Optics and Telescopes

Most telescopes are used to collect electromagnetic radiation (Notable exception: neutrino telescope).

Design of a telescope depends on type of electromagnetic radiation you want to collect and what you want to study. e.g.

X-ray telescopes use grazing incidence mirrors to focus the radiation.

UV, optical, and IR telescopes use lenses or mirrors to focus the radiation.

Radio telescopes use wires and metal to focus the radiation.

The `collecting area' of a telescope determines how much electromagnetic radiation from an object can be collected and focused in a given interval of time. By making the collecting area larger, fainter objects can be observed.

Collecting Area of circular Telescope = $0.25\ \pi\ D^2$

where D= telescope diameter.

Clarity of an image formed by a telescope.

Determined by:

the telescope resolution and/or

atmospheric blurring (seeing).

Resolution

How well two nearby objects are separated.

The theoretical resolution (or diffraction limit) of a telescope depends on:

the wavelength (λ) of the radiation

distance between different parts of the telescope's collecting area (D).

Resolution (in radian) = 1.22 (λ / D)

Resolution (in arc seconds) = 2.52×10^5 (λ / D)

Observations at **longer wavelengths** (eg radio waves) result in **poorer resolution.**

Smaller distances between different parts of a telescope's collecting area also result in **poorer resolution.**

At radio wavelengths, a telescope's resolution is limited by the theoretical considerations.

At visible wavelengths, a telescope's resolution is **limited by atmospheric seeing.** The typical resolution of an optical telescope is 1 arc second (1/3600 of a degree).

NB. Moon has diameter of:

30 arcminutes

1800 arcseconds

1 arcsecond corresponds to a dime (1.5cm) seen at 3 km.

OPTICAL TELESCOPES

Many optical telescope designs.

Design determines :

cost

feasibility of a particular observation.

Some popular standard designs:

Refracting telescopes

Focus light with lenses

Disadvantages:

Costly

Images often suffer from chromatic aberration (i.e., all the different colors of light from an object are not focused at the same place).

Difficult to mount large lenses

Difficult to make large lenses.

Advantages:

Long focal length gives good plate scale for astrometry.

Refractors can produce superb images if made properly.

Largest:

40 inch: Yerkes Observatory

36 inch: Lick Observatory

Reflecting telescopes

Focus light with mirrors. Mirror generally parabolic in shape.

Numerous designs

Newtonian

Cassegrain

Gregorian

Ritchey-Chretien, etc.

which vary in cost.

Aberrations (imperfections) in the image are determined by the design.

Advantages:

No chromatic aberration

Primary mirror easier to build.

Primary mirror can be supported at base.

Disadvantages:

Small fields due to Coma (an aberration). "A parabola is only symmetric for on Axis rays"

Schmidt telescopes

Focus light with both mirrors and lenses.

Use a spherical mirror. The "thin" lens across the entrance aperture corrects for the "spherical" aberration introduced by the spherical mirror.

Provides accurate images over a wide field of view.

Generally costly.

Used for survey work.

Sensitivity: - Detect a 20 watt globe at distance of moon.

Image Scale: - A telescope's focal length determines the scale of an image formed.

I**mage brightness:** The telescope's f-value or focal ratio (i.e., focal length divided by diameter) determines image brightness.

Magnification (`power'): Depends on the telescope's focal length and the eyepiece used to view the image. Eyepiece enlarges the scale.

Telescope Design Considerations:

Diameter (collecting area)
Cost
Focal Length
Focal Ratio
Field of view

Site Selection:

Weather
Transparency (haze, water vapor)
Seeing
Away from pollution (smog, visible light , radio)
(Access)

Gamma-Ray Astronomy

No true imaging telescopes - (1 deg resolution)
(moon is half a degree in diameter)
Collimator limits field of view
Space based

X-Ray Telescope

Use grazing incidence mirrors
(X-rays pass through ordinary mirrors)
Theoretical resolution better than optical telescope but limited by mirror technology.
Rosat has 2 instruments with resolutions of 30
and 4 arcseconds.
False color images used to display data.

Ultraviolet Astronomy

Similar techniques to optical astronomy
Space craft observations
IUE, Hubble

Infrared Telescope

Best observing from space.
Telescope is warm.
Observing in IR is like observing with lights on in the optical region.
“Clean “ Telescope
Cool Detectors (liquid Nitrogen and Helium)

Radio Telescopes

Distinct Technology

Dishes made of wire and metal ---- irregularities whose size are less than **1/10 th** of the wavelength of the radiation to be observed are unimportant.

Can observe through clouds, and even snow and rain storms at longest wavelengths.

Single dishes have much lower resolution than optical telescopes.

eg 200 ft (60m) radio dish has resolution of 15 arcminutes at a wavelength of 21cm

To improve resolution two (or more) telescopes can be used simultaneously --- called **interferometry**

Very Large Array has 27 dishes spread out in a Y shape over approximately 30km.

Resolution determined by the largest distance between telescopes (i.e their separation).

Data Collection

Astronomers today no longer make measurements by looking through a telescope. A detector attached to a scientific instrument (e.g. a spectrograph) at the telescope's focus makes a permanent record of the observations. Data are later analyzed with the aid of a computer. The type of detector used depends on the electromagnetic radiation being observed.

Past observations with optical telescopes often used photographic plates as detectors.

- ☹ Poor detection efficiency
- ☹ Non-linear detector
- ☺ Large area.

High-grade CCDs (charge coupled devices), similar to the low-grade ones used in home video cameras, are now generally used.

- ☺ High detection efficiency.
- ☺ Linear detector
- ☹ Small area

The detector in a radio telescope is an antenna with a receiver. Detectors on modern telescopes are very efficient.

Today's Generation of New Telescopes

NASA's Great Observatories Program to put telescopes in space will cover all regions of the electromagnetic spectrum not observable from the ground:

- Hubble Space Telescope (UV, optical, and IR) was put in orbit in 1990.
- Gamma Ray Observatory [Compton] was put in orbit in 1991.
- Advanced X-Ray Astronomical Facility [AXAF] will be put in orbit in about 5(?) years.
- Space Infrared Telescope Facility [SIRTF] will be put in orbit in about 10(?) years.

Large modern ground-based optical telescopes

- low-cost designs
- advanced technology to overcome resolution limitations caused by atmospheric seeing effects.
- e.g.
  - Keck (segmented mirror)
  - MMT replacement mirror --- honeycomb structure

Modern radio telescopes being designed like the Very Large Baseline Array will have very high resolution and sensitivity.