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Tidal Decay and Disruption of Short-Period Gaseous Exoplanets

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Abstract Many gaseous exoplanets in short-period orbits are on the verge or are actually in the process of tidal disruption. Moreover, orbital stability analysis shows tides can drive most known hot Jupiters to spiral inexorably into their host stars. Thus, the coupled processes of orbital decay and tidal disruption likely shape the observed distribution of close-in exoplanets and may even be responsible for producing the shortest-period rocky planets. However, the exact outcome for a disrupting planet depends on its internal response to mass loss and variable stellar insolation, and the accompanying orbital evolution can act to enhance or inhibit the disruption process, depending on the geometry of the atmospheric outflow. In some cases, strong stellar insolation can produce a deep radiative zone in a planet's atmosphere, which can also influence the disruption and therefore the orbital evolution. Understanding these coupled processes and making accurate predictions requires a model that includes both the internal and the orbital evolution of the planet. In this presentation, we will discuss our preliminary work on tidal decay and disruption of close-in gas giants using the fully-featured and robust Modules for Experiments in Stellar Astrophysics (MESA) suite, the capabilities of which were recently upgraded to model gaseous planets with inert, rocky cores.

Keywords First keyword · Second keyword · More

1 Introduction

2 Introduction

The following lines of evidence point to or are at least consistent with tidal decay and subsequent atmospheric disruption of short-period gaseous exoplanets:

1. The majority of hot Jupiters are formally unstable against tidal decay.
2. Among the many *Kepler* targets for which rotation periods have been estimated, short-period planets are less commonly observed transiting the most rapidly rotating stars.

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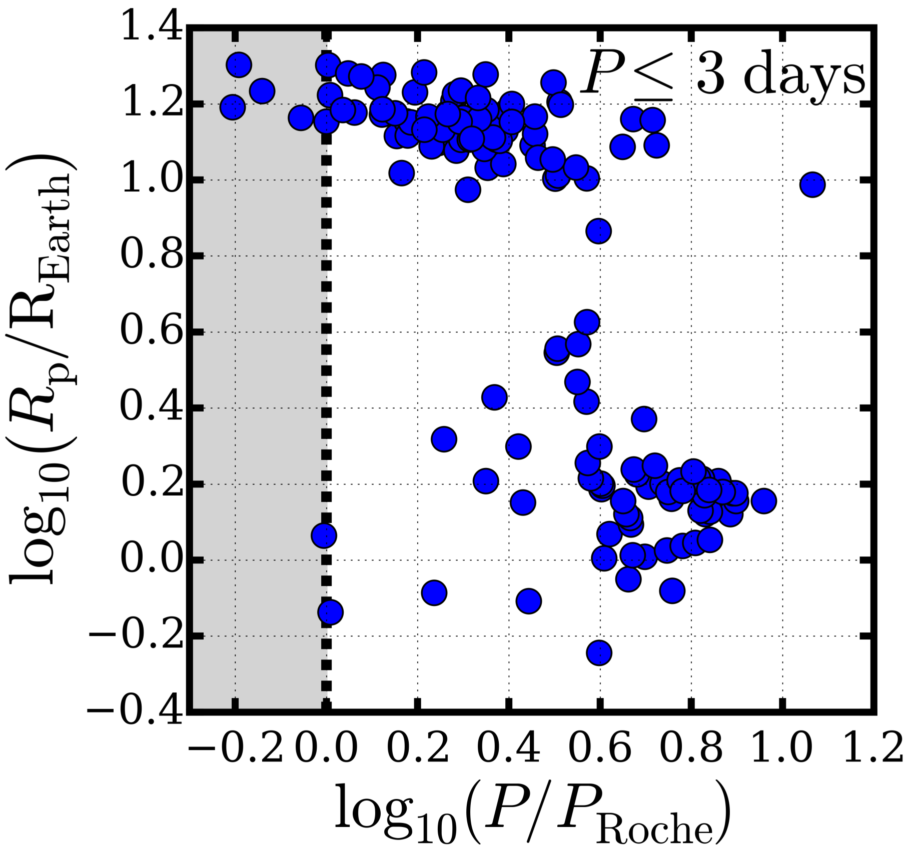

Fig. 1 Planetary radius $R_{\rm p}$ in Earth radii ($R_{\rm Earth}$) vs. the ratio of orbital period P to its Roche period $P_{\rm Roche}$ for $P \leq 3$ days. Data collected from exoplanets.org on 2015 Dec 7.

3. Poppenhaeger & Wolk (20XX) estimated x-ray activity (which scales with stellar rotation frequency) for several widely separated binary stars in which one of the stars hosted a short-period planet and the other did not. Those stars with relatively deep convective zones exhibited enhanced x-ray activity, and hence more rapid rotation, than expected based on the x-ray activity of the partner stars without planets.
4. There is a dearth of super-Earth/sub-Neptune gas-rich planets in the shortest orbital periods compared to longer orbital periods. This observation has been attributed to photoevaporative loss of the atmospheres, though.

The following lines of evidence argue against tidal decay and subsequent atmospheric disruption of short-period gaseous exoplanets:

1. No short-period planets are currently observed undergoing disruption.
2. Where are the remnants of decay/disruption? The population of small ultra-short period planets are too close to be the remnants.

As a first approximation to the mass-period relationship expected for the remnants, we use the $M_{\rm p} - R_{\rm p}$ relationship for sub-Neptunes provided in [], produced by fitting a combination of power laws to their more detailed atmospheric models:

$$R_{\rm p} \approx 2.06\,{\rm R_{Earth}} \left(\frac{M_{\rm p}}{\rm M_{Earth}}\right)^{-0.21} \left(\frac{f_{\rm env}}{0.05\%}\right)^{0.59} \left(\frac{F_{\rm p}}{\rm F_{Earth}}\right)^{0.044} \left(\frac{\rm age}{\rm 5\ Gyrs}\right)^{-0.18} + 1\,{\rm R_{Earth}} \left(\frac{M_{\rm core}}{\rm M_{Earth}}\right)^{0.25}, \tag{1}$$

where $f_{\rm env}$ is the fraction of the planet's mass in the gaseous envelope, $F_{\rm p}$ the stellar insolation received by the planet, and $R_{\rm core}$ is the radius of the planet's solid, rocky core. Equation 1 involves a number of approximations, including neglecting the contribution to $R_{\rm p}$ of a radiative outer atmosphere, which [] indicate is usually small (0.1 $\rm R_{Earth}$). The last term represents the radius of the solid core, which is insensitive to the exact proportion of iron and rock.