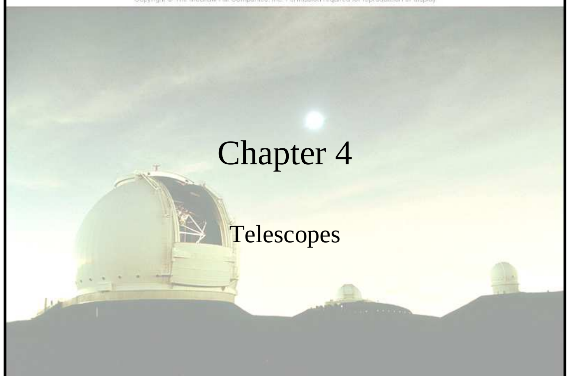
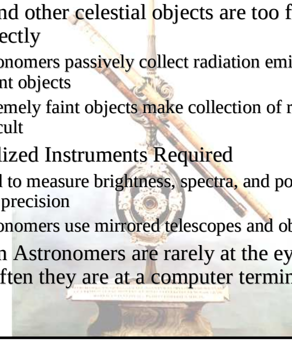


Chapter 4

Telescopes

Tools of the Trade: Telescopes



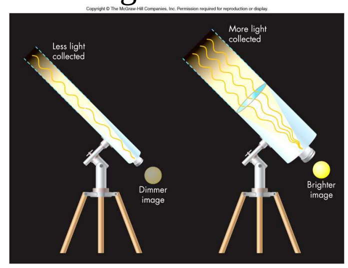
- Stars and other celestial objects are too far away to test directly
  - Astronomers passively collect radiation emitted from distant objects
  - Extremely faint objects make collection of radiation difficult
- Specialized Instruments Required
  - Need to measure brightness, spectra, and positions with high precision
  - Astronomers use mirrored telescopes and observatories
- Modern Astronomers are rarely at the eyepiece, more often they are at a computer terminal!

The Powers of a Telescope

- Collecting Power
  - Bigger telescope, more light collected!
- Focusing Power
  - Use mirrors or lenses to bend the path of light rays to create images
- Resolving Power
  - Picking out the details in an image

Light Gathering Power

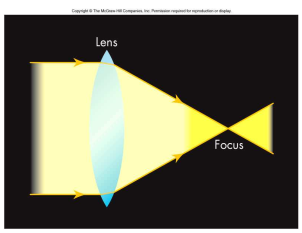
- Light collected proportional to "collector" <u>area</u>
  - Pupil for the eye
  - Mirror or lens for a telescope
- Telescope "funnels" light to our eyes for a brighter image
- Small changes in "collector" radius give large change in number of photons caught



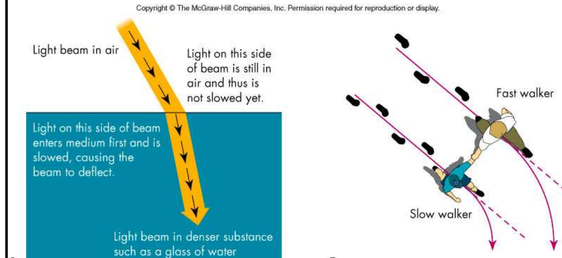
- Telescopes described by lens or mirror diameter (inches)

Focusing Power

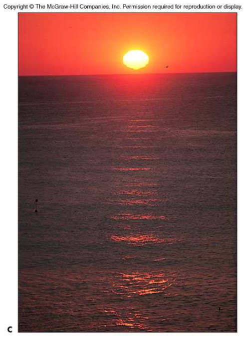
- Refraction
  - Light moving at an angle from one material to another will bend due to a process called ***refraction***
  - Refraction occurs because the speed of light is different in different materials



Refraction



Refraction

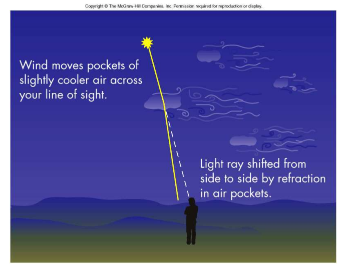


C

– ***Dispersion*** causes different colors to travel at different speeds through the same material
– Refraction is responsible for the distortion of the Sun near the horizon, but not the ***Moon illusion***

Refraction

- Refraction is also responsible for *seeing*
  – Twinkling of stars
  – AKA ***Scintillation***
- Temperature and density differences in pockets of air shift the image of the star



Refracting Telescopes

- A lens employs refraction to bend light
- Telescopes that employ lenses to collect and focus light are called ***refractors***

Lens 1 meter (40 inches) in diameter

Disadvantages to Refractors

- Lenses have many disadvantages in large telescopes!
  – Large lenses are extremely expensive to fabricate
  – A large lens will sag in the center since it can only be supported on the edges
  – Dispersion causes images to have colored fringes
  – Many lens materials absorb short-wavelength light

Reflecting Telescopes

A

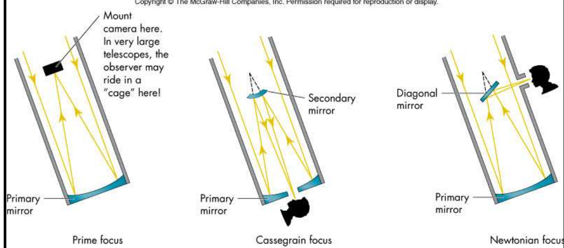
- Reflectors
  – Used almost exclusively by astronomers today
  – Twin Keck telescopes, located on the 14,000 foot volcanic peak Mauna Kea in Hawaii, have 10-meter collector mirrors!
  – Light is focused in front of the mirror

Reflecting Telescopes

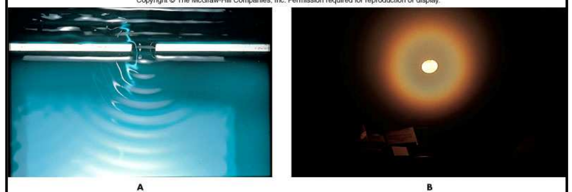
- A ***secondary mirror*** may be used to deflect the light to the side or through a hole in the ***primary mirror***
- ***Multi-mirror instruments*** and ***extremely thin mirrors*** are two modern approaches to dealing with large pieces of glass in a telescope system

B

Styles of Refractors

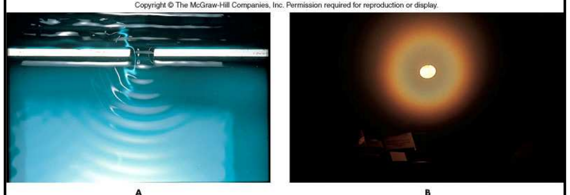


Resolving Power



- A telescope's ability to discern detail is referred to as its ***resolving power***
- Resolving power is limited by the wave nature of light through a phenomenon called ***diffraction***
- Waves are diffracted as they pass through narrow openings
- A diffracted point source of light appears as a point surrounded by rings of light

Resolving Power and Aperture

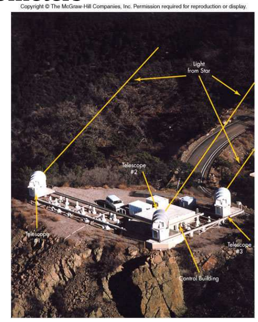


- Two points of light separated by an angle α (in arcsec) can be seen at a wavelength λ (in nm) only if the telescope diameter D (in cm) satisfies:

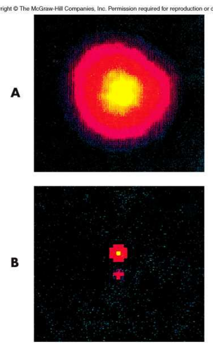
$$D > 0.02\ \lambda/\alpha$$

Increasing Resolving Power: Interferometers

- For a given wavelength, resolution is increased for a larger telescope diameter
- An ***interferometer*** accomplishes this by simultaneously combining observations from two or more widely-spaced telescopes



Interferometers

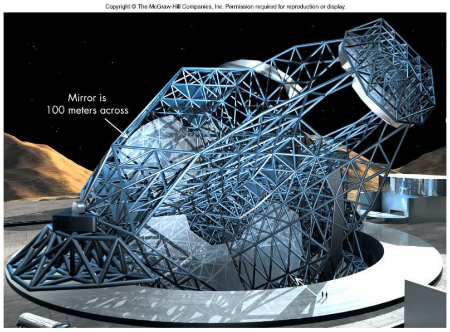


- The resolution is determined by the individual telescope separations and not the individual diameters of the telescopes themselves
- Key to the process is the wave nature of interference and the electronic processing of the waves from the various telescopes

Observatories

- The immense telescopes and their associated equipment require observatories to facilitate their use and protection from the elements
- Thousands of observatories are scattered throughout the world and are on every continent including Antarctica
- Some observatories:
  - Twin 10-meter Keck telescopes are largest in U.S.
  - The Hobby-Eberly Telescope uses 91 1-meter mirrors set in an 11-meter disk
  - Largest optical telescope, VLT (Very Large Telescope) in Chile, is an array of four 8-meter mirrors

The “OWL” Telescope

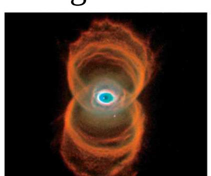


Detecting the Light

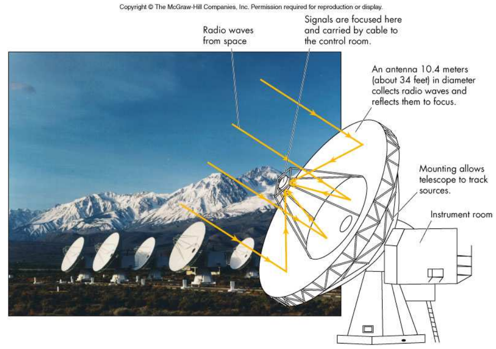
- The Human Eye
  - Once used with a telescope to record observations or make sketches
  - Not good at detecting faint light, even with the 10-meter Keck telescopes
- Photographic Film
  - Chemically stores data to increase sensitivity to dim light
  - Very inefficient: Only 4% of striking photons recorded on film
- Electronic Detectors
  - Incoming photons strike an array of semiconductor pixels that are coupled to a computer
  - Efficiencies of 75% possible
  - ***CCD*** (Charged-coupled Device) for pictures

Nonvisible Wavelengths

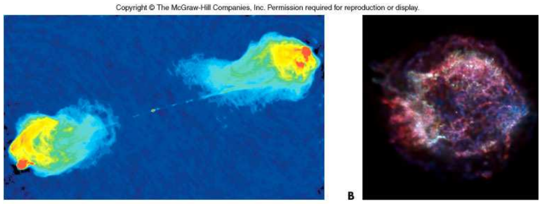
- Many astronomical objects radiate in wavelengths other visible
  - Cold gas clouds radiate in the radio
  - Dust clouds radiate in the infrared
  - Hot gases around black holes emit x-rays



Radio Observatories



Radio Observations



- False color images are typically used to depict wavelength distributions in non-visible observations

Gamma Rays Bursts

- Exploring New Wavelengths: Gamma Rays
  - Gamma-ray astronomy began in 1965
  - By 1970s, gamma rays found to be coming from familiar objects: Milky Way center and remnants of exploded stars
  - 1967 gamma-ray bursts from space discovered by military satellites watching for Soviet nuclear bomb explosions
  - Source of gamma-ray bursts is likely due to colliding neutron stars!

The Crab Nebula

- In A.D. 1054, ancient Chinese noticed bright “new star” in the sky, which then faded from view in just over a year
- In 1731, with the help of a telescope, a fuzzy patch was discovered in the area of the former “new star”
- In 1844, filaments were noticed that gave the fuzzy nebula the appearance of a crab
- In 1921, comparison of photographs lead to idea that the nebula was expanding
- By 1928, it was realized that the ancient Chinese had observed a supernova explosion – the death of a massive star – and the nebula was the result

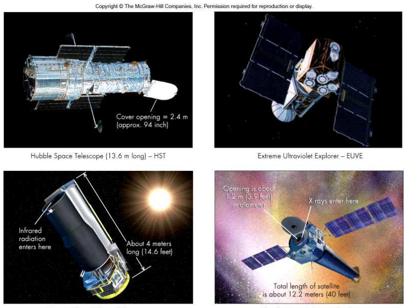
Observations of the Crab Nebula

- Since 1928, Crab has been investigated at all wavelengths:
  - Powerful source of radio waves
  - Further radio observations revealed the remnant of the supernova explosion – a rapidly spinning “star” (30 times per second)
  - Radio waves also indicated that charged particles are moving at near the speed of light

A

- Visible light indicates expansion of nebula at about 1000 km/s
- Source of x-rays

Major Space Observatories



Hubble Space Telescope (13.6 m long) – HST

Extreme Ultraviolet Explorer – EUVE

Spitzer Infrared Space Telescope

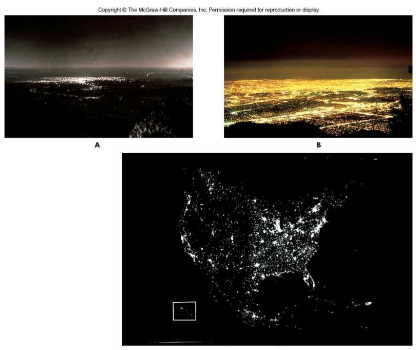
Chandra X-ray Telescope Satellite

- Why put them in space?

Atmospheric Blurring

- Twinkling of stars in sky, called ***scintillation,*** is caused by moving atmospheric irregularities refracting star light into a blend of paths to the eye
- The condition of the sky for viewing is referred to as the ***seeing***
- Distorted seeing can be improved by ***adaptive optics,*** which employs a powerful laser and correcting mirrors to offset scintillation

Light Pollution



A B C

Space vs.Ground-Based Observatories

- Space-Based Advantages
  - Freedom from atmospheric blurring
  - Freedom of atmospheric absorption
- Ground-Based Advantages
  - Larger collecting power
  - Equipment easily fixed
- Ground-Based Considerations
  - Weather, humidity, and haze
  - Light pollution

Going Observing

- To observe at a major observatory, an astronomer must:
  - Submit a proposal to a committee that allocates telescope time
  - If given observing time, assure all necessary equipment and materials will be available
  - Be prepared to observe at various hours of the day
- Astronomers may also “observe” via the Internet
  - Large data archives now exist for investigations covering certain wavelengths sometimes for the entire sky
  - Archives help better prepare astronomers for onsite observations at an observatory

Computers and Astronomy

- For many astronomers, operating a computer and being able to program are more important than knowing how to use a telescope
- Computers accomplish several tasks:
  - Solve equations
  - Move telescopes and feed information to detectors
  - Convert data into useful form
  - Networks for communication and data exchange