Short-Answer Problems (3 points each)

1) Arrange the following scientists in order of when they lived, earliest to latest: Isaac Newton, Aristarchus, Albert Einstein, Nicolaus Copernicus.

Aristarchus, Copernicus, Newton, Einstein

2) You step outside on a clear night in Ohio. Over the course of the night, do stars appear to circle *clockwise* or *counterclockwise* around Polaris?

counterclockwise

3) Name one of the reasons why the heliocentric model of Copernicus met with initial resistance.

1) It was contrary to church doctrine.
2) It implied the Earth was moving at a flabbergasting speed.
3) It implied the stars were at a flabbergasting distance.

4) Which is longer, a *sidereal* day or a *solar* day?

solar

5) Suppose that mischievous space aliens move the Earth so that it's on a *larger* orbit around the Sun. On its new orbit, would the Earth's orbital period be *longer* or *shorter* than it is now?

longer

6) Which has the shorter wavelength, red light or violet light?

violet

7) The star named "Sirius" is just under 3 parsecs from us. Which technique would be most useful for accurately determining its distance: the radar method, the parallax method, or the standard candle method?

parallax

8) Arrange the following objects in order of increasing distance from the Earth: the Sun, the Andromeda Galaxy, Proxima Centauri, the Moon.

Moon, Sun, Proxima Centauri, Andromeda Galaxy

9) If a star is at a distance of 4 parsecs, what is its parallax, in arcseconds?

$p = \frac{1}{d} = \frac{1}{4}$ arcsecond $=$ 0.25 arcsecond

10) Seen through a good pair of binoculars, the star Betelgeuse is red and the star Rigel is blue. Which of the two stars has a higher temperature?

Rigel

11) A galaxy is moving away from us with a radial velocity v = 21,300 km/sec. From Hubble's Law, what is its distance?

$$d = \frac{v}{H_0} = \frac{21{,}300 \text{ km/sec}}{71 \text{ km/sec/Mpc}} = 300 \text{ Mpc}$$

12) Which of the following temperatures is closest to the temperature of the air in this room: 3 Kelvin, 30 Kelvin, 300 Kelvin, or 3000 Kelvin?

300 Kelvin

13) Which contributes most to the average density of the universe: dark matter, ordinary matter, dark energy, or photons?

dark energy

14) When the Milky Way Galaxy and the Andromeda Galaxy collide, will they form a large *spiral* galaxy or a large *elliptical* galaxy?

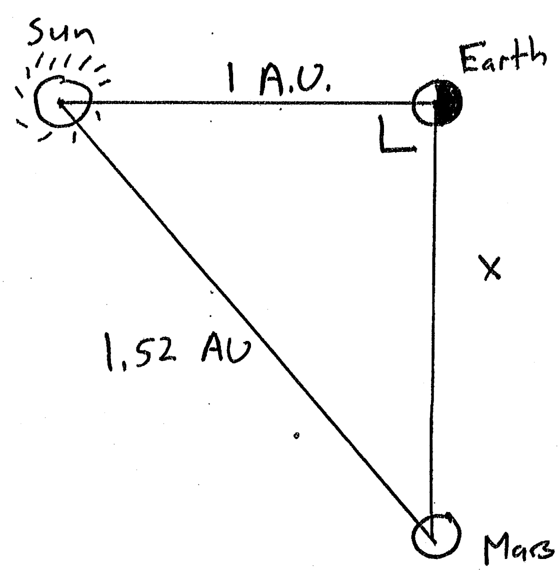
elliptical galaxy

15) In a cosmological context, what does the acronym "WIMP" stand for?

Weakly Interacting Massive Particle

Mathematical Problems (10 points each)

16) An astronaut travels to Mars. Turning her telescope on the Earth, she sees that the Earth is in its *first quarter* phase. Given that the distance from the Earth to the Sun is 1 A.U., and the distance from Mars to the Sun is 1.52 A.U., what is the distance from Mars to the Earth at the instant when the astronaut sees the Earth in its first quarter phase? [Hint: you may find that drawing a diagram is useful.]



For an astronaut on Mars to see the Earth in its 1st quarter phase, the Mars-Earth-Sun angle must be 90°, and the Sun-Mars side of the triangle will be the hypoteneuse.

$$(1\ \text{A.U.})^2 + X^2 = (1.52\ \text{A.U.})^2$$

$$X^2 = 2.3104\ \text{A.U.}^2 - 1\ \text{A.U.}^2$$

$$X^2 = 1.3104\ \text{A.U.}^2$$

$$\boxed{X = 1.145\ \text{A.U.}}$$

17) Ordinary matter (made of protons, neutrons, and electrons) provides 4% of the critical density of the universe.
a) What is the average density of ordinary matter in the universe, given in units of kilograms per cubic meter? [Hint: the critical density is a Potentially Useful Number.]
b) If the density of ordinary matter were contributed entirely by stars identical in mass to the Sun, how many stars (on average) would there have to be per cubic parsec of the universe?

a) $\rho_{ordinary} = 0.04\, \rho_{crit}$

$$= 0.04 \times 10^{-26} \text{ kg/m}^3$$

$$\boxed{\rho_{ordinary} = 4 \times 10^{-28} \text{ kg/m}^3}$$

b) $\rho_{ordinary} = 4 \times 10^{-28} \dfrac{\text{kg}}{\text{m}^3} \left(\dfrac{1\ M_{sun}}{2 \times 10^{30} \text{ kg}} \right) \left(\dfrac{3.1 \times 10^{16} \text{ m}}{1 \text{ pc}} \right)^3$

$$= 6.0 \times 10^{-9}\ M_{sun} / pc^3$$

There would be only 6 billionths of a star per cubic parsec, on average

18) The stars named "Arcturus" and "Vega" has the same flux as seen from the Earth. Arcturus is at a distance of 11 parsecs from the Earth; Vega is at a distance of 7.8 parsecs from the Earth. What is the ratio of the luminosity of Arcturus to the luminosity of Vega?

f_A = flux of Arcturus
L_A = luminosity of Arcturus
r_A = distance to Arcturus

f_V = flux of Vega
L_V = luminosity of Vega
r_V = distance to Vega

$$f_A = \frac{L_A}{4\pi r_A^2}$$

$$f_V = \frac{L_V}{4\pi r_V^2}$$

$$f_A = f_V$$

$$\frac{L_A}{4\pi r_A^2} = \frac{L_V}{4\pi r_V^2}$$

$$\frac{L_A}{L_V} = \left(\frac{r_A}{r_V}\right)^2$$

$$= \left(\frac{11\ pc}{7.8\ pc}\right)^2$$

$$\boxed{\frac{L_A}{L_V} = 1.99}$$

Note: this is just one possible lecture to Fred - yours may differ.

Essay Question (25 points)

19) During lecture, it was asserted that galaxies like the Milky Way Galaxy are surrounded by large, nearly spherical "halos" of dark matter. Naturally, our skeptical friend "Flat-Earth Fred" refuses to believe in the existence of dark matter, since he can't see it. Explain, in a straightforward way that Flat-Earth Fred would understand, what evidence there is that these halos of dark matter exist. Include a description of the observations you would have to make in order to detect a galaxy's halo of dark matter.

Well, Fred, since dark matter (by definition) doesn't emit, absorb, or reflect light, you're probably wondering how we can detect it. Dark matter, despite its invisibility, can be detected indirectly, by its gravitational influence on ordinary luminous matter. Consider a spiral galaxy, such as the Andromeda Galaxy. When we observe the spectra of stars in the Andromeda Galaxy, we find, from the Doppler shifts in their spectra, that the stars are going around the galaxy's center on nearly circular orbits, with speeds of hundreds of kilometers per second. From the formula $V_{circ} = \sqrt{\frac{GM}{r}}$, we can compute the mass inside any star's orbit around the galaxy's center. It is found that for stars on the outer fringes of the galaxy (that is, with large values of r), the computed mass M required to anchor the stars on their circular orbits is very large - much larger, in fact, than can be accounted for by the visible stars and gas in the galaxy. The remaining mass must then be invisible, or "dark", matter.