



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Astrophysics (3.9)

A Level Physics (7408) · Section 3.9

40 questions · 315 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

 [guidemygrades.com](https://www.guidemygrades.com)

 [@Guidemygrades](https://www.instagram.com/Guidemygrades)

 [@Guidemygrades](https://twitter.com/Guidemygrades)

 [@Guidemygrades](https://www.youtube.com/Guidemygrades)

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

QUESTION	SOURCE	MARKS	PAGE
3.9.1 TELESCOPES		10 Qs · 82 marks	4
1. Q1	7408/3 Section B: Astrophysics June 2017	2	5
2. Q2	7408/3 Section B: Astrophysics June 2017	7	6
3. Q1	7408/3 Section B: Astrophysics June 2018	8	7
4. Q1	7408/3 Section B: Astrophysics June 2019	8	9
5. Q5	7408/3 Section B: Astrophysics November 2021	8	11
6. Q1	7408/3 Section B: Astrophysics June 2022	9	13
7. Q2	7408/3 Section B: Astrophysics June 2023	9	15
8. Q1	7408/3 Section B: Astrophysics November 2020	10	17
9. Q2	7408/3 Section B: Astrophysics June 2025	10	19
10. Q1	7408/3 Section B: Astrophysics June 2024	11	21
3.9.2 CLASSIFICATION OF STARS		17 Qs · 138 marks	23
11. Q4	7408/3 Section B: Astrophysics November 2020	4	24
12. Q2	7408/3 Section B: Astrophysics November 2021	4	25
13. Q1	7408/3 Section B: Astrophysics June 2025	5	27
14. Q5	7408/3 Section B: Astrophysics June 2025	5	28
15. Q3	7408/3 Section B: Astrophysics November 2021	6	29
16. Q2	7408/3 Section B: Astrophysics June 2024	6	30
17. Q4	7408/3 Section B: Astrophysics June 2017	7	32
18. Q1	7408/3 Section B: Astrophysics June 2023	7	33
19. Q3	7408/3 Section B: Astrophysics June 2024	7	36
20. Q3	7408/3 Section B: Astrophysics June 2023	8	38
21. Q3	7408/3 Section B: Astrophysics June 2019	9	40
22. Q3	7408/3 Section B: Astrophysics November 2020	10	41
23. Q2	7408/3 Section B: Astrophysics November 2020	11	43
24. Q1	7408/3 Section B: Astrophysics November 2021	11	46
25. Q2	7408/3 Section B: Astrophysics June 2018	12	48
26. Q3	7408/3 Section B: Astrophysics June 2017	13	50
27. Q2	7408/3 Section B: Astrophysics June 2019	13	53
3.9.3 COSMOLOGY		13 Qs · 95 marks	55
28. Q4	7408/3 Section B: Astrophysics June 2019	5	56
29. Q5	7408/3 Section B: Astrophysics June 2023	5	57
30. Q3	7408/3 Section B: Astrophysics June 2025	5	59



QUESTION	SOURCE	MARKS	PAGE
31. Q5	7408/3 Section B: Astrophysics June 2017	6	60
32. Q4	7408/3 Section B: Astrophysics June 2018	6	61
33. Q4	7408/3 Section B: Astrophysics November 2021	6	62
34. Q4	7408/3 Section B: Astrophysics June 2022	6	63
35. Q4	7408/3 Section B: Astrophysics June 2023	6	64
36. Q3	7408/3 Section B: Astrophysics June 2018	9	65
37. Q3	7408/3 Section B: Astrophysics June 2022	9	67
38. Q4	7408/3 Section B: Astrophysics June 2025	10	69
39. Q2	7408/3 Section B: Astrophysics June 2022	11	72
40. Q4	7408/3 Section B: Astrophysics June 2024	11	75



QUESTIONS

40 questions · 315 marks · 3 sub-topics



SUB-TOPIC 3.9.1

TELESCOPES

Sub-topic 3.9.1 · 10 questions · 82 marks · lowest tariff first



0	1
---	---

Draw the ray diagram for a Cassegrain telescope. Your diagram should show the paths of two rays, initially parallel to the principal axis, as far as the eyepiece.

[2 marks]



0 2

The Kielder Observatory in Northumberland includes two optical telescopes attached to the same mount, so that they can be used to view the same object. Some of the properties of these telescopes are summarised in **Table 1**.

Table 1

Telescope	Type	Objective diameter/mm
A	refractor	70
B	reflector	400

0 2 . 1

The telescopes are used to view the same object.

Suggest which telescope in **Table 1** produces the brighter image. Support your answer with a suitable calculation.

[3 marks]**0 2 . 2**

The minimum angular resolution of a telescope can be determined using the Rayleigh criterion.

Explain what is meant by the Rayleigh criterion.

[2 marks]

0 2 . 3

Discuss which of the two telescopes in **Table 1** would be better at resolving the images of two objects that are close together.

[2 marks]

0	1
---	---

The Griffith Observatory in Los Angeles includes an astronomical refracting telescope (Griffith telescope) with an objective lens of diameter 305 mm and focal length 5.03 m

0	1	.	1
---	---	---	---

Calculate the wavelength of light for which the Griffith telescope has a minimum angular resolution of 1.8×10^{-6} rad

[2 marks]

wavelength = _____ m

0	1	.	2
---	---	---	---

The Griffith telescope is used to observe two point objects which subtend an angle of 1.8×10^{-6} rad at the unaided eye.

The typical human eye has a minimum angular resolution of approximately 3.2×10^{-4} rad

Calculate the focal length of the eyepiece lens so that an observer can just resolve the two objects when observing them through the Griffith telescope.

[3 marks]

focal length = _____ m



01.3 The asteroid Apophis has a diameter of 325 m

It has been calculated that, in 2029, its distance of closest approach to the Earth's surface will be 3.0×10^4 km

The Griffith telescope may be used to view Apophis using the eyepiece calculated in question **01.2**

Deduce whether this telescope is suitable to obtain a detailed view of Apophis. Support your answer with a calculation.

[3 marks]



0 1 . 1 The lenses used in refracting telescopes can cause chromatic aberration.

Complete **Figure 1** to show how a lens produces chromatic aberration.

[1 mark]

Figure 1



0 1 . 2 A Cassegrain telescope uses mirrors.

What are the shapes of the primary and secondary mirrors in a Cassegrain telescope?

Tick (✓) **one** box.

[1 mark]

Primary mirror	Secondary mirror	
concave	concave	
concave	convex	
convex	concave	
convex	convex	

0 1 . 3 **Table 1** contains information about two telescopes, **A** and **B**. Each telescope is planned to be the biggest of its type in the world.

Table 1

Telescope	A	B
Type	Optical reflecting telescope	Radio telescope
Diameter / m	39.3	110
Range of wavelengths detected	350 nm to 1800 nm	2.5 mm to 1000 mm

Discuss the similarities and differences between optical reflecting telescopes and radio telescopes. Your answer should include references to:

- structure
- positioning
- collecting power.

Go on to discuss which telescope, **A** or **B**, will give a more detailed image of an astronomical object that emits both radio waves and visible light.

[6 marks]

[illegible]

Question 1 continues on the next page



0 5 . 1

Explain what is meant by the Rayleigh criterion.

[2 marks]

0 5 . 2

A telescope uses wavelengths in the range 90 nm to 120 nm.

Explain why this telescope must be located in space.

Go on to discuss **one** advantage that this telescope has compared to a telescope with the same aperture that uses visible light.**[3 marks]**

Question 5 continues on the next page

05.3

Table 1 shows information about two telescopes.

Table 1

Telescope	Diameter / m	Dish shape
Arecibo	305	spherical
Lovell	76	parabolic

Each telescope detects radio waves with a wavelength of 21 cm.

Compare the performances of the telescopes in **Table 1** when both are used to observe the same faint radio objects.

[3 marks]

END OF QUESTIONS

0	1	.	1
---	---	---	---

Draw a ray diagram to show how a converging lens can cause spherical aberration.

[1 mark]

_____ principal axis

0	1	.	2
---	---	---	---

Draw a labelled ray diagram for an astronomical refracting telescope in normal adjustment.

Show **three** non-axial rays passing through both lenses.
Label the principal foci of the lenses.

[3 marks]

_____ principal axis



0 1 . 3

The James Lick telescope is an astronomical refracting telescope. When in normal adjustment, the distance between the lenses of the telescope is 17.4 m and the angular magnification is 750

Calculate the focal length of the eyepiece lens.

[2 marks]

focal length = _____ m

0 1 . 4

The James Lick telescope can be used to identify binary stars.

Two techniques are available using this telescope:

- using a processed image from a CCD, and
- direct observation using the naked eye.

Compare the use of a CCD with the use of the naked eye to observe binary stars with this telescope.

[3 marks]

0 2 . 1

State what is meant by normal adjustment when applied to an astronomical refracting telescope.

[1 mark]

0 2 . 2

Which combination of lenses gives the largest angular magnification when used as an astronomical telescope in normal adjustment?

Tick (✓) **one** box.

[1 mark]

Objective lens		Eyepiece lens	
Focal length / cm	Type	Focal length / cm	Type
5	diverging	100	converging
5	converging	100	converging
100	diverging	5	converging
100	converging	5	converging

V1031 and WASP-82 are two stars in the constellation Orion.
 V1031 appears 40 times brighter than WASP-82 when viewed from Earth.
 The apparent magnitude of V1031 is 6.0

0 2 . 3

Calculate the apparent magnitude of WASP-82.

[2 marks]

apparent magnitude = _____



0 2 . 4

V1031 is just visible to the naked eye of an astronomer when her pupil diameter is 7 mm.

Suggest whether she can observe WASP-82 using a telescope with an objective diameter of 60 mm.

Support your answer with a calculation.

[2 marks]

0 2 . 5

CCDs are often connected to telescopes.

Explain **two** reasons why this improves the ability of astronomers to observe dim stars.

[3 marks]

1

2



0 1 . 1

Draw a ray diagram for a Cassegrain telescope.
Your diagram should show the paths of **two** rays up to the eyepiece lens.
The rays should initially be parallel to the principal axis.

[2 marks]

_____ principal axis

0 1 . 2

A spacecraft passes Pluto at a distance of 12 500 km. The telescope on board has an aperture of diameter 0.21 m and operates at a wavelength of 450 nm.

Discuss whether this telescope is suitable for studying a crater with a diameter of approximately 1 km on Pluto.

[3 marks]

01.3

The Hubble telescope has an aperture of diameter 2.4 m.

Compare the collecting power of the Hubble telescope with the telescope on the spacecraft in Question **01.2**.

[2 marks]

01.4

An astrophysicist had to decide whether to use a reflecting telescope or a refracting telescope on the spacecraft in Question **01.2**.

Discuss which type of telescope to use.

[3 marks]

0 2 . 1

Draw a ray diagram for an astronomical telescope in normal adjustment.

Include in your diagram:

- three non-axial rays
- labelled principal foci for the lenses.

[2 marks]**Question 2 continues on the next page**

0 2 . 2 An astronomer has two telescopes **A** and **B**.

The astronomer uses each telescope to make observations of Mars when Mars is 0.55 AU from the Earth.

Table 1 gives information about **A** and **B**.

Table 1

Telescope	Type	Objective diameter / m	Angular magnification
A	refractor	0.12	25
B	reflector	0.18	40

diameter of Mars = 6.8×10^3 km
angular resolution of the eye $\approx 3 \times 10^{-4}$ rad

Compare the images formed by **A** and **B**.

- In your answer, refer to:
- the relative brightness of the images
 - the ability of each telescope to show features on Mars
 - the effect of any aberrations caused by each type of telescope.

[6 marks]

Question 2 continues on the next page

0 2 . 3 One advantage of using a CCD with a telescope is that the data can be stored and processed on a computer.

Explain **two** other advantages of using a CCD rather than the eye when making an observation with a telescope.

[2 marks]

- 1 _____

- 2 _____

0 1

A student uses a refracting telescope in normal adjustment to make observations of Jupiter.

The telescope has an angular magnification of 75

0 1 . 1

The eyepiece has a focal length of 22 mm.

Determine the distance between the eyepiece and the objective lens.

[2 marks]

distance = _____ m

0 1 . 2

When viewed through the telescope, the image of Jupiter subtends an angle of 1.7×10^{-2} rad.

Calculate, in km, the distance between the Earth and Jupiter.

mean radius of Jupiter = 7.0×10^4 km

[2 marks]

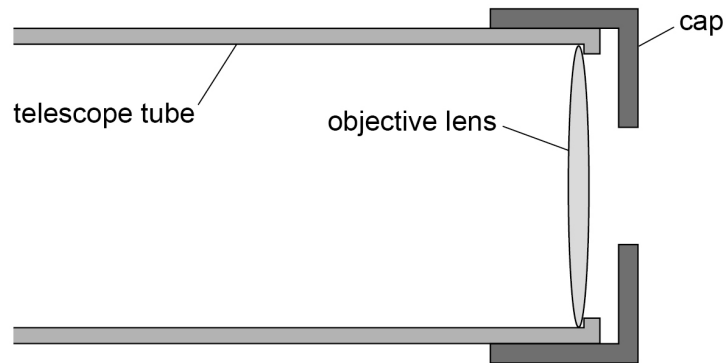
distance = _____ km



The student places a cap over one end of the telescope. The cap has a circular hole in its centre.

Figure 1 shows the end of the telescope, the objective lens and the cap.

Figure 1



0 1 . 3

State and explain the effect that the addition of the cap has on the chromatic aberration caused by the lens.

[3 marks]

0 1 . 4

Explain **two** other effects that the addition of the cap has on the image of Jupiter.

[4 marks]

1

2

SUB-TOPIC 3.9.2

CLASSIFICATION OF STARS

Sub-topic 3.9.2 · 17 questions · 138 marks · lowest tariff first



0 4

Table 2 gives data about the supergiant star Melnick 34 and the Sun.

Table 2

Name	Radius / m	Surface temperature / K
Melnick 34	1.4×10^{10}	53 000
Sun	7.0×10^8	5 700

0 4 . 1

Calculate $\frac{\text{power output of Melnick 34}}{\text{power output of the Sun}}$.

[2 marks]

answer = _____

0 4 . 2

Discuss why the evolution of a supergiant star in the local part of our galaxy could be dangerous for life on Earth.

[2 marks]

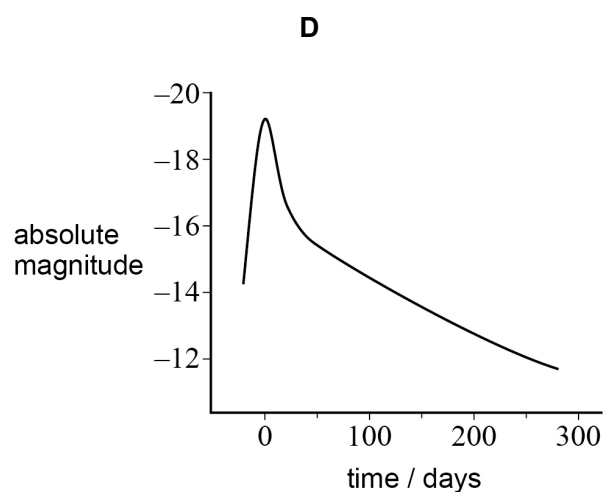
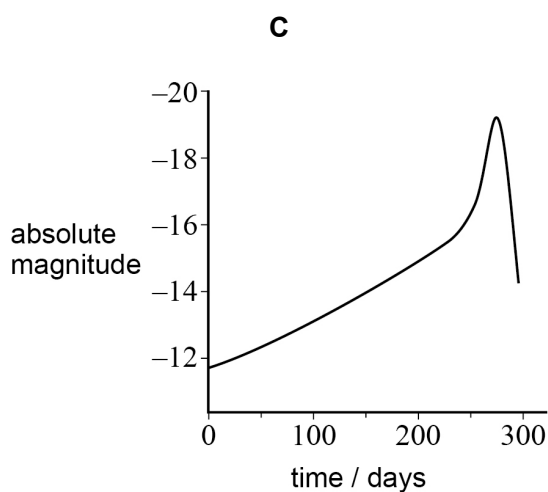
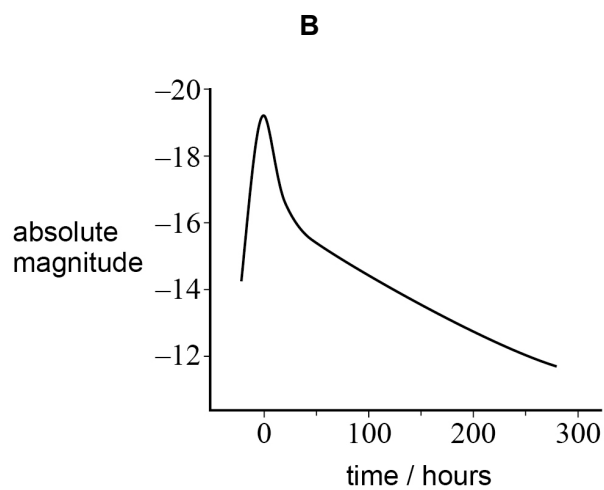
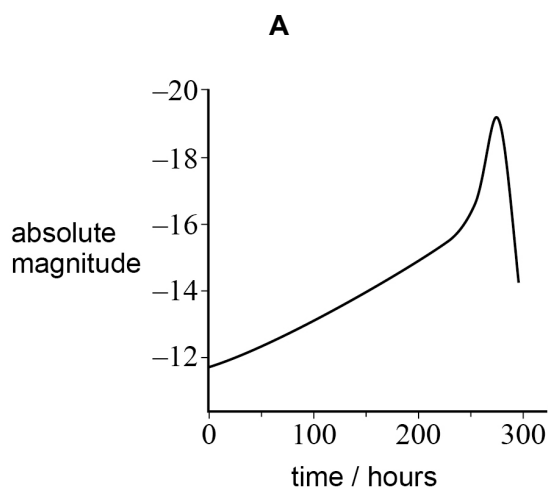
END OF QUESTIONS



0 2 . 1 Which graph shows the light curve for a typical type 1a supernova?

Tick (✓) **one** box.

[1 mark]



A

☐

B

☐

C

☐

D

☐

0 2 . 2 The Andromeda galaxy is approximately 7.7×10^5 pc from Earth.

Deduce whether a type 1a supernova which occurred in Andromeda can be observed from Earth with the naked eye.

[3 marks]

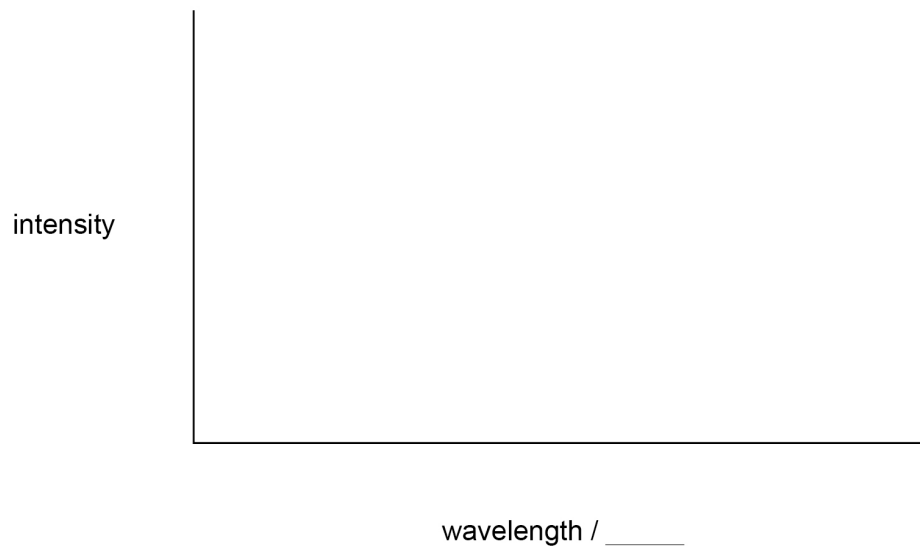


0 1

HIP 56948 is a star with a black-body temperature of 5800 K. The star is at a distance of 210 ly from the Sun.

0 1 . 1

Sketch, on **Figure 1**, the black-body curve for HIP 56948. Label the wavelength axis with a suitable scale and unit.

[3 marks]**Figure 1****0 1 . 2**

The diameter of HIP 56948 is the same as the diameter of the Sun.

Suggest a value for the absolute magnitude of HIP 56948.

[1 mark]

absolute magnitude = _____

0 1 . 3

Astronomers study HIP 56948 in their search for Earth-like exoplanets because HIP 56948 is similar to the Sun.

Suggest **one** difficulty in detecting an Earth-like planet around HIP 56948.

[1 mark]

0	5
---	---

Early observations of the star Betelgeuse indicated that:

radius r of Betelgeuse = $700 \times$ radius of the Sun
distance d of Betelgeuse from the Earth = 548 ly
intensity received from Betelgeuse = I .

Recent data suggest that the intensity received from Betelgeuse is actually $1.15I$.

Based on these recent data, two groups of students reach different conclusions.

Group **X** suggest that:

- r is correct
- d is actually 530 ly.

Group **Y** suggest that:

- d is correct
- r is actually $750 \times$ radius of the Sun.

Discuss for each group whether their conclusion could be correct.
Assume that the measured temperature of Betelgeuse is constant.

[5 marks]

END OF QUESTIONS



0 3

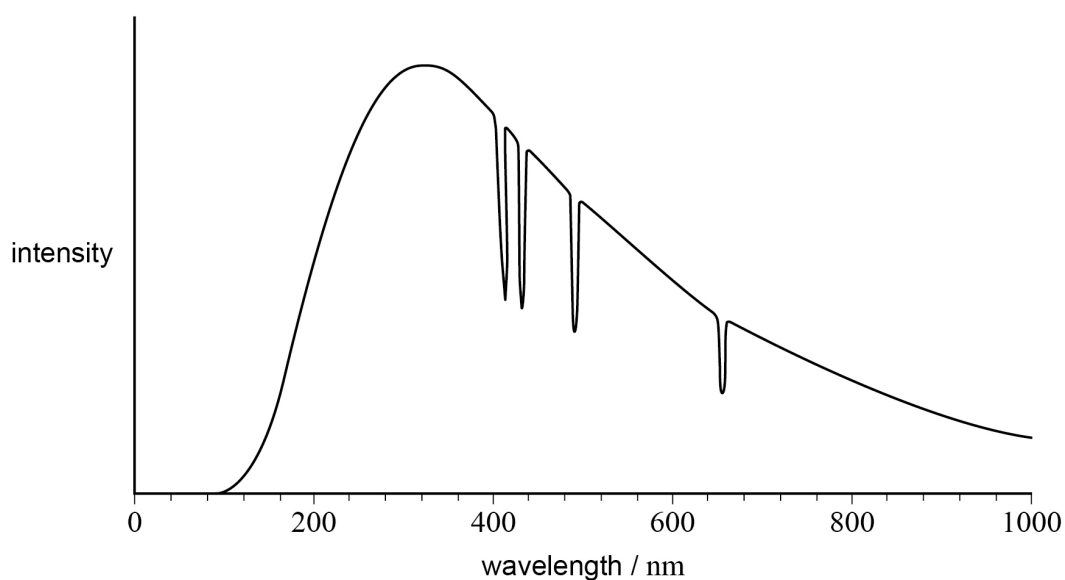
Miaplacidus and Avior are two stars in the constellation Carina.

Miaplacidus is a class A star.

Avior is a class K star.

Figure 2 shows how the intensity of radiation arriving at the Earth varies with wavelength for **one** of these stars. Only the important features of the variation are shown.

Figure 2



Deduce, with reference to **Figure 2**, the identity of the star.

In your answer you should:

- explain the overall shape of the graph
- describe the processes in the star that lead to the decreases in intensity
- state the identity of the star.

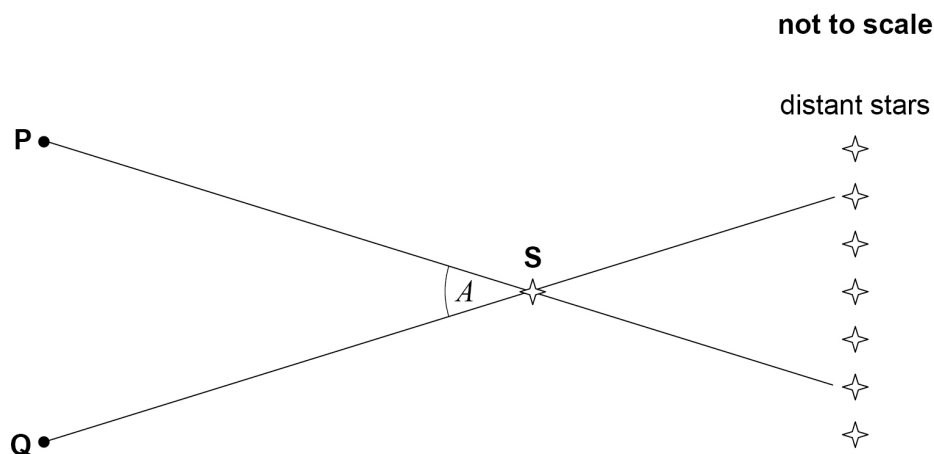
[6 marks]

0 2

The apparent change in position of a nearby star relative to distant stars is due to an effect known as parallax.

Figure 2 shows how parallax arises. As the Earth moves from point **P** to point **Q**, an observer on the Earth sees the position of a nearby star **S** change in relation to distant stars.

Figure 2



Angle A is the parallax angle. This angle can be used to determine the distance to a nearby star, provided that the relative motion between the star and the Sun is negligible between observations.

0 2 . 1

The distance from the Sun to **S** is 79 ly.
The Earth takes 6 months to move from point **P** to point **Q**.

Calculate, in degrees, angle A .

[2 marks]

$A =$ _____ °



0 2 . 2

Parallax is used to determine the distance to a different star. Observations of the star produce the following data:

distance determined using parallax = 0.40 pc

apparent magnitude = 13.5

absolute magnitude = 16.7

An astronomer suggests that the star moved significantly relative to the Sun between the two parallax observations.

Discuss whether this suggestion is valid.

[4 marks]



0	4	1
---	---	---

Sketch, on the axes in **Figure 1**, the light curve for a typical type 1a supernova. Label the axes with suitable scales.

[3 marks]

Figure 1



0	4	2
---	---	---

Type 1a supernovae can be used as standard candles.

Explain what is meant by a standard candle.

[1 mark]

0	4	3
---	---	---

Measurements of type 1a supernovae in 1999 led to a controversy concerning the behaviour of the Universe.

Describe this controversy and how the measurements led to it.

[3 mark]

01.1

Draw a labelled diagram to define the parsec (pc).

[1 mark]

Table 1 shows data for two stars: Rigel and the Sun.

Table 1

Star	Surface temperature / K	Absolute magnitude	Mass / kg
Rigel	12 000	−7.84	3.6×10^{31}
Sun	5700	4.83	2.0×10^{30}

01.2

State the spectral class of Rigel.

[1 mark]



0 1 . 3 The apparent magnitude of Rigel is 0.11

Calculate, in pc, the distance from Rigel to the Earth.

[2 marks]

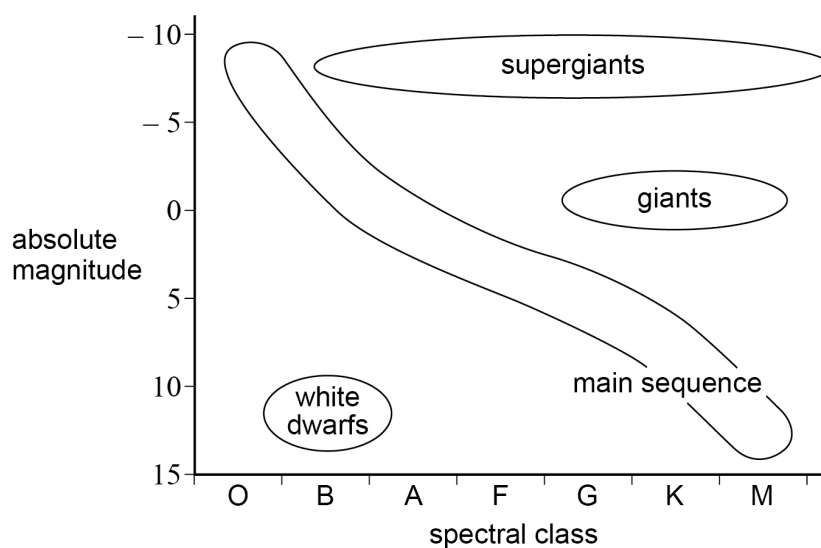
distance = _____ pc

Question 1 continues on the next page



0 1 . 4 Figure 1 shows a Hertzsprung–Russell (HR) diagram.

Figure 1



Draw a line on **Figure 1** to show the evolution of the Sun from formation to white dwarf.

[1 mark]

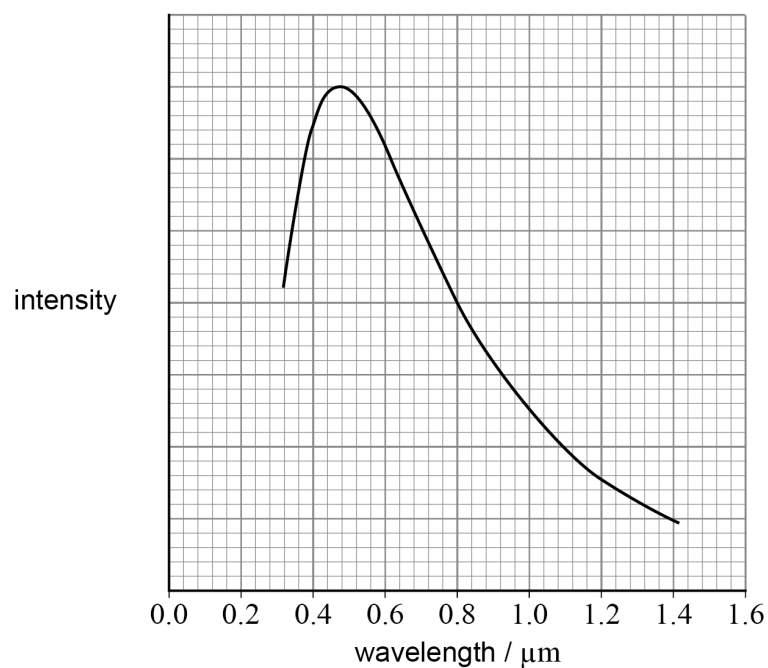
0 1 . 5 One stage in the evolution of Rigel includes the emission of a gamma ray burst.

Outline the circumstances during which a gamma ray burst will be emitted by Rigel.

[2 marks]

0 3 . 1 Figure 3 shows the variation of intensity with wavelength for a star.

Figure 3



Show that **Figure 3** is consistent with a black-body temperature of about 6.0×10^3 K. **[2 marks]**

0 3 . 2 The radius of the star is 9.6×10^6 m.

Calculate the power output of the star.

[2 marks]

power output = _____ W



03.3

Which row gives the type and spectral class of the star?

Tick (✓) **one** box.

[1 mark]

Type of star	Spectral class	
white dwarf	F	☐
main sequence	G	☐
red giant	K	☐
main sequence	F	☐
red giant	G	☐
white dwarf	K	☐

03.4

The light from the star passes through an interstellar dust cloud before reaching Earth. The reduction in intensity when light passes through a dust cloud is assumed to be inversely proportional to the wavelength of the light.

An astronomer on the Earth estimates the black-body temperature of the star.

Discuss the effect that the dust cloud has on this estimate.

[2 marks]



0 3 . 1 State the defining property of a black hole.

[1 mark]

0 3 . 2 In 2019, astronomers linked several radio telescopes to produce a single telescope called the EHT. The resolution of the EHT is the same as the resolution that a telescope with an aperture equal to the diameter of the Earth could achieve.

Table 2 shows data about the EHT and the Hubble telescope.

Table 2

	Aperture	Operating wavelength
EHT	1.3×10^7 m	1.3 mm
Hubble	2.4 m	410 nm

Galaxy M87 is 5.3×10^7 light years from Earth. The supermassive black hole at the centre of M87 has a mass 6.5×10^9 times the mass of the Sun.

The radius of the event horizon is R .

The astronomers propose to use either the EHT or the Hubble telescope to observe stars whose distance from the centre of the black hole is less than $1000R$.

Discuss, with calculations, which telescope is more suitable for this observation.

[4 marks]



0	3	.	3
---	---	---	---

A star is orbiting the black hole in M87. The star is observed in the plane of its orbit. The wavelength of a spectral line observed in the light emitted from the star varies between a maximum and a minimum value.

maximum value observed = 374.96 nm

minimum value observed = 373.53 nm

Calculate the orbital speed of the star.

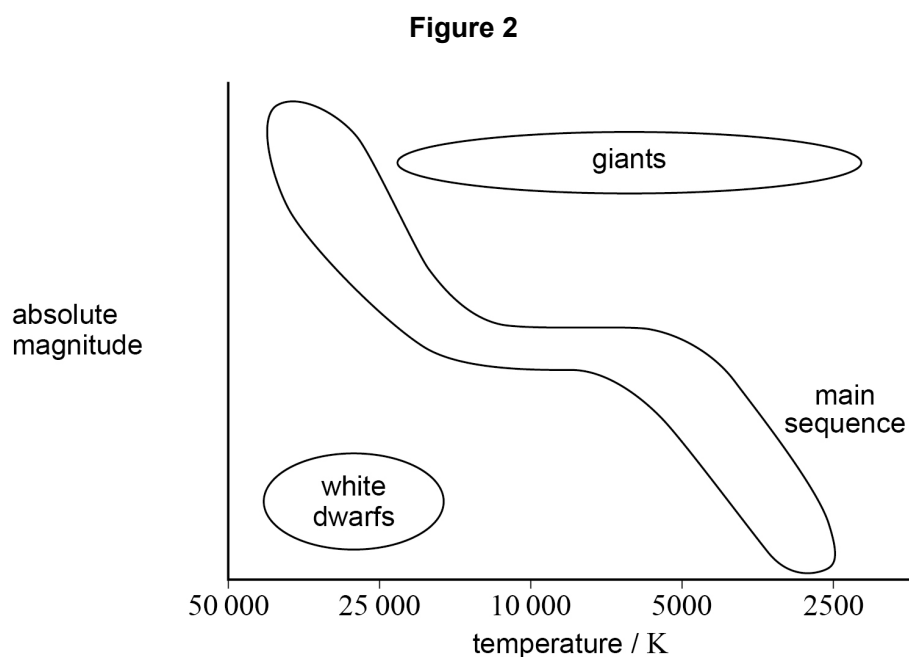
[3 marks]

orbital speed = _____ m s⁻¹



0 3

Figure 2 is a Hertzsprung-Russell (HR) diagram.



0 3 . 1

Label the absolute magnitude axis with a suitable scale.

[1 mark]

0 3 . 2

Label with an **S** the position of the Sun on the HR diagram.

[2 marks]

0 3 . 3

Draw a line on the HR diagram to show the evolution of a star similar to the Sun from formation to white dwarf.

[2 marks]

0 3 . 4

Label with a **P** the position on the HR diagram of a star much redder, and with a greater power output, than the Sun.

[1 mark]

0 3 . 5

A star much more massive than the Sun may become a supernova and then a black hole.

Discuss whether supernovae and black holes can be placed on the HR diagram in **Figure 2**.

[3 marks]

0 3

Type 1a supernovae can be used as standard candles.

0 3**1**

State what is meant by a standard candle.

[1 mark]

0 3**2**Sketch on **Figure 2** the light curve for a type 1a supernova.
Annotate your graph with suitable scales and a unit for time.**[3 marks]****Figure 2**absolute
magnitude

time /

Question 3 continues on the next page

0	3	.	3
---	---	---	---

Measurements of type 1a supernovae are used to find a value for the Hubble constant.

The distance from Earth is known for many type 1a supernovae.

Describe how these values of distance are used, with other data, to find the Hubble constant.

Your answer should include:

- the other data needed and how these data are used
- the graph plotted, including appropriate units for the axes
- how the Hubble constant is obtained and any limitations on the result.

[6 marks]



0 2

Table 1 summarises some information about four stars in the constellation Cassiopeia.

Table 1

Name	Colour	Apparent magnitude	Distance / ly
Caph	white	2.3	55
Ruchbah	blue/white	2.7	99
Schedar	orange	2.2	228
Tsih	blue	2.2	610

0 2 . 1

Which star has the highest surface temperature?
Tick (✓) **one** box.

[1 mark]

Caph

☐

Ruchbah

☐

Schedar

☐

Tsih

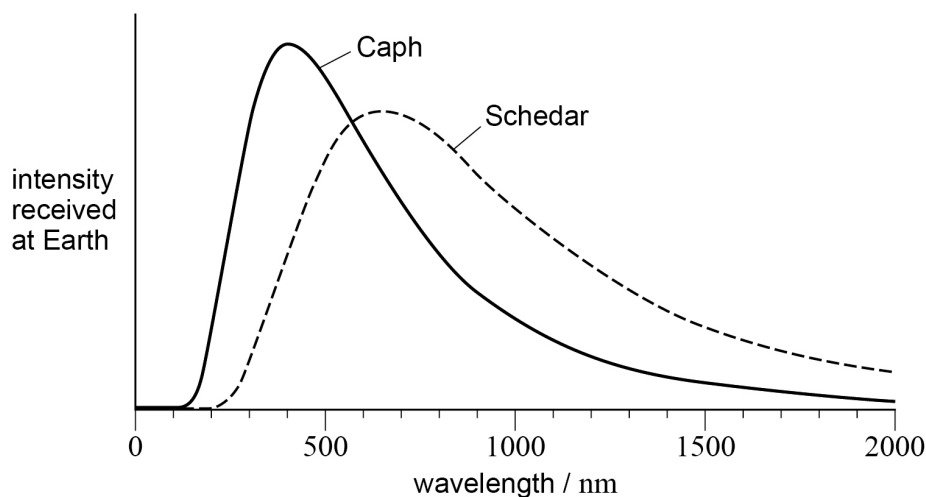
☐

0 2 . 2

Figure 1 shows the intensity received at Earth from two of the stars, plotted against wavelength.

The effect of absorption by the Earth's atmosphere is not shown.

Figure 1



Discuss what information can be found from **Figure 1** about the temperature and colour of these stars.

Support your answer with suitable calculations.

[4 marks]

Question 2 continues on the next page



0 2 . 3 State which star in **Table 1** is dimmest on the absolute magnitude scale.

[1 mark]

0 2 . 4 Calculate the absolute magnitude of Schedar.

[3 marks]

absolute magnitude = _____

0 2 . 5 Tsih has a mass over 15 times the mass of the Sun.
Tsih may eventually collapse to form a black hole.

Calculate the radius of the event horizon for a black hole with a mass 15 times that of the Sun.

[2 marks]

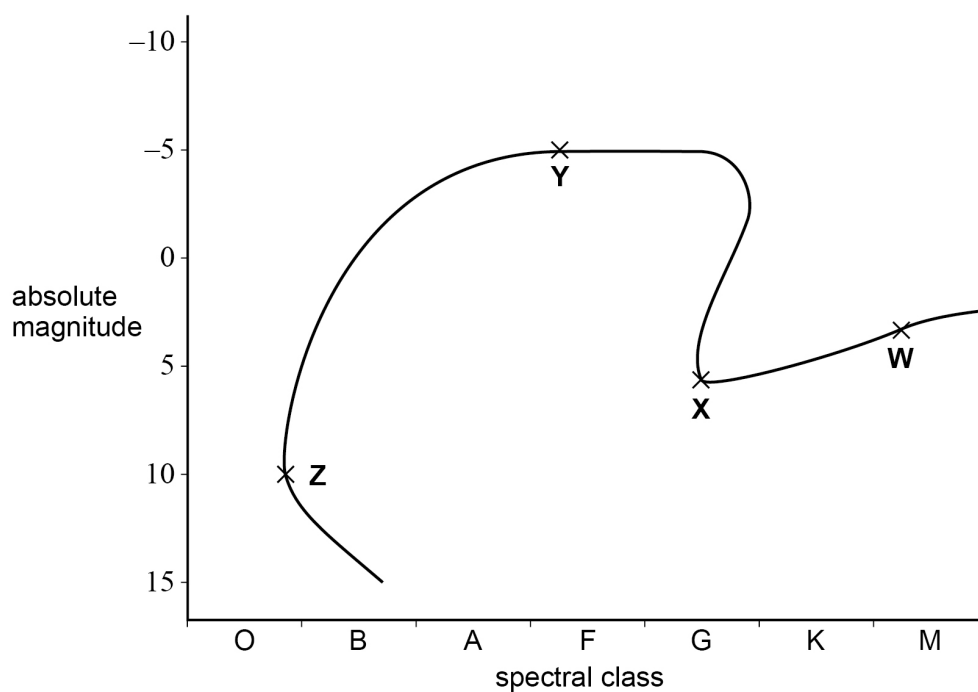
radius = _____ m



0 1

Figure 1 shows the evolution of a star similar to the Sun on a Hertzsprung-Russell (HR) diagram.

Figure 1



0 1 . 1

State the evolutionary stage of the star at each of the points **W**, **X**, **Y** and **Z**.

[3 marks]

W _____

X _____

Y _____

Z _____

Theta Carinae is a star with a radius five times that of the Sun. It has a surface temperature of 31 000 K.

0 1 . 2

Annotate **Figure 1** with a **T** to show the position of Theta Carinae.

[1 mark]

An astronomer suggests that an Earth-sized planet orbits Theta Carinae.

0 1 . 3

Explain **one** difficulty with using the transit method to detect this planet.

[2 marks]

0 1 . 4

The astronomer suggests that the Earth-sized planet receives a similar amount of power from Theta Carinae as the Earth does from the Sun.

The average power output of the Sun is 3.8×10^{26} W.

Determine the orbital radius of the Earth-sized planet orbiting Theta Carinae.

[5 marks]

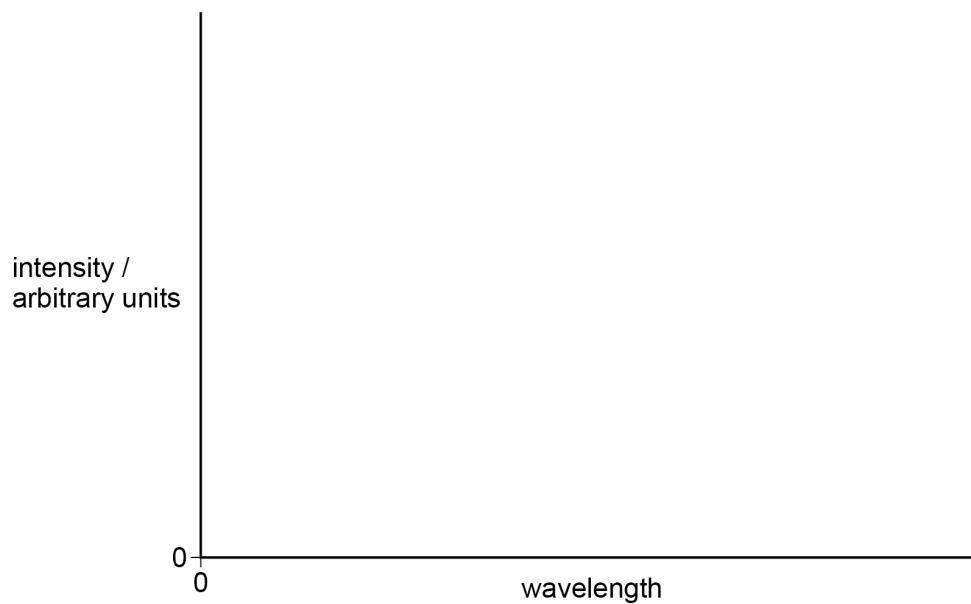
orbital radius = _____ m



0 2 . 1 Sketch, on the axes in **Figure 1**, the black-body radiation curve for a typical star.

[2 marks]

Figure 1



0 2 . 2 Explain, with reference to the SI units involved, how the curve you have drawn can be used to determine the black-body temperature of the star.

[3 marks]

Question 2 continues on the next page

0 2 . 3

Two stars, 61 Cygnus A and 61 Cygnus B, can be seen very close together in the constellation Cygnus. Early astronomers were unsure whether the two stars form a binary system, or simply appear in the same line of sight.

Table 1 shows some of the properties of the two stars.

Table 1

	Temperature / K	Radius / km	Apparent magnitude
61 Cygnus A	4500	4.7×10^5	5.2
61 Cygnus B	4100	4.1×10^5	6.1

Evaluate whether the data support the suggestion that the two stars form a binary system.

In your answer you should

- compare the two stars as seen by an observer on Earth
- support your evaluation with suitable calculations.

[6 marks]

0 2 . 4

What is the spectral class of 61 Cygnus A?

Tick (✓) the correct box.

[1 mark]

A

☐

F

☐

G

☐

K

☐

03

Table 2 summarises some of the properties of four stars in the constellation Hercules.

Table 2

Star	Distance/pc	Spectral class	Apparent magnitude
Kornephoros	43	G	2.8
Rasalgethi	110	M	3.0
Rutilicus	11	G	2.8
Sarin	23	A	3.1

03.1

Define the parsec. You may use a diagram as part of your answer.

[2 marks]

03.2

Deduce which star is larger, Kornephoros or Rutilicus.

[3 marks]



0 3 . 3

One of the four stars has the peak in its black-body radiation curve at a wavelength of $1.0 \mu\text{m}$.

Calculate the corresponding temperature for this curve.

[2 marks]

temperature = _____ K

0 3 . 4

Explain which star produced the black-body radiation curve described in question **03.3**.

[2 marks]

0 3 . 5

Which star has the brightest absolute magnitude?
Tick (✓) the correct box.

[1 mark]

Kornephoros

☐

Rasalgethi

☐

Rutilicus

☐

Sarin

☐

Question 3 continues on the next page



0	3	.	6
---	---	---	---

Determine the absolute magnitude of Sarin.

[3 marks]

absolute magnitude = _____



0 2

Table 2 shows some properties of the four brightest stars in the constellation Canis Minor.

Table 2

Name	Apparent magnitude	Absolute magnitude	Spectral class
Gamma A	4.46	−0.50	K
Gomeisa	2.89	−0.70	B
HD 66141	4.39	−0.13	K
Procyon	0.34	2.65	F

0 2 . 1

Discuss, with reference to the Hipparcos scale, why many star maps show only two stars in the constellation Canis Minor.

[3 marks]

0 2 . 2

State and explain which star in **Table 2** has the most prominent Hydrogen Balmer absorption lines.

[2 marks]

Question 2 continues on the next page



0 2 . 3 Deduce which star, Gamma A or HD 66141, has the larger diameter.

[3 marks]

0 2 . 4 Astronomers recently used the radial velocity method to discover an exoplanet orbiting HD 66141.

Describe the main features of the radial velocity method in the detection of planets.

[2 marks]

0 2 . 5 Calculate the distance from the Earth to Procyon.
Give an appropriate unit for your answer.

[3 marks]

distance = _____ unit _____



SUB-TOPIC 3.9.3

COSMOLOGY

Sub-topic 3.9.3 · 13 questions · 95 marks · lowest tariff first



04.1
Table 3 contains information about two galaxies.

Table 3

Galaxy	Red shift, z	Distance from Earth / ly
NGC 936	4.8×10^{-3}	6.8×10^7
NGC 3379	3.0×10^{-3}	3.2×10^7

Discuss whether these data are consistent with Hubble's Law.

[3 marks]

04.2
Quasars are the most distant measurable objects.

Discuss **one** problem associated with the determination of the distance from the Earth to a quasar.

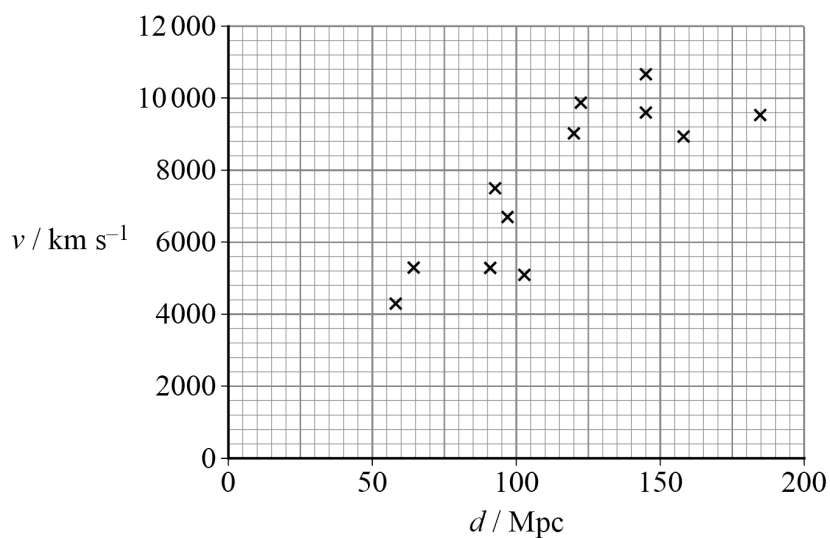
[2 marks]

END OF QUESTIONS



0 5

Figure 2 shows, for some galaxies, how their recession speed v varies with distance d from the Earth.

Figure 2**0 5 . 1**

Estimate, using **Figure 2**, the age in seconds of the Universe.

[3 marks]

age of Universe = _____ s



0 5 . 2

The estimate in Question **05.1** assumes that the Universe has expanded at a constant rate. Measurements involving type 1a supernovae that are at large distances from Earth caused astronomers to make a modification to this assumption.

State:

- the modification
- the explanation that was proposed to account for this modification.

[2 marks]

END OF QUESTIONS

0 3 . 1 The galaxy M87 is at a distance of 5.3×10^7 ly from the Earth.

Determine, in m s^{-1} , the recessional velocity of M87 relative to the Earth.

[3 marks]

recessional velocity = _____ m s^{-1}

0 3 . 2 Astronomers believe that M87 has an active supermassive black hole at its centre.

Suggest **one** observation that leads to this conclusion.

[1 mark]

0 3 . 3 Which provides evidence for the existence of dark energy?

Tick (✓) **one** box.

[1 mark]

Some type 1a supernovae are brighter than expected.

☐

Hubble's constant changes with time.

☐

The light from some galaxies is blue-shifted.

☐

0	5
---	---

According to NASA nearly 2000 exoplanets had been discovered by 2016, and the search continues. One aim of this search is to find an Earth-like planet orbiting a Sun-like star.

Discuss the difficulties associated with the detection of an Earth-like planet orbiting a Sun-like star.

In your answer you should compare the methods that are used in the search and suggest which may be the most successful.

[6 marks]

END OF QUESTIONS



0 4

Evidence to support the Big Bang theory comes from cosmological microwave background radiation and the relative abundance of hydrogen and helium in the Universe.

0 4 . 1

Explain what is meant by cosmological microwave background radiation and how its existence supports the Big Bang theory.

[3 marks]**0 4 . 2**

Explain how the relative abundance of hydrogen and helium supports the Big Bang theory.

[3 marks]

END OF QUESTIONS

0 4

IC2497 is a galaxy that contained a quasar. It is believed that the quasar stopped emitting radiation several thousand years ago.

0 4 . 1

Suggest why the quasar stopped emitting radiation.

[2 marks]

0 4 . 2

IC2497 has a red shift of 0.0516

Determine the distance from the Earth to IC2497.
Give an appropriate unit for your answer.

[4 marks]

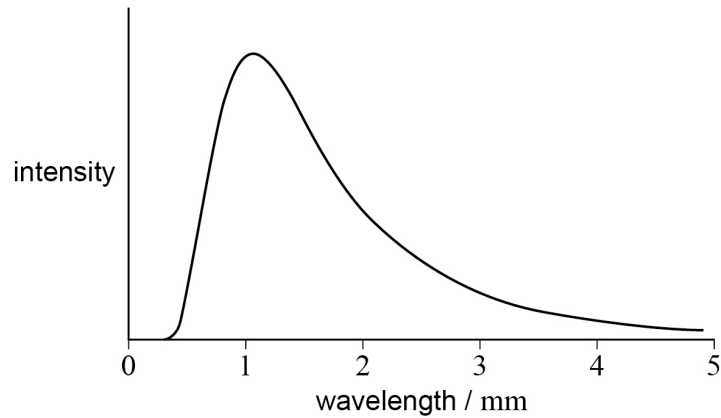
distance = _____ unit = _____



0	4
---	---

In the middle of the 20th century, there were two competing theories of the Universe. In 1964, electromagnetic radiation was observed coming from all directions in space. **Figure 2** shows the distribution of this radiation as observed from Earth.

Figure 2



The graph provides evidence for one of these theories of the Universe.

Discuss the main features of this theory of the Universe.

In your answer, you should include:

- the main predictions and evidence for the theory, and
- a suitable calculation.

[6 marks]

END OF QUESTIONS

04

M40 A and M40 B are two stars that appear very close to each other when viewed from Earth.
There are two possible reasons for this:

- they are an orbiting binary system
- they are distant from each other and only appear in the same line of sight.

In an orbiting binary system, the difference between the apparent magnitude and the absolute magnitude for each star is similar.

Table 3 shows data about these two stars.

Table 3

	Temperature / K	Radius of star / m	Apparent magnitude
M40 A	6000	6.3×10^9	9.7
M40 B	4700	1.1×10^{10}	10.1

Discuss the appearance of the two stars to an astronomer on the Earth.
In your answer you should:

- compare the colour of the stars
- compare the brightness of the stars
- deduce, with a calculation, whether the stars form an orbiting binary system.

[6 marks]



0 3 . 1

Describe the links between galaxies, black holes and quasars.

[2 marks]

0 3 . 2

At a distance of 5.81×10^8 light year, Markarian-231 is the closest known quasar to the Earth. The red shift z of Markarian-231 is 0.0415

Use these data to estimate an age, in seconds, of the Universe.

[4 marks]

age = _____ s



0	3	.	3
---	---	---	---

A typical quasar is believed to be approximately the size of the solar system, with a power output similar to that of a thousand galaxies.

Estimate, with reference to the inverse-square law, how much further the most distant visible quasar is likely to be compared to the most distant visible galaxy.

[3 marks]



0 3

3C 273 was the first quasar to be discovered.

IC 1101 is one of the largest galaxies known.

Table 2 shows some information about these objects.**Table 2**

	Absolute magnitude	Apparent magnitude	Distance / Mpc
quasar 3C 273	X	12.8	760
galaxy IC 1101	−22.8	14.7	320

0 3 . 1

State the property of the quasar that led to its discovery.

[1 mark]

0 3 . 2Show that the absolute magnitude **X** of quasar 3C 273 is about -27 **[2 marks]**

0 3 . 3 Assume that the quasar and the galaxy are both viewed from the same distance.

Explain which would be the brighter object.

Go on to calculate the ratio $\frac{\text{brightness of brighter object}}{\text{brightness of dimmer object}}$.

[3 marks]

ratio = _____

0 3 . 4 The black hole at the centre of IC 1101 has a mass of $7.1 \times 10^{11} M_{\text{S}}$ where M_{S} is the mass of the Sun.

Calculate the average density within the event horizon of the black hole.

[3 marks]

average density = _____ kg m^{-3}



04

Mintaka Aa1 and Mintaka Aa2 are two stars in a binary system. This means that they orbit their common centre of mass with the same period.

Table 2 gives information about the two stars.

Table 2

Star	Absolute magnitude	Apparent magnitude	Spectral class
Mintaka Aa1	−5.4	2.5	O
Mintaka Aa2	−2.9	5.0	B

04.1

Show that the data in **Table 2** are consistent with the two stars being in a binary system.

[3 marks]

04.2

State the most prominent absorption lines in the spectrum of Mintaka Aa2.

[1 mark]



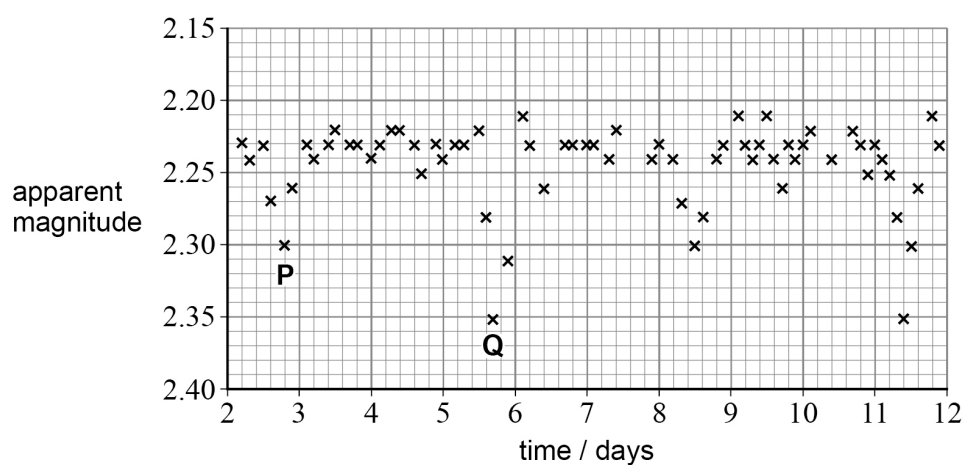
0 4 . 3 Explain which star in **Table 2** has the greater temperature.

[1 mark]

Question 4 continues on the next page

Figure 2 shows how the apparent magnitude of the binary system varies with time.

Figure 2



0 4 . 4 Explain the variation in apparent magnitude shown in **Figure 2**.

In your answer you should explain:

- the changes in observed brightness at **P** and **Q**, as shown in **Figure 2**
- why the observed brightness at **P** is different from the observed brightness at **Q**.

[3 marks]

0 4 . 5 Determine the angular velocity of the binary system.

[2 marks]

angular velocity = _____ rad s^{-1}

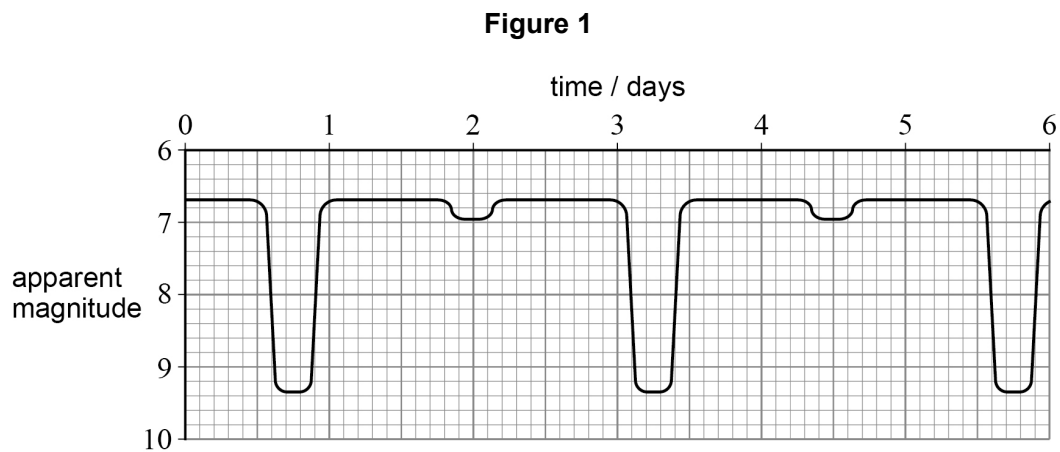


0 2

U Cephei is an eclipsing binary system consisting of two stars that orbit their common centre of mass.

The primary star is class B; the secondary star is class G.

Figure 1 shows the variation of apparent magnitude of U Cephei with time as observed from Earth.

**0 2 . 1**

Explain the shape of the graph in **Figure 1**.

[2 marks]

Question 2 continues on the next page

A particular spectral line has a wavelength of 486.136 nm when measured from a source in the laboratory.
 This line is also present in the absorption spectrum of the primary star of U Cephei.
 When observed from Earth, the wavelength of the primary star's absorption line varies as shown in **Table 1**.

Table 1

	Wavelength / nm
maximum value	486.498
minimum value	485.672

02.2 State why the average of the values in **Table 1** is different from the laboratory value. [1 mark]

02.3 Show that the orbital speed of the primary star is about 250 km s^{−1}. [3 marks]



0 2 . 4 Calculate the orbital radius of the primary star.

[2 marks]

orbital radius = _____ m

0 2 . 5 Which absorption lines would be most prominent in the spectrum of the primary star?
Tick (✓) **one** box.

[1 mark]

hydrogen

☐

hydrogen and helium

☐

ionised metals

☐

neutral metals

☐

0 2 . 6 A different eclipsing binary star system is thought to consist of a white dwarf star and a neutron star.

Discuss how astronomers could confirm this.

[2 marks]

0 4

The Earth is in the galaxy known as the Milky Way. The Andromeda Galaxy is one of the closest galaxies to the Milky Way.

0 4 . 1

The Andromeda Galaxy approaches the Milky Way at a speed of 110 km s^{-1} . The distance between the galaxies is 770 kpc.

Discuss whether these data can be used to estimate an age for the Universe.

[2 marks]

0 4 . 2

There is a supermassive black hole at the centre of the Andromeda Galaxy. The mass of this black hole is 1.60×10^8 solar masses.

Calculate the radius of the event horizon of this black hole.
State an appropriate unit for your answer.

[3 marks]

radius = _____

unit = _____

Question 4 continues on the next page

0	4	.	3
---	---	---	---

Scientists predict that a quasar will be produced as the Milky Way and the Andromeda Galaxy merge.

Explain what is meant by a quasar.

Go on to suggest why a quasar may be produced as galaxies merge.

In your answer you should:

- describe the typical properties of a quasar
- explain how observations of quasars provide evidence for these properties
- suggest the process of quasar formation that is likely when two galaxies merge.

[6 marks]

END OF QUESTIONS



MARK SCHEMES

official mark schemes



01	Diagram of Cassegrain telescope with Both mirrors correct ✓ Two rays correct. ✓	The first mark is for a concave primary mirror and convex secondary. Condone lack of shading. No gap needed in primary. Primary should not look like two mirrors Condone flat secondary if labelled convex. Do not condone concave secondary The second mark is for the two rays, initially parallel to the principal axis, reflecting from the primary mirror to the secondary, and then crossing (as they pass through the primary). Ignore arrows on rays. No lens needed, but ignore rays after lens if drawn. Poorly drawn rays eg curved, loses mark.	1 1	A01a
Total			2	



Question	Answers	Additional Comments/Guidance	Mark	ID details
		Allow 'reflecting telescope' R		



02.1	B brighter with support (eg diameter of B bigger) ✓ (The brightness of the image is determined by the collecting power and) collecting power related to D^2 or area ✓ Calculation of areas or d^2 ✓	Allow 'reflecting telescope' B.	1	A03/1a
		An unsupported answer gains no marks	1	
		Ignore references to resolving power or unit W.	1	
02.2	Two objects will just be resolved when the first minimum/edge of the airy disc in the diffraction pattern of one image ✓ Coincides with central maximum/centre of the airy disc of the other. ✓	Correct diagrams can gain both marks	1	A01/1a
		Ignore references to formula	1	
02.3	B is better because it has a larger diameter ✓ Minimum angular separation/angular resolution depends on $1/D$	No mark awarded for an unsupported answer. The first is for arguing that B is better due to larger diameter The second mark is for identifying the relationship between angular resolution and diameter. Correct calculations can gain both marks, using any wavelength.	Max 2	A03/1a
Total			7	

Question	Answers	Additional Comments/Guidance	Mark	ID details



01.1	To give $\lambda = 1.8 \times 10^{-7} \times 0.305$ $= 5.5 \times 10^{-7} \text{ m}$ ✓	Allow 1 max for one POT error. Allow ecf for incorrect D unless 5.03 m used. Award full credit if factor of 1.22 included (to give $4.5 \times 10^{-7} \text{ m}$)	1	AO2/1d
01.2	$M = 3.2 \times 10^{-4} / 1.8 \times 10^{-6}$ ✓ $= 178$ Use of $M = f_o/f_e$ to give $f_e = f_o/M = 5.03/178$ ✓ $= 0.028 \text{ m}$ ✓	The first mark is for evidence of use of angular magnification equation. The second mark is for evidence of the use of the magnification focal lengths equation. The third is for the final answer. Do not credit 0.03. Allow ecf for M. Allow 2 max for one POT error.	1 1 1	AO2/1d AO2/1h AO2/1d
01.3	Either Telescope can resolve objects down to $1.8 \times 10^{-6} \text{ rad}$ At $3.0 \times 10^4 \text{ km}$, this angle is subtended by an object of size $3.0 \times 10^4 \text{ km} \times 1.8 \times 10^{-6} \text{ rad} = 54 \text{ m}$ ✓ This is $54/325 = 1/6^{\text{th}}$ size of asteroid ✓ would not be suitable for viewing detail. ✓ OR Angular size of asteroid $= 325/3 \times 10^7 = 1.1 \times 10^{-5}$. ✓ As $1.1 \times 10^{-5} > 1.8 \times 10^{-6}$ asteroid can be seen/ $1.1 \times 10^{-5} / 1.8$	The first mark is for the calculation. The second mark is for the comparison. Allow ecf. The angular resolution of the telescope should be quoted. The third mark is for reaching the judgement. This mark cannot be given if simple statement that asteroid can be seen. Condone correct use of sin and tan. Full credit can also be given if they use	1 2	AO3/1a AO3/1b

	$\times 10^{-6}$ 6 times minimum angular resolution. ✓ Too small for detail to be seen. ✓	magnification and compare angular size with the resolution of the eye.		
Total			8	



Question	Answers	Additional Comments/Guidance	Mark	ID details
	Curve with a single peak ✓ Steepest part of LHS steeper than steepest part of RHS ✓	If multiple curves seen all of them must be	2	AO1/1a



01.1		Accept any two colours in the right order Accept initials for colours Accept hand-drawn rays unless obviously curved Rays can bend at centre of lens or at either (or both) surfaces(s)	1
01.2	Concave convex ✓		1



01.3	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.		The following statements are likely to be present. A Structure Similarity: both use reflecting (parabolic) surface. L1 Difference: Radio – no secondary reflector, detector placed at focal point of primary, wire mesh for dish L1 Treat as neutral: radio telescope arrays, optical only during dark B Positioning Similarity: both capable of being on Earth's surface as little absorption by atmosphere at optical or radio wavelengths. The presence of both on the planet can be inferred if reference is made to altitude. L2 Difference: Light pollution requires optical telescopes to be away from centres of population; distortions due to atmosphere require optical to be high up; obscuration by clouds requires optical to be high up or in dry places/radio telescopes need to be located in a (radio) quiet area/radio can be at lower altitude. L2 Treat as neutral: comments about placing either A or B in space, C Collecting power D^2: much larger D for radio means much greater collecting power /8× greater (but sources tend to be very weak) compared to optical. $CPB/CPA = 110^2/39.3^2 = 7.8$ D Resolving power λ/D; B large D but extremely large λ means generally low resolving power compared to A. So A likely to provide more detailed image.	6 AO1-1a (2) AO2-1a (2) AO3-1b (2)
	Mark	Criteria		
	6	All 4 aspects analysed, including calculation of resolving power/ratio of resolving powers for two telescopes. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.		
	5	A good attempt to analyse 3 aspects, which must include quantitative or algebraic discussion of resolution or collecting power		
	4	Two aspects successfully discussed and one partially discussed. Whilst there will be gaps, there should only be an occasional error.		
	3	Two aspects discussed, or one discussed and two others covered partially. There may be several errors and omissions in the discussion.		
	2	Only one aspect discussed successfully, or makes a partial attempt at more than one aspect.		
	1	None of the four aspects covered without significant error; at least one relevant comment.		
	0	No relevant analysis.		

		Evidence of calculations, eg For optical min λ angle = 8.9×10^{-9} rad For radio min λ angle = 2.3×10^{-5} rad (could compare max λ angle; 4.6×10^{-8} and 9.1×10^{-3})	
Total			8

Question	Answers	Additional Comments/Guidelines	Mark
	Hipparcos scale: (brightest 1) down to 6 dimmest (visible in good conditions) ✓	6 dimmest may be inferred. Accept reverse argument.	1
	Gamma A and HD 66141 much dimmer than two brightest stars / not		2



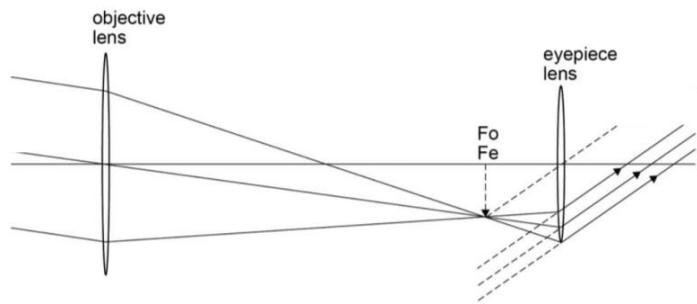
05.1	Rayleigh criterion identifies the minimum subtended angle between two objects whose (images) can be resolved. ✓ ₁ (Minimum angle is when) the central maximum of (the diffraction pattern of light from) one object coincides with the first minimum of (the diffraction pattern) of the second object. ✓ ₂		2	AO1-1a
-------------	--	--	---	--------

Question	Answers	Additional comments/Guidance	Mark	AO
05.2	Telescope is detecting U-V/wavelengths smaller than visible light ✓ ₁ Which is absorbed by (ozone in) the atmosphere so must be in space ✓ ₂ Explains why U-V light gives better resolution ✓ ₃	MP3 needs ref to λ/D or good detail about diffraction.	1 2	AO3-1a AO2-1e

Question	Answers	Additional comments/Guidance	Mark	AO
05.3	Quantitative comparison of collecting power or resolution ✓ ₁ Arecibo brighter image or more detail ✓ ₂ Links spherical aberration to detail of image ✓ ₃	e.g. Collecting power $\frac{305^2}{76^2} = 16$ times brighter or calculation of resolutions There is no absolute conclusion - Image from Arecibo will be brighter - Lovell likely to be better detail because no spherical aberration No mention of the effect of shape – MAX 2	3	AO3-1a
Total			8	



01.1	Two pairs of rays drawn parallel to the principal axis coming to different foci. Outer rays focus closer to lens than inner rays. ✓		1	AO1
------	--	--	---	-----

Question	Answers	Additional Comments/Guidance	Mark	AO
01.2	Both focal points labelled, on the principal axis, and coincide, with $f_o > f_e$ ✓ Three off-axis rays through objective lens correct, as far as the eyepiece ✓ Three rays through eyepiece correct, parallel to a construction line ✓ 	$f_o > f_e$ judged by eye. Condone a single label F or '(principal) foci'. Ignore labels outside the space between the two lenses. Rays must be off-axis to get the second mark. Construction line does not need to be drawn. If only two rays drawn then max 2.	3	3 x AO1

Question	Answers	Additional Comments/Guidance	Mark	AO
01.3	$(f_o / f_e = 750 \text{ and } f_e + f_o = 17.4)$ $f_e = (f_e + f_o)/751 \checkmark$ $= 17.4/751$ $f_e = 2.3(17) \times 10^{-2} \text{ m } \checkmark$	Accept any correct unit Use of $f_e = (f_e + f_o)/750$ without explanation scores 0 (Calculator value = 0.0231691079) If no other mark given award max 1 for 0.023 or 0.0232 but treat evidence of incorrect calculation as a talkout.	2	2 x AO2



Question	Answers	Additional Comments/Guidance	Mark	AO
01.4	Resolution is limited by the diameter of the objective ✓_a so it will make no difference ✓_b OR CCD has better resolution due to having smaller pixels ✓_a so the stars could be more easily seen as separate (OWTTE) ✓_b (candidates may combine these ideas) CCDs have higher quantum efficiency and/or can be exposed for a long time ✓_a so dimmer or more distant binaries can be observed ✓_b CCDs can detect a wider range of wavelengths ✓_a enabling the observation of more binary pairs. ✓_b Description of why CCD is more convenient in use ✓_a with a specific example of why this helps in the observation of binary stars. ✓_b	General principle is difference ✓_a followed by consequence. ✓_b If no consequence relevant to observation of binary stars, then max 2 Examples of 'convenience' include use when astronomer not present, image can be stored and analysed (on computer). Ignore reasons based on cost.	Max 3	3 x AO3
Total			9	

Question	Answers	Additional Comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



02.1	Final image at infinity. ✓	Accept answers which describe how the telescope is set up with named lenses unless f_o and f_e are used e.g. the focal plane/point of the eyepiece and objective lenses are co-incident. OR ‘distance between lenses is $f_o + f_e$’ Condone ‘rays leaving eyepiece/entering eye are parallel’ If F_o and F_e are used they must be defined.	1	1 × AO1
------	----------------------------	--	---	---------

Question	Answers	Additional comments/Guidance	Mark	AO
02.2	100 converging 5 converging ✓		1	1 × AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	(Each step on magnitude scale is 2.51) (Hence) $2.51^x = 40$ $x = \log_{2.51}(40) = 4(.01)$ OR Adding 6 to their x ✓ $(6 + 4 =)10$ ✓	Condone trial and error (2.51^1, 2.51^2, ...). Award MAX 1 if no working shown for a bald correct answer.	2	$2 \times \text{AO2}$

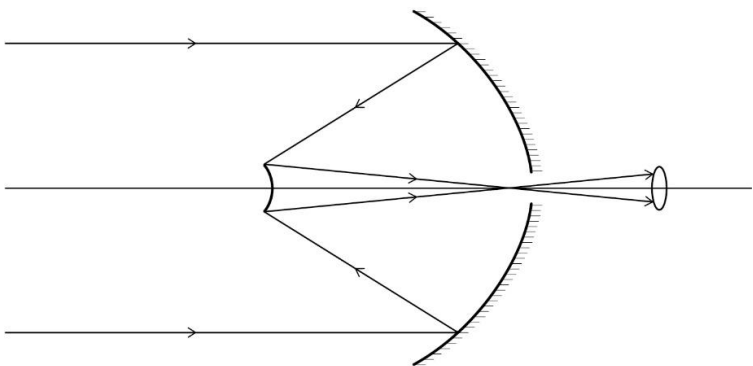


Question	Answers	Additional comments/Guidance	Mark	AO
02.4	(Collecting power of telescope is) $\left(\frac{60}{7}\right)^2 = 73 \text{ or } 74 \text{ (times greater than naked eye) } \checkmark$ 73 (or 74) is greater than 40 so the astronomer can see WASP-82. $\checkmark$	MP1 can be given for 73 or 74 seen. Accept $\left(\frac{7}{60}\right)^2 = 0.014$ for MP1 Allow an ecf in MP2 from '8.6 times greater' $\left(\frac{60}{7} = 8.6\right)$, with idea that 8.6 is less than 40 and therefore astronomer cannot see Wasp-82. Allow ecf in MP2 for an arithmetic error in MP1.	2	2 × AO3



Question	Answers	Additional comments/Guidance	Mark	AO										
02.5	Two clear reasons given ✓✓	If no justification given then MAX 2 . In the first row: Do not allow 'efficiency' alone. The reason and justification marks can both be awarded for an answer based on the definition of 'quantum efficiency' e.g.a greater proportion/percentage of the incident photons are detected (by the CCD). In the justification condone 'light' for 'photons' and condone 'number' for 'proportion' Treat 'image processing' as neutral. Ignore references to resolution.	3	3 × AO1										
	Correct justification linked to one reason ✓													
	<table><tr><th>Reason</th><th>Justification</th></tr><tr><td>Better/greater quantum efficiency</td><td>A greater proportion of (incident) photons are detected</td></tr><tr><td>Can expose for long periods / many images can be combined</td><td>More light is collected / better image contrast</td></tr><tr><td>Can operate remotely</td><td>The telescope can be positioned where light pollution/atmospheric absorption is minimised</td></tr><tr><td>Idea that it can detect (more) wavelengths beyond the visible</td><td>More energy is collected from the star</td></tr></table>				Reason	Justification	Better/greater quantum efficiency	A greater proportion of (incident) photons are detected	Can expose for long periods / many images can be combined	More light is collected / better image contrast	Can operate remotely	The telescope can be positioned where light pollution/atmospheric absorption is minimised	Idea that it can detect (more) wavelengths beyond the visible	More energy is collected from the star
	Reason				Justification									
	Better/greater quantum efficiency				A greater proportion of (incident) photons are detected									
	Can expose for long periods / many images can be combined				More light is collected / better image contrast									
	Can operate remotely				The telescope can be positioned where light pollution/atmospheric absorption is minimised									
Idea that it can detect (more) wavelengths beyond the visible	More energy is collected from the star													
MAX 3														
Total			9											

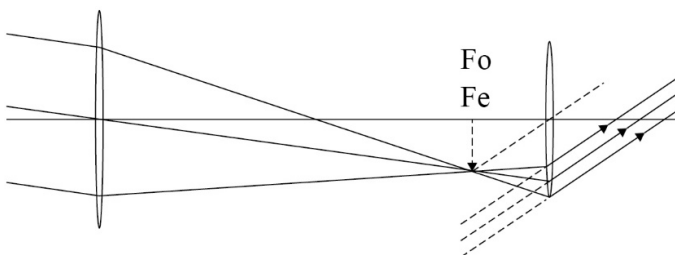
Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----

01.1	Diagram of Cassegrain telescope with both mirrors correct ✓ two rays correct ✓ 	The first mark is for a concave primary mirror and convex secondary. Condone lack of shading. Hole in primary can be inferred from rays passing through. Primary must not look like two mirrors. Condone flat secondary if labelled convex. Do not condone if concave. The second mark is for the two rays, initially parallel to the principal axis, reflecting from the primary mirror to the secondary, and then crossing on the principal axis after secondary and before passing through primary. Condone crossing after primary if before a lens. Ignore arrows on rays. No lens needed; ignore rays after lens if drawn. Poorly drawn rays, eg curved, loses mark.	2	AO1.1b
01.2	Resolution = $\frac{450 \times 10^{-9}}{0.21} = 2.14 \times 10^{-6}$ (rad) ✓ Smallest detail = $2.14 \times 10^{-6} \times 12.5 \times 10^6 = 27$ m ✓ Sensible comment about comparison and decision made ✓	For MP2 student may find angle subtended by 1 km crater (8.0×10^{-5} rad) then compare angles for MP3 MP3 for example 27 m is 1/40th of crater.	3	AO3.1a

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	Collecting power area ✓ $\text{Ratio} = \frac{2.4^2}{.21^2} = 130$ OR calculates both areas and states Hubble is much bigger ✓	MP1 is for student showing they know dependence on area. Condone collecting power d^2 if it is clear that d is diameter. MP2 for clear comparison	2	AO2.1f
01.4	At least 2 clear comparisons made ✓✓ Decision made about which telescope, justified in terms of the impact of at least one comparison on the image (likely to be reflecting). ✓	Problems of refractors: Can suffer spherical aberration and chromatic aberration. Reflecting are lighter. Reflecting are shorter. Mirrors do not suffer from chromatic aberration. Problems of reflectors: Spider/secondary mirror block some of the light/reduce image brightness/cause diffraction effects. Ignore discussion of cost/difficulty of construction/air trapped in refracting telescope.	3	AO3.1b
Total			10	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



02.1	Diagram correct with a set of three non-axial rays ✓ Both focal points labelled with common focus closer to eyepiece lens ✓ 	Allow MP2 only for axial ray diagram Condone missing arrows Condone missing construction line Treat 'focal length' as neutral. Insist that focal points are common and on principal axis.	2	AO1
------	--	--	---	-----

Question	Answers	Additional comments/Guidance	Mark	AO										
02.2	The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4- mark (L2) and 5- or 6- mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist in marking this question.	Relative brightness (partial 1/2; full 2/2) (Image formed by) B brighter than A (because B larger diameter than A) or B has a greater collecting power than A - Collecting power $B = 2.25 \times$ collecting power A Show features (partial 1/ first 3; full = partial + 2/last 3) (angular) resolution of $B > A$ or Resolution of $B = 1.5 \times A$ - Angular size of Mars $= 8.2 \times 10^{-5}$ rad [allow 4.1×10^{-5} rad from radius] - Magnified A $= 25 \times 8.2 \times 10^{-5}$ $= 2.1 \times 10^{-3}$ rad and Magnified B $= 40 \times 8.2 \times 10^{-5} = 3.3 \times 10^{-3}$ rad or minimum angle resolvable with the eye using this telescope: A $= 1.2 \times 10^{-5}$ rad and B $= 7.5 \times 10^{-6}$ rad - Both better than resolution of eye - A can resolve separation 990 km (15% diameter of Mars) or B can resolve 620 km (9% diameter of Mars) - Images in B appear $1.6 \times$ larger than A Aberrations (partial 1/3; full 3/3) (Dispersion due to lenses so) A shows (more) chromatic aberration - Idea that the use of a parabolic mirror produces no spherical aberration with B - B better than A for aberrations.	6	2 × AO1 3 × AO2 1 × AO3										
	<table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>All three areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr><tr><td>5</td><td>A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.</td></tr><tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td></tr><tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr><tr><td>2</td><td>Only one area discussed or makes a partial attempt at two areas.</td></tr><tr><td>1</td><td>None of the three areas covered without significant error.</td></tr></table>				Mark	Criteria	6	All three areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.	5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
Mark	Criteria													
6	All three areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.													
5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.													
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.													
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.													
2	Only one area discussed or makes a partial attempt at two areas.													
1	None of the three areas covered without significant error.													



Question	Answers	Additional comments/Guidance	Mark	AO
02.3	Two from: ✓✓ • Better quantum efficiency and therefore more (of the incident) light/photons detected (per second) • Pixels smaller than rods/cones/retinal cells therefore better resolution • Detects light outside visible spectrum so more information / more (of the incident) light detected with CCD • Longer exposure (time) possible so more light/photons detected	If no other marks given: award MAX 1 for two features / two advantages without explanation	Max 2	AO1
Total			10	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



01.1	Determination of focal length of objective OR adds their f_o and f_e ✓ 1.67 (m) CAO ✓	$f_o = M \times f_e = 75 \times 0.022 = 1.65$ (m) No sf penalty Condone 2 sf 1.7	2	AO2
-------------	---	--	---	-----

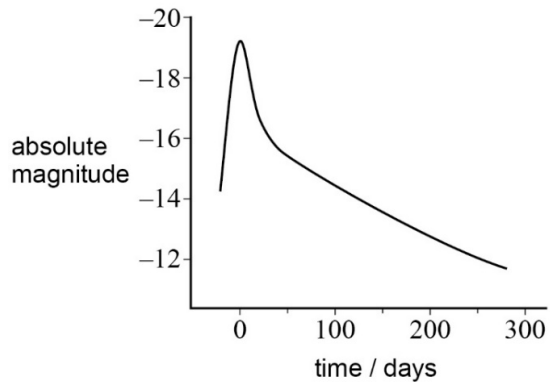
Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Determination of angle subtended by Jupiter at unaided eye OR uses: distance to Jupiter = diameter of Jupiter ÷ angle subtended with their diameter OR their angle ✓ distance = 6.2×10^8 (km) ✓ CAO	E.g. $1.7 \times 10^{-2} / 75 = 2.3 \times 10^{-4}$ (rad) $2 \times 7.0 \times 10^4 / 2.3 \times 10^{-4}$ In MP1 allow use of trig and angle in degrees or radians. Condone use of 1.7×10^{-2} degrees. Do not award MP1 if both angle and diameter are incorrect.	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	Idea that chromatic aberration is caused by dispersion of light passing through lens OR different colours/wavelengths being refracted by different amounts/to different focal points. ✓ Idea that effect is greatest at greatest curvature/edge of lens OR least at centre of lens OR Idea that light can only travel through part of lens with little curvature ✓ therefore chromatic aberration is reduced. ✓	Marks can be given for labelled diagram. Credit answers that suggest edges of lens act like a triangular prism. MP3 is contingent on MP2.	3	1 × AO1 2 × AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	(Diameter (d) is reduced and therefore:) Idea that the image is dimmer ₁ ✓ collecting power proportional to area / d^2 ₂ ✓ Idea that the image less clear ₃ ✓ minimum angular resolution is proportional to $1/d$ ₄ ✓	Treat any comments about the path through the atmosphere as neutral. For ₃ ✓ do not allow 'lower resolution' for 'less clear' Alternative for ₃ ✓ ₄ ✓ Idea that the image is more clear as spherical aberration is reduced as only rays near axis form image	4	AO3
Total			11	
Question	Answers	Additional comments/Guidance	Mark	AO



04.1	Use of $P = \sigma AT^4$ ✓ $\text{Ratio} = \frac{\sigma A_M T_M^4}{\sigma A_S T_S^4} =$ $(1.4 \times 10^{10})^2 \times 53000^4 / (7.0 \times 10^8)^2 \times 5700^4 = 3.0 \times 10^6 \quad \checkmark$	Award mp 1 for substituting data for either the Sun or Melnick 34	2	AO2.1f
04.2	Star will undergo supernova collapse or Star will form a neutron star/black hole ✓ which produces a <u>gamma ray burst</u> and consequence for life or reference to being highly collimated ✓	Examples of consequence for life :kills cells/ damages DNA.	2	AO3.1b
Total			4	

02.1	D		1	AO1-1a
------	---	---	---	--------

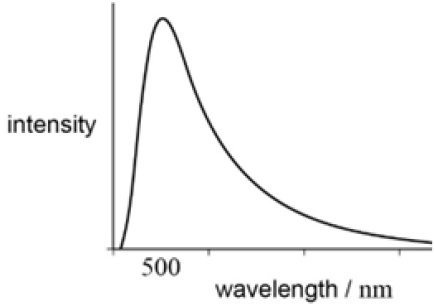
Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Use of $m - M = 5 \log(d/10)$ to give $m = 5 \log(d/10) + M = 5 \log(7.7 \times 10^4) - 19.3$ giving $m = 5.1$ ✓ ₁ which is brighter than their quoted Hipparcos limit ✓ ₂ Qualitative comparison of the brightness of their m with 6 leading to a conclusion ✓ ₃	Allow -19.0 to -19.5 for M giving $m = 5.4$ to 4.9 MP1 finds apparent magnitude MP3 comparative statement about answer that relates the 2 brightnesses correctly (allow ecf)	3	AO3-1b

8

Total		4
-------	--	---

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



01.1	Evidence of $\lambda_{\max} = 500 \text{ nm} / 0.5\mu\text{m}$ etc. (seen in calculation or graph) ✓ Shape correct ✓ i.e.  Scale with their $\lambda_{\max}$ at their peak and unit shown on scale consistent with value ✓	No sf penalty MP1 value consistent with their unit (can be shown as calculation) MP2: Single peak shown with clearly steeper LHS than RHS AND correct shape on RHS MP3: scale shown with indication of $\lambda_{\max}$. Allow zero on axis.	3	1 × AO1 1 × AO2 1 × AO3
------	--	---	---	--

Question	Answers	Additional comments/Guidance	Mark	AO
01.2	5	accept answers that round to 5	1	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	(Idea that the planet is much smaller than the star and therefore): variation of quantity AND named/described method of measurement ✓	Mark as list. Answer must refer to a method of detecting exoplanets Treat comments about direct observations of the planet as neutral	1	AO3
Total			5	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



05	Group X: Use of inverse-square law (to arrive at a value for I or d): $_1✓$ $(I \propto \frac{1}{d^2})$ (Ratio of intensities: $\frac{I_1}{I_2} = \frac{530^2}{548^2}$) $I_1 = 1.07 I_2$ or $d = 511 \text{ (ly)}$ $_2✓$ Group Y: Use of $P \propto r^2$ (to arrive at a value of P_1 or r) $_3✓$ $(A = 4\pi r^2)$ (Ratio of power: Use of $\frac{P_1}{P_2} = \frac{750^2}{700^2}$ or alternative) leading to a calculation of $P_1 = 1.15 P_2$ or $r = 75(0)r$. $_4✓$ So Group Y could be correct AND Group X not correct. $_5✓$	Allow any subscripts, e.g. $1/2$, x/y, etc. Allow conclusion to be drawn on basis of ratios When $I \propto \frac{r^2}{d^2}$ is seen and used, award $_1✓$ and $_3✓$. Expect $k = 0.613$. Accept I for P Alternative approach: When $2.51^{0.0725} = 1.07$ seen, award $_1✓$ and $_2✓$. Some evidence of relevant working for both X and Y must be seen to award $_5✓$	5	AO3
Total			5	

03	Mark	Criteria	Examples of points made in a good answer	4 2	AO1-1b AO3-1b
	6	All 3 areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.			
	5	All 3 areas covered at least 2 in detail. Whilst there will be gaps, there should only be an occasional error.			
	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.			
	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.			
	2	Only one area discussed or makes a partial attempt at two areas.			
	1	None of the three areas covered without significant error.			
	0	No relevant analysis.			
			Overall shape • Overall curve is a black body spectrum • Links λ_{max} to temperature • Continuous spectrum emitted by star Absorption lines • Dips are due to absorption • Light of particular wavelengths absorbed by gases in outer layers • And re-emitted in random directions • Leaving dark lines • E.g. Balmer lines are produced by hydrogen The hydrogen must be excited to the $n = 2$ state Choice of star • Miaplacidus (class A) • Temperature calculated (~ 9000 K) • temperature is class A OR • Miaplacidus (class A) • Absorption lines are Hydrogen (Balmer) lines • strong Hydrogen/Balmer absorption lines seen in class A but not in class K		

9

Total			6
-------	--	--	---

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



02.1	Determines s and r in consistent units OR Uses $A = 2 \times \text{parallax angle} = 2 \times (1 \div (\frac{79}{3.26}))$ ✓ 2.3×10^{-5} degrees CAO ✓	eg for MP1 • $s = 2 \times 1.5 \times 10^{11} \text{ m}; r = 79 \times 9.46 \times 10^{15} \text{ m}$ • $s = 2 \div 2.06 \times 10^5 \text{ pc}; r = 79 \div 3.26 \text{ pc}$ • $\tan(A/2) = \text{orbital radius} \div \text{distance to star}$ with consistent units $A = 4.0 \times 10^{-7} \text{ rad} = 2.3 \times 10^{-5} \text{ degrees}$ Evidence for MP1 can be seen in Figure 2.	2	AO2
------	--	--	---	-----

Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Use of $m - M = 5 \log (d/10)$ with two correctly substituted from m, M or d ₁✓ Obtains correct value of m, M or d ₂✓ Compares their value with value given in question ₃✓ Makes comment about significance of difference between their values related to the distance AND some idea of whether the astronomer's suggestion is valid consistent with their values.₄✓	If no other mark given, award 1 mark for recognition that 0.40 pc is a lot less than the distance to nearest known star and therefore determination must be incorrect. For MP2 expect to see $d = 2.3$ pc OR $m = 9.7$ OR $M = 20.5$ Alternative for MP1 and MP2 using m, M and d in $m - M = 5 \log (d/10)$ ₁✓ seeing -3.2 for LHS and -7.0 for RHS ₂✓ MP3 and MP4 cannot be awarded without a comparison of the distances. MP4 is for a recognition of the large difference between their calculated value and value given in question eg by proportion, >>, 6 x bigger, significantly bigger etc. If a difference is calculated in MP3, for MP4 to be awarded the difference must be compared to one of the distances.	4	AO3
Total			6	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



04.1	Absolute magnitude scale getting more negative going up and Time scale with 0 along axis, going up to between 10 and 400 ✓ Line drawn going up and down, with LHS steeper than steepest part of RHS ✓ Line drawn increasing quickly with peak at absolute magnitude between -18 and -20 ✓	The first mark is for the scales The second is for the curve The third is for the value of the peak	3	A01/1a
04.2	Object whose absolute magnitude is known (and whose apparent magnitude can be measured.) ✓	Do not allow fixed or constant for 'known' But condone predictable Do not allow 'directly measured' Condone intrinsic or inherent brightness, or luminosity for absolute magnitude	1	A01/1a
04.3	Measurements of supernovae do not agree with predictions (from Hubble's Law) ✓ So Universe must be expanding at increasing rate/accelerating ✓ (Controversial as) no known energy source for expansion or reference to dark energy ✓		1 1 1	A01/1a
Total			7	

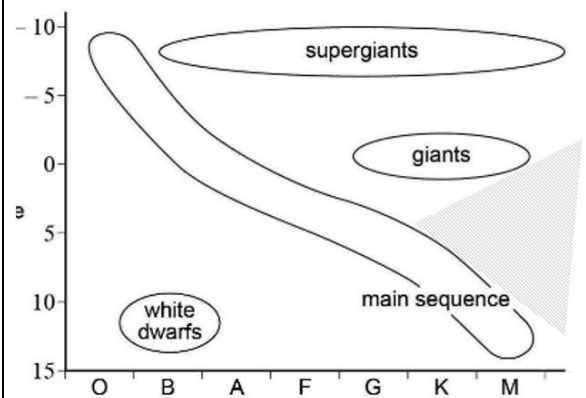
Question	Answers	Additional Comments/Guidance	Mark	ID details
----------	---------	------------------------------	------	------------



01.1	Diagram with 1 AU, 1 pc and $\frac{1}{3600}^\circ$ labelled ✓	Allow 1 arc second or 1'' or $2.8 \times 10^{-4}^\circ$ or 4.8×10^{-6} rad for angle. 1 AU can be shown as Sun–Earth distance. Condone 'au' for 'AU'. 1 pc can be either long side. Condone label <i>d</i> for 1 pc.	1	1 × AO1
------	--	---	---	---------

Question	Answers	Additional comments/Guidance	Mark	AO
01.2	B ✓		1	1 × AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	evidence of 10^x seen OR evidence of $0.11 - (-7.84)$ seen ✓ $d = 390$ (pc) ✓	condone $0.11 + 7.84$ provided $m-M$ seen. Calculator value is 389.0451	2	$2 \times \text{AO2}$

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Line coming in from the right to mag 5/class G then to giants and then to white dwarfs (in that order) ✓	Condone lack of arrow. The shaded area shows the acceptable region for the initial line (from protostar). 	1	$1 \times \text{AO1}$

Question	Answers	Additional comments/Guidance	Mark	AO
01.5	(GRB produced when) supergiant collapses ✓ (and) forms a neutron star OR a black hole ✓	Ignore references to 'supernova'	2	1 × AO2 1 × AO3
Total			7	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



03.1	Use of $\lambda_{\max}T = \text{constant}$ to determine their $\lambda_{\max}$, their T or their constant ✓ Comparison with $\lambda_{\max} = 0.48 \times 10^{-6} \text{ (m)}$ OR $T = 6.0(4) \times 10^3 \text{ (K)}$ OR constant = 0.0029 m K AND conclusion that the graph is consistent. ✓	Throughout the answer: Allow 0.47 to 0.49 μm for $\lambda_{\max}$ from the graph Allow 6.17×10^3 to $5.92 \times 10^3 \text{ (K)}$ for their calculated T. Allow 2.82×10^{-3} to $2.94 \times 10^{-3} \text{ (m K)}$ for their calculated constant.	2	1 × AO3 1 × AO2
-------------	--	---	---	-------------------------------

Question	Answers	Additional comments/Guidance	Mark	AO
03.2	Using $P = \sigma AT^4$ to give $P = 5.67 \times 10^{-8} \times 4\pi \times (9.6 \times 10^6)^2 \times 6000^4$ ✓ $8.5 \times 10^{22} \text{ (W)}$ ✓	In MP1 condone one error from - missing the 4 - missing the π - doubling the radius and using it as r in an area calculation - POT errors Condone σ for 5.67×10^{-8} Allow full credit for use of their T from 03.1 eg $T = 6.04 \times 10^3 \text{ (K)}$ gives $8.75 \times 10^{22} \text{ (W)}$	2	2 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	✓ in top box (white dwarf, F)		1	AO3
Question	Answers	Additional comments/Guidance	Mark	AO
03.4	Shorter wavelengths will have been removed (more) OR star's observed spectrum has lower intensity at shorter wavelengths OR (observed) peak of black-body is at a greater value of λ (than shown in Figure 3)/shifted to the right. ✓ ($\lambda_{\text{max}}T = \text{constant}$,) therefore the (observed/estimated) value of T is lower than the actual T / value of T in 03.1 ✓	Allow reverse arguments MP2 is contingent on MP1	2	AO3
Total			7	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



03.1	An object that has an escape velocity greater than the speed of light. OR An object that has a gravitational field strength that is so great that light cannot escape. ✓	Reject idea of 'beyond' or 'past' the event horizon if the direction is unclear. Do not accept 'mass' 'density' 'light cannot escape' 'light cannot escape its gravity' on their own.	1	1 × AO1
------	--	--	---	---------

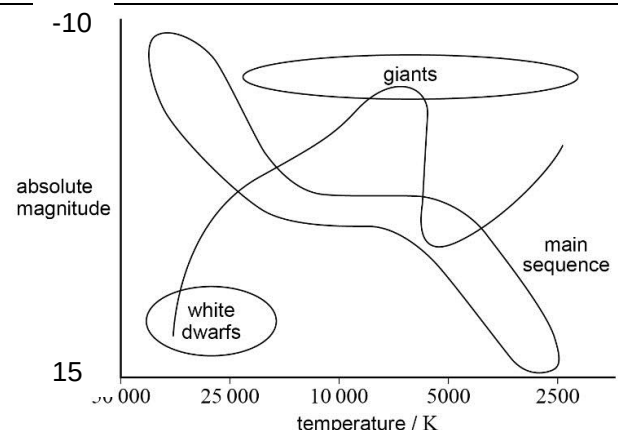
Question	Answers	Additional comments/Guidance	Mark	AO
03.2	$R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 6.5 \times 10^9 \times 1.99 \times 10^{30}}{(3 \times 10^8)^2} 1 \checkmark$ Angle subtended by region around event horizon of black hole $= \frac{1.917 \times 10^{13} \times 2 \times 1000}{5.3 \times 10^7 \times 9.46 \times 10^{15}} = 7.64 \times 10^{-8} \text{ (rad)} 2a \checkmark$ resolution of EHT = $\left(\frac{1.3 \times 10^{-3}}{1.3 \times 10^7}\right) = 1(.0) \times 10^{-10} \text{ (rad)}$ OR resolution of Hubble = $\left(\frac{410 \times 10^{-9}}{2.4}\right) = 1.71 \times 10^{-7} \text{ (rad)} 3 \checkmark$ Both resolutions calculated correctly and conclusion drawn that EHT is better than Hubble. $4 \checkmark$	Condone rounding errors in this question. Award MP1 for $R_s = 1.9(17) \times 10^{13} \text{ (m)}$ seen Condone missing mass of Sun (1.99×10^{30}) in MP1 Condone missing '2' in MP2. Award MP2 for $7.6(4) \times 10^{-8}$ OR $3.8(2) \times 10^{-8}$ seen. Allow POT error in MP1 and MP3 ALTERNATIVE $R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 6.5 \times 10^9 \times 1.99 \times 10^{30}}{(3 \times 10^8)^2} \checkmark$ One resolution calculated $2 \checkmark$ Determination of the size of the object that can be resolved by a telescope at the distance of black hole For EHT size = $5(.0) \times 10^{13} \text{ (m)}$ OR For Hubble size = $8.6 \times 10^{16} \text{ (m)} 3 \checkmark$ Both sizes calculated correctly and conclusion drawn that EHT is better than Hubble. $4 \checkmark$	4	4 × AO3

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	Evidence of difference in wavelength = $374.96 - 373.53$ ✓ (= 1.43 nm) Evidence of sum of wavelengths = $374.96 + 373.53$ ✓ (= 748.49 nm) $(z = \frac{\Delta\lambda}{\lambda} = \frac{0.72}{374.25} = 1.9 \times 10^{-3})$ $(v = zc = 1.9 \times 10^{-3} \times 3.00 \times 10^8 =)$ $5.7 \times 10^5 \text{ (m s}^{-1}\text{)} \checkmark$	MP1 can be given for determination of $\Delta\lambda$ (= 0.72 nm) MP2 can be given for determination of average (= 374.25 or 374.24(5) nm) Alternative method for z: $z = \frac{374.96 - 373.53}{374.96 + 373.53} = 1.9 \times 10^{-3}$	3	3 × AO2
Total			8	

15

Question	Answers	Additional comments/Guidance	Mark	AO
	The mark scheme gives some guidance as to what statements			

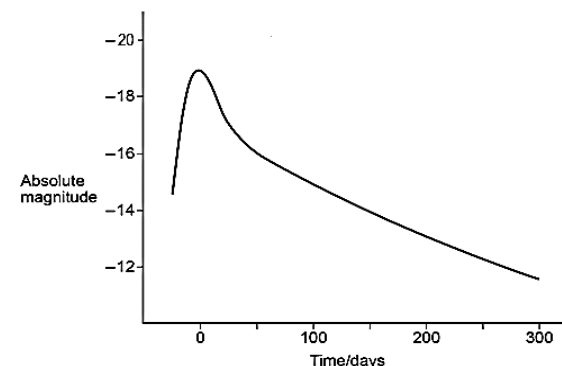


03.1	Scale labelled from +15 up to -10 ✓	+15 bottom or white dwarves at the maximum. -10 top of giants at the lowest.	1
03.2	S between 5000 K and horizontal section of bottom line of main sequence. ✓ ₁ Within main sequence and at 'correct' abs mag 5 ✓ ₂	Marks are independent For the second mark the S should be closer to +5 than 0 or +10 on 'correct' scale. If only "S" is seen, assume middle of the "S". If a clearly labelled dot or × is seen, that should be used for marking.	2
03.3	Line drawn coming from the right to S, ✓ ₁ Line drawn from S up to giants and round to white dwarfs ✓ ₂	 Accept convoluted lines. Must touch giants and dwarves but does not need to go into area. Arrows are not required, but penalise any that go in the wrong direction with max 1.	2
03.4	Point P to the right and above their S ✓	Accept P on same horizontal level as S	1

3.5	Absolute magnitude of supernova (is about -20), beyond scale of HR diagram OR Supernova is shortlived / varies so cannot be assigned a position ✓₁ Temperature of a supernova (peak) is too high (greater than 50 000 K) ✓₂ Black hole – escape velocity greater than c OR no light emitted / absolute magnitude too dim to fit on scale ✓₃ Temperature of a black hole would be too low (less than 2500 K) ✓₄	Accept “too hot”/“too cold” for temperature Insist on “absolute magnitude” not “brightness”. Condone: A supernova does not last very long. Do not accept ‘absolute magnitude would be zero’ Max 3	Max 3
Total			9

Question	Answers	Additional Comments/Guidelines	Mark
	Correct use of Doppler equation for both Galaxies✓ Correct use of Hubbles law for both Galaxies✓ Justified comparison leading to conclusion✓	Award full credit for calculation:- 1. Hubble's constant for two galaxies and then related to Hubble's constant value in data booklet or to each other: NGC 936 is consistent ($H=69 \text{ km s}^{-1} \text{ Mpc}^{-1}$) NGC 3379 is not consistent ($H=92 \text{ km s}^{-1} \text{ Mpc}^{-1}$) 2. Using Hubble constant from data booklet to deduce if z or d in table are in agreement with calculated values for both galaxies. 3. Calculate ratio z/d for both galaxies and compare	1



03.1	It has a known absolute magnitude. ✓	Other wordings are possible. It must be clear that the candidate knows that it is the intrinsic power/brightness that must be known.	1	AO1.1a
03.2	Peak between -18 and -20 AND axis correct direction ✓ Time scale 40 to 500 days ✓ Lhs steeper than rhs (by eye) ✓	-ve sign essential Allow magnitude and/or time axes starting at 0 Accept any unit for time which fits with the 40-500 days range. Ideal graph: 	3	AO1.1a

Question	Answers	Additional comments/Guidance	Mark	AO																
03.3	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist in marking this question <table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>All 3 areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr><tr><td>5</td><td>A fair attempt to analyse all 3 areas. If there are several errors or missing parts then 5 marks should be awarded.</td></tr><tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td></tr><tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr><tr><td>2</td><td>Only one area discussed or makes a partial attempt at two areas.</td></tr><tr><td>1</td><td>None of the three areas covered without significant error.</td></tr><tr><td>0</td><td>No relevant analysis.</td></tr></table>	Mark	Criteria	6	All 3 areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.	5	A fair attempt to analyse all 3 areas. If there are several errors or missing parts then 5 marks should be awarded.	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.	2	Only one area discussed or makes a partial attempt at two areas.	1	None of the three areas covered without significant error.	0	No relevant analysis.	Examples of points which might be made in a good answer. Data - Also need z (or red shift). - Use z value to find velocity ($v = zc$). - Measure wavelength of spectral lines Graph - Plot graph of velocity on y-axis vs distance on x-axis. v in km/s, distance in Mpc. H is gradient of graph. Limitations - Value of apparent magnitude may be affected by what the light passes through. - Much variation in the data (there must be specific reasons given e.g. variations between galaxies or random errors in measurement). - At large distances accelerating universe will affect graph. - Need data from lots of supernovae	2	AO1.1a
		Mark	Criteria																	
		6	All 3 areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.																	
		5	A fair attempt to analyse all 3 areas. If there are several errors or missing parts then 5 marks should be awarded.																	
		4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.																	
		3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.																	
		2	Only one area discussed or makes a partial attempt at two areas.																	
		1	None of the three areas covered without significant error.																	
		0	No relevant analysis.																	
		2	AO2.1a																	
2	AO3.1b																			
Total			10																	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----

02.1	Tick (✓) only against Tsih	Accept other clear indication (eg x)	1	AO1.1b
02.2	Temperature: Attempt to use Wiens Law. ✓ Correct calculation of T for both stars. ✓ Colour: Links colour to wavelengths produced ✓ Schedar longer wavelengths so 'redder' than Caph ✓ Or Links temperature to spectral class ✓ Caph F (therefore White), Schedar K (therefore Orange) ✓	For Caph $T = \frac{2.9 \times 10^{-3}}{410 \times 10^{-9}} = 7250 \text{ K (6900–7630)}$ For Schedar $T = \frac{2.9 \times 10^{-3}}{660 \times 10^{-9}} = 4400 \text{ K (3600–5200)}$ Allow ecf for incorrect temperatures. No mark for just stating colours	4	1× AO1.1b 1× AO2.1f 2× AO3.1a
02.3	Caph ✓		1	AO2.1e
02.4	Conversion of distance to parsec (70) ✓ Use of $m - M = 5\log\left(\frac{d}{10}\right)$ to give $M = m - 5\log\left(\frac{d}{10}\right)$ ✓ $(M = 2.2 - 5\log\left(\frac{70}{10}\right)) = -2.0 (-2.025)$ ✓	1 mark for correct distance conversion 1 mark for re-arranging formula 1 mark for correct answer (min 2 sf) Ecf for incorrect conversion only if there is an attempt to convert.	3	3× AO2.1b

Question	Answers	Additional comments/Guidance	Mark	AO
02.5	$R_s \left(= \frac{2GM}{c^2} \right) = \frac{2 \times 6.67 \times 10^{-11} \times 15 \times 1.99 \times 10^{30}}{(3.00 \times 10^8)^2} = \checkmark$ $4.4 \times 10^4 \text{ m } \checkmark$	OK to use $\approx$ instead of $=$ (as in the specification) Allow ecf for POT error only.	2	2× AO2.1b
Total			11	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



01.1	W – protostar/gas cloud ✓ ₁ X – main sequence star ✓ ₂ Y – (Red) giant AND Z – (white) dwarf ✓ ₃	Candidates may add to the diagram – this should be credited Accept formation stage for W Condone Supergiant for Y	3	AO1-1a
------	---	---	---	--------

Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Positioned magnitude less than 5 ...and class O ✓	Grey box shows accepted region	1	AO3-1a

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	Transit method measures how much light is blocked by planet. ✓ ₁	MP1 Candidate demonstrates they know what the transit method is. Any suggestion that method involves seeing a dot moving across the face of the star award 0 marks.	1	AO1-1b
	Planet is small (and star is very big) so little light blocked out. ✓ ₂	MP2 Links this to Earth-sized planet.	1	AO2-1e

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Use of σAT^4 ✓ ₁	Condone incorrect A formula but must include other quantities.	3	AO2-1f
	$= 8.0 (7.97) \times 10^{30} \text{ (W)} \checkmark_2$ Attempt to use inverse square law for Earth or find ratio of powers (allow ecf) ✓ ₃ Equates intensities for Earth and planet orbiting TC ✓ ₄ $\sqrt{\text{their ratio}} \times 1.5 \times 10^{11} \text{ or } \sqrt{\frac{\text{their power for TC}}{1.7 \times 10^4}} \checkmark_5$ $(= 2.2 (2.17) \times 10^{13} \text{ m})$	For example Power output of Theta Carinae = $\sigma AT^4 =$ $5.67 \times 10^{-8} \times 4\pi R^2 \times 31000^4 \checkmark_1$ $= 8.0 (7.97) \times 10^{30} \text{ W} \checkmark_2$ Ratio of power outputs = $\frac{7.97 \times 10^{30}}{3.8 \times 10^{26}}$ $= 2.10 \times 10^4 \checkmark_3$ So planet must be $\sqrt{2.10 \times 10^4} = 1.45 \times 10^2$ times further away ✓ ₄ $= 1.45 \times 10^2 \times 1.5 \times 10^{11} = 2.2 \times 10^{13} \text{ m} \checkmark_5$	2	AO3-1b

Total			11
--------------	--	--	-----------

Question	Answers	Additional comments/Guidance	Mark	AO
-----------------	----------------	-------------------------------------	-------------	-----------



02.1	Steepest part of LHS steeper than steepest part of RHS ✓	correct. Do not condone curves with negative gradient on LHS		
02.2	Mention of use of peak wavelength ✓ Quoting use of Wien's law and that wavelength is in metres ✓ Use of $\lambda_{\text{max}} T = 0.0029 \text{ m K}$ ✓ and mention of temperature in kelvin. ✓	This mark may be awarded for a label on the wavelength axis of the graph. Do not condone biggest or maximum. If no peak in graph 2 max. Only the first mark can be awarded if there is a suggestion that 'm' in the equation represents 'milli', or K represents Boltzmann's constant. Ignore references to Stefan's Law.	3	AO2/1g

Question	Answers	Additional Comments/Guidelines	Mark								
2.3	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question. <table><tr><th>Level</th><th>Criteria</th><th>QoWC</th></tr><tr><td>6 marks</td><td>Correct calculations of power output. Comparison of brightness, Leading to similar distance away and therefore binary (or not if supported).</td><td rowspan="2">The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.</td></tr><tr><td>5 marks</td><td>There may be an error in the calculations but POT errors can be condoned.</td></tr></table>	Level	Criteria	QoWC	6 marks	Correct calculations of power output. Comparison of brightness, Leading to similar distance away and therefore binary (or not if supported).	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.	5 marks	There may be an error in the calculations but POT errors can be condoned.	Stars compared for colour: Cygnus B will appear more red than Cygnus A as it is cooler Or both stars orange. (L1) Ignore calculation of λ_{max} unless linked correctly to colour. Stars compared for brightness. Cygnus A will appear (approximately 2 times) brighter than Cygnus B, as the apparent magnitude is approximately 1 less than that of Cygnus B. (L2) Difference in magnitude = 0.9 ratio in brightness = $2.51^{0.9} = 2.3$ Distance discussed Powers compared: (L2) Using $P = \sigma AT^4$ Gives For A: $P = 5.67 \times 10^{-8} \times 4\pi \times (4.7 \times 10^8)^2 \times 4500^4 = 6.45 \times 10^{25}\text{W}$ (L2/3) For B: $P = 5.67 \times 10^{-8} \times 4\pi \times (4.1 \times 10^8)^2 \times 4100^4 = 3.38 \times 10^{25}\text{W}$ (L2/3) As power output of A is about twice that of B, and A appears about twice as bright, they must both be about the same distance away.(L2/3)	6
Level	Criteria	QoWC									
6 marks	Correct calculations of power output. Comparison of brightness, Leading to similar distance away and therefore binary (or not if supported).	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.									
5 marks	There may be an error in the calculations but POT errors can be condoned.										

4	Attempt to calculate power outputs or quantitative analysis of brightness, with some relevant comment. Condone some errors including POT, missing “4” or use of “4/3”. Do not condone more serious errors in calculation. If the brightness is the wrong way round (B>A) ignore brightness comparison.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.	Evaluation Being about the same distance away is consistent with idea that they form a binary system. (L2/3)	
3	Only a qualitative response. Reference to r and T suggesting that Power output of A greater than B. This can be seen in an (incorrect) equation. OR straight forward comparison of brightness. (eg A is			

		about twice as bright).			
2	Two aspects of star correct – eg A brighter than B, both appear orange (do not accept red), B redder than A.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.			
1	Only one aspect statement comparing stars correct. eg A brighter than B, both appear orange (do not accept red), B redder than A.				
0	Unsupported evaluation or no relevant analysis	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.			



02.4	K ticked		1	AO1/1a
Total			12	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	Quasars are produced by (supermassive) black holes. ✓		2	AO1/1a



03.1	Distance at which 1AU✓ subtends an angle of 1/3600 th degree ✓ or Diagram with 1AU, 1pc and 1/3600 th degree labelled ✓	Allow 1 arc second for angle 1AU can be shown as Sun Earth distance 1pc can be either long side	2	A01/1a A01/1b
03.2	They are the same spectral class and therefore have similar temperatures. ✓ They have the same apparent magnitude, but K is significantly further away, therefore K has a greater power output (P)/ brighter absolute magnitude ✓ As $P = \sigma AT^4$ to have a greater power output than R at the same temperature, K must have a greater area, and therefore be bigger. ✓	No mark for the answer on its own. First mark for identifying same T Second mark for identifying greater P Condone greater for brighter Condone luminosity for absolute magnitude Third mark for use of Stefan's Law and obtain the answer.	3	A03/1a
03.3	Substitution into $\lambda_{\max} T = 0.0029 \text{ mK}$ ✓ To give $T = 2.9 \times 10^{-3} / 1.0 \times 10^{-6} = 2.9 \times 10^3 \text{ K}$ ✓	Condone power of ten errors in first mark	2	A02/1f
03.4	The spectral class is related to the temperature ✓ So the star is in spectral class M And is therefore Rasalgethi ✓	Allow ecf from 03.3 – see spec for table of spectral class and temperature The second mark is for the correct class and therefore star identified	2	A02/1e
03.5	Rasalgethi		1	A02/1e



Question	Answers	Additional Comments/Guidance	Mark	ID details
03.6	Use of $m-M = 5 \log (d/10)$ To give $3.1 - M = 5 \log(2.3) \checkmark$ $3.1 - M = 1.8 \checkmark$ $M = 1.3 \checkmark$	First two marks are for the substitution of M, m and unit of d and correct log. Detect one mark for each error; more than two errors give 0/3 Third mark for the correct calculation: allow ecf for up to two errors	3	A02/1f
Total			13	



Question	Answers	Additional Comments/Guidance	Mark	ID details
----------	---------	------------------------------	------	------------



02.1	Gamma A and HD 66141 much dimmer than two brightest stars / not much brighter than magnitude 6 ✓ Only two stars (Gomeisa and Procyon) likely to be seen (unless conditions are good) ✓		
02.2	Gomeisa (is a B class star) ✓ (B class stars are hot enough) to have electrons/hydrogen in n=2 state ✓	Condone "The B class star" for first mark	1 1
02.3	Same spectral class so similar temperature ✓ Absolute magnitude of Gamma A (and therefore power output) brighter (greater) than HD 66141 ✓ Due to Stefan's Law, Gamma A has larger area, and therefore larger diameter ✓	Accept same temperature Confusion with apparent magnitude, max 1 Accept power ,but Not brightness, of Gamma A is greater without direct reference to Abs Mag P prop to A at constant T equivalent to is enough for Stefans Law	3

02.4	Periodic Doppler shift in light received (from star) ✓ Due to star and planet orbiting common centre of mass ✓	Statement or implication that light is from planet loses this mark. Red and Blue shift is equivalent. Red shift could increase and decrease. Periodicity could be implied Ignore 'wobble' unless clearly explained.	2
02.5	Use of $m - M = 5 \log (d/10)$ To give $0.34 - 2.65 = 5 \log (d/10)$ ✓ $\log (d/10) = -2.31/5$ $d = 3.45$ ✓ pc ✓	Reversing magnitudes (giving 29pc) is a physics error. Can score unit mark only. Beware of $\log_e$ in expression – PE max 1 for unit Condone parsec, PC or Pc but Not ps OR pC. Unit mark cannot be awarded without an attempt at calculation. Allow correct converted unit. (e.g. 11.2 or 11.3 ✓ ly ✓; 7.1×10^5 AU; 1.1×10^{17} m) Other units can only be awarded if clear intention of conversion. (e.g. AE in calculating parsecs correctly converted to metres)	3
Total			13

Question	Answers	Additional Comments/Guidelines	Mark
	Scale labelled from +15 up to -10 ✓	+15 bottom of white dwarves at the maximum -10	



04.1		3. Calculate ratio z/d for both galaxies and compare. $z/d = 4.8/6.8 = 0.7$ and $z/d = 3/3.2 = 0.9$ Condone POT errors when compared in a ratio. ECF for comparison if at least one calculation correct. (max 2/3) Candidate who calculates values for only one galaxy can only score 1 mark. Credit discussion suggesting that other factors also affect galaxy velocity or distance measurements and difference not large so Hubble's Law is OK.	2
------	--	---	---

04.2	Distant quasars are very faint; or Type 1a supernova (or standard candle) in associated galaxy would be very faint ✓ Reference to inverse square law ✓ or Due to dark energy/accelerating universe, ✓ use of Hubble's Law/inverse square law not reliable over large distances. ✓	Condone 'barely detectable OWTTE' for faint. Condone Some quasars are situated behind intervening galaxies/gas clouds Affecting data/light received from quasar	2
Total			5



05.1	Line of best fit <u>drawn through origin</u>. ✓ Evidence of $\frac{\Delta v}{\Delta d}$ used. ✓ Age in range 4.1 to 5.1×10^{17} s ✓	Accept lines that intersect $v / \text{km s}^{-1} = 12000$ somewhere between $d / \text{Mpc} = 160$ and 200 Do not accept use of $H = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ unless obtained from gradient.	3	$1 \times \text{AO2}$ $2 \times \text{AO3}$
-------------	--	---	---	---

Question	Answers	Additional comments/Guidance	Mark	AO
05.2	expansion is accelerating OR rate of expansion is increasing ✓ (due to) dark energy ✓	Treat descriptions of how the rate is increasing as neutral Do not allow 'dark matter'	2	$2 \times \text{AO1}$
Total			5	

03.1	Evidence of use of Hubble equation with H value from data booklet ✓ Evidence of conversion of unit for d OR H to give consistent units for d and H ✓ $1.1 \times 10^6 \text{ (m s}^{-1}\text{)} \checkmark$	Condone POT error in MP1 e.g. for MP2 d in m and H in $(\text{k})\text{ms}^{-1} \text{ m}^{-1}$ or d in $(\text{M})\text{pc}$ and H in $(\text{k})\text{ms}^{-1} (\text{M})\text{pc}^{-1}$ d in ly and H in $(\text{k})\text{ms}^{-1} \text{ ly}^{-1}$ etc. expect to see: 16(.3) Mpc for d Expect rounding to $1.06 \times 10^6 \text{ (m s}^{-1}\text{)}$ when ≥ 3 sf Note that incorrect use of 3.26 may appear as a POT error. In this case MP2 and MP3 are withheld	3	AO2
------	--	---	---	-----

Question	Answers	Additional comments/Guidance	Mark	AO
03.2	One from: ✓ (idea of) very intense radio-wave emitter bright X-ray source	Condone ‘quasar’ or description of quasar Condone “jets” of (sources of) electromagnetic radiation Do not accept ‘γ-ray burst’	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	Some type 1a supernovae are brighter than expected. ✓		1	AO1
Total			5	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



05	The mark scheme gives some guidance as to what statements are expected to be seen in 1 or 2 mark (L1), or 3 or 4 mark (L2) and 5 or 6 mark (L3) answers. Guidance provided in section 3.10 of the 'Mark Scheme instructions' document should be used to assist in marking this question.				
	Mark	Criteria	QoWC		
	6	All three methods described. All three methods applied to Earth-like planets. Judgement reached	The student presents relevant information coherently, employing structure, style and spg to render meaning clear. The text is legible		
	5	Only two methods described and all three applied, Or All three described and only two applied.			
				Transit – dips in brightness as planet crosses in front of star from our point of view. Alignment must be correct for planets to eclipse, so many possible candidates not observed. Earth-like planet could be observed provided not too far away. Radial velocity (Doppler) – periodic shift in spectra of star due to star's movement around common centre of mass with planet. Earth-like planet mass much less than mass of Sun-like star so effect slight. Earth-like planet could be detected with highly sensitive spectrometers. Direct observation – very unlikely as Earth-like planet too small and too near star and too cool to be detected against the brightness of the Sun-like star. Unlikely to be detected.	3
				3	AO3/1b

	4	Two methods described and applied, Or three described and only one applied	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SPG are sufficiently accurate not to obscure meaning			
	3	Three methods described, Or Two methods described and one applied				
	2	Only one method described and applied Or two methods described with application	The student presents some relevant information in a simple form. The text is usually legible. SPG allows meaning to be derived although errors are sometimes obstructive.			
	1	Only one method described				
	0	No relevant information	The student's presentation, SPG seriously obstruct understanding			



	Higher Level (5 or 6 marks) All three methods of measurement are described (transit, radial and direct observation) Problems associated with each one are discussed, with particular reference to detecting an object an Earth – like planet. Intermediate Level (3 or 4 marks) Only two of the three methods are described and little effort is made to link the methods to the detection of an Earth-like planet. Low level (1 or 2 marks) Only one method is described, or two methods poorly. Little or no reference is made to the detection of an Earth-like planet. <i>(a more detailed mark scheme will be produced with levelled statements)</i>			
Total			6	

04.1	it is the radiation coming from all parts of the Universe ✓ when the Universe cooled sufficiently for matter and radiation to 'decouple', with the combination of protons and electrons to form neutral atoms ✓ this radiation has been red-shifted into the microwave region as the Universe has expanded ✓ OR This is (em) radiation from all parts of the Universe, ✓ the spectrum has a peak in the microwave region / corresponds to a temperature of 2.7 K ✓ It can be interpreted as the radiation left over from the Big Bang / the photons having been stretched to longer wavelengths and lower energies. ✓	One mark is for stating that CMBR comes from all parts of Universe. Accept Isotropic condone homogeneous condone same at all points in universe Another is for referencing the idea that the radiation has a peak in the microwave region The third is for linking it to the Big Bang theory. Condone "left over heat from Big Bang"	3	AO1a
04.2	(The Big Bang theory suggests that a very brief period of) fusion occurred (when the Universe was very young), resulting in the production of helium from fusing hydrogen. ✓ Fusion stopped as the Universe then expanded and cooled ✓ resulting in a relative abundance of hydrogen and helium in the ratio of 3:1/ cooled too rapidly for the creation of larger nuclei, or suitable relevant observation ✓	One mark is for linking helium production to fusion in the early Universe. This mark can also be awarded for description of proton and neutron creation/ 7:1 ratio	3	AO1a
Total			6	

04.1	Quasars are formed around black holes ✓ ₁ <u>Black hole</u> (at the centre of IC2497) no longer has matter falling into it ✓ ₂	MP2 – allow black hole no longer feeding; Black hole no longer active. If no mention of black holes no marks can be awarded.	2	AO2-1e
------	---	--	---	--------

Question	Answers	Additional comments/Guidance	Mark	AO
04.2	use of $z = v/c$ to give $v = zc = 0.0516 \times 3.00 \times 10^8$ ✓ ₁ $= 1.55 \times 10^7 \text{ m s}^{-1} = 1.55 \times 10^4 \text{ km s}^{-1}$ use of $v = Hd$ to give $d = \frac{v}{H}$ ✓ = $\frac{1.55 \times 10^4}{65}$ $= 238$ ✓ ₃ Mpc ✓ ₄	Accept 2sf in final answer. Condone Megaparsec, MPC or Mpc but not Mps OR MpC. Unit mark cannot be awarded without an attempt at calculation. Allow correct converted unit. (eg 782 ✓ Mly ✓; 4.93×10^{10} AU; 7.40×10^{21} m) Units other than Mpc can only be awarded if there is a correct conversion – but allow ecf. (eg AE in calculating Mpc correctly converted to m)	3 1	AO2-1b AO1-1a
Total			6	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----

04	6	A coverage of all three aspects. There may be the occasional slip-up.	There must be an attempt at a relevant calculation for 5 or 6 marks (this could be the age of universe). Points made in a good answer could include: Aspect 1 - RedShift - Theory predicts that distant galaxies are all moving away from us - The further away the galaxy the faster it moves - Reference to Hubble's Law Aspect 2 -CMBR - Theory predicts black body radiation at microwave wavelengths (2.7 K) - from all directions which indicates that the universe was once very small/in a hot dense state - Graph shows peak in microwave region - General shape of graph is the same as a black body - CMBR is not predicted by any other theory - Condone suggestion that it's leftover radiation from Big Bang Aspect 3 - Hydrogen/Helium ratio and/or Wien's Law calculation. Treat calculation of age of universe as partial Aspect 3. Answers	6	4 x AO1 2 x AO3
	5	Two aspects are well covered and partial coverage of the other. There may be some misunderstanding – for example that stars are moving away from us.			
	4	Two aspects are well covered, or one well covered and a brief coverage of the others. There may be some misunderstanding – for example that stars are moving away from us.			
	3	Includes a clear coverage of one aspect and at least an attempt at another OR a partial coverage of all three.			
	2	Includes a clear coverage of one aspect OR a partial discussion of two.			
	1	Partial coverage of one aspect.			
	0	No relevant comment.			

		which cover H/He and Wien's Law can be used to support partial Aspect 1 or 2. • Theory predicts 3:1 H/He ratio • In deep space (not stars) this is observed in practice • Calculation shows peak corresponds to 2.7 K (approx)		
Total			6	



04

The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria
6	All three areas (as outlined alongside) covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all three areas, with two areas discussed successfully and one area partially.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed successfully and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed successfully, or makes a partial attempt at two areas.
1	One of the three areas covered partially. There are likely to be many errors or omissions.
0	No relevant analysis.

Area 1: Stars compared for colour

M40 B will appear more red than M40 A as it is cooler.

M40 A is an F/G star; M40 B is a K class star
Therefore M40 A is white/yellow-white and M40 B is orange

Ignore calculation of λ_{max} unless linked correctly to colour.

Classes are related to colour/temperature

Area 2: Stars compared for brightness

M40 A will appear (~1.5 times) brighter than M40 B, as the apparent magnitude is 0.4 less than that of M40 B.

Difference in magnitude = 0.4

Ratio in brightness = $2.51^{0.4} = 1.5$

Area 3: Distance discussed

Powers compared:

Using $P = \sigma AT^4$ gives

For A: $P = 5.67 \times 10^{-8} \times 4\pi \times (6.3 \times 10^9)^2 \times 6000^4 = 3.66 \times 10^{28} \text{ W}$

For B: $P = 5.67 \times 10^{-8} \times 4\pi \times (1.1 \times 10^{10})^2 \times 4700^4 = 4.22 \times 10^{28} \text{ W}$

As power output of **A** is less than that of **B** but **A** appears brighter, **A** must be closer and therefore they are not a binary.

6

4 × AO2

2 × AO3

Total			6
-------	--	--	---

17

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----

03.1	These black holes are at the centre of (active) galaxies (active galactic nuclei.) ✓			
03.2	Using $v = cz$ gives $v = 3 \times 10^8 \times 0.0415 \checkmark = 1.25 \times 10^7 = 1.25 \times 10^4 \text{ kms}^{-1}$ Using $1\text{pc} = 3.26 \text{ lyr}$ $d = 5.81 \times 10^8 \text{ lyr} = 5.81 \times 10^8 / 3.26 \checkmark = 1.78 \times 10^8 \text{ pc}$ $= 1.78 \times 10^2 \text{ Mpc } (= 5.5 \times 10^{24} \text{ m})$ Using $v = Hd$ $(H = v/d = 1.25 \times 10^4 / 1.78 \times 10^2 = 70 \text{ kms}^{-1} \text{ Mpc}^{-1})$ Age of Universe $= 1/H = d/v \checkmark$ $= 5.81 \times 10^8 \times 9.47 \times 10^{15} / 1.25 \times 10^7 = 4.42 \times 10^{17} \text{ s} \checkmark$	The first mark is for use of zc The second mark is for a calculation of d The third mark is for using the idea that the age of the Universe is $1/H$ The fourth mark is for the answer. Allow own H for 3rd and 4th marks.	4	AO2/2b

Question	Answers	Additional Comments/Guidance	Mark	ID details
03.3	Both quasar and galaxy should have same brightness (and therefore similar received power). ✓ Use of Inverse square law eg Power of quasar/(distance to quasar) ² = power of galaxy / (distance to galaxy) ² ✓ Or $1000/d^2 = 1/1$ So distance to quasar = $(1000)^{1/2}$ = about 30 times greater than distance to galaxy. ✓	The first mark is for relating the similar “brightness”. Accept intensity. Accept in form of equation linking quasar and galaxy.	1	AO2/1c
		The second mark is for applying the inverse square law. Simply quoting it does not get this mark. The final mark is for coming to a valid conclusion related to the distance to the quasar compared to the distance to the galaxy Do not accept answers involving square roots. These are standalone marks..	2	AO3/1b
Total			9	

Question	Answers	Additional Comments/Guidance	Mark	ID details
----------	---------	------------------------------	------	------------



03.1	High power/powerful radio emitter. ✓	Some indication of high power needed.	1	AO1
------	--------------------------------------	---------------------------------------	---	-----

Question	Answers	Additional Comments/Guidance	Mark	AO
03.2	Use of $m - M = 5 \times \log \frac{d}{10}$ ✓ $M = m - 5 \times \log \frac{d}{10}$ $M = 12.8 - 5 \times \log \frac{760 \times 10^6}{10} = -26.6$ ✓		1 1	1 x AO1 1 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
03.3	Quasar is brighter because more negative abs magnitude. ✓ Difference in absolute magnitudes $26.6 - 22.8 = 3.8$ ✓ Brighter by $2.51^{3.8} = 33$ times ✓	Use of -27 (giving 48 times brighter) scores mp2 and mp3 Allow any value of absolute magnitude which rounds to -27. Use of apparent magnitudes scores no marks.	3	3 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
03.4	$R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 7.1 \times 10^{11} \times 1.99 \times 10^{30}}{3.00 \times 10^8{}^2} = \checkmark (2.1 \times 10^{15} \text{ m})$ $\text{volume} = \frac{4}{3} \pi R_s^3 = \frac{4}{3} \pi 2.1 \times 10^{15}{}^3 = \checkmark (3.9 \times 10^{46} \text{ m}^3)$ $\rho = \frac{\text{mass}}{\text{volume}} = \frac{7.0 \times 10^{11} \times 1.99 \times 10^{30}}{3.7 \times 10^{46} \text{ m}^3} = 3.7 (3.67) \times 10^{-5} \text{ kg m}^{-3} \checkmark$	If the mass of the Sun is not included mp1 is not awarded – ecf for mp2 and mp3. 2.094 × 10¹⁵ m 3.85 × 10⁴⁶ m³	1 2	1 x AO1 2 x AO2
Total			9	

Question	Answers	Additional Comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



04.1	Correct substitution into $m - M = 5 \log \left(\frac{d}{10} \right)$ or rearrangement for d ✓ Calculation for Aa1 $d = 380$ pc AND Calculation for Aa2 $d = 380$ pc OR $m - M = 7.9$ stated for both stars ✓ Statement that their two calculated distances are the same distance from Earth / away OR Statement that as $m - M$ is the same they must be the same distance from Earth / away ✓	$d = 380.189$ pc	3	AO2
------	---	------------------	---	-----

Question	Answers	Additional comments/Guidance	Mark	AO
04.2	H AND He ✓	Reject when other elements given Reject when ions implied	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	(Mintaka Aa1) Reference to O hotter than B ✓		1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
04.4	(idea that) when one star passes in front of the other the amount of light received changes / light intensity 'dips'. ✓ (idea that) the brightest (lowest value of) apparent magnitude occurs when both stars can be seen. ✓ Max 1 from: ✓ - The difference in the 'dips' suggests that the stars have different temperatures / brightnesses. - The biggest change / Q is when the cooler/dimmer star is in front of the hotter/brighter / when Aa2 is in front of Aa1.	In MP3 do not condone "size / bigger / smaller" etc. unless they are linked to temperature / brightness Accept the converse for smallest change / P.	3	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
04.5	$T \approx 5.7$ days. ✓ (Calculation of $\omega = \frac{2\pi}{T}$) $\omega = (\frac{2\pi}{5.7 \times 24 \times 60 \times 60} =) 1.3 \times 10^{-5} \text{ (rad s}^{-1}\text{)} \checkmark$	Range in T : 5.6 – 5.8 days Allow MAX 1 for use of half of the time period. Accept $(1.25 - 1.30) \times 10^{-5} \text{ (rad s}^{-1}\text{)}$	2	AO2
Total			10	

Question	Answers	Additional comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



02.1	The minima are caused when one star passes in front of the other. ✓ Deeper minima are caused by the cooler star passing in front of the hotter star. ✓	For mp2 it must be clear that dip size is related to temperature. NB this is NOT related to the diameter of the star.	1 1	1 x AO2 1 x AO3
------	---	--	------------	------------------------

Question	Answers	Additional Comments/Guidance	Mark	AO
02.2	The system is moving towards us AND mention of Doppler effect/red shift OR The system is moving so the light is blue shifted✓	Condone 'star is, or stars are moving towards us'	1	AO3

Question	Answers	Additional Comments/Guidance	Mark	AO
02.3	$\Delta\lambda = \frac{486.498 - 485.672}{2} = 0.413 \text{ nm} \checkmark$ $z = \frac{\Delta\lambda}{\lambda} = \frac{0.413}{486.085} = 8.50 \times 10^{-4}$ $v = zc = 8.50 \times 10^{-4} \times 3.00 \times 10^8 = 2.55 \times 10^5 \text{ m s}^{-1} = 255 \text{ km s}^{-1} \checkmark$	Alternative for mp1 use of average and one of the other values. For mp2 must see evidence of correct use of average value (NB use of other wavelengths likely to give same answer to 3 sf). Average value (486.085) Final answer must be seen to more than 2sf For mp3 Allow ecf from mp1 and mp2 if answer is in range 250-260	2 1	2 x AO2 1 x AO3

Question	Answers	Additional Comments/Guidance	Mark	AO
02.4	Identifies period (T) is 2.5 days $\checkmark$ $v = \frac{2\pi R}{(\text{their value of})T}$ $R = \frac{v \times T}{2\pi} = \frac{2.55 \times 10^5 \times 2.5 \times 24 \times 3600}{2\pi} = 8.76 \times 10^9 \text{ m} \checkmark$	Allow ecf from 02.3 Use of 250 km s^{-1} gives $8.59 \times 10^9 \text{ m} \checkmark \checkmark$	1 1	1 x AO3 1 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
02.5	hydrogen and helium ✓		1	AO1
Question	Answers	Additional Comments/Guidance	Mark	AO
02.6	Observable property of Neutron Star or White Dwarf ✓ Property of the other object AND coincident in space OR idea of how a property varies ✓	Observable properties WD – O or B class/ H-He absorption lines/ high temp AND not very bright abs mag. NS – radio emissions/Pulsars Variations include radio emissions from neutron star blocked by white dwarf ✓ Spectroscopic variation in white dwarf seen ✓	2	2 x AO3
Total			11	

Question	Answers	Additional Comments/Guidance	Mark	AO
----------	---------	------------------------------	------	----



04.1	Idea that Hubble's Law is used to estimate the age of the Universe. ✓ So no, as Andromeda is approaching / is blue-shifted ✓	Allow determination of H^{-1} or H for the values in the question. Accept idea that age is related to gradient of graph of v against d . Allow "Hubble's Law is only used with receding/redshifted galaxies."	2	AO3
------	---	---	---	-----

Question	Answers	Additional comments/Guidance	Mark	AO
04.2	Calculates mass of black hole = $1.60 \times 10^8 \times 1.99 \times 10^{30}$ $_1$ ✓ Use of $R_s = \frac{2 \times 6.67 \times 10^{-11} \times \text{their mass of black hole}}{(3 \times 10^8)^2}$ $_2$ ✓ = 4.7×10^{11} m $_3$ ✓	Correct answer gets $_1$ ✓ $_2$ ✓ Correct answer with correct unit gets $_1$ ✓ $_2$ ✓ $_3$ ✓ Also accept 4.7×10^8 km 3.1 AU 1.5×10^{-5} pc 5.0×10^{-5} ly Unit mark is based on correct calculation.	3	$2 \times \text{AO2}$ $1 \times \text{AO1}$

Question	Answers	Additional comments/Guidance	Mark	AO																
04.3	The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question. <table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>All three areas (as outlined alongside) covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr><tr><td>5</td><td>Two areas successfully discussed and one covered partially. Whilst there will be gaps, there should only be a very occasional error.</td></tr><tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td></tr><tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr><tr><td>2</td><td>Only one area discussed or makes a partial attempt at two areas.</td></tr><tr><td>1</td><td>Only one area covered, and that partially.</td></tr><tr><td>0</td><td>No relevant analysis.</td></tr></table>	Mark	Criteria	6	All three areas (as outlined alongside) covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.	5	Two areas successfully discussed and one covered partially. Whilst there will be gaps, there should only be a very occasional error.	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.	2	Only one area discussed or makes a partial attempt at two areas.	1	Only one area covered, and that partially.	0	No relevant analysis.	Treat 1 point from an area as partial and 2 points from an area as complete Note that '<i>supermassive</i>' must be seen at least once for P1 and/or F1 to be rewarded. Properties P1 Associated with a <i>supermassive</i> black hole P2 Large power output (for their size) OR power output $\sim 10^{42}$ W/idea of bright absolute magnitude P3 Distant P4 Small (relative to host galaxy)/about size of solar system Treat any comment about age as neutral. Evidence E1 (seen) in centre of (active) galaxies (producing jets) E2 Bright radio source OR far brighter than their host galaxy E3 Large red-shift E4 Rapid fluctuations in power output. How quasar forms F1 (merging causes) material/stars to move towards the <i>supermassive</i> black hole(s) F2 Black hole(s) become active 'consuming' nearby stars/material and emitting radiation	6	AO1
Mark	Criteria																			
6	All three areas (as outlined alongside) covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.																			
5	Two areas successfully discussed and one covered partially. Whilst there will be gaps, there should only be a very occasional error.																			
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.																			
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.																			
2	Only one area discussed or makes a partial attempt at two areas.																			
1	Only one area covered, and that partially.																			
0	No relevant analysis.																			
Total			11																	