Shedding Light on Obscura - Confirming the Existence of an Exoplanet

Researchers: Angelina Deighton, Joshua Gohres, Sarah Jauregui, Audrey Omand, Mackaelan Songco, Flora Wang

Mentors: Andrew McHaty, Colin Smith

University of California, Berkeley - Undergraduate Lab at Berkeley, Physics & Astronomy Division

Introduction

In our project we sought to confirm an undiscovered exoplanet. Using data from the TESS (Transiting Exoplanet Survey Satellite) database (1), we identified potential candidates by analysing their light curves and parameters. With our chosen candidate we used the Leuschner Observatory (2) in an attempt to capture a transit of the exoplanet. Refining code that was handed down to us, we ran the data we collected to generate a light curve. By analysing the shape of the light curve we are able to determine whether the candidate was in fact an exoplanet or not. Also, to decrease our error and ensure our light curve is not the result of noise, a binary star system, or an orbiting non-planet object we had multiple observations.

Background: Exoplanets are planets that exist outside our solar system and orbit a host star. The first confirmed detection of an exoplanet was in 1995, and since then over 5000 have been confirmed.(3) A common way to detect exoplanets is via the transiting method which works by waiting for the hypothetical exoplanet to pass in front of the star, causing a dip in the star's flux.(4) Looking at the curve created by plotting the star's flux as a function of time, we can tell whether or not the transit was caused by an exoplanet. For an exoplanet we look for a u-shaped curve, otherwise the curve may be a false positive, dips in flux due to a binary star system, noise, or non-planet orbiting bodies.

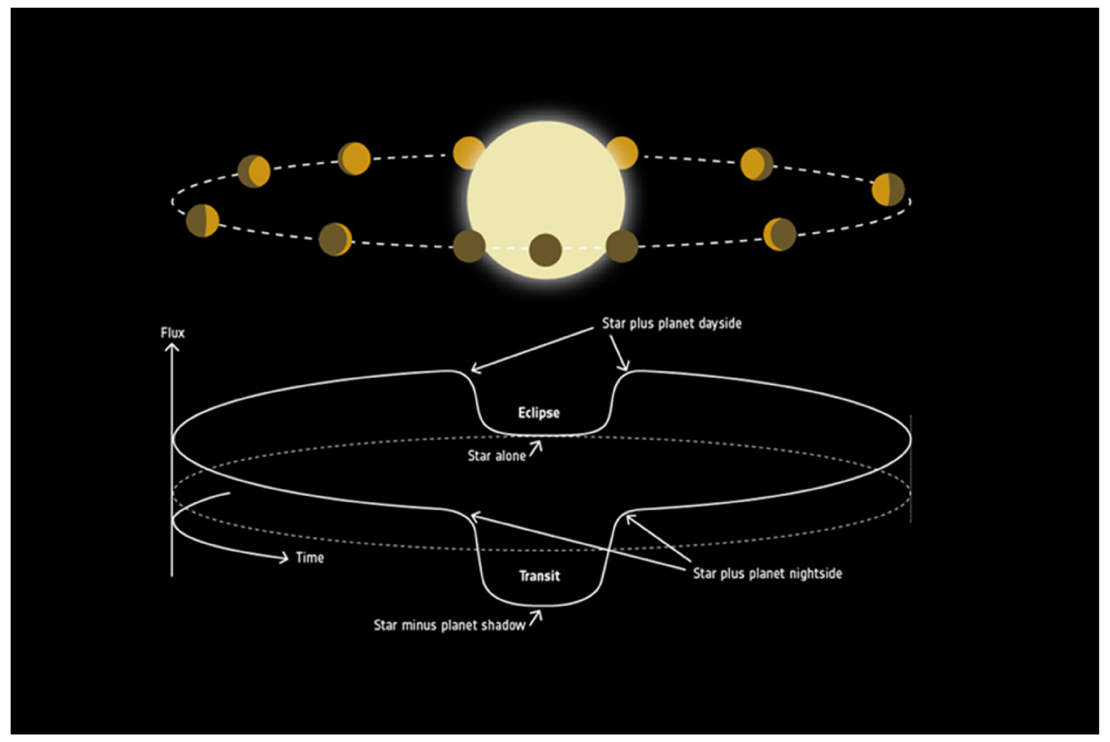

Figure 1. Depiction of Exoplanet Transit[5]

Methodology - Choosing a Candidate

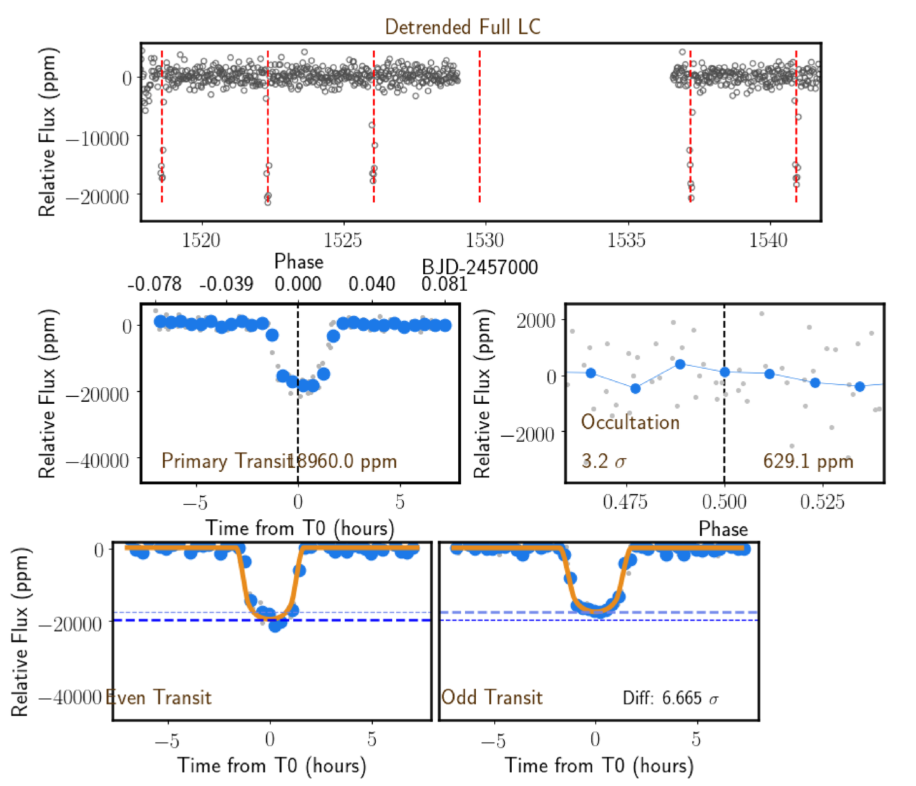

Figure 2. TESS Report[1]

In the first stage of our project, we identified high-probability exoplanet candidates by analyzing key features in TESS reports: relative flux graph, signal-to-noise ratio (SNR), and occultation number. For relative flux, a U-shaped flux curve suggests a planet transit, while a V-shape may indicate a variable star. An SNR above 50 is key for clarity in our observations and an occultation difference or transit difference under 5σ is ideal to rule out multiple-body systems. Candidates also needed a radius under 20 for it to plausibly be a planet. An R_p/R_{star} ratio near 0.1 for the flux dip is required to be detectable. To ensure observability from the Leuschner Telescope in Lafayette, CA, we needed an RA between 8–12 hours and DEC between 5–70°. We prioritized candidates with multiple monthly transits that lasted under six hours to increase observation opportunities.

Observations

Having chosen our candidate, we began observing transit. We observed three times with two of them being full transits. In addition to the potential candidate we found, we also spent a night observing the candidate from last year, "Sundialia."

On observation nights, we would set up the Leuschner telescope to focus on the exoplanet we were observing. For transits, we would take 120-second-long exposures. In addition, we would also take photos of transit, we would take darks and bias frames. We would take around 10 to 20 of these. In addition, during sunset or sunrise, we would take flats because this was the only time they could be taken, being around 15 minutes after either, leading us to take them before or after observing the transit. The dome that houses the Leuschner telescope has an auto-adjustment feature that moves when the telescope moves to follow the exoplanet. Due to programming errors, during two of our observations, it did not work, so we had to manually rotate the dome to prevent it from blocking the telescope.

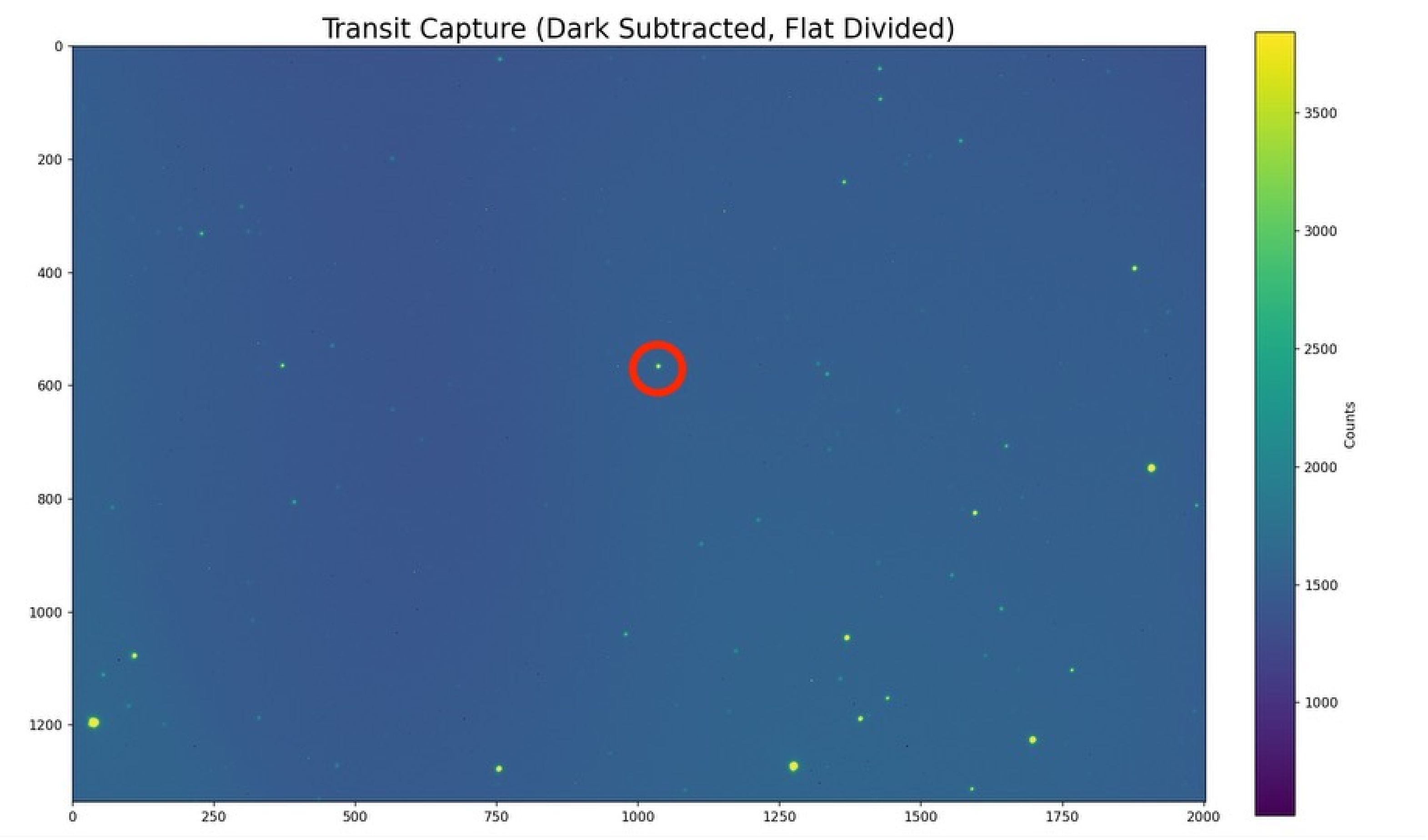

Figure 3. Caption

Air Mass Correction

For our air mass correction computation we first needed to convert from flux to magnitudes using the conversion:

$$\frac{F_2}{F_1} = 10^{-0.4\,(m_2 - m_1)},$$

and then used the Kasten-Young formula to find the air mass at the given zenith-angle:

$$\mathrm{X_{KY}} = \frac{1}{\cos z + 0.50572\left(96.07995° - z\right)^{-1.6364}},$$

This fit is more ideal for our observations as it can account for altitudes approaching 10 degrees and our last observation remained within a relatively low altitude threshold throughout the transit. With this, the first-order correction becomes:

$$\mathrm{F_{corrected}} = F_{\mathrm{obs}} \times 10^{0.4\,k\,X},$$

With our k value being set to roughly 0.25-0.4, or the average V-band extinction for earth on a clear or dusty night respectively.

Acknowledgements

We would like to express our deepest gratitude to Professor Alan Chew for his invaluable mentorship throughout this project. His guidance in telescope operation, data collection, and observational troubleshooting was crucial to the success of our transit measurements. We also sincerely thank the Undergraduate Lab at Berkeley (ULAB) leadership team for providing us with this research opportunity and supporting our academic growth: Saahit Mogan (Director), Jordan Duan (Director), Andrew McHaty (Lab Manager), Yaamini Jois (Lab Manager), Brianna Peck (Curriculum Manager), Caitlin Begbie (Python Lecturer), and Faculty Sponsor Dan Kasen. Finally, we are grateful to the UC Berkeley Astronomy Department for providing access to the Leuschner Observatory, without which this project would not have been possible.

Generating the Light Curve

To create our light curve, we took three types of calibration frames along with the light exposures: flat frames (to correct vignetting and dust), dark frames (to subtract hot or cold pixels), and bias frames (to calibrate the sensor). We uploaded the FITS files using the glob package and converted them into 2D NumPy arrays. We subtracted the bias and dark frames from the light exposures and divided by the flat frames to get a clean image of our star. We manually recorded the coordinates of the target and reference stars, then performed aperture photometry by summing pixel values in a given radius and subtracting the background. We calculated the background noise (σ) and SNR for error bars. Finally, we divided the star's flux by that of the reference star and plotted the result over time to produce our light curve.

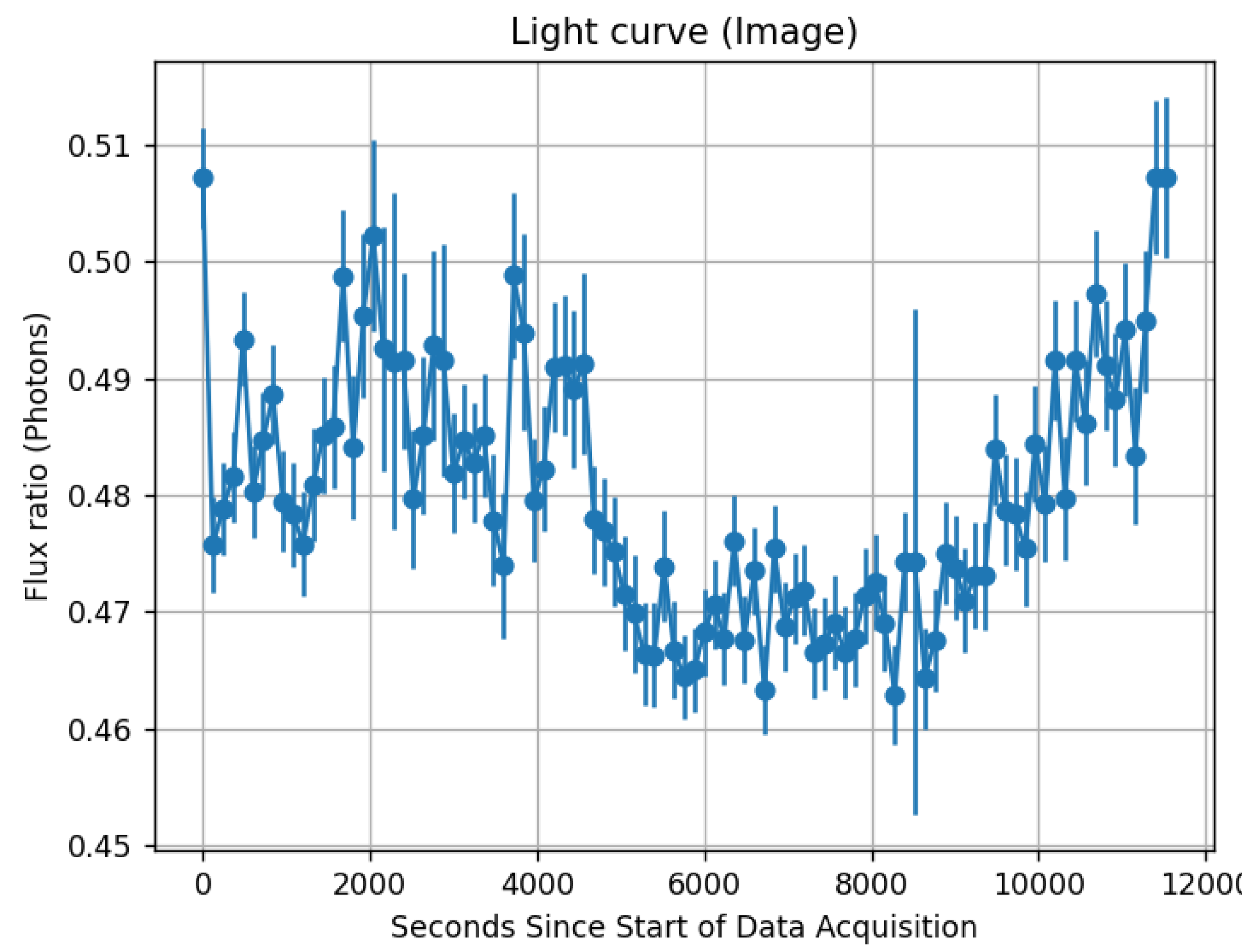

Figure 4. Light Curve of Star

Conclusion

Based on our observations and analysis, we found evidence that our candidate star (TIC 348756659) very likely has an exoplanet orbiting around it. The transit depth, shape, and timing we measured are consistent with predictions from TESS data, supporting the classification of the observed object as planet. However, additional observations are necessary to further reduce uncertainties and fully, officially confirm their planetary status according to standard follow-up protocols. Our results demonstrate that ground-based observations with modest equipment can play a valuable role in exoplanet confirmation efforts.

Future Work

While we successfully observed one full transit for our candidate, more observations are needed to reduce statistical uncertainties and strengthen the confirmation of their planetary status before the findings can be reported to the authorities. In future work, we aim to monitor additional transit events to improve our light curve precision and enable more detailed modeling of the exoplanets' orbits and physical properties. We are also aiming to further refine our code and re-evaluate our existing data, looking at all visible bodies in the frame to see if we can aid in the discovery of new objects of interest in the future.

References

1. "TESS Project Pipeline." Data, MIT, tev.mit.edu
2. "Leuschner Observatory." UC Berkeley Department of Astronomy
3. https://science.nasa.gov/exoplanets/how-we-find-and-characterize/
4. https://lco.global/spacebook/exoplanets/transit-method/
5. "Revised optical air mass tables and approximation formula" Kasten and Young, https://pubmed.ncbi.nlm.nih.gov/20555942/