Journal of Astronomical History and Heritage, 2(2):87-110, 1999

Plato's place in the history of Greek astronomy: restoring *both* history *and* science to the history of science

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I am the owner of the sphere,
Of the seven stars and the solar year,
Of Caesar's hand and Plato's brain,
Of Lord Christ's heart and Shakespeare's strain.
Ralph Waldo Emerson
May-Day and Other Pieces. History

Abstract
The history of ancient Greek geometrical astronomy often is written as a mathematical *tour de force* rather than history, with technical details of quantitative geometrical constructions the centre of attention, studied as if they were independent of the culture within which they flourished. Much of science is eliminated as well in focusing only on observations and the mathematical consequences of an initial hypothesis about the fundamental character of the movements of the planets. Plato with his philosophical vision exemplifies the influence of humanistic concerns in ancient science more broadly conceived. This study casts new light on both the ruling paradigm of Greek geometrical astronomy and the long-standing debate over whether ancient Greek astronomers were instrumentalists or realists, and also opens to view a deeper and richer understanding of science.

Key words: *Plato, Eudoxus, Ptolemy, Greek astronomy instrumentalism, realism*

1 INTRODUCTION

An intellectual fault line cleaves the history of science. On one side are internalists knowledgable about the effect of observation and the consequent advance of scientific theory, but dismissive of possible societal factors. Across the chasm, externalists ignore the science for the history.

No where is the rift between internalists and externalists greater than in the history of ancient Greek astronomy. The late, great, Otto Neugebauer, for whom the history of ancient astronomy became a mathematical *tour de force*, saw:

> ... no need for considering Greek philosophy as an early stage in the development of science ... Astronomy had at its basis simple observable facts, and elementary mathematics sufficed to lead to significant results, leaving only little room for philosophical doctrines. (Neugebauer, 1975:*ii*, 572)

In his magisterial history of ancient mathematical astronomy, Neugebauer chose to deal:

> ... neither with early cosmogony nor with philosophy, but exclusively with mathematical astronomy, i.e. with the numerical, geometrical, and graphical methods devised to control the mechanism of the planetary system. (Neugebauer, 1975:*i*, 1)

This is all he considered worthy of his effort:

> In many years of study I have tried to become familiar with the ancient methods of mathematical astronomy, to realize their problems, and to understand their

> interconnections and development. ... I have tried to come as close as possible to the astronomical problems themselves without hiding my ignorantia behind the smoke-screen of sociological, biographical, and bibliographical irrelevancies. (Neugebauer, 1975:*i*, 7)

Working out the technical details in quantitative geometrical constructions was central to Neugebauer's endeavour, to the exclusion of almost every other issue imaginable.

Neugebauer also refrained from comparisons of ancient with modern numerical data; rather than explain how 'good' or 'bad' ancient astronomy was, he tried instead "to describe what seemed to be the essential problems and the methods developed toward their solution" (Neugebauer, 1975:*i*, 2). The goal of studying science in its historical technical context could scarcely be articulated better. Enforced, Neugebauer's strictures would preclude much intellectual pollution of scholarly literature.

Nonetheless, it seems worth the risk to attempt to transcend Neugebauer's sharply-focused vision of both science and its history and to trace the influence of broad humanistic concerns in the work of ancient scientists, if indeed such concerns can be shown to exist. The history of science encompasses both internalist and externalist approaches, and is the richer for it.

Potential rewards from an expanded historical study of ancient Greek astronomy are considerable. First, the astronomy might be more fully understood as not merely a continuation of Mesopotamian science, but rather a new creation following from speculative theories and inseparable from Greek philosophy (Hetherington, 1997a; Høyrup, 1996; Kahn, 1991); the history could be restored to the history of science. Furthermore, much of the science could be regained as well. Neugebauer (1946) admitted only mathematical computation together with empirical observation as the necessary characteristics of science. The ancient activity he so ably recovered is little more than a set of mechanical procedures, albeit comprehending much observational data, but with scarcely more theoretical content than recipes in a cookbook. Narrow, mathematically-based activity, with no role for speculative hypotheses of a theoretical nature, is not all of science, nor even the heart of science.

Neugebauer (1969:152), emphasizing exact over theoretical science, explicitly chose to exclude Plato from his version of history. *Contra* Neugebauer, the following study focuses on Plato and his philosophical vision of reality. New light is cast upon both the ruling paradigm of Greek geometrical astronomy and the long-standing debate over whether ancient Greek astronomers were instrumentalists or realists. Furthermore, a deeper understanding of science emerges.

Though ambitious to expand the boundaries of what legitimately constitutes the history of ancient astronomy, this study nevertheless remains very limited in scope. It does not, for example, explore changes in Greek philosophy of nature from Plato onward and corresponding changes in Greek astronomy, as will be necessary for a more nuanced history, nor are other essential elements of cultural context included in this initial examination limited largely to Platonic philosophy.

2 UNIFORM MOTION AND THE PLAN OF THE WORLD

Little in Plato's surviving writings explicitly links him to the Greek tradition of representing the motions of the planets with a combination of uniform circular motions. His thoughts on the structure of the universe appear in the *Timaeus*. Some scholars believe that Plato intended his cosmology as a literally-true account of the cosmos (even including the prefatory narrative on an ancient maritime empire of Atlantis overwhelmed by a sudden catastrophe and disappearing into the sea). Others, including Plato's immediate disciples, have favoured a metaphorical reading (Knorr, 1993).

The object of scientific study was not a description of the world of the senses, wrote Plato, but discovery of the plan of the Creator for the world. Confusion and disorder were bad; therefore the Divinity fabricated an orderly and hence beautiful universe. Anything moving with confusion and disorder was evil, and to be reduced to order:

> And for shape he [the Divinity] gave it [the world] that which is fitting and akin to its nature ... he turned its shape rounded and spherical ... a figure the most perfect and uniform of all; for he judged uniformity to be immeasurably better than its opposite ... he assigned to it the motion proper to its bodily form, namely that one ... which above all belongs to reason and intelligence; accordingly, he caused it to turn about uniformly in the same place and within its own limits and made it revolve round and round ... he made it smooth and uniform ... one world alone, round and revolving in a circle ... (*Timaeus*, 33b-34b)

The planets moved in circular orbits, with the circles apparently varying in size. The orbits also revolved with a spiral motion that produced the wandering (retrograde) motion of the planets:

> ... Sun and Moon and five other stars [planets] – 'wanderers', as they are called – were made ... in seven circuits seven bodies: the Moon in the circle nearest the Earth; the Sun in the second above the earth; the Morning Star [Venus] and the one called sacred to Hermes [Mercury] in circles revolving so as, in point of speed, to run their race with the Sun [seen always at but a small angle from the Sun], but possessing the power contrary to his; whereby the Sun and the star of Hermes and the Morning Star alike overtake and are overtaken by one another [retrograde motion] ... revolve by way of the Different, which was aslant, crossing the movement of the Same and subject to it; some moving in greater circles, some in lesser; those in the lesser circles moving faster, those in the greater more slowly....
>
> So, by reason of the movement of the Same, those which revolve most quickly appeared to be overtaken by the slower, though really overtaking them. For the movement of the Same, which gives all their circles a spiral twist because they have two distinct forward motions in opposite senses, made the body which departs most slowly from itself – the swiftest of all movements – appear as keeping pace with it most closely....
>
> To describe the evolutions in the dance of these same gods, their juxtapositions, the counter-revolutions [retrograde motions] of their circles relatively to one another, and their advances [increase in speed following retrogradation]; to tell which of the gods come into line with one another at their conjunctions, and which in opposition, and in what order they pass in front of [transit] or behind one another [occultation], and at what periods of time they are severally hidden from our sight [eclipse] and again reappearing send to men who cannot calculate panic fears and signs of things to come – to describe all this without visible models of these same would be labour spent in vain. So this much shall suffice on this head, and here let our account of the nature of the visible and generated gods come to an end. (*Timaeus*, 38c-40d)

Plato had a good sense of the qualitative problem posed by planetary motions, but begged off presenting anything approaching a detailed, quantitative solution. Nonetheless, later attributions to Plato of the paradigm of Greek geometrical astronomy – to save the appearances with uniform circular motions – are not incompatible with what Plato wrote in the *Timaeus*.

3 SIMPLICIUS' COMMENTARY

Plato's place in the history of Greek geometrical astronomy traditionally has followed from Simplicius' sixth-century AD commentary on Aristotle's *De caelo*. The chain of transmission between Plato and Simplicius is uncertain, and not without justification have some scholars doubted Simplicius' authority and questioned Plato's putative role in the development of Greek planetary astronomy (Goldstein and Bowen, 1983). Perhaps it was only later commentators who saw adumbrations of later astronomical models in Plato's earlier cosmological accounts (Knorr, 1990). Passages from the *Timaeus*, however, leave little doubt of Plato's intellectual infatuation with circular motion, and there are resonances between Plato's philosophical values and Simplicius' comments on astronomy.

Plato taught his ideas to pupils at the Academy, which he founded in Athens in about 380 BC. Eudoxus, the greatest genius in mathematics and astronomy of his time, may have attended Plato's lectures at the Academy, and certainly he was familiar with Plato's ideas. Upon Eudoxus' report of what Plato said a string of statements followed. Eudoxus' report is lost; however, it was summarized by Eudemus (around 350 BC; a pupil of Aristotle) in his own *History of Astronomy*. This work, too, is lost; but it was commented upon by Sosigenes in the second century AD (not the Sosigenes who lived in the time of Julius Caesar and advised Caesar on the calendar reform of 45 BC). Sosigenes' work also is lost; it was used, however, by Simplicius, with whom the string of lost but summarized works ends, in sixth-century Athens. Simplicius wrote:

> Plato lays down the principle that the heavenly bodies' motion is circular, uniform, and constantly regular. Thereupon he sets the mathematicians the following problem: what circular motions, uniform and perfectly regular, are to be admitted as hypotheses so that it might be possible to save the appearances presented by the planets? (Duhem, 1969:5)

Continuing, Simplicius explained:

> The curious problem of astronomers is the following: first, they provide themselves with certain hypotheses ... Starting from such hypotheses, astronomers then try to show that all the heavenly bodies have a circular and uniform motion, that the irregularities which become manifest when we observe these bodies ... are but appearances and not realities. (Duhem, 1969:23)

4 PLATO'S PHILOSOPHY OF REALITY

As Simplicius noted, astronomers pursuing the problem set by Plato deemed real not the irregularities observed in planetary motions – the actual appearances – but instead believed that reality consisted of uniform circular motions. However absurd such a stance on first glance may seem to modern-day empiricists, it is readily understandable in the context of Plato's philosophy.

For Plato, the only real world existed in the mind. This concept is nicely illustrated in a letter of Plato's, albeit a letter whose authenticity is not beyond question (Morrow, 1962:3-16; Friedlander, 1969:236-245). Plato wrote:

> There is something called a circle ... 'The figure whose extremities are everywhere equally distant from its centre' is the definition of precisely that to which the names 'round', 'circumference', and 'circle' apply ... what we draw or rub out, what is turned or destroyed; but the circle itself to which they all refer remains unaffected, because it is different from them. (*Epistles*, VII:342a-344a)

The circle scratched on a slate is not a real circle, no matter how skilled the draftsman. The drawn circle is an imperfect representation in the visible world of experience of a perfect circle. The perfect circle exists only in the mind, only in the world of thought.

Plato's emphasis on idea over sense experience recalls the famous meeting between Goethe and Schiller in Italy on 1794 July 14. Goethe created with a few strokes of his pen a symbolic plant, or *Urpflanze*. Schiller responded: "That is not experience, that is an Idea." Goethe replied: "That's a strange business, that I have ideas without knowing it, and *that I even see them with my own eyes*." As had Plato, Goethe now saw with the eyes of his soul (Friedlander, 1969:20-21).

Plato argued that reality exists not in the visible world but rather in the world of ideas. The implications of this argument for the study of astronomy are presented in Plato's *The Republic*. Here Plato took up the question of how society might be shaped to bring out the best in people. He asked what justice is and how it is to be attained, and concluded that a philosopher-king is needed to bring the ideal state into existence. How such a person might be educated was one of Plato's concerns. In this context, the nature of reality and the study of astronomy were introduced.

In a parable to illustrate the degrees to which man may be enlightened, Plato presented his famous allegory of the cave. He imagined men chained from childhood in a cave, so shackled that they must sit still, looking in only one direction. A fire behind them casts shadows of objects upon the cave wall in front of them. In the absence of any other experience, the prisoners accept the shadows as reality. Furthermore, the objects casting the shadows are not real men, but statues of men. Plato explained that the prison of the cave corresponds to the part of the world revealed by the sense of sight. Escape from the cave corresponds to the use of intelligence to reach the real world of knowledge (*The Republic*, VII, 514a-517a).

The next issue in *The Republic* is how to bring people to a state of enlightenment: how to convert the soul. Education is the answer. Education will enable the soul to look in the right direction and learn the truth. The forms of study leading the soul away from the world of change and to the world of reality are the sciences. They deal with certain knowledge and immutable truths. Arithmetic, geometry, solid geometry, astronomy, and harmonics quicken the mind and help a pupil gain understanding of the essential form of goodness, so Plato believed. Studying these subjects for ten years would release the prisoner from the cave and enable him to look at shadows and reflections. Five more years of study were devoted to dialectics.

Discussing astronomy, Plato first mentioned its utilitarian benefits: agriculture, navigation, and war. Not for these purposes, however, was astronomy to be esteemed. The true utility of the regimen of study prescribed in *The Republic* was saving the soul. An obvious approach to astronomy was to observe the motions of the objects in the heavens, but only a discipline dealing with unseen reality would lead the mind upward. True motions were not to be seen with the eye; not by looking at the heavens could one become truly acquainted with astronomy. As he often did, Plato put his ideas in a dialogue, in this instance between Socrates and Glaucon (one of Plato's older brothers):

> [Socrates] Then let us assign the fourth place in our studies to astronomy.
>
> [Glaucon] *It is a reasonable idea. And to return to the rebuke which you gave me a little while ago for my vulgar commendation of astronomy, I can now praise the plan on which you pursue it. For I suppose it is clear to everyone that astronomy, at all events, compels the soul to look upward and draws it from the things of this world to the other.*
>
> It may be clear to everyone else, but it is not clear to me.
>
> *What is your opinion?*
>
> It seems to me that astronomy, as now handled by those who study philosophy, positively makes the soul look downward.
>
> *How so?*
>
> I think you have betrayed no want of intrepidity in the conception you have formed of the true nature of that learning which deals with the things above. For probably if a person were to throw his head back and learn something from the contemplation of a carved ceiling, you would suppose him to be contemplating it not with his eyes but with his reason. Now perhaps your notion is right; perhaps mine is foolish. But I cannot conceive that any science makes the soul look upward unless it has to do with the real. And the real is invisible. It matters not whether a person stares at the ground or at the heavens. As long as he is trying to study any sensible object, he cannot be said to have learned anything, because no objects of sense admit of scientific treatment. And I maintain that his soul is looking downward, not upward, though he may be lying on his back staring upward.
>
> *I am rightly punished, for I deserved your rebuke. But what did you mean by saying that astronomy ought to be studied on a system very different from the present one if it is to be studied profitably for the purposes that we have in view?*
>
> I will tell you. Since this decorated sky is still a part of the visible world, we are bound to regard it, though the most beautiful and perfect of visible things, as far inferior to those true revolutions which real velocity and real slowness, existing in

> true number and in all true forms, accomplish relatively to each other, carrying with them all that they contain, which are truly discerned by reason and thought, but not by sight. Or do you think differently?
>
> *No, indeed.*
>
> Therefore we must use observations of this decorated sky as a pattern or plan to forward the study which aims at those higher objects, just as we might use the drawings of a draftsman as a model or pattern of the true and real but not reality itself. For, I imagine, a person acquainted with geometry, on seeing such diagrams, would think them most beautifully finished, but would regard it as ridiculous to study them seriously in the hope of detecting the truths of equality or duplicity or any other ratio.
>
> *No doubt it would be ridiculous.*
>
> And do you not think that the genuine astronomer will view with the same feelings the motions of the stars? That is to say, will he not regard the heaven itself and the bodies which it contains as framed by the heavenly architect with the utmost beauty of which such works are susceptible? But as to the proportion which the day bears to the night, both to the month, the month to the year, and the other stars to the sun and moon and to one another – will not the genuine astronomer look with scorn upon whomever believes such corporeal and visible objects to be changeless and exempt from all perturbations. And will he not believe it absurd to devote extraordinary effort to the attempt to observe and record the motions of the stars, sun, and moon?
>
> *Yes, I think so, now that I hear you suggest it.*
>
> Therefore we shall study astronomy with the help of problems, just as we study geometry. But we shall let the heavenly bodies alone, if it is our design to become really acquainted with astronomy and by that means to convert the natural intelligence of the soul from a useless into a useful possession. [*The Republic*, VII, 529d-530c]

Plato's instruction to 'let the heavenly bodies alone' has dismayed supporters and delighted detractors. On its face, the admonishment is anti-empirical, especially so if the translation produces in place of 'let alone' or 'leave' the stronger sense of 'dismiss' or 'abandon'. An injunction to astronomers to dismiss celestial phenomena from the subject matter of their science and to ban sense-perception would mean not a reform of astronomy but its liquidation (Vlastos, 1980).

A few lines earlier Plato instructed his followers to 'use observations of this decorated sky as a pattern or plan to forward the study which aims at those higher objects ...' This phrase Plato's supporters might construe as scientific. Plato's science cannot be equated with modern science, however, because Plato began with an a priori assumption regarding the true nature of the movements of the heavenly bodies and then sought to fashion the details of the scheme to explain away the apparent irregularities observed (Wasserstein, 1962).

Plato's interest lay not so much in inquiry into nature, but in how astronomy could be used in the education of philosopher-kings. Plato was talking not to astronomers but to educators. The astronomy that Plato would have eschew observation was not the science of astronomy as we think of it, but a propaedeutic to dialectic (Lloyd, 1981; Mourelatos, 1980). Plato's astronomy was highly abstract, with an emphatic contrast between the domain of the visible heavens and that of intelligible truth and reality. Plato intended to assimilate astronomy to a pure intellectual vision of points and lines, with the observed motions suggestive exemplars, at most. It is in this sense that Plato instructed his readers to 'use observations of this decorated sky as a pattern or plan to forward the study ...' He did not intend that observations be in any way central to the subject of astronomy as designed for educational purposes. Plato's astronomy was one of pure kinematics focusing on rotatory motion, of which the best visible concrete realization happened to be in the heavens. This is why he called it astronomy, but it is better thought of as a purely mathematical study, with selective empirical interpretations (Berggren, 1991; Mourelatos, 1981; Mueller, 1980).

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This is not to say, as some might, that Plato abandoned a quest for reality. He could not 'conceive that any science makes the soul look upward unless it has to do with the real.' Plato's science of astronomy had as its subject reality – just not reality as is now commonly understood. This is evident from the sentence immediately following: 'And the real is invisible.' The type of reality discussed in the allegory of the cave is real for Plato; the idea of a perfect geometrical figure rather than its imperfect realization in the world of the senses is real. Plato continued: 'It matters not whether a person stares at the ground or at the heavens. As long as he is trying to study any sensible object, he cannot be said to have learned anything, because no objects of sense admit of scientific treatment.' This statement may be anti-empirical and anti-observational, but it is not anti-reality.

Plato's mathematical structures exiting in a realm of reality other than the physical world we observe are characterized most concisely and most wittily as 'π in the sky' (Brown, 1991:49). A serious case can be made, though, for the reality of Platonic entities. For those seeking empirically-testable knowledge, it is reasonable to think that sensibles are real; for those seeking logical certainty, it is equally reasonable to think that Platonic Forms are real. Plato thought that Forms were cognitively more real than their sensible instances because logical necessity or logical certainty is more binding than contingent truth, which is fallible: capable of being proved false by refinements and extensions. Logical inference and analysis produce more secure statements than does sensory observation; hence sensible particulars are judged to be less real than their respective Forms (Vlastos, 1965).

5 PLATO'S LIFE

The philosophy of an individual can be studied using the assumption, or working hypothesis, that philosophy is a response to the environment. Intellectual historians prefer this approach. Philosophers, in contrast, typically concentrate upon the ideas themselves, not biographical details or societal context. In what follows, causal connection between environment and philosophy is suggested but not necessarily asserted. A selective biographical sketch serves as a heuristic analogy for Plato's ideas. His philosophy and its implications for the study of astronomy are particularly understandable as a response to social and political troubles in which Plato found himself.

In 479 BC, a year after the Persians under Xerxes I had captured and burned Athens, thirty-one Greek city-states defeated the Persians in decisive land and sea battles. The victory brought to a successful resolution some twenty years of struggle to stop the westward expansion of the great Persian Empire and began for Greece a 'Golden Age'. Increasingly, Greece was dominated by Athens, whose population rose to perhaps 400,000. Tribute poured in from other city-states, furnishing liberal support for Athenian writers and artists. The subject city-states shared in the general prosperity, but resentment at the loss of political independence grew. Led by Sparta, several Greek city-states revolted against Athenian rule, setting off the Peloponnesian War of 431-404 BC. Initially Athens had no great difficulty maintaining dominance, but the fortunes of battle shifted after an unsuccessful attack by Athens on Syracuse in 413 BC, and Athens surrendered to Sparta in 404 BC.

Political conditions in Athens and then the death of Socrates, Plato's teacher and close friend, could well have affected Plato. Born in 427 BC, Plato was of an age to enter public life at the time of the defeat of Athens. Furthermore, both his mother's brother and cousin were members of the oligarchy of the Thirty Tyrants designated by Sparta to rule Athens. As can be read in an autobiographical letter, purportedly Plato's and accepted by many, but not all, scholars as genuine:

> When I was a young man I had the same ambition as many others: I thought of entering public life as soon as I came of age. And certain happenings in public

> affairs favoured me, as follows. The constitution we then had ... was overthrown; and a new government was set up consisting of ... and above them thirty other officers with absolute powers. ... Some of these men happened to be relatives and acquaintances of mine, and they invited me to join them at once ... (*Epistles*, 324c-d)

But the actions of the tyrants – they quelled criticism by intimidation and opposition by assassination, and met treasury deficits by the arbitrary execution of wealthy individuals for treason, followed by confiscation of the alleged traitors' properties – disgusted Plato. Also, they attempted to involve Socrates in their illegal actions. Plato chose not to join the government:

> I thought that they were going to lead the city out of the unjust life she had been living and establish her in the path of justice ... But as I watched they showed in a short time that the preceding constitution had been a precious thing. ... I was appalled and drew back from that reign of injustice. (*Epistles*, 325b-c)

A year later, the democratic faction having driven out the tyrants, Plato again considered entering politics:

> Not long afterwards the rule of the Thirty was overthrown and with it the entire constitution; and once more I felt the desire, though this time less strongly, to take part in public and political affairs. (*Epistles*, 325a-b)

But then the democracy persecuted Socrates. Plato now thought to set aside political ambition and begin his search for unchanging standards to hold against the shifting judgments of men:

> ... certain powerful persons brought into court this same friend Socrates, preferring against him a most shameless accusation ... and the jury condemned and put to death the very man. The more I reflected upon what was happening ... the more I realized ... the corruption of our written laws and our customs was proceeding at such amazing speed that whereas at first I had been full of zeal for public life, when I noted these changes and saw how unstable everything was, I became in the end quite dizzy ... At last I came to the conclusion that all existing states are badly governed and the condition of their laws practically incurable, without some miraculous remedy and the assistance of fortune; and I was forced to say, in praise of true philosophy, that from her height alone was it possible to discern what the nature of justice is, either in the state or in the individual, and that the ills of the human race would never end until either those who are sincerely and truly lovers of wisdom come into political power, or the rulers of our cities, by the grace of God, learn true philosophy. (*Epistles*, 325b-326b)

Subsequent experiences confirmed Plato in this opinion. In about 388 BC he was in the presence of the dictator of Syracuse, Dionysius I. According to legend, the tyrant asked Plato if he did not think that he, Dionysius, was a happy man. Plato answered that he thought no one who was not mad would become a tyrant. Enraged, Dionysius supposedly ordered Plato sold into slavery, from which he was rescued by a friend arriving just in time with ransom money. More likely, whatever the exchange between Plato and Dionysius, on Plato's return voyage to Athens his ship was captured and he was put up for sale in the slave market at Aegina, where a friend ransomed him. Of all this, however, there is no mention in Plato's autobiographical letter.

Plato does describe his association with Dion, Dionysius' brother-in-law, to whom Plato imparted his ideas, particularly the love of virtue above pleasure and luxury. When Dionysius died, Dion in 367 BC asked Plato to return to Syracuse to help arouse in his nephew, the new tyrant Dionysius II, the desire for a life of nobility and virtue. Dion even persuaded the young ruler to send for Plato. Plato went, though not without trepidation. His worst apprehensions quickly were surpassed:

> When I arrived – to make the story short – I found the court of Dionysius full of faction and of malicious reports to the tyrant about Dion. I defended him as well as I

> could, but was able to do very little; and about the fourth month Dionysius, charging Dion with plotting against the tyranny, had him put aboard a small vessel and exiled in disgrace. Thereupon we friends of Dion were all afraid that one of us might be accused and punished as an accomplice in Dion's conspiracy. About me there even went abroad in Syracuse a report that I had been put to death by Dionysius as the cause of all that had happened.... Dionysius ... devised a means for preventing my departure by bringing me inside the citadel and lodging me there, whence no ship's captain would have dared to take me away ... Nor would any merchant or guard along the roads leading out of the country have let me pass alone, but would have taken me in charge at once and brought me back to Dionysius ... I made every effort to persuade Dionysius to let me depart, and we came to an agreement that when peace was restored [war was then going on in Sicily] and when Dionysius had made his empire more secure, he would recall both Dion and me.... On these conditions I promised that I would return. (*Epistles*, 329b-e; 338a)

With peace restored, Plato initially disregarded the summons from Dionysius. But, lest reports of Dionysius' new-found appreciation of philosophy prove true, Plato did not want to be blamed for denying assistance. The enterprise ended badly, and some readers may sense in Plato's apologetic and self-exculpatory explanation a whining tone; scholars have divined a more noble and principled stand. It may also have flattered Plato that Dionysius sent a trireme to ease his journey. Furthermore, Dionysius threatened to cut off Dion's income if Plato did not come. On arriving in Syracuse, Plato was not pleased:

> When I arrived, I thought my first task was to prove whether Dionysius was really on fire with philosophy ... those who are really not philosophers but have only a coating of opinions, like men whose bodies are tanned by the sun, when they see how much learning is required, and how great the labour, and how orderly their daily lives must be to suit the subject they are pursuing, conclude that the task is too difficult for their powers ... I went through the matter [the first and highest principles of nature] with him once only ... Was it that Dionysius ... thought he understood well enough ... Or did he think that what I said was of no value? Or ... did he realize that this teaching was beyond him ... (*Epistles*, 340b-e; 345a-b)

Dionysius now cut off Dion from the revenues of his properties. An indignant Plato again wanted to leave Syracuse, and again was held against his will.

The changing, visible world all too evidently was without permanent values. For Plato in his time this was far more of a disappointment than it would be today, with a plethora of alternative professions beckoning. Even the haven and the professional and intellectual opportunity offered by the Christian church lay centuries ahead. If Plato could not become a political being, the essential part of human existence was denied him. He turned to the world of ideas in which he might hope to find the real and unchanging standards absent in the world of experience.

6 THE ONTOLOGICAL STATUS OF ASTRONOMICAL HYPOTHESES

Plato believed that astronomical hypotheses were descriptions of reality. This much is clear from brief glances at his life and philosophy. It is also clear that Plato's reality existed in the world of ideas rather than in the world of the senses.

For subsequent Greek astronomers, the claim on reality of any particular combination of uniform circular motions might well have been diminished after Hipparchus (*c*. 150 BC) showed that the eccentric hypothesis (Figure 1) and the epicycle hypothesis (Figure 2) for the Sun's motion were mathematically and observationally equivalent.

In addition to the need to save the phenomena with some scheme of uniform circular motions, the ontological status of astronomical hypotheses also received attention from Simplicius in his commentary on Aristotle's *De caelo*:

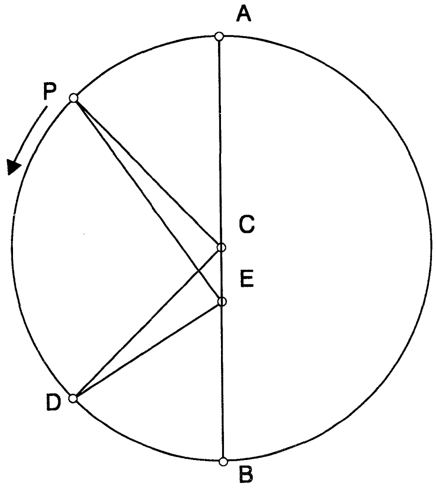

Figure 1. In the eccentric hypothesis, the planet/Sun, P, moves with uniform circular motion along the circle APDB with its centre at C. The observer on Earth is at E, thus the planet's circular orbit is not around Earth, but is eccentric. The planet is at apogee at A and perigee at P.

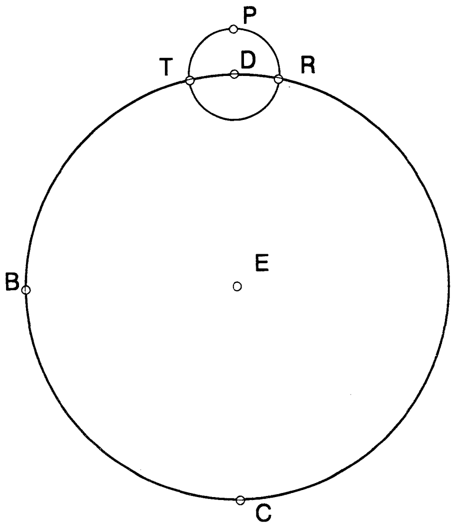

Figure 2. In the epicycle hypothesis, the planet/Sun, P, moves with uniform circular motion along the epicycle, circle PRT, whose centre, D, simultaneously travels along the deferent, circle DBC with Earth, E, at its centre.

> ... so an explanation which conforms to the facts does not imply that the hypotheses are real and exist. By reasoning about the nature of the heavenly movements, astronomers were able to show that these movements are free from all irregularity, that they are uniform, circular, and always in the same direction. But they have been unable to establish in what sense, exactly, the consequences entailed by these arrangements are merely fictive and not real at all. So they are satisfied to assert that it is possible, by means of circular and uniform movements, always in the same direction, to save the apparent movements of the wandering stars. (Duhem, 1969:23)

Simplicius also addressed the ontological status of astronomical hypotheses in his commentary on Aristotle's *Physics*. Here Simplicius reported Geminus' abridged version (in an elementary astronomical handbook written at Rhodes in about 70 BC) of what Posidonius (at Rhodes sometime between 135 and 51 BC) had asserted in his *Meteorology*. Astronomy differed from physics:

> To physical theory belongs the study of all that concerns the essence of the heavens and the stars ... Astronomy, on the other hand, is not prepared to say anything about the former. Its demonstrations concern the order of the heavenly bodies ... the shapes, sizes, and relative distances ... Often the physicist will fasten on the cause and direct his attention to the power that produces the effect he is studying, while the astronomer draws his proofs from circumstances externally related to that same effect. The astronomer is not equipped to contemplate causes ... he feels obliged to posit certain hypothetical modes of being which are such that, once conceded, the phenomena are saved. For example, the astronomer asks why the sun, the moon, and the other wandering stars seem to move irregularly. Now, whether one assumes that the circles described by the stars are eccentric or that each star is carried along by the revolution of an epicycle, on either supposition the apparent irregularity of their course is saved. The astronomer must therefore maintain that the appearances may be produced by either of these modes of being ... (Duhem, 1969:10-12)

Continuing his explanation of the difference between astronomy and physics, Simplicius considered a heliocentric hypothesis:

> This is the reason for Heraclides Ponticus' contention that one can save the apparent irregularity of the motion of the sun by assuming that the sun stays fixed and that the earth moves in a certain way. The knowledge of what is by nature at rest and what

> properties the things that move have is quite beyond the purview of the astronomer. He posits, hypothetically, that such and such bodies are immobile, certain others in motion, and then examines with what [additional] suppositions the celestial appearances agree. His principles, namely, that the movements of the stars are regular, uniform, and constant, he receives from the physicist. (Duhem, 1969:18)

Seemingly according the standard geocentric hypothesis and Heraclides Ponticus' heliocentric hypotheses equal standing, Simplicius apparently opted for a merely fictive status for astronomical hypotheses.

The ancient discussion of possibly fictive astronomical hypotheses was continued in modern times by the physicist and historian of science Pierre Duhem. A hypothetical status for hypotheses about nature had become particularly convenient for French Catholic scientists during the middle ages. Nicole Oresme (1320-1382), for example, in discussing the possible rotation of Earth, came too close to asserting truths that could be contradictory to dogmas of the Christian faith, and wisely chose to present his work in the context of a nominalist thesis: that we cannot insist upon the truth of any particular working hypothesis because God could have made the world in some different manner that nonetheless has the same set of observational consequences (Hetherington, 1993b). While conceding the divine omnipotence of Christian doctrine, the nominalist thesis would free natural philosophy from religious authority. Duhem, both Catholic and French, became an eager champion of his earlier compatriots. His personal philosophy of science also resonated with what he understood theirs to be.

In his study of the history of astronomy from Plato to Galileo, Duhem seized upon ancient Greek astronomy, especially as purveyed in Simplicius' commentaries, to establish early in the twentieth century an instrumentalist view – an understanding of scientific theories as useful fictions – of the relationship between theory and observation. The better to contrast Greek with Arab science, Duhem emphasized supposed Greek instrumentalism more than was warranted. In rendering Greek text into French, Duhem occasionally produced translations of ancient opinion more in line with instrumentalism than other scholars will willingly concede (Duhem, 1969:10, footnote 13; Lloyd, 1991:267-268).

Later, Duhem would display a more subtle understanding of Greek astronomers and recognize that many of them subordinated mathematical astronomy to physical theory (Ragep, 1990). Indeed, Duhem would come to seek a middle way between realism and instrumentalism, rejecting along with realism also the reduction of science to a set of practical prescriptions for action, which would have deprived science of its status of objective knowledge (McMullin, 1990).

At the centre of a partisan polemical battle, Duhem initially carried nearly single-handedly the instrumentalist standard into battle against British mechanistic philosophy (Duhem, 1969:ix-xxvi). Only the briefest of sketches anent the debate must suffice here. For William Thompson (Lord Kelvin), theories were presented in terms of mechanical models; he wrote: 'I never satisfy myself until I can make a mechanical model of a thing. If I can make a mechanical model I can understand it.' The reality of theoretical entities depended upon the ability to sense their behaviour. Theoretical expressions were acceptable only to the degree that they were accessible to seeing and feeling, to direct sensory perception (Smith and Wise, 1989:464-465). Duhem, observing the British recourse to mechanical models, wondered if the scientists had been inspired by the mills and factories of Victorian Britain: 'We thought we were entering the tranquil and neatly ordered abode of reason but we found ourselves in a factory' (Duhem, 1962:71).

Physicists generally believed that their work related to physical reality. Duhem's extreme opposite view was that laws are merely convenient formulae, to be reshuffled at will. For example, the interaction of charged particles in an electromagnetic field need not rely on the postulation of an underlying medium; instead, the scientific law is a mathematical fiction, its sole function to save the phenomena (Duhem, 1969:xv-vi). Duhem rejected scientific realism in which the explanatory success of a theory was taken as reason to believe in the existence of underlying entities postulated by the theory; he associated model-realism with the 'broad but weak' English mind (McMullin, 1990). Such, caricatured in broad strokes, were the rival views of scientific theory at the turn of the century.

Some scholars see as a dominant strand in ancient Greek astronomy 'a lack of concern with the physics of the problem in favour of a preoccupation with the mathematics, the construction of models that are purely calculating devices with nothing to do with any underlying physical realities' (Lloyd, 1987:312). Known empirical data were suspended and the study then became one of pure geometry, not solving but still relevant to the astronomical problem. What remained were simple mathematical fictions and pure conceptions, with no question of their being true or in conformity with the nature of things, or even probable (Lloyd, 1987:312-313; Musgrave, 1991). For so-called instrumentalists, it is enough that a scientific theory yields predictions corresponding to observations; theories are simply calculating devices.

Realists, on the other hand, insist that theories pass a further test: that they correspond to underlying reality. Greek astronomers were describing concrete bodies and movements that actually were accomplished. Realists believe that scientific theories are descriptions of reality. *Dogmatic* realists insist on the truth of a theory; *critical* realists concede a theory's conjectural character without necessarily becoming instrumentalists. A disappointed realist may appear to be a *local* instrumentalist with regard to a particular failed theory retaining instrumental value, but is far from becoming a *global* instrumentalist (Musgrave, 1991:244).

As Duhem recapitulated:

> the hypotheses of astronomy can be viewed as mathematical fictions which the geometer combines for the purpose of making the celestial motions accessible to his calculations; or they can be viewed as a description of concrete bodies and of movements that are actually realized. In the first case, only one condition is imposed on hypotheses, namely, that they save the appearances; in the second, the intellectual freedom of the astronomer turns out to be much more limited, for if he is an advocate of a philosophy which claims to know something about the celestial essence, he will have to reconcile his hypotheses with the teachings of that philosophy. (Duhem, 1969:28)

Modern debate over the ontological status of ancient astronomical hypotheses has been confined largely to the terminology and classifications developed in the battle between instrumentalists and realists. A fresh look at this issue viewed from the perspective of Plato's philosophy may be productive.

6 EUDOXUS

Whether there would be progress toward a solution to the astronomical problem purportedly set by Plato, that of saving the phenomena, or indeed any sustained attention to any scientific project, depended, in part, upon the level of encouragement and support furnished by society to individual philosopher-scientists. Greek society supported playwrights when the citizens of Athens paid to see the productions of Aeschylus, Sophocles, and Euripides, and prizes were offered at festivals for the labours of poets and musicians. Scientists, however, were not as generously supported, at least not until the establishment of the Museum and the Library in Alexandria. Plato lamented that inasmuch as no city held geometry in high regard, inquiries in the subject languished. The practicing physician and architect charged fees for their services, and so could the theoretically-inclined scientist or philosopher, were he able to attract a group of pupils. Alternatives included inherited wealth and the beneficence of a wealthy patron.

Eudoxus, thought to have lived from 408 to 355 BC, came to Athens as a poor youth, about 23 years old, travelling as assistant to a physician. Later Eudoxus proceeded to Egypt with another physician. There Eudoxus stayed for more than a year, perhaps for several years, and became familiar with the priests' astronomical observations. Later he established a school at Cyzicus, a city on the southern coast of the Sea of Marmara, and later yet he moved with some of his pupils to Athens, where presumably he renewed discussions with Plato and others at the Academy (Santillana, 1949).

Unfortunately, nothing Eudoxus wrote on astronomy has survived. His system was described briefly by Aristotle in the *Metaphysics* (Hope, 1952), and many centuries later in Simplicius' commentary on Aristotle's *De caelo*. According to Aristotle, Eudoxus's system consisted of spheres rotating with uniform speeds:

> Now, Eudoxus taught that the paths of the sun and of the moon each encompassed three spheres, the first of these being the sphere of the fixed stars, the second being along the middle line of the zodiac, and the third being inclined across the breadth of the zodiac; the path of the moon is inclined at a greater angle than the path of the sun. And the path of the planets is in each case within four spheres, the first and the second of these also being the same as the first two just mentioned (for the sphere of the fixed stars moves all the spheres, and the sphere placed next inward from this and having its path bisecting the zodiac is common to all), but the third sphere of each planet having its poles in the circle bisecting the zodiac, and the fourth sphere having its path inclined to the equator of the third; the poles of the third sphere being different for each of the other planets, but the poles of Venus and Mercury being the same.
>
> Callippus made the position of the spheres the same as did Eudoxus and assigned the same number as did Eudoxus to Jupiter and to Saturn; but he held that two more spheres are to be added to the sun as well as to the moon, if one is to account for the phenomena, and one more to each of the other planets.
>
> However, if all the spheres combined are to account for the phenomena, there must be for each of the planets other spheres, one less than those enumerated, moving counter to these and bringing back to the same position the outermost sphere of the star [planet] located inwards from the respective star [planet]; for thus alone can all the movements combine to produce the complex movement of the planets.
>
> Summing up, the spheres required by the movements of the planets themselves are: for Saturn and Jupiter, eight; for the others, twenty-five; and of these only those need to have countermoving spheres which are required by the movement of the innermost planet, that is, the spheres moving counter to those of the next two must be six, and the spheres moving counter to those of the next four must be sixteen; so that the total number of moving and countermoving spheres is fifty-five. But if one does not add to the sun and to the moon the movements we have suggested, all the spheres will number only forty-seven. So much for the number of the spheres. (*Metaphysics* I 8, 1073b17-1074a15)

Neither Aristotle's nor Simplicius' surviving descriptions of Eudoxus' astronomical system was sufficiently precise to stimulate much interest in the model until little more than a century ago, when Giovanni Schiaparelli, an Italian astronomer more widely known for his observation of 'canali' on Mars, attempted to reconstruct Eudoxus' system (Dreyer, 1953; Forbes, 1973; Hargreave, 1970; Heath, 1913; Hetherington, 1993a; Maula, 1974; Neugebauer, 1953). The reconstruction is compatible with what Aristotle and Simplicius wrote about Eudoxus, but also depends upon the assumption that Eudoxus' system accounted for many of the astronomical phenomena known in Schiaparelli's time. There is a decided danger of attributing to Eudoxus a more advanced knowledge of astronomy than he actually possessed and a more accurate astronomical model. Nor is it necessarily safe to assume that every astronomical phenomenon known in Eudoxus' time also was recognized as in need of explanation within his system.

Eudoxus could easily have accounted for the apparent movement of the stars overhead each evening by placing them on a sphere rotating with a uniform speed around the central Earth, with a period of twenty-four hours. For the Sun, Eudoxus would have needed two spheres, one rotating with the 24-hour period and another, its axis tilted to that of the first, to move the Sun higher in the sky in summer and lower in winter and around the heavens with a period of a year. Eudoxus apparently ignored the changeable velocity of the Sun, already discovered by his time, but did add a third sphere to account for a belief now known to have been mistaken. A similar system of spheres took care of the Moon, though the arrangement as reported by Aristotle and Simplicius cannot produce the variations in latitude now known (reversing the reported order of the middle and inner spheres brings the model into better agreement with modern observations). Planetary motions presented a more difficult problem, but a clever combination of third and fourth spheres would have been capable of producing in approximate fashion the observed retrograde motions (Figures 3 and 4).

Neither Aristotle nor Simplicius provides Eudoxus' inclination for any planet, and they give his planetary periods only in round numbers of years. Perhaps Eudoxus, once he had solved the problem of the stations and retrogradations of the planets qualitatively and geometrically, did not proceed to provide complete parameters for the individual planets (Lloyd, 1979:170). Perhaps the mathematical work of determining the various curves traced by a point on the innermost sphere was so

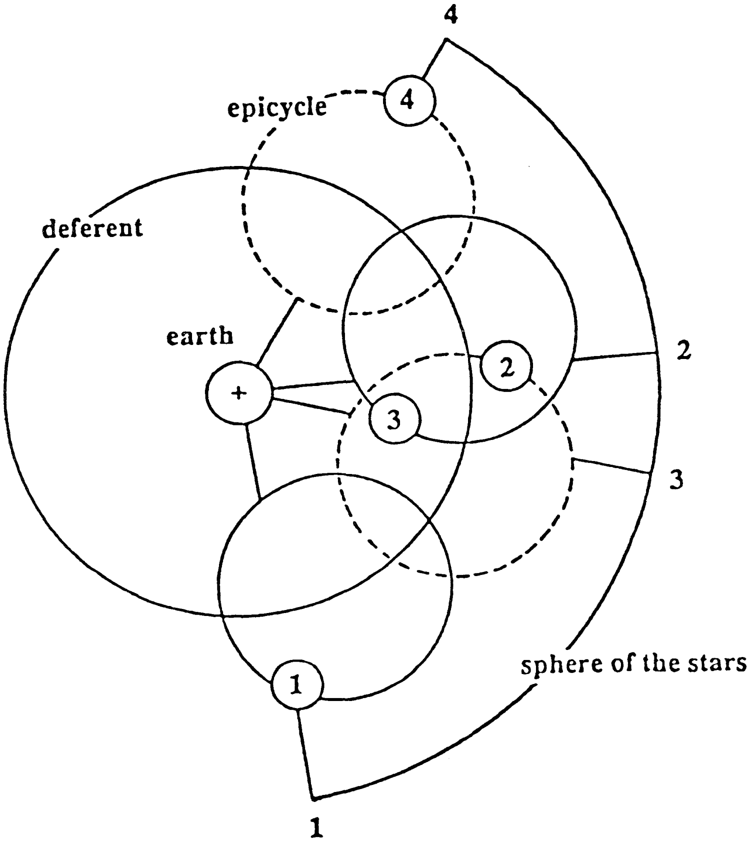

Figure 3. Apparent Retrograde Motion of a Planet. As seen from Earth at times 1, 2, 3, and 4, the planet apparently moves against the sphere of the stars from 1 to 2, turns back to 3, and then resumes its forward motion to 4. Earth, moving faster than the outer planet, overtakes and passes it.

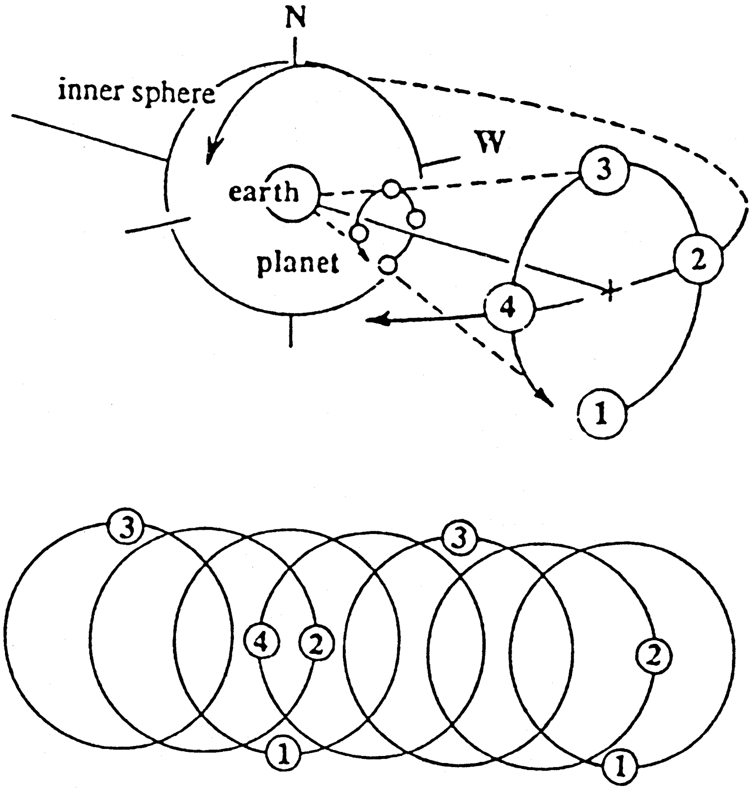

Figure 4. Retrograde Motion from Homocentric Spheres. Eudoxus could have, but did not necessarily, account for retrograde motion in the following manner. The apparent path of the planet, generally from right to left as seen against the sphere of the stars, due to the motions of the inner and outer spheres is shown immediately above, moving slightly right from 1 to 2, largely left to 3 and then to 4, slightly right to 1 and to 2, and then largely left to 3 and onward. The two spheres at the top of this figure have the same centre; they are concentric. The outer sphere is not shown in the drawing. Its axis of rotation is vertical, in the plane of the paper, in a north-south direction. The outer sphere carries everything within it eastward. The axis of the inner sphere is horizontal and in the plane of the paper. The motion of a planet carried about by the inner sphere is up (north) and down (south) and into (west) and out of (east) the plane of the paper. The planet appears to move north and west from 1 to 2, north and east to 3, south and east to 4, and south and west back to 1. When the inner sphere is imparting an eastward motion to the planet, moving the planet from 2 to 3 to 4, the total eastward motion, including the steady eastward motion imparted by the outer sphere, will be very rapid. If the westward speed imparted by the inner sphere is greater than the steady eastward motion imparted by the outer sphere, then the planet will appear to slow down and briefly move west during the passage from 4 to 1 to 2, when the westward velocity of the inner sphere is greater than the eastward velocity of the outer sphere. (After Hetherington, *Astronomy and Civilization*)

stupendous and absorbing that it provided its own justification for the project (Mourelatos, 1981). Lack of descriptive and predictive accuracy would not necessarily have weighed heavily against a theory intended primarily to give conceptual unity to the celestial motions, intended to show in a rather coarse and general way that the assumption of a very few principles could account for a large number of phenomena (Wright, 1973).

Four homocentric spheres cannot simultaneously produce with complete quantitative accuracy both the length of the retrograde motion westward and the length of the motion in latitude for all the planets. Evidently Eudoxus' contemporaries detected flaws in his system, because a series of modifications occurred after his death, first at his school in Cyzicus by his pupil, Polemarchus, and then by Polemarchus' pupil, Callippus. Later the work was continued in Athens, to which city both Polemarchus and Callippus moved, and where Callippus worked with Aristotle.

Aristotle would not have been content with a purely geometrical system; he would have sought to understand the forces causing the motions of the planets. For

Aristotle, the spheres were not merely representations of mathematical formulae, but physically existing parts of a vast machinery by which the celestial bodies were kept in motion (Dreyer, 1953:112). One historian of astronomy has complained of Aristotle that 'he adopted the planetary scheme of Eudoxus and Callippus, but imagined on "metaphysical grounds" that the spheres would have certain disturbing effects on one another, and to counteract these found it necessary to add 22 fresh spheres, making 56 in all. At the same time he treated the spheres as material bodies, thus converting an ingenious and beautiful geometrical scheme into a confused mechanism' (Berry, 1961:29). Aristotle was not attempting to improve on Eudoxus' geometrical solution, or to give a new solution; he was making changes necessary if the mathematical solution were to be applicable as a physical model (Bechler, 1970).

Eudoxus' system of homocentric spheres was improved and brought into better agreement with observed planetary motions, but there was one phenomenon for which it could not account: the movement of the planets closer to and farther from Earth. A system of homocentric spheres cannot produce changes in distances of objects from the centre of the spheres.

This oversight led one scholar to characterize Eudoxus as seeking a geometrical construction accounting for a selected set of phenomena, not a physical or mechanical model true to reality. He was not talking about the world as it is, but was giving a possible solution to a geometrical problem. It was not a real problem, but purely a geometrical exercise (Wasserstein, 1962). Other scholars argue that if Eudoxus' system had been intended merely as a computational device, it could have been less complex and more accurate (Musgrave, 1991; Wright, 1973).

Neither interpretation of Eudoxus, as an instrumentalist or as a realist, is without difficulty. An instrumental scheme, intended merely as a computational device, could have been less complex and more accurate. And a realist should have dealt with changing distances from the centre. Eudoxus is better understood as following in the same vein as Plato, with a highly idealized, but not instrumentalist, vision of what it meant to practice astronomy. Eudoxus' system of homocentric spheres was far more than a mere calculating device, but less – and more – than the concrete empirical reality of realists. Eudoxus' reality was the reality of Plato: a penetrating intellectual understanding of the world.

7 PTOLOMY

The most substantial surviving body of ancient Greek geometrical astronomy in which Platonic resonances might be sought is Ptolemy's *Almagest*. Intervening advances toward the goal of saving the phenomena achieved during the half a millennium between Eudoxus and Ptolemy were summed up so well by Ptolemy in his handbook on mathematical astronomy that 'his treatise became canonical and eliminated its predecessors' (Toomer, 1970). 'Being obsolete, they ceased to be copied' (Toomer, 1984).

After the death of Aristotle, the preponderance of scientific activity in the Greek intellectual world shifted from Athens to the new and wealthy port city of Alexandria, founded on the western edge of the Nile River Delta by Alexander the Great. The Museum, created around 290 BC, became home to as many as a hundred scholars subsidized by the government. Much prestige attached to scholarship and scientific research, and kings sought thus to enhance their reputations. Not to be outdone, a subsequent ruler established the Library, whose large and famous collection of books, built up from the purchase of private libraries, possibly including Aristotle's, may have numbered as many as half a million. Astronomical instruments were constructed for use at the Library, and observations and the matching of theory with fact were undertaken on a systematic and sustained basis. Galen in the biological sciences, Euclid in geometry, and Ptolemy in astronomy all flourished in Alexandria. Of

Ptolemy, the man, almost nothing is known. His own recorded observations purportedly were made (some assert they were fabricated; Hetherington, 1997b) between AD 125 and 141. The Library provided Ptolemy with observations of his predecessors, upon which he constructed his great synthesis.

The *Almagest* proceeds in logical order, beginning with a brief introduction to the nature of astronomy. Ptolemy makes a distinction between mathematics and physics, and also between these two disciplines and theology. He chooses the mathematical discipline to cultivate, particularly with respect to divine and heavenly things. His task is to describe what has already been discovered and to add his own original contributions. The motivation for studying astronomy echoes that given earlier by Plato. Ptolemy wrote:

> ... Hence we thought it fitting to guide our actions ... to strive for a noble and disciplined disposition ... to devote most of our time to intellectual matters, in order to teach theories, which are so many and beautiful, and especially those to which the epithet 'mathematical' is particularly applied. The division [of theoretical philosophy] which determines the nature involved in forms and motion from place to place, and which serves to investigate shape, number, size, and place, time, and suchlike, one may define as 'mathematics'. ... it can be conceived of both with and without the aid of the senses, and, secondly, it is an attribute of all existing things without exception, both mortal and immortal: for those things which are perpetually changing in their inseparable form, it changes with them, while for eternal things which have an aethereal nature, it keeps their unchanging form unchanged.
>
> ... only mathematics can provide sure and unshakeable knowledge to its devotees provided one approaches it rigorously. For its kind of proof proceeds by indisputable methods, namely arithmetic and geometry. Hence we were drawn to that part of theoretical philosophy ... concerning divine and heavenly things. For that alone is devoted to the investigation of the eternally unchanging. For that reason it too can be eternal and unchanging (which is a proper attribute of knowledge) in its own domain, which is neither unclear nor disorderly. ... it ... only ... can make a good guess at that activity which is unmoved and separated; it is familiar with the attributes of those beings which are on the one hand perceptible, moving and being moved, but on the other hand eternal and unchanging, having to do with motions and the arrangements of motions. ... almost every peculiar attribute of material nature becomes apparent from the peculiarities of its motion from place to place. ... the corruptible from the incorruptible by motion in a straight line or in a circle ... With regard to virtuous conduct in practical actions and character, this science, above all things, could make men see clearly; from the constance, order, symmetry, and calm which are associated with the divine, it makes its followers lovers of this divine beauty, accustoming them and reforming their natures, as it were, to a similar spiritual state.
>
> It is this love of the contemplation of the eternal and unchanging which we constantly strive to increase, by studying those parts of these sciences which have already been mastered by those who approached them in a genuine spirit of enquiry, and by ourselves attempting to contribute as much advancement as has been made possible by the additional time between those people and ourselves. (*Almagest*, I, 1)

Ptolemy would teach beautiful theories conceived of with, and without, the aid of the senses, concerning divine and heavenly things, eternally unchanging the incorruptible by motion in a circle. Astronomy could make men see clearly, reforming their natures. Admittedly a different selection of excerpts could equally make of Ptolemy an Aristotelian (Taub, 1993); the object here is not to choose one influence over the other, but to demonstrate links to Plato's philosophy.

In Book III of the *Almagest*, Ptolemy took up the problem of the Sun's motion. He described previous observations of the length of the year and summarized in a table the results of the Sun's regular movement. The next task, he wrote, was to explain the apparent irregularity of the Sun's motion as a combination of regular circular motions:

> Our next task is to demonstrate the apparent anomaly [irregularity in motion] of the sun. But first we must make the general point that the rearward displacements [retrograde motions] of the planets with respect to the heavens are, in every case, just like the motion of the universe in advance, by nature uniform and circular. That is to say, if we imagine the bodies or their circles being carried around by straight lines, in absolutely every case the straight line in question describes equal angles at the centre of its revolution in equal times. The apparent irregularity in their motions is the result of the position and order of those circles in the sphere of each by means of which they carry out their movements, and in reality there is in essence nothing alien to their eternal nature in the 'disorder' which the phenomena are supposed to exhibit. *(Almagest*, III, 3)

At the end of the *Almagest*, realizing that his readers would react unfavourably to the plethora of devices he had found necessary to incorporate into theory if it were to save the phenomena, Ptolemy pleaded that when it was not possible to fit the simpler hypotheses to the movements in the heavens, it was proper to try any hypotheses:

> Now let no one, considering the complicated nature of our devices, judge such hypotheses to be over-elaborated. For it is not appropriate to compare human [constructions] with divine, nor to form one's beliefs about such great things on the basis of very dissimilar analogies. For what more dissimilar than the eternal and unchanging with the ever-changing, or that which can be hindered by anything with that which cannot be hindered even by itself? Rather one should try, as far as possible, to fit the simpler hypotheses to the heavenly motions, but if this does not succeed, [one should apply hypotheses] which do fit. For provided that each of the phenomena is duly saved by the hypotheses, why should anyone think it strange that such complications can characterize the motions of the heavens when their nature is such as to afford no hindrance, but of a kind to yield and give way to the natural motions of each part, even if [the motions] are opposed to one another? Thus, quite simply, all the elements can easily pass through and be seen through all other elements, and this ease of transit applies not only to the individual circles, but to the spheres themselves and the axes of revolution. We see that in the models constructed on earth the fitting together of these [elements] to represent the different motions is laborious, and difficult to achieve in such a way that the motions do not hinder each other, while in the heavens no obstruction whatever is caused by such combinations. Rather, we should not judge 'simplicity' in heavenly things from what appears to be simple on earth especially when the same thing is not equally simple for all even here. For if we were to judge by those criteria, nothing that occurs in the heavens would appear simple, not even the unchanging nature of the first motion, since this very quality of eternal unchangingness is for us not [merely] difficult, but completely impossible. Instead [we should judge 'simplicity'] from the unchangingness of the nature of things in the heaven and their motions. In this way all [motions] will appear simple, and more so than what is thought 'simple' on earth, since one can conceive of no labour or difficulty attached to their revolutions. (*Almagest*, XIII, 2)

This passage, especially the argument that parts of the models must pass through each other without hindrance or obstruction, raises the question of whether Ptolemy envisioned actual physical structures in the heavens carrying around the planets. Duhem concluded that Ptolemy had refused to impose on the movements of the heavenly bodies the obligation of letting themselves be modelled by wooden or metal contraptions, and thus Ptolemy's many motions compounded to determine the trajectory of a planet 'have no physical reality; only the resultant motion is actually produced in the heavens' (Duhem, 1969:17).

The passage in question, however, seems more straightforwardly understood as indicating that there is a construction in the heavens controlling the motions of the planets, and that it is made not of wood, nor of metal, nor of other earthly material, but of some divine celestial material offering no obstruction to the passage of one part of the construction through another. If Ptolemy were interested only in the resulting motion, he would not have had to trouble himself with a discussion of the complicated nature of his devices. Ptolemy at the end of the Almagest seems closer in spirit to Lord Kelvin than to Duhem, not satisfied until he could make a mechanical model, or at least imagine such a model.

The most persuasive point advanced in arguments for Ptolemy as an instrumentalist involves his lunar theory. While it predicted lunar longitude and latitude accurately, the theory greatly exaggerated the monthly variation in the Moon's distance from Earth. Since the theory of the Moon, realistically interpreted, would yield an obviously false prediction about the variation in the apparent size of the Moon, Ptolemy – so the argument goes – could not have intended that the theory be interpreted realistically. Ptolemy had measured the variation in the angular diameter of the Moon, and he must have known that his theory failed in this aspect (Dreyer, 1953:196). Ptolemy, however, is silent on the matter; he does not explicitly recognize the fact of instrumentalism that some scholars have been so ready to discern nearly two millennia later.

Ptolemy's silence is not inconsistent with an implicit understanding that theory was merely a calculating device. His silence, however, does not prove beyond reasonable doubt that he set aside the problem as one of purely mathematical complexity. He could equally have been overcome by the physical complexity of the situation (Lloyd, 1978). A disappointed realist is not automatically rendered an instrumentalist. Ptolemy addressed at great length in the concluding section of the *Almagest* the issue of the physical complexity of his system. 'He adduces physical arguments from the nature of the substance of the heavenly region ... to support the possibility of the types of motion he proposes. Here too, then, the influence of his underlying realist assumptions is apparent' (Lloyd, 1978).

Proponents of Ptolemy as a realist cannot entirely deny the argument from lunar distances; they must try to overwhelm it with an abundance of contrary evidence. In one of his other books, the *Planetary Hypotheses*, Ptolemy nested the mechanism of epicycles and deferents for each planet inside a spherical shell between adjoining planets (Evans, 1993; Murschel, 1995). Even more so than in the *Almagest*, Ptolemy here showed his concern with the physical world.

Proponents of the instrumentalist interpretation must resort to a schizophrenic Ptolemy, now a realist but earlier, in the *Almagest*, an instrumentalist. Duhem wrote of the author of the *Almagest* and the author of the *Planetary Hypotheses* without noting that they were the same person, and another scholar spoke of the two souls dwelling together in the breast of many a scientist. Either Ptolemy was a 'bundle of contradictions' or he was a realist; the later interpretation has the decided advantage of simplicity (Musgrave, 1991).

Ptolemy shared Plato's philosophy, as selected excerpts from the preface to the *Almagest* demonstrate. Seemingly Ptolemy did not carry Plato's analogy of the cave to the extreme conclusion that reality exists only in the mind, that reality is found not in the visible façade of phenomena but in the mathematical structures that generate the phenomena (Graßhoff, 1990:199). Ptolemy's reality existed in the heavens, but it was not made of wood or metal. Ptolemy was not an instrumentalist. Nor was he a realist, at least in the strict sense of believing in wood and metal constructions filling the heavens. In changing the location of reality from the mind to the heavens, if that is what he did, Ptolemy was more of a realist than was either Plato or Eudoxus. Ptolemy's reality was not, however, an earthly materialistic reality, but rather an aethereal reality corresponding to nothing on earth: still π in the sky.

8 AN ALTERNATIVE MODEL OF SCIENCE

In ancient Greek geometrical astronomy the calculating or predictive power of theory apparently received less weight than modern instrumentalists and realists accord it, and reality was sought more in the world of ideas than in the empirical world (Hetherington, 1996). This philosophy might be likened to Gerald Holton's (1978) description of modern science, in which themata lie behind the quasi-aesthetic choices scientists make and guide their leaps across the chasm between experience and basic principle.

Regarding the relative importance of theory and observation, Einstein wrote: "I do not by any means find the chief significance of the general theory of relativity in the fact that it has predicted a few minute observable facts, but rather in the simplicity of its foundation and in its logical consistency" (Brush, 1989; see also Hetherington, 1989 and 1990). The astronomer Arthur Eddington, one of the first to understand relativity theory, elaborated: "For those who have caught the spirit of the new ideas the observational predictions form only a minor part of the subject. It is claimed for the theory that it leads to an understanding of the world of physics clearer and more penetrating than that previously attained" (Brush, 1989).

Might not Plato and his followers have believed their vision of the universe so penetrating that observation was rightly to be consigned to a minor role? And if they did, can modern scientists aware of their own heritage in Einstein, Eddington, and others, reject such an attitude as non-scientific?

Copernicus saw in his own heliocentric version of Greek geometrical astronomy a penetrating vision of reality, however much the unsigned preface to *De revolutionibus*, added without Copernicus' knowledge, argued for an instrumentalist approach to science (Goddu, 1990; Jardine, 1979 and 1982). Copernicus' understanding of the ontological status of his combination of uniform circular motions was quite otherwise, as a single example suffices to show.

His objection to Ptolemaic astronomy was not on observational grounds; Ptolemy had saved the phenomena about as well as Copernicus managed to. It was with the manner in which Ptolemy saved the phenomena that Copernicus quarrelled. One point of criticism, noted by Copernicus in his prefatory letter to *De revolutionibus*, was that the ancients had not been able:

> ... to discern or deduce the principal thing – namely the shape of the Universe and the unchangeable symmetry of its parts. With them it is as though an artist were to gather the hands, feet, head and other members for his images from diverse models, ... and since they in no way match each other, the result would be monster rather than man. [Kuhn, 1957:139]

This objection is amplified and clarified in section 10 of Book I. Various ancient opinions existed on the order (distance from the central body) of the planets, but planetary arrangements arbitrary in Ptolemy's system followed automatically in the heliocentric hypothesis; connections in the Copernican arrangement of the planets were more than happenstance. In such determination was perceived the theory's penetrating understanding of reality, and hence its own reality. Copernicus found:

> ... underlying this ordination an admirable symmetry in the Universe, and a clear bond of harmony in the motion and magnitude of the Spheres such as can be discovered in no other wise. For here we may observe ... why Saturn, Jupiter and Mars are nearer to the Earth at opposition to the Sun than when they are lost in or emerge from the Sun's rays. ... All these phenomena proceed from the same cause, namely Earth's motion. [Kuhn, 1957:180]

To keep Saturn, Jupiter, and Mars nearer to Earth at opposition (on the opposite side of Earth from the Sun) than at conjunction (seen in the same direction as the Sun) required careful juggling of orbit sizes and speeds in Ptolemy's system, but was a necessary consequence of the Copernican system (Figures 5 and 6). In a similar manner other observed phenomena that were *ad hoc*, arbitrary arrangements in a geocentric system followed automatically from a heliocentric hypothesis. The element of completeness of the heliocentric hypothesis gave Copernicus confidence that he had discovered the real order of the cosmos, not merely a mathematical fiction.

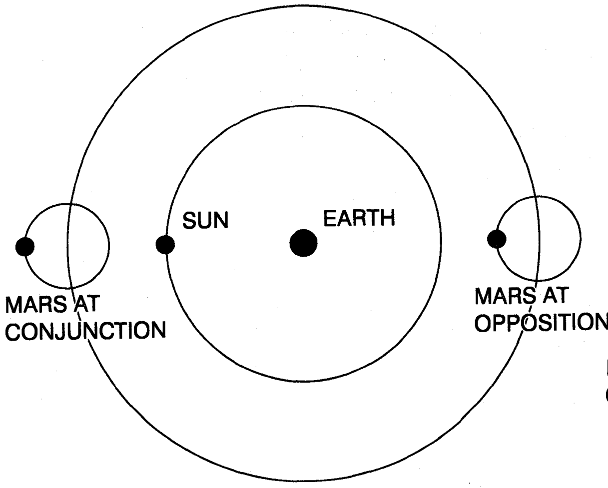

Figure 5. Earth, Sun, and Mars in the Ptolemaic System. Mars is carried on the small circle, its epicycle, which in turn is carried around Earth on the large circle, its deferent. Great care must be taken with the sizes and speeds of the circles to ensure that Mars is at the appropriate place on its epicycle at opposition and at conjunction.

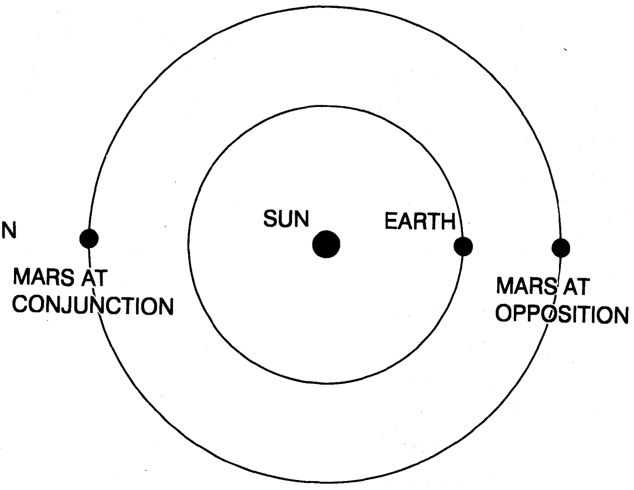

Figure 6. Sun, Earth, and Mars in the Copernican System. In the Copernican system Mars at opposition automatically is closest to Earth, and automatically is farthest from Earth at opposition.

The mathematical realism of Copernicus, as it has been called (Duhem, 1969:xxiv), is not entirely dissimilar to considerations present in contemporary cosmology. The standard big bang theory is in agreement with observation, as was Ptolemaic astronomy in Copernicus' time, but the standard theory requires some extremely stringent initial conditions to be 'put in by hand', as did Ptolemaic astronomy (to ensure, among many arrangements, that Mars always was nearest Earth at opposition and farthest from Earth at conjunction). The inflationary universe theory, in contrast to the standard theory and in comparison to the advantage of Copernican over Ptolemaic theory, does not require that the initial energy density be incredibly close to unity nor does it require a primordial spectrum of inhomogeneities; these follow automatically from the initial inflation and phase transition in the first fraction of a second of the history of the universe (Guth, 1993).

The greater degree of completeness of a theory relative to its rivals does not, of course, guarantee continued agreement between the theory and observation, nor continued acceptance of the theory. A single example from Kepler suffices here. In his *Mysterium Cosmographicum* of 1595, Kepler wrote that he had spent an entire summer racking his brain to discover how the cosmos expressed the nature of its Creator. What Kepler hit upon in a moment of divine inspiration was nothing less than a convincing explanation for the observed fact that there were six planets (his theory was Copernican, in the sense that the Sun and Moon were not planets, but Earth was). There are exactly five regular solids (each with all sides and faces identical), no more and no less. If one of these regular solids is circumscribed about the first circular planetary orbit, and the next planetary orbit put around that solid, etc., one has exactly six planets and five intervening regular solids, no more and no less. Here, seemingly, was the reason for the number of the planets. For Kepler, regular solids did not exist physically in the heavens; rather they were conceived of as archetypes governing the disposition of the planetary orbits (Donahue, 1993a, 1993b).

A scientific theory is, at least for some connoisseurs, more penetrating and more complete and more satisfying to the extent that observed phenomena follow automatically from theory rather than require arbitrary and meticulous adjustments to initial conditions if they are to be reproduced. Rival theories may be equal in an instrumentalist sense, in that both save the same phenomena, but the greater ease with which one saves phenomena can evoke a greater sense of satisfaction, even a sense of beauty. Furthermore, a sense of having discovered reality may well be invoked, but not necessarily on the basis of agreement between theory and observation. If restricted to classification as either instrumentalism or realism, much of science may be closer to realism than instrumentalism – but more a realism of Platonic ideas than an empirical realism.

9 CONCLUSION

Historians need exercise care, of course, lest they read current understanding of the nature of science back into the past and force into a procrustean bed ancients who may have been thinking and doing something very different. Yet at the same time, historians would be foolish not to take advantage of modern formulations of issues and use them to probe the past. The charge of 'presentism' or 'Whig history' is a potent but indiscriminate club, too quickly raised by contextualists and prigs against historians who would use their own experience in science to help understand and empathize with the emotional state of past researchers (Harrison, 1987; Brush, 1995).

The nature of modern science, itself, remains in debate as well. On a personal note, one of the long-term, festering incentives for this study of Plato and science was hearing an otherwise seemingly knowledgeable and sensible philosopher of science deny that a sense of beauty could ever be evoked in anyone by a scientific theory because he, himself, was blind and deaf (these may not be his exact words) to such beauty.

Modern science has an aesthetic element, possibly comparable to that found in ancient Greek geometrical astronomy. The continuation of a cultural value over millennia and over vastly different civilizations would be a remarkable occurrence. No less remarkable would be genetic wiring of the human brain, shaping our requirements for an aesthetically-satisfying understanding of nature. Such speculations are premature, but do suggest further study of the nature of ancient and modern science and possible similarities between ancient and modern aesthetic philosophical values and ways of thinking.

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