EPSC Abstracts
Vol. 12, EPSC2018-1115-2, 2018
European Planetary Science Congress 2018

Ultra-short Period Rocky Super-Earths

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Abstract

Ultra-short period (USP) planets are a class of low-mass planets with periods shorter than one day and radii smaller than 2 R_E. An early hypothesis suggested that USP planets and small planets in general were originally Hot Jupiters (HJs) that underwent strong photo-evaporation due to the high insolation flux, (e.g., thousands of times that of Earth, Lecavelier des Etangs et al. 2004) ending up with the complete removal of their gaseous envelope and their solid core exposed. Recent studies determined that the metallicity distributions of HJs and USP planets are significantly different, supporting instead a similar hypothesis in which the progenitors of USP planets are not the HJs but the so-called mini-Neptunes, i.e., planets with rocky cores and hydrogen–helium envelopes, typically with radii between 1.7 and 3.9 R_E and masses lower than ~10 M_E. Alternatively, USP planets may represent the short-period tail of the distribution of close-in rocky planets migrated inwards from more distant orbits (e.g., Lee & Chiang 2017) or formed in situ (e.g., Chiang & Laughlin 2013). It appears clear that only a systematic study of the internal and atmospheric composition of USP planets, in conjunction with the amount of irradiation to which they are subjected and the presence of other companions in the system, can shed light on their origin. In order to do so, we need precise and accurate measurements of both their radius and mass.

So far only a handful of USP planets have reliable density estimates, and only for two of them have the secondary eclipse and phase variations have been detected, namely Kepler-10b (Batalha et al. 2011) and Kepler-78b (Sanchis-Ojeda et al. 2013). Formation scenarios differ radically in the predicted composition of USP planets, and it is therefore extremely important to increase the still limited sample of USP planets with precise and accurate mass and density measurements.

We report here the characterization of a USP planet with a period of 0.28 days around K2-141 (EPIC 246393474), and the validation of an outer planet with a period of 7.7 days in a grazing transit configuration. We derived the radii of the planets from the K2 light curve and used high-precision radial velocities gathered with the HARPS-N spectrograph for mass measurements. For K2-141b, we thus inferred a radius of 1.51 ± 0.05 R_E and a mass of 5.08 ± 0.41 M_E, consistent with a rocky composition and lack of a thick atmosphere. We also report the detection of secondary eclipses and phase curve variations for K2-141b. The phase variation can be modeled either by a planet with a geometric albedo of 0.30 ± 0.06 in the Kepler bandpass, or by thermal emission from the surface of the planet at ~3000 K. Follow-up observations at longer wavelengths will allow us to distinguish between these two scenarios. If USP planets were really lava-ocean worlds, their atmospheres would be likely made of heavy-element vapors with a very low pressure and, being tidally locked, would experience extremely high day-night contrasts (Léger et al. 2011). The discovery of an outer planet with a period of 7.7 days in a grazing transit configuration, K2-141c, corroborates the previously observed trend that USP planets are often found in multi-planet systems (Sanchis-Ojeda et al. 2014).

We conclude discussing future perspectives in USP planet detection with *TESS* and *PLATO* and the characterization of their atmosphere and surface properties with the *CHEOPS*, the *Hubble Space Telescope* and the *James Webb Space Telescope*

1. Figures

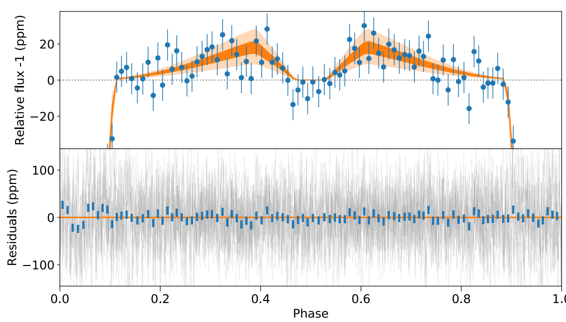

Figure 1: *Top*: The detrended data phase-folded on the period of planet b with the transits of planet c removed, the data have been binned by a factor of thirty for clarity. The 1 and 3 σ credible intervals calculated from the posterior are overplotted in dark and light orange respectively. *Bottom*: The residuals to the best fitting model, the binned data are plotted as thick blue lines and the unbinned data is plotted as thin grey lines.

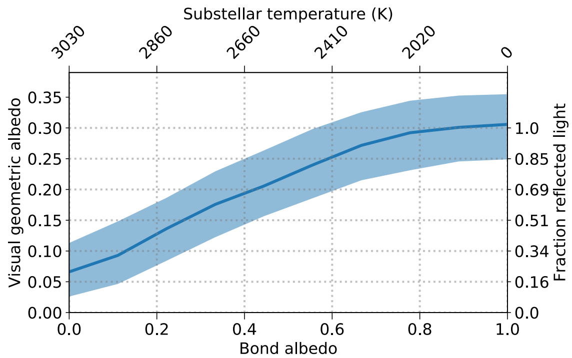

Figure 1: The best fitting visual geometric albedo as a function of the Bond albedo. The shaded area is the 68% credible region for the geometric albedo. The corresponding substellar temperature for the planet is plotted on the top axis, and the fraction of the occultation depth from the reflected light alone is calculated using the best fitting Bond albedo for the corresponding visual albedo.