An Astrometric Observation of Binary Star Systems STF 42AB and STF 1169AB

Introduction

Looking into the night sky, about half of the stars we can see are actually part of a binary system or a double star. The term "double star" refers to any set of two stars that can be observed very closely together from Earth. A double star can pertain to many types of binary systems, mainly being optical, visual, and non-visual binaries, but this project pertains directly to visual binaries. A visual binary is a double star that can be directly observed from Earth with a telescope, meaning that all components of the system are observable. An important element of a visual binary system is that the components must be gravitationally bound. In contrast, there are also double stars that are classified as non-visual binaries, which just means that the binary status was found in a way that was not direct observation with a telescope. Finally, an optical double is simply two stars that appear to be close together, but they are actually not gravitationally bound and just appear that way due to the Earth's alignment with the stars. Though they appear to be very close to each other, an optical double is two completely unrelated stars that look similar to a visual binary.

When observing these star systems, the aim is to distinguish between the visual binaries and optical doubles, so that it can be verified that a star from the Washington Double Star database is indeed a double star. In other words, the data that others have collected previously will be used to corroborate the recently obtained data from Las Cumbres Observatory. The goal of this research is to add to the already existing data on these star systems, STF 42AB and STF

1169AB, and potentially find the orbit of the stars from the measured separation and position angle.

Historically, visual double stars were measured by visual measurement and a micrometer, but astrophotography allows for much easier analysis of the relative positions of the stars in the system. The relative position of the separate components are measured using the angular separation and the position angle, which are denoted as “rho” and “phi” (or theta) respectively. While a digital image processing software, such as AstroImageJ (Collins), will process the relative positions of the stars easily, a micrometer involves the use of any system of adjustable webs, needlepoints, or an eyepiece reticle with graduated lines on the glass used with a telescope. Since these measurements would have been taken by a micrometer directly on the telescope or, the separate steps of taking digital images and processing them was eliminated, but some accuracy and convenience is sacrificed.

The measurements of these stars will be in terms of angular separation as well as position angle, which will determine the relative position of these stars to each other. Comparing the collected data to historical data will either confirm a projected orbit or add data to the historical positions. If the new data is added to that of the historical projected orbit, then the orbit received will be more accurate and help future researchers who would like to observe these double stars.

Methods

The two double stars from the Washington Double Star database, STF 1169 AB and STF 42AB, were selected based on their listed separations and magnitudes. For ideal observing conditions with a 0.4 meter telescope, the separation between the two stars needed to be greater than about 3 arcseconds, and the magnitudes of both stars had to be between magnitudes of 7 and

10. By filtering the WDS catalog, the stars were then selected by which systems fit these parameters, and which stars were highly visible during the month of November, 2022. In addition to these parameters, the binary systems were also selected to be only physical doubles, eliminating the possibility of uncertain doubles cataloged in the system. Each of the selected double star systems are ranked as a grade 5, which is ranked on a scale of certainty from 1 to 9, with 1 being definitive and 9 being indeterminable. This ranking provides relative certainty that these double stars are physical, and the data collected aims to corroborate these historical findings.

The Signal to Noise Ratio was also calculated for each of these stars, which confirmed that the stars would be visible to measure photometrically. The integration time for each picture was picked as one second to reduce the ratio accordingly, and the obtained values implied that the SNR would not be too great.

Star	Filter	F (photons/s/cm^2)	SNR
1169	V	307.75	191.6
1169	B	495.23	243.4
1169	i	402.44	219.3
1169	r	332.16	199.1
42	V	210.96	158.5
42	B	339.48	201.3
42	i	275.87	144.9
42	r	227.69	164.7

Figure 1. Signal to Noise ratio calculations for STF 1169 AB and STF 42AB under selected filters.

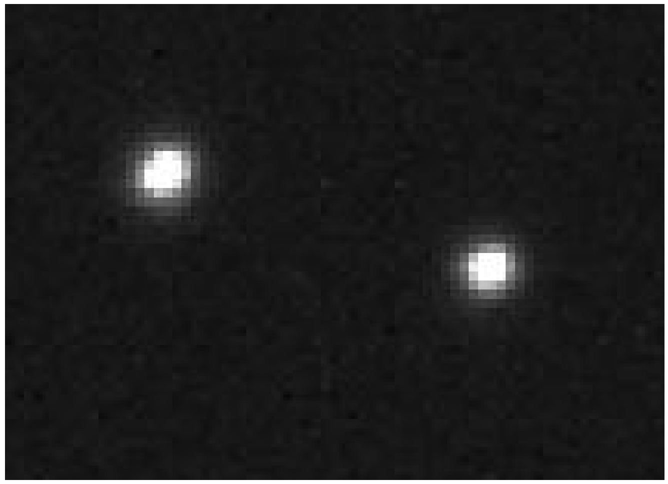

Figure 2. STF 1169AB taken with Los Cumbres Observatory Telescope in AstroImageJ Software.

There is historical data for both of these double stars on WDS, but there are limited measurements based on digital images, and the orbital plots provided are based on interferometric measurements. Additionally, for STF 42AB, there are two different posted orbital plots of differing results from 2000 and 2015 respectively.

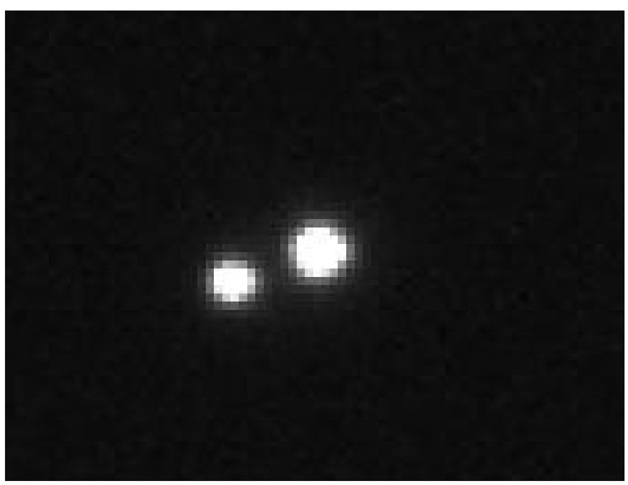

Figure 3. STF 42AB. taken with Los Cumbres Observatory Telescope in AstroImageJ Software.

In order to find the relative positions of the stars to each other, the stars must be imaged and analyzed, which is done using the Las Cumbres Observatory (LCO) via the University of

California, Santa Barbara. The specific telescope used to take these images was a 0.4 meter telescope at the McDonald, Teide, and Haleakala Observatories in the LCO global telescope group. Every 0.4 meter telescope in the LCO system is equipped with a SBIG STL6303 camera, capturing a large number of stellar objects closer to Earth. This camera takes images that translate one pixel to approximately 0.571 arc seconds, which can be used to measure the angular separation between the two stars. Each photo of the star systems was taken with an exposure time of one second, and 60 images were taken of each double star respectively. Fifteen images were taken under the Bessel B filter, fifteen were taken under the Bessel V filter, and the other two sets of fifteen were taken under the SDSS . This allows the observers to see the stars under different conditions, so if the objects are easier to see under one filter, then they will have multiple photos to measure and average from that data set. One second exposure times reduce the signal to noise ratio of the images, allowing the observers to have clearer images and more accurate measurements of angular separation and position angle. The exposure time was determined using the magnitudes of the primary stars, in which case was about one second for both systems observed.

After obtaining the images from the LCO, they were processed in AstroImageJ to do the actual measurements of separation of position angle. An aperture radius of 7 was selected to take the measurements for each image of the systems, as it appeared to fit the stars the best, and the RA and DEC values were recorded in order to calculate the position angle and angular separation later using the following equations:

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

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

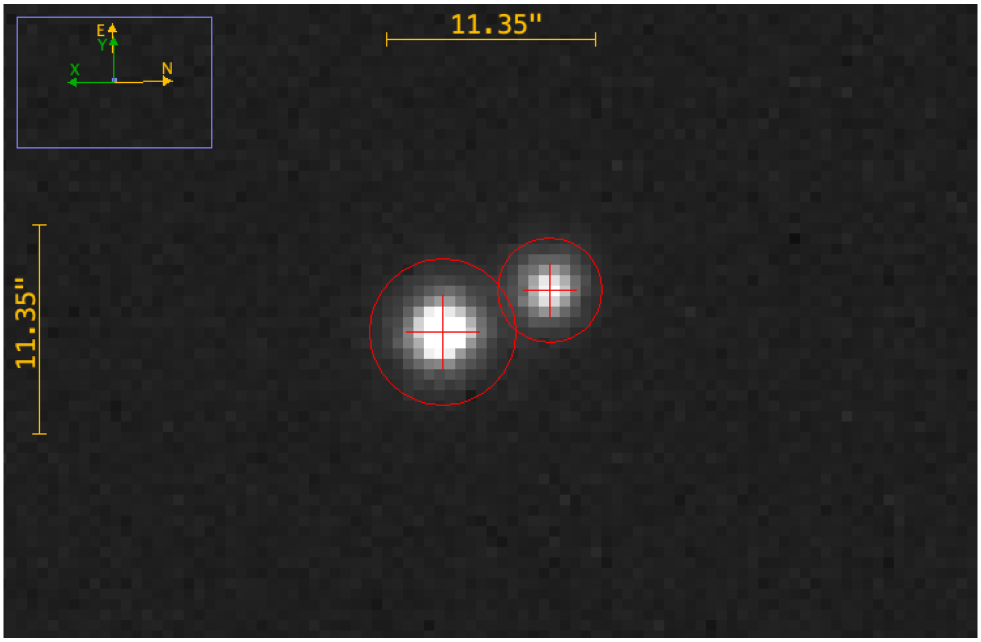

Figure 4. Shown is STF 42AB under the V filter being processed in AstroImageJ using the Aperture tool.

The obtained measurements were averaged. The obtained data was then plotted and compared to the historical data, which corroborated the findings in a cartesian coordinate system.

Next, the data is plotted in excel using Richard Harshaw's Plot Tool 3.19 to create an orbital plot with the historical data requested from the U.S. Naval Observatory, but there is just enough data to begin this plot, ideally following the trend of this previously collected data in the WDS catalog. The Plot Tool uses the data request files from the WDS to generate Cartesian plots of the measurement history (Harshaw). It efficiently allows users to detect short arc binaries if there are enough prior trends in the historical data.

Data and Results

	B	**V**	**R**	**I**	**Final data**
1169	0146-e91-0160-e91	Phys 134L - ST…	0284-e91-0298-e91	Phys 134L - STF…	Finalized Data

	Teide Observatory	Teide Observatory	McDonald Observatory	McDonald Observatory	
42	0107-e91-0121-e91 McDonald Observatory	Phys 134L - ST… McDonald Observatory	0093-e91-0107-e91 Haleakala Observatory	Phys 134L - STF… Haleakala Observatory	

Figure 5. Position Angle and Angular Separation of A and B stars of STF 1169 and STF 42.

Averages		
Filter	Sep	PA
Bessel B	21.07904	14.6371
Bessel V	20.77305	15.07388
SDSS r'	20.8617	15.71672
SDSS i'	21.06166	16.39462
Standard Deviation	0.15063952	0.767158
Standard Error	0.07531976	0.383579
Average	20.9438625	15.45558

Figure 6. Position Angle and Angular Separation of A and B stars of STF 1169 Averaged Final Results.

Average		
Filter	SEP	PA
B	6.32571547	21.6405913
V	6.23405391	20.1582282
r’	6.26558127	19.959984
i’	6.22141116	19.8640892
Stdev	0.0465494	0.83230682
Std Error	0.0232747	0.41615341
Avg	6.26169045	20.4057232

Figure 7. Position Angle and Angular Separation of A and B stars of STF 42 Averaged Final Results.

To gather the required data, our images of star systems STF 42 AB and STF 1169 AB were processed under filters covering as many wavelengths as possible. Both systems are highly observable in the gathered timeframe, which helped in the decision to study these stars, and they were both able to be imaged relatively clearly. The calculated average angular separation of STF 1169 AB is 20.9 arcseconds, and the position angle is 15.5 degrees. For STF 42 AB, the average values were 6.3 arcseconds and 20.4 degrees. These are relatively close to the most recently obtained experimental values, which will be discussed in the next section. The raw data gathered was that of the RA and DEC values, which were then used in calculating the position angle and angular separation with trigonometric functions.

The images for STF 42AB initially proved difficult to analyze, as there was some overlap between the stars in the images. This was rectified with another data request, which was taken at a different telescope location and showed separation in the images.

Based upon the data, it seems that STF 1169AB is a visual double that follows the orbital plot of previously collected data, but the status of STF 42AB as a double star or optical double is unclear. Based on other papers from the JDSO, some evidence obtained may suggest that STF 42AB is not a visual binary at all, but the majority of historical data suggests that it is a physical system with a short arc solution.

Discussion

The intent of this research was to measure the angular separation and position angle of a binary star system to evaluate whether it is a visual or optical double. The values would then be corroborated with previous research done in the WDS system, and the orbital plots would be created in both polar and cartesian coordinates.

Overall, the gathered data is very similar to that of the historically calculated position angle and angular separation found on the WDS. STF 42 AB has a separation of 6.3, with respective magnitudes 8.39 and 9.05. STF 1169 AB has a larger separation of 20.6, with respective magnitudes 8.4 and 8.64. Comparing these to the obtained values, they differ by a couple arcsecs, but the error stays relatively low at less than 5%.

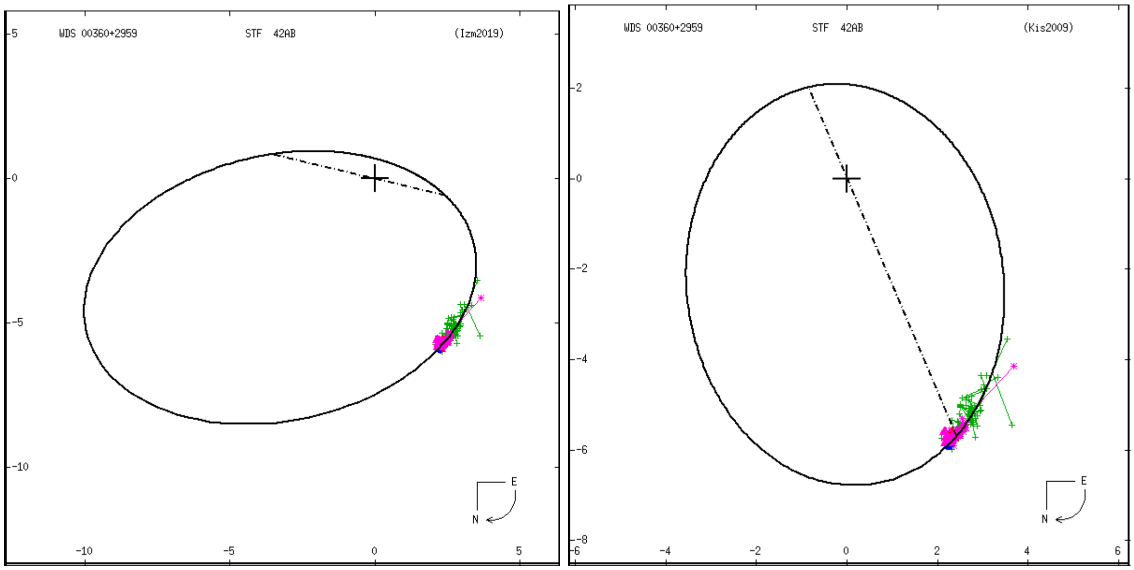

Figure 8. Historical orbital plot results of A and B stars of STF 42 from the WDS from 2019 and 2009 respectively.

The orbital plots obtained by request from WDS historical data archive demonstrate that each binary system seems to have stars that are gravitationally bound by one another. The obtained position angle and angular separation are comparable to the historical data, suggesting that the collected data would create similar plots using Harshaw's plotting tool. Unfortunately, the WDS did not have the required information to create this plot, so the collected values were compared to that of the previously created plots. Based on that information, manually plotting the collected data on top of the previously created graphs, it can be concluded that STF 1169 AB is a physical double. According to the WDS, the system has an rPM of 0.036, which means that the stars are gravitationally bound to one another. A double is physical if the rPM value is less than 0.3, putting STF 1169 AB well within the range and corroborating the collected results for position angle and angular separation. For STF 42 AB, the rPM is even lower, at 0.023, also implying a physical double.

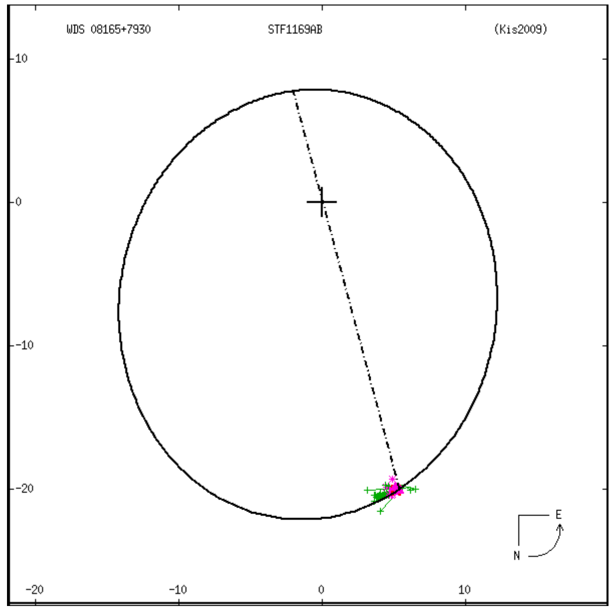

Figure 9. Historical orbital plot results of A and B stars of STF 1169 from the WDS.

Though the results are similar to previously done studies, they are not identical. There may be several variables that contribute to this difference. The historical data suggests that both of these double stars are visual binaries, and the collected data corroborates that, but there are several factors that might alter the observed values.

One such factor would be that the images had to be taken from multiple telescopes at two separate occasions. Initially, it was unknown that the 0.4m telescope offered by the LCO did not have Bessel filters beyond B and V. As a result, the request had to be resubmitted in SDSS filters r' and i', which was approximately ten days after the first observation. Though it is unlikely that the different locations of telescopes had an impact on the resultant data, it is possible that there was some difference in the angle of the photo.

Another factor that may have affected the calculated results of rho and phi for STF 42 AB and STF 1169 AB would be the selected aperture size in AstroImageJ. The aperture size was selected to be 7 for both stars in STF 1169 AB and 7 for the A star in STF 42 AB and 5 for the B star. These apertures were selected due to the fact that they seemed to fit the images of the stars the best, but there is obvious room for error in several senses. One instance might be that the apparent magnitude of the stars is incorrect, as noise in the image could cause the star to appear larger than it may be. Another issue could be that the apertures were not centered on the star. If there was too much noise in the image, the center of the star would photometrically appear to be in a different location than it actually is.

In addition, the WDS did not have the necessary historical data to use Harshaw's Plot Tool and create an orbital plot for the doubles, which means that more observations and measurements need to be recorded and reported to the database first. Otherwise, the historical data was very helpful to compare the newly obtained data to.

In future instances, it might be beneficial to utilize AstroImageJ's centroid function to calculate the position angle and angular separation, as it would eliminate the in-between step of calculating in Excel. This way, more images could be processed more efficiently, and perhaps consequently yield more data with closer values to the obtained ones in the WDS catalog. The tool was forgone in favor of hand-completing calculations in Excel and using the same file to create averages of the data, too.

Another way to ensure that the data is more uniform would be to have them taken at the same time from the same location, also in filters of corresponding wavelengths. The filters used this time were two Bessel Filters and two SDSS filters. The filters were all of different wavelengths, but they did not cover as great a spectrum as pictures taken in each filter for a filter system. Using all of the same kind of filter increases ease of data request as well as ensures that all wavelengths are being accounted for.

Overall, the technique of selecting the aperture size on AstroImageJ limits the reliability of separation measurement, especially in instances where the stars have a very small separation or appear to overlap. The systems chosen, STF 1169 AB and STF 42 AB seem to have relatively constant angular separation and position angle values, with no overtly large changes in the measured values since the discovery. STF 1169 AB is a physical binary and STF 42 AB appears to be a short-arc binary system, as its data shows a trend increase. The systems are both physical, visual binaries.

Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. This work makes use of observations from the Las Cumbres Observatory global telescope network.

References

Araújo C. G. (2014). Detailing the writing of scientific manuscripts: 25-30 paragraphs. Arquivos brasileiros de cardiologia, 102(2), e21–e23. https://doi.org/10.5935/abc.20140019

Beish, J. (2006). Measuring double stars with a micrometer and digital image. ALPO astronomy. Retrieved November 22, 2022, from https://alpo-astronomy.org/jbeish/TDLdoubles.pdf

"Binary and Multiple Star Systems". Lawrence Hall of Science at the University of California. Archived from the original on 2006-02-07.

"Binary Stars". Astronomy. Cornell University.

Collins, K., Kielkopf, J., Stassun, K, and Hessman, F., 2017, "AstroImageJ: Image processing and photometric extraction for ultra-precise astronomical light curves", A J, 153:77, 13pp.

Harshaw, Richard, 2020, "Using Plot Tool 3.19 to Generate Graphical Representations of the Historical Measurement Data", *JDSO*, **16**, No. 4; 386-400.

Heintz, W. D. (1978). Double Stars. Dordrecht: D. Reidel. p. 17. ISBN 90-277-0885-1.

"Las Cumbres Observatory Global Telescope Network", Brown, T. M. et al., Publications of the Astronomical Society of the Pacific, 2013, Volume 125, issue 931, pp.1031-1055

p. 2, p. 155-157, Observing and Measuring Double Stars, Bob Argyle, ed., London: Springer-Verlag, 2004, ISBN 1-85233-558-0.

Sixth Catalog of Orbits of Visual Binary Stars Archived 2009-04-12 at the Wayback Machine, William I. Hartkopf and Brian D. Mason, United States Naval Observatory, accessed online November 21, 2022.

The Binary Stars, Robert Grant Aitken, New York: Dover, 1964, p. 1.

Worth, M. "Binary Stars". Stephen F. Austin State University. Archived from the original (PowerPoint) on 3 September 2003.