Astrometry of STF 2448 on the Mount Wilson 1.5 m Telescope with a Novel Video Eyepiece

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Abstract: The Mt. Wilson Double Star Workshop was organized to provide a hands-on educational and research opportunity for students and amateur astronomers to learn and carry out astrometric eyepiece measurements of double stars. Due to the unique operating characteristics of the Mt Wilson 1.5 meter telescope and the limited time available for observations, a Bell & Howell DNV16HDZ high definition video camera was adapted to a Celestron 12.5mm astronomic eyepiece to record the position and separation of double star STF2448. This paper records the results of the team's observations and their techniques used to record and analyze the data.

Introduction

Observations took place on the evening of July 9, 2013 using Mount Wilson Observatory's 1.5 meter telescope (located at approximately 38°13'24" N and 118°03'29" W) (Figure 1). The Mt. Wilson Observatory staff measurements of sky quality indicated that seeing was on the order of 0.5 arc seconds for the viewing period. This was later verified by the CHARA array group. The seeing quality was independently verified by Dave Jurasevic, Mt. Wilson's Deputy Director, who was observing in the same location and reported 0.4 arc second seeing.

The Mt Wilson 1.5 meter telescope was operated in a bent Cassegrain configuration with a focal length of 2438cm which gave a focal F-ratio of F/16. Combined with the Celestron 12.5mm eyepiece and extraordinarily good seeing conditions, stars with separations less than 3 arc seconds were reviewed in the *Washington Double Star Catalog* (*WDS*) catalog for consideration.

Double star STF 2448 was selected as the target

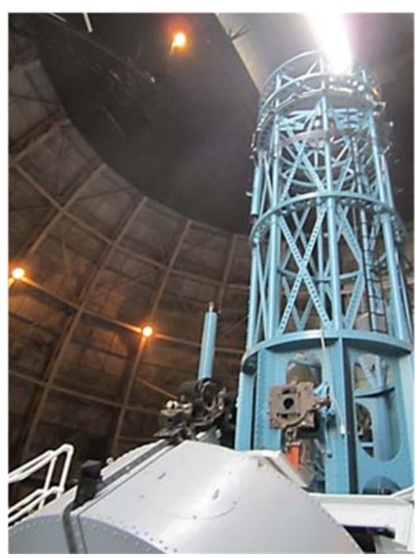

Figure 1. The 1.5 m (60") telescope located on the Mount Wilson Observatory used in the astrometry measurements. This photograph was taken on the day of the observations.

double. The pair is well studied, with more than 70 prior observations, and had little change in separation and position angle over the period of these observations. This stability provided a good 'fixed' reference for validation of the measurement technique on the 1.5 meter telescope.

First recognized by Otto Wilhelm Struve in 1825, the double star STF2448 is located in the constellation Lyra. According to the *Washington Double Star catalog*, both stars are white in color (spectral type A3), their magnitudes are very similar at 8.75 and 8.8, and they have small common proper motions (+000-010). The last recorded separation was between two and three arc seconds (Mason et al., 2013).

Other identifiers listed by SIMBAD include WDS J19037+3545AB, ADS1222002AB, AG +35 1705, BD +35 3460, CCDM J19037+3545AB ,GC 26231, HD 177543, HIC 93596,IDS 19001+3536, 2MASS J19033966+3544349, PPM 82250, SAO 67752, TD1 23835. Its precise coordinates are Right ascension 19 03 39.66; and Declination +35 44 34.4.

Methodology

The telescope was fitted with a Celestron Micro Guide 12.5 mm astrometric eyepiece with no filter (Figure 2). The Bell & Howell DNV16HDZ 46 mm f/2.8-3.5 high definition video camera was adapted to the Celestron astrometric eyepiece, with a 46 mm filter ring allowing recorded views of most of the eyepiece's back-lighted field. This configuration did not allow a full view of the compass ring in the astronomic eyepiece and was a limitation of the video method. The eyepiece was attached to the telescope, and then best focus was attempted by driving the secondary mirror to its closest possible position to the primary mirror. The secondary mirror reached focus at the limit stop so back focus was not achievable to verify that the system was at optimum focus for the eyepiece.

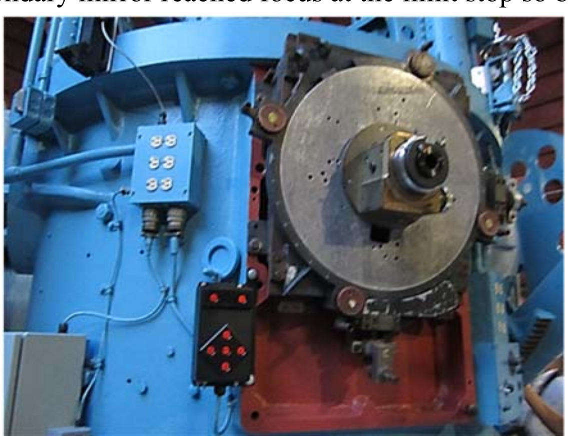

Figure 2. *The bent Cassegrain eyepiece of the 1.5 meter telescope where the astrometric eyepiece was attached. Photograph was captured by the authors during observation period.*

Calibration

Following verification of the double star brightness and separation, eyepiece telescope calibration was accomplished using a modified version of Frey's drift method (Frey, 2008). The bright single star Alshain in the constellation Aquila (RA 19'55' 18" Dec +6° 24' 23") was selected as the reference star in accordance with the telescope altitude and azimuth limitations. The reference star was centered in the scope view and then positioned out of the field of view. The drive was disabled and the star was permitted to drift along the central ruler.

Data was collected using both the stopwatch and video capture method. The magnification and location of the star resulted in extremely fast drift times, making stopwatch measurements exceedingly difficult. Because of the difficulty using the stop watch, this method was abandoned and the video drift measurements were made and used for calibration. For the video data runs, the centering and stop drive process was repeated and recorded 10 times.

The drift time from the recorded video was calculated by running each of the videos frame by frame through the Adobe Premiere Pro CC video editing software. This allowed the star to be precisely positioned at the 20 tic mark and then run forward to the 50 tic mark, giving a one half scale drift (Figure 3). The centroid of the star was visually aligned with the start and stop tic marks.

The Premiere software displays the frame number at the start point and the end point for both tic mark alignments. The change between frame rates was obtained and then multiplied by the high definition camera recording sample rate of 59.96 frames per second. This number was doubled to obtain the full scale drift time. Each measured time was recorded in the double star Excel data sheet used for the night's observation runs. Several less capable software programs were tested, but the results were unreliable because the software dropped frames during the analysis. The Adobe Premiere software has a dropped-frame alarm that was activated during the analysis runs to ensure all the captured video frames were evaluated.

These average drift times were then used to calculate the scale constant Z, using the formula Z = [15.0411 · $T_{average}$ · the cosine of the declination angle] divided by 60 (the number of reticule divisions, D) (Frey 2008). The formula can be expressed as:

$$Z = [15.0411\ T_{avg} \cos(\delta)\ ] / D$$

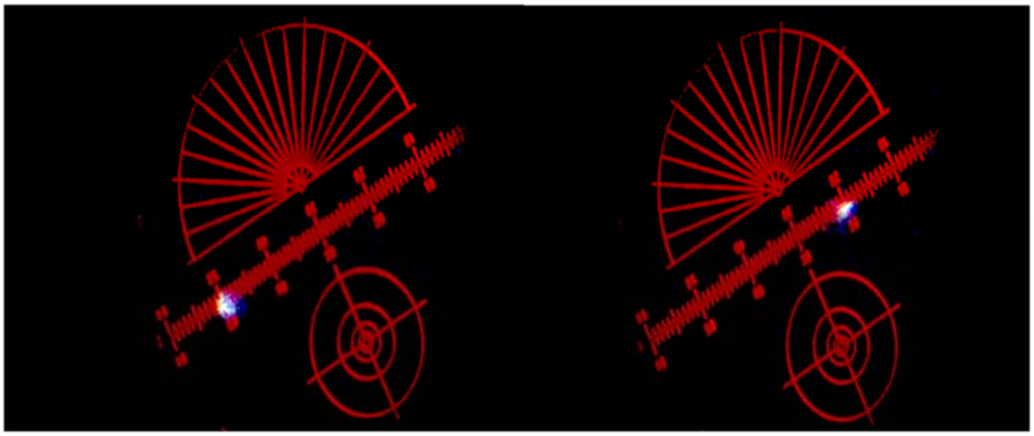

Figure 3. *A sample image taken from a video frame for the drift time calibration of the Alshain star. The image on the left represents the start point of the video time run while the image on the right is the image end point.*

During the calibration measurements, the average drift time for ten runs was 3.34 seconds with a standard deviation of 0.05, and a standard error of the mean of 0.02 was obtained (Table 1). A scale constant of 0.832 arc seconds per tic mark was also derived.

Observations

Following calibration, the double star STF2448 was selected from Joseph Carro's modified WDS star catalogue and the position was verified using The Sky 6 software (Carro, 2013). The star pair was placed into the field of view and its identity was confirmed using its color and estimated separation. The close visual magnitude of the stars made it initially necessary to guess the primary and secondary orientation, with the prediction being supported by early data analysis provided by the Excel worksheet used to capture data.

Table 1. Calibration Data. The calibration drift time of the star Alshain was found to be 3.34±0.05 s.

Calibration Star	Drift Time (sec)
Average Drift Time	3.34
Std. Dev.	0.05
Median	3.30
Standard Error of the Mean	0.02
Declination angle (rad)	0.11
Divisions	60
Scale Constant	0.83

Separation estimates were determined using a combination of two methods. The pair of stars was placed along the linear scale and the number of scale divisions between the stars was estimated. In the first method, visual observation, the camera was detached and the team members looked directly through the eyepiece per Frey's procedure (Frey, 2008). Teammates were rotated through the visual stand on the telescope and ten data sets were recorded.

This was followed by re-installing the Bell & Howell DNV16HDZ video camera onto the eyepiece. A single 30-second HD video was captured (2000 frames) and still photographic capture runs were performed and recorded for later analysis.

During the following day's data analysis, another technique was developed by utilizing a rudimentary lucky imaging technique. Again, the video of the separation was evaluated frame-by-frame using Adobe Premiere Pro CC. The frames with the smallest, clearest star shapes and best scale alignments were selected for evaluation.

The next method used Adobe Photoshop Pro CC software to evaluate the video capture stills. The sample photos derived from the frame by frame analysis were displayed in the software and the digital ruler tool, available in the program, was utilized to measure separation using the following procedure.

The digital ruler displays a numeric value for the number of picture pixels between the two objects in the photograph. The ruler was used to measure the pixel separation of the stars from centroid to centroid. This number was then evaluated against the same delta ruler measurement of the pixel tic mark separation of the

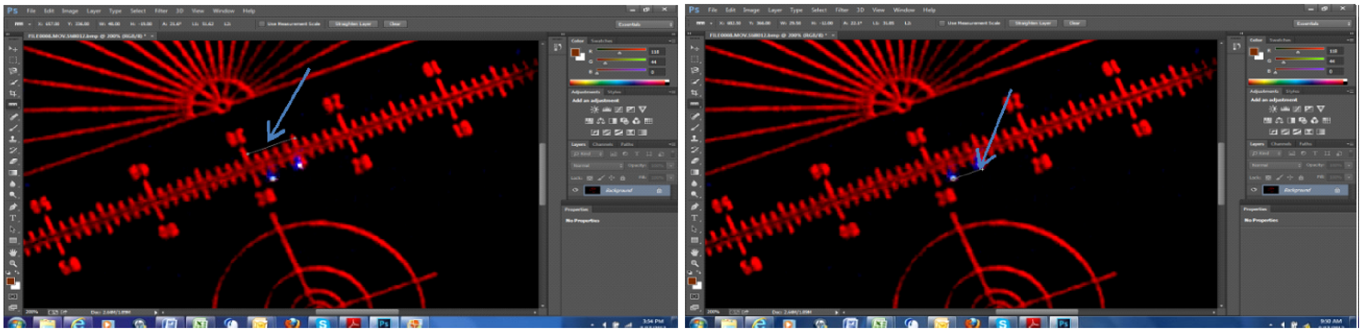

Figure 4: A screen shot of Adobe Pro CC software being used to analyze video still shorts. The image on the left is using a ruler tool to measure the eyepiece tic-to-pixel ratio while the image on the right is measuring star separation centroid to centroid. Note the extremely tight star spots; this is evidence of exceptional seeing conditions coupled with the superior optics of the 1.5 meter Mount Wilson Telescope.

Table 2. Using the video capture technique, the separation of STF 2448 was 2.1 ± 0.16 arcsec.

Run	Divisions
Average	3.07
Std. Dev.	0.16
Median	3.00
Standard Error of the Mean	0.03
Average Div. x scale Constant in Arc Seconds	2.55
Separation (Arc Seconds)	2.12

eyepiece scale using the same photograph (Figure 4). The stellar separation was then derived mathematically using a ratio of tic mark measurements versus star separation measurements.

The combination of the eyepiece and camera did not allow the inclusion of the eyepiece compass in the video field of view, resulting in the necessity of angle measurements being made visually, according to Frey's method (Frey, 2008). The most experienced team member, Chris Estrada, made all measurements because of observation time constraints. Following each measure-

Table 3. The calculated position angle of STF 2448 was 193 ± 0.75°.

Observation	Reading of Eyepiece	Position Angle Degree
Average	103	193
Std. Dev.	0.75	0.75
Standard Error of the Mean	0.17	0.17

ment, the tracking feature was enabled and the process was repeated 10 times. All of the data was captured on an Excel spreadsheet that was automated to perform the necessary mathematical calculations.

Observational Results

The separation of STF 2448 was calculated to be 2.1 arc seconds within a standard deviation of 0.16 arc seconds. The position angle was measured at 193° with a standard deviation of 0.75° (Tables 2 and 3). Table 4 gives our observational results. Table 5 depicts previous recorded measurements of the STF 2448 double star as well as the values calculated using our data.

Conclusions

Overall, the use of the Celestron 12.5 mm astronomic eyepiece on the telescope and the video capture method were successful. The setup afforded a focal length of 24.3 m and magnified the field of view to 1,950X power. This, along with the 1.5 meter aperture,

Table 4. Observational results

NAME	RA + DEC	MAGS	PA	SEP	DATE	N	NOTES
STF 2448	19 03 39.66 +35 44 34.4	8.75, 8.8	193	2.1	2013.520	1	1

***Table5**: Comparing previously recorded separation and position angle of the STF 2448 double star to the Mt. Wilson observation values (Comellas, 2003).*

Reference name	Sep	PA
Struve 1825	2.7	193
CCDM (Dommanget 1998)	-	192
Eagle Creek Observatory (Muentzler 2003)	2.7	191
Herschel Double Star Catalog 1835 data (MacEvoy 2011)	2.7	193
HIPARCOS Catalog (Perryman, *et al*. 1993)	2.4	193
O. A. G. Catalog (Comellas 1973)	2.4	194
Washington Double Star Catalog 2008 data (Mason 2013)	2.4	191
Washington Double Star Catalog 2009 data (Mason 2013)	2.4	191
Washington Double Star Catalog 2010 data (Mason 2013)	2.5	191
*Measurements by the authors July 2013 (**Current Experiment)***	*2.1*	*193*

allowed for adequate visual split against the eyepiece scale of this close double as well as significant star brightness of the near magnitude 9 star pair. With this eyepiece and focal length combination, it was possible to measure stars down to 2.5 arc second separation, nearly an order of magnitude closer than those measured by Frey's astrometric visual observations (Frey, 2008). During later analysis of video data, several frames were noted for having excellent seeing and focus that produced pinpoint star images with adequate stable separation. The night's work was validated by the position angle and separation measurements agreeing with previously established observation methods within the sky seeing limits.

Results indicate that video capture of separation information and drift time offers an effective way of collecting astrometric data. The compact size, portability, and easy setup of the camera and eyepiece combination offer a viable research tool that could be adapted to many telescopes, from the very large observatory grade scopes to the small amateur-owned systems. The ability to capture the high fidelity raw data during the run on the telescope and store it for later analysis was evaluated and found to be very useful. Despite the technique's advantages, further development is needed in the eyepiece-adapter connection in order to include the compass scale in the camera's field of view. Additionally, it was shown that evaluation of video data should be accomplished on robust video editing software, because errors in playback and frame drop were evident when using products like Microsoft Movie Maker and ArcSoft Total Video Extreme.

Future work necessary to extend this investigation is two-fold. First, the position angle and separation of STF2448 should continue to be measured in order to make calculating an accurate orbit possible. Second, more measurements need to be made of other stars with other telescopes in order to verify the effectiveness of the video capture method. In this experiment, it was not possible to back-focus the telescope because of mirror motion limitations, so sightings recorded with a telescope that has been verified to be properly focused would be beneficial. Finally, a study in the properties of various video playback and editing software is necessary in order to develop a more standard procedure of the video analysis portion of the measurements.

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