High Speed Astrometry of STF 2848 With a Luminera Camera and REDUC Software

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Abstract: The double star STF 2848 was observed at high speed with a Luminera SKYnyx 2-0m camera controlled with Lucam Recorder software. The observations were reduced using the interferometry feature of REDUC, the software developed by Florent Losse. Some 2000 frames were recorded on the first night, and 7500 on the second night. The sensitivity of the results to reduction settings and number of frames was found to be small. The precision of the results was examined both within and between nights, and also as a function of three integration times: 32, 16, and 8 milli-seconds. Finally, these observations were compared with recent published observations.

Introduction

A recently acquired high speed Luminera SKYnyx 2-m CCD camera was used to observe the double star STF 2848 at high speed. The objectives of these observations were to: (1) gain experience with this camera and its associated Lucan Recorder software, (2) learn how to reduce these observations with the recent interferometry addition to Florent Losse's REDUC program, (3) explore the effects of changing reduction and observational parameters on the precision of the results, and (4) compare my observations with recent past observations.

Figure 1: The author and 10-inch telescope at the Orion Observatory. The laptop on the left controls the telescope and acquisition camera, while the laptop on the right controls the high-speed Luminera camera.

The Carro Double Star Catalog (Carro 2012) was used to search for an appropriate double for these initial observations. STF 2848 (WDS 21580 +0556, SAO 127196) was well positioned in the sky, and its separation of almost 11 arc seconds made it easy to observe without the complication of using a Barlow lens. While my eventual goal is speckle interfreometry measurements of much closer double stars with larger telescopes, I purposely began with this rather wide double and small telescope (without any Barlow magnification) to simplify these initial observations. As expected, the short effective focal length (only

Figure 2: Instrument cluster on the back of the 10-inch telescope. An Orion Telescopes flip mirror is directly below the telescope, with the Luminera high speed camera to the left of the flip mirror and the SBIG ST-402 camera below it.

about 100 inches—2540 mm) did not bring out true speckles, although one could observe “splotches” dancing about at high speed.

Observations were made on the evenings of September 19 and 21, 2012, at the Orion Observatory near Santa Margarita Lake, just inland from San Luis Obispo on California’s central coast. The observatory has 8-, 10-, and 11-inch Schmidt-Cassegrain telescopes

Telescope and Instrument Configuration

Observations were made with the Meade 10-inch, f/10 Schmidt Cassegrain, equatorial, fork-mounted telescope shown in Figure 1. The original LX-200 control system was replaced with a Sidereal Technology (SiTech) control system. SiTech control systems have numerous advanced features, and are utilized on many telescopes large and small. The telescope was controlled from a laptop running the SiTech software, The Sky 6, and CCD Soft (to control the acquisition CCD camera).

The overall instrument layout is shown in Figure 2. An Orion Telescopes 1.25 inch flip mirror was modified by replacing its 1.25 inch female nose piece with an SCT threaded coupler. This not only allowed the flip mirror to be more firmly coupled to the backplane of the telescope, but also provided additional, much needed clearance between the telescope and the equatorial wedge.

There was insufficient clearance below the fork on this telescope to have a “straight through” optical path through the flip mirror leading directly to the Luminera camera. Although it might have been desirable to avoid any distortions introduced by the flip mirror, there simply wasn’t enough clearance for this option.

Lumenera Camera and Lucam Recorder Software

A high speed camera, the Luminera SKYnyx 2-0M, was used for the observations. This camera, made in Canada, currently costs $1095 (Oceanside Photo Optical USD). It employs a Sony IXC424 monochrome progressive scan CCD sensor with 480x640 (4.9 x 5.3 mm) square 7.4 micron pixels. Although the camera was designed for astrophotography of the Moon and planets (lucky imaging), it is also useful for scientific observations such as double star speckle interferometry, high speed photometry of variable stars, asteroid occultations of background stars, and lunar occultations of double stars.

The camera’s well depth is 40,000 electrons, with a read noise of 10 electrons and a dark noise of < 1 electron/second (the camera is not cooled). Full frames can be read out at 60 frames/second. Both power and communications are provided through a standard USB 2.0 interface. The camera weighs 320 grams and features a solid anodized aluminum body which measures 2.5 x 3.8 x 1.7 inches.

Integration times can be varied from 1 millisecond to many seconds, and the gain, gamma function, and contrast settings can all be varied through the controlling software. Output can be set to 8 or 12 bits, and 2x2 binning can be employed. Of significant interest to double star observers (and those with an interest in high speed photometry) is a completely software settable Region of Interest (RoI). A small RoI not only reduces data storage and transmission requirements, but it allows faster frame rates. For the observations reported in this paper a RoI of only 64x64 pixels was used, allowing frame rates of up to 116 frames/second.

The Lumenera camera is supported by several third party software suites such as Maxim DL. I used Lucam Recorder, developed by Heiko Wilkens. A free, limited version Lucam Recorder can be downloaded from the Internet. A license for an advanced version can be purchased for a modest fee. The license, which is camera serial number specific, can be used on any number of computers. Lucam Recorder is easy to use, well thought out, and has many fine features.

REDUC Speckle Interferometry Reduction Software

Florent Losse's REDUC double star reduction and analysis software has been refined over the years and is used by many double star observers around the world. This free software is user friendly and well documented. Losse recently added an interferometry reduction capability to his software suite.

The interferometry feature is easy to use. One loads in the observations, which can be in FITS (8, 16, or 32 bit integer, or 32 or 64 bit real), Bitmap, or AVI. REDUC has provisions for converting AVI files to Bitmap before proceeding. One then clicks Auto Correlation. The program automatically conducts a fast Fourier transform (FFT) if the images are square (such as 64x64, 128x128, etc., pixels). If the images are not square, REDUC has a routine to square them. REDUC even has a procedure to take care of non-square individual pixels.

The autocorrelation diagram (image), i.e., the "autocorrelogram," labeled as S0 is difficult to use directly because the peaks are often imbedded in noise and hence are difficult to measure. To overcome this difficulty, the autocorrelogram is repeatedly processed by subtracting a mean mask that uses a growing kernel of 3x3, 5x5, … 19x19 pixels. These are labeled S1 – S9, respectively. One can then choose an autocorrelogram appropriate to the observational situation. Losse suggests that for an Airy disk of 2 or 3 pixels to use S2, an Airy disk of 5 pixels to use S3, etc.

The position angle of the double star as measured from the autocorrelogram normally has an ambiguity of 180°. This ambiguity is inherent in the usual speckle reduction process. The brighter star will always be flanked by two identical dimmer stars exactly 180° apart. If one knows from other (previous) observations the approximate position angle, then this ambiguity is resolved. If not, then one either needs to obtain at least a rough position angle by other means (such as lucky imaging), or one can use the REDUC Cross Correlation feature if the two components of the double star are of significantly different brightness. The ambiguity will then be resolved in the cross correlation autocorrelogram as one of the two flanking stars will be noticeably dimmer than the other.

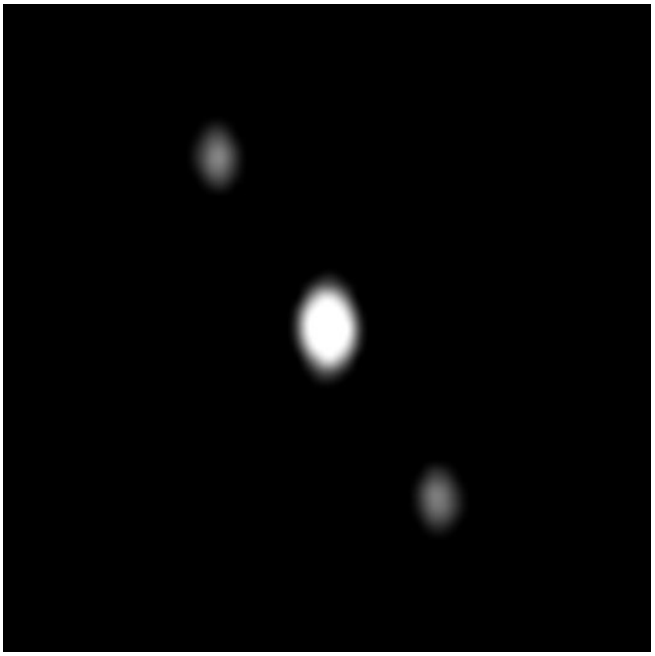

Figure 3: Typical autocorrelogram from REDUC. This one is of STF 2848 from 500 frames taken on the first night. Measurement of the position angle and separation from the centroid of the central image to either of the two flanking images provides the result, albeit with a 180° ambiguity.

Instead of calculating a normal Autocorrelation, the autocorrelation can be calculated with an Enhanced Power Spectrum, which is calculated with the square of the images. This procedure increases the contrast of the fringes during the creation of the power spectrum.

Camera Calibration

The orientation and plate scale of the Luminera camera were determined though astrometry of M-39 on the evening of September 21, 2012 (the camera had remained in place for both nights). Two 20-second images were taken, slightly offset from the center of M-39 to avoid the brightest stars. The two images were offset from each other by about 1 minute of arc to provide independent astrometric solutions.

CCD Soft, linked to The Sky 6, was used to obtain the two astrometric solutions. The solutions both yielded a plate scale of 0.54 "/pixel. CCD soft's plate scale only reports the plate scale to two decimal

Figure 4: A typical frame from the first set of observations on the second night. The image has been cropped and enlarged from the original 64x64 pixel image.

places—more would have been appropriate. The two camera angles were in close agreement; 271.56° and 271.79°. Although the two values could have been averaged, just the first value was used in the analysis.

STF 2848 Observations

STF 2848 was observed on two evenings, September 19 and 21, 2012. No filter was employed. On the first evening, 2000 frames were obtained. Each frame had an integration time of 32.6 milli-seconds taken at a frame rate of 28.9 frames/second. The total capture time was 64.86 seconds. Data were recorded in an 8-bit AVI format. Gamma was set at 1.0. Subsequent to the observations the data were divided into four sets, each consisting of 500 frames.

On the second night, September 21, 2012, some 7,500 frames were taken of STF 2848 in 15 separately recorded observations of 500 frames each. The 15 observational sets (each consisting of 500 frames) were recorded at three different frame rates as shown in Table 1.

Repeatability of REDUC Calculations

A check was made to determine if, with the same settings and input data set, REDUC always produced the same results. The same data set was repeatedly loaded and analyzed. If the same procedure was used, such as selecting the same mean mask, the results were always identical. Thus, as expected, REDUC is entirely deterministic.

Table 1: Specifics for the 7500 frames captured on September 21st .

Exposure (milli-seconds)	Frame Rate (frames/second)	# Sets	Frames/Set
32.6	28.9	5	500
16.4	57.8	5	500
8.2	116.0	5	500

Sensitivity of Results to REDUC Settings

The first set of 500 frames from the evening of September 19th was used to compare changes in the reduction settings. The baseline setting was an S5 median mask and a pixel area of 5x5. Running Autocorrelation gave a value for STF 2848 of 55.49° position angle and 10.832" separation. Still using Autocorrelation and the S5 result, increasing the pixel area to 15x15 gave 55.55° and 10.822". When the settings were the baseline (S5 and 5x5) and Cross Correlation was run instead of Autocorrelation, the values were 55.29° and 10.872". While changing the settings does change the results, the changes are fairly small. As Florent Losse pointed out, if one considers this from the viewpoint of pixels in rectangular coordinates, all three points are contained in an area of just 0.015x0.070 pixels. The largest distance between the three points is 0.070 pixels or only 38 milli-arc seconds at the camera's plate scale.

Sensitivity of Results to Number of Observations and Enhanced Power Spectrum

As mentioned above, with settings of S5 and 5x5 running Autocorrelation on the first 500 frames gave values 55.49° and 10.832". When all 2000 frames were combined as one observation with the same settings, the result were an almost identical 55.49° and 10.833". With everything the same and Enhanced Power Spectrum checked, the result was 55.37° and 10.759"; as above this is a very small change when one considers the plate scale and pixel size.

Within and Between Night Variations

Observations from the two nights were examined. Both nights had some 32.6 ms exposures, and these were reduced with Autocorrelation (not Enhanced) with settings S5 and 5x5. The first night

Table 2: Variations within and between nights.

Night	19 Sep	21 Sep	Difference
PA Average (°)	55.50	55.55	0.05
PA Std Dev (°)	0.059	0.007	0.062
Sep Average (")	10.80	10.93	-0.13
Sep Std Dev (")	0.180	0.002	0.178

(September 19) had four observations of 500 frames each, while the second night had five observations of 500 frames each.

As can be seen from Table 2, the differences in the average values between the nights were small. However, the variance (standard deviation) of the position angle on the first night was over 8 times as high as on the second night, while the separation difference was 90 times. The second night appeared to be a much better night—perhaps better seeing and also better focus (the images from the first night were slightly elongated). As frames were not checked individually for errant observations, a few deviant observations on the first night could have caused its larger variance.

Integration Time Variations

On the second night (September 21st), beside the set of observations at 30 frames/second, two additional sets (five observations for each set, with each observation consisting of 500 frames) were made. One set was taken at roughly 60 frames/second, while the other at roughly 116 frames/second. The results are given in Table 3.

As can be seen, shortening the individual frame exposure times did not seem to affect the results. Presumably this would, even for such a wide pair, eventually no longer be the case if one observed significantly fainter stars. For more closely spaced doubles (with the isoplanatic patch), and higher magnification, shortening the exposure times might have significantly improved precision because it would have "frozen" the true speckles.

Comparison with Previous Observations

The position angle and separation of the past 10 observations (from 2001 to 2011) reported in the Washington Double Star Catalog (Mason 2012) were compared with the best night's results (21 Sep with low variances in Table 2 above). Past observations were not corrected for different epochs as the pair has remained essentially unchanged for 200 years. This comparison is shown in Table 4.

Table 3: Effects of integration time on position angle and separation precision.

Exposure (ms)	Rate (fps)	Time (sec)	PA Avg (°)	PA SD (°)	Sep Avg (")	Sep SD (")
32.6	28.9	16.22	55.55	0.007	10.930	0.002
16.4	57.8	8.09	55.56	0.044	10.929	0.004
8.19	116.0	4.06	55.54	0.004	10.930	0.003

Table 4: Past versus current observations.

Observations	Position Angle (°)		Separation (")	
	Mean	Std Dev	Mean	Std Dev
Past	56.25	0.35	10.84	0.04
Current	55.55	0.007	10.93	0.002

The difference in position angle was 0.70°, and in separation was 0.09". In both cases, if one considers the standard deviation of the previous observations, the current observations are about 2 sigma different than the previous observations. As these two stars have similar small proper motions, and the past observations were only over a single decade, one might question whether the camera calibration observations were sufficient. It might have been appropriate to have made calibrations before and after the program observations on both nights and, perhaps to have made the calibrations in the same area of the sky as the program double.

Conclusions

The Luminera camera and associated Lucam Recorder software is easy to use, as is the interferometry feature of the REDUC software. With the same input data and settings, REDUC always gives the same results. Variations of various adjustable parameters do change the results, but not by much.

Within and between night variations were small, suggesting the observations were fairly precise. Changing the integration time on the individual frames did not have much effect on the results.

Although the differences between these observations and past observations were not large, the means did differ by about 2 sigma. This may have been due to insufficient calibration.

Speckle Interferometry Background Papers

Antoine Emile Henry Labeyrie (1970) is often accredited with initiating speckle interferometry, while Harold A. McAlister (1985) and his many students and associates widely applied speckle interferometry to double stars. Elliott Horch (2006) has summarized the status of speckle binary star research. Nicholas Law (2006), in his doctoral dissertation on lucky imaging also provided much useful information on speckle interferometry. Finally, Nils Turner (2012) reviewed speckle interferometry for small telescopes.

Acknowledgments

Ed Wiley kindly assisted with the REDUC interferometry reduction procedure. Brian Mason provided past observations of STF 2848. Bruce Holenstein and Frank Suits helped in the selection of high speed camera. Heiko Wilkens and Florent Losse provided, respectively, the Lucan Recorder and REDUC software suites and helped in their use. Joseph Carro provided the most recent Excel version of the Carro Catalog. Finally, my thanks to Joseph Carro, William Hartkopf, Florent Losse, Francisco Rica, Tom Smith, Ed Wiley, and Vera Wallen for their reviews of this paper prior to publication.

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