The Astronomical Journal, 154:200 (9pp), 2017 November https://doi.org/10.3847/1538-3881/aa803e

Binary Star Orbits. V. The Nearby White Dwarf/Red Dwarf Pair 40 Eri BC

Brian D. Mason, William I. Hartkopf, and Korie N. Miles[1]
U.S. Naval Observatory, 3450 Massachusetts Avenue, NW, Washington, DC, 20392-5420, USA; brian.d.mason@navy.mil, william.hartkopf@navy.mil
Received 2017 June 13; revised 2017 July 7; accepted 2017 July 7; published 2017 October 31

Abstract

A new relative orbit solution with new dynamical masses is determined for the nearby white dwarf–red dwarf pair 40 Eri BC. The period is 230.29 ± 0.68 years. It is predicted to close slowly over the next half-century, getting as close as $1\overset{''}{.}32$ in early 2066. We determine masses of 0.573 ± 0.018 $\mathcal{M}_\odot$ for the white dwarf and 0.2036 ± 0.0064 $\mathcal{M}_\odot$ for the red dwarf companion. The inconsistency of the masses determined by gravitational redshift and dynamical techniques, due to a premature orbit calculation, no longer exists.

Key words: binaries: general – binaries: visual – stars: individual (40 Eri BC) – techniques: interferometric

Supporting material: machine-readable table

1. Introduction

One of the more widely separated physical multiples in the sky, 40 Eri consists of a nearby, naked-eye star (HR 1325A) and a closer pair (BC) sharing the same, very large, proper motion over a minute of arc away. Parameters for the multiple system are presented in Table 1. In that table, Column 1 provides the relevant parameter, Columns 2, 3, and 4 give the values for A, B, and C, respectively, while Column 5 gives the reference(s) for the parameter. Note that we do not give the position for C, although Table 5 does provide the δ from the B position. This multiple system was listed as #518 in Struve's (1837) catalog of double stars. Due to the immensity of this catalog and its logical structure, the star number in this catalog is taken as its "discovery designation" despite being measured first by William Herschel (1785) almost 50 years earlier. The first accurate observation would wait another 14 years (Dawes 1867) after Struve's catalog. The AB pair, having only changed its position angle by 6° since its first measure 233 years ago, would have a very long orbital period. However, BC was recognized as more rapidly moving and interesting. This interest went beyond just being a potentially faster moving orbit pair when Adams (1914) noted it as "an A-type star of very low luminosity," i.e., a white dwarf. It appears and is described as an outlier in one of the very first color-luminosity diagrams (Russell 1914, see Figure 1). The star is, in fact, the second brightest known white dwarf, with an apparent magnitude $V = 9.53$ (Kidder et al. 1991); versus $V = 8.44$ for Sirius B (Bond et al. 2017). It is also by far the easiest to see, as Sirius B is lost in the glare of its primary (Bond et al. 2017), while the primary here is not only fainter ($V = 4.43$; Ducati 2002), but much farther from its companion ($\rho \sim 83\overset{''}{.}7$).

Due to the long period of most visual binaries (and the understandable impatience of calculators), orbits are often calculated when they "can" be and not necessarily when they "should" be. The first known orbit of the pair was by Gore (1886). In the Catalog of Visual Binary Star Orbits (Finsen 1934), the preferred orbit for 40 Eri BC was that of van den Bos (1926), as it was in the 2nd Catalog (Finsen 1938). By the time of the 3rd Catalog (Finsen & Worley 1970), the preferred orbit was Orbit III of Wielen (1962), and this was updated again for the 4th Catalog (Worley & Heintz 1983), where the preferred orbit was that of Heintz (1974). It remained so in the 5th Catalog (Hartkopf et al. 2001) and later electronic catalogs until the current calendar year. Heintz's (1974) mass estimates were 0.43 ± 0.02 $\mathcal{M}_\odot$ for the white dwarf and 0.16 ± 0.01 $\mathcal{M}_\odot$ for the M dwarf companion. Using the modern *Hipparcos* parallax (van Leeuwen 2007), the masses would be 0.48 ± 0.02 $\mathcal{M}_\odot$ for the white dwarf and 0.17 ± 0.01 $\mathcal{M}_\odot$ for the M dwarf companion.

Unfortunately, the dynamical mass of the white dwarf was rather different from the result obtained through analysis of the gravitational redshift, for example, 0.53 ± 0.04 $\mathcal{M}_\odot$ from Koester & Weidemann (1991). Indeed, much ink has been spilled seeking to reconcile the differences between these two approaches (Koester et al. 1979; Wegner 1979, 1980; Reid 1996; Provencal et al. 1998).

2. Measures of 40 Eri BC

2.1. New Measures

The pair is suitable for observation by the USNO speckle camera on the 26″ refractor in Washington (Mason et al. 2011a, 2011b); at the suggestion of Howard Bond, the pair was repeatedly observed until it was too far off the meridian at twilight. Observed three times per night on six different nights, the calibration and methodology are as described in B. D. Mason & W. I. Hartkopf (2017, in preparation). The mean positions from these observation are presented in Table 2. In that table, Columns 1, 2, 3, 4, and 5 provide the mean epoch of observation (in fractional Julian year), the position angle (in degrees), its error (in degrees), the separation (in seconds of arc), and its error (in seconds of arc). Note that the position angles have not been corrected for precession and are thus based on the equinox for the epoch of observation. Column 6 gives the number of nights in the mean position and Columns 7 and 8 provide residuals to the orbit presented in Section 3. The "weight" of each measure used in the orbit solution is given in Column 9 while Column 10 identifies the source of the observation.

The mean intranightly error is $0\overset{\circ}{.}04$ for the position angle (θ) and $0\overset{''}{.}0039$ for the separation (ρ). The errors presented for position angle and separation presented in Table 2 are the internightly errors.[2]

The pair will be observable again in mid-September, but as described in Section 3 below, the accumulation of additional

[1] SEAP Intern.

[2] The error in position angle for the USNO speckle measures are not zero, but round to 0.0 when given at the precision of the measure.

Table 1
40 Eri Component Properties

	A	B	C	Source
α(2000)	04 15 16.32			van Leeuwen (2007)
		04 15 21.79		Zacharias et al. (2003)
				Table 5
δ (2000)	−07 39 10.3			van Leeuwen (2007)
		−07 39 29.1		Zacharias et al. (2003)
				Table 5
μ_α	−2240.12 mas yr^{-1}			van Leeuwen (2007)
		−2228.3 mas yr^{-1}		Zacharias et al. (2003)
			−2239 mas yr^{-1}	Salim & Gould (2003)
μ_δ	−3420.27 mas yr^{-1}			van Leeuwen (2007)
		−3377.1 mas yr^{-1}		Zacharias et al. (2003)
			−3419 mas yr^{-1}	Salim & Gould (2003)
Parallax	200.62 mas			van Leeuwen (2007)
Spectral type	K0.5V			Gray et al. (2006)
		DA2.9		Gianninas et al. (2011)
			M4.5V	Alonso-Floriano et al. (2015)
V mag	4.43			Ducati (2002)
		9.53		Kidder et al. (1991)
			11.17	Holberg et al. (2012)

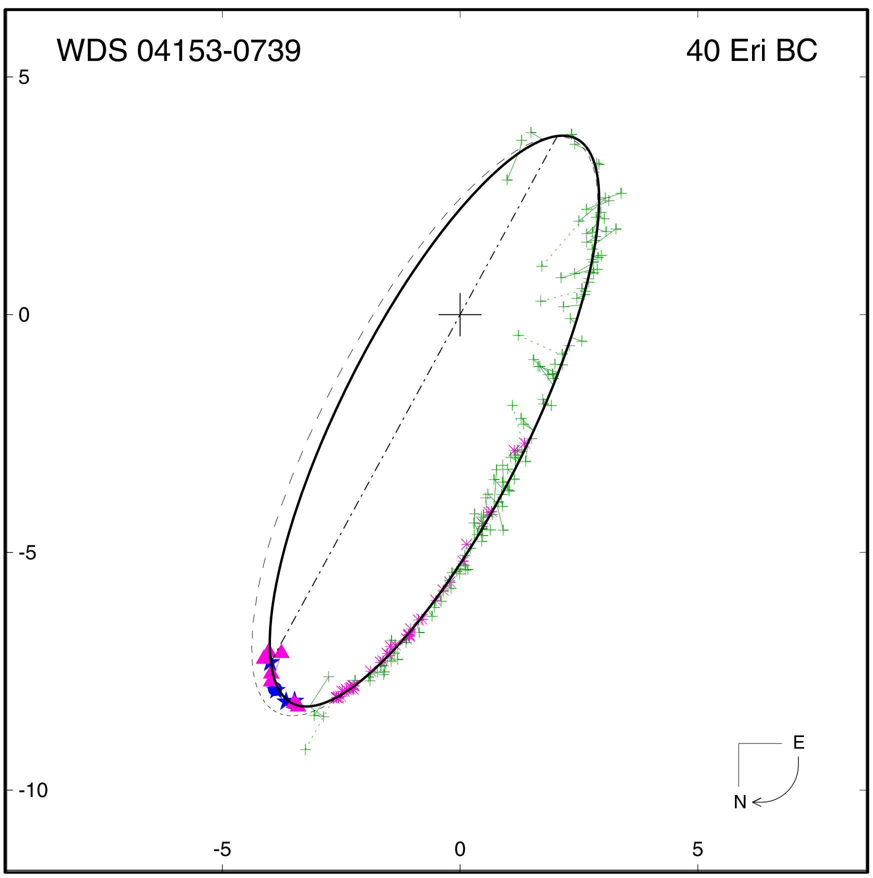

Figure 1. New orbit of 40 Eri BC as described in the text. The solid curve is the solution presented in Table 4. The dashed curve is the orbit of Heintz (1974). The zero-weighted and aberrant measures of Schembor (1939), Van Biesbroeck (1974), and Chaname & Gould (2004) are not plotted for cosmetic reasons.

data will only make minute incremental improvement until, probably, the second half of the 21st Century.

Also presented in Table 2 are measures obtained by matching the components with objects in large catalogs with reliable astrometry. Using the same methodology as described in Wycoff et al. (2006), the pair was matched with the 2MASS Point Source Catalog.[3] Similarly, the pair was matched with UCAC4 (Zacharias et al. 2013) using the techniques described in Hartkopf et al. (2013). Errors, when they can be determined from multiple measures, are presented as well.

[3] 2003 All-sky Release. See `Vizier On-line Data Catalog: II/246`.

Table 2
New Measurements of 40 Eri BC

Julian Epoch	θ (°)	$\sigma\theta$ (°)	ρ ($''$)	$\sigma\rho$ ($''$)	n	$O-C$ (°)	$O-C$ ($''$)	Weight	Source
1998.87	336.8	...	8.84		1	0.6	−0.052	20.0	2MASS[a]
1999.97	335.8	0.1	8.924	0.011	4	−0.1	0.042	40.0	UCAC4[b]
2006.8773	333.9	0.1	8.797	0.003	1	−2	0.050	25.0	HST[c]
2017.1322	331.5	0.0	8.334	0.017	2	0.2	0.060	28.3	USNO Speckle
2017.1901	331.4	0.0	8.337	0.007	4	0.1	0.067	40.0	USNO Speckle

Notes.
[a] Cutri et al. (2003), All-sky Release. See `Vizier On-line Data Catalog: II/246`.
[b] Zacharias et al. (2013).
[c] Hubble Space Telescope/Advanced Camera for Surveys archival observation (Program ID GO-10895, PI P. Kalas), measured and communicated privately by H. E. Bond. Original position angle at J2000 precessed to that of date of observation as per IAU resolution. The stellar images are saturated, but were centroided using the diffraction spikes, similar to the procedures used for Sirius in Bond et al. (2017).

2.2. Measures from the WDS

Measures used in the orbit solution (Section 3), from the Washington Double Star Catalog (hereafter, WDS, Mason et al. 2001) are presented in Table 3. In this table, Columns 1, 2, and 3 provide the mean epoch of observation, position angle, and separation, respectively. Again, the position angles are for the equinox of the epoch of observation. Column 4 lists the number of nights in the mean position, Columns 5 and 6, the $O-C$ residuals to the orbit, while Column 7 is the "weight" used in the orbit solution. Column 8 is the source of the measure and Column 9 is reserved for notes.

Despite IAU resolutions (IAU 1977) recommending that observations be published using dates given in Julian epoch (JE), classic double star data have primarily been published with the date of observation given at the fractional Besselian epoch (BE). We are in the process of evaluating the 9341 references used in the compilation of the WDS and adjusting the observation epoch from BE to JE when appropriate. Accordingly, the measures listed in Table 3 have been converted to JE, using the IAU approved conversion,

$$\mathrm{JY} = (\mathrm{BY} \times 0.999978641) + 0.041439661. \qquad (1)$$

The difference is slight, and given their published precision, only 41 dates in the table have been changed.

2.3. Zero-weighted Measures

Measures not appearing in Table 3 and not used in the orbit solution include those that are incomplete and list only the position angle and no separation (Herschel 1785; Struve 1837; Plummer 1878; Howe 1879; Doberck 1896, 1902; Comstock 1906; Lohse 1908) as well as those that are measures of magnitude difference only (Kuiper 1950; Wieth-Knudsen 1957; Pettit 1958; Rakos et al. 1982).

Another not included is the measure of Schembor (1939), which has an extremely large residual and appears to be a measure of the position angle of the AB pair of this multiple system coupled to the separation of BC. Also excluded is the measure of Van Biesbroeck (1974). The residual is much larger than is typical for measures from this very experienced observer. In that paper, the measure of 40 Eri BC in Table 1 is listed as having very small residuals to the orbit of Wielen (1962).[4] However, there is either a typo in both of the measures or there was a typo in the orbit residual. Given the ambiguity, this mean position is not included. Had Van Biesbroeck been able to see the final manuscript to completion, it would, no doubt, have been corrected. The measure of Chaname & Gould (2004) has a very large difference in position angle from contemporaneous measures and is given an observation date of "approximately 2000," which is insufficiently precise for orbit determination and is also not included.

[4] This is, presumably, Orbit III, as this was the preferred orbit in the 3rd Catalog (Finsen & Worley 1970), although four sets of elements are in Wielen (1962).

3. The Orbit of 40 Eri BC

Using the elements of Heintz (1974) to provide a first guess at the period, time of periastron passage, and eccentricity, a method of differential correction was applied with the "grid-search" routine described in Hartkopf et al. (1989). Weights to the measures were applied using the methodology of Hartkopf et al. (2001). Briefly describing the weighting methodology, the following factors were considered: telescope aperture, separation, number of nights, and method of data acquisition. Arriving at the factors used in weighting was accomplished by evaluating approximately 66,000 observations of 450 well-characterized orbits in the generation of the orbit catalog Hartkopf et al. (2001). After performing the adaptive "grid-search" until the step size is very small, rms values are determined and weights adjusted. Measures made by micrometry are zero-weighted when the residual is three times the rms. Measures made by photography or CCD have their weights reduced to 25% of their previous value. The "grid-search" is then repeated until lower tolerances in step size are met. These final weights are provided in Tables 2 and 3.

Table 4 lists the seven Campbell elements: P (period, in years), a (semimajor axis, in arcseconds), i (inclination, in degrees), Ω (longitude of node, equinox 2000, in degrees), T_0 (epoch of periastron passage, in fractional Julian year), e (eccentricity), and ω (longtitude of periastron, in degrees). Formal errors are listed with each element. Also provided in Table 4 are the parallax and mass ratio from van Leeuwen (2007) and Heintz (1974), respectively, used to determine their individual masses. This pair was identified by one of the authors (KNM) in Summer 2016 as a pair suitable for orbit improvement and a preliminary version of these elements (determined without the measures of Table 2) appeared in the Commission G1 (née 26) Information Circular (Miles & Mason 2017). For historical context, the earlier orbital elements of Heintz (1974; equinox 2000), Orbit III of Wielen (1962 equinox unspecified), van den Bos (1926; equinox 1900), and Gore (1886; equinox 1880) are also given.

Table 3
Catalog Measurements of 40 Eri BC

Julian Epoch	θ (°)	ρ (″)	n	$O-C$ (°)	$O-C$ (″)	Weight	Source	Notes
1851.06	160.0	3.	1	0.6	−0.599	1.1	Dawes (1867)	⋯
1851.22	159.8	3.89	4	0.7	0.269	4.3	Struve (1878)	⋯
1855.06	158.0	4.11	6	4.1	0.040	5.6	Struve (1878)	⋯
1864.84	147.6	4.46	2	4.3	0.032	3.5	Struve (1878)	⋯
1864.85	147.61	4.455	2	4.3	0.027	2.1	Winnecke (1869)	⋯
1866.96	145.4	4.32	3	4.3	−0.062	4.1	Struve (1878)	⋯
1873.85	137.3	4.29	5	4.1	0.262	5.3	Struve (1878)	⋯
1875.90	136.6	4.3	1	6.1	0.420	0.0	Lewis (1906)	A, B
1877.12	126.4	4.24	2	−2.4	0.453	3.3	Struve (1893)	⋯
1877.12	120.0	2.	1	−8.8	−1.787	0.0	Flammarion (1878)	A, C
1877.79	129.2	3.46	2	1.3	−0.274	1.9	Stone (1878)	D
1877.86	128.2	3.92	7	0.4	0.192	16.3	Burnham (1879)	⋯
1877.87	127.6	3.18	2	−0.2	−0.547	2.9	Howe (1878)	⋯
1877.95	126.8	3.94	4	−0.8	0.219	7.0	Dembowski (1884)	⋯
1879.05	125.4	3.66	4	−0.6	0.029	11.4	Burnham (1883)	⋯
1879.181	125.0	3.52	2	−0.8	−0.101	11.6	Hall (1877)	E
1879.68	123.0	3.64	2	−2.0	0.060	3.7	Burnham (1887)	⋯
1879.75	119.3	3.29	1	−5.6	−0.284	1.3	Stone (1882)	⋯
1880.09	121.3	3.28	5	−3.0	−0.266	11.5	Burnham (1883)	⋯
1880.95	122.0	3.16	5	−0.9	−0.314	11.1	Burnham (1883)	⋯
1881.84	119.0	3.53	6	−2.4	0.131	13.5	Burnham (1883)	⋯
1882.119	118.2	3.24	2	−2.7	−0.135	10.3	Hall (1892)	E
1883.00	119.2	3.07	2	−0.1	−0.231	6.8	Burnham (1883)	⋯
1883.807	115.8	3.10	2	−1.9	−0.133	9.8	Hall (1892)	E
1884.16	118.2	3.74	1	1.2	0.536	2.1	Struve (1893)	⋯
1886.00	111.9	3.14	2	−1.3	0.087	9.6	Leavenworth & Beal (1930)	⋯
1886.002	112.2	3.22	3	−1.0	0.167	12.1	Leavenworth & Muller (1915)	E
1886.095	112.2	3.00	6	−0.8	−0.045	16.2	Hall (1892)	E
1886.92	111.0	3.01	3	−0.1	0.031	2.6	Tarrant (1889)	⋯
1887.14	109.2	2.56	4	−1.4	−0.402	8.7	Schiaparelli (1909)	⋯
1888.08	109.5	2.26	2	1.1	−0.630	5.7	Schiaparelli (1909)	⋯
1888.121	107.7	3.04	5	−0.6	0.153	15.1	Hall (1892)	E
1888.84	106.8	2.94	3	0.3	0.107	5.7	Burnham (1894)	⋯
1888.870	105.0	2.81	3	−1.4	−0.021	2.4	Tarrant (1890)	E
1889.03	107.6	2.87	2	1.6	0.050	6.7	Schiaparelli (1909)	⋯
1889.123	103.6	2.79	4	−2.2	−0.023	12.2	Hall (1892)	E
1890.73	100.0	2.68	4	−1.5	−0.022	15.9	Burnham (1894)	⋯
1890.98	99.0	1.72	3	−1.8	−0.966	0.0	Hough (1894)	A
1891.00	101.5	2.62	2	0.8	−0.064	6.3	Schiaparelli (1909)	⋯
1891.056	98.6	2.65	5	−1.9	−0.031	12.9	Hall (1892)	E
1891.78	97.4	2.48	4	−1.0	−0.156	14.4	Burnham (1894)	⋯
1893.212	93.8	2.18	1	−0.3	−0.375	2.6	Comstock (1896)	E
1895.912	87.4	2.32	2	2.2	−0.116	1.4	Collins (1896)	E
1897.97	77.2	2.62	3	−0.8	0.239	4.0	Aitken (1914)	⋯
1899.11	73.6	2.39	2	−0.2	0.025	2.9	Aitken (1914)	⋯
1899.803	68.4	2.30	3	−2.9	−0.061	4.4	Doolittle (1905)	E
1900.743	70.	1.3	1	2.2	−1.061	0.0	Comas Sola (1900)	A, C, E
1900.926	63.4	2.40	2	−3.8	0.038	3.7	Doolittle (1905)	E
1902.002	61.9	2.25	4	−1.4	−0.123	5.3	Comstock (1906)	E
1903.142	55.2	2.24	4	−4.0	−0.156	5.0	Doolittle (1905)	E
1903.183	55.9	1.97	1	−3.1	−0.427	2.3	Comstock (1906)	E
1903.87	56.8	2.31	2	0.2	−0.106	7.4	Aitken (1914)	⋯
1904.105	58.0	1.81	1	2.2	−0.613	2.2	Doolittle (1905)	E
1904.70	55.2	2.38	3	1.5	−0.063	13.6	Burnham (1906)	⋯
1905.11	56.5	2.00	1	4.2	−0.459	0.2	Lohse (1908)	C
1907.80	43.8	2.49	4	0.1	−0.101	16.7	Burnham (1913)	⋯
1907.97	44.6	2.71	2	1.4	0.109	4.4	Wirtz (1912)	⋯
1908.83	42.6	2.57	5	2.0	−0.083	19.5	Burnham (1913)	⋯
1912.04	29.6	2.66	2	−2.4	−0.225	8.9	Aitken (1914)	⋯
1912.11	30.0	2.53	1	−1.9	−0.361	1.3	Vanderdonck (1912)	F
1913.138	29.5	3.01	3	0.1	0.035	5.0	Van Biesbroeck (1920)	E
1914.063	23.6	3.38	1	−3.8	0.326	3.2	Van Biesbroeck (1920)	E
1915.09	29.5	2.2	1	4.3	−0.946	0.0	Rabe (1923)	A, C

Table 3
(Continued)

Julian Epoch	θ (°)	ρ ($''$)	n	$O-C$ (°)	$O-C$ ($''$)	Weight	Source	Notes
1915.13	26.2	3.02	5	1.1	−0.129	12.5	Olivier (1920)	⋯
1915.64	21.30	3.077	8	−2.8	−0.119	16.6	Heintz (1974)	⋯
1915.860	23.8	3.16	3	0.2	−0.056	12.0	Van Biesbroeck (1927)	E
1916.83	20.9	3.22	3	−0.9	−0.087	4.8	Olivier (1917)	⋯
1917.08	19.1	3.18	1	−2.2	−0.151	7.6	Aitken (1923)	⋯
1917.16	22.6	3.09	2	1.4	−0.248	4.6	Comstock (1921)	⋯
1918.14	20.9	3.17	3	1.5	−0.263	5.7	Comstock (1921)	⋯
1919.09	16.7	3.40	3	−1.1	−0.127	6.0	Leavenworth & Beal (1930)	⋯
1920.008	17.8	3.64	3	1.5	0.022	7.3	Bernewitz (1962)	⋯
1920.132	15.2	3.85	3	−1.0	0.219	13.2	Pavel (1962)	⋯
1921.134	14.9	3.82	5	0.3	0.088	10.1	Bernewitz (1962)	⋯
1921.516	13.8	3.63	3	−0.3	−0.141	12.0	Van Biesbroeck (1927)	⋯
1921.79	11.2	3.54	2	−2.5	−0.259	10.8	Aitken (1923)	⋯
1922.00	15.4	3.29	2	2.0	−0.531	2.1	Abetti (1922)	⋯
1922.02	12.6	3.88	2	−0.8	0.057	1.9	Nechvile (1924)	⋯
1922.988	11.1	4.02	2	−1.0	0.097	5.5	Dick (1962)	⋯
1923.010	12.1	4.13	2	0.1	0.205	12.3	Struve (1962)	⋯
1924.07	8.4	3.82	2	−2.3	−0.216	10.8	Aitken (1927)	⋯
1924.142	10.9	4.62	2	0.3	0.576	5.5	Dick (1962)	⋯
1925.02	12.8	3.35	5	3.3	−0.786	10.1	van den Bos (1925)	⋯
1925.87	7.87	4.200	3	−0.7	−0.025	22.5	Heintz (1974)	⋯
1926.19	8.7	4.26	5	0.5	0.001	26.9	van den Bos (1928)	⋯
1926.65	8.7	4.19	1	1.0	−0.118	13.0	Alden (1936)	⋯
1927.06	7.6	3.89	6	0.4	−0.461	7.9	Rabe (1930)	⋯
1928.07	5.8	4.42	1	−0.4	−0.038	13.3	Alden (1936)	⋯
1928.15	6.3	4.24	1	0.2	−0.226	4.0	van den Bos (1928)	⋯
1928.16	5.6	4.48	1	−0.5	0.013	4.2	van den Bos (1928)	⋯
1928.90	7.6	4.57	3	2.3	0.024	13.3	Voute (1932)	⋯
1929.04	5.1	4.79	1	−0.1	0.230	13.3	Finsen (1929)	⋯
1929.04	5.4	4.52	2	0.2	−0.040	17.0	van den Bos (1929)	⋯
1929.04	5.4	4.54	1	0.2	−0.020	13.3	Finsen (1929)	⋯
1929.56	3.4	4.39	2	−1.3	−0.226	10.8	Aitken (1935a)	⋯
1929.72	5.5	4.67	3	1.0	0.037	13.3	Voute (1932)	⋯
1930.60	5.6	4.28	4	1.9	−0.446	3.7	Wamer (1932)	⋯
1930.82	4.1	4.64	3	0.6	−0.109	4.7	Wallenquist (1934)	⋯
1931.18	3.8	4.20	3	0.6	−0.587	2.0	Baize & Igounet (1932)	⋯
1932.26	1.3	4.83	1	−1.0	−0.071	13.9	Alden (1936)	⋯
1932.70	2.2	4.92	4	0.3	−0.027	15.3	Voute (1932)	⋯
1934.16	0.9	5.37	6	0.2	0.270	9.3	Baize (1935)	⋯
1934.45	1.4	5.36	7	0.9	0.230	10.1	Baize (1942)	⋯
1934.97	359.6	5.45	4	−0.5	0.266	2.8	Inaba (1935)	⋯
1935.04	0.7	5.27	4	0.7	0.079	24.1	van den Bos (1935)	⋯
1935.31	0.34	5.182	10	0.5	−0.037	44.3	Heintz (1974)	⋯
1936.03	0.8	5.06	2	1.5	−0.234	7.6	Rabe (1939)	⋯
1936.85	358.9	5.40	4	0.2	0.022	11.8	Simonov (1951)	⋯
1938.15	359.3	5.35	2	1.5	−0.161	8.0	Rabe (1939)	⋯
1938.76	357.9	5.43	4	0.5	−0.142	15.3	Voute (1947)	⋯
1939.35	357.49	5.627	8	0.4	−0.005	39.2	Heintz (1974)	⋯
1939.93	357.8	5.76	5	1.1	0.070	9.1	Baize (1942)	⋯
1941.26	356.17	5.804	8	0.3	−0.018	39.6	Heintz (1974)	⋯
1942.05	355.9	6.04	4	0.5	0.140	24.1	van den Bos (1948)	⋯
1942.12	357.4	5.59	2	2.0	−0.317	8.4	Rabe (1953)	⋯
1942.76	356.2	5.83	3	1.2	−0.140	10.5	Voute (1955)	⋯
1943.14	354.7	6.18	3	−0.1	0.174	11.3	Rabe (1953)	⋯
1943.88	354.85	6.028	14	0.5	−0.050	52.4	Heintz (1974)	⋯
1945.53	354.4	6.37	5	0.9	0.135	10.1	Baize (1948)	⋯
1948.12	352.58	6.454	10	0.4	−0.022	44.3	Heintz (1974)	⋯
1948.40	351.97	6.479	4	−0.1	−0.022	28.0	Heintz (1974)	⋯
1949.00	352.4	6.74	2	0.6	0.185	17.0	van den Bos (1951)	⋯
1950.71	350.83	6.690	6	−0.2	−0.018	34.3	Heintz (1974)	⋯
1951.733	350.65	6.809	1	0.1	0.012	14.0	The (1970)	⋯
1951.812	350.70	6.823	1	0.2	0.019	14.0	The (1970)	⋯
1951.829	350.61	6.832	1	0.1	0.027	14.0	The (1970)	⋯

Table 3
(Continued)

Julian Epoch	θ (°)	ρ (″)	n	$O - C$ (°)	$O - C$ (″)	Weight	Source	Notes
1951.886	350.84	6.847	1	0.4	0.037	14.0	The (1970)	…
1952.89	350.37	6.911	10	0.3	0.015	44.3	Heintz (1974)	…
1953.99	350.4	6.99	3	0.8	0.002	20.8	van den Bos (1956)	…
1955.13	349.5	7.37	4	0.4	0.287	18.7	Worley (1956)	…
1955.18	348.67	7.077	4	−0.4	−0.010	28.0	Heintz (1974)	…
1955.84	348.5	7.43	4	−0.3	0.290	18.9	Worley (1957)	…
1956.855	347.90	7.124	1	−0.5	−0.097	14.0	The (1970)	…
1957.73	348.8	7.25	3	0.7	−0.040	20.8	van den Bos (1959)	…
1957.748	348.10	7.315	1	0.0	0.024	14.0	The (1970)	…
1957.88	347.8	7.74	4	−0.2	0.439	20.0	Worley (1960)	…
1957.890	347.62	7.286	1	−0.4	−0.016	14.0	The (1970)	…
1958.07	347.9	7.00	3	−0.1	−0.316	24.8	Couteau (1958)	…
1959.51	347.8	7.68	2	0.4	0.254	17.0	van den Bos (1960)	…
1959.852	347.23	7.460	1	−0.1	0.009	14.0	Kamper (1976)	…
1959.92	347.0	7.58	4	−0.3	0.123	25.3	Worley (1962)	…
1960.62	346.91	7.499	6	−0.1	−0.010	34.3	Heintz (1974)	…
1961.86	347.2	7.56	4	0.6	−0.038	24.1	van den Bos (1962)	…
1963.92	345.73	7.729	4	−0.2	−0.012	28.0	Heintz (1974)	…
1964.710	345.6	7.86	1	−0.0	0.066	12.6	Worley (1971)	E
1965.04	346.0	7.93	3	0.5	0.114	20.8	van den Bos (1966)	…
1965.96	346.8	7.72	2	1.6	−0.156	7.9	Newburg (1967)	…
1968.01	343.8	8.00	1	−0.8	−0.004	9.4	Knipe (1969)	…
1969.883	343.89	8.116	1	−0.1	0.002	14.0	Kamper (1976)	E
1969.97	343.70	8.117	8	−0.3	−0.002	39.6	Heintz (1974)	…
1970.006	343.89	8.120	1	−0.1	−0.001	14.0	Kamper (1976)	E
1970.733	343.79	8.174	1	0.1	0.012	14.0	Josties et al. (1974)	E
1970.763	343.57	8.170	1	−0.1	0.006	14.0	Josties et al. (1974)	E
1970.93	343.46	8.198	9	−0.2	0.025	42.0	Heintz (1974)	…
1971.047	343.92	8.195	1	0.3	0.015	14.0	Josties et al. (1974)	E
1972.00	342.97	8.238	6	−0.4	0.007	34.3	Heintz (1974)	…
1972.97	342.78	8.288	6	−0.3	0.006	34.3	Heintz (1974)	…
1973.84	342.48	8.300	3	−0.3	−0.026	24.2	Heintz (1974)	…
1974.809	342.5	8.41	1	−0.0	0.037	14.0	van Albada-van Dien (1983)	E
1975.862	342.25	8.438	1	0.0	0.016	14.0	Josties et al. (1978)	E, G
1975.892	341.97	8.463	1	−0.2	0.039	14.0	Josties et al. (1978)	E
1975.927	342.01	8.456	1	−0.2	0.031	14.0	Josties et al. (1978)	E, G
1976.047	342.22	8.460	1	0.1	0.029	14.0	Josties et al. (1978)	E, G
1977.919	340.3	9.71	1	−1.4	1.198	0.0	Holden (1978)	A, E
1982.661	339.9	8.97	2	−0.5	0.284	9.7	Argyle (1983)	E
1988.101	340.0	8.10	1	1.1	−0.725	7.2	Popovic (1989)	E
1988.23	341.2	8.93	4	2.3	0.103	3.7	Sturdy (1992)	…
1994.128	337.5	8.92	1	0.1	0.022	20.0	Abad & Della Prugna (1995)	E, H
1995.024	336.82	8.89	5	−0.4	−0.011	44.7	Abad et al. (1998)	E
2006.922	333.72	8.781	1	−0.4	0.039	18.4	Heinze et al. (2010)	E
2009.036	332.3	8.53	1	−1.3	−0.142	18.4	Mason et al. (2011a)	…
2010.720	332.8	8.68	2	−0.3	0.074	28.3	Mason et al. (2011b)	…
2011.883	332.23	8.05	1	−0.6	−0.506	5.0	Fay (2013)	E, I
2011.9903	330.5	8.16	1	−2.3	−0.391	5.0	Micello (2012)	E, I
2016.129	330.41	8.332	1	−1.2	−0.003	20.0	Locatelli (2017)	E

Note. A: Measure given zero weight in final orbit solution due to excessive residuals. B: Measure by J. Gledhill cited by Lewis. C: Measure uncertain or estimated by observer. D: Number of nights varies 50% or more between angle and separation measures. In this case, $N = \frac{N_\theta}{N_\rho}$, rounding down. E: Original data published at the Besselian Epoch converted to the Julian Epoch as described in the text. F: Identification error in publication corrected. G: Mean of multiple measures on the same photographic plate. H: Quadrant flipped 180° from published value. I: Measure given reduced weight in final orbit solution due to large residuals.

(This table is available in machine-readable form.)

Figure 1 illustrates the new orbital solution, plotted together with all published data in the WDS database as well as the heretofore unpublished data in Table 2. In this figure, micrometric observations are indicated by plus signs, photographic measures by asterisks, adaptive optics by filled circles, CCD measures by triangles, and the five new measures from Table 2 as stars. "$O - C$" lines connect each measure to its predicted position along the new orbit (shown as a thick solid line). Dashed "$O - C$" lines indicate measures given zero weight in the final solution. A dot-dash line indicates the line of nodes, and a curved arrow in the

Table 4
Orbital Elements of 40 Eri BC

Element	New Orbit	Heintz (1974)	Wielen (1962)	van den Bos (1926)	Gore (1886)
Period; P (yrs)	230.30 ± 0.68	252.1	251.988 ± 5.824	247.92 ± 9.7	139.0
Semimajor axis; a ($''$)	6.930 ± 0.050	6.943	7.0453 ± 0.0925	6.8945	5.99
Inclination; i (°)	107.56 ± 0.29	108.9	108.540 ± 0.375	71.55	76.3
Longitude of Node; Ω (°)	151.44 ± 0.12	150.9	150.958 ± 0.426	150.96	146.3
Epoch (2000) of Periastron; T_o (yrs)	1847.7 ± 1.1	1849.6	1848.872 ± 0.876	1848.93 ± 0.93	1863.88
Eccentricity; e	0.4294 ± 0.0027	0.410	0.4147 ± 0.0100	0.4024 ± 0.020	0.136
Longitude of Periastron; ω (°)	318.4 ± 1.1	327.8	326.497 ± 1.765	326.96	354.4
					…
Parallax (mas, van Leeuwen (2007))	200.62 ± 0.23	…	…	…	…
Fractional Mass ($f = \frac{C}{B+C}$, Heintz (1974))	0.262 ± 0.01	…	…	…	…
White Dwarf Mass ($\mathcal{M}_\odot$)	0.573 ± 0.018	0.43 ± 0.02	$\Sigma\mathcal{M}$ = 0.678 ± 0.055	0.44 ± 0.11	$\Sigma\mathcal{M}$ = 1.003
Red Dwarf Mass ($\mathcal{M}_\odot$)	0.2036 ± 0.0064	0.16 ± 0.01	…	0.20 ± 0.05	…

lower right corner indicates the direction of orbital motion. The scale, in arcseconds, is given on the left and bottom axis. Finally, the orbit of Heintz (1974) is shown as a dashed ellipse.

Table 5 gives the ephemerides for the orbit over the years 2018 through 2027, in annual increments.

While the orbit has only completed 71% of a full cycle, the orbit is quite well characterized. The criteria of Aitken (1935b, p. 110):

> "... it is not worth while to compute the orbit of a double star until the observed arc not only exceeds 180 degrees, but also defines both ends of the apparent ellipse ..."

having been met. The orbit of Heintz (1974) lists no errors on the orbital elements, which is reflected in his very low mass errors. That orbit was premature and appeared 22 years prior to reaching the northern limit of the orbit; this appears to be the primary reason for the incongruous mass solutions for these two stars. In addition to both ends of the apparent ellipse now being well characterized, a more accurate and precise parallax (200.62 ± 0.23 mas, van Leeuwen 2007) has been determined and the number of measures has increased by 14%. Note that the parallax is for the primary of the physical multiple. If we assume the AB mean motion of $0\overset{\circ}{.}026\ \mathrm{yr}^{-1}$ is representative, then the parallax difference for BC would be quite close to this value and within 0.066%. While SIMBAD lists 198.24 mas for B (Holberg et al. 2002) this corresponds to the original *Hipparcos* solution (ESA 1997) for A. We use the re-reduction of the *Hipparcos* value. The orbit has very small errors of 0.7% in the semimajor axis (a'') and 0.3% in the period (P), yielding an error of 3.1% in the mass sum. The mass sum, $\mathcal{M}_{A+B}$ is 0.777 ± 0.024 $\mathcal{M}_\odot$. Using the mass ratio from Heintz (1974) gives individual masses of 0.573 ± 0.018 $\mathcal{M}_\odot$ for the white dwarf and 0.2036 ± 0.0064 $\mathcal{M}_\odot$ for the M dwarf companion.

The newly determined mass for the M dwarf companion falls within the 1σ error of its value in Henry et al. (1999) of 0.177 ± 0.029 $\mathcal{M}_\odot$. The mass error here is comparable to the other mass errors of Table 11 of Benedict et al. (2016). The mass is less than that of GJ 791.2, also classified as M4.5V, determined in Benedict et al. (see their Tables 2 and 10).

If the solution presented in Table 4 is representative of the true motion and we were to wait two more observing seasons and observe the pair monthly, when accessible, the resulting errors would improve less than a tenth of a percent in P, a'' or $\mathcal{M}_{A+B}$.

Table 5
Ephemerides of 40 Eri BC

Epoch	θ (deg)	ρ (arcsec)
2018.0	331.0	8.225
2019.0	330.7	8.158
2020.0	330.4	8.088
2021.0	330.0	8.014
2022.0	329.7	7.936
2023.0	329.4	7.855
2024.0	329.1	7.771
2025.0	328.7	7.682
2026.0	328.4	7.590
2027.0	328.0	7.494

The most significant improvements could occur with data obtained as it approaches the next periastron passage (predicted for 2078.0) or when the system has been observed for a complete revolution (predicted for 2081.5). Due to the geometry of the system, the closest approach of $1\overset{''}{.}32$ is predicted to occur more than a decade before periastron: 2066.3.

With the post-AGB mass loss of the B component of the system, the orbital elements must have gone through significant evolution. Zhao et al. (2011) determine ages of A and C through analysis of chromospheric activity of $5.0^{6.1}_{4.0}$ Gyr and an age of $4.9^{6.0}_{3.9}$ Gyr for B based on the evolutionary lifetime of the progenitor plus cooling time. Sousa et al. (2008) determine metallicity of A as −0.31 ± 0.03. These two accurate and precise results coupled with the very accurate and precise masses determined here, will help enable study of the complicated interplay between mass, age, and metallicity of all three components in this hierarchical multiple.

In addition to determining a mass for the red dwarf, the value of 0.573 ± 0.018 $\mathcal{M}_\odot$ for the white dwarf is now in agreement with those determined using the gravitational redshift (for example, within 1σ of the result 0.53 ± 0.04 $\mathcal{M}_\odot$ from Koester & Weidemann 1991). While the results match well here, it is unclear if they agree well-enough to make one determination redundant. For example, in the case of Sirius B, the results are slightly discrepant with a dynamical mass of 1.018 ± 0.011 $\mathcal{M}_\odot$ (Bond et al. 2017) and a mass from the gravitational redshift of 0.978 ± 0.005 $\mathcal{M}_\odot$ (Barstow et al. 2005).

Now that the mass from the orbit matches that from the gravitational redshift, this source of consternation has gone away and it is not necessary to invoke other more exotic solutions to the problem. Patience is a virtue.

Howard Bond who suggested examining the object and publishing the orbit now rather than waiting on more data is gratefully thanked. The best is the enemy of the good. The referee is heartily thanked for many helpful suggestions. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. This research has also made use of the SIMBAD database, operated at CDS, Strasbourg, France and NASA's Astrophysics Data System. Thanks are extended to Brian Luzum and the U.S. Naval Observatory for their continued support of the Double Star Program. Howard Bond is also thanked for finding and reducing data from the HST archive.

References

Abad, C., & Della Prugna, F. 1995, A&AS, 111, 229
Abad, C., Docobo, J., & Della Prugna, F. 1998, A&AS, 133, 71
Abetti, G. 1922, MmArc, 39, 3
Adams, W. S. 1914, PASP, 26, 198
Aitken, R. G. 1914, PLicO, 12, 1
Aitken, R. G. 1923, LicOB, 11, 58
Aitken, R. G. 1927, LicOB, 12, 173
Aitken, R. G. 1935a, LicOB, 17, 91
Aitken, R. G. 1935b, The Binary Stars (2nd ed.; New York: McGraw-Hill)
Alden, H. L. 1936, AJ, 45, 73
Alonso-Floriano, F. J., Morales, J. C., Caballero, J. A., et al. 2015, A&A, 577, 128
Argyle, R. W. 1983, A&AS, 53, 177
Baize, P. 1935, JO, 18, 148
Baize, P. 1942, JO, 25, 28
Baize, P. 1948, JO, 31, 99
Baize, P., & Igounet, Mme. 1932, JO, 15, 96
Barstow, M. A., Bond, H. E., Holberg, J. B., et al. 2005, MNRAS, 362, 1134
Benedict, G. F., Henry, T. J., Franz, O. G., et al. 2016, AJ, 152, 141
Bernewitz, E. 1962, Pub. Berlin Babelsberg Obs., 14, 1
Bond, H. E., Schaefer, G. H., Gilliland, R. L., et al. 2017, ApJ, 840, 70
Burnham, S. W. 1879, MmRAS, 44, 141
Burnham, S. W. 1883, MmRAS, 47, 167
Burnham, S. W. 1887, PLicO, 1, 24
Burnham, S. W. 1894, PLicO, 2, 3
Burnham, S. W. 1906, A General Catalogue of Double Stars Within 120° of the North Pole (Washington, DC: Carnegie Institution of Washington)
Burnham, S. W. 1913, Measures of Proper Motion Stars Made with the 40-inch Refractor of the Yerkes Observatory in the Years 1907 to 1912 (Washington, DC: Carnegie Institution of Washington)
Chaname, J., & Gould, A. 2004, ApJ, 601, 289
Collins, W. H. 1896, AJ, 16, 14
Comas Sola, J. 1900, AN, 154, 149
Comstock, G. C. 1896, Pub. Washburn Obs., 10, 1
Comstock, G. C. 1906, Pub. Washburn Obs., 10, 3
Comstock, G. C. 1921, Pub. Washburn Obs., 10, 4
Couteau, P. 1958, JO, 41, 81
Cutri, R. M., Skrutskie, M. F., van Dyk, S., et al. 2003, yCat, 2246, 0
Dawes, W. R. 1867, MmRAS, 35, 135
Dembowski, H. 1884, Mis. Micrometriche II (Rome: Coi tipi del Salviucci)
Dick, J. 1962, Pub. Berlin Babelsberg Obs., 14, 1
Doberck, W. 1896, AN, 141, 289
Doberck, W. 1902, AN, 159, 85
Doolittle, E. 1905, Pub. Univ. Penn., 2, 3
Ducati, J. R. 2002, yCat, 2237, 0
ESA 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200) (Noordwijk: ESA)
Fay, M. 2013, OED, 10, 38
Finsen, W. S. 1929, CiUO, 80, 59
Finsen, W. S. 1934, CiUO, 4, 23
Finsen, W. S. 1938, CiUO, 4, 466
Finsen, W. S., & Worley, C. E. 1970, ROCi, 7, 203
Flammarion, C. 1878, Catalogue des Etoiles Doubles (Paris: Gauthier-Villars)
Gianninas, A., Bergeron, P., & Ruiz, M. T. 2011, ApJ, 743, 138
Gore, J. E. 1886, MNRAS, 46, 291
Gray, R. O., Corbally, C. J., Garrison, R. F., et al. 2006, AJ, 132, 161
Hall, A. 1877, Washington Observations, Appendix 6
Hall, A. 1892, Washington Observations for 1888, Appendix 1
Hartkopf, W. I., Mason, B. D., Finch, C. T., et al. 2013, AJ, 146, 76
Hartkopf, W. I., Mason, B. D., & Worley, C. E. 2001, AJ, 122, 3472
Hartkopf, W. I., McAlister, H. A., & Franz, O. G. 1989, AJ, 98, 1014
Heintz, W. D. 1974, AJ, 79, 819
Heinze, A. N., Hinz, P. M., Sivanandam, S., et al. 2010, ApJ, 714, 1551
Henry, T. J., Franz, O. G., Wasserman, L. H., et al. 1999, ApJ, 512, 864
Herschel, W. 1785, Phil. Trans. R. Soc., 75, 40
Holberg, J. B., Oswalt, T. D., & Barstow, M. A. 2012, AJ, 143, 68
Holberg, J. B., Oswalt, T. D., & Sion, E. M. 2002, ApJ, 571, 512
Holden, F. 1978, PASP, 90, 463
Hough, G. W. 1894, AN, 135, 281
Howe, H. A. 1878, PCinO, 4, 1
Howe, H. A. 1879, PCinO, 5, 1
IAU 1977, in Proc. Sixteenth General Assembly, Trans. IAU, XVIB, ed. E. Müller & A. Jappel (Dordrecht: Reidel), 1976
Inaba, M. 1935, BuKwa, 3, 297
Josties, F. J., Dahn, C. C., Kallarakal, V. V., Miranian, M., & Douglass, G. G. 1974, PUSNO, 22, 6
Josties, F. J., Kallarakal, V. V., Douglass, G. G., & Christy, J. W. 1978, PUSNO, 24, 5
Kamper, K. W. 1976, PASP, 88, 444
Kidder, K. M., Holberg, J. B., & Mason, P. A. 1991, AJ, 101, 579
Knipe, G. F. G. 1969, ROCi, 128, 177
Koester, D., Schulz, H., & Weidemann, V. 1979, A&A, 76, 262
Koester, D., & Weidemann, V. 1991, AJ, 102, 1162
Kuiper, G. P. 1950, JO, 33, 1
Leavenworth, F. P., & Beal, W. O. 1930, Measures of Double Stars (Minneapolis, MN: Univ. Minnesota Press)
Leavenworth, F. P., & Muller, F. 1915, PMcCO, 1, 45
Lewis, T. 1906, MmRAS, 56, 1
Locatelli, G. 2017, Il Bollettino Delle Stelle Doppie, 20, 19
Lohse, O. 1908, Pub. Obs. Potsdam, 20, 58
Mason, B. D., Hartkopf, W. I., & Wycoff, G. L. 2011a, AJ, 141, 157
Mason, B. D., Hartkopf, W. I., & Wycoff, G. L. 2011b, AJ, 142, 46
Mason, B. D., Wycoff, G. L., Hartkopf, W. I., Douglass, G. G., & Worley, C. E. 2001, AJ, 122, 3466
Micello, G. 2012, JDSO, 8, 193
Miles, K. N., & Mason, B. D. 2017, IAUC, 26, 191
Nechvile, V. 1924, JO, 7, 69
Newburg, J. L. 1967, ROCi, 126, 135
Olivier, C. P. 1917, AJ, 30, 157
Olivier, C. P. 1920, PMcCO, 3, 679
Pavel, F. 1962, Pub. Berlin Babelsberg Obs., 14, 1
Pettit, E. 1958, AJ, 63, 324
Plummer, W. E. 1878, Oxford Astron. Obs., 1, 17
Popovic, G. M. 1989, BOBeo, 140, 83
Provencal, J. L., Shipman, H. L., Høg, E., & Thejll, P. 1998, ApJ, 494, 759
Rabe, W. 1923, AN, 217, 413
Rabe, W. 1930, AN, 239, 369
Rabe, W. 1939, PMunO, 2, 1
Rabe, W. E. 1953, AN, 12, 3
Rakos, K. D., Albrecht, R., Jenkner, H., et al. 1982, A&AS, 47, 221
Reid, I. N. 1996, AJ, 111, 2000
Russell, H. N. 1914, PA, 22, 275
Salim, S., & Gould, A. 2003, ApJ, 582, 1011
Schembor, F. 1939, AN, 268, 257
Schiaparelli, G. 1909, Pub. Brera Milan, 46, 1
Simonov, G. V. 1951, AnBos, 9, 1
Sousa, S. G., Santos, N. C., Mayor, M., et al. 2008, A&A, 387, 373
Stone, O. 1878, PCinO, 4, 1
Stone, O. 1882, PCinO, 6, 1
Struve, F. G. W. 1837, Mensurae Micrometricae Petropoli (Tartu: Academiae scientiarum caesareae petropolitaneifique)
Struve, G. 1962, Pub. Berlin Babelsberg Obs., 14, 1
Struve, O. 1878, Pulkova Observatory Observations, 9, 1
Struve, O. 1893, Pulkova Observatory Observations, 10

Sturdy, K. 1992, Webb Soc., Double Star Circ., 5, 1
Tarrant, K. J. 1889, AN, 121, 273
Tarrant, K. J. 1890, AN, 125, 225
The, P. S. 1970, A&AS, 1, 357
van Albada-van Dien, E. 1983, A&AS, 52, 193
Van Biesbroeck, G. 1920, Ann.R. Obs. Belgium, 14
Van Biesbroeck, G. 1927, Pub. Yerkes Obs., 5, 1
Van Biesbroeck, G. 1974, ApJS, 28, 413
van den Bos, W. H. 1925, Ann. Leiden Obs., 14, C1
van den Bos, W. H. 1926, Bill. Astron. Inst. Neth., 3, 128
van den Bos, W. H. 1928, Ann. Leiden Obs., 14, 4
van den Bos, W. H. 1929, CiUO, 80, 59
van den Bos, W. H. 1935, CiUO, 94, 149
van den Bos, W. H. 1948, CiUO, 107, 259
van den Bos, W. H. 1951, CiUO, 111, 13
van den Bos, W. H. 1956, CiUO, 115, 266
van den Bos, W. H. 1959, ApJS, 4, 45
van den Bos, W. H. 1960, CiUO, 119, 321
van den Bos, W. H. 1962, AJ, 67, 555
van den Bos, W. H. 1966, ROCi, 125, 93
van Leeuwen, F. 2007, A&A, 474, 653
Vanderdonck, J. 1912, Journal Astronomique, 1, 134
Voute, J. G. 1932, AnBos, 6, A1
Voute, J. G. 1947, AnBos, 6, D1
Voute, J. G. 1955, JO, 38, 109
Wallenquist, A. 1934, AnBos, 6, B1
Wamer, W. P. 1932, Pub. Univ. Penn., 5, 1
Wegner, G. 1979, AJ, 84, 650
Wegner, G. 1980, AJ, 85, 1255
Wielen, R. 1962, AJ, 67, 599
Wieth-Knudsen, N. 1957, JO, 40, 93
Winnecke, A. 1869, AN, 73, 145
Wirtz, C. 1912, AnOSt, 4, 2
Worley, C. E. 1956, AJ, 61, 162
Worley, C. E. 1957, AJ, 62, 153
Worley, C. E. 1960, AJ, 65, 156
Worley, C. E. 1962, AJ, 67, 403
Worley, C. E. 1971, PUSNO, 22, 2
Worley, C. E., & Heintz, W. D. 1983, PUSNO, 24, 7
Wycoff, G. L., Mason, B. D., & Urban, S. E. 2006, AJ, 132, 50
Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, AJ, 145, 44
Zacharias, N., Urban, S. E., Zacharias, M. I., et al. 2003, yCat, 1289, 0
Zhao, j. K., Oswalt, T. D., Rudkin, M., Zhao, G., & Chen, Y. Q. 2011, AJ, 141, 107