

# Searching For Evidence of Extrasolar Planet Evaporation in the Transits of HD209458b

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Extrasolar planets have characteristics that differ greatly from planets in our own solar system. In particular, the close-in, hot Jupiter planets have such high temperatures that a number of researchers speculate some of these planets upper atmospheres are being “boiled” away by their parent star. Evidence of this comes from the signature of an inflated planet in hydrogen absorption spectra. Several studies have shown that there is a 15% decrease in flux in Lyman alpha wavelengths during transit, compared to ~2% in the optical continuum in HD209458b. Confirmation of this result is important. We use very high quality HST STIS optical continuum data to search for an asymmetry between ingress and egress phases. A program was created using transits for HD209458b to examine this hypothesis. The code created and interpolated models to examine the transits for evidence of loss. We were unable to confirm the planet is losing its upper atmosphere. However, the data showed something else: a slight tilt was discovered in the out-of-transit sections of the light curve, which should be taken note of for future work.

## Introduction

HD209458b is the first transiting extrasolar planet to be discovered in 1999 (Brown et. al. 2001). It is known as a “hot Jupiter”, a planet with a radius and mass approximately the size of Jupiter, which orbits its star at semi-major axes that can be as small as 0.03 AU, and orbital periods lasting as little as a few days. Due to our ability to observe the planet passing directly in front of the star, many physical parameters can be determined by examining its transits, such as mass and radius, and also some characteristics of its atmosphere. Studies have been conducted and predictions have been made that these planets could be losing their upper atmospheres in comet-tail like features, due to the intense stellar flux experienced while orbiting at such small semi-major axes.

In 2003, a study conducted by a team lead by Alfred Vidal-Madjar examined transits of HD209458b in Lyman alpha. When observed, they found a decrease in flux by 15% (Vidal-Madjar et. al. 2003). Since the implied radius at this wavelength exceeds the Roche limit of the planet, it led them to conclude that the object was losing material. Another study published in *Nature* in 2007 by Ballester et. al. reported that hot hydrogen gas was escaping the upper atmosphere of HD209458b in a process created by extreme UV flux and stellar radiation pressure pushing hydrogen atoms away from the atmosphere (Ballester et. al. 2007). The data collected and interpreted by these studies shows evidence in spectra. However, a more complete picture is needed to determine whether the planet is actually losing its atmosphere.

While these observations were done by examining HD209458b in Lyman alpha absorption spectra, we aim to examine the much higher signal-to-noise optical continuum data to search for evidence of atmospheric evaporation. This can be done by comparing the ingress and egress: they should be identical if there is no evaporation; but the egress should be depressed (deeper transit depth) if there is trailing material due to evaporation.

## Observations and Reduction

In order to test the comet-tail hypothesis, we used a series of light curve data sets for HD209458b. The Hubble Space Telescope’s (HST) Space Telescope Imaging Spectrograph (STIS) was used by Timothy M. Brown in 2001 to observe a series of transits. Four transits were studied by using 20 HST orbits that lasted 18 days over four visits. These gave a total number of 664 spectra, with wavelength range 582-638 nm (Brown et. al. 2001). The data received from these observations

was phase folded, converting it from HJD to phases. These high precision observations from HST were then used in the linear interpolation modeling program.

First, the “model” was created: the model is really the mirror image of the ingress. The phases were changed by subtracting one from the phases of the ingress, creating a mirror image of the egress. Once the mirror image was created, the data in the “model” was then linearly interpolated. Next, the “model” data were compared with the actual egress observations. After making the model and placing it over the observed data, the difference of the observed minus calculated was taken to find the residuals. The program found the difference between the two sets of flux values, creating a data file containing the phases and the new observed minus calculated (O-C) flux. Finally, the residuals were binned. Several different versions of binning were evaluated to find the best possible display of the output. Data were placed in binned sets of 10, 15, and 20 points each, where the mean and root mean square were calculated for O-C, giving y error bars of one sigma.

### Analysis

After the residuals were binned, it was possible to fully analyze the data sets. The binning was necessary to search for trends in the difference between the “model” and the actual egress. If the data does contain evidence to suggest planetary evaporation, the points would have shown a consistent trend in two cases—the observed versus model figure, and the binned residuals. For the observed versus model graph, the observed would have shown a lower flux than the “model”, and the curve of the egress would have been lower than the “model”. In the case of the residuals, there should have been a trend where the points were found below zero in the late phases.

The initial comparison between the observed data and the model showed no large difference in the curve as the planet leaves transit. When examining the binned data, it was found that there was no significant decrease in flux to provide support to the comet tail hypothesis. The model and observed transit curves followed each other too close to show any significantly lower curve in the actual egress.

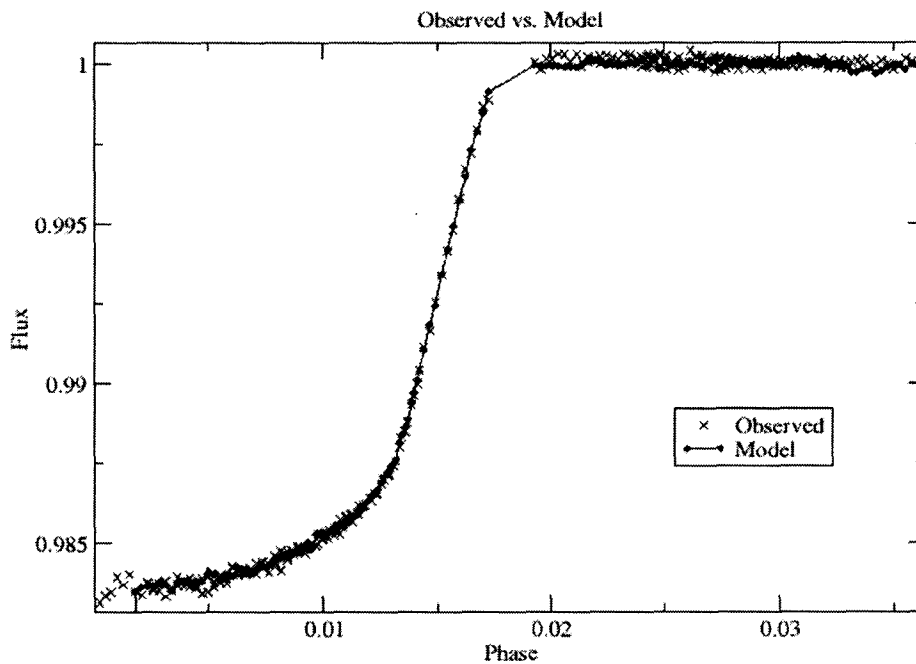


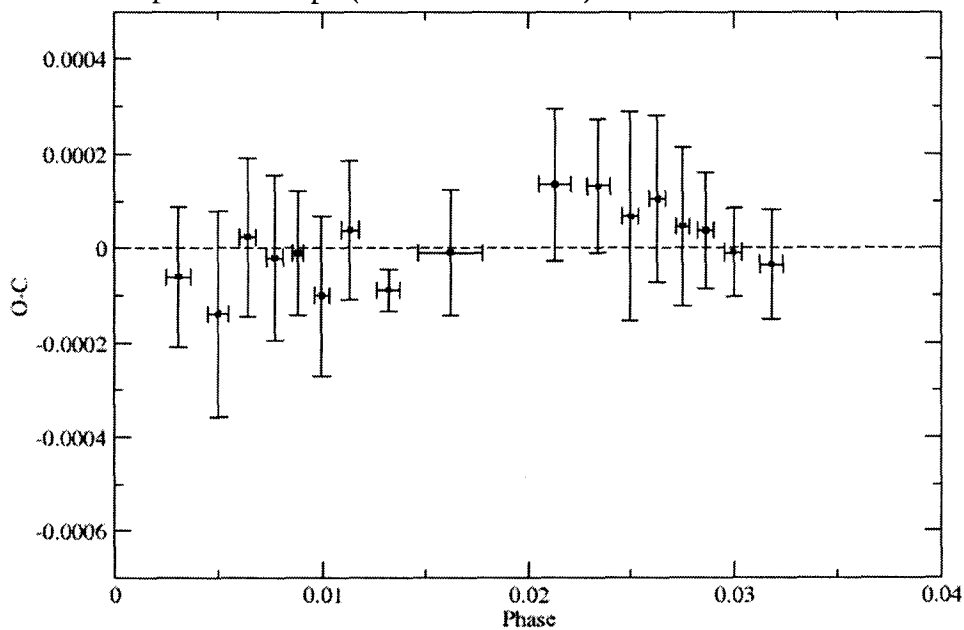
Figure 1. Observed egress versus model data.

The binned data set ultimately chosen to best represent the results took data in sets of 20 points each. When studying the binned observed minus calculated results, most points fell close to zero. No significant trend below zero in the O-C was seen that could suggest evidence for an

asymmetry that would suggest atmospheric loss in the optical data. The set did show a positive slope, though not due to atmospheric loss, but rather a possible calibration error.

Despite the lack of evidence supporting planet evaporation, the residuals did provide one less important but nevertheless interesting discovery. The data sets for STIS were found to have a slight tilt in the out of transit portions of the curves making the left half of the set slightly lower than the right portion. While this tilt could occur if this were ground-based data, this explanation is not relevant with space telescope-based data, and needs further analysis and explanation, but could possibly be due to a calibration error. This tilt could have future implications for the difficulty of examining the residuals and looking for certain trends, and should be noted in future research with the STIS data used in this study.

Future work can be done using the mirror ingress model method. Other data sets can be used in the modeling program to get a more complete picture of the properties of transits for HD209458b and other extrasolar planets classified as hot Jupiters. In this particular case, other high quality data that could be used include those observed using STIS by Knutson et. al. (2006), and also those obtained by Schultz et. al. (2003) using the photomultiplier tubes of the Fine Guidance Sensor (FGS), also on the Hubble Space Telescope (Schultz et. al. 2003).



**Figure 2.** Residuals of data, binned in sets of 20 points each. No trend is seen prior to phase 0.02, indicating no asymmetry is present. The high points after phase 0.02 are post-transit, and are likely a calibration

## Conclusions

The STIS data set used for this study was found to not have asymmetry between ingress and egress phases, and had residuals with no trend towards a low flux that would be consistent with an escaping atmosphere. While other studies have found support in the spectra of HD209458b in this study using the Brown et. al. (2001) STIS data and the mirror ingress model did not observe evidence for the comet tail hypothesis. However, a discovery was made in that a tilt in the transit was found after calculating the residuals. Knowing and taking note of this slope could be useful to future studies.

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