During the **2026 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. The non-relativistic Larmor's formula is given by

$$P = \frac{2q^2}{3c^3}\boldsymbol{a}\cdot\boldsymbol{a}$$

  where $\boldsymbol{a}$ is the ordinary (3-vector) acceleration of the particle with charge q. Show that the radiated power as measured by an observer moving with velocity v is $2q^2/(3c^3)\vec{a}'\cdot\vec{a}'$ (the relativistic Larmor formula).

- B. Explain why the following lines are classified as allowed, forbidden, semi-forbidden and forbidden transitions. Provide the rationale for each classification. For reference, a Grotrian diagram of NII is provided; further study material may be found in §6.7 of Draine's book on ISM. Separately, comment on transition (E).

  (A) N II 1084 Å $1s^2 2s^2 2p^2\ ^3P_0 - 1s^2 2s^2 2p3s\ ^3D^o_1$

  (B) N II] 2143 Å $1s^2 2s^2 2p^2\ ^3P_2 - 1s^2 2s 2p^3\ ^5S^o_2$

  (C) [N II] 6549 Å $1s^2 2s^2 2p^2\ ^3P_1 - 1s^2 2s^2 2p^2\ ^3D_2$

  (D) [N II] 205 μm $1s^2 2s^2 2p^2\ ^3P_0 - 1s^2 2s^2 2p^2\ ^3P_1$

  (E) $2s\ ^{1/2}S_{1/2} - 1s\ ^{1/2}S_{1/2}$

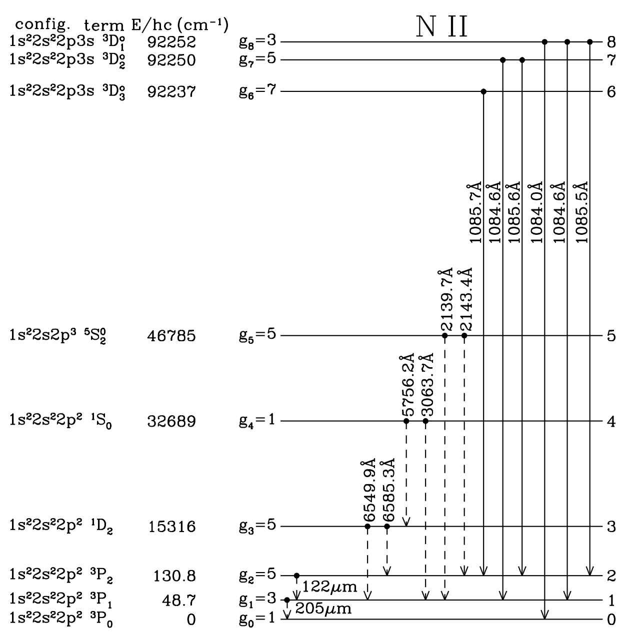

Figure 1: Grotrian diagram for N II (from Draine §6.7).

- C. RXJ 1856.5−3754 is one of the nearest neutron stars. The X-ray spectrum can be approximated by a black-body temperature, $kT_\infty = 32\,\mathrm{eV}$ and radius, $R_\infty = 16\,\mathrm{km}$. Assume that the photo-ionization cross-section can be approximated by $\sigma(\nu) = \sigma_0(h\nu/I_\mathrm{H})^{-3}$ where $\sigma_0 = 6.3\times10^{-18}\,\mathrm{cm}^2$ and I_H is the ionization potential of hydrogen. Compute the mean time for a hydrogen atom to be ionized at a distance of 1 pc.

  If this was assigned as a homework problem then you could use Python to integrate. However, it is an oral exam and we are not looking for precision. So, use clever approximation!

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 $3M_\odot$ 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 $M_\odot$. 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. Consider a fully convective M-dwarf of mass 0.3 $M_\odot$, radius 0.3 $R_\odot$, and luminosity 0.01 $L_\odot$. Compute a rough estimate (i.e., ignoring factors of order unity) of
  1. The central density and temperature of the star
  2. The sound speed near the center of the star
  3. The typical convective velocity in the deep interior of the star

How does the convective velocity compare to the sound speed in the deep interior of the star? Explain why the sound speed becomes much smaller, and the convective velocity becomes much larger, near the surface of the star.

GALAXIES

- J. What is the local space density of 'typical' L_* galaxies (in number Mpc^{-3})? (b) Give L_* in your favorite astronomically useful system of units. (c) what baryon mass and (d) what virialized dark matter halo mass would be typical of an L_* galaxy?
- K. Explain, using physical arguments, why star clusters undergo core collapse, and why the timescale for core collapse is a multiple of the 2-body relaxation time in the initial core. Discuss briefly what is the influence of binary stars on the dynamical evolution of the cluster before and after core collapse.
- L. Explain the 'final parsec problem' for merging supermassive black holes.

HIGH ENERGY

- M. Derive the maximum mass of a white dwarf. Must a white dwarf exceed this maximum mass to explode as a Type Ia supernova?
- 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.