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Topsy-Turvy World: Circular Motion, Contrariety, and Aristotle’s Unwinding Spheres

Abstract: In developing his theory of *aether* in *De Caelo* 1, Aristotle argues, in *DC* 1.4, that one circular motion cannot be contrary to another. In this paper, I discuss how Aristotle can maintain this position and accept the existence of celestial spheres that rotate in contrary directions, as he does in his revision of the Eudoxan theory in *Metaphysics* 12.8.

Keywords: Aristotle, *De caelo*, *aether*, astronomy, cosmology, circular motion, contrariety

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In *DC* 1.2–4, Aristotle argues for the existence of a celestial element, *aether*, whose natural motion is in a circle about the center of the cosmos. On the account Aristotle offers there, this celestial body is neither generable nor destructible, and is, indeed, exempt from all change apart from its circular motion, which proceeds eternally. The opening chapters of *DC* 1 are, however, hardly Aristotle’s last word on the physics of celestial motion. In addition to *aether*, Aristotle cites soul and unmoved movers as causes of the rotation of the celestial spheres, and it is disputed how, and to what extent, these different factors contribute to a single coherent explanation of celestial motion.[1] Further – and this is the issue I will discuss in this paper – there is a puzzle about how *DC* 1.4’s thesis that circular motion has no contrary fits with the astronomical model presented in *DC* 2 and *Metaphysics* 12.8, which calls for celestial spheres that

1 In *DC* 2.2, Aristotle claims that each celestial sphere is ensouled, which suggests that celestial motions represent a special case of animal motion. *Physics* 8 develops the proposal that the motions of the spheres are actuated by an unmoved mover, while *Metaph.* 12.8 indicates that there is a distinct mover for each sphere. Two fundamental interpretative issues are why movers are required, if the *aether* that composes the spheres moves naturally in a circle, and what role the movers and soul respectively play in explaining the motion of the spheres.

rotate in contrary directions. These two positions have sometimes been thought to be in tension. In this paper, I will offer an account of how they may be seen to be compatible.

The relevant astronomical facts are as follows. At *DC* 2.2, 285b16–33, Aristotle accepts that the sphere of the fixed stars rotates westwards, whereas the spheres responsible for planetary motion rotate eastwards around axes that are tilted relative to that of the starry sphere. Aristotle's remarks at *DC* 2.6, 288a15–17, as well as *DC* 2.12, 291b28–292a1 and 292b31–293a11, indicate the more complex picture that the motion of each planet is the product of the motions of several nested celestial spheres. And this picture is further articulated at *Metaph.* 12.8, 1073b17–1074a17, where, working from Eudoxus' and Callippus' models of the motion of each planet as the product of several circular motions, Aristotle outlines a comprehensive astronomical model. According to this model, each celestial sphere rotates freely on its axis, while this axis is attached at its poles to the sphere above it. As a result, the lower sphere rotates around a moving axis. In a system of several nested spheres, the lowest sphere – which carries the planet – will have a highly complex motion. This mechanism, however, gives rise to a problem, since Aristotle needs to prevent the sphere carrying the planet from imparting its complex motion to the first sphere in the planetary system below it. To prevent this from happening, Aristotle introduces several 'unwinding' spheres situated between the sphere that carries the planet and the first sphere of the next planetary system. Each of these unwinding spheres rotates on the same axis as one of spheres above it, and with the same rotational velocity, but in precisely the opposite direction. The net effect of these unwinding spheres is to allow that the first sphere in the next planetary system – which is attached at its poles to the last unwinding sphere in the system above it – rotate on an axis that is, like the axis of the starry sphere, at absolute rest.

The suggestion that the opposed rotations involved in the astronomical model just sketched are at odds with *DC* 1.4's thesis that circular motion has no contrary has had both ancient and modern proponents. Notoriously, John Philoponus attacks the thesis of *DC* 1.4 by contending that the westward motion of the fixed stars and the eastward motion of the plants relative to the stars quite evidently represent contrary circular motions.[2] And some modern scholars have thought that, if not the motions of the stars and the planets, then certainly the counter-rotating unwinding spheres required by a Eudoxan-style astronomy and their 'cancellation' of the effects of spheres above them are irreconcilable

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2 *Contra Arist.*, fr. 103 = Simpl. *In de Caelo*, 192,5–14, and *Contra Arist.*, fr. 102 = Simpl. *In de Caelo*, 189,22–190,31.

with *DC* 1.4.[3] Recently, however, R. J. Hankinson has proposed that the motions of the spheres called for by a Eudoxan-style astronomy do not count as contrary motions on the grounds that, for motions to be genuinely contrary, they must not just tend in opposite directions, but also have a tendency to impede one another (what he dubs 'contrariety of opposition'); hence, as the celestial spheres in Aristotle's astronomy rotate unimpeded on their axes, their motions cannot qualify as contrary.[4]

Below, in the final part of this paper (Section 3), I will show how the thesis of *DC* 1.4 can be reconciled with the counter-rotating celestial spheres that figure in Aristotle's revision of the Eudoxan theory in *Metaphysics* 12.8. Although I concur with Hankinson that there is no conflict, my strategy for reconciliation differs from his on a key issue, and goes beyond it in others. To set up this discussion, however, I will first need to revisit how the thesis that circular motion has no contrary figures in the development of the theory of *aether* (Section 1), and how Aristotle defends this thesis in *DC* 1.4 (Section 2).

1 The purpose of *DC* 1.4

The discussion to which *DC* 1.4 contributes begins in *DC* 1.3, 270a12–22, where Aristotle argues that *aether* is not subject to generation and destruction. For *aether* to be subject to substantial change, he claims, there must be some contrary body from which it could be generated and into which it could be destroyed. And in

3 See Wildberg 1988, 97: 'This theory [sc. 'Eudoxus' theory of homocentric spheres as worked out by Aristotle in *Metaph.* 12.8'] presupposes the interaction and mutual cancellation of the movements of spheres revolving in contrary directions, a fact which seems to be explicitly ruled out in *De caelo* 1.4. It is important to recognise that in Aristotle the theory of *aether* and the physical theory of homocentric spheres are incongruous.' Kouremenos 2003, following a developmental hypothesis proposed in Easterling 1961, argues that *DC* 2.12 represents a later stage in the evolution of Aristotle's theory than *DC* 1.3–4 on the grounds that it endorses features of the Eudoxan-style model, which he takes to be incompatible with *DC* 1.4.

4 Hankinson 2010, 114–116, contrasts 'contrariety of opposition' and 'contrariety of direction'. On this distinction, Aristotle's criterion for genuine contrariety is 'contrariety of opposition'. Bodnár 2005, 257 n. 1, credits Hankinson with the proposal that celestial motions are not contrary because they manifest neither 'topological' contrariety (in that motions are not between contrary regions) nor 'dynamical' contrariety (in that motions do not impede each other). It is true that celestial motions do not exhibit what Bodnár labels 'topological contrariety', but it is not clear that he is right to suggest that this is so because there are not 'regions of different status' in the heavens. At any rate, several of the arguments in chapter 4 seem to allow that opposed points on a circle may count as contrary places, but seek to show that true circular motion should not be thought of as motion *between* two such points.

order to show that there is no body that satisfies this requirement, Aristotle relies on the premises: (i) that contrary bodies exhibit contrary motions, and (ii) that circular motion, which is the natural motion of *aether*, has no contrary.

Aristotle does not justify the first of these two assumptions, (i) that contrary bodies exhibit contrary motions. Nonetheless, it is possible to reconstruct a plausible story about why he might have felt entitled to it. If there were some body from which *aether* were generated and into which it were destroyed, it would need to be some body other than the four sublunary elements. Since their essences consist in the pairs of contraries hot/cold and wet/dry – earth (cold/dry), water (cold/wet), air (hot/wet), and fire (hot/dry) – a substantial change for any one of these elements will result in its transformation into one of the other three (*GC* 2.3, 330a30–b5). The sublunary elements thus form a closed system. So if *aether* is generable from or destructible into some other body, then there must be some further element beyond it and the four sublunary elements. As Aristotle assumes here that bodies exhibiting the contrariety required for inter-transformation *also* exhibit motive contrariety, he must think that this principle holds true for the four sublunary elements. There is a puzzle about how each of the four elements can be said to exhibit motive contrariety to the other three elements into which it can be transformed. But, presumably, the correct solution is that each element, in its motion to its natural place, exhibits one of the two contrary rectilinear motions ('up' or 'down') relative to each of the other three elements. Thus, for example, water moves up relative to earth (which moves down relative to water), while water moves down relative to both air and fire (which move up relative to water).[5] Considered in this way, the sublunary elements confirm the principle that elements that possess the contrariety required for inter-transformation also exhibit motive contrariety to one another.

By contrast with premise (i), Aristotle does defend premise (ii), that circular motion has no contrary, at considerable length. Indeed, this defense spans the whole of chapter 4. In the lines leading up to the start of chapter 4, we find that Aristotle takes this thesis to support, not just the claim of *DC* 1.3, 270a12–22, that there is no element that is *aether*'s contrary, but also the claim that there exists no element beyond the five already identified.[6] This is a new inference,

5 An account along these lines seems to be implicit in Aristotle's suggestion that heaviness and lightness may be relational (e.g. water is lighter than earth, and earth is heavier than water) together with the coordination of heaviness and lightness with downwards and upwards motion respectively (*DC* 1.3, 269b20–29). For evidence that water and air have both upward and downward motive tendencies, see *DC* 4.3, 310a17–18, and Morison 2002, 28–31.

6 Commentators fail to note chapter 4's connection to the closing lines of chapter 3. Leggatt finds these lines of chapter 3 'oddly placed, fitting more comfortably with the arguments of but it complements the strategy of the earlier argument for *aether*'s ungenerability and indestructibility, insofar as that argument turns upon the idea that *aether* is eternal because there exists no element suitable for it to be transformed into (or vice versa).

> Φανερὸν δ' ἐκ τῶν εἰρημένων καὶ διότι τὸν ἀριθμὸν ἀδύνατον εἶναι πλείω τὸν τῶν λεγομένων σωμάτων ἁπλῶν· τοῦ μὲν γὰρ ἁπλοῦ σώματος ἀνάγκη τὴν κίνησιν ἁπλῆν εἶναι, μόνας δὲ ταύτας εἶναί φαμεν ἁπλᾶς, τήν τε κύκλῳ καὶ τὴν ἐπ' εὐθείας, καὶ ταύτης τὰ δύο μόρια, τὴν μὲν ἀπὸ τοῦ μέσου, τὴν δ' ἐπὶ τὸ μέσον.
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> But it is also clear from the things that have been said why (1) it is impossible that the number of the aforementioned simple bodies be greater; (2) for it is necessary that the motion of a simple body be simple, but we say that these are the only simple motions: motion in a circle and motion in a straight line, and the latter has two parts, the motion from the middle and the motion to the middle.[7] (270b26–31)

Here in these lines we get two claims:
(1) There can be no more simple bodies than those [five] already mentioned.
(2) The motion of a simple body must be simple and there are only three simple motions, viz. the two parts of rectilinear motion (i.e. motion towards and motion away from the center of the cosmos) and circular motion.

Claim (1) is supposed to follow from claim (2). But exactly how it follows requires some unpacking.

To begin with, how does limiting the simple motions to these three enable Aristotle to conclude that there are no more elements than the five already identified?[8] In Chapter 2, Aristotle had claimed that motions are circular, rectilinear, or some combination of these two simple motions (268b16–17). Circular motion was identified as motion around the center of the cosmos, whereas rectilinear motion was identified as taking two forms: motion towards the center of the cosmos ('downwards') or away from the center of the cosmos ('upwards')

chapter 2' and suggests that, had the technology existed, Aristotle 'would have relegated the passage to the relative obscurity of a footnote'.

7 Unless otherwise indicated, translations from the Greek are my own. For *De Caelo*, I have used Moraux's *Budé* for the text (though I reject his transposition of 271a23–28 to 271a19 in *DC* 1.4). I also make reference to the diagrams in Allan's *OCT*.

8 The inference from the claim that there are just three kinds of simple motion to the claim that there are no more than five elements has been seen as problematic. Because he takes Aristotle to be committing himself here to the claim that there are just as many elements as there are kinds of simple motion, namely, three, Moraux 1949, 160, identifies *DC* 1.3, 270b26–31, as one of several 'erratische' passages that have 'keine Beziehung zu den Darlegungen, in welche sie eingefügt sind'. Wildberg 1988, 92, following Moraux, concurs that this passage appears to be 'impossible to reconcile with the doctrine of five elements'.

(268b19–24). Aristotle further contends that each simple body exhibits simple motion (269a2–4). Thus, for any simple body, the available natural motions will be downwards, upwards, or in a circle about the center of the cosmos. Above I have suggested that, for each of the sublunary elements, its distinctive natural motion can be specified as a function of the contraries upwards and downwards. To wit, earth moves downwards and fire moves upwards relative to all the other sublunary elements, whereas water moves downwards relative to air and fire and upwards relative to earth, and air moves upwards relative to earth and water but also downwards relative to fire. Aristotle's division of the rectilinear into the two contrary trajectories upwards and downwards allows him to distinguish at least two, but in principle an unlimited number of, distinct motive tendencies. That there are in fact four (rather than just two, three, or more than four) sublunary elements is not determined by facts about rectilinear motion, but rather by other physical considerations.[9] In any case, by the time Aristotle introduces *aether*, he seems to take for granted that all the simple bodies with rectilinear motion – earth, water, air, and fire – have been identified.[10] So if there are any further simple bodies, they must have circular motion. In chapter 2, Aristotle argues that the circular motions of the heavens must indeed be traced to the natural circular motion of some simple body (269a2–18). Thus, Aristotle has argued that there is at least one body whose natural motion is in a circle, and so, at least five elements. In order to cap the number of elements at five, Aristotle must show that there is *only* one simple body with natural circular motion. But if, like rectilinear motion, circular motion is divided into 'two parts', it is possible that there be two or more kinds of simple body with natural circular motion. On the other hand, if as Claim (2) above states, there must be no more than one kind of circular motion, this unwelcome consequence is supposed to be blocked.[11]

Chapter 4 supports the conclusion that there are no further elements, and, thereby, the conclusion that *aether* is neither generable nor destructible, by arguing for the claim that there is no more than one kind of circular motion. This objective is announced in the first sentence of chapter 4.

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9 For some of these considerations, see *GC* 2.2–3, 329b7–331a6.

10 See e.g. 'For if its motion is upwards, it will be fire or air, whereas if it is downwards, it will be water or earth' (269a17–18), which presupposes that earth, water, air, and fire exhaust the elements with upwards and downwards movement.

11 Aristotle's case for just five elements seems to rely on the implicit premise that no two simple bodies have precisely the same kind of natural motion. Otherwise, the fact that there is just one kind of circular motion does not entitle him to conclude that there is just one celestial element.

> Ὅτι δ’ οὐκ ἔστι τῇ κύκλῳ φορᾷ ἐναντία ἄλλη φορά, πλεοναχόθεν ἄν τις λάβοι τὴν πίστιν·
>
> [ch.4] And one could be convinced in a number of ways that to motion in a circle there is no other motion that is its contrary. (270b31–33)

Now, what Aristotle says here is that there is no other motion (of any kind) that is contrary to circular motion. However, in practice, the work that remains to be done is to argue that circular motions cannot be contraries. Aristotle has already contended that no rectilinear motion is contrary to circular motion, on the grounds that each motion has at most one contrary and that the two kinds of rectilinear motion are contraries to one another (269a9–16). So there is no simple motion that could be opposed to circular motion other than another circular motion. But how does showing that no two circular motions are *contrary* to one another license the conclusion that there is just one kind of circular motion? Here the argument seems to be that there are multiple species of a given kind only if there is contrariety within the genus. Because those things that are most opposed within a genus are by definition contraries (cf. *Metaph*. 5.10, 1018a26–31), there will be contrariety within the genus of circular motion if and only if there are two or more kinds of circular motion. On this assumption that kinds within a genus implies contrariety within a genus, to show that no two circular motions are contrary just amounts to showing that there is at most one kind of circular motion. And this conclusion in turn allows Aristotle to secure chapter 3’s position that there are just five elements, and thus, no element that could exhibit contrariety to *aether*.

2 Why circular motion has no contrary

Before turning to the arguments in chapter 4, I want to call attention to a principle Aristotle consistently appeals to in order to assess whether two motions are contrary. In *Physics* 5.5, 229b21–22, Aristotle enunciates the general principle that two *kinēseis* are contrary if one proceeds from A to B, and the other proceeds from B to A, where A and B exhibit contrareity (henceforth, the ‘Contrary Changes Principle’ or ‘CCP’).

> κίνησις μὲν δὴ κινήσει ἐναντία οὕτως ἡ ἐξ ἐναντίου εἰς ἐναντίον τῇ ἐξ ἐναντίου εἰς ἐναντίον.
>
> Thus two changes are contrary to each other only when one is a change from a contrary to the opposite contrary and the other is a change from the latter to the former. (229b21–22, trans. Hardie and Gaye modified)

Applied to locomotion in particular, motions will be contrary strictly in virtue of the one being from place A to place B, and the other being from place B to place

A, where A and B are opposed places. Aristotle employs this principle, which defines contrary changes solely in terms of their start- and endpoints, in *DC* 1.4, where it is enunciated (at least in part) repeatedly over the course of the chapter.[12]

Let us now turn to the broad structure of Aristotle's argument in *DC* 1.4 to see how this principle comes into play. This overview is on some points controversial, but I will defend my readings below.

First, at 270b32–271a5, Aristotle tries to motivate the suggestion that rectilinear motion is the 'best candidate' for circular motion's opposite on the basis of the fact that a straight line and a circle may be thought of as opposed figures. He then goes on to argue, by CCP, that one rectilinear motion has another rectilinear motion as its contrary. But if the best candidate for circular motion's contrary is not its contrary, then we should conclude that no motion is circular motion's contrary.

Second, at 271a5–19, Aristotle looks to CCP and suggests that circular motions would be contrary by traversing the (semi-)circular path between points on opposite sides of a circle. He then argues that this proposal fails, not because such motions cannot be contrary, but because a motion between opposed start- and endpoints does not count as a circular motion, the curvature of its trajectory notwithstanding. True circular motions are open-ended motions along a full circular path.[13]

Third, at 271a19–22, 23–28, starting from the conclusion that true circular motion traverses a full circular path, Aristotle considers the possibility that such motions might be contrary by proceeding in opposite directions on that path. But such motions do not satisfy CCP either. Given that clockwise and counterclockwise motion will both proceed to all points on a circle, what the clockwise motion is to is not the contrary of what the counterclockwise motion is to.

Fourth, at 271a22–23, 28–33, Aristotle argues against the existence of a further celestial element by *reductio*. Even if circular motions in contrary directions were contrary circular motions (something CCP precludes), elements corresponding to each of these motions would tend to be at loggerheads and thereby impede the realization of each other's motion. But an element that does not

12 References to the principle that motions are contrary in virtue of being between opposed points appear at 271a3–5 ('Motions on a straight path are opposed to one another on account of their places; for up and down are differentia and contrariety of place.'), 271a7–8 ('Motion from A to B is the contrary of motion from B to A.'), and 271a21–22 ('A contrary motion is defined by being from one contrary to the other.').

13 See, e.g. *Physics* 8.9, 265a27–b1, where Aristotle says that, whereas rectilinear motion has a definite beginning, middle, and end because the motion has a start- and endpoint, circular motion does not.

realize its natural motion would be pointless. And nature makes nothing pointless.

I will now consider these arguments in more detail, setting aside the first argument, whose specifics are not so important for establishing why Aristotle is committed to the claim that no two circular motions are contrary.

Let us begin, then, with the second argument. Since my reading of this argument is at odds with a traditional reading of the passage, I will need to say some things to set up my interpretation. Here is the relevant passage:

> Ἔπειτ' εἴ τις ὑπολαμβάνει τὸν αὐτὸν εἶναι λόγον ὅνπερ ἐπὶ τῆς εὐθείας καὶ ἐπὶ τῆς περιφεροῦς (τὴν γὰρ ἀπὸ τοῦ Α πρὸς τὸ Β φορὰν ἐναντίαν εἶναι τῇ ἀπὸ τοῦ Β πρὸς τὸ Α), τὴν ἐπὶ τῆς εὐθείας λέγει· αὕτη γὰρ πεπέρανται, περιφερεῖς δ' ἄπειροι ἂν εἶεν περὶ τὰ αὐτὰ σημεῖα.
>
> Next, if someone assumes that the same account that applies to the straight applies to the circular (for the motion from A to B is the contrary of the motion from B to A [CCP] [14]), **he is talking about motion along a straight path. For that [sc. the straight path] is limited, whereas circular [paths] through the same points would be unlimited.** (271a5–10)

Let us start with what is clear. Aristotle is here considering the possibility that circular motions might be contrary in virtue of the same facts that make rectilinear motions contrary, namely, by being between opposed points. Driving this proposal is CCP. Such a motion between opposed points would necessarily be on some partial circular path. However, Aristotle claims that, in applying the account that makes two rectilinear motions contrary to circular motion, someone would be ‘talking about rectilinear motion’. Further down, at 271a12–13, Aristotle claims that a motion on a diameter is ‘the same’ as the motion between the same start- and endpoints on a corresponding semi-circle. In other words, motions on a semi-circle do not count as circular motions at all, but rather as rectilinear motions, despite the fact that these motions traverse some part of a circular path. One of the puzzles here is why Aristotle is prepared to regard motions on an arc as rectilinear motions.

There is a traditional reading of the first part of our passage advanced by the ancient commentators, reflected in Fig. I in Allan’s *OCT* (as well as in Fig. 5 of Moraux), and adopted by Leggatt. Here is the figure that corresponds to these readings:

14 This is (strictly) only a partial statement of CCP, since it does not mention that A and B are contraries.

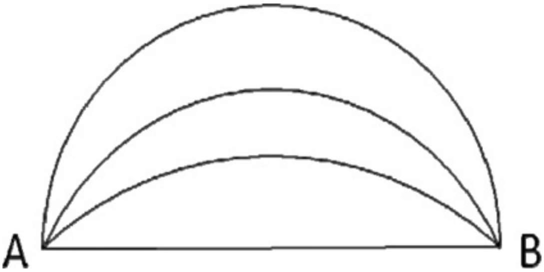

Fig. I: (Traditional)[15]

I find the traditional reading inadequate precisely because it fails to address why semi-circular motions should be regarded as rectilinear motions. Looking to the part of the text in bold in my translation, these interpreters suggest that Aristotle's point is that, whereas a single straight line connects two points, an indeterminate number of arcs can pass through the same two points.[16] This reading involves taking '*peparantai*' as 'limited in number' and '*periphereis apeiroi*' as denoting an unlimited number of distinct circular paths. But the fact that the path that a rectilinear motion travels 'is limited' (*peparantai*), whereas

15 Although variants on the diagram printed in the *OCT* do appear in some manuscripts, not all diagrams indicate the interpretation that Aristotle is contrasting the determinate straight line that connects two points with the unlimited number of circles whose arcs may intersect these same two points. For example, the 12th century *Marcianus gr.* 214 only renders the semi-circle and straight line connecting A and B, and so, takes no explicit stance on the identity of the '*periphereis apeiroi*' with which these trajectories are contrasted. An interpretation that differs from the traditional one, as well as my own, *may* be reflected by the diagram in the 10th century *Parisianus gr.* 1853:

[Assuming that the semi-circular lines in this diagram are meant to illustrate the '*periphereis apeiroi*', there are (I think) three possible ways of understanding what they represent: (1) the unlimited number of (non-semi-circular) arcs connecting the points A and B (= traditional interpretation), (2) the unlimited number of concentric semi-circles connecting the opposed sides of the heavens represented by the points A and B, or (3) the unlimited number of semi-circles that connect points A and B on a sphere.] Nonetheless, since there is no reason to think that any of the diagrams in manuscripts of *DC* go back to Aristotle, these diagrams should be regarded as possessing no more interpretative authority than other ancient interpretations of Aristotle's text. (Thanks to Lutz Koch at the Aristoteles Archiv for directing me to these diagrams.)

16 This is the reading of Leggatt as well as the ancient commentators.

the circular paths are ‘unlimited’ (*apeiroi*) is supposed to support (*gar*) the claim that semi-circular motions count as rectilinear motions. But how can the fact that an unlimited number of different arcs pass through the two points A and B yield the conclusion that the motions along these arcs should be regarded as rectilinear motions? Moreover, it is far from clear how the fact that two points are insufficient to specify a determinate arc would count as an objection to treating motions along some given arc as contrary motions. Finally, a crucial supposition of this interpretation is that the arcs intersecting the points A and B are of different lengths, which is only possible if the circles they belong to do not share a common center. But simple circular motion is conceived of as motion on a circular path centered on the earth. Since I think that these difficulties cannot be satisfactorily resolved, I will not pursue this option further, but instead propose an alternative construal of the passage.

Peparantai/*apeiroi* might instead be taken to distinguish a finite path and unlimited circuits (i.e. laps) along the same circular path. On this reading, *apeiroi* may be read either as the claim that these circuits are unlimited in that they are not bounded by endpoints, or as the claim that the circuits traversed are unlimited in number. This construal would provide a clear contrast between rectilinear motions and open-ended circular motions (N.B.: If this is correct, then the diagram printed in the Oxford text, as well as in Moraux and Legatt, reflects a mistaken interpretation of the argument). On this proposed reading, a motion along a semi-circular arc can qualify as rectilinear motion precisely because it traverses a finite path, but cannot qualify as a circular motion because that motion traverses a series of unbounded (or an unlimited series of) circular paths, i.e. circuits. This interpretation might be represented diagrammatically as:

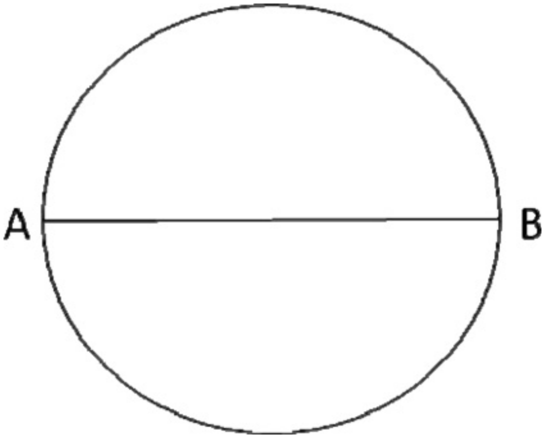

Fig. I: (Alternative)

Whereas the motion on the arc from A to B (like the motion on the straight line from A to B) is finite, the motion on the corresponding circle is unlimited. But why assume that circular motions must be open-ended, and not just a single lap around a circular track? And why assume that it is inappropriate to think of a continuous open-ended motion as nonetheless proceeding from and to the opposed points it traverses? On the former issue, since the target of our investigation is the natural motion of the elements, the possibility that the nature of an element would be to make a single (or intermittent) revolution from and to the same point on a circular path is hardly worth countenancing. And, as Aristotle holds at *Physics* 8.9, 265a27–b2, true circular motion – by contrast with a finite motion on a circular path – has no beginning, middle, or end. If we treat the motion as between any start- and endpoints, we are no longer talking about true circular motion. On the latter issue, treating an open-ended circular motion as nonetheless between the two opposed points it (repeatedly) traverses, Aristotle raises an objection to this characterization of circular motion in *Physics* 8.8. There the objection runs that if a circular motion is a motion from A to C, it will at the same time be a motion from C to A, but these two motions are contrary, and nothing can undergo contrary changes at the same time (*Phys.* 8.8, 264a7–21 and 264a21–b1).

Still, even if it is accepted that circular motion is not properly a motion between two points on opposed sides of a circle, it is nonetheless counterintuitive to claim that a motion along a curved path is a *rectilinear* motion in virtue of being delimited by those points. It seems natural to say rather that such a motion would be neither circular nor rectilinear. The next set of lines (in **bold**) suggest a way to address this problem.

> Ὁμοίως δὲ καὶ ἐπὶ τοῦ ἡμικυκλίου τοῦ ἑνός, οἷον ἀπὸ τοῦ Γ ἐπὶ τὸ Δ καὶ ἀπὸ τοῦ Δ ἐπὶ τὸ Γ· ἡ γὰρ αὐτὴ τῇ ἐπὶ τῆς διαμέτρου ἐστίν· ἀεὶ γὰρ ἕκαστον ἀπέχειν τὴν εὐθεῖαν τίθεμεν.
>
> The same goes for [the motion along] a single semi-circle as well, e.g. from Γ to Δ and Δ to Γ. **For that motion is the same as the motion along the diameter. For we suppose each thing is always a straight line away.** (271a10–13)

The *OCT* offers the following accompanying diagram:

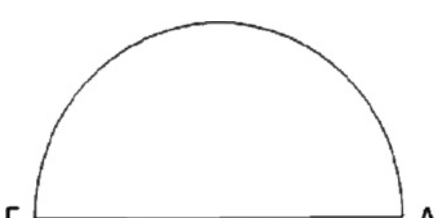

Fig. II

Here Aristotle seems to offer a second consideration in favor of treating motions on a semi-circular path as rectilinear motions, namely, that we think of the interval between any two points as described by a straight line. But how should the fact that we think of the interval between any two points as described by a straight line lead us to conclude that the motion between these two points on an arc is a rectilinear motion? Here we can ascribe to Aristotle the principle that motions defined by the same startpoint and the same endpoint are the same in kind. This principle is, at any rate, implied by the principles that each thing has only one contrary (269a14) together with the principle that, for all motions *m* and *n*, if the start- and endpoint of *m* are the contrary of the start- and endpoint of *n*, then *m* and *n* are contrary (CCP). For example, in Fig. II, the diameter motion Γ → Δ should have as its contrary the semicircular motion Δ → Γ as well as the diameter motion Δ → Γ. But if Γ → Δ has one contrary, the two forms of Δ → Γ motion must be the same in kind. And Aristotle's observation that we think of path from Δ to Γ as a straight line gives us a reason to privilege the description of the Δ → Γ motion as rectilinear to its description as semi-circular.

Of course, semi-circular motions need not proceed along the same side of the circle. But we are no better off if the motions between the two opposed points are not on the same arc, but on the arcs on opposite sides of the circle. Aristotle considers this case next.

> Ὁμοίως δὲ κἂν εἴ τις κύκλον ποιήσας τὴν ἐπὶ θατέρου ἡμικυκλίου φορὰν ἐναντίαν θείη τῇ ἐπὶ θατέρου, οἷον ἐν τῷ ὅλῳ κύκλῳ τὴν ἀπὸ τοῦ Ε πρὸς τὸ Ζ τοῦ Η ἡμικυκλίου τῇ ἀπὸ τοῦ Ζ πρὸς τὸ Ε ἐν τῷ Θ ἡμικυκλίῳ. Εἰ δὲ καὶ αὗται ἐναντίαι, ἀλλ' οὔτι γε αἱ ἐπὶ τοῦ ὅλου κύκλου φοραὶ ἀλλήλαις διὰ τοῦτο ἐναντίαι. *—*
>
> Likewise, if someone, having drawn a circle, supposed the motion upon one semi-circle to be contrary to the motion on the other, e.g. on a whole circle the motion from E to Z on semi-circle H in relation to the motion from Z to E on semi-circle Θ. But even if these are contraries, it is certainly not the case that the motions on the whole circle are thereby contraries. *—*[17] (271a13–19)

For the accompanying diagram in the *OCT*, see Fig. III blow.

The *homoiōs* that introduces the example indicates that the same objection presented in the previous argument – that semi-circular motions are tantamount to rectilinear motions – applies to this particular scenario is well. But here Aristotle has an additional objection to make. Once we make the motion between E

17 Moraux and Leggatt transpose lines 271a23–28 to this point. I agree that the location of those lines in the manuscripts is not unproblematic, but I do not think that transposing them to this point in the text is the best solution. I will discuss this problem below.

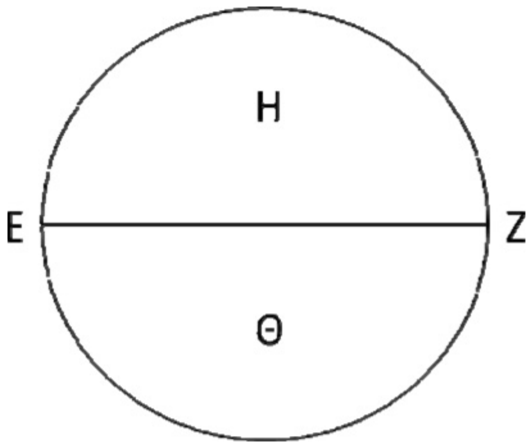

Fig. III

and Z on semi-circle H and the motion between Z and E on semi-circle Θ true circular motions, i.e. open-ended motions, they turn out to be precisely the same motions, i.e. circular motions along the same path in the same direction. Hence, Aristotle says that even if the two semi-circular motions were opposed, the corresponding circular motions would not be. Of course they would not – they would be the same clockwise motion!

So much then for semi-circular motions, and for true circular motions on the same path in the same direction. But what about true circular motions on the same path in opposite directions? This is the question Aristotle addresses in the third argument. Let us look at the text.

> Ἀλλὰ μὴν οὐδ' ἡ ἀπὸ τοῦ Α ἐπὶ τὸ Β κύκλῳ φορὰ ἐναντία τῇ ἀπὸ τοῦ Α ἐπὶ τὸ Γ· ἐκ ταὐτοῦ γὰρ εἰς ταὐτὸ ἡ κίνησις, ἡ δ' ἐναντία διωρίσθη φορὰ ἐκ τοῦ ἐναντίου εἰς τὸ ἐναντίον. … * ἐπὶ τὸ αὐτὸ γάρ, ὅτι ἀνάγκη τὸ κύκλῳ φερόμενον ὁποθενοῦν ἀρξάμενον εἰς πάντας ὁμοίως ἀφικνεῖσθαι τοὺς ἐναντίους τόπους (εἰσὶ δὲ τόπου ἐναντιότητες τὸ ἄνω καὶ κάτω καὶ τὸ πρόσθιον καὶ ὀπίσθιον καὶ τὸ δεξιὸν καὶ ἀριστερόν), αἱ δὲ τῆς φορᾶς ἐναντιώσεις κατὰ τὰς τῶν τόπων εἰσὶν ἐναντιώσεις· *
>
> But surely, not even the circular motion from A to B is contrary to the circular motion from A to Γ.[18] For the motion is from the same to the same, whereas contrary motion is

18 It is hard to see how this assessment can be reconciled with a comment at *Physics* 8.8, 262a6–12: 'And an indication that the motion from A to B is contrary to the motion from B to A is that, if they occur at the same time, they arrest and stop one another. And the same goes for motions on a circle, e.g. the motion from A to B is the contrary of the motion from A to C (for they arrest each other, if they are continuous and do not turn back, due to the fact that opposites destroy and hinder one another)' (trans. Hardie and Gaye modified). Apparently, Aristotle entertained different views about whether circular motions in contrary directions on the same path count as contrary motions. Faced with the inconsistency between this passage in the *Phy-*

> defined as motion from contrary to contrary. ... * For it would be to the same, because it is necessary that what moves in a circle from any point arrive at all the contrary places alike (and the contraries of place are above and below, in front and behind, right and left), and the contrarieties in motion are in accordance with the contrarieties of places. * (271a19–22, 23–28)

This argument corresponds to the following diagram in the *OCT*:

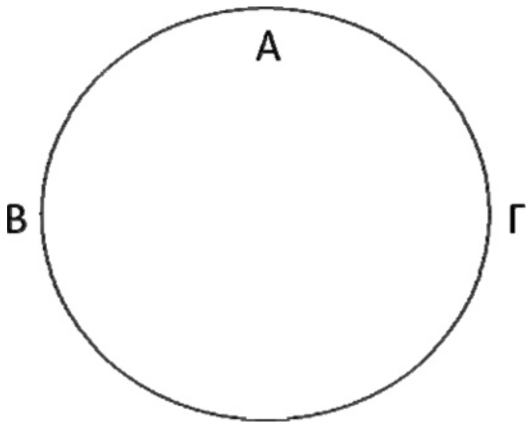

Fig. IV

Unfortunately, there is a messy textual problem here – Moraux wants to transpose the text between the asterisks to 271a19.[19] I think this emendation is not

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sics and *DC*, the *DC* passages, where the denial that circular motion can have a contrary is pervasive (*DC* 1.3, 270a19–20; 1.4 *passim*; 2.3, 286a3; 2.5, 287b22–24) and plays a key structural role in the argument for *aether*, seem to have a better claim to represent Aristotle's considered view than these lines of *Physics* 8.8, where the claim that circular motions may be contrary functions as supporting evidence for the thesis that the rectilinear motions from A to B and from B to A are contrary motions.

19 What is generally agreed upon is that lines 271a22–23 are continuous in sense with 271a28–33. The question then is what should be done with the intervening lines, 271a23–28. As I see it, there are two reasonable options. We could follow Moraux and transpose to 271a19. In that case, these lines emphasize that the semi-circular motions described there, if extended to true circular motions, are the same kind of motion, since they traverse the same path in the same direction. Alternatively, we could take it that they belong in sense with 271a19–22 and that the interruption in the thought at 271a22–23 is either due to a corruption, or simply an intrusive anticipation of a point to be taken up later. In this case, the lines claim that circular motions in opposite directions on the same path are the same in kind because they are from and to all the same points. I think Moraux's solution is the less attractive of these two proposals. First, if the text is in fact dislocated, his proposal opts for the more radical dislocation. Second, it is obvious that circular motions on the same path in the same direction are the same in kind. What is not so obvious is how it is that circular motions on the same path in opposite directions are our best option, and that treating lines 23–28 as belonging to this argument gives a better reading. Nonetheless, an intelligible rationale for denying that clockwise and counterclockwise motions are contrary can be found, wherever we come down on this textual issue. In lines 19–22, Aristotle claims that each motion, regardless of direction, is from the same to the same. This could reasonably taken as the claim that both motions are from A to A (cf. *Phys.* 8.8, 264b9–19). And if this reading is right, then Aristotle is contending that circular motions in opposite directions do not count as contrary motions because neither motion is a motion from one point to its contrary, as CCP requires. If we concede to Aristotle CCP, this is all he needs to say to block the hypothesis that circular motions in opposite directions can count as contraries. However, if lines 23–28 are part of this argument, and function as an explication (*gar*) of 'to the same', the picture is a bit more complicated. In this case, Aristotle is arguing that the counterclockwise A–B motion and the clockwise A–Γ motion, are not contrary motions because *both* the counterclockwise A–B motion *and* the clockwise A–Γ motion can be said to be 'to' the diametrically opposed points B and Γ. The description of the counterclockwise motion as a motion from A to B and the description of the clockwise motion as a motion from A to Γ might suggest that these two motions are contrary, given that B and Γ are opposed points. But if it is right that both motions are, strictly speaking, both to B and to Γ, it is not the case that *what clockwise motion is to* can be opposed to *what counterclockwise is to*.[20] And, consequently, these two motions would not be contrary to one another in accordance with CCP.

The foregoing discussions of motion on a semi-circle and true circular motion together form a neat demonstration of the claim that circular motions cannot satisfy the criterion for motive contrariety, CCP. Again, this principle requires that, if two motions are to be contrary, one must be from A to B and the other must be from B to A, where B and A are contrary places. Suppose that points A and B on opposite sides of a circle are contraries. If we take a motion on a circular path as 'from' and 'to' these points, then we are treating these points as start- and end-points, and the motion will not be a true circular motion. If we treat A and B, however, simply as points traversed in the course of a true circular motion, circular motions in both directions are both alike to A and to B, and so, clockwise and

the same in kind by being 'to the same'. This is a point that may be thought to call for some further explication. And if we take these lines as elaboration on 271a19–22, they supply the required explication.

20 Note that Aristotle denies that a circular motion is from A to B (*Phys.* 8.8, 264a7–b1), but allows that a circular motion is from A to A (*Phys.* 8.8, 264b9–19). If Aristotle here contends that a circular motion is to A and to B (*DC* 1.4, 271a28–23), this claim should accordingly be expandable to the claim that a circular motion is both to A *from A* and to B *from B*, but not to the claim that the motion is to A from B and from B to A.

counterclockwise motion cannot be opposed in the way CCP requires. So on a proper understanding of how true circular motion traverses points on opposite sides of the circle, the search for contrariety between circular motions fails.

Finally, in the fourth argument of the chapter, which takes the form of a *reductio*, Aristotle offers a reason for thinking that even if two circular motions were in fact contrary, elements with these contrary motions would not exist.

> Εἰ δὲ καὶ ἦν ἡ κύκλῳ τῇ κύκλῳ ἐναντία, μάτην ἂν ἦν ἡ ἑτέρα· … εἰ μὲν γὰρ ἴσαι ἦσαν, οὐκ ἂν ἦν κίνησις αὐτῶν, εἰ δ' ἡ ἑτέρα κίνησις ἐκράτει, ἡ ἑτέρα οὐκ ἂν ἦν. Ὥστ' εἰ ἀμφότερα ἦν, μάτην ἂν θάτερον ἦν σῶμα μὴ κινούμενον τὴν αὐτοῦ κίνησιν· μάτην γὰρ ὑπόδημα τοῦτο λέγομεν, οὗ μή ἐστιν ὑπόδεσις. Ὁ δὲ θεὸς καὶ ἡ φύσις οὐδὲν μάτην ποιοῦσιν.
>
> But even if circular motion were contrary to circular motion, one of the two circular motions would be in vain. (271a22–23) … For if the motions were equal, there would not be a motion of the bodies, but if one of the two motions were to prevail, the other motion would not exist. As a result, if there were both bodies, one of the two bodies would be in vain since it would not be moving with its natural motion. For we say that the shoe which is not worn is in vain. But god and nature make nothing in vain. (271a28–33)

The scenario Aristotle has in mind here is one where there is one element with a natural tendency to move clockwise in the heavens and another element with a natural tendency to move counterclockwise in the heavens. In this case, Aristotle thinks, these bodies would be at loggerheads and neither would realize its natural motion, or one would prevail, and the other would not realize its natural motion. Aristotle's claim that one of the bodies would be in vain is that there would be some natural body that does not fulfill its natural motion, and so, is to no purpose. And that, Aristotle contends, is anathema to the way nature works. Therefore, we should think that there is no such body.

The argument Aristotle offers here may not be a decisive case against the existence of two elements with natural circular motions in contrary directions. The problematic scenario Aristotle describes could perhaps be avoided if the two proposed elements were to move along different paths in the heavens. Nothing in the argument, so far as I can tell, positively rules this scenario out. But it should be noted that such a harmonious arrangement could not arise purely as a function of the natural motions of these two elements. If two circular motions *were* to be contrary (something precluded by CCP), they would be contrary just in virtue of having natural tendencies to move about the cosmos' center in contrary directions.[21] So if the elements described here were to exercise

21 We might worry about what this argument implies for the sublunary elements. If bodies with natural circular motions in contrary directions would impede each other's motion, why does this objection not apply equally to elements with natural motions upwards and down-their natural motions along different paths, *that* arrangement would require some cause other than the natural motive tendencies of the elements. (Below we will need to consider how Aristotle himself can account for the fact that celestial motions in contrary directions are not at loggerheads.)

Now, given that the problematic scenario Aristotle envisages is one where there are elements with natural tendencies to move in opposed directions in the heavens, there is an issue about how to read the counterfactual *protasis*: 'but even if circular motion were contrary to circular motion'. One way of reading the *protasis* is to take it that Aristotle agrees that the clockwise motion *x* on circle *z* and the counterclockwise motion *y* on circle *z* would be contrary motions, whereas the thesis for *reductio* is just that bodies with such natural motions actually exist. But this is a problematic reading, as it would appear to be inconsistent with the verdict of the third argument that even two motions in contrary directions on the same circle do not count as contrary motions. Presumably, Aristotle is rather saying that, even on the assumption that the clockwise motion *x* on circle *z* and the counterclockwise motion *y* on circle *z* were contrary motions (a claim he has already given reasons not to endorse), there would not be different elements that have each of these motions as their natural motion. Given that Aristotle has been assuming that there are distinct elements with natural circular motions *only if* two circular motions are contrary, the assumption of elements with distinct natural circular motions entails the assumption that their motions would be contrary. So it makes good sense that Aristotle allows, *for the sake of the reductio*, that counterclockwise and clockwise motions on the same circle count as contrary. But Aristotle himself is no more committed to the claim that circular motions in contrary directions are contrary than he is to the claim that there exists one element with natural clockwise motion and another with natural counterclockwise motion.

Earlier I suggested that the aim of *DC* 1.4 is to exclude the possibility that there might be an element with motion contrary to that of *aether*. Whereas the previous arguments in *DC* 1.4 attempt to exclude this possibility by arguing that no motion would count as the contrary of circular motion, the final argument of *DC* 1.4 defends the conclusion that there is no such element in another way, by

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wards? Here it may be important that the sublunary elements proceed to their natural places, and then stop. If I drop an earthen ball from the fire sphere, it will move downwards towards the surface of the earth. The ball's motion will not ordinarily be impeded by a body moving upwards. Only if the ball *were* to encounter a fountain or jet of air directed upwards, would its downwards motion would be hindered. But for bodies with tendencies *always* to be moving in opposed directions on the same path, which is only possible on a circular path, a scenario where bodies are at loggerheads may be expected to be the norm.

suggesting that, even if circular motions in contrary directions were contrary, the postulation of two elements with the corresponding motions would lead to impossible consequences.

3 *DC* 1.4 and Aristotle's unwinding spheres

We are now in a position to consider whether an astronomy that involves counter-rotating spheres is in tension with the thesis that circular motion has no contrary.

To begin with, the worry that the thesis of *DC* 1.4 is logically incompatible with counter-rotating spheres is unfounded. To be sure, there are spheres in the Eudoxan-style model that rotate in contrary directions. But spheres rotating in contrary directions do not count as having contrary motions by Aristotle's explicit criterion for contrariety (CCP), as Aristotle himself observes at 271a19–28. Nor do counter-rotating Eudoxan-style spheres run afoul of considerations adduced in the final argument. The sort of cancelling-out that Aristotle's counter-rotating spheres achieve does not involve one sphere impeding the rotation of another sphere around its axis. And the cancelling-out that counter-rotating spheres perform is not 'in vain', since the role the counter-rotating spheres play in insulating one planetary system from the system above it is, Aristotle thinks, integral to the optimal construction of the heavens.

As far as the compatibility of *DC* 1.4 with Aristotle's astronomy goes, Hankinson's view that the positions are consistent is to be preferred. But his account of how they are compatible is, I think, not wholly satisfying.[22] While Hankinson concedes that Aristotle 'feels constrained to argue' from CCP that circular motions are not contrary, he sees the real motivation for arguing that circular motions are not contrary to be enunciated in the final argument of chapter 4. In that final argument, since Aristotle seems to suggest that contrary circular motions would be at loggerheads, Hankinson takes the upshot of this argument to be that motions are 'genuinely' contrary, not merely by proceeding in contrary directions (which would make the motions of the spheres in the Eudoxan-style model contrary), but in virtue of also exhibiting the tendency to impede one another (what Hankinson calls 'contrariety of opposition'). That kind of opposition (and more generally the existence of 'mutually destructive tendencies' in the heavens) is, on Hankinson's view, what Aristotle seeks to rule out.

22 For this account, see Hankinson (2010), 114–116.

But this story cannot be quite right. Here Hankinson's reading requires that clockwise and counterclockwise motions on the same path count as contrary motions, and that they are contrary in virtue of impeding each other. However, Aristotle, relying on CCP, explicitly denies at *DC* 1.4, 271a19–20, that motions in opposite directions on the same circular path count as contrary motions. And these motions, since they would impede each other, if they were to occur simultaneously, should count as contrary motions by Hankinson's criterion. So, unless Aristotle is operating with different senses of contrariety in this chapter, Hankinson's account of contrariety appears to be incompatible with Aristotle's earlier argument. As I have suggested above, Aristotle cannot consistently accept that the prime candidates for contrary circular motions – clockwise and counterclockwise motions on the same path – are in fact contrary motions. But since the supposition that one circular motion is contrary to another is a counterfactual premise in a *reductio*, we need not (and should not) take it that Aristotle himself accepts that such motions are contrary. As to why Aristotle is so concerned to show that no two circular motions are contrary, Hankinson is right that the broader agenda is to exempt the heavens from destructive processes. But this agenda does not require that the correct criterion for motive contrariety be Hankinson's 'contrariety of opposition'. As we have seen, for Aristotle, the crucial issue is just that circular motion not be divided into contrary kinds, lest there be two corresponding celestial elements, *aether* and another element into which *aether* could be destroyed.[23]

Nor is there good evidence to think that Aristotle, in light of accepting the existence of spheres that rotate in opposite directions, came to repudiate the thesis of *DC* 1.4. To begin with, at the time when he developed his theory of *aether*, Aristotle could hardly have been innocent of the theory that the planets move eastwards against the background of, and are carried along by, a westwards-rotating starry sphere. This astronomical model figures prominently already in Plato's account of the construction of the circles of the Same and the Different at *Timaeus* 36 B–D, and nothing suggests that Aristotle ever adhered to any other astronomical framework than one involving both eastwards- and westwards-rotating spheres.[24] And it is difficult to see how the refinement of

23 It is, I think, not altogether clear whether Aristotle thinks that the existence of an additional kind of simple motion would imply the existence of a corresponding element or only the possibility of its existence.

24 To explain the phenomenon that the planets appear to move westward more slowly than the stars, one could in principle suppose that all celestial bodies move to the west, albeit at different speeds (as the Epicureans did, D. L. 10.113–114), but both Plato and Aristotle consistently endorse variations on a basic 'two circles' model, according to which planetary motion is this picture by the introduction of spheres that rotate in *precisely* opposite directions, as the model of *Metaphysics* 12.8 requires, could have provided any grounds for reassessing the thesis of *DC* 1.4. The only evidence that Aristotle might have thought of celestial motions in opposite directions as contrary motions is his characterization of the eastwards motion of planets as 'contrary' to the westwards motion of the stars at *DC* 2.2, 285b31.[25] But, just a few lines later, at *DC* 2.3, 286a3–7, Aristotle asks why, *given that one circular motion is not contrary to another*, celestial bodies rotate in different directions, and two chapters later, at *DC* 2.5, 287b22–24, he reiterates his view that motions in opposite directions on a circle are not contrary.[26] In light of these reaffirmations of the principle that no two circular motions are contrary, the phrasing at 285b31 is better taken as an infelicitous way of expressing the idea that the starry sphere and planetary spheres rotate in contrary directions than as a renunciation of the position that circular motions cannot be contrary.[27] As we will see below, despite the verbal dissonance between *DC* 2.2, 285b31, and other passages in *DC* 1 and 2, the content of this passage of *DC* 2.2 helps clarify how even circular motions in contrary directions can be seen as exhibiting the very same motive tendency.

Now, one might think that, even if there is no logical conflict between the thesis that circular motions cannot be contrary and counter-rotating spheres, and even if Aristotle did not come to think of spheres rotating in contrary directions as engaging in contrary motions, there are theoretical tensions of another sort.

To begin with, one might be concerned that once counter-rotating spheres are accepted, the right thing to say (as a matter of the best philosophical view) is that they have contrary motions, and that, therefore, Aristotle would have been well advised to restrict the scope of his criterion for contrary changes, CCP, to just those changes bounded by true start- and endpoints. This concern was voiced long ago by John Philoponus, who contended that the (westerly)

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the product of a faster westward-moving circle (or sphere) carrying a slower eastward-moving circle (or sphere) (see Mendell 2000, 62–63).

25 'The principle of motion for them [sc. the planets] is in the reverse position [to that of the starry sphere] since their motions are contrary (*dia to enantias einai phoras*) [to that of the starry sphere], ...' (285b30–32).

26 'Since one circular motion (*kinēsis he kuklōi*) is not contrary (*enantia*) to another circular motion (*tēi kuklōi*), we should consider why there are a multitude of motions (*phorai*) ...' (286a3–4). 'Now, there are two ways of moving along a circle, from A to B or from A to C, and we have already explained that these motions are not contrary to one another' (287b22–24).

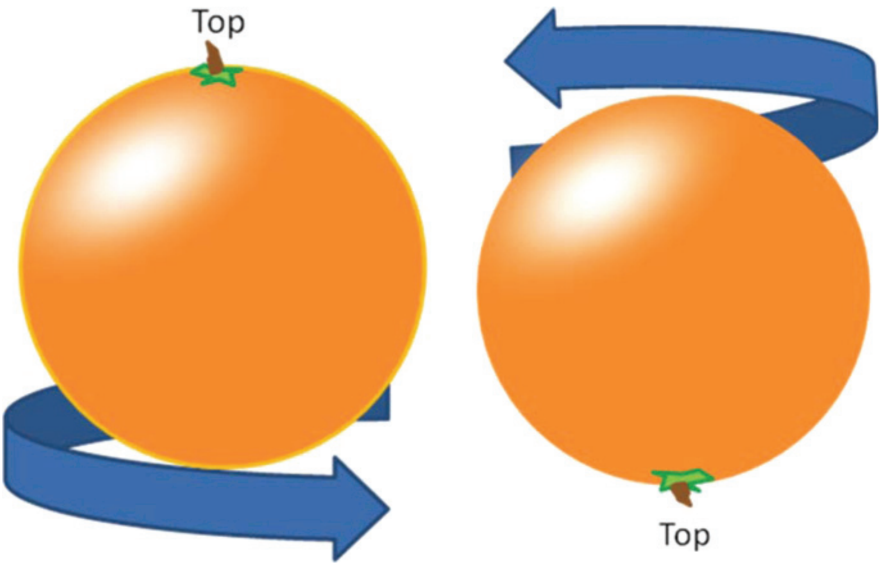
27 Given that *DC* 2.3, 286a3, and *DC* 2.5, 287b22–24, reiterate the position of *DC* 1.4, the attempt of Kouremenos 2003, 168, to support a developmental picture on the basis of the phrasing of *DC* 2.2, 285a31, seems ill-advised.

motion of the sphere of the fixed stars, and the (easterly) motion of the planets are contrary motions (*Contra Aristotelem*, fr. 103 = Simpl. *In de Caelo*, 192,5–14), urging that different kinds of contrariety apply to circular and rectilinear motions (*Contra Aristotelem*, fr. 102 = Simpl. *In de Caelo*, 189,22–190,31, cf. 192,15–23). The nub of Philoponus' charge is that, since circular motions in opposite directions are clearly contrary, CCP is an improper criterion for assessing whether circular motions are contrary. Both Aristotle and Philoponus accept the premise: 'If CCP, then it is not the case that two circular motions are contrary'. But whereas, for Aristotle, this premise is part of a *modus ponens* argument, Philoponus takes the sound argument to take the form of a *modus tollens*.

This is a serious challenge, but perhaps not a dispositive one. Here the intuition that clockwise and counterclockwise motions are contrary should be set against the virtues of holding to the general principle (CCP) that leads Aristotle to deny that such motions are contrary. In finite motions, the change from A to B has as its result that the changed thing is (at) B, and the change from B to A has as its result that the changed thing is (at) A. If A and B are contraries, then these two changes, which are in contrary directions vis-à-vis the start- and endpoints of the change, bring about contrary states of affairs. But in the case of *circular* motions that are in contrary directions, it is not so clear that this is the case. Viewed from the standpoint of where the change proceeds from (all the points on the circle) and where the change is to (all the points on the circle), there is no distinction to be drawn between circular motions in contrary directions. Faced with this fact, Aristotle could have tried to work out a different account of what it is to be contrary *for circular motions* that privileges directionality or the sequence of points traversed over what the change is from and to. But such a solution would come at the price of abandoning a fully general account of contrary changes grounded in the intuition that contrary changes are from and to contrary states of affairs. Considered in isolation from other changes, it may be attractive to see clockwise and counterclockwise motions as contrary changes. However, once one considers what it is for other changes to be contrary, there is at least some theoretical pressure to resist the intuition that forms the basis of Philoponus' challenge.

Related to this concern about what it is for two changes to be contrary is a concern about how to account for the existence of circular motions in opposed directions. If Aristotle has just one natural motive tendency responsible for circular motion, how do circular motions in opposite directions come to be? If these circular motions in opposite directions require distinct motive tendencies, the position that circular motion is not divisible into kinds is a hard line to hold. In what follows, I hope to show that Aristotle has an explanation for why celestial bodies move in opposite directions that does not require the supposition that such motions reflect contrary motive tendencies. Given that Aristotle has, I think, a coherent story to tell about how it is that all spheres exhibit the same kind of motive tendency, he also has resources to resist Philoponus' contention that eastwards and westwards motions are contrary motions.

The following is a fruitful way of thinking about how the rotations of the celestial spheres can be regarded as exhibiting a single motive tendency. Take an orange.



Orange rotating counterclockwise in relation to its top (Eastward)

Orange rotating counterclockwise in relation to its top (Westward)

Suppose that this orange is a celestial sphere with a tendency to rotate – if it is actually rotating, it has an axis and it is rotating counterlock wise in relation to one of its poles. Call that pole the 'top'. Suppose that the earth is contained inside the orange and the top of the orange aligns with the north pole of the earth. In this case, the orange's counterlockwise rotation in relation to its top is, from the perspective of the earth, a motion from west to east. How can we get the orange to rotate from east to west? Flip the orange upside down so that its top aligns with the south pole of the earth. In reorienting the orange, we do not need to take it that the orange engages in a different kind of motion about its axis. The motion is the same. It is just that the orientation of the top of its axis of rotation is different. Now expand the picture to nested oranges. Those oranges that rotate in opposite directions could be explained as a function of the 'tops' of some being aligned with the 'bottoms' of others. In this way, one can construct a Eudoxan-style model of nested counter-rotating spheres. Eastward and westward celestial motion need not be thought of as due to different natural motions defined in relation to some absolute frame of reference, e.g. the earth, but rather as due to the fact that the top poles of spheres with the same natural motion have different orientations.

Now there is good evidence that Aristotle himself adopts a perspective along the lines of the orange illustration. In *DC* 2.2, Aristotle contends that (as the Pythagoreans had held) there is a cosmic left and right (284b6–10). But given that left and right only apply to animals, left and right apply to the sphere of the fixed stars in virtue of the fact that this sphere is ensouled (284b10–285a31). Moreover, since, in every animal, motion proceeds from its right, the (westward) motion of the sphere of the fixed stars is from the right of its top, (i.e. counterlockwise), and so, the top of the starry sphere must align with our south pole (285b14–29).[28] However, just like the starry sphere, the motion that each of the planetary spheres itself engages in is from its own right, and thus, the tops of these spheres are aligned with our north pole (285b29–32). Given that top/bottom and left/right are functionally defined in an organism, Aristotle has a systematic basis for thinking that each sphere is rotating in the same fashion.[29] Although Aristotle does, as I have noted above, refer here to the motion of planetary spheres as 'contrary' to that of the starry sphere (285b31), the moral he draws from this is not that they engage in a different kind of motion, but rather that the planetary spheres are engaging in the same kind of circular motion, but are flipped upside down. The above account is applied explicitly to the planetary spheres and the starry sphere, but as a fully general account of how to think about the motion of celestial spheres, it applies equally well to the spheres that explain the motion of a given planet and their rewinding spheres in the revised Eudoxan model, e.g. in Jupiter's system, sphere 4 (which carries the planet Jupiter) and sphere 5 (its corresponding rewinding sphere).

As for the natural motive tendency of *aether* itself, *DC* 2.2 suggests Aristotle can account for the varied trajectories of the spheres while insisting that *aether* exhibits the same motive tendency in all cases. But how exactly *aether* gets the directionality of its motion depends upon how we understand the relationship between *aether* and the spheres. On one possible interpretation of this relation-

28 Aristotle says that the rotation 'proceeds from (*apo*) the right and is carried to (*epi*) the right' (285b19–20). The fact that the top of the sphere of the fixed stars is aligned with the south pole indicates that this motion 'from the right' is to be understood as a counterclockwise rotation (as viewed from the top of the sphere).

29 For Aristotle's idea that right and left are defined in an animal by reference to their organic functions and the application of this principle in *DC* 2.2, see Lennox 2010, 198–201.

ship, *aether* is a material substratum for the celestial spheres. In this case, since motion from the right is determined by having an animal soul, *aether*'s tendency to rotate from the right relative to the top of the sphere would seem to be determined by its animal soul.[30] This would imply a peculiar disanalogy between the natural motion of *aether* and the natural motions of the sublunary elements, in that *aether*'s circular motion would owe its directionality to being the matter for some further substance.[31] Alternatively, one might hold that *aether* is not the matter for an animate sphere, but rather that the essence of *aether* is simply to be identified with that of the animate spheres, and that the structural features of the spheres are given by that essence. Support for this interpretation might be seen in passages of the *Metaphysics* that indicate that the celestial spheres have matter for local motion alone (*Metaph.* 8.1, 1042b3–6; 8.4, 1044b6–8; 12.2, 1069b24–26). For if this is taken to imply that *aether* is not the matter for the substantial form of the spheres, then whatever features are essential to the celestial spheres, including their shape and internal structure, will simply be due to the essence of *aether* itself.[32]

But whether or not *aether* is the matter for the spheres, Aristotle is in a good position to deny that celestial motions reflect different motive tendencies. That is, Aristotle can say that the (determinate) motive tendency of all the spheres is one in kind, and that the same is true of *aether*'s natural motive tendency, whether or not the directionality of its motion is due to some further substantial form. Aristotle would thus seem to have a response to Philoponus' insistence that eastward and westward motions are evidently contrary motions. Namely, Aristotle can reply that these motions reflect both one and the same motive ten-

30 Judson 1994, 160–161, noting Aristotle's contention that left-right orientation applies only to animals, proposes that one purpose of assigning a soul to a celestial sphere is to give *aether*'s rotation a determinate orientation. Falcon 2005, 84 n. 33, points out that, according to Simplicius (*In de Caelo*, 380,1–3), this proposal was advanced in Antiquity by an obscure figure named Julianus of Tralles.

31 Given that *aether's* natural motive tendency can only realize a determinate trajectory in the context of a body with left/right orientation, and given that such orientation only applies to animals, it would seem to follow that *aether* is a spherical organism or the matter thereof essentially.

32 One might, however, challenge the inference from the claim that the spheres do not have matter for substantial change to the claim that they do not have matter for substantial form. Since the celestial spheres differ in size, this feature cannot be part of the essence of *aether*. So it would seem that each of the spheres is a substratum for a certain quantity, even though they do not (*ex hypothesi*) have matter for quantitative change. Hence, in the case of the spheres, not having 'matter for becoming F' need not imply not having 'matter for being F' in any sense. (I wish to thank Stephen Menn for drawing my attention to these passages of the *Metaphysics*, and for discussing their possible implications with me.)

dency on the part of *aether*, and that they represent one and the same type of animal motion, with differences in direction of rotation being a result of the various ways in which the tops and bottoms of the spheres are oriented with respect to one another.

The account of *DC* 2.2 also gives us a solution to a problem to which Hankinson's interpretation rightly draws attention. The final argument of *DC* 1.4 urges that it would be a problematic outcome if the heavenly bodies were at loggerheads, since the natural motions of the celestial bodies would then not be realized. It is worth asking what rules out such a scenario on Aristotle's own view, given that he accepts that *aether* does in fact move in contrary directions. Here it may be important that Aristotle accepts that the orientation of *aether*'s natural motion is given by the structure of the sphere it constitutes. Given the view that a circular motion in a determinate direction can only be realized within the structure of spheres centered on the center of the cosmos, all *aether* will be found within bodies structured in this way. And, on this picture, it will be physically impossible for celestial bodies to be so situated that they move in opposition to one another. The spheres do not impede each other's motion, not because of Aristotle's special views about what contrariety amounts to, but because *aether* needs to be organized into spheres, and nested spheres cannot travel on precisely the same paths.

In the centuries after Aristotle, there was a vigorous debate over whether there is a special celestial element responsible for the circular motions in the heavens. In citing one of Philoponus' challenges to *DC* 1.4, I have touched upon just one move in this exchange. But although *DC* 1.4 was one front in this conflict, its importance should not be overstated. By the time Aristotle turns to this chapter, he has already made his positive case that there is at least one element with a natural tendency to move in a circle. At this point, the question at issue is whether there is more than one. If we are with Aristotle up to this point, the answer that there is just one such natural motive tendency is, viewed from the perspective of his astronomical requirements, obviously the right one. Aristotle had better not posit more than one element with natural circular motion. Another element that has the same tendency toward circular motion as *aether* would be superfluous. Whereas if he attributes eastwards and westwards motion to different elemental tendencies, he will either be forced to concede that the various axial tilts are at odds with one of the two 'natural' axes of rotation, or he will need a different element for every new celestial trajectory. Strikingly, Aristotle prefers to show that there is just one celestial element without appealing to astronomical considerations of this sort, perhaps because he takes the physical considerations he advances in *DC* 1.4 to represent what is better known without qualification (*haplōs*), and to express the more fundamental physical explanation of why the cosmos has the elemental constituents it does. That said, Aristotle might, with some justification, have found that no more than one natural circular motion coheres with the most parsimonious explanation of the varied trajectories of the celestial spheres required by the best available astronomical theory. But that confirmation of the conclusion reached in *DC* 1 would hardly have come as a surprise, if to say that nature makes nothing in vain is also to say it makes the cosmos in the best way possible.[33]

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