Lucky Imaging of 59 And.

High School Research

and Beyond

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February 10, 2013
Maui International Double Star Conference

Topics

- About me, and High School Research
- Lucky Imaging of 59 Andromeda
- Comparison of Past High School Research to Today's Research
- The Future of High School Research

About Me

- Arroyo Grande High School, California
- Activities and Interest
- Meeting Dr. Gene
- Now and Future

Lucky Imaging of 59 Andromeda

Besselian Epoch	Frames	Sep. (arc sec)	PA (°)	dMag
B2012.865	000-499	16.156	36.18	1.08
B2012.865	500-999	16.136	36.44	1.10
B2012.865	1000-1499	16.167	36.38	1.07
B2012.868	000-499	16.209	36.27	1.06
B2012.868	500-999	16.149	36.40	1.07
	Average	16.160	36.33	1.08
	St. Dev.	0.03	0.11	0.02
	St. Err. Mean	0.01	0.05	0.01

Figure 5: Left is the first 500 images just stacked. Right is the best 10% of the first 500 images (i.e. 50 images) stacked and aligned.

- Results:
  - Separation: 16.16"
  - Position Angle: 36.33°

Lucky Imaging of 59 Andromeda

- Conclusions
  - Past observations
  - Binary double? Or just an optical pair?
  - JDSO

- What I've learned:
  - Hard work
  - Managing a team
  - Astronomy is cool!

Real High School Students

High School Research

- Why do High School research?
  - Learning Opportunities (good for student)
  - College (good for student)
  - Outreach (good for science)
    - ~~Classes~~
    - Clubs
    - Conferences (i.e. going to Maui)

Lucky Imaging Astrometry of 59 Andromedae

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Abstract: Students from Arroyo Grande High School, as members of a Cuesta College research seminar, observed the double star 59 Andromedae (STF 222) using the lucky imaging technique. The measured separation was 16.16" and the position angle was 36.33°. The pair have maintained approximately the same separation and position angl since observations began. Consideration of historic observations, proper motion vector and parallaxes were insufficient to conclude whether the double was a chance optical double or gravitationally bound binary.

Introduction

This paper reports on one of four research projects that were part of the Fall Cuesta College Astronomy Research Seminar held at Arroyo Grande High School. Observations were conducted at the Orion Observatory near Santa Margarita Lake o nights of November 11 and 12, 2012 (B2012.865 and B2012.868) with a Sidereal Technology controlled 10-inch Meade LX200 telescope equipped with an Andor Lu emCCD camera.

Figure 1: From left to right: Bobby Johnson, Everett Heath, Sophia Bylsma, Camero Arnet, Kaela Yancosek, and Jason Olsen.

The primary objective of this project was to add a current observation of the position angle and separation of 59 Andromedae to the growing set of observations began over two centuries ago. The secondary objectives were to provide students w opportunity to collect data with an advanced astrometry technique (lucky imaging), reduce and analyze their data, and determine if the double star is likely optical or bi

The double star 59 Andromeda (WDS J02109+3902 STF 222) was chosen a relatively wide, bright pair appropriate for beginning observers. Three sets of observations were made as detailed below: (1) drifts to determine camera angle with respect to north, (2) observations of two standard double stars to determine camera's angle and pixel scale factor, and (3) observations of the selected double star.

Lucky Imaging

The atmosphere is composed of many small air cells of slightly different temperature and density. Each cell is typically about 8 inches across. The cells at h altitude slightly deflect the path of starlight as they move across the telescope's fiel view, causing the rapid movement of stars (jitter) that blurs the star's image during normal exposures. This degrading effect of poor "seeing" can be reduced by locatin telescopes on mountaintops with smooth, laminar air flow.

For a small area of the sky known as an "isoplanatic patch," the effects of po seeing over this small area (about 10" in diameter) can also be overcome through lu imaging or speckle interferometry (Law 2006). Within the isoplanatic patch, the jitt motion of stars is correlated—*i.e.* stars move together. By taking very short exposu (10 to 30 milli-seconds) it is possible to essentially "freeze" the images and thus ren the blurring effects of seeing (Anton 2012).

Even then, most images are still blurry. Fortunately, a small percentage can quite clear, although, thanks to the short exposures, they are also faint. Lucky imag simply takes many exposures, saves the best ones, and discards the rest of them. Si the small percentage of clear exposures still "bounce" around from one exposure to next due to atmospheric jitter, they have to be individually aligned. Once aligned, t images can then be "stacked," essentially adding all the clear images together to for final, much brighter, single image. The selection of the clearest images (often from hundreds or even thousands of images) and aligning and stacking them would be ve tedious if it had to be done manually. Thankfully this process has been automated.

Equipment and Software

A 10-inch Schmidt-Cassegrain telescope, made by Meade and equipped wit Sidereal technology control system, was used to make the observations. An 80 mm scope, equipped with a Santa Barbara Instruments Group (SBIG) ST-402 CCD cam provided field identification and initial centering.

A high-speed Andor Luca-S electron multiplying CCD camera was used (unfiltered) for lucky imaging astrometry. This camera's high speed is achieved, in through a software-selectable Region of Interest (RoI), allowing just a small, selecte portion of the overall pixel array to be read out.

Normally, reading out CCD cameras at high speed is very much nosier than slow speeds thanks to the inherent nature of an analog-to-digital (A/D) converter at chip's output. However, by adding a special row of pixels to the chip just before th A/D converter, with each pixel being at a slightly higher voltage level than its predecessor, the electron charges corresponding to the observed light levels can be multiplied by a factor of up to 1000 or more as they are clocked through this electro multiplying row. Although this amplification does in itself introduce some noise, fo

read noise of the A/D converter and, as a result, the effect of the read noise is great reduced from what it would have been without electron multiplication (EM).

While EM can greatly reduce overall noise at high speeds and low light leve the slow readout speeds and high light levels typical of many CCD applications, the noise is comparatively low and EM can actually increase overall noise. The Andor S camera we used actually has two different selectable outputs—one with and one without EM.

The telescope was controlled with hardware and software supplied by Sider Technology. Software Bisque's *The Sky 6* was used as the "planetarium" program, the SBIG ST-402 camera was controlled with Software Bisque's *CCD Soft*. The An Camera was controlled with the Andor's *SOLIS*. Although, the data was initially gathered as data cubes in the Andor camera's native .sif format, a *SOLIS* batch conversion process was used to transform and unpack the cubes to produce individu images. Finally, the data was analyzed with *REDUC*, a sophisticated freeware doub analysis program developed by Florent Losse, a very active double star observer in France.

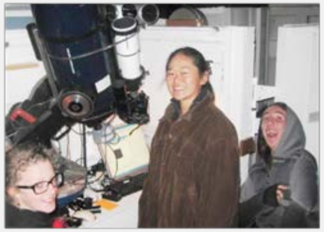

Figure 2: Sophia Bylsma, Everett Heath, and Anna Zhang at the Orion Observatory. The Andor Luca-S high-speed emCCD camera can be seen just below the telescope.

Calibration

Calibration observations were made on the second night. "Drifts" were obta by moving a star to one edge of the camera's field and then temporarily turning off telescope's drive, causing the star to drift across the field-of-view as the Earth turne while multiple images were taken. A feature of REDUC provides a least squares fit straight line through the star's centroids on the multiple images, thus establishing an west line from which the orientation (angle) of the camera with respect to North can deduced. Five drifts were obtained so we could estimate the precision with which t

Observations were also made of two calibration binary stars. These binaries have well-established orbits and, at any point in time, their position angle and separation can be determined via simple interpolations from ephemerides provided by the U.S. Naval Observatory. Each calibration binary observation consisted of 2000 exposures which we divided into four sets of 500 exposures. Each set was then analyzed with REDUC for the "best" exposures, using the "brightest pixel" technique. The light on blurry images is more spread out, while sharp images have concentrated light with higher pixel values. The exposures were then rank-ordered, and the top 10% of the images were saved while the other 90% were discarded. The remaining images (50 of 500) were then aligned and stacked. With the position angle and separation of the calibration pair known, the camera position angle and plate scale (arc seconds per pixel) for each set were provided by *REDUC*, and we calculated the means, standard deviations, and standard errors of the mean across the four sets.

Our calibration results are shown in Table 1. The calibration pair STT 547 provided the most precise results, with standard deviations of less than one half of those of the other calibration pair, STF 742, and (for the camera angle) less than one third that of the drifts. While we could have used a precision-weighted means to combine our calibration results, we chose instead to exclusively utilize the most precise results, those of STT 547.

	Angle (degrees)	One Sigma Std. Deviation	Scale Factor (Arcsec/Pixel)	One Sigma Std. Deviation
Drifts	-7.63	0.25	N/A	N/A
STF 742	-8.33	0.19	0.229	0.0008
STT 547	-7.93	0.07	0.222	0.0003

Table 1: Calibration results: The camera angles and scale factors and standard deviations.

While we are reasonably confident in the precision of our calibration as given in Table 1, there were insufficient calibration observations to estimate their accuracy; we expect that their accuracy could be less than could have been achieved for two reasons. First, observations of the program star (59 Andromedae) were made on the first night, while calibration observations were only made on the second night. Accuracy could have been improved by bracketing program observations with calibration observations. Second, the calibration pairs were not positioned close in the sky to the program pair, and hence inaccuracies in the polar alignment of the telescope could have affected their accuracy.

Program Observations

Some 2500 frames (images) were recorded for our program double 59 Andromedae. As was the case for the calibration doubles, we split the data into four sets of 500 frames each, applied REDUC's "best of max" brightest pixel sorting, saved the best 10% (50 frames from each set), and aligned and stacked these images. Assuming the camera angle and plate scale provided from our observations of the calibration pair STT 547, we obtained the results shown in Table 2.

Besselian Epoch	Frames	Sep. (arc sec)	PA (°)	dMag
B2012.865	000-499	16.156	36.18	1.08
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Table 2. Separation, position angle, and difference in magnitude measurements for 59 Andromedae with the averages, standard deviations, and standard errors of the mean.

It is instructive to compare, for the same total integration time, what the ima looks like with and without lucky imaging. Figure 3, left, shows the image that resu from stacking all 500 of the first set of frames without any alignment or selection— "raw" image. The image on the right is of the best 50 of the 500 frames shown afte alignment and stacking—the lucky image. While the raw image is brighter (500 ins of 50 stacked frames), the lucky image is much more sharply defined (higher resolu and, as a result, provides astrometry of significantly higher precision.

These two images clearly demonstrate how lucky imaging overcomes atmospheric distortion. If the separation of the two stars had been such that the raw image stars were merging together, the stars in the lucky image could still have bee usable. Lucky imaging allows closer doubles to be measured.

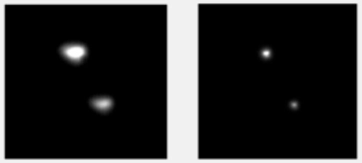

Figure 3: Left is the first 500 images just stacked. Right is the best 10% of the first 500 ima (i.e. 50 images) stacked and aligned.

Comparison with Previous Observations

In 1783, William Herschel was the first astronomer to report the separation position angle of the pair (Smyth 1844). John Herschel and James South observed double in 1822 (South and Herschel 1824). Friedrich von Struve, for whom the ST designation was given, observed 59 Andromedae twice, in 1822 and 1831 (Struve More recently, David Arnold visually observed the pair in 2005 (Arnold 2006). M al used speckle interferometry to measure the double star in 2006 (Mason et al 20 CCD imaging in 2007, 2008, and 2011 (Mason et al 2008, Mason et al 2010, and and Hartkopf 2012). A total of 83 measurements of separation and 85 of position a have been made since 1783.

To consider, roughly, the accuracy of our measured separation and position an average of observations over the last 25 years (supplied by Brian Mason at the Naval Observatory) was used as a comparison. The average separation of the past years is 16.68" while the observed separation of the present study is 16.16", a 0.52 difference. The average position angle of the past 25 years is 35.60° while the obs position angle of the present study is 36.33°, a 0.73° difference. We attribute this significant difference to possible calibration inadequacies discussed above.

Is 59 Andromedae an Optical Double or a Binary?

All nine measurements from the first 50 years of observation, beginning in were averaged to determine how the pair has changed over time. The average sepa of the first 50 years, as show in Table 3 is 16.53", a 0.15" difference from the last years. The average position angle of the first 50 years is 34.89°, a 0.71° difference the last 25 years. Both differences are within the standard deviations of early and measurements and therefore insignificant.

The spectral type of 59 Andromedae's primary component (SAO 55330) is and its magnitude is 6.05. The spectral type of the secondary component (SAO 55 A1V and its magnitude is 6.71. The B9 and A1 stars probably have a similar brigh because they are each just one tenth of a "class" away from A0. Since their spectra are so similar and both are on the main sequence, the stars could be roughly the sa distance from Earth.

	First 50 Years Sep (")	Last 25 Years Sep (")	Diff (")	First 50 Years PA (°)	Last 25 Years PA (°)
Average	16.53	16.68	0.15	34.89	35.60
St. Dev.	0.37	0.92		0.93	0.90
St. Err. Mean	0.07	0.17		0.17	0.17

Table 3: Average separation and position angle for observations in first 50 years and last 25 years with standard deviations and standard errors of the mean.

On the other hand, SAO 55330 has a parallax of 0.01241" ± 0.00283" whic corresponds to a distance of 263 light years. SAO 55331 has a parallax of 0.00192 0.01175"which yields a distance of 1699 light years. However, the error for the

secondary star's distance is sizable, ranging from 236 light years to infinity. Thus, ba on parallaxes, it is possible, though unlikely, that the two stars are at the same distan from Earth. If they were both 263 light years from earth, they would be 76,711AU ap just over 1 light year—perhaps too far apart to be gravitationally bound.

Finally, double stars are most likely binary if the proper motion vectors of the stars are similar. The proper motion of SAO 55330 is -7.99 in RA and -19.97 in Dec. proper motion of SAO 55331 is -7.60 in RA and -21.52 in Dec. These values are of similar magnitude and direction, suggesting the 59 Andromedae system may be bina

Conclusions and Recommendations

While some research seminar projects are continuing to make double star measurements with astrometric eyepieces, this was the first semester we employed a more advanced and precise technique, lucky imaging. We were, generally, pleased our results and recommend that at least some future teams continue to use the high s EMCCD camera for their projects.

Future projects will, hopefully, improve on our calibration procedures. They could consider measuring multiple or dimmer doubles, perhaps some with much clo separations.

In analyzing whether or not 59 Andromedae is binary or optical in nature, we were unable to draw a decisive conclusion due to the conflicting parallax and proper motion evidence. The pair's separation and position angle also have not changed significantly enough to determine if their motion is linear or elliptical.

Finally, future student lucky imaging projects might consider reporting on mo stars in a single paper. They might also attempt to view dimmer, smaller separation doubles, exploring the limits of the observing equipment.

Acknowledgments

We thank Florent Losse for use of his REDUC software, the American Astronomical Society for providing a Small Research Grant to purchase the camera, Andor for supplying the camera at a discounted cost, and Jordan Fluitt for aiding us i observations. In addition, we made use of the U.S. Naval Observatory's Washington Double Star Catalog. We thank our external reviewers: Vera Wallen, ____. Finally, w would like to thank the Orion Observatory for the use of their telescope.

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Advancements in High School Research

- Evolution of the seminar
- Other advanced technique
  - Lyot Filar Micrometer
  - Speckle Interferometry
- More, More, More
  - More Stars
  - More Students
  - More Papers

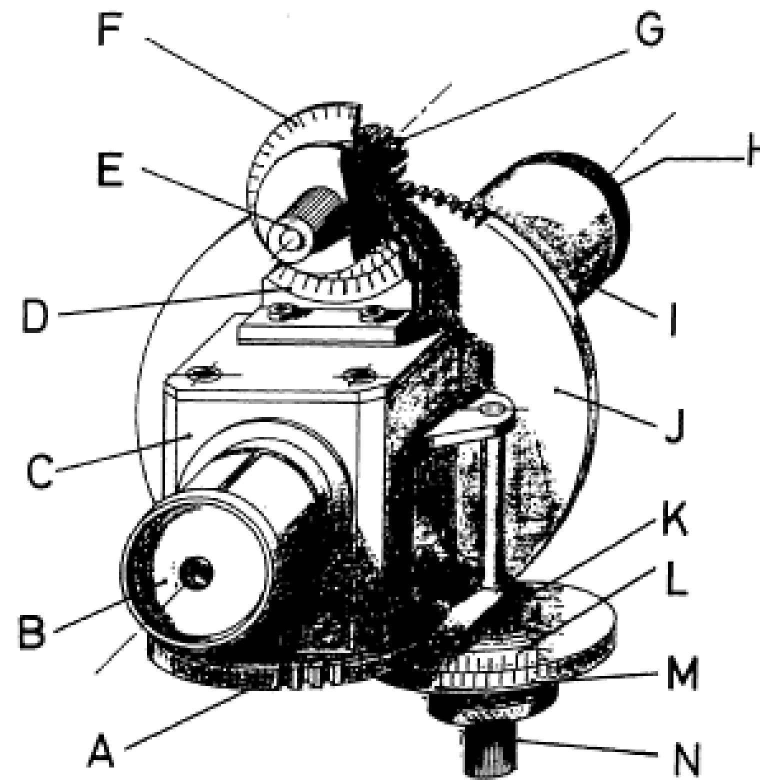

Figure 1. Mechanical details of the micrometer.
A – toothed wheel (120 teeth); B – eyepiece; C – main body; D – vernier; E – knurled knob; F – graduated drum (40 divisions); G – pinion (20 teeth); H – Barlow lens; I – sliding tube; J – toothed wheel (180 teeth); K – pinion (20 teeth); L – vernier; M – graduated drum (60 divisions); N – knurled knob.

The Future

- Possible outreach to younger students
  - "Get 'em while they're young!"
  - Down the road, there will be more students in Astronomy
- Spreading seminars like the plague
  - More seminars = more students in Astronomy
- Make Astronomy the new Football
  - ≈2500 NFL footballers
  - ≈1500 professional astronomers
    - (statistics from WolframAlpha)

Thank You