M1.(a) (i) largest distance = 2.57 + 1 = 3.57 AU ✓

$3.57 \text{ AU} = 3.57 \times 1.5 \times 10^{11}\text{m}$

$= 5.36 \times 10^{11}\text{(m)}$ ✓

The first mark is for the correct distance in AU.

The second mark is for the correct conversion to metres. Allow c.e.

2

(ii) angle = s / r

$= 5.4 \times 10^{5} / 1.73 \times 10^{11}$ ✓

$= 3.12 \times 10^{-6}$ (rad) ✓

Working needs to be shown for the first mark.

At least two sf needed for final mark.

2

(b) (i) mirrors correct ✓

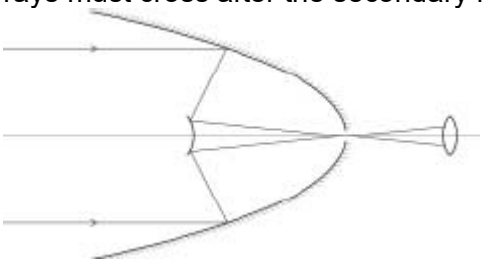
primary concave, secondary convex. No shading needed

primary mirror should be continuous i.e. not two mirrors

if no hole, evidence can be given by rays passing through

rays correct ✓

rays must cross after the secondary mirror



The lens does not need to be included.

2

(ii) angular resolution = λ / D D = $1 \times 10^{-6} / 3.3 \times 10^{-7}$ ✓

D = 3.0 m 2 sf needed ✓

Allow use of factor of 1.22.

Allow 1 sf if justified by discussion of approximate nature of calculation.

2

(c) minimum angular resolution is better / smaller than the size of the asteroid ✓

The first mark is for qualitative comparison.

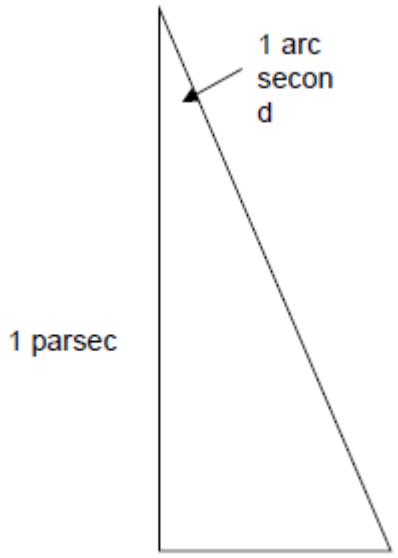
details of about 1/10 the angular size of Vesta / 50km can be seen ✓

the second for the quantitative analysis.

2

[10]

M2.(a) Diagram showing Earth, Sun and star, with 1AU clearly marked, and 1 arc second angle at the star, with distance between Sun and star as one parsec.



1 pc is the distance at which 1AU subtends an angle of 1 arc second

A diagram with fewer labels can be supported by a correct statement.

If either the angle or base are incorrect, 1 max.

Right angle does not need to be at the Sun. Triangle does not need to be a right angle.

Parsec could be the hypotenuse.

Ignore writing if the diagram is correct.

Base can be either Sun, Earth, or 1AU.

No diagram, 1 max.

2

(b) d = 1 / p

= 1 / 0.002 parsec
= 500 pc ✓
= 500 × 3.1 × 10^{16} m
= 2 × 10^{19} m ✓ 1sf ✓

Allow ce for d in pc.

If tan (0.002 / 3600) = 1AU / d used, allow ce for wrong value of 1AU.

Allow use of tan or sin.

3

(c) (i) Two components are 178 pc apart
or
Distance apart too great
(for gravity to have any significant effect between them)

Penalise attempts to hedge bets by references to apparent magnitude or class.

1

(ii) More distant star will not appear to move as much as nearest star (against the fixed background)

Allow discussions involving parallax.
Give credit to correct diagram.

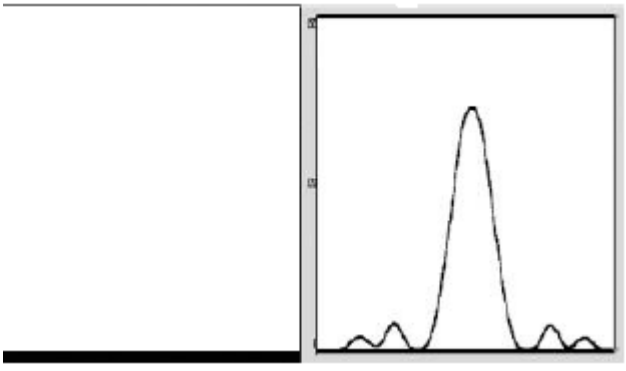
1

[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 $R_s = 2GM/c^2$

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

$= 1.2 \times 10^{10}$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) x-rays are absorbed by the Earth's atmosphere **(1)**

1

(b) (i) an object whose escape velocity is greater than the speed of light **(1)**

1

(ii) use of $Rs = 2GM/c^2$

to give $Rs = 2 \times 6.67 \times 10^{-11} \times 7 \times 2 \times 10^{30}/(3 \times 10^8)^2$ **(1)**

$= 2.08 \times 10^4$ (m) **(1)**

2

(c) CCD consists of silicon (chip) **(1)**

incident photons cause electrons to be released **(1)**

electrons are trapped in potential wells in the CCD **(1)**

3

[7]

M5. (a) diagram to show:
correct curvature of mirrors **(1)**
rays crossing in the hole in the objective mirror **(1)**

2

(b) (i) $\theta \left(= \frac{\lambda}{d}\right) = \frac{2.0 \times 10^{-6}}{3.8}$ **(1)**

$= 5.3 \times 10^{-7}$ rad **(1)** $(5.26 \times 10^{-7}$ rad)

(ii) visible wavelengths shorter (than infra red) **(1)**
∴ smaller resolving angle (∴ better resolving power) **(1)**

4

(c) (i) water vapour **(1)** (or carbon dioxide)

(ii) longer wavelengths absorbed **(1)**
shifts peak of graph to shorter wavelengths **(1)**
star appears hotter [or reference to appropriate equation] **(1)**

max 3

[9]