Photometric analysis using light curve of eclipsing binary SW Lac

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ABSTRACT

Photometric analysis of eclipsing binaries (EB), systems of two stars orbiting one another, allow astronomers to better understand their physical qualities by tracking the system's brightness through a light curve. SW Lac is a bright EB star system with a short period, making it a good source to observe due to its variable light curve. Aperture photometry was used to track the brightness of SW Lac based on images of our observations from the 0.4 meter telescopes from the Las Cumbres Observatory. We found the brightness of SW Lac relative to BD+37 4715, a second bright standard star in the field of view, giving us the relative magnitude of SW Lac. By plotting the brightness over time, we were able to create a light curve and add a point to an *O-C* (*Observed Eclipse Time - Calculated Time*) diagram originally from Yuan & Şenavcı (2014). After aligning our light curve with archival data from Albayrak et al. (2004), we found that the light curves did not match up exactly and concluded that the orbit of SW Lac is changing. In addition, we found that the new *O-C* point matched the trend of the archival *O-C* diagram.

I. INTRODUCTION

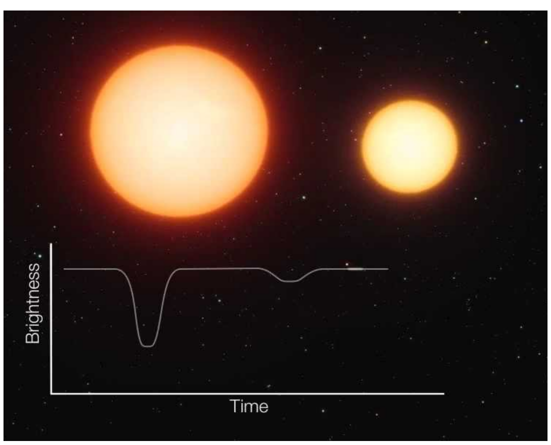

FIG. 1. Artist's impression of an eclipsing binary star and it's varying brightness over time (Youtube - AlphaOmegaParadigm)

FIG. 2. An image of SW Lac acquired from Aladin Lite

Eclipsing binaries are systems of two stars that orbit each other, rotating around a common center of mass. Depending on the inclination of the binary, or how the plane of the binary is angled, we can observe the stars eclipsing each other from Earth, producing a light curve of brightness vs. time as seen in Fig. 1. The dips in the light curve occur when one star eclipses the other, and in a normal two star binary system, two dips, or minima, can be seen on the light curve. Analyzing light curves of eclipsing binaries (EB) allow astronomers to better understand their physical qualities, such as inclination, period, and transit depth. It can also help identify the type of eclipsing binary. The W UMa-type eclipsing binary is a special case of eclipsing binary where the stars are in contact with each other, transferring energy and mass. SW Lac, as shown in Fig. 2, is a bright W UMa-type eclipsing binary star system with a short period, making it a good source to observe due to the continuous variable light curve it produces. Essam, A., et al (2014) suggests it has ellipsoidal components and peaks of similar magnitude. Access to the Las Cumbres Observatory enabled us to use their network of 0.4 meter telescopes to observe the eclipsing binary SW Lac. In order to maximize our observations, we applied the g filter with an exposure time of 50 seconds to prevent oversaturation and an adequate signal to noise ratio. We used Python to generate new light curves of SW Lac from data based on our observations and used the data from the light curve to add a new point to the *O-C* (*Observed Eclipse Time - Calculated Time*) diagram originally from Yuan & Şenavcı (2014). We also validated our data with previous archival data.

II. METHODOLOGY

We are using data obtained from the network of 0.4 meter telescopes at the Las Cumbres Observatory. By remotely scheduling observation times, we took 8 shots of the SW Lac binary at different times to track its eclipsing path. We chose the gp filter (G), since we used SW Lac's G filter magnitude (8.9455) while looking for a suitable star to study.

Aperture photometry was used to find the difference between the aperture summed flux of SW Lac and the second brightest standard star near it as a relative anchor star. The flux was then used to calculate the instrumental magnitude, which is similar to brightness, with the equation below in Fig. 3. Since the standard star should remain constant, if both SW Lac and the standard star have a large shift in brightness, we know that the change is not a result of SW Lac's variability. Thus, anchoring the brightness of SW Lac to a standard star will give us more accurate results.

$$m = -2.5\log_{10}((sw\_lac\_aperture\_sum - bd\_37\_4715\_aperture\_sum)/exposure\_time)$$

FIG. 3. Relative magnitude of SW Lac calculation

$$f_t = (brightness\_star - brightness\_comp\_star)/exposure\_time$$

$$\sigma^2_{ft} = \frac{var\_brightness\_star + var\_brightness\_comp\_star}{exposure\_time^2}$$

$$\sigma^2_{\text{magnitude}} = \sigma^2_{ft}\left(\frac{2.5}{f_t\ln(10)}\right)^2$$

FIG. 4. Formal propagation of uncertainty to get the uncertainty of the instrumental magnitude. The variables $var\_brightness\_star$ and $var\_brightness\_comp\_star$ represent the variance of $brightness\_star$ and $brightness\_comp\_star$ respectively.

We used the Python programming language and many popular scientific Python libraries to aid our research. We used `numpy` and `astropy` to handle and manipulate our data for our photometric techniques. We used `photutils` to locate stars based on their apparent brightness in the `FITS` files (Fig. 5 and 6), which helped us pinpoint the location of SW Lac and neighboring anchor stars and calculate the aperture sum of those stars. We then calculated the instrumental magnitudes and fluxes of the stars (Fig 3. and Fig 4.), then plotted those values on a graph using `matplotlib`. We also used `symfit` to help generate a line of best fit. To calculate the value of *O-C*, we used the methods detailed by Sterken, C. (2005) for constant periods. We also used Python as a tool to calculate and plot our *O-C* graph.

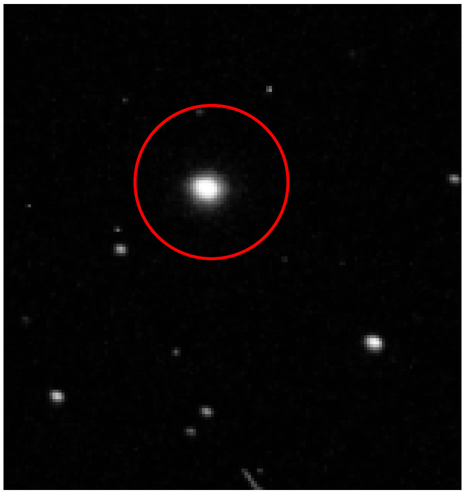

FIG. 5. `FITS` file image of SW Lac (circled) from our observations.

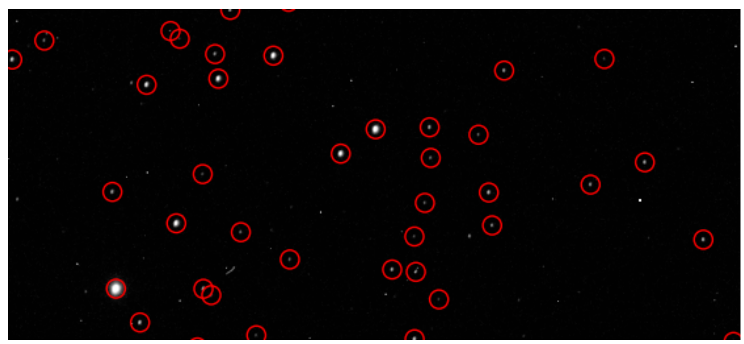

FIG. 6. Algorithm using **`photutils`** to locate stars (circled in red). SW Lac (bottom left) is the brightest star in the field of view, which makes it easy to locate.

Since the period of SW Lac is greater than our given observation time, we were limited in the number and length of the observations. In order to remedy this, eight observations of varying times between 22.5 minutes to 45 minutes were taken, allowing us to cover each quarter of the 7.6 hour orbit. In total, we had 137 observations. However, small differences in SW Lac's orbit over each period would have skewed our results. We decided to take two observations at the same quarter of the period in an attempt to get overlapping data. However, we noticed that our second observation had varied significantly in magnitude in the short observation period, compared to the other observations. Thus, we ruled that this observation was an outlier and removed it from further processing.

For calculating our *O-C* value, some sources of error may have arisen from our time of observation. We were not able to find the exact time of minimum brightness for the eclipse, so our *O-C* value could be off by a few minutes. Additionally, we were unable to find the uncertainty of the values from our archival data, so we could not find the uncertainty of our *O-C* value.

III. RESULTS / ANALYSIS

A. Light curve of SW Lac

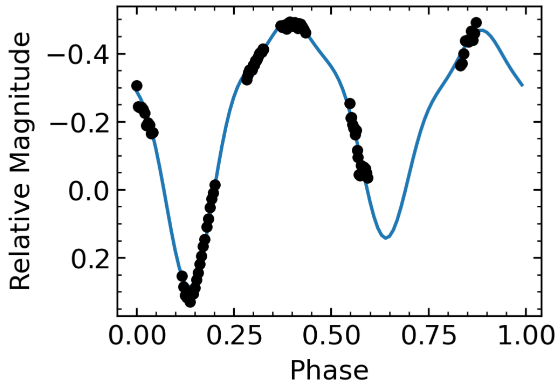

FIG. 7. First light curve generated of SW Lac. Solid blue line represents Fourier fitted line of best fit.

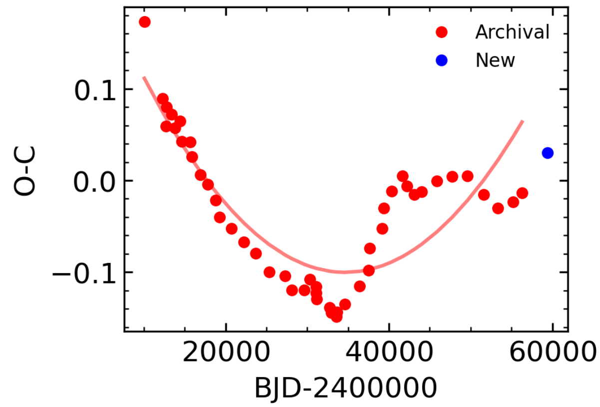

FIG. 8. Graph of *O - C* diagram. Red data points are from archival data (#) and blue data point is our new data. Solid red line is a second degree polynomial line of best fit.

We obtained the light curve of SW Lac (Fig. 7) from eight 22 - 45 minute observations over the span of a week. Though our light curve is segmented, we have enough data to understand what the complete light curve would look like and compare it with other curves in literature. The light curve is ellipsoidal, has eclipse times larger than 0.25 phases with no flat segments. These features are indicative of a contact binary's light curve.

The line of best fit was created using the Python package `symfit` with a Fourier series also used by Dey et al. (2015) for light curve fitting.

Due to our segmented observations, we were unable to produce a light curve that would give us an accurate period. We decided to use the period, 0.320722, found by Peña, J. H., et al. (1993) to calculate the phase, or the part of the period, of each observation, which we then used to graph the relative magnitude of each observation, as seen in Fig. 10.

B. *O-C* diagram of SW Lac

From our observation of the eclipse minima, we were able to calculate and add a new point to the *O-C (Observed Eclipse Time - Calculated Time)* diagram (Fig. 8) originally produced by Yuan & Şenavcı (2014). To compute the calculated eclipse time, we used the same equation as Yuan & Şenavcı (2014), which was given by Kreiner, Kim & Nha (2000).

$$Min\ I = JD\ Hel\ 24\ 38708.323 + 0.3207183 * E$$

The value of *O-C* was 0.0301592 days or 43 minutes, meaning that our observed time was 43 minutes past our calculated time. The value follows the archival trend of the *O-C* diagram where the values of *O-C* are starting to increase past 0.

IV. DISCUSSION / CONCLUSION

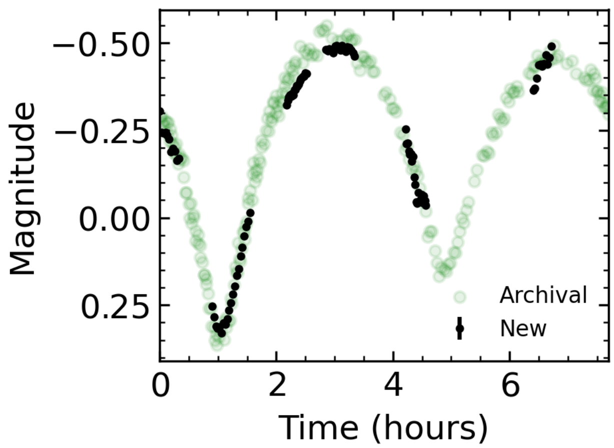

FIG. 10. Light curve generated of SW Lac overlaid with the the light curve from Albayrak et al. (2004)

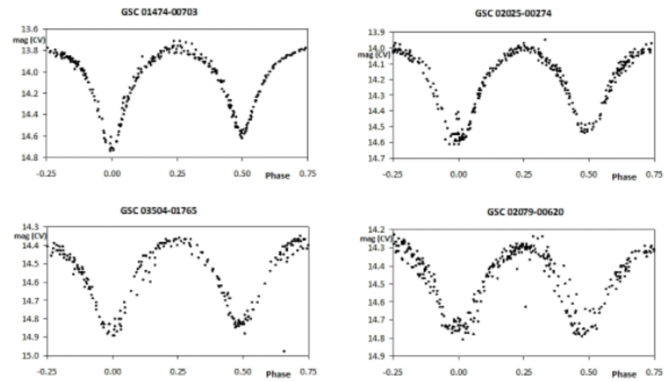

FIG. 11. Light curves of 4 different W UMa-type binaries from Hummerich, Bernhard & Srdoc (2013). Notice the ellipsoidal shape and similar magnitude minima.

In order to compare our light curve to archival data, we overlaid the light curve from Albayrak et al. (2004), as seen in Fig. 10. The light curves have a similar structure, but do not fit perfectly. We conclude that the orbit of the contact binary is changing slightly and is thus changing the brightness of the system at each phase. We also compared our light curve's structure to other light curves of W UMa-type binary systems. Our light curve has many of the same characteristics seen in other W UMa-type light curves, such as those in Fig. 11, like peaks with similar magnitudes and ellipsoidal components, and the lack of flat segments which can often be seen in other light curves of non W-UMa type binaries (such as in Algol-type binaries). Thus, we can conclude that SW Lac is indeed a W UMa-type binary as seen by its light curve.

Using the eclipse time equation from Kreiner, Kim & Nha (2000), we found the predicted eclipse time to be 2021-07-16 03:38:37.239 or 2459411.651819896 JD. In comparison, we observed the eclipse time to be 2021-07-16 04:22:03.000 or 2459411.681979167 JD. Thus, there is a 0.0301592 difference in JD, which is our *O-C* value. We concluded that the small *O-C* value followed the trend of the archival *O-C* diagram (Fig. 8) from Yuan & Şenavcı (2014), which, based on a parabolic fit, predicted an increase in *O-C*. The *O-C* value shows that SW Lac's period and orbit are still varying. There are various different explanations for changes in orbital period, but we believe the one that is most relevant in this situation is that mass from one star in SW Lac's system is being transferred to the other star. This behavior has been exhibited in other W UMa-type binary star systems, and, as detailed by Livaniou (2020), could also explain SW Lac's variation.

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AUTHOR CONTRIBUTION STATEMENT

J.Y. constructed the *O-C* graph. All authors worked on creating the light curve, scheduled observations, and collaborated on the research slides and presentation script.