# TRANSIT METHOD OF EXOPLANET RADIUS CALCULATION FOR HD 189733b

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## ABSTRACT

Aperture photometry was performed on data collected from the Spitzer Space Telescope InfraRed Array Camera, program 30825: a transit of planet HD 189733b at 8μm observed on October 29, 2006. In addition to all frames already being flat-fielded, debiased, and darkened according to IRAC data processing, further processing including median sky subtraction and sigma rejection were performed on the data. Data to report includes an eclipse depth of 0.02375 ± 0.000003, a planet to star radius ratio of 0.1541 ± 0.00001 and a calculated radius for the planet being 0.1166 ± 0.0003 $R_{sun}$ .

## 1. INTRODUCTION

Over 500 exoplanets have been discovered in the past two decades. Among these are a class that are roughly Jupiter-mass objects that orbit their host stars within 0.05 AU, known as hot Jupiters. (Seagar et al. 2000). The relatively large sizes of these objects along with their close proximity to the host star allow for transits of the planet across the host star along the line of sight to be relatively easy to detect. Aperture photometry performed on such stars with close orbiting planets reveal a light curve with a distinct transit depth. From analyzing the light curve such information as planetary size and planetary mass can be determined (Langford et al. 2011).

## 2. APERTURE PHOTOMETRY

### 2.1 DATA

Data from HD 189733b was collected for roughly 3.8 hours total using the 8μm channel of the InfraRed Array Camera (IRAC) (Fazio, G. G. et al. 2004). IRAC images in sets of 64 frames are collected along with UTC time data from the corresponding FITS headers. All frames are median background subtracted. A two-dimensional Guassian is fitted to a subarray of data roughly centered on the star for each frame of data, yielding fitted coordinates and an average width value of 0.705. HD 189733 has a companion star which is masked so that its flux doesn't contaminate the data.

### 2.2 FRAME CORRECTION

All frames feature calibrated data as per the Spitzer's preprocessing pipeline. Bad pixels are detected by grouping sets of 64 frames and doing two-iteration sigma rejection at each pixel location. The routine calculates the standard deviation from the median and masks any pixels with greater than 5σ deviation (Nymeyer, Harrington et al. 2011). The routine proved useful in masking momentary cosmic ray hits to the array.

### 2.3 PHOTOMETRY

Using the Gaussian fitted centers and widths for the stellar data of each frame, aperture photometry is performed while recording integrated stellar flux, average sky values, and bad pixel counts for the aperture for each frame. An aperture with a radius of 4.5 pixels along with inner and outer annuli for sky subtraction of radii 6.3 pixels and 9.1 pixels respectively are used to maximize signal-to-noise. From the raw data large outliers likely arising from abnormally high background or micrometeorite impacts to the spacecraft are ignored (45 frames). The resulting light curve from collected stellar flux along with an averaged plot show a distinct eclipse depth (see Figures 1 & 2).

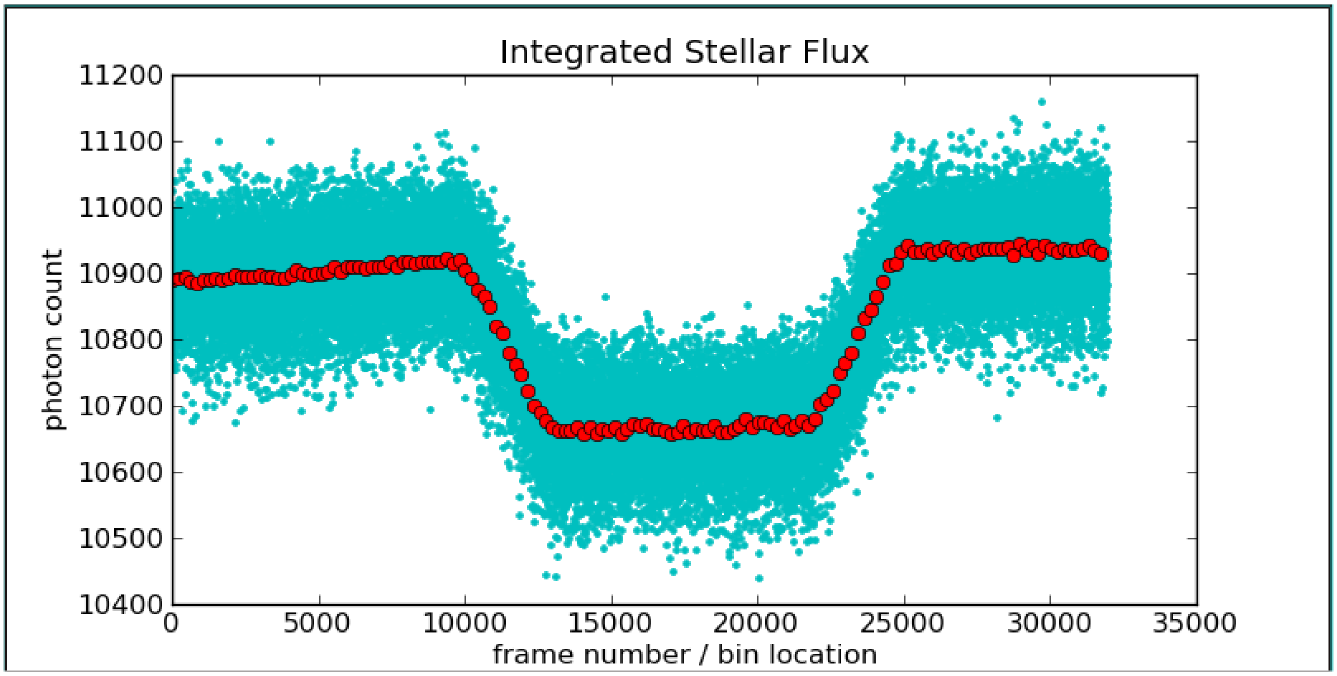


**Figure 1.** Light curve with binned average flux curve. Cyan data points represent raw data for flux while red data points represent binned flux averages for 150 bins across the data interval.

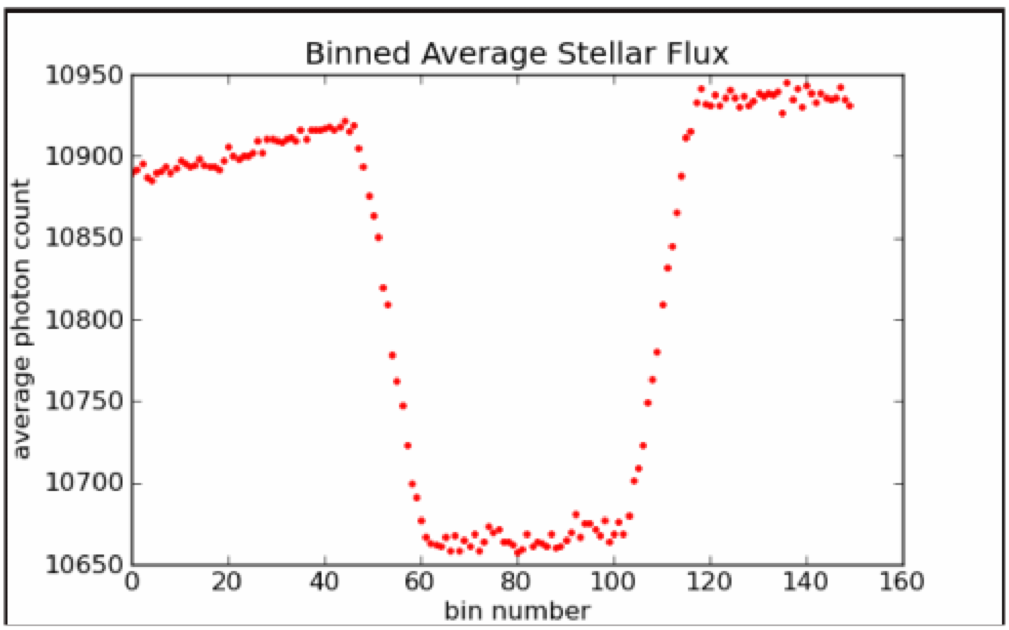


**Figure 2.** Binned average stellar flux for 150 bins. Raw data was binned into 150 bins excluding rejected frames and bins were averaged.

## 2.4 DATA CORRECTION

An overall ramp on the raw data can be observed from the initial frame up to frame 10000 (see Figure 1). This ramp is due to charge trapping by impurities in the array, causing the detector to become more sensitive over time. In order to correct this a quadratic is fit to the data outside of transit and the corrected parabolic function is used to normalize each flux value (see Figure 3) (Knutson, H.A., Charbonneau et al. 2009). The solutions to the quadratic fit minimize the squared error.

$$E=\sum_{j=0}^{k}|p(x_j)-y_j|^2$$

Data used for further calculation is taken from frame 7800 to 27000 to further reduce the effect of charge trapping on data analysis.

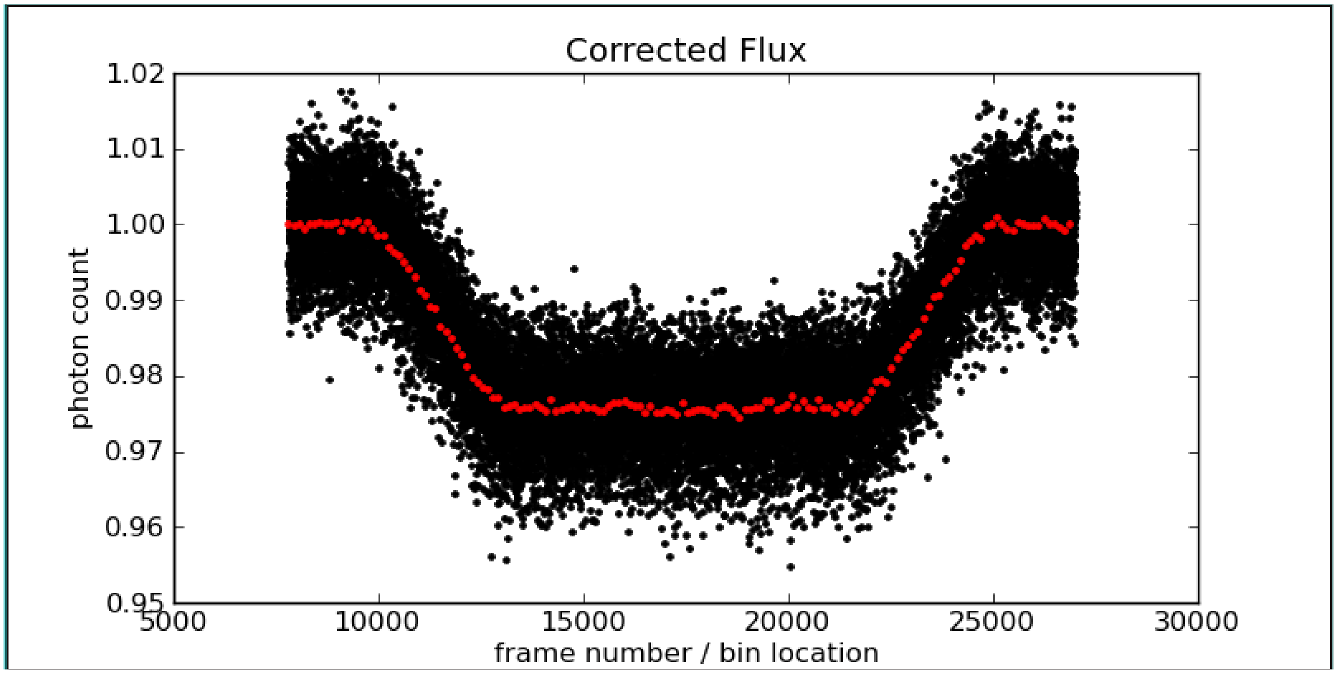


**Figure 3.** Corrected flux data with averaged bins. Flux data normalized with a quadratic fit to minimize the squared error.

## 3. RESULTS

From the corrected data a flat run is found so that the standard error for the stellar photometry level is determined to be 0.0053. From this the signal-to-noise ratio is determined to be 188.76. The eclipse depth can be calculated by determining the ratio of the cross-sectional area of the planet to the cross-sectional area of the star.

$$\frac{A_p}{A_S}=\frac{\bar{F}_s-\bar{F}_p}{\bar{F}_s}$$

Using this relation the mean stellar flux outside of transit and the mean stellar flux during transit are calculated. The uncertainties are propagated through the error-propagation equation.

$$\sigma_x^2\simeq\sigma_u^2\left(\frac{\partial x}{\partial u}\right)^2+\sigma_v^2\left(\frac{\partial x}{\partial v}\right)^2+\ldots+2\sigma_{uv}^2\left(\frac{\partial x}{\partial u}\right)\left(\frac{\partial x}{\partial v}\right)$$

Propagation of the error through the mean is as follows.

$$\sigma_x \simeq \frac{\sqrt{n^2 \sigma}}{n} = \frac{\sigma}{\sqrt{n}}$$

The ratio of the planetary area to stellar area is determined to be 0.02375 ± 0.000003. The ratio of planetary radius to stellar radius can be determined by squaring the previous result and propagating the error through the square root.

$$\frac{r_p}{R_s} = \sqrt{\frac{\bar{F}_s - \bar{F}_p}{\bar{F}_s}}$$

$$\frac{\sigma_x}{x} \simeq \frac{\sigma_u}{2\mathrm{u}}$$

The planet to star radius ratio is calculated to be 0.1541 ± 0.00001. Using the host star HD 189733's radius in terms of the solar radius, 0.757 ± 0.003 $R_{Sun}$ (Knutson, H.A., Charbonneau et al. 2009), the radius of HD 189733b is determined to be 0.1166 ± 0.0003 $R_{sun}$ .

## 4. DISCUSSION

The values reported are an eclipse depth of 0.02375 ± 0.000003, a planet to star radius ratio of 0.1541 ± 0.00001 and a calculated radius for the planet being 0.1166 ± 0.0003 $R_{sun}$ . Knutson, H.A., Charbonneauu et al. reported a planet to star radius ratio of 0.1545 ± 0.0002 which is relatively close to my results. The calculated radius of the planet implies a planetary size slightly larger than Jupiter, as Jupiter's own radius compared to that of the Sun's yields a ratio around 0.1.

## 5. CONCLUSION

Aperture photometry was performed on data collected from the Spitzer Space Telescope InfraRed Array Camera. Data reported includes an eclipse depth of 0.02375 ± 0.000003, a planet to star radius ratio of 0.1541 ± 0.00001 and a calculated radius for the planet being 0.1166 ± 0.0003 $R_{sun}$ . These results suggest that the exoplanet revolving around the star HD 189733 is a little larger than the size of our own gas giant Jupiter.

## REFERENCES

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