Observing and Obtaining a Light Curve from a Potential Transiting Exoplanet

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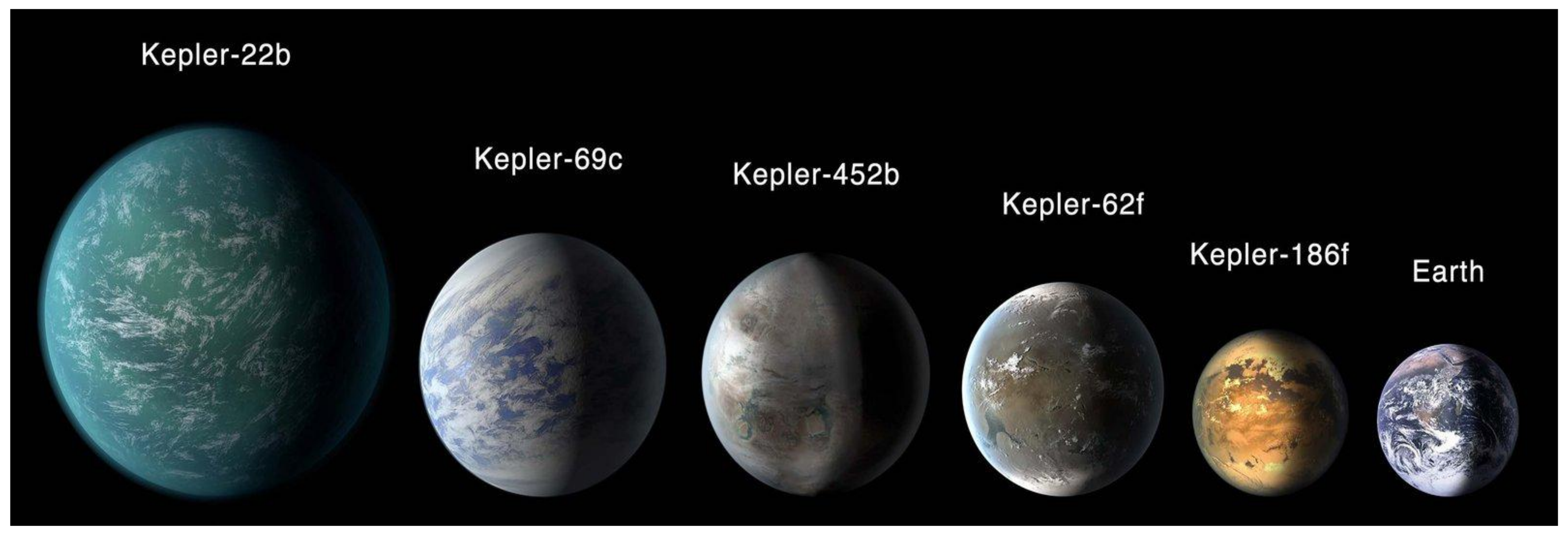
Introduction

An exoplanet is a planet outside of the solar system, and there are a number of ways of detecting them such as radial velocity, transit method, astrometry, direct imaging, and microlensing. Such methods enable us to gather detailed data which aids in the process of identifying exoplanets and exoplanet candidates. An exoplanet candidate is a potential exoplanet that has yet to be confirmed through multiple lines of evidence.

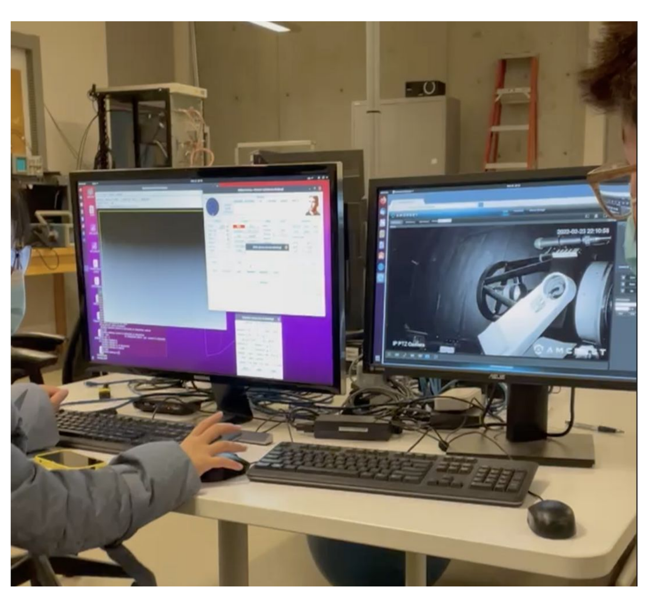
There are many instruments that are being used to discover new exoplanets such as the Kepler, Spitzer, and Hubble telescopes. One of those instruments is the Transiting Exoplanet Survey Satellite (TESS). TESS gathers its data by focusing on a section of the sky for a period of 27 days, collecting the light from distant stars. It records the light curves of the stars, making sure to catch any statistics and abnormalities within its observations. This data is then compiled and sent to a pipeline through which we can access it. The TESS database is the source of all our planet candidates in this project. We used it to sift through thousands of planet candidates by looking at the valuable measurements and statistics that it provided.

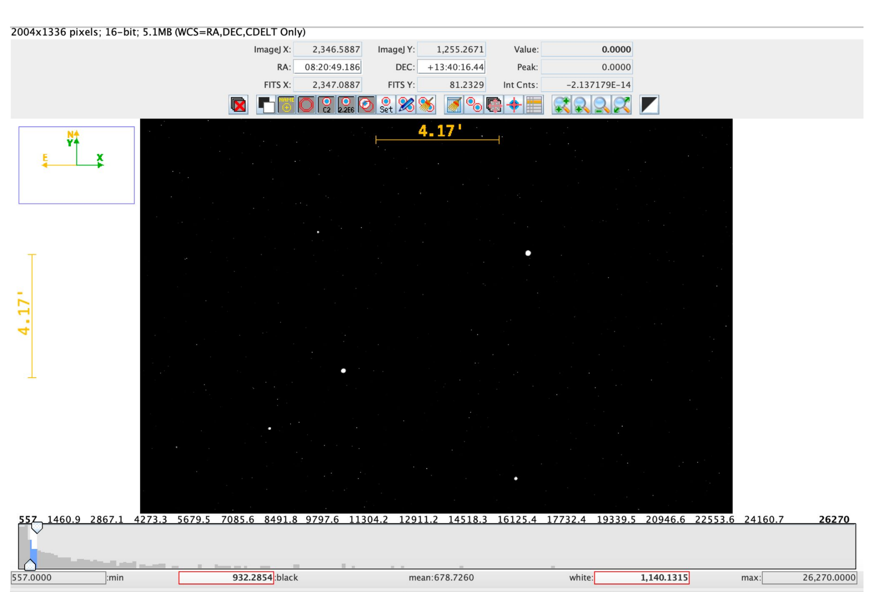


Methodology — Observe & Analyze

In order to collect our own data independent of TESS, we planned to observe our chosen planet candidates with the Leischner telescope. To successfully observe a transit, we first calculated the future transit times of each planet candidate. Picking the transit times which coincided with our access to the telescope, the weather conditions, the time of year and other details, we reserved our telescope times with the help of Prof. Gaspard Duchêne. Operating the Leuschner telescope required specific procedures and protocol, such as monitoring a webcam located at the observatory, navigating the software of the telescope, and finally producing images.

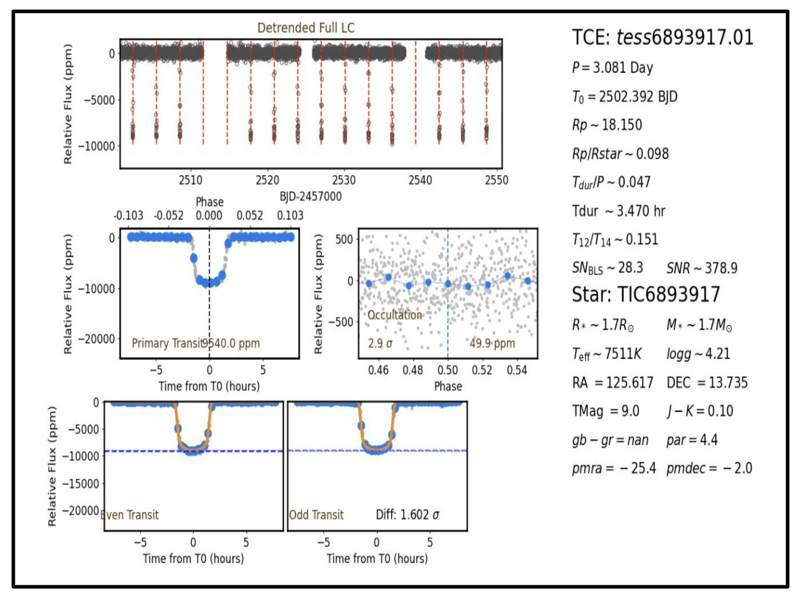
Analyzing the images recorded by Leuschner consisted of overlaying hundreds of images in an image analysis software called AstroImageJ. To help the data come out as clean as possible, 'darks'–images taken while the telescope dome was closed–as well as 'flats'–images taken at sunset for near maximum light exposure–are compiled and subtracted from the other data to account for any potential imperfections in the telescope lens. With the resulting data, we produce a light curve by comparing the target planet candidate against a reference star to observe the relative dip in light of the transiting object.

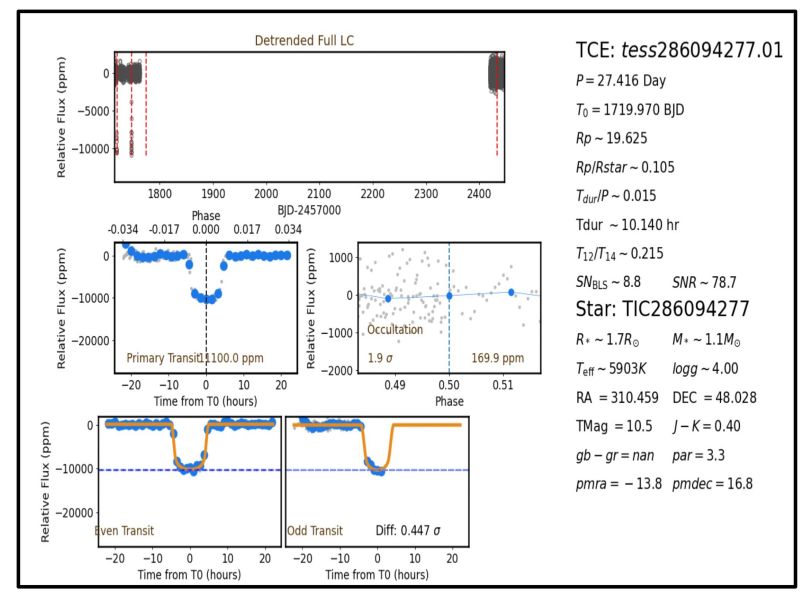




Methodology — Potential Candidates

We chose potential candidates to observe by setting constraints on the desired exoplanet characteristics. Certain characteristics were chosen for observational convenience. We selected TESS candidates with RA values between 100 and 200, and DEC values between -10 and 70 to ensure that our candidate is observable from Berkeley during the spring semester. We also made calculations based on the time of the TESS observation (T_0) to ensure that the candidate would transit after nightfall in Berkeley. Candidates with transit periods around 13.5 days were desired, since transits are frequent enough to have ample observation opportunities throughout the semester, but long enough that TESS had not collected as much data (and our data addition would be more significant).





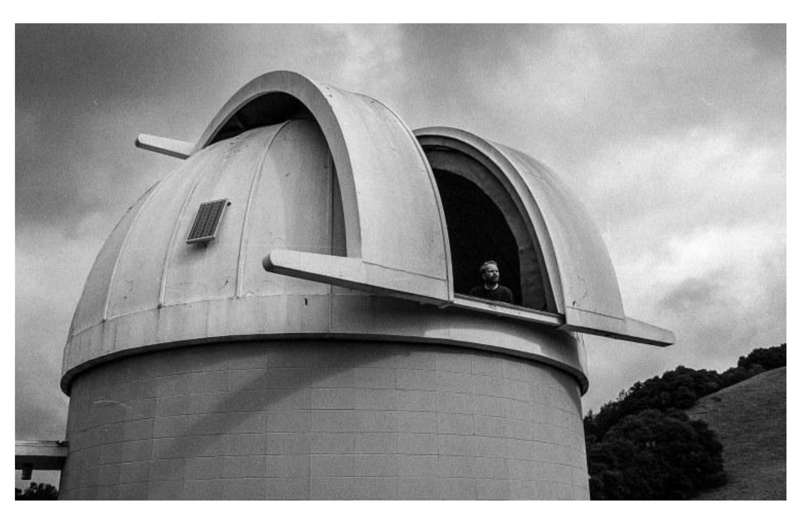
Other desired characteristics were quantified to increase the likelihood of our candidate being an exoplanet (rather than a binary star system or some other anomaly). We chose candidates with radii between 2.5 and 22 Earth radii, transit depths between 8000 and 15000 ppm, secondary eclipses and even-odd tests less than 5σ, signal-to-noise ratios greater than 10, and planet to star radius ratios less than 0.16. Qualitatively, candidates with U-shaped curves were selected.

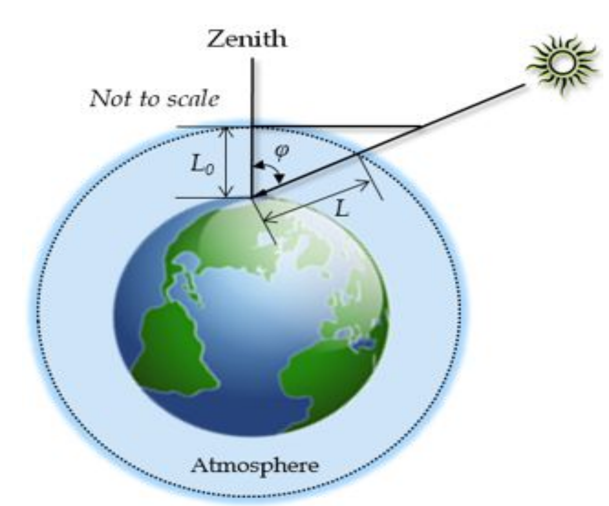
Problems & Limitations

There were a number of different logistical factors that limited the number of observations we could take. One such factor, the time of the exoplanet's transit, greatly affected the logistics of our research; due to the fact that a candidate would have to transit at 7:30pm at the earliest, this ruled out numerous transits of our chosen candidates. Our location of observation was also a factor; the location of the Leischner telescope would require us to only pick candidates that had an RA between 100 and 200 and a DEC between -10 and 70– this also ruled out numerous prime candidates that we had found. Additionally, clear skies and low humidity were also necessary for a successful observation– that is, we would have to shut down the telescope if humidity exceeded 90% and cloudy skies would create too much noise in our data for it to be usable; this factor made numerous observations impossible.

Another issue was the air mass in the atmosphere between Leuschner and the star observed. As the star moved closer to the horizon over time, the air mass obstructing flux increased, causing a gradually increasing error.

Hardware also proved to be an issue. Leischner telescope had connection issues at certain times and we also noticed that it was unable to stay in the same place over time– that is, the telescope would slowly 'drift,' causing streaks of light to show up on certain exposures. Due to the limitations that we experienced throughout our research, we were only able to obtain one set of data, which made our calculations of results more difficult.



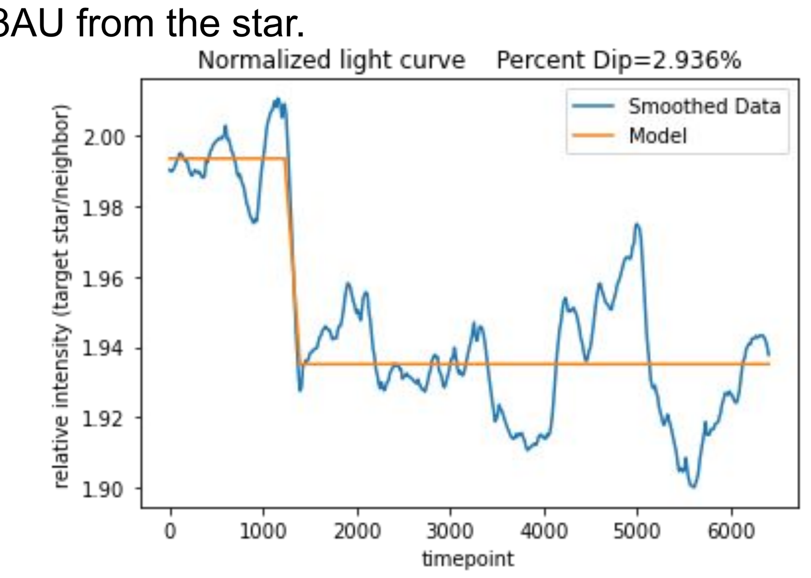


Results

We chose several exoplanet candidates by filtering through thousands of data from TESS. We narrowed down to one candidate and observed it using the Leuschner 30" Optical Telescope. We created a light curve from over 400 images taken during the transit observation with the software AstroImageJ, and were able to calculate characteristics of the candidate.

From the depth of the dip we observed, we calculated that the radius of the planet candidate is approximately 30% of that of the Sun. This value is too large for a transiting exoplanet, so we can consider a few potential explanations. There is a possibility that the object is not an exoplanet but rather a binary star or other object. Another likely cause of the large radius is systematic error which may have skewed the results and resulted in such a large dip in the light curve.

However, we were able to calculate the planet's semimajor axis, at around 8×10^{11}cm or ~0.05AU. Using the semimajor axis and TESS' measurement of the host star's temperature, we are able to determine that this planet candidate is not in the habitable zone, the distance of 0.13AU to 0.23AU from the star.



Light curve plotted along a model after smoothing with Savitzky-Golay filter.

Future Work

In the future, we hope to observe the planet more times to gain more data; by doing this, we will be able to get a much more accurate light curve and reduce error greatly. Additionally, in these future observations, performing aperture photometry on as many potential comparison stars as possible would reduce error even further; this would allow us to find the least variable stars for comparison. Furthermore, while observing, it would be beneficial to find the pixel space of our chosen star in each image; this will allow us to check if changes in the x/y positions of the star correlate with changes in flux. Lastly, we could improve accuracy further by making sure that our flats and darks are optimal for subtraction. By doing all of these things, we should be able to obtain a transit from our data.

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