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

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

= 5.0×10^{17} s ✓

age of Universe = 1 / H

= 1 / 62

= 1.6×10^{-2} Mpc s km^{-1}

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

= 5.0×10^{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) An object that produces a rapid increase in brightness ✓

Allow lowering in value of absolute magnitude

1

(b) Extremely dense ✓

Ignore descriptions of Neutron star surface

1

Made up of neutrons ✓

Ignore refs to spinning or producing radio waves

1

(c) Use of $Rs = 2GM / c^2$

To give

$Rs = 2 \times 6.67 \times 10^{-11} \times 2 \times 2 \times 10^{30} / (3 \times 10^8)^2$ ✓

First mark is for substitution

1

$= 5.9 \times 10^3$ m ✓

Second mark for answer

1

(d) Collapsing star can produce gamma ray bursts with energy similar to total output of Sun ✓

First mark is for gamma ray burst and an idea of the amount of energy

1

Highly collimated – if in direction of Earth, could cause mass extinction event ✓

Second mark is for consequence.

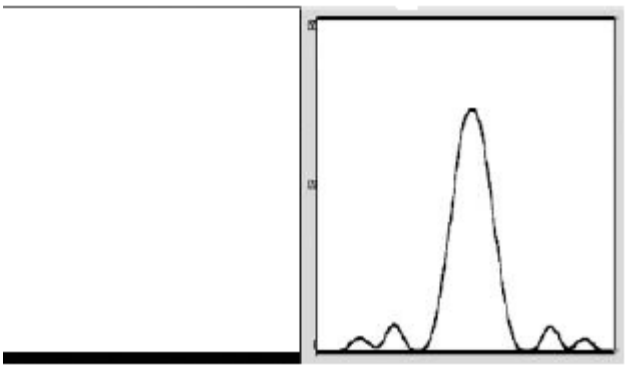
1

[7]

M3.(a) (i) central maximum at least twice the height of adjacent maxima ✓

Allow graph to be above angle axis

Subsequent narrower maxima✓



Any further maxima should not get bigger.

2

(ii) Two sources will be (just) resolved if the central maximum of the diffraction pattern of one coincides ✓

Central max and first min may be labelled on diagram in ai

with the first minimum of the other. ✓

If they use the term 1st maximum it must be clear that it is the central maximum

Second mark is for correct part of the second diffraction pattern.

Clearly labelled diagram can get both marks.

2

(b) Use of $Rs = 2GM/c^2$

*Allow ce for **one** from:*

missing out million; missing out mass of Sun; square in equation, but no square of speed of light in calculation

to give $Rs = 2 \times 6.67 \times 10^{-11} \times 4.1 \times 10^{6} \times 2 \times 10^{30} / (3 \times 10^{8})^2$ ✓

$= 1.2 \times 10^{10}$m ✓

2sf ✓

Sf mark stands alone but must be a number (not just stated 2 sf)

3

(c) (i) use of $\theta = \lambda/D$

The first mark is for calculating the wavelength

to give $\theta = (3 \times 10^{8} / 230 \times 10^{9})$ ✓ $/ 5000 \times 10^{3}$

$= 2.6 \times 10^{-10}$ (rad) ✓

The second mark is for the use of the equation to give the final answer

Allow c.e. for an a.e. in the first mark.

If frequency used treat as p.e. – no marks

2

(ii) use of $s = r\theta$

First mark is for the angle subtended (5.12×10^{-11})

to give $\theta = 5 \times 1.2 \times 10^{10} / (25\,000 \times 9.46 \times 10^{15})$ ✓

$= 2.5 \times 10^{-10}$ (rad) ✓

Second mark is for showing that this is 5 × answer to c(i).

which is (approximately) the answer to ci

Alternatives:
Calculate size of object that could just be resolved at this distance, and showing that this is 5 × radius of black hole.

2

[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]