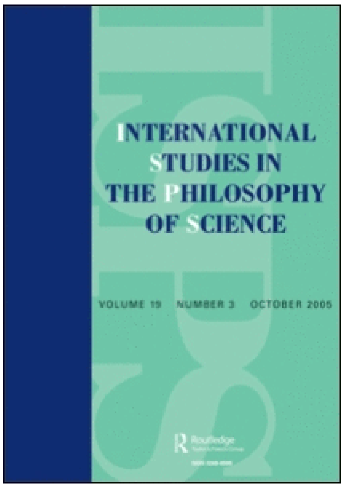

International Studies in the Philosophy of Science
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713427740

On the Determination of Planetary Distances in the Ptolemaic System

Christián C. Carman

Online publication date: 06 January 2011

To cite this Article Carman, Christián C.(2010) 'On the Determination of Planetary Distances in the Ptolemaic System', International Studies in the Philosophy of Science, 24: 3, 257 — 265
To link to this Article: DOI: 10.1080/02698595.2010.522408
URL: http://dx.doi.org/10.1080/02698595.2010.522408

International Studies in the Philosophy of Science
Vol. 24, No. 3, September 2010, pp. 257–265

On the Determination of Planetary Distances in the Ptolemaic System

Christián C. Carman

In 1975, Imre Lakatos and Elie Zahar claimed that the determination of planetary distances represents excess empirical content of Copernicus's theory over that of Ptolemy. This claim provoked an interesting discussion during the first half of the 1980s. The discussion started when Alan Chalmers affirmed that it is not correct to attribute this advantage to the Copernican system over the Ptolemaic. Other scholars criticized Chalmers's assertion, reaffirming the position of Lakatos and Zahar: one went even further, asserting that Copernicus has not one but two methods for calculating distances, even though this claim was subsequently also criticized. But all participants assumed that Ptolemy has no method for calculating planetary distances. In this article, I argue that this is not correct. I argue, in fact, that Ptolemy has two independent methods for calculating the distances of some of the planets and, therefore, as far as the calculation of planetary distances is concerned, Ptolemy's system surpasses that of Copernicus.

In 'Why did Copernicus' Research Program Supersede Ptolemy's?', Imre Lakatos and Elie Zahar (1975, 379) asserted that 'the determination of planetary distances represents excess empirical content of Copernicus's theory over Ptolemy's'. This assertion provoked an interesting discussion in the *British Journal for the Philosophy of Science* during the first half of the 1980s. The discussion was started by Alan Chalmers (1981) who claimed that if Ptolemaic astronomers had happened to inhabit the sun rather than the earth, then they would have been able to calculate the planetary distances within the Ptolemaic system. Actually, Chalmers says:

> in the Copernican system there are three 'points' that serve as the vertices of the triangles that enable the magnitude of planetary orbits to be compared. They are the sun, which is the centre of planetary orbits, the earth, where the observer is situated, and the planet under consideration. In the Ptolemaic system the centre of the orbits and

Christián C. Carman is at the Department of Social Sciences, National University of Quilmes. Correspondence to: Departamento de Ciencias Sociales, Universidad Nacional de Quilmes, Roque Sáenz Peña 352, Bernal B1876BXD, Buenos Aires, Argentina. E-mail: ccarman@unq.edu.ar

ISSN 0269–8595 (print)/ISSN 1469–9281 (online) © 2010 Open Society Foundation
DOI: 10.1080/02698595.2010.522408

> the point of observation coincide. Consequently the three points are reduced to two and the appropriate triangles cannot be constructed. (Chalmers 1981, 374)

Therefore, 'the fact that the magnitude of planetary orbits can be compared in the Copernican theory but not in the Ptolemaic theory is due to the situation of the observer in the planetary system' and 'such an attribution may have been appropriate within Aristotelian theory, but it is hardly appropriate now' (Chalmers 1981, 374, 375).

The December 1983 issue of the *British Journal for the Philosophy of Science* carried two comments on Chalmers's work together with a short reply by him. In the first, Martin Curd (1983) held that it is not true that Ptolemaic astronomers who happened to inhabit the sun would be able to calculate planetary distances. In the second comment, Keith Hutchison presented an objection similar to that of Curd, while adding a new element to the discussion: 'while it is true that the Copernican theory allows one to measure planetary distances by triangulation, it is also true—and highly significant—that the theory also allows one to determine these distances *without* triangulation. A Copernican astronomer can evaluate the relative distances of the planets from the centre of the Solar System, directly from the tracks of the planets through the Zodiac … without reference to the triangulations at the centre of Chalmers's discussion.' Thus, 'the Copernican can predict the results of solar triangulations before they are carried out. In doing this, he runs a real risk of having his theory falsified. … It is then, not simply the fact that the planetary distances can be determined which distinguishes for the Copernican theory, it is the fact that they can be *doubly* determined' (Hutchison 1983, 370). In his reply, Chalmers (1983) accepted that Hutchison's suggestion regarding two independent methods was significant to the debate.

Three years later, Angelo M. Petroni and Lucio Scolamiero showed that the second method proposed by Hutchison and accepted by Chalmers was not independent of the triangulation method. Hence, 'the claimed *double* determinability of the planetary distances in the Copernican system is not a genuine one. It is just a double way of doing the very same calculation' (Petroni and Scolamiero 1986, 339). So, Petroni and Scolamiero conclude, 'if one accepts the thesis that a theory (or one of its consequences) has no empirical value unless there exists an independent empirical test of it, then the determination of planetary distances does not belong to the empirical aspect of Copernicus' system. It constitutes only a part of its *systematic superiority* over the Ptolemaic system' (Petroni and Scolamiero 1986, 339).

Finally, Hutchison replied to Petroni's and Scolamiero's objection in a brief footnote. Hutchison said that he does not 'understand why they say this, as as in my original discussion I pointed out that a Copernican astronomer can determine the relative distances "without reference to the existence or visibility of the Sun" … Two calculations can hardly be the same if one requires the sun to exist and the other does not' (Hutchison 1990, 73n20). This is not a good answer, however, because, even if it is true that in describing the calculation proposed, Hutchison (1983, 370) talked about the 'centre of the "Solar" System' without mentioning the sun, it is also true that when the geometrical equivalence of the models is accepted—and Petroni and Scolamiero have shown that it is necessary to accept this—the 'centre of the "Solar" System' must be identified with the sun in order to render the Ptolemaic values for the radii of the

Copernican deferent and epicycle meaningful. Actually, this is exactly what Hutchison himself affirms when he says that the Copernican astronomer can predict the results of solar triangulation only when 'the existence of a visible Sun near the centre of the system is assumed' (Hutchison 1983, 370). Otherwise, the Ptolemaic values are meaningless from the Copernican point of view. Therefore, the Copernican astronomer does not run any risk when the results of the two methods are compared.

Hutchison asserted that 'to argue that the Ptolemaic theory has equal capacity to determine planetary distances, one must show that it provides two independent routes to these distances' (Hutchison 1983, 370). There would be no need to reopen a discussion closed two decades ago, were it not for the fact that in Ptolemy's system there are actually not one but two independent methods of calculating planetary distances. This fact was unjustifiably ignored in all the debate.

Actually, Ptolemy tries to obtain the absolute planetary distances in his *Planetary Hypotheses* (Heiberg 1907; Goldstein 1967). The calculation method is briefly described by Thomas S. Kuhn (1957, 81–82), even if Kuhn attributed it to Arabic astronomers: the discovery of Ptolemy's authorship of the calculation came in 1967 when the part of the *Planetary Hypotheses* dedicated to calculations of distance was found and translated. The method allows Ptolemy to calculate all distances, including that of the sun from the earth.[1] In fact, in the *Almagest*, making use of his system of deferents and epicycles, Ptolemy was able to establish the ratio of the radii of the deferent and of the epicycle. Had he also considered the eccentric, he would have been able to calculate the ratio of a planet's maximum and minimum distances. The maximum would be, in most cases, the addition of the three values, and the minimum could be obtained subtracting the addition of the epicycle radius and eccentric value from the deferent radius (Figure 1).

Furthermore, as Ptolemy says, 'for it is not conceivable that there be in Nature a vacuum or any meaningless and useless thing' (Goldstein 1967, 8), the maximum distance of a planet (apogee) corresponds to the minimum distance of the immediately superior planet (perigee). If he had one absolute distance and the order of the distances of the heavenly bodies, then taking these ratios into account he would be able to calculate the maximum, mean, and minimum distances of each planet. In the *Almagest* (V, 13; Toomer 1998, 247–251), using parallax, Ptolemy calculated the moon's maximum distance as 64.16 tr (terrestrial radii). In the *Planetary Hypotheses*, he rounded the value down to 64 tr (Goldstein 1967, 7). He therefore puts Mercury's minimum distance at 64 tr and, taking Mercury's ratio to be 88/34, he calculates Mercury's maximum distance to be 166 tr, which then coincides with the minimum distance of the following planet, Venus. The ratio of Venus's distances is 104/16, so Venus's maximum distance would be 1,079 tr. There were several reasons to think that the sun should be located after Venus, and so Venus's maximum distance should be equal to sun's minimum distance. The same method applies to Mars, Jupiter, Saturn, and, finally, to the fixed stars (Figure 2).

Ptolemy, however, had calculated the sun's mean distance in the *Almagest* (V, 15; Toomer 1988, 255–257) with another method, absolutely independent of the nesting spheres method, as Albert van Helden (1985) has called it. The *Almagest* calculation is

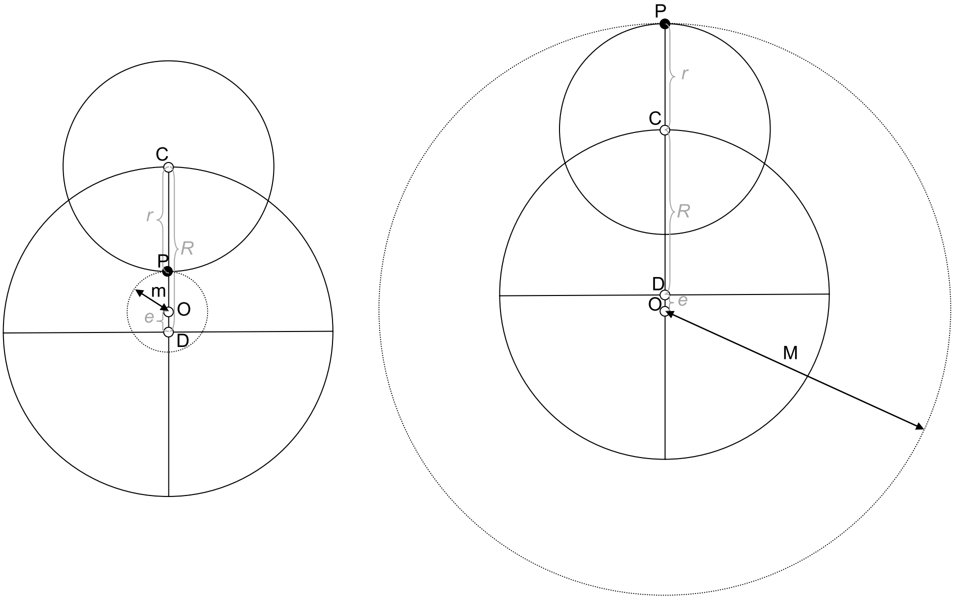

Figure 1 The observer is located at the Earth (O), the center of the deferent is D, the center of the epicycle is C and the planet is at P. Consequently, the distance OD is the eccentric (*e*), the distance DC is the radius of the deferent (*R*) and the distance CP is the radius of the epicycle (*r*). The minimum distance of a planet (m) is equal to $R - e - r$ (left) and the maximum distance (M) is equal to $R + e + r$ (right).

based on a diagram representing at the same time both solar and lunar eclipses and enables a calculation of the sun's distance using only three data: the moon's greatest distance, the apparent moon and sun radii when the moon reaches its greatest distance, and the radius of the earth's shadow, also at the moon's greatest distance (see Pedersen 1974, 203–214). This method is independent of the heliocentric or geocentric assumption and was used for the first time by Aristarchus, then by Hipparchus and many others after Ptolemy, including Nicholas Copernicus ([1543] 1952, 710–713). The value obtained by Ptolemy in the *Almagest* for the sun's mean distance is 1,210 tr and so, using Ptolemy's value for the eccentricity of the sun's orbit, the sun's least distance would be 1,160 tr. This result does not coincide with the value of 1,079 tr obtained in the *Planetary Hypotheses* calculation, but it is extraordinarily close. Ptolemy realizes the discrepancy and affirms that 'since the least distance of the Sun is 1160 earth radii, as we mentioned, there is a discrepancy between the two distances which we cannot account for: but we were led inescapably to the distances which we set down' (Goldstein 1967, 7). Curiously enough, a great part of the discrepancy could be avoided if Ptolemy had not rounded the ratios used and had not committed some arithmetical mistakes. The relevant thing, however, is that Ptolemy possessed two independent methods for calculating planetary distances. One way to argue for the independence is to highlight that the results of the nesting spheres method depend directly on the values of the eccentric and the radii of the planets' deferents and epicycles, and that these values do not play any role in the eclipse diagram method. Nevertheless, the

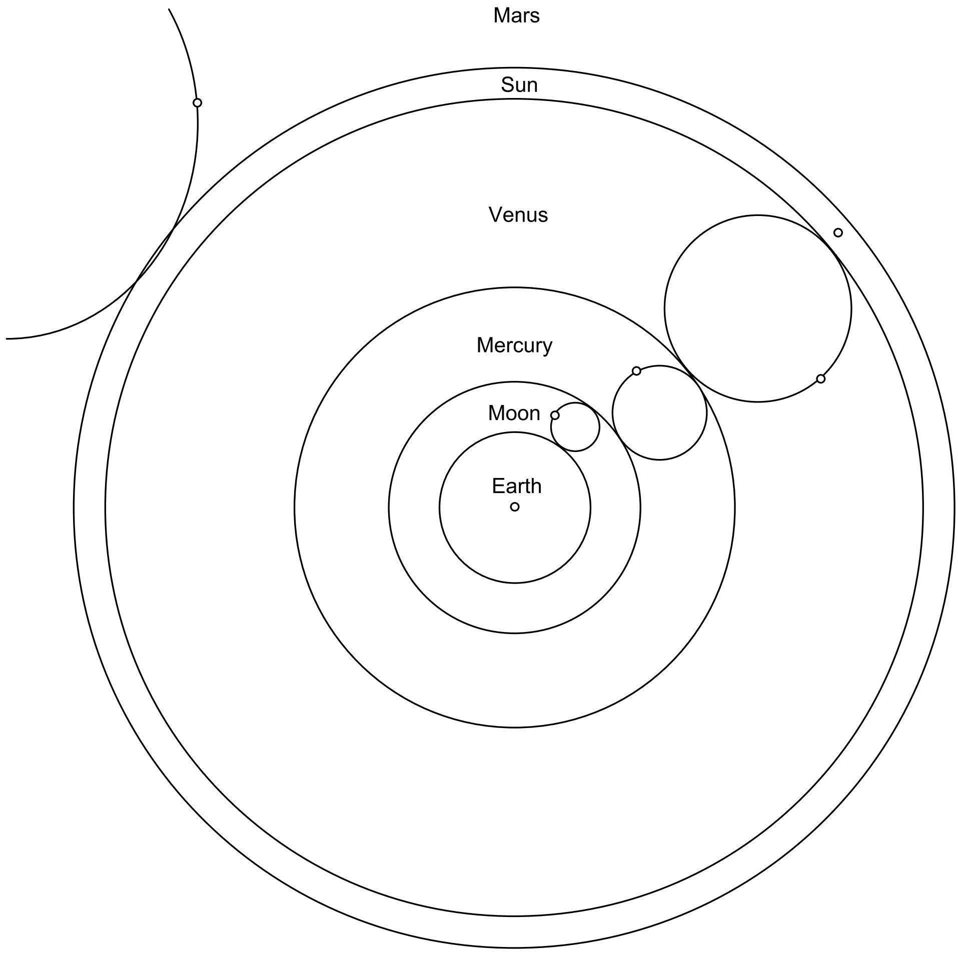

Figure 2 The Ptolemaic nested spheres method. The maximum distance of a planet is equal to the minimum distance of the immediately superior planet. This is simplified version, not scaled, and ignoring eccentricities.

discrepancy of the results is the best proof of the independence of the two methods (Carman 2009).

Moreover, because of the peculiar characteristics of the nesting spheres method—which used as input the moon, Venus, and Mercury distances—the double calculation is also an indirect corroboration of these distances. So, Ptolemy has, if not for all planets, at least for the sun directly, and for the other three indirectly, two independent methods, as Hutchison required.

Needless to say, the fact that Copernicus also used the eclipse diagram method for obtaining the earth–sun distance does not imply that he had two independent methods for obtaining the sun distance, because the sun distance is, together with that of the moon, the distance that cannot be obtained by triangulation. Remember that Chalmers showed that 'in the Copernican system there are three "points" that serve as the vertices of the triangles that enable the magnitude of planetary orbits to be compared. They are the sun, which is the centre of planetary orbits, the earth, where the observer is situated, and the planet under consideration'. Furthermore, Chalmers added that in 'the Ptolemaic system the centre of the orbits and the point of observation coincide. Consequently the three points are reduced to two and the appropriate triangles cannot be constructed.' Moreover, we should add that in the Copernican system the appropriate triangle cannot be constructed for the sun either, because the centre of the planet's orbit (the sun) and the *planet* under consideration coincide. In the case of Ptolemy's system the situation is different because both methods used by him, i.e. the nesting spheres and the eclipse diagram methods, allow him to calculate the sun distance and so there is a risk of failure.

These two methods were inexcusably ignored in the 1980s debate. It is difficult to acknowledge that such well-informed scholars ignored Goldstein's translation of *Planetary Hypotheses*. It is true that van Helden's book (1985), which devoted an entire chapter to Ptolemy's methods, was published almost at the end of the debate and later than the majority of the contribution—except that of Petroni and Scolamiero (1986) and the last reply of Hutchinson (1990); but Otto Neugebauer (1975, 917–922) developed the topic (in the very work that was quoted by Hutchison as his source for the non-triangulation method),[2] as did also Olaf Pedersen (1974, 391–397), not to mention Kuhn's brief reference in *The Copernican Revolution*, already noted. Maybe, therefore, one could argue that Ptolemy's nested sphere model was neglected in the 1980s debate, not because it was unknown but because it was judged to be irrelevant: the core issue was whether the relative distances of the planets from the centre (either of the earth, for Ptolemy, or of the sun, for Copernicus) could be calculated with astronomical observations using only the intrinsic geometrical structure of the theories in question. On that score, Copernicus's theory is superior to Ptolemy's. Nevertheless, leaving aside our own epistemological preferences, there is no reason for preferring geometry to, for example, metaphysics. The key point was whether there was a risky way to calculate the planetary distances, and there was such a way in Ptolemy's system.

To take into account these two methods does not imply that Ptolemy's programme surpassed that of Copernicus, but it does imply that if we consider only the distance calculation issue it is at least not evident that the Copernican system has an advantage over the Ptolemaic system. This is, in any perspective, an amazing conclusion, bearing in mind that, starting with Copernicus ([1543] 1952, preface) himself, it is a commonplace to assert not only that the planetary distance calculation is an advantage of the Copernican model over the Ptolemaic but also that this particular advantage played an important role on the final acceptance of the heliocentric theory.

Only considering that while Ptolemy has two independent methods for calculating the distances of some of the planets—as independent as to yield different results, as we saw in the case of the sun distance—Copernicus has just one, we can certainly assert that in this particular respect Ptolemy's system surpasses Copernicus's.

Nevertheless, we should not evaluate this advantage in isolation. There are many other aspects that should be carefully analysed. On the one hand, in favour of Copernicus's system we can mention the necessity of the distances. See, for example, Kuhn's testimony that in the Ptolemaic model, 'the order of the orbits *may be* determined by assuming a relation between size of orbit and orbital period [and] the relative dimensions of the orbits *may be* worked out with the aid of the further assumption… that the minimum distance of one planet from the earth is just equal to the maximum distance between the earth and the next interior planet' (Kuhn 1957, 175; emphasis as in the original). Even though these assumptions could seem natural, they are not necessary. Thus, the situation is different in the Copernican model because 'there is no similar freedom in [it]. If all the planets revolve in approximately circular orbits about the sun, then both the order and the relative sizes of the orbits can be determined directly from observation without additional assumptions. Any change in order or even in relative size of the orbits will upset the whole system' (Kuhn 1957, 175). I agree with Kuhn that the geometrical necessity present in the Copernican system is indeed an advantage over the Ptolemaic system. Nevertheless, the fact that the Ptolemaic system offers an independent way of testing the 'natural but not necessary' metaphysical assumptions, even having two ways for calculating the sun distance (one purely geometrical and the other plenty of metaphysical assumptions), should also count as an advantage. Whether we should prefer the systematic advantage over the possibility of an empirical test is a pragmatic decision, for it depends on which competing epistemic value is privileged.

The second advantage of Copernicus's system that I can mention, which is related to the previous one, consists in the fact that with only one method Copernicus can calculate the planetary distances and their order at the same time, while Ptolemy presupposes an order to obtain the distances. It is true, however, that the order of the planets is not an ad hoc hypothesis for Ptolemy. In *Planetary Hypotheses*, for example, he says that the order depends on the complexity of the models for the inner planets—the more complex, the further to the sun—and, for the outer planets, the period of planetary orbits is relevant (Goldstein 1967, 7). Nevertheless, it is still true that the order has to be supposed in order to obtain the distances.

On the other hand, in favour of Ptolemy, and not considering the already mentioned double-check possibility offered by some planetary distances, we should consider that Ptolemy can predict (in a novel prediction, on Zahar's criterion) the non-existence of more planets than those known between the moon and the sun, because they would have no place to fit. This fact is only a contingency for Copernicus.

Finally, another advantage of Ptolemy's proposal is that it can explain why the planetary distances are what they actually are, i.e., why the planets are at the distance at which they actually are. The width of an orbit depends on the sizes of the epicycle and deferent, as well as the size of the eccentric, and all these values are what they are in order to predict the longitudes. If it is accepted that there is no 'vacuum or any meaningless and useless thing', then the planets could not be further from or closer to the earth than they actually are. Ptolemy has a reason for the distances. On the contrary, Copernicus can calculate the distances but he cannot give a reason for them. Each period is univocally related with one and only one distance, but nothing prevents the planets having some other distance (with, consequently, a different period). Copernicus cannot explain why the planets are at the distances at which they actually are. It is worth noting that Johannes Kepler and Isaac Newton cannot either—at least, not using only geometrical models. Kepler, for example, proposed hypotheses at least as strange as Ptolemy's for calculating the planetary distances. He was first influenced by the nesting spheres method (but in a more Platonic approach), when in his first major astronomical work, *Mysterium Cosmographicum*, published in 1600, he proposed that by nesting the five Platonic solids in the correct order, you would find the absolute distances of the planets (Kepler 1981). Later, at the end of his career, in 1619, Kepler published the *Harmonice Mundi* (Kepler 1997), in which he attempted to explain the ratios of the natural world in terms of music. So, surprisingly, it is now the Copernicans—and not Ptolemy—who are introducing strange (metaphysical?) non-geometrical hypothesis.

Since the advantages of each proposal are related to different epistemic values, we would not hope to find a quasi-algorithmic solution to the question. So, two conclusions can be stated: first, that the determination of planetary distances achieved by the Copernican proposal is not a clear advantage over Ptolemy's system and, second, that the discussion is much more complicated than the one developed in the *British Journal for the Philosophy of Science* in the 1980s.[3]

Acknowledgements

I would like to thank Dennis Duke and Ignacio Silva for reading previous drafts of this article and making helpful comments, and the two anonymous referees whose smart objections were very helpful for improving this article.

Notes

[1] There is a reference to this method in Lakatos and Zahar too. They assert in a footnote that 'one may use also the Aristotelian "doctrine of plenitude" to arrive at distances; but this doctrine is again heuristically ad hoc, besides being both false and, within Ptolemy's program, unfalsifiable' (Lakatos and Zahar 1975, 379n72). But the *horror vacui* hypothesis is clearly not ad hoc in the sense of being postulated in order to obtain the distances. The reasons for its acceptance are previous and absolutely independent of others. Of course it is unfalsifiable if it is considered in isolation, but applied to the distances calculation method it becomes falsifiable. Finally, it is obviously false, but no one asks for a hypothesis to be true in order to be scientific. Cf. Thomason (1992, 187n25). Neither Chalmers in his two discussions, nor Curd, nor Hutchison mentioned Ptolemy's methods.

[2] Hutchinson (1983, 370) quotes Neugebauer (1975, 146–147).

[3] See for example Riddell (1980, especially 131–137), who discusses with much detail many of the supposed Copernican advantages enumerated by Lakatos and Zahar (1975).

References

Carman, C. 2009. Rounding numbers: Ptolemy's calculation of the earth–sun distance. *Archive for History of Exact Sciences* 63: 205–242.

Chalmers, A. 1981. Planetary distances in Copernican theory. *British Journal for the Philosophy of Science* 32: 374–375.

———. 1983. Planetary distances and Copernican theory: A reply. *British Journal for the Philosophy of Science* 34: 372–374.

Copernicus, N. [1543] 1952. *On the revolutions of the heavenly spheres.* Translated by C. G. Wallis. Republished in *Great books of the Western world,* vol. 16. Chicago, IL: Encyclopædia Britannica, 1952.

Curd, M. 1983. The superiority of the Copernican system: A reply to Chalmers. *British Journal for the Philosophy of Science* 34: 367–369.

Goldstein, B. R. 1967. The Arabic version of Ptolemy's *Planetary hypotheses*. *Transactions of the American Philosophical Society,* n.s. 57, no. 4: 3–55.

Heiberg, J. L., ed. 1907. *Claudii Ptolemaei opera quae extant omnia.* Vol. 2, *Opera astronomica minora.* Leipzig: Teubner.

Hutchison, K. 1983. Planetary distances as a test for the Copernican theory. *British Journal for the Philosophy of Science* 34: 369–370.

———. 1990. Sunspots, Galileo, and the orbit of the earth. *Isis* 81: 68–74.

Kepler, J. 1981. *Mysterium cosmographicum: The secret of the universe.* Translated by A. M. Duncan. New York: Abaris Books.

———. 1997. *The harmony of the world.* Translated by E. J. Aiton, A. M. Duncan, and J. V. Field. Philadelphia, PA: American Philosophical Society.

Kuhn, T. S. 1957. *The Copernican revolution: Planetary astronomy in the development of Western thought.* New York: Vintage Books.

Lakatos, I., and E. Zahar. 1975. Why did Copernicus' research program supersede Ptolemy's? In *The Copernican achievement,* edited by R. S. Westman, 354–383. Berkeley: University of California Press.

Neugebauer, O. 1975. *A history of ancient mathematical astronomy.* 3 vols. Berlin: Springer.

Pedersen, O. 1974. *A survey of the Almagest.* Odense: Odense University Press.

Petroni, A. M., and L. Scolamiero. 1986. On the determination of planetary distances in the Copernican system. *British Journal for the Philosophy of Science* 37: 335–340.

Riddell, R. C. 1980. Parameter disposition in pre-Newtonian planetary theories. *Archive for History of Exact Sciences* 23: 87–157.

Thomason, N. 1992. Could Lakatos, even with Zahar's criterion for novel fact, evaluate the Copernican research programme? *British Journal for the Philosophy of Science* 43: 161–200.

Toomer, G. J. 1998. *Ptolemy's Almagest.* Princeton, NJ: Princeton University Press.

Van Helden, A. 1985. *Measuring the universe: Cosmic dimensions from Aristarchus to Halley.* Chicago, IL: University of Chicago Press.