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Binary Star Orbits. V.
The Nearby White Dwarf - Red Dwarf pair 40 Eri BC

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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 230.09±0.68y. It is predicted to close slowly over the next half-century getting as close as 1.″32 in early 2066. We determine masses of 0.575±0.018 $\mathcal{M}_\odot$ for the white dwarf and 0.2041±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.

Subject headings: binaries: general — binaries: visual — binaries: orbits — techniques: interferometry — stars:individual (40 Eri BC)

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 gives the value for A, B and C, respectively, while Column 5 gives the reference(s). 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 F.G.W. Struve's (1837) catalog of double stars. Due to the immensity of this catalog and it's logical structure the star number in this catalog is taken as it's "discovery designation" despite being measured first by William Herschel (1785) almost 50 years earlier. The first accurate observation would wait another 14 years

[1]SEAP Intern.

(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 ($\rho \sim 83\farcs7$).

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 Catalogue 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 2^{nd} Catalogue (Finsen 1938). By the time of the 3^{rd} Catalogue (Finsen & Worley 1970), the preferred orbit was Orbit III of Wielen (1962), and this was updated again for the 4^{th} Catalog (Worley & Heintz 1983), where the preferred orbit was that of Heintz (1974). It remained so in the 5^{th} 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,b) 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 Mason & Hartkopf

(2017). The mean positions from these observation are presented in Table 2. In that table, Columns 1, 2, 3, 4 and 5 provides 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 §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 $0''.0039$ for the separation (ρ). The errors presented for position angle and separation presented in Table 2 are the internightly errors[1].

The pair will be observable again in mid-September, but as described in §3 below the accumulation of additional data will only make minute incremental improvement until, probably, the second half of the 21^{st} 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[2]. 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.

2.2. Measures from the WDS

Measures used in the orbit solution (§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. 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 & 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

[1]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.

[2]2003 all-sky release. See `Vizier On-line Data Catalog: II/246`.

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 Julian epoch, using the IAU approved conversion,

$$JY = (BY \times 0.999978641) + 0.041439661. \quad (1)$$

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 which 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 which are measures of magnitude difference only (Pettit 1958, Kuiper 1950, Wieth-Knudsen 1957, Rakos et al. 1982).

Others 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 not included 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)[3]. 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.

[3]This is, presumeably, Orbit III, as this was the preferred orbit in the 3^{rd} Catalogue (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 & 3.

Table 4 lists the seven Campbell elements: P (period, in years), a (semi-major 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.

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 four 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 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):

> ... 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 ...

have 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 0.026 °/yr 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 this 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 0.776±0.024 $\mathcal{M}_{\odot}$. Using the mass ratio from Heintz (1974) gives individual masses of 0.575±0.018 $\mathcal{M}_{\odot}$ for the white dwarf and 0.2041±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 Tables 2 & 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 $\mathcal{M}_{A+B}$. The most significant improvements could occur with data obtained as it approaches the next periastron passage (predicted for 2077.7) or when the system has been observed for a complete revolution (predicted for 2081.2). Due to the geometry of the system, the closest approach of 1.″32 is predicted to occur more than a decade before periastron : 2066.2.

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 $0.575 \pm 0.018\ \mathcal{M}_\odot$ for the white dwarf is now in agreement with those determined using the gravitational redshift (for example, within 1σ of the result $0.53 \pm 0.04\ \mathcal{M}_\odot$ 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 $1.018 \pm 0.011\ \mathcal{M}_\odot$(Bond et al. 2017) and a mass from the gravitational redshift of $0.978 \pm 0.005\ \mathcal{M}_\odot$(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.

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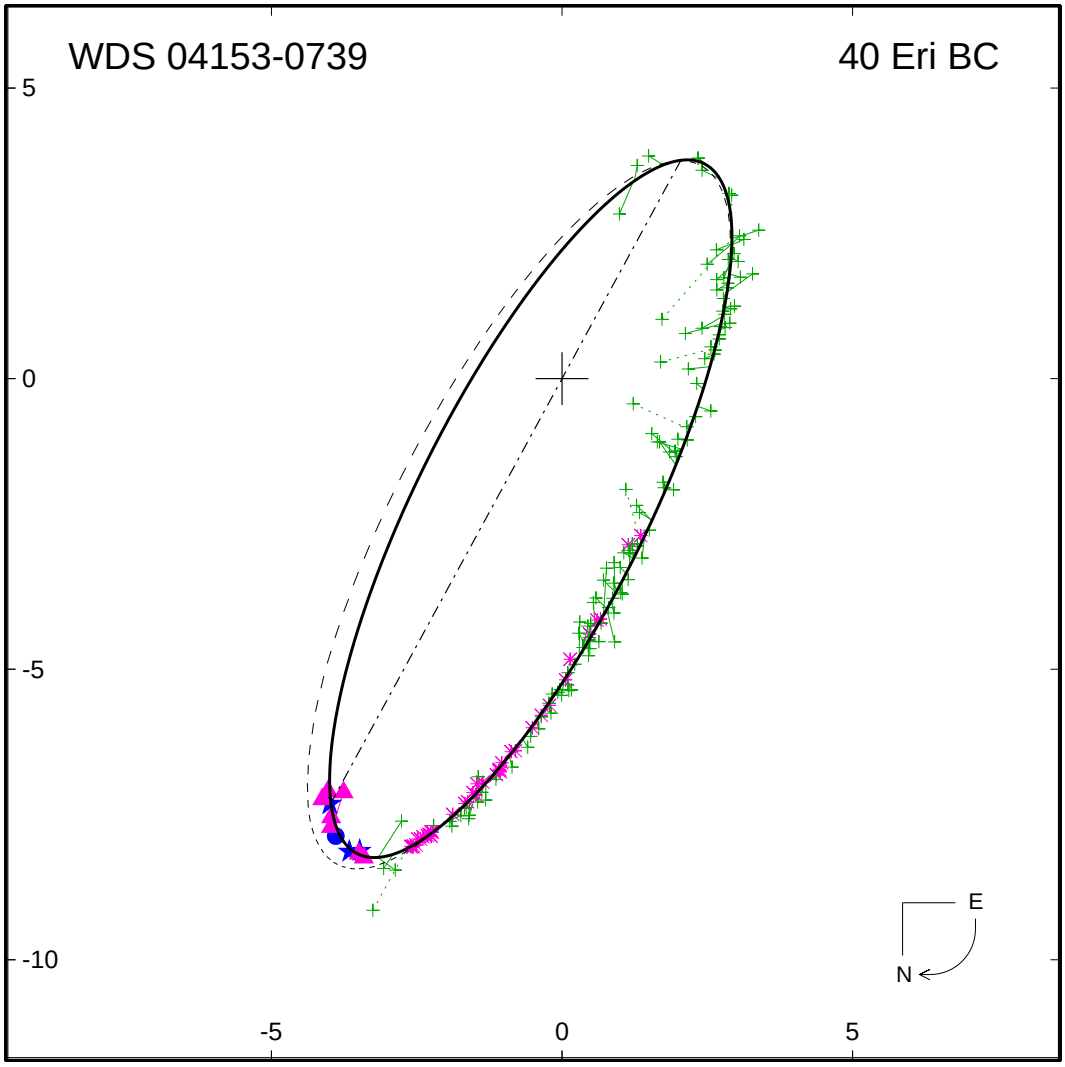

Fig. 1.— New orbit of 40 Eri BC as described in the text. The solid curve is the solution presented in Table 4. The dashed curve is the orbit of Heintz (1974). The zero-weighted and aberrant measures of Schembor (1939), Van Biesbroeck (1974), and Chaname & Gould (2004) are not plotted for cosmetic reasons.

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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			van Leeuwen 2007
		−2228.3 mas/yr		Zacharias et al. 2003
			−2239 mas/yr	Salim & Gould 2003
μ_δ	−3420.27 mas/yr			van Leeuwen 2007
		−3377.1 mas/yr		Zacharias et al. 2003
			−3419 mas/yr	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

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[1]
1999.97	335.8	0.1	8.924	0.011	4	−0.1	0.042	40.0	UCAC4[2]
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

1 : Cutri et al. (2003), All-sky Release. See `Vizier On-line Data Catalog: II/246`.

2 : Zacharias et al. 2013

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	

Table 3—Continued

Julian Epoch	θ (∘)	ρ (″)	n	O−C (∘)	O−C (″)	Weight	Source	Notes
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	

Table 3—Continued

Julian Epoch	θ (∘)	ρ (″)	n	O−C (∘)	O−C (″)	Weight	Source	Notes
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
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 1926	
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	

Table 3—Continued

Julian Epoch	θ (∘)	ρ (″)	n	O−C (∘)	O−C (″)	Weight	Source	Notes
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 1930	
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	

Table 3—Continued

Julian Epoch	θ (∘)	ρ (″)	n	O−C (∘)	O−C (″)	Weight	Source	Notes
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	
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

Table 3—Continued

Julian Epoch	θ (∘)	ρ (″)	n	O−C (∘)	O−C (″)	Weight	Source	Notes
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

Table 3—Continued

Julian Epoch	θ (°)	ρ (″)	n	O−C (°)	O−C (″)	Weight	Source	Notes
2016.129	330.41	8.332	1	−1.2	−0.003	20.0	Locatelli 2017	E

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.

Table 4. Orbital Elements of 40 Eri BC

Element	New Orbit	Heintz (1974)	Wielen (1962)	van den Bos (1926)	Gore (1886)
Period; P (yrs)	230.09 ±0.68	252.1	251.988 ±5.824	247.92 ±9.7	139.0
Semi-major axis; a (″)	6.931 ±0.050	6.943	7.0453±0.0925	6.8945	5.99
Inclination; i (°)	107.53 ±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)	1847.6 ±1.1	1849.6	1848.872 ±0.876	1848.93 ±0.93	1863.88
Eccentricity; e	0.4300±0.0027	0.410	0.4147±0.0100	0.4024±0.020	0.136
Longitude of Periastron; ω (°)	318.2 ±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 ($\mathcal{M}_\odot$)	0.575 ±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 ($\mathcal{M}_\odot$)	0.2041±0.0064	0.16±0.01		0.20 ±0.05	

Table 5. Ephemerides of 40 Eri BC

Epoch	θ (deg)	ρ (arcsec)
2018.0	331.0	8.219
2019.0	330.7	8.151
2020.0	330.4	8.081
2021.0	330.0	8.007
2022.0	329.7	7.929
2023.0	329.4	7.847
2024.0	329.1	7.762
2025.0	328.7	7.674
2026.0	328.4	7.581
2027.0	328.0	7.484