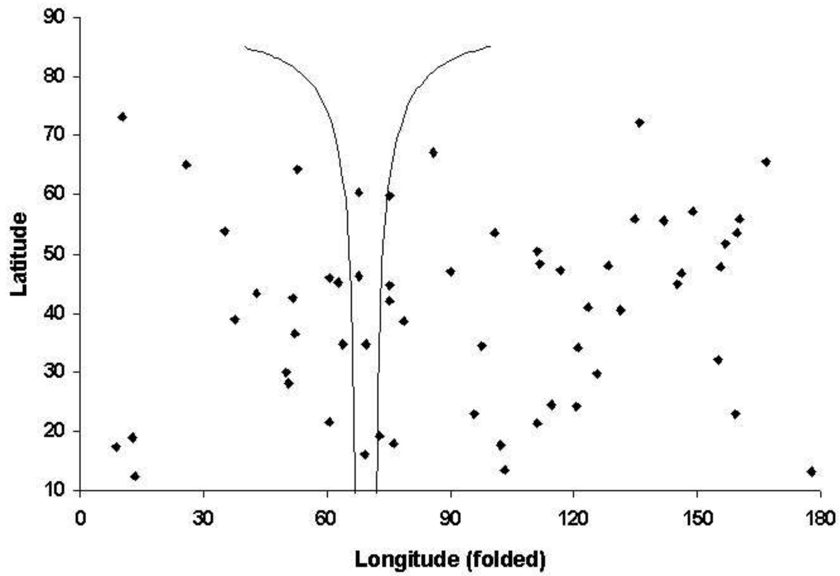

Figure 7: Stars brighter than magnitude 4.5 missing from the northern part of the ASC. Note that none are missing above latitude 75°, possibly indicating that a different kind of instrument was used in this small region of the sky.

measurements are being made; and these successive clampings tend to push the longitudes lower than true, because the earth rotates during these brief intervals. In other words, there is a systematic error in rotation of the astrolabe around the equatorial axis.

D4 Rawlins 1982 has shown that misrotation of the astrolabe with respect to the real sky will make itself known by the presence of a cosine error wave in the observed latitudes. Further, the amplitude of this cosine error wave is proportional to the amount of astrolabe misrotation. And in fact there is just such an error in the latitudes of the northern stars. This error wave has an amplitude of 10.6 ±1.8 arcmin, implying that the astrolabe was systematically misrotated by 24.2 ±4.2 arcmin. It took precession 29.2 years to move a star that far in longitude, meaning that the actual epoch of observation for the northern stars was −128 ±59 years. This is very nearly the epoch implied by Ptolemy's precessional constant.

References

Rawlins, Dennis (1982). An Investigation of the Ancient Star Catalog. *PASP* 94, 359.
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‡5 A Re-identification of some entries in the Ancient Star Catalog

by KEITH A.PICKERING

A Introduction

A1 The realization that the Ancient Star Catalog (ASC) is in fact a precessed version of the earlier catalog of Hipparchos leads research in some fruitful directions. It has already been shown[1] that some entries in the ASC were originally observed using equatorial coordinates; and it has been shown[2] that at least some entries in Hipparchos's *Commentary on Aratus and Eudoxus* were originally observed using ecliptical coordinates; and we also know[3] that there is a strong correlation between positional errors in the *Commentary* and errors in the ASC. The emerging picture tends to support Graßhoff's supposition that the *Commentary* and the ASC were both derived from a common "proto-catalog" of observations, but this proto-catalog was observed with various instruments, recorded in various co-ordinates, and perhaps also observed from various locations at various times.

A2 This realization allows us to broaden our perspective when identifying certain stars in the ASC which have had troublesome identifications in the past. The number of possible errors that might have been encountered between the recordation of a datum at the time of observation, and the centuries-later recordation in extant manuscripts, has grown larger, and so has the range of likely possibilites to explain such errors. In particular, the possibility that stars may have been observed and originally recorded in equatorial[4] coordinates (rather than the ecliptical coordinates of the ASC as written) expands the range of likely scribal errors.

B Common errors

B1 Ancient Greek was written in uncial (single case) characters, and numbers were written using letters, in the following fashion:

Α	1	Ζ	7
Β	2	Η	8
Γ	3	θ	9
Δ	4	ι	10
ϵ	5	κ	20
ς	6	Λ	30

So, for example, 32 would be written: ΛΒ. Fractions are written using reciprocal integers and their sums, indicated by appending the integer with a prime symbol ('). Thus, 1/2 is B', 1/6 is ς', and 3/4 is B'Δ'. In addition, there were a variety of special symbols in use for common fractions, especially 1/2, 1/3, and 2/3, whose usage varied among times and places.

[1] Rawlins 1994, Duke 2002 (*DIO* 12 ‡3 in this issue).
[2] Pickering 1999.
[3] Graßhoff 1990.
[4] Obviously, evidence of such equatorial observation strikes yet another blow against the theory that Ptolemy observed the ASC. Ptolemy claimed not only that he observed all the stars himself, he also claimed to have done so with an ecliptic astrolabe — an instrument that records only ecliptical coordinates.

B2 The most common scribal error is mistaking "A" (1) for "Δ" (4), or vice-versa. Mistakes between "ϵ" (5) for "θ" (9) is also common, as are instances of dropped (or inadvertantly added) ' signs. Peters & Knobel (1915) have already corrected the most obvious such occurrances.

B3 In the discussion below, we use the standard astronomical symbols β for ecliptic latitude, λ for ecliptic longitude, δ for declination, and α for right ascension. We assume throughout that the longitudes appearing in the *Almagest* are precessed from original Hipparchan coordinates by adding $2^2/_3$ degrees. Further, where appropriate, we also may assume that the Hipparchan ecliptic coordinates were in turn derived (via spherical trig) from earlier coordinates in the equatorial reference frame. The ASC star numbers prefixed "PK" are those originally of Baily, and adopted by Peters & Knobel,[5] indicating the number of the star in the Ancient Star Catalog. Star numbers prefixed "HR" are Harvard Revised numbers used in the *Yale Bright Star Catalog*, 5th edition. I have taken the star identifications of Baily, Pierce, and Schjellerup from Peters & Knobel (P&K).

C Star Identifications

C1 PK18: Commonly thought to be ϕ UMa, based on verbal description and longitude; but this may be a hybrid with χ UMa, using its latitude (41) which was very early on misread for 44.

C2 PK40, PK41, & PK42: These three *informata* (unformed stars, i.e., not forming part of the "picture" of the constellation) in Ursa Major have caused a lot of head-scratching, because although PK40 is fairly near 10 LMi, there is nothing much near the cataloged positions of PK41 and PK42, especially considering that the systematic error in this part of the sky is south or southeast. Our interest is piqued by the observation that these three stars lie nearly on the same line; and that this line would be on Hipparchos's western horizon as these stars are setting. In other words, these stars have nearly the same Phenomenon 4, and this Phenomenon is compellingly integral: both PK41 and PK42 set with degree 137 of the ecliptic, while PK40 sets with degree 135.5. This value, when combined with the Hipparchan Phenomenon 5 (polar longitude), would be enough to determine the star's position, after conversion to ecliptical coordinates. A simple scribal error in this process could account for the misplacment of all three stars: the polar longitudes of these would be written as 16, $11^2/_3$, and $10^1/_2$ degrees of Libra respectively, all of which start (in ancient Greek) with the letter ι. If this small letter had been inadvertantly added (perhaps as part of a column divider), just prior to conversion to ecliptical coordinates, all three stars would (after removing the erroneous ι) slide northwest ten degrees along the western setting horizon line, and become placed nicely near HR3579, HR3508, and HR3422.

C3 PK98: 48χ Boo (HR5676), agreeing with Baily and Schjellerup, is four times closer to the cataloged position than than η CrB, given by P&K and Toomer. The easterly systematic error in this part of the sky is not hugely compelling for these dimmer stars; nearby PK102 being a good counterexample.

C4 PK191: NGC869, the western half of the double cluster in Perseus. For error analysis purposes, I use a bright star in the center (HD14134) for its position.

C5 PK233: 4ω Aur (HR1592) is demanded by the descriptive position, agreeing with Baily and Pierce. This better than 14 Aur given by P&K and Toomer, which is not "over the left foot" as described. The identification helps us to sort out the variations in coordinates by using $\beta = 16$ (in the Greek tradition) and agreeing with Toomer on $\lambda = 50^2/_3$ (which is a Hipparchan 48).

[5] I adopt this prefix not to slight Baily, whose work I admire, but because the work of Peters & Knobel deserves recognition as unmatched in the field, and because "B" seems too short and cryptic a prefix.

C6 PK251: 39o Oph (HR6424/5), as suggested by Rawlins 1992 (*DIO* 2.1 ‡4 §C5). Hipparchos' original $\lambda = 21^1/_2$ was misread as $24^1/_2$ by Ptolemy, who added $2^2/_3$ getting $27^1/_6$ as seen in the *Almagest*. The negative sign of the latitude was also dropped along the way.

C7 PK371: 63 Ari (HR1015) is not only brighter than Toomer's τ Ari, it is also much closer to the cataloged position.

C8 PK405: Based on relative position, should be 41 Tau (HR1268), not 44 Tau as given by other sources. The other three stars in this quadrilateral are all in error to the southeast by 20 to 60 arcmin. But 44 Tau would be in error to the west, while 41 Tau is in error to the south. It is also .3 mag brighter than 44 Tau.

C9 PK410: 17 Tau (HR1142), agreeing with Manitius, fits both the descriptive and numerical positions better than Merope, as given by P&K, Baily, and Toomer.

C10 PK417, 418: The brightest candidates fitting the descriptive positions are 119 Tau (HR1845) and 126 Tau (HR1989), respectively, although all identifications are unfirm. The numerical position of PK417 is badly wrong in both coordinates. Based on the frequency of integer longitudes, all of the Taurus *informata* may be Ptolemy's observations, not Hipparchos'. Another possibility is that Hipparchos may have precessed early (and therefore, more likely inaccurate) observations by $1/3$ degree to the later epoch of his catalog; Ptolemy's addition of $2^\circ\ ^2/_3$ would then restore the integer fractions. In this context, the error in PK417 can be mostly explained if, in converting from equatorial coordinates to ecliptical, Hipparchos inadvertently used the star's polar longitude (55°) instead of its right ascension ($52^\circ.5$). The remainder of the position error is about 1° too high in declination.

C11 PK432: 63 Gem (HR2846), agreeing with Manitius. The largest part of the position error is a missing negative sign in the latitude, which we restore. P&K and Toomer give 58 Gem, but at visual magnitude $V = 6.17$, this is most unlikely.

C12 PK448: ζ Cnc is OK (agreeing with all other sources). The error in longitude is probably a slip in spherical trig, since the given position (88° Hipparchan epoch) is two degrees west of the solstical colure, while the actual star was very nearly two degrees east of the solstical colure.

C13 PK457: β Cnc is correct, agreeing with other sources. The three-degree error in position is due to a scribal error in zenith distance. The star was observed equatorially: the observed zenith distance of $21^1/_6$ was misread as $24^1/_6$, and combined with a correct polar longitude to arrive at the reported position. This error is possible only from the latitude of Rhodes City ($36^\circ\ 24'$).

C14 PK458: The descriptive position ("above the *joint* of the claw", i.e., the part of the claw closest to the body) demands 62o Cnc (HR3561), agreeing with P&K, not π Cnc as given by Toomer, Baily, Schjellerup, Pierce, and Manitius. 62 Cnc is also brighter, especially when combined with nearby 63 Cnc. We adopt Peters' $\lambda = 15^2/_3$ as the original, which is entirely reasonable despite Toomer's doubts: this is the most logical starting point from which all textual variants can be simple transcription errors.

C15 PK482: 81 Leo (HR4408), agreeing with Toomer, is fine here. Most of the longitude error is easily accounted for: Hipparchos writes $14^2/_3$, Ptolemy misreads as $11^2/_3$, then adds $2^2/_3$ to get $14^1/_3$ as given in the *Almagest*.

C16 PK504: P&K, Toomer, Baily, and Pierce all give 46 Vir (HR4925) at $V = 5.99$; but 44 Vir (HR4921) at $V = 5.80$ is more likely seen, and the position is slightly better too.

C17 PK512-515 (Vir 16-19): The "quadrilateral in the left thigh" of Virgo, which under the previous identification (shared by P&K, Manitius, and Toomer) is not a quadrilateral at all. There is a quadrilateral in the sky, however, formed by 74 Vir, 80 Vir, 82 Vir, and 76 Vir (HR numbers 5095, 5111, 5150, and 5100); but the positions and descriptions have become corrupt. The latitude of dim PK513, given as $^1/_6$ in Toomer, has an Arabic tradition of 6 which we adopt; at some early time, the original 6 was incorrectly copied as 1/6 by a scribe. (This is still in error by more than a degree, but given the dimness of the star, the error is not unreasonable). But that would have made PK513 not the northernmost of the lead pair, as described, but the southernmost. Therefore, the same scribe or a later one "corrected" the text by switching the north-south descriptions of PK512 and PK513, while leaving the magnitudes alone. Finally, the latitude of PK515, given as -3 in Toomer, has an Arabic tradition of $-1/3$ which we also adopt, and the quadrilateral is complete.

C18 PK541-542: P&K and Toomer give HR5810 for PK542 at $V = 5.82$; since the *Almagest* magnitude is 4, this seems unlikely. Better is κ Lib (HR5838, $V = 4.75$) for PK541, agreeing with P&K, and then for PK542, 42 Lib (HR5824) at $V = 4.95$. The error in position of PK542 is just a 1-for-4 scribal slip in the latitude ($-1\,^1/_2$ becomes $-4\,^1/_2$), as confirmed by the descriptive position.

C19 PK567: Graßhoff gives the open cluster M7 (NGC6475), called "Ptolemy's cluster" for this reason; but at about 3 degrees away from the cataloged position, this is most unlikely. Much better is HR6630, agreeing with P&K, Manitius, and Toomer, which is much closer in position and brighter. The "nebulous" magnitude is due to adjacent NGC 6441, a dim globular cluster. Assigning PK567 to M7 makes HR6630 one of the brightest stars in the sky not in the catalog.

C20 PK586: Toomer and Manitius give 57 Sgr, apparently on the basis of magnitude alone (Ptolemy gives 6, while 57 Sgr is $V = 5.90$ by modern measurement). But 56 Sgr (HR7515), agreeing with P&K, is much better in position, and at $V = 4.88$ is more likely to be seen. The one-magnitude brightness error is not unusual.

C21 PK595: Toomer gives $\kappa_1 + \kappa_2$ Sgr, apparently a misprint for $\theta_1 + \theta_2$ Sgr (HR7623 and HR7624).

C22 PK657: Toomer has ψ_3 Aqr, but brighter ψ_2 Aqr (HR8858) is more likely to have been taken, and is also much better in position. The slight error in magnitude is unimportant.

C23 PK658: Toomer has HR8598, which is awful. In spite of the longitude error, brighter, fits the descriptive position better, and has the correct latitude. There are two possibilities for the longitude error. First: Hipparchos' original longitude was $15^2/_3$, which is about right for his epoch. This was misread by Ptolemy (or an earlier scribe) as $19^2/_3$ in the common theta-for-epsilon slip; Ptolemy added $2^2/_3$ degrees to this, getting $22^1/_3$, written in Greek κBΓ', which was misread (or miswritten) as κB'Γ', or $20^5/_6$ as recorded. Second: Hipparchos' original longitude was $15^1/_2$, to which Ptolemy added $2^2/_3$, getting $18^1/_6$. Then, shortly afterward, Ptolemy inadvertantly added $2^2/_3$ a second time, getting $20^5/_6$ as recorded.

C24 PK699-700: P&K's and Toomer's identifications of 68 Psc and 67 Psc are unconvincing due to the extreme dimmness of 67 Psc ($V = 6.08$). Better fits for visibility and the descriptive positions are σ Psc and 68 Psc. The error in PK699 (about three degrees) can be explained if, in conversion from equatorial coordinates, the computer mistook a zenith distance of $16^2/_3$ for a declination of $16^2/_3$. Of course, this only makes sense for an observer at the latitude of Hipparchos.

C25 PK707: An inconvenient orphan. The descriptive position demands 81ψ_3 Psc, but there is no obvious explanation for the 3 degree longitude error.

C26 PK728-PK731: Star PK729 is a repeat of PK728 (both are ϕ_2 Ceti); and PK731 is a repeat of PK730 (both are ϕ_1 Ceti). Each repeat has the same magnitude as the previous entry, and each is 1 degree south in latitude and 1/3 degree west in longitude from the previous entry. This is almost directly south in declination by 1 degree, implying that the positions were converted from equatorial coordinates. (In each case the first postion shares the error common to other stars in this part of the sky, while second position is more accurate.) Alternate identifications are too dim and too misplaced to be convincing. Note that the *Almagest* description of this asterism as a "quadrilateral" indicates that the author of the description was working from a list of stellar positions, and was a different person from the actual observer of these stars — since no such quadrilateral exists in the sky. This implies that Ptolemy may be the author of the descriptive positions, in at least some cases. There are a number of scenarios that can account for the double entry. The stars may simply have been re-observed equatorially and re-computed at a later time. For example, ϕ_2 Cet may have been originally observed at $\alpha = 345^1/_2$, $\delta = -21^1/_6$, and converted to ecliptical coordinates. This would produce the value for PK728. At the same time, ϕ_1 Cet was observed at $\alpha = 343^2/_3$, $\delta = -21^1/_6$ and converted the same way to produce PK730. Then at some later time, the stars were re-observed (more accurately) in zenith distance, producing declinations of $-22^1/_6$ for both stars. Using the same right ascensions, Hipparchos recomputes and arrives at the positions given for PK729 and PK731. Similar multiple observations are common in Hipparchos' *Commentary*, his only surviving work; a clerical error put both positions in the catalog. Yet another possibility: they may have been observed once equatorially, then converted incorrectly to ecliptic coordinates due to a confusion between ordinal and cardinal numbers. E.g., ϕ_2 Cet was recorded as being at the 58th degree of the zenith. The computer subtracts 58 from the latitude $35^5/_6$, getting a declination of $-22^1/_6$; but since the first degree of the zenith is the same as $Z = 0°$, the computer should have subtracted $35^5/_6 - 57 = -21^1/_6$. A recomputation gave Hipparchos the correct coordinates, but both numbers ended up in the catalog.

C27 PK787, PK788: These are ρ_2 Eri (HR917) and η Eri (HR874). The magnitudes of PK787 and PK788 have been reversed, causing a number of unconvincing identifications; e.g. P&K give HR859 for PK788, but at $V = 6.31$ this is hard to accept.

C28 PK802, 803, 804: Best fit for position are HR1214, HR1195 and HR1143, agreeing with P&K. The large latitude error in PK804 may be a trig slip, since 2crd $52°\ 34'$ (which rounds to the latitude given in the *Almagest*) is 95 18$'$ in the ancient system of chords of a circle with a radius of 60. Meanwhile 2crd $55°$ (the actual latitude) is 99 18$'$. The 5 and 9 digits are easily confused in Greek.

C29 PK859: This star is described in the *Commentary* as the triple star under the tail of the dog (Canis Major); while in the *Almagest* it becomes the northern of the two stars in the stern-keel of Argo (the southern of which is π Pup). This firmly identifies PK859 as a combination of HR2819, HR2823, and HR2834, of which the latter is the brightest and closest to the *Almagest* position.

C30 PK870: Toomer has HR3439 at $V = 5.21$. Based on the cataloged magnitude (< 4) and possible scribal errors, most likely is HR3591 at $V = 4.46$. The position error is then a A-for-Δ slip in the latitude ($-51^1/_2$ should be $-54^1/_2$), and-or an ϵ-for-θ slip in Ptolemy's longitude ($125^2/_3$ should be $129^2/_3$, which is Hipparchos' 127). The remaining error puts the cataloged position northwest of the star, matching the errors of PK871 and PK872.

C31 PK882: Toomer has HR3055 at $V = 4.11$; from both magnitude and position, much better is HR2998 at $V = 5.05$ (since the *Almagest* magnitude here is 6).

C32 PK887: P&K and Toomer both give f Car (HR3498), which at $V = 4.50$ is far too dim for a star described as second magnitude. Better is ι Car (HR3699, $V = 2.21$), which is the only second-magnitude star in the region unaccounted for, and which also matches both the descriptive position and the latitude quite well. The huge thirteen-degree error in longitude (five degrees along the great circle) can be explained if Hipparchos mis-recorded the longitude interval by one step.[6] (The astrolabe was graduated in step intervals of fifteen degrees.)

C33 PK905: α Hya is of course correct, as given by all others. But the latitude error proposed by P&K and endorsed by Toomer has no textual support, and the alleged scribal error (23 read as 20 $^1/_2$) is weak. The error is actually due to a dropped minus sign in declination prior to conversion to ecliptical coordinates (see PK920 below for another example of this in Hydra.) The star was accurately observed with a declination of -1 and a polar longitude of 113.5 (or a right ascension of 115.5). After dropping the minus sign in declination, and using the Hipparchan obliquity of $23°\ 51'$, the position converts to $\lambda = 117\,^1/_3$, $\beta = 20^1/_2$ after ancient rounding. Then adding Ptolemy's $2^2/_3$ to the

[6] My thanks to Dennis Rawlins for this suggestion.

longitude, we have exactly the position given in the *Almagest*.

The descriptive position claims that PK905 is "close" to PK904, but this is only true for their cataloged positions, not their positions in the sky. This is another indication that in some cases the descriptive positions were written by a person working from the cataloged list, not the actual observer (see §C26 above for another example).

C34 PK920: Based on the given magnitude (3) and descriptive position, this must be λ Hya (HR3994), with a mistaken plus-for-minus in declination prior to conversion to ecliptic coordinates. Other stars suggested by Toomer (ϵ Sex) and P&K (α Sex) are far too dim and misplaced to be convincing. Without this identification, λ Hya would easily be the brightest star in Hydra missing from the catalog. A similar error is given above at §C33.

C35 PK962 is ϵ Cen, which would be missing otherwise under the proposal below. The magnitude is a poor fit, but the position is much better than the alternative HR5172.

C36 PK963-969. The hind legs of Centaurus, today mostly part of the constellation Crux, the Southern Cross. This area of the sky is a mess, with all stars having large positional errors, and all identifications uncertain. Standard practice has been to assign the right hind leg (PK965 and PK966) to γ Cru and β Cru, which means the left hind leg (PK 967 and PK968) becomes δ Cru and Acrux (α Cru). This puts all stars east or northeast of their cataloged positions by a huge 3 to 5 degrees.

I was intrigued by the description of PK968 as being "on the frog of the hoof" (i.e., on the underside of the hoof) rather than the more straightforward "on the hoof"; this is the only place in the *Almagest* where this term is used. My interest was heightened even further by the only other description of this part of the sky in the *Almagest*, in the delineation of the Milky Way at VII.2, where Ptolemy mentions "the stars on the hock"[7] of this leg — a clear distinction from the frog, for two reasons: first, because the "star" on the frog is singular, while the "stars" on the hock are plural; and second, because the frog is on the bottom of the hoof, while the hock is just above the hoof, between the hoof and the ankle.

Therefore I propose that PK968, the frog of the hoof, is really λ Cen, and the "stars on the hock" are formed by the corona of 5th magnitude stars[8] HR4511, HR4499, HR4487, and HR4475 — a unique feature not present in any other celestial equine leg. (Acrux has no visible stars above it to form a hock.) Then PK967, the knee-bend of that leg, becomes o_1+o_2 Cen (HR4441 + 4442), whose combined magnitude of 4.39 fits just fine. This in turn means that the right hind leg becomes Acrux (the hoof) for PK966 and δ Cru (the knee-bend) for PK965. This proposal greatly reduces the positional errors for all four stars.

Bright γ Cru and β Cru are not left out, however; I assign them to PK963 and PK964 respectively, described as the two stars under the belly. The magnitudes of these two fit well, although the positional errors are quite bad; however, the standard identifications of ϵ Cen and HR5141 are not much better. In this context, it's interesting to note that the cataloged position of PK964 rises (at Rhodes) at the same time as β Cru (i.e., it has the same Hipparchan Phenomena 1 and 2), and its setting phenomena (Hipparchan Phenomena 3 and 4) are off by almost exactly 10 degrees. So this may be a scribal slip just before a spherical trig conversion.

This means that λ Cen (at $V = 3.12$) becomes the southernmost star in the catalog at Ptolemy's epoch ($-53°07'$, compared to $-52°51'$ for Acrux). At Hipparchos' epoch, Canopus remains the southernmost. Star PK968 has the southernmost cataloged position at either epoch.

C37 PK971 must be ϵ Cru (HR4700) under the above proposal. The positional error is not hugely different from other stars in the region, and less than the standard μ Cru.

[7] Toomer 400.

[8] Some might oppose this identification on the grounds that these stars would have post-extinction magnitudes of 6.95, 6.77, 6.92, and 6.81 under Schaefer's atmosphere (see ‡1 fn 6) at the latitude and epoch of Ptolemy; so this identification implies that even Ptolemy observed under an atmosphere of $k_a \leq .01$. But I have no better explanation for what these "stars on the hock" might be.

C38 PK982-983: P&K and Toomer give ρ Lup and ι Lup. I prefer ι Lup (HR5354) and HR5364. The descriptive and numerical positions are both better, although the magnitudes are worse; they may have been reversed.

C39 PK987-988: We follow P&K, not Toomer, as χ Lup (HR5883) and ξ_1 Lup (HR5925) here. Most positions in this part of the sky are displaced to the west and a bit north, which makes these identifications preferable.

C40 PK1017: P&K and Toomer give ζ PsA (HR8570), extremely dim at $V = 6.43$; much better is HR8563 at $V = 5.94$, which is also slightly closer in position.

D The Unique Mistake of ϕ Ceti: A Datum Recovered

D1 This pair of inadvertant repeats (cf. above at §C26) gives us a unique opportunity to determine the original coordinate system used by Hipparchos and the way positions were converted. We would like to know two things: first, the obliquity that Hipparchos used when doing coordinate conversions;[9] and second, whether the original east-west coordinate was measured in Right Ascension or polar longitude. For this analysis, I make these assumptions: that the stars are indeed repeats; that the original east-west equatorial coordinates were the same for each pair; and that the original declinations for each pair differed by exactly one degree.

D2 We would like to find the original equatorial coordinates for each star, rounded according to ancient rounding rules. Normally this is not difficult, since ancient rounding is fairly loose. In this case, however, we have the rounded results of two different computations with the same east-west coordinate, which tightens the fit somewhat.

D3 For example, suppose that Hipparchos used an obliquity of 23° 40′ and measured RA (instead of polar longitudes) as the east-west coordinate. Looking at PK728, if we back-compute the equatorial coordinates, we see the original rounded coordinates must have been close to $\delta = -21°10'$, $\alpha = 345°30'$. But when we forward-convert these into the ecliptical frame (following the computations we suppose for Hipparchos, including rounding the final result according to ancient rules), the result becomes $\beta = -13°45'$, $\lambda = 338°20'$. The longitude is fine, but the latitude differs from that of the *Almagest*, which is $-13°40'$. Tweaking the starting declination up to -21 results in $\beta = -13°30'$, skipping right over the desired result. So we know that this combination of obliquity and Right Ascension does not work.

D4 In practice such exclusions are rare, because one is usually able to find a combination that computes correctly by tweaking the starting coordinates a bit. But with the addition of a second conversion for the same star, any tweaking of the input coordinates becomes less likely to succeed, because the same tweak must be simultaneously successful for both conversions of that star.

Obliquity $23°40'$ RA: Conversion for PK728 fails. PL: Conversion for PK728 fails.
Obliquity $23°51'$ RA: Conversion for PK728 fails. PL: All conversions work.
Obliquity $23°55'$ RA: All conversions work. PL: The conversion for PK728 fails at $\delta = -21°1/4$, while the alternative ($-21°1/6$) fails for PK729.

D5 There are only two possibilites: either Hipparchos used $23°55'$ as his obliquity, combined with RA as the east-west coordinate; or, he used $23°51'$ as the obliquity, and polar longitudes as the east-west coordinate. The latter combination has better textual support in both elements, and is therefore much preferred.

D6 Although all conversions work under these parameters, the conversion for PK731 appears to fail at first, giving λ = 335 1/4 and not the expected 335 1/3; but this is deceiving, because of Ptolemy's "slide & hide" procedure: any Hipparchan longitude ending with 1/4 was rounded up an extra 5 arcmin, to avoid disallowed fractions in the *Almagest*. Thus, 335

[9] There are three possibilities: $23°40'$ (*DIO* 1.2), $23°51'$ (*Almagest*),and $23°55'$ (Rawlins 1982, Rawlins 1994).

1/4 is perfectly acceptable, and indeed this becomes the first (and so far only) example of a lost Hipparchan 1/4-degree fractional longitude being recovered.

E The Strange Case of Pi Hydrae

E1 The odd case of π Hydrae (PK918) has been noted by others (e.g., Graßhoff 1990), who have pointed out that not only does this star have a huge error — over five degrees — but also that the same error appears in this star's position in the *Commentary*, proof positive that the ASC coordinates were taken from Hipparchos and not observed independently.
E2 But until now, there has been no compelling explanation for the five-degree error. The mystery is cleared up when we realized that other stars in Hydra (PK901, PK920) were observed equatorially, then converted to ecliptical coordinates. It then becomes clear that almost the entire error in the position of π Hya is in declination. Converting back to the original equatorial coordinates (after subtracting Ptolemy's $2°2/3$ precession), the Hipparchan equatorial coordinates would have been $\delta = -20.5$, $\alpha = 182°.5$. The actual declination of π Hya was very nearly $-15°.5$ at Hipparchos' epoch. So the error is a simple scribal slip: the written number ιε (15) was misread as κ (20) due to a malformed or missing cross-stroke on the ϵ.
E3 Astoundingly, Ptolemy may have observed this star himself, and then *thrown away his own correct observation* in favor of Hipparchos' huge error! In the *Almagest* VII.1, Ptolemy records[10] that π Hya is on a straight line with α Lib and β Lib. This observation is true for the actual star; but it is *not* true for the erroneous position of π Hya as recorded in the ASC. Just prior to this, Ptolemy claims that he had observed this alignment himself, and that it had not been recorded by any previous astronomer.[11] Of course, there is no evidence that Ptolemy's alignment observation also included a position measurement.

F Stars Observed Equatorially

F1 It is clear that a number of stars, especially in the south, were observed with equatorial instruments, and had their coordinates transformed into ecliptical coordinates for the catalog. The following cases have good evidence for this process: β Cnc (PK457), σ Psc (PK699), ϕ_2 Cet (PK728/9), ϕ_1 Cet (PK730/1), α Hya (PK901), π Hya (PK918), and λ Hya (PK920).

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[10] Toomer 326.
[11] Toomer 325.

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