Aristotle on the Great Year, Eudoxus, and Mesopotamian Goal Year Astronomy

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Résumé. Il est montré que l’*annus maximus* d’Aristote était la période de 12 960 ans qu’il admettait entre deux retours du ciel et des planètes à une même configuration. Probablement, Platon et Eudoxe de Cnide s’intéressèrent également à la question, mais obtinrent d’autres résultats. Les périodes planétaires utilisées pour le calcul d’Aristote sont d’origine mésopotamienne, et furent probablement empruntées par Eudoxe en Égypte.

Abstract. Aristotle’s *annus maximus* is shown to have been a supposed period of 12 960 years between two returns of the sky and the planets to the same configuration. It is likely that Plato and Eudoxus of Cnidus also investigated this period, but arrived at different results. The planetary periods used in Aristotle’s calculation are of Mesopotamian origin and were probably borrowed by Eudoxus in Egypt.

I Aristotle on the “Great Year”

12 954 is the number of solar years in one *annus magnus* (henceforth “Great Year”) according to the *Hortensius* of Cicero, a number which is confirmed by three independent sources, Tacitus, Servius and Solinus:

A) Cicero, *Hortensius*, fr. 80 (Grilli) = Tacitus, *Dialogus de oratoribus*, 16.7
nam si, ut Cicero in Hortensio scribit, is est magnus et verus annus, quo eadem positio caeli siderumque, quae cum maxime est, rursum existet, isque annus horum quos nos vocamus annorum duodecim milia nongentos quinquaginta quattuor complectitur, incipit Demosthenes [*vester*], *quem vos veterem et antiquum fingitis, non solum eodem anno quo nos, sed etiam eodem mense extitisse.*
nongentos *coni. Nicolaus Loensis* : septingentos A octingentos *codd. cett.* ‖ vester *ut glossema del. Halm* ‖ etiam *Michaelis* : fere *B* fama *codd. cett.*
For if, as Cicero writes in the *Hortensius*, the true great year is that in which the position of the sky and the stars at a given time recurs, and if this year embraces twelve thousand nine hundred and fifty four of what we call years, then [your] Demosthenes, whom you imagine to be old and ancient, was born not only in the same year, but in the same month as ourselves.

B) Cicero, *Hortensius*, fr. 81 (Grilli) = Servius, *Commentary on Virgil’s Aeneid*, I.269, p. 99, 16-20 (Thilo)
tria sunt genera annorum : aut enim lunaris annus est XXX dierum, aut solstitialis XII mensium, aut secundum Tullium magnus qui tenet $\overline{XII}DCCCCLIIII$ *annos ut in Hortensio : “Horum annorum quos in fastis habemus magnus* $\overline{XII}DCCCCLIIII$ *amplectitur”.*
“There are three sorts of years : either it is the lunar year of 30 days, or the solstitial (*sc.* year) of 12 months, or, according to Tullius, the great (*sc.* year) which has 12 954 years, as in the *Hortensius* : ‘The great (*sc.* year) embraces 12 954 of the years which are in our calendars’.”

C) Cicero, *Hortensius* (not recorded by Grilli) = Servius, *Commentary on Virgil's Aeneid*, *ad v*. III.284, p. 391, 24 – p. 392, 2 (Thilo)

antiqui tempora sideribus computabant et dixerunt primo lunarem annum XXX dierum: unde invenitur in aliquibus DCCCC annorum vita, scilicet lunarium. postea solstitialis annus repertus est, qui XII continet menses. mox maiore cura annum esse magnum voluerunt omnibus planetis in eundem recurrentibus locum, et hic fit, ut supra diximus, secundum Ciceronis Hortensium post annos $\overline{XII}$*DCCCCLIIII solstitiales scilicet. bene ergo nunc 'magnum' addidit, ne lunarem intellegeres; bene solis nomen, ne, quia dixerat 'magnum', illum planetarum acciperes. de quo varia dicuntur et a Metone et ab Eudoxo et a Ptolomaeo et ab ipso Tullio; nam in libris de deorum natura tria milia annorum dixit magnum annum tenere.*

The Ancients used the stars to calculate time and spoke firstly of a lunar year of 30 days (whence in some authors one finds a life-span of 900 years – that is, lunar). Thereafter was found the solstitial year, which is made up of 12 months. Soon, with greater care, they wished that there be a great year when all planets returned to the same place, and this, as we have said above, happens according to Cicero's *Hortensius* after 12 954 years – that is, solstitial. He (*sc*. Virgil) was therefore right to add "great" at this point, that one might not understand "lunar", and he was right to add the name of the sun, that one might not, because he had said "great", understand that (*sc*. the year) of the planets. On this topic (*sc*. the "Great Year"), different things are said by Meton, Eudoxus, Ptolemy and Tullius himself; indeed, in his books *On the nature of the gods* he said that the great year lasts 3 000 years.

D) C. Iulius Solinus, *Collectanea*, 33.13 (Mommsen)

Cum huius vita magni anni fieri conversionem rata fides est inter auctores : licet plurimi eorum magnum annum non quingentis quadraginta, sed duodecim milibus nungentis quinquaginta quattuor annis constare dicant.

The revolution of the great year occurs with its (*sc*. the phoenix') life, according to our authors; yet many of them say the great year is made up not of five hundred and forty, but of twelve thousand nine hundred and fifty four years.

From the texts quoted above, it appears that the "Great Year" described the lapse of time between two conjunctions of the seven planets at a given point on the sphere of the fixed stars (Text A: *magnus et verus annus, quo eadem positio caeli siderumque, quae cum maxime est, rursum existet* and Text C: *annum esse magnum voluerunt omnibus planetis in eundem recurrentibus locum*). This can conveniently be termed a *conjunctional* "Great Year" (as opposed to other periods sometimes called "Great Year" by the ancients, such as luni-solar intercalation cycles)[1].

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[1] For a list of world cycles in Greek, Latin and Arabic sources see G. de Callataÿ, *Annus platonicus. A Study of World Cycles in Greek, Latin and Arabic Sources*, Louvain-la-Neuve, 1996, pp. 253-258; add the attestations of 30 000- and 7 000-year periods in the recently published Papyrus Fouad inv. 267 A, with J.-L. Fournet and A. Tihon, *Conformément aux observations d'Hipparque: le Papyrus Fouad inv. 267 A*, Louvain-La-Neuve, 2014, pp. 117-119.

Let us represent the motion of the sun and moon by the so-called "Saros" period of 18 years, which was used in antiquity for the prediction of eclipses, that is conjunctions of these two heavenly bodies[2]. The number 12 954 is approximately equal to the product of the five planetary periods quoted in Cicero's *De natura deorum* (II, 52-53) and of the "Saros":

> 30 (Saturn) x 12 (Jupiter) x 2 (Mars) x 1 (Venus) x 1 (Mercury) x 18 (Saros) = 12 960 solar years.

G. de Callataÿ seems to be the first scholar to have pointed out this striking equality, in his comprehensive study of cosmic periods in Greek, Latin and Arabic texts[3]. As he also mentioned, the planetary periods quoted by Cicero in his *De natura deorum* go back all the way to Eudoxus of Cnidus, the Greek scientist and philosopher of the 4th c. BCE, who was close to both Aristotle and Plato[4]. Eudoxus' sidereal periods for the five planets are known to us through Simplicius' commentary on Aristotle's *De caelo*, who quotes a treatise of Eudoxus by the title περὶ ταχῶν through a chain of sources which starts with Eudemus of Rhodes' *History of Astronomy*[5]:

> ἐπὶ μὲν τοῦ τε Ἑρμοῦ ἀστέρος καὶ τοῦ Ἑωσφόρου ἐνιαυτῷ φησι τὴν τῆς δευτέρας σφαίρας συντελεῖσθαι, ἐπὶ δὲ τοῦ Ἄρεος ἔτεσι δυσίν, ἐπὶ δὲ τοῦ Διὸς δώδεκα ἔτεσι, ἐπὶ δὲ τοῦ Κρόνου τριάκοντα.
>
> Concerning the star of Mars and the Morning-star, he says the rotation of the second sphere is accomplished in a year, for the star of Ares, in two years, for the star of Zeus, in twelve years, and for the star of Kronos, in thirty.

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2 On the prediction of eclipses in Mesopotamia through the "18-year" (18 MU.MEŠ) cycle, which consisted of 223 synodic months but was considered as lasting 18 years, as indicated by its name, see J. Steele, « Eclipse Prediction in Mesopotamia », *Archive for the History of Exact Sciences* 54, 2000, pp. 421-454.
On the historically inaccurate designation of this period as a "Saros" (from Sumerian šár = Akkadian *šār*), see O. Neugebauer, *The Exact Sciences in Antiquity*, pp. 134-136, as well as his earlier expositions in "Untersuchungen zur antiken Astronomie III. Die babylonische Theorie der Breitenbewegung des Mondes", *Quellen und Studien zur Geschichte der Mathematik* B 4, 1937, pp. 193-346, here: pp. 241-245; *id.*, "Untersuchungen zur antiken Astronomie V. Der Halleysche "Saros" und andere Ergänzungen zu UAA III", *Quellen und Studien zur Geschichte der Mathematik* B 4, 1938, pp. 407-411.

3 See G. De Callataÿ, *op. cit.*, pp. 54-58.

4 See *id.*, *ibid.*, p. 46, n. 126. On Eudoxus and Plato's Academy, see recently V. Gysembergh, "Émendations dans le *Commentaire* d'Hipparque: Sur le *Miroir* d'Eudoxe de Cnide", *Revue de philologie, de littérature et d'histoire anciennes*, 2012, pp. 43-51; *id.*, "Une référence à la médecine de Cnide dans le débat entre Platon et Eudoxe", *Revue des études grecques* 126, 2013, pp. 615-622.

5 See Simplicius of Athens, *Commentary on Aristotle's De Caelo*, p. 495, 26-29 Heiberg (= Eudoxus of Cnidus, F 124 Lasserre). Note that the periods for Mars, Jupiter and Saturn are confirmed by a papyrus text from the 2nd c. BCE (cf. "Ars Eudoxi", col. V, ll. 13-20, edited by F. Blass, *Zeitschrift für Papyrologie und Epigraphik* 115, 1997, pp. 79-101. As demonstrated by Blass in the introduction, the main text of the papyrus was written by a student who had taken a course on astronomy based on Eudoxus.

Moreover, Eudoxus' student Helicon is reported to have accurately predicted the date of a solar eclipse[6]: though the method used is unknown, it is likely that this prediction involved knowledge of elementary Near Eastern astronomy, in particular of the Saros cycle and of some records of past eclipses.

It is well known that the lost *Hortensius* was a Latin adaptation of the young Aristotle's *Protrepticus*, which has likewise been lost[7]. Furthermore, it is generally assumed that the *Protrepticus* also contained Aristotle's theory of the "Great Year" (called *annus maximus* by Censorinus)[8]. In view of the evidence on Eudoxus' planetary periods and of the well-established relationship of the *Hortensius* to the *Protrepticus*, it seems reasonable to hypothesize that Aristotle's "Great Year" also had a duration of 12 960 solar years.

This hypothesis is confirmed by textual criticism. Let us assume that the *Protrepticus* used not the alphabetic numeral system familiar to the classical scholars of today, but the acrophonic numeral system, which was most current in Athens in the classical period. 12 960 would then have been written as follows:

MXX𐅅HHHH𐅄Δ [*i.e.* 10 000 + 2 x 1 000 + 500 + 4 x 100 + 50 + 10]

A later scribe who was not well acquainted with acrophonic numerals – or was it Cicero himself? – appears to have misinterpreted δ as "4", according to its value in the widespread Greek alphabetic system. This error explains Cicero's value of 12 954 as a corruption of the number 12 960, originally written in acrophonic numerals, which must have been the duration of the "Great Year" according to the main source of the *Hortensius*, i.e. Aristotle's *Protrepticus*.

II Eudoxus and the "Great Year"

Eudoxus is not explicitly credited with a "Great Year" of 12 960 years. Yet, as mentioned above, the sidereal periods of the five planets underlying Aristotle's "Great Year" are first attested in relationship with Eudoxus. They then recur in a number of authors, in contexts where they are often associated with the idea of the "Great Year", as is made clear in the following table:

Table 1. Eudoxus' sidereal periods in later Greek and Latin texts

	Saturn	Jupiter	Mars	Mercury	Venus
Epinomis, 986e – 987c				+	+
[Aristotle], De mundo 6, 399a8-11	+	+	+	+	+

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[6] See Plutarch of Chaeronea, *Life of Dion*, 19.

[7] See W. Jaeger, *Aristoteles. Grundlegung einer Geschichte seiner Entwicklung*, Berlin, ^{2}1955, pp. 53-102.

[8] See Aristotle of Stagirus, *fr. adesp*. 828 (Gigon) = Censorinus, *De die natali* 18.11. For the *Protrepticus* as the most probable source of this fragment, see W. Jaeger, *op. cit*., p. 158, n. 1 and G. de Callataÿ, *op. cit*., p. 34 with n. 88.

"Ars Eudoxi"[9]	+	+	+		
Geminus, *Isagoge* 1, 24-29	+	+	-	+	+
Philo, *De providentia* 2, §69 Richter	+		+	+	+
Cicero, *De natura deorum* 2, 52-53	+	+	-	+	+
Hyginus, *Astronomica* 4, 14-19	+	+	+	-	+
Pliny, *Nat. Hist.* 2, 6, 32-39	+	+	+	-	-
Theo of Smyrna, p. 136 (Hiller)	+	+	+	+	+
Aetius, *Plac.* 2, 32, 1 [= Theophrastus?]	+	+	+	+	+
Cleomedes 1, 2, 22-36 (Todd)	+	+	-	+	+
Apuleius, *De mundo* 29	+	+	+	+	+
[Censorinus], *Comp. Discipl.* 3, 3-4	+	+	-	+	+
Achilles, *Isagoge*, 18	+	+	+	+	+
Schol. Arat. MDΔUA 455	+	+	-	+	-
Calcidius, *Comm. in Timaeum*, §70	+	+	+	+	+
Macrobius, *De somnio Scipionis* 1, 19, 3	+	+	+	+	+
Macrobius, *De somnio Scipionis* 2, 11, 7	+	+	+	+	+
Martianus Capella 8, 852 sq.	+	+	+	+	-
John Philoponus, *De aetern. mundi* 16, 4	+	+	+	+	+
Photius, *Bibl.* cod. 249, 440a	+	+	+	+	+
Psellus, *De omnifaria doctrina* 137	+	+	-	+	+
CCAG IV, 114-115	+	+	+	+	

Legend:

+	Same period as Eudoxus
-	Different period than Eudoxus
	No period indicated
Cicero	Context concerns the "Great Year".

The question thus arises: did Eudoxus also attempt to determine the duration of the "Great Year", understood as the period between two conjunctions of the seven planets at a given point on the sphere of the fixed stars? Along with the "Great Year" in Aristotle's *Protrepticus* as restored above, Plato's *Timaeus* (39c-d) demonstrates that there was a strong interest for the conjunctional "Great Year" in Plato's Academy[10]:

[9] See F. Blass, "Eudoxi ars astronomica qualis in charta Aegyptiaca superest", Kiel, 1887 (Universitätsprogramm) – reprinted in: *Zeitschrift für Papyrologie und Epigraphik* 115, 1997, pp. 79-101.

[10] The evidence studied in this article thus contradicts Alan C. Bowen's claim that the interest of Greek astronomers for planetary phenomena dates to a much later time (see A.C. Bowen, "Simplicius and the History of Early Greek Astronomy", *Perspectives on Science* 10, 2002, pp. 155-167; *id.*, *Simplicius on the Planets and Their Motions: In Defense of a Heresy*, Leiden, 2013, with further bibliography).

τῶν δ' ἄλλων τὰς περιόδους οὐκ ἐννενοηκότες ἄνθρωποι, πλὴν ὀλίγοι τῶν πολλῶν, οὔτε ὀνομάζουσιν οὔτε πρὸς ἄλληλα συμμετροῦνται σκοποῦντες ἀριθμοῖς, ὥστε ὡς ἔπος εἰπεῖν οὐκ ἴσασιν χρόνον ὄντα τὰς τούτων πλάνας, πλήθει μὲν ἀμηχάνῳ χρωμένας, πεποικιλμένας δὲ θαυμαστῶς. ἔστιν δ' ὅμως οὐδὲν ἧττον κατανοῆσαι δυνατὸν ὡς ὅ γε τέλεος ἀριθμὸς χρόνου τὸν τέλεον ἐνιαυτὸν πληροῖ τότε, ὅταν ἁπασῶν τῶν ὀκτὼ περιόδων τὰ πρὸς ἄλληλα συμπερανθέντα τάχη σχῇ κεφαλὴν τῷ τοῦ ταὐτοῦ καὶ ὁμοίως ἰόντος ἀναμετρηθέντα κύκλῳ.

"Of the other stars (*sc.* the five planets) their revolutions have not been discovered by men (save for a few out of the many); wherefore they have no names for them, nor do they compute and compare their relative measurements, so that they are not aware, as a rule, that the "wanderings" of these bodies, which are hard to calculate and of wondrous complexity, constitute Time. Nevertheless, it is still quite possible to perceive that the complete number of Time fulfils the Perfect Year when all the eight circuits, with their relative speeds, finish together and come to a head, when measured by the revolution of the Same and Similarly-moving." (Tranlation after R.G. Bury)

It is beyond the scope of this paper to investigate what value Plato may have given to the "Perfect Year" (clearly described in the *Timaeus* as a conjunctional "Great Year"). In any case, considering the use of Eudoxus' planetary periods in Aristotle's calculation, it is plausible that the statement that only "a few among the many" understand the revolutions of the five planets refers first of all to Eudoxus and his school, and secondly to those members of the Academy who, like Aristotle, had taken to studying Eudoxean planetary theory. In this context, it is hardly conceivable that Eudoxus should have neglected to offer his own calculation of the conjunctional "Great Year".

Indeed, he is explicitly credited with a "Great Year" by two sources. In Text C (quoted above), Eudoxus is credited with a "Great Year" of unstated duration. In a scholium to Lucan, he is credited with a "Great Year" lasting eight solar years:

Adnotationes ad Lucanum WUAa, X.187, p. 403, 22-26 (Endt)

Eudoxus enim ad cursum suum post octo annos solem reverti dixit et esse annum magnum.

reverti *WUa*: ruenti *A*.

Indeed Eudoxus said that the sun returns to its course after eight years, and that this is the great year.

The idea of an eight-year period must be based on ancient reports of a Eudoxean octaeteris (a luni-solar intercalation cycle of eight years)[11]. Therefore, at face value, this scholium informs us that Eudoxus' "Great Year" was not a conjunctional "Great Year". However, these reports of a Eudoxean octaeteris, which were already doubted by Eratosthenes of Cyrene, have been definitively debunked by a recently published, authoritative scholium to Ptolemy's *Almagest*, crediting Eudoxus not with an octaeteris, but, much more plausibly, with a more accurate 19-year intercalation cycle of the type

[11] See Censorinus, *De die natali* 18.5 (= Eudoxus of Cnidus, F 131 Lasserre).

introduced into Greek astronomy by Meton of Athens[12]. Furthermore, in spite of its original nature as a luni-solar intercalation cycle, the eight-year cycle is confused by some sources with a conjunctional "Great Year"[13]. The scholium to Lucan quoted above offers a possible explanation for this confusion: it may have arisen from an amalgamation of reports on Eudoxus' (spurious) eight-year intercalation cycle and on his (authentic) conjunctional "Great Year". In any case, the information contained in this scholium is to be considered with utmost caution.

The search for evidence explicitly crediting Eudoxus with a conjunctional "Great Year" proves inconclusive: Text C offers no specification as to the nature of Eudoxus' "Great Year", and the Lucan scholium provides, at best, only tentative evidence, if one accepts that it is the result of a confusion. Nevertheless, as stated at the beginning of this section, because of the strong interest for the conjunctional "Great Year" in Plato's Academy, we may reasonably assume that Eudoxus also attempted to calculate its duration. Did he arrive at the same result of 12 960 years as Aristotle? If the answer is yes, then arguably the "Great Year" mentioned in the *Protrepticus* is merely borrowed from Eudoxus. That this "Great Year" should have inspired the young Aristotle would come as no surprise considering the influence of Eudoxus' planetary theory on Aristotle's astronomy, as is most blatantly illustrated by its reelaboration in *Metaphysics* Λ 8.

However, the calculation by which this result is arrived at, i.e. the multiplication of planetary periods, is erroneous[14]. It is very unlikely that Eudoxus, the prime mathematician and astronomer of his time and inventor of the intricate account of planetary motions by homocentric spheres, shared in Aristotle's error. From a geocentric point of view, the correct way of determining the shortest period between two conjunctions is to determine the least common multiple of the periods posited. Indeed, we know from Proclus' *Commentary to the Timaeus* that certain anonymous scholars calculated the "Great Year" in this way, by determining the least common multiple of planetary periods, although Proclus preserves neither the parameters nor the results of such calculations[15]. Accordingly, it is very likely that Eudoxus was the inventor of this method. The least common multiple of Eudoxus' planetary periods as handed down to us by Simplicius as well as of the "Saros" of 18 years is 180 years. Yet it is not clear why Eudoxus should have used the "Saros" instead of the sidereal periods of the sun and moon. Thus, in all probability, the length of Eudoxus' "Great Year" (however he may have called it) was 60 solar years (i.e. the least common multiple of 1, 2, 12 and 30).

What's more, the figure of Eudoxus in the Platonic corpus now comes into sharper focus. Of course, as with all other living contemporaries of Plato, he is never explicitly

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[12] See A. Jones, "A Posy of Almagest Scholia", *Centaurus* 45, 2003, pp. 69-78, here: Text 3, pp. 74-75.

[13] See C. Iulius Hyginus, *Astronomia* IV.2.3; [Plutarch], *Placita* II.32.

[14] On Aristotle's "patchy" knowledge of astronomy, see G.E.R. Lloyd, *Aristotelian Explorations*, Cambridge, 1996, pp. 160-183.

[15] See Proclus of Athens, *Commentary to Plato's Timaeus*, III.91.19 – 92.6.

named in the dialogues[16]. Yet not unlike the uncaptioned figures in a mosaic intended for a philosophically schooled public, his presence is recognizable by those who know his work[17]. It is well known that his conception of twelve calendar gods is behind the myth of the *Phaedrus* and is the object of further allusions, especially in the *Laws*[18]; and that he is part of the debate on hedonism mirrored by Plato's *Philebus*[19]. Recognition of the reference to Eudoxus' planetary periods in the *Timaeus* makes it plausible that (1) it is a theory inspired by Eudoxus which the Stranger in the *Laws* wishes to put in the center of the Magnetes' astronomical curriculum (821b5 – 822 b 2) because it shows that among the "heavenly gods" (θεῶν τῶν κατ᾽ οὐρανόν), not only the fixed stars, but also each of the planets, far from "wandering about", follows one same path all along[20], and (2) the astronomy hinted at in this passage of the *Laws* and in the *Timaeus* (38c-40d *passim*) are one and the same[21]. The lack of any clear reference in the dialogues to Eudoxus' system of several embedded homocentric spheres for each planet may be due to Plato's awareness of the system's flaws (e.g. its inability to explain variations in the planets' distance from the sun[22]), or to a philosophical disagreement, Plato having perhaps considered that it was not properly derivable from the principles of the "Same" and the "Other": this matter will require further investigation. It may be considered further evidence of Eudoxus' anonymous presence in Plato's dialogues that a pun on his name occurs twice in later additions to the Platonic corpus (εὐδόξως in *Hippias Major* 287e[23] and εὐδοξῇς in *Letters* XIII, 360e – in the latter, the fact that Eudoxus is previously named confirms the intentional character of the pun)[24].

III Eudoxus' sidereal periods and Near Eastern astronomy

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[16] On this rule of historical fiction in Plato's dialogues, see A.E. Taylor, *Plato. The Man and His Work*, London, 1937, pp. 24 sq.
[17] See K. Gaiser, *Das Philosophenmosaik in Neapel: eine Darstellung der Platonischen Akademie*, Heidelberg, 1980; M. Rashed, "La mosaïque des philosophes de Naples : une représentation de l'Académie platonicienne et son commanditaire", in: C. Noirot et N. Ordine (edd.), *Omnia in Uno. Hommages à Alain-Philippe Segonds*, Paris, 2012, pp. 27-49.
[18] See K. Kerényi, "Astrologia Platonica. Zum Weltbilde des Phaidros", *Archiv für Religionswissenschaft* 22, 1923, S. 245-256.
[19] See e.g. H. Tarrant, "'A Taste of the Doctrines of Each Group of Sages': Plato's Midwifery at Work in the Academy", in: J. Dillon and L. Brisson (edd.), *Plato's Philebus. Selected Papers from the Eighth Symposium Platonicum*, Sankt Augustin, 2010, pp. 110-119.
[20] On this passage see K. Schöpsdau, *Platon. Nomoi (Gesetze). Buch IV-VII. Übersetzung und Kommentar*, Göttingen, 2003, pp. 617-624.
[21] This confirms the assumption of Cornford, *Plato's Cosmology*, London, 1937 p. 92 and is equivalent to hypothesis c) in K. Schöpsdau, *op. cit.*, p. 622.
[22] See Simplicius of Athens, *Commentary on Aristotle's De Caelo*, p. 504, 16-26 Heiberg.
[23] See H. Thesleff, "The Date of the Pseudo-Platonic Hippias Major", *Arctos* N.S. 10, 1976, pp. 105-117, here: pp. 110 sq.
[24] On the *Epinomis* see below, Part III.

It has often been asked to what extent Plato and his school interacted with Near Eastern scholars, as Greek intellectuals had done before him and as they would continue to do even more obviously after the conquests of Alexander. For instance, an anecdote from Philodemus of Gadara's *History of the Philosophers* (quoting Neanthes quoting Philip of Opus) seems to bear witness to such interaction:

> Γεγηρακὼς ἤδη Πλάτων ξέν[ον] ὑπεδέξ[ατ]ο Χαλδα[ῖο]ν... (col. 3, ll. 39-41).
>
> Grown old, Plato received as a guest a Chaldaean.

J. Bidez and A.J. Festugière have collected considerable evidence of borrowings by Plato from various traditions of Near Eastern thought, which even the most radical sceptic will not deny entirely[25]. We will now argue that the planetary periods underlying the "Great Year" can be added to the list of such evidence.

What we know of Greek astronomy in the fourth c. BCE suggests that the empirical data used by Eudoxus in his planetary system could not be based on a program of observations accomplished by himself or other Greeks[26]. Accordingly, it is fair to assume that Eudoxus borrowed planetary data from elsewhere. Mesopotamian astronomical observations, which at the time had been gathered for centuries and had given birth to complex mathematical models[27], are an ideal suspect.

As a matter of fact, the sidereal periods used by Eudoxus for the five planets appear to derive from Mesopotamian astronomical data. The data in question is recorded on a type of tablets called "Goal Year Texts", which were characterized by A.J. Sachs as containing "raw materials for the prediction of planetary and lunar phenomena for a given year"[28]. For each planet, the "Goal Year Texts" indicate the date at which certain phenomena will take place *N* years before the "Goal Year"[29]. For instance, they indicate

[25] See J. Bidez, *Eos ou Platon et l'Orient*, Brussels, 1945; A. Festugière, "Platon et l'Orient", *Revue de Philologie, de littérature et d'histoire anciennes*, 1947, pp. 5-45.

[26] See e.g. D.R. Dicks, *Early Greek Astronomy to Aristotle*, London, 1970, p. 167.

[27] See M. Ossendrijver, *Babylonian Mathematical Astronomy: Procedure Texts*, New York, 2012.

[28] See A.J. Sachs, "A Classification of Babylonian Astronomical Tablets of the Seleucid Period", *Journal of Cuneiform Studies* 2, 1948, pp. 271-290, especially p. 282. Extant texts are edited in H. Hunger, *Astronomical Diaries and Related Texts from Babylonia. Volume VI. Goal Year Texts*, Vienna, 2006. A useful presentation is given in J.M. Steele, "Goal-Year Periods and Their Use in Predicting Planetary Phenomena", in: G.J. Selz and K. Wagensonner (edd.), *The Empirical Dimension of Ancient Near Eastern Studies*, Vienna-Berlin, 2011, pp. 101-109.

[29] See O. Neugebauer, *A History of Ancient Mathematical Astronomy*, New York, 1975, vol. 1, pp. 151-152 ; H. Hunger et D. Pingree, *Astral Sciences in Mesopotamia*, Leiden, 1999, pp. 167-168. The parameters R and P do not appear explicitly in the "Goal Year Texts": they are reconstructions based on the various planetary periods attested in the entire corpus of cuneiform astronomical texts. It is extremely unlikely that these reconstructions should some day be called into question. They are also ascribed to Hipparchus by Ptolemy, *Almagest*, IX, 3 (see O. Pedersen, *A Survey of the "Almagest"*, New York, ²2011, p. 473, *add.* to p. 269). Further reflections of the parameters used in

the dates of Saturn's phenonema 59 years before the "Goal Year" (N = 59). During these periods, there occur *R* revolutions of the planet in question: for instance, Saturn accomplishes 2 revolutions in 59 years (R = 2). It is then possible to calculate the sidereal period *P*. Note that for the planets Jupiter and Mars two values of *N* are given, depending on the type of planetary phenomena accounted for[30] – this is of no import for our inquiry.

Table 2. Sidereal periods of the five planets in the "Goal Year Texts" and Eudoxus

	N (years)	*R*	*P* (Goal Year Texts)	*P* (Eudoxus)
Saturn	59	2	29,5	30
Jupiter	71	6	11,833	12
Jupiter	83	7	11,857	—
Mars	79	42	1,881	2
Mars	47	25	1,88	–
Venus	8	8	1	1
Mercury	46	46	1	1

The sidereal periods of the outer planets (Saturn, Jupiter and Mars) according to Eudoxus are equal to the rounded Mesopotamian periods. It is more revealing yet that the periods of the inner planets (Venus and Mercury) are the same according to the "Goal Year Texts" and to Eudoxus. Indeed, they exhibit a considerable difference from the real periods (i.e. $P_{♀} \approx 0{,}615$ et $P_{☿} \approx 0{,}240$). The error may be due to the fact that observing the inner planets poses specific difficulties[31].

This conjunctive error in the periods of Venus and Mercury is revealing of borrowed astronomical data. The fact that Eudoxus uses planetary periods also known from the "Goal Year Texts" reveals that he was acquainted with central elements of Mesopotamian astronomy. Such knowledge could only have been obtained through direct interaction with scholars well versed in the methods of Mesopotamian astronomy.

Eudoxus' planetary model is well known and has been studied numerous times[32]: its profound originality in bringing order into the apparent chaos of the "wandering" stars should not conceal that it could not have been invented without access to Near Eastern astronomical records.

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the "Goal-Year Texts" are found in an astronomical table at the end of Cleomedes' astronomical handbook, which may be a later accretion to the text (see C. Williams[-Montelle], *International Journal of the Classical Tradition* 13/3, 2007, p. 478).

[30] These are respectively the "Greek-letter phaenomena" ($N_{♃}$=71 et $N_{♂}$=79) and the "Normal Star passages" ($N_{♃}$=47 et $N_{♂}$=83).

[31] D. R. Dicks, *op. cit.*, p. 256, n. 345, imputes the error to "the very large parallax effects caused by the earth's rotation in the case of the error planets". On the peculiarities of Mercury and Venus' apparent motions, see e.g. M. Ossendrijver, *op. cit.*, §3.4.1 and 3.5.1.

[32] See e.g. O. Neugebauer, *A History…*, *op. cit.*, pp. 677-685.

Interestingly, the astronomical passage of the *Epinomis*[33] (probably written by Philip of Opus[34]) shares in this error, stating that the sidereal periods of both inner planets are equal to one year, and puts those of the outer planets in the same order as Eudoxus, i.e. $P_{♄} > P_{♃} > P_{♂}$ (without, however, revealing the actual values of these periods). This order was singled out by Plato as a striking feature of the new astronomy[35], so that in the Epinomis as well it is surely a theory inspired by Eudoxus which is meant. At the same time, it also gives the five planets the same names as those used by Eudoxus, claiming that these denominations are novel. Planetary astronomy is not the only area in which Philip seems to have followed in Eudoxus' footsteps: in his determination of the latitude of Greece as well he took over Eudoxus' results[36]. This shows that the debt contracted towards Near Eastern astronomy by Eudoxus on his own behalf and on that of the Academy did not go extinct after Plato's passing, but was inherited by his most faithful successor Philip.

There is little evidence in cuneiform sources for interest in long cosmic periods based on the movements of the stars. The calculation of the "Great Year" may be a Greek innovation, illustrating the dynamic character of cultural interaction, which seldom consists of a mere unilateral borrowing. Perhaps such an invention was stimulated by interest in other Near Eastern traditions which did feature long cosmic periods: Eudoxus was well aware of the Zoroastrian period of 6 000 years[37]. Yet there was also a Greek tradition of "Great Years" previous to Plato: thus Heraclitus assumed an unexplained "Great Year" of 10 800 (or 18 000) years[38].

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33 See *Epinomis*, 986e – 987c.

34 See L. Tarán, *Academica: Plato, Philip of Opus and the Pseudo-Platonic Epinomis*.

35 See Plato of Athens, *Laws*, 822 a 8 – b 1.

36 See Hipparchus of Bithynia, *Commentary to the Phenomena*, I, 3, 10-11 with my correction from RPh 86, pp. 47 sq.: ἔτι δὲ μᾶλλον θαυμάσειεν ἄν τις, πῶς ποτε οὐκ ἐπέστησε τοῦ Εὐδόξου ἐν τῷ ἑτέρῳ συντάγματι διαφόρως ἐκθεμένου καὶ γράφοντος, ὅτι τὸ ὑπὲρ γῆν τοῦ τροπικοῦ τμῆμα πρὸς τὸ ὑπὸ γῆν λόγον ἔχει, ὃν <ἔχει> τὰ ιβ′ πρὸς τὰ ζ′, ὁμοίως δὲ τούτῳ καὶ τῶν περὶ Φίλιππον ἀναγραφόντων καὶ ἄλλων πλειόνων. πλὴν, ἐπεὶ (*conjeci*: ἐπὶ M ἐπι- *codd.*) συντετάχασι μὲν τὰς συνανατολάς τε καὶ συγκαταδύσεις τῶν ἄστρων ὡς ἐν τοῖς περὶ τὴν Ἑλλάδα τόποις τετηρημένων, κατὰ δὲ τὸ ἔγκλιμα τῶν τόπων τούτων διημαρτήκασι, παραπέμψαντες τοῦτο τὸ ἀγνόημα τὴν ὅλην αὐτῶν σύνταξιν ἐπεσκεψάμεθα πρὸς τὸν ἐν τῇ Ἑλλάδι ὁρίζοντα. "One might wonder even more that he (*sc*. Attalus) was not arrested by the fact that Eudoxos in his other treatise (*sc*. the *Mirror*) sets forth another exposition and writes that the arc of the tropic above earth and the arc below earth have a ratio of 12 to 7, and that the school of Philipp and many others write their lists similarly. Well, since they (*sc*. Eudoxus and Aratus) have put together their simultaneous risings and settings of the constellations as if they had been observed in the vicinity of Greece, but were mistaken regarding the inclination (*sc*. latitude) of these places, we have put aside this mistake and inspected the entirety of their treatises for the latitude of Greece."

37 See C. Plinius Secundus, *Natural History*, XXX, 1, 3 (= Eudoxus of Cnidus, F 342 Lasserre).

38 See Heraclitus of Ephesus, D 38 Mouravieff (= F 3D).

Finally, where did the borrowing take place? It is not possible to provide a definitive answer. Yet evidence from the *Epinomis,* Aristotle, Seneca, Diogenes Laertius (perhaps quoting Sotion of Alexandria) and an anonymous author of Aratean lore points towards Egypt. The *Epinomis* mentions Egypt and Syria together as the places from which age-old astronomical observations have come to Greece[39]. Aristotle also mentions Egyptian and Babylonian astronomical records together[40]. Seneca claims explicitly that Eudoxus "brought back from Egypt to Greece" "the courses of the five planets"[41]. Diogenes Laertius mentions Egypt in connection with Eudoxus' astronomical activity[42]. Finally, an anonymous introduction to Aratos states that Eudoxus introduced into Greece an "Assyrian sphere"[43]. If one understands "Syria" to include Mesopotamia as well[44], then these sources taken all together indicate, albeit tentatively, that it is during his stay in Egypt that Eudoxus borrowed data from Mesopotamian astronomical records.

Addendum

Several scholars, such as A. Diès in his monograph on *Le nombre de Platon* (Paris, 1936), have arrived at the conclusion that the "Geometrical Number" described by Plato in the *Republic* (546 a-d) is 12 960 000. If it was based on this figure for the "Geometrical Number", Aristotle's calculation of the conjunctional "Great Year" as lasting 12 960 years, though erroneous from a strictly astronomical point of view (as explained above in section II), had some degree of philosophical justification as an attempt to determine the "Perfect Number of Time" which is the duration of the "Perfect Year" according to the *Timaeus* (39c-d). Indeed, the "Perfect Number" is said to encompass the period of the "divine begotten" (θειῷ γεννήτῳ), i.e. the stars and planets, whereas the "Geometrical Number" is said to measure both celestial and human cycles (cf. *Republic* 546 ab); and it is stated repeatedly that the period of metempsychosis lasts 1 000 years (cf. *Phaedrus*, 249ab ; *Republic*, 614e-615a ; *ibid.*, 621d). Hence, taking the "Perfect Number" (pertaining to celestial cycles alone) as equal to the "Geometrical Number" (presiding over celestial *and* human cycles) divided by the period of metempsychosis:

$$\frac{12960000\ (Nuptial\ Number)}{1000\ (Cycle\ of\ Metempsychosis)} = 12960\ (Perfect\ Number)$$

Plato, however, seems to suggest in the *Timaeus* that the "Perfect Number" is beyond calculation, as it depends on the "impracticable amount" of each planetary period (cf. 39d1: πλήθει ἀμηχάνῳ, referring perhaps to irrational numbers).

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[39] See *Epinomis*, 986e sq.

[40] See Aristotle of Stagirus, *De caelo* 292b.

[41] See L. Annaeus Seneca, *Naturales Quaestiones*, 7.3.2.

[42] See Diogenes Laertius, *Lives and Opinions of Famous Philosophers*, VIII, 87.

[43] See J. Martin, *Scholia in Aratum vetera*, pp. 318, 23 – 319, 4.

[44] On this frequent use of the term see Th. Nöldeke, "ΑΣΣΥΡΙΟΣ ΣΥΡΙΟΣ ΣΥΡΟΣ", *Hermes* 5, 1871, pp. 443-468 (here: pp. 452-454) and, for subsequent literature, R. Rollinger, "The Terms 'Assyria' and 'Syria' Again", *Journal of Near Eastern Studies* 65, 2006, pp. 283-287.

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