**Kepler-730b is Probably a Hot Jupiter with a Small Companion**

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WASP-47 is so far the only confirmed system with a hot Jupiter and small, nearby companions (Becker et al. 2015). This system challenged the high-eccentricity migration for hot Jupiter formation (e.g., Dawson & Johnson 2018). To enable a systematic understanding of the prevalence of such systems, more detections are needed.

Here we draw attention to a candidate system with one hot Jupiter and one small, nearby companion. The recent Kepler data release (DR25; Thompson et al. 2018) revealed a small inner companion to the already confirmed hot Jupiter Kepler-730b. With the updated Gaia stellar parameters from Berger et al. (2018), the host star (KOI-929, KIC 9141746) is an F-type main-sequence star with effective temperature $T_{\text{eff}} = 6126 \pm 214$ K and radius $1.30^{+0.13}_{-0.11} R_\odot$, and has an apparent Kepler magnitude $K_p = 15.6$. Kepler-730b has updated radius $R_p = 11.36^{+1.14}_{-0.98} R_\oplus$ and orbital period $P = 6.492$ d, and the newly discovered companion, KOI-929.02, has $R_p = 1.45^{+0.15}_{-0.20} R_\oplus$ and $P = 2.852$ d. The phase-folded light curves of both transits are shown in Figure 1. The small companion was detected at S/N = 10.1, thus above the standard threshold (7.1), and it also passed all the validation test performed by the automated search pipeline. We refer to the Kepler Candidate Overview Page 1 under the NASA Exoplanet Archive (Akeson et al. 2013) for details of the detection, validation, and planetary parameters.

Although the small companion passed all the validation tests, there remains a possibility that this small companion transits a star that is different from the hot Jupiter host. In principle, such a scenario can be excluded if one can measure the centroid shift between in and out of transit in Kepler images. However, such an effect is not measurable in the current case. The closest star (KIC 9141752, with $K_p = 19.1$) is 5'8 away from the target position, and if this is the real host of the small companion, the transit depth should be $\sim 0.0025$, and the expected centroid shift is small enough to remain undetected. Nevertheless, follow-up observations with 10-m telescopes can potentially resolve this issue by detecting (or not detecting) such a transit on the 19.1 magnitude star at the given ephemeris.

The transit timing variation (TTV) effect would be the ideal way to confirm the nature of such systems (e.g., Becker et al. 2015). However, given the marginal detection of the small companion transit, TTV was not detected. Nevertheless, we find consistent mean stellar densities $\rho_* = 0.57 \pm 0.09$ g cm$^{-3}$ and $0.83 \pm 0.62$ g cm$^{-3}$ from modeling the light curves of the hot Jupiter and the small companion, respectively, under the reasonable assumption that both objects have (nearly) circular orbits. The two consistent densities agree with that the two companions indeed orbit around the same host. Furthermore, they are also more consistent with the density $\rho_* = 1.89^{+0.42}_{-0.55}$ g cm$^{-3}$ of the assumed host (KIC 9141746) than the density $\rho_* = 0.65^{+0.17}_{-0.15}$ g cm$^{-3}$ of the background star (KIC 9141752). These values are derived by the isochrones code (Morton 2015) from fitting the Dartmouth stellar evolutionary models (Dotter et al. 2008) to observed colors from the Kepler Input Catalog (grizJHK for KIC 9141746 and gri for KIC 9141752, corrected following Pinsonneault et al. 2012) and parallax information from the Gaia DR2 (Gaia Collaboration et al. 2018).

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1 https://exoplanetarchive.ipac.caltech.edu/cgi-bin/DisplayOverview/nph-DisplayOverview?objname=KOI-929.02&type=KEPLER_CANDIDATE
Figure 1. Phase-folded transit light curve, best-fit model, and residuals of the hot Jupiter Kepler-730b (left panel) and the small companion KOI-929.02 (right panel). The black dots are the individual data points, and the orange bars are the binned data points.

For the parallax values we adopted the distance estimates provided by Bailer-Jones et al. (2018). We note that the parallax of KIC 9141752 is not well constrained and thus the result depends on the adopted distance prior.

To summarize, the KOI-929 system is probably another planetary system with hot Jupiter and small, nearby companion, after the outstanding WASP-47 system (Becker et al. 2015), and so far the only such system (out of 46 reliable hot Jupiter systems in Berger et al. 2018) in the prime Kepler mission. The nature of this system, if confirmed, would suggest that hot Jupiters with small, nearby companions are probably more common than we used to believe. Detailed studies of such systems will help in resolving the puzzle of hot Jupiter origin. The ongoing Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2014) mission can potentially discover more systems similar to KOI-929 and WASP-47.

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