

Aristotle Corrects Eudoxus

Met. 1073b 39—1074a 16

by

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1759 pdf
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1970

1. In *Metaphysics*, Book A, in the course of his development of the theory of God, Aristotle digresses somewhat in order to describe the astronomical system of Eudoxus and Callippus. After describing this system, Aristotle points out a certain defect in it and then goes on to correct this defect. In order to accomplish this, he increases the number of celestial spheres from 33 to 55.

My purpose here is to analyze the factors which probably prompted Aristotle to consider the system of the mathematicians as inadequate. Obviously, a detailed analysis of this problem is necessary in order to understand Aristotle's own contribution to the history of astronomical systems. His own words in this connection are rather ambiguous:

"But it is necessary, if all the spheres combined (*συντεθεσθαι*) are to explain the observed facts that . . ." (Oxford translation).

Here, the main question which arises is the interpretation of the phrase "all the spheres combined". There are two current interpretations of this term. The first, which will be referred to here as the 'unity interpretation', assumes that the mathematical solution lacks unity of structure, and that this is what Aristotle means when he says that the "combination" of the spheres does not explain the phenomena. The second proposal, which we shall denote as the 'plenum interpretation',

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Centaurus 1970: vol. 15, nr. 2: pp. 113-123

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assumes that Aristotle realized that the mathematicians' model involves the existence of a void, the latter being incompatible with Aristotelian physics.

2. As long as the unity interpretation is merely presented in general terms, it tells us nothing. If we say that Aristotle tried to construct a 'unified', or 'whole', or 'organic', astronomical system, then these terms require explanation just as much as Aristotle's own term "combination". The real question to be asked is the following: what is it that was not unified, whole, or organic in the Eudoxus-Callipus system? By trying to explain these terms, some are led to the conclusion that Aristotle changed the system of Eudoxus

"in order to adapt it to his principle of the motive power working from the outer surface of the Cosmos towards the center".!

For example, if the force that moves the outermost sphere, the 'universe', is also assumed to move all the planets, then this leads to the desired unified, whole, and organic system. It is assumed here that the counteracting spheres proposed by Aristotle functioned as transmitters of motion from the outer sphere of fixed stars to the spheres of the planets (cf. Heath).² Thus, the 'unity interpretation' in turn leads to the 'transmission interpretation'. The latter identifies the flaw which Aristotle found in the Eudoxus system with the fact that the outermost sphere of each planetary sphere-group had no causal connection with the more outlying spheres. The establishment of such a causal connection between the sphere of the fixed stars and the outermost sphere of each planet was the purpose of Aristotle's system of counteracting spheres. The rotation of the sphere of the stars will mechanically cause the rotation of the outermost sphere of Saturn, the outermost sphere of Jupiter, etc. The desired unity will thus be achieved by this causal connection. According to this interpretation, the counteracting spheres were proposed by Aristotle to serve as causal mechanical links between the sphere of the stars and the spheres of the planets.

How valid is the foregoing interpretation? This can be decided only on the basis of: a) the evidence for it, b) its plausibility, and c) its usefulness in explaining some obscure details in Aristotle's astronomical supplement.

3. None of the adherents of the foregoing interpretation have cited any evidence that Aristotle anywhere expresses the principle that the eighth sphere moves all the other spheres. One of the clearest and most characteristic passages related to this is *De Gen. et Corr.*, Book II, Chapter 10, which presents an astronomical theory of climatic changes. According to this theory, the motion of the sun is the resultant of two motions, the motion of the Same and the motion of the Different (to use Platonic terms). The motion of the Same, which Aristotle denotes as "the motion of the whole", (336 b 3), or "the primary motion" (336 a 32), is the cause of the continuity in the solar motion. The motion of the Different, on the other hand (the motion along the inclining circle), causes the discontinued motion (changing distance of the sun). Aristotle also mentions (318 a 7)

"... that which sets everything else in motion by being itself continuously moved..."

This theory is also mentioned in *Met.*, Book A, at the end of Chapter 6.

In *De. Gen. et Corr.* (337 a 20), Aristotle described the relation between the principles of circular motion (perhaps the prime movers) and the prime mover:

"... if the circular movements are more than one, their initiating causes must all of them, in spite of their plurality, be in some way subordinated to a single 'originative source'."

The idea that there must be a single source for all the motion in our world appears in many places in Aristotelian physics. However, does this really constitute evidence in favour of the unity-transmission interpretation? Actually, all that can be gathered directly from these passages is a metaphysical principle of hierarchy of motion: the primary motion (that is, the motion generated directly by the prime mover) is especially significant and has a special function in the cosmos. All other motions are inferior in comparison with the primary motion (the motion along the ecliptic is inferior to the diurnal motion along the equator). The same is true of the causes of the motions: the various secondary causes are all subordinate to the primary cause. As to the specific character of this subordination and hierarchy, however, the most specific information we have is that the primary motion (that is, the motion of the whole) has a special metaphysical status, in that it represents the fixed element

in the cosmic change. The relevant passages do not specify whether this motion is transmitted mechanically to the various parts of the cosmos or not.

In some passages, on the other hand, it would have been quite natural to mention such a mechanical transmission of motion from the sphere of the fixed stars to all other spheres, if Aristotle had really believed in this. For example, in *De Caelo*, Book II, Chapter 12, the following question is posed:

"Why is it that the primary motion includes such a multitude of stars . . . while in the case of the planets each one is separate and in no case do we find two or more which undergo the same motion?"

In his answer, Aristotle indicates that the prime mover and the other movers differ in force or intensity. Consequently, the prime mover is able to move the entire mass of fixed stars in a single motion. Nowhere in this chapter, however, is it said that the prime mover causes the motion of all the other spheres as well. On the contrary, it is made clear that it moves only one sphere. Moreover, it is stated distinctly in this chapter that the sphere on which a planet is located does not cause the movement of other spheres. Thus, at that time Aristotle did not assume that motion is transmitted mechanically from the sphere of fixed stars to the spheres of the planets.

The assumption that Aristotle does not ascribe a mechanical causality to the transmission of motion is verified in *De Caelo*, Book II, Chapter 10. In this passage, the effect which the planet's distance from the prime mover has on the planet's motion is discussed. However, in this case too, a mechanical connection between the motions is not sought. On the contrary, the connection is obviously a purely teleological one.

To sum up, I found no direct evidence that Aristotle assumed a mechanical transmission of motion from the prime mover to the planetary spheres. Rather, it is clear that the causality which unifies the system of spheres is essentially teleological, as the following passage indicates:

"The prime mover . . . necessarily exists, its mode of being is good, and in this sense it constitutes a first principle" (1072 b 12).

4. It is a bit hard to believe that in *Metaphysics*, Book A, where he presents his theory of teleological movement of the world, Aristotle suddenly found it necessary to introduce the mechanical transmission

of motion as a basic feature of his astronomy. Moreover, the "mechanical transmission interpretation" becomes even less plausible when we recall that the astronomical passage is introduced into this otherwise purely metaphysical-theological treatise only in order to calculate the number of teleological causes (that is, unmoved movers) in the cosmos. Book *A* (especially Chapter 9 of Book *A*) is so saturated with a teleological atmosphere and spirit that it is rather difficult to see how a mechanistic transmission system could find a place in this context. Moreover, it is extremely unlikely that Aristotle would attempt to supply his cosmology with such a mechanism at this point of the argument.

5. The third factor is just as important as the first two factors of evidence and plausibility. Let us consider, then, to what degree this interpretation aids us in understanding Aristotle's astronomical supplement itself.

The use of intentions and motivations as a basis for understanding a passage is an act analogous to postulating a scientific hypothesis as a basis for understanding some facts in the natural sciences. Any hypothesis which fails to introduce order into the facts, and which, on the contrary, heightens the disorder, is, of course, simply a failure. The purpose of any hypothesis, moreover, is to make the treatment of the subject as rational as possible, as well as to introduce more order. A hypothesis which fails to do these things is, in most cases, inadequate, and it should be rejected as soon as a better hypothesis is formulated.

If we assume that Aristotle's intention was to unify the spheres of Eudoxus by binding them mechanically to the sphere of the fixed stars, then it is quite evident that he failed to achieve his aim. Moreover, he did not fail to do this in any trivial manner, but in a very strange way indeed. The attempt at unification failed exactly at a crucial point in his whole astronomical system, just at the point where, according to the present hypothesis, he should have focused all his attention. Consequently, the unity-transmission hypothesis intensifies our curiosity instead of satisfying it. Moreover, this hypothesis needs an additional ad-hoc hypothesis to the effect that Aristotle became confused and made a mistake, in order to explain why he did not achieve his hypothetical aim. It is my opinion that Aristotle is entitled to an interpretation which will decrease, rather than increase, the number of obscure points in his work.

In order to evaluate the 'unity-transmission' interpretation properly, let us consider the astronomical mechanism described in Chapter 8. The main purpose of this mechanism is to reduce every celestial motion to a set of uniform circular motions. Each sphere is assigned two components of motion, one of which is self-caused and the other of which is caused by the adjacent outlying sphere. The first motion, which we may denote as the 'proper' motion, can be only circular and uniform, while the second, which we here denote as the 'transmitted' motion, can be of any sort. The vector sum of these two components is equal to the absolute motion of the sphere and planet in Aristotelian space. This will be referred to here as the 'absolute', or 'resultant', motion. Aristotle express this combination thus (D.C. 293-a-9):

"Each sphere has its own proper and natural motion, and this one is added."

In this system, each sphere has its own proper and natural motion. It is very important to note that Aristotle ascribed a proper motion to each sphere. A further proof of this is the rule by which the number of unmoved movers is fixed:

"Therefore each of these movements (the eternal spatial movements) must likewise be caused by a substance which is immovable in itself and eternal" (1073 a 32-37).

It is evident that every single sphere has, according to Aristotle, a proper motion which is uncaused by any more outlying (anterior) sphere.

The question as to whether Aristotle assumed one or many movers is of no importance here. In *Metaphysics*, Book *A*, Chapter 8, it is clear that he assumes a plurality of movers, and this is sufficient to decide the point in question. Jaeger³ believes that the plurality of movers is a late theory in Aristotle, while Merlan⁴ is of the opinion that even without postulating a chronological sequence of the ideas it is possible to consider the whole of Chapter 8 as being free of contradictions. According to him:

"Chapter 8 . . . teaches one consistent doctrine, to the effect that there is but one heaven and that, within it, there are 47 (or 55) independent and eternal movements caused by as many unmoved movers whose number is thus precisely limited and determined. The chapter does not reveal any trace of doubt, uncertainty, inconsistency, selfcontradiction or self correction."

However, apart from this somewhat muddled question, it is quite clear that in the astronomical passage (1073 b 9 to 1074 a 32) there is a definite belief in the plurality of movers. Moreover, this, together with the assumption of a one-to-one mutual correspondence between the number of spheres and the number of eternal movers, is the real reason for including this astronomical passage in the metaphysics! This is clear from the fact that the sole purpose of the astronomical analysis is to determine the exact number of eternal movers, as the preface to this analysis states:

"That the movers are substances, then, and that one of these is first and another second according to the same order as the movements of the stars, is evident. But in the number of the movements we reach a problem which must be treated from the stand point of . . . astronomy." (1073 b 1)

The rule that to each sphere there corresponds a proper motion, however, is strictly incompatible with the idea of a unity-by-transmission mechanism. Such a unification is possible only on condition that proper motions be ascribed just to some of the 55 spheres rather than to all of them. The spheres without proper motions will then have transmitted motions only. In this way alone is it possible to establish a mechanical connection between the sphere of fixed stars and the other 54 spheres. Such a connection will be achieved if the seven primary spheres of the planets have no proper motion. If the latter spheres receive all their motion from the spheres immediately anterior to them (the innermost counteracting spheres of the next planet out), and if they possess no proper motions, only then will a mechanical connection be established between the planets and the sphere of the fixed stars. There will thus be just 48 prime movers, or proper motions, for the 55 spheres.

On the other hand, if the seven primarily planetary spheres have proper motions as well as transmitted motions, then it follows that the whole Aristotelian system is worthless, because it cannot even explain the phenomena qualitatively. This is quite evident in the case of Saturn, the planet lying nearest to the sphere of the fixed stars. The sphere of fixed stars makes one complete revolution every 24 hours, and the one adjacent to it, the outermost sphere of Saturn, has a proper motion with a 24-hour period. Thus, if the transmitted motion from the sphere of fixed stars is superimposed onto the motion of Saturn's outermost sphere, its resultant or absolute motion will have a period of

12 hours. This would result in a diurnal period of 12 hours for Saturn, which contradicts the observations. Moreover, this process would be repeated in turn for each planet. Thus, if a mechanical causal connection existed between all the spheres of the Aristotelian system, the faults of the system would be too obvious not to have been detected by Aristotle. On the other hand, if we assume that the system does not possess this strange defect, then it follows that Aristotle misunderstood his own astronomical system: since he did not grasp the fact that not every sphere in this system possesses a proper motion, he formulated a spurious rule of correspondence between the number of spheres and the number of movers. Either way, we must assume gross misunderstandings and ridiculous mistakes on the part of Aristotle, in order to be able to accept the unity-transmission interpretation.

6. Let us now discuss the alternative assumption concerning Aristotle's purpose: the filling up of the vacuum and the establishment of a plenum between the groups of planetary spheres in the mathematical model of Eudoxus. This alternative has been discussed in outline by Duhem⁵ and Ross⁶. Let us attempt to develop this suggestion, after first checking its supporting evidence, its contextual plausibility, and its value as an explanatory hypothesis. According to this interpretation, Aristotle recognised that the following is true: If Eudoxus's system is taken as a physical model, then the kinematic independence of every planet seems to require the presence of a vacuum between each pair of adjacent groups of planetary spheres. Since such a vacuum was forbidden in Aristotle's physics, this space must be filled up with matter. The specific purpose of Aristotle's astronomical correction, then, was to explain away this vacuum. The "combination" of spheres which he mentions thus should be understood as such an association of spheres that the entire physical model becomes rid, once and for all, of any interspherical vacuum.

7. The absence of any vacuum, whether separate or related to physical bodies, is a familiar tenet of Aristotelian physics. The passages relevant to this (*De Caelo*, Book I, Chapter 9; Book 4, Chapters 4 to 9) need only be mentioned here. The rejection of a vacuum between the celestial spheres, of course, follows directly from this law, and moreover it is stated explicitly in a number of passages.⁷

8. When Aristotle attempted to establish an astronomical basis for his theory of God, it became clear to him that the existing mathematical solutions had never been intended as, and could not possibly have served as, a description of the real mechanism of the world. This became clear to him when he realized that the Eudoxus-Callippus system can function as a real model only if the seven groups of planetary spheres are separated from one another. Such a separation is feasible in this model only if we assume the presence of a separating vacuum layer between adjacent groups, and this immediately disqualifies the model with respect to Aristotle's theological cosmology. Such a model could not possibly describe the actual structure of the world, and in addition the number of proper motions and unmoved movers could not be derived from it. Consequently, before Aristotle begins to use it as a source of cosmological and theological information, he must first make sure that the model describes the true structure of the world. This is the reason for Aristotle's astronomical digression in the midst of a metaphysical treatise.

9. In order to evaluate this assumption as an explanatory hypothesis, let us now attempt to expand it a bit to show that counteracting spheres constitute a logical, necessary, and simple solution to the following problems: How is it possible to fill the vacuum between the groups of spheres, and at the same time to keep them separate; to preserve the overall kinematic state of the Eudoxus-Callippus system, and to obey the laws of Aristotle's physics? The following is a possible reconstruction of the logic behind Aristotle's solution to this problem.

a) The intermediate layer must be a layer of the celestial element, ether.

b) If this layer moves, its proper motion must be circular and uniform.

c) The motion of the ether layer must separate the innermost sphere of the outer group from the outermost sphere of the inner group.

d) One possibility is to ascribe to the intermediate layer a proper motion which is equal and opposite to the *absolute motion* of the innermost sphere of the outer group (on which the planet is situated). The resultant motion of the intermediate layer will then be zero, and the two groups will be separated mechanically. However, this solution is unten-

able, since the intermediate layer must then possess a complex proper motion (a hypopede) instead of simple circular motion.

e) Another possibility is that the proper motion of the intermediate layer is equal and opposite to the *proper motion* of the innermost sphere of the outer group. Although in this case it will have a simple circular proper motion, the resultant motion of the intermediate layer will be equal to the resultant motion of the penultimate sphere of the outer group, and so will not be zero. Accordingly, this brief survey does not indicate much probability of achieving a lawful separation of spheres by means of only one intermediate filling layer. If we continue along these lines, in each case canceling the proper motions by contrary proper motions, we are led to the counteracting-spheres solution. The filling-in process, by the way, may cease when a zero resultant is obtained (this requires n counteracting spheres for n planetary spheres), or else it may stop before this, when a resultant equal to the diurnal motion of the outermost planetary sphere is obtained (this requires only $n-1$ counteracting spheres for n planetary spheres). Aristotle chose the second solution, since it needed less spheres.

This analysis suggests, then, that here Aristotle is not offering a new explanation. On the contrary, he is quite willing to accept the explanation already given by the mathematicians. However, since the latter explanation included some points which contradicted his laws of physics, Aristotle determined which changes would be necessary in order for this mathematical solution to be applicable as a physical model. He is not concerned with giving an improved solution, but rather wishes to adapt the old solution so that it can serve as a description of a law-abiding cosmos. Moreover, since he is not attempting to improve the system, it is understandable why there is a certain amount of redundancy in his solution (for instance, the motion of the outermost sphere in every group is identical with the motion of the innermost counteracting sphere of the adjacent group). Consequently, according to this interpretation, the absence of a transmission mechanism (between the innermost counteracting sphere of each group and the outermost sphere of the next group) ceases to seem a mistake, because it is simply irrelevant to Aristotle's purpose. He is concerned with a law-abiding system, and not with a better system. Thus, although he assumes the Eudoxus-Callippus solution to be the best derived up to that time, he cannot use it until it has been purged of all the points which contradict his physics.

Let us conclude by noting that this same problem was one of the main motives for the anti-Ptolemaic movement among the Arab astronomers of the 11th and 12th centuries. If Ptolemy's system is taken as a physical model, a vacuum must exist as a result of the eccentric motion. According to Maimonides,⁸ if we accept that there is no vacuum, and also the assumed eccentricity and independence of the spheres, then

"it follows that in every two spheres the motion of the upper one should cause the lower sphere to move in the same way and around the same center. But this is not the case; . . . each of them has its peculiar motion. For this reason, it has been assumed that between every two spheres there are substances different from those of the spheres".

Some Arab astronomers (for instance, Averroës, Ibn-a-Tufayl, Al-Bitruji, and Avempace) attempted to construct a system which would be free of eccentrics and epicycles. One of their main motives for this was to return to a true Aristotelian physics and to construct a continuous voidless astronomical system. This, of course, was an extremely difficult undertaking. Averroës states that:⁹

"... accepting eccentrics we would have to find among heavenly bodies some superfluous ones, useful merely to fill spaces . . ."

"A body moving in a circle can only move about a center; hence eccentrics are impossible unless between celestial bodies there is either a vacuum or filling-in bodies which are neither naturally round nor naturally moved".

NOTES

1. J. L. E. Dreyer: *A History of Astronomy from Thales to Kepler* (Dover, 1953) p. 112.
2. T. Heath: *Aristarchus of Samos* (Oxford, 1959) pp. 226, 228.
3. W. Jaeger: *Aristotle*, (Oxford paperbacks, 1962) ch. 14.
4. P. Merlan: *Aristotle's Unmoved Movers*. *Traditio* 4, (1946) p. 14.
5. P. Duhem: *Le Systeme du Monde*, (Paris, 1954) II p. 126.
6. W. D. Ross: *Aristotle*, (Meridian Books, Cleveland, 1963) p. 98 On the other hand see his commentary in his *Aristotle's Metaphysics* (Oxford, 1924) vol. II, p. 391: "Aristotle aims at a mechanical account, and can not isolate the system of one planet from that of the next."
7. *De Caelo*: 287 a 4-10, 287 b1, 290 a 5.
8. M. Maimonides: *Guide of the Perplexed* trans. Friedlander, Part II, ch. 24, p. 197.
9. F. J. Carmody: *The Planetary Theory of Ibn Rushd* *Osiris*, 10 (1952) pp. 568, 570.