1. The Sun emits energy at a rate of $L_\odot = 3.9 \times 10^{26}$ W. At any distance from the Sun d, the energy flux from the Sun can be determined by recognizing that the luminosity is uniformly distributed over the surface area of an imaginary sphere with radius d and area $4\pi d^2$.

   a). Determine the solar flux at Earth, $d = 1.496 \times 10^{11}$ m. The solar flux at Earth is called the solar constant.
   b). At what distance from a 100 W light bulb is the energy flux equal to the solar constant?
   c). Calculate the total power that Earth receives from the Sun.

2. The mean densities of stars can vary by enormous factors. For purposes of illustration, calculate the mean densities for each of the following:

   a). the Sun,
   b). the supergiant star Betelgeuse, with a mass of 10 $M_\odot$ and a radius of 300 $R_\odot$,
   c). a 1.4 $M_\odot$ white dwarf, with a radius of 5×10^7 m, and
   d). a 1.4 $M_\odot$ neutron star, with a radius of 2×10^4 m.

3. You are to make use of observational data in order to make a table of the luminosities, surface temperatures, radii, and mean densities of main-sequence stars of 50, 1.0, and 0.1 solar masses. Show your calculations, or, at least, examples of your calculations.

   a). With the aid of the mass-luminosity relation $(L / L_\odot) = (M / M_\odot)^3$ and the Hertzsprung-Russell diagram, tabulate the luminosities (in units of the solar luminosity) and surface temperatures of stars of 50, 1.0, and 0.1 solar masses.
   b). With the aid of Stefan-Boltzmann law, $L = 4\pi R^2 \sigma T^4$, determine the radii (in units of solar radius) of stars of 50, 1.0, 0.1 solar masses.
   c). Calculate the mean densities of stars of the three masses in kg / m^3.
   d). In a simple sentence, describe the qualitative relationship between the mass and mean density of a star that is indicated by your results. (In other words, what is the trend in the variation of the mean densities of stars with their masses?

4. In our class discussions, it was shown that, if the mass M of a main-sequence star is known, then the luminosity L, the surface temperature T, and the radius R of the star can be determined with the aid of the mass-luminosity relation, the Hertzsprung-Russell diagram, and the Stefan-Boltzmann law, respectively. The point really is that, if any one of the four quantities (M, L, T, R) is known for a main-sequence star, then the other three quantities can be determined. For example, assume that the surface temperature T of a certain main-sequence star is known, and describe the steps by which you would determine the mass, luminosity, and radius. Illustrate your methods with sketches of the HR diagram and mass-luminosity relation and with appropriate algebraic formulae as required.

5. The average person has 1.4 m^2 of skin at skin temperature of roughly 306 K. Consider the average person to be an ideal radiator.

   a). Calculate the power radiated by the average person in the form of blackbody radiation. Express your answer in watts.
   b). Determine the peak wavelength λ_{max} of the blackbody radiation emitted by the average person. In what region of the electromagnetic spectrum is this wavelength found?

6. Consider two of the brighter stars in the night sky. Betelgeuse has a surface temperature of 3,400 K, while Rigel has a surface temperature of 10,100 K. Apply Wien's Law and calculate the wavelengths of maximum emission λ_{max} and identify the corresponding regions of the electromagnetic spectrum.

7. Consider a model for the star Dschubba, the center star in the head of the constellation Scorpius, consisting of a spherical blackbody with a surface temperature of 28,000 K and a radius of 5.16 x 10^9 m. If the star is located at a distance of 180 pc from Earth. Determine the following for the star:

   a). Luminosity.
   b). Energy flux (radiant flux) at the star's surface.
   c). Radiant flux at Earth's surface and compare with the solar constant.
   d). Peak wavelength, λ_{max}.

8. Bohr derived the formula

$$E_n = -\frac{2\pi^2}{h^2}\frac{m_e e^4}{n^2}$$

   for the energy of a hydrogen atom in the state with quantum number n. This formula that gives the energy of the atom in the nth energy level, starting with this formula, and using appropriate relationships between energy and wavelength, derive a formula for the wavelength λ of the electromagnetic radiation emitted when an electron falls from a higher level E_n to a lower level E_m. [CGS units]

9. Using the formula you derive from (8), calculate the wavelengths corresponding to the first possible downward electron transitions in the Lyman, Balmer, and Paschen series for hydrogen. Identify the regions of the electromagnetic spectrum in which these wavelengths are to be found.

10. Let assume that the Bohr model can also explain the pattern of singly ionized helium (i.e. a helium atom with only one electron) spectral features. Draw an energy level diagram of the singly ionized helium ion. The energy level of the helium ion can be calculated with the following formula:

$$E_n = -\frac{2Z^2\pi^2}{h^2}\frac{m_e e^4}{n^2}$$

where Z is the atomic number (Z = 2, for helium). Your diagram should indicate the helium "Lyman, Balmer, and Paschen" series. What is the ionization energy for the remaining electron? What is the wavelength of the ionizing photon? [CGS units]

11. Calculate the energy of the following photons in eV and Joules.

    a). Radio wave with λ = 10 m.
    b). Microwave with λ = 0.001 m.
    c). Infrared wave with $\lambda = 10^{-5}$ m.
    d). X-ray with $\lambda = 10^{-10}$ m.

12. The object 3C 273 is a "stellar-like" source of light located at the position of a strong radio source. Its spectrum contains a series of bright spectral lines that, prior to 1963, no one was able to identify. In 1963, a breakthrough occurred when Martin Schmidt at Caltech, realized that four of these lines were simply Balmer lines of hydrogen that were significantly redshifted. Two of these features were found at wavelengths of 7546 Å and 5590 Å. Show that these two features are compatible with the conclusion that they correspond to the first two transitions of the Balmer series (H_α and H_β) and determine the velocity with which 3C 273 is moving away from us. To what fraction of the speed of light does its velocity correspond?

13. Why do you think police radars are designed to work at high frequencies [36 billion hertz (GHz)]-- what would be the difficulty if speed trap radars worked at frequencies in, for example, the AM radio band? [Hint: Compute the wavelength of a radio wave in the AM band, at say 1,500 kilohertz (kHz), and compare the result with the typical size of the object whose speed is being measured.]

14. When Tycho Brahe (1546 - 1601) studied the heliocentric model of the solar system proposed by Copernicus, he understood that the model predicts that the apparent positions of nearby stars in the sky should shift periodically as the Earth moves around the Sun. This is an observable effect that he was interested in detecting-- stellar parallax. Tycho was a gifted observer, able to measure the apparent positions of stars in the sky, and hence shifts in the apparent positions, to within one arcminute. He was unable to detect the parallactic shifts in the positions of stars. What does the null result imply about the distances of the stars, if the heliocentric model is correct? In particular, what is the minimum distance to the stars that is implied by Tycho's result?

15. Consider a star, which is observed to have a parallax of 0.01 arcsecond. Determine the distance to this star, both in AU and in meters.

16. M_v = absolute visual magnitude; m_v = apparent visual magnitude.

a). K0V star has a parallax of 0.15 arcsecond and $m_v = +5.2$ and $B\text{-}V = 0.8$. What is its absolute visual magnitude?
b). An F0V star has a parallax of 0.01 arcsecond and $m_v = +8.0$ and $B\text{-}V = 0.3$. What is its absolute visual magnitude?
c). A cluster of stars is found that yields a well-defined main sequence. Stars with $B\text{-}V = 0.3$ have $m_v = 12$; stars with $B\text{-}V = 0.8$ have $m_v = 15$. How far away is the cluster?
d). Another cluster is found, with main sequence stars that have $B\text{-}V = 0.8$ at $m_v = 18$. No stars on the main sequence have $B\text{-}V = 0.3$. How far is this cluster?
e). The cluster in (d) has RR Lyrae variable stars with $m_v = 12$. What is the absolute visual magnitude for these variables?
f). A nearby dwarf galaxy has variable stars with the same periods (~0.5 days) as those of the cluster of (d). The stars of the dwarf galaxy have $m_v = 23$. What is the distance of the galaxy?
g). The galaxy in (f) has longer period variables as well. The apparent visual magnitude of variables with periodic light variations $P = 40$ days is 18.0. Find the absolute visual magnitude for these long period variables.
h). A distance galaxy has Cepheid variables ($P = 40$ days) with $m_v = 25$. What is the distance of the galaxy?
i). The galaxy of (h) has a number of H II regions (H_α emitting gas around a cluster of 50 - 100 O stars). The brightest of these has a total integrated apparent magnitude of 18. What is the absolute magnitude for this brightest H II region?
j). A galaxy has 25 H II regions, the brightest has a total integrated apparent magnitude of 22, the faintest being 26th magnitude. How far is the galaxy? [Note that observing the faintest ones would require the Hubble Space Telescope.]
k). The galaxy of (j) was the site of a Type I supernova 10 years ago. It was determined that there was no reddening. It reached $m_v = 15$ at its brightest point within one day of discovery. What is M_v for the supernova?
l). A Type I supernova found in a faint galaxy reached $m_v = 17.5$ before fading. If all such supernova have the same peak brightness, and if this one is free of reddening, what is the distance to the faint galaxy?

17. A large spiral galaxy (A) is seen edge-on, and a small irregular galaxy (B) lies directly in lie with the galactic disk, so the disk and the irregular galaxy fit into the slit of a spectrograph. The emission line of [O III] at 5007 Å is observed. The center of the disk gives λ[O III] = 5407 Å, the edges of the disk give 5403 Å and 5411 Å. The disk in visible light extends 10 arcseconds on the sky. The irregular galaxy is 30 arcseconds from the center and the [O III] line appears at 5411 Å.

a). Sketch the galaxies, indicating relative distances and motions.
b). What is the distance to the pair?
c). What is the rotation speed at the edge of the disk?
d). What is the total mass of the large galaxy?

e). Another companion (C) appears 30 arcseconds on the other side of A from B, with [O III] at 5407 Å. What can you conclude about its motion?

18. This problem is concerned with the simple derivation of Kepler's Law:

$$m_1 + m_2 = \frac{4\pi^2}{G}\frac{R^3}{P^2}$$

a). Draw a picture of two stars rotating around the center of mass, so $m_1 r_1 = m_2 r_2$.
b). Equate the central force on star 1 to the gravitational force between the stars. The force acts over a distance of $R = r_1 + r_2$.
c). Noting that both stars have the same orbital period, $P = P_1 = P_2 = \frac{2\pi r_1}{v_1} = \frac{2\pi r_2}{v_2}$, solve for v_1 in terms of P and r_1 . Substitute for v_1 in part (b).
d). Note that $R = r_1(1 + \frac{r_2}{r_1})$.
e). Now solve for r_2 / r_1 from the center of mass definition, in terms of m_1 and m_2 , and substitute for r_2 / r_1 in part (d) with the relevant mass ratio. Solve for r_1 in terms of R, m_1, and m_2.
f). Group constants and R on one side, and terms in m and P on the other. Note that $m_1 + m_2 \equiv M$.

19. A hunter points his gun barrel directly at a monkey in a distant palm tree. Will the bullet follow the line of sight along the barrel. Explain. Will the monkey, startled by the flash, help itself by dropping out of the tree at the very instant of firing? Explain.

20. We showed that the pressure at the center of a main sequence star is given by the expression

$$P_c = \frac{3}{8\pi}\frac{GM^2}{R^4}$$

where G (= 6.67 x 10^{-11} Nm^2 / kg^2) is the gravitational constant, M is the mass of the star, and R is the radius of the star.

The pressure attributable to an ideal gas is given by

$$P = N_o k \frac{\rho T}{\mu}$$

where ρ is the mass density, T is the temperature, μ is the mean molecular mass per particle, N_o (= 6.02 x 10^{23} molecules / mole) is the Avogadro's number, and k (= 1.38 x 10^{-23} J / K) is the Boltzmann's constant.

a). Assuming the ideal gas pressure is a good approximation to the pressure at the center of main sequence star, equate the two expressions for pressure above, and show that the central temperature is given by

$$T_c = \frac{G\mu M}{2N_o kR} \ .$$

b). Estimate the central temperature of the Sun, with μ = 0.5.

21. Early experimental studies of the scattering of α-particles (the nuclei of helium atoms) served to provide important constraints on the size and structure of the nuclei of atoms. In this context, we can determine a plausible upper limit for the effective size of a gold nucleus from the following facts and hypotheses:

i). A beam of α-particles with average velocity v_o = 2 x 10^7 m / s is scattered from a gold foil in a manner only if the α-particles were repelled by nuclear charges that exert a Coulomb's repulsion on the α-particles.
ii). Some of the α-particles come straight back after scattering. They therefore approached the nuclei up to a distance r from the nucleus' center, when the initial kinetic energy has been completely changed to the potential energy of the system.
iii). The potential energy of the system is given by

$$E = (9x10^9)\frac{Zq_e}{r}(2q_e)$$

where ($2q_e$) is the total charges of a α-particle, (Zq_e / r) is the nucleus electric potential at distance r.

Now, you can compute the distance r, by equating the kinetic and potential energies. The mass of an α-particle is 7 x 10^{-27} kg, the nuclear charge Z for gold is 79, and q_e = 1.6 x 10^{-19} C. The nucleus radius must be equal or less than r. Thus we have a plausible upper limit for the size of gold nucleus. How does this compare to a typical size of an atom?

22. The first observed nuclear transformation (obtained by Rutherford in 1919) was the reaction:

$$^{14}N \quad + \quad ^{4}He \quad \rightarrow \quad ^{17}O \quad + \quad ^{1}H.$$

The atomic masses for these elements are:

^{14}N:	14.0030744 amu
^{17}O:	16.9991333 amu
^{4}He:	4.00260326 amu
^{1}H:	1.00782522 amu

where the units are 1 amu = 1.66×10^{-27} kg.

a). Determine whether the energy is absorbed or released in the reaction.
b). Calculate the amount of energy (absorbed or released) in this reaction.

23. Using the masses given in problem (22), compare the mass of a ^{4}He atom with the sum of masses of four H atoms.

    a). Calculate the amount of energy released in the reaction.
    b). Determine how many such reactions per second are required to provide the Sun's luminosity.

24. Estimate the main sequence lifetime for a 100 solar mass, 10 solar mass, 1 solar mass, 0.1 solar mass, and a 0.01 solar mass main sequence star. When a star goes through the main-sequence phase, does its luminosity remain constant? Explain.

25. What internal physical changes within a main sequence star when it is almost exhausted its hydrogen fuel in its core? What will be the "main" energy source after hydrogen-burning?

26. A nova binary system consists of a low mass ($0.5 M_\odot$) main sequence star and a white dwarf ($1\ M_\odot$) in orbit about their common center of mass. The orbital period of such a system is typical P ~ 4 hours.

    a). Estimate the mean orbital separation for this system. Compare the result with the radius of the Sun and with that of a $0.5\ M_\odot$ main sequence star.
    b).When the nova explosion occurs, the hydrogen burning shell on the white dwarf provides a luminosity of $3 \times 10^4\ L_\odot$. Observationally, the nova at the peak of its outburst appears as a giant star of surface temperature of 10,000 K and luminosity of $3 \times 10^4\ L_\odot$. Using Stefan-Boltzmann Law, determine the radius of the "giant" and compare it to the original dimensions of the system. Where is the main sequence companion star now?

27. A nova outburst occurs when hydrogen-rich matter, which has been transferred to the surface of the white dwarf star from its binary companion, is ignited and burns violently. (Here it is again the CNO-cycle reactions that are involved in hydrogen burning.) Typically, approximately $10^{-6}\ M_\odot = 2 \times 10^{24}$ kg of hydrogen are burned into helium in such an event. Recall that the burning of hydrogen to helium releases approximately 7 MeV / nucleon = 1.1×10^{-12} J / nucleon.

    a). What is the total amount of energy released (in Joules) in the "burning" of $10^{-6}\ M_\odot = 2 \times 10^{24}$ kg of hydrogen to helium? (Remember that one gram of matter contains Avogadro's number of protons and neutrons.)
    b). The nova is powered by energy generation from hydrogen burning at a luminosity of approximately $3 \times 10^4\ L_\odot$. For how long can the total energy calculate in part (a) provide this luminosity? (Give your answer in years.)

28. This problem is concerned with the relationship between the mass and radius for a white dwarf or a neutron star. Recall that we have derived an expression for the central pressure necessary to maintain a star in hydrostatic equilibrium against the force of gravity:

$$P_c = \frac{3}{8\pi}\frac{GM^2}{R^4} \ .$$

For the case of a degenerate electron gas, the pressure is given by:

$$P_c = k_{wd}\,\rho_c^{5/3}$$

where k_{wd} = 3.1 x 10^6, for a typical He or CO white dwarf. Equating these two expressions for the central pressure, show that the radius R of a white dwarf is related to its mass by:

$$R = \frac{2k_{wd}}{G}\left(\frac{3}{4\pi}\right)^{2/3}\frac{1}{M^{1/3}} \ .$$

When the mass of the white dwarf increases, does the radius increase or decrease? (Note that a similar equation can be derived for the case of a neutron star, the difference is that the value of the corresponding constant k_{ns} = 5.4 x 10^3.)

29. The Schwarzschild radius R_{Sch} for a black hole with mass M corresponds to the radius at which the escape velocity is equal to the velocity of light. Use the equation for escape velocity, show that the Schwarzschild radius of a black hole is given by:

$$R_{Sch} = \frac{2GM}{c^2} \ .$$

30. The expressions derived in the two previous problems now allow us to estimate some basic properties of stellar remnants. We will consider specifically the cases of white dwarf, neutron star, and black hole remnants of 1.4 solar mass (the Chandrasekhar Limit). It might be useful here to make a table of the quantities you calculate.

A). Calculate the radii (in meters) for a white dwarf, a neutron star, a black hole of 1.4 solar mass.
b). Calculate the gravitational energy released (in Joules) in the formation of the corresponding remnants.
c). Calculate the densities of the corresponding remnants.

31. Recent studies of the abundances in one extremely metal deficient star (a star with an iron abundance less than 1/1000th that of the Sun) reveal the presence of the element thorium. This implies the presence of the long lived isotope ^{232}Th, with a radioactive half life of $\tau_{1/2}$ = 1.4 x 10^{10} years. Numerical studies of the r-process of nucleosynthesis in which ^{232}Th is formed reveal that the ratio of the two elements thorium to europium at the site of formation is [Th / Eu] = 0.463. The corresponding ratio in the halo star CS 22892-052 is [Th / Eu] = 0.219. The element Eu is stable. The change (reduction in the [Th / Eu] ratio in the star must therefore result from the decay of the thorium over the lifetime of the star. We can calculate the abundance of a radioactive species as a function of time is:

$$N(t) = N(t=0)e^{-0.693\frac{t}{\tau_{1/2}}}$$

Calculate the age of this star. What does this imply for the age of the Universe?

32. The mean color index <*B* - *V*> for an observed star cluster is 1.20, and the mean color index for the main-sequence turn-off is 0.90. The mean apparent visual magnitude for G2V stars in this cluster is 20.0.

a). How far away is this cluster? [M_v(G2V) = 5.0]
b). What spectral type of stars at the main-sequence turn-off? What is the mean spectral type of stars for this star cluster?
c). What is the average mass for stars near the main-sequence turn-off?
d). What is the age of this star cluster?
e). What underlying assumption(s) for the estimate of the age of this cluster?…

33. Synchronized clocks are stationed at regular intervals, 10^6 km apart, along a straight line. When the clock next to you reads 12 noon.

a). What time do you *see* on the 90th clock down the line?
b). What time do you *observe* on that clock?

34. A rocket ship leaves Earth at a speed of 0.6 c. when a clock on the rocket says 1 hour has elapsed, the rocket sends a light signal back to Earth.

a). According to Earth clocks, when was the signal sent?
b). According to Earth clocks, how long after the rocket left did the signal arrive back to Earth?
c). According to the rocket observer, how long after the rocket left did the signal arrives back on Earth?

35. Sophia Zabar, clairvoyant, cried out in pain at precisely the instant her twin brother, 500 km away, hit his thumb with a hammer. A skeptical scientist observed both events (brother's accident, Sofia's cry) from an airplane travelling at 12/13 c away from Sofia's brother location and heading towards Sophia

location. Which event occurred first, according to the scientist? How *much* earlier was it, in seconds?

36. After an engagement with a Borg scout vessel, starship Voyager with only its impulse engine working, try to escape from the damage Borg scout vessel, with velocity of 0.75 c. The damage Borg scout vessel which could travel at 0.5 c, fire a plasma beam towards Voyager. The beam velocity is 1/3 c. Will Voyager being hit by the plasma beam

    a). according to Galileo,
    b). according to Einstein?

37. Show that in Special Relativity

$$(\Delta x')^2 = (\Delta x)^2 - (\Delta t)^2$$

the same for all reference frames.

38. A galaxy containing hot stars and H II regions at v_{rec} = 10,000 km /s emits H_α photons equivalent to 10^7 solar luminosities. Calculate the amount of photons (in number) and energy received by a 1 m telescope on Earth in a second.

    a). Write the equation for detected photons from a distant source (luminosity in photons, divided by the area of a sphere with radius equal to the Earth-galaxy distance, times the collecting area.
    b). Find the galaxy distance with Hubble Law.
    c). Modify the detected photon rate for Doppler Effect [f'= fγ (1-v)], where f is the photon per second (and energy per second) assuming no recession velocity, f' is the value for moving objects and v is the velocity in units of c, the speed of light. Find f' , in photon per second.
    d). Now, convert the "photon flux" f' to energy per second. Recall $E = h\nu$, where the Planck constant $h = 6.625 \times 10^{-34}$ J-s, and ν is the photon frequency which must be converted for Doppler shift as well. (Why?)

39. Time dilation and length contraction problem.

    a). A moving observer flashes two flashlights on at the same time, holding one in each hand, separated by 1.5 m. How far apart are the beams according to the fixed observer if the moving observer is moving with a speed of 0.96 c?
    b). A space ship moves toward a fixed observer, A. The captain flashes a light twice, 3 seconds separate the flashes according to the captain's clocks. How far apart are the flashes as seen by A if the spaceship moves at 0.8 c?
    c). An object falls from 10 Mpc to a point r near a black hole of 5.75×10^{12} $M_\odot$. What is r, when $\gamma = 5/3$? Give your answer in parsecs.

d). A pulsar at a distance of 20 pc from Earth moves 3 arcseconds per year. Is the motion relativistic to an Earth observer?

40. A jet is beamed toward Earth at 20,000 km / s from a galaxy at $z = 1$. H_α photons, which appear at $\lambda = 6563$ Å in a lab on Earth are emitted by recombining hydrogen atoms in the jet.

a). At what wavelength do they appear to an Earth observer? [Hint: First, assume the object is at $z = 0$ and use the relativistic redshift. Then , imagine the object at $z = 1$ and recall that in the expanding Universe, all length scales increase with expansion, including wavelengths.]
b). At what wavelength does an observer at the center of the galaxy, from which the jet originates, see the H_α photons.

41. Atoms fall from 10 Mpc towards a $10^6\ M_\odot$ black hole. Assume they go into orbit at 100 AU and collide with other atoms, so the energy of motion is randomized.

a). What temperature will the resulting gas achieves? [Hint: Compute the change in potential energy for each atom, then equate that to the change in kinetic energy times -1. Then recall that for a gas in equilibrium, $(1/2)mv^2 = (3/2)kT$, k is the Boltzmann constant, m is the mass of the atoms or ions (assume they are protons)].
b). As the gas heats up, at what temperature will all the atoms be ionized if they are hydrogen. [$E_{ionization} = 13.6$ eV]

42. The scale factor is $a = 1/(1 + z)$. It gives the relative size of entities in the expanding Universe (outside the regions of strong gravitational fields where galaxies are bound to massive objects and not free to participate in the Universal expansion.). All lengths, including wavelengths, scale accordingly.

a). Give the size of what will be a 50 Mpc void today at the time we see it, if a galaxy at its edge has a redshift of 1.
b). Two small galaxies at $z = 2$ are separated by 3 Mpc. How far are they apart today?

43. The Newtonian crisis (the mathematical impossibility of an expanding Universe with $E = 0$, if space expands linearly with time) is avoided by making the scale factor $a \propto t^{2/3}$.

a). When the scale factor is 1/2 ($z = 1$), at what age are we seeing the Universe?
b). When the scale factor is 1/6 ($z = 5$), at which age do we see objects at that redshift?
c). What is the lookback times ($t_o - t$) in parts (a) and (b)?
d). Could heavy elements exist before $z = 3$, if heavy elements are made only in stars? From Type II supernovas? From Type I supernovas?
e). Starting at $z = 3$, how much time passes to $z = 1$?

f). At what redshift are we seeing objects as they appeared when Earth formed?

44. In a closed Universe,

$$H^2 = \frac{8\pi G\rho}{3} \ .$$

a). If H_o = 65 km / s / Mpc today, calculate ρ_o.
b). If there were one galaxy with M_v = -22 every 5 Mpc, and if no other galaxies were in existence, and if the galaxies are made of G2V stars (predominantly). What is the mean density of matter in star-material (usually called luminous matter).
c). What is the implication of the difference in parts (a) and (b)?
d). What was the mean density at z = 3?

45. In the expanding Universe, at what temperature is the radiation when z = 30. Is hydrogen ionized or neutral? At what wavelength would the Lyα photons appear? [λ(Lyα) = 1216 Å]

46. Assume the speed of light is constant in all reference frames to all observers. Compute the lookback time for the following events? For each item, describe the conditions on Earth at that time, in a few words.

a). A supernova in a galaxy 10 Mpc away.
b). A nova in a cluster 1 kpc away.
c). A galaxy at the edge of the observable Universe.
d). A supernova in a galaxy 50 kpc away.
e). Birth of an O star in a galaxy 3 Mpc distant.

47. Consider the special redshifts of z = 0, 0.6, 3, 5, 20, 1000, & 10^6. What is special about these? To find out, calculate and tabulate the following:

a). T = radiation temperature
b). t = age of the Universe
c). ρ = total matter density in (eV / cm^3)
d). ρ_l = luminous matter density (eV / cm^3)
e). ρ_r = radiation energy density (eV / cm^3)
f). R = the horizon size (ct)
g). hc/λ_{max} = energy of photons at the peak of the blackbody curve (eV)

48. A 5 kpc diameter galaxy is observed at z = 1 and a similar size galaxy is observed at z = 5. What are their angular diameters as seen from Earth? [Hint: Find their distances at the time the light was emitted $r = Ro$.]

49. The following are expressions for calculating the Jean's mass and Jean's radius:

$$M_J = 100T\sqrt{\frac{T}{n_H}}\ M_\odot ,$$

and

$$R_J = 10\sqrt{\frac{T}{n_H}}\ \text{pc} ,$$

where T is the temperature of the gas in kelvin, and n_H is the number of atoms per cubic centimeters. Calculate the Jean's mass and Jean's radius and identify the astronomical environments for the following conditions.

a). $n_H = 1000\ \text{cm}^{-3}$, $T = 10$ K
b). $n_H = 1\ \text{cm}^{-3}$, $T = 10{,}000$ K
c). $n_H = 0.1\ \text{cm}^{-3}$, $T = 6{,}000$ K

50. After $z = 1000$, the radiation cools as $1 + z$ but the matter, no longer tied tot he radiation cools faster, as $(1+ z)^2$. If the Universe is completely homogeneous, what is the lowest z at which a 100 solar mass star can form?

51. The average number density of hydrogen today in the Universe is $10^{-5}\ \text{cm}^{-3}$. What is the Jean's mass and Jean's radius at recombination ($z \sim 1{,}000$, $T \sim 3{,}000$ K)? Can you identify what kind of objects will have this mass and size?

52. What are the standard problems in the Big Bang Model before 1970s?

53. What is Inflationary Cosmologies?

54. What are MACHOs and WIMPs? Give examples. Are there any searches for MACHOs and WIMPs?

55. What is the dark matter problem?

56. What is the Hubble constant? What are the latest measurements of Hubble constant? (Cited three different results.)What implication(s) for a large value of Hubble constant?

57. Define the luminosity function of galaxies. What is the use of luminosity function of galaxies in observational cosmology?

58. Design an observational program to study galaxy evolution. We may need to address the following questions:

a). What is the density-morphology relationship?
b). Could we explain morphology of galaxies?
c). Was there an epoch of galaxy formation?

d). How do we relate observations of nearby galaxies to distant galaxies?
e). Are there differences in evolution for galaxies in clusters and galaxies in the field?
f). Do we need to consider galaxies in Voids?

59. What are QSO absorption lines systems? What are *standard* classifications for these systems?

60. Briefly describe procedures to obtain astronomical images with a CCD camera from a telescope and processing theses images within IRAF.

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