Retrieval of the fluid Love number $k_2$ from transit light curves

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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.

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).

Planets orbiting close to their Roche limit exhibit large tidal surface 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 $\psi$.

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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 plateau 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.

Using only one transit observation of WASP-121b from the GEMINI-North telescope, we managed to provide a rough $1.6\sigma$ detection of its Love number:

\[ k_2 = 0.29_{-0.15}^{+0.22} \]

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.

Certain noise levels can be achieved by observing facilities with 10 observed transits.

<table>
<thead>
<tr>
<th>Noise level (ppm/2 minute)</th>
<th>Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>JWST (NIRspec)</td>
</tr>
<tr>
<td>45</td>
<td>Kepler*</td>
</tr>
<tr>
<td>63</td>
<td>PLATO*</td>
</tr>
<tr>
<td>71</td>
<td>CHEOPS*</td>
</tr>
<tr>
<td>360, 1e3, 2e3, 5e3</td>
<td>TESS*</td>
</tr>
</tbody>
</table>

Application: WASP-103b

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

Data: one transit observed by the GMOS instrument at the 8.1m GEMINI-North telescope [7].

Result: we obtained a Love number equal to $k_2 = 0.29_{-0.15}^{+0.22}$.

Reference & Acknowledgements


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