Ge/Ay 137 HW 4

1. Get up to speed with N-body simulations. The simplest way to do this is to grab mercury from github (requires gfortran) or REBOUND (python).

2. Ceres and Pluto

Using your newly acquired powers of numerical integration, perform a long-term (10 Myr) integration of asteroid Ceres and Kuiper belt object Pluto.

Plot their evolution (a, e, i as functions of time).
Compute the Tisserand parameter for both bodies. How well is it conserved?

3. Jupiter & Saturn

In the same integration as (2), examine the dynamics of Jupiter and Saturn. In particular, take a look at how orbital eccentricities vary in time and compare this with time-series of the difference in the *longitudes* of perihelion of the two planets. Do you see a correlation? Repeat this exercise for inclinations and the difference in the longitudes of ascending node. Finally, examine the behavior of the semi-major axes - do they change appreciably throughout the integration?

What were your expectations of the dynamics of Jupiter and Saturn based upon secular theory that we discussed in class? Now, compute the analytic Lagrange-Laplace solution of Jupiter and Saturn’s long-term evolution as shown in Chapter 7 of MD99 and over-plot the answers. Is the agreement good? bad? satisfactory?

4. NEAs

Explore the long-term behavior of near-Earth asteroids that are in mercury’s small.in file by default. Particularly, how does asteroid Toutatis behave?

5. Kozai RIP

Find the orbital parameters of asteroid Kozai and integrate it forward in time. Check out the evolution of eccentricity and inclination. Examine the conservation of the integral of motion (what is it?) numerically. Plot asteroid Kozai's phase-space trajectory in the variables (e cos (w) vs e sin (w) where w is the *argument* of perihelion). By hand, draw a picture of the separatrix on the same plot.

6. The Galilean satellites

Let us finally examine the classic example of mean motion resonances in the solar system. First, change the mass of the central object to the mass of Jupiter (in the <u>param.in</u> file), clear <u>small.in</u> and input the orbital parameters of Io, Europa, Callisto and Ganymede into <u>big.in</u>. Perform a forward integration (remember to change the timestep accordingly - it should be ~1/20th of Io's orbital period). Examine the evolution of the resonant angles (e.g., 2 \lambda' - \lambda - \varpi, etc). As we discussed in class, a slowly acting, dissipative force is required for the assembly of the satellites into their current multi-resonant configuration. What effect was responsible here?