

# CCD Measurements of 8 Double Stars With Binary Nature

## The Autumn 2015 Observing Program at Brilliant Sky Observatory, Part 2

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**Abstract:** Results of CCD measures of five pairs are reported as well as three cases of speckle interferometry. Results show that the Skyris 618 CCD camera and an 11-inch SCT can do serious and accurate double star astrometry

### The Observing Program

From October 23 to December 1, 2015, a vigorous program of measuring double stars with a Skyris 618C CCD camera was done at Brilliant Sky Observatory (Cave Creek, Arizona). Over 18 different nights, over 220 double stars were imaged and their FITS cubes reduced using Plate Solve 3.47B. This report focuses on 8 pairs that either have known orbits (one case), or are showing strong arc-like shapes of the plots of their measurements (four pairs), or are close pairs (three) best analyzed with speckle interferometry.

### Equipment Used

The equipment used in this observing program is described in detail in Harshaw 2016. This includes the telescope (a C-11), the mount (CGEM-DX), camera (Celestron Skyris 618c), and data reduction software (Plate Solve 3.47B).

### Procedure

When doing speckle interferometry, I select pairs that are no farther apart than 7 arc seconds and with both magnitudes being brighter than 8.50, since fainter stars require integration times of greater than 100ms. (The “rule of thumb” for speckle integration times says 50ms or less, which is considered by many to be about as long as one can image without smearing out the speckles created by the atmosphere. But this rule was established with large research-grade telescopes which

must look through many millions of Fried turbulence cells compared to a smaller telescope’s thousands of cells. A member of our speckle “community”, Clif Ashcraft of New Jersey, has been getting good speckle results with integration times in the 100ms range.) The magnitude limit comes into play when one considers that when obtaining speckles, I use a Johnson-Cousins “R” filter to reduce atmospheric dispersion. This means that there are only a little over 180 pairs that can be analyzed with speckle using a Skyris 618C on a C-11.

For speckle, I obtain 1,000 FITS frames (which Plate Solve converts into a FITS cube for processing), and generally run 3 to 8 sets of frames.

The speckle procedure also requires obtaining 1,000 FITS frames of a single “deconvolution” star. The Fourier Transform that Plate Solve develops for the deconvolution star is then applied to the double star to enhance the clarity of the data and produce a high-quality autocorrelogram.

For CCD measures, I find that taking 100 frames and then selecting the best 25% for signal to noise ratio yields 25 frames that Plate Solve can work with very nicely. I find that as a general rule, Plate Solve gives more accurate solutions than lucky imaging.

For a description of my processing method, see Harshaw 2016.

### Results, Part 1: One Grade 3 Orbit

First to report is the one pair with a known orbit

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that was imaged during the Autumn 2015 observing season at Brilliant Sky Observatory. The results are shown in Table 1.

In Table 1, Last  $\theta$  and Last  $\rho$  are the measures of  $\theta$  and  $\rho$  (respectively) in the year shown in Last Year. Meas. Made is the number of measurements made of the autocorrelograms. Meas.  $\theta$  and Meas.  $\rho$  and Resid.  $\theta$  and Resid.  $\rho$  are the measurements (and residuals) of the measurement made. With only six measures made of three FITS cubes, the standard error is of little value.

The PNG file for this pair from the U. S. Naval Observatory is shown in Figure 1.

After obtaining the measurement history of this pair from the U. S. Naval Observatory, the past measurements were corrected for precession of the equinoxes and plotted in Cartesian coordinates using Microsoft's Excel. The result of that plot, showing the 2015.855 measure, is the red box in Figure 2.

### Results, Part 2: 4 Pairs That Show A Short Arc

Short arc binaries are pairs whose data plot is beginning to show an arc, the telltale sign that the pair is probably physically bound, as the arc is the projection of the orbital path on the plane of the sky.

However, do not interpret short arc to mean short period. In some cases, the arc may be revealing itself at periastron (or apastron) and the arc may be a small piece of a huge and highly inclined orbit.

But the arcing does suggest, no matter the orbital period that may someday be derived, that the pair is gravitationally bound. It may take centuries more of measurement to collect enough data to permit an orbital solution, but the existence of such pairs should warrant special attention by astrometrists in the future.

To determine a pair to be a short arc binary, it is necessary to obtain the measurement data from the U. S. Naval Observatory and then to enter the values of theta and rho into a spreadsheet that can then translate the values into X, Y coordinates, thus allowing the user to plot the data in Cartesian space. This is done by the simple mathematical conversions of

$$\begin{aligned} X &= \rho * \sin(\theta) \\ Y &= \rho * \cos(\theta) \end{aligned}$$

In addition, we must adjust  $\theta$  for the precession of the equinoxes to normalize the measurements for different epochs to the present day. All of this is done in an Excel program I wrote for the purpose of plotting the measurement histories.

Excel has a trend line function that can be invoked by right-clicking on any data point in the graph of the

measurements and selecting Insert Trend Line. This allows us to select a polynomial line that takes on the shape of an arc. We can also ask for the  $R^2$  value, a number that reflects the goodness of the fit of the data to the curve. However, Excel assigns equal weights to all the data points, which is not how we analyze historical data in double star astrometrics. The higher the  $R^2$  value, the more likely it is that we are indeed seeing the emergence of a short arc and hence have a clue about the physical/binary nature of the pair. The lower the  $R^2$  value, the more scatter or noise in the data and the less likely we are looking at a true binary system.

The format of Table 2 is the same as Table 1 but with the addition of the  $R^2$  value column.

### Results, Part 3: 3 Speckle Interferometry Pairs

In the autumn 2015 observing program at Brilliant Sky Observatory, three pairs were measured using speckle interferometry. This process has been documented in Harshaw (2015).

All three speckle measurements were made at f/30 and consisted of pairs bright enough to image at integration times of under 50ms and with separations of 7 arc seconds or less, using a Johnson-Cousins "R" filter. (Two stars are borderline cases for  $\theta$ . As a general rule, stars wider than 7 arc seconds will probably have their light passing through different isoplanatic patches, so true speckle interferometry is not usually reliable at these separations. However, exceptionally good seeing might extend the patch a bit.)

In all three pairs, the stars have common proper motion.

The data for the speckle measurements are in Table 3.

### Discussion

The Autumn 2015 observing program at Brilliant Sky Observatory proved that speckle interferometry on close double stars can be done with amateur-class equipment and inexpensive CCD cameras.

The one known orbit pair that was measured showed results that are in good conformance with the ephemerides from the Sixth Catalog of Orbits of Visual Binary Stars.

The short arc binaries deserve special attention by astrometrists in the coming years.

### Recommended Future Observations

Observations of the pairs featured in Table 2 would be a good investment of amateur observing time as we may be only a few measurements away from deriving

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Table 1: Measure of WDS 00491+5749 (STF 60 AC)

WDS Number	Disc	Comp	Date	Last $\theta$	Last $\rho$	Last Year	Meas. Made	Meas $\theta$	Meas $\rho$	Resid $\theta$	Resid $\rho$	Notes
00491+5749	STF 60	AB	2015.855	324.3	12.78	2014	6	324.783	13.696	-0.483	-0.916	1

Table 2: Short Arc Binaries

WDS Number	Disc	Comp	Date	Last $\theta$	Last $\rho$	Last Year	Meas. Made	Meas $\theta$	Meas $\rho$	Resid $\theta$	Resid $\rho$	R <sup>2</sup>	Note
00089+6627	FAB 1		2015.858	178.9	14.65	2011	2	181.034	14.905	-2.134	-0.255	0.5461	2
00311+5648	ES 2	AB	2015.890	112.1	5.93	2012	8	112.686	5.854	-0.586	0.076	0.7661	3
00546+3910	STF 72		2015.855	172.5	23.03	2014	2	172.969	23.339	-0.469	-0.309	0.7203	4
01373+6344	MLB 383	AD	2015.877	165.6	31.96	2011	6	164.809	31.752	0.791	0.208	0.0478	5

Table 3: Speckle Interferometry on Three Pairs

WDS Number	Disc	Comp	Date	Last $\theta$	Last $\rho$	Last Year	Meas. Made	Meas $\theta$	Meas $\rho$	Resid $\theta$	Resid $\rho$	Plot
00499+2743	STF 61		2015.855	115.0	4.50	2014	20	113.529	4.200	1.471	0.300	6
01001+4443	STF 79		2015.855	194.1	7.90	2013	10	192.327	7.842	1.773	0.058	7
01535+1918	STF 180	AB	2015.855	0.9	7.41	2014	10	359.704	7.362	-0.604	0.048	8

Notes to Tables:

- Using the Sixth Orbit Catalog ephemerides and extrapolating for 2015.855, the projected values for  $\theta$  and  $\rho$  are 323.642° and 13.346". The residuals for the 2015.855 measurement are +1.141°  $\theta$  and +0.353"  $\rho$ . See Figures 1 and 2.
- The trend line (Figure 3) is actually "reversed"—the concave side of the curve points away from the system's center of mass. May not be a true short arc binary.
- In this case, the trend line has the pair's center of mass on the correct side of the curve. See Figure 4.
- Parallaxes for both stars are known, but neither is reliable as a test for distance and physical separation of the two stars. The parallax values are  $1.33 \pm 1.30$  mas for the primary and  $12.33 \pm 5.51$  mas for the companion. See Figure 5.
- See Figure 6 for a plot of WDS 01373+6344.
- See Figure 7 for a plot of WDS 00499+2743, a speckle measurement.
- See Figure 8 for a plot of WDS 01001+4443, a speckle measurement.
- See Figure 9 for a plot of WDS 01535+1918 AB, a pair with several anomalous measurements.

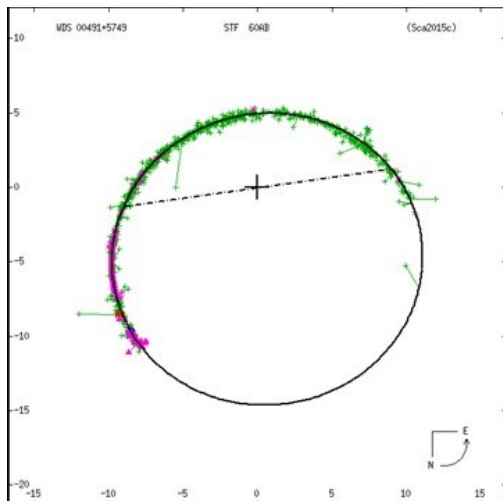


Figure 1: PNG plot of WDS 00401+5749.

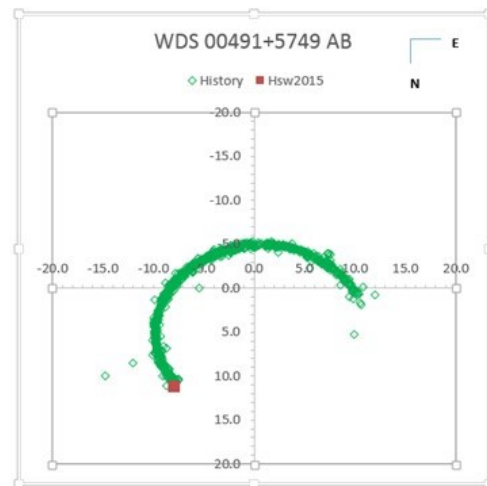


Figure 2: Plot of WDS 00491+5749 AB history showing the 2015.855 measurement (red box).

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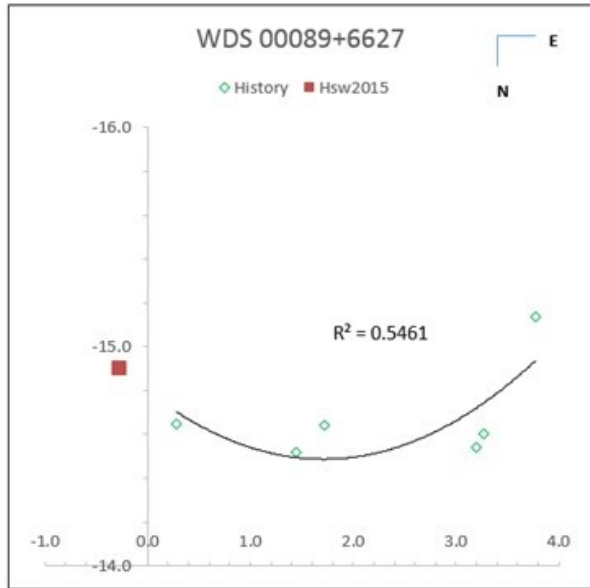


Figure 3: Plot of WDS 00089+6627, a curious case of a reverse trend curve.

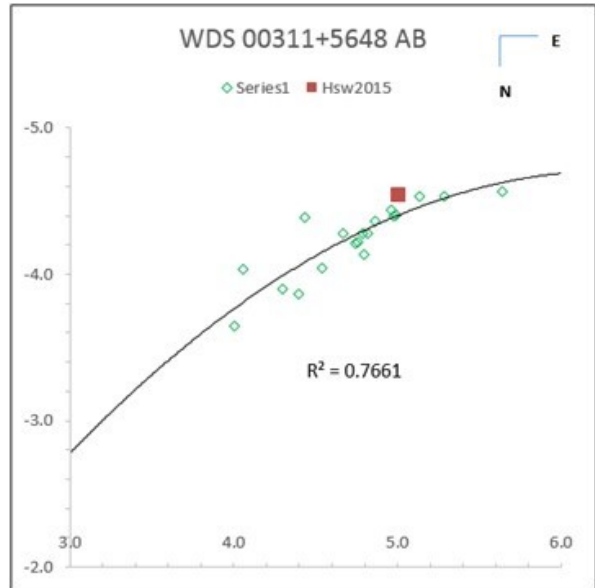


Figure 4: Plot of WDS 00311+5648 AB.

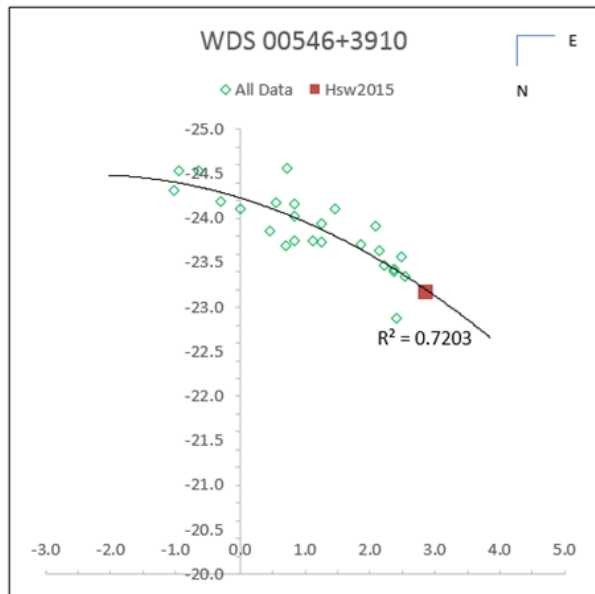


Figure 5. Plot of WDS 00546+3910.

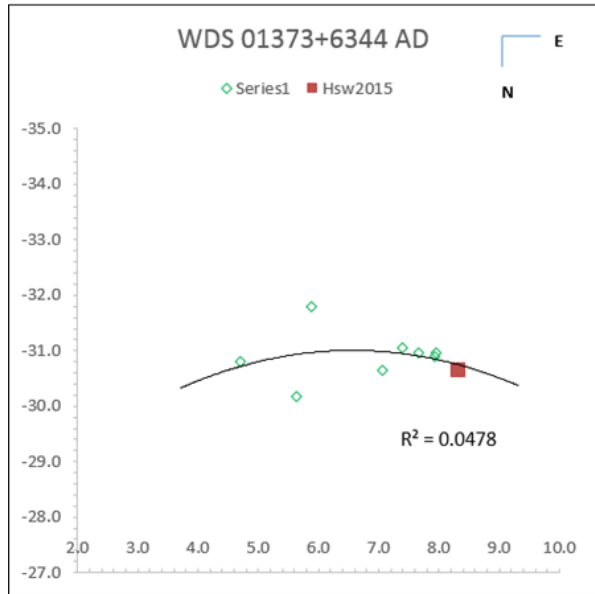


Figure 6: Plot of WDS 01373+6344 AD.

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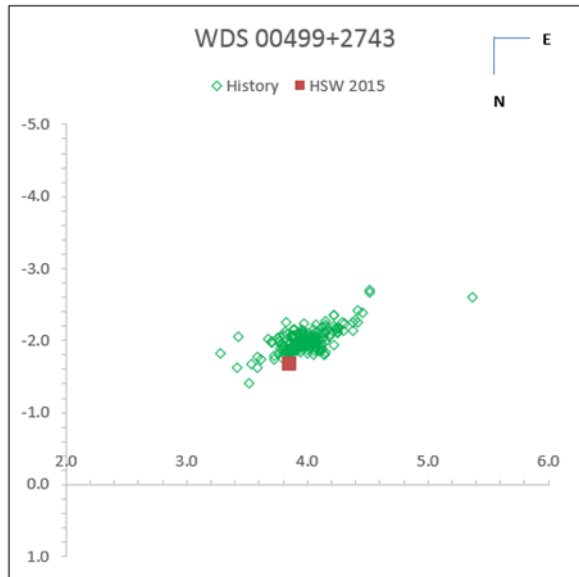


Figure 7. Plot of WDS 00499+2743, a speckle measurement.

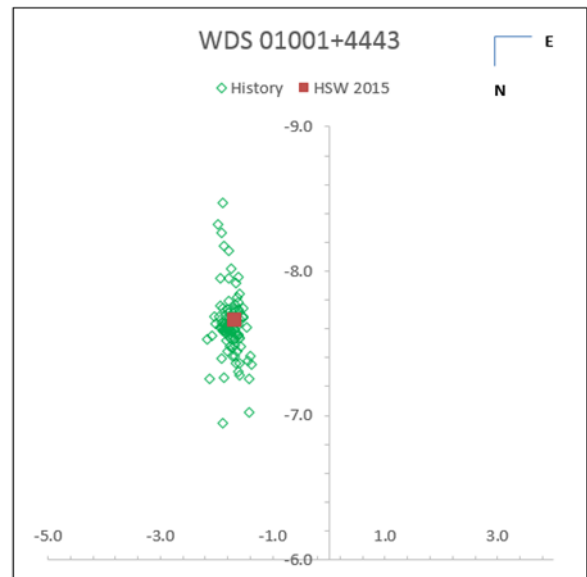


Figure 8. Plot of WDS 01001+4443.

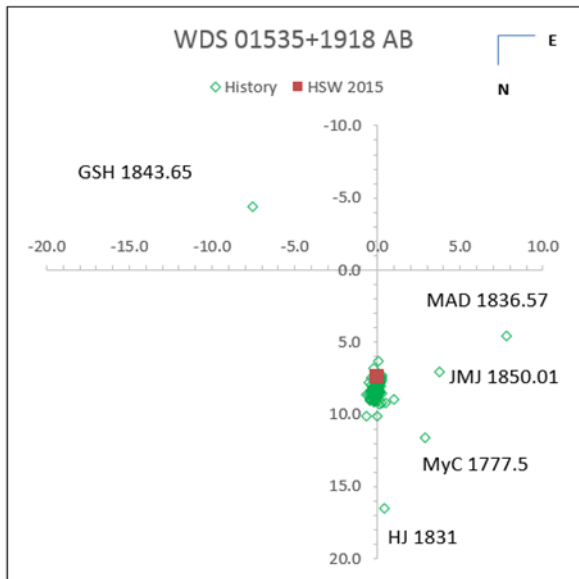


Figure 9. Plot of WDS 01535+1918 AB, a pair with several anomalous measurements.

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an orbital solution.

**Acknowledgments**

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. Use was also made of the VizieR service of the Centre de Données astronomiques de Strasbourg and the Hipparcos 2 Output Catalog as well as the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf and Mason, June 2015).

**References**

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