Que	Question		Answers	Marks	Guidance	
	(a)		The universe is homogeneous. and isotropic (on a large scale).			
	(b)		The intensity of the microwaves is the same in all directions.	B1	Allow the microwave (background radiation) is isotropic.	
			These microwaves correspond to a temperature of 2.7 K or The temperature of the universe is 2.7 K.	B1	Allow 3 K	
			The expansion of the universe following the big bang led to cooling and hence we observe microwaves rather than short wavelength e.m. waves / gamma waves.	B1	Allow - The short e.m. / gamma waves during the early stages of the universe have been 'stretched out' / 'red-shifted' to microwaves by the expansion.	

Question	Answer	Marks	Guidance
(a)	The night sky should be bright / have uniform brightness (but it is not) The line of sight ends on (the surface of a star) or 'number of stars $\propto r^2$ and intensity $\propto 1/r^2$ .  Any $two$ assumptions about the Universe: Infinite / uniformly distributed matter or stars throughout / static / infinite age	B1 B1 B1	
(b)	(recessional) speed of galaxy ∞ its distance (from the Earth)  The universe is finite / it is expanding / it has a beginning / visible light is red-shifted (because of expansion of space) (AW)	B1 B1	<b>Allow</b> : $v = H_0 x$ , $v =$ (recessional) speed of galaxy, $x =$ distance and $H_0$ is Hubble constant / a constant
(c) (i)	$v = H_0 x$ $3.4 \times 10^7 = H_0 \times 1.4 \times 10^{25}$ $H_0 = 2.4 \times 10^{-18}$ unit: s <sup>-1</sup>	C1 A1 B1	Note: This is an independent mark Note: Allow full credit for an Hubble constant of 75 with unit km s <sup>-1</sup> Mpc <sup>-1</sup>
(ii)1	age = $\frac{1}{2.4 \times 10^{-18}}$ age = $4.17 \times 10^{17}$ (s) age = $1.3 \times 10^{10}$ (years)	C1	Possible ecf from (i)
(ii)2	distance = $4.17 \times 10^{17} \times 3.0 \times 10^{8}$ (= $1.25 \times 10^{26}$ m) distance = $\frac{4.17 \times 10^{17} \times 3.0 \times 10^{8}}{3.1 \times 10^{16}}$ distance = $4.0 \times 10^{9}$ (pc)	C1	Possible ecf from (ii)1
	Total	12	

Question	Answer	Marks	Guidance	
(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 <sub>o</sub> / Chandrasekhar limit Not: It is a collapsing red giant	
(b)	(parallax = $1/d$ ) $d = 0.0059^{-1}$ (pc = 169 .49 pc) distance = $0.0059^{-1} \times 3.26$	C1	Allow other correct methods	
111	distance = 550 ly	A1		
(c) (i)	power per (unit) area or power/area	B1	<b>Allow</b> 'energy per (unit) area per unit time' <b>Not</b> : power per m <sup>2</sup>	
(ii)	ratio = $\frac{12}{(1.1 \times 10^{5})^{3}}$ ratio = $9.0 \times 10^{-15}$ 2 (power = intensity × surface area) power $\propto 7^{4}r^{2}$ ratio = $\frac{4300^{4} \times (1.1 \times 10^{5})^{2}}{25000^{4}}$	C1 A1 C1 C1	<b>Allow</b> : $9.0 \times 10^{-15}$ : 1 <b>Allow</b> : 1 sf answer of $9 \times 10^{-15}$	
	ratio = $1.1 \times 10^7$	A1	<b>Note</b> : Answer to 3 sf is $1.06 \times 10^7$ <b>Allow</b> : $1.1 \times 10^7$ : 1	

uest	ion	Answer	Marks	Guidance
(a)		recessional speed / velocity of galaxy is proportional to its distance (from us)	B1	<b>Allow</b> : recessional speed of $\underline{\text{galaxy}}$ = Hubble constant $\times$ distance
(b)	(i)	$v = 1010 (10^3 \text{ m s}^{-1})$ d in the range 4.47 to 4.54 (10 <sup>23</sup> m)	B1 B1	<b>Note</b> : Answer to 4 sf is 1014 (10 <sup>3</sup> m s <sup>-1</sup> )
	(ii)	(Straight line drawn through the points gradient = Hubble constant, $H_0$ )  gradient = $2.24 \times 10^{-18}$ (s <sup>-1</sup> )  age = $(2.24 \times 10^{-18})^{-1}$ age = $4.46 \times 10^{17}$ (s)  age = $1.4 \times 10^{10}$ (y)	C1 C1 A1	Allow: gradient in the range 2.21 to 2.27 × 10 <sup>-18</sup> 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 two 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 × 2	Not: More matter than antimatter / baryonic asymmetry
		Total	9	

Question	Answers	Marks	Guidance
(a)	$V = \frac{4}{3}\pi \times (6 \times 10^{3})^{3}  \text{or}  V = 9.05 \times 10^{11} \text{ (m}^{3}\text{)}$ $\text{density} = \frac{2.0 \times 10^{30}}{\frac{4}{3}\pi \times (6 \times 10^{3})^{3}}$	C1	<b>Note</b> : An incorrect equation here for <i>V</i> prevents this and any subsequent marks.
	density = 2.2 × 10 <sup>18</sup> kg m <sup>-3</sup>	A1	The correct unit must also be included to score this A1 mark. <b>Allow</b> 2 marks for 2.76 $\times$ 10 <sup>17</sup> kg m <sup>-3</sup> – 12 km used instead of 6 km for the radius.
(b)	$g \propto 1/r^{2}$ ratio = $\left(\frac{1.4 \times 10^{9}}{12 \times 10^{3}}\right)^{2}$ or ratio = $\left(\frac{0.7 \times 10^{9}}{6 \times 10^{3}}\right)^{2}$ ratio = 1.4 × 10 <sup>10</sup>	C1 A1	Note: The answer to 3 sf is $1.36 \times 10^{10}$ .  Allow 1 mark for $7.3 \times 10^{11}$ – inverse of the ratio.
(c)	$(p = 1/d)$ $d = \frac{8.6 \times 9.5 \times 10^{15}}{3.1 \times 10^{16}} \text{ (pc)} \qquad \text{or}  d = 2.64 \text{ (pc)}$ $p = 0.38 \text{ (arc seconds)}$	C1 A1	Allow full credit for alternative methods.
(d)	$(\frac{\Delta \lambda}{\lambda} = \frac{v}{c})$ fractional change = $\frac{7600}{3.0 \times 10^8}$ percentage change = $2.5 \times 10^{-3}$ %	C1 A1	Allow 1 mark for $2.5 \times 10^{-5}$ (factor of 100 missed out).
(e)	The suggestion is incorrect because Hubble's law applies to (distant receding) galaxies. or The suggestion is incorrect because Hubble's law does not apply to stars in our own galaxy.	B1	Do <b>not</b> allow this mark if 'Sirius / star is moving towards us' is also included.
	Total	10	

uestion		Answer	Marks	Guidance	
(a)		(distance =) $3.0 \times 10^8 \times 3.16 \times 10^7$ distance = $9.48 \times 10^{15}$ (m) $\approx 9.5 \times 10^{15}$ (m)	B1	Allow: (distance =) $3.0 \times 10^8 \times 365(\frac{1}{4}) \times 24 \times 3600$ Allow 1 mark for bald $9.48 \times 10^{15}$ (m)	
(b)		Correct labelling of 1 pc, 1 AU and 1"	B1	Allow: 'hypotenuse' labelled as 1 pc	
(c)	(i)	(distance =) $9.5 \times 10^{15} \times 2.1 \times 10^{7}$ (m) or $2.0 \times 10^{23}$ (m) (distance in pc =) $2.0 \times 10^{23}/3.1 \times 10^{16}$ distance = $6.4 \times 10^{6}$ (pc)	C1 A1	Possible ecf from (a)	
	(ii)	(time =) $10^{44}/4 \times 10^{26}$ (s) or $2.5 \times 10^{17}$ (s) (time =) $2.5 \times 10^{17}/3.16 \times 10^{7}$ time = $7.9 \times 10^{9}$ years	C1 A1	Allow: 1 sf answer of 8 × 10 <sup>9</sup> years	
(d)		Any one from:  Very dense / infinite density / very small / singularity  Any one from:  (Very strong gravitational field therefore) light cannot escape from it / curves space / slows down time / emits Hawking radiation	B1		
1					

Questi	ion	Answer	Marks	Guidance
(a)	(i)	$H_0$ = 1/age $H_0$ = 1/(13.7 × 10 <sup>9</sup> × 3.16 × 10 <sup>7</sup> ) $(H_0$ =) 2.31 × 10 <sup>-18</sup> (s <sup>-1</sup> ) $(H_0$ =) $\frac{2.31 \times 10^{-18} \times 3.09 \times 10^{16} \times 10^6}{10^3}$ Hubble constant = 71.4 (km s <sup>-1</sup> Mpc <sup>-1</sup> )	C1 C1	<b>Allow:</b> 2 sf answer <b>Special case:</b> Using $H_0 = 1/13.7 \times 10^9 = 7.30 \times 10^{-11} \text{ (y}^{-1)}$ gives an answer of $2.26 \times 10^9 \text{ (km s}^{-1)} \text{ Mpc}^{-1)} - \text{allow 1 mark}$
	(ii)	$v = H_0 d$ ( $v = ) 71.4 \times 50 \text{ or } 3.57 \times 10^3 \text{ (km s}^{-1}) \text{ or } 3.57 \times 10^6 \text{ (m s}^{-1})$	C1	Possible ecf from (a)
		$\frac{\Delta \lambda}{\lambda} = \frac{3.57 \times 10^6}{3.0 \times 10^8} (= 1.19 \times 10^{-2})$	C1	
		$\Delta \lambda = 656 \times 1.19 \times 10^{-2} \text{ or } \Delta \lambda = 7.80 \text{ (nm)}$	C1	
		wavelength = 656 + 7.80		
		wavelength = 664 (nm)	A1	Allow: 2sf answer
(b)		Big bang: Creation of the universe (from which space/time evolved) (AW) Any three from:  1. (At the start) the universe was hot / infinitely dense 2. Expansion of the universe led to cooling 3. The (current) temperature of universe is 2.7 K / 3 K 4. (The universe as a black body) is associated with microwaves at this temperature (AW) or The (wavelength of the) gamma radiation stretched to microwaves (by the expansion).  QWC: (Cosmological principle is supported because) MBR is isotropic	B1 × 3	Not: The universe now has microwaves. (The microwaves must be linked with current temperature)  Allow: Microwaves have the same intensity in all directions
Questi	on	Answer	Marks	Guidance
(c)		(For an open / flat universe)  Further expansion will lead to cooling / temperature lower than 3K / temperature tend to absolute zero (AW)  The wavelength (of the EM radiation) gets longer / frequency (of the EM radiation) gets smaller / energy of photons decreases / microwaves become radio waves	B1	Alternative: Temperature (will eventually) increases if <u>closed</u> universe B1 The wavelength (of EM radiation) get smaller B1
(d)		Graph starting from origin and having a shape consistent with either open or accelerated universe	B1	Not a straight line
		Total	15	

Ques	tion	Expected Answer	Mark	Additional Guidance
(a)		Diagram showing (star,) 1 AU, 1 pc and angle of 1 arc second  Distance from a base length of 1 AU that subtends an angle of 1 (arc) second or Parsec is a distance that gives a (stellar) parallax of 1 second (of arc) / 1/3600°	B1	Allow: 1 pc is the <u>distance</u> calculated using: 1 AU/tan(1/3600°) Not: 1 pc = 3.26 ly Not: 1 pc = 3.1 ×10 <sup>16</sup> m
(b)	(i)	distance (pc) = 1 / 0.275 distance = 3.64 (pc)	B1	
	(ii)	distance in m = $3.1 \times 10^{16} \times 3.64 = 1.127 \times 10^{17}$ (m) distance in ly = $1.127 \times 10^{17}/9.5 \times 10^{15}$ distance in ly = $11.9$	C1	Possible ecf from <b>(b)(i)</b> Alternative:  1 pc = 3.26 ly  distance = 3.26 × 3.64  distance 11.9 (y)  A1
		Total	5	

Q	uesti	ion	Expected Answer	Mark	Additional Guidance
	(a)		The speed of recession of a galaxy is proportional to its distance (from Earth / observer)	B1	
	(b)	(i)	$v = \frac{\Delta \lambda}{\lambda} \times c$ $v = 0.15 \times 3.0 \times 10^{8}$ speed = 4.5 × 10 <sup>7</sup> (m s <sup>-1</sup> )	M1 A0	Allow: '15% of $3.0 \times 10^8 = 4.5 \times 10^7$ (m s $^{-1}$ )' Not: '0.15c'
		(ii)	distance = $v/H_0$ (Any subject) distance = $\frac{4.5 \times 10^7 \times 3.1 \times 10^{22}}{65 \times 10^3}$ distance = $2.15 \times 10^{25}$ (m)	C1 A1	Possible ecf from <b>(b)(i)</b> Allow: 1 mark for 2.15 × 10 <sup>n</sup> , n ≠ 25
		(iii)	$H_0 = \frac{65 \times 10^3}{3.1 \times 10^{22}} $ (= 2.10 × 10 <sup>-18</sup> s <sup>-1</sup> ) age = 1/ $H_0$ = 4.77 × 10 <sup>17</sup> (s)	C1	
	(c)		age = 1.49 × 10 <sup>10</sup> (y)  Any two from:  1. Spectra from galaxies show shift to longer wavelengths (suggests galaxies are moving away from the Earth)	A1 B1 × 2	Allow: 1 mark for 1.49 × 10 <sup>n</sup> , n ≠ 10  Not 'red-shift' for 1.
			The more distant galaxies are moving faster (than the ones closer to our galaxy)     Existence of microwave background radiation (which is the same in all directions) / The temperature of universe is 3 K (after cooling due to expansion) / gamma (radiation) became microwaves (as the universe expanded)		Allow: Reference to CMB (radiation) in 3.
			Existence of primordial helium (produced in the early stages of the universe)     Temperature fluctuations (predicted and observed)		Not bald 'ripples' for 5.
			Total	8	

Quest	ion	Expected Answer	Mark	Additional Guidance
(c)	(i)	<ol> <li>Any <u>four</u> from:         <ol> <li>Protons / hydrogen <u>nuclei</u> to produce He <u>nuclei</u> (positrons and neutrinos)</li> <li>There is electrostatic repulsion (between the protons) / The protons repel (each other because of their positive charge)</li> <li>High temperatures / 10<sup>7</sup> K needed (for fusion)</li> <li>(At high temperatures some of the fast moving) protons come close enough to each other for the strong (nuclear) force (to overcome the electrostatic repulsion)</li> </ol> </li> <li>High density / pressure (in the core of the Sun)</li> <li>There is a decrease in mass, hence energy is released / products have greater binding energy</li> </ol>	B1 × 4	<b>Not</b> : 'heat' in place of temperature in 3.
	(ii)	Kinetic (energy) Electromagnetic / photons	B1 B1	Not: heat / thermal (energy) Not: 'radiation' / 'wave energy'' Allow: Gamma
	(iii)	BE = $4 \times 7.2 = 28.8$ (MeV) BE = $28.8 \times 1.6 \times 10^{-13}$ BE = $4.6 \times 10^{-12}$ (J)	C1	Possible ecf if BE value is incorrect
		Total	19	

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Que	stion	Expected Answer	Mark	Additional Guidance
Que (c		Any four from:      Protons / hydrogen nuclei to produce He nuclei (positrons and neutrinos)      There is electrostatic repulsion (between the protons) / The protons repel (each other because of their positive charge)	Mark B1 × 4	Additional Guidance
		<ol> <li>High temperatures / 10<sup>7</sup> K needed (for fusion)</li> <li>(At high temperatures some of the fast moving) protons come close enough to each other for the strong (nuclear) force (to overcome the electrostatic repulsion)</li> <li>High density / pressure (in the core of the Sun)</li> <li>There is a decrease in mass, hence energy is released / products have greater binding energy</li> </ol>		Not: 'heat' in place of temperature in 3.
	(ii)	Kinetic (energy) Electromagnetic / photons	B1 B1	Not: heat / thermal (energy) Not: 'radiation' / 'wave energy' Allow: Gamma
	(iii)	BE = $4 \times 7.2 = 28.8$ (MeV) BE = $28.8 \times 1.6 \times 10^{-13}$ BE = $4.6 \times 10^{-12}$ (J)	C1	Possible ecf if BE value is incorrect
		Total	19	

Question	Answers	Marks	Guidance
(a)	Any four from:  (Sun / star formed from) dust cloud /nebula / (hydrogen) gas  Gravitational collapse (AW)  Temperature of (dust) cloud increases / KE (of cloud) increases / (cloud) heats up  Fusion occurs (when temperature is about 10 <sup>7</sup> K)  Protons / hydrogen nuclei combine to make helium (nuclei)  Stable size star is produced when thermal / radiation pressure is equal to gravitational pressure	B1×4	Must use ticks on Scoris to show where the marks are awarded
	Steps sequenced correctly – QWC mark	B1	
(b)	Any two from:  1. Very dense star  2. Hot star / high surface temperature / low luminosity  3. No fusion reactions take place / leaks away photons (from earlier fusion reactions)  4. Its collapse is prevented by Fermi pressure / mass less than 1.4 solar masses (AW)	B1×2	Must use ticks on Scoris to show where the marks are awarded  Not: small in size, but allow 'smaller than main sequence star / Sun'
(c) (i)	Flat or universe will expand towards a (finite) limit or the rate of expansion will become/tend to zero	B1	
(ii)	Hubble constant = 1/age $H_0 = 1/4.4 \times 10^{17} (= 2.273 \times 10^{-18} \text{ s}^{-1})$ density = $\frac{3H_0^2}{8\pi G}$	C1	
	density = $\frac{3H_0^2}{8\pi G} = \frac{3\times(2.273\times10^{-18})^2}{8\pi\times6.67\times10^{-11}}$ density = 9.2 × 10 <sup>-27</sup> (kg m <sup>-3</sup> ) or 9.24 × 10 <sup>-27</sup> (kg m <sup>-3</sup> )	C1 A1	Allow: 2 marks for a bald 9.24 × 10 <sup>-27</sup> (kg m <sup>-3</sup> ) answer Note: This mark can only be scored if working is
	density is about 10 <sup>-26</sup> (kg m <sup>-3</sup> )	A0	shown

Quest		Answers	Marks	Guidance
	(iii)	number = $9.24 \times 10^{-27}/1.7 \times 10^{-27}$	C1	Possible ecf from <b>(c)(ii) Allow</b> : 2 marks for '10 <sup>-26</sup> /1.7 × 10 <sup>-27</sup> = 5.9 or 6'
		number = 5.4 (Allow 5)	A1	Allow: 2 marks for '10 = 71.7 × 10 = 5.9 or 6'
(d)		$\frac{1}{2}mv^2 = \frac{3}{2}kT  /  \text{speed } \infty \sqrt{T}$	C1	
		ratio = $\sqrt{\frac{10^8}{2.7}}$ ratio = 6.1 × 10 <sup>3</sup> or 6.09 × 10 <sup>3</sup>	A1	
		Total	15	

Question	Answer	Marks	Guidance
(a)	<ol> <li>Any four from:</li> <li>(Fusion is the ) joining / fusing together of ('lighter') nuclei / protons (to make 'heavier' nuclei)</li> <li>Mass decreases in the reaction and this is transformed into energy OR the products have greater binding energy</li> <li>High temperatures / ~10<sup>7</sup> K needed for fusion</li> <li>High pressure / density (required in the core)</li> <li>The protons / nuclei repel (each other because of their positive charge)</li> <li>The strong (nuclear) force comes into play when the protons / nuclei are close to each other</li> </ol>	B1×4	Not: Atoms / particles for nuclei /protons.
(b)	(When hydrogen / helium runs out) the outer layers of the star expands / a (super) red giant is formed  The core (of the star) collapses (rapidly) / a supernova is formed  (Depending on the initial mass of the star the remnant is either a) neutron star or a black hole	B1 B1 B1	
	Total	7	

Question	Answer	Marks	Guidance
(a)	$F = \frac{GMm}{r^2}$	C1	
	force = $\frac{6.67 \times 10^{-11} \times (10^{41})^2}{(4 \times 10^{22})^2}$ force = $4.2 \times 10^{26}$ (N)	C1 A1	<b>Allow</b> : $4 \times 10^{26}$ (N) or $10^{26}$ since this is an estimation <b>Allow</b> : 2 marks for $4.2 \times 10^{n}$ ; 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		Expected Answers	Marks	Additional guidance	
(a)		The critical density is the density for which the universe will expand towards a (finite) limit or rate of expansion <b>tends</b> to zero / which will result in a <u>flat</u> universe	B1	<b>Not:</b> critical density is given by $\frac{3H_0^2}{8\pi G}$	
(b)		$\begin{aligned} &\text{Hubble constant} = \frac{65 \times 10^3}{10^6 \times 3.1 \times 10^{16}} \\ &\text{Hubble constant} = 2.1 \times 10^{-18}  \text{s}^{-1} \\ &\text{critical density} = \frac{3H_0^{\ 2}}{8\pi G} \\ &\text{critical density} = \frac{3 \times (2.1 \times 10^{-18})^2}{8\pi \times 6.67 \times 10^{-11}} \\ &\text{critical density} = 7.9 \times 10^{-27}  (\text{kg m}^{-3}) \end{aligned}$	B1 C1 A1	Possible e.c.f. from value of Hubble constant within this calculation	
(c)	(i)	open: (density of universe < critical density hence) the universe will expand forever  closed: (density of universe > critical density hence) the universe will (eventually stop expanding and then) contract / big crunch  flat: (density of universe = critical density hence) the universe will expand towards a (finite) limit / rate of expansion tends to zero	B1 B1	Allow: 'universe continues to expand'  Not: 'The universe stops expanding'  Special case: Award 1 mark for correct sketches if no explanation is given for open, closed and flat	
	(ii)	Any <u>one</u> from: Existence of dark matter / black holes / neutrinos / dark energy / H <sub>0</sub> is not known accurately	B1		
$\rightarrow$		Total	8		

Qu	Question		Expected Answers	Marks	Additional Guidance
П	а		static / homogeneous	B1	Uniform (density)
			infinite / infinite number of stars	B1	Do not allow isotropic or fixed
П	b	(i)	gradient of graph = H <sub>0</sub>	C1	
Ш			value H <sub>0</sub> = 66 ± 4 (km s <sup>-1</sup> Mpc <sup>-1</sup> ) age = 1 / H <sub>0</sub> (H <sub>0</sub> = 2.1 x 10 <sup>-18</sup> s <sup>-1</sup> )	A1	
		(ii)	age = 1 / H <sub>0</sub> (H <sub>0</sub> = 2.1 x 10 <sup>-10</sup> s <sup>-1</sup> )	C1	ecf from H₀ value
			= $(1/66 \times 3.2 \times 10^{-20} \times 3.2 \times 10^{7})$	C1	Or correct age in seconds (4.7 x 10 <sup>17</sup> s)
			= 1.5 x 10 <sup>10</sup> (1.48 x 10 <sup>10</sup> ) (year)	A1	Answer will depend on H₀ value in (b)(i) Minus one if Mega or kilo omitted
	С	(i)	$\rho_{c} = 3H_{0}^{2} / 8\pi G$ $= [3 \times (2.1 \times 10^{-18})^{2}] / (8 \times \pi \times 6.67 \times 10^{-11})$	-	If with a fill and any coded as any coded in correctly the a
				C1	If units of H₀ not converted or converted incorrectly then maximum one out of two
			= $7.9 \times 10^{-27}$ (kg m <sup>-3</sup> )	A1	
					ecf from H₀ value in (b)(i)
П		(ii)	,		do not allow answers open, closed and flat
			critical then it will be too small to stop it expanding / it goes on forever	B1	
			expanding / it goes on forever	ы	
			if the average density of the Universe is greater		
			than the critical value it will cause the contraction (and produce a big crunch)	B1	
			, ,	ы	
			close to critical value and therefore a universe expands that will go towards a limit / expands		
Ш			at an ever decreasing rate asymptotic	B1	
-	d		galaxies are moving apart / universe is		Allow stars for galaxies
			expanding	(B1)	-
			if galaxies have always been moving apart then		allow from a singularity
			at some stage they must have been closer		,
			together / or started from a point	(B1)	
			evidence in red shift either optical / microwave	(B1)	allow statement that red shift is observed or that blue light becomes red or gamma from big bang has become microwave
			further away the galaxy the faster the speed of		becomes red or gamma from big bang has become microwave
			recession	(B1)	
			the existence of a (2.7 K) microwave		
			background radiation	(B1)	
			there is more helium in the universe than		
			expected	(B1)	
			MAX 4	` '	
				В4	
			Total	[16]	
				[]	

Que	stion	Answer	Marks	Guidance
(a		Any three from:     (Interstellar dust and gas) cloud is drawn together by gravitational force / gravity     Loss in (gravitational) PE / KE increases / temperature increases     Fusion (of protons / hydrogen nuclei) takes place     Energy is released in fusion reactions     A stable star is formed when gravitational pressure is equal to internal / gas / radiation pressure  QWC: The steps in the process are correctly sequenced	B1 × 3	Allow: 'gravitational collapse'
(t	) (i)	Any two from:  (extremely) dense / (very) hot / low luminosity  no fusion reactions occur  it is a remnant of a low-mass star  correct reference to Fermi pressure / electron degeneracy / Chandrasekhar's limit	B1 × 2	
	(ii)	Red giant identified  (It is cooler but has) large <u>surface</u> area (and therefore radiates large amounts of energy)	B1 B1	
		Total	8	

Questi	ion	Answer		Guidance
(a)		The night sky should be bright / have uniform brightness (but it is not)	B1	
		The line of sight ends on (the surface of a star) or 'number of stars $\propto r^2$ and intensity $\propto 1/r^2$ '	B1	
		Any two assumptions about the Universe: Infinite / uniformly distributed matter or stars throughout / static / infinite age	B1	
(b)		(recessional) speed of $galaxy \propto$ its distance (from the Earth)	B1	<b>Allow</b> : $v = H_0 x$ , $v =$ (recessional) speed of galaxy, $x =$ distance and $H_0$ is Hubble constant / a constant
		The universe is finite / it is expanding / it has a beginning / visible light is red-shifted (because of expansion of space) (AW)	B1	
(c)	(i)	$v = H_0 x$		
		$3.4 \times 10^7 = H_0 \times 1.4 \times 10^{25}$	C1	
		$H_0 = 2.4 \times 10^{-18}$	A1	
		unit: s <sup>-1</sup>	B1	Note: This is an independent mark Note: Allow full credit for an Hubble constant of 75 with unit km s <sup>-1</sup> Mpc <sup>-1</sup>
	(ii)1	$age = \frac{1}{2.4 \times 10^{-18}}$	C1	Possible ecf from (i)
		age = $4.17 \times 10^{17}$ (s) age = $1.3 \times 10^{10}$ (years)	A1	
	(ii)2		C1	
		distance = $\frac{4.17 \times 10^{17} \times 3.0 \times 10^{8}}{3.1 \times 10^{16}}$		
		distance = 4.0 × 10 <sup>9</sup> (pc)	A1	Possible ecf from (ii)1
		Total	12	