Astrometric Measurements of Double Stars Using AstroImageJ and Astrometry.Net

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Abstract: From the Fall of 2016 through the Fall of 2017 students at Keene State College and Physics Department Faculty analyzed double star data using software and online resources including AstroImageJ (AIJ), Deep Sky Stacker (DSS), Double Star Astrometry (DSA, an in-house-written application) and Astrometry.net. The raw binary star images taken with a Digital Single Lens Reflex (DSLR) camera were converted to FIT files using DSS. The equatorial celestial coordinates of each image were found using the technique of plate solving using Astrometry.net. The coordinates of the primary and secondary were then measured and the separation and position angle (PA) calculated using DSA (Goodale). Anywhere from 5 to 24 images of each binary pair were analyzed, providing average and standard deviation values for PA and separation measurements. Limitations of this method occur when the magnitude differences are relatively large and the separations are relatively small; sometimes the centroid cannot be determined by the software.

Introduction

Since the Fall of 2014 Physics Faculty have been working closely with students on observing, imaging and measuring double stars. Initially, students learned how to measure PA and separation using an eyepiece micrometer. Although accurate measurements can and often are made this way, the inherent difficulties associated with this method made the process very tedious and time consuming. Given that our micrometer scale's smallest division was 4", the need to interpolate between divisions provided uncertainties that were too large given our expectations. This led us to explore capturing digital images and later analyzing them using BackyardEOS and Adobe Photoshop, which proved to be easier and more accurate than previous measurements made at the eyepiece (Walsh 2015). Here we now describe our most current measurement method which enables us to locate and resolve the centroids of the primary and secondary to milli-arc seconds in right ascension (RA) and tenths of an arc second in declination (DEC). Use of astrometric and plate solving techniques also eliminated the need for the group to perform star drifts in the field with the clock drive off to determine West, reducing the time needed for data acquisition.

Binary Star Research Group members met off campus for telescope imaging sessions at nearby Otter Brook Dam in Roxbury NH (see figure 1). The Dam is situated between two hills, one of which adequately blocks most sky glow from nearby Keene, NH. Results obtained were compared to, and found to be consistent with the most recent values listed in the WDS and are reported in Table 1.

Equipment

The group used a Celestron 9.25 inch Schmidt-Cassegrain telescope, a Canon 6D DSLR camera and a laptop computer. The telescope was set up, polar aligned and a three star alignment performed. The doubles were located by entering their RA and DEC into the telescope's hand controller and allowing the telescope to slew to the proper coordinates. Depending on the magnitudes of the components, an appropriate length exposure was taken at ISO 1600. Images were captured and saved using BackyardEOS.

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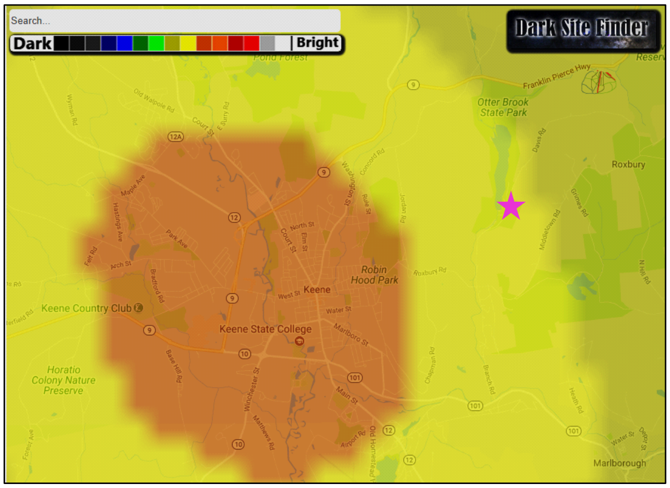

Figure 1. Light pollution map of the greater Keene, NH area including our observing location (pink star) in Roxbury, NH, according to the Dark Site Finder website. We estimate our sky to be between 3 and 4 on the Bortle Sky Scale.

Procedure

All images were captured as raw CR2 files and converted to FIT files using DSS. The files were then uploaded to the website nova.astrometry.net to be plate solved, which determines the RA and DEC for every pixel in the image. The images were then downloaded for analysis in AIJ, in which the location of the cursor on the image is shown as RA and DEC in the text boxes at the top of the AIJ analysis window (Figure 2). The image of the primary was first enlarged and placed at the center of the circular aperture using the multi-aperture photometry tool, which defines the region in which the intensity centroid will be determined. The size of the aperture is chosen to encompass the majority of the star's intensity distribution at a relatively high contrast (as typified in the figure). Once the centroid has been determined, it is indicated as a crosshair inside the aperture. The user then simply places the cursor directly over the crosshair and records the RA in hours, minutes and seconds and DEC in degrees, minutes and seconds. This was repeated for the second component. Last, the coordinates of each component are used to determine the pair's separation (ρ) and PA (θ) through the equations:

$$\rho = \sqrt{\left(\Delta\alpha\cos\delta_1\right)^2 + \left(\delta_2 - \delta_1\right)^2}$$

$$\theta = \arctan\left(\frac{\Delta\alpha\cos\delta_1}{\delta_2 - \delta_1}\right)$$

where, Δα is the difference in RA, δ_1 is DEC of the pri-

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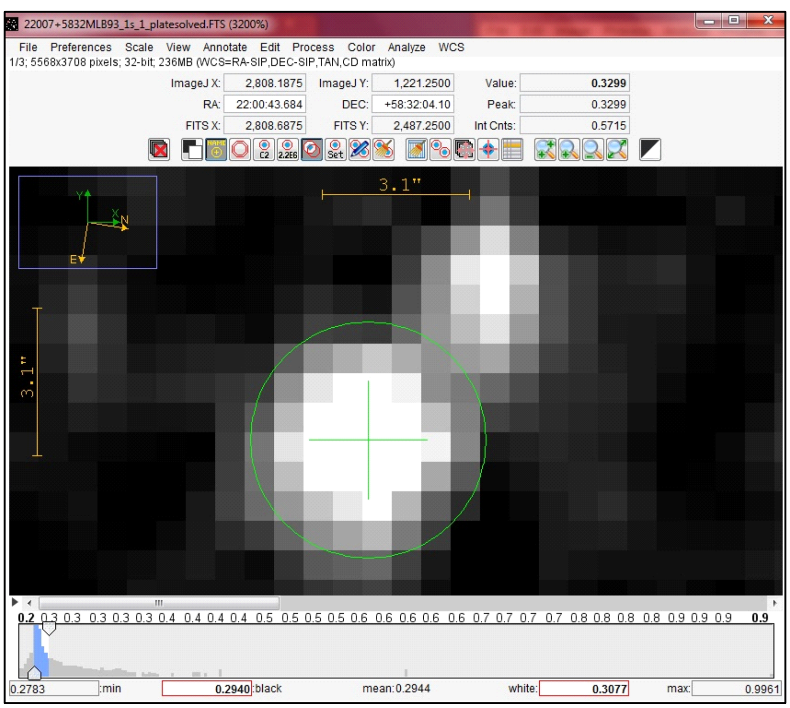

Figure 2. Primary centroid determination for WDS ID 22007+5832MLB 993. An appropriate sized aperture was chosen such that the secondary's intensity distribution didn't significantly fall within the aperture; using a larger aperture for closer pairs often fails.

mary and δ_2 is the DEC of the secondary (Buckheim 2008). It should be noted that none of the star images used for centroid calculations were saturated.

Students constructed an Excel spreadsheet to perform the ρ and θ calculations. To further streamline the analysis process, a computer program (Double Star Astrometry) was written in VB.net (see Figure 3), which became the preferred method as the WDS database could be loaded into the program and searched automatically and easily compared to our measured values. Depending on the pair, from 5 to 24 images of each binary were analyzed providing an average and standard deviation for both separation and PA (see number of images measured, N, in Table 1).

The AIJ software was at times unable to determine a centroid of one or both of the components. This was due to the pair being too closely separated, and given their relative magnitude difference, their intensity distributions overlapped too much to be deconvoluted from one another. Overcoming this issue and determining the pairs' centroids when they are either too close, too great in magnitude difference, or both is currently being explored.

Results

The results and statistics for 27 star pairs are summarized in Table 1. Values compared better to WDS values using the described astrometric method than previous methods used by the group.

Conclusion

The technique is limited in how close the separation can be reliably measured due to having to select the stars with the photometry aperture, which was difficult to impossible, for relatively large magnitude difference and small separation pairs.

Acknowledgements

Thanks to student researchers who contributed to this project: Trisha Braught, Katherine Marinoff, Alex Percy, Briae Robillard, Brian Stevens, Mary Swain and Felicia DeSteph. This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

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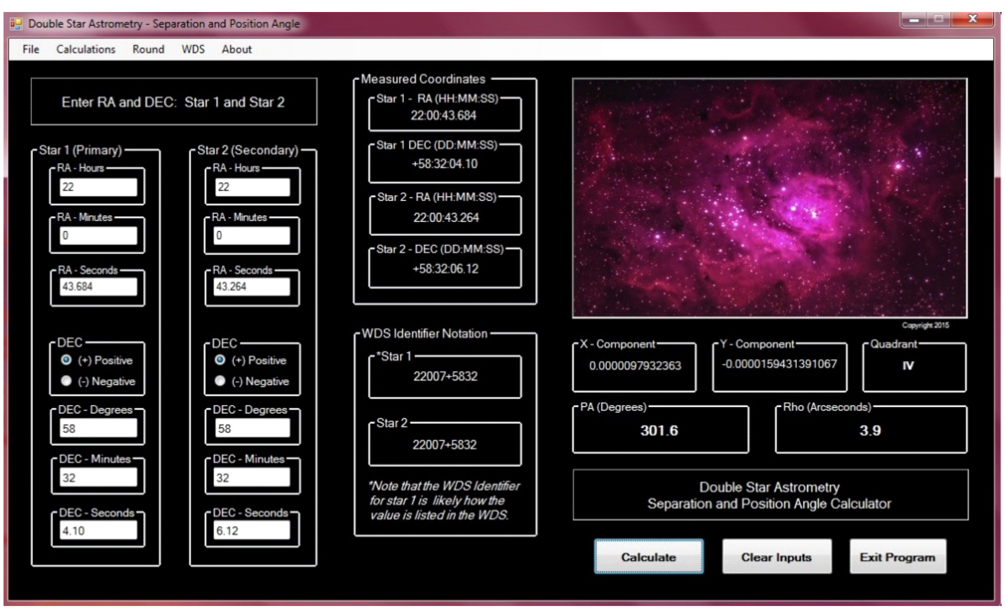

Figure 3. Double Star Astrometry (DSA) user interface as applied to binary WDS ID 22007+5832MLB 993 (see Figure 2, the secondary's RA-DEC were determined similarly). The coordinates of the primary are entered in the first column and the secondary in the second column. The calculation for separation and position angle are quickly obtained by clicking the Calculation button. To aid searching in the WDS data, a suggested WDS identifier is automatically generated from the RA and DEC of the primary.

Table 1. Results of Data Analysis. Columns 2 through 6 give our measurements: the date imaged, the separation in arcseconds, the PA in degrees, standard deviations of the separation and PA and the number of images measured (N). The last three columns list the most recent WDS values and the year measured (Mason & Hartkopf, 2017).

WDS Name	Year	ρ (")	θ (°)	σ(ρ)	σ(θ)	N	WDS ρ	WDS θ	Year
13000-0407UC 2446	2017.43	32.5	204.0	0.4	0.2	5	32.4	204	2010
13001+0018STF1706	2017.43	28.1	179.3	0.1	0.1	7	31.0	179	2012
13006+1822BU112A,BC	2017.43	138.5	359.7	0.1	0.04	5	139.2	0	2012
13007+7343HJ2633	2017.43	4.5	89.8	0.3	2.2	15	4.7	90	2013
13008+1423STF1705	2017.43	26.7	187.7	0.1	0.3	7	26.8	188	2012
13008+0252HLD14AC	2017.43	49.1	100.7	0.2	0.3	8	48.5	100	2012
13008+5545STI2293	2017.43	9.6	115.2	0.1	0.5	8	9.6	115	2010
13009+2134GRV 860	2017.43	30.6	231.7	0.1	0.3	9	30.5	232	2010
13013+0358GWP1890	2017.42	112.0	77.6	0.3	0.2	12	112.7	78	2010
13016+2924SKF 491	2017.42	8.9	143.6	0.3	2.8	12	8.9	144	2004
13029+2935SLE908	2017.42	9.0	235.3	0.2	1.6	8	9.6	241	2001
13030+0819GRV861	2017.42	61.0	197.9	0.4	0.2	6	61.0	198	2010
15301+3232UC 3016	2017.47	22.4	243.9	0.4	0.5	12	22.6	244	2010
15303+1543HJ 254AB	2017.47	17.1	277.8	0.1	0.2	24	17.2	277	2013
15303+1543HJ 254BC	2017.47	60.3	2.3	0.2	0.1	24	61.0	2	2003
15303+1543HJ 254BD	2017.47	74.8	258.7	0.4	0.3	22	74.7	259	2003
15308+2408POU3191	2017.55	9.7	283.4	0.4	1.6	12	9.8	283	2010
15309+4145KZA92AB	2017.47	15.1	278.9	0.2	0.5	10	14.8	278	2007
15309+4145KZA 92AC	2017.47	25.8	332.9	0.3	0.4	10	25.6	333	2007
15311+3925KZA94	2017.47	15.6	257.2	0.2	0.3	12	15.8	256	2013
15311+4022KZA93AC	2017.47	49.7	90.9	0.1	0.1	11	50.1	91	2006
15311+4022KZA93AD	2017.47	70.5	16.9	0.3	0.4	11	71.1	17	2006
15317+3941KZA95	2017.51	39.3	142.3	0.2	0.2	11	39.6	141	2010
15317+3903KZA 96	2017.51	43.5	88.3	0.3	0.5	21	43.5	88	2010
15318+4054KZA97AB,D	2017.51	118.3	318.8	0.4	0.2	16	119.0	319	2002
19513+3829ALI 903	2017.73	10.9	200.5	0.2	0.5	11	9.9	201	2002
22005+6445SMA 157	2017.73	20.5	82.2	1.1	0.4	13	20.3	82	2012

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