Measurements of Stellar Inclinations for Kepler Planet Candidates

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The origin of close-in giant planets (so-called “hot Jupiters”) has been the most enduring problem since the discovery of the first extrasolar planet. Measurements of the spin-orbit angle (the relation between the stellar spin axis and planetary orbital axis) are a promising tool to uncover the formation and evolution (migration) history of exoplanetary systems. This is because different evolution models predict different distributions for the spin-orbit angle and measurements of the angle provide us an insight into the origin of exoplanets.

So far, the Rossiter-McLaughlin (hereafter RM) effect for transiting exoplanets has been the major channel to measure the spin-orbit angle. However, the RM effect is only applicable to giant planets orbiting at the proximity of their host stars. When the size of planet is small, the RM signal becomes weaker, which makes the measurement unreliable. In order to measure the spin-orbit angle for a smaller and distant exoplanet, we focused on the measurements of stellar inclinations I_s (see Figure 1). In a transiting exoplanetary system, where the planetary orbit is edge-on from our direction, the stellar inclination I_s is a useful indicator of the spin-orbit alignment/misalignment; when I_s turns out to be deviated from 90° through observations, it suggests a spin-orbit misalignment along the line-of-sight. This method to constrain the spin-orbit angle can be applied regardless of the size and orbital distance of the transiting planet.

In order to measure stellar inclinations for transiting systems, we focused on the *Kepler* photometry. Among the planet-hosting stars detected by *Kepler*, some show periodic flux variations due to starspots. A period analysis of such a periodic flux variation will give us the rotational period P_r of the star. Meanwhile, the projected rotational velocity $V \sin I_s$ could be obtained via spectroscopy. Combining these measurements along with the stellar radius estimated from spectroscopy, one can put a constraint on the stellar inclination I_s.

We picked up about 10 systems among the “Kepler Object of Interest (KOI)” list, all of which show periodic flux variations, and conducted spectroscopic observations with Subaru/HDS. Figure 2 shows the projected rotational velocity $V \sin I_s$ as a function of the rotational velocity at the stellar equator ($V_{\rm eq}$). The equatorial rotational velocity were estimated by combining the rotational periods P_s from the *Kepler* photometry with the stellar radii from the Subaru spectroscopy. While most of the systems are along the solid line (I_s = 90°), suggesting spin-orbit alignments, at least one system, KOI- 261, significantly deviates from the solid line. This most likely implies a spin-orbit misalignment along the line-of-sight. We note that all the systems shown in Figure 2 have Earth-sized or Neptune-sized exoplanets (no Jovian one), providing us a unique opportunity to discuss the evolution history of smaller exoplanets [1].

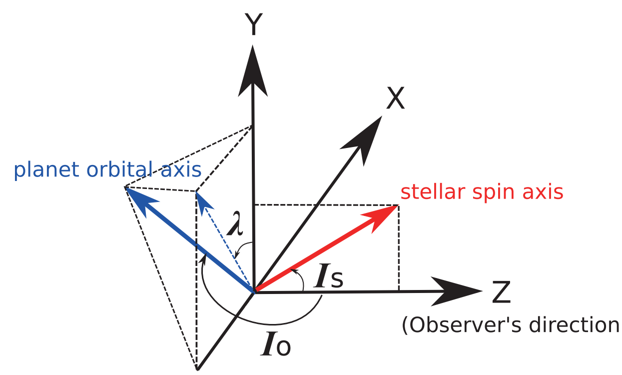

Figure 1: Schematic figure for the spin and orbital axes. The stellar inclination I_s is defined as the angle between the stellar spin axis (red) and line-of-sight.

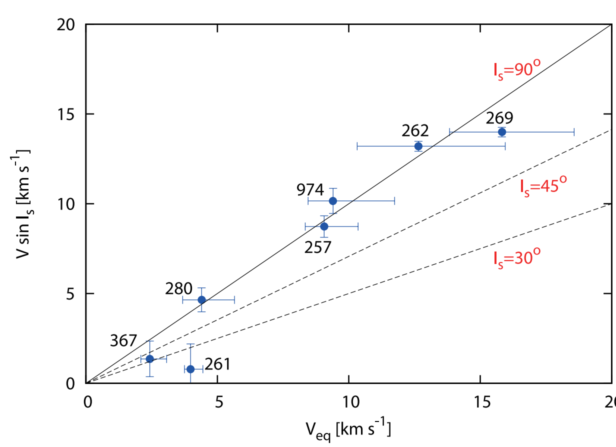

Figure 2: The estimated $V_{\rm eq}$ and $V \sin I_s$. The solid line indicates the case that our line-of-sight is vertical to the stellar spin axis.

Reference

[1] Hirano, T., Sanchis-Ojeda, R., Takeda, Y., Narita, N., Winn, J. N., Taruya, A., Suto, Y.: 2012, *ApJ*, **756**, 66.