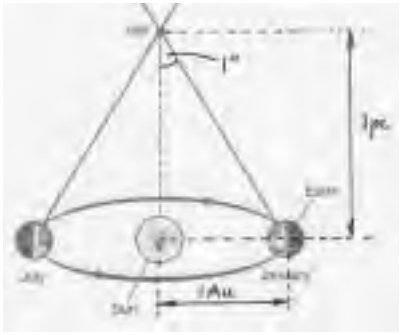
Question			Answer	Marks	Guidance
1	(a)		A core / 'star' left behind after a red giant (has shed its outer layers)	B1	**Allow**: It is the core of a red giant **Allow**: It is the remnant of a low-mass star **Allow**: A core / 'star' • supported by Fermi pressure / electron degeneracy (pressure) • with 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 = $\frac{12}{(1.1\times10^5)^3}$ ratio = 9.0×10^{-15} **2** (power = intensity × surface area) power $\propto T^4r^2$ ratio = $\frac{4300^4\times(1.1\times10^5)^2}{25000^4}$ 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
			Total	**9**	

Question			Answer	Marks	Guidance
2	(a)		recessional speed / velocity of galaxy is proportional to its distance (from us)	B1	**Allow**: recessional speed of galaxy = 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 $\times 10^{-18}$ **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 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 B1 × 2	 **Not**: More matter than antimatter / baryonic asymmetry
			Total	**9**	

Question			Answers	Marks	Guidance
3	(a)		$V = \frac{4}{3}\pi \times (6\times10^3)^3$ or $V = 9.05 \times 10^{11}$ (m^3) density = $\frac{2.0\times10^{30}}{\frac{4}{3}\pi\times(6\times10^3)^3}$ density = 2.2×10^{18} kg m^{-3}	C1 C1 A1	**Note**: An incorrect equation here for *V* prevents this and any subsequent marks. The correct unit must also be included to score this A1 mark. **Allow** 2 marks for 2.76.... $\times 10^{17}$ kg m^{-3} – 12 km used instead of 6 km for the radius.
	(b)		$g \propto 1/r^2$ ratio = $\left(\frac{1.4\times10^9}{12\times10^3}\right)^2$ or ratio = $\left(\frac{0.7\times10^9}{6\times10^3}\right)^2$ ratio = 1.4×10^{10}	C1 A1	**Note**: The answer to 3 sf is 1.36×10^{10}. **Allow** 1 mark for 7.3×10^{-11} – inverse of the ratio.
	(c)		($p = 1/d$) $d = \frac{8.6\times9.5\times10^{15}}{3.1\times10^{16}}$ (pc) or $d = 2.64$ (pc) $p = 0.38$ (arc seconds)	C1 A1	**Allow** full credit for alternative methods.
	(d)		$(\frac{\Delta\lambda}{\lambda} = \frac{v}{c})$ fractional change = $\frac{7600}{3.0\times10^8}$ percentage change = 2.5×10^{-3} %	C1 A1	**Allow** 1 mark for 2.5×10^{-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 **not** allow this mark if 'Sirius / star is moving towards us' is also included.
			Total	**10**	

Question			Answers	Marks	Guidance
4	(a)		The universe is homogeneous. and isotropic (on a large scale).	B1 B1	
	(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.
	(c)		$(\rho = \frac{3H_0^{\ 2}}{8\pi G})$ $H_0 = \sqrt{\frac{8\pi \times 6.67 \times 10^{-11} \times 9.7 \times 10^{-27}}{3}}$ $H_0 = 2.328 \times 10^{-18}$ (s^{-1})	C1	**Allow** any subject
			(age = $1/H_0$) age = $\frac{1}{2.328 \times 10^{-18}}$ or age = 4.3×10^{17} (s)	C1	
			age = 1.4×10^{10} (y)	A1	Answer to 3 sf is 1.36×10^{10} (y)
			Total	**8**	

Question			er	Marks	Guidance
5	(a		(distance =) $3.0 \times 10^8 \times 3.16 \times 10^7$ distance = 9.48×10^{15} (m) $\approx 9.5 \times 10^{15}$ (m)	B1	**Allow**: (distance =) $3.0 \times 10^8 \times 365(¼) \times 24 \times 3600$ **Allow** 1 mark for bald 9.48×10^{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 2.0×10^{23} (m) (distance in pc =) $2.0 \times 10^{23}/3.1 \times 10^{16}$ distance = 6.4×10^6 (pc)	C1 A1	Possible ecf from **(a)**
		(ii)	(time =) $10^{44}/4 \times 10^{26}$ (s) or 2.5×10^{17} (s) (time =) $2.5 \times 10^{17}/3.16 \times 10^7$ time = 7.9×10^9 years	C1 A1	 **Allow**: 1 sf answer of 8×10^9 years
	(d)		Any <u>one</u> from: • Very dense / infinite density / very small / singularity Any <u>one</u> from: • (Very strong gravitational field therefore) light cannot escape from it / curves space / slows down time / emits Hawking radiation	B1 B1	
			Total	**8**	