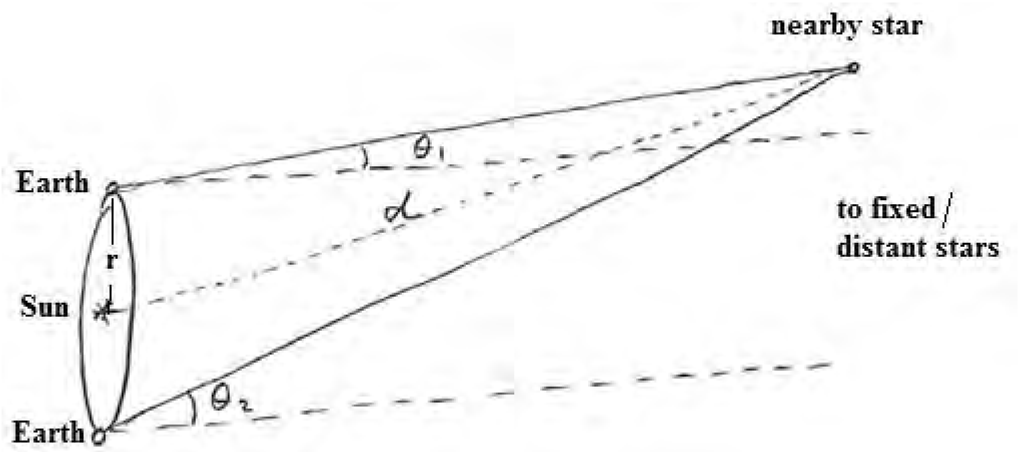
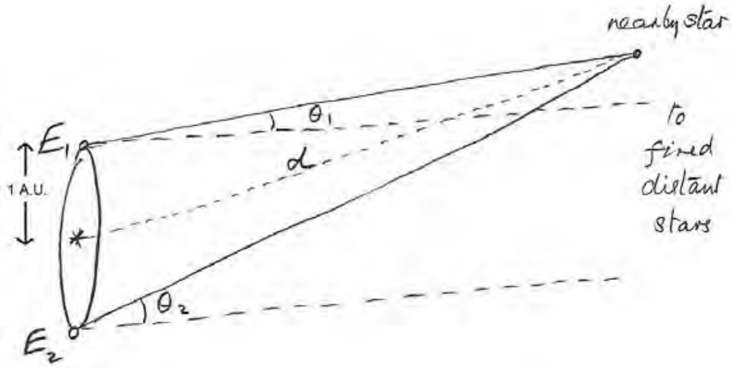
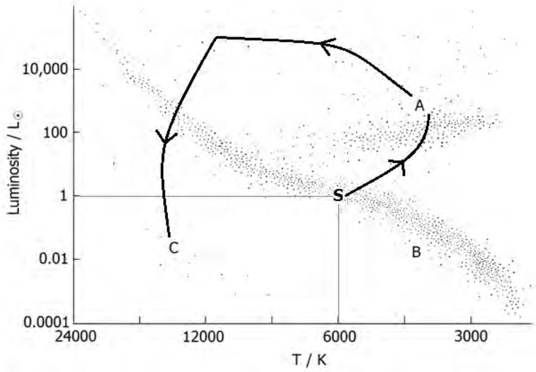
Question Number	Answer	Mark
1	QWC – Work must be clear and organised in a logical manner using technical wording where appropriate **Parallax:** The star is viewed from two positions at 6 month intervals **Or** the star is viewed from opposite ends of its orbit diameter about the Sun (1) The (change in) angular position of the star relative to fixed/distant stars is measured (1) The diameter/radius of the Earth's orbit about the Sun must be known and trigonometry is used (to calculate the distance to the star) [Do not accept Pythagoras] (1) [the marks above may be obtained with the aid of a suitably annotated diagram] e.g  [Accept the symmetrical diagram seen in many text books] **Standard candle:** Flux/brightness/intensity of standard candle is measured (1) (1) Luminosity of standard candle is known [accept reference to absolute magnitude **Or** total power output of star] (1) Inverse square law is used (to calculate distance to standard candle)	6
	Total for question	**6**

Question Number	Answer		Mark
2	**MAX 3** The existence of the microwave background: • Originates from the Big Bang • Microwave radiation comes from the universe itself **Or** it is <u>cosmic background</u> radiation [accept CMB] • Microwave wavelength linked to temperature of universe [e.g. indicates a temperature of space of about 3 K] • Originally the universe was a hotter place than it is now **O**r temperature decreases as the universe expands • Wavelength has been increased Or frequency decreased. (Do not credit changes due to movement of galaxies)	 **(1)** **(1)** **(1)** **(1)** **(1)**	 **3**
	Total for question		**3**

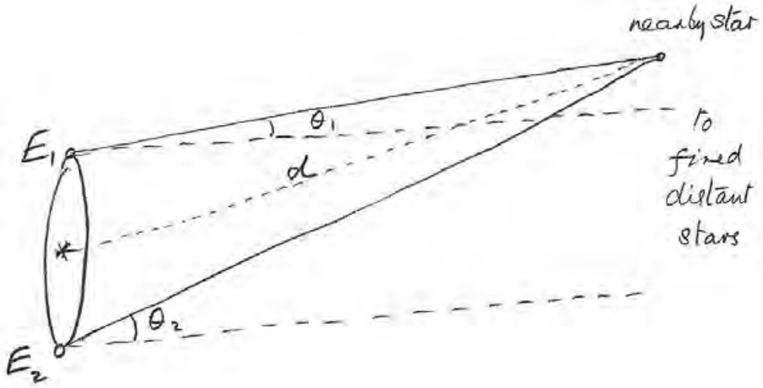
Question Number	Answer	Mark
3(a)	**Max 2** • Angles are measured using the fixed background of more distant stars **(1)** • Find angular displacement of the star (as Earth moves around the Sun) over a 6 month period / over a diameter of the Earth's orbit **(1)** • Diameter of the Earth's orbit about the Sun must be measured/known **(1)** [Full marks can be obtained from an annotated diagram]  	**2**
3(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 **(1)** (due to) recession of the source from the Earth/observer **(1)** Doppler/red shift is used to find v (allow reference to use of red shift equation e.g. $v = zc$) **(1)** Appropriate reference to Hubble's Law **Or** $v = H_0 d$ **(1)** [for 1st marking point allow "decrease in frequency" for "increase in wavelength"]	**4**
	Total for question	**6**

Question Number	Answer		Mark
4(a)(i)	A = Red Giants **Or** Giants B = Main Sequence C = White Dwarfs **Or** Dwarfs	**(1)** **(1)** **(1)**	**3**
4(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**
4(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**
	Total for question		**8**

Question Number	Answer	Mark
5(a)	(A star/astronomical) object of known luminosity (due to some characteristic property of the star/object) **(1)**	**1**
5(b)	Use of $F=L/4\pi d^2$ **(1)** $F = 1.09 \times 10^{-7}$ W m^{-2} **(1)** <u>Example of calculation</u> $F = \frac{L}{4\pi d^2} = \frac{8.94 \times 10^{27}\text{ W}}{4\pi(8.08 \times 10^{16}\text{ m})^2} = 1.0896 \times 10^{-7}\text{ W m}^{-2}$	**2**
	Total for question	**3**

Question Number	Answer	Mark
6(a)(i)	Gravitation OR gravity OR gravitational attraction / pull / force **(1)**	**1**
6(a)(ii)	Use of $F=Gm_1m_2/r^2$ **(1)** F = 4.2×10^{35} (N) (no u.e.) **(1)** <u>Example of calculation</u> $F = \frac{Gm_1m_2}{r^2}$ $F = \frac{6.67\times10^{-11}\text{ N m}^2\text{kg}^{-2}\,(1.6\times10^{39}\text{kg})(4.0\times10^{37}\text{kg})}{(3.2\times10^{15}\text{ m})^2}$ $F = 4.17 \times 10^{35}$ N	**2**
6(a)(iii)	Use of $F = m\omega^2r$ or $F = mv^2/r$ **(1)** Use of $T=2\pi/\omega$ or $T=2\pi r/v$ **(1)** T = 108 (years) [accept 107 – 111 years] (no ue) **(1)** [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> $\omega = \sqrt{\frac{4.2\times10^{35}\text{ N}}{(1.6\times10^{39}\text{ kg})\times7.7\times10^{13}\text{ m}}}$ $\omega = 1.85 \times 10^{-9}$ rad s^{-1} $T = \frac{2\pi\text{ rad}}{1.85\times10^{-9}\text{ rad s}^{-1}} = 3.40\times10^9$ s $T = \frac{3.40\times10^9\text{ s}}{365\times24\times60\times60\text{ s year}^{-1}} = 108$ years	**3**

***6(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 **(1)** This indicates that distant galaxies are receding / distance between galaxies is increasing/galaxies are moving apart **(1)** (Hence) the universe is expanding / provides evidence for Big Bang **(1)**	**3**
6(b)(ii)	The rotational motion (of the black holes) is small compared with that due to the overall recession **(1)** (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 **(1)** ALTERNATIVE APPROACH: Reference to plane of orbit being perpendicular to line of sight from the Earth **(1)** Therefore there is no change in wavelength due to rotation of black holes **(1)**	**2**
6(b)(iii)	Use of $z = v/c$ **(1)** Use of $v = H_0 d$ **(1)** $d = 7.1 \times 10^{25}$ m **(1)** Example of calculation $v = Zc = 0.38 \times 3 \times 10^8 \text{ m s}^{-1} = 1.14 \times 10^8 \text{ m s}^{-1}$ $d = \frac{1.14 \times 10^8 \text{ m s}^{-1}}{1.6 \times 10^{-18} \text{ s}^{-1}} = 7.13 \times 10^{25}$ m	**3**
	Total for question	**14**

Question Number	Answer		Mark
7(a)	Idea that the Earth is orbiting the Sun Reference to (trigonometric) parallax Idea that more distant stars have "fixed" positions	(1) (1) (1)	**(3)**
7(b)	Diagram to show how to measure angular displacement of star over a 6 month period e.  [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 [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 [This may be marked on the diagram or seen in a trigonometric formula]	 (1) (1) (1)	**(3)**
7(c)	Standard candle/Cepheid variable/supernovae	(1)	**(1)**
	Total for question		**(7)**

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

8(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)**
8(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)**
8(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)**
	Total for question	**(16)**