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Measurability of the fluid Love number k_2 in WASP-121b

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Abstract

We are witness to a great and increasing interest in internal structure, composition and evolution of exoplanets. However, direct measurements of exoplanetary mass and radius are insufficient to distinguish between different internal structure and composition models–known as the mass-radius degeneracy– justifying the need for an additional observable [6]. As already introduced in the litterature [1, 2], we show that planetary surface deformations coming from tidal and rotational effects cause distortions in the transit curves. These distortions can be expressed through the fluid Love numbers k_j, providing additional information on the planetary internal structure [3]. We discuss detectability of non-sphericity effects in transit curves of WASP-121b in the light of dedicated space missions (*e.g.* Kepler, TESS, JWST, PLATO).

1. Introduction

Close-in objects with typical orbital periods shorter than ten days undergo strong rotational and tidal distortions, modifying their shape from spherical to more complicated ones. We assume both components in hydrostatic equilibrium, hence behaving as a fluid, critical to interpret the shape in terms of internal structure. The surficial deformations depend on the body's internal structure, and may be expressed through the fluid Love numbers k_j [4, 5] (section 2). In particular, the second-degree Love number k_2 tells us how much mass is concentrated towards the component's centre. As a result of these deformations, the stellar eclipsed area or planetary reflecting area will differ, changing the corresponding transit curves (section 3).

2. Model

The perturbing potential arises from the centrifugal force due to the planet's self rotation and from the tidal force coming from its host star. One may assume a tilted spin axis w.r.t. the orbital plane. By expressing the perturbing potential in spherical harmonics, Love (1911) and Kopal (1959) [5, 4] showed that the surface radius is given by

$$\begin{aligned} r(\theta,\phi) &= R_p\left(1+q\sum_{j=2}^{4}h_{j,p}P_j(\lambda)\left(\frac{R_p}{d}\right)^{j+1}\right. \\ &\quad \left. -\frac{1}{3}(1+q)h_{2,p}F_p^2\left(\frac{R_p}{d}\right)^3 P_2(\cos(\Theta))\right) \end{aligned} \qquad (1)$$

where θ is the co-latitude, ϕ is the longitude, R_p is the planetary mean radius, $q = \frac{m_s}{m_p}$ is the mass ratio, P_j is the Legendre polynome of degree j, d is the orbital distance, $F_p = \frac{\omega_{rot}}{\omega_{orb}}$ is the planetary angular rotation ratio. λ and Θ are angles which depend on θ, ϕ, and on the tilted angle of the spin axis, and $h_{j,p} = 1 + k_{j,p}$ are the planetary fluid Love numbers. A value of $h_2 = 1$ means the mass is concentrated at the body's centre (mass-point model), while $h_2 = 2.5$ is reached for a fully homogeneous body. A similar expression can be found for the stellar surface deformations through an obvious interchange of signs.

We assume synchronously locked orbits, *i.e.* $F_p = F_s = 1$, with a non-tilted spin axis, *i.e.* $\Theta = \theta$. For the star, the mass-point model is a good approximation, *i.e.* $h_{j,s} = 1$. Hence, depending on the planetary internal structure (enclosed in $h_{j,p}$), the planet's resulting projected shape onto the plane-of-sky will differ, leading to different photometric curves.

We compute transit curves for WASP-121b, for different values of $h_{2,p}$ and keeping $h_{3,p} = h_{4,p} = 1$.

3. Results

In Figure 1 we present a single transit event for $h_2 = 1.3$, and its best spherical fit. One may recognize the highest distoritions in the ingress and egress phases of the transit. The maximum distortion amounts to roughly 900 ppm. This is explained by the fact that WASP-121b orbits close to its Roche limit (at roughly

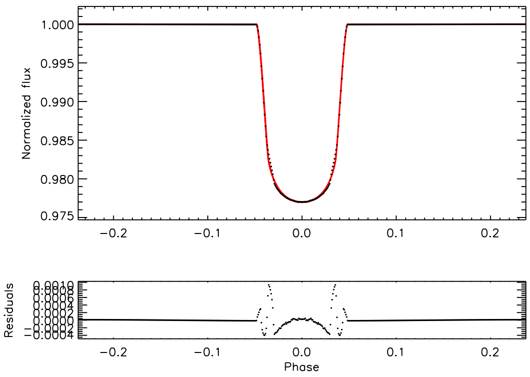

Figure 1: Upper panel: single transit event of WASP-121b for $h_2 = 1.3$ (black dots), and its best spherical fit (red line). Lower panel: residuals (distorted - spherical).

twice its Roche limit), and thus is subjected to huge tidal deformations. Figure 2 presents the expected signal-to-noise ratio (S/N) of this effect, as a function of h_2 (*i.e.* internal structure). The noise levels have been computed for a composite light curve from 10 observed transits, binned into 2 minute intervals. With the exception of TESS, we show that PLATO, Kepler, JWST and CHEOPS reach a $S/N > 3$, hence providing the means to constrain the internal structure of WASP-121b.

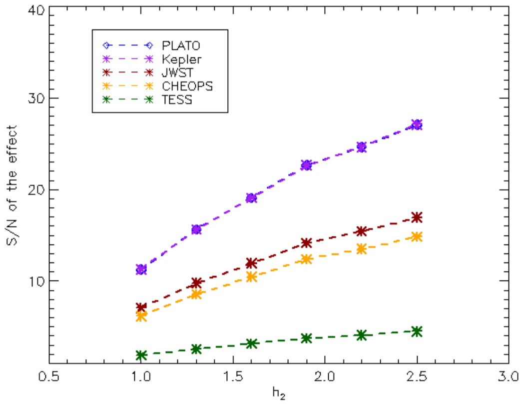

Figure 2: S/N of the distortions as a function of the internal structure (h_2), for PLATO, Kepler, JWST, and TESS.

4. Summary and Conclusions

Close-in planets are subjected to high tidal and rotational surface deformations, leading to transit curve distortions. The magnitude of these distortions depend on the planetary internal structure, expressed through the Love numbers k_j (or equivalently h_j). We showed that PLATO, Kepler, JWST and CHEOPS have the means to constrain the second degree Love number of WASP-121b, providing additional invaluable information on its internal structure.

Acknowledgements

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References

[1] Carter, J. A., and Winn, J.N.: Empirical constaints on the oblateness of an exoplanet, ApJ, 709:1219-1229, 2010.

[2] Correia, A.C.M.: Transit light curve and inner structure of close-in exoplanets, A&A, 570, L5, 2014.

[3] Kellermann, C., Becker, A., Redmer, R.: Interior structure models and fluid Love numbers of exoplanets in the super-Earth regime, A&A, accepted: February 2018.

[4] Kopal, Z.: Close binary systems, New York: Wiley, 1959

[5] Love, A.E.H.: Some problems of geodynamics, Cambridge University Press, 1911

[6] Sohl, F., Wagner, F.W., Rauer, H.: Mass-radius relationships of rocky exoplanets, Proceedings IAUS 293, 2012.