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ARISTOTLE ON UNIFORM CIRCULAR MOTION

Abstract

Uniform circular motion has an important role in Aristotle's physical world. In this paper a correspondence is built up between: the unique state of being of necessary beings, which are ἀεὶ (eternally), outside time; the periodic sequence of identical states of uniform circular motion of the heavens, which are ἀεὶ (over and over again) moving in circle; the sequences of different states of change of sublunar bodies, which are ἀεὶ (always) changing, in time.

Keywords

Aristotle, Circular Motion,
Potential Infinite, Iteration, Time

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Introduction

In the list of the infinite processes allowed by Aristotle in his cosmos – time, number, the division (and a specific increase) of continuous magnitudes, the generation and corruption of human beings, and the circular motion of the heavens – the circular motion of the heavens occupies a particularly significant place, for reasons which are both physical and metaphysical.

In fact, the state of ἀεί (over and over again) be moving in circle of the heavens can be read as a sort of mean proportional between the state of pure being of necessary beings, which ἀεί (eternally) are, outside time, and the state of perpetual motion of sublunar beings, which ἀεί (always) are changing, in time. In this paper I will show how this can be done, by analyzing the iterative structure of the process of being in circular motion.

An important role in my analysis will be played by the adverb ἀεί, which in its iterative meaning 'over and over again' can be used – and, in fact, is used in Greek mathematics – in order to transform a single action into an infinite process. The idea is to build up a correspondence between the unique state of being of necessary beings and one of the infinite identical states of being-in-circular-motion of the heavens. Analogously, a correspondence will be built up between the continuous sequence of identical states of being-in-circular-motion of the heavens and the contiguous sequence of different states of change of sublunar bodies.

In Section 1, the ultimate iterative structure of circular motion is investigated with particular emphasis on its properties of uniformity (the speed is constant), continuity (no interruptions are allowed) and infiniteness (there is no beginning nor end). Read as a purely iterative process, the uniform circular motion of the heavens is then contrasted, on the one hand (Section 2), with the state of being of necessary things, and, on the other hand (Section 3), with the process of change in the sublunar world.

1. Infiniteness and Periodicity

Aristotle's notion of infiniteness is constrained by the indispensable requirement of compatibility with the finiteness of his cosmos, that is, a sphere of actually finite radius, containing an actually finite multitude of objects. This excludes any form of infinite in actuality and limits the range of acceptable instances of potential infinite. Denying the actuality of the infinite simply means that the infinite cannot exist either as an object[1] – the infinite *per se* – or as the attribute of an object – an infinite collection of things, a straight line of infinite length and so on.[2] Instead, allowing its potentiality means that, under certain conditions, it can exist as the attribute of a process. In modern terms, it is the attribute of an iterative process.[3] In Aristotle's own terms:

D: the infinite is in virtue of [**D1**] another and another thing being taken, over and over again (ἀεί); and [**D2**] what is taken is finite, over and over again (ἀεί); but [**D3**] it is a different thing, over and over again (ἀεί). (*Ph*. III 6.206a27-29)[4]

As this definition shows, the existence of the infinite is linked to three requirements. The first, **D1**, is that there are no obstructions to the repetition of a given action, in such a way that it can turn into an unending series of identical steps: for each thing one takes (*first step*), there is another thing to take beyond that (*second step*), and another to take beyond that (*third step*) again, and so on, over and over again (ἀεί, *next steps*).[5] The second requirement, **D2**, is that the thing taken must be limited, at any step, in such a way that no actual infinities are involved in the process. The third requirement, **D3**, is that the process must be a genuine progression, which always goes on without starting from scratch.

In fact, **D3** is not a mandatory condition for the existence of the infinite. Instead, it distinguishes between processes that are infinite in a proper

[1] *Ph*. III 4.203a4-16; 5.204a8-34.
[2] *Ph*. III 4.203a16-b2; 5.204b4-206a7.
[3] Aristotle's iterative notion of infinity is discussed in Ugaglia (2009) and (2018).
[4] ὅλως μὲν γὰρ οὕτως ἔστιν τὸ ἄπειρον, τῷ ἀεὶ ἄλλο καὶ ἄλλο λαμβάνεσθαι, καὶ τὸ λαμβανόμενον μὲν ἀεὶ εἶναι πεπερασμένον, ἀλλ' ἀεί γε ἕτερον καὶ ἕτερον (*Ph*. III 6.206a27-29).
[5] On the meaning of ἀεί in Greek mathematics, see Mugler (1958-1959), pp. 43-4 and Federspiel (2004).

sense[6] and processes that are infinite solely because they are periodic – in this case, after a certain number of steps, one comes back to something already taken, and the process is repeated identically, over and over again.

The division of the continuum is the paradigmatic example of the first type of process, which is genuinely infinite: take a segment AB, and divide it at C_1 (*first step*), then take the resulting segment C_1B and divide it at C_2 (*second step*), then take the resulting segment C_2B and divide it at C_3 (*third step*), and so on, over and over again (ἀεί, *next steps*):[7]

Figure 1

Due to Aristotle's definition of the continuum as having no inner limits, the division can go on over and over again (**D1** is satisfied). Due to the finiteness of the starting segment, the segments produced at any step of the division are also finite (**D2** is satisfied). Due to the division itself, the segment produced at any step is different from the ones produced at the previous steps (**D3** is satisfied).

[6] Aristotle's examples are number, time, the generation of men, but also increasing, or shortening, a given magnitude.

[7] The paradigmatic examples of iterative procedures are those employed in mathematics, and I mean particularly the procedure of reciprocal subtraction, employed in Euclid's *Elements* VII 1-2; X 2-3, and the method of exhaustion, employed in Euclid's *Elements* XII 2, 5, 10, 11, 12; VIII 9; IX 34 and in Archimedes's *Quadratura Parabolae* Prop. 20 and its corollary, and Prop. 24. The pivotal idea is to constrain an *a priori* infinite sequence of steps in a finite procedure of demonstration. As is well known, Greek mathematics is written in natural language; notwithstanding, it is possible to isolate the presence of words, or strings of words, which are intentionally employed in a technical sense, to enunciate a formal scheme, or algorithm. In the case of iterative demonstrations, the algorithmic scheme is particularly evident: after a detailed description (*first step*) of a precise operation, a first repetition of the operation (*second step*) is briefly set forth, and the subsequent identical steps of the process are only alluded to by means of a conventional phrase. The situation can vary in detail, but the way of denoting iteration is fixed: the adverbial ἀεί followed by a verbal form denoting the action of doing or of producing something (καὶ τοῦτο ἀεὶ ποιοῦντες, καὶ τοῦτο ἀεὶ ποιῶμεν, καὶ τοῦτο ἀεὶ γινέσθω, καὶ ἀεὶ ἑξῆς ἑνὶ πλείους... *next steps*). The important point is that the grammatical structure is the same in Aristotle and in Greek mathematics. On the relevance of the algorithmic feature of the method of exhaustion, see Vitrac (2001) p. 249.

Uniform circular motion is the paradigmatic example of the second type of process, which is infinite and periodic: chose a point on the circle, call it a beginning (A_1), and go from this beginning A_1 to an end B_1 (*first step*), then call this end B_1 a beginning A_2 and go from this new beginning A_2 to a new end B_2 (*second step*), then call this new end B_2 a beginning A_3 and go from this new beginning A_3 to a new end B_3 (*third step*), and so on, over and over again (ἀεί, *next steps*):

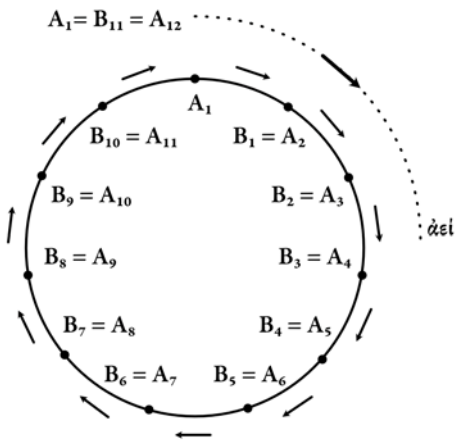

Figure 2

Due to the fact that a circle is a closed line which has no endpoints (limits), motion can go on over and over again (**D1** is satisfied). Due to the finiteness of the circle, the portions traveled at any step are also finite (**D2** is satisfied). Due to the fact that a circle is a closed line, after a given number of steps one comes to a portion of the circle already traveled (**D3** is not satisfied).

Although Aristotle has no hesitation in listing circular motion among the manifestations of the infinite allowed in his cosmos, he also stresses that it is not infinite in a proper sense. As I will show in the next sections, it is something more perfect than that.

2. Circular Motion vs *Rectilinear Motion*

A crucial point to clarify, concerning Aristotle's treatment of circular motion, is the difference between a generic, constrained motion *on a* circle (κύκλον φέρεσθαι) and motion *in* circle (κύκλῳ φέρεσθαι), that we could more properly call natural circular motion and is the theme of this paper.[8] Of course, some of the features of natural circular motion are due exclusively to the geometrical structure of the circle, so that they are common to every motion on a circle, whether natural or not. Other features, however, depend on the specific bodies which naturally move circularly, and this would be of a certain importance in the following. Indeed, everything can be constrained to move *on* a circle, but only celestial eternal beings naturally move *in* circle, just as everything can be constrained to move down *on* a straight line, but only the heavy elements naturally move *in* this way.[9]

In particular, natural circular motion is uniform (that is, the speed is constant),[10] continuous and infinite. I will clarify the meaning of these features by contrasting circular natural motion with a more familiar – from an Aristotelian perspective – natural change, which is continuous but finite and non-uniform.

2.1 Uniformity and Circularity

A natural change in Aristotle's sublunar world is a teleological process, resulting from the interaction between a mobile object and its proper mover. At the beginning (A) the mobile object only potentially possesses the form that its mover actually possesses, while at the end (B) the mobile object, which is now moved, also actually possesses that form.[11] For this reason, the final point B is not just the end of the change, it is its aim. But for Aristotle,

[8] οὐ γὰρ ταὐτὸν κύκλῳ φέρεσθαι καὶ κύκλον (for to travel in circle is not the same as to move on a circle: *Ph.* VIII 8.262a15-16).

[9] Of course, due to an external intervention, a stone can move up, or sideways, or no matter where, and can do it with a variable speed, depending on the intensity of the intervention. Indeed, no connection exists in this case between the (form of the) mover and the end of the motion.

[10] More properly, the angular rate of rotation is constant, and so is the speed of a point on the circumference, but not its velocity, a vector which changes its direction during the motion.

[11] See, e.g., *Ph*. III 2.202 a7-12.

the closer a process gets to its aim – that is, the better – the more its efficiency – that is, its speed – increases.

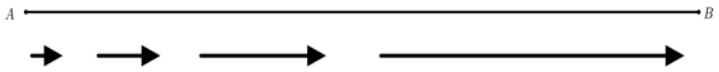

Figure 3

Among natural changes, local motion – that is, a change of place – plays an important role because it occurs both in the sublunar world and in the heavens. In both cases, it results from the interaction between a mobile object and its mover; but while a sublunar local motion is a process towards perfection, the mobile object and the mover involved in a celestial motion are both eternal and complete, so that they cannot aim to any further perfection. As a result, while a natural sublunar element, for instance a falling stone,[12] naturally moves on a finite, oriented path,[13] in a non-uniform way,[14] the local motion of celestial bodies is an infinite, non-oriented, uniform process.

It is non-oriented because, given that any point A is equivalent and indistinguishable from any point B, it is impossible to order them.[15] It is uniform because, having no aim, there is no reason for its speed to increase approaching a given point.[16] Finally, it is infinite because, having no aim, it has no end (and no beginning).

[12] The question of the mover in natural locomotion is a complex one. I accept here Aristotle's statement that the mover of a heavy (resp. light) element is what made it heavy (resp. light), as stated in *Ph*. VIII 4.255b6-256a3. For a detailed analysis of the problem, see Bodnár (1997).
[13] Once motion is an oriented process, its trajectory is an oriented path, too.
[14] In modern terms, the motion of a stone is an accelerated rectilinear motion.
[15] In Aristotle's words, celestial beings have only a "from here to there" (ποθὲν ποί) potentiality (*Metaph*. Θ 8.1050b20-22; Λ 2.1069b25-26). I think that it is not by chance that, in the first case, where the reference to celestial beings is explicit, Aristotle uses 'here' and 'there', avoiding any reference to place: place, in its proper sense, is something qualitatively characterized. Cf. *Metaph*. H 1.1042b5-6, where the matter, and hence the potentiality, is called "local" (τοπική).
[16] *Ph*. VIII 9.265b11-16.

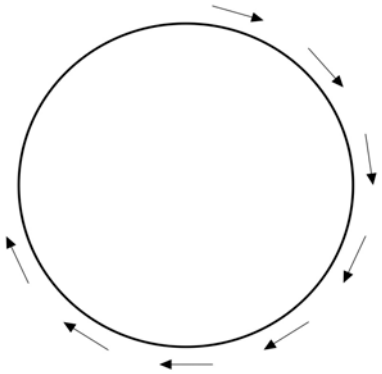

Figure 4

As Aristotle shows in *Ph*. VIII, the only motion in his cosmos that complies with these constraints is uniform circular motion,[17] so this must be the motion of celestial beings. I will briefly go over the main topics here, slightly reformulating them.

First, from a purely geometrical point of view, the constraint of uniformity – every portion of motion must be equivalent to every other – reduces the number of possible paths to two: the straight line and the circle. The straight line and the circle are the only known examples of homeomeric lines, that is, lines that perfectly overlap with themselves.[18]

Moving from purely geometric considerations to cosmological ones, the possibility of a straight path is definitely excluded. Since Aristotle's cosmos is oriented – it is qualitatively characterised and involves a difference in degrees of perfection going from the center to the periphery – two points at a different distance from the center are different not only geometrically but also qualitatively. When, however, a straight line is placed with respect to the center, their points lie at a different distance from it. But if they lie at a

[17] *Ph*. VIII 10.267b2-5.

[18] Something which is homeomeric (ὁμοιομερής) has parts similar to each other and to the whole (*Cael*. III 4.302b15-20; *GC* I 10.328a10-12; *PA* II 1-2; *Mete*. IV 10.388a10-20; *HA* 486a4-5; cf. Plat. *Prt*. 329d6-8). In fact, also the spiral line satisfies the request, but Aristotle does not list it among the homeomeric lines. On the opposition between circle and straight line, see especially *Metaph*. Δ 6.1016b16-17.

different distance from the center, they do not have the same degree of perfection, and they cannot define the path of a uniform motion.

On the contrary, the circle is defined exactly as the locus of points equidistant from a given point, called the center of the circle. Therefore, it is enough that the center of the circle coincides with the center of the cosmos for there to be a uniform path on which a uniform motion can take place.

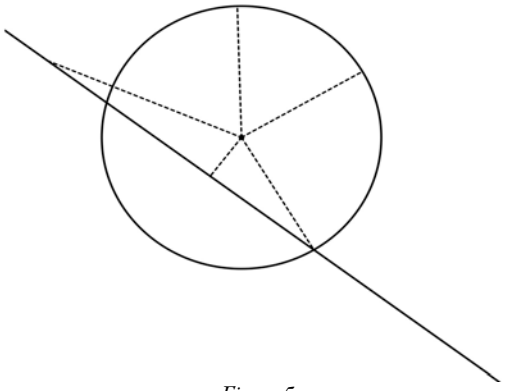

Figure 5

Moreover, a uniform circular motion can be continuous and infinite, while a continuous infinite rectilinear motion is incompatible with the finiteness of Aristotle's cosmos. Let us see how this immediately follows from the definition of the infinite discussed in Section 1.

2.2 Continuity and Infiniteness

First of all, Aristotle's definition excludes the possibility of a rectilinear motion which is infinite because its path is infinite: moving in a straight line, and more generally in an open line, at a given point one will reach the boundary of the cosmos, and it will be impossible to go on. In other words, the condition **D1** is not satisfied.

But an infinite rectilinear motion on a finite path must also be excluded. Of course, it is possible to go on infinitely on a segment, running through it in one direction and then in the opposite direction, and repeating that journey; but the outcome of this reiteration is not a unique, continuous motion.

It is a series of disconnected, limited motions, and, for this reason. It cannot be the natural motion of the heavens.

Indeed, when the mobile object reaches the turning point, it must use this point as two: as the end of its outward journey and as the beginning of its return. This division cannot be only potential – as when the traveling body passes the middle point of a straight line – but must be an actual one. But the actualization of a division breaks continuity; such a break of continuity gives rises to limits, and this prevents infinity of motion.

While in a rectilinear motion it is impossible to go from the beginning to the end and again from the end to the beginning, and so on, without changing the direction of motion, thus breaking its continuity, such a break is not needed in circular motion.[19] Imagine curving the segment until its ends A and B join, resulting in a circle; in this case any order between points is destroyed, and every point can serve indifferently as a beginning or as an end.

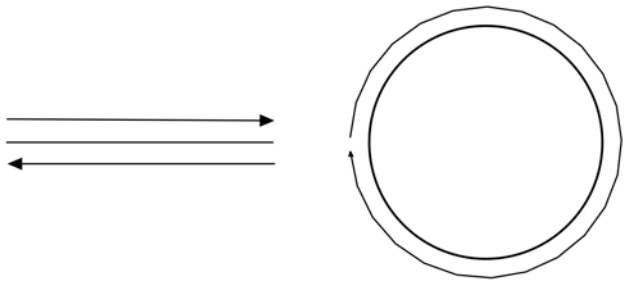

Figure 6

Imagine one arrives at a supposed end: one can call this end a beginning and go on from this new beginning to an end. But now one can call this end a beginning and go on from this new beginning to an end. And then one can call this end a beginning and go on from this new beginning to an end... and so on. As was anticipated in Section 1, such a motion is a perfect example of a purely iterative process: go from a beginning to an end and call it a beginning (*first step*);

[19] A detailed comparison between rectilinear and circular motion is made in *Ph*. VIII 8 and 9.

then go from this new beginning to an end, and call it a beginning (*second step*), and so on, over and over again (*next steps*), as in Figure 2.

In fact, this is another way of saying that every portion of a circular motion is perfectly equivalent to the one following it, and to the one preceding it, so that motion can go on indefinitely: why should it stop here instead of there? And why should it have started here instead of there?

Moreover, the way of being infinite which is peculiar to uniform circular motion – **D1** and **D2** are satisfied, **D3** is not – is something more perfect than being infinite in a proper way. Indeed, Aristotle often stresses the incomplete nature of the infinite, contrasting it with the perfection of the whole: the infinite is not that beyond which there is nothing – as in the case of a whole – but that beyond which there is always (ἀεί) something. In other words, a genuine infinite is always lacking something.

In the case of circular motion, however, this is not completely true. It is true that there is always something beyond, but it is false that this something is absolutely lacking – in some sense, it is already present, so that circular motion is complete.[20] And in some sense, it is always (ἀεί) present, so that circular motion can be read both as an instance of motion (an ongoing procedure always lacking something) and as an instance of being (a persisting, complete state); uniform circular motion is ἀεί both in the mathematical iterative sense of going on over and over again, without limit, and in the metaphysical absolute sense of being eternal. I will elaborate on this point, which is crucial for my analysis, in the following sections.

3. Circular Motion between Necessary Beings and Physical Bodies

For Aristotle, mathematical objects are nothing but physical objects, just considered by the mathematician under a particular (and hence partial) perspective, that is, disregarding change.[21] In order to obtain a mathematical sphere from a sphere of bronze, for instance, the mathematician has to

[20] *Ph*. VIII 8.264b27-28; 9.265a16-22; *Cael.* I 2.269a18-21. See also Quarantotto (2015), where circular motion is read as an *energeia* in the sense of *Metaph*. Θ 6.

[21] In Aristotle's system, to disregard change means to disregard any qualitative differences, which means to disregard any sort of teleology. For this reason, I will treat the three features as equivalent.

subtract all features of bronze; in order to obtain a geometrical trajectory from a physical change, he has to subtract every teleological feature, that is, those qualitatively differentiating the beginning from the end. But in order to obtain a mathematical object from a uniform circular motion, he does not have to subtract anything: since it is devoid of any qualitative feature, the physical object 'uniform circular motion' must coincide with the mathematical object 'uniform circular motion'.[22] But mathematical objects are eternal and necessary, and so, too, must circular motion be.

Summarizing, we have an object that, on the one hand, as I have shown in Section 2.2, is both infinite (imperfect) and complete, and, on the other hand, is both mathematical (necessary, outside time) and physical. I will use this double nature of the uniform circular motion in order to build up a sort of connection between the eternity of necessary beings, complete and perfect, which ἀεί are the same, and the time of sublunar contingent beings, incomplete and imperfect, which ἀεί are changing (toward their completion).

The idea is to interpret the state of *ἀεί being in circular motion* in two slightly different manners: as a continuous sequence of states of being and as a continuous sequence of states of change.[23] As a sequence of states of being, complete and perfect, uniform circular motion pertains to eternal beings: while eternal unmoved beings are ἀεί are, celestial beings ἀεί are in circular motion. In a similar way, if circular motion is read as a sequence of states of change, it pertains to sublunar beings: while particular sublunar beings ἀεί are in motion, the sublunar world in its totality ἀεί is in circular motion.

3.1 Necessary Beings: To-ἀεί-Be

Both in Greek mathematics and in the Aristotelian corpus, the adverb ἀεί has a precise iterative meaning when it is associated with an action verb, the indefinite repetition of which it denotes. Nevertheless, the same adverb assumes in Aristotle a slightly different meaning when it is associated with the verb *to be*. In this case, the separation between the verb and the adverbial particle seems to disappear, as if *to-ἀεί-be* were for Aristotle a new verb,

[22] It is not by chance that astronomy in ancient Greece was considered a branch of mathematics.
[23] I employ the phrase 'states of motion' to mean an extended portion, or a 'segment' of movement, and not a snapshot, or point. In fact, like anything which is continuous, a movement is made of segments and not of points.

completely distinct from the verb *to be*.[24] For here we have no iteration of an action – the action of *being* – but instead a single indivisible action, which makes *to-ἀεί-be* equivalent to *to be eternally*.

For Aristotle, things that *eternally are* (τὰ ἀεὶ ὄντα) are unchangeable and necessary,[25] and belong to three main classes: mathematical objects (and propositions), first principles, and celestial (divine) beings.

Mathematical objects (and first principles, if read as indemonstrable propositions) *eternally are* because they *ἀεί* are true.[26] They are necessary, so that every time one deduces,[27] or verifies them, the result is the same.[28] In this sense, they are unchangeable, and they are outside time. Aristotle's typical examples of such kinds of object are the incommensurability of the diagonal and the side of a square or the property of the interior angles of a triangle of summing up to two right angles.

Analogously, celestial beings (and first principles, if read as first acting causes) *eternally are* because they are *ἀεί* the same. Once again, *to be* is obviously not an action verb: as pure actuality,[29] what *eternally is* cannot contain any differentiation.

In short, when it refers to eternal things, the adverb ἀεί loses the idea of processuality: *to-ἀεί* (eternally)*-be* means immobility, no change, no time,[30] pure actuality.[31] But except for the first unmoved mover, which *eternally* is,

[24] On the use of *to-ἀεί-be*, see in particular *Cael.* I 12 and Thomas Aquinas's commentary. Thomas's proposal of interpretation in this sense, as discussed in Williams (1965), is at the basis of Waterlow (1982). On the consequent coincidence between possibility and actuality of what *ἀεί-is*, see also *Ph*. III 1.203b30.

[25] On the relation between always and necessarily, see *De Int*. 9; *Metaph*. Δ 5.1015b9-15 and *Metaph*. E 2.

[26] On the applicability of such a criterion to eternal divine beings as well, see *Metaph*. α 2.993b26-31.

[27] Differently from first principles, mathematical truths might have something 'before' them: another mathematical truth, which acts as the cause. See *Ph*. VIII 1.252b2-5; *GA* II 6.742b26-35.

[28] See especially Aristotle's discussion of the permanent properties (τὰ ἀεὶ ἴδια) in *Top.* V 1, and 128b39-129a2.

[29] *Metaph*. Θ 8.1050b16-18.

[30] *Ph*. IV 12.221b3-4: ὥστε φανερὸν ὅτι τὰ αἰεὶ ὄντα, ᾗ αἰεὶ ὄντα, οὐκ ἔστιν ἐν χρόνῳ.

[31] On the relation between immobility and lack of purpose, see, e.g., *Metaph*. B 2.996a21-b1.

and is unmoved, celestial beings both *eternally are* and *eternally are moved* (in circle);[32] how to reconcile the two forms of being?

3.2 The Heavens: To-ἀεί-Be in Circular Motion

As discussed in Section 2, circular motion is a rather ambiguous object in Aristotle's system. It is a local motion – the first local motion – but it is only improperly located.[33] It has neither end nor beginning, because it lacks any teleological perspective;[34] but it has an end and a (new) beginning at every point, because it is continuous and infinite.[35] It is a natural object, for it is the motion of the aether, which is a natural body;[36] however, it is not a change, because the nature of the aether is not a principle of change, but a principle of being (yet in motion), and as such it is not a genuine potentiality. It is instead an act, whose only possible form of being is to persist in its state of motion.[37]

One can then read uniform circular motion both as an infinite sequence of states of motion and as an eternal persistence of the same state of being. Grammatically, it is sufficient either to link or not to link the adverbial ἀεί to the verb *to be*.

In this sense, the linked form, the *ἀεί-being* in circular motion, is the proper state of celestial beings: something very similar to, and absolutely compatible with, their *ἀεί-being*, where instead of having a single, local (punctual) act of being, we have a single, local act of being in circular motion. Indeed, since uniform circular motion is not only infinite, but also periodic, it cannot even bear the basic differentiation between before and after, even in a purely logical sense: every step both precedes and follows every other step, so that they are completely indistinguishable. For this reason, the iteration involved in a uniform circular motion is something more than the repetition of an action: it is the iteration of a unique (numerically

[32] *Ph*. IV 4.211a13-14; VIII 10.267b16-17; *Metaph*. Γ 8.1012b30-31; H 4.1044b6-9.
[33] *Ph*. IV 5.212b7-13. See also I 3.186a16-18; VI 9.240a29-b7.
[34] *Cael.* I 3; *Cael.* II 3.286a7-12.
[35] *Ph*. VIII 8.264b9-28; 9.265a27-b1.
[36] *Cael.* I 2.
[37] *Cael.* I 9.279b1-3: Καὶ ἄπαυστον δὴ κίνησιν κινεῖται εὐλόγως· πάντα γὰρ παύεται κινούμενα ὅταν ἔλθῃ εἰς τὸν οἰκεῖον τόπον, τοῦ δὲ κύκλῳ σώματος ὁ αὐτὸς τόπος ὅθεν ἤρξατο καὶ εἰς ὃν τελευτᾷ.

and specifically) state. But this is the same as to say an everlasting single state, that is, a manifestation of actuality.[38]

In this way a local correspondence has been built up between the unique act of being of eternal beings and each single identical step of their being in circular motion. Whether eternity is read as a sort of 'static' process, or uniform circular motion is read as a sort of 'processual' state, in any case they can be obtained from each other.

3.3 Physical Bodies: To-ἀεί-Change

Given the continuity between the mode of being of uniform circular motion and the mode of being of eternal beings, in what follows I suggest an analogous way of establishing a relationship of continuity between the mode of being of uniform circular motion and the mode of being of the sublunar processes of change.

Again, the crucial point will be the notion of iteration, since a local correspondence will be built up between the infinite (iterative) motion of the heavens and the infinite (iterative) chain of finite changes which characterizes Aristotle's sublunar world. In fact, even if physical changes, individually taken, are finite and oriented, they are part of a unique universal process, which does not have the nature of a change but rather of a motion on a circle and which, as Aristotle says, imitates the perfection of eternal beings.

To see how this imitation works, we have to go back to the semantic framework of Section 3.1, where the adverbial ἀεί was not linked to the verb *to be*, in a single composed verbal form, but was acting on the verb, as an iterative operator, as in mathematics: not to-*ἀεί-be* in circular motion, which is the proper state of celestial beings, but to-*ἀεί*-be in motion on a circle.[39] If read in

[38] *Cael.* I 9, *passim*. Cf. *Metaph*. E 2.1026b27-29; *Ph*. VIII 6.259b33-260a19.

[39] I employ the phrase "motion on a circle" for the unceasing chain of sublunar changes in order to emphasize the difference from the celestial circular motion of the heavens, which is a proper "motion in circle". In the latter case, we have a single subject, performing a single movement, while in the first case we have infinitely many individual limited motions which are connected, or literally strung together, so that they perform a motion that covers a circle. I would like to thank the anonymous referee for bringing this point to my attention.

this way, as the indefinite iteration of the action of moving in circle, the notion of uniform circular motion is consistent with that of a physical process.[40]

3.3.1 To-ἀεὶ-Be in Motion on a Circle

The process of change that characterizes the sublunar world is made up of finite and separated teleological sub-processes. Since each of these sub-processes has well-defined and qualitatively characterized extremes, two changes cannot be continuous, but only contiguous, like two legs of a relay race,[41] because the ending point of the first change, as such, is qualitatively different from the starting point of the second one. Moreover, they have a different subject, and that they can be viewed as a unique continuous process is absolutely not obvious. But the reference to the uniform circular motion of the heavens gives a solution to both the difficulties. Let see how.

As Aristotle explains in *De generatione et corruptione*,[42] physical changes can combine to form a single, infinite, periodic process: a circular motion which imitates, as far as possible, the perfection of eternal beings. This combination involves the two levels of inanimate and animate beings.

At the level of inanimate beings, the infinite process is realized by means of a composition of locomotion, alteration and changes of elements into each other.[43] A slightly different state of affairs is represented at the level of animate beings: because they are composed of elements, they are subjected (at a purely material level) to the kind of changes just seen; but because they are animated, they are subjected to another process, in which eternity manifests itself in a more perfect way. This is the continuous generation of individuals, which, as Aristotle affirms in *De generatione animalium* and in *De generatione et corruptione*, is the best possible way for animated beings to imitate eternity:

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[40] In this perspective, the notion of uniform circular motion is strictly related to the notion of (infinite) time, which is absolutely extraneous to the notion of eternity, and impossible to be inferred from it.

[41] *Ph*. V 4.

[42] *GC* II 10.

[43] *GC* II 10.337a4-6: "When from water air comes to be, and from air fire, and again (πάλιν) from fire water, we say that generation has come round in circle because it has come back again (πάλιν ἀνακάμπτειν)".

For these reasons there is generation of animals. For, since the nature of such kind cannot be eternal, that which comes into being is eternal in the way that is possible for it. Now it is not possible in number (for the being of existing things is in the particular, and if this were such it would be eternal) but it is possible in form.[44] That is why there is continuously (ἀεί) a kind – of men and of animals and of plants.[45]

This means that, if it is seen from a sufficient 'distance' – that is, if it is considered at a certain level of generality – the global process appears to be composed of identical steps, where a single step is not the generation (and corruption) of particular individuals, but the instantiations of the same, identical form.

The idea, as usual, is to disregard some qualitative feature of the processes involved. Take a natural change, a process of generating men, for example, where the beginning (the birth of the father) and the end (the birth of the son) are naturally separated and pertain to two separate individuals. Now disregard any accidental difference between the two men, and consider them as two instances, or two states, of the same subject: the human form.

What we see at this level is a purely iterative process: go from a father to a son, and call him a father (*first step*); then go from this new father to a son, and call him a father (*second step*); then go from this new father to a son, and call him a father (*third step*), and so on, over and over again (*next steps*).[46] Or, in more abstract terms of form: a human form is generated (*first step*); then a human form is generated (*second step*); then a human form is generated (*third step*), and so on, over and over again (*next steps*).

This can be done for every species, so that there are many circular processes of the generation of a form, just as there are many circular celestial motions.

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[44] *De an.* II 4.415a26-b7: "In fact, this is the most natural function of animate beings, [...] to reproduce another like themselves (ἕτερον οἷον αὐτό), an animal an animal, a plant a plant, in order that they partake of the ἀεί and the divine in the only way they can [...] Since they cannot partake of the ἀεί and the divine by continuity, for no perishable thing can remain numerically one and the same, they partake of it in the only way they can, some to a greater and some to a lesser extent: what persists is not the same, but something like it, one not numerically but specifically" (cf. *De an.* II 4.416b14-17; *Metaph*. Γ 5.1010a24-25). On the subject see Lennox (2001) and Quarantotto (2005).

[45] *GA* II 1.731b32-732a1.

[46] Like in the case of circular motion as discussed in Section 2, there is no a last step but there is neither a first step. Indeed, one must imagine indefinitely carrying on the procedure also in the opposite direction, so that the procedure will never end and has always yet started.

Of course, in Aristotle's world, nothing actually exists as a form separated from physical bodies; but to acknowledge it as something common and preserved in the process of generation allows Aristotle to treat the process as eternal and necessary, and to study it with the instruments of a demonstrative science, disregarding the possibility of failure connected with the individual. The coincidence, at any step, of the form as beginning (formal cause) and as end (final cause) transforms the hypothetical necessity,[47] which holds at the level of the single step, into an absolute necessity acting at the level of the process. While any step is completely subject to the indeterminacy of physical world, the iterative structure of the process as a whole, considered from the point of view of the form, is completely determined by the fact that it is nothing but the manifestation, in the sublunar world, of the necessity of eternal beings, with the mediation of the motion of the heavens.

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[47] Aristotle firmly denies any form of determinism, but the question of how reconcile passages apparently contradictory is not straightforward. See for instance McCall (1969), McKim (1971), Williams (1978).

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