During the **2025 Qualifying Exam**, following your research presentation and discussion, the first question that you will be asked will be drawn from the list below. You may be asked more than one question from this list.

RADIATIVE PROCESSES

- A. An interstellar absorption line of a certain permitted resonance line in the blue part of the spectrum is observed to have a FWHM line width of 10km s^{-1}. The flux at line center is 0.08 of the flux in the surrounding continuum. Estimate the column density (in atoms cm^{-2}) of ground state atoms along the line of sight. Be sure to state any assumptions you make, and explain on what part of the curve of growth is the line.

- B. Explain the relationships between specific intensity, flux and energy density for a general photon field. For the specific case of a black body radiation field at temperature T, give explicit functional forms for the three quantities.

- C. A galaxy at redshift $z = 9$ contains, among other things, stars, magnetic field, and cosmic ray electrons. At a position in that galaxy where the energy density in starlight is 10^2eV cm^{-3}, the magnetic field is 20μG. 1. What radiative process dominates the cooling of the cosmic ray electrons? 2. For what electron Lorentz factor will the cooling time (to lose of order half their energy) equal the 10^7y lifetime of the galaxy's starburst? 3. What electron Lorentz factor will be responsible for producing most of the radiation from this galaxy which is observed by the VLA at 1.4 GHz? What will be their cooling time?

INSTRUMENTATION (note that you are responsible only for the course you took, i.e. not optical if you participated only in the radio class, and not either if you are a declared theorist taking six electives instead of four)

- D. Derive a general expression for the signal-to-noise ratio of a point source seen by an optical / near-infrared telescope as a function of seeing, telescope diameter, sky brightness (expressed in mag/$arcsec^2$), detector noise and dynamic range, and total integration time.

- E. How many photons per second are received by Keck from a 20th magnitude object in the R band filter?

- F. Derive an expression for the point source sensitivity of a radio interferometer as a function of the frequency, bandwidth, system temperature, diameter of each dish, and number of dishes.

STARS

- G. A $3, M_\odot$ star overflows its Roche lobe as it leaves the main sequence and begins to stably transfer mass to a binary companion. Eventually, most of its envelope is stripped off, exposing material that was inside the convective core during the star's main-sequence evolution. How will the chemical abundances of this star (as measured with spectroscopy) differ from abundances measured for a normal main-sequence star of the same mass?

- H. Consider main-sequence stars with masses between 1 and 10 solar masses. Write down a scaling relation between their mass and luminosity. Now, derive the relation, starting with the radiative diffusion equation. What are the main assumptions you are making, physically? Red giants have a different mass-luminosity relation. Why? Which of the assumptions you listed break down for giants?

- I. Sketch the interior structure of a neutron star, labeling regions where you expect changes in composition. Describe how and why the composition changes as you move from the surface toward the interior. What is neutron drip? Explain why the lowest energy equilibrium state includes free neutrons at high densities, but not at low densities. What is the expected ratio of protons to neutron at arbitrarily high densities?

GALAXIES

- J. Draw a typical galaxy rotation curve (for a Milky Way-like galaxy). Explain how rotation velocity relates to enclosed mass. Draw the curve we would typically get if we predicted this from just the observable baryonic matter, and discuss the difference and what it means physically.

- K. What do we mean when we say stars or dark matter are "collisionless"? Quantitatively, how does their "collision" time compare to the Hubble time (write an expression or explain how you would estimate this)? Give an example of qualitatively different behavior between a "collisionless" and a "collisional" fluid, in galaxies.

- L. Define the Toomre Q parameter, and describe qualitatively how it is derived and what its value implies. Explain what each term means and how it contributes to stabilizing or de-stabilizing a galaxy. How does the situation differ for a gas versus stellar disk?

HIGH ENERGY

- M. Explain the significance and differences between the dynamical, thermal and viscous timescales in an accretion disk. Derive simple expressions for each of them in terms of the disk thickness and viscosity parameter α.

- N. What are magnetars and what provides their radiated energy? Describe at least 3 observed phenomena they have been invoked to explain.

- O. Derive the Alfven radius. Explain how this separates different classes of Cataclysmic Variables.

INTERSTELLAR MEDIUM

- P. Draw the cooling function (cooling rate vs. T) for gas of solar metallicity, and describe the dominant cooling mechanisms in each part of the curve. Explain the relevance of this function to multi-phase ISM models.

- Consider an HII region, at a known distance, with a pulsar located immediately behind it. How would we estimate the electron density in the HII region from observations of the pulsar dispersion measure, and the Halpha line intensity emitted by the HII region? How do the uncertainties in this estimate compare (qualitatively) with an estimate based on observations of various important line transitions?

- R. Explain why the CO molecule is used as the most convenient tracer of the molecular gas content of galaxies. What is the (qualitative) justification for the often-used assumption that a measurement of I(CO $1 \rightarrow 0$), for example, can be used to estimate the total mass of molecular material? Under what circumstances might the assumption(s) break down?

COSMOLOGY

- S. What is the difference between the growth of density perturbations in the matter-dominated era versus the radiation-dominated era? Write down or explain how you would estimate expressions for both.

- T. Write down the Friedmann equation, including matter, dark energy, radiation, and curvature terms. How does each of these scale with redshift? What does that mean for the relative times when each term would dominate?

- U. Explain what is meant by the "bias" of a cosmological population (e.g. galaxies). Give an equation relating the clustering of that population to the clustering of matter. Physically, explain how this arises. Explain how bias depends on the mass of dark matter halos.

RANDOM TOPIC

- V. What is the most interesting colloquium, tea talk, or theory seminar that you attended over the past year? Summarize the topic and the main take-aways from the presentation.