(OT01) **Discovery of ‘Z’** **[25 marks]**

You are given a sky map “Map-OT01” along with the question paper. This map shows only stars but no diffuse objects.

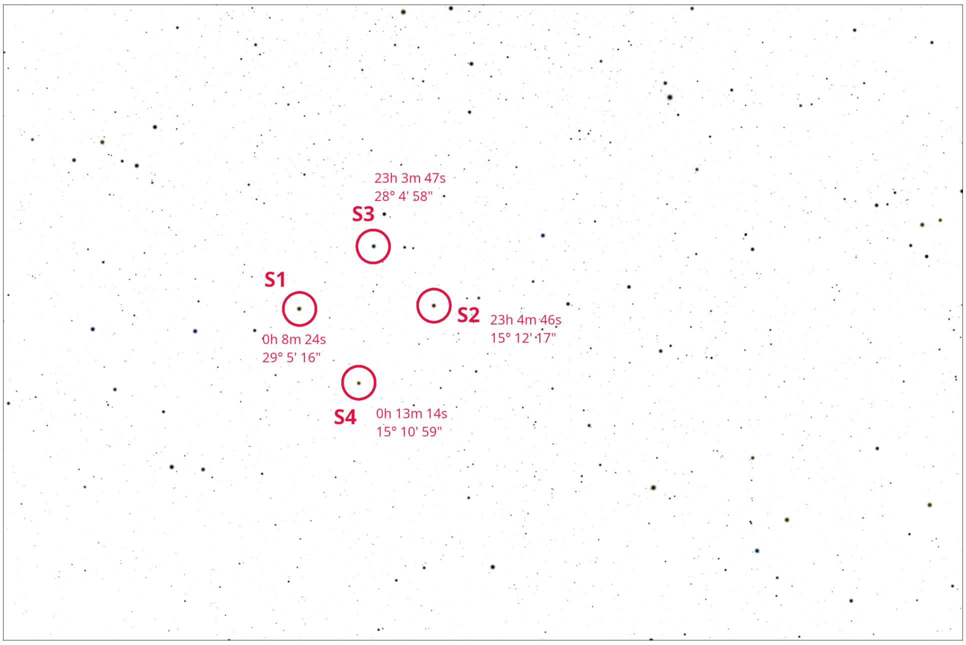
Four known stars (S1, S2, S3 and S4), which are present in the map above, are given in the table below with their Common names, Bayer designations and Equatorial coordinates.

Sr. No.	Common Name	Bayer Name	RA	Dec
S1	Alpheratz	α Andromedae	00h 08m 24s	$29°5'16''$
S2	Markab	α Pegasi	23h 04m 46s	$15°12'17''$
S3	Scheat	β Pegasi	23h 03m 47s	$28°4'58''$
S4	Algenib	γ Pegasi	00h 13m 14s	$15°10'59''$

Complete the tasks (OT01.1) and (OT01.2) while you are planning the observations.

(OT01.1) Your first task is to mark these 4 stars (with a circle around each star) and label them as S1, S2, S3 and S4 on the sky map “Map-OT01” provided to you. **6**

Solution:



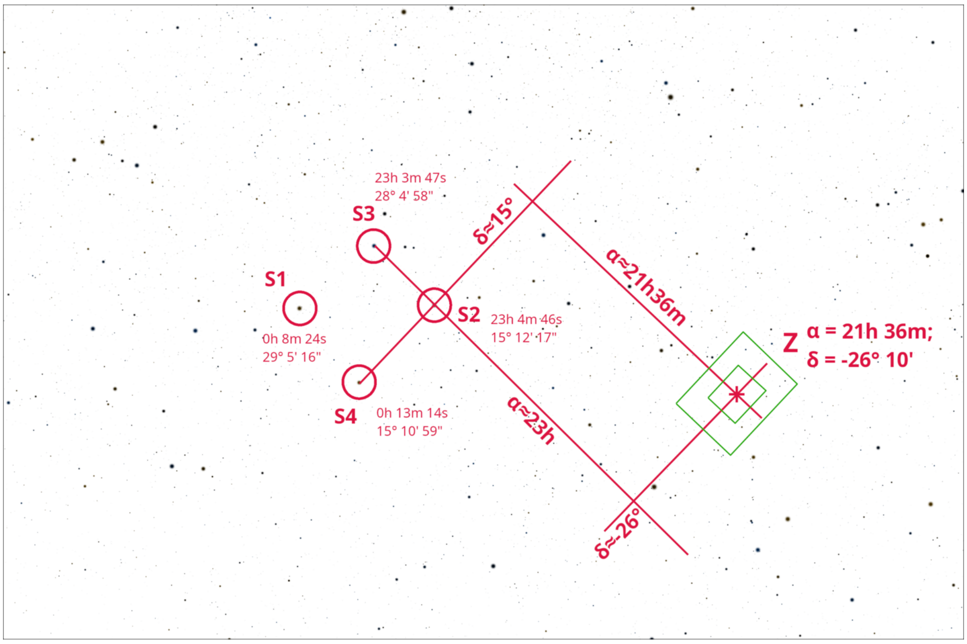
Circle around each correct star	0.5
Correct identification as S1–S4 of each star	1.0

(OT01.2) An astronomer has discovered a new diffuse object ‘Z’ at the following coordinates – RA: 21h 36m 10.6s, Dec: $-26°10'24.4''$
Mark the position of this diffuse object on the same sky map “Map-OT01” with a $\oplus$ sign and label it as ‘Z’. Assume that a linear rectangular grid for equatorial coordinates is valid in the relevant region of the map. **7**

Solution:

- Realize that two stars have almost the same RA and two of them have almost same declination.

- We draw a line through them indicating constant RA and constant Declination.
- Given the scale of the map and the separation between the 4 stars and the new object we can assume that the celestial grid will be almost linear.
- We can thus mark ‘Z’ at its given coordinates.



Object marked within inner rectangle	7.0

Object marked between outer and inner rectangles	4.0

The following task is to be performed once you reach the telescope station.

On the screen diagonally opposite to your station, initially a welcome message, followed by a sample sky (sky unrelated to the question) will be displayed along with a countdown timer. You may use this time to orient the telescope towards the screen and familiarize yourself with other equipment provided at the station. At the end of this time a part of the sky given in the map “Map-OT01” will be projected on the screen for the next 6 minutes. Note that the scale of the projection shown on the screen is different from the actual scale seen in the sky.

(OT01.3) Find the new object ‘Z’ with the telescope using any appropriate eyepiece. Then centre the object properly in the field of view of the eyepiece with the crosshair, and show it to the examiner at your station. **12**

At the end of 6 minutes, the projection will be blurred for 20 seconds. At this point you must step away from the telescope. The projection will be restored for the examiner to check the view through the telescope. This marks the end of the first task.

Solution:

- After marking the new object on the given sky map, we carefully look at its position and the star pattern surrounding it
- Using the 25 mm focal length eyepiece we try to locate it

- By doing some fine adjustments, we try to bring the same pattern in the 10 mm focal length eye piece (which has a crosshair)

Pointing towards the screen	1.0

If 10mm objective is used:

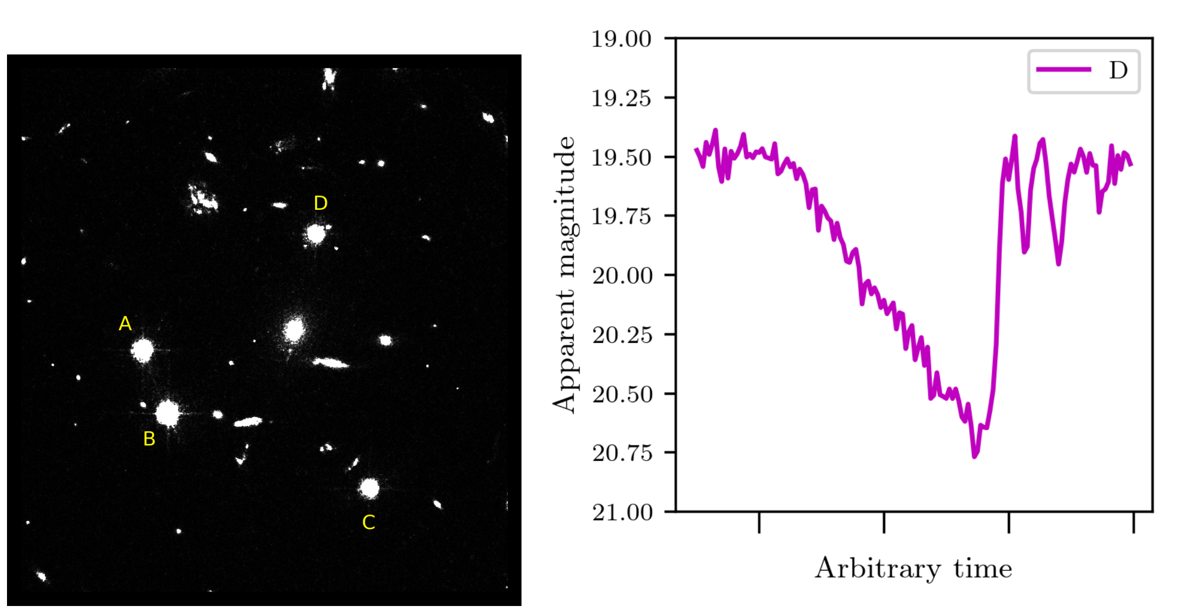
Correct choice of eyepiece	2.0
Object is anywhere in FOV	3.0
Any part of the object is touching the origin of crosshair	6.0

If 25mm objective is used:

Object is anywhere in FOV	3.0

(OT02) **Lensing Time Delay** **[25 marks]**

Gravitational lensing can result in multiple images of a background source if the source, the lensing object and the observer are nearly aligned. These multiple images take different times to reach the observer, and if the background source is variable, each image shows the same feature in its variability after specific time delays. These time delay measurements are extremely useful to estimate the current expansion rate of the Universe, the Hubble constant.



We will consider the gravitational lens system shown in the above figure. The left hand panel shows a galaxy cluster (lens) together with 4 images of a background quasar formed due to gravitational lensing. The 4 images, labelled A, B, C and D, have different fluxes as each image is magnified by a different amount. For any given image the magnification does not change with time. Light takes the largest time to travel for the image labelled D.

The light coming from this quasar is variable, and astronomers have monitored this system for more than a decade now. The right hand panel of the figure shows the light curve for the image D.

On the screen opposite to your station you will see a movie of the gravitational lens system. This movie is 28 s long and will loop 6 times with a breaks of 1 minute or 2 minutes between runs. Every second on the watch corresponds to 250.0 days in the actual lens system.

(OT02.1) Let the time delays of image D with respect to images A, B and C be given as $t_{\rm DA} = t_{\rm D} - t_{\rm A}$, $t_{\rm DB} = t_{\rm D} - t_{\rm B}$, and $t_{\rm DC} = t_{\rm D} - t_{\rm C}$, respectively. Find these time delays, taking any necessary steps to reduce the uncertainty in your results. **25**

Solution:

The solution is $t_{\rm DA} = 1694\,\mathrm{d}$, $t_{\rm DB} = 1651\,\mathrm{d}$ and $t_{\rm DC} = 2485\,\mathrm{d}$.

Pointing towards the screen	1.0
Choice of correct eyepiece	1.0

For each of images A, B, C, D

Timings of image	2.0

At least one reading	1.0
Extra reading (0.5 each, maximum 1.0)	1.0

Calculation of time differences

Calculation each of t_{DA}, t_{DB} and t_{DC}	3.0

Half credit lower limit	Full credit range	Half credit upper limit
Value -50 d	Value -25 d to Value $+25$ d	Value $+50$ d

Scaling from seconds to days for each interval	1.0

Correct order ($t_{\mathrm{DC}} > t_{\mathrm{DA}} > t_{\mathrm{DB}}$)	3.0