Doppler Tomographic Analysis for the Planetary Orbital Precession of WASP-33b

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The apparent angle between the stellar spin axis and the planetary orbital axis, which is called orbital obliquity (λ), is one of the important parameters for understanding the orbital evolution. If a planet has followed an orbital evolution like those in our solar planets evolve, its orbit will be aligned with the stellar spin. This orbit is called a prograde orbit ($|\lambda| < 90$ deg) and many exoplanets orbit with the direction. However, it is clear that there are few exoplanets with retrograde orbits ($|\lambda| > 90$ deg), which is the opposite case of our solar system. Doppler tomography (DT) is one of the methods to measure λ. In this method, when a planet covers part of the stellar surface during a planetary transit, a planetary shadow appears in the stellar line profile which is broadened by its rapid stellar spin. Then, λ can be derived by the track of the shadow. The distance between the center of the stellar surface, which is called the impact parameter (b), can be measured by DT. Moreover, The planetary shadow appears more easily when the central star spins faster, which makes the measurement of these parameters more easily.

The previous study [1] found that the values of λ and b of the hot Jupiter WASP-33b, which has a 1.2-day period retrograde circular orbit around a rapidly rotating and pulsating A-type star, changed slightly from 2008 and 2014. They detected its orbital precession due to its slightly flattened central star. However, only two observational epochs, from 2008 and 2014, were used in the previous study [1]. We aim to confirm and more precisely measure the precession using not only the dataset of 2008 and 2014 but also a previously unpublished dataset from 2011.

In our research, we used observational data of WASP-33 which was obtained using the High Dispersion Spectrograph (HDS) on the 8.2m Subaru telescope on 19th October 2011 (UT), as well as data sets of the previous study [1] which has already been analyzed up to their line profiles. First, we obtained the average line profile of each exposure from a large number of absorption lines by Least-Squares-Deconvolution (LSD). Subtracting the average stellar line profile of all exposures from the one from each exposure, we got the planetary shadow showing a retrograde orbit and a component from stellar pulsations. In order to make the measurement of the planetary parameters more easily, we extracted only the planetary shadow by Fourier filtering used in the previous study [1].

In order to make the measurement of the planetary parameters, we adopted an MCMC analysis for the three filtered data with our planetary shadow model with Fourier filtering. Considering b and λ of WASP-33b is changeable, our results show that b changed linearly, but the change of λ was not so that λ in 2011 was not intermediate between ones in 2008 and 2014. In the case that λ is fixed but b is changeable, we found that the change of b was comparable to one of the former case. In either case, our results indicated that the orbital precession seems to be different than one from the previous study [1].

[1] Johnson et al. 2015

