Analyzing the Proper Motion of Two Double Star Systems from Astrometric Measurements

Alex Falatoun[1], Janet Barrera[1], Anna de Neef [2], Aura Gonzalez[3], Jae Calanog[1], Pat Boyce[4], and Grady Boyce[4]

1. San Diego Miramar College, San Diego, California, USA
2. MiraCosta College, Oceanside, California, USA
3. San Diego Mesa College, San Diego, California, USA
4. Boyce Research Initiatives and Education Foundation (BRIEF), California, USA

Abstract: The iTelescope network was used to obtain astrometric measurements of double star systems WDS 12202-1408 (STF 1631) and WDS 12339+5522 (STI 2286). Through astrometric measurement softwares SAOImage DS9 and Mira Pro x64, a mean position angle for STF 1631 of 304.8° ± 0.9° and a mean separation 14.7" ± 0.2" was measured. For STI 2286, a newly measured mean position angle of 85.9° ± 0.9° and mean separation 11.5" ± 0.3" were obtained. The relative proper motion of 1631 shows that the system could be demonstrating a linear path or an approximately circular orbit with a period of ~1400 years. Parallax measurements of the secondary star will aid in classifying if this system is a physical or a visual pair. The proper motion of STI 2286 indicates that it could be a physical pair, featuring an orbit nearing a turning point. Follow-up observations in three to four year intervals will further validate or refute this claim and constrain the shape of a possible orbit.

Introduction

The Astronomy Research Seminar is a project offered by San Diego Miramar Community College for students to gain insight on how research is performed in the real world. This program allows students to learn about binary stars and the basics of astronomy. This project was supervised by Jae Calanog at Miramar College and was supported by the Boyce Research Initiatives and Education Foundation (BRIEF).

Double stars consist of any two stars in the sky within close proximity when viewed from Earth. Some double stars are physically associated or gravitationally bound to each other, commonly referred to as binary stars. However, it is also possible that some double stars are aligned by chance along our line of sight, appearing close to each other when observed but are actually hundreds or thousands of light years apart (Buchheim, 2015). A straightforward method of gathering evidence in order to classify a double star as a visual or a physical pair is to track their positions over time. If the position of each star is determined, the double star's position angle, θ, and separation distance, ρ, can be measured and one can effectively visualize the relative proper motion when compared with historical data.

For this research, the Washington Double Star Catalog (WDS) by Brian Mason (2012) was used to select two double star systems, WDS 12202-1408 (hereafter referred to as STF 1631) and WDS 12339+5522 (hereafter referred to as STI 2286). The double star systems were selected based on their visibility in the Northern Hemisphere during the spring semester (January - June). The WDS catalog was used to search for systems with a right ascension between 12 and 18 hours. In addition, a minimum separation of 6 arc seconds and a magnitude difference no greater than 6 was preferred. Both double star systems met the criteria and had less than 15 observations making them favorable to study because our research would provide valuable information for their classification.

The first star system was selected because it was labeled as a linear system yet the data presented did not seem to support that statement. This star system was discovered in 1831 by John Frederick Herschel, son of astronomer William Herschel. In 1816 Herschel was

Analyzing the Proper Motion of Two Double Star Systems from Astrometric Measurements

Table 1. Historical measurements for STF 1631. Position angle is measured in degrees and separation distance in arcseconds.

WDS 12202-1408 (STF 1631)		
Epoch	θ (°)	ρ (")
1831.35	268.0	21.0
1900.34	278.3	15.63
1905.35	276.0	15.753
1906.32	277.5	15.926
1909.34	278.3	15.63
1930.42	283.0	15.29
1991.25	298.08	14.681
1991.25	292.7	14.665
1991.69	298.0	14.984
1998.29	300.0	14.73
2000.085	299.9	14.625

directed to continue his father's work and in 1820 became a member of the Astronomical Society. In addition to astronomy, John Herschel is known for many of his accomplishments in mathematics, chemistry, and photography (Lankford, 1997). The star system's observation history and data can be viewed in Table 1.

The second star system, STI 2286, had a noticeable difference in its position angle as well as its separation, which indicated significant movement away from the primary star. It was first observed in 1917 by astronomers at the Vatican Observatory Foundation (2015-2016), a few years after Pope Leo XIII re-founded the institution in 1891. He wanted to demonstrate that the Church was not against science, but instead, promoted it. Based on the information from the WDS catalog and the historical data, these systems seemed to be appropriate candidates to be binary systems. Observation history and data is outlined in Table 2.

The goal of this study was to measure the current separation distances and position angles from the selected double star systems. In obtaining these measurements, we can provide supporting evidence whether or not these systems are either physically associated or just aligned by chance along our line of sight.

Table 2. Historical data for STI 2286. Position angle is measured in degrees and separation distance in arcseconds.

WDS 12339+5522 (STI 2286)		
Epoch	θ (°)	ρ(")
1917.28	176.7	5.7
1917.28	176.7	5.685
2000.26	80.0	10.18
2003.16	81.1	10.472
2006.408	82.3	10.84
2010.5	84.0	11.25

Figure 1. *The iTelescope Network's T18 used for the astrometric measurements of STF 1631 and STI 2286.*

Equipment, Observations, and Data Analysis Procedures

Equipment

iTelescope Network's T18 (Figure 1) is located at the AstroCamp Observatory in Nerpio, Spain. The attached charged coupled device (CCD) has a 100,000e-non anti-blooming gate and uses a Planewave CDK optical tube assembly on a Paramount PME externally guided mount. This telescope provides 0.73"/pixel resolution, and images were taken using an Astrodon Series E LRGB (Luminance, Red, Green, Blue) filters (Jenkins, 2003).

Observations

The date of observation was chosen to align as closely as possible to a new moon phase in order to have the lowest luminosity from the moon as determined by the Staralt visibility tool (Sorensen, 2002). The first date of observation was in late March and the

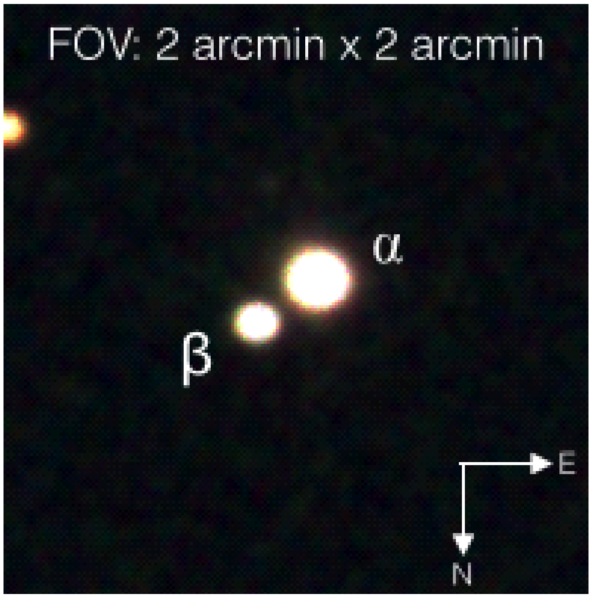

Figure 2. Three color image of STF 1631 with combined filters red, green and blue. Field of view is 2 arcmin x 2 arcmin.

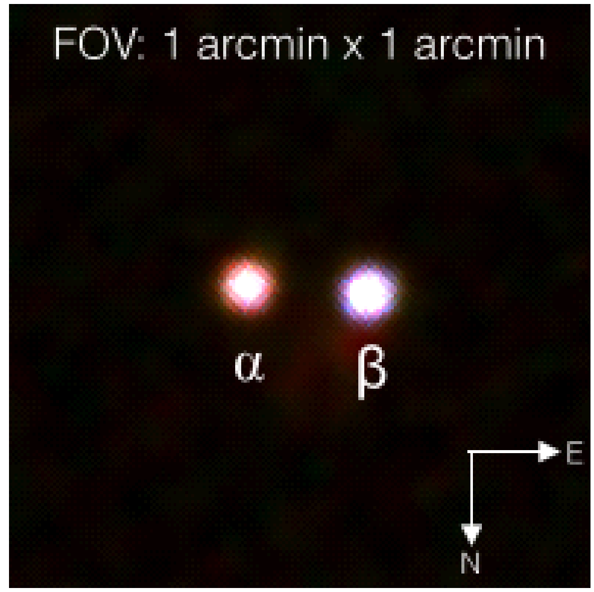

Figure 3. Three color image of STI 2286 with combined filters red, green and blue. Field of view is 1 arcmin x 1 arcmin.

second date of observation in early May.

Four images were taken in total of STF 1631 at 60 seconds exposures each, using a luminance, red, green and blue filter. Five images of STI 2286 were taken in total, two using a luminance filter for unbiased viewing at 60 and 120 second exposures, and one of each red, green, and blue filters, each with 60 second exposures. See Figures 2 and 3.

Analysis Procedures

All images were preprocessed (flat-fielded and dark subtracted) by the iTelescope network. The pixels that contained our double star systems were checked for counts to make sure that none of the images were oversaturated. After assessing the quality of the images, they were imported to MaximDL in order to assign World Coordinate System (WCS) positions using the Pinpoint Astrometry feature, which compares the image to the Naval Observatory's Catalog (UCAC4). The UCAC4 catalog matched 110 out of 148 catalog stars with an average residual of .1 arcseconds for STF 1631 and 104 out of 174 image stars with an average residual of .1 arcseconds for STI 2286.

The image analysis software SAOImage DS9 (referred to henceforth as DS9) was used to consistently measure the position angle (θ) and separation distance (ρ) for each image. First, a 7" circle was created using the Regions feature and placed over the A star, followed by a circle of the same radius around the B star. DS9's auto-centroiding feature was used to find the center of each star, which effectively calculates the weighted mean position of all the counts per pixel enclosed in the circle. The coordinates for the centroid of each star were recorded and then placed as endpoints of a line segment. The length of the line segment provided the separation distance in arcseconds and its orientation relative to some reference provided the position angle.

To further validate the measurements taken by SAOImage DS9, images were cross referenced with Mira Pro x64. Both results provided considerable overlap in each measurement, verifying the precision of each software.

Results

We list our astrometric measurements in Table 3 and Table 4 for STF 1631 and STI 2286, respectively. For the epoch, 2017.33, we measure STF 1631 at a mean position angle of 304.8° ± 0.9° and separation distance of 14.7" ± 0.2". For STI 2286, we measure a position angle of 85.9° ± 0.9° and separation distance, 11.5" ± 0.3". Assuming that the 1-σ uncertainties associated with the last measurement for STF 1631 (Hartkopf et al. 2013) and STI 2286 (Cutrie et al. 2012) are of the magnitude of the smallest significant figure listed, then one can conclude that both systems have exhibited a significant change in position between the primary and the secondary.

Discussion

Figure 4 shows an increasing trend in the position

Table 3. Position angle, separation distance, and uncertainties for STF 1631

WDS 12202-1408 STF 1631					
Epoch	Number of Images	Mean θ (°)	σ_θ (°)	Mean ρ (″)	σ_ρ (″)
2017.33	4	304.8	0.9	14.7	0.2
2000.085	Last Measurement (Hartkopf, et al 2013)	299.9	0.5	14.6	0.1

Table 4. Position angle, separation distance, and uncertainties for STI 2286

WDS 12339+5522 STI 2286					
Epoch	Number of Images	Mean θ (°)	σ_θ (°)	Mean ρ (″)	σ_ρ (″)
2017.33	5	85.9	0.9	11.5	0.3
2010.5	Last Measurement (Cutrie et al 2012)	84.0	0.8	11.3	0.2

angle for STF 1631. It is difficult to determine whether the trend over the past ~200 years has been approximately linear, since we do not have knowledge of the uncertainties associated with the first measurement in 1831. We reach a similar conclusion when examining the longitudinal data associated with the separation distance (Figure 5). All subsequent measurements after the first observation show the separation distance to be slowly decreasing at a steady rate. Figure 6 shows the relative proper motion of STF 1631. If we treat the 1831 measurements as an outlier, then the subsequent data shows two possibilities: First, STF 1631 is a visual pair, with the primary and secondary exhibiting a high degree of relative proper motion. Second, STF 1631 is a binary system in an elliptical orbit, and the current set of data points are only a fraction of the orbital path. This could be indicative of a special case in which a circular orbit with a period of ~1400 years (determined assuming a constant rate of change in theta and estimating the time for the secondary star to complete 360 degrees around the primary), as explained by the separation remaining statistically constant since its last measurement, and a constant increase in position angle. In addition, we also note that the recent data release from the GAIA satellite (Arenou et al. 2017) provides a parallax measurement of the primary star and has an estimated distance of 109 ± 3 parsecs (~350 light years). If STF 1631 is indeed a binary system, then we would expect the secondary star to have a similar distance, therefore highlighting the importance of the secondary star's parallax measurement for future observations.

Figure 7 shows a peculiar measurement in STI 2286's initial position angle, measured by the Vatican Observatory in 1917. It is significantly larger and does not fit the trend of measurements in later years. We have explored different possibilities on how this measurement could have been so different, such as a North-South switch, a nearby star that could have been mistaken for the secondary, or an initial observation that was taken at the end of a period and subsequent observations were measured once the position angle had reset back to zero. None of these scenarios were able to reproduce the initial measured position angle. In addition, the initial separation distance measured also adds complexity to the issue (of disregarding the 1917 meas-

(Text continues on page 255)

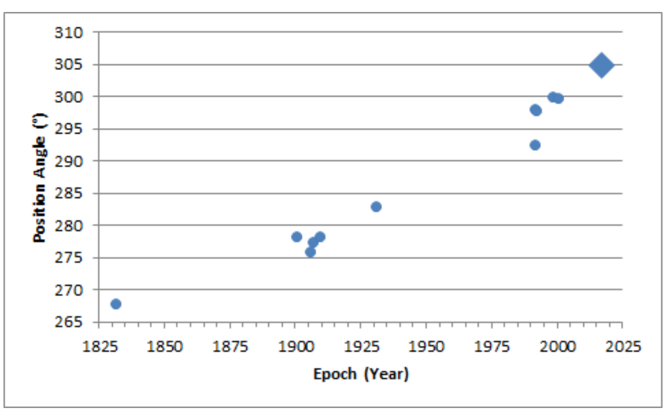

Figure 4. Position angle in degrees and epoch in years for STF 1631, including historical data and new measurement (large diamond). Since its observation, the position angle has steadily increased, which could indicate a constant angular velocity.

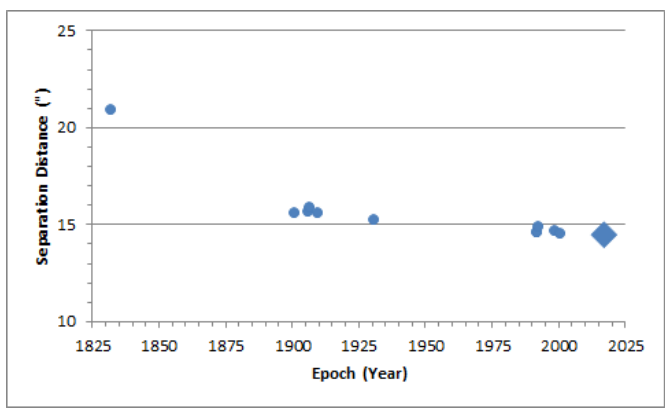

Figure 5. Graph of separation *distance in arcseconds and epoch in years for STF 1631, including historical data and new measurement (large diamond). Aside from the first observation, the separation distance appears to be steadily decreasing but could also be statistically constant if the uncertainties from previous measurements overlap with the more recent measurements.*

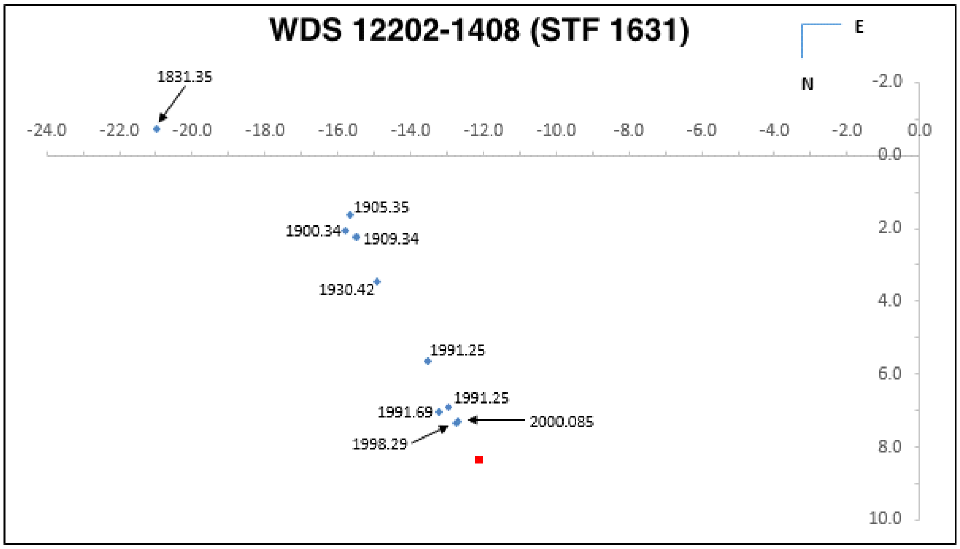

Figure 6. Relative proper motion plot of STF 1631, expressed as ΔRA vs. ΔDEC relative to the primary, placed at the origin. Subsequent measurements from Herschel show two possibilities: a linear solution, which would classify the system as a visual pair or a binary system with an approximately circular orbit, indicated by the steadily changing position angle and an approximately constant separation distance.

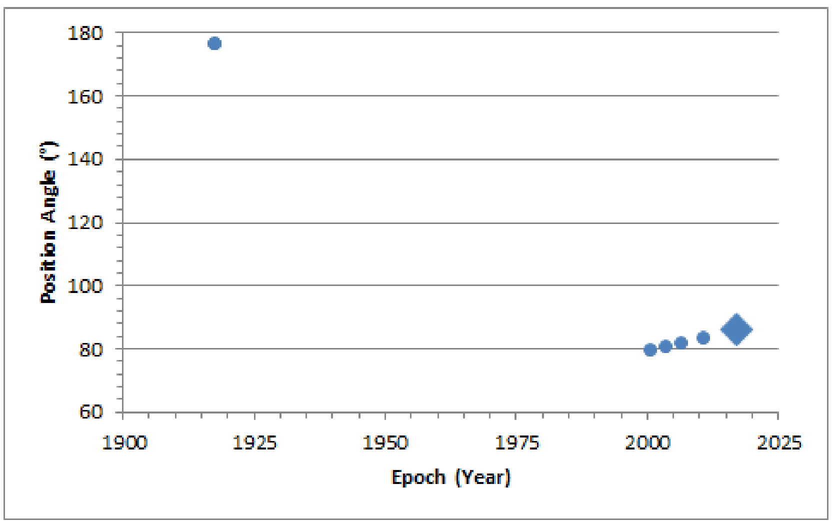

Figure 7. Graph of position angle in degrees and epoch for STI 2286, including historical data and new measurements (large diamond). The first observation in 1917 does not fit the trend displayed by subsequent measurements and is likely an outlier.

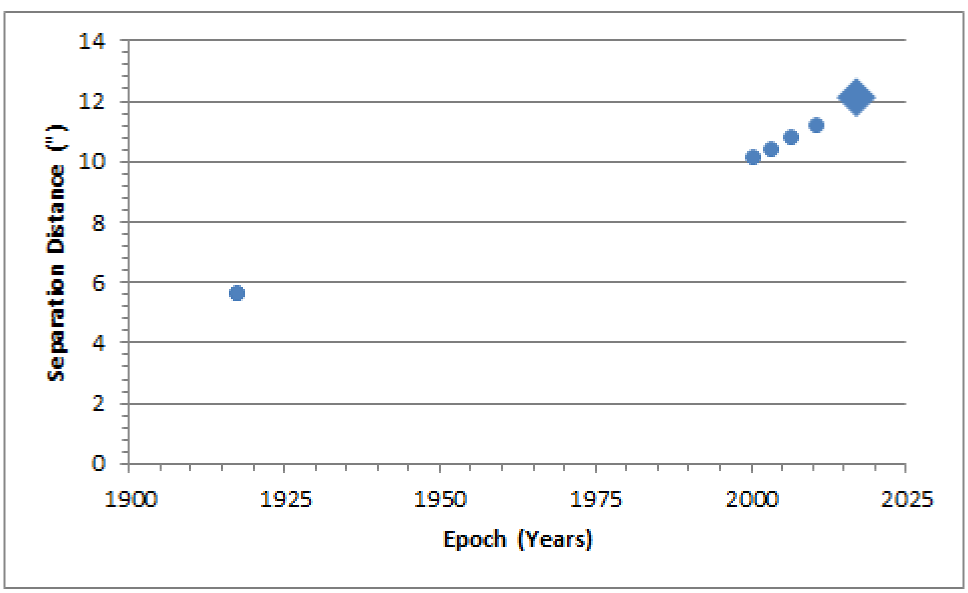

Figure 8. Graph of separation distance in arcseconds and epoch for STI 2286, including historical data and new measurements (large diamond). Subsequent measurements after 1917 show a steadily increasing separation distance.

Analyzing the Proper Motion of Two Double Star Systems from Astrometric Measurements

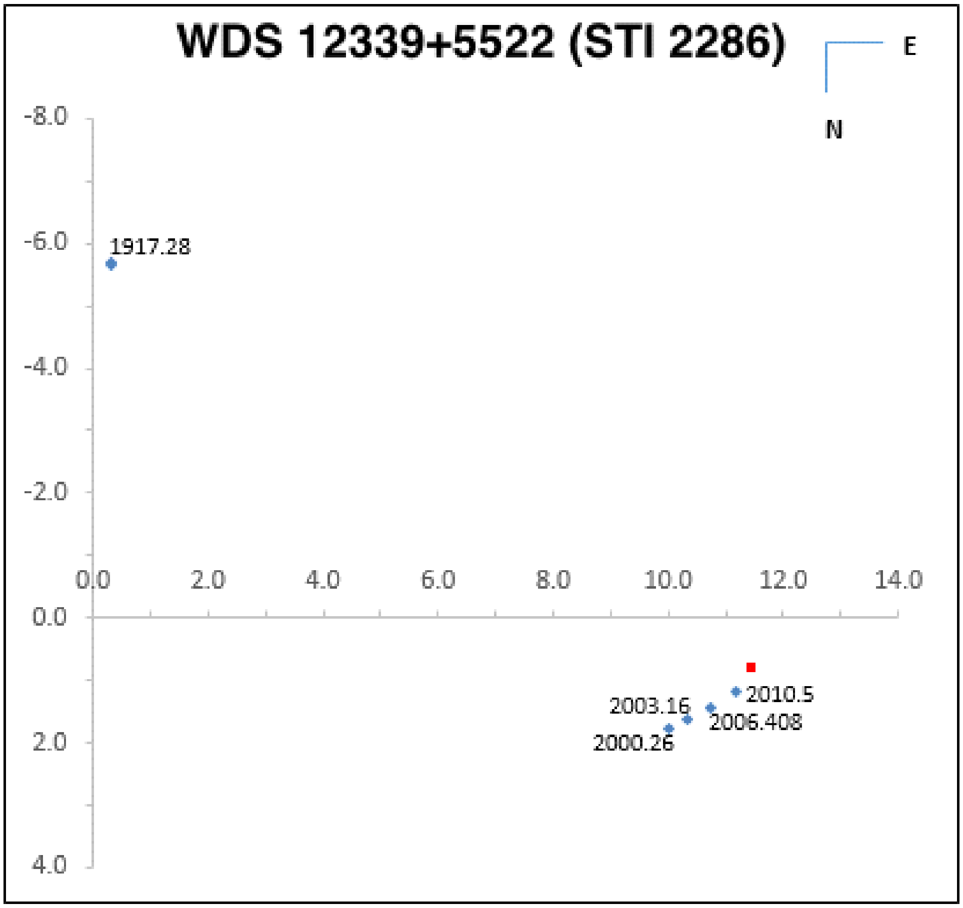

Figure 9. Relative proper motion plot of STI 2286, expressed as ΔRA vs. ΔDEC relative to the primary, placed at the origin. Excluding its first observation in 1917 (likely an outlier), STI 2286 follows a curved path that could indicate an orbit around the primary star.

(Continued from page 253)

urements) since it could be consistent with a nonlinear, increasing trend (Figure 8). If we choose to omit the 1917 measurements, then Figure 9 shows that the secondary's relative proper motion is exhibiting some curvature, consistent with an orbit around the primary. Furthermore, from the shape of the secondary's curved path, it looks to be that it might be nearing a turning point. Given that the historical data for STI 2286 listed in Table 2 shows that the position angle has been changing at a rate of 1-2° per every 3-4 years and its possible current stage in an elliptical orbit, follow-up observations of this double star system in those time intervals will provide critical longitudinal information in classifying whether or not this system is a physical or a visual double.

Conclusion

We have successfully measured the position angles and separation distances of the star systems, WDS 12202-1408 (STF 1631) and WDS 12339+5522 (STI 2286), using observations from iTelescope's T18 telescope. Both measurements showed a significant change in position from their last measurements. Our conclusions for each system are as follows:

1. The current set of data for STF 1631 currently shows a proper motion that could be linear or part of orbit with a small degree of eccentricity and a period of ~1400 years.
2. The first set of measurements for STF 2286 is likely an outlier. If we make this assumption, STF 2286 could represent a physical double star system with the secondary nearing a turning point. Observations every 3-4 years will prove very beneficial in constraining a possible orbit for this system.

Acknowledgements

This research was supported by the Boyce Research Initiatives and Education Foundation (BRIEF). We thank Brian D. Mason for past observations on both

STF 1631 and STI 2286 from the Washington Double Star Catalog.

We are grateful to the San Diego Community College for allowing us to hold meetings on campus. We also would like to thank the members of the Boyce Astro community for the resources and financial donations that have allowed us to carry out our research.

This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

References

Arenou, F., et al., 2017, "Gaia Data Release 1. Catalogue Validation", *Astronomy & Astrophysics*, **599**, 35.

Boyce, G. and Boyce, P. Boyce, Research Initiatives and Education Foundation (BRIEF), http://www.boyce-astro.org/home.html.

Buchheim, R., Johnson, J., Harshaw, R., & Gennet, R. (2015). Small Telescope Astronomical Research Handbook. Collins Foundation Press.

Cutri, R. M., et. al., 2012, WISE All-Sky Data Release (Cutri+ 2012), http://adsabs.harvard.edu/abs/2012yCat.2311....0C.

Jenkins, A., 2003, *iTelescope Network News – Remote Internet Telescope Network – Online Imaging & Telescope Hosting Service*, N., Mortillano and I. Musgrave, eds., http://www.itelescope.net/.

Lankford, J., 1997. *History of Astronomy: An Encyclopedia*, Garland Publishing Inc., New York.

Mason, Brian., 2012, *Washington Double Star Catalog.* Astronomy Department, United States Naval Observatory, http://ad.usno.navy.mil/proj/WDS/.

Sordiglioni, Gianluca, 2016, Stella Doppie Double Star Catalog, http://stelledoppie.goaction.it/.

Sorensen, P., Azzaro, M., Méndez, J., 2002, *Isaac Newton Group of Telescopes,* http://catserver.ing.iac.es/staralt/.

Vat. Obs. Foundation. 2015-2016. *Specola Vaticana History*, https://www.vofoundation.org/mission.

Hartkopf, William, Mason, Brian, Finch, Charlie, Zacharias, Norbert, Wycoff, Gary, and Hsu, Danley, "Double Stars in the USNO CCD Astrographic Catalog", *The Astronomical Journal*, **146**, no. 4, 2013.