The formation of transiting circumplanetary debris discs from the disruption of satellite systems during planet–planet scattering

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Summary

Several stars have exhibited deep dips in their brightness, consistent with the passage of a large disc or planetary ring system through the line of sight between observer and star. We show how such discs/rings can be generated by the collisions between planetary satellites.
For full details, see Mustill, Davies & Kenworthy, *MNRAS*, 530, 3606; arXiv:2404.12239

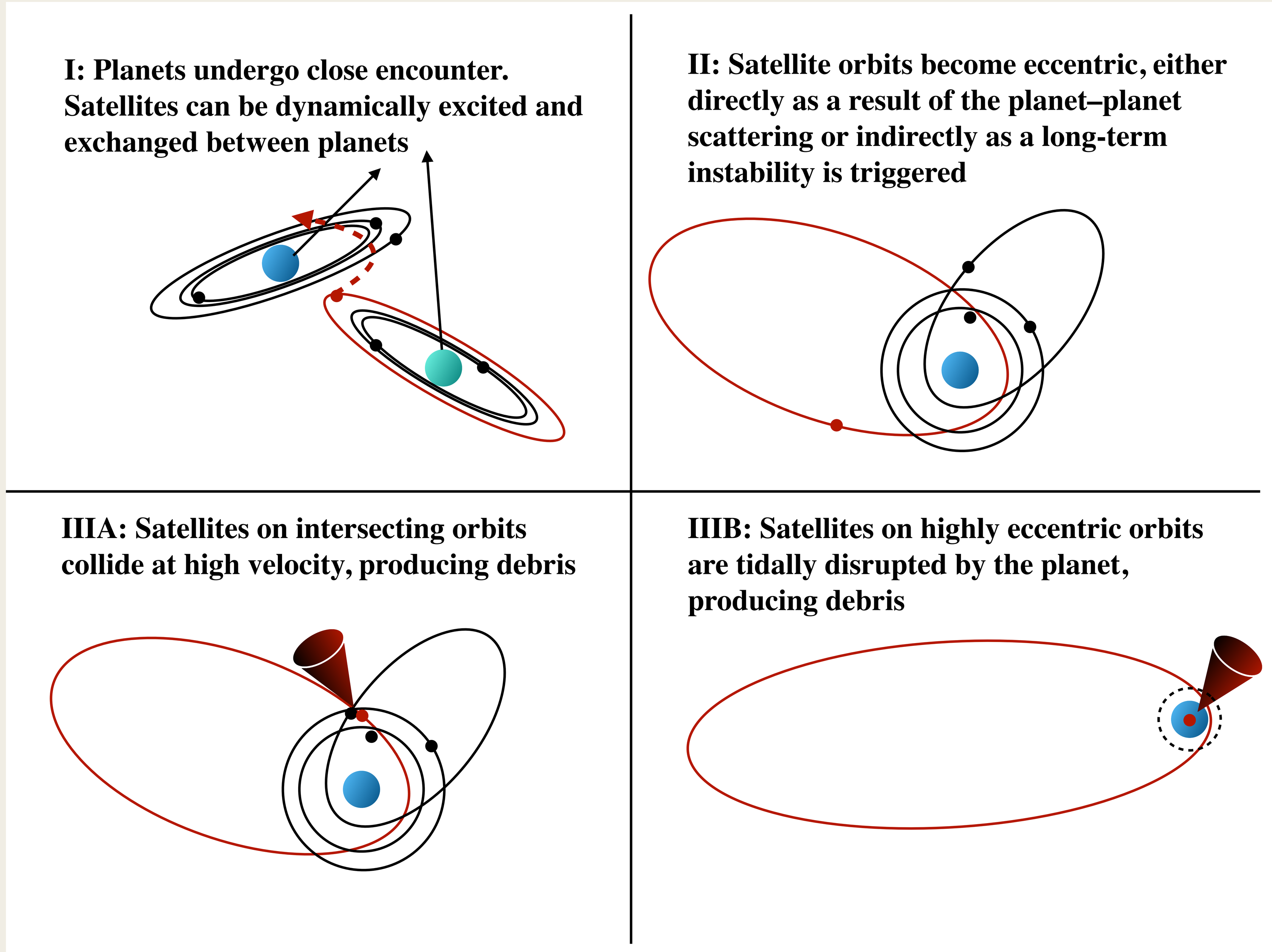
Background

Modern photometric measurements of stars from space-based observatories such as *Kepler, TESS* and *CHEOPS,* with high precision, high cadence, and surveying many targets, are able to detect planets and related phenomena as the planet or other object is seen to pass in front of the star, causing a dip in brightness.
One class of objects exhibits long, deep dips in brightness consistent with **the transit of a planet surrounded by a disc or ring system** (van der Kamp *et al.,* 2022). Common features are:

- **Depth** larger than a planetary transit.
- **Shape** consistent with an elliptical disc, not a spherical planet.
- **Duration** too short for a circular orbit, implying orbital eccentricity ≳0.3.
- **Amount of material** comparable to bodies 100s of km in size, if collected together.
- **Size of structure** (~1 Solar radius) that requires a giant planet at the centre to retain the material in its Hill sphere.

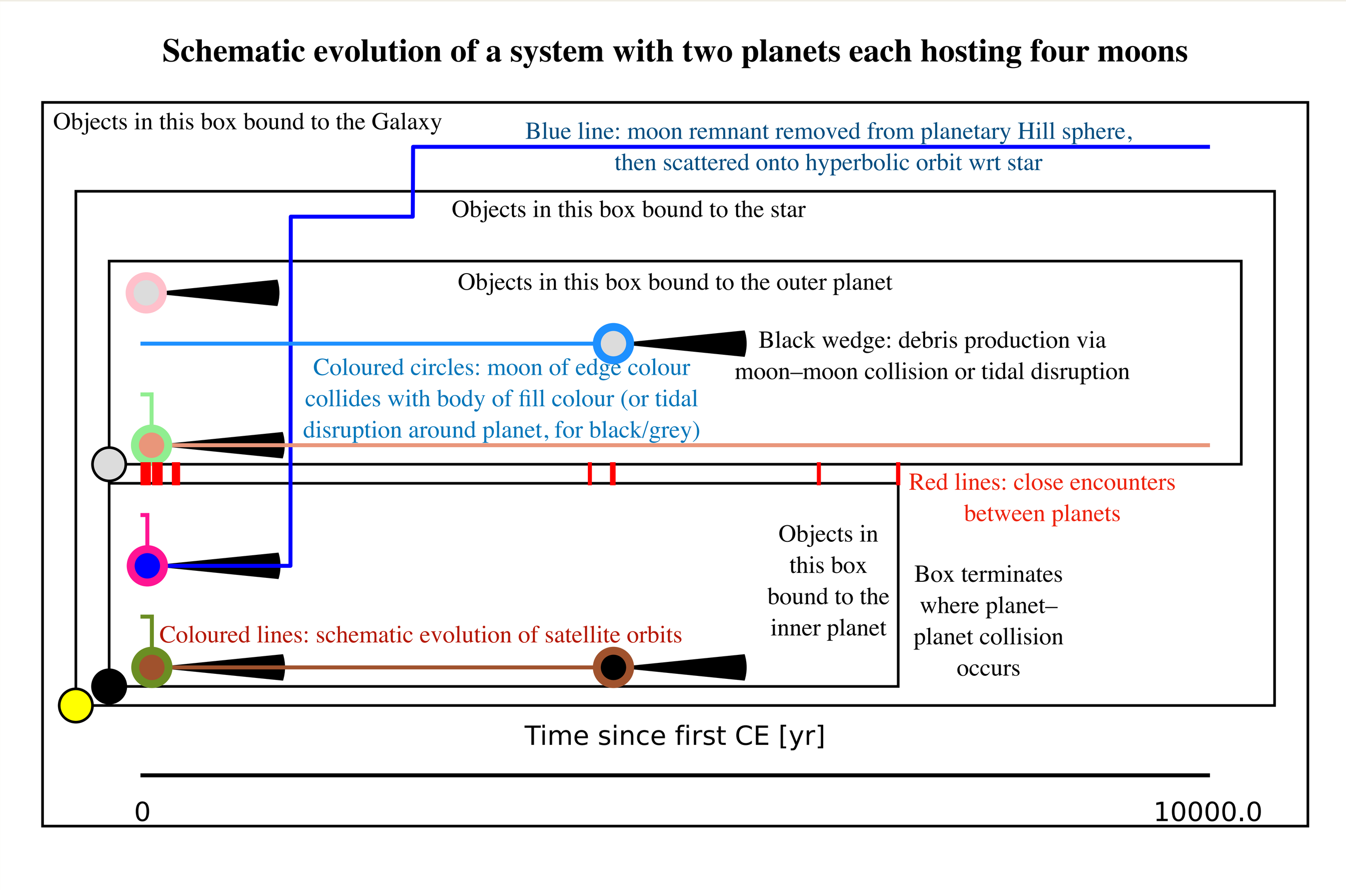
Proposed solution

The existence of these large discs is a natural result of **giant planets which possess satellite systems undergoing planet–planet scattering,** though to be common for giant planets that often have high orbital eccentricities. The scattering excites the eccentricities of the planets' orbits around the host star, while close encounters between the planets destabilises the satellite systems and leads to the exchange of satellites between planets. The satellite orbits are excited and often unstable, leading to **collisions between the satellites or tidal disruption of a satellite by a planet.** In each case, the debris produced by the satellites will in time settle into an observable disc. The size of progenitor body needed (> 100s of km) is much smaller than the size of Jupiter's Galilean satellites (1000s of km).

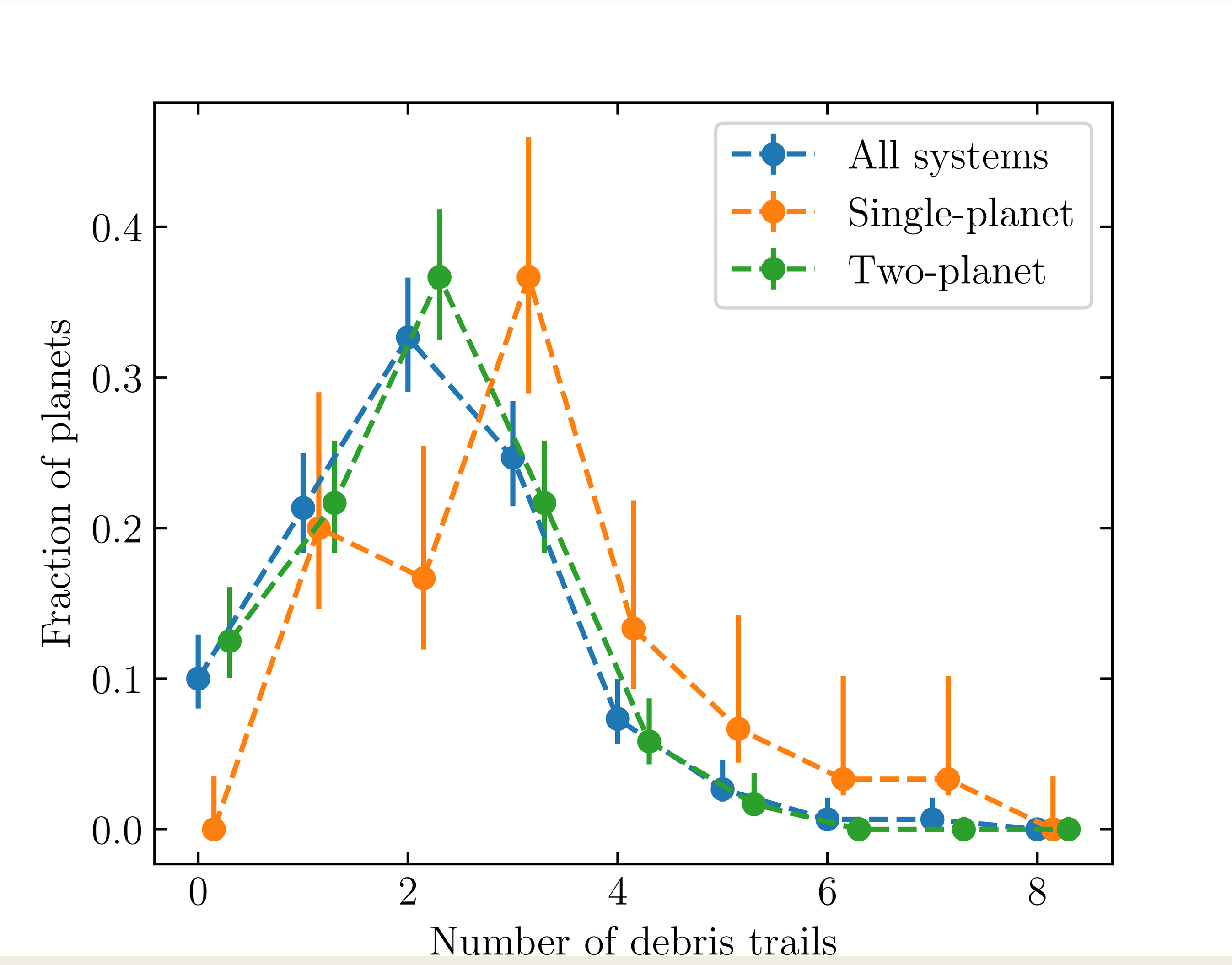


Simulations

We use the IAS15 integrator of the REBOUND package (Rein & Liu 2012, Rein & Spiegel 2015) to **simulate systems of two planets each with a copy of the Galilean satellite system** as the planets undergo scattering, logging collisions between satellites as well as tidal disruptions. Simulations are run with only planets until planets undergo close encounters, at which point the satellite systems are inserted (the short orbital periods of the satellite necessitate a very short integrator time-step). In 10kyr of simulation time, **90% of systems experiencing planet–planet scattering had also lost at least one satellite to collision or tidal disruption.** Most satellite losses occur due to tidal disruption. The orbits of the resulting debris trails are often tilted by several tens of degrees to the planetary orbits, consistent with the inclinations of the observed discs. **Scattering of planets possessing satellite systems thus explains the properties of the observed disc systems.**



Example evolution of a 2-planet, 8-satellite system which experiences repeated close encounters between the planets triggering collision and tidal disruption of 6 satellites.



Number of debris trails (each formed by collision or tidal disruption of a satellite) in our simulations, divided according to the number of surviving planets.

References and Acknowledgements

Mustill, Davies & Kenworthy, 2024, MNRAS, 530, 3606
Rein & Liu, 2012, A&A, 537, A128
Rein & Spiegel, 2015, MNRAS, 446, 1424
van der Kamp *et al.*, 2022, A&A, 658, A38

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