ASTRO 4410 LAB 2

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1 Objectives

1. Produce a brigthness curve of a star undergoing a planetary transit.
2. Find the radius of the transiting planet.

2 Setup

2.1 Image acquisition

Observations were made during the night of September 17th, 2015 at the Hartung-Boothroyd Observatory (HBO) located at Mount Pleasant, Ithaca, NY. The HBO houses the James R. Houck telescope, a fork mounted cassegrain reflector telescope whose primary mirror is 25 inches (0.635 meters) in diameter. It has a f/13.5 lens, with a native plate scale of 24 arcsec/mm. Photon detection was performed using an Andor iDus 440 CCD, which sports a coated e2v CCD 42-10 BV sensor. Image resolution was of 2048 by 512 pixels, with a pixel size of 13.5e-6 m, a plate scale of 0.3"/pixel, a field of view of 10.7' by 2.6', and a read noise of 4 e^-. Exposure time for each of the transit images was 30 seconds.

2.2 Target object

The object observed was the star WASP-10, located 90.0 (ś 20.0) pc away from Earth. Its spectral class is K5, and its equatorial coordinates are 23:15:58.0 RA and +31:27:46 Dec. WASP-10b, the transiting planet, was discovered on 2008 and is a gas giant with a mass of 3.16 M_J.

2.3 Bias and flat noise

Before observations began, 10 images with exposure time of 0.00001 seconds were taken in order to obtain data that was later used to compensate for bias. No photons were allowed to enter the CCD while these images were taken. In addition to this, 50 images of exposure time of 2 seconds under a flat bright light field were performed in order to properly compensate for imperfections in the subsequent image acquisition.

3 Data reduction

The data reduction was performed using Python. The original 231 transit images containing the target star and several others were inspected in order to look for obvious errors. It was found that image number 132 was considerably brighter than the rest, so it was not used in the analysis. The bias was calculated by averaging, pixel by pixel, the 10 zero second exposures performed before observation. This bias was substracted, again pixel by pixel, from each of the transit images. Compensating for the flat noise involved finding the pixelwise median for each of the flat images taken and then dividing by their average, again pixel by pixel. Then, each of the transit images were divided pixelwise by the flat noise.

Tracking of the target star was performed by comparing the position of the star in the first image vs the position of the star in the final image, enabling the construction of a box that was able to encompass the star in each of the 230 images without encompassing other surrounding stars. This box was subsequently analyzed, image by image, in order to locate its maximum value in each of them, thus finding the coordinates of the star's center for every one of the images. Finally, these coordinates were used to construct a new, smaller box centered on the star with its edges effectively framing it, obtaining something akin to a circle (the star) inscribed in a square (the box). Obtaining the relative brightness of the star for each of the images was then done simply by calculating the average of the values of the pixels within that box.

Compensating for atmospheric effects involved using the same tracking technique described above on another star within the field that was always present throughout the images, calculating its brightness in each case, then scaling and subtracting that brightness to the target star's at the corresponding observation time. The scaling was done using the data points at t=175 (image number 175) at which point none of the stars was undergoing transit.

All the previous steps returned a list of 230 values which corresponded to the adjusted relative brightness of the target star for each of the acquired images. Since the star was supposed to be undergoing a planetary transit during the time the data was obtained, plotting this list of values as a function of time should produce a planetary transit curve.

4 Results and Analysis

4.1 General analysis

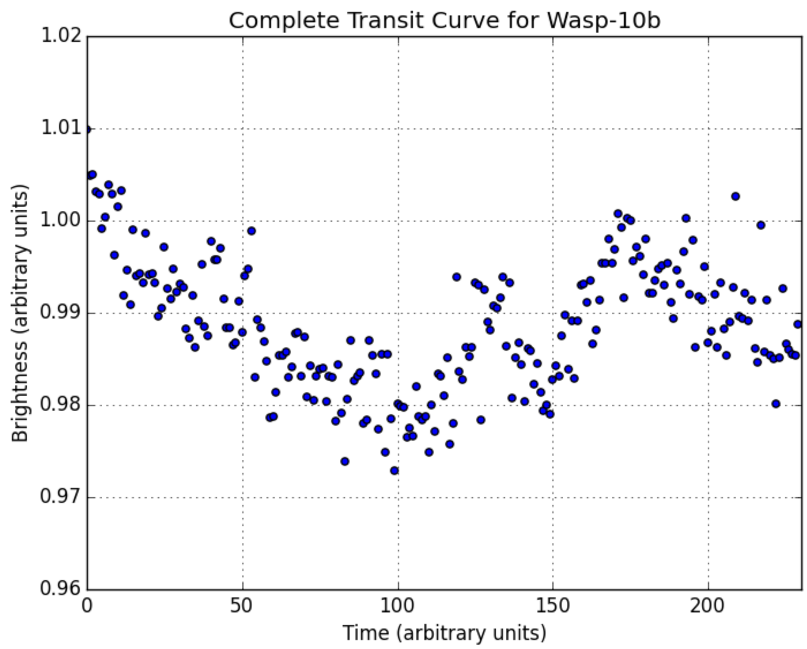

Figure 1: Complete transit curve

Figure 1 contains the complete planetary transfer curve extracted from the observations. It is immediately apparent that the results are not perfect. In particular, there are two things that must be analyzed in more detail. First of all, the choice of scale point caused the observed brightness to start at about 101% instead of 100%, as would be expected. However, careful observation reveals that there is only one point at or near B=1.01, with the following point being near B=1.005, so the error is not too big so as not to be possible to attribute it to noise that was not taken into account during data processing. For instance, it must be noted that there was no adjustment done in order to compensate for limb darkening, and the code used to analyze the images assumed that the center of the star was located at the pixel that had the maximum relative brightness, which is not necessarily true. Calculation of the planet's radius will be done by ignoring this 0.5% discrepancy and taking the percentage darkening to be unity minus the minimum value of the brightness that can be extracted from the plot.

The other thing that demands an explanation is the shape of the curve after t=175. Instead of the star's brightness being constant from that point on, our observations appear to imply that after reaching its original value, the brightness starts going down again, which of course does not make sense since the planetary transit was already over. I do not have a completely satisfying explanation for this. It is possible that it is just noise: that some atmospheric phenomenon that was not accounted for (such as a cloud) produced uneven distortion that only affected either the target start or the star used to compensate for atmospheric effects. A more detailed analysis, taking into account the brightness evolution of more of the stars observed throughout the night could determine whether this hypothesis is correct. For now, though, it is possible to ignore this noise and use the curve from Figure 2 in order to estimate the radius of the planet.

4.2 Calculation of planetary radius

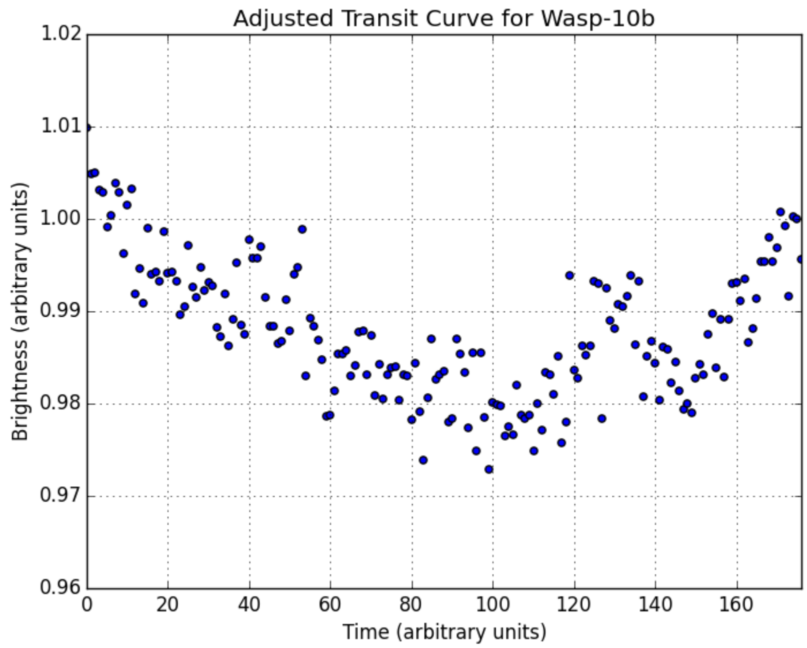

Figure 2: Adjusted Transit Curve

An estimate of the planetary radius can be made by looking at the percentage of brightness coming from the star that the planet was able to block, which can be obtained by looking at the lowest point in the transit curve. This can be quantified by the following equation:

$$\frac{L_T}{L_0} = 1 - \left(\frac{R_P}{R_S}\right)^2 \tag{1}$$

Where $L_0$is the star's original brightness, $L_T$is the star's brightness with the planet under transit, $R_P$is the planet's radius, and $R_S$is the star's radius. Solving for R_P, we have:

$$R_P = R_S\sqrt{1 - \frac{L_T}{L_0}} \tag{2}$$

From the transit curve, the maximum value for L_T/L_0 is

$$\frac{L_T}{L_0} = 0.9765 \pm 0.0035 \tag{3}$$

The radius of the star is (from the Extrasolar Planet Encyclopaedia)

$$R_S = (0.783 \pm 0.071) R_{Sun} \tag{4}$$

Plugging this into (2) gives

$$R_P = (0.120 \pm 0.014) R_{Sun} \tag{5}$$

The same Extrasolar Planet Encyclopaedia gives the radius of the planet as

$$R_P = (1.08 \pm 0.02) R_J \tag{6}$$

With $\mathrm{R_J}$ being the radius of Jupiter. Since

$$R_{Sun} = 9.73 R_J \tag{7}$$

(5) can be written as

$$R_P = (1.17 \pm 0.14) R_J \tag{8}$$

Which, given the instrumentation used and the not very sophisticated method used to analyze the data, is in reasonable agreement with the accepted value.

5 Conclusion

The purpose of this lab was to observe a planetary transit using the James R. Houck telescope at HBO, extract a planetary transit curve from the data obtained and use this curve to find the radius of the planet in question, in this case, WASP-10b. The objectives were fulfilled and reasonable agreement was obtained between the results obtained and those that were expected, save for a strange feature of the curve that was mentioned in section 4.1, but which does not appear to have affected the calculation of the planetary radius. Further refinements in the data reduction process, as well as data from other transit events for the same planet, would probably produce a better estimate for the planetary radius, but this can be regarded as a good first approximation.

References

exoplanet TEAM. "WASP-10b". *The Extrasolar Planets Encyclopaedia.* Observatoire de Paris. Accessed on 10/20/2015. <http://exoplanet.eu/catalog/wasp-10_b/>