General Qualifying Exam Questions 2017

I. Cosmology

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1. What is recombination? At what temperature did it occur? How does this relate to 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. Sketch a graph of speed vs. distance for galaxies out to and beyond the Hubble distance.

7. Why are only light elements synthesized in the first three minutes of the Big Bang?

8. Explain how Type Ia Supernovae are used in the measurements of cosmological parameters.

9. Rank the relative ages of the following universes, given an identical current-day Hubble constant for all of them: an accelerating universe, an open universe, a flat universe.

10. What are the currently accepted relative fractions of the various components of the matter-energy density of the universe? (i.e., what are the values of the various Omega_i's)

11. Outline the history of the Universe. Include the following events: reionization, baryogenesis, formation of the Solar system, nucleosynthesis, star formation, galaxy formation, and recombination.

12. Explain how measurements of the angular power spectrum of the cosmic microwave background are used in the determination of cosmological parameters.

13. Explain how measurements of baryon-acoustic oscillations can be used in the determination of cosmological parameters.

14. Explain how weak lensing measurements can be used in the determination of cosmological parameters.

15. Describe cosmological inflation. List at least three important observations it is intended to explain.

16. Define and describe the 'fine tuning problem'. How do anthropic arguments attempt to resolve it?

17. 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?

18. 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.

19. Define and describe the epoch of reionization. What are the observational constraints on it?

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. How do we know that the intergalactic medium is ionized?

4. 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?

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

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

7. What is the X-ray background and how is it produced?

8. Describe the currently accepted model for the formation of the various types of galaxies. What are the lines of evidence to support this model?

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

10. 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?

11. 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.

12. What are Lyman-Break Galaxies and how do we find them?

13. 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 1216A.

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

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

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

17. Describe and give results from simulations of large scale structure in the universe. What role do they have in understanding the formation of large scale structure and Galaxy formation? What are their limitations?

III. Galactic
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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.

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?

5. Given that only a tiny fraction of the mass of the ISM consists of dust, why is dust important to the process of star formation?

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. What is the difference between a globular cluster and a dwarf spheroidal galaxy?

8. 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?

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

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

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

12. 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.

13. 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 of these are younger than 100 Myrs?

14. 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?

15. 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.

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

17. 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 v) a typical elliptical galaxy.

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

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

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, including planets, brown dwarfs and white dwarfs. Explain the mass-size relationship for rocky and gaseous objects.

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

4. Describe the processes that can cause pulsations in a star‚Äôs luminosity, and provide at least one example of a class of stellar pulsation.

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

6. Define and describe Type Ia, Type Ib, Type Ic, and Type II supernovae.

7. Describe the condition for a star‚Äôs envelope to become convective. Why are low mass stars convective in their outer envelopes while high mass stars are convective in their inner cores?

8. What is Eddington‚Äôs luminosity limit?

9. Explain why we know what the Sun‚Äôs central temperature ought to be, and how we know what it actually is.

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

11. Derive the scaling of luminosity with mass for a (mostly) radiative star. Do you need to know the source of energy for the star to derive this scaling?

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 infrared luminosity of Jupiter, Earth, and Io?

16. Write out the p-p cycle. Summarize the CNO cycle.

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

18. Explain the effects of an atmosphere on a planet,Äôs surface temperature and the position of the ,Äúhabitable zone,Äù.   What special considerations must one make for habitability around M-type stars?

19. How do stellar mass black holes form? What properties of the progenitor star are most important for the remnant black hole mass?

20. What is Fermi,Äôs Paradox? Assess the current state of the Paradox in light of modern knowledge regarding exoplanets.

V. Physics

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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. Define and describe the 'diffraction limit' of a telescope. List at least three scientifically important telescopes that operate at the diffraction limit, and at least three which do not. For the ones which do not, explain why they do not. In both categories include at least one telescope not operating in optical/near-IR wavelengths.

4. 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?

5. Before the LHC came online there were claims it would produce microscopic black holes in their high energy proton-anti-proton collisions that might destroy the Earth? Was this a legitimate concern? Why or why not?

6. How is synchrotron radiation generated?

7. What are "forbidden lines" of atomic spectra? In what conditions are they observationally important?

8. What is a polytropic equation of state? Give examples of objects for which this is a very good approximation.

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

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

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

12. Give examples of degenerate matter.

13. 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?

14. The equivalence principle for gravity corresponds to being able to find a coordinate system for a region of spacetime. What kind of coordinate system is this?

15. What are the typical detectors used in gamma-ray, X-ray, UV, visible, infrared, sub-mm, and radio observations?

16. 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?

17. 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.

18. Describe linear and circular polarizations.

19. 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 is 20 micron. If you bring this to a 10-m telescope with the same focal ratio, what will be the field of view? You may wish to answer using the Etendue conservation rule.

20. 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.

21. 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.

22. 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)?

23. 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.