Tidal disruption of extremely eccentric asteroids around pre-polluted white dwarfs

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Asteroids play a vital role in producing observable signatures in post-main sequence planetary systems. The growing interest in these systems is largely fuelled by precise, unambiguous detections of metal pollutants in white dwarf atmospheres and the presence of gas and solids surrounding some of these polluted stars. Asteroids are thought to be the primary progenitor of both the pollution and these orbiting structures.

Many unanswered questions remain about the processes which transport rocky material directly onto white dwarfs, including the manner in which debris streams and discs are formed. As a first step, here we establish that a single asteroid on an extremely eccentric bound ($e \gg 0.98$) orbit around a white dwarf tidally breaks up into a *highly eccentric, collisionless ring* through gravity alone. We investigate the disruption mechanism analytically and numerically by modeling asteroids as rubble piles. We find that the disruption timescale and mechanism is most highly-dependent on the pericentre of the orbit. The time spent within the Roche radius is largely independent of the asteroid's semimajor axis for $a \gtrsim 1$ au. We analytically compute the eccentric ring-formation timescales for all possible disruptive orbits (see e.g. the Figure), and show how these results compare with a few fully self-consistent numerical simulations using the rubble-pile N-body `PKDGRAV` integrator. We further reveal that the maximum allowable integration timestep for simulations which model orbits that skim the white dwarf surface may be lower than one second, two orders of magnitude shorter than typical dynamical timescales adopted for rubble pile simulations. These findings provide an important foundation for constraining the delivery mechanism of asteroids on eccentric orbits to white dwarfs by incorporating additional and necessary forces such as those arising from the white dwarf's radiation.

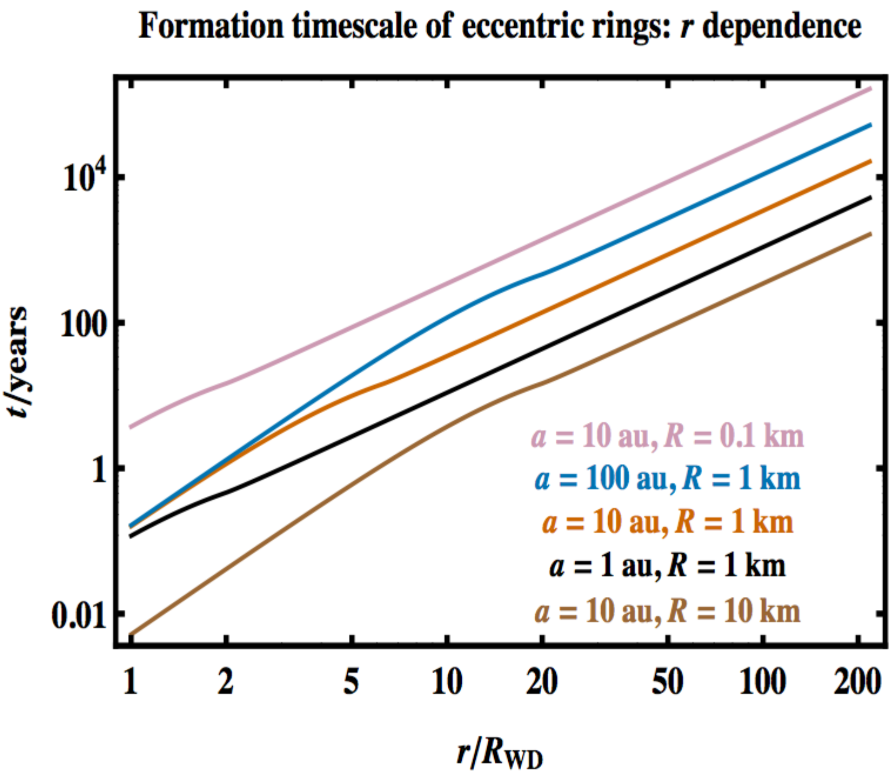

Figure: The time t needed for debris to fill out an eccentric ring after an instantaneous disruption of an asteroid at a distance r from a white dwarf of mass $0.6M_{\odot}$ and radius $R_{\rm WD} = 8750$ km. Before disruption, the asteroid's original radius and original orbital semimajor axis were R and a. The plot demonstrates that when disruption occurs within $10R_{\rm WD}$, the ring will fill out within about 100 years.

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