Final Announcements

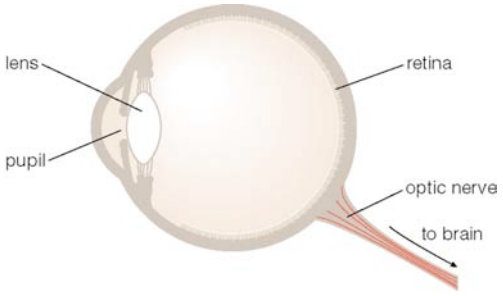
- Turn in the homework#6 NOW.
- Homework#5 and Quiz#6 will be returned today.
- Today is the last lecture.
- Final exam on Thursday
  - Be sure to clear up any questions at the last help session today at 5:30pm.

Lecture25
Telescopes

Reading: Chapter 7

Parts of the Human Eye

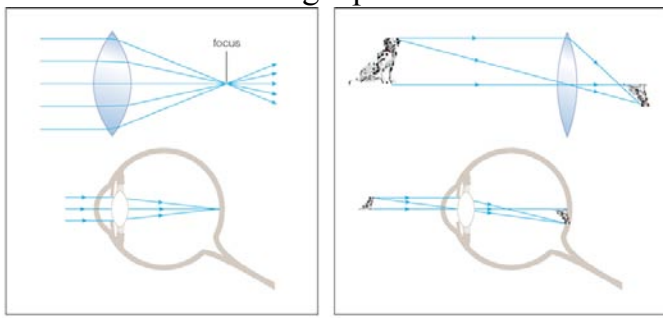
- **pupil** – allows light to enter the eye
- **lens** – focuses light to create an image
- **retina** – detects the light and generates signals which are sent to the brain



A camera works in the same way where the *shutter* acts like the *pupil* and the *film* acts like the *retina*!

The Bending of Light

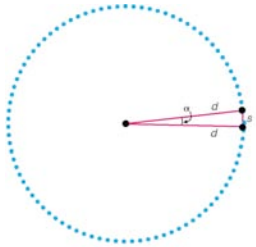
Focus – to bend all light waves coming from the same direction to a single point

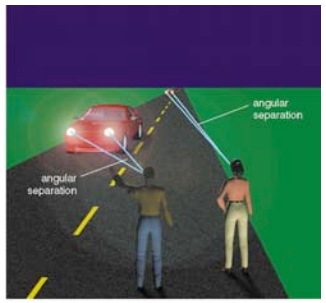


Light rays which come from different directions converge at different points to form an *image*.

Angular Resolution

- The ability to separate two objects.
- The angle between two objects decreases as your distance to them increases.
- The smallest angle at which you can distinguish two objects is your *angular resolution*.
- At best, the human eye has an angular resoluton of about 1 arcminute.
  - 1/30 of the size of full moon.





Recording Device

- Film
  - **The chemicals** in films change in response to light, thereby recording an image.
  - Very important leap in astronomical data collection in the mid-1800s.
  - Not very efficient -- fewer than 10% of the visible photons cause a change in the chemicals. More than 90% are simply lost!
- Electronic Detectors
  - Degital cameras
  - **Carge-Coupled Devices (CCDs)** can record more than 90% of the photons that strike them.
  - When a photon hits a silicon chip, it causes a bit of electric charge to accumulate.
  - Subsequent photons will accumulate more charges -- the amount of charges will be translated into the number of photons. It's degital!

Why need telescopes?

- Our eyes are too small!
  - Angular resolution is too large.
    - For example, eyes cannot tell difference between binary stars and single stars.
  - Stars and galaxies are very faint.
    - Eyes are too small to collect enough number of photons.
- We need bigger eyes --- telescopes!

Telescope Types

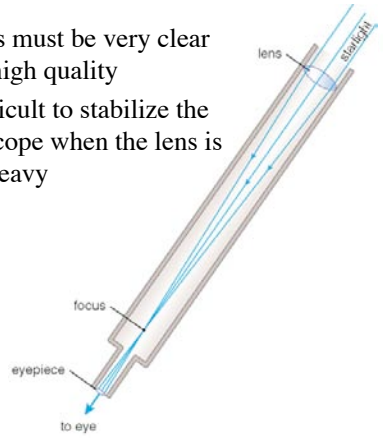
- Refractor
  - focuses light using lenses
  - operates more like an eye
  - Galileo's very first telescope was a refractor.
- Reflector
  - focuses light using mirrors
  - used exclusively in professional astronomy today

Refractor

Yerkes 40-inch diameter telescope (University of Chicago) Largest refractor in the world.

•Lens must be very clear and high quality

•Difficult to stabilize the telescope when the lens is too heavy

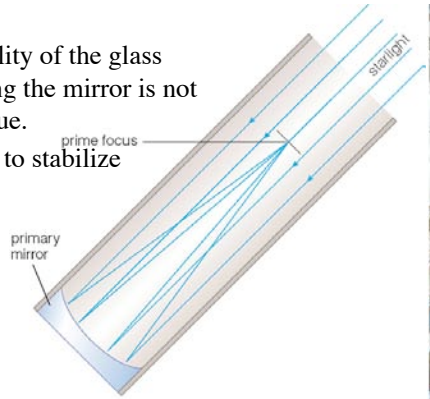


Reflector

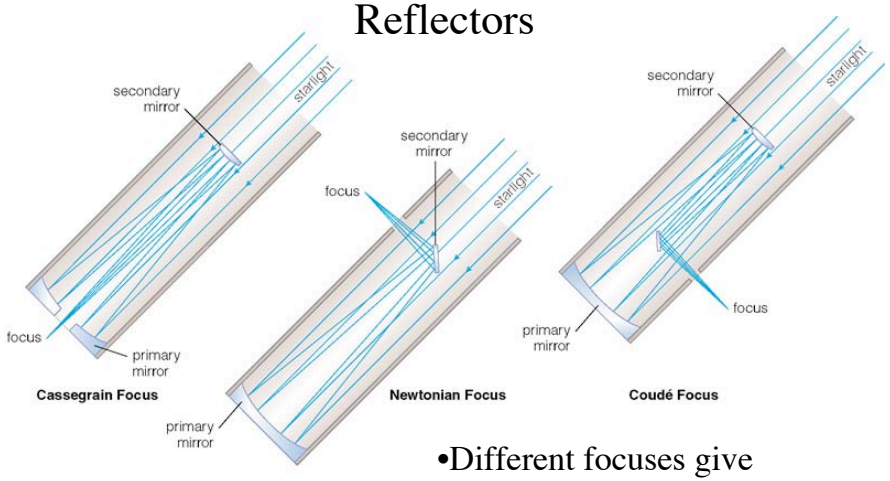
Gemini 8-m Telescope, Mauna Kea, Hawaii

•Quallity of the glass making the mirror is not an issue.

•Easy to stabilize



Reflectors



•Different focuses give convenient sites for viewing and attaching instruments.

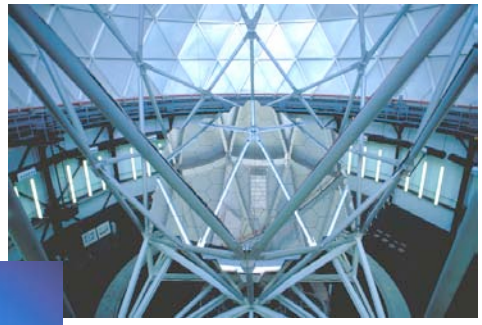
Reflectors

MMT – Mt. Hopkins, AZ

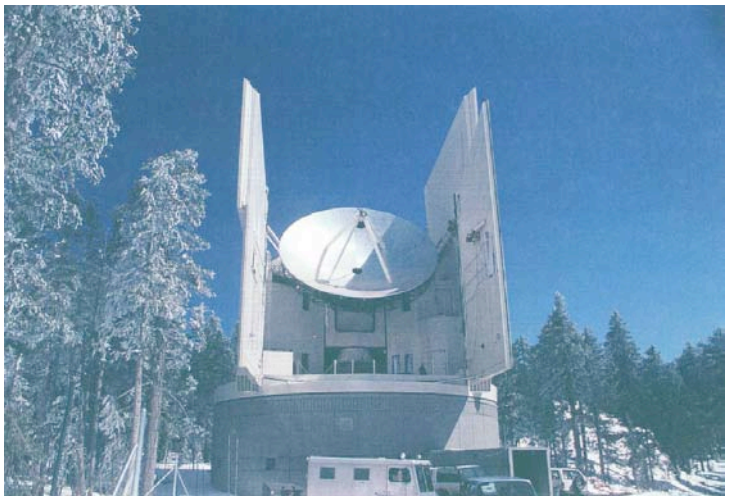
SUBARU – Mauna Kea, HI

Hobby-Eberly Telescope

•McDonald Observatory



Reflector -- Radio

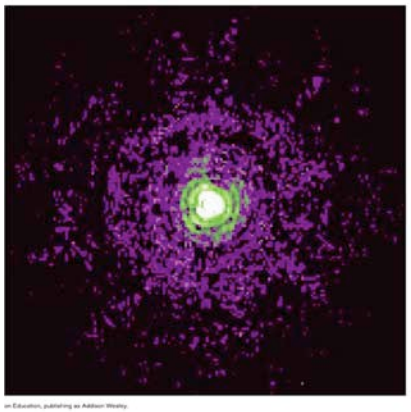


Heinrich Hertz Telescope – Mt. Graham, AZ

Two Fundamental Properties of a Telescope

1. Resolution
   - smallest angle which can be seen
   - $\theta = 1.22 \lambda / D$
     - This is called the "***diffraction limit***". A longer wavelength light has more interference which causes a blurring of images.
     - The reason why radio telescopes are much bigger than optical telescopes.
2. Light-Collecting Area
   - think of the telescope as a "photon bucket"
   - its area: $A = \pi (D/2)^2$

Interference and Diffraction Limit



•Diffraction limited image

•Interference of two waves

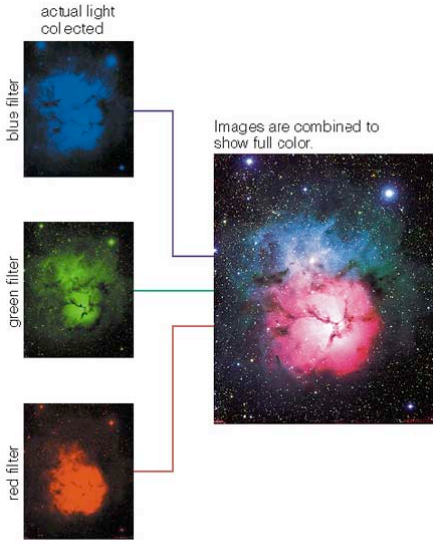
Instruments in the Focal Plane

How do astronomers use the light collected by a telescope?

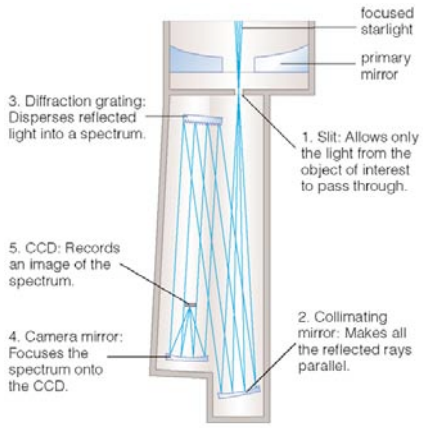
1. Imaging
   - use a camera to take pictures (images)
   - Photometry → measure total amount of light from an object
2. Spectroscopy
   - use a spectrograph to separate the light into its different wavelengths (colors)
3. Timing
   - measure how the amount of light changes with time (sometimes in a fraction of a second)

Imaging

- ***Filters*** are placed in front of a camera to allow only certain colors to be imaged
- Single color images are superimposed to form true color images.



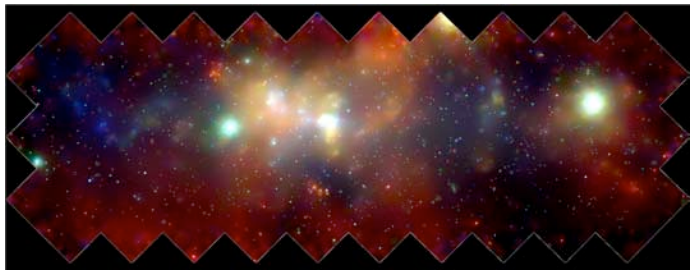
Spectroscopy



- The spectrograph reflects light off a *grating*: a finely ruled, smooth surface.
- Light interferes with itself and disperses into colors.
- This ***spectrum*** is recorded by a digital detector called a CCD.

Nonvisible Light

- Most light is invisible to the human eye.
- Special detectors/receivers can record such light.
- Digital images are reconstructed using false-color coding so that we can see this light.



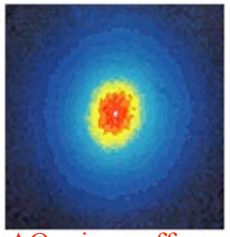
Chandra X-ray image of the Center of the Milky Way Galaxy

Seeing Through the Atmosphere

- Earth's atmosphere causes problems for astronomers on the ground.
- Bad weather makes it impossible to observe the night sky.
- Air turbulence in the atmosphere distorts light.
  - That is why the stars appear to "twinkle".
  - Angular resolution is degraded.
- Man-made light is reflected by the atmosphere, thus making the night sky brighter.
  - this is called **light pollution**

Adaptive Optics (AO)

- This is a brand-new technology!
- It is possible to "de-twinkle" a star.
- The wavefronts of a star's light rays are deformed by the atmosphere.
- By monitoring the distortions of the light from a nearby bright star (or a laser):
  - a computer can deform the secondary mirror in the opposite way.
  - the wavefronts, when reflected, are restored to their original state.

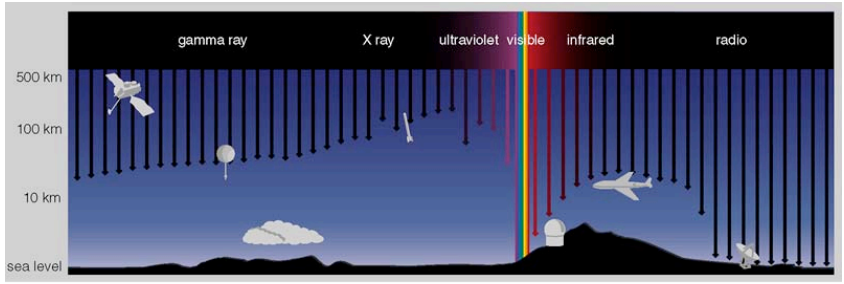


AO mirror off AO mirror on

- Angular resolution improves.
- These two stars are separated by 0.38″
- Without AO, we see only one star.

Atmospheric Absorption of Light

- Earth's atmosphere absorbs most types of light.
  - good thing it does, or we would be dead!
- Only visible, radio, and certain IR and UV light make it through to the ground.



To observe the other wavelengths, we must put our telescopes in space!

Space Based Telescopes -- no twinkles!

Chandra X-ray Obs.

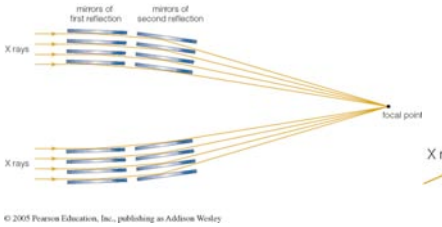
Hubble Space Telescope

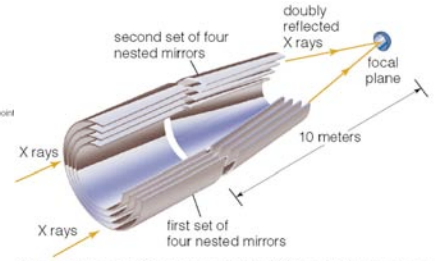
•Why going up into space? Because we don't want atmosphere!

•Absolutely NOT because we are closer to the stars!!!

X-ray Telescopes

- Different types of photons behave differently.
- X-rays will pass right through a mirror.
- They can only be reflected/focused at shallow angles
  - like "skimming stones"





Mirror elements are 0.8 m long and from 0.6 m to 1.2 m in diameter.

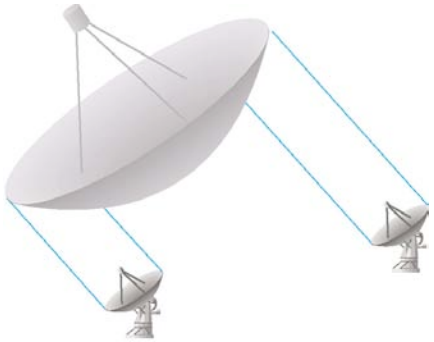
Radio Telescopes

- The wavelengths of radio waves are long.
- So the dishes which reflect them must be very large to achieve any reasonable angular resolution.

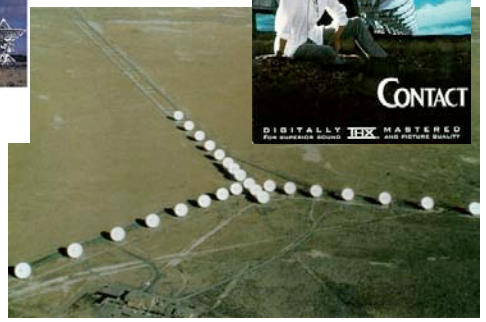
305-meter radio telescope at Arecibo, Puerto Rico

Interferometry

- Two (or more) radio dishes observe the same object.
- Their signals are made to interfere with each other.
- An image is reconstructed with the angular resolution one would get from a dish the size of the distance between them.
- The light-collecting area is still only the sum of the areas of the individual dishes.



Very Large Array (VLA) New Mexico



- 27 telescopes!
- Can achieve resolution equivalent of that for a 40-km telescope.

Our Journey Finished.

- Good luck! Final exam on Thursday
  - Be sure to clear up any questions at the last help session today at 5:30pm.
  - 40 multiple questions.
  - No short-answer questions.
- Thank you for taking part in this journey, and I hope you enjoyed it.