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GREEK STAR CATALOGS AND THE MODERN ASTRONOMICAL ZODIAC

The sidereal zodiac of the Babylonians was the first scientifically defined zodiac. After the conquest of Babylon by Alexander the Great, in 331 B.C., the center of cultural activity shifted from Mesopotamia to Greece, and in the process the Babylonian zodiac was transmitted to the Greeks. It was used by Greek and Egyptian astrologers in Alexandria, and it was transmitted to Rome and all the way to India, as discussed in my paper "The Indian Zodiac". However, Greek astronomers arrived at their own definitions of the zodiac as an astronomical frame of reference. The two most important zodiacs defined by Greek astronomers are: (1) the tropical zodiac that was introduced by Hipparchus (second century B.C.) into astronomy; and (2) the astronomical zodiac specified by Ptolemy (second century A.D.) on the basis of his extensive stellar observations. This paper is concerned initially with the origin of the ecliptic coordinate system of the tropical zodiac and then with Ptolemy's star catalog from which the modern astronomical zodiac subsequently became defined, and also with two earlier Greek star catalogs from the pre-Christian era – namely Hipparchus' catalog and a "Hermetic" star catalog (attributed to the legendary Egyptian sage Hermes Trismegistus). In two of these three catalogs the stars are located according to their longitudes in the tropical zodiac. Although Hipparchus referred to "zodiacal signs" (meaning *any* 30-degree arc), he used mainly *polar longitude* as his astronomical coordinate system[1], while

"Hermes Trismegistus" and Ptolemy gave stellar positions in the ecliptic coordinate system in terms of longitudes of stars in the twelve signs of the tropical zodiac. The star catalog of Ptolemy includes – in addition to the longitudes of stars in the tropical zodiac – also their latitudes, this being the first historical use of the full ecliptic coordinate system of latitude and longitude.

Firstly, let us consider the origin of the tropical zodiac. The *tropical calendar*, which will be considered in more detail below, was already defined by Euctemon (ca. 430 B.C.)[2] approximately three hundred years before Hipparchus introduced the tropical zodiac into astronomy. There is a possibility that the tropical zodiac as originally applied in astronomy by Hipparchus was actually the sidereal zodiac of the Babylonians, as it is known that Hipparchus adopted various astronomical parameters from the Babylonians[3]. In order to clarify this hypothesis, it is helpful to consider the view put forward by G.P. Goold in his introduction to the *Astronomica* by the Roman author Manilius. But before quoting from this introduction it must be borne in mind that all Babylonian, Egyptian, Greek, Roman, and Hindu astrologers – in fact, all astrologers of antiquity – used the sidereal zodiac. The Babylonian sidereal zodiac was the sole frame of reference used by astrologers in antiquity for casting horoscopes, and the question of the location of the vernal point in the sidereal zodiac engaged their attention as well as the attention of astronomers like Hipparchus. Prior to the discovery of the precession of the equinoxes by Hipparchus, before it was known that the vernal point moves in relation to the sidereal zodiac, various "systems" were used. For example, the Babylonians used two astronomical systems now referred to as System A and System B. In System A, the vernal point was located at 10 degrees in the sign of Aries and in System B it was placed at 8 degrees Aries. Commenting on this, B.L van der Waerden writes:

> In 1963 I made an attempt to estimate the accuracy of ancient Babylonian observations of the equinoxes and solstices. I found that about 400 B.C. or even earlier the summer solstice was known to within one or two days...Kugler also investigated Tablet ACT 60 (old signature SH 93), which belongs to System A and in which the spring equinox was assumed at 10° of Aries. His conclusion was: "An analogous calculation for Tablet No. 93 would bring us back to 500 B.C. ± several years."[4]

Assuming that the vernal point was at 10 degrees Aries in about 500 B.C.[5], and since it moves retrograde through the sidereal zodiac at a rate of approximately one degree in 72 years, it is easy to see that the vernal point was located at 8 degrees Aries at around the middle of the fourth century B.C.

B.L. van der Waerden also concluded that the Greek astronomers Meton and Euctemon drew their knowledge of the zodiac from the Babylonians, adopting System B:

> These two astronomers observed the summer solstice in Athens in 432 B.C. (Ptolemy, *Almagest* III, 1)...Meton placed the equinoxes and solstices at 8 degrees Aries, 8 degrees Cancer, etc. (Columella, *De re rustica* IX, 14), exactly like the Babylonian System B calculations.[6]

If the specification of 500 B.C. is fairly accurate, it follows that the vernal point was located at 8 degrees Aries actually around 356 B.C., that is, 144 years (2 x 72 years) after 500 B.C., since it moved two degrees from 10 degrees to 8 degrees of Aries in 144 years, moving back through the zodiac at a rate of approximately one degree every 72 years. Evidently Meton was approximately one degree in error, since the vernal point was at 9 degrees Aries in about 430 B.C., midway between 500 and 356 B.C.

Now we can consider G.P. Goold's hypothesis that Hipparchus believed that in his day the vernal point was at 0 degrees Aries. If Hipparchus did believe this, again—like Meton—he was in error, because, in fact, the vernal point did not reach 0 degrees Aries until about A.D. 220[7]. Therefore, at the time of Hippar-chus (around 140 B.C.) the vernal point was actually at 5 degrees Aries, since it shifted back five degrees in the 360 years (5 × 72 years) between 140 B.C. and A.D. 220. Nevertheless, there is evidence that Hipparchus believed that the vernal point was located at 0 degrees Aries at his time.

> 10° and 8° were the Babylonian longitudes for the equinoxes, and particularly the latter norm also found widespread acceptance in the west. Hipparchus informs us that Eudoxus placed the midpoints (15°) of the signs at these points whereas he himself, following "most of the old mathematicians" (and Aratus), reckoned the seasons from the beginning of the signs[8].

This dispels the supposition that Hipparchus invented the tropical zodiac. All he did – in agreement with "most of the old mathematicians" – was to (wrongly) assume that the vernal point *in his day* was located at 0 degrees Aries. And just as Meton assumed that the vernal point was at 8 degrees Aries some three hundred years *before* Hipparchus, Ptolemy assumed that the vernal point was at 0 degrees Aries some three hundred years *after* Hipparchus when, in fact, at the time of Ptolemy it was actually at 1 degree Aries[9].

> It is the great glory of Hipparchus to have discovered the precessional shift, apparently by comparing his observations of Spica with those of Timocharis...Eudoxus, we are told (Hipparchus 2.1.18) placed the vernal point at 15 degrees Aries, Aratus at the beginning of the sign [0 degrees Aries]. Now since their chronological difference corresponds to a precessional shift of not much more than one degree, it is obvious that both are struggling to preserve conventions that do not fit the phenomena. Occasional references to 8 degrees [Aries] may be related, as Neugebauer suggests, to the vernal point of System B of the Babylonian lunar theory; and 8 degrees [Aries] or thereabouts may well have marked the [vernal]

> equinox when the zodiac as we know it was devised (the Romans—Caesar, Vitruvius, Columella, Pliny—generally adopted 8 degrees [Aries])...If in the time of Hipparchus the vernal equinox occurred at the first point of Aries [0 degrees Aries], then in the time of Ptolemy it must have occurred at about 26 degrees Pisces, and today it must occur at about 1 degree Pisces.[10]

Note that this last sentence of G.P. Goold, if it were to be reformulated giving more precise positions of the vernal point in the Babylonian sidereal zodiac at that time and in the present, should read: "At the time of Hipparchus the vernal equinox occurred at 5 degrees Aries, then in the time of Ptolemy it must have occurred at about 1 degree Aries; and today it must occur at about 5 degrees Pisces."[11]. Continuing with the words of G. P. Goold:

> Today in fact the effect of precession has been to move every zodiacal sign twenty-nine degrees away from where, according to astrological doctrine, it ought to be. Oddly enough it is Ptolemy who has saved the day for astrologers. In *Tetrabiblos* I, 22 the astronomer virtually says that for astronomical purposes he will define the first point of Aries as the vernal equinox. If that moves, then the whole zodiac will just have to move with it. For astrological purposes men had better look to this movable, artificial zodiac. And so it has come to pass. When today's readers of almanacs are informed that the Sun travels through Aries from March 21 to April 20, the name Aries denotes not the group of stars so identified and marked in our star atlases, but thirty degrees of the ecliptic measured off from the vernal equinox, a length of line constantly moving and today almost entirely contained in the astronomical constellation of Pisces.[12]

The current position of the vernal point in the Babylonian sidereal zodiac is not at 1 degree Pisces but rather, having shifted back approximately 26 degrees from Ptolemy's day, its present location is at about 5 degrees Pisces. Nevertheless, G.P. Goold's statement quoted above still holds some validity, provided we modify 29 to 25 degrees. It is clear that in antiquity there were various "systems" locating the vernal point at different degrees in the sidereal sign of Aries, and Hipparchus' "system"—locating the vernal point at 0 degrees Aries—was one of them. Yet it was Ptolemy who "absolutized" Hipparchus' system by fixing the vernal point eternally at 0 degrees Aries. According to Goold this signified the creation of a "movable, artificial zodiac." It is this that is now known as the *tropical zodiac*. Whether or not we accept G.P. Goold's interpretation, it is clear that the new zodiac changed things completely. As long as the Babylonian sidereal zodiac was the only zodiac that was known of in antiquity, it was quite natural to ask what degree the vernal point was located in the zodiac (meaning the *sidereal zodiac*, as there was no other zodiac). By fixing the vernal point at 0 degrees Aries a new zodiac – the *tropical zodiac* – was created and the original sidereal zodiac became "eclipsed" by the new zodiac until it was rediscovered through the deciphering of cuneiform texts from Babylon around the start of the twentieth century. As discussed in my paper on "The Indian Zodiac", the sidereal zodiac was not completely eclipsed because it lived on in India, albeit with a minor shift (about one degree) from the original Babylonian zodiac.

The Babylonian sidereal zodiac was transmitted to Greek astrologers, who continued to use it at least until the fourth century A.D., as is apparent from the testimonies of Hephaestion of Thebes[13] and the "Anonymous of the Year 379"[14] referred to in my paper on "The Babylonian Zodiac". However, apart from the fragment of the Babylonian star catalog translated by Abraham Sachs[15], no other trace of the Babylonian star catalog defining the Babylonian zodiac has been found in cuneiform sources, and there is no direct reference to it in the corpus of Greek astrology[16]. There are only two other pre-Christian star catalogs that are known of[17]: the stellar observations of Hipparchus found in his *Commentary to Aratus* which presumably were later included in his lost star catalog[18], and the star catalog preserved in the Latin text, *Liber Hermetis Trismegisti*[19]. The *Commentary to Aratus* deals with the risings and settings of stars for the latitude of Rhodes, based on Hipparchus' observations made in the decades from 150 to 130 B.C.[20] The catalog in *Liber Hermetis Trismegisti* stems from the period immediately following Hipparchus, 130 to 60 B.C.[21], and it is not known if the use of the ecliptic coordinate system in the form of longitudes in the tropical zodiac in this catalog was independent of Hipparchus or whether it was influenced by Hipparchus in some way.

Although the terminology it uses agrees with that of Hipparchus in the *Commentary to Aratus*, most of the stars in the Hermetic catalog are defined by longitude in zodiacal signs, whereas in Hipparchus' *Commentary to Aratus* he does not use ecliptic longitudes in the normal sense, but gives the location of stars primarily in *polar longitude*, a parameter which is also found in Indian astronomy. This is despite the fact that Hipparchus uses "zodiacal signs" in the *Commentary to Aratus*, although in rather a loose sense, namely to mean *any* 30-degree arc on the celestial sphere[22].

Although both catalogs agree with the earlier zodiac of the Babylonians in respect of a twelvefold division, there is a major innovation in these catalogs which serves to distinguish Greek astronomy from Babylonian astronomy. The distinction is that whereas Babylonian astronomers used the zodiacal belt as their frame of reference – first in terms of the system of Normal Stars, then later in terms of sidereal zodiacal signs defined in relation to the two prominent Normal Stars Aldebaran and Antares – Greek astronomers adopted the *ecliptic* as their frame of reference, i.e., in Greek astronomy the apparent path of the Sun became all important. This is evident in the work of Hipparchus and also in the Hermetic star catalog and in Ptolemy's star catalog in the *Almagest.*

The innovation of Greek astronomy was the adoption of the ecliptic indicated by the apparent path of the Sun as the basic astronomical frame of reference. Thus, Greek astronomy displays a markedly different orientation to that of the Babylonians. The latter astronomy related the movements not only of the Moon and the planets to the background of fixed stars, but also the apparent movement of the Sun was specified in relation to its passage through the fixed star (sidereal) signs comprising the zodiacal belt. In Greek astronomy, however, the emphasis became shifted away from the background of fixed stars to become focused on the Sun and phenomena of the Sun. Instead of measuring the position of the Sun against the background of fixed stars, as the Babylonians did, Greek astronomers took the Sun's path, the ecliptic, and measured the positions of the fixed stars in relation to this new frame of reference. This is precisely the case with the Hermetic star catalog, in which the positions of stars are given in terms of ecliptic longitude measured to the nearest degree in zodiacal signs of the tropical zodiac. Moreover, what can be deduced from an analysis of the stellar positions given by Hipparchus in his *Commentary to Aratus* is that the location of most of the stars is given in polar longitude that is measured along the ecliptic to the point where the meridian (extending up perpendicularly from the equator) through the star intersects the ecliptic[23].

With the adoption of the ecliptic as the basic frame of reference, instead of the fixed stars comprising the zodiacal belt, the question arises: Where does the ecliptic begin? By observation of the Sun and its phenomena during the course of one year, i.e., during one revolution of the Sun around the ecliptic, four possible alternatives are given – corresponding to the four major solar phenomena of the year – for the choice of starting point of the apparent path of the Sun. These four phenomena are: vernal equinox, summer solstice, autumnal equinox, and winter solstice. Each of these phenomena could be considered as a candidate for the start of the solar year and hence for the beginning of the path of the Sun on its apparent orbit of the ecliptic. Thus, Ptolemy writes:

> To be sure, one could not conceive what starting point to assume in a circle, as a general proposition; but in the circle through the middle of the zodiac one would properly take as the only beginnings the points determined by the equator and the tropics, that is, the two equinoxes and the two solstices. Even then, however, one would still be at a loss which of the four to prefer. Indeed, in a circle, absolutely considered, no one of them takes the lead, as would be the case if there were one starting point, but those who have written on these matters have made use of each of the four, in various ways assuming some one as their starting point, as they were led by their own arguments and by the natural characteristics of the four points. This is not strange, for each of these parts has some special claim to

> be reasonably considered the starting point and the new year. The spring equinox might be preferred because first at that time the day begins to be longer than the night and because it belongs to the moist season...the summer solstice because the longest day occurs at that time and because to the Egyptian it signifies the flooding of the Nile and the rising of the dog star; the autumn equinox because all the crops have by then been harvested, and a fresh start is then made with the sowing of the seed of future crops; and the winter solstice because then, after diminishing, the day first begins to lengthen."[24]

In practice Greek astronomers adopted the vernal equinox as the start of the year, as Ptolemy writes (concerning the ecliptic) elsewhere in the *Tetrabiblos*:

> Although there is no natural beginning...they assume that...the vernal equinox... is the starting point of them all.[25]

The vernal point, i.e., the location of the Sun in the ecliptic at the time of vernal equinox, was adopted in Greek astronomy as the beginning of the ecliptic, apparently because the vernal equinox was considered by Greek astronomers as the start of the year. This represents another point of difference between Greek and Babylonian astronomy. Since the Babylonian year consisted of twelve or thirteen lunar months, the start of the year was related to a lunar phenomenon, namely the appearance of the first new Moon of the year, which was, generally speaking (at least in later Babylonian times), the new Moon falling nearest to the vernal equinox. However, as early as the fifth century B.C., the Greek astronomer Euctemon defined a season calendar, consisting of twelve (approximately) equal solar months, related to the solar phenomena of equinoxes and solstices[26]. The months in Euctemon's calendar have the same names – the equivalent Greek names – as the signs of the zodiac in Babylonian astronomy. Thus the solar month commencing on the day of the vernal equinox was called by Euctemon the *month of Aries*. Similarly, the solar month commencing on the day of the summer solstice was called the *month of Cancer* (see Figure 1). This calendar system is the forerunner of the application of the tropical zodiac that is still in vogue today, whereby someone born in the (approximately) 30-day period following the summer solstice (the solar month of Cancer) is said to be "born under Cancer."

At first glance it might seem that Euctemon's seasonal calendar came to serve in Greek astronomy as the basis for the division of the ecliptic known as the *tropical zodiac*. This new zodiac, in which the ecliptic (instead of the zodiacal belt) was divided into twelve zodiacal signs, is generally believed, as discussed above, to have been introduced into astronomy by the Greek astronomer Hipparchus in the second century B.C., although it is not known whether or not Hipparchus had any acquaintance with Euctemon's calendar. In fact, a case can be made for Euctemon as the originator of the tropical zodiac. Although he did not actually define the tropical zodiac, his calendar provides a theoretical basis

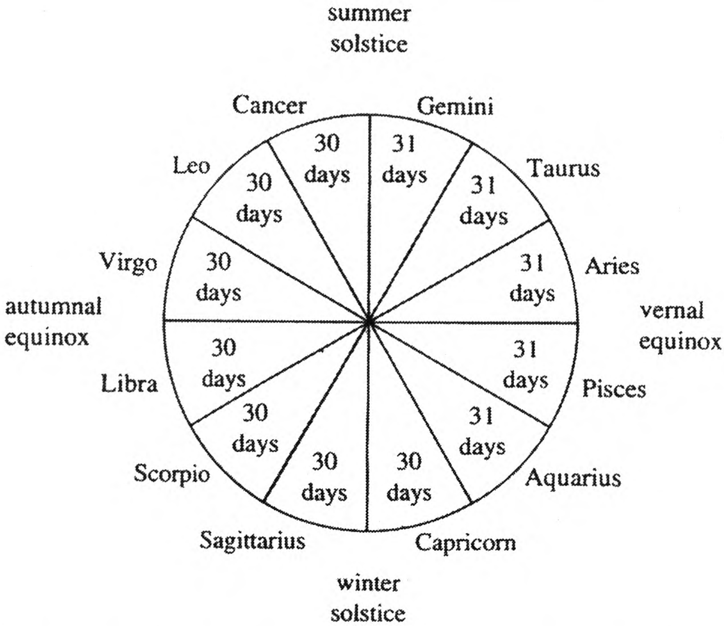

Fig. 1. Euctemon's seasonal calendar, with twelve solar months.

for the tropical zodiac, which can be regarded as a spatial projection of the time division into twelve solar months specified by Euctemon's calendar. Thus, the twelve signs of the tropical zodiac correspond to the location of the Sun during the twelve solar months in Euctemon's tropical calendar.

The division of the ecliptic given by the tropical zodiac is exactly analogous to the division of the zodiacal belt into twelve zodiacal signs by Babylonian astronomers. Just as Babylonian astronomers divided the *zodiacal belt* into twelve 30-degree signs, so in Greek astronomy, analogously, the *ecliptic* was divided into twelve 30-degree signs beginning with the vernal point, and these signs correspond to the twelve solar months in Euctemon's calendar. The tropical zodiac, as mentioned above, is effectively a spatial projection of the time-based division (twelve solar months) of Euctemon's seasonal calendar. The difference between the signs of the zodiac in the Greek tropical zodiac and those in the Babylonian sidereal zodiac is that the former comprise a division of the ecliptic, the apparent path of the Sun, into twelve 30-degree sectors, while the latter constitutes a twelvefold division of the zodiacal belt of fixed stars into twelve equal 30-degree segments. The Babylonian sidereal division is based on the spatial arrangement of fixed stars in the zodiacal belt, while the Greek tropical zodiac – when conceived of as a spatial projection of Euctemon's tropical calendar – can be seen in relation to the seasonal cycles of the year. Aratus, when speaking of the vernal equinox and the beginning of spring, writes:

> In it the days are equal to the nights...the sign appointed for it is the Ram.[27]

H. Vogt, in his analysis of the stellar positions given by Hipparchus in his *Commentary to Aratus*, converted them to ecliptic coordinates, in terms of the signs of the tropical zodiac, starting with the vernal point as 0 degrees of the sign of Aries[28]. He found that the stellar longitudes thus derived are compatible with the location of the vernal point in the year 139 B.C. The error in stellar longitude measured from the vernal point is statistically at a minimum for the year 139 B.C.[29] Hipparchus was certainly making observations of the stars at this time, but this date cannot necessarily be taken as precisely defining the epoch of his stellar observations recorded in the *Commentary to Aratus*, since it depends upon an accurate location of the vernal point, which degree of accuracy Hipparchus did not necessarily achieve. However, it is almost certainly true that the epoch of these stellar observations made by Hipparchus was *around* this date of 139 B.C. A remark by Ptolemy leads to the conclusion that Hipparchus made the later observations, that he recorded when compiling his star catalog, in 129 B.C.[30] The earlier stellar observations, those recorded in the *Commentary to Aratus*, were probably included in Hipparchus' star catalog that was drawn up later (but which is no longer extant).

In consideration of the fixed star catalog given in *Liber Hermetis Trismegisti*, the stellar longitudes, measured from the vernal point and expressed in terms of degree and sign in the tropical zodiac, are compatible with the location of the vernal point between 130 and 60 B.C.[31] To illustrate the radical difference between the Greek tropical zodiac based on the ecliptic, and the Babylonian sidereal zodiac which is related to actual stellar configurations, it suffices to consider the longitude of the 1st magnitude star Regulus, the "heart of the Lion" in the constellation of Leo. In the Babylonian zodiac Regulus is located at 5° Leo, i.e., at 5 degrees in the sidereal sign of Leo. In the Hermetic star catalog, however, the longitude of Regulus is given as 28° Cancer, i.e., at 28 degrees in the tropical sign of Cancer[32]. Measuring Regulus to be 28 degrees from the summer solstice point meant that it fell in the tropical sign of Cancer, although (as the "Lion's heart") it clearly belongs to Leo. In Greek astronomy, as pioneered by Hipparchus, the signs of the zodiac became defined by the path of the Sun in relation to the equinoxes and solstices, and not to the background of fixed stars. The location of stars in the zodiacal belt for (post sixth century) Babylonian astronomers was fixed *by definition* in the twelve signs/constellations comprising the zodiacal belt, but the Hermetic star catalog reveals a quite different principle, namely the measurement of the location of fixed stars in relation to the apparent path of the Sun along the ecliptic associated with the seasons of the year.

The most famous star catalog of antiquity, that of Ptolemy (epoch date A.D. 138), follows the same principle as the Hermetic star catalog. The longitude of the 1022 stars cataloged by Ptolemy are expressed by degree (and fraction of a degree) in the signs of the tropical zodiac, giving also their latitudes north or south of the ecliptic. As Ptolemy himself points out, his catalog was compiled independently of, but was based on, former catalogs:

> We have not used for each of the stars altogether the same formations as our predecessors, just as they did not use the same as their predecessors. But often we use others according to the greater propriety and fittingness of the configurations – as, for example, when those stars which Hipparchus places in the shoulders of the Virgin, we call her sides because their distance from the stars in the head appears greater than that from the hands.[33]

In contrast to the Babylonian division of the zodiacal belt into twelve equal signs, Ptolemy's star catalog defined a division of the zodiacal belt into twelve unequal constellations, known as the *astronomical zodiac.*

The emergence of the astronomical zodiac as specified by Ptolemy in the second century A.D. was the culmination of a long history of divisions of the zodiacal belt, which is roughly traceable as follows: from the Normal Star system (seventh century B.C.), to the Babylonian zodiac (sixth or early fifth century B.C.), then to the zodiac of Hipparchus' star catalog (second century B.C.), and finally to the zodiac defined by Ptolemy's star catalog (second century A.D.). This "history" offers a purely schematic outline and, of course, the actual development was much more complex.

It is evident among civilizations of antiquity that long before the seventh century B.C. there was a perception of the stellar universe which was not just in terms of individual stars but rather consisted of grouping certain stars together into constellations – not just the twelve constellations belonging to the zodiacal belt, but also extra zodiacal constellations. An expression of this relationship to the world of stars in antiquity can be found in ancient myths and folklore relating to the constellations[34]. Ptolemy's star catalog may be considered as a kind of "crystallization" of the ancient constellations, a definition of that which, with the exception of the precise definition of the zodiacal signs/constellations given by the Babylonians, was previously largely undefined. The Greek names for the twelve constellations making up the zodiac are seen in most cases to be direct translations from the corresponding Babylonian names for the twelve signs of the Babylonian fixed star (sidereal) zodiac. However, the names given by Ptolemy to many of the 36 extra zodiacal constellations in his catalog are of obscure origin, such as *Coma Berenices*, which was evidently added to the ancient constellations about 200 B.C.[35] In addition to the twelve zodiacal constellations, it is clear from Ptolemy's star catalog that by the second century A.D. 36 extra-zodiacal constellations were known.

As already pointed out, Ptolemy's star catalog, like the Hermetic star catalog, lists the longitudes of stars in terms of the tropical zodiac, which is a mathematical division of the ecliptic into twelve 30-degree signs starting with the vernal point as 0 degrees of the (tropical) sign of Aries. The fact that the pictorially defined zodiacal constellations (from Ptolemy's star catalog) and the mathematically defined signs of the tropical zodiac have the same names has led to confusion between the two systems, especially since they almost exactly coincided at the time that Ptolemy compiled his catalog. It is also to be noted in Ptolemy's catalog that, owing to the unequal lengths of the pictorially defined divisions (in relation to the equal-length mathematical division of the tropical zodiac), stars of one zodiacal constellation sometimes fall into another sign of the tropical zodiac (a sign with a different name). For example, Ptolemy locates the star 98K in the constellation of Virgo, and at the same time he gives its longitude as 7 degrees 20 minutes in the tropical sign of Libra[36].

Since the constellations in Ptolemy's star catalog are pictorially described, strict boundaries between them are not clearly defined (by longitude in the tropical zodiac, for example). In fact, owing to the complex shape of the constellations, it is not generally possible to draw distinct lines at given longitudes in order to separate them. Some long constellations like Hydra extend above or below several zodiacal constellations (in the case of Hydra, below Cancer, Leo, Virgo and Libra), and one extra zodiacal constellation, Ophiucus, actually straddles the ecliptic in the region of the constellation of Scorpio.

Ptolemy's star catalog is of central importance in the history of astronomy for two fundamental reasons: (1) the constellations in this star catalog are based on earlier divisions of the celestial sphere, and thus can be considered as the product of a historical development which reached its culmination with Ptolemy; and (2) it formed the basis for nearly all subsequent star catalogs – in particular for the modern formal definition of the celestial sphere into constellations drawn up by the International Astronomical Union (IAU) in 1928, which ultimately is based on Ptolemy's star catalog[37].

It is often assumed that Ptolemy inherited the star catalog of Hipparchus and simply adjusted it for his own time by taking account of the amount of precession between the time of Hipparchus and his own. However, the fact that, with respect to (1), as already pointed out, Ptolemy made adjustments to the definitions of the constellations that were transmitted to him indicates that his star catalog was compiled to a certain extent independently of that of Hipparchus and other predecessors. It is evident that Ptolemy changed the appearance of two zodiacal constellations radically[38], but otherwise it is generally assumed that his changes to the configurations described by his predecessors were probably more "cosmetic" in nature. Thus, his star configurations are believed to agree reasonably well with the earlier groupings into constellations, apart from minor adjustments. For example, the agreement between the Babylonian zodiac and the astronomical zodiac, as defined by Ptolemy's star catalog, is reasonably close, with the exception of the boundary between Virgo and Libra. The Babylonian zodiac can be considered as a "good fit" around the zodiacal belt – with the mathematically desirable property of consisting of twelve equal fixed star divisions – in relation to Ptolemy's astronomical zodiac and, by supposition, to other divisions of the zodiacal belt prior to Ptolemy's such as that of Hipparchus and that of *Liber Hermetis Trismegisti*.

With respect to (2), namely the use of Ptolemy's star catalog as the standard definition of the celestial sphere into constellations, the great importance of Ptolemy's catalog cannot be underestimated. From the time of its compilation in the second century A.D. it was not until the publication of Johann Bayer's *Uranometria* in 1603 that significant additions to the 48 configurations in Ptolemy's catalog became included. These new constellations – twelve new southern constellations were added – are those that are visible from the southern hemisphere. Altogether a total of 40 new southern constellations have been added to Ptolemy's original 48, bringing the number of constellations up to 88. Distinct boundaries between the constellations were drawn up by Johann Bode in his *Uranographia* (1801), and definitive boundaries were specified at the IAU conference of 1928. The IAU specification of the boundaries is fairly complex, defined by a system of arcs of constant right ascension and declination for the equinox of 1875[39]. In relation to the zodiacal belt, a simple and straightforward division into twelve zodiacal constellations is hardly possible from the IAU definition, as some of Ophiucus, which was previously ignored when considering the zodiacal belt, ought now to be taken into consideration according to the IAU definition. To do this the IAU constellation boundaries given as arcs of constant right ascension and declination have to be converted into ecliptic longitude and latitude.

By converting to ecliptic coordinates the *modern astronomical zodiac*, a version of Ptolemy's twelve zodiacal constellations in which the twelve constellations are separate and non-overlapping and occupy the 360-degree circle of the zodiacal belt, can be derived. Generally the part of Ophiucus that straddles the ecliptic is ignored and instead only the constellation of Scorpio is taken into consideration in this region of the ecliptic (in order to keep to the twelvefold division of the constellations of the zodiac)[40]. The modern astronomical zodiac that is used conventionally in popular astronomy of the present day is derived from the IAU defined constellations, which in turn – at least for the original 48 constellations – are based ultimately on the depictions of the constellations given by Ptolemy in his star catalog in the *Almagest*. The approximate location of the boundaries of the constellations of the modern astronomical zodiac in relation to the Babylonian zodiac is shown in Figure 2. Although the modern astronomical zodiac has an independent origin (originally based on Ptolemy's observations) from that of the earlier Babylonian zodiac, there is by and large not a great deal of difference between them. Most of the constellations of the unequal length divisions of the astronomical zodiac can be derived from the Babylonian equal division signs simply by shifting the boundaries of the signs a few degrees – with the exception of the boundary between Virgo and Libra, where the astronomical constellation of Virgo extends almost halfway into the Babylonian sign of Libra. With this exception, it can be seen that the astronomical zodiac stemming from Ptolemy's star catalog could be regarded theoretically as a modification of the division of the zodiacal belt by Babylonian astronomers into twelve 30-degree signs. Whether or not one considers the prototype of the astronomical zodiac drawn up by Ptolemy to be the Babylonian zodiac, a basic similarity between the two is apparent (see Figure 2).

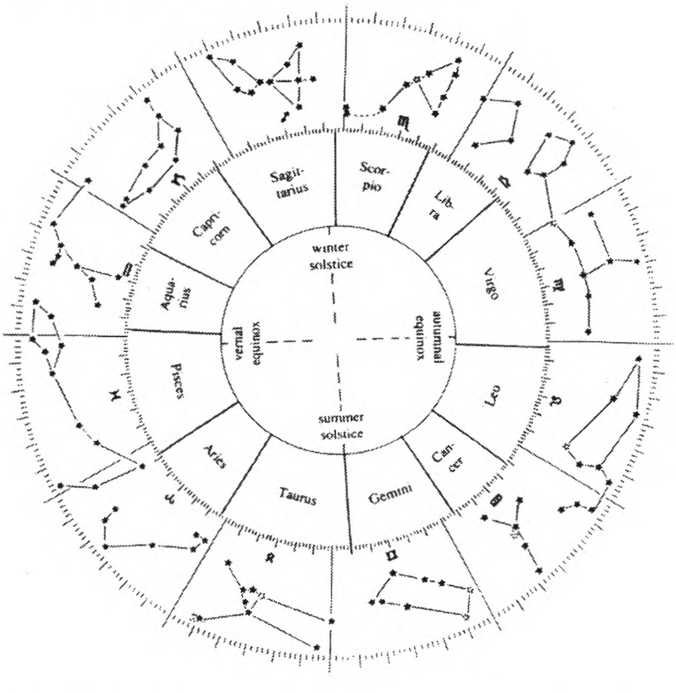

Fig. 2. The modern astronomical zodiac and the Babylonian sidereal zodiac.

Figure 2: The modern astronomical zodiac in relation to the Babylonian sidereal zodiac (with the vernal point as it stands at the present time located at approximately 5 degrees Pisces in the Babylonian zodiac) with twelve equal (30°) fixed star (sidereal) signs in the outer circle, and the inner circle shows the twelve unequal length constellations of the astronomical zodiac according to the IAU definition made in 1928.

To summarize, three zodiacs have been mentioned in this paper:

(1) The *Babylonian sidereal zodiac* consisting of twelve equal (30°) fixed star signs.

(2) The *Greek tropical zodiac* consisting of twelve equal (30°) tropical signs.

(3) The *astronomical zodiac*, originally specified by Ptolemy's star catalog, consisting of twelve unequal constellations. In its present form this is the *modern*

astronomical zodiac used in popular astronomy of the present day, formally defined by the IAU in 1928, in which the boundaries of the twelve pictorially described zodiacal constellations specified by Ptolemy have received a fixed definition. Figure 2 shows the relationship between the modern astronomical zodiac and the Babylonian zodiac.

Przypisy

[1] Cf. O. Neugebauer, *A History of Ancient Mathematical Astronomy* (3 vols; Berlin-Heidelberg-New York, 1975), vol. i, p. 278 and p. 283. Hereafter cited as HAMA.

[2] W.K. Pritchett – B.L. van der Waerden, "Thucydidean Time-Reckoning and Euctemon's Seasonal Calendar," *Bulletin de Correspondance Hellénique* 85 (1961), pp. 17–52.

[3] Cf. O. Neugebauer, HAMA i, pp. 309–315.

[4] B.L. van der Waerden, *Science Awakening, vol. II: The Birth of Astronomy* (Noordhoff International Publishing, Leyden, 1974), p. 266.

[5] This location of the vernal point in the Babylonian sidereal zodiac for the year 500 B.C. agrees with Peter Huber's specification of the zero point of the Babylonian zodiac. Cf. P. Huber, "Über den Nullpunkt der babylonischen Ekliptik," *Centaurus* 5 (1958), pp. 192–208.

[6] B.L. van der Waerden, op. cit., p. 246.

[7] Based on an average rate of motion of the vernal point of one degree in 72 years, it would have moved backwards from 10 degrees Aries in 500 B.C. to 0 degrees Aries in about A.D. 220 – moving ten degrees in 720 years, in agreement with Peter Huber's specification referred to in note 5.

[8] O. Neugebauer, HAMA i, p. 278.

[9] Ptolemy, *Tetrabiblos* I, 22: "It is reasonable to reckon the beginnings of the signs also from the equinoxes and solstices" (trsl. F.E. Robbins, Loeb Classical Library, 1980, p. 109). Ptolemy wrote the *Tetrabiblos* around A.D. 150, at which time the vernal point was at 1 degree Aries in the Babylonian sidereal zodiac.

[10] Manilius, *Astronomica*, introduction by G.P. Goold, pp. lxxxii–lxxxiii (Loeb Classical Library, 1977). [Additions in brackets by R.A. Powell].

[11] According to Peter Huber's specification of the zero point of the Babylonian sidereal zodiac, as we have already seen in notes 5 and 7, the vernal point at the time of Ptolemy (ca. A.D. 150) was located at about 1 degree Aries. Going back from Ptolemy almost three hundred years to Hipparchus, the vernal point was located at 5 degrees Aries in about 140 B.C., since it moved four degrees in approximately 288 years. Similarly, going forward from the time of Ptolemy to the present time, again allowing a rate of precession of 1 degree in 72 years, the present location of the vernal point must be around 5 degrees Pisces, a movement of approximately 26 degrees backwards through the zodiac from A.D. 150 to A.D. 2022 ($26 \times 72 = 1872$ added to A.D. $150 =$ A.D. 2022).

[12] Manilius, *Astronomica*, introduction by G.P. Goold, pp. lxxxiii–lxxxiv (Loeb Classical Library, 1977).

[13] *Hephaestionis Thebani Apotelesmaticorum Liberi Tres* (2 vols., ed. D. Pingree, Leipzig, 1971, 1973).

[14] O. Neugebauer, HAMA, vol. ii, p. 960.

[15] A. Sachs, "A Late Babylonian Star Catalogue," *Journal of Cuneiform Studies* 6 (1952), pp. 146–150.

[16] All known Greek astrological texts have been collected and published, cf. *Catalogus Codicum Astrologorum Graecorum* (12 vols; Brussels, 1898 to 1953).

[17] It is customary to ascribe a catalogue of stars to Eratosthenes, but as O. Neugebauer points out: "There remains no trace of a catalog of stars by Eratosthenes" (HAMA i, p. 288).

[18] *Hipparchi in Arati et Eudoxi Phenomena Commentarium* (ed. and German trsl. C. Manitius, Leipzig, 1894). The second part of the *Commentary to Aratus* contains a large amount of observational material which it is reasonable to assume was later included in Hipparchus' lost star catalog, cf. O. Neugebauer, HAMA i, p. 281.

[19] Cf. W. Gundel, "Neue astrologische Texte des Hermes Trismegistos," *Abhandlungen der Bayerischen Akademie der Wissenschaften,* NF 12 (1936), reprinted with an appendix by H.G. Gundel, Hildesheim, 1978.

[20] Cf. O. Neugebauer, HAMA i, pp. 274–292, esp. p. 276.

[21] Cf. O. Neugebauer, *The Exact Sciences in Antiquity* (Providence, 1957), pp. 68f. Hereafter referred to as ESA.

[22] Cf. O. Neugebauer, HAMA i, p. 278 and p. 283.

[23] Cf. O. Neugebauer, HAMA i, p. 283.

[24] Ptolemy, *Tetrabiblos II*, 10 (ed. and trsl. F.E. Robbins, Cambridge, Mass., 1940. p. 195).

[25] Ibid., *Tetrabiblos I*, 10 (Robbins, pp. 59/61).

[26] Cf. W.K. Pritchett – B.L. van der Warden, "Thucydidean Time-Reckoning and Euctemon's Seasonal Calendar," *Bulletin de Correspondance Hellénique* 85 (1961), pp. 17–52.

[27] Aratus, *Phaenomena* (trsl. G.R. Mair, Loeb Classical library, London, 1955, p. 247).

[28] H. Vogt, "Versuch einer Wiederherstellung von Hipparchs Fixsternverzeichnis," *Astronomische Nachrichten* 224 (1925), Nr. 5354–55, cols. 17–54.

[29] Cf. O. Neugebauer, HAMA i, p. 284, n. 19.

[30] Cf. O. Neugebauer, HAMA i, p. 275.

[31] Cf. O. Neugebauer, ESA, pp. 68f.

[32] Cf. W. Gundel, op, cit., p. 24, line 5 and p. 148, star no. 8.

[33] Ptolemy, *Almagest* VII, 4 (trsl. R.C. Taliafero, *Great Books of the Western World*, vol. 16, Chicago, 1952, pp. 233–234).

[34] Aratus, *Phaenomena* (trsl. G.R. Mair, Loeb Classical Library, 1955) is the classic reference concerning the constellations as well as being an excellent instructional poem about celestial phenomena.

[35] Cf. *Norton's Star Atlas* (16th. Edition, 1973, p. 86).

[36] Ptolemy, *Almagest* VII, 5/VIII, 1 (trsl. R.C. Taliafero, op. cit., pp. 244–282, esp. p. 261).

[37] Cf. *Transactions of the International Astronomical Union* iii (1929), p. 13.

[38] Ptolemy made striking changes to the constellations of Virgo and Libra. When compared with ancient depictions such as those from Egypt, cf. O. Neugebauer and R.A. Parker, *Egyptian Astronomical Texts, vol. III: Plates* (Brown University Press, 1969), Plates 40 and 43 (to mention only two), these clearly depict the constellation of Virgo *as a standing figure* and the constellation of Libra *with a standing figure holding the scales*, whereas Ptolemy describes the Virgin as a *reclining* figure and has *no figure* holding the scales. It can be assumed that these Egyptian representations of the zodiacal figures are based on images of the figures of the Babylonian zodiac which became known in Egypt when the Babylonian zodiac became transmitted to Egypt around 300 B.C. in the wake of Alexander the Great's conquest of Babylon and his founding of the city of Alexandria some thirty years previously.

[39] Cf. E. Delporte, *Atlas céleste* (Cambridge, 1930) and *Délimitation scientifique des constellations* (Cambridge, 1930).

[40] In the modern astronomical zodiac the Sun passes through the constellation of Scorpio in the period from 23 November to 18 December at the present time. However, if Ophiucus is included as a thirteenth zodiacal constellation, the Sun's passage through Scorpio is only from 23 November to 29 November, and its passage through Ophiucus is from 29 November to 18 December (all dates may vary by a day or so).

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GRECKIE KATALOGI GWIAZD I WSPÓŁCZESNY ZODIAK ASTRONOMICZNY

Układem odniesienia dla późnej astronomii babilońskiej był starożytny zodiak gwiazdowy Babilonczyków oparty na podziale pasa zodiakalnego gwiazd stałych na dwanaście równych znaków/konstelacji zodiaku. W astronomii greckiej, przynajmniej od czasu Hipparcha a nawet nieco wcześniej, dokonała się zmiana perspektywy – to nie tło gwiazd stałych, lecz trajektoria Słońca w jego pozornym ruchu rocznym, tj. ekliptyka, stała się astronomicznym układem odniesienia, w oparciu o który wyznaczano ruchy planet. W ten sposób, posługując się kategoriami współrzędnych ekliptycznych, wyznaczono nowy zodiak – zodiak zwrotnikowy. Powszechnie sądzi się, że nowy zodiak został wprowadzany do astronomii przez Hipparcha, jednak Hipparch nie stosował – przynajmniej w ogólnie przyjętym rozumieniu – współrzędnych ekliptycznych dla gwiazd, które skatalogował w swym *Komentarzu* do *Aratosa*. Jest jednocześnie faktem, że wkrótce po epoce, w której żył i działał Hipparch, system współrzędnych ekliptycznych w postaci systemu długości ekliptycznych zodiaku zwrotnikowego posłużył jako podstawa opracowania katalogu gwiazd, zachowanego w łacińskim tekście *Liber Hermetis*

Trismegisti (Księga Hermesa Trismegistosa); podobnie było dwa i pół wieku później w przypadku katalogu gwiazd Ptolemeusza, zamieszczonym w jego Almageście (uwzględniono tu także szerokość ekliptyczną). Swoistym prekursorem zodiaku zwrotnikowego – chociaż w formie kalendarza – był kalendarz słoneczny Euktemona, nie wiadomo jednak czy był on znany Hipparchowi. Współczesny zodiak astronomiczny oparty jest na ptolemejskim katalogu 48 gwiazdozbiorów, do których dodano 40 nowych konstelacji odkrytych i wyznaczonych w okresie od XVI wieku, kiedy to rozpoczęły się dokładne obserwacje nieba z półkuli południowej.