Speckle Interferometry of Binary Star HIP 4849

Matthew Kehrli, Heather David, Evan Drake, Corina Gonzalez,
Joe Zuchegno, and Russell Genet

California Polytechnic State University, San Luis Obispo, California

Abstract: Binary star HIP 4849 was observed on October 18, 2013 UT, using an EMCCD camera on the 2.1-Meter telescope at Kitt Peak National Observatory. HIP 4849 had a separation, ρ, of 0.725″ and a position angle, θ, of 79.32°. This observation did not deviate significantly from the predicted orbit.

Introduction

In 1970, French astronomer Antoine Labeyrie published a paper detailing a tool for the study of double stars. Labeyrie's background in holography aided his understanding of atmospheric speckles, or as he called them, "the grainy structure observed when a laser beam is reflected from a diffusing surface" (Labeyrie 1970). He suggested exposing speckle-affected images of double stars using a high-speed camera. This technique, known as speckle interferometry, allows astronomers to circumvent resolution limitations due to the "instantaneous image broadening ... or erratic displacement of the image," otherwise known as astronomical *seeing* (Vernin 1995). Based on the premise that "speckle-affected images contain more information on smaller features than long exposure images with a blurred speckle," speckle interferometry captures many short exposure images of double stars to take full advantage of the aperture of the telescope (Labeyrie 1970).

Many new double stars were discovered by the European Space Agency's Hipparcos satellite, starting in August 1989. Hipparcos was the first space mission dedicated to "measuring positions, distances, motions, brightness, and colors of stars" (Erickson 2015). The satellite was named in honor of Greek astronomer Hipparchus and abbreviated from High Precision Parallax Collecting Satellite to Hipparcos (Watson 1997). Data collected by Hipparcos resulted in a star catalog considered to be "the most accurate database of stellar positions ever produced" (Schilling 2004).

After achieving its goal as a pioneer for astrometric research, the Hipparcos observations were completed in March 1993. Michael Perryman, the project scientist and operations manager of the mission, offers insight on Hipparcos in *The Making of the World's Greatest Star Map* (2010). He documents that Hipparcos' success was due to the work of over 2,000 individuals. When the Hipparcos mission was planned in the 1980s, computational abilities were not yet advanced enough to reduce the data. Trusting Moore's Law, the increased computational capacity by the early 1990s made data release available (Perryman 2010).

Hipparcos made observations of more than 100,000 stars, many of which were doubles. Of the 12,000 double stars observed, Hipparcos discovered 3,406 new systems (Mason et al. 1999). Shortly after the Hipparcos results were published in 1997, astronomers began follow-up observations on the newly discovered double stars. Some of these showed the beginnings of apparent orbits, and prominent double star astronomers such as Elliott Horch on the 3.5-Meter WIYN telescope at Kitt Peak National Observatory, Yuri Balega on the 6-Meter BTA-6 telescope in Zelenchuksky, Russia, and Andrei Tokovinin on the 4.1-Meter SOAR telescope in Chile worked to compile additional measurements and determine these apparent orbits.

By now, astronomers have added many observational points beyond the original data published from Hipparcos in 1997. Many of the Hipparcos discoveries have proven to be binaries, some with short orbital periods. As a result, some of these observed doubles now have calculated orbits. This current study adds another observational point to the binary HIP 4849. Out of the 12 Hipparcos discoveries that now have published orbits and were also observed during the 2013 run at Kitt Peak National Observatory, we chose HIP 4849 based

Speckle Interferometry of Binary Star HIP 4849

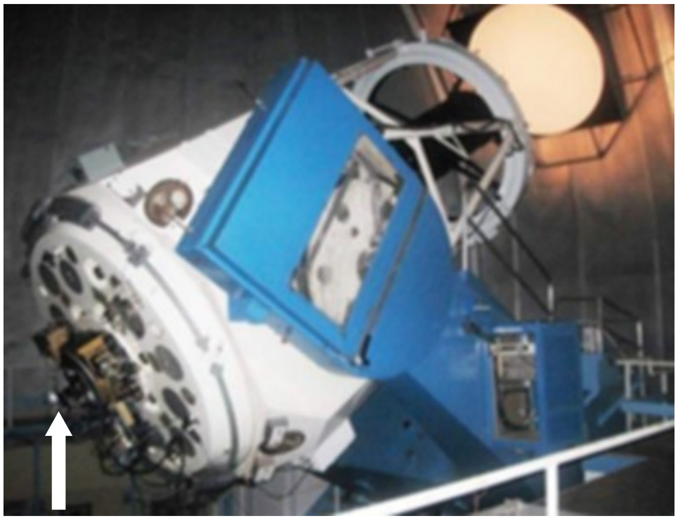

Figure 1. Kitt Peak 2.1-Meter Telescope (arrow denotes the EMCCD camera)

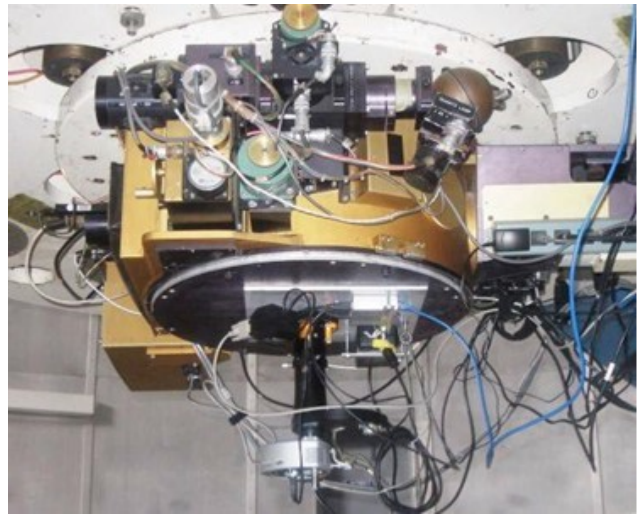

Figure 2. Camera System used at Kitt Peak

on its well-defined orbit with multiple plotted points.

The two goals of this study were to contribute a new position angle and separation to the published observations of HIP 4849, and serve as a pilot and companion project for a further study on the remaining 11 Hipparcos discoveries with known orbits observed at Kitt Peak.

Instrumentation, Observations, Calibration, and Reduction

Telescope

The binary HIP 4849, also identified as WDS 01024+0504, was observed on October 18, 2013 at 6:25:27 UT from Kitt Peak National Observatory. The observations were made on Kitt Peak's 2.1-Meter telescope, shown in Figure 1, which has a focal length of 16,200 mm (Genet et al. 2015b). The 2.1-Meter telescope is primarily used for imaging and spectroscopy (*2.1-Meter Telescope on Kitt Peak* 1998).

The instrumentation for Kitt Peak's 2.1-Meter telescope has undergone several upgrades since its creation. Originally equipped with an imaging camera and several spectrographs, it now includes modern infrared (IR) array cameras and spectrometers, the GoldCam Spectrograph, a charge-coupled device (CCD) imager, and the Phoenix infrared spectrometer (*2.1-Meter Telescope on Kitt Peak* 1998). Since Kitt Peak's 2.1-Meter telescope did not include the high-frame-rate, low-read noise camera needed for speckle interferometry observation, the observers supplied their own speckle interferometry camera (Genet 2013). The camera was attached to the acquisition guider unit and dwarfed by the 2.1-Meter telescope as shown in Figure 1.

Camera System

Inspired by the U.S. Naval Observatory's successful speckle observations of binaries using a portable image intensified charged coupled device (ICCD) speckle camera, a more portable, low-cost camera system, seen in Figure 2, was developed that featured an EMCCD camera (Genet 2013). The primary benefit of an EMCCD camera over an ICCD camera is that the "electron multiplication (EM) boosts the signal to a level where the high speed read noise is insignificant" (Genet et al. 2015a). The front-illuminated Andor Luca-R EMCCD had a quantum efficiency of about 50%, a dark noise of 0.05 electrons/pixel/second, and a read noise well under one electron RMS. The speckle camera system had a magnification of approximately 8x to provide an overall focal length of 129,600 mm and an F/ratio of 61.7 when attached to the 2.1-meter telescope (Genet et al. 2015b). The employed Andor Luca R EMCCD had "10 μ square pixels in a 658x496 pixel array" (Genet et al. 2015c).

Observations

The National Optical Astronomy Observatory's Time Allocation Committee granted eight nights of observing time to a team of university students and supporters. The team tested the equipment and conducted their observations on the nights of October 16th through 23^{rd,} 2013 at Kitt Peak National Observatory (Genet et al. 2015b).

Calibration

Observations were calibrated with data collected from multiple observations of six binaries with previously published orbits. The camera angle and plate scale were determined by comparing the data collected

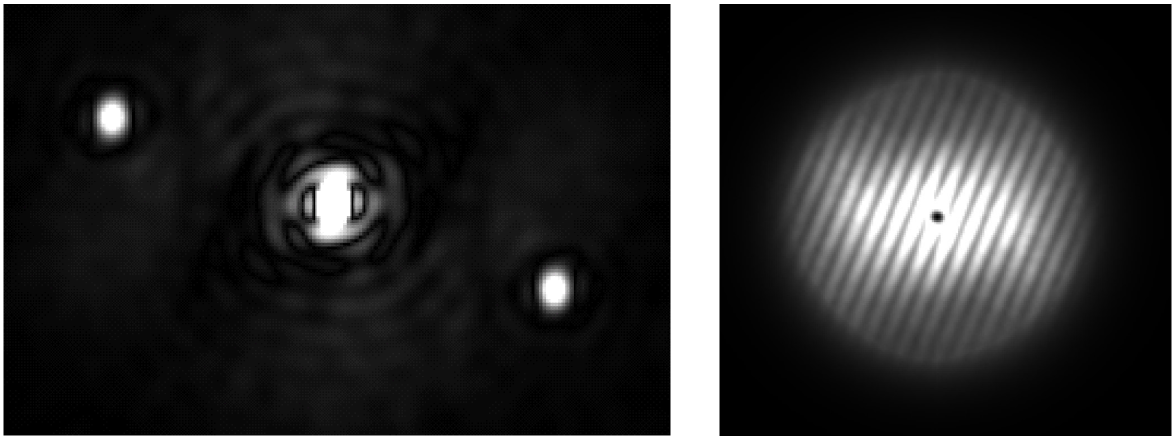

Figure 3. (Left): Autocorrelogram of the Binary HIP 4849; (Right): Power Spectral Density of the Binary HIP 4849

from the run with observed binaries with measured orbits (Wallace 2015). On the week of the observations, the camera angle was established as -11.0492° from true north and the plate scale was found to be 0.01166″ per pixel. Internal precision for the run was determined to be 0.027° and 0.00226″, while the overall accuracy was determined to be 0.4138° and 0.0147″. These values were taken from the statistical analysis of five calibration binaries made during the run (Wallace, 2015).

Reduction

HIP 4849 observations were reduced with PlateSolve 3.44, developed by David Rowe to create an autocorrelogram and power spectral density display of the double star, shown in Figure 3 (Rowe & Genet 2015). The autocorrelogram provided data on the position angle and separation between the stars. The Gaussian Lowpass was set to a 30-pixel radius while the Gaussian Highpass was set to a 3-pixel radius. The high and lowpass filters are important as they improve the signal-to-noise ratio of the images. These filters included the maximum amount of useful data while excluding all unwanted noise.

Results

The single FITS Cube was reduced six times using PlateSolve 3.44 Speckle Reduction tool. The annulus size and center of the target star were selected manually, producing the angle (θ) and separation of the binary (ρ) values as shown in Table 1. Note that the values for the standard deviation and standard error reflect only the internal precision of manually locating the reduction annulus to match the first airy null. These values do not account for any other sources of error that may result from calibration, instrumentation, et cetera.

Table 1. Reduced Data for HIP 4849 (taken from the manual data set)

Reduction	θ°	ρ"
1	79.23	0.724
2	79.44	0.724
3	79.31	0.723
4	79.36	0.725
5	79.21	0.730
6	79.38	0.723
Mean	79.32	0.725
Standard Deviation	0.09	0.003
Standard Error	± 0.04	± 0.001

Speckle Interferometry of Binary Star HIP 4849

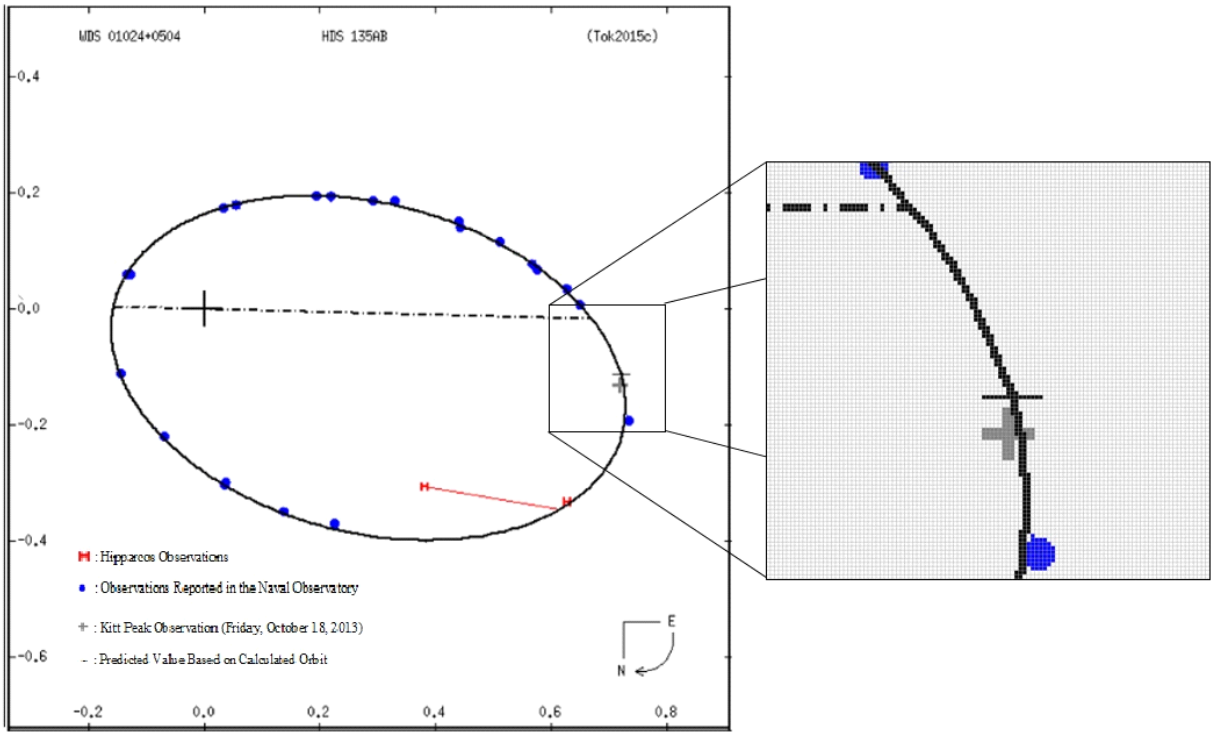

Figure 4. Orbit of Binary Star System HIP 4849. (the plus symbol denotes the added observation of HIP 4849 and the dash crossing the orbit is the predicted position provided by Jack Drummond)

Discussion

The autocorrelogram provided the position angle and separation of the secondary star relative to the primary star. HIP 4849 was compared with previous observations provided by the U.S. Naval Observatory. Using Microsoft Paint, it was determined that there were 0.2" in 97 display pixels. Therefore, the ratio of pixels per arcsecond was determined to be 485:1. This pixel ratio was calculated from the scales shown on the margins in Figure 4. Given the separation distance and angle found using PlateSolve, the distance in both the x and y direction was calculated in arcseconds. Once these values were converted to pixels, they were used to plot the binary (marked as a plus symbol in Figure 4). Our observation of HIP 4849 was plotted on the orbit showing previous observations and one subsequent observation. The location of our added observation in Figure 4 was only 0.0277" (13 pixels) away from the predicted orbit of the system.

To further evaluate the results of this study, the predicted values for the separation and position angle of the binary were determined. This was done using a binary calibration Excel spreadsheet which solves Kepler's equation for any given date. This spreadsheet, created and provided by Jack Drummond, can calculate the position of the secondary star given all published orbits (Drummond 2011). When the October 18, 2013 date was entered into the spreadsheet, it calculated a position angle for 81.0° and separation of 0.742″ for HIP 4849, marked as a dash on Figure 4. This small deviation is consistent with the other small deviations made by other observers since the binary's discovery.

Conclusion

By analyzing a 2013 observation made at Kitt Peak National Observatory of HIP 4849, this study accomplished the goal of adding a new point to the orbital ellipse of the binary. The plotted point did not deviate from patterns observed in previous research. The research served as a successful pilot project by highlighting the processes required for an expanded study on 11 additional binaries discovered by Hipparcos and observed in the Kitt Peak run.

Acknowledgments

We thank Kitt Peak National Observatory for providing the 2.1-Meter telescope used for observations, as well as the 2013 Kitt Peak observers. The speckle interferometry camera system was purchased with funds from the American Astronomical Society's Small Research Grant. We thank David Rowe for developing the PlateSolve 3.44 Speckle Reduction Tool. This research made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. We thank Jack Drummond for providing the calibration binaries spreadsheet. In addition, we are grateful for the reviews of this paper provided by Robert Buccheim, Richard Harshaw, William Hartkopf, Thomas C. Smith, and Vera Wallen. Finally, we would like to thank William and Linda Frost for providing funding for the Frost Undergraduate Summer Research Program at California Polytechnic State University, San Luis Obispo, California.

References

Drummond, J. 2011, "Calibration Binaries", *Proceedings of the Advanced Maui Optical and Space Surveillance Technologies Conference*, S. Ryan (Ed.), Wailea, Maui, Hawaii.

Erickson, K. Hipparcos. 2015. science.nasa.gov/missions/hipparcos/

Genet, R., Rowe, D., Smith, T. C., Teiche, A., Harshaw, R., Wallace, D., Weise, E., Wiley, E., Boyce, G., Boyce, P., Brantson, D., Chaney, K., Clark, K. R., Estrada, C., Frey, T., Estrada, R., Wayne, G., Huarberg, N., Kenney, J., Jones, G., Loftin, S., McGieson, I., Patel, R., Plummer, J., Ridgely, J., Trueblood, M., Westergren, D., and Wren, P., 2015a, "Kitt Peak Speckle Interferometry of Close Visual Binary Stars", *Journal of Double Star Observations,* **11**, 234 - 244.

Genet, R., M., Smith, T. C., Clark, K. R., Wren, P., Mathis, H., Summers, D., and Hansey, B. 2015b. "Portable Interferometry Camera Checkout at Kitt Peak", *Journal of Double Star Observations,* **11**, 226 - 233.

Genet, R. M., 2013, "Portable Speckle Interferometry Camera System", *Journal of Astronomical Instrumentation* **2**, 2.

Genet, R. Zirm, H., Francisco, R., Richards, J., Rowe, D., Gray, D. 2015c, "Two New Triple Star Systems with Detectable Inner Orbital Motions", *Journal of Double Star Observations* **11**, 200 - 213.

Hartkopf, W. I., Mason, B. D., Wycoff, G. L., McAllister, H.A. 2014, April 28. *Fourth Catalog of Interferometric Measurements of Binary Stars*.

Labeyrie, A., 1970, "Attainment of Diffraction Limited Resolution in Large Telescopes by Fourier Analysing Speckle Patterns in Star Images", *Astronomy and Astrophysics,* **6**, 85 - 87.

Mason, B., Martin, C., Hartkopf, W. I., Barry, D. J., Germain, M. E., Douglass, G. G., Worle, "Speckle Interferometry of New and Problem Hipparcos Binaries", *The Astronomical Journal*, **117**, 4, 1999.

Perryman, M., 2010, *The Making of History's Greatest Star Map*. New York: Springer.

Rowe, D. and Genet, R. M., 2015, "User's Guide to PS3 Speckle Interferometry Reduction Program", *Journal of Double Star Observations* **11**, 266 - 276.

Schilling, G., 2004, "Putting the Stars in Their Places", *Science* 306, 5700. 1312, *2.1-Meter Telescope on Kitt Peak*. 1998, July 31. www.noao.edu/kpno/40th/2.1m.html

Vernin, J. and Muñoz-Tuñon, C., 1995, "Measuring Astronomical Seeing: The DA/IAC DIMM", *Publications of the Astronomical Society of the Pacific* **107**, 709. 265-272.

Wallace, D., 2015, *An Investigation of Six Poorly Described Close Visual Double Stars Using Speckle Interferometry*, Master's Thesis, Dept. of Space Science, University of North Dakota, Grand Forks.

Watson, A. 1997, "Hipparcos Charts the Heavens", *Science*, **275**, 5303. 1064-1065.