Exploring Short Period Red Dwarf Binaries in the Solar Neighborhood Speckle Interferometry and Gaia - IV

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Abstract

Speckle interferometry observations were made of double stars within 30 parsecs of Earth with a late K or M dwarf component using the Sloan r' filter on the 24-inch Planewave Telescope at El Sauce Observatory. Observations were made in January of 2022, on the 18th and 23rd. Targets were a mix of candidates with few prior observations and ones with well-defined orbits. Seven targets were successfully observed. Three targets had defined orbits, three had orbital uncertainty, and one target, ARG 72AB, appears to not be gravitationally bound. Further research is needed to determine the behavior of the uncertain targets.

1. Introduction

This project (RDSN IV) is a continuation of the Red Dwarf (RD) Binaries in the Solar Neighborhood (RDSN) campaign initially started in 2019 using the Orange County Astronomers (OCA) 22-inch telescope (Wasson et al. 2020). It was then continued in 2020 with RDSN-II (Altunin et al. 2020) which was aimed at obtaining speckle interferometry measurements of binary stars that contain a red dwarf within the solar neighborhood. RDSN-II used the Fairborn Institute Robotic Observatory (FIRO) 11-inch telescope. The survey of red dwarfs was further continued with the RDSN-III (Risin, et al. 2022) which highlighted targets with few to no prior observations as well as a late K or M dwarf component. RDSN IV is a continuation of the series of RD speckle by observing targets in the southern hemisphere. Observations for this project were taken during testing of automatic speckle observations on the 24-inch Planewave telescope in Chile.

2. Target Selection

Targets were selected from a list of known binaries in the southern hemisphere and chosen for their corresponding right ascension to ensure observation ability during January of 2022 as seen in Table 1.

Table 1: Gaia Information. Column 1, J2000 coordinates. Column 2, Gaia primary/secondary mags. The remaining columns are the spectral type (taken from the Washington Double Star Catalog), the proper motion in right ascension for the primary and secondary, the proper motion declination for the primary

and secondary, the parallax for the primary and secondary, and the discovery designation. N/A is notated for unknown values.

Coords (2000) UCAC4	GMag$_A$ GMag$_B$	Spec	PMRA$_A$ PMRA$_B$	PMD$_A$ PMD$_B$	π_A π_B	WDS Discovery
08221-4059	7.58 7.98	F5V	+0.12 +0.12	+0.39 +0.39	12.5 N/A	HJ 4087AB
06048-4828	7.300 7.69	G6V	-106 -106	-27 -27	N/A 33.33	DUN 23
05407-0157	1.880 3.70	O9.2I+ O9.7	+4 +4	+3 +3	4.43 4.43	STF 774AB
08568-1726	7.230 7.40	F3/5V	-37 -47	-1 -11	16.05 16.05	ARG 72AB
05569-4656	10.780 13.89	M	+71 +67	+487 +489	N/A 42.43	HDS804
07542-5359	10.420 11.09	K5	+73 +73	-31 -31	N/A N/A	HU1587
08144-5348	10.590 11.61	K7V	+60 +60	-8 -8	N/A 25.13	HDS1174
11477-5914	10.960 11.59	N/A	-214 -214	+80 +80	N/A N/A	TDS8027
11148-2306	9.130 12.58	K4V	-292 -295	-365 -366	N/A 43.39	DON466
05336-5104	9.470 9.94	K2V	+4 +4	+28 +28	N/A 23.62	HU1566

3. Instrumentation and Procedures

Observation Images were taken using a Planewave CDK24 telescope located at El Sauce Observatory in the Atacama Desert in Chile, as seen in Figure 1. This telescope has a 24-inch aperture and a focal length of 3974 mm, giving it a Focal Ratio of 6.5. It is mounted on a Planewave L-600 mount. The telescope uses a QHY600M-Pro camera with 3.76-micron pixels, a full-frame sensor with dimensions of 36mm * 24mm, and a peak QE of 80%. The telescope system thus provides a resolution of 0.2 arcsecond per pixel and a field of view of 0.52 degrees by 0.35 degrees. An R-band filter was used.

Figure 1: Planewave CDK 24 telescope at El Sauce Observatory

To reduce the data, the software, Speckle Toolbox 1.14 (Rowe 2020) was used. The data reduction started with calibration of the plate scale and camera orientation from plate-solved, full-frame images taken each night. Speckle images were taken in the region of interest (ROI) mode. The images were turned into Bispectrum files and phase reconstruction was then conducted, as seen in Figure 2. After phase reconstruction, the position angle and separation were calculated.

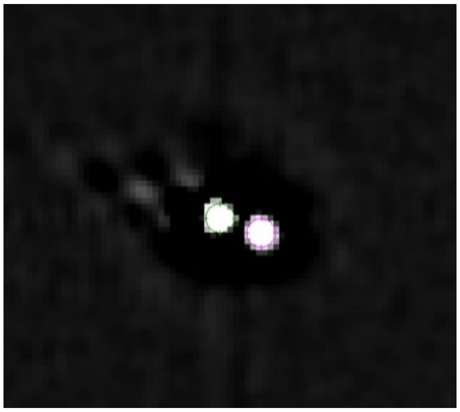


Figure 2: Sample Reconstructed Image of HJ4087AB

4. Results

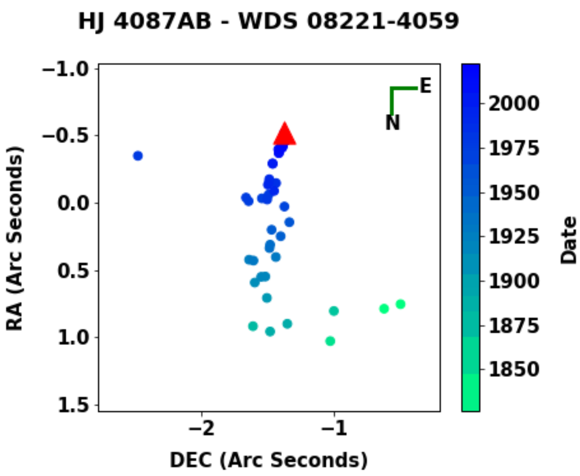
Of the 10 targets observed, only seven were successfully resolved. These unresolved targets include 05407-0157, 05569-4656, and 05336-5104.

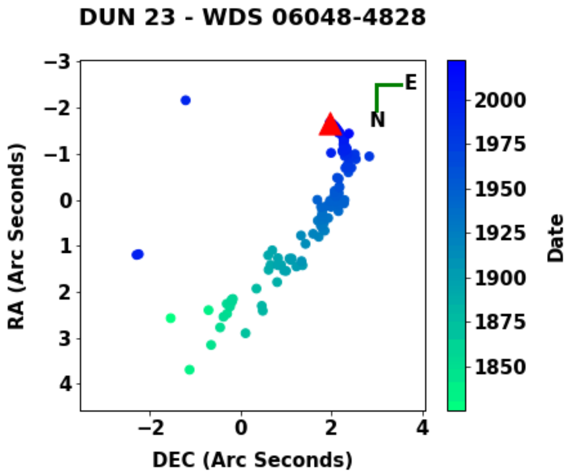
Table 2: Speckle Astrometric Results. Column 1 is the Besselian observation date. Column 2 is target RA and Dec Coordinates (2000.0) in hh mm ss.s+dd mm ss format. The remaining columns are the average Position Angle (θ) in degrees, standard deviation of Position Angle, Standard Error of Position Angle, average Separation (ρ), standard deviation of Separation, and the standard error of separation in arc-sec. The Average, Standard Deviation and Standard Error results include all filters and multiple-night data, weighted equally regardless of quality. N/A denotes cells where data for the systems were unable to be calculated.

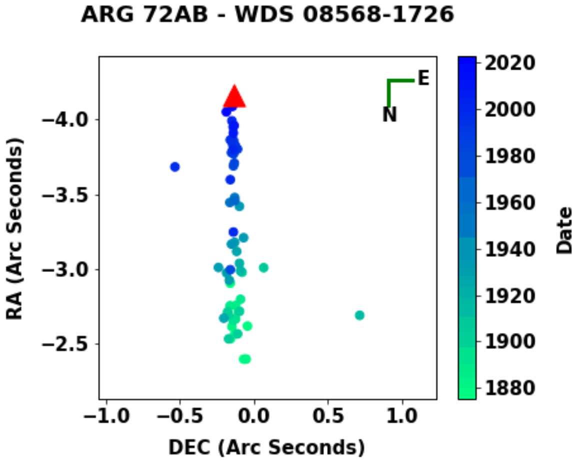
Date	**Coord**	**θ**	**Std Dev**	**Std Error**	**ρ**	**Std Dev**	**Std Error**
2459597.5	08 22 08.18 -40 59 29.6	249.34	0.68	0.39	1.47	0.02	0.01
2459597.5	06 04 46.76 -48 27 30.3	130.55	0.66	0.38	2.59	0.02	0.01
2459597.5	08 56 49.69 -17 26 00.2	181.81	0.05	0.03	4.16	0.01	0.01
2459602.5	07 54 15.94 -53 58 47.5	216.12	N/A	N/A	1.07	N/A	N/A
2459602.5	08 14 25.01 -53 48 23.2	229.98	1.41	0.82	1.38	0.05	0.03
2459602.5	11 47 41.66 -59 14 12.3	118.55	N/A	N/A	1.72	N/A	N/A
2459602.5	11 14 48.17 -23 06 17.7	219.52	N/A	N/A	2.91	N/A	N/A

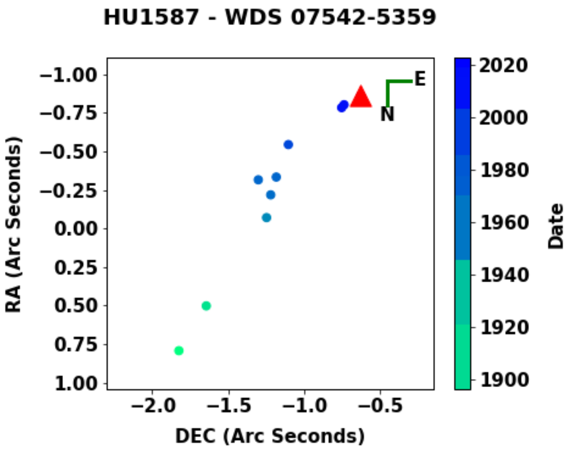
5. Analysis

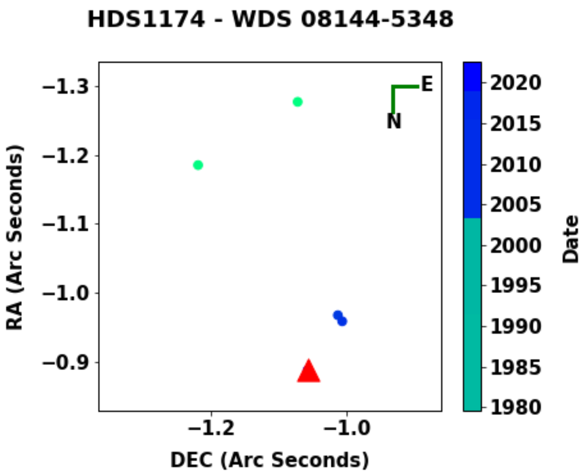
Systems fell into a few categories, with this study focusing on a range of binaries from few prior observed and ill-defined orbits to systems with better-defined orbits and more observations.

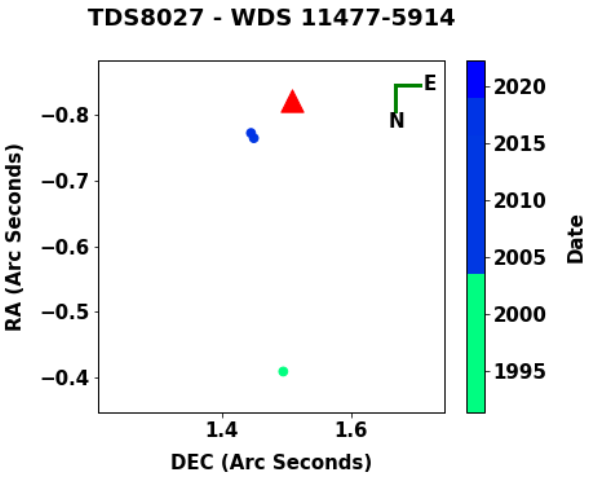

HJ 4087AB - WDS 08221-4059


DUN 23 - WDS 06048-4828


ARG 72AB - WDS 08568-1726


HU1587 - WDS 07542-5359


HDS1174 - WDS 08144-5348


TDS8027 - WDS 11477-5914

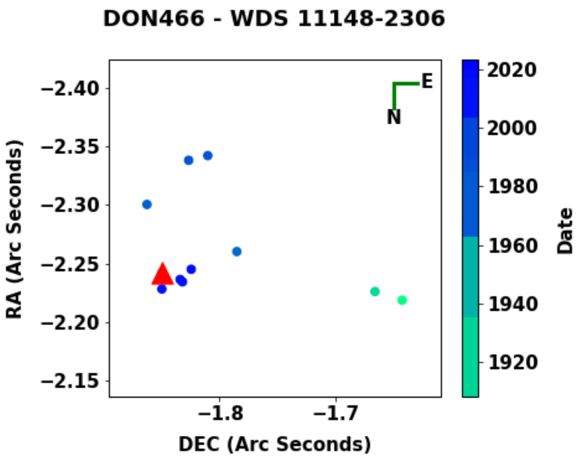


Figure 4: Orbits. Plots include positions of each star (Dec, RA) including the measurements from the WDS. Our observation is denoted by the red triangle. Other coloring follows the scale on the right of the graph with bluer colors representing more recent historical observations from the Washington Double Star Catalog.

One system in particular, ARG 72AB, has a near linear relationship, suggesting the system may not be gravitationally bound. ARG 72AB has a relative 3D space velocity of approximately 8750 m/s. Based upon the estimated mass of each star, this relative velocity is higher than the expected escape velocity of 1229 m/s (calculation shown in equation 2 below), leading to the presumption that the system is unbound. The value received for the relative proper motion was 0.22 arcsec/year, meaning it is classified as a system with similar proper motion (SPM). However, given that the error bars of the parallax for the component stars overlap, the stars could have a much lower separation. If the component stars in the system are closer than expected, then the stars would be more strongly bounded to one another, thereby increasing the system escape velocity. The uncertainty in the parallax of the component stars warrants further investigation.

Table 3: Gaia's Early Data Release 3 provided the 3D spatial separation, relative proper motion, and relative radial motion for ARG72AB (Gaia Collaboration et al. 2020). Equations 1, 2, and 3 were used to calculate the system's relative transverse motion, 3D motion, and escape velocity respectively.

3D Separation (pc)	Relative Proper Motion (arcsec/year)	Relative radial motion (m/s)	Relative Transverse Motion (m/s)	Relative 3D Space Velocity (m/s)	3D Escape Velocity (m/s)
0.04	0.22	8240	2944	8750	1229

Equation 1: Formula for relative transverse motion (rtm). rpm stands for relative proper motion, and plx_pri is the parallax of the primary component.

$$rtm \;=\; (4740 * rpm) \,/\, (plx\_pri)$$

Equation 2: Formula for relative 3D motion (v_{3D}). rtm is the relative transverse motion, and rrm stands for relative radial motion.

$$V_{3D} = \sqrt{rtm^2 + rrm^2}$$

Equation 3: Formula for escape velocity. m_1 and m_2 are the estimated masses of the primary and secondary stars from the Hertzsprung-Russell relationship.

$$V_{esc} = \sqrt{2G(m_1 + m_2)/sep_{3D}}$$

DON 466, HDS1174, and TDS8027 have very few prior observations making any determination of curvature difficult. Further observations are needed to determine the orbits of the systems. HU1587 does not have a published orbital solution but recent measurements seem to indicate curvature. Further observations are needed to determine the orbit.

DUN 23 and HJ 4087AB have well defined orbits and the observations are in line with the expected measurements and prior calculations for orbit (Izmailov 2019).

6. Conclusions

This paper built on the prior research conducted in RDSN-I, RDSN-II, and RDSN-III by examining known red dwarf binaries in the southern hemisphere. Ten known and potential binaries were observed, all containing a red dwarf companion. Targets included well-defined binaries and potentially gravitationally bound systems.

From these 10 systems, we were able to obtain measurements in line with the previous observations for seven potential binaries, and confirm predicted orbits as well as add further observations to systems that are probably bound. Speckle interferometry was used to resolve the pairs successfully. The program was also able to test the lower bound of separation able to be resolved with the 24-inch telescope. We were able to determine that ARG 72AB is mostly likely not gravitationally bound and requires further observation.

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