*.[97] Indeed the adverse reception of the heliocentric theory itself surely tells against the view that Greek astronomers were, in general, indifferent to the physical implications of the hypotheses they adopted.

None of this is to deny that the great strength of Greek theoretical astronomy lies in its application of mathematics to the problems of celestial motion—a point that Duhem was, of course, absolutely right to emphasize, as he was also in drawing attention, in particular, to the influence of Plato. The chief task of the astronomer *qua* astronomer was to work out mathematical models from which the observed courses could be derived, and for that purpose Greek astronomers often simplify their problems, as Ptolemy, for example, does when he omits movement in latitude from his discussion of the planets until book xiii of the *Syntaxis* or when he argues that the earth has the ratio of a point to the heavens (i. ch.6). On occasions Greek astronomical assumptions are not merely not translatable back into physical terms, but known by their proponents to be incorrect. Here I would agree with Wasserstein and others that this is the most likely interpretation of the hypothesis we find in Aristarchus' *On the Sizes and Distances of the Sun and Moon* when he takes 2^0 as the value of the angular diameter of the moon. One presumes he knew this value to be grossly inaccurate, but in this context any value will do since his aim is to solve the geometrical problems of the question.[98] Yet the important point is surely this: the astronomers' interest in the mathematics of their problems often *did* presuppose a concern with the physics and often again did not exclude such a concern.[99]

To conclude: some of the support Duhem claimed for his general thesis from particular texts depends on a questionable, in places I should say certifiably incorrect, understanding of them. Where it is perfectly fair to say that the Greeks distinguished, even contrasted, mathematics and physics, it is an exaggeration to claim they advocated a mathematical astronomy divorced from physics or sought to liberate astronomy from all the physical conditions imposed on it.[100] Where we may well agree that the astronomers (like other scientists)

[97] In Geminus, too, although it is not the astronomer's business to decide which bodies are at rest and which in movement, he takes his starting-points from the physicist, see above, pp.213 f.

[98] See Wasserstein (1962), pp.57 f. and cf. e.g. Neugebauer (1972), p.248.

[99] Even though no ancient astronomer was successful in giving an adequate *dynamical* account of the movements of the heavenly bodies, that did not preclude their being interested in the *physics* of their problems—a point sometimes obscured by Duhem's concentration on a simple contrast between 'mathématique' and 'physique' even though he was well aware of certain differences between his own 'physique' and ancient φυσική e.g. Duhem (1908), p.114. So far as attempted dynamical theories go, an important feature of some of the vitalist views that stem from Plato is their dualism: Plato himself identified the moving force as an (incorporeal) soul different *in kind* from the (corporeal) heavenly body it moves (e.g. *Laws* 898 e f).

[100] e.g. Duhem (1908), p.129: 'les partisans de Ptolémée étaient tenus . . . d'affranchir les hypothèses astronomiques des conditions auxquelles les physiciens les avaient, en général, asservies.' Cf. also Mittelstrass (1962), p.164.

often simplified their problems and sometimes advanced positions for the sake of argument, Duhem again exaggerated in representing Greek astronomical hypotheses in general as adopted purely for the sake of calculations. Dynamical and other physical factors, as well as considerations of mathematical simplicity, could be appealed to in deciding between theories. It was sometimes not just a matter of saving the appearances but of giving the true, *κατὰ φύσιν*, account, and even 'saving the appearances' sometimes meant more than just providing calculations that corresponded with the data, but 'saving' the *φαινόμενα* by relating them to *ὄντα*, with the emphasis on the distinction between the mere 'appearances' and the underlying 'realities'.[101] Duhem represented the major Greek thinkers as coming down on the side of Osiander and Ursus against Kepler and Galileo, and he thereby joined the controversy that Ursus and Kepler themselves engaged in on the nature of Greek astronomy. Yet so far as our evidence goes, it would be truer to say that the aims and presuppositions of many Greek writers on astronomy have more in common with those of Kepler than with those of Ursus—as Kepler himself suggested.[102] The question of the emergence and development of this recurrent debate in European astronomy, and that of the relevance of this for Duhem's reading of the Greeks, are, however, issues beyond the scope of this paper.

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[101] As in e.g. Simplicius (see above, p.214 and n. 64). On the ambiguities of the expression *σώζειν τὰ φαινόμενα* see Mittelstrass (1962), pp.140 ff.

[102] In his *Apologia Tychonis contra Ursum* (*Opera Omnia*, ed. C. Frisch, Vol. i, Frankfurt 1858), referred to by Duhem (1908), pp.574 ff.

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