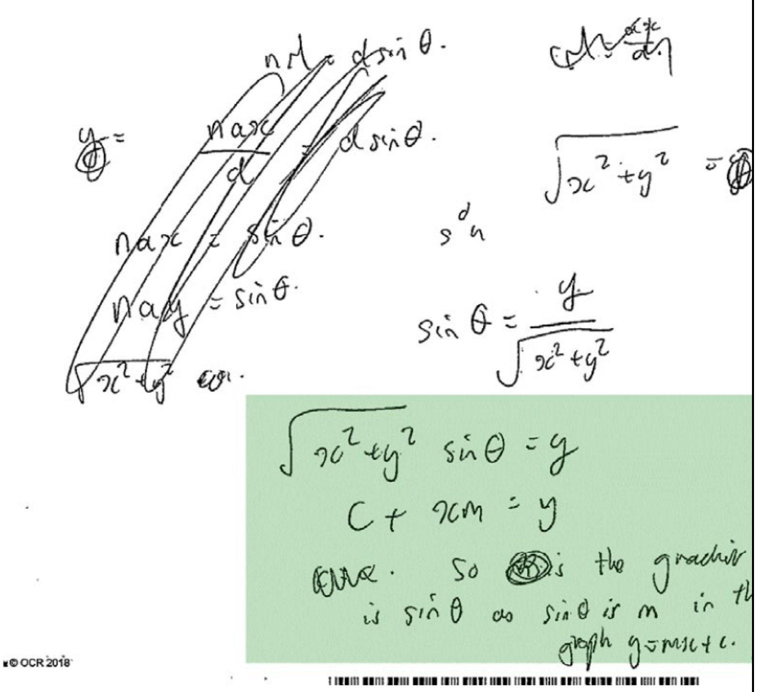
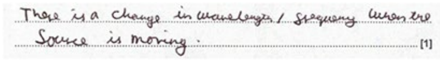
Mark scheme – Astrophysics and Cosmology

Question			Answer/Indicative content	Marks	Guidance
1	a		y = sin (θ) $\sqrt{x^2+y^2}$ compared with "y=mx+c"	B1	**Allow:** gradient = $\frac{\Delta y}{\Delta(\sqrt{x^2+y^2})}$ with sin (*θ*) = O/H **Not:** gradient = $\frac{y}{(\sqrt{x^2+y^2})}$ **unless** "c=0" seen. **<u>Examiner's Comments</u>** Candidates found this item tricky even if they realised that $\sin(\theta) = y/\sqrt{x^2+y^2}$ and then re–arranged the equation into a form comparable with the general equation of a straight line, "y=mx +c". Unless that comparison was clear, then the mark could not be credited. **Exemplar 8**  The exemplar shows a clear way of demonstrating how to show that the gradient of the line of the graph should be sin(*θ*).
	b	i	(Straight line of best fit showing) <u>gradient</u> = 0.73 (*d*sin *θ* = *nλ*) $\frac{1.0 \times 10^{-3}}{600} \times 0.73 = 2 \times \lambda$ *λ* = 6.1 × 10^{-7} (m)	C1 C1 A1	**Allow:** gradient in range 0.70–0.76. **Allow:** evaluation of *θ* = 44–50 (degrees) in place of gradient **Allow:** any subject **Note:** Gradient in range 0.70−0.76 gives λ in range (5.8 – 6.4) × 10^{-7} m **<u>Examiner's Comments</u>**

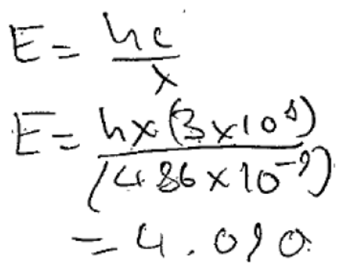
					Many candidates could plot the best fit straight line and attempted to calculate the gradient. Not many candidates after that point realised that the gradient had given them sin(*θ*) and could make no further meaningful progress. Common errors included not calculating *d* correctly from the quoted number of lines mm^{-1} or, less frequently, was using a value different from 2 for *n*.
		ii	(Scales/distances are large compared with the absolute uncertainty so) **<u>absolute uncertainty</u> is too small** to be shown (reasonably on this graph's scale) (AW)	**B1**	**Ignore: error** too small **<u>Examiner's Comments</u>** 20 per cent of candidates did not attempt this item. Some candidates were on the right lines but very few mentioned about absolute uncertainty and that for these instruments and this graph, the absolute uncertainty was too small to view on this scale.
		iii	(The values for λ or *θ* will be) less precise (as independent measurements less likely to agree) (AW)	**B1**	**<u>Examiner's Comments</u>** About two fifths of candidates appreciated that the precision would not be as good with a protractor, as repeated measurements would be less likely to cluster in close proximity. *Precision* The term 'precision' is defined of page 40 the Practical Skills Handbook, along with other useful terms that attempt to describe the quality of data
			Total	**6**	
2			C	1	
			Total	**1**	
3			Observed frequency is different to source frequency when source moves relative to observer.	B1	**Allow** synonyms for 'observed' e.g. perceived / detected / measured **Allow** any correct description of relative motion e.g. when source moves towards an observer (but **not** when source / observer moves) **Allow** the change in <u>observed</u> frequency / the <u>apparent</u> change or shift in frequency when source moves relative to observer **Allow** wavelength in place of frequency Answers must convey the difference between observed frequency and source frequency rather than a change in source frequency **<u>Examiner's Comments</u>** Very few candidates were able to score this mark.

					Misconception When a wave source moves towards or away from an observer, the frequency of the wave does not change; it only appears to have changed when viewed by the observer. **Exemplar 9**  There is a change in wavelength / frequency when the Source is moving. [1] Exemplar 9 illustrates a typical incorrect response.
			Total	**1**	
4			Dark matter / black holes	B1	**Allow**: anti-matter / dark energy
			Total	**1**	
5			(A white dwarf has mass equal to or) less than 1.4(4) solar masses / Chandrasekhar limit (ORA)	B1	**Allow** $M_{\odot}$ for solar mass **Allow** reference to neutron star (over Chandrasekhar limit) **Allow** correct reference to electron degeneracy pressure / Pauli Exclusion Principle
			Total	**1**	
6			Recessional speed / velocity of galaxy is proportional to its distance (from us)	B1	
			Total	**1**	
7			**A =** white dwarf and **B =** red giant	**B1**	**Allow:** red supergiant for B **Not:** neutron star for A
			Total	**1**	
8			Arrow acting along line from planet towards sun	B1	Any arrow length
			Total	**1**	
9			A	1	
			Total	**1**	
10			A	1	
			Total	**1**	
11			**D**	**1**	<u>**Examiner's Comments**</u> The key to this question is to find the energy of the photon (from E = hf) which gives 2.72×10^{-19} J. The energy level X is this amount of energy *below* -5.40×10^{-19} J, which can only be answer D.
			Total	**1**	

12			C	1	
			Total	**1**	
13			A	1	
			Total	**1**	
14			B	1	
			Total	**1**	
15			C	1	
			Total	**1**	
16			Uniform distribution of matter (everywhere in the Universe)	**B1**	**Allow:** density of Universe (approximately) constant throughout **Not:** references/idea of isotropic/"looks the same in all directions" **Examiner's Comments** Just under half of the candidates got this term correct. The majority that did not confused this term with isotropic or used insufficiently clear language, such as 'the universe is the same everywhere'.
			Total	**1**	
17			D	1	
			Total	**1**	
18			A	1	
			Total	**1**	
19			D	1	**Examiner's Comments** The Chandrasekhar limit for the mass of a white dwarf is 1.4 solar masses. The mass of the Sun is 2.0×10^{30} kg, so the mass limit for a white dwarf is 2.8×10^{30} kg. Only star D exceeds this limit, so it cannot be a white dwarf.
			Total	**1**	
20			B	1	**Examiner's Comments** Option D is the speed of light, so the galaxy cannot be travelling this fast. The change in wavelength for the galaxy is 20 nm. The laboratory wavelength for this light is 590 nm. The relationship we need is that the fractional change in wavelength for light from a galaxy approximately equals the fraction of the speed of light for that galaxy.

					The fractional change in wavelength is 20/590 = 3.39 % 3.39% of the speed of light = 1.02 × 10^7 m s^{-1}, i.e. option B. Option A was the most common incorrect response, which is the speed when the change is wavelength is divided by the wavelength of light from the galaxy.
			Total	**1**	
21			D	1	
			Total	**1**	
22			D	1	
			Total	**1**	
23			B	1	
			Total	**1**	
24			B	1	
			Total	**1**	
25			**B**	1	**Examiner's Comments** This question required the temperatures to be converted into kelvin before finding the peak wavelength, giving option B rather than option A. This question provided opportunities for middle-grade candidates.
			Total	**1**	
26			**B**	1	**Examiner's Comments** This question did not discriminate very well at all. The key point is that the emission lines all undergo the same **fractional** wavelength increase, so that the longer wavelengths will have larger absolute increase, as indicated by option B. Option A gives lines which are all the same absolute increase.
			Total	**1**	
27			**C**	1	**Examiner's Comments** This question proved particularly straightforward and accessible to nearly all candidates.
			Total	**1**	
28			C	1	
			Total	**1**	

29			B	1	
			Total	**1**	
30			Any <u>two</u> from: • Black hole has smaller mass / radius / size • Black hole has higher density/gravitational field strength/ stronger gravitational field • black hole absorbs light / does not emit visible light • Has an escape velocity => c • No fusion in a black hole (ORA)	B1 B1	**Allow** black hole emits Hawking radiation
			Total	**2**	
31			λ_1 = d sin 12.5 = 4.33 × 10^{-7} m giving 1/d = 5 × 10^5 or d = 2 × 10^{-6}	C1	or λ_2 = d sin 14.0 = 4.84 × 10^{-7} (m)
			λ_3 = sin 19.0/5 × 10^5 = 6.51 × 10^{-7} (m) **or** λ_1 = d sin 12.5 = 4.33 × 10^{-7} and λ_3 = d sin 19.0 so λ_3 = 4.33 × 10^{-7} sin 19.0/sin 12.5 = 6.51 × 10^{-7} (m)	A1	or use λ_2 = d sin 14.0 = 4.84 × 10^{-7} m sin 19.0/sin 12.5 = 0.326/0.216 = 1.50
			Total	**2**	
32		i	(Stronger) gravitational attraction between nearby galaxies affects motion / clustering of galaxies	B1	
		ii	Expansion rate may not have been constant / non-linear expansion / effect of dark energy causing accelerating rate of expansion	B1	
			Total	**2**	
33			λ_{max} × *T* should be constant if Wien's law is obeyed.	M1	
			At least data from three stars is used to carry out the test and a clear conclusion.	A1	**Ignore** POT **Note** λ_{max} × *T* values are 2.91 (× 10^{-3}), 2.91 (× 10^{-3}), 2.88 (× 10^{-3}) and 2.99 (× 10^{-3}) − hence expect '*yes the law is obeyed*'.
			Total	**2**	

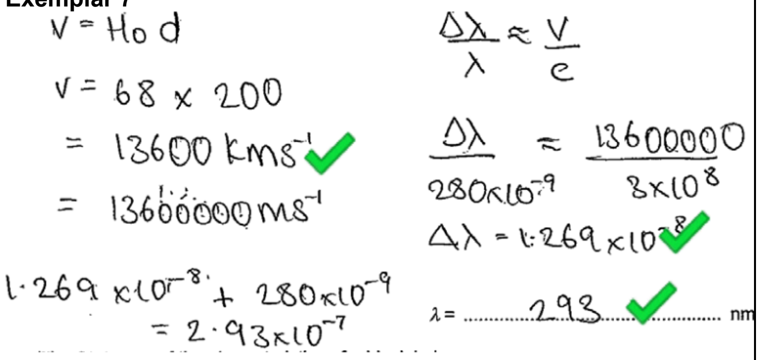
34		i	$E = (hc/\lambda) = 6.63 \times 10^{-34} \times 3(.00) \times 10^{8} / 486 \times 10^{-9}$ $E = 4.09 \times 10^{-19}$ (J)	B1 B1	This is a 'show that' question so the mark is for giving the full substitution of values leading to an answer correct to 3 SF **Examiner's Comments** This question was successfully attempted by the majority of candidates. **Exemplar 8**  Exemplar 8 shows the most common incorrect response. The candidate has not realised that, in a 'show that' question, an equation, full substitution and calculated response are all required. This includes inserting numerical values for the constants h and c.
		ii	(vertical) arrow pointing downwards from -1.36 to -5.45	B1B1	**Examiner's Comments** The majority of candidates scored at least 1 mark, although some would have been helped by better presentation.
			Total	**3**	
35		i	(λT = constant) $550 \times 5800 = 370 \times T$ T = 8600 (K)	**C1** **A1**	**Allow** however expressed Answer is 8620 to 3 sf
		ii	**P** on the main sequence and to LEFT of Sun.	**B1**	**Allow:** ECF from **(b)(i)** **Note:** temperature of Sun is 5800 K. **Examiner's Comments** This whole question was well answered in general. Very few could not identify white dwarf and red giant stars. The calculation of the surface temperature was straightforward with a minority suggesting that $\lambda_{max} \propto T$. In either case, most candidates plotted the position of Beta Pictoris on the HR plot successfully.
			Total	**3**	
36	a	i	**X** at closest point on orbit to the Sun	B1	**Allow X** on the orbit to the <u>left</u> of the Sun
		ii	(When the asteroid orbits the sun a) line segment joining the asteroid to the	B1	**Allow** this mark on diagram (no labelling required) **Allow** 'equal area swept in same time'

			Sun sweeps out equal areas in equal time (intervals) Longer distance (in orbit for the same time)	B1	
	b	i	Work done per unit mass to move an object from infinity (to that point)	B1	**Not '** work done on 1 kg'
		ii	Manipulation of $V_{(g)} = (-)\ GM/r$	B1	
		iii	gradient = (−)30.4 or equivalent working candidate's gradient or expression = $6.67 \times 10^{-11} \times M$ and M calculated correctly from that gradient $M = 4.6 \times 10^{11}$ (kg)	C1 C1 A0	**Allow** ± 2 Possible ECF from incorrect gradient **Allow** any subject
	c		**Method 1:** Evidence of 2.3×10^{-3} and 600^{-1} or $(2.3 \times 10^{-3})^{-1}$ and 600 $\frac{1}{2} v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$ $v = 0.20$ (m s^{-1}) **Method 2:** Evidence of 7.0×10^{-2} and 5.1×10^{-2} from graph $\frac{1}{2} v^2 (= \Delta V_{(g)}) = 7.0 \times 10^{-2} - 5.1 \times 10^{-2}$ $v = 0.19$ (m s^{-1})	C1 C1 A1 (C1) (C1) (A1)	Possible ECF from **(b)(iii)** for either value of *GM* or *M* **Allow** $\frac{1}{2} v^2 = 30 \times (2.3 \times 10^{-3} - 600^{-1})$ **Note** answer can be 0.19 or 0.20 or 0.2 m s^{-1} **Note** answer can be 0.19 or 0.20 or 0.2 m s^{-1} **Allow** correct use of one piece of data arriving at a value for v for 1 mark max
			Total	**10**	
37	a	i	Electron(s) makes a transition to a lower (energy) level / loses energy **and** emitting a photon(s) / EM radiation	**B1**	**Examiner's Comments** Many candidates muddled up emission (lines emitted by a source) and omission (as in lines absorbed by a low pressure gas when a continuous spectrum passes through it, as in an absorption spectrum), so could not score the mark. Some focused on the experimental procedure of using a diffraction grating. A third of candidates correctly stated that the electron dropped down to a lower energy state, releasing a photon or the equally acceptable 'EM radiation'
		ii	Reduce grating separation / increase distance between grating and screen	**B1**	**Allow** 'use finer grating' or 'use grating with more lines mm^{-1}' **Not** 'smaller slit size' **Examiner's Comments** This item tested knowledge of specification 5.5.2 (g) and PAG 5. It would be advisable for Centres, where possible, to allow candidates to observe the effect of changing the slit separation and the grating-

					screen separation independently. Approximately a third of students correctly suggested making one of those adjustments, even if they expressed the former as 'increase the number of lines per mm'. Some candidates presented arguments about plotting the graph on a smaller scale or measuring the wavelength in picometres in an attempt to resolve the peaks in the plot, which was a mis-interpretation of the question.
		iii	wavelength (of peak) = 661.5 nm $v = 3.0 \times 10^8 \times (661.5 - 656.3) / \mathbf{656.3}$ recession velocity = 2.4×10^6 (m s^{-1})	**C1** **C1** **A1**	**Allow:** between 661 and 662 nm **Note:** check divided by 656.3 nm Range of acceptable answers. 2.1(5)−2.6(1) × 10^6 **Examiner's Comments** Examiners were pleased to see this item answered well, with the majority of candidates gaining either two or three marks. Those that did not either misread the position of the red-shifted spectral peak, did not recognise that they were looking for the peak wavelength or did not use the 'at rest' wavelength for the denominator of the expression for the change in wavelength.
		iv	(Relative) abundance of hydrogen (AW)	**B1**	**Allow** 'Hydrogen commonly found in stars' (AW) **Examiner's Comments** Just over half of all candidates realised that the useful property of hydrogen was its relative abundance in stars and hence galaxies.
	b		Less intense Galaxy is moving faster **and** therefore greater / longer wavelength (AW) Periodic shift in wavelength (if plane of orbit is in line of sight) (ORA)	**B1** **B1** **B1**	**Allow** 'greater red shift' / 'greater Doppler shift' / 'to the right' for longer wavelength **Allow** argument referring to splitting of line because of relative velocities of two component stars. **Not** idea of blue shift. **Examiner's Comments** Some 9% of all candidates declined to answer this item, the highest rate for any item on this paper. The most common correct response linked higher distance with higher recessional velocity and thus higher increase in wavelength. Higher ability candidates explained that the orbiting stars would have different velocities relative to the Earth resulting in a periodic change in wavelength from the central peak. References to blue-shifting were erroneous and contradictory.
			Total	**9**	
38			Apparent motion or displacement of a star relative to the position of more distant stars.	B1	
			Caused by the Earth's orbit around the Sun.	B1	

			An angle of parallax of 1 arcsecond when displacement of Earth is 1AU corresponds to distance 1 pc	B1	
			Total	**3**	
39		i	the uncertainty in the measurement of angle is the same for all angles and the bigger the angle measured the smaller the % error	B1	
		ii	n_{max} = d sin 90	C1	
		ii	= 1/(5 × 10^5 × 4.33 × 10^{-7}) = 4.6 but n is an integer so n = 4	A1	
			Total	**3**	
40			Any **four** from • reduction in energy released by fusion • gravitational force is greater than that from radiation and gas pressure • core collapses • fusion no longer takes place in the core • fusion continues in the shell around the core • outer layers of star expand and cool • outer layers are released • reference to planetary nebula • reference to <u>white</u> dwarf (left as remnant hot core)	B1 × 4	**Ignore** current or previous stages of the Sun's evolution
			Total	**4**	
41		i	v = 68 × 200 = 13600 (km s^{-1}) or 13.6 × 10^6 m s^{-1} $(\Delta\lambda = \frac{v}{c} \times \lambda)$ (change in λ =) 13600 × 10^3 × 280/3.00 × 10^8 or 13 (nm) or 13 × 10^{-9} (m) (λ = 280 + 13) λ = 290 (nm)	**C1** **C1** **A1**	**Allow:** Any correct velocity if unit matches. **Allow:** ECF for incorrect v **Answer to 3 sf is 293 (nm)** **Allow:** ECF for incorrect $\Delta\lambda$ **<u>Examiner's Comments</u>** This is a more challenging question with several steps. In multiplying the distance in Mpc by the H0 as quoted, the velocity of the galaxy

					was 13600 km s^{-1}. Some candidates handled the units well in this question, reaching a change in wavelength of 13 nm. If the candidate got as far as that, then approximately half then went on to add the change in wavelength correctly. The change is added as the galaxy is going away from us. **Exemplar 7**



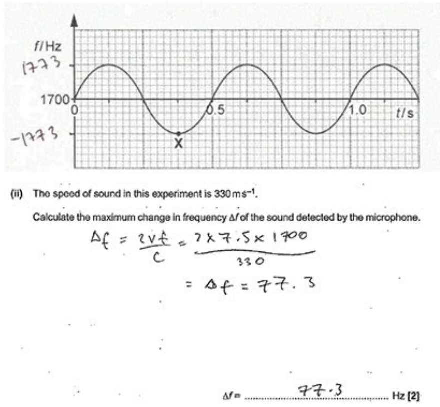
					This candidate has laid out the calculation very carefully. It is obvious that they have handled the idea that the speed of light is given in m s^{-1} and that the galaxy's velocity is in km s^{-1}. This gives the correct change in wavelength and eventually the correct wavelength.
		ii	Any suitable <u>one</u> from: • Very/infinitely dense • Idea that escape velocity ≥ or 'light cannot escape it'	**B1**	**Allow:** singularity **Allow:** physical radius ≤ event horizon radius **Allow:** Distorts space(time) **significantly** / bends light **significantly** **Allow:** Emits Hawking radiation **<u>Examiner's Comments</u>** Lots of candidates had some good ideas here, and had clearly read widely about black holes. The better answers were those that were specific to black holes rather than merely 'high mass', for example. Good ideas included: • 'has an escape velocity greater (or equal to) the speed of light' • 'infinitely dense' • 'emits Hawking radiation' • 'event horizon greater than physical radius'
			Total	**4**	
4 2		i	λT = constant however expressed $500 \times 5.8 \times 10^3 = 240 \times T$ <u>and</u> T correctly evaluated T = 12000 (K)	C1 C1 A0	**Note** answer is 12080 (K) to 4 SF **Allow** any subject
		ii	($L = 4\pi r^2 \sigma T^4$)	C1	**Note** 12080 K gives 5.5×10^{10} (m)

			$4.62 \times 10^{31} = 4\pi \times 5.67 \times 10^{-8} \times r^2 \times 12000^4$ radius = 5.6×10^{10} (m)	A1	
			Total	**4**	
43			Any three from: 1. At the Big Bang the Universe is a singularity / very dense / very hot 2. Expansion / inflation / high energy (gamma) photons but no matter 3. Quarks and leptons form / Quark−Gluon Plasma phase 4. Quarks combine to form neutrons / protons / hadrons 5. **Hadrons / neutrons and protons / nucleons combine** to make nuclei All candidate's points in the correct sequence	**M1x3**	**Allow for point 1:** fundamental forces unified **Ignore:** Any phase after nuclei phase e.g. recombination era /formation of atoms/formation of CMBR **Examiner's Comments** Many candidates did well on this question as they had learnt the stages and the order of those stages well. The most common reason for loss of marks was not including details about leptons or getting the stages in the wrong order.
			Total	**4**	
44		i	3 downward arrows correctly labelled.	B1	longest being 4.33×10^{-7} (m)
		ii	$\Delta E = hc/\lambda$	C1	
		ii	$\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 4.8 \times 10^{-20}$ $= 4.1(4) \times 10^{-6}$ (m)	A1	
		ii	region: infra red	B1	**allow** ecf if wavelength calculation incorrect.
			Total	**4**	
45	a	i	$F = GMm/r^2$ $F = G \times (2.0 \times 10^{41})^2 / (1.4 \times 10^{23})^2$ force = 1.4×10^{26} (N)	C1 A1	**Note** the mark is for substitution, value of G is not required **Ignore**: minus sign **Allow** 1 mark for 1.4×10^4 N ;use of mass of star instead of mass of galaxy. **Examiner's Comments** While some lower level responses included an attempt to find the gravitational field strength rather than the force most selected the correct formula. After selecting the correct relationship, most candidates could then correctly find the force, provided that they remembered to multiply the masses and square the distance of separation.

		ii	density = 10^{11} x 2.0 x 10^{30}/2.7 x 10^{69} density = 7.4 x 10^{-29} (kg m^{-3})	M1 A0	
		iii	Any reasonable answers questioning modelsuch as observed average distance may be different, average mass may be wrong etc.	B1	**e.g.** black holes, dark energy/matter, expanding universe **<u>Examiner's Comments</u>** This was a question about challenging the model of the universe. The model takes into account an average mass and average distance of separation, so answers that referred to a variation in masses or distances between galaxies did not score. Higher level responses included that the universe was expanding, so that the distances involved were always changing, or that dark matter was not included in the calculations. There was no indication that candidates were constrained by time in this paper.
	b	i	distance between positions = 3.1 cm 2*p* = 3.1/2 (any subject) *p* = 0.78 arc seconds	M1 M1 A0	**Allow** distance in the range 2.9 to 3.2 cm **<u>Examiner's Comments</u>** Almost all candidates scored a mark for measuring the distance between promixa centauri's positions 6 months apart. The scale was well understood, giving an angle of approximately 1.5 arc seconds. The parallax angle is defined to be half of this value, giving a parallax angle in this case of 0.75 arc seconds. This final step was what prevented candidates receiving the second mark.
		ii	(*d* = 1 / *p*); d = 1 / 0.8) or 1.25 (pc) *d* =1.25 x 3.26 *d* = 4.1 (ly)	C1 A1	**Allow**: their value for p Possible ECF from **(a)(i)** Answer is 4.2 using 0.78 arc seconds **<u>Examiner's Comments</u>** Most candidates used the data in the previous part of the question ie that the parallax angle was 0.8 arc seconds or trusted their own value which was close to 0.8 arc seconds. Nearly everyone that presented a distance in parsecs could then calculate the distance in light years.
			Total	**8**	
46		i	L (= $4\pi r^2\sigma T^4$) = 4 × π × (7.0 × 10^8)^2 × 5.67 × 10^{-8} × 5800^4 L = 3.95 × 10^{26} (W)	M1 A0	Mark is for substitution of values **Allow** σ for 5.67 × 10^{-8} **<u>Examiner's Comments</u>** Most candidates successfully used the formula for Stefan's Law.
		ii	By ratios: 25 = 1.7^2 x $(T/5800)^4$	C1 C1	**or** $T^4 = 25L/4\pi\sigma(1.7r)^2$ $= \frac{25 \text{ x } 3.95 \text{ x} 10^{26}}{4\pi \text{ x } 5.67\text{x } 10^{-8} \text{ x } (1.7 \text{ x } 7 \text{ x } 10^8)^2}$ **ECF** for L in **a(i)** but only if L = 4 x 10^{26} to 1s.f. **ECF** for incorrect σ in **a(i)**

			$T^4 = 9.8 \times 10^{15}$ $T = 9950$ (K)	A1	**Allow** 9.9×10^{15} (using $L = 4 \times 10^{26}$) **Allow** 10,000 K **Examiner's Comments** Higher ability candidates successfully used the more elegant ratios method to reach the correct response. Lower ability candidates had more success if they broke their calculation down into smaller steps, such as calculating and writing down T^4 rather than going straight to T. Candidates should be encouraged to consider whether their responses to calculations are reasonable as this will alert them to a possible error. For example, some candidates calculated the temperature of Sirius (which they were told is the brightest star in the night sky) to be less than 1K.
			Total	**4**	
47		i	$v = \frac{(489.8 - 486.1) \times 3 \times 10^8}{486.1}$ (= 2.28×10^6 age = $1/H_o = \frac{16.5 \times 10^6 \times 3.1 \times 10^{16}}{2.28 \times 10^6}$ age = 2.2×10^{17} (s)	C1	
		i		C1	
		i		A1	
		ii	Hydrogen is most common element in stars or Hydrogen has most intense (spectral) lines.	B1	
		ii	Intensity of light from other elements may be too low for accurate measurement.	B1	
			Total	**5**	
48		i	electron bound to nucleus / represents energy electron must gain to leave the atom / total energy of electron in atom is less than that of a free electron	**B1**	**Allow** ionisation level defined as zero as AW for 'represents electron must gain energy to leave atom / move up energy level' **Allow** potentials for attractive forces are negative. **Examiner's Comments** This item provided good discrimination between the candidates. Many responses referred incompletely to the negative charge of the electron being the only factor, whereas the correct explanation is much more to do with the electron requiring energy to leave the atom and the ionization level being defined as the zero point. Some candidates were on the right path when they referred to the equivalent statement for gravitational potential energies.
		ii	**1** energy = 2.55 (eV) **2** energy = $2.55 \times 1.60 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.55 \times 1.60 \times 10^{-19}}$ (Allow any subject)	**B1** **C1** **C1**	Ignore sign Possible ECF from **(ii)1**

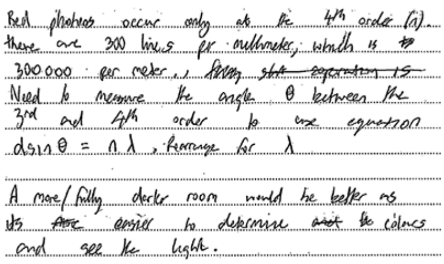
			wavelength = 4.9 × 10^{-7} (m) wavelength = 490 (nm)	A1	**Note:** wavelength = 488 (nm) to 3 sf **Examiner's Comments** Virtually all candidates correctly evaluated the energy difference to be 2.55 eV. Negative values were condoned but are unlikely to be accepted in future series. Many candidates correctly calculated the wavelength of emitted light, although a minority did not convert the energy into joules or performed the required conversion to nanometres incorrectly.
			Total	**5**	
49		i	$\Delta\lambda = \frac{\lambda v}{c} = \frac{486\times10^{-9}\times960\times10^{3}}{3.00\times10^{8}}$	C1	
		i	Δλ = 1.56 (nm)	C1	
		i	λ = 486 + 1.56 = 488 (nm)	A1	
		ii	*d* = 1.25 × 10^{-6} m $\theta = \sin^{-1}\left(\frac{2\times486\times10^{-9}}{1.25\times10^{-6}}\right)$	C1	
		ii	θ = 51°	A1	**Allow** 1 mark $\theta = \sin^{-1}\left(\frac{2\times488\times10^{-9}}{1.25\times10^{-6}}\right)$ = 51° ; incorrect 488 nm used instead of 486 nm.
			Total	**5**	
50		i	*T* = 0.50 (s) **or** *f* = 2.0 (Hz) *v* = (2πr/T =) 2π x 0.60/0.5 *v* = 7.5 (m s^{-1})	C1 M1 A0	**Allow** 1.2π/0.5 or 2.4π = 7.54 (m s^{-1}) Alternative method: ω = 4π or 12.6 (rad s^{-1}) (**C1**) v (= r ω) = 0.60 x 12.6 or 2.4π (**M1**) = 7.54 (m s^{-1}) (**A0**) **Examiner's Comments** Most candidates scored this mark. Some tried to use the Doppler equation to find the speed of the sound (rather than the speed of the loudspeaker).
		ii	Δ*f* (≈ *vf/c*) = (7.5 x 1700) / 330 Δ*f* = 40 (Hz) (or 39Hz)	C1 A1	Note that c represents the velocity of sound **Examiner's Comments** The question had stated clearly that the students were investigating the Doppler effect, and candidates were expected to use the Doppler equation Δf/f ≈ v/c.

		iii	y-axis labelled with correct scale	B1	**Allow** as a minimum one labelled point i.e. 1740 **or** 1660 **ECF(c)(ii)** for incorrect Δf **Examiner's Comments** Many candidates left 6(c)(iii) blank, although full marks could have been given from ECF from (c)(ii). The most common error here was using + and – the value obtained in (c)(ii), rather than subtracting or adding it to 1700, as demonstrated in Exemplar 10 below. **Exemplar 10** 
		iv	**X** labelled at lowest point of circle on Fig. 6.1	B1	**Examiner's Comments** The purpose of this question was to test whether candidates could associate a maximum decrease in observed frequency (a 'red shift') with motion directly away from the observer / microphone. Unfortunately, not many were able to place the cross correctly, with many leaving this response blank.
			Total	**6**	
51			**Level 3 (5−6 marks)** Correct calculations for radius and temperature range or distance or intensity for Earth-like temperature within given distance range, with clear explanation. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3−4 marks)** Radius calculated or at least one temperature of planet calculated and some explanation. *There is a line of reasoning presented with some structure. The information*	B1x6	Use level of response annotation in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks etc. **Indicative scientific points may include:** **Explanation** • TRAPPIST-1 is cooler than the Sun • The planets are closer to TRAPPIST-1 • Possible for temperature on planets to be like Earth • For life to exist, temperature is not the only factor • $L = 4\pi r^2\sigma T^4$ (Any subject) **Calculations** • Calculation of 'constant' for Earth: 4(.19) x 10^5 • For inner-most planet, T = 430 K • For outer-most planet, T = 180 K • Calculation of distance for T = 290 K, i.e. 3.4 x 10^9 (m)

			presented is in the most-part relevant and supported by some evidence. **Level 1 (1−2 marks)** Some explanation and an attempt at least one calculation. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		• There must therefore be a planet with temperature similar to that of the Earth • $L = 4\pi r^2\sigma T^4$ used to calculate radius of TRAPPIST-1 • Radius of TRAPPIST-1 is 8.5 x 10^7 (m) **or** L/T^4 is smaller for TRAPPIST-1 • Comparison of calculated intensities at extreme distances around TRAPPIST-1 to intensity at Earth **<u>Examiner's Comments</u>** This level of response question was very well answered, largely due to the highly mathematical content. Higher level responses showed clarity of method as well as one of a range of ways of supporting the idea that life may be possible on the planets of TRAPPIST-1. Many candidates opted to show that that the temperature of the nearest planet was approximately 430 K while that at the furthest planet was approximately 180 K. The argument went that there must be a distance at which the temperature was approximately 290 K. Other methods found the distance from TRAPPIST-1 that would give a surface temperature of 290 K and showed that lay within the range of distances given in the table.
			Total	**6**	
52			***Level 3 (5–6 marks)** Expect T1 and T2 for the Big Bang Theory Expect full discussion of red shift points R1, 2, 3 and 4 Expect at least B1 and B2 for the Blue Shift Expect C1 and any three from C2, C3, C4, C5 for CMBR *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Expect T1 and T2 for the Big Bang Theory Expect R1 and R2; red shift identified but no explanation why it implies an expanding Universe Expect B1 and B2; blue shift identified with no explanation of cause Expect any three from C1, 2, 3, 4 and 5; CMBR evidence recalled but linked to the Big Bang *There is a line of reasoning presented with some structure. The information*	B1 × 6	**Big Bang Theory (T)** 1. Predicts that all galaxies will be receding. 2. Galaxy velocity proportional to distance from Earth. **Red Shift (R)** 1. Radiation from Virgo shows increase in wavelength or red shift 2. Change in wavelength caused by motion of galaxy or reference to Doppler Effect 3. Evidence that Virgo is receding from Earth. 4. Support for Big Bang theory. **Blue Shift (B)** 1. Andromeda shows blue shift 2. Andromeda approaching Earth 3. Caused by gravitational attraction. **CMBR (C)** 1. Formed as gamma radiation at Big Bang 2. Galactic red shift to microwave wavelength 3. Intensity is uniform in all directions 4. Corresponds to a temperature of 2.7K

			presented is in the most-part relevant and supported by some evidence. **Level 1 (1–2 marks)** Expect T1 or T2 for the Big Bang Theory Expect R1, R2 or B1, B2; red shift or blue shift identified but without explanation or link to Big Bang Theory Expect at least one from C1, 2, 3, 4 and 5; CMBR evidence recalled but not linked to the Big Bang *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		5. (Very small) ripples in intensity corresponding to formation of first stars or galaxies.
			Total	**6**	
53		i	$E = hc/\lambda$; $\Delta\varepsilon = E1 - E_2 = hc\Delta\lambda/\lambda^2$	C1	**allow** calculation of $E = hc/\lambda$ twice and difference taken
		i	$\Delta\varepsilon = 6.63 \times 10^{-34} \times 3 \times 10^8 \times 0.6 \times 10^{-9} / 5.9^2 \times 10^{-14}$	C1	
		i	$\Delta\varepsilon = 3.4 \times 10^{-22}$ (J)	A1	
		ii	$\sin\theta = n\lambda/d$; $1/d = 3 \times 10^5$ (m^{-1})	C1	
		ii	$\theta_1 - \theta_2 = \sin^{-1}(2 \times 589.6 \times 3 \times 10^{-4}) - \sin^{-1}(2 \times 589 \times 3 \times 10^{-4})$	M1	**or** similar
		ii	$\theta_1 - \theta_2 = 20.717 - 20.695 = 0.022^0$	A1	**allow** 20.72 − 20.70
			Total	**6**	
54			***Level 3 (5-6 marks)** Clear use of data and discussion of MBR. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** Some use of data and discussion of MBR. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant*	B1x6	**Indicative scientific points may include:** **Use of data** • The table of values for *d* and *v* support the idea of an expanding Universe. • Calculate of H_0 more than once using data. • age = $t = \frac{1}{H_0}$ used correctly to calculate *t*. • Age calculated correctly in s or in y. • Furthest galaxies travelling faster. • Space expanding in all directions.

			and supported by some evidence. **Level 1 (1−2 marks)** Limited use of data or limited discussion of MBR. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		• Use data to plot graph of v against d to determine H_0 / graph of d against v to find t. • More data needed since anomalies in the table. **Discussion of MBR (microwave background radiation)** • Early Universe extremely hot / very dense. • High energy gamma photons existed in the early Universe. • As space expanded the wavelength of these photons / waves 'stretched' out. • We now observe this as microwave background radiation. • Temperature of the Universe is now 2.7 K
			Total	**6**	
5 5			**Level 3 (5 - 6 marks)** Clear procedure or correct determination of wavelength, plus reasonable estimation of uncertainty in λ or (sin) θ *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)** Description of procedure or correct determination of λ, but no estimation of uncertainty **or** Clear estimation of uncertainty in wavelength but limited description of procedure and/or determination of λ or (sin) θ **or** Some description of procedure, an attempt to determine the wavelength, and an attempt to estimate uncertainty in some of the measurements (e.g. in x) *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** A limited selection from the scientific points worthy of credit. *There is an attempt at a logical structure with a line of reasoning. The*	1 (AO3)	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. <u>L1 maximum for any answers which use formula λ = *ax*/D</u> **Indicative scientific points may include:** **Procedure** • use formula $n\lambda = d\sin\theta$ • n = 1 since first order spectrum • find d using number of lines/mm = 300 mm-1 • find θ using distance of grating from plastic ruler = 0.50 m and x = 0.10 m (**not** protractor) **Determination of wavelength** • calculate d (= $10^{-3}/300$) = 3.3×10^{-6} m • use x = 0.10 m and distance to grating = 0.50 m to calculate tan θ (= 0.2) • θ = 11.3° • sin θ = 0.196 • alternatively, calculate hypotenuse of triangle (using Pythagoras's theorem) = 0.51 m, giving sinθ (= 0.10/2600½) = 0.196 • allow use of small angle rule (sinθ ≈ tanθ ≈ θ = 0.2) • calculate λ (= 0.196 x 10-3/300) = 650 nm **Estimation of uncertainty** • negligible uncertainty in d (and n) • uncertainty in sin θ is found using uncertainty in distance measurements • uncertainty in each distance measurement is ± 1.0 mm or ± 0.5 mm **or** ± 2.0 mm

			information is in the most part relevant. **0 marks** *No response or no response worthy of credit.* Frontal		• maximum % uncertainty in tan θ / θ / sin θ = 3% • so % uncertainty in ϯ = % uncertainty in sin θ = 3% **Examiner's Comments** Unfortunately, a significant number of candidates did not recognise the diffraction grating experiment here, confusing it with the double slit experiment and so using the formula λ=ax/D. This may be because the formula nλ = dsinθ is in the astrophysics section of the formula sheet. Candidates who chose to use the correct formula nλ = dsinθ were given for choosing the correct values for n, d and θ, for a correct calculation of λ, and for an accurate error analysis. Candidates who did not calculate λ could still gain full marks, as long as they gave accurate instructions as to how this could be done. Strong candidates successfully calculated a reasonable estimate of uncertainty in λ by combining the uncertainties in the distance measurements which had been used to find sin θ. **AfL** The experiment to measure the wavelength of light using a diffraction grating is PAG 5.1 and so is often carried out in Year 12. It may be beneficial to carry out this practical activity in Year 13 instead during the study of spectral lines, to reinforce use of the formula *nλ = dsinθ*. **OCR support** Being aware of the contents of the data, formulae and relationship booklet and its layout will support candidates, alleviating the need to recall numerical values of constants and allowing retrieval of correct formulae, or giving assurance that the student has recalled correctly. **Exemplar 7**  Red photons occur only at the 4th order (ii). there are 300 lines per millimeter, which is 300 000 per meter, , ~~slit separation is~~ Need to measure the angle θ between the 3rd and 4th order to use equation dsin θ = n λ , Rearrange for λ A more/fully darker room would be better as its ~~Are~~ easier to determine ~~and~~ the colours and see the light. Exemplar 7 illustrates many aspects of a Level 1 response. Although the correct formula has been identified, it will not give a correct value

					for λ because incorrect values for *n*, *d* and *θ* have been chosen. The response has been put at the bottom of Level 1 because, although there is an attempt at a logical structure, almost all of the information it contains is inaccurate and therefore not relevant.
			Total	**6**	
56		i	Velocity determined by Doppler shift of spectral lines	B1	
		ii	Suitable straight line of best fit though origin	M1	
		ii	Appropriate pair of values (d, v) taken from line, $H_0 = v/d$	M1	
		ii	400 km s^{-1} Mpc^{-1} ≤ H_0 ≤ 600 km s^{-1} Mpc^{-1}	A1	
		iii	$H_0 = 500 \times 10^3 / 10^6 \times 3.1 \times 10^{16} = 1.6 \times 10^{-17}$ s^{-1}	C1	
		iii	$t = 1 / H_0 = 1 / 1.6 \times 10^{-17} = 6.2 \times 10^{16}$ s	C1	
		iii	age = 2.0×10^9 (years)	A1	Accept answers between 1.6×10^9 (years) and 2.5×10^9 (years) CF
			Total	**7**	
57		i	The (total radiant) power (of a star) /AW	B1	
		ii	($L = 4\pi r^2 \sigma T^4$) ratio = $\sqrt{(\frac{6.92 \times 7500^4}{10.0 \times 4500^4})}$ ratio = 2.3(1)	C1 A1	**Allow** 1 mark for 5.3; square root omitted **Allow** 1 mark for 1:2.3 or 0.43
		iii	$\lambda_{(max)} \propto \frac{1}{T}$ Lower temperature star will have the longest wavelength, so it is Aa2	B1 B1	**Allow** word equation **Note** Must mention wavelength <u>and</u> temperature
		iv	From their (different) colours	B1	
		v	Any <u>three</u> from: • Continuous spectrum • Light / radiation / photons passes through cooler gas/star's atmosphere • Photon(s) absorbed by electron(s) • Electron(s) excited / jump / make transition to higher energy level(s)	B1 × 3	

			• Electron only promoted if energy of photon matches energy gap between two given levels • Photons remitted in different directions • (so) idea of contrast with non-absorbed wavelengths		
			Total	**9**	