0 3 . 1 Describe the links between galaxies, black holes and quasars.

[2 marks]

0 3 . 2 At a distance of 5.81×10^8 light year, Markarian-231 is the closest known quasar to the Earth. The red shift z of Markarian-231 is 0.0415

Use these data to estimate an age, in seconds, of the Universe.

[4 marks]

0 3 . 3 A typical quasar is believed to be approximately the size of the solar system, with a power output similar to that of a thousand galaxies.

Estimate, with reference to the inverse-square law, how much further the most distant visible quasar is likely to be compared to the most distant visible galaxy.

[3 marks]

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Question	Answers	Additional Comments/Guidance	Mark	ID details
03.1	Quasars are produced by (supermassive) black holes. ✓ These black holes are at the centre of (active) galaxies (active galactic nuclei.) ✓		2	AO1/1a
03.2	Using v = cz gives $v = 3 \times 10^8 \times 0.0415$✓ $= 1.25 \times 10^7 = 1.25 \times 10^4$ kms^{-1} Using 1pc = 3.26 lyr $d = 5.81 \times 10^8$ lyr $= 5.81 \times 10^8/3.26$✓ $= 1.78 \times 10^8$ pc $= 1.78 \times 10^2$ Mpc (= 5.5 x 10^{24} m) Using v = Hd ($H = v/d = 1.25 \times 10^4/1.78 \times 10^2 = 70$ kms^{-1} Mpc^{-1}) Age of Universe = 1/H = d/v ✓ $= 5.81 \times 10^8 \times 9.47 \times 10^{15}/1.25 \times 10^7 = 4.42 \times 10^{17}$ s✓	The first mark is for use of zc The second mark is for a calculation of d The third mark is for using the idea that the age of the Universe is 1/H The fourth mark is for the answer. Allow own H for 3rd and 4th marks.	4	AO2/2b

Question	Answers	Additional Comments/Guidance	Mark	ID details
03.3	Both quasar and galaxy should have same brightness (and therefore similar received power).✓ Use of Inverse square law eg Power of quasar/(distance to quasar)^2 = power of galaxy / (distance to galaxy)^2 ✓ Or $1000/d^2 = 1/1$ So distance to quasar = $(1000)^{½}$ = about 30 times greater than distance to galaxy. ✓	The first mark is for relating the similar "brightness". Accept intensity. Accept in form of equation linking quasar and galaxy. The second mark is for applying the inverse square law. Simply quoting it does not get this mark. The final mark is for coming to a valid conclusion related to the distance to the quasar compared to the distance to the galaxy Do not accept answers involving square roots. These are standalone marks..	1 2	AO2/1c AO3/1b
Total	www.mathswithmatt.co.uk		**9**	

0 4 Evidence to support the Big Bang theory comes from cosmological microwave background radiation and the relative abundance of hydrogen and helium in the Universe.

0 4 . 1 Explain what is meant by cosmological microwave background radiation and how its existence supports the Big Bang theory.

[3 marks]

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0 4 . 2 Explain how the relative abundance of hydrogen and helium supports the Big Bang theory.

[3 marks]

6

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.1	it is the radiation coming from all parts of the Universe✓ when the Universe cooled sufficiently for matter and radiation to 'decouple', with the combination of protons and electrons to form neutral atoms ✓ this radiation has been red-shifted into the microwave region as the Universe has expanded✓ OR This is (em) radiation from all parts of the Universe, ✓ the spectrum has a peak in the microwave region / corresponds to a temperature of $2.7\ \mathrm{K}$ ✓ It can be interpreted as the radiation left over from the Big Bang / the photons having been stretched to longer wavelengths and lower energies. ✓	One mark is for stating that CMBR comes from all parts of Universe. Accept Isotropic condone homogeneous condone same at all points in universe Another is for referencing the idea that the radiation has a peak in the microwave region The third is for linking it to the Big Bang theory. Condone "left over heat from Big Bang"	3	AO1a
04.2	(The Big Bang theory suggests that a very brief period of) fusion occurred (when the Universe was very young), resulting in the production of helium from fusing hydrogen. ✓ Fusion stopped as the Universe then expanded and cooled ✓ resulting in a relative abundance of hydrogen and helium in the ratio of $3{:}1$/ cooled too rapidly for the creation of larger nuclei, or suitable relevant observation✓	One mark is for linking helium production to fusion in the early Universe. This mark can also be awarded for description of proton and neutron creation/ 7:1 ratio	3	AO1a
Total			**6**	

Do not write outside the box

0 4 . 1 **Table 3** contains information about two galaxies.

Table 3

Galaxy	Red shift, z	Distance from Earth / ly
NGC 936	4.8×10^{-3}	6.8×10^{7}
NGC 3379	3.0×10^{-3}	3.2×10^{7}

Discuss whether these data are consistent with Hubble's Law.

[3 marks]

Do not write outside the box

0 4 . 2 Quasars are the most distant measurable objects.

Discuss **one** problem associated with the determination of the distance from the Earth to a quasar.

[2 marks]

5

END OF QUESTIONS

Question	Answers	Additional Comments/Guidelines	Mark
04.1	Correct use of Doppler equation for both Galaxies ✓ Correct use of Hubbles law for both Galaxies ✓ Justified comparison leading to conclusion ✓	Award full credit for calculation:- 1. Hubble's constant for two galaxies and then related to Hubble's constant value in data booklet or to each other: NGC 936 is consistent (H=69 km s^{-1} Mpc^{-1}) NGC 3379 is not consistent (H=92 km s^{-1} Mpc^{-1}) 2.Using Hubble constant from data booklet to deduce if z or d in table are in agreement with calculated values for both galaxies. 3.Calculate ratio z/d for both galaxies and compare. $z/d = 4.8/6.8 = 0.7$ and $z/d = 3/3.2 = 0.9$ Condone POT errors when compared in a ratio. ECF for comparison if at least one calculation correct. (max2/3) Candidate who calculates values for only one galaxy can only score 1 mark. Credit discussion suggesting that other factors also affect galaxy velocity or distance measurements and difference not large so Hubble's Law is OK.	1 2

04.2	Distant quasars are very faint; or Type 1a supernova (or standard candle) in associated galaxy would be very faint ✓ Reference to inverse square law ✓ or Due to dark energy/accelerating universe, ✓ use of Hubble's Law/inverse square law not reliable over large distances. ✓	Condone 'barely detectable OWTTE' for faint. Condone Some quasars are situated behind intervening galaxies/gas clouds Affecting data/light received from quasar	2

Total			**5**

0 4 IC2497 is a galaxy that contained a quasar. It is believed that the quasar stopped emitting radiation several thousand years ago.

0 4 . 1 Suggest why the quasar stopped emitting radiation.

[2 marks]

0 4 . 2 IC2497 has a red shift of 0.0516

Determine the distance from the Earth to IC2497.
Give an appropriate unit for your answer.

[4 marks]

distance = _____ unit = _____

6

Question	Answers	Additional comments/Guidance	Mark	AO
04.1	Quasars are formed around black holes ✓1 Black hole (at the centre of IC2497) no longer has matter falling into it ✓2	MP2 – allow black hole no longer feeding; Black hole no longer active. If no mention of black holes no marks can be awarded.	2	AO2-1e

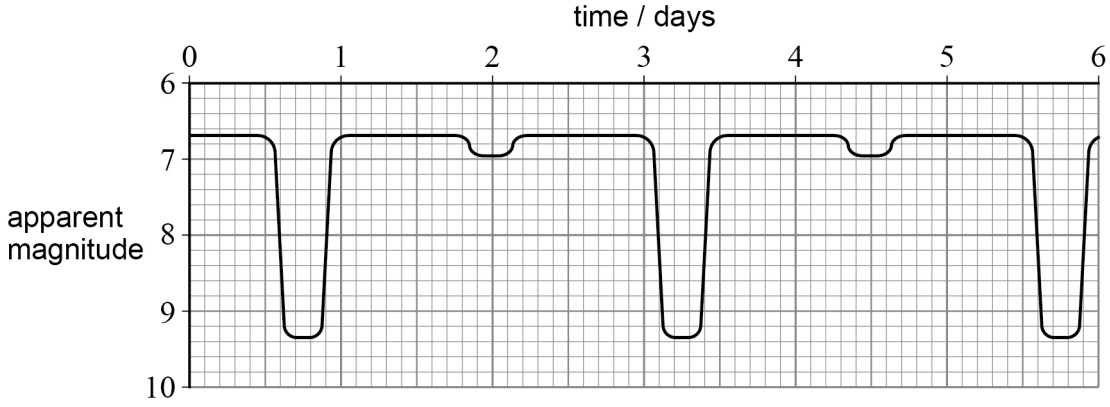
Question	Answers	Additional comments/Guidance	Mark	AO
04.2	use of $z = v/c$ to give $v = zc = 0.0516 \times 3.00 \times 10^8$ ✓1 $= 1.55 \times 10^7$ m s^{-1} $= 1.55 \times 10^4$ km s^{-1} use of $v = Hd$ to give $d = \frac{v}{H}$ ✓ $= \frac{1.55 \times 10^4}{65}$ $= 238$ ✓3 Mpc✓4	Accept 2sf in final answer. Condone Megaparsec, MPC or MPc but **not** Mps OR MpC. Unit mark cannot be awarded without an attempt at calculation. Allow correct converted unit. (eg 782 ✓ Mly ✓; 4.93×10^{10} AU; 7.40×10^{21} m) Units other than Mpc can only be awarded if there is a correct conversion – but allow ecf. (eg AE in calculating Mpc correctly converted to m)	3 1	AO2-1b AO1-1a
Total			**6**	

Do not write outside the box

0 2 U Cephei is an eclipsing binary system consisting of two stars that orbit their common centre of mass.
The primary star is class B; the secondary star is class G.

Figure 1 shows the variation of apparent magnitude of U Cephei with time as observed from Earth.

Figure 1



0 2 . 1 Explain the shape of the graph in **Figure 1**.

[2 marks]

Question 2 continues on the next page

Do not write outside the box

A particular spectral line has a wavelength of $486.136\ \text{nm}$ when measured from a source in the laboratory.
This line is also present in the absorption spectrum of the primary star of U Cephei.
When observed from Earth, the wavelength of the primary star's absorption line varies as shown in **Table 1**.

Table 1

	Wavelength / nm
maximum value	486.498
minimum value	485.672

0 2 . 2 State why the average of the values in **Table 1** is different from the laboratory value.

[1 mark]

0 2 . 3 Show that the orbital speed of the primary star is about $250\ \text{km s}^{-1}$.

[3 marks]

Do not write outside the box

0 2 . 4 Calculate the orbital radius of the primary star.

[2 marks]

orbital radius = _____ m

0 2 . 5 Which absorption lines would be most prominent in the spectrum of the primary star? Tick (✓) **one** box.

[1 mark]

- hydrogen ☐
- hydrogen and helium ☐
- ionised metals ☐
- neutral metals ☐

0 2 . 6 A different eclipsing binary star system is thought to consist of a white dwarf star and a neutron star.

Discuss how astronomers could confirm this.

[2 marks]

_____

_____

_____

_____

_____

_____

_____

11

Question	Answers	Additional Comments/Guidance	Mark	AO
02.1	The minima are caused when one star passes in front of the other. ✓ Deeper minima are caused by the cooler star passing in front of the hotter star. ✓	For mp2 it must be clear that dip size is related to temperature. NB this is NOT related to the diameter of the star.	1 1	1 x AO2 1 x AO3

Question	Answers	Additional Comments/Guidance	Mark	AO
02.2	The system is moving towards us AND mention of Doppler effect/red shift OR The system is moving so the light is blue shifted✓	Condone ‘star is, or stars are moving towards us’	1	AO3

Question	Answers	Additional Comments/Guidance	Mark	AO
02.3	$\Delta\lambda = \frac{486.498-485.672}{2} = 0.413$ nm ✓ $z = \frac{\Delta\lambda}{\lambda} = \frac{0.413}{486.085✓} = 8.50 \times 10^{-4}$ $v = zc = 8.50 \times 10^{-4} \times 3.00 \times 10^{8} = 2.55 \times 10^{5}$ m s^{-1} = 255 km s^{-1} ✓	Alternative for mp1 use of average and one of the other values. For mp2 must see evidence of correct use of average value (NB use of other wavelengths likely to give same answer to 3 sf). Average value (486.085) Final answer must be seen to more than 2sf For mp3 Allow ecf from mp1 and mp2 if answer is in range 250-260	2 1	2 x AO2 1 x AO3

Question	Answers	Additional Comments/Guidance	Mark	AO
02.4	Identifies period (T) is 2.5 days ✓ $v = \frac{2\pi R}{(their\ value\ of) T}$ $R = \frac{v \times T}{2\pi} = \frac{2.55\times10^{5} \times 2.5 \times 24 \times 3600}{2\pi} = 8.76 \times 10^{9}$ m ✓	Allow ecf from **02.3** Use of 250 km s^{-1} gives 8.59×10^{9} m✓✓	1 1	1 x AO3 1 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
02.5	hydrogen and helium ✓		1	AO1

Question	Answers	Additional Comments/Guidance	Mark	AO
02.6	Observable property of Neutron Star or White Dwarf ✓ Property of the other object AND coincident in space OR idea of how a property varies ✓	Observable properties WD – O or B class/ H-He absorption lines/ high temp AND not very bright abs mag. NS – radio emissions/Pulsars Variations include radio emissions from neutron star blocked by white dwarf ✓ Spectroscopic variation in white dwarf seen ✓	2	2 x AO3
Total			**11**	

Do not write outside the box

0 3 3C 273 was the first quasar to be discovered.
IC 1101 is one of the largest galaxies known.
Table 2 shows some information about these objects.

Table 2

	Absolute magnitude	**Apparent magnitude**	**Distance / Mpc**
quasar 3C 273	**X**	12.8	760
galaxy IC 1101	−22.8	14.7	320

0 3 . 1 State the property of the quasar that led to its discovery.

[1 mark]

0 3 . 2 Show that the absolute magnitude **X** of quasar 3C 273 is about −27

[2 marks]

Do not write outside the box

0 3 . 3 Assume that the quasar and the galaxy are both viewed from the same distance.

Explain which would be the brighter object.

Go on to calculate the ratio $\frac{\text{brightness of brighter object}}{\text{brightness of dimmer object}}$.

[3 marks]

ratio = _____

0 3 . 4 The black hole at the centre of IC 1101 has a mass of $7.1 \times 10^{11}\ M_S$ where M_S is the mass of the Sun.

Calculate the average density within the event horizon of the black hole.

[3 marks]

average density = _____ kg m^{-3}

9

Question	Answers	Additional Comments/Guidance	Mark	AO
03.1	High power/powerful radio emitter. ✓	Some indication of high power needed.	1	AO1

Question	Answers	Additional Comments/Guidance	Mark	AO
03.2	Use of $m - M = 5 \times \log\frac{d}{10}$ ✓ $M = m - 5 \times \log\frac{d}{10}$ $M = 12.8 - 5 \times \log\frac{760 \times 10^6}{10} = -26.6$ ✓		1 1	1 x AO1 1 x AO2

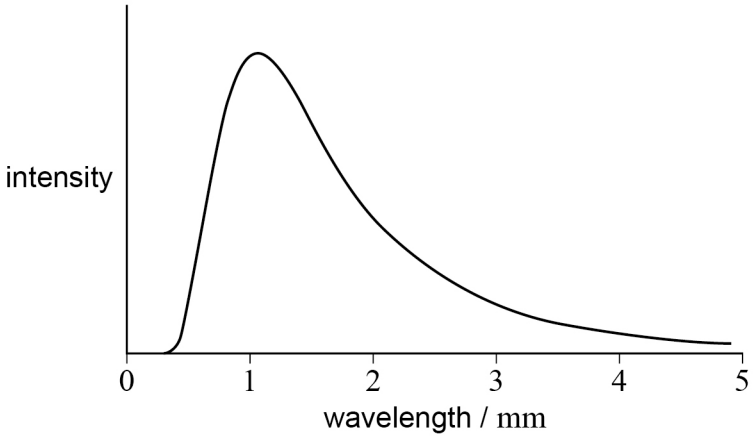
Question	Answers	Additional Comments/Guidance	Mark	AO
03.3	Quasar is brighter because more negative abs magnitude. ✓ Difference in absolute magnitudes $26.6 - 22.8 = 3.8$ ✓ Brighter by $2.51^{3.8} = 33$ times ✓	Use of -27 (giving 48 times brighter) scores mp2 and mp3 Allow any value of absolute magnitude which rounds to -27. Use of apparent magnitudes scores no marks.	3	3 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
03.4	$R_s = \frac{2GM}{c^2} = \frac{2\times6.67\times10^{-11}\times7.1\times10^{11}\times1.99\times10^{30}}{3.00\times10^{8}{}^2} =$ ✓ $(2.1 \times 10^{15}\ \text{m})$ volume = $\frac{4}{3}\pi R_s{}^3 = \frac{4}{3}\pi 2.1 \times 10^{15}{}^3 =$ ✓ $(3.9 \times 10^{46}\ \text{m}^3)$ $\rho = \frac{\text{mass}}{\text{volume}} = \frac{7.0\times10^{11}\times1.99\times10^{30}}{3.7\times10^{46}\text{m}^3} = 3.7\ (3.67)\times 10^{-5}\ \text{kg m}^{-3}$ ✓	If the mass of the Sun is not included mp1 is not awarded – ecf for mp2 and mp3. 2.094×10^{15} m $3.85 \times 10^{46}\ \text{m}^3$	1 2	1 x AO1 2 x AO2
Total			**9**	

Do not write outside the box

0 4 In the middle of the 20th century, there were two competing theories of the Universe. In 1964, electromagnetic radiation was observed coming from all directions in space. **Figure 2** shows the distribution of this radiation as observed from Earth.

Figure 2



The graph provides evidence for one of these theories of the Universe.

Discuss the main features of this theory of the Universe.

In your answer, you should include:
- the main predictions and evidence for the theory, and
- a suitable calculation.

[6 marks]

<table>
<tr><th>Question</th><th>Answers</th><th>Additional Comments/Guidance</th><th>Mark</th><th>AO</th></tr>
<tr>
<td>04</td>
<td>
<table>
<tr><td>6</td><td>A coverage of all three aspects. There may be the occasional slip-up.</td></tr>
<tr><td>5</td><td>Two aspects are well covered and partial coverage of the other. There may be some misunderstanding – for example that stars are moving away from us.</td></tr>
<tr><td>4</td><td>Two aspects are well covered, or one well covered and a brief coverage of the others. There may be some misunderstanding – for example that stars are moving away from us.</td></tr>
<tr><td>3</td><td>Includes a clear coverage of one aspect and at least an attempt at another OR a partial coverage of all three.</td></tr>
<tr><td>2</td><td>Includes a clear coverage of one aspect OR a partial discussion of two.</td></tr>
<tr><td>1</td><td>Partial coverage of one aspect.</td></tr>
<tr><td>0</td><td>No relevant comment.</td></tr>
</table>
</td>
<td>There must be an attempt at a relevant calculation for 5 or 6 marks (this could be the age of universe).

Points made in a good answer could include:
Aspect 1 - RedShift
• Theory predicts that distant galaxies are all moving away from us
• The further away the galaxy the faster it moves
• Reference to Hubble’s Law

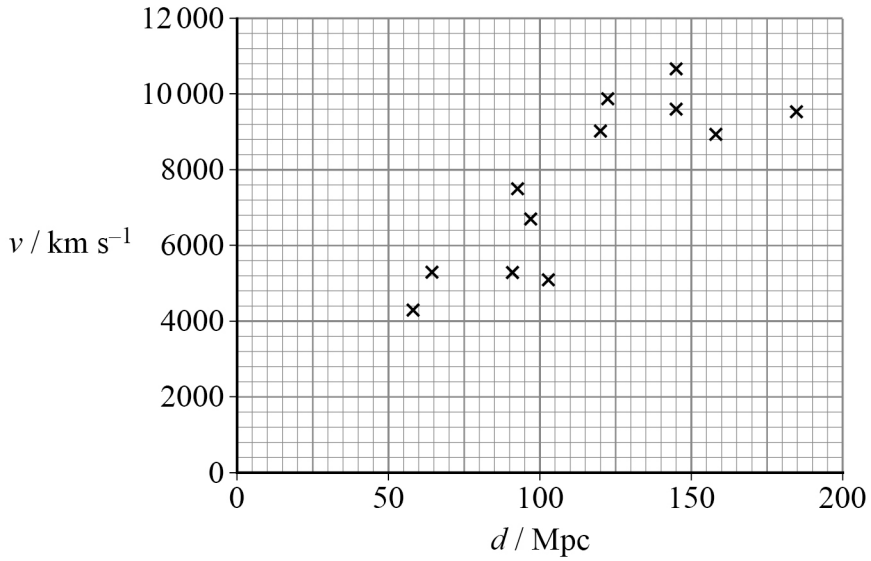
Aspect 2 -CMBR
• Theory predicts black body radiation at microwave wavelengths (2.7 K)
• from all directions which indicates that the universe was once very small/in a hot dense state
• Graph shows peak in microwave region
• General shape of graph is the same as a black body
• CMBR is not predicted by any other theory
• Condone suggestion that it’s leftover radiation from Big Bang
Aspect 3 - Hydrogen/Helium ratio and/or Wien’s Law calculation. Treat calculation of age of universe as partial Aspect 3. Answers</td>
<td>6</td>
<td>4 x AO1
2 x AO3</td>
</tr>
</table>

		which cover H/He and Wien's Law can be used to support partial Aspect 1 or 2. • Theory predicts 3:1 H/He ratio • In deep space (not stars) this is observed in practice • Calculation shows peak corresponds to 2.7 K (approx)		

Total			**6**

0 5 **Figure 2** shows, for some galaxies, how their recession speed v varies with distance d from the Earth.

Figure 2



0 5 . 1 Estimate, using **Figure 2**, the age in seconds of the Universe.

[3 marks]

age of Universe = _____ s

0 5 . 2 The estimate in Question **05.1** assumes that the Universe has expanded at a constant rate. Measurements involving type 1a supernovae that are at large distances from Earth caused astronomers to make a modification to this assumption.

State:

- the modification
- the explanation that was proposed to account for this modification.

[2 marks]

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5

Question	Answers	Additional comments/Guidance	Mark	AO
05.1	Line of best fit <u>drawn through origin</u>. ✓ Evidence of $\frac{\Delta v}{\Delta d}$ used. ✓ Age in range 4.1 to 5.1×10^{17} s ✓	Accept lines that intersect *v* / km s $^{-1}$= 12000 somewhere between *d* / Mpc = 160 and 200 Do not accept use of $H = 65\ \text{km s}^{-1}\ \text{Mpc}^{-1}$ unless obtained from gradient.	3	1 × AO2 2 × AO3

Question	Answers	Additional comments/Guidance	Mark	AO
05.2	expansion is accelerating **OR** rate of expansion is increasing ✓ (due to) dark energy ✓	Treat descriptions of how the rate is increasing as neutral Do not allow 'dark matter'	2	2 × AO1
Total			**5**	

Do not write outside the box

0 4 The Earth is in the galaxy known as the Milky Way. The Andromeda Galaxy is one of the closest galaxies to the Milky Way.

0 4 . 1 The Andromeda Galaxy approaches the Milky Way at a speed of $110\ \text{km s}^{-1}$.
The distance between the galaxies is $770\ \text{kpc}$.

Discuss whether these data can be used to estimate an age for the Universe.

[2 marks]

0 4 . 2 There is a supermassive black hole at the centre of the Andromeda Galaxy. The mass of this black hole is 1.60×10^8 solar masses.

Calculate the radius of the event horizon of this black hole.
State an appropriate unit for your answer.

[3 marks]

radius = _____

unit = _____

Question 4 continues on the next page

Do not write outside the box

0 4 . 3 Scientists predict that a quasar will be produced as the Milky Way and the Andromeda Galaxy merge.

Explain what is meant by a quasar.
Go on to suggest why a quasar may be produced as galaxies merge.

In your answer you should:

- describe the typical properties of a quasar
- explain how observations of quasars provide evidence for these properties
- suggest the process of quasar formation that is likely when two galaxies merge.

[6 marks]

Question	Answers	Additional comments/Guidance	Mark	AO
04.1	Idea that Hubble's Law is used to estimate the age of the Universe. ✓ So no, as Andromeda is approaching / is blue-shifted ✓	Allow determination of H^{-1} or H for the values in the question. Accept idea that age is related to gradient of graph of v against d. Allow "Hubble's Law is only used with receding/redshifted galaxies."	2	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
04.2	Calculates mass of black hole = $1.60 \times 10^8 \times 1.99 \times 10^{30}$ $_1$✓ Use of $R_s = \frac{2 \times 6.67 \times 10^{-11} \times \ their\ mass\ of\ black\ hole}{(3 \times 10^8)^2}$ $_2$✓ $= 4.7 \times 10^{11}$ m $_3$✓	Correct answer gets $_1$✓$_2$✓ Correct answer with correct unit gets $_1$✓$_2$✓$_3$✓ Also accept 4.7×10^8 km 3.1 AU 1.5×10^{-5} pc 5.0×10^{-5} ly Unit mark is based on correct calculation.	3	2 × AO2 1 × AO1

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidance</th><th>Mark</th><th>AO</th></tr>
<tr><td>04.3</td><td>The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question.

<table>
<tr><th>Mark</th><th>Criteria</th></tr>
<tr><td>6</td><td>All three areas (as outlined alongside) covered with at least two aspects covered in some detail.
6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr>
<tr><td>5</td><td>Two areas successfully discussed and one covered partially. Whilst there will be gaps, there should only be a very occasional error.</td></tr>
<tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td></tr>
<tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr>
<tr><td>2</td><td>Only one area discussed or makes a partial attempt at two areas.</td></tr>
<tr><td>1</td><td>Only one area covered, and that partially.</td></tr>
<tr><td>0</td><td>No relevant analysis.</td></tr>
</table></td><td>Treat 1 point from an area as partial and
2 points from an area as complete
Note that 'supermassive' must be seen at least once for P1 and/or F1 to be rewarded.
Properties
P1 Associated with a supermassive black hole
P2 Large power output (for their size) OR power output ~ 10^{42} W/idea of bright absolute magnitude
P3 Distant
P4 Small (relative to host galaxy)/about size of solar system
Treat any comment about age as neutral.

Evidence
E1 (seen) in centre of (active) galaxies (producing jets)
E2 Bright radio source OR far brighter than their host galaxy
E3 Large red-shift
E4 Rapid fluctuations in power output.

How quasar forms
F1 (merging causes) material/stars to move towards the supermassive black hole(s)

F2 Black hole(s) become active 'consuming' nearby stars/material and emitting radiation</td><td>6</td><td>AO1</td></tr>
<tr><td>Total</td><td></td><td></td><td>11</td><td></td></tr>
</table>