New Observation and Physical Nature of Double Star WDS 23134-7821 AB

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ABSTRACT

WDS 23134-7821 AB (HJ 5385), a binary star system candidate, was observed by two telescopes – one in Cerro Tololo, Chile and the other in Siding Spring, Australia. Both are members of the Las Cumbres Observatory Network (LCO). Seven usable images were obtained and we recorded an average separation of 57.11 +/- 0.35 arcseconds and position angle 316.68 +/- 0.15 degrees using AstroImageJ. After receiving historical data on the system from the US Naval Observatory, we found that the relative motion of the stars is consistent with a straight line and would be moving at a speed greater than escape velocity. Therefore, we conclude that this system is not a physical binary.

1. INTRODUCTION

Distinguishing between binary star systems, where two stars orbit one common center of mass, and optical double stars, which appear near each other but are not gravitationally bound, is an urgent and critical question in modern astronomy. This is because of the usefulness of confirmed binary star systems for determining stellar masses and studying stellar evolution and because it is estimated that fully two-thirds of all stars in the universe form in binary or higher-multiple star systems. Differentiating between optical double stars and true binary star systems can require multiple observations over tens or hundreds of years which makes finding absolute conclusions difficult.

The primary goal of our research was to understand and characterize the orbit of a potential binary star system. We wanted to observe a double star system for which one or two further observations would be enough to conclusively determine the nature of the system. Both historical data and images from the LCO telescope network answered these questions for our chosen star system, WDS 23134-7821 AB (HJ 5385).

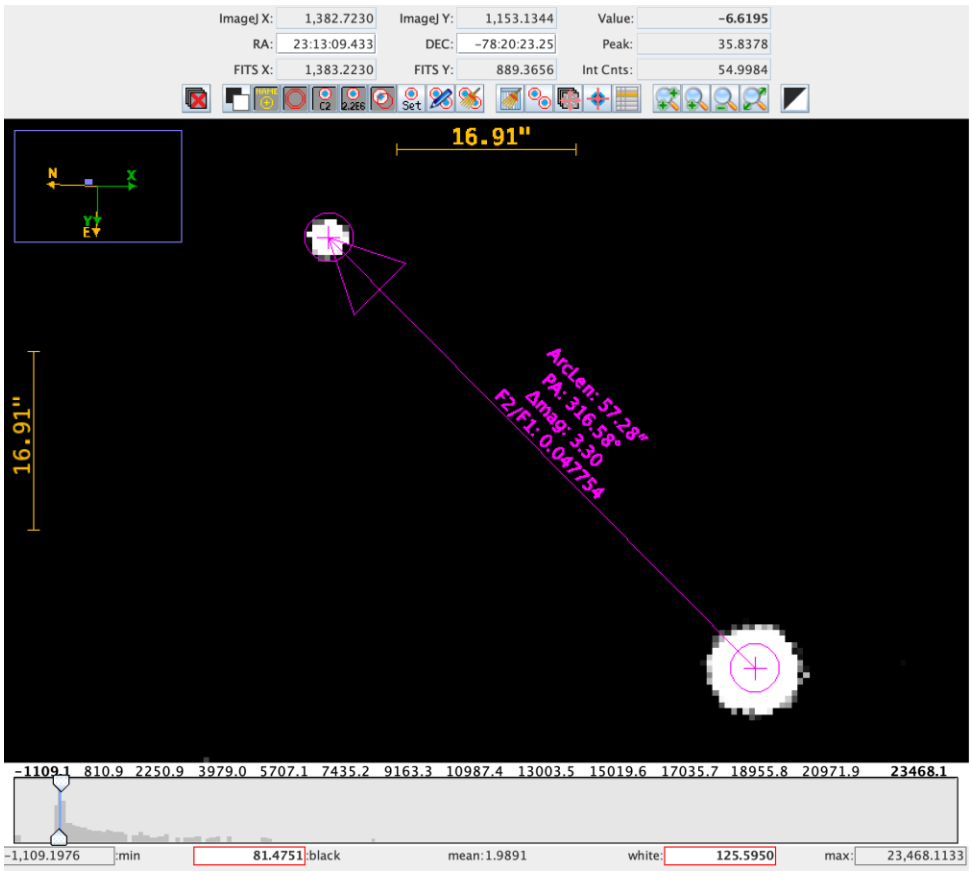
This double star was discovered in 1835 by John Herschel (Herschel 1847), and had five more observations on record over the 186-year period between 1835 and the present. However, only one of these, in 1918, appears to have been an individual measurement (Dawson 1922). The remaining observations have occurred as part of large surveys (Harshaw 2013), including an 1895 plate from the Astrographic Catalogue analyzed much later as part of a large data set (Urban et al., 1998). We find no recorded evidence of an attempt to fit an orbit or determine whether this system is a physical binary. Both the Stelle Doppie Double Star Database and a large analysis of Washington Double Star Catalog (WDS) and Gaia data (Harshaw 2018) list this system's nature as unknown. In this paper, we add a seventh position measurement and determine that WDS 23134-7821 AB is not a physical binary.

2. METHODS

We used the SBIG STL-6303 CCD camera on the 0.4 m LCO telescopes in Siding Spring, Australia and Cerro Tololo, Chile, to obtain ten 3-second exposures on May 17, 2021 (2021.37).

Once we received all ten image files, we used the photographic analysis tool AstroImageJ to determine the separation (ρ) and position angle (θ) between the stars in the potential binary system (Fig. 1). Three of the ten images we received from the LCO telescopes were distorted from atmospheric effects that blurred the stars and rendered them unusable for our purposes. The other seven images we received were of good quality and the measurements we took from them were consistent, so we do not expect the loss of those three images has impacted our findings significantly. We averaged the seven remaining values to obtain $\rho = 57.11'' \pm 0.35''$ and $\theta = 316.68° \pm 0.15°$. The uncertainty for our new measurement is given by the standard deviation of the separation and PA values from the seven usable telescope images.

Figure 1. AstroImageJ characteristic image file and measurement of the arclength, position angle, and apparent magnitude between the stars; the lower right star is the primary.



3. RESULTS

Our values, along with the historical data obtained from Dr. Brian Mason at the Naval Observatory, are listed in Table 1 and plotted in Figure 2. In the absence of recorded uncertainties for the historical measurements of ρ and θ for this system, we assumed that a rough estimate for the minimum error in the historical measurements would be the error associated with the diffraction limit,

$$\theta_{min} = 1.22\frac{\lambda}{D},$$

where λ is the wavelength of light (we chose 500 nm as an approximation) and D is the aperture of the telescope used to record the historical measurements. These values, converted from radians to arcseconds, are recorded in Table 1 for reference.

Observation Date	Separation (a.s.)	PA (degrees)	Diffraction Limit Resolution (a.s.)
1835.72	25	337.9	0.25
1895.79	35.55	327.1	0.42
1918.78	40.1	325	0.31
1976.655	49.36	319.5	0.10
1984.748	50.64	319.1	0.13
1994.651	52.52	318.1	0.10
2021.37	57.11 +/- 0.35	316.68 +/- 0.15	0.31

Table 1. Historical distance and separation angle between stars of WDS 23134-7821 AB and our most recent observation (2021). The historical sources do not give uncertainties, so we estimate a lower bound for each using the diffraction limit.

The measurements we took were approximately linear and seemed consistent with the historical data when graphed in Figure 2. The colored dots represent the position of the secondary star over time, while the primary star's position remains constant at the origin.

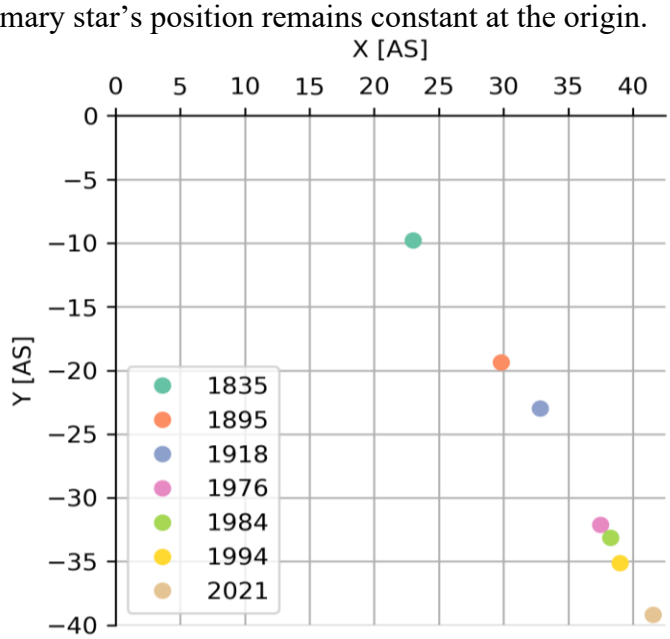


Figure 2. The colored dots represent the position of the secondary star relative to the primary star, whose position is fixed at the origin.

4. DISCUSSION

We do not believe that Figure 2 demonstrates strong evidence for a binary star system, as the secondary star seems to consistently move away from the primary star and there is no visual evidence of periodic motion. Furthermore, the primary star's distance is approximately known to be 110.62 pc (Gaia Collaboration, 2016). If we assume the secondary star is the same distance away, then the 27.11" of distance that star has moved over almost 200 years translates to a distance travelled of 3541.5 AU. Although not impossible, that separation would be very wide for a gravitationally bound binary system, as nearly all known gravitationally bound systems are within 3000 AU of each other and most are separated by no more than 1000 AU (Harshaw 2018). However, there is selection bias as long periods make systems more difficult to identify and confirm, and it is also possible that the system of interest is being viewed edge-on or that it has a very eccentric or long-period orbit. We now examine this question more carefully in order to rule out these other possibilities.

Analyses of double stars often use the square of Pearson's correlation coefficient, r^2, as a measure of linearity, and interpret $r^2 \sim 1$ as evidence that the system is not physical. However, position data from a bound system viewed nearly edge-on can still have r^2 close to 1. To avoid this limitation, we used a least-squares analysis of our data to estimate the relative velocity and see whether there is any acceleration of the secondary star consistent with orbital motion (i.e. non-zero in both the x- and the y-directions).

Specifically, we represent the relative motion e.g. in the x direction as

$$x(t) = x_0 + \mu_x t + \frac{1}{2}\alpha_x t^2,$$

where μ represents proper velocity (a.s. / yr) and α represents acceleration (a.s. / yr^2). For convenience, we take t = 0 at the initial observation (1835.72), so the constant x_0 is the position in arcseconds at that time. Taking a directly analogous expression for motion in the y-direction, in each case we are determining 3 constants based on 7 data points, leaving 4 degrees of freedom.

Our least-squares fit obtained values as shown in Table 2. The uncertainty in each parameter is defined as the range of values giving $\Delta\chi^2 \leq 1$ compared with the value of χ^2 at the best-fit parameter; if the measurement errors are normally-distributed then this corresponds to 1σ. The fit to x parameters gave $\chi^2 = 5.66$ or $\chi^2/d.o.f. = 5.66/4 = 1.42$, and the fit to y parameters gave $\chi^2 = 4.90$ or $\chi^2/d.o.f. = 1.23$, indicating that the hypothesis and best-fit parameters describe the data well (Cowan, 1998).

	x_0 (a.s.)	μ_x (a.s./yr)	α_x (a.s./yr^2)	y_0 (a.s.)	μ_y (a.s./yr)	α_y (a.s./yr^2)
Best-fit value	23.25	0.1174	-222×10^{-6}	-9.46	-0.1608	6.0×10^{-6}
Uncertainty	0.06	0.0004	5.2×10^{-6}	0.06	0.0004	5.2×10^{-6}

Table 2: Best-fit parameters for relative motion of the stars in the x- and y-directions, and associated uncertainty estimates ($\Delta\chi^2 \leq 1$).

Based on this, the relative proper motion of the stars is $\mu = 0.1992$ a.s./yr. Interestingly, while the y-acceleration is consistent with zero, the x-acceleration shows a definite preference for a nonzero value. Over the 186-year time span we consider, this corresponds to a slowdown of magnitude $\Delta\mu_x = \alpha_x \Delta t = 0.0413$ a.s./yr, about one-third of the best-fit x-velocity. Since the quoted value for relative velocity would be the velocity at t = 0 (taken as the discovery date), this would mean that the current value is around $\mu_x = 0.0761$ a.s./yr or slightly lower overall $\mu = 0.1779$ a.s./yr. This is intriguing, but the significance is unclear. Without future data or a better understanding of relative uncertainties between the historical measurements, the uncertainty estimates should only be interpreted as approximate guidelines.

We can now compare the stars' relative velocity to an estimate of the escape velocity,

$$v_{esc} = \sqrt{2GM/R}.$$

We only have parallax data for the primary star, so we can't determine the line-of-sight distance between the stars. Our above estimate of 3500 AU therefore represents the minimum separation, so our calculation will represent an estimate of the maximum possible escape velocity.

The primary star, HD 218827, is a G0 star (Houk & Crowley, 1975), so it would be only slightly less massive than the Sun. This leads to a maximum escape velocity estimate of ~1 km/s. On the other hand, a relative proper motion between the stars of 0.2 a.s./yr corresponds to ~100 km/s at a distance of 111 pc. This represents a minimum speed, since it ignores the possibility of a line-of-sight component. We find that the minimum relative speed is much greater than the maximum escape velocity, so despite unknown line-of-sight components of relative position and velocity we are able to conclude that the stars are not gravitationally bound.

5. CONCLUSIONS

We added a new observation to the historical catalog of positions of WDS 23134-7821 AB, and analyzed historical data to determine that the stars' relative motion was a very good fit to linear proper motion at a speed greater than escape velocity. Based on this, we concluded that the system cannot be gravitationally bound, and is not a physical binary.

We are unable to confirm or rule out any gravitational interaction between the stars, and we note that the uncertainties in our best-fit parameters rely on assumptions about historical measurements. In fact, Herschel himself wrote of his own observations that included discovery of this system: "a peculiar bias of judgment seems in some cases to have influenced [measurements] [...] This is, no doubt, partly owing to the different position of the person and head of the observer at the two instruments" - referring to comparison between southern and equatorial measurements of stars (Herschel 1847). Our analysis favors some acceleration that could suggest gravitational interaction, but the difficulty of comparing uncertainties between measurements across two centuries leaves us unable to determine whether this effect is physical.

Finally, we hope to correct a typographic error. The historical data as currently represented in historical databases lists the separation between the two stars in WDS 23134-7821 AB (HJ 5385) as 62.52" in 1994, while Richard Harshaw's paper "Using VizieR/Aladdin to Measure Neglected Double Stars" (Harshaw 2013), which is the source of the 1994 data point, lists the separation as 52.52".

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