Measurements of 42 Wide CPM Pairs with a CCD

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Abstract: This paper addresses the use of a Skyris 618C color CCD camera as a means of obtaining data for analysis in the measurement of wide common proper motion stars. The equipment setup is described and data collection procedure outlined. Results of the measures of 42 CPM stars are presented, showing the Skyris is a reliable device for the measurement of double stars.

Introduction

In late 2014, the author acquired a Celestron Skyris 618C CCD camera (made by The Imaging Source of Germany) for use as a speckle interferometry camera. The Skyris has a wide range of shutter speeds (integration times) from 0.0001 seconds to 30 seconds, making it an ideal speckle instrument. The observing project reported here was conducted to test the calibration results and assess the viability of the Skyris as a strong CCD and speckle platform.

After carefully calibrating the Skyris with the three focal-ratio setups used at Brilliant Sky Observatory [Harshaw 2015], a test run was set up to measure wider common proper motion (CPM) pairs to validate the calibration of the camera and to gain experience with the critical skills of exposure settings, gain, and drift analysis (for obtaining the camera angle).

Drift analysis is a technique made possible by Florent Losse's reduction program REDUC [Losse, 2014] and consists of placing a bright star on the east edge of the camera chip and then turning off the telescope's clock drive, letting the earth's rotation carry the star to the west side of the chip, at which point the drive is repowered. This method allows a precise determination of true north and is independent of any polar alignment errors that may be inherent in the telescope mount. Similar work has been reported by Iverson and Nugent [2015].

The first round of observations focused on 42 pairs that met these criteria: they could be observed when within one hour of the meridian (to reduce air mass) in the first quarter of 2015 and could easily be resolved in the camera at f/10 (field of view being 240 minutes by 180 minutes), f/25 (FOV 99 min by 74 min) or f/50 (44 min by 33 min). In addition, the stars needed to be north of -20° declination (again, to avoid air mass issues) and of magnitude 11.00 or brighter. The Washington Double Star Catalog was downloaded from the U. S. Naval Observatory and a filter created to extract qualifying pairs. From a list of over 2,500 pairs, stars were chosen that exhibited common proper motion and had not shown any significant motion in decades, if not centuries.

After obtaining the video data files, the images were analyzed using two programs. One (already mentioned) was Losse's REDUC version 4.47, and the other is called Plate Solve version 3.33, a program written by David Rowe, chief technical officer for PlaneWave Instruments. I obtained Plate Solve from its author via private emails as Plate Solve is still in development and not in general release to the public (although Mr. Rowe would probably provide a copy to any who requested it; contact the author for Mr. Rowe's email). REDUC can be obtained by sending an email requesting a copy to Mr. Losse at his Yahoo account, florent_losse@yahoo.fr.

REDUC is well-known to the amateur double star CCD community and will not be explained in detail here. Plate Solve, however, takes a different approach to the problem of resolving double stars captured by a CCD camera. Because of these differences in design, the author wanted to compare the outputs of both pro-

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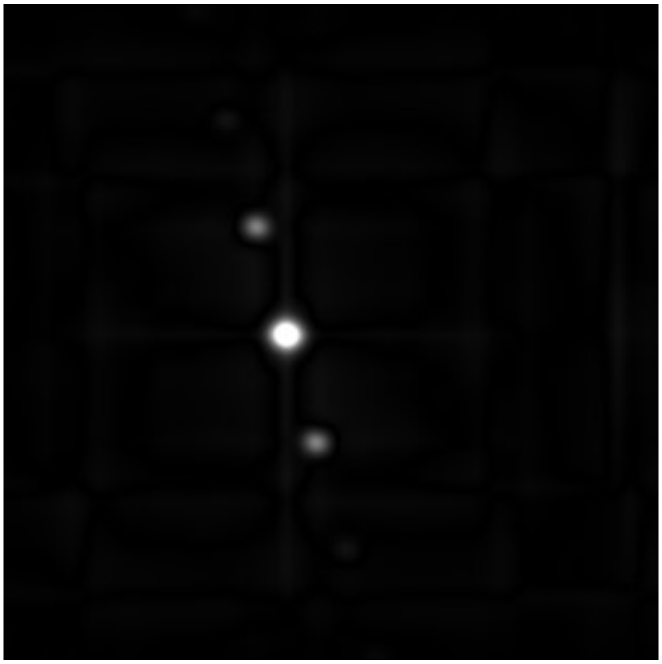

Figure 1. Autocorellogram of STF1627 by Plate Solve.

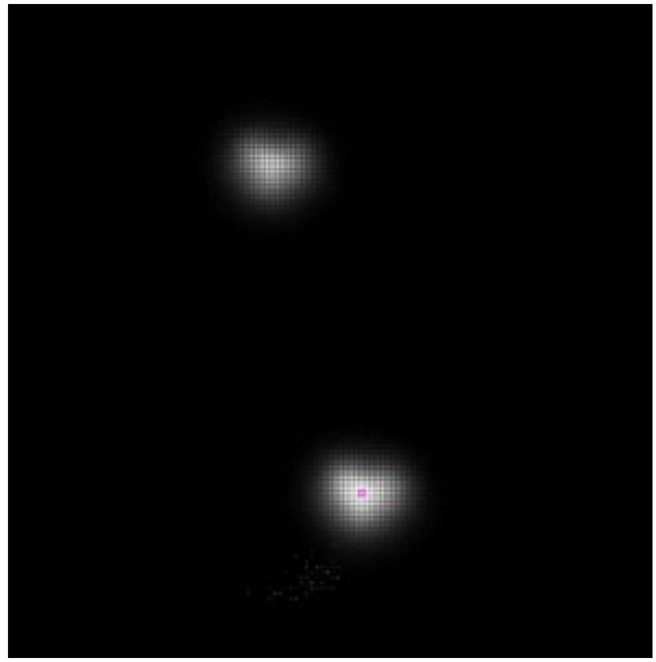

Figure 2. STF1627 as rendered by the align and stack function in REDUC.

grams. Napier-Munn and Jenkinson [2014] have already documented well the issues surrounding accurate reduction using REDUC.

Plate Solve began its incarnation as a program that did what its name says—analyze a wide field frame and determine the plate scale and camera angle by comparing the imaged stars to known stars. But as time went on and Mr. Rowe became more actively involved in the speckle interferometry community, he began to add powerful features to Plate Solve that make it, in this author's opinion, one of the most powerful and accurate programs of its kind in existence [Genet, Rowe 2014].

For speckle interferometry, Plate Solve uses a Fourier Transform algorithm to reduce the vast amount of data in what is known as a FITS cube (Flexible Image Transport System), a cube being a stack of 1,000 individual FITS frames. Plate Solve analyzes the energy density of each pixel in each frame and accurately determines the point spread function (PSF) of the starlight and then builds the power spectrum from that information. The power spectrum is then displayed in an image called an autocorellogram. An example of an autocorellogram is shown in Figure 1.

The autocorellogram produces a symmetric image due to the symmetry of the power spectrum function. Note the clean appearance of the image, and also note that the autocorellogram is technically a graphical display of the power spectrum of the star, not the actual star images themselves. However, since the power spectrum functions will be congruent with the centroids of the stars, it is, for all practical purposes, an image of the double star.

Compare that to the stacked and aligned image generated by REDUC shown in Figure 2.

Note that in the REDUC image, the centroid of the primary star is marked by a pink pixel. But where is the centroid for the companion star? It must be selected by hand, and this is (in this author's opinion) a weakness that Plate Solve addresses automatically.

An added bonus of using Plate Solve is that every FITS cube generates a symmetric autocorellogram. By measuring what Plate Solve thinks is the companion, one can get a solution for theta and rho. And by selecting the mirror image of the companion, one can get a complimentary solution (after adding or subtracting 180° to theta), so that each FITS cube lets the researcher derive two measurements of theta and rho. In a good, clean FITS file (very high signal-to-noise ratio) the mirror image measurement will exactly equal the main measurement (except for theta being 180° larger or smaller than the main measurement). When the FITS cube quality is not quite as good as it could be, the mirror image measures will often be very close to (but not equal to) the main measurements.

Although designed to do speckle analysis of extremely close pairs (rho less than 5"), Plate Solve does a superb job of analyzing *any* two stars that can fit on the camera's field of view.

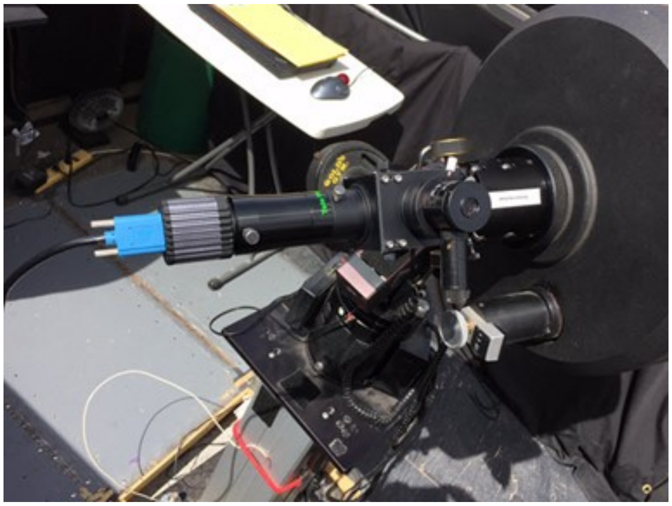

Figure 3: The C-11 set up for imaging.

2. Equipment Used

The equipment used for the measurements reported in this paper were obtained with a Celestron C-11 SCT telescope mounted on a CI-700 equatorial mount permanent set on a permanent pier in Brilliant Sky Observatory, the author's observatory in the back yard of his home. Figure 3 shows the optical train used for both f/25 and f/50 imaging.

In Figure 3, the components of the optical train are (from left to right): USB cable to computer (blue plug at end of camera), the Skyris 618C, a Televue PowerMate (2.5x or 5.0x model, depending on focal ratio desired), Orion 2-inch flip mirror, Celestron MicroGuide acquisition eyepiece, JMI Crayford focuser (bottomed out and locked in place), and, just below the Crayford, a JMI digital focus counter for the C-11 primary focus.

By locking the Crayford focuser in its bottomed-out position and using a digital focus counter, the mirror position of the SCT could always be set at precisely the same point as used during the calibration process. This insures that the pixel scale on the camera remains constant from one run to another.

3. Methodology

Stars were acquired by the use of the mount's digital setting circles. Once the star was located, a 32mm Plössl eyepiece with a wide field of view was used to center the star in the Plössl's field of view. At that point, the Plössl was switched out for the 12.5mm Celestron MicroGuide at which point the star was centered on the MicroGuide's central scale. The flip mirror was then moved to the camera position and the star centered on the camera chip. Any minute adjustments needed for focus were made (sometimes, the focus had to move as many as 8 counts on the readout—perhaps 1/10 of a revolution or so of the focus knob, not enough to cause problems with pixel calibration). The camera integration time and gain were set to give a good image on the computer screen. Once everything was ready, the camera would be instructed to start recording data. The data was sent to a 2TB external hard disk drive via a Lenovo laptop computer.

For brighter pairs, 100 frames were obtained; for fainter ones, 200 frames were obtained and the best 50% (based on signal to noise ratio) were kept. Each 100 frame set was then "bound" into a FITS cube using the FITS cube compilation feature of REDUC. FITS cubes were then pre-processed using Plate Solve. (Preprocessing does the fundamental Fourier Transform on each image in the FITS cube and saves a great deal of time during final processing as well as disk space.)

If the pair being measured was faint, integration times had to be set fairly long and the gain run up fairly high to obtain an image. In such cases, a dark frame was also made so REDUC could subtract the darks from the images.

Finally, a drift image was made. This is a vital step in doing CCD astrometry as it is imperative to accurately determine the camera angel with respect to true north. It was quickly learned that if the camera was not touched during the night, that the best stars to use for a drift file were bright ones (such as Capella or Arcturus). A bright star leads to very short integration times which in turn means a large number of frames for the drift file.

The drift file would then be analyzed in REDUC using the Drift Analysis function. To insure accuracy and reduce errors, on average ten drift analyses were done per drift file, selecting different and ending images for the analysis. (This is important because as the star drifts across the camera chip, turbulence causes it to dance. The star could jump several pixels between two consecutive frames. Doing multiple starting and stopping frames helped eliminate these spurious images as sources of error.)

Processed FITS cubes were then fed into Plate Solve using the Speckle Reduction function (even though the stars under study were not being analyzed with speckle). The camera angle and pixel scale were given to Plate Solve, which then determined the values for theta and rho directly from the autocorellogram. See Figure 4.

4. Results

Results of all measurements are shown in Table 1.

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Table 1: CCD Measurements of Double Stars

WDS No.	ID	Date Observed	f ratio	No. Obs.	Measured Theta	Measured Rho	Std. Dev. Theta	Std. Dev. Rho	Std. Errors Theta	Std. Errors Rho	Residuals Theta	Residuals Rho	Notes
08122+1739	STF1196AB-C	2015.312	50	3	67.629	6.058	0.072	0.011	0.042	0.006	-1.371	-0.042	
08268+2656	STF1223	2015.285	50	10	218.526	5.255	0.207	0.009	0.119	0.005	2.526	-0.145	CPM
08399+1933	S 571AC	2015.332	25	10	156.394	45.136	0.294	0.135	0.093	0.043	-0.606	0.036	CPM
08467+2846	STF1268	2015.332	25	8	307.839	30.125	0.773	0.210	0.247	0.074	2.839	-0.875	CPM
09001-0706	WFC 247	2015.356	25	1	58.234	11.107	N/A	N/A	N/A	N/A	0.234	-1.593	CPM
10040-1806	STF1520	2015.351	25	6	274.386	21.139	0.171	0.069	0.070	0.028	0.386	-0.061	
10178+7104	STF1415AB	2015.351	25	10	167.851	16.553	0.173	0.059	0.055	0.019	0.851	-0.047	1
10320+2202	STF1442	2015.357	25	10	156.685	13.091	0.035	0.012	0.011	0.004	0.685	-0.109	CPM
10433+0445	STF1466AB	2015.285	50	3	239.948	6.848	0.020	0.006	0.012	0.004	-0.052	0.148	CPM
11016+6627	STF1498AC	2015.351	25	6	292.440	29.078	0.255	0.116	0.104	0.047	0.440	-0.222	CPM
11157-1621	SHJ 372	2015.357	25	8	299.126	18.822	0.064	1.072	0.023	0.379	-0.874	-0.378	CPM
11161+5246	STF1520	2015.351	25	10	344.624	12.392	0.061	0.053	0.035	0.030	1.624	0.292	2
11268+0301	STF1540AB	2015.329	25	2	149.026	28.630	0.031	0.751	0.010	0.237	-0.974	0.430	CPM
11313+5942	STF1544	2015.329	25	10	91.172	12.196	0.181	0.072	0.105	0.011	0.172	-0.104	3
11396+1900	STF1565	2015.357	25	10	303.874	21.689	0.040	0.018	0.013	0.006	-1.126	-0.211	
11520+0850	STF1575	2015.356	25	10	208.860	30.354	0.022	0.008	0.007	0.002	-1.140	-0.146	CPM
11551+4629	STF1579AB-D	2015.329	25	5	113.747	63.191	0.266	0.542	0.119	0.242	-0.253	0.091	CPM
12081+5528	STF1603	2015.357	25	10	82.427	22.112	0.008	0.010	0.003	0.003	-0.573	-0.088	CPM
12162+8008	STF1625AB	2015.357	25	10	216.995	14.454	0.044	0.011	0.014	0.004	-2.005	-0.046	CPM
12182-0357	STF1627	2015.329	25	2	196.429	19.927	0.268	0.006	0.155	0.004	-0.572	-0.674	CPM
12182-0357	STF1627	2015.356	25	10	194.852	19.884	0.545	0.019	0.172	0.006	-2.148	-0.716	CPM
12225+0518	STF1636	2015.357	25	8	336.894	20.920	0.020	0.035	0.007	0.012	-0.106	0.012	CPM
12351+1823	STF1657	2015.357	25	10	269.921	20.055	0.033	0.015	0.010	0.005	-0.079	-0.045	
12453-0353	STF1677	2015.357	25	10	348.440	15.915	0.538	0.334	0.170	0.011	0.440	-0.085	CPM
12492+8325	STF1694AB	2015.356	25	10	323.985	21.318	0.121	0.041	0.038	0.013	-0.015	0.418	CPM
12519+1910	STF1685AB	2015.356	25	10	200.416	15.779	0.058	0.024	0.018	0.008	-0.584	-0.121	CPM
12560+3819	STF1692	2015.329	25	3	229.735	19.157	0.227	0.020	0.131	0.011	0.735	-0.043	CPM
12560+3819	STF1692	2015.351	25	3	227.291	19.381	0.031	0.008	0.010	0.003	-1.709	0.181	CPM
13237+0243	STF1740	2015.329	25	2	75.401	26.226	0.004	0.012	0.001	0.004	1.401	-0.074	CPM
13237+0243	STF1740	2015.356	25	10	74.221	26.055	0.035	0.022	0.011	0.007	0.221	-0.245	CPM
13239+5456	STF1744AB	2015.351	25	10	153.065	14.449	0.334	0.047	0.106	0.015	0.065	-0.051	CPM
13381+3910	STF1769AC	2015.329	25	6	258.679	56.459	0.722	0.426	0.323	0.191	-1.321	0.159	4
14020+1926	STF1797	2015.356	25	8	157.878	20.697	0.052	0.008	0.018	0.003	-0.122	-0.104	
14020+5713	STF1800AB-C	2015.356	25	8	19.940	28.362	0.031	0.021	0.011	0.007	-1.060	-0.238	CPM
14056-1804	S 659	2015.356	25	8	169.957	31.110	0.032	0.015	0.011	0.005	-0.043	-0.090	
14068+5946	LDS2700AB	2015.329	25	6	149.819	48.978	0.801	0.518	0.327	0.212	-1.181	0.478	5
14234+0827	STF1835A-BC	2015.329	50	3	195.206	5.937	0.213	0.013	0.123	0.008	1.206	-0.063	6
14257+2338	BU 1442AB	2015.353	25	4	73.382	45.650	0.247	0.539	0.123	0.269	-0.618	0.350	
14257+2338	BU 1442AC	2015.353	25	4	62.464	75.874	0.517	0.063	0.258	0.031	-12.536	-5.925	7
14298+7355	SKF1233	2015.329	25	6	328.127	48.879	0.701	0.246	0.286	0.100	-2.873	0.079	
14323+8020	STTA130	2015.329	25	7	296.719	51.439	1.721	1.352	0.651	0.511	-2.281	0.239	8

Notes:

1. Linear pattern starting to emerge.
2. Linear pattern; companion moving north.
3. Linear pattern; companion moving north.
4. Analyzed with REDUC only.
5. Analyzed with REDUC only.
6. 2013 has a quadrant flip. CPM pair.
7. Strongly linear plot, C star is very rapid proper motion; probably optical.
8. Analyzed with REDUC only. Very strong linear plot.

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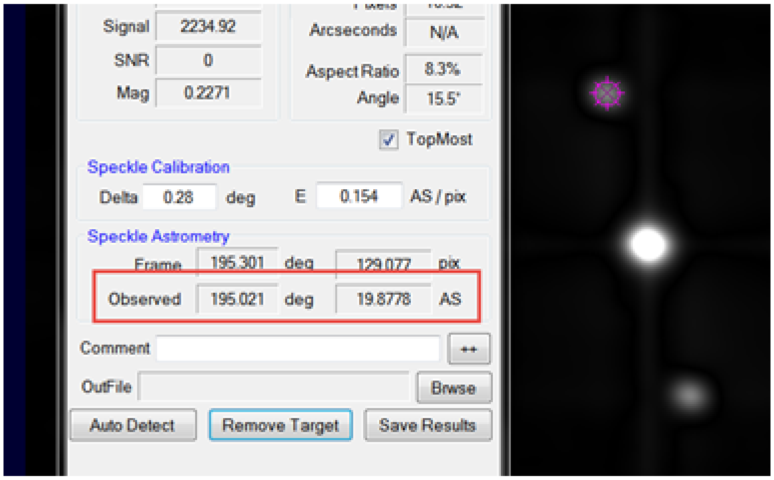

Figure 4: Plate Solve solution for STF1627. Solution shows 195.021° for theta and 19.878" for rho.

Also of note is the difference between the average in residuals for stars analyzed with REDUC versus those analyzed with Plate Solve. Although in no case did the author use *both* programs to analyze data, comparison of the two methods showed that the mean residuals using REDUC were -1.259° theta and +0.242" rho, versus -0.475° theta and -0.279" rho for Plate Solve. Whether these differences are statistically significant or not will need a more robust comparison and the measuring of the same stars with each method to remove the uncertainties caused by using different stars.

6. Conclusion

After careful calibration and proper use in the field, the Skyris 618C can be used to obtain very reliable data sets for double star astrometry.

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5. Discussion

The Skyris, at f/25 and f/50, with the proper integration settings, gain, and processing, does an excellent job of capturing the information needed to make high quality measurements. The measurement histories of each of these stars was obtained from the Washington Double Star Catalog and the data plotted using an Excel spreadsheet the author created for that purpose. This spreadsheet adjusts the value of theta for precession of the equinoxes, and allows the user to plot the latest data point as a special symbol compared to the symbols used for the historical data. Because of this, the latest measure stands out clearly so results can be compared to history to check for conformity (or anomalies).

In every case but one—WDS 09001-0706 (WFC 247)— the results were in excellent agreement with the historical data. Only one measurement of WFC 247 was made, and the data point plotted well away from the cluster of the historical data points, lying approximately 2" away from the data cluster. Clearly more data is needed before a final ruling can be made in this case.

7. Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

8. References

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