Astrometric Measurements of WDS 02132+5412 STF 225 AB and AC

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Abstract

Observations of WDS 02132+5412 (STF 225, HD 13452) AB and AC were made over 2 days, and analyzed to add to the historical record of this triple star component's positions. Using the Las Cumbres Observatory remote telescope network, images were taken using Sloan r filters. Our analysis of the AB component showed a mean separation of 5.97" and a mean position angle of 79.25º, and the AC component showed a mean separation of 152.964" and a mean position angle of 160.334º. Based on our analysis of the apparent separation, radial distance, Harshaw statistic, and proper motion vector, we have concluded that there is a small possibility that the AB pair is gravitationally bound, and the AC pair does not appear gravitationally bound.

1. Introduction

The hypothesis of this research is that every star in the triple star system WDS 02132+5412 STF 225 is gravitationally bound to at least one other star in the system. This star system was selected due to possessing appropriate conditions for using the Las Cumbres Observatory Global Telescope Network (LCOGT), a global network of remote observatories (Brown 2013). Using the Stelle Doppie search engine (Sordiglioni, 2018), this system was selected because its components exhibited a separation of more than 5 arcseconds, a magnitude of greater than 12, and a difference in magnitude between the stars of less than 3. In addition, since observations were to be made between October and November of 2024, only stars with right ascension (RA) of 22 to 06 hours were considered. Declination (Dec) was not a limiting factor in selection due to LCOGT having observatories in both the northern and southern hemispheres.

The Washington Double Star Catalog (WDS) lists 02132+5412 STF 225 as a triple star system (Mason, 2018). The AB pair was discovered in 1831 by Friedrich Georg Wilhelm von Struve (Struve, 1837). Since then there have been 20 observations made. The initial separation of the pair was 5.7 arcseconds, and the initial position angle was 78 degrees. The most recent observation records the separation as 5.982 arcseconds, and position angle as 79.6 degrees. The C star was discovered in 1881 (Ball, 1884), with 14 observations. The initial separation and position angle of the AC pair were 149.7 arcseconds and 161 degrees respectively, and the most recent separation and position angle were 152.788 arcseconds and 160.4 degrees respectively. This star system is listed as No. 10338 in the Hipparcos Catalog (ESA, 1997).

2. Equipment and Methods

2.1 Equipment

The equipment used were LCOGT's 0.35 meter DeltaRho 350 telescopes with QHY600 CMOS cameras (as shown in Figure 1), which have a 1.9º×1.2º field of view. The resolution was 0.74 arcseconds per pixel. The sites automatically chosen by LCOGT were the McDonald Observatory located in Fort Davis, Texas, USA, and the Teide Observatory located in Tenerife, Spain, Canary Islands, as shown in Table 1.

Table 1. List of STF 225 (WDS 02132+5412) science images taken with LCOGT.

Date	Epoch	Observatory	Filter	Measured Images
2024-11-12	2024.8631837	LCOGT Teide, Tenerife, Canary Islands, Spain	Sloan R	7
2024-11-13	2024.8661232	LCOGT McDonald Fort, Davis, Texas, USA	Sloan R	7

2.2 Methods

Twenty-eight initial test images were taken over four days using green, red, blue, and visible filters. Ten images taken with a green filter on November 11, 2024, and twelve images taken with a red filter on Nov. 17, 2024, were rejected, because the images did not exhibit adequate differentiation between the A and B stars. Finally, 14 science images (example shown in Figure 2(a)) were taken on Nov. 12 and 13, 2024, (Julian dates 2024.8632 and 2024.8661, respectively) using a red filter, 7 on each night. These observations, listed in Table 1, were used for the measurements reported in the rest of this paper.

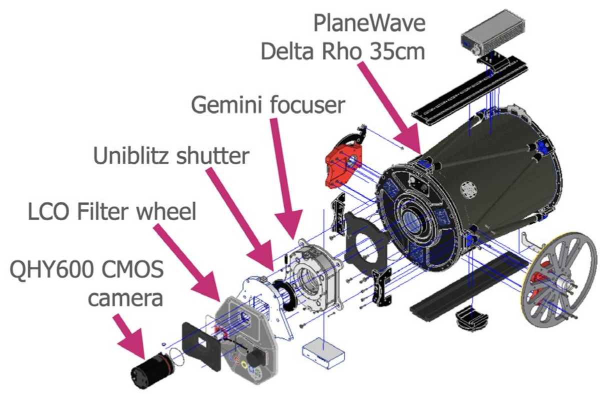

Figure 1: Schematic of the Delta Rho 350 observatories used in this work (Harbeck 2024)

AstroImageJ (Collins, 2017) was used to measure the position angle (PA) in degrees (theta), separation in arcseconds (rho) and delta magnitude of the AB and AC pairs; an example is shown in Figure 2(b). To do this, the images were first imported to AstroImageJ, the ROI aperture set to the approximate size of the stars, and the cursor dragged from the center of one star to the other; AstroImageJ (AIJ) automatically calculates the centroid of each object and resulting separation and position angle. The process is repeated for every image in the set, generating a table of measurement results and statistics. The measurements on each pair (AB, AC) were repeated by 2 team members, generating a combined total of 8 tables of 7 measurements each. The aggregate data were then used to find the mean, standard deviation, and standard error of the mean for PA and Separation.

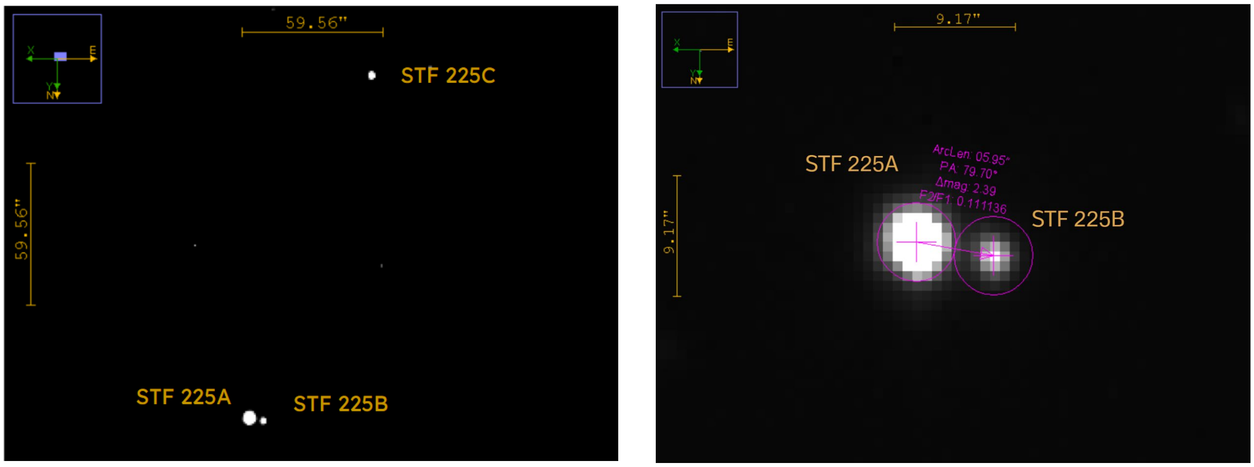

Figure 2. (a) Image of STF 225 A, B, C taken with LCOGT Teide telescope; (b) One example analysis of STF 225 A, B measurements in AIJ

3. Data

Measurements of WDS 02132+5412 are summarized in Table 1. The astrometric results, shown in Tables 2 and 3, set forth the mean, standard deviation, and standard error of the mean for the position angle, separation, and delta magnitude (with Sloan red filter) of the AB and AC pairs.

Table 2. Summary of astrometric measurements of WDS 02132+5412 STF 225 AB.

WDS 02132+5412 STF 225 AB				
Epoch	**Measurement**	**Theta (degrees)**	**Rho (arcseconds)**	**Delta Magnitude (Sloan r)**
2024.87	Mean	79.250	5.97	2.547
	Standard Deviation	0.748	0.045	0.056
	Standard Error of the mean	0.141	0.009	0.011
2015.0	Last Measurement	79.693	5.982	-

Table 3. Summary of astrometric measurements of WDS 02132+5412 STF 225 AC.

WDS 02132+5412 STF 225 AC				
Epoch	**Measurement**	**Theta (degrees)**	**Rho (arcseconds)**	**Delta Magnitude (Sloan r)**
2024.87	Mean	160.334	152.964	2.031
	Standard Deviation	0.038	0.105	0.029
	Standard Error of the mean	0.007	0.02	0.006
2015.0	Last Measurement	160.449	152.788	-

4. Discussion

In order to determine whether each component pair (AB and AC) is gravitationally bound, it is useful to consider apparent separation, radial distance, the Harshaw statistic (Harshaw, 2014), proper motion, and historical plots. Data taken from Gaia Data Release 3 (Gaia, 2016; Gaia, 2023), shown in Table 4, were used to calculate the apparent separation and the radial distances of the AB and AC pairs. This data was also utilized in the process of calculating the Harshaw statistic.

Table 4. Data acquired from GAIA DR 3.

WDS 02132+5412 STF 225: GAIA DR3 Data				
Component	**Parallax (mas)**	**Std. Error of Parallax**	**RA Proper Motion (mas/yr)**	**Dec Proper Motion (mas/yr)**
A	1.9506	0.0350	9.845	-5.801
B	2.0281	0.0183	10.640	-5.162
C	4.7422	0.0165	42.289	-19.500

The apparent separation of stars measures the closest distance two stars can be on the X-Y plane, ignoring the radial axis. Studies have shown that for two stars to be gravitationally bound they generally need to be less than one light year apart (Reipurth, 2012). The apparent separation of the AB and AC pairs was calculated using their separation angle and the distance to the A star as determined by the parallax measurement reported in Gaia DR3. We used the following formula to calculate linear separation in light years, D: $D = X\frac{d}{206265}$ where X is the separation angle measured in arcseconds, and d is the distance from the observer in light years. The apparent separation of the AB pair is calculated as 0.04837 light years, and the apparent separation of the AC pair as 1.23940 light years. These results indicate that the AB pair may be gravitationally bound, while the AC pair is unlikely to be gravitationally bound.

Another factor to be considered is whether the two stars are within one light year of each other in the radial direction. Table 5 shows the parallax and distance to each star in parsecs and light years. Using the parallax and parallax error measurements from Gaia DR3, the probability that the AB and AC pairs are within one light year of each other radially was produced by calculating the standard error of the mean (SEM) of the A-B probability distribution function. This calculation is represented mathematically as $SEM(A-B) = \sqrt{(SEM\ A)^2 + (SEM\ B)^2}$. This calculation resulted in a 0.4% probability that the AB pair is within one light year radially, and a 0.0% probability that the AC pair is within one light year radially. These results indicate only a small probability that AB is gravitationally bound, and that the AC pair is likely not gravitationally bound.

Historical data provided by the United States Naval Observatory (USNO) was used to create a plot of STF 225 A, B and C, as set forth in Figure 3, with STF 225 A positioned at the origin. Figure 4(a) shows the same plot, with a closer look at the AB pair, and Figure 4(b) shows the same plot with a closer look at the AC pair.

Table 5. The parallax, calculated distances and error for each of the three stars in the STF 225 system.

	Parallax (mas)		**Parsecs**			**Light Years**		
		SEM	*-1 SEM*	*Mean*	*+1 SEM*	*-1 SEM*	*Mean*	*+1 SEM*
Star A	1.9506	0.0350	503.63	512.66	522.03	1641.821	1671.281	1701.817
Star B	2.0281	0.0183	488.66	493.07	497.56	1593.041	1607.416	1622.052

Star C	4.7422	0.0165	210.14	210.87	211.61	685.061	687.445	689.845

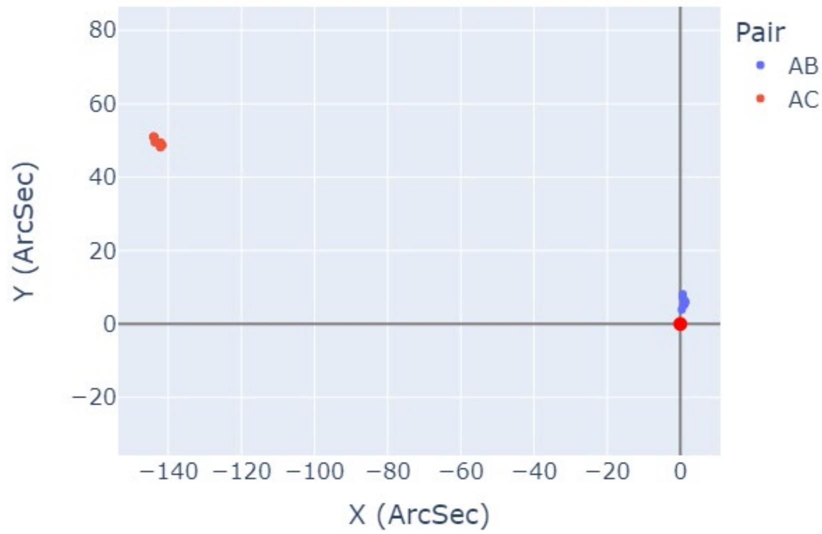

Figure 3. Historical plot of WDS 02132+5412 STF 225 AB and BC with A at origin, from approximately 1850 to 2015. The historical progression of the B and C components can be seen in Fig.4

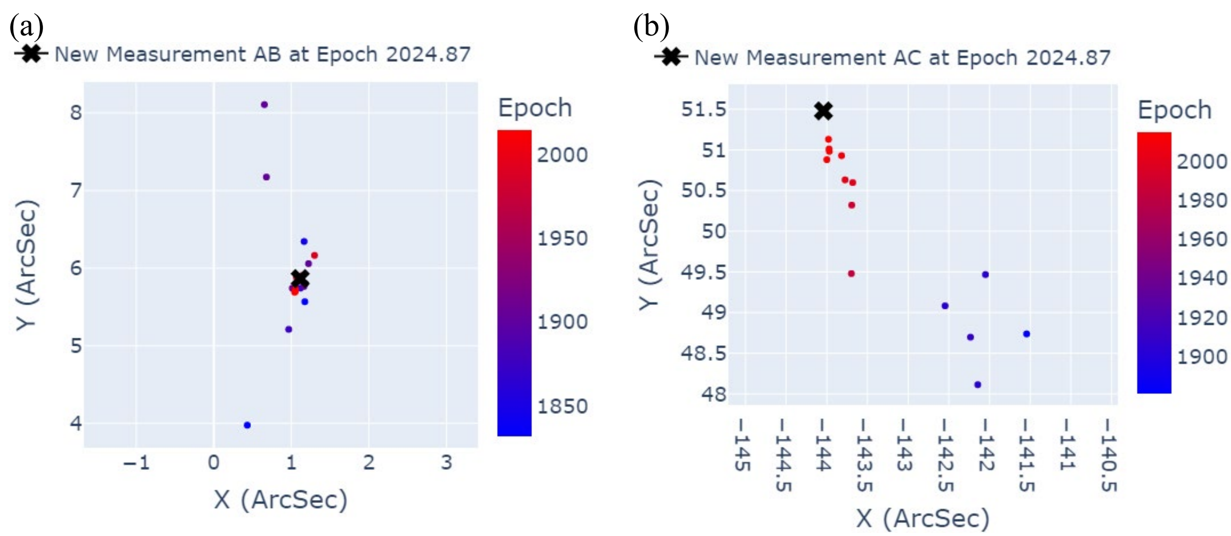

Figure 4. Historical plot of WDS 02132+5412 STF 225, (a) component AB, and (b) component AC; both with A at origin (0,0). Measurements added in this work are indicated by the **X** *marker.*

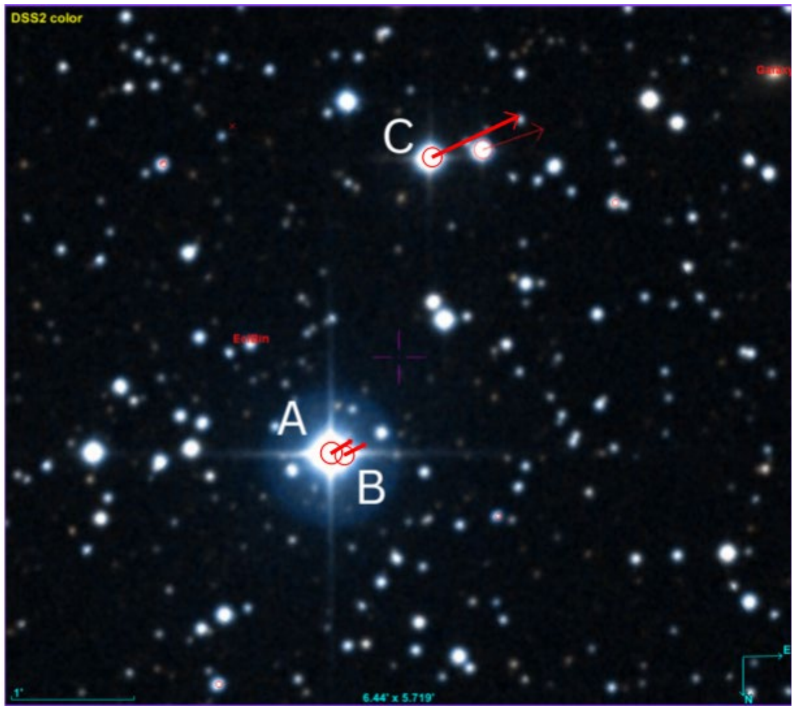

Figure 5. Proper motion vector image of STF A, B, and C.

In addition, a proper motion vector image of STF A, B and C was produced using Aladin 11, shown in Figure 5 (Bonnarel, 2000). Although this proper motion vector image indicates that the A, B and C stars are moving in the same approximate direction, they have significantly different magnitudes. This visual analysis can be quantified by considering the Harshaw statistic (Harshaw, 2014), which analyzes the similarity of the proper motion vectors of two stars. The Harshaw statistic (alternatively rPM, ratio of Proper Motion) is calculated as the magnitude of the difference vector between the two stars' proper motions, divided by the magnitude of the larger proper motion vector. A statistic closer to 0.0 indicates that two stars are more likely to be traveling together, while a statistic closer to 1.0 indicates that the motion vectors are dissimilar, and the two stars have low likelihood of being gravitationally bound. Gaia DR3 reports the proper motions for each component, which are listed in Table 4. The Harshaw statistic for the AB pair is .044, suggesting that the two stars have very similar motion vectors and thus a possibility that the two stars are physically bound. In contrast, the Harshaw statistic for the AC pair is .607, indicating a lower probability that the AC stars are binary (Harshaw, 2014).

5. Conclusions

5.1 AB Pair

Although the apparent separation of the AB pair indicates that the AB pair may be close enough to be gravitationally bound, the radial distance probability calculation indicates that they are likely too far apart radially (>1 ly.) to be binary, although a small possibility does exist (0.4%). An examination of the proper motion vectors and the Harshaw statistic again indicates a possibility that the AB pair is binary. These factors, taken collectively, indicate a need for further research on this star system to conclusively determine the nature of the AB pair.

5.2 AC Pair

All statistics related to the AC pair suggest that it is not gravitationally bound; the stars are too far apart to be gravitationally bound, and their motion vectors are not well aligned. We recommend that a "Y" notation be added to the description of the AC pair in the Washington Double Star Catalog to indicate that this star pair is not a physical double.

Acknowledgments

This work utilizes observations from the Las Cumbres Observatory global telescope network; the images used in this research were taken with the McDonald Observatory in Fort Davis, Texas, USA, and the Teide Observatory in Tenerife, Canary Islands, Spain. This research has made use of the Washington Double Star Catalog (Mason, 2018) maintained in the U.S. Naval Observatory, along with the "Aladin sky atlas" developed at CDS, Strasbourg Observatory, France (Bonnarel, 2000; Berriman, 2022), and the Stelle Doppie search engine. This work has also 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.

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