‡3 Hipparchos' Rhodos Observatories Located: Lindos & Cape Prassonesi

Spherical Trig's Existence in the 2nd Century BC

Claudius Ptolemy's Stellar Sneak-Thievery Established: R. Newton's Star Catalog Theory Utterly Vindicated

by Rawlins[1]

The more *outré* . . . [evidence] is, the more carefully it deserves to be examined; and the very point which appears to complicate a case is, when duly considered and scientifically handled, the one which is most likely to elucidate it.[2]

Dedication

To Noel Michelson Swerdlow (*JHA* Advisory Editor and History-of-science MacArthur Fellow), who couldn't have better timed his prominent *JHA* "moratorium"-proposal (Swerdlow 1992 p.182),[3] which suggests that, since research on the Ancient Star Catalog is (NMS believes) getting nowhere in discovering the Catalog's authorship, scholars should cease wasting further labor on such a barren mine.

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[1] Rawlins is: Impossible. [The succinct & infallible judgement of no less than the dear *J.Hist.Astr.*'s dearer Editor-for-Life. See *DIO-J.Hyster.Astr 1.2* §§B1, C2, & G6.]

[2] A.C.Doyle *Hound of the Baskervilles* last chapter. See also Doyle's *Study in Scarlet* Chap.7.

[3] Swerdlow's precious *JHA* paper is critiqued at *DIO 2.3* ‡8 §C. One is similarly grateful for Evans 1993, which appeared at the very time the present paper's discoveries were being accomplished. (Evans 1993 arrived at the JHU Library only 2 days after DR's 1993/3/17 finding of the §C2&§C3 evidence which confirmed RN's slide&hide explanation of the Star Catalog — hitherto attacked by *JHA* authors, including Evans 1987.) Considering that it appeared in the *JHA*, Evans 1993 is downright friendly, merely (warming the *JHA* putative editorship's putative heart by) accusing RN of "ahistorical" work. (Evans 1993 at least credits RN with stimulating some current investigations. See *DIO 2.3* ‡6 §E1 & P.Huber at *DIO 2.1*. So: why's there still no symposium debate of these matters? — this despite DR's various challenges, including material distributed to Hist.sci worthies preceding & even during the Muffia's 1994/5/6-8 Dibner Institute conference at M.I.T.) Evans 1993 concludes by croc-tearfully regretting that RN "squandered his considerable talent". In the context of the Hist.sci community, one is tempted say no more than: at least RN had talent to squander. But the more relevant point is that, as always, the Muffia cannot admit that the RN-DR axis has made any substantial discoveries in ancient astronomy. Such behavior is not scholarly. It's religious. One used to suppose that theocratic dictatorships had withered away since the demise of Austria's Franz-Josef & Russia's Nicky 2. But, luckily, the extremely handsome *JHA* has clone-resurrected these pious caesars' spirits, in order to thrill us with a sociological counterpart to *Jurassic Park* — as gov't-fed, idea-eating behemoths lightfootedly (*DIO 1.1* ‡5 fn 12 & *DIO 2.1* p.2 *Info-Note*) roam academe, permitting no heresy to escape their eye and tooth.

Summary

From the Ancient Star Catalog and Hipparchos' stellar declinations, we discover his Rhodos Island astronomical observing sites' precise locations, unknown for 2000^{y}. The main observatory, where his high-precision star declinations were measured, was within a mile or two of his adopted latitude $\phi = 36°08'$N — perhaps upon a hill in Lindos' northwest suburbs. The less accurate southern portion of his famous ecliptical Ancient Star Catalog was observed by crude transit instrument, at Rhodos Island's southern tip ($\phi = 35°53'$N), which he took to be at latitude $\phi = 35°50'$N.

A Thurston's Skepticism

A1 On 1993/1/10, Hugh Thurston (Dep't Math, University of British Columbia) wrote *DIO* a letter which would shortly prove fateful for historians of the immortal ancient astronomer, Hipparchos of Nicaea. We recall that one of the two[4] most compelling arguments for Hipparchos' authorship of the Ancient Star Catalog is the finding by R.Newton (RN) that, while the Catalog's latitude fraction-endings exhibit the usual empirical excess of 00′s (due to naïve observers' natural tendency to round data) and 30′s (§B4), the longitudes' fractions show a different pattern: 40′s outnumber 00′s, and 10′s outnumber 30′s — just as one would expect if (as 1st publicly charged by Tycho in 1598, on other grounds) Ptolemy had stolen Hipparchos' star catalog by merely updating it for precession: adding 2°40′ onto all the longitudes, while leaving the latitudes unchanged. Commenting on this famous RN fractions argument (R.Newton 1977 pp.245f; summary: *DIO 2.3* ‡8 §C7), Thurston said:

> Many thanks for *DIO* [2.3]; I've been wondering how you'd react to Swerdlow. . . . I tested the [RN fractional] distribution for myself. (Yes, I'm a skeptic.) For the northern constellations the RN distribution showed up well; for the zodiac, weakly;[5] in the south, not at all.

A2 DR responded (1/28):

> Does "skeptic" mean that you don't believe it likely that Ptolemy just added 2°40′ onto most of the Catalog stars' longitudes to get the places he reports as [his own] "observations"? If so, I'm surprised — but will want to hear your reasoning anyway, and will even publish it if you wish.

A3 Thurston replied 2/25:

> A skeptic is someone who does not take everything on trust but likes to check things for himself or herself. Aren't you a skeptic? Anyway, when I read RN's account of the arc-minute endings (way back before he was well known, at least to me) I decided to check for myself. . . . the southern constellations: RN effect absent. . . . [As to whether I think it] likely that Ptolemy added 2°40′ to most of the [Catalog longitudes] the answer would [be] *yes*; in fact, not so much likely as almost certain. . . . If you had asked "Do you believe that Ptolemy added 2°40′ to the longitudes of all (or almost all) of the stars in the catalog?" the answer would have been *no*. Reason: the strong argument for this suggestion, namely the [RN] arc-minute distribution [excess of 40′ fractions], does not apply to the whole catalog. . . . the origin of the southern part of the catalog is a complete mystery . . . . Presumably it was not observed by Ptolemy, unless he corrected his error[6] in the latitude of Alexandria.

A4 A few weeks later (3/20), Thurston added:

> Two odd facts may be significant in some way. The northern constellations have a huge preponderance of zero endings for latitudes . . . . The zodiac latitudes have substantially more halves than zeroes . . . . [However, Ptolemy at *Almajest* 5.1] said that his [astrolabe rings'] scales were graduated in fractions of a degree as small as practical.[7] This cannot mean whole degrees nor, unless we interpret it extraordinarily liberally, half-degrees. So if the scales were graduated in whole or half degrees here is another bit of evidence that Ptolemy was not telling the truth. . . . Finally, a quotation from Bishop Berkeley that you might think applies to the muffia: "I observed how unaccountable it was, that men so easy to confute should yet be so difficult to convince."

A5 It will be seen that the paper which follows here grew out of Thurston's queries (§A1 & §A3) on the southern part of the Catalog. After completing the core of the math research, DR wrote Thurston (1993/5/5):

> Thanks for your letters of 1993/2/25 & 3/20, which were nicer than I deserved. . . . I am just finishing up the computer work for a *DIO* paper (whose underlying new finds commenced 1993/3/9-10), the upshot of which may interest you. An oddity: though one of the main programs is rather long . . . and occasionally intense, nonetheless, its key discovery (1993/4/8) is so simple that a [gradeschooler] should be able to follow it. Even a Muffioso might. Might.

As noted, the paper in question is the same one you are reading — which owes its very inception to Thurston's frequently fruitful skepticism.[8]

[4] For the other, see *DIO 2.3* ‡8 §§C10-C15.

[5] There have been a number of attempts to split the Catalog's zodiacal stars, in order to show that only part of this sample exhibits the RN distribution. Shevchenko 1990 p.194 suggests that only Sgr through Gem (7 constellations) do so, while Cnc through Sco (5 constellations) don't. A friend of mine suggests that the split ought to be: the 6 north constellations (Ari through Vir) don't, while the southern ones (Lib through Psc) do. The catch with such schemes is that the deviation from the RN distribution is so weak that, when one takes into account all the ways one may split the sample, the full-contextual probability is not statistically significant. (The fundamental sample-splitting underlying the current paper's start is merely: north, zodiac, south. But these are Ptolemy's divisions, not DR's. See similar approach at fn 45.) Also, while it is true that, for the north half of the zodiac, 00′s outnumber 40′s (contra the RN distribution), this result is due to the eleven Tau informata stars, which are so peculiar (the first 9 are all 00′s, an anomaly noted by Włodarczyk 1990 p.294) that even the Shevchenko 1990 attack on RN throws them out. Using the numbers of Shevchenko 1990 (Table 4, p.193, which contains some small errors, and a *JHA* typo of 11 where 1 is meant for the Psc 50′s): we have more 40′s than 00′s AND (the most dramatic contrast, noted at *DIO 2.3* ‡8 §C22 item [e]) far, far more 10′s than 30′s. And these RN-profile patterns hold both for the northern and southern half of the zodiac. Note that, though including the Tau informata will (for the northern zodiac) permit the 00′s to outnumber the 40′s, this will have null effect upon the enormous 10′ vs. 30′ contrast.

[6] This refers to *DIO 2.3* ‡8 §C22 item [f] (Rawlins 1987 p.236 item 2): the discovery (Rawlins 1982C p.367) that the Catalog's indicated latitude error $\Delta\phi$ is incompatible with Ptolemy's $\Delta\phi = -14'$. (Cataloger's $\Delta\phi = 0' \pm 1'$: *idem* Table V, zodiac stars, column y. See also §G3 & fn 19 here.) It should be noted that there is a reverse incompatibility for Ulugh Beg's star catalog: though UB estimated his latitude correctly, the meridian ring of his astrolabe was mis-set ordmag 0°.1 high. (As accurately confirmed in 1992 by K.Krisciunas. See *BullAAS 24.4* & *JHA 24.4*:269. I disagree with the explanation given for the discrepancy.) This is less suspicious than the case of Ptolemy, whose defenders must assume that, though he had the wrong latitude for his nonexistent Alexandria observatory, he accidentally happened to set his equally nonexistent (fn 7) astrolabe's meridian ring right smack on the correct latitude. (Suspicion independently confirmed at §F9 via star declinations.)

[7] DR comment (expanding upon Thurston's observations): Can one imagine an astronomer describing *his own* astrolabe in such a vague fashion? *An instrument on which he has personally measured the λ & β of 1000+ stars?* (Would not an observer, so intimate with the instrument, specify precisely that its long-familiar-to-him rings were graduated in quarter-degrees or sixth-degrees or whatever? Doesn't he even *know* which it is?) Such considerations long ago revealed the phoniness, of Ptolemy's pretensions, to the perceptive (& highly competent) astronomer Delambre 1817 1:xxvii.

[8] See Thurston's erudite survey of the history of yearlength measurements, which the *Griffith Observer* deserves commendation for running as the lead article in its 1993/6 issue. (I would add only 2 small observations: [a] Ancients preferred solstices to equinoxes for estimating the year's length. And they were wise — at least in theory — to do so. See R.Newton 1977 pp.81-82, *DIO 1.1* ‡5 fn 20, & *DIO 1.3* §K4. [b] The *GO*'s diagram at the top of p.5 makes the Winter Solstice noon zenith distance of the Sun in ancient Alexandria equal to 55°.2 instead of the correct value, 54°.9. See Rawlins 1982G pp.261 & 264.)

B Randomness Unperceived: JHA Wetdream-Comes-Nightmare

B1 As Thurston has scrupulously remarked (in his 1993/1/10 letter), the fact that the southern part of the Catalog does not exhibit the usual dominance of 40′s had already been pointed out by Shevchenko 1990 p.195 and Włodarczyk 1990 pp.290-291. Unlike Thurston, both of these contributors to the extremely handsome *Journal for the History of Astronomy* attempted to use this discrepancy to attack the credibility of the *JHA*-hated RN's entire Catalog analysis. We are about to discover the very reverse of this *JHA* wetdream, once we observe a remarkably elementary point which our *JHA* authors overlooked.

B2 RN's critics appear to have forgotten that the whole *basis* for RN's expected distribution was simply: the latitude-fractions' frequency-profile with 40′ added. So, for any *portion* of the Catalog where there is no unusual statistical excess of latitude 00′s, there need be no excess of longitude 40′s. When we examine the southern part of the Catalog, this is precisely what we find. Thus, the nonexistence of an excess of 40′s (for the southern stars) has — with delicious perversity — provided complete vindication for RN, instead of the longed-for refutation which our judicious *JHA* so fervently desired when it spotlighted the southern 40′ nonexcess. (See §C3.)

B3 Both to understand this point and to see why it has not been previously discovered, we must first examine the peculiar ancient convention for writing fractions of degrees, which was accomplished via "unit fractions", i.e., inverse integers. (E.g., 15′ was written as 1/4 degree, and 45′ or 3/4 of a degree was expressed as 1/2 + 1/4.) The Catalog latitudes were entirely expressed in whole degrees, halves, thirds, quarters, sixths. The result is that all the Catalog latitude fractions are (if we express them in arcmin): 00′, 10′, 15′, 20′, 30′, 40′, 45′, 50′. However, note that these eight possible fractions *do not cover equal empirical ranges*. Taking midpoints (between these values) as bounds, the eight corresponding ranges' upper bounds are, respectively, 05′, 12′1/2, 17′1/2, 25′, 35′, 42′1/2, 47′1/2, 55′; thus, the size of the eight ranges are, respectively, 10′, 7′1/2, 5′, 7′1/2, 10′, 7′1/2, 5′, 7′1/2. Dividing by 60′, we have the expected frequency[9] of each fraction in a random case: 1/6 (00′), 1/8 (10′), 1/12 (15′), 1/8 (20′), 1/6 (30′), 1/8 (40′), 1/12 (45′), 1/8 (50′). For the 317 southern stars, the predicted (random case)[10] distribution would thus be: 53 (00′), 40 (10′), 26 (15′), 40 (20′), 53 (30′), 40 (40′), 26 (45′), 40 (50′).

B4 Previous researchers, glancing at the latitude-fractions distribution for the Catalog's southern stars (Table 2), noticed that the 00′ & 30′ fractions were slightly more numerous than other fractions and so naturally assumed that the Catalog's southern latitudes followed the RN mean profile for the whole Catalog. (Thus the seeming mystery of why the southern longitudes didn't do so.) But, what has been previously overlooked is that *a completely random* set of star observations would also display (§B3 & §B5) a modest excess of 00′ & 30′ fractions — merely because of the large 10′ *ranges* (55′ to 05′ & 25′ to 35′, respectively) associated with these two fractions, a result of nothing more than the range-inequalities (§B3) inherent in the ancients' fashion of using unit fractions for degree-division. This situation is in contrast to the mean total 00′ plus 30′ excess (of the entire Catalog) found by RN, which for 00′ was clearly over&above the random-profile frequency of §B3, and was due to a common observer's bias (§A1) toward rounding data to whole degrees.

B5 To attack the question of the fractions in the Catalog's 317 southern stars, we start with a straight χ^2 test upon the observed southern latitudes vs. the random-case profile of §B3. The observed[11] profile is (see Table 2): 52 (00′), 43 (10′), 33 (15′), 39 (20′), 55 (30′), 38 (40′), 17 (45′), 40 (50′). The expected random profile — already given at §B3 — is strikingly similar. Comparing the two distributions statistically, we find χ^2 = 5 for df = 7, not a significant discrepancy. (Probability $P > 50\%$.) By contrast, the same test (also df = 7) for the latitude-fractions (Table 2) of the zodiacal and northern stars (vs. the random profile of §B3) yields, respectively, χ^2 = 22 (probability P = 1/300) and 70 (P = forget-it) — highly significant in both cases. So only the southern section of the Catalog reveals a random profile. Later, below (§D), we will see that there is a simple, revealing explanation for why the southern stars' latitudes exhibit random fractions. However, before coming to this, I wish to confirm the randomness hypothesis by examining the southern stars' longitudes.

[9] I note that these probabilities were earlier computed by R.Newton 1977 p.247. Incidentally, there is little evidence that 30′ Hipparchos Catalog endings were more likely than the random probability (1/6). True (§A4), as seen in Table 2, for zodiac β, 23% have 30′ endings, which is well (3.4σ) above chance; however, zodiac β is a separate sample from the rest (§C5), presumably older (see Rawlins 1982C p.369& *DIO-J.HA 1.2* fn 152, 1992/12 bracket). Possibly zodiac β were observed with an astrolabe graduated in half-degrees. See Neugebauer 1975 p.699.

[10] Compare to the distribution if degree-fifths are allowed: §F2.

[11] To avoid needless disagreements with the Muffia, I have here throughout rigorously adopted the fractions given in the scrupulous rendition by Toomer 1984. (His misprinted fraction for PK575's latitude I have taken to be 1/6, in agreement with PK & Manitius 1912-3 2:50.) Of the 1028 stars in the Catalog, 3 redundant stars are here dropped: PK147 (= PK96), PK230 (= PK400), PK670 (= PK1011). (Which leaves a total of 1025 separate stars. This correct count first appeared at Rawlins 1982C p.359.) Of the 349 zodiacal longitudes, 5 exhibit 15′ endings — thus they are not included in Table 1. (See *DIO 2.3* ‡8 fn 20.) No other Catalog longitudes have either 15′ or 45′ endings.

Table 1: Fractional Endings: Star Catalog Longitudes

Region	Totals	00′	10′	20′	30′	40′	50′
North	359	62	61	67	29	95	45
Zodiac	344	81	52	58	36	94	23
South	317	79	66	55	34	51	32
Sums	1020	222	179	180	99	240	100

Table 2: Fractional Endings: Star Catalog Latitudes

Region	Totals	00′	10′	15′	20′	30′	40′	45′	50′
North	359	108	29	33	39	75	36	10	29
Zodiac	349	68	30	28	33	82	49	20	39
South	317	52	43	33	39	55	38	17	40
Sums	1025	228	102	94	111	212	123	47	108

C Ptolemy's Slide&Hide Sleight: Final Confirmation of R.Newton

C1 RN was the first to discover how Ptolemy had solved a potentially-embarrassing difficulty implicit in his method of stealing the Catalog. Our standard eight fraction-endings' frequencies are listed in §B3; when Ptolemy's theft (§A1) slid each of these fractions upward by 40′, the resulting fractions had a displaced set of frequency rates: 1/8 (00′), 1/6 (10′), 1/8 (20′), 1/12 (25′), 1/8 (30′), 1/6 (40′), 1/8 (50′), 1/12 (55′). Obviously, the 25′ & 55′ fractions jarred with the other fractions (especially with no 15′ or 45′ fractions at all resulting from the 40′ shift!), and so — if left unaltered — would have revealed Ptolemy's plagiarism of the Catalog. Thus, he hid his trail by changing all 25′ fractions to 20′ and all 55′ fractions to 00′. *Sneeakeey*. (Note: This RN hypothesis[12] was thus the first to explain the virtual lack of 15′ & 45′ fractions in the Catalog longitudes, a deficit which — before RN — had previously seemed particularly odd, since the Catalog latitudes had plenty of these fractions.) For brevity, we will call the full (2 stage) Ptolemy plagiarism-procedure: "slide&hide". Two comments: [a] This is deliberate, conscious fraud. [b] It

[12] R.Newton 1977 pp.250-254. RN concludes this discussion with the comment: "Ptolemy would surely be startled if he could know how much we can learn about his fabrication simply from studying the fractions in the star catalogue."

necessitated Ptolemy's **knowing destruction of data**. For that substantial fraction of the Catalog whose longitudes were expressed with 15′ or 45′ endings, he fudged them (by 5′) & thus hid-merged them with other data — with the result that when we now try to reconstruct Hipparchos' longitudes, we cannot know for sure which stars (of those with 0′ or 20′ endings in Ptolemy's rendition) have been altered by 5′. Again: understand that we are talking about the deliberate & clandestine annihilation — forever — of some of the scientific data in a classic, legendary scientific opus. All this, in order to hide one's own theft of another scientist's greatest work: the Hipparchos star catalog, which Pliny 2.95 justly refers to as "a legacy to all mankind". Question. If Historians-of-science do not regard data-destruction & data-theft as scientific crime, then: what ARE they willing to call criminal?[13]

C2 Once the latitude distribution's consistency with randomness is realized, we apply the "hide" part of the foregoing slide&hide technique to the 40′-slide-displaced longitude distribution of §C1 (random); i.e., we merge the 25′ & 55′ counts with the 20′ & 00′ counts, respectively. The result is the following predicted profile of probabilities: 5/24 (00′), 1/6 (10′), 5/24 (20′), 1/8 (30′), 1/6 (40′), 1/8 (50′). In short, this is the expectation-profile if RN's hypothesis is correct. For 317 southern stars, the expected numbers would be: 66 (00′), 53 (10′), 66 (20′), 40 (30′), 53 (40′), 40 (50′). The actual numbers of stars in each cell are (Table 1): 79 (00′), 66 (10′), 55 (20′), 34 (30′), 51 (40′), 32 (50′). The resulting χ^2 = 10, which is not a significant discord (P = 1/13) for df = 5. (The same computation for the zodiacal & northern Catalog stars will produce χ^2 = 38 and 29, respectively, both grossly significant.) Incidentally, if we jettison RN's slide&hide hypothesis and simply test the southern star fractions profile for straight randomness (which would theoretically produce equal numbers of stars for each fraction: 53 stars), we get χ^2 = 31 for df = 5 — which is almost excessively significant (probability P = ordmag 1/100,000). Thus, the southern longitude fractions are wildly incompatible with straight randomness, though they are compatible with a random distribution, after application (to it) of the Ptolemy slide&hide process discovered by RN. (Virtual fractions-randomness in the southern part of the Catalog was established above: §B5.)

C3 Another test: slide by 40′ the actual (not random-theoretical) latitude-fractions profile (§B5 or Table 2) and then hide-merge the 25′ and 55′ entries (§C2), in order to predict the longitude profile. This transformation results in the following expected distribution for the southern stars: 72 (00′), 55 (10′), 55 (20′), 40 (30′), 52 (40′), 43 (50′). Comparing to the actual distribution (§C2 or Table 1), we find[14] χ^2 = 3. So the discord is not remotely significant. (For df = 5, $P > 2/3$.) Thus, the southern stars — which the extremely handsome *JHA* had adduced to tear down its RN-satan by splitting the Catalog sample into finer portions (lower statistical significance) — have ironically provided instead a lovely vindication of his slide&hide thesis: showing that RN's theory is correct for the Catalog not only in-the-large but in-the-fine.

C4 We may apply the same empirical-expectation-profile test to zodiacal and northern portions of the Catalog, as well. For the northern stars, the actual latitude-fractions profile is (Table 2): 108 (00′), 29 (10′), 33 (15′), 39 (20′), 75 (30′), 36 (40′), 10 (45′), 29 (50′). The slide&hide process transforms this into an expected longitude-fractions profile: 72 (00′), 75 (10′), 46 (20′), 29 (30′), 108 (40′), 29 (50′). The actual longitude numbers (Table 1): 62 (00′), 61 (10′), 67 (20′), 29 (30′), 95 (40′), 45 (50′). Which yields χ^2 = 10; thus, for df = 5, the discrepancy is not statistically significant. For the zodiacal stars, the latitude profile is (Table 2): 68 (00′), 30 (10′), 28 (15′), 33 (20′), 82 (30′), 49 (40′), 20 (45′), 39 (50′). The slide&hide process transforms this into an expected longitude-fractions profile: 61 (00′), 82 (10′), 69 (20′), 39 (30′), 68 (40′), 30 (50′). The actual longitude profile (Table 1): 81 (00′), 52 (10′), 58 (20′), 36 (30′), 94 (40′), 23 (50′), and χ^2 = 16 or (without Tau informata) χ^2 = 13. Either way, the discrepancy is statistically significant for df = 5.

C5 The upshot: using the RN slide&hide hypothesis, we find for the northern and southern stars, compatibility between the longitudes and latitudes. The exception is the zodiac. However, it was proposed years ago by DR on completely independent grounds that the zodiac longitudes and latitudes are not from the same set of observations. (See Rawlins 1982C pp.369-371.)

C6 Follow-up: χ^2 tests[15] show that all three longitude profiles (north, zodiac, south) are statistically incompatible with each other, and all three latitude profiles are likewise, except that the discrepancy is too weak to be statistically significant for zodiac vs. south (χ^2 = 11 for 7 df, so P = 1/6). However, we already found (§B5) that the latter is consistent with randomness while the former is not. The reasonable conclusion is, then, that all 3 portions of the Catalog were observed under different conditions; thus, the north, zodiac, and south portions of the Catalog represent independent samples, perhaps taken by 3 members of the same Rhodos team of astronomers.

D Randomness: Hipparchos' Possession of Sph Trig

D1 The explanation for randomness' domination (§B5) of the southern portion of the Catalog has been around for years. It is simply: these stars were mostly observed with a transit instrument (the sort described at *Almajest* 1.12), not the armillary astrolabe (*Almajest* 5.1) that was used for the majority of the Catalog's stars. Rawlins 1991H fn 25 already suggested[16] this theory for a few patches of southern stars.

D2 The reason this will produce random Catalog fractions is that, when sph trig is used to transform equatorial coordinates to ecliptical coordinates, the resulting fractions will not be subject to eyeballing's natural tendency (§A1) to produce whole-degree measurments. (This proclivity is the basis of the RN fractions-frequency profile for the non-south sections of the Catalog.) Thus, randomness in the southern part of the Catalog's ecliptical coordinate-fractions provides hitherto-unperceived evidence for the existence[17] of sph trig in the 2nd century BC.

D3 This is also evidence against the long-attractive theory (e.g., Graßhoff 1990 pp.182, 190-191) that Hipparchos might have used a globe as an analog-calculator (equatorial-to-ecliptical transformation in the present case) — perhaps in preference to computing his Catalog's ecliptical coordinates via sph trig. Use of a globe would entail eyeballing the ecliptical coordinates that went directly into the Catalog; and this would produce a notable excess of whole-degree ecliptical data, an excess which (as we saw above at §B5, §C2, §C3) is not found in the southern part of the Catalog.

E Hipparchos' Southern-Outpost Observatory Located

E1 The theory that the southern stars were originally observed & recorded in equatorial coordinates could be expected to have certain consequences. So, DR decided upon the

[13] For an ironic answer, see *DIO 2.1* ‡3 §C10 (& fn 32).

[14] The formula for finding χ^2 for several samples is provided at R.Burington & D.May *Handbook of Probability & Statistics with Tables* 1970 ed, p.234. Włodarczyk 1990 p.292 gives a much neater version of this formula for the special case of two samples. (Proving the latter expression from the former is a fun student exercise.)

[15] The longitude χ^2 (df = 5) are: 11.5 (north-zodiac), 17 (north-south), & 15 (zodiac-south). The latitude χ^2 (df = 7): 17 (north-zodiac), 27 (north-south), & 10.8 (zodiac-south). The last is not significant ($P > 0.15$).

[16] DR first proposed this theory in private correspondence not later than 1987/12/20. The spark that launched his suspicion: there are huge group-errors in some southern constellations which appear to be impossible without presuming equatorial errors. Does this paper's finding (southern portion of Ancient Star Catalog originally taken in equatorial coordinates) partly vindicate the Muffia opinions cited at *DIO 1.2* §I1? DR's view: it is by now obvious (especially given the non-Ptolemaic ϵ = 23°11/12 of §§E2-E7) that virtually every star in the Catalog came from Hipparchos (*Almajest* 7.1; rare exceptions: *DIO 2.3* ‡8 fn 20) to Ptolemy, already rendered in ecliptical coordinates, no matter whether originally observed via armillary astrolabe or transit circle. (See also the *Almajest* 7.3 passage noted at *DIO 1.2* §I1.) Thus, resemblance of Muffia opinion and the present paper's results is but partial.

[17] Therefore, this paper will hopefully dampen the absurd longtime Muffia passion for denying that sph trig existed in Hipparchos' time. (See Rawlins 1984A p.982 and *DIO 2.1* ‡3 §A2 & fn 3.) DR first realized the randomness of the fractional endings in the southern section of the Catalog (& explored the randomness-equatorial link) on 1993/3/12.

following test: [a] convert (by sph trig) all southern stars, from their ecliptical Catalog positions, into the hypothesized original equatorial positions (rt asc α & decl δ), and [b] then (choosing an assumed value ϕ for the observer's adopted observatory latitude ϕ) recover the observed zenith distances Z, and [c] finally, in that set of data, look for an empirical excess (§A1) population in the whole-degree Z cell (i.e., the reconstructed Z that fall into the range $55'$ to $05'$).

E2 Since Hipparchos had used 2 different obliquities[18] during his career, both were tried. It would transpire that the earlier value, $\epsilon = 23°55'$, was the one used by Hipparchos' mathematicians for the sph trig equatorial-to-ecliptical transformations (the reverse of the sph trig transformations of the modern ecliptical-to-equatorial reconstruction performed here at §E1) required to produce the southern part of the Catalog from the original transit-instrument observations underlying the published data.

E3 It is wellknown[19] that the ancients determined celestial objects' declinations δ just as modern astronomers do: observe the upper-transit zenith distance Z (positive to the south), and then subtract it from the adopted latitude ϕ of one's observatory. Simple arithmetic:

$$\delta = \phi - Z \qquad (1)$$

— which may be rewritten:

$$Z = \phi - \delta \qquad (2)$$

Thus, once the declinations δ are regenerated (sph trig of §E1) out of the Catalog's ecliptical data, we need only subtract them from an assumed latitude ϕ, to find the fractions-distribution of the raw Z data which are here hypothesized to underlie the southern part of the Catalog.

E4 Almost immediately (1993/3/23), DR found that, if the observer's ϕ ended in $50'$, there is a spectacular excess of stars falling into the Z whole-degree cell.[20] Since Hipparchos worked on the island of Rhodos, the natural suggestion is that the southern part of the Catalog

[18] The earlier of Hipparchos' two long-adopted obliquities was $\epsilon = 23°55'$ (fn 34); later, Hipparchos switched to the much more accurate obliquity, $\epsilon = 23°40'$. Details in Rawlins 1982C and *DIO 1.1* ‡6 fn 21, *DIO 1.2* fn 104, *DIO 3* fn 70. (Explicit ancient attestation of $23°55'$ cited at Rawlins 1985G fn 6.)

[19] *Almajest* 1.12, 5.12-13. A byproduct of the current paper is verification that the procedure Ptolemy reports was indeed standard for ancient scientists. This is the basis of a DR argument (fn 6) that Ptolemy's declinations were not his own. (See also §F9.)

[20] As an example, we examine the star PK805, θEri. (The significance of this star's huge errors in position & magnitude are intelligently analysed by Graßhoff 1990 pp.170-171. PK805's rating as 1st magnitude — mindlessly copied by Claudius Indoor Ptolemy — was obviously due to an early confusion with Achernar.) Observed $Z = 84°$ (so using $\phi = 35°5/6$ in eq. 1 yields $\delta = -48°10'$), and observed $\alpha = 27°$. Thus, for $\epsilon = 23°11/12$ (fn 18 & fn 34), sph trig calculation-transformation from equatorial to ecliptical coordinates produces: $\lambda = 357°33'.9$ & $\beta = -53°30'.1$ — which round to λ = Psc 27° 1/2 & $\beta = -53°1/2$; Ptolemy added 2° 2/3 to λ, leaving: λ = Ari 0° 1/6. These are precisely the coordinates we find in the Star Catalog (*Almajest* 8.1; Manitius 1912-3 2:57 and Toomer 1984 p.386).
Another example is perhaps afforded by PK964, a star listed in the Catalog as m = 3, though no star of such brightness exists near the given place. (PK964 has been noted as anomalous for over 1000 years: PK p.112.) DR proposes that PK964 may actually be a bungled version of δ Cen (real -126.3 coordinates: $\alpha = 157°06'$, $\delta = -39°08'$), a star already listed (uncontroversially: PK p.118) as PK960. Assume observed values (rather typically-rounded) for δ Cen: α = 10h7/12, error $\Delta\alpha = +6^m.6$ at Catalog epoch ($-127/9/24$, fn 27); and $Z = 75°$, error $\Delta Z = +3'$ (-126.3 transit at C.Prassonesi, $\phi = 35°53'$). Thus, $\alpha = 158°3/4$, while eq. 1 gave $\delta = 39°1/6$. Transformation (again, $\epsilon = 23°11/12$) gave: $\lambda = 179°56'$ & $\beta = -43°44'$, which rounded to $\lambda = 180°$ & $\beta = -43°3/4$. (Note that the other Hipparchos Catalog listing for δ Cen, PK960, does give precisely $\lambda = 180°$: PK p.94.) Hipparchos, originally expressing (or computing) the λ in "steps" of 15° each (Neugebauer 1975 pp.302, 669f, 1049), correctly put λ at the start of the 13th step. But, there was later a unit-mis-step during conversion of steps into degrees for the Catalog: $\lambda = 13 \cdot 15° = 195°$. The Hipparchos Catalog position of PK964 was indeed (PK p.94): $\lambda = 195°$ & $\beta = -43°3/4$. And PK964 is the right magnitude (Catalog m = 3) for δ Cen: pre-extinction $m = 2.60$; -126.3 C.Prassonesi culmination null-dust post-extinction $\mu = 3.12$. (One might possibly argue that our $\lambda = 180°$ version of PK964 is μ Vel, the brightest seemingly-omitted star in the Catalog: $m = 2.69$, $\mu = 3.19$. Real -126.3 coordinates: $\alpha = 140°05'$, $\delta = -39°05'$. This star's -126.3 C.Prassonesi-transit $Z = 74°55'$ is in fact close to 75°; but, since the star's α is nowhere near 158° 3/4, one must then propose the accidental occurrence of two large Hipparchos-calculation errors, not the δ Cen hypothesis' single slip. [But see retractive conclusion at *DIO 4.3* ‡14.]) Suggestions implicit in the speculation that PK964 = δ Cen: [a] At least some star-observations were doubled. (Similar occasional doublings in Ptolemy's geographical records are noted by Rawlins 1985G §§8&10 & fn 6.) [b] The count at §E5 may be $n_\circ = 76$.

was largely observed at the south tip of the island, Cape Prassonesi, which is at latitude $\phi = 35°53'$N (longitude 27°46'E of Greenwich), a figure evidently set at 35° 5/6 by the observer. (Hipparchos and other ancient astronomers normally expressed their parameters in conveniently rounded fractions. See fn 37.) Given the large and varying systematic errors affecting this part of the Star Catalog, it is reasonable to suppose that the chosen transit instrument was portable and was not scrupulously maintained & checked for proper orientation. This sloppiness is probably related (fn 47) to the outsize number of whole-degree Z that the observer recorded.

E5 For random observations of Z, we would expect the fraction-cells to exhibit the same frequency distribution[21] already set out in §B3: 53 (00′), 40 (10′), 26 (15′), 40 (20′), 53 (30′), 40 (40′), 26 (45′), 40 (50′). Instead, for $\phi = 35°50'$N, the Z data, reconstructed by the math of §E1 & §E3, results in: 75 (00′), 39 (10′), 27 (15′), 30 (20′), 57 (30′), 37 (40′), 23 (45′), 29 (50′). For the whole-degree entry, standard-deviation $\sigma = \sqrt{Npq} = 6.64$, since probability $p = 1/6$, $q = 1 - p = 5/6$, & $N = 317$ stars; $n_\circ = 75$ hits is 24%, same as the entire unprecessed (original Hipparchos) Catalog's λ whole-degree frequency. This is far above the random-profile expected number, $Np = 53$ (more exactly: $Np = 317/6 = 52\ 5/6$), 17%. Indeed, the normalized deviation $\nu = (n_\circ - Np)/\sigma = (75 - 317/6)/6.64 = 3\ 1/3$ — which corresponds to odds of more than 1000-to-1 against the whole-degree total $n_\circ = 75$ having occurred merely due to chance.

E6 DR later discovered (1993/4/11) that there is an even more refined correlation between [a] size (southerliness) of Z, and [b] the percentage of whole-degree-cell Z. Examining the 317 southern stars in cumulative stages (starting at the horizon), one finds that the statistical significance, of the south-sky whole-degree Z excess, peaks at about $\delta = -18°$ or $Z = 54°$. To be precise: in the southern portion of the Catalog, of the 209 stars which are south of $\delta = -18°$, 58 stars' Z fall[22] into the whole-degree cell,[23] where the expected number would be 209/6 = 34 5/6. Since $\sigma = \sqrt{Npq} = 5.39$ then $\nu = (58 - 209/6)/5.39 = 4.30$ — thus, odds of about 60,000-to-1.

E7 Examining the number of whole-degree Z, from the horizon up to anywhere between $Z = 49°$ and $Z = 57°$: one finds that ν exceeds 4 — which corresponds to odds of over 15000-to-1. When evaluating the significance of such odds, one must of course take into account the range of option-choices (obliquity ϵ, latitude ϕ degree-fractions, transit-data north-bound) that went into the hypothesized scenario. But even if one divides by 2 (ϵ options) and by 10 (ordmag the number of common ancient-rounded ϕ degree-fraction

[21] Actually, as we will see later here (§F1), Z observations were probably written more finely than celestial latitudes β (since ancients normally used fifths of degrees for equatorial coordinates: *Almajest* 7.3). But this will have no effect at all upon the count in the crucial Z whole-degree-cell.

[22] The full 209 star distribution: 58 (00′), 24 (10′), 18 (15′), 15 (20′), 35 (30′), 27 (40′), 17 (45′), 15 (50′).

[23] These 58 transformations, from Catalog (λ & β) to α & Z, are the reverse of reality. Checking the real transformations, from observed Z & α to Catalog λ & β, one finds that (primarily because most β cell-ranges are smaller than the whole-degree cell's) some of the 58 stars do not succeed. However, since the latter part of the slide&hide hypothesis merges 15′ longitude fractional-endings with 20′s, and 45′s with 40′s, this makes feasible the transformations for, e.g., PK728 & PK859. Also, the Cataloger tended to avoid 45′ fractional endings (a point noted at R.Newton 1977 p.248 & Graßhoff 1990 p.85 with respect to β — and confirmed in the current analysis as regards α); this habit assists a few more whole-degree-Z places to yield the Catalog position — e.g., PK790 & PK842. Permitting α to be expressed to the most basic standard ancient precision (§B3), as well as degree-fifths & (corresponding to half-timemins) degree-eighths, we can specify 54 stars with integral Z (00′ ending) which could have transformed to the Catalog's ecliptical coordinates (*Almajest* 8.1). (If we allow degree-tenths, 57 stars.) One more if PK964 is added (fn 20). Accounting for the smaller cell-ranges noted above, we would expect to lose about 5 stars when reverse transformations are checked (we are implicitly assuming precise, infallible Hipparchan sph trig computers, which is unrealistic); and this is roughly what has been found. So the high odds (against chance producing our results) persist, though this check is actually superfluous, since the analyses of §E5-§E6 have already statistically established the correlation between the Catalog's southern part and Z whole-degree fractions for $\phi = 35°50'$N. The strength of the excess in our Z whole-degree-cell can be underscored by noting that its members comprise 58 out of 209 data = 28% (vs. 17% expected: §E5 or §F2), similar to the (unprecessed) Hipparchos 00′ rates for north & zodiac λ ([95 + 94]/[359 + 344] = 27%) or north β (108/359 = 30%).

options),[24] and by 2 (number of rough north bounds for transit data),[25] still: the odds are hundreds-to-1 against the findings here being due to chance.

F Locating Hipparchos' Main Observatory: Lindos

F1 Having used the foregoing logic to locate the latitude ϕ of the observer of the southern part of the Catalog, DR next decided to see if one could draw revealing information from Hipparchos' surviving explicit declination data. These δ (the error of whose mean is virtually null: fn 51 & Rawlins 1982G n.17) are of far higher quality than the star Catalog's λ&β. Thus, they presumably represent work done at his main observatory, not a perhaps-temporary southern outpost.

F2 There are extant 20 high-quality Hipparchan values of δ: 18 stars in *Almajest* 7.3; also Polaris in *GD* 1.7.4 and Schedar in Strabo.[26] Dropping the spurious[27] value for Arcturus, we have 19 data. There are 12 permissible degree-fraction cells, since degree-fifths are used for ancient declinations. The cell-counts[28] are: 3 (00′), 2 (10′), 0 (12′), 0 (15′), 1 (20′), 3 (24′) 1 (30′), 3 (36′), 1 (40′), 3 (45′), 2 (48′), 0 (50′). This may be compared to the expected frequency[29] distribution for a random set of data: 1/6 (00′), 1/10 (10′), 1/24 (12′), 1/15 (15′), 3/40 (20′), 1/12 (24′), 1/10 (30′), 1/12 (36′), 3/40 (40′), 1/15 (45′), 1/24 (48′), 1/10 (50′).

F3 On 1993/4/8, I realized that the information for locating Hipparchos has lain before our eyes for two millennia — right there in the δ-fraction distribution of §F2. The key clue is the pair[30] of nulls at δ = 12′ and 15′. These would be expected if, when Z observations were converted to δ data (by eq. 1), the automatic data-contraction,[31] occurring around Z whole-degree readings, was carried into the δ fractions. With this thought in mind, it was easy to see that if ϕ ended in 08′-10′, then null δ-fraction cells would have to occur[32] at 12′

[24] The most popular fractions are the 8 cited at §B3. Using fifths as well can bring the total to 12 (§F2). If we add in eighths (§F3) and tenths & twelfths (*DIO 1.1* ‡6 §D9), this brings the top possible total of allowable Hipparchan degree-fractions to 24.

[25] The rough northern boundary for the southern transit data is, *a priori*, not likely to be outside the region where $45° < Z < 60°$. So, given that boundaries extending over 8° (§E7) all produce $\nu > 4$, one must note that the number of 8° regions covering this 15° range in Z is merely about 2. Dividing high odds by this amount does not seriously degrade the large unlikelihood that our results here are the product of chance.

[26] From Strabo 2.5.41, we have α Cas's North Polar Distance θ = 31700 stades or 45° 1/4, so declination δ = 44° 3/4.

[27] Hipparchos' Arcturus δ = 31° (*Almajest* 7.3 & Hipparchos *Comm* 1.8.16), though the star's real δ = 31° 17′ at Hipparchos' epoch, −127/9/24 (Rawlins 1991H eq.28 & §§F4-F5). The −17′ error appears to be based on Hipparchos' false Alexandria latitude ϕ plus his sign confusion for the star's Alexandria zenith distance Z. Strabo 2.5.38 (part of his summary of Hipparchos' geography) states that Arcturus transitted slightly *south* of the zenith (positive Z: see §E3), though the truth is that it transitted about 5′ *north* (Z = −5′) of Alexandria's zenith at Hipparchos' −127 epoch. Since Hipparchos took Alexandria's latitude to be ϕ = 31° 05′N (fn 44), this theory perfectly explains his curiously false Arcturus δ: taking Hipparchos' Z = +5′, then, by eq. 1, δ = 31° 05′ − 5′ = 31° 00′. Arcturus is dropped from the sample for all main Hipparchos (& Timocharis) analyses here. (Regardless, inclusion of its whole-degree ending would upset none of this paper's conclusions. See, e.g., fn 49.) I note the provocative coincidence that this worst declination of the *Almajest* 7.3 set happens to have by far the highest declinational proper motion.

[28] Throughout this part of the analysis, it is important to note that (for reasons of analytic consistency) all degree-fractions for negative δ are subtracted from 60′ before being entered into a δ distribution.

[29] See the chance distribution (without degree-fifths) given at §B3.

[30] Note that the 50′ null is accidental by the 36° 08′N hypothesis. But this is not a problem since: [a] only 1 hit is expected in this cell for a 19 star distribution, & [b] had the actual 19 declinations of the sample been observed exactly correctly (no rounding), none would have ended up in the 50′ cell.

[31] I.e., due to ancient rounding convention (§B3), all data between 55′ & 05′ are sucked into one cell: that for 00′.

[32] Take the (Hipparchos) case of ϕ ending in 08′. By eq. 1, those Z ending in 00′ would produce δ ending in 08′, which rounds to 10′. Those Z ending in 50′ would produce δ ending in 18′, which rounds to 20′. (I.e., 12′ & 15′ endings are impossible.) Those Z ending in 48′ would produce δ ending in 20′ — adding more to the 20′ cell. Those Z ending in 45′ would produce δ ending in 23′, which rounds to 24′. Continuing to proceed similarly, one may produce an expected δ distribution exhibiting both nulls as well as shifted and-or merged probabilities from the Z distribution. E.g., since the 48′ & 50′ cells for Z were (via eq. 1 & the 08′ ending of ϕ, as just noted) merged

& at 15′, just as we find[33] in §F2. However, a 10′ ending for ϕ would produce a null δ cell at 48′, which is in fact filled (see §F2). And 09′ is too unrounded for Hipparchos. So, since Hipparchos is known to have used eighths of degrees (07′1/2, evidently interchangeably with 08′: see *DIO 1.3* fn 251), the natural conclusion is that his main observatory's adopted ϕ ended in 08′. On the island of Rhodos (where Hipparchos observed: *Almajest* 5.3&5, 6.5), this has to be 36° 08′N. Going clockwise around Rhodos Island, its 4 major cities were:[34] Kamiros (ϕ = 36° 20′N), Ielysos (ϕ = 36° 24′N), Rhodos city (ϕ = 36° 26′N), & Lindos (ϕ = 36° 05′N). Thus, our result (ϕ = 36° 08′N) unambiguously identifies Hipparchos' city as Lindos. According to the Army Map Service[35] there is a hill 371 m high, just (3 1/2 nmi) NW of Lindos, at ϕ = 36° 08′N, near the ancient town of Kalathos (modern Calato).

F4 There are several simple ways to confirm our finding for Lindos. First, we turn to Hipparchos *Comm* (his sole surviving work), where — though many stars' positions are given crudely (to whole degrees) — 10 declinations[36] show fractions (R.Newton 1974 p.339). Again, we find null[37] δ cells for 12′ and for 15′. Adding (to our previous sample) these 10 stars from Hipparchos *Comm*, we have (dropping[38] the 00′, 10′, & 50′ cells, as in fn 37) a Hipparchan set of 24 stars, the actual fractions-distribution of which is: 0 (12′), 0

into the 20′ cell (for δ), we must add the associated probabilities (§F2): 1/24 + 1/10 = 17/120. The full δ expected distribution is generated in the same fashion (displaying nulls at 12′ & 15′): 17/120 (00′), 1/6 (10′), 0 (12′), 0 (15′), 17/120 (20′), 1/15 (24′), 19/120 (30′), 1/20 (36′), 1/20 (40′), 1/12 (45′), 3/40 (48′), 1/15 (50′).

[33] It is worth noting that, had these 20 data been observed exactly correctly (& never rounded), 15% of them would have ended up in the 15′ cell. See §F9.

[34] *GD* 5.3.34 (Nobbe 1843-5 2:16, Müller 1883&1901 p.837, or E.Stevenson 1932 ed. p.114) gives for Rhodos Island (latitude & longitude E. of the [Cape Verde] Islands): Panos Akra (35° 11/12 & 58°; Nobbe 2:16 has 58° 1/3), Kamiros (35° 1/4 & 58° 1/3), Lindos (36° & 58° 2/3), Ielysos (36° & 58° 1/3). As revealed in Rawlins 1985G (pp.261f), ancients commonly derived their geographical manuals' ϕ lists from klimata data for longest day M. Presuming 35° 15′N (grossly erroneous) is a scribal error for 36° 15′N, we find that all four *GD* Rhodos ϕ are mere calculations from M = 14h1/2 (M/2 = 108° 3/4), using $\tan\phi = -\cos(M/2)/\tan\epsilon$, where ϵ = 23° 51′ (Eratosthenes), ϵ = 23° 11/12 (early Hipparchos), and ϵ = 23° 2/3 (late Hipparchos). The 3 calculations produce, respectively (rounding to the nearest 1/12th of a degree, as the *GD* always does): ϕ = 36° 00′, ϕ = 35° 55′, & ϕ = 36° 15′. (Note that Strabo attests ϕ = 25400 stades = 36° 1/4 for the Hipparchos Rhodos klima. See Diller 1934 and Rawlins 1985G.)

[35] A.M.S. M506 Balkans 1:250,000, "Scarpanto-Rhodos" Sheet G18, (1948). (Originally compiled in Britain: Royal Engineers, 1944.) The Army Map Service is now the US "Defense Mapping Agency".

[36] There are 12 fractional declinations in Hipparchos *Comm*, but two of these stars also appear in *Almajest* 7.3.

[37] Except for 36° 08′N and the 35° 58′-36° 01′N interval, all other possible Rhodos ϕ entail nulls in δ-fraction cells which are in fact filled. However, ϕ = 36° 08′N is nearer a major city than 36° 00′N, and Hipparchos was a man of the world (§G3). (South of Lindos, the east coast of Rhodos swings sharply to the west; so, any site near 36° 00′N would be about 10 nmi from the nearest city, Lindos. By contrast, at 36° 08′N, Hipparchos would be in the city's north suburbs.) Making a meaningful statistical choice between 36° 00′N and 36° 08′N is best accomplished by the following logic: before applying the null-cell test, it was already known that 36° 00′N would not be testable (since no null cells at all can result from a 00′ shift of Z's original fraction-ending via eq. 1). However, Hipparchos' finest known precision for geographical latitudes is 1°/12, same as Ptolemy's standard *GD* precision. (E.g., ϕ = 23° 55′ for Elephantine Island at *GD* 4.5.70 is probably from Hipparchos, since it equals his first adopted obliquity: fn 18.) Thus, 36° 00′N would have been Hipparchos' formal ϕ — if he believed that his latitude was in the range 36° 00′N±2′ (5 possible whole-arcmin endings out of 60). However, the *a priori* odds are but 5/60 = 1/12 that such an ending is true; in the other 11/12 of a large sample of such cases, the null-cells-test filter will reveal the genuine value(s) that ϕ may take. And there is further evidence against ϕ = 36° 00′N, namely, the comparison of expected distribution (for 36° 00′N) vs. observed distribution (§F4 & fn 38), for the cells from 12′ through 48′. The 00′, 10′, & 50′ cell-counts were of course ruined by rounding in the *Comm*. Thus, we subtract their sum probabilities from unity and divide into 10 to find the true probable total of *Comm* stars to add onto the previous sample of 19. This patchwork total is 34.79 for ϕ = 36° 00′N. For ϕ = 36° 08′N, it's 35.00. For ϕ = 35° 58′N, it's 33.47. So the expected cell-counts are, for ϕ = 36° 08′N: 0 (12′), 0 (15′), 4.96 (20′), 2.33 (24′), 5.54 (30′), 1.75 (36′), 1.75 (40′), 2.92 (45′), 2.63 (48′). For ϕ = 36° 00′N: 1.42 (12′), 2.27 (15′), 2.55 (20′), 2.83 (24′), 3.40 (30′), 2.83 (36′), 2.55 (40′), 2.27 (45′), 1.42 (48′). For ϕ = 35° 58′N: 2.20 (12′), 0 (15′), 3.85 (20′), 1.38 (24′), 3.30 (30′), 3.99 (36′), 1.24 (40′), 3.58 (45′), 3.30 (48′). Vs. the distribution of §F4, we have χ-square: 4.9 (ϕ = 36° 08′N), 10.7 (ϕ = 36° 00′N), 10.9 (ϕ = 35° 58′N). The associated probabilities P are, respectively: P = 0.77 (ϕ = 36° 08′N), P = 0.22 (ϕ = 36° 00′N), P = 0.21 (ϕ = 35° 58′N). The last solution (ϕ = 35° 58′N) survives the null-filter test — but it's more precise than any of hundreds of surviving Hipparchan expressions for angles. Regardless, let us note that all 3 solutions resulting from our analysis are in the range 35° 58′N-36° 08′N, and are thus: [i] in the southern part of Rhodos Island, & [ii] have Lindos as their nearest city.

[38] Of the original 19 Hipparchos declinations, 5 were in the now-dropped cells; thus, adding ten *Comm* stars to the remaining 14 stars yields 24 stars in all.

(15′), 3 (20′), 4 (24′), 6 (30′), 3 (36′), 1 (40′), 5 (45′), 2 (48′).

F5 Second, we may use the fact that 3 other ancient astronomers — all of whom probably observed in Alexandria ($\phi = 31^\circ 12'$N) — also left us declination data. In these cases, we know at the outset (within a few arcmin) the degree-fraction for ϕ. So, we may use this knowledge, as a check, to see if the same test (which we just used here for Hipparchos) is consistent with reasonable ϕ for the other 3 ancient observers. Keep in mind that the only possible accurate Alexandria ϕ which follow ancient rounding convention are: $31^\circ 10'$N, $31^\circ 12'$N, and $31^\circ 15'$N. Each ϕ entails giveaway nulls: $12'$ & $15'$ ($31^\circ 10'$N), $10'$ & $15'$ ($31^\circ 12'$N), and $12'$ & $20'$ ($31^\circ 15'$N).

F6 The most obvious case is Timocharis (c.300 BC: Rawlins 1982G p.263), who is directly attested (*Almajest* 7.3) as having observed in Alexandria. He left us 12 declinations, which come to us via Ptolemy (*idem*) through Hipparchos. If he used the correct value, $\phi = 31^\circ 12'$N, then we would expect null δ cells for $10'$, $15'$, & $45'$. And we indeed find null cells at $10'$ & $15'$, though a single star[39] possesses the disallowed $45'$ fractional ending.

F7 From Aristyllos, a 260 BC[40] follower of Timocharis, we have only 6 data (*Almajest* 7.3). It is generally presumed that he too observed in Alexandria. His results are consistent with his having used $\phi = 31^\circ 15'$ — which would require null δ cells at $12'$, $20'$, & $48'$. All 3 of these cells are in fact empty. Indeed, all the δ data he left us are rounded to the nearest 1/4 degree.[41]

F8 Finally, we turn to the Anonymous from whom Ptolemy lifted the declinations he presents as his own in *Almajest* 7.3. As in the case of Aristyllos, it seems likely that he adopted $\phi = 31^\circ 15'$N — since this implies the same null δ cells ($12'$, $20'$, & $48'$), and they are indeed again found to be null.

F9 Some comments. Firstly, in each of the foregoing cases, were the δ observations exactly accurate & unrounded (including the effect of refraction, which the ancients didn't correct for), some of the δ cells here required (by rounding & choice of ϕ) to be null would instead be filled. (Three stars each for Hipparchos[42] and Timocharis.) This is further evidence for the effect of rounding, which is the basis of the foregoing conclusions from nulls. Secondly, there has long been a controversy regarding the reality of the largely inaccurate six declinations which Ptolemy uses (at *Almajest* 7.3) to prove precession. (Were they faked? — or just conveniently selected?) The fact that not one of these suspicious stars breaks the null-cell requirement of §F8 suggests that perhaps they are real. (Rawlins in-prep D tentatively took this position about a decade ago. DR remains agnostic on the point, but wishes to note that this latest evidence is somewhat[43] in favor of Ptolemy.) Thirdly, least-squares analyses (Rawlins in-prep D) of the three Alexandrian observers' data (including refraction) have produced estimates of each observer's error $\Delta\phi$ in his adopted latitude (ϕ). All these $\Delta\phi$ are quite small[44] and are roughly in agreement with the foregoing. Timocharis (11 stars, dropping spurious Arcturus): $\Delta\phi = -2' \pm 3'$. Aristyllos (6 stars): $\Delta\phi = +1' \pm 3'$. Anonymous (the 12 nonsuspect stars): $\Delta\phi = +4' \pm 2'$. (Utterly incompatible with the $\Delta\phi = -14'$ of Ptolemy, who falsely claimed to have observed these stars: see fn 6.) In each of the 3 cases, the sign of the $\Delta\phi$ solution is consistent with the difference between the observer's adopted ϕ and the real Alexandria ϕ (Museum $31^\circ 12'$N, Lighthouse $31^\circ 13'$N). Including Hipparchos (§G3), the star-declination-based solutions for epoch[45] E & latitude ϕ (both actual, not adopted values) are as set forth in Table 3.

[39] For $\phi = 31^\circ 12'$N, a null δ cell is required at $45'$, but this is filled by Aldebaran, whose $\delta = 8^\circ 3/4$. However, given [a] the 3rd hand nature of the Timocharis δ data, & [b] the outsized Aldebaran δ residual ($-12'$), one may hypothesize that the Aldebaran δ is affected by an ancient scribal error. (Possibly, a highly accurate North Polar Distance $\theta = 81^\circ 1/15$ was later inadvertently miswritten as $\theta = 81^\circ 15'$. Similar errors: *DIO 1.3* §O3, [*GD* 8.3.4 XZ mss].) Note: no other Alexandrian ϕ (§F5) produces a distribution that fits better than that for $\phi = 31^\circ 12'$N.

[40] Rawlins 1982G p.263 (fn 17). (Based upon Rawlins in-prep D; see here at §F9.) So Aristyllos' correct declination-deduced date was prominently published by DR some years before Y.Maeyama's 1984 paper (*Centaurus* 27:280), which is unfailingly cited by Hist.sci in this connection, despite the paper's exceedingly odd statistical treatment of data. (See *J.Hysterical Astron 1.2* fn 126.)

[41] This point has long since led DR to reject (see *J.HA 1.2* fn 53) the common assertion that degrees did not exist in 3rd century BC Greek science. The current paper's findings (nulls in the fractional distributions of Timocharis' & Aristyllos' declinations) add yet more support for this conclusion.

[42] See fn 33.

[43] The probability is about 35% that all 6 stars would accidentally miss the 3 null-expectation cells. Not statistically significant, but: at least it's better than 50%.

[44] By contrast, inaccurate ϕ values for Alexandria are: Eratosthenes' $31^\circ 04'$N (Rawlins 1982G eq.10) and Hipparchos' $31^\circ 05'$N. Strabo 2.5.39 (Hipparchan data): 25400 stades (fn 34) minus 3640 st = 21760 st = $31^\circ 05'$N.

Table 3: Ancient Observers' Epochs & Geographical Latitudes

Observer	Epoch E	$\pm\sigma_E$	Latitude ϕ	$\pm\sigma_\phi$
Timocharis	-295	$\pm 11^y$	$31^\circ 14'$N	$\pm 3'$
Aristyllos	-257	$\pm 10^y$	$31^\circ 14'$N	$\pm 3'$
Hipparchos	-131	$\pm 05^y$	$36^\circ 08'$N	$\pm 1'$
Anonymous	159	$\pm 08^y$	$31^\circ 11'$N	$\pm 2'$

G Hipparchos' Sites

G1 For centuries, astronomers have wondered where exactly on Rhodos lie the remains of the great central observatory of Hipparchos, the legendary[46] "father of astronomy". (The remains of Hipparchos himself almost certainly lie at the same site.) Now, at last, we have some probable answers.

G2 From the foregoing, we find that the southern stars of the Ancient Star Catalog were observed with an inferior[47] transit instrument at Cape Prassonesi, the southern tip of the island of Rhodos. The site is reasonable for deep-south observations, since: [a] it permitted a more unobstructed view of the southern horizon than did any other readily-accessible part of Rhodos Island, and [b] observing from the most southerly latitude on the island

[45] The deduced epochs E of Table 3 are consistent ($\pm\sigma_E$) with the start of the following (19^y) cycles of Meton's famous calendar (starting epoch = -431 Summer Solstice): Timocharis, 8th Metonic cycle (-298); Aristyllos, 10th Metonic cycle (-260); Hipparchos, 17th Metonic cycle (Egyptian calendar Thoth 1 = -127/9/24: *DIO 1.1* ‡6 eq.28 & §D8); Anonymous, 32nd Metonic cycle ($+158$). (If the *Almajest* 7.3 nonsuspect 12 stars' epoch E is assumed to be 137 AD — the same epoch which the 1025-star Catalog was ineptly faked to agree with — then one is tempted to drop conspicuously-discrepant α Ori from the sample. However, our analyses treat E as an unknown — one of two. If we omit α Ori, leaving an 11-star sample, then least-squares analysis produces: $E = 152 \pm 8^y$ & $\Delta\phi = 3' \pm 2'$. But including α Ori only trivially increases our calculated standard deviations, while gratifyingly producing a 12-star median error which is fully $1'$ lower than the 11-star median error. The E & $\Delta\phi$ based on the unfiltered 12-star sample were adopted for Table 3. Thus, as in fn 5, we base our work on Ptolemy's own sample-splitting.) If the last date is correct, then the *Almajest* was completed c.160 AD (ordmag a decade later than now generally believed): during the reign of Marcus Aurelius (1st regnal year's Thoth 1 = 160/7/14), which is in fact the epoch assigned to Ptolemy in the Suda vol.1 part 4 (1935) p.254 entry 3033. (I was initially inclined to a contingent crude redating of the *GD* to c.170 AD because, at the time of the *Almajest*'s final rendition, the *GD* — largely a cumbrous collection of thousands of places' longitudes & latitudes — was evidently just at the pre-planning stage: see the observant remarks of Toomer 1984 p.130 n.109. However, the *GD*'s sloppy dependence upon prior authors — especially Marinos of Tyre — hints at oft-indiscriminate high-speed borrowing: see Rawlins 1985G §10. So the *GD*'s compilation could have taken alot less than 10^y. Thus, I'll let stand my earlier rough estimated *GD* date: c.160 AD.) Note that the very idea of stellar-epoch would be meaningless for Timocharis & Aristyllos if stellar precession was then-unknown, as most scholars now accept. (Rawlins 1999 produces evidence that precession was known to Timocharis' & Aristyllos' contemporary, Aristarchos of Samos.)

[46] That Hipparchos' rôle in ancient astronomy has been overestimated is something that Muffiosi & DR can agree upon in general, whatever the disagreement on particulars. For Hipparchos' debits, see *DIO 1.1* ‡6 (Rawlins 1991H) §E5, *DIO 1.3* §§N8, O1, R14, S1, fnn 224, 226, 235, 253, 288. For his credits, see both articles, *passim*, especially *DIO 1.3* §S2.

[47] In the southern part of the Catalog, there is a correlation between [a] inaccuracy of data, and [b] frequency of whole-degree Z. No surprise (§E4).

ensured that the sea-horizon was the most southerly possible from coastal[48] Rhodos. Note that Rawlins 1982C found the odds slightly higher for southern than northern Rhodos as Hipparchos' location, though the northern part of the island was not statistically ruled out by the 1982 analysis.

G3 There is but one legend that survives regarding Hipparchos' personal life: it has him astonishing a king with a bit of weather astrology. (See Dicks 1960 pp.48-49: Fragm.C.) This does not sound like a fellow who lived in remote woodlands. So, once we have the center of Hipparchos' operations (where his high-quality observations were made) near latitude $\phi = 36°08'$N, it is not difficult to find his longitude, since anything but the vicinity of Lindos ($\phi = 36°05'$N, longitude $28°05'$E of Greenwich) would put him far from high civilization. His 19 accurate declinations[49] reveal that he observed them in $E = -131{\pm}5^{\mathrm{y}}$ (Rawlins in-prep D), and that his $\Delta\phi = 0'{\pm}1'$. (See *idem* & §F1. Confirmed: fn 6.) Thus, we may say that his main observatory's latitude $\phi = 36°08'$N$\pm 1'$ — which is an unexpectedly & gratifyingly precise probable solution to this ancient mystery. As remarked at §F3: since Lindos' $\phi = 36°05'$N (just $3'$ less),[50] it is indicated that Hipparchos worked in the hills just NW of the city. (The 371 m hill mentioned in §F3 is at $36°08'$N, $28°03'$E.) Perhaps the observatory was adjacent to (or part of) a local ruler's estate.

G4 As noted by Neugebauer 1975 (p.275 n.11), the Keskinto inscription — evidently from near Hipparchos' century (Neugebauer 1975 pp.698-705) — reveals that other astrologers were working on the island of Rhodos. Keskinto is a west suburb of Lindos — just 3 nmi south (& a little west) of the hill suggested above as a possible site of Hipparchos' observatory. The finding that he observed almost nextdoor[51] to Keskinto suggests that several astronomer-astrologers worked in the Lindos region — with a cohesion which we can now only guess at. It is possible that the southern portion of the Catalog was observed by an astronomer at the south end of the island who was part of a team effort (§C6) to cover the sky, presumably supervised by Hipparchos.

G5 Perhaps it is too much to hope that fragments of (or inscriptions from) Hipparchos' legendary observatory might someday be recovered. In any case, one hopes that the foregoing will assist in greatly narrowing the range of search.

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[48] Terrain over 200 m high is available near C.Prassonesi, which could assist observations by slightly reducing extinction & by producing a horizon dip of nearly a half-degree. Rhodos' tallest mountain, 1215 m-high Mt.Atabyron, at $36°12'$N, would offer a sea-horizon ordmag $10'$ more southerly, but the difference would hardly be worth the trouble of building & supplying an observatory at such a remote site.

[49] Sample described at §F2. Results (for E & $\Delta\phi$) based upon same sort of 2-unknown least-squares analyses as those of §F9. Adding the 10 fractional δ from Hipparchos *Comm* (producing a 29 star sample, net), we have instead $E = -138{\pm}7^{\mathrm{y}}$ & $\phi = 36°06'{\pm}2'$N. Adding Arcturus to these (30 stars in all) produces: $E = -134{\pm}7^{\mathrm{y}}$ & $\phi = 36°07'{\pm}2'$N. (For just our ten fractional Hipparchos *Comm* stars: $E = -159{\pm}19^{\mathrm{y}}$ & $\phi = 36°02'{\pm}4'$N.) However, using the Hipparchos *Comm* stars here alters the 19 star result only slightly and brings less reliable data into the problem. (DR's prime statistical rule: a small clean sample is preferable to a big dirty one.)

[50] An ancient geographer of c.100 BC, using the Eratosthenes-Hipparchos scale (700 stades/degree), placed Lindos 4500 stades north of Alexandria (Müller 1855&1882 2:479). All ancients knew that the distance from Alexandria to Rhodos was under 4000 stades, thus the 4500 stades figure is likely to be an error for 3500 stades — which is precisely $5°$. Eratosthenes put Alexandria at $\phi = 31°04'$N — evidently rounded by Hipparchos to $\phi = 31°05'$N (fn 44) — so we may take the $5°$ difference as indicating that some ancients (contra fn 34) placed Lindos at $\phi = 36°04'$N or $36°05'$N, which is within a mile of the truth. I note that the same geographer also reports (Müller 1855&1882 2:479) the Tanais (Don River) klima, where M = 17 hrs, to be 18056 stades north of Alexandria. Well, using Eratosthenes' obliquity (*Almajest* 1.12: $\epsilon = 23°51'20''$) in the formula of fn 34, we find $\phi = 54°00'18''$N. (Toomer 1984 p.87 n.56 gets precisely the same result.) At 700 stades/degree, this is 37803 stades and Alexandria's $\phi = 31°04'$N = 21747 stades. The difference is 16056 stades, which disagrees with the text (18056 st) by precisely 2000 st. Thus, if we again (as for the Alexandria-Lindos latitude difference) suppose there to be an ancient error (or discrepant convention) in the thousands-place, the passage has been restored. (Some uncertainty in the latter case's thousands-place is discussed in the notes of Müller *loc cit*.)

[51] It is of course possible that Hipparchos worked in the region of Lardo ($36°05'.4$ N, $28°02'$E) or Keskinto ($36°04'.7$ N, $28°01'$E), the 2 towns Neugebauer 1975 p.698 n.1 mentions in connection with the inscription. (The inscription's numbers are not related to what we now know of Hipparchos' work.) Given (via least-squares: §G3) that Hipparchos' adopted ϕ ($36°08'$ or $36°07'1/2$, perhaps interchangeably: §F3) was high by $0'.2{\pm}1'.2$, the inscription-site latitude's 95%-confidence statistical incompatibility with it is too borderline for safe exclusion.

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[Note added 1996: In the larger context of the controversy over Ptolemy's integrity (which has in late years lingered on only because his defenders understand so little science that they don't know it's over), the significance of the foregoing paper may be not be fully appreciated unless the reader realizes that the popular "pedagogical" apology (e.g., 0 Gingerich *Q. Jl Roy. Astr. Soc.* *21*:253) for Ptolemy's nonstellar fakery is irrelevant to excusing his sneak-theft-plagiarism of virtually the entire Ancient Star Catalog, of which *very few stars were used* in any of his *Almajest* computational examples. (For details on this and related matters, see, e.g., *DIO 2.3* ‡8 §§C2, C22-C23, C31-33, & fn 22. In truth, most of these "examples" were intended not to instruct his readers but rather to fool them into accepting that his astronomical models were precisely & universally accurate because they were founded, by rigorous mathematics, upon outdoor observations. And most of these "observations" were also pretenses.) The bottom line here: no honest pedagogue would resort to the slide&hide ploy to hide a massive plagiarism: a *thousand* stars.]