Comparison and CCD Measurements of Four Double Star Systems: WDS 03003+1432, 03009+5221, 03001+3911, 08165+7930

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Abstract: As a class, we examined the double star systems WDS 03003+1432, 03009+5221, 03001+3911, and 08165+7930. CCD measurements made using the Skynet robotic telescope network are in good agreement with the historical trends for these stars. For 08165+7930, we confirm a curved trend-line suggestive of an elliptical orbit, validating its current status as a short-arc binary system. For the other systems, there is not yet enough data to infer a relationship, gravitational or otherwise.

Introduction

Understanding the orbits of stars that are gravitationally bound to each other was the genesis of the field of astrophysics, in which the laws of physics are applied to astronomical systems. Since the 1700's, astronomers have been studying stars that appear close together, looking for evidence of gravitational relationships. Given the orbital parameters governing the motion of such binary stars, it is possible to calculate the mass of the system. Together with other data, individual star masses can be determined, which helps to constrain the mass-luminosity relationship for stars in general (Wikipedia, 2018). Because the mass-luminosity relationship is fundamental for many applications of astronomy, the continuing study of double stars remains essential.

Since the orbital periods of binary star systems can span millennia, even historical data that stretches very far back does not always include all or even most of the orbit. Sometimes, only a tiny fraction of the arc is visible over multiple hundreds of years. Such systems are called Short-Arc Binaries, or SAB's. In such cases, it is sometimes possible to estimate orbital parameters, with the caveat that these have a high uncertainty. Careful and persistent collection of data is necessary to ensure that astronomers of the future are able to calculate the orbital parameters with greater accuracy.

Four star systems were selected for this study. Three are double star systems with unknown classification, and the fourth has been classified as an SAB. In this paper, we compare and contrast the data for these four systems, and the inferences that can be drawn about each. We also contribute a measurement of three of the four systems for inclusion in the Washington Double Star Catalog.

Target Selection

The stars for this study were chosen to be 5 arcseconds or more apart so they could be resolved in the image. They were chosen to have a magnitude difference of no more than 3 so that the same exposure time would be appropriate for both. These constraints came about because of the limitations of the telescopes on the Skynet Robotic Telescope Network.

History of the Stars

The four chosen star systems are shown in Table 1. Interestingly, the change in position angle and separation between the first and most recent observation does not distinguish the SAB from the other systems.

The immediate surroundings of each of the stars is shown in Figure 1. The small red squares represent other stars in the field, some of which are too dim to be visible in the image.

A brief synopsis of the discovery and historical ob-

Table 1: WDS data for the double star systems in this study

Star	Number of Past Observations	Observation Timespan	Change in Separation From First to Most Recent Observation (as)	Change in Position Angle From First to Most Recent Observation (deg)	Classification
WDS 03001+3911	14	1928-2014	0.1	1	Uncertain
WDS 03003+1432	20	1897-2018	1.59	2.1	Uncertain
WDS 03009+5221	92	1793-2018	2.1	4	Uncertain
WDS 08165+7930	95	1832-2018	-0.16	4.74	Short-Arc Binary

servations of each system follows.

WDS 03001+3911 ST Per

WDS 03001+3911 ST Per was discovered by Dr. Akbar Ali on October 24, 1928, when the stars were measured to have a separation of 11.6″ and a position angle of 6.2°. Dr. Ali was the director of the Nizamiah Observatory, which is located on the campus of Osmania University in Hyderabad, India. He died on February 7, 1960. This double star system is in the constellation Perseus, and whether a gravitational relationship exists between the stars is currently uncertain.

WDS 03003+1432 AG 60

WDS 03003+1432 AG 60 is also a double star system with an uncertain nature. Its discovery was first published in 1897 in a periodical called the "Astronomische Gesellschaft" (Astronomische Gesellschaft, 2016). This star is in the constellation Aries.

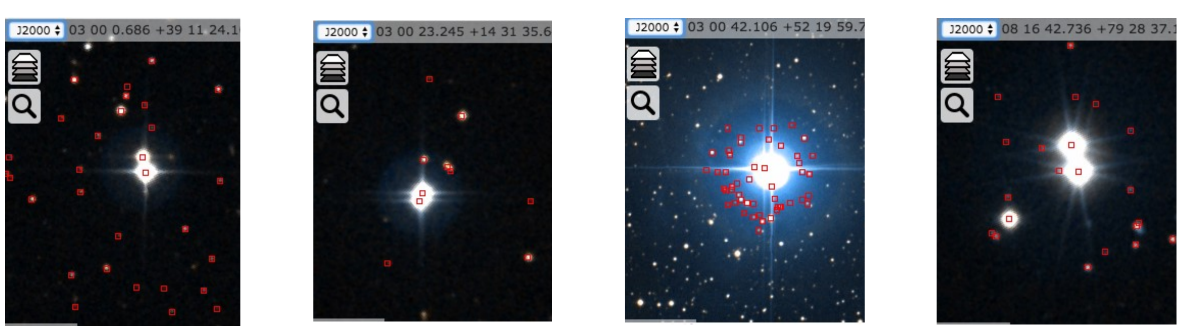
WDS 03009+5221 STF 331

WDS 03009+5221 STF 331 was discovered in 1793 and the last measurement prior to this work was made in 2016, with a total of 75 observations taken. This double star is in the constellation Perseus. Despite substantial changes in both position angle and separation, the nature of the double star is uncertain. The spectral class of the stars is B7V+B9V, and their magnitude difference is 0.96.

This double was first officially studied by Friedrich Georg Wilhelm Von Struve, a German-Russian astronomer. He was born on April 15, 1793 in Altona, Germany, and died on November 23, 1864 in St. Petersburg, Russia. Struve grew up in a family of astronomers, and became known for studying double stars (Encyclopedia Britannica, 2015). He discovered 03009+5221 STF 331 in 1837. During this time Struve was working at the Dorpat Observatory, in Tartu, Estonia. In this same year, he published his findings on multiple star systems in *Mensurae Micrometricae* (Encyclopedia of World Biography, 2010). His study on multiple star systems demonstrated that such systems are not rare, and their abundance exemplified Isaac Newton's law of gravitation operating outside the solar system (Encyclopedia Britannica, 2015).

WDS 08165+7930 STF 1169AB

Friedrich Georg Wilhelm von Struve was also the discoverer of WDS 08165+7930 STF 1169AB, and the discovery of this star was also made during his research at the University of Dorpat (Tartu, Estonia) in 1832. His first measurements were made on a telescope with



03001+3911 03003+1432 03009+5221 08165+7930

Figure 1: Double star systems in the study, screenshots from Aladin

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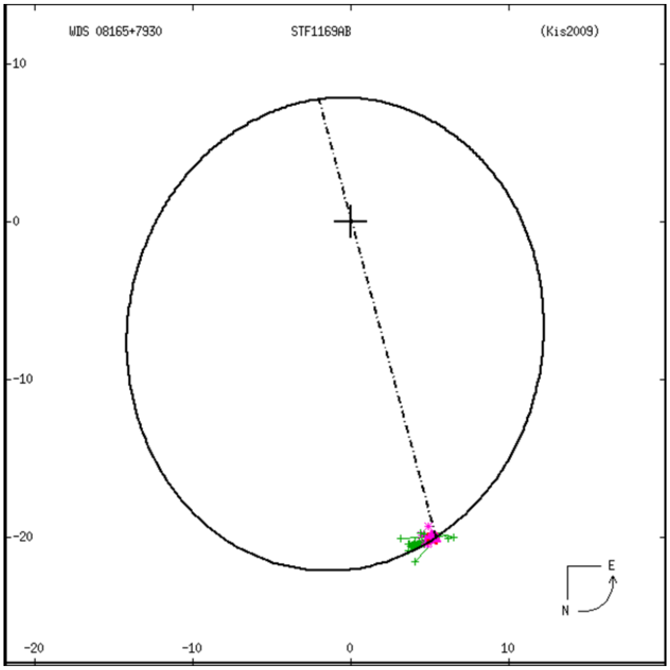

Figure 2: WDS orbital solution for 08165+7930AB STF1169AB

an aperture of 0.3m, the position angle to be approximately 10.1°, and the separation to be 20.74" (Encyclopedia Britannica, 2015). As time progressed, the observed PA rose steadily from Struve's initial measurement of 10° to approximately 14.84°. The star is located in Camelopardalis.

WDS 08165+7930 was classified as an SAB in 2009. As with all SABs, the data points that potentially form an arc make such a slight and small curve relative to the hypothetical orbit that it is challenging to evaluate the accuracy of the proposed orbit. For example, the arc that is currently visible for WDS 08165+7930 could fit into several different elliptical solutions. This is because only approximately 3-5% of the orbit has been observed, contributing to a proposed period of 200c (See Figure 2). Given the paucity of the observations, it is even possible that this orbit may be premature, and that this is not even a binary.

Gaia DR1

The Gaia DR1 database on VizieR was used to find information about each of the stars using their coordinates. The Gaia telescope is a European Space Agency telescope launched in 2013. It is equipped with a dual telescope system with a common structure and a common focal plane, blue and red photometers, and a radial velocity spectrometer. From the magnitudes presented and the configuration of the Aladin Lite images, the desired stars were determined to be the two brightest stars out of their respective fields. The proper motion of the secondary star was only available for 08165+7930 (see Table 2). Parallax data was only available for the primary star in each pair.

Our Measurements

We used the Skynet Robotic Telescope Network for this study. The telescopes used were the Athabasca University Robotic Telescope (AURT) in Canada and the 17-inch telescope at the Dark Sky Observatory in North Carolina.

AURT

The Athabasca University Robotic Telescope, or AURT, is located at Athabasca University in Alberta, Canada. It is used to take detailed images of the northern night sky. The telescope has an aperture of 0.4 meters and is remotely controlled. The focal length is 3868.0 mm and the f-ratio is 10.9. We used the Lum filter, which blocks the infrared and ultraviolet rays. It has a field of view of 24.6 x 16.4 arcminutes. Stars

Table 2: Available Data on Targets from Gaia DR1

	03003+1432	03009+5221	03001+3911	08165+7930
Precise coordinates	030020.97+143152.5	030052.18+522106.5	030005.70+391124.9	081631.05+793003.5
Primary Magnitude	9.56 (WDS), 9.406 (Gaia)	5.21	9.63	8.40
Secondary magnitude	10.0 (WDS), 9.946 (Gaia)	6.17	11.99	8.64
Parallax (mas)	3.78 ± 0.36	6.77 ± 0.44	3.11± 0.29	13.82 ± 0.45
Distance (ly)	863 ± 82.2	482 ± 31.96	1049 ± 97.5	236 ± 7.68
Primary PM (mas/yr)	12.927, -2.614	27.129, -24.901	-4.412, -21.319	-50.676, -65.684
Secondary PM (mas/yr)	not known	not known	not known	-48.095, -66.258
Spectral class (from WDS)	G5 (primary)	B7V+B9V	A3V	G0 (primary)

03003+1432 and 03001+3911 had exposure times of 10 seconds, and stars 03009+5221 and 08165+7930 had exposure times of 5 seconds.

DSO-17

The Dark Sky Observatory 17, or DSO-17 is a telescope located in North Carolina. The telescope has an aperture of 0.4 meters and is remotely controlled. The focal length is 2951.0 mm and the f-ratio is 6.8. We used the Lum filter for this also. Stars 03003+1432 and 03001+3911 had exposure times of 10 seconds, and stars 03009+5221 and 08165+7930 had exposure times of 5 seconds. These were the lowest exposure times that gave good images.

After collecting images from the AURT and DSO-17, the image analysis software AstroImageJ was used to reduce the data. The aperture size was selected as 6-pixels. Some of the images were blurry and some were out of frame. Possibly the images were distorted by a cloud in the field of view or movement of the telescope while the images were being taken. An example of the "swishy stars" is shown in Figure 3. There may have been a collimation problem with the telescope, which caused the centroid to be spread out off-center (Harshaw, 2018). Values highlighted yellow in Table 3 came from images of these stars. As is evident from Table 4, the yellow highlighted values are generally in poorer agreement with the historical values.

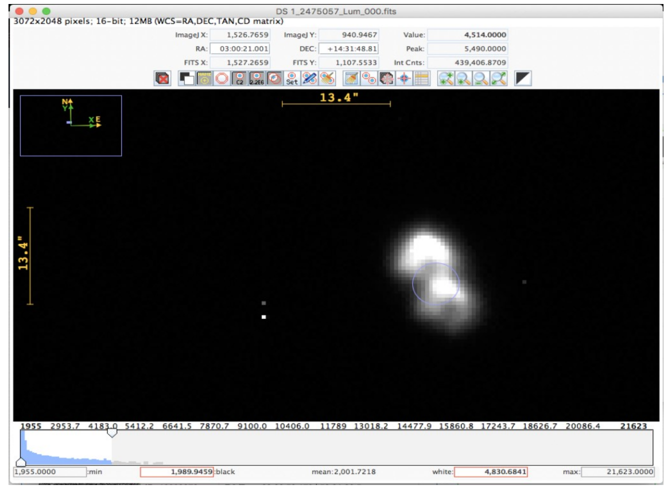

Figure 3. Distorted stars for which it was difficult to locate a centroid.

Analysis

Comparison with Historical Data

As is shown in Table 5, the position angle for WDS 03009+5221 remains relatively constant over time, with no big increases or decreases (bar the few early data points that are likely due to obsolete instruments). Similarly, the graph for WDS 03001+3911 also seems to

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Table 3: Measurements of the four systems with yellow values indicating stars that appear distorted

System	03001+3911		08165+7930		03003+1432		03009+5221		03001+3911		08165+7930	
Date	Feb 06, 2018		Feb 06, 2018		Feb 06, 2018		Feb 09, 2018		Feb 06, 2018		Feb 06, 2018	
Telescope	DSO-17		DSO-17		AURT		AURT		AURT		AURT	
Measure	PA	Sep	PA	Sep	PA	Sep	PA	Sep	PA	Sep	PA	Sep
Image 1	10.47	12.13	14.92	20.75	161.68	5.79	84.3	11.86	16.64	10.54	15.06	20.64
Image 2	10.38	12.15	14.95	20.83	159.61	5.82	84.48	11.93	10.07	12.16	14.97	20.66
Image 3	10.28	12.15	15.03	20.77	157.97	5.9	83.75	11.83	9.54	12.08	15	20.16
Image 4	10.28	12.08	14.97	20.69	159.77	5.9	84.75	11.94	9.76	12.08	15.14	20.69
Image 5	10.39	12.06	14.97	20.78	159.54	5.94	84.73	11.8	10.27	12.1	15.04	20.61
Average	10.36	12.14	14.97	20.76	159.71	5.78	84.40	11.87	11.26	11.30	15.04	20.55
Std Error	0.036	0.019	0.018	0.023	0.59	0.028	0.183	0.027	1.352	0.313	0.029	0.099

Table 4: Comparison of average measurement to most recent measurement for each system, where yellow shading indicates some image distortion

System	03001+3911		08165+7930		03003+1432		03009+5221		03001+3911		08165+7930	
Measure	PA	Sep	PA	Sep	PA	Sep	PA	Sep	PA	Sep	PA	Sep
Most recent measurement	11	12.2	15	20.8	160	6.4	86	12	11	12.2	15	20.8
Average	10.36	12.14	14.97	20.76	159.71	5.78	84.40	11.87	11.26	11.30	15.04	20.55

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Table 5: Position angle vs time and separation vs time, our observation in red

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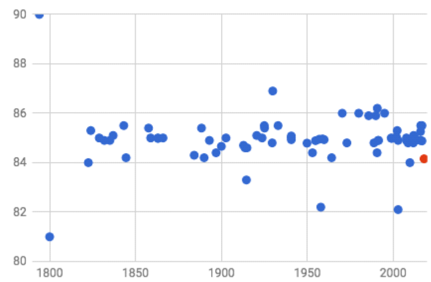
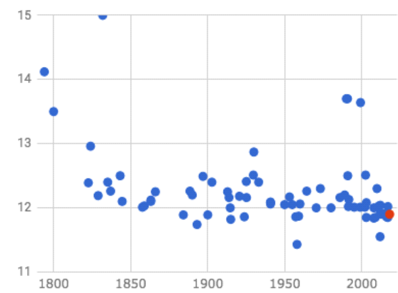
<tr><th>System</th><th>Position Angle Versus Date</th><th>Separation Versus Date</th></tr>
<tr><td>03009+5221</td><td>
</td><td>
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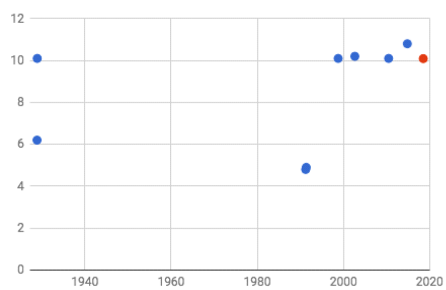
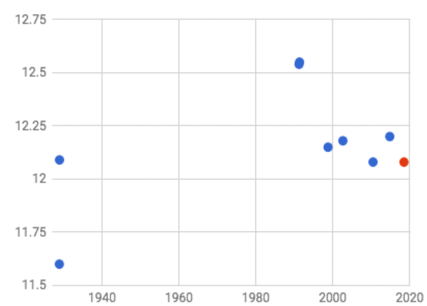
<tr><td>03001+3911</td><td>
</td><td>
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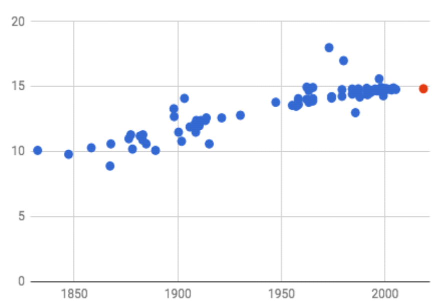
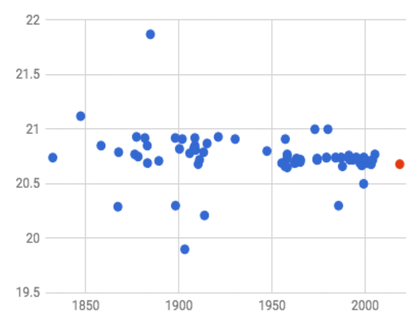
<tr><td>08165+7930</td><td>
</td><td>
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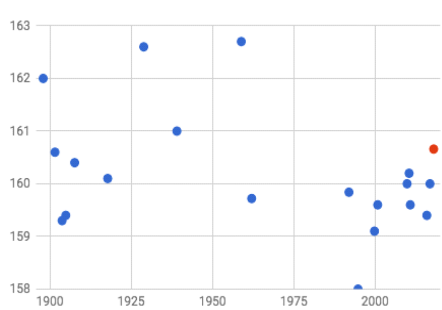
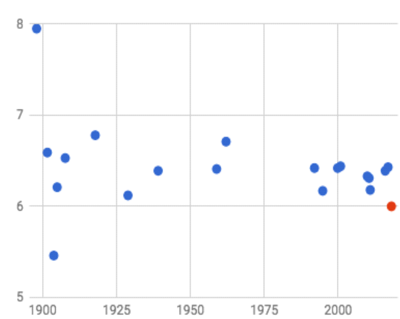
<tr><td>03003+1432</td><td>
</td><td>
</td></tr>
</table>

Table 6. Relative position of the secondary star relative to the primary: our measurement in red, historical measurements in blue.

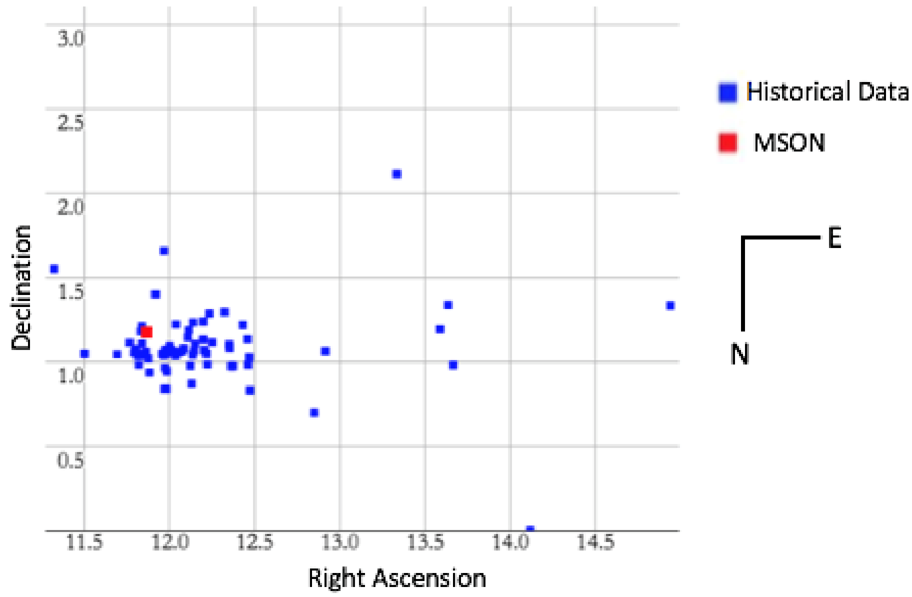
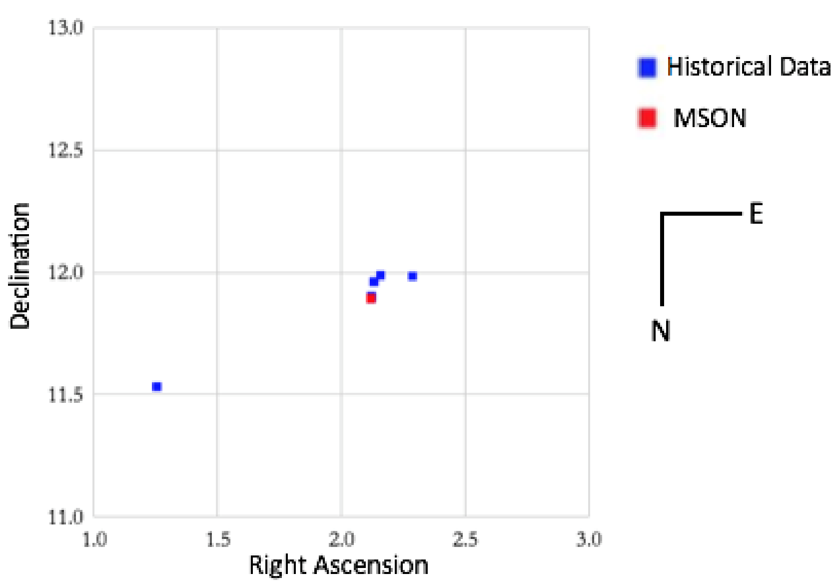
System	Secondary Star Position Relative to Primary
03009+5221	
03001+3911	

Table 6 concludes on the next page.

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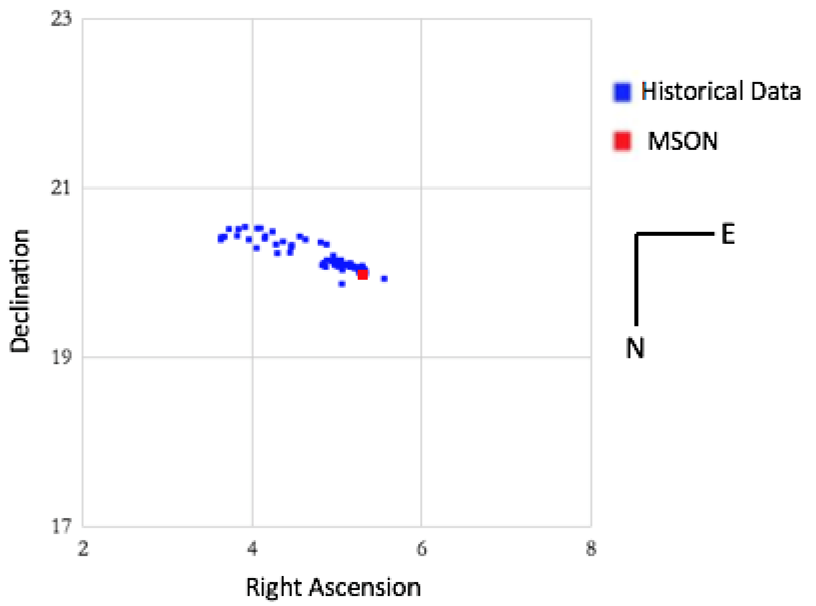
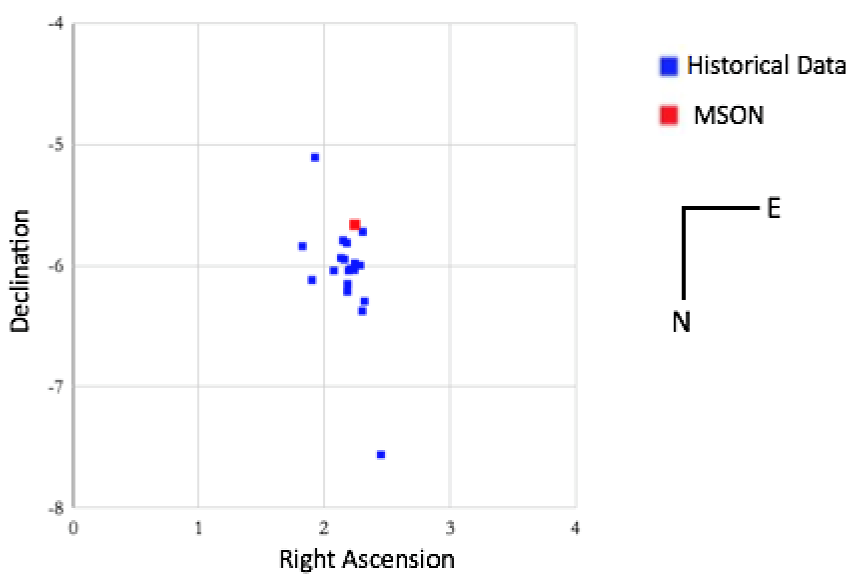
Table 6 (conclusion). Relative position of the secondary star relative to the primary: our measurement in red, historical measurements in blue.

System	Secondary Star Position Relative to Primary
08165+7930	
03003+1432	

(Continued from page 697)

have a position angle that relatively remains the same, with no big increases or decreases. It is possible that the position angle of WDS 03001+3911 could potentially be increasing slightly, but there are not enough historical observations to make this conclusion definitive. The separations for these systems exhibit similar features: a separation that becomes clustered to a certain value as the observations become more recent. For some of the systems, there may be an indication that the measurements could one day exhibit a curved path, but there are too few observations to conclude this with certainty.

For 08165+7930, our measurement of 14.88° reflects and confirms the historical trend of increasing position angle. The historical measurements for separation have remained at a relatively constant 20.6-20.7"; thus, our observation of 20.66" is consistent with past observations. Also for the other systems, the average measurements from the non-distorted images are consistent with historical position angle and separation observations. This is expected, because the stars have shown little relative movement in the past. As is evident from Table 5, the only noticeable trend in the historical data is the increasing position angle for 08165+7930.

Plots of the historical observations along with our observation (in red) are shown in Table 6. WDS 08165+7930 shows evidence of the beginnings of an arc, traced out over almost 200 years of observations.

Proper Motion of 08165+7930

Since Gaia has data on the proper motion of both stars in 08165+7930, it is possible to graph the primary and secondary motions as vectors on the Cartesian plane, as is done in Figure 4.

When the smaller vector is subtracted from the larger vector, the magnitude of the resulting vector can be found using this equation:

$$|v| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

The magnitude of the difference vector was divided by the magnitude of the largest proper motion vector (in this case the primary proper motion vector). The result of these calculations was (2.236)/(82.961)= 0.02. Any ratio less than 0.2, as this one is, indicates that the movement of the stars relative to each other is small compared to their movement across the sky (Harshaw 2016). This is strong evidence that the stars are moving together, as they must be if they are gravitationally bound to each other.

Fitting in Excel: Line Versus Curve

When making a scatterplot of 08165+7930, the data points indicate that the separation has remained relatively constant throughout historical observations,

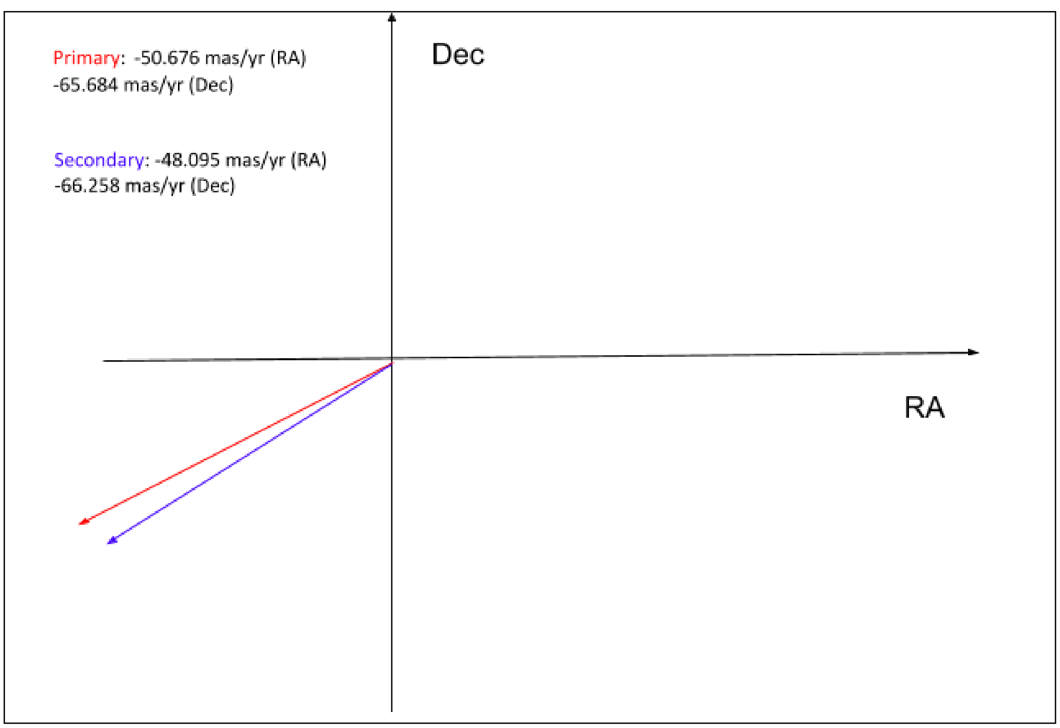


Figure 4: Proper motion vectors for WDS 08165+7930

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while the position angle has steadily increased from approximately 10 degrees in 1832 to nearly 15 degrees in 2018. Using Google Sheets, the r-squared values were compared for both linear and polynomial trendlines from the plot. Given that r-squared is a statistical measure of accuracy to a given regression line, a higher value for the polynomial line than the linear one indicates that a curve describes the stars' relative motion better than a line. The actual determined value for the curved trendline is 0.851, while the determined value for the linear trendline is 0.835; thus, the secondary star appears to be taking a curved path relative to the primary. The trendlines are shown in Figures 5 and 6.

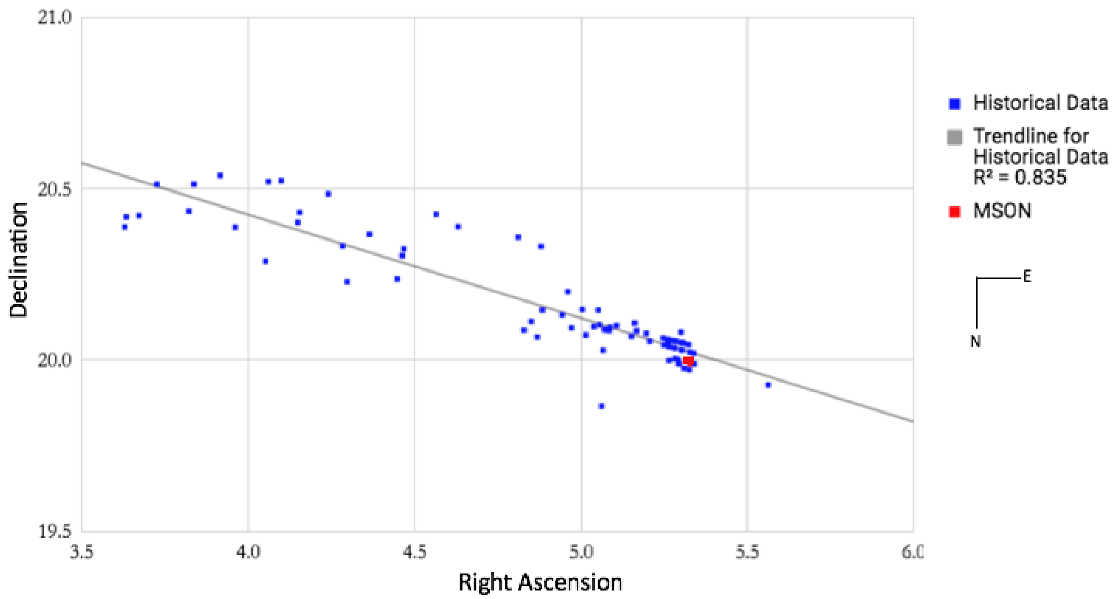


Figure 5: Linear trendline for WDS 08165+7930

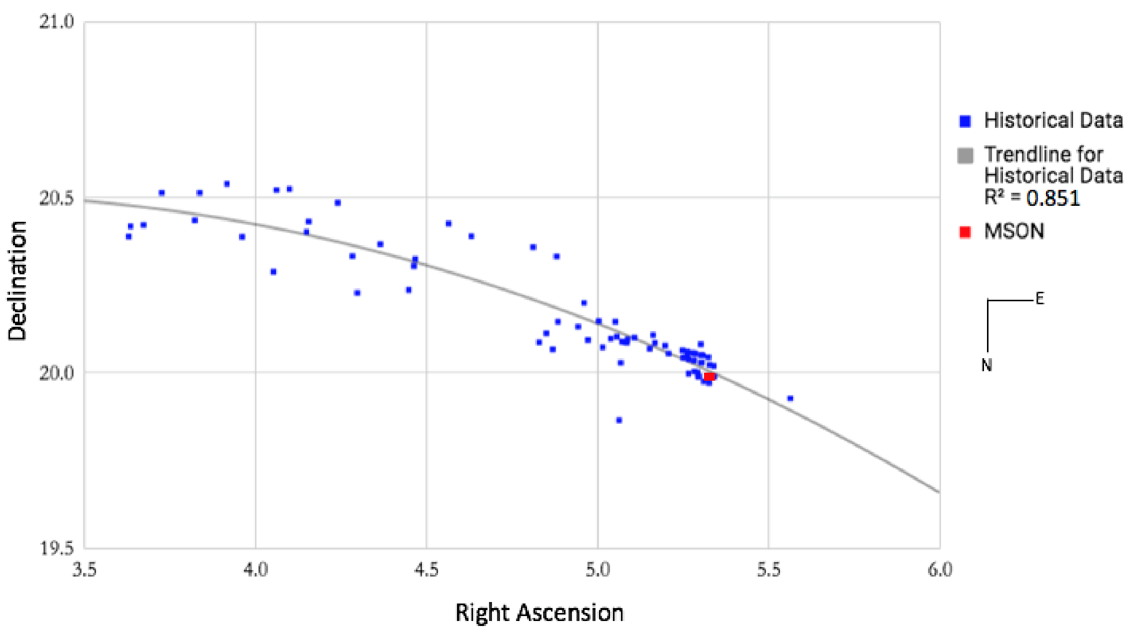
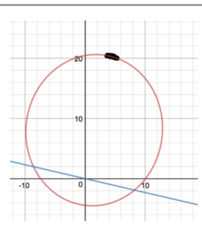
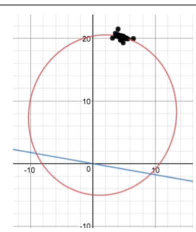
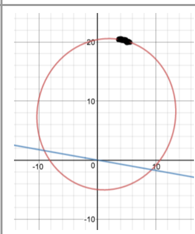
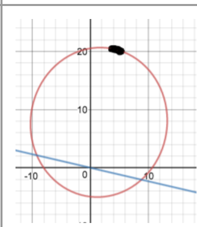
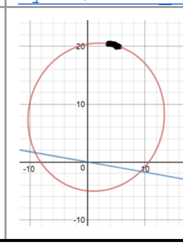


Figure 6: Polynomial trendline for WDS 08165+7930

Table 7: Desmos fit parameters for 50-point subsets of data for WDS 08165+7930

	Jack	Zoe	Grace	Mac	Kalée	Published Solution
a	15	15	15	15	15	15
e	0.651	0.615	0.615	0.618	.615	0.48
i	147	149	149	149	149	3
Ω	257	260	260	257	260	15
ω	88	91	91	88	91	157
M	191	192	189	193	550	8800
p	4950	3500	4550	3500	4400	20,000
R^2	0.76	0.68	0.83	0.86	0.89	--
Link	http://tiny.cc/08165_1	http://tiny.cc/08165_2	http://tiny.cc/08165_3	http://tiny.cc/08165_4	http://ti-ny.cc/08165_5	--
Fig						--

Desmos fits

The Desmos orbital plotting tool authored by Hensley was used in order to estimate the orbit for 08165+7930 (Hensley, 2018). Each team member selected 50 points from the data on 08165+7930, making sure that the spread between individual years was not too great (i.e. no 7+ year gaps between points). These points were then inserted into the plot tool and the parameters were adjusted to find the best R^2 value. It should be noted that this Desmos analysis was unweighted according to the criteria outlined in the *Sixth Catalog of Orbits of Visual Binary Stars*. A full orbital solution for the system would entail evaluating the data using these criteria. However, a full orbital solution is superfluous given the large period of this system and the fact that it was only 9 years ago that the solution was published (Kisselev, 2009, Van den Bos, 1962, Dommanget, 1994). As is evident from Table 7, it is possible to achieve respectable fits with varying parameters. Notably, the five spatial parameters (a, e, i, Ω, and ω) appear to be more stable than the time-dependent parameters, M and p, which also vary relative to the published solution (Kisselev, 2009). The seemingly large discrepancies in the spatial parameters between Desmos and the published solution arise from choice of coordinate axes.

Conclusion

Most of the systems studied in this paper seem to have separations and position angles that have remained relatively constant, with no big increases or decreases. The early data shows characteristic evidence of noise, while the later data becomes more tightly clustered. We contribute a measurement for three of these four systems for 2018: WDS 03009+5221, 03001+3911, and 08165+7930. The distortion of the stars in the images of the fourth system (WDS 03003+1432) calls our measurement into question, despite the fact that our measured values seem plausible based on historical data. Among the systems, 08165+7930's position angle versus time graph shows a definite trend over time, consistent with its status as a Short-Arc Binary. In all four cases, more time is needed to reveal the nature of the relationship between the stars.

Acknowledgements

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Louisville, updated for double star astrometry by Karen Collins.

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