M1.(a) an object with an escape velocity greater than the speed of light ✓

Ignore references to singularity and density etc.

Allow gravity so strong light cannot escape.

1

(b) mass of black hole = $1 \times 10^{10} \times 1.99 \times 10^{30} = 2 \times 10^{40}$ kg ✓

M correct for the first mark

Use of

$R = 2GM / c^2$

$= 2 \times 6.67 \times 10^{-11} \times 2 \times 10^{40} / (3.00 \times 10^{8})^2$

$= 3 \times 10^{13}$ m ✓ allow 2.9 or 2.95 etc.

Final answer correct for the second mark.

Allow ce for the mass.

No sf penalty.

2

(c) $V = Hd$

v (in kms^{-1}) = 6300

D (in MPc) = $3.3 \times 10^{8} / 3.26 \times 10^{6}$

= 101 ✓

$H = v / d = 6300 / 101 = 62$ kms^{-1} Mpc^{-1} ✓

Alternatively.

Age of universe = 1 / H

= D / v

$= 3.3 \times 10^{8} \times 9.47 \times 10^{15}$ ✓ $/ 6.3 \times 10^{6}$ ✓

$= 5.0 \times 10^{17}$ s ✓

age of Universe = 1 / H

= 1 / 62

$= 1.6 \times 10^{-2}$ Mpc s km^{-1}

$= 1.6 \times 10^{-2} \times 3.1 \times 10^{16} \times 10^{6} / 10^{3}$

$= 5.0 \times 10^{17}$ s ✓

The first mark is for calculating D, the second for substituting correctly to find H

The third is for determining 1 / H in seconds.

If other value of H used, 1 mark max.

3

[6]

M2.(a) Gives the ratio of the (recessional) velocity (of galaxies) to distance from Earth

Accept equation with terms defined

not

v depends on d,

the relationship between them, shows the relationship between them

B1

1

(b) *d* changed to Mpc (2.45×10^2)
or 1.8×10^4 / their attempt to convert distance

Or d change to m and v to m s^{-1}

B1

(H=) 73.35 or 73.47 seen to at least 3 sf

B1

2

(c) (i) $T = 1 / H$ or $H = 2.4 \times 10^{-18}$ s seen

e.g. $3.08 \times 10^{-19} / 73$

C1

Value in s calculated (4.2×10^{17})

A1

Correct conversion to years 1.3×10^{10}

Allow their value in s

B1

3

(ii) Universe is expanding at constant / steady rate

B1

1

[7]

M3.(a) (i) Similarity both would appear the same <u>brightness</u>
As the apparent magnitudes are the same ✓

Description and explanation needed for mark.

Any references to same size gets zero for 1st mark.

Difference Kocab would appear orange / red, Polaris yellow / white
Due to their spectral classes / different temperatures ✓

Allow different colours + ref to spectral class for second mark

If colour named, should be correct.

2

(ii) Polaris is further from Earth:

Alternative:

Polaris hotter and same size

Both stars same size and Polaris is hotter ✓

As $P = \sigma AT^4$

Hence, Polaris has brighter absolute magnitude / is intrinsically brighter

Same A, would mean that Polaris has greater power output. ✓

Polaris must be further from Earth to appear same brightness as Kocab. ✓

Same apparent brightness, therefore Polaris is further away.

3

(b) (i) $v = Hd$

$v = 0.025 \times 3 \times 10^5 = 7.5 \times 10^3$ km s^{-1} ✓

1st mark is for calculating v

$d = 340 \times 10^6$ l yr = 340 / 3.26 Mpc = 104 Mpc ✓

2nd mark is for working out d in Mpc

$H = 7.5 \times 10^3 / 104 = 72$ kms^{-1} Mpc^{-1} ✓

3rd mark is for calculating H in the correct unit.

3

(ii) Age of Universe = 1 / H

1st mark is for the equation

$= 0.014 \times 10^6 \times 3.26 \times 9.5 \times 10^{15} / 1000$

2nd is for the answer with working

$= 4.3 \times 10^{17}$ seconds

(= 13.6 billion years)

Unit consistent with calculation.

3rd is for a time unit consistent with their answer / working

3

[11]

M4. (a) (i) increase in wavelength (of em radiation) due to relative recessive velocity between observer and source ✓

1

(ii) use of v = Hd

to give $v = 65 \times 25$ ✓

$= 1.6 \times 10^{3}$ (km s^{-1}) ✓

2

(b) (i) all type 1a supernovae have same **peak** absolute magnitude ✓

apparent magnitude can be measured ✓

ref to m-M log (d/10) or inverse square law ✓

max 2

(ii) use of m-M = 5 log (d/10)

gives 12.9 – (–19.3) = 5 log (d/10) ✓

log (d/10) = 6.44

d = 27.5 (Mpc) ✓

2

(c) to make the accepted value for the distance more reliable ✓

1

[8]

M5. (a) (use of $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ gives) $\frac{(660.86 - 656.28)}{656.28} = (-)\frac{v}{3.0 \times 10^8}$ **(1)**

v = (–)2094 km s^{-1} **(1)**

2

(b) graph to show:
correct plotting of points **(1)**
straight line through origin **(1)**

$H = \frac{v}{d}$ = gradient = 70 km s^{-1} Mpc^{-1} **(1)**

(must show evidence of use of graph in calculation)

3

[5]

M6. (a) (i) $d = \frac{20 \times 10^6}{3.26}$ = 15.3 × 10^6 (pc)

(ii) (use of $v = Hd$ gives) v = 65 × 10^{-6} (km s^{-1} pc^{-1}) × 15.3 × 10^6 **(1)**

≈ (1000 km s^{-1})

(iii) (use of $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ gives) $\Delta\lambda = \frac{1000 \times 10^3}{3 \times 10^8}$ × 656.3 (nm) = 2.19 (nm) **(1)**

(allow C.E. for value of v from (ii)

λ_{galaxy} = 656.3 + 2.19 = 658.5 nm **(1)**

4

(b) for the furthest point of the Universe, $d = \frac{c}{H}$ **(1)**

age of Universe = $\frac{d}{c} = \frac{1}{H}$ **(1)**

[or use of $v = Hd$ and $t = \frac{d}{v}$ **(1)**

if all started from same point t = age of Universe = $\frac{1}{H}$ **(1)**]
assumption: that H remains constant

3

[7]