Computing assignement

In this assignment we will study the evolution of planetary systems in stellar binaries using REBOUND focusing on the stability of the system and secular evolution of the system.

First, install rebound and use the Jupyter notebook with Python to set up the systems and do some coding/plotting. Use the IAS integrator package.

Part 1: testing planetary stability

Consider the triple system composed of $1M_\odot$ host star orbited by a planet with mass $m_{\rm pl} = 1M_\oplus$ at $a_{\rm pl} = 1$ AU and stellar binary companion with mass $M_b = 0.5M_\odot$ and semi-major axis a_b. We will start with an almost circular orbit for the planet $e_{\rm pl} = 0.01$ and $e_b = 0.3$ and zero inclinations.

a) Evolve the systems for 10^3 yr for a_b in the range of $3-7$ AU and plot the evolution of the eccentricity of the planet. Try different values of a_b and plot the evolution of $a_{\rm pl}$ and $e_{\rm pl}$

Are the any of these systems (un)stable? Are any of these systems chaotic? (Hint: you can start from a shadow trajectory with $e_{\rm pl} = 0.01001$ and see if the solutions diverge exponentially).

b) Based on this inspection, give an estimate a critical separation of the binary (a_b) at which the systems stability remains stable.

Part 2: Kozai-Lidov oscillations

Consider the same triple system in part 1, but fix $a_{\rm b} = 6$ AU and $e_b = 0.01$ and give an initial eccentricity to the planetary orbit of $e_{\rm pl} = 0.01$.

a) Give some inclination to the planet $i_{\rm pl}$ in the range of $40° - 80°$ and evolve for 5×10^3 yr. Plot the eccentricity and inclination of the planet. Fix the arguments of pericenters and the longitudes of the ascending nodes to 0.

b) Compute the periodicity of the oscillations using FFT (e.g., the Fast Fourier Transform package in numpy). Plot the oscillation period obtained as a function of $\cos(i_{\rm pl})$ and find a fit to the relation.

Part 3: precession in multi-planet systems

The Kozai-Lidov oscillations can be quenched if the planetary orbits precess ($\dot{\varpi} \neq 0$) fast compared to the oscillation timescales. We will try to estimate the precession rate that our Earth-mass planet experiences when we add an extra planet to system (no stellar binary companion). Now place a Jupiter-mass planet at $a_J \lesssim 0.5$ AU and estimate the precession rate fitting the variation of $\dot{\varpi}$ vs t. Try a different values of a_J to see how it scales with a_J. Can you roughly estimate what values of a_J would quench the Kozai-Lidov oscillations computed in part 2?