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Eccentricity and the Lifetimes of Closely-Spaced Five-Planet Systems

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With the discovery that many exoplanetary systems harbor several closely-spaced planets, questions relating to their stability have become relevant. We have integrated closely-spaced planetary systems, with the goal of quantifying their stability times over very long time scales (up to ten billion years). Each of our systems started out with five identical, Earth-mass planets orbiting a solar-mass star, with orbits being spaced as a geometric sequence, and initial eccentricities up to e = 0.05 given to either one, or all, planets. For all planets eccentric, we ran several sets of simulations: one where the initial periapses were aligned, and others with randomized (either over all azimuths or a restricted range) initial periapse angles. In all cases, the trend in system lifetimes follows a log-linear relationship between time to close encounter and initial separation (with differing slopes). We confirmed this relationship up to initial orbit separations of approximately 10 Hill radii for small eccentricity (e=0.01), and up approximately 13 Hill radii for the largest considered eccentricity (e=0.05). to On a more granular level, we find substantial differences in life times at resonances for low eccentricity systems, but those differences are reduced in magnitude for higher eccentricities and/or randomized periapses. For systems with just one planet eccentric, the time to close encounter depends on which planet starts out eccentric: an eccentric intermediate planet typically shortens the time to close encounter compared to the same value of eccentricity given to either the inner or outer planet. If all planets start out with the same eccentricity and aligned periapses, stability is restored — such systems are on average only slightly less stable than initially circular ones. Angular momentum deficit does not appear to influence stability times, suggesting that mean motion resonances play the dominant role over secular resonances. This was checked by comparing systems with identical total angular momentum deficit for the same initial separations. We chose to compare systems with innermost planet eccentric with their corresponding systems with outermost planet eccentric (i.e., identical AMD, implying smaller initial eccentricity). Survival times were consistent with merely initial separation and eccentricity playing the dominant roles: AMD does not appear to influence the behavior of those systems. Finally, survival probabilities are calculated for any given initial separation and given time for systems where all five planets start out with eccentricity 0.05 and randomized periapses. Here we considered batches with periapses randomly chosen within 45, 90, 135, 180, and 360 degrees, respectively. A broader choice of periapse angles is inversely correlated with the appearance of clear peaks and troughs in survival times. For periapse angles chosen within the full circle, we plot probabilities of survival at some fixed given times, as a function of initial separation. We show that their trends exhibit significantly different behaviors depending on initial system eccentricity.