Determining the Separation and Position Angles of Orbiting Binary Stars: Comparison of Three Methods

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Abstract: To initiate a long term binary star research program, undergraduate students compared the accuracy and ease of measuring the separations and position angles of three long period binary pairs using three different measurement techniques. It was found that digital image capture using BackyardEOS software and subsequent analysis in Adobe Photoshop was the most accurate and easiest to use of our three methods. The systems WDS J17419+7209 (STF 2241AB), WDS 19418+5032 (STFA 46AB), and WDS 16362+5255 (STF 2087AB) were found to have separations and position angles of: 30", 16°; 39.7", 133°; and 3.1", 104°, respectively. This method produced separation values within 1.3" and position angle values within 1.3° of the most recently observed values found in the *Washington Double Star Catalog*.

Introduction

During September and October of 2014 seven undergraduates and two faculty members from Keene State College (KSC, Figure 1) compared three different methods to measure separations and position angles (PA) of binary stars: direct measurement through a micrometer reticule eyepiece, analysis using the software package BackyardEOS, and through captured images evaluated in Adobe Photoshop.

KSC has made it a priority to provide students of any discipline the opportunity to conduct meaningful undergraduate research. KSC physics faculty members attended the 2014 Stellafane Workshop on Binary & Multiple Star Astronomy to evaluate the potential of initiating an undergraduate binary star research program. After the daylong experience they felt confident that this work could be implemented at KSC and make significant contributions to binary star research. Our logical first step was to evaluate and develop the best methods available to collect and analyze binary star data. Here we present our results from data collected during the fall semester 2014, our first steps in implementing a long term research program. The majority of the measurements were taken at Otter Brook Dam in Roxbury, NH (chosen due to the dark skies and proximity to the college) and the remaining measurements were made along Apian Way on the KSC campus (introducing some difficulties in acquiring data due to the ambient light pollution).

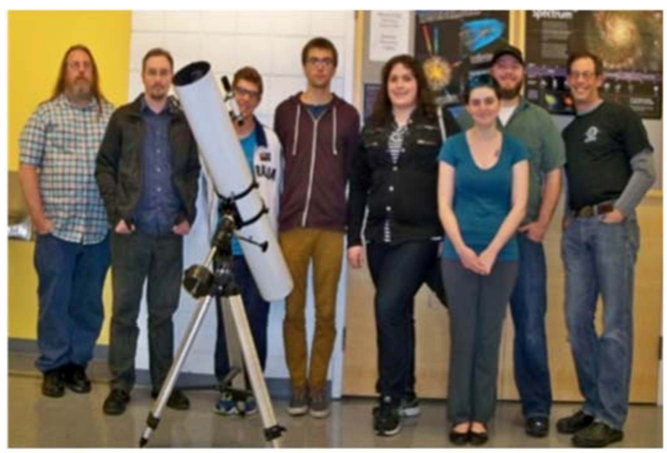

Figure 1: Researchers from left to right: Adjunct Professor Keith Goodale, Students: Ian Ross, Andrew Penfield, Cory Boulé, Trisha Braught, Katelyn Andrews, Ryan Walsh, and Professor Steven Harfenist.

The stars WDS J17419+7209 (STF2241AB-Psi Draconis), WDS 19418+5032 (STFA 46AB - 16 Cygni), and WDS 16362+5255 (STF2078AB - 17 Draconis) were chosen for our methods comparison due

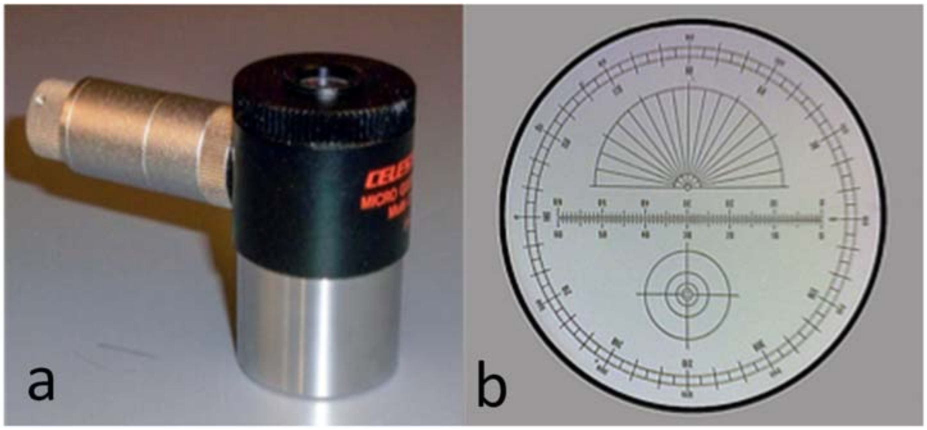

Figure 2: (a) The illuminated Celestron MicroGuide Eyepiece and (b) image of the micrometer reticule scales used to make separation and position angle measurements.

to their relatively long orbital periods (~104 year, Kisselev 2009, Hauser & Marcy 1999, Tolbert 1964), which ensures there will be no noticeable change in separation or PA enabling comparison with recent measurements found in the Washington Double Star catalog (WDS) (Mason & Hartkopf 2013). Their seasonal visibility and the fact that they are bright and relatively easy to locate made them logical choices for us. A detailed discussion of the three methods is given below.

Equipment and Methods

A 9.25 inch (f = 2350mm) Celestron Schmidt-Cassegrain telescope (SCT) on a computerized Orion Atlas equatorial mount, a Celestron MicroGuide Eyepiece (Figure 2a), a 2X Barlow lens, a Canon digital single lens reflex (DSLR) camera mounted to the back of the telescope (at prime focus), and a laptop computer were utilized for the observations. For all digitally captured images, BackyardEOS was used (Nikon DSLR users would use BackyardNik, see http://www.otelescope.com). Digital analysis was performed using both BackyardEOS and Adobe Photoshop. For the micrometer reticule and Backyard EOS analysis methods, each student made measurements of separation and PA. A group average was calculated which was then compared to the WDS values.

The reticules provided a linear scale and a 360˚ protractor (Figure 2b, Figure 3). The linear scales were calibrated using the drift method (Teague 2012). After the clock drive was turned off, the time for the star Altair to drift across the linear scale was measured. Each researcher made measurements of the time it took for Altair to drift across the linear scales for both BackyardEOS and the reticule eyepiece. These times were averaged and the scale constant (Z, number of arc seconds per division) were calculated using the equation:

$$Z = \frac{15.0411\cos(\delta)t}{N}$$

Here, t is our average drift time in seconds, $\delta = 8.8683^{o}$ is the known declination (epoch j2000.0) in arc seconds of Altair, N is the number of divisions swept in time t, and the coefficient 15.0411 is the Earth's angular rate of rotation in arc seconds per second. The value of Z for the micrometer reticule eyepiece was determined to be 4.0" per division and 7.8" per division for BackyardEOS.

Measurement with MicroGuide Reticule Eyepiece

Separation measurements were performed by first centering the primary in the crosshair, aligning the two components on the linear scale through rotation of the eyepiece, and then the number of divisions between each star image's centroid was recorded (Figure 2b). The eyepiece was then rotated 180° and the same measurement made to reduce systematic error. All division measurements were converted to arc seconds using the value of Z = 4.0" per division. Separation standard deviations were found following the procedure outlined in Weise, et. al., 2014.

To determine the PA for each pair, the primary was centered in the reticule and oriented such that the 0-180° line of the protractor was aligned along the line segment joining the pair of stars. With the clock drive turned off the stars drifted across the outer protractor scale from east to west, enabling the direction of west to be determined. In a SCT used with a star diagonal, north will be 90° clockwise from west. North is 0° and the PA is

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Figure 3: Screen capture image showing the protractor and linear reticule scales for performing drift alignment in BackyardEOS, here used to make separation and PA measurements. Note that only one half of the linear scale was used since the width of the center division is variable.

measured eastward from north.

Measurement with BackyardEOS

BackyardEOS is a versatile astrophotography software package that provides complete control for capturing digital images with Canon DSLR cameras. We used the premium version of BackyardEOS 3.0.3 that provides a reticule and protractor as shown in Figure 3. The reticule is ordinarily used for drift alignment when polar aligning the mount, but here we explored its use in making position angle and separation measurements of binary pairs. Separations were measured in the field using the reticule in Live View mode, while PA measurements were performed using the protractor in Drift Align mode, which stacks Live View frames into one image file as the pair drifts with the clock drive turned off (see Figure 4). The image file for the PA measurement was saved and analyzed at a later time.

The same measurement procedures were followed as performed with the reticule eyepiece, with two exceptions: the linear reticule scale in BackyardEOS was calibrated using only half the scale to avoid complications with the variable width drift alignment crosshairs in the center and north will be 90º counterclockwise from west. One advantage of this software is that it allows the user to enlarge the screen image (at the same resolution), better facilitating the separation measurement of the two stars (see upper right hand corner of screen capture in Figure 3). Since the resolution is limited by the software in Live View mode, a disadvantage is that close pairs can be difficult to split on the computer screen.

Measurement with Adobe Photoshop

Digital images of binary pairs captured in BackyardEOS were made at ISO 800 using short exposures from 1-10 seconds depending on the brightness of the pair. A separate 15-second exposure was made with the pair initially centered in the field and the clock drive disengaged. This produced a star trail that indicated west as the pair drifted across the field during the exposure.

The images were later opened in Adobe Photoshop for analysis. Photoshop's Measure tool was utilized for measuring the separation between the centroid of each component of the pair in pixels (Figure 5). The PA was determined using the Measure tool in angle mode of an overlay of both the short exposure and the 15 second trailed exposure (Figure 6). The pixels to arc second conversion is defined by the focal length of the telescope and the sensor size of the camera. The following formula (Wilmslow Astro website, http://www.wilmslowastro.com/software/formulae.htm) may be used to calculate arc seconds per division when using small angles:

$$arc\ seconds\ /\ pixel\ = \frac{pixel\ [mm]}{f\ [mm]}\ x\ 206{,}265''$$

The Canon manufacturer's specifications for the 60Da camera model specify a pixel size (*pixel*) of 4.3 μm and Celestron lists the focal length (*f*) of the telescope as 2350 mm. The value of 206,265" converts the angular field of view of one pixel in radians to arc sec-

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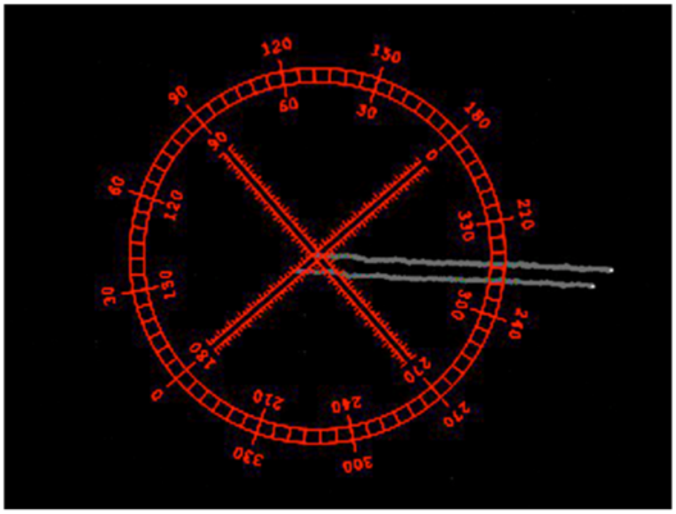

Figure 4. Position Angle determination in BackyardEOS. A 45 second drift image of 16 Cygni (STFA 46AB) is used to determine west. The primary is centered on the protractor scale which is rotated to align the pair along the 0-180° line. The PA is then measured from north counter clockwise to the 0-180° line, here measured to be 133°.

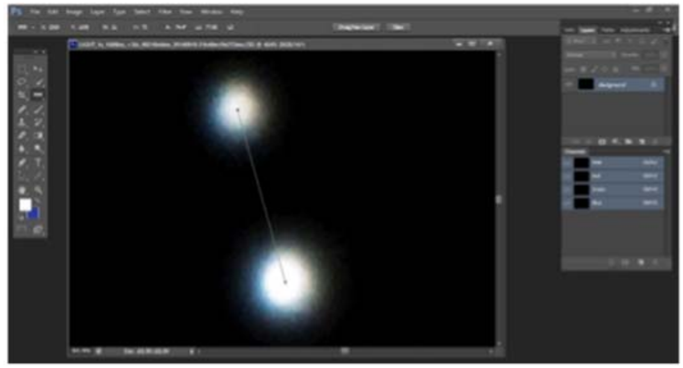

Figure 5. Separation determination using Photoshop's Measure tool. In ruler mode the separation of Psi Draconis is found to be 77.88 pixels = 29.4".

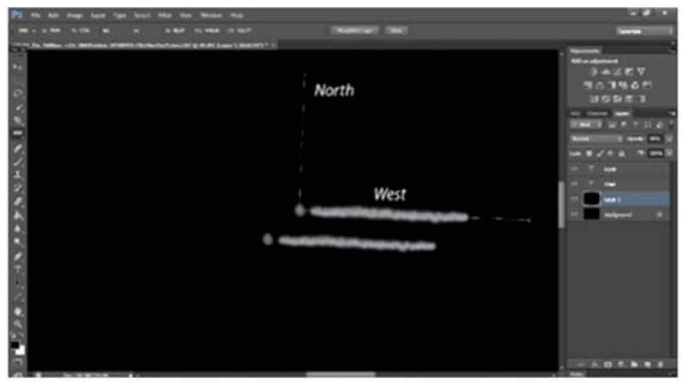

Figure 6: Photoshop's Measure tool in Angle mode used to measure the PA of 16 Cygni as 133.3°. North is directed almost straight up in the image.

onds. Using the formula above, the number of arc seconds per pixel for our telescope and camera combination is .377.

Separation measurements using Photoshop began with zooming on the pair in the short exposure image. We placed the Measure tool cursor (in Ruler mode) on the primary star and clicked and dragged the tool out to the secondary component, producing a line between the two stars (Figure 5). Further enlargement of the image and minor corrections in the cursors' locations allowed more accurate centering of the Measure tool endpoints on each star's centroid. We then recorded the number of pixels between the pair, which were later converted to arc seconds. For our purposes here, a reasonable estimate of the separation measurements' largest uncertainties is the half width at half maximum of the widest intensity profile from each star pair. We estimate these values to be 3.4" for 16 Cygni, 3.8" for ψ Draconis, and 1.4" for 17 Draconis.

Position angle measurements were determined by using both the short exposure and the 15-second drift exposure images simultaneously (Figure 7). The drift image was copied and pasted as a second layer into the short exposure image. The transparency for the top layer was changed to approximately 30% - 40% to line up the two stars in the short exposure with the initial location of the stars in the trailed image.

The Measure tool (Angle mode) was placed at the primary star's initial position and traced along the star trail to indicate west. As with separations, further zooming of the trailed image enabled more accurate correspondence between the drift direction and Measure tool orientation. Double clicking on the initial crosshair of the Measure tool initialized the Angle measurement mode that provided a second line/leg to measure angles. This new leg was rotated 90 degrees counterclockwise from west to determine north. Once north was found, the Measure tool was dragged, as a whole, such that the vertex was centered on the primary star in the un-trailed image without changing the orientation of the north pointing leg. Setting the transparency back to 0%, the remaining leg of the measurement tool was then swept so as to pass directly from the center of the primary through the center of the secondary. The position angle was then measured from north (0°) counterclockwise to the line made from the primary to the secondary.

Discussion

In recent years the micrometer reticule eyepiece has all but replaced the traditional filar micrometer, making

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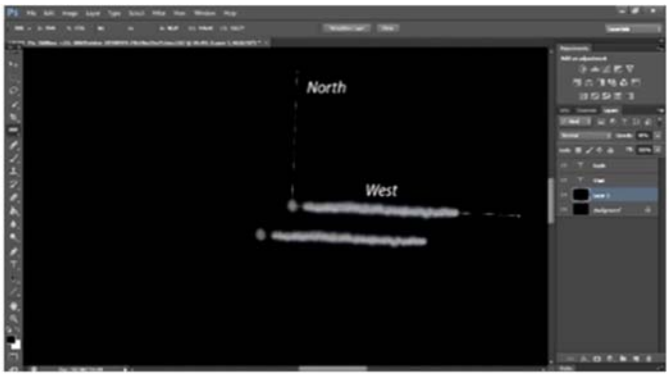

Figure 7: Position angle determination in Photoshop. A five second exposure is overlaid with a trailed 15 second exposure (transparency ~ 40%). West is determined from the direction of the drift and north is known to be 90º counterclockwise from west using this method.

for dramatic improvements in ease of measurement at lower cost. More recently, digital capture and analysis of astronomical images has begun to replace those made at the eyepiece. Our results show that digital measurements are not only more precise and accurate, but much easier to implement. However, we do find that a micrometer reticule eyepiece is still a valid method of measurement, whose accuracy can approach digital methods if care is taken during measurement.

Table 1 compares the three measurement techniques' values found for each of the three binary pairs. Compared to the WDS, it was found that Photoshop gave the most accurate results, followed closely by BackyardEOS and then the micrometer eyepiece. Even though BackyardEOS is not intended for this type of measurement, data analysis using its protractor and linear scale produced results comparable to those found with analysis in Photoshop for wider separated pairs.

Photoshop analysis provided separation values within 1.3" and PA values within 1.3° from the WDS values. BackyardEOS analysis provided separations within 1.3" and PA data values within 2° from WDS values. This data does not include 17 Draconis, which could not be split by BackyardEOS in Live View mode. The micrometer eyepiece measurements had separation deviations between 0.8" and 1.9" and PA deviations between 1° and 3° from WDS values.

All of our methods suffer from the systematic uncertainties caused by the flaring of scattered light due to atmospheric seeing combined with optical aberrations. The micrometer reticule has additional measurement error associated with the parallax experienced while looking through the eyepiece, especially for novice astronomers. At times atmospheric turbulence made the closely separated pairs quite difficult to measure with respect to centering the primary on the protractor and aligning the pair along the 0º to 180º line. Even so, with meticulous attention made using the micrometer reticule, the accuracy of this method could certainly approach that of Photoshop analysis.

The advantages of analysis in Photoshop are numerous. It provides the best separation measurement resolution (±1 pixel / ±0.377"). The precision of the Measure tool in Angle mode (~0.01°) is much better than those made in the field by eye on a protractor reticule (smallest division of 5º). Last, data analysis can be performed indoors at a later time, minimizing time spent in the field. The main disadvantage is the cost of the software (~$600/year for a new user) and the need of a computer for analysis (if using a computer in the field, additional image capture software will be required, such as BackyardEOS, MaxIm DL, IRIS, or Nebulosity)

The use of BackyardEOS for these measurements employs nearly identical methodologies as the micrometer reticule eyepiece, but with a few advantages. Measurements can be made on a computer screen that can zoom in on the image. It also enables easier centering of the stars, having the capability to move and rotate the scales to the objects of interest. BackyardEOS does have some disadvantages when used in this way. As with the micrometer reticule eyepiece, it uses a linear and protractor scale to make measurements and is subject to human measurement error. Its Live View resolution is dependent upon good seeing to split close binaries, often requiring many various duration exposures and ISO settings. Even so, some binaries were not resolvable (STF2078AB -17 Draconis).

The micrometer eyepiece has the advantage of utilizing the human eye's ability to capture short moments of good seeing, it can be used with a Barlow lens, and has higher magnification than BackyardEOS implemented in this way with a Canon DSLR camera (this version of BackyardEOS only works with Canon EOS DSLR cameras). A further disadvantage of the micrometer eyepiece is that they are becoming harder to find since they are being produced more infrequently as digital capture and analysis methods become more common, affordable, and versatile.

Conclusion

We found that all three measurement methods are valid, but will continue to focus on using BackyardEOS for image capture and Photoshop for analysis in the immediate future, as we found this combination to work best for us. Going forward, our undergraduate research group will continue to catalog binary stars with the aim to image and analyze close binary pairs, those with larg-

*Table 1. Comparison of separation and position angle measurements using three different methods: the MicroGuide (Micrometer) Reticule Eyepiece, the astrophotography software package BackyardEOS, and analysis of digital images using Adobe Photoshop. *Could not resolve the pair using BackyardEOS Live View mode at the time of measurement.*

WDS Designation	Discoverer Designation	Method	Sep"	PA°	Date	N
J17419+7209	STF2241 AB	Micrometer	30.8±2.6	19±3	2014.821	12
		BackyardEOS	30.9±1.4	14±0.5	2014.717	6
		Photoshop	29.2	17.3	2014.717	7
		WDS Catalog	30.0	16	2012	
19418+5032	STFA 46AB	Micrometer	41.6±2.9	132±3	2014.821	12
		BackyardEOS	41.6±0.9	133±0	2014.717	6
		Photoshop	38.4	133.3	2014.717	7
		WDS Catalog	39.7	133	2013	
16362+5255	STF2078AB	Micrometer	4.0±0.5	103±5	2014.821	4
		BackyardEOS	N/A*	N/A*	2014.717	6
		Photoshop	3.1	104.0	2014.739	7
		WDS Catalog	3.1	104	2013	

er magnitude differences, and neglected pairs. We will improve our separation measurement accuracy through curve fitting intensity profiles for better determination of the star image's centroid.We will continue to work toward improving our measurement accuracy. As hoped for, this type of binary star research is easily within the reach of undergraduate science students and can undoubtedly lead to more advanced and in-depth binary star projects including eclipsing binary star photometry, orbital calculations, lucky imaging, and speckle interferometry. Additionally, we found BackyardEOS to be an ideal software package for capturing DSLR images.

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