PHYS 480/581

Homework #6

Fall 2024
Due Monday, December 2 in class

1) ***(Mandatory for PHYS 581 students; optional for PHYS 480 students, who may choose to do this question for bonus points.)***
In this problem, you will investigate planet migration and resonant trapping using REBOUNDx. REBOUNDx is a library for additional effects for REBOUND N-body simulations (https://github.com/dtamayo/reboundx). REBOUNDx offers additional physical effects which can be easily added to an existing REBOUND simulation. These effects include radiation forces, relativistic corrections, gravitational corrections for oblate objects (e.g. J2, J4 harmonics), and various options to model migration. You will use REBOUNDx' module exponential migration to simulate a migrating, Neptune-sized planet which can capture an existing inner planet in a resonance.
Setup a simulation with the Sun, Neptune at 24 AU and an inner Earth-mass planet at 10 AU. Migrate Neptune from 24 to 10 AU with an e-folding time of 10^5 years. Try a few other values of the e-folding time (migration speed): 10^6 years and 10^4 years. Depending on the migration speed, Neptune will be able to capture the inner planet in a resonance.

For each migration rate, integrate the system for at least one million years. Plot the evolution of the semi-major axes and eccentricities of the planets for different migration rates of Neptune. Additionally, track the ratio of the orbital periods of the two planets. What do you find?

2) Calculate the growth time for Neptune assuming *in situ* ordered growth (i.e. not runaway accretion; use $F_g = 10$) in a minimum-mass nebula. Is this model realistic? Why or why not?

3) Assume that a rocky, Earth-like planet accreted solid bodies from the surrounding planetesimal disk and grew to 1 Earth mass, at 1AU from the sun. Typical collision velocity was 1.2X the escape speed from the planet's surface, and remained constant at every stage of growth. The planet kept a constant density $\rho = 4000$ kg/m^3 during its growth. The gravitational focusing factor was also constant, and the rate of supply of material was proportional to the planet's radius squared. Its formation took 30 Myr. At what rate was the collision energy supplied to the planet? What was the equilibrium temperature of the surface of the planet, assuming it emitted like a blackbody (i.e. energy gain always balancing energy loss). Was the heating by solar radiation (assume a steady luminosity of 1 L№) more or less effective in heating the planet during its formation time? Consider how the answers to those questions evolve as the planet's mass and radius grew from an asteroid to an Earth.

4) Problem 13.14 (a and b) from the **second** edition of *Planetary Sciences* (de Pater & Lissauer).