Subaru Measurements of Spin-Orbit Alignment Angles of Exoplanets

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Since the discovery of the first exoplanet in 1995, scientists have identified more than 700 exoplanets, planets outside of our solar system, nearly all of which are giant planets. Most of these giant exoplanets closely orbit their host stars, unlike our solar system's giant planets, like Jupiter, that orbit the Sun from a distance. Accepted theories propose that these giant planets originally formed from abundant planet-forming materials far from their host stars and then migrated to their current close locations. Different migration processes have been suggested to explain close-in giant exoplanets.

Disk-planet interaction models of migration focus on interactions between the planet and its protoplanetary disk, the disk from which it originally formed. Sometimes these interactions between the protoplanetary disk and the forming planet result in forces that make the planet fall toward the central star. This model predicts that the spin axis of the star and the orbital axis of the planet will be in alignment with each other. Planet-planet interaction models of migration have focused on mutual scatterings among giant planets. Migration can occur from planet scattering, when multiple planets scatter during the creation of two or more giant planets within the protoplanetary disk. While some of the planets scatter from the system, the innermost one may establish a final orbit very close to the central star. Another planet-planet interaction scenario, Kozai migration, postulates that the long-term gravitational interaction between an inner giant planet and another celestial object such as a companion star or an outer giant planet over time may alter the planet's orbit, moving an inner planet closer to the central star. Few-body interactions, including planetplanet scattering and Kozai migration, could produce an inclined orbit between the planet and the stellar axis.

Overall, the inclination of the orbital axes of close-in planets relative to the host stars' spin axes emerges as a very important observational basis for supporting or refuting migration models upon which theories of orbital evolution center. For this reason, we have conducted observations with the Subaru Telescope to measure the Rossiter-McLaughlin (hereafter, RM) effect of transiting planetary systems so as to investigate these inclinations.

The RM effect refers to apparent irregularities in the radial velocity or speed of a celestial object in the observer's line of sight during planetary transits. Unlike the spectral lines that are generally symmetrical in measures of radial velocity, those with the RM effect deviate into an asymmetrical pattern. Such apparent variation in radial velocity during a transit reveals the sky-projected angle between the stellar spin axis and planetary orbital axis [1]. Subaru Telescope has participated in previous measurements of the RM effect, which we have investigated for over ten exoplanetary systems. In 2011, we newly found that XO-2b has a well-aligned orbit [2], whereas XO-3b has highly inclined orbits (Figure 1) [3].

The latest observational results about the RM effect, including those obtained independently of the findings reported here, suggest that about one-third of the observed hot Jupiter systems have highly inclined planetary orbits. Also, it has now turned out that the latest distribution of the spin-orbit alignment angles have dependences on stellar temperature and age [4,5].

We plan to extend our targets to smaller planets in the future aiming to uncover the whole picture of planetary migration mechanisms.

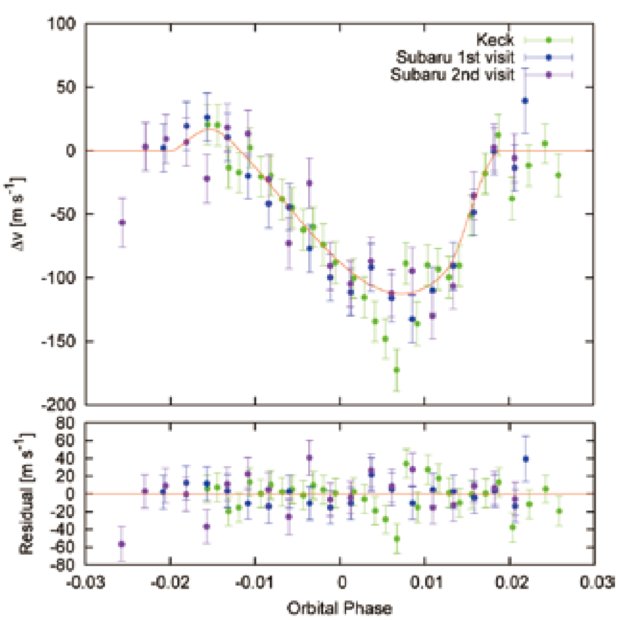

Figure 1: The Rossiter-McLaughlin effect of XO-3b taken with the Subaru HDS (purple and blue points). Also plotted are the Keck HIRES data (green) which cover a partial transit.

References

[1] Hirano, T., et al.: 2011, *PASJ*, **63**, S531-S536.
[2] Narita, N., et al.: 2011, *PASJ*, **63**, L67-L71.
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[4] Winn, J. N., et al.: 2010, *ApJ*, **718**, L145-L149.
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