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Exploring the orbital inclination of extrasolar systems

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Abstract

We present a state-of-the-art report of observed results in the measurement of spin-orbit angles of extrasolar systems. The wide variety of obliquities will be discussed in the context of the wide range of theoretical processes proposed for explanation, especially those involving the tidal effects and history of orbital evolution.

1. Introduction

By measuring the inclination of the extrasolar orbital planes relative to the stellar equatorial plane, one may constrain the formation mechanisms and the history of orbital evolution. Such measurements are performed since 2000, through the Rossiter-McLaughlin (RM) effect, giving access to the *projected* obliquity angle along the line of sight. This measurement demands high-precision radial-velocity spectrographs, such as SOPHIE at the Observatoire de Haute Provence or HARPS at La Silla Observatory. It requires monitoring the radial velocity of the star during a transit; if the system is aligned with the stellar equatorial plane, the anomaly consists of a redshift followed by a blueshift. The RM radial-velocity anomaly is now measured for about 40 transiting systems, which makes first statistical analyses possible. About one third of the systems show a projected obliquity angle which is significantly different from zero; this points to a variety of formation/migration scenarii, involving other companions, or an unstability of the star spin axis in some conditions.

2. Observations

There is only a handful of instruments capable of performing the RM measurements in the world. This requires both a high-precision in RV, a large telescope and high efficiency, to optimize the temporal sampling in the limited time of a planetary transit.

At Observatoire de Haute Provence, we are using the spectrograph SOPHIE to observe the transit sequences and derive the spin-orbit projected angles in transiting systems, for stars typically brighter than 12 magnitudes. A dozen of such measurements have been secured, from 2000 (the first RM measurement of HD 209458 [1]) to 2011 [2]. We have discovered two famous misaligned systems, XO-3 [3] and HD 80606 [4,5] and explored the variety of obliquities in the systems HD 189733 [6], HAT-P-2 [7], HAT-P-6 [8], HAT-P-8, HAT-P-9, HAT-P-16, HAT-P-23.

With HARPS at La Silla, we have observed the RM anomaly of transiting candidates discovered by CoRoT, within the process of establishing their planetary nature: CoRoT-1, 6, 9 [9,10]. We collected all RM measurements obtained sofar, and show their behaviour with respect to the planetary mass and stellar effective temperature (Figure 1).

3. Discussion

The total number of systems with good-quality measurements of the projected spin-orbit angles is 37. Ten of them are in the range $|\lambda| = 20\text{-}120^\circ$, 7 are retrograde (more than ~120°), 22 are less than ~20°. It is striking that only planets less massive than 3 MJup are retrograde. The current sample of planets with measured spin-orbit projection angle hinders statistically significant conclusions concerning the difference between planets orbiting hot and cold host stars from being drawn [11,12]. Indeed, considering Teff = 6250 K as the limiting temperature between samples, a Kolmogorov-Smirnov test on the data fails at rejecting the null hypothesis. At the 1-σ level, there exists a 28% of chance of erroneously rejecting the hypothesis that both populations are one and the same. Interestingly, we found slightly lower values for the significance when the limiting Teff is slightly higher: for Teff between 6300 K and 6450 K, the null hypothesis can be rejected at the 1-σ level with a significance $\alpha = 0.2$.

Several theories are proposed, that explain the diversity of obliquities with dynamical interactions with other planets or stars in the system. The next steps are thus to systematically complete our understanding of the systems, both by following up known transiting hot Jupiters in radial velocity on the long term, and by deriving detection limits of stellar companions by direct imaging.

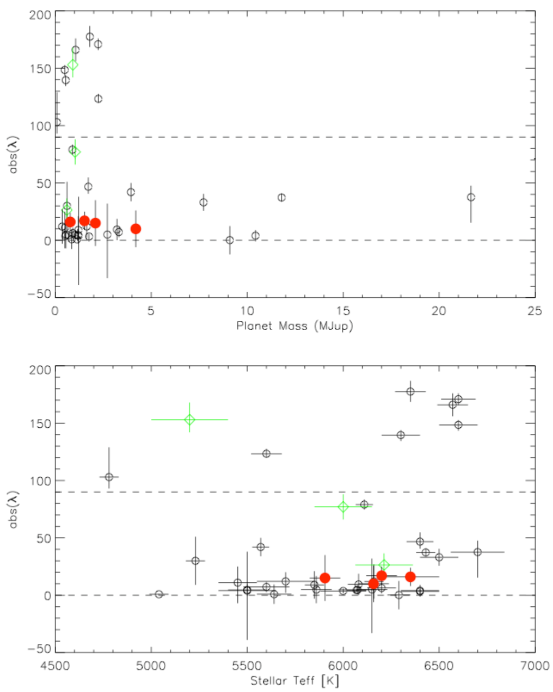

Figure 1: Spin-orbit angle versus planet mass (top) and stellar effective temperature (bottom).

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