Modeling Recent Asteroid Disruptions in the Solar System

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Abstract

We study the dynamical evolutions of the byproducts of recent asteroid disruptions to understand the population of small particles in near-Earth and cislunar space, which can post threats to spacecraft, satellites, and long-term lunar missions like Artemis. To assess this population, we track the dynamical evolution of dust particles created in a catastrophic asteroid disruption. Particle sizes ranging from a few microns to a few cm are modeled using a code that accounts for both the gravitational and radiative forces to accurately predict the orbital elementals of the dust particles in the Datura and Emilkowalski asteroid clusters. The resulting models show that the smaller particles decay into the inner solar system at a faster rate than their larger counterparts, meaning they are more likely to be dispersed throughout the solar system. Comparison of these models with infrared satellite observations allows us to put constraints on the size-distribution and amount of dust present which not only helps us contain the treat these particles may pose, but also understand the amount of surface regolith that was on the parent body asteroids.

I. Background

- We are tracking the dynamical evolution of dust released in the creation of the Datura and Emilkowalski asteroid families, which represent two recent (less than .5 Myr ago) asteroid disruptions.
- By tracking this evolution under both radiative and gravitational forces, we can create models of the resulting dynamical structures and compare these models to infrared satellite observations.
- We use an IDL code that takes the current orbital parameters of the family, integrates then backwards in time to the age of their breakup and then integrates the ejected small particles forwards in time under both radiative and gravitational forces.
- Radiation forces cause the particles to slow down and lose energy resulting in their orbital decay from the asteroid belt into the inner solar system and near-Earth and cislunar space.

II. Theory

- Radiative forces become important for small dust-marble sized grains because of their greater surface area to mass ratio.
- The main radiative force is Poynting-Robertson drag which acts like a "headwind of photons" and causes particles to spiral into the Sun on a timescale related to their size—larger particles take longer to spiral in.
- As the particles are decaying inwards, they experience gravitational perturbations dominated by Jupiter which act to sculpt the dust particles into observable dust structures known as dust bands.

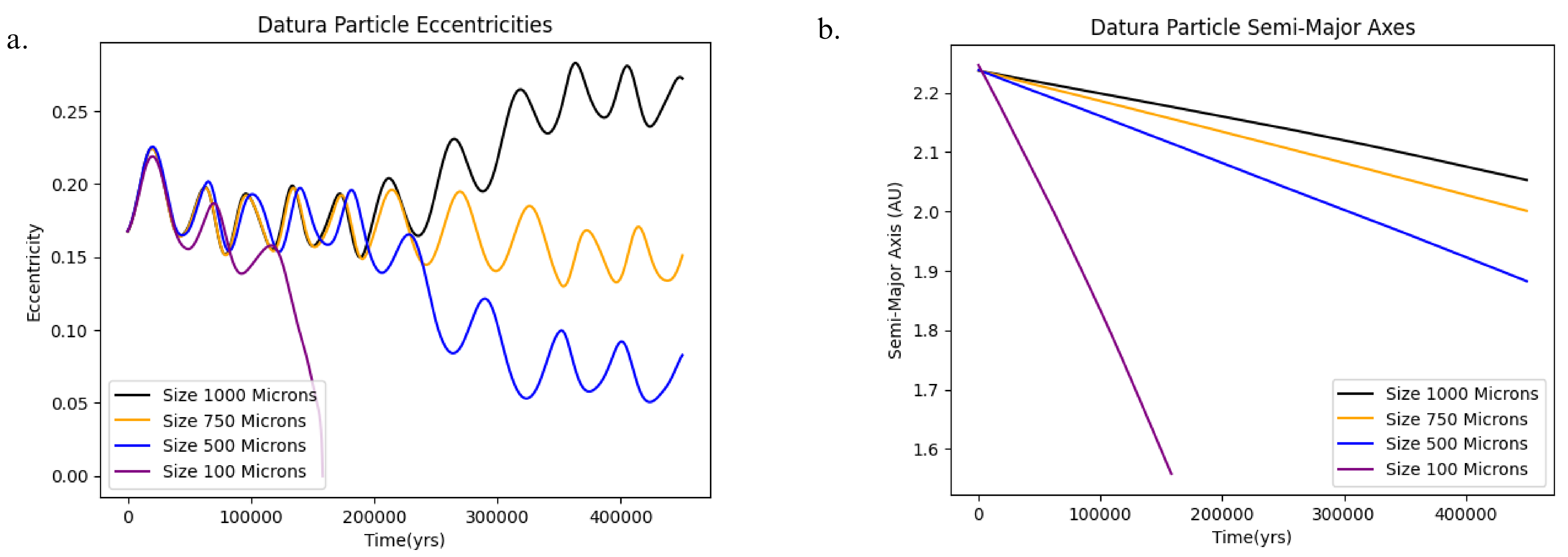

Figure 1: (a) Evolution of eccentricity and (b) semi-major axes of a particle originating from Datura for particle sizes of 100, 500, 750, and 1,000 microns over a span of 450,000 years.

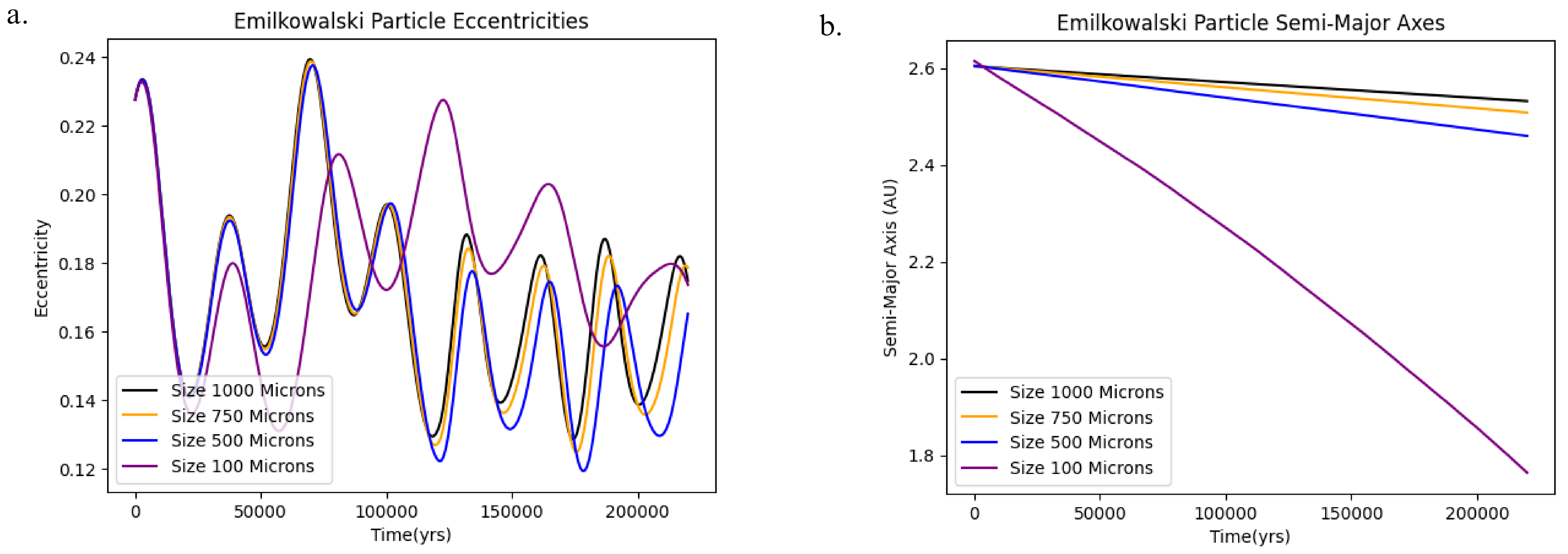

Figure 2: (a) Evolution of eccentricity and (b) semi-major axes of a particle originating from Emilkowalski for particle sizes of 100, 500, 750, and 1,000 microns over a span of 220,000 years.

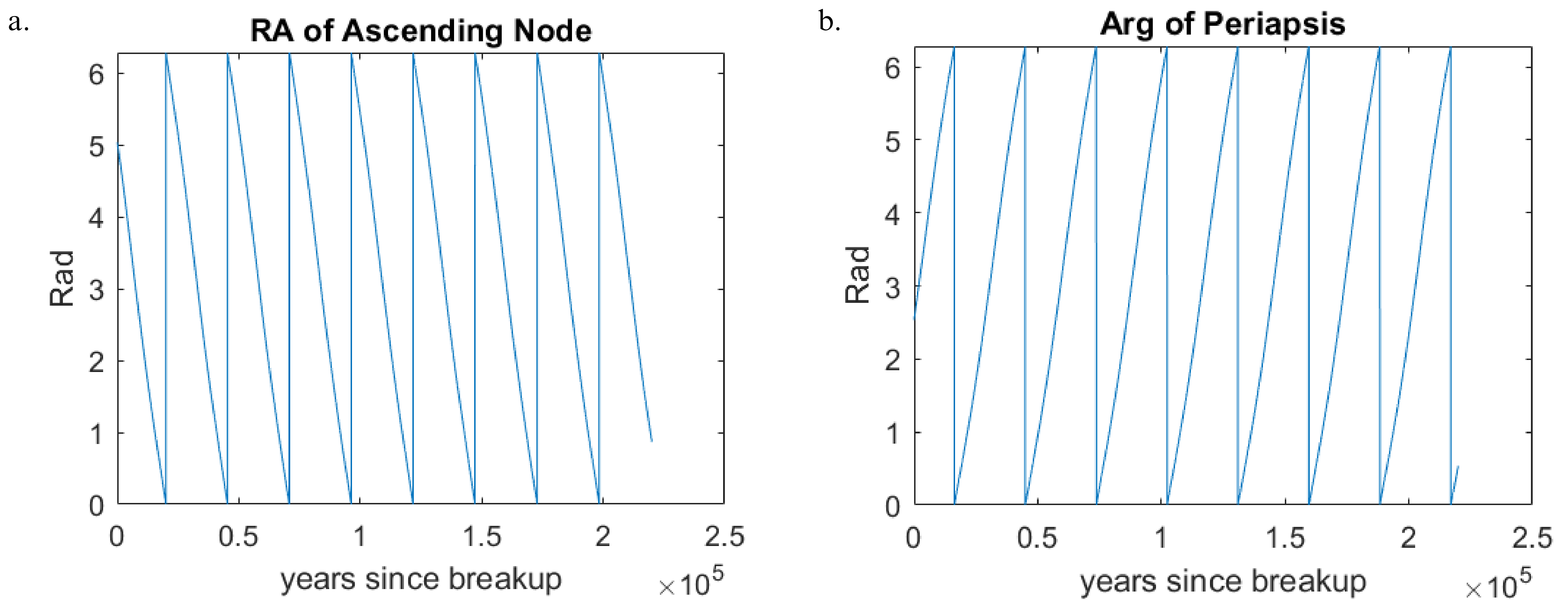

Figure 3: (a) Evolution of right accension of ascending node and (b) arguement of periapsis axes of a particle originating from Emilkowalski for particle sizes of 200 microns over a span of 220,000 years.

III. Results & Discussion

The Semi-Major axis and Eccentricity of the Datura and Emilkowalski families were compared to determine these similarities:

- That the the particles start out following Jupiters eccentricity variation, but as time goes on the smaller particles drift away due to Poynting-Robertson drag and radiation forces. As they get farther from Jupiter, moving into the inner solar system, the perturbations become less dominated by Jupiter and they can be seen to be more and more uncoupled.
- Smaller particles, such as 100 microns, are affected more by the breakup of the parent body as can be seen in the differences in their initial values.
- The smaller particles do decay into the inner center of the solar system more quickly since they have a greater surface area to mass ratio which makes radiative forces more effective on these particles. This can be seen by the semi-major axis decaying to smaller than 1.6 astronomical units in much shorter time frame than the larger size particles
- The right accension of the ascending node and the argument of periapsis see similar effects from the perturbations of Jupiter in that they at first track Jupiter's precession rates but slow down in their precessions as they move inward and away from the planet.

Differences seen between each family:

- Since the Datura family broke up at a smaller semi-major axis than the Emilkowalski family, we see that it evolves into center of the solar system more quickly. The 100 micron particles do not last remain in the region of interest for the full span of the lifetime in the Datura lifetime family while the same size particles in the Emilkowalski family remain in this region for lasts its full life span due to its larger initial semi-major axis and younger age.
- The particles move through the secular resonance (nu 6) at the inner edge of the main belt sooner (due to the smaller initial semi major axis) and therefore become more dispersed from this passage.

IV. Conclusions & Future Work

- By integrating particle sizes back in time, and then forward again while taking various radiative and gravitational forces into account, we are able to effectively discern their origins and evolutionary pathways after an asteroid disruption.
- A total rework of the simulation is planned in order to have a more accessible codebase. The end goal of such a rework is to have a more modular and scalable particle simulation written in another language. The greater accessibility and larger addon ecosystem would allow us to integrate plots and models with the simulation itself.
- The next step, for this dataset is to use the orbital elements obtained in these orbital simulations as inputs into another suite of codes which produces simulated infrared emission that can be compared directly to satellite observations