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ST. HELENA, EDMOND HALLEY, THE DISCOVERY OF STELLAR PROPER MOTION, AND THE MYSTERY OF ALDEBARAN

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Abstract: St. Helena was the location of Halley's observatory in 1677-1678. The site has been identified and I report on a visit in November 2006. The principal use of the observatory was to accurately map the stars of the southern sky. In the summary of his work, the *Catalogus Stellarum Australium*, Halley noted evidence for the "… mutability of the fixed Stars." He would not return to this subject until much later in his career. Halley later compared contemporary positions of Arcturus, Sirius, and Aldebaran with the ancient positions recorded in the *Almagest*. He found that these stars had apparently moved southward by >30′ and concluded that they had their own particular motions. Modern proper motion measurements are consistent with this conclusion for Arcturus and Sirius, but are not even close for Aldebaran. While some authors are aware of the problem, it generally is not mentioned in books on the history of astronomy or in biographical works on Halley. Errors in the *Almagest* positions can be ruled out; an error of 30′ in the early eighteenth century position is highly unlikely; a misidentification of the star is implausible; and, we are left with the conclusion that there is most likely an error in Halley's calculations.

Keywords: St. Helena, Edmond Halley, proper motion, Aldebaran.

1 INTRODUCTION

Our modern view of the heavens holds that the stars are independent, luminous bodies. The stars, including the Sun, have their own particular motions and share a general motion around the center of the Milky Way Galaxy. Because of these motions, the positions of stars show small changes as seen from the Earth, called proper motions. This modern view did not reign three centuries ago when the stars were thought to be just points of light embedded in the Starry Firmament. The road to overturning the old view and establishing our modern view began on a small, remote island, St. Helena. Edmond Halley would note concerns about the mutability of the fixed stars in his catalogue reporting the positions of the southern stars. He would return to the subject decades later and discover stellar proper motions. Despite the fundamental importance of this discovery, it would be one of the least appreciated facets of Halley's illustrious career.

2 ST. HELENA, EDMOND HALLEY AND HIS OBSERVATORY

2.1 The Island

The island of St. Helena sits in splendid isolation in the South Atlantic Ocean, approximately 2,000 km (1,200 miles) from continental Africa and even further from South America (see Figure 1). I was fortunate to visit the island on 14 November 2006 during a call by Holland America's *Prinsendam*. The weather was mild—a tropical, marine weather tempered by trade winds. Clouds and light rain were frequent. The island was discovered circa AD 1500, and since 1673 Great Britain has had continuous control. The capital is Jamestown on the north coast. The population is approximately 5,000.

St. Helena's supreme isolation was utilized in the second exile of Napoleon Bonaparte. The sites associated with his exile are the principal tourist attractions on the island. In addition to the remarkable historical significance of the Napoleon-related sites, St. Helena for an astronomer is fascinating because of an expedition by Edmond Halley in 1677-1678. Observations at this site began the investigations that would lead Halley to one of his most important and least appreciated discoveries.

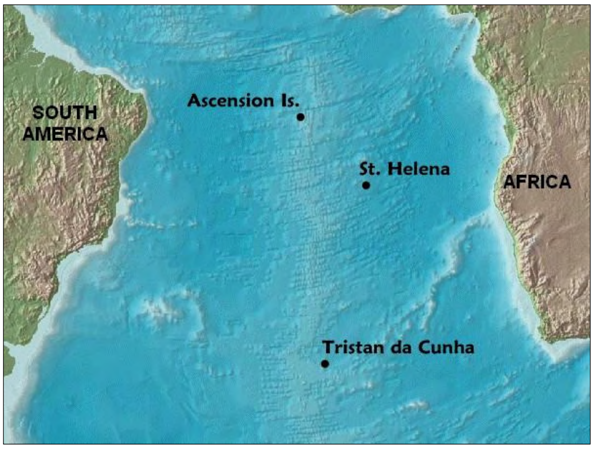

Figure 1. The South Atlantic Ocean and islands of interest. Modified from a map on web pages maintained by Barry Weaver (2009a), University of Oklahoma.

2.2 The Observatory Site

A substantial rise along the northward extension of the Diana's Peak-Mt. Actaeon ridge (Tatham and Harwood, 1974: 493) has been known as Halley's Mount since the time of Halley's visit or shortly thereafter; see Figure 2. However, in 1968, Tatham and Harwood (1974) found that there was no consensus on the location of the observatory. The prime candidate was the site identified by astronomer David Gill (1877). He stopped at St. Helena in 1877 on his way to Ascension Island to determine an accurate value of the astronomical unit. As reported by Mrs Gill (1878), Mr.

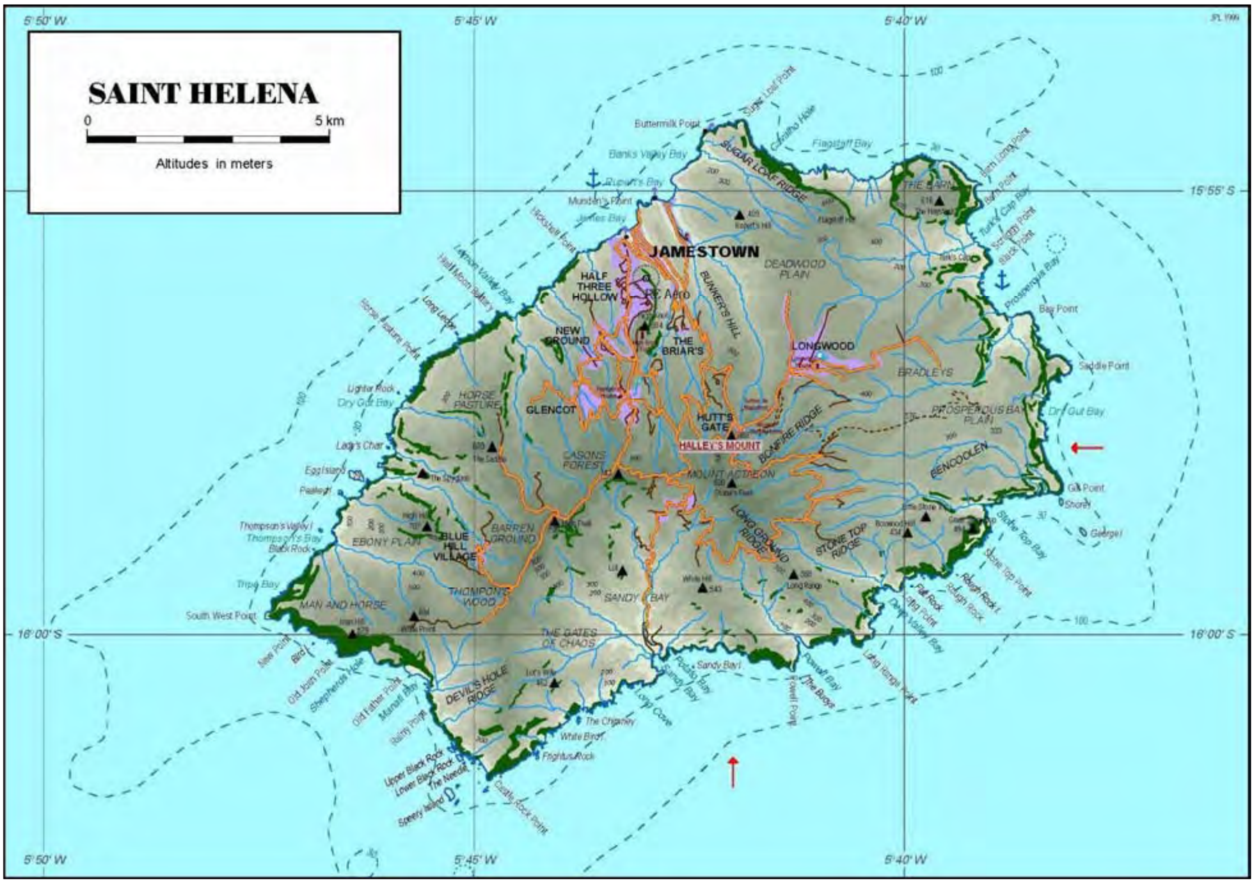

Figure 2. The Island of St. Helena. Halley's Mount, close to the center of the island, is labeled in red inside a gray box, and marked by two red arrows outside of the island. Adapted from a map on web pages maintained by Barry Weaver (2009b), University of Oklahoma.

Gill felt that "… this had been the Observatory, without doubt." The site was convenient to Jamestown; the only level one in the area; was suitable for astronomical observations; and was sheltered from the trade winds by a little knoll to the south that formed a windbreak. Still, there were conflicting views, and Tatham and Harwood (1974) undertook to rediscover the site. Their paper reviews the evidence for the observatory site. They found the site discovered by Gill. With the assistance of volunteers, the site was excavated and they uncovered "… four almost complete walls of dressed stone." The walls were found to be closely aligned to north/south and east/west. They also found a small quarry nearby which had also been noted by Gill. The walls had dimensions of about 12 by 14 feet, dimensions appropriate for the base of a structure sheltering Halley's instruments. Finally, the area, where not too precipitous, was searched by a slowly-moving line of volunteers, and no other plausible sites were found.

Cook (1998: 69-72) provides a description of Halley's principal instrument on St. Helena, the one used for his catalogue of the southern stars. He used a 1.7-meter radius sextant fitted with telescopic sights. Two stars could be observed simultaneously. Generally, one star would be one of Tycho's bright stars and the other a southern hemisphere star. The position of the southern star can be determined by spherical trigonometry when the arcs from two stars of known position are measured. Halley's large sextant and his other instruments presumably were housed in the building at the observatory site.

A significant problem is the excellent condition of the walls and the likelihood that the site was used as a signal station in the early nineteenth century. Because so much evidence points to this site for Halley's use as an astronomical observatory, Tatham and Harwood (1974) conclude that the lower stones in the walls were laid in 1677 and that the upper stones were part of the probable later use of the site as a signal station. Specifically, the view of A.W. Mawson (Ashbrook, 1970) that there was no observatory and that the site was used for an alarm cannon cannot be supported.

The investigation by Tatham and Harwood and the volunteers on St. Helena was clearly a labor of love. Tatham was honorary archivist to the Government of St. Helena, and Harwood was an English ophthalmic optician who made regular visits to the island to examine and prescribe for the eyes of the residents. Their words summarize the conclusion well (Tatham and Harwood, 1974: 501-502):

> Absolute proof concerning this site is not likely. But it seems certain that the early use of the name 'Halley's Mount' indicates that Halley operated somewhere on this hill … This spot was almost certainly Halley's Observatory, and should be marked and preserved as such for ever, by some enclosure and monument.

A commemorative plaque (see below) has been placed at the site.

Other locations on the island have astronomical interest. Nevil Maskelyne observed the transit of Venus in 1761 from a site near Halley's observatory (Tatham and Harwood, 1974; Warner, 1982). Later, Manuel Johnson built an observatory on Ladder Hill just to the west of Jamestown and some 700 feet above it. From this observatory, Johnson produced his *Catalogue of 606 Principal Fixed Stars in the Southern Hemisphere* published in 1835 (Tatham and Harwood, 1974; Warner, 1982).

2.3 Edmond Halley and Reasons for the St. Helena Expedition

Edmond Halley (1656–1742) is one of the most famous astronomers of all time; see Figure 3 for a portrait of Halley done some ten years after his visit to St. Helena. Some major works on Halley are Armitage (1966), British Astronomical Association (1956), Cook (1998), De Morgan (1847), Lancaster-Brown (1985), MacPike (1932), Ronan (1969) and Thrower (1990). A diagram by Hughes (1990: 327) nicely illustrates the breadth of Halley's scientific interests.

Halley wanted to produce a catalogue of the southern stars and selected the island of St. Helena because it was under British control and because it was reputed to have good weather. The latter information was faulty and the bad observing conditions were a major obstacle to his observing program. In a letter from Halley to Sir J. Moore (a patron of Halley's expedition) dated 22 November 1677, written on St. Helena, we find:

> But such hath been my ill fortune, that the Horizon of this Island is almost always covered with a Cloud, which sometimes for some weeks together hath hid the Stars from us, and when it is clear, is of so small continuance, that we cannot take any number of Observations at once; so that now, when I expected to be returning, I have not finished above half my intended work; and almost despair to accomplish what you ought to expect from me. (MacPike, 1932: 39-41).

While the latitude was only 16º S, it was a major improvement from London's latitude of 51.5º N.

2.4 My Visit: 14 November 2006

Curiously, in November 2006 the path to Halley's observing site was not marked on the paved road. The route is described by Mathieson and Carter (1993, Walk No. 22). At first, the route follows a steep, wide, grassy path up Halley's Mount. A short distance up the path, a sign marks a narrow path that leads to the site. Although the observatory building is long gone, what appear to be foundation walls remain (Figure 4).

There is also a gray plaque (Figure 5) that shows considerable deterioration, but the text is legible and reads: "The Site of the Observatory of Edmond Halley. He came to Catalogue the Stars of the Southern Hemisphere 1677-1678". While I was visiting the site, fog with a light mist moved in. I could not help imagining a young Edmond Halley in similar conditions over three centuries ago hoping for the skies to clear.

3 *CATALOGUS STELLARUM AUSTRALIUM* AND THE DISCOVERY OF STELLAR PROPER MOTION

Halley made observations of some 350 stars not included in Tycho Brahe's catalogue. Upon his return to England, the observations were expeditiously reduced and the catalogue—as was the custom of the day—was published in Latin. The catalogue was hailed as a great achievement and Halley was considered to be the 'Southern Tycho'. The *Catalogus Stellarum Australium* is now available electronically, and a summary in English was published in the *Philosophical Transactions of the Royal Society* for 1678 (actually printed in 1679). Despite being in the third person, the summary was probably written by Halley himself.

Figure 3. Portrait of Halley painted around 1687 by Thomas Murray (Royal Society, London). Public domain.

In the summary (Halley, 1678: 1033), we find the first inklings of the discovery of stellar proper motions. Halley's new observations were compared to some old catalogues and this statement follows:

> It might evidently appear how very much the Ancient Globes do almost every where differ from the Heavens. From these Observations, as he proceeds, he also proposeth some conjectures of the corruptibility, or at least the mutability of the fixed Stars.

Halley did not return to the question of stellar proper

Figure 4. The Observatory site showing the walls (see text for discussion) and the commemorative plaque. Photograph by the author.

Figure 5: Close-up view of the plaque. Image processing was used to enhance legibility. Photograph by the author.

motions for decades (Aitken, 1942). He maintained his lifelong interest in stellar positions, but this was primarily for the stellar side of a method to determine time or geographic longitude by lunar occultations.

In 1717, Halley published an extraordinary three-page paper in the *Philosophical Transactions of the Royal Society*. The paper's title is "Considerations of the Change of the Latitudes of some of the principal fixt Stars", and a full electronic copy is available through JSTOR. It is also reprinted in Aitken (1942), which is available through ADS. During an investigation into the value of the obliquity of the ecliptic and the precession of the equinox, Halley found some large changes in latitudes or declinations for some stars. Halley's paper contains the usage of his time of simply Latitude and Longitude, but Declination is used interchangeably with Latitude a few times in the paper. Precession is a well-understood phenomenon; its discovery is generally credited to Hipparchus (Dreyer, 1953; Pannekoek, 1961; Sarton, 1959), who compared his observations to those made by Timocharis approximately 140 years earlier. For technical details on precession see Kovalevsky and Seidelmann (2004), Smart (1949) and van de Kamp (1967).

Halley compared contemporary positions for the bright stars Sirius, Arcturus, and Aldebaran with the positions given by Ptolemy, Timocharis, and Hipparchus. Note that Aldebaran is called 'Palilicium' or 'the Bulls Eye' in Halley's paper. Halley took the time span between the old observations and his to be 1,800 years. He noted problems with the latitudes (or declinations) of these stars and wrote:

> All these three Stars are found to be above half a degree more *Southerly* at this time than the Antients reckoned them … What shall we say then? It is scarce credible that the Antients could be deceived in so plain a matter, three Observers confirming each other. Again, these Stars being the most conspicuous in Heaven, are in all probability the nearest to the Earth, and if they have any particular Motion of their own, it is most likely to be perceived in them, which in so long a time as 1800 Years may shew itself by the alteration of their places, though it be utterly imperceptible in the space of a single Century of Years. (Halley, 1717: 737).

Near the end of his paper, Halley (1717: 738) wrote: "This Argument seems not unworthy of the *Royal Society's* Consideration, to whom I humbly offer the plain Facts as I find it, and would be glad to have their Opinion."

This was the discovery of stellar proper motions—that stars move. The astronomers and the educated public of the time were still digesting the Copernican view of the Solar System and searching for conclusive proof (see the fascinating treatises by Johnson (1937) and Van Helden (1985)). Recall that two conclusive measurements—stellar aberration (Bradley, 1728) and stellar parallaxes (Bessel, 1838; 1839; Henderson, 1839; Struve, 1840)—had not yet been accomplished. Of course, some 'perturbations' in the heavens were known. The supernovae of 1572 (Tycho's) and 1604 (Kepler's) had been observed, and the brightness variations of Mira were well known. Also, there were speculations on the size and distance of the stars. Still, almost everyone at the time, including luminaries, believed that the stars were fixed in space, points of light embedded in the starry firmament. Clerke (1908: 9) summarized the situation:

> Until nearly a hundred years ago the stars were regarded by practical astronomers mainly as a number of convenient fixed points by which the motions of the various members of the solar system could be determined and compared. Their recognized function, in fact, was that of milestones on the great celestial highway traversed by the planets, as well as the byeways of space occasionally pursued by comets.

The changes in star latitudes from antiquity to the beginning of modern astronomy were, in fact, discovered by Tycho Brahe (1648). This has been described by Moesgaard (1989) and by Evans (1998). Tycho used the same data from the *Almagest* that Halley would use over one hundred years later. Because Tycho believed that the relative positions of the fixed stars did not change, he concluded that the changes were due to a decrease in the obliquity of the ecliptic. This result required Tycho to adjust some ancient positions that he believed to be in error.

Halley's discovery started a changed view of the heavens. The basis of his argument was accurate contemporary positions and positions determined by ancient astronomers. The difference of more than half a degree is greater than the angular diameter of the Moon, and indeed the ancient observers were unlikely to have made an error this large.

4 THE ALDEBARAN PROBLEM

However, there is a significant complication (Brandt, 2008). Modern proper motion measurements are readily available (Allen, 1955; Urban et al., 2004). Over a time span of 1,800 years, Sirius, Arcturus and Aldebaran have moved 36.7′, 60.0′ and 5.7′ southward respectively (see Table 1). Thus, the consistency check is fine for Sirius and Arcturus, but the proper motion value is not even close for Aldebaran. This problem is worth pursuing because, although it is known to some writers (e.g., Evans, 1998; Fomenko et al., 1993;) it generally is not mentioned in encyclopedias or history of astronomy books (a link to a paper with the list of references is given in Section 7), or in the biographical works on Halley cited in Section 2.3. Also, the problem is not mentioned in that venerable astronomy text of the nineteenth century, *Outlines of Astronomy*, by J. Herschel (1871), nor in a modern astrometry text that covers classical astronomy (Kovalevsky and Seidelmann, 2004). An additional curiosity is that Delambre (1827) provides almost no coverage of stellar proper motion in his history of eighteenth century astronomy. Halley's discovery is not mentioned, and the confirmation for Arcturus by Cassini (1738), discussed in Section 5, merits only a single sentence.

Certainly, there is indirect evidence of some additional knowledge of the problem. Sometimes there is no mention of Aldebaran, but Procyon is listed as the third star along with Arcturus and Sirius (Abetti, 1952; British Astronomical Association, 1956; Ronan, 1969). This substitution might indicate knowledge of the problem, yet Procyon is not mentioned in Halley's (1717) paper. Some textbooks (e.g. Russell et al., 1927; Young, 1895; 1904; 1912) mention only Arcturus and Sirius. Because these texts quote correct values for the proper motions of Arcturus and Sirius, it is likely that the Princeton University astronomers were aware that Aldebaran's proper motion was much too small.

Halley (1717) thought that he had three independent measurements. These were taken from Ptolemy's *Almagest* and the observers were thought to be Timocharis (ca. 270 BC), Hipparchus (ca. 130 BC) and Ptolemy (ca. AD 140). The translation of the *Almagest* I have consulted for this paper is that by Toomer (1998).

Before the discussion can continue, the nature and status of the *Almagest* must be examined. Historical evidence, long available, strongly suggests that Ptolemy's star catalogue in the *Almagest*, often called the Ancient Star Catalogue (ASC), was not completely original. Dreyer (1953: 202) would succinctly write:

> The great work of Ptolemy also contains a catalogue of stars, which, however, is nothing but the catalogue of Hipparchus brought down to his own time with an erroneous value of the constant of precession.

Table 1: Proper motion summary.

Star	Proper Motion* (″/year)	Motion in 1,800 Years (′)
Sirius	1.223	36.7
Arcturus	1.999	60.0
Aldebaran	0.189	5.7

* All motion southward.

The literature on this subject is extensive and opinions have evolved with time. Evans (1998: 264-274) has given a concise history of the varying views on Ptolemy's reliability. For a recent view, see, for example, the papers on the ASC in the September 2002 issue of *DIO: The International Journal of Scientific History*. The papers by Duke (2002a; 2002b) and Pickering (2002a; 2002b; 2002c) convey the flavor and intensity of the debate. Duke (2002b) presents a short summary of the current consensus view of the ASC:

- Someone, perhaps Hipparchus, measured a fairly complete catalogue of star in *equatorial* coordinates.
- That catalog was the basis for the results presented in Hipparchus' *Commentary to Aratus.*
- Analog computation was used to convert most of the catalog to *ecliptic* coordinates.
- It is this converted catalog, with longitudes shifted by 2° 40′, that we have received through Ptolemy and the *Almagest*.

The *Almagest* catalogue is given in Books VII and VIII and occupies pages 341-399 of Toomer (1998). The catalogue gives a single ecliptic latitude for each star. The ASC is unlikely to be the source of positions believed to be based on three independent observers. However, three positions are given for a short list of stars (pages 331-332) as part of the discussions with page headings "Comparative declinations of stars…" and "Constancy of latitudes deduced from declinations." On page 331, three declinations are listed for Sirius ("The Bright star in the mouth of Canis Major"), credited to Timocharis, Hipparchus, and Ptolemy ("… as found by us."). The values are 16⅓°, 16°, and 15¾°, South, respectively. On page 332, three declinations are listed for Arcturus credited to the same observers. The values are 31½°, 31° and 29⅚°, North, respectively. On page 331, three declinations are listed for Aldebaran ("The bright star in the Hyades") credited to the same observers. The values are 8¾º, 9¾º, and 11º, North, respectively. The systematic progression of these positions with time is the result of precession, as noted by Ptolemy. Independent of any details, there was clearly a source for three positions.

I have used a Precession Routine (2009) to calculate the ancient positions of all three stars from modern positions, both B1900.0 (Allen, 1955) and J2000.0 (Urban et al., 2004). Precession and proper motion are included, and the expected accuracy is about 0.1″. The results show remarkable agreement between the modern positions precessed with proper motion and the positions as reported for Timocharis, Hipparchus, and Ptolemy. The average difference in declination for all nine comparisons is 0.23º. However, one difference (for Timocharis' measurement of Arcturus) is 1.94 times higher than the next highest difference. If this one is removed, the average difference is 0.17º, or ~10′ to 11′. There is little significant difference between observers. This means that the original positions as recorded in the *Almagest* (Toomer, 1998) appear to be accurate.

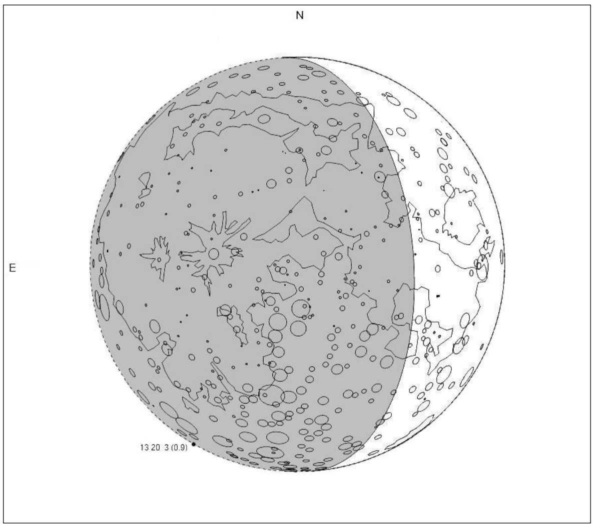

Figure 6. The lunar occultation of Aldebaran on 11 March 509. The calculation was run using the Occultv4 software authored by David Herald, Canberra (2009), and available at the International Occultation Timing Association (IOTA) web site. The shading has been added.

The net result is the remarkable agreement of the positions to within 0.17º. Thus, Halley's results for Sirius and Arcturus are sound and the discovery of stellar proper motions is secure. Still, there is a major problem with Aldebaran. Given the history—probable change of coordinate system, possible transcription and translation problems, and attempts to 'correct' the observations—an erroneous value should not be surprising. Note that some of the steps just cited may not have occurred for declinations that are given in the text and are not part of the ASC. Possible errors through history may explain the single discordant value for Arcturus but does not reasonably explain three ancient positions for Aldebaran that are systematically in error by 0.5º or more in declination. The plausible explanations are that the observed ancient positions for Aldebaran used by Halley were in error or systematically altered at some time through the years and were not the ones in the current version of the *Almagest*, or that Halley's calculations were in error, or that the star was misidentified. It seems inconceivable that the position of Aldebaran could be in error by some 30′ in the early eighteenth century, although Fomenko et al. (1993) suggest that an erroneous position may have come from a preliminary version of Flamsteed's catalogue.

There has been some confusion about the third star, Aldebaran, cited by Halley. Recall that Halley gave the star as Palilicium or the Bull's Eye. Clerke (1908: 10) adds Betelgeux to the list of stars. Betelgeux has a small proper motion and is highly unlikely to be a candidate. Abetti (1952: 143) and Ronan (1969: 201) list Halley's three stars as Arcturus, Procyon and Sirius. Procyon is a viable candidate for the third star in the sense that it is bright and has a large proper motion. But Aldebaran and Procyon are separated by about 3 hours in right ascension, and confusing the two seems unlikely. I have been unable to find any convincing evidence that the star cited by Halley as Palilicium, or the Bull's Eye, is not Aldebaran.

Halley (1717) cited a lunar occultation of Aldebaran on AD 11 March 509 to bolster his case for the southward motion. The text, in part, reads:

> But a further and more evident proof of this change is drawn from the Observation of the application of the Moon to *Palilicium* … when in the beginning of the Night the Moon was seen to follow that Star very near, and seemed to have Eclipsed it … Now from the undoubted principles of Astronomy, it was impossible for this to be true at *Athens* or near it, unless the Latitude of *Palilicium* were much less than we at this time find it.

To verify this statement, Peter Zimmer, University of New Mexico, kindly ran the program Occultv4 available through the International Occultation Timing Association (IOTA) (Herald, 2009). The results (Figure 6) confirm the occultation close to the Moon's *south* limb.

Unfortunately, there are significant problems with the records of the occultation and the occultation itself. As noted on Figure 6, the occultation occurred in daylight at 13:20 UT. The local time would have been approximately 14:55 or 2:55 pm, i.e., mid-afternoon. Thus, it was probably not observed directly at Athens. The occultation may have been inferred from the location of the Moon after dark (Neugebauer, 1975: 1038, 1041) or the occultation was observed from another location. Alexandria has been suggested, but Aldebaran was not occulted by the Moon as seen from Alexandria. The difficulties with this occultation were known in the seventeenth century (Riccioli, 1665: 154). Thus, a fair conclusion may be that the cited record of the occultation is unreliable. But the report is probably too much to ascribe to coincidence, and thus an inferred occultation is probably the best explanation.

A more important question for the problem with Aldebaran is how things would have appeared to Halley. The calculation should have been difficult and Halley may or may not have been aware that the occultation took place in daylight. If he did notice this problem, he may not have regarded an error of a few hours in time as significant. Or, he may have used the idea that the occultation could be inferred from the Moon's location after dark. In any event, Halley's paper makes clear that his results for the occultation supported his large proper motion for Aldebaran.

Comparison of Figure 6 with Halley's text leaves us in the unenviable position of trying to determine Halley's meaning when he wrote that Aldebaran's latitude needed to be "… much less than we at this time find it." Aldebaran's position for 509 in Figure 6 is based on the modern position and small proper motion. Halley wanted 30′ or more of proper motion in 1,800 years. On this assumption, Aldebaran would have moved southward by 10′ or more from ancient times to 509, or it would be roughly at most 20′ north of the calculated 509 position. It would have undergone occultation at this position, but not if it were at the original ancient position that Halley believed. The star would have needed to move southward by roughly 10′ to have the 509 occultation occur close to the Moon's *north* limb.

Thus, the modern calculations confirm the 509 occultation, but also show that it is not evidence confirming a large proper motion for Aldebaran. The results seem to imply that Halley's ancient positions for Aldebaran were some 30′ north of the correct position. The possibility that the version of the *Almagest* available to Halley contained erroneous values for Aldebaran's declinations (Evans, 1998) should be considered. All in all, the putative occultation of Aldebaran by the Moon as seen from Athens in 509 has no value in the discussion. It is simply a major red herring.

Several editions of the *Almagest* could have been available to Halley, and we should remember that the same source may have been used by Tycho when he discovered the changes in star latitudes as he observed them as compared with latitudes recorded in antiquity (Evans, 1998; Moesgaard, 1989). An easy edition to check is the English translation in the series *Great Books of the Western World*. Taliaferro (1952: 229) gives the same triad of values: 8¾°, 9¾° and 11°.

Pedersen (1974: 11-25) has summarized the history of the *Almagest* through the ages, and specific editions are listed. The first complete, printed Latin translation from an Arabic version appeared in 1515 (Ptolemy, 1515). A Latin translation from a Greek version was published in 1528 (Ptolemy, 1528). Owen Gingerich (Harvard-Smithsonian Center for Astrophysics) has these two Latin editions in his personal library and when he checked them he found the same triad of declinations.[1] Pedersen (1974: 21) notes that these Latin sixteenth century versions were "… the only translations for centuries to come."

A printed version of the original Greek text (Ptolemy, 1538) was prepared from a manuscript (now lost) at Nuremberg that was formerly in the possession of Regiomontanus (Pedersen, 1974). This edition may have been consulted by Halley (see below).

In the seventeenth century, astronomy texts would contain the ancient positions of interest. In Tycho's *Progymnasmata* (Brahe, 1648: 169), the declinations for Aldebaran are listed. Again, they are the same triad and presumably came from the *Almagest*. In addition, in his monumental work, Riccioli (1651: 442) clearly lists the same triad of positions for Aldebaran along with Tycho's declination of 15° 38′. Certainly, the presumed correct positions for Aldebaran were available in the seventeenth century.

The books in Halley's personal library may provide a clue to the origin of the ancient positions that he used. His books were offered for sale after his death and, fortunately, the sale catalogue has been preserved (Feisenberger, 1975), but with a complication. Halley's books were commingled with those of an anonymous "… late eminent Serjeant at Laws." However, it is safe to assume that astronomy books generally and books by Ptolemy specifically belonged to Halley. The list appears to show five copies of Ptolemy's *Geographica*, his other famous writing; these are items numbered 813-816 and 2027 (Feisenberger, 1975). No copy of the *Almagest* is listed. Even though there is evidence (Cook, 1998: 344) that Halley planned to produce an edition of Ptolemy's *Geographica*, the possibility that Halley owned five copies of *Geographica* and no copies of the *Almagest* seems unlikely. A closer examination of the list indicates that some of the listings may be in error. Specifically, item No. 814 is given as an edition of *Geographica* in Greek published at Basel in 1538. Eames (1886) has published a listing of the editions of *Geographica* for the years 1475-1730 and no edition is listed for 1538. But the language (Greek), the place of publication (Basel), and the year (1538) match the first Greek text printed version of the *Almagest*. The entry was probably mistitled in the listing. Halley read Greek and apparently had this edition in his personal library. Thus, the 1538 Greek edition emerges as the prime candidate for Halley's ancient declinations.

I have consulted a scan of the 1538 Greek-language edition (Ptolemy, 1538), Book VII, Chapter 3, kindly provided by the University of Minnesota. Again, the positions given in this edition are exactly the same as those found in Toomer (1998). For completeness, I have also checked the Greek text for the *Almagest* published by Heiberg (1903). Note that Heiberg uses a symbol for ½ that is different from the classical Greek number system (Greek Numbers and Arithmetic, 2009) and that does not have an MS Unicode (Re: Greek fractions, 2010). Again, the declinations are exactly the same.

While we cannot be absolutely certain, the evidence against Halley using erroneous ancient declinations is quite strong. Many editions of the *Almagest* from the sixteenth century on, including the edition likely owned by Halley, all give exactly the same positions. The solution must be elsewhere. Note that erroneous positions could have entered Halley's calculations by a misreading of the *Almagest* or by a conscious adjustment.

Unfortunately, Halley did not provide details of his calculations. Still, definitive resolution of this problem might be possible if Halley's original calculations can be located. Halley's papers were presented to the Royal Society in 1765 by his daughter Catherine Price. They were originally deposited at the Royal Greenwich Observatory and now reside at Cambridge University. An extensive, detailed description of Halley's papers at the Royal Greenwich Observatory Archives (2009) is available on-line, and there is no entry identifiable as relating to his proper motion calculations. In addition, there is no relevant material in MacPike's (1932) compendium of Halley's correspondence and papers. Lacking additional input, the question of Aldebaran's role in the discovery of proper motion is likely to remain a mystery, but an error in Halley's calculations is the prime candidate.

5 CONFIRMATION OF PROPER MOTION

Observing techniques improved rapidly in the eighteenth century, and Halley's discovery of stellar proper motion was confirmed by J. Cassini (1738) using Arcturus. He compared his observations with observations taken in 1690 by Flamsteed, in 1672 by Richter at Cayenne (French Guiana) and in 1586 by Tycho Brahe. Cassini (1738: 338) concluded that the extensive evidence constituted irrefutable proof (*preuve incontestable*) for the proper motion of Arcturus. Recall that Arcturus has a proper motion close to 2.0″ per year southward. Thus, this relatively short time span was sufficient to clearly show the proper motion. Halley's health began to decline in 1738, and I have found no mention in his biographies to indicate that he was aware before his death in 1742 of Cassini's confirmation. Hornsby (1773-1774: 93) states that the proper motion result for Arcturus "… cannot possibly be attributed to the uncertainty of observation …" and quotes a value close to modern results. The discovery could be considered well established when W. Herschel (1783: 247) would succinctly write: "That several of the fixed stars have a proper motion is now already so well confirmed, that it will admit of no further doubt."

6 DISCUSSION AND CONCLUSION

The discovery of proper motion constituted one of the most fundamental discoveries in astronomy and led to a completely changed view of the Universe beyond the Solar System. As obvious as the significance of the discovery is in retrospect, it was not universally appreciated in the eighteenth century. In his biography of Halley, Ronan (1969: 202) notes that this discovery was not mentioned "… in at least three of the obituary notices prepared after his death."

Neglect of this important discovery persists. On 13 November 1986, a memorial to Edmond Halley was unveiled in the Cloisters of Westminster Abbey (Henbest, 1987; Laufer, 1986). Although Laufer (1986) reports that Halley's discovery of stellar proper motion was noted by the dean of Westminster Abbey and it was also mentioned in the ceremonial booklet, the memorial summarizing Halley's achievements did not include it.

The problem with the results for Aldebaran is a mystery. Perhaps further historical research can definitively determine the source of the error. In the meantime, the regular return of Halley's Comet serves as a reminder of this great astronomer. Let us remember that his genius extended well beyond his work on comets and included the proper motion of stars.

7 ON-LINE RESOURCE

The on-line paper is an expanded version of this paper. The additional material includes more coverage of St. Helena, Halley's career, his observatory site, and Halley-related sites in London, in addition to the references mentioned in Section 4. See http://panda.unm.edu/jbrandt/Halley.pdf or contact the author at jcbrandt@unm.edu.

8 NOTES

1. Another Latin edition of the *Almagest* was published in 1541, but is not mentioned by Pedersen (1974). The WorldCat description suggests that it is based on earlier translations. The declinations listed for Aldebaran, verified by Owen Gingerich from a copy in his personal library, are the same. The abbreviated reference is*: Claudii Ptolemaei Pelusiensis Alexandrini omni, quae extant, opera.* Basel, Henricus Petrus, 1541.

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