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Constraining properties of disintegrating exoplanets

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Abstract

Evaporating and disintegrating planets provide unique insights into chemical makeup and physical constraints. The striking variability, depth (~10 − 60%) and shape of the photometric transit curves due to the disintegrating minor planet orbiting white dwarf WD 1145+017 has galvanised the post-main-sequence exoplanetary science community. We have performed the first tidal disruption simulations of this planetary object, and have succeeded in constraining its mass, density, eccentricity and physical nature. We illustrate how our simulations can bound these properties, and be used in the future for other exoplanetary systems.

1. Introduction

Observations of the fates of planetary systems help constrain their formation and subsequent evolution, and provide unique insights into their bulk composition. Planets, moons and asteroids which survive engulfment from their parent star's giant branch evolution represent a sufficient reservoir of material to eventually 'pollute' tens of per cent of all Milky Way white dwarfs with metals. Dynamical interactions perturb predominantly small bodies close to the white dwarf, where the bodies break up, form discs, and pollute the star.

Before the year 2015, what was missing from the framework detailed above were detections of asteroids breaking up within the Roche radius of a white dwarf. That situation changed with the discovery of photometric transits from K2 light curves of WD 1145+017 [4]. These strongly suggest that at least one body around this white dwarf is disintegrating. The transit signatures change shape and depth on a nightly basis [1,3].

A plausible interpretation of the observations, exemplified by fig. 7 of [3], is that a single asteroid is disintegrating and producing multiple nearly co-orbital fragments. However, the actual tidal disruption has not yet been modelled numerically, and, with the exception of [2], all previous studies on this system have been observationally focused.

In [5], we perform this task, and utilize both homogeneous and differentiated rubble piles to model the evolution of an object which could create the observational transit signatures.

2. Figures

We use the PKDGRAV numerical code to model asteroids (Fig. 1) disrupting around WD 1145+017.

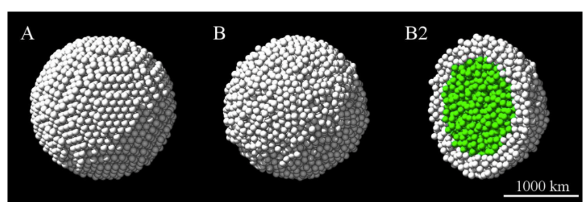

Figure 1: Rubble pile representations of asteroids which are homogeneous (A and B) and differentiated (B2).

Our goal is to reproduce transit signatures which last for the duration of the observations (several years). For homogeneous rubble piles, we find that they either remain intact with no disruption over this timescale, or disrupt catastrophically quickly (within 1 day). See Fig. 2.

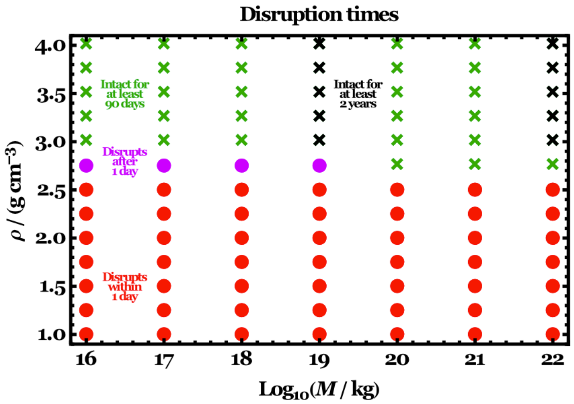

Figure 2: Disruption characteristics (density, mass and timescale) for homogeneous rubble piles.

Differentiated rubble piles, with a core four times as dense as the mantle, fare better. We find that they produce intermittent disruption which lasts for the desired timescales (Figs. 3 and 4).

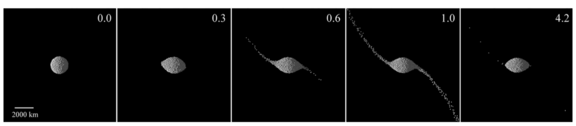

Figure 3: Mantle disruption of a differentiated synchronously spinning rubble pile on a circular orbit with ρ = 3.5 g cm^{-3}. After about half of an orbit, mantle particles start streaming from the L1 and L2 Lagrange points. After about four orbits, the streaming became intermittent.

3. Conclusions

We find that primarily rocky differentiated bodies with moderate (~3–4 g cm^{-3}) bulk densities on near-circular (e ~ 0.1) orbits can remain intact while occasionally shedding mass from their mantles. These results suggest that the asteroid orbiting WD 1145+017 is differentiated, resides just outside of the Roche radius for bulk density but just inside the Roche radius for mantle density, and is more akin physically to an asteroid like Vesta instead of one like Itokawa.

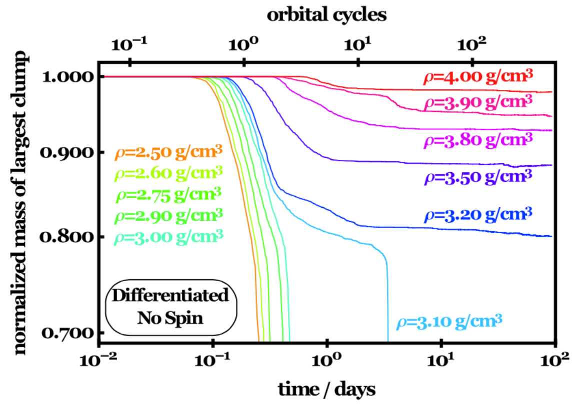

Figure 4: Disruption timescales for differentiated rubble piles. A density of about 3.10 g cm^{-3} is the transition between partial and complete disruption.

Acknowledgements

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