

Visual Double Star Measurements with Equatorial and Alt-Azimuth Telescopes

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Introduction

Professional astronomers have carried out visual double star measurements for over 200 years. These scientists measured the separation between double stars in arc seconds and the position angle in degrees that defined the orientation of pairs with respect to celestial north. There are two types of double stars: binary stars and optical doubles. A binary star consists of two stars revolving around a common center of mass. Over time, the orbital motion of each star can create an elliptical change in the observed separation and position angle if the pair proves to be binary in nature. Conversely, if the two stars are an optical pair, meaning they do not orbit around a common center of mass, there will be a linear change in separation or position angle over time.

Today's astronomers continue to observe these changes with fairly simple equipment. The typical setup for visual observations includes an equatorial mounted telescope with tracking motors, a laser etched astrometric eyepiece, and an inexpensive digital stopwatch that reads to the nearest 0.01 seconds. Not only is this procedure used by professional astronomers but it can be performed accurately by amateur astronomers and students as well. In fact, this type of research is particularly well suited for students for several reasons, including experience collecting and analyzing data, working as a team, and opportunity to promptly publish scientific papers (Johnson 2008). Figure 1 (next page) shows a student observing the double star Alberio.

Astrometric Eyepieces

Both equatorial and alt-az telescopes can be equipped with an illuminated reticle eyepiece such as the 12.5 mm Celestron Micro Guide or the 12.0 mm Meade astrometric eyepiece. Both eyepieces have similar configurations: a linear scale in the middle and a 360° protractor scale around the circumference of the eyepiece. The linear scales are divided into 60 or 50 equal divisions on the Celestron and Meade eyepieces, respectively. Some observers mount

an external protractor scale on the base of the eyepiece to more accurately measure position angles, as described by Tanguay (1999, p.116) and Johnson (2008, p.147). An example of the Celestron eyepiece is shown in Figure 2. The Celestron model has two parallel lines running the length of the linear scale instead of just a single line as on the Meade model. Faint stars are more visible between two lines than behind or on a single line.

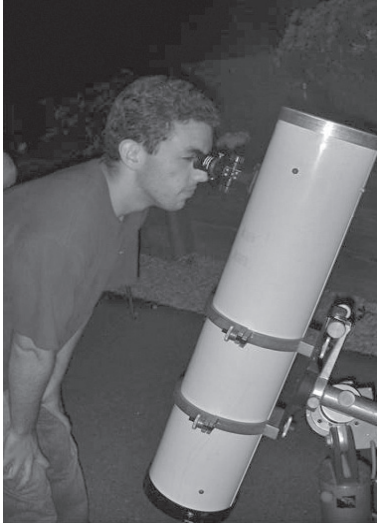


Figure 1: Hairold Lopex, a student at Arroyo Grande High School, observes the double star Alberio.

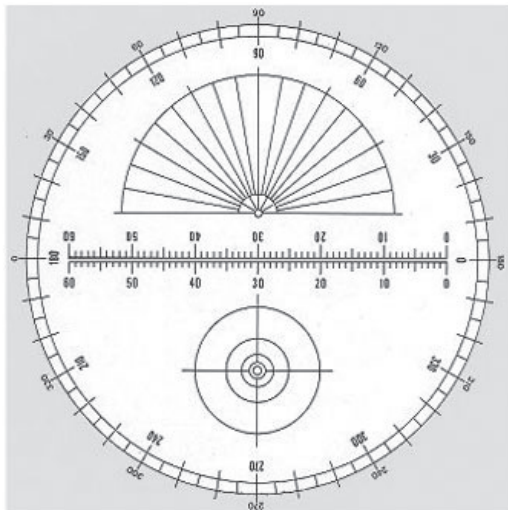


Figure 2: An example of a 12.5mm Celestron Micro Guide astrometric eyepiece.

Calibration of the Astrometric Eyepiece

The linear scale of the reticle eyepiece must be calibrated to the telescope being used. To determine the number of arc seconds per division, Argyle (2004, p. 152) recommends using a star of medium brightness (magnitude 5-6) with a declination of 60-75° and allowing it to pass along the length of the linear scale. This is carefully timed to the nearest 0.01 seconds. To reduce random errors in the process, 8-10 different drift times should be recorded and the average determined. The average drift time is used in the following equation:

$$Z = \frac{15.0411 T \cos(\delta)}{D}$$

where Z is the scale constant in arc seconds per division, T is the average drift time of the reference star across the scale in seconds, 15.0411 is the sidereal motion in arc seconds per second of Earth's rotation, $\cos(\delta)$ is the cosine of the declination of the reference star, and D is the number of divisions on the linear scale of the eyepiece.

Calculating Statistics

Once enough data has been collected, the standard deviation and standard error of the mean should be calculated. The standard deviation is a measure of the degree of variance of your data. To calculate it, simply use the following equation:

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - x)^2}$$

where s is the standard deviation of the sample set, x_i stands for each measured value, x is the average of all of the values, and N is the number of measurements.

The standard error of the mean is the standard deviation of mean values of the data, meaning that it should change depending on the sample size (where the standard deviation would ideally be the same regardless of sample size) and can be calculated by the following equation:

$$\sigma_{\text{mean}} = \frac{\sigma}{\sqrt{N}}$$

where σ_{mean} is the standard error of the mean, σ is the standard deviation and N is the number of measurements. The standard deviation and standard error of the mean are both good estimates of the internal error of the experiment and provide an estimate of the precision of the observations. Clearly, the lowest possible standard deviation and standard error is preferable and can be achieved by refining the techniques used and making a sufficient number of observations.

Procedure for Measuring Separation

The procedure for measuring the separation using both equatorial and alt-az telescopes is similar. The telescope is aligned and the tracking motors are engaged. The primary star is then centered in the eyepiece and the eyepiece rotated so that both stars are co-aligned on the linear scale. The number of divisions between the stars is noted and estimated to the nearest 0.1 division. The slow motion control should then be used to move the double star along the scale to a new location and another reading recorded. This is done to reduce observational bias in assigning the number of divisions. To further reduce observational bias, the observer should record the separation as three numbers: the number of major divisions between the stars, the distance from the nearest major division to the primary, and distance from the nearest major division to the secondary. Usually, no fewer than 10 readings are recorded and the average number of divisions calculated. The separation in arc seconds is calculated by multiplying the scale constant, Z , by the average number of divisions between the double stars. As a standard scientific practice, standard deviations should be calculated along with the standard errors of the mean.

Procedure for Measuring Position Angle

When using an equatorial telescope, position angles are measured by using slow motion controls to move the primary star to the center of the linear scale. The eyepiece is rotated until the secondary star is also on the linear scale. The drive motors are turned off and the pair drifts across the field of view until the primary reaches the protractor scale at the outer edge of the field. The drive motors are re-engaged and the position angle is indicated by the position of the primary star on the protractor scale.

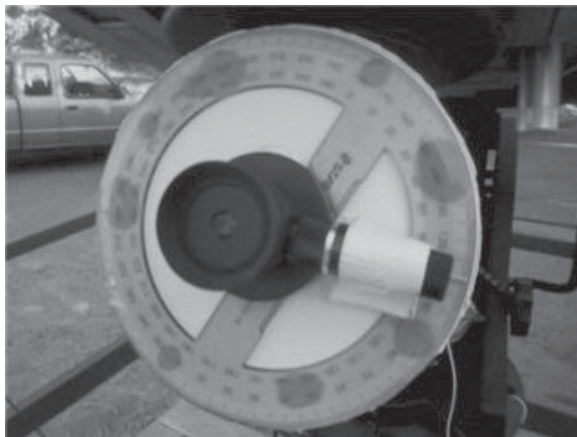


Figure 3: A protractor pointer built by Johnson and Genet to observe the double star STF 2079.

A protractor-pointer (Figure 3) can be built by gluing or cementing a plastic protractor to a piece of foam board and fitting it around the eyepiece. A pin is then attached to the red light switch on the eyepiece to act as a pointer. In the protractor-pointer method, position angles are determined by rotating the eyepiece so that the primary star moves along the linear scale with minimal deviation as the telescope slews in right ascension. The pin is aligned horizontally to the linear scale in the eyepiece and pointed to 90° on the external protractor. The eyepiece is readjusted so the linear scale passes through the centers of both stars. The angle indicated by the pointer is then estimated to the nearest 0.1° (Johnson 2007).

The procedure is slightly more complicated when using an alt-az telescope to account for field rotation. The tracking motors are disengaged after the separation measurements are conducted. This allows manual movement of the telescope and does not require repetitive two star alignments. The eyepiece is then rotated until the double stars are aligned on the linear scale. Then the telescope is moved so that the primary star accurately drifts through the central division mark. In practice, the primary is situated about 5-8 division marks away from the central mark and allowed to drift. If the star drifts through the central mark, the drift sequence is allowed to continue until the primary star passes across the outer protractor scale and the angle recorded to the nearest 0.5° . If it misses the central mark, the scope should be moved back and another pass attempted. After the position angle is recorded, the telescope should be moved immediately until the double star is repositioned in the center of the field of view so another drift may be attempted.

The reticle eyepiece should be rotated 180° after every other drift measurement to allow constant realignment of the double stars with linear scale. This mitigates observational bias to assuming similar readings. Of course 180° will have to be subtracted from half of the measurements so correct position angles are evaluated. Again, multiple trials should be recorded and standard deviations should be calculated along with standard errors of the mean.

Authors' Note

This paper has been adapted and modified from "Visual Double Star Measurements with an Alt-Azimuth Telescope" by Thomas G. Frey, which described a new method to measure double stars in the Spring 2008 Volume of the *Journal of Double Star Observations*.

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