Name:____KEY___________

University of California, Santa Barbara
Department of Physics

Astronomy 2 | MIDTERM EXAM | Prof. Antonucci
Tuesday, May 6 | Spring 2008

I give my permission for my graded exam to be left in a public place: YES___ NO___

FACTS OF POSSIBLE INTEREST

Hubble Law: $v = H_0 d$

$G = 6.67 \times 10^{-11}$ newton $m^2 kg^{-2}$ in MKS units

Newton's law of gravitation: $F = \frac{GMm}{r^2}$

1 light year $\approx 1 \times 10^{16} m$

Small angle formula: actual size = distance $\times \frac{\text{angular size in arc sec}}{206{,}265}$

Doppler Shift: $\frac{v}{c} = \frac{\Delta\lambda}{\lambda}$

1 pc $= 3 \times 10^{16} m$

Inverse square law: $F = \frac{L}{4\pi d^2}$

Calculations can be approximate; verbal answers should be quite brief (2 or 3 sentences) and to the point.

Important note: Of the 120 total points on this test, you only have to do 100! Mark clearly the twenty point's worth of problems that you do not wish us to grade! Work in units of 5 or more points.

I. TRUE OR FALSE – (15 POINTS)

a) We can estimate the temperature of elliptical galaxy halos by the frequency at which their X-ray emission peaks. **T**

b) We could calculate the mass of the Earth simply by knowing the radius, the air pressure and the gravitational constant. **F**

c) Globular clusters are distributed on the Celestial Sphere in an isotropic (same in every direction on the Celestial Sphere) manner. **F**

d) We know none of the Dark Matter is baryonic (protons and neutrons); otherwise we would predict the wrong abundances for primordial nucleosynthesis of the light elements. **F**

e) We can watch the stars very close to the Milky Way center orbiting our Supermassive Black Hole! **T**

f) Our Milky Way lives in a small gravitationally bound group of a couple dozen galaxies. **T**

g) We can't use the rotation-curve method to measure the masses of Elliptical galaxies because they have little overall rotation. **T**

h) Processes inside stars and in Supernovae explain the abundance of all of the elements of the periodic table. **F**

i) Iron is the heaviest element produced abundantly in stars because it has the greatest mass per nuclear particle. **F**

j) Gravitational microlensing observations show that most of the Milky Way dark matter is in the form of objects like Jupiter in mass, but unassociated with stars. **F**

k) Any weakly interacting massive particles that contribute to the Milky Way dark halo would probably be traveling at nearly the speed of light. **F**

l) The stars very close to the supermassive black hole at the exact center of the Milky Way obey all of Kepler's Laws. **T**

m) We can get the approximate age of galaxies by counting the number of turns of the spiral arms. **F**

n) Radio loud active galactic nuclei are found almost exclusively in elliptical galaxies. **T**

II. 10 POINTS TOTAL, 5 POINTS EACH

a) Derive the Formula $M = \frac{rv^2}{G}$ for the mass interior to the path of any object in a circular orbit. (The force required to keep a mass in a circular orbit is $\frac{mv^2}{r}$).

The force required to keep a mass in orbit, to keep it from flying out into space (ask if you want to see the derivation of that), is provided by the gravitational force: F= $\frac{GMm}{r^2}$ **. Equating these two and solving for** M **gives:**

$$F = \frac{mv^2}{r} = G\frac{mM}{r^2} \quad \Rightarrow \quad M = \frac{mv^2}{r} \times \frac{r^2}{Gm} \quad \Rightarrow \quad M = \frac{rv^2}{G}.$$

b) If the Sun's orbital velocity is 200 $\frac{km}{\sec}$ and its distance from the Galactic Center is 25,000 light years, what is the approximate mass of the Milky Way interior to the Suns's orbit?

Here we use the above equation, noting that the velocity is given in $\frac{km}{\sec}$ **.**

$$v = 200\ \frac{km}{\sec} = 2 \times 10^5\ \frac{m}{\sec}, \quad v^2 = (2 \times 10^5\ \frac{m}{\sec})^2 = 4 \times 10^{10}\ \frac{m^2}{\sec^2}$$

$$r = 25{,}000 ly = 2.5 \times 10^{20} m$$

$G = 6.67 \times 10^{-11}$ Newton $m^2 kg^{-2}$, **in MKS units**

$$\Rightarrow M = \frac{2.5 \times 10^{20} m \times 4 \times 10^{10}\ \frac{m^2}{\sec^2}}{6.67 \times 10^{-11} kgm \sec^{-2} \times m^2 kg^{-2}} = 1.5 \times 10^{41} kg$$

III. 10 POINTS TOTAL, 5 POINTS EACH

Historically, it was difficult to find the optical objects corresponding to radio sources because the angular resolution of single radio telescopes was so poor.

a) Why was the angular resolution so poor?

Radio waves have very long wavelengths. Looking at the equation for angular resolution $\theta = \frac{\lambda}{D}$ **we can see that a long wavelength makes** θ**, the smallest angle that we can resolve, big.**

b) How do we get around the problem today?

With λ **big, the only way to make** θ **small is to make** D**, the diameter of the telescope, big. Interferometry with radio waves makes it possible to link the signal from many telescopes together making the effective size of the telescope the size of a whole array of telescopes. An array of telescopes can be very large, giving us very good angular resolution.**

IV. 15 POINTS, 5 POINTS EACH

Freedman et al. (1994) found $H_0 = 80 \frac{km}{\sec}$ per megaparsec from Hubble Space Telescope observations of the Cepheids in the Virgo Cluster galaxy M10. (This group later refined the value to 70 km/sec per megaparsec, but use the original value of 80 for this problem.)

a) What is the distance to Cygnus A, a powerful radio galaxy with a redshift of $\frac{\Delta\lambda}{\lambda} = 0.06$?

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} = 0.06 \quad \Rightarrow \quad v = 0.06c = 0.06 \times 3 \times 10^5 \frac{km}{\sec}$$

$$v = H_0 d \quad \Rightarrow \quad d = \frac{v}{H_0} = \frac{0.18 \times 10^5 \frac{km}{\sec}}{80 \frac{\frac{km}{\sec}}{Mpc}} = 225Mpc$$

225 Mpc

b) What is the physical size of the radio source? The angular size is about two arcminutes, or ~120 arcseconds.

$$\text{D}= \frac{\theta}{206{,}265} d = \frac{120''}{206{,}265} \times 225Mpc = 0.13Mpc$$

c) What is the Power output in the radio region of the spectrum? The radio flux (or "brightness") received is $\sim 1 \times 10^{-14} \frac{Joules}{m^2 \sec}$.

$$d = 225 \times 10^6\ pc = 225 \times 3 \times 10^{22}\ m = 6.75 \times 10^{24}\ m$$

$$F = \frac{L}{4\pi d^2} \quad \Rightarrow \quad L = F 4\pi d^2 = 1 \times 10^{-14} \frac{Joules}{m^2 \sec} 4\pi (6.75 \times 10^{24}\ m)^2 = 5.7 \times 10^{36} \frac{Joules}{\sec}$$

V. 15 POINTS TOTAL

For 3 points each, list five spectacular consequences of Hubble's Law that we discussed in class.

1) The Universe is expanding
2) We can get recessions speeds, thus approximate distances to very distant objects
3) We can look back in time by looking at distant objects
4) The Universe has a finite age
5) There is a distance past which we can't see called the "cosmic horizon"

VI. 15 POINTS TOTAL

For 3 points each, name up to five fundamental pieces of observational evidence for the Big Bang (the idea that the universe is expanding and has finite age).

1) The Universe is expanding (Hubble's Law)
2) We can see the CMB, almost to the cosmic horizon
3) The young universe looks different from the present universe
4) The elements not produced in stars are present in abundances exactly predicted by primordial nucleosynthesis.

VII. 10 POINTS TOTAL

What factors go into the duration of a microlensing event? Explain quantitatively. I'm thinking of 3 things.

1) Mass of Macho
2) Distance to Macho
3) Speed of Macho

VIII. 20 POINTS TOTAL, 5 POINTS EACH

Which is TRUE?

1. a) Big G, the gravitational force constant, can be found from observations of celestial bodies. **F**

   b) Kepler's Third Law $P^2 = a^3$, can only be used in that simple for planets and moons in the solar system. **F**

   c) An astronomer viewing a cold cloud with a blackbody behind it sees an absorption spectrum. However, if the photons which are absorbed by atoms in the gas cloud aren't destroyed but are just scattered into all directions, an astronomer looking at the cloud from the side sees an emission line spectrum. **T**

   d) In the above situation, the astronomer seeing the absorption line spectrum gets just as many of the emission-line photons as the astronomer who sees the emission line spectrum. **T**

   e) According to the Special Theory of Relativity, light is made of particles rather than waves. **F**

2. a) Seyfert galaxies differ from most other galaxies in that they show strong emission lines in the spectra of their nuclei. **T**

   b) Active galactic nuclei in Spiral Galaxies generally are associated with 100-kpc-scale radio lobes. **F**

   c) Even radio telescope arrays (interferometers) have much poorer angular resolution than optical telescopes. **F**

   d) The size of an object is given by the small angle formula, Size = (angular extent in arcsec) x (distance). **F**

   e) It has been shown that Seyfert nuclei of Type 2 (Narrow Lines only) in fact do have the variable continuum and the Broad Emission lines characteristic of Type 1 nuclei, but they are hidden from our point of view by a dust toroidal (doughnut) shaped cloud of dusty gas. **T**

3. a) A dense ionized gas produces permitted and forbidden lines of comparable strength. **F**

   b) Radio galaxies show "Type 2" optical spectra in general; they only have narrow emission lines, both permitted and forbidden. **T**

c) The proper motions measured inside quasars with radio very long baseline interferometry correspond to speeds much greater than c, using the small angle formula. **T**

d) The approximate density of matter, both visible and dark, is equal to about 0.3 times the critical density. Do not include dark energy. **T**

e) The visible ordinary matter in the universe is just equal to the value required for conditions in the first 3 minutes of the Big Bang to produce the elements and isotopes which are not created in stars. **F**

Which is <u>FALSE</u>?

a) At the present time there are no radio telescopes in space. Therefore we are limited in our ability to see extremely fine detail in radio images because of the finite size of Earth. **T**

b) If we assume that a supernova is approximately spherical, we can use its Doppler shift and proper motion of expansion to get the distance. **F**

c) Using radian measure, the small angle formula reads simply:
linear size = angular size x distance. **T**

d) The luminosity and distance of a star allows us to calculate the radius of the star. **F**

e) Iron has the lowest mass per nuclear particle. You can produce energy by fusing lighter nuclei, or splitting (“fissioning”) heavier nuclei. **T**

<u>IX</u>. 10 POINTS TOTAL, 5 POINTS EACH

a) If we discover intelligent life on another planet, their technology is extremely unlikely to be at a level similar to ours. Why is that?
Our civilization has advanced extremely quickly when viewed on astronomical timescales. Our technology has advanced even faster. If there is another civilization in an other solar system reasonably close to us in the universe, it is very likely that their Sun and solar system or even just evolutionary development are far ahead or behind our, easily in the thousands of years if not millions.

b) What two properties of the Binary Pulsar allow us to confirm Einstein's theory of gravity? These are two behaviors that do not occur in Newton's theory. Hint: one shows specifically that the binary must be emitting gravitational waves at exactly the predicted rate.
The two properties I was looking for are the precession of the orbit and the shrinking of the orbital radius.