Astronomy 122

This Class (Lecture 9):

Telescopes

Homework #4 is posted.

Next Class:

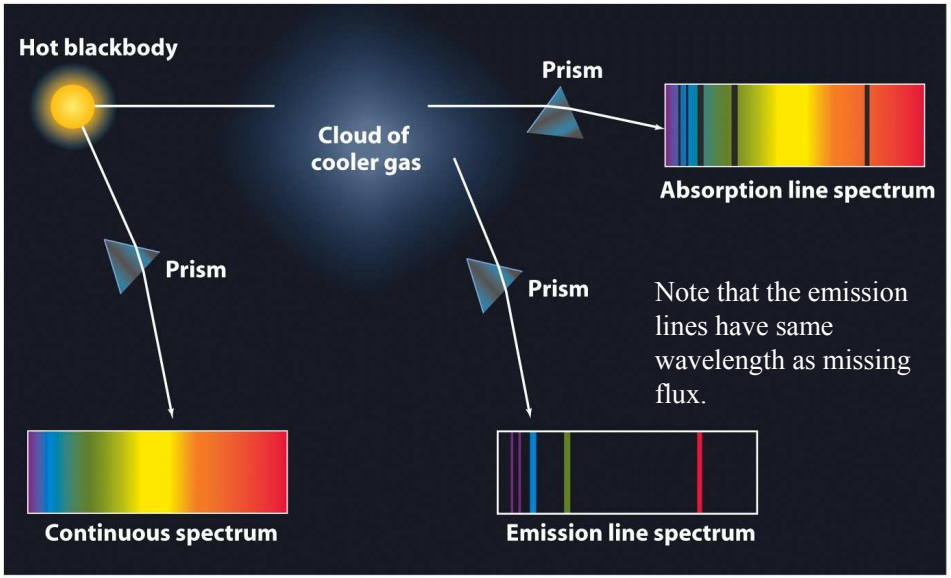
The Solar System

Music: *The Universe is You?* – Sophie Ellis-Bextor

Outline

- Spectral Features
- Telescopes

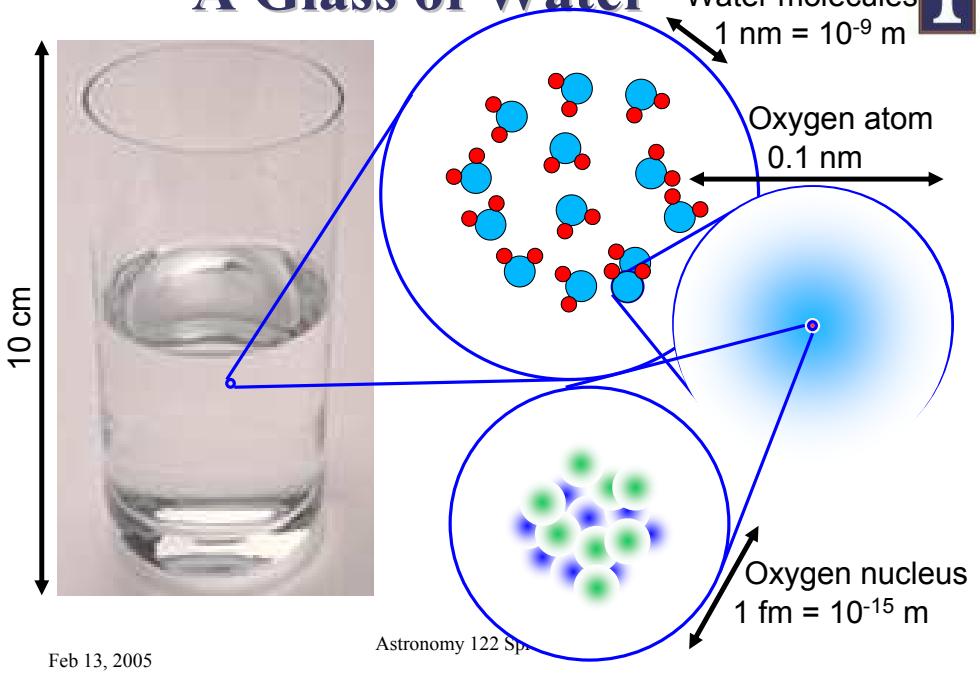
Kirchoff's Laws



How Do Spectrum Lines Form?

To answer this question, we need to delve into the structure of matter itself…

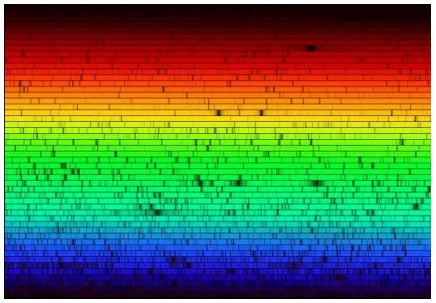
A Glass of Water

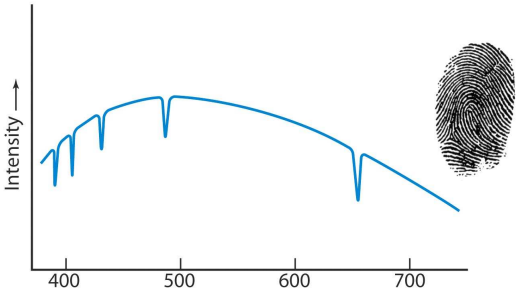


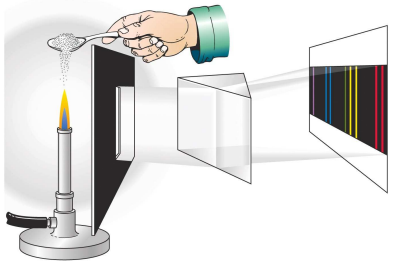
Atoms and Elements

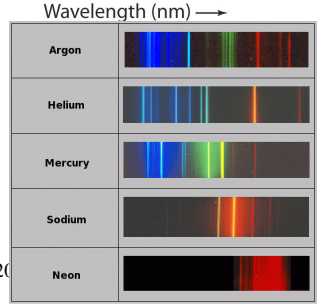
- All matter is made of **elements**
  - 92 natural and 23+ artificial
  - Hydrogen, Carbon, Oxygen, Iron, Uranium, etc.
  - Each element is composed of a different kind of **atom**
- The number of protons (or Z) in an atom determines the type of element
  - Hydrogen has 1 proton (Z=1), oxygen has 8 protons (Z=8), etc.
- Neutrons are "packing material".
- Atoms interact via electrons
  - Shared among atoms to make **molecules**
  - Atoms missing or with extra electrons are called **ions**

Spectrum Lines

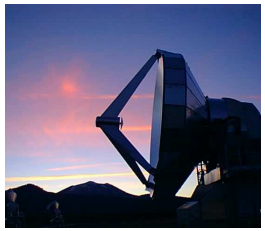








We need telescopes to observe Starlight



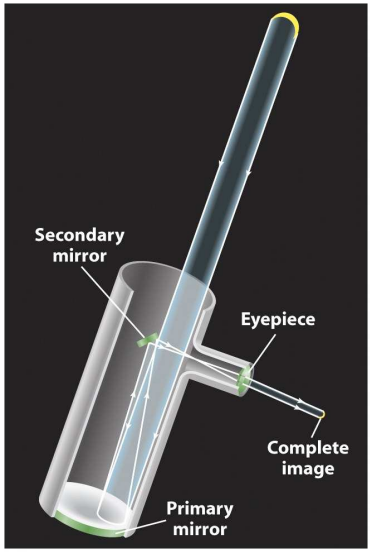
Telescopes & Astronomy

- The single most important tool to astronomers is the telescope
  - They collect more light than the eye
  - Allow us to see heavenly objects more clearly and to greater distances
- Astronomers have been using telescopes for about 400 years to explore the Universe
- *Need telescopes which work at all wavelengths*


Johannes Hevelius observing with one of his telescopes (1647).

Functions of a Telescope

- Telescope functions
  - Collect light over a large area
  - Resolve image onto an eyepiece or a scientific instrument
- Extract maximum possible information
  - Form image or take spectrum
- Can do this with either lenses (refracting) or mirrors (reflecting)
- Three priorities (in order)
  - Gathering light
  - Angular resolution
  - Magnification

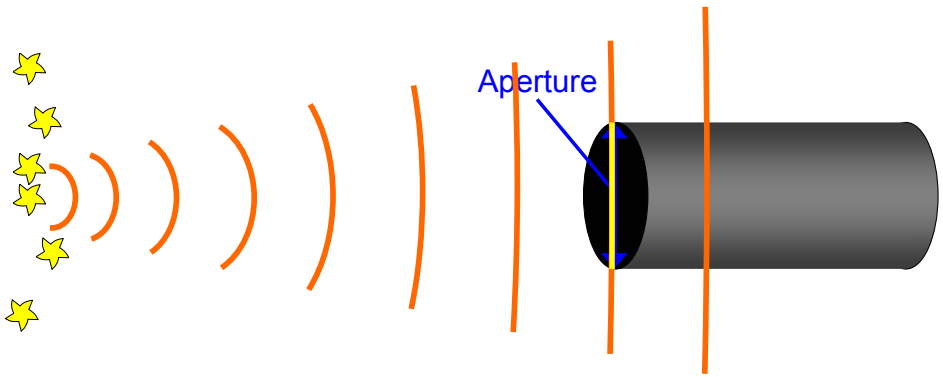


Light Gathering

- Top priority since most celestial objects are dim
- Telescope = "light bucket"
- Key: ***collecting area***
- Human eye – ~5 mm,
- Subaru telescope mirror – 8.3 m
  - 3 million times the area of your eye!

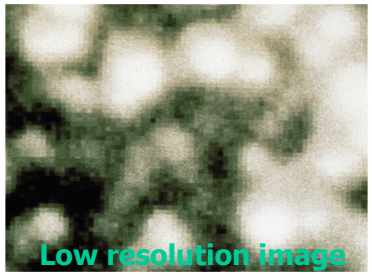
Telescopes

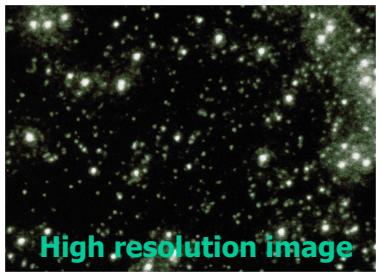
- A **telescope** collects light
- The larger the **aperture**, the more light can be collected in a given amount of time



Angular Resolution

- Reveal details of objects
- Angular resolution:
  - Measures finest detail that is not smeared out
  - Smallest angle for which two stars aren't smeared together to one
    - e.g., human eye resolution = 1/60th of a degree
    - Hubble Space Telescope resolution < 1/36,000th of a degree





Resolve This

- What is the limitation on how well a telescope can resolve objects?
  - The size of the telescope, silly
  - The best resolution of a telescope is

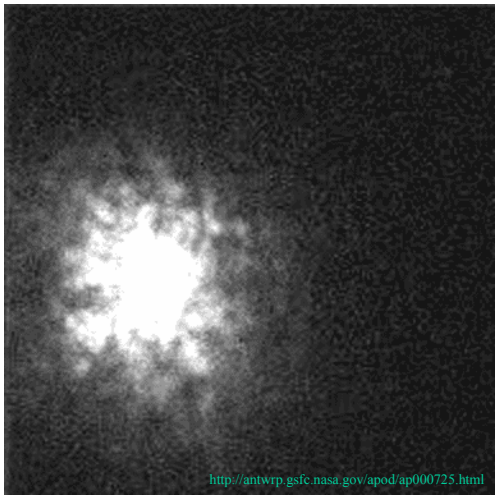
$$\theta_{diff} = 2.5 \times 10^5 \, \lambda / D$$

λ and D in meters, then θ in arcsec

    - We want the angle to be small as possible
    - So, again we want a large telescope!
    - The Keck 10 meter has a $\theta_{diff} = 0.05$ arcsec
  - But, there is another limitation!
    - The atmosphere

Twinkle, Twinkle Little Star

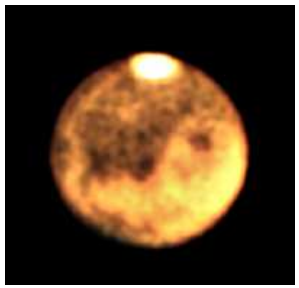
- Turbulence in the atmosphere "jiggles" image
- We see it as stars "twinkling"
- A good atmosphere will allow $\theta \sim 1$ arcsec.
- So for modern telescopes, we are limited by the atmosphere.



Magnification

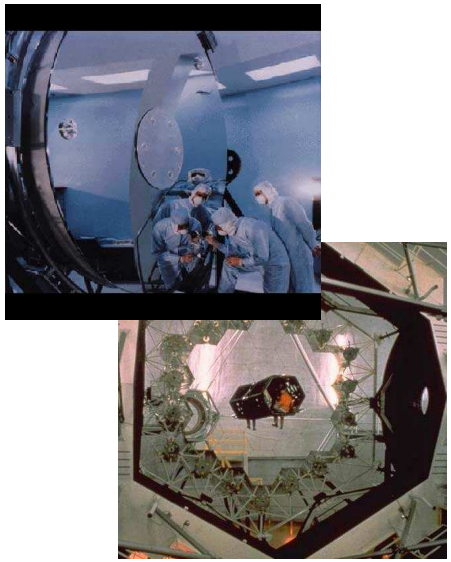
- Makes the object appear larger
- Useful for studying detail
- Least important issue
  - If you don't have the other two,
  - this is not at all relevant
  - No good to magnify a blurry
  - image
- Magnification is ratio of focal length of telescope and focal length of eyepiece

$$f_{tel}/f_{eye} \propto D$$

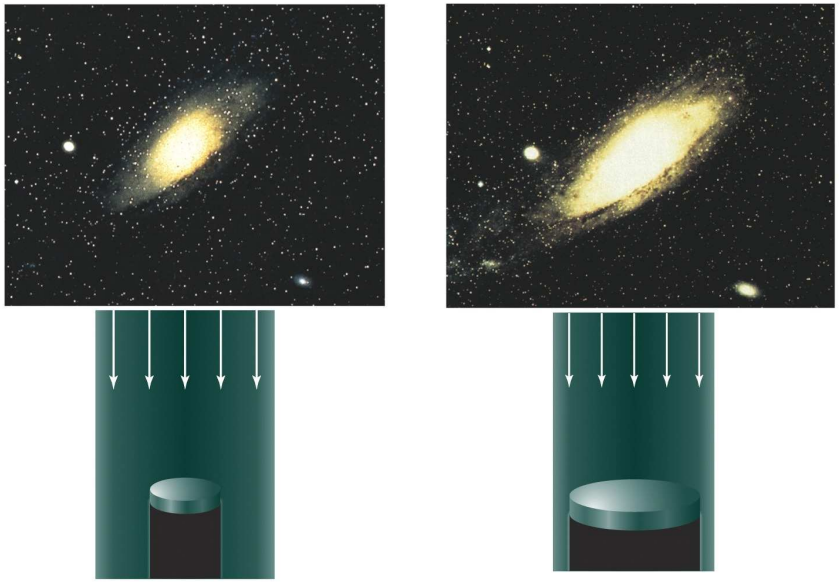


In The End Size Does Matters

- Both light collecting and resolution improve as the diameter of the scope – its lens or mirror – increases
- **Bigger is better!**



Bigger Is Better!



Focusing

Telescope job:

✓ collect rays over large area

✓ focus to a point

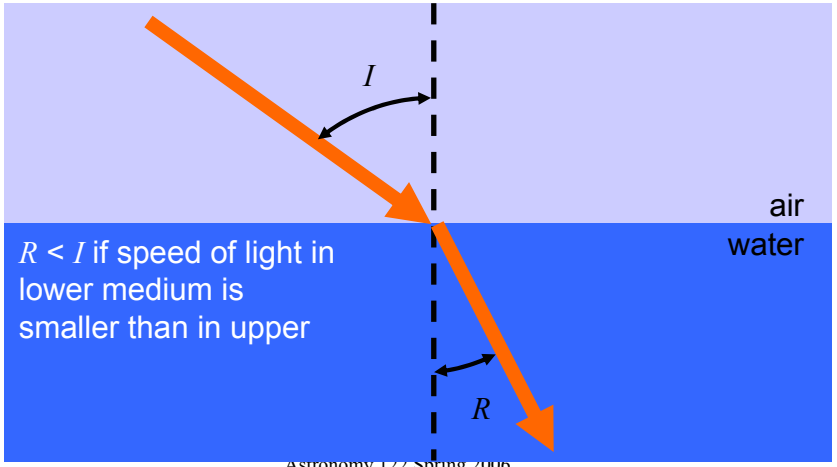
✓ then re-straighten over smaller area: brighter

Telescope Types

- Optical (visible light)
  - Refracting
  - Reflecting
- Radio, infrared, ultraviolet
  - Reflecting
- X-ray
  - Reflecting (grazing incidence)

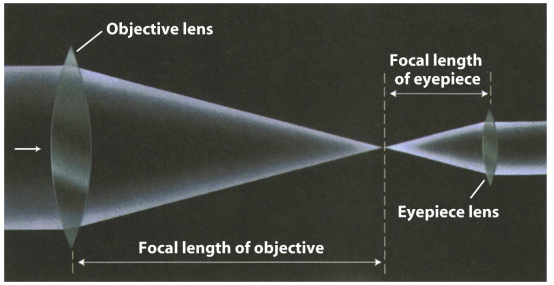
Refraction

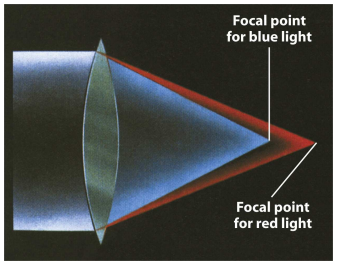
- Light travels more slowly in transparent materials than it does in vacuum
- When passing from one medium to another (e.g. air to water), light is bent (**refracted**)



Refracting Telescopes: Lenses

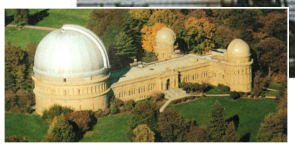
- Use Lenses
  - Curved glass
  - Light bent to focus
- Problems:
  - Lenses focus colors differently
  - Sag of lens from gravity
    - Large lens distorted as it hangs
    - Limits lens size
  - Limited wavelengths





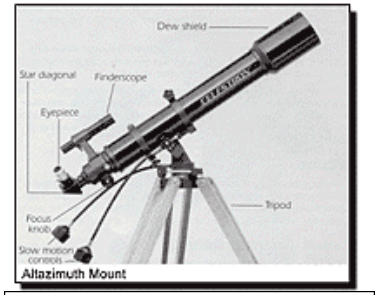
The Largest Refractor

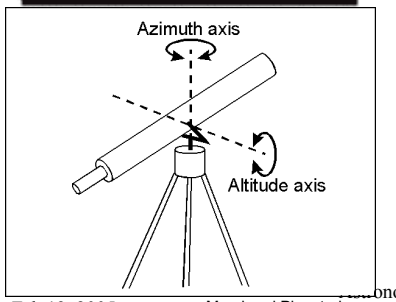
- At Yerkes Observatory near Chicago
- 40 inch diameter lens, 63½ feet long!



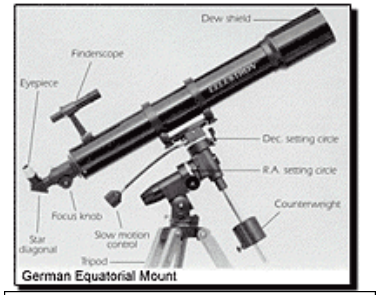
Telescope mounts

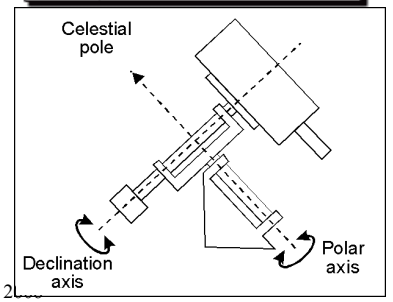
Altitude-azimuth (alt-azimuth)



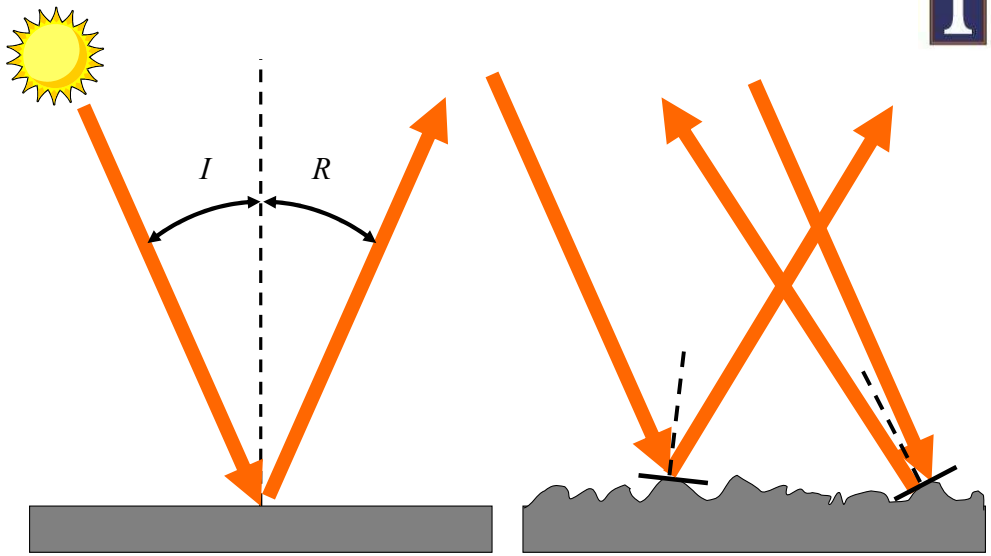


Equatorial





Reflection



Smooth surface **Rough surface**

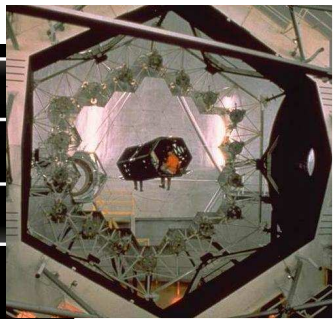
Angle of incidence I = Angle of reflection R

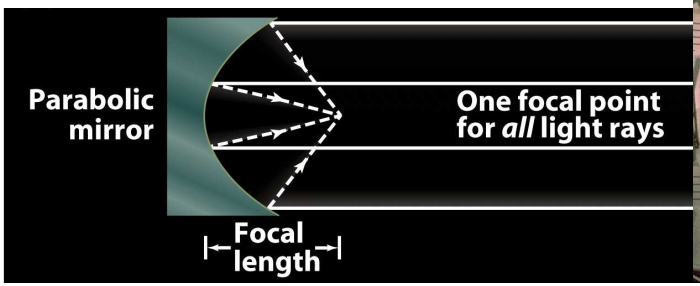
Reflecting Telescopes

- Use Mirrors
  - Sag not a problem – support the mirror from below
  - Parabolic mirror gives good focus
- Today, all large professional telescopes are reflectors

Hubble Telescope Mirror (2.4 m)

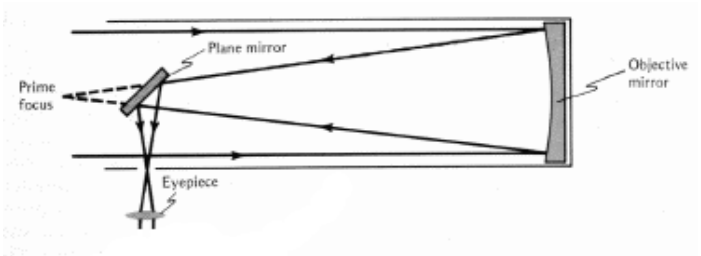
Keck Telescope Mirror (10m)



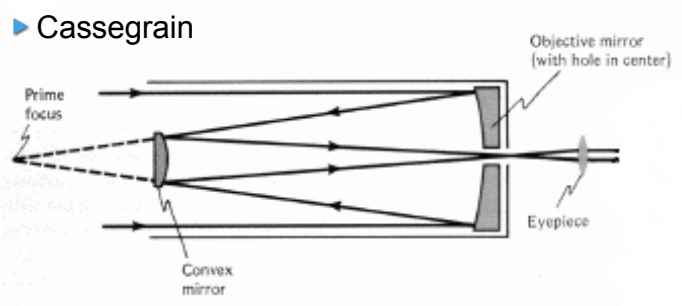


Reflecting telescope designs

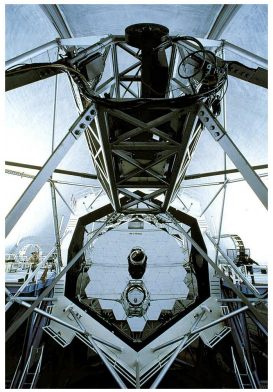
- Newtonian

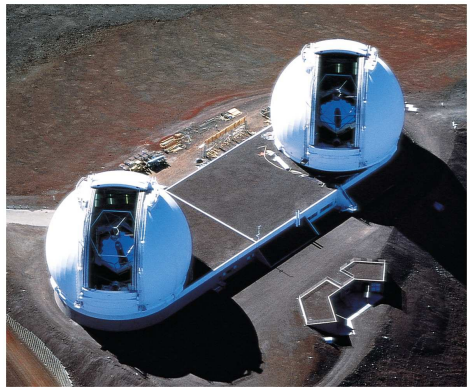


- Cassegrain



The Largest Reflector



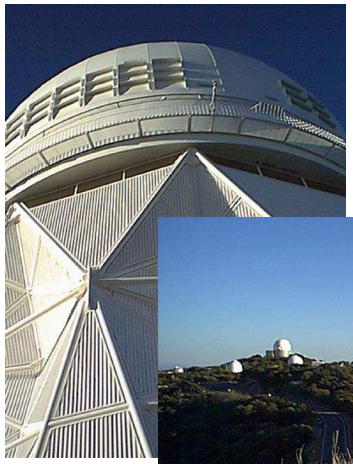


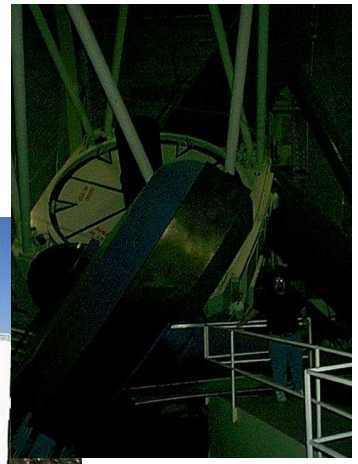
- Keck Observatory on Mauna Kea in Hawai'i
- Twin 10-meter reflecting telescopes
- Completed 1993 & 1996

Gemini Telescopes

- Twin telescopes
- One in Hawaii, one in Chile
- 8-meter mirrors

Kitt Peak, Arizona





Astronomy as a Hobby

- Did you know you can see a galaxy 2½ million light-years away with your unaided eyes?
- Or that you can see craters on the Moon with binoculars?

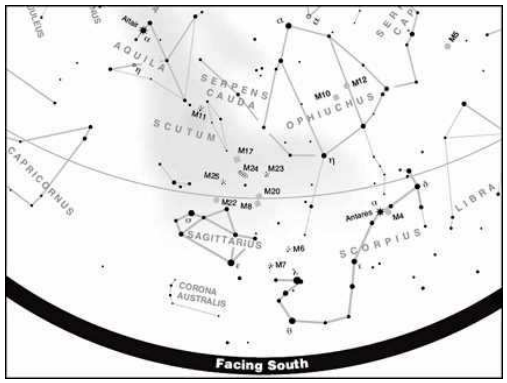
Your First Steps…

- **Read**
  - The night sky is beautiful to behold, but astronomy is a *learning* hobby
  - You can find good guides to the night sky at your local library or bookstore

  - Get a copy of *Sky & Telescope* from the library
    - Offers a big evening-sky map for beginners
    - Practical observing tips

Learn The Sky

- **Learn the sky with the naked eye**
  - Download star charts from *Sky & Telescope*
  - Buy a planisphere from a bookstore
  - Generate sky charts with the Starry Night software that came with your textbook



Start With Binoculars

- Binoculars are an ideal first telescope
  - Wide field of view, making it easy to find your way around
  - Relatively inexpensive
  - Widely available
  - Easy to carry and store
  - Allow you to easily see lunar craters, Jupiter's moons, and the brighter star clusters, galaxies, and nebulae
  - The larger the front lenses are the better

Seek Out Others

- There are two amateur astronomy clubs here
  - University of Illinois Astronomical Society
  - Champaign-Urbana Astronomical Society
- Attend star parties where you can meet members and discuss astronomy
  - Try out different types of telescopes
  - Get advice

Your Own Telescope

- When you're ready, its time for your own telescope
- Don't skimp on quality, you'll regret it later
- What do you want?
  - Solid, steady, smoothly working mount
  - High quality optics
  - Large aperture – but not too large, you have to carry it!
  - The best telescope for you *is the one you'll use most!*

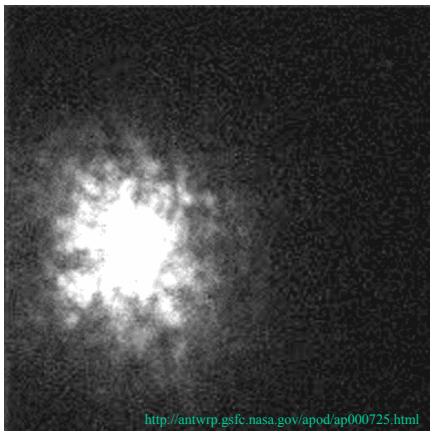
Relax and Have Fun!

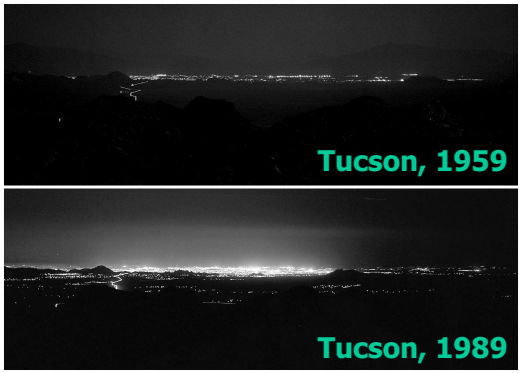
- This is the most important step!
- Take pleasure in whatever your eyes, binoculars, or telescope can show you
- The more you look, the more you will see, and the more you will become at home in the night sky
- Set your own pace, and revel in the beauty and mystery of our amazing universe!

Light Pollution

- Another problem for astronomers is light pollution
- City lights raise the "background light" level
- Makes it more difficult to collect light from stars

Twinkling & Light Pollution

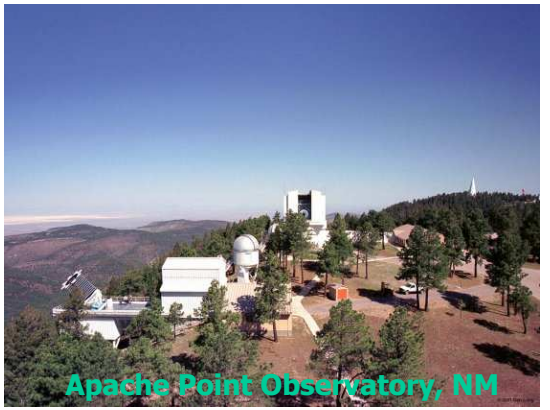




How do we combat these problems?

Remote Mountains

- One solution: Build telescopes at sites high, dry, and away from civilization
- While this solves the scientific problems, it introduces its own complications
  - Providing facilities
  - Environmental impact
  - Cultural conflicts



Mauna Kea, Hawai'i

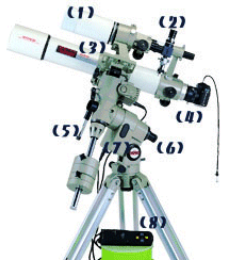
- Mauna Kea is the best place on Earth for astronomical telescopes
  - High elevation
  - Far from urban lights
  - Reasonably easy access
  - Generally good weather
- Mauna Kea is also a sacred place
- Also an environmentally sensitive area

Light Detection

Once light collected and focused need detector

Human eye— just look
- Least sensitive (1% of photons)
- No permanent record
- Only optical wavelengths

Photographic film
- Telescope as camera
- Accumulates light: see dimmer objects
- Provides a permanent record
- Small efficiency (a few % of photons)
- Non-linear response

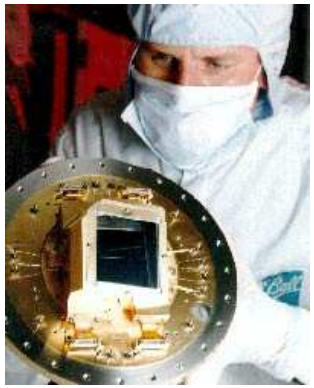


http://www.pandia.com/graphics/hemera/womanandchildlooking.jpg
http://www.sundu.co.kr/telescope/camera/main.gif

Light Detection

Once light collected and focused need detector

Electronic "film" (CCD)
- Charged Coupled Device
- Like Digital camera/camcorder
- Photons hit silicon chip and electrons kicked-out
- One measures the electrons created in a pixel.

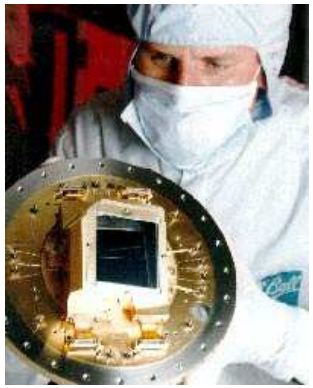


Hubble Telescope CCD

Light Detection

Once light collected and focused need detector

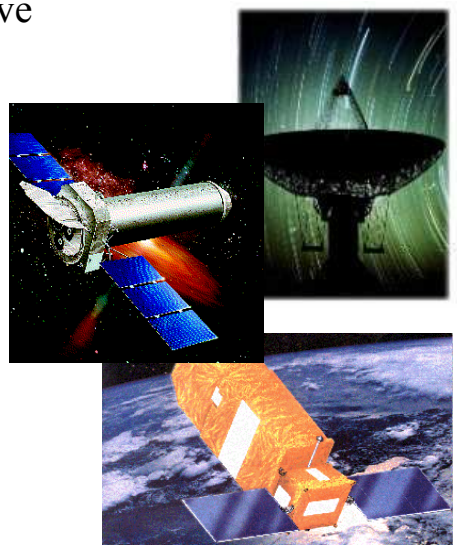
Electronic "film" (CCD)
- Charged Coupled Device
- Like Digital camera/camcorder
- Photons hit silicon chip and electrons kicked-out
- One measures the electrons created in a pixel.
- About 80% photons detected
- Much more sensitive
- Detector of choice!
- All modern professional astronomy done this way— costly to make large CCDs
- Bonus: digital data great for computers!



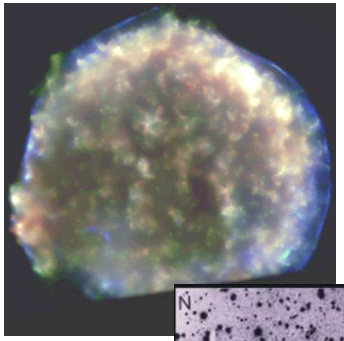
Hubble Telescope CCD

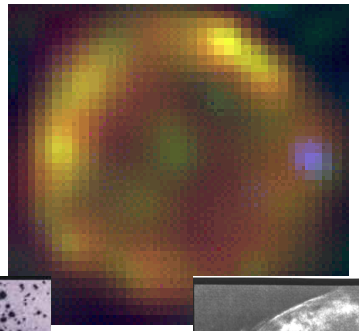
Invisible Astronomy

- Astronomers want to observe all types of light
  - To see into the dust-enshrouded regions of newly-forming stars
  - To peer into the heart of the Milky Way itself
  - To study the remains of solar-type stars
  - To detect the emission from gases heated to millions of degrees by the powerful explosions of dying massive stars



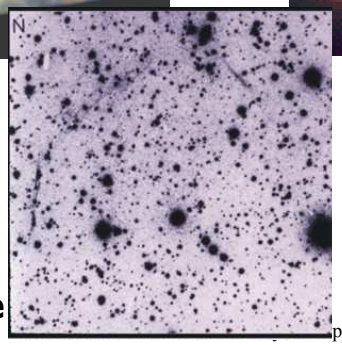
Tycho's Supernova



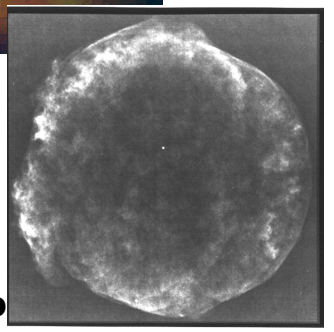


Infrared

X-rays



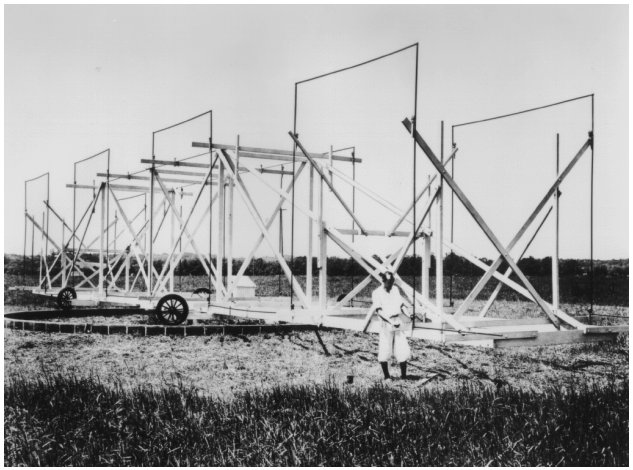
Visible



Radio

Radio telescopes

First detection of cosmic radio sources by Karl Jansky at Bell Labs (1932)



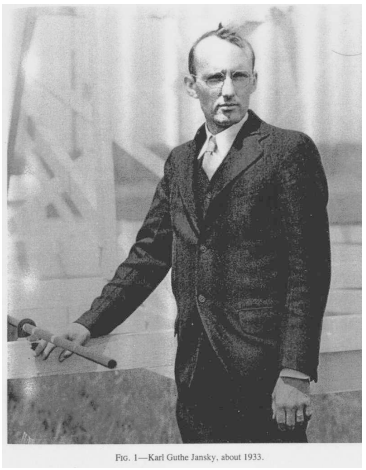


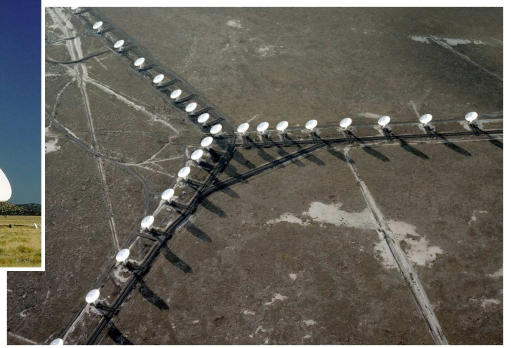
Fig. 1—Karl Guthe Jansky, about 1933.

Radio telescopes

Pioneering work by Grote Reber in back yard, Wheaton, Illinois. (He died in 2002)

Arecibo Observatory, Puerto Rico

Very Large Array (VLA), NM



CARMA

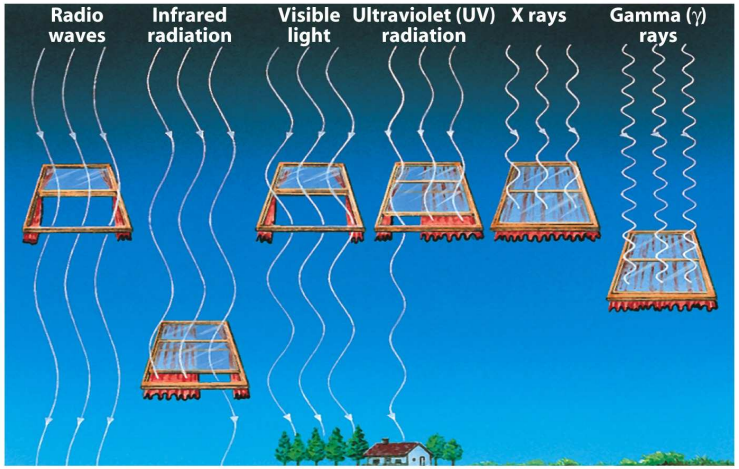
A millimeter array of 15 telescopes (9 six meter and 6 ten meter) owned and operated by CalTech, UC Berkeley, **UIUC**, and UMd in White Mountains, California. Wavelength of 1.4 millimeters – frequency of 220 GHz. Works night and day. Why?

Question

Why would it be useful to place telescopes in space?

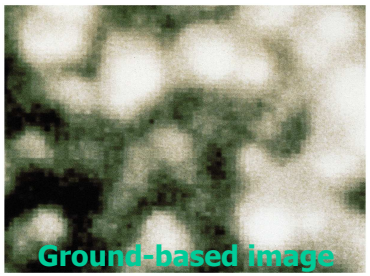
Opaque Atmosphere

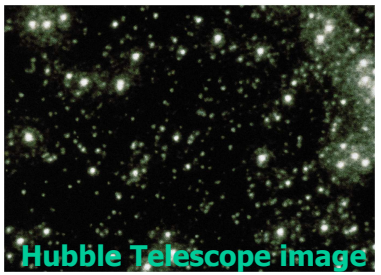
- The atmosphere blocks some wavelengths
- Must observe some wavelengths from space!



Hubble Space Telescope

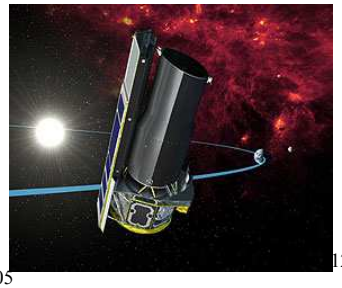
- 2.5 meter reflecting telescope in space
- Above the atmosphere
  - No "twinkling" effects
  - No light pollution

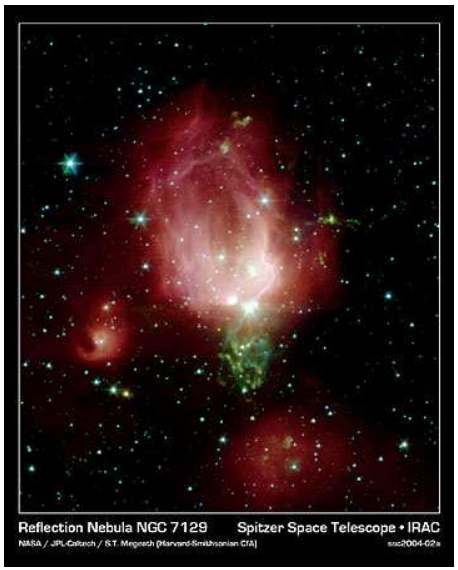




Spitzer Space Telescope

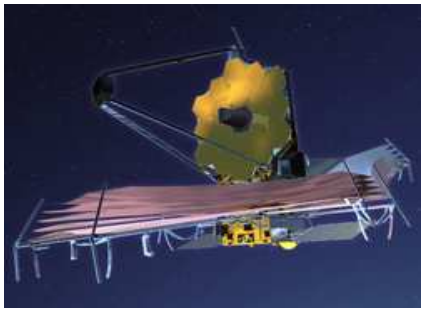
- 0.85 meter infrared telescope
- Launched August 2003
- Cooled to near absolute zero so that its own heat doesn't confuse the results





James Webb Space Telescope

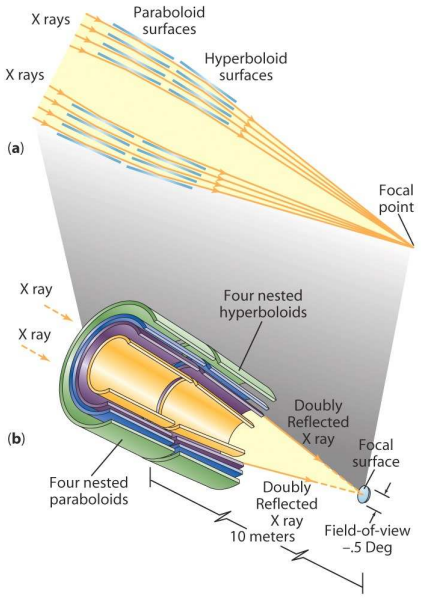
- The next space telescope – 2011
- Observe in the near and mid-infrared
- Will be the biggest telescope in space – 6 meters! (Must fold up for launch)
- Will take 3 months to reach position – no service missions



Chandra X-ray Observatory

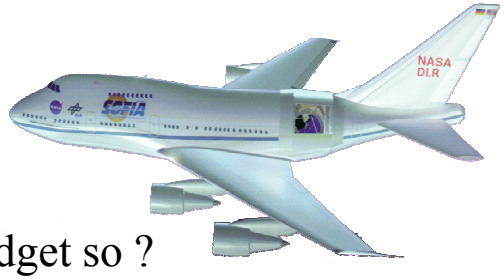
Launched 1999

Crab Nebula in X-rays



SOFIA

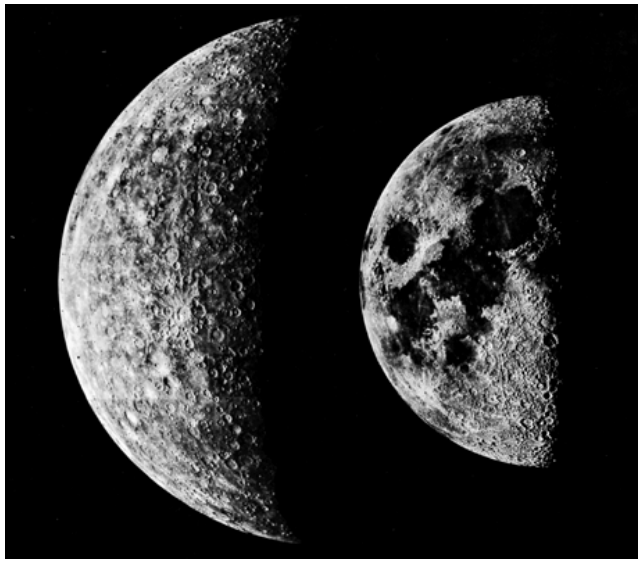
- Stratospheric Observatory For Infrared Astronomy (SOFIA)
- Modified Boeing 747
- Operation height: 39000 to 45000 ft (11.8 to 13.7 km)
- 2.7m telescope
- Currently in ground-based testing
- Cut out of NASA budget so ?



The Big Picture

- Today, we can observe in almost every part of the electromagnetic spectrum
- Only 100 years ago, we were blind to the big picture of the Universe
- As we begin to piece together the big picture, our understanding of the cosmos grows .
- But there is more out there than photons too:
  - Neutrinos
  - Cosmic rays
  - Gravity waves

What's this Picture of?



http://www.whfreeman.com/discovering/DTU/EXMOD36/F3609.HTM