November 5, 2004 Name:________________________

Astronomy 102: Stars and Galaxies

Exam 3

Instructions: Write your answers in the space provided; indicate clearly if you continue on the back of a page. No books, notes, or assistance from anyone is allowed. You are allowed to use, and will need, a calculator. The exam has five questions, each with equal weight.

Possibly Useful Constants and Formulae

Earth-Sun Distance: 1.000 AU

$$1\,\text{pc} = 206,265\ \text{AU} = 3.086 \times 10^{16}\,\text{m}$$

$$1\,\text{kpc} = 10^3\,\text{pc} \qquad 1\,\text{Mpc} = 10^6\,\text{pc}$$

$$1\,\text{km} = 1,000\,\text{m} = 0.62\,\text{miles}$$

$$1\,\text{Å} = 10^{-10}\,\text{m}$$

$$1\,\text{year} = 3.156 \times 10^7\,\text{s}$$

$$L_\odot = 3.85 \times 10^{26}\ \text{W}$$

$$M_\odot = 2.00 \times 10^{30}\,\text{kg}$$

$$L_{\text{Vega}} = 55\,L_\odot$$

$$d_{\text{Vega}} = 7.8\,\text{pc}$$

$$\pi\ \text{radians} = 180^\circ$$

$$206,265'' = 1\ \text{radian}$$

$$60'' = 1' \qquad 60' = 1^\circ$$

$$A = \frac{h}{d}$$

$$L = A\,\sigma\,T^4$$

$$L = 4\pi\,R^2\,\sigma\,T^4$$

$$\sigma = 5.67 \times 10^{-8}\ \text{W}\,\text{m}^{-2}\,\text{K}^{-4}$$

$$\lambda_{\text{max}} = \frac{2.9 \times 10^7\,\text{Å}\,\text{K}}{T}$$

$$B = \frac{L}{4\pi\,d^2}$$

$$F = \frac{G\,M_1\,M_2}{d^2}$$

$$v = H_0\,d$$

$$t_H = \frac{1}{H_0}$$

$$c = 3.00 \times 10^5\,\text{km}\,\text{s}^{-1}$$

$$G = 6.67 \times 10^{-11}\,\text{m}^3\,\text{kg}^{-1}\,\text{s}^{-2}$$

$$1\,\text{W} = 1\,\text{J}\,\text{s}^{-1}$$

$$P^2 = A^3$$

$$P^2 = \left(\frac{4\pi^2}{GM}\right) A^3$$

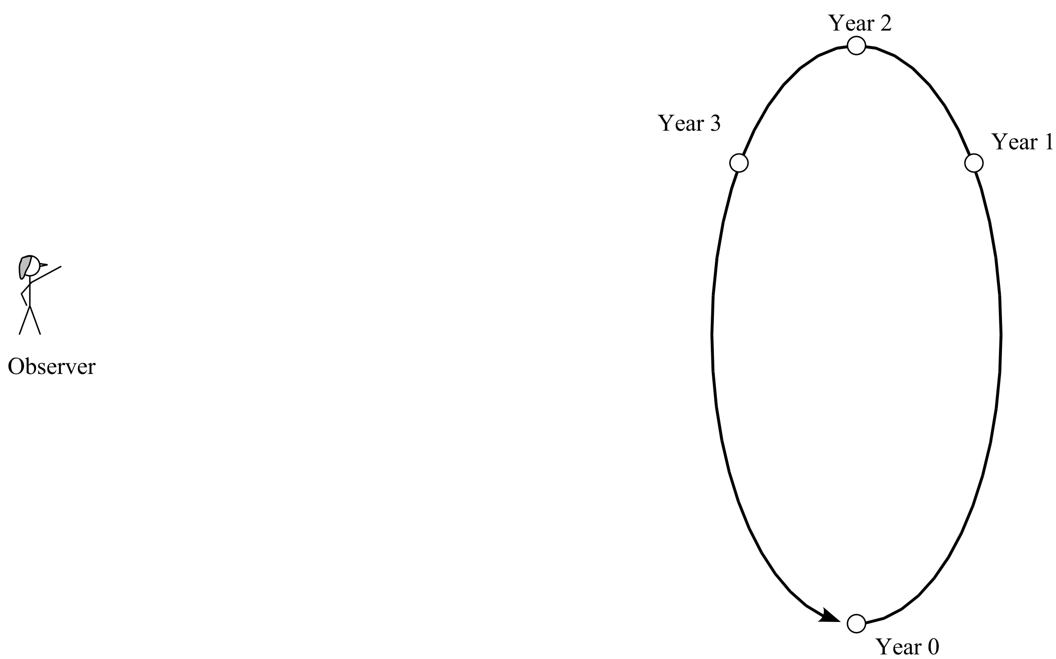
$$z = \frac{\lambda_{\text{obs}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}} = \frac{\Delta\lambda}{\lambda}$$

$$z = \frac{v}{c} \qquad (\text{for}\ \ v \ll c)$$

$$(1+z) = \frac{\text{Size Now}}{\text{Size Then}}$$

1. Consider a binary system with an elliptical orbit; one star in the binary is more massive than the other. Below is drawn the ellipse that is the orbit of the less massive star. The less massive star's orbit takes four years to complete; its position at the beginning of years 0, 1, 2, and 3 are shown on the digram. (By year 4, it's back where it started.)

While the drawing shows the binary system looking down on it's orbit (face-on), an observer (shown to the left of the page) observes this system edge on.

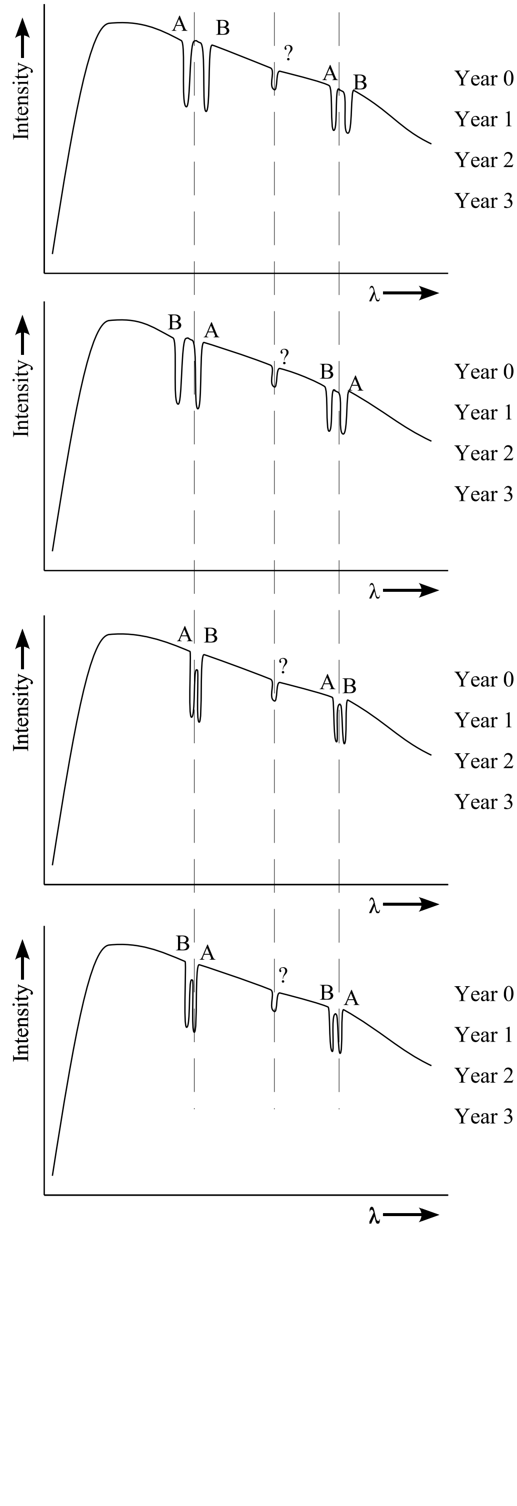


(a) Draw the orbit of the more massive star in the binary on the diagram above, including an arrow that indicates the direction of motion. Draw and label four spots that indicate the position of the more massive star at each of year 0, year 1, year 2, and year 3.

. . . continued on next page. . .

1. (Continued)

To the right are four spectra taken by the observer drawn on the previous page; the observer used a space telescope to take these spectra. The spectra include the light from *both* of the stars. The absorption lines labelled A come from one of the stars in the binary system, and the absorption lines labelled B come from the other. (The "?" line is a mystery absorption line which you can ignore for now.) The dashed vertical lines drawn through the four spectra indicate the rest wavelengths of each line.



(b) Is Star A or Star B from the spectra to the right the *more* massive star in the binary system? Explain.

(c) For each spectrum, circle the time at which this spectrum was taken (Year 0, Year 1, Year 2, or Year 3).

(x) **Extra credit– 1 point** Explain where the mystery line is coming from.

...continued on next page...

2. (a) Make a sketch of two rotation curves (orbital speed as a function of distance from the center). Make sure to label your axes, and which curve is which. One rotation curve should be for Keplerian orbits, i.e. orbits that obey a $P^2 \propto A^3$ law. The second should be the one observed in the Milky Way.

(b) Is the matter in the Milky Way *more centrally concentrated* or *more spread out* than matter that would lead to Keplerian orbits?

(c) Sketch the rotation curve of a merry-go-round (that is, the rotation of a rigid disk). To get this from gravitational orbits, would you need matter that is *more centrally concentrated* or *more spread out* than the matter is in the Milky Way?

. . . continued on next page. . .

3. Theories of how planets form suggest that smaller, rocky planets form closer to parent star, and larger gas giants form farther from the star. Our solar system is a nice example: Mercury, Venus, Earth, and Mars are small rocky planets; farther out, Jupiter and Saturn are gas giants.

These theories are still believed to be essentially correct.

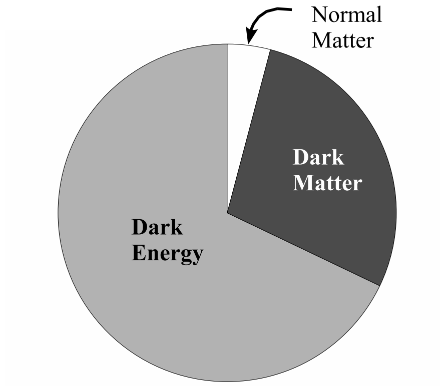
(a) Of the first batch of extra-solar planets found, roughly how big were they (compared to either the Earth or to Jupiter), and roughly how far were they from their parent star (compared to Earth's distance from the Sun)?

(b) Comment on what this may say about the theories of planet formation.

(c) Explain why the observational methods used to discover many of the currently known extrasolar planets would have made it easiest to find planets like those you describe in (a), as compared to planets like those seen in our solar system.

...continued on next page...

4. The Universe is made up of about 70% Dark Energy, about 25% Dark Matter, and about 5% normal matter:



Cup your hands before you. In your hands, you have the following:

- 0.01 g of normal matter (in the form of air)
- 10^{-23} g of dark matter
- 10^{-28} g (equivalent) of dark energy

(a) How do you resolve the apparent contradiction between what makes up the Universe and what you have in your hands?

(b) The Cosmological Principle states that we do not live in a preferred place in the Universe. Most astronomers believe that it is valid. Is it at odds with your answer to (a)? If so, how can you explain the contradiction?

. . . continued on next page. . .

5. One type of standard candle used by astronomers is Type Ia supernovae. A Type Ia supernova (SN Ia) has a luminosity of $5.8 \times 10^9\, L_\odot$ at maximum light; it is this high luminosity that makes them visible to such great distances.

(a) You discover and observe a supernova in a distant galaxy. In your telescope, you observe it to have a brightness that is 1.6×10^{-7} times the brightness you observe for Vega. How far away is this galaxy (in Megaparsecs (Mpc))?

(b) You measure a redshift for this galaxy of $z = 0.062$. Using just the data from this galaxy and this supernova, what would you calculate the expansion rate of the Universe to be?

(c) Given your expansion rate, how old would the Universe be (in billions of years) if the expansion rate had been constant throughout its history?

(d) If a second supernova explodes in this galaxy 200 million years after the supernova you observed, how long from now *or* how long ago does this second supernova explode? (Be sure to indicate whether it happens in the future or the past.)

. . . this is the last page.