CHAPTER 33: Astrophysics and Cosmology

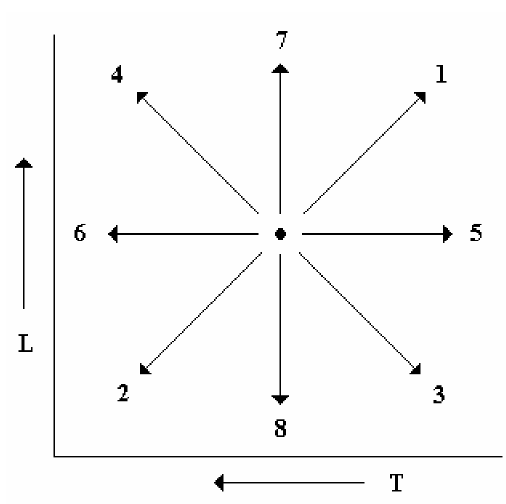
Answers to Questions

1. Long ago, without telescopes, it was difficult to see the individual stars in the Milky Way. The stars in this region of the sky were so numerous and so close together and so tiny that they all blended together to form a cloudy or milky stripe across the night sky. Now using more powerful telescopes, we can see the individual stars that make up the Milky Way galaxy.

2. When a star generates more energy than it radiates, its temperature increases, which produces a greater outward pressure that overcomes the inward gravitational forces and the star increases in size. When a star generates less energy than it radiates, its temperature decreases, which produces a smaller outward pressure and the star decreases in size as the inward gravitational forces start to overcome the outward radiation pressure.

3. A red giant star is extremely large in size, it has a very high luminosity, but it has a relatively cool surface temperature that causes it to be red in color.

4. See the H-R diagram:
   (1) Star is getting cooler and redder, it is increasing in size and mass (higher luminosity).
   (2) Star is getting hotter and whiter, it is decreasing in size and mass (lower luminosity).
   (3) Star is getting cooler and redder, it is decreasing in size and mass (lower luminosity).
   (4) Star is getting hotter and whiter, it is increasing in size and mass (higher luminosity).
   (5) Star is getting cooler and redder, it is increasing in size, but has same mass and luminosity.
   (6) Star is getting hotter and whiter, it is decreasing in size, but has same mass and luminosity.
   (7) Star has same temperature and color, but it is increasing in size and mass (higher luminosity).
   (8) Star has same temperature and color, but it is decreasing in size and mass (lower luminosity).



5. Although the H-R diagram only directly relates the surface temperature of a star to its absolute luminosity (and thus doesn't directly reveal anything about the core), the H-R diagram does provide clues regarding what is happening at the core of a star. Using the current model of stellar evolution and the H-R diagram, we can infer that the stars on the main sequence are fusing hydrogen nuclei to helium nuclei at the core and that stars in the red giant region are fusing helium and beryllium to make heavier nuclei such as carbon and that this red giant process will continue until fusion can no longer occur and the star will collapse.

6. The initial mass of a star determines its final destiny. If, after the red giant stage of a star's life, its mass is less than 1.4 solar masses, then the star cools as it shrinks and it becomes a white dwarf. If its mass is between 1.4 and 2-3 solar masses, then the star will condense down to a neutron star, which will eventually explode as a supernova and become a white dwarf. If its mass is greater than

2-3 solar masses, then the star will collapse even more than the neutron star and it will form a black hole.

7. Yes. Since the population of hotter stars on the H-R diagram is relatively low compared to other regions of the diagram, it seems to imply that these hotter stars stay on the main sequence for a shorter period of time and, thus, have shorter lives. (This also makes sense from a fuel standpoint, since these hotter stars will "burn" up their fuel more quickly.)

8. When measuring star parallaxes from the Moon, there are two different cases: (1) If you did the measurements two weeks apart (one at full moon and one at new moon), you would need to assume that the Earth did not move around the Sun very far, and then the *d* shown in Figure 33-12 would be the Earth-Moon distance instead of the Sun-Earth distance. (2) If you did the measurements six months apart and at full moon, then the *d* shown in Figure 33-12 would be the Sun-Earth distance plus the Earth-Moon distance instead of just the Sun-Earth distance. From Mars, then the *d* shown in Figure 33-12 would be the Sun-Mars distance instead of the Sun-Earth distance. You would also need to know the length of a Mars "year" so you could take your two measurements at the correct times.

9. Measure the period of the changing luminosity of a *Cepheid variable*, and then use the definite relationship between the period and absolute luminosity to determine the absolute luminosity (L) of the star. Then use $\ell = L/\left(4\pi d^2\right)$ to find the relationship between the apparent brightness $\left(\ell\right)$ and the distance to the star $\left(d\right)$. Once the apparent brightness is experimentally determined, we can then find the distance to the star.

10. A geodesic is the shortest distance between two points on a surface. Its role in General Relativity is to help us explain curved space-time. Light always travels by the shortest and most direct path between two points (a geodesic) and if this path is curved it means that space itself is curved. Seeing gravity as the cause of this curvature is a fundamental idea of General Relativity.

11. If the redshift was due to something besides expansion, then the Big Bang theory and the view of an expanding universe would be called into question, since the redshift is a major piece of evidence for the expanding universe. Also, the cosmic microwave background data would be conflicting evidence to this new data. Cosmic microwave background is seen as a confirmation of an expanding universe. Thus if there were some other explanation for the redshift, there might be two distinct schools of thought based on these two conflicting pieces of evidence.

12. No, just because everything appears to be moving away from us does not mean we are at the center of the universe. Here is an analogy. If we were sitting on the surface of a balloon and then more air was put into the balloon causing it to expand, notice that every other point on the balloon is now farther away from you. The points close to you are farther away because of the expansion of the rubber and the points on the other side of the balloon are farther away from you because the radius of the balloon is now larger.

13. If you were located in a galaxy near the boundary of our observable universe, galaxies in the direction of the Milky Way would be receding from you. The outer "edges" of the observable universe are expanding at a faster rate than the points more "interior", thus, due to a relative velocity argument, the slower galaxies in the direction of the Milky Way would look like they are receding from your faster galaxy near the outer boundary. Also see Figure 33-20.

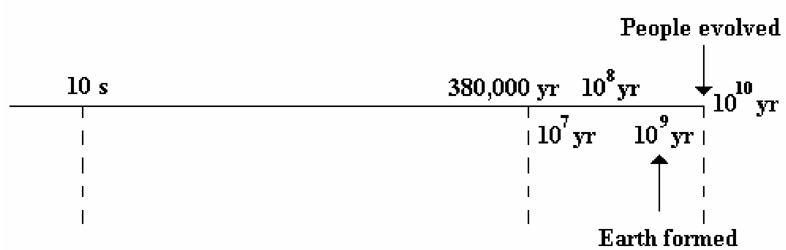
14. An explosion on Earth blows pieces out into the space around it, but the Big Bang was the start of the expansion of space itself. In an explosion on Earth, the pieces that are blown outward will slow down due to air resistance and the farther away they are the slower they will be moving and then they will eventually come to rest, but with the Big Bang, the farther away galaxies are from each other the faster they are moving away from each other. In an explosion on Earth, the pieces with the higher initial speeds end up farther away from the explosion before coming to rest, but the Big Bang appears to be relatively uniform where the farthest galaxies are moving fastest and the nearest galaxies are moving the slowest. An explosion on Earth would correspond to a closed universe, since the pieces would eventually stop, but we would not see a "big crunch" due to gravity as we would with an actual closed universe.

15. To "see" a black hole in space we need indirect evidence. If a large visible star or galaxy was rotating quickly around a non-visible gravitational companion, the non-visible companion could be a massive black hole. Also, as matter begins to accelerate toward a black hole, it will emit characteristic X-rays, which we could detect on Earth. Another way we could "see" a black hole is if it caused gravitational lensing of objects behind it. Then we would see stars and galaxies in the "wrong" place as their light is bent as it passes past the black hole on its way to Earth.

16. The Schwarzschild radius of a hydrogen atom in its ground state would be caused by a mass of:

$$R = 5.29\times10^{-11}\,\text{m} = \frac{2\left(6.67\times10^{-11}\,\text{N}\bullet\text{m}^2/\text{kg}^2\right)M}{\left(3\times10^{8}\,\text{m/s}\right)^2} \quad\rightarrow\quad M = 3.57\times10^{16}\,\text{kg}$$

17. If we look closely at the top of the right-hand side of Figure 33-25:



The Earth formed 4 billion years ago and people evolved 1 million years ago. These events are both very close to the very end of the timeline shown in Figure 33-25.

18. The material contained in the universe is at some average temperature and, thus, it radiates a blackbody spectrum that is characteristic of this temperature. This temperature is now so low because of the expansion of the universe. When the universe was extremely small and the sum total energy of the universe was trapped in that extremely small volume, the average temperature of the universe was amazingly high. As this energy has been spread out over our expanding universe, the average temperature has decreased to its current low level.

19. Atoms were unable to exist until hundreds of thousands of years after the Big Bang because the temperature of the universe was still too high until that time. At those incredibly high temperatures, the free electrons and nuclei were moving so fast and had so much kinetic energy, and they had so many high energy photons colliding with them, that they could never combine together to form atoms. Once the universe cooled below 3000 K, this coupling could take place, and atoms were formed.

20. The universe would eventually collapse in on itself if it had a positive curvature. This would mean that there is so much mass in the universe that the gravitational attraction would pull all of the mass of the universe back into a "big crunch." In this situation, the average density of the universe would be greater than the critical density.

Solutions to Problems

1. See Figure 13-11 in the textbook. The parsec is the distance D when the angle ϕ is 1 second of arc.

$$\phi = 1'' \times \frac{1^\circ}{3600''} \times \frac{\pi \text{ rad}}{180^\circ} = 4.848 \times 10^{-6} \text{ rad}$$

$$\tan\phi = \frac{d}{D} \quad \rightarrow \quad D = \frac{d}{\tan\phi} = \frac{1.496 \times 10^{11} \text{ m}}{\tan\left(4.848 \times 10^{-6} \text{ rad}\right)} = 3.086 \times 10^{16} \text{ m}$$

$$D = 3.086 \times 10^{16} \text{ m}\left(\frac{1 \text{ ly}}{9.461 \times 10^{15} \text{ m}}\right) = \boxed{3.26 \text{ ly}}$$

2. Use the angle to calculate the distance in parsecs, and then convert to other units.

$$d\left(\text{pc}\right) = \frac{1}{\phi''} = \frac{1}{0.38''} = 2.63 \text{ pc}\left(\frac{3.26 \text{ ly}}{1 \text{ pc}}\right) = \boxed{8.6 \text{ ly}}$$

3. Convert the angle to seconds of arc, reciprocate to find the distance in parsecs, and then convert to light years.

$$\phi = \left(1.9 \times 10^{-4}\right)^\circ \left(\frac{3600''}{1^\circ}\right) = 0.684''$$

$$d\left(\text{pc}\right) = \frac{1}{\phi''} = \frac{1}{0.684} = 1.46 \text{ pc}\left(\frac{3.26 \text{ ly}}{1 \text{ pc}}\right) = \boxed{4.8 \text{ ly}}$$

4. The reciprocal of the distance in parsecs is the angle in seconds of arc.

(*a*) $$\phi'' = \frac{1}{d\left(\text{pc}\right)} = \frac{1}{36 \text{ pc}} = 0.02778'' \approx \boxed{\left(2.8 \times 10^{-2}\right)''}$$

(*b*) $$0.02778''\left(\frac{1^\circ}{3600''}\right) = \left(7.717 \times 10^{-6}\right)^\circ \approx \boxed{\left(7.7 \times 10^{-6}\right)^\circ}$$

5. Convert the light years to parsecs, and then reciprocate the parsecs to find the parallax angle in seconds of arc.

$$55 \text{ ly}\left(\frac{1 \text{ pc}}{3.26 \text{ ly}}\right) = 16.87 \text{ pc} \approx \boxed{17 \text{ pc}} \qquad \phi = \frac{1}{16.87 \text{ pc}} = \boxed{0.059''}$$

6. The parallax angle is $\boxed{\text{smaller}}$ for the further star. Since $\tan\phi = \frac{d}{D}$, as the distance D to the star increases, the tangent decreases, so the angle decreases. And since for small angles, $\tan\phi \approx \phi$, we

have that $\phi \approx \dfrac{d}{D}$. Thus if the distance D is doubled, the angle ϕ will be $\boxed{\text{smaller by a factor of 2}}$.

7. Find the distance in light years. That value is also the time for light to reach us.

$$35\,\text{pc}\left(\frac{3.26\,\text{ly}}{1\,\text{pc}}\right) = 114\,\text{ly} \approx 110\,\text{ly} \quad \rightarrow \quad \text{It takes light } \boxed{110\text{ years}} \text{ to reach us.}$$

8. (*a*) The apparent brightness is the solar constant, $\boxed{1.3\times10^{3}\ \text{W/m}^2}$.

   (*b*) Use Eq. 33-1 to find the absolute luminosity.

$$l = \frac{L}{4\pi d^2} \quad \rightarrow \quad L = 4\pi d^2 l = 4\pi\left(1.496\times10^{11}\,\text{m}^2\right)^2\left(1.3\times10^{3}\ \text{W/m}^2\right) = \boxed{3.7\times10^{26}\,\text{W}}$$

$\boxed{9.}$ The apparent brightness of an object is inversely proportional to the observer's distance from the object, given by $l = \dfrac{L}{4\pi d^2}$. To find the relative brightness at one location as compared to another, take a ratio of the apparent brightness at each location.

$$\frac{l_{\text{Jupiter}}}{l_{\text{Earth}}} = \frac{\dfrac{L}{4\pi d^2_{\text{Jupiter}}}}{\dfrac{L}{4\pi d^2_{\text{Earth}}}} = \frac{d^2_{\text{Earth}}}{d^2_{\text{Jupiter}}} = \left(\frac{d_{\text{Earth}}}{d_{\text{Jupiter}}}\right)^2 = \left(\frac{1}{5.2}\right)^2 = \boxed{3.7\times10^{-2}}$$

10. The angular width is the inverse tangent of the diameter of our Galaxy divided by the distance to the nearest galaxy. According to Figure 33-2, our Galaxy is about 100,000 ly in diameter.

$$\phi = \tan^{-1}\frac{\text{Galaxy diameter}}{\text{Distance to nearest galaxy}} = \tan^{-1}\frac{1.0\times10^{5}\,\text{ly}}{2.4\times10^{6}\text{ly}} = \boxed{4.2\times10^{-2}\,\text{rad}} \approx 2.4^\circ$$

$$\phi_{\text{Moon}} = \tan^{-1}\frac{\text{Moon diameter}}{\text{Distance to Moon}} = \tan^{-1}\frac{3.48\times10^{6}\,\text{m}}{3.84\times10^{8}\text{m}} = 9.1\times10^{-3}\,\text{rad}\left(\approx 0.52^\circ\right)$$

$\boxed{\text{The galaxy width is about 4.5 times the moon width.}}$

11. The density is the mass divided by the volume.

$$\rho = \frac{M}{V} = \frac{M}{\frac{4}{3}\pi R^3} = \frac{1.99\times10^{30}\,\text{kg}}{\frac{4}{3}\pi\left(1.5\times10^{11}\,\text{m}\right)^3} = \boxed{1.4\times10^{-4}\ \text{kg/m}^3}$$

12. The angular width is the inverse tangent of the diameter of the Moon divided by the distance to the Sun.

$$\phi = \tan^{-1}\frac{\text{Moon diameter}}{\text{Distance to Sun}} = \tan^{-1}\frac{3.48\times10^{6}\,\text{m}}{1.496\times10^{11}\text{m}} = \boxed{2.33\times10^{-5}\,\text{rad}} \approx \left(1.33\times10^{-3}\right)^\circ \approx 4.79''$$

$\boxed{13.}$ The density is the mass divided by the volume.

$$\rho = \frac{M}{V} = \frac{M_{\text{Sun}}}{\frac{4}{3}\pi R^3_{\text{Earth}}} = \frac{1.99\times10^{30}\,\text{kg}}{\frac{4}{3}\pi\left(6.38\times10^{6}\,\text{m}\right)^3} = \boxed{1.83\times10^{9}\ \text{kg/m}^3}$$

Since the volumes are the same, the ratio of the densities is the same as the ratio of the masses.

$$\frac{\rho}{\rho_{\text{Earth}}}=\frac{M}{M_{\text{Earth}}}=\frac{1.99\times10^{30}\,\text{kg}}{5.98\times10^{24}\,\text{kg}}=\boxed{3.33\times10^{5}\text{ times larger}}$$

14. The density of the neutron star is its mass divided by its volume. Use the proton to calculate the density of nuclear matter.

$$\rho_{\substack{\text{neutron}\\\text{star}}}=\frac{M}{V}=\frac{M_{\text{Sun}}}{\frac{4}{3}\pi R_{\text{Earth}}^{3}}=\frac{1.5\left(1.99\times10^{30}\,\text{kg}\right)}{\frac{4}{3}\pi\left(11000\,\text{m}\right)^{3}}=5.354\times10^{17}\,\text{kg/m}^{3}\approx\boxed{5.4\times10^{17}\,\text{kg/m}^{3}}$$

$$\frac{\rho_{\substack{\text{neutron}\\\text{star}}}}{\rho_{\substack{\text{white}\\\text{dwarf}}}}=\frac{5.354\times10^{17}\,\text{kg/m}^{3}}{1.83\times10^{9}\,\text{kg/m}^{3}}=\boxed{2.9\times10^{8}}\qquad\frac{\rho_{\substack{\text{neutron}\\\text{star}}}}{\rho_{\substack{\text{nuclear}\\\text{matter}}}}=\frac{5.354\times10^{17}\,\text{kg/m}^{3}}{\dfrac{1.673\times10^{-27}\,\text{kg}}{\frac{4}{3}\pi\left(1\times10^{-15}\,\text{m}\right)^{3}}}=\boxed{1.3}$$

15. From Equation 30-2, the Q-value is the mass energy of the reactants minus the mass energy of the products.

$${}^{4}_{2}\text{He}+{}^{4}_{2}\text{He}\ \rightarrow\ {}^{8}_{4}\text{Be}$$

$$Q=m_{\text{Be}}c^{2}-2m_{\text{He}}c^{2}=\left[2\left(4.002603\,\text{u}\right)-8.005305\,\text{u}\right]c^{2}\left(931.5\,\text{Mev}/c^{2}\right)=\boxed{-0.092\,\text{MeV}}$$

$${}^{4}_{2}\text{He}+{}^{8}_{4}\text{Be}\ \rightarrow\ {}^{12}_{6}\text{C}$$

$$Q=m_{\text{Be}}c^{2}-2m_{\text{He}}c^{2}=\left[4.002603\,\text{u}+8.005305\,\text{u}-12.000000\right]c^{2}\left(931.5\,\text{Mev}/c^{2}\right)$$

$$=\boxed{7.366\,\text{MeV}}$$

16. Wien's law says that the $\lambda_{\text{p}}T=\alpha$, where α is a constant, and so $\lambda_{\text{P1}}T_1=\lambda_{\text{P2}}T_2$. The Stefan-Boltzmann equation says that the power output of a star is given by $P=\beta AT^{4}$, where β is a constant, and A is the radiating area. The P in the Stefan-Boltzmann equation is the same as the luminosity L in this chapter. It is given that $l_1=l_2$ and $r_1=r_2$. We assign $\lambda_{\text{P1}}=800\,\text{nm}$ and $\lambda_{\text{P2}}=400\,\text{nm}$.

$$\lambda_{\text{P1}}T_1=\lambda_{\text{P2}}T_2\quad\rightarrow\quad\frac{T_2}{T_1}=\frac{\lambda_{\text{P1}}}{\lambda_{\text{P2}}}=2$$

$$l_1=l_2\quad\rightarrow\quad\frac{L_1}{4\pi d_1^{2}}=\frac{L_2}{4\pi d_2^{2}}\quad\rightarrow\quad\frac{d_2^{2}}{d_1^{2}}=\frac{L_2}{L_1}=\frac{P_2}{P_1}=\frac{\beta A_2T_2^{4}}{\beta A_1T_1^{4}}=\frac{4\pi r_2^{2}T_2^{4}}{4\pi r_1^{2}T_1^{4}}=\frac{T_2^{4}}{T_1^{4}}=\left(\frac{T_2}{T_1}\right)^{4}\quad\rightarrow$$

$$\frac{d_2}{d_1}=\left(\frac{T_2}{T_1}\right)^{2}=\left(2\right)^{2}=4$$

The star with the peak at 400 nm is 4 times further away than the star with the peak at 800 nm.

17. Wien's law says that the $\lambda_{\text{p}}T=\alpha$, where α is a constant, and so $\lambda_{\text{P1}}T_1=\lambda_{\text{P2}}T_2$. or . The Stefan-Boltzmann equation says that the power output of a star is given by $P=\beta AT^{4}$, where β is a constant, and A is the radiating area. The P in the Stefan-Boltzmann equation is the same as the luminosity L in this chapter. It is given that $l_1/l_2=0.091$, $d_1=d_2$, $\lambda_{\text{P1}}=500\,\text{nm}$ and $\lambda_{\text{P2}}=700\,\text{nm}$.

$$\lambda_{P1}T_1=\lambda_{P2}T_2 \rightarrow \frac{T_2}{T_1}=\frac{\lambda_{P1}}{\lambda_{P2}}=\frac{5}{7} \qquad l_1=0.091l_2 \rightarrow \frac{L_1}{4\pi d_1^2}=0.091\frac{L_2}{4\pi d_2^2} \rightarrow$$

$$1=\frac{d_2^2}{d_1^2}=\frac{0.091L_2}{L_1}=\frac{0.091P_2}{P_1}=\frac{0.091A_2T_2^4}{A_1T_1^4}=\frac{(0.091)4\pi r_2^2T_2^4}{4\pi r_1^2T_1^4}=0.091\frac{T_2^4}{T_1^4}\frac{r_2^2}{r_1^2} \rightarrow$$

$$\frac{r_1}{r_2}=\sqrt{0.091}\left(\frac{T_2}{T_1}\right)^2=\sqrt{0.091}\left(\frac{5}{7}\right)^2=0.15$$

The ratio of the diameters is the same as the ratio of radii, so $\frac{D_1}{D_2}=\boxed{0.15}$

18. The Schwarzschild radius is given by $R=\frac{2GM}{c^2}$.

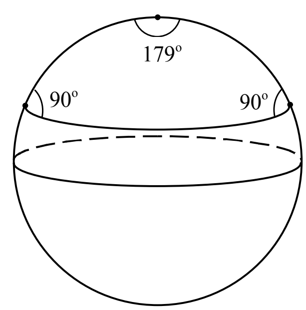
(*a*) $$R_{\text{Sun}}=\frac{2GM_{\text{Sun}}}{c^2}=\frac{2\left(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(1.99\times10^{30}\ \text{kg}\right)}{\left(3.00\times10^8\ \text{m/s}\right)^2}=2950\ \text{m}=\boxed{2.95\ \text{km}}$$

(*b*) $$R_{\text{Earth}}=\frac{2GM_{\text{Earth}}}{c^2}=\frac{2\left(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(5.98\times10^{24}\ \text{kg}\right)}{\left(3.00\times10^8\ \text{m/s}\right)^2}=8.86\times10^{-3}\ \text{m}\approx\boxed{8.9\ \text{mm}}$$

19. The Schwarzschild radius is given by $R=\frac{2GM}{c^2}$.

$$R=\frac{2GM}{c^2}=\frac{2\left(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(3\times10^{41}\ \text{kg}\right)}{\left(3.00\times10^8\ \text{m/s}\right)^2}=\boxed{4\times10^{14}\ \text{m}}$$

20. (*a*) For the vertices of the triangle we choose the North pole and two points on a latitude line on nearly opposite sides of the Earth, as shown on the diagram. Let the angle at the North pole be 179°.



(*b*) If the triangle is drawn on a small enough portion of the sphere that the portion is flat, then the sum of the angles will be 180°.

21. The limiting value for the angles in a triangle on a sphere is $\boxed{540^\circ}$. Imagine drawing an equilateral triangle near the north pole, enclosing the north pole. If that triangle were small, the surface would be approximately flat, and the each angle in the triangle would be 60°. Then imagine "stretching" each side of that triangle down towards the equator, while keeping sure that the north pole stayed inside the triangle. The angle at each vertex of the triangle would expand, with a limiting value of 180°. The three 180° angles in the triangle would add up to 540°.

22. Use Eq. 33-6, Hubble's law.

$$v=Hd \rightarrow d=\frac{v}{H}=\frac{(0.010)\left(3.00\times10^8\ \text{m/s}\right)}{2.2\times10^4\ \text{m/s/Mly}}=\boxed{140\ \text{Mly}}=1.4\times10^8\ \text{ly}$$

23. Use Eq. 33-6, Hubble's law.

$$v = Hd \quad \rightarrow \quad d = \frac{v}{H} = \frac{3500\,\text{km/s}}{22\,\text{km/s/Mly}} = \boxed{160\,\text{Mly}} = 1.6\times 10^{8}\,\text{ly}$$

24. Use Eq. 33-6, Hubble's law.

$$v = Hd = \left(22000\,\text{m/s/Mly}\right)\left(12000\,\text{Mly}\right) = 2.64\times 10^{8}\ \text{m/s}\left(\frac{c}{3.00\times 10^{5}\ \text{m/s}}\right) = \boxed{0.88\,c}$$

25. We find the velocity from Hubble's law (Eq. 33-6), and the observed wavelength from the Doppler shift, Eq. 33-3.

(*a*) $$\frac{v}{c} = \frac{Hd}{c} = \frac{\left(22000\,\text{m/s/Mly}\right)\left(1.0\,\text{Mly}\right)}{3.00\times 10^{8}\ \text{m/s}} = 7.33\times 10^{-5}$$

$$\lambda = \lambda_0\sqrt{\frac{1+v/c}{1-v/c}} = \left(656\,\text{nm}\right)\sqrt{\frac{1+7.33\times 10^{-5}}{1-7.33\times 10^{-5}}} = 656.05\,\text{nm} \approx \boxed{656\,\text{nm}}$$

(*b*) $$\frac{v}{c} = \frac{Hd}{c} = \frac{\left(22000\,\text{m/s/Mly}\right)\left(1.0\times 10^{2}\ \text{Mly}\right)}{3.00\times 10^{8}\ \text{m/s}} = 7.33\times 10^{-3}$$

$$\lambda = \lambda_0\sqrt{\frac{1+v/c}{1-v/c}} = \left(656\,\text{nm}\right)\sqrt{\frac{1+7.33\times 10^{-3}}{1-7.33\times 10^{-3}}} = 660.83\,\text{nm} \approx \boxed{661\,\text{nm}}$$

(*c*) $$\frac{v}{c} = \frac{Hd}{c} = \frac{\left(22000\,\text{m/s/Mly}\right)\left(1.0\times 10^{4}\ \text{Mly}\right)}{3.00\times 10^{8}\ \text{m/s}} = 0.733$$

$$\lambda = \lambda_0\sqrt{\frac{1+v/c}{1-v/c}} = \left(656\,\text{nm}\right)\sqrt{\frac{1+0.733}{1-0.733}} = 1671.3\,\text{nm} \approx \boxed{1670\,\text{nm}}$$

$\boxed{26.}$ Use Eqs. 33-4 and 33-5a to solve for the speed of the galaxy.

$$\Delta\lambda = 610\,\text{nm} - 434\,\text{nm} = 176\,\text{nm}$$

$$z = \frac{\Delta\lambda}{\lambda_0} = \sqrt{\frac{1+v/c}{1-v/c}} - 1 \quad \rightarrow \quad \frac{v}{c} = \frac{\left(\frac{\Delta\lambda}{\lambda_0}+1\right)^2 - 1}{\left(\frac{\Delta\lambda}{\lambda_0}+1\right)^2 + 1}\ \frac{v}{c} = \frac{\left(\frac{176\,\text{nm}}{434\,\text{nm}}+1\right)^2 - 1}{\left(\frac{176\,\text{nm}}{434\,\text{nm}}+1\right)^2 + 1} = \frac{0.9755}{2.9755} = 0.327c \quad \rightarrow$$

$$v \approx \boxed{0.33c}$$

Use Hubble's law, Eq. 33-6, to solve for the distance.

$$v = Hd \quad \rightarrow \quad d = \frac{v}{H} = \frac{\frac{v}{c}}{\frac{H}{c}} = \frac{0.3278}{\frac{\left(22000\,\text{m/s/Mly}\right)}{3.00\times 10^{8}\ \text{m/s}}} = 4.47\times 10^{3}\,\text{Mly} \approx \boxed{4.5\times 10^{9}\,\text{ly}}$$

27. Use Eq. 33-35a to solve for the speed of the galaxy.

$$z=\sqrt{\frac{1+v/c}{1-v/c}}-1 \;\rightarrow\; \frac{v}{c}=\frac{(z+1)^2-1}{(z+1)^2+1}=\frac{1.6^2-1}{1.6^2+1}=0.44 \;\rightarrow\; v=\boxed{0.44c}$$

28. Use Eq. 33-35a to solve for the redshift parameter.

$$z=\sqrt{\frac{1+v/c}{1-v/c}}-1=\sqrt{\frac{1+0.50}{1-0.50}}-1=\boxed{0.73}$$

29. Eq. 33-3 states $\lambda=\lambda_0\sqrt{\frac{1+v/c}{1-v/c}}$.

$$\lambda=\lambda_0\sqrt{\frac{1+v/c}{1-v/c}}=\lambda_0\left(1+\frac{v}{c}\right)^{1/2}\left(1-\frac{v}{c}\right)^{-1/2}\approx\lambda_0\left(1+\tfrac{1}{2}\frac{v}{c}\right)\left(1-\left(-\tfrac{1}{2}\right)\frac{v}{c}\right)=\lambda_0\left(1+\tfrac{1}{2}\frac{v}{c}\right)^2$$

$$\lambda\approx\lambda_0\left(1+2\left(\tfrac{1}{2}\frac{v}{c}\right)\right)=\lambda_0\left(1+\frac{v}{c}\right)=\lambda_0+\lambda_0\frac{v}{c} \;\rightarrow\; \lambda-\lambda_0=\Delta\lambda=\lambda_0\frac{v}{c} \;\rightarrow\; \boxed{\frac{\Delta\lambda}{\lambda_0}=\frac{v}{c}}$$

30. Wien's law is given as Eq. 27-2 in chapter 27.

$$\lambda_P T=2.90\times10^{-3}\,\text{m}\bullet\text{K} \;\rightarrow\; \lambda_P=\frac{2.90\times10^{-3}\,\text{m}\bullet\text{K}}{T}=\frac{2.90\times10^{-3}\,\text{m}\bullet\text{K}}{2.7\,\text{K}}=\boxed{1.1\times10^{-3}\,\text{m}}$$

31. We use the proton as typical nuclear matter.

$$10^{-26}\,\frac{\text{kg}}{\text{m}^3}\times\frac{1\,\text{nucleon}}{1.67\times10^{-27}\,\text{kg}}=\boxed{6\,\text{nucleons/m}^3}$$

32. If the scale of the universe is inversely proportional to the temperature, then the scale times the temperature should be constant. If we call the current scale "1", and knowing the current temperature to be about 3 K, then the product of scale and temperature should be about 3. Use Figure 33-25 to estimate the temperature at various times. For purposes of illustration, we assume the universe has a current size of about $10^{10}\,\text{ly}$.

(*a*) At $t=10^6\,\text{yr}$, the temperature is about 1000 K. Thus the scale is found as follows.

$$(\text{Scale})(\text{Temperature})=3 \;\rightarrow\; \text{Scale}=\frac{3}{\text{Temperature}}=\frac{3}{1000}=\boxed{3\times10^{-3}}\approx3\times10^{7}\,\text{ly}$$

(*b*) At $t=1\,\text{s}$, the temperature is about $10^{10}\,\text{K}$.

$$\text{Scale}=\frac{3}{\text{Temperature}}=\frac{3}{10^{10}}=\boxed{3\times10^{-10}}\approx3\,\text{ly}$$

(*c*) At $t=10^{-6}\,\text{s}$, the temperature is about $10^{13}\,\text{K}$.

$$\text{Scale}=\frac{3}{\text{Temperature}}=\frac{3}{10^{13}}=\boxed{3\times10^{-13}}\approx3\times10^{-3}\,\text{ly}\approx3\times10^{13}\,\text{m}$$

(*d*) At $t=10^{-35}\,\text{s}$, the temperature is about $10^{27}\,\text{K}$.

$$\text{Scale}=\frac{3}{\text{Temperature}}=\frac{3}{10^{27}}=\boxed{3\times10^{-27}}\approx3\times10^{-17}\,\text{ly}\approx0.3\,\text{m}$$

33. The temperature corresponding to the average kinetic energy needed to produce a particle of mass m is given by $\frac{3}{2}kT = mc^2 \rightarrow T = \frac{2}{3}\frac{mc^2}{k}$.

(*a*) $$T = \tfrac{2}{3}\frac{mc^2}{k} = \tfrac{2}{3}\frac{\left(500\times10^6\ \text{ev}/c^2\right)c^2\left(1.60\times10^{-19}\ \text{J/ev}\right)}{1.38\times10^{-23}\ \text{J/K}} = 3.86\times10^{12}\,\text{K}$$

From Figure 33-25, this corresponds to a time of $\boxed{\sim 10^{-5}\,\text{s}}$.

(*b*) $$T = \tfrac{2}{3}\frac{mc^2}{k} = \tfrac{2}{3}\frac{\left(9500\times10^6\ \text{ev}/c^2\right)c^2\left(1.60\times10^{-19}\ \text{J/ev}\right)}{1.38\times10^{-23}\ \text{J/K}} = 7.34\times10^{13}\,\text{K}$$

From Figure 33-25, this corresponds to a time of $\boxed{\sim 10^{-7}\,\text{s}}$.

(*c*) $$T = \tfrac{2}{3}\frac{mc^2}{k} = \tfrac{2}{3}\frac{\left(100\times10^6\ \text{ev}/c^2\right)c^2\left(1.60\times10^{-19}\ \text{J/ev}\right)}{1.38\times10^{-23}\ \text{J/K}} = 7.73\times10^{11}\,\text{K}$$

From Figure 33-25, this corresponds to a time of $\boxed{\sim 10^{-4}\,\text{s}}$.

34. A: temperature increases, luminosity stays the same, size decreases
B: temperature stays the same, luminosity decreases, size decreases
C: temperature decreases, luminosity increases, size increases

35. The apparent luminosity is given by Eq. 33-1. Use that relationship to derive an expression for the absolute luminosity, and equate that for two stars.

$$l = \frac{L}{4\pi d^2} \rightarrow L = 4\pi d^2 l$$

$$L_{\substack{\text{distant}\\\text{star}}} = L_{\text{Sun}} \rightarrow 4\pi d^2_{\substack{\text{distant}\\\text{star}}} l_{\substack{\text{distant}\\\text{star}}} = 4\pi d^2_{\text{Sun}} l_{\text{Sun}} \rightarrow$$

$$d_{\substack{\text{distant}\\\text{star}}} = d_{\text{Sun}}\sqrt{\frac{l_{\text{Sun}}}{l_{\substack{\text{distant}\\\text{star}}}}} = \left(1.5\times10^{11}\,\text{m}\right)\sqrt{\frac{1}{10^{-11}}}\left(\frac{1\,\text{ly}}{9.461\times10^{15}\,\text{m}}\right) = \boxed{5\,\text{ly}}$$

36. The angular momentum is the product of the rotational inertia and the angular velocity.

$$\left(I\omega\right)_{\text{initial}} = \left(I\omega\right)_{\text{final}} \rightarrow$$

$$\omega_{\text{final}} = \omega_{\text{initial}}\left(\frac{I_{\text{initial}}}{I_{\text{final}}}\right) = \omega_{\text{initial}}\left(\frac{\frac{2}{5}MR^2_{\text{initial}}}{\frac{2}{5}MR^2_{\text{final}}}\right) = \omega_{\text{initial}}\left(\frac{R_{\text{initial}}}{R_{\text{final}}}\right)^2 = \left(1\,\text{rev/month}\right)\left(\frac{7\times10^8\,\text{m}}{1\times10^4\,\text{m}}\right)^2$$

$$= 4.9\times10^9\ \text{rev/month} = 4.9\times10^9\ \frac{\text{rev}}{\text{month}}\times\frac{1\,\text{month}}{30\,\text{d}}\times\frac{1\,\text{d}}{24\,\text{h}}\times\frac{1\,\text{h}}{3600\,\text{s}} = \boxed{1900\,\text{rev/s}}$$

37. The rotational kinetic energy is given by $\frac{1}{2}I\omega^2$. The final angular velocity, from problem 36, is about $4.9\times10^9\ \text{rev/month}$.

$$\frac{\text{KE}_{\text{final}}}{\text{KE}_{\text{initial}}} = \frac{\frac{1}{2}I_{\text{final}}\omega^2_{\text{final}}}{\frac{1}{2}I_{\text{initial}}\omega^2_{\text{initial}}} = \frac{\frac{2}{5}MR^2_{\text{final}}\omega^2_{\text{final}}}{\frac{2}{5}MR^2_{\text{initial}}\omega^2_{\text{initial}}} = \left(\frac{R_{\text{final}}\omega_{\text{final}}}{R_{\text{initial}}\omega_{\text{initial}}}\right)^2$$

$$= \left(\frac{\left(1\times10^{4}\,\text{m}\right)\left(4.9\times10^{9}\ \text{rev/month}\right)}{\left(7\times10^{8}\,\text{m}\right)\left(1\,\text{rev/month}\right)} \right)^2 = \boxed{4.9\times10^{9}}$$

38. The power output is the energy loss divided by the elapsed time.

$$P = \frac{\Delta\text{KE}}{\Delta t} = \frac{\frac{1}{2}I\omega^2\left(\text{fraction lost}\right)}{\Delta t} = \frac{\frac{1}{2}\frac{2}{5}MR^2\omega^2\left(\text{fraction lost}\right)}{\Delta t}$$

$$= \frac{1}{5}\frac{\left(1.5\right)\left(1.99\times10^{30}\,\text{kg}\right)\left(1.0\times10^{4}\,\text{m}\right)^2\left(2\pi\,\text{rad/s}\right)^2\left(1\times10^{-9}\right)}{\left(1\,\text{d}\right)\left(24\,\text{h/d}\right)\left(3600\,\text{s/h}\right)} = \boxed{2.7\times10^{25}\,\text{W}}$$

39. Use Newton's law of universal gravitation.

$$F = G\frac{m_1m_2}{r^2} = \left(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2\right)\frac{\left(3\times10^{41}\,\text{kg}\right)^2}{\left[\left(2\times10^{6}\,\text{ly}\right)\left(\frac{9.46\times10^{15}\,\text{m}}{1\,\text{ly}}\right)\right]^2} = 1.68\times10^{28}\,\text{N}$$

$$\approx \boxed{2\times10^{28}\,\text{N}}$$

40. (*a*) Assume that the nucleons make up only 2% of the critical mass density.

$$\text{nucleon mass density} = 0.02\left(10^{-26}\ \text{kg/m}^3\right)$$

$$\text{nucleon number density} = \frac{0.02\left(10^{-26}\ \text{kg/m}^3\right)}{1.67\times10^{-27}\ \text{kg/nucleon}} = 0.12\,\text{nucleon/m}^3$$

$$\text{neutrino number density} = 10^9\left(\text{nucleon number density}\right) = 1.2\times10^{8}\ \text{neutrino/m}^3$$

$$\frac{0.98\left(10^{-26}\ \text{kg/m}^3\right)}{1.2\times10^{8}\ \text{neutrino/m}^3} = 8.17\times10^{-35}\ \frac{\text{kg}}{\text{neutrino}}\times\frac{9.315\times10^{8}\ \text{eV}/c^2}{1.66\times10^{-27}\,\text{kg}} = \boxed{46\,\text{eV}/c^2}$$

(*b*) Assume that the nucleons make up only 5% of the critical mass density.

$$\text{nucleon mass density} = 0.05\left(10^{-26}\ \text{kg/m}^3\right)$$

$$\text{nucleon number density} = \frac{0.05\left(10^{-26}\ \text{kg/m}^3\right)}{1.67\times10^{-27}\ \text{kg/nucleon}} = 0.30\,\text{nucleon/m}^3$$

$$\text{neutrino number density} = 10^9\left(\text{nucleon number density}\right) = 3.0\times10^{8}\ \text{neutrino/m}^3$$

$$\frac{0.95\left(10^{-26}\ \text{kg/m}^3\right)}{3.0\times10^{8}\ \text{neutrino/m}^3} = 3.17\times10^{-35}\ \frac{\text{kg}}{\text{neutrino}}\times\frac{9.315\times10^{8}\ \text{eV}/c^2}{1.66\times10^{-27}\,\text{kg}} = \boxed{18\,\text{eV}/c^2}$$

41. The temperature of each star can be found from Wien's law.

$$\lambda_{\text{P}}T = 2.90\times10^{-3}\,\text{m}\bullet\text{K} \quad\rightarrow$$

$$T_{600} = \frac{2.90\times10^{-3}\,\text{m}\bullet\text{K}}{600\times10^{-9}\,\text{m}} = 4830\,\text{K} \qquad T_{400} = \frac{2.90\times10^{-3}\,\text{m}\bullet\text{K}}{400\times10^{-9}\,\text{m}} = 7250\,\text{K}$$

The luminosity of each star can be found from the H-R diagram.

$$L_{600} \sim 10^{26}\,\text{W} \qquad L_{400} \sim 10^{27}\,\text{W}$$

The Stefan-Boltzmann equation says that the power output of a star is given by $P = \beta A T^4$, where β is a constant, and A is the radiating area. The P in the Stefan-Boltzmann equation is the same as the luminosity L. Form the ratio of the two luminosities.

$$\frac{L_{400}}{L_{600}} = \frac{\beta A_{400} T_{400}^4}{\beta A_{600} T_{600}^4} = \frac{\pi r_{400}^2 T_{400}^4}{\pi r_{600}^2 T_{600}^4} \rightarrow \frac{r_{400}}{r_{600}} = \sqrt{\frac{L_{400}}{L_{600}} \frac{T_{600}^2}{T_{400}^2}} = \sqrt{\frac{10^{27}\,\text{W}}{10^{26}\,\text{W}} \frac{(4830\,\text{K})^2}{(7250\,\text{K})^2}} = 1.4$$

The diameters are in the same ratio as the radii.

$$\frac{d_{400}}{d_{600}} = \boxed{1.4}$$

The luminosities are fairly subjective, since they are read from the H-R diagram. Different answers may arise from different readings of the H-R diagram.

42. The number of parsecs is the reciprocal of the angular resolution in seconds of arc.

$$100\text{ parsec} = \frac{1}{\phi''} \rightarrow \phi = (0.01'')\left(\frac{1'}{60''}\right)\left(\frac{1^\circ}{60'}\right) \approx \boxed{(3\times10^{-6})^\circ}$$

43. From Eq. 27-16, we see that the wavelengths from single-electron energy level transitions are inversely proportional to the square of the atomic number of the nucleus. Thus the lines from singly-ionized helium are usually one fourth the wavelength of the corresponding hydrogen lines. Because of their red shift, the lines have four times their usual wavelength. Use Eq. 33-3.

$$\lambda = \lambda_0 \sqrt{\frac{1+v/c}{1-v/c}} \rightarrow 4\lambda_0 = \lambda_0 \sqrt{\frac{1+v/c}{1-v/c}} \rightarrow 16 = \frac{1+v/c}{1-v/c} \rightarrow \frac{v}{c} = \frac{15}{17} \rightarrow v = \boxed{0.88c}$$

44. From section 33-7, we can approximate the temperature – kinetic energy relationship by $\frac{3}{2}kT = \text{KE}$.

$$\tfrac{3}{2}kT = \text{KE} \rightarrow T = \tfrac{2}{3}\frac{\text{KE}}{k} = \tfrac{2}{3}\frac{(1.8\times10^{12}\text{eV})(1.60\times10^{-19}\text{ J/eV})}{1.38\times10^{-23}\text{ J/K}} = \boxed{1.4\times10^{16}\,\text{K}}$$

From Figure 23-25, this is in the $\boxed{\text{hadron era}}$.

45. We assume that gravity causes a centripetal force on the gas. Solve for the speed of the rotating gas, and use Eq. 33-5b to find the Doppler shift.

$$F_{\text{gravity}} = F_{\text{centripetal}} \rightarrow G\frac{m_{\text{gas}} m_{\text{black hole}}}{r^2} = \frac{m_{\text{gas}} v_{\text{gas}}^2}{r} \rightarrow$$

$$v_{\text{gas}} = \sqrt{G\frac{m_{\text{black hole}}}{r}} = \sqrt{(6.67\times10^{-11}\,\text{N}\bullet\text{m}^2/\text{kg}^2)\frac{(2\times10^9)(1.99\times10^{30}\,\text{kg})}{(60\,\text{ly})\left(\frac{9.46\times10^{15}\,\text{m}}{1\,\text{ly}}\right)}} = 6.84\times10^5\text{ m/s}$$

$$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c} = \frac{6.84\times10^5\text{ m/s}}{3.00\times10^8\text{ m/s}} \approx \boxed{2\times10^{-3}}$$

This is the Doppler shift as compared to the light coming from the center of the galaxy.

46. (*a*) Use Eqs. 33-4 and 33-5a to solve for the speed of the galaxy.

$$\Delta\lambda = 650\,\text{nm} - 434\,\text{nm} = 216\,\text{nm}$$

$$z = \frac{\Delta\lambda}{\lambda_0} = \sqrt{\frac{1+v/c}{1-v/c}} - 1 \quad \rightarrow$$

$$\frac{v}{c} = \frac{\left(\frac{\Delta\lambda}{\lambda_0}+1\right)^2 - 1}{\left(\frac{\Delta\lambda}{\lambda_0}+1\right)^2 + 1} \qquad \frac{v}{c} = \frac{\left(\frac{216\,\text{nm}}{434\,\text{nm}}+1\right)^2 - 1}{\left(\frac{216\,\text{nm}}{434\,\text{nm}}+1\right)^2 + 1} = \frac{1.243}{3.243} = 0.383c \quad \rightarrow \quad v \approx \boxed{0.383\,c}$$

(*b*) Use Hubble's law, Eq. 33-6, to solve for the distance.

$$v = Hd \quad \rightarrow \quad d = \frac{v}{H} = \frac{\frac{v}{c}}{\frac{H}{c}} = \frac{0.383}{\frac{(22000\,\text{m/s/Mly})}{3.00\times10^8\,\text{m/s}}} = 5.22\times10^3\,\text{Mly} \approx \boxed{5.2\times10^9\,\text{ly}}$$

47. (*a*) Find the *Q*-value for this reaction. From Equation 30-2, the *Q*-value is the mass energy of the reactants minus the mass energy of the products.

$${}^{12}_{6}\text{C} + {}^{12}_{6}\text{C} \rightarrow {}^{24}_{12}\text{Mg}$$

$$Q = 2m_\text{C}c^2 - m_\text{Mg}c^2 = \left[2(12.000000\,\text{u}) - 23.985042\,\text{u}\right]c^2\left(931.5\,\text{Mev}/c^2\right) = \boxed{13.93\,\text{MeV}}$$

(*b*) The total kinetic energy should be equal to the electrical potential energy of the two nuclei when they are just touching. The distance between the two nuclei will be twice the nuclear radius, from Eq. 30-1. Each nucleus will have half the total kinetic energy.

$$r = \left(1.2\times10^{-15}\,\text{m}\right)(A)^{1/3} = \left(1.2\times10^{-15}\,\text{m}\right)(12)^{1/3} \qquad \text{PE} = \frac{1}{4\pi\varepsilon_0}\frac{q^2_\text{nucleus}}{2r}$$

$$\text{KE}_\text{nucleus} = \tfrac{1}{2}\text{PE} = \tfrac{1}{2}\frac{1}{4\pi\varepsilon_0}\frac{q^2_\text{nucleus}}{2r}$$

$$= \tfrac{1}{2}\left(8.988\times10^9\,\text{N}\bullet\text{n}^2/\text{C}^2\right)\frac{(6)^2\left(1.60\times10^{-19}\,\text{C}\right)^2}{2\left(1.2\times10^{-15}\,\text{m}\right)(12)^{1/3}} \times \frac{1\,\text{eV}}{1.60\times10^{-19}\,\text{J}} = \boxed{4.71\,\text{MeV}}$$

(*c*) We can approximate the temperature – kinetic energy relationship by $\frac{3}{2}kT = \text{KE}$.

$$\tfrac{3}{2}kT = \text{KE} \quad \rightarrow \quad T = \tfrac{2}{3}\frac{\text{KE}}{k} = \tfrac{2}{3}\frac{\left(4.71\times10^6\,\text{eV}\right)\left(\frac{1.60\times10^{-19}\,\text{J}}{1\,\text{eV}}\right)}{1.38\times10^{-23}\,\text{J/K}} = \boxed{3.6\times10^{10}\,\text{K}}$$

48. (*a*) Find the *Q*-value for this reaction. From Equation 30-2, the *Q*-value is the mass energy of the reactants minus the mass energy of the products.

$${}^{16}_{8}\text{C} + {}^{16}_{8}\text{C} \rightarrow {}^{28}_{14}\text{Si} + {}^{4}_{2}\text{He}$$

$$Q = 2m_\text{C}c^2 - m_\text{Si}c^2 - m_\text{He}c^2 = \left[2(15.994915\,\text{u}) - 27.976927\,\text{u} - 4.002603\right]c^2\left(931.5\,\text{Mev}/c^2\right)$$

$$= \boxed{9.954\,\text{MeV}}$$

(*b*) The total kinetic energy should be equal to the electrical potential energy of the two nuclei when they are just touching. The distance between the two nuclei will be twice the nuclear radius, from Eq. 30-1. Each nucleus will have half the total kinetic energy.

$$r = \left(1.2\times10^{-15}\,\mathrm{m}\right)\left(A\right)^{1/3} = \left(1.2\times10^{-15}\,\mathrm{m}\right)\left(16\right)^{1/3} \qquad \mathrm{PE} = \frac{1}{4\pi\varepsilon_0}\frac{q_{\mathrm{nucleus}}^2}{2r}$$

$$\mathrm{KE}_{\mathrm{nucleus}} = \tfrac{1}{2}\mathrm{PE} = \tfrac{1}{2}\frac{1}{4\pi\varepsilon_0}\frac{q_{\mathrm{nucleus}}^2}{2r}$$

$$= \tfrac{1}{2}\left(8.988\times10^{9}\,\mathrm{N{\bullet}n^2/C^2}\right)\frac{(8)^2\left(1.60\times10^{-19}\,\mathrm{C}\right)^2}{2\left(1.2\times10^{-15}\,\mathrm{m}\right)\left(16\right)^{1/3}}\times\frac{1\,\mathrm{eV}}{1.60\times10^{-19}\,\mathrm{J}} = \boxed{7.61\,\mathrm{MeV}}$$

(*c*) We can approximate the temperature – kinetic energy relationship by $\tfrac{3}{2}kT = \mathrm{KE}$.

$$\tfrac{3}{2}kT = \mathrm{KE} \;\rightarrow\; T = \tfrac{2}{3}\frac{\mathrm{KE}}{k} = \tfrac{2}{3}\frac{\left(7.61\times10^{6}\mathrm{eV}\right)\left(\dfrac{1.60\times10^{-19}\,\mathrm{J}}{1\,\mathrm{eV}}\right)}{1.38\times10^{-23}\,\mathrm{J/K}} = \boxed{5.9\times10^{10}\,\mathrm{K}}$$

49. We use the Sun's mass and given density to calculate the size of the Sun.

$$\rho = \frac{M}{V} = \frac{M}{\tfrac{4}{3}\pi r_{\mathrm{Sun}}^3} \quad\rightarrow$$

$$r_{\mathrm{Sun}} = \left(\frac{3M}{4\pi\rho}\right)^{1/3} = \left[\frac{3\left(1.99\times10^{30}\,\mathrm{kg}\right)}{4\pi\left(10^{-26}\,\mathrm{kg/m^3}\right)}\right]^{1/3} = 3.62\times10^{18}\,\mathrm{m}\left(\frac{1\,\mathrm{ly}}{9.46\times10^{15}\,\mathrm{m}}\right) = 382\,\mathrm{ly} \approx \boxed{400\,\mathrm{ly}}$$

$$\frac{r_{\mathrm{Sun}}}{d_{\mathrm{Earth\text{-}Sun}}} = \frac{3.62\times10^{18}\,\mathrm{m}}{1.50\times10^{11}\,\mathrm{m}} \approx \boxed{2\times10^{7}} \;;\; \frac{r_{\mathrm{Sun}}}{r_{\mathrm{galaxy}}} = \frac{382\,\mathrm{ly}}{50{,}000\,\mathrm{ly}} \approx \boxed{8\times10^{-3}}$$