Reclassification of WDS 18224+4545 from a Binary to Optical Double Star

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Abstract: In 1998, based exclusively on visual observations, Wulff Heintz calculated an orbital path, with a period of 234 years and a semi-major axis of 0.55″, and determined that WDS 18224+4545 (A700) was a gravitationally bound binary star system. The research presented here disputes this and presents an optical double star system solution with a linear trajectory. Using data from the first speckle interferometry observation for A700, collected on October 22, 2013, with the 2.1-meter telescope at Kitt Peak National Observatory (KPNO), new separation and position angles were determined to be 0.623″ and 127.872°, respectively. These results diverge radically from Heintz's predicted orbit, and when correlated with past observational data, they follow a linear trend that returns a fit with an R^2 value of 0.977. New calculations predict a minimum separation of 0.076″ in the year 1953.

Introduction

This paper is the product of a summer Cuesta College Astronomy Research Seminar (ASTR 299) designed to introduce student teams to the processes of scientific research and subsequent publishing. Our team's specific goal was to obtain a data point to add to the orbit of a star system published in the Washington Double Star (WDS) catalog (Mason et al. 2012) with the hope that an accurate speckle interferometry observation would contribute to the accuracy of that system's published orbit. The importance of obtaining accurate orbits was best highlighted by the late Wulff Heintz, then a Professor Emeritus of Astronomy at Swarthmore College, in his seminal book *Binary Stars:* "Stellar masses are basic quantities for the theory of stellar structures and evolution, and they are obtained from binary-star orbits where they depend on the cube of observed parameters; this fact illustrates the significance of orbits as well as the accuracy requirements" (Heintz 1978).

Figure 1. Team picture - From left to right: Russell M. Genet, Jordan Steed, Ian R. Parent, Michelle Williams, Daniel Orman, Ellery Conover, S. Taylor Vaughn, Nels Siverson, Jessica C. Gardella, and Jonathan Ogden.

The student team (Figure 1) chose double star WDS 18224+4545 (A700) as a research subject for four specific reasons. First, on the night of October 22, 2013, double star A700 was observed on the 2.1-meter telescope equipped with a speckle interferometry camera at Kitt Peak National Observatory (KPNO) during an observing run of multiple stars believed to be binary. Second, the lack of any previous speckle interferometry observations meant that A700 was ripe for potential new discoveries. Third, A700 also only had ten published observations, with nine out of the ten being visual observations, plus one by Tycho-2 (Høg 2000). Finally, the Tycho-2 observation appeared to lie outside of the calculated orbit, lending reason to believe the system's orbit might need to be updated. This discrepancy could have come about because Wulff Heintz first determined the orbit solely from visual observations (he did not have access to the Tycho-2 plotted location at that time). Alternatively, the Tycho-2 observation could have been in error. Either way, the student team thought that an additional speckle interferometry observation might help decide between these two alternatives. Unsurprisingly, A700's orbit is classified in the Sixth Catalog of Orbits of Visual Binary Stars (ORB6) as a grade five, or indeterminate, which is the lowest quality orbit in the catalog.

These facts about A700 made it clear while conducting research that there appears to be a potential issue concerning many orbits of binary star systems in the WDS, and more specifically in the ORB6. For varying and often uncontrollable reasons, many of the cataloged stars lack enough highly accurate observations to form a precise orbit. Such was the case with A700. A 2012 paper in the Astronomical Journal, titled *Speckle Interferometry at SOAR in 2010 and 2011: Measures, Orbits, and Rectilinear Fits,* pointed out that, "of the 113,366 pairs in the Washington Double Star Catalog (WDS) (Mason et al. 2001), only 2,158 (or 1.9%) have orbital determinations of any quality. Of these, only 310 have orbits graded as either 'definitive' or 'good' in the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf et al. 2001), while 60% of cataloged orbits (excluding astrometric solutions) are considered either 'preliminary' and 'indeterminate'" (Hartkopf et al. 2012). These statistics further highlight the importance of conducting this kind of research into binary and optical star systems.

The discovery and first visual observation of A700 was in 1904 by Robert G. Aitken. Many of the subsequent observations of A700 were made by astronomers George A. Van Biesbroeck (1961), Paul Couteau (1972), and Wulff D. Heintz (1978).

Past Observations and Observers

Robert G. Aitken

In an editorial (Clark 2006), it was written that, "[Robert] G. Aitken was the grand old man of double star astronomy and still observed doubles visually long after others had turned to photography." R.G. Aiken was on the Board of Directors of the Astronomical Society of the Pacific for decades and penned the influential book *The Binary Stars*, originally published in 1918. He is ranked sixth on the list of the total number of double star observations. Over his entire career, Aitken discovered 3,087 new double stars and performed measurements of 26,560 pairs. Aitken was born in 1864 and passed away in 1951. In Figure 2, R.G. Aitken is in a pose he often held in his life looking up to the stars.

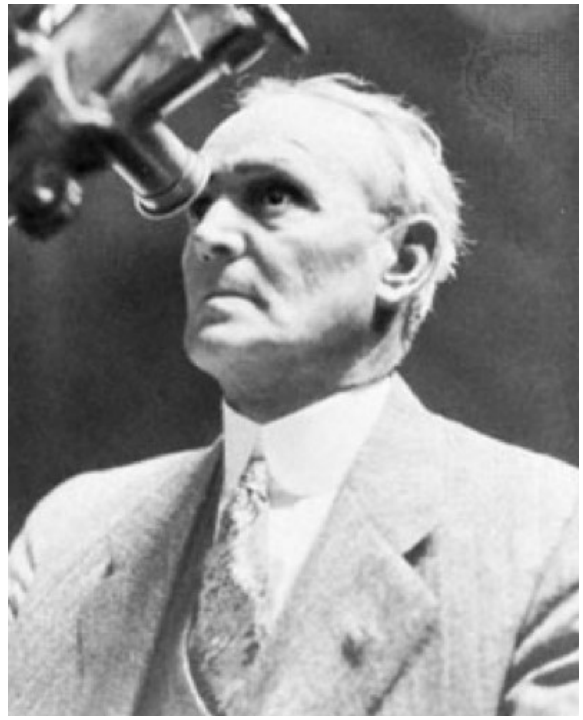

Figure 2. *Robert Grant Aitken in his later life doing what he did best—observing the stars with a filar micrometer on the great 36-inch refractor at Lick Observatory.*

R.G Aitken made the first recorded observation of double star A700 using a filar micrometer on the historic 36-inch–refractor at Lick Observatory on Mount Hamilton (Aitken 1904). He subsequently observed A700 in 1917 and 1928 (Aitken 1937).

Wulff D. Heintz

Wulff-Dieter Heintz wrote the seminal book on double star research, aptly named *Double Stars*, which is often attributed as the "field standard" by many experts in astronomy. Born in 1930 in Germany, he moved to the US where he was Professor of Astronomy at Swarthmore College in Pennsylvania during the latter half of his professional life. His productive career made him into one of the most respected scientists in double star research. He calculated the orbits of over 900 binary stars. Figure 3 shows Heintz along with his preferred instrument for observation. Heintz passed away in 2006.

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Figure 3. *Wulff Heintz posing with filar micrometer attached to the refractor at Swathmore Observatorty*

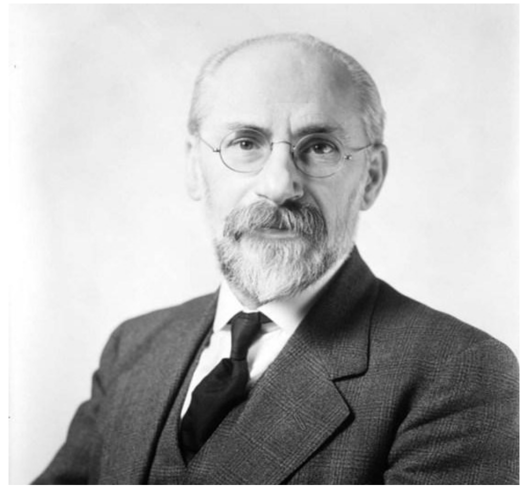

Figure 4. *George A. Van Biesbroeck.*

Heintz observed A700 in 1977 (Heintz 1978) and 1983 (Heintz 1985) and made his last visual observation in 1996 (Heintz 1998). He made these observations on the 61 cm refractor at Swarthmore Observatory. He has long been regarded as one of the best at using a filar micrometer for stellar observations. Nonetheless, the margin of error for this method, compared to more modern techniques, such as speckle interferometry, must be acknowledged. It was his last observation, straying into what looked like the beginnings of an orbital pattern, which may have led him to interpret the trajectory of A700 as binary. Still, a well-known double star expert suggested to our team that, "Given the number of orbits he [Heintz] did it's not surprising to see an error made by the 'Swarthmore Orbit Machine.' Still, I'd be willing to bet his percent wrong is lower than most!"

George A. Van Biesbroeck

George A. Van Biesbroeck (Figure 4) was an observational astronomer of double stars, comets, and asteroids. He was known for discovering the faintest star of its time. He was born in Belgium in 1880. After fleeing Europe at the end of WWI and becoming a US citizen, he began his career in astronomy. He went on to earn a degree in theoretical astronomy and pursued many challenging astronomical research projects, even in some of the most impoverished unstable regions of the world. He was a supervisor of the construction of the McDonald Observatory at the University of Texas.

He observed A700 in 1951, 1954, and 1960, using a filar micrometer on the 82 inch reflector at the McDonald Observatory (Biesbroeck 1965). Unfortunately, the 1951 and 1954 observations were both unresolved because, most likely, the secondary star passed near primary at this point in time. Then in 1961, he published his own Star Catalogue (Biesbroeck 1961) consisting of many small faint stars, including Red Dwarfs, for which he is most well-known. Even after a lifetime of success, he continued astronomy research to within a few months of his death in 1974.

Observation and Calibration

The observational data used for A700 was obtained on October 22, 2013, with the 2.1-meter telescope at KPNO and a speckle interferometry camera. The telescope had an effective focal length of 16,200 mm. With an 8x magnification Barlow lens before the speckle camera (Figure 5), the increased overall effective focal length was 129,600 mm with F/ratio of 61.7. This setup translates into a calibrated plate scale of 0.01166″/pixel (Genet 2015).

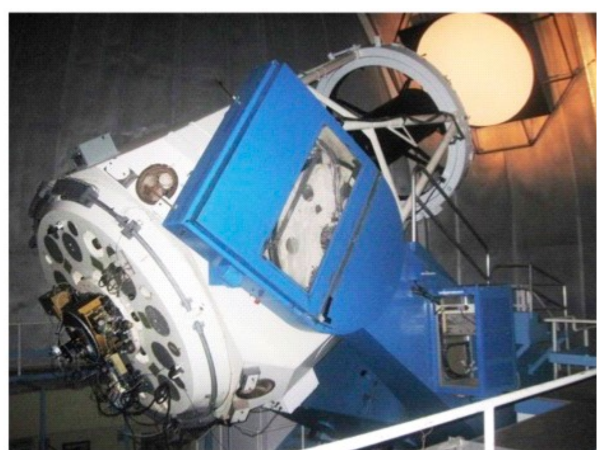

Figure 5. *2.1-meter telescope with speckle camera as used for the observations.*

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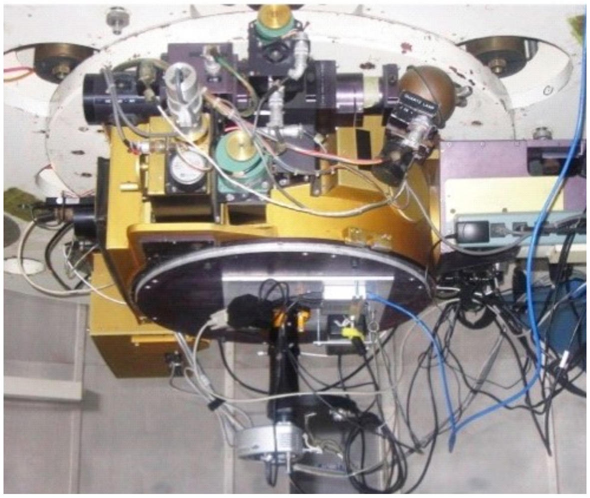

Figure 6. *Speckle camera installed on the 2.1-meter telescope at KPNO.*

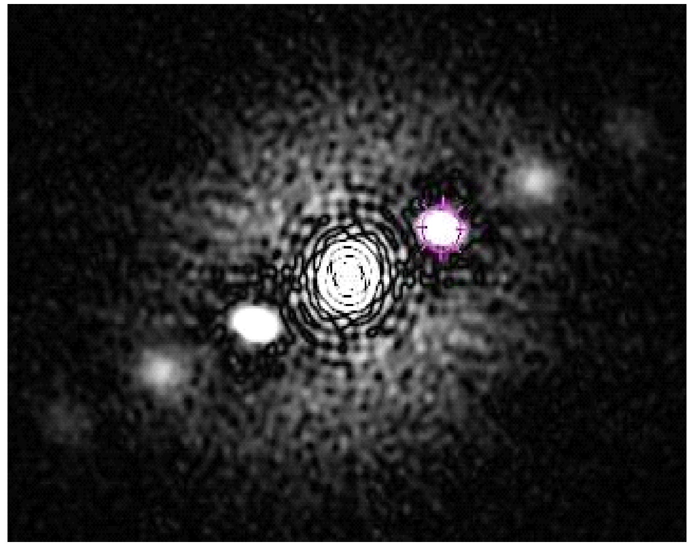

Figure 7. *Autocorrelogram of A700 with the "Captain's wheel" marking the secondary star.*

Frames were taken with an Andor Luca-R electron multiplying charge coupled device (EMCCD) camera. To minimize atmospheric dispersion, observations were made using a Sloan 'i' filter. The observations yielded a FITS data cube of 512 x 512 pixels x 1000 frames, with each frame having an exposure time of 10 milliseconds. The camera was attached to the acquisition-guider unit at the Cassegrain focus of the telescope (Figure 6). The camera's angle was additionally calibrated to -11.049° (Genet 2013).

Results

The 1000 images of A700 from the speckle observation were consolidated during the observation into a FITS data cube. The FITS cube was processed in PS3 reduction software to produce an autocorrelogram (Figure 7) and determine a new separation of 0.623″ and a new position angle of 127.872°. A FITS cube of deconvolution star HIP93713 was used in the processing to reduce atmospheric and telescope-induced distortions.

Discussion

Comparison to Past Observations

To identify any trends and/or deviations, A700 was analyzed using past observational data obtained from the WDS Catalog along with the new data point from the KPNO observation (Table 1). A deviation was identified when comparing the KPNO and the Tycho-2 data points to the Heintz orbital plot prediction, as both of these plot points fell outside the predicted orbital path (Figure 8). It was evident that, with the addition of the KPNO observation, the trend in the data does not support the established orbit as calculated by Heintz.

To investigate these deviations further, the data points for the KPNO and Tycho-2 observations were first analyzed individually against Heintz's orbital predictions, and then correlated with the full data set. For the night of the KPNO observation, the orbital elements, derived by Heintz, were used to determine a predicted separation and position angle of 0.118″ and 152.49°, respectively. However, the results from the KPNO speckle interferometry observation determined a separation and position angle of 0.623″ and 127.876°, respectively, and greatly deviated from the Heintz orbital prediction. In comparison to the published orbit,

Table 1.

Year	Rho (ρ)	Theta (θ)	Ap. (m)	Reference
1904.58	0.49	322	0.9	A_1904b
1917.13	0.44	328.4	0.9	A_1932a
1928.8	0.29	319.8	0.9	A_1937b
1960.55	0.15	105.3	2.1	VBs1965
1970.47	0.21	116.7	0.7	Cou1972e
1973.62	0.29	114.6	0.7	Wor1978
1977.57	0.25	112.7	0.6	Hei1978b
1983.52	0.33	116.5	0.6	Hei1985a
1991.61	0.47	121.1	0.3	TYC2002
1996.65	0.32	128.3	0.6	Hei1998
2013.81	0.623	127.872	2.1	Parent et al.

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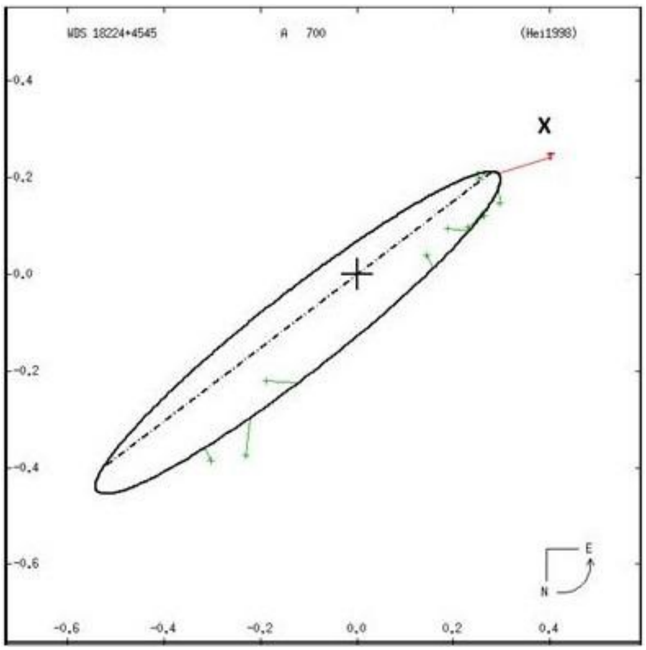

__Figure 8.__ WDS Catalog orbital plot with X marking the KPNO speckle interferometry point deviating from the orbit. The other outlier to the data set, when compared to the orbital plot, is the Tycho-2 observation from 1991.

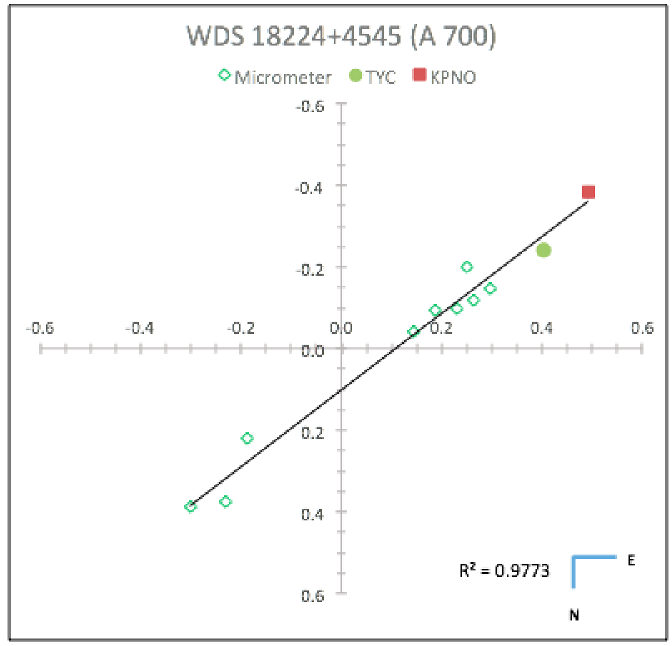

__Figure 9.__ X vs Y graph shows a linear trend, in arcseconds, that represents the motion of the companion star, derived from the separation (ρ) and position angle (θ) of each observation, relative to the primary at point (0,0). Plot points are distinguished by the method of observation.

our results missed the predicted plot point by a separation difference of 0.505″, which in comparison, is nearly the length of the semi-major axis, and an angular difference of roughly 24.61° (Figure 8).

Analyzing the Tycho-2 observation, a separation of 0.359″ and position angle of 125.36° were predicted by the Heintz orbit for the night of the Tycho-2 observation and instead, a separation of 0.47″ and position angle of 121.1° were found from the KPNO observation. This yields a difference of 0.11″ and 4.26°. While the difference in position angle is not highly significant, the difference in separation is approximately ten times greater than the difference in separation for the other observations versus their corresponding predicted positions along the orbital path, excluding the KPNO observation. This lends to the argument that the Tycho-2 observation deviates from the predicted orbital path.

When calculating the orbit for A700, Heintz did not have the results from the Tycho-2 or the KPNO observations, and only had access to the data from the nine visual observations that were made between 1904 and 1996. Thus, either the KPNO and Tycho-2 results deviated due to inaccuracies in the observational methods used, or they are valid data points that challenge the integrity of Heintz's calculated orbit. According to the book *Small Telescope Astronomical Research Handbook* (Genet et al. 2015), speckle interferometry can be used to measure the separation of double stars within a fraction of an arcsecond and is one of the most accurate methods for observing double stars. Similarly, the Tycho-2 observation was taken from a satellite in orbit which removes any error due to atmospheric turbulence. The high precision and accuracy of these two observational methods lends credence to the integrity of the KPNO and the Tycho-2 data points. Conversely, using a micrometer is one of the oldest historical methods for observing double star systems, but it is also one of the least accurate of the three methods by modern standards.

To identify any trends, the entire data set of separations and position angles were adjusted for precession to the epoch of 2000 and plotted in an X vs Y graph, a separation vs time graph, and a position angle vs time graph. After plotting the

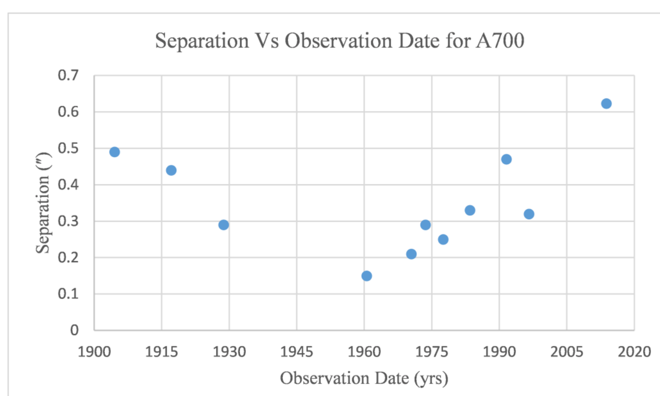

__Figure 10.__ Plot of separation versus time graph shows a linear trend. As the companion star approaches T_0 the separation approaches a minimum. After passing through this minimum, the separation increases at a roughly constant rate.

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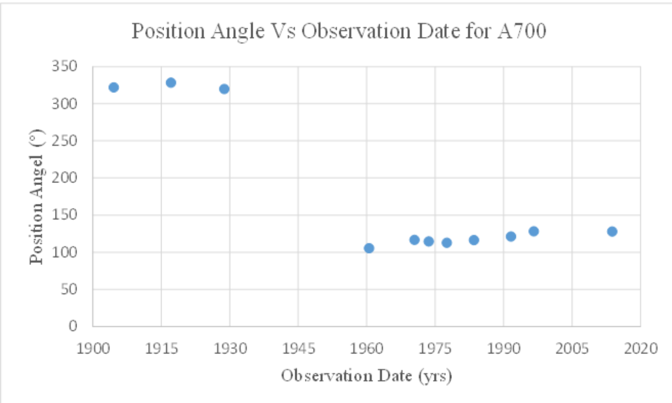

Figure 11. Change in position angle versus time. What appears is the convergence of the data at an upper limit starting after the companion star reached T_0 that will continue as it gains distance from the primary at a constant linear trajectory.

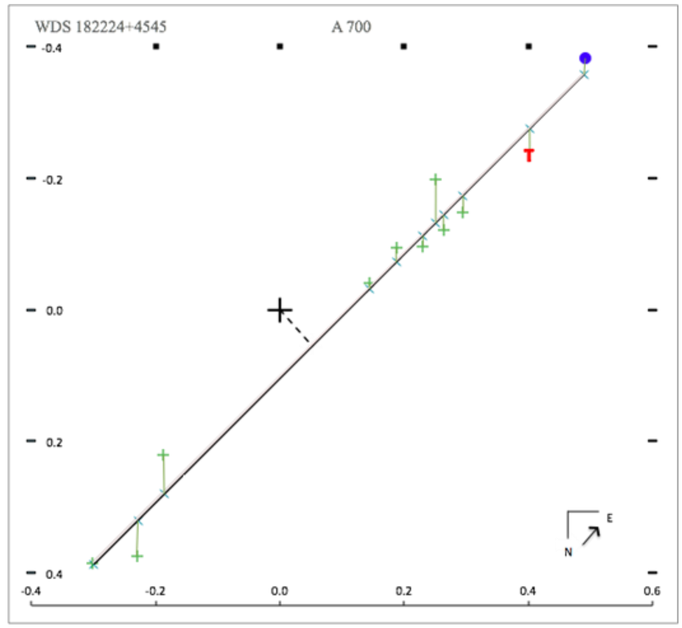

Figure 12. Rectilinear plot, in arcseconds. The black line represents the linear path of the secondary relative to the primary as time evolves. Measurements are connected to their predicted location with a line indicating a weighted calculation.

data in an X vs Y graph, a tight linear trend emerged that returned a linear fit with an R^2 value of 0.9773 (Figure 9). This is significant because the R^2 value is a statistical measure of how close the data is to the fitted regression line. The closer this is to the value of one, the better the data fits the model. Having such a high R^2 value yielded a strong argument that the linear trajectory describes the relative motion of the secondary to the primary better than the previously predicted Keplerian orbit. If A700 was a binary star with the orbit that Heintz calculated, this data plot would show a short arc-like trend describing the orbital motion of the secondary relative to its primary. Instead, the linear trend in the data is evidence that A700 is not a gravitationally bound binary and may just be optical in nature (i.e. a mere chance alignment as seen from Earth) with a linear trajectory. After plotting the data in a separation versus time graph (Figure 10), a linear trend emerges that further supports the argument that A700 is an optical double star.

Similarly, plotting the data in a position angle versus year graph (Figure 11) also points to a contradiction in the orbital solution. If A700 was a binary, a sinusoidal trend, representing the orbital motion as the companion moves through quadrant to quadrant, would have been expected. Furthermore, had the KPNO results followed the established orbit, the corresponding data point in Figure 10 would have fallen south-west of the 1996 observation, tending toward the third quadrant. This would have supported a sinusoidal trend for Figure 11. Instead, the position angle vs time graph shows a trend converging to an upper limit that is representative of a linear path.

Looking at the observational data as the companion star passes T_0, theta appears to be converging to a limit caused by the linear trajectory continuing its path in the fourth quadrant, with no indication that it will cease to do so. This can be detected starting with the 1960 observation all the way to the most recent KPNO observation. As time evolves, future observations should continue to support this trend.

New Rectilinear Elements and Linear Ephemerides

Having established that a linear trajectory best de-

Table 2. New Rectilinear Elements

WDS Designation	Discoverer Designation	X_0 (")	X_a ("/yr)	Y_0 (")	Y_a ("/yr)	T_0 (yr)	ρ_0	θ_0
18224+4545	HEI1998	0.052339	0.0075	0.055494	-0.00708	1953.321	0.076	43.36

Table 3. New Linear Ephemerides

WDS Designation	Discoverer Designation	2020		2025		2030		2035		2040	
		ρ_0	θ_0	ρ_0	θ_0	ρ_0	θ_0	ρ_0	θ_0	ρ_0	θ_0
18224+4545	HEI1998	0.692	127.03	0.743	127.46	0.495	127.85	0.846	128.18	0.897	128.48

scribes the relative motion of the secondary to the primary (Figure 12), the rectilinear elements (Table 2) and linear ephemerides (Table 3) were derived. In order to calculate a precise trajectory, a weighted least squares linear fit was applied to the data set. The weights for individual measures were determined using the technique outlined in the Sixth Catalog of Orbits of Visual Binary Stars. After taking these parameters into consideration for each observation, a weight of three was assigned to the KPNO and Tycho-2 observations, due to their increased accuracy, and a weight of three quarters was applied to the visual observations. A new trend line with a slope of -0.9442 and y-intercept of 0.1050 was determined. Both the rectilinear elements and the linear ephemerides were derived from this trend line as shown in Tables 2 and 3.

Conclusion

Using the new data point derived from reducing the speckle interferometry observation and correlating it with past observational data, this research suggests that the grade five orbital solution calculated by Heintz should be replaced with a linear solution, and that A700 should be reclassified from a binary star system to an optical double.

Acknowledgements

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. The researchers are indebted to Cuesta College for hosting the seminar. The researchers would like to especially thank Richard Harshaw, Joylon Johnson, and Bill Hartkopf for their advice. This research opportunity would not have been possible if it wasn't for the work and dedication put in by the observational team on the 2.1-meter telescope at Kitt Peak National Observatory. Last but not least, the researchers would like to thank Vera Wallen for her helpful suggestions.

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