The Fairborn Institute Robotic Observatory: First Observations

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Abstract: Speckle data were remotely collected across five nights as the first observations of the Fairborn Institute Robotic Observatory. Measurements of 24 close double star systems with separations ranging from 1.49 to 4.52 arcseconds are reported

Introduction

The Fairborn Institute Robotic Observatory (FIRO) is focusing on measuring close double stars using speckle interferometry — a technique developed by Labeyrie (1970). Speckle interferometry enables double stars below the seeing limit to be resolved, shifting the limiting factor from atmospheric seeing to the aperture of the telescope, thus allowing the diffraction limit of the telescope to be reached. Short exposures, typically less than 40 milliseconds, are taken of the target, which freezes the seeing and prevents the stars from blurring together. A Fourier transform is then applied to the images to generate an autocorrelogram. Bispectrum analysis is a further refinement beyond the autocorrelogram: it removes the extraneous sideband, and transforms the autocorrelogram back into a real image.

Target Selection

The FIRO observatory's horizon is restricted by trees, so target selection was limited to stars within a region corresponding roughly to declinations between +13 and 60 degrees and a right ascension angle of six hours.

Targets were further limited to having separations of 1.4″ and wider, delta magnitudes of 3 or less, and secondary magnitudes of 12 or brighter. These constraints avoided pushing the limitations of the FIRO telescope, based on the telescope's aperture pixel scale, and the seeing conditions. Finally, only stars that were already in the WDS were selected. All targets were chosen using the Gaia Double Star (GDS) search tool, which draws from the Gaia DR2 database (Rowe, 2018).

The Gaia DR2 contains information about the surface temperature and luminosity (Andrae et al, 2018). Using this information, some targets were specifically chosen because the secondary star, while dimmer, had a hotter surface temperature than the primary. This trait is fairly uncommon, and it was speculated that the secondaries of these systems—listed below in Table 1--were white dwarfs. But when the stars were plotted on HR diagrams, using the luminosity and surface temperature given by Gaia, it was clear that all of the secondaries were much too luminous to be white dwarfs. For some of the systems, both stars were on the main sequence and the difference between the stars' luminosity and surface temperature was minor. For the rest of the systems, shown in Figure 2, the primary star did not fall on the main sequence, but with the red giants: stars in the last stages of stellar evolution characterized by their inflated sizes and cooler temperatures. With a few of these, such as STF 1783, the secondary may also be in the process of becoming a red giant. All other observed stars are on the main sequence.

Instrumentation

FIRO has an 11-inch aperture C-11 telescope mounted on a custom mount designed by Genet and built by students at California Polytechnic State University. The C-11 is f/10, having a focal length of 2800mm. The ZWO ASI 1600mm camera has 3.8 µm pixels, giving a scale of approximately 0.26 ″/pixel. This sampling allows 1.0″ separation double stars to be resolved. The theoretical diffraction limit of an 11-inch telescope is 0.4″, however the sampling does not allow this to be reached. The sampling is relatively coarse for speckle, and at least four to five pixels between the centroids are needed to make confident measurements. However, the course sampling has the advantage of packing more light into each pixel,

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System	Primary Luminosity ($L_\odot$)	Secondary Luminosity ($L_\odot$)	Primary Surface Temperature (K)	Secondary Surface Temperature (K)
STF 1783	52.6	6.8	4939	5153
STF 1808	1.3	0.7	5828	5831
STF 2035	8.3	3.0	6449	6876
STT 314	63.5	3.8	4562	4854
STF 2112	15.1	6.6	5350	5861
STF 2210	44.0	7.8	4962	7381
HU 1286	1.5	1.4	5440	5726

Table 1: Gaia DR2 luminosity and surface temperature for targets where the secondary had a hotter surface temperature.

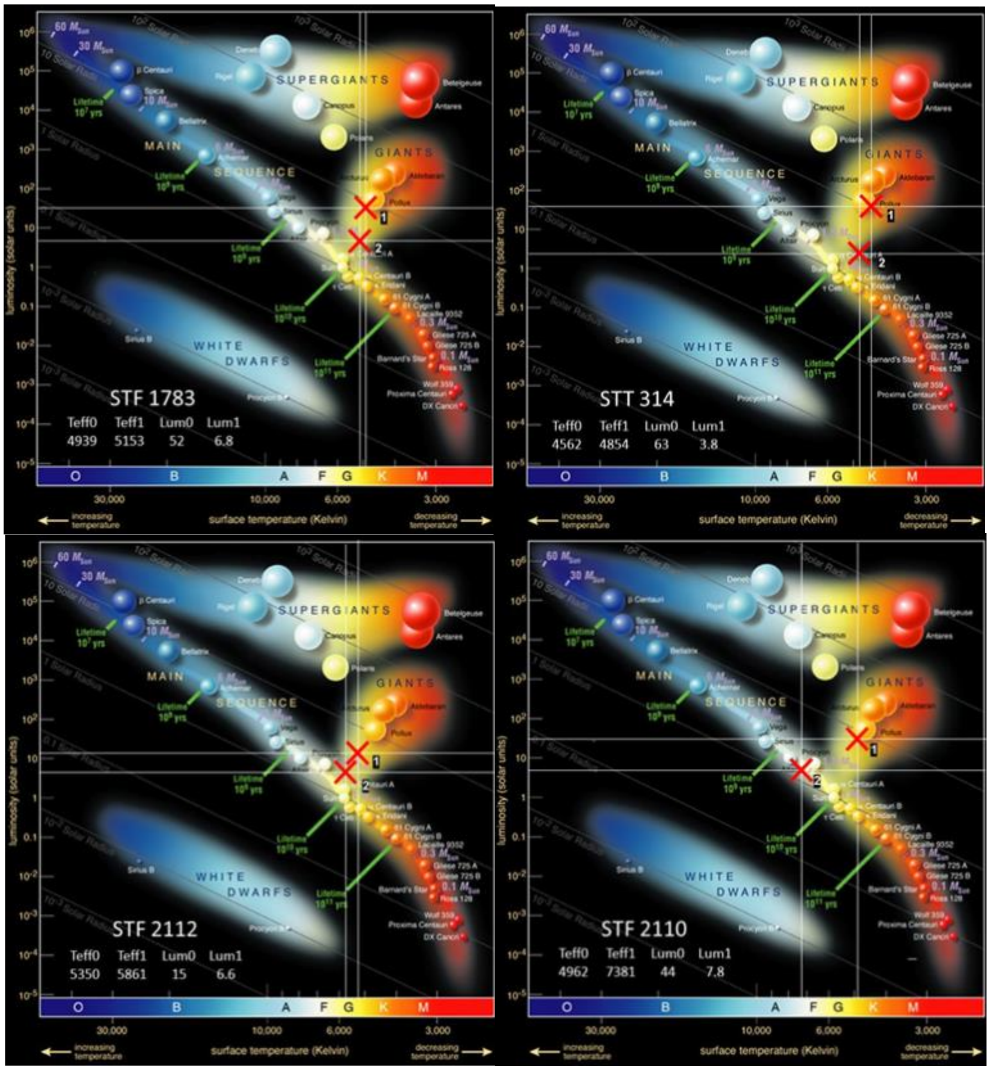

Figure 2: Target systems where one or more of the stars are potential red giants, plotted on an HR diagram.

meaning fainter doubles can be measured. In addition, there was no filter used to restrict the bandpass. By definition, this transmits the most light, helping to measure faint double stars.

Figure 3: The FIRO telescope in its enclosure.

Procedure

For these observations, Genet opened the observatory's roof and powered up the equipment. Other than that, the telescope was controlled remotely by Marchetti and Caputo. Observations took place between July 2-10, 2020.

All mount control software was interfaced through the SiTechZWOCam software (Gray, 2020) and Sidereal Technology (SiTech). Cartes du Ciel (Chevalley, 2020) was used to slew the telescope to the target and reference stars, and Nighttime Imaging 'n' Astronomy (NINA) (Berg, 2020) was used to correct for pointing error by doing a platesolve and resync routine. SharpCap (Glover, 2020) was used to capture the speckle images. The process was similar to Caputo et al. (2020).

The speckle interferometry data reduction used David Rowe's SpeckleToolBox (STB) (Rowe, 2019). This software generates FITS cubes, performs the Fourier analysis, and then presents the resulting autocorrelogram. The data can further be processed using bispectrum, which transforms the power spectrum density (PSD) that the autocorrelogram generates back into an image and removes the sidebands and resolves the 180o position angle ambiguity. We used bispectrum to process these observations, as it results in a more accurate measurement than just performing autocorrelation.

Measurements

We report measurements of 24 double stars. Some stars were measured across multiple nights to check for consistency, and an overall average and standard error is reported. For every night that a star was measured, four captures of 1000 frames were taken.

The pixel scale was calibrated each night. It was approximately 0.245″ per pixel for the first two nights and .278″ per pixel for the remaining nights. This difference is most likely due to Genet adjusting the telescope during the day and moving the primary mirror. This has the effect of changing the back focus and therefore the magnification of the telescope. The data were processed with bispectrum analysis using STB 1.14. Results of the bispectrum analysis are summarized in Table 2, with systems listed in order of right ascension.

Discussion

As stated above, some stars were measured across multiple nights. For these stars, we examined the standard errors associated with each night compared to the overall standard error to see how measuring across multiple nights affected the accuracy of the measurements. As shown in Table 3, some of the overall standard errors are larger than the individual errors, which initially, we thought was problematic. But the larger overall error is probably caused by nightly variation in temperature or other atmospheric qualities that affect the resulting measurement. The larger error is likely a more accurate representation of the error involved in measuring double stars; taking back-to-back measurements within a single night produces a low error, but perhaps artificially so.

Conclusion

We presented measurements on 24 double stars with most separations below the seeing limit. Speckle interferometry, specifically bispectrum processing, allowed these measurements to be made. Considering the FWHM of the stars was around 3″ during image acquisition, our measurement of a 1.5″ split shows the power of speckle interferometry. Bispectrum processing is a further application of speckle interferometry and is an alternative way of measuring position angle and separation. It is useful as it generates a real image instead of an autocorrelogram, and resolves the position angle ambiguity.

These 24 double stars represent the first science that was done with the Fairborn Institute Robotic Telescope. Our measurements of 24 double stars, in addition to being the first science, contributed to the development and usability of FIRO by fine-tuning the data acquisition process.

System	Date	Number of Nights	Position Angle (°)	Standard error of Position Angle (°)	Separation (″)	Standard Error of Separation (″)
STF 1730	2020.52	1	338.37	0.12	1.996	0.010
STF 1783	2020.51	1	48.10	0.17	2.559	0.007
STF 1808AB	2020.52	1	82.58	0.25	2.723	0.009
STF 1826AB	2020.52	1	310.32	0.05	4.526	0.005
STF 1858AB	2020.51	2	38.15	0.04	3.083	0.029
STF 1884	2020.50	1	55.34	0.17	2.252	0.011
A 1629	2020.52	1	281.12	0.25	2.135	0.011
ES 774	2020.52	1	230.44	0.17	3.459	0.002
ES 1252	2020.52	1	15.51	0.28	1.645	0.013
HU 148	2020.51	1	207.36	0.13	1.699	0.007
STT 296AB	2020.51	1	272.73	0.11	2.302	0.005
STF 2000	2020.51	1	226.41	0.11	2.619	0.012
BU 811AB	2020.52	1	262.16	0.11	1.726	0.008
STF 2035	2020.52	1	35.51	0.07	2.698	0.003
STT 314	2020.51	5	233.94	0.11	3.841	0.023
J 1124	2020.51	1	276.11	0.04	3.859	0.002
STF 2112	2020.51	2	262.54	0.17	2.255	0.029
STT 322	2020.51	2	200.85	1.01	1.497	0.032
A 1875	2020.51	5	189.64	0.13	2.592	0.012
STF 2153	2020.50	1	243.93	0.36	1.568	0.041
HEI 247	2020.52	1	103.16	0.20	2.109	0.008
TDS 867	2020.52	1	247.91	0.33	1.956	0.010
STF 2210	2020.51	4	122.26	0.07	3.321	0.015
HU 1286	2020.51	4	268.75	0.14	3.234	0.014

Table 2: Position angle and separation measurements of the target systems, as well as date observed, number of nights observed, and standard errors.

	System	**July 2-3 Standard Error**	**July 3-4 Standard Error**	**July 4-5 Standard Error**	**July 7-8 Standard Error**	**July 9-10 Standard Error**	**Overall Standard Error**
STF 1858AB	Position Angle	0.04	--	--	--	0.03	**0.04**
	Separation	0.008	--	--	--	0.005	**0.029**
STT 314	Position Angle	0.21	0.30	0.04	0.03	0.07	**0.11**
	Separation	0.025	0.015	0.007	0.004	0.004	**0.023**
STF 2112	Position Angle	0.32	--	--	0.08	--	**0.17**
	Separation	0.053	--	--	0.008	--	**0.029**
STT 322	Position Angle	0.42	--	--	0.41	--	**1.01**
	Separation	0.033	--	--	0.018	--	**0.032**
A 1875	Position Angle	0.39	0.19	0.11	0.16	0.08	**0.13**
	Separation	0.035	0.022	0.011	0.004	0.008	**0.012**
STF 2210	Position Angle	0.03	0.22	0.09	--	0.09	**0.07**
	Separation	0.180	0.025	0.004	--	0.005	**0.015**
HU 1286	Position Angle	0.40	0.25	0.07	--	0.09	**0.13**
	Separation	0.004	0.009	0.003	--	0.003	**0.014**

Table 3: Standard error of individual nights along with the overall standard error for stars measured across multiple nights.

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