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An astronomical analysis of the data in the pseudo-Hipparchus palimpsest in the Codex Climaci Rescriptus

Gerd Grasshoff
Institut für Philosophie, Humboldt Universität zu Berlin, Germany

Susanne M. Hoffmann
Friedrich Schiller University Jena/Michael Stifel Center Jena, Germany

Abstract
In 2022, Gysembergh *et al.* published a paper in *JHA* claiming 'New evidence for Hipparchus' Star Catalogue'. In this paper we challenge this hypothesis by stating that (a) we disagree with their astronomical dating and find inconsistencies by using the given numbers, and (b) the terminology and the data format used in the palimpsest do not match Hipparchus or anybody else. Therefore, the palimpsest does not prove anything about Hipparchus's star catalogue nor did Hipparchus use rectangular constellation borders. Specifically, the constellation of Corona Borealis, typically depicted as a circle since Babylonian times, is not considered a rectangle by Hipparchus. Furthermore, a palimpsest that cannot be dated properly does not confirm the long-known relationship between Hipparchus and Ptolemy as the authors claim.

Keywords
Hipparchus, palimpsest, Ptolemy, star catalogue

Introduction

Peter J. Williams published a newly discovered palimpsest of the mediaeval *Codex Climaci Rescriptus* (henceforth *CCR*).[1] In *JHA* 55, 4, Gysembergh, Williams and Zingg[2]

Corresponding author:
Susanne M. Hoffmann, Friedrich Schiller University Jena/Michael Stifel Center Jena, Jena 07737, Germany.
Email: susanne.hoffmann@uni-jena.de

proposed an interpretation of one fragment, claiming that it contains new evidence for Hipparchus' lost Star Catalog being significantly more accurate than his successor Claudius Ptolemy.

In this article, we check their astronomical interpretation. Thankfully, we made use of the edition and translation of Hipparchus's *Commentary to Aratus and Eudoxus* by Manitius (1894),[3] the unpublished English translation by MacFarlane and Mills provided in 2014,[4] Toomer's (1984)[5] translation of the *Almagest* that is based on Heiberg's (1898) edition of the text and the free astronomy software *Stellarium*.[6] Additionally, we have drawn on a dissertation on the reconstruction of Hipparchus's celestial globe[7] whose findings were not considered by the interpretation of the palimpsest presented by Gysembergh *et al.*

Extraction of information

The text preserves a characterization of the constellation Corona Borealis (στέφανος) as a constellation of the northern hemisphere (ἐν τῷ βορείῳ ἡμισφαιρίῳ). In antiquity, a constellation was considered 'northern' if it was north of the ecliptic. However, the constellation is both, 'north of the ecliptic' and 'north of the equator', so this statement does not point to any specific coordinate system. The equatorial coordinate system would be the more intuitive one because of the continuous apparent motion of the celestial sphere during the night. However, the star catalogue in Ptolemy's *Almagest* uses an ecliptic coordinate system in order to provide stability one coordinate (latitude) over time and make the other coordinate (longitude) easily computable for readers in the centuries to come after the author.[8] In another book (*Alm.* V), Ptolemy describes a complex instrument of multiple rings with which he claims to be able to measure the ecliptic coordinates directly.[9] Gysembergh *et al.* (2022) claim to have found that Hipparchus used an armillary sphere and that he used an equatorial frame of reference. Hence, this hypothetical armillary sphere would be different from the instrument described in the *Almagest*. As there is no older description of an armillary sphere (only a later one, called 'meteoroscope' in Ptolemy's *Geography*[10] which is even more complex than the one described in the *Almagest* consisting of six rings instead of eight), there is no reason to conclude from the numbers found in the palimpsest that Hipparchus used an armillary sphere.

The text of the palimpsest continues with a rough characterization of the area of Corona Borealis in the sky by its northernmost, southernmost, easternmost and westernmost star. The westernmost point of a constellation does not automatically imply a westernmost line of a rectangle[11]; a circle would also have a westernmost point. The modern readers seem to derive the rectangle from the fact that a point is simultaneously northernmost and easternmost but considering the spherical motion of the sky this conclusion is not necessary. The width and height of the area in degrees on the sphere indicate roughly an area but not necessarily a boundary box. The *CCR* fragment mentions three stars with the data compiled in Table 1:

Table 1. Extracted information from the *CCR* fragment. The circles parallel to the celestial equator are today measured from the equator and this angular separation is called 'declination'; alternatively, they could be measured from the pole (with an angular distance called 'co-declination' or 'polar angle')[12] or from any other parallel circle (as Hipparchus and Aratus do it).[13]

Designation of star in *CCR*	Modern identification	Role of star in constellation according to *CCR*	Given number	Polar angle 90°-DE	Declination DE
The star to the west next to the bright one	β CrB	Westernmost ['leads']	Sco 0.5		
The fourth star to the east of the bright one	ι CrB	Northernmost and easternmost ['last'][14]		49°	41°
The southernmost, the third counting from the bright one towards the east	δ CrB	Southernmost		55° ¾	34° ¼

We will examine whether they are taken from Hipparchus' texts. His *Commentary* on the poem by Aratus and a now lost star catalogue (or register) by Eudoxus has three parts. In the first part, Hipparchus discusses inaccuracies in the popular verses and their supposed source in Eudoxus's writings. In the second part, Hipparchus presents his own very schematic way of describing risings and settings of constellations with simultaneous culminations. As culminating stars are a measure of time, Hipparchus appends a list of 'hour stars', that is, stars marking hour lines (or lines of right ascension/hour angle as it is called in our terminology), which forms the third part of his book. This last part already demonstrates that right ascensions are used by Hipparchus and there is no need for this to be proven by modern scholarship. The research question on Hipparchus' coordinate system targets the state of the ecliptic coordinate system: (i) did he use orthogonal ecliptic coordinates in his lost star catalogue, which Ptolemy could have directly copied? (ii) did Hipparchus measure direct ecliptic coordinates (which Ptolemy claims to have performed with the armillary sphere in *Alm*. V), or was the equatorial 'longitude' in his star catalogue (the right ascension) measured with a clock, or were they even copied from earlier Greek or Babylonian measurements? These questions are discussed in Hoffmann, *Hipparchs Himmelsglobus* but the new *CCR* manuscript is unfortunately not able to contribute to this research.

Hipparchus's frame of reference in the first and second part of his *Commentary* is bound to Aratus's description and therefore uses simultaneously rising/setting ecliptic degrees and simultaneously culminating ecliptic degrees. This is not an orthogonal coordinate system. For example he states in I.5.4

> For, no star lies under the one in the tip of the Dragon's tail, except the northern of those which lead in the Rectangle [of UMa]. The star in the tip of the Dragon's tail holds its place on a parallel circle at about 3° of the Lion. And the star in question, the one of the Rectangle, holds its place a little less than 3° of the Lion.

Here, Hipparchus describes the position of two culminating stars (λ Dra, α UMa) by stating that the point of the ecliptic 'Leo 3° culminates simultaneously. Rephrased in our mathematical language, he states that this point and the two stars share a common right ascension (which we are able to compute with a simple coordinate transformation[15] of the point with ecliptic coordinates (λ, β) = (Leo 3°, 0) to equatorial coordinates). Although he does not mention a specific equatorial coordinate (RA, DEC), it is clear from geometry that he uses an equatorial frame of reference although the only given number is on the line of the ecliptic.

Similar passages are found in I.7.11[16] where he connects a star in the 'middle of the heaven' (culminating) to a simultaneously culminating point of the ecliptic and a simultaneously rising point of the ecliptic, and in II.2.25[17] where he directly gives a declination of a star. Thus, there is absolutely no doubt from Hipparchus directly that he used both orthogonal equatorial coordinates, right ascension and declination. However, this does not at all prove anything concerning his lost star catalogue because its format might have deviated from the direct measurements and the information read from a globe (an analogue calculator) which he used to write his *Commentary*. For instance, Hoffmann, *Hipparchs Himmelsglobus*[18] pointed out that Hipparchus while writing his *Commentary* did not use magnitudes. If Pliny's[19] claim is correct that he measured (and possibly invented) magnitudes as an expression of stellar brightness for his lost star catalogue and the surviving *Commentary* does not witness them, there could have been a step of reformatting in between. In other words: it is not excluded that Hipparchus observed equatorial coordinates and computed ecliptic coordinates from them using a globe or an analemma instrument, as Sidoli has also suggested.[20]

Comparison of terminology

Number format

Half degrees. The new palimpsest states for Corona Borealis: 'τοῦ σκορπίου τῆς $\overline{\alpha}$ μ°τὸ ἥμισυ' which is translated by Gysembergh *et al.* (Note 2) as '0.5 degrees of the Scorpion'. Literally it is written 'of the Scorpion of the first degree the half' better rendered as 'the half of the first degree of the Scorpion'.

When Hipparchus refers to the first part of an ecliptic sign, his terminology is ἀρχή (origin or beginning) because zero as a number was not yet in use. In Book III, V.8 he describes the hour circle of β CrB in these terms: 'The second one-hour interval is delineated at about the beginning of (ἀρχή) the Scorpion by . . . '. The number '0.5°' or 'zero plus a half' is not easily expressible with 'a half after the origin' and he uses another number format anyway. In case of the hour stars Hipparchus mentions intervals of angular separation from the hour line. In his originally own text on rising and setting constellations,[21] half degrees are expressed with a reference to the next full degree, for example,

Table 2. Comparison of wording in the palimpsest and Hipparchus.

Wording in the palimpsest	Wording in Hipparchus's text
[sign name] τῆς α̅μ̊ τὸ ἥμισυ	[sign name, number] μοίρας μέσης

in the case of the rising of the Crown[22]: Χηλῶν ε' μοίρας μέσης (. . . the fifth degree halved),[23] in our numbers: 4.5° (or 5° minus a half). The case of the first half degree of a sign would be given by Hipparchus as 'the first degree halved' as proven in the case of the rising of the Snake[24]: ἕως Τοξότου μοίρας α' μέσης ('the first degree halved' or 1° minus a half). Although the mathematical meaning is the same, Hipparchus differs from wording in the new palimpsest which gives 'one degree, the half' (cf. Table 2).

Hipparchus's manuscript has the schema '[constellation] rises/sets with the fraction of the ecliptic from X to Y'. Thereafter, he gives the stars that he used to determine these degrees. In contrast, the palimpsest directly speaks of star coordinates. Hoffmann, in her reconstruction of Hipparchus's globe, argued that this globe was embedded in a (wooden?) horizontal plane and had a physical (wooden?) meridian circle.[25] Hipparchus would have used this globe to write his scholarly commentary on Aratus and, as physically built circles and planes have a thickness, these tools of measurement will have covered a fraction of the globe's scales (e.g. the scale engraved in the ecliptic). Hippachus's 'μοίρας' would therefore not refer to points (ticks on a line) but to the segments of the great circle that are covered by a physically built plane or circle. Together with the fact that the smallest unit Hipparchus uses is 0.5°, this leads to the conclusion that the built measurement tools on his globe covered sections of half degrees.[26]

Rendering of size. An additional issue is the terminology concerning the size of a constellation. The palimpsest uses the terms 'length' and 'width' which is interpreted by Gysembergh *et al.* as referring to the extent in ecliptic longitude and latitude, respectively. In Hipparchus's preserved text on the rising and setting of constellations, he does not use these terms. His rather schematic descriptions of the simultaneously rising/setting and culminating degrees of the ecliptic are always concluded with the statement about the duration of the process of rising or setting of the specific constellation. For Corona Borealis, his data of simultaneously passing ecliptic degrees is summarized in Table 3: supposing that he took one of these intervals as 'length' of the constellation, would that be the 7.5°λ (or 10.5°λ) that transit the horizon simultaneously during the rising (setting) or one of the intervals of culmination?

Table 3 shows that for Hipparchus, the rising Crown was shorter than the setting Crown. This is a strong argument against the claim by Gysembergh *et al.* that there had been constellations borders similar to those internationally defined in the 1920s.[27]

Thus, Gysembergh *et al.* interpret their text in the *CCR* as a *rephrasing* of Hipparchus's terminology concerning half degrees by the later scribe. Furthermore, Hipparchus does not speak about the 'length' and 'width' of a constellation but only about the *duration* of its rising and setting. Hipparchus does not give degrees but hours (or fractions of hours) to describe their size which again emphasizes the rephrasing. *The palimpsest does not have Hipparchus's terminology and style!*

Table 3. Data given by Hipparchus and intervals computed by us (bold).

Hipparchus' data			**Interval**	Hipparchus' data		**Interval**	Duration (min)
	At the horizon		Length	Culmination		Length	
	From λ_{H1}	To λ_{H2}		From λ_{C1}	To λ_{C2}		
Rise of CrB (Book. II, V.2)	Vir 27	Lib 4 1/2	**7.5°λ**	Gem 25 1/2	Cnc 4 1/2	**9°λ**	40
Set of CrB (Book. II, VI.2)	Sgr 23	Cap 3.5	**10.5°λ**	Psc 1	Psc 13.5	**12.5°λ**	60

Star names

The designations of the stars in the ancient star lists are compared in Table 4. The first star rising is β CrB in all three texts, the *Almagest*, Hipparchus' *Commentary* and the *CCR* fragment. It is described as 'the most advanced one' in the *Almagest* while Hipparchus' designates it 'the one in front of the bright one'[28] and the *CCR* fragment calls it 'the star to the west next to the bright one'. The first star setting is not the same as the first star rising.[29] The first one setting is 'the bright one' (α CrB, see Figure 1) which is correctly stated by Hipparchus – but not distinguished in the *CCR* fragment. In terms of the last star of the constellation that rises and sets, Hipparchus, the *Almagest* ('rear of all') and the *CCR* manuscript all refer to ι CrB although this is not true for the setting as shown in Figure 1. It is a common mistake of all three star lists.

Actually, ι CrB is mentioned twice in Hipparchus's section on setting stars: First, as the last star setting of Corona Borealis where he calls it 'the rather faint one and outermost in the rear arc'[31] and second, as 'the last one of the Crown'[32] culminating simultaneously with the beginning of the setting of Auriga (ι Aur) at the right ascension of the section Vir 2 on the ecliptic.[33] In the *Almagest* star catalogue ι CrB is listed as 'the rear of all in the crown' with fourth magnitude like all the other stars in the ring. In contrast, Hipparchus is right that ι CrB is rather faint (4.95 mag) in comparison to the other stars (typically roughly 4 mag with the exception of α CrB with 2.2 mag).[34] Independently of the magnitudes, because of the simple shape of the asterism the identifications are certain although the wording to describe the star is not consistent.

Concluding, the designations of β CrB and δ CrB in the new fragment are more similar to Hipparchus's wording than to Ptolemy's because these two authors refer all stars to the bright one while Ptolemy's designators refer some points to the previous in his list. Obviously, Ptolemy's method only works in a catalogue with a subsequent listing and not in a plain text like Hipparchus's one. As in Hipparchus' *Commentary*, the fragment does not provide a complete list of stars (like in a catalogue).

However, the exact wordings in Hipparchus and the *CCR* fragment are different and the new palimpsest does not provide more than three star names while Hipparchus's *Commentary* gives 505 designators, referring to 320 different stars[35] among which 20% (62–67 depending on identification) can be reconstructed with full coordinates and 73% are given with their right ascension.[36] As the three phrases to designate the stars in the

Table 4. Comparison of the designators in the *CCR* fragment with the known sources.

In the *CCR* fragment [Gysembergh *et al.*]	Identification	Name in Almagest [Toomer]	Name in Hipparchus's *Commentary* [Manitius]
The star to the west next to the bright one	β CrB	The star most in advance of all	Der dem hellsten30 vorangehende The one preceding (or 'leading') the bright one.
The fourth star to the east of the bright one	ι CrB	The star to the rear of all [the others] in the crown	'der ziemlich lichtschwache und äußerste im nachfolgenden Bogen' The rather faint one and outermost in the rear bow. 'von der Krone der nördlichste' The northernmost of The Crown.
The southernmost, the third counting from the bright one towards the east	δ CrB	The one to the rear again of these [the one to the rear of the bright star from the south and the one to the rear of the latter], close by	'der dritte vom hellen nach Osten' The third from the bright one towards east.

CCR and Hipparchus's text deviate from each other and more samples are not provided, it cannot be concluded whether the text of the *CCR* palimpsest is or is not based upon Hipparchus's work. The description of star positions may be independently written or may share common sources.

This does not allow for any conclusion on the source of the fragment: We can only state that the exact wording in the fragment is neither copied from any of the preserved texts by Ptolemy nor by Hipparchus.

Comparison of numbers

Ptolemy. The ecliptic coordinates given in the *Almagest*, provide longitudinal degrees in Libra for all three stars (Table 5). Therefore, the degrees in the *CCR* fragment are not copied from the *Almagest*.

The table shows that even the polar angle in Ptolemy's time does not match the angle given in the text. The fractions of the degrees in the *CCR* manuscript are not as small (10′) as in the Almagest, too.

Hipparchus. For Hipparchus' manuscript the situation is a bit more complicated because there are no orthogonal coordinates. The computed coordinate 'ecliptic longitude' λ for the three stars would still be in Libra implying that the palimpsest does certainly not fit Hipparchus's time if this number is interpreted as ecliptic longitude. β CrB had the

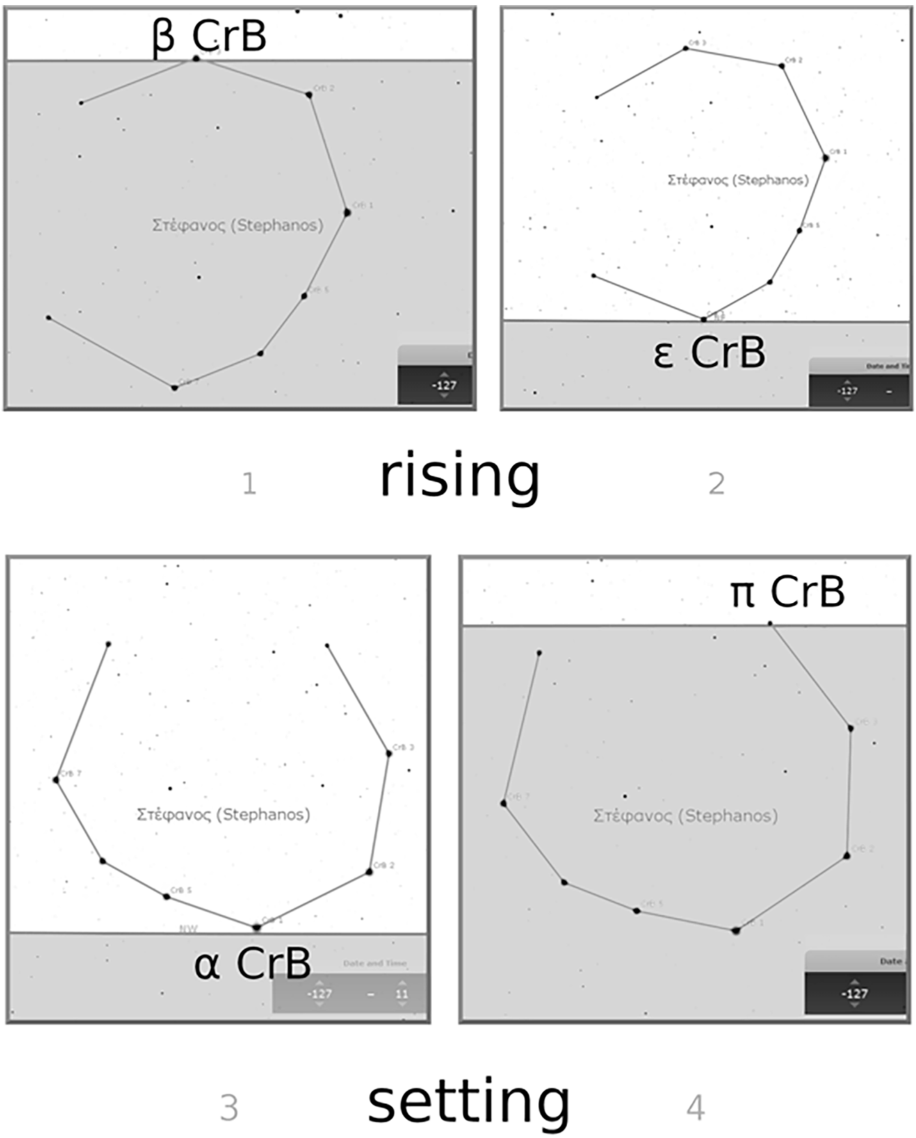

Figure 1. Corona Borealis rising (subfigures 1+2) and setting (subfigures 3+4) at the 36° latitude north for which Hipparchus made his computations. Straight line: local horizon, simulation with Stellarium (the inner label is the constellation name displayed in the software). First star rising β CrB, last one rising ε CrB, first one setting α CrB, last one setting π CrB.

ecliptic degree of Sco 0.5 (210°30′λ) as late as the years 1383–1385 CE. Supposing that the text underlying the Coptic manuscript is more than a millennium older, this number

Table 5. Comparison of the data in the fragment with the preserved data and computed with Stellarium for the epoch and equinox of 137 CE.

Ptolemy's time							CCR fragment
	Almagest		Computed				
	Longitude	Latitude	Longitude	Latitude	DE	Pole angle	Pole angle
β CrB	Lib 11 2/3	46 ½	193°09′12.8″ Lib 13° 1/6	46°11′40.6″	36.7	53.3	
ι CrB	Lib 21 2/3	49 1/3	202°56′25.8″ Lib 23°	49°21′8.6″	36.36	53.64	49°
δ CrB	Lib 19 1/6	44 5/6	200°59′34.7″ Lib 20°		33.1	56.9	55° ¾

cannot refer to ecliptic longitudes directly. Yet, as Hipparchus uses various frames of reference that are not necessarily orthogonal, one might find a different type of coordinate.[37] In the first part of his *Commentary* (II.1–II.4), discussing Aratus verse-by-verse is bound to his frame of reference of observable risings/settings (horizon frame). Yet, Hipparchus gives 42 declinations,[38] 34 transits through the horizon, 5 pairs of coordinates (right ascension, declination) and 27 longitudes and right ascensions.[39] In the second part (Book II.5–III.4), he follows a very strict new schema of simultaneously rising/setting ecliptic longitudes and simultaneously culminating longitudes (in our language: right ascensions or hour angles defined by points on the ecliptic)[40] while in the third part (Book III.5) of his commentaries, he defines hour stars with mere right ascensions[41] and without any reference to the ecliptic. Hence, Hipparchus' last section cannot be related to the new palimpsest, only the simultaneous culminations fulfil the criteria of matching the format 'zodiacal sign, number'.

As stated above, nobody seriously doubts that Hipparchus made use of an equatorial frame of reference because it is explicitly given in the text but this frame is not unique to Hipparchus (it is the traditional frame of reference that has been used in Babylonian astronomy and by Hipparchus' contemporary, cf: the many examples that are compared to Hipparchus in Hoffmann, *Hipparchs Himmelsglobus*). The uniqueness in Hipparchus's frame of reference is his simultaneously culminating ecliptic degree. It appears as if he was about to change to ecliptic coordinates (which was already common in contemporary Babylonian lists of 'normal stars'[42]), but was bound to Aratus's horizonframe when he commented on him. His resulting schema of reading right ascensions by using the meridian of a globe marking a section of the ecliptic with a scale is a non-orthogonal frame that combines all three coordinate systems.

The studies of errors in Hipparchus's text in comparison to other historical sources, for example, Ptolemy's *Almagest, studied by* Grasshoff in *The History of Ptolemy's Almagest*, and various Babylonian texts, studied by Hoffmann in *Hipparchs Himmelsglobus*, contributed to the understanding of transfer of knowledge.[43] Hipparchus never confuses right ascensions and ecliptic longitudes as it would be

Table 6. Comparison of the data in the fragment with the preserved and computed data. The simulation (with Stellarium) proves Hipparchus correct and the *CCR* deviating.

Star	*CCR*	Computed for −127			Hipparchus in his *Commentary* (2.5.9)
		Ecliptic longitude	RA	Simulated culmination	Simultaneous culmination (with the last star of Cas) RA expressed as λ[46]
β CrB	Sco 0.5 210.5	189°29′38.0″ Lib 9 ½	210.05 14h 00 10.9	Sco 3	Sco 2.5[47]

required by Gysembergh *et al*. when they read 'Sco 0.5', equalling 210°λ as 210.5°RA (their Table 5). It is part of his criticism of Aratus that one could misunderstand from the poem that the zodiacal signs could be used in the same way as right ascensions/hour angles for time keeping. We will discuss this issue in the following paragraphs on the specific information in the palimpsest.

β CrB. Hipparchus mentions β CrB culminating simultaneously with the ecliptic degree Sco 2.5 while the last star of Cassiopeia (ζ Cas) rises (Book II, Cap. V, §9).[44] In this frame of reference (simultaneous culminations), Hipparchus (Sco 2.5) is not consistent with the *CCR* fragment (Sco 0.5). In other words: if the newly discovered *CCR* fragment gave a simultaneous culmination, it would contradict Hipparchus' original text by 2° which cannot be explained by a simple writing error.

β CrB is also mentioned by Hipparchus in his list of hour stars in the second appendix of the text (Book III.V.8). There, he states that the star is 2 hours and 2 minutes east of the autumn colure. Translated to our common terms for coordinates, this equals the right ascension 12 hours + 2 hours 2 minutes = 14 hours 02 minutes (210.5°RA). Here, obviously Hipparchus contradicts his earlier statement of β CrB being at right ascension Sco 2.5 (=212.5°RA). He states that the 'middle one among the three bright stars in the forehead' (δ Sco) of the Scorpion is at the same right ascension. This star (δ Sco) is also given as simultaneously culminating with the end of the rising of Cassiopeia and simultaneously culminating with the ecliptic degree Sco 2.5 which is identical with the simultaneous culmination directly given for β CrB itself (cf. Table 6).[45] The fact that Hipparchus' statements about the right ascension of these two stars (β CrB and δ Sco) in the second part of his *Commentary* contradicts his statements in its third part is a specific confirmation of the conclusion by Hoffmann that Hipparchus's hour stars are based on a different source than his schematic risings and settings because of different error bars of the two data sets.

The number given in the text ('Sco 0.5') is not a right ascension but a point on the ecliptic. This ecliptic degree has a right ascension of 208.5°RA in Hipparchus' time. Hipparchus referring to the star β CrB at 210.5°RA culminating during the rise of the last star of Cassiopeia correctly gives the degree of the ecliptic that culminates with this right ascension (Sco 2.5). The palimpsest simply takes 'Sco 0.5' which means '210.5° of along the ecliptic' (or 210.5°λ) as '210.5° along the equator' which is mathematically wrong. The author of the *CCR* mixes the coordinate systems.

In other words: Hipparchus states β CrB to be at 210.5°RA and culminating together with Sco 2.5 (=212.5°λ) while the palimpsest claims β CrB to be at Sco 0.5 (=210.5°λ) equalling 208.5°RA.

Conclusion: Hipparchus's *Commentary* to Aratus gives no reason to interpret the number connected to the star β CrB in the *CCR* fragment as a derivative of Hipparchus' text.

ι CrB. The *CCR* preserves a pole distance for this star but in Hipparchus's *Commentary* to Aratus, no measure for the latitude or declination of this star is mentioned. Thus, we cannot compare it.

CCR mentions the westernmost point of CrB at Sco 0.5 equalling 210.5° longitude. As the length (or width) is given in the text as 9 1/4 degree, the easternmost point should be at 219.75° longitude (Sco 9 ¾).[48] Supposing that the easternmost and westernmost points of the constellation are marked by stars, the easternmost point should be at the 'last star rising' or/and 'last star setting' which is in all of our texts ι CrB. If this proved correct and the 'length' or 'width' is given in the ecliptic coordinate system, ι CrB should be at 219.75°.

However, none of the premisses here is certain: (i) It is not at all certain that the beginning and end of a constellation are marked by stars, and (ii) it is not given in what coordinate system the 'length' is meant. In Ptolemy's works (the *Almagest* and the *Geography*), the Greek terms 'length' and 'width' are used for the coordinates in orthogonal spherical coordinates (modern: longitude and latitude). In contrast, Hipparchus gives 'durations' for the processes of risings and settings implying that he has a concept of width or length that equals the modern right ascension. For Corona Borealis, he states ⅔ of an hour (40 minutes, 10°RA) for the rising of the constellation but 1 hour (60 minutes, 15°RA) for its setting. Astronomically, this makes sense only if he simulated the rising and setting with an instrument (e.g. with a globe as assumed by Hoffmann, or with an analemma tool as Sidoli proposed) because this is where the astronomical effect of image field rotation over a circular horizon line comes into play (cf. Figure 1). The different durations for rising and setting also prove that he did not have the concept of a fixed 'length' (or boundary lines) of a specific constellation.

It should be remarked that the duration of 10° for the rising of Corona Borealis fits the 'length' in the *CCR* fragment within the error bars for right ascensions of roughly 1° (Hoffmann)[49] but the difference between the length (9.25°) and the setting duration (15°RA) exceeds the typical uncertainty of Hipparchus's measurements by 288%. The fact that the values (9.25° and 10°, or 9.25° and 15°) differ at all, disproves Hipparchus as the source for the *CCR*. These two numbers could still be derived from the same source (the same globe or armillary sphere) but the *CCR* data is not a copy of Hipparchus's text. However, it should be pointed out that Hipparchus's data can be interpreted in the way that 9° of the ecliptic culminate simultaneously while the constellation of CrB sets (Table 7) but the rest of Hipparchus's data says that 7.5° of the ecliptic rise simultaneously, 10.5° set simultaneously and 12.5° culminate during its setting. Thus, no certain conclusion can be drawn from the few numbers of the manuscript.

Conclusion: we cannot establish that the information about ι CrB in *CCR* are taken from Hipparchus. The only number directly written in *CCR* (the pole distance) has no counterpart in the *Commentary* and the possibly indirectly given number of the longitude-like coordinate cannot be properly interpreted as the frame of reference is unknown.

Table 7. Comparison of the data in the fragment with the preserved and computed data.

	CCR	Computed for −127 (Stellarium)		Hipparchus' *Commentary*	
ι CrB	Pole angle	DE	Polar angle	–	
	49°	37°29′15.8″	52 ½		
	Coordinate computed from width	Longitude	RA	Sim. culm.	–
	Sco 9.75 219.75°	199°15′53.0″ Lib 19 ¼	219.23° 14h36 56.13	Sco 12	
Duration	9.25°		–	40–60 min 10°–15°	

Table 8. Comparison of the data in the fragment with the preserved and computed data.

Star	*CCR*	Computed for −127 (Stellarium)					Hipparchus' *Commentary*
		Longitude λ	RA	Sim. culm.	DE	Polar angle	Sim. culm. λ of RA
δ CrB	–	197°19′23.7″ Lib 17 1/3	215.26 14h21 02.49	Sco 8			Sco 8.5
	55° ¾				34°15′41.9″	55 3/4	–

δ CrB. δ CrB is mentioned by Hipparchus as culminating simultaneously with the ecliptic degree Sco 8.5 during the rising of the last star in Sagittarius but no longitude or right ascension is given in the *CCR* fragment. The only number given in the palimpsest is the polar distance of 55° ¾ but no star of Corona Borealis is mentioned with a declination-like coordinate in Hipparchus' critique on Aratus. The computation with Stellarium proves Hipparchus's number for the simultaneous culmination correct and matches the polar angle in the palimpsest. However, no certain statement can be made on the connection of the two datasets because no direct comparison is possible (see Table 8).

Conclusion on the date of the *CCR* fragment

Trying to derive the date of the text from the coordinates is challenging: For the longitude-like coordinate it is unknown if an ecliptic longitude or a right ascension is meant. The latitude-like coordinate is a declination (expressed in a different way than defined today).

If the longitude-like coordinate for β CrB (0.5°) referred to an ecliptic longitude, the historical date of this number would be the 14th century CE. If it was a right ascension read at the point where the RA-circle intersects the ecliptic (during the simultaneous culmination, cf. figures of the reconstructed globe and its practice in Hoffmann, *Hipparchs Himmelsglobus*), the date would be roughly 300 BCE, that is, much before Hipparchus' time. Thus, the given numbers do not match Hipparchus's time. The only way to match them to Hipparchus is the assumption of a misreading.

Tables 6 and 7 both display the same decimal number in the field of 'ecliptic point mentioned in the *CCR*' and 'right ascension in Hipparchus' time'. Hence, Hipparchus made a star catalogue in his observational coordinates (according to Duke in 2002, Sidoli in 2004, Hoffmann in 2017 his observational frame was equatorial: RA, DEC), and somebody else some centuries later interpreted these mere numbers as ecliptic coordinates (like in the *Almagest*). It appears as if the scribe of these numbers misread a given number of right ascension from Hipparchus' time as an ecliptic degree. It cannot be excluded that this earlier writing under the Coptic manuscript was erased because it was found erroneous. If this proves correct and the numbers date back to Hipparchus, it will disprove the assumption by Gysembergh *et al.* that palimpsest's coordinates were given in any correct frame of reference (neither in equatorial coordinates nor in ecliptic coordinates nor in any sort of projection that Hipparchus used).

However, the construction of the connection to Hipparchus with the longitudes given in the manuscript, needs to be cross-checked with the declinations and this does not lead to a common date (Table 9). The dates for which the polar distances of δ CrB and ι CrB match the numbers given in the palimpsest are around 150 BCE and around 900 BCE, respectively. The declination value for ι CrB deviated from the one in Hipparchus' time by 2.5°. The error bar of the declinations given by Hipparchus is 1° (Hoffmann, *Hipparchs Himmelsglobus*); it applies for his direct measurements but the declinations of these specific stars are not given in the text. As Gysembergh *et al.* claim the differences of the

Table 9. A summarizing comparison of historical epochs for which the data directly given in the *CCR* fragment are valid.

Star and coordinate	Epoch	Historical context
DE (ι CrB)	900 BCE	Before Homer, Babylonian MUL.APIN (CrB: 'asterism of Dignity')
DE (δ CrB)	150 BCE	Time of Hipparchus
The latitude-like coordinate as ecliptic latitude λ	–	Doesn't work, that is, the coordinate would be wrong and they would not allow for dating because λ doesn't change with precession
β CrB at Sco 0.5 (as simultaneously culminating, i.e. as right ascension)	300 BCE	Interpretation in Hipparchus's unique frame of reference but contradicting Hipparchus Book II, 5.9 where he states that β CrB culminates with Sco 2.5 roughly matches Aratus' time
β CrB at 210.5°RA, implying the mistake/liberty of the scribe to rewrite data	130 BCE	Matching Hipparchus's hour stars (Book III, V.8) that are supposed to be from a different source than Hipparchus's other dataset
β CrB at Sco 0.5 (as ecliptic longitude)	14th c. CE	Time between late Dante Alighieri and early Copernicus

numbers in the palimpsest result from copying text, the argument of error bars for the palimpsest is not allowed: The concept of an error bar derives from statistics (e.g. hundreds of measurements of positions with the same globe or armillary sphere) and is irrelevant for the process of copying text. It does not allow conclusions on (random) transformation of the original dataset by copyists.

Taking all data (declinations and longitudes) of the palimpsest into account, they do *not* point to Hipparchus as source. Instead, they lead to different conclusions of the date and the differences in numbers can by no means made fitting by applying error bars (as suggested by Gysembergh *et al.*): see Table 9 for the summary.

The summary of the derived historical epochs in the *CCR* fragment clearly shows this data's inconsistency. Only one of four numbers matches Hipparchus's time (50%–75% don't) and to interpret it this way, we need to suppose a mistake by the scribe. This suggests that the *CCR* fragment is corrupted and cannot be interpreted in connection to any specific historical author (might it be Aratus, Hipparchus or anyone else).

In order to link the data in this fragment to Hipparchus' schematic description of rising and setting constellations which is suggestive because of the similar data format, we need to interpret additional mistakes by the mediaeval scribe: postulating that the scribe took the liberty to rewrite a number he found in earlier text, we could assume the following procedure:

1. Hipparchus' star catalogue had been written in equatorial coordinates. That means, he probably wrote a tabular list with the columns 'star name', 'right ascension', 'declination' (or polar angle) as already suggested by Duke in 2002 (Note 37). With this list he made a globe as virtually modelled by Hoffmann, *Hipparchs Himmelsglobus*. When Hipparchus wrote the *Commentary* on Aratus, he framed his 'right ascensions' as 'simultaneously culminating degrees of the ecliptic'.
2. The scribe of the *CCR* fragment did not understand that Hipparchus projected the ecliptic degrees on the equator by giving 'simultaneously culminating ecliptic degrees'. He considered the list of 'right ascensions' as a list of ecliptic longitudes like in Ptolemy's *Almagest*.
3. So, this scribe re-wrote a number of right ascension like '210 degrees' (written in Greek letters as σ καὶ ι μ°) as a number of parts 'from Scorpius' (τοῦ σκορπίου) which is astronomically wrong because the number was defined in a different coordinate system (right ascension is defined on the celestial equator, zodiacal signs are defined on the ecliptic, and equator and ecliptic are inclined by 23.5°–24°).
4. Still, the declinations must be copied from a different source because they don't match Hipparchus's time – even when applying Hipparchus's error bars. If we followed Gysembergh's conclusion that the scribe copied the right ascensions from Hipparchus' lost star catalogue (with equatorial coordinates, both RA and DEC), we would wonder why he took the effort to get declinations from another source.

Concluding, we have either the possibility to read the text of the *CCR* fragment literally and the astronomical dating returns divergent numbers scattering more than a millennium. Alternatively, we postulate several mistakes by an inexperienced scribe and link the data to Hipparchus's time without matching Hipparchus's terminology.

In either case, the data in the given fragment cannot be used to reconstruct Hipparchus's star catalogue directly and they neither prove nor disprove that Hipparchus used an armillary sphere – in contrast, they prove an equatorial setup for Hipparchus's measurements (as long known) and the (known) non-orthogonal frame of reference. The armillary sphere as Ptolemy describes it in *Alm*. V. is invented to measure ecliptic coordinates directly in the sky, and Hoffmann, *Hipparchs Himmelsglobus* has pointed out that Hipparchus had more than one source of equatorial data because various subsets of data have different error bars. Furthermore, in either way of the interpretation, the Greek astronomical text underlying the *CCR* fragment seems to be erroneous. It is not to be considered as the 'lost star catalogue of Hipparchus' but as an erased text that was corrupted in the moment of its writing.

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ORCID iD

Susanne M. Hoffmann https://orcid.org/0000-0001-5384-7545

Notes

1. See P.J. Williams, P. James, J. Klair, P. Malik and S. Zaman, "Newly-Discovered Illustrated Texts of Aratus and Eratosthenes Within *Codex Climaci Rescriptus*," *The Classical Quarterly*, 72 (2022), 504–531. Facsimiles of the Sinai Palimpsests Project in <https://sinai.library.ucla.edu/>. <https://www.cambridge.org/core/journals/classical-quarterly/issue/79FE4F3476563EF624AA003C00BD2FD4>.
2. V. Gysembergh, P. Williams and E. Zingg, "New Evidence for Hipparchus' Star Catalogue Revealed by Multispectral Imaging," *Journal for the History of Astronomy*, 55 (2022), 383–93.
3. C. Manitius. *Hipparchos: Kommentar zu den "Himmelserscheinungen" des Aratos und des Eudoxos* (Leipzig: Teubner Verlag, 1894).

4. R.T. Macfarlane and P.S. Mills, *Hipparchus' Commentaries on the Phaenomena of Aratus and Eudoxus*, draft of an English translation dating November 2009, provided on personal request in 2014, to date still unpublished.
5. G.J. Toomer, *Ptolemy's Almagest* (Princeton, NJ: Princeton University Press, 1998, First publication: London, 1984).
6. This software invented by Fabien Chéreau was developed specifically for purposes of cultural astronomy: G. Zotti, S.M. Hoffmann, A. Wolf, F. Chéreau and G. Chéreau, "The Simulated Sky: Stellarium for Cultural Astronomy," *Journal for Skyscape Archaeology*, 6 (2020), 221–58.
7. S.M. Hoffmann, *Hipparchs Himmelsglobus – Ein Bindeglied in der babylonisch-griechischen Astrometrie?* (Wiesbaden/New York, NY: Springer Research, 2017).
8. Ptolemy argues for the "longue durée" validity of his choice in *Alm*. VII, 1-3 by explaining how the precession of the equinoxes changes declination and right ascension in a complex way whereas the shift of ecliptic longitudes proceeds with a smooth rate of one degree per century (as he finds).
9. For details of this practice see: J. Wlodarczyk, "Observing with the Armillary Astrolabe," *Journal for the History of Astronomy*, 18 (1987), 173; J. Evans, *The History and Practice of Ancient Astronomy* (New York, NY: Oxford University Press, 1998); P. Protte and S.M. Hoffmann, "Reconstruction of Ptolemy's Armillary Sphere," in G. Wolfschmidt and S.M. Hoffmann (eds), *Applied and Computational Historical Astronomy* (Hamburg: tredition, 2021), pp. 137–44.
10. J.L. Berggren and A. Jones, *Ptolemy's Geography* (Princeton, NJ: Princeton University Press, 2002).
11. Hoffmann, *op. cit*. (Note 7), has shown in many star charts that the constellation of all ancient star lists (might this be Babylonian compendium MUL.APIN or Ptolemy's *Almagest* or the reconstructed star catalogue of Hipparchus) are irregular polygons: cf., e.g., her page 40, 64, 97–9, 103, 214–26, 237, 247, 349, 361, 538. . .
12. Modern mathematics would use the term "polar angle" in a polar coordinate system.
13. Hipparchus gives 43 equatorial latitudes, among them 21 are measured from the pole, 14 from the equator, 8 from one of the tropics (cf. Hoffmann, *op. cit*. (Note 7), p. 187).
14. The translation by Gysembergh *et al.* (Note 2) adds "to rise" but we prefer to leave this open: The identified star is the first to rise and it is also the first star to culminate but it is not the first star to set. By no means does the context of the palimpsest allow for a decision on the specific configuration that is meant here.
15. Cf. H. Vogt, „Versuch einer Wiederherstellung von Hipparchs Fixsternverzeichnis," *Astronomische Nachrichten*, Bd. 224 (1925), Nr.5354–5, cols. 17–54, Hoffmann, *op. cit*. (Note 7).
16. Translation according to MacFarlane and Mills: "The head of the Small Bear is located along a parallel to the equatorial circle at the end of the Scorpion; but when this is in the middle of heaven, in the zodiac 3° of the Archer is in the middle of heaven — and when this is in the middle of heaven in locations around Hellas, even there, where the longest day is 14 hours long, 17° of the Water-pourer is rising."
17. MacFarlane and Mills: "But for the moment, let it be given that the southernmost star of those in the left foot of Arctophylax is placed upon the horizon toward the west. This, though, is the star north of the equatorial circle by 27 1/3°, of which there is a circle that extends 360° through the poles."
18. Findings on p. 92 and again p. 194.
19. Pliny, *Natural History*, II, pp. 24–6 mentions Hipparchus's work.
20. N. Sidoli, "Hipparchus and the Ancient Metrical Methods on the Sphere," *Journal for the History of Astronomy*, 35 (2004), 71–84.

21. Hipparchus's *Commentary* has three sections: In the first one, he discusses Aratus' poem verse by verse, and, in the second one, he gives his own version of an accurate description of rising and setting constellations. This is the part of the text where the expression of half degrees frequently occurs. In the third section, Hipparchus appends a list of hour stars, i.e., stars that culminate at one-hour intervals. This section might originate in a different tradition (Hoffmann, *op. cit*. (Note 7), p. 189) because different language and different units are used. For example, fractions of "signs" (unit of 30°) are used to measure declinations.
22. Manitius, *op. cit*. (Note 3), p. 186. Lib II, Cap. V, § 2 "The Crown rises with the part of the ecliptic from 27 Virgo up to 4.5 Libra." Τοῦ δὲ Στεφάνου ἀνατέλλοντος συνανατέλλει μὲν αὐτῷ τοῦ ζῳδιακοῦ τμῆμα τὸ ἀπὸ Παρθένου ζ' καὶ κ' μοίρας ἕως Χηλῶν ε' μοίρας μέσης.
23. We consider Hipparchus's concept of a degree not as a point on a scale but a section (tiny bow) of the full circle (cf. Hoffmann, *op. cit*. (Note 7), pp. 70 and 161). In this reading, he refers to the half of the section of a tiny arc rather than to a point in the middle of two. This is consistent with his error bar.
24. Manitius, *op. cit*. (Note 3), p. 190. Lib II, Cap. V, § 5 "The Snake rises from Libra 8 to 0.5 Sagittarius." Τοῦ δὲ ῞Οφεως, ὃν ἔχει ὁ ᾿Οφιοῦχος, ἀνατέλλοντος συνανατέλλει μὲν αὐτῷ ὁ ζῳδιακος ἀπὸ Χηλῶν μοίρας η' ἕως Τοξότου μοίρας α' μέσης.
25. Hoffmann, *op. cit*. (Note 7), chapter 5.5 is the conclusion on all details worked out in the previous chapters.
26. Hoffmann, *op. cit*. (Note 7), p. 69 and 161 give a graphics.
27. E. Delporte, *Délimitation scientifique des constellations: (tables et cartes)* (IAU, Cambridge : University Press, 1930).
28. τοῦ στεφάνου ὁ προεγούμενος τοῦ λαμροτάτου "der dem hellsten vorangehende" (Manitius, *op.cit.* (Note 3), p. 186).
29. For more elaboration on this effect, its cause and implication for Hipparchus see Hoffmann, *op. cit*. (Note 7), pp. 78–81.
30. The same wording Hipparchus uses among the hour stars.
31. ὁ ἀμαυρότερος καὶ ἔσχατος ὢν τῆς ἑπομένης περιφερειας . . . "der ziemlich lichtschwache und äußerste im nachfolgenden Bogen" according to Manitius, *op. cit*. (Note 3), p. 202.
32. Τοῦ Στεφάνου ὁ βορειοτατος . . . "von der Krone der nördlichste" (Manitius, *op.cit.* (Note 3), p. 216).
33. Hipparchus considers the "degrees" of the ecliptic as arcs, so "Vir 2" is a little bow along the ecliptic, a section of the ecliptic. The culmination of a star is indicated on his globe when the star vanishes under the physical meridian circle and the given section of the ecliptic (here: the arc Vir 2) simultaneously does.
34. A fifth magnitude star is roughly 2.5 times fainter than a fourth magnitude star. It is known that magnitudes in all pre-telescopic star catalogues have error bars of roughly 1.5 mag (P. Protte and S.M. Hoffmann, "Accuracy of Magnitudes in Pre-telescopic Star Catalogues," *Astronomical Notes*, 341 (2020), 827–40). As magnitudes in Ptolemy's *Almagest* are not necessarily observational but serve to build a globe, S.M. Hoffmann, in her "Essay: On Ptolemy's Stellar Magnitudes," in S.M. Hoffmann and G. Wolfschmidt (eds), *Astronomy in Culture – Cultures of Astronomy* (2022), tredition (Ahrensburg) & OpenScience Technology (Berlin), pp. 426–9, suggested that they just served globemakers to choose the correct template for the star size. This would explain the apparent sloppiness because the visualisation may also depend on the perspective of meaning (like the reddish highlighting of Sirius as a marker for the prime meridian).
35. As it becomes obvious in Tab. 3 in case of ι CrB Hipparchus does not use always the same wording to describe the same object; ι CrB is designated differently at different sections of his text.

36. Cf. Hoffmann, *op. cit*. (Note 7), pp. 115 and 134 for the exact numbers and explanations.
37. cf. D. Duke, "Hipparchus' Coordinate System," *Archive for History of Exact Sciences*, 56 (2002), 427–33 in agreement with Delambre, "Histoire de l'astronomie ancienne," (Paris: Vve Courcier, 1817) Vol. 2 and in rejection of a sloppy statement by Neugebauer, "A History of Ancient Mathematical Astronomy," (Berlin: Springer, 1975) Vol. 3, argues for an equatorial system, and Hoffmann, *op. cit*. (Note 7), conclusions in her Chapter 5.5 to point out that he did not use an orthogonal frame of reference.
38. Duke, *loc. cit*. (Note 37) pointed to declinations and right ascensions directly given by Hipparchus; Hoffmann, *op. cit*. (Note 7), p. 187 shows the distribution of his ways to give declinations: Among 43 given numbers, only 14 are measured as angular separation from the celestial equator while the rest is referred to the pole or a tropical circle. Apparently, there was no strict convention.
39. Cf. Hoffmann, *op. cit*. (Note 7), p. 212.
40. This schema he already uses occasionally in his first part, e.g. sections I.5.4 or 1.7.11.
41. Hoffmann, *op. cit*. (Note 7), p. 134 points out that the accuracy of right ascensions of Hipparchus's hour stars exceeds the accuracy of right ascensions for culminating stars by a factor ten (0.1° verses 1°) which may point to different sources of the two equatorial (time frame) datasets he used.
42. Investigation of possible correlation in Hoffmann, *op. cit*. (Note 7), pp. 449–59.
43. G. Grasshoff, *The History of Ptolemy's Almagest* (New York, NY: Springer, 1990), pp. 184–97 used correlation plots to visualize common errors in Hipparchus and the *Almagest* which Hoffmann, *op. cit*. (Note 7), p. 459 also applied to the comparison of Hipparchus's and Babylonian hours stars. Hoffmann, *op. cit*. (Note 7), p. 106 also shows that Hipparchus's biggest errors have vanished in the *Almagest*.
44. Manitius, *op. cit*. (Note 3), pp. 192–5.
45. Hipparchus 2.5.11: "While Cassiepeia is rising, . . . on the meridian the portion from 11° of the Claws until 3° of the Scorpion. . . . The first star on the meridian is the southern of those under the Centaur's right shoulder, and also Arcturus; the last are the middle star of those in the Scorpion's forehead and the one that leads the bright star in the Crown. (MacFarlane and Mills restore "leads", ἡγούμενος, against Manitius' "preceeds" προηγούμενος.)"
46. Hipparchus determines the ecliptic degree that has the same RA as a given star. Hence, he expresses a RA of a star with an ecliptic degree. Neugebauer seems to call this "polar longitude" (O. Neugebauer, *History of Ancient Mathematical Astronomy*, 3 Bd. (New York, NY: Springer, 1975), p. 277–80), but a term for this is not common in modern mathematics.
47. In Manitius, *loc. cit*. (Note 3), it is written 2.5 while the version of the unpublished English translation available to us gives "3" (without the subtraction of a half); the according edition is not available to us.
48. Gysembergh *et al., loc. cit*. (Note 2) take this value as 220° 15'. This also does not match the other interpretation that the westernmost point could be at Sco 1.5, plus 9 ¼ this would give 220 ¾, still a half degree off.
49. For simultaneous culminations and rising signs the average error in right ascensions is 0.85 to 1° (Hoffmann, *op. cit*. (Note 7), p. 121 "Befund 2.15") and for the right ascensions in the first part of the text, the average error is 1.5 °RA (Hoffmann, *op. cit*. (Note 7), p. 203, "Befund 2.49").