# Determining the Gravitationally Bound and Optical Components of Quadruple System WDS 18136-1536

Sierra Kasl-Godley[1], Dylana Wagorn[2], Joshua Curiel[3], Shannon Pangalos-Scott[2,6], Alexander Vasquez[2,7], Dag Harmsen[4], Bebe Simone Hart[2], Rachel Freed[5], Rebecca Chamberlain[2]

1. University of Washington, Seattle, WA
2. The Evergreen State College, Olympia, WA
3. Los Angeles Mission College, Sylmar, CA
4. University of Munster, Germany
5. Institute for Student Astronomical Research, Sonoma, CA
6. Quadrivium STEAM & Astronomical Society, Olympia, WA
7. The Evoked Scion Institute, Lacey, WA

**Abstract**

Data was collected for the quadruple system, WDS 18136-1536, where according to Stelle Doppie the nature of this system was previously uncertain. New images were obtained using the Las Cumbres Observatory global telescope network. The current separations and position angles were measured with Skynet's Afterglow Access and compared with historical records from the United States Naval Observatory. The AB separation was found to be 2.96 arcseconds and the position angle was found to be 275.74 degrees. Based on the parallax and proper motion values retrieved from the Gaia catalog, it has been determined that the AB pair are likely gravitationally bound, and the C and D components are only optically aligned.

## 1. Introduction

WDS 18136-1536, is a quadruple system in the constellation of Serpens Cauda, and is located at a right ascension of $18^h$ $13^m$ $35.49^s$, and at a declination of -15° 35' 54.1". The research objective was to examine and determine the nature and relationships of the gravitationally bound and optical components of this quadruple system. Historical records of the AB pair were first recorded in 1873 by American astronomer, Sherburne Wesley Burnham. These measurements gave a separation of (ρ) 2.0″, with a position angle (θ) of 270° (Burnham, 1873). The primary star of this system has a magnitude of 7.54, the secondary star has a magnitude of 11.75 (Stelle Doppie). In 1880 the tertiary star (C) of this system was discovered, also by Burnham, with an 11.75 magnitude. The AC pair was first recorded with a separation of 7.1″, and a position angle of 279°, and a delta magnitude of 4.21. The BC pair was recorded with a separation of 4.6″, and a position angle of 278°. Thirty-three years later in 1913, the quaternary star (D) was discovered by Phillip Fox (Fox, 1925), with a magnitude of 12.52. The AD pair was first recorded with a separation of 35.0″ and a position angle of 36°. The nature of each of these component pairs is logged in Stelle Doppie (Stelle Doppie) as "Uncertain."

Several of the team researchers attended the "Astronomy and Cosmology: Stars and Stories" program at the Evergreen State College in Olympia, Washington. As part of the astronomy field studies, mentor Alexander Vasquez took the photo shown in Figure 1 of this multiple-star system (circled in red) in Serpens Cauda.

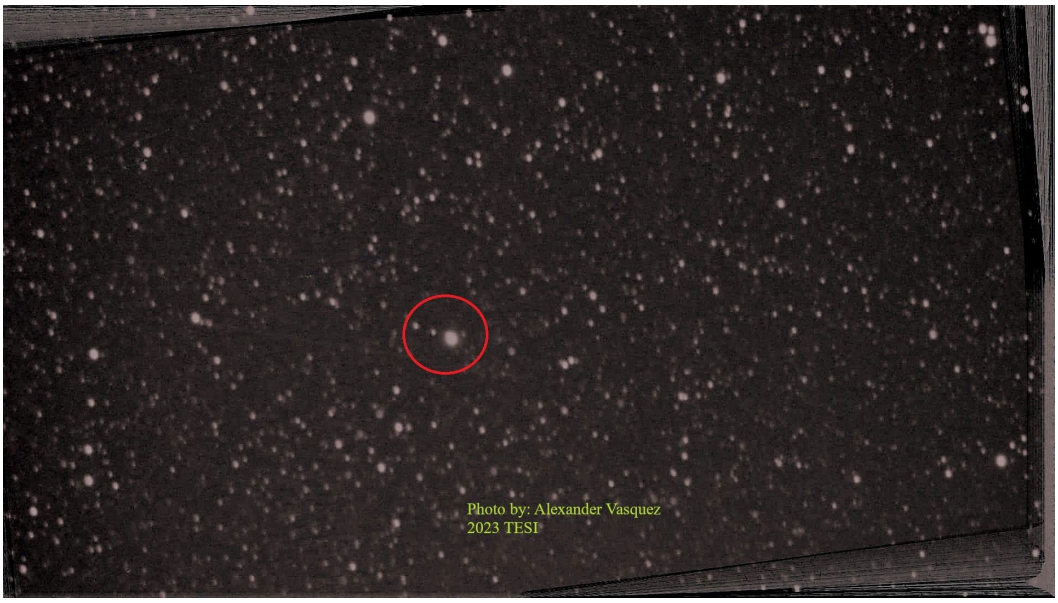


*Figure 1: Dwarf2 Digital telescope (Sensor: SONY IMX415 Starvis 8 Megapixel, AD:24mm, FL(equiv.):100mm(675mm) F4.2, FOV:3°) (2*2 binning, FITS, exp:2secs, Gain:70, Shots Taken: 238, Stacked:222) Coords: 47.0730 -122.9762, Bortle:5. Image taken at the Evergreen State College, Olympia, Washington. Alexander Vasquez, 07/27/2023.*

## 2. Equipment and Procedure

WDS 18136-1536 was selected by utilizing the Advanced Search selection tool available through Stelle Doppie, given the parameters specified in Table 1. The search was narrowed through this filter, and it was eventually decided that there was merit in doing further observations of this quadruple star system.

| | RA | Dec | Pri. Mag | Sec. Mag | Δ Mag | Sep. | Last Observed |
|---|---|---|---|---|---|---|---|
| Min. | 13h 00m 00s | N/A | 9 | - | 0 | 5" | Before 2015 |
| Max. | 23h 00m 00s | N/A | 11 | - | 3 | 10" | |

*Table 1: Parameters used to select WDS 18136-1536 in the Stelle Doppie Database Selection Tool. Declination did not need to be specified because the telescope network has telescopes in the northern and southern hemispheres.*

Once a candidate was selected, an observation request for images was submitted to the Las Cumbres Observatory global telescope network (LCO). On July 16, 2023, sample images were requested with a 1-sec., 5-sec., 7-sec., and a 10-sec. exposure time, using a Bessel-V (visible) filter. A 0.4-meter robotic telescope located at the Teide observatory in Tenerife, Canary Islands, Spain provided these images. After evaluation, it was determined that a 1-sec. exposure time would provide optimal contrast with minimal visual noise. On August 22, 2023, ten additional images with a 1-sec. exposure time and a Bessel-V filter were requested. The 0.4-meter telescope at the Haleakala Observatory on the island of Maui, Hawaii, provided these images using the site's SBIG STL6303 CCD camera.

Of these ten images, the FITS files of two were of sufficient resolution and were analyzed with the image analysis software, Skynet's Afterglow Access (Reichart, 2021), to determine the current position angle and separation of the stars within this system. Afterglow Workbench's plotter tool was used for these measurements as shown in Figure 2.

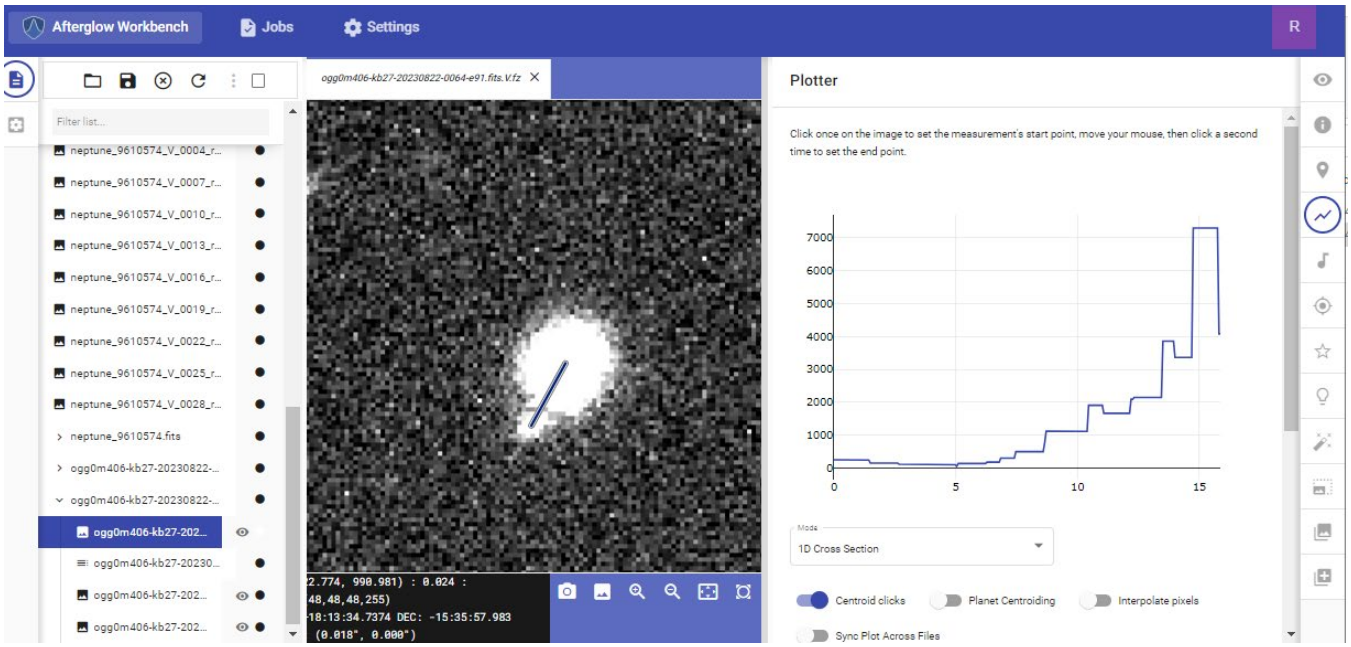


*Figure 2: Afterglow Access was used to measure the position angle and separation of the components of WDS 18136-1536.*

Though the primary and secondary stars appear unresolved, Afterglow was able to determine the individual centroids in three of the images, as indicated by the measurement line between A's centroid and B's centroid as shown in Figure 3.

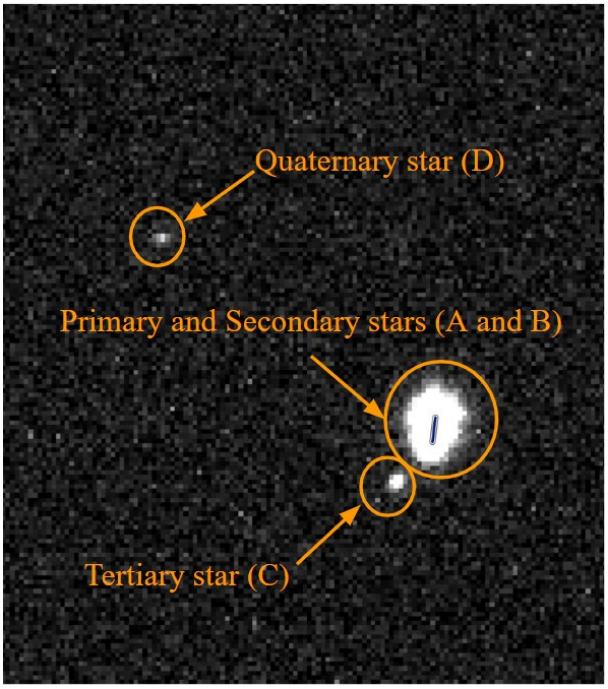


*Figure 3: Image of WDS 18136-1536 showing the four component stars. Afterglow was able to determine the individual centroids in several of our images, as indicated by the measurement line between A's centroid and B's centroid.*

Historical data for the position angle and separation was requested from Dr. Rachel Matson of the United States Naval Observatory (USNO) and compared to current astrometric measurements. Finally, the VizieR catalog was referenced (Vizier, 2022), and data from the Gaia DR3 for the components of WDS 18136-1536 were retrieved (Table 4). Further information about the components of the quadruple star system was gathered using Simbad's collection of images (Table 4).

## 3. Results

Images were collected on July 16th and August 22nd, 2023 as shown in Table 2 below.

| Image # | File name | Date |
|---|---|---|
| 1 | tfn0m410-kb24-20230716-0116-e91.fits.fz | 2023-07-16 |
| 2 | ogg0m406-kb27-20230821-0058-e00.fits.fz | 2023-08-22 |
| 3 | ogg0m406-kb27-20230821-0061-e00.fits.fz | 2023-08-22 |

*Table 2: Summary of images received from LCO, used to determine the current position angles and separations for WDS 18136-1536 and their respective dates.*

Data analysis of 3 images resulted in a mean separation of 2.96 arcseconds and a position angle of 275.74 degrees for the AB pair. The standard deviation and standard error of the mean were calculated for all four component pairs and are displayed in Table 3.

| **AB** | Sep. (arcseconds) | PA (degrees) |
|---|---|---|
| Mean | 2.96 | 275.74 |
| St. Dev. | 0.15 | 1.49 |
| Error | 0.08 | 0.86 |

| **AC** | Sep. (arcseconds) | PA (degrees) |
|---|---|---|
| Mean | 9.00 | 301.05 |
| St. Dev. | 0.26 | 0.09 |
| Error | 0.15 | 0.05 |

| **BC** | Sep. (arcseconds) | PA (degrees) |
|---|---|---|
| Mean | 6.45 | 312.32 |
| St. Dev. | 0.13 | 0.54 |
| Error | 0.08 | 0.31 |

| **AD** | Sep. (arcseconds) | PA (degrees) |
|---|---|---|
| Mean | 41.64 | 33.830 |
| St. Dev. | 0.81 | 0.29 |
| Error | 0.47 | 0.17 |

*Table 3: Summary of data analyzed via Afterglow Access for the four different components.*

The current right ascension and declination of the AB pair was plotted with the historical data provided by the USNO by converting measurements from polar to cartesian coordinates (Figure 4). The current data point is indicated in orange.

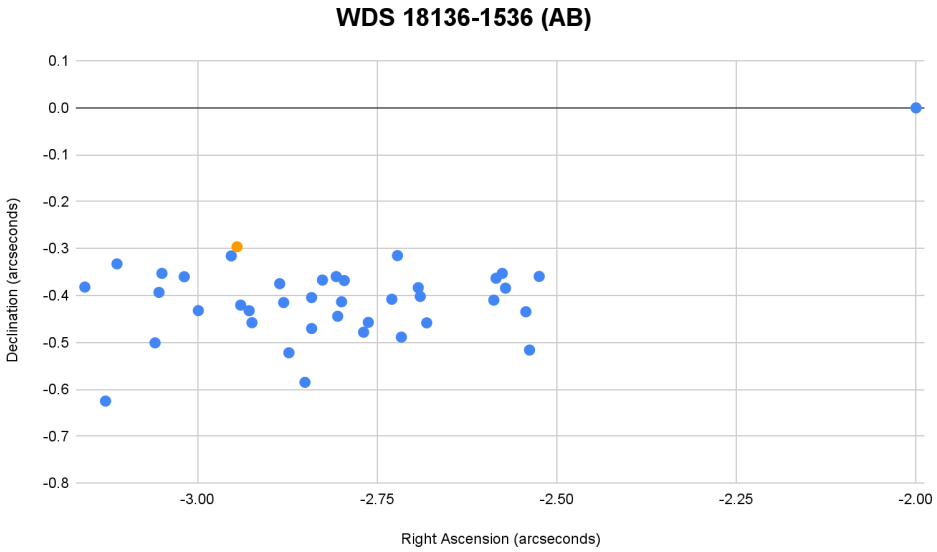


*Figure 4: Plot of WDS 18136-1536 (AB) historical data (blue dots) and current data (orange dot).*

## 4. Discussion

### AB

The current position angle and separation for the AB components in this system are 275.74 degrees and 2.96 arcseconds. It was concluded that Afterglow Access could not distinguish between the A and B centroids when images were taken with 5-sec. exposures. Images with 1-sec. exposures were of sufficient resolution to distinguish an A and B centroid, and thus a position angle and separation could be measured.

According to the historical data from the USNO, the measurement of the AB components of this star last occurred in 2005. The reported position angle and separation were 276.9 degrees and 3.18 arcseconds, respectively. The current observation–indicated in orange (Figure 5)–does not indicate any major change from the 2005 observation. According to Figure 5, there is a slight overall downward trend in the position angle and a slight overall upward trend in the separation. The current data point matches these overall trends. The initial observation from 1873 does not appear to follow either of these trends, suggesting it is an outlier.

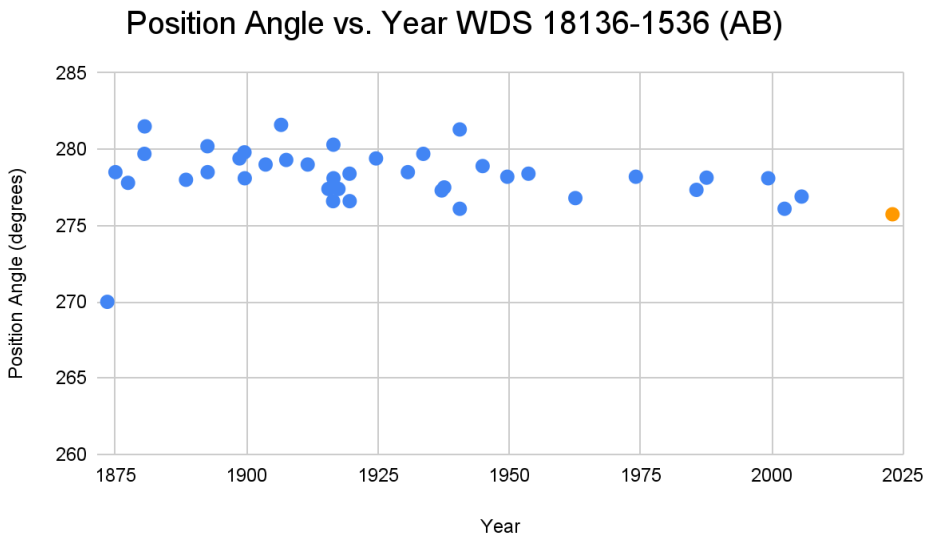


*Figure 5: Position angle of WDS 18136-1536 (AB) as a function of time beginning in 1873. The most recent observation from 2023 is indicated in orange.*

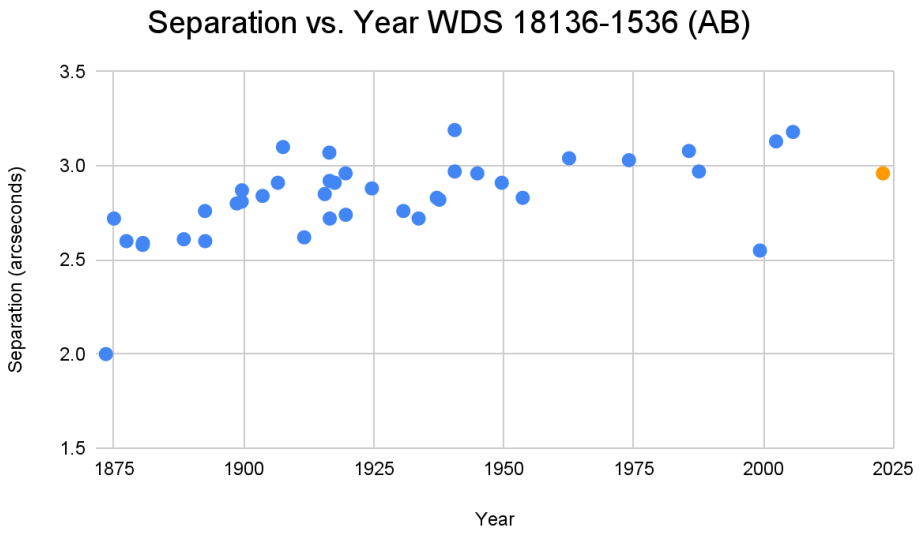


*Figure 6: Separation of WDS 18136-1536 (AB) as a function of time beginning in 1873. The most recent observation from 2023 is indicated in orange.*

When the parallax values and the proper motions in right ascension and declination of the individual components were compared using Gaia DR3 data, noticeable similarities and differences were analyzed (Table 4). Components A and B are at the same distance from Earth based on their parallax values of 13.55 and 13.81 mas, respectively (Table 4). This suggests that they could be gravitationally bound. Their proper motions in declination are similar, at -29.615 and -30.801 mas/yr, while their proper motions in right ascension differ significantly at 3.58 and 0.74 mas/yr.

| Designation in Gaia DR3 | **A** 4145814493585839744 | **B** 4145814493572563328 | **C** 4145814493585843712 | **D** 4145814523609659520 |
|---|---|---|---|---|
| Parallax (mas) | 13.55 ± 0.2 | 13.81 ± 0.01 | 0.40 ± 0.03 | 0.83 ± 0.01 |
| Proper Motion in RA (mas/yr μ) | 3.58 ± 0.24 | 0.74 ± 0.02 | -1.04 ± 0.03 | 3.26 ± 0.02 |
| Proper Motion in Dec (mas/yr μ) | -29.62 ± 0.17 | -30.80 ± 0.02 | -3.83 ± 0.02 | -9.7 ± 0.02 |

*Table 4: Parallax and Proper Motion (μ) data retrieved from the VizieR Catalog and Simbad.*

**CD**

Based on the data retrieved from Gaia for the C and D components, these two stars are not gravitationally bound to the A and B components (Table 3). The parallax values are 0.4048 and 0.8298 mas, respectively, which is too dissimilar from 13 milliarcseconds for these stars to be gravitationally bound. The proper motions in RA are -1.044 and 3.255 mas/yr. The proper motions in declination are -3.825 and -9.695 mas/yr. The parallax values indicate that the C and D stars do not interact with the AB pair (Harshaw, 2018).

## 5. Conclusions

Analysis of the data obtained from Gaia DR3 put the A and B components at similar distances from Earth, suggesting that they could be a gravitationally bound pair, or at least a common proper motion pair. The C and D components are not at this same distance, making it extremely unlikely for there to be a gravitational interaction between all four components. The current data for position angle and separation of the AB pair align with the overall historical trends and have not changed significantly since the system was previously observed in 2005. Further observation of this system is necessary to clarify the nature of the AB pair.

**Acknowledgments**
This research was made possible by the continuing support from the Las Cumbres Observatory who provided digital images for our analysis and Dr. Rachel Matson of the U.S. Naval Observatory who provided this system's historical data. The Washington Double Star Catalog, The European Space Agency Gaia Archive, and Stelle Doppie provided technical information on this system's individual star components. We acknowledge our institutions and those who helped us facilitate this research opportunity. From The Evergreen State College, we thank Ryan Geiser, Evergreen student and mentor in "Astronomy and Cosmology: Stars and Stories," who participated in the research.

**References**

Burnham, S. W. (1873). A third catalog of 76 double stars discovered with a 6-inch Alvan Clark refractor. Monthly Notices of the Royal Astronomical Society, Vol. 34, p. 59, 34, 59.

Fox, P. (1925). Measures of Double Stars. Annals of the Dearborn Observatory, 2, 1-219.

Gaia DR3 content - Gaia - Cosmos. (2022). GAIA EARLY DATA RELEASE 3 (GAIA DR3). Retrieved July 16, 2023, from https://www.cosmos.esa.int/web/gaia/earlydr3

Harshaw, R. (2018). Gaia DR2 and the Washington Double Star Catalog: A Tale of Two Databases. Journal of Double Star Observations. Vol 14, No 4.

Reichart, D. E. (2021). Robotic telescope labs for survey-level undergraduates. The Physics Teacher, 59(9), 728–729. https://doi.org/10.1119/10.0007416

Stelle Doppie - Double Star Database. (2022). Stelle Doppie. Retrieved July 16, 2023, from https://www.stelledoppie.it/index2.php?iddoppia=73722

VizieR. (2022). VizieR. Retrieved July 16, 2023, from https://vizier.cds.unistra.fr/viz-bin/VizieR