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Seeing an Exoplanet

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Senor Research Project-Phys 373

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Abstract

The telescope at the Saint John's University Observatory was used to measure the brightness of three stars. These stars where reported by outside databases to have exoplanets orbiting them. The existence of exoplanets around two of the stars could not be confirmed, but there was good evidence for the third, HD189733 b.

Interdiction

The first exoplanet was discovered in 1992, and humans have been searching the skies for them since[1]. As more exoplanets were discovered, better methods and instruments for finding them were created. Currently, the Kepler Space Telescope is the leading instrument used in the hunt for exoplanets and has found over 4000 planets. With thousands of new worlds being discovered new categories emerged ranging from the hellish hot jupiter, to the precious, potently habitual earth-like planet, to the bazaar 55 Cancri E, made of diamond. Hot jupiters were the easiest, and first, type of planet to be found, as their large size and closeness to their star made their effect more visible. This new type of planet threw conventional theories on plant formation into question, as it was thought gas giants could only form in the outer reaches of a Steller system.

Each of these new discoveries led to new methods, which reviled different characteristics of these distant heavenly bodies. Among these two stand out. The first method, and the one used

1 SUMMERS, MICHAEL. "Exoplanets: Diamond Worlds, Super Earths, Pulsar Planets, and the New Search for Life Beyond Our Solar System." SMITHSONIAN BOOKS, 2018.

in 1992 to discover the first exoplanet, is the Doppler shift method. This method works because as a planet orbits a star both bodies pull on each other. While the mass of the star makes the planet move a lot, the mass of the planet only moves the star little, but that little bit is enough to cause a noticeable Doppler Effect. By observing the spectrum of a star over a long period, it is possible to see it red-shift, then blue-shift, as the motions of the orbit causes it to move closer and further away from Earth.[2]

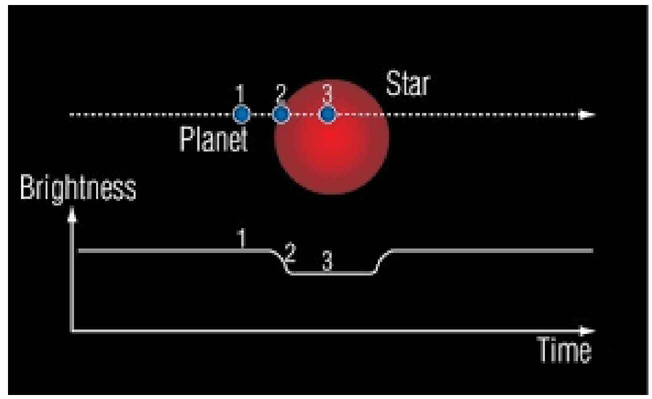

Figure 1: A simplified version of a nexoplanet transit dip

Theory

The second method, and the one used in this experiment, is the 'transit' or 'dip' method. It got these names because it involves monitoring the brightness of a star as an exoplanet transits it, which will cause the brightness to dip (Figure 1). This method can reveal the relative radius of the exoplanet to the star, as well as the orbital period (if the exoplanet is observed more than once). There is one obvious disadvantage with this method: if the exoplanet, the star and Earth are not on roughly the same plane, it is impossible to see. Despite this, the transit method is the most commonly used method and the one used by the Kepler Space Telescope. There is one main reason for this; it is relatively easy to scan multiple stars simultaneously for exoplanets. This method was chosen in this experiment because it is able to detect exoplanets even from a medium sized telescope on

2Johnson, John Asher. How Do You Find an Exoplanet? Princeton University Press, 2016.

Earth.

Before getting into the details of the experiment, it is important to mention the equipment that was used, both physical and digital. This data was taken at the Saint John's Observatory in Collegeville Minnesota, which is located at a longitude of 94.396^{o}N and a latitude of 45.575^{0}W. A Meade LX200 Telescope was used with a 12" aperture mounted on a Paramount ME by Software Bisque and controlled by theSkyX. A SBIG ST_1001E NABG camera collected the data.

A variety of computer programs were used as well. To ensure favorable weather conditions, the Canadian Meteorological Center's Clear Sky Chart[3] was primarily used to predict acceptable weather conditions, with other sites were occasionally used for conformation. The Swarthmore College transit finder[4] was utilized to find exoplanet candidate after which the Sky-Map.org[5] star finder would be used to locate the candidate stars in the sky. For analysis, Gaia was used to measure the magnitude of the stars, and CCDops helped controlled the camera during collection and performed flat field and dark corrections.

Experiment

The main limiting factor for conducting the experiment was the weather. Perfectly clear skies were required, with near zero chance of even the thinnest of clouds obscuring the star during the observation. In addition, it was unfortunately found that temperatures under

[3] http://www.cleardarksky.com/c/StJhUObMNkey.html
[4] http://astro.swarthmore.edu/transits.cgi
[5] http://www.sky-map.org/

freezing could result in the camera malfunctioning. If the weather permitted, the transit finder would be consulted. To ensure noticeable results, a candidate would have to cause a dip of 20 mmag or more and orbit a star that was at least 30^{O} above the horizon to minimize atmospheric interference. Both the transit time and the brightness of the star would also have to be considered before observation could begin. If the above criteria were met, observations would begin about an hour before sunset.

The experiment would start by setting up the equipment and taking flat fields. Flat fields are uniform pictures of the sky that must be used to adjust for individual pixels' sensitivity to light. Once that was complete and the sky was beginning to darken, it would be time to take darks. Darks are photos taken with the shutter closed, which can be subtracted from an image to reduce noise. The star formations around the target star on the sky-map would then be compared to what was observed in the telescope in order to confirm the correct star was being observed. The last step was to attempt to focus the telescope. This was done by monitoring the amount of light hitting each pixel from a single star. It would be in focus when the minimum number or pixels were required to capture a star’s light, which would result in the maximum amount of light hitting a single pixel.

After preparations were complete, the camera was set to take pictures with a certain exposer level aand intervals. These would vary depending on the brightness of the star and the length of the transit. Low brightness stars would require longer exposures while long transits wouldn't require as frequent data collection. If the required exposure was low enough, there would be enough time to take darks while collecting data. After the predicted transit time was over, ten to thirty more data points would be collected to establish the unobscured brightness before concluding the observation.

After all the photos were taken, it was time to move on to analyzing them. The first step was to utilize the flat-fields and darks which was done utilizing a program called CCDops. Each image would have to first be dark subtracted using an equally exposed image taken at the beginning of the observing session with the shutter closed. If darks were able to be taken with the data they would be automatically subtracted during the observation and this step could be skipped. Dark subtracted images would then be flat field corrected and exported as a new image. The brightness of the stars would then be determined in the program Gaia. After changing the settings as needed, the data would collected by clicking on a series of about nine stars, also in the frame, before selecting the target star. The other stars would serve as a control group in order to insure any dip was from an exoplanet, not a change in the atmosphere. It was very important to click the stars in the same order every time, to insure the data was in the same order for every image. After highlighting all the required stars in an image, Gaia would output the magnitude of each star, which would be compiled into a spreadsheet. With the magnitudes recorded, all that was left to do was subtract the control stars' magnitudes from the target star's and plotting the result.

Analysis

Due to the many conditions required to take data, the experiment was only able to run three times, of those one was a success. Starting with the success, data was taken on 28th of November, 2018 on the star HD 189733. Published observations give the star a V magnitude of 7.7. The planet was reported to causing a dip of 24 mmag and have an orbital period of 2.2 days. It was still light out when the transit begin, preventing observation of the initial dip, but the transit took about 1:50 hours, allowing data to be collected during the middle and end of the event.

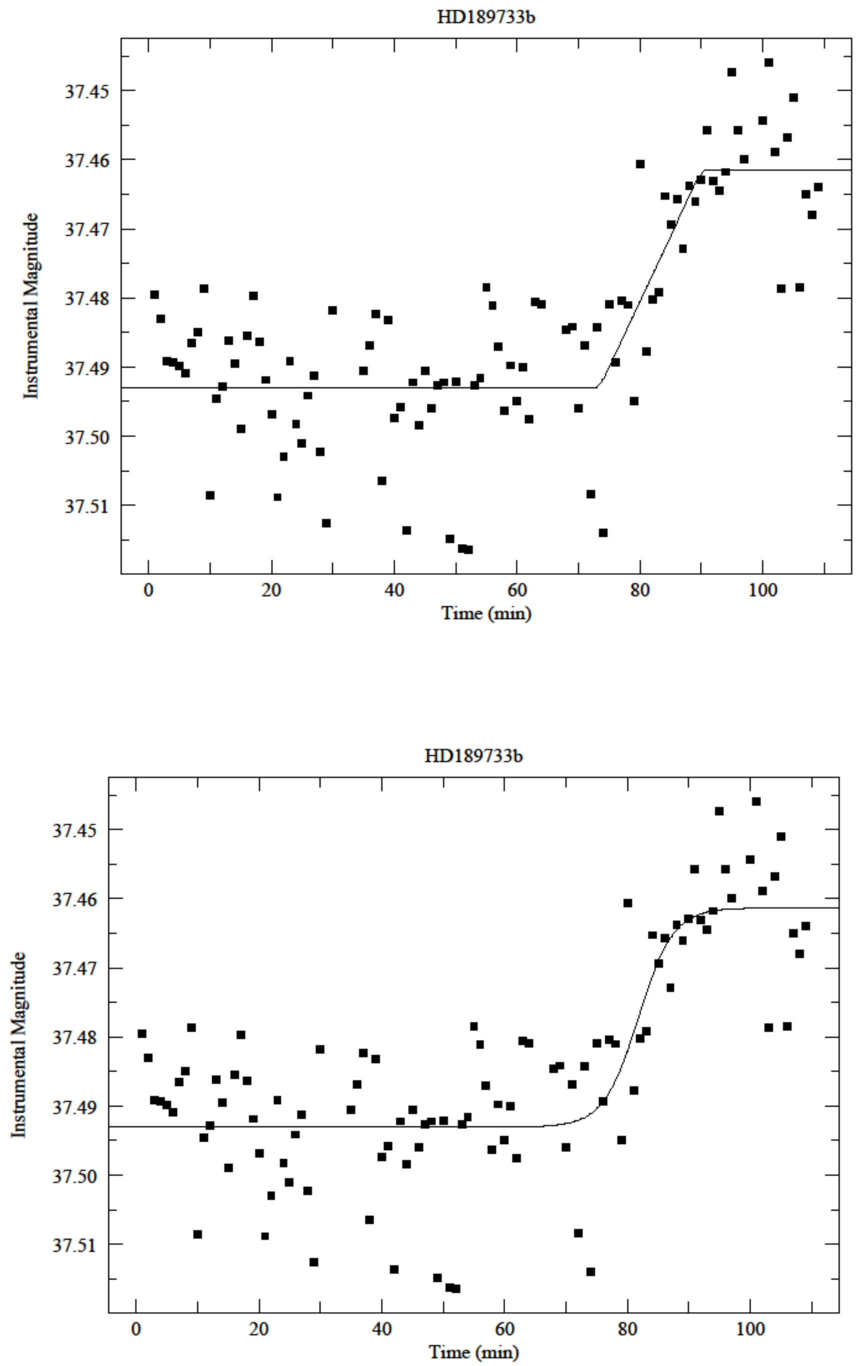

Figure 2: Both display the same data with different fits. The data indicates a clear jump once the transit is over

The results of the experiment are displayed in Figures 2. Both graphs display the same data, but the top uses a linear fit, which had an equation of $f(x) = K1 + \frac{x-k2}{k3-k2} * WIND\big((x - k2) * (k3 - x)\big) * k4 + k4 * WIND(x - k3)$ and a RMS deviant of $\sqrt{.009598}$. The bottom, however, uses a smooth fit, with its equation begin $f(x) = k1 + k4 * \frac{\tanh\left(\frac{x-k2}{k3}\right)}{2}$ and a chi value of $\sqrt{.009641}$. These two graphs clearly indicate the presence of an object transiting HD189733. The dip appears to be approximately 25 mmag, similar to the prediction. From this data alone it is not possible to determine the type of planet HD 189733 b is. However, outside sources indicate it can be classified as a hot jupiter, which this data supports.

Of the two failed experiments, the observation of Qatar 1 was closer to success. However, the transit was earlier than expected, and data collection begin after the planet was already partially done with its eclipse. Because of this, not enough data was taken during the transit to create a noticeable dip. The final observation had to be called off, because despite weather predictions, clouds obscured the area around the target star.

There are three basic ways to improve this experiment going forward. First is to use the Doppler shift method to calculate the mass of the target stars. This can only be done by gaining telescope time on a much larger telescope with a spectrograph. The second improvement would to be to observe multiple transits of the same exoplanet, which would give the orbital period of the exoplanet. Combined, these two measure would provide a much better picture of the exoplanet; with both the mass and the radius it is possible to know the density and thus what class of planet it is. The orbital distance could reveal the temperature, verifying the earlier hypothesis. The easiest way to reduce error for future experiments is to use a space telescope. Without the atmosphere or the need to consider weather more data could be collected and that data would have significantly less interference.

Conclusion

Using the transit method, the existence of HD 189733 b was confirmed. The experiment was also attempted on two other stars, but neither succeeded. Throughout the experiment, the atmosphere was the single largest source of error, as was to be expected.

Acknowledgment

This experiment would have not been possible without Dr. Thomas Kirkman, who helped put the experiment together and provided incalculable help and advice. Prof. Dean Langley and Prof. Todd Johnson were both also huge helps as advisers for both the performance of the experiment and the writing of the results. Lastly, thank you to The College of Saint Benedict and Saint John’s University for allowing the use of their telescope, programs, and facilities.

Works Sited:

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