<u>Black Holes and type 1a supernovae</u>

Describe a Black Hole and how they are created.
Explain how type Ia supernovae can be used as standard candles.

Black Holes

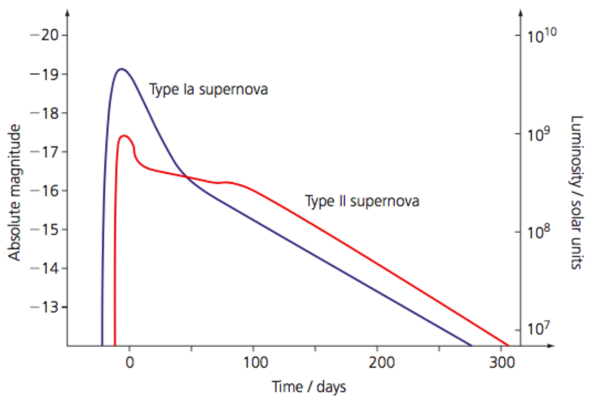
For extremely massive stars, whose core after a supernova is more than three solar masses, gravitational compression in the neutron star continues, producing a **black hole**. A black hole is a region of space-time with an escape velocity greater than the speed of light, *c*, which from Einstein's theory of special relativity is impossible to achieve. This is due to such a strong gravitational field that no particles or electromagnetic radiation can escape from it.

Then we can obtain the maximum value of R as: $R = R_S = \frac{2GM}{c^2}$

This radius R_S is called the ***Schwarzschild radius.*** *The Schwarzschild radius tells* us, for a given mass, how small an object must be for it to trap light around it and therefore appear black. This radius effectively forms a boundary that we call the **event horizon** of the black hole. Within this, the escape velocity is greater than or equal to the speed of light. Hence, all information from inside the event horizon is lost. Since black holes cannot be directly seen, information about them can only be inferred from the effects they have on nearby objects.

Supermassive Black Holes

Observations have shown that stars and gas orbiting near the centres of galaxies are being accelerated to very high orbital velocities. This can be explained if a large supermassive object with a strong gravitational field in a small region of space is attracting them. The most likely candidate is a **supermassive black hole**.



Type Ia (1a) Supernovae as Standard Candles

Type I supernovae, when matter accretes onto one star in a binary system, has a sub-type called Type Ia (or 1a). Supernovae undergo a rapid increase in brightness. Their absolute magnitude increases rapidly, reaching a peak absolute magnitude and then dimming over a period of several months. A graph of absolute magnitude versus time is called a light curve. The light curves for Type Ia and Type II supernovae are different. All Type Ia supernovae explosions occur at the same critical mass, and thus produce very consistent light curves, with the same peak value of absolute magnitude, –19.3, about 20 days from the beginning of the collapse.

Because of their known luminosity and absolute magnitude, type Ia supernovae can be used as **standard candles.** We can measure the distance *d* in parsecs of an object by measuring its apparent magnitude *m* using the relation $m - M = 5\log_{10}(\frac{d}{10})$. So, since we know the absolute magnitude *M* of a Type Ia supernova, we can calculate how far away it is.

These emit so much energy and are so bright that they can be seen at distances out to 1000Mpc (3.26 billion light years), which is a significant fraction of the radius of the known Universe. Such distances are known as **cosmological distances.** One of the most surprising findings from using Type Ia supernovae to measure cosmological distances was that the data suggested, controversially, that the expanding Universe is *accelerating* and not slowing down. For this to happen implies that there is some as-yet undetected energy permeating the Universe that acts in opposition to gravity. This has been given the name **dark energy** and its origin is currently a mystery to astrophysicists.

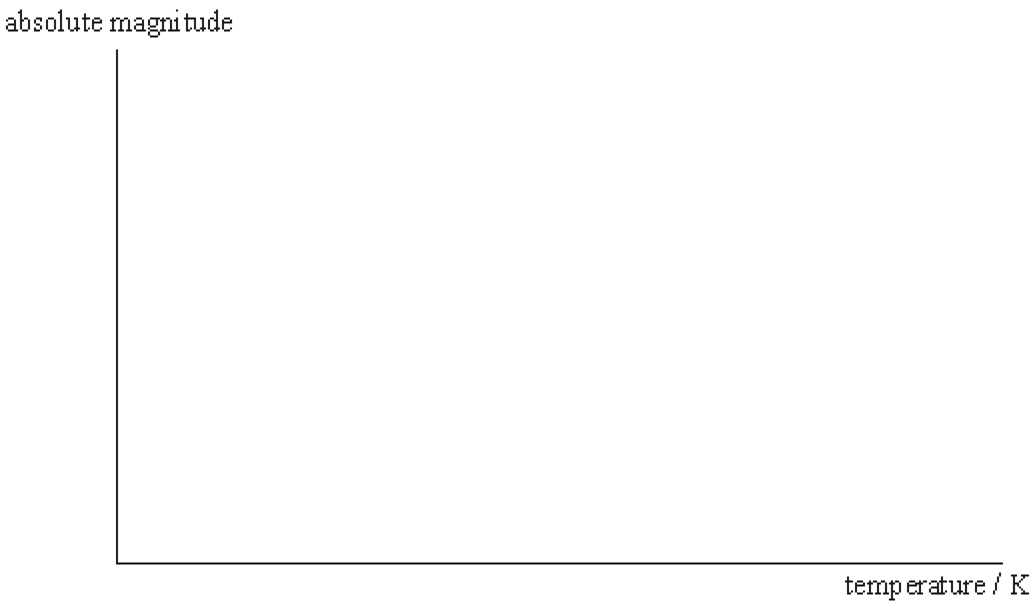
Q1. (a) Define the *absolute magnitude* of a star.

....

....

(1)

(b) The figure below shows the axes of a Hertzsprung-Russell (H-R) diagram.



(i) On each axis indicate a suitable range of values.

(ii) Label with an S the current position of the Sun on the H-R diagram.

(iii) Label the positions of the following stars on the H-R diagram:

(1) star W, which is significantly hotter and brighter than the Sun,

(2) star X, which is significantly cooler and larger than the Sun,

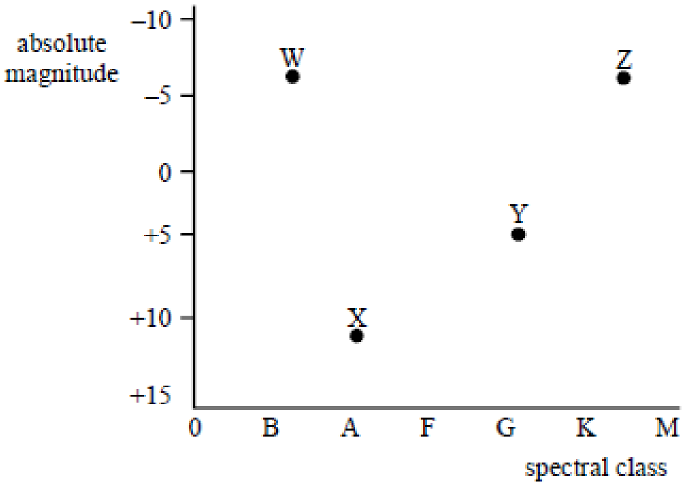
(3) star Y, which is the same size as the Sun, but significantly cooler,

(4) star Z, which is much smaller than the Sun, and has molecular bands as an important feature in its spectrum.

(7)

(Total 8 marks)

Q2. The absolute magnitude and spectral class of four stars W, X, Y and Z are plotted using the axes below.



(a) Draw and label, on the diagram above, the regions occupied by the main sequence, white dwarf stars and red giant stars.

(2)

(b) The following observations were made for the star Alnilam in the constellation of Orion.

apparent magnitude: 1.7
distance from Earth: 1350 light years
spectrum: strong hydrogen Balmer absorption lines

(i) Explain what is meant by *apparent magnitude*.

....

....

(ii) Calculate the distance in parsecs of Alnilam from the Earth.

....

....

(iii) Hence calculate the absolute magnitude of Alnilam.

....

....

....

....

(iv) Which of the stars, W, X, Y or Z is Alnilam? Explain your answer.

....

....

(7)

(c) The stars shown on the graph could represent the position of a star at different times during its evolution. Write down the correct sequence, using some or all of the letters, that would best represent the evolution of the Sun starting from its present position.

....

(1)

(Total 10 marks)

Q3. Antares is a red supergiant star in the constellation of Scorpio. It has a mass about 18 times that of the Sun.

Eventually the star will become a supernova, leaving behind a core that could form a neutron star or a black hole.

(a) State what is meant by a supernova.

....

....

(1)

(b) State the defining properties of a neutron star.

....

....

....

(2)

(c) To become a black hole it is likely that the core would have to have a mass at least twice that of the Sun.

Calculate the Schwarzschild radius of a black hole with a mass twice that of the Sun.

radius = ____________________ m

(2)

(d) Some scientists are concerned about the consequences for the Earth of a supernova occurring in a nearby part of the galaxy.

Explain the cause of this concern.

....

....

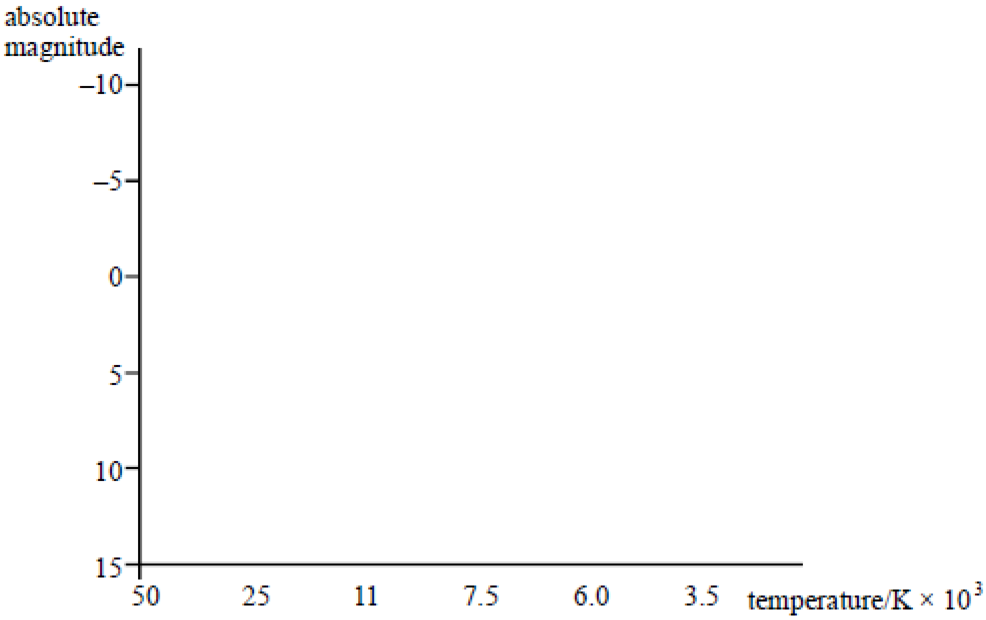
....

....

(2)

(Total 7 marks)

Q4.(a) Sketch a Hertzsprung-Russell diagram using the axes below. Label the approximate positions of main sequence stars, Red Giant stars, White Dwarf stars and the Sun.



(3)

(b) The evolution of a star from the main sequence depends on its mass. A certain star in the main sequence, in a position close to the Sun, evolves into a Red Giant.

(i) Compare the brightness of this star when it is a Red Giant to when it was in the main sequence.

....

(ii) Given that the hydrogen in this star undergoes fusion, suggest a sequence of events which causes this star to evolve into a Red Giant.

....

....

....

....

....

....

(4)

(c) Nova Muscae is believed to be a black hole with a mass approximately three times that of the Sun.

(i) What property of this star causes it to be a black hole? Explain why it is so named.

....

....

(ii) State what is meant by the term *event horizon* and calculate the radius of the event horizon for this star, using data from the Data booklet.

....

....

....

(5)

(Total 12 marks)

M1. (a) brightness (or apparent magnitude) of star from a distance of 10 pc **(1)**

1

(b) (i) temperature from 50000 K to 2500 K **(1)**
absolute magnitude from +15 to –10 **(1)**

(ii) S at 6000 K, and abs mag 5 **(1)**

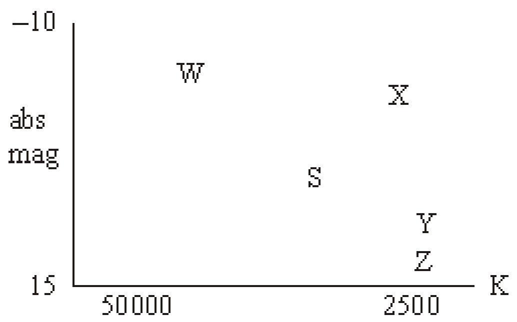
(iii) W above and to left of S **(1)**

X above and to right of S **(1)**

Y below and to right of S **(1)**

Z below and to right of S **(1)**

7



[8]

M2.(a) region of white dwarfs drawn around X and
region of red giants drawn around Z **(1)**
main sequence (band from W, dipping, flatter at Y, down to right) **(1)**

2

(b) (i) (apparent magnitude) brightness (of star) as seen from Earth **(1)**

(ii) $d = \frac{1350}{3.26}$ = 414 (pc) **(1)**

(iii) (use of $m - M = 5 \log \frac{d}{10}$ gives) $M = 1.7 - 5 \log \left(\frac{414}{10}\right)$ **(1)**

(allow C.E. for value of d from (ii))

M = –6.39 **(1)**

(iv) (Alnilam is) W **(1)**
correct absolute magnitude **(1)**
B or A class due to strong Balmer lines **(1)**

7

(c) (evolution of the Sun is) Y → Z → X

1

[10]

M3.(a) An object that produces a rapid increase in brightness ✓

Allow lowering in value of absolute magnitude

1

(b) Extremely dense ✓

Ignore descriptions of Neutron star surface

1

Made up of neutrons ✓

Ignore refs to spinning or producing radio waves

1

(c) Use of Rs = $2GM / c^2$

To give

Rs = $2 \times 6.67 \times 10^{-11} \times 2 \times 2 \times 10^{30} / (3 \times 10^{8})^{2}$ ✓

First mark is for substitution

1

= 5.9×10^{3} m ✓

Second mark for answer

1

(d) Collapsing star can produce gamma ray bursts with energy similar to total output of Sun ✓

First mark is for gamma ray burst and an idea of the amount of energy

1

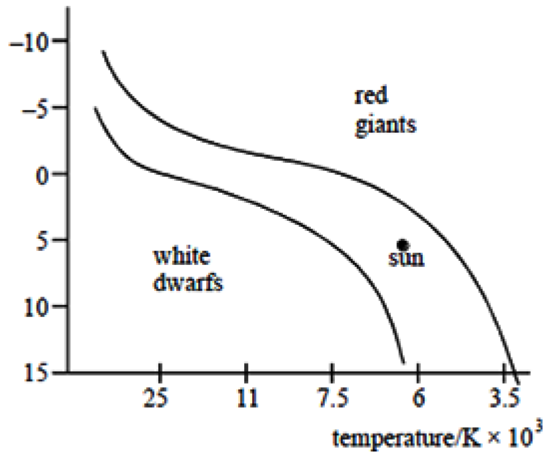
Highly collimated – if in direction of Earth, could cause mass extinction event ✓

Second mark is for consequence.

1

[7]

M4.(a)



correct position of main sequence **(1)**

correct position of White Dwarfs and Red Giants **(1)**

correct position of Sun labelled **(1)**

(3)

(b) (i) brightness when Red Giant > brightness when in main sequence **(1)**

(ii) hydrogen exhausts itself **(1)**

core collapses causing temperature to increase **(1)**

outer part of star expands **(1)**

causes decrease in temperature **(1)**

causing star to appear red **(1)**

(max 4)

(c) (i) very large gravitational field **(1)**

prevents light escaping **(1)**

(ii) event horizon is boundary or surface at which escape speed = c **(1)**

radius $\left(=\frac{2GM}{c^2}\right) = \frac{2 \times 6.67 \times 10^{-11} \times (3 \times 2 \times 10^{30})}{9 \times 10^{16}}$ **(1)**

= 8.9×10^3 m **(1)**

(5)

[12]