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Aristotle asserts at 1073b10-13 that he intends to give in *Metaphysics* XII.8 a definite conception about the multitude of the divine transcendent entities, which function as the movers of the celestial spheres. In order to do so, he describes several celestial theories. First Eudoxus's, then the modifications of this theory propounded by Callippus, and finally his own suggestion, the introduction of yet further spheres which integrate the celestial spheres into a single overarching scheme. For this, after explaining the spheres providing the component motions of each planet, Aristotle introduces so-called rewinding spheres (*anelittousai*), which perform contrary revolutions<sup>1</sup> to the ones performed by the spheres carrying the planet.

The aim of this setup is that the spheres carrying the next planet can be attached directly to the last rewinding sphere of the preceding planet.<sup>2</sup> As a result of the operation of the rewinding

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<sup>1</sup> I will describe a revolution as contrary to another one if and only if [1] the two revolutions have the same period, [2] are around the same axis, and [3] revolve in an opposite sense.

Note that the use of the term 'contrary' is my shorthand. Aristotle rejects in *de Caelo* I.3 270a12-22 that celestial revolutions could have contraries indeed that is a key component in his proof of the eternity and inalterability of the celestial realm. As the considerations of *de Caelo* I 4 make it clear, both topological and dynamical contrarieties are ruled out (cf. further n. 11). Topological contrariety is ruled out, because revolutions do not occur between contrary regions, i.e. regions of different status, like the rectilinear motions between up and down or right and left. Dynamical contrariety is not applicable to the celestial domain, because if one circular motion were eliminated by the influence of another one, this would make either or both of these revolutions superfluous. (I owe the distinction of topological and dynamical contrariety to Jim Hankinson.)

Later, at *de Caelo* II.2 285b28-33 when Aristotle talks about the motions of the planets, he says that they are contrary to the diurnal celestial revolution of the fixed stars. My terminology is a more restricted variant of that usage (cf. also *de Generatione et corruptione* II.10 336a23-31).

<sup>2</sup> 'But it is necessary, if all the spheres combined are to render the phenomena, that for each of the planets there should be other spheres (one fewer than those hitherto assigned) which do the rewinding and bring back to the

spheres, the motions of the preceding planet will not carry over to the next planet.<sup>3</sup> But Aristotle constructs this scheme in a strange fashion. He submits that in the case of each planet we do not need as many rewinding spheres as the number of the spheres carrying the planet, but rather one fewer. As a result the last rewinding sphere (e.g., in the case of Saturn,  $\text{Saturn}_{\text{rew } 2 \rightarrow 1}$ ), to which the first sphere of the next planet (in this case,  $\text{Jupiter}_{\text{w } \rightarrow 1}$ ) is attached, is not stationary.<sup>4</sup> Instead, after all the rewinding it has the same motion as the first sphere of the upper planet. As the first spheres of all the planets perform the same motion—the diurnal celestial motion, which is most perspicuous in the case of the fixed stars—we have to admit some rather strange consequences. Either we have to admit that Aristotle’s account contains an embarrassing slip, and consequently the first sphere of the lower planet ( $\text{Jupiter}_{\text{w } \rightarrow 1}$ ) does not move in relation to the last sphere of the upper one ( $\text{Saturn}_{\text{rew } 2 \rightarrow 1}$ ), in which case it cannot have an unmoved *mover*. Even if in each case there is a transcendental entity which governs the motion of the first sphere of the embedded planetary systems,<sup>5</sup> all that transcendent entity does is that it instructs the sphere not to modify the motion taken over from the last sphere of the preceding planet. Other alternatives are to suggest some realignment of the Aristotelian celestial mechanism, either by introducing new rewinding spheres, or by dropping some of the spheres which carry the planets. Yet a further alternative could be to maintain, as Jonathan Beere submitted in a recent article,<sup>6</sup> that Aristotle’s celestial setup can be salvaged if the motion of the last spheres of each upper planet is not transmitted to the first sphere of the following planet. If this motion is not transmitted, the

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same position in each case the first sphere of the star which is situated below; for only this way can they all carry out the motion of the planets.’ (Metaphysics XII.8 1073b38-1074a5, Revised Oxford Translation, somewhat modified)

<sup>3</sup> See Simplicius, *Commentary on de Caelo*, 504.9-10

<sup>4</sup> See the Appendix for the description of the notation I use to refer to planetary spheres and their motions.

<sup>5</sup> In what follows I shall use the expression “planetary system” to refer to those spheres which directly provide the component motions of a planet. Such planetary systems are composed of the sphere that contains the planet, and the ones immediately preceding this sphere, up until (but excluding) the rewinding spheres of the preceding planet. My terminology is modeled on Simplicius’s usage at *Commentary on de Caelo*, 490.20 and 29, where he speaks about the *suntaxis* of the spheres carrying a planet.

<sup>6</sup> Jonathan B. Beere, “Counting the Unmoved Movers: Astronomy and Explanation in Aristotle’s *Metaphysics* XII.8,” *Archiv für Geschichte der Philosophie* 85 (2003), 1-20.

embedded sphere will also need an unmoved mover.

In what follows I will submit that the project Aristotle pursues in this chapter—to provide a unified celestial mechanism which satisfies his strictures of causal relevance—will incur some significant difficulty on any of the above alternatives. But these inherent difficulties are different in the case of each alternative. Hence, a discussion of these alternatives can shed light on possible considerations shaping the account Aristotle endorsed among the several problematic options.

## 1

The last rewinding sphere of the preceding planet (e.g., in the case of Saturn,  $\text{Saturn}_{\text{rew } 2 \rightarrow 1}$ ), after all the winding and rewinding, performs the daily revolution of the stars. If that is transmitted to the next embedded sphere—to the first sphere carrying the next planet, in this case, to  $\text{Jupiter}_{\text{w } \rightarrow 1}$ —there are going to be several problems. One is that the mover pertaining to this embedded sphere will not cause any additional motion in this sphere: it will be a contradictory entity, a non-moving mover. As the embedded sphere will not perform any additional motion relative to the containing sphere, it will not make sense to settle along what axis the lower sphere is embedded in the containing sphere: any axis will be just as good as any other.<sup>7</sup>

Or rather, any axis will be just as bad as any other, as it will hardly make sense to speak about an axis of rotation around which no rotation takes place. Accordingly, the two spheres might as well be joined to each other along the entirety of the common surface they have. Even then the two spheres will remain distinct: the outer one receives some motion from yet previous spheres, and performs a revolution on its own, under the causal influence of its mover, whereas the internal sphere takes over the entirety of the ensuing motion. The fact that this can happen along the whole of the adjacent peripheries of the two spheres highlights that the causally

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<sup>7</sup> That any axis transmits the motion of the outer sphere in its entirety to the inner sphere is a fundamental presupposition of the theory of homocentric spheres. In this theory revolutions are combined by embedding one sphere along an axis not coinciding with the axis of the containing sphere. No matter how the two non-coinciding axes relate to each other, the revolution of the external sphere is transferred to the embedded sphere. Note, however, that the stipulation in the lines above, that the axes of the motions combined do not coincide, will receive further scrutiny in Section 3 below.

relevant entity responsible for the fact that there is not any further component motion performed by the embedded sphere is exceptional: it is a non-moving mover. Clearly, if possible, the introduction of such non-moving movers should be avoided.

As it is, there are at least two ways open for Aristotle to avoid such non-moving movers. One option would be to introduce an additional rewinding sphere for each planet, so that this last sphere rewinds and eliminates the daily motion of the stars.<sup>8</sup> Accordingly, this ultimate rewinding sphere would perform a rewinding motion, which would cancel the motion this sphere receives. This additional sphere, then, would be completely at rest. Attached to this sphere at absolute rest,<sup>9</sup> the first sphere of the next planet—which we now can designate  $\text{Jupiter}_{w_{0 \rightarrow 1}}$ —could perform the daily motion of the stars under the causal influence of its mover.<sup>10</sup>

But there are several problems with this proposal. To begin with, it would be strange that in the celestial domain, which according to Aristotle is in constant motion, there would be spheres which as a result of the combination of their own motion and the motion imparted to them externally, are eternally at absolute rest. Furthermore, the solution would arguably be against the principle of relevance Aristotle formulates at the end of 1074a25-31. That passage says that

[...] for if everything that moves is for the sake of that which is moved, and every movement belongs to something that is moved, no movement can be for the sake of itself or of another movement, but all movements must be for the sake of the stars. For if a movement is to be for the sake of a movement, this latter also will have to be for the sake of something else; so that since there cannot be an infinite regress, **[Principle of Relevance]** the end of every movement will be one of the divine bodies, which move through the heaven. (Revised Oxford Translation)

The principle formulated in the last two clauses of this passage submits that each and every celestial motion has to contribute to the activity of a planet. Motions which do not contribute to such planetary activity would be superfluous—their presence would contradict the fundamental

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<sup>8</sup> Between the planetary spheres of Saturn and Jupiter this would mean the introduction of the additional sphere,  $\text{Saturn}_{rew_{1 \rightarrow 0}}$ , contributing the component motion  $\bar{d}$ , contrary to the diurnal motion.

<sup>9</sup> The frame of reference in the Aristotelian cosmos is the stationary Earth at the centre of the celestial spheres. Every region on a stationary celestial sphere would always keep its position relative to the surface of the Earth.

<sup>10</sup> A proposal formulated and set out in detail by Norwood Russell Hanson, *Constellations and conjectures* (Dordrecht—Boston: Reidel 1973), 66-78.

Aristotelian assumption that “nature does nothing in vain.”<sup>11</sup>

Note, however, that this principle of relevance does not mean that the motions of the planets should be produced by the minimum number of celestial spheres and celestial movers. Instead the principle of relevance formulated here requires that any motion of a celestial sphere has to contribute to its end, which is a planet as a beneficiary of the motion. Accordingly, there can be no motions which are not integrated with this interlocking system of revolutions. Moreover, provided the beneficiary of a motion is always the planet coming next in the celestial system, we cannot admit the existence of a motion which is cancelled before contributing to the motion of the lower planet. If such motions, which are cancelled before exerting their influence on a planet, were admissible, the number of spheres, and their movers could proliferate without any limit. One could postulate any number of motions, with suitable further motions, which neutralize their effect. As a corollary to this exclusion principle one can formulate the following rule:

**Corollary to the Principle of Relevance:** There cannot be any pair of contrary revolutions, one immediately following the other, unless there is a planet on the outer sphere performing the first of these revolutions.

This corollary follows from the principle of relevance, because if there existed such a pair of contrary revolutions, the second would cancel the first one, and as the following planet is not on the first sphere, this first motion cannot contribute to the motion of any of the planets.<sup>12</sup>

Now note, that the proposal, which requires Aristotle to introduce an additional rewinding sphere for each planet, would contravene this Corollary: before the first sphere of the embedded

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<sup>11</sup> Cf. *de Caelo* I.4 277a22-33, where Aristotle refers to the assumption that god and nature do nothing in vain at the end of a passage which intends to show that celestial motions cannot be contrary to one another, because otherwise one would cancel the other, thereby making either or both of them superfluous.

<sup>12</sup> Note that the stipulation that the first sphere in this pair does not carry a planet is not redundant. In Aristotle's interlocking celestial system, in the case of every planet (except for the Moon) the sphere carrying the planet (i.e. Saturn<sub>w</sub> 3→4, Jupiter<sub>w</sub> 3→4, Mars<sub>w</sub> 4→5, Venus<sub>w</sub> 4→5, Mercury<sub>w</sub> 4→5 and Sun<sub>w</sub> 4→5,) is directly followed by a rewinding sphere (i.e., respectively, Saturn<sub>rew</sub> 4→3, Jupiter<sub>rew</sub> 4→3, Mars<sub>rew</sub> 5→4, Venus<sub>rew</sub> 5→4, Mercury<sub>rew</sub> 5→4 and Sun<sub>rew</sub> 5→4), canceling the motion of the carrying sphere. Nevertheless, the introduction of these two spheres cannot be excluded by the Corollary to the Principle of Relevance, as the motion of the first sphere does contribute to the motion of the planet on this sphere, before it would be cancelled by the following sphere.

planet (e.g. before Jupiter<sub>w 0→1</sub>), performing the diurnal revolution of the stars (component  $d$ ), it would introduce another sphere (Saturn<sub>rew 1→0</sub>), performing the contrary motion,  $\bar{d}$ . By Aristotle's principle of relevance this should not then be admissible: the introduction of these additional rewinders is ruled out, because they would not contribute to the motion of a planet. There is no planet attached to them, which they could carry, and the following sphere in the celestial setup immediately cancels the motion they impart, as it moves with a contrary revolution. Hence, contrary to the suggestion, Aristotle's celestial system cannot accommodate an additional rewinding sphere after the rewinding spheres of the planets, unless the import of the principle of relevance enunciated in 1074a30-31, or the principle itself must be readjusted.<sup>13</sup>

## 2

But if these additional rewinding spheres cannot be introduced, because if introduced, then according to the principle of relevance they would have to be dropped together with the immediately following spheres, which supply the daily revolution of the stars as the component

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<sup>13</sup> Needless to say, such a readjustment is not impossible. One could, e.g. submit that the causal efficacy of the rewinding spheres should be considered a negative one. If an embedded sphere is moved by a number of carrying spheres, and then unwound by a number of rewinders, although the overall motion of the sphere is caused by all the movers operative on the moving and rewinding spheres, in a stricter sense we can claim that the overall motion is caused only by those movers the motion of which is not removed by rewinders. If this is so, two spheres performing contrary revolutions can be adjacent to each other not only when the first of these contains a planet, but also if the motion imparted by the first one is not immediately removed by the second one. This is eminently the case on Hanson's proposal: the last rewinding spheres do not *contribute* a motion, rather they *remove* one, and hence their motion will not be removed by the following sphere. (In a similar vein, one could submit, as G.E.R. Lloyd does in his "*Metaphysics*  $\Lambda$  8," in: Michael Frede and David Charles [eds.], *Aristotle's Metaphysics Lambda: Symposium Aristotelicum* [Oxford: Clarendon 2000], 265, that the beneficiary of Jupiter's rewinding spheres is Jupiter, and not Mars, which is next in the celestial order. One way, e.g. the rewinding spheres contribute to Jupiter is that they make it possible for Jupiter to move with the motions it has and at the same time be fully integrated within the overall celestial mechanism.)

The revision of the import of the principle of relevance does not address the other issue, namely that Hanson's proposal introduces *stationary* celestial spheres before each embedded planetary system.

motion of the planets, one might suggest that Aristotle should not have introduced these first spheres of the embedded planetary systems in the first place. This is so because the last of the rewinding spheres of each planet already performs the diurnal rotation of the stars. This suggestion had been formulated by anonymous interpreters of Aristotle, only to be rejected by Sosigenes and Simplicius.<sup>14</sup> One reason Simplicius quotes for rejecting this suggestion is hardly compelling: he says that if we dropped these spheres, we would not arrive at the number of rewinding spheres specified by Aristotle, unless we counted these spheres twice.<sup>15</sup>

As there is no reason to accept the total Aristotle gives before agreeing upon the existence of the spheres to be counted, Simplicius's objection cannot carry much weight. But more compelling arguments can also be added. These arguments will refer to Aristotle's wording about the task of the last of the rewinding spheres of each planet.

According to this, these spheres 'bring back (*apokathistasas*) to the same position the first sphere of the star which in each case is situated below the star in question' (1074a3-4). Sosigenes, in his remarks preserved by Simplicius, stresses several times that this underlines the fact that the rewinding spheres have something more to do than simply to produce the required velocities in the celestial system. By Sosigenes's lights it is just as important that the position of

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<sup>14</sup> Simplicius, *Commentary on de Caelo*, 502.19-25. This suggestion has been endorsed in the literature by J.L.E. Dreyer, *A history of astronomy from Thales to Kepler* (New York: Dover 1953), 113; Thomas Heath, *Aristarchus of Samos: the ancient Copernicus* (New York: Dover 1981), 218-19, and in Ross's comments to 1073b38, quoting Heath's considerations.

<sup>15</sup> 'For this happens to them, that they count the same sphere twice as they try to save the figure provided by Aristotle for the rewinding spheres' (502.25-27, cf. 503.35-504.3).

It is a moot point whether Simplicius refers here by the word *anelittousôn* (the rewinding spheres) only to the ones that Aristotle interleaved between the planetary systems, or whether he uses the word in the looser sense, according to which the carrying spheres also can be called rewinders. I am inclined to take Simplicius' objection about rewinders in this latter, looser sense. First, strictly speaking, these interpreters need not exclude any *rewinders* by dropping the first *carrying* sphere in the case of each planetary system. Moreover, if Simplicius actually repeats the same objection in the lines 503.35-504.3, then the term may be used also at 502.25-27 in the more inclusive sense, and the objection can go back to Sosigenes. (Occurrences of the term "rewinder" in this looser sense are collected by Henry Mendell, "The Trouble with Eudoxus," in: Patrick Suppes, Julius Moravcsik and Henry Mendell [eds.], *Ancient and medieval traditions in the exact sciences: Essays in memory of Wilbur Knorr* [Stanford: CSLI Publications 2000], in nn. 40 and 41 on p. 92.)



the embedded first spheres should be adequate.<sup>16</sup> This, as D.R. Dicks submitted, should mean that the first sphere of each planetary system must represent the sphere of the fixed stars exactly. The last of the rewinding spheres is not appropriate for this task, since it has an axis of motion—the one around which it does the rewinding—that is not identical to the axis of the revolution of the fixed stars.<sup>17</sup>

Dicks's point can be further elucidated, as Beere has argued, in that each last rewinding sphere can be described from two vantage points. In so far as its own motion is concerned, it is a rewinding sphere, removing the motion of the planet along the ecliptic. As a result of this rewinding, it will have an overall motion, which is identical to the diurnal revolution of the stars and accordingly in addition to the axis of its own motion, it will have an additional axis of its composite motion, which will be identical to the fixed, North-South axis of celestial revolution.<sup>18</sup> But if the last rewinding sphere, performing the diurnal revolution, were simply to transmit this motion to that sphere which contributes the motion of the embedded planet along the ecliptic (e.g. if Saturn<sub>rew 2→1</sub> were followed immediately by Jupiter<sub>w 1→2</sub>, contributing  $e_{\text{Jupiter}}$ ) the diurnal component of the motion of this embedded planet, unlike all the other components it has, would lack a distinct cause of its own.<sup>19</sup>

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<sup>16</sup> This double role is stressed throughout in Sosigenes's account, see most specifically Simplicius, *Commentary on de Caelo*, 498.1-7, 499.7-11 (or 12, depending on whether ll.11f should be bracketed with Aujac, in the Testimonia part of his edition of Autolycus, on p. 170) and 502.11-19.

<sup>17</sup> D.R. Dicks, *Early Greek astronomy to Aristotle* (Ithaca, New York: Cornell University Press 1970), 202.

<sup>18</sup> This is brought out in my notation by the number 1 on the right-hand side of the index of e.g. Saturn<sub>rew 2→1</sub>.

<sup>19</sup> Note that it is a mistake to claim, as Beere does, that '[o]ne could not say that the sphere of the fixed stars itself is responsible for this [i.e. for the diurnal revolution around the North-South axis, as the motion imparted to the first sphere of Jupiter by the last rewinding sphere of Saturn], since its motion has been filtered out by unwinding spheres.' (Beere, "Counting the Unmoved Movers," 13) On the contrary, the motion imparted by the mover of the first sphere of Saturn is not cancelled by a rewinding sphere. Hence this mover would impart the diurnal rotation to all the spheres of Saturn, and so, on this setup, it would be causally responsible for the diurnal rotational component of all the ensuing spheres, and with them, of every single planet. Hence one could claim that the own motion of the last rewinding sphere of Saturn— $\bar{e}_{\text{Saturn}}$ , along the plane of the ecliptic, in an opposite sense to the motion of Saturn's second sphere—is caused by its own mover, whereas the resulting revolution,  $d$ , around the North-South axis of the universe is causally dependent on the unmoved mover of the first sphere. What this

As a result, it would not be on a par with the other planetary component motions in terms of explanation and causation. Hence, Aristotle cannot drop the first moving sphere of each planet, performing the diurnal revolution of the stars, unless he is willing to revise the basic principle at work in setting out the details of his celestial theory of interlocking planetary systems, that each eternal planetary component motion should have a mover of its own.<sup>20</sup>

### 3

The third option to save Aristotle from the charges of an erroneous celestial theory, is to suggest, as Jonathan Beere does, that the way an enveloping sphere transmits motion to an embedded sphere is by carrying the axis of the embedded sphere on a path, which may be simple or complex. If, as in the case of the interaction of the last rewinding sphere of a planet, and the first sphere of the planetary system of the following planet, the axis of the embedded sphere is

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explanation does not provide, is a distinct cause for each planet, which would be exclusively responsible for the component of diurnal rotation of the spheres of this planetary system only.

<sup>20</sup> Again, such a revision is not impossible, all one needs to grant is that the status of the diurnal revolution is unique in the celestial realm, and accordingly the first moving sphere of Saturn—or indeed, the sphere of the fixed stars—imparts the diurnal revolution to each and every celestial sphere.

Note, however, that even if we adopted this suggestion, this still does not imply that one should accept the more radical proposal of Ido Yavetz, “On the Homocentric Spheres of Eudoxus,” *Archive for the History of Exact Sciences* 51 (1998), 237 n. 16, that, from a purely geometrical standpoint, after the elimination of the first spheres of the planetary systems, the last rewinders of the upper planet, performing a rotation along the plane of the ecliptic (e.g. Saturn<sub>rew 2→1</sub>), and the now adjacent second spheres of the planetary system of the next planet (e.g. Jupiter<sub>w 1→2</sub>), also performing a rotation along this plane, but in an opposite sense, could be replaced by a single sphere, performing the rotation along the plane of the ecliptic combined from these two ecliptical rotations. On this suggestion, the cause of the ecliptical motion of Jupiter would be the cause effecting the ecliptical motion of Saturn, combined with an additional mover, which is responsible for the increase in speed along the same orbit. (This sphere could be designated Jupiter<sub>w 2→2'</sub>.) Similarly, as we proceed inwards in the cosmos—with the exception of Venus, Mercury and the Sun, which have the same ecliptical revolution—these motions will be adding up in a linear fashion. In general, then, the cause of the ecliptical motion of an inner planet would be the combination of all the preceding ecliptical movers there are in the celestial system. This would be in breach of the rule that every eternal component motion needs to be produced by the operation of a *single* cause.

stationary—this is so, because the enveloping sphere performs a rotation as its composite motion exactly around the axis of the embedded sphere—the rotation of the enveloping sphere is not transmitted along the stationary axis to the embedded sphere. For the next sphere to have the same rotation, this sphere, too, will need a motion, and a corresponding mover, of its own.<sup>21</sup>

We should note that this suggestion does not lead to a proliferation of celestial motions and movers. Even though in principle no purely astronomical consideration would exclude that any number of spheres aligned on the same axis should follow one another, each of them performing some rotation under the causal influence of its unmoved mover, and only the last contributing the diurnal revolution of the stars to the planet, the principle of relevance, quoted from 1074a30-31 forecloses the introduction of any such spheres. The putative intermediate spheres would not contribute to the motion of any planet, and hence they can be definitively excluded from the celestial realm.

Nevertheless, the suggestion has some unexpected consequences. Most notably, we should ask whether the principle that rotations are transmitted only by the translation of axes, and never by the rotation of the axes themselves, is operative only in case the axes in question are stationary. Answering this question in the affirmative will mean that a major presupposition of the theory of homocentric spheres is overruled in this instance. This major presupposition submits that the way the revolutions of two consecutive homocentric spheres are combined does not depend on external factors. The combined motion of the two spheres is simply superadded to any motion the external sphere may receive from the outside.

But rejecting this presupposition will have counter-intuitive consequences. Most notably, if there are two spheres, one embedded in the other, both performing the very same rotation, say *b*, both of them will need a mover to effect this revolution. Even so, as soon as the outer sphere will in turn be embedded in yet a further enveloping sphere, with a motion around a different axis, say *a*, the whole system will behave differently. The outer sphere will now perform a composite motion, combined from the revolution of the outermost embedding sphere, *a* and from its own revolution *b*. The innermost sphere, however, will perform a different motion. We have just stipulated that once the axis of rotation is not stationary, the rotation around this axis gets

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<sup>21</sup> On this setup, again, we can designate this embedded sphere e.g.  $\text{Jupiter}_{w\ 0 \rightarrow 1}$ , indicating that it does not receive a motion from the spheres preceding it.

transmitted to the embedded sphere, and hence the motion of the innermost sphere, performed under the causal influence of the mover of its own, will be added to the composite motion of the preceding sphere, producing the motion combined from  $a$  and twice the component motion  $b$ .

The upshot of this thought experiment is that if we restrict the applicability of Beere's suggestion, and would stipulate that rotations around an axis are transmitted through the axis if it is not stationary, we will need to ask what is the causal explanation for the vastly different behaviour of stationary axes, as opposed to the ones which perform some motion. Such a causal explanation might take many forms. Aristotle may be thought to employ tacitly some such causal explanation when formulating his interlocking celestial system, but up until the point one has been formulated along the lines of Aristotle's overall considerations about celestial theory, the restriction of the claim to stationary axes will have to remain a special pleading and hence suspect.

On the other hand, if embedded spheres receive the motion of the enveloping ones only as a result of the fact that their axes are carried along a trajectory by the enveloping sphere, the status of the movers of the rewinding spheres will be in jeopardy. In each of the cases where a rewinding sphere is operative, the motion of the sphere in which this rewinder is embedded can be divided into two aspects. First there is that revolution which the rewinding sphere will remove by a contrary revolution, but there is also the additional, possibly composite motion which is not affected by the operation of the rewinding sphere. E.g., the rewinder designated here as  $\text{Saturn}_{\text{rew } 4 \rightarrow 3}$ <sup>22</sup> is embedded in a sphere— $\text{Saturn}_{\text{w } 3 \rightarrow 4}$ —which performs four motions. The rewinder is introduced by Aristotle to remove one of these four motions, notably  $g_{\text{Saturn}}$ , whereas both the rewinder and the sphere in which it is embedded will perform the combination of motions  $d$ ,  $e_{\text{Saturn}}$  and  $f_{\text{Saturn}}$ .

One should note that these two aspects are distributed over the axis of the rewinding sphere. The possibly composite motion which is taken over by the rewinding sphere is exactly the motion imparted by the enveloping sphere as a result of moving the axis of the rewinding sphere

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<sup>22</sup> Note that we need to use this more circumspect formulation, that this sphere is *designated here* as  $\text{Saturn}_{\text{rew } 4 \rightarrow 3}$ , because strictly speaking this designation will not be accurate on this account. Here the suggestion is that the inner sphere turns out to be attached to the preceding sphere through an axis which does not transmit the last, fourth component motion of  $\text{Saturn}_{\text{w } 3 \rightarrow 4}$ .

along a trajectory, whereas the rotation which has to be removed by the rewinding sphere is a revolution around the axis of the rewinding sphere. In this case, however, provided revolutions are not transmitted along axes, Aristotle would need to give an account that is somewhat different from the one he gives here. He should avoid saying what he says at 1074a17-24, that both the carrying and the rewinding spheres perform rotations. Instead, he should formulate the role of these rewinders in terms of their being set into their enveloping sphere exactly along the axis of the rotation which is to be cancelled at that point, so that as a result of this exact orientation they do not take over that component of the composite motion of the enveloping sphere, without themselves performing any motion of their own at all.<sup>23</sup>

On this account not only will the role of the rewinding spheres turn out to be different from the role of the carrying spheres, their mover will also have a rather peculiar status. Recall that our original problem was that the first spheres of the planetary systems, if they receive the diurnal revolution from the sphere into which they are embedded, will not perform any further additional rotation, and hence the unmoved movers which are causally responsible for their behaviour will turn out to be unmoved and non-moving movers. Once we follow Beere's suggestion, that revolutions are not communicated through the spinning of embedded axes, and do not restrict it to cases where the axes of rotation are stationary, the movers of the rewinding spheres will have a similar paradoxical status. They will not impart motion, hence they will still have to be described by the self-contradictory label 'non-moving movers.' Nevertheless, depending on what we take to be causally responsible for setting the axes of the embedded spheres, they might be causally efficacious in an important way. If the embedded sphere were attached to the enveloping sphere along any other axis than the actual one, it would take over the entire composite motion of the enveloping sphere, and would not filter out the rotation the rewinding sphere was introduced to filter out in the first place. Accordingly, provided that the

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<sup>23</sup> We have precious little evidence about the rewinding spheres in Theophrastus. That he also included such spheres is clear from the testimony of Simplicius (*Commentary on de Caelo*, 504.7-8), that he called these spheres *antanapherousai*, back bringers, because they bring back the poles of the spheres beneath them. This terminological point, however, is not conclusive as to whether these spheres perform the motion of their own, or perform their back-bringing function by not taking over some component motions. In the case of Sosigenes (and Simplicius), however, it is clear that the rewinding spheres do the rewinding by performing a motion of their own, see Simplicius, *Commentary on de Caelo*, 502.2-6, 7-9, 11-15.

axes of the embedded spheres are set by the material setup of these spheres—say, by one sphere being joined to the next literally by axels or pegs, around which the motion of the embedded sphere is performed—these spheres do not require a mover for performing the task of rewinding.

One, however, may insist that setting an axis of rotation is part of the task of the mover which causes the revolution about this axis. On this view, the mover of a rewinder is causally responsible for setting the axis of the rewinding sphere along which the sphere does not receive the rotational component of the enveloping sphere. In this case, the most precise description of these “movers” would be that they are degenerate cases of unmoved movers. They perform only half the task of a normal unmoved mover. They set the axis of rotation, around which the sphere could move, but they do not impart a component rotation around this axis: they are unmoved axis setters.<sup>24</sup>

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Now it should be plain that each of the suggestion in the literature about the problem of interaction between the last rewinding sphere of a planet, and the first sphere of the following planetary system involves some significant difficulty. In a way this fact can be used to Aristotle's advantage. Even if the traditional understanding of the option he propounds in 1073b38-1074a14 remains problematic, the fact that the other available options are no less problematic suggests that this interpretation cannot be rejected outright. Even if the actual celestial system Aristotle propounds on this interpretation might be the result of a simple mistake in the introduction of the rewinding spheres, the considerations above suggest that this mistake could not be localized and eliminated in a trivial manner, because from among the available options this is one which satisfies several requirements of the utmost importance at the same time. First, each and every one of the celestial spheres is in motion, none of them is at rest. Moreover, Aristotle's celestial system is causally articulated and perspicuous. It creates the closest match between the components of planetary motions and the spheres involved in the celestial system, in just the way Eudoxus and Callippus provided a one-to-one correspondence between the components of

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<sup>24</sup> I am indebted for clarification on this issue to Gábor Betegh and Henry Mendell.

planetary motions and the component spheres of their non-interlocking planetary systems. No component motion—not even the diurnal rotation, which every single sphere performs in the celestial system—is an exception. The diurnal rotation of each planet requires the additional motion of a separate sphere, with its dedicated unmoved mover, in each of the planetary systems.

Furthermore, Aristotle intended to arrive at a causally perspicuous system, which also unifies the different planetary motions into a single overarching system, with a unified account of the integration of the motions of different planetary systems. This is necessary, as he puts it ‘if all the spheres combined are to explain the phenomena. [...] for only this way can they all carry out the motion of the planets’ (1073b38-1074a1 and 1074a4-5, Revised Oxford Translation, slightly modified),<sup>25</sup> even though—as should be clear from the considerations above—there was no trivial

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<sup>25</sup> Note that something went seriously wrong in the paraphrase cum translation Beere gives of Sosigenes’s remarks on Theophrastus’s description of the rewinding spheres as *antanapherousai*, back bringers at Simplicius, *Commentary on de Caelo*, 504.4-15 (Beere, “Counting the Unmoved Movers,” n.26, on pp. 14-15). The concluding claims in this passage should be rendered as stating that it is the task of the compensatory effect of these additional back-bringers that ‘the poles of the lower spheres have to fall on the same perpendicular as the poles of the similar upper ones [...] for only this way, he says, can they all carry out the motion of the fixed stars.’ Already the similar wording of *Metaphysics* XII.8 1074a4-5 makes it certain that in the last clause the embedded object of the accusative cum infinitive construction is not the pronoun *hapanta*, as Beere’s translation has it, but rather the nominal phrase *tên tôn aplanôn phorân*.

The important difference between the Aristotelian passage and this clause in Simplicius is that in the *Metaphysics* the motion which is carried out by all is the motion of the planets (as if that were one single motion, or at least as if the several planetary motions could be lumped together and be designated collectively as *the* motion of the planets, which the entirety of the planetary entities carry out collectively), whereas in the clause in Simplicius the motion which they all carry out is the motion of the fixed stars. But the difference might as well be just the result of some error in the tradition: Around the end of this paragraph—which started out by calling attention to a terminological point about Theophrastus’s usage—Simplicius indicates, by interjecting “he says” twice into his text (*Commentary on de Caelo*, 504.12 and 14), that he renders somebody else’s words. The first sentence he flags with this tag is a slightly paraphrased version of *Metaphysics* XII.8 1074a3-4, whereas the second sentence is identical with 1074a4-5, but for the use of *houtôs* instead of *houtô*, and the fact that the *Metaphysics* speaks about the motion of the planets (*planêtôn*) whereas the sentence in Simplicius mentions the motion of the fixed stars (*aplanôn*). One could still maintain that Theophrastus reformulated Aristotle’s claims, in almost the same words, making only some minor stylistic and doctrinal changes, and Simplicius, through the testimony of Sosigenes, is referring to him. But this is excluded by the final flourish Simplicius closes his sentence with, when he adds that what the author—be it Aristotle or Theophrastus—says is ‘as we have already

way to pursue these different objectives at the same time, *Metaphysics* XII.8, then, on this understanding, is a chapter where Aristotle set the outlines of such a celestial system, but he did not appreciate the internal tensions involved and did not work out all the ramifications of the principles operative in his celestial system.<sup>26</sup> \*

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said, said appropriately.’ As up until this point Simplicius has only endorsed Aristotle’s (and not Theophrastus’s) doctrines, he clearly is thinking he renders Aristotle’s lines and points out that Theophrastus’s terminology, that the rewinding spheres are *antanapherousai*, back bringers, spells out the very feature that Aristotle expressed in 1074a3-4.

If this is so, one should also ask whether the discrepancy between the text of the *Metaphysics* and of Simplicius’s *Commentary on de Caelo* is due to scribal error after Simplicius, and as such should be emended away (as Aujac does, in the Testimonia part of his edition of Autolycus, on p. 179), or whether Simplicius is quoting here Aristotle from memory or through the intermediary of Sosigenes, who had a slightly altered text. In this case the text of the *Commentary on de Caelo* should not be tampered with (as Fortenbaugh *et al.* decide in their edition and translation of Theophrastus 165D FHSG). The second alternative cannot be ruled out, but it needs to be stressed that even if Simplicius is quoting a different version of the Aristotelian passage from Sosigenes, he is apparently not aware of the textual differences.

<sup>26</sup> Such considerations could be used to suggest that *Metaphysics* XII.8 was composed late in Aristotle’s life: otherwise, it might be claimed, Aristotle would have removed what apparently is a computational slip at 1074a12-14 and could settle one way or another the problems I have been canvassing here. I should stress that I do not subscribe to this inference. The fact that Aristotle, as far as we are aware of this through the Aristotelian corpus and through the testimonies of his commentators, did not revisit these issues elsewhere, does not imply that he must have been dead soon after the composition of *Metaphysics* XII.8. A host of other considerations could have kept Aristotle from revising his position on these issues.

\* I have been working on issues of Aristotle’s celestial theory for quite some time. Nevertheless, it should be clear from the paper how much my approach is indebted now to Jonathan Beere’s article.

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## Appendix

The winding spheres, constituting the planetary system of Saturn, and the attached rewinding spheres can be referred to as follows:

Sphere	Motion contributed by this sphere	
Saturn <sub>w</sub> →1	$d_{\text{Saturn}}$	(the diurnal motion)
Saturn <sub>w</sub> 1→2	$e_{\text{Saturn}}$	(the ecliptical motion of Saturn)
Saturn <sub>w</sub> 2→3	$f_{\text{Saturn}}$	
Saturn <sub>w</sub> 3→4	$g_{\text{Saturn}}$	
Saturn <sub>rew</sub> 4→3	$\bar{g}_{\text{Saturn}}$	(contrary of $g_{\text{Saturn}}$ )
Saturn <sub>rew</sub> 3→2	$\bar{f}_{\text{Saturn}}$	(contrary of $f_{\text{Saturn}}$ )
Saturn <sub>rew</sub> 2→1	$\bar{e}_{\text{Saturn}}$	(contrary of $e_{\text{Saturn}}$ )

Read: Saturn's winder to one motion, Saturn's winder from one to two motions, etc. and then Saturn's rewinder from four to three motions, Saturn's rewinder from three to two motions, etc.

The last rewinding sphere of this group is followed immediately by the first sphere of Jupiter, Jupiter<sub>w</sub> →1 performing  $d$ , the diurnal motion. (Subscripts after component motions  $d$  can be dropped, as the diurnal component of the motion of the different planets is identical.)

The subscripts of each winding or rewinding sphere indicate how many component motions are communicated to the sphere, and then, as a result of its winding or rewinding, how many motions this sphere performs. Each winding sphere adds a further component motion, each rewinding sphere removes one. The contribution of a winding sphere is eliminated by the rewinder which has the same subscripts, in reverse order (e.g. Saturn<sub>w</sub> 2→3—contributing  $f_{\text{Saturn}}$ —is rewound by Saturn<sub>rew</sub> 3→2—contributing motion  $\bar{f}_{\text{Saturn}}$ ). The left-hand subscripts of the first spheres of the planets are left blank in order to leave open what motion these spheres take over from the ones immediately preceding them. (This may also apply to Saturn<sub>w</sub> →1, as the sphere of the fixed stars may well be different from this sphere.)

Jupiter has four winding and three rewinding spheres, like Saturn. In the case of Mars, Venus, Mercury and the Sun yet another pair of winding and rewinding spheres is added, e.g. between Venus<sub>w</sub> 3→4 and Venus<sub>rew</sub> 4→3, there is Venus<sub>w</sub> 4→5, contributing the additional component,  $h_{\text{Venus}}$ , followed by the rewinder Venus<sub>rew</sub> 5→4, contributing component  $\bar{h}_{\text{Venus}}$ . The Moon has five winding spheres only, their motions are not eliminated by rewinding spheres.

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