**Q1.**(a) The table summarises some of the properties of Vesta, one of the largest objects in the asteroid belt between Mars and Jupiter.

| **Diameter / m** | **Distance from the Sun / AU** | |
|---|---|---|
| | smallest | largest |
| $5.4 \times 10^5$ | 2.15 | 2.57 |

(i) Calculate the largest possible distance, in m, between the Earth and Vesta.

distance = ..... m

**(2)**

(ii) Show that when Vesta is at a distance of $1.73 \times 10^{11}$d m from Earth, the angle subtended by Vesta to an observer on Earth is about $3 \times 10^{-6}$ radian.

**(2)**

(b) Observations of Vesta have been made by the Infrared Telescope Facility (IRTF) in Hawaii.

(i) Draw a ray diagram for a Cassegrain telescope.

**(2)**

(ii) The IRTF includes a camera capable of detecting infrared radiation with wavelengths in the range 1.0 μm to 5.0 μm.

The smallest angle the telescope can resolve is $3.3 \times 10^{-7}$ radian.

Calculate the diameter of the objective of the telescope.
Give your answer to a suitable number of significant figures.

diameter of objective = ..... m

**(2)**

(c) Discuss the level of detail the IRTF would be able to detect on the surface of Vesta, when Vesta is $1.73 \times 10^{11}$ m from Earth.

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**(2)**
**(Total 10 marks)**

**Q2.**(a) Explain what is meant by a parsec. Draw a labelled diagram in support of your answer.

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**(2)**

(b) The Hipparcos satellite used the parallax method to measure the distance to more than 100 000 stars with a precision of 0.002 arc seconds.
Calculate, in metres, the maximum distance measurable by Hipparcos.
Give your answer to an appropriate number of significant figures.

distance ..... m

**(3)**

(c) The star Alpha Capricorni is in fact two stars that appear very close together. Some data about the two stars are summarised in the following table.

| Star | Distance / pc | Apparent magnitude | Class |
|---|---|---|---|
| Alpha-1 capricorni | 211 | 4.3 | G |
| Alpha-2 capricorni | 33 | 3.6 | G |

(i) Explain how data in the table indicate that the two stars are **not** part of a binary system.

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**(1)**

(ii) Explain why the angular separation of the two stars changes when observed from the Earth during a 12 month period.

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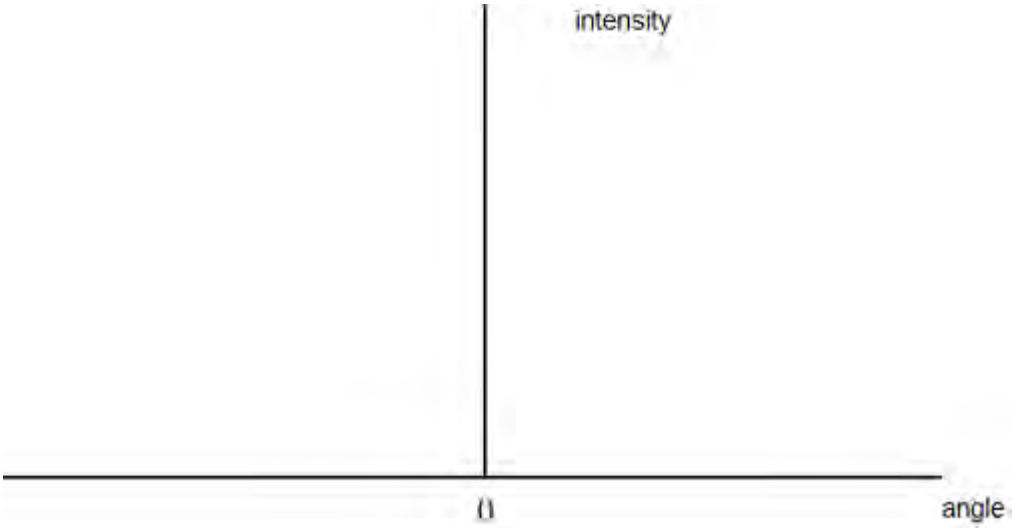
**(1)**
**(Total 7 marks)**

**Q3.** There is a supermassive black hole at the centre of the Milky Way galaxy. It is difficult to resolve images of the region around this black hole directly.

(a) (i) Sketch, on the axes, the variation in intensity of the diffraction pattern produced when light from a point object passes through a circular aperture.




**(2)**

(ii) The *Rayleigh criterion* is used to determine the smallest angular separation between two point objects which can be resolved by a telescope. With reference to the diffraction patterns formed, explain what is meant by the Rayleigh criterion. You may draw a diagram to aid your explanation.

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**(2)**

(b) The supermassive black hole at the centre of the Milky Way galaxy has a mass equal to 4.1 million solar masses.
Calculate the Schwarzschild radius, $R_s$, for this black hole.
Give your answer to an appropriate number of significant figures.

$R_s$ ..... m

**(3)**

(c) Astronomers investigating the supermassive black hole at the centre of the Milky Way galaxy detect radio waves at a frequency of 230 GHz. By correlating the information from several radio telescopes, they can obtain images with the same resolution as a single radio telescope with a diameter of 5000 km.

(i) Calculate the minimum angular separation which could be resolved by a radio telescope of diameter 5000 km detecting waves of frequency 230 GHz.

angular separation ..... rad

**(2)**

(ii) The centre of the Milky Way galaxy is 25 000 light years from the Earth.

Show that the limit of the resolution of the telescope is approximately five times the angle subtended by the Schwarzschild radius of the black hole at this distance.

**(2)**
**(Total 11 marks)**

**Q4.** The Chandra X-ray Observatory was launched into orbit in 1999. It is used to observe hot and turbulent regions of space.

(a) Explain why X-ray telescopes need to be in orbit.

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**(1)**

(b) In 2000, the Chandra telescope was used to observe a *black hole* in Ursa Major.

(i) Explain what is meant by a black hole.

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**(1)**

(ii) The black hole is believed to have a mass 7 times that of the Sun. Calculate the radius of its event horizon.

mass of the Sun = $2.0 \times 10^{30}$ kg

radius = ..... m

**(2)**

(c) Chandra makes use of a charge coupled device (CCD) to detect the X-ray photons. Describe the processes involved in the detection of photons by a CCD.

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**(3)**
**(Total 7 marks)**

**Q5.** (a) Draw a ray diagram to show the path of two rays, parallel to the axis, through a Cassegrain telescope, as far as the eyepiece.

**(2)**

(b) The UKIRT is a Cassegrain telescope capable of detecting both infrared and visible radiation. It has an objective diameter of 3.8 m.

(i) Calculate the resolving power of this telescope for infrared light of wavelength 2.0 μm.

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(ii) Explain why the resolving power of this telescope is better in the visible region than in the infrared region.

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**(4)**

(c) To reduce atmospheric absorption problems, the telescope was built at the top of Mount Mauna Kea in Hawaii.

(i) What, in the atmosphere, is responsible for absorbing infrared radiation?

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(ii) The spectrum of light from a star can be used to determine its temperature. Explain why this absorption can lead to errors in the value.

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**(3)**
**(Total 9 marks)**