DEPT. OF ASTRONOMY & ASTROPHYSICS - GENERAL QUALIFIER 2020 QUESTION BANK

1. Cosmology & Extragalactic Astronomy

(1) What is recombination? At what temperature did it occur? Explain why this does not match the ionization potential of hydrogen.
(2) The universe is said to be "flat", or, close to flat. What are the properties of a flat universe and what evidence do we have for it?
(3) Outline the development of the Cold Dark Matter spectrum of density fluctuations from the early universe to the current epoch.
(4) State and explain three key pieces of evidence for a Big Bang origin for the observable Universe.
(5) Describe Big Bang nucleosynthesis. Why are only very light elements (H, D, He, and traces of Li) produced?
(6) Explain how and why Type Ia Supernovae are used in the measurements of cosmological parameters.
(7) Describe as many steps of the distance ladder and the involved techniques as you can.
(8) Describe a method, other than Type Ia supernovae and CMB foregrounds, by which the cosmological parameters can be determined by astronomical observations, and describe the current status of constraints from this method.
(9) Why is the cosmic microwave background expected to be weakly polarized, and what is practically required to observe this signal?
(10) Our view of the cosmic microwave background is affected by what is along the line of sight. Give two examples of CMB secondary anisotropies that also provide information about the cosmic parameters.
(11) Describe cosmological inflation. List at least three important observations it is intended to explain.
(12) Define the two-point correlation function of a Gaussian random field. How is it related to the power spectrum of that field? Describe how the above two concepts are used in cosmology.
(13) How is the angular (C_ℓ) power spectrum of the CMB related to the matter power spectrum and how can we use the C_ℓs to learn about the initial conditions of the universe?
(14) Consider a cosmological model including a positive cosmological constant. Show that, in such a model, the expansion factor eventually expands at an exponential rate. Sketch the time dependence of the expansion factor in the currently favoured cosmological model.

(15) Define and describe the epoch of reionization. What are the observational constraints on it?
(16) The 21 cm line of hydrogen is expected to show up in absorption against the cosmic microwave background at some redshifts, and in emission at other redshifts. What physical processes lead to this behaviour?
(17) What are the similarities and differences between the cosmic neutrino background and the cosmic microwave background?
(18) Give three examples of possible dark matter candidates (current or historical). What is their status observationally?
(19) What are galaxy clusters? List and explain three methods for detecting them or determining their basic properties.
(20) What is star formation quenching in galaxies? What is the evidence for it, and why is it thought to happen?

2. Galaxies

(1) What is the total mass (in both dark matter and in stars) of the Milky Way galaxy? How does this compare to M31 and to the LMC? How is this mass determined?
(2) What evidence is there that most galaxies contain nuclear black holes? How do those black holes interact with their host galaxies?
(3) What are AGN? Describe different observational classes of them and how they may relate to each other.
(4) Draw a spectrum of a high-redshift quasar. What do quasar emission lines typically look like? Explain what we see in the spectrum at rest wavelengths bluer than 1216 Angstroms.
(5) Describe three different methods used in the determination of the mass of a galaxy cluster.
(6) Draw the spectral energy distribution (SED) of a galaxy formed by a single burst of star formation at the ages of 10 Myrs, 2 Gyrs, and 10 Gyr. Please highlight the change over time in the 4000 Angstrom break.
(7) What is galactic spiral structure and why is it thought to occur?
(8) What is a stellar Initial Mass Function (IMF)? Explain how it is determined and how it is used.
(9) Characterize the stellar populations in the following regions: i) the Galactic bulge ii) the Galactic disk, outside of star clusters iii) open star clusters iv) globular clusters v) the Galactic halo
(10) What is the G-dwarf problem in the solar neighbourhood?
(11) Describe the orbits of stars in a galactic disk and in galactic spheroid.
(12) What is dynamical relaxation? Explain why this operates in star clusters but not in an elliptical galaxy.
(13) What is dynamical friction? Explain how this operates in the merger of a small galaxy into a large one.

(14) Stars typically rotate around the Galaxy more slowly than a circular orbit, so an observer on a circular orbit sees a stellar "headwind". What is the physical origin of this effect?
(15) The stars in the solar neighbourhood, roughly the 300 pc around us, have a range of ages, metallicities and orbital properties. How are those properties related?
(16) Estimate how often a supernova explosion occurs within 3 pc of the Earth. What evidence do we have of past supernovae in the vicinity of the Solar System?
(17) Sketch the SED, from the radio to Gamma, of a spiral galaxy like the Milky Way. Describe the source and radiative mechanism of each feature
(18) What are the main mechanisms of cooling in molecular cloud cores and the cold ISM? Why are H and He not important?
(19) What are the main sources of heat in the interstellar medium?
(20) What thermal phases are postulated to exist in the interstellar medium? Describe the dominant mechanism of cooling for each phase.
(21) Given that only a tiny fraction of the mass of the interstellar medium consists of dust, why is dust important to the chemistry of the medium and to the formation of stars?
(22) Draw an interstellar extinction curve (ie, opacity), from the x-ray to the infrared. What are the physical processes responsible?
(23) Describe what happens as a cloud starts to collapse to form a star. What is the difference between the collapse and contraction stages, and what sets the beginning and end of each phase?
(24) How can one determine the temperature of an H II region?

3. Stars and planets

(1) Sketch out a Hertsprung-Russell diagram. Indicate where on the main sequence different spectral classes lie. Draw and describe the post main-sequence tracks of both low- and high- mass stars.
(2) Sketch a plot of radius versus mass "cold" objects made of normal matter, including the mass range of planets, brown dwarfs and white dwarfs. How does composition affect the curve? Why is there an upper mass limit?
(3) Describe the physical conditions that lead to the formation of absorption or emission lines in stars' spectra. Relate line formation to the equation of radiative transfer.
(4) What is a polytropic equation of state? Give examples of objects for which this is a very good approximation, and explain why it is.
(5) Describe these important sources of stellar opacity: electron scattering, free-free, bound-free, and the H- ion.
(6) Describe the processes that can cause pulsations in a star's luminosity, and provide at least one example of a class of stellar pulsation.
(7) What is a supernova? Describe the major observational types and what is thought to cause them.

(8) Describe the condition for a star's envelope to become convective. Why are low mass stars convective in their outer envelopes while high mass stars are convective in their inner cores?

(9) What is Eddington's luminosity limit? Explain why this limit is important for the properties of massive stars.

(10) Explain why we know what the Sun's central temperature ought to be, and how we know what it actually is.

(11) Which have higher central pressure, high-mass or low-mass main-sequence stars? Roughly, what is their mass-radius relation? Derive this.

(12) Sketch the SEDs of O, A, G, M, and T stars. Give defining spectral characteristics, such as the Balmer lines and Balmer jump and Calcium doublets, and describe them physically.

(13) Sketch the spectral energy distribution (SED) of a T Tauri star surrounded by a protoplanetary disk. How would the SED change: (a) if the disk develops a large inner hole, (b) if the dust grains grow by agglomeration from sub-micron to meter sizes?

(14) Describe the known classes of extrasolar planets.

(15) What are the primary origins of the infrared luminosities of Jupiter, Earth, and Io? (When this is different from the source of internal heat, explain the difference.)

(16) Explain the observational problem of radius inflation for hot Jupiters and describe the pros and cons of two proposed solutions.

(17) Explain the effects of an atmosphere on a planet's surface temperature and its position of the "habitable zone". How might this depend on the stellar type of its host star?

(18) Explain the process of nuclear fusion and give two examples of important fusion processes that affect stars at different phases of their lives. When is fusion stable and when is it not?

(19) What stellar properties determine the luminosity of a star in its pre-main-sequence, main sequence, and giant evolutionary phases?

(20) The so-called r- and s- processes are mechanisms that produce elements heavier than iron. Describe these mechanisms and evidence for them from abundance patterns. They are thought to be caused by which stellar phenomena?

4. Physics and Fundamentals

(1) A two-element interferometer consists of two telescopes whose light is combined and interfered. Explain how this might be accomplished in practice, and sketch the response of such an interferometer to a nearby red giant star, as a function of the (projected) separation between the two telescopes.

(2) You don't usually need to cool down the detectors for short wavelength (e.g., X-ray) observations, but it's critical to cool down the detectors in long wavelength (e.g., far-IR) observations. Why is this, and why is it usually less essential or unnecessary for radio observations?

(3) What's the field of view of a 2K x 2K CCD camera on a 5-m telescope with f/16 focal ratio? The pixel size of the CCD is 20 micron. How does the field of view change if we bring it to a 10-m telescope?
(4) Explain why diffraction-limited detectors tend to have sidelobes, and how sidelobes can be suppressed in optical and radio observations.
(5) Compare the S/N ratios between the following two cases where photon noise is dominant (assume an unresolved point source): [A] 1-minute exposure with a 10-m telescope; [B] 10- minute exposure with a 1-m telescope.
(6) You are trying to determine a star's flux from a CCD image using aperture photometry, measuring source(+sky) within some radius (in pixels), and sky within some annulus. How would you propagate errors to estimate the uncertainty of your measurement, given a flux calibration uncertainty?
(7) Describe three methods for detecting extrasolar planets and indicate the contribution of each to the population of known exoplanets.
(8) Sketch and give the equations for each of the following distributions: Gaussian (normal) distribution; Poisson distribution; log-normal distribution. Give examples from astrophysics where these distributions apply.
(9) Suppose you measure the brightness of a star ten times (in a regime where source-noise dominates. (1) How do you calculate the mean, median, and mode and standard deviation? (2) How can you tell if any points are outliers? Say some points are outliers, what do you do now (ie. how does this impact the calculation of the quantities in part 1)?
(10) Suppose you do an imaging search for binaries for a sample of 50 stars, and that you find companions in 20 cases. What binary fraction do you infer? Suppose a binary-star fraction of 50% had previously been found for another sample (which was much larger, so you can ignore its uncertainty). Determine the likelihood that your result is consistent with that fraction.
(11) How is synchrotron radiation generated? How can the synchrotron luminosity be used to infer a minimum energy for the emitting region?
(12) What are "forbidden lines" of atomic spectra? In what conditions are they observationally important? In what conditions do they control the temperature of interstellar material?
(13) Describe linear and circular polarizations of electromagnetic waves and give examples of their relevance to astronomical observations.
(14) How would you estimate the characteristic temperature and wavelength of emission by an accreting object? Identify your assumptions.
(15) What are the primary frequency bands at which searches for gravitational waves are conducted? What techniques are used to search in each band? What are the sources of gravitational waves in each band? What can we learn from detections (or non-detections)?
(16) Draw the geometry of gravitational microlensing of one star by another, and estimate the angular displacement of the background star's image. Why does magnification occur?

(17) What's the minimum mass of a black hole for which you could survive a fall through the event horizon without being ripped apart (assume 1 ton tensile strength)? How does this relate to the BH mass range for which we expect tidal disruption flares caused by shredding main-sequence stars?

(18) What was the solar neutrino problem, and how was it resolved?

(19) Why do neutrons inside a neutron star not decay into protons and electrons?