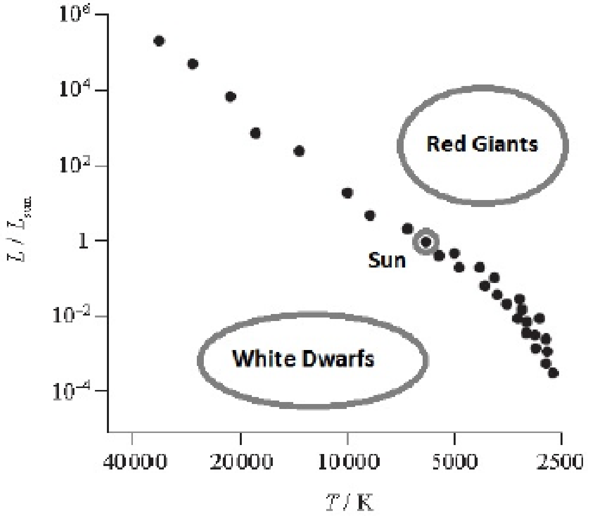
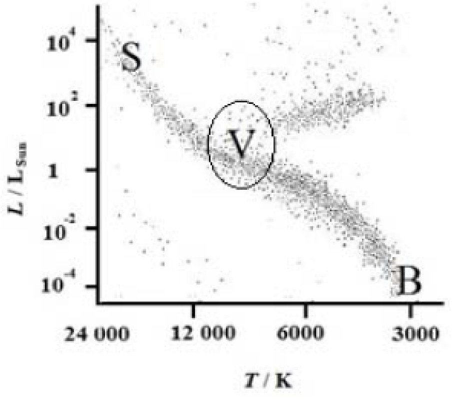
1.

Question Number	Answer		Mark
18(a)			
(i)	Sun's position identified [single point identified]	(1)	
(ii)	White dwarf region Red giant region	(1) (1)	3
*18(a)(iii)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) White dwarf stars have: high temperature T (because λ_{max} is small) low luminosity L $L = \sigma A T^4$ linked to a determination of the surface area	 (1) (1) (1)	3

2.

Question Number	Answer		Mark
18(a)(i)	**Star** — **Type of Star**		
	Spica (S) — **Main sequence [accept blue giant]**	(1)	
	Vega (V) — **Main sequence [accept giant]**	(1)	
	Barnard's Star (B) — Dwarf		2
18(a)(ii)	S, V and B correctly marked  	(1)	1
18(b)	Use of $\lambda_{max}T = 2.898\times10^{-3}$	(1)	
	$\lambda_{max} = 9.7 \times 10^{-7}$ m	(1)	
	This is in the infra-red region (so any visible light will be in red end of spectrum)	(1)	
	Example of calculation $\lambda_{max}T = 2.898\times10^{-3} = \dfrac{2.898\times10^{-3}\,\text{mK}}{3000\text{K}} = 9.66\times10^{-7}\,\text{m}$		3

18(c)	Use of $L = 4\pi r^2 \sigma T^4$ **Or** use of $L = \sigma A T^4$ and $A = 4\pi r^2$ r = 1.8×10^9 m <u>Example of calculation</u> $r = \sqrt{\frac{L}{4\pi\sigma T^4}} = \sqrt{\frac{50.1 \times 3.85 \times 10^{26}\,\text{W}}{4\pi \times 5.67 \times 10^{-8}\,\text{W m}^{-2}\text{K}^{-4} \times (9500\,\text{K})^4}} = 1.82 \times 10^9\,\text{m}$	**(1)** **(1)**	**2**
18(d)	The brightness of a source , F, is given by $F = \frac{L}{4\pi x^2}$ where L is the luminosity and x the distance to the source **Or** reference to the inverse square law for brightness If distance is increased, then the brightness decreases [dependent upon MP1] Vega must be much closer than Spica	**(1)** **(1)** **(1)**	**3**

3.

Question			Answer	Marks	Guidance
10	a		Reference to $d\sin\theta = (n)\lambda$	B1	
			Reference to the Doppler equation $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$	B1	
			Determination of wavelength of a spectral line from receding galaxy and of an identical line in the laboratory and correct description of how $\Delta\lambda$ is calculated	B1	
	b	i	Hubble constant = $\frac{740}{11}$	C1	
			Hubble constant = 67 (km s^{-1} Mpc^{-1})	A1	
		ii	Hubble constant = $\frac{67\times10^3}{10^6\times3.1\times10^{16}}$ or 2.16×10^{-18} (s^{-1})	C1	Possible ecf from **(i)**
			age = $\frac{1}{2.161\times10^{-18}} = 4.63\times10^{17}$ (s)		
			age = 1.446×10^{10} (y)	C1	
			uncertainty = $\left(\frac{2}{11}+\frac{20}{740}\right)\times1.446\times10^{10}$	C1	
			age = $(1.4 \pm 0.3)\times10^{10}$ (y)	A1	
		iii	Determine the gradient from the *v*-*d* graph which is (an average value for) Hubble constant.	B1	
			The age of the universe is the inverse of this gradient	B1	
		iv	distance = $4.63\times10^{17}\times3.0\times10^{8}$	C1	Possible ecf from **(ii)**
			distance = 1.4×10^{26} (m)	A1	

4.

Question			Answer	Marks	Guidance
5	**a**		positron and (electron) neutrino	B1	
	b		The total mass of the protons is <u>greater</u> than the total mass of the 'product' particles (ora) energy released = change in mass × c^2	B1 B1	
	c		High temperatures / quoted value of $T \sim 10^7$ K This allows the protons to come close together (to enable strong nuclear force to act) High pressure / density The ensures that there is a greater rate of fusion reactions (AW)	M1 A1 M1 A1	 **Allow:** protons to overcome (electrostatic) repulsive force
	d		Gravitational collapse (of the dust cloud) increases the temperature of the cloud Fusion (of hydrogen) generates energy or A stable star is produced when gravitational pressure is balanced by pressure from gas / radiation When there is no more hydrogen, the outer layers of the star expand / (super) red giant formed Eventually the <u>core</u> collapses resulting in a supernova The remnant core is either a neutron star or a black hole The sequence of gravitational collapse, fusion / star formed, supernova and neutron star/black hole is correctly set out in the text.	B1 B1 B1 B1 B1 B1	

5.

Question			Answers	Marks	Guidance
11	(a)		angle = $\tan^{-1}(1.3\times10^{20}/2.4\times10^{22})$ angle = 0.31 (°)	B1	**Note**: Using $\sin^{-1}$ is correct; it gives the same answer of 0.31°
	(b)		$(\frac{\Delta\lambda}{\lambda}=\frac{v}{c})$ $\frac{\Delta\lambda}{656.3}=\frac{2.5\times10^5}{3.0\times10^8}$ (Any subject) $\Delta\lambda$ = 0.55 (nm)	C1 A1	**Note**: Answer to 3 sf is 0.547 (nm) **Note**: 5.5×10^{-10} on the answer line scores 1 mark
	(c)		$\frac{GMm}{r^2}=\frac{mv^2}{r}$ or $\frac{GM}{r}=v^2$ $\frac{GM}{0.65\times10^{20}}=(2.5\times10^5)^2$ (Any subject) mass = 6.09×10^{40} (kg) (number of stars = $6.09\times10^{40}/2.0\times10^{30}$) number of stars = 3.0×10^{10}	C1 C1 C1 A1	**Allow** other correct methods. **Allow** the following for the first two C1 marks: $F=\frac{2.0\times10^{30}\times(2.5\times10^5)^2}{0.65\times10^{20}}$ or 1.92×10^{21} (N) C1 $\frac{GM\times2.0\times10^{30}}{(0.65\times10^{20})^2}=1.92\times10^{21}$ (Any subject) C1 **Allow**: 2 out of 3 marks for use of 1.3×10^{20} (m); this gives an answer of 1.2×10^{41} (kg) Possible ECF from incorrect mass of galaxy **Allow** 1 SF answer for the estimation

6.

Question			Answer	Marks	Guidance
10	(a)		A core / 'star' left behind after a red giant (has shed its outer layers)	B1	**Allow**: It is the core of a red giant **Allow**: It is the remnant of a low-mass star **Allow**: A core / 'star' • supported by Fermi pressure / electron degeneracy (pressure) • with maximum mass of 1.4(4) solar masses / 1.4(4) M_o / Chandrasekhar limit **Not**: It is a collapsing red giant
	(b)		(parallax = 1/*d*) $d = 0.0059^{-1}$ (pc = 169 .49 .... pc) distance = $0.0059^{-1} \times 3.26$ distance = 550 ly	 C1 A1	 **Allow** other correct methods
	(c)	(i)	power per (unit) area or power/area	B1	**Allow** 'energy per (unit) area per unit time' **Not**: power per m^2
		(ii)	**1** (density = mass/$\frac{4}{3}\pi r^3 \propto$ mass/r^3) ratio = $\dfrac{12}{(1.1\times10^5)^3}$ ratio = 9.0×10^{-15} **2** (power = intensity × surface area) power $\propto T^4r^2$ ratio = $\dfrac{4300^4\times(1.1\times10^5)^2}{25000^4}$ ratio = 1.1×10^7	 C1 A1 C1 C1 A1	 **Allow**: 9.0×10^{-15} : 1 **Allow**: 1 sf answer of 9×10^{-15} **Note**: Answer to 3 sf is 1.06×10^7 **Allow**: 1.1×10^7 : 1

7.

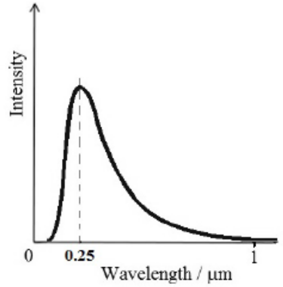
Question			Answer	Marks	Guidance
11	**(a)**		recessional speed / velocity of <u>galaxy</u> is proportional to its distance (from us)	B1	**Allow**: recessional speed of <u>galaxy</u> = Hubble constant × distance
	(b)	**(i)**	v = 1010 (10^3 m s^{-1}) d in the range 4.47 to 4.54 (10^{23} m)	B1 B1	**Note**: Answer to 4 sf is 1014 (10^3 m s^{-1})
		(ii)	(Straight line drawn through the points gradient = Hubble constant, H_0) gradient = 2.24×10^{-18} (s^{-1}) age = $(2.24 \times 10^{-18})^{-1}$ age = 4.46×10^{17} (s) age = 1.4×10^{10} (y)	 C1 C1 A1	 **Allow**: gradient in the range 2.21 to 2.27 × 10^{-18} **Allow** ecf from incorrect value of the gradient **Allow**: A maximum of 2 marks if values from the table are used instead of the gradient of the line drawn on Fig. 11.2 **Note**: No marks for a bald 14 billion years
	(c)		Big bang: Creation / birth / expansion / evolution of the universe or The universe was very hot / very dense / singularity (at the start) Evidence: Any <u>two</u> from: • Microwave / background radiation / 3 K (or 2.7 K) • Existence of (primordial) helium / lithium / lighter elements • Tiny variation (or ripples) in (background) temperature	 B1 B1 × 2	 **Not**: More matter than antimatter / baryonic asymmetry

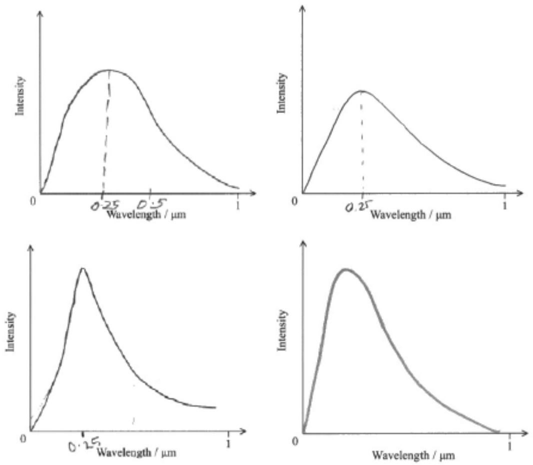
8.

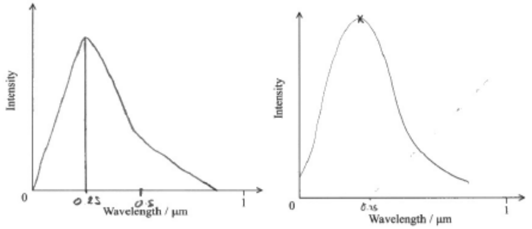
Question			Answer	Marks	Guidance
10	(a)		$F = \frac{GMm}{r^2}$ force = $\frac{6.67\times10^{-11}\times(10^{41})^2}{(4\times10^{22})^2}$ force = 4.2×10^{26} (N)	C1 C1 A1	**Allow**: 4×10^{26} (N) or 10^{26} since this is an estimation **Allow**: 2 marks for 4.2×10^{n}; $n \neq 26$ (POT error)
	(b)		Allow any one from: • The galaxies are receding / moving away from each other (because of the big bang) • Other galaxies may be pulling them in opposite direction • The acceleration is too small to collapse (other than over a very long period of time)	B1	
	(c)		Any six from: 1. (At the start it was) very hot / extremely dense / singularity 2. All forces were unified 3. Expansion led to cooling 4. Quarks / leptons (soup) 5. More matter than antimatter 6. Quarks combine to form hadrons / protons / neutrons 7. Imbalance of neutrons and protons / (primordial) helium produced 8. Atoms formed 9. Idea of gravitational force responsible for formation of stars / galaxies 10. Temperature becomes 2.7 K / 3 K or (the universe is saturated with cosmic) microwave background radiation	B1×6	**Show annotation on Scoris**
	(d)	(i)	Dark lines / bands against a background of continuous spectrum	M1 A1	

Question			Answer	Marks	Guidance
		(ii)	$\frac{v}{c} = \frac{\Delta\lambda}{\lambda}$ speed = $\frac{86.6}{393.4} \times 3.0 \times 10^8$ (Any subject) speed = 6.6×10^7 (m s^{-1}) or 66000 (km s^{-1}) $v = H_0 d$ $66000 = 50 \times d$ distance = 1300 (Mpc)	C1 C1 A1	**Allow**: 1 mark for $\frac{86.6}{480.0} \times 3.0 \times 10^8 = 5.41 \times 10^7$ (m s^{-1}) **Allow**: 2 marks for 1.3×10^n; $n \neq 3$ (POT error) **Note**: Answer is 1080 (Mpc) if 5.4×10^7 (m s^{-1}) is used; this value will score 2 marks

9.

<table>
<tr><th>Question Number</th><th>Answer</th><th></th><th>Mark</th></tr>
<tr><td>17(a)</td><td>Curve with peak at 0.25μm (labelled or in correct position)</td><td>(1)</td><td></td></tr>
<tr><td></td><td>Shape must be an asymmetric curve and must not have intensity at λ = 0


Examples of acceptable shapes:


Examples of unacceptable shapes:


</td><td>(1)</td><td>2</td></tr>
</table>

17(b)(i)	$T = 11\ 500$ K (allow 11 250 K to 11 750 K)	**(1)**	**1**
17(b)(ii)	At least 2 pairs of values read from graph Use of $\lambda_{max} T$ = constant Use values to show $\lambda_{max} T$ = a constant <u>Example of calculation:</u> $\lambda_{max} T = 0.25 \times 10^{-6} \times 11500 = 2.9 \times 10^{-3}$ $\lambda_{max} T = 0.5 \times 10^{-6} \times 5800 = 2.9 \times 10^{-3}$	(1) (1) (1)	**3**