Four Billion Year Stability of the Earth–Mars Belt

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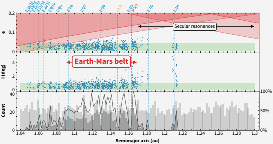
Wait! an Earth–Mars Belt?



Top two: Distributions of surviving particles at 4.5 Gyr. Green boxes denote initial orbital range studied. Red regions show Earth and Mars crossing at 5th and 95th percentile of that planet's long-term eccentricity distribution. **Bottom:** The semimajor axis histogram at the start (light grey shading) and survivors (dark grey shading). The solid lines shows the initial to final ratio for each bin (right scale). **Vertical lines:** MMRs with three terrestrial planets.

①

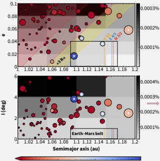
- Evans & Tabachnik (2002) numerically demonstrated ***100 Myr*** stability for many orbits between a = (1.08, 1.28);
- ***We extend to 4.5 Gyr and show > 50% of orbits in a = (1.09, 1.17), e < 0.04, I < 1°, persist the age of the Solar System; we call this the Earth–Mars Belt;***
  - Beyond 1.17 au, secular resonances destabilize orbits on Gyr time scale.
  - Closer than 1.09 au, mean motion resonances provide some stability.
  - In the belt, some gaps are associated with mean motion resonances.

Could there be a primordial population?

What is Nearby Today? NEOs!

②

- Normal NEA dynamics constantly delivers main-belt asteroids to the vicinity of the Earth–Mars belt;
  - Only small (D < 150m) NEOs are near the Earth–Mars belt today; larger ones would have been easily detected by NEO surveys.
  - Nearly all known NEOs are unstable in < 1 Myr (red circles below).
  - A few are longer lived (although < 2 Gyr), but still consistent with NEA supply (greyscale projections are steady-state NEA model).
- ***Earth–Mars belt is essentially unreachable by NEOs.***



Caption

(a, e) and (a, I) projections of all known NEOs surrounding the Earth–Mars belt (rectangular outlines). Objects are colour-coded by dynamical lifetime with symbol radius proportional to estimated diameter; the largest circle is ~150m and the smallest ~2m. White crosses mark the four NEOs whose stability lifetime exceeds 10 Myr when we integrated them. Dashed vertical lines mark three important MMRs affecting belt stability (Fig. 1). The two upper-left red bands (same as in Fig. 1) denote Earth intersection, and the expected additional reach over +3 R_Hill (yellow highlight) is where longer-lived metastable behavior is confirmed. The background grayscale heatmap is a projection of the percentage of steady-state NEOs in each cell (Greenstreet et al. 2012). The white cell at lower right has zero power (there are no objects in this a,e cell at any I), and the two cells with a = (1.10, 1.15) and e < 0.04 only have power for I > 1° and thus avoid the belt.

Cosmogonic Implications

③

- For < 40 km asteroids, Yarkovsky drift rates measured for NEAs (ref. 3) allow primordial asteroids to leave the belt.
- Therefore, if 100 km scale planetesimals existed here 4 billion years ago, they should remain.
- ***Terrestrial planet formation must nearly empty the Earth–Mars belt.***
  - That is, leave no large objects with e < 0.04 and I < 1°.

References

1. Evans, N. W., & Tabachnik, S. A. MNRAS, 2002
2. Greenstreet, S., Ngo, H., & Gladman, B. Icarus, 2012
3. Margot (this meeting) presents Greenberg, A. H. et al. AJ, 2020
4. This work submitted to MNRAS, July 2020.