A LESSON FROM THE ARCANE WORLD OF THE HEAVENLY SPHERES ACCORDING TO MAIMONIDES

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The Teaching and the Text

So that the ordinary Jew have an informed view of creation as a step toward true conviction about God, Maimonides devotes chapter three of "*Hilkot yesôdê hattôrāh*" of the *Mišne Tôrāh* to an exposition of medieval astrophysics. The system he expounds has several traits that are strange to modern ears: first, it is geocentric; second, the heavenly bodies do not move by themselves in space but are embedded in transparent spheres which move; third, there is no empty space at all between these spheres; and fourth, Aristotelian physics demanded a system with circular uniform movement about a single fixed center. However, since the actually observed motions of the heavenly bodies do not fit this model, ancient and medieval astrophysicists invented a complicated series of spheres-within-spheres to account for the actual phenomena. This attempt to "save the phenomena," as Simplicius put it, seems very artificial to us, particularly since we now know it to have been a useless undertaking. We reject geocentrism, we accept the idea of space, and we are not bound by the idealist definitions of motion in Aristotelian physics. Maimonides, however, accepted all this and, as we shall see, took an important place in the extended fight over which of the explanations available to him was the correct one.[1]

1. The best history of these matters remains the classic by Duhem (1913). Volumes I and II cover antiquity and the middle ages. Duhem's explanations are of an exceptional clarity.

The bibliography on the history of science is extensive though still rather sparse in the area of Islamic science. The following deserve note: Duhem (1969), with an excellent introductory essay, is an epitome of the larger work; Neugebauer (1975) is *the* technical work in the field; Kuhn (1966); Dreyer (1953); the very fine technical studies of D. Pingree, B. Goldstein, and E. S. Kennedy; and Nasr (1976). None are as clear for the layperson as

Maimonides begins his exposition by enumerating the Hebrew words which denote the spheres and then by listing the spheres in order, remarking that they are transparent (paragraph 1). He continues by stating that they are divided into many layers "as the layers of an onion," that they rotate in different directions, that there is no empty space between them (paragraph 2), and that they have no accidental properties such as weight or color[2] (paragraph 3). Maimonides, then, describes the heavenly system as follows (paragraphs 4 and beginning of 5):

> All these spheres which encompass the earth are round like a ball, and the earth is suspended in the middle. A few of the stars have small spheres in which they are set. Those spheres do not encompass the earth; rather the small sphere which does not encompass [it] is set in the larger encompassing sphere. The number of spheres which encompass the world is eighteen and the number of spheres which do not encompass [it] is eight.

The rest of the chapter is devoted to the parameters by which the movement of the stars is calculated, the constellations, the relative size of the heavenly bodies, and the elements.

The questions of this essay are: What were the various types of spheres which Maimonides mentions, and how did Maimonides arrive at his calculation of the number of the spheres?

The Conceptual Problem

Maimonides' image of an onion is wonderful. It catches the spheres-within-spheres, the solidity, the uniformity of motion, and the transparency. The reader need only picture him/herself at the immobile center of the onion looking outward to capture the sense of this system.[3]

Duhem. On the issue of who asked whom to "save the phenomena," cf. B. Goldstein (1980).

A word about terms: "Astrophysics" is, of course, a modern term. The proper medieval term is "physics" or "cosmology." But, because these men tried to apply precision mathematics to the heavenly bodies, I have chosen the modern term. "Space," too, is a modern concept, the proper medieval term being "vacuum." Since, however, space is not completely empty, I prefer that term.

My thanks to my colleagues Bernard Goldstein and Tsvi Langermann who patiently helped me with the more arcane aspects of this material. They are, however, not responsible for my errors.

2. The blueness of the sky is, then, an illusion as Maimonides states. Cf. E. Wiedemann (1915), strangely not included in the two-volume collection of Wiedemann's work. For the color of the dawn sky as a function of the atmosphere, cf. Maimonides, ***Pērûš hammišnā***, Berak̲ot 1:1.

3. Three facts about the earth were basic to all antique and medieval astrophysics: that the earth is round, that it is immobile, and that it is the center of the universe. All three

The onion image, which occurs in the *Rasāʾil ʾIkhwān al-Ṣafāʾ*, Third Letter,[4] is based on the assumption that there can be no movement at a distance, or, worded positively, that motion-change is continuous: A pushes B which pushes C and so on. The moving beings, thus, must be in contact with one another. This derives from Aristotle,[5] and it was dogma in the middle ages. Maimonides repeats it in his *Guide for the Perplexed*, II:1, beginning, and it forms the basis of his proofs for the existence of a prime mover. This assumption, in turn, implies that there is no empty space, as Maimonides indicates here and in *Guide*, I:72, beginning ("they cling to each other"); II:24, 30; etc., following Aristotle, *Physics*, IV:1–9 (Duhem, 1913, I, pp. 189–91, 197–205) and Alfarabi's well-known treatise on the impossibility of a vacuum.

In a system rotating like an onion, all layers rotate uniformly at a speed proportional to their distance from the center. The various stars and planets, thus, would appear to the observer on the immobile core to rotate in unison. The actually observed heavenly movements, however, do not conform to this model. Some appear to move faster than others; some appear to change directions. J. Bronowski (1973, p. 191) has a startlingly clear photograph, taken with time exposure in the Munich Planetarium, showing the apparent paths across the sky of Mercury, Venus, Mars, Jupiter, and Saturn. It shows clearly a circling-back motion for the planets, called "retrograde" motion, and one can appreciate the difficulty of the ancients who tried to account for this motion, given Aristotelian physics.[6]

The conceptual question, then, was: "What are the circular and perfectly regular movements which one can accept as hypotheses so that

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ideas are drawn from Aristotle. On the roundness of the earth, cf. *De Caelo*, II:14 (Duhem, 1913, I, p. 211). That the earth is immobile was a matter of argument in antiquity, but Aristotle defended it strongly in *De Caelo*, II:3 (Duhem, 1913, I, pp. 220–30). The basic argument is that the rotation of a sphere implies a real fixed body at its center, not a theoretical geometric point. This is supported by Simplicius, Alexander of Aphrodisias, Themistius, Ptolemy, and others. Although strange to us, it was clear doctrine in earlier times. On the earth as the center of the universe, cf. *De Caelo*, II:14 (Duhem, 1913, I, pp. 217–19). All these ideas preceded Aristotle. Duhem (1913, I, pp. 8–9) ascribes them to Pythagoras. Maimonides repeats them in *Guide*, I:72.

4. Beirut edition, I, p. 115, l. 8; Cairo edition, I, p. 74; Bombay edition, I, p. 57. For cross-referencing, cf. D. Blumenthal, "A Comparative Table of the Bombay, Cairo, and Beirut Editions of the *Rasāʾil ʾIkhwān al-Ṣafāʾ*," *Arabica*, 21:2, 16–203. Cf. also Sh. Abramson, *Ozar Yehûdê Sefarad* 11–12 (1969–70) 52–53.

5. *Physics*, III:2:202a:5 ["But it does this by contact"]; VIII:5; *Metaphysics*, XII:6, 7.

6. Bronowski also has several pictures of a clock (pp. 194–96) designed by Giovanni de Dondi in 1350, which depicts the motion of the planets, including the epicyclic motion. Each is depicted on one of the seven faces of the clock.

one can save the appearances presented by the errant stars?" (Simplicius, *Commentary to De Caelo*, II:12, cited in Duhem, 1913, I, p. 103). Put differently: How can the observer at the immobile center of Maimonides' transparent onion who sees the irregular motion of the planets, sun, and moon account for that motion in a systematic fashion, given the ideal of circular and regular movement?

Three Solutions

There were three systems of spheres-within-spheres that were designed to answer the conceptual question. The first was the system of *homocentric* spheres. According to this hypothesis, there are many spheres-within-spheres, all of which have the earth as their center. They do not, however, all rotate in the same direction. Some rotate from east to west and some from west to east. This counter-directional rotation slows some of the spheres. In all cases, the observer on earth sees only the luminous bodies in the spheres, not the spheres themselves. These bodies (planets, sun, and moon) appear to trace an irregular path across the heavens; see Duhem (1913, I, pp. 55–56) for a very clear account of the apparent spiral that is thus generated. This system, then, is an attempt to account for the irregular motion of some of the heavenly bodies using *only* homocentric spheres but with three variables: different directions, different velocities, and different poles (i.e., with axes inclined with respect to one another). It is the system of Eudoxus, Callipus, and Aristotle.[7] The system of homocentric spheres, however, did not work well; it did not, and could not, account for all the observed facts. So astronomers and mathematicians tried another idea.

The second system was that of the *eccentric* spheres. An eccentric sphere is a sphere whose center is *not* the earth. It rotates about a theoretical point somewhere else in the universe. It is, however, contiguous with the other spheres, there being no empty space. For this reason, its movement affects the movement of the regular homocentric spheres. The variables here are the same as above—different speeds, different directions, and different poles—but with an addition: variation in the number of eccentric spheres needed to account for the movement of the specific heavenly body. The luminous body (star) is, thus, pulled and pushed in various directions which, in sum, describe its irregular path across the heavens of the observer; see Duhem (1913, I, pp. 430–31) for an exceptionally lucid presentation. This was the system of Heraclides

7. Duhem, 1913, I, pp. 102–29; Aristotle, *Metaphysics* XII:8; Goldstein and Bowen, 1983.

of Pontus and Hipparchus. The system of eccentric spheres, too, did not work well. It contradicted the logic of Aristotle's physics by positing non-homocentric (i.e., abnormal) spheres, and it did not fit all the facts. So astronomers and mathematicians turned to another idea.

The third system is that of the *epicyclic* spheres. An epicyclic sphere is a smaller sphere that rotates around its own center. It is, at the same time, embedded in the surface of its "deferent" (= host) sphere. To grasp this, one must imagine a round grape embedded in the surface of a round peach such that the center of the grape is on the surface of the peach. Both the grape and the peach rotate, though at different speeds, in different directions, and possibly with axes that are not parallel. The grape is the epicyclic sphere; the peach is the deferent sphere. Both the epicyclic sphere and the deferent sphere are invisible; the luminous body (or star) is embedded in the epicyclic sphere. Seen from the point of view of the observer inside the transparent onion (= on the immobile circular pit of the peach), the star would appear to follow a very, very complex path (Duhem, 1913, I, pp. 431–34). To this, however, we must add the variables of different directions and velocities and we must compound the system by using homocentric, eccentric, and epicyclic spheres all at once. Ptolemy, in his *Almagest*, even added an angle of inclination for the epicyclic sphere with respect to its deferent and endowed the epicyclic sphere with irregular velocities (Duhem, 1913, I, pp. 491–95; II, pp. 90–99). There is an added complication: In some models, the epicyclic sphere does not remain fixed in its deferent but is pushed or "rolled" along by the complex forces acting on it. Here, too, variables of direction, speed, etc., have an effect. The system of epicyclic spheres was much better. It did account, with great accuracy, for almost all the observed astronomical facts.[8] However, it too contradicted Aristotle's physics, and a real war of words and numbers developed between those favoring Aristotle's idealistic view of the world and those who wanted to account for as many facts as possible (Duhem, 1913, II, chapters 10, 11; Goldstein, 1980b). Maimonides had his place in this great debate.

Maimonides' Position

Maimonides was part of the Spanish Aristotelian revival which questioned Ptolemy's astrophysics because it contradicted the laws of motion established by Aristotle. The revival included Ibn Ṭofayl, Ibn Bajja, Maimonides, Averroes, Ibn ʾAflaḥ, and al-Bitruji (Duhem, 1913, II,

8. The full epicyclic system, however, had its limits too. Toulmin and Goodfield (1961, pp. 141–42) show how such a system could produce almost any orbit desired, including a square orbit!

pp. 131–78). The core of their objection to the system of epicyclic-eccentric-homocentric spheres is based upon five arguments: (1) It contradicts Aristotle's law of natural movement. The eccentric and epicyclic spheres have centers that are not the fixed immobile body which is at the center of the universe (the earth). Those spheres are non-geocentric and have points (not bodies) as their centers. Maimonides was particularly vexed by this because the center of some of these spheres is not even below the sphere of the moon, i.e., close to earth (Goldstein, 1980a; 1980b, pp. 138–39). (2) It contradicts Aristotle's law of regular bodies by creating irregular shapes within the realm of the spheres. A non-geocentric sphere, contiguous with a geocentric sphere, creates an irregular shape where they meet, something akin to the inside of an avocado with an irregularly-sized pit. Ptolemy and his defenders responded with an inter-spherical fluid which filled these spaces, there being no empty space in medieval science. (3) It violates Aristotle's laws of uniform motion with Ptolemy's irregular speeds for epicyclic spheres. (4) It violates Aristotle's law of perfect circular motion, because the epicyclic spheres do not move in the same circle as the other spheres and, in the "rolling" models, change location in the surface of the host spheres or in the tube interface. And (5) there was an alternate system by al-Bitruji which, while not explaining all the facts, came more within the idealistic physics of Aristotle. This system used only homocentric spheres, kept the one fixed center, but varied the angle of the axis of rotation considerably (Duhem, 1913, II, pp. 148–71; Goldstein, 1980b, p. 140).

The fight thus resolved itself into a conflict between Aristotelian orthodoxy and practical astronomy. In Duhem's words, "C'est un devoir d'étudier l'Astronomie des réalités, l'Astronomie géométrique; seule elle peut dissiper les erreurs nées de l'Astronomie d'observation . . . seule elle prépare nos âmes à la contemplation du Bien suprême . . ." (1913, I, p. 101).

The position of Maimonides is quite clear.[9] First, he understood fully the nature of the argument (*Guide*, II:24; transl., S. Pines 325–6):

> If what Aristotle has stated with regard to natural science is true, there are no epicycles or eccentric circles and everything revolves round the center of the earth. But in this case how can the various motions of the stars

9. For the views of Maimonides, cf. Duhem (1913, II, pp. 139–46) and Nutkiewicz (1978). Cf. also the highly technical article of Neugebauer (1949) with the response by Gandz (1950; 1951). The difference of opinion between the latter two revolves around the definition of the *molad*, Gandz retaining the traditional usage as the moment of conjunction between the paths of the sun and the moon and Neugebauer proposing a new definition. Gandz' language in defense of the tradition is quite colorful.

> come about? Is it in any way possible that motion should be on the one hand circular, uniform, and perfect, and that on the other hand the things that are observable should be observed . . . unless this be accounted for by making use of one of the two principles [epicyclic or eccentric spheres] or both of them? This consideration is all the stronger because of the fact that if one accepts everything stated by Ptolemy concerning the epicycle of the moon . . . it is not at fault by even a minute. The truth of this is [also] attested by the correctness of the calculations . . . concerning eclipses . . . Furthermore, how can one conceive the retrogradation of a star, together with its other motions, without assuming the existence of an epicycle?

Second, Maimonides knew that the true function of an Aristotelian astronomer was to build a system that was ideal (ibid.; cf. also *Guide*, II:11):

> For his purpose is not to tell us in which way the spheres truly are, but to posit an astronomical system in which it would be possible for the motions to be circular and uniform *and* to correspond to what is apprehended through sight, regardless of whether or not things are thus in fact.

Third, Maimonides knew full well the problems inherent in the various theories of the spheres. He lists the problems with the homocentric system in *Guide*, II:19: the spheres should rotate at velocities proportional to their distance from the center, and they do not; they should all be rotating in the same direction, and they do not; the stars should be of the same matter as the spheres and hence indistinguishable from them, and they are not; and the stars in the eighth sphere should be regularly distributed, and they are not. He lists the problems with the eccentric and epicyclic systems in *Guide*, II:24: the path traced by the epicyclic sphere in the surface of its deferent sphere implies a movement in the heavens that is not circular but is a change of place, but the heavens are immutable and no such change can occur in them; both violate the laws of natural motion (see above); both violate the law of the immobile center (see above); and both could imply an infinite series of spheres and centers to account for all motion. Infinite series of bodies are impossible.

Fourth, Maimonides realized that, while science had advanced a great deal since Aristotle, humankind still could not grasp the reality of the heavenly universe (*Guide*, II:24, end).

In sum: Maimonides expounds the homocentric model throughout the *Guide*, esp. in I:72, as well as here, 3:1–2. He expounds the eccentric model in *Guide*, I:72 and II:11 (for the sun), as well as here in 3:4 and *Mišne Tôrāh*, *Qidduš haḥōdeš* 11:13–14. And he even accepts the epicyclic model in *Guide*, II:24 (for the moon, the eclipses, and the retrograde motion of the planets) and in *Guide*, I:72 (where the issue is left open), as well as here, 3:4 and in *Mišne Tôrāh*, *Qidduš haḥōdeš*, 14:1. To put it differently, Maimonides accepts the Ptolemaic system of eccentric and epicyclic spheres *faute de mieux*. It is, thus, *not* the case, as some have maintained,[10] that Maimonides accepts the Ptolemaic option in *Mišne Tôrāh* but rejects it in the *Guide*.

The Problem of the Number of the Spheres in "Hilkôt yesôdê hattôrāh"

At the beginning of paragraph five, Maimonides set forth the number of the spheres: "The number of spheres which encompass the world is eighteen and the number of spheres which do not encompass [it] is eight." Maimonides was not clear on the details of the system, but the anonymous commentator published in the standard editions of "*Hilkôt yesôdê hattôrāh*" understood Maimonides to be advocating the following: for Saturn, Jupiter, and Mars—one homocentric, one eccentric, and one epicyclic sphere; for the sun—one homocentric and one eccentric sphere; for Venus—one homocentric, one eccentric, and two epicyclic spheres; for Mercury—one homocentric, two eccentric, and two epicyclic spheres (this is the most complex part); and for the moon—one homocentric, two eccentric, and one epicyclic sphere. This, together with the homocentric sphere of the fixed stars and that of the outermost (diurnal) sphere, yields eighteen "spheres which encompass the earth" (i.e., homocentric and eccentric [the latter must contain the earth within their volume]) and eight "spheres which do not encompass it" (i.e., epicyclic), which totals 26, as specified in "*Hilkôt yesôdê hattôrāh*" 3:5. The sources of the anonymous commentator are unknown to me.

Not everyone, however, agreed with the anonymous commentator. One of the most interesting of Maimonides' commentators on this issue was an early Arabic interpreter who had the advantage of reading Islamic science in its original Arabic: ᶜAlāᵓ al-Dīn [Abū-l-Ḥasan ᶜAlī ibn Ṭibgha al-Ḥalabī al-Ḥanafī] al-Muwaqqit (cf. Straus-Ashtor, 1944, p. 355), a well-known Syrian astronomer who died in 1391 and who commented on Maimonides' "*Hilkôt yesôdê hattôrāh*" (British Museum ms. 498, Ad. 27, 294).[11] He lists the stars with their respective homo-

10. Nikiprowetsky (1961, p. 50, n.); Neugebauer (1949, p. 336).

11. For the Arabic text of "*Hilkôt yesôdê hattôrāh*" upon which ᶜAlāᵓ al-Dīn's commentary is based, cf. D. Blumenthal, 1984.

centric and eccentric spheres according to their Arabic names and continues:

> As to the remaining spheres which do not encompass the universe, they are called "epicyclic spheres." They are six [in number]. The author, however, has mentioned that they are eight. But this is only a moment of absent-mindedness for him, or a slip of the pen. Indeed, human nature has no refuge from this [folio 100a] . . . As to the epicyclic spheres, they are six [in number]: one for the Moon and five for the five wandering stars [Saturn, Jupiter, Mars, Venus, Mercury], one for each. As to his saying "eight," it has no relation to what was said previously [folio 108a].[12]

ʿAlāʾ al-Dīn, then, simply considers the number eight for the epicyclic spheres to be wrong, a slip of the pen!

Similarly, Zeḵarya ha-Rofeʾ,[13] a well-known Yemenite author of the fifteenth century who also commented on Maimonides' "*Hilḵôt yesôdê hattôrāh*" (Jewish Theological Seminary ms. 6978, fol. 49a; ibid., ms. 6982, fol. 149a; private ms. fol. 53a), lists only the number of the respective homocentric and eccentric spheres and, then, continues:

> [as for his saying "eight":] to each of the seven [Saturn, Jupiter, Mars, Sun, Venus, Mercury, and Moon] there is one epicyclic sphere although scholars differ about the Sun as mentioned. Indeed, our Rabbi has dealt with important thoughts and in the matter of [general] instruction, not with precise thoughts.[14] So it is with the eight epicyclic spheres. Whoever wishes to investigate this should study it in places that deal specially with it.

For Zeḵarya, then, the issue of the number eight is far from clear.

Other commentators, early and late, ignore the issue: Judah Romano (Paris ms. 1005, fol. 61a and parallel texts); Ephodi and Shem Tov (to *Guide* I:72, where they could have dealt with this and did not); Munk (ibid.); and Nikiprowetsky, Rubenstein, and Krakowsky (in their commentaries to "*Hilḵôt yesôdê hattôrāh*, ad loc.).

The issue of how Maimonides reaches his calculation of the number of heavenly spheres thus remains hidden from us.

12. In Arabic, *ṣahw minhu ʾaw sabaq min al-qalam faʾinna al-ṭabīʿa al-bašarīya lā maḥīṣ lahā ʿan dhālika . . . fa-mā lahu sabab ʾilā mā taqaddama qawluhu*. In this last clause, ʿAlāʾ al-Dīn is probably referring to his careful exposition of Maimonides' astrophysics (fol. 98b–106a). He may, however, be saying that this simply has no basis in Maimonides' own text here.

13. On Zeḵarya, cf. D. Blumenthal (1981, Index).

14. In Arabic, *bi-jalīl al-naẓar wa-ʿalā sabīl al-ʾiršād lā bi-tadqīq al-naẓar*.

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