# Mark schemes

## Q1.

(a) Determination of focal length of objective

OR adds their $f_o$ and $f_e$ ✓

*$f_o = M \times f_e = 75 \times 0.022 = 1.65$ (m)*

1.67 (m) CAO ✓

*No sf penalty*

*Condone 2 sf 1.7*

**2**

(b) Determination of angle subtended by Jupiter at unaided eye

OR uses:

distance to Jupiter = diameter of Jupiter ÷ angle subtended with their diameter OR their angle ✓

*E.g.*

*$1.7 \times 10^{-2} / 75 = 2.3 \times 10^{-4}$ (rad)*

*$2 \times 7.0 \times 10^{4} / 2.3 \times 10^{-4}$*

*In MP1 allow use of trig and angle in degrees or radians. Condone use of $1.7 \times 10^{-2}$ degrees.*

distance = $6.2 \times 10^{8}$ (km) ✓ CAO

*Do not award MP1 if both angle and diameter are incorrect.*

**2**

(c) Idea that chromatic aberration is caused by dispersion of light passing through lens
OR
different colours/wavelengths being refracted by different amounts/to different focal points. ✓

*Marks can be given for labelled diagram.*

*Credit answers that suggest edges of lens act like a triangular prism.*

Idea that effect is greatest at greatest curvature/edge of lens
OR least at centre of lens
OR
Idea that light can only travel through part of lens with little curvature ✓

*MP3 is contingent on MP2.*

therefore chromatic aberration is **reduced**. ✓

**3**

(d) (Diameter ($d$) is reduced and therefore:)

Idea that the image is dimmer $_1$✓

collecting power proportional to area / $d^2$ $_2$✓

*Treat any comments about the path through the atmosphere as neutral.*

Idea that the image less clear $_3$✓

minimum angular resolution is proportional to $1/d$ $_4$✓

*For $_3$✓ do not allow 'lower resolution' for 'less clear'*

*Alternative for $_3$✓$_4$✓*

*Idea that the image is more clear as spherical aberration is reduced as only rays near axis form image*

4

[11]

## Q2.

(a) Final image at infinity. ✓

*Accept answers which describe how the telescope is set up with named lenses unless $f_o$ and $f_e$ are used e.g.*

*the focal plane/point of the eyepiece and objective lenses are co-incident.*

***OR***

*'distance between lenses is $f_o + f_e$'*

*Condone 'rays leaving eyepiece/entering eye are parallel'*

*If $F_o$ and $F_e$ are used they must be defined.*

1

(b) 100 converging 5 converging ✓

1

(c) (Each step on magnitude scale is 2.51)

(Hence) $2.51^x = 40$

$x = \log_{2.51}(40) = 4(.01)$

**OR**

Adding 6 to their $x$ ✓

(6 + 4 = )10 ✓

*Condone trial and error ($2.51^1$, $2.51^2$,...).*
*Award MAX 1 if no working shown for a bald correct answer.*

2

(d) (Collecting power of telescope is)

$\left(\frac{60}{7}\right)^2$ = 73 or 74 (times greater than naked eye) ✓

*MP1 can be given for 73 or 74 seen.*

*Accept* $\left(\frac{7}{60}\right)^2$ *= 0.014 for MP1*

73 (or 74) is greater than 40 so the astronomer can see WASP-82. ✓

*Allow an ecf in MP2 from '8.6 times greater'*

*(*$\frac{60}{7}$ *= 8.6) , with idea that 8.6 is less than 40 and therefore astronomer cannot see Wasp-82.*

*Allow ecf in MP2 for an arithmetic error in MP1.*

**2**

(e) Two clear reasons given ✓✓

Correct justification linked to one reason ✓

| Reason | Justification |
|---|---|
| Better/greater quantum efficiency | A greater proportion of (incident) photons are detected |
| Can expose for long periods / many images can be combined | More light is collected / better image contrast |
| Can operate remotely | The telescope can be positioned where light pollution/atmospheric absorption is minimised |
| Idea that it can detect (more) wavelengths beyond the visible | More energy is collected from the star |

**MAX 3**

*If no justification given then* ***MAX 2****.*

*In the first row:*

*Do not allow 'efficiency' alone.*

*The reason and justification marks can both be awarded for an answer based on the definition of 'quantum efficiency' e.g.a greater proportion/ percentage of the incident photons are detected (by the CCD).*

*In the justification condone 'light' for 'photons' and condone 'number' for 'proportion'*

*Treat 'image processing' as neutral.*

*Ignore references to resolution.*

**3**

**[9]**

## Q3.

(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 = $(\frac{410 \times 10^{-9}}{2.4} =)$ $1.71 \times 10^{-7}$ (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 ($1.99 \times 10^{30}$) 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 = $8.6 \times 10^{16}$ (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:*

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

3

**[8]**

## Q4.

(a) Two pairs of rays drawn parallel to the principal axis coming to different foci.
Outer rays focus closer to lens than inner rays. ✓

1

(b) Both focal points labelled, on the principal axis, and coincide, with $f_o > f_e$ ✓

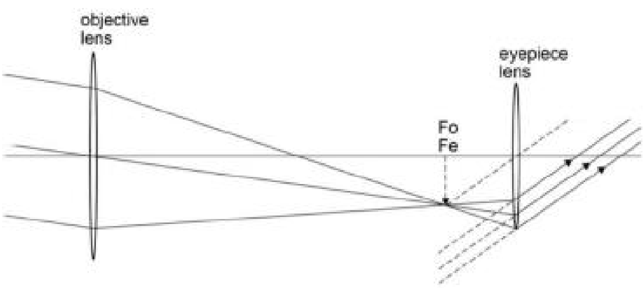
*$f_o > f_e$ judged by eye. Condone a single label F or '(principal) foci'.*

Three off-axis rays through objective lens correct, as far as the eyepiece ✓

*Ignore labels outside the space between the two lenses.*

*Rays must be off-axis to get the second mark.*

Three rays through eyepiece correct, parallel to a construction line ✓




*Construction line does not need to be drawn.*

*If only two rays drawn then max 2.*

**3**

(c) ($f_o$ / $f_e$ = 750 and $f_e$ + $f_o$ = 17.4)

*Accept any correct unit*

$f_e$ = ($f_e$ + $f_o$)/751 ✓

*Use of $f_e$ = ($f_e$ + $f_o$)/750 without explanation scores 0*

= 17.4/751

*(Calculator value = 0.0231691079)*

$f_e$ = 2.3(17) × $10^{-2}$ m ✓

*If no other mark given award max 1 for 0.023 or 0.0232 but treat evidence of incorrect calculation as a talkout.*

**2**

(d) Resolution is limited by the diameter of the objective ✓a
so it will make no difference ✓b
OR
CCD has better resolution due to having smaller pixels ✓a
so the stars could be more easily seen as separate (OWTTE) ✓b

*General principle is difference ✓a followed by consequence. ✓b*

*If no consequence relevant to observation of binary stars, then max 2*

(candidates may combine these ideas)

CCDs have higher quantum efficiency and/or can be exposed for a long time ✓a
so dimmer or more distant binaries can be observed ✓b

CCDs can detect a wider range of wavelengths ✓a
enabling the observation of more binary pairs. ✓b

Description of why CCD is more convenient in use ✓a with a specific example of why this helps in the observation of binary stars. ✓b

*Examples of 'convenience' include use when astronomer not present, image can be stored and analysed (on computer).*

*Ignore reasons based on cost.*

**Max 3**

**[9]**