Alexandria in Egypt, the Native Town of the Natural Sciences

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(dedicated to B.L. van der Waerden)

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SUMMARY

Looking at Alexandria as the native town of natural sciences the most interesting question will be: What happened to the heliocentric idea of Aristarchos of Samos? Has the group of the famous Alexandrian scientists, Aristarchos of Samos, Archimedes of Syracuse, Eratosthenes of Kyrene and Apollonius of Perge, be able to develop this idea further to a complete methodology of celestial mechanics? Did they at least have had the mathematical tools at hand? Did some Greeks use the heliocentric concept? The paper will give a possible answer to those questions: It was not only possible for them, it is also likely that they did it and that this methodology was used by all "other astronomers" at the time of Hipparch.

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1. INTRODUCTION

Natural sciences in the modern sense started in Alexandria in the third century b.c. with the foundation of the Museion by king Ptolemy I and probably by the first "experimental physicist" Straton of Lampsakos (330-270/68 b.c.), later elected as third leader (after Aristoteles and Theophrastus) of the Lyceum, the philosophical school founded by Aristoteles. The muse of astronomy Urania was certainly worshipped by the natural scientists of the Museion.

A group of the most famous natural scientists of all times got together during that century in Alexandria:

- Aristarchos of Samos (310-230 b.c.), the scientist who established the heliocentric concept of the world;
- Archimedes of Syracuse (287-212 b.c.), the scientist of whom it is said that he stated: Provide me a place where I can stand and I myself will move the earth;
- Eratosthenes of Kyrene (275-195 b.c.), the scientist who introduced, according to Strabo, the concept of geometry into geography and who estimated already, according to Galenus, an astonishingly precise figure for the distance earth/sun;
- Apollonius of Perge (262-190 b.c.), the ancient scientist nicknamed "Epsilon" because he had known so much about the moon.

The fame of those scientists in ancient times may be grasped from a sentence of the roman architect Vitruvius (1. century b.c.) in his work "de Architectura": "Such men [he talks about "mathematicians"] cannot be found often, as it had been in former times Aristarchos of Samos, Philolaos and Archytas of Tarent, Apollonius of Perge, Eratosthenes of Kyrene as well as Archimedes and Skopinas of Syracuse."

Precise observation data for the planets obtained from the Alexandrian astronomers Timocharis, Aristyllos and other contemporaries of Aristarchos have been handed down by Ptolemy in the Mathematike Syntaxis (Almagest); they show an accuracy, compared with modern information, of about a few arc minutes. The Alexandrian inventor/technician Ctesibios was very famous for the invention of, among other things, a precise water clock, the "Klepsydra", needed for astronomical observations.

In order to make use of those precise observations, however, equivalently precise geometric/cinematic concepts had to be developed too. What did the Alexandrians do in this respect?

The Alexandrians based their developments of the geometric concepts of a requirement which Platon (427-347 b.c.), very famous already under the ancient mathematicians, has laid down in his treatise “Republika VII”. There he had formulated a curriculum for the education of the leaders of a republic state:

- Arithmetic and “Logistike” (numerical computations)
- Geometry (that is pure planimetry in the modern sense)
- Stereometry (space and bodies)
- Astronomy and Cinematics.

Platon’s main argument for such a curriculum was that before astronomical phenomena could be really understood stereometry must be developed much further as a basis for astronomical studies. He complained therefore the deficiencies in the knowledge about stereometry among the Greeks and expressed the hope that one day wise leaders of a state would strongly support research in stereometry.

This was the case certainly in Alexandria during the reign of the first Ptolemy kings in the third century b.c. When Eratosthenes used the title “Platonikos” for his (lost) treatise about geometry the only plausible answer can be: It was a book about stereometry. In his famous scientific letter “Methodos”, dedicated to Eratosthenes, Archimedes mentions indeed, that they both together had compared already before konoides (rotation paraboloids, -ellipsoids and –hyperboloids) and spheres and their segments, regarding their sizes with respect to the figures of cones and cylinders. And it is said by Plutarch that on the tombstone of Archimedes a graph was shown documenting the relation 2 : 3 between the volume of a sphere and the cylinder encircling the sphere.

We certainly may get a plausible understanding of the ancient history of geodesy as well as astronomy only by an investigation of the role of stereometry in the development of both sciences.

At least since Zenon of Elea (490 - 430 b.c.) the Greeks have been aware that “movement” is a notion from the category “relations”; Zenon’s concept of the “always motionless arrow” has again fascinated Bertrand Russel even about 2500 years later. Herakleides of Pontos (< 364-315/10 b.c.), a member of the Akademia, the philosophical school of Platon, had then stated, that the celestial phenomena of the daily movement of a “sphere of fixed stars” could also be explained by a daily rotation of the earth itself. This concept was probably rejected as physical nonsense by Aristoteles (and later on by Hipparch and Ptolemy), certainly not on ground of religious reasons but of theoretical physical considerations. Nevertheless, in the frame of the concept of Herakleides, the fixed stars could then be considered as distributed in depth (and not only on a sphere) as was then believed also e.g. by Geminos (Neugebauer 1975, p.584).

In any case the introduction of stereometric concepts together with the relativity concept for movements into astronomy must have led sooner or later to a heliocentric concept as developed by Aristarchos of Samos.

Certainly, the fundamental question in the history of astronomy is: What happened to the heliocentric concept of Aristarchos? In regarding this question the famous historian Otto Neugebauer says (1975, p.698): “Without the accumulation of a vast store of empirical data and without a serious methodology for their analysis the idea of heliocentricity was only a useless play on words”. Did the Greeks have such a serious methodology? What would be the requirements for such a kind of methodology?

Of course, a vast store of observation data was not necessary; based on a serious methodology only a few, but purposefully chosen precise data would have been sufficient for the confirmation of the concept. Ptolemaios has shown this very skillfully in the Mathematike Syntaxis.

The fundamental, very simple geometric concepts necessary to develop such kind of methodology will be discussed in the next sections. Whether the Alexandrians really had developed it that must be answered by the historians.

2. ARISTARCHOS: THE EPICYCLIC AND THE MOBILE ECCENTRIC MODEL

In one respect the letter “Sand Reckoner” (Arenarius), where Archimedes describes the heliocentric concept of Aristarchus, seems to be unique. Whereas all his other letters are dedicated to scientific colleagues in Alexandria (Eratosthenes, Konon of Samos and after his dead to his pupil Disotheos of Pelusion), the Arenarius was devoted to his king Hieron. Indeed, only at the end of the Arenarius Archimedes mentioned the reason for this letter, namely, to inform his king what the contemporary mathematicians are thinking about the nature of the universe.

In any case the whole concept of heliocentricity would certainly have been remained a “useless play of words” without developing a concept how the situation could be seen from the point of view of the earth, since measurements are always made on the earth. Here we have to distinguish the different cases of the inner and outer planets.

In the case of inner planets (Venus, Mercury) a simple epicyclic model may have been arisen more or less by looking at the sky in the frame of the heliocentric concept (see Fig.1a). In the case of the outer planets (Mars, Jupiter, Saturn) an ingenious “mobile eccentric model” was developed by the Alexandrians (see Fig.1b), where the distance earth/sun was used as a mobile eccentric.

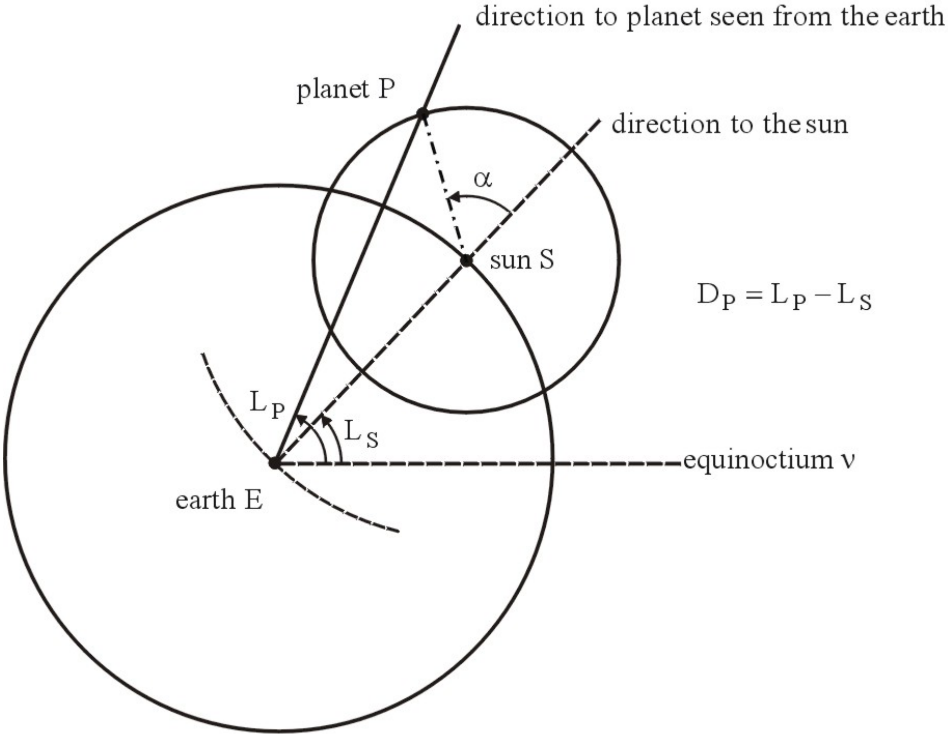


Fig. 1a: Earth, sun and inner planet in the ecliptic plane : epicycle-concept

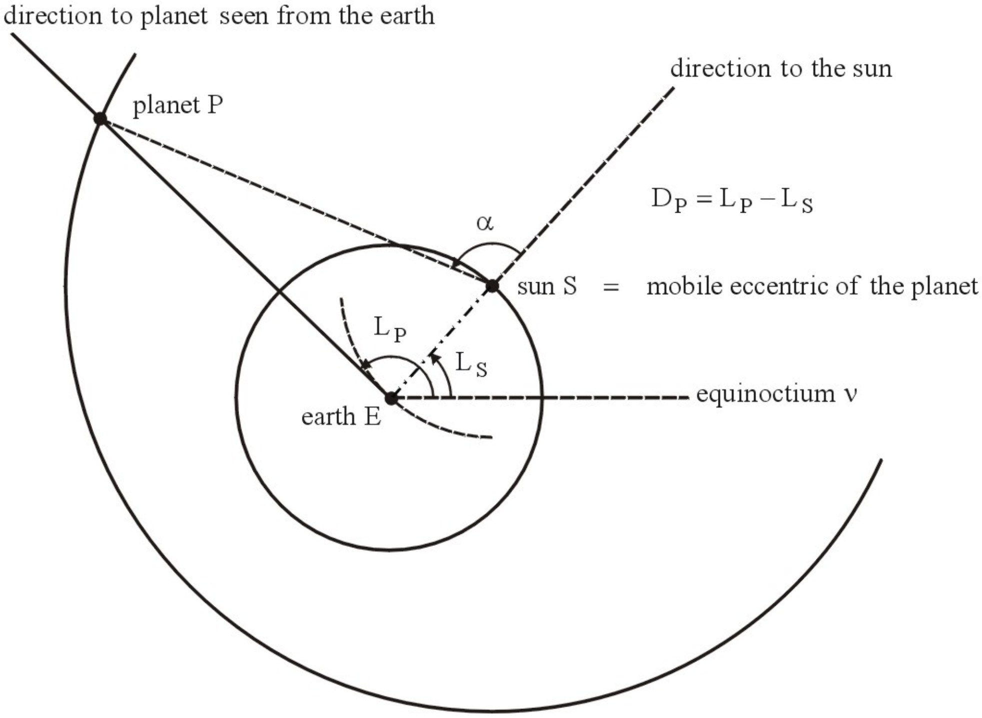


Fig. 1b: Earth, sun and outer planet in the ecliptic plane : mobile eccentric-concept

There can be no doubt that both concepts have been developed (or at least used) by the Alexandrians in the third century b.c. In book XII of the Mathematike Syntaxis, when Ptolemy treated the mathematical description of the retrogression of the outer planets as seen from the earth he based his treatise on two theorems of Apollonius of Perge, one for the epicyclic model and another one for the mobile eccentric model.

Ptolemy demonstrates subsequently that both models will end up with the same result, that is, they can be exchanged. This becomes immediately evident if somebody would be able to look from an outer planet to earth. In this case the movement of the earth becomes an epicycle and the direction planet to earth is of course just opposite to the direction earth to planet.

Taking already into account for a moment the elliptical disturbance of the planetary orbits, such an exchange will be very expedient in case of the outer planets. In this case an “outer” eccentricity e* of the earth orbit, defined by e* = eccentricity of the earth orbit: distance of the outer planet from the sun, becomes negligibly small, that is, the orbit of the earth can be approximated from this point of view just by a circle (see Tab.1b), at least for Jupiter and Saturn.

In the Mathematike Syntaxis Ptolemy has chosen always 60^P for the radius of the outer planet and got therefore for the epicycle radius (that is the radius of the earth orbit) $r = 60^P (1/R)$ where R is the mean distance sun/outer planet in “Astronomical Units” (distance sun/earth). Therefore, from his data one gets immediately the distance R of the outer planets expressed in Astronomical Units by $R = 60^P/r$, of course in sexagesimal digits (see Tab.1.a).

The reader may keep in mind that without the development of the epicyclic and mobile eccentric model even the simplified circular heliocentric concept would be indeed just a “useless play of words”, but together with the development of those models it was a very important step for the development of a serious methodology to analyze precise observations for the purpose of celestial mechanics.

Of course such a simplified model did not explain some phenomena arising from the variable distances of the planets from the sun:
- the different length of the seasons, well-known due to the precise observations made already by Kallippos of Kyzikos (about 334 b.c.);
- the different length of the retrogression of the outer planets depending on their variable distance from the sun;
- the different length of the maximal elongations (angular distances from the sun) of the inner planets Venus and Mercury.

It can hardly be doubt that the Alexandrians did not recognize that the simple circular concept of Aristarchos needed some small modifications to explain all the mysterious phenomena of celestial mechanics.

3. ERATOSTHENES: THE ASTRONOMICAL UNIT AND THE TOPOCENTRIC PARALLAX TO SUN ANDVENUS

It remains somewhat mysterious that modern historians such as Otto Neugebauer did not recognize that Galenus of Pergamon (129-199 A.D.) has reported in one of his many publications that Eratosthenes had provided for the distance sun/earth the value AU = 804 000 000 stadia (~10 000 earth diameter ~ 128 000 000 km), a surprisingly accurate value. According to (Neugebauer 1975, p. 656/657), also Poseidonios estimated the distance to the sun to be fairly large, AE = 10 000 earth radii (~ 400 000 000 stadia); Poseidonios is also mentioned by Pliny as having reckoned 500 000 000 stadia for the distance to the sun.

This numbers are about ten times larger than the figure Aristarchos had given, namely (Neugebauer 1975, p. 637/638) $18 \leq AU \leq 20$ radii of the moons orbit (about 1260 earth radii or 50 000 000 stadia), a value, Claudius Ptolemy most probably has used as a guideline for his estimation in the Mathematike Syntaxis. His result in any case agrees conspicuously well with Aristarchos' figure.

Through observations Archimedes had established, as he tells in the Sand-Reckoner, that the sun appears under an angle δ which lies within the limits (Neugebauer 1975, p.644)

$$27' \sim 90°/200 < \delta < 90°/164 \sim 33' \text{ (in reality } \delta \sim 32'\text{)}.$$

From this estimate of the AU and a value $\delta = 34'$ Eratosthenes could get the

$$\text{sun diameter} = 20\,000 \tan 17' = 99 \text{ earth diameter.}$$

A corresponding statement comes from some (Christian) anonymous (Neugebauer 1975, p.663) who ascribes to Eratosthenes the opinion that the size of the sun was 100 times greater than the size of the earth. The sun was obviously a very huge body compared to the earth; therefore, one important question will immediately arise. Is it true that

- the huge sun moves with an unbelievable velocity once a day around the tiny earth (geocentric concept) or does
- the tiny earth moves with a moderate velocity once a year around the huge sun (heliocentric concept).

There can be no doubt, considering their huge values for the Astronomical Unit neither Eratosthenes nor Poseidonius could believe anymore in a geocentric concept for the world.

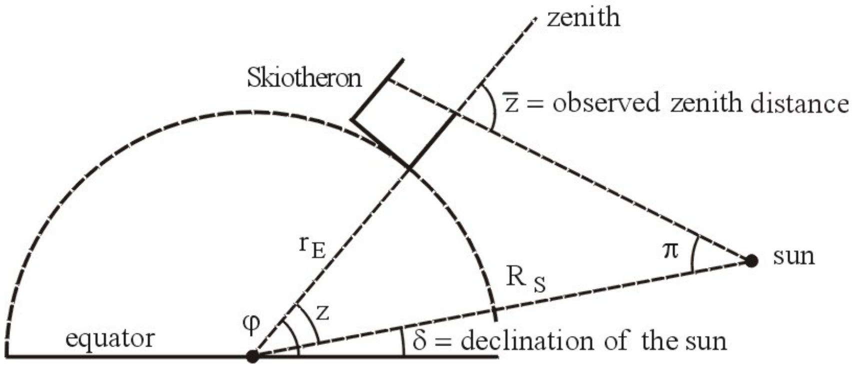
Two other questions will arise:

- What was the motive for Eratosthenes to determine the distance to the sun?
- What could have been a possible method to obtain such a good result?

Looking for a possible motive one have to regard that for correct measurements of geographical latitudes using a "Skiotherikos Gnomon" (see Strabo, II) Eratosthenes had to reduce the observed zenith distances for topocentric parallax (see Fig.2a). And the topocentric parallax for e.g. the moon was fairly large, of about 1°. And in order to compute the topocentric parallax p or π, respectively, using the simple relation

$$\sin \pi = (r_E/R_S) \sin z = p \sin z,$$

he had to know the distance R_S to the sun.



geographical latitude $\varphi = \delta + z$; $\bar{z} = z + \pi$; $\sin\pi = \left(r_E / R_S\right) \sin\bar{z} = p \sin\bar{z}$

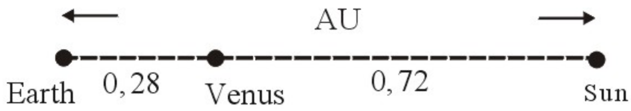


Fig. 2: Geographical latitude φ and topocentric parallax $p = (r_E/R_S)$

Starting with Aristarchos' estimate he would have get the same value as later on Ptolemy got in the Mathematike Syntaxis, namely

$$p = r_E/R_S = (1/1260)(180/\pi) = 0.05° = 3'.$$

In the frame of the heliocentric concept, however, there was obviously a convenient check. The Venus in inferior conjunction (between earth and sun) was also very near to the earth, namely at a distance of about D = 0,28 AU. Therefore, its parallax must be correspondingly larger, about

$$p_V = (1/0.28)p_S = 11'.$$

This could in any case be verified by observations and those observations must fail.

Indeed, Ptolemy points out several times in the Mathematike Syntaxis that no planet should be permitted to show a perceptible topocentric parallax, a fact obviously accepted by all Greek scientists. Therefore we are forced to assume that somebody must have tried very hard to observe topocentric parallax for the planets without any success.

If we assume that the accuracy limit of such observations was estimated by the Greeks to be one minute of arc (the angular diameter of Venus), we would get for the distance earth/Venus

$$D > (180 * 60 / p) \sim 3\,500 \text{ earth radii} \sim 140\,000\,000 \text{ stadia}$$

and for the Astronomical Unit

$$AU = D / 0.28 = 12\,600 \text{ earth radii} = 490\,000\,000 \text{ stadia},$$

just the number Pliny reported about the estimate of Poseidonios.

A similar explanation for the value AE = 800 000 000 stadia (4 000 000 stadia is the radius of the sun!) or D = 225 000 000, respectively, will be obtained when we assume that Eratosthenes used an accuracy limit for the parallax for Venus of $p_V = (6/10)'$.

In any case the already very good specifications of Eratosthenes and Poseidonios for the Astronomical Unit can plausibly be explained by a very careful observation of a possible topocentric parallax for Venus or, as the Romans named it, Luzifer, but only by this.

4. APOLLONIOS: A GEOMETRIC FOUNDATION OF THE EQUANT MODEL?

The most advanced concept of ancient mathematical astronomy is without doubt the brilliant concept of the equant model. (Neugebauer 1975, p.155) mentions: “To philosophical minds it appeared to be the major blemish of the Ptolemaios system. Copernicus tried to achieve the same practical results by means of secondary epicycles; but Kepler not only reintroduced the equant for the planetary motion but applied it also for better representation of the earth’s motion, eventually to become the second focus of the elliptic orbit”.

In the Mathematike Syntaxis Ptolemaios introduced the equant concept within the discussion of the Venus orbit; without any further comment he just used it then also for the outer planets (but not, and that is very interesting, for his disastrous lunar theory where he obviously followed Hipparch and where it would have been of particular need). He only stated: “For the other three planets Mars, Jupiter and Saturn we have found that the same theory of motion fits all three of them, and this is the same theory that we found for Venus”. Ptolemy does not say explicitly, that he has invented the equant concept; this was only inferred in modern times from the text in the Mathematike Syntaxis.

Is it plausible that Ptolemy invented it without any geometric considerations, just from an ingenious analysis of astronomical observations? The kind of errors occurring when Robert Newton tried to reconstruct such an analysis in chapter XI of (Newton 1977) makes it very hard to believe that this can be true. Is it possible then to derive the equant model from some geometric construction?

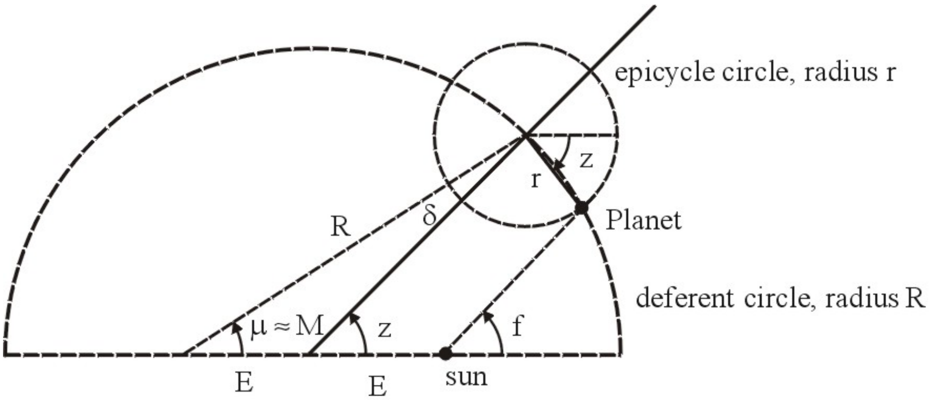
Indeed, this was and is not too complicated for an adherent of the heliocentric concept. As mentioned already at the end of section 2 the first idea of Aristarchos using simply circles for the planetary orbits did not explain some phenomena correctly. Was it then possible to modify in a proper way those circles by an additional epicycle?

Indeed, they can be modified very efficiently by a very small epicycle, the planet moving with exactly the same velocity on the epicycle as the center of the epicycle on the deferent circle but in opposite direction (see Fig.3a). The result will be a perfect ellipse for the motion of the planet; the angle z is exactly the so-called eccentric anomaly of a Keplerian motion. Moreover, the radius r of the epicycle is very small; we just have

$$R = (a + b)/2 \approx a(1-e^2/4) \quad = \text{radius of the deferent circle}$$

$$r = (a - b)/2 \approx ae^2/4 \quad = \text{radius of the epicycle.}$$

For all practical purposes of celestial mechanics we may choose r = 0 and will then end up with the equant model.



$x = (R + r) = \cos\varphi = a \cos\varphi$
$y = (R - r) = \sin\varphi = b \sin\varphi$ orbit of the planet = Keplerian ellipse

$R = (a + b)/2 = a (1 - e^2/4)$, $r = (a - b)/2 = a e^2/4$ = very small
Z = eccentric anomaly , f = true anomaly
$M = z - e \sin z$ = mean anomaly
$\mu = z - \delta$; $\delta \sim \sin\delta = E \sin z / (R + E \cos z) \approx (E/a) \sin z = e \sin z$

Fig. 3a: Epicycle concept of a Keplerian ellipse

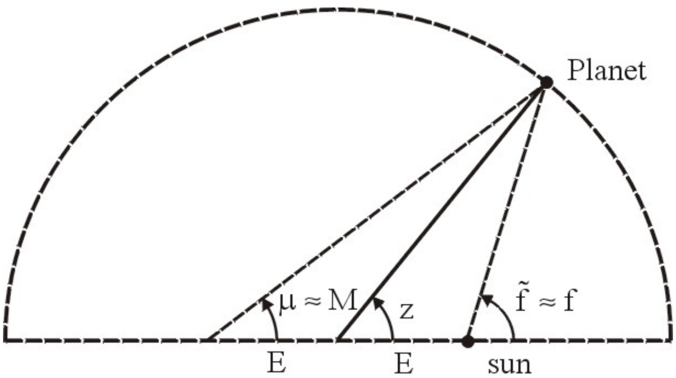


Fig. 3b: The equant model ; r = 0

Apollonios of Perge, the author of the “Conica”, did he know how to draw an ellipse simply with ruler and circle/compass by using an epicycle? We do not know it from the literature, but without a doubt, Apollonios was equally familiar with conics as with epicycles. And such a geometric evolution would be far more plausible than an invention based only on the analysis of complex and wrong astronomical data for the planet Venus.

It may be mentioned that for the anomaly M as defined by Kepler the angle μ is by far the best geometric representation one can find for Kepler's mean anomaly M. The difference $(M - \mu)$ is nearly zero, since

$$M = (z - e \sin z) \quad \text{and} \quad \mu = (z - \delta)$$

$$\text{with } \delta \approx \sin \delta = E \sin z / (R + E \cos z) \approx (E/a) \sin z = e \sin z.$$

From what generating source originated the equant model, from geometry or from observations, this remains one of the key questions for an understanding of the history of ancient astronomy.

5. PTOLEMY: THE HELIOCENTRIC CONCEPT IN THE MATHEMATIKE SYNTAXIS

The Alexandrians, Aristarchos, Eratosthenes and Apollonios would at least have been able to develop a simple but very efficient methodology, based on the heliocentric idea, for the analysis of their observation data. The question is: Did somebody else use it? We can find the answer to this question in the Mathematike Syntaxis: All his contemporary astronomers but Hipparch used it.

A scientific geocentric methodology is without doubt only the work of Ptolemy; he mentions explicitly in the Mathematike Syntaxis Book IX, chapter 2, that Hipparch has not even laid a ground for a theory of the five planets, that he merely arranged observations for a more beneficial employment. Before Ptolemy there was no serious methodology for the geocentric concept.

In book IX, chapter 2 of the Mathematike Syntaxis, when Ptolemy starts to develop his geocentric theory of the planetary motions, he tells us explicitly that **all other astronomers but Hipparch** had based their proofs on geometric constructions. As he pointed out, they did it in two steps.

In the first step they used one and only one anomaly, with respect to the sun, and got always the same length of the retrograde arcs. This is only the case if they used circular orbits for the planets, as already recognized in (Neugebauer 1975, p.191): "So far we have disregarded eccentricities. Obviously this would imply retrograde arcs of constant length, in contradiction to the experience that these arcs differ in different parts of the ecliptic".

In a second step those other astronomers added, as Ptolemy is telling us, a second anomaly with respect to the ecliptic, that is, they have taken the elliptic form of the planetary orbits into account. Unfortunately, Ptolemy did not tell us how they did it; with the equant model?

There is in addition a well-covered hint that Ptolemy itself has based (or at least adjusted) his geocentric model on the work of those other astronomers. In his treatise "The crime of Claudius Ptolemy" Robert Newton from the John Hopkins University has demonstrated by a careful analysis of the numerical values for the observations used in the Mathematike Syntaxis that many of those data must be "simulation data". Of course, all astronomers used and use simulated or predicted data when performing observations. And if Ptolemy considered his work as a compendium just about the mathematical aspects of astronomy the crime will be left to those who interpreted it otherwise.

Nevertheless, when Ptolemy wanted to introduce "simulation data" in this compendium e.g. for the sake of more clearness of the complicated mathematical procedures, then necessarily he had to use

- good or bad models, whatever, and those he describes in fully detail, but also
- **numerical values for the model parameters**, used to compute his simulated "observations".

In return, from the simulated data, he has described very carefully the mathematical methods to get back to the numerical parameters he has used as input. In this way he would have got a very good check for the not uncomplicated computations as published in the Mathematike Syntaxis. We do the same today in developing computer software.

Under such an assumption, nevertheless, one has to compare, of course, the numerical values not of the "observations" but of the model parameters with modern information in order to get an understanding of the quality of ancient astronomy and celestial mechanics. And this may lead to some surprises. For each planet, for Venus, Mars, Jupiter and Saturn, Ptolemy introduced and determined 6 parameters and his numerical values are in excellent agreement with the corresponding modern **heliocentric** values. The interested reader can easily convince himself of this fact by just comparing Ptolemy's data with modern estimates. And this remains true also for the orbit of the moon despite the fact that Ptolemy's model can only be judged as disastrous. As examples for the excellent agreement of Ptolemy's data with modern heliocentric data, a comparison is given for the mean distance R = (a + b)/2 of the planets, for the eccentricities of the planetary orbits and for the synodic periods of the planets in Tab.1.a,b,c.

	Modern data			**Ptolemy**			
planet	**R = (a + b)/2**	**$R \cdot 60^P$**	**$60^P/R$**	**$R \cdot 60^P$**	**diff.**	**$60^P/R$**	**diff.**
Mercury	0.378 856	$22;44^P$	–	$22;30^P$	$+ 0;14^P$	–	–
Venus	0.723 309	$43;24^P$	–	$43;10^P$	$+ 0;14^P$	–	–
Earth	0.999 847	$60;00^P$	–	$60;00^P$	0	–	–
Mars	1.517 271	–	39;33	–	–	39;30	$+ 0;03^P$
Jupiter	5.197 339	–	11;33	–	–	11;30	$+ 0;03^P$
Saturn	9.527 574	–	6;18	–	–	6;30	$- 0;12^P$

The distances are given in Astronomical Units: a (Earth) = 1. The values $R \cdot 60^P$ and $60^P/R$, respectively, are the radii of the epicycles in the terminology of Ptolemy.

Tab. 1a: Ancient/modern mean distances of the planets from the sun

	Modern data			Ptolemy	
planet	**e**	**e · 60^P**	**e***	**e**	**diff.**
Mercury	0.205 255	$12;19^P$	–	3;00	?
Venus	0.007 718	$0;28^P$	–	1;15	Earth
Earth	0.017 506	$1;03^P$	–	1;15	– 0;12
Mars	0.091 618	$5;30^P$	$0;41^P$	6;00	– 0;30
Jupiter	0.045 383	$2,43^P$	$0;00^P$	2;45	– 0;02
Saturn	0.062 102	$3;44^P$	$0;00^P$	3;25	+ 0;19

e* = e (earth) / distance of the planet from the sun (scale factor)

Tab. 1b: Ancient/modern eccentricities of the planetary orbits

	Modern data		Ptolemy	
planet	**sidereal period**	**synodic per.**	**synodic per.**	**diff.**
Mercury	87^d $23;15^h$	115^d $21;07^h$	115^d $21;05^h$	+ 2^m
Venus	224^d $16;49^h$	583^d $22;05^h$	583^d $22;24^h$	– 19^m
Earth	365^d $6;14^h$	–	–	–
Mars	686^d $23;31^h$	779^d $22;34^h$	779^d $22;30^h$	+ 4^m
Jupiter	$4\,332^d$ $14;07^h$	398^d $21;07^h$	398^d $21;16^h$	– 9^m
Saturn	$10\,759^d$ $5;02^h$	378^d $2;10^h$	378^d $2;14^h$	– 4^m

Ptolemy provides the rate of the synodic period in α [degrees/day];
360°/α= synodic period.

Siderial periods for the interior planets (Mercury, Venus):
sideral period = s (1 + s) ; s = synodic period /365,25

Siderial periods for the outer planets (Mars, Jupiter, Saturn)
siderial period = (1 + s) / s ; s = (synodic period – 365,25) / 365,25

Tab. 1c: Ancient/modern synodic periods of the planets

If Robert Newton is right and Ptolemy has founded his mathematical compendium on simulation data, then we cannot do but to assume that he has based his work on the results of the “other” astronomers. And it would then be not astonishing that the methods described in the Mathematike Syntaxis have been in use for about 1500 years; they provided excellent results due to their original sources.

It may also be revealing what Ptolemy says finally in the Mathematike Syntaxis, IX,2 about certain imperfections concerning his own work about his geocentric theory for the planets. He admits

- that he uses sometimes expedient means not in fully accordance with logic,
- that he must presuppose certain axioms which have been established not from an obvious origin but by the way of coherent tests and adoptions and
- that he was forced to assume not for all planets an indiscriminative same form of their movement as well as of the inclinations of their circles.

Was this in contrast to what the “other” astronomers did? Of course, none of those problems could have been occurred in a proper heliocentric theory.

6. FINAL REMARKS

It is simply not true, as pretended by Otto Neugebauer, that the Hellenistic scientists did not have had a serious methodology to make use of the idea of heliocentricity; the epicycle/mobile eccentric concept, applied in an appropriate way, was and is a very ingenious concept of celestial mechanics and was completely sufficient to analyze even very precise data.

It is simply not true what Neugebauer (1975, S.108) says at the end of his discussion about the lunar theory of Claudios Ptolemaios: “It makes no sense to praise or to condemn the ancients for the accuracy or for the errors in their numerical results. What is really admirable in ancient astronomy is its theoretical structure, erected in spite of the enormous difficulties that beset the attempts to obtain reliable empirical data”. Not only do agree the numerical orbital parameters in the Mathematike Syntaxis for Venus, Mars, Jupiter and Saturn very well with the modern heliocentric estimates (the second, ecliptic anomaly of the Venus orbit expresses of course the eccentricity of the earth orbit). But also the orbital parameters for the moon agree very well with modern estimates.

After Eudoxos (400 – 350 b.c.) had introduced the concept of planetary orbital planes, after Platon had required to introduce stereometry into astronomy and after Herakleides of Pontos had developed the idea, that some of the celestial phenomena may be explained also by a rotation of the earth itself, it was only a small but important step further to develop the heliocentric idea. But to proceed from just an idea to a serious methodology for analysing precise astronomical observation data for celestial mechanics that certainly required some very good mathematicians like those Vitruvius mentioned in “de Architectura”. It was in Alexandria in Egypt where the two closely related natural sciences, geodesy and astronomy, have been born.

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