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A Search for Exotrojans in Transiting Exoplanetary systems

N. Madhusudhan & Joshua N. Winn

Department of Physics and Kavli Institute for Astrophysics and Space Research, MIT, Cambridge, MA 02139; nmadhu@mit.edu

Abstract. We present a search for Trojan companions to 25 transiting exoplanets. We use the technique of Ford & Gaudi, in which a difference is sought between the observed transit time and the transit time that is calculated by fitting a two-body Keplerian orbit to the radial-velocity data. This technique is sensitive to the imbalance of mass at the L4/L5 points of the planet-star orbit. No companions were detected. The median 2σ upper limit is 60 $M_\oplus$, and the most constraining limit is 2.5 $M_\oplus$ for the case of GJ 436.

1. Introduction

Trojan companions are bodies in a 1:1 mean-motion resonance with a planet, librating around one of the two Lagrange points (L4 and L5) of the planet's orbit around the star. Several methods have been proposed to detect Trojan companions to exoplanets (Laughlin & Chambers 2002, Croll *et al.* 2007, Ford & Holman 2007, Ford & Gaudi 2006). In this paper, we present a search for Trojan companions to 25 known transiting exoplanets for which suitable data are available, using the method of Ford & Gaudi (2006, hereafter, "FG"). An important virtue of this method is that a sensitive search for Trojans can be performed using only the RV and photometric data that are routinely obtained while confirming transit candidates and characterizing the planets.

2. Method

The basic idea of the FG method is to compare the photometrically observed transit time (t_O) with the expected transit time (t_C) that is calculated by fitting a two-body Keplerian orbit to the RV data, i.e. assuming no Trojan. The presence of a Trojan companion as a third body would cause a timing offset $\Delta t = t_O - t_C$.

In the case of a circular orbit, if there is no Trojan companion, the force vector on the star points directly at the planet and the observed transit time t_O coincides with the time t_V when the orbital velocity of the star is in the plane of the sky (i.e., the time of RV null). If instead there is a single Trojan located at the L4 or L5 Lagrange point (or librating with a small amplitude), then the force vector on the star does not point directly at the planet; it is displaced in angle toward the Trojan companion. As a result, t_O occurs earlier or later than t_V. The magnitude of $t_O - t_V$ is proportional to the Trojan mass m_T, for small values of the Trojan-to-planet mass ratio (Ford & Gaudi 2006): $\Delta t \simeq \pm 37.5$ min $(P/3\,\mathrm{days})(m_T/10\,M_\oplus)(0.5\,M_J/(m_P + m_T))(1)$. The positive sign corresponds to a mass excess at the L4 point (leading the planet) while the negative sign corresponds to that at the L5 point (lagging the planet). For an eccentric two-body orbit, t_C does not generally coincide with t_V. We calculate t_C by fitting a two-body Keplerian orbit to the RV data and calculating the expected transit time based on the fitted orbital parameters.

3. Data Analysis

The RV data were taken from the available literature on each system. We fitted the Keplerian model to the RV data using a Markov Chain Monte Carlo (MCMC) technique, employing a Metropolis-Hastings algorithm (see, e.g., Ford 2005). In general, uniform priors were used for all parameters. A prior constraint on $e\cos\omega$ was used where secondary eclipse measurements are available in literature. A single chain of $\sim 10^6$ links was used for each system. For each parameter, we found the mode of the *a posteriori* distribution, and the 68.3% confidence interval, defined as the range that excludes 15.9% of the probability at each extreme of the distribution. We thus obtained t_C from fitting the RV data. We determined t_O using the most precise published photometric ephemeris, and then computed $\Delta t = t_O - t_C$. The results for Δt are translated into constraints on the Trojan mass m_T using Eq. (1) for circular orbits, and using equivalent expressions for eccentric orbits obtained by numerical integrations of three-body orbits.

4. Results

The 95.4% (2σ) upper limits on m_T and on m_T/m_P are shown in Figure 1. The median upper limit on m_T is 60 $M_\oplus$, with the most constraining limit of 2.5 $M_\oplus$ holding for GJ 436. This powerful upper limit is possible for this case because of the small stellar and planetary masses, and the copious RV data available for this system. The median upper limit on the mass ratio m_T/m_P is 0.1, with a best-case value of 0.015 for HD 17156. The powerful constraint in this case is a result of the unusually long orbital period of 21 days and plentiful precise RV data.

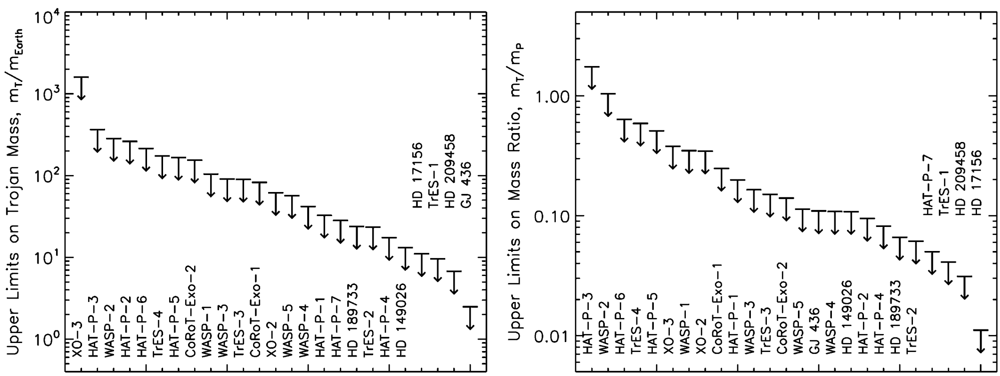

Figure 1. 95.4 % upper-limits on trojans masses and on trojan-planet mass ratios. The systems are ordered from least constrained to most well constrained, going from left to right of the figure.

In all cases but two, the result for Δt was consistent with zero within 2σ. The exceptions were CoRoT-Exo-2 and WASP-2, for which $\Delta t = 30^{+17}_{-14}$ and -142^{+53}_{-44} minutes respectively. The results for these two systems are worth following up with additional RV data. However, in a sample of 25 systems, even if Δt is always consistent with zero, one expects approximately one 2σ outlier. There were no cases in which Δt was inconsistent with zero at the 3σ level. Hence, we conclude that there is no compelling evidence for a Trojan companion in this ensemble.

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