Observations of Three Double Stars with Varied Separations

Eric Weise[1], Emily Gaunt[2], Elena Demate[3], Chris Maez[2], Nelly Etcheverry[2], Jacob Hass[4], Lindsey Olson[3], Andrew Park[3], and Michael Silva[2]

1. University of California, San Diego, CA
2. Cuesta College, San Luis Obispo, CA
3. California Polytechnic State University, San Luis Obispo, CA
4. Atascadero High School, Atascadero, CA

Abstract: As part of a summer semester introductory astronomy course, college students measured the position angles and separations of STF 2010AB, STF 2007AB, and STFA 48AB. The averages of our measurements are as follows: STF 2010AB had a ρ and θ of 25.71" and 10.78°. STF 2007AB had a ρ and θ of 38.63" and 320.3°. STFA 48AB had ρ and θ of 42.87" and 147.1°. Students compared recordings with averages of the past ten observations in the *Washington Double Star Catalog* and found that the agreement between our measurements and the past observations improved with increasing separation

Introduction

Observations of three double stars, STF 2010AB, STF 2007AB, and STFA 48AB were made as part of an introductory Astronomy course at Cuesta College during the 2013, six week summer semester. The observations were made at the Orion Observatory in Santa Margarita, California. Weather conditions on the first and last observing nights were ideal. On the second night, however, several clouds drifted into our field of view, making the process take a little longer than expected.

The goals of the project were two-fold: to contribute to our knowledge of double stars, and to give students first hand experience doing scientific research. We chose to observe three double stars of different separations in hopes of seeing how the variances in our measurements were affected by differences in apparent separation. Organizing and delegating tasks to our team of students of varied backgrounds was a great learning experience, and we were each able to learn how to work together toward a common goal.

Figure 1. The team poses at the Cuesta College Campus. From left to right: Nelly, Elena, Emily, Lindsey, Eric, Chris, Michael, Andrew, and Jacob.

Methods and Equipment

To gather observations, we used the Orion Observatory's 10 inch, f/10, equatorial mounted telescope with a Sidereal Technology control system equipped with a Celestron astrometric eyepiece. The control system was integrated with TheSky6 to help point the telescope at the target systems. After each measurement was made, the observer was changed so that all participants were given ample observing time.

We used the drift method to calibrate the linear scale in our eyepiece (Teague 2012). Following the steps of this method, the telescope tracking was turned off to allow a calibration star to drift along the linear scale. Drift times were recorded using a cell-phone application accurate to the nearest hundredth of a second. Ten drift times were recorded. The average drift time was used to calculate the scale constant, Z, in units of arc seconds per tick, using the equation below:

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

where δ is the declination of the calibration star, dt is the average drift time, and N is the number of ticks in the scale, in our case, sixty. We calibrated our eyepiece using Arcturus and found our scale constant to be 6.72 arc seconds per tick, with a standard deviation of 0.05 arc seconds per tick.

The separation of each double star system was found by placing both stars on the linear scale and counting the ticks between the stars. The stars were randomly placed along the linear scale for each observation to reduce systematic bias. Each observer measured the separation of a system until ten data points were recorded. The average of these separations in ticks was multiplied by the scale constant, Z, to determine the separation of the system in arc seconds.

The position angle was found by aligning the primary star in the center of the eyepiece, and then rotating the eyepiece so that the secondary star was on the linear scale, and then turning off the tracking of the telescope to allow the primary star to drift to the outer protractor on the eyepiece. In order to reduce systematic bias, the protractor on the eyepiece was rotated 180 degrees between observations, and 180 degrees was then subtracted or added to the observations in order to disambiguate the results. Furthermore, a ninety degree correction was applied to correct for the rotational alignment of the protractor in the Celestron eyepiece.

At first our position angle measurements were considerably off from published results. However, further investigation proved this was because the image in the eyepiece was in fact real and not imaginary, therefore the inner protractor should have been used. The numbers on the inner protractor increase in a counter-clockwise direction. The outer protractor is converse. This issue was resolved by subtracting our measurements from 360, and then applying the 180 degree disambiguation and 90 degree correction.

History

The first double star officially recorded was Mizar. In 1650, Giovanni Battista Riccioli discovered this star in Ursa Major (Ondra 2013). Since then double stars have been discovered by astronomers such as Robert Hooke, Fontenay, and many others. At least 1 in 18 stars brighter than 9.0 magnitude in the northern half of the sky are known to be double stars visible with a 36-inch (910 millimeter) telescope (Aitken 1964).

One of the doubles we observed was discovered in the 17th century by Friedrich Wilhelm von Struve. It is known as Kappa Herculis and has been given the discover code STF 2010AB. It is a binary star with primary and secondary magnitudes of 5.10 and 6.21 in V band, respectively. The primary is a yellowish white and the secondary is a blue star (Sordiglioni 2013). According to the *Washington Double Star Catalog* (WDS), the double star has been observed since 1779. Figure 2 below is a graph of observations of STF 2010AB, courtesy of the U.S. Naval Observatory.

The system STF 2007AB has primary and secondary magnitudes of 6.89 and 7.98, respectively. The double star is located in the constellation Serpens Caput. According to the *WDS*, the star has been observed since 1823, and past observations suggest that this pair may

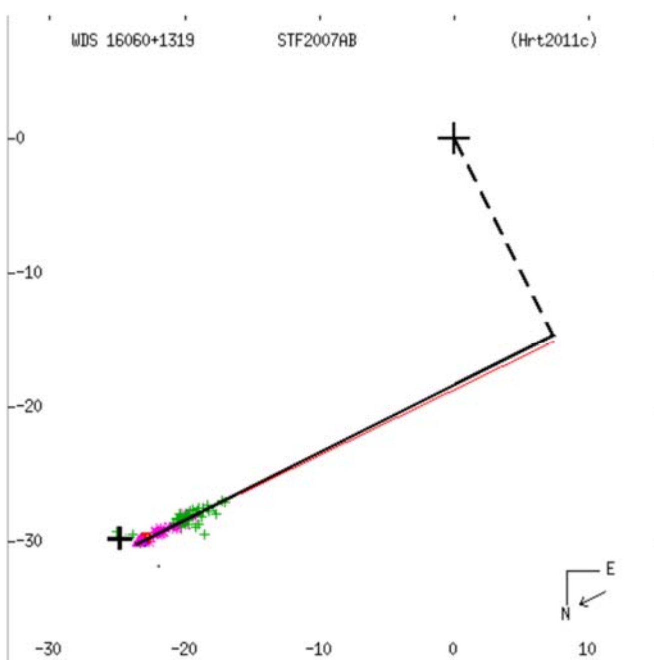

Figure 2: Graph of the motion of STF 2007AB (Mason and Hartkopf 2013). Our observation has been marked with the black plus to the lower left. The scale is marked in arc seconds.

(Continued on page 147)

Observations of Three Double Stars with Varied Separations

be an optical binary.

The system STFA 48AB has primary and secondary magnitudes of 7.14 and 7.34, respectively, and is located in the constellation Vulpecula. According to the *WDS*, STFA 48AB has been observed since 1782.

Results

In Tables 2 through 4, we present our data compared with the last ten observations reported to the Washington Double Star Catalog, which we obtained from the U.S. Naval Observatory (Mason and Hartkopf 2013). The standard deviation of our separation was found by adding in quadrature the standard deviations of the scale constant, *Z*, and the separation in ticks, using the equation below:

$$\frac{\sigma_\rho}{\rho} = \sqrt{\left(\frac{\sigma_{ticks}}{ticks}\right)^2 + \left(\frac{\sigma_z}{Z}\right)^2}$$

where ρ is the separation in arc seconds, "ticks" is the number of divisions on the linear scale between the star images, *Z* is the scale constant calculated in the Equipment and Methods section, and σ represents the standard deviation of the corresponding subscript.

Analysis

Comparisons with Past Observations

In the tables 5 and 6 we compare our values to the average of the ten most recent observations reported to the WDS. The values in the table rows have he following significance: Δ is representative of the accuracy of our measurements, σ is the statement of our precision, and Δ/σ is the unit-less value telling us how many standard deviations we were off from past observations.

Comparisons to Rectilinear Elements

Two of the double star systems that we observed have solutions in the Catalog of Rectilinear Elements that is maintained by the USNO (Mason and Hartkopf 2013). The ephemerides for 2010 and 2015 were obtained for these two systems from this catalog. The position angle and separation were calculated for the dates we observed each star. These values were calculated using the following method: First the 2014 and 2015 ephemeris values for position angle and separation, θ and ρ, were converted into Cartesian coordinates, x and y. Assuming that the velocity of the secondary star relative to the primary is constant, then the velocity components, v_x and v_y, will also be constant. Thus, the change in either coordinate can be calculated by:

$$r_{epoch} = r_{2010} + \frac{(r_{2015} - r_{2010})(epoch - 2010)}{5}$$

Table 2: STF 2010AB, observed on B2013.494. Only nine measurements were made of the position angle during the observation run. This was not noted until during the data analysis. Past observations from the WDS were made between 2007.534 and 2012.491.

	Our Data		Past Data from the WDS	
	Separation	Position Angle	Separation	Position Angle
Number of Obs.	10	9	10	10
Average	25.71''	10.78°	27.14''	13.40°
Standard Deviation	1.43''	2.11°	0.33''	1.89°
Standard Error of the Mean	0.45''	0.70°	0.11''	0.60°

Table 3: STF 2007AB, observed on B2013.503. Past observations from the WDS were made between 1998.8 and 2012.491.

	Our Data		Past Data from the WDS	
	Separation	Position Angle	Separation	Position Angle
Number of Obs.	10	10	10	10
Average	38.63''	320.30°	38.00''	322.19°
Standard Deviation	1.92''	4.21°	0.39''	0.33°
Standard Error of the Mean	0.61''	1.33°	0.13''	0.10°

Table 4: STFA 48AB, observed on B2013.514. Past observations from the WDS were made between 1993.31 and 2012.588.

	Our Data		Past Data from the WDS	
	Separation	Position Angle	Separation	Position Angle
Number of Obs.	10	10	10	10
Average	42.87''	147.10°	42.26''	147.30°
Standard Deviation	2.52''	1.73°	0.56''	0.66°
Standard Error of the Mean	0.80''	0.55°	0.18''	0.21°

Observations of Three Double Stars with Varied Separations

where Epoch is the Besselian date of the observation, and *r* is either Cartesian coordinate, *x* or *y*. These coordinates are then converted back into θ and ρ. For the Epoch of our observations we found STF 2007AB to have ρ = 38.275" and θ = 321.93°, and STF 2010AB to have ρ = 27.103" and θ = 13.439°.

When comparing our values of Δ and Δ/σ in Tables 5 and 6 to the values in Table 7, one can see that our results are much closer to the ephemerides from the *Catalog of Rectilinear Elements* than to the averages of the last ten observations reported to the WDS. This is not surprising. However, it does not make sense to draw conclusions about the accuracy of our measurements using the data in Table 7, because the system STF 48AB does not have published rectilinear or orbital elements. The strongest statement that can be made is that, for published rectilinear systems with large numbers of past observations (STF 2010AB has 191 past observations, and STF 2007AB has 77), using the rectilinear elements published by the WDS will probably be closer to observed measurements.

While we did not measure enough stars to make an accurate or informative least squares model, we can still see that, universally, the closeness of measurements to the past ten observations from the WDS (Δ) did improve when we increased the separation of our target star. Interestingly, this trend does not hold for the precision of our data. The standard deviation (σ) of our separation measurements increases with the separation of the target system, and the standard deviation of our position angle measurements has no correlation to separation. We speculate that the increasing uncertainty of the separation measurements is due to the difficulty to count the ticks between wider pairs when using an astrometric eyepiece.

Table 5: Separation measurements; precision and accuracy.

	STF 2010AB	STF 2007AB	STFA 48AB
WDS Separation (ρ)	27.14"	38.00"	42.26"
$\|\rho_{ours} - \rho_{WDS}\|$ (Δ)	1.43"	0.63"	0.61"
Std. Dev., our data, (σ)	1.43"	1.92"	2.52"
Δ/σ	1.00	0.33	0.24

Table 6: Position Angle; precision and accuracy.

	STF 2010AB	STF 2007AB	STFA 48AB
WDS Separation (ρ)	27.14"	38.00"	42.26"
$\|P.A._{ours} - P.A._{WDS}\|$ (Δ)	2.62°	1.89°	0.2°
Std. Dev., our data, (σ)	2.11°	4.21°	1.73°
Δ/σ	1.24	0.45	0.12

Table 7: Comparing our measurements to the ephemerides calculated from the Catalog of Rectilinear Elements.

	STF 2010AB		STF 2007AB	
	Position Angle	Separation	Position Angle	Separation
Our Measurement	10.78°	25.71"	320.30°	38.63"
Standard Dev. (σ)	2.11°	1.43"	4.21°	1.92"
Calculated Ephem.	13.44°	27.10"	321.93°	38.28"
|Ours - Ephem.| (Δ)	1.66°	1.39"	1.63°	0.35"
Δ/σ	0.7867	0.97	0.3872	0.1823

Conclusion

We started our research project with two goals: to contribute to the growth of scientific knowledge of double stars, and to demonstrate that research is accessible and beneficial to students of many experience levels. During our project, we encountered problems such as undesirable weather and errors in our observing techniques. Despite these setbacks, we continued to work and eventually solved the issues we came up against.

Acknowledgments

We thank the Orion Observatory and Russell Genet for providing all necessary equipment and facilities for collecting data. In addition, we thank Ryan Gelston, David Ho, and Russell Genet for providing guest observations. This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. Brian Mason provided specific data regarding the observed stars. Finally, we thank Russ Genet, Vera Wallen, Tom Smith, Bobby Johnson, Ryan Gelston, and Nate Kleinsassar for reviewing our paper.

References

Aitken, Robert Grant, 1964, *The Binary Stars*. New York: Dover, p. 260.

Mason, Brian, and Hartkopf, William, July 2013, *The Washington Double Star Catalog*. Astronomy Department, U.S. Naval Observatory, Personal correspondence.

Mason, Brian, and Hartkopf, William. September 9, 2013, *Catalog of Rectilinear Elements*, Astronomy

Observations of Three Double Stars with Varied Separations

Department, U.S. Naval Observatory, *http://ad.usno.navy.mil/wds/lin1/lelements.html*.

Ondra, Leos, 16 July 2013, *A New View of Mizar*. http://www.leosondra.cz/en/mizar/.

Sordiglioni, Gianluca, 13 July 2013, *Stelle Doppie*, http://stelledoppie.goaction.it/index2.php?menu=39&iddoppia=65102.

Teague, Tom, 2012, "Simple Techniques of Measurement." , *Observing and Measuring Visual Double Stars*, Bob Argyle, ed., Springer, New York, p. 161-162.