HAT-P 20 b Exoplanet Transit Observation

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Through methods of photometry on a candidate star, we were able to observe and analyze data from an exoplanet transit. We used was HAT-P 20 as our target star where we were able to determine the radius and transit duration of the exoplanet to be $R_p = 0.885366 Rj$ (Jupitr Radii) and $T_{14} = 0.098170 \pm 0.015929$ days respectively. The measured radius of the planet was found to be consistent with the accepted value of $R_p = 0.86 Rj$ with a percent difference of 2.32%. The measured transit duration was not consistent with the accepted value and was out of its error range of the value 0.077 days with a percent difference of 27.5%.

I. BACKGROUND/THEORY

THE method of photometric observations allows us to be able to determine the extrasolar planet's radius. As a planet passes or transits in front of its "parent star's disk," the observable brightness of that star decreases by a certain amount depending on the size of the planet in comparison to its star [1]. For ground-based observations, the best type of exoplanet target is a "hot Jupiter". This means that the planet is a gas giant that has a close orbit around its parent star. We want the orbit to be close because this means that the transits will occur more frequently as well as they're able to be observed over the course of one night. A large planet is easier to observe using the transit method, because the "dip in brightness is around 1%[2].
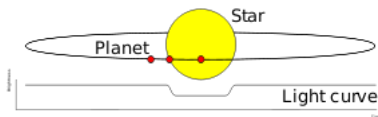

FIG. 1. "Transit method of detecting exrasolar planets. The graph below the [star] demonstrates the light levels received over time by Earth".[1]

In order to determine what exoplanet transit we are able to observe, we must use the following requirements:

- Observing a "hot Jupiter" =the dip in brightness is 1%, in other word, the transit depth percentage should be at least about 1% so that the dip in brightness is observable enough to where we can see a large enough difference from the star.
- A close orbit to the star which allows us to observe the transit in one sitting/night.
- The star should be 30° above the horizon because of how low the telescope can observe and the layers

of atmosphere the telescope would have to observe through would alter the data.
- The star should be 11th mag or brighter so that we can distinguish it among the other stars.
- Need a minimum of an hour before and after the transit to get base brightness data on the star pre and post transit.
- The star should be within the calculated constraints we solved for in part 2 of Lab 2.
- The weather forecast closer to the observation day should show a clear prediction.

Using the observable option for Lowell observatory, we found two options for possible observation from NASA's Exoplanet Archive catalog. The two exoplanet options were WASP-12 b and HAT-P 20 b.

The basic background information on HAT-P 20 b is as follows:

- Orbits an 11.34 magnitude star
- Right Ascension: 07h27m39.95s Declination: 24d20m11.87s
- Transit Depth: 0.9898% Transit Duration: 1.848hr
- Star Observability (Prescott Time)
  Start Observability: 2/27/2019 7:15PM
  Mid Transit: 2/28/2019 12:23AM
  End Observability: 2/28/2019 2:54AM

II. HAT-P 20 B

In this section of the lab we observed the exoplanet transit, and used it to measure the radius and transit duration of the planet.

A. Measurement Method and Procedure

TO begin, we set up all the equipment in the observatory that we needed. We started by opening the dome and then removing the cover from the telescope. Next, we removed the protective bag and lens cap, set

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up the finder scope, and plugged in the telescope, camera, and computer. After starting the computer, we ran TheSkyX, connected the telescope, and connected the imaging camera. In order to locate our star we used a TYC location which was near 1910:871 as our star did not hacv a TYC on SIMBAD.

After locating our star, we clicked Camera → Focus Tool→ 1 second → Take Photo, then

- Telescope → Guide and then centered our star in the observing screen
- Autoguide → Take Photo → double click on brightest guide star → Auto guide
- Camera → Abort
- Camera → Take Series → Take Series

    Whenever we observed either our guide star looking weird of our actual star drifting from the center, we would follow:

- Camera → Take Series → Abort
- Autoguide → Abort

    And then repeated the previous steps in order to retake data. If we observed the guide star looking funky, it most likely meant that the dome was in the way of the guider and so we had to adjust the dome to remain in view of the guider.

The night of observing went pretty well, except the star was drifting a lot more frequently than we had thought. The ending part of our data is not too great because everything was getting severely pixelated and we lost our guide star.

B.   Results and Analysis

To begin, we each downloaded the Apaerature Photometry Tool software. Next, we each chose a star that we would observe/collect data from. Noura was in charge of HAT-P 20 b whereas Emily and I worked on the two different comparison stars within the field of observation. The reason we are also collecting data from additional stars is to make sure there isn't any strange fluctuation in our photometry as well as to be able to compare the magnitude of a star with and without a transit. Once we opened the software, was changed the tool kit from option A to option B so that we weren't using averaged data. Next we clicked the big button to adjust the differential photometry rings to where we had annulus values of 9,10,15.

Once we finished adjusting all our settings, we were able to begin collecting data. To begin, we uploaded the first image, located our star, clicked on it, zoomed into the image 20%, re-centered our star, and moused over the center of the star. On the left side of the screen displayed some basic information about our star. For this lab, we only needed to focus on the time, magnitude, uncertainty, and the x and y coordiantes of our star. When collecting the information of the time, we added 30 seconds as the camera would image every minute, so half of that time is 30 seconds.

We repeated these steps for roughly about 200 images and collected our data in an Excel sheet on Google Docs. During the process of entering in our data, we marked our skeptical fuzzy data in yellow and our totally unusable images in red. The reason for fuzzy images is most likely due to us re-adjusting the telescope, the guide star becoming off center, or the telescope observing through thicker airmasses.

Once this data collection was complete, we uploaded our data into Mathematica as well as converted our time into Julian Date hours. Next we plotted the two comparison star's magnitude over time to make sure our observations were consistent, so the plotted points should relatively follow a straight line/area.

We then plotted the magnitude vs. time of our HAT-P 20 star and were able to see a dip in our data which is exciting and means that we were able to observe the transit. Using the following equation, we converted the magnitude into flux and normalized our data around one.

$$m_1 - m_2 = -2.5log(\frac{f_1}{f_2}) \tag{1}$$
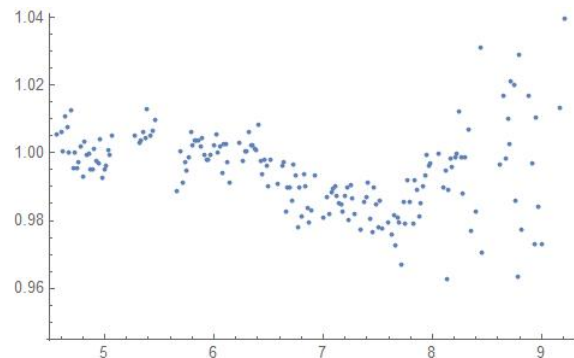
where m is the magnitude and f is the flux.

FIG. 2. This graph shows the change in flux (y-axis) over time (x-axis in Universal Hours) on the star, HAT-P 20. As one can see, there's a dip in flux at around time 6.4 hours. This shows that, at this time, the exoplanet began its transit, passing in front of rhte star in relation to our position.

We then extract the data points for flux and time, convert time into days, and input our data into NASA's exoplanet archive. This archive has the ability to fit our data as well as tell us a lot of information about the star and planet based on our observation.

Using the χ^2 fit and the Monte Carlo (MCMC) fit, we were able to get data regarding the radius and transit duration of our exoplanet. Applying the χ^2 fit, we found the planet radius to be $R_{pc} = 0.885366$Rj (Jupiter Radii). The accepted radius value is $R_p = 0.86$Rj. Comparing the two, we can conclude that we collected very good data from our night of observation as we have a percent difference of 2.32%! We found the transit duration to be $T_{14c} = 0.054519$days. The accepted duration is $T_{14} = 0.077$days. Comparing the two, we
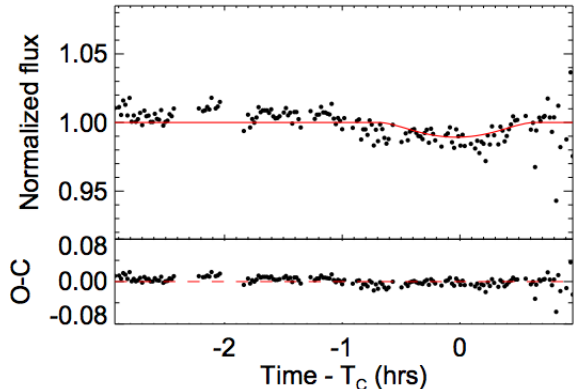
FIG. 3. This graph shows the data we collected from Figure 2 fit to an exoplanet function created by NASA's Exoplanet Archive. We ultimately decided to omit a handful of points as they were outliars that read values that were either too high or too low in flux. We also left off the end of out data because the points were just everywhere.

can conclude that this data is not that great because of how bad the data was towards the end of the transit. Applying the Monte Carlo fit, which usually take errors into account, we got a planet radius of $R_{pm} = 1.910113 + 6.157523 - 1.116505Rj$. This range is super large, but does include our accepted value. We found the transit duration to be $T_{14m} = 0.098170 \pm 0.015929 days$. Unfortunately, this is not within range of the accepted value, but it's a bit closer to the transit value than that of the χ^2 value if we take the uncertainty into account. Comparing the values from the two fits, we can conclude that the χ^2 fit is better for determining the exoplanet's radius, and the MCMC fit is better for determining the transit duration.

In conclusion, we were able to find that the radius of HAT-P 20 b is $R_{pc} = 0.885366Rj$ and the duration is $T_{14m} = 0.09817days$. In order to better this experiment, I would maybe take another night's worth of data to prevent the end of the transit data from being cut off.

[1] Wikipedia *Methods of Detecting Exoplanets*
[2] Dr. Brian Rachford / Techniques of Observational Astron-omy, *Observing Project Handout* February, 2019