1)

(a)	Object must have a standard/known luminosity OR luminous properties independent of its position (1) It can be used to calculate distances (1) Reference to any **two** of the following: ♦ Radiation/energy flux measured (1) ♦ Observed brightness compared with luminosity (1) ♦ Use of inverse square law [accept if equation quoted] (1) ♦ Object must be commonly found in the universe (1)	Max 4
(b)	When star contracts (front of) star is moving away from observer OR explanation in terms of a rotating/binary star (1) Movement away from observer results in a decrease in the frequency of the radiation/red shift (1) Accept converse argument for an expanding star	2

2)

(a)	Use of $L/4\pi d^2$ **or** $F \propto 1/d^2$ (1) $F_{mars} / F_{earth} = 0.43$ (1) Accept 1 : 2.35 or other ratio simplifying to 0.43 Example of calculation $F = \frac{L}{4\pi\pi^2}$ $\frac{F_{mars}}{F_{earth}} = \frac{d^2_{earth}}{d^2_{mars}} = \left(\frac{1.5 \times 10^{11} m}{2.3 \times 10^{11} m}\right)^2 = 0.43$	2
(b)	Observation that (radiation) flux is about half that on the Earth OR Earth has about double the (radiation) flux of Mars (ecf answer to (a)) (1) Sensible comment that makes reference to energy/intensity/number of photons OR sensible comparison with polar or deep sea regions on the Earth OR reference to a thinner atmosphere (allowing a greater fraction of photons get through to surface) (1)	2

3)

(a)	Use of $P = 4\pi r^2 \sigma T^4$ Power = 2.3 × 10^{17} W [Temperature in °C or incorrect conversion to Kelvin can score 1st mark] Example of calculation $P = 4\pi(6.4\times10^6 \text{ m})^2 \times 5.67\times10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (298\text{ K})^4$ $\therefore P = 2.3\times10^{17}$ W	**(1)** **(1)**	**2**
(b)	Use of $\lambda_{max}T = 2.898\times10^{-3}$ $\lambda_{max} = 9.7\times10^{-6}$ m [Temperature in °C or incorrect conversion to Kelvin can score 1st mark] Example of calculation $\lambda_{max} = \frac{2.898\times10^{-3} \text{ m K}}{298\text{ K}} = 9.7\times10^{-6}$ m	**(1)** **(1)**	**2**
(c)	Infra-red (radiation/light/wave) [accept Infrared/IR]		**1**

4)

(a)	QWC – Work must be clear and organised in a logical manner using technical wording where appropriate **Process of fusion: Max 2** In nuclear fusion small nuclei fuse / join together to produce a larger nucleus Mass of the fused nucleus < total mass of initial nuclei (Energy is released as) $\Delta E = c^2 \Delta m$ **Or** B.E./nucleon increases (so energy is released) **Conditions: Max 3** A very high temperature To overcome the (electrostatic) repulsion between nuclei A (very) high pressure/density To maintain a high/sufficient collision rate **Difficult to replicate: Max 2** (Very high) temperatures lead to confinement problems Contact with container causes temperature to fall (and fusion to cease) Very strong magnetic fields are required	 **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**Max 6**
(b)	Idea that ^{56}Fe is the peak of the graph If nuclei were to be formed with A > 56, the B.E./nucleon would decrease This would require a net input of energy (and so does not occur)	**(1)** **(1)** **(1)**	**3**
(c)(i)	(A star/astronomical) object of known luminosity (due to some characteristic property of the star/object)	**(1)**	**1**
(c)(ii)	Use of $F = \frac{L}{4\pi d^2}$ Distance = 9.3×10^{24} m Example of calculation $d = \sqrt{\frac{2.0 \times 10^{36}\ \text{W}}{4\pi \times 10^{-15}\ \text{W m}^{-2}}} = 9.30 \times 10^{24}\ \text{m}$	**(1)** **(1)**	**2**
(c)(iii)	The galaxy is receding / moving away from the Earth	**(1)**	**1**
(c)(iv)	Use of $Z = v/c$ Use of $v = Hd$ Hubble constant = 2.1×10^{-18} s^{-1} Example of calculation $v = Zc = 0.064 \times 3 \times 10^8\ \text{m s}^{-1} = 1.92 \times 10^7\ \text{m s}^{-1}$ $H = \frac{v}{d} = \frac{1.92 \times 10^7\ \text{m s}^{-1}}{9.30 \times 10^{24}\ \text{m}} = 2.06 \times 10^{-18}\ \text{s}^{-1}$	**(1)** **(1)** **(1)**	**3**

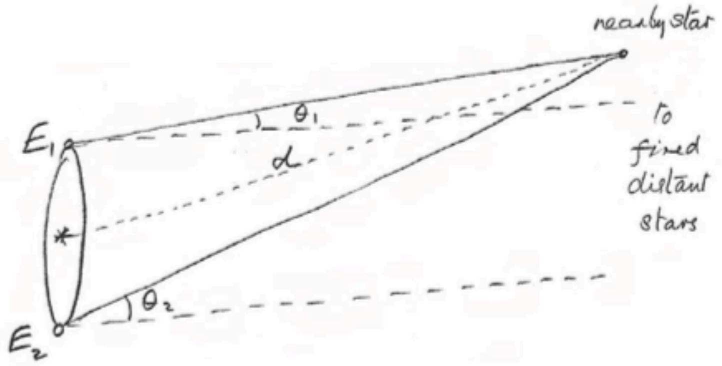
5)

	QWC – Work must be clear and organised in a logical manner using technical wording where appropriate		
	Standard candles are (stellar) objects of known luminosity	**(1)**	
	Standard candle's brightness on earth is measured/known/found [accept apparent magnitude or flux in place of brightness] [Do not accept 'used' in place of 'measured']	**(1)**	
	Use inverse square law [$F=L/4\pi d^2$] **Or** use distance modulus method [$M - m = 5\log(d/10)$]	**(1)**	
	(Hence) distance to standard candle is calculated	**(1)**	
	Dust layer will reduce brightness /magnitude/flux of Cepheid	**(1)**	
	Cepheid will appear to be further away than it is	**(1)**	**6**
	[accept "star" for "standard candle" or for "Cepheid" for MP2 to MP6]		

6)

(a)	Calculate gradient of line Identify gradient with H **Or** use of v = Hd for a point on the line Use of t = 1/H $t = 4.5 \times 10^{17}$ s (accept answers in range 4.2×10^{17} s to 4.8×10^{17} s) **Alternative method:** Pair of d, v values read from the line Values chosen from the upper end of the line Use of t = d/v $t = 4.5 \times 10^{17}$ s [$\pm 0.3 \times 10^{17}$ s] [$t = 1.4 \times 10^{10}$ yr [$\pm 0.1 \times 10^{10}$ yr] Example of calculation $H = \text{gradient} = \frac{(11000-0)\times 10^{3}\,\text{m s}^{-1}}{(50-0)\times 10^{23}\,\text{m}} = 2.2\times 10^{-18}\,\text{s}^{-1}$ $t = \frac{1}{H} = \frac{1}{2.2\times 10^{-18}\,\text{s}^{-1}} = 4.5\times 10^{17}\,\text{s}$	(1) (1) (1) (1) (1) (1) (1) (1)	4
(b)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** Measure wavelength of light (from the galaxy) Compare it to the wavelength for a source on the Earth Reference to spectral line **or** line spectrum Reference to Doppler effect/shift **Or** redshift v is found from: fractional change in wavelength equals ratio of speed of source to speed of light **Or** see reference to $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with terms defined **Or** see reference to $z = \frac{v}{c}$ with terms defined [accept answers in terms of frequency rather than wavelength]	(1) (1) (1) (1) (1)	5
(c)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** **Max 3** (Due to the) difficulty in making accurate measurements of distances to galaxies Hubble constant has a large uncertainty **Or** age = 1/H may not be valid as gravity is changing the expansion rate Because of the existence of dark matter Values of the (average) density/mass of the universe have a large uncertainty [accept not known] (Hence) measurements of the critical density of the Universe have a large uncertainty Dark energy may mean we don't understand gravity as well as we thought we did (so it's hard to predict how gravity will determine the ultimate fate)	(1) (1) (1) (1) (1) (1)	3

7)

(a)	Idea that the Earth is orbiting the Sun (1) Reference to (trigonometric) parallax (1) Idea that more distant stars have “fixed” positions (1)	**(3)**
(b)	Diagram to show how to measure angular displacement of star over a 6 month period e.g.  (1) [Diagram should indicate the Earth in two positions at opposite ends of a diameter, with lines drawn heading towards a point with a relevant angle marked; accept the symmetrical diagram seen in many textbooks.] Use trigonometry to calculate the distance to the star (1) [May be indicated by an appropriate trigonometric formula. Do not accept use of Pythagoras] Need to know the diameter/radius of the Earth’s orbit about the Sun (1) [This may be marked on the diagram or seen in a trigonometric formula]	**(3)**
(c)	Standard candle/Cepheid variable/supernovae (1)	**(1)**

8)

(a)(i)	Use of $\lambda_{max}T=2.898 \times 10^{-3}$	(1)	
	Correct answer	(1)	**(2)**
	Example of calculation: $T = \frac{2.898 \times 10^{-3}\ \text{mK}}{5.2 \times 10^{-7}\ \text{m}} = 5570\ \text{K}$		
(a)(ii)	Use of $F=L/4\pi d^2$	(1)	
	Correct answer	(1)	**(2)**
	Example of calculation: $L = 1370\ \text{Wm}^{-2} \times 4\pi \times (1.49 \times 10^{11}\ \text{m})^2 = 3.8 \times 10^{26}\ \text{W}$		
(a)(iii)	Use of $L=4\pi r^2\sigma T^4$	(1)	
	Correct answer (7.46×10^8 m)	(1)	**(2)**
	Example of calculation: $r^2 = \frac{3.82 \times 10^{26}\ \text{W}}{4\pi \times 5.67 \times 10^{-8}\ \text{Wm}^{-2}\text{K}^{-4} \times (5570\ \text{K})^4} = 5.57 \times 10^{17}\ \text{m}^2$ $r = \sqrt{5.57 \times 10^{17}\ \text{m}^2} = 7.46 \times 10^8\ \text{m}$		
(b) **QWC**	The answer must be clear, use an appropriate style and be organised in a logical sequence		
	High temperature AND high density/pressure	(1)	
	Any **two** reasons from: Overcome coulomb/electrostatic repulsion Nuclei come close enough to fuse/for strong (nuclear) force to act High collision rate/collision rate is sufficient	 (1) (1) (1)	**(max 3)**

	3.8×10^{-26} W	**4×10^{26} W**
5570 K	7.46	7.6
6000 K	6.4	6.6

9)

(a)(i)	Calculation of time period Use of $v = \frac{\Delta s}{\Delta t}$ *or* $\omega = \frac{2\pi}{T}$ Use of $a = \frac{v^2}{r}$ *or* $a = r\omega^2$ Correct answer Example of calculation: $T = \frac{24 \times 60 \times 60\,s}{15} = 5760\,s$ $v = \frac{2\pi r}{T} = \frac{2\pi \times 6.94 \times 10^6\,m}{5760 s} = 7.57 \times 10^3\,ms^{-1}$ $a = \frac{v^2}{r} = \frac{(7.6 \times 10^3\,ms^{-1})^2}{6.94 \times 10^6\,m} = 8.26\,ms^{-2}$ OR $\omega = \frac{2\pi}{T} = \frac{2\pi}{5760\,s} = 1.09 \times 10^{-3}\,ms^{-1}$ $a = r\omega^2 = 6.94 \times 10^6 \times (1.09 \times 10^{-3})^2 = 8.26\,ms^{-2}$	(1) (1) (1) (1)	**(4)**
(a)(ii)	mg equated to gravitational force expression g (= a) = 8.3 ms^{-2} substituted Correct answer Example of calculation: $mg = \frac{GMm}{r^2}$ $\therefore 8.3\,ms^{-2} = \frac{6.67 \times 10^{-11}\,Nm^2\,kg^{-2} M}{(6.94 \times 10^6\,m)^2}$ $\therefore M = \frac{8.3\,ms^{-1} \times (6.94 \times 10^6\,m)^2}{6.67 \times 10^{-11}\,Nm^2 kg^{-2}} = 6.0 \times 10^{24}\,kg$	(1) (1) (1)	**(3)**
(b)	The observed wavelength is longer than the actual wavelength / the wavelength is stretched out One from: The universe is expanding (All distant) <u>galaxies</u> are moving apart The (recessional) velocity of <u>galaxies</u> is proportional to distance The furthest out <u>galaxies</u> move fastest	(1) (1) (1) (1) (1)	**(max 2)**

(c)(i)	A light year is the distance travelled (in a vacuum) in 1 year by light / em-radiation (1) The idea that light has only been able to travel to us for a time equal to the age of the universe. (1)		(2)
(c)(ii)	(Use of v = H_o d to show) $H_o = \frac{1}{t}$ (1) Correct answer (1) Example of calculation: $H_o = \frac{1}{t} = \frac{1}{12 \times 3.15 \times 10^{16}\, s} = 2.65 \times 10^{-18}\, s^{-1}$		(2)
(c)(iii) QWC	The answer must be clear and be organised in a logical sequence There is considerable uncertainty in the value of the Hubble constant (1) Any sensible reason for uncertainty (1) Idea that a guess implies a value obtained with little supporting evidence OR the errors are so large that our value is little better than a guess (1)		(3)

10)

(a)	(A star/astronomical) object of known luminosity (due to some characteristic property of the star/object)	(1)	1
(b)	Use of $F = L/4\pi d^2$ $F = 1.09 \times 10^{-7}$ W m^{-2} Example of calculation $F = \frac{L}{4\pi d^2} = \frac{8.94 \times 10^{27}\,\text{W}}{4\pi(8.08 \times 10^{16}\,\text{m})^2} = 1.0896 \times 10^{-7}\,\text{W m}^{-2}$	(1) (1)	2

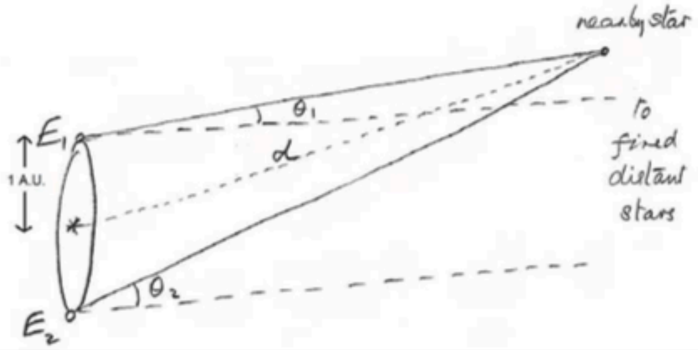
11)

(a)(i)	Gravitation OR gravity OR gravitational attraction / pull / force	(1)	**1**
(a)(ii)	Use of $F = Gm_1m_2/r^2$ $F = 4.2 \times 10^{35}$ (N) (no u.e.) <u>Example of calculation</u> $F = \frac{Gm_1m_2}{r^2}$ $F = \frac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}\ (1.6 \times 10^{39}\ \text{kg})(4.0 \times 10^{37}\ \text{kg})}{(3.2 \times 10^{15}\ \text{m})^2}$ $F = 4.17 \times 10^{35}$ N	(1) (1)	**2**
(a)(iii)	Use of $F = m\omega^2 r$ or $F = mv^2/r$ Use of $T = 2\pi/\omega$ or $T = 2\pi r/v$ $T = 108$ (years) [accept 107 – 111 years] (no ue) [If r^3 appears in solution, max 1 mark out of 3. If $\omega = \sqrt{\frac{G(M+m)}{(R+r)^3}}$ used, then full credit may be given. This method leads to T = 109 years] <u>Example of calculation</u> $\omega = \sqrt{\frac{4.2 \times 10^{35}\ \text{N}}{(1.6 \times 10^{39}\ \text{kg}) \times 7.7 \times 10^{13}\ \text{m}}}$ $\omega = 1.85 \times 10^{-9}\ \text{rad s}^{-1}$ $T = \frac{2\pi\ \text{rad}}{1.85 \times 10^{-9}\ \text{rad s}^{-1}} = 3.40 \times 10^9$ s $T = \frac{3.40 \times 10^9\ \text{s}}{365 \times 24 \times 60 \times 60\ \text{s year}^{-1}} = 108$ years	(1) (1) (1)	**3**
(b)(i)	(QWC- Work must be clear and organised in a logical manner using technical wording where appropriate.) Radiation (is received) with a longer/stretched wavelength (compared to that emitted) OR lower/smaller frequency This indicates that distant <u>galaxies</u> are receding / distance between <u>galaxies</u> is increasing/<u>galaxies</u> are moving apart (Hence) the universe is expanding / provides evidence for Big Bang	(1) (1) (1)	**3**
(b)(ii)	The rotational motion (of the black holes) is small compared with that due to the overall recession (So) both black holes are still moving away OR (hence) the overall effect when the black hole is approaching is to cause a small reduction in the observed red (rather than a blue) shift ALTERNATIVE APPROACH: Reference to plane of orbit being perpendicular to line of sight from the Earth Therefore there is no change in wavelength due to rotation of black holes	(1) (1) (1) (1)	**2**
(b)(iii)	Use of $z = v/c$ Use of $v = H_0 d$ $d = 7.1 \times 10^{25}$ m <u>Example of calculation</u> $v = Zc = 0.38 \times 3 \times 10^8\ \text{m s}^{-1} = 1.14 \times 10^8\ \text{m s}^{-1}$ $d = \frac{1.14 \times 10^8\ \text{m s}^{-1}}{1.6 \times 10^{-18}\ \text{s}^{-1}} = 7.13 \times 10^{25}$ m	(1) (1) (1)	**3**

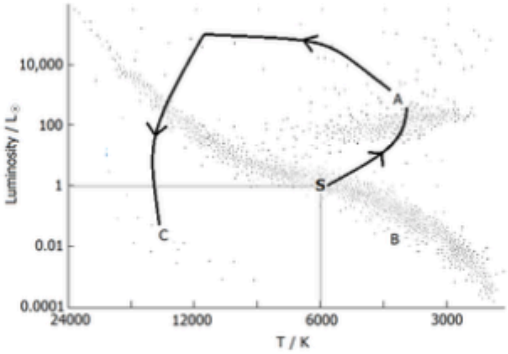
12)

(a)(i)	16 μm [accept ±1μm]	**(1)**	**1**
(a)(ii)	Use of $\lambda_{max}T = 2.898\times10^{-3}$ Temperature = 180 K (ecf from (a)(i)) [161 K for 18 μm, 170 K for 17 μm, 193 K for 15 μm, 207 K for 14 μm] Example of calculation $T = \frac{2.898\times10^{-3}\text{ mK}}{16\times10^{-6}\text{ m}} = 181\text{K}$	**(1)** **(1)**	**2**
(b)	Mass of the Sun G **Or** gravitational constant **Or** 6.67×10^{-11} (N m^2 kg^{-2}) [can be next to either answer prompt]	**(1)** **(1)**	**2**
(c)	Use of $g = \frac{GM}{r^2}$ Field strength = 5.6×10^{-6} N kg^{-1} [accept m s^{-2}] Example of calculation $g = \frac{6.67\times10^{-11}\text{ N m}^2\text{ kg}^{-2}\times1.9\times10^{27}\text{ kg}}{(1.5\times10^{11}\text{ m})^2} = 5.63\times10^{-6}\text{ N kg}^{-1}$	**(1)** **(1)**	**2**

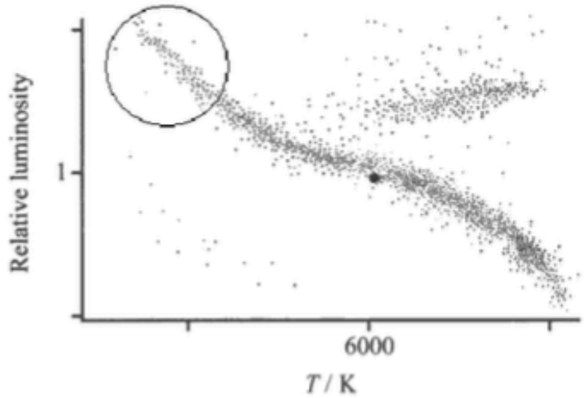
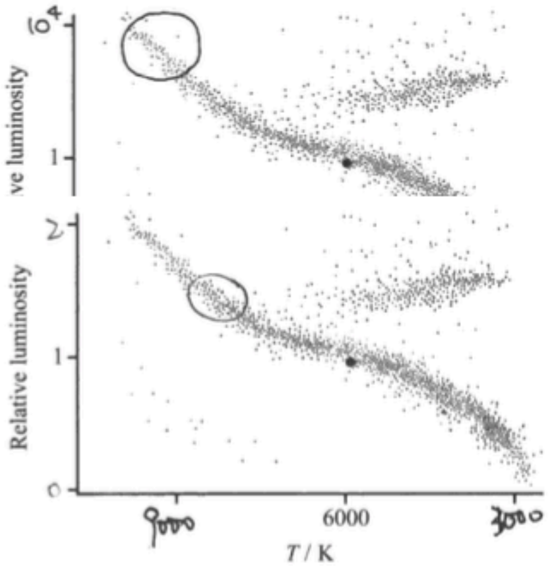
13)

(a)	**Max 2** • Angles are measured using the fixed background of more distant stars • Find angular displacement of the star (as Earth moves around the Sun) over a 6 month period / over a diameter of the Earth's orbit • Diameter of the Earth's orbit about the Sun must be measured/known [Full marks can be obtained from an annotated diagram] 	**(1)** **(1)** **(1)**	**2**
(b)	QWC – Work must be clear and organised in a logical manner using technical wording where appropriate Idea that red shift is the (fractional) increase in wavelength of light received (due to) recession of the source from the Earth/observer Doppler/red shift is used to find v (allow reference to use of red shift equation e.g. $v = zc$) Appropriate reference to Hubble's Law **Or** $v = H_0d$ [for 1[st] marking point allow "decrease in frequency" for "increase in wavelength"]	 **(1)** **(1)** **(1)** **(1)**	**4**

14)

(a)(i)	A = Red Giants **Or** Giants B = Main Sequence C = White Dwarfs **Or** Dwarfs	**(1)** **(1)** **(1)**	**3**
(a)(ii)	 S → A correctly marked (straight line or curve starting at S going near A) A → C correctly marked (some upward curving from near A, near to C but can go beyond C)	**(1)** **(1)**	**2**
(b)	We determine the star's • temperature T (from Wien's law) • luminosity L (from the H-R diagram) • (Then) r is calculated using (Stefan's Law) $L=4\pi r^2\sigma T^4$ **Or** $L=A\sigma T^4$ [accept a re-arranged equation for A **Or** r]	**(1)** **(1)** **(1)**	**3**

15)

(a)	Luminosity scale: Log scale [$10^3 \rightarrow 10^6$ (top) and $10^{-3} \rightarrow 10^{-6}$ (bottom)] Temperature scale: reverse log/power scale [e.g. 12,000 (left) and 3000 (right)]	**(1)** **(1)**	**2**
(b)(i)	(Fusion of) hydrogen into helium [accept symbols]	**(1)**	**1**
(b)(ii)	Circle around stars top left of main sequence [included in the area indicated below]  **Max 2** They have the highest temperatures **Or** they are the most luminous [accept brightest] (Because) they fuse H (into He) at the highest/higher rate (Because) they have the largest/larger gravitational forces [Max 1 mark if no comparative]  Both scale marks and correct area identified Neither scale mark and area too low	**(1)** **(1)** **(1)** **(1)**	**3**

16)

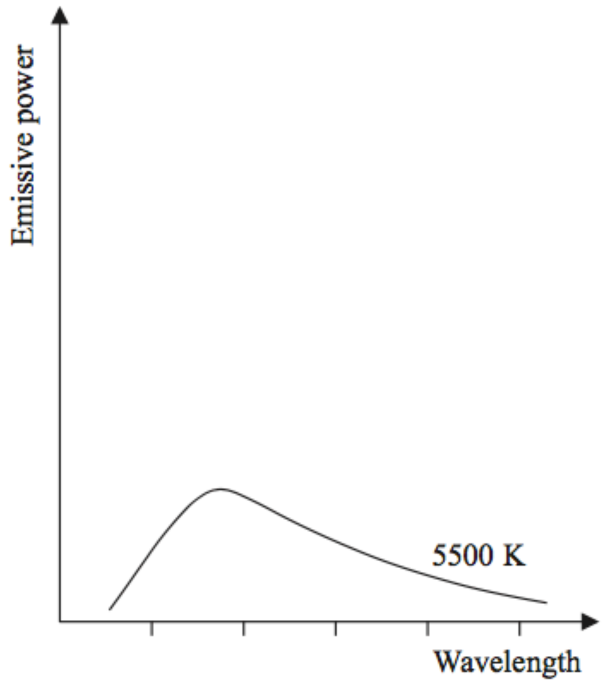
(a)(i)	(A standard candle is) an object of known luminosity	**(1)**	**1**
(a)(ii)	Flux/brightness/intensity of standard candle is measured Inverse square law used (to calculate distance to standard candle) [Reference to measurement of apparent magnitude of star, m, and distance calculated using $m - M = 5\log(d/10\text{ pc})$ can score 2 marks]	**(1)** **(1)**	**2**
(b)(i)	An increase in the wavelength (of radiation) received from a receding source [accept in terms of a decrease in the frequency]	**(1)**	**1**
(b)(ii)	Use of $z = v/c$ and $v = H_0 d$ [$z = H_0 d/c$] $d = 1.7 \times 10^{25}$ m <u>Example of calculation:</u> $v = zc = 0.12 \times 3\times10^8 \text{ m s}^{-1} = 3.6 \times10^7 \text{ m s}^{-1}$ $d = v/H = 3.6 \times10^7 \text{ m s}^{-1}/2.1 \times 10^{-18} \text{ s}^{-1} = 1.71 \times 10^{25}$ m	**(1)** **(1)**	**2**
(c)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Max 3** Dark matter has mass but does not emit e-m radiation [accept light] (Dark matter proposed when) observations of galaxies indicated that they must contain more matter than could be seen. The existence of dark matter will increase the (average) density of the universe This may make it more likely that the universe is closed [accept will contract **Or** end with a "Big Crunch"] **Or** Idea that this may make the ultimate fate of the Universe less certain	**(1)** **(1)** **(1)** **(1)**	**3**
(d)	**Max 2** The universe started from a small initial point [accept Big Bang] Idea that universe has a finite age Idea that (observable universe is finite because) we can only see as far as (speed of light) × (age of universe) **Or** light reaching us must have travelled a finite distance since the Big Bang **Or** some parts of the universe are so distant, light has not had time to reach us yet	**(1)** **(1)** **(1)**	**2**

17)

The graph shows how the emissive power varies with wavelength for a star of surface temperature 5500 K.

On the same axes sketch graphs to show how the emissive power varies with wavelength for stars with surface temperatures of 5000 K and 6000 K. Label each graph clearly.

(3)



18)

Proxima Centauri is a red dwarf star about 4.2 light years away from the Earth with an average surface temperature of 3.04×10^3 K.

(a) Calculate the wavelength λ_{max} at which peak power emission from Proxima Centauri occurs.

(2)

....

....

λ_{max} = ...

(b) The radius of Proxima Centauri is estimated to be 3.2×10^6 m.

(i) Show that its luminosity is about 6×10^{20} W.

(2)

....

....

....

(ii) When measured on the surface of the Earth the radiation flux from the Sun is 1.38×10^3 W m^{-2}.

At a point in space the radiation flux from Proxima Centauri also has this magnitude.

Calculate the distance of this point from Proxima Centauri.

(2)

....

....

....

....

Distance ....