Planet-Planet Eclipse and the Rossiter-McLaughlin Effect of a Multiple Transiting System

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Transiting exoplanetary systems provide us a unique opportunity to measure the stellar obliquity with respect to the planetary orbital plane. When we observe radial velocities (hereafter RVs) during a planetary transit, an anomalous RV variation is manifested in addition to the normal sinusoidal RV variation inspired by the Keplerian motion of the planet. This phenomenon, called the Rossiter-McLaughlin (RM) effect, has been exploited to measure the sky-projected angle between the stellar spin axis and planetary orbital axis (the spin-orbit angle). Measurements of the spin-orbit angle provide an important observational clue to distinguish among the possible scenarios for the formation and evolution of exoplanetary systems.

So far, the RM effect has been measured for single transiting systems. Since the *kepler* space telescope was launched in 2009, however, many multiple transiting systems are now available, and their origin and evolution history are of primary interest. In order to discuss the spin-orbit angle for multiple transiting systems, we focused on "KOI-94," one of the planet-hosting candidate detected by *Kepler*. KOI-94 is comprised of four planet candidates with relatively packed orbits. As a result of conducting the measurement of the RM effect for KOI-94.01 (the largest candidate among the four), we obtained Figure 1 and the RV anomaly due to the RM effect shows that the planetary orbital axis is well aligned with the stellar spin axis [1].

In addition to the measurement of the RM effect, we discovered a very unique astronomical event for this multiple transiting system, which we call a "planet-planet eclipse." Figure 2 indicates the archived data of the KOI-94 light-curve, delivered by Kepler. This clearly shows a double transit event, in which the two planets (KOI-94.01 and 94.03) transit the host star simultaneously. Interestingly enough, there is a bump around the bottom of the double transit. This bump most likely represents an overlapping event of the two transiting planets on the stellar disk ("planet-planet eclipse"). The planet-planet eclipse is not only an astronomically rare event, but also provides us a unique opportunity to put a tight constraint on the "mutual inclination" between the two planetary orbits. From the timing and size of the bump in Figure 2, we showed that the two planetary orbits (of KOI-94.01 and 94.03) are well aligned at least in the sky.

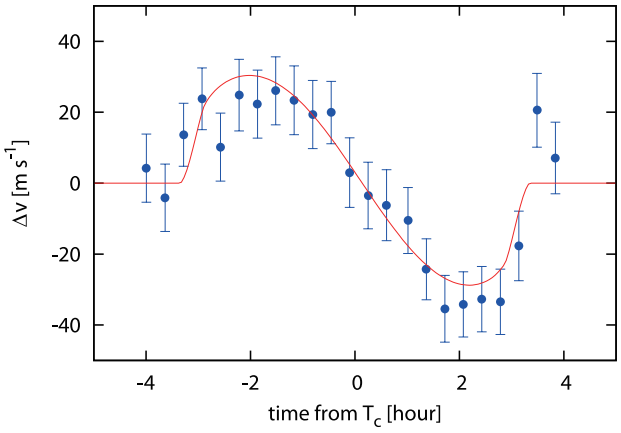

Figure 1: RV variation of KOI-94 during the transit of KOI-94.01.

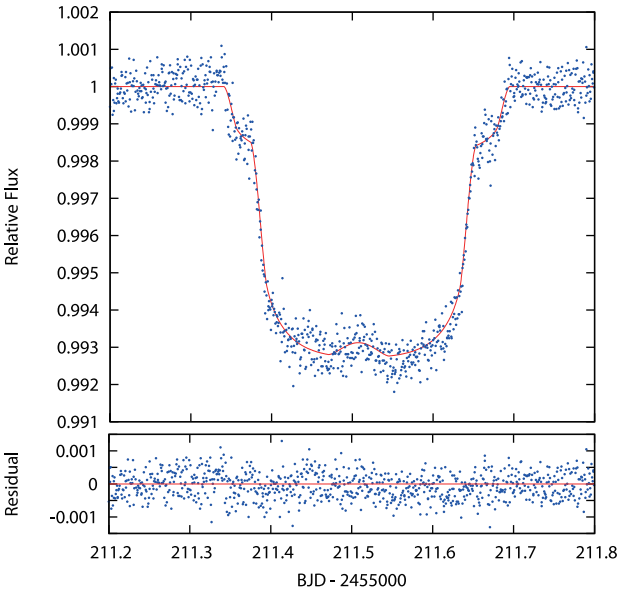

Figure 2: A part of the public light-curve delivered by the Kepler space telescope.

Reference

[1] Hirano, T., Narita, N., Sato, B., Takahashi, Y. H., Masuda, K., Takeda, Y., Aoki, W., Tamura, M., Suto, Y.: 2012, *ApJ*, **759**, L36.