Accepted for publication by the *Journal of Double Star Observations* (JDSO) on March 4, 2016.

Measurements of Multi-star Systems LEO 5 and MKT 13

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Abstract: We report measurements of the position angles and separations of two multi-star systems observed during the fall of 2015. Image data was obtained using an online 17-inch iTelescope system in Nerpio, Spain. Image data was analyzed using Maxim DL Pro 6 and Mira Pro x64 software tools at the Army and Navy Academy in Carlsbad, California. Our measurements of the LEO 5 system are consistent with historical data, although inconclusive as to the nature of the system. Our measurements and the historical data for the MKT 13 system show a consistent linearity in the position angle and separation.

Introduction

As a part of an educational course on double stars at the Army and Navy Academy in Carlsbad, California, we obtained images for multi-star systems LEO 5 and MKT 13 in order to measure the relative positions and separations of these systems. Using the Washington Double Star catalog (WDS), we chose star systems which would meet a set of criteria which would allow us to make good measurements with the equipment and tools available. These criteria included star systems with separations of 4 arc seconds or more, visual magnitude of 12 or brighter, and difference in visual magnitude less than 3. Our team, shown in Figure 1, selected two candidate star systems which had not recently been measured.

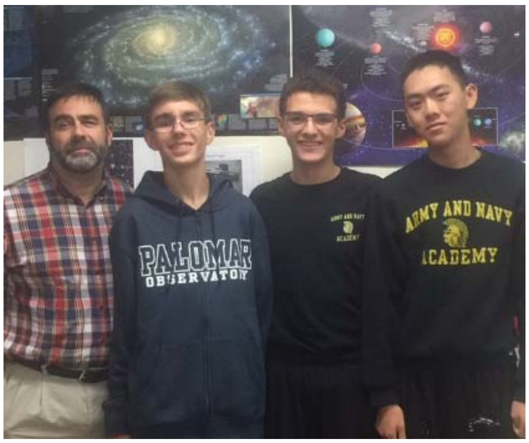

Figure 1. Allen Priest, Stephen Priest, Faisal AlZaben, and Rex Qiu

Attempts were made to acquire images using an 11-inch Celestron Schmidt-Cassegrain telescope at Tierra Del Sol, near San Diego, California, but weather conditions prevented us from acquiring any useful images. We utilized the iTelescope network of remotely operated telescopes to acquire CCD images of the candidate systems. We used the iTelescope T7 system located in Nerpio, Spain, which is a 17-inch CDK with a focal ratio of f/6.8, equipped with an SBIG STL11000M monochrome camera (Figure 2). The field of view is 28x42 arcminutes with 0.63 arcseconds per pixel scale. This telescope provided a large enough aperture to acquire high quality images of the 11th magnitude stars in one of the systems we chose. We chose to use a telescope in Spain because of the good weather available at the time of the observations.

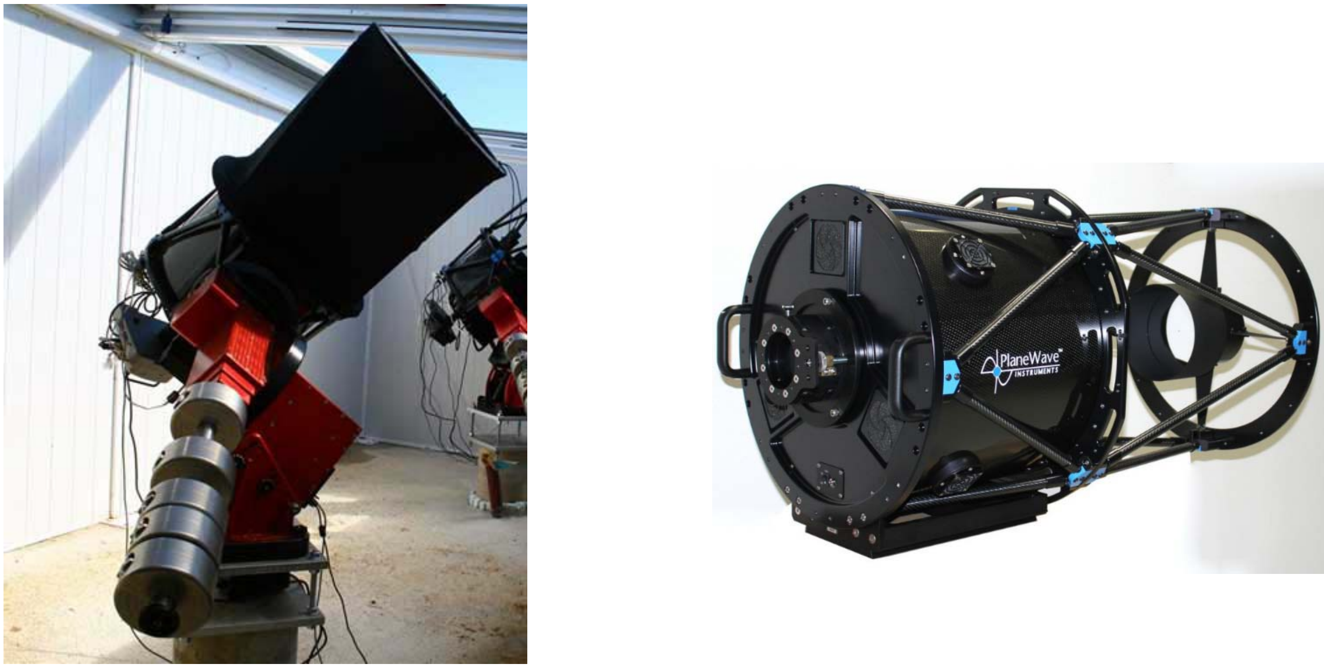

Figure 2. T7 17-inch Planewave f/6.8 Corrected Dall-Kirkham (CDK) Astrograph in Spain

We imaged both LEO 5 and MKT 13 on two different nights. On each night we acquired four images per system using a luminance filter and four images using a hydrogen alpha (H_a-7nm) filter. These two filters were chosen in order to ensure that we would have good measurements on the fainter stars while also ensuring that we would not have blooming problems on some of the brighter stars.

Star system LEO 5 is a triple system in the constellation Perseus. The AB pair of this system has not had reported observations since 2006, while the AC pair was last reported in 2012. The stars in the system are faint, all with visual magnitudes of about 11. The AB pair of stars in this system appear fairly close to one another with a visual separation of about 4.5 arc seconds. The AC pair has a separation of about 48 arc seconds.

Star system MKT 13 is a quintuple system in the constellation of Taurus. While there are five stars in this system, the Aa and Bb stars are each actually very close binary stars with separations of 0.1 arc seconds or less and too close for us to measure with our equipment. The AB pair of this system last reported observations were in 2011. The AC pair was last reported in 2000. The WDS catalog reports that the A and B stars in the system have visual magnitudes of about 3.41 and 3.94 while the C star is fainter, measuring about 11.96 in magnitude. Because of the wide difference in brightness, we were unable to obtain measurements on the AC pair with the images we acquired. Thus, we focused on measurements of the AB pair which have a visual separation of about 341 arcseconds.

Methods and Procedures

Each observation was scheduled via the iTelescope internet portal where we designated: RA & Dec coordinates, image time, number of images, date and time to acquire the image, and filters to be used. Once the images were acquired, they were calibrated by the automated iTelescope systems and made available to us through an FTP server. The calibration procedure utilized dark frames, bias frames, and flat frames to correct for anomalous effects of the optical system and camera used.

Pinpoint Astrometry, a plug-in for the popular Maxim DL software, was then used to obtain a plate solution for each image by locating a number of stars in the image and comparing their positions against the Fourth U.S. Naval Observatory CCD Astrograph Catalogue (UCAC4). This procedure is crucial to determine the exact pixel scale and rotation angle of the image which are then used in determination of the star's separations and angles. This information is placed into the FITS header for the image when saved. Even though all of our images were taken on the same telescope with the same camera, we performed this plate solving process on every image that we used to guarantee highest accuracy of our measurements. This process confirmed a pixel resolution of 0.63″/pixel and a camera rotation angle of 272°.

Each WCS calibrated image was then opened with Mira Pro x64, a software product from Mirametrics, Inc. This software enables making many different photometric measurements of the stars in the image including visual magnitude, absolute position in RA and Dec, and separation in arc seconds, and relative position angles. As we were initially unfamiliar with these star systems, it was also helpful to use star charting software such as The SkyX and Stellarium to verify the appearance of the stars in our systems. These tools allowed us to visually identify the positions of the star pairs within the field of view of our images to quickly begin the process of measuring the stars' separations.

Using the point and click Distance & Angle function of Mira Pro x64, we measured the position angle and separation of the binary stars. When the first star is clicked upon, Mira calculates the centroid of the star and synchronizes the start of the measurement from that point. Releasing the mouse button on the second star allows the Mira software to locate that star's centroid position and provide the desired measurement from these centroid positions. An example of this process is shown in Figure 3. The software calculates the centroid of each star based on the image data. In most cases, this provides a very accurate location for the star and minimizes the effects of noise. The parameters of this calculation can be adjusted if necessary to account for the size of the stars in the image. In some cases, where the star might be overexposed resulting in blooming, it is possible to disable this centroid measurement and use other methods of pinpointing a star's location. For example, if there are diffraction spikes in the image, these can be used to locate the center of the star. However, for our images, this was not necessary, and we relied on the centroid measurement. Because this measurement is based on the brightness data for many

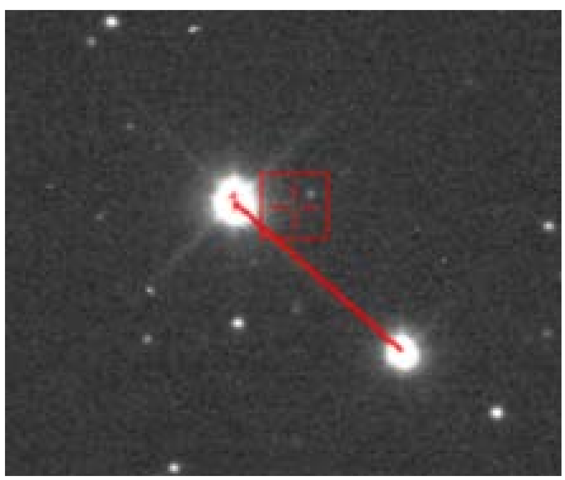

Figure 3. Example Position Angle and Separation measurement procedure with Mira Pro.

pixels in the star image, it is possible for this centroid calculation to pinpoint a star's location within a fraction of a pixel. This resulted in very accurate measurements even for the faintest stars.

After completion of the position angle and separation measurements, the data were placed into an Excel spreadsheet to calculate the mean, standard deviation, and standard error of the mean for each binary star system. Once these were calculated, each measurement was compared to the data available in the Washington Double Star catalog (WDS). This comparison allowed us to confirm that the measurements are being made appropriately and that our data is in agreement with previously published data. If there had been an error in the processing, such as an incorrect image angle or pixel scale, this error would show up in the comparison and let us know that there was a problem. In one case, early in the process of learning to use the Mira software, it was found that the FITS image was inverted due to an improper setting when opening the file. This gave double star angles which were obviously incorrect based on the historical measurements in the WDS. We were then able to go back to verify the mistake and to correct it.

Star System LEO 5 [WDS 02191+5422]

The AB pair required an additional effort to obtain accurate measurements because of the small ~4.5 arc second separation. Initially, this required adjustment of the contrast stretching of the image in order to identify the two stars. The default stretching performed by Mira Pro x64 caused the two stars to appear as a single star. By adjusting the amount of stretching, and viewing the image as a negative, it was fairly easy to view the 2 stars. Adjustment of the sample radius of the centroid calculation was necessary so that the centroid measurement accurately identified the 2 stars separately rather than combining them together as a single star.

Sixteen images were acquired of this system on 2 nights of observing, October 10th and 21st of 2015. An example image with the stars labeled is shown in Figure 4. Eight of these images were taken using the H_a filter and eight were taken with a luminance filter. Exposure times on the first observing night were varied from 60 seconds to 120 seconds. The H_a-filtered images taken on the first night were found to be under-exposed resulting in poor signal-to-noise ratio on 2 of the images. These 2 images were therefore discarded as no measurements could be obtained. On the second night of observations, the exposure times for the H_a-filtered images were doubled and ranged from 120 to 240 seconds.

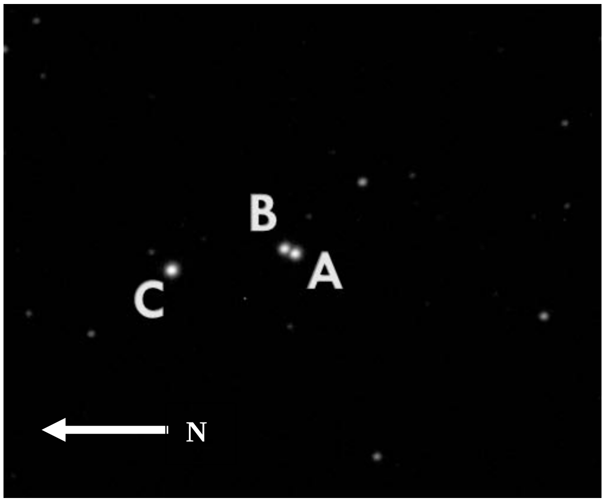

Figure 4. Sample Image of LEO 5 with Stars Labeled

The mean, standard deviation, and the standard error of the mean for the separation distance in arc seconds and the angle in degrees were calculated from these data as shown in Table 1. The date is the mean of the two observation dates.

WDS No.	ID	Date	Observations		PA	Separation
02191+5422	LEO 5AB	2015.79	14	**Mean**	338.53	4.18
				Std Dev	1.075	0.333
				Std Error	0.287	0.089
02191+5422	LEO 5AC	2015.79	14	**Mean**	10.07	47.95
				Std Dev	0.095	0.073
				Std Error	0.025	0.019

Table 1. Measured Data Results for LEO 5

Historical Data for LEO 5

We requested the historical data from the US Naval Observatory. The data we received, along with our measured data, are shown graphically in Figures 5 and 6.

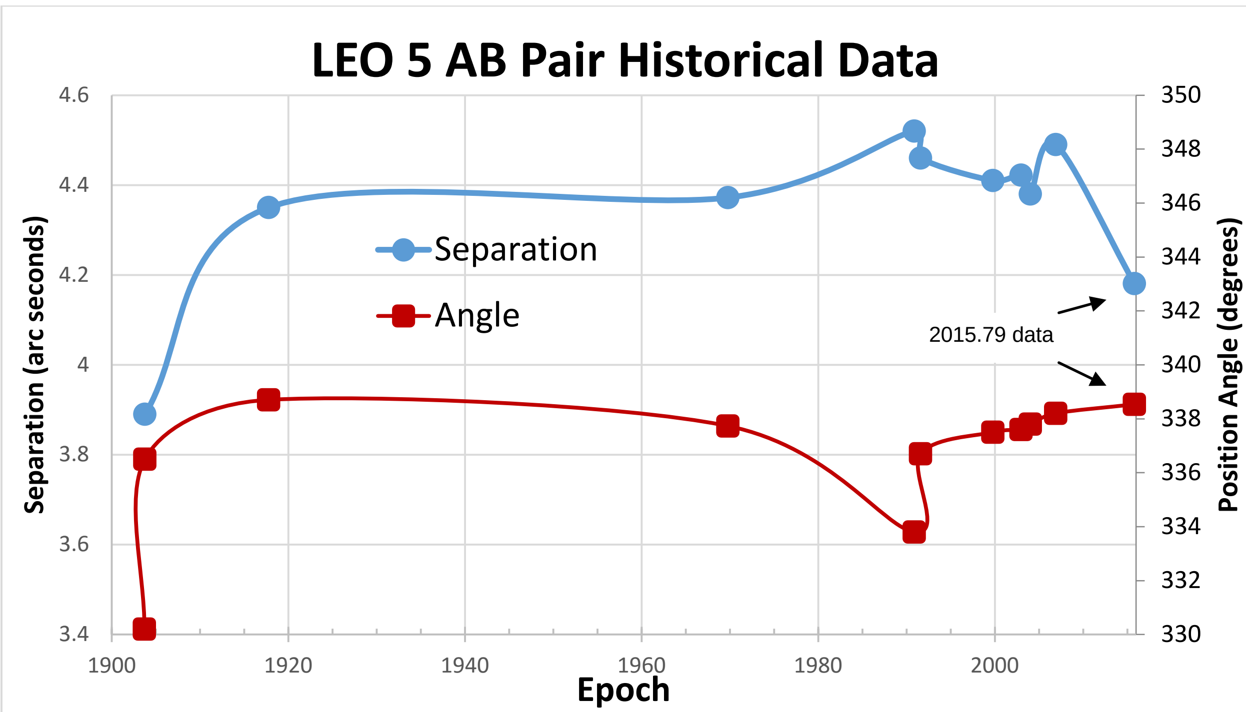

Figure 5. Graphical Representation of Historical Data Points for LEO 5 AB Pair

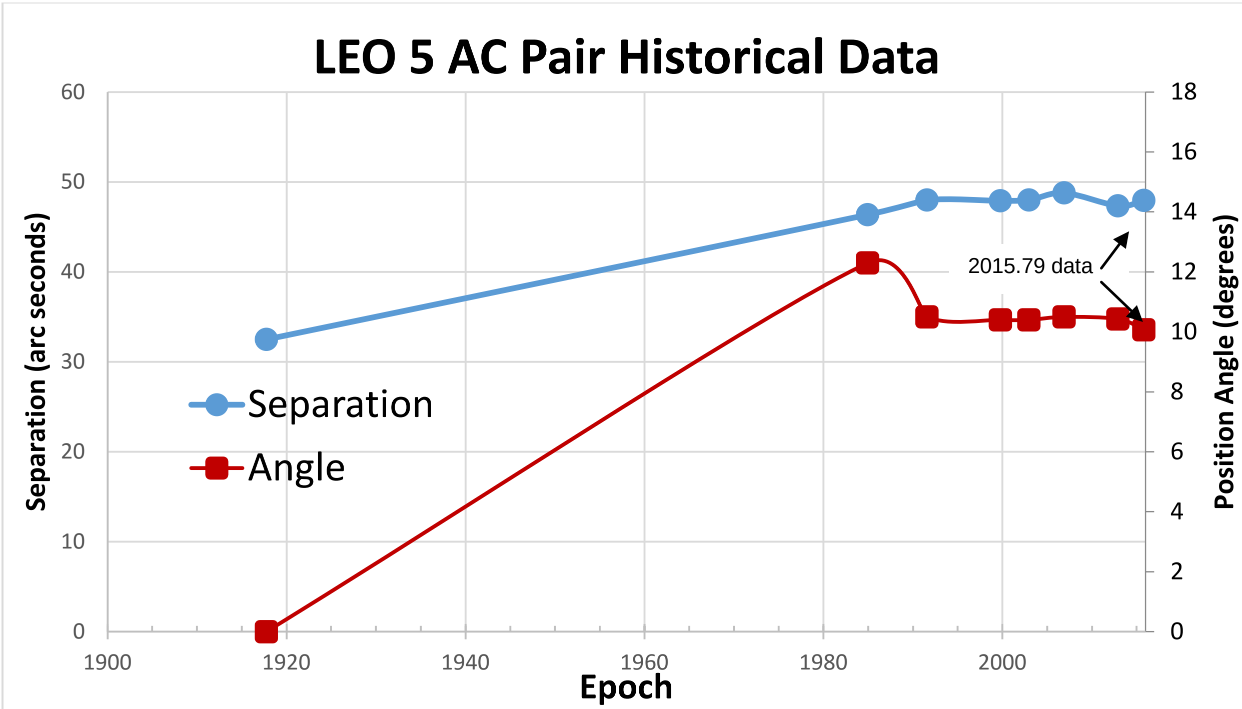

Figure 6. Graphical Representation of Historical Data Points for LEO 5 AC Pair

Discussion of Results for LEO 5

Our data agreed well with the historical data and the calculated standard deviation indicates that our measurements were accurate. The historical trend of the measured data does not provide enough information to draw conclusions about whether these star pairs are physical doubles or not. A search of other databases did not yield any additional information about these stars.

Star System MKT13 [WDS 04287+1552]

This is a quintuple star system with each of the A and B stars being, themselves, binary pairs with known orbital data. The orbital parameters are available from the Sixth Catalog of Orbits of Visual Binary Stars. As mentioned earlier, the Aa pair and the Bb binary pairs are too close for us to separate using the observing techniques we employed. In addition, while the A and B stars are very visible with magnitudes of 3.41 and 3.94, respectably, the C star in this system is much dimmer with a magnitude of 11.96. Because of this large variation in visual magnitude, we were unable to measure the separation and angle for the AC pair.

We were able to make 13 measurements from the images acquired. From these data, we calculated the mean, standard deviation, and the standard error of the mean for the separation distance in arc seconds and the position angle in degrees. These are shown in Table 2. The date observed is the mean of the two observation dates. There were seven and six observations on the first and second nights, respectively.

WDS No.	ID	Date	Observations		PA	Separation
04287+1552	MKT13AB	2015.79	13	**Mean**	346.72	337.97
				Std Dev	0.435	3.033
				Std Error	0.121	0.841

Table 2. Measured Data Results for MKT 13

Historical Data for MKT 13

We requested the historical data from the US Naval Observatory. The data we received is shown in the graph in Figure 7. Because of the large number of historical data points received (42), we chose to plot the angle and separation vs. observation date in order to look for trends in the data.

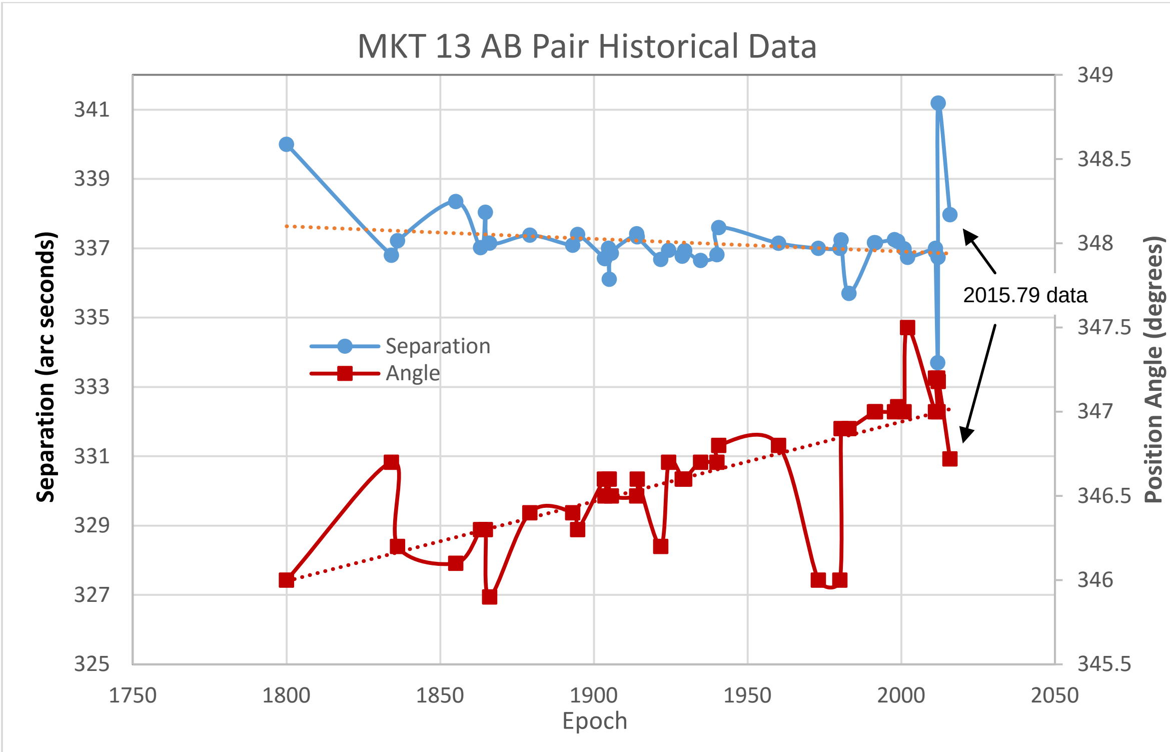

Figure 7. Graph of Historical Data Points for MKT 13 AB

Discussion of Results for MKT 13

From the graphed data, there does appear to be a trend in the position angle of this pair. A linear fit gives a trend of about 4.7 millidegrees per year with an R^2 value of 0.54. The separation appears to be decreasing very slowly but a trend in this data is uncertain. A linear fit to the trend for the separation measures about 3.6 milliarcseconds per year with an R^2 value of 0.04.

Acknowledgements

We would like to thank Russell Genet for his assistance and guidance which allowed us this opportunity to do research and for introducing our team to the study of binary stars. Additionally, we thank the Boyce Research Initiatives and Education Foundation (B.R.I.E.F.) for their instructional support and financial donation that allowed us to use the iTelescope robotic telescope system and the Maxim DL Pro 6 and Mira Pro x64 software tools. This research made extensive use of the Washington Double Star catalog maintained by the U.S. Naval Observatory.

References

Genet, R. M., Johnson, J. M., Buchheim, R., and Harshaw, R. 2015. *Small Telescope Astronomical Research Handbook.* In preparation.

Hartkopf, W.I., Mason, B.D 2006, *Sixth Catalog of Orbits of Visual Binary Stars*. US Naval Observatory, Washington. http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/orb6

Mason, B. and Hartkopf, W. *USNO CCD Astrograph Catalog (UCAC)*, March 2011. Astrometry Department, U.S. Naval Observatory. http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/ucac.

Mason, B. and Hartkopf, W. *The Washington Double Star Catalog, October 2015.* Astrometry Department, U.S. Naval Observatory. http://ad.usno.navy.mil/wds/wds.html.
Stelle Doppie Double Star Database Search Engine, http://stelledoppie.goaction.it