COSMOLOGY (EARLY UNIVERSE, CMB, LARGE-SCALE STRUCTURE)

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 the Big Bang theory of the origin of the 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 recession speed vs. distance for galaxies out to and beyond the Hubble distance.

7. What happened in the first 3 minutes after the Big Bang? Why is only He (and tiny traces of Li) synthesized in the Big Bang?

8. Explain how Supernovae (SNe of Type Ia in particular) 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 bayron-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 which 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?

EXTRAGALACTIC ASTRONOMY (GALAXIES AND GALAXY EVOLUTION, PHENOMENOLOGY)

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 typical ages of globular clusters. 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, 2Gyrs, 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?
18. What is the Sunyaez-Zeldovich effect and where is it detected? What are some challenges in using SZ measurements to determine the values of the cosmological parameters?

GALACTIC ASTRONOMY (INCLUDES STAR FORMATION/ISM)

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's 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 clusters v) a typical elliptical galaxy.
18. How can you determine the temperature of HII regions?

STARS AND PLANETS (INCLUDES COMPACT OBJECTS)

1. Sketch out an H-R 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 which lead to the formation of absorption lines in stars' spectra. What leads to emission lines?

4. Why do some stars pulsate while some others do not? Consider Cepheids as an example.

5. Define the terms "thermal equilibrium" and "hydrostatic equilibrium". How do they apply to stars? If a solar-type star is out of dynamical equilibrium, how long does it take to restore it? What is the time scale to restore thermal equilibrium?

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

7. Small asteroids are usually odd shaped, while larger celestial bodies are round. The dividing line occurs at around 200 km. Explain what this is determined by. Using the same logic, can you estimate the tallest mountain that can stand on Earth and Mars, respectively?

8. Why are low mass stars convective in their outer envelopes while high mass stars are convective in their inner cores?

9. Describe and compare the ages of the surfaces of Mercury, Venus, Earth and Mars.

10. What is the Eddington Luminosity? Give examples where it is important.

11. State the central temperature of the Sun.

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

13. 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?

14. What source of pressure prevents gravitational collapse in a normal star, a white dwarf, and a neutron star? Why, physically, is there a maximum mass for the latter two? And why can we calculate this easily for a white dwarf, but not for a neutron star?

15. Sketch the SED of an O, A, G, M, and T star. Give defining spectral characteristics, and describe physically.

16. What physical and orbital parameters of an extra-solar planet can be determined
    (a) from radial velocity (Doppler) measurements alone,
    (b) from transit observations alone, and
    (c) from the combination of both Doppler and transit observations?

17. What spectroscopic signatures help distinguish a young (pre-main sequence) star from a main sequence star of the same spectral type?

18. 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?

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

20. Consider a small test-mass orbiting around a compact object. What are the essential differences in the properties of its orbits between Newtonian gravity and General Relativity?

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

MATH AND GENERAL PHYSICS (INCLUDES RADIATION PROCESSES, RELATIVITY, STATISTICS)

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 which 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. Let's say the LHC produces microscopic black holes in their high energy proton-anti-proton collisions? What will happen to them? Will they destroy the Earth?

6. How is synchrotron radiation generated? In outline, how can it be removed from Cosmic Microwave Background maps?

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 weak 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, and why?

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 the difference between 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? Give your 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; you will be given 10 values for the total number of counts): (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.