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Planetary occultations from KEPLER data

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Abstract. The *KEPLER* spacecraft provides accurate (up to 40 ppm of flux for stars near 7 mag) light-curves (LCs), enough to theoretically distinguish the occultation of the exoplanet by its parent star (e.g. the secondary minimum). We have selected *KEPLER* Objects of Interest KOI-2.01 and KOI-13.01 with the deepest secondary minima; co-added many single phase LCs and modeled them with a simplex algorithm to measure the depths of primary and secondary minima; and calculate the radii of the star and the exoplanet.

Key words: stars – variables – exoplanets – photometry

Our motivation was the paper by Coughlin & López-Morales (2012) who tried a systematic approach. We have used their results to select potential candidates with the highest significance of the detection of the secondary minimum: KOI-13.01, KOI-2.01, KOI-1541.01, and KOI-254.01. To compare our approach to the data we have selected systems KOI-2.01 and KOI-13.01 with previously identified secondary minima and without flux variations due to the presence of photospheric spots.

We have used publicly available data from quarters Q0-Q6 from the Mikulski Archive for Space Telescopes (MAST). All LCs were processed with an updated PDC[1] pipeline and their flux was normalized. To keep better time resolution we limited the selection only to short-cadence (58.85 s) LCs. We have applied a running linear fit with anchor points around orbital phases $\varphi = 0.25$ and $\varphi = 0.75$ to remove trends from the raw data. Additionally, we have corrected the measured flux of KOI-13.01 by $\approx 45\%$ (Szabó et al., 2011) of the total maximum flux to remove the parasitic light of the second stellar component which affects the depth of both minima (compare with Borucki *et al.*, 2011).

We divided the time series into separate epochs. Then we selected only phased LCs with duration longer than $0.5\,P_{\rm orb}$ which contained data around the planetary occultation at $\varphi = 0.5$. We have then used a spline interpolation based on the Hermite polynomials (Press et al., 1992) to co-add the particular phased LCs. LCs were re-binned in 1/1000 of phase. For KOI-2.01 and KOI-13.01 we added together 148 and 93 full and/or partial exoplanet orbits,

[1]Pre-search Data Conditioning corrects systematic errors, removes excess light contamination from nearby field stars, removes outliers and corrects discontinuities in data.

Table 1. Results from the LC modeling (bold face), compared to: (1) Borucki *et al.* (2011); (2) Coughlin & López-Morales (2012); (3) Szabó *et al.* (2011).

	KOI-2.01			KOI-13.01		
i [deg]	$\mathbf{83.68 \pm 0.51}$	83.92 ± 0.64	2	$\mathbf{81.00 \pm 0.57}$	79.79 ± 0.46	2
Δ_{I} [ppm]	$\mathbf{6297 \pm 26}$	6716 ± 0	1	$\mathbf{7830 \pm 10}$	4644 ± 0	1
Δ_{II} [ppm]	$\mathbf{68 \pm 21}$	130 ± 0	1	$\mathbf{157 \pm 15}$	120 ± 48	3
R_P [$\mathrm{R}_\odot$]	$\mathbf{0.100 \pm 0.059}$	0.102 ± 0.073	2	$\mathbf{0.204 \pm 0.094}$	0.162 ± 0.116	2
R_S [$\mathrm{R}_\odot$]	$\mathbf{1.336 \pm 0.951}$ (fixed)		2	$\mathbf{2.454 \pm 1.758}$ (fixed)		2
$\Delta_{\mathrm{II}}/\Delta_{\mathrm{I}}$	$\mathbf{0.011}$	0.019		$\mathbf{0.020}$	0.026	
R_P/R_S	$\mathbf{0.075}$	0.078		$\mathbf{0.083}$	0.067	

respectively. The resulting co-added LCs show that the noise was decreased to $\leq 50\%$ of the previous value, which allowed us to measure the depths of primary Δ_{I} and secondary minima Δ_{II} (see Table 1).

We have used a simplex algorithm to minimize analytical expressions of the transit geometry (Mandel & Agol, 2002) to fit primary and secondary minima for both planetary candidates. Initial values of the ratio of the planetary and stellar radii (R_P/R_S), the ratio of the stellar radius to the separation (R_S/a) and the time of primary minimum (t_0) were adopted from MAST. Initial inclination (i_0) was adopted from Coughlin & López-Morales (2012). Quadratic limb darkening coefficients were interpolated from Sing (2010).

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References

Borucki, W.J. *et al.*: 2011, *Astrophys. J.* **736**, 19

Coughlin, J.L., López-Morales, M.: 2012, *Astron. J.* **143**, 39

Mandel, K., Agol, E.: 2002, *Astrophys. J.* **580L**, 171

Press, W.H, Teukolsky, S.A., Vetterling, W.T., Flannery, B.P.: 1992, *Numerical Recipes in FORTRAN*, Cambridge University Press, Cambridge

Sing, D.K.: 2010, *Astron. Astrophys.* **510**, A21

Szabó, Gy.M., Szabó, R., Benkő, J.M., Lehmann, H., Mező, Gy., Simon, A.E., Kővári, Zs., Hodosán, G., Regály, Zs., Kiss, L.L.: 2011, *Astrophys. J.* **736L**, 4