Retrieval of the fluid Love number k_2 from transit light curves

Hugo Hellard[1,2], Szilárd Csizmadia[1], Sebastiano Padovan[1], Heike Rauer[1,2,3], Juan Cabrera[1], Frank Sohl[1], Tilman Spohn[1], and Doris Breuer[1]

[1]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany
[2]Technische Universität Berlin, Berlin, Germany
[3]Freie Universität Berlin, Berlin, Germany

Introduction

Knowledge of the planetary radius and mass is not sufficient to infer the interior structure, as different composition and density profiles can lead to the same solution [**1**], justifying the need for an additional observable.

The second-degree fluid Love number [**2**], k_2, is proportional to the mass concentration towards the body's center, hence providing valuable information on the interior.
$k_2 = 0$ is a mass-point, $k_2 = 1.5$ is a fully homogeneous body, while its full derivation depends on the internal radial density profile [**3**].

Assuming hydrostatic equilibrium, k_2 is a direct function of the planetary shape.

Planets orbiting close to their Roche limit and outer planets with high rotation rates undergo strong tidal and rotational deformations, respectively, which modify their shape from spherical to more complicated ones.

As a result, the corresponding transit light curve will differ with respect to a transiting sphere.

Question: can we measure the shape of an exoplanet from transit curves ?

Shape model

Assumptions: spherical star, circular orbit, no interactions between tides and rotation, tilted spin axis with obliquity Θ.

The tidal and rotational potentials can be expanded and expressed in spherical harmonics. Kopal [**4**] showed that omitting terms with degree j < 4 is equivalent to considering the Roche limit (mass-point surrounded by a massless envelope).

Following Love [2] and Kopal [4], the three-dimensional planetary surface shape is given by

$$r(\theta,\phi) = R_p\left(1 + q\sum_{j=2}^{4} h_j P_j(\lambda)\left(\frac{R_p}{a}\right)^{j+1} - \frac{1}{3}h_2(1+q)F_p^2\left(\frac{R_p}{a}\right)^3 P_2(\cos\Theta)\right)$$

Planetary mean radius; $\frac{M_s}{M_p}$; Legendre polynome of degree j; $h_j = 1 + k_j$; $\frac{P_{orb}}{P_{rot}}$; Semi-major axis

Our model allows direct fitting of the fluid Love numbers and rotational parameters.

Conclusions

- Our model allows direct fitting of the fluid Love number k_2
- Planets orbiting close to their Roche limit exhibit large tidal surface deformations, making them the best candidates for the retrieval of k_2.
- The precision in k_2 reaches a pleateau where a better photometric precision does not lead to a better precision in k_2. Only an improved knowledge of the planetary mean radius would improve the precision in the Love number.
- Using only one transit observation of WASP-103b from the GEMINI-North telescope, we managed to provide a rough 1.6σ detection of its Love number:

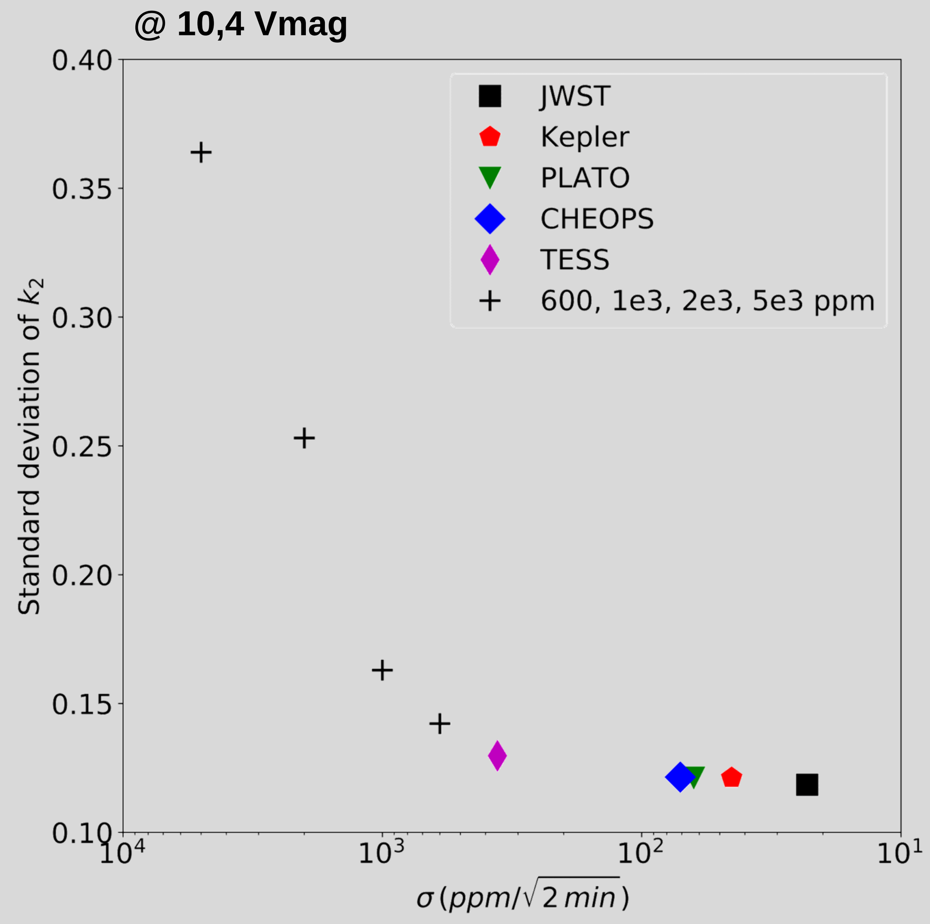
$$\boldsymbol{k_2 = 0.29^{+0.20}_{-0.18}}$$

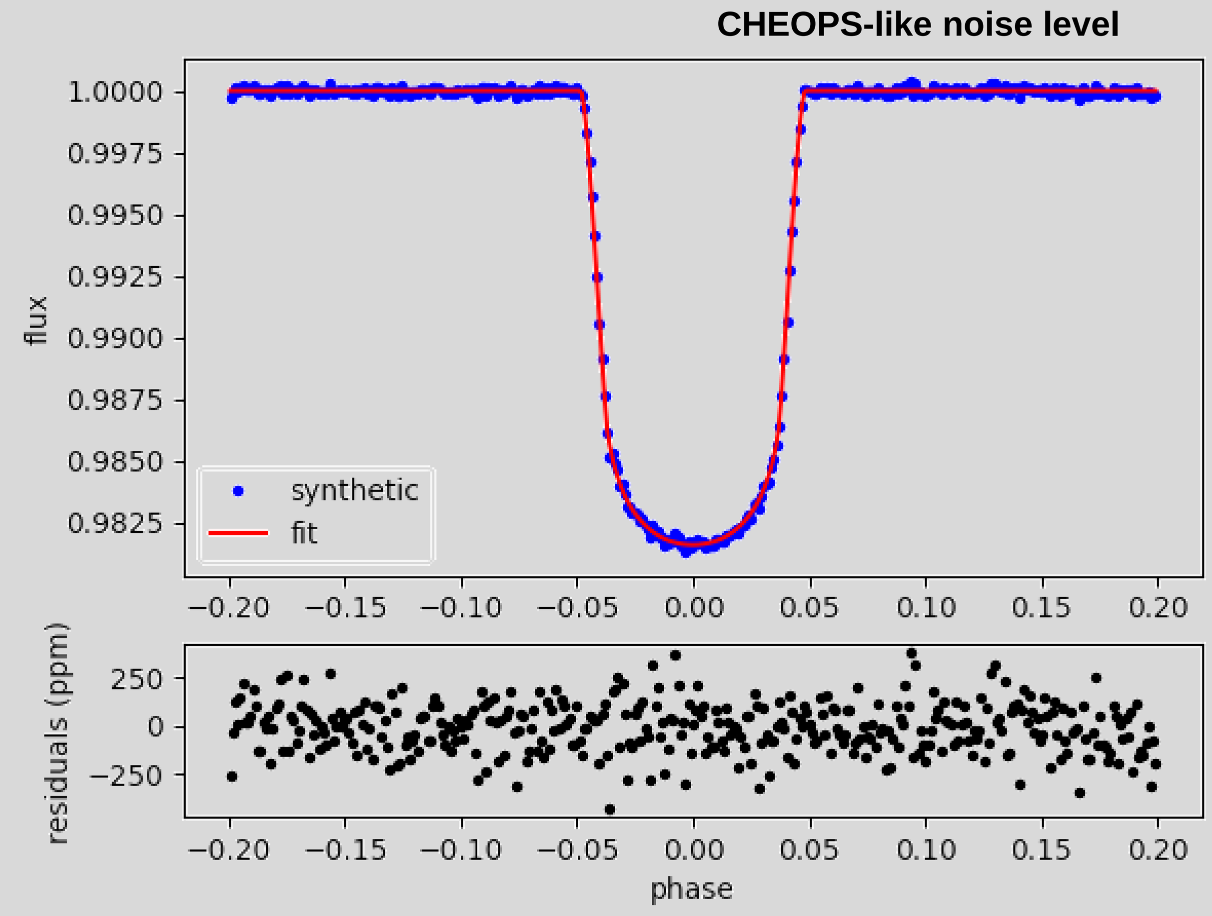
- The current TESS and upcoming CHEOPS missions will help further constrain the interior of exoplanets by providing the first reliable k_2 estimations of exoplanets.

Feasibility: WASP-121b [5]

We considered several white noise levels and injected them into a simulated WASP-121b transit light curve, binned into 2 minute measurements.
We assumed a planetary Love number $k_2 = 0.5$ [**6**].
Certain noise levels can be achieved by observing facilities with 10 observed transits.

Noise level ($ppm/\sqrt{2min}$)	Facility (* @ 10,4 Vmag, for 10 observed transits)
23	JWST (NIRSpec)*
45	Kepler*
63	PLATO*
71	CHEOPS*
360	TESS*
600, 1e3, 2e3, 5e3	e.g. Spitzer, ground-based surveys



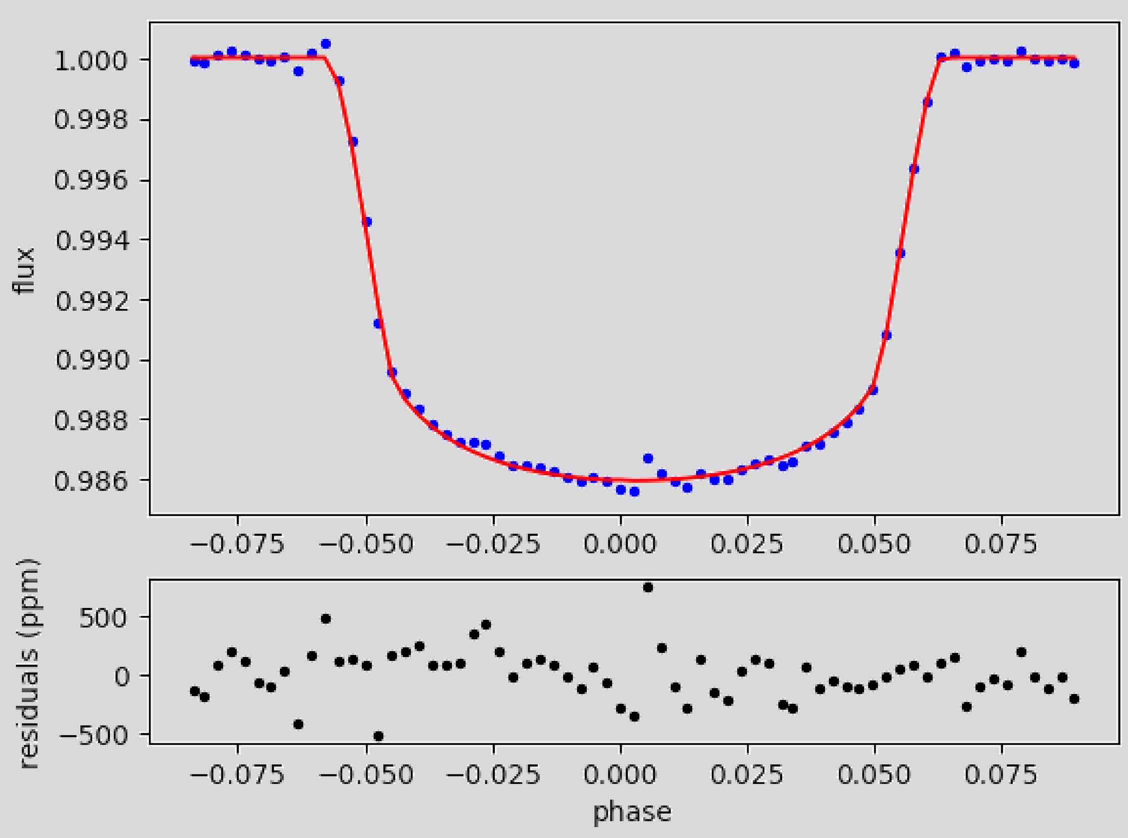


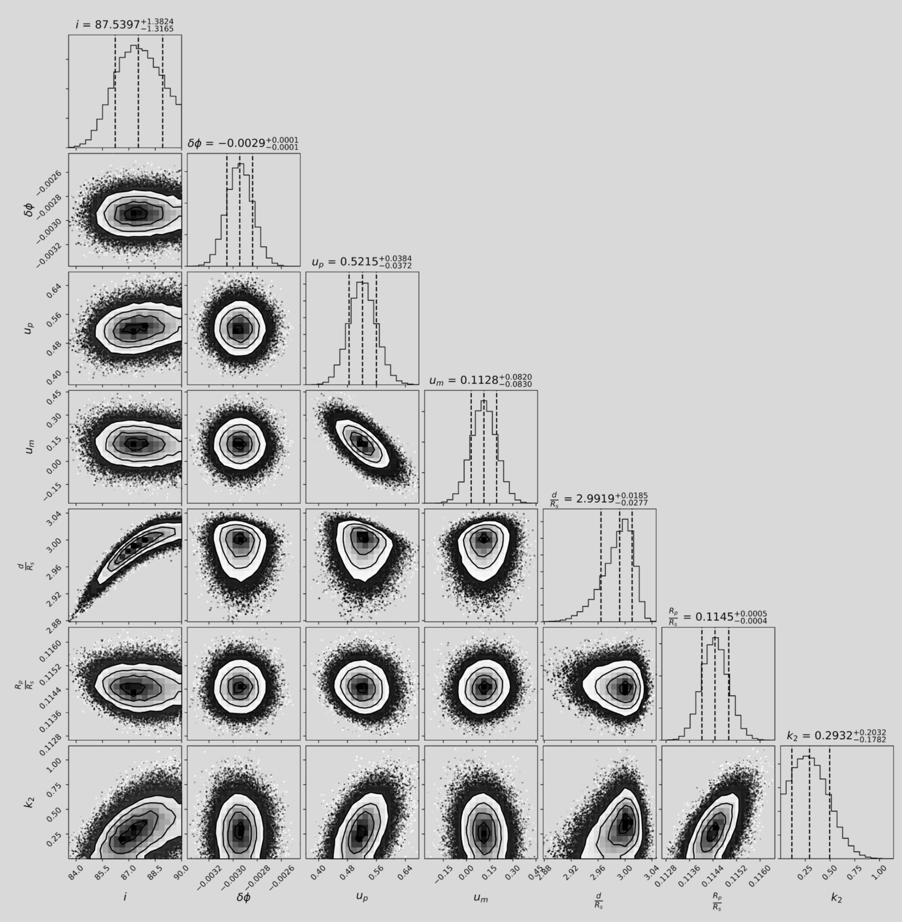
Application: WASP-103b

System: 1.53 R_J hot Jupiter orbiting a 1.44 $R_\odot$, 12.0 V_{mag} star, at roughly 2.3 its Roche limit.

Data: <u>one transit</u> observed in by the GMOS instrument at the 8.1m GEMINI-North telescope [**7**].

Result: we obtained a Love number equal to $k_2 = 0.29^{+0.20}_{-0.18}$





Reference & Acknowledgements

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Contact: hugo.hellard@dlr.de

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