Speckle Interferometry with a Low Read-Noise CMOS Video Camera

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Abstract This paper demonstrates that speckle interferometry of close double stars (Rho < 1″) can be done with a small (11 inch aperture) telescope equipped with a sensitive, low noise, and low read-noise CMOS camera.

Introduction

For the past several years I have not been active in double star observations while I became quite involved with high resolution planetary imaging. In the early years we did this with ordinary webcams like the Philips ToUcam, but more recently we began to use what I call "industrial strength" webcams: cameras developed by firms like The Imaging Source and Point Gray for machine vision and surveillance applications, but inexpensive enough for amateurs to afford and quite suitable for high resolution planetary work. For this we employed the so-called "lucky imaging" approach of aligning and stacking the best frames from videos taken at focal ratios long enough for Nyquist sampling of the planetary images.

This area of amateur involvement has progressed rapidly to the point that we can now routinely take images of the Moon, Mars, Jupiter, and Saturn that not too many years ago took a NASA mission to obtain. For much of this period the cameras we used were based on mature CCD technology, but in recent years, cameras based upon sensitive, low noise CMOS sensors have become available, notably, the ASI series of cameras from ZWO. The amateur planetary imaging community immediately began to use them. As a result, when I read (on the Binary-Stars-Uncensored Yahoo discussion group) that the new low read-noise chips from Sony might make it possible for amateur astronomers to get into speckle interferometry, a province heretofore only possible with 2 meter class telescopes and very expensive EMCCD cameras, I found that I already had in my possession just the camera to try this out. In the report that follows, I present my speckle interferometric measures of close double stars made with this remarkable camera, a modest eleven inch aperture telescope, and the formidable number crunching capability of a home computer running software developed by fellow amateur astronomers.

My Equipment

I use a Celestron CPC-1100EdgeHD telescope. The telescope is fork mounted and computer controlled with GoTo RA and Dec capability. It is an excellent telescope for planetary imaging and, as it turns out, speckle interferometry. Its native focal ratio is f/10, but for the observations reported here, I used a 3x Televue Barlow lens to amplify the focal ratio to f/31.14. A remote motorized focuser is needed for both the planetary work I do and is very helpful for the speckle imaging too. Mine is a Baader SteelDrive Crayford type focuser. I initially set it at 1.5 cm and adjust the focus with the mirror moving focuser, and then lock the mirror down and do all subsequent focusing with the motorized focuser. This is to maintain the same focal ratio and image scale throughout all my observations.

My primary imaging camera is the ZWO ASI224MC with an uncooled 4.8x3.6 mm Sony IMX224 sensor having a 1296x960 array of 3.75 micron pixels overlaid by a Bayer matrix RGB filter. The camera is described in detail elsewhere in this journal (Genet et al. 2015). I also use an Imaging Source DBK21 camera fitted with a 70mm, f/1.3 C-mount lens as a video finder. Without the video finder, locating the faint doubles in the light polluted skies of central NJ would be difficult if not impossible, even with a GoTo telescope mount. My setup is shown in Figure 1.

Figure 1. Telescope with attached cameras

Software and Computer

The cameras are connected by USB cables to my personal computer running Windows 10 Pro. I use Torsten Edelmann's FireCapture[1] to record the speckle images from the ASI224MC. I use IC Capture (supplied by The Imaging Source[2]) to give a 2.4x1.8 degree view of the sky through the video finder using the DBK21. An overlay with a movable double crosshair from Al's Reticule[3] allows me to accurately position faint double stars so they become visible in the tiny 1.69' x 1.25' field of the imaging camera.

To process the speckle images, I use David Rowe's PS3 program[4], initially developed as a plate solve program, but with added tools for constructing and processing FITS cubes and for displaying speckle autocorrelograms and interferograms. For drift calibration and other functions I use Florent Losse's REDUC[5] and MaximDL[6]. For the lucky imaging comparison with speckle results I used Emil Krailkamp's Autostakkert 2.5[7] and Cor Berrevoit's Registax6[8].

[1] http://www.firecapture.de/
[2] http://www.astronomycameras.com/products/software/iccaptureas/
[3] http://www.iceinspace.com.au/forum/showthread.php?t=21798&page=3
[4] http://jdso.org/volume10/number4/Genet140912.pdf
[5] http://www.astrosurf.com/hfosaf/uk/tdownload.htm
[6] http://www.cyanogen.com/maxim_main.php
[7] http://www.autostakkert.com/wp/download/
[8] http://www.astronomie.be/registax/

My computer was built for me by PC Warehouse and contains a 7-core Intel processor running at 3.6 gigaherz and is equipped with 7.25 terrabytes of hard disc storage and 15 gigabytes of RAM. For this work, you need lot of storage space.

Calibration

My camera calibration was based upon a trailed exposure of Albireo giving a camera angle (Delta) value of 0.4465°. The scale factor (E) of 0.0889″/pixel was from the measurement of the separation of the components of Albireo in a lucky image stack using MaximDL for measuring the separation of the centroids of the components. After the measures on September 12, the camera was rotated slightly and a new Delta calibration obtained using REDUC on a series of FITS images taken of Albireo while the star drifted through the field of the camera. The new Delta value of -12.75° was used for the remainder of the measures.

I intend to calibrate the focal length of my system by imaging a bright star through an H-a filter and a coarse grating. The plate scale from this calibration will be used in my future observations.

The Targets

My initial speckle interferometry targets were picked from a list prepared by Richard Harshaw from entries in the WDS. Additional targets were taken from the 20-hour RA section of WDS, as the targets from Richard's list began to be significantly west of the meridian when I began my observing sessions. I tried to pick known doubles with Rho values below 2 arc seconds and brighter than 12th magnitude, and I attempted to make my observations when the stars were as close to the meridian as possible.

The Results

Table 1 shows my measures on 19 stars, several of which are discussed below.

WDS 19177-2302

The first set of five measures was done on BU249AB, a 5.43, 8.75 magnitude pair with a Rho value of 1.7″, last measured in 2013. I chose this double as an easy target to start with and to see how reproducible my measures were. I used relatively high gain settings on the camera, in the range of 492-600 (maximum is 600) and exposures of from 2.9 to 7.5 milliseconds. My average Theta of 126.6 ± 2.1° and Rho of 1.74 ± 0.02″ are consistent with the most recent WDS measures.

WDS 19224+4205

I also took multiple measures of A 592, a severe test for an 11-inch aperture and low cost camera, since the last reported value for Rho was only 0.6″, and both components are fainter than 10^{th} magnitude. I obtained an average Theta of 238.8 ± 6.2° and an average Rho of 0.69 ± 0.02″ from my five observations. Compare this with the last reported values in the WDS of 247° and 0.6″. The large uncertainty in Theta is in part due to the closeness of the pair.

WDS 19338+4222

The final system for which I have variance information is A 597. My five observations of gave an average Theta of 81.9 ± 0.6° and an average Rho of 1.69 ± 0.07″. Compare these values with 84° and 1.4″ as the last reported values in the WDS.

The remainder of the observations reported here consist of only one set of FITS files each consisting of 300 to 3500 speckle images that were processed into autocorrelograms which resolved the components of the double and allowed me to estimate the Theta and Rho values, but with no information about the variance.

WDS 19202+3411

HU 1300 is notable in being quite a close pair with a last reported Rho of only 0.7″. I got 0.74″ with a Theta of 184.23° compared with the WDS last reported Theta of 182°.

WDS 19214+4831

TDS 983 is also notable in that there was only one previous measure and that by the Hipparcos satellite. My measures of Theta = 82.34°, Rho = 1.12″ are close but not identical to the 1991 value of Hipparcos of 79° and 0.9″, but in 24 years perhaps this much motion could take place.

WDS 19238+3119

A 2196BC is part of a triple star system with AG 230A,BC. The very close BC pair with a Rho of only 0.7″ is probably at the very edge of the capability of my telescope and camera system and is not completely resolved in my autocorrelograms. My measure of Rho is 0.77″ and I get a significantly different Theta of 188° compared with the 2008 value of 234° in the WDS. I also report a measure for the wide pair in the system AG 230A,BC. I get Theta = 71.11°, Rho = 5.64″ in reasonable agreement with 70°, and 5.5″ as last reported in the WDS.

WDS 10010+3742

Another very close double is BU 1289AB. The WDS last reported values from 2012 are Theta = 54°, and Rho = 0.7″. I got 55.11° and 0.73″.

If you plot my measures of all 19 stars against the latest measures in the WDS you get a reasonable correlation except at very small Rho values. This is most likely uncertainty in the measures, but it could be actual changes in the positions of the stars. More observations are necessary to verify whether this is the case. Figure 2 is a plot of my observations of Theta vs the last reported values in the WDS and Figure 3 is a plot of my observations of Rho vs the last reported values in the WDS.

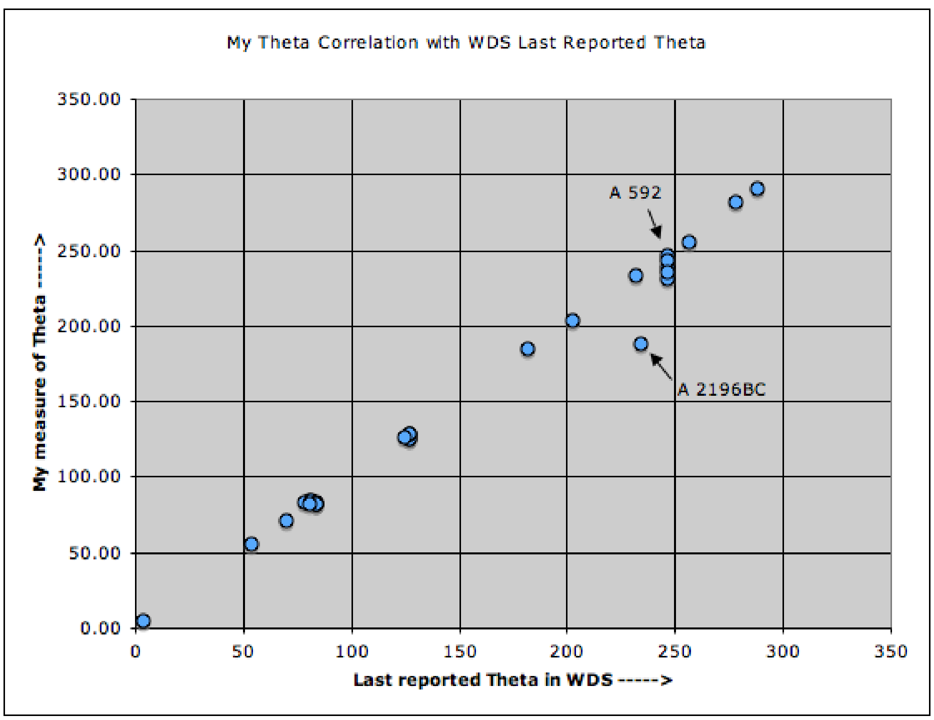

Figure 2. My measures of Theta vs. last reported value in WDS

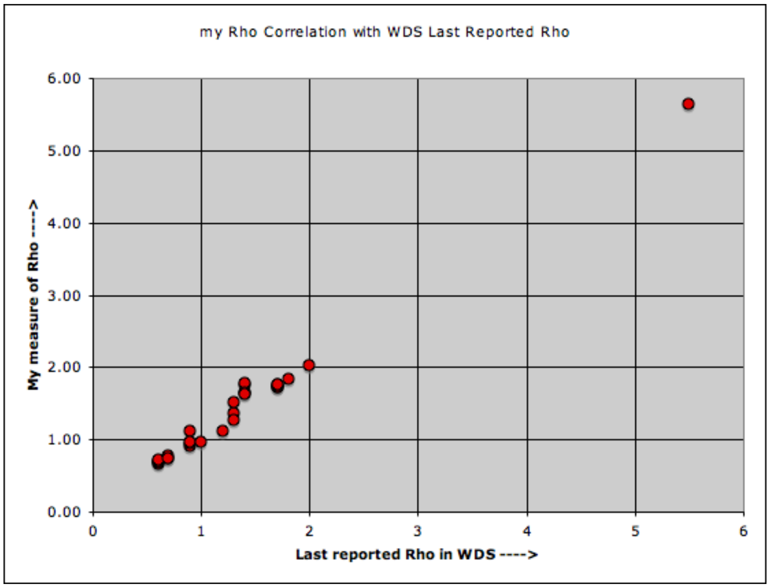

Figure 3. My measures of Rho vs. last reported value in WDS

I was also able to obtain lucky images for several of the stars to compare with the autocorrelograms from speckle interferometry. These images were obtained by aligning and stacking the best 5% of the frames from either AVI files or the FITS that were used to make the FITS cubes for the speckle work using the program Autostakkert 2.5. The result were sharpened with wavelets using Registax6. This comparison is shown below in Figure 4. Measurements of the double stars could be made from the lucky images, but would not be nearly as high in precision as those obtained from the autocorrelograms. They are useful, however, in helping to resolve the 180 degree phase ambiguity of speckle interferometry. Thus far, any double I have resolved by speckle interferometry has also shown at least partial resolution (enough to resolve the ambiguity) by lucky imaging.

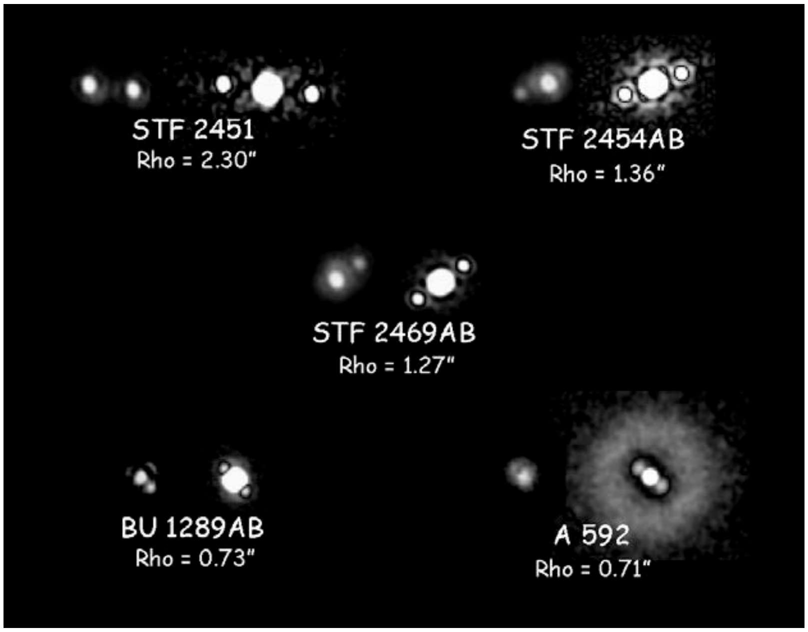

Figure 4. Comparison of Lucky Images with Autocorrelograms

Conclusions

These results demonstrate that one can resolve close double stars by speckle interferometry using the new low read-noise CMOS cameras on small telescopes. I plan to continue work in this area to better define its potential and to make measures of double stars with Rho values in the 1″ to 5″ and magnitudes as faint as 10 or 11 suitable for inclusion in the WDS, and to use the ASI224MC for speckle work on larger telescopes, such as the 24” Ritchey-Chrétien at Sperry Observatory. A particularly useful application of this technology would be to check suspected close doubles for later measurement with speckle cameras on larger telescopes.

Acknowledgements

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Reference

Genet, R., Rowe, D., Ashcraft, C., Wen, S., Jones, G., Schillings, R., Harshaw, R., Ray, J., and Hass, J. 2015. Speckle interferometry of close visual binaries. *Journal of Double Star Observations*, Vol.12 No.3, 270.

Table 1. Observations

See below

Table 1. Observations

WDS Identifier	Discoverer Code	Epoch First	Epoch Last	# Obs.	Theta, ° First	Theta, ° Last	Rho " First	Rho " Last	Magnitudes Pri	Magnitudes Sec	Date M/D/YY	Camera Gain	Exp. ms.	Frames taken	Theta degrees	Rho arc sec.	Notes
					Camera oriented with North approximately down in final image, camera angle = -0.4465 degrees												1
19177+2302	BU 248AB	1875	2013	62	125	127	1.9	1.7	5.43	8.75	9/1/15	583	7	4152	124.3	1.73	
19177+2302	BU 248AB	1875	2013	62	125	127	1.9	1.7	5.43	8.75	9/2/15	582	7	3307	124.2	1.71	
19177+2302	BU 248AB	1875	2013	62	125	127	1.9	1.7	5.43	8.75	9/5/15	492	3	1471	128.3	1.76	
19177+2302	BU 248AB	1875	2013	62	125	127	1.9	1.7	5.43	8.75	9/5/15	600	3	2225	128.2	1.74	
19177+2302	BU 248AB	1875	2013	62	125	127	1.9	1.7	5.43	8.75	9/5/15	481	8	652	127.9	1.77	
20396+4035	STT 410AB	1843	2013	131	23	4	0.5	0.9	6.73	6.83	9/6/15	556	7	1208	4.5	0.92	
19030+5135	STF 2451	1831	2011	53	58	81	2.6	2	9.29	9.47	9/7/15	532	59	508	84.0	2.03	
19062+3026	STF 2454AB	1831	2013	175	205	288	0.8	1.3	8.34	9.72	9/7/15	532	61	494	290.9	1.36	
19078+3856	STF 2469AB	1831	2010	51	121	125	1.3	1.3	7.93	9.13	9/7/15	532	42	669	126.3	1.27	
19190+3916	STF 2502	1831	2012	19	206	203	1.8	1.2	8.06	10.3	9/7/15	532	42	708	203.4	1.12	
19202+3411	HU 1300	1904	2012	15	172	182	0.8	0.7	8.92	9.56	9/8/15	532	57	528	184.2	0.74	
19214+4831	TDS 983	1991	1991	1	79	79	0.9	0.9	9.78	11.12	9/8/15	532	94	321	82.3	1.12	
19222+2230	BU 141AB	1873	2010	41	85	82	0.4	0.9	7.61	9.21	9/8/15	556	7	3229	83.9	0.94	
19224+4205	A 592	1903	2010	14	217	247	0.3	0.6	10.11	10.52	9/8/15	532	99	305	246.4	0.67	
19238+3119	AG 230A,BC	1902	2008	16	74	70	5.5	5.5	9.76	10.8	9/11/15	600	100	901	71.1	5.64	
19238+3119	A 2196BC	1910	2008	8	234	234	0.6	0.7	10.8	11.2	9/11/15	600	100	901	188.0	0.77	
19241+4626	STT 373	1843	1991	20	233	232	1.8	1.8	7.63	9.93	9/11/15	600	26	3515	233.5	1.84	
19258+2328	DOO 74	1904	1991	5	252	257	1	1.3	10.04	10.99	9/12/15	600	100	901	254.9	1.52	
					Camera rotated about 12 degrees counterclockwise before next data set, camera angle = -12.75 degrees												2
19224+4205	A 592	1903	2010	14	217	247	0.3	0.6	10.11	10.52	9/13/15	600	97	6172	238.3	0.69	
19338+4222	A 597	1903	2008	33	154	84	1.1	1.4	8.28	10.8	9/14/15	500	75	4003	81.6	1.64	
19338+4222	A 597	1903	2008	33	154	84	1.1	1.4	8.28	10.8	9/15/15	500	80	7958	83.0	1.76	
19338+4222	A 597	1903	2008	33	154	84	1.1	1.4	8.28	10.8	9/15/15	500	75	7959	81.9	1.78	
19224+4205	A 592	1903	2010	14	217	247	0.3	0.6	10.11	10.52	9/17/15	600	80	2245	231.1	0.70	
19338+4222	A 597	1903	2008	33	154	84	1.1	1.4	8.28	10.8	9/17/15	600	40	4470	81.5	1.64	
19224+4205	A 592	1903	2010	14	217	247	0.3	0.6	10.11	10.52	9/17/15	600	100	1801	243.4	0.69	
19224+4205	A 592	1903	2010	14	217	247	0.3	0.6	10.11	10.52	9/17/15	600	120	1501	235.0	0.72	
19338+4222	A 597	1903	2008	33	154	84	1.1	1.4	8.28	10.8	9/17/15	600	80	2246	81.8	1.63	
20137+1609	STF 2651AB	1830	2011	84	280	278	1.6	0.9	8.41	8.44	9/19/15	600	20	8912	282.0	0.97	A 592
20074+3543	STT 398AB	1845	2012	31	62	81	0.8	1	7.45	9.2	9/19/15	600	20	8897	82.0	0.96	
10010+3742	BU 1289AB	1899	2012	19	58	54	0.8	0.7	8.15	9.2	9/23/15	600	40	5000	55.1	0.73	

Notes

1 Albireo, drift gives delta = -0.44656 degrees, stack of all frames gives FITS file measured in MaximDL for scale factor= 0.0889" per pixel

2 Albireo trail of FITS REDUC gives Delta = -12.75 degrees, no change in scale factor.