Characterizing Exoplanet Habitability

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Introduction

In modern astronomy, the study of exoplanets is a key way of learning about our own solar system. Currently, the most common method of identifying planets outside of our solar system is through the transit method. Some of the most critical characteristics for identifying the habitability of an exoplanet are its stellar effects, its location within its solar system, and its composition. Throughout our project we have tested the habitability of an exoplanet by analyzing its transit. By using already existing databases, we identified a good candidate for the study of habitability and used the remote telescope, MicroObservatory, to more closely analyze whether the exoplanet fits the criteria for possible habitability. With both the data found through existing databases and the data collected through the MicroObservatory we will compare the characteristics of the selected exoplanet and an ideal habitable exoplanet and determine the extent of the selected exoplanet's habitability.

Background

The transit method works by taking images of a star and collecting the brightness of the star before, during and after an exoplanet orbits in front of the star. This causes a dip in the brightness of the star which can be analyzed to determine characteristics of the exoplanet.[4]

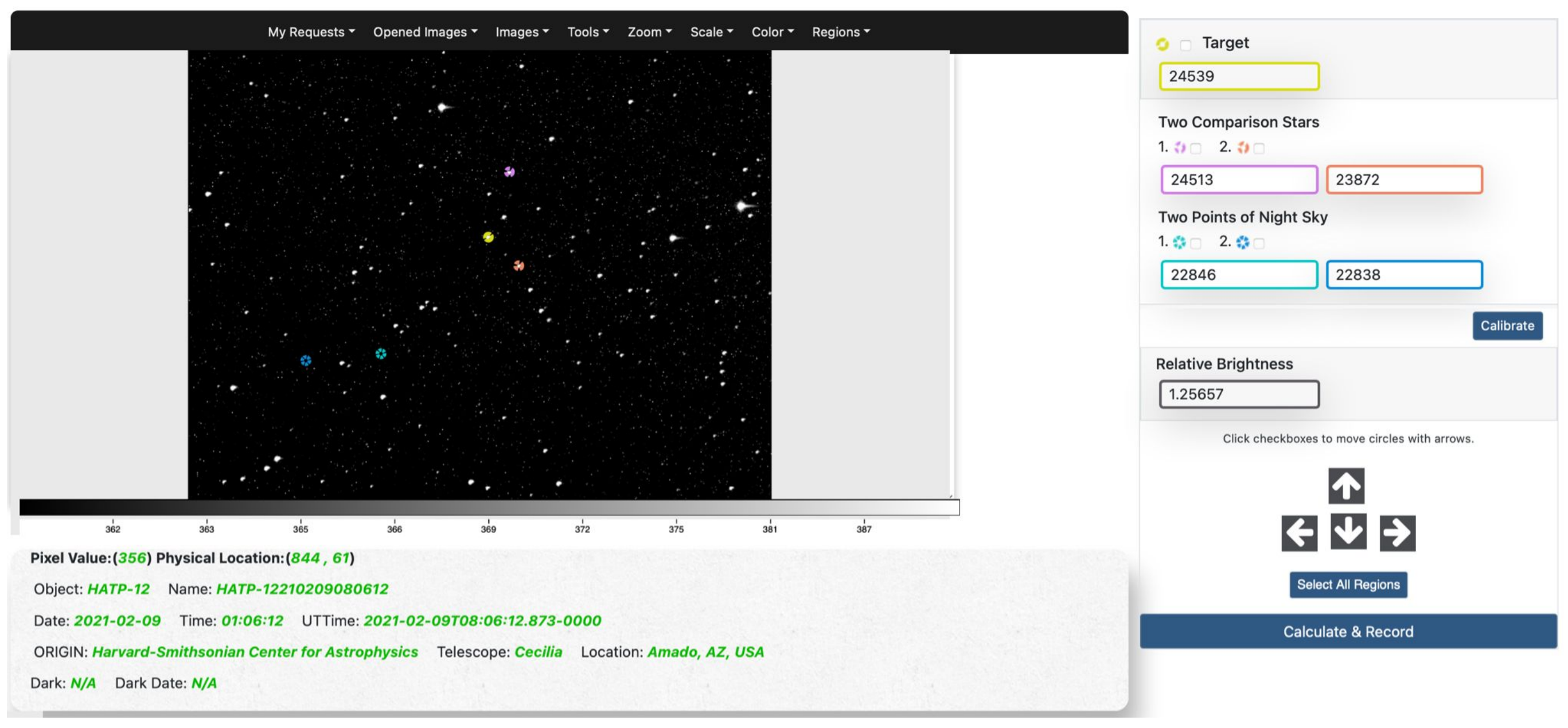
In addition to this, many of these exoplanets are in a "habitable zone" which is the area around a star in which a rocky, Earth-like planet can possess and sustain liquid water on its surface which is critical to life.[9]

Another method used to check an exoplanet's habitability is through transmission spectroscopy. The key idea behind transmission spectroscopy is that transit depth is wavelength dependent. The absorption of certain wavelengths by atoms and molecules in the atmosphere of the exoplanet affect the amount of stellar flux absorbed[4].

Methodology

The first step in performing the experiment involved picking which exoplanet we wanted to study, from those available on MicroObservatory, a network of telescopes.

Next, we had to collect transit data through MicroObservatory. Specifically, we request data for HAT-P-12b on a night when the transit is visible. Through the request, we received 80-90 images individually and we were able to locate the target star HAT-P-12, two reference stars, and two reference dark spots. For the target star, MicroObservatory measured the relative brightness of the star over a period of about 4 hours.



Target: 24539

Two Comparison Stars: 1. 24513 2. 23872

Two Points of Night Sky: 1. 22846 2. 22838

Relative Brightness: 1.25657

Pixel Value:(356) Physical Location:(844 , 61)

Object: HATP-12 Name: HATP-12210209080612

Date: 2021-02-09 Time: 01:06:12 UTTime: 2021-02-09T08:06:12.873-0000

ORIGIN: Harvard-Smithsonian Center for Astrophysics Telescope: Cecilia Location: Amado, AZ, USA

Dark: N/A Dark Date: N/A

Figure 1: MicroObservatory control panel for measuring brightness of our star. Image shown is HATP-12210209080312 (Image #2/77) taken on 02/08/2021 at 1:00AM in Arizona.

Next, we used Python to clean the data we collected by MicroObservatory and create the transit light curves. Additionally, through the brightness data collected, we were able to determine exoplanet habitability through calculations (orbital radius, transit period, planet radius). The following equations were used:

$$Drop = \frac{r^2}{R^2} \quad \text{axis} = \sqrt[3]{M_s \cdot T^2}$$

$$M_{exo} = \left(2.1 \cdot 10^{-4}\right) \frac{M_s \cdot V_s \cdot T}{2\pi a}$$

$$T = \frac{n}{t} \quad \rho = \frac{M}{V}$$

In order to understand the extent to which the exoplanet was habitable, our team had to find an exoplanet that was confirmed as ideally potentially habitable and then compare the characteristics between that planet and the one that we observed and did calculations for. Once this was complete, we were able to make a *limited* prediction on how habitable our exoplanet of study was.

Analysis

Transit Analysis:

Once we collected our data from MicroObservatory, we exported the data into Jupyterhub in order to analyze the data using python.

We began by sorting our data into arrays and plotting it into a relative brightness vs. time graph, using the matplotlib library. With our data plotted we highlighted the images that had substantial noise and were creating outliers during the expected transit (predicted by MicroObservatory). We then used numpy's polyfit with degree 2 to help highlight the transit (Figure 2).

With our outliers identified we removed them and then highlighted the data points inside and outside of the transit (*Figure 3*). We then used python to average the brightness during the transit and outside of the transit and used that information to calculate the dip (*Figure 5*). Lastly we binned our data by a factor of two to illustrate the transit curve clearly (*Figure 4*).

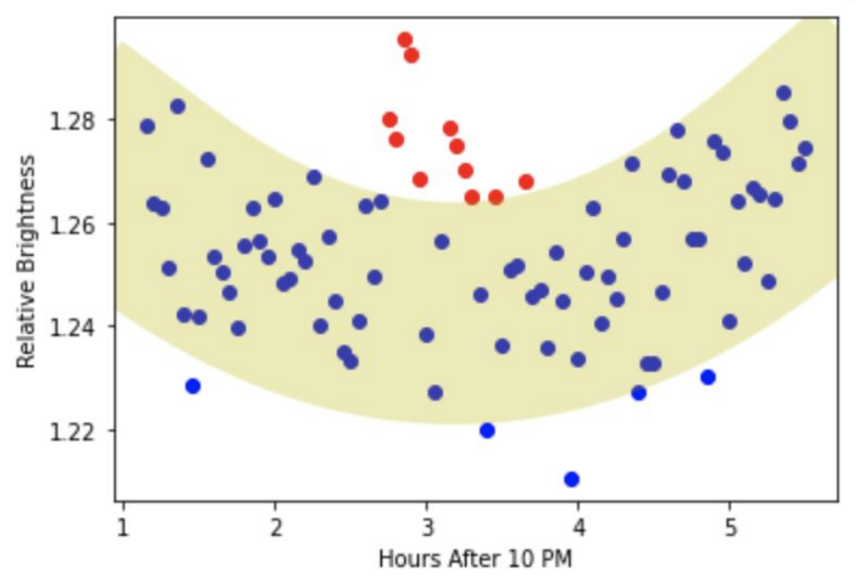


Figure 2: Python plot of data points highlighting outliers

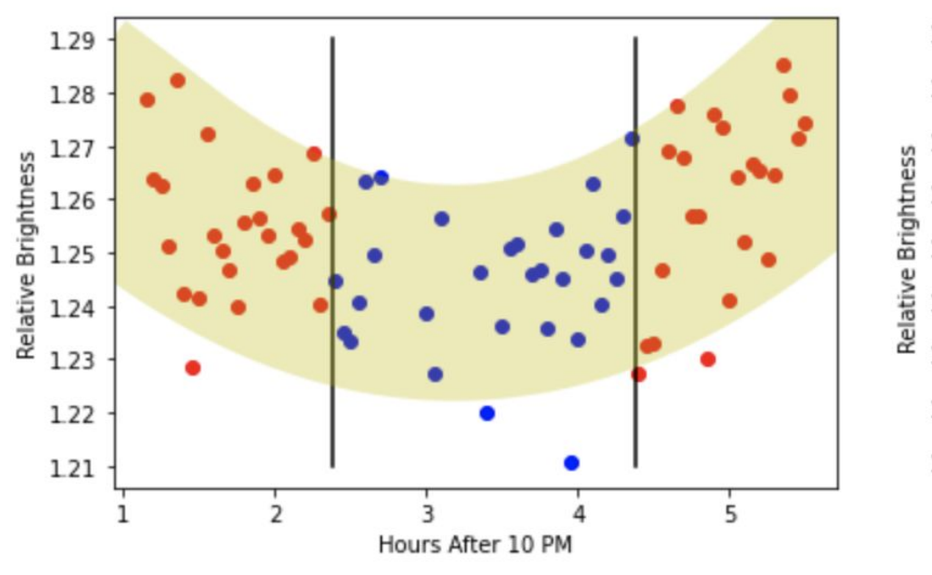


Figure 3: Python plot of transit data points with transit times

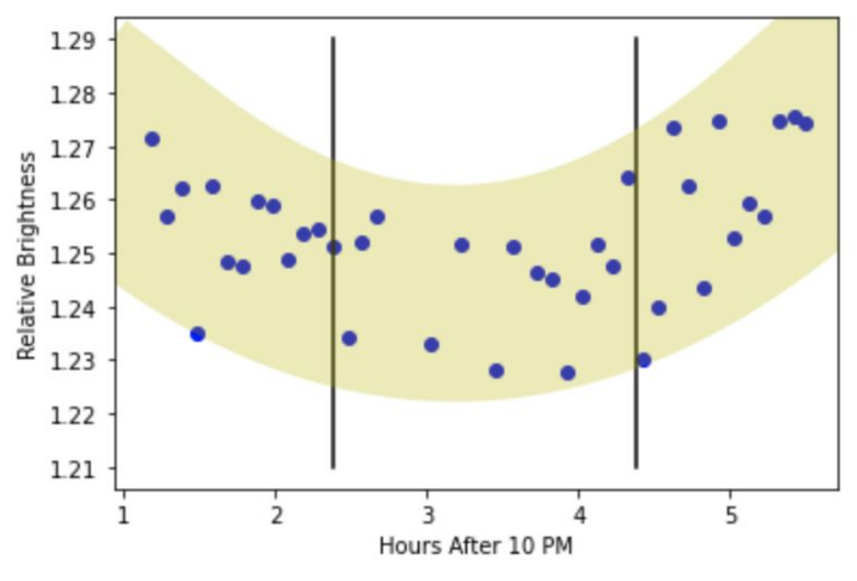


Figure 4: Python plot of transit with binned data

Average Relative Brightness Outside of Transit	1.257102083333333
Average Relative Brightness During Transit	1.2451172413793101
Dip	0.01198484195402294

Figure 5: Average Brightness and Dip calculations

Comparison Between Exoplanets:

	HAT-P-12B[2][5]	Barnard's Star B (Super Earth)[7]	Jupiter[3]	TRAPPIST-1f (Ideal Potentially Habitable Planet)[7]	Earth[1]
Radius (km)	4.5e4(±3.0e3)	2.22e4	6.99e4	6.66e3	6.38e3
Velocity (km/s)	135.39(±10)	3.02	13.07	434.75	29.78
Semi Major Axis (km)	5.7e6(±1.0e6)	6.04e7±(2.69e6)	7.78e8	5.5e6	1.496e8
Eccentricity	0	0.32	0.0489	0.063	0.01671
Period (days)	3.213(± 2.1e-06)	232.8(±0.4)	4,332	9.2	365
Mass (kg)	3.987e26	1.93e25(±1.42e24)	1.898e27	4.061e24	5.9724e24
Type	Gas Giant	Confirmed to be Rocky	Gas Giant	Confirmed to be Rocky	Rocky
Star Type	K4	M4.0V	G2V	M8V	G2V

Figure 6: We compiled a chart comparing characteristics of HAT-P-12B, a super Earth, Jupiter, an ideal potentially habitable planet, and Earth.

Radius: HAT-P-12b has a radius of 4.5e4(±3.0e3), which is much larger than Earth—as well as the Super Earth Barnard's Star B—and aligns more with the radius of Jupiter, which has a radius of 6.99e4.

Velocity: HAT-P-12b's velocity is significantly faster than all of our comparison planets, with the exception of Trappist-1f, an exoplanet widely considered potentially habitable. When compared to other planets, we noticed HAT-P-12B is nearly 4.5 times faster than Earth, over 10 times faster than Jupiter, and about 45 times faster than Barnard's Star B.

Semi-Major Axis: HAT-P-12B has a semi-major axis of 5.7e6(±1.0e6). The habitable zone for HAT-P-12 is between 4.9052603e7 km and 1.03317554e8 km[2], which puts HAT-P-12B outside the habitable zone, as it is too close to its star. Earth is the only planet in our solar system within the habitable zone, as Mercury and Venus are too close to the sun and Mars and the outer planets are too far from the sun. TRAPPIST 1-f, though it has a similar semi major axis to HAT-P-12B is within the habitable zone for the TRAPPIST system, as its star is a M8V type, which is much cooler than HAT-P-12, a K4. Barnard's Star B, on the other hand, borders the snowline of the habitable zone, in which water will not be liquid, making it unlikely to be habitable.

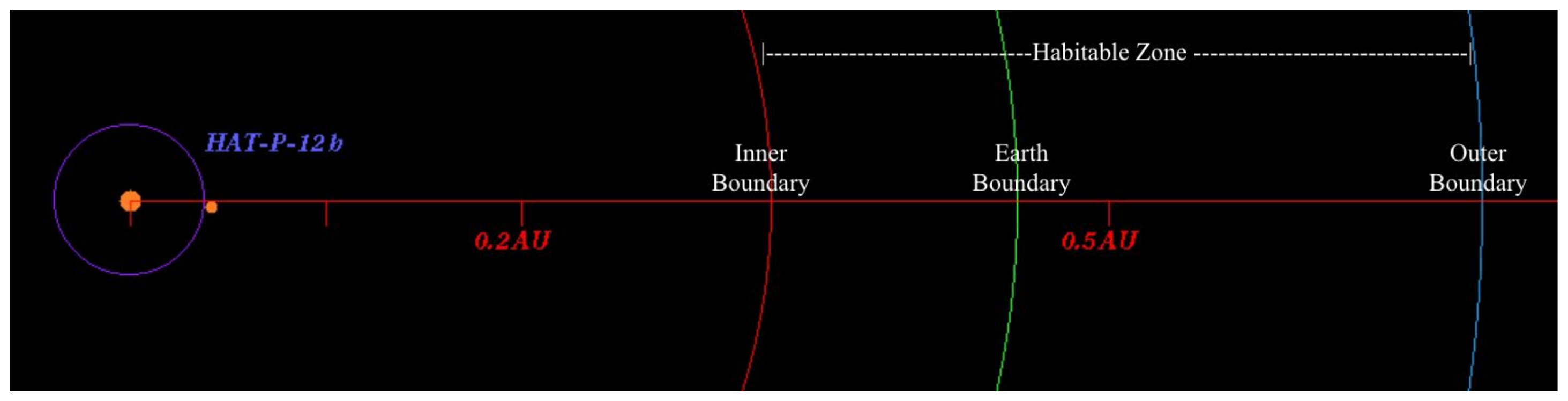


Figure 7: A visualization of HAT-P-12B's orbit in comparison to its star's habitable zone.

Eccentricity: An ideal habitable planet will have a low eccentricity, as a nearly circular orbit lessens the temperature fluctuations on the surface of the planet. HAT-P-12B has an eccentricity of 0 which essentially means it has a circular orbit. Earth, while not having a completely circular orbit, has a low eccentricity of 0.01671. Jupiter and TRAPPIST-1f also have relatively low eccentricities, at 0.0489 and 0.063 respectively. Barnard's Star B has a much higher eccentricity, with 0.32.

Period: HAT-P-12B has an extremely short period of approximately 3 (Earth) day—substantially shorter than all of our comparison planets, with the exception of Trappist-1f. The closest related period would be Trappist-1f with an orbital period of about 9 days.

Mass: In comparison to Earth and Trappist-1f, we noticed that HAT-P-12B is two orders of magnitude more massive. When compared to our super earth model (Barnard's Star b), HAT-P-12B was found to be one order of magnitude higher. HAT-P-12B was slightly smaller than a magnitude less massive than Jupiter, making it close in mass to a small gas giant like Jupiter.

Results

Through our research we can conclude that our exoplanet, HAT-P-12B is not likely habitable. In fact, our exoplanet more closely resembles a Jupiter-like gas giant than Earth. We've found that our exoplanet's relatively fast velocity is likely a direct result of its relatively high mass and large size along with its proximity to its host star. These factors lead us to best model our exoplanet after a small gas giant, as it most directly relates to features shown by Jupiter. Additionally since our host star is a K type, our exoplanet is well below the habitable zone making it far too hot and too close to its star, exposing it to dangerous amounts of ultraviolet rays. We did find that HAT-P-12B had a near perfect circular orbit, which would be a beneficial factor for habitability, as a less eccentric orbit keeps surface temperatures more stable. Unfortunately, that would be the only habitable factor in HATP-12B's favor. Based on the current factors that we have looked at, HAT-P-12B doesn't uphold enough characteristics of our habitable models in order to be classified as potentially habitable.

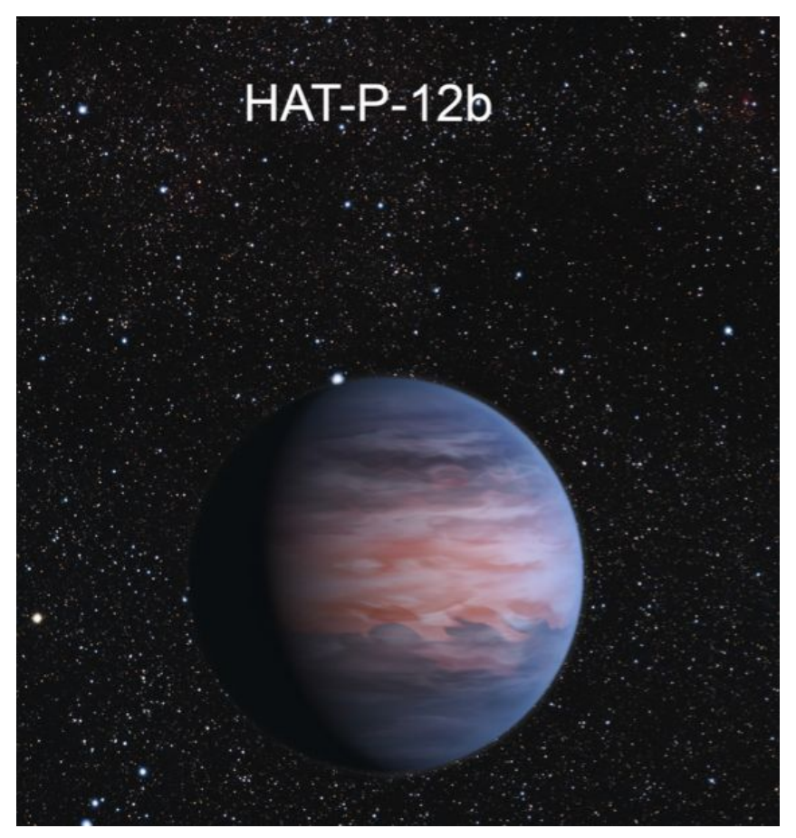


Figure 8: Artist rendering of HAT-P-12b

Limitations of our Experiment

It is important to consider the constraints of our analysis on exoplanet habitability for HAT-P-12B. Specifically, the exoplanet's atmospheric conditions and compositions were not considered. Atmospheric composition can dictate biosignatures that can allude to possible habitability. Another limitation of our experiment includes that we only compared one prospective habitable planet to a confirmed one. This sample size is too small to make any large conclusions or to see a greater (more holistic) trend in how planet composition and characteristics affect their habitability. Lastly, there was also the component of human error when we created our dataset from the images and our software was not the most accurate either.

Future Work

In order to reduce the limitations of our experiment, we would use spectroscopy to determine the atmospheric composition and see if the planet could support different forms of life. We can also look at a lot more exoplanets and use the 'Earth Similarity Index' or some sort of habitability index to quantify the probability of habitability given certain exoplanet characteristics and composition[8]. For example, if we take the presence of oxygen as a measure of habitability, we could look for oxygen or indicators of oxygen in our spectroscopy data. Lastly, considering the atmospheric evolution of exoplanets over time and tides will also be critical in improving the accuracy of characterizing exoplanet habitability[9].

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