NAME:________________________________

Astronomy 350 **Fall 2012**

HOUR EXAM 2

November 2, 2012

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1. DO NOT OPEN THIS EXAM UNTIL INSTRUCTED TO DO SO.
2. Write you name above.
3. Show all of your work, and indicate clearly your final answer! A correct final answer may not receive credit if no work is shown.
4. Budget your time! Don't get stalled on any one question.
5. Short answer questions can be answered in 1-2 sentences, unless indicated otherwise. If you are writing paragraphs, you may have misread or misunderstood the question.
6. For your reference there are constants listed below.
7. The total number of points on the exam is 100.

Possibly Useful Information

Note that a symbol may take different meanings in different equations.

$\Delta x = v \times \Delta t$	$\Delta v = a \times \Delta t$
$P_{\rm yr}^2 = a_{\rm AU}^3$	$GMP^2 = 4\pi^2 a^3$
$F = ma$	$F = Gm_1 m_2/R^2$
$a_{\rm circ} = v_{\rm circ}^2/r$	
$KE = \frac{1}{2}mv^2$	$PE = -Gm_1 m_2/R$
$v_{\rm esc} = \sqrt{2GM/R}$	$M = v_{\rm circ}^2 R/G$
$F = L/4\pi R^2$	$d = 1\ {\rm pc}/p_{\rm arcsec}$
$L \propto M^4$	$\tau = 10^{10}\ {\rm yr}\ (M/M_\odot)^{-3}$
$\Delta t_{\rm obs} = \Delta t_{\rm rest}/\sqrt{1 - v^2/c^2}$	$L_{\rm obs} = L_{\rm rest}\sqrt{1 - v^2/c^2}$
$E = mc^2/\sqrt{1 - v^2/c^2}$	$KE = E - mc^2$
$R_{\rm Sch} = 2GM/c^2$	$R_{\rm Sch,\odot} = 2GM_\odot/c^2 = 3$ km
$\Delta t_{\rm obs}/\Delta t_{\rm em} = \lambda_{\rm obs}/\lambda_{\rm em} = \sqrt{\frac{1-R_{\rm Sch}/r_{\rm obs}}{1-R_{\rm Sch}/r_{\rm oem}}}$	
$z = (\lambda_{\rm obs} - \lambda_{\rm em})/\lambda_{\rm em}$	$v = cz$
$v = H_0 r$	$H = (da/dt)/a = (\text{rate of change in } a)/a$
$a = 1/(1+z)$	$z = (1-a)/a$
$G = 6.7 \times 10^{11}\ {\rm m^3/kg\ s^2}$	$c = 3.0 \times 10^8$ m/s
$1\ {\rm AU} = 1.5 \times 10^{11}$ m	$1\ {\rm pc} = 3.1 \times 10^{16}\ {\rm m} = 3.3$ lyr
$1\ {\rm kpc} = 10^3\ {\rm pc} = {\rm c} \times (3300\ {\rm yr})$	
$M_\odot = 2.0 \times 10^{30}$ kg	$M_{\rm Earth} = 6.0 \times 10^{24}$ kg
$L_\odot = 3.8 \times 10^{26}$ Watts	$\tau_\odot = 10^{10}\ {\rm yr} = 10$ billion yrs
$H_0 = 72\ {\rm km\ s^{-1}\ Mpc^{-1}}$	
$t_{\rm H} = 1/H_0 = 14$ billion years	$d_{\rm H} = c/H_0 = 4200$ Mpc

Multiple Choice

Circle the single *best* answer for each question. Be sure clear indicate only **one** final answer.

1 . **[5 points]** Star Gaga is found to have heavy elements in an abundance $1/100,000 = 10^{-5}$ the heavy-element abundance in the Sun. Thus we expect the *helium* abundance in star Gaga to be ____________ the helium abundance of the Sun.

(a) larger than
(b) **smaller than**
(c) the same as

As discussed in class and on HW4, during their lives stars produce helium and heavier elements. These are partly returned to the rest of the universe when stars die. Thus, as generations of stars live and die, the amount of helium and heavy elements both go up. So if we see a star with low heavy element abundances, then the star must have been born from primitive material that also therefore had a lower helium abundance.

2 . **[5 points]** Astronauts Michelle and Ann are in two identical spaceships, moving with towards each other with relative speed $v = c/2$. Michelle measures her spaceship to have a length of 10 meters. Michelle will observe Ann's spaceship to have length ____________, while Ann will observe Michelle's spaceship to have length ____________.

(a) **less than 10 meters, less than 10 meters**
(b) less than 10 meters, greater than 10 meters
(c) greater than 10 meters, less than 10 meters
(d) greater than 10 meters, greater than 10 meters

Special relativity teaches us that moving objects appear shorter along the directin of motion–this is length contraction. Since Ann and Michelle each sees the other as moving and herself as still, both *report the other as contracted.*

3 . **[5 points]** Which of the following *must* be *forbidden* by the Cosmological Principle? Note: in answering, only consider the Cosmological Principle in assessing each case.

(a) a universe that is contracting
(b) a universe containing only spiral galaxies
(c) **a universe in which all matter is contained inside a sphere of radius 4000 Mpc**
(d) both (a) and (b)
(e) all of (a), (b), and (c)

The cosmological principle requires that the universe is homogeneous and isotropic. Answer (c) is clearly not homogenous–it has an edge. But the other two answers need not require a Universe that is not homogeneous and isotropic.

4 . **[5 points]** In a universe containing matter, a galaxy's *past* speed relative to us would have been ____________ the galaxy's present speed relative to us.

(a) **faster than**
(b) slower than
(c) the same as

In a universe with matter, the attraction of galaxies for each other causes the universe to decelerate. This means that speeds get smaller over time, and thus galaxies were faster in the past.

5 . **[5 points]** In our current understanding, which of the following is only *approximately* but not exactly true?

(a) **the cosmological principle**
(b) the principle of relativity
(c) the equivalence principle

The equivalence principle and principle of relativity are completely correct as far as we can tell. But the cosmoloigcal principle (isotropic and homogeneous universe) is only true on large length scales, and not for example, on Earth.

6 . **[5 points]** A certain atom emits light with wavelength $\lambda_{\rm em} = 100$ nm (where 1 nm $= 10^{-9}$ meters). In the spectrum of galaxy A, this line is observed at $\lambda_{\rm A} = 125$ nm. In the spectrum of galaxy B, the same line is observed at $\lambda_{\rm B} = 150$ nm. Both galaxies obey Hubble's law. From this we conclude that, of the two galaxies, galaxy B

(a) is farther from us
(b) is moving faster away from us
(c) is seen as it was longer ago in the past
(d) both (a) and (b)
(e) **all of (a), (b), and (c)**
(f) none of the above

Galaxy B has a longer observed wavelength than galaxy A, and thus a higher redshift z. But higher redshift means faster motion ($v = cz$), and then via Hubble's law, larger distance $d = v/H$. But due to the larger distance, light takes a longer time to reach us, and so it is also seen longer ago in the past.

Short Answer

Answer briefly but completely. Your responses should not require more than 1-2 sentences.

1. *Neutrinos and dark matter.*

   (a) **[10 points]** As described in class, neutrinos coming from an object in the Solar System have been detected on Earth.

   - What Solar System object is producing the neutrinos we observe?
   - What does the detection of neutrinos teach us about this object?

   The Sun is a prodigious source of neutrinos, as confirmed by direct observation of solar neutrinos. Neutrinos are only produced in some kinds of nuclear reactions, and thus the detection of solar neutrinos confirms that the Sun runs by nuclear power.

   (b) **[5 points]** Give two properties of neutrinos that make them good dark matter candidates.

   Neutrinos are weakly interacting and thus do not emit electromagnetic radiatin (light) of any kind: they are certainly dark. And they have mass, albeit small, and so they are indeed sources of gravity. Neutrinos are excellent dark matter candidates.

2. **[5 points]** Where is the center of the Universe? Briefly explain.

   The Universe is homogeneous and thus has no center. Some people prefer to say the everywhere is the center of the unierse, which was fine, but to me this no longer corresponds to what the word "center" is supposed to mean.

3. *General Relativity: Black Holes.* Astronauts Angelina and Brad each hover near a black hole, but at different distances. They have identical clocks, and identical lasers that emit red light.

   Angelina observes Brad's laser beam to have a blue color.

   (a) **[10 points]** Who is closer to the black hole? Briefly explain your reasoning.

   Distant observers see light from emitters near the black hole as being redshifted, i.e., having a longer wavelength than that emitted. Near observer see the light of distant observers as blueshifted to shorter wavelengths. Since here Angelina sees a shift is from red to blue, i.e., a blueshift, then she mus be closer to the black hole.

   (b) **[10 points]** From *Brad*'s point of view, will Angelina's clock appear to tick faster than his, slower, or at the same rate? Briefly justify your answer.

   Very loosely speaking, the intense gravity of a black hole "slows down time." More carefully, an observer near a black hole sees more distant observers a sped up, while more distant observers see the near observer as slowed down.

   Since Angelina is closer, we conclude that Brad will see her watch as slowed down.

   (c) *Black holes as dark matter.*

i. **[10 points]** In class, we saw that dark matter in the halo of our own Galaxy *cannot* be in the form of black holes. What observation(s) led to this result?

When looking at stars in a nearby galaxy, their light passes through the halo of our Galaxy. If there were many black holes in our Galactic halo, they would be a source of gravitational lensing (in fact, microlensing) and we would see this as amplifications of light in the nearby galaxy. We do not however observe such effects coming from our halo (this was the MACHO experiment). Thus we conclude that the halo is not full of black holes.

ii. **[10 points]** Based on the results in part (a), cosmologists go on to conclude it unlikely that black holes are the dark matter in the halos of *other* galaxies. Briefly (1-2 sentences) explain why cosmologist reach this conclusion.

The cosmological principle says that the composition of our Galaxy should be similar to that of other galaxies. If we do not have black hole dark matter, neither should they.

4. *Supernovae and Standard Candles.*

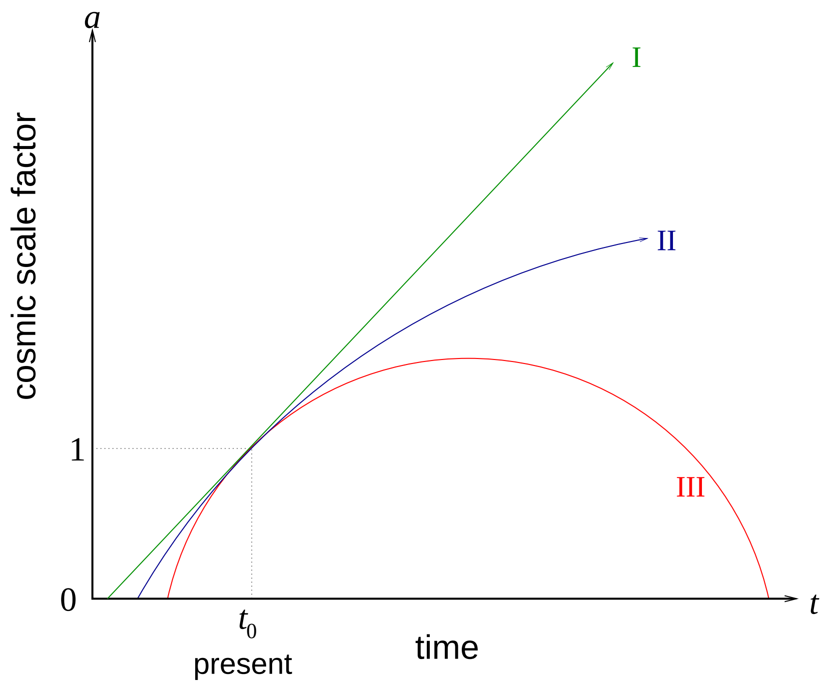
(a) **[5 points]** What is a standard candle?

A standard candle is an object with known luminosity, i.e., a known amount of light output. Measuring the flux (apparent brightness) of such an object, and using the inverse square law $F = L/4\pi r^2$*, we can find the distance* $r = \sqrt{L/4\pi F}$*.*

(b) **[5 points]** Why are supernovae useful as standard candles?

Supernovae are at their peak enormously bright, comparable in luminosity to an entire galaxy. Thus they can be seen from great distances. So they can be used to measure cosmological distances over much of the universe.

5. **[5 bonus points]** Below are shown the scale factor evolution in three different universes. Consider a galaxy which has a redshift $z = 2$. In which universe is this galaxy the *farthest* from us? Briefly explain.



At $z = 2$, the scale factor is $a = 1/(1+z) = 1/3$. From the graph we see that at this scale factor (horizontal line at $a = 1/3$), Universe I has existed for the longest time before now. In this universe, galaxies have gone the farthest.