Astrometric Measurements of the Visual Double Star δ Boötis

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Abstract: During the summer 2010 Astronomy Research Seminar at Pine Mountain Observatory, a group of students from Oregon Episcopal School met with three goals in mind: to learn essential skills necessary for astrometry, to observe and measure the double star δ Boötis and compare their results with published literature, and to use proper motion vectors to determine the type of double star. The astrometric eyepiece was calibrated using the drift method. The separation and position angle of δ Boötis was determined respectively to be 109" and 164.4˚. These where compared with data in the Washington Double Star catalog and found to be within 5% of previous measurements.

Introduction

One of the double star observational teams at the summer 2010 Astronomy Research Seminar at Pine Mountain Observatory consisted of students and faculty from Oregon Episcopal School in Portland and J. Joseph Daglen, a retired physician and teacher from Caldwell, Idaho (see Figure 1). They met with their team leader, Chris Estrada, for guidance on double star observations. The students had very little experience with double stars and astronomy. Joe Daglen had previous experience with astronomy and helped the team by sharing his knowledge.

This project's three goals were:

1 . To familiarize students with methods used by astrometrists, including the process of collecting data, calibrating the eyepiece/telescope using the drift method, and determining the separation and position angle of a double star.

2 . To give the students the opportunity to make their first quantitative measurements and use formulas to estimate the precision of the observations to determine if the observations were accurate in comparison to literature data (Johnson, 2008).

Figure 1: Left to Right:10-inch F6 equatorial scope, Alyssa, Bevin, Andrew, Aaron, Manav, Joseph, and (kneeling) Chris

3 . To determine if the double star is an optical pair or a gravitationally bound binary system by using proper motion vectors.

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The double star δ Boötis was chosen based on its sizable separation and large disparity in luminosity between the primary and secondary stars. Such differences enable the observer to clearly distinguish between the two stars (Haas, 2006). By continuously collecting data from binary star separations and position angles over extended periods of time, their orbits and periods can be determined (Johnson & Genet, 2007).

Calibration

The primary goal of the calibration process was to determine the number of arc seconds represented by each division on the linear scale of the astrometric eyepiece. Alpha Cephei (Alderamin) was chosen to calibrate the astrometric eyepiece because its declination was between the recommended values of 60° and 75°. The calibration star was aligned with the linear scale to begin the drift procedure.

The drift method included aligning the calibration star with the linear scale, turning off the motor of the telescope, and then recording the time it took for the star to travel from the first to the last division (Teague, 2004). Although the entire group was involved in the drift procedure, only three students conducted each trial. The first student observed the star through the astrometric eyepiece and signaled when the star passed through the first and last divisions on the linear scale. The second student recorded the time (to the nearest 0.01 second) it took for the calibration star to pass through the linear scale, while the third student recorded the data. However, there was only one timekeeper and one recorder for the entire calibration process in order to reduce bias. Although the group conducted 16 trials, two were omitted due to wind interference. The average drift time was 116.3 seconds and the standard deviation of the drift time was found to be 1 second.

The group used the drift times to determine the number of arc seconds per division on the linear scale (the scale constant) of the astrometric eyepiece. The equation used to determine the scale constant was:

$$Z = \frac{15.0411\, t \cos\delta}{60}$$

where 15.0411 is the earth's rotational constant in arc seconds per second, t is the average drift time, $\cos\delta$ is the cosine of the declination of the star, and 60 is the number of divisions on the linear scale (Estrada *et al.*, 2010). We found that there were 13.4 ± 0.1 arc seconds per division on the linear scale of our telescope, the standard deviation of the scale constant was 0.1 arc seconds per division, and the standard error of the mean was 0.038 arc seconds per division.

Separation

The separation between the primary and secondary stars was measured by positioning and rotating the astrometric eyepiece so that the linear scale passed through the two stars. The number of divisions between the primary and secondary stars was estimated to the nearest 0.1 of a division and recorded. To avoid bias, the telescope was adjusted so that the primary star lay in a different portion of the linear scale for each trial. A major division on the linear scale was placed between the primary and secondary stars. The division was used as a "zero" point from which divisions were estimated left and right on each star. The measurements from the "zero" point were then added together to yield the total number of divisions. A total of sixteen trials yielded an average of 8.15 divisions between the stars. This figure was then multiplied by the scale constant (13.4"/ division) obtained during calibration. Thus, the average separation was 109", its standard deviation was 0.44", and the standard error of the mean was 0.11".

Position Angle

To obtain position angle using the drift method, the primary star was first set in the center of the linear scale of the astrometric eyepiece (Frey & Frey 2010). The clock drive was subsequently disabled, allowing the primary star to drift toward the protractor scale on the outer ring of the eyepiece. The angle where the primary star passed through was recorded to the nearest 0.5 degree. Although 16 trials were recorded, one outlier was eliminated due to novice error. The remaining 15 trials yielded an average of 164.4°, a standard deviation of 0.9°, and standard error of the mean of 0.25°. The data was then corrected for the Celestron eyepiece, providing a final position angle measurement of 74.4° ± 0.25°.

Analysis

According to previous literature from the Washington Double Star (WDS) catalog, the last measured separation angle for δ Boötis in 2009 was 104.7", and the position angle was 78° (Mason, 2010). This study's measured separation of 109" is 4.3" (~4.5%) greater than those of the last recorded measurement. The measured position angle of 74.4° is 3.6° (~4.6%) less than the last recorded measurement. According to Ronald Tanguay (1998), these differences of less than

5% between our measurements and past measurements suggest that our data can be considered of reasonable accuracy.

The proper motion vectors cataloged in the WDS catalog from 2009 show the primary star of δ Boötis to have a proper motion of +85 arc seconds per 1000 years in right ascension, and -111 arc seconds per 1000 years in declination. The secondary star was reported to have a proper motion of +84 arc seconds per 1000 years in right ascension and -110 arc seconds per 1000 years in declination (Mason, 2010). This difference of only one milli-arc second per year in both right ascension and declination strongly suggests that the primary and secondary stars are a gravitationally bound system moving together through space (Grocheva & Kiselev, 1998).

Conclusions

As mentioned earlier, the goals of this project were for students to gather and communicate original data regarding the double star δ Boötis, to compare their results with previously published literature on δ Boötis, and to use proper motion vectors to establish whether δ Boötis is a true binary or an optical double. During this project, the students learned how to gather original data on the double star δ Boötis, and mastered the techniques of telescope collimation and operation, calibration of an astrometric eyepiece, separation and position angle measurements, and data analysis.

In comparison to previously published literature, the students found that the results of this study can be considered reasonably accurate due to the difference of less than 5% between the experimental data and the literature. Finally, by using proper motion vectors, the students learned to determine whether or not δ Boötis may be a true binary system.

During this project, the students learned many skills essential to astrometric research. In their effort, the students faced many of the challenges common to astronomers including wind interference and reweighting the telescope to avoid backlash. They also calculated the scale constant for the astrometric eyepiece and conducted statistical analysis to verify the significance of their data. Finally, this project allowed students to communicate their original findings to the larger community both through writing a scientific paper and presenting their results to a large group of both students and teachers of astronomy.

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