1)

A Cepheid variable star contracts and expands repeatedly and as it does, so its luminosity varies. By measuring the period of this variation, astronomers can determine the star's average luminosity.

(a) A Cepheid variable star is a type of standard candle. Discuss the use of standard candles in astronomy.

(4)

(b) As well as the variation in luminosity of the Cepheid, changes in the frequency of the detected radiation are also observed.

Suggest how the Doppler effect may account for these changes.

(2)

2)

The planet Mars has a mean distance from the Sun of 2.3×10^{11} m compared with the Earth's mean distance from the Sun of 1.5×10^{11} m.

(a) Calculate the ratio $\frac{\text{Sun's radiation flux at distance of Mars}}{\text{Sun's radiation flux at distance of Earth}}$.

(2)

Ratio = ...

(b) With reference to your answer in (a), comment on the suggestion that Mars could be capable of supporting life.

(2)

(Total for Question 12 = 4 marks)

3)

The Earth can be considered to be a black body radiator at a temperature of 25 °C.

radius of Earth = 6380 km

(a) Calculate the total power radiated from the Earth.

(2)

Total power radiated = ...

(b) Calculate the wavelength of the peak energy radiation for the Earth.

(2)

Wavelength of the peak energy radiation = ...

(c) State the region of the electromagnetic spectrum in which this wavelength is found.

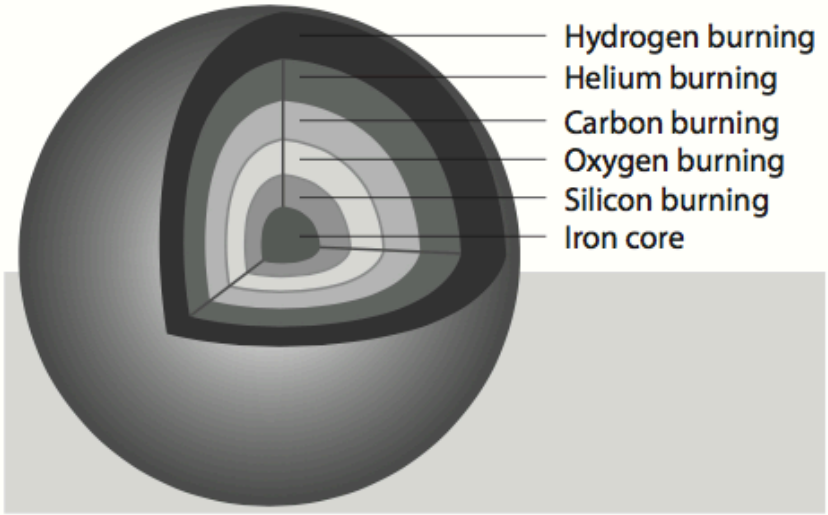
(1)

4)

The following passage is taken from a newspaper article.

Stars exist by fusing hydrogen within their cores. This process generates heat which pushes the star outwards. This outward pressure is matched by the gravitational forces pulling the star inwards. This maintains an equilibrium, allowing the star to radiate away vast amounts of energy for long periods of time. Our Sun has been in this state for about 4.5 billion years.

Eventually the star runs out of hydrogen to fuse, and so changes occur which allow fusion of helium to form heavier elements. Massive stars can produce elements up to iron in their cores by fusion.



Once a star's core has been converted into iron no further fusion can take place and the rapid collapse of the star results in a supernova explosion.

The remnant of the supernova may be a neutron star or black hole, depending upon the remnant's mass.

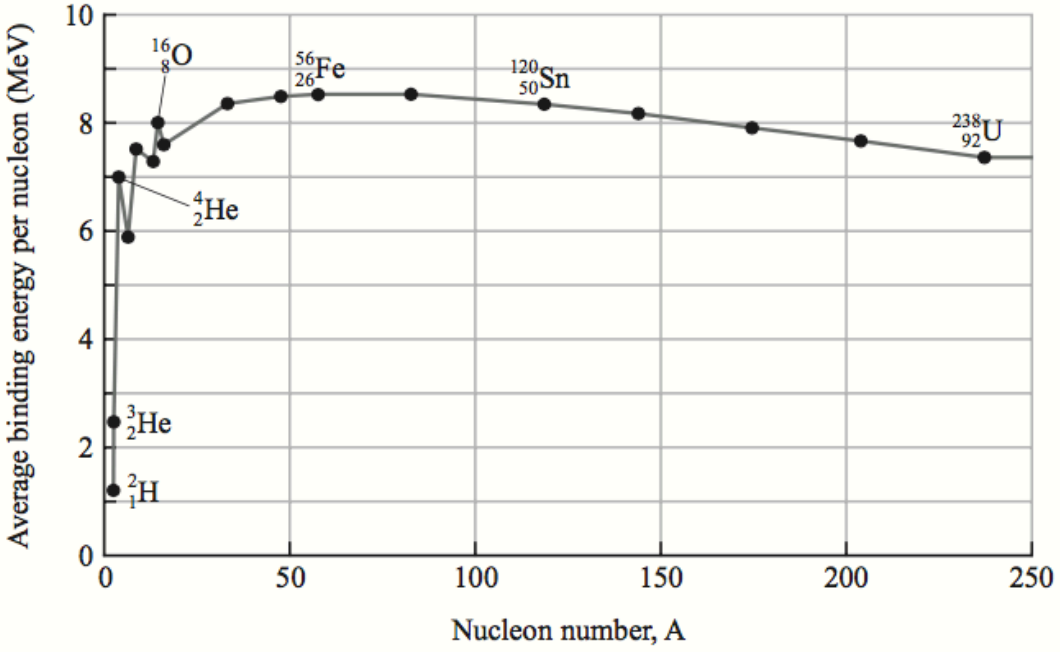
*(a) The conditions needed for fusion to occur make it difficult to replicate outside of a star.

State and explain:

- how the process of fusion is able to release energy
- the conditions necessary for fusion to occur
- why the conditions are difficult to replicate outside of a star.

(6)

(b) The graph shows the average binding energy per nucleon for a range of isotopes.



Massive stars can only produce elements up to iron (Fe) in their cores by fusion.
Use information from the graph to explain why.

(3)

A type 1a supernova occurs when a white dwarf star in a close binary system accumulates matter from its companion star. This eventually leads to a supernova outburst. Type 1a supernovae are used by astronomers as standard candles.

(c) (i) State what is meant by a standard candle.

(1)

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(ii) A type 1a supernova is observed in a distant galaxy. Its flux at the Earth is measured to be 1.84×10^{-15} W m^{-2}. Theory predicts that it has a luminosity of 2.0×10^{36} W.

Show that the distance of the galaxy from the Earth is about 9×10^{24} m.

(2)

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(iii) The light from the galaxy is found to be red-shifted. State what this tells us about the galaxy.

(1)

.....

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(iv) The redshift is measured to be 0.064. Calculate a value for the Hubble constant.

(3)

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Hubble constant = ...

5)

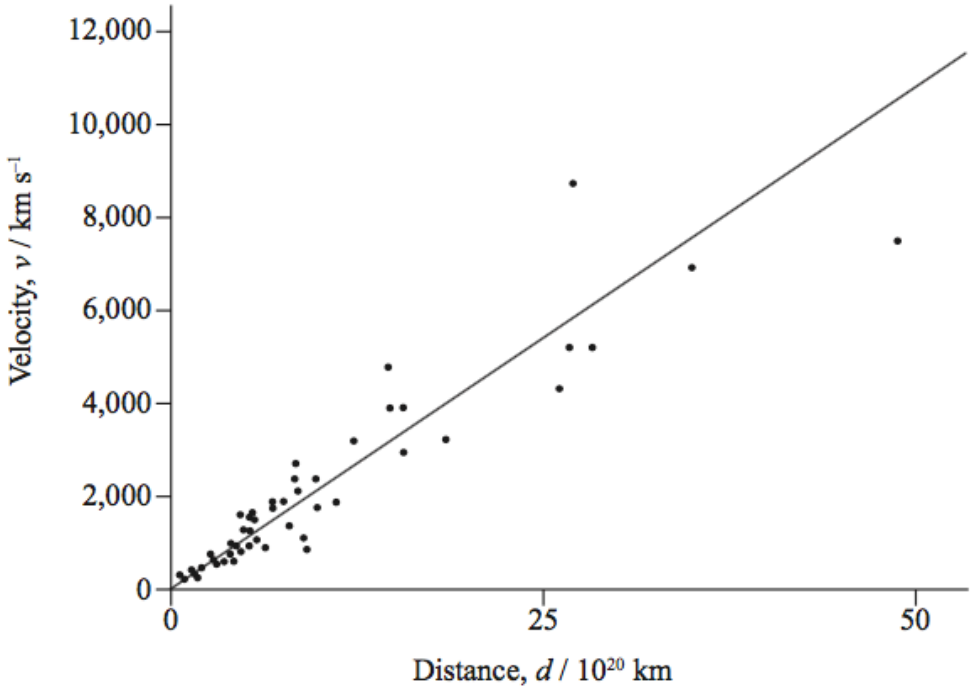
Cepheid variable stars have long been seen as examples of standard candles. Recent measurements have indicated that the movement of the star through interstellar material might result in the formation of a layer of dust around the star. This affects how bright the star appears.

Explain how standard candles are used in astronomy, and suggest how the existence of a layer of dust around a Cepheid variable star might affect the conclusions drawn by astronomers.

(6)

6)

The graph shows how the velocity varies with distance for a number of distant galaxies. All the galaxies are receding from Earth, and there appears to be a linear relationship between the velocity of recession and the distance to the galaxy.



(a) Use the graph to estimate an age for the Universe.

(4)

Age of the Universe = ...

*(b) Describe how astronomers would have determined the velocity of each galaxy.

(5)

*(c) Scientists are uncertain about the ultimate fate of the Universe.

Explain why.

(3)

7)

When nearby stars are observed over a period of a year, their positions are seen to move in tiny ellipses relative to the background of more distant stars.

(a) Explain why relative movement of these nearby stars is observed.

(3)

(b) By means of a labelled diagram, outline the steps necessary for this effect to be used to find the distance to nearby stars.

(3)

(c) The effect is too small for the distances to more distant stars to be determined. Outline a method which can be used for more distant stars.

(1)

8)

The Sun behaves as an approximate black-body radiator with peak energy radiation occurring at a wavelength of 5.2×10^{-7} m.

(a) (i) Show that the Sun has a surface temperature of about 6000 K.

(2)

(ii) The radiation received from the Sun at the top of the atmosphere is 1.37 kW m^{-2}. Show the Sun's luminosity is about 4×10^{26} W.

Distance from the Sun to the Earth = 1.49×10^{11} m

(2)

(iii) Hence calculate the radius of the Sun.

(2)

Radius = ...

(b) The huge power output of the Sun is due to nuclear fusion reactions taking place within its core. State and explain the conditions necessary for fusion to occur.

(3)

9)

The Hubble Space Telescope (HST) was launched in 1990 into an orbit of radius 6940 km. The satellite makes 15 complete orbits of the Earth every 24 hours and its position high above the Earth's atmosphere has allowed high quality images of extremely distant objects to be produced.

(a) (i) Show that the HST has a centripetal acceleration of about 8 m s^{-2}.

(4)

(ii) The HST is kept in orbit by the gravitational pull of the Earth. Use your answer to (a)(i) to calculate a value for the mass of the Earth.

(3)

Mass = ...

b) The telescope was named in honour of Edwin Hubble who measured the red shift of light from a number of galaxies and related it to their distance from the Earth.

Explain what is meant by the term *red shift* in this context and state the inference that Hubble made from his measurements.

(2)

(c) The song "Nine Million Bicycles" by Katie Melua includes the lines, "We are 12 billion light years from the edge, that's a guess, no one can ever say it's true".

(i) Explain how the line "12 billion light years from the edge" implies an age of 12 billion years for the universe.

(2)

(ii) Calculate the value of the Hubble constant consistent with an age of 12 billion years for the universe.

1 billion years = 3.15×10^{16} s

(2)

Hubble constant = ...

(iii) These lyrics were famously contested by Dr Simon Singh in the Guardian newspaper. He argued that the correct age was 13.7 billion years, and disputed that scientists had guessed the age of the universe. As a result Katie performed the song with revised lyrics.

Discuss the suggestion in the song that values for the age of the universe are only guesses.

(3)

10)

(a) State what astronomers mean by a standard candle.

(1)

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(b) The luminosity of Sirius is 8.94×10^{27} W and its distance from the Earth is 8.08×10^{16} m.

Calculate the radiant energy flux of Sirius at the Earth.

(2)

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Radiant energy flux = ...

11)

Current theory predicts that there is a massive black hole at the centre of every galaxy. It is suggested that if galaxies approach, then their central black holes begin to orbit each other until the galaxies merge.

In 2009, astronomers found convincing evidence of two such black holes orbiting as a binary system. From data collected, they estimated that the separation of the black holes was 3.2×10^{15} m and that their masses were 1.6×10^{39} kg and 4.0×10^{37} kg.

(a) (i) State the origin of the force that maintains the black holes in an orbit.

(1)

.....

(ii) Show that the magnitude of this force is about 4×10^{35} N.

(2)

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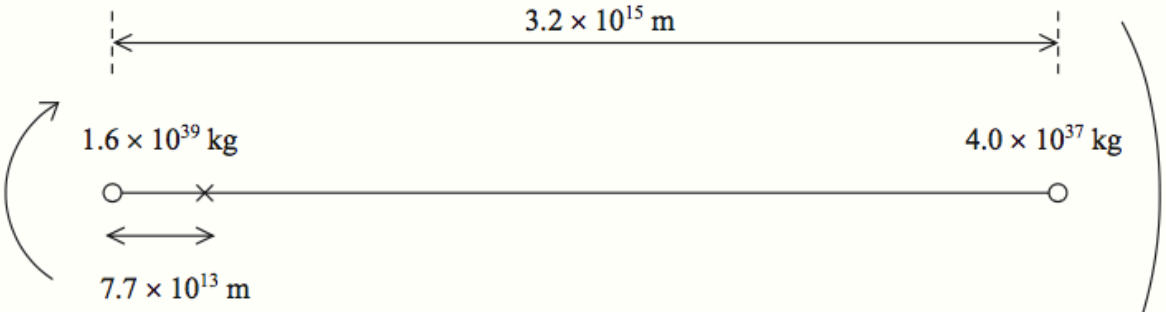
(iii) The black holes orbit about a point 7.7×10^{13} m from the larger mass black hole.



Not to scale

Show that the orbital time of the binary system is about 100 years.

(3)

(b) As the black holes swallow up matter, radiation is emitted. To observers on Earth this radiation appears to be red shifted.

*(i) State what red shift means and discuss the conclusions that can be drawn from the observation that radiation from all distant galaxies is red shifted.

(3)

(ii) Suggest why the light from both black holes is red shifted, even though the black holes are orbiting each other and hence moving in opposite directions.

(2)

(iii) The observed red shift for the two black holes was 0.38.

Calculate the distance of the merging galaxies from the Earth.

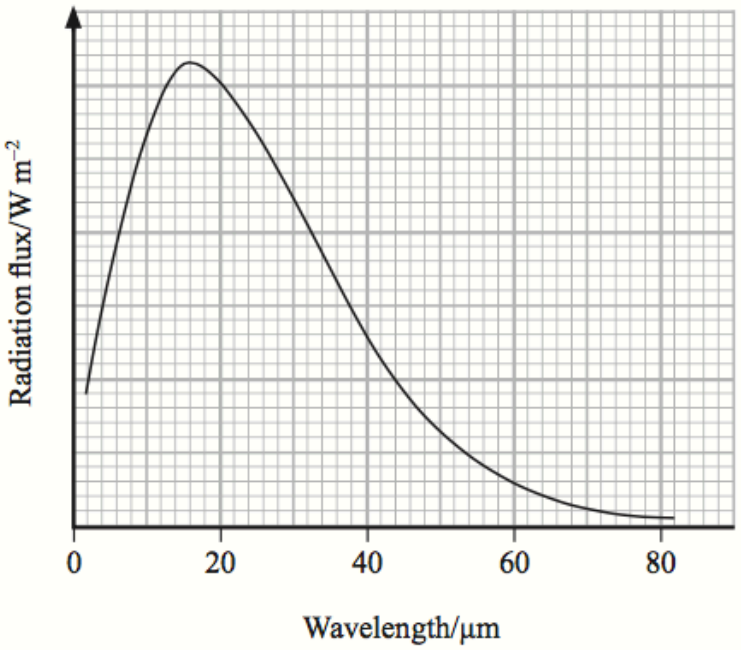
$H_o = 1.6 \times 10^{-18}\ s^{-1}$

(3)

Distance from the Earth = ...

12)

The radiation emitted from an asteroid is monitored and the following spectrum obtained.



(a) (i) State the wavelength at which the peak radiation flux from the asteroid occurs.

(1)

Wavelength of peak radiation flux = ...

(ii) Use the data to estimate the temperature of the asteroid.

(2)

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.....

Temperature of asteroid = ...

(b) The asteroid is in a circular orbit, of known radius, about the Sun. The average speed of the asteroid cannot be determined directly.

State the two extra data values that you would need in order to calculate the orbital period of the asteroid.

(2)

1 .....

2 .....

(c) This asteroid is about 1.5×10^{11} m from the planet Jupiter.

Calculate the magnitude of the gravitational field strength of Jupiter at this distance.

mass of Jupiter = 1.9×10^{27} kg

(2)

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Gravitational field strength of Jupiter = ...

13)

(a) Astronomers determine the distance to a nearby star using trigonometric parallax.

Describe the measurements that must be taken to determine this distance.

You may use a diagram to aid your description.

(2)

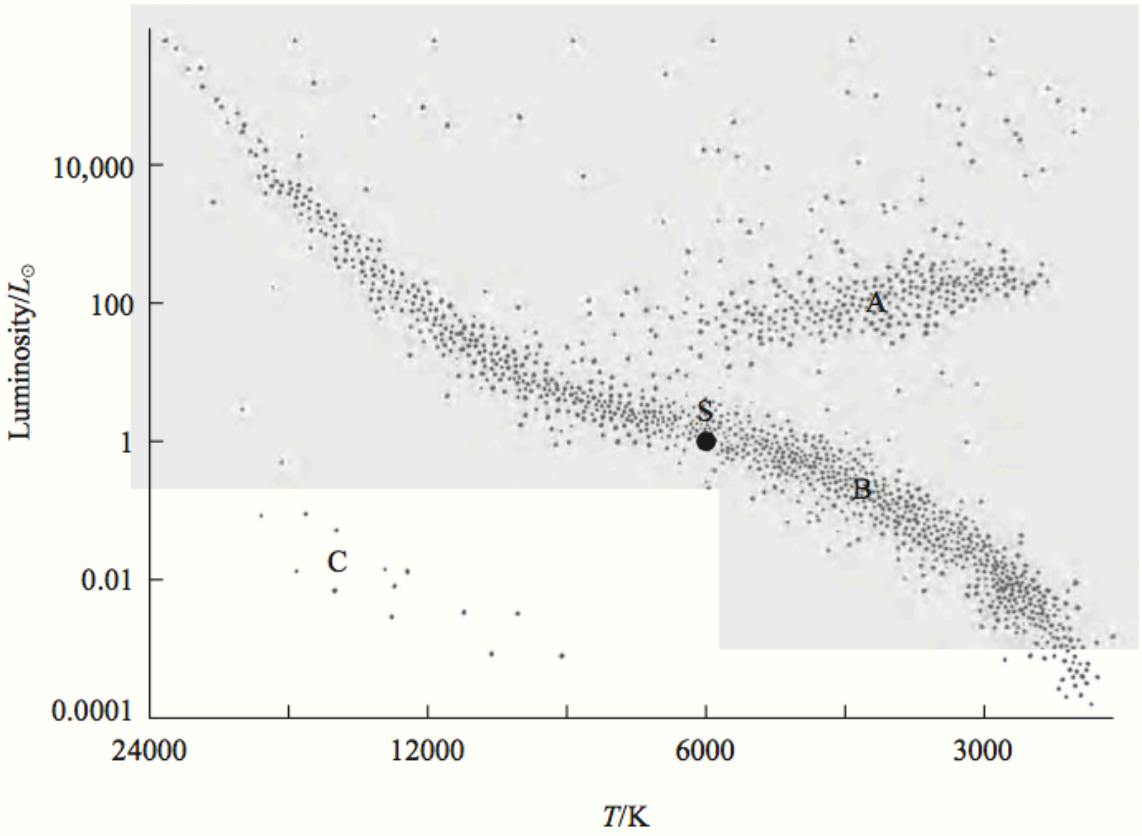
(b) Radiation received at the Earth from a distant galaxy is redshifted. The distance to the galaxy can be determined from this redshift.

State what is meant by redshift, and explain how it allows the distance to the galaxy to be determined.

(4)

14)

(a) The position of our Sun, S is shown on the Hertzsprung-Russell (H-R) diagram below.



(i) Identify the three main regions of the H-R diagram.

(3)

Region A = ...

Region B = ...

Region C = ...

(ii) Add lines to the diagram to show the evolutionary path of our Sun from the time when it comes to the end of its hydrogen-burning phase.

(2)

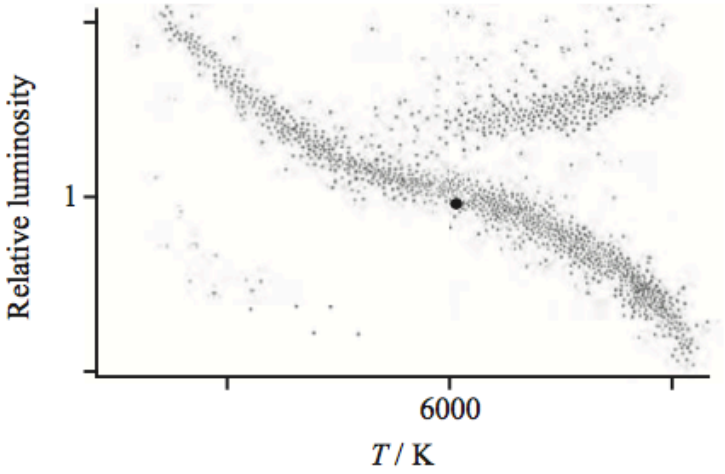
(b) Most stars are too far away from the Earth for astronomers to observe them as anything more than a point source of radiation.

Explain how astronomers calculate the sizes of these stars using information from the H-R diagram.

(3)

15)

This Hertzsprung-Russell diagram is a plot of relative luminosity against temperature for a large number of stars.



The position of the Sun, at a surface temperature of about 6000 K and a relative luminosity of 1, is marked on the diagram.

(a) Complete the temperature and relative luminosity scales by adding values at the positions shown.

(2)

(b) The Sun is an example of a main sequence star.

(i) State the fusion process taking place in the core of all main sequence stars.

(1)

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(ii) Draw a circle where the most massive main sequence stars are located on the diagram and explain why they are found in this position.

(3)

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16)

According to astronomers in Denmark and Australia a common type of active galactic nucleus (AGN) could be used as an accurate "standard candle" for measuring cosmic distances. The technique has been used to measure distances corresponding to redshifts significantly larger than was previously possible.

(a) (i) State what is meant by a standard candle.

(1)

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.....

(ii) Explain how a standard candle is used to measure cosmic distances.

(2)

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(b) (i) State what is meant by redshift.

(1)

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(ii) Calculate the distance to a galaxy with a redshift $z = 0.12$

$H_0 = 2.1 \times 10^{-18}\ s^{-1}$

(2)

.....

.....

.....

.....

Distance to galaxy = ...

*(c) Discuss how astronomers were led to propose the existence of dark matter and the consequences of its existence for the ultimate fate of the universe.

(3)

(d) Explain why the observable universe has a finite size.

(2)

17)

One peak is higher than the 5500 K peak and one is lower than the 5500K peak.	**(1)**	
One peak is to the left of the 5500 K peak and one is to the right of the 5500K peak	**(1)**	
Both graphs correct (6000 K peak is the left of and above the 5500 K peak and the 5000 K peak is to the right of and below the 5500 K peak) **and** both labelled	**(1)**	**3**

18)

(a)	Use of $\lambda_{max}\, T = 2.898 \times 10^{-3}$ $\lambda_{max} = 9.5\times10^{-7}$ m Example of calculation $\lambda_{max} = \frac{2.898\times10^{-3}\ \text{m K}}{3.04\times10^{3}\ \text{K}} = 9.53\times10^{-7}\ \text{m}$	**(1)** **(1)**	**2**
(b)(i)	Use of $L = 4\pi r^2\sigma T^4$ $L = 6.2\times10^{20}$ (W) Example of calculation $L = 4\pi r^2\sigma T^4$ $L = 4\pi\left(3.2\times10^{6}\right)^2 \times 5.67\times10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4} \times \left(3.04\times10^{3}\ \text{K}\right)^4$ $L = 6.23\times10^{20}\ \text{W}$	**(1)** **(1)**	**2**
(b)(ii)	Use of $F = \frac{L}{4\pi d^2}$ $d = 1.9 \times 10^{8}$ m Example of calculation $d = \sqrt{\frac{L}{4\pi F}} = \sqrt{\frac{6.2\times10^{20}\ \text{W}}{4\pi\times1.38\times10^{3}\ \text{W m}^{-2}}} = 1.89\times10^{8}\ \text{m}$	**(1)** **(1)**	**2**