Astro Formative *[87 marks]*

1a. Distinguish between the solar system and a galaxy. *[1 mark]*

Markscheme

a galaxy is much larger in size than a solar system

a galaxy contains more than one star system / solar system

a galaxy is more luminous

Any other valid statement.

[1 mark]

1b. Distinguish between a planet and a comet. *[1 mark]*

Markscheme

a comet is a small icy body whereas a planet is mostly made of rock or gas

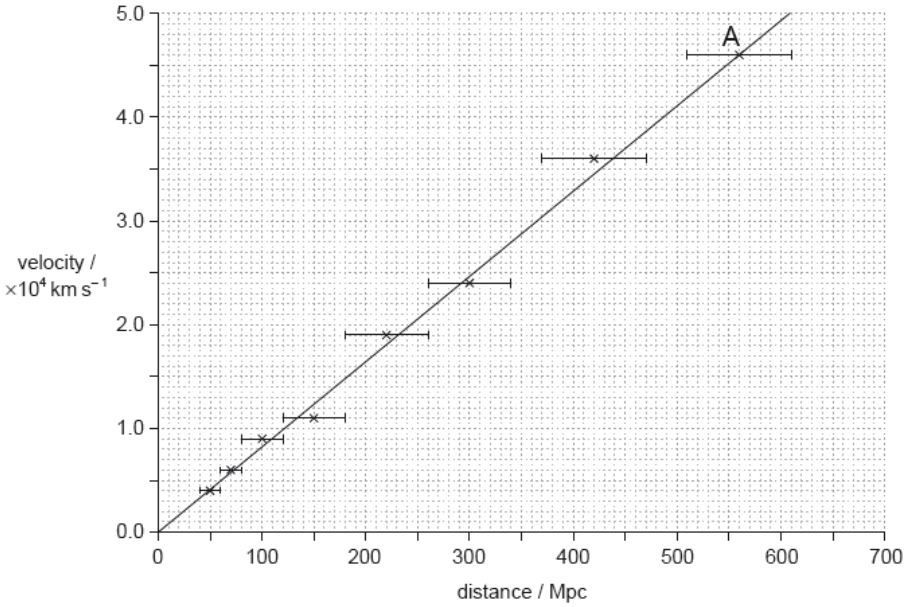
a comet is often accompanied by a tail/coma whereas a planet is not

comets (generally) have larger orbits than planets

a planet must have cleared other objects out of the way in its orbital neighbourhood

[1 mark]

Data from distant galaxies are shown on the graph.



2a. Estimate, using the data, the age of the universe. Give your answer in seconds. *[3 marks]*

Markscheme

use of gradient or any coordinate pair to find H_0 «= $\frac{v}{d}$» or $\frac{1}{H_0}$ «= $\frac{d}{v}$»

convert Mpc to m and km to m «for example $\frac{82\times10^3}{10^6\times3.26\times9.46\times10^{15}}$»

age of universe «= $\frac{1}{H_0}$» = 3.8 × 10^{17} «s»

Allow final answers between

3.7 × 10^{17} and 3.9 × 10^{17} «s» or 4 × 10^{17} «s»

[3 marks]

2b. Identify the assumption that you made in your answer to (a). *[1 mark]*

Markscheme

non-accelerated/uniform rate of expansion

OR

H_0 constant over time

OWTTE

[1 mark]

2c. On the graph, one galaxy is labelled A. Determine the size of the universe, relative to its present size, when light from the galaxy labelled A was emitted. *[3 marks]*

Markscheme

z « =

$\frac{v}{c}$» = $\frac{4.6\times10^4\times10^3}{3.00\times10^8}$ = 0.15

$\frac{R}{R_0}$ = «z + 1» = 1.15

$\frac{R_0}{R}$ = «

$\frac{1}{1.15}$ =» 0.87

OR

87% of the present size

[3 marks]

3a. Describe the formation of a type Ia supernova. *[2 marks]*

Markscheme

a white dwarf accretes mass «from a binary partner»

when the mass becomes more than the Chandrasekhar limit (1.4M_s) «then asupernova explosion takes place»

[2 marks]

Type Ia supernovae typically have a peak luminosity of around 5×10^5 L_s, where L_s is the luminosity of the Sun (3.8×10^{26} W). A type Ia supernova is observed with an apparent peak brightness of 1.6×10^{-6} W m^{-2}.

3b. Show that the distance to the supernova is approximately 3.1×10^{18} m. *[2 marks]*

Markscheme

$d = \sqrt{\frac{L}{4\pi b}} = \sqrt{\frac{5\times10^{5}\times3.8\times10^{26}}{4\pi\times1.6\times10^{-6}}}$

$d = 3.07 \times 10^{18}$ «m»

At least 3 sig fig required for MP2.

[2 marks]

3c. State **one** assumption made in your calculation. *[1 mark]*

Markscheme

type Ia supernova can be used as standard candles

there is no dust absorbing light between Earth and supernova

their supernova is a typical type Ia

[1 mark]

4a. Outline, with reference to the Jeans criterion, why a cold dense gas cloud is more likely to form new stars than a hot diffuse gas cloud. *[2 marks]*

Markscheme

«For a star to form»: magnitude of PE of gas cloud > KE of gas cloud

OR

Mass of cloud > Jean's mass

OR

Jean's criterion is the critical mass

hence a hot diffuse cloud could have KE which is too large/PE too small

OR

hence a cold dense cloud will have low KE/high PE

OR

a cold dense cloud is more likely to exceed Jeans mass

OR

a hot diffuse cloud is less likely to exceed the Jeans mass

Accept $E_p + E_k < 0$

[2 marks]

4b. Explain how neutron capture can produce elements with an atomic number greater than iron. *[2 marks]*

Markscheme

Neutron capture creates heavier isotopes / heavier nuclei / more unstable nucleus

β^- decay of heavy elements/iron increases atomic number «by 1»

OWTTE

[2 marks]

5a. Explain the evidence that indicates the location of dark matter in galaxies. *[3 marks]*

Markscheme

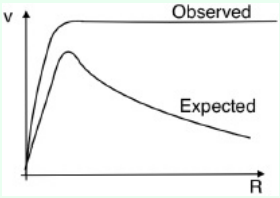
«rotational» velocity of stars are expected to decrease as distance from centre of galaxy increases

the observed velocity of outer stars is constant/greater than predicted

implying large mass on the edge «which is dark matter»

OWTTE

1st and 2nd marking points can be awarded from an annotated sketch with similar shape as the one below



[3 marks]

5b. Outline why a hypothesis of dark energy has been developed. *[3 marks]*

Markscheme

data from type 1a supernovae shows universe expanding at an accelerated rate

gravity was expected to slow down the expansion of the universe

OR

this did not fit the hypotheses at that time

dark energy counteracts/opposes gravity

OR

dark energy causes the acceleration

OWTTE

[3 marks]

Sirius is a binary star. It is composed of two stars, Sirius A and Sirius B. Sirius A is a main sequence star.

6a. State what is meant by a binary star. *[1 mark]*

Markscheme

two stars orbiting a common centre «of mass»

Do not accept "stars which orbit each other"

6b. The peak spectral line of Sirius B has a measured wavelength of 115 nm. Show that the surface temperature of Sirius B is about 25 000 K. *[1 mark]*

Markscheme

«$\lambda \times T = 2.9 \times 10^{-3}$»

$T = \frac{2.9 \times 10^{-3}}{115 \times 10^{-9}} = 25217$ «K»

6c. The mass of Sirius B is about the same mass as the Sun. The luminosity of Sirius B is 2.5 % of the luminosity of the Sun. Show, with a calculation, that Sirius B is **not** a main sequence star. *[2 marks]*

Markscheme

use of the mass-luminosity relationship ***or*** $\left(\frac{M_{\text{Sirius}}}{M_{\text{Sun}}}\right)^{3.5} = 1$

if Sirius B is on the main sequence then $\left(\frac{L_{\text{Sirius B}}}{L_{\text{Sun}}}\right) = 1$ «which it is not»

Conclusion is given, justification must be stated

Allow reverse argument beginning with luminosity

The Sun's surface temperature is about 5800 K.

6d. Determine the radius of Sirius B in terms of the radius of the Sun. *[2 marks]*

Markscheme

$\left(\frac{L_{\text{Sirius B}}}{L_{\text{Sun}}}\right) = 0.025$

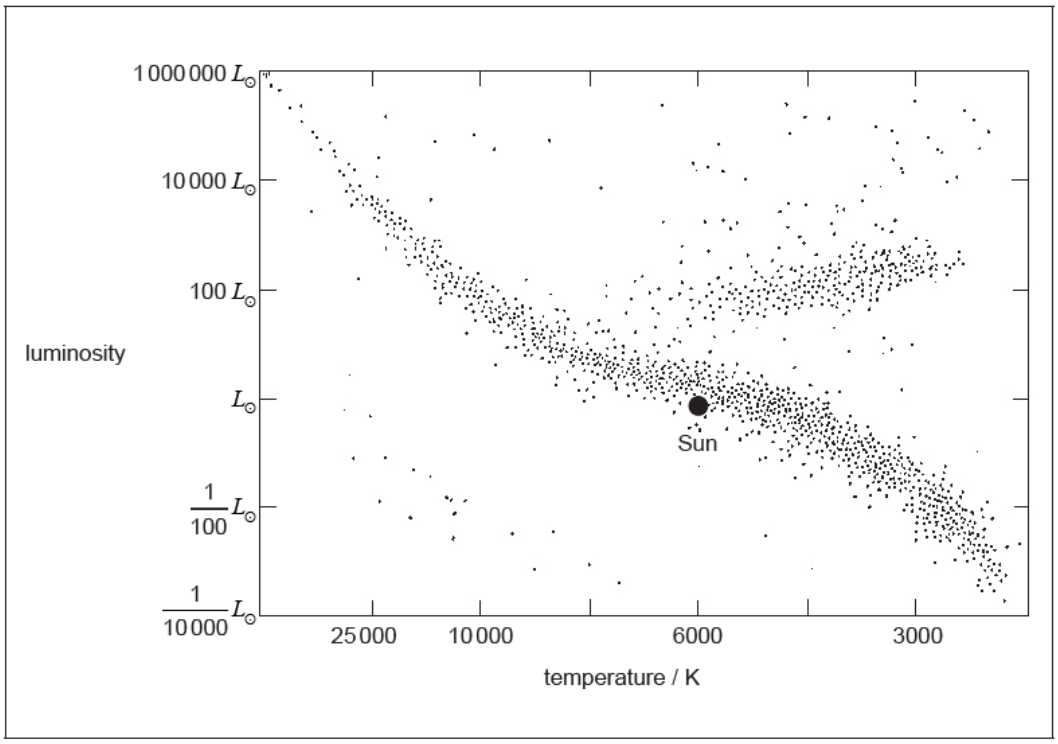
$r_{\text{Sirius}} = \text{«}\sqrt{0.025 \times \left(\frac{5800}{25000}\right)^4}\text{ =»}\ 0.0085\ r_{\text{Sun}}$

6e. Identify the star type of Sirius B. *[1 mark]*

Markscheme

white dwarf

The image shows a Hertzsprung–Russell (HR) diagram.



The mass of Sirius A is twice the mass of the Sun. Using the Hertzsprung–Russell (HR) diagram,

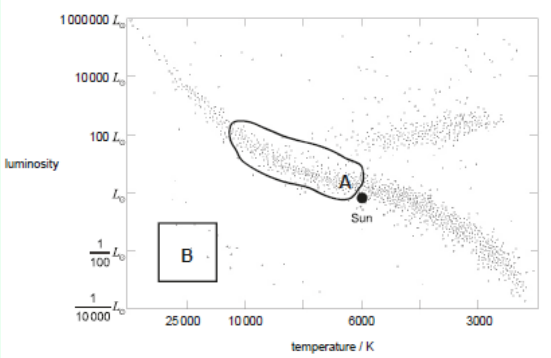
6f. draw the approximate positions of Sirius A, labelled A and Sirius B, labelled B. *[1 mark]*

Markscheme

Sirius A on the main sequence above and to the left of the Sun ***AND*** Sirius B on white dwarf area as shown

Both positions must be labelled

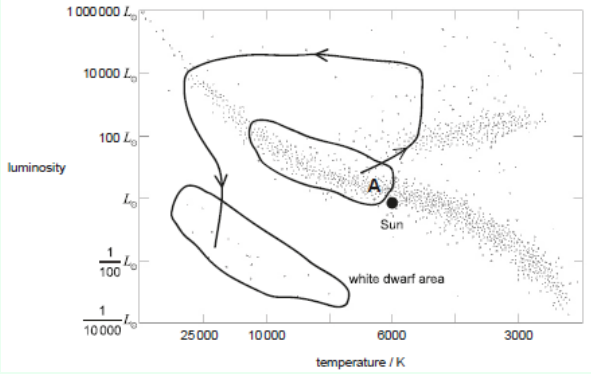
Allow the position anywhere within the limits shown.



6g. sketch the expected evolutionary path for Sirius A. *[1 mark]*

Markscheme

arrow goes up and right and then loops to white dwarf area



The collision of two galaxies is being studied. The wavelength of a particular spectral line from the galaxy measured from Earth is 116.04 nm. The spectral line when measured from a source on Earth is 115.00 nm.

7a. Outline **one** reason for the difference in wavelength. *[1 mark]*

Markscheme

galaxies are moving away

OR

space «between galaxies» is expanding

Do not accept just red-shift

7b. Determine the velocity of the galaxy relative to Earth. *[2 marks]*

Markscheme

«$\frac{\Delta\lambda}{\lambda}$ =» $\frac{1.04}{115} = \frac{v}{c}$

0.009*c*

Accept 2.7×10^6 «m s^{-1}»

*Award **[0]** if 116 is used for* λ

8a. State **two** characteristics of the cosmic microwave background (CMB) radiation. *[2 marks]*

Markscheme

black body radiation / 3 K

highly isotropic / uniform throughout
OR
filling the universe

Do not accept: CMB provides evidence for the Big Bang model.

[2 marks]

8b. The present temperature of the CMB is 2.8 K. Calculate the peak wavelength of the CMB. *[1 mark]*

Markscheme

«$\lambda = \frac{2.9\times10^{-3}}{2.8}$» ≈ 1.0 «mm»

[1 mark]

8c. Describe how the CMB provides evidence for the Hot Big Bang model of the universe. *[2 marks]*

Markscheme

the universe is **expanding** and so the wavelength of the CMB in the past was much smaller

indicating a very high temperature at the beginning

[2 marks]

A spectral line in the light received from a distant galaxy shows a redshift of $z = 0.16$.

8d. Determine the distance to this galaxy using a value for the Hubble constant of $H_0 = 68$ km s^{-1} Mpc^{-1}. *[2 marks]*

Markscheme

«$z = \frac{v}{c} \Rightarrow$» $v = 0.16 \times 3 \times 10^5$ «$= 0.48 \times 10^5$ km s^{-1}»

«$d = \frac{v}{H_0} \Rightarrow v = \frac{0.48\times10^5}{68} = 706$» ≈ 710 «Mpc»

*Award **[1 max]** for POT error.*

[2 marks]

8e. Estimate the size of the Universe relative to its present size when the light was emitted by the galaxy in (c). *[2 marks]*

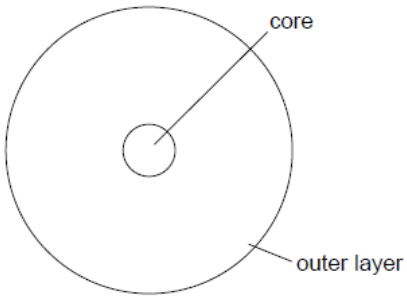
Markscheme

$z = \frac{R}{R_0} - 1 \Rightarrow \frac{R}{R_0} = 1.16$

$\frac{R_0}{R} = 0.86$

[2 marks]

The diagram shows the structure of a typical main sequence star.



9a. State the most abundant element in the core and the most abundant element in the outer layer. *[2 marks]*

core: .....

outer layer: .....

Markscheme

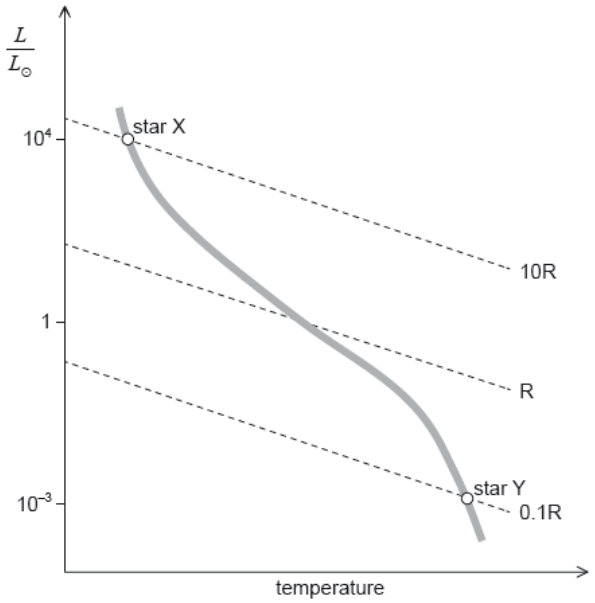
core: helium

outer layer: hydrogen

Accept no other elements.

[2 marks]

9b. The Hertzsprung–Russell (HR) diagram shows two main sequence stars X and Y and includes lines of constant radius. *R* is the radius of the Sun. *[3 marks]*



Using the mass–luminosity relation and information from the graph, determine the ratio $\frac{\text{density of star X}}{\text{density of star Y}}$.

Markscheme

ratio of masses is $\left(\frac{10^4}{10^{-3}}\right)^{\frac{1}{3.5}} = 10^2$

ratio of volumes is $\left(\frac{10}{10^{-1}}\right)^3 = 10^6$

so ratio of densities is $\frac{10^2}{10^6} = 10^{-4}$

Allow ECF for MP3 from earlier MPs

[3 marks]

Star X is likely to evolve into a neutron star.

9c. On the HR diagram in (b), draw a line to indicate the evolutionary path of star X. *[1 mark]*

Markscheme

line to the right of X, possibly undulating, very roughly horizontal

Ignore any paths beyond this as the star disappears from diagram.

[1 mark]

9d. Outline why the neutron star that is left after the supernova stage does not collapse under the action of gravitation. *[1 mark]*

Markscheme

gravitation is balanced by a pressure/force due to neutrons/neutron degeneracy/pauli exclusion principle

Do not accept electron degeneracy.

[1 mark]

9e. The radius of a typical neutron star is 20 km and its surface temperature is 10^6 K. Determine the luminosity of this neutron star. *[2 marks]*

Markscheme

$L = \sigma A T^4 = 5.67 \times 10^{-8} \times 4\pi \times (2.0 \times 10^4)^2 \times (10^6)^4$

$L = 3 \times 10^{26}$ «W»
OR
$L = 2.85 \times 10^{26}$ «W»

*Allow ECF for **[1 max]** if*
πr^2 used (gives 7×10^{26} «W »)

Allow ECF for a POT error in MP1.

[2 marks]

9f. Determine the region of the electromagnetic spectrum in which the neutron star in (c) (iii) emits most of its energy. *[2 marks]*

Markscheme

$\lambda = \frac{2.9 \times 10^{-3}}{10^6} = 2.9 \times 10^{-9}$ «m»

this is an X-ray wavelength

[2 marks]

10a. Describe what is meant by the Big Bang model of the universe. *[2 marks]*

Markscheme

theory in which all space/time/energy/matter were created at a point/singularity

at enormous temperature

with the volume of the universe increasing ever since ***or*** the universe expanding

OWTTE

[2 marks]

10b. State **two** features of the cosmic microwave background (CMB) radiation which are consistent with the Big Bang model. *[2 marks]*

Markscheme

CMB has a black-body spectrum

wavelength stretched by expansion

is highly isotropic/homogenous

but has minor anisotropies predicted by BB model

T «= 2.7 K» is close to predicted value

For MP4 and MP5 idea of "prediction" is needed

[2 marks]

A particular emission line in a distant galaxy shows a redshift $z = 0.084$.

The Hubble constant is $H_0 = 68$ km s^{-1} Mpc^{-1}.

10c. Determine the distance to the galaxy in Mpc. *[2 marks]*

Markscheme

$\frac{v}{c} = z \Rightarrow v = 0.084 \times 3 \times 10^5 = 2.52 \times 10^4$ «km s^{-1}»

$d = \frac{v}{H_0} = \frac{2.52 \times 10^4}{68} = 370.6 \approx 370$ «Mpc»

Allow ECF from MP1 to MP2.

[2 marks]

10d. Describe how type Ia supernovae could be used to measure the distance to this galaxy. *[3 marks]*

Markscheme

type Ia have a known luminosity/are standard candles

measure apparent brightness

determine distance from $d = \sqrt{\frac{L}{4\pi b}}$

Must refer to type Ia. Do not accept other methods (parallax, Cepheids)

[3 marks]

11a. Describe what is meant by dark matter. *[2 marks]*

Markscheme

dark matter is invisible/cannot be seen directly
OR
does not interact with EM force/radiate light/reflect light

interacts with gravitational force
OR
accounts for galactic rotation curves
OR
accounts for some of the "missing" mass/energy of galaxies/the universe

OWTTE

[6 marks]

11b. The distribution of mass in a spherical system is such that the density ρ varies with distance r from the centre as *[1 mark]*

$\rho = \frac{k}{r^2}$

where k is a constant.

Show that the rotation curve of this system is described by

v = constant.

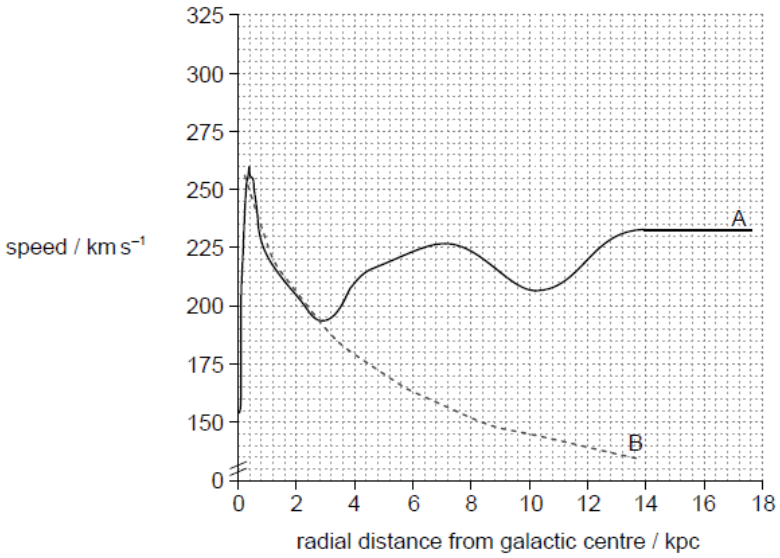
Markscheme

«from data booklet formula» $v = \sqrt{\frac{4\pi G\rho}{3}}r$ substitute to get $v = \sqrt{\frac{4\pi Gk}{3}}$

Substitution of ρ must be seen.

[1 mark]

11c. Curve A shows the actual rotation curve of a nearby galaxy. Curve B shows the predicted rotation curve based on the visible stars in the galaxy. *[2 marks]*



Explain how curve A provides evidence for dark matter.

Markscheme

curve A shows that the outer regions of the galaxy are rotating faster than predicted

this suggests that there is more mass in the outer regions that is not visible
OR
more mass in the form of dark matter

OWTTE

[2 marks]

Alpha Centauri A and B is a binary star system in the main sequence.

	Alpha Centauri A	**Alpha Centauri B**
Luminosity	$1.5L_{\odot}$	$0.5L_{\odot}$
Surface temperature / K	5800	5300

12a. State what is meant by a binary star system. *[1 mark]*

Markscheme

two stars orbiting about a common centre «of mass/gravity»
Do not accept two stars orbiting each other.

12b. (i) Calculate $\frac{b_A}{b_B} = \frac{\text{apparent brightness of Alpha Centauri A}}{\text{apparent brightness of Alpha Centauri B}}$. *[4 marks]*

(ii) The luminosity of the Sun is 3.8×10^{26} W. Calculate the radius of Alpha Centauri A.

Markscheme

i

stars are roughly at the same distance from Earth

OR

d is constant for binaries

$\frac{L_{\mathrm{A}}}{L_{\mathrm{B}}} = \frac{1.5}{0.5} = 3.0$

Award **[2]** for a bald correct answer.

ii

$r = \sqrt{\frac{1.5 \times 3.8 \times 10^{26}}{5.67 \times 10^{-8} \times 4\pi \times 5800^4}}$

= 8.4 × 10^8 «m»

*Award **[2]** for a bald correct answer.*

12c. Show, without calculation, that the radius of Alpha Centauri B is smaller than the radius of Alpha Centauri A. *[2 marks]*

Markscheme

«$A = \frac{L}{\sigma T^4}$» B and A have similar temperatures

so areas are in ratio of luminosities

«so B radius is less than A»

12d. Alpha Centauri A is in equilibrium at constant radius. Explain how this equilibrium is maintained. *[3 marks]*

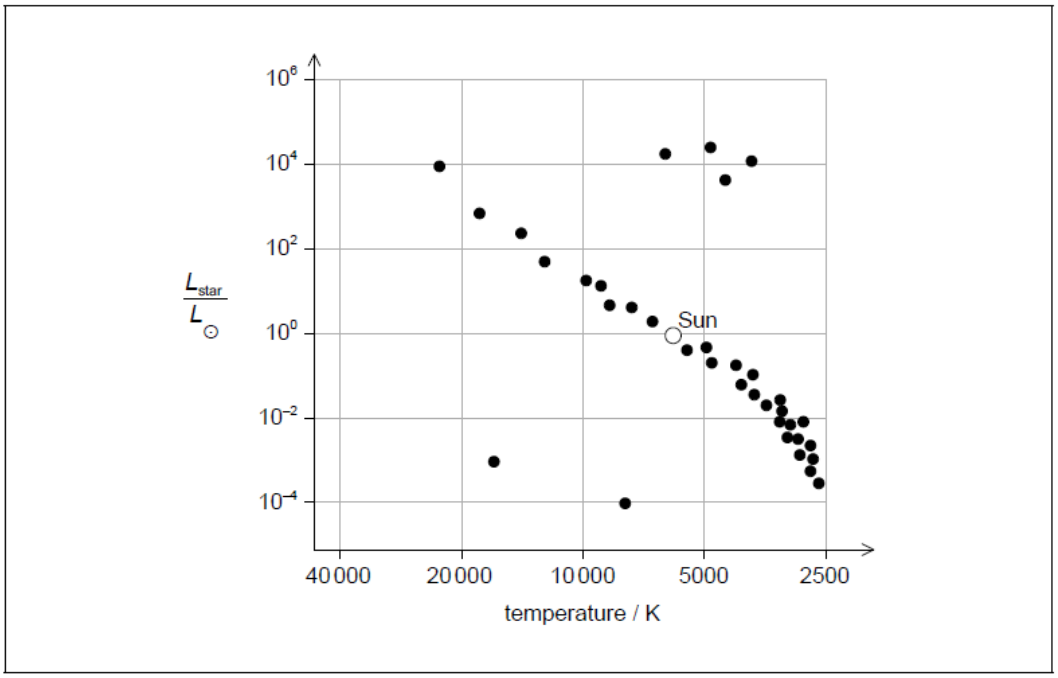
Markscheme

radiation pressure/force outwards

gravitational pressure/force inwards

forces/pressures balance

12e. A standard Hertzsprung–Russell (HR) diagram is shown. *[2 marks]*

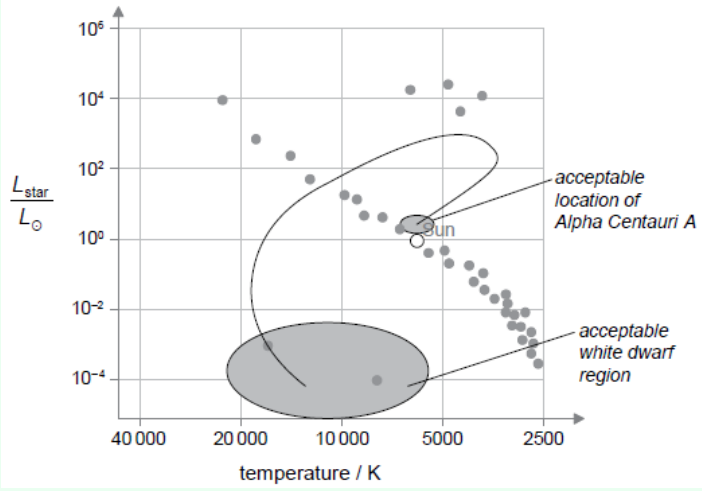


Using the HR diagram, draw the present position of Alpha Centauri A and its expected evolutionary path.

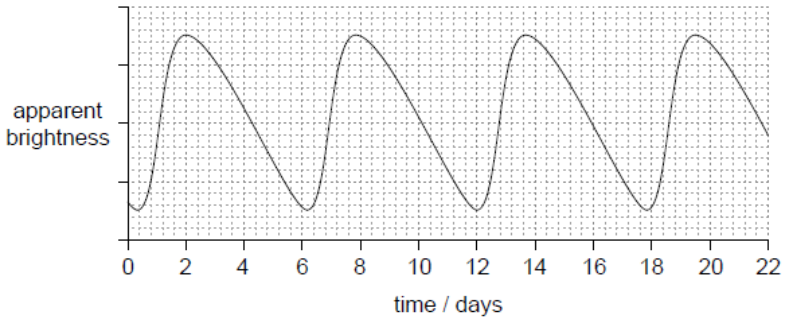
Markscheme

Alpha Centauri A within allowable region

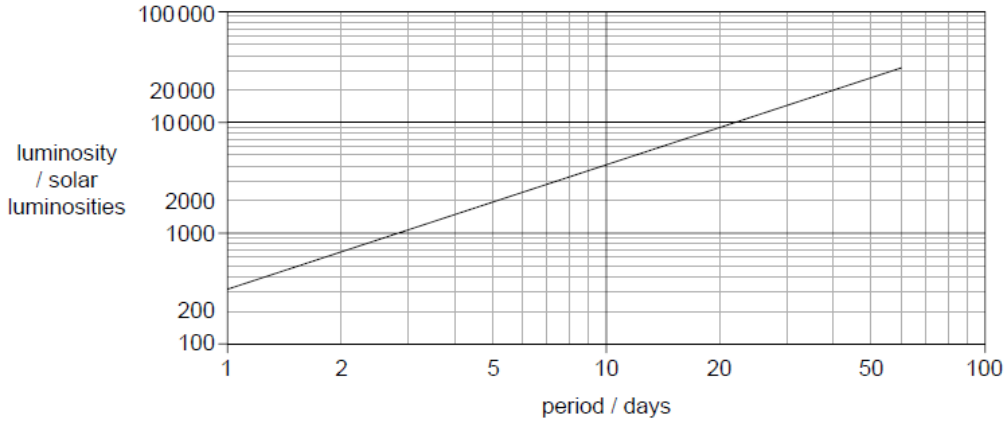
some indication of star moving right and up then left and down ending in white dwarf region as indicated



The first graph shows the variation of apparent brightness of a Cepheid star with time.



The second graph shows the average luminosity with period for Cepheid stars.



13a. Determine the distance from Earth to the Cepheid star in parsecs. The luminosity of the Sun is 3.8×10^{26} W. The average apparent brightness of the Cepheid star is 1.1×10^{-9} W m^{-2}. *[3 marks]*

Markscheme

from first graph period=5.7 «days» ±0.3 «days»

from second graph $\frac{L}{L_{\text{SUN}}} = 2300$ «± 200»

d = «$\sqrt{\frac{2500 \times 3.8 \times 10^{26}}{4\pi \times 1.1 \times 10^{-9}}} = 8.3 \times 10^{18}\text{m}$» =250 «pc»

Accept answer from interval 240 to 270 pc If unit omitted, assume pc.
Watch for ECF from mp1

13b. Explain why Cephids are used as standard candles. *[2 marks]*

Markscheme

Cepheids have a definite/known «average» luminosity

which is determined from «measurement of» period
OR
determined from period-luminosity graph

Cepheids can be used to estimate the distance of galaxies

Do not accept brightness for luminosity.