AST 308 – STUDY GUIDE FOR FINAL EXAM

The final exam will be on Tuesday, Dec 13 at 12:45PM, in room BPS 1420. It will be two hours in length. The final is over the whole course, but at least half of it will be on the material after Midterm 2. See the answer sheets for Midterms 1 and 2 for my idea of complete responses.

Some big-picture themes that you should be able to expound upon in an essay format. I will ask you to write roughly a page each about two or three of the following topics. The questions are likely to be broken down into sub-sections to guide you a bit. But not as finely broken down as in Midterm 2.

- Hubble galaxy types, including a description of each type of galaxy.
- The structure of the Milky Way, composition and approximate ages of components, relative masses.
- Chemical evolution… what does this mean? What elements were created in the big bang and what ones in stars? How does chemical enrichment work?
- The cosmic distance ladder. What is it? Give a general outline of the steps involved in extending our distance measurements out to very distant galaxies.
- The overall evolution of the universe. What steps did it go through (in their correct order, with some idea of when each one happened).
- Cosmology. The cosmological principle. Possible universes in terms of $R(t)$ vs t and in terms of curvature. What does it mean for the universe to be curved?
- What measurements have led to the current "concordance" (or ΛCDM) cosmological model, and what are the values of the key parameters in that model?
- What is the CMB, and in what ways (several) is it of key importance?

Study Guide for the part after Midterm 2 (overlaps some with big-picture topics above, but looking for more detailed answers):

- In what ways and by what means did structure (i.e. the degree and general character of density fluctuations) evolve from the Big Bang through our present highly structured universe?
- Overlapping the previous question… How and when did the first stars and galaxies form?
- What is the general structure of the Local Group?
- What is the relationship between the Local Group and the Local Supercluster? What are their approximate total masses and total sizes? What large galaxy cluster is the central component of the Local Supercluster?
- What is the Hubble Flow? What is the large scale pattern of peculiar velocities of galaxies and galaxy clusters in the local universe? What is the Great Attractor? How do we know it is there?
- How was the cell-like or bubble-like large scale structure of the local universe discovered? What was measured, using what (very general) technique? You don't need to tell me exactly what telescopes were used, but convince me that if you were given time on a suitable telescope you would have a general idea of what measurements you needed to make.
- What are the various ways that we detect the existence of dark matter, on different size scales? This is a long list. I discussed some methods of measuring dark matter in much greater detail than others. You should know correspondingly more about those methods. They include:
  - Galaxy rotation curves (from earlier in the course).
  - Use of virial theorem in individual galaxies or clusters.
  - Gravitational lensing.
- Why are giant galaxy clusters taken to be the best objects in which to measure the baryonic/dark mass ratio? What fraction of the mass in these clusters is in: stars, intergalactic gas, dark matter? How is the amount of mass in each of these components best measured? Incidentally, what does "baryonic" mean?

- Gravitational lensing again:
  - What is the condition for seeing an Einstein ring?
  - What is the condition for seeing weak vs. strong lensing?
  - Sketch the general paths of light rays through a gravitational lens, and also the wavefront at different positions as it passes the lens.
  - Besides producing multiple images, what other important effects does gravitational lensing have on images of background light sources?
  - What is meant by the terms "caustic" and "conjugate caustic", and by "critical curve"? Draw a sketch of a wavefront and the paths of light rays as they relate to caustic surfaces.
  - Why, and a word description of "how", can the total mass of a complicated galaxy cluster be measured by means of gravitational lensing?
  - What is the difference between a Manatee and a Bird Wrasse?[1]
- What are the three general classes of candidates for Dark Matter?
- What does MACHO refer to, and how were they ruled out?
- What are the arguments against hot dark matter being the major matter component of the Universe? Give 1-2 sentence descriptions of each argument… not just a buzz word. What is meant by "hot" in this context?
- In very general terms, what sorts of particles are candidates for Cold Dark Matter? What is meant by "cold"?
- What, in physical terms, is meant by the "Jeans mass"? What happens to a blob of mass that has greater than the Jeans mass? What happens if it has less than the Jeans mass, and you give it a nudge?
- Sketch how the Jeans mass depends on temperature in the early universe, both before and after decoupling (see CO. fig 30.7, *and also* the similar figures in the lecture notes). How does the Jeans mass before decoupling compare to the mass within the particle horizon before decoupling? What does this tell us about the behavior of photons and baryons up until the time of decoupling?
- What does the above have to do with the temperature variations seen in the CMB by COBE and WMAP? What do the temperature variations map out?
- What is the "power spectrum" of the CMB fluctuations, as measured by BOOMERANG and WMAP? What is meant by "power" in this context? Be able to sketch the power spectrum (see CO figs 30.13, 30.17 and also the similar figures in the lecture notes).What causes the peaks seen in the power spectrum? Think in terms of taking a snapshot of oscillating blobs of many different mass (= size) scales. Why do we see lots of power in the brightness (= density) fluctuations on some specific size scales, but not on others? This is a fundamental thing to have clear in your mind.
- How do we know what linear size corresponds to the angular size of the first peak in the above power spectrum?
- Knowing the above linear and angular sizes, why does that let us figure out the geometry of the universe? What geometry (curvature) do we find?
- How does that result combine with other results (Type 1a supernovae, galaxy cluster growth rates) to pin down a unique cosmological model? Think of the Ω_{matter}–Ω_{Λ} diagram (e.g. CO figs 29.21, 29.28, 30.22), and *why* these different tests restrict the cosmology to different lines across this diagram. Is the position of our universe on this diagram the whole answer, or is some additional information needed in order to be able to correctly plot $R(t)$ vs t?
- What observational results, combined with what theoretical results, show that Dark Matter density perturbations are needed in order to explain the highly structured universe that we see by redshift $z \sim 6$? Look at CO example 30.2.1 involving the QSO at $z = 6.43$, and think through the implications about $\delta\rho/\rho$ at different times. How does Dark Matter solve the problem raised in that example? How do CDM perturbations grow during the period before decoupling, as compared to how photon+baryonic perturbations behave?

[1] Copious extra points if you answer that it's easy to confuse the two.

- What do we mean by "bottom-up" and "top-down" structure formation? Which type of dark matter produces which? Which type of structure formation is expected to actually be happening?
- What observational evidence favors bottom-up structure formation? What evidence do we have for galaxy mergers, at all distances and lookback times including here in the Local Group?
- What is the evidence for top-down vs. bottom-up formation of the Milky Way? What are the ELS (often called "ELBS") collapse model and the Hierarchical Merger (often called Zinn & Searle) model?
- What is meant by the "dark ages"? What ended that period? What evidence do we have for when the first stars formed?
- Describe the basic observed properties of quasars (and, synonymously, Active Galactic Nuclei): luminosity, physical size of the "central engine", relationship to galaxies, co-moving space density as a function of time.
- Sketch the general model of a quasar, and provide a brief description of each component part. The parts are: black hole, accretion disk, broad emission-line region, torus, narrow-emission line region, surrounding (host) galaxy. What viewing angle leads to seeing what type of AGN?
- What is the basic energy source of a quasar? How does this energy get processed into the luminous continuum radiation that we measure?
- Describe, concisely but also precisely, the meaning of and differences between: luminosity distance, angular-size distance, and the current proper distance to a far-off object.
- If an astronaut fell into a non-rotating black hole, what would be the differences between what the astronaut would see while approaching the event horizon and what would be seen by a person watching from far away? What features of the Schwarzschild metric and of the basic way that General Relativity works would you make use of to derive the mathematical expressions for what each person would see?
- What extra things happen if the Black Hole is rotating? Not just the names of the phenomena, but also a description of them. (But there is no need to memorize or to be able to work with the Kerr metric)

Problem(s) to be able to work on the final.

The final is likely to include 1 or 2 problems to work out, at the same level of difficulty as the ones on the midterms. I will give ample partial credit if you get as far as having the correct equations written down ready to solve, with all of the correct integration limits in place and substitutions of variables made, so that it is clear that you know how to solve the problem and would get the correct answer if you just had a bit more time to do the algebra and/or integrations.

Some equations you *SHOULD* know and be able to work with:

- The virial theorem.
- Simple cases of rotation curves (and be able to derive them).
- The relationship between flux and luminosity.
- Definition of $R(t)$, and how $R(t)$ depends on t for radiation-dominated and mater-dominated universes.
- The relationship between R(t) and redshift.
- The definitions of Ω_{total}, Ω_{matter}, etc. in terms of ρ/ρ_{crit}, and how ρ_{matter}, ρ_{rad} and ρ_{Λ} depend on $R(t)$.
- Radiation energy density for a black body = $u = aT^4$
- $\lambda_{\max} = c/\nu_{\max} \propto T^{-1}$
- $T \times R(t)$ = constant

You should also know what the following three equations mean and how to solve straightforward problems using them, but you do *NOT* need to memorize the equations. I will provide you with the equations if I ask questions about them:

- Friedman Equation
- Robertson-Walker metric
- Schwarzschild metric