A Comparison of Two Double Star Astrometry Techniques: Visual and DSLR

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Abstract: Three investigators carried out a comparison study involving an astrometric eyepiece and a digital single-lens reflex (DSLR) camera to determine position angles and separations of five double stars. A comparison of the precision and accuracy of each technique was accomplished.

Introduction

Two students and an experienced double star observer participated in the Pine Mountain Observatory (PMO) Summer Research Workshop July 7-12, 2013. Past double star research projects at PMO all involved visual observations using astrometric eyepieces. In addition to using visual methods, it was decided to use a DSLR camera to measure the same five double stars, and compare the results with those obtained from using the astrometric eyepiece.

The schedule was the following:

First night: Calibrate astrometric eyepiece and visually measure one double star

Second night: Visually measure four additional double stars

Third day/night: Present project outline to workshop participants; then DSLR photography of the same five double stars

Fourth day: Analyze data; present results to workshop participants

The double star team was comprised of three observers with varying experience (Figure 1). Frey, team leader, has been studying double stars since 2007. Hernandez-Frey participated in the 2011 PMO summer workshop. Hartshorn had no astronomy experience. All three investigators equally shared observing and data recording duties.

Figure 1. Thomas Frey, Brandon Hartshorn, and Navarre Hernandez-Frey with the 18 inch Obsession alt-az telescope used in the investigation.

Background

Giovanni Roccioli, an Italian Catholic priest, was one of the first Europeans to note that Mizar in Ursa Major is a double star. But it wasn't until the 1770's that Sir William Herschel began making measurements of double stars as a first step in measuring stellar parallax. Herschel used a filar micrometer, originally developed by William Gascoigne. Filar Micrometers have

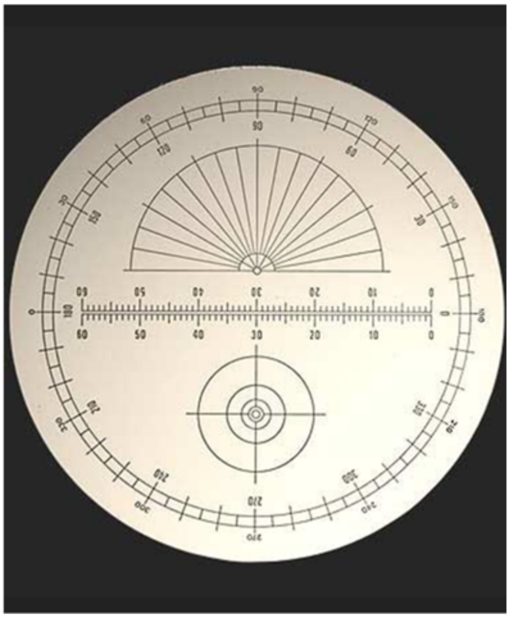

Figure 2: *Celestron 12.5mm illuminated reticle*

Figure 3: *Obsession alt-az telescope with Canon T2i DSLR at prime focus*

been used to measure visual binaries for over 200 years. Visual observations today use reticle astrometric eyepieces as those manufactured by Celestron or Meade. Such laser-etched eyepieces have a linear scale for measuring angular separation and a protractor scale for determining position angle (Figure2).

Advancing to the digital age, photographic instruments such as the charge-coupled device (CCD) have mainly taken over the task of documenting double star parameters. A majority of astronomers use equatorially mounted telescopes with CCDs rather than alt-az (Dobsonian) mounted telescopes due to field rotation encountered with the latter type of mount that can affect the measurement of position angle. The smallest field rotation experienced by an alt-az telescope would be for observation made directly east or west and close to the horizon [1].

Yet there are many alt-az mounted telescopes in use. One way to circumvent the problem of field rotation would be to take short exposure DSLR photographs of double stars and convert these images into position angle and separation measurements with a series of available software programs (Figure 3).

Therefore our team chose to compare the advantages, disadvantages, precision and accuracy of the astrometric eyepiece and DSLR techniques. Due to the wide range of team experience and that the DSLR technique was a virtually new approach to the team, it seemed like an appropriate project for PMO research.

Locale and Observing Conditions

The study was carried out at Pine Mountain Observatory, near Bend, Oregon. The site is located at 43.79 degrees north latitude and 120.94 degrees west longitude. The first night of observation we experienced intermittent wind gusts. For the rest of the observing sessions we were rewarded with clear, dry, conditions and moderate to excellent seeing.

Instrumentation and Software

Our telescope was an 18 inch f/4.5 Newtonian manufactured by Obsession. The astrometric eyepiece was a 12.5 mm Celestron laser illuminated eyepiece. The reticle is shown in Figure 2. The DSLR camera was a Canon T2i. Accurate focus was accomplished by using a Bahtinov mask [2]. The setup is shown in Figure 3. The team used a MacBook Pro equipped with OS 10.8.4 and a partitioned hard drive with Microsoft Windows 7. Utilized software included ImageJ [3], IrfanView [4], and Herbert Raab's Astrometrica [5] to obtain right ascension (RA) and declination (Dec) values of each star. The data were then processed with an Excel spreadsheet [6] to yield the position angle and separation.

Five Double Stars Studied

Table 1 shows some of the specifications of the double stars investigated. The proper motion is in arc seconds per 1000 years. The spectral types and some parallax data were obtained from SIMBAD [7].

Brian Mason, who maintains the Washington Double Star (WDS) [8] catalog, kindly supplied the historic record of position angle and separation for each of the

Table 1: *Data for the five double stars studied.*

Object	WDS Ident.	Constellation	SpecType Prim/Secnd	Proper Motion (mas/yr)		Parallax (mas)	
				Primary	Secondary	Primary	Secondary
ES2710	20459+4448	Cygnus	A7V/F2III	+004 -003	-010 -017	20.4200	21.4000
STF2474AB	19091+3436	Lyra	G1V/GV	+056+191	+069+197	23.48*	23.48*
STF2681AC	20228+5325	Cygnus	A0V/A3	+013+016	+032+032	2.23*	7.17*
STF2241AB	17419+7209	Draco	F5IV/G0V	+025-268	+029 -277	45.3800	44.8000
STF2664	20196+1300	Delphenius	K/K0	+009 -014	+011 -014	2.44*	7.59*
				From WDS catalog		* SIMBAD	

five double stars. Tables 2-6 show the first and most recently reported WDS observations along with three other intermediate observations used for comparison with our data. The data show the general trend in changes over the years.

ES 2710 is an optical binary with a separation of 51.1 arc seconds (WDS 2008), which was selected due to its wide separation.

STF 2474AB is reported as part of a four star system in the WDS. The A component is actually an Aa,Ab spectroscopic binary (CHR 84Aa,Ab) with a 0.1 arc second separation. Both Aa and B components are solar-like G stars. There is a report [9] of a low-mass companion orbiting the B star. The planet was detected using radial velocity measurements and has a period of 71.5 days and a minimum mass of 6.3 M_J. The AC component (WAL 105AC) has a separation of 96.8 arc seconds (WDS 1998).

STF 2681AC is part of a four star system in the WDS. The AB components are separated by 6.9 arc seconds (WDS 2003). The AC components, both A-type stars, are separated by 38.5 arc seconds (WDS 2012). Proper motion and parallax indicate AC components are probably optical double stars.

STF 2241AB is a part of a four star system in the WDS. The AB components are separated by 30.0 arc seconds (WDS 2010). Similar proper motion and parallax suggest the AB components are a binary pair or a common proper motion pair .

STF 2664 is a binary pair of two K-type stars separated by 27.4 arc seconds (WDS 2008).

Visual Measurements

The determination of the scale constant for the Celestron eyepiece was done using techniques previously described [10]. Briefly, a reference star is allowed to drift along the linear scale with the tracking motors off. The drift time is measured to the nearest 0.01 seconds. The average drift time of 10-20 trials is used to calculate

Table 2: *Past measurements for ES 2701*

Object	Year	PA(deg)	Sep (asec)
ES 2701	1898	80.0	52.93
	1918	80.0	53.60
	1957	80.1	51.90
	1999	80.8	51.38
	2008	80.9	51.10

Table 3: *Past measurements for STF 2474AB*

Object	Year	PA(deg)	Sep (asec)
STF 2474AB	1823	259.5	17.12
	1866	260.0	17.10
	1912	261.1	16.51
	1974	261.9	16.23
	2012	262.9	15.85

Table 4: *Past measurements for STF 2681AC*

Object	Year	PA(deg)	Sep (asec)
STF 2681AC	1831	203.7	41.84
	1901	201.7	40.10
	1949	200.7	39.58
	1999	199.3	38.42
	2012	199.0	38.51

the scale constant. The double star Dubhe (Alpha Ursae Majoris), was used as the reference. The results are given in Table 7. SD and SEM are the standard deviation and standard error of the mean statistics; they are defined and discussed in section Discussion and Technique Comparison.

Tables 8 and 9 list, respectively, the averaged separation and position angle visual measurements for the five double stars investigated. Separation measurements were made when the tracking motors were engaged. The non-tracking drift method was used to determine the position angle [10]. Also listed for comparison are the WDS measurements for the most recent entry. ES 2701 was measured on Besselian Epoch (BE) 2013.5156. The other four double stars were measured on BE 2013.5183.

DSLR Technique and Measurements

The following procedure was carried out to obtain the separation and position angle of the five double stars using a Canon T2i DSLR camera, the 18 inch Obsession and a computer. The initial photos were taken in both CR2 and JPEG mode. Focusing was assisted by use of a Bahtinov mask and a small hand magnifier to enlarge the image on the camera screen. The JPEG was examined for saturation and focus with ImageJ software. Once corrected for proper exposure and focus, six sci-

Table 5: *Past measurements for STF 2241AB*

Object	Year	PA(deg)	Sep (asec)
STF 2241AB	1800	14	32
	1857	14.5	30.78
	1912	14.7	30.93
	1949	15.2	30.36
	1980	15.9	30.42
	2010	16.0	29.99

Table 6: *Past measurements for STF 2241AB*

Object	Year	PA(deg)	Sep (asec)
STF 2664	1825	322.8	28.38
	1866	322.3	27.80
	1908	321.9	27.75
	1957	321.2	27.52
	2005	321.6	27.59
	2008	320	27.4

Table 7: Scale constant determination

Reference Star	Besselian Epoch	Declination (degs)	# Observat.	Ave. Drift Time(secs)	SD/SEM (sec)	Scale Const. (asec/div)
Dubhe	2013.5156	61.7511	20 (2 outliers)	85.51	0.71/0.16	10.15

Table 8: Visual separation measurements for five double stars

Object	WDS Ident.	# Observ.	Literature Epoch	Lit Separ (arc sec)	Obser Separ (arc sec)	SD/SEM (arc sec)
ES2710	20459+4448	12	2008	51.1	51.8	0.343/0.009
STF2474AB	19091+3436	12	2012	15.9	14.8	0.307/0.165
STF2681AC	20228+5325	12	2012	38.5	36.3	0.549/0.159
STF2241AB	17419+7209	12	2010	30.0	30.5	0.027/0.008
STF2664	20196+1300	12	2008	27.4	29.7	0.238/0.069

Table 9: Visual position angle measurements for five double stars

Object	WDS Ident.	# Observ.	Literature Epoch	Lit PA (degs)	Obser PA (degs)	SD/SEM (degs)
ES2710	20459+4448	10	2008	81	82.2	0.510/0.161
STF2474AB	19091+3436	10	2012	263	263	1.887/0.770
STF2681AC	20228+5325	10	2012	199	195	1.110/0.621
STF2241AB	17419+7209	9	2010	16	14.5	1.803/0.601
STF2664	20196+1300	10	2008	320	324	1.660/0.525

ence images were taken in rapid succession and downloaded into iPhoto. The CR2 files were downloaded into Windows 7 on the hard drive partition using the Bootcamp feature on the MacBook Pro. The CR2 files were converted to Tif files using IrfanView. The Tif files were converted into Fits files using ImageJ. The Fits files were reduced in Astrometrica to determine the right ascension (RA) and declination (Dec) for the primary and secondary stars. The position angle and separation were computed with a spreadsheet using Bob Buchheim's equations from R.W.Argyle's text [6].

Tables 10 and 11 list, respectively, the averaged observed DSLR separation and position angle of the five double stars along with the most recently reported WDS literature and visually determined values. All DSLR photos were taken on BE 2013.5211. The SD and SEM listed pertain only to the six DSLR science images for each double star.

Discussion and Technique Comparison

Hernandez-Frey and Hartshorn accomplished most of the calibration of the astrometric eyepiece after a demonstration by Frey. Twenty observations were carried out mainly to get the students use to manually moving the telescope.

All three observers took visual separation and position angle measurements with the astrometric eyepiece. Twelve separation observations were done for each double star and ten position angle observations were done for each. An outlier caused only 9 position angle measurements to be processed for STF 2241AB. The visual observations were done over two nights so that the students were not too rushed in taking these measurements that involved a lot of manual manipulation of the telescope.

The DSLR photos were all taken in one session. After focusing and saturation issues had been resolved, the six science images were taken.

Table 10: Visual/DSLR separation measurements for five double stars

Object	Lit Sep/Epoch (arc sec)	Visual Sep (arc sec)	DSLR Sep (arc sec)	DSLR SD/SEM (arc sec)
ES 2710	51.1/2008	51.8	50.857	0.345/0.141
STF 2474AB	15.9/2012	14.8	15.624	0.462/0.189
STF 2681AC	38.5/2012	36.3	38.790	0.724/0.296
STF 2241AB	30.0/2010	30.5	30.028	0.806/0.329
STF 2664	27.4/2008	29.7	27.309	0.473/0.193

Table 11: Visual/DSLR position angle measurements for five double stars

Object	Lit PA/Epoch (degs)	Visual PA (degs)	DSLR PA (degs)	DSLR SD/SEM (degs)
ES 2710	81/2008	82.2	80.434	0.444/0.181
STF 2474AB	263/2012	263	262.197	1.430/0.584
STF 2681AC	199/2012	195	200.071	1.505/0.615
STF 2241AB	16/2010	14.5	16.232	1.772/0.723
STF 2664	320/2008	324	321.818	0.282/0.115

The different division of labor between the two techniques became obvious. With the visual method, the lion's share of time involved observation at the eyepiece and recording data. The determination of averages and statistical data required much less time. The reverse was true for the digital camera method. Once focus and saturation issues had been solved, the recording of the science images went rapidly. Then this data was downloaded into the computer, CR2 files needed to be converted to Fits file, and then reduced by Astrometrica. Each of the 30 science images needed to be reduced separately, which took some finesse. Then right ascension and declination values for each component (60 total each) required conversion to position angle and separation with the spreadsheet. At the workshop we only had time to reduce 1-2 images for each target before preparing the power point presentation for the workshop participants. All six images of each target were processed later.

Double star research should involve some statistical analysis to evaluate the precision of the measurements. Two functions are calculated for this project. Standard deviation (SD) represents the spread of numbers in a series of measurements. The smaller the SD the more tightly grouped and precise are the measurements. For a bell curve, approximately 68% of the data are within ±1 standard deviation. The standard error of the mean (SEM) is also determined. In scientific studies multiple measurements are mandatory to reduce random error and observer bias. The SEM takes this into account; it is the standard deviation divided by the square root of the number of observations. The greater the number of observations recorded, the smaller the SEM.

We noticed that there was quite a spread of standard deviations among the five targets when comparing visual and DSLR methods. We also thought it would be interesting to check the variance of a particular target by checking: 1) SD and SEM of six different images of the same star; and 2) SD and SEM of the same image reduced six times.

This analysis would show if there was a significant difference in how each image was processed. STF 2664 was chosen for this test. All images for this double star were taken at ISO 800 with an exposure of 0.5 seconds. These data are shown in Table 12.

The standard deviation of the position angle where all images were the same (all 6073 reduced six times) was 40.33% of the standard deviation of the position angle where six different images (6073-6078) were reduced. The standard deviation of the separation where all images were the same was only 9.02% of the standard deviation of the separation where six different images were reduced. It showed that the "all the same image" separation values had a much tighter grouping than the six different image reduction. Yet the "same image" po-

Table 12: *DSLR statistical comparisons of STF 2664; six different images and same image six times.*

Object	**STF 2664;different images**			**Object**	**STF 2664;same image**	
Image	**Position Angle**	**Separation**		**Image**	**Position Angle**	**Separation**
6073	321.85401	27.21128		6073.1	321.854011	27.221281
6074	321.85401	27.21128		6073.2	321.854011	27.221281
6075	321.79822	26.4686		6073.3	321.854017	27.2212787
6076	322.12812	27.61645		6073.4	321.854011	27.221281
6077	322.03295	28.03275		6073.5	321.612797	27.3017968
6078	321.24223	27.31475		6073.6	321.612797	27.3017968
Average	321.818257	27.309185		**Average**	321.773607	27.2414526
Std Dev	0.28192	0.473241		**Std Dev**	0.113710	0.0426698
SEM	0.11511	0.193239		**SEM**	0.046431	0.0174234

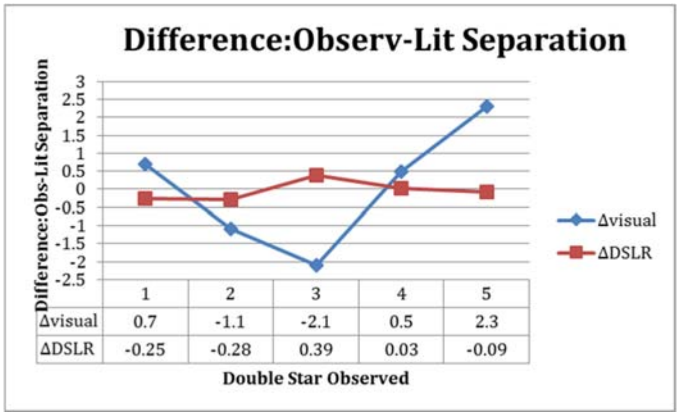

Figure 4. Difference between observed and literature separation values (arc seconds) for visual and DSLR data.

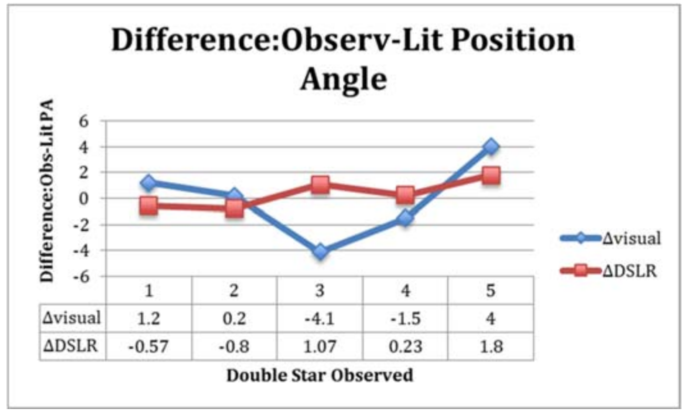

Figure 5: *Difference between observed and literature position angle values (degrees) for visual and DSLR data.*

sition angle values with SD 0.1137 were scattered to a greater extent than the corresponding “same image” separation values with SD 0.0427. And both the position angle and separation SD values for “same image” were measurably lower than the corresponding “six different image” statistics. So clicking on the star image in Astrometrica (e.g. the placement of the crosshairs) affected the distribution of the position angle orientation more than the separation between components. This suggests that additional images should be taken and processed. Most of the six star images for each double star were round but some were elongated or smeared due to camera movement. With additional images, selection of only the roundest images should be used for Astrometrica reduction to give more accurate and precise results.

When the differences between the observed values and the most recently reported WDS literature values of separation and position angle for both visual and DSLR methods were compared, an interesting correlation developed. Figure 4 plots the difference between the observed and the latest reported WDS literature separation (Y-axis) in arc seconds vs target double stars on the X-axis. Figure 5 plots the difference between the observed and literature position angle (Y-axis) in degrees vs target double stars on the X-axis. The target double stars are numbered to clarify the chart display:

Double Star	Number	Double Star	Number
ES 2701	1	STF 2241AB	4
STF 2474AB	2	STF 2664	5
STF 2681AC	3		

Figure 4 shows the range of the difference between observed and the latest reported WDS literature separation values. They varied over 4.4 arc seconds for the visual observations and only 0.67 arc seconds for the DSLR observations. For the astrometric eyepiece values, this 4.4 arc seconds only differed by 43% of one division on the linear scale. Yet the DSLR range of 0.67 arc seconds was only 15% of the visual range. This showed a tight group distribution for DSLR and closer to the literature values. Also, the large range in separations for the targets were chosen to see how well the DSLR technique could handle both large and small separations during reduction. The concern is as the separations got closer that the images might merge and prevent a good reduction. This concern was eliminated when it was shown the double star with the smallest separation, STF 2474AB (15.9 asec), was easily reduced by Astrometrica.

Figure 5 shows the range of difference between the observed and the latest reported WDS literature position angle values. They varied from 8.1 degrees for the visual observations and only 2.6 degrees for the DSLR data. The fairly large range in the visual position angle values for an alt-az telescope always comes down to two situations: (1) field rotation and/or (2) inherent difficulty in lining up the two stars on the linear scale prior to using the drift method to obtain the position angle. There is little correlation between the alignment problem on the linear scale and separation since the two smallest differences (1.2 degs for ES 2701 and 0.2 degs for STF 2474AB) also have the highest and lowest separations (51.1 asec for ES 2701 and 16.0 asec for STF 2474AB). Yet the information on Tables 8 and 9 shows that STF 2474AB, with the smallest separation studied, 15.9 arc seconds, had the largest SD (so the largest data spread) for position angle data in the visual study. This indicates the difficulty in aligning two stars on the linear scale that are only about 1.5 divisions apart, contributed to the larger SD. The use of a Barlow lens with closer pairs might have helped visually and should be considered in future studies.

It should be mentioned that the most recent WDS literature values listed in Tables 8 and 9 were not precessed to J2000 values. Future studies should include this computation for more accurate comparison between observed and literature values.

The altitude of the double star may also have been a factor in the large visual position angle range. The closer to the zenith the double star, the harder it is to maneuver the telescope to allow for proper drift. But we have no direct evidence to account for this in the present study.

The DSLR position angle range of 2.6 degrees is only 32% of the visual range. Taking the photographs over short exposures captures the parameters and stores them more efficiently and does not suffer the problems of field rotation, improper alignment and extended drift times.

Repeatability of Measurements

Figure 6 shows one of the double stars studied at PMO. It plots the right ascension on the X-axis and the declination on the Y-axis for STF 2474AB. The left graph shows the primary star positions for six different images; the right graph shows the secondary star positions. This shows six differrent photo images taken. Note the exponential number on the far right of the X-axis. This value is to be added to the value indicated on the X-axis to determine the actual value in degrees. A similar value is at the top of the Y-axis for the declination. In the left graph we see how the primary stars are closely grouped and the slight spread and change of position angle of the secondary stars on the right. The circles centered on the averages in each graph correspond to 0.500 arc second radii.

Figure 7 shows the same double star, STF 2474AB, as in Figure 6. But in Figure 7, the same image (6048) was reduced six times with Astrometrica. Again, it plots the right ascension on the X-axis and the declination on the Y-axis. Note the very tight grouping indicated by the three circles in each graph. And, in Figure 7, the circles only represent 0.100 arc second radii. This shows that variance in solving the same image is very small; the SD for the separation and position angle values in Figure 7 are 0.1475 and 0.3977, respectively. This indicates that reducing the same image in Astrometrica multiple times shows little change in the generated right ascension and declination results compared to reducing multiple different images. This shows a high reproducibility when using Astrometrica.

Summary of the Advantages and Disadvantages of Each Technique

Advantages and disadvantages of the visual astrometric eyepiece method are:

Advantages

- Inexpensive; the eyepiece cost about $150
- Short setup time
- Easily understood introduction to double star astrometry

Disadvantages

- Lots of time spent at the eyepiece making many observations to avoid random error and bias
- With alt-az telescopes, field rotation occurs; this is maximum in the north, south and at the zenith
- Scintillation effects make the star images jump around making readings difficult for both separation and position angle
- Wind gusts make position angle drift measurements prone to error

Advantages and disadvantages of the DSLR photographic method are:

Advantages

- Rapid image exposure time (0.15-1.5 seconds); can record many digital images in a few minutes
- Can effectively measure separations less then 15 arc seconds using Astrometrica
- There is an increase in accuracy and precision
- Permanent images are stored for later study
- Lots of software is available to reduce photographic data

Disadvantages

- Equipment is more expensive: camera, computer, some software
- Processing many images to determine parameters takes more time

The team felt that both techniques have their place in double star research. The hands-on astrometric eyepiece method is a good introduction to the science and the DSLR camera technique has the advantage of less time in the field and greater overall accuracy and precision.

Workshop Reflections

Hernandez-Frey (NHF) had attended PMO in 2011 and worked with a group of 5 students making visual double star observations [11]. Hartshorn (BH) had never done any astronomy science and said he had never seen the Milky Way prior to the PMO workshop. Team leader Frey (TF) asked both students for a summary of their experiences at PMO in 2013. Paraphrased summaries of their statements are given below.

[*NHF*]*: The research exposed me to new types of technology that could be used to analyze the universe. I couldn't possibly comprehend this unless I saw it with my own eyes. A skill I gained was how to accurately take measurements with the telescope as well as documenting*

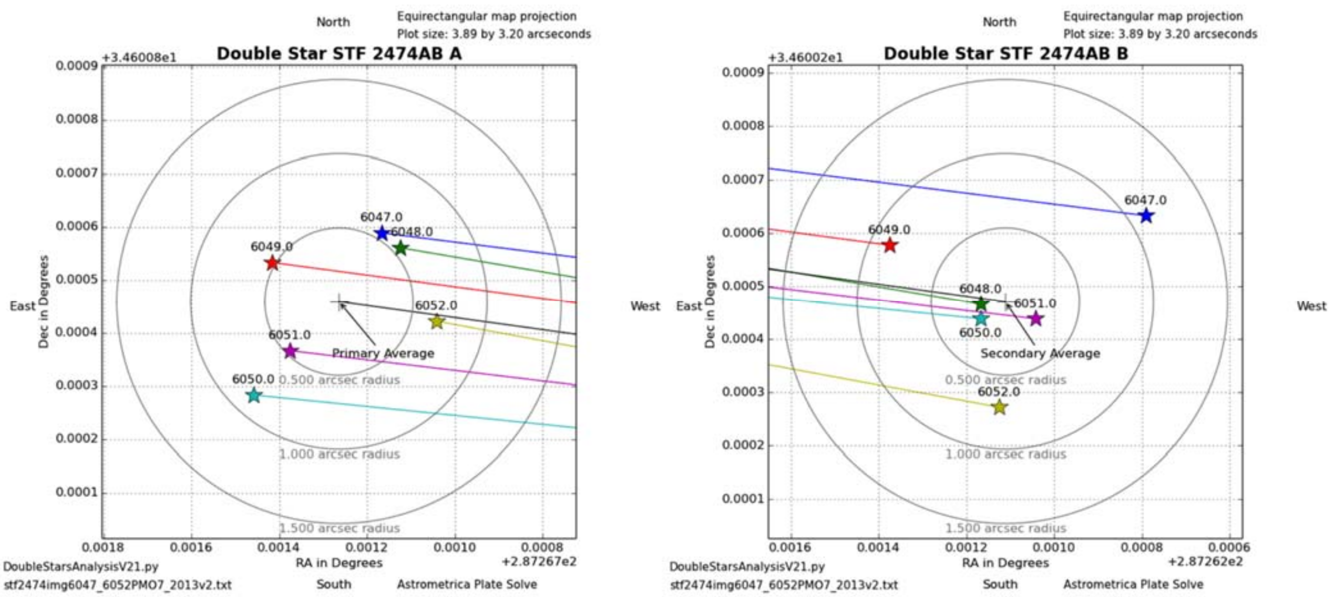

Figure 6. STF 2474AB primary and secondary star coordinates and their averages, showing the general grouping and changes in position angle. Data is taken from images 6047-6052.

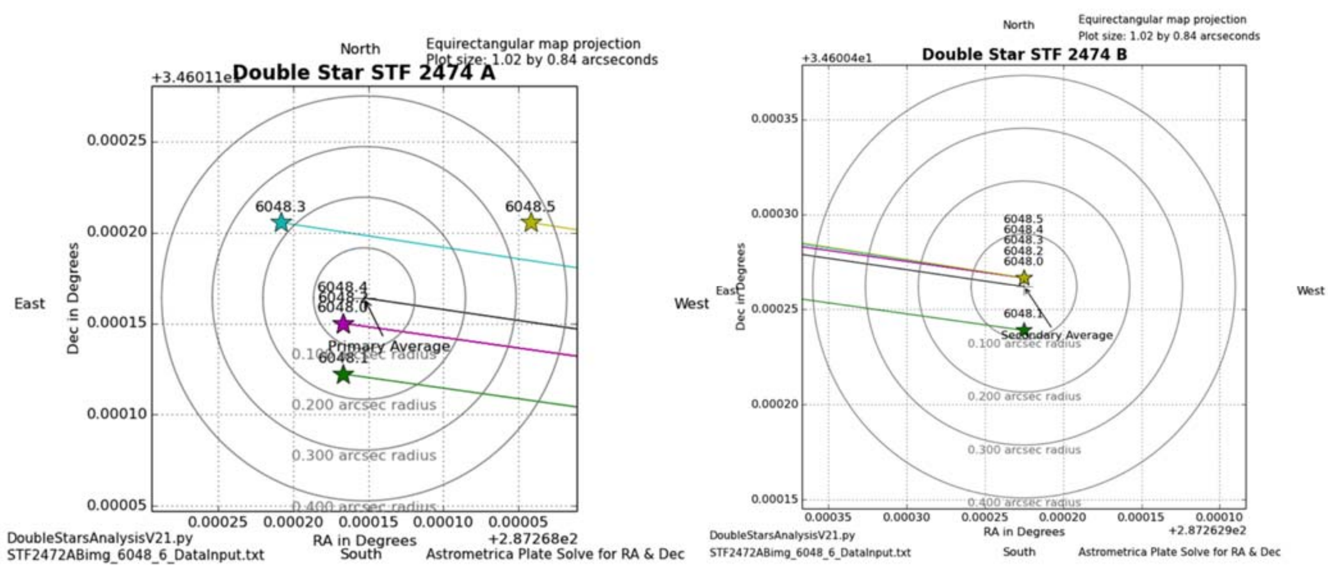

Figure 7. STF 2474AB primary and secondary star coordinates and their averages, showing the general grouping and changes in position angle. Data is taken from image 6048 alone.

the results. My team had gathered extensive information on five double stars. I believe the DSLR technique was a more viable option because it contributed results closer to WDS values than the astrometric eyepiece method. Also, the DSLR technique only took one night to gather the data whereas using the astrometric eyepiece took two nights. So I preferred the DSLR technique. I did have fun working with my team but also met individuals from other groups. The workshop, while challenging, also showed that everyone could enjoy the process. I learned a lot more at this, my second workshop, since I had an idea of the goals from the first PMO workshop.

[BH]: The most rewarding aspect of the PMO workshop was the chance to see the true beauty and complexity of double stars. I realized calculating the distance between two celestial objects involve interesting methods. The most challenging part of the workshop was taking the astrometric eyepiece measurements that required

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a steady hand and sharp eyes. Even though this was the most challenging aspect, I do believe that it is a very essential piece to fully understand astrometric measurements. The hands-on experience of getting to physically use the telescope and take measurements with my own eyes was phenomenal. The DSLR method was much faster, but I did not have the same wondrous feeling as working with the Celestron eyepiece. I do not believe that the DSLR method, though very effective, should be done solely with beginning astronomers like me, because I received a better understanding of the measurements using the astrometric eyepiece. The workshop was a mind broadening experience. This brilliant new view of the universe has taught me that while the world is a big complex place, the universe is an ever changing carrier that houses countless stars and galaxies. I am very glad that my eyes have been opened by this experience.

Acknowledgements

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