# Astrometric Observations and Analysis of the Physical Binary Pair STF 296AB

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**Abstract**: We obtained astrometric measurements of the double star WDS 02442 +4914 (STF 296AB) using the iTelescope Network. By performing CCD astrometry, a position angle of 305.4° ± 0.3° and an angular separation of 21.14" ± 0.09" was determined. Based on historical data, the position angle and angular separation have changed from the previous measurement of 304.7° and 20.69" (2013).

## Introduction

Double stars have been a major part of astronomy since their discovery in the 17th century (Aitken, 1935). Astrometry, the process of measuring the positions and motions of stars, is a major component in the study of double stars because it can reveal physical information about the system. If enough measurements are taken over time, it can be determined if two stars are indeed gravitationally bound (in the case of binary stars), which can then permit the calculation of stellar mass.

We selected a double star system that met the following criteria using the Washington Double Star (WDS) catalog: (a) observable during the fall semester in the northern hemisphere, (b) a right ascension between 00 and 05 hours, a declination between -10 and 80, and (c) a magnitude difference ($\Delta m$) of 6 or less. WDS 02442+4914 (hereafter referred to as STF 296AB) satisfied these criteria. This star system has a $\Delta m$ of 5.84, which is not ideal for closely spaced pairs, as it can cause the brighter star to bloom into the secondary. However, its separation of 20.34" allowed for observations in this system.

The first observer of STF 296AB was Frederick William Herschel. His early work with double stars led him to the hypothesis that two stars might be orbiting under mutual gravitational attraction, which he would later confirm. In 1782, Herschel made his first observation of STF 296AB, and recorded a position angle of 290° and an angular separation of 13.52" (Herschel, 1785). Herschel noted that the star is "In sinistro humero (In the left upper arm). Double. Extremely unequal. L (primary). w (white). inclining to r (red).; S (secondary). d (dim)...."

The WDS catalog grades star system orbital plots based on orbital coverage, number of observations, and their overall quality, using a numerical scale from 1-5, with 1 being definitive and 5 being indeterminate. STF 296AB has an orbital plot that is categorized as grade 5 due to little curvature, and has 76 observations spanning 231 years. Yet despite the number of observations, it remains unclear whether the A and B components are physically associated. The most recent observation in 2013 shows that the angular separation rose to 20.69", while the position angle went up to 304.7° (Riddle et al, 2015).

The orbital elements were first published by German astronomer Josef Hopmann in 1958, which highlighted STF 296AB's large period and periastron (Hopmann, 1958). The orbital elements allowed Hopmann to give the position of the orbit in space. In his publication, Hopmann concluded from the orbital plot that STF 296AB is most likely a physical system. Although the information is useful, the calculated orbital plot of the star system is a grade 5, indicating that the orbit is indeterminate (Figure 1). Furthermore, a French paper published in 1989 noted "orbite dénuée de signification", which translates to "orbit with no meaning"(Baize & Petit, 1989).

## Procedure

Images used in this project were taken using

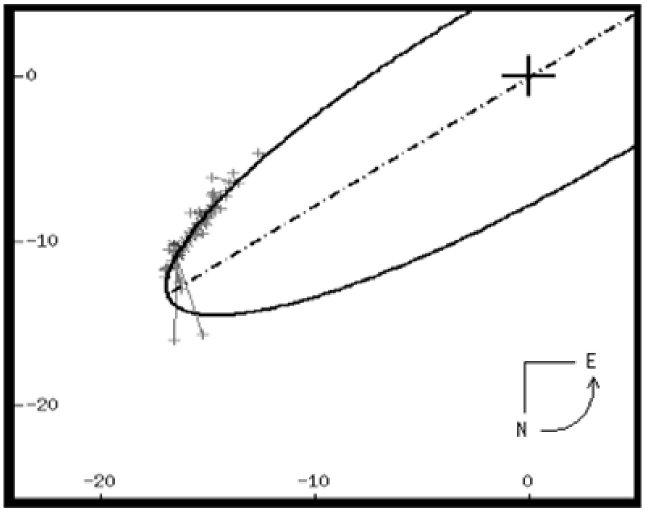

*Figure 1. Hopmann's original 1958 orbital plot.*

Charged Coupled Device (CCD) cameras. By using CCD devices for observation and analysis, we can utilize software to analyze the data, leading to increased precision for results. The earliest example of this technique in reference to STF 296AB, is a paper published in 1998 where a position angle of 304.01° ± 0.14° and a separation of 20.07" ± 0.07" was measured (Abad et al., 1998). Due to the ease of analyzing data using software, our measurements were taken using similar cameras.

### *Equipment*

All images were taken by telescopes provided by the iTelescope network (Figure 2). The telescopes, T21 located in Mayhill, New Mexico at an elevation of 2,225 m, and T7 located in Nerpio, Spain at an elevation of 1650 m, were chosen to take a total of 12 images. T21 is composed of a CCD camera with 3072 x 2048-pixel array, a pixel scale of 9 µm square mounted on a Planewave 17" CDK 0.43 m f/6.8 reflector with a f/4.5 focal reducer for a resultant resolution of 0.96" per pixel. T7 is composed of a CCD camera with a 4008 x 2672-pixel array, a pixel scale of 9µm square mounted on a Planewave 17" CDK 0.43 m f/6.8 reflector for a resultant resolution of 0.63" per pixel.

A total of 6 images were taken on each telescope. Images for T21 were taken on epoch 2016.836 and images for T7 on 2016.852. Both telescopes used the same exposure times for each filter. Different filters were used to observe STF 296AB to verify if there are any differences in measurement that could be wavelength dependent. Hydrogen-alpha and Red filters were used to take 90 second and 120 second exposures. A luminance filter was used for an exposure time of 30 seconds and 60 seconds.

### *Analysis/ Data Reduction*

All 12 images were processed through Maxim DL 6 to add World Coordinate System (WCS) positions to the FITS files by comparing the star field to U.S. Naval Observatory CCD Astrograph Catalog (UCAC4). All 12 images successfully matched an average of 373 stars to the 2079 imaged by comparison to the 3028 cataloged stars.

Two image analysis applications, SAOImage DS9 and Mira Pro x64, were used to analyze the images after being calibrated with WCS information. STF 296AB features a Δ*m* of 6 between the primary and the secondary star. The primary star was oversaturated in most of the images, causing diffraction spikes and blooming in T21-Luminance-60. The blooming would

*Figure 2. iTelescope 21 (left) and iTelescope 7.*

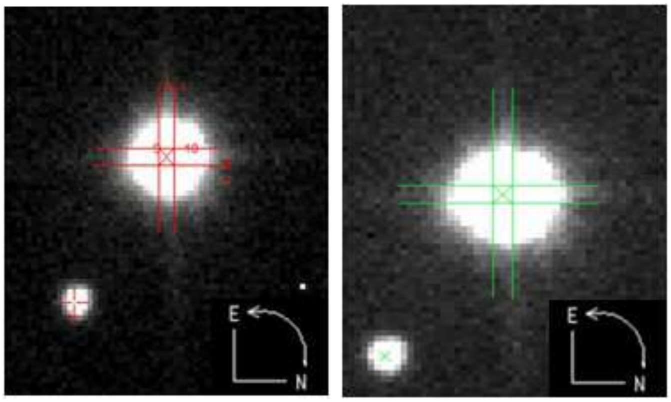

*Figure 3. Shows on the left, Mira program using the diffraction line method to locate the centroid, and on the right SAOImage DS9 using the same method to locate the centroid.*

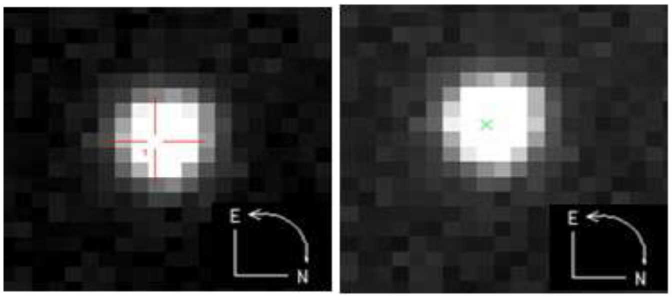

***Figure 4:*** *Shows the location of the centroid in the secondary star by means of location by high pixel value. Left image represents the location in Mira while the right represents SAOImage DS9.*

have resulted in inaccurate measurements so diffraction spikes were used instead to locate the centroid of each component. Both SAOImage DS9 and Mira Pro x64 allowed us to verify the measurements of our method successfully, without any significant difference between results.

To locate the centroid of the primary star, lines were drawn along the diffraction spikes to find the center of the star and line segments were drawn between the intersections to find the centroid of that image, as seen in Figure 3. Due to pixels of the secondary star being contaminated from the primary star, we could not use the automatic centroid locator feature of Mira Pro x64 for the secondary star. Instead, the centroid of the secondary star was located by finding the highest value pixel, as seen in Figure 4. Once the centroids of both stars were located, a line segment was placed between the two points. The line segment represents the distance between both stars. Both SAOImage DS9 and Mira Pro x64 have features that allow analysis of the segment and the end points. The analysis showed the length of the line segment in arc-seconds, and showed the right ascension and declination of the end points which are the centroids of both the primary and secondary.

After converting the right ascension and declination into radians, the position angle was calculated using the following relationship (Genet, 2015):

$$\theta = \arctan\left(\frac{\Delta\alpha \cos\delta_1}{\delta_2 - \delta_1}\right) \quad \text{(radians)} \qquad \text{Eq. 1}$$

where $\delta_1$ and $\delta_2$ are declination of the primary and secondary, respectively, and where $\alpha_1$ and $\alpha_2$ are the right ascension of the primary and secondary, respectively.

By determining the angular separation and positional angle for all 12 images, the standard mean of error (SEM) was calculated. This was done by using the following equation (Genet, 2015):

$$SEM = \frac{\sigma}{\sqrt{N}}$$

where $\sigma$ is the standard deviation from all of the measurements and $N$ is the number of images.

## Observations and Results

Please note the measurements taken from SAOImage DS9 and Mira Pro x64 were identical to 2 decimal places. Therefore the results shown below only reflect the data taken from Mira Pro x64.

Tables 1 and 2 display the separation and the position angle for every filter that was used in observing STF 296AB for both T21 and T7. Please note Luminance-60 for T21 on the table below. The declination of the secondary was measured to be 49º 13' 54.677", which was over 1.1" in error of position by comparison to all other images taken by T21. The position angle of this image was determined to be an outlier, due to oversaturation of the secondary star from the primary star and resolution of the telescope.

In addition, we also list the mean separation distance and position angle of T21 and T7. We note that the resolution associated with T7 is larger relative to T21. However, measurements from both telescopes appear consistent with each other and well within the uncertainties associated in making an individual measurement. However, we summarized the results from T7 due to better resolution and therefore report an angular separation of 21.14" ± 0.09" and position angle of 305.4° ± 0.3°. This result supports that STF 296AB has indeed shifted its position in the sky, since its last measurement (Riddle et al., 2015).

## Discussion

We note that Hopmann's model currently has an orbital grade of 5 in the WDS (Hartkopf et al. 2001),

*Table 1. Data Table of Astrometric Measurements, Mean and Standard Error of T21. *Measurement omitted due to blooming effect in the image.*

| iTelescope | T 21 | |
|---|---|---|
| ***Filters-Exposure Time*** | θ | ρ |
| Red-90s | 305.76° | 21.305" |
| Red-120s | 304.70° | 21.479" |
| Hydrogen Alpha-90s | 303.39° | 21.603" |
| Hydrogen Alpha-120s | 304.86° | 21.947" |
| Luminance-30s | 305.45° | 21.245" |
| *Luminance-60s | 310.21° | 21.527" |
| Mean | 304.83° | 21.516" |
| Std. Deviation | 0.9 | 0.3 |
| SEM | 0.4° | 0.1" |

*Table 2. Data Table of Astrometric Measurements, Mean and Standard Error of T7. *Measurement omitted due to blooming effect in the image.*

| iTelescope | T7 | |
|---|---|---|
| ***Filters-Exposure Time*** | θ | ρ |
| Red-90s | 304.81° | 20.951" |
| Red-120s | 306.37° | 20.948" |
| Hydrogen Alpha-90s | 304.93° | 21.462" |
| Hydrogen Alpha-120s | 304.78° | 20.956" |
| Luminance-30s | 305.58° | 21.237" |
| *Luminance-60s | 305.73° | 21.281" |
| Mean | 305.37° | 21.139" |
| Std. Deviation | 0.6 | 0.2 |
| SEM | 0.3° | 0.09" |

which is indeterminate. Although our measurement does show a shift in STF 296AB's previous position, the change is still too short to differentiate between a curved or linear path.

Comparing the new measurement with William Herschel's in Figure 5, the trend seems more linear then the orbital plot that Hopmann originally proposed. If we assume that STF 296AB is a visual double, then Figure 6 could indicate that the secondary's separation from the primary is continuing to increase at a rate of 0.0314 arcsec/year.

Our measured position angle in Figure 7 is also consistent with the trend in Figure 6, showing a change in the previously measured position angle. However, at this time the rate of the position angle with respect to time (i.e. 0.0663 degrees/year) has stayed relatively

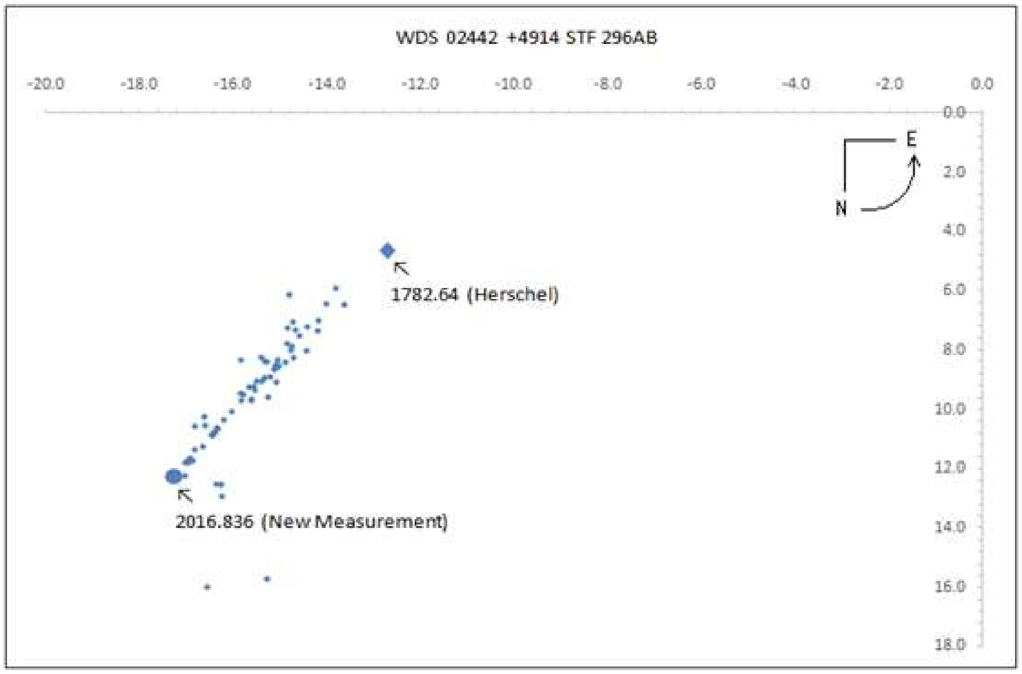

*Figure 5. Orbital plot of STF 296AB. The figure shows the secondary star relative to the primary (origin).*

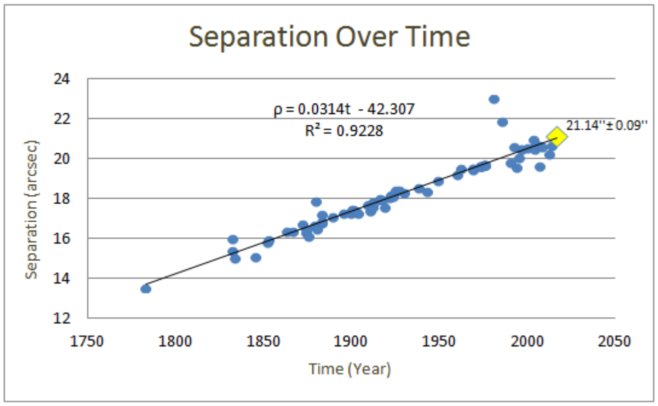

*Figure 6. Separation versus time of STF 296AB. The diamond symbol represents our measurement.*

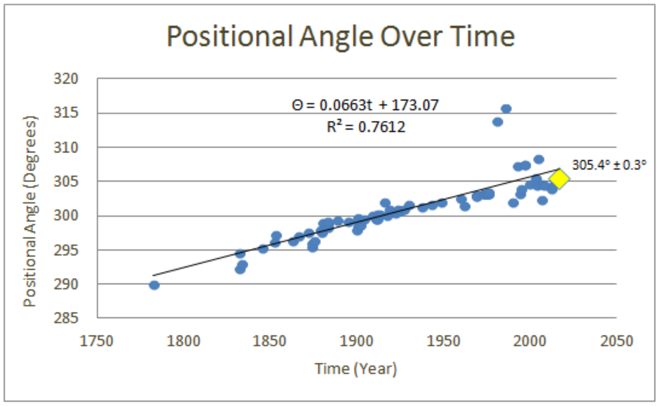

*Figure 7. Position angle versus time of STF 296AB. The diamond symbol represents our measurement.*

constant. If future observations determine that the rate at which the positional angle is changing is decreasing, then this supports our claim that this is not a gravitationally bound binary and may be just an optical double.

## Conclusion

We observed STF 296AB using two different telescopes in the iTelescope network for a total of 12 images. Combined with historical data, our measurements show that both the position angle and separation have changed and indicate an optical system over a physical system. Our results have shown a shift in position for the star system. However, future observations are necessary in order to help establish the true nature of this pair. This will either further constrain the apparent orbital path of STF 296AB or classify it as a visual double star system.

## Acknowledgements

We thank the Boyce Research Initiatives and Education Foundation (BRIEF) for providing access to the iTelescope network and the BARC server for providing software like Mira Pro x64 and Maxim DL. Additionally, we thank the Smithsonian Astrophysical Observatory for providing SAOImage DS9, as it allowed us to make precise astrometric measurements of our binary star system during our analysis. Lastly, we thank the United States Naval Observatory for providing the historical measurements of STF 296AB.

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