EPSC Abstracts
Vol. 12, EPSC2018-858, 2018
European Planetary Science Congress 2018

Interior structure of WASP-18b through its apsidal motion

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Abstract

Exoplanets and their host stars exhibit a mutual tidal interaction. One of the consequences of this phenomenon is the so-called apsidal motion: the major axis of the eccentric orbits rotate around the host star and it is called either apsidal motion or periastron precession. The rate of this precession linearly depends on the k_2 fluiud Love-number of the planet and therefore this effect, when this motion is observable, provides an opportunity to measure it. Theoretical predictions suggest that WASP-18b is one of the systems which features the biggest apsidal motion rate which should be observable by radial velocities and by transit timing variations within a few years. We analyze the available archival radial velocity data and we are able to give an upper limit for its Love-number.

1. Introduction

Increasing our knowledge of the interior structure, composition and density distribution of exoplanets is crucial to make progress in the understanding of formation, migration, habitability etc. of exoplanets. However, the directly-measurable mass and radius values offer little constraint on interior structure, because the problem is highly degenerate. Therefore there is a clear need for a third observable of exoplanet interiors: the Love-number that is a measure of internal density distribution of planets.

Tidal interactions between exoplanets and their host stars can be much stronger than experienced in our own Solar System. This is because exoplanets may have much shorter orbital periods and smaller orbital distances than Mercury (88 days). Many exoplanets have an orbital period less than 10 days which increases the efficiency of the star-planet interaction.

The consequences of tidal interaction in close-in systems are – among others – change in the semi-major axis (tidal decay) on a time-scale of billions years, change in the eccentricity in hundreds of millions of years (circularization), change in the rotational rate (synchronization) in tens of millions of years and precession of the major axis of the orbit around the star (apsidal motion) which occurs on the time scale of years to decades [1].

Since a few exoplanets were already discovered ten-twenty years ago it is valuable and feasible to search for this kind of apsidal motion and to utilize it in planet interior studies.

2. Theoretical background

Periastron precession consists of a general relativistic term (GR) and a classical, Newtonian term (N):

$$\dot{\omega} = \dot{\omega}_N + \dot{\omega}_{GR}$$

The GR term is:

$$\dot{\omega}_{GR} = \frac{6\pi G M_{star}}{a c^2 (1-e^2)}$$

while the tidal-term (Newtonian-term) is

$$\dot{\omega}_N = \frac{n}{2} \Sigma_{i=1}^{2} \left(\frac{R_i}{a}\right)^5 k_{2,i} F\left(P_i, P_{orb}, M_{planet}, M_{star}, e\right)$$

where we used the usual notation (G is the gravitational constant, M are the masses, c is the speed of the light, n is the mean motion, a is the semi-major axis, R is the radius, e is the eccentricity, Ps are the rotational and orbital periods).

The apsidal motion is reflected in the measured radial velocities because its zero point is calculated from the periastron point that precesses.

In Figure 1 we show the magnitude of the change in argument of periastron over 10 years (i.e. $\Delta\omega = 10\ years \times \dot{\omega}$). Notice that we assumed k_2 = 0.4 for the Jupiter-sized exoplanets and k_2 = 0.8 for the superearths.

Presently, the most accurate measurements are able to obtain the value of omega with 2-3 degrees. Considering this value and Figure 1, we feel we are able to measure k_2 from the periastron precesion.

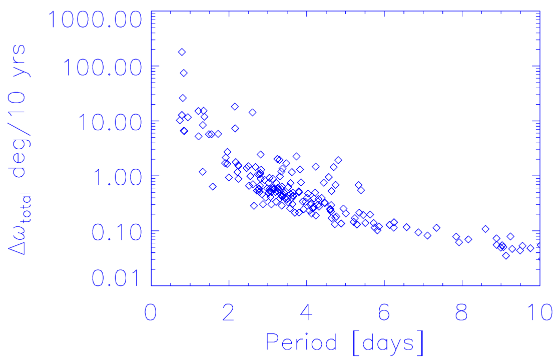

Figure 1: Orbital period vs expected periastron precession rate for exoplanets. Eccentricity and other values were taken from www.exoplanet.eu. Notice the logarithmic scale on y-axis. Exoplanets below 1 day orbital period gives chance to measure this apsidal motion and to determine the Love-number of some exoplanets.

3. WASP-18b

WASP-18b has an orbital period of only 0.94 days, a mass of 10.4 Jupiter-mass and a radius of 1.17 Jupiter-radii. The eccentricity is small, ~0.01, but significant and confirmed by the Spitzer Space Telescope [2]. Therefore it is an ideal target for such studies.

We collected all archival radial velocity measurements and modelled them [3,4,5,6]. Our preliminary result is that

$$\dot{\omega} = 0.008 \pm 0.003\, degree/day.$$

This yields approximately $k_2 < 0.50$, a value not far from Jupiter's value ($k_2 \sim 0.4$) in our own Solar System.

We submitted proposals to get telescope time in order to obtain a more precise value and to confirm our previous, preliminary findings.

4. Outlook

We started a work to measure the k_2 fluid Love-number of close-in exoplanets via the apsidal motion of them. We utilize archival and new data for this unique work.

New results can be expected between the submission of the abstract and the presentation of this work during EPSC. With this method we can present a few upper limits as well as precisely measured Love-number values which are fundamental for planetary interior studies.

Acknowledgements

We acknowledge support from the DFG via the Research Unit FOR 2440 Matter under planetary interior conditions and from the DFG German Priority Program SPP 1992 'Mass-radius diversity of exoplanets'.

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