The Astrophysical Journal, 536:L47–L48, 2000 June 10

SEARCH FOR TRANSITS OF A SHORT-PERIOD, SUB-SATURN EXTRASOLAR PLANET ORBITING HD 46375

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Received 2000 April 4; accepted 2000 April 26; published 2000 June 6

ABSTRACT

Precise brightness measurements of HD 46375 have been acquired with an automatic telescope to search for transits of its short-period, sub-Saturn extrasolar planet. Transits of the companion do not occur, indicating that the inclination of the orbit i is less than 83° and $\sin i$ is less than 0.992. This upper limit on $\sin i$ still preserves the possibility that the mass of the planet is less than Saturn's. Analysis of the photometry for HD 46375 reveals no photometric variability larger than 0.0001 ± 0.0002 mag at the orbital period of the planet. This effectively eliminates starspots and stellar pulsations as the cause of the radial velocity variations used to infer the planet's existence.

Subject headings: planetary systems — stars: individual (HD 46375)

1. INTRODUCTION

Marcy, Butler, & Vogt (2000) recently announced the discovery of two short-period extrasolar planets with minimum masses somewhat less than that of Saturn, which has a mass of 0.30 $M_{\rm Jup}$. One of them, the companion to HD 46375 with $M = 0.25\ M_{\rm Jup}/\sin i$, has the shortest orbital period yet found for any extrasolar planet (3.024 days) and orbits at a distance of only 0.041 AU, making it an ideal candidate for the detection of planetary transits. Of the 34 extrasolar planets discovered to date, eight of which have orbital periods less than 10 days, only HD 209458 is known to exhibit transits (Henry et al. 2000b; Charbonneau et al. 2000). Detection of transits in HD 46375 would confirm that the planet's true mass is less than Saturn's and allow the determination of its radius, mean density, and approximate composition.

According to Marcy et al. (2000), HD 46375 is a chromospherically inactive K1 IV–V star with greater than solar metallicity that lies approximately 1.0 mag above the main sequence. They estimate its mass to be $1.0 \pm 0.1\ M_{\odot}$.

2. PHOTOMETRIC OBSERVATIONS

Between 2000 January 9 and April 2, a total of 58 differential measures of HD 46375 were acquired through Strömgren b and y filters with the T8 0.80 m automatic photoelectric telescope (APT) at Fairborn Observatory in southern Arizona.[2] The comparison star was HD 43856 ($V = 7.96$, $B-V = 0.51$, F6 V). The observations were corrected for differential extinction with nightly extinction coefficients and then transformed to the Strömgren system with long-term mean transformation coefficients. The b and y observations were combined into a single value, $\Delta(b+y)/2$, to increase the precision of the resulting differential magnitudes. The nominal precision of a single observation with this APT is 0.0011 mag. Complete details on the telescope and photometer, observing procedures, and reduction of the data can be found in Henry (1999).

HD 46375 lies at a distance of 33.4 pc (Perryman 1997) and in the foreground of the outer region of the Rosette Nebula. However, the increased sky brightness due to the Rosette is negligible compared to the brightness of HD 46375. The standard deviation of the 58 observations of HD 46375 from their mean is 0.0012 mag, so the precision of the photometry is not compromised by the presence of the nebula.

3. DISCUSSION

From $V = 7.91$, $B-V = 0.86$, and $\pi = 29.93$ mas from the *Hipparcos* catalog (Perryman 1997) along with the $T_{\rm eff}$ calibration of Flower (1996), the radius of HD 46375 is estimated to be 1.1 $R_{\odot}$. To estimate the photometric depth of possible transits of the sub-Saturn companion, I assumed a radius for the companion of 1.4 $R_{\rm Jup}$ (the measured radius of the gas giant planet around HD 209458 from Henry et al. 2000b). Combined with the estimated stellar radius, this gives a photometric transit depth of approximately 0.018 mag. The probability of these transits occurring is 12.5%, assuming random orbital inclinations and computing the probability as the ratio of the stellar radius to the semimajor axis of the planetary orbit (Schneider 1996).

To search for these transits, I plot the 58 Strömgren $\Delta(b+y)/2$ magnitudes in Figure 1. Phases in both panels have been computed with the ephemeris

$$\mathrm{JD_{conj}} = 2{,}451{,}603.508 + 3.024E, \quad (1)$$

where the epoch is a time of inferior conjunction of the planet (a time of midtransit for favorable orbital inclinations) derived from the orbital elements of Marcy et al. (2000), and the period is their planetary orbital period. The top panel plots the complete data set, while the bottom panel uses an expanded scale on the abscissa to plot only the observations near the time of conjunction. The predicted depth and duration of the transit light curve are shown schematically. The horizontal error bar immediately below the transit window in the lower panel gives the uncertainty of the predicted time of midtransit. The vertical error bar in the lower right of the panel indicates the precision of a single observation.

It is clear that transits of the expected depth do not occur. The mean of the 21 observations within the transit window agrees with the mean of the 37 observations outside the window to better than 0.0001 mag. This eliminates the occurrence of transits, even for a small planet with a radius about twice Earth's. Therefore, the inclination of the orbit i is less than 83°, and $\sin i$ is less than 0.992. However, this upper limit on the

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[2] These observations are available at http://schwab.tsuniv.edu/t8/hd46375/hd46375.html.

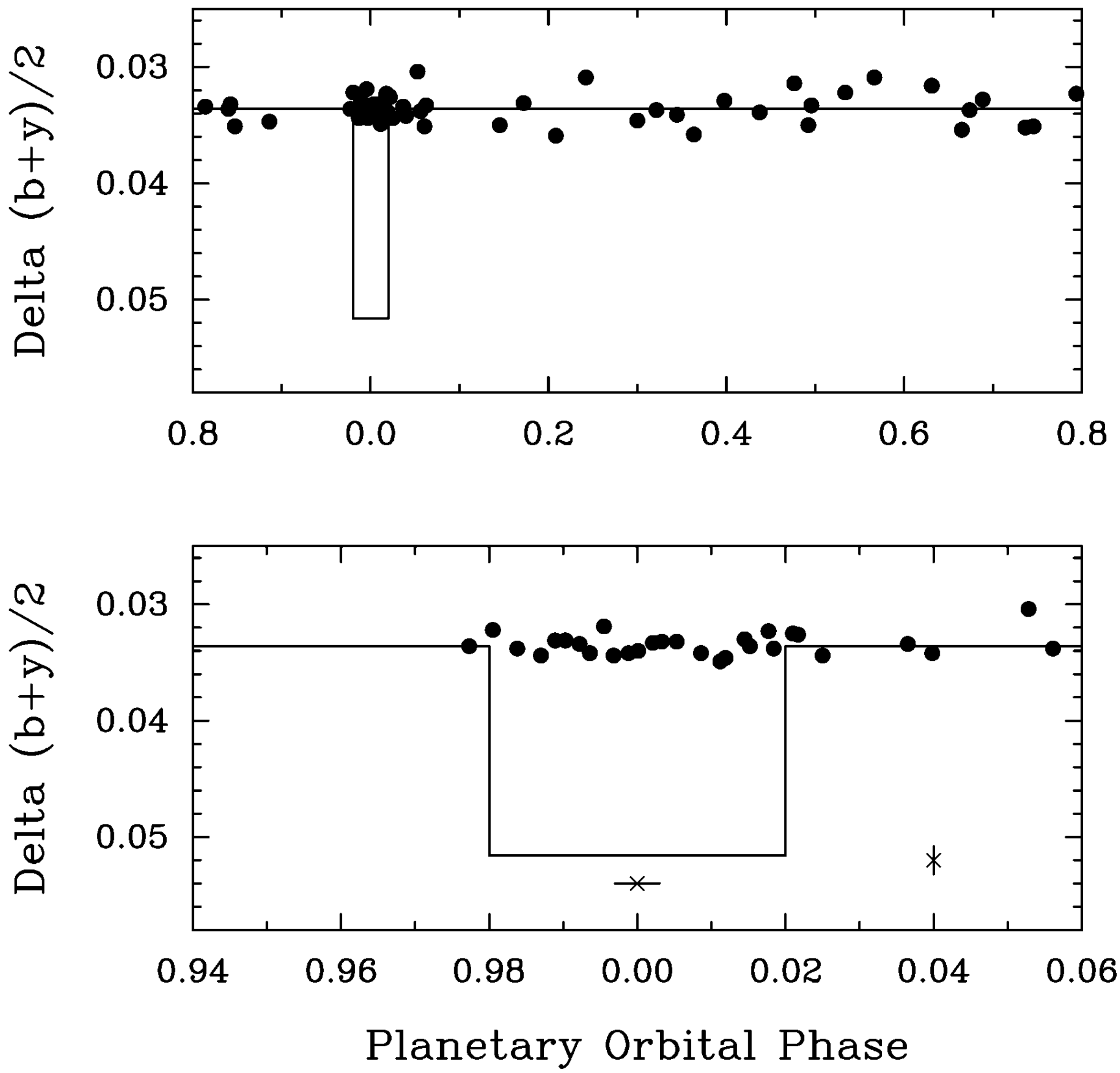

FIG. 1.—*Top*: Complete set of Strömgren $\Delta(b+y)/2$ differential magnitudes for HD 46375 plotted against orbital phase of the companion. The predicted depth and duration of the transit light curve are shown schematically. The star has no light variability on the planetary period larger than about 0.0001 mag or so. *Bottom*: Observations around the phase of predicted transit are replotted with an expanded scale on the abscissa. The horizontal error bar gives the uncertainty in the predicted time of midtransit. The vertical error bar indicates the precision of a single observation. Transits deeper than about 0.0001 mag are ruled out by these observations.

inclination still allows the possibility that the mass of the planet is less than Saturn's.

The semiamplitude of a sine-curve fit to the complete $\Delta(b+y)/2$ photometric data set with the period fixed to the planetary orbital period is 0.0001 ± 0.0002 mag. This very low limit of possible variability in HD 46375 confirms that neither starspots nor stellar pulsations are the cause of the radial velocity variations (see Henry et al. 2000a) and, thus, strongly supports the existence of the planet even in the absence of transits.

The author acknowledges Lou Boyd and Don Epand for their efforts in support of the automatic telescopes at Fairborn Observatory. Astronomy with automated telescopes at Tennessee State University is supported through NASA grants NCC5-96 and NCC5-228, which fund TSU's Center for Automated Space Science, and NSF grant HRD-9706268, which funds TSU's Center for Systems Science Research. Additional support for the planetary search program comes from the Richard Lounsbery Foundation.

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