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Orbital Evolution of Asteroids

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Abstract

The synthetic orbital frequencies and eccentricities of main belt asteroids computed by Knezevic and Milani [2] show evidence that the structure of the asteroid belt has been determined by a dense of web of high-order resonances. By examining the orbital frequency distribution at high resolution, we discover a correlation between asteroid number density, mean orbital eccentricity and Lyapunov Characteristic Exponent. In particular, the orbital eccentricities of asteroids trapped in resonance tend to be higher than those of non-resonant asteroids and we argue that this is observational evidence for orbital evolution due to chaotic diffusion.

1. Orbital Eccentricities

We analyze the distribution of the synthetic orbital frequencies and eccentricities of over 200,000 numbered asteroids in the main belt computed by Knezevic and Milani [2] and catalogued in the AstDys proper element database. The distribution of these orbital elements is determined by a dense web of resonances and we show that at any given heliocentric distance, across the whole main belt, overlapping of high-order resonances determines the observed upper bound on the eccentricities (Fig. 1).

The libration widths of all two-body resonances of order q≤30, plus the stronger three-body resonances, are used in this plot. In the inner main belt (a<2.8 AU) two-body resonances with Mars are dominant, while in the outer main belt (a>2.8 AU) jovian two-body resonances determine the upper bound on the eccentricities confirming an earlier result of Dermott and Murray [1].

However, the asteroids in the catalogued dataset are not a bias-free set. In the inner main belt, for absolute magnitude H>15.5, mean orbital eccentricity increases with increasing H because of well-understood observational selection effects. However, for H<15.5, the inner main belt is probably complete and we observe that the mean orbital eccentricity of the these larger asteroids increases with increasing size (Fig. 2).

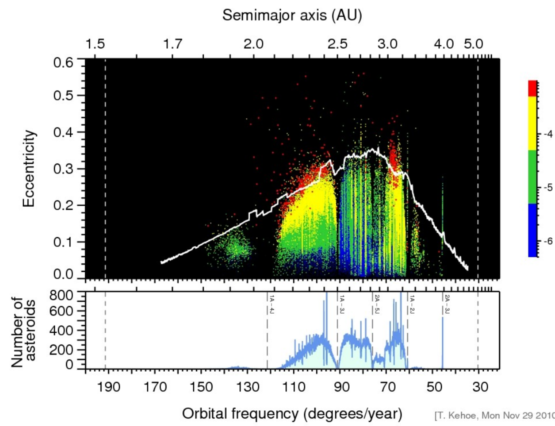

Figure 1: The white line in this figure, which we refer to as “the shoreline of the chaotic sea”, is determined by the eccentricity at which neighboring mean motion resonances overlap.

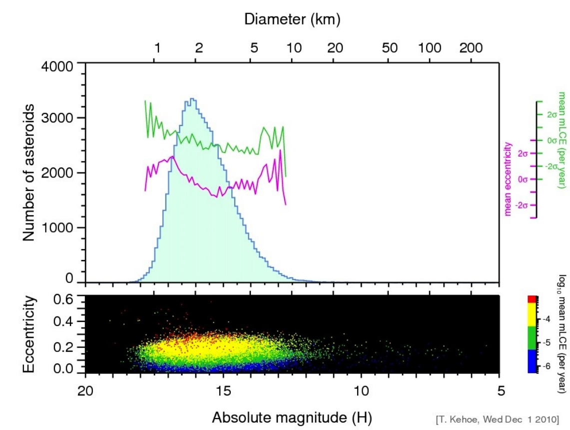

Figure 2: We use a running box to show the variations of the mean LCE (Lyapunov Characteristic Exponent – green plot) and the mean eccentricity (red plot) with mean asteroid diameter of all asteroids in the inner main belt (a<2.5 AU). For H≤15.5, the data set is complete and hence there can be no significant observational selection of high eccentricity orbits. We observe that the mean eccentricity of the asteroids in this bias-free set increases with increasing diameter, and hence age, of the asteroid. The lower, color-coded plot of the distribution of eccentricity and LCE with respect to diameter confirms that the largest and therefore oldest asteroids tend to be in the most stable orbits.

2. Resonant Structure

We also show that there is a correlation between asteroid number density, mean orbital eccentricity and Lyapunov Characteristic Exponent. In particular, the orbital eccentricities of asteroids trapped in resonance tend to be higher than those of non-resonant asteroids and we argue that this is observational evidence for orbital evolution due to chaotic diffusion (Fig. 3). It is possible that Yarkovsky forces have driven small asteroids into some of these resonances and we assess the influence of this mechanism by comparing the number of asteroids in the bias-free set trapped in a particular resonance with the expected number estimated from the observed number density of the neighboring asteroid population.

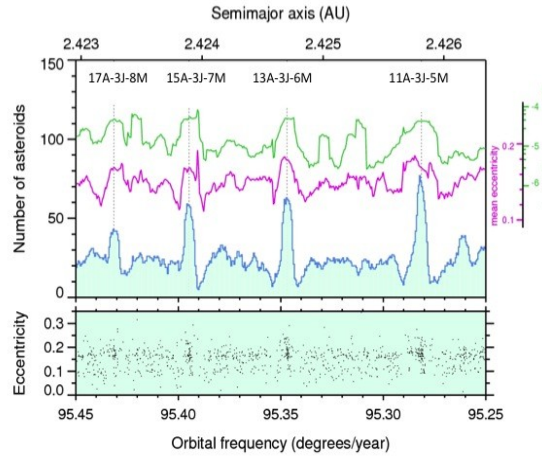

Figure 3: We use a running box with a resolution of 0.002 degree/year to show the variation of number density, Lyapunov Characteristic Exponent (LCE – green plot) and mean orbital eccentricity (red plot) with orbital frequency. The four resonances shown are three-body resonances involving the orbital frequencies of an asteroid (A), Jupiter (J) and Mars (M) and are part of a series of three-body resonances that converge from both sides on the two-body 2A-1M resonance.

References

[1] Dermott, S.F. and Murray, C.D.: Nature of the Kirkwood gaps in the asteroid belt, Nature, Vol. 301, pp. 201-205, 1983.

[2] Knezevic, Z. and Milani, A.: Synthetic proper elements for outer main belt asteroids, Celest. Mech. Dynam. Astron. Vol. 78, pp. 17-46, 2000.