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Comparison of Archived 3.8-Meter UKIRT J-Band Image Astrometry with Gaia and Recent Small Telescope Speckle Interferometry

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Abstract Images were retrieved from the United Kingdom Infrared Telescope Survey (UKIRT) archives on a subset of the stars studied during two recently completed Red Dwarf Binary Stars in the Solar Neighborhood (RDSN) speckle interferometry campaigns. We found that the speckle interferometry results from about 1000 short exposures by the 0.28 and 0.56 m telescopes used in RDSN were comparable in accuracy to the single long exposures obtained with the 3.8 m telescope used in the UKRIT survey.

Introduction

The paucity of measurements of Red Dwarf double stars (RD) in the solar neighborhood, despite their abundance, lead to a program that observed the brightest nearby binary systems containing a RD with components having similar proper motions and parallaxes. Targets included systems containing one or two RD components already in the Washington Double Star (WDS) catalog, as well as systems not in the WDS but in a Gaia Double Star (GDS) database derived by Rowe (2018) from Gaia Data Release 2 (DR2). The campaign stated in 2019 using the Orange County Astronomers 22-inch telescope (Wasson et al. 2020, hereinafter RDSN-I). In 2020 the project was continued with the Fairborn Institute Robotic Observatory (FIRO) 11-inch telescope (Altunin et al. 2020, hereinafter RDSN-II).

Thirty-five speckle and quasi-speckle observations were made in RDSN-I with about half not found in the Washington Double Star Catalog (WDS). An additional 12 speckle and quasi-speckle observations were made during RDSN-II with, again, half not being in the WDS, although all but one was found in the newly revised Washington Double Star Supplement (WDSS).

Objective

Historically, large-scale ground surveys, such as SDSS, have not had resolutions better than about 5". Although the SDSS pixel scale is 0.396", the long exposures to reach its intended faint targets blooms brighter stars to several arcsec, making close double stars difficult to resolved (York et al. 2000). On the other hand, speckle interferometry—even on small telescopes—routinely achieves resolutions of 1" or better (Genet et al. 2015, Losse 2020). For close double-star systems, with separations well under 5", often the only available past PA and Sep observations are those from Gaia (and occasionally Hipparcos/Tycho).

To expand the number of past observations that we could combine with small-telescope speckle interferometry and Gaia observations, we evaluated the use of images retrieved from the UKIRT, archived since the survey started in 2004. The UKIRT telescope was not, obviously, limited in its resolution by its 3.8-m aperture; rather it was limited by seeing on Mauna Kea which, in the J-band observations, was about 1", comparable in resolution to small telescopes equipped for speckle interferometry.

The objective of this project was to determine if, in addition to Gaia astrometry, astrometry of archived UKIRT images could provide useful past position angle and separation (PA and Sep) measurements to complement our current speckle interferometry. However, unlike Gaia, the UKIRT PA and Sep measurements automatically measured, requiring us to manually make astrometric measurements of the retrieved UKIRT images.

UKIRT Images

All of the UKIRT J-band images used in this project were acquired by the UKIRT Hemisphere Survey (UHS; Dye et al. 2017) apart from the image of WDS 15461+0441 which was acquired by the Large Area Survey (LAS) as part of the UKIRT Infra-red Deep Sky Survey (UKIDSS; Dye et al. 2006; Warren et al. 2007, Lawrence et al. 2007). Both surveys used UKIRT's Wide Field Camera (WFCAM; Casali et al. 2007) which has a field of view of approximately 0.8 square degrees and a native pixel scale of 0.4 arcsec (Image 1). All UHS images have the native WFCAM pixel scale whereas the LAS uses 2x2 microstepping which results in images with a pixel scale of 0.2 arcsec. All imaging data was obtained via the WFCAM Science Archive (WSA; Hambly et al. 2008) (wsa.roe.ac.uk). We used the WSA's 'MultiGetImage' tool selecting stacked images from both the 'UKIDSSDR11PLUS' and 'UHSDR1' data releases and using an extraction field of view of 1 arcmin.

Image 1: The UKIRT telescope with the WFCAM camera.
Source: https://news.arizona.edu/story/hawaiian-eye-to-the-sky-now-under-ua-directorship

Processing Techniques

UKIRT images were obtained on a total of 27 stars, 20 from RDSN-I and 7 from RDSN-II. The image files were opened in Speckle Toolbox (STB) 1.14 (Rowe 2015) and the measurements of PA and Sep were made using STB's astrometry measurement tool with the plate calibration values and dates obtained from the UKIRT image FITS header.

Results

The results from the data processing can be seen in Table 1a and 1b. This is the first time our UKIRT measurements are being reported for these stars. The other measurements (Gaia and speckle interferometry) were reported in the two previous RDSN papers.

As mentioned in the RDSN-II paper, it was assumed that astrometric measurements do not change systematically in different wavelengths, allowing us to compare PA and Sep in different filters. This assumption has not been explored and warrants further investigation (Altunin et. al 2020).

Identification	UKIRT			Gaia		RDSN-I			ABS U-G		ABS G-RDSN-1	
	Date	PA	SEP	PA	Sep	Date	PA	Sep	PA	Sep	PA	Sep
WDS 00220+4913	2014.941	303.24	2.14	300.89	2.27	2019.764	302.70	2.31	2.35	0.13	1.81	0.04
003317.5+341910	2013.928	174.03	3.09	174.64	3.14	2019.846	176.04	3.17	0.61	0.06	1.40	0.02
032829.3+351519	2012.835	197.95	1.36	200.15	1.23	2020.074	202.02	1.29	2.20	0.13	1.87	0.05
WDS 15461+0441	2008.290	230.60	2.34	232.50	2.34	2019.501	233.10	2.36	1.90	0.00	0.60	0.02
WDS 16042+4620	2012.548	57.27	6.47	58.20	6.49	N/A			0.93	0.02	N/A	
WDS 16468+0531	2012.504	170.07	4.41	170.00	4.47	2019.501	170.38	4.50	0.07	0.06	0.38	0.02
164940.5+280004	2013.115	43.86	3.51	43.30	3.51	N/A			0.56	0.04	N/A	
170648.9+321159	2013.665	27.20	3.26	27.30	3.28	2019.600	26.98	3.24	0.10	0.02	0.32	0.04
171044.6+272743	2013.402	270.01	2.10	269.00	2.12	2019.600	264.53	2.16	1.01	0.02	4.47	0.04
180512.0+180719	2013.268	18.46	5.00	18.8	5.02	2019.600	18.42	5.11	0.34	0.02	0.38	0.09
180931.7+040045	2012.589	132.81	2.55	132.40	2.58	2019.600	132.35	2.59	0.41	0.031	0.05	0.01
182044.1+320633	2013.282	44.39	2.69	44.60	2.76	2019.633	43.79	2.75	0.21	0.079	0.81	0.01
195852.2+513050	2013.512	130.05	2.75	130.20	2.77	2019.728	130.54	2.84	0.15	0.023	0.34	0.07
WDS 20573+1200	2012.698	164.01	3.36	164.25	3.44	2019.728	168.77	3.56	0.24	0.079	4.52	0.12
210532.1+060916	2013.350	166.62	5.04	166.00	5.09	2019.663	165.34	5.06	0.62	0.05	0.66	0.03
210957.5+032122	2012.537	185.64	2.64	185.30	2.66	2019.764	185.73	2.63	0.34	0.01	0.43	0.02
WDS 21174+2053	2013.651	340.98	4.28	341.20	4.30	2019.663	340.94	4.43	0.30	0.02	0.26	0.12
WDS 22077+2521	2013.670	237.95	8.07	238.13	8.20	2019.728	238.83	8.27	0.18	0.13	0.70	0.06
WDS 22212+3745	2013.725	252.97	1.92	250.41	1.98	2019.764	248.89	2.05	2.56	0.07	1.52	0.07
234314.8+233625	2013.725	328.21	5.74	327.70	5.79	2019.846	327.49	5.84	0.51	0.05	0.21	0.05
							Average		0.70	0.046	1.10	0.052
							STD Dev		0.78	0.040	1.30	0.032

Identification	UKIRT			Gaia		RDSN-II			ABS U-G		ABS G-RDSN	
	Date	PA	SEP	PA	Sep	Date	PA	Sep	PA	SEP	PA	Sep
170648.9+321159	2013.665	26.84	3.24	27.30	3.28	2020.591	26.59	3.27	0.46	0.04	0.71	0.01
173307.3+091437	2012.548	73.61	4.54	72.30	4.69	2020.589	70.07	4.65	1.31	0.14	2.23	0.04
WDS 18277+5016	2012.671	237.39	4.88	236.70	4.92	2020.611	237.86	5.05	0.69	0.03	1.16	0.14
184930.9+414635	2012.600	89.11	4.02	89.50	4.18	2020.600	89.85	4.20	0.39	0.15	0.35	0.02
WDS 19260+3555	2013.257	106.22	6.03	106.30	6.04	2020.603	106.33	5.95	0.08	0.01	0.03	0.09
WDS 19529+4316	2012.835	257.32	5.06	257.10	5.09	2020.622	257.10	5.10	0.22	0.03	0	0.01
202201.6+214720	2012.764	67.44	5.42	67.46	5.44	2020.622	67.57	5.45	0.02	0.03	0.11	0.01
							Average		0.45	0.063	0.66	0.045
							STD Dev		0.44	0.061	0.81	0.049

Table 1: The first column contains the identifier of the stars observed in RDSN-II. The following 3 sections contain columns on the date the observations were taken, the position angle in degrees, and separation in arcseconds. Only stars that with UKRIT images were included. The last section contains the absolute value of the difference between Gaia (G) and the UKIRT (U) measurements and the Gaia (G) and the RDSN measurements. The last two rows contain the standard deviation and average of these absolute values.

Analysis/Discussion

Considering the absolute values of the difference of measurements between Gaia (G), and, respectively, the UKIRT images (U), and RDSN speckle interferometry in Table 1, it does *not* appear that there is any significant motion—in most cases, less than 1 degree of motion in PA in almost a decade. While the RDSN targets were selected to be somewhat close to Earth (within 100 parsecs), their separations were quite wide (3" to 6"). Thus, despite the observations covering ~a decade of time, with UKIRT being the earliest (2006), then Gaia (2015.5), and then RDSN (2019 and 2020), this lack of detectable motion is not surprising.

There also does not appear to be any significant difference between the average absolute values of the difference between Gaia and UKIRT measurements and Gaia and RDSN measurements in either PA or Sep (both within one standard deviation of each other). Thus, it appears, that with respect to relative astrometry of somewhat close double stars, the UKIRT 3.8-m telescope on Mauna Kea with long single exposures, and the RDSN telescopes (FIRO 0.28-m and Orange County Astronomers 0.56-m telescopes) near sea level with a thousand short exposures (speckle interferometry via bispectrum analysis), have about the same precision. This demonstrates the power and usefulness of double star follow up observations made by small telescopes with speckle and quasi-speckle interferometry. Large and small telescopes can work synergistically together.

Something that was not clear at the start of this study, was whether or not useful astrometric measurements could be obtained from the UKIRT images. UKIRT surveys were designed to observe faint, remote-galaxies, so nearby bright (12-15 mag) stars were, out of necessity, overexposed. Yet, despite many of the stars having totally overexposed centers, it appears that the STB centroid tool successfully did its job, allowing astrometric measurements to be extracted. (Image 2) This finding confirms the utility of UKRIT images to obtain historical measurements of double star systems.

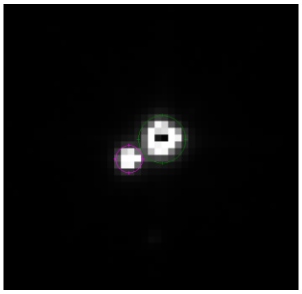

Image 2: The UKIRT image 002158.2+491237. Despite the overexposed center (black pixels) the STB centroid tool was able to center around the primary and secondary stars allowing astrometric measurements to be made.

Using astrometrically-measured, archival UKIRT images in conjunction with Gaia's data and recent speckle observations, the curved orbital motion of short period binaries over an observational interval of approximately a decade may be detectable. Underway is an observational program using the 11" FIRO telescope that is focused on observing nearby red dwarf doubles with the potential of being binaries with short periods (less than 500 years) whose changing position angles (binary rotations), if real, should be detectable over the UKIRT / Gaia / FIRO time scale of almost a decade.

Conclusion

We have successfully demonstrated that past UKIRT images can be used to obtain historical measurements of double star systems. The measurements could, in the future, be used in conjunction with Gaia and our own speckle estimates of PA and Sep, to look for short, curved arcs on potential short-period, gravitationally bound doubles.

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