Selection of Homework Questions

Topic 12: Interactions & Mergers

(1) Dynamical Friction

a. Derive an expression for the gravitational drag force F_{drag} felt by a large mass M moving at velocity V through a static uniform distribution of smaller masses m with space density n per unit volume. Describe in words how the drag force arises.

b. State how your expression for F_{drag} is modified if the smaller masses have an isotropic velocity distribution with f(v) masses per unit volume in the range v to v+dv (you don't need to derive this modification). By what factor does F_{drag} change if f(v) is Maxwellian with dispersion $\sigma = V/\sqrt{2}$. Why is the drag force reduced if the smaller masses are moving?

c. Consider a galaxy cluster dominated by dark matter which is distributed as a singular isothermal sphere with dispersion σ = 800 km/s. Using the example in the notes for guidance (Topic 12.3aiii) find how long it takes for a galaxy of mass $M_{gal} \sim 10^{11}\ M_\odot$ to spiral into the center if it starts from a circular orbit 0.5 Mpc from the cluster center.

d. Repeat this calculation for a black hole of mass $M_{BH} \sim 10^{9}\ M_\odot$ entering an isothermal bulge of dispersion 200 km/s on a circular orbit of radius 3 kpc.

e. Using these two example as starters, briefly review the various contexts in which dynamical friction is important in modern astrophysics.

(2) Tidal Radius

a. Two masses, μ & M ($\mu \ll$ M), separated by D are in circular orbit about each other. Derive an expression for the Jacobi/Roche distance, r_J, around μ.

b. Consider two isolated circular orbits: μ about M, and a test particle at r_J about μ. Find relationships between:
(i) the two mean densities, $\langle\rho_M\rangle$ and $\langle\rho_\mu\rangle$ where the mean densities refer to the mass interior to the two orbits.
(ii) the two orbital periods, P_M (μ about M), and P_μ (test particle about μ).

c. What is r_J for:
(i) the Moon in orbit around the Earth? (Answer in units of the Moon's radius, and give an equivalent angle on the sky as seen by the earth)
(ii) the Earth in orbit about the Sun? (Answer in units of the Moon's mean orbital radius).
(iii) When Star Trek stages a story on a planet for which the month is longer than the year, why is

it an example of "Bad Science"?

d. One solar mass main sequence and giant stars have radii of ~1 $R_\odot$ (duh) and ~1AU. What are the threshold black hole masses which shred these two classes of stars **before** they cross the event horizon, assuming they are in roughly circular orbits.

(3) Galaxy Mergers

a. Two identical disk galaxies with identical (anti-aligned) spin pass by each other. Their flyby is such that for galaxy A the flyby is prograde (orbital and spin angular momenta aligned), while for galaxy B the flyby is retrograde (orbital and spin angular momenta opposite). Describe how the two galaxy disks respond to the flyby, explaining any differences in the response of the two galaxies.

b. How does the presence of a dark halo affect the interaction of two galaxies whose trajectories are initially mildly hyperbolic, with impact parameter larger than the stellar size but smaller than the halo size.

c. A massive elliptical galaxy has recently "ingested" a smaller gas-free companion galaxy. How might you tell whether the "eaten" galaxy was a disk galaxy (spiral or S0) or an elliptical galaxy?

d. Compare the behavior of stars and gas in the merger of two roughly equal mass disk galaxies. How is it possible for the gas to lose so much angular momentum that much of it can "fall" to the center?

e. More common than major mergers are minor mergers, where a small "satellite" galaxy enters the environment of a large galaxy. Describe the various physical processes that affect (i) the satellite, and (ii) the larger galaxy.

(4) Tidal Shocks

a. Consider a kinematically cold disk galaxy falling into a cluster. It quickly flies past a number of cluster galaxies, and experiences a "tidal shock". What does this phrase mean?

b. How do these tidal shocks affect the properties of the disk?

c. Review the various circumstances in which tidal shocks play an important role in the structure and evolution of galaxies.

(5) Merger origin for Ellipticals

It is now thought that at least some elliptical galaxies were formed by the merger of two massive galaxies. However, this idea took time to be accepted despite a concerted effort by a few astronomers (notably Francois Schweizer at DTM) to argue for its reality. Summarize the history of this debate, carefully detailing (a) the reasons why the idea was resisted; (b) the counter arguments to these reasons; (c) the various lines of observational evidence which supported the idea.
