Mt. Wilson Meets the Lyot Double Image Micrometer

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Abstract: As part of the Mt. Wilson Double Star Workshop, the authors used a double image micrometer to observe two double stars, STF2383CD and STF2583AB, on the night of July 19, 2013 (B2013.547). The instrument was designed in 1949 by Bernard Lyot and built by Meca-Precis. We found separations of 2.53±0.29" for STF2383CD and 1.58±0.40" for STF2583AB, and positions angles of 77.8±2.3° for STF 2383CD and 103.4±1.6° for STF2583AB. The scarcity of double image micrometers and the opportunity to use the historic 60 inch telescope at Mt Wilson made this workshop a very unique experience.

Introduction

The Mount Wilson Double Star Workshop was held to bring together double star enthusiasts at one of the cathedrals of astronomy, the historic and hallowed site where great discoveries about the universe have been made. To do research in a place covered by the footprints of great men such as Albert Michelson, Milton Humason, George Hale, Edwin Hubble, and Albert Einstein is a dream come true for many scientists. Our brief stint as researchers at Mount Wilson was a half night of observations on Friday July 19, 2013, and two days of data analysis and paper writing in the historic Mt Wilson Library.

We used the 60 inch telescope that Edwin Hubble was groomed on before using the 100 inch Hooker telescope. Thomas Barnes, the grandfather of one of our team members, Cheryl Genet, was the foreman for the construction of the 60 inch telescope, and ground the mirror with George Ritche. Merritt Dowd, Thomas Barnes's brother-in-law and the Chief Electrician at Mt Wilson, and Catherine Dowd Barnes, Thomas Barnes's wife, stayed on Mt Wilson during the entire construction of the 60 inch observatory. To the three generations of descendants of Thomas and Catherine Barnes who were present at the workshop (Cheryl Genet, John Davidson, and Noah and Adam Tassell), this was much more than a scientific endeavor.

Figure 1. The participants of the Mt Wilson Double Star Workshop pose in front of the 100 inch Hooker telescope. In order from left to right: (Standing) Rick Wasson, Mark Brewer, Reed Estrada, Cheryl Genet, Russ Genet, Adam Tassell, Noah Tassell, Joseph Carro, Inga Kenney, and Ryan Gelston. (Sitting and Kneeling) Vera Wallen, Rafael Ramos, John Davidson, Eric Weise, Cassie Hollman, and Chris Estrada.

Our observing session started with a spectacular viewing of Saturn with a visual eyepiece. The seeing was extraordinary, less than half of an arc second. The

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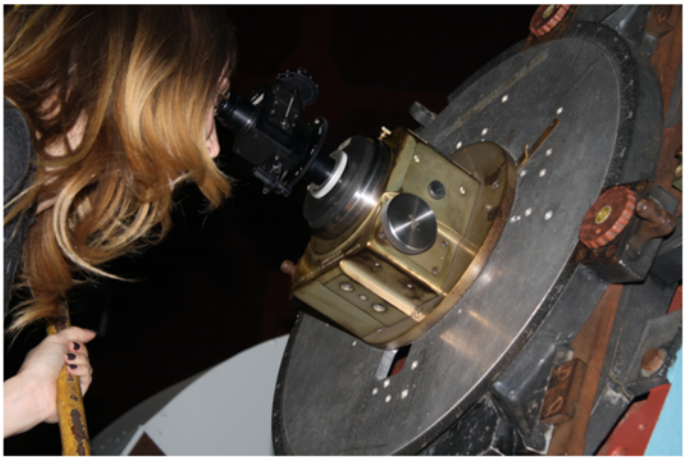

Figure 2. Christine Gerhart, who also worked for the observatory as a telescope operator, making a measurement with the Lyot double-image micrometer.

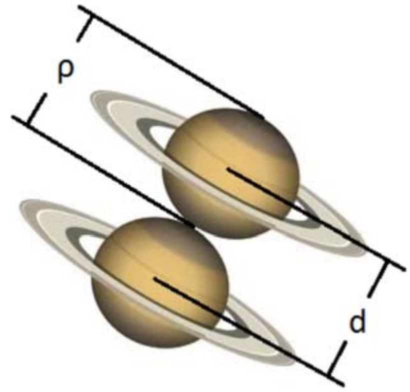

Figure 3. When two images of a planet are arranged as seen using a double image micrometer, the angular diameter of the planet (ρ) is equal to the artificial separation of the two images (d) created by the instrument.

image of the planet was incredibly crisp and detailed. Even the various longitudinal strata of swirling gas were visible and appeared like layers of a cake. After this "Oh, ah" session, our scientific observations began. The first two hours were devoted to an astrometric eyepiece, while the second two hours were given to the double image micrometer.

Historical Perspective

The Double Image Micrometer

The concept of doubling the image of an astronomical object for the purpose of angular measurements has been known for some time. Ole Römer suggested this method in 1675 (Lord 1994-B), although the technique was not put into practice for three quarters of a century. Some of the first known descriptions of such a device were given by Servington Savery in 1743 (Short 1753) and John Dolland (1953). Many adaptations were made to these early designs by George Airy (1845), Simms (1858), and others.

A double image micrometer works by creating two images of an object that are, for all intents and purposes, identical. If an observer can put the two images (i.e. images of a planet) into a certain configuration (i.e. such that the images of the planets are touching), then one can calculate the angular separation between the two images. Figure 3 shows this arrangement. These micrometers have been used to measure an assortment of stellar objects, including the diameters of planets, the phases of the sun and moon during partial eclipses, and, of course, the separation of double stars. These early devices, however, do not even remotely resemble the most recent double image micrometer. Dolland's and Airy's double image micrometers were of a subclass called the "divided lens" micrometer, and consisted of four lenses, one of which was split along its diameter (Lord 2012). These predecessors to the modern version were all notorious for lengthy calibration procedures and chromatic aberrations to varying degrees (Lohse 1902).

In 1949, French astronomers Bernard Lyot and Henri Camichel patented a double image micrometer that used calcite as a means of producing two images of stellar objects. The birefringent properties of calcite mean that two images can be made by one crystal "Spar plate" and an eyepiece, rather than a divided lens and multiple focusing lenses. This improvement single-handedly eliminated the long calibration procedures and the chromatic aberrations that plagued this instrument's predecessors. Lyot contracted the company Meca-Precis to construct his micrometer, although only a handful of the lavishly expensive, yet beautifully simplistic instruments were built. The particular micrometer we used in this paper is serial number 10. In tribute to its innovator we fondly call our micrometer "the Lyot".

The 60 Inch Telescope

George Ellery Hale was a prolific scientific organizer. He was the driving force behind the establishment of four of the world's largest telescopes: the Yerkes 40 inch (completed in 1887), the Mt Wilson 60 inch (first light in 1908), the Mt Wilson 100 inch "Hooker" telescope (first light in 1917), and the Palomar 200 inch "Hale" telescope that was completed after his death (first light in 1949). He also co-founded the California Institute of Technology—Cal Tech (1891). When he decided to build the 60 inch telescope on Mt Wilson, he

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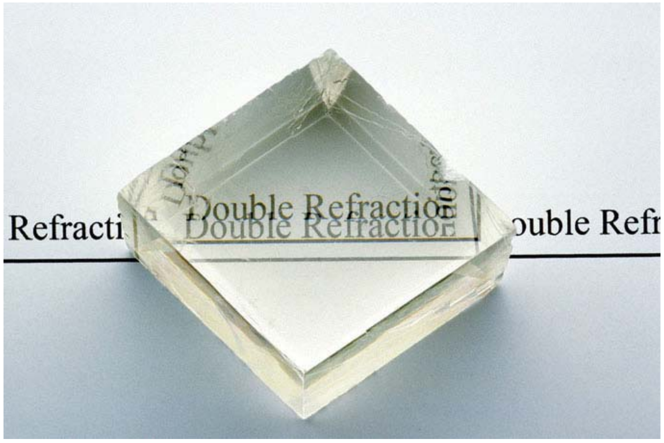

Figure 4. When an object is viewed through a calcite prism, two images are seen. The distance between these two images is a function of the angle at which the observer sits. If the observer places his eye on the line orthogonal to the surface of this crystal, only one image of "Double Refraction" will be seen.

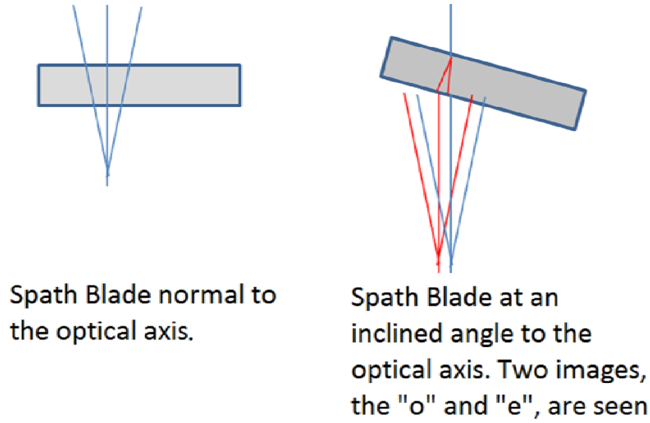

Figure 5. Principle of operation of Lyot double-image micrometer

chose this location for its excellent seeing. The peak stands in the Los Angeles National Forest at 5713 feet above sea level, just a 25 mile drive (or buggy ride in those days) away from Cal Tech. The blank for the 60 inch mirror was donated in 1896 and was ground by George Ritchey and his right hand man Thomas Barnes, Cheryl Genet's grandfather. During the first light ceremony of the telescope, Thomas and Catherine Barnes, their son Frederick, and Merritt Dowd were present; the only known first-hand account of the event is contained in a diary written by Catherine Barnes. This diary is in the possession of John Davidson, Cheryl Genet's son, and was exhibited at the workshop.

The time the 60 inch spent as the world's largest active telescope was short. In 1906, two years before first light on the 60 inch, Hale ordered the casting of the mirror blank for the 100 inch Hooker telescope. In 1917, after spending only nine years as the world's largest telescope, the 60 inch was surpassed in size by its big sister. In 1986, 37 years after Bernard Lyot invented his double image micrometer, the Mt Wilson Institute took over operation of the observatory (http://www.mtwilson.edu/cent.php). This time-line, and the scarcity of Lyot's micrometer, leads us to believe that our observation with his double image micrometer was the first time in the history of the 60 inch that one of these instruments was used.

Methods

The methods employed by the authors as well as detailed operations of the Lyot can be found in Lord (1994-A).

The Lyot micrometer is a double-image micrometer, implemented by a prism of calcite crystal, which is birefringent, meaning it has two indices of refraction. The "Spath blade," which holds the calcite crystal, is located just before the telescope focus, and is followed by a reticle eyepiece with which the operator views the image plane. The micrometer has two vernier dials that enable precise rotation of the calcite Spath blade, as well as rotation of the entire instrument around the optical axis. An example of the refractive properties of a calcite crystal is shown in Figure 4.

If a single star is viewed, the calcite Spath blade places two images at the image plane (Figure 5). The two images are the "ordinary" and "extraordinary" refracted rays of the incoming starlight. The angular separation between these two images is a function of the "inclination angle" of the calcite crystal with respect to the incident light path. When the face of the calcite prism is normal to the light of the star, the ordinary and extraordinary images coincide. When the plate is rotated, the "o" and "e" images separate; greater inclination of the Spath blade provides wider separation of the "o" and "e" images. These two images have perpendicular polarizations, but they are indistinguishable to the visual observer. When a double star is viewed through an inclined Spath blade, a total of four star images are visible –two of the primary member and two of the secondary member of the pair.

The other alignment configuration we used strives to place the four star images into a perfect square (following a procedure similar to the one described in the previous paragraph). Again, the human eye is remarkably adept at detecting very slight asymmetries in such a pattern, which enables the observer to achieve excellent alignment and measurement of the pattern. The

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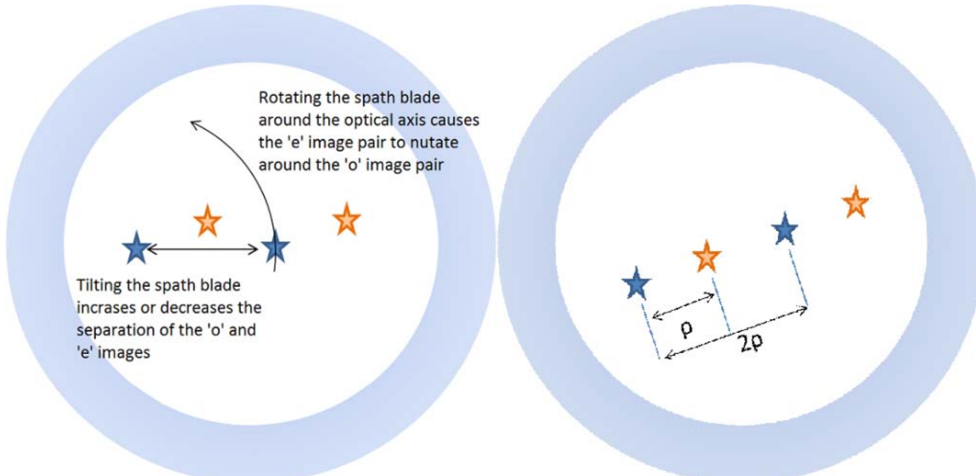

Figure 6. Lyot instrument provides two adjustments of the image: tilting the Spath blade changes the separation of the "o" and "e" images, and rotating the instrument around the optical axis causes the "e" images to nutate around the "o" images. It is also possible to arrange the star images in a line such that ρ is half of the image separation.

interpretation of separation (vs. Spath blade tilt) is identical to the equidistant-linear alignment pattern, but the interpretation of the position angle (vs. instrument rotation angle around the optical axis) is 90 (or 270) degrees different from the linear pattern. Thus it is important to record in the observer's notes which pattern was used!

Our observation method incorporated an "adjust and confirm" approach to achieving the desired alignment of the pattern. The first observer adjusted the tilt and rotation to create the desired equidistant-linear pattern, and then the second observer examined the image to confirm the pattern. The tilt and rotation were then recorded. The Spath blade was then tilted in the opposite direction, the star pattern adjusted, and a second observer confirmed the pattern before the tilt and rotation orientations were recorded. The use of both "positive" and "negative" tilt directions of the Spath blade turned out to be valuable because it highlighted a small but significant zero-point offset in the readings of the tilt orientation of the Spath blade.

One of the features of the Lyot instrument is that reading the star-image orientation does not depend on an illuminated reticle. This avoids the potential glare from the reticle interfere with observation of the target pair (or reading of the reticle); and it eliminates the need for achieving focus on both the reticle and the target stars. The absence of the illuminated reticle makes the colors of the stars delightfully apparent: one of our pairs presented a pretty contrast between its gold and the white components.

No calibration of the Spath blade tilt angle reading was required; the scale factor is provided by the manufacturer's calibration curve for the "angular distance factor" in addition to the focal length of the telescope. Our limited experimentation with this device indicates that the manufacturer's calibration is still very good, and is applicable when the precise focal length of the telescope is known. However, we will remain diligent to conduct observation/measurement of well-attested pairs as a way of confirming the validity of the tilt calibration.

The rotational alignment is calibrated using a single-line reticle. The observer selects a single star, places it on this reticle line, turns off the telescope drive, and rotates the instrument so that the path of drift is collinear with the reticle. This rotation-orientation reading defines the E-W celestial axis and calibrates the position angle measurements. We found north to be at 3.16° with respect to the position angle dial on the instrument. The standard deviation and standard error of the mean for north were 1.18° and 0.42°, respectively.

Data

Our data is presented below in Table 1, and is compared to past observations reported to the WDS in Table 2. A note on the standard deviation of the separation values: to find the separation of a system, the inclination, í, of the Spath blade is recorded, and the "Angular Distance Factor", φ(í), is used to convert this value into a separation in arc seconds.

$$\phi(i) = \frac{648000}{\pi}\frac{\sin(2i)}{\sqrt{2}}\left(\frac{1}{\sqrt{2n_e^2-1+\cos(2i)}}-\frac{1}{\sqrt{2n_o^2-1+\cos(2i)}}\right)$$

Table 1. Our Data. Epoch, B2013.547.

	STF 2383CD		STF 2583AB	
	PA	Sep.	PA	Sep.
Number of Observations	6	11	8	8
Average	77.8°	2.53"	103.4°	1.58"
Standard Deviation	5.6°	0.95"	6.6°	1.12"
Standard Error of the Mean	2.3°	0.29"	1.6°	0.40"

The derivation of the formula φ(í) is given by Lord (2012). Each measurement of the separation is converted to the image separation, *d*, by

$$d = \frac{e}{F}\phi(i)$$

where *e* is the thickness of the Spath blade (we used the Meca-Precis stated value e = 4mm) and F is the effective focal length of the telescope (in our case, F = 24m). The image separation, *d*, is related to the separation of the stars by a factor of ½, 1, or 2, depending on how the two images of the binary stars were arranged during observations (see methods section). To find the standard deviations of our data, each observation was converted to a separation using the above formulas and then applying the standard formulas.

The position angle was obtained by reading the position angle dial on the instrument and applying our offset from the E-W celestial axis. Due to the zero point offset, our position angle measurements have a double peak distribution. Until we have more data to quantify this offset, we calculate the standard deviation of each of these peaks and then add these in quadrature:

$$\sigma = \sqrt{\sigma_A^2 + \sigma_B^2}$$

During the observations of STF 2383CD the micrometer was twisted in the drawtube assembly. We had not taken any calibration measurements to establish the direction of North before this happened. Because of this, we lost five position angle measurements. To compensate, we made extra observations of this system. Thus we have a different number of position angle and separation measurements for STF 2383CD, measurements that are usually made concurrently.

Table 2. Past 10 observations from the WDS.

	STF 2383CD		STF 2583AB	
	PA	Sep.	PA	Sep.
WDS Average	78.25°	2.294"	105.04°	1.422"
WDS - Ours (Δ)	0.49°	-0.235"	1.65°	-0.161"
% Diff (Δ/ours)	N/A	9.3%	N/A	10.2%
Our Standard Deviation (σ)	5.59°	0.948"	6.63°	1.121"
Δ/σ	0.088	0.248	0.249	0.144

Analysis

To check the validity of our measurements, we compared our data to the average of the past ten observations reported to the *Washington Double Star* Catalog (WDS) (Mason and Hartkopf 2013). For the system STF 2383CD these observations were made between 2009.803 and 2012.628, and for the system STF 2583AB these observations were made between 2008.560 and 2012.729. We show these averages in Table 2.

We used three values to compare our data to the past observations. First we used the difference between our measurements and the average of the past ten observations (Δ). This value shows how much our value is over or under the past observations. Second, the Percent Difference shows how significant our under/overestimate is. Finally, we looked at how many standard deviations we were off from the past ten observations (Δ/σ).

For both target systems, our Position Angle data are in agreement with the past observations. Our separation data, on the other hand, are not. While the differences between our data and the past observations are less than one arc second, they are still significant compared to the separation of the systems, as evidenced by the Percent Difference values. One might comment that we should have observed wider pairs, but this is not possible, owing to the narrow field of view of the instrument. However, considering the time constraints and that the majority of observers were using the Lyot for the first time this night, we concluded that our observations were satisfactory.

Acknowledgments

We are grateful to the Mt. Wilson Institute for the use of the famous 60-inch telescope for our research, and for allowing us to use the historic library where we analyzed our data and wrote our papers. We are also thankful to Dave Jurasevich, then the Deputy Director for Operations at Mt Wilson, for an incredible and more

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than extensive tour of the facilities at Mt Wilson. Our research made use of the *Washington Double Star Catalog*, maintained by Brian Mason and William Hartkopf at the United States Naval Observatory.

References

Airy, G. B. 1845. On a New Construction of the Divided Eye-Glass Double-Image Micrometer. *MNRAS*, Volume 6, No. 16, Pp. 29-31. *http://adsabs.harvard.edu/abs/1845MNRAS...6..229A*. Accessed May 2014.

Dolland, John. 1753. A Description of a Contrivance for Measuring Small Angles. *Philosophical Transactions*, Issue 48, pg. 178. *http://rstl.royalsocietypublishing.org/content/48/178.full.pdf+html*. Accessed March 2014.

Lohse, J. Gerhard. 1902. On A New Double Image Micrometer. *Annals of the Royal Observatory*, Edinburgh, vol. 1, pg. 152. *http://adsabs.harvard.edu/full/1902AnEdi...1..152L*. Accessed June 2014.

Lord, C. J. R. 2012. Troughton & Simms Divided-Lens Double Image Micrometer. *Brayebrook Observatory Website, http://www.brayebrookobservatory.org/BrayObsWebSite/BOOKS/T%26S_D-L_DIM.pdf*. Accessed December 2013.

Lord, C. J. R. 1994-A. Measuring Close Double Stars with a Lyot Micrometer. *Brayebrook Observatory Website*, *http://www.brayebrookobservatory.org/BrayObsWebSite/BOOKS/Using%20the%20Lyot%20Micrometer.pdf*. Accessed July 2013.

Lord, C. J. R. 1994-B. History & Development of the Divided-Lens Micrometer & Calcite Double-Image Micrometer. *Baybrook Observatory Website*, *http://www.brayebrookobservatory.org/BrayObsWebSite/BOOKS/DOUBLE%20IMAGE%20MICROMETER.pdf*. Accessed December 2013.

Mason, Brian D., and Hartkopf, William I. 2013. *The Washington Double Star Catalog*. Personal Correspondence.

Simms, William. 1858. Notice of an Improvement in the Double-Image Position Micrometer. *MNRAS*. Volume 18. Pg .64. *http://adsabs.harvard.edu/full/1858MNRAS..18...64S*. Accessed June 2014.

Short, James. 1753. A Letter from Mr. James Short F.R.S. to the right honourable the Earl of Macclesfield, President, concerning a Paper of the late Servington Savery, Esq; Relating to his Invention of a new Micrometer. *Philosophical Transactions*, Issue 48, pg. 165. *http://rstl.royalsocietypubl*