Question			Answer	Marks	Guidance
1	(a)	(i)	H_0 = 1/age $H_0 = 1/(13.7 \times 10^9 \times 3.16 \times 10^7)$ $(H_0 =)\ 2.31 \times 10^{-18}\ (s^{-1})$ $(H_0 =)\ \frac{2.31\times10^{-18}\times3.09\times10^{16}\times10^6}{10^3}$ Hubble constant = 71.4 (km s^{-1} Mpc^{-1})	C1 C1 A1	 **Allow:** 2 sf answer **Special case**: Using $H_0 = 1/13.7 \times 10^9 = 7.30 \times 10^{-11}\ (y^{-1})$ gives an answer of 2.26×10^9 (km s^{-1} Mpc^{-1}) – allow 1 mark
		(ii)	$v = H_0$ d $(v =)\ 71.4 \times 50$ or 3.57×10^3 (km s^{-1}) or 3.57×10^6 (m s^{-1}) $\frac{\Delta\lambda}{\lambda} = \frac{3.57\times10^6}{3.0\times10^8} (= 1.19\times10^{-2})$ $\Delta\lambda = 656 \times 1.19 \times 10^{-2}$ or $\Delta\lambda = 7.80$ (nm) wavelength = 656 + 7.80 wavelength = 664 (nm)	C1 C1 C1 A1	Possible ecf from **(a)** **Allow**: 2sf answer
	(b)		Big bang: Creation of the universe (from which space/time evolved) (AW) Any <u>three</u> 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 B1 × 3 B1	 **Not**: The universe now has microwaves. (The microwaves must be linked with current temperature) **Allow**: Microwaves have the same intensity in all directions

Question			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 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**	

Question			Answer	Marks	Guidance
2	(a)		Any <u>four</u> from: 1. (Fusion is the) joining / fusing together of ('lighter') <u>nuclei</u> / <u>protons</u> (to make 'heavier' nuclei) 2. Mass decreases in the reaction and this is transformed into energy OR the products have greater binding energy 3. High temperatures / ~10^7 K needed for fusion 4. High pressure / density (required in the core) 5. The protons / nuclei repel (each other because of their positive charge) 6. The strong (nuclear) force comes into play when the protons / nuclei are close to each other	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 <u>supernova</u> is formed (Depending on the initial mass of the star the remnant is either a) <u>neutron star</u> or a <u>black hole</u>	B1 B1 B1	
			Total	**7**	

Question			Answer	Marks	Guidance
3	(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 <u>one</u> 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 <u>six</u> 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 <u>continuous</u> <u>spectrum</u>	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
			Total	**15**	

Question			Expected Answers	Marks	Additional guidance
4	(a)		The critical density is the density for which the universe will expand towards a (finite) limit or rate of expansion **tends** to zero / which will result in a <u>flat</u> universe	B1	**Not:** critical density is given by $\frac{3H_0^{\ 2}}{8\pi G}$
	(b)		Hubble constant = $\frac{65\times10^{3}}{10^{6}\times3.1\times10^{16}}$ Hubble constant = 2.1×10^{-18} s^{-1} critical density = $\frac{3H_0^{\ 2}}{8\pi G}$ critical density = $\frac{3\times(2.1\times10^{-18})^{2}}{8\pi\times6.67\times10^{-11}}$ critical density = 7.9×10^{-27} (kg m^{-3})	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 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_0 is not known accurately	B1	
			Total	**8**	