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The random walk evolution of asteroid families

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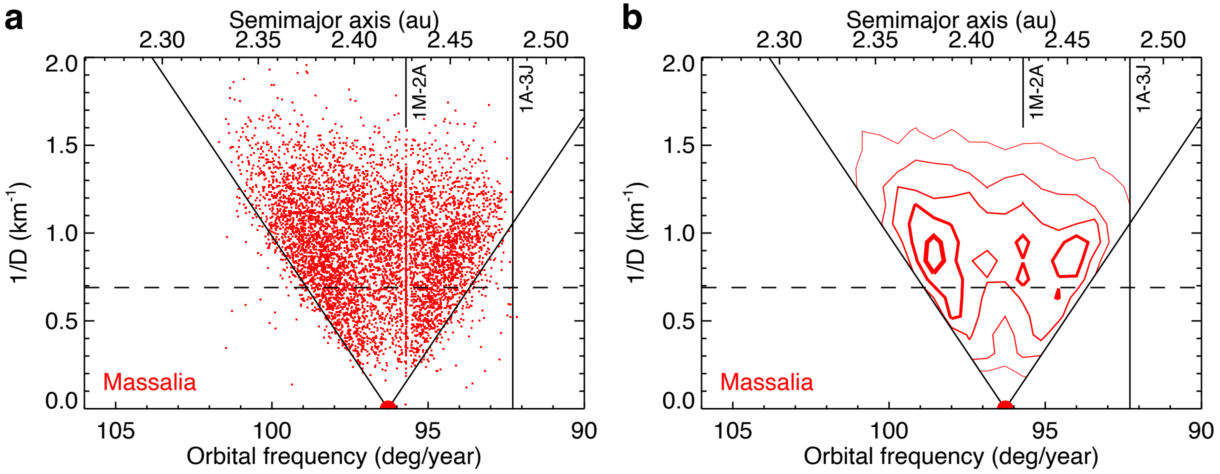
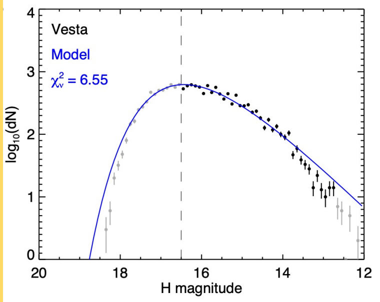
The dynamical evolution of asteroid families is determined by a range of mechanisms that include: (1) catastrophic collisions, (2) changes in spin direction and (3) evolution of the semimajor axes driven by Yarkovsky radiation forces, but the timescales of these mechanisms are uncertain. **Yarkovsky evolution of family asteroids in *a-1/D* space can result in a V-shaped distribution that can be used to estimate the age of the family.** Using **Massalia** (Nesvorný et al. 2015) as an example:

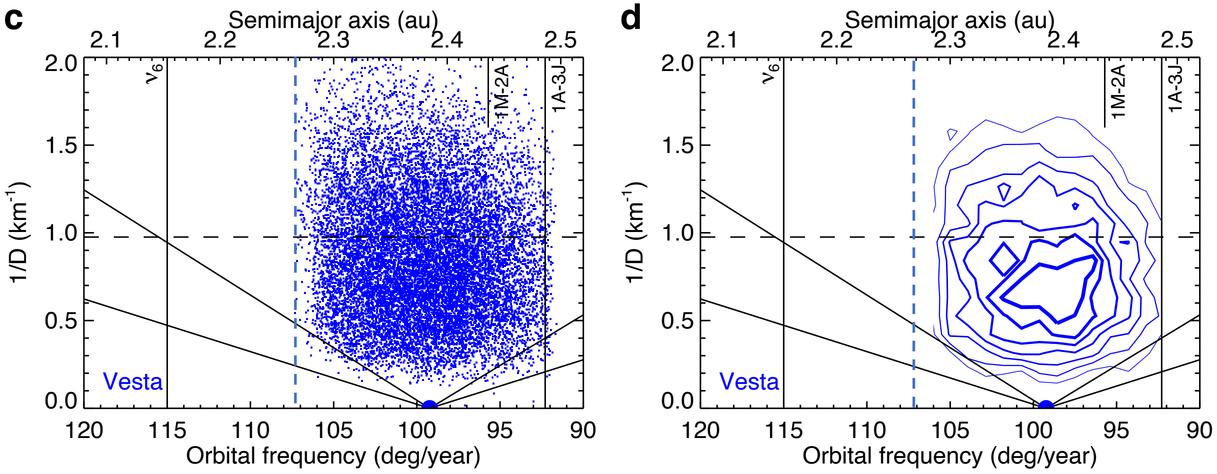


The clear **V-shape distribution** (panel a) of **Massalia** can be attributed to the Yarkovsky effect alone. This is because the Massalia family is so young that impacts of the collisional evolution and changes in the spin directions on the V-shaped distribution are minimal. This is supported by the number density plot (panel b), where the central depletion implies that most asteroids have been moving in one direction, either towards or away from the Sun, since the formation of the family. The slope of the V-shaped lines is $\Delta a = \pm 0.063$ *au* for $D = 1.45$ *km* (Milani et al. 2014). Assuming a density of ~3,000 *kg*/*m*^{3} for the family members, and using the NEA observations (Greenberg et al. 2020), we calculate that for the Massalia family asteroids, $\boldsymbol{T_Y}$ **(Yarkovsky timescale) ~6 *Gyr* and the age of the family is ~0.16 Gyr.** See our paper (and the talk by Stan F. Dermott) for more details.



We have developed a model to simulate the evolution of the size frequency distribution (SFD) of an asteroid family driven by the Yarkovsky forces, and to put constrains on the Yarkovsky timescale (T_Y) and the age of the family. For Vesta, the best-fitting model suggests $t_{Vesta}/T_Y = 0.33 \pm 0.02$. Using the value of T_Y = 4 *Gyr* derived from the NEA observations (Greenberg et al. 2020), we estimate that $\boldsymbol{t_{Vesta}}$ **= 1.3±0.1 *Gyr*.**

However, the simplifying assumptions **no change in mass or spin direction** may not be valid for **older families**. Using **Vesta** (Nesvorný et al. 2015) as an example:



Quite different from that of the young Massalia family, the **Vesta** distribution (panel c) shows a strong central concentration (panel d), implying that over the full semimajor axis range of the family, the asteroids could be evolving both towards and away from the Sun (i.e., like **a random walk**), as a result of the collisional evolution and significant changes in spin directions they have experienced since the formation of the family. Consequently, the age of Vesta (1.3±0.1 *Gyr*; see the sticky note above) estimated from the SFD fitting, which ignores the mass and spin direction evolution, must be an underestimate. In our paper, we argue that the Vesta family and high-inclination, non-family asteroids in the Inner Main Belt have had similar evolution histories and that both have ages **comparable to the age of the solar system**.