Mark schemes

Q1.

(a) Idea that Hubble's Law is used to estimate the age of the Universe. ✓

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.

So no, as Andromeda is approaching / is blue-shifted ✓

Allow ";Hubble's Law is only used with receding/redshifted galaxies."

2

(b) Calculates mass of black hole = $1.60 \times 10^8 \times 1.99 \times 10^{30}$ $_1$✓

Correct answer gets $_1$✓$_2$✓

Correct answer with correct unit gets $_1$✓$_2$✓$_3$✓

Use of

$$R_S = \frac{2 \times 6.67 \times 10^{-11} \times \textit{their mass of black hole}}{(3 \times 10^8)^2}$$ $_2$✓

$= 4.7 \times 10^{11}$ m $_3$✓

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

(c) **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.**

Mark	Criteria
6	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.
5	Two areas successfully discussed and one covered partially. Whilst there will be gaps, there should only be a very occasional error.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed or makes a partial attempt at two areas.
1	Only one area covered, and that partially.
0	No relevant analysis.

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

6

[11]

Q2.

(a) An object that has an escape velocity greater than the speed of light.

Reject idea of 'beyond' or 'past' the event horizon if the direction is unclear.

OR

An object that has a gravitational field strength that is so great that light cannot escape. ✓

Do not accept 'mass' 'density' 'light cannot escape' 'light cannot escape its gravity' on their own.

1

(b) $R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 6.5 \times 10^9 \times 1.99 \times 10^{30}}{(3 \times 10^8)^2}$ 1✓

Angle subtended by region around event horizon of black hole

$= \frac{1.917 \times 10^{13} \times 2 \times 1000}{5.3 \times 10^7 \times 9.46 \times 10^{15}} = 7.64 \times 10^{-8}$ (rad) 2a✓

resolution of EHT = $(\frac{1.3 \times 10^{-3}}{1.3 \times 10^7} =)$ $1(.0) \times 10^{-10}$ (rad)

OR

resolution of Hubble = $(\frac{410 \times 10^{-9}}{2.4} =)$ 1.71×10^{-7} (rad) 3✓

Both resolutions calculated correctly **and** conclusion drawn that EHT is better than Hubble. 4✓

Condone rounding errors in this question.

Award MP1 for $R_s = 1.9(17) \times 10^{13}$(m) seen

Condone missing mass of Sun (1.99×10^{30}) in MP1

Condone missing '2' in MP2.

*Award MP2 for $7.6(4) \times 10^{-8}$ **OR** $3.8(2) \times 10^{-8}$ seen.*

Allow POT error in MP1 and MP3

ALTERNATIVE

$R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 6.5 \times 10^9 \times 1.99 \times 10^{30}}{(3 \times 10^8)^2}$ ✓

One resolution calculated 2✓

Determination of the size of the object that can be resolved by a telescope at the distance of black hole

*For EHT size = $5(.0) \times 10^{13}$ (m) **OR***

For Hubble size = 8.6×10^{16} (m) 3✓

*Both sizes calculated correctly **and** conclusion drawn that EHT is better than Hubble.* 4✓

4

(c) Evidence of difference in wavelength = 374.96 - 373.53 ✓

(= 1.43 nm)

Evidence of sum of wavelengths = 374.96 + 373.53 ✓

(= 748.49 nm)

($z = \frac{\Delta\lambda}{\lambda} = \frac{0.72}{374.25}$ = 1.9 × 10^{-3})

($v = zc$ = 1.9 × 10^{-3} × 3.00 × 10^{8} =)

5.7 × 10^{5} (m s^{-1}) ✓

MP1 can be given for determination of Δλ (= 0.72 nm)

MP2 can be given for determination of average (= 374.25 or 374.24(5) nm)

Alternative method for z:

$z = \frac{374.96-373.53}{374.96+373.53}$ = *1.9 × 10^{-3}*

3

[8]

Q3.

(a) 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 km s^{-1} Mpc^{-1} unless obtained from gradient.

3

(b) 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

[5]

Q4.

(a) High power/powerful radio emitter. ✓

Some indication of high power needed.

1

(b) Use of $m - M = 5 \times \log\frac{d}{10}$ ✓

1

$M = m - 5 \times \log\frac{d}{10}$ ✓

$M = 12.8 - 5 \times \log\frac{760 \times 10^6}{10} = -26.6$ ✓

1

(c) 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

(d) $R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 7.1 \times 10^{11} \times 1.99 \times 10^{30}}{3.00 \times 10^{8^2}} =$ ✓ $(2.1 \times 10^{15}\ \text{m})$

volume $= \frac{4}{3}\pi R_s{}^3 = \frac{4}{3}\pi 2.1 \times 10^{15^3} =$ ✓ $(3.7 \times 10^{46}\ \text{m}^3)$

If the mass of the Sun is not included mp1 is not awarded – ecf for mp2 and mp3.

2.094×10^{15} m

3.85×10^{46} m^3

1

$\rho = \frac{\text{mass}}{\text{volume}} = \frac{7.0 \times 10^{11} \times 1.99 \times 10^{30}}{3.7 \times 10^{46}\text{m}^3}$ = 3.7 (3.67)× 10^{-5} $kg\ m^{-3}$ ✓

2

[9]

Q5.

6	A coverage of all three aspects. There may be the occasional slip-up.
5	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.
4	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.
3	Includes a clear coverage of one aspect and at least an attempt at another OR a partial coverage of all three.
2	Includes a clear coverage of one aspect OR a partial discussion of two.
1	Partial coverage of one aspect.
0	No relevant comment.

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 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)

[6]