STF 42 AB Measurement and Reclassification

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Abstract: This paper investigates the double star STF 42 AB. STF 42 AB was imaged on January 13, 2021 (2021.036) using a five-second exposure for each of eleven images. In these images, it had a position angle of 20.76 ± 0.14 (1 ± SEM) degrees and a separation of 6.25 ± 0.011 arcseconds. Using parallax and proper motion data from Gaia Early Data Release 3, relative velocity and escape velocity were calculated. From these measurements and historical data plots, there is evidence that STF 42 AB is not gravitationally bound despite currently being classified as a true binary.

Introduction

STF 42 AB is a double star located in the constellation Andromeda as shown in Figure 1. It's coordinates are $00^h\ 36^m\ 02.39^s$ +29° 59' 34.2". Both the primary and the secondary stars are listed in the Washington Double Star (WDS) catalog as main sequence stars (G2V and G7V). The two stars have similar parallaxes and proper motions, indicating that they may be physically related. STF 42 AB is interesting because this pair is currently classified as gravitationally bound (Izmailov, 2019) with an orbital solution shown in Figure 2. Additional measurements may help to confirm this classification or suggest reclassification. If a double star is not a true binary, an orbital solution may result in an incorrect total mass of the system calculated using Kepler's third law, which may in turn lead to incorrect mass-luminosity inferences.

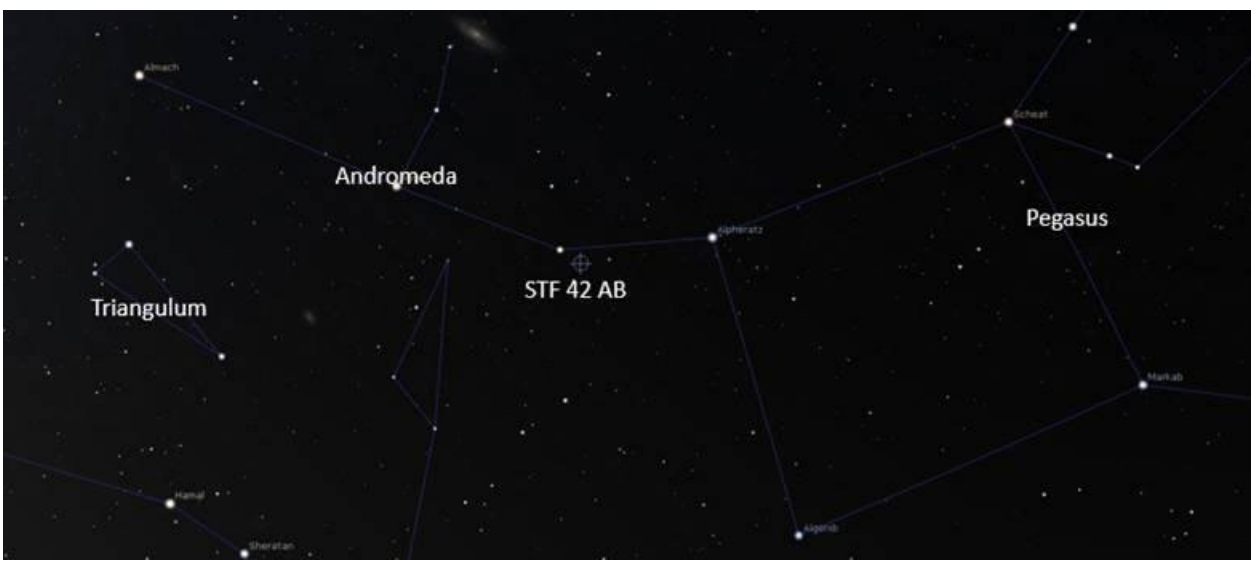

Figure 1: *Location of STF 42 AB in the sky taken in Stellarium.*

Target Selection

The Stelledoppie database was used to identify double stars imageable using the Las Cubres Observatory at the time of the study. To ensure the target was both visible and possibly gravitationally bound, constraints were employed on Right Ascension (RA), Separation (Sep), difference in magnitude (Δmag), magnitude, parallaxes, and proper motions. In particular, to ensure that the double star was visible by the Las Cubres Observatory at the time of the study, we constrained the RA to between 3 and 13 hours, the Sep to more than 5 arcseconds, the Δmag to less than 3, and the magnitudes to less than 13. The targets were also constrained to have similar parallaxes and proper motions so as to narrow the target list to double

stars that could be gravitationally bound. Double star STF 42 AB fulfilled all of these criteria. Double star STF 42 AB was selected because it was classified as a true binary, but visually seemed to be traveling in a line, as shown in Figure 2.

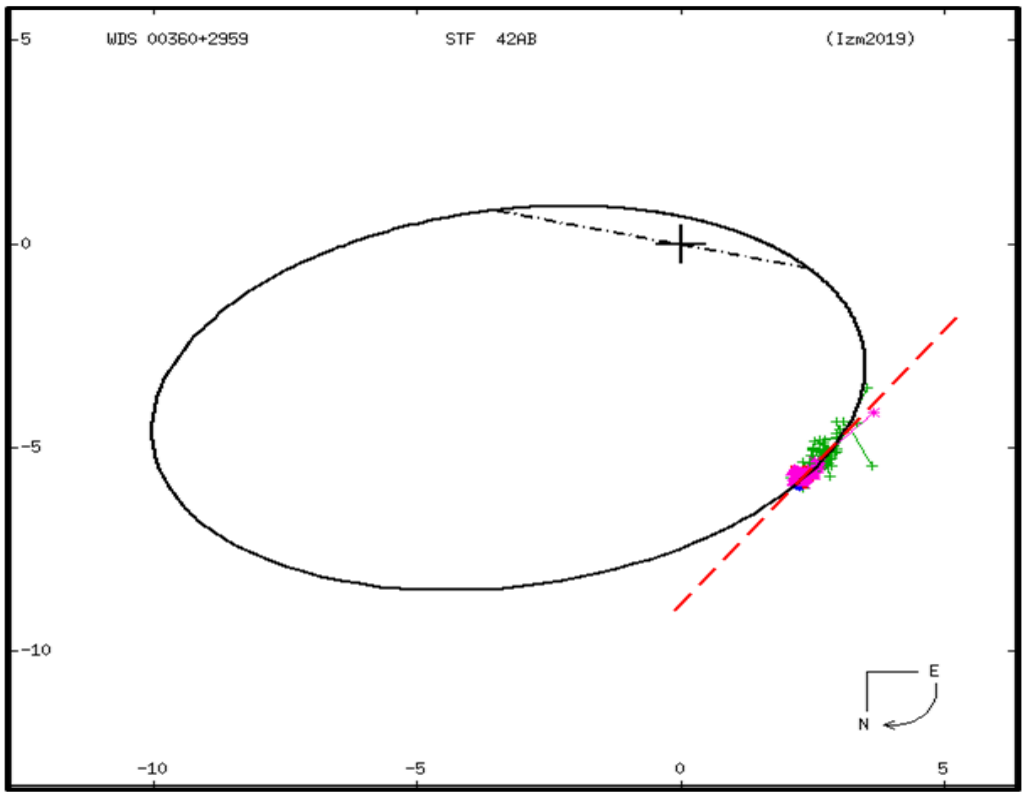

Figure 2: *The WDS Plot for STF 42 AB. The black ellipse represents the orbital solution to the data. The dotted red line demonstrates that, visually, the measurements appear to follow a line.*

Images of STF 42 AB

Eleven images of STF 42 AB were taken by the LCO 0.4-meter telescope in Haleakala, Hawaii on January 13, 2021 using five-second exposures. This telescope has a focal length of 4064 mm and uses a six megapixel CCD camera with a 29.2x19.5 arcminute field of view. Each pixel covers an angle of 0.571 arcseconds in the telescope. Each star has a radius of approximately 5 pixels in these images. No filters were used in imaging the double stars.

Measurements

The position angle (PA) and separation (Sep) of STF 42 AB were calculated using the AstroImageJ image reduction feature, as shown in Figure 3. Eleven images of STF 42 AB with an exposure time of five seconds were taken, and each was measured to find the PA and Sep. The average PA and Sep for these measurements are shown in Table 1.

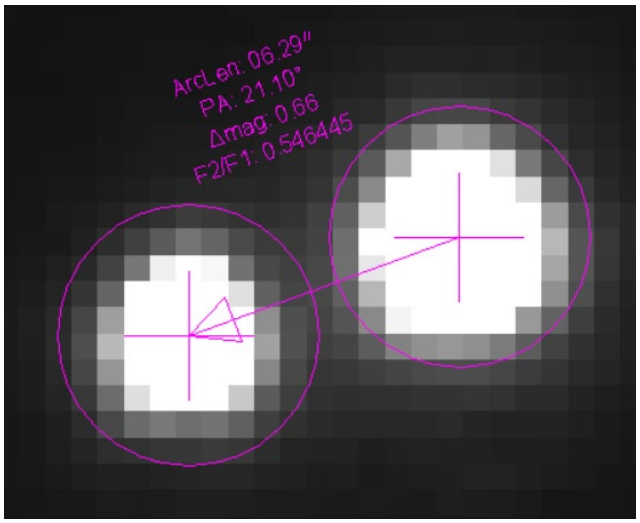

Figure 3: *Example measurement of double star STF 42 AB.*

Measurement #	PA	Sep
1	21.10	6.29
2	21.31	6.30
3	21.17	6.28
4	21.04	6.29
5	21.09	6.28
6	21.06	6.28
7	20.91	6.27
8	21.04	6.29
9	20.80	6.21
10	20.82	6.21
11	20.61	6.22
Mean	21.00	6.27
Standard Error	0.059	0.010
Previous Measurement	20.70	6.42

Table 1: *PA and Sep measurements based on observations on 1/13/21. Previous PA and Sep columns represent the previous measurement by de Pont, Lluis Ribe (2020).*

Results

We first compute the Relative Proper Motion (rPM) for the double star system using measurements, shown in Table 2, from the Gaia Early Data Release 3 database (Gaia 2016, Gaia 2020b) obtained using VizieR. The rPM is a metric proposed by Richard Harshaw (Harshaw 2018) to estimate whether or not a double star system may be gravitationally bound. The rPM is defined as

$$\text{rPM}= \frac{\|\overrightarrow{PM_1}-\overrightarrow{PM_2}\|}{\max\left(\|\overrightarrow{PM_1}\|,\|\overrightarrow{PM_2}\|\right)}.$$

An rPM less than 0.2 for a double star system represents Common Proper Motion and signifies that the stars are likely comoving in space. From these measurements, we compute an rPM for STF 42 AB of 0.017. Since this rPM value is less than 0.2, the primary and secondary stars are likely moving together through space.

System	Parallax of Primary (mas)	Parallax of Secondary (mas)	Proper Motion of Primary (mas/yr)		Proper Motion of Secondary (mas/yr)		rPM
			RA	Dec	RA	Dec	
STF 42 AB	18.5754 ± 0.0721	19.0812 ± 0.0249	184.207 ±0.090	-408.269 ± 0.058	179.310 ± 0.049	-402.641 ± 0.018	0.017

Table 2: *Gaia EDR3 data for STF 42 AB, along with rPM value.*

Historical Data

The average of the PA and Sep were added to a table of existing measurements, and the results were plotted, as shown in Figure 4. The PA and Sep marked "Gaia" was computed from the Gaia RA and Dec measurements of the two stars using AstroPy (AstroPy Collaboration et. al., 2013; AstroPy Collaboration et. al., 2018). The plot of STF 42 AB appears to be moving down and to the left. However, as of now, there is inconclusive evidence regarding an orbit.

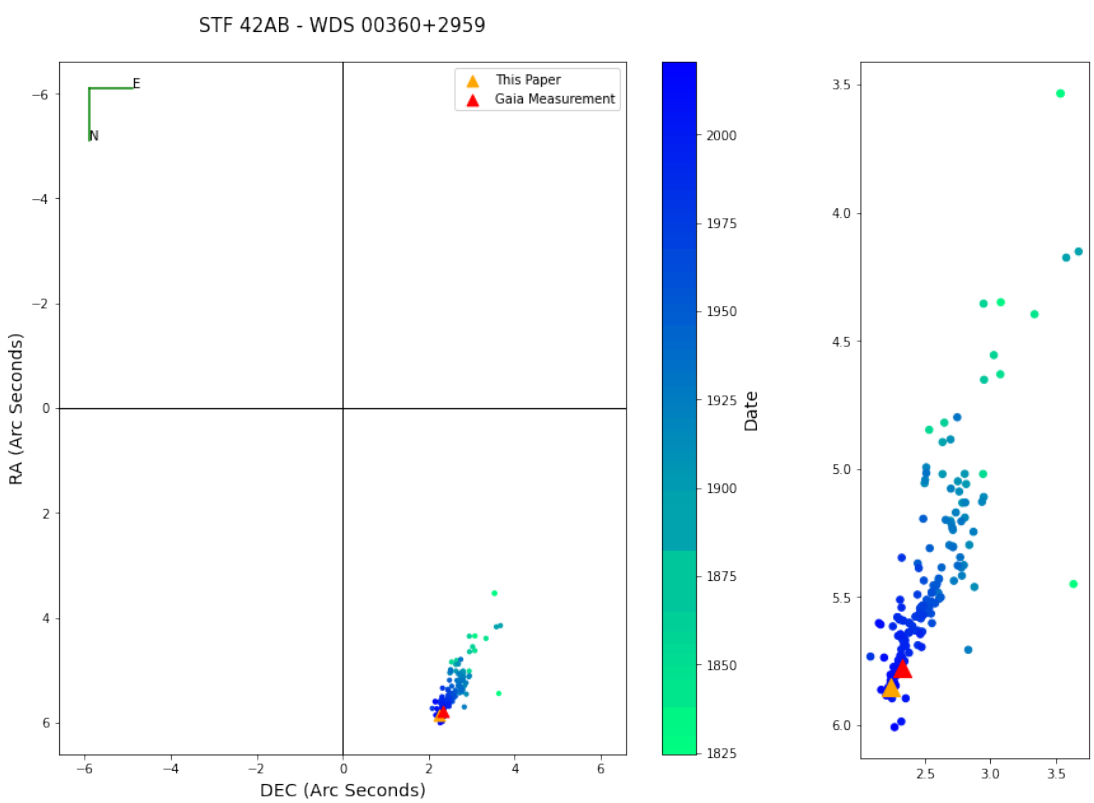

Figure 4: *Plot of location of secondary star relative to primary star for STF 42 AB. In this figure, the color scale represents time. This plot was made using a color-scale plotting tool developed by Ivan Altunin (I. Altunin, personal communication, April 24, 2022).*

Calculating Masses

The masses of the primary and secondary stars are needed to calculate the escape velocity. The first step in this calculation is to solve for L/L□ in

$$M = M_{Sun} - 2.5 \cdot \log_{10}\left(\frac{L}{L_{\odot}}\right) \tag{1}$$

In this equation, M stands for absolute magnitude. The next step is to plug L/L□ into the correct formula for the Mass Luminosity relationship,

$$\text{EQ I: } \frac{L}{L_{\odot}} \approx 0.23\left(\frac{M}{M_{\odot}}\right)^{2.3} \qquad \left(M < 0.43M_{\odot}\right)$$

$$\text{EQ II: } \frac{L}{L_{\odot}} = \left(\frac{M}{M_{\odot}}\right)^{4} \qquad \left(0.43M_{\odot} < M < 2M_{\odot}\right)$$

$$\text{EQ III: } \frac{L}{L_{\odot}} \approx 1.4\left(\frac{M}{M_{\odot}}\right)^{3.5} \qquad \left(2M_{\odot} < M < 55M_{\odot}\right)$$

$$\text{EQ IV: } \frac{L}{L_{\odot}} \approx 3200\left(\frac{M}{M_{\odot}}\right) \qquad \left(M > 55M_{\odot}\right)$$

Figure 5: *Equations to estimate mass based on luminosity by Salaris, Maurizio et. al. (2005).*

The correct case was found by computing the mass for each case and choosing the case which predicts a mass that lies within the required mass constraints for that case. For example, for the primary star of STF 42AB, we first calculated the mass using EQ I in Figure 5, obtaining a mass of 2.06 $M_{\odot}$**.** Because this is greater than 0.43 $M_{\odot}$ this case does not apply. Next we tried the second case using EQ II in Figure 5, obtaining a mass of 1.05 $M_{\odot}$**.** Because this is between 0.43 $M_{\odot}$ and 2 $M_{\odot}$, we know this case is the correct case for this star. Thus, the primary star is estimated to have a mass of 1.05 $M_{\odot}$. For the secondary star, the same process was used. Table 3 shows each star's calculated mass, computed according to this process.

Star	Primary	Secondary
M/M⊙	1.05	0.85

Table 3: *Masses of the two stars calculated for STF 42 AB.*

Calculating the escape and relative velocities

The escape velocity can be calculated according to

$$V_{escape} = \sqrt{\frac{2G(m_1 + m_2)}{r}}, \tag{2}$$

where m_1 and m_2 are the masses of the primary and secondary stars, respectively, G is the gravitational constant, and r is the separation between the two stars. We can calculate r according to

$$r = \sqrt{d_r^2 + d_t^2}, \tag{3}$$

where d_r stands for the radial distance between the stars, which is given by the difference of the two stars' distances from Earth, and d_t stands for the tangential separation between the stars, which is given by

$$d_t = \frac{separation}{parallax}, \tag{4}$$

The relative velocity is given by

$$v = \sqrt{v_r^2 + v_t^2} \tag{5}$$

where v_r is the relative radial velocity, which can be calculated by subtracting the radial velocities of the primary and secondary stars. Because the Gaia database did not include the radial velocity of the primary star, a lower bound for relative velocity v may be obtained by setting v_r to zero. The computed relative velocity becomes v_t, which can be calculated as

$$\frac{\text{mas}}{\text{yr}} \cdot \frac{1''}{1000\ \text{mas}} \cdot \frac{1°}{3600''} \cdot \frac{2\pi}{360°} \cdot \left(\frac{1}{plx}\right) \text{pc} \cdot \frac{3.086 \cdot 10^{13}\ \text{km}}{1\ \text{pc}} \cdot \frac{1\ \text{yr}}{3.54 \cdot 10^7\ \text{s}} \tag{6}$$

In Equation 6, the values in red come from Gaia EDR3, and the values in black are conversion factors (Caputo, 2020). The calculated 3-dimensional relative velocity and escape velocity for STF 42 AB are shown in Table 4.

Because the relative velocity is an order of magnitude larger than the escape velocity, it appears likely that the system is not gravitationally bound. Measurement error appears unlikely to account for the 1797 m/s difference between the two velocities. Because relative radial velocity was ignored, the true relative velocity may be much higher. Analysis by Knapp (2019) similarly suggests that the two stars are unlikely to be gravitationally bound.

Star	Relative Velocity (m/s)	Escape Velocity (m/s)
STF 42 AB	1904	107

Table 4: *Relative and escape velocities for STF 42 AB computed using measurements from the Gaia catalogue (Gaia 2020b).*

Conclusion

Double star STF 42 AB was studied. The primary and secondary stars have similar parallaxes, and STF 42 AB has an rPM of 0.017, which suggests that the double star pair may be physically related. The PA and

Sep of STF 42 AB were calculated through AstroImageJ to be 20.76 ± 0.14 degrees and 6.25 ± 0.011 arcseconds, respectively. When calculated, the relative velocity of the system exceeded the escape velocity by a factor of over 17, which suggests that STF 42 AB is not gravitationally bound and is a promising candidate for reclassification as STF 42 AB is currently classified as a true binary.

Future Work

The next step for this project is to fit linear and orbital solutions to the data.

Acknowledgements:

This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France (DOI : 10.26093/cds/vizier). The original description of the VizieR service was published in 2000, A&AS 143, 23.

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.

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

This work makes use of observations taken by the 0.4m telescopes of Las Cumbres Observatory Global Telescope Network, and the fits-align module maintained by Edward Gomez of the LCO Education Division.

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