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2000

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On Copernicus' Success and Aristarchus' Failure

I.

It is well known that the main point of Copernicus' heliocentric theory was anticipated in the first half of the third century B.C. by Aristarchus of Samos.¹ The manuscript version of *De Revolutionibus* contained a direct reference to Aristarchus; in the printed version it was however omitted.²

It is natural to wonder what caused unequal fate of the two similar proposals. Thomas Kuhn in his now classic *The Structure of Scientific Revolutions* suggested the following explanation. The passage quoted below comes from the chapter "Crisis and the Emergence of Scientific Theories":

"It is often said that if Greek science had been less deductive and less ridden by dogma, heliocentric astronomy might have begun its development eighteen centuries earlier than it did. But that is to ignore all historical context. When Aristarchus' suggestion was made, the vastly more reasonable geocentric system had no needs

1 Sir Thomas Heath, *Aristarchus of Samos, the Ancient Copernicus*, Oxford 1913, 299ff. Ancient testimonies about Aristarchus' heliocentric theory are available in English translation in Sir Thomas L. Heath, *Greek Astronomy*, New York 1991, (repr. of ed. 1932), 105-109. There are some indications in the sources for the date of Aristarchus. Either Aristarchus himself or someone of his disciples observed the solar solstice in 280 B.C. (Ptol., *Synt.* 3,1; see also p. 137f. of G.J. Toomer's translation). Aristarchus is said to have been an auditor of Strato of Lampsacus – see Hermann Diels, *Doxographi Graeci*, Berlin 1958, (repr. of ed. 1879), 313. Strato became the head of the Peripatetic school "in the 123rd Olympiad", i.e. 288 B.C. or a few years later; before that Strato was invited to teach for extremely good pay the future Egyptian king Ptolemy Philadelphus; thus he had already an established reputation (Diog. Laert. 5,58). One should assume that Aristarchus studied with Strato before his departure for Alexandria. Ptolemy Philadelphus was born in 308 B.C., and Aristarchus must have been born some years earlier, say, c. 320 B.C.

2 Nicolaus Copernicus, *Opera omnia*, Varsaviae/Cracoviae 1975, 2,341: *Credibile est hisce similibusque causis Philolaum mobilitatem terrae sensisse: quod etiam nonnulli Aristarchum Samium ferunt in eadem fuisse sententia.* ("It is plausible that for these and similar reasons Philolaus thought that the earth moves; some say that also Aristarchus of Samos held the same view.")

that a heliocentric system might even conceivably have fulfilled. The whole development of Ptolemaic astronomy, both its triumphs and its breakdown, falls in the centuries after Aristarchus' proposal. Besides, there were no obvious reasons for taking Aristarchus seriously. Even Copernicus' more elaborate proposal was neither simpler nor more accurate than Ptolemy's system. Available observational tests ... provided no basis for a choice between them. Under those circumstances, one of the factors that led astronomers to Copernicus (and one that could not have led them to Aristarchus) was the recognized crisis that had been responsible for innovation in the first place. Ptolemaic astronomy had failed to solve its problems; the time had come to give a competitor a chance."³

Thomas Kuhn is right rejecting arbitrary statements about the dogmatism of Greek science. It is also possibly true that the new system as presented by Copernicus was neither simpler nor more accurate than that of the *Almagest*.⁴ Does it follow from this that the presence *resp.* absence of a crisis in geocentric astronomy was crucial for the success *resp.* failure of the two similar initiatives? We shall see that Kuhn's interpretation is historically mistaken and yet heuristically valuable. That is, there was a crisis in the time of Aristarchus too. I mean crisis in the Kuhnian sense, namely a discrepancy between growing complexity of the established astronomical system, on the one hand, and the failure of this system to produce really accurate results, on the other hand. I will argue, however, that what constituted the crisis and especially related scientific *development* was not so much disappointment with respect to a previous theory, but rather an explicit *challenge* to it, the appearance of a rival theory.⁵

3 Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2nd ed. (International Encyclopedia of Unified Science, Vol. 2, No 2), Chicago 1970, 75f. It is probably worth recalling that Thomas Kuhn was also the author of *The Copernican Revolution*, Cambridge, Mass. 1957.

4 See Owen Gingrich, "'Crisis' versus Aesthetic in the Copernican Revolution", in his *The Eye of Heaven: Ptolemy, Copernicus, Kepler*, New York 1993, 193-204.

5 This differs mainly in emphasis from what Kuhn himself writes in his next chapter: "Once it has achieved the status of paradigm, a scientific theory is declared invalid only if an alternate candidate is available to take its place." (Ibid., 77)

II.

The theory rejected by Aristarchus was the theory of homocentric (or concentric) spheres advanced by Eudoxus of Cnidus in the second quarter of the fourth century B.C. To be sure, this theory was a work of genius. However it was one that immediately called for improvement by means of increasing complexity. Two younger contemporaries of Eudoxus, Callippus and Aristotle, introduced one after the other more and more additional spheres in the Eudoxian celestial arrangement.⁶ The necessary accuracy had not yet been reached. Should one call it the crisis? We have no evidence that the astronomers of Eudoxian school felt themselves embarrassed. Moreover, Epicurus portrays them as very self-confident.⁷ The European astronomers of the early sixteenth century seem also not to have been embarrassed by the complexity of the Ptolemaic system, nor did they have much, or any, *new* observational data clearly contradicting this system, nor were they reluctant to produce astronomical tables based on this system;⁸ yet they had at their disposal a number of late classical and medieval, mostly Islamic, texts where doubts had been raised about the validity of the system that resorted to eccentrics and epicycles. Thus we have no evidence in either case for a crisis as something manifested in a general state of mind; however, there was a certain objective state of affairs which could stimulate and justify a radical innovation, provided that a person of an adequate temper were present.

Fortunately, we know a bit more about the state of affairs in Greek astronomy in the late third of the fourth century B.C. Valuable testimony comes from Peripatetic tradition of commenting on writings of Aristotle; Simplicius quotes Sosigenes (who was active in the second half of the second century A.D.):

6 Francois Lasserre, *Die Fragmente des Eudoxos von Knidos*, Berlin 1966, F 121-126. Most important passages are available in English translation in Heath, *Greek Astronomy*, 65-70. For the general exposition and further references see D.R. Dicks, *Early Greek Astronomy to Aristotle*, Ithaca 1970, 176-88, 190-93, 200-203; *A History of Ancient Mathematical Astronomy*, New York etc. 1975, II 677-85.

7 Epic., *Letter to Pythocles* (Diog. Laert. 10,93); see further David Sedley, *Epicurus and the Mathematicians of Cyzicus*, *Cronache Ercolanesi* 6, 1976, 23-54. Aristotle displays high respect to the contemporary astronomy, he considers its basic achievements as firmly established truth (An. Pr. 46 a 19; Meteor. 339 b 8, 30; De Cael. 297 a 4; Part. anim. 639 b 8), so that its previous development becomes rather a matter of history, and his disciple Eudemos writes indeed the first *History of Astronomy*. The only qualification needed is that Aristarchus was apparently one generation younger than Epicurus (341-271 B.C.) and Eudemos was born before Epicurus.

8 See Owen Gingrich, 'Crisis' versus Aesthetic (as in n. 4).

"Nevertheless the theories of Eudoxus and his followers fail to save the phenomena, and not only those which were first noticed at a later date, but even those which were before known and actually accepted by the authors themselves ... I confine myself to one fact which is actually evident to the eye; this fact no one before Autolycus of Pitane⁹ even tried to explain by means of hypotheses, and not even Autolycus was able to do so, as clearly appears from his controversy with Aristotherus.¹⁰ I refer to the fact that the planets appear at times to be near to us and at times to have receded. This is indeed obvious to our eyes in the case of some of them; for the star called after Aphrodite and also the star of Ares seem, in the middle of their retrogradations, to be many times as large, so much so that the star of Aphrodite actually makes bodies cast shadows on moonless nights. The moon also, even in the perception of our eye, is clearly not always at the same distance from us, because it does not always seem to be of the same size under the same conditions as to medium. The same fact is, moreover, confirmed if we observe the moon by means of an instrument ... In addition to this, there is evidence for the truth of what I have stated in the observed facts with regard to total eclipses of the sun; for when the centre of the sun, the centre of the moon, and our eye happen to be in one straight line, what is seen is not always alike; but at one time the cone which comprehends the moon and has its vertex at our eye comprehends the sun itself at the same time, and the sun even remains invisible to us for a certain time, while again at another time this is so far from being the case that a rim of a certain breadth on the outside edge is left visible all round it at the middle of the duration of the eclipse. Hence we must conclude that the apparent difference in sizes of the two bodies observed under the same atmospheric conditions is due to the inequality of their distances (at different times) ... But indeed the inequality in the distances of each star at different times cannot even be said to have been unknown to the authors of the concentric

9 Astronomer of the late fourth century B.C. Two of his treatises came down to us, *On Risings and Settings* and *On the Moving Sphere*, none of which, however, mentions the system of homocentric spheres.

10 He is said to have been a teacher of Aratus, the poet who composed the famous *Phenomena*. In his descriptions of constellations Aratus followed Eudoxus; it seems that in controversy with Autolycus Aristarchus represented the Eudoxian school.

theory themselves. For Polemarchus of Cyzicus¹¹ appears to be aware of it, but to minimise it as being imperceptible, because he preferred the theory which placed the spheres themselves about the very centre in the universe."¹²

One can see that difficulties related to the assumption of the theory of homocentric spheres were recognised, both within the school advocating this theory and outside of it (Autolycus of Pitane). The initial reaction to it was to adjust the assumed celestial mechanism by increasing the number of spheres. We have not heard that such efforts were undertaken after Aristotle. It apparently became clear that a solution lay elsewhere. The high status of the school (achievements of which were by no means confined to the homocentric theory) made it easy to tolerate the drawbacks of the theory. Dissenting views of an outsider like Autolycus had no significant consequences, and probably this was such because he did not advance an alternative proposal. The case of Aristarchus was essentially different.

The difficulties of the homocentric theory probably account for the fact that the heliocentric hypothesis of Aristarchus attracted much attention among the scientists and philosophers. Archimedes, the greatest mathematician of that epoch, refers in his *Sand-reckoner* to Aristarchus' theory as quite reasonable (Aren. 1). Cleanthes, the head of the Stoic school, that is apparently the most respectable figure among the contemporary philosophers, devotes a special treatise to Aristarchus (Diog. Laert. 7,174), a polemical one, in which he said that

"it was the duty of Greeks to indict Aristarchus of Samos on the charge of impiety for putting in motion the Hearth of the Universe, this being the effect of his attempt to save the phenomena¹³ by

11 A disciple of Eudoxus. It was in Cyzicus where Eudoxus established his school, Callippus was from Cyzicus too.

12 Heath, *Greek Astronomy*, 68f.; original text: Simplicii in Aristotelis "De Caelo" commentaria, ed. I.L. Heiberg, Berlin 1894, 504.17.

13 For the important notion of saving the phenomena, mentioned by Plutarch, see Pierre Duhem, "ΣΩΖΕΙΝ ΤΑ ΦΑΙΝΟΜΕΝΑ", *Annales de Philosophie Chrétienne* 6, 1908 113-39, 277-302, 352-77, 482-514, 561-92; Jürgen Mittelstrass, *Die Rettung der Phänomene: Ursprung und Geschichte eines antiken Forschungsprinzips*, Berlin 1962, 140ff.; G.E.R. Lloyd, "Saving the Appearances", in his *Methods and Problems in Greek Science*, Cambridge 1991, 248-277. Dicks, *Early Greek Astronomy*, 258, n. 358 attributes the invention of the formula to Peripatetic Sosigenes. But he lived about a century later than Plutarch. The fact that the formula σῶζειν τὰ φαινόμενα appears in Plutarch, who was basically a Platonist, in the Peripatetic tradition and in a text which goes back to the Stoic Poseidonius (fr. 18 Edelstein-Kidd) shows that it was widely

supposing the heaven to remain at rest, and the earth to revolve in an oblique circle, while it rotates, at the same time, about its own axis." (Plut., *De fac. in orb. lun.*, 923 a; Heath's transl.)¹⁴

The heliocentric view as well as some other views of Aristarchus are included in compendia of philosophical and scientific doctrines.¹⁵ In general, though not only due to the heliocentric hypothesis, he acquired the reputation of an outstanding man of science (Vitruv 1,1,16); philologists (P.Oxy. 3710 col. II)¹⁶ and engineers (Vitruv 9,2,3) resorted to his authoritative opinions.

One can see that the publication of the heliocentric hypothesis did not pass unnoticed.¹⁷ Moreover, it seems to have brought about a real crisis. We do not know what arguments Aristarchus cited or introduced against the theory of homocentric spheres. They were, however, such that this theory was given up by Greek astronomy. The new theory still had its own difficulties. Aristarchus took into account the problem of stellar parallax,¹⁸ but he could not "save" all phenomena. Placing the sun strictly in the centre of the earth's orbit would not account for unequal length of the seasons, which was a traditional concern of Greek astronomers.¹⁹ The main difficulty pertained, however, to the physical interpretation of the heliocentric system. The Greeks succeeded in providing reasonable explanations of how the huge body of the earth can remain in space without any support on the assumption that the earth occupies the centre of the

accepted and originated in an authoritative source. But we cannot say confidently whether or not Aristarchus used it.

¹⁴ It is tempting to guess that the familiarity with this passage made Copernicus suppress his reference to Aristarchus (cf., however, Owen Gingerich "Did Copernicus Owe a Debt to Aristarchus?", in his *The Eye of Heaven*, 185-192). It is interesting that Cleanthes, who claimed the charge of impiety against Aristarchus, was one of the first champions of the "heliolatry" (so prominent in Florentine neoplatonism, which is occasionally invoked as a train of thought prompting heliocentrism). Diverging from other Stoics, he called the sun the ruling power of the world (τὸ ἡγεμονικὸν τοῦ κόσμου), I. von Arnim, *Stoicorum Veterum Fragmenta*, Leipzig 1905, I, fr. 499.

¹⁵ Hermann Diels, *Doxographi Graeci* 313; 314; 355 (the heliocentric passage); 404.

¹⁶ See *The Oxyrhynchus Papyri* LIII, ed. with translations and notes by M.W. Haslam, Oxford 1986.

¹⁷ Dreyer's assertion that "the hypothesis does not appear to have attracted much attention" hardly needs further comment (J.L.E. Dreyer, *A History of Astronomy from Thales to Kepler*, 2nd ed. revised with a foreword by W.H. Stahl, New York 1953, 139).

¹⁸ This follows from the fact that he made the sphere of the fixed stars immensely large (Archim., *Aren.* 1); see also Jürgen Mittelstrass, *Die Rettung der Phänomene*, 172.

¹⁹ Pierre Duhem, *Le système du monde: Histoire des doctrines cosmologiques de Platon à Copernic*, Paris 1913, I, 426; see also Heath, *Aristarchus of Samos*, 308.

cosmos.²⁰ It was much more difficult to explain how the earth should move round the sun without falling down. Some further difficulties related to the assumption of a moving earth were also recognised (see Ptol. *Synt.* 1,7). The time of the interregnum had come.

An acceptable solution was found by Apollonius toward the end of the century and especially by Hipparchus in the next century. They advanced a new geocentric theory, the one based on epicycles and eccentrics. That geocentric system which in its classic version is associated with the name of Ptolemy came to be as a response to crisis, the crisis caused by the publication of the heliocentric hypothesis of Aristarchus.²¹

The geocentric system was retained, however, at a high cost. The physical mechanism of the movement of the planets in renewed geocentrism remained rather obscure and therefore problematic. A special epistemological theory was advanced which split the domains of physics and mathematics,²² but this was of limited help. In the course of centuries, the growing respect for the system presented in the *Almagest* went hand in hand with the accumulation of doubts raised about its validity.²³

²⁰ The *locus classicus* is Book 2, chapter 13 of Aristotle's *De Caelo*. For alternative explanations of the earth's stability, both before and after Aristotle, see my "Homoios and homoiotes in Anaximander and Thales", *Hyperboreus* 1, 1994, 28-55, esp. 50ff.

²¹ Cf. Dietrich Ehlers, *Geschichte des wissenschaftlichen Denkens im Altertum*, Berlin 1982, 423: "Die nachfolgende Entwicklung der Epizykeltheorie ... kann man als unmittelbare Reaktion auf die geodynamisch-heliozentrische Hypothese verstehen." As an example of a standard account (which does not take the challenge from Aristarchus into consideration) the closing pages of Dicks' *Early Greek Astronomy* (218f.) may be referred to.

²² Simplic., In *Aristot. Phys.*, 291,21ff. Diels. The relevant passage was translated by Heath in his *Greek Astronomy*, 123ff. For interpretation cf. Jürgen Mittelstrass, *Die Rettung der Phänomene*, 170f.; idem, *Neuzeit und Aufklärung*, Berlin/New York 1970, 256f.

²³ As to the direct continuation of the tradition of Aristarchus in antiquity, he seems to have had only one follower of any significance, Seleucus of Seleucia on Tigris, who lived a century or two later. According to Plutarch (*Plat. quest.* 1006 c), Aristarchus advanced the notion of a turning and revolving earth as a hypothesis, while Seleucus held this as a certain truth. The ground for such a change of the attitude is unknown. Otto Neugebauer, *A History of Ancient Mathematical Astronomy*, II 697 draws conclusions about the character of Seleucus' approach from the fact that "in his discussion concerning the infinity of the world there is not a trace of any mathematical argument". One may wonder, however, what kind of mathematical apparatus must be imagined as applied to discussing the infinity of the world in the first or second century B.C. In any case Neugebauer himself is not certain whether the discussion he refers to goes really back to Seleucus (II 611, n. 29).

III.

Let us now turn to the situation of the first half of the sixteenth century. Copernicus was not alone in criticising and trying to replace the Ptolemaic system. Some of his contemporaries made efforts to restore the physically more plausible system of Eudoxus and Aristotle. In 1529 the 'Book on Sphere' by Al-Petravius was newly translated and published in the next year. This treatise, composed at the end of the twelfth century, defended the theory of homocentric spheres. In successive years there appeared treatises by Giovan Battista Amico (1537)²⁴ and Girolamo Fracastoro (1538), in both of which a homocentric system of the universe was developed.²⁵ I think this manifest conflict of two authoritative traditional systems was a more essential aspect of the crisis of the geocentric astronomy than the alleged tiredness of its complexity. The competition called for a choice between competitors. But the choice proved too difficult because both competitors had obvious imperfections. As a consequence, such a situation stimulated to search for something different from both systems. Copernicus himself explicitly connected his initiative with the imperfection of *both* geocentric systems. What is of special importance is that he does so not only in the preface to *De Revolutionibus* (where various diplomatic motives may be suspected), but also in his *Commentariolus*:

"Our ancestors assumed, I observe, a large number of celestial spheres for this reason especially, to explain the apparent motion of the planets by the principle of regularity ... Callippus and Eudoxus, who endeavored to solve the problem by the use of concentric spheres, were unable to account for all the planetary movements ... Therefore it seemed better to employ eccentrics and epicycles, a system which most scholars finally accepted. Yet the planetary theory of Ptolemy and most other astronomers, although consistent with the numerical data, seemed likewise to present no small difficulty. For these theories were not adequate unless certain equants were also conceived; it then appeared that a planet moved with uniform velocity neither on its deferent nor about the center of its epicycle. Hence a system of this sort seemed neither sufficiently

²⁴ Recently reedited with a valuable preface by Mario Di Bono, *Le sfere omocentriche di Giovan Battista Amico nell'astronomia del Cinquecento; con il testo del "De motibus corporum coelestium"*, Genova 1990.

²⁵ It is likely that the idea of the restauration of the homocentric theory was current in Italy already in the beginning of the century, when Copernicus was there. See Leonardo Olschki, *Geschichte der neusprachlichen wissenschaftlichen Literatur*, Vaduz 1965; (original ed. Leipzig etc. 1922) II, 56f., esp. 57, n. 3.

absolute nor sufficiently pleasing to the mind. Having become aware of these defects, I often considered whether there could perhaps be found a more reasonable arrangement of circles, from which every apparent inequality would be derived and in which everything would move uniformly about its proper center, as the rule of absolute motion requires."²⁶

It is clear that the very existence of two geocentric systems undermined an unshakeable faith in geocentrism. But there was something even more important in the situation. A geocentric system can be conceived either as homocentric or as eccentric: *tertium non datur*. It was possible to save geocentrism after Aristarchus by replacing the former of the two systems by the latter. Such a possibility no longer existed after Copernicus. There remained, however, a possibility of the geo-heliocentric compromise suggested by Tycho Brahe. But rapid progress in astronomy, stimulated to a palpable degree by publishing *De Revolutionibus*, soon brought about the triumph of heliocentrism, even though essentially modified by Kepler. It was just in the logic of things that heliocentrism should have succeeded in two steps. A necessary prerequisite for Copernicus' success was that the first step was taken by Aristarchus. And this makes the real debt of heliocentric astronomy to the ancient predecessor of Copernicus.

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²⁶ Three Copernican Treatises, translated with introduction and notes by Edward Rosen, 2nd ed., New York 1959, 57f.