The Southern Double Stars of James Dunlop IV: Rectilinear and Orbital Motion of Some Very Slow Moving Doubles

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Abstract: We present rectilinear and orbital elements and their plots of some very slow moving doubles from the first published dedicated catalogue of southern double stars. Of the 12 Dunlop doubles analysed, DUN 4*, 42*, 138*, 251 probably are not binaries; DUN 38*, 52*, 111*, 116*, 168, 230, 246 have uncertain but possible binarity; and only DUN 5* is a confirmed binary. The orbital parameters for DUN 52*, 230 and 246 we consider to be grade 5. Of those grade 5 orbits, curvature was detected in the historical data for DUN 230, with a probability of binarity of ~50.5%.

1. Introduction

This paper (Dunlop Paper IV) concludes a series of papers on the double stars of James Dunlop, one of three astronomers who worked at the privately owned observatory in Parramatta, NSW Australia in the 1820's. The Parramatta Observatory was the venture of Sir Thomas Makdougll Brisbane (1773-1860) the 6th British Governor of the Colony of NSW from 1822 to 1825.

In Dunlop Paper I (Letchford, White and Ernest, IN PRINT) we presented a history and description of the first published dedicated catalogue of southern double stars, by James Dunlop (1793-1848) and issued in 1829 as Approximate Places of Double Stars in the Southern Hemisphere, observed at Paramatta in New South Wales (Dunlop 1829). In Dunlop Paper II (Letchford, White and Ernest, IN PRINT) we presented modern designations of the pairs in Dunlop's original catalogue. In Dunlop Paper III (Letchford, White and Ernest, IN PRINT) we gave a detailed analysis of the original catalogue, comparing Dunlop's measurement accuracy with modern precessed data, as well as presenting modern data on each double star.

The Dunlop papers follow three papers (Rümker Papers I, II, and III) previously published in this journal on the double star work of another of the Parramatta astronomers, Carl Rümker (Letchford, White, and Ernest 2017; Letchford, White, and Ernest 2018a; Letchford, White, and Ernest 2018b).

Using the methods detailed in Rümker Papers II and III, in this paper we calculate and compare the rectilinear and orbital elements of 12 wide southern binaries first discovered by James Dunlop in the 1820s. Such a comparison will enable the probability of their binarity to be quantified directly by comparing their relative motions as if they were optical doubles (rectilinear) and then as physical binaries (orbital).

Distinguishing between optical and physical doubles is one of the fundamental aims of double star study because it has important implications for stellar formation models (Guinan, Harmanec, and Hartkopf 2007). There has been renewed interest in wide binary systems (of which the Dunlop pairs may be considered a subset) because of their potential to distinguish between the mainstream-accepted WIMP-based hypothesis of dark matter, and Modified Newtonian Dynamics (Longhitano, Binggeli, and Zejda 2010; Németh et al. 2016; Chanamé and Gould 2004). Relatively slow moving doubles may be either chance alignments of unrelated stars or very long period bound pairs. A comparison of the best-fit rectilinear motion and curved orbital motion should result in a clear distinction between these two types, since it is the variations from linearity that allows a sensitive identification of a Keplerian system.

2. Method for finding Rectilinear Elements

White, Letchford, and Ernest (2018) have shown that the precision of historic ground observations of double stars has improved with time; from ~0.6 arcsec to 0.14 arcsec in ρ (separation), and 0.74 degree to 0.5 degree in PA, over our period of interest (~1820 to the present). These uncertainties are dwarfed by the precisions of the HIPPARCOS and GAIA spacecraft (milli-arcsecond and micro-arcsecond respectively), and the inclusion of historic ground data in the rectilinear analysis presented here would not contribute to the accuracy of that analysis.

To find non-subjective rectilinear elements, we follow the method detailed in our paper Letchford, White, and Ernest (2018a), except that we used the second data release from the GAIA spacecraft (GAIA DR2) instead of the first data release (GAIA DR1).

3. Rectilinear Results

Rectilinear elements are given in Table 1; associated plots are in the Appendix. An ephemeris, based on these elements is given in Table 3.

4. Method for finding Orbital Elements

To find non-subjective orbital elements, the probability of binarity, and the detection of curvature in the historical data, we follow the methods detailed in our paper, Rümker Paper III (Letchford, White, and Ernest, 2018b), except for the following improvements:

We used GAIA DR2 data instead of GAIA DR1.

We obtained better estimates of masses using the luminosity (L) data from GAIA DR2 (instead of estimates from spectral types) and employing the following

Table 1: Rectilinear Elements and their uncertainties, all ICRS (Equinox effectively = J2000.0)

DUN	x0 (DE) " +/-	xa (DE) "/yr +/-	y0 (RA) " +/-	ya (DE) "/yr +/-	t0 yr +/-	θ0 ° +/-	ρ0 " +/-
4*	2.865	0.001	1.936	-0.002	6990.235	34.048	3.458
	1.578	0.000	0.945	0.000	1882.256	19.559	1.411
5*	-10.723	-0.014	-3.319	0.045	1971.528	197.199	11.225
	0.010	0.000	0.006	0.000	15.192	0.033	0.010
38*	4.421	-0.008	10.661	0.003	-157.102	67.478	11.541
	1.695	0.001	1.611	0.001	231.210	8.356	1.623
42*	9.324	-0.003	-2.483	-0.011	1049.013	345.090	9.649
	0.329	0.000	0.265	0.000	84.445	1.602	0.325
52*	0.837	-0.011	8.261	0.001	1509.641	84.218	8.303
	0.069	0.000	0.067	0.000	50.434	0.475	0.067
111*	0.285	-0.005	-0.579	-0.002	165.241	296.242	0.645
	0.188	0.000	0.180	0.000	40.084	16.576	0.182
116*	-5.951	-0.001	-1.114	0.007	4348.536	190.600	6.054
	0.927	0.000	1.225	0.001	685.732	11.510	0.939
138*	-4.668	-0.002	-6.004	0.001	-831.590	232.134	7.605
	0.566	0.000	0.744	0.000	393.019	4.812	0.682
168	-4.716	0.000	0.956	0.002	3495.603	168.542	4.812
	0.145	0.000	0.139	0.000	396.499	1.653	0.145
230	-6.926	-0.002	3.205	-0.004	3509.310	155.167	7.632
	0.226	0.000	0.250	0.000	348.436	1.848	0.231
246	2.907	-0.006	-5.916	-0.003	1068.301	296.171	6.592
	0.146	0.000	0.097	0.000	76.607	1.199	0.109
251*	2.158	0.003	-2.210	0.003	2522.161	314.321	3.089
	0.069	0.000	0.054	0.000	163.319	1.158	0.062

mass-luminosity relationship (Duric 2004):

$$M_{star} = \begin{cases} \left(\frac{L_{star}}{0.23}\right)^{1/2.3} \\ \left(L_{star}\right)^{1/4} \text{ if } M_{star} > 0.43 \\ \left(\frac{L_{star}}{1.4}\right)^{1/3.5} \text{ if } M_{star} > 2 \end{cases}$$

Where the units are solar units. The mass constraint on the orbits was ±10% of the combined masses of the pair calculated as above.

In section 7 we discuss our probability of binarity for each pair. Our method of quantifying this is detailed in Rümker Paper III (Letchford, White, and Ernest, 2018b).

5. Orbital Results

Orbital elements are given in Table 2; associated plots are in the *Appendix*. An ephemeris, based on these elements is given in Table 3.

7. Notes on Each Double

DUN 4* (WDS 01388-5327, DUN 4) Our probability of binarity ~49.8%. A probability <= 50% means that curvature in the historical data was not detected (Letchford, White, and Ernest 2018b). Closing. Separation at 2015.5 ≈ 1.83 pc ≈ 377386 AU. Separation calculated by subtracting the parallax (from GAIA DR2) of each after converting to parsecs. Cannot be binary given our probability and a separation larger than ~1 pc ≈ 206265 AU. Harshaw's (2018) Supplemental Download rates the binary probability as 0.88, and physical relationship as "definitely physical".

DUN 5* (WDS 01398-5612, DUN 5) Our probability of binarity ~99.5%. A probability > 50% means that curvature in the historical data was detected. Widening. Separation at 2015.5 ≈ 0.01 pc ≈ 1081 AU. Binarity confirmed. Harshaw's (2018) Supplemental Download rates the binary probability as 0.00 and physical relationship as "unknown". At the time of writing the orbital elements in the 6th orbit catalogue for DUN 5* were (in the order and units presented in Table 2; no uncertainties recorded): 475.2, 7.826, 140.5, 13.7, 1811.90, 0.513, 18.6, Equinox 2000. DUN 5* has been

Table 2: Orbital Elements and their uncertainties, all ICRS (Equinox effectively = J2000.0)

DUN	P yrs +/-	a " +/-	i ° +/-	Ω ° +/-	T yr +/-	e +/-	ω ° +/-
4*	43597.01	15.92	108.63	98.21	4911.46	0.82	109.66
	5257.54	1.38	0.61	16.29	1779.57	0.01	45.78
5*	501.08	8.59	128.22	15.26	1803.09	0.37	27.13
	322.45	3.48	6.86	5.64	34.22	0.01	55.24
38*	34763.12	76.49	75.27	1.09	-1064.62	0.94	301.90
	52206.44	64.38	9.06	137.64	13585.65	0.45	182.72
42*	165670.81	122.85	111.60	104.37	1991.81	0.87	146.22
	31501.46	20.2	0.301	5.087	21.717	0.1	8.708
52*	44933.72	58.15	78.58	172.73	1929.16	0.28	276.56
	9733.39	8.54	0.59	0.11	355.68	0.06	4.89
111*	192603.07	163.67	91.11	31.42	1503.81	0.98	104.21
	1.11	26.83	0.37	0.92	71.38	0.01	11.90
116*	24679.17	29.50	105.29	84.23	3779.97	0.62	283.00
	16148.66	12.51	1.23	1.67	288.37	0.09	13.93
138*	195827.60	55.08	108.38	4.11	1993.19	0.81	160.43
	60072.53	12.09	0.07	0.02	3.68	0.07	0.07
168	73574.55	15.95	123.13	43.83	1998.33	0.58	218.30
	30197.20	3.48	1.66	12.32	20.67	0.00	14.44
230	55471.40	26.88	60.04	51.52	6199.20	0.67	183.75
	1508.32	0.15	2.27	7.11	448.80	0.12	19.96
246	88826.31	65.77	98.19	27.25	1945.37	0.30	97.07
	0.01	2.23	0.51	0.10	604.64	0.00	2.26
251*	10633.66	8.49	66.90	93.59	2192.45	0.56	215.63
	1709.50	1.00	0.80	0.23	33.10	0.07	4.58

included here to demonstrate the veracity of our brute force monte-carlo method of finding orbits for very slow wide binaries. Except for i and e, our uncertainties of the orbital elements encompass the values of the 6th orbit (and i, inclination, not by much). Our orbit could be improved using differential corrections (e.g. van den Bos (1937)) and/or the "grid-search" method of Hartkopf, McAlister, and Franz (1989).

DUN 38* (WDS 07040-4337, DUN 38AB) Our probability of binarity ~49.6%. A probability <= 50% means that curvature in the historical data was not detected. Widening Separation at 2015.5 ≈ 0.0004 pc ≈ 90 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.00, and physical relationship as "unknown".

DUN 42* (WDS 07087-7030, DUN 42) Our probability of binarity ~55.2%. A probability > 50% means that curvature in the historical data was detected. Widening. Separation at 2015.5 ≈ 2.71 pc ≈ 558334 AU. If separation at 2015.5 is approximately correct, pair cannot be binary despite our probability. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.83 and physical relationship as "highly likely to be physical".

DUN 52* (WDS 07343-2328, H N 19) Our probability of binarity ~49.9%. A probability <= 50% means that curvature in the historical data was not detected. Widening. Separation at 2015.5 ≈ 0.06 pc ≈ 13080 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.88 and physical relationship as "definitely physical".

DUN 111* (WDS 11323-2916, H 3 96) Our probability of binarity ~50.6%. A probability > 50% means that curvature in the historical data was detected. Widening. Separation at 2015.5 ≈ 0.06 pc ≈ 12129 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.89 and physical relationship as "definitely physical".

DUN 116* (WDS 11567-3216, DUN 116AB) Our probability of binarity ~50.0%. A probability <= 50% means that curvature in the historical data was not detected. Closing. Separation at 2015.5 ≈ 0.02 pc ≈ 3,227 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.89 and physical relationship as "definitely physical".

DUN 138* (WDS 13368-2630, H N 69AB) Our probability of binarity ~50.1%. A probability > 50% means that curvature in the historical data was detected. Widening. Separation at 2015.5 ≈ 2.80 pc ≈ 576861 AU. Cannot be binary. Harshaw's (2018) Supplemental Download rates the binary probability as 0.88 and physical relationship as "definitely physical".

DUN 168 (WDS 14428-5511, DUN 168) Our probability of binarity ~50.2%. A probability > 50% means that curvature in the historical data was detected. Closing. Separation at 2015.5 ≈ 0.68 pc ≈ 140947 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.90 and physical relationship as "definitely physical".

DUN 230 (WDS 20178-4011, DUN 230) Our probability of binarity ~50.5%. A probability > 50% means that curvature in the historical data was detected. Closing. Separation at 2015.5 ≈ 0.13 pc ≈ 26510 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.89 and physical relationship as "definitely physical".

DUN 246 (WDS 23072-5041, DUN 246) Our probability of binarity ~50.0%. A probability <= 50% means that curvature in the historical data was not detected. Widening. Separation at 2015.5 ≈ 0.03 pc ≈ 6809 AU. Binarity uncertain but possible. Harshaw's (2018) Supplemental Download rates the binary probability as 0.88 and physical relationship as "definitely physical".

DUN 251* (WDS 23395-4638, DUN 251) Our probability of binarity ~52.1%. A probability > 50% means that curvature in the historical data is detected. Closing. Separation at 2015.5 ≈ 2.60 pc ≈ 536972 AU. Cannot be binary. Harshaw's (2018) Supplemental Download rates the binary probability as 0.85 and physical relationship as "definitely physical".

8. Conclusion

Of the 12 Dunlop doubles whose possible rectilinear and orbital motions were analysed, only DUN 4* had a binarity probability of ≤ 50% and a 2015.5 separation ≥ 1pc making it very unlikely to be a physically bound pair. DUN 42*, 138* and 251* had a binary probability of ≥ 50% but a 2015.5 separation ≥ 1 pc, again making them unlikely to be physical pairs. DUN 38* and 52* had binary probabilities of < 50% and a 2015.5 separation < 1pc making them possible but unlikely binaries. DUN 5*, 111*, 116*, 168, 230 and 246 had a binary probability of ≥ 50% and a 2015.5 separation < 1pc making them possible binaries. Only DUN 5* is a confirmed binary. The orbital parameters for DUN 52*, 230 and 246 we consider to be grade 5 (on grade 5 orbits see Letchford, White, and Ernest 2018b). Of those grade 5 orbits, curvature was detected in the historical data for DUN 230, with a probability of binarity of ~50.5%.

9. Acknowledgements

We acknowledge the use of the following online data bases:

The Washington Double Star Catalogue maintained

by the USNO. (WDS)

All-sky Compiled Catalogue of 2.5 million stars, 3rd version (ASCC)

The Gaia Catalogue (Gaia DR2, Gaia Collaboration, 2018), from VizieR. (GAIA DR2)

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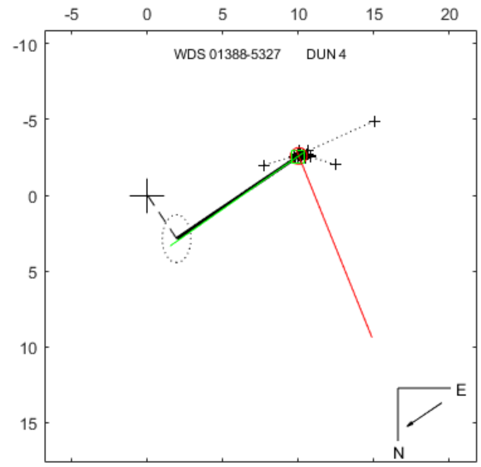
Appendix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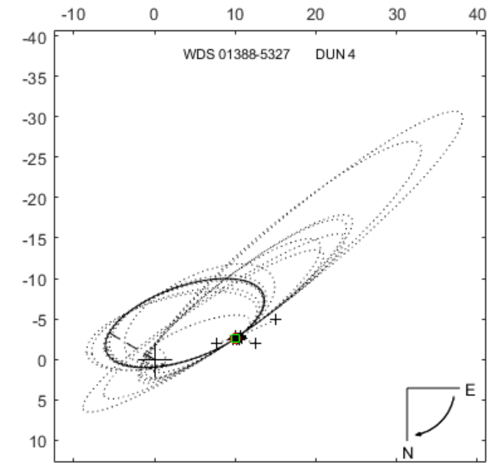
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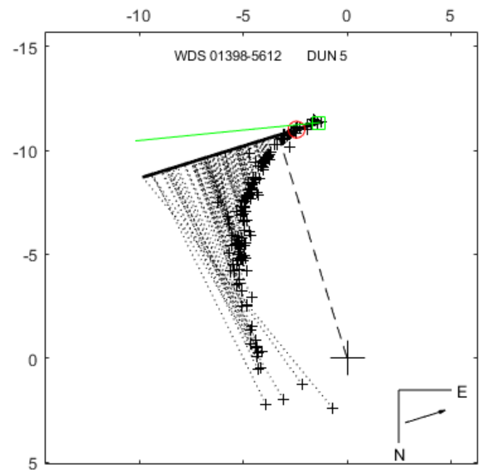
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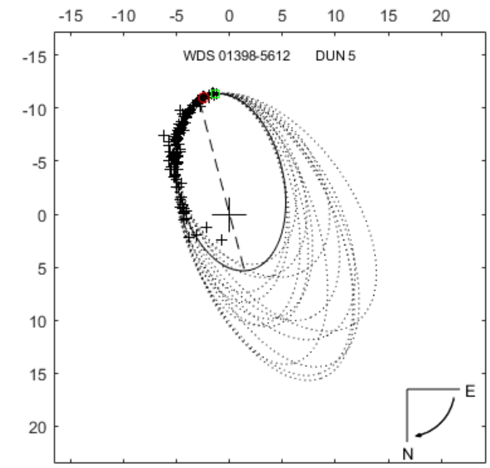
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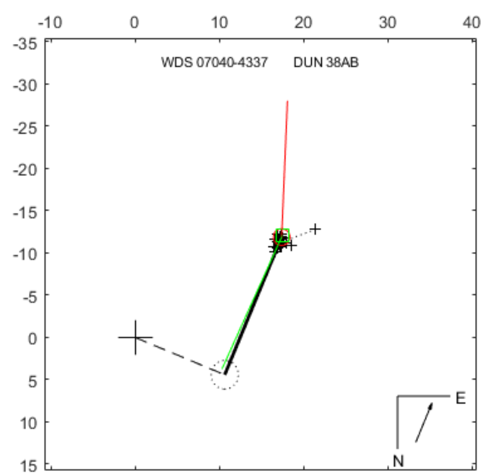
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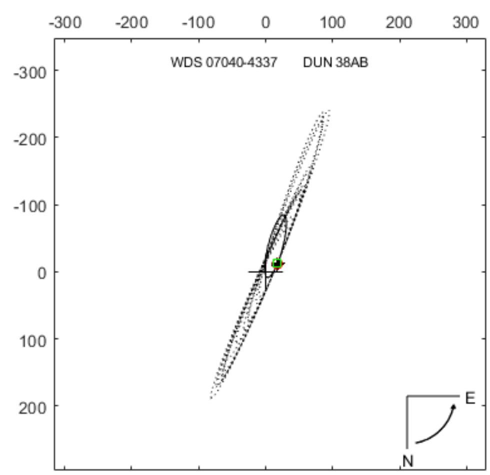
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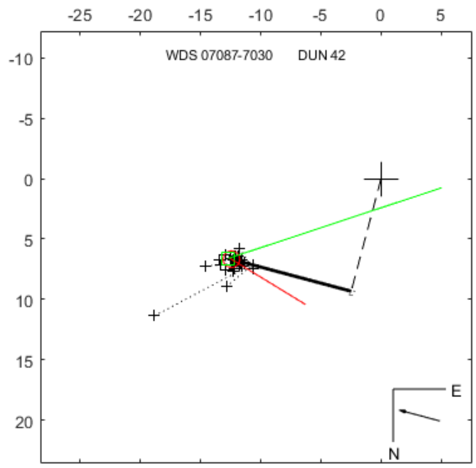
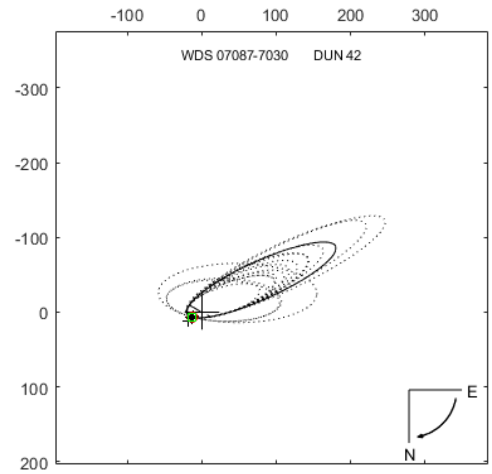
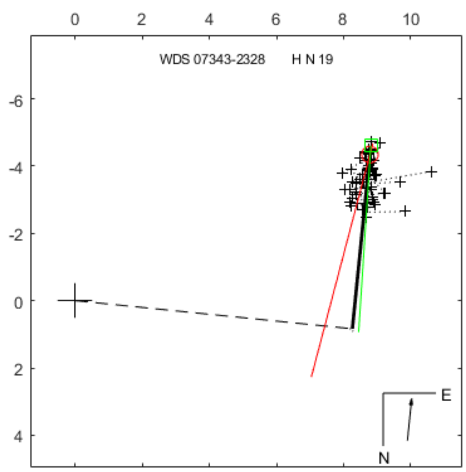
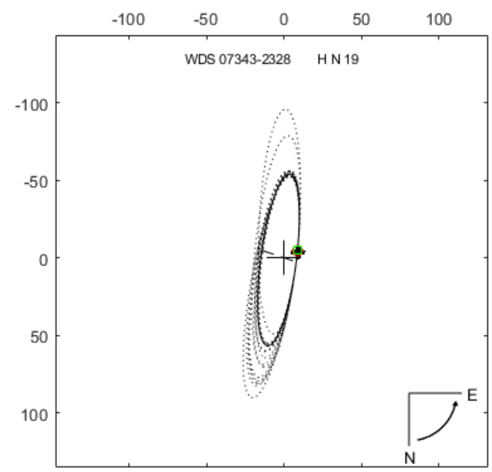
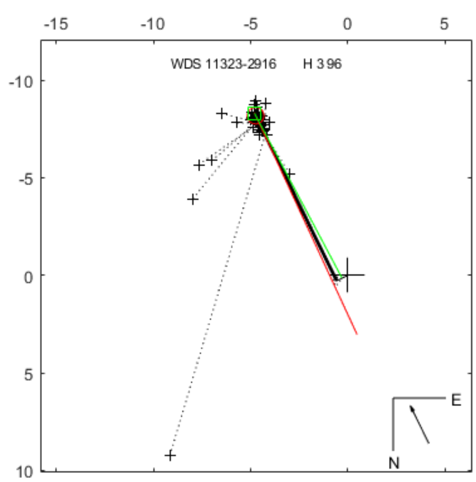
The Southern Double Stars of James Dunlop IV: Rectilinear and Orbital Motion of Some ...

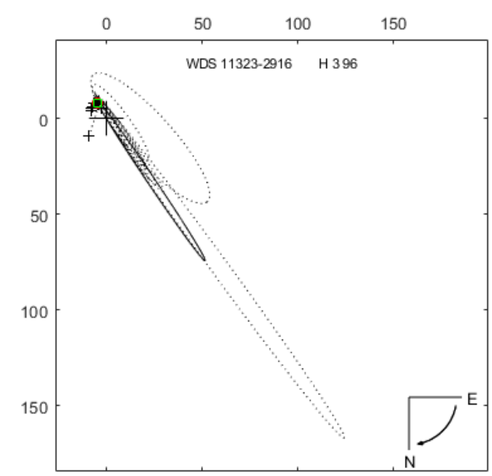


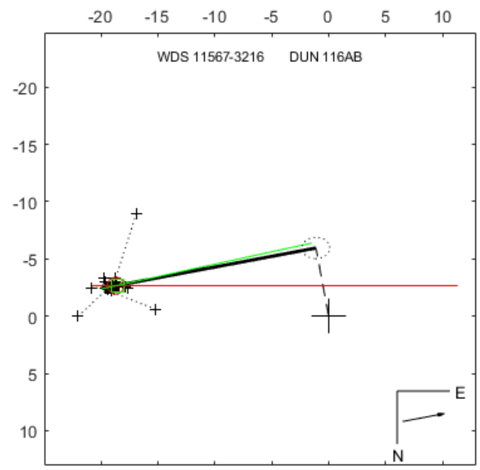








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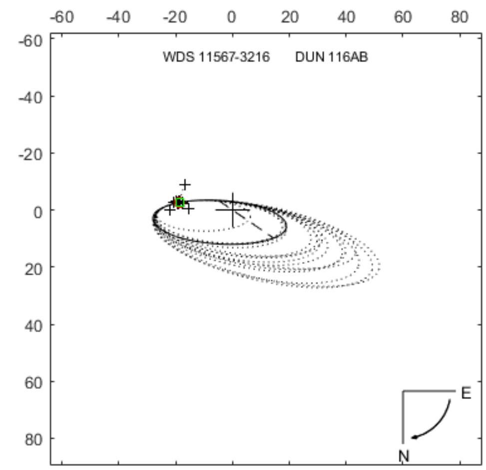
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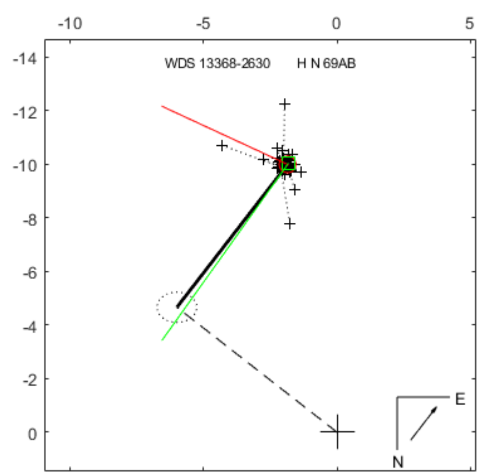
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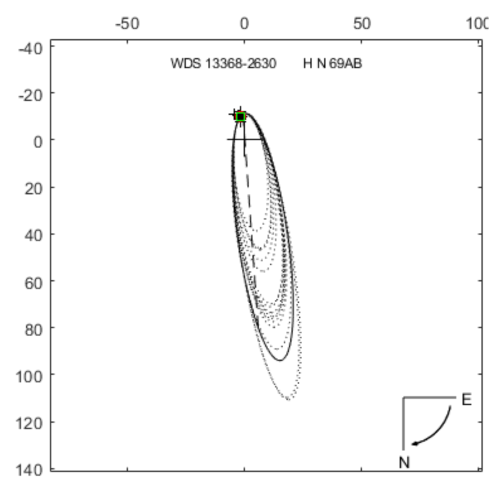
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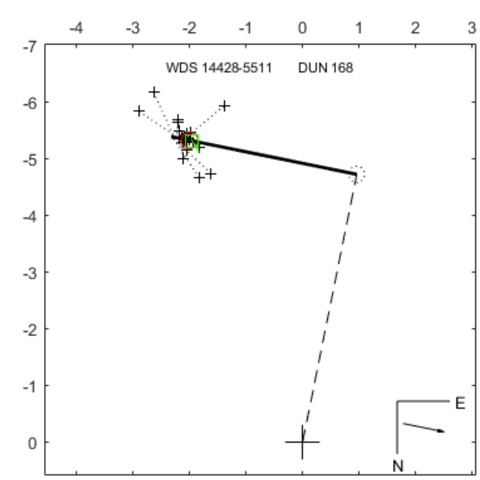
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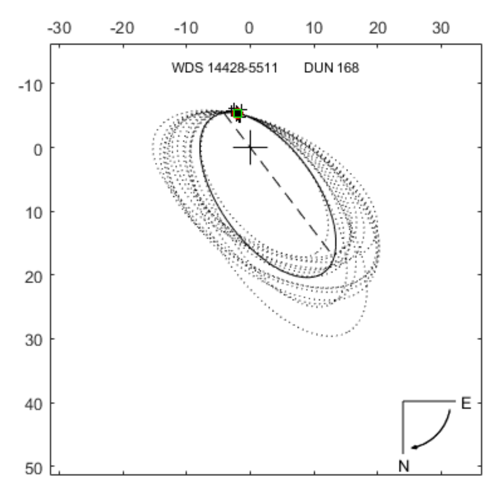
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