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JOHN GREAVES' *ASTRONOMICA QUAEDAM*: ORIENTALISM AND PTOLEMAIC COSMOGRAPHY IN SEVENTEENTH CENTURY ENGLAND

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An English translation of *Astronomica quaedam*, the brief first chapter to the introductory section in a truncated Persian *Zīj* apparently completed at the court of Maḥmūd Shāh Khilji in the middle of the ninth AH / AD fifteenth century is presented here. Greaves acquired the manuscript in the East and published the Persian text, with facing Latin translation, in London (1650). The chapter begins with geometrical definitions, mainly from Euclid, and proceeds to a simplified description of the Ptolemaic universe, including some basic parameters of the celestial spheres. The treatise ignores sophisticated non-Ptolemaic cosmographical discussions that had already developed in Islamic civilization. The *Astronomica quaedam* marks the high point of a movement in the decades preceding the English Civil War in which Oxford scholars with interests in natural philosophy and aptitudes for oriental languages attempted, unsuccessfully, to re-kindle enthusiasm for the tradition of Ptolemaic cosmography and astronomy.

Key words: Al-Farghānī, Alī Qushjī, *Astronomica quaedam*, John Greaves, Maḥmūd Shāh Cholgi (Khiljī), *Zīj al-Jāmī*

In *Astronomica quaedam*,[1] John Greaves (1602-1652) published the Persian text and Latin translation of a brief introduction to geometry and traditional Islamic *hay'a*.[2] This material constituted the first chapter of an anonymous Persian astronomical text, the *Zīj al-Jāmī*,[3] which is now extant in an incomplete unique manuscript.[4] The manuscript was apparently among those acquired by Greaves during his extended visit to the Eastern Mediterranean (1637-1640) under the patronage of Archbishop William Laud.

Greaves was certainly competent to undertake this publishing venture. Trained in natural philosophy and mathematics, as well as oriental languages,

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during his days at Oxford, he was professor of geometry at Gresham College (1630-1643) until he was named Savilian Professor of Astronomy at Oxford (1643-1648). As a linguist, he had considerable talent in Persian. His grammar of the Persian language dominated the British scene for decades. A royalist sympathizer during the Civil War, he was forcibly removed from his Oxford professorship in 1648. He retired to London, where he died in 1652.[5]

The colophon of the manuscript names Maḥmūd Shāh Khiljī,[6] who has most frequently been identified as the ruler of Malwā between 839 / 1436 and 873 / 1469. Although some have identified him as the actual compiler of this treatise, I am inclined to doubt that claim. A brief autobiographical note preceding this introductory chapter to the treatise notes that the work was begun in Egypt in 852 / 1448 and resumed in 865 / 1460-1461. (The reason for the lengthy interruption is not made clear.) A year later, in the disorder at Badr, the author lost most of his possessions, including approximately the last half of his treatise.[7] I presume that Badr is a variant form of Bīdar, the chief city of the region of the same name in central India.[8] We know that Maḥmūd Shāh Khiljī was attacking the region of Bīdar in 866,[9] which would tend to confirm my interpretation of this introduction. But it is difficult to imagine that the prince and military leader of this expedition would have lost most of his possessions during the attack. Such a fate might have befallen a low-ranking member of his entourage, however. This leads to a possible alternative interpretation of the colophon. Perhaps Maḥmūd Shāh Khiljī was not the actual author, but rather the patron of an anonymous court astrologer who dedicated his work to his benefactor.[10] Whatever the case may be, the *zīj* has become inextricably associated with the Indian ruler.

The *Astronomica quaedam* presents its readers with a introduction to Islamic *hay'a* on its simplest level. Not only it is simple when viewed against the background of the highly sophisticated discussions of the late medieval period in the Islamic world,[11] but it must also have seemed quite primitive to Latin scholars of the mid-seventeenth century.[12] It often seems little more than a vocabulary or glossary of important technical terms in the field. Such glossaries are attested in both Arabic and Latin traditions.[13]

Translation is never an easy process, and Greaves was forced to deal with several problems as he rendered the Persian text into Latin. One of the most difficult occurs when terminology in the source language does not map to an equivalent in the target language. Greaves faced several such problems in his translation of the treatise. For example, he uses the Latin word *sphaera* to translate both the Persian / Arabic terms *kura* and *falak*.[14] In its primary meaning, the term *kura* is applied to the spherical surface that results when we revolve a semi-circle around its stationary diameter. It is used in this *zīj*, by analogy, to describe a region of the sub-lunary world. *Falak*, on the other hand, refers to a three-dimensional physical sphere.[15] In this case, the Latin term blurs a distinction that is present within the Persian text. In a parallel situation, we find that Greaves' Latin expresses a distinction that is not verbally explicit in the Persian. Greaves habitually distinguishes between *sphaera* and *orbis*. The former term refers to the entire mechanism of spherical objects that together produce the observed changes in planetary positions. The term *orbis*, however, indicates each of the individual spherical components of the spherical shells that in their entirety comprise the mechanism that moves the planet.[16] The Persian employs the term *falak* indiscriminately to describe both classes of solid spherical objects.

Similarly, Greaves distinguishes between *stella* and *planeta* when translating the Persian term *kavkab* (and its plural form, *kavākib*). The former term designates the "fixed" or constellation stars. *Planeta*, on the other hand, does not refer to a non-self-luminous body orbiting our Sun. It refers, instead, to the "wandering" stars in the classical Greek sense of the term. We must guard against the tendency to read into the text a meaning that neither the original author nor the translator intended. At the same time, the intention of the author, while absolutely clear (he explains in a marginal note that the term *kavkab* designates any star, whether it is fixed in a constellation or moves about among the constellations), seems more than a little quaint or even reactionary in 1650. We are often so accustomed to thinking of "the Scientific Revolution" of the seventeenth century that we forget that not all scientists were revolutionaries during this century. Greaves, although one of the foremost scientific minds of his day, remained, as noted earlier, an adherent to the Ptolemaic system throughout his life.

Greaves orientation toward traditional Greek, Ptolemaic cosmology is implicit already in his preface to readers of his translation. He explicitly situates this treatise within a tradition that takes its rise from Prolemy's *Almagest* and from the *Planetary Hypotheses*. The figures that he mentions as predecessors are significant: al-Battānī, al-Farghānī, Qusṭā ibn Lūqā, Naṣīr al-Dīn al-Ṭūsī, al-Qūshjī, for example, all played a significant role in elaborating aspects of the Ptolemaic heritage in the Arabic/Islamic world. But important contributions from Ibn al-Haytham and the Marāgha scholars of the thirteenth and fourteenth centuries who developed non-Ptolemaic forms of the *hay'a* are passed over without notice. Similarly, in the Latin West, he mentions Puerbach, Regiomontanus, Erasmus Reinhold, Michael Maestlin and Sir John Bainbridge (his predecessor in the Savilian Chair of Astronomy at Oxford). No mention is made, though, of Copernicus, Tycho, Kepler, Galileo, nor of Digges and Gilbert, the English popularizers of Copernicus, nor even of Henry Savile, who had endowed the chair at Oxford only recently vacated by Greaves. It appears that his exclusion of anyone not completely Ptolemaic in outlook was both consistent and deliberate.[17]

I have used both the Latin and the Persian text to create this translation. I have decided not to retain all the late Renaissance Latin punctuation conventions used by Greaves, but to use only the more standard modern English forms. Similarly, I have not retained the frequent use of italic type, which might be distracting to the modern reader. Like Greaves himself, I have tried to remain close to the intended meaning of the original author, without slavishly imitating word order and/or spelling. Words or phrases appearing between brackets (<. . .>) indicate additions or explanations I have made in the text in order to make the sense clear in English. Words which Greaves introduced into his Latin translation, either for grammatical reasons or as explications of the Persian, are enclosed in square brackets ([. . .]). Persian words which Greaves transliterates into Latin have been indicated with quotation marks. When Greaves uses Arabic or Persian script, I place the word or phrase in italic and enclose it with quotation marks. In transliterating Persian terms, I follow the Library of Congress romanization forms.

Translation

To His Most Noble And Learned Friend, John Marsham[18]

After I was brought into your friendship at Oxford by your renowned comrades, nothing was more desirable for me than that <social> intercourse.

Soon there arose (by perpetual outbreaks of wars of nations) that sad time both sorrowful for the fatherland and calamitous for both of us, by which I was torn resentfully from your side: whose modesty, candor, faith and disciplined judgment in humane letters I will especially <both> revere and love from just causes alone. These at first hastened me uninvited into your love: afterward there were those acts of humanity, the τεκμρια of true friendship, which, added to you in name a short while ago, inflamed me more and more. I will testify openly, repugnant though it be to your modesty, that I know no one among so many educated men whom I cherish and venerate in respect to merit, in whose highest teaching such modesty shines out: indeed, conquering to such an extent that had I not become like a certain machine — even a battering ram – I would never have wrested from your hands the *Diatribam Chronologicam,* a golden pamphlet indeed. Finally, when there occur very many matters, by which you are at present distracted, you may permit the leaving of a memorial to your outstanding genius, impugned by no one that I know, revealed to public light. In as much as you excel, I have sent you this small book, a testimony to my mind's great devotion to you, but also begging a favor: namely it asks you whole heartedly that, although modest, you not refuse my request stubbornly, as you are wont to do.

<Preface> To The Reader

Gerard of Cremona, a man very familiar with the Arabic language but not versed in astronomy at the same level, edited a little less than four hundred years ago a theory of the planets.[19] Its errors, being accepted again and again in schools and being affirmed thoughtlessly by professors to those ignorant of the arts, the most learned Regiomontanus first refuted.[20] A little before Regiomontanus, Georg Peuerbach, eminent and himself an astronomer, as well as the teacher of Regiomontanus, since he saw that this study was neglected and that there was no one who was solid and insightful, translated the first principles of that art, to produce an εισαγογή <or précis> of the subordinate movements; a work of small size but most useful in the matter. For in the splendid opuscule, *de Theorica planetarum*, he explained an easy way for reading Ptolemy and ancient astronomers.[21] Even though now ancient, there was maintained long before by that same Ptolemy, now an old man, (I will omit the intermediaries after Ptolemy, those Arabs and Persians <such as> al-Battānī [commonly Albetegnius], al-Farghānī [i.e., Alfreganus],Qusṭā ibn Lūqā, Naṣīr al-Dīn al-Ṭūsī, Qushjī and others) who, after he felicitously set forth the *Megale Syntaxis*, whether produced for the sake of those whose memory is exalted or of tyros, also conjoined to it the *Hypotheses*, as crowning [effort]. But these <*Hypotheses*>, wrapped in night, were scarcely known to any Greeks, still less to the Latins, until the most outstanding John Bainbridge restored it not long ago from the shadows to its <rightful> place.[22] Wherefore Puerbach is deserving of praise, who first, after literacy reappeared in Europe, carried the torch for our people and presented a brief instruction into the depths of the more secret arts. After this, many followed, who either published elements of astronomy or edited commentaries on them. Among those who easily obtained the palm were Erasmus Reinhold,[23] a most learned mathematician, and Michael Maestlin,[24] not celebrated in a single elegy by Tycho.

But still it must be acknowledged that, although indeed exceptional men, not everything was explicated by them to such a degree of clarity that nothing remains to be desired by the sagacious and attentive reader. For there frequently occur many terms, since I have omitted other things, <which are> irregular and unpleasant to the ears of Latins; indeed, untouched by them yet still received into usage, as though granted citizenship into the state, they are incorporated familiarly into nearly all the writings of the astronomers; whose origin it is the interest of literary <men> to know. For from that time that Alphonso, having summoned at immense expense and by royal decision, Hebrews, Moors and Arabs, constructed those tables which were published under his name;[25] these alien dregs of vocabulary inundated Latin writing for the first time, or certainly not long before then. Indeed, juzahar, zenith, nadir, buth and a hundred other <terms are> either transliterated from the Arabs or constructed in imitation of them. Hence, because the Arabs call the aux or apogee "*al-bu'd al-ab'ad*" and the opposite of the aux "*al-bu'd al-aqra*", the pedants, frequently imitating the worst features, introduce the <terms> more distant longitude and nearer longitude, <each of which is> a completely foreign <expression>.[26] And, because they called the intersection of the orb of the eccentric with the zodiac "*ra's*" and "*dhanab al-tanīn*", these <terms> have replaced head and tail of Draco. Indeed, the Greeks understood <these> much more informatively, the one <as> σύνδεσμον ιναβιβαζοντα, the other <as>καταβιβαζοντα. Similarly, in <the case of> the epilogismos of the planets, <what> is known to modern astronomers as the center is not a certain point but <rather> the arc of the zodiac from the line of apogees ειζταεπόσυα of the signs to the line, reckoned either from the mean or the true motion, <which> is so-called on account of nothing other than the fact that "*al-markaz*" signifies the same thing to the Arabs.

Since, therefore, in earlier ages, after the time of al-Ma'mūn (under whose auspices Greek authors first were translated into Arabic in Babylonia),[27] all <knowledge>, especially mathematics and medicine, was advanced by Arab scholars: it is not to be wondered at if, in that circumstance, some words indicative of their origin should remain. For the same thing <has> occurred in the terminology of science, either in a region or <in multiple> places, so that those <expressions> which once were vulgar <but now> having become accepted are scarcely <able> to be obliterated in an eternity of time. Wherefore, if they are considered deserving of praise who, in writing the annals of a people, record their origins and growth, I <may> hope that I will not receive ingratitude if I uncover the origins and, as it were, the birthplace of these exotic words. By how much greater faith should these be set forth, since I believed that what was done by me would be worth the effort, if I should produce these same <results> from some other genuine and praised author.

Since, however, it does not signify much, whether we should derive these <terms> from a Persian or an Arabic text, for they <both> make use of the same terms in transmitting learning, I have put forward no preference in this brief opuscule, which we have given from the commentary of Maḥmūd Shāh Cholgi.[28] From study of such treatises, <students> may receive a dual benefit. Experienced astronomers may perceive the origins of many words, without which they would understand nothing at all of the tables of secondary motions, either in the writings of the Arabs or of the Persians and Indians. For they should realize that the celestial hypotheses of the Arabs, Persians and Indians now in use are conformed completely to Ptolemy; and these <hypotheses are> expressed here quite succinctly and clearly and, with respect to the mean motions of the planets <are> adapted from the most accurate observations by Naṣīr Eddīn in the city of Marāgha.[29]

Also, it will not be unwelcome to those who cultivate the oriental languages, because now at last there is indeed something in Persian, and in the original idiom, produced in public light, by whose assistance they may undertake instruction with greater utility for their students. For those <Persian texts> which have been published so far, whether the *Pentateuch* of Tawushio Judeao or the *History of Xaviar* by that most outstanding man, Doctor Ludovico de Dieu: have been produced badly, so that <they are> completely devoid of any of the beauty which they ought to have had, <as> anyone may judge from their imitation of solecisms alone.

It remains that I say something about the author. It is established, from the location of the stars <mentioned in> the recension itself and from other evidence that he flourished in the year of the Hijra, the epoch of the Mohammedans, 866, that is, in the Christian year 1461, at which time he composed his most illuminating commentary on the "*Zīj al-Ilkhānī*", that is, the astronomical tables dedicated by Naṣīr al-Dīn to the Tartar Ilkhān. Whether he <our commentator> has written other treatises in addition to this commentary, a part of which we now present, is not known to me. This I boldly assert to be possible, whether on the basis of these things alone, that many things added incorrectly into astronomy have been refuted; <and> many things that were misrepresented in the *Chronologica* by Jos. Scaligero,[30] that otherwise outstanding man, and those things that are believed thoughtlessly on account of authority of men have been refuted. Finally, many things have been adduced with regard to illuminating Arabic writings, especially in mathematics.

Concerning Things which are Necessary to Know for Astronomical Practice

"Zīj",[31] in the Arabic language, is derived from "*zīk*", and that may be translated as the filaments from which embroiderers fashion variegated vestments, and these <filaments> are a canon <or warp thread?> for a weaver when he weaves them with many colors. In the same way, a *zīj* is a canon for an astronomer, for the drawing out of the true positions of the planets and for the working out of nativities. For the lines and tables of a *zīj* are similar to the filaments of "*zīk*" which are produced in regard to both longitude and latitude.

"Raṣad"[32] is contemplation of heavenly bodies using instruments, especially those which have been developed by astronomers for this end, so that they find out therefrom the positions of the stars on the sphere and the amount of <their> motion in longitude and latitude and their distances from one another and from the earth, as well as the magnitude or smallness of their bodies. Wherefore, indeed, they call that book a *zīj* in which the fundamentals of the motions of stars are made known and displayed in tables. And from the zīj [i.e., astronomical tables] they derive the position of the stars in relation to the meridian for each day of the year, and they inscribe in small opusculae, which they call "taqwīm" [i.e., ephemeredes], their mutual contacts, conjunctions, oppositions, occultations, eclipses, ascendant, phases of the new moon and other things like that. Indeed, they chiefly include in ephemeredes the places and appearances of the seven planets in relation to the meridian <and> its opposite for each day.

"Taqvīm", however, according to the usage of those who discuss planetary theory <or "hay'a">, is an arc of the ecliptic <or> zodiac between the first point of Aries, and the extremity of a line extending from the center of the earth which passes through the center of the star and reaches to the eighth sphere. If this line were produced to the ecliptic, there will be no latitude for the star, for if the line should be extended outside the ecliptic, a circle will be described which passes through the extremity of that line and the two poles of the zodiac and <which> cuts the ecliptic at a right angle; this [arc] from the first <point of> Aries to the point of intersection will be the "taqwīm" and that star will have a latitude.

We now say that the intelligible <Persian: ᶜarẓiy> point is the opposite of the sensible <Persian: ḥissiy> <point>, and in each case it is devoid of division.[33]

The line is length divisible at a point, and, if it should be terminated, the place of termination is a point.[34]

The surface is <that> to which length and width are appropriate, and it is terminated at the locale <where> a line <is> placed.

The mathematical body <Persian: jism taᶜlīmiy ᶜarẓiy> has length <Persian: ṭūl>and width <Persian: ᶜarẓ> and depth <Persian: ᶜamq>.

The line is divided into three species: straight <Persian: musṭaqīm> and circular <Persian: mustadīr> and "twisted <Persian: munḥaná>" [or mixed].[35]

The straight line is <that> whose extremity <ṭarf> occults, or lies over, its middle, when a visual ray <Persian: intidād shuᶜāᶜ baṣar> falls on its own extension.

The circular line is <that> within whose interior a point is able to be found from which all straight lines produced to that line[36] are equal.

The remaining lines besides these are called "twisted".

Surfaces are also divided into three parts: into plane, convex,[37] and "twisted" [or mixed].

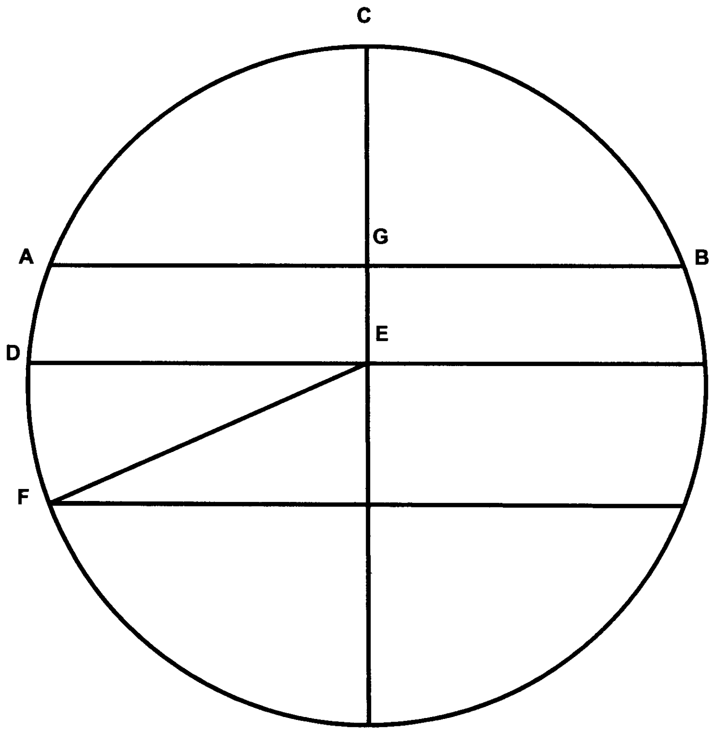
The plane <Persian: mustavá> surface is <that> in which all the lines described are straight.

The convex surface is <that> within which a point is able to be found from which all lines produced to the surface are equal to one another.

The "twisted" surface is that which is different from these two <previously> mentioned surfaces.

A circle is a plane figure comprehended by a circular line. This line is called the periphery <or circumference> <Persian: muḥīṭ> of the circle. There exists a point in the center of the circle such that all lines produced from it to the circumference are equal to one another; that point is called the center of the circle, and these lines <from it> are <called> semi-diameters <Persian: anṣāf aqṭār>. Each straight line which passes through the center and on either side reaches the circumference is called the diameter <Persian: qaṭr>; <it> divides that circle into two equal parts. Any straight line that divides the circle into two unequal parts is called the chord <Persian: vatr> [or subtensa]. Some call the diameter a chord, and it is the greatest <chord> of all.

And the chord [or subtensa] is a straight line whose two extremities are on the arc.An arc is part of the periphery of a circle.A segment of a circle is an area bounded by an arc and a chord. A sector of a circle is a figure bounded by an arc and two semi-diameters.



AB = a chord, ABC = the segment of the circle, DEF = the sector of the circle, BG = sinus rectus of arc CB, CG = sinus versus of arc CB

Fig. 1. Chords and the Circle

The sinus rectus <Persian: jayb mustavá> is half the chord of a double arc. Alternatively, it may be defined as a straight line extended from the extremity of the arc to the perpendicular from a diameter which joins the arc on the other side.

The sagitta [or axis] <Persian: sahm> of this arc is [a part] of the mentioned diameter [extended] from the perpendicular to the extremity of the arc, which is also called the sinus versus <Persian: jayb maᶜkūs>. <Fig.1> is an illustration.

A figure is comprehended either by one boundary <Persian: ḥadd>, as a circle, or by two, as a segment of a circle, or three, as a sector of a circle and a triangle, or four, as a quadrilateral, or more, such as the pentagon, hexagon, etc.

The triangle is bounded by three straight lines and is divided into seven types.

First, the equilateral triangle, whose three sides and also the three angles opposite <them> are equal to one another, and, therefore, all of its angles are acute <Persian: ḥāda>, as in this figure<Fig.2.1>:

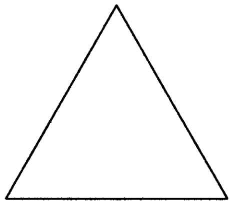


Fig.2.1

Second, the isosceles right <Persian: qā'im al-zāwiya> triangle, two of whose sides <Persian: sāqayn> are equal to one another and the third is somewhat longer<Fig.2.2>. Indeed, the angle which lies at the mutual concurrence of the two equal sides is right.

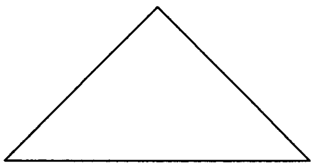


Fig.2.2

Third, the isosceles obtuse <Persian: faraja> triangle is an <isosceles> triangle one angle of which is obtuse<Fig.2.3>:

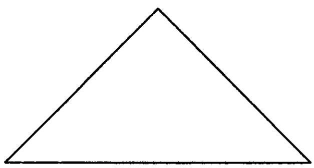


Fig.2.3

Fourth, the isosceles acute <triangle> is a triangle, two sides of which are equal to one another and whose third side may be somewhat greater or less, but whose three angles are acute<Fig.2.4>:

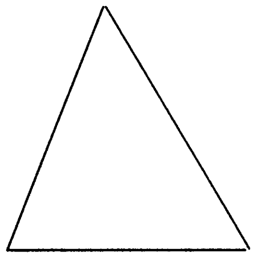


Fig. 2.4

Fifth, the scalene right <triangle> is a triangle, whose sides are unequal <Persian: mukhtalaf> and one angle is right<Fig.2.5>:

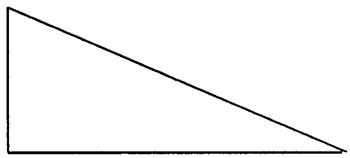


Fig. 2.5

Sixth, the scalene obtuse <triangle> is a triangle, one of whose angles is obtuse and the other two remaining are unequal to one another<Fig.2.6>:

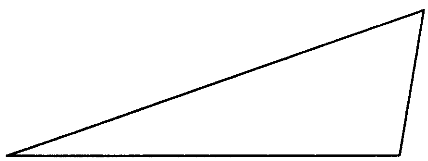


Fig. 2.6

Seventh, the scalene acute <triangle> is a triangle, all of whose angles are acute <and> of different quantity, and whose lines are also of diverse lengths<Fig.2.7>:

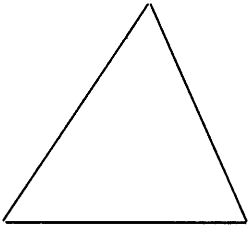


Fig. 2.7

The square <murabba^{c}> is commonly supposed <to be> a figure bounded by four straight lines equal to one another, all of whose angles are right<Fig.3.1>:

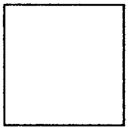


Fig. 3.1

The oblong / rectangle <Persian: mustaṭīl> is <that> whose sides are unequal and <whose> opposite sides are equal to one another alternately<Fig.3.2>.

Fig. 3.2

The rhombus <Persian: mu^{c}ayyan> is <that> whose four sides are equal to one another and whose angles are not right, but of the opposite angles, two <are> acute and two <are> obtuse <Fig.3.3>:

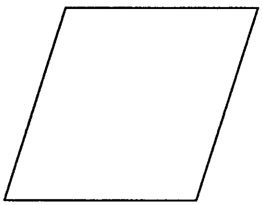


Fig. 3.3

The rhomboid <Persian: shabīḥ bi-mu^{c}ayyan> is <that> whose sides are not equal nor its angles right, but opposite sides and angles are equal to one another<Fig.3.4>:

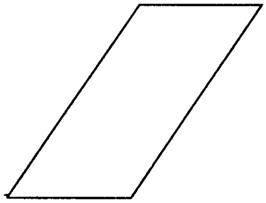


Fig. 3.4

The remaining quadrilaterals other than those mentioned are called "*monharef,*" <Persian: munḥaraf> [or trapezia]<Fig.3.5>:[38]

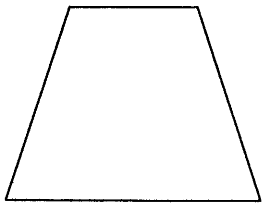


Fig. 3.5

The pentagon is <that> whose five sides are equal to one another in the same periphery<Fig. 4>. The hexagon has six, the heptagon seven, the octagon eight, and so on for the others:

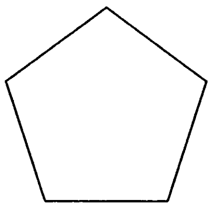


Fig. 4

The lunular shape <Persian: ihlâljiy> is what is comprehended by two arcs, each of which is equal to the other and less than a semicircle<Fig.5>:

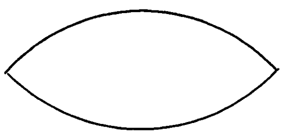


Fig. 5

When, indeed, the two arcs of the two unequal circles on a <single> line are produced from the same point, the space which both of them cut off is called a lunula <hilāliy><Fig.6>.

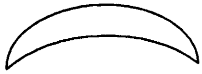


Fig. 6

If two equal and parallel circles should comprehend a figure and between the two circles there is a certain space, and <if> a straight line be described between both circles and rotated through the periphery and touch the surface through an entire revolution, that body is called a circular cylinder <Persian: usṭavāna> and each circle <is> a base of the cylinder. The line which connects the centers of both circles is named sagitta <sahm> [or axis]. If this axis be perpendicular to each center, it is called a right cylinder; if less, a scalene <cylinder>.

If a surface in the shape of a pine nut <Persian: ṣanaubariy> be erected from the periphery of a circle, continually decreasing in part in which it is raised, until at the end of the elevation it end in a point, (its surface, however, may be extended at will) and a straight line be extended between that point and the periphery of the circle, and that <line> be conducted in an entire revolution touching the surface of the circle, that body is named a circular cone <Persian: makhrūṭ>, and the circle <is> the base of the cone, and the line running from the point to the center of the base <is> the sagitta <Persian: sahm> [or axis] of the cone. And if the axis be perpendicular, it is named a right cone; if less, a scalene <cone>. If a cone be cut by a plane parallel to its base, that part which is opposite the base is called a truncated cone <Persian: makhrūṭ nāqis>.

If the two bases of the cylinder or the base of the cone be rectilinear – triangular or square, or another <shape>, they call that cylinder a multilateral cylinder <Persian: usmṭavāna muḍalla^{c}> and that cone a multilateral cone <Persian: makhrūṭ muḍalla^{c}>.

Whenever two segments of a sphere, less than a hemisphere, be equal to one another, if one base be applied to the other base, the new figure which is thus produced is called a lenticular body <Persian: mujism ^{c}adsiy>.

Every body comprehended by two triangles whose sides are equal and parallel to one another and by three parallelograms is designated a prism <Persian: manshūr>.[39]

Every body containing six squares coming together at right angles is called a cube <Persian: Muka^{cc}ab>.

In any figure, which may be erected and in any plane, the line produced perpendicularly from its highest point to its base is the altitude <Persian: irtifâ^{c}> of that body.

If, on a plane surface two lines be inclined to one another, so that they constitute an angle, it is called a plane angle <Persian: zāwiya musaṭḥa>. And if one of the two lines be produced or extended, another angle is formed by its side. If the angles be equal, each is called a right angle, and then the line which comes together with the other is perpendicular.

If two angles be not equal, that angle which is greater than a right <angle> is obtuse, that which is smaller <is> acute.

If in a body two planes / surfaces come together, that concurrence is called a solid angle <Persian: zâwiya mujisma>.

Then, if one of these should be perpendicular to the other, it will be a solid right angle; if less, either obtuse or acute.

A sphere <Persian: kura> is a body comprehended within one circular surface. Whenever a sphere revolves in local motion, and completes a full circuit, any point will describe a circle except two, which are completely quiescent. These two points are called the poles <Persian: quṭb> of the sphere. And the straight line which passes through the center of the sphere and each of the poles is named the axis <Persian: miḥvar>.[40]

The greatest of these circles which are described in the sphere is the "mantaka,"[41] [or circle intermediate between the poles], the distance from whose circumference to either pole is equal.

If two spherical surfaces be made parallel, the segment between the two surfaces they call the "dofiyah".[42]

The sphere <Persian: falak> is an orbicular volume <Persian: jismiy kuriy> perpetually moving in local motion, and it is <classifiable into> two kinds: either comprehending the earth <Persian: shāmil al-^{c}arẓ> or not comprehending the earth <Persian: ghayr shâmil al-^{c}arz >. <That which is> not comprehending the earth is contained by one spherical surface and is a solid orb <Persian: muṣmat>, that is, <it is> without cavity, such as the five epicycles of the five planets[43] and the moon. On the other hand, <that> comprehending the earth is contained by two parallel spherical surfaces. They call the exterior convex <Persian: muḥaddab>, the interior concave <Persian: muqa^{cc}ar>.

Parallelism <Persian: tavāziy> in surfaces is when the distances between them in any direction are equal, that is, uniform in thickness, not having one part thinner or thicker than another.

Among circular lines there exists a similar situation. Parallelism of straight lines, however, is that, in the same plane, if extended indefinitely in either direction, they do not meet. And on a plane surface, if each be produced indefinitely, they never approach one another.

There are nine spheres <Persian: aflāk>. First, the sphere of the moon; second, the sphere of Mercury; third, the sphere of Venus; fourth, the sphere of the Sun; fifth, the sphere of Mars; sixth, the sphere of Jupiter; seventh, the sphere of Saturn; eighth, the sphere of the fixed stars; ninth, the crystalline sphere, which is also called the sphere of spheres. This comprehends the eighth sphere, the eighth <comprehends> the seventh, and so on until the first sphere. The sphere of the Moon comprehends the sphere <Persian: kura> of fire, the sphere of fire <comprehends> the sphere of air, the sphere of air <comprehends> the sphere of water <Persian: māk'>. <In the case of> the earthy <globe>, water <Persian: āb> does not surround earth <Persian: zamīn> completely. The Earth is in the middle of the universe like a center.[44] The name of these, taken together, is commonly given as the corporeal world.

The greatest of the spheres is a simple orb <Persian: falak>, whose motion is from east to west, <and> completes a complete circuit, which is a civil day, and all the spheres <Persian: aflāk> within its concavity are carried around in a similar motion. On this motion depend the civil day, the rising and settings of stars, as well as the motion of all the parts interlinked to the sphere of the universe.

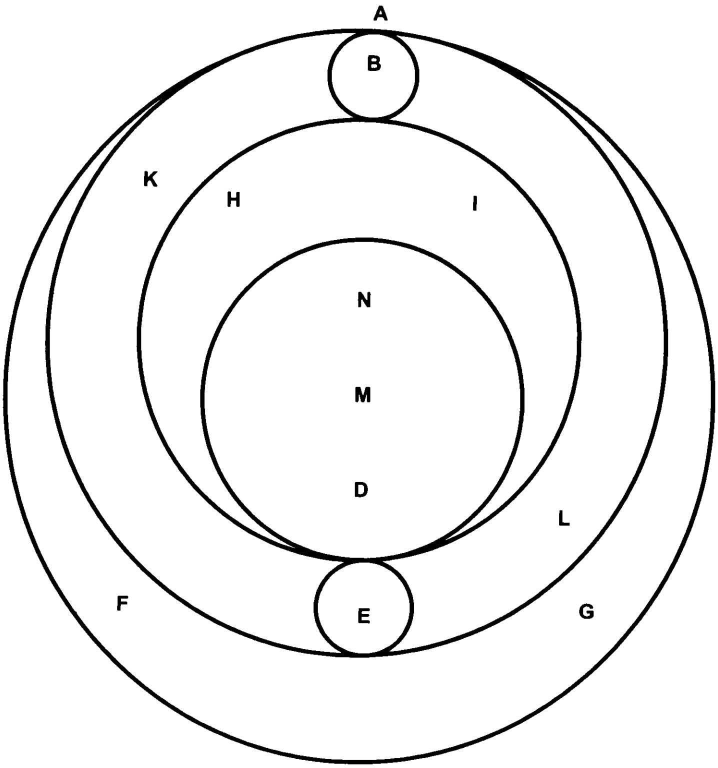
The sphere of the fixed stars is a simple orb according to more informed opinion. Its motion is from west to east, and it is scarcely slowed. The ancients, indeed, were ignorant <of this motion> but later on, others, with diligent practice, observed its sensible motion; yet, they did not determine <its> quantity. Then, in the time of Ptolemy it was ascertained to be one degree in a century. Whence, according to them, the period <of revolution> is completed in 36,000 years. Afterward, astronomers in the time of al-Ma'mūn, comparing their observations with <those of> Ptolemy, established that it is advanced one degree in 66 years and 8 months. Based on this measure, it passes through a complete revolution in 24,000 years and passes through one zodiacal sign in two thousand years. Then, from new observations made in Marāgha, it became well known that it passes through a single degree in 70 years, a zodiacal sign in 2100 years and a complete circle in 25,200 years. And on the basis of this observation <astronomers> now carry out their calculations. In one year it is moved 51″ and 26‴ and in one month 4″ and 17‴ and in one day 8‴ and a half.

The sphere of Saturn consists of three orbs. The first is the deferent of the apogee and perigee <Persian: mumaṣṣal>, which encloses the other orbs. Its convex surface touches the concave surface of the sphere of the fixed stars and its concave <surface touches> the convex surface of <the sphere of> Jupiter. Its motion is similar to the motion of the sphere of the fixed stars, both in quantity and quality. The center of each one of <its spherical> surfaces is the center of the world, as is also the case for the eighth and ninth spheres. Within the thickness of this orb another is inserted such that its two <spherical> surfaces are parallel, whose center is outside the center of the world.[45] This they call the deferent orb <Persian: ḥāmil > [or simply eccentric], because it carries the center of the epicycle.[46] The epicycle <Persian: tadvīr> is a solid orb, that is, without concavity, fixed within the thickness of the deferent and thus immersed within it so that its diameter is equal to the thickness of the deferent.[47] Saturn, then, is attached to the epicycle and immersed <in it> so that one of its points touches the surface of the epicycle. One point, then, of the epicycle touches the convex surface of the eccentric. This <point> they call "dervah"[48] [or point of superior contact]. The other point touches the concave surface of the deferent. This they call the "Hadhid"[49] [or point of inferior contact of the epicycle]. The convex surface of the eccentric touches the convex surface of the deferent at apogee in one common point which they call the "aux"[50] of the eccentric.[51] And the concave surface of the eccentric touches the concave surface of the deferent in a common point. This they denominate "Hadhid" [or opposite of the aux].[52] Now, motion of the eccentric is from west to east and completes one complete period in approximately thirty solar years. In one year it passes through

12° 12′ 48″ , in one month 1° 0′ 13″ and a half, and in one day 2′ 0″ 27‴ . The motion of the epicycle they call "chassah" <Persian: khāṣṣah> [or proper] <motion of the planet>. The planet <Persian: kavkab> within one epicycle is moved from east to west in half its cycle and in the other <half> from west to east. The epicycle of Saturn competes a revolution in one year and thirty days. In one month it is moved 28°33′32″ and in one day 57′7″44‴ . The deferens apogee of the eccentric orb is compounded of two complementary <parts>, of which one comprehends [the eccentric] and the other is comprehended [by the eccentric]. Neither of the comprehending surfaces is parallel <to the other>. The thinner part of the orb comprehending the eccentric is opposite the "aux" <or apogee> and the thicker part is opposite the perigee. And the thinner part of the orb comprehended by the eccentric is at the perigee and its thicker part is at the "*aux*". The "*aux*" is called the larger distance, that is, a point on the orb <that is> most remote from the earth. The "Hadhid" is called the shorter distance,[53] that is, the point closest to the Earth. The shape of Saturn's orbs on a plane surface is like that in Fig. 7.

The sphere of Jupiter, like the sphere of Saturn, is composed of three orbs, a deferens apogee, an eccentric, and an epicycle situated as was described in the case of Saturn. The deferens apogee of Jupiter is in the concavity of the deferens apogee of Saturn and its concave surface touches the convex surface of the sphere of Mars. The eccentric is <embedded> within the thickness of the deferens apogee and the epicycle within the thickness of the eccentric and Jupiter within the epicycle in the same way as has been described. The motion of the deferens apogee is similar to the motion of the eighth sphere both in respect to quantity and in respect to the place toward which it turns. The eccentric of Jupiter, just like the remaining eccentrics, moves westerly: in one civil day 4′ 59″ 8‴ ; in one month 2° 29′ 33″58‴ ; in a complete year 1 <zodiacal> sign 6° 19′43″14‴ ; and in nearly twelve years it completes a full revolution. The epicycle of Jupiter completes a full circuit in 1 year, 1 month and 4 days. In one civil day it moves 54′0″3‴ ; in one month 27° 4′31″30‴ ; in one year 10 <zodiacal> signs 29° 25′5″24‴. The drawing of Jupiter's sphere is similar to the drawing of the sphere of Saturn.

The sphere of Mars is similar to the two above it in number of orbs and in arrangement; that is, its deferens apogee is in the concavity of the deferens



A = Apogee, D = Perigee, B = Epicycle at Apogee, E = Epicycle at Perigee, FG = Complement enclosing the Deferent, HI = Enclosed complement of Deferent , FKH = Deferent orb, KL = Eccentric orb, M = Center of the world, N = Center of the eccentric.

Fig. 7. The spheres of Saturn (after J. Graves, *Astronomica Quaedam*, London, 1652, p.36)

apogee of Jupiter and its eccentric <is embedded> within the thickness of the deferens apogee and its epicycle within the thickness of the eccentric and Mars within the <thickness of the> epicycle in the same way as has been described. The [motion] of the deferent is similar to the motion of the remaining deferent <orbs>. The eccentric of Mars makes a complete circuit in one year, ten months, twenty two days. And in one year it is moved six <zodiacal> signs 11°16′19″ 25‴; in one month 15° 43′15″34‴; and in one civil day 31′26″31‴ . Its epicycle completes a full circuit in two years and fifty days. In one year it is moved five <zodiacal> signs 18°28′29″13‴; in one month 13°50′50″4‴; in a civil day 27′ 41″40‴. The epicycle of Mars is very large, so that it is much larger than the deferens apogee of the sun. The figure of the sphere of Mars is similar to the figure of the spheres above it.

The sphere of the Sun is composed of two orbs. One is the deferens apogee, beneath the concavity of Mars. Its motion is similar to the motion of the other deferent <orbs>, both in respect to the direction of its motion and with respect to its quantity. The other is an eccentric orb <which is> inserted within the thickness of the deferens apogee, just like the other eccentrics.[54] The Sun is a planet whose diurnal motion is fixed within the eccentric in the same way as the epicycle <is> within the eccentric. The period of the eccentric of the Sun is completed in 365 days and six hours very nearly. In one month it is moved 29° 34′5″38‴ ; in one civil day 59′8″1‴ . The drawing of the sphere of the Sun is similar to that of the superior planets except that it lacks an epicycle.

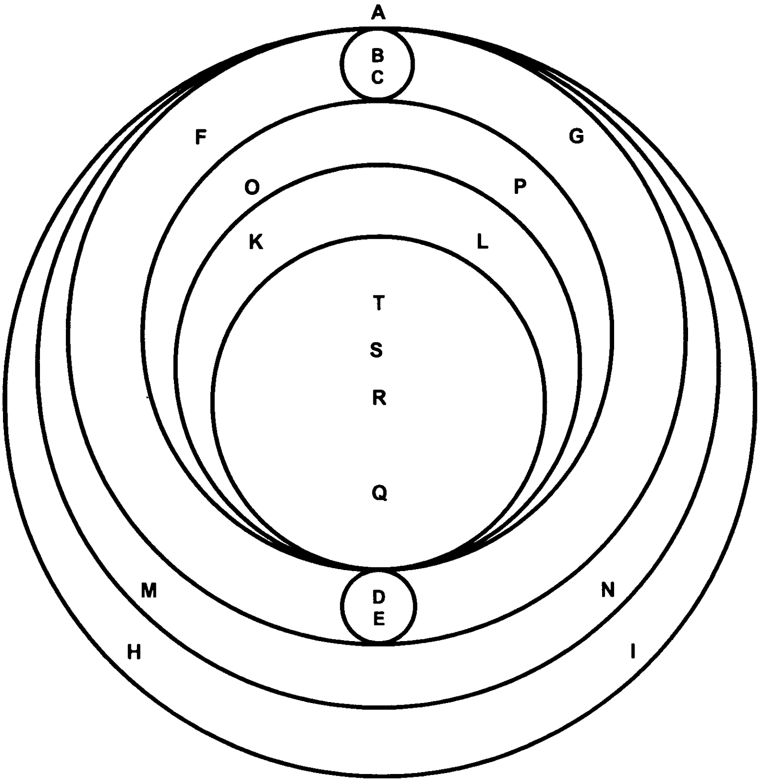
The sphere of Venus is composed of three orbs <which are> similar to the orbs of the superior planets.[55] The deferens apogee is beneath the concave sphere of the Sun and the eccentric is immersed in the thickness of the deferent, just as for the rest of the eccentrics. The epicycle is embedded within the eccentric and Venus <is embedded> within the epicycle. The motion of the deferens apogee is similar to the [motion] of the other deferent <orbs> and the motion of the eccentric of Venus is similar to the motion of the eccentric of the Sun in respect to quantity and place toward which it tends. Its epicycle completes a full period in one year, seven months and ten days nearly. In one civil day it is moved 36′59″28‴ ; in one month 18° 29′44″6‴ ; in one year 7 <zodiacal> signs 15°1′46″38‴ .

The sphere of Mercury is composed of four orbs.[56] The first is the deferent of the apogee of the equant <Persian: awj mumassal> located under the concavity of the sphere of Venus. The second, "modair" <Persian: mudayr> [i.e., the deferens apogee of the eccentric], is within the thickness of the deferens apogee of the equant just as the eccentric is within the deferent. The third, the eccentric <Persian: ḥāmil> <is> within the thickness of the deferens apogee of the eccentric. The fourth, the epicycle, <is> within the thickness of the eccentric, in the same way as the rest of the epicycles.

Thus, there are two apogees for Mercury; one is the apogee of the equant, the other, the "modair", [or the apogee of the eccentric]. There are, likewise, two perigees. The motion of the deferent of the apogee of the equant tends toward the east and is similar to the [motion] of the other deferent <orbs> in respect to quantity. The motion of the deferent of the apogee of the eccentric is toward the west, contrary to the order of the zodiacal signs, in the same quantity as the eccentric of the sun is moved in the sequence of the signs. The motion of the eccentric is from the west, according to the succession of the zodiacal signs and is twice the quantity of the motion of the deferens apogee of the eccentric. In one civil day it is moved 1°58′16″22‴ ; in one month 1 <zodiacal> sign 29° 8′11″16‴ . A complete period requires six months, two days and fifteen hours. The epicycle completes its entire period in 3 months and twenty six days. In one month it is moved 3 <zodiacal> signs 3° 12′ 11″ 4‴ ; in one civil day 3° 6′ 24″ 22‴ . The figure of the sphere of Mercury is shown in Fig. 8.

The sphere of the Moon <also> comprises four orbs.[57] The first is the deferent of the caput draconis [or equant] <Persian: mumassal>, which they also call "juzahar". The center of each of its surfaces is the center of the world, and its place is under the concavity of the sphere of Mercury. Its motion is from east to west, and one period is completed in eighteen years seven months and eighteen days. In one year it is moved 19° 19′ 43″ 23‴ ; in one month 1° 35′ 21″. The second, the "mail" [that is, declination orb or deferens apogee of the eccentric], is in the concavity of the "juzahar". The center of each of its surfaces is the center of the earth and its motion is contrary to the order of the <zodiacal> signs, that is, from east to west. In one civil day it is moved 11° 9′ 7″ 54‴; in one month 11 <zodiacal> signs 4° 33′ 57″ . And a complete period requires 32 days, 6 hours, 45 minutes. The third orb is the eccentric <Persian: ḥāmil> inserted within the thickness of the deferens apogee, just like the remaining eccentric <orbs are> within the deferent <orbs>.[58] Its motion is from the west, following the order of the <zodiacal> signs. In one civil day it is moved 24° 22′ 53″ 23‴ ; a complete period requires 14 days, 18 hours, and 24 minutes. The fourth orb is the epicycle, and it is within the thickness of the eccentric in the same way as has been described above.[59] The epicycle of the Moon is moved 13° 3′ 53″ 56‴ in one civil day and completes a full period in 27 days, 14 hours nearly. The figure of the sphere of the Moon is given in Fig. 9.

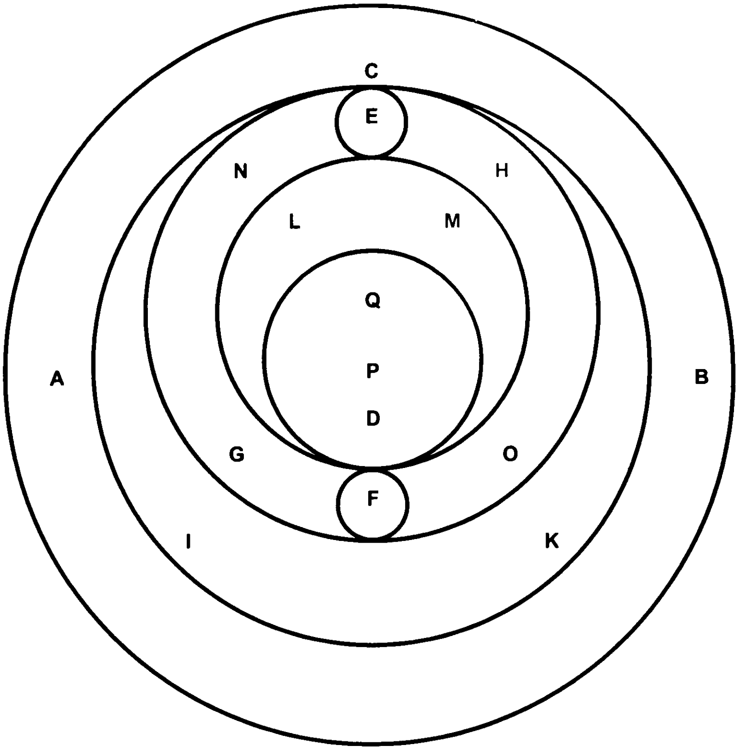
The circle[60] through the middle of the highest [or ninth] sphere they call the equinoctial <Persian: muᶜaddal al-nahār>; the circle through the middle of the eighth sphere <they call> the zodiac <Persian: Manmaqat al-burūj> and the orb of the signs <Persian: falak al-burūj>.[61] Since the circle of the zodiac



A = Superior contact of the Epicycle, B = Superior contact of the Eccentric Sphere, C = Epicycle Sphere Apogee, D = Inferior contact of the Eccentric Sphere, E = Epicycle Sphere Perigee, FG = Eccentric Sphere, HIKL = Two complementary parts of the Equant Sphere, HI = surrounding complement of the Equant Sphere, KL = surrounded complement of the Equant Sphere, MNOP = Two complementary parts of Eccentric Sphere, MN = Surrounding complement surrounded of Eccentric Sphere, OP = Surrounded Complement of the Eccentric Sphere, Q = Inferior contact of the Epicycle, R = Center of the World (or the Earth), S = Center of Equant Sphere, T = Center of Eccentric Sphere.

Fig. 8. The Sphere of Mercury (after J. Graves, *Astronomica Quaedam*, London, 1652, p.48)

divides the world into two parts, in the ninth sphere there will be a new circle which intersects the equinoctial at two opposite points. These they call the two equinoctial points <Persian: i^ctidālayn> because, the Sun being present in either one of them, the day and night of people everywhere become equal <in length>. The ecliptic of the Sun is always in the plane of the zodiac. And that point from which the Sun moves away when passing toward the north, that is, <when it> approaches more closely toward the north pole, they name the vernal equinox



AB = Juzahar Sphere, C = Superior Contact of the Eccentric, D = Inferior Contact of the Eccentric, E = Epicycle at Apogee, F = Epicycle at Perigee, GNHO =Eccentric Sphere, IKLM = Deferent Sphere, IK = Surrounding Complement of the Deferent, P = Center of the World, Q = Center of the Eccentric Sphere

Fig. 9. Spheres of the Moon (after J. Graves, *Astronomica Quaedam*, London, 1652, p.52)

<Persian: i^{c}tidāl rabī^{c}iy>. And the other point <they name> the autumnal equinox <Persian: i^{c}tidāl kharīfiy>. Similarly, new circles are formed on the surfaces of the deferens apogee orbs; these they also call "momaththal"[62] [that is, analogous circles] since they are analogous to the zodiac in respect to motion and directions <of motion>.[63] All analogous circles are in the plane of the zodiac and their poles correspond to its poles. Indeed, the greatest distance between the equinoctial <circle> and the zodiac is the same as the distance between their poles. This, according to the observations of the Khwaja [Nasir Eddin], is 23 degrees 30′ of circles passing through the four poles [i.e., solstitial colure] and this circle is the third of the great circles.

You must know that the circumference of any circle described in a sphere is divided into 360 parts, each part being called a degree, and each degree <is divided> into 60 minutes, each minute into 60 seconds and each second into 60 tertia, progressing thus to the decima.

The zodiac is divided into twelve parts, each of which is called a sign. Each sign [is divided] into 30 parts, which they call a degree, and each degree <is divided> into sixty [prima], and so on, progressing to the decima.

Each circle passing through the poles of the equinoctial is called a circle of declination <Persian: mayl>: <it is> on this <circle that> the distance of a star from the equator is denominated. This is the fourth of the great circles.

Each circle passing through the two poles of the eighth sphere is called a circle of latitude. Latitude <Persian: ᶜarẓ> is the distance of a star from the zodiac. This is the fifth of the great circles.

The sixth great circle is the meridian <Persian: niṣf al-nahār>, which passes through the two poles of the ninth sphere, as well as through the overhead point <Persian: semit> of the head and feet [or through the vertical point and its opposite].[64] This circle designates the relation <Persian: nesbet>, or longitude of places, that is, of each city, on Earth. Indeed, in whatever part of the orb of the Earth someone and another person may be, that by which they differ <in location> is predicated with reference to <this> fifth circle. When the Sun reaches this circle, it is midday in that city, and the sun reaches <its> maximum altitude.

The seventh of the great circles is the circle of the altitude, passing through the overhead and underfoot <points> as well as the center of the Sun or star. In this circle one may know the altitude of a star from the plane of the horizon, which is the surface of the Earth.[65]

The eighth great circle is the horizon <Persian: ufuq>, which passes though the plane of the Earth and divides <the celestial> sphere into two parts, the visible and the hidden. This circle is at right angles to the two preceding <circles>. The two points in common between this circle and the meridian are called the northern and southern <limits>.

The point at which the horizon and the altitude circles intersect is the "semit" point. From the "semit" point (from either side) to the eastern edge of the equator to the western edge is the arc of "semit". Its greatest arc is ninety [degrees]. If it be less than ninety, its complement from the ninety is the complement of the "semit". The eastern limit of the equator is the point of intersection of the equator and the eastern horizon. The western limit of the equator is the western point of the intersection of these two circles.

The ninth of the great circles is the prime vertical <Persian: avval sumūt>. It is the circle passing through the "semit" of the head and feet and through the eastern and western equatorial points. This circle and the meridian intersect one another at the "semit" of the head and the feet, which [intersection points] are the poles of the horizon <circle>. The eastern and western points <of the horizon> are the poles of the meridian <circle>. The northern and southern points <of the horizon> are the poles of the prime vertical <circle>. The two poles of the altitude circle lie on the horizon, and change perpetually as we travel from one region to another, according to the different values of the altitude <of the places>. The poles of the circles passing through the four poles [i.e., the solstitial colure] are the two equinoctial points. The poles of the circles of declination lie on the equator. The poles of the latitude circles are on the ecliptic.

The diurnal parallels are small circles equidistant from each part of the equator. Their poles are the poles of the equator. Indeed, circles parallel to the zodiac and described by the motion of the eighth sphere are called the circles of latitude. Their poles are the two poles of the zodiac.

The motion of the center is an expression for the motion of the eccentric of the Sun, as well as for the motion of the deferent <or carrier> of the center of the epicycle in the remaining planets.

The "chassah" motion[66], or <motion> proper to the planet [that is, thz anvmaliaz] is applied to the motion of the epicycle which carried around the center of the planet.

The motion of the apogees is the motion of the deferent <orbs>. All apogees and equator circles[67] of the deferent <orbs> are equally in the plane of the ecliptic. The equator circles of the eccentric <orbs> (because that they are supposed to divide the world into two parts) intersect the ecliptic of the zodiac and the ecliptics of the deferent <orbs> of the apogees in two opposite points. One of them is called the caput <or head> and the other the cauda <or tail>.[68]

The caput is when the center of the epicycle, moving from its intersection <with the ecliptic>, is deflected toward the north.[69]

The cauda is when the center of the epicycle, moving from its intersection <with the ecliptic>, declines toward the south.[70]

The caput and cauda of the three superior planets and of the two inferior are carried along with the motion of the eighth sphere. But the caput and cauda of the Moon are moved by the "juzahar" orb [or the deferent of the nodes].

"Juzahar", in the Arabic tongue, is derived from "kuzahar" and signifies "place of poison" <Persian: zahr>.[71] They form that which resembles the intersection of two circles, that is, two snakes, which they call "azhdha" <Draco>, according to which the caput and cauda are of Draco.

Moreover, they call the caput, as well as the cauda <by the name> "juzahar", and <they call> both of them "juzaharayn" and the two <are> nodes. We shall indicate the locations of the caput and cauda of the planets in proper tables, god willing.

Saturn, Jupiter and Mars are called superior planets because they are above the Sun. Venus and Mercury are inferior <planets> because their spheres are below the sphere of the Sun. The Sun and Moon are called lumenaria. The Sun is the greater light and the Moon is the lesser light.

Now, however, we shall explain the arc.

The center of the Sun is the arc of the eccentric of the ecliptic between the apogee of the Sun and a line going out from the center of the eccentric and produced through the solar body to the zodiac.[72]

The equation of the Sun is the arc of the ecliptic of the deferens apogee between two lines from the centers (one from the center of the deferent, which is also the center of the world, the other from the center of the eccentric) each one to the center of the solar body, intersecting one another at the center of the body and terminating at the zodiac.[73]

The apogee of the Sun, or its greatest longitude, is an arc of the orb of the deferens apogee between the first point of Aries and the point of apogee.[74]

The mean motion of the Sun is the arc of the ecliptic of the deferens apogee between the point of the vernal equinox and the extremity of a line from the center of the eccentric which passes through the center of the solar body and reaches to the ecliptic.[75]

The true position of the Sun is the arc of the ecliptic of the deferens apogee between the first point of Aries and the extremity of a line from the center of the world, which passes through the center of the Sun and extends to the ecliptic.[76]

The center of the Moon, which is also called the double distance or the center of the celestial body, is the arc of the ecliptic of the deferens apogee or of the eccentric between their apogees and the extremity of a line from the center of the world which passes through the center of the epicycle and extends to the ecliptic.[77]

The proper motion of the Moon or a planet is an arc of the circumference of the epicycle between the median apogee of the epicycle and the centers of their bodies in the direction of the motion of the epicycle.

The mean apogee of the epicycle is the extremity of a line from a point opposite the center of the diameter of the eccentric of the Moon, or from the center of the equant <in the case of Mercury>, passing through the center of the epicycle. The point opposite it is the mean perigee.[78]

The diametral opposition point is a point whose distance form the center of the world, in the direction of the perigee of the eccentric, is equal to the distance of the center of the eccentric from the center of the world in the direction of the apogee.

The equant center is a point whose distance from the center of the eccentric in the direction of the apogee is equal to the distance of the center of the eccentric from the center of the world.

The mean motion of the Moon is the arc of the ecliptic of the deferens apogee of the Moon between the first point of Aries and the extremity of the line produced from the center of the world which passes through the center of the epicycle and reaches to the ecliptic.[79]

The first equation of the Moon or Planet, which is also called the proper equation, is the arc of the epicycle between the apparent apogee and the mean apparent apogee.[80] The apparent apogee is the extremity of a line from the center of the world through the center of the epicycle which extends to the periphery. Its opposite <point> is the apparent perigee.

The uniform motion of the epicycle of the Moon or Planet, which is also called the apparent proper motion, is the arc of the ecliptic of the epicycle between the apparent apogee and the center of the lunar body or planet in the direction of signs.

The second equation of the Moon or planet, which is also called the simple equation, is the arc of the eccentric between the extremes of two lines from the center of the world, one of which passes through the center of the epicycle and the other through the center of the Moon or planet.

The apogee [in a second signification] of the Moon or planet is the arc of the deferent between the first point of Aries and the point of the apogee.

The true place of the Moon or planet is the arc of the deferent of the nodes of the ecliptic between the first point of Aries and the intersection of [the circle intermediate between] the orb of the deferent of the apogee of the Moon and the orb of the deferent of the nodes of the ecliptic.[81]

The latitude of the Moon or planet is the arc of a circle of latitude between the center of the body of the Moon or planet and the ecliptic of the deferent of the apogee in that part in which the inclination exists.[82]

The proportional part of the latitude of the Moon is the arc of the deferent of the nodes between the zenith and the intersection of the circle of latitude <of the Moon> with the deferent.[83]

The "subec"[84] of the Moon is the excess of the motion of the Moon over the motion of the Sun.

The "buht"[85] is the motion of the planet in some designated time, e.g., in one day or one hour.

The degree of ascension of the planet in the zodiac is the degree when the planet is ascending.

The degree of transit in the zodiac is the degree when the planet crosses the meridian.

The degree of descending in the zodiac is the degree when the planet is descending.

The equation of the civil days is the difference between the median day and the true day.

The mean [or equal] day is the duration of the rotation of the equator together with the added motion of the mean sun in one day.

The true day is the duration of one rotation of the equator, with a part which the Sun passes through in each rotation and which ascends with the equator.

The daily equation of the planet, or any other part [of the zodiac] is the arc of the circle of diurnal motion of the planet, or of the part of the zodiac between the horizon and the circle of the declination though which it passes in its equatorial ascending and descending.[86]

The amplitude of easterly <position> of a planet, or any part of the zodiac, is the arc of the horizon between the diurnal circling of the planet, or part of the zodiac, and the equatorial ascending.

The amplitude of westerly <position> is the arc of the horizon between the diurnal circle and the equatorial descending.

The diverse aspect [or parallax] is the arc of the circle of altitude between the extremities of two lines, one of which proceeds from the center of the world, the other from the surface of the earth and from the eye of the observer, and each passing through the center of the planet.

The declination of a star from the equator is the arc of the circle of declination between the star and the equator.

The prime declination of any part of the zodiac is the arc of a great circle which, passing through that part and both poles of the equator, is intercepted between that part and the equator.

The second declination of each part of the zodiac is the arc of a great circle passing through that part and both poles of the zodiac that is intercepted between that part and the equator.

The maximum declination is the arc of the circle passing through the four poles that is intercepted between the zodiac and the equator.

The arc of retrograde motion is the arc of the epicycle between the first station and the second in whose center the point of perigee appears.[87]

The arc of direction is the arc of the epicycle which is divided into two equal parts by the apparent apogee.[88]

The emersion of a star[89] from the rays of the Sun <or the heliacal rising> is the arc of the zodiac which is defined in tables as the distance of the star at which it first appears before the rising Sun, or, similarly after its setting.

The arc of occultation under the rays of the Sun [or arc of combustion] is where the distance between the star and the sun being equal to a definite numerical quantity, the star is occulted now in the east, now in the west.[90]

The gnomon of a shadow is a rod erected above the plane of the horizon or erected at right angles to a horizontal plane parallel to it.

The umbra is a line in the plane in which the rod was erected vertically, between the base [of the rod] and the extremity of the solar radii of this umbra, that is, of this line. Then, if the rod be parallel to the horizon, they name that shadow the first, and also both reversed and inverted. And if the rod be perpendicular to the horizon, they call it the second umbra and right.

The line, however, from the ray of the Sun through the summit of the rod produced to the end of the shadow they call the diameter of the umbra.

The "semit" [or vertical point] of Mecca or any other place that you wish to know is found when we imagine producing a circle through the vertex of the given place and <through> the vertex of the place sought. The intersection of this circle with the horizon is the "semit" of the place. From that point to the eastern edge of the equator or the western is the "semit" arc of that place. From that point to the northern or southern point is the arc of inclination.

The longitude of a place is the arc of the equator intercepted between the meridian, which passes through the insulae fortunatae, because they are the extreme part of the habitable world toward the west, or through the edge of the Atlantic Ocean and the meridian assigned to that place.[91]

The latitude of a place is the arc of the meridian between the vertical point of the given place and the equator.[92] And that arc is equal to the arc between the pole of the place and the horizon.

The difference of two longitudes is the arc of the equator intercepted between the two meridian circles passing through the given cities. The distance between the two horizons of the two cities is equal to their difference in longitude.

The altitude of the Sun or a star is the arc of the altitude circle between its intersection with the horizon and the center of the Sun or star.

The "semit" of the altitude is the arc of the horizon between its intersection with the circle of altitude and the ascending or descending of the equator.

The maximum altitude of a star is the arc of the meridian between the star and the horizon.

The meridian arc of daily motion is the arc of the parallel of daily motion between the horizon and the meridian, of which the diurnal arc is double.

The ascension of signs is the arc of the equator which rises together with the arc of one sign of the zodiac, whether more or less.

The ascension of a part of the zodiac is the arc from the equator from the beginning of the revolution which is the initial point of Aries, to that point which raises with the other part of the zodiac.

The ascension of signs in a right sphere is the arc of the equator which ascends with the arc of the zodiac on the horizon, under the equinoctial line.

The equinoctial line is a line on the surface of the Earth between the ascending and descending of the equator and it always in the plane of the equator.

The ascension of signs above a certain place is the arc of the equator that ascends, with the arc of the zodiac, above the horizon of that place.

The ascension of the horoscope is universally the circle of the ascension of the star with <its> degree of co-ascension.

The "daïr" <Persian: dayr> is the arc of the diurnal <motion> parallel to the star, between the star and the horizon, at a designated place.

The excess of the "daïr" is the arc of the diurnal <motion> parallel to the star between the star and the meridian.

The horoscope is the point of the zodiac which at a given time is in the east.

The west [or seventh house] is the point at a given time in the west and it is the seventh from the horoscope.

The tenth house is the point at that time on that meridian above the earth. That they name the middle of the heavens.

The fourth house is the point at that time on the meridian under the earth. That they call the axis of the Earth.

Note

In the *Planetary Hypotheses* [of Ptolemy], the schemata which are delineated in MS codices and indeed in print by diagrams do not correspond exactly to the true orbs as regards their magnitudes. Nevertheless, their number, motion, figure, position, which only our author has proposed, are sufficiently clearly indicated from these theories. The remaining are able to be supplied from books of astronomers.

It was decided, so that the following pages not be totally empty, to annex certain of the elements of the astronomers al-Farghānī and Alī Kushjī.

Al – Farghānī Elements of Astronomy (Chapter Sixteen)[93]

What relations the epicycles have to the orb of the eccentric, and how much the center of the eccentric is distant from the center of the Earth.

The Sun, as has been shown, is strictly speaking, and eccentric orb. The center of its orb is distant from the center of the Earth by two and a half parts when the semi-diameter of the eccentric is 60, which, indeed, is the median distance of the Sun from the Earth. What pertains to the six remaining stars we have already declared concerning the fact that each one of their two centers are different from the center of the Earth. And of the five wandering stars that have two centers fixed and immobile, are constituted in a straight line with the center of the Earth, and the intervals of their centers remain equal. Mercury, however, has a third center which moves the other two in a circle in that interval such that the interval of those remaining <centers> is equal. That the Moon has two centers <of motion> we have also demonstrated, of which the one should be fixed, the other turned round the center of the Earth in the same interval in which the fixed center is distant.

The radius of the eccentric being 60 parts (of which the mean distance of the Sun in its eccentric from the Earth, one may obtain <the motion> of those stars in equal intervals. Saturn, indeed, has three parts and a quarter and a sixth; Jupiter two parts and a half and a quarter; Mars six parts; Venus one part and a quarter; Mercury three parts; the Moon twelve parts and a half.

Finally, he looks to the quantities of the epicycles, the radius of the eccentric being assumed to be sixty parts, the radius of the epicycle of Saturn is 6, of Jupiter eleven and a half; of Mars, 39 and a sixth; of Venus 43 and a sixth; of Mercury 22 and a half; of the Moon 6 and a half.

Alī Qushjī on the Magnitude of the Earth and the Distance of the Celestial Spheres from the Earth

From observations and by calculation it is known that the circumference of the greatest circle described on Earth is 8000 parsangs. The parsang contains three "milliare", and the "milliare" contains three thousand "ulna"; an "ulna" <a cubit?> contains thirty two digits; a digit is the quantity of length of six grains of barley. The length of a grain of barley is six hairs from the tail of a horse.

The diameter of the Earth is 2545 parsangs. the entire surface of the Earth is 20,363,636 parsangs. The habitable surface of the Earth, however, is 4,376,940 parsangs.

The concavity <of the sphere> of the Moon is 41,936 parsangs from the center of the Earth.

The convexity <of the sphere> of the Moon, which is the concavity of the sphere of Mercury, is 85,303 parsangs distant from the center of the Earth.

The convexity <of the sphere> of Mercury, which is the concavity of the sphere of Venus, is 275,380 parsangs distant.

The convexity <of the sphere> of Venus, which is the concavity of the sphere of the Sun, is 1,848,382 parsangs distant.

The convexity <of the sphere> of the Sun, which is the concavity of the sphere of Mars, is 2,027,934 parsangs distant.

The convexity <of the sphere> of Mars, which is the concavity of the sphere of Jupiter, is 14,770,370 parsangs distant.

The convexity <of the sphere> of Jupiter, which is the concavity of the sphere of Saturn, is 23,991,250 parsangs distant.[94]

The convexity <of the sphere> of Saturn, which is the concavity of the sphere of fixed stars, is 33,305,180 parsangs distant.

The convexity <of the sphere of > the fixed stars, which is the concavity of the greatest (or ninth) sphere, is 33,524,309 parsangs distant.

The convexity <of the greatest> sphere is known to no one except God alone.

Notes and References

1. John Greaves, *Astronomica quaedam ex traditione Shah Cholgii Persae una cum planetarum,* London, 1650/1652.

2. *Hay'a*, the science of the configuration of the universe, as an aspect of Islamic study of the heavens, is not easy to define. Saliba has suggested that the discussion arose from an explicit rejection of the astrological features of Greek mathematical astronomy. See G. Saliba, "Islamic Astronomy in Context: Attacks on Astrology and the Rise of the Hay'a Tradition," *Bulletin of the Royal Institute of Interfaith Studies*, 4 (2002) 25-46. See also D. King, J. Samsó and B. R. Goldstein, "Astronomical Handbooks and Tables from the Islamic World (750 – 1900): An Interim Report," *Suhayl* 2 (2001) 9-106, especially 69-72 and D. Pingree, "ᶜIlm al-Hay'a," in *Encyclopedia of Islam*, 2nd ed., vol. 3, pp. 1135-1138. In many ways parallel to or overlapping with *tarkîb al-aflâk*, or study of the arrangement of the celestial spheres, it carries also ideas of mathematical model building.

3. Greaves does not mention the title of the treatise. It was identified as the introductory chapter of the *Zîj al-Jâmiᶜ* in R. Ramsey Wright, "Über die Schrift „Astronomica quaedam" von Greaves," *Sitzungsberichte der physikalisch-medizinischen Sozietät zu Erlangen*, 58-59 (1926-1927) 381-386, especially 381. The general characteristics of the *zîj* are outlined in S. A. Khan Ghori, "Development of Zîj Literature in India," *IJHS*, 20 (1985), 21-48, esp. 31-32. See also E. S. Kennedy, "A Survey of Islamic Astronomical Tables," *Transactions of the American Philosophical Society*, new series, 46 (1956) 123-177, esp. 138, entry X220.

4. Oxford, Bodleian Library, MS. Greaves 6 (104 folios). See C. A. Story, *Persian Literature: A Bio-Bibliographical Survey* (London: Luzac, 1958), vol. 2, pt. 1, p. 74-75.

5. There is no scientific biography of Greaves. The preface of Th. Birch, *Miscellaneous Works of John Greaves*, London, 1737, pp. i-lxxii and J. Ward, *Lives of the Professors of Gresham College*, London, 1740, pp. 135-153 are the most complete of the traditional biographical accounts. G. J. Toomer, *Eastern Wisedome and Learning: The Study of Arabic in Seventeenth Century England*, Oxford, Clarendon Press 1996, pp. 127-142 and 167-176; Z. Shalev, "Measurer of All Things: John Greaves (1602-1652), the Great Pyramid, and Early Modern Metrology," *Journal of the History of Ideas*, 63 (2002) 555-575 and R. Mercier, "English Orientalists and Mathematical Astronomy," in G. A. Russell, ed., *The —Arabick' Interests of the Natural Philosophers in Seventeenth Century England*, Brill, Leiden 1996, pp. 158-214, offer modern insight into specific aspects of his career.

6. ᶜAlī ibn Muḥammed al-Kirmānī , *Ma'âthir-i Maḥmûd Shāhī* (Oxford, Bodleian Library, MS. Elliot 237) is the most detailed summary of his reign. See also the condensed version in Nūr al-Ḥassan Ansārī, ed., *Ma' āthir-i Maḥmūd Shāhī* , Dānishgāh-i Dilhi, New Delhi, 1968. Neither work is available to me. For a brief summary, see M. Hassan, "Maḥmūd Khaldjī I," *Encyclopedia of Islam*, 2nd ed., vol. 6, pp. 52-54.

7. Oxford, Bodleian Library, MS. Greaves 6, fol. 1a.

8. Story, *Persian Literature*, vol. 2, pt. 2, p. 74, note 3 has proposed the same interpretation. Wright, *op. cit.*, p. 382, has suggested that the name may refer to the town in Saudi Arabia where the supporters of the Prophet Muḥammed from Medina clashed with his opponents from Mecca.

9. See T. W. Haig, "Mālwā," in *Encyclopedia of Islam*, 2nd ed., vol. 6, p. 310.

10. Wright, *op. cit.*, p. 382 has reached a similar conclusion.

11. For an introduction to the richness of the tradition, see G. Saliba, *A History of Arabic Astronomy: Planetary Theories during the Gold en Age of Islam*, New York University Press, New York, 1994.

12. To judge its elementary character, one has only to compare it to the *Theoricae novae planetarum* of Georg Peurbach. His text had been published only in 1472, although the draft may have been in nearly final form as early as 1454. It was one of the most widely used astronomy texts in the sixteenth century. The text has been published in E. J. Aiton, "Peurbach's *Theoricae novae planetarum*: A Translation with Commentary," *Osiris*, 2nd series, 3 (1987) 5-44.

13. See, for example, C. E. Bosworth, "A Pioneer Arabic Encyclopedia of the Sciences: al-Khwārismī 's Keys of the Sciences," *Isis*, 54 (1963) 97-111. The treatise has been published in G. van Vloten, ed., *Liber mafatih al-olum explicans vocabula technica scientiarum*, Brill, Leiden, 1895. See also, O. Pedersen, "A Fifteenth Century Glossary of Astronomical Terms" in: O. S. Due, H. F. Johansen, B. D. Larsen, eds., *Classica et Mediaevalia Francisco Blatt septuagenaria dedicata*, Gyldendaliana, Copenhagen, 1973, pp. 584-594.

14. This particular question of terminology is of interest because of the debates that have occurred concerning the interpretation of the term "orbis" by Copernicus and whether that interpretation may indicate possible influence from the Islamic astronomers. See E. Rosen, "Copernicus' Spheres and Epicycles," *Archives internationales d'histoire des sciences* 25 (1975) 82-92; N. M. Swerdlow, "Pseudodoxia Copernicana," *Archives internationales d'histoire des sciences* 26 (1976) 108-158.

15. Note that this usage is quite different from that of Ibn al-Haytham, one of the early influential exponents of *hay'a* in the Islamic world. See Y. T. Langermann, "A Note on the Use of the Term Orbis (*Falak*) in Ibn al-Haytham's Maqālah fī Hay'at al-ᶜÂlam," *Archives internationales d'histoire des sciences* 32(1982) 112-113.

16. Peurbach had used this terminology the same way in his *Theoricae novae planetarum.* One cannot help but wonder about possible lines of influence in this context. See E. J. Aiton, "Celestial Spheres and Circles," *History of Science* 19 (1981) 75-114, esp. p.94.

17. Despite Greaves' orientation toward a Ptolemaic vision of the universe, the *Astronomica qua edam* begins its actual discussion of *hay'a* with the outermost sphere and works its way systematically inward to the sphere of the Moon. This is the reverse of the approach of Ptolemy, who begins with the Sun and Moon, and gradually works outward toward the "fixed stars". Thus, despite retaining important Ptolemaic structures, the treatise departs from the Ptolemaic style in important ways. Apparently, this divergence did not trouble Greaves unduly.

18. Sir John Marsham (1602-1685) had been a student with Greaves at Oxford (St. John's College), where he received his BA in 1623 and MA in 1625. He was widely respected for his knowledge of history, chronology, and languages, interests shared by Greaves. In the estimation of Wotton, "Marsham was the first who made the Egyptian antiquities intelligible" (*Dictionary of National Biography*, vol. 12, p. 139). Greaves, during his trip to the eastern Mediterranean, had spent several weeks in Alexandria and had twice visited Cairo and the pyramids. Greaves first major publication, *Pyramidographia* (1646), is indicative of the confluence of their scholarly interests. See Z. Shalev, "Measureer of All Things: John Greaves (1602-1952)".

19. The reference here appears to be to a popular treatise, *Theorica planetarum*, that was widely attributed to Gerard of Cremona, although modern scholars remain sharply divided on the validity of that ascription. See R. Lemay, "Gerard of Cremona," in C. C. Gillispie, ed., *Dictionary of Scientific Biography*, Scribner, New York 1978, [hereafter *DSB*] vol. 15, pp. 173-192, especially 189. See also, O. Pedersen, "The Theorica Planetarum Literature of the Middle Ages," *Classica et mediaevalia*, 23 (1962) 225-232. The text has been edited and privately published in F. J. Carmody, ed., *Theorica planetarum Gerardi*, Berkeley, 1942.

20. Regiomontanus, *Disputationes contra deliramenta Cremonensia*, in F. Schmeidler, ed., *Joannis Regiomontani opera collectanea* , Zeller, Osnabrück 1972, pp. 513-530. There is no modern translation of the treatise.

21. The reference appears to be to Peurbach's *Theoricae novae planetarum*. This work, printed after the death of Peurbach, was extremely popular as an introductory text. See C. Doris Hellman and N. Swerdlow, "Peurbach, Georg," in *DSB*, vol. 15, pp. 473-479, especially 475. See also the sources in note 12.

22. The reference seems to be to the translation of Ptolemy's text, which John Bainbridge, Savilean Professor of Astronomy at Oxford from 1610 until his death in 1643, published under the title *de planetarum hypothesibus* (1620).

23. Erasmus Reinhold (1511-1553) published a commentary on Peurbach's *Theoricae novae planetarum* (1542), which after being issued in a revised edition in 1553, was reprinted at least 10 times in the next century. See O. Gingerich, "Reinhold, Erasmus," in *DSB*, vol. 11, pp. 365-376.

24. Maestlin (1550-1631), observing that the comet of 1577 displayed no parallax, concluded that it must be situated outside the sphere of the moon (an observation made also by Tycho Brahe). This helped to convince him of the validity of the Copernican heliocentric model of the universe. Nevertheless, he wrote his popular introductory textbook, *Epitome Astronomiae*, from a Ptolemaic point of view because he believed it was easier for students to understand. See E. Rosen, "Mästlin, Michael," in *DSB*, vol. 9, pp. 167-170, especially 168.

25. P. D. Thomas, "Alfonso el Sabio," in *DSB*, vol. 1, p. 122. See also E. Poule and D. Savoie, "La survie de l'astronomie Alphonsine," *Journal for the History of Astronomy* 29 (1998) 201-207.

26. For the term "aux" and its rival constructions, see E. Poulle, "Le vocabulaire de l'astronomie planétaire du XIIe au XIVe siècle" in: *La diffusione delle scienze islamiche nel medio evo europeo*, Accademia nazionale dei Lincei, Rome, 1987, pp. 193-212, esp. pp.201-203.

27. R. Mercier, "English Orientalists," p. 158, suggests that these early translations formed part of a broad effort to legitimate the Abbasid rule.

28. Greaves considered this *zîj* to be a commentary on al-Ṭūsī 's *Zîj al-Ilkhānī*. See *Astronomica quaedam*, sig. A4v. C. Rieu accepted this claim at face value. See *Catalog of the Persian Manuscripts in the British Museum* , London, 1881, vol. 2, pp. 454-455. Story, however, does not agree. See *Persian Literature*, vol. 2, pt. 1, p. 59 and p. 74, note 4.

29. Note that it is the observations, not the model building, that Greaves sees as the important contribution of al-Ṭūsī.

30. Joseph Scaliger (1540-1609) occupied the chair of Arabic at the University of Leiden from 1593 until his death. He was deeply interested in calendar systems and chronology. He is best known today for his introduction of the Julian Period in which one calculates dates from a presumed origin at AD –4713 December 31. The Julian period is still used in astronomical calculations today. The most complete study of Scaliger and his career is the two-volume biography by A. Grafton, *Joseph Scaliger: A Study in the History of Classical Scholarship* (Oxford: Oxford U Press, 1983-1993). For an introduction to his study of chronology, see A. Grafton, "Joseph Scaliger and Historical Chronology: The Rise and Fall of a Discipline," *History and Theory* 14 (1975) 156-185.

31. Greaves adds a marginal note (p. 2): That is, an astronomical table.

32. Greaves adds a marginal note (p.2): That is, astronomical observation of stars.

33. The choice of terminology is unusual. We should have expected *ᶜaqliy* (intelligible) rather than *ᶜarẓ iy* (accidental). The distinction between intellectual and physical geometry is typically neo-Platonic and is found in the Islamic tradition as early as the *Rasâ'il Ikhwān al-bafā'* (Basra, 3rd / 10th century). See G. De Young, Euclidean Geometry in two Medieval Islamic Encyclopaedias," *al-Mashāq* 14 (2002) 47-60, especially pp. 49-50.

34. Greaves' translation is rather free: "and if it acquires a position, it is terminated by a point (p. 6)."

35. An interest in classification is typical of the neo-Platonic approach. The *Rasā 'il Ikhwā n al-ṣ afā'* adopt a variant terminology: mustaqîm, muqawwas, munḥannsā. See *Rasā'il Ikhwân al-ṣ afā"* (Beirut, 1376 / 1957), vol. 1, p. 81.

36. Greaves translates "that line" as "periphery" (p. 8).

37. I follow Greaves in translating the term "*mustadîr*" as "convex" (p. 8). More literally, it means a surface of uniform curvature, which may appear either convex or concave depending on our position relative to the surface.

38. Greaves transliterates the Persian term, although he offers the Latin equivalent in brackets. It is not clear why he chooses to transliterate rather than use a Latin term.

39. This term appears to be misprinted in the *Astronomica quaedam*. The more typical form used in the Euclidean tradition is "manshūr" although one occasionally finds "mawshūr". Greaves (p. 19) has inadvertently omitted the second letter (nūn or waw).

40. It is not clear why our anonymous author has chosen to use a different term for the axis in the case of the sphere. Greaves, however, translates both *sahm* and *miḥvar* by the Latin term axis.

41. Greaves retains the Persian *manṭaka* in is translation, although he explains that it is the circle intermediate between the poles – which is already obvious from the remainder of the sentence. He includes a marginal definition (p. 24): a belt. It is not clear why Greaves chooses to transliterate here, rather than translate.

42. Greaves again retains the Persian term in his Latin translation (p. 24). It appears that he was unaware of a Latin equivalent; at least he does not offer one. He does add a marginal note: that is, the tail of a pigeon.

43. The Persian says, literally, "*tadâvîr khamsa mutaḥayyira ve qamr*" (p. 25) which Greaves has rendered into Latin as "quinque epicycli quinque erraticorum & lunae" (p. 26). The term *mutaḥayyira* is used to describe the sphere carrying each planet in the solid-sphere version of Ptolemy's epicycle. Hence, it is necessary to separate the moon, which is itself such a solid sphere, from the epicycles of the other planets, within which ride the planets. The use of the term here reminds us, metaphorically, of the variations that occur in retrograde motion.

44. Greaves has omitted a diagram found in the manuscript at this point. Oxford, Bodleian Library. MS. Greaves 6, fol. 6b. This diagram consists of a series of concentric circles, none of which are labeled, and within these, an eccentric point, apparently to represent the earth. Because the diagram adds nothing to the text, I do not reproduce it here.

45. That is, this sphere is eccentric with respect to the earth.

46. Cf. Pedersen, "Glossary," p. 590, #44.

47. Cf. Pedersen, "Glossary," p. 591, #46.

48. Today we would transliterate the term as *zervah*.

49. Today we would transliterate the term as *ḥaẓīẓ*. It is not clear why Greaves chooses to transliterate, rather than translate.

50. Today we would transliterate the term as *awj*.

51. Cf. Pedersen, "Glosssary," p. 588, #4.

52. Cf. Pedersen, "Glossary," p. 588, #5.

53. Greaves is here translating the Arabic equivalent: bu[c]d al-aqrab.

54. Cf. Pedersen, "Glossary," p. 588, #2.

55. Cf. Aiton, "Theoricae novae planetarum," p. 22.

56. Cf. Aiton, "Theoricae novae planetarum," p. 22.

57. Cf. Aiton, "Theoricae novae planetarum," p. 12.

58. Cf. Pedersen, "Glossary," p. 588, #11.

59. Cf. Pedersen, "Glossary," p. 588, #12.

60. Greaves adds a marginal note (p. 54): In Arabic, "mantaka" literally means a belt, but metaphorically it means the greatest circle of a sphere.

61. The term "zodiac," it is clear, does not mean the twelve constellations as it so often does when used by astrologers today. Rather, it is a great circle defined by the sun's annual motion through the heavens. Cf. Pedersen, "Glossary," p. 593, note 1.

62. Greaves adds a marginal note (p. 56): In Arabic, assimilating.

63. Cf. Pedersen, "Glossary," p. 588, #3, where he defines concentric circles.

64. He inserts a marginal note (p. 58): In Arabic semt; commonly zenith. It is not clear why he retains the Persian term rather than providing a Latin translation.

65. At the end of the treatise, Greaves has an "Addendum to page 60" which, apparently, should be inserted at this point. This material reads:

> Circles parallel to the horizon they call "mokantarat". Those above the horizon they name "mokantarat" of altitude and those below the horizon "mokantarat" of depression.

66. Again, we find that Greaves has preferred to retain the Persian, rather than translate into Latin.

67. Greaves has a marginal note: In Arabic, "manâtek", belts. From the singular "*mantaka*", a belt. Metaphorically, a great circle midway between the two poles.

68. On this terminology see Aiton, "Theoricae novae planetarum," p. 14, note 28.

69. Cf. Pedersen, "Glossary," p. 590, #34.

70. Cf. Pedersen, "Glossary," p. 590, #35.

71. This is another example of Greaves' retention of Persian terminology. On the etymology of the terminology, see W. Hartner, "al-Djawzahar," in *Encyclopedia of Islam*, 2nd ed., vol. 2, pp. 501-502. Pedersen, "Glossary," p. 594, implies that the term was somehow relegated only to the caput draconis (ascending node of the moon's trajectory).

72. Clearly, the center is not a point as the terminology might initially seem to indicate. Rather, it is an angular coordinate measured on the ecliptic from aux or apogee. See Pedersen, "Glossary," p. 593, note 3. The Persian term used here is "markaz" (p. 67).

73. Cf. Pedersen, "Glossary," p. 588, #8. Cf. Aiton, "Theoricae novae planetarum," p. 12. The term *aequatio* is the equivalent of the Greek *postaphaeresis*, which is the term used in the *Almagest*. It always denotes the difference between mean and true values of some angular coordinate. See Pedersen, "Glossary," p. 593, note 3.

74. Cf. Pedersen, "Glossary," p. 588, #10. See also, Aiton, "Theoricae novae planetarum," p. 12.

75. Cf. Pedersen, "Glossary," p. 588, #6. The term "motion" (*ḥarakat*) is not found in the Persian text. Presumably this is to indicate that we are not considering locomotion here. Instead, we should consider this a kind of time-dependent celestial coordinate akin to "longitude" as measured on some great circle. See Pedersen, "Glossary," p. 593, note 3. See also Poulle, "Vocabulaire," p. 197.

76. Cf. Pedersen, "Glossary," p. 588, #7. See also, Aiton, "Theoricae novae planetarum," p. 12.

77. Cf. Pedersen, "Glossary," p. 589, #15. See also Aiton, "Theoricae novae planetarum," p. 14. On the terminology, see also Poulle, "Vocabulaire," pp. 204-205.

78. Cf. Pedersen, "Glossary," p. 589, #20. See also Aiton, "Theorica novae planetarum," p. 15.

79. Cf. Pedersen, "Glossary," p. 589, #18.

80. See Aiton, "Theoricae novae planetarum," p. 16.

81. Cf. Pedersen, "Glossary," p. 589, #19. See also Aiton, "Theoricae novae planetarum," p. 15

82. Cf. Pedersen, "Glossary," p. 590, #37.

83. Cf. Aiton, "Theoricae novae planetarum," p. 16.

84. Greaves adds a marginal note (p. 74): In Arabic <pronounced> "sabk"; commonly "subec".

85. Greaves adds a marginal note (p. 74): In Arabic <pronounced> "baht".

86. It is not clear to me whether this is the same as that defined in Pedersen, "Glossary," p. 593, #75.

87. Cf. Pedersen, "Glossary," p. 592, #70. See also Aiton, "Theorica novae planetarum," p. 27.

88. See Aiton, "Theoricae novae planerarum," p. 27.

89. Greaves adds a marginal note (p. 80): <In Arabic>, "caucab" signifies, in an absolute sense, a star, whether it be fixed or moving, as the planets.

90. On emersion and occultation, see Aiton, "Theoricae novae planetarum," p. 28.

91. Cf. Pedersen, "Glossary," p. 593, #80.

92. Cf. Pedersen, "Glossary," p. 593, #81.

93. This appears to correspond to chapter nineteen in the summary of the contents of al-Farghânī 's treatise as found in J. Delambre, *Histoire de l'astronomie du moyen âge*, Paris, 1819, p. 67.

94. There is a printing error (p. 96) in the Latin text, where the figure is given as 2,399,250.