Photodynamical analysis of the exomoon candidate around Kepler-1513b

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Looking at our own Solar System, we find that moons are ubiquitous with a total of over 200 moons orbiting only 8 planets. As more and more exoplanets are being discovered, about 4000 of which have been observed to transit their host star, the potential to find exomoons around them becomes increasingly promising. Here we perform a photodynamical analysis of Kepler-1513b, which is the newest of the three known exomoon candidates so far. To that purpose we use `Pandora`, the first open-source software that models all the relevant photometric effects of exoplanet-exomoon systems, including mutual eclipses, transit timing variations etc. We pay particular attention to the detrending process of the eight transits in the *Kepler* light curve.

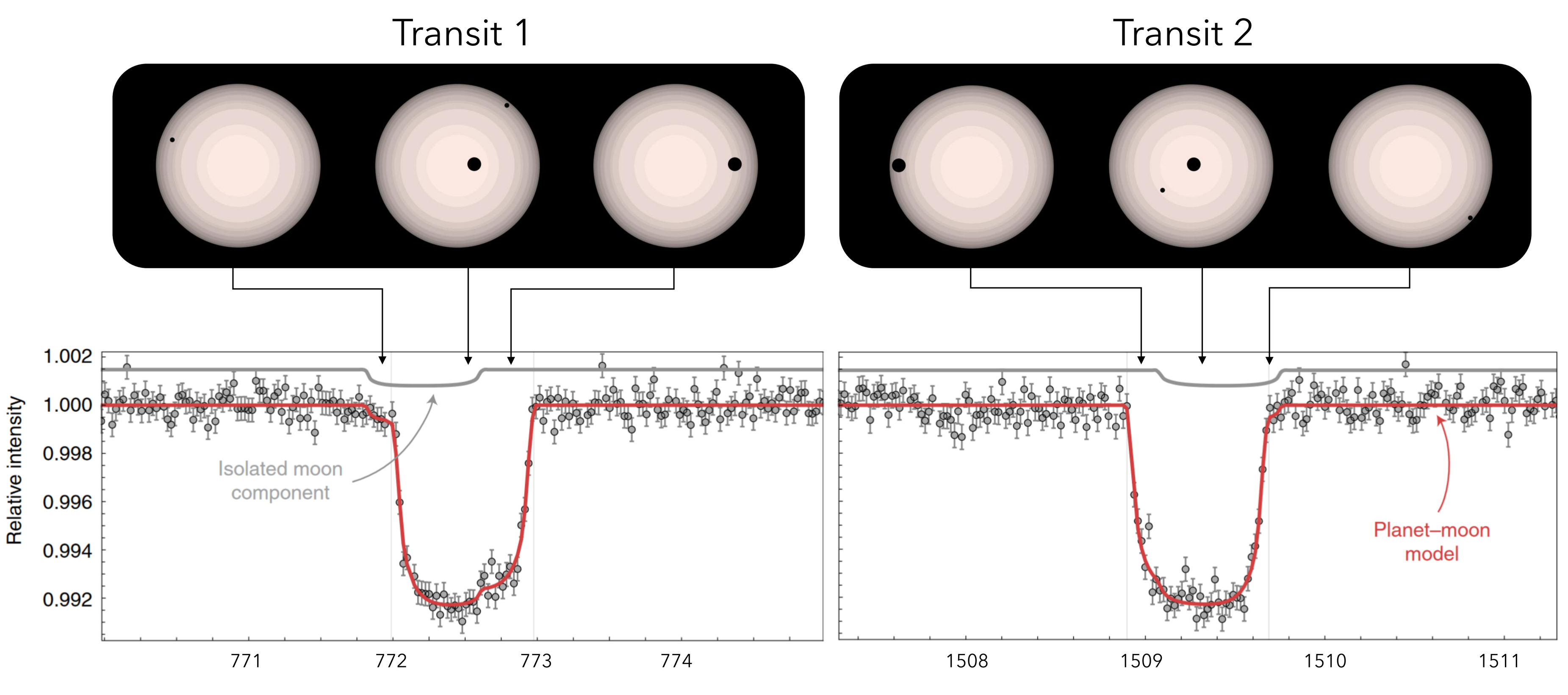
Exomoon detection through photometry

Transiting exomoons can be found indirectly from the **transit timing variations (TTVs)** of their host planets or via their own **photometric transits**. Three exomoon candidates exist so far:

1. Kepler-1625b: Exomoon-like transit features + TTVs
2. Kepler-1708b: Exomoon-like transit features
3. Kepler-1513b: TTVs

Detection limit: The minimum size required for an exomoon to be detected photometrically in the light curves of Kepler-1513 can be approximated as:

$$R_* \left(\frac{\sigma}{\sqrt{N}}\right)^{1/2} \approx 0.6\, R_E$$

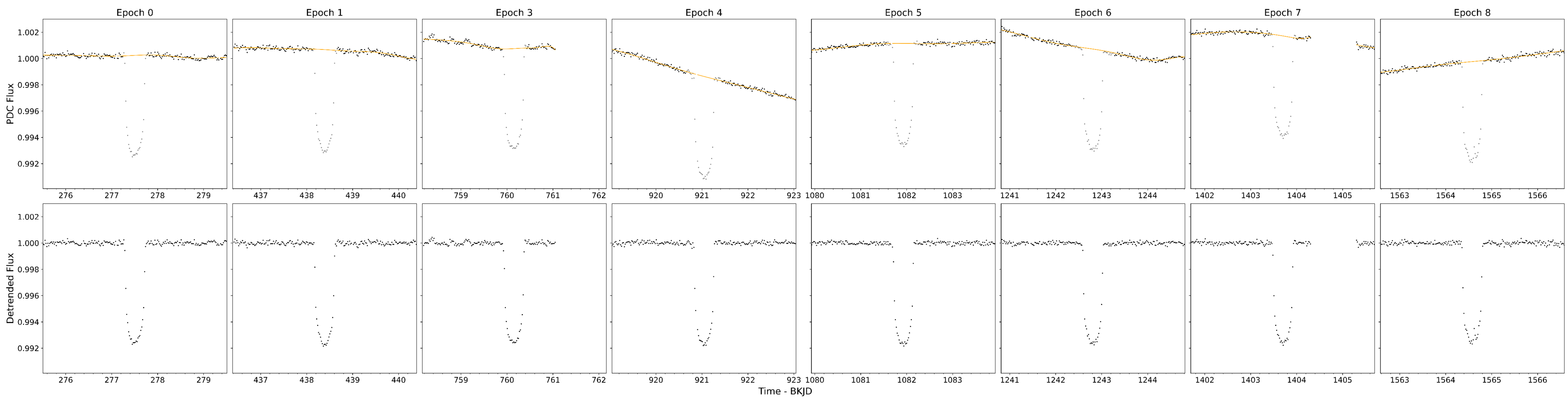


Transit light curves of Kepler-1708b

Kipping et al. (2022)

Data preparation and fitting

- The *Kepler* light curves are detrended using `Wōtan`.
- Each epoch is detrended separately with parameters chosen by the Durbin-Watson statistic.

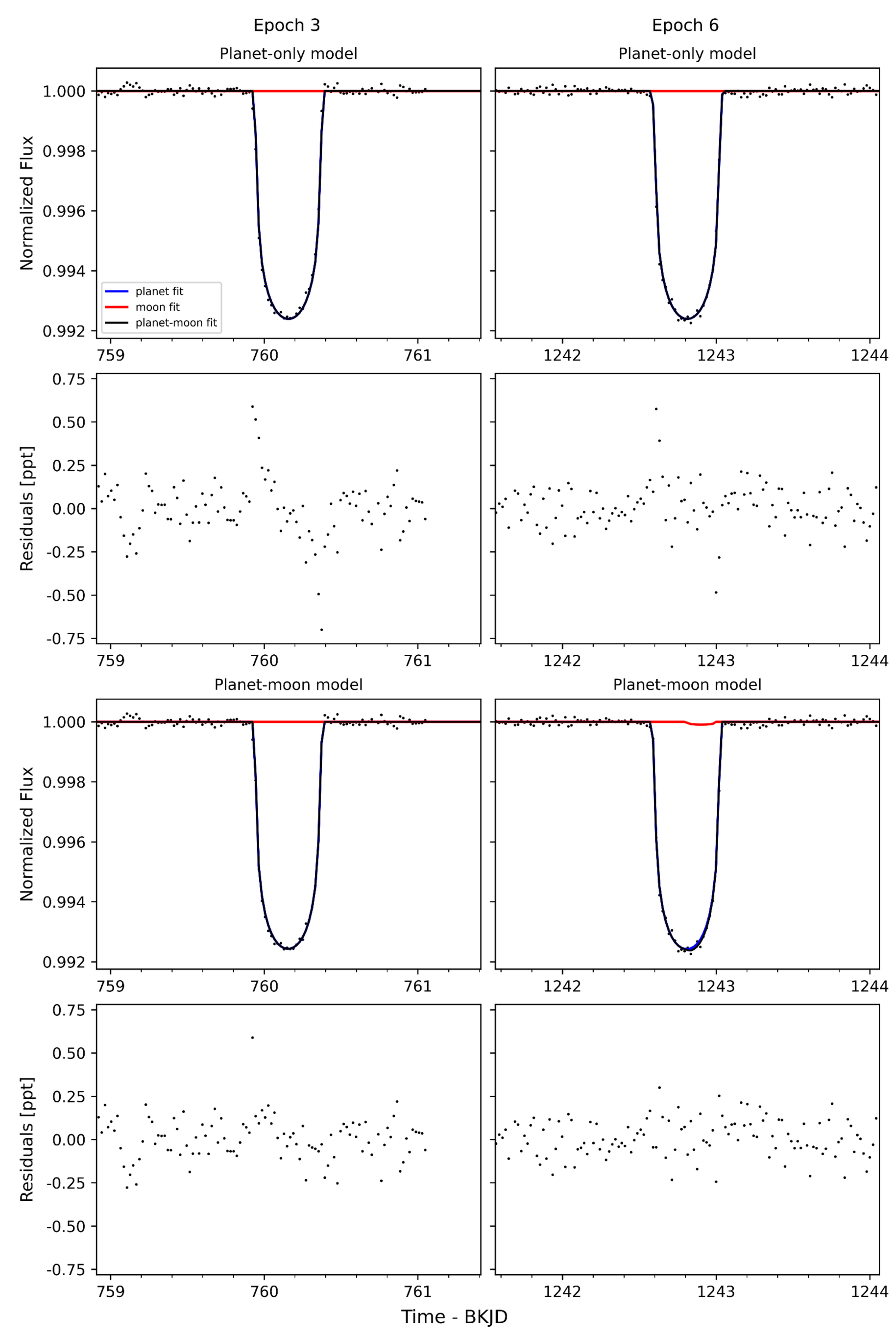


- Photodynamical modeling is done by `Pandora`.
- We use the nested sampler `UltraNest` to fit the detrended data.

Results and discussion

Parameters	Planet-only	Planet-moon
P_{bary} [d]	$160.8845^{+5.87e-5}_{-5.56e-5}$	$160.8843^{+5.86e-5}_{-6.18e-5}$
a_{bary} [R_*]	$112.7^{+2.2}_{-1.7}$	$116.8^{+4.0}_{-2.4}$
R_p [R_*]	$0.07980^{+0.00052}_{-0.00070}$	$0.07892^{+0.00052}_{-0.00075}$
b_{bary}	$0.37^{+0.037}_{-0.058}$	$0.27^{+0.067}_{-0.23}$
$t_{0,offset}$ [d]	$-0.000839^{+0.000266}_{-0.000287}$	$0.000606^{+0.000302}_{-0.000291}$
q_1	$0.54^{+0.076}_{-0.058}$	$0.56^{+0.014}_{-0.037}$
q_2	$0.28^{+0.037}_{-0.035}$	$0.28^{+0.027}_{-0.014}$
R_* [$R_\odot$]		$0.97^{+0.046}_{-0.024}$
M_p [M_J]		$0.96^{+0.22}_{-0.22}$
R_m [R_E]		$0.6943^{+0.31}_{-0.21}$
P_m [d]		$9.81^{+8.88}_{-1.61}$
τ_m		$0.16^{+0.52}_{-0.13}$
Ω_m [deg]		32^{+39}_{-24}
i_m [deg]		73^{+9}_{-6}
M_m [M_E]		$4.50^{+1.85}_{-1.20}$

Median values of the posterior distribution.



Best fitting planet-only and planet-moon models in two epochs.

References

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