UNIT 3 ASTRONOMICAL TECHNIQUES

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3.1 INTRODUCTION

In Unit 1 you have learnt about various measurable astronomical quantities and the methods of measuring some of them such as distance, size and mass. You have also studied about the radiant flux or brightness of different astronomical sources like the planets, the sun, stars and galaxies. A great deal of information in astronomy is gathered with the help of ground-based instruments. Therefore, in this unit we describe some instruments as well as the techniques used to measure radiant flux and to analyse the radiation emitted by astronomical objects. We shall first revisit the basic optical definitions, viz. magnification, light gathering power and resolving power, relevant to astronomy. You may recall having studied them in Unit 11 of the Physics elective PHE-09 entitled Optics.

In Sections 3.3 and 3.4, we shall describe instruments like **optical telescopes** and **detectors** that help us measure radiant flux from stars and other objects. A telescope is like a camera. It is a light-focusing instrument, while a detector, like a photographic film, is the medium on which the photons leave an impression, which can be measured later.

You know the poem ‘Twinkle-twinkle little star’ from your early days. In this unit, you will study how the Earth’s atmosphere, that makes the stars twinkle, affects the observations made with telescopes on the ground. Finally, you will learn about techniques to detect faint astronomical light, which originates from very distant objects.

In the next unit we discuss the basic principles of physics applicable in astronomy and astrophysics.

Objectives

After studying this unit, you should be able to:

- define angular magnification, light gathering power and resolving power of a telescope;
- describe different types of reflecting telescopes and telescope mountings;

- explain how atmosphere affects the incoming starlight;
- describe the different detectors and techniques used for observations; and
- estimate detectability limit of a telescope.

3.2 BASIC OPTICAL DEFINITIONS FOR ASTRONOMY

The telescope is the most common instrument used in ground-based astronomy. Most people think of a telescope only in terms of its **magnifying power**. However, magnification is only one of three powers of a telescope, the other two being its **resolving power** and **light gathering power**. Before we describe various telescopes, we would like to discuss these concepts as applicable in astronomy.

3.2.1 Magnification

As you know from the course in Optics, the magnifying power of a telescope refers to its ability to make the image appear bigger. If the angle subtended by a distant object at the objective of a telescope is β and that subtended by the virtual image at the eye is α (Fig. 3.1), then the **angular magnification** (A.M.) of the telescope is given by

$$\text{A.M.} = \frac{\alpha}{\beta} \tag{3.1}$$

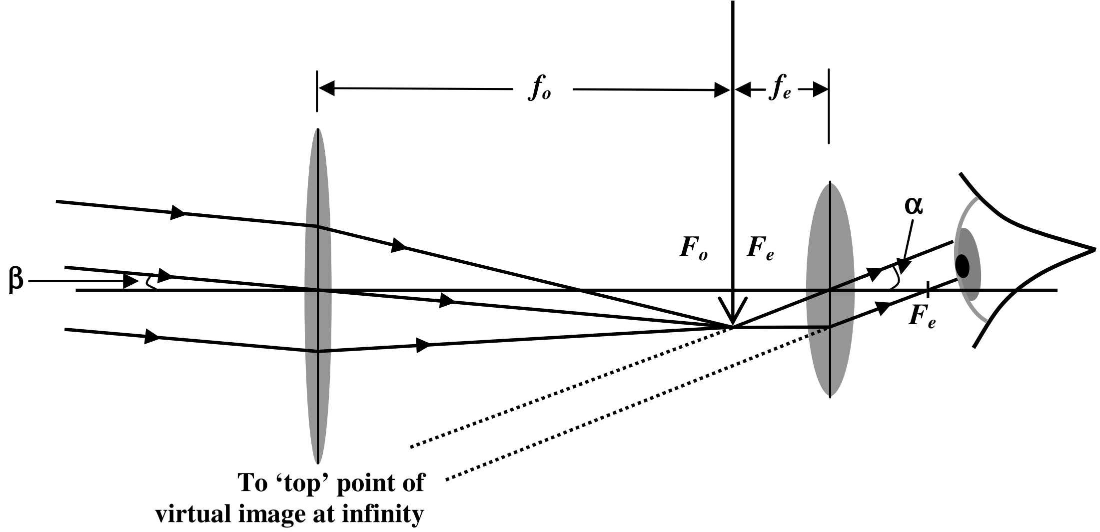


Fig.3.1: The image of a distant object is formed at the focal plane of the objective. The rays entering the eye are rendered parallel by the eye-piece. The eye sees the image at infinity

We calculate the A.M. of a telescope by dividing the objective's focal length by the focal length of the eyepiece.

$$\text{A.M.} = \frac{f_o}{f_e} \tag{3.2}$$

For example, if a telescope has an objective with a focal length of 60 cm and an eyepiece of focal length 0.5 cm, its angular magnification is 60/0.5, or 120 times. We say that the magnification is 120 X.

Further, the A.M. is also equal to the ratio of entrance pupil (e.g., the objective lens diameter) to the human eye's pupil diameter. If we assume the diameter of a normal human eye pupil to be about 8 mm for the eye adapted to perfect darkness, then the lowest possible magnification will be equal to the ratio of objective diameter (in mm) to 8. Similarly, if we assume a normal pupil diameter of 3 mm, the highest possible magnification will be the diameter of the objective divided by 3.

The highest possible magnification of a telescope is limited by its optics which includes the quality of lenses and mirrors and the thermal insulation of the telescope tube so that the exchange of heat does not disturb the air inside the tube. The magnification is also limited by the disturbance of light rays suffered in the Earth's atmosphere. Also, the higher the magnification, the smaller is the *field of view*, i.e., the area of the sky which can be observed by the telescope becomes smaller (see Fig. 3.2).

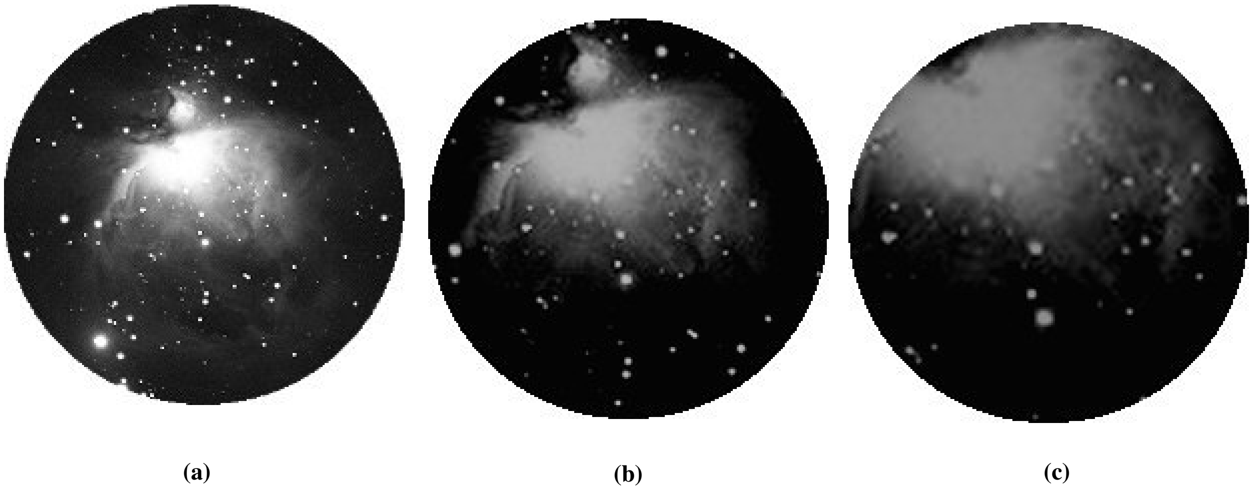


Fig.3.2: Increasing the magnification decreases the field of view and makes the image dimmer. Pictures show simulated views of the Orion Nebula at magnifications of approximately 50x, 80x, and 120x

Notice that the images in Figs. 3.2 b and c are dimmer compared with the one in Fig. 3.2a. Is there a way to make it brighter? We can do so by gathering more light from the object. This brings us to the concept of light gathering power of a telescope.

3.2.2 Light Gathering Power

The **light gathering power** of a telescope refers to its ability to collect light from an object. Most interesting celestial objects are faint sources of light and in order to get an image we need to capture as much light as possible from them. This is somewhat similar to catching rainwater in a bucket, the bigger the bucket, the more rainwater it catches.

Similarly, the light gathering power of a telescope is proportional to the area (i.e., diameter squared) of the telescope objective. Now, the area of a circular lens or mirror of diameter D is $\pi\,(D/2)^2$. Thus, the ratio of light gathering powers of two telescopes is given by

$$\frac{LGP_1}{LGP_2} = \left(\frac{D_1}{D_2}\right)^2 \qquad (3.3)$$

For example, a telescope of 100mm diameter can gather $(100/8)^2 = 156.25$ times more light than a human eye with a typical pupil diameter of 8 mm.

Similarly, if we compare telescopes of 24 cm and 4 cm diameters, the former gathers $(24/4)^2 = 36$ times more light than the latter. Thus, even a small increase in telescopes diameter produces a large increase in its light gathering power and allows astronomers to study much fainter objects.

The ability of a telescope to reveal fine detail of an object is determined by its **resolving power**, which we now discuss.

3.2.3 Resolving Power and Diffraction Limit

You have learnt in Sec. 11.2 of Unit 11 of Optics that the image of a point object through an optical instrument is not a sharp point-like image but a bright circular disc called the **Airy disc**. The disc is surrounded by a number of alternate bright and dark fringes produced due to diffraction. The central bright disc represents the image of the object.

Now suppose we wish to observe two close stars that appear equally bright. We should be able to see two Airy discs. However, whether we see them as distinct discs or overlapping each other, depends on the **resolving power** of the telescope. Fig. 3.3 shows three situations where two equally bright stars are closely placed. The pattern of rings seen at each star image is called the **Airy pattern**. The two stars are said to be just resolved when we can just infer their images as two distinct Airy discs (Fig. 3.3b). To resolve these Airy discs, we use the **Rayleigh criterion**.

Rayleigh criterion

Two equally bright stars are said to be resolved when the central maximum of one diffraction pattern coincides with the first minimum of the other.

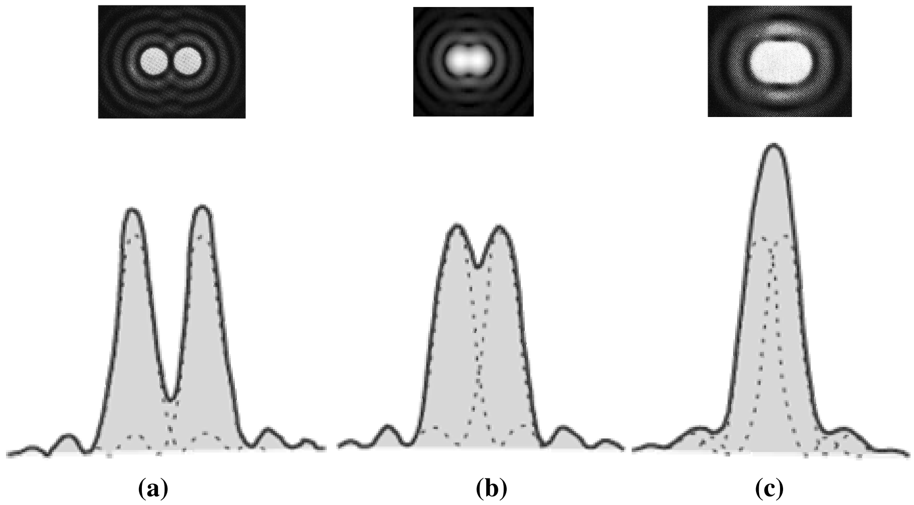


Fig.3.3: Resolving a pair of two equally bright stars. In a) the stars are easily resolved; in b) the stars are JUST resolved, and in c) the stars are too close and not resolved.

You may like to ask: What factors determine a telescope's resolving power? Naturally, the quality of lenses is a major factor. But even with perfect optics, the resolving power of a telescope is limited by diffraction.

The **diffraction limit of resolution** (R) of a telescope is defined as

$$R \text{ (in radians)} = (1.22\,\lambda / D), \tag{3.4}$$

where λ is the wavelength of light and D is the telescope diameter. Both λ and D have to be expressed in the same units. [Note that 1 degree = 60 arc-minutes ($60'$) = 3600 arc-seconds ($3600''$)]. R can be expressed in arc-seconds as

$$R \text{ (arc-sec)} = \frac{1.22\lambda}{D}(206265) \tag{3.5}$$

For human eye

$$R \sim 1' \text{ for absolute sharp vision,}$$

$R \sim 2'$ for clear vision and

$R \sim 4'$ for comfortable vision.

Remember that the smaller the value of R, the better is the instrument's ability to resolve nearby objects.

Example 1: Diffraction limit of resolution of telescopes of different sizes for a given wavelength

Table 3.1 shows the diffraction limit of resolution of telescopes of different sizes for $\lambda = 457$ nm.

Table 3.1: Diffraction limit of resolution of various telescopes

Telescope Diameter (mm)	R (″)
50	2.3
100	1.15
200	0.58
400	0.29
500	0.23

You may like to calculate R for a telescope.

SAQ 1

Spend 10 *min.*

Calculate the diffraction limit of resolution of Mount Palomar telescope of 200 inch diameter for $\lambda = 457$ nm. Compare its light gathering power with a telescope of 200 mm diameter.

Based on size alone, the largest telescopes should have large resolving powers. But the resolution of large telescopes is limited by the passage of light through the Earth's atmosphere. When we look through a telescope, we are looking through several kilometres of turbulent air, which blurs the image. The Earth's atmosphere does not allow ground-based telescopes to resolve better than 1-2 arc-seconds in the sky (for even the best astronomical sites).

The major limitation for ground-based astronomy is the Earth's atmosphere and it can affect the observations in many ways. Moreover, all wavelengths cannot pass through the atmosphere. This brings us to the concept of atmospheric windows.

3.2.4 Atmospheric Windows

Some of the effects of the Earth's atmosphere on electromagnetic radiation are: Absorption, scintillation, scattering and turbulence. Atmospheric molecules such as carbon dioxide and water vapour give rise to absorption. Thus, only certain bands of frequencies in the electromagnetic spectrum pass through the atmosphere. These regions of the electromagnetic spectrum are called **atmospheric windows**. Fig. 3.4 shows the absorption properties of the Earth's atmosphere. On the x-axis is the wavelength in cm and on the y-axis is the altitude in km at which the intensity of the radiation entering the atmosphere is reduced to half.

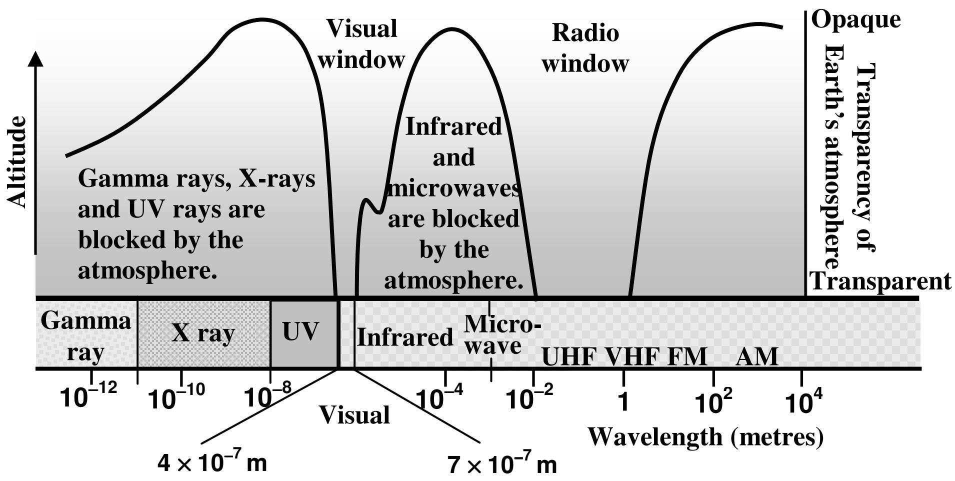


Fig.3.4: The spectrum of electromagnetic waves from gamma rays to long radio waves showing the optical and radio 'windows' and the regions of atmospheric transparency

The atmosphere allows only visible radiation and radio waves to come through to the surface of the Earth. For observations at other wavelengths we have to fly detecting instruments to altitudes at which these wavelengths are not completely absorbed. Before the advent of artificial satellites, the instruments were flown in balloons and rockets. Now-a-days observations are carried at various wavelengths by instruments on board the space satellites. It is important to remember that astronomers like to observe objects in as many wavelengths as possible. This helps them to understand astronomical objects better.

Spend 5 min.

SAQ 2

For the same diameter, compare the resolving power of an optical telescope operating at λ 457 nm and a radio telescope operating at λ 1 cm.

You have learnt in SAQ 2 that the resolving power of a radio telescope is quite poor. Therefore, radio telescopes need to have very large apertures.

So far we have discussed some optical definitions relevant to astronomy. We now turn our attention to the instruments and techniques used for making astronomical observations from the Earth. Let us now learn about optical telescopes.

3.3 OPTICAL TELESCOPES

Telescopes have undergone tremendous evolution from Galileo's times when only refracting telescopes were used. The most recent telescopes have mirrors that can be actively shaped according to the observer's need. The **refracting telescopes** became outdated very soon because

i) it was difficult to make good large lenses required for large gathering area,

ii) large lenses were very heavy and balancing the telescope became difficult, and

iii) lenses suffered from optical aberrations.

Reflecting telescopes with mirrors (parabolic or hyperbolic) have been around for more than a century. In the last few decades, advanced technologies have been developed which allow the observer to effectively control the optical system so that it can be adapted to the needs of the observations.

Such **active** and **adaptive** optics have completely changed this basic tool of observational astronomy. We now describe various types of reflecting telescopes.

3.3.1 Types of Reflecting Telescopes

James Gregory of Scotland (1638-75) proposed the first design for a reflecting telescope in which he used a paraboloidal mirror as the objective (primary mirror) to minimize chromatic and spherical aberrations (Fig. 3.5).

In this type of telescope, light from a distant object hits the primary mirror and is reflected to a secondary mirror which reflects it down to the telescope tube again to a secondary focus. The light emerges from the telescope through a small central hole in the primary mirror and is observed with an eyepiece or a detector.

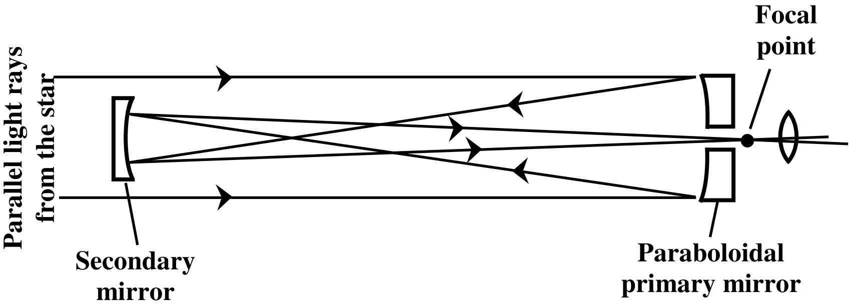


Fig.3.5: Gregorian reflecting telescope with equatorial mounting; ray diagram for the telescope

The performance of the Gregorian telescope was not satisfactory and Newton (1642-1727) built a working reflector.

A Newtonian telescope (Fig. 3.6) uses a parabolic primary but a flat mirror as a secondary, which is set at 45° to the axis of the tube. The light is brought to a focus at the side of the telescope where the eyepiece is placed. This system is widely used even now.

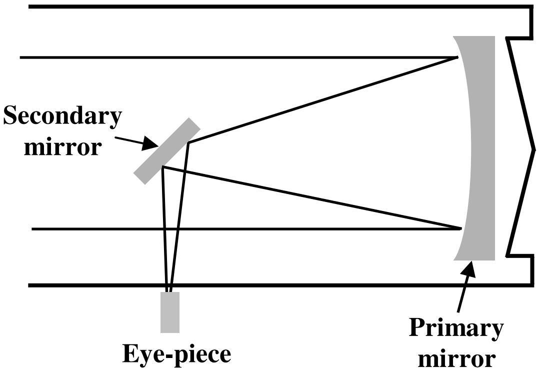


Fig.3.6: Newtonian reflecting telescope

A little later, a French optician, G. Cassegrain (who lived at the time of Newton), designed another reflector (Fig. 3.7).

Now-a-days the most commonly used telescope is the Cassegrain type with a central hole in the primary mirror which allows the light to come out for placing an eyepiece or any other general detector or instruments. This design also allows the folding of the focussed beam and thus provides a very compact telescope.

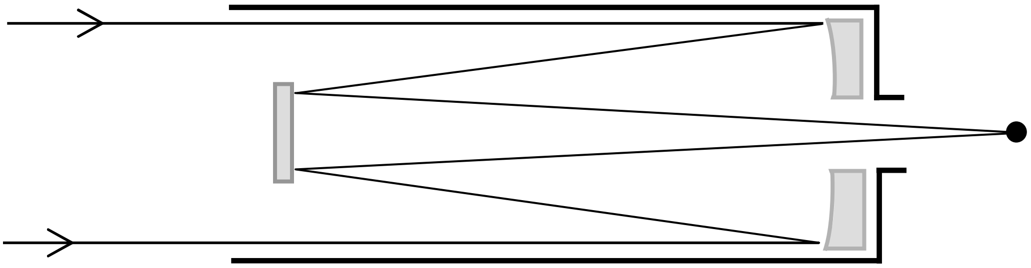


Fig.3.7: Cassegrain reflecting telescope

All telescopes need to be pointed at the desired part of the sky, and then they have to follow or **track** the objects in the sky as their direction changes due to Earth's rotation. For example, suppose you are viewing Jupiter and its moons with a telescope. Due to the Earth's rotation, you will see Jupiter moving across your view until it is gone. You will have to move your telescope to follow Jupiter if you want to keep viewing it. However, to track it, you will need a mounting for the telescope so that it can be turned in the desired direction. We will now briefly describe telescope mountings.

3.3.2 Telescope Mountings

Most of the small telescopes (less than 1 metre diameter) use the **equatorial mount** (Fig. 3.8). In an equatorial mounting, the pier or the base on which the telescope is mounted is set so that its axis points to the North Pole. This is done by raising the axis by an angle equal to the latitude of the place. This axis is called the polar axis. A rotation about the polar axis is used for adjustment in right ascension. The telescope is also provided with motion about an axis perpendicular to the polar axis, called the declination axis, for adjustment in declination. Thus, a combination of these two motions allows the telescope to point to any object whose equatorial coordinates are known.

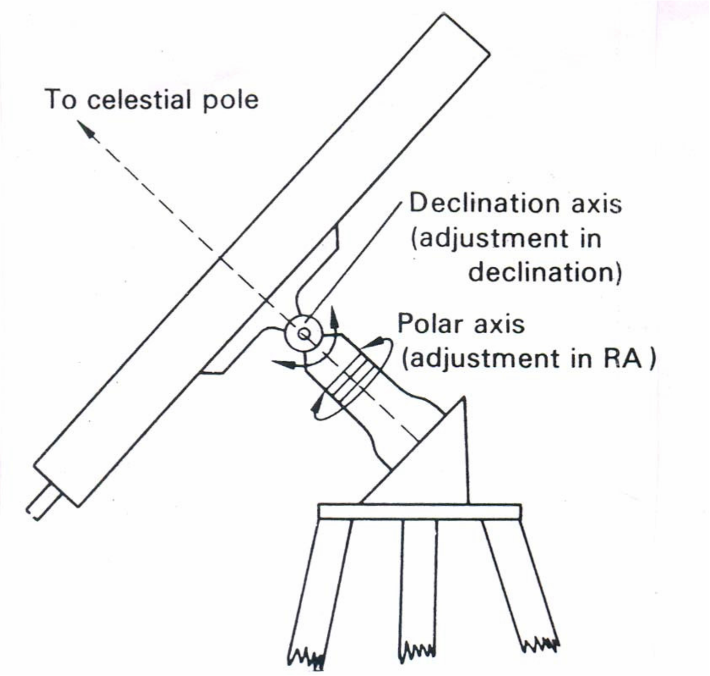


Fig.3.8: The equatorial mounting

Since the telescope is fixed on the Earth, it moves with the Earth. In order that the object remains in the field of the telescope, the mounting is made to rotate in the direction opposite to that of the Earth with the same speed as that of the Earth. All these adjustments make this type of mounting heavier than the altitude-azimuth mounting described ahead. That is why it is not used with very big telescopes.

All modern telescopes (larger that 2 m diameter) use Alt-Azimuth type mount shown in Fig. 3.9. You have learnt in the last unit that altitudes and azimuths of objects change with the location of the observer and with time for the same observer. This was a major limitation of this type of mounting in earlier times but with advances in the technology using computers in the past few decades, it is no more an issue.

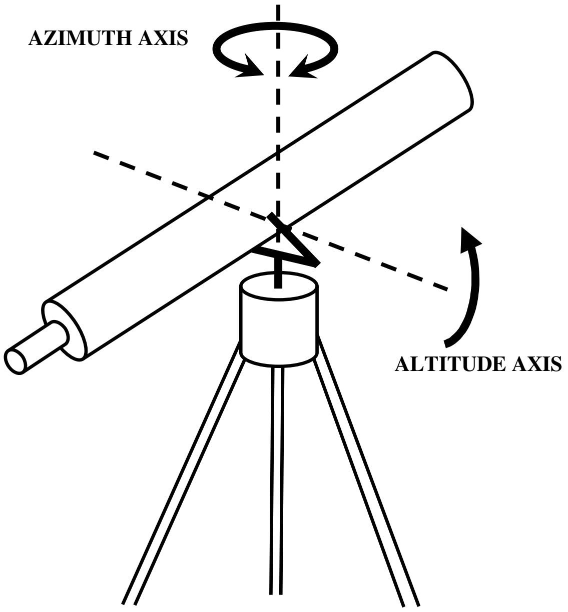
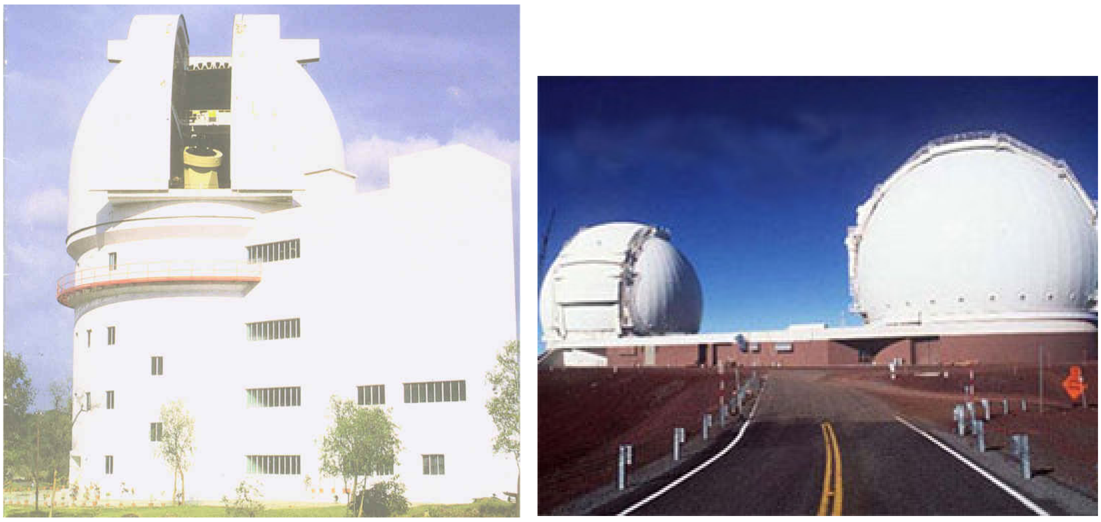


Fig.3.9: The Alt-Azimuth type mount

In Fig. 3.10a we show the largest telescope in India set up by the Indian Institute of Astrophysics at Kavalur Observatory in Karnataka.



(a) **(b)**

Fig.3.10: a) The Vainu Bappu telescope in Kavalur Observatory; b) domes housing twin Keck telescopes

At present, the largest operating telescopes are the twin Keck 10 m telescopes at Mauna Kea, in Hawaii, placed at about 4200 m height above sea-level (Fig. 3.10b). There are plans now for making very large aperture (up to 20 – 30 m) telescopes!

3.3.3 Space Telescopes

You have learnt in Sec. 3.2 that the main advantages of a telescope over direct observation with the human eye, are **magnification, light collection** and **resolution**. For light collection, one could fabricate telescopes of increasingly large diameters. But these will be limited by the effect of the Earth's atmosphere. However, if we could put a telescope in space (high above the Earth's atmosphere, in a balloon or a satellite), then the Earth's atmosphere would not be a limiting factor, and we could achieve diffraction-limited images. In such situations the size of the telescopes that can be built for such platforms is the only limitation due to the costs involved and limitations of available technology.

The Hubble Telescope of about 2 m diameter is the best example of this type of telescope (Fig. 3.11). Over the past decade it has made very high quality observations of stars, nebulae, galaxies, supernovae and other objects. Some of these objects belong to a very early phase of the universe. These observations have led to improved understanding of these objects.

Fig.3.11: The Hubble Space Telescope

Both the types of telescope – ground-based and space-based – have somewhat different roles to play and complement each other. That is why there is always a demand to build large diameter ground-based telescopes.

The **active** and **adaptive** telescopes are the latest instruments in use today. In the **active telescopes**, the shape of the primary mirror can be changed (although it retains its parabolic form) according to the observer's need. This is done with the help of small peizo driven pistons placed at the back of the mirror support. This is now routinely done for large mirror based telescopes. In the **adaptive telescope** the changes in the shape of the primary mirror are done in a controlled manner depending upon the changes in the Earth's atmosphere during night. In some sense, the adaptive telescopes can beat the effect of the atmosphere and render images as good as the space telescopes for some duration in the night!

Telescopes must use detectors to help us obtain useful information about the universe. We now discuss various detectors and how these are used with telescopes.

3.4 DETECTORS AND THEIR USE WITH TELESCOPES

Detectors are used for measuring the light output from a telescope and play a major role in obtaining information about the stars, galaxies, etc. The actual light available from an astronomical object is very small as will be clear from the following example.

Example 2: Estimate of Available Light from a Star

Vega is one of the bright stars in the sky and is about 26 light years away. The radiation emitted in visible band at the star's surface is 175,000 $\mathrm{Wcm^{-2}}$. This reduces by 10^{-16} times on its arrival outside Earth's atmosphere. Another 20% is lost in the atmosphere due to absorption and scattering. About 30% is lost in the telescope optics.

Thus, if we use a 25 cm (10″) telescope to collect this light, then only about 0.5×10^{-9} W is available at its Cassegrain focus. Eventually only a fraction of this is actually detected since the detector is never an ideal one and has an efficiency of at best 80%. It is amazing that even with such a small amount of light detected, we can study many things about a star, e.g., its light variation, brightness, composition. We can even take a spectrum (which actually divides this small available light into smaller bits of wavelengths)!

Detectors are used with telescopes in the following two modes of operation:

- **Imaging:** This involves taking direct pictures of star fields and extended objects like gas clouds or galaxies. Since sharp images are required over a wide field which may extend up to several square degrees, careful optical design is a natural requirement.

- **Photometry:** This involves measuring total brightness, spectrum etc. of single objects. Compared to imaging mode, poorer images are acceptable in this case but the stellar image has still to be small enough to enter an aperture or slit of a spectrograph.

We now briefly describe various types of detectors.

3.4.1 Types of Detectors

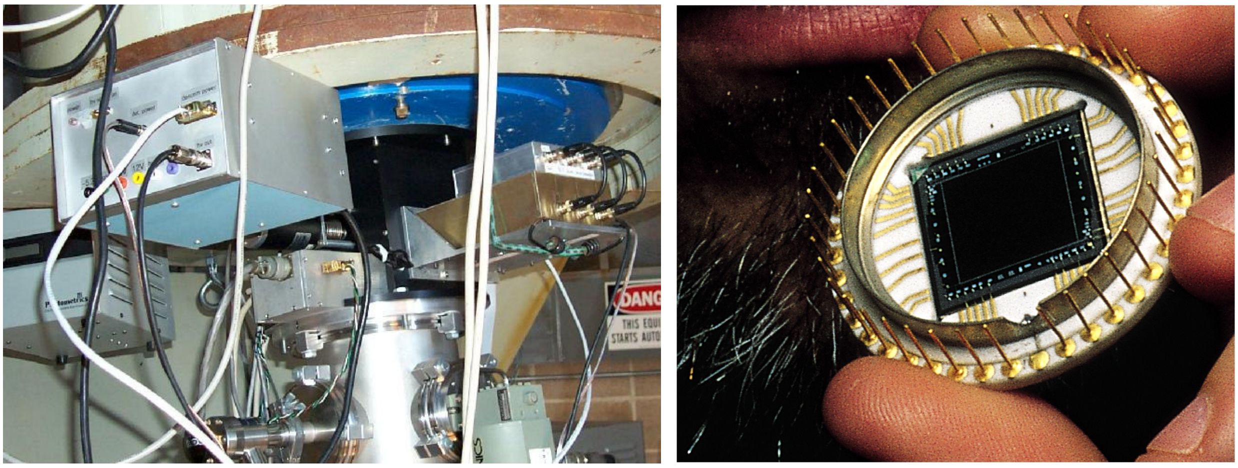
Detectors used in the imaging mode are mainly 2-dimensional (2D type) since we are trying to form images of objects in a given area. Examples of such detectors are the **photographic emulsion**, human eye and the most modern detector, the **charge-coupled device** (CCD). Detectors used for photometry of single objects are 1D type (one dimensional), since they receive photons from one object only. The photometer is a 1D detector.

Photometer

Before the advent of CCDs, the measurements of light intensity and colour were made using a photometer, a highly sensitive light meter attached to a telescope (Fig. 3.12a). A photometer is still used in the photometry of single stars. It is used more commonly for stars whose light output varies with time, called **variable** stars. The most important component of a photometer is a **photomultiplier tube** that is based on the **photoelectric effect** about which you have studied at +2 level. A photon when incident on a photocathode emits an electron. The electric current thus generated is amplified further and can be measured directly. The calibration of intensity or colour is done by observing a comparison star. Today, however, most photometric measurements are made on CCD images.

Charge-coupled device

A charge-coupled device (CCD) is a special computer chip of the size of a postage stamp (Fig. 3.12b). It contains a large number (~ millions) of microscopic light detectors arranged in an array. A CCD can be used like a small photographic plate, though it is much more sensitive. CCDs detect both bright and faint objects in a single exposure. The image from a CCD is stored in a digitised form in a computer. Therefore, brightness and colour can be measured to high precision. Moreover, it is easy to manipulate the image to bring out details. At present, the only major drawback of CCD is that its maximum size is limited (about 70 mm square) as compared to the most basic 2D detector, i.e., photographic plates which can be as large as 300 mm square. This disadvantage of CCD is also being overcome by combining a large number of CCDs.



(a) (b)

Fig.3.12: a) Photometer attached to a telescope; b) a CCD

Efficiency of a Detector

A basic parameter which defines the efficiency of any detector is its **Quantum Efficiency** (Q.E.). It is the ratio of number of photons actually detected (or recorded) by it to the number of photons recorded by an ideal and perfect detector. Since ideal detector by definition would detect all photons incident on it with 100% efficiency, this ratio is nothing but the ratio of actually detected photons by the detector versus the number of photons incident on it. Fig. 3.13 gives the efficiency curves for various detectors.

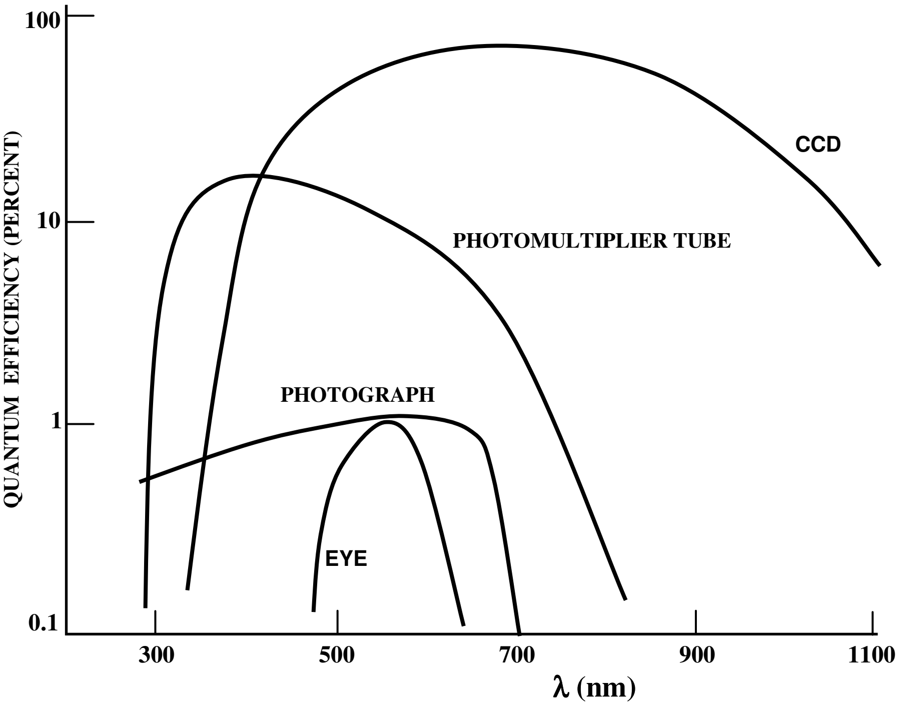


Fig.3.13: Quantum efficiency of various detectors in terms of wavelength of light

Note that the human eye and photographic emulsion are detectors with the lowest sensitivity and photomultiplier tubes are only marginally better. The CCD works over a large wavelength region in the visible band with a Q.E. of the order of 60-80%. You must remember that the *y*-axis in Fig. 3.13 is in log scale.

As you have read in Unit 1, the limiting magnitude of the naked eye is about +6. This means that the faintest object visible under normal observing conditions, with an eye adapted to darkness has a magnitude of +6. It takes 25-30 minutes for the eye to get completely dark-adapted, otherwise we can see only up to fourth or fifth magnitude.

Experiments have, however, shown that a dark-adapted eye, looking at a patch of dark sky through a modest telescope can see stars as faint as $m_v = +8.5$. This corresponds to a flux of about 200 photons per second.

We would also like to find out how far the limits of detection are extended when we use a telescope with various detectors.

In spectroscopy or spectrophotometry, we analyze the light in great detail by using a spectrograph which spreads the light into a spectrum according to wavelength. You are familiar with a prism dispersing white light into its component colours. Nearly all modern spectrographs use a grating instead of a prism and the spectrum is recorded directly on a CCD camera. Since we understand how light is emitted, scattered, or absorbed by matter, a spectrum carries a lot of information about the source of light and the medium through which it has passed. We shall discuss this in detail in Unit 7.

3.4.2 Detection Limits with Telescopes

Modern detectors like CCDs can detect individual photons, and the limiting magnitude is normally governed by the background noise.

For a typical photographic plate, only about 0.1% of the incident photons are recorded depending on the type of grains on the film. On such a plate, an image is detectable only after about 5×10^4 photons have been received.

At 200 photons per second, the photographic plate can match eye's limit with an exposure of about 4 minutes.

Obviously, the plate can detect much fainter objects with longer duration exposures.

The limit to the flux of visible radiation which is detectable is given by

$$F_{\lim}^{vis} \propto \frac{1}{D^2 t} \tag{3.6}$$

where *t* is the exposure time and *D* is the telescope aperture.

For a telescope, the magnitude limit in the visible range, in a very approximate manner without considering any efficiency factors etc., is given by

$$m_v^{\lim} \sim 2 + 5\log_{10} D \tag{3.7}$$

where *D* is in mm.

Thus using the human eye as the detector along with a telescope we can have the limiting magnitudes as $m_v \sim 12.9$ for a 6 inch and $m_v \sim 15.3$ for an 18 inch telescope.

SAQ 3

Spend 5 min.

Find the magnitude of the faintest object that the 3.5 metre New Technology Telescope at the European Southern Observatory in Chile can detect.

With this we come to the end of the unit. We now summarise its contents.

3.5 SUMMARY

- If a telescope has an objective of local length f_0 and the eye-piece has a focal length f_e, then **angular magnification** is equal to the ratio f_0/f_e.

- The **light gathering power** of a telescope refers to its ability to collect light from an object.
- The **resolving power** of a telescope is its ability to reveal fine detail. The resolving power of a telescope is given by

  $$\alpha = \frac{11.6}{D}$$

  where D is the diameter of the telescope's objective. A point light source observed through a telescope would not appear as a point source. **Diffraction** would cause the image to appear as a round disk of light, called **Airy's disk**. The diffraction limit of resolution in radians is given by

  $$R = 1.22\frac{\lambda}{D}$$

  where λ is the wavelength of light. Both λ and D must have the same units.
- At the Earth's surface, electromagnetic radiation can be detected only in the **radio**, **infrared** and **optical windows**.
- Telescopes can be of **refracting** or **reflecting** types.
- All modern telescopes are reflecting type. There are three kinds of reflectors: **Gregorian**, **Newtonian** and **Cassegrain**. The Cassegrain reflectors are the most popular.
- Telescopes can be operated in imaging or photometry mode.
- The larger is the diameter of the objective, the fainter is the source that a telescope can detect.
- The human eye, photographic emulsion, photometer and charge-coupled devices are various types of **detectors**.
- Of these the **CCDs** are used most by modern astronomers. These are used for recording images, measuring brightness and colour of celestial objects.

3.6 TERMINAL QUESTIONS

Spend 30 *min.*

1. Why can infrared observations be made from high mountains while X-ray observations can be made only from space?
2. Nocturnal animals have large pupils in their eyes. Can you relate that to astronomical telescopes?
3. The moon has no atmosphere. If we had an observatory on the moon, at what wavelengths could we observe the astronomical objects?
4. What is the resolving power of a 20 cm telescope if observations are made at λ 550nm?
5. What do two stars 1.5 arc-seconds apart, look like through a 25 cm telescope ?
6. Compare the light gathering powers of the 5 m telescope and a 0.5 m telescope.

3.7 SOLUTIONS AND ANSWERS

Self Assessment Questions (SAQs)

1. $$R = \frac{1.22\lambda}{D} \times 206265 \quad \text{arc - sec}$$

$$= \frac{1.22.457 \times 2.06265}{2 \times 2.54} \times 10^{-2} \quad \text{arc - sec}$$

$$= .023 \text{ arc - sec}$$

$$\frac{\text{LGP}_{\text{MP}}}{\text{LGP}_{\text{200mm}}} = \left(\frac{200 \times 2.54 \times 10}{200} \right)^2 = (2.54)^2 \times 10^2 = 645.2$$

2. Ratio of resolving powers $= \frac{1.22\lambda_1}{D} \times 206265 \times \frac{D}{1.22\lambda_2} \times \frac{1}{206265}$

$$= \frac{\lambda_1}{\lambda_2} = \frac{4.57 \times 10^{-9} \times 10^2}{1}$$

$$= 4.57 \times 10^{-7}$$

The resolving power of the radio telescope is 4.57×10^{-7} times the resolving power of an optical telescope operating at 4.57 nm.

3. Limiting magnitude

$$m_v = 2 + 5\log_{10} D$$

$$= 2 + 5\log_{10}(3.5 \times 100 \times 10)$$

$$= 2 + 15 + 5\log_{10}(3.5)$$

$$= 19.7$$

Terminal Questions

1. At the top of a high mountain, we can receive only *IR*. *X*-rays are available only much above the top of the highest mountains. Therefore, to observe in *X*-ray band, we will need to observe from a space-based telescope.
2. The larger the diameter of the pupil, larger is the light gathering power. Nocturnal animals are adapted to night vision by virtue of this. Astronomical telescopes also require bigger and bigger objectives to see fainter and fainter objects.
3. At all wavelengths, provided we have detectors sensitive in those regions.
4. 0.58 arc-seconds.
5. Resolved.
6. The 5 m telescope has 100 times the light gathering power of a 0.5 m telescope.