Eccentricities and the Stability of Closely-Spaced Five-Planet Systems

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Abstract

We investigate the stability of idealized planetary systems consisting of five one Earth mass planets orbiting a one solar mass star. All planets orbit in the same plane and in the same direction, and the planets are uniformly spaced in units of mutual Hill Sphere radii. We integrate systems where either one, or all planets begin on eccentric orbits, with eccentricities as large as 0.05 being considered. For a given initial orbital separation, larger initial eccentricity generally leads to shorter system lifetime, regardless of which planet is initially on an eccentric orbit, however systems with middle planet eccentric will have the shortest life times. The approximate trend of instability times increasing exponentially with initial orbital separation of the planets found previously for planets with initially circular orbits is also present for systems with planets initially eccentric orbits. Mean motion resonances also tend to destabilize these systems, although the decreases in system lifetimes are not as large as for initially circular orbits. For systems with all planets eccentric, we find that interestingly, they are almost as long lived as circular systems, i.e. substantially longer than systems with any one planet eccentric.

Methodology

Planetary characteristics:
• five identical, 1 M\(_{\oplus}\) planets, orbiting a 1 M\(_{\odot}\) star in the same direction;
• initially separated by a multiple of their mutual Hill radius, defined below;
• co-planar, i.e. inclinations are zero at all times;
• initial eccentricity of one planet at either 0.01, 0.02, 0.03, or 0.05; one case of all planets eccentric at 0.05;
• initial true longitude: 2\(\pi\) or 0.05; one case of all planets eccentric at 0.05;
• initial true longitude: 2\(\pi\), where \(\lambda\) is the golden ratio.

Mutual Hill radius: \(R_{H,j} = \left(\frac{m_j + m_{j+1}}{m_j}\right)^{\frac{1}{3}}(\frac{a_j + a_{j+1}}{3})\)

Simulation setup:
• increment in \(\beta\) for each new simulation: 0.01
• time measured in units of Earth years;
• total number of simulations such that exactly five systems are generated for each new simulation: 0.01
• symplectic WHFast integrator from REBOUND;
• close encounter when distance \(d\) is less than 0.01 AU.

Conclusions

We investigated closely-spaced five-planet systems starting out at different eccentricities. Even for relatively small eccentricities up to 0.05, substantial differences in close encounter times are manifest, while the log-linear behavior is preserved in all cases. Initially eccentric intermediate planets appear to make a system go unstable faster than initially eccentric inner or outer planets. Finally, larger relative (rather than absolute) eccentricities appear to be the dominant factor for shortened close encounter times in eccentric systems, unless initial periapses are chosen randomly. (Gratia & Lissauer [1998.01117])