Satellite Formation around the Rapidly Rotating, Oblong Asteroid Kleopatra

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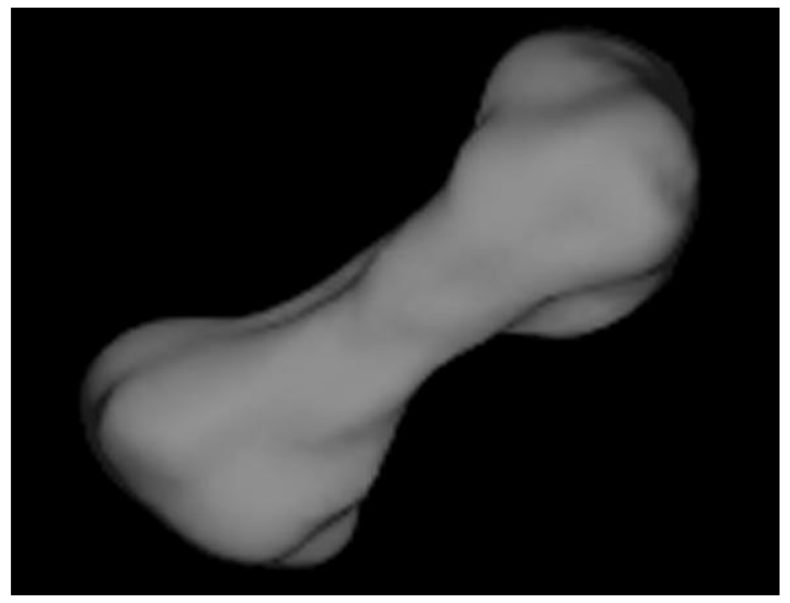
(216) Kleopatra

Kleopatra is a large, M-type asteroid orbiting in the main asteroid belt with an elongated dog-bone shape and two natural satellites orbiting around it. The main body measures 217 km along its longest axis, and the two satellites measure 6.9 km and 8.9 km in diameter [Descamps 2011].



Radar Shape Model of Kleopatra [NASA]

Observations

The bulk density of Kleopatra has been measured to be 3.6 g/cm^3.

Radar observsations suggest Kleopatra is composed primarily of metal.

The density and composition observations yield a porosity of 30-50%.

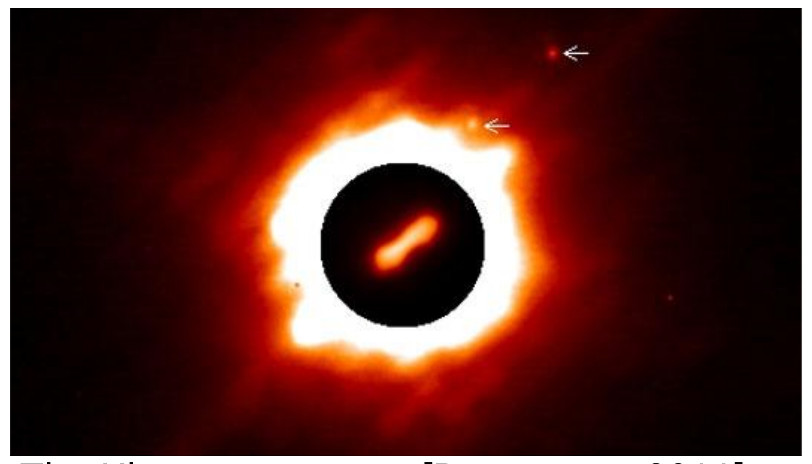
How did Kleopatra get its satellites?

There are several possibilities for the formation of Kleopatra's satellites:

1) One large, recent impact gave the asteoid its shape and satellites. Assuming Kleopatra is a rubble pile, the satellites' ages can be estimated from the tidal evolution timescale to be 10-100 Myr old [Descamps 2011, Weidenschilling 1989]. However, we do not see a clear collisional family for Kleopatra, meaning members of such a family would be smaller than ~5 km to elude detection.

2) The satellites formed from the accumulated impact ejecta over a long period of time. Kleopatra's elongated shape allows ejecta to remain in orbit for an extended period of time, however our work suggests this mechansism may not be sufficient to account for the mass of the satellites.

3) One large, ancient impact gave Kleopatra its shape and satellites. A metal composition for the asteroid may result in a higher rigidity for the body due to a cold welding affect [Consolmagno, 2004]. This would allow for an older asteroid with a dispersed collisional family.



The Kleopatra system [Descamps, 2011]

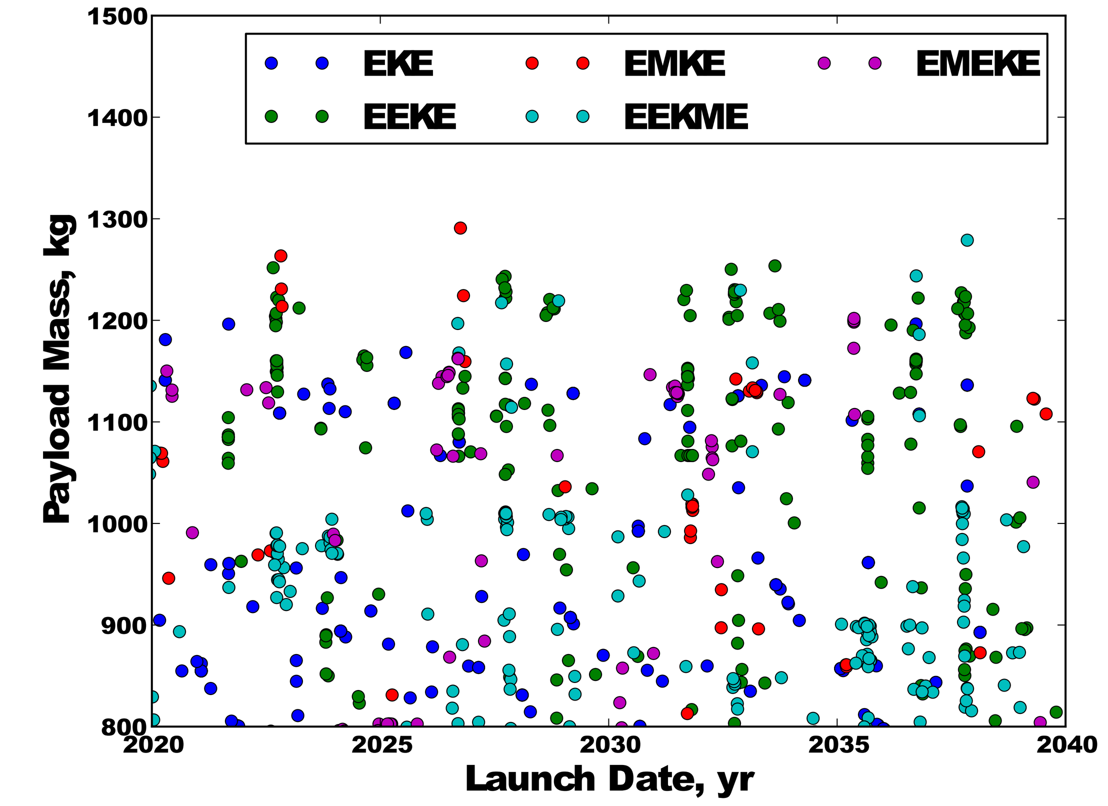
If Kleopatra is as old as the Solar System, we could expect about **7.1 x 10^{16} kg** of ejecta to have been produced in impacts, assuming a collisional history similar to that of Vesta [Marchi, 2012].

The satellites are about **2.13 x 10^{15} kg** total, or **3%** of the total ejecta mass.

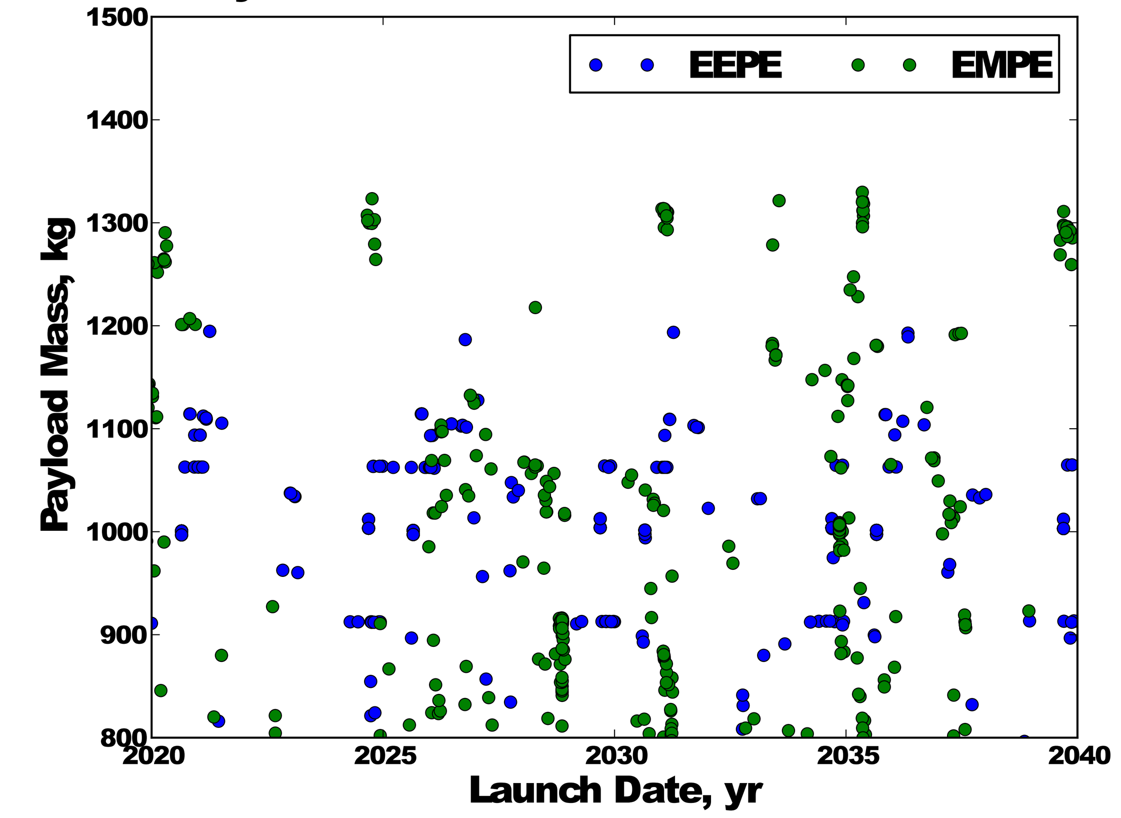
To estimate the fraction of the satellites' mass that comes from accumulated impact ejecta, we propagate the trajectories of ejecta particles and track the time each particle spends in the satellites' orbits. Factoring in the volume fraction of space occupied by each satellite, we can estimate the probability a given ejecta particle would impact one of the satellites. These calculations suggest only **0.05%** of the satellites' mass may be comprised of accumulated ejecta.

Metal Asteroid Sample Return

Kleopatra Mission

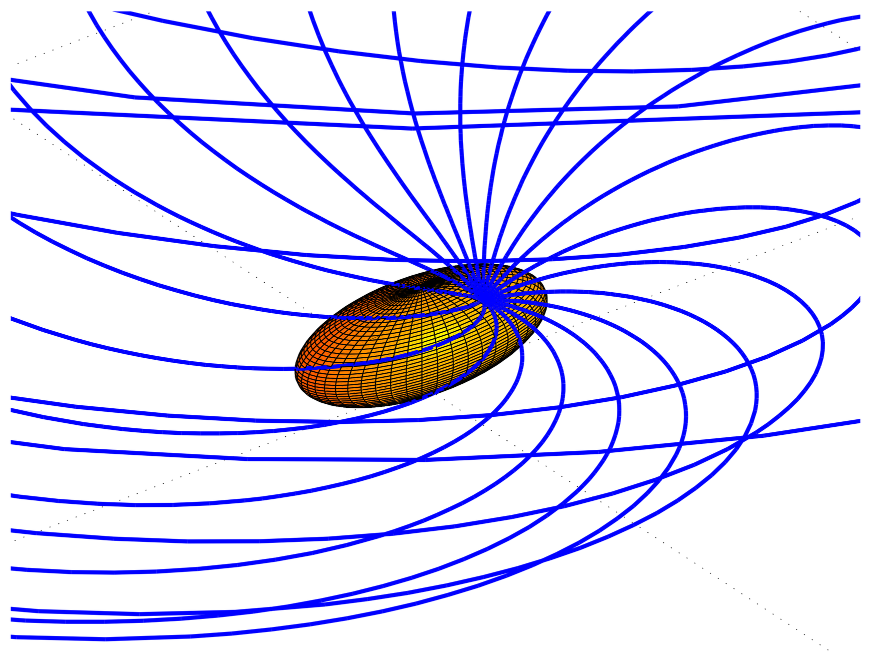


Psyche Mission

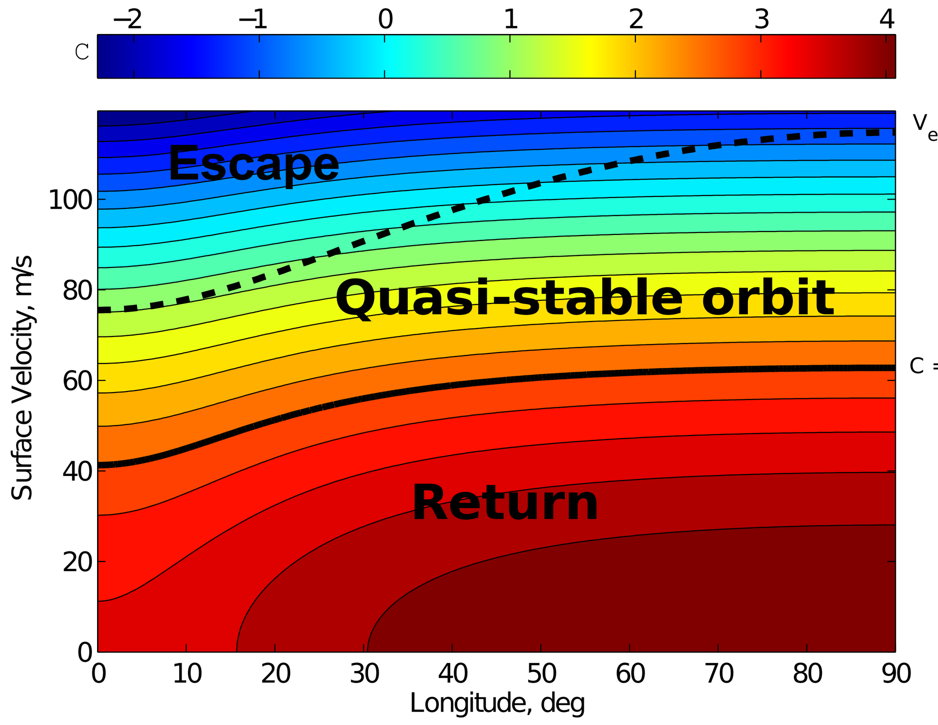


A sample return mission to Kleopatra could be performed within the New Frontiers class of missions. Using solar electric propulsion with gravity-assist trajectories, neutral masses of greater than 1200 kg are attainable with a 2500 kg initial mass and 20 kW power system. A mission study for a Psyche sample return showed similar results. (Letters indicate body sequence, e.g. EMKE means Earth-Mars-Kleopatra-Earth.)

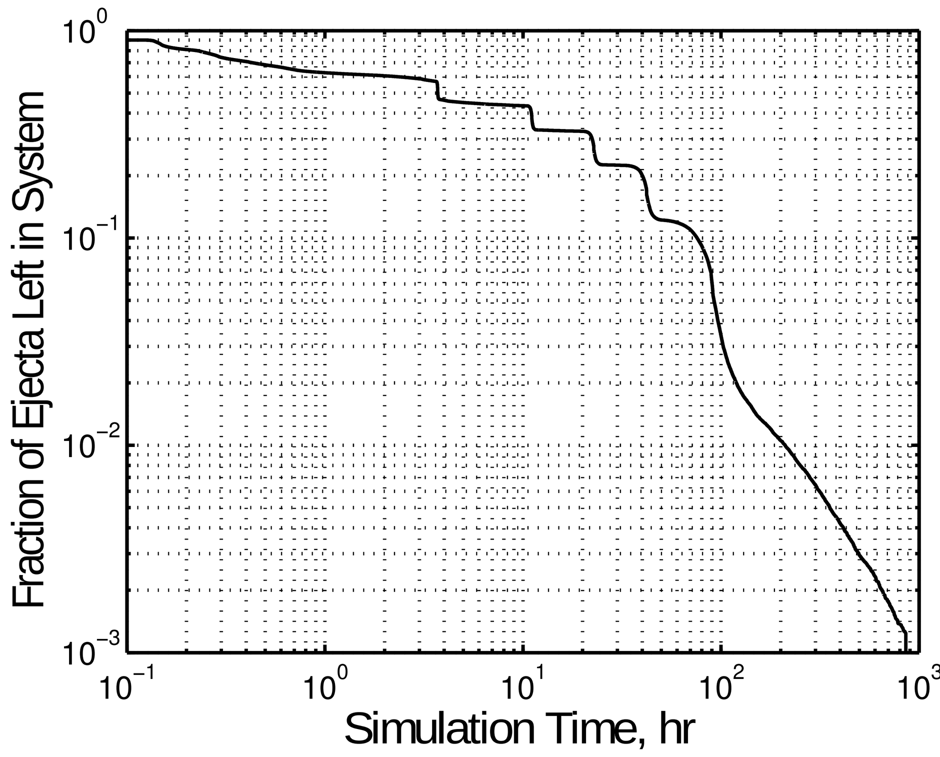
Motion of Ejecta around a Highly Elongated Body: Examining the Ejecta Accretion Hypothesis



To examine whether the satellites may have formed out of the gradual accretion of impact ejecta, we simulated impacts over the surface of a Kleopatra-sized ellipsoid and tracked the motion of the ejecta particles.



Ejecta leaving the surface of an elongated object like Kleopatra may remain in a quasi-stable orbit around the body. This behavior is in contrast to a spherical body, where ejecta either departs the system or returns to the surface within one orbit.



The above plot shows the rate at which ejecta leaves orbit, either through re-impact or escape. On average, half the ejecta is gone after 4 hours, with 1% left after 200 hours.

References

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