ASTRONOMY 2 — Overview of the Universe
Second Practice Problem Set — Solutions

Problem: 1. Consider a 2 $M_\odot$ neutron star. The mass of a neutron is 1.67×10^{-24} g, and 1 $M_\odot = 2 \times 10^{33}$ g.

(i) How many neutrons are in this neutron star? (*1 point*)

Solution:
$N_{neutrons} = M_*/m_{neutron}$
$N_{neutrons} = 2 \times 2 \times 10^{33}\text{g}/1.67 \times 10^{-24}$ g
$N_{neutrons} = (4/1.67) \times 10^{57} = 2.4 \times 10^{57}$ neutrons, **D**

A. 6.0×10^{23} neutrons
B. 1.2×10^{23} neutrons
C. 1.2×10^{57} neutrons
D. 2.4×10^{57} neutrons
E. 6.7×10^{9} neutrons

Problem:

(ii) Assuming the energy released during core bounce and supernova phase of this neutron star was 2 MeV per neutron, calculate the total energy output of the supernova in ergs. Note that 1 MeV = 1.6×10^{-6} ergs. (*2 points*)

Solution:
$E =$ (Number of neutrons)×(Energy per neutron)
$E = 2.4 \times 10^{57}$neutrons × 2 MeV/neutron
$E = 2.4 \times 10^{57} \times 2$ MeV $\times 1.6 \times 10^{-6}$ ergs/MeV
$E = 2.4 \times 2 \times 1.6 \times 10^{51} = 7.7 \times 10^{51}$ ergs, **C**

A. 1.5×10^{63} ergs
B. 3.8×10^{51} ergs
C. 7.7×10^{51} ergs
D. 7.7×10^{57} ergs
E. 4.8×10^{57} ergs

2. Galaxy A is observed to have a velocity of $v_{\rm obs} = -350$ km/s and is known to have a peculiar velocity of $v_{\rm pec} = -500$ km/s.

Problem

(i) Use the formula: $v_{\rm obs} = v_{\rm Hubble} + v_{\rm pec}$, to calculate the Hubble expansion velocity $v_{\rm Hubble}$ for this galaxy. (*1 point*)

Solution:

$v_{\rm obs} = v_{\rm Hubble} + v_{\rm pec}$

$v_{\rm Hubble} = v_{\rm obs} - v_{\rm pec}$

$v_{\rm Hubble} = -350$ km/s – (-500) km/s = 150 km/s, **A**

A. 150 km/s
B. −150 km/s
C. −850 km/s
D. 850 km/s
E. π km/s

Problem:

(ii) Galaxy B has a Hubble expansion velocity of $v_{\rm Hubble} = 2.8$ km/s. Using Hubble's Law $v_{\rm Hubble} = H_0\, d$ where $H_0 = 70$ km/s/Mpc, determine the distance d to this galaxy. (*2 points*)

Solution:

$v_{\rm Hubble} = H_0\, d$

$d = v_{\rm Hubble}/H_0$

$d = (2.8$ km/s$)/(70$ km/s/Mpc$) = 0.04$ Mpc, **B**

A. −196 Mpc
B. 0.04 Mpc
C. 196. Mpc
D. 25 Mpc
E. −0.04 Mpc

Problem:

(iii) What is the most likely identity of galaxy B? (*1 point*)

Solution:

From Arny, p. 490: Large Magellanic Cloud is about 150,000 light years away.
From Seeds, p.257: Andromeda is about 2 million light years away
(see also Problem 3 below).
0.04 Mpc $\times 3.26 \times 10^6$ light years/Mpc $= 1.3 \times 10^5$ light years,
B Large Magellanic Cloud

A. Milky Way galaxy
B. Large Magellanic Cloud galaxy
C. Andromeda galaxy
D. The most distant known galaxy
E. The most distant known quasar

Problem: 3. Our neighbor galaxy, Andromeda, has a luminosity (intrinsic brightness) 3 times as bright as the Luminosity of our Milky Way galaxy, $L_{\rm Andromeda} = 3L_{\rm MW}$, and is at a distance of $d_{\rm Andromeda} = 0.7$ Mpc. The flux we observe from the Andromeda galaxy (apparent brightness) is 10,000 times brighter than the flux observed from a distant quasar, $f_{\rm Andromeda} = 10^4 f_{\rm quasar}$. This quasar has a luminosity that is 1000 times the luminosity of our Milky Way galaxy, $L_{\rm quasar} = 10^3 L_{\rm MW}$. What is the distance d to the quasar? (*4 points*)

[**HINT:** *Use the formula: $f \propto L/d^2$. Write two relations, one for Andromeda and another for the quasar. Divide one relation by the other.*]

Solution:

$f_{\rm Andromeda}/f_{\rm quasar} = (L_{\rm Andromeda}/L_{\rm quasar})(d^2{}_{\rm quasar}/d^2{}_{\rm Andromeda})$

$d^2{}_{\rm quasar}/d^2{}_{\rm Andromeda} = (f_{\rm Andromeda}/f_{\rm quasar})(L_{\rm quasar}/L_{\rm Andromeda})$

$d_{\rm quasar}/d_{\rm Andromeda} = \sqrt{(f_{\rm Andromeda}/f_{\rm quasar})(L_{\rm quasar}/L_{\rm Andromeda})}$

$d_{\rm quasar}/d_{\rm Andromeda} = \sqrt{(10^4)(10^3 L_{\rm MW}/3L_{\rm MW})}$

$d_{\rm quasar} = \sqrt{10^7/3} \times 0.7$ Mpc $= 1826 \times 0.7$ Mpc $= 1.28 \times 10^3$ Mpc, **C**

A. 1.28×10^{-1} Mpc
B. 3.85 Mpc
C. 1.28×10^3 Mpc
D. 2.36×10^6 Mpc
E. 3.85×10^{12} Mpc

Problem: 4. An astronomer observes a bright star (Altair) that has a parallax angle of $p = 0.20$ arcseconds. The flux f from Altair is approximately 9.4×10^{-12} times the flux from the Sun. The distance d from the Earth to the Sun is (1/206265) pc.

(a) What is the distance d to Altair star in units of parsecs (pc)? (*2 points*)

[**HINT—** *Use the formula: $d = 1/p$, with distance d in units of pc and parallax p in units of arcseconds.*]

Solution:

$d = 1/p = 1/0.20 = 5$ pc, **D**

A. 0.20 pc
B. 2.06 pc
C. 3.14 pc
D. 5 pc
E. 50 pc

Problem:

(b) What is the luminosity L of Altair in units of the solar luminosity $L_\odot$? (*4 points*)

[**HINT—** *Use the formula: $f \propto \frac{L}{d^2}$ or $f = C\frac{L}{d^2}$, where C is a constant. Write one equation for Altair and one for the sun. Divide one equation by the other.*]

Solution:

$f_{\text{Altair}}/f_\odot = (L_{\text{Altair}}/L_\odot)(d_\odot^2/d_{\text{Altair}}^2)$
$L_{\text{Altair}}/L_\odot = (f_{\text{Altair}}/f_\odot)(d_{\text{Altair}}^2/d_\odot^2)$
$L_{\text{Altair}} = 9.4 \times 10^{-12} \times (5 \text{ pc})^2/(1/206265 \text{ pc})^2 \ L_\odot$
$L_{\text{Altair}} = 9.4 \times 10^{-12} \times 25/2.4 \times 10^{-11} \ L_\odot = 0.94 \times 25/2.4 \ L_\odot = 10 L_\odot$, **E**

A. $2.35 \times 10^-10 \ L_\odot$
B. $0.016 \ L_\odot$
C. $0.40 \ L_\odot$
D. $1.00 \ L_\odot$
E. $10.00 \ L_\odot$

Problem: 5. A distant quasar is observed to have a redshift $v/c = 0.15$, where v is the recession velocity of the quasar, and $c = 300,000$ km/s is the speed of light.

(a) What is the recession velocity v of the quasar in units of km/s? (*2 points*)

Solution:
$v/c = 0.15$
$v = 0.15c = 0.15 \times 3 \times 10^5$ km/s $= 45,000$ km/s, **B**

A. 7.47×10^{-5} km/s
B. 45,000 km/s
C. 0.059 km/s
D. 1.43 km/s
E. 1.97×10^6 km/s

Problem:

(b) Using the Hubble expansion formula: $v = H_0 d$, where the Hubble constant $H_0 =$ 70 km/s/Mpc, calculate the distance d to the quasar in units of Mpc? (*3 points*)

Solution:
$v = H_0 d$
$d = v/H_0$
$d = (4.5 \times 10^4$ km/s$)/(70$ km/s/Mpc$) = 642.9$ Mpc, **A**

A. 642.9 Mpc
B. 0.038 Mpc
C. 4.77×10^{-12} Mpc
D. 6.77 Mpc
E. 5.35×10^{10} Mpc

Problem:

(c) How long ago was the light we are now seeing from the quasar emitted? Note, 1 Mpc = 3.26 million light years. (*3 points*)

Solution:
642.9 Mpc $\times$ 3.26 million light years/Mpc $= 2.096 \times 10^3$ million years, **C**

A. 2.96×10^{-14} million years
B. 0.00032 million years
C. 2.096×10^3 million years
D. 1.66×10^{-4} million years
E. 9.27 million years

Problem: 6. Kepler's Third Law can be written as $P^2 = CR^3/M$, where C is a universal constant and M is the mass of the central object. The Moon orbits the Earth with a period of $P = 27.32$ days, at a distance of $R = 384,400$ km. (*7 points total*)

(a) The mass of Saturn is 95 times the mass of the Earth. If a moon of Saturn is in orbit around it with a period of $P = 234.01$ days. What is the radius of the orbit of Saturn's moon? (*4 points*)

[**HINT:** *Write one equation for the Earth-Moon system and another equation for Saturn and its moon. Divide one equation by the other.*]

Solution:
$(P_{\text{Saturn's moon}}/P_{\text{Moon}})^2 = (R_{\text{Saturn's moon}}/R_{\text{Moon}})^3(M_{\text{Earth}}/M_{\text{Saturn}})$
$(R_{\text{Saturn's moon}}/R_{\text{Moon}})^3 = (P_{\text{Saturn's moon}}/P_{\text{Moon}})^2(M_{\text{Saturn}}/M_{\text{Earth}})$
$(R_{\text{Saturn's moon}}/R_{\text{Moon}}) = (P_{\text{Saturn's moon}}/P_{\text{Moon}})^{2/3}(M_{\text{Saturn}}/M_{\text{Earth}})^{1/3}$
$(R_{\text{Saturn's moon}}/R_{\text{Moon}}) = (234.01 \text{ days}/27.32 \text{ days})^{2/3}(95)^{1/3}$
$(R_{\text{Saturn's moon}}/R_{\text{Moon}}) = (8.6)^{2/3}(95)^{1/3} = 4.2 \times 4.6$
$R_{\text{Saturn's moon}} = 4.2 \times 4.6 R_{\text{Moon}} = 19.1 \times 3.844 \times 10^5 \text{ km} = 7.34 \times 10^6 \text{ km}$, **B**

A. 6.78×10^2 km
B. 7.34×10^6 km
C. 4.63×10^{19} km
D. 3.13×10^8 km
E. 3.19×10^{-9} km

Problem:

(b) If the Earth's mass were tripled, while keeping the Earth-Moon distance the same, what would the period of the Earth's Moon's orbit now be? (*3 points*)

[**HINT:** *Write two equations for the Earth-Moon system, one for the 'normal' Earth and another for the case where the Earth mass is tripled. Divide one equation by the other.*]

Solution:
$(P_3/P_1)^2 = M_1/M_3$
$P_3^2 = (M_1/M_3)P_1^2$
$P_3 = \sqrt{M_1/M_3}P_1 = \sqrt{1/3} \times 27.32 \text{ days} = 15.77 \text{ days}$, **D**

A. 2.24×10^3 days
B. 47.32 days
C. 0.109 days
D. 15.77 days
E. 81.96 days