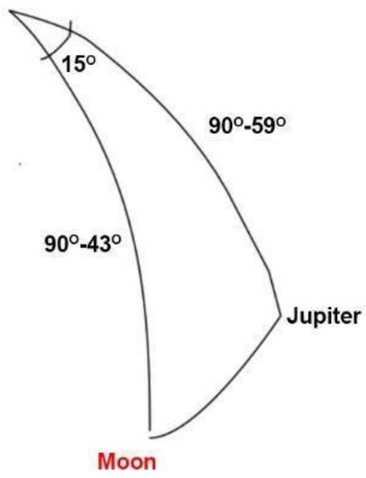
This document contains sample solutions to the problems in MyAO 2022 Final Round. Note that many alternative solutions can also be accepted for full credit; these are merely suggestions on how to approach the problems.

THEORETICAL ROUND

1.

A) Since they're both on the eastern hemisphere, they're rising

B)



The Az. Diff. is 15deg

Using the cosine rule,

Cos(MS)=cos(MZ)cos(ZJ) + sin(MZ)sin(ZJ)cos(z)

Cos(MS)=cos(47).cos(31) + sin(47).sin(31)cos(15)

Cos(MS)=0.94

MS=18°28'53"

2.

Note that periapsis distance is fixed for all flybys $d_p = a_1(1-e) = 6.0 \times 10^7$ m. Final orbital has apoapsis distance equals to radius of circle, $a_2(1+e_2) = 7.0 \times 10^7$ m, and also $d_p = a_f(1-e_f)$, giving $a_f = 6.5 \times 10^7$ m and $e_f = 1/13$. With vis-viva $v^2 = GM(2/r - 1/a)$ (using d_p for both r) we have $u = 2.00$ km s^{-1} and $v = 1.55$ km s^{-1}. $\Delta v = 0.45$ km s^{-1}. (Error from the author's calculations gave a wrong n, so the marks for determining n will be waived).

Full marks for correct dv, otherwise

Usage of dp=a(1-e)	
Correct periapsis distance calculation dp=6e7m (also given if vi is correct)	
vi=2e3 ms^-1	
Usage of da=a(1+e)	
Notes that periapsis stays constant Eg af(1-ef)=6e7m	
Notes that af(ef+1)=7e7m	
Gets e=1/13 or af=6.5e7m	
Use vis viva or energy equations to relate velocity	
vf=1.55e3 ms^-1	
dv=450ms^-1	

3.

Using the Doppler Shift Formula:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

where $\lambda_0 = 550\,\text{nm}$

v = speed of particles in A ring

c : speed of light

$$v = \frac{2\pi \times 136{,}500 \times 10^3\,\text{m}}{14.5 \times 3600\ \text{seconds}}$$

$$= 1.64 \times 10^4\,\text{m-s}^{-1}$$

$$= 16.4\ \text{km per second}$$

Therefore, $\Delta\lambda = \lambda_1 - \lambda_0 = \frac{v}{c}\lambda_0$

$$\lambda_1 = \frac{v}{c}\lambda_0 + \lambda_0$$

$$= \frac{1.64 \times 10^4\,\text{m-s}^{-1}}{3 \times 10^8\,\text{m-s}^{-1}} \times 550\,\text{nm}$$

$$= 0.0301\,\text{nm} + 550\,\text{nm}$$

$$= 550.03\,\text{nm}$$

Difference in wavelength between opposite edges of the A ring is:

$0.0301\,\text{nm} \times 2 = 0.602\,\text{nm}$

4.

On average, the Sun will be 227.9 * 10^6km from Mars

With the Sun's diameter of 1.392 * 10^6km,

The Sun would appear to be $206265 \times \left(\frac{1.392 \cdot 10^6}{227.9 \cdot 10^6}\right) = 1259.85''$

Mean motion of the earth: 360/365.25=0.9856263deg/day

Mean motion of Mars: 360/686.98=0.5240327 deg/day

Difference in mean motion; 0.4615936 deg/day

Using mean distance, $r = \frac{R_e}{R_m - R_e} = \frac{1}{1.5-1} = 2$

Apparent angular speed: $r \times v = 2 \times 0.4615936 = 0.9232° / day$

The duration $\Delta t = \frac{1259.85''}{3600 \times 0.9232} = 0.37910\ days = 9hrs\ 5\ min\ 54s$

5.

Denote displacements from A. From Kepler's Third Law $P^2 = \frac{4\pi^2}{G(M_A+M_B)}a^3$, we get $a = 6.3209 \times 10^{11}$ m. From $M_A x_{COM} = M_B(a - x_{COM})$, we get $x_{COM} = 4.214 \times 10^{11}$ m. Total flux is $F = \frac{4\pi R_A^2 T_A^4}{4\pi x_{min}^2} + \frac{4\pi R_B^2 T_B^4}{4\pi (a-x_{min})^2}$. Use differentiation $\frac{dF}{dx_{min}} = 0$, we get

$$x_{min} = \frac{a}{(\frac{R_B^2 T_B^4}{R_A^2 T_A^4})^{1/3} + 1} = 4.672 \times 10^{11} \text{ m}$$

$\Delta x = 4.63 \times 10^{10}$ m.

Full marks for correct final answer

Usage of correct Kepler's Third Law	
Correct evaluation of semi-major axis a=6.3e11 m (4.23 AU)	
Usage of correct centre of mass equation $M_A x_{COM} = M_B(a - x_{COM})$	
Correct evaluation of x_COM 4.2e11 m (2.81 AU) from A or 2.1e11 m (1.40 AU) from B	
Usage of correct Stefan-Boltzmann Law F=sigma T^4	
Usage of correct luminosity-flux relationship to get total flux from star (radius seen)	
Usage of correct luminosity-flux relationship to get flux at a point (x_min seen)	
Differentiation attempt, dF/dx=0 seen All 3 marks above awarded if correct expression of x_min given $x_{min} = \frac{a}{(\frac{R_B^2 T_B^4}{R_A^2 T_A^4})^{1/3} + 1}$	
Correct evaluation of x_min 4.67e11 m (3.12 AU) from A or 1.63e11 m (1.09 AU) from B	
dx = 4.6e10 m (0.307 AU)	

6.

the telescopes length (l) = 58 cm

the overall magnification of telescope (M) = 124X

$l=f_{eye}+f_{obj}$

$f_{obj}=58-f_{eye}$ —(1)

$M = f_{obj} / f_{eye}$

$f_{ob} = 124 f_{eye}$ —--(2)

substituting (2) into (1)

$124 f_{eye}=58-f_{eye}$

$f_{eye}=4.64cm$

$f_{obj}=57.54cm$

7.

6. Use Pogson/distance modulus $m_{app} - m_{abs} = 5 \log \frac{d}{10}$ to get distance $d = 2884$ pc(optional), but most importantly to convert star magnitude to absolute

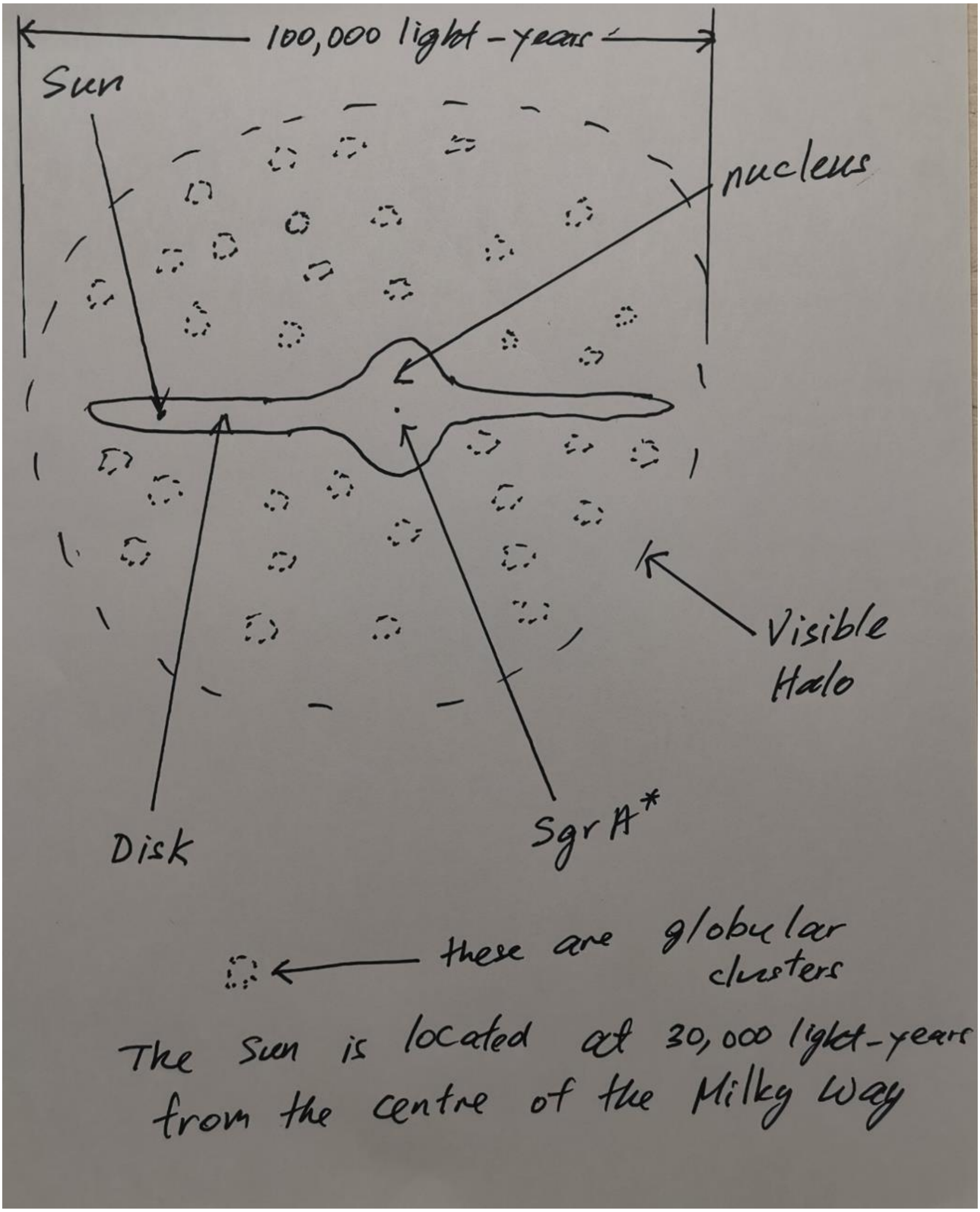
$$m_{app,star} - m_{abs,star} = m_{app,supernova} - m_{abs,supernova}$$

$m_{\text{abs}} = -1.3$. Use Pogson comparing luminosity and absolute magnitude with the Sun to get luminosity of the star $m_{star} - m_{sun} = -2.5 \log \frac{L}{L_{Sun}}$ so $L = 283 L_{\text{Sun}} = 1.084 \times 10^{29}$ W. Use Wien's displacement law to get star surface temperature $T = b/\lambda = 4140$ K. Use Stefan-Boltzmann Law to get radius $L = 4\pi R^2 \sigma T^4$, $R = 2.275 \times 10^{10}$ m $= 32.7 R_{\text{Sun}}$

Full marks for correct answer, otherwise

Correct form of distance modulus $m_{app} - m_{abs} = 5 \log \frac{d}{10}$ or correct substitution of flux with L/4\pi d^2	
Correct distance evaluated d=2884pc Scoring this awards total 2 marks above OR Correct relationship between magnitudes $m_{app,star} - m_{abs,star} = m_{app,supernova} - m_{abs,supernova}$	
Correct absolute magnitude evaluated m_abs=-1.3 Scoring this awards the total 3 marks above	
Use of Pogson to compare star and Sun absolute magnitudes correctly $m_{star} - m_{sun} = -2.5 \log \frac{L}{L_{Sun}}$	
Correct luminosity obtained L=1.084e29 W (283 L_sun)	
Use of Wien's displacement law $T = b/\lambda$	
Correct effective temperature evaluated T=4140 K	
Stefan-Boltzmann Law T^4 seen	
Correct form of luminosity-radius-temperature or flux relationship (L=4\pi R^2 F)	
Correct radius evaluated R = 32.7 R_sun	

8.


100,000 light-years
Sun
nucleus
Visible
Halo
Disk
Sgr A*
these are globular
clusters
The Sun is located at 30,000 light-years
from the centre of the Milky Way

9. Choose any THREE of the answers below:

(i) The James Webb Space Telescope (JWST) is the most powerful telescope ever launched into space, its greatly improved infrared resolution and sensitivity will allow it to view objects too old, distant, and faint for the Hubble Space Telescope (HST).

(ii) The JWST has a mirror three times wider than the mirror of the Hubble Space Telescope (HST) and the JWST will be able to see objects almost nine times fainter than Hubble, allowing us to peer even further into space

(iii) The JWST observes the universe in infrared wavelengths. By observing in the infrared spectrum, the JWST will be able to look straight through the clouds of space dust in the Milky Way and the universe to observe the astronomical objects. Thus, the JWST can observe in the infrared and maintain high-resolution imaging with high sensitivity.

(iv) In addition to studying planets outside our solar system, JWST will be able to observe our home planetary system. Its great sensitivity will enable the identification and characterisation of comets and other icy bodies in the outermost regions of the solar system.

(v) JWST is designed to look deeper into space than the Hubble Space Telescope (HST) to see the earliest stars and galaxies that formed in the Universe and to look deep into nearby dust clouds to study the formation of stars and planets. JWST will tell us about the very beginning of the universe.

(vi) JWST will tell us why are there supermassive black holes at the centres of galaxies.

(vii) JWST will tell us how are new stars born in the Milky Way Galaxy.
(viii) JWST can give us more detailed information on the exoplanets that have been discovered that are similar to Earth.
(ix) JWST can detect possible chemical signatures of life on exoplanets

10. Choose any THREE of the answers below:
(i) Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit. So, astronomers use other indirect ways to detect and study these distant planets. They search for exoplanets by looking at the tiny effects these planets have on the stars they orbit.
(ii) Direct imaging is a very difficult and limiting method for discovering exoplanets. First of all, the star system with the exoplanets has to be relatively close to Earth. Next, the exoplanets in that system must be far enough from the star so that astronomers can distinguish them from the star's glare
(iii) The main problem is that exoplanets are almost always too small and too dim to look at directly. The only ways we can discover them are by observing them indirectly – we have to look at how the exoplanets influence the star that they're orbiting around.
(iv) The problem is that exoplanets are not that big, and they're extremely far away from Earth. Even detecting them at all against the glare of their star is hard.

PRACTICAL ROUND

1.

For the first exoplanet, TRAPPIST-1b
we use the small angle formula,

$D = l\theta$

where D is the diameter of TRAPPIST-1 star

l is the distance between the first exoplanet to the star

θ is the angle in radians

we have, $\theta = \dfrac{D}{l}$

$$= \frac{2 \times 84{,}180 \text{ km}}{0.0115 \times 1.49 \times 10^{8} \text{ km}}$$

$$= 0.09825 \text{ radian}$$

Referring to the photometry light-curve for TRAPPIST-1b, the total transit time for the exoplanet is $2 \times 17 = 34$ minutes

Therefore this exoplanet moves an angle of 0.09825 radian in 34 minutes

For this exoplanet to make a full orbit around the star, it would take

$$\frac{2\pi \text{ radians}}{0.09825 \text{ radian}} \times 34 \text{ minutes}$$

$$= 2,174 \text{ minutes}$$

$$= \underline{1.51 \text{ days}}$$

Anywhere between 1.40 days to 1.60 days is correct

For the second exoplanet TRAPPIST-1c

$$\theta = \frac{D}{\ell}$$

$$= \frac{2 \times 84,180 \text{ km}}{0.0158 \times 1.49 \times 10^{8} \text{ km}}$$

$$= 0.07151 \text{ radian}$$

Referring to the photometry light-curve for TRAPPIST-1c, the total transit time for the exoplanet is

$2 \times 20 = 40$ minutes

For this exoplanet to make a full orbit around the star, it would take

$$\frac{2\pi \text{ radians}}{0.07151 \text{ radian}} \times 40 \text{ minutes}$$

$= 3{,}515$ minutes

$= \underline{2.44 \text{ days}}$

Anywhere between 2.40 days to 2.50 days is correct

For the third exoplanet, TRAPPIST-1d

$$\theta = \frac{p}{l}$$

$$= \frac{2 \times 84{,}180 \text{ km}}{0.0220 \times 1.49 \times 10^{8} \text{ km}}$$

$$= 0.05136 \text{ radian}$$

From the light-curve for TRAPPIST-1d, the total transit time for the exoplanet is

$$2 \times 24 = 48 \text{ minutes}$$

This exoplanet will make a full orbit around the star in

$$\frac{2\pi \text{ radians}}{0.05136 \text{ radian}} \times 48 \text{ minutes}$$

$$= 5{,}872 \text{ minutes}$$

$$= \underline{4.08 \text{ days}}$$

Anywhere between 4.00 days and 4.20 days is correct

For the fourth exoplanet, TRAPPIST-1e,

$$\theta = \frac{D}{\ell} = \frac{2 \times 84{,}180 \text{ km}}{0.0290 \times 1.49 \times 10^{8} \text{ km}}$$

$$= 0.03896 \text{ radian}$$

From the light curve for TRAPPIST-1e, the total transit time for the exoplanet is $2 \times 29 = 58$ minutes

This exoplanet will make a full orbit around the star in

$$\frac{2\pi \text{ radians}}{0.03896 \text{ radian}} \times 58 \text{ minutes}$$

$$= 9{,}355 \text{ minutes}$$

$$= \underline{6.49 \text{ days}}$$

Anywhere between 6.00 days and 7.00 days is correct

For the fifth exoplanet, TRAPPIST-1f,

$$\theta = \frac{D}{\ell} = \frac{2 \times 84{,}180\text{ km}}{0.0380 \times 1.49 \times 10^{8}\text{ km}}$$

$$= 0.02973 \text{ radian}$$

From the light-curve of TRAPPIST-1f, the total transit time for the exoplanet is $2 \times 33 = 66$ minutes

This exoplanet will make a full orbit around the star in

$$\frac{2\pi \text{ radians}}{0.02973 \text{ radian}} \times 66 \text{ minutes}$$

$$= 13{,}950 \text{ minutes}$$

$$= 9.7 \text{ days}$$

Anywhere between 9.0 days and ~~10.0 days~~

10.0 days is correct

For the sixth exoplanet, TRAPPIST-1g,

$$\theta = \frac{D}{l} = \frac{2 \times 84{,}180 \text{ km}}{0.0470 \times 1.49 \times 10^{8} \text{ km}}$$

$= 0.02404$ radian

$= \cancel{0.05337 \text{ radians}}$

From the light curve of TRAPPIST-1g, the total transit time for the exoplanet is $2 \times 35 = 70$ minutes

The exoplanet will make a full orbit around the star in

$$\frac{2\pi \text{ radians}}{0.02404 \text{ radian}} \times 70 \text{ minutes}$$

$= 18{,}297$ minutes

$= \underline{12.7 \text{ days}}$

Anywhere between 12.0 days and 13.0 days is correct

For the seventh exoplanet, TRAPPIST-1h,

$$\theta = \frac{D}{\ell} = \frac{2 \times 84{,}180 \text{ km}}{0.0620 \times 1.49 \times 10^{8} \text{ km}}$$

$$= 0.01822 \text{ radian}$$

From the light curve of TRAPPIST-1h, the total transit time for the exoplanet is $2 \times 37 = 74$ minutes

The exoplanet will make a full orbit around the star in

$$\frac{2\pi \text{ radians}}{0.01822 \text{ radian}} \times 74 \text{ minutes}$$

$$= 25{,}522 \text{ minutes}$$

$$= \underline{17.7 \text{ days}}$$

Anywhere between 15.0 days to 20.0 days is correct

2.

Solution.

$$v = c\frac{(1+z)^2 - 1}{(1+z)^2 + 1}$$

Galaxy ID	$\lambda_{\mathrm{H}\alpha}$ (Å)	λ_{OII} (Å)	$\Delta\lambda_{\mathrm{H}\alpha}$ (Å)	$\Delta\lambda_{\mathrm{OII}}$ (Å)	$z_{\mathrm{H}\alpha}$	z_{OII}	z	v (km s^{-1})	D (Mpc)
A	6809	3861	244	133	0.03717	0.03568	0.03642	10720	153
B	7306	4150	741	422	0.11287	0.11320	0.11303	31983	457
C	7710	4382	1145	654	0.17441	0.17543	0.17492	47912	684
D	8173	4647	1608	919	0.24494	0.24651	0.24572	64830	926
E	8960	5087	2395	1359	0.36481	0.36454	0.36468	90319	1290
F	9780	5549	3215	1821	0.48972	0.48847	0.48909	113435	1621

If the student uses $v \approx zc$, mark the last two columns with the values below.

v (km s^{-1})	D (Mpc)
10919	156
33887	484
52440	749
73666	1052
109327	1562
146626	2095

Note: the spectra data can be found at SDSS with their corresponding SpecObjID:

- 1276868368297252864
- 12768853250012370944
- 12768860671715858432
- 12768855998791440384
- 6182339029696272384
- 7220554813435828224

As values are from measurement of figures on screen, allow values to deviate from the table above, as long as the candidate has demonstrated their ability to measure and calculate to an acceptable degree of accuracy, as judged by the marker. Ignore stray signs. If the student has minor mistakes but otherwise scored some other marks, award those marks and deduct 1 (for example, wrong calculations on less than half of the rows). Also minus one if no table and score is not zero or one. SDSS

Correct equation for v-z	
Correct $\lambda_{\mathrm{H}\alpha}$ (Å)	
Correct λ_{OII} (Å)	
Correct $\Delta\lambda_{\mathrm{H}\alpha}$ (Å) with their LHa	
Correct $\Delta\lambda_{\mathrm{OII}}$ (Å) with their LOII	
Correct $z_{\mathrm{H}\alpha}$ with their dLHa	

Correct $\overline{z_{\mathrm{OII}}}$ with their dLOII	
Correct $\overline{z}$ with their zHa zOII	
Correct $\overline{v\ (\mathrm{km\ s^{-1}})}$ with their equation either the one given in mark scheme (or equivalent, or an incorrect attempt from it) or the approximation v=zc mark sure their v is reported in kms^-1 Some students will use numerical solutions on their calculators. Allow this mark but not the equation mark.	
Correct $\overline{D\ (\mathrm{Mpc})}$ with their v	

SpecObjID
12768868368297252864

12768853250012370944

12768860671715858432

12768855998791440384

6182339029696272384

7220554813435828224

3. Data below is a sample from survey result from GAIA data release 2 of a small section of the sky, with a field of view of 2 arc-minutes, observing a star cluster. The explanation on the columns are as follow: -

Designation= the star's designation based on the survey run

ra= right ascension

DEC= declination

Parallax = parallax measurement of the star

Pmra = Proper motion in along the RA

Pmdec = proper motion along the DEC

bp_rp = colour index, Bp-Rp in magnitude scale

bp_g = Bp-G colour index in magnitude scale

g-rp = G-Rp colour index in magnitude scale

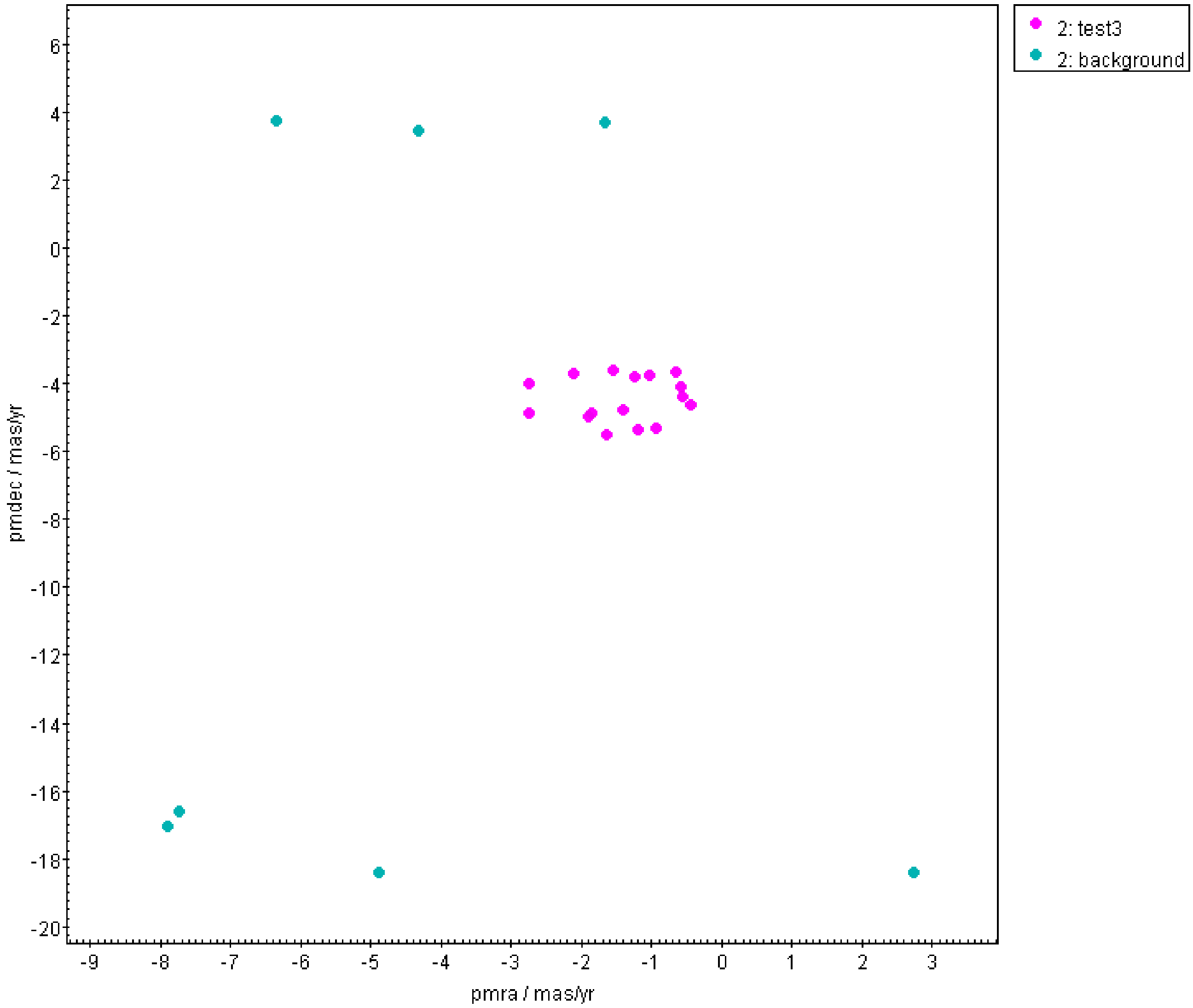
1. plot a graph to distinguish the background star(s) from the members of the star cluster
2. Which star(s) are not part of the star cluster? explain.
3. What type of star cluster do you think this is? explain.

designation	ra	DEC	parallax	pmra	pmdec	bp_rp	bp_g	g_rp
	(deg)	(deg)	(mas)	(mas/yr)	(mas/yr)	(mag)	(mag)	(mag)
Gaia DR2 5911045876101163136	268.6732725	-62.95797388	0.035346927	-2.747837152	-4.011306292	0.8889027	0.3508816	0.5380211
Gaia DR2 5911047357868692736	268.69226	-62.94320783	5.334672108	-0.439949041	-4.63957735	1.271437	0.5886822	0.6827545
Gaia DR2 5911045876101143552	268.6932591	-62.96512409	-0.054874647	-1.650236919	-5.524856736	0.936821	0.4047031	0.5321178
Gaia DR2 5911047357872637568	268.6685437	-62.94123109	0.72390481	-4.324863447	3.481813972	1.451584	0.6441116	0.8074722
Gaia DR2 5911047353569955328	268.6623582	-62.93966589	0.454466531	-1.91441602	-4.944018941	1.609177	0.6741772	0.9349995
Gaia DR2 5911045811683988992	268.6516786	-62.96814676	0.238536739	-2.749121893	-4.884225005	1.545485	0.6802444	0.8652401
Gaia DR2 5911045910467068800	268.6383319	-62.96119536	0.054601778	-1.849106994	-4.855207369	0.8162727	0.2868423	0.5294304
Gaia DR2 5911045674245030016	268.7064336	-62.96774359	0.237330996	-1.42175612	-4.7647103	0.8508816	0.3458557	0.5050259
Gaia DR2 5911045910460886912	268.6557342	-62.9636614	0.294043411	2.736804761	-18.38743159	1.920782	0.8467331	1.074049
Gaia DR2 5911047147411481216	268.717263	-62.96112876	0.901134811	-0.561064268	-4.400704205	1.663218	0.7971306	0.866087
Gaia DR2 5911045807381673728	268.6260166	-62.96278639	0.149021227	-0.938978045	-5.319009921	1.68104	0.8410473	0.8399925

Gaia DR2 5911045910469773056	268.6224786	-62.95047343	1.077163731	-0.648972099	-3.64314446	2.46719	0.9316063	1.535583
Gaia DR2 5911047392231960064	268.6653616	-62.92936522	0.322107837	-0.595207989	-4.098902721	1.190125	0.5273933	0.6627321
Gaia DR2 5911046670677455360	268.6186966	-62.95506832	0.413299776	-1.031643514	-3.751552674	1.195462	0.5296707	0.6657915
Gaia DR2 5911047186068569216	268.7269734	-62.94522935	-0.344003832	-1.665040995	3.70233005	0.4404087	-0.054049	0.4944572
Gaia DR2 5911045674241195264	268.7311587	-62.96648606	1.025491803	-1.543724115	-3.611270115	1.873917	0.7262173	1.147699
Gaia DR2 5911045669942693760	268.7327342	-62.97192517	0.405133858	-1.255678619	-3.790852347	1.04237	0.430397	0.6119728
Gaia DR2 5911047078691993856	268.7434949	-62.96214387	0.605958112	-2.127562689	-3.68992146	1.411715	0.5108852	0.9008293
Gaia DR2 5911045846039881728	268.6650341	-62.95831193	-0.140492359	-7.89766198	-17.03217025	2.097893	0.9504356	1.147457
Gaia DR2 5911047289153160320	268.7213425	-62.92932972	0.223058773	-1.208848777	-5.371177117	1.036034	0.4230251	0.6130085

Solution:

a. graph of pm_dec vs pm_ra is plot.



b. Gaia DR2 5911045846039881728 , Gaia DR2 5911045674241195264, Gaia DR2 5911045910469773056, Gaia DR2 5911045910460886912

Since the star cluster is gravitationally bound, they would move along with relatively close proper motion. The stars that are out of the group are most likely background stars.

c. member stars redder - older- globular cluster

OBSERVATIONAL ROUND

Solutions to Q1

For each of the diagrams below, give the name of the constellation.

(a)

AQUILA the Eagle

(b)

CANCER the Crab

(c)

CEPHEUS the King of Aethiopia

(d)

CYGNUS the Swan

or Northern Cross

(e)

HERCULES the Hercules

(f)

PHOENIX the Phoenix

or Mythical Firebird

(g)

PEGASUS the Winged Horse

(h)

VIRGO the Maiden

or Virgin

For each of the pictures below, give the name of the astronomical object.

(i)

Veil Nebula

or NGC 6960

or NGC 6992

or NGC 6995

or NGC 6974

or Cygnus Loop

(j)

Cat’s Eye Nebula

or NGC 6543

or Caldwell 6

or Snail Nebula

or Sunflower Nebula

(k)

Eskimo Nebula

or NGC 2392

or Clown Face Nebula

or Lion Nebula

or Caldwell 39

(l)

486958 Arrokoth

or Arrokoth

or Ultima Thule

(m)

Mice Galaxies

or NGC 4676

(n)

Whirlpool Galaxy

or Messier 51

or M51

or NGC 5194

(o)

Hubble Ultra Deep Field

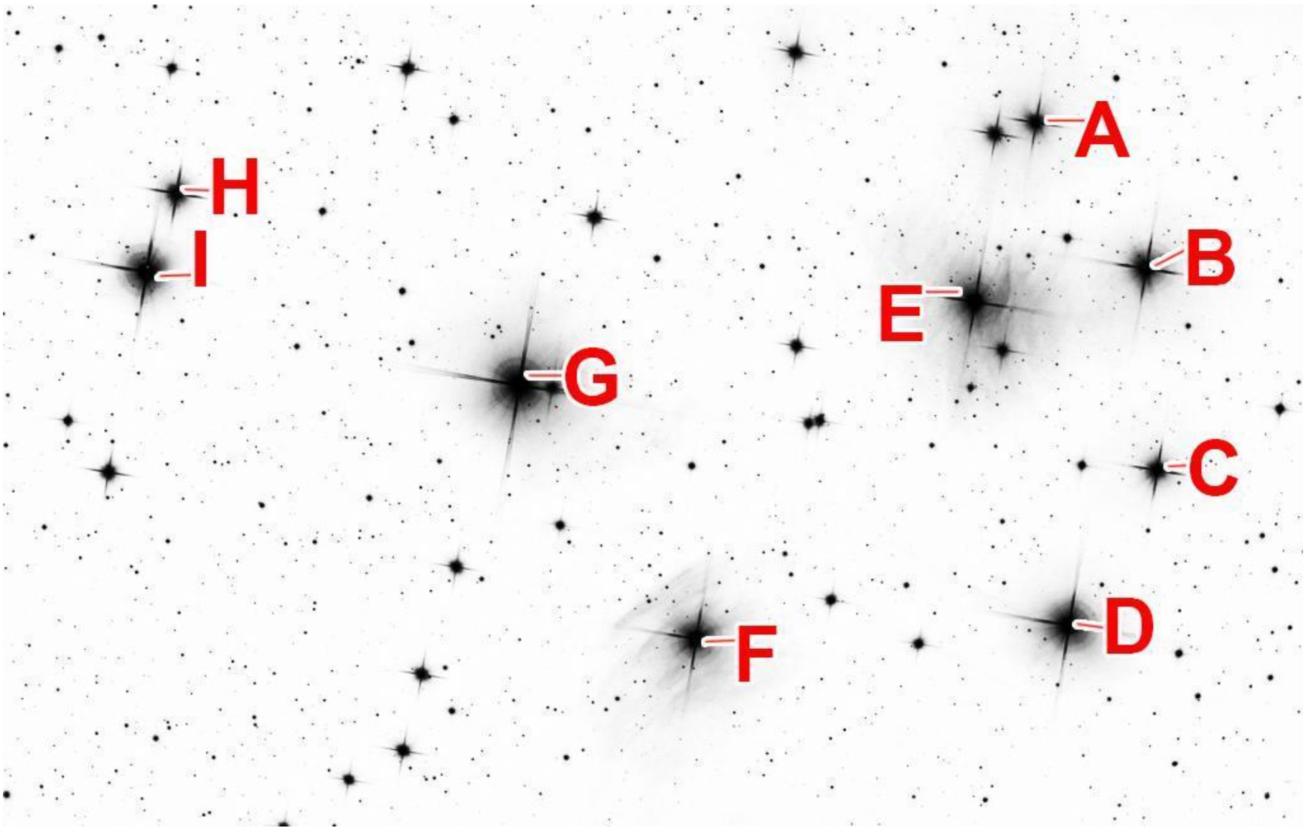
(p)

Eta Carinae

or η Carinae

or η Car

2.

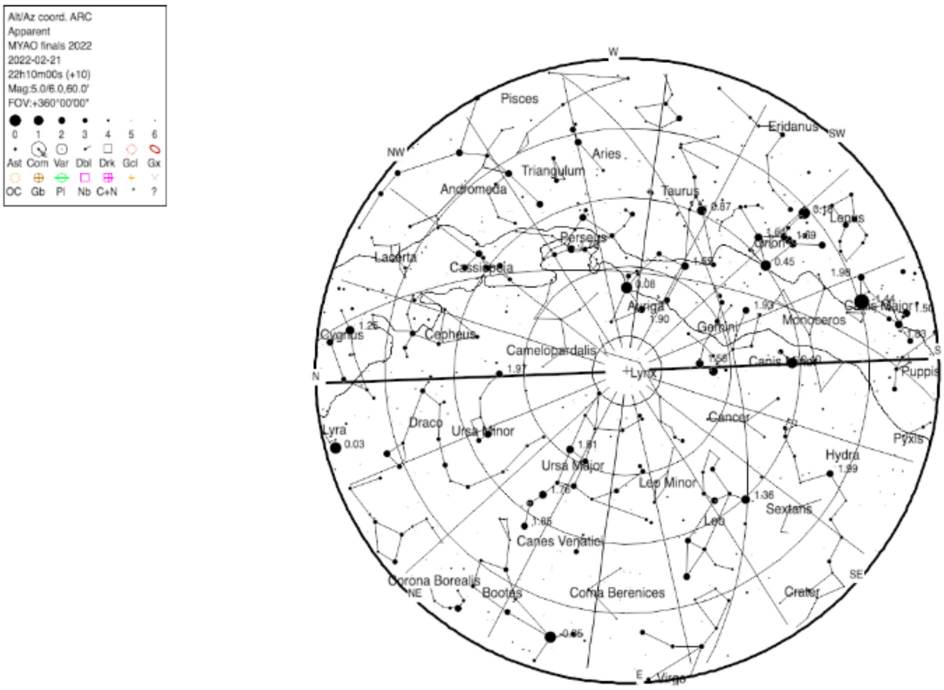


Picture shows a star cluster in the night sky. List the stars from brightest to dimmest, as seen from Earth

Solution: G, I, D, E, F, B, H, C, A.

3.

Solution The star chart is generated for 52°52′ N 141°33′ E at 10.10pm (UTC+12), 21st February 2021.



(a) 2 (accept 1 or 3)

(b) Auriga (Aur)

(c) Leo (Leo)

(d) 17/18 - 8/9 or the other way around.

(e) Lynx (Lyn)

(f) Any 2 from Lep, Ori, Gem, Mon

(g) Any 1 from CrB, Boo, CVn, UMa

(h) $53 \pm 10°$

(i) 9 or 10

(j) February (accept January and March)