Short-Period Eclipsing Binary KIC 3833859

June 2023 • University of California, Santa Barbara

KIC 3833859 is an eclipsing binary star system observed by NASA's Kepler satellite with right ascension 19:03:29.729 and declination +38:54:13.97, effective temperature 6011 K and an average magnitude of 11.9. Our goal was to measure the magnitude of KIC 3833859 over its 9.6 hour period and plot a light curve for the eclipsing event.

I. Introduction

Binary stars were first discovered in 1617 by Galileo Galilei, when he was observing the Big Dipper constellation with his telescope[1]. The term "binary" was first used to describe these objects by Sir William Herschel in 1802, who cataloged hundreds of binary systems[1]. The majority of the stars in the universe ($M \geq M_{\odot}$) are in a binary system, and how these systems form is a continual area of research that has provided the fields of astronomy and astrophysics with a wealth of information. There are two main processes that scientists have found that explain the formation: disk fragmentation and turbulent fragmentation. Disk fragmentation is a result of gravitational instability and results in the formation of close binary systems, whereas turbulent fragmentation of the star-forming molecular cloud can produce close or wide systems[2]. NASA's Kepler mission, launched March 2009, has observed over 200,000 of these binary systems with unprecedented photometric precision, which has revolutionized both the eclipsing binary and the exoplanet fields[3]. The light curves produced by observing eclipsing

---

KIC 3833859

KIC 3833859 has the following values in the Kepler Input Catalog:

Teff	kmag	RA	DEC	GLon	GLat
6011.0000	11.9870	285.8739	38.9039	69.5529	14.4743

1 ephemeris in the catalog:

InCat	period	period error	bjd_0	bjd_0 error	pdepth	sdepth	pwidth	swidth	sep	morph	LC data
True	0.4317433	0.0000003	54954.084827	0.025281	0.0879	0.0887	0.2328	0.2462	0.5009	0.99	data pf freq etv

Fig 1: KIC 3833859's input in the Kepler Catalog.

binary systems provide scientists with critical mass and radius measurements for each of the stars in the system, which allow for the testing of stellar evolution models.[3] These systems are also frequently used to determine astronomical distances, through luminosities calculated from the absolute radii of orbit and the stars' effective temperatures.[3] Distances measured to galaxies using values derived from eclipsing binary light curves are accurate to within 5%[4]. In particular, short-period binaries like KIC 3833859 are important for researching the evolution of low mass stars and the orbital period cutoff of 0.22 days, below which few systems have been observed.[5]

II. Methods

From Earth's point of view, the stars in the KIC 3833859 system eclipse each other, meaning at certain points in their orbit each star will pass in front of the other. This will dim the light from the system, and it is possible to observe the resulting drops in magnitude. There will be a more intense drop as the hotter (brighter) star is eclipsed, called the primary eclipse, and one less intense drop as the hotter star eclipses the dimmer and cooler star, called the secondary eclipse[6]. These drops in magnitude can be seen photometrically by imaging the star system over its period of orbit, which ensures the transit event is observed. The magnitude of the system can then be determined from the series of images, and when plotted against time produces a light curve that shows the changes in magnitude.

For our photometric observation of KIC 3933859, we submitted a request to the Las Cumbres Observatory (LCO), which is a network of 25 telescopes located across the globe. Our images were taken by the 0.4m telescopes fitted with an SBIG STL-6303 camera. We requested the observatory to take 5-10 photos over the system's 9.6 hour period, and by having a number of images over the system's period of orbit, we planned to find the magnitude of the star from each image and plot those data against time to produce a light curve of the transit event.

Target Name	RA (J2000)	Dec (J2000)	Filter	# Exposures	Integration Time (s)	Observational Windows
KIC 3833859	285.8739	38.9039	g	4	12	Period: 0.4 days 5-10 photos within that frame
KIC 3833859	285.8739	38.9039	g	1-2	12	Period: 9 hours 5-10 photos over full 9 hours
KIC 3833859	19 03 29.729	+38 54 13.97	R	6	10	[redacted]
KIC 3833859	19 03 29.729	+38 54 13.97	B	6	10	[redacted]

Fig 2: Our observational requests for the system.

The LCO's SBIG STL-6303 camera has a field of view of 29.2 x 19.5 arcminutes, a pixel size of 0.571 arcseconds, and has filters SDSS (Sloan Digital Sky Survey) u', g', r', i', Johnson-Cousins B, V, and Pan-STARRS w, z_s. Because the KIC 3833859 system is a visual binary, and it therefore made the most sense to have the photos taken in the visible light spectrum, the SDSS g, r, and Bessell B (green, red, and blue, respectively) filters were used. These different color filters were used to achieve the best possible resolution of the system and to provide a RGB color photo of the stars.

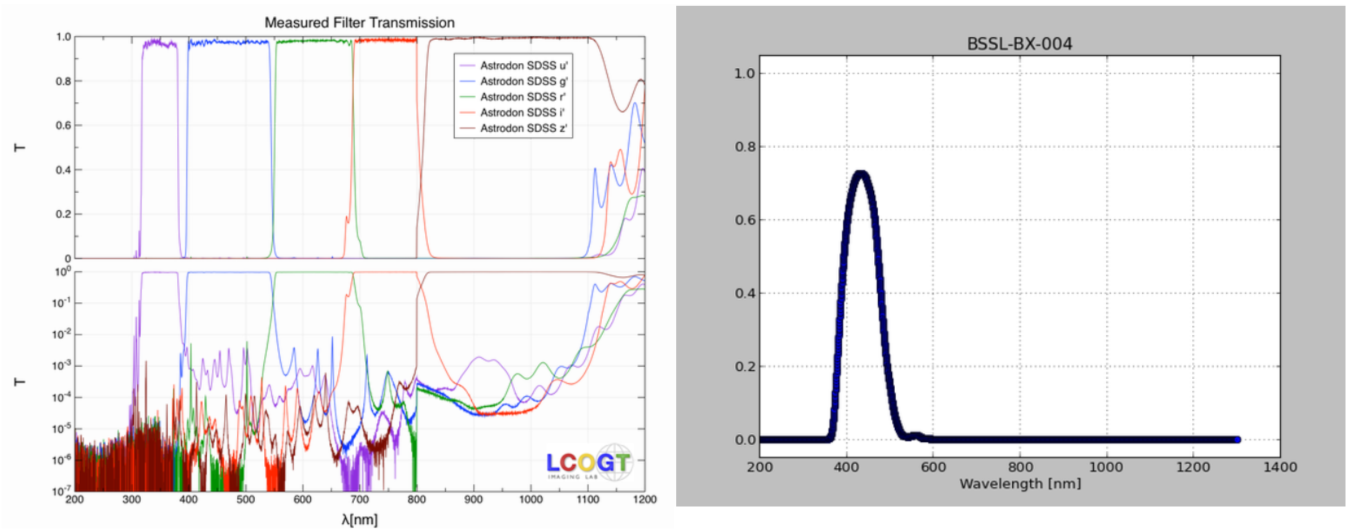

Fig 3: Transmitted wavelengths of the SDSS and Bessell B filters[7][8].

The images were automatically processed by the LCO using their BANZAI pipeline, which performs bad-pixel masking, bias and dark subtraction, flat-field correction, and astrometric calibration. The pipeline, coded in python and launched in April 2016, evolved from a group of image processing algorithms written by the 2014 Global Supernova Project team. It runs automatically and is maintained by the scientists of the LCO[9]. This processing helped sharpen our images and reduce a lot of the background noise. Once we had the photos, we converted them from .fz files to .fits files as described for the Windows operating system on the LCO website[10]. We then loaded them into AstroArt to begin processing the data. Using AstroArt's preprocessing tool, we summed the images in each time frame and in each color filter to obtain an average image. Next, we needed to increase the clarity of the images we downloaded, and we did this using the Deconvolution tool in AstroArt. Once the images were summed and sharpened, we determined which star in each image was our system using AstroArt's Star Atlas tool. To do this we selected the brightest 5-7 stars in each image, opened the Star Atlas, and selected the "Reference Stars: Automatic" tool which automatically matches the stars in the image to the correct area of the sky. KIC 3833859 was located in the GAIA catalog of stars. We then used the cursor to find the exact right ascension and declination of the system and located the correct star. Next, because we wanted to measure the magnitude of KIC 3833859, we needed to align the stars in our images with the Star Atlas. This is because AstroArt does not have the Kepler catalog in its system, and it needed to reference the magnitudes of the other stars in the catalogs it does have. Once the images were aligned we were able to determine the magnitude of our star, which on average was 11.8. To produce a color image of our system, we summed the images in each filter category and used AstroArt's Color tool, which outputs an RGB image from individual red, green, and blue filter images (Figure 5).

III. Results

Our initial observation request for KIC 3933859 was only over approximately an hour (data listed in Table 1). We then realized that this was not enough data to accurately observe the transit event, so we submitted another request for a roughly 20-hour period (data listed in Table 2). The data from our first request does show an increase in magnitude (decrease in brightness), and we initially believed this was the transit event; however, the data from the second request shows a larger increase in magnitude overall, preceded by a smaller increase in magnitude (see Figure 3). The data appear to indicate that the increase in magnitude in our initial observation correlates to the initial magnitude "bump" that precedes the largest in our second observation.

Table 1: Magnitude of KIC 3833859 over one hour; times measured from when observation began.

Time (hrs)	Magnitude
0.105	11.90
0.194	11.83
0.268	12.33
0.437	11.82
0.937	11.81

Table 2: Results from our second observational request. Magnitudes obtained during hours ≈ 5 - 16 may correspond to the data in Table 1.

Time (hrs)	**Magnitude**
0.00	11.87
0.89	11.21
1.89	11.03
2.89	11.18
3.94	11.09
4.91	11.18
5.89	11.05
14.36	12.08
14.98	12.23
15.90	11.86
16.89	14.27
17.89	11.94
18.89	10.94
19.89	12.77

Although there is no way to align the timestamps between the two sets of data because the times listed are hours after observation began and not absolute time, given the apparent close correlation between the changes in magnitude in each set it is likely that our first observation only saw the beginning of the transit event. If that is true, then the first set of data would correspond to the magnitudes obtained during hours ≈ 5 - 16 in the second set. A weakness in this correlation is the shape of the curves in Figures 4 and 5. After the peak at magnitude ≈ 12.3 ($t = 0.27$) in Figure 5, the curve flattens out relatively quickly, whereas after the small peak at $t = 15$ in Figure 4 the curve drops sharply. This could be a result of scaling factors in the graphs, or an indication that the two peaks do not represent the same event in the orbital period.

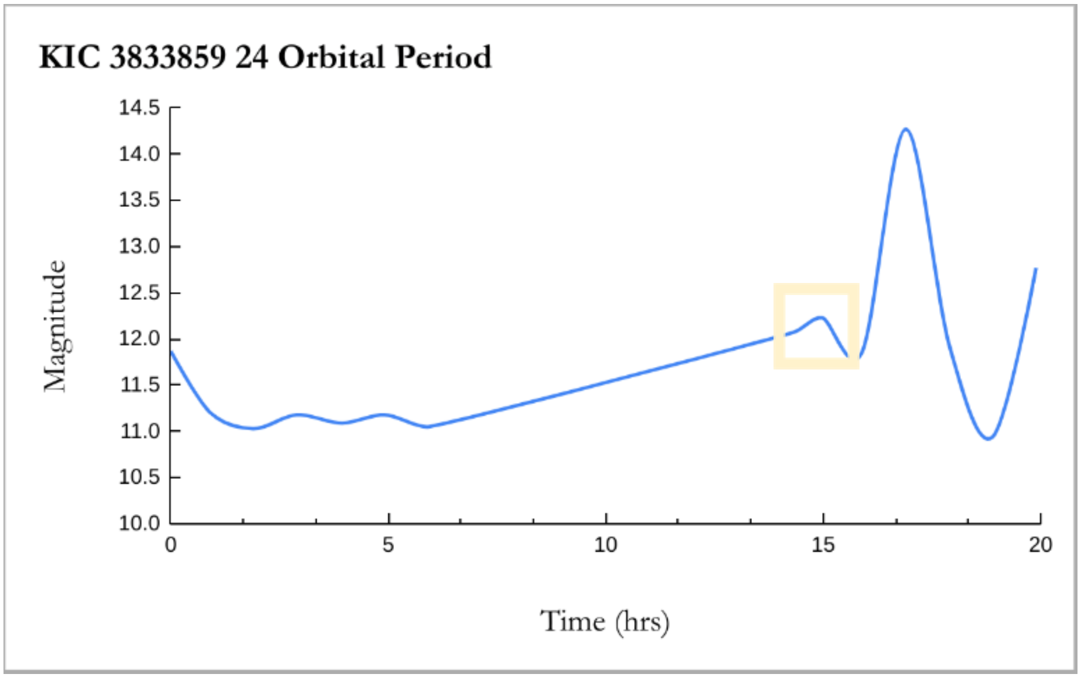

Fig 4: Magnitude of KIC 3833859 over roughly a day.

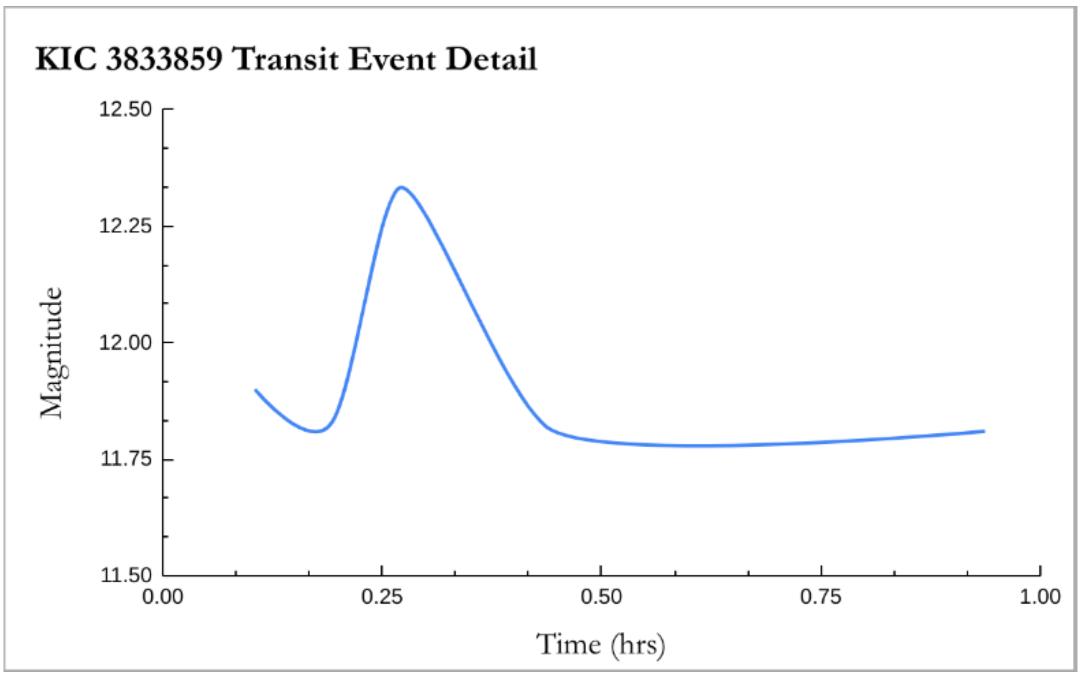

Fig 5: Possible second eclipse of the system, outlined in yellow on Figure 4.

In order to determine the uncertainty in the magnitudes we found for KIC 3833859, we needed to calculate a signal-to-noise ratio, using (1)[11].

$$\frac{S}{N} = \frac{FA\tau}{[N_R^2 + \tau N_T]^{1/2}} \quad (1)$$

where

$$N_T = FA + i_{DC} + F_\beta A\Omega \tag{2}$$

Table 3: Values from our observation request, and the LCO site[12].

$N_R\ (e^-)$	N_T	τ (s)	$F\ (\gamma/s\ cm^2)$	$A\ (cm^2)$	Ω (arcsec)	$i_{DC}\ (e^-)$
14.5	337.3	12	10^{-2}	5026	0.571	0.03

We used the values listed in Table 3, which resulted in a $\frac{S}{N}$ of 92.43, which gave us an uncertainty in magnitude ($\frac{1}{S/N}$) of 0.011. Because the signal-to-noise ratio is high, it means there was not a lot of background noise in the images we received. This is due in large part to the BANZAI processing that LCO performed. The unprocessed images have a greater amount of noise compared to the processed ones (Figure 6).

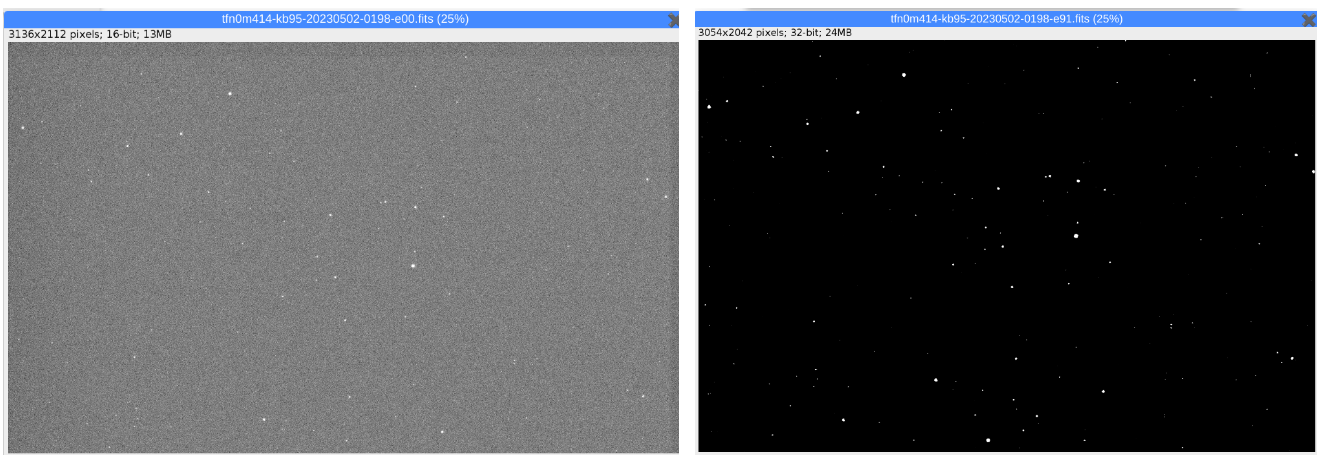

Fig 6: Raw image (left), BANZAI processed image (right).

The main source of error in our research was a lack of data; while we had enough measurements to produce a light curve of the transit event and determine the magnitude of KIC 3833859 over its period of orbit, more data over multiple days would have resulted in more accurate magnitude measurements and would have allowed us to produce a smoother light curve. Despite having only minimal data, we did not have a large percent error with regard to the average magnitude calculated. From our first observation, the average magnitude calculated was

11.938, which gives a percent error of 0.4% from its value of 11.987 in the Kepler catalog. From our second observation the average was 11.764, which gives a percent error of 1.86%.

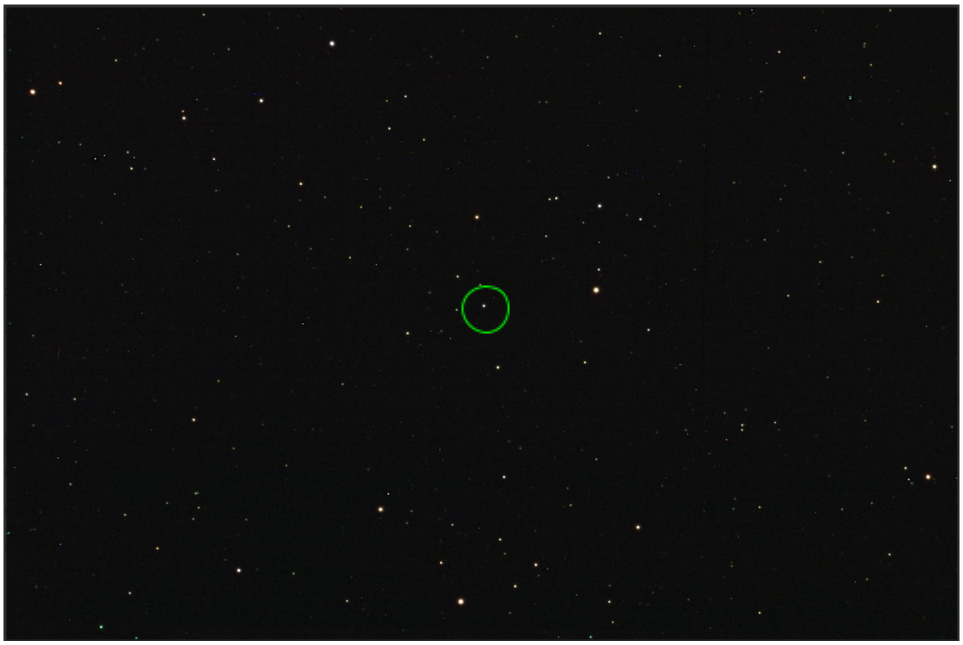

Fig 7: RGB image of KIC 3833859 (green circle)

IV. Discussion

Our results for the most part match what we expected to see: a fairly constant magnitude over most of the observational period and a dip in brightness (increase in magnitude) while one of the stars in the system occults the other. While the two drops in magnitude we observed could be a result of errors in our data collection, it is more likely that they represent the primary and secondary eclipses of the system. The first and shallowest dip in brightness would correspond to the secondary eclipse when the brighter star in KIC 3833859 occults the dimmer star. The largest dip in brightness would then be the primary eclipse, as the brighter star is occulted. However, due to our lack of repeated observation, we cannot know for certain if this is the case.

The light curve we produced is an integral part of determining astronomical distances. Along with radial velocity curves, it provides the fractional radii of each star and when those are combined with the spectroscopic data of the system, can be used to determine the physical radii and temperatures of the stars. Comparison of the system's observed spectrum to theoretical ones provides luminosity, and when the luminosity of the stars are compared to their observed brightness, the redshift and therefore distance to the system can be determined[3].

The main limitation in our research was the lack of data, as mentioned in the Results section. If we were to continue researching the system, it would be beneficial to observe the system over a longer period of time, at least 10 days. This would ensure we had multiple sets of data over the full period of orbit, which would lead to more accurate magnitude measurements and a better light curve. Data taken over a long period of time would allow us to see a better pattern of the transit event and the dimming and brightening of the stars. From the data we have now it is not completely evident whether we are indeed witnessing two eclipses or if the two dips in brightness are a result of imprecision in our measurements and background noise. An improved light curve could then be used to determine the physical parameters of the system as detailed above.

References

[1] Space.com Staff. “Binary Star Systems: Classification and Evolution.” *Space.Com*, 17 Jan. 2018, www.space.com/22509-binary-stars.html.

[2] Tobin, John J., et al. “The VLA/Alma Nascent Disk and Multiplicity (VANDAM) Survey of Perseus Protostars. vi. Characterizing the Formation Mechanism for Close Multiple Systems.” *The Astrophysical Journal*, vol. 867, no. 1, 2018, p. 43, https://doi.org/10.3847/1538-4357/aae1f7.

[3] Kirk, Brian, et al. “*Kepler* Eclipsing Binary Stars. Vii. The Catalog of Eclipsing Binaries Found in the Entire *Kepler* Data Set.” *The Astronomical Journal*, vol. 151, no. 3, 2016, p. 68, https://doi.org/10.3847/0004-6256/151/3/68.

[4] Bonanos, Alceste Z. “Eclipsing Binaries: Tools for Calibrating the Extragalactic Distance Scale.” *Proceedings of the International Astronomical Union*, vol. 2, no. S240, 2006, pp. 79–87, https://doi.org/10.1017/s1743921307003845.

[5] Bienias, John, et al. “Background Short-Period Eclipsing Binaries in the Original Kepler Field.” *The Astrophysical Journal Supplement Series*, vol. 256, no. 1, 2021, p. 11, https://doi.org/10.3847/1538-4365/ac10c0.

[6] Nave, R. “Eclipsing Binary Stars.” *HyperPhysics*, 2016, hyperphysics.phy-astr.gsu.edu/hbase/Starlog/bispect.html.

[7] “SDSS G’.” *Las Cumbres Observatory*, lco.global/observatory/instruments/filters/sdss-g/. Accessed 13 June 2023.

[8] “Bessell B.” *Las Cumbres Observatory,* lco.global/observatory/instruments/filters/bessell-b/.Accessed 13 June 2023.

[9] “Data Pipeline.” *Las Cumbres Observatory,* lco.global/documentation/data/BANZAIpipeline/.Accessed 3 June 2023.

[10] “Decompressing FPacked Data.” *Las Cumbres Observatory,*https://lco.global/education/observing/fpack/.Accessed 10 June 2023.

[11] Lubin, Philip. “Notes for PHYS 134: Observational Astrophysics .” Physics 134L, 2022. University of California, Santa Barbara.

[12] “SBIG STL-6303.” *Las Cumbres Observatory,* https://lco.global/observatory/instruments/sbig-stl-6303/.Accessed 3 June 2023.