

**The Extent at which Transit Light Curve Detection Using a Mid-Level Telescope to
Calculate TOI-3819 b's Planetary Radius Compares to NASA's Planetary Radius for
TOI-3819 b.**

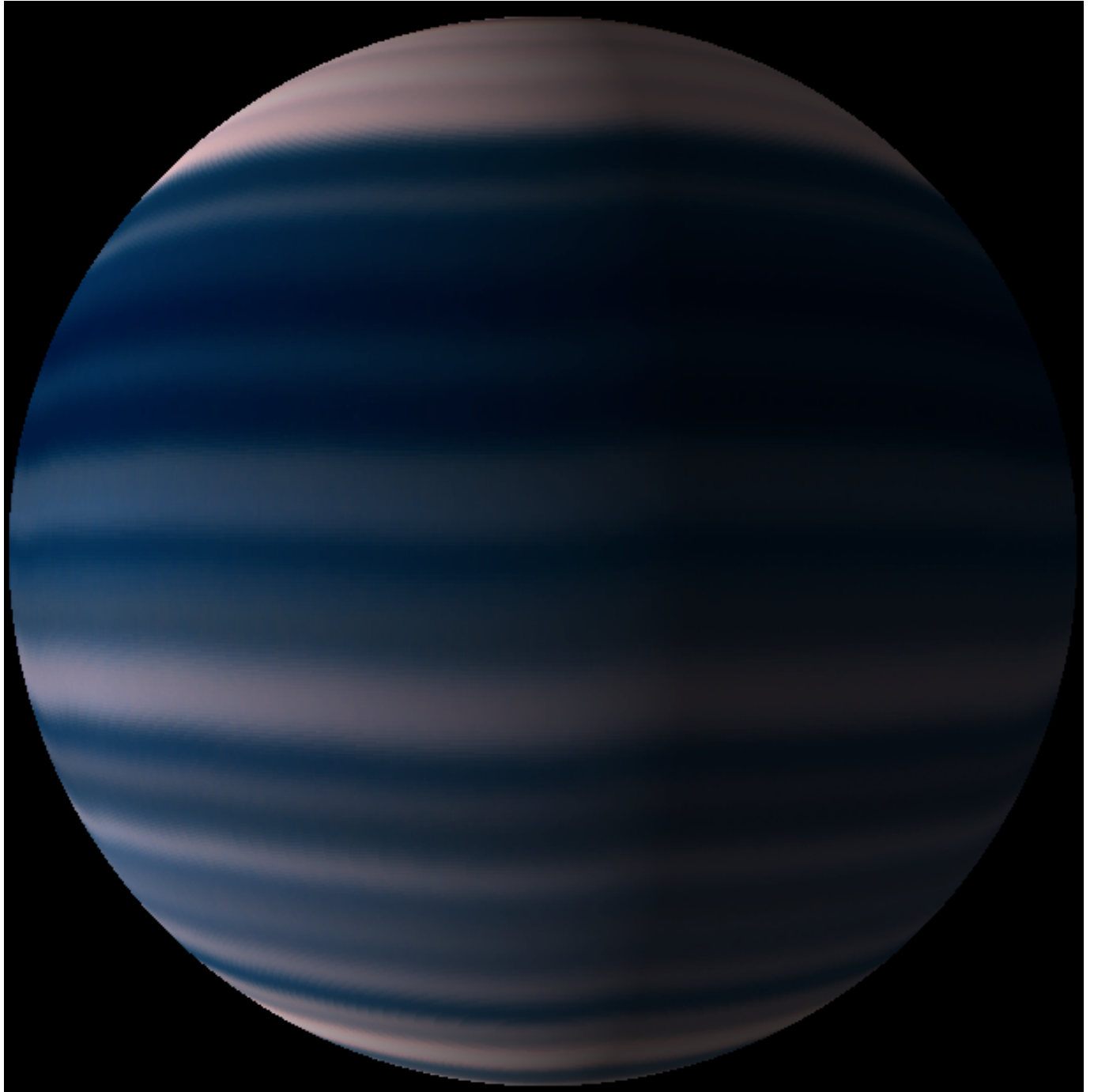


Figure 0, Imaginary Picture of TOI-3819 b

Word Count: 5410

1. Literature Review

1.1 Introduction

Among the deep, dark universe lie many hidden gems. Those small, seemingly microscopic specks glistening in the night sky hold the key to our existence. Virtually every star has an orbiting exoplanet (Welsh, 2013). Exoplanets are defined as planets outside our solar system (NASA, 2021). The sheer number of exoplanets to discover and collect data from in our universe is almost endless, leaving vast room for top universities and organizations to conduct research on these exoplanets. They observe the characteristics of their atmosphere, orbits, and even the elements they're composed of. Advancements in astronomical research play a significant role in society. However, the quantity of viable data still remains low (Walker, 2017). Rather than using only professional equipment through highly experienced and specialized individuals and organizations, expanding this field of research to the amateur level will catalyze data expansion.

Every bit of data on exoplanets adds to our understanding of the universe. Transiting exoplanets, in particular, offer valuable insights into the properties of planets outside our solar system. Collecting accurate data can help astronomers refine their models, study the atmospheres of exoplanets, and learn more about their formation and evolution. Moreover, amateur astronomers can validate professional observations. The reliability of scientific findings can be improved by independently verifying transits on exoplanets. In addition, owing to the high demand for observations, there is a shortage of time in which expert observatories can make observations. By contributing their data, amateur astronomers can extend the observation period and allow for more frequent and extended observation of the planets. It's also possible that amateurs have the advantage of monitoring specific exoplanets for a longer period, which is

crucial to studying changes in atmospheric conditions, climate, and orbital parameters. Through amateur observations, astronomers may stumble upon unexpected phenomena or events during their observations, which can lead to the discovery of rare events or unusual exoplanet behaviors. For example, in 2019, the star Betelgeuse was found to have dimmed in brightness. Many astronomers believed it was a warning sign that Betelgeuse was about to go supernova. However, images from fellow astronomers from France's Université Côte d'Azur over a two-year period showed the star went back to its normal brightness. If it weren't for the amateurs imaging it over the course of those two years, scientists wouldn't have had much data on the star's dimming. Thus, the scientists concluded the dimming in brightness was caused by a phenomenon where the star released gas (Rao, 2023). In a way, this makes amateur astronomers a part of a global community. Their collective efforts can provide a distributed network of observations, enhancing our ability to study exoplanets from different geographic locations and angles. Think of the hundreds of thousands to even millions of amateur astronomers as a portal into the future of technological advancements. A once niche field now has the power to improve and impact the world.

1.2 What Are Transit Light Curves?

Transit Light Curves (TLCs) are one of the most popular ways to detect exoplanets. However, with the equipment I have, the most reasonable method of detecting transiting exoplanets is through TLCs. The way TLCs work is by plotting points on a graph of a star's brightness (photon flux) versus time. Using this method, I'm able to see what percentage of the star's light the exoplanet blocks, as well as the time it takes for the exoplanet to cross the star's

disk (Walker, 2017). Large exoplanets block out more starlight than smaller exoplanets relative to their star size and brightness at the same distance from their host star.

Essentially, a TLC is a method to detect slight or major transits, which is an exoplanet orbiting in front of the star. This all depends on the number of data points and flux throughput collected (Mandel, 2002). The data points are all images collected from a telescope (more on this in Methods). The more data points, the more accurate the TLC will be.

Moreover, bigger exoplanets block more light coming from the star, which on a TLC is a large dip. The dip size is proportional to the exoplanet radius. The relationship between the radius of the star and the radius of the transiting planet is determined from transit depth measurement and is represented by Equation 1, where ΔF is the change in flux of the star in question, R_{planet} is the radius of the exoplanet, and R_{star} is the radius of the host star.

$$\text{Equation 1: } \Delta F_{star} = R_{planet}^2 / R_{star}^2$$

By rearranging this equation, I can solve for R_{planet} :

$$\text{Equation 2: } R_{planet} = R_{star} \sqrt{\Delta F}$$

This relationship provides a convenient way to determine the radius of the observed planet. The depth of the transit is linearly proportional to the size of the planet (Izuagbe, 2015). To note, a larger exoplanet further from its host star can block out the same fraction of light as a smaller exoplanet closer to its host star. Thus, determining the characteristics of these exoplanets becomes crucial in the process of understanding the data. Luckily, through TLC's, astronomers are able to characterize the orbital and physical properties of exoplanets (Walker, 2017).

1.3 What Makes NASA's Data so Reliable?

NASA's commitment to scientific integrity and excellence is demonstrated by a number of elements that contribute to its dependability in supplying exoplanet data.

Their data collection process is distinguished by strict quality control. The agency employs teams of expert scientists and engineers to carefully examine the raw data collected by its telescopes.

In addition, NASA encourages transparency and collaboration in the scientific community. NASA's mission data is subjected to independent expert peer review prior to publication or public distribution. For instance, the American Astronomical Society, the Royal Astronomical Society, and the Astrophysical Journal all have their own experts who peer-review papers. These reputable organizations publish the greatest astrophysics research available in the world. Peer reviews guarantee that research findings are carefully examined for precision, coherence, and scientific value. Furthermore, NASA promotes free access to its data archives so that scholars from all around the world can independently confirm and expand on the agency's results.

1.3.1 NASA's Exoplanetary Archive

NASA's Exoplanet Archive is a comprehensive and publicly accessible database managed by NASA's Exoplanet Science Institute at the California Institute of Technology. The archive acts as a central repository for data and information about exoplanets gathered from several sources, such as international collaborations, missions, and ground-based observatories. For astronomers, scientists, and the amateur crowd, it's an essential resource.

The Exoplanet Archive houses a wealth of data on thousands of confirmed exoplanets and candidate exoplanets discovered through different detection techniques, such as transit photometry, radial velocity measurements, microlensing, and direct imaging. One of the key features of the archive is its user-friendly interface, which allows users to easily search, filter,

and visualize exoplanet data. Each entry in the archive provides detailed information about the exoplanet's properties, including its size, mass, orbital characteristics, and host star properties.

1.3.2 Transiting Exoplanet Survey Satellite (TESS)

NASA's Transiting Exoplanet Survey Satellite (TESS) stands as a cornerstone in the agency's quest to uncover new exoplanets and deepen our understanding of these distant worlds. Launched in 2018, TESS is designed and run by the Massachusetts Institute of Technology, the Center for Astrophysics (CfA), Harvard, and the Smithsonian to survey the sky, dividing it into sectors for observation. TESS utilizes the TLC method to detect a variety of potential exoplanets.

TESS's small-large aperture, a diameter of .1 meters, is one of its characteristics. The primary feature is that it achieves a focal ratio of 1.4 thanks to the short focal length (wide field of view) and small aperture. Astronomics, a global supplier of optical equipment, says, "This is the optics speed, calculated by dividing the focal length by the aperture in a telescope." The smaller the f/number, the brighter the image, the wider the field, and the lower the magnification. TESS's fast focal ratio allows it to detect minute variations in brightness resulting from a transit, allowing it to gather substantial light from the star in frame.

Follow-up observations are carried out utilizing space-based telescopes and ground-based observatories to confirm the presence of potential exoplanet candidates identified by TESS and to further characterize their features. This cooperative strategy guarantees the validity and reliability of TESS's findings.

1.4 Gap in the Literature

The gap in the literature is that while professional organizations and wealthy universities have been actively studying exoplanets through TLCs, amateurs are also able to. The real question is, although amateurs can collect data through TLC's, is it as good as NASA's data? There is little to no research on the comparison between professional data and amateur data, leaving a new field to be studied.

Furthermore, heavily funded universities and organizations with high-grade equipment conduct the majority of the current research on the size, mass, and radius of exoplanets. This allows for standardized data for all other astronomers to use; however, many amateur astronomers are able to contribute to this research through their own personal means as well. The data found in this study will allow amateurs to understand how their data compares to NASA and the nuances within the calculations for size. This allows amateurs to strengthen their own findings and calculations, as the percent error will illuminate their understanding of their data's accuracy. This will help determine whether amateurs could truly contribute to larger research studies by means of TLC's and exoplanetary characteristics.

This led me to my research question: To what extent does the Transit Light Curve Detection Method Using a Mid-Level Telescope to Calculate TOI-3819 b's Planetary Radius Compare to NASA's Planetary Radius for TOI-3819 b?

1.5 Hypothesis

I hypothesize my data will result in an exoplanetary radius with a 30% deviation from NASA's exoplanet radius value.

2. Method Section

In order to test my hypothesis, an experimental study was conducted. This was the most suitable method for my hypothesis, because it allowed me to collect quantitative data, enabling me to compare my results to the results from NASA's database. The TLC was used to calculate the planetary radius of TOI-3819 b using Equations 1 and 2 through AstroImageJ. The value I got for it was compared to the planetary radius NASA has.

2.1 Equipment

- William Optics GT71 (Refractor Telescope)
- William Optics Bahtinov Mask (Focus tool)
- William Optics Flat 6aiii (Flattener/ Reducer)
- Sky-Watcher Heq5-pro (Equatorial Mount)
- ZWO-ASI533mc-pro (Dedicated Astronomy Camera)
- Orion 50mm Guidescope
- ZWO-ASI120mm-mini (Guide Camera)
- ZWO ASI Air Pro (Computer)
- AstroImageJ (Transit Light Curve Software)
- ASIAIR (software controlling telescope system)



Figure 1, Image of the Equipment Assembled Together

I chose the William Optics (WO) GT71 as my refractor because it's under .1 meters, making it an amateur level telescope. I used the ASI 533MC-Pro, which has a resolution of 9.05 megapixels and makes use of a Complementary Metal Oxide Semiconductor (CMOS) sensor, making it very sensitive to light, which helps it detect smaller changes in brightness. Which, in turn, made the TLC more accurate. The correct camera is important in detecting transits since some exoplanets are radially small, which can go undetected (Ventrudo, 2020). The Sky-Watcher Heq5-pro was chosen because it's an equatorial mount that could sustain the weight of the rest of the equipment. All together, the system is considered amateur level, thus sufficient for this experimental study.

2.2 Exoplanet TOI-3819 b

TOI-3819 b is an intriguing exoplanet discovered by TESS. Located about 209 light-years away from Earth in the constellation of Sculptor, TOI-3819 b orbits a G-type star, which is slightly cooler and smaller than our Sun. This exoplanet belongs to the category of "hot

Neptunes," meaning it's a Neptune-sized planet orbiting close to its host star, resulting in high temperatures.

One of the remarkable aspects of TOI-3819 b is its relatively short orbital period. It completes an orbit around its host star in just 3.2 days, making it one of the fastest-orbiting exoplanets known to date. Such a short orbital period suggests TOI-3819 b is located very close to its host star, likely within the star's habitable zone, where conditions may be too extreme to support life as we know it but are still fascinating for scientific study.

During the selection process for a candidate exoplanet for my research, there were a few criteria I had to look at. The website I used to find candidates is <https://astro.swarthmore.edu/transits/>. It searches through 4,166 known exoplanets using NASA's exoplanetary archive database. This website sifts through all of these exoplanets in the database to fit my timing criteria, because finding a clear night was the biggest challenge in the data collection process. To do this, I had to specify a time window and my observing location (latitude and longitude). The website then outputs a list of exoplanets that meet my time and location criteria, which could then be sorted by features like brightness, magnitude, and depth. My mentor and I determined we needed to find a star with a brightness magnitude in the V filter (visible light) less than 14, because my telescope has a small aperture, therefore we needed a decently bright star; a transit depth greater than 10, because the size of my telescope prevents it from detecting small transit depths; a full transit to ensure a complete TLC could be made; and a duration less than two and a half hours for convenience.

With these criteria in mind, I found exoplanet TOI-3819 b, as seen in Figure 4. It has a magnitude of 12.5, a duration of 2 hours and 20 minutes, and a full transit. However, TOI-3819 b

only has a depth of 5.9 parts per thousand. Due to time constraints and poor weather, I decided TOI-3819 b was the best candidate for the night.

Local evening date	Name	V or Gaia mag	Start—Mid—End	Duration	BJD _{TDB} start-mid-end	Elev. at start, mid, end ±1 hrs	% of transit (baseline) observable, Suggested obs. start, end	Az. at start, mid, end ±1 hrs	HA at start, mid, end ±1 hrs	RA & Dec (J2000)	Period (days)	Depth (ppt)
Mon. 2024-01-29	Nautical twilight	2024-01-29 18:17 — 2024-01-30 06:10	local time	/	2024-01-29 23:17 — 2024-01-30 11:10	UTC						
Mon. 2024-01-29	☐ TOI-3819 b Finding charts , Annotated Aladin , SkyMap , Airmass plot , ACP plan Info , Exoplanet Archive , Simbad , Gaia , TLC	12.5	23:14 00:16— 01:26 —02:36 03:38 ±0:02	2:20	10339.7256 10339.7741 10339.8227	79° 76° 65° 52° 40°	 100% (100%) 23:14—03:38	156° 222° 254° 268° 278°	-0.3 +0.7 +1.9 +3.0 +4.1	08:07:27.18 +29:23:19.12	3.24	5.9

Figure 4, Sorted features of TOI-3819 b from Database

2.3 The Telescope

In this experiment, the size of the refractor telescope plays a crucial role in data accuracy. Specifically, my telescope has a 71 mm aperture and a focal ratio of F/5.9. The aperture and focal ratio are key specifications determining the telescope's light-capturing capacity. Traditionally, larger telescopes, typically one meter or larger, are favored in research studies for their ability to collect more light and thus produce images with fewer errors (Gary, 2009). However, this study employs a significantly smaller telescope (.07 meters), approximately one tenth the size, requiring more data to make up for its size (Dymock, 2019). To mitigate this limitation, longer exposures are taken for each image, allowing more light to enter the camera sensor and reducing error in the measurement of starlight collected, ultimately enhancing the accuracy of the TLC data (Ventrudo, 2020).

2.4 Method

The experimental procedure involved several key steps. First, the equipment was meticulously assembled, all wires were connected, and the system was balanced. Following this, the equatorial mount was aligned with the North Star using the viewfinder, and the ASI AIR software was employed to confirm polar alignment. The telescope aligns relative to the North

Star because I use an equatorial mount, meaning when my mount is aligned to the polar axis, I can easily track the night sky. As seen in Figure 2, fine adjustments to the mount's latitude and longitude knobs were made to ensure precise alignment. Subsequently, I was able to achieve 50 arcseconds of error, which is relatively low.

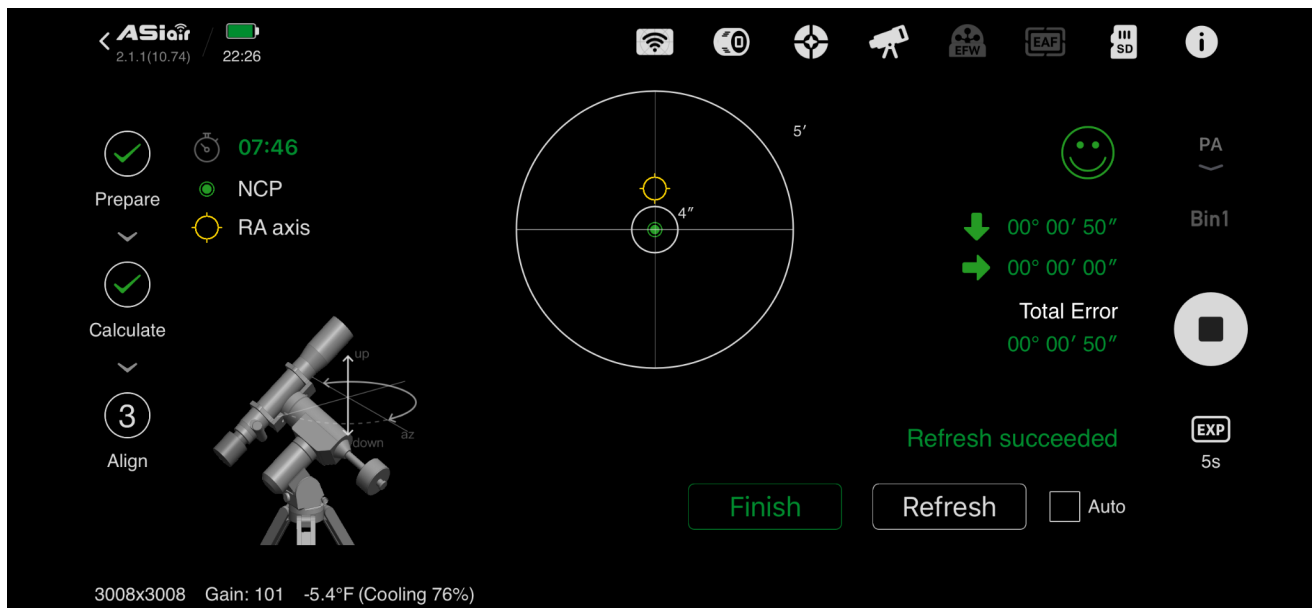


Figure 2, Polar Alignment Page on ASI AIR

Then, a Bahtinov mask was used to achieve optimal focus on the telescope. A Bahtinov mask is used to achieve focus, since it's the most user-friendly: As seen below in Figure 3, the diffraction spikes from stars were aligned to form near perfect symmetry, thus achieving focus.



Figure 3, Diffraction Spikes from Bahtinov Mask

TOI-3819 b's coordinates were input into the system, and the telescope slewed to align with the target. Initial test exposures of 30 seconds were captured to set the stage for the data collection process. 30-second exposures are optimal to ensure the target is centered in the frame, as well as gauging the proper brightness of the field to reach optimal exposures.

Autoguiding was then initiated, and calibration of the guide camera and guide scope were performed automatically by the software using surrounding stars. This process allowed for exposures lasting longer than 30-seconds.

After autoguiding was set up, I began to take 90-second exposures of the star in which TOI-3819 b orbits. In order to compensate for the significantly smaller aperture in comparison to professional research, longer exposure times were needed. So, I chose to take 90-second exposures for each frame as it'll allow more light to hit the camera's sensor, in theory yielding stronger data. This exoplanet had a total transit duration of two hours and 20 minutes, but the time between the exoplanet first visually touching the star and it fully crossing over was 4 hours and 24 minutes. To make sure I imaged the full transit from the first to the final crossings, I started imaging 15 minutes before and stopped imaging 15 minutes after the full transit. This left

the imaging of the exoplanet to occur for 4 hours and 54 minutes, which is a sum of 174 90-second exposures. Mathematically, I would have gotten 178 exposures, but my equipment had to perform a meridian flip part way through the data collection session, so I lost about 4 exposures. These exposures are known as the light frames, which are the images of the star.

In order to achieve as accurate as possible data, calibration frames are needed. My calibration frames consisted of bias, dark, and flat frames. I took 20 images of each calibration frame type in order to get a good average of random noise and reduce outliers. I could have taken more calibration frames, but the calibration frames follow a diminishing returns rule. It's important to average out the noise because noise is inherently random and has to do with random photons that have enough energy to be detected by the camera sensor. Since these photons are random, it's important to get an average so that noise doesn't influence my results. There are different types of noise, including read noise and thermal noise, which is why I took bias frames and dark frames. Bias frames are meant to capture only the noise that is inherent to the camera sensor capturing data (read noise), so the exposure time was as short as possible and the telescope cap was on. My camera's shortest exposure time is 0.001 seconds, so my bias frames were taken using this exposure time. Dark frames are meant to capture the noise during the length of the exposure time of the light frames (thermal noise), which is why they were 90 seconds long. I kept the telescope cap on for these exposures as well, since I only wanted noise in these images. Lastly, flat frames are meant to capture the aberration (visual distortion) of the telescope's optics, which may cause vignetting (the center is brighter than the corners) in the corners of my light images. To take my flat frames, I needed to create a diffuse and flat area to image and make sure my exposure was set so I was not overexposing or underexposing any part of the frame. To do this, I kept the telescope cap off and, using some rubber bands, securely

attached a white t-shirt to the end of the telescope. I then made sure the light coming into the telescope was as flat as possible, so as not to arbitrarily introduce a gradient into the flat frame, which would unintentionally propagate into my light frames if kept. After ensuring a flat frame and adjusting the exposure time so I was not overexposing or underexposing my frame, I settled on an exposure time of 108 milliseconds.

When it comes to converting the data from images to numerical values, I used AstroImageJ for image processing and photometric extraction for generating astronomical light curves since it's open source, free, and utilizes a simpler user interface than other methods, making it accessible to any level of user expertise. Finally, I used the transit light curve method because it's the most suitable for the equipment and specific data I need for my experimental study. It allowed me to take advantage of AstroImageJ's ability to convert image frames to then calculate an exoplanet's radius.

Next, I downloaded all 174 light frames and 60 calibration frames from the USB drive to my local computer for processing. Once the data was transferred to a computer, I processed the data in AstroImageJ using the calibration frames. Once each image was calibrated, I separated the images before and after the meridian flip, since the meridian flip caused image rotation issues in AstroImageJ. I started by opening the images from before the meridian flip and aligning each image to the first image in the dataset by using the sky coordinates embedded in the image. Once the images were aligned, I used the Multi-Aperture Photometry tool to place the target star aperture. AstroImageJ automatically produces a plot with each pixel's brightness plotted versus the distance from the center of the aperture, and it also shows the regions recorded as the source star and the background. After making sure the background region did not overlap with my star's signal and confirming the default aperture radius settings were sufficient, I began processing

each image. AstroImageJ automatically selects sufficient reference stars to compare the target star flux with, so I didn't have to worry about selecting reference stars. After AstroImageJ finished processing each image, I saved the aperture measurements for the target star and each reference star, and then moved on to process the images from after the meridian flip using the same method. Once I had both sets of measurements, I combined the measurement files in the correct order in order to plot the entire dataset in one image. With the entire dataset loaded at once, I was able to begin modeling the data. First, I enabled auto-generated error bars from the aperture photometry, and then I tried fitting the data with a full transit curve. I used a spline fit using the Legacy Spline Smoother option with 86 points. Using this fitting method, I then moved to the Data Set Fit Settings window, where I fixed the ratio of the semi-major orbital axis to the radius of the host star to a value of 6.43, the transit center time to January 29, 2024 at 01:26:6.98 EST (Hour: Minute: Seconds), and the stellar radius to 1.538 solar radii (Yee, 2023). The radius of the host star is included because, in order to find the exoplanet's radius, the values of the star's radius and the change in flux are needed as per Equation 2. Therefore, AstroImageJ is able to calculate the exoplanet's radius.

After a TLC was produced, AstroImageJ used Equations 1 and 2 to calculate the exoplanet's radius. Luckily, this software calculated it automatically, showing its value in the data table. Additionally, the software ran a Chi-Squared test, a degree of freedom calculation, and a ratio between chi-squared and degree of freedom. I conducted the statistical test to ensure the significance of my line of best fit and TLC, as these tests are able to determine if the data is luck or if it has significance.

The final step involved a comparative analysis of the planetary radius I calculated versus the planetary radius NASA calculated. This analysis involved the use of a percentage error test to

see how far off my calculated radius is from NASA's. This was chosen because it's the most sensible method of comparing two single data values. Overall, every decision and choice I made was reasoned for the specific purposes of this experimental study, which provided a structured approach to gathering and evaluating data for my research hypothesis.

3. Data Section

3.1 Complications and Fixes within Data Collection

Along the process of collecting data, I ran into complications that eminently had an effect on my data. 52-minutes into imaging, my telescope had to complete a meridian flip. A meridian flip is when the telescope gets flipped and rotated to the west side of the mount. This flip is done automatically, preventing the telescope and camera from bumping into the equatorial mount and the wires from getting tangled. This meridian flip stopped the imaging for a few minutes, which is evident by the blue line on Figure 5 with the gap in the curve. The data collected before the flip was in a different orientation than after the flip, preventing the data from being analyzed properly as one entire group of frames. In order to fix this issue, I had to split apart the data into before the meridian flip and after. In doing this, I had to solve and analyze the light frames by group. So, after analyzing and solving the two groups, I got a table of data values for each group and had to manually combine them together in the chronological order of the images. After doing this, I took the combined dataset and opened it in AstroImageJ, giving me access to all the settings to create a TLC.

Furthermore, another issue arose when I tried to use advanced functions in AstroImageJ. These functions go beyond the software's simple use. When forming the TLC, I had to try different functions between the relative flux of TOI-3819 and comparison star 7. When plotting

the data on a TLC, the data points are plotted by either subtracting or dividing the two star's fluxes. When I was computing and attempting to execute this function, the software started to glitch, and I had to restart the software and redo the entire process a few times until it worked. This glitch caused some corners to be cut when analyzing data, which could be a reason for the results I yielded.

3.2 Results

3.2.1 TLC

After fixing the complications I ran into, the software was able to produce a TLC, as seen in Figure 5.

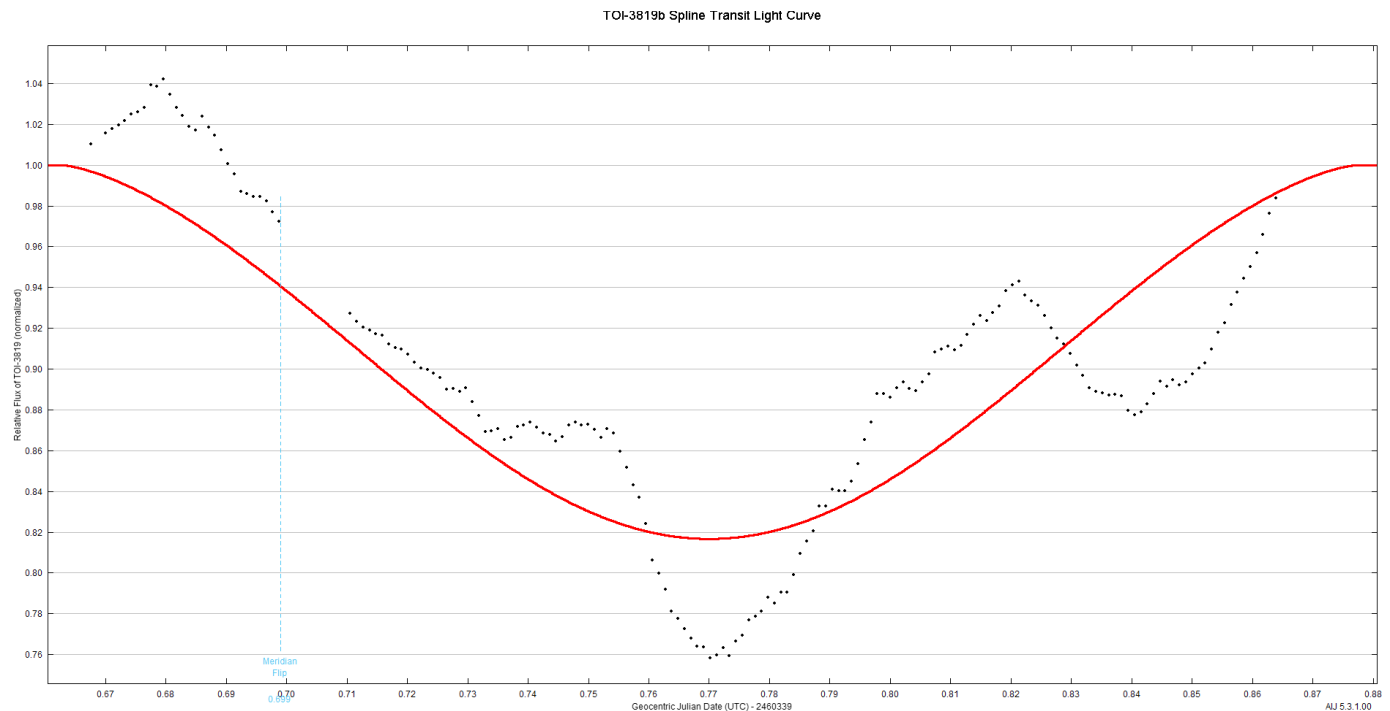


Figure 5, TLC of TOI-3819 b

The TLC above shows the relative flux of the host star changing over time. It's clearly visible that a transit occurred, as seen by the dip in the red line of best fit. Each dot represents a data point, and the line of best fit follows the average trend of the data.

3.2.2 Fit Statistics (Chi-Squared and Degrees of Freedom)

AstroimageJ was able to calculate fit statistics of the line of best fit.

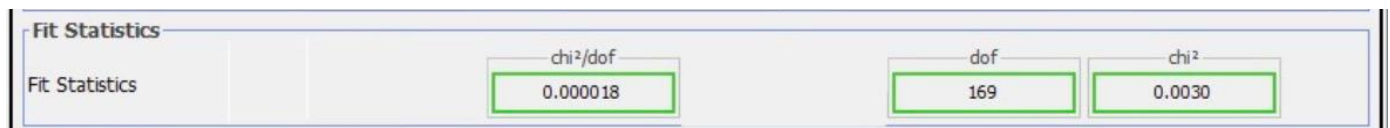


Figure 6, Fit Statistics

The statistics it calculated, as seen in Figure 6, were the chi-squared over degrees of freedom (DOF), chi-squared, and degrees of freedom. The chi-square test determines if a difference between the observed and expected data is due to chance or if there's actually a relationship between the variables (Nigam, 2024). Also, it determines the goodness of fit through determining if a sample matches the population. The value calculated is $P = 0.003$. A $P\text{-value} \leq 0.05$ is considered statistically significant. Thus, I reject the null hypothesis of no fit, meaning there is a good fit in the line. Moreover, the calculated DOF is 169. This means there are up to 169 logically independent values, which represents the number of variables changing in a calculation (Ganti, 2024).

By taking these two values and setting up a ratio, I'm able to see if my observed data closely matches my expected data. It's important to note that there is no universal fixed threshold for what constitutes a significant ratio of chi-squared over DOF; it's just the closer to zero, the better. Since the chi-squared over DOF ratio of my fit data is 0.000018, it suggests the observed

data is closer to the expected data when it comes to the line of best fit. In other words, the observed data fit the expected distribution very well.

3.2.3 Amateur Calculated TOI-3819 b Radius

AstroImageJ was also able to calculate the radius in Jupiter radii of exoplanet TOI-3819 b. The calculated value is 8.91 Jupiter radii, as seen below in Figure 7.



Figure 7, Amateur Calculated Radius of TOI-3819 b

3.2.4 NASA's Calculated TOI-3819 b Radius

TOI-3819 b was discovered by Samuel W Yee, who has a PhD in Astrophysics from Princeton University and currently works at the CfA, in a study conducted by him and his team, where they used TESS's grand unified hot Jupiter survey data to discover 20 new giant exoplanets. In Figure 8 below, it shows the radius of the exoplanet Yee's team, in collaboration with NASA, got through the transit method, which is the same method I used. The difference is their equipment and analytical processes are much more sophisticated and complicated than mine.



Figure 8, NASA's Calculated Radius of TOI-3819 b (Yee et al., 2023)

3.2.5 Comparison of the Data

In a statistical comparison of my amateur data of TOI-3819 b's radius versus NASA's data on the radius, there are a few obvious conclusions. My radius value of about 8.91 is significantly larger than NASA's value of 1.172, beyond their estimated value of plus or minus .036. Although the data I collected is significant and means something, the radius I calculated is completely off. To prove this, I calculated the percentage error amongst the two values (amateur and NASA) using Equation 3 below.

$$\text{Equation 3: } \text{Percentage Error} = (M - A/A) \times 100$$

M: Estimated Value (Amateur)

A: Actual Value (NASA)

After plugging in the values into the equation and solving for percentage error, I calculated the percentage error to be 660.24%. This means my initial hypothesis is incorrect and should be rejected. I hypothesized my percentage error would be around 30%; however, the calculated percentage error is significantly higher.

3.2.6 Implications of the Results

Although my data is statistically significant, in comparison to NASA's data, it's insignificant. This means although amateurs can collect significant data that is not due to luck or randomness, they can't necessarily compare it to NASA's data, which uses high grade equipment.

The data is valid but unreliable. Some amateurs can't really contribute; it all depends on the equipment they have. The optimal equipment should have a larger aperture and shorter exposures, which would reduce atmospheric distortion. Atmospheric distortion is easily seen at longer exposures because the distorting saturates, compared to shorter exposures, prevent any distortion from showing. For example, Bowen Cameron, a student at the University of Leiden, conducted a similar study observing exoplanets, in which he detected the transit of an exoplanet using an 8-inch reflector telescope and 30-second exposures. He was able to successfully obtain two TLCs and the characteristics of the exoplanets (Cameron, 2021).

Cameron's study is an indicator that some amateurs could really contribute to the greater research; however, my study concludes although the data is significant, the radius obtained is not significant, meaning I couldn't contribute to the greater research.

4. Conclusion

4.1 Improvements in the Research

In order to improve this research study, there are a few measures to take. Using a telescope with a larger aperture and a shorter exposure time would allow for more accurate data points in light frames and more exposures to be taken. This would contribute to a denser TLC filled with hundreds of data points. Using a larger aperture and shorter exposures could potentially lead to a more accurately calculated radius of the exoplanet with a much smaller percentage error. This is evident in Bowen's paper, where he uses an 8-inch reflector telescope and 30-second exposures. This yielded him significant results, allowing him to contribute to exoplanetary research (Cameron, 2021).

Additionally, another improvement that could be made is to gain more experience using AstroImageJ. This could be done by watching more tutorial videos, training with better test data, and reading papers on the software. Since the software is filled with complicated tools, having a better understanding of this software would allow for better analysis of the data. Specifically, future researchers should look into the data calibration process in AstroImageJ, as well as the graphing properties and flux ratios.

4.2 Conclusion of the Findings

When it comes to imaging and analyzing exoplanet TOI-3819 b using amateur-level equipment, the data calculated from the TLC was significant, as the chi-squared test yielded a P-value of 0.003, which falls under the threshold for making it significant. However, the data from my amateur equipment compared to NASA's data is insignificant, as the percentage error calculated was 660.24%, making the comparison insignificant by means of exoplanetary radius.

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