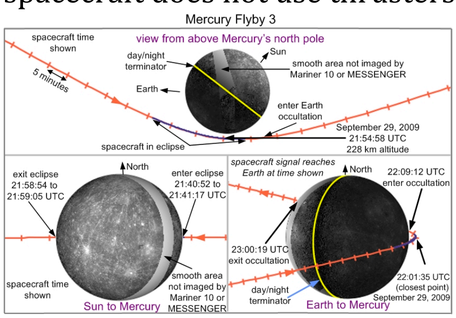
Earth and Planetary Surface Processes
Winter 2017
Problem set 1

Due in class Wed 18 Jan, 3pm. Office hours 9am-10am, Hinds 467 Friday 13 January.

Collaboration policy. You may discuss homework questions with each other, but you should not be in the same room as another student when you are writing up the answers. Questions in this problem set are “open book” and may draw on concepts in the required reading.

Question 1. Single flybys. (Assume Newtonian gravity and assume that the spacecraft does not use thrusters during the flyby).



Example geometry of a planetary flyby.

Suppose I use a spacecraft to make a single flyby of a nonrotating world using a hypothetical navigation system with arbitrarily good precision. Explain why no matter how good the navigation system, the trajectory of the flyby is insufficient information to map the planet’s nonhydrostatic gravity.

Suppose I make an equatorial (constant latitude = 0) flyby of a world with a featureless surface. I do not have a Doppler radar so my tools for determining rotation rate are gravity and shape. (i) Explain why I cannot use gravity to constrain the rotation rate. (ii) Will shape measurements give me an upper limit or a lower limit on the rotation rate? Why? (iii) I nevertheless need gravity in order to use shape information to put a limit on the rotation rate? What information do I need and why?

Question 2. The kinetic energy of rotation of a body with a principal moment of inertia I about some axis is given by $E = 0.51\omega^2$, where ω is the angular rotation rate (radians/s). The angular momentum L of a rotating body is given by $L = I\omega$. For fixed angular momentum, show that the kinetic energy of a rotating body is a minimum if it rotates about the axis with the maximum moment of inertia C of the three principal moments $C \geq B \geq A$. (Melosh question 2.3)

Question 3. Lucy’s targets. The target list for the “Lucy” spacecraft (named after the hominin fossil) was announced on Wed 4 Jan 2017. The largest target is the binary minor planet Patroclus-Menoetius. The members of the binary are 141 km (Patroclus) and 112 km (Menoetius) in diameter. For uniform density and water-ice composition what is the central pressure inside Patroclus? Menoetius? Do we expect these worlds to be roughly spherical, and if so why? Suppose Lucy finds that these worlds are roughly spherical, what would that tell us about their history?

Emails about clarification are allowed and substantive answers will be re-circulated to the class mailing list.

Question 4. In class we mentioned that the lithospheric thickness is time-dependent, but we did not quantify this. Here we shall. Assume that the temperature in the upper mantle of the earth is 273K at the surface and rises linearly to 1473K at 100 km depth (roughly the source depth of basaltic rocks that erupt at this temperature). Still deeper the temperature, controlled by convection, is approximately constant. Use the following wet olivine creep law

strain rate (s^{-1}) = $10^{4.0}\,\sigma^{3.4}$(σ in MPa) exp (-444 kJ mol^{-1} / RT)

with R = 8.314 J/K, to estimate the Maxwell time as a function of depth for a typical stress $\sigma \approx 30$ MPa (produced by loads ca. 1 km thick). Upper mantle shear modulus $\mu = 65$ GPa. How thick is the "lithosphere" for loads applied for: 1 Myr, 10 Myr, 100 Myr, and 1 Gyr? How sensitive is this thickness to the assumed stress? Beware of unit conversions! (Melosh question 4.3)