

Probing the Outskirts of an Extrasolar Planet with HST Time-Series Photometry

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Abstract. We observed 4 planetary transits of HD 209458 with the STIS spectrograph on *HST*, and generated a photometric time series with extremely rapid cadence and high precision. We use these data to better constrain the orbital, stellar, and planetary parameters, and to search for circumplanetary rings and planetary satellites.

1. Planetary Transits as Seen by HST

The detection¹ of planetary transits across the star HD 209458 has enabled the first direct estimate of the radius, mass, average density, and surface gravity of an extrasolar planet (Charbonneau et al. 2000; Henry et al. 2000; Mazeh et al. 2000). We obtained 5 orbits of HST observations on each of 4 transits of this system. The detailed analysis of these data, of which the following is a brief summary, is presented in Brown et al. (2001).

We used the STIS spectrograph to disperse the light over a large number of detector pixels. We obtained 684 such spectra of HD 209458 spanning 582–638 nm, with a resolution of 0.11 nm, and a SNR of 400 per one-dimensional resolution element. By taking the ratio of coadded spectra in and out of transit, we will search for additional absorption features, due to light passing through the limb of the planetary atmosphere (Seager & Sasselov 2000; Brown 2001).

Summing the counts yields a photometric time series with 80 s time sampling and relative precision of 1.1×10^{-4} . We derive a best-fit time for the midpoint of the first transit of $T_c = 2451659.93675 \pm 0.0001$ HJD. Comparing this with other measured transit times (Charbonneau et al. 2000; Jha et al.

¹Based on observations with the NASA/ESA *Hubble Space Telescope*, obtained at STScI, which is operated by the AURA, Inc., under NASA contract No. NAS5-26555.

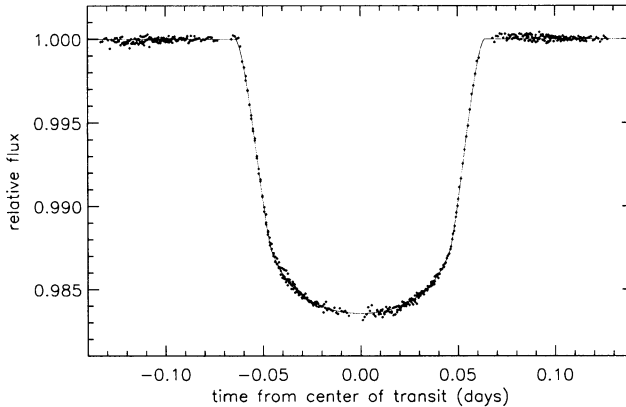


Figure 1. Phased light curve for all 4 transits. The solid line is the best-fit model light curve of the planetary transit.

2000), we find a period of $P = 3.52480 \pm 0.00004$ d. This value is in agreement with the values derived with similar precision from *Hipparcos* archive photometry (Castellano et al. 2000; Robichon & Arenou 2000).

The folded light curve (see Figure 1) can be fit within observational errors using a model of an opaque planet transiting a limb-darkened stellar disk. In contrast to previous estimates of the system parameters, these data are sufficiently accurate that we do not require an assumption of the stellar radius. We estimate the planetary radius $R_p = 1.347 \pm 0.060 R_{\text{JUP}}$, the orbital inclination $i = 86.68 \pm 0.14^\circ$, the stellar radius $R_* = 1.146 \pm 0.050 R_\odot$. A precise estimate of R_p places a useful constraint on evolutionary models (Burrows et al. 2000).

If the planet were circled by a system of rings of sufficient size and opacity, the rings would cause distortions of the light curve that would be detectable as a small dip before first contact and after last contact. We find no evidence for such a system of rings. We can exclude rings with a radius as small as $1.8 R_p$ at the 3σ confidence level. This is slightly smaller than the radius of Saturn's ring system, measured in units of Saturn's radius.

By examining the residuals in the time series from the best-fit planetary transit light curve, we search for the additional dimming of the stellar flux due to the passage of a planetary satellite (Sartoretti & Schneider 1999). These dimmings may lead or trail the planetary transit, and vary in duration, depending upon the satellite orbital phase and period. We can exclude satellites larger than $1.5 R_\oplus$ (see Figure 2). Satellites may also induce variations in the observed time of the center of the planetary transit, as the planet orbits the center of mass of the planet-satellite system. For a $1-M_\oplus$ satellite orbiting HD 209458 b at the Hill sphere radius, the maximum temporal excursion is 13 s. Taking the observed transit time variations to be an upper limit on the displacement caused by an unseen satellite, we can exclude the presence of satellites more massive than $3 M_\oplus$ with an orbital radius equal to the Hill sphere radius.

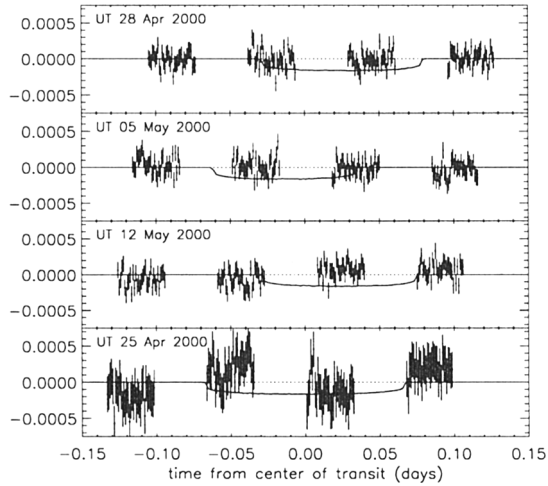


Figure 2. Residuals from the best-fit planetary transit model. The solid lines show a typical light curve one would expect given the presence of a $1.5-R_{\oplus}$ satellite, which is excluded by the data. The relatively large errors for the transit on UT 25 April 2000 are due to an offset of the spectrum in the CCD subarray.

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