Uncertainties in Separation and Position Angle of Historic Measures – Alpha Centauri AB Case Study

Graeme L. White[1], Roderick R. Letchford[2], Allan D. Ernest[3].

1) University of Southern Queensland, QLD Australia, graemewhiteau@gmail.com
2) Vianney College Seminary, NSW Australia, rodvianey@yahoo.com.au
3) Charles Sturt University, NSW Australia, aernest@csu.edu.au

Abstract: Accurate uncertainties in the Separations and Position Angles of historic measures of double stars are needed for the study of the motion (rectilinear or orbit) of the individual members of the pair. As a guide for workers in this field, we present an assessment of these uncertainties for the most well studied pair α Cen AB, over a period of some 260 years, that shows the accuracy of both the Separation and Position Angle measures has improved. Standard Deviation estimates of Separations falls from about 0.5 arcsec in the mid-1800s to 0.07 arcsec by the late twentieth century. Standard Deviation estimates of Position Angles fall from about 2 degree in the mid-1800s to about 0.3 degree by the late twentieth century. In addition, there seems to be a falling away of accuracy in the twenty first century data. As expected, here is an increase in the spread of uncertainties, and a bias, apparent at small separations.

Introduction

This paper is part of a series relating to our study of the double star discoveries at the Brisbane Observatory at Parramatta (then the British Colony of New South Wales (NSW) and now in the state of NSW, Australia). Two previous papers are reported in the JDSO. Letchford, White, and Ernest (2017) outline the historic content of this work and defines the research, and Letchford, White and Ernest (JDSO in press) define the rectilinear motion of some pairs discovered at Parramatta.

The Parramatta Observatory (1821/2–1847) was the private venture of the Governor of the Colony of NSW. Three astronomers were associated with the Observatory. They were Governor Brisbane (Sir Thomas Macdougall Brisbane (1773-1860)), Carl Rümker (Christian Carl Ludwig Charles Rümker (1788-1862)) and James Dunlop (1793-1848). Brisbane was Governor of NSW from 1821 to 1825, and the Australian capital city of Brisbane (capital of the state of Queensland) is named after him. Many histories are available but the comprehensive website by James (1914) is recommended.

The necessity for accurate estimates of the uncertainties associated with double stars became apparent to the authors whilst preparing the rectilinear motion of double stars in the Rümker catalogue where statistical weights associated with historic data were asked for. No timely and satisfactory method could be found to determine these weights, and at that stage it was agreed that a detailed search for such numbers was not warranted. Our work was made simple by the adoption of space-based data.

For future work we present here a summary of typical values of uncertainties of historic data based on one well observed pair. The philosophy being adopted is not to rummage through historic literature for the internal estimates of uncertainties professed by individual workers, but rather, to adopt the most recent orbit determination as our best estimate of the true Separation and Position Angles, and to then recognise the difference to that orbit as the best estimate of the uncertainties in individual measures. For this we are comparing historic Separation and Position Angle measures made over a period of nearly 260 years with the 2016 orbit of the binary pair Alpha Centauri AB.

Why Alpha Centauri?

Alpha Centauri (Rigil Kentaurus) is a text-book binary star system. It is the closest stellar system, and α Cen AB are bright, and probably the most common

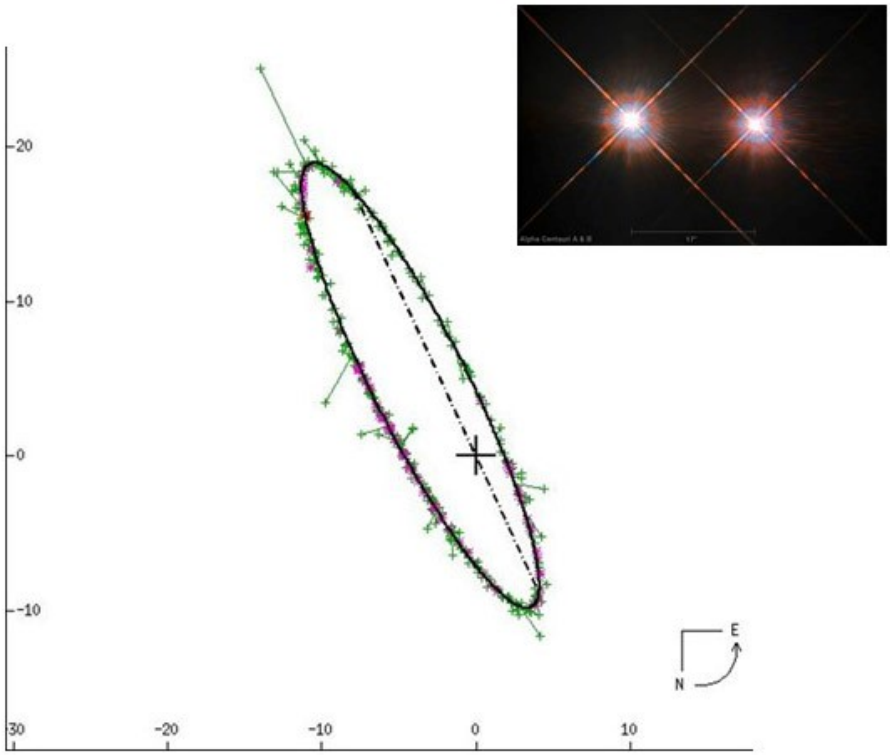

Figure 1. The observed and computed orbit of α Centauri AB.

double star used as an introduction for most amateur and professional astronomers. Details of the α Cen system are given by Wikipedia and α Cen AB is listed in the WDS as 14396-6050. Father Richaud is the discover (RHD 1AB) and the first measured Separation and Position Angle was obtained by LaCaille in 1752.

There are 480 observations of α Cen AB available in the Washington Double Star Catalog. Being such a popular object this pair has been observed by a cross section of double star observers using a variety of instruments both professional and amateur.

The reason why we have chosen α Cen AB for this study is that it has an orbital period of about 80 years, and has been observed over 2½ complete orbits, and hence the orbit is well defined. In addition, the two stars are bright, and of approximately the same magnitude, and hence easily measured – the precision of the historic measures should be good.

Figure 1 shows the observed and computed orbit of α Cen AB taken from the WDS 6th Orbit catalog. Axes have units of arcseconds (arcsec). The cross is the position of α Cen A, and orientation is shown. Individual measures are connected to the orbit at the observed epoch. The dashed line is the line of nodes. The inserted is a HST image of a Cen AB taken when the separation was about 17 arcsec (from the ESO web page).

Figure 2 shows the Separation and Position Angle for α Cen AB between 1750 and 2020 in steps of one-half year computed from the orbit of Pourbaix and Boffin (2016). The shape of these figures is best understood in reference to the orbit in Figure 1.

Parramatta Observations of α Cen AB

Alpha Cen AB is also part of our study of Parramatta observations, being observed by Rümker, Dunlop, and possibly Brisbane. Table 1 details these observations. The observation noted as "Brisbane Obs." is reported by Herschel (1847) and most probably is computed from positions published in the *Brisbane Catalogue* of 1835 (Richardson (1835); the observations reported there were made by all three astronomers.

The Rümker Separation and Position Angle is computed from the differences in RA and Dec given by Rümker (1832) and the estimated date of observation of 1829 is based on his statement that it was 77 years since the 1752 observation of Lacaille. The Dunlop observation is from Dunlop (1829). The differences in Separation and Position Angle are relative to the com-

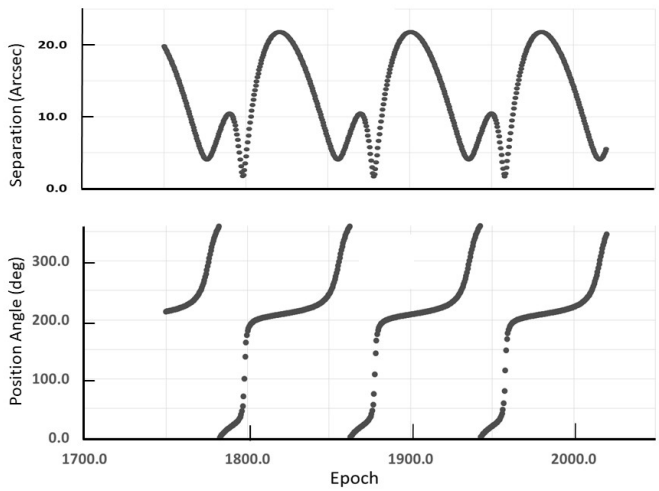

Figure 2. The Separation and Position Angle for α Cen AB from 1750 to 2020.

puted orbit (see below).

However, Alpha Cen AB is not, itself, listed as a double star in the table of Rümker (1832), but it is mentioned in the text of the paper. Rümker has a footnote to his table of double stars to the effect that "α Centauri" (along with 4 other southern doubles) was observed resulting in difference in RA of 24.72 arcsec, and difference in declination of 19.54 arcsec. Rümker compares this measures with the 1752 measures of LaCaille, (LaCaille *et al.*, 1847; Glass, 2013) who gave 26.0 and 16.0 arcsec respectively, and concludes that (sic) "therefore in 77 Years no important change (has) taken place in the relative Situation of these 2 Star's".

We here note the obvious in that the period of α Cen AB is 79.91 years, and that the similar appearance of the system was the result of almost one complete rotation of the pair in the 77 years between observations. Rümker therefore missed the discovery of the motion - and hence the binary nature - of this pair.

Indeed, prior to about 1850, and because of the relative poor quality and scarcity of the data, it is most probable that there was no clear evidence for orbital motion of α Cen AB, and perhaps that discovery, when made, initiated the observational effort seen in Figure 3 about that epoch.

Observations of α Cen in the WDS

A total of 480 measures of α Cen AB are recorded in the WDS. In this study, we have rejected 31 as blunder observations using Chauvenet's Rejection Criteria (see Wikipedia). Figure 3 shows the history of observations from 1750 to 2020, and clearly shows that measures of double stars was a main stream endeavour for the century 1850 to 1950. There has been a steady falling off of interest since about 1950 as resources have been thrown into more fashionable astronomical research, but it is to be hoped that interest in small angle astrometry will be revived with the advent of high resolution imaging and space-based observation.

Orbit and Computed Separation and PA values.

The objective of this paper is to examine the uncertainties associated with the measures of the well understood, and well-studied, α Cen AB, with the intention of developing a systematic understanding of uncertainties of historic double star measurements.

As stated, we are assuming that the computed orbit - computed over two and a half complete orbits - represents the best estimate of the Separation (Rho, ρ) and

Table 1: Parramatta Observations of a Centauri AB.

Paramatta Observer	Reference	Epoch	Rho Arcsec	Rho O-C Arcsec	PA Degree	PA O-C Degree
Brisbane Obs.	Herschel (1847)	1824	22.45	0.9	214.2	1.9
Dunlop	Dunlop (1829)	1826.01	22.45	2.4	212.7	0.2
Rumker	Rumker (1832)	1829	23.1	2.9	212.2	-0.6

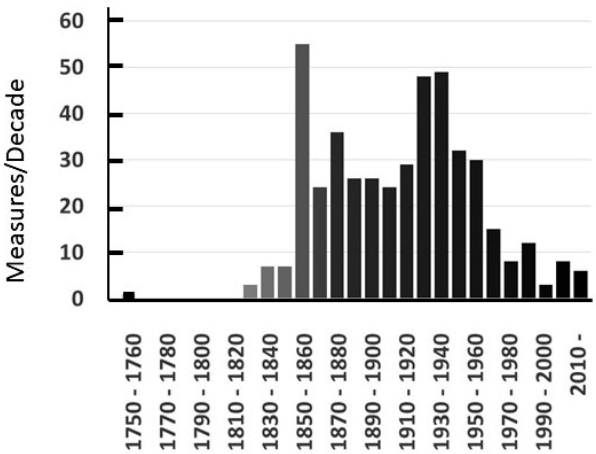

Figure 3. The number of measures as a function of date.

Position Angle (PA) of the pair, and that the individual differences between measures and the computed orbit is the best estimate of the uncertainty of that observation.

Colloquially, the uncertainty in a measurement is called the "error". In this work we differentiate between (i) uncertainty and (ii) blunder/error. We use 'uncertainty' rather than 'error'. Two different types of blunders are (a) an obvious blunder resulting perhaps from a misreading of a scale or a typo, or (b) an unacceptable statistical outlier. Unacceptable statistical outliers are identified using Chauvenet's Rejection Criteria and those that can be safely corrected have been corrected.

In the present data set, three measurements have been corrected on the basis of an obvious reading error and three more of suspected blunder rejected. See Appendix 1.

The orbital parameters adopted for this study are from Pourbaix and Boffin, (2016), …

Period (years)	P	79.91 ± 0.013
Semi major axis (arcsec)	a	17.66 ± 0.026
Orbit inclination (deg)	i	79.32 ± 0.044
PA of ascending node (deg)	Ω	204.75 ± 0.087
Epoch of periastron passage	T	1955.66 ± 0.014
Eccentricity	e	0.524 ± 0.0011
Argument of periastron (deg)	ω	232.3 ± 0.11

and the ρ and PA of α Cen B relative to α Cen A has been computed for the epoch of the historic measures. These J2000 PAs were then precessed to the epoch of observation using equation (1) of Aitken (1935), and the correction to the PA needed for the proper motion of the primary star following equation (2). Similar equations are given in Greaney (2014).

The differences in the ρ and PA were computed for all measures. The sense of the difference is observed (historic ρ and PA) minus calculated (computed ρ and PA from orbital elements). That is, the sense is (O-C).

Differences Relative to the Computed Orbit.

Vectorial Differences

In addition to the calculation of the differences (O-C) in ρ and PA, the vectorial difference in position is calculated for each epoch. The vectorial difference is defined as the distance between the observed measures and the calculated positions in arcseconds.

Figure 4 shows the vectorial differences as a func-

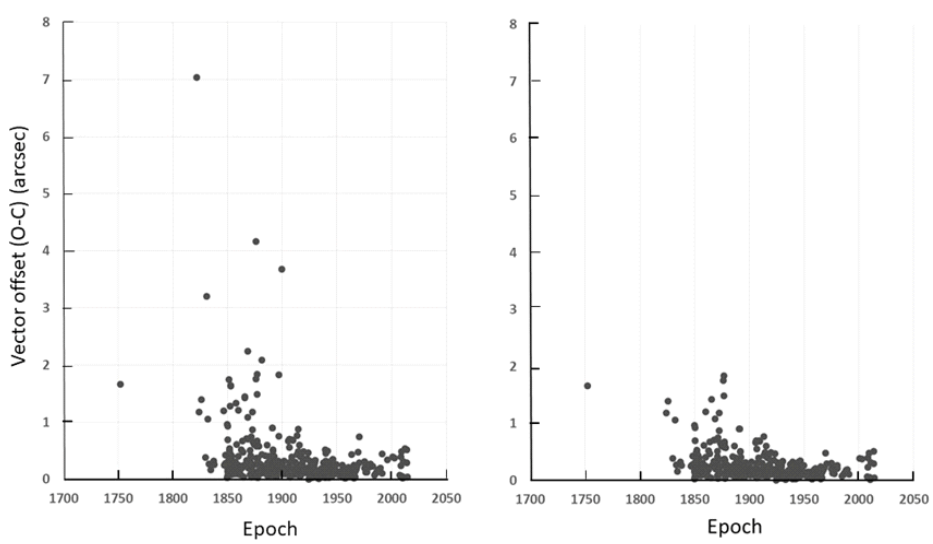

Figure 4. The vector differences as a function of epoch of observation before outliers are removed by Chauvenet's Rejection Criteria (LHS), and after (RHS).

tion of epoch. The LHS is the raw difference after the three corrected observations have been added. For the RHS we invoke Chauvenet's Rejection Criteria to reject data that is statistically inconsistent with the overall statistical spread. The maximum difference values are substantively reduced with the elimination of the outliers.

It is worthy of note that the earliest observation by Lacaille in 1752 has withstood the rejection test, and the authors stand in awe at that achievement given that a modern-day replica instrument (with 26 inches focal length and half-inch aperture (Warner, 2002)) would struggle to achieve this result.

Differences in Separations and Position Angles

Figure 5 shows the differences (O-C) in ρ and PA as a function of the observation epoch. The three obvious errors have been corrected but no data has been rejected using Chauvenet's Rejection Criteria. The differences in ρ are in units of arcsec, and the units for difference in PA is degrees.

Serious observations of this star started in about 1850 and there is a feature of "wild" observations of PA at about 1875. This 1875 feature represents a time when the two stars were at close approach and where accurate measurement was difficult and high uncertainties predictable (see below). A similar effect may be seen around 1940 at the next close approach.

Figure 6 shows the four "cross plots" of differences with measure parameter. The two top plots show a general disinterest in measurement when the separation was mid-range, in particular when the PA was in the range 50 to 180 degrees.

The two figures showing differences with separation clearly show that the differences are larger for smaller separations. The plot of uncertainty in PA with Separation is discussed below. In this figure, the data is a mixture of early measures, which have larger uncertainties, and modern values. The emphasis on the larger spread at small separation is not so obvious being confused by this mixture.

The differences in both ρ and PA with Position Angle show no peculiar feature and shows no stand-out dependence of uncertainties with Position Angle.

Decade-by-Decade Analysis

A more precise understanding of the uncertainties relative to the computed orbit is obtained by tracking their evolution over the ~200 years of observation with a resolution of a decade. Table 2 gives, on a decade-by-decade basis, (i) the number of observations made that decade and, (iii) the number that can be safely rejected using the formal Chauvenet's Rejection Criteria. A list of the observations that have been rejected is in Appendix 2. Column (iv) of Table 2 gives the mean epoch of the observations made in that decade.

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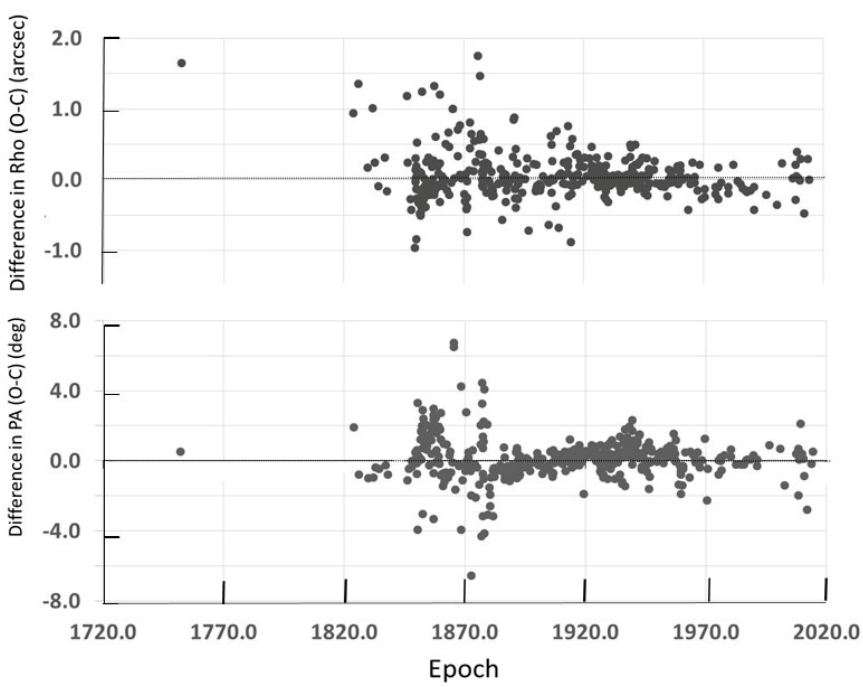

Figure 5. The differences between measures and the computed orbit for Separation and Position Angle, as a function of observation epoch.

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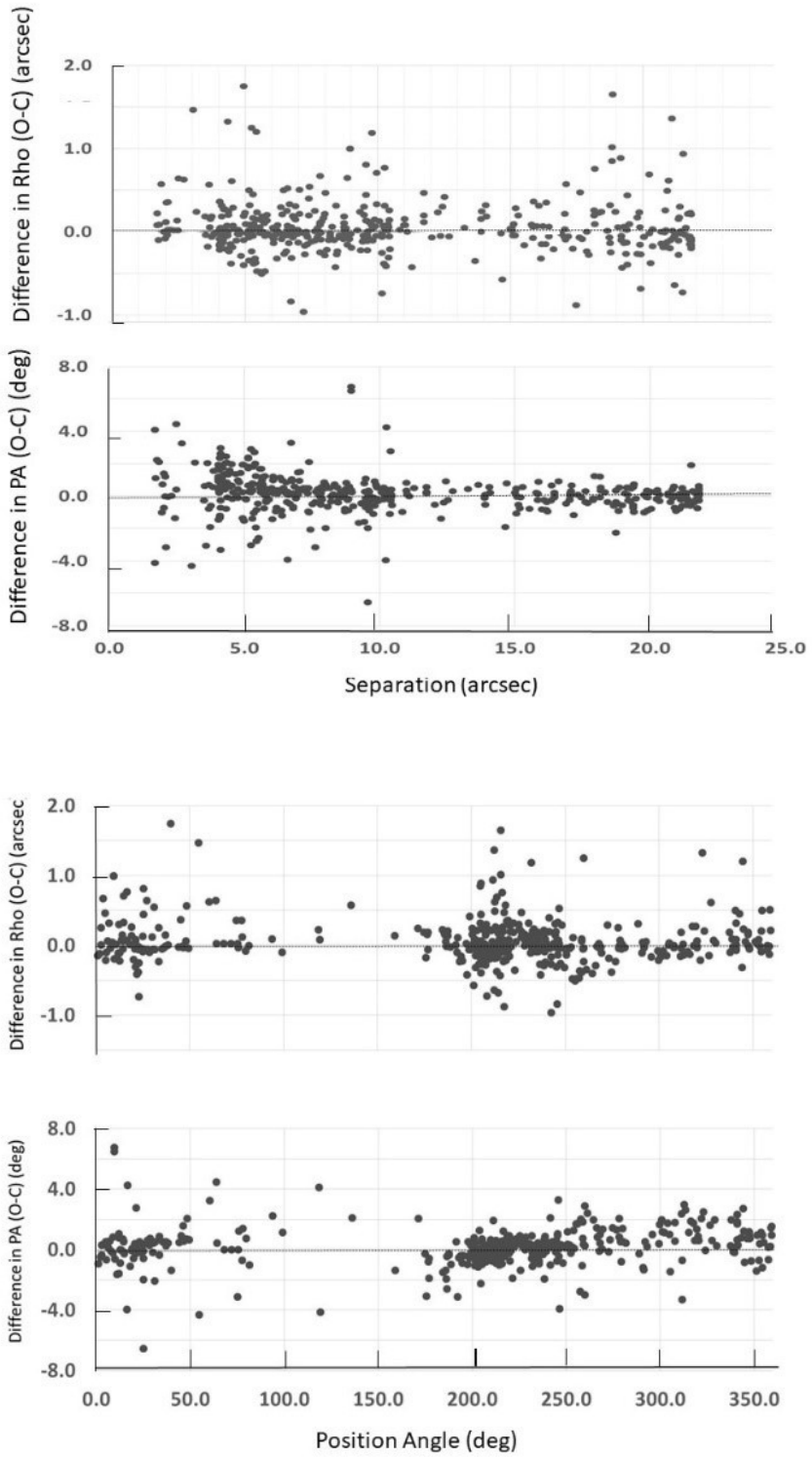

Figure 6. The differences between measures and the computed orbit for Separation and Position Angle as a function of Separation (top) and the Position Angle.

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Column (v) is the mean bias between the Separation (Rho) measures and the orbit, in the sense (O-C) and column (vi) is the Standard Error (SEM) in that bias. The Standard Deviation (SD), in the differences is in column (vii). The last three columns give (viii) the mean Position Angle bias between the measures and the orbit, (ix) the SEM of that bias, and (x) the SD of the differences.

There is no evidence for a bias in the Separation or Position Angle measures, as would be expected as the orbit is computed to minimize any bias. The average bias in the Separation is 0.063 arcsec (over all observations) and reduces to 0.006 arcsec for the period 1950 to present. Similarly, for the Position Angle, the overall bias is 0.08 degree, but is 0.13 degree for the period 1950 plus. Most of the biases are well behaved within their standard errors.

Among the 31 rejected observations (Appendix 2), five authors appear two times. Measures are rejected because of 14 outliers in Separation and 18 in Position Angle.

Figure 7 is developed from Table 2 and shows, on the decade-by-decade basis, the Standard Deviation (SD) of the difference between the historic measures and the computed orbit. These values are now the best guess of the uncertainties in this set of observations.

As expected, the SD of the Separation measures has been progressively improving over time, with an accelerated improvement in the early 20th century. Typically the SD falls from about 0.43 arcsec in the mid-1800s to better than 0.07 arcsec in the late 20th Century. This substantive change in accuracy starting in the 20th Century may be the consequence of a technique change, such as the movement from filar micrometer to photographic measures. The increase in the uncertainties in the Separation in 21st century is difficult to explain.

There is a similar story with the SDs of the differences of the Position Angles. Here the accuracy rises quickly from about 2.2 degrees to about 0.4 degrees at about 1900. Again, the increase in the uncertainties in the Position Angles in 21st century is difficult to explain.

In Figure 8, we have developed target-type plots of the differences for the half-century periods 1800-1850, 1850-1900, 1900-1950, and the period 1950 to present.

The general improvement in the quality of the ob-

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Table 2.

Period	Number Measures	Number Rejected	Mean Epoch	Rho Bias (O-C) Arcsec	Rho SEM Arcsec	Rho SD Arcsec	PA Bias (O-C) Degree	PA SEM Degree	PA SD Degree
1750 - 1760	1	0	1752.2	0.55			1.65		
1760 - 1770									
1770 - 1780									
1780 - 1790									
1790 - 1800									
1800 - 1810									
1810 - 1820									
1820 - 1830	3	1	1825.0	1.15	0.15	0.3	0.56	1.35	1.91
1830 - 1840	7	1	1835.0	0.26	0.17	0.42	-0.55	0.13	0.32
1840 - 1850	7	1	1848.7	-0.24	0.17	0.42	0.00	0.14	0.35
1850 - 1860	55	5	1854.3	0.00	0.06	0.44	0.30	0.56	3.94
1860 - 1870	24	3	1863.9	0.23	0.08	0.39	-0.31	0.36	1.66
1870 - 1880	36	1	1875.2	0.29	0.09	0.56	-0.05	0.40	2.35
1880 - 1890	26	2	1885.1	-0.03	0.04	0.20	-0.68	0.14	0.67
1890 - 1900	26	1	1893.3	0.12	0.10	0.50	-0.19	0.10	0.48
1900 - 1910	24	0	1904.8	-0.01	0.07	0.32	-0.05	0.08	0.41
1910 - 1920	29	1	1915.2	0.13	0.04	0.23	0.15	0.11	0.56
1920 - 1930	48	0	1926.5	0.04	0.02	0.15	0.11	0.07	0.46
1930 - 1940	49	2	1934.7	0.00	0.02	0.10	0.43	0.12	0.79
1940 - 1950	32	2	1944.4	0.05	0.03	0.15	0.41	0.11	0.60
1950 - 1960	30	2	1955.9	0.01	0.02	0.08	0.29	0.11	0.57
1960 - 1970	15	2	1964.6	0.03	0.04	0.15	0.00	0.15	0.55
1970 - 1980	8	2	1975.1	-0.16	0.04	0.09	-0.12	0.17	0.42
1980 - 1990	12	3	1986.7	-0.11	0.02	0.06	0.10	0.09	0.27
1990 - 2000	3	1	1991.2	-0.16	0.05	0.08	0.49	0.42	0.59
2000 - 2010	8	0	2007.8	0.09	0.09	0.26	0.06	0.45	1.27
2010 -	6	1	2013.1	0.27	0.10	0.22	-0.18	0.23	0.51

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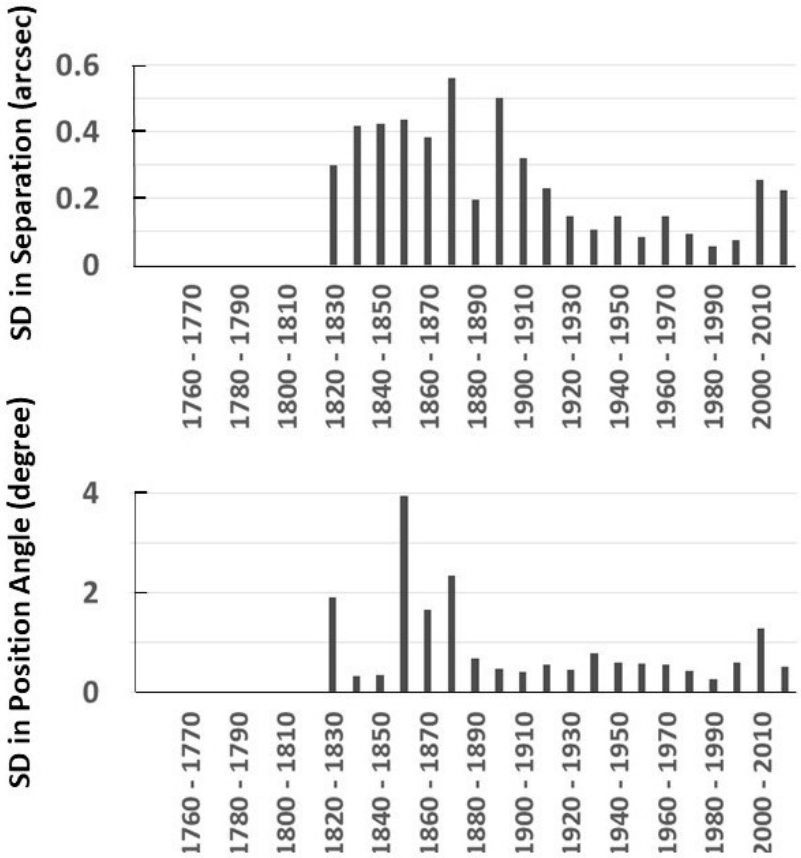

Figure 7. The Standard Deviations (SD) of the differences between historic measures and the computed orbit on a decade-by-decade basis.

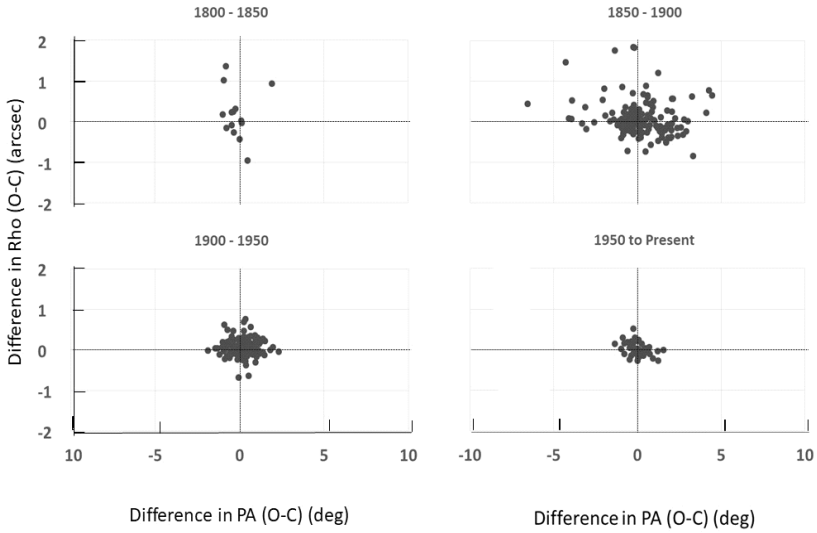

Figure 8. Differences in Separation and Position Angle for the periods 1800 to 1850, 1850 to 1900, 1900 to 1950 and from 1950 to the present (2014). Chauvenet's Rejection Criteria has been applied on a decade-by-decade basis. Details are given in Table 2.

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Table 3. Data for 50 Year Intervals

Period	Rho Bias (O-C) Arcsec	Rho SEM Arcsec	Rho SD Arcsec	PA Bias (O-C) Degree	PA SEM Degree	PA SD Degree
1800-1850	0.17	0.17	0.61	-0.19	0.21	0.75
1850-1900	0.08	0.01	0.08	0.14	0.13	1.63
1900-1950	0.04	0.01	0.19	0.24	0.05	0.62
1950-present	-0.01	0.02	0.14	0.13	0.07	0.54

(Continued from page 438)

servation is evident in the contraction of the data targets. Formal uncertainties for these periods are given in Table 3 which follows a similar format to Table 2.

Small Angle Bias

Measurement of both Separation and Position Angle are harder for small angular separations. Figure 9 gives the differences between the historic measures and the computed orbit for both Separation and Position Angle for the period 1950 to present. Here the differences are normalised by the separations ((Difference in Rho)/Rho), accentuating the difference for smaller separations.

Figure 9 shows that there is both a bias and a spreading of the data that occurs at small angles. A close-in bias of ~2% is obvious for Separation measures of <6 arcsecond, and ~1% in PA for separations of <10 arcsecond. A spreading of the uncertainties in both Separation and PA to ~ 6% is obvious compared with ~ 3% at the widest separations (ρ >20 arcsec).

Space-Based Observations

Alpha Cen A and B was observed by the HIPPARCOS mission at epoch 1991.25 yielding ρ = 19.07 arcsec and PA = 215.4 degree. Reduction relative to the orbit of Pourbaix and Boffin (2016) results in an O-C for ρ of -0.101 arcsec and PA of 0.077 degree. These differences are subject to the caveat that the HIPPARCOS mission had technical difficulties handling double stars within specific separation and magnitude limits (Lindegren *et al.*, 1997), and may also result from a small bias in the orbit parameters resulting from the inclusion of the historic observations.

There are no Gaia data available for α Cen A and B.

Summary and Conclusions

Accurate uncertainties in the Separation and Position Angles of historic measures of double stars are needed to allow the study of the motion of the individual members of the pair. These studies may include the calculation of relative proper motion, rectilinear motion and the computation of orbits.

An assessment of these uncertainties of the most well studied pair α Cen AB, over a period of some 260 years, and $2^1/_2$ completed orbits, shows clearly that:-

a) With time, the accuracy of both the Separation and Position Angle measures improve – see Figures 4, 5 and 7. This may reflect improvements in techniques.
b) The Standard Deviation estimates of Separations falls from a peak of about 0.5 arcsec in the mid-1800s to about 0.07 arcsec by the late twentieth century. The period of fastest fall was about 1900.
c) The Standard Deviation estimates of Position Angle falls from a peak of about 2 degree in the mid-1800s, to about 0.3 degree by the late twentieth century. The period of fastest fall was about 1880.
d) There seems to be a falling away of accuracy in the twenty first century. Standard deviations for Separation and Position Angle are about 0.25 arcsec and 1.3 degree respectively.
e) There is both an increase in the spread of the relative (%) uncertainties, and a bias in these uncertainties, at small separations. For the separation, the spread in uncertainties is about 8% and the bias is about 1% for small separations. For the Position Angle, the spread in uncertainties is about 6% and the bias is about 1.5% for small separations.

Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

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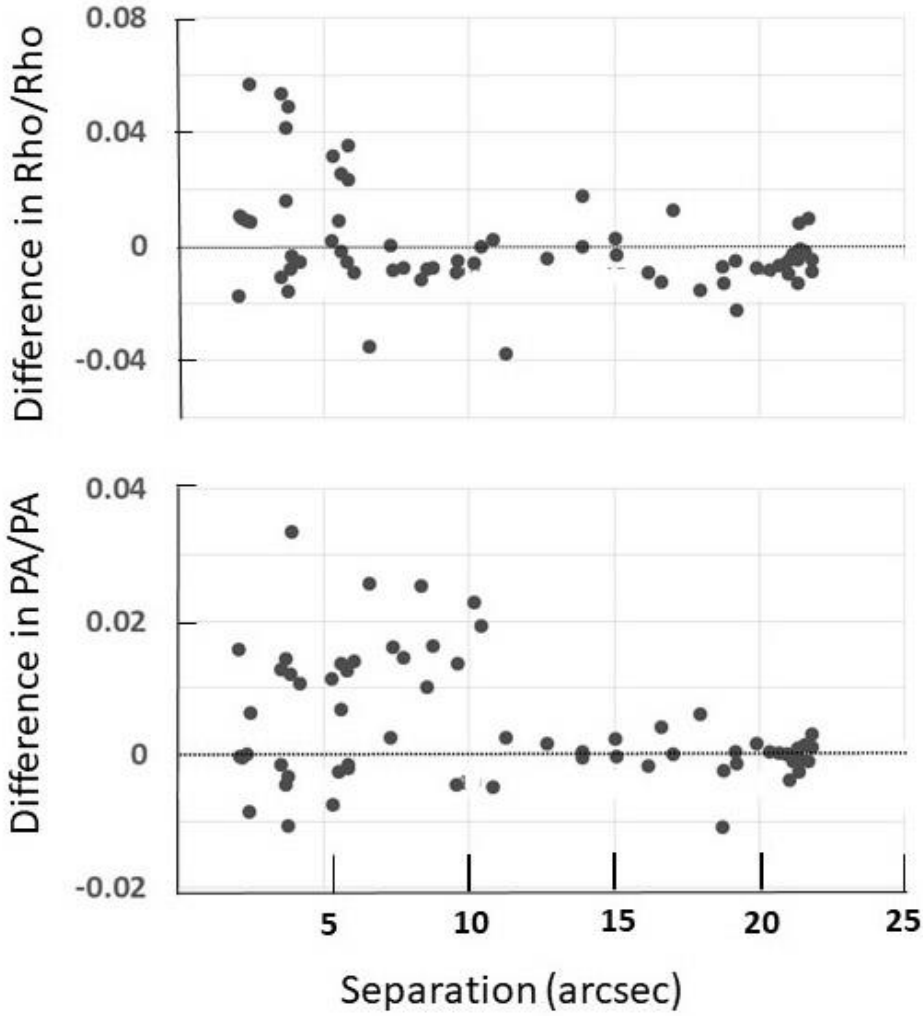

Figure 9. The differences for the measures made after 1950.

Appendix 1.

Pairs with Measures That Have Been Corrected

Epoch	Observer	PA reading (degree)	Assumed to be (degree)	Changed to (degree)
1872.55	Ellery, (1877)	9.735	10	-0.265
1926.32	Voute, (1926)	20.055	20	-0.055
2013.71	Anton, (2014)	-9.974	-10	-0.239

Appendix 2.

Pairs Rejected During the Decade-by-Decade Analysis Using Chauvenet's Rejection Criteria

Epoch Rejected	Observer	Rejected Separation	Rejected Position Angle
1822	Fallows, (1847).		X
1831	Madras Obs. (1854).		X
1846.21	Jacob, (1847).	x	X
1851.28	Gilliss, (1868).		X
1852.5	Gilliss, (1868).		X
1852.87	Jacob, (1854).	x	
1852.99	Jacob, (1854).	x	
1857.82	Maclear, (1911).		x
1865.56	Ellery, (1877).	x	
1865.56	Ellery, (9999).	x	
1868.27	Maclear, (1911).		x
1875.94	Walker, (1881).	x	
1881.28	Hargrave, (1884).		x
1881.54	Hargrave, (1884).	x	
1899.41	Cruls, (1884).	x	x
1914.74	Beattie, (1914).		x
1939.5	Geddes & Thomsen, (1940)		x
1939.76	Iannini, (1942).		x
1941.6	Iannini, (1942).		x
1946.37	Gottlieb, (1948).	x	
1954.94	Churms, (1956).		x
1959.457	Kamper & Wesselink, (1978).	x	
1960.24	de Freitas-Mourao, (1960).	x	
1963.6	Holden, (1965).		x
1970.513	Worley, (1972).	x	
1976.31	Holden, (1977).		x
1982.49	Torres, (1985).		x
1991.186	Warren, (1992).		x
1996.156	Prieto, (1997).	x	
2012.015	Krawczenko, (2013).	x	