Problem 1. (30 points)

Pre-midterm material.

(a) (5 points) What is meant by thermal equilibrium and why is it relevant in determining the structure of the ISM?

(b) (5 points) Explain what is meant by the “epicycle approximation” in disk galaxies. Draw a figure of the typical effective gravitational potential in such a galaxy to help you answer this question.

(c) (5 points) Explain why young stars in the inner disks \((R < R_{\text{CR}})\) of spiral galaxies are located on the outside edge of spiral arms while the dust lane is found on the inside edge.

(d) (5 points) Based on the Ostriker-Peebles stability criterion, what are the best conditions for the formation of a stellar bar?

(e) (5 points) What is the Tully-Fisher relation and what does it imply physically?

(f) (5 points) Dr. X (to remain nameless) derived an Oort constant \(A = +25 \text{ km s}^{-1} \text{kpc}^{-1}\). Explain why this is physically impossible if the rotation velocity is indeed \(\sim 200 \text{ km s}^{-1}\) in the solar neighborhood.

Problem 2. (25 points)

Elliptical galaxies

(a) (5 points) What is the fundamental plane of elliptical galaxies?

(b) (5 points) What is meant by the “relaxation timescale” of a stellar system? How does it vary with stellar density? Compare the relaxation timescale of a typical elliptical galaxy with the age of the Universe (order-of-magnitude estimate is sufficient here). What does your answer imply?

(c) (10 points) Describe how you would determine the three-dimensional mass distribution of an elliptical galaxy: describe the observational quantities you would need and the mathematical tools you would use. Make sure to mention the assumptions you are making in your derivation.

(d) (5 points) In the standard picture of galaxy formation, elliptical galaxies form early through rapid collapse and accretion. Describe recent observational and
theoretical results which suggest that some elliptical galaxies formed much later.

**Problem 3. (20 points)**

Supermassive black holes and nuclear activity in galaxies.

(a) (5 points) Describe the latest observational evidence for a supermassive black hole at the center of our Galaxy and sketch the theoretical principles and assumptions that was used to derive the mass of the putative black hole.

(b) (5 points) Why are the masses of dormant black holes in giant ellipticals more model-dependent than in dwarf ellipticals? How can this possible bias modify the current demography of black holes in nearby, non-active galaxies?

(c) (5 points) Why do we need supermassive black holes to explain the properties of active galactic nuclei? Give at least two reasons. Use the concept of the Eddington luminosity in part of your answer.

(d) (5 points) What is the unified model for Seyfert galaxies? Describe two observational results that seem to support this model.

**Problem 4. (25 points)**

Galaxy evolution and the environment

(a) (5 points) What is the “G-dwarf problem”? Give two possible solutions to this problem and explain clearly why they solve the problem.

(b) (5 points) Explain the physics of dynamical friction. How would you expect it to depend on the mass (M) and velocity (V) of the perturber, and on the mass (m) and density (\(\rho\)) of the background objects (assume \(m << M\))? Give two examples of systems where dynamical friction may be important.

(c) (5 points) Apart from dynamical friction and full-blown galaxy collisions or mergers, describe two other phenomena that can transform galaxies in a cluster environment. When are they important?

(d) (5 points) Explain why the time scale for a galaxy merger is considerably shorter when the two initial galaxies are in a prograde orbit rather than in a retrograde orbit.

(e) (5 points) The observed relation between the mass of the black hole and the stellar velocity dispersion of the spheroidal component hosting this black hole is often said to imply a causal connection between black hole growth and spheroid formation. Briefly describe a possible theoretical scenario for this connection and why feedback processes associated with the AGN also seem to be needed for this scenario to work.