Gaia and CCD Measurements of WDS 00458 + 5108 A, CD Suggest that it is not a Physically Associated System

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Abstract: Images of WDS 00458 + 5108 A, CD, obtained with the Great Basin Observatory telescope, were used to determine whether or not the A and C components of the system are physically associated. By comparing our observations to the historical ones found in the WDS, we examined the motion of this system. The measurements showed a linear motion for the C component, and suggested that the components are not physically bound. Proper motion and parallax data of the components were extracted from the Gaia database. The A component has a parallax of 1.147±0.0271 (mas) and a distance of 520-530 pc, while the C component has a parallax of 1.8963 ±0.0139 (mas) and a distance of 850-890 pc. This suggests that this star system is not physically bound.

Introduction

For this project, we set out to observe a star system that had few historical observations and was visible from the Great Basin Observatory (GBO) telescope. Furthermore, we aimed to select a system in order to determine whether the components were physically bound. The system we selected was WDS 00458 + 5108 A, CD. The A and B as well as the C and D components of the system were unresolvable with the GBO, so we chose to analyze the A and C components. These components were first observed in 1898 by S. W. Burnham at the Yerkes observatory, and most recently in 2000 by F. Damm, for a total of 3 previous observations. The separation and angle of the stars has slowly changed over time: in 1898 the angle was 217º while in 2000 it was 216º, and the separation in 1898 was 89” and in 2000 it was 89.5”.

Since there are very few observations of this system, more data is needed to determine its physicality. Additionally, it has been two decades since the last observation, so by observing it again we hope to determine the nature of this system. We will do this by measuring separation and position angle of observations taken at the GBO. These observations will be supplemented by data retrieved from the Gaia database. In particular, parallax and proper motion measurements of the system will be useful in determining the physical relationship of the A and C components. Gaia is uniquely suited for determining parallax and proper motion because all of the measurements in the survey were acquired by a single, space-based instrument (Brown 2021).

Methods

The images collected were taken at the Great Basin Observatory (GBO), located at Great Basin National Park. It is overseen by several institutions, including the Great Basin National Park, the Great Basin National Park Foundation, Southern Utah University, Concordia University, the University of Nevada-Reno, and Western Nevada College. The GBO telescope is a PlaneWave 0.7m CDK 700. It has an SBIG STX-16803 CCD camera, resulting in a plate scale of 0.4 arcseconds per pixel. The

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combination of the telescope's f/6.5 focal ratio and the camera allows for a field view of 27x27 arcminutes. The following 16 filters are equipped on the telescope: LRGB, Ha, OIII, SII, BVRI, g'r'i'z', and a diffraction grating (Anselmo, 2018).

On November 11, 2020, a total of 20 images of WDS 00458 + 5108 A, CD were acquired remotely (see Figure 1). The exposure time was 180 seconds and a seeing profile was plotted to ensure the stars were not overexposed, which they were not. For the exposures, we used a V filter, and the images were binned 1x1. We then plate solved the images utilizing a plate-solving feature found at http://nova.astrometry.net/ (Lang, 2010). Bias, dark, and flat frames were used to calibrate the images with AstroImageJ version 2.4.1 (Collins et al. 2017). Separation (ρ) and position angle (θ) of the stars were also measured using AstroImageJ. We used the centroid feature to select the center of each star, which improved accuracy. Finally, the data were transferred to Microsoft Excel to calculate the means, standard error, and standard deviations for ρ and θ (Matson, 2021).

Results:

Table 1 shows our measurements that we took. The position angle, separation, mean, standard deviation, and the standard error are all included in this table.

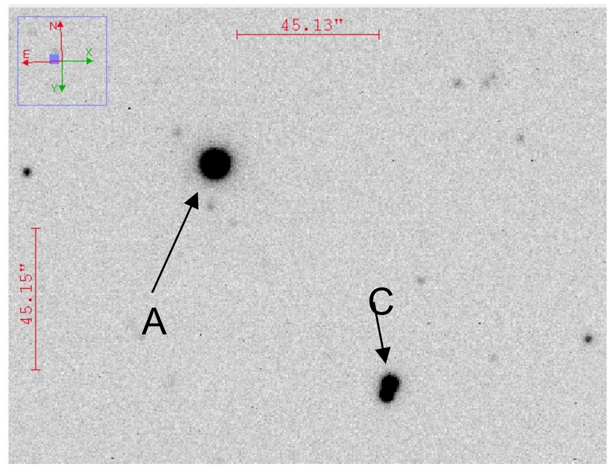

Figure 1: Image of the A and C components of WDS 00458 + 5108 A, CD. The image has a plate scale of 0.4" arcsec/pixels.

WDS No.	Date		Position Angle (degrees)	Separation (arcsec)
WDS000458+ 5108 A, CD	Nov. 11 2020	Mean	216.8	90.056
		Std Dev.	0.012	0.028
		Std. Error	0.103	0.168

Table 1: Observations from the data collected. Position angle (θ), Separation (ρ), mean, standard deviation, and standard error. A total of 20 pictures were taken of the A and C components in WDS 00458 + 5108 A, CD.

Discussion

As shown in Table 2, there are 4 measurements of the C and A components of WDS 00458 + 5108 A, CD in the Washington Double Star Catalog (Matson, 2021). The first measurement was recorded in 1898, and the most recent is from 2000. Plotted in Figure 2 are the measurements from these previous endeavors as well as our recent measurement together with a linear fit. The large R^2 value of 0.98 for this fit suggests that the motion of WDS 00458 + 5108 A, CD is linear. This could mean that the A and C components are not physically bound.

To more fully study the motion of this system, we extracted parallax and proper motion data from the Gaia DR2 database (Gaia Collaboration et al. 2018a), which are shown in Table 3. This table includes measurements for all components (A-D) of the system. Looking at the parallax and distance measurements, it would appear that the A and B components may be binaries. This also appears to be the case for the C and D components. The physicality of the C and D components appears to be supported by the proper motion information, although the picture is less clear for the A and B components. In any case, it seems clear that the A and C components are unrelated. To illustrate this, we have plotted the proper motion of these components as red arrows in Figure 3. The proper motions of these stars are significantly different, further confirming the idea that they are not physically bound. However, it may be worth noting that, depending on the orientations of their orbits, even gravitationally bound stars may exhibit differences in their proper motions (Gaia Collaboration, 2018a).

When examining Gaia data, one wonders what constitutes "good" measurements. There are several indicators within the Gaia database that can be used to evaluate the quality of data. The stated uncertainties for parallax and proper motion tell us about the internal consistency of the data. These formal uncertainties are affected by a number of factors, principally by the magnitude of the source (Lindegren 2018). Many authors (e.g Gaia Collaboration et al. 2018b, Brown 2021) consider parallaxes to be precise when their formal uncertainty is less than 20% of the measured parallax (i.e. σ/ϖ < 20%). By this standard, the parallax measurements in Table 3 are quite good, as they have very small uncertainties: for the A component σ/ϖ < 2% and for the C component σ/ϖ < 1%. However, Both the A and C components are considered bright (i.e. V<11) by Gaia standards. This means that the parallax uncertainties for these components could be underestimated by up to 30% (Luri et al. 2018). Despite this possibility, the significant differences in the parallax data for these stars suggest that the A and C components are not gravitationally bound.

Another way of assessing the quality of Gaia astrometry is to examine how consistent measurements are with the Gaia five-parameter model. Measurements that are consistent with this model must have a well defined center of light over many observations; they must also be free from perturbations from nearby sources. The most commonly used quality indicator for this goodness of fit to the model is the re-normalized unit weight error (RUWE; Lindegren 2018). The unit weight error (UWE), sometimes called the standard error of unit weight, was found to have a magnitude and color dependence, which was therefore renormalized to produce the RUWE. We expect the RUWE to be close to 1.0 for stars with well-behaved solutions to the model, and an analysis performed by Lindegren 2018 suggests that a cut around RUWE = 1.4 is a natural breakpoint for selecting objects with well-behaved solutions to the five-parameter model. The RUWE for the components of WDS 00458 + 5108 is provided in the last column of Table 3. It can be seen that the A component has an RUWE of 1.52, which is just outside what is considered good. On the other hand the C component has an RUWE of 0.982, which is very near the expected value of 1.0, suggesting that the parallax for the C component is accurate.

Considering our observations together with the Gaia parallax and proper motion measurements suggests that the A and C components are probably not physical. The small separation of the A and B components and their comparable Gaia measurements suggest that they are physical: the same is probably true for the C and D components. However, further observations of this system will be needed to determine if this is the case.

Year	rho	theta
1898	89	216.8
1998	89.37	216.1
2000	89.54	215.9
2020	90.056	215.35

Table 2: Historical Data for WDS 00458 + 5108 A, CD.

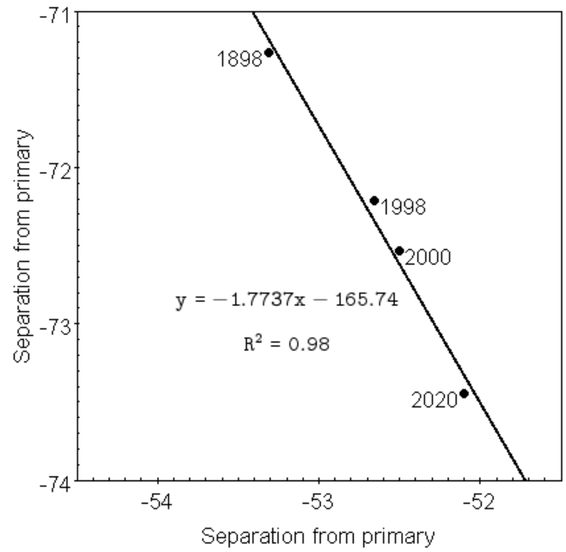

Figure 2: A plot of our measurement and the historical measurements of the system, in arcseconds. A linear fit and its parameters are shown. It can be seen that the motion of the C component is roughly linear.

Star	Parallax (mas)	Distance (pc)	Right Ascension Proper Motion (error)	Declination Proper Motion (error)	RUWE
A	1.147±0.027	850-890	1.454±0.026	-1.907±0.021	1.52
B	1.251±0.047	770-830	1.993±0.040	-2.357±0.035	1.65
C	1.896 ±0.014	520-530	5.346±0.012	-16.532±0.010	0.98
D	1.761 ±0.030	560-580	5.814±0.027	-15.182±0.021	2.17

Table 3: Parallax and proper motion data for WDS 00458 + 5108 A, CD from ESA's Gaia database. These data indicate that this is not a gravitationally bound system.

Gaia and CCD Measurements of WDS 00458+051808 A, CD Suggest that it is Not a Physically Associated System

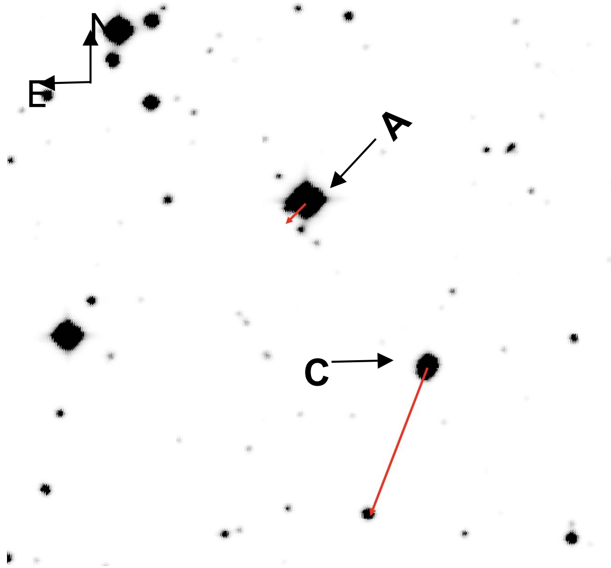

Figure 3: Shows the difference in magnitude and direction of the proper motion of A and C. As this figure shows, both the magnitude and direction of the components are completely different suggesting that these stars are not physically bound.

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