ASTRONOMY 1102 – 1

Instructor: Juhan Frank

Study Guide for Final Exam – Friday May 7, 1999
In this classroom 3:00pm – 5:00pm

PLEASE NOTE: NO MAKE UPs WILL BE ALLOWED. STUDENT IDs WILL BE CHECKED WHEN THE EXAM IS COLLECTED. This test will be COMPREHENSIVE and based on material we have covered in class, supported by the material in chapters 4 and 21–36 of *Astronomy: From the Earth to the Universe*. The test will consist as usual of two parts: multiple choice questions and problems. The mix will be a bit different: 160 points in multiple choice questions (32) on 4 pages, and 4 problems worth 10 pts each on 2 pages. I expect the mix to reflect approximately a balance of 50%/50% of new and old material covered in previous tests. I give below an example of what the test will look like and a couple of examples of questions and problems.

Review class notes: do not memorize first, understand first, and then commit to memory only a few basic definitions and laws. Review homework.

For the material covered since the third test, chapters 31–36, I provide a detailed guide below. For material covered by earlier tests, refer to the corresponding test guides and review homework and the tests themselves. All these materials will be available on the web at the following URL

http://www.phys.lsu.edu/faculty/frank/courses.html

Chapter 31: The Structure of the Milky Way Galaxy

A modern definition of a galaxy. The Milky Way is our Galaxy. Why do we see our Galaxy as the Milky Way. Effect of our perspective. Galactic coordinates Galactic plane or Galactic Equator, Galactic Center. Recall transparencies showing our galaxy in optical and IR wavelengths (see figures in the text). Are "Spiral Nebulae" in our Galaxy or are they Island Universes? The great Debate of 1920 between Heber Curtis and Harlow Shapley. Curtis claimed that the Galaxy was small and that spiral nebulae were external. Shapley maintained that the Galaxy was large and that spiral nebulae were in it. Now we know that the Galaxy is large as Shapley claimed, but spiral nebulae are nevertheless extragalactic as Curtis stated. The controversy is resolved when Hubble demonstrates in 1929 that the Cepheids in the Andromeda Nebula place the nebula well outside the Galaxy. Harlow Shapley's work, RR Lyrae and the system of galactic globular clusters. The center of the Galaxy moves to a point 8.5 kpc away in Sagittarius. The size and shape of the Galaxy. Main components identified: galactic center, bulge, disk, halo, outer halo or corona, globular clusters.

Spiral arms of external galaxies (Andromeda Nebula, M51, etc) are delineated by "spiral arm tracers" such as bright blue (O, B) stars and HII regions, galactic/open clusters. Optical studies of our own galaxy reveal that O and B stars are near the galactic plane, and their spectroscopic parallaxes place them in three bands suggesting spiral structure. This is confirmed by HI (21 cm) and CO studies in radio wavebands.

The Galaxy rotates with *differential rotation*: interior rotates faster around the GC than the sun, while the disk outside the solar orbit rotates slower. The sun moves at a speed of 220 km/s around the GC. The central regions of the bulge rotate like a "solid body". The disk appears to rotate with more or less constant speed (velocity) (so it takes longer to go around a larger circle).

Spiral Structure. Why not material spiral arms? The "winding problem". The Spiral Density Wave theory. The spiral arms we see are just a snapshot of where the compression wave is "now" with an "error" of a few million years [the lifetime of O and B stars] compared with galactic year of 250 Myr. The chain reaction model or self–propagating supernovae model: the SN shock triggers star formation, etc.

Dark Matter: The visible mass extends out to 15 kpc or so while the galactic rotation curve goes well beyond that. There must be a lot of invisible objects which contribute to gravitational attraction but emit no light. Are they brown/black dwarfs? or Jupiter-size objects? or black holes (mini or supermassive)? or are they neutrinos, or other weakly interacting massive particles (WIMPs)?

The galactic center: Sagittarius A*. Latest evidence: stellar motions (both radial velocities and proper motions) near the center indicate more than 2 million invisible solar masses lurk there. Why is it likely to be a BH? How big would the event horizon be? Compare to solar radius and the AU.

Chapter 32: The Interstellar Medium (ISM)

The types of nebula we have covered: reflection, emission, dark, planetary, etc. Neutral atomic hydrogen: HI regions. Ionized atomic hydrogen and partially ionized atoms of other elements in HII regions.

Dust grains: size 0.1 μm (microns) or less, scatter blue light more than red causing more extinction in the blue than in the red. In the 8.5 kpc to the galactic center the extinction is at least 25 magnitudes which is equivalent to a drop by a factor of 10^{10} in brightness: only one of every 10 billion photons emitted by stars near the galactic center survive the trip to us. What are grains made of? Why is the sky blue?

We've seen that radio and IR are the wavelengths to use to study the galactic center. In addition we can study the ISM by observing continuum radio emission by synchrotron radiation (relativistic electrons spiraling around a magnetic field). Neutral atomic Hydrogen (HI) emits a spin flip line at $\lambda = 21$ cm when the electron spin (like a spinning top) flips from being parallel to the proton spin to being anti-parallel (see Fig. 32-11). It can also absorb at 21 cm by flipping from anti-parallel back to parallel. Using the 21 cm line astronomers have mapped the HI in our galaxy. Can HII also emit 21 cm?

The rotation curve of our galaxy (see Fig 32-17). The mass of our Galaxy inside the solar orbit (see HW8). The outer regions are mapped using a CO line well beyond the solar orbit and the circular velocity still increases.

Chapter 33: Galaxies

Hubble's tuning fork scheme. Spiral and Elliptical galaxies, Barred spirals. Catchall: Irregulars. Bulge/Disk ratio, spiral arm opening (tightness) and development. Bars and dust lanes. Arms and dust lanes. The "tuning fork" is just a pictorial of the classification scheme: No evolution on/along the Hubble diagram. Properties of the basic types (compare Sa with Sb, etc; E2 with E5, etc). The distribution of galaxies in space. The local group. Main members and satellites. Extending the distance scale. Other standard candles: SN I and PN. Clusters of Galaxies. Compare Group with Cluster. The Virgo Cluster contains $\sim$ 2500 galaxies within $\sim$ 3 Mpc. Clusters of clusters: superclusters. The Local Supercluster. Galaxy Masses: rotation curves, binary galaxies and galaxy clusters. Dark Matter in the Universe.

Chapter 34: The Expanding Universe

Spectra of galaxies painstakingly gathered overnight by Vesto Slipher indicated already before the Great Debate of 1920 that spiral galaxies had large redshifts. After Edwin Hubble had conclusively demonstrated that M31 was a distant galaxy, he and Milton Humason discovered the famous Hubble's Law $v = H_0 d$. This implies that the Universe is expanding as illustrated by the "Rising Raisin Cake" analogy. Early determinations of the rate of expansion as measured by the Hubble Constant yielded estimates 10 times higher than current values (HW9). Given the redshift $z = v/c$, the distances to galaxies can be estimated from Hubble's Law (See HW and Example 34.1).

Cepheids are *primary* distance indicators which can be used to calibrate other methods such as SNIa, planetary nebulae, surface brightness fluctuations, brightest galaxy in cluster, magnitudes of supergiant stars, or HII regions. Recent values of H_0 are converging to around $65 - 70$ km/s/Mpc (see fig. 34- 10). Measuring H_0 involves measuring redshifts (straightforward in principle) and distances which are difficult to determine and contain systematic errors. But the velocity measured may not be a good measure of the "Hubble Flow". Need to get far enough so that all "local" disturbances caused by for example the Virgo Cluster and the Great Attractor are negligible when compared to the overall Expansion of the Universe. Steps needed: determine distance to Virgo Cluster by primary methods (e.g. Cepheids). Determine distance *ratio* between Coma Cluster and Virgo Cluster by secondary or relative methods. Measure redshift of Coma. Calculate H_0.

Large Scale Structure: slices of the Universe, the Local Supercluster, The Great Wall, voids, filaments and sheets. A bubbly universe at scales of $\sim$ 100 Mpc. So, whence and wherefore "uniform and isotropic"?

Current record for a distant galaxy is $z = 6.68$. You cannot use the classical Doppler formula $z = v/c$ to get v from the redshift (Why not?).

Numerical simulations of the Standard Big Bang model with cold and hot dark matter can reproduce the kind of structure that we observe in the Universe by gravitational clustering. Ultimately gravity may explain the formation of galaxies, clusters and superclusters. The main point of this is: given enough data on the structure of the visible Universe and enough computing power we may one day simulate the history of the Universe and verify/falsify our theories.

Chapter 35: Quasars

A *very* interesting chapter about the most powerful and distant(?) accretion–driven engines in the Universe. (Active Galactic Nuclei: Seyfert Galaxies, radio galaxies, and quasars: we may not have time to cover this properly)

Chapter 36: Cosmology

Olbers' Paradox: Why is the sky dark? Because a) radiation from large distances is redshifted, and b) the *visible* Universe is finite for any model in which the universe has a finite age. Need to "see" out to 10^{24} LY to "see" a star on average, which is >> than the distance traveled by light since the Big Bang. The Cosmological Principle: the Universe is homogeneous and isotropic. Then various Big Bang theories can be proposed in which the past Universe had a very high (even infinite) density and temperature. Newtonian cosmological model: an explosion of "dust" with each grain a galaxy. Geometry of open, flat, and closed universes. The 2D analogies: saddle, sheet, and balloon for 3D, generally curved, open, flat and closed universes. The microwave background: 2.73 K, the dipole anisotropy of ± 3 mK (milli–Kelvin) and the smaller 30 μK (micro-Kelvin) fluctuations.

SAMPLES:

Part I – Multiple Choice questions (5 pts/question; total = 160 pts)
Identify the correct answers by placing a check between the brackets [ ]. Check **ALL** correct answers in the questions identified by a *.

1) A galaxy of type E3
   [ ] is truly more elliptical than an E5 galaxy.
   [ ] appears more elliptical than an E5 galaxy.
   [ ] is truly less elliptical than an E5 galaxy.
   [ ] appears less elliptical than an E5 galaxy.
   [ ] is a barred spiral galaxy.

2) M31 (Andromeda Nebula) and the Milky Way are members of
   [ ] the Local Group but not the Local Supercluster.
   [ ] the Virgo Cluster.
   [ ] the Coma Cluster.
   [ ] the Great Attractor.
   [ ] the Local Group and the Local Supercluster.

3*) In the expansion of the Universe
   [ ] the galaxies do not expand, they are gravitationally bound objects.
   [ ] everything expands at the same rate given by the Hubble constant.
   [ ] some parts expand faster than others.
   [ ] the universe can only be uniform and isotropic on the largest scales..
   [ ] the Local Group expands.

Part II – Problems (10 pts/problem; total = 40 pts)
Problem 1: Large ground telescopes having a limiting magnitude of about 25 can detect Cepheids out to the Virgo Cluster (16 Mpc). The Hubble Space Telescope can go 5 magnitudes deeper. Estimate the distance out to which the HST should be able to find Cepheids.

Problem 2: The average redshift of galaxies in the Coma Cluster has been determined to be $z = 0.022 = 2.2 \times 10^{-2}$. An average distance modulus determined from SNIa and surface brightness fluctuations is approximately $m - M = 35$. Estimate the Hubble constant.