M1.(a) Concave mirror with parallel incident rays reflecting to different focal points. ✓

PA does not need to be drawn.

1

Rays further from PA brought to focus nearer the mirror. ✓

1

(b) **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 in marking this question.**

Mark	Criteria	QoWC
6	All three aspects covered: A full comparison of location in terms of the affect of atmosphere on the GTC, and the difficulties of maintaining, servicing and obtaining data from IUE. A quantitative comparison of the collecting power with conclusion that GTC has 530x collecting power of IUE. A quantitative comparison of minimum angular resolution, with conclusion that GTC is 5x better.	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible
5	Two of the three aspects fully covered, with some detail missing from the third.	
4	One aspect fully covered,	The student presents

	with some detail missing from the other two Or Two aspects fully covered, with little or no relevant information about the third.	relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
3	All three aspects partially covered, with some detail missing from each Or One aspect fully covered, with little or no relevant information about the other two.	
2	Two aspects partially covered, with little or no relevant information about the third.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
1	One aspect partially covered, with little or no relevant information about the other two.	
0	Little or no relevant information about any of the three aspects.	The student's presentation, spelling punctuation and grammar seriously obstruct understanding.

The following statements are likely to be present:

Location

- light must travel through some of the atmosphere to reach GTC which affects the amount of light arriving and resolution.
- IUE In orbit needs its own power source,
- and information needs to be sent to ground for analysis.
- position of IUE inconvenient as, if something goes wrong, it is difficult to service an orbiting satellite.

Collecting power

- Collecting power is proportional to D^2.
- So ratio is $10.4^2 / 0.45^2 = 530$
- GTC has 530x collecting power.
- GTC better as bigger diameter telescopes make brighter images.

Minimum angular resolution

- Minimum angular resolution is proportional to 1 / D
- $\theta = \lambda / D$ so ratio of min angular resolution is $(1 \times 10^{-6} / 10.4) / (2 \times 10^{-7} / 0.45) = 0.2$
- GTC is 5× better at resolving
- GTC better as bigger diameter telescopes make clearer images.

6

(c) QE. = $\frac{\text{no. of photons arriving at detector and being detected}}{\text{total arriving at detector}}$

1

For CCD QE> 80%✓

For eye QE = 1%✓

Both needed

1

[10]

M2. The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of written communication but the quality of written communication will be one of the criteria used to assign the answer to one of three levels.

The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.

There are three areas:

Structure: silicon chip into pixels

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

Function: photon incident, electron excited, electron trapped in potential well, one electron per photon, no of electrons (and therefore charge) proportional to number of incident photons, after sufficient exposure charge on each pixel measured and image produced

Advantage: most will say the QE>70%

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

A 6 mark answer need not be "perfect" but should be substantially complete, correct and free from major errors.

One of the above points may be missing. Eg charge integration

The candidate provides a comprehensive and logical description of the structure of the CCD. The answer includes a clear description of how the light causes a release of charge and why the charge is stored. The answer also includes an explanation of what is meant by quantum efficiency and a correct value for the q.e. of a CCD.
Confusion with the photoelectric effect would reduce a 6 mark answer to 5.

5 marks may have 2 missing eg silicon chip and charge integration

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

4 probably has more than 2 missing or no correct advantage

The candidate provides a comprehensive and logical description of the CCD. The answer demonstrates some understanding of how the light is used to generate charge. The answer also includes some reference the efficiency of the CCD or other advantage

Low Level (Poor to limited): 1 or 2 marks.
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate demonstrates an understanding that an image is formed on the CCD and that this image is transferred to a computer.

Zero: Incorrect, inappropriate or no response.

Points that can be used to support the explanation:

- The CCD is a silicon chip
- The chip is divided into picture elements
- Each picture element is associated with a potential well in the silicon
- Incident photons are focused on the CCD
- The photons cause the release of electrons within the semiconductor
- The number of electrons liberated is proportional to the intensity of the light.
- Electrons are trapped in the potential wells
- An electron pattern is built up which is identical to the image formed on the CCD
- When exposure is complete the charge is processed to form an image.

Advantages:
High quantum efficiency > 70%
Light integration – using long exposure times to capture faint images.
Device can be directly linked to computer for capture and analysis.

6

[6]

M3. (a) (i) (use of $\theta = \frac{\lambda}{d}$ gives) $\frac{\theta_{reflector}}{\theta_{refractor}} = \frac{d_{refractor}}{d_{reflector}}$ **(1)**

$= \left(\frac{0.9}{1.52}\right) = 0.59(2)$ **(1)**

(ii) use of, energy collected per sec $\propto$ = area $\propto = d^2$ **(1)**

$\frac{P_{refl}}{P_{refr}} = \left(\frac{d_{refl}}{d_{refr}}\right)^2 = \left(\frac{1.52}{0.9}\right)^2 = 2.85$ **(1)**

3

(b) (i) correct diagram showing four parallel co-axial rays, with outer rays brought to focus at a point closer to mirror than inner rays **(1)**

(ii) (use of) parabolic mirror **(1)**

2

(c) (i) correct diagram showing two mirrors, one concave, one convex **(1)**

(ii) mirror blocks light so less light hits objective mirror **(1)**
light diffracted passing secondary mirror affects image **(1)**

3

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M4. (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)**

= 5.3×10^{-7} rad **(1)** (5.26×10^{-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]