

Mark schemes

1.

- (a) W – protostar/gas cloud ✓
- ₁

Candidates may add to the diagram – this should be credited
Accept formation stage for W

- X – main sequence star ✓
- ₂

- Y – (Red) giant AND Z – (white) dwarf ✓
- ₃

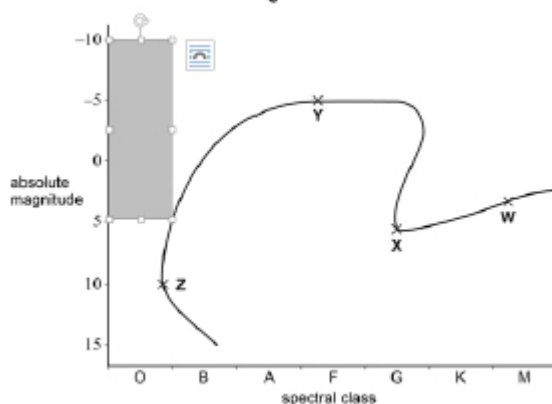
Condone Supergiant for Y

3

- (b) Positioned magnitude less than 5

...and class O ✓

Grey box shows accepted region



1

- (c) 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

Planet is small (and star is very big) so little light blocked out. ✓₂

MP2 Links this to Earth-sized planet.

1

- (d) Use of
- σAT^4
- ✓
- ₁

Condone incorrect A formula but must include other quantities.

3

$$= 8.0 (7.97) \times 10^{30} \text{ (W)} \checkmark_2$$

Attempt to use inverse square law for Earth or find ratio of powers (allow ecf) ✓₃Equates 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

$$\text{Power output of Theta Carinae} = \sigma AT^4 =$$

$$5.67 \times 10^{-8} \times 4\pi R^2 \times 31000^4 \checkmark_1$$

$$= 8.0 (7.97) \times 10^{30} \text{ W} \checkmark_2$$

$$\text{Ratio of power outputs} = \frac{7.97 \times 10^{30}}{3.8 \times 10^{26}}$$

$$2.10 \times 10^4 \checkmark_3$$

So planet must be $\sqrt{2.10 \times 10^4}$ 1.45 × 10² 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

[11]

2.

- (a) Tick (✓) only against Tsih

Accept other clear indication (eg x)

1

- (b) 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) ✓

$$\text{For Caph } T = \frac{2.9 \times 10^{-3}}{410 \times 10^{-9}} = 7250 \text{ K (6900–7630)}$$

$$\text{For Schedar } T = \frac{2.9 \times 10^{-3}}{660 \times 10^{-9}} = 4400 \text{ K (3600–5200)}$$

*Allow ecf for incorrect temperatures.**No mark for just stating colours*

4

- (c) Caph ✓

- (d) 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

(e) $R_s (= \frac{2GM}{c^2}) = \frac{2 \times 6.67 \times 10^{-11} \times 15 \times 1.99 \times 10^{30}}{(3.00 \times 10^8)^2} = \checkmark$

$4.4 \times 10^4 \text{ m}$ ✓

OK to use \approx instead of $=$ (as in the specification)

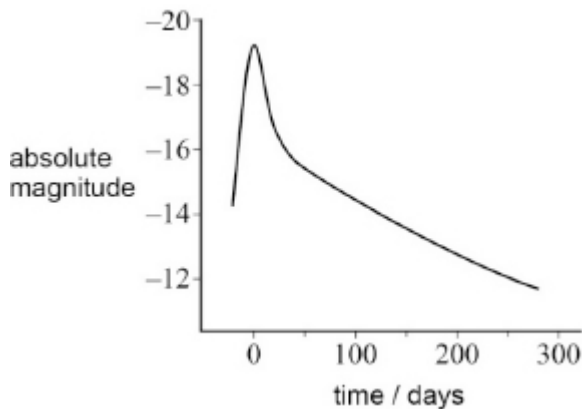
Allow ecf for POT error only.

2

[11]

3.

- (a) D



1

- (b) Use of
- $m - M = 5 \log(d/10)$
- to give

$m = 5 \log(d/10) + m = 5 \log(7.7 \times 10^4) - 19.3$

Allow -19.0 to -19.5 for M giving $m = 5.4$ to 4.9

MP1 finds apparent magnitude

giving $m = 5.1$ ✓₁

which is brighter than their quoted Hipparcos limit ✓₂Qualitative comparison of the brightness of their m with 6 leading to a conclusion ✓₃

MP3 comparative statement about answer that relates the 2 brightnesses correctly (allow ecf)

3

[4]

4.

Mark	Criteria
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.

Examples of points made in a good answer

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

AO1 - 4
AO3 - 2**[6]****5.**

- (a) Absolute magnitude scale getting more negative going up
and

Time scale with 0 along axis, going up to between 10 and 400 ✓

The first mark is for the scales

Line drawn going up and down, with LHS steeper than steepest part of RHS ✓

The second is for the curve

Line drawn increasing quickly with peak at absolute magnitude between -18 and -20 ✓

The third is for the value of the peak

3

- (b) 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

- (c) Measurements of supernovae do not agree with predictions (from Hubble's Law) ✓

1

So Universe must be expanding at increasing rate/accelerating ✓

1

(Controversial as) no known energy source for expansion or reference to dark energy ✓

1

[7]

6.

- (a) Curve with a single peak ✓

Steepest part of LHS steeper than steepest part of RHS ✓

If multiple curves seen all of them must be correct.

Do not condone curves with negative gradient on LHS.

2

- (b) Mention of use of peak wavelength ✓

Quoting use of Wien's law and that wavelength is in metres ✓

Use of $\lambda_{\max}T = 0.0029 \text{ m K}$ ✓ 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

- (c) **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.**

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.
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.

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: $P = 5.67 \times 10^{-8} \times 4\pi \times (4.7 \times 10^8)^2 \times 4500^4 = 6.45 \times 10^{25} W$ (L2/3)

For B: $P = 5.67 \times 10^{-8} \times 4\pi \times (4.1 \times 10^8)^2 \times 4100^4 = 3.38 \times 10^{25} W$ (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)*

Evaluation

Being about the same distance away is consistent with idea that they form a binary system. (L2/3)

6

(d) K ticked

1

[12]

7.

(a) Hipparcos scale: (brightest 1) down to 6 dimmest (visible in good conditions) ✓

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) ✓

6 dimmest may be inferred.

Accept reverse argument.

1

2

(b) 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

- (c) 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

- (d) 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

- (e) Use of
- $m - M = 5 \log (d/10)$

To give

$$0.34 - 2.65 = 5 \log (d/10) \checkmark$$

$$\log (d/10) = -2.31/5$$

$$d = 3.45 \checkmark \text{ pc } \checkmark$$

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

[13]

8.

- (a) It has a known absolute magnitude. ✓

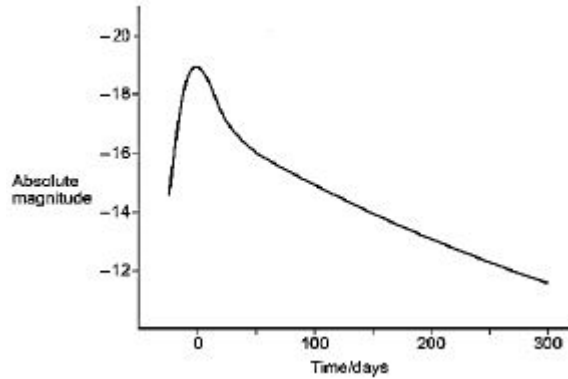
Other wordings are possible. It must be clear that the candidate knows that it is the intrinsic power/brightness that must be known.

1

- (b) 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

- (c) 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 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

2

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.

2

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

[10]

- 9.** (a) Use of $P = \sigma AT^4$ ✓

$$\text{Ratio} = \frac{\sigma_M T_M^4}{\sigma_S T_S^4} =$$

$$\frac{(1.4 \times 10^{10})^2 \times 53000^4}{(7.0 \times 10^8)^2 \times 5700^4} = 3.0 \times 10^6 \quad \checkmark$$

Award mp 1 for substituting data for either the Sun or Melncik 34

2

- (b) Star will undergo supernova collapse or

Star will form a neutron star/black hole ✓

which produces a gamma ray burst

and

consequence for life or reference to being highly collimated ✓

Examples of consequence for life: kills cells / damages DNA.

2

[4]

- 10.** (a) Scale labelled from +15 up to -10 ✓

+15 bottom of white dwarves at the maximum. -10 top of giants at the lowest.

1

- (b) S between 5000 K and horizontal section of bottom line of main sequence. ✓₁

Within main sequence and at 'correct' abs mag 5 ✓₂

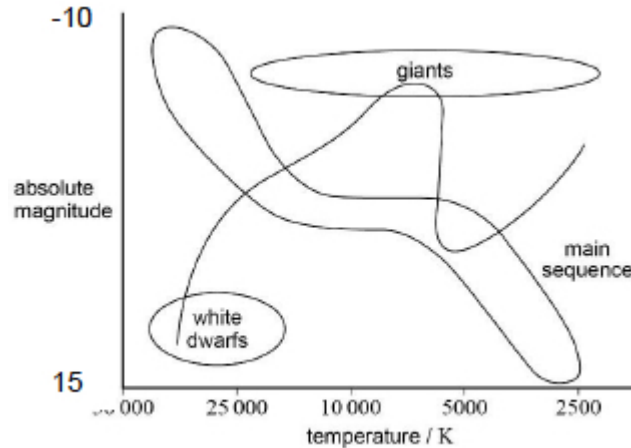
Marks are independent

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 x is seen, that should be used for marking.

- (c) 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

- (d) Point P to the right and above their S ✓

Accept P on same horizontal level as S

1

- (e) 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

[9]

11.

- (a) Quasars are produced by (supermassive) black holes. ✓

These black holes are at the centre of (active) galaxies (active galactic nuclei.) ✓

2

(b) 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

(c) Both quasar and galaxy should have same brightness (and therefore similar received power) \checkmark

Use of Inverse square law eg

$$\text{Power of quasar}/(\text{distance to quasar})^2 = \text{power of galaxy} / (\text{distance to galaxy})^2 \checkmark$$

$$\text{Or } 1000/d^2 = 1/1$$

So distance to quasar = $(1000)^{1/2} =$ about 30 times greater than distance to galaxy \checkmark

The first mark is for relating the similar "brightness". Accept intensity. Accept in form of equation linking quasar and galaxy.

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.

1
2

[9]

12.

- (a) 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

- (b) They are the same spectral class and therefore have similar temperatures. ✓

No mark for the answer on its own.

First mark for identifying same T

They have the same apparent magnitude, but K is significantly further away, therefore K has a greater power output (P)/ brighter absolute magnitude ✓

Second mark for identifying greater P

Condone greater for brighter

Condone luminosity for 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. ✓

Third mark for use of Stefan's Law to obtain the answer.

3

- (c) 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

- (d) The spectral class is related to the temperature ✓

So the star is in spectral class M

Allow ecf from (c) – see spec for table of spectral class and temperature

And is therefore Rasalgethi ✓

The second mark is for the correct class and therefore star identified

2

- (e) Rasalgethi

1

(f) Use of $m-M = 5 \log (d/10)$

To give

$$3.1 - M = 5 \log(2.3) \checkmark$$

$$3.1 - M = 1.8 \checkmark$$

First two marks are for the substitution of M , m and unit of d and correct log.

Deduct one mark for each error; more than two errors give 0/3

$$M = 1.3 \checkmark$$

Third mark for the correct calculation: allow ecf for up to two errors

3

[13]