IOAA 2013

Volos, Greece

7th International Olympiad
on Astronomy & Astrophysics
VOLOS 2013 HELLAS

THEORY

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Table of Constants

Mass ($M_\oplus$)	5.98×10^{24} kg	**Earth**
Radius ($R_\oplus$)	6.38×10^{6} m	
Acceleration of gravity	$9.8\ m/s^2$	
Obliquity of Ecliptic	23°27′	
Length of Tropical Year	365.2422 mean solar days	
Length of Sidereal Year	365.2564 mean solar days	
Albedo (a)	0.39	
Mass($M_☾$)	7.35×10^{22} kg	**Moon**
Radius ($R_☾$)	1.74×10^{6} m	
Mean distance from Earth	3.84×10^{8} m	
Orbital inclination with the Ecliptic	5.14°	
Albedo	0.14	
Apparent magnitude (mean full moon)	−12.74	
Mass ($M_\odot$)	1.99×10^{30} kg	**Sun**
Luminosity ($L_\odot$)	3.83×10^{26} W	
Absolute Magnitude ($\mathcal{M}_\odot$)	4.72 mag	
Angular diameter	0.5 degrees	
Effective Surface Temperature	5800 K	
Jupiter's orbit semi-major axis	5.204 AU	**Jupiter**
Jupiter's orbital period	11.8618 yr	
Diameter of human pupil	6 mm	**Distances and sizes**
1 AU	1.50×10^{11} m	
1 pc	206,265 AU	
Distance from Sun to Barnard's Star	1.83 pc	
Mars orbit semi-major axis	1.52 AU	
Gravitational constant (G)	$6.67 \times 10^{-11}\ N \cdot m^2 \cdot kg^{-2}$	**Physical constants**
Planck constant (h)	$6.62 \times 10^{-34}\ J \cdot s$	
Boltzmann constant (k_B)	$1.38 \times 10^{-23}\ J \cdot K^{-2}$	
Stefan-Boltzmann constant (σ)	$5.67 \times 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$	
Hubble constant (H_0)	$72\ km\ s^{-1}\ Mpc^{-1}$	
Speed of light (c)	299,792,458 m/s	
Proton mass	$938.27\ MeV \cdot c^{-2}$	
Deuterium mass	$1875.60\ MeV \cdot c^{-2}$	
Neutron mass	$939.56\ MeV \cdot c^{-2}$	
Helium-3 mass	$2808.30\ MeV \cdot c^{-2}$	
Helium-4 mass	$3727.40\ MeV \cdot c^{-2}$	

The brightest stars visible from Greece

Star		α (2000)	δ (2000)	m(V)	M(V)	B−V	Spectral
		h m	° ′	mag	mag		Type
Alpheratz	α And	00 08	+29 05	2.03	−0.9	−0.10	A0 p
Caph	β Cas	00 09	+59 09	2.26	+1.5	+0.34	F2 IV
Schedar	α Cas	00 40	+21 26	2.22	−1.0	+1.17	K0 II
Diphda	β Cet	00 44	−17 59	2.04	+0.2	+1.04	K0 III
Mirach	β And	01 10	+35 37	2.06	−0.4	+1.62	M0 III
Achernar	α Eri	01 38	−57 15	0.48	−1.6	−0.18	B5 IV
Almach	γ And	02 04	+42 20	2.13	−0.1	+1.20	K2 III
Hamal	α Ari	02 07	+23 28	2.00	+0.2	+1.15	K2 III
Mira	o Cet	02 19	−02 59	2.0	−1.0	+1.42	M6 e
Polaris	α UMi	02 32	+89 16	2.02	−4.6	+ 0.6	F8 Ib
Algol	β Per	03 08	+40 57	2.2	−0.3	−0.1	B8 V
Mirfak	α Per	03 24	+49 51	1.80	−4.3	+0.48	F5 Ib
Aldebaran	α Tau	04 36	+16 30	0.85	−0.3	+1.54	K5 III
Rigel	β Ori	05 15	−08 12	0.11	−7.0	−0.03	B8 Iα
Capella	α Aur	05 17	+46 00	0.08	+0.3	+0.80	G8 III
Bellalrix	γ Ori	05 25	+06 21	1.63	−3.3	−0.22	B2 III
EINath	β Tau	05 26	+28 36	1.65	−1.6	−0.13	B7 III
Mintaka	δ Ori	05 32	−00 18	2.19	−6.1	−0.21	O9.5II
Alnilam	ε Ori	05 36	−01 12	1.70	−6.2	−0.19	B0 Iα
Alnitak	ζ Ori	05 41	−01 57	1.79	−5.9	−0.21	O9.5 Ib
Saiph	κ Ori	05 48	−09 40	2.05	−6.8	−0.18	B0.5 Iα
Betelgeuse	α Ori	05 55	+07 24	0.50	−5.6	+1.86	M2 Iab
Menkalinan	β Aur	06 00	+44 57	1.90	+0.6	+0.03	A2 IV
Mirzam	β CMa	06 23	−17 57	1.98	−4.5	−0.24	Bl II
Canopus	α Car	06 24	−52 42	−0.73	−4.7	+0.16	F0 Ib
Alhena	γ Gem	06 38	+16 24	1.93	+0.0	+0.00	A0 IV
Sirius	α CMa	06 45	−16 43	−1.45	+1.4	+0.00	Al V
Adhara	ε CMa	06 59	−28 58	1.50	−5.0	−0.22	B2 II
Wezen	δ CMa	07 08	−26 24	1.84	−7.3	+0.67	F8 Ia
Castor	α Gem	07 35	+31 53	1.58	+0.8	+0.04	Al V
Procyon	α CMi	07 39	+05 14	0.35	+2.7	+0.41	F5 IV
Pollux	β Gem	07 45	+28 01	1.15	+1.0	+1.00	K0 III
Naos	ζ Pup	08 04	−40 00	2.25	−7.0	−0.27	O5.8
—	γ Vel	08 10	−47 20	1.83	−4.0	−0.26	WC 7
Avior	ε Car	08 23	−59 30	1.87	−2.1	+1.30	K0 II
—	δ Vel	08 45	−54 43	1.95	+0.1	+0.0	A0 V4
Suhail	λ Vel	09 08	−43 26	2.26	−4.5	+1.69	K5 Ib
Miaplacidu	β Car	09 13	−69 43	1.68	−0.4	+0.00	A0 III

The brightest stars visible from Greece (cont.)

Star			α (2000) h	m	δ ° ′	m (V) mag	M (V) mag	B–V	Spectral Type
Scutulum	ι	Car	09	17	−59 16	2.24	−4.5	+0.18	F0 Ib
Alphard	α	Hya	09	28	−08 40	1.99	−0.4	+1.43	K3 III
Regulus	α	Leo	10	08	+11 58	1.35	−0.6	−0.11	B7 V
Algeiba	γ	Leo	10	20	+19 51	2.1	−0.5	+1.12	K0 III
Dubhe	α	UMa	11	03	+61 45	1.79	−0.7	+1.06	K0 III
Denebola	β	Leo	11	49	+14 34	2.14	+1.6	+0.09	A3 V
Acrux	α	Cru	12	27	−63 06	0.9	−3.5	−0.26	Bl IV
Gacrux	γ	Cru	12	31	−57 07	1.64	−2.5	+1.60	M3 III
Muhlifain	γ	Cen	12	42	−48 58	2.16	−0.5	−0.02	A0 III
Mimosa	β	Cru	12	48	−59 41	1.26	−4.7	−0.24	B0 III
Alioth	ε	UMa	12	54	+55 57	1.78	−0.2	−0.02	A0 p
Mizar	ζ	UMa	13	24	+54 56	2.09	+0.0	+0.03	A2 V
Spica	α	Vir	13	25	−11 09	0.96	−3.4	−0.23	Bl V
—	ε	Cen	13	40	−53 28	2.30	−3.6	−0.23	Bl V
Alkaid	η	UMa	13	48	+49 19	1.86	−1.9	−0.19	B3 V
Hadar	β	Cen	14	04	−60 22	0.60	−5.0	−0.23	Bl II
Menkent	θ	Cen	14	07	−36 22	2.06	+1.0	+1.02	K0 III
Arcturus	α	Boo	14	16	+19 11	−0.06	−0.2	+1.23	K2 IIIp
Rigil Kent	α	Cen	14	40	−60 50	−0.1	+4.3	+0.7	G2 V
Kochab	β	UMi	14	50	+74 09	2.07	−0.5	+1.46	K4 III
Alphecca	α	CrB	15	35	+26 43	2.23	+0.5	−0.02	A0 V
Antares	α	Sco	16	29	−26 26	1.0	−4.7	+1.81	Ml Ib
Atria	α	TrA	16	49	−69 02	1.93	−0.3	+1.43	K4 III
—	ε	Sco	16	50	−34 18	2.29	+0.7	+1.15	K2 III
Shaula	λ	Sco	17	34	−37 06	1.62	−3.4	−0.22	Bl IV
Ras–Alhague	α	Oph	17	35	+12 34	2.07	+0.8	+0.15	A5 III
—	θ	Sco	17	37	−43 00	1.87	−4.5	+0.40	FO I
Eltanin	γ	Dra	17	57	+51 29	2.22	−0.6	+1.52	K5 III
Kaus Australis	ε	Sgr	18	24	−34 23	1.83	−1.5	−0.02	B9 IV
Vega	α	Lyr	18	37	+38 47	0.04	+0.5	+0.00	AO V
Nunki	σ	Sgr	18	55	−26 18	2.08	−2.5	−0.20	B2 V
Altair	α	Aql	19	51	+08 52	0.77	+2.3	+0.22	A7 IV
Sadir	γ	Cyg	20	22	+40 15	2.23	−4.7	+0.67	F8 Ib
Peacock	α	Pav	20	26	−56 44	1.93	−2.9	−0.20	B3 IV
Deneb	α	Cyg	20	41	+45 17	1.25	−7.3	+0.09	A2 Ia
Al Na' ir	α	Gru	22	08	−46 58	1.74	+0.2	−0.14	B5 V
—	β	Gru	22	42	−46 53	2.20	−1.5	+ 1.6	M3 II
Fomalhaut	α	PsA	22	58	−29 37	1.16	+1.9	+0.09	A3 V

The brightest stars of the sky with m(V) ≤ 1.00

Star			α (2000)		δ (2000)	m(V)	M(V)	B–V	Spectra-type
			h	m	° ′	mag	mag		
Sirius	α	CMa	06	45	−16 43	−1.4	+1.4	+0.00	Al V
Canopus	α	Car	06	24	−52 42	−0.7	−4.7	+0.16	F0 Ib
Rigil Kent	α	Cen	14	40	−60 50	−0.1	+4.3	+0.7	G2 V
Arcturus	α	Boo	14	16	+19 11	−0.0	−0.2	+1.23	K2 IIIp
Vega	α	Lyr	18	37	+38 47	0.0	+0.5	+0.00	AO V
Capella	α	Aur	05	17	+46 00	0.08	+0.3	+0.80	G8 III
Rigel	β	Ori	05	15	−08 12	0.11	−7.0	−0.03	B8 Iα
Procyon	α	CMi	07	39	+05 14	0.35	+2.7	+0.41	F5 IV
Achernar	α	Eri	01	38	−57 15	0.48	−1.6	−0.18	B5 IV
Betelgeuse	α	Ori	05	55	+07 24	0.50	−5.6	+1.86	M2 Iab
Hadar	β	Cen	14	04	−60 22	0.6	−5.0	−0.23	Bl II
Altair	α	Aql	19	51	+08 52	0.7	+2.3	+0.22	A7 IV
Aldebaran	α	Tau	04	36	+16 30	0.85	−0.3	+1.54	K5 III
Acrux	α	Cru	12	27	−63 06	0.9	−3.5	−0.26	Bl IV
Spica	α	Vir	13	25	−11 09	0.9	−3.4	−0.23	Bl V
Antares	α	Sco	16	29	−26 26	1.0	−4.7	+ 1.81	Ml Ib

Theoretical Exam - Short Questions

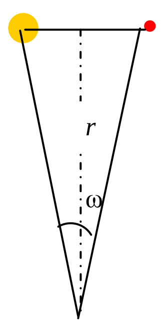
1. What would be the mean temperature on the Earth's surface if we ignore the greenhouse effect, assume that the Earth is a perfect black body and take into account its non-vanishing albedo? Assume that the Earth's orbit around the Sun is circular.

Answer : $T_{\oplus} = T_{\odot}(1-\alpha)^{1/4}\sqrt{\dfrac{R_{\odot}}{2r_{\oplus}}} = 246\text{ K}$ or $\mathbf{T_{\oplus} = -27^{o}\,C}$ **(10 Points)**

(Note: $r_{\oplus}$ = average Earth-Sun distance, the albedo, a = 0.39 is given in the *additional material*).

2. Let us assume that we observe a hot Jupiter planet orbiting around a star at an average distance d = 5 AU. It has been found that the distance of this system from us is r = 250 pc. What is the minimum diameter, D, that a telescope should have to be able to resolve the two objects (star and planet)? We assume that the observation is done in the optical part of the electromagnetic spectrum (λ~500nm), outside the Earth's atmosphere and that the telescope optics are perfect.

Answer: From the figure we have:



$$\omega(rad) \simeq \frac{d}{r} = \frac{5AU}{250\,pc} = \frac{5\times1.5\times10^{11}m}{250\times3.09\times10^{16}m} = 9.70\times10^{-8}rad$$ **(5 Points)**

Let us assume that D is the minimum diameter of our space telescope.

Its angular resolution is

$$\Delta\theta = 1.22\times\frac{\lambda}{D} \;\rightarrow\; 9.70\times10^{-8}rad = 1.22\times\frac{500\times10^{-9}m}{D} \;\rightarrow\; \boldsymbol{D = 6\ m}$$

(5 Points)

3. It is estimated that the Sun will have spent a total of about t_1 = 10 billion years on the main sequence before evolving away from it. Estimate the corresponding amount of time, t_2, if the Sun were 5 times more massive.

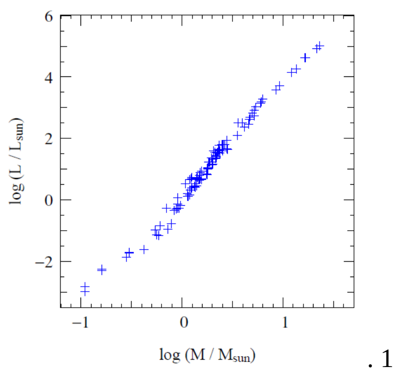


Figure 1: Mass to Luminosity relation

Answer: For the average luminosity of a main sequence star we have: $L \propto M^4$ (where M the initial mass of the star). We assume that the total energy E that the star produces is proportional to its mass $E \propto M$ **.** Therefore the amount of time that the star spends on the main sequence is approximately $t_{MS} \approx \dfrac{E}{L} \propto \dfrac{M}{M^4} \approx M^{-3}$.

(5 Points)

Therefore, $\frac{t_1}{t_2} \approx \frac{1^{-3}}{5^{-3}} = 5^3 \;\rightarrow\; t_2 = \frac{1}{125} \times 10^{10}\, yr$ or $\boldsymbol{t_2 = 8\times10^7}$ **yr**. **(5 Points)**

4. Figure 2 shows the relation between absolute magnitude and period for classical cepheids. Figure 3 shows the light curve (apparent magnitude versus time in days) of a classical cepheid in a local group galaxy . (a) Using these two figures estimate the distance of the cepheid from us. (b) Revise your estimate assuming that the interstellar extinction towards the cepheid is A = 0.25 mag.

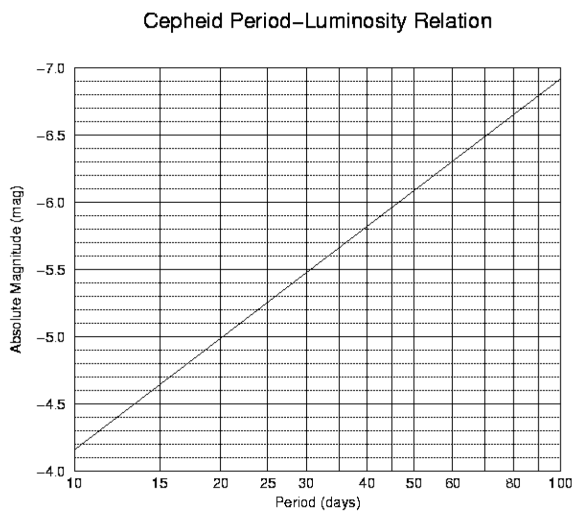


Figure 2

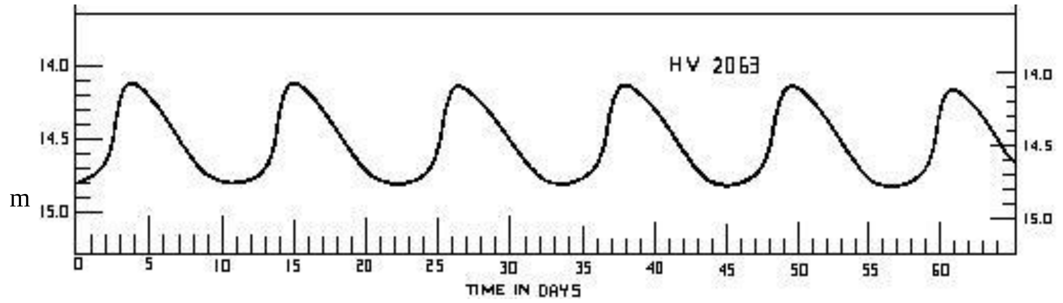


Figure 3

Answer : (a) From Figure 2, the period of the cepheid is P ~ 11 days and its average apparent magnitude is ~(14.8+14.1)/2 mag, i.e. m = 14.45 mag. **(2 points)**

[A careful student will notice that the graph is not *upside-down* symmetrical so he/she choose some value closer to the bottom; that is m=14.5 mag. **(1 point)**]

From Figure 1, we derive that for a period of 11 days the expected absolute magnitude of the cepheid is $M \approx -4.2$. **(1 point)**

[A careful student will notice that the graph is logarithmic so he/she choose a value closer to 4.3]
(1 point)

Using the formula $m - M = -5 + 5\log r$, where r is the distance of the cepheid, we get

$\log r = (14.45 + 4.2 + 5)/5 = 4.73$, thence $r = 10^{4.73} \approx 57500$ pc or $\boldsymbol{r = 57.5}$ **kpc** **(3 points)**

(b) Assuming $A = 0.25$, then $\log r = (14.45+4.2+5+0.25)/5 = 4.78$, thence $r = 10^{4.78}$ ~53000 pc or

$\boldsymbol{r = 64.5}$ **kpc.** **(2 points)**

5. The optical spectrum of a galaxy, whose distance had been measured to be 41.67 Mpc, showed the Balmer Hα line ($\lambda_o = 656.3$ nm) redshifted to $\lambda = 662.9$ nm. (a) Use this distance to calculate a value of the Hubble constant, H_o. (b) Using your results, estimate the Hubble time of the Universe.

Answer: (a) $z = \dfrac{\lambda - \lambda_o}{\lambda_o} = \dfrac{662.9 - 656.3}{656.3} \approx 0.01$. **(3 Point)**

This is small enough that we can use the classical equation for the expansion of the Universe.

$H_o = \dfrac{cz}{r} = \dfrac{3\times10^5\,km\,s^{-1}\times10^{-2}}{41.67\,Mpc}$ or $\boldsymbol{H_o} =$ $72.4\,\dfrac{km\,s^{-1}}{Mpc}$ **(4 Points)**

(b) $t_H \approx \dfrac{1}{H_o}$ or $\boldsymbol{t_H}$ **= 13.5 Gyr** **(3 Point)**

6. A star has an effective temperature $T_{eff} = 8700$ K, absolute magnitude $M = 1.6$ and apparent magnitude $m = 7.2$. Find (a) the star's distance, r, (b) its luminosity, L, and (c) its radius, R. (Ignore extinction).

Answer : (a) Its distance is calculated from equation: $m - M = 5\log(r) - 5$,
or $7.2 - 1.6 + 5 = 5\log(r)$ → $\log(r) = 2.12$ and $\boldsymbol{r =}$ **132 pc** **(3 Points)**

(b) Its Luminosity is calculated from equation: $M_\odot - M = 2.5\log\left(\dfrac{L}{L_\odot}\right)$ or

$4.8 - 1.6 = 2.5\log\left(\dfrac{L}{L_\odot}\right)$ or $\log\left(\dfrac{L}{L_\odot}\right) = 1.28 \rightarrow \left(\dfrac{L}{L_\odot}\right) = 19.05$ or $L = 19.15\times L_\odot =$
$19.15\times3.9\times10^{33}$ and $\mathbf{L = 7.4\times10^{34}}$ **erg sec^{-1}** **(4 Points)**

(c) Its radius can be easily calculated from equation: $L = 4\pi\sigma R^2\,T^4_{eff}$, from which

$R = \dfrac{1}{T_{eff}^2}\sqrt{\dfrac{L}{4\pi\sigma}}$ from which we get: $\mathbf{R = 1.35\times10^{11}}$ **cm** **(3 Points)**

7. A star has visual apparent magnitude m_v = 12.2 mag, parallax $\pi = 0''.001$ and effective temperature T_{eff} = 4000 K. Its bolometric correction is $B.C.$ = –0.6 mag. (a) Find its luminosity as a function of the solar luminosity. (b) What type of star is it? (i) a *red giant*? (ii) a *blue giant*? or (iii) a *red dwarf*? Please write (i), (ii) or (iii) in your answer sheet.

Answer : (a) First its bolometric magnitude is calculated from equation: $M_V - m_V = 5 - 5\log(r)$ or equivalent: $M_V - m_V = 5 + 5\log\pi \rightarrow M_V = 12.2 + 5 + 5\log(0''.001) = 12.2 + 5 - 15 = 2.2$ mag. Its barycentric correction is: $B.C. = M_{bol} - M_V$ and $M_{bol} = B.C. + M_V$ or $M_{bol} = -0.6 + 2.2$ or M_{bol} = 1.6 mag . **(4 Points)**

Then its Luminosity is calculated from:

$$M_\odot - M_{bol} = 2.5\log\left(\frac{L}{L_\odot}\right), \text{ or } 4.72 - 1.6 = 2.5\log\left(\frac{L}{L_\odot}\right) \text{ or } \log\left(\frac{L}{L_\odot}\right) = 1.25 \text{ and } \boldsymbol{L = 17.70\, L_\odot}$$

(2 Point)

(b) Type of star: A star with M_{bol} = 1.6 mag, $L = 17.7\,L_\odot$ and T_{eff} = 4000 K is much brighter and much cooler than the Sun (see *Table of constants*). Therefore it is **(i)** a red giant star. **(4 Points)**

8. A binary system of stars consists of star (a) and star (b) with brightness ratio 2. The binary system is difficult to resolve and is observed from the Earth as <u>one star</u> of 5th magnitude. Find the apparent magnitude of each of the two stars (m_a, m_b).

Answer : The apparent magnitude of star (a) is m_a, of star (b) is m_b and that of the system as a whole is m_{a+b}. The corresponding apparent brightnesses are ℓ_a, ℓ_b and $\ell_{a+b} = \ell_a + \ell_b$.

For star (a) :

$$m_{a+b} - m_a = -2.5\log\left(\frac{\ell_a + \ell_b}{\ell_a}\right) \text{ and because } \frac{\ell_b}{\ell_a} = \frac{1}{2}, \text{ we get } m_a = m_{a+b} + 2.5\log(1 + ½) \text{ or}$$

$m_a = 5 + 2.5\log(3/2)$ and finally $\boldsymbol{m_a = 5.44}$ **mag** . Similarly for star (b): **(5 point)**

$$m_{a+b} - m_b = -2.5\log\left(\frac{\ell_a + \ell_b}{\ell_b}\right) \text{ and because } \frac{\ell_a}{\ell_b} = 2, \text{ we get } m_b = m_{a+b} + 2.5\log(3) \text{ or}$$

$m_b = 5 + 2.5\log(3)$ and finally $\boldsymbol{m_b = 6.19}$ **mag**. **(5 Point)**

9. Find the equatorial coordinates (*hour angle* and *declination*) of a star at Madrid, geographic latitude φ = 40^o, when the star has zenith angle z = 30^o and azimuth A = 50^o (azimuth as measured from the South)

Answer : From the position triangle $\Pi Z_v \Sigma$ (Figure 3) of the star, Σ, we get, by using the *cosine law* for a spherical triangle:

cos (90 – δ) = cos(90 – a)×cos(90 – φ) + sin (90 – a)×sin(90 – φ)×cos (180 – A) **(2 Point)**

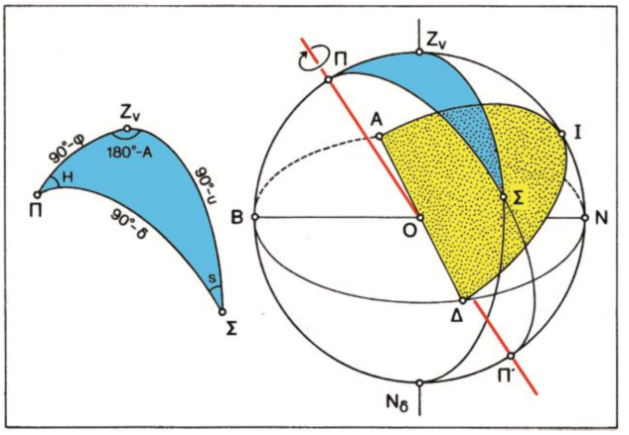


Figure 3. The position triangle

where δ is the star's *declination*, *a* its *altitude* ($a = 90° - z$), φ the *geographical latitude* of the observer, H the stars *hour angle* and A the star's *azimuth*.

This can be written as:

$\sin\delta = \cos z \times \sin \varphi - \sin z \times \cos\varphi \times \cos A$ or
$\sin\delta = \cos30^o \times \sin40^o - \sin30^o \times \cos40^o \times \cos50^o$ **(2 Point)**
or
$\sin \delta = 0.866 \times 0.643 - 0.500 \times 0.766 \times 0.643 = 0.311$. $\boldsymbol{\delta = 18° 05'}$ **(1 Point)**

Using the sine law for the spherical triangle, we get:

$$\frac{\sin H}{\sin(90-a)} = \frac{\sin(180^o - A)}{\sin(90^o - \delta)} \quad \text{or} \quad \frac{\sin H}{\sin z} = \frac{\sin A}{\cos\delta}$$ **(2 Point)**

$$\rightarrow \quad \sin H = \sin 50^o \times \frac{\sin 30^o}{\cos\left(18^o\, 07'\right)} = \frac{0.766 \times 0.5}{0.950}$$ **(2 Point)**

or $\sin H = 0.403$. Therefore: $H = 23° 46'$ or $\mathbf{H = 1^h\ 35^m\ 03^s}$. **(1 Point)**

10. In the centre of our Galaxy, in the intense radio source Sgr A*, there is a black hole with large mass. A team of astronomers measured the angular distance of a star from Sgr A* and its orbital period around it. The maximum angular distance was 0.12″ (arcsec) and the period was 15 years. Calculate the mass of the black hole in solar masses, assuming a circular orbit.

Answer: $F = -\frac{GM_{BH}M_*}{R^2} = -\frac{M_* v^2}{R}$ **(2 Point)**

But $v = \frac{2\pi R}{P}$. Therefore $\frac{GM_{BH}}{R^2} = 4\pi^2 \frac{R}{P^2}$ or $GM_{BH} = 4\pi^2 \frac{R^3}{P^2}$ **(2 Points)**

Similarly:

$$GM_{\odot} = 4\pi^2 \frac{(1AU)^3}{(1yr)^2} \quad ή \quad G = \frac{1}{M_{\odot}} 4\pi^2 \frac{(1AU)^3}{(1yr)^2}$$ **(2 Point)**

From Kepler's 3^{rd} law we get: $\frac{M_{BH}}{M_{\odot}} = \frac{(R/1AU)^3}{(P/1yr)^2}$ **(1 Point)**

Inserting the given data we find the distance of the star from the black hole:

$$R = \frac{0.12}{200,000}(8000)(3\times10^{18} cm) = 1.4\times10^{16} cm = 960 AU$$ **(2 Point)**

Therefore: $\frac{M_{BH}}{M_{\odot}} = \frac{(960)^3}{(15)^2} = 4\times10^6$ form which we calculate the mass of the black hole:

$$M_{BH} = 4\times10^6 M_{\odot}$$ **(1 Point)**

11. What is the maximum altitude, a_M (max), at which the Full Moon can be observed from Thessaloniki? The geographical latitude of Thessaloniki is $\varphi_\Theta = 40°37'$. Take into account as many factors as possible.

Answer: In order to have Full Moon, the Moon should be diametrically opposite the Sun, i.e. the three bodies, Sun – Earth – Moon should be on a straight line. If the orbital plane of the Moon coincided with the ecliptic, the maximum altitude of the Full Moon would be $90° - \varphi_{\Theta} + 23.5°$. **(2 point)**.

Because the orbital plane of the Moon is inclined by 5.14° (5°18′) to the plane of the ecliptic, the maximum angle is larger: 90° – 40.6° + 23.5° + 5.3°, or (P)

$\boldsymbol{\alpha_M(\max) = 79.8°}$ **(3 points)**

Geocentric parallax of Moon for this situation is 0.33°, **(3 points)**

whereas refraction is only 0.2′. **(1 point)**

Final answer is therefore: 79.8° - 0.3° = **79.5°** **(1 point)**

12. *Sirius A*, with visual magnitude $m_V = -1.47$ (the brighter star on the sky) and with stellar radius $R_A = 1.7R_{\odot}$, is the primary star of a binary system. The existence of its companion, *Sirius B*, was deduced from astrometry in 1844 by the well known mathematician and astronomer Friedrich Bessel, before it was directly observed. Assuming that both stars were of the same spectral type and that *Sirius B* is fainter by 10 mags ($\Delta m = 10$), calculate the radius of *Sirius B*.

Answer: The distance of the two stars from our solar system is the same. Therefore

$$m_B - m_A = 2.5 \log \frac{\frac{L_A}{4\pi r^2}}{\frac{L_B}{4\pi r^2}} = 2.5 \log \frac{L_a}{L_B}$$ **(5 Point)**

From which we get $L_A = 10^4 L_B$. From equation $L = 4\pi R^2 \sigma T_{eff}^4$ βwe get

$$L_A/L_B = (R_A/R_B)^2 (T_A/T_B)^4$$

Assuming that the two stars belong to the same spectral type (and therefore $T_A = T_B$) we get

$R_B = 0.01R_A = 0.01\times1.7\times696000$ km or $\boldsymbol{R_B = 1.2\ 10^4}$ **km** **(5 Point)**

13. Recently in London, because of a very thick layer of fog, the visual magnitude of the Sun, became equal to the (usual – as observed during cloudless nights) magnitude of the full Moon. Assuming that the reduction of the intensity of light due to the fog is given by an exponential equation, calculate the exponential coefficient, τ, which is usually called *optical depth*.

Answer: The absorption due to the fog in London is obviously

$A = -26.8 - (-12.74) = -14.06$ mag. **(2 Point)**

Rearranging the equation $I_\nu(r) = I_\nu(0) \times e^{-\tau}$, we get $\frac{I_\nu(0)}{I_\nu(r)} = e^{\tau}$, **(5 Points)**

or

$A = \Delta m = 2.5 \times \log(e) \times (-\tau)$ or $\tau = (-A)/(2.5 \times \log e) = 14.06/1.08$ ή $\boldsymbol{\tau = 12.9}$ **(3 Points)**

14. What is the hour angle, H, and the zenith angle, z, of *Vega* ($d = 38° 47'$) in Thessaloniki ($\lambda_1 = 1^h32^m$, $\varphi_1 = 40°37'$), at the moment it culminates at the local meridian of Lisbon ($\lambda_2 = -0^h36^m$, $\varphi_2 = +39°43'$)?

Answer: By definition at the moment when the star culminates in Lisbon, its hour angle is exactly 0°. Therefore its hour angle in Thessaloniki is $0^o + (\lambda_1 - \lambda_2)$ or $\boldsymbol{H = 02^h08^m}$. **(3 Points)**

Using the cosine law equation $\cos z = \cos(90-\varphi)\times\cos(90-d) + \sin(90-\varphi)\times\sin(90-d)\times\cos H$, **(4 Points)**

the zenith distance at Thessaloniki can be calculated to **24° 33′** **(3 Points)**

15. The Doppler shift of three remote galaxies has been measured with the help of Spectral observations:

Galaxy	Redshift, z
3C 279	0.536
3C 245	1.029
4C41.17	3.8

(a) Calculate their apparent recession velocity (1) using the classical approach, (2) using the approximate formula $v = c \ln(1+z)$, that is often used by cosmologists and (3) using the special relativistic approach.
(b) For all three formulae, at what percentage of the speed of light do they appear to recede?
(c) Which of (1) classical, (2) special relativity (3) approximate cosmological.

Answer: The recession velocity is calculated by either the classical relation, $v_c = z\times c$, or the relativistic relation, $v_r = \dfrac{(1+z)^2-1}{(1+z)^2+1}c$. The calculations for the three galaxies are summarized in the following Table:

Galaxy	v_c (km/s)	V_a (km/s)	v_r (km/s)	$v_r/c\times 100$
3C279	160800	128750	121390	40%
3C245	308700	212260	182740	61%
4C41.17	1140000	470580	275040	92%

(1) Table 1, Columns 2,3,4 **(5 Points)**

(2) Column 5 **(3 Points)**

(3) If the student answers "Classical" (0 Points)
If the student answers "Special Relativity" (1 Point)
If the student answers "Approximate formula" **(2 Points)**

Theoretical Exam - Long Questions

Question 1

In a homogeneous and isotropic universe, the matter (baryonic matter + dark matter) density parameter $\Omega_m = \frac{\rho_m}{\rho_c}$ = 32%, where ρ_m is the matter density and ρ_c is the critical density of the Universe.

(1) Calculate the average matter density in our local neighbourhood.
(2) Calculate the escape velocity of a galaxy 100 Mpc away from us. Assume that the recession velocity of galaxies in Hubble's law equals the corresponding escape velocity at that distance, for the critical density of the Universe that we observe.
(3) The particular galaxy is orbiting around the centre of our cluster of galaxies on a circular orbit. What is the angular velocity of this galaxy on the sky?
(4) Will we ever discriminate two such galaxies that are initially at the same line of sight, if they are both moving on circular orbits but at different radii (answer "Yes" or "No")?
[Assume that the Earth is located at the centre of our local cluster.]

Answer:

(1) The critical density $\rho_c = \frac{3H_0^2}{8\pi G}$ **(9 points)**

If the matter density parameter $\Omega_m = \frac{\rho_m}{\rho_c}$ is 32% , thus $\rho_m = 0.32\frac{3H_0^2}{8\pi G}$. **(3 points)**

From the latest estimate of $H_0 = 67.8\ \frac{km\,s^{-1}}{Mpc}$ we obtain $\rho_m = 8.6\times10^{-27}$ kg m^{-3} **(4 points)**

(2) The escape velocity is $\upsilon_{esc} = \sqrt{\frac{2GM}{d}}$. **(4 points)**

By replacing $M = \rho_c \frac{4\pi}{3} d^3$ **(2 points)**

we obtain, for the escape velocity within d = 100 Mpc

$$\upsilon_{esc} = \sqrt{\frac{8\pi}{3} G \times 0.32 \times \frac{3H_0^2}{8\pi G}} \times 100\,\mathrm{M}pc = 3835 \text{ km s}^{-1}$$ **(8 points)**

(3) If a galaxy is orbiting around the centre of our galaxy, its velocity is $\frac{1}{\sqrt{2}}$ of its escape velocity. Thus

$$\omega = \frac{v}{d} = \frac{v_{esc}/\sqrt{2}}{d} = \frac{H_0 d\sqrt{\Omega_m/2}}{d} = \frac{\sqrt{0.32}\,(67.8\times10^3 m/s)/(3.09\times10^{22} m)}{\sqrt{2}} = 8.8\times10^{-19} rad/s$$ **(12 Points)**

This is

$1.8\times10^{-13}\,arc\,\mathrm{sec}/s$ and it does not depend on the distance d.

(4) Therefore we will never be able to resolve them and the answer is "No". **(8 Points)**

Question 2

A spacecraft is orbiting the Near Earth Asteroid (2608) *Seneca* (staying continuously very close to the asteroid), transmitting pulsed data to the *Earth*. Due to the relative motion of the two bodies (the asteroid and the Earth) around the *Sun*, the time it takes for a pulse to arrive at the ground station varies approximately between 2 and 39 minutes. The orbits of the Earth and *Seneca* are coplanar. Assuming that the *Earth* moves around the *Sun* on a circular orbit (with radius a_{Earth} = 1 AU and period T_{Earth} = 1 yr) and that the orbit of *Seneca* does not intersect the orbit of the *Earth*, calculate:
(1) the semi-major axis, a_{Sen} the eccentricity, e_{Sen} of *Seneca's* orbit around the *Sun*
(2) the period of *Seneca's* orbit, T_{Sen} and the average period between two consecutive oppositions, T_{syn} of the *Earth-Seneca* couple
(3) an approximate value for the mass of the planet Jupiter, M_{Jup} (assuming this is the only planet of our Solar system with non-negligible mass compared to the Sun). Assume that the presence of Jupiter does not influence the orbit of Seneca.

Answer :
(1) For Δt_b = 2 min = 120 sec, the distance travelled by a light pulse is $R_1 = c\times\Delta t$ or R_1 = 0.24 AU, while for Δt_a = 39 min the maximum distance is $R_2 = c\times\Delta t$ or R_2 = 4.67 AU. **(4 points)**

Since the orbits do not intersect and the R_2 exceeds by far 1 AU, the orbit of *Seneca* is exterior to that of the *Earth*. R_1 corresponds to the minimum relative distance of the two bodies (i.e. at opposition), while R_2 corresponds to the maximum relative distance (i.e. at conjunction).

If $q = a\times(1–e)$ is the perihelion and $Q = a\times(1+e)$ the aphelion distance of *Seneca*, then $R_1 = q–1$ AU (the minimum distance of *Seneca* from the *Sun* minus the semi-major axis of the *Earth's* orbit), while $R_2 = Q+1$ AU (the maximum distance of *Seneca* from the *Sun* plus the semi-major axis of the *Earth's* orbit). **(6 points)**
Thus,

$a_{\text{Sen}}(1–e_{\text{Sen}}) = 1+R_1$ = 1.24 AU
$a_{\text{Sen}}(1+e_{\text{Sen}}) = R_2–1$ = 3.67 AU from which one finds $\boldsymbol{a_{\text{Sen}}}$ ~ 2.46 AU **(2 point)**
and $\boldsymbol{e_{\text{Sen}}}$ ~ 0.49 **(2 points)**

(figures rounded to 2 dec. digits)

(2) The period, T_{Sen}, of *Seneca's* orbit can be found by using Kepler's 3rd law for *Seneca* and the *Earth* (ignoring their small masses, compared to the Sun's):

$a_{\text{Sen}}^3 / T_{\text{Sen}}^2 = a_{\text{Earth}}^3 / T_{\text{Earth}}^2 = 1$ **(6 points)**

from which one finds $\boldsymbol{T_{\text{Sen}}}$ ~ 3.87 yr **(2 point)**

(Alternatively one can use Kepler's law for *Seneca* only and use natural units for the mass of the *Sun* and G, i.e. [mass] = 1 M_{Sun}, [t]= 1 yr and [r] = 1 AU, in which case $\boldsymbol{T_{\text{Sen}} = a_{\text{Sen}}^{3/2}}$ = 3.86 yr)
(8 points)

Assuming non-retrogate orbit, the synodic period, T_{syn} of *Seneca* and *Earth* is given by

$1/T_{syn} = 1/T_{Earh} - 1/T_{Sen}$ (*Seneca* is superior) **(6 points)**

which gives $\boldsymbol{T_{syn}}$ **=** 1.35 yr **(2 point)**

(3) From Kepler's law, we can calculate the mass of the *Sun*

$4\pi^2 a_{Sen}{}^3 / T_{Sen}{}^2 = G M_{Sun}$, i.e. $M_{Sun} \sim 1.988\times10^{30}$ kg (depending on accuracy) **(4 points)**

Then, using Kepler's 3rd law for *Seneca* and *Jupiter*, one gets

$(a_{Jup}{}^3 / T_{Jup}{}^2) / (a_{Sen}{}^3 / T_{Sen}{}^2) = (M_{Sun} + M_{Jup}) / M_{Sun} = 1 + x$ **(4 points)**

where $x =$ is the mass ratio of *Jupiter* to the *Sun*. Then, solving for x we get (depending on the accuracy used in determining the elements of *Seneca's* orbit)

$x = 0.0016$, thus $M_{Jup} = 3.2\times10^{27}$ kg **(4 points)**

Question 3

(1) Using the *virial theorem* for an isolated, spherical system, i.e, that $-2<K>=<U>$, where "K" is the average kinetic energy and "U" is the average potential energy of the system, determine an expression for the total mass of a cluster of galaxies if we know the radial velocity dispersion, σ, of the cluster's galaxy members and the cluster's radius, R. Assume that the cluster is isolated, spherical, has a homogeneous density and that it consists of galaxies of equal mass.
(2) Find the *virial mass*, i.e. the mass calculated from the *virial theorem*, of the Coma cluster, which lies at a distance of 90 Mpc from us, if you know that the radial velocity dispersion of its member galaxies is $\sigma_{\upsilon_r} = 1000 km/s$ and that its angular diameter (on the sky) is about 4^o.
(3) From observations, the total luminosity of the galaxies comprising the cluster is approximately $L = 5\times10^{12}\, L_\odot$. If the mass to luminosity ratio, M/L, of the cluster is ~1 (assume that all the mass of the cluster is visible mass), this should correspond to a total mass $M \sim 5\times10^{12}\, M_\odot$ for the mass of the cluster. Give the ratio of the luminous mass to the total mass of the cluster you derived in question (2).

Answer:

(1) Using the virial theorem for our isolated, spherical system of N galaxies of mass m, each, we get

$$-2\langle K\rangle = \langle U\rangle \Rightarrow -\frac{2}{N}\sum_1^N \frac{1}{2} m_i u_i^2 = <U> \Rightarrow -\frac{m}{N}\sum_1^N u_i^2 = \frac{U}{N}$$ **(3 point)**

where $\frac{1}{N}\sum_1^N u_i^2 \approx \langle u^2\rangle = \langle u_r{}^2\rangle + \langle u_\theta{}^2\rangle + \langle u_\phi{}^2\rangle$, where u_r, u_θ and u_φ are the radial velocity and the two perpendicular velocities on the plane of the sky of the members of the cluster. **(6 points)**

Assuming that $\langle u_r^{\,2}\rangle \sim \langle u_\theta^{\,2}\rangle \sim \langle u_\phi^{\,2}\rangle$, we have

$$-3m\langle u_r^2\rangle = U/N = (-\frac{3}{5}\frac{GM^2}{R})/N = -\frac{3}{5}\frac{GMm}{R} \Rightarrow M \approx \frac{5R\langle u_r^2\rangle}{G}$$ **(13 points)**

(where we used the gravitational potential of a spherical homogeneous mass M enclosed within radius R)

Alternatively the student can give a rougher order of magnitude estimate

$-2\langle K\rangle = \langle U\rangle \Rightarrow -2.\frac{1}{2}\langle u_r^2\rangle \approx -\frac{GM}{R}$ etc If they do not use the exact formula: (11 Points)

(2) From the result of the previous question we have $M \approx \frac{5R\langle u_r^2\rangle}{G}$, where

$$\sqrt{\langle u_r^2\rangle} = \sigma = 1000\ km\,s^{-1}$$ **(8 points)**

The angular diameter of the cluster is φ = 4° at a distance of *d* = 90 Mpc. Therefore the diameter D of the cluster in Mpc is calculated from:

$$\tan\phi = \frac{D}{d} \Rightarrow \phi(rad) \approx \frac{D}{d} \Rightarrow D \approx 4\times\frac{\pi}{180}\times 90\,Mpc \approx 6.3Mpc \Rightarrow R \approx 3Mpc$$ **(11 points)**

Therefore $M \approx \frac{5R\langle u_r^2\rangle}{G} = 3.6\times10^{15}\mathrm{M}_\odot$ **(3 point)**

(3) $\frac{M_{virial}}{L_{galaxies}} = \frac{3.6\times10^{15}\mathrm{M}_\odot}{5\times10^{12}L_\odot} = 720\frac{\mathrm{M}}{L}$ This is obviously much larger from $\frac{\mathrm{M}_\odot}{L_\odot} = 1$ which is found from the visible mass of the cluster. Thus $\frac{M}{M_{virial}} = \frac{1}{720}$. **(6 points)**

OBSERVATION

7th International Olympiad on Astronomy & Astrophysics
VOLOS 2013 HELLAS

Observational Test

Question 1.

Find the field of view of the telescope with the eyepiece provided by the attendant.

Answer: The attendant will provide a chronometer.

The student should select and observe any star from the "*Bright Stars catalogue visible from Greece*" that is provided by the attendant. The name of the star and its declination is written on the data sheet. **(1 point)**
(Note: If the student selects α UMi the attendant should not warn him).

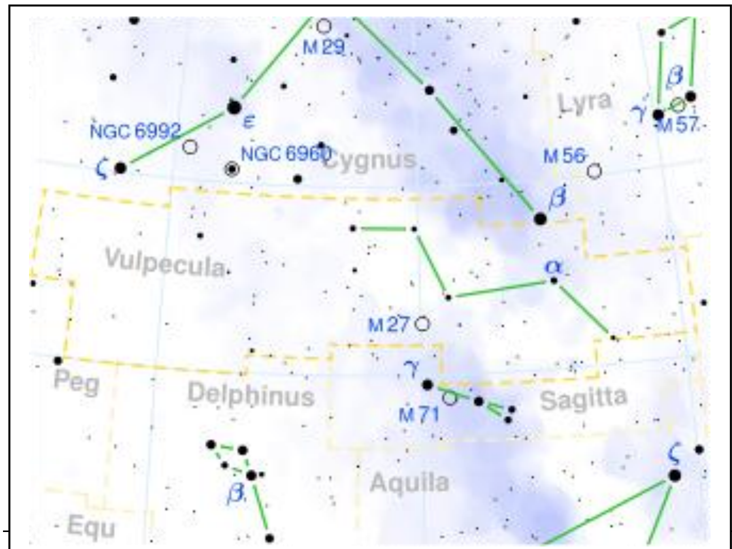
The student measures and writes down the *crossing time* of the star that he/she has selected.
(Marking scheme: ±4 s: 100%, ±6 s: 80%, ±8 s: 60%, ±12 s: 40%, ≥ 12 s: 0). **(5 points)**
The field of view is then calculated by the student on the spot, by using the formula:

$$FoV = \omega \times t \times \cos(dec) = \frac{360^\circ}{23^h\,56^m\,4^s.1} \times t \times \cos(dec)$$ **(4 points)**

(Example: for Capella [dec = 46°.0, cos (46.0) = 0.6947] and transit time t = $3^m 31^s$ = 3.53 min we get: $FoV = \frac{(360 \times 24)'}{1436.001\,\text{min}} \times 3.53\,\text{min} \times 0.6947 = 36'.9$)
[Maximum allowed time **10 minutes**]

Question 2.

Locate the bright star *γ Sagitta* (*RA* = $19^h\,58^m\,45.39^s$, *Dec* = +19° 29′ 31.5″), which lies between the constellations of Lyra and Delphinus. Then aim and locate the famous Dumbbell Nebula, M27 (*RA* = $19^h\,59^m\,36.34^s$, +22° 43′ 16.09″) in the center of the field of view. The observing spot is rather dark and you cannot read the setting circles!



The field in the vicinity of the Dimbell Nebula

Answer: The student should recognize the constellation of Sagitta and tell the attendant to which direction is the "*head of the arrow*" **(2 point)**
Then points the telescope at *γ Sagitta*, which is the brightest star of the constellation. **(3 point)**
The students should notice that the two targets have very similar *Right Ascension*. Therefore given the *RA* and *Dec* of the bright star *γ Sagitta* (m =

3.51 mag), should be able to quickly locate *M27* as the equatorial mounting is already aligned. Then should keep the *RA* axis locked, release the Dec knob and turn the telescope by about 3.25 degrees towards Polaris. The Dumbell Nebula will appear in the field of view.

(5 point)

[Marking scheme: Points given according to time spent. Total time required: ≤4 min: 100%, ≤5 min: 80%, ≤6 min: 50%.

[Maximum allowed time **6 minutes**]

(Note: If the student fails to locate M27 and complains, the attendant does it 30 s)

Question 3:

At 14 o'clock local time in the morning of the spring equinox a rare transit of Mercury is going to take place. A team of astronomers reaches a mountain top, early in the morning, in order to align his telescope and then observe the transit. The site is new and they do not know the geographical coordinates. Unfortunately the sky is covered with clouds. No stars are visible. The telescope cannot be aligned. The sky is overcast until 11 o'clock. The Sun becomes visible. An experienced astronomer manages to roughly align the telescope in less than 2 minutes! He only uses a water bubble.

You are given the telescope of the 7th IOAA and a water level. Assume that it is spring equinox and that the time is 12 o'clock. A fake Sun is shining. Could you align the telescope?

(Note: Obviously for this exercise, a telescope tube is not necessary, therefore, for the sake of convenience, the telescope will be equipped with a rough paper-tube and without counter weights.

Answer: First the student levels the tripod with the help of the water bubble. Then he/she adapts the equatorial mount on the tripod. Because it is spring equinox, the declination of the Sun is 0°. At this point the student should immediately set the Declination circle of the telescope at 0° and secures the break knob. The declination axis is calibrated. Then he/she rotates the RA axis and, by using the water bubble, makes the tube of the telescope horizontal (pointing toward the East). He rotates the RA setting circle to show 0 hours. Then he/she rotates again the RA axis until the setting circle shows 6 hours. Obviously, if the azimuth axis had been correctly set, at this point the telescope should be pointing somewhere on the local meridian. Then, exactly at 12 o'clock, when the sun crosses the meridian, he turns the azimuthal axis of the telescope until the he observes the Sun above or below the direction where the telescope is pointing. Now the telescope is pointing toward the local meridian. Finally he turns the latitude (altitude) axis of the telescope, up or down, until he aims the sun. The polar axis of the telescope is immediately aligned!

(Note: This is an indoors exercise). [Maximum allowed time **16 minutes**]

Observational test

Question:

At 14 o'clock local time in the morning of the spring equinox a rare transit of Mercury is going to take place. A team of astronomers reaches a mountain top, early in the morning, in order to align his telescope and then observe the transit. The site is new and they do not know the geographical coordinates. Unfortunately the sky is covered with clouds. No stars are visible. The telescope cannot be aligned. The sky is overcast until 11 o'clock. The Sun becomes visible. An experienced astronomer manages to roughly align the telescope in less than 2 minutes! He only uses a water bubble.

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(Note: Obviously for this exercise, a telescope tube is not necessary, therefore, for the sake of convenience, the telescope will be equipped with a rough paper-tube and without counter weights.

DATA ANALYSIS

7th International Olympiad
on Astronomy & Astrophysics
VOLOS 2013 HELLAS

Data analysis

Question 1.

In Figure 1, part of the constellation of Ursa Major is shown. It was taken with a digital camera with a large CCD chip (17mm × 22mm). Find the focal length, *f*, of the optical system and give the error of your results.

Figure 1. Part of the constellation of Ursa Major.

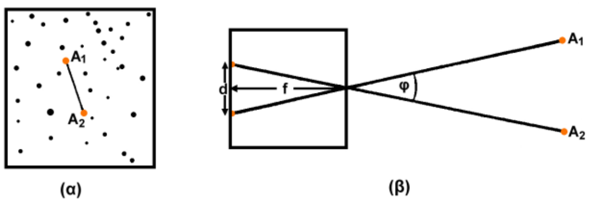


Figure 1A.Calculating the distance scale.

Answer: Calculate the angular distance, φ, (in degrees or minutes of arc), of two bright stars, whose coordinates are given in the *List of Bright stars*. Preferably these stars should be chosen to be far apart (e.g. α *UMa* [$a_1 = 11^h03^m$, $\delta_1 = +61°45'$] and η *UMa* [$a_2 = 13^h48^m$, $\delta_2 = +49°19'$]).

1. In order to calculate the angular distance of the two stars, the coordinates should be converted to decimal degrees (e.g. α *UMa* [$a_1 = 165°.75$, $\delta_1 = +61.75°$] and η *UMa* [$a_2 = 207.0°$, $\delta_2 = +49°.32$]) **(2.5 Point)**

2. Use the *cosine law* to calculate the angular distance between the two stars:

$\varphi = \arccos(\sin\delta_1 \times \sin\delta_2 + \cos\delta_1 \times \cos\delta_2 \times \cos(a_1 - a_2)$ → $\varphi = 25°.8448$ **(10 Points)**

3. Measure the distance, d_0, of the two stars in mm in Figure 1. $d_0 = 138$ mm. **(2.5 Points**

4. The photograph in Figure 1 does not have the same dimensions as the original photograph. Measure the length, ℓ, of the photograph in mm. $\ell = 140$ mm. This length corresponds to 22 mm. Convert d_0 to the distance, *d*, of the original photograph, $d = 138 \times \frac{22}{140}$ mm. $d = 21.6857$ mm **(1.5 Points)**

4. The *image scale* $\left(\frac{\varphi}{d}\right)$ of the original photograph is $\frac{\varphi}{d} = \frac{25^o.8448}{21.6857} = 1.1918 \frac{deg}{mm}$ **(2.5 Points)**

5. The focal length is given from equation (see Figure 2): $\tan\frac{\varphi}{2} = \frac{d}{2f}$ or $f = \frac{d}{2\tan\frac{\varphi}{2}}$ from

which the focal length is calculated: $f = \frac{21.6857}{2 \times 0.2294}$ or $\mathbf{f = 47.3\ mm}$ (**1.5 Points**)

(If errors are included **(4 Points)**

Question 2.

You are given 5 recent photographs of the solar photosphere shot at exactly the same time every two days (May 1 – May 9, 2013) in equatorial coordinates. You are also given two transparent Stonyhurst grids, which display heliocentric coordinates (heliocentric longitude, $\ell_\odot$, and heliocentric latitude, $b_\odot$). They cover the interval between April 28 to May 15. As the Earth does not orbit exactly around the Sun's equator, so, through the year, the solar equator seems to move up and down a little more than 7 degrees from the centre of the solar disc. This angle, B_0, varies sinusoidally through the year. Furthermore, the axis of rotation of the Sun, as seen from the Earth, does not coincide with the axis of rotation of the Earth. The angle on the plane of the sky between the two axes, P_0, also varies though the year. The numerical value of these angles (B_0 and P_0) are indicated on each of the 5 image of the Sun.

(1) Mark the axis of rotation of the Sun on each photograph.

(2) Choose 3 prominent sunspots that can be followed in all (or most) photographs and mark them as *S1*, *S2* and *S3* on the photos. Using the appropriate Stonyhurst grids, find their coordinates ($\ell_\odot, b_\odot$) for every day (May 1 to May 9) and note them down in Table 1.

Table 1

Date	Sunspot S1		Sunspot S2		Sunspot S3	
	$\ell_\odot$	$b_\odot$	$\ell_\odot$	$b_\odot$	$\ell_\odot$	$b_\odot$
May 1						
May 3						
May 5						
May 7						
May 9						

(3) Construct the diagrams $\Delta\ell_\odot/\Delta t$ for each sunspot.

(4) Calculate its synodic period (P) of rotation **in days** for each sunspot. Write down the result for each sunspot, P_{S1}, P_{S2}, P_{S3}.

(5) Calculate the average synodic period ($P_\odot$) of rotation of the Sun in days.

Answer: Five large photographs of the solar photosphere (adapted from www.spaceweather.com) and the appropriate (and on-scale) Stonyhurst grids will be given to the students (Figure 3A)**.** The photographs given to the students, will not be annotated. Each photograph is accompanied by the angle B_0 and P_0 of the day of the observation. The student should calculate the rotation of the Sun by measuring the coordinates of at least 3 well recognized sunspots as they follow the rotation of the Sun.

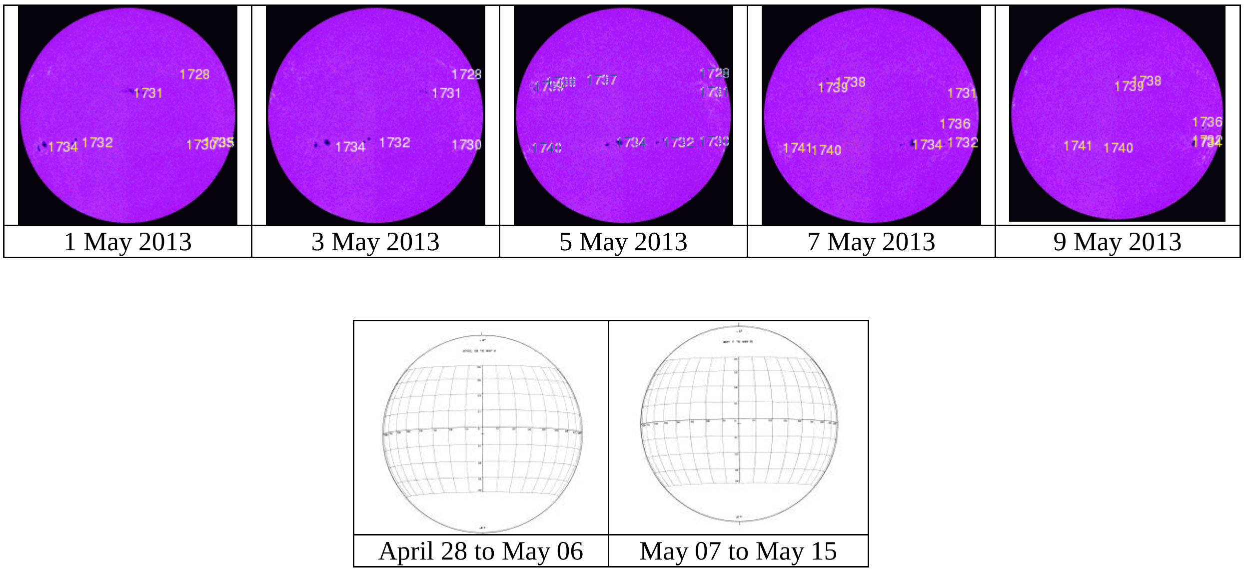


Figure 3A. Five photographs of the solar photosphere (top) and the corresponding Stonyhurst grids

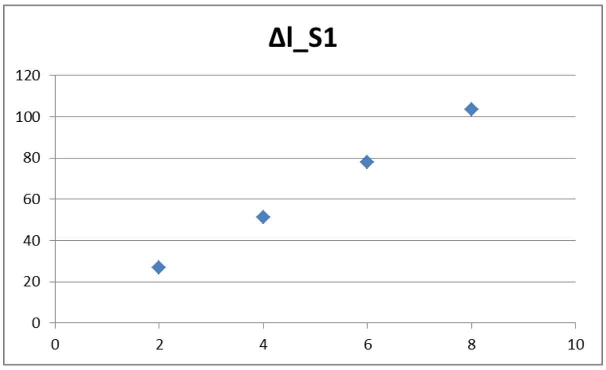
1. Correctly draw the axis of rotation of the Sun. This can be done by drawing a straight line at an angle of P_0 degrees anticlockwise from the vertical for each photograph (note: the photographs are given in equatorial coordinates.) **(4 Points)**

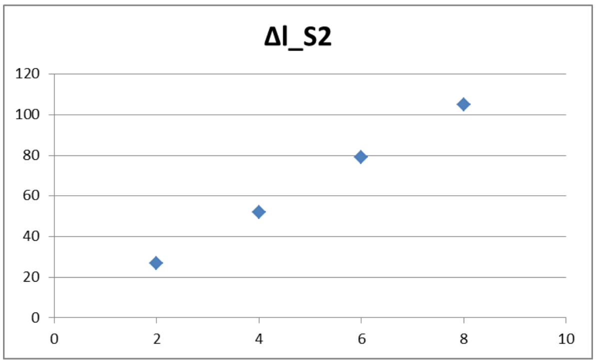
2. Choose the correct Stonyhurst grid and place it on each photograph, so that the solar axis on the grid coincides with the solar axis of the photograph. Estimate the heliocentric longitude, ($\ell_\odot$), and heliocentric latitude ($b_\odot$) with the help of the grid. Write down these coordinates in Table 1 for each of the 5 photographs.

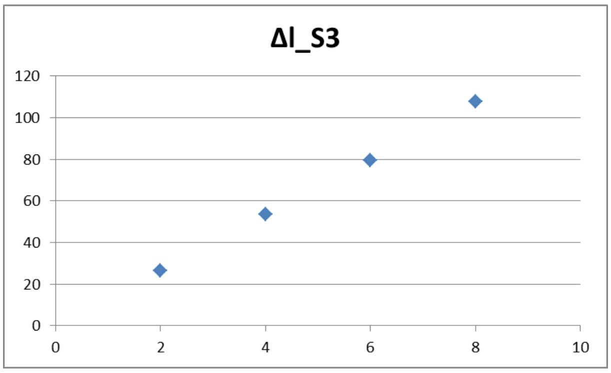
Date	Sunspot S1		Sunspot S2		Sunspot S3	
	$\ell_\odot$	$b_\odot$	$\ell_\odot$	$b_\odot$	$\ell_\odot$	$b_\odot$
May 1	54	17.5	33	18.5	30.5	16
May 3	27	18	6	19	4	16
May 5	3	18.5	-19	18.5	-23	17
May 7	-24	18	-46	18	-49	16
May 9	-49.5	19	-72	18	-77	17

(12 Points)

3. Construct the diagram $\Delta\ell_{\odot}/\Delta t$ for each sunspot:







(2 for each graph) **(6 Points)**

4. Calculate the rotation $(\Delta\ell_{\odot}/\Delta t)$ of the Sun for each sunspot.

$$P_i = 8 * \frac{360}{\Delta\ell_{\odot i}}, \qquad P_1 = 27.8\ days, \qquad P_2 = 27.4\ days, \qquad P_3 = 26.8\ days$$

(3 for each graph) **(9 Points)**

5. Calculate the average period of the Sun

$P_{\odot} = (P_1 + P_2 + P_3)/3 = 27.3\ days$ **27.3 days** **(1.5 Point)**

Question 3.

Figure 2 shows a photograph of the sky in the vicinity of the Hyades open cluster. The V-filter in the Johnson's photometric system was used. Figure 3 is a chart of the region with known V-magnitudes (m_V) of several stars (note that in order to avoid confusion with the stars, no decimal point is used, i.e. a magnitude $m_V = 8.1$ is noted as "81"). Hint: some of the stars may not be in the chart.
(a) Identify as many of the *stars shown with a number and an arrow* in Figure 3 and mark them on Figure 2.
(b) Comparing the V-magnitudes of the known stars in Figure 2, estimate the V-magnitudes of the *stars shown with a number and an arrow* in Figure 3.

Answer: The human eye can easily recognize differences of the order of $\Delta m_V = 0.1 – 0.2$ mag. The student should first align the photograph with the chart, which has a different scale and orientation. Then the magnitudes of the stars can easily be recognized. Note: not all arrowed stars can be found in the photograph. (0.5 Point for each star that has been correctly identified and 0.5 point for every correct magnitude within ±0.3 magnitude **(18 Points**)

Star	3	4	5	6	7	8	9	10	11
m	7.3 – 7.9	5.3 – 5.9	5.2 – 5.8	4.6 – 5.2	5.2 – 5.8	4.5 – 5.1	4.3 – 4.9	4.9 5.5	5.3 – 5.9

Stars 1, 2 and 12 are outside the boundaries of the photograph

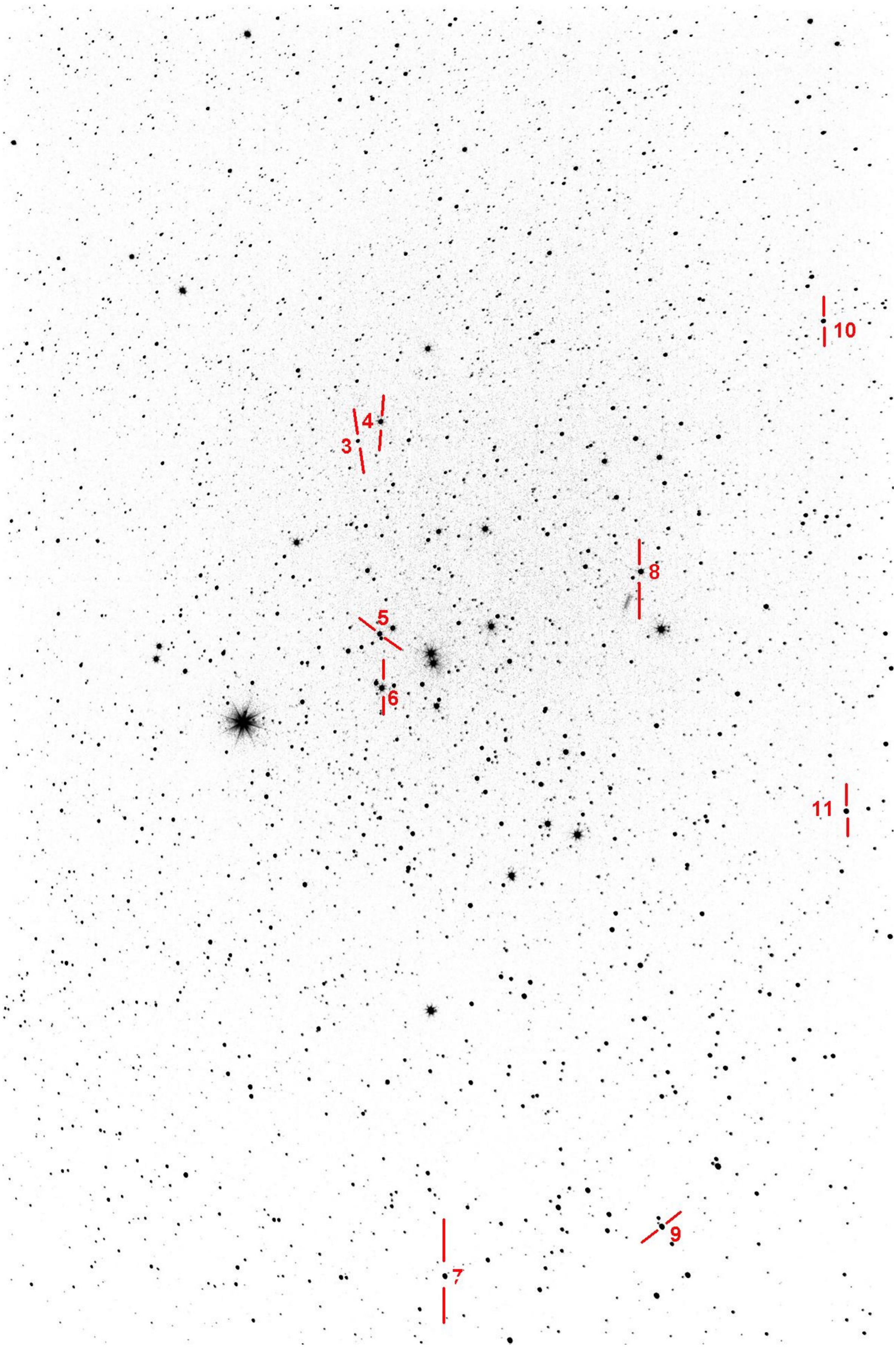


Figure 2. Photograph of the sky in the vicinity of the Hyades open cluster

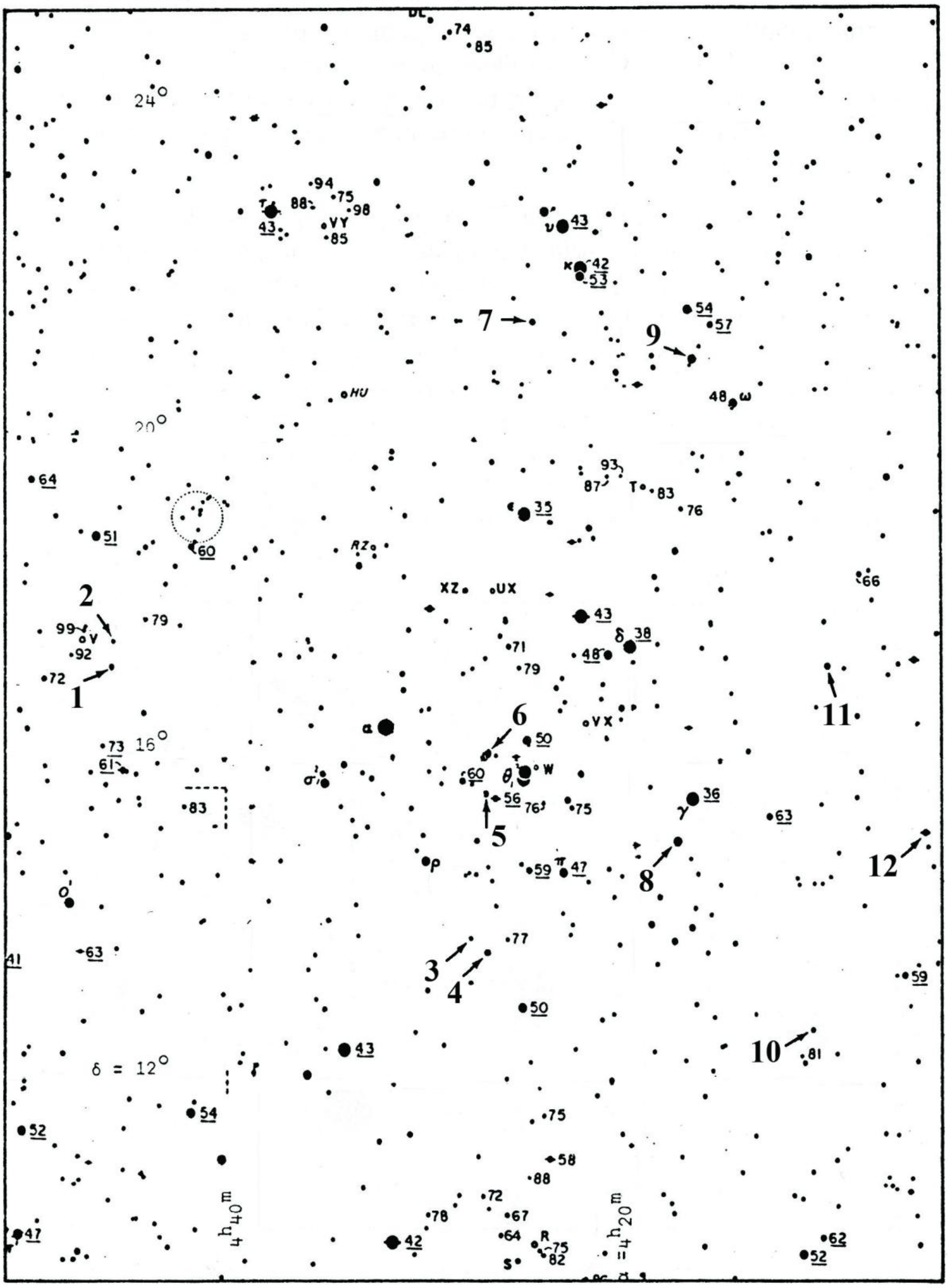


Figure 3. Sky chart of the region in the vicinity of the Hyades open cluster

Question 4.

Calculate the distance of the Hyades cluster using the *moving cluster* method (Figure 5).

1. In a *Text* file (*Hyades-stars.txt*) you are given a list of 35 stars from the field of the Hyades open cluster, observed by the Hipparcos space telescope.

The information listed in the columns of the text file for each of the 35 stars is: (a) The Hipparcos catalogue number (*HIP*). (b) Their *right ascension* (alpha – α) [h m s]. (c) Their *declination* (delta – d) [° ′ ″]. (d) Their *trigonometric parallax* (p – π) [$'' \times 10^3$]. (e) Their *proper motion in right ascension* multiplied by cos d (mu_axcosd – $\mu_\alpha \times \cos d$) [$'' \times 10^3$/yr]. (f) Their *proper motion in declination* (mu_d – μ_d) [$'' \times 10^3$/yr]. (g) Their radial velocity (v_r – v_r) [km/s].

```
 HIP      alpha       delta       p    mu_axcosd mu_d    v_r
============================================================
 13834  2 58  5.08  20 40  7.7  31.41  234.79 -31.64   28.10
 14838  3 11 37.67  19 43 36.1  19.44  154.61  -8.39   24.70
 18170  3 53  9.96  17 19 37.8  24.14  143.97 -29.93   35.00
 18735  4  0 48.69  18 11 38.6  21.99  129.49 -28.27   31.70
 19554  4 11 20.20   5 31 22.9  25.89  146.86   5.00   36.60
 20205  4 19 47.53  15 37 39.7  21.17  115.29 -23.86   39.28
 20261  4 20 36.24  15  5 43.8  21.20  108.79 -20.67   36.20
 20400  4 22  3.45  14  4 38.1  21.87  114.04 -21.40   37.80
 20455  4 22 56.03  17 32 33.3  21.29  107.75 -28.84   39.65
 20542  4 24  5.69  17 26 39.2  22.36  109.99 -33.47   39.20
 20635  4 25 22.10  22 17 38.3  21.27  105.49 -44.14   38.60
 20711  4 26 18.39  22 48 49.3  21.07  108.66 -45.83   35.60
 20713  4 26 20.67  15 37  6.0  20.86  114.66 -33.30   40.80
 20842  4 28  0.72  21 37 12.0  20.85   98.82 -40.59   37.50
 20885  4 28 34.43  15 57 44.0  20.66  104.76 -15.01   40.17
 20889  4 28 36.93  19 10 49.9  21.04  107.23 -36.77   39.37
 20894  4 28 39.67  15 52 15.4  21.89  108.66 -26.39   38.90
 20901  4 28 50.10  13  2 51.5  20.33  105.17 -15.08   39.90
 21029  4 30 33.57  16 11 38.7  22.54  104.98 -25.14   41.00
 21036  4 30 37.30  13 43 28.0  21.84  108.06 -19.71   38.80
 21039  4 30 38.83  15 41 31.0  22.55  104.17 -24.29   39.56
 21137  4 31 51.69  15 51  5.9  22.25  107.59 -32.38   36.00
 21152  4 32  4.74   5 24 36.1  23.13  114.15   6.17   39.80
 21459  4 36 29.07  23 20 27.5  22.60  109.97 -53.86   43.30
 21589  4 38  9.40  12 30 39.1  21.79  101.73 -14.90   44.70
 21683  4 39 16.45  15 55  4.9  20.51   82.40 -19.53   35.60
 22044  4 44 25.77  11  8 46.2  20.73   98.87 -13.47   39.60
 22157  4 46  1.70  11 42 20.2  12.24   67.48  -7.09   43.00
 22176  4 46 16.78  18 44  5.5  10.81   73.03 -69.79   44.11
 22203  4 46 30.33  15 28 19.6  19.42   91.37 -24.72   42.42
 22565  4 51 22.41  18 50 23.8  17.27   79.66 -32.76   36.80
 22850  4 54 58.32  19 29  7.6  14.67   63.32 -28.41   38.40
 23497  5  3  5.70  21 35 24.2  20.01   68.94 -40.85   38.00
 23983  5  9 19.60   9 49 46.6  18.54   63.54  -7.87   44.16
 24019  5  9 45.06  28  1 50.2  18.28   55.86 -60.57   44.90
```

Import the *txt* file in *MS Excel*

2. Convert the coordinates in degrees (with 4 decimal points).

3. Calculate the angular distance, φ, between each of the stars and the point of convergence, which is at ($\alpha_c = 6^h7^m$, $\delta_c = +6°56'$).

4. Calculate the proper motion of each star, μ [″/yr], using $\mu_\alpha\cos\delta$ and μ_δ given in the list.

5. Use the above data to calculate the distance, r_μ, for each star using the following equation:

$$r_\mu = \frac{v_r \tan\varphi}{4.74047\mu}$$

where r_μ is the distance of the star in parsecs, v_r is the radial velocity of the star in km/sec, φ is the *angular distance* between the star and the point of convergence that you have already estimated in step 3, while μ is the total proper motion estimated in step 4. Do all stars belong to the Hyades cluster? You can assume that any stars whose distance from the centre of the cluster (r_μ = 46.34pc) is larger than 10 pc, are not part of the cluster.

6. Independently, calculate the distance, r_π, of each star in the list using the trigonometric parallax angle, π.

7. Find the average distance of the Hyades cluster, $\overline{r_\mu}$ and $\overline{r_\pi}$, and its standard deviation, σ_μ and σ_π, for each method (*moving cluster* and *trigonometric parallax* methods).

8. Which method is more accurate: (*i*) the *moving cluster* method, (*ii*) the *trigonometric parallax* method? Please answer with (*i*) or (*ii*).

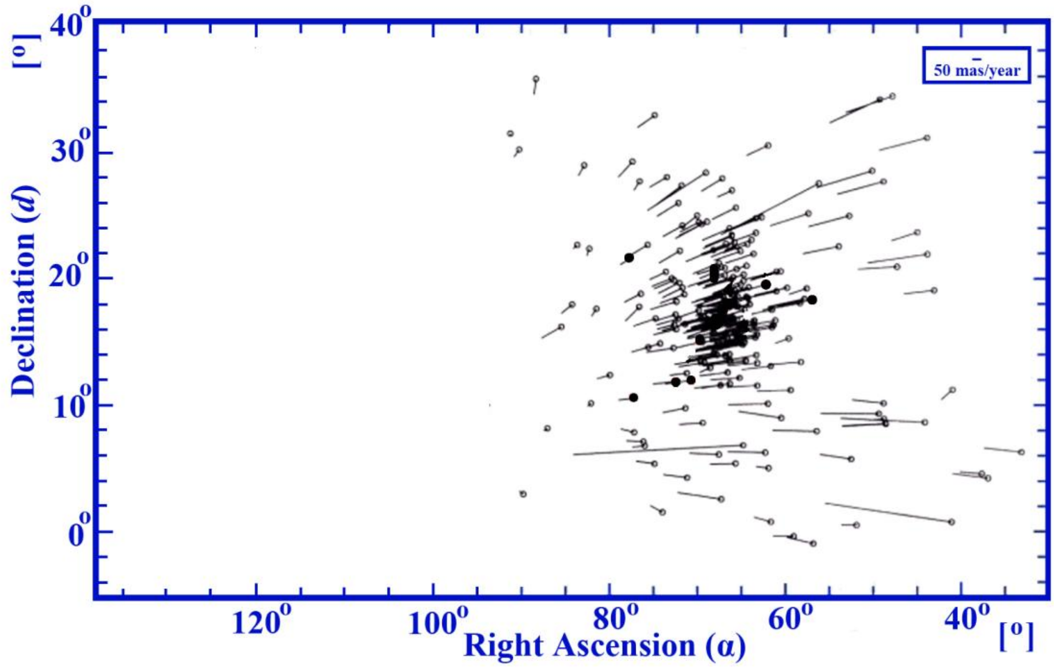


Figure 4. The distance of the Hyades open cluster using the *moving cluster* method

Answer: (1) The student should be able to import the ascii data of the *txt* file in the *MS Excel* spreadsheet application. **(12 Points)**

(2) In order to calculate the angular distance φ (next step), all coordinates should be converted into decimal degrees. The students should be able to convert the [hours, min, sec] and the [°, ′, ″] into decimal degrees, using . For the right ascension: $\alpha_{\deg} = h \times 15 + \frac{m}{60} + \frac{s}{3600}$ and for the declination: $\delta_{\deg} = {}^{\circ} + \frac{'}{60} + \frac{''}{3600}$. All coordinates are positive, so the student does not have to worry about checking the sign, which is not trivial. **(12 Points)**

(3) Using the cosine law, $\varphi = \arccos(\sin\delta_1 \times \sin\delta_2 + \cos\delta_1 \times \cos\delta_2 \times \cos(a_1 - a_2)$, the angular distance, φ, between each of the stars and the point of convergence should be calculated **(15 Points)**

(4) The student should easily calculate the proper motion of each star, by inserting the given equation, $\mu = \sqrt{(\mu_a \cos\delta)^2 + \mu_d^2}$, in the spreadsheet. **(9 Points)**

(5) Again, inserting the given equation, $r_\mu = \frac{v_r \tan\varphi}{4.74047\mu}$ in the spreadsheet (remembering to divide the given values of μ by 1000 to get arcseconds), the student should be able to calculate the distance, r_μ, of each star. Any star whose distance from the centre of the cluster is larger than 10 pc should be omitted from the following calculations. **(12 Points)**

(6) The trigonometric parallax distance is given by $r_\pi = \frac{1}{\pi \times 10^{-3}}$. This equation should be inserted in the spreadsheet. The result is in parsecs [pc]. **(6 Points)**

(7) Using the statistical functions *AVERAGE* and *STDEV* of MS Excel, the student should easily calculate the *average* and the *standard deviation* of r_{μ} and r_{π}. **(6 Points)**

(8) The method with the smaller standard deviation is, obviously more accurate. **(3 Point)**

(*macros* are allowed)

GROUP COMPETITION

7th International Olympiad on Astronomy & Astrophysics
VOLOS 2013 HELLAS

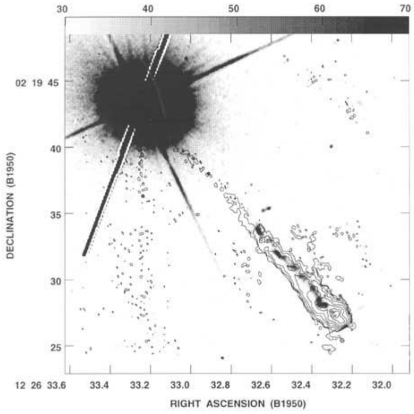
A.

i. first astronomer to suggest that the Earth is not the center of the Universe? [1] - 2

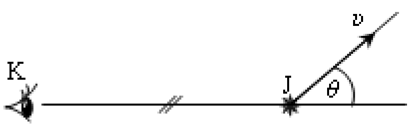
1.Galileo
2.Aristarchus
3.Copernicus
4.Cassini
5.Zhang Heng
6.al-Biruni
7.Kepler
8.Brahe
9.Aryabhatta

ii. The obliquity of the ecliptic in degrees. (one decimal) [3] - 234

iii. The first known and brightest quasar is 3C_. [3] - 273



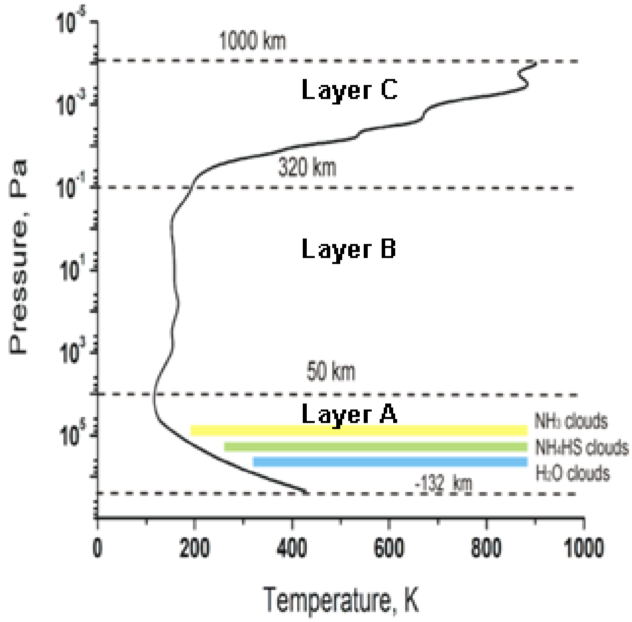
iv. A relativistic jet moves at 0.83c. If no Doppler shift is observed, how many degrees is the angle between the jet and the line of sight, assuming that the source has negligible velocity? (integer) [3] - 122



v. This nebula is NGC_. [4] - 7000

vi. Choose the names of the layers A, B and C of the Jovian atmosphere, beginning from Layer A. **[3] – 195**

1.Troposphere
2.Magnetosphere
3.Ionosphere
4.Ozone layer
5.Thermosphere
6.Lithosphere
7.Chromosphere
8.Photosphere
9. Stratosphere

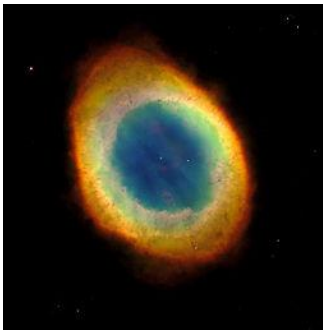


B.

i. How many AU is one parsec? (integer) **[6] – 206265**

ii. Jupiter–Sun–Trojan Asteroids angle (degrees). (integer) **[2] – 60**

iii. This nebula is M_. **[2] – 57**



iv. On the 25th of August, at a latitude of $\phi > 0$ and longitude $\lambda_L = 37^o W$ *(time zone = GMT - 2hrs)*, we observe a star with Declination (δ) such that $\phi + \delta = 90$, and Right Ascension $\alpha = 67.5^o$. What is the local civil time at the hh:mm during the lower culmination of the star? It is given that at 00:00hrs on the 24th of August, hour angle of vernal equinox is $21^h 58^m$. **[4] – 1857**

v. During a Meteor Shower, in a radius of 100km, an observer counted 600 meteors/min. If the rest frame velocity of the meteors was 10km/s with opposite direction to that of the Earth's orbital velocity, what is the mean distance between two meteors in km? Assume cylindrical geometry. (integer) **[2] – 50**

vi. The photon's spin. **[1] – 1**

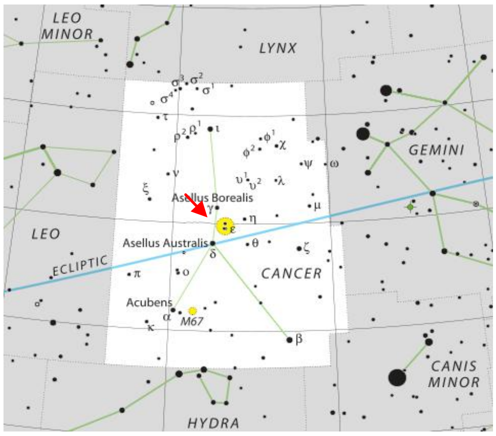
C.

i. Difference between sidereal time of two places is $2^h\ 47^m\ 24^s$. The difference in their longitude is (in deg and min). [4] – 4151

ii. A galaxy in the constellation Triangulum is M_. [2] – 33

iii. Pluto's moons. [1] – 5

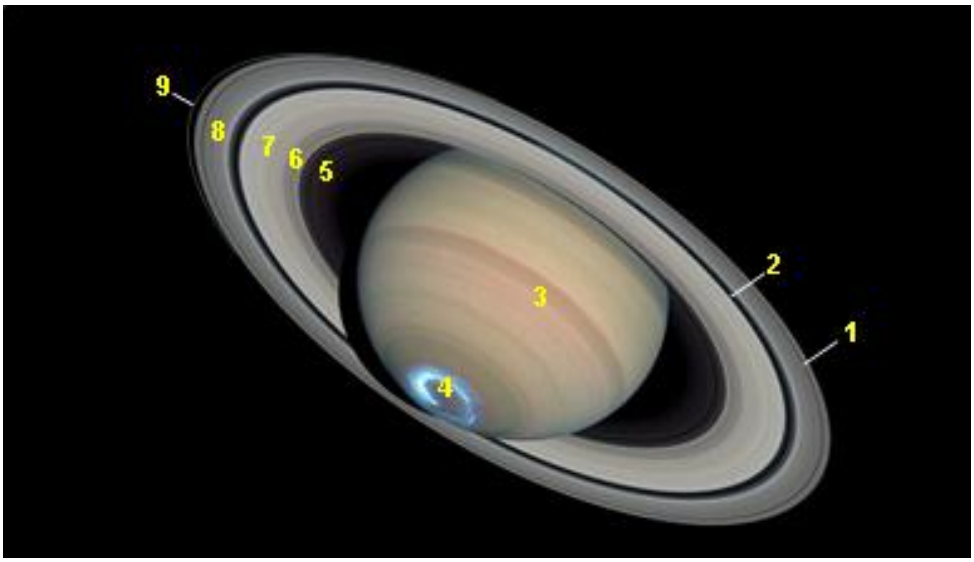
iv. The Beehive Cluster is M_. [2] – 44



v. Tidal forces are proportional to R^{-n}. Value of n is [1] – 3

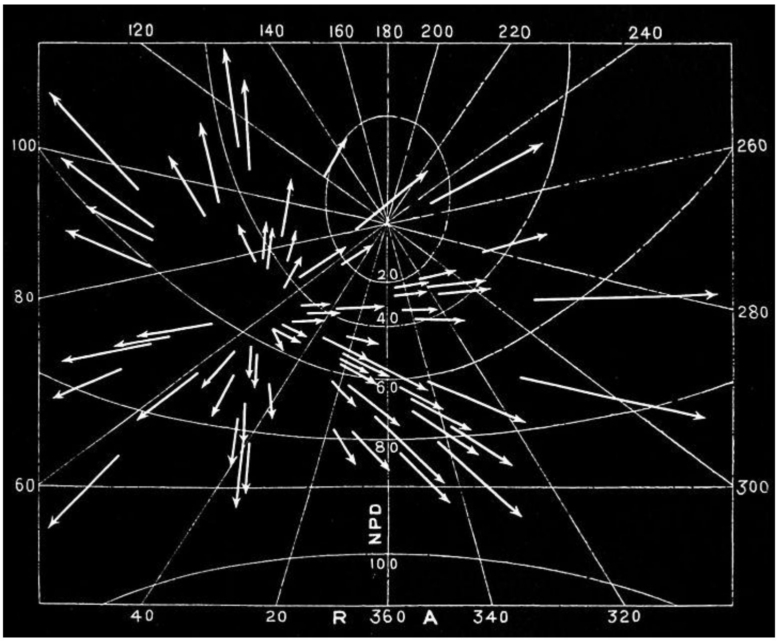
vi. Proxima Centauri is *4.243ly* distant. It has apparent magnitude of *11.5mag* and approaches Earth at *21.7km/s*. After how many thousands of years will it be visible to the naked eye? (integer) [2] – 54

vii. Cassini Division, D Ring, Encke Gap, A Ring [4] – 2518



viii. The radiant of this meteor shower is in: [1] - 4

1.Cygnus
2.Gemini
3.Leo
4.Perseus
5.Cetus
6.Orion



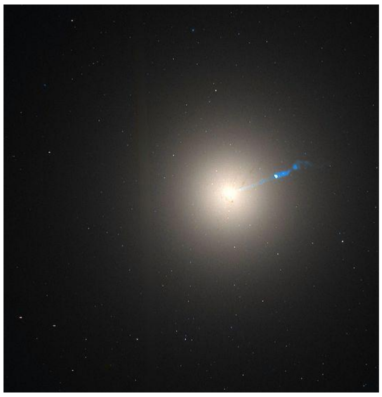
D.

i. At this Lagrange point on the orbit of Jupiter lies a Trojan camp! [1] - 5

ii. Kiloparsec to light-years. (integer) [2] - 3262

iii. The mean distance of Venus from Sun (AU). (two decimals) [3] - 072

iv. The supergiant elliptical galaxy near the centre of the Virgo Galaxy Cluster is M_. [2] - 87



v. The molar mass of the substance that forms clouds in the upper atmosphere of Venus. [2] - 98

vi. spin of an electron (one decimal) [2] - 05

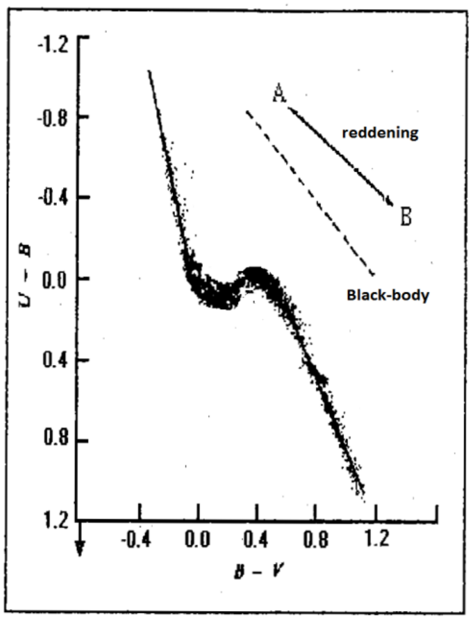
vii. Capella's parallax is 77.3 milliarcseconds. Find its distance in light years (2^{nd} decimal) [3] - 422

E.

i. A $A\,0V$ star has observed Colour Index $B-V=0.70$. How many times brighter would the star look if there was no interstellar extinction? Consider that $A_V = 3\times E_{B-V}$, where E_{B-V} is the Colour Excess and A_V is the Visual Absorption. (integer) [1] – 7

ii. The sidereal rotation period at the equator of the Sun (days). At the spectrum of the Sun, the line H_α (λ=6,563Å) has a broadening of 0.089Å. (integer) [2] – 25

iii. One star has a B–V colour index of *0.2mag* and a U–B colour index of *–0.1mag*. What is its Colour Excess E_{B-V}? (one decimal) [2] – 03



iv. Chandrasekhar Mass limit in solar radii. (two decimals) [3] - 144

v. The orbital period of Mercury (days). (integer) [2] – 88

vi. The axial tilt of an exoplanet without atmosphere is 0°. Its orbital period is really long. How many times greater is the mean temperature of the illuminated (by the corresponding star) hemisphere when the planet spins really slowly compared to when it spins really quickly? (one decimal) [2] – 12

vii. The atomic mass (in a.m.u.) of the heaviest element which can be produced in a star, before it meets its end. [2] – 56

viii. Diameter of the biggest single aperture optical telescope in meters (integer) [2] – 10

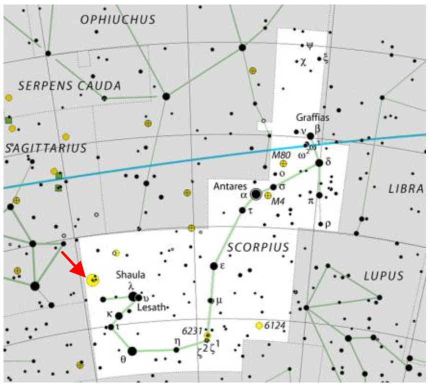
ix. The inventor of the telescope. [1] – 4

1.Demisianos
2.Brache
3.Ibn Sahl
4.Lippershey
5.Huygens
6.Harriot
7.Marius
8.Newton
9.Galileo

F

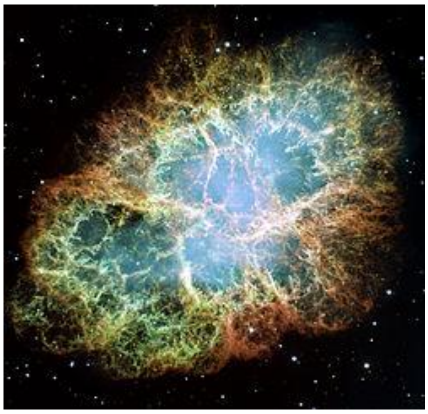
i. A binary system is consisted of two stars that revolve around the centre of mass with semi-major axes of 11.25 A.U. And 18.62 A.U. If the total mass of the system is 5 solar masses, calculate the period (in years) of the system. (integer) **[2] – 73**

ii. Ptolemy's Cluster is M_. **[1] – 7**



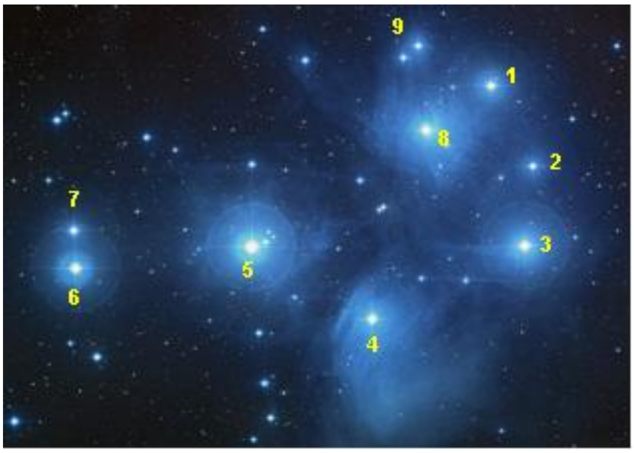
iii. What will be the diameter of the telescope (in meters) required to resolve a planet revolving around a star with orbital radius 1 A.U., if the distance to star is 226.26 light years? Ignore seeing. (one decimal) **[2] – 96**

iv. Castor is a multiple star of how many components? **[1] – 6**



v. The picture shows SNR _. **[4] – 1054**

vi. Luminosity class of sub-dwarfs **[1] – 6**



vii. Alcyone, Taygeta, Maia, Electra, Atlas **[5] – 51836**

viii. Luminosity class of the Sun **[1] – 5**

G

i. Bode's Galaxy is M_. [2] – 81

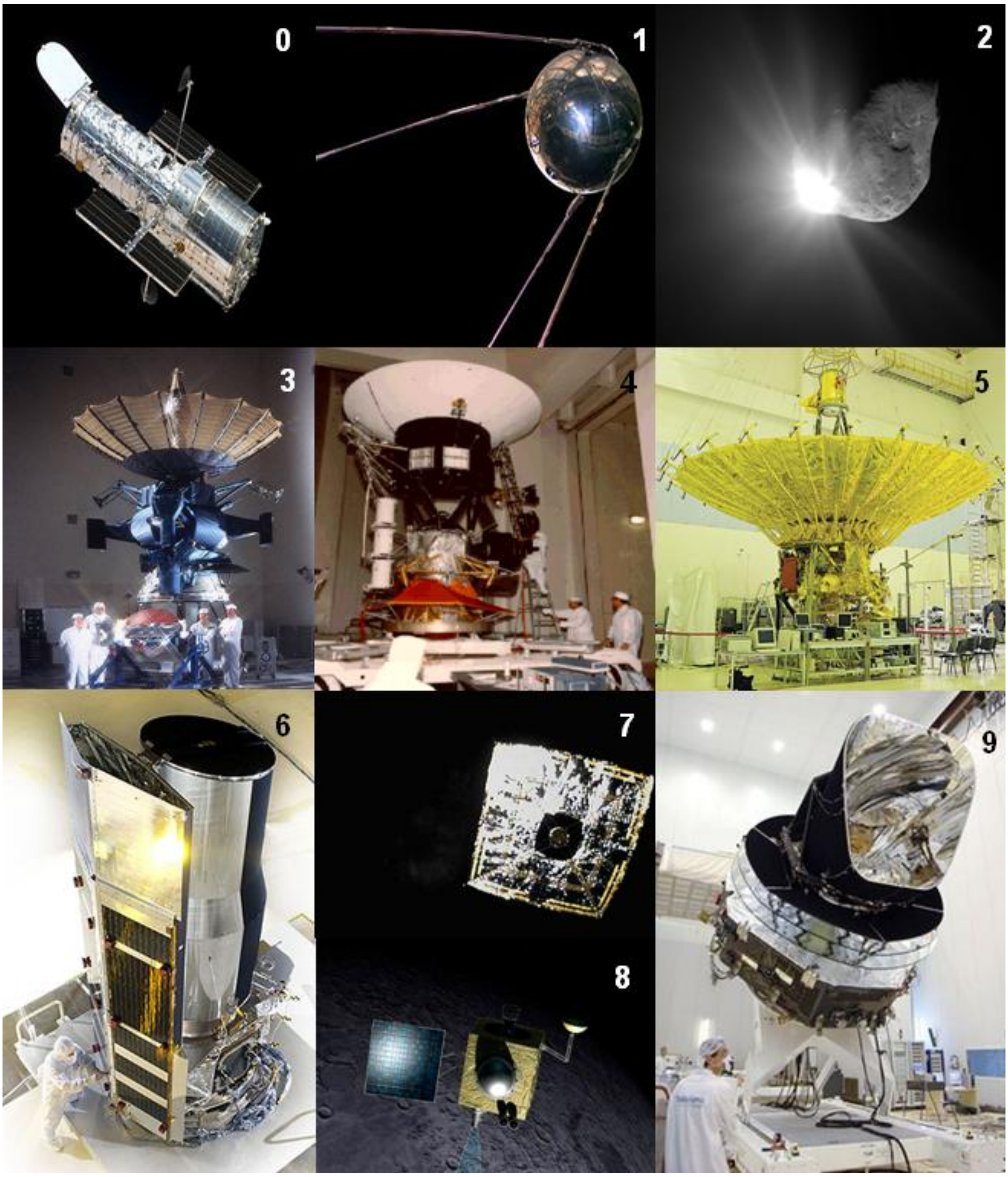
ii. Cigar Galaxy is M_. [2] – 82

iii. How many times fainter will a star become if its magnitude is increased by 1mag? (three decimals) [4] – 2512

iv. A Globular Cluster near the nostril of Pegasus is M_. [2] – 15

v. Hipparchus described a Solar Eclipse which was seen as Total in the Hellespont (*40° 25'N, 29° 43'E*) but Partial in Alexandria (*31° 12'N, 29° 55'E*), where at maximum *4/5* of the Sun was hidden. Hipparchus calculated the parallax of the limb of the Moon between the Hellespont and Alexandria, assuming that the parallax of the Sun is 0. He also knew that the Moon has the same apparent angular diameter as the Sun, with a value of *1/650* of the circle. Finally, by applying simple trigonometry, he calculated the approximate distance between the Earth and the Moon in Earth radii. How many Earth radii is the Earth-Moon distance? (integer) [2] – 64

vi. Chandrayan-1, Deep Impact, Planck Telescope, Hubble Space Telescope [4] – 8190



vii. If the mass of a star is *5 solar masses*, and its initial radius and rotation period is $21x10^5 km$ and *4.083 days* respectively, how many microseconds will be its period when it turns into a Pulsar with a radius of *10km*? Assume the star is a homogenous sphere and does not lose mass. [1] – 8

H.

i. How many planets of the Solar System have rings? [1] – 4

ii. Angle corresponding to $16^h\ 16^m$ (integer) [3] – 244

iii. The Saros in _y _d. [4] – 1811

iv. If a more accurate indicator existed for the latitude scale of the telescopes you are going to use during the observational part, it would show _°_'. [4] – 3922

v. R.A. of Duschbba i.e. δ Scorpii (hh). [2] – 16

vi. An asteroid is *2.8AU* away from the Sun. At opposition, its visual brightness *was* $1.46 x 10^{-16}$ $Watt/m^2$. What is its radius (in meters) if its albedo is 1.00? (integer) [3] – 496

I

i. On 11^{th} December 2117 a Venus Transit will take place. How many years later is the next one? [1] - 8

ii. An Open Cluster in Canis Major is M_. [2] - 41

iii. Write the numbers of the three brightest stars in descending order of brightness: [3] - 324

1. Betelguese
2. Vega
3. Canopus
4. α Centauri
5. Capella
6. Procyon
7. Altair
8. Rigel
9. Arcturus

iv. A circumpolar star's altitude at upper culmination is 76.8° and at lower culmination is 10°. What is the latitude of the place? [3] - 434

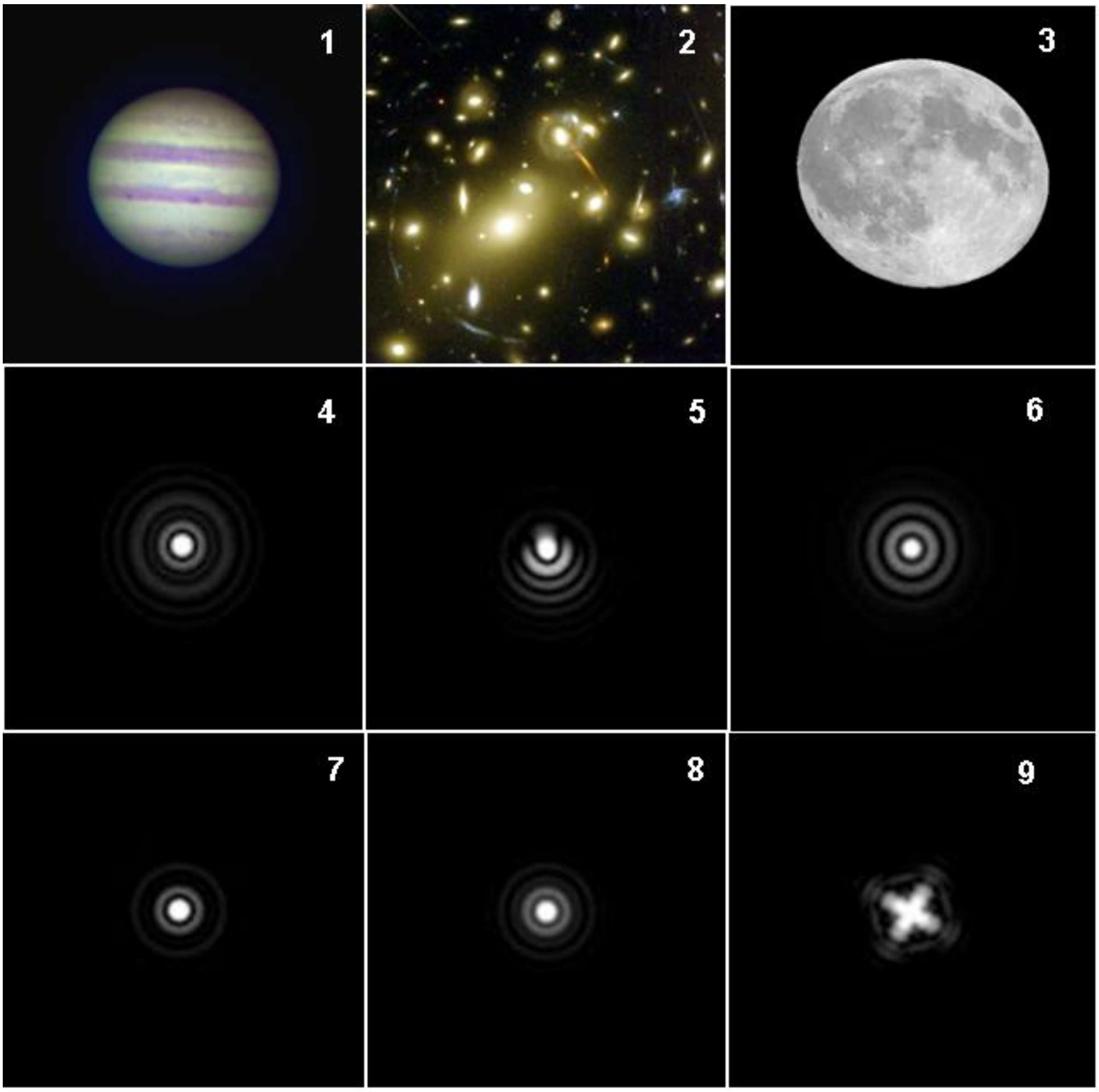
v. Leo is N^{th} zodiacal sign. N is [1] - 5

vi. The Solar System lies within this arm of the Milky Way: [1] - 4

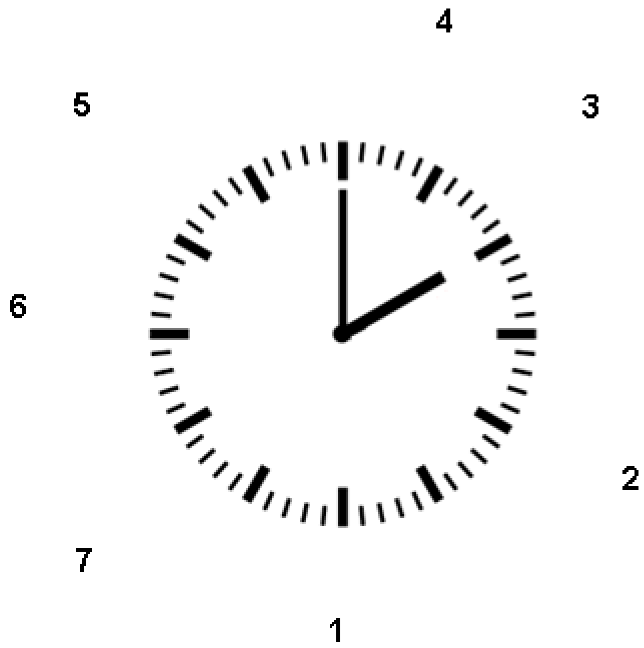
1. Sagittarius-Carina
2. Scutum-Crux
3. Norma
4. Orion
5. Perseus
6. Cygnus
7. Outer

vii. The resonance between Pluto and Neptune is _:_. [2] - 23

viii. Distortion, Coma, Astigmatism [3] - 359



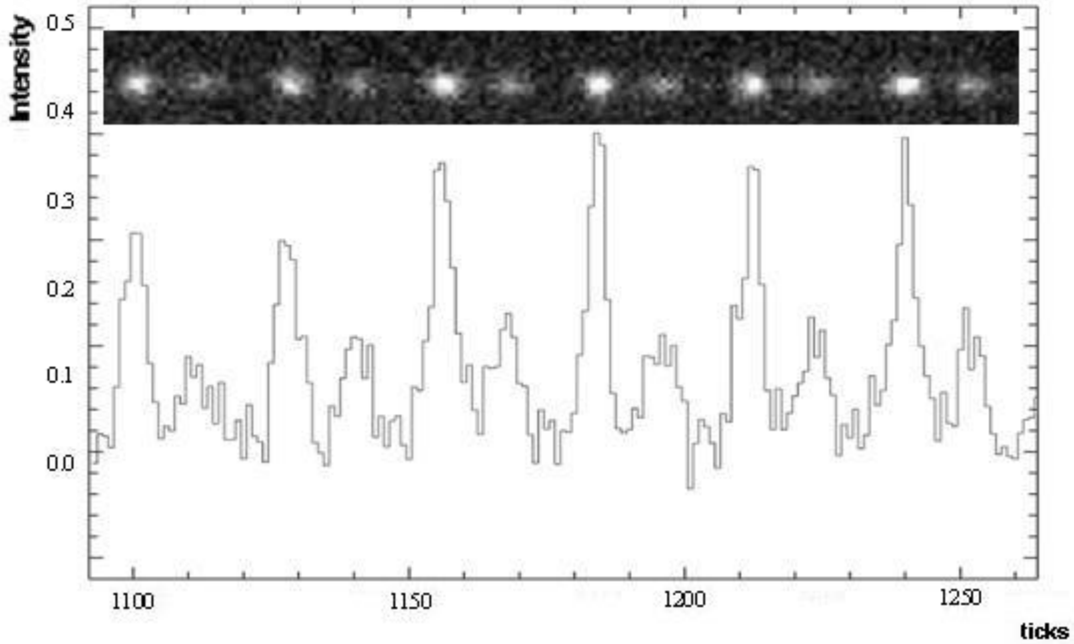
ix. On 16th December you visit a country of the Southern Hemisphere which uses Daylight Saving Time. When it is 2 o' clock, you place your watch so as the hour hand points to the projection of the Sun to the horizon. Which number indicates North (approximately)? [1] - 3



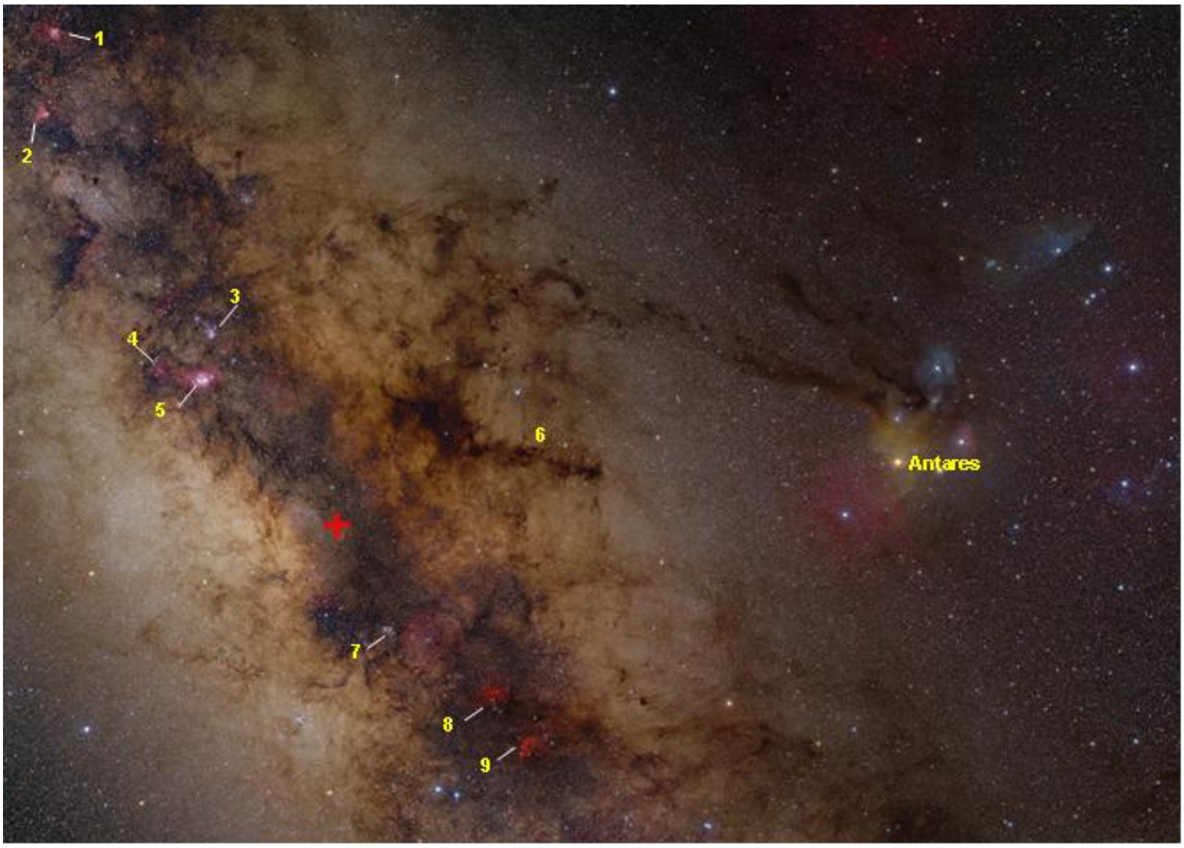
J.

i. Each Zodiacal Sign extends for that many degrees along the ecliptic. [2] – 30

ii. You are given the light curve of a pulsar. What is its rotation period (ms) if the time interval between two "ticks" is 1.1965ms? (one decimal) [3] – 335



iii. Pipe Nebula, Trifid Nebula, Lagoon Nebula, Cat's Paw Nebula, Eagle Nebula [5] – 63591


1
2
3
4
5
6
7
8
9
Antares

iv. Write the corresponding numbers of the three biggest asteroids in descending order: [3] – 248

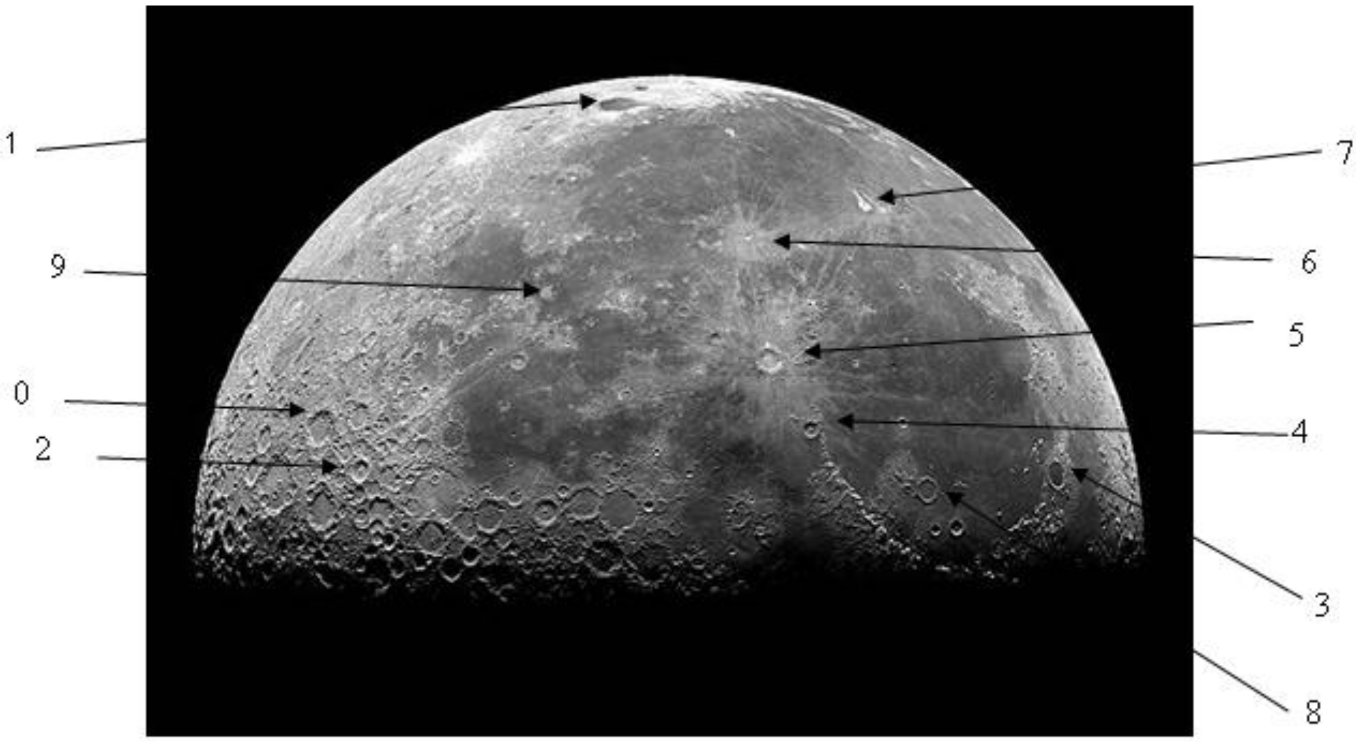
1.Hygiea
2.Ceres
3.Eugenia
4.Pallas
5.Fortuna
6.Aurora
7.Nemesis
8.Vesta
9.Psyche

v. Baade and Hubble measured the distance to NGC 1049 to be 188 kpc. Thus the distance modulus (m - M) they would get for this galaxy is (2 decimal points) [4] - 2137

K.

i. Two stars have angular separation of 13.84 arcsec. We are photographing them with a f/10 telescope with a diameter of 20 cm. What is their linear separation on the photograph in micrometers? (integer) **[4] - 1342**

ii. Grimaldi, Plato, Tycho, Eratosthenes **[4] – 1324**



iii. How many degrees under the horizon is the centre of the Sun when the Astronomical Twilight ends? **[2] – 18**

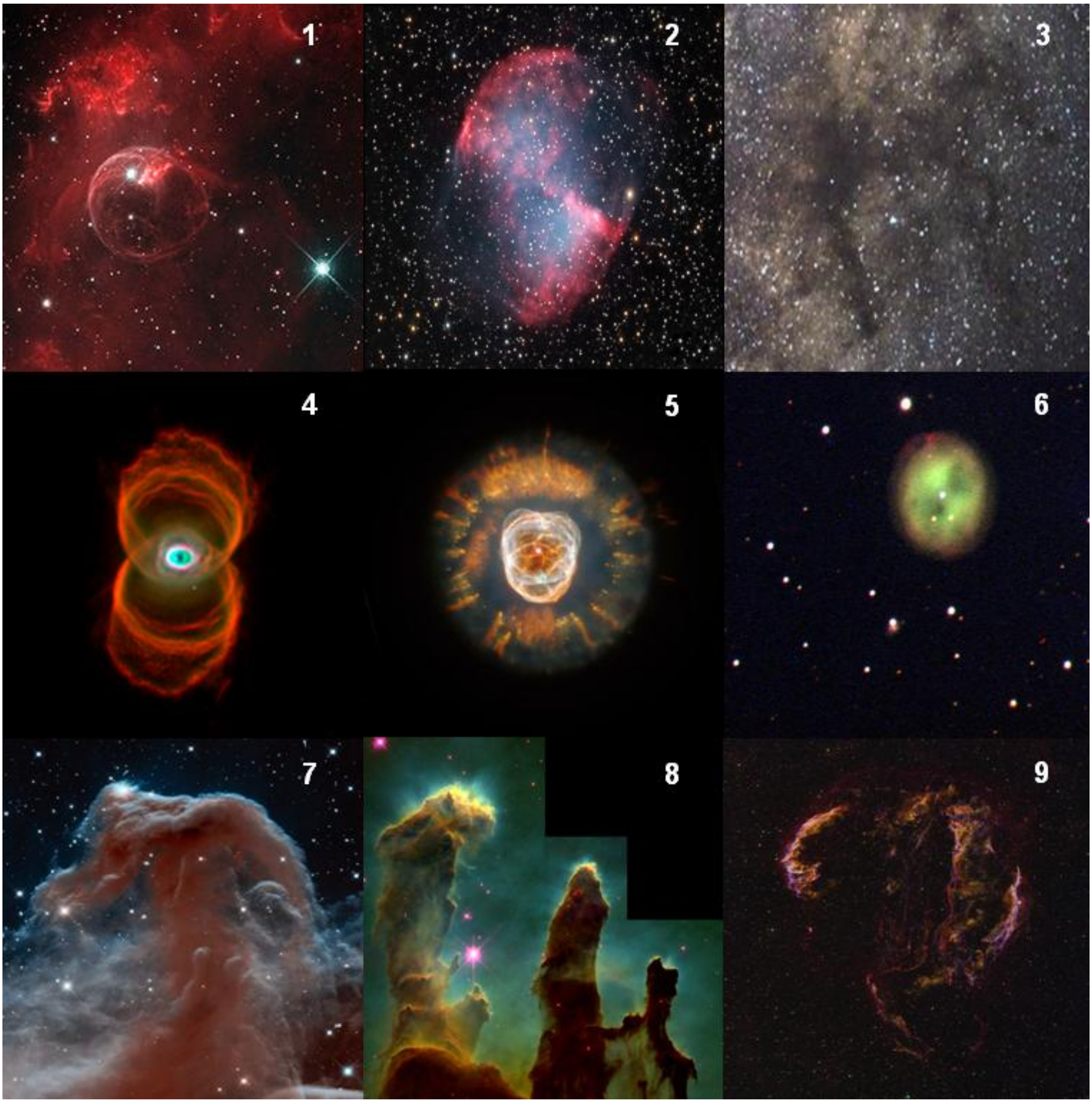
iv. The mission of Apollo __ was aborted after an oxygen tank exploded on the way to the Moon. **[2] – 13**

v. If the Observatory Factor is *0.95*, what is the Wolf Number if the number of sunspot groups is *13* and the number of individual spots is *14?* (integer) **[3] – 137**

vi. A star is *100pc* away. Its Apparent Visual Magnitude is $m_V=13.0mag$, its Apparent Photographic Magnitude is $m_{pg}=14.6mag$ and its Absolute Visual Magnitude is $M_v=4.7mag$. What is its Colour Excess? Consider that $A_V = 3\times E_{B-V}$, where E_{B-V} is the Colour Excess and A_V is the Visual Absorption. (one decimal) **[2] – 11**

L.

i. Pillars of Creation, Dumbell Nebula, Dark Horse Nebula (Great Dark Horse), Bubble Nebula, Engraved Hourglass Nebula [5] - 82314



ii. What is the wavelength of the spectral line H β ? (integer) **[4] – 4862**

iii. First planet to be discovered using Telescope (Mercury is 1, Neptune is 8) **[1] – 7**

iv. Consider an eclipsing binary, with central eclipses. Time between the first and fourth contact of primary eclipse is 1.5 hours and time between the 2^{nd} and 3^{rd} contact is 1 hour. Find the ratio of their radii. (integer) **[1] – 5**

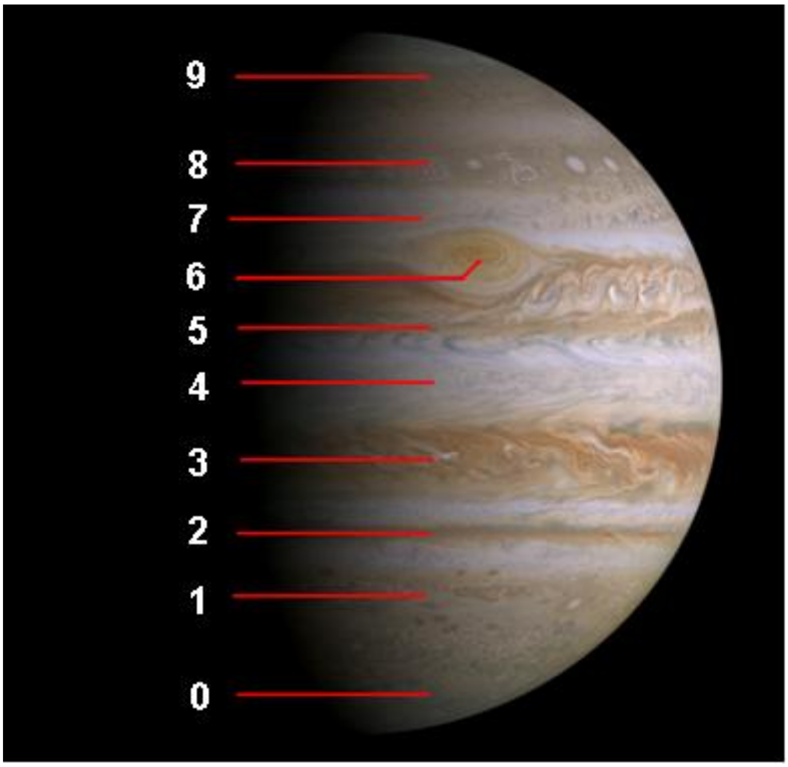
v. The final Apollo lunar mission is Apollo _. **[2] – 17**

vi. How many times greater is the escape velocity of a satellite compared to the velocity that is required for an orbit with radius equal to the celestial body's radius? (one decimal) **[2] – 14**

vii. A star is behind the Coalsack Nebula in a distance of *200pc*. If its apparent magnitude is $m=18mag$ and the optical depth of the Nebula is $\tau=1.38$, what is its Absolute Magnitude? (integer) **[2] – 10**

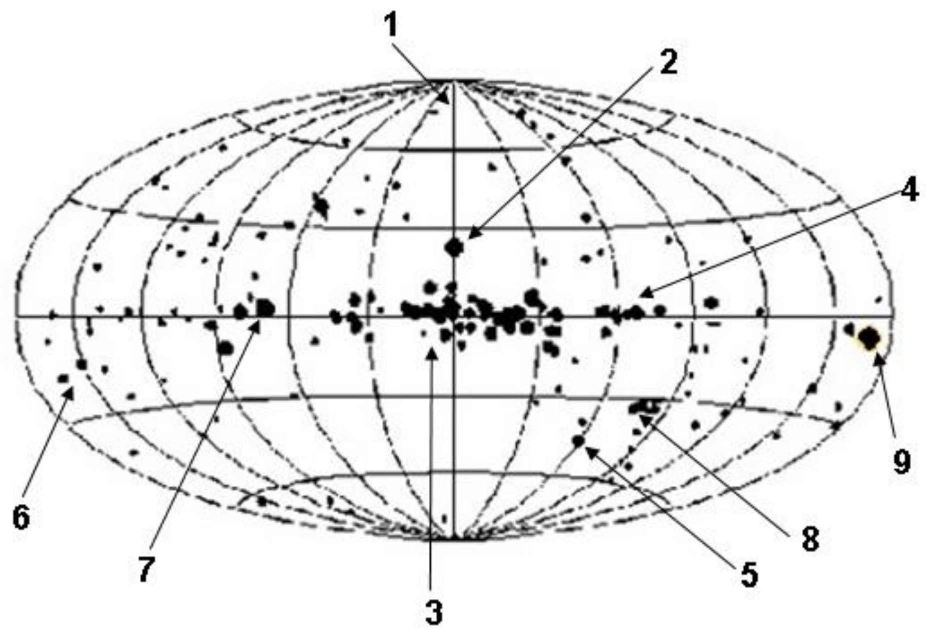
M.

i. Great Red Spot, North Polar Region, South Equatorial Belt, Equatorial Zone [4] - 6054



ii. This is a map of the sky in X-rays using galactic coordinates. [5] - 82971

÷ Large Magellanic Cloud
÷ Scorpio X-1
÷ Cancer Nebula
÷ Cygnus X-1
÷ Coma


1
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6

iii. The table shows the composition of the atmosphere of Mars, Earth, Jupiter, Neptune and Venus. Find Jupiter, Venus, Neptune. [3] – 532

	1	2	3	4	5
H_2	0.000055%	80.0	-	-	86.4
He	0.000524%	19.0	12 ppm	-	13.6
CH_4	0.000179%	2	-	10.5 ppb	0.0018
NH_3	trace	<600 ppb	-	-	0.0006
H_2O	locally 0.001%–5%	-	20 ppm	210 ppm	520 ppm
H_2S	-	<3 ppm	-	-	70 ppm
CO_2	0.0397%	0.3 ppb	96.5%	95.32%	30 ppb
HCN	-	60 ppb	-	-	60 ppb
N_2	78.084%	-	3.5%	2.7%	-
O_2	20.946%	-	-	1300 ppm	-
Ar	0.9340%	-	70 ppm	1.6%	-
H_2SO_4*	-	-	150 ppm	-	-

iv. Lagoon nebula is M _. [1] – 8

v. Sequence in which following discoveries received Nobel prizes. [4] – 4253

1. Cepheid Period–Luminosity relation
2. Discovery of pulsars
3. Accelerated Expansion of the Universe
4.Discovery of cosmic rays
5. Chandrasekhar Mass Limit

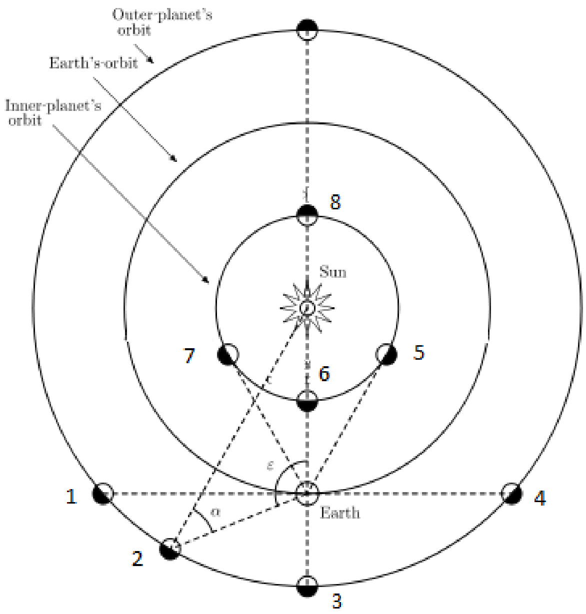
A.

i. M31 is NGC_. [3] – 224

ii. The effective temperature of the solar surface in Kelvin. (integer) [4] – 5778

iii. Sun's Absolute Visual Magnitude. (two decimals) [3] - 483

iv. Eastern quadrature, Superior conjunction [2] – 18



v. Hour angle of setting sun on the equinox day [1] – 6

B.

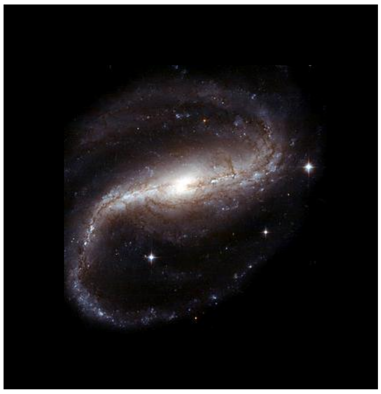
i. The Trifid Nebula is M_. [2] – 20

ii. The temperature at an exoplanet's atmosphere is $336K$. The mean speed of the nitrogen molecules ($m=4.7x10^{-26}kg$) in the same temperature is $0.5km/s$. The mean speed (km/s) that the nitrogen molecules acquire when the temperature becomes four times greater is_. [1] – 1

iii. The emission spectral line H α is the result of the transition of an electron between energy levels _ to _. [2] – 32

iv. The morphological class of this galaxy. [1] – 3

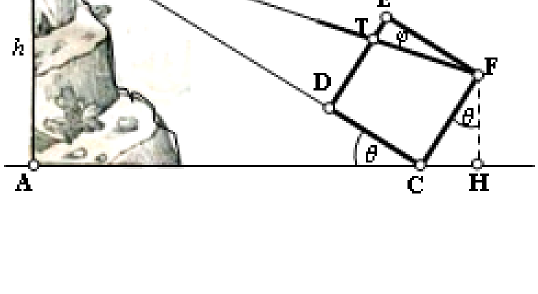
1. SBa
2. SBb
3. SBc
4. S0
5. SB0
6. Irr
7. Sa
8. Sb
9. Sc



v. Io, Europa and Ganymede revolve in a _:_:_ resonance. [3] – 124

vi. Vega's B-V Colour Index. [1] – 0

vii. Find the height of the mountain (metres). $FE/TE=800$ and $CH=0.4m$. EFCD is a square and FH is vertical to CH. [3] – 320



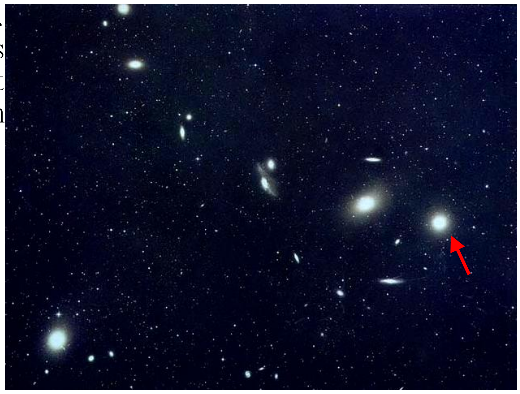
C.

i. The Julian century has _days. [5] – 36525

ii. The first to measure Earth's radius, only using data from a single location. [1] – 7

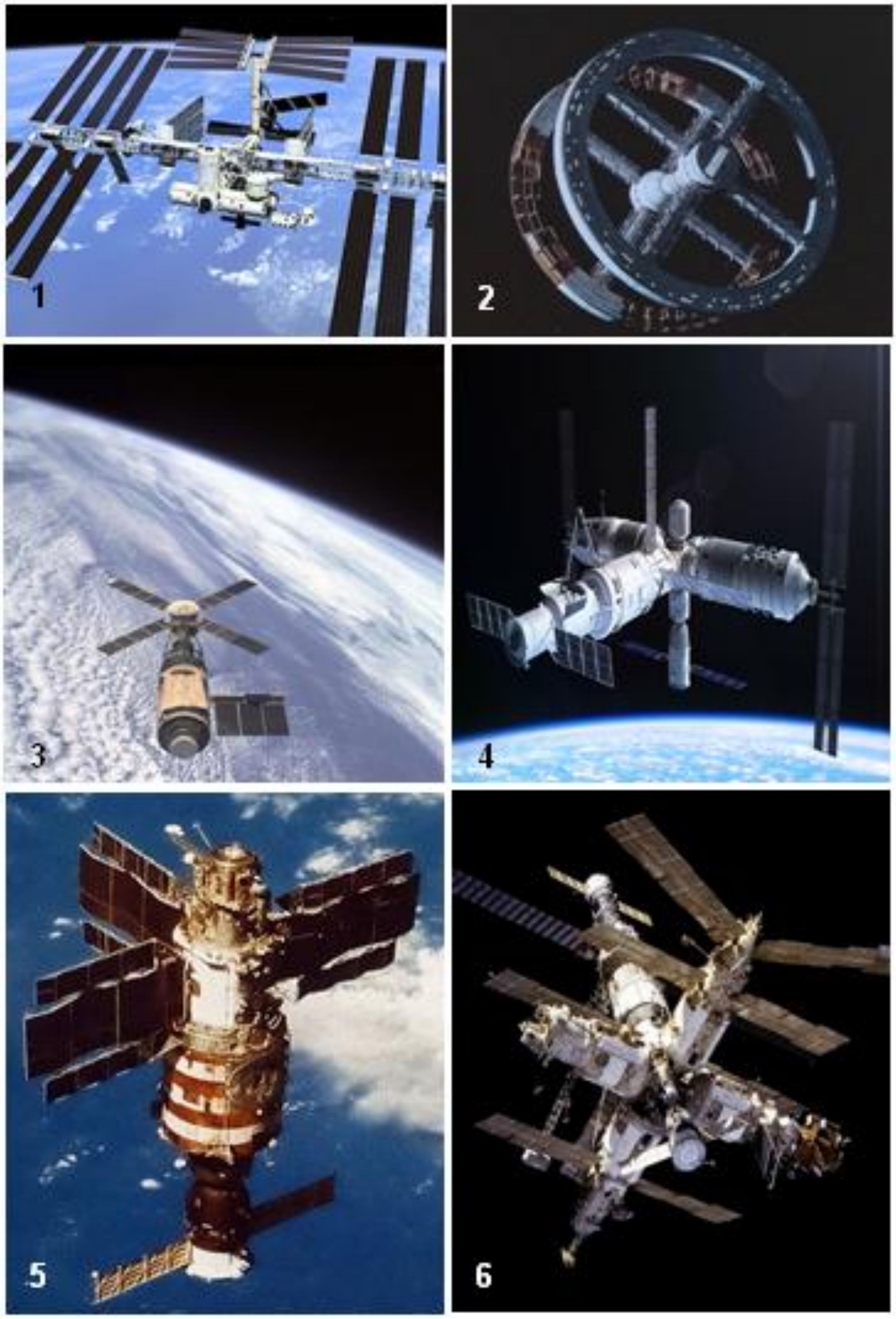
1.Posidonius
2.Picard
3.al-Ma'mun
4.Eratosthenes
5.al-Farghani
6.Snell
7.al-Biruni
8.Cassini
9.Gauss

iii. This image shows a part of the Virgo Galaxy Cluster. The long chain of galaxies is known as Markarian's Chain. At the bottom right, pointer shows a giant elliptical galaxy (also a powerful radio source) known as M_. [2] – 84



iv. A star cluster which lies between η and ζ Herculis is M_. [2] – 13

v. Tiangong-3, Skylab, Salyut-7 [3] - 435



D.

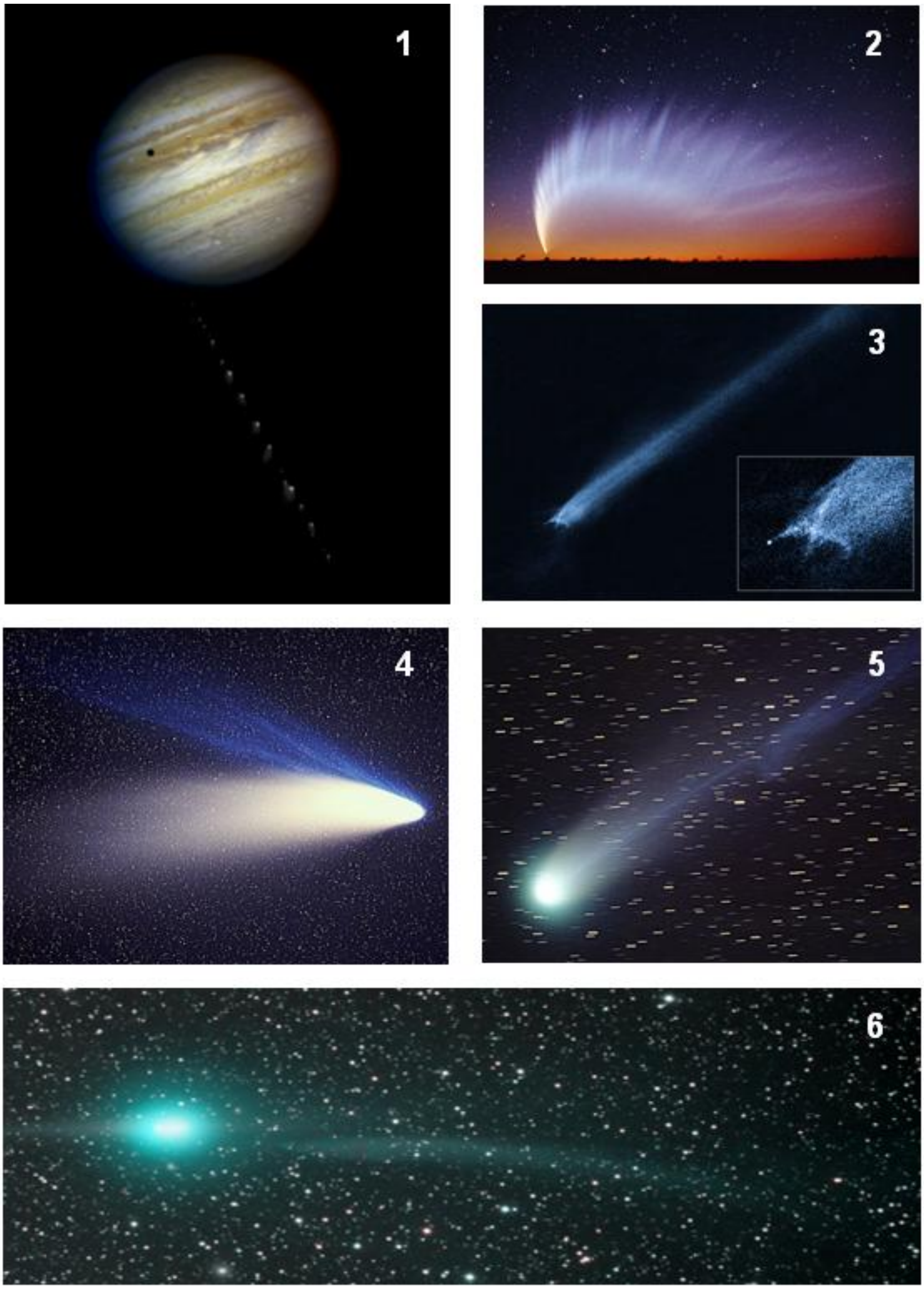
i. The Orion Nebula is M_. [2] – 42

ii. This year Galileo observed the sky with a telescope for the first time. [4] – 1609

iii. R

iv. N

v. C



E.

i. What would have been temperature of CMBR at z=8.63? (upto 1st decimal) [3] – 263

ii. The axial tilt of the Earth (integer) [2] – 23

iii. Number of planets of the Solar System that have moons. [1] – 6

iv. The wavelength used to chart the Milky Way (in cm). [2] – 21

v. Pleiades is M__. [2] – 45

vi. Write scientist number in correct sequence [3] – 148

- He confirmed the Big Bang Theory by observing the CMBR
- He coined the name "Big Bang Theory"
- He introduced Big Bang Nucleosynthesis

1. Robert Wilson
2. Alexander Friedmann
3. Edwin Hubble
4. Fred Hoyle
5. George Lemaitre
6. Fritz Zwicky
7. Arthur Walker
8. George Gamow

F.

i. Every _ years (integer), Halley's comet appears! [2] – 75

ι.

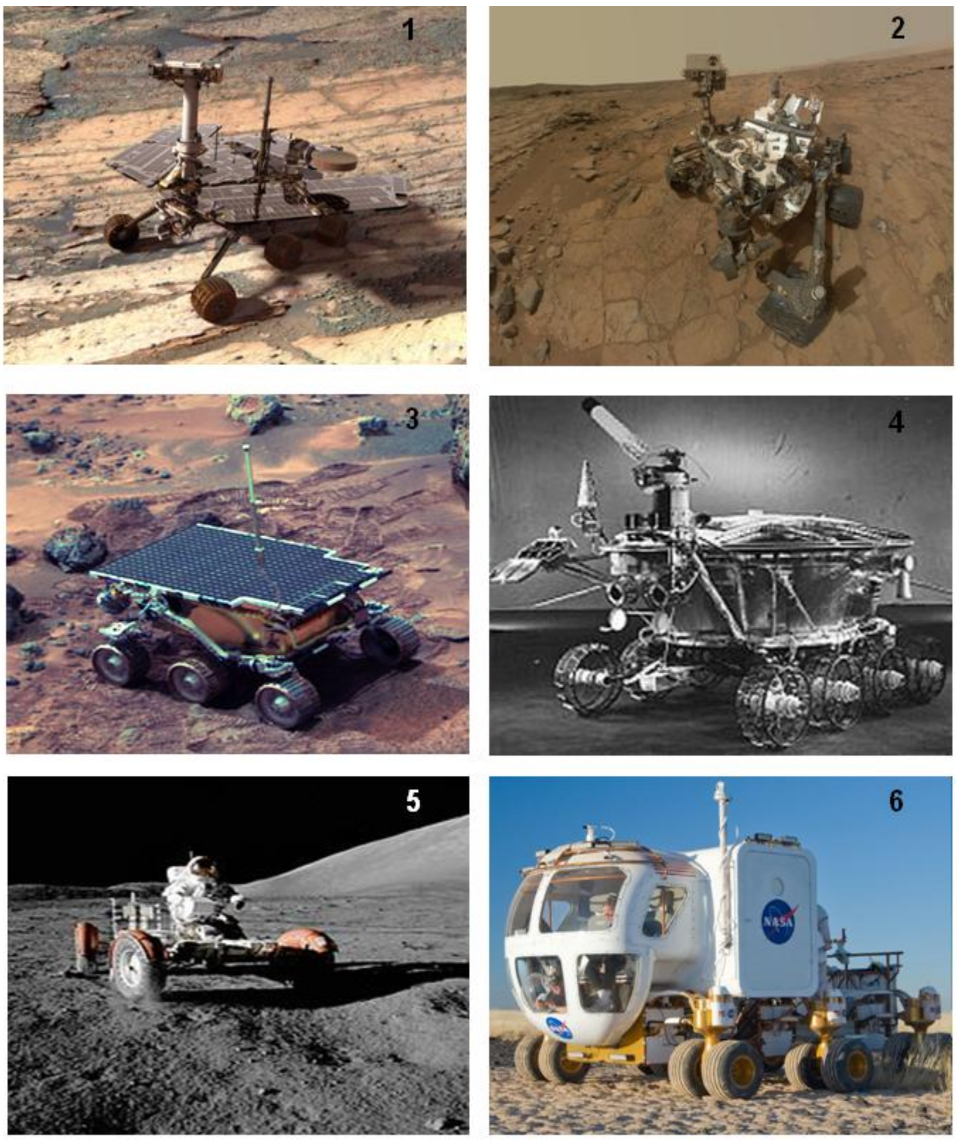
ii. The relative error of the spectroscopic parallax is *15%* and the absolute error of the trigonometric parallax is *0.005″* . Over which distance (pc) the spectroscopic parallax becomes more accurate than the trigonometric? (integer) [2] – 30

iii. The molecular weight (in a.m.u.) of the main constituent of Titan's oceans [2] – 16

iv. 189.08 light years in parsec (integer) [2] – 58

v. In the beginning of July this planet stopped its retrograde motion. How many AU is its mean orbital radius? (one decimal) [2] – 96

vi. Sojourner, Lunokhold 1, Curiosity [3] – 342

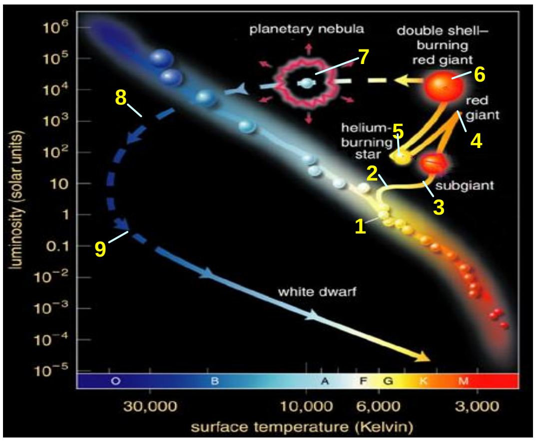


G.

i. The four greatest celestial objects in descending order of size: [4] – 3657

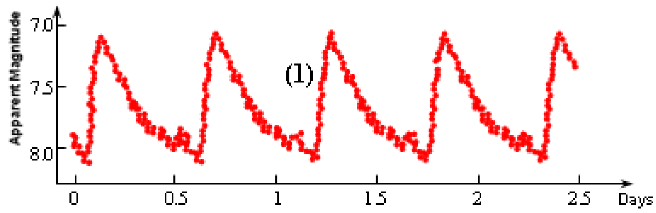
1.Moon
2.Europa
3.Ganymede
4.Io
5.Mercury
6.Titan
7.Callisto
8.Triton
9.Titania

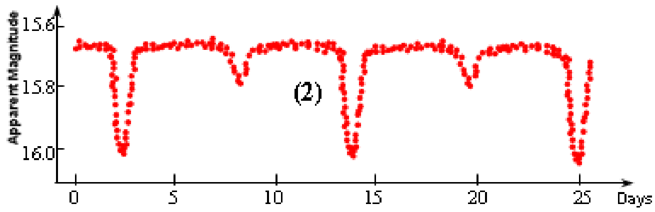
ii. At which point does the Helium Flash occur? [1] – 4

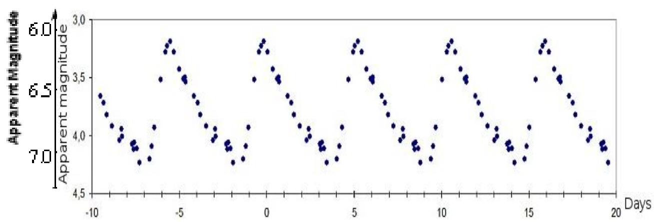


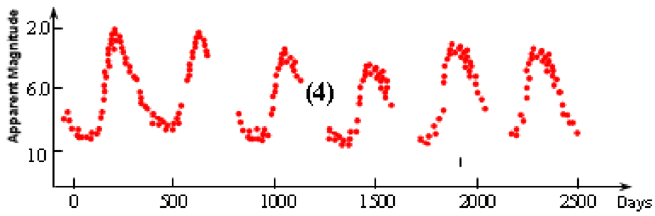
iii. The polarity of the solar magnetic field is reversed every _years. (integer) [2] – 11

iv.RR Lyrae, Mira, Classical Cepheid, Eclipsing Binary [4] – 1432

1


2


3


4


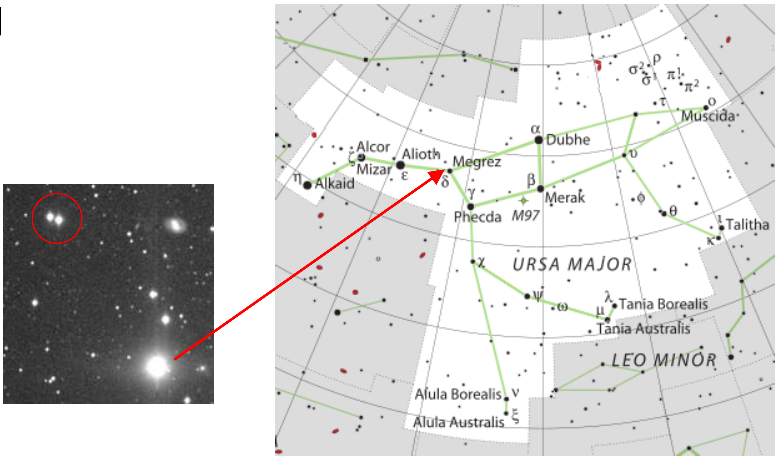
v. Days between the longest day in southern hemisphere and the next equinox. [2] – 89

H.

i. Sombrero galaxy is M_. [3] – 104

ii. Number of martian satellites. [1] – 2

iii. The circle marks is M_. [2]
– 40



iv. Arrange the following in the increasing order of masses [6] – 213546

1. Hyades Cluster
2. Eta Carinae
3. Omega Centauri
4. M31
5. LMC
6. Virgo Cluster

v. Number of crew members who perished in challenger space shuttle disaster. [1] – 7

I.

i. Assuming you are seeing the moon in the sky from Greece, how many days have passed since the last New Moon? (integer). **[2] – 25**

ii. Difference between the solar day and the sidereal day in minutes. **[1] – 4**

iii. The number of constellations **[2] – 88**

iv. The Whirlpool Galaxy is M_. **[2] – 51**

v. The four closest galaxies to the Milky Way in ascending order: **[4] – 3491**

1.SMC
2.Andromeda
3.Canis Major Irregular Dwarf
4.Saggitarius dwarf irregular galaxy
5.Triangulum galaxy
6.Fornax Dwarf Spheroidal
7.Barnard's galaxy
8.Maffei I
9.LMC

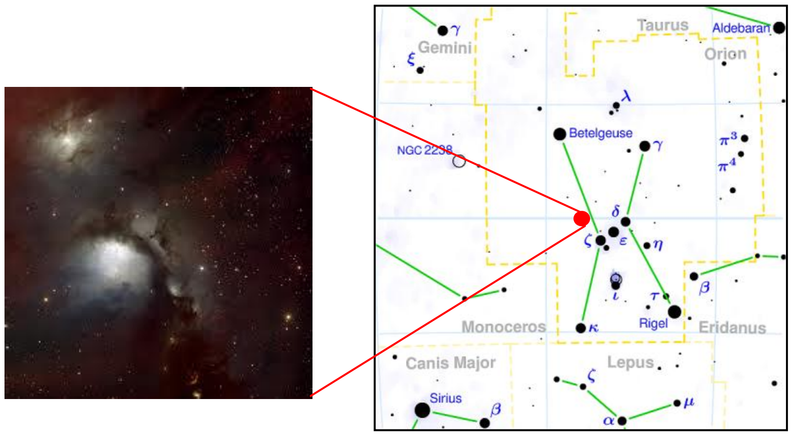
vi. Number of Van Allen Radiation Belts. **[1] – 2**

vii. The L point through which matter from one star of a binary system escapes to the other. **[1] – 1**

J.

i. The CMBR has a thermal black body spectrum at a temperature of _Kelvin. (two decimals) [3] – 273

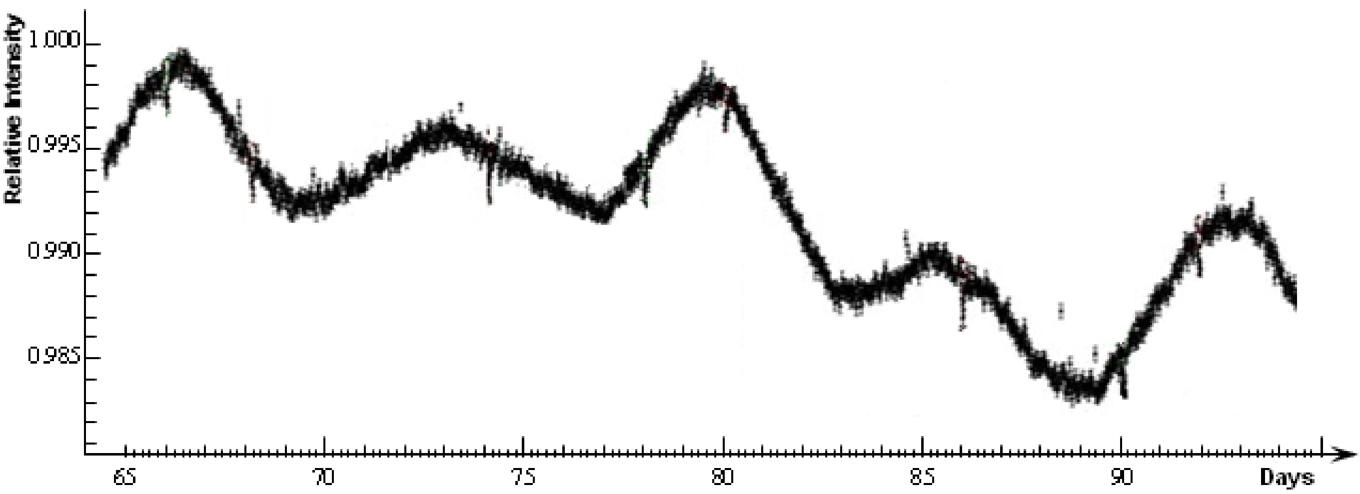
ii. This nebula is M_. [2] – 78



iii. Radiation with an energy of 2.5eV. [1] – 4

1.gamma-ray
2.X-ray
3.Ultraviolet
4.Visible
5.Infrared
6.Far Infrared
7.Microwave
8.Radio
9.Super Low Frequency

iv. Two exoplanets with a radius five times the radius of Earth rotate around a star (radius equal to this of the Sun). Find the shortest orbital period (days). (two decimals) [3] – 595

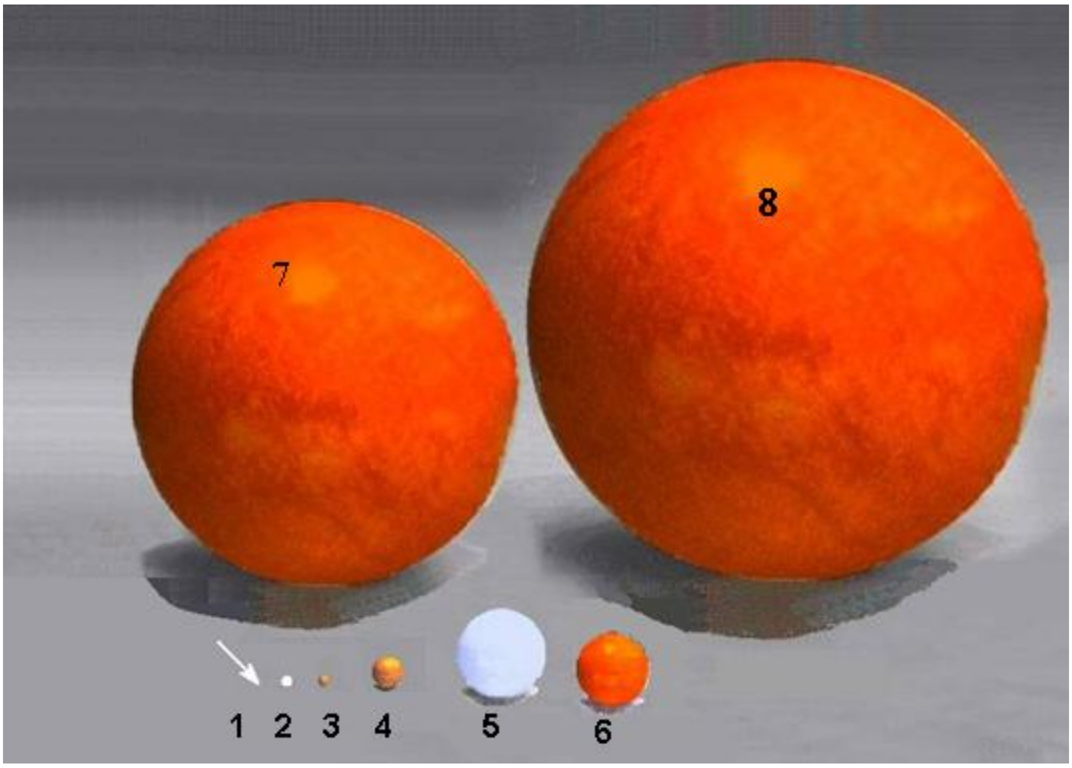


v. The first to calculate the AU by measuring the parallax of a planet: [1] – 1

1.Cassini
2.Aristachus
3.Hipparchus
4.Horrocks
5.Halley
6.Bayly
7.Euler
8.Lomonosov
9.Newcomb

vi. The diameters of the stars (Sirius, Betlegeuse, Aldebaran, Antares, Rigel, Pollux, Arcturus, Sun) are to scale. [3] – 875

Betlegeuse, Antares, Rigel

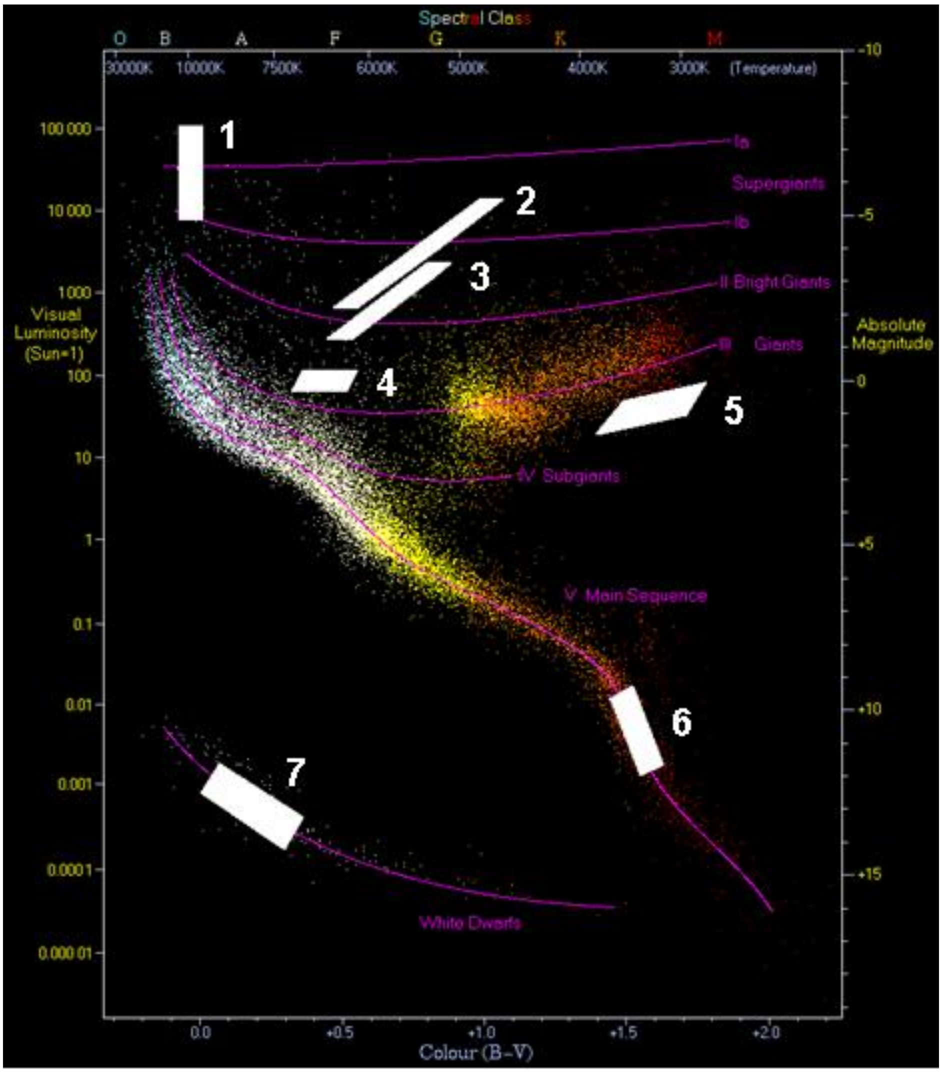


K.

i. Every that many years, the orientation of Earth's axial tilt shifts by 1°. (two decimals) **[4] – 7159**

ii. When we swim in the sea, the height of our eyes from its level is *20cm*. How many kilometres away can we look on the surface of the Earth? (one decimal) **[2] – 16**

iii. Flare Stars, Type I Cepheids, RR Lyrae Variables **[3] – 624**



iv. The first Pulsar discovered was nicknamed LGM-1. Its official name is now PSR J1921 +2153. Its declination is _ °_'. **[4] – 2153**

L.

i. What is the L.S.T. (hh:mm) at the culmination of the Sun on 53rd day after the longest day in the northern hemisphere? [4] – 0848

ii. The axial tilt of Mars. (integer) [2] – 25

iii. How many images of the same distant quasar appear at the Einstein Cross? [1] – 4

iv. mass of the Pluto in kg (exponent of 10 only) [2] – 22

v. Put in the right order the meteor showers according to when their peak occurs, starting from the earlier one: [4] – 4312

1.Perseids
2.Orionids
3.Eta Aquarids
4.Quadrantids

M.

i. Two white dwarfs have the same effective temperature. The one dwarf has an Absolute Bolometric Magnitude of $M_{bolA}=10.5mag$ and a mass $m_A=1$ *solar mass*, while the other has $M_{bol\,B}=10mag$. What is the second dwarf's mass in solar masses? The mass-radius relationship of a white dwarf is $R^3 \sim 1/M$. (one decimal) **[2] - 05**

ii. The value of the Constant of Aberration (arcseconds). (one decimal) **[3] - 205**

iii. Because of the solar parallax, the time the Sun stays below the horizon of the North Pole is longer. How many minutes is this increase in time? (integer) **[2] - 18**

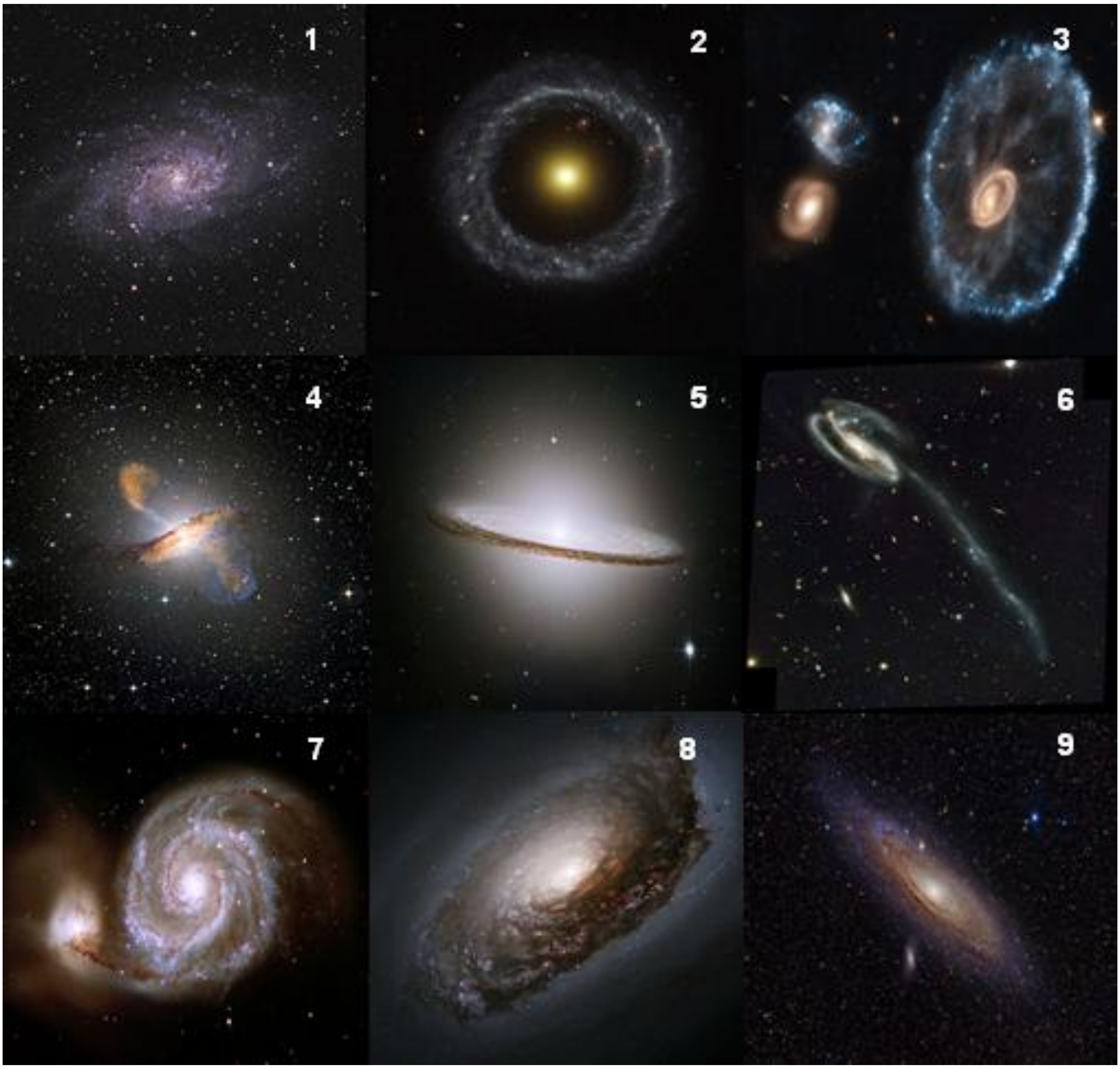
iv. How many billions of years is the age of the Universe? (one decimal) **[3] - 138**

v. What is the maximum ecliptic latitude that can be acquired by Pluto? Pluto's aphelion is $49.30AU$, its perihelion is $29.58AU$ and its orbital inclination is 17.17^o. Earth's aphelion is $1.017AU$ and its perihelion is $0.983AU$. (one decimal) **[3] - 178**

N.

i. By how many magnitudes will the magnitude of the faintest stars that can be detected by a CCD increase, if the exposure time is doubled? (up to two decimals) [3] – 075

ii. Sombrero Galaxy, Tadpole Galaxy, Black Eye Galaxy, Hoag's Object [4] – 5682



iii. How many flavours do the quarks have? [1] – 6

iv. How many colours do the quarks have? [1] – 3

v. A star with R.A. = $17^h\ 8^m$ rises in the sky at L.S.T. = $5^h\ 31^m$. How long the star will stay above the horizon (hh:mm)? [4] – 2314 o.

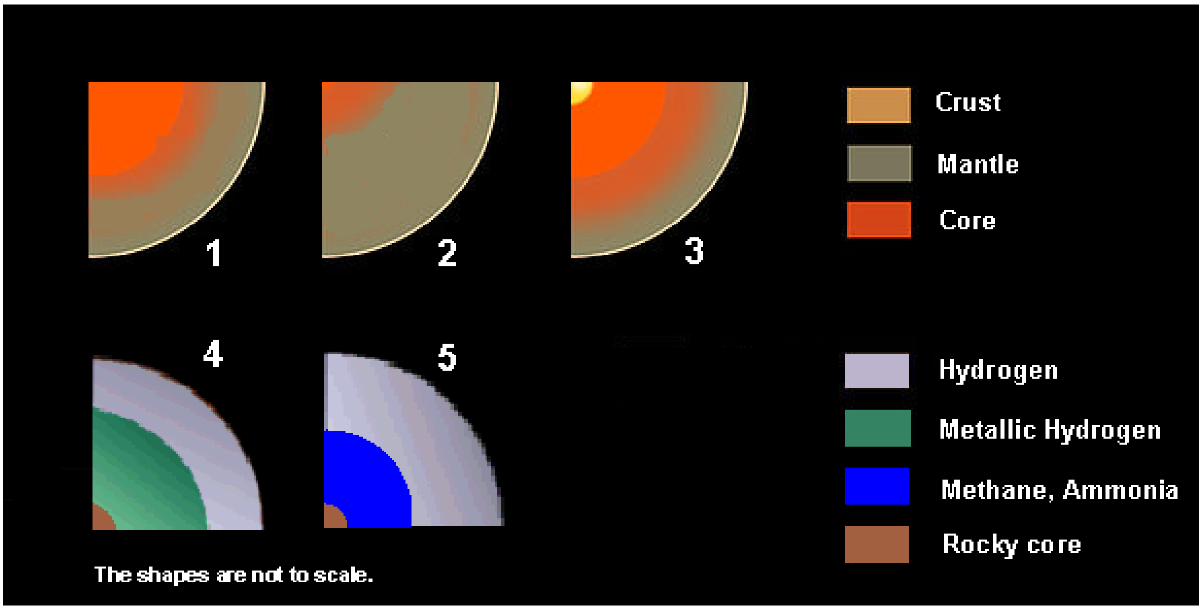
i. The maximum effective temperature of the surface of a Cepheid is $9{,}000K$ and the minimum is $7{,}000K$. The difference between its brightness maximum and minimum is 2.0 Absolute Bolometric Magnitudes. How many times bigger is the maximum radius of the Cepheid than its minimum radius? (one decimal) [2] – 15

ii. In 2013, after how many days after the Summer Solstice did the Earth reach Aphelion? (integer) [2] – 14

iii. The Sun belongs to the Population _ stars. [1] – 1

iv. The comet LINEAR is a periodic comet with aphelion distance of 5.29 A.U. And aphelion velocity as 10.45km/s. What is the semi-major axis of its orbit in A.U.? (up to 1^{st} decimal) [2] – 39

v. Identify the following planets by recognizing their internal structure: Jupiter, Neptune, Mercury [3] – 451



vi. A main sequence star "fuses" Hydrogen at a rate of 1.178×10^{12} kg/s. Its luminosity (in 10^{24} W) if mass-defect is only 0.007. (integer) [3] – 742

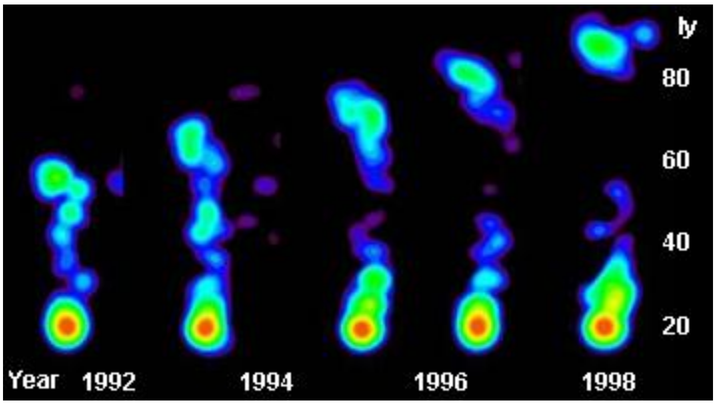
P.

i. What is the Azimuth of the point ♈ (degrees) at the 18^{th} Sidereal Hour? (integer) **[2] – 90**

ii. Shape of Analemma of the Sun as seen from the Earth **[1] – 8**

iii. What is the distance of a galaxy (in Mpc) with recession velocity of 13966.8km/s? **[3] – 206**

iv. The apparent speed of this active galaxy's jet is *3.6c*! If the angle of the jet with the line of sight is 1.5°, what is the true speed of the jet? (up to 3^{rd} decimal) **[4] – 0993**

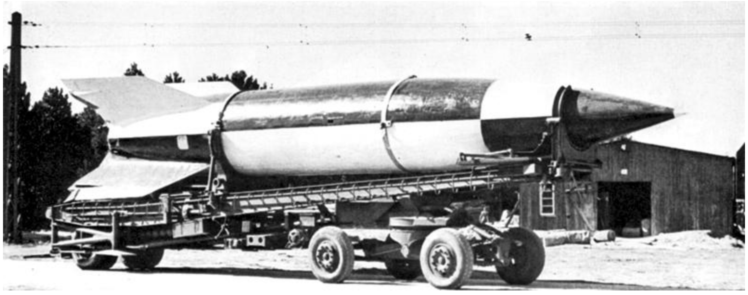


v. On the 21^{st} of March, at a place with latitude $\phi = 35^o$, during the sunset, a star on the ecliptic is at its upper culmination. What is its zenith distance in degrees? (one decimal) **[3] – 115**

Q.

i. 294° 30' in radians **[3] – 514**

ii. The first photo from space was taken from a V–_. **[1] – 2**



iii, A mission is sent to Mars by following a Hohmann–Vetchinkin orbit. How many days is the minimum time interval that the mission's members will have to stay on Mars before they find the first opportunity to come back to Earth by following once more a Hohmann–Vetchinkin orbit? Consider that the orbits of Earth and Mars are circular and coplanar and that the distance of Mars from the Sun is *1.52AU*. (one decimal) **[4] – 4586**

iv. Mass of the supermassive black hole at the galactic centre in kg (exponent of 10 only) **[2] – 37**

v. distance of globular cluster M68 (in kpc) given its parallax = 97.2 μarcsec **[3] – 103**