General Qualifying Exam Question Bank for 2018

I. Cosmology

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. Define and describe the "tired light hypothesis" and the "steady state universe" as alternatives to the Big Bang. How have they been disproved observationally?

6. Why are only very light elements (H, D, He, and traces of Li) synthesized in the first three minutes of the Big Bang?

7. Explain how and why Type Ia Supernovae are used in the measurements of cosmological parameters.

8. Describe two methods, other than Type Ia supernovae, by which the cosmological parameters can be determined by astronomical observations.

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 foregrounds 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 and describe a 'fine tuning problem'. How do anthropic arguments attempt to resolve it?

13. Define the two-point correlation function. How is it related to the power spectrum? How is the C_l spectrum of the CMB related to low redshift galaxy clustering?

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 is the difference between scalar and tensor modes of perturbation in the early universe, and how can you detect their presence?

18. What are the similarities and differences between the cosmic neutrino background and the cosmic microwave background?

19. What is the difference between an isocurvature mode and an adiabatic mode, in terms of the initial density perturbations in the early universe? How do we know that the initial conditions are mostly adiabatic?

20. Give three examples of possible dark matter candidates (current or historical). What is their status observationally?

II. Extragalactic

1. Sketch out the Hubble sequence. What physical trends are captured by the classification system?

2. 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?

3. Describe as many steps of the distance ladder and the involved techniques as you can. What are the rough distances to the Magellanic Clouds, Andromeda, and the Virgo Cluster?

4. What evidence is there that most galaxies contain nuclear black holes? How do those black holes interact with their host galaxies?

5. Define and describe globular clusters. Where are they located? What are their typical ages, and how is this determined?

6. Describe three different methods used in the determination of the mass of a galaxy cluster.

7. What is the density-morphology relation for galaxies? How is that related to what we know about the relationship between galaxy density and star formation rates in galaxies?

8. 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.

9. How are galaxy redshifts estimated by photometric techniques?

10. 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.

11. Sketch the SED from the radio to gamma of extragalactic radiation on large angular scales. Describe the source and emission mechanism for each feature.

12. What are AGNs? Describe different observational classes of them and how they may relate to each other.

13. What are galaxy clusters? What are their basic properties (eg, mass, size). List and explain three ways they can be detected.

14. What is star formation quenching? What is the evidence for it, and why is it thought to happen?

15. Provide three examples of ways in which feedback processes are important on galactic and intergalactic scales.

III. Galactic

1. What is a stellar Initial Mass Function (IMF)? Sketch it. Give a couple of examples of simple parametric forms used to describe the IMF, such as the Chabrier, Kroupa, or Salpeter functions.

2. Describe the orbits of stars in a galactic disk and in galactic spheroid.

3. Every now and then a supernova explosion occurs within 3 pc of the Earth. Estimate how long one typically has to wait for this to happen. Why are newborn stars likely to experience this even when they are much younger than the waiting time you have just estimated?

4. Galactic stars are described as a collision-less system. Why? (Don't forget the influence of gravity.)

5. 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?

6. The ISM mainly consists of hydrogen and helium, which are very poor coolants. How, then, do molecular cloud cores ever manage to lose enough heat to collapse and form stars? Why are H and He such poor coolants?

7. 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?

8. What are the main sources of heat in the interstellar medium?

9. Draw an interstellar extinction curve (ie, opacity), from the X-ray to the infrared. What are the physical processes responsible?

10. What is dynamical friction? Explain how this operates in the merger of a small galaxy into a large one.

11. 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.

12. How many stars does one expect to find within 100 pc of the Sun? If all stars are distributed evenly across the galaxy, how many of these will be B spectral type or earlier? How many are younger than 100 Myrs?

13. Describe what happens as a cloud starts to collapse and form a star. What is the difference between the collapse and contraction stages? What happens to the internal temperature in both? When does the contraction phase end, and why does the end point depend on the mass of the object?

14. Sketch the rotation curve for a typical spiral galaxy. Show that a flat rotation curve implies the existence of a dark matter halo with a density profile that drops off as 1/r^2.

15. What thermal phases are postulated to exist in the interstellar medium? Describe the dominant mechanism of cooling for each phase.

16. 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 vi) a typical elliptical galaxy.

17. How can one determine the temperature of a HII region?

18. What is the G-dwarf problem in the solar neighborhood?

19. Describe the general characteristics of spiral structure in galaxies.

IV. Stars and stellar astronomy

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 for various "cold" objects made of normal matter, including planets, brown dwarfs and white dwarfs. Explain the mass-size relationship for rocky and gaseous objects. Why is there an upper mass limit?

3. Describe the physical conditions that lead to the formation of absorption lines in stars' spectra. What leads to emission lines?

4. Describe these important sources of stellar opacity: electron scattering, free-free, bound-free, and the H- ion.

5. Describe the processes that can cause pulsations in a star's luminosity, and provide at least one example of a class of stellar pulsation.

6. Briefly describe the sources of thermal energy for stars and planets.

7. Describe the process by which supernovae produce light. Why are Type Ia supernovae generally brighter than Type II events?

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 and lifetimes 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 SED of an O, A, G, M, and T star. Give defining spectral characteristics, such as the Balmer lines and Balmer jump and Calcium doublets, and describe physically.

13. What can be learned about young stars (T Tauri and pre-main-sequence stars) from an analysis of their spectral features?

14. 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 in the disk grow in size by agglomeration (with the same total mass)?

15. What are the primary origins of the heat lost to space by infrared luminosity of Jupiter, Earth, and Io?

16. Explain the observational problem of radius inflation for hot Jupiters and describe two possible solutions.

17. Explain the effects of an atmosphere on a planet's surface temperature and the position of the "habitable zone". What special considerations must one make for habitability around M-type stars?

18. Explain the process of nuclear fusion and give two examples of important fusion processes that affect the lives of stars.

19. What is Fermi's Paradox? Explain its logic and assess the current state of the Paradox in light of modern knowledge.

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. Where is the process thought to act?

V. Physics

1. Draw the geometry of gravitational microlensing of one star by another, and estimate the angular displacement of the background star's image.

2. A two-element interferometer consists of two telescopes whose light is combined and interfered. Sketch the response of such an interferometer to a nearby red giant star, as a function of the (projected) separation between the two telescopes. The red giant subtends one-fiftieth of an arc second on the sky, and the telescope operates at a wavelength of 2 microns.

3. What's the minimum mass of a black hole you could survive a fall through the event horizon without being ripped to shreds? Why would you be ripped to shreds for smaller black holes? How does this relate to the BH mass range for which we expect tidal disruption flares caused by shredding main-sequence stars?

4. How is synchrotron radiation generated, and how was it used to demonstrate the energy required to power radio galaxies?

5. 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?

6. What is a polytropic equation of state? Give examples of objects for which this is a very good approximation, and explain why it is.

7. What was the solar neutrino problem, and how was it resolved?

8. Why is nuclear fusion stable inside a main-sequence star? Under what conditions is nuclear fusion unstable? Give examples of actual objects.

9. Why do neutrons inside a neutron star not decay into protons and electrons?

10. What is the typical temperature of matter accreting on a star, a white dwarf, a neutron star, a stellar mass black hole, and a supermassive black hole? In what wavelength range would one best find examples of such sources?

11. 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 not necessary for radio observations?

12. 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.

13. Describe linear and circular polarizations of electromagnetic waves and give examples of their relevance to astronomical observations.

14. 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. Now, let's bring this to a 10- m telescope with the same focal ratio.

Explain how the field of view changes on the 10-m telescope (compared to that of the 5-m telescope) based on the Etendue conservation rule.

15. Sketch and give the equations for each of the following distributions: 1. Gaussian (Normal distribution); 2. Poisson distribution; 3. Log-normal distribution. Give two examples from astrophysics where each of these distributions apply.

16. You are trying to determine a flux from a CCD image using aperture photometry, measuring source(+sky) within a 5-pixel radius, and sky within a 20-25 pixel annulus. Assume you find 10000 electrons inside the aperture and 8100 electrons in the sky region, and that the flux calibration is good to 1%. What is the fractional precision of your measurement? (Ignore read noise.) More generally, describe how you propagate uncertainties, what assumptions you implicitly make, and how you might estimate errors if these assumptions do not hold.

17. 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)?

18. 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 been found previously for another sample (which was much larger, so you can ignore its uncertainty). Determine the likelihood that your result is consistent with that fraction.

19. What are the primary wavelength 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)?

20. Self-similarity is a useful idealization of many astrophysical systems. Explain what self-similarity means, when it works, and why it is so useful, and provide two examples from any field.

21. Explain why diffraction-limited detectors tend to have sidelobes, and how sidelobes can be suppressed in optical and radio observations.