For the 2020 Qualifying Exam, the first question that you will be asked following your research presentation and discussion, will be drawn from the list below. You may be asked more than one question from this list.

*RADIATIVE PROCESSES*

- A. Briefly explain Bremsstrahlung radiation. Draw a diagram including an acceleration vector attached to the electron. Describe the small angle scattering approximation. How does thermal free-free opacity scale with plasma electron density and temperature as well as frequency?
- B. Explain the connection between detailed balance, the Einstein A and B relations, Kirchoff's law and the Milne relations, and give an example of their use to connect the bremsstrahlung emission spectrum and the free-free absorption coefficient.
- C. Derive an expression for the electron cyclotron frequency of a non-relativistic electron of charge $e$ and mass $m$, spiraling in an external magnetic field of strength $B$.

*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. Describe quantitatively the point spread function of a diffraction-limited optical telescope. Explain how diffraction spikes arise, and what determines their positions and intensities. Under what circumstances will the PSF be broadened by atmospheric turbulence?
- E. 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.
- 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. Give relevant ranges along the main sequence for stellar parameters such as mass, radius, luminosity, surface temperature, central pressure, central temperature, etc. Explain why the central temperature does not vary with mass as much as the other parameters.
- H. What is the Gamow peak, why is it relevant, what are its dependencies, and how does it factor into the post-main sequence evolution of stars?

- I. Stars along the Hayashi track (low-mass post-main sequence or pre-main sequence stars) can be approximated as fully convective polytropes and their surface opacities are dominated by H- opacity. Using a polytropic equation of state, the ideal gas law, the blackbody radiation law, the photospheric relation $P = 2g/(3\kappa)$, and the H- opacity scaling $\kappa \propto \rho^{1/2}T^9$, show that the surface temperature scales extremely weakly with luminosity for a star ascending or descending a Hayashi track. Hint: For a $\gamma = 5/3$ polytrope, the pressure and temperature are related by $P = KT^{\gamma/(\gamma-1)}$, the polytropic constant $K$ scales as $K \propto M^{-1/2}R^{-3/2}$.

*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. Draw a typical galaxy SED from FUV through FIR. Label broad portions of the spectrum in wavelength, and explain what they are coming from. What sources dominate the UV? What dominate the optical/NIR? What dominates the M/FIR?

- L. A satellite galaxy falls onto the Milky Way. Assume the galaxy is small compared to the Milky Way, what will happen to its orbit? Name some processes that will act to modify the secondary galaxy? What, approximately, is the "tidal radius" and what happens there? How is this different (qualitatively) if that galaxy has equal mass to the Milky Way?

*HIGH ENERGY*

- M. What condition triggers explosion of a white dwarf into a Type Ia supernova? Could this happen before the white dwarf reaches the Chandrashekhar mass limit? Sketch condition on a density temperature diagram.

- N. Explain the compactness problem for Gamma Ray Bursts. What are typical Lorentz factors for jets?

- O. Derive the Eddington luminosity. Explain its relevance to the peak frequency of the emitted radiation. Explain its consequences for accretion onto neutron stars and black holes.

*INTERSTELLAR MEDIUM*

- P. Discuss the main heating mechanisms and cooling transitions that determine the temperature of the principal phases of the interstellar medium: cold molecular, cool neutral, warm neutral, warm ionized, and hot ionized.

- Q. Explain quantitatively what determines the temperature of dust grains and their thermal emission spectrum. Give examples of astrophysical environments with different dust temperatures.

- R. What is the mean free path of a hydrogen atom in a typical place in the ISM? How does the mean collision time depend on density and temperature?

*EXTRAGALACTIC/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. Draw a cartoon of the size of the co-moving region containing some mass that will collapse into a dark matter halo. Label the maximum/turnaround size. Label the time of virialization. What is meant by the critical (linear) density at which a structure will collapse? What is meant by virialization? How does the virial radius relate to the turnaround radius?

*SURPRISE TOPIC*

- What is the most interesting colloquium or tea talk that you attended (in person or virtually) over the past year? Summarize the results.