The tools of an astronomer
Activity: Seeing further

- If you had to build a device to see something far away how would you do it? What items and materials would you need and why, and how would you put them together?

- What key properties of light that you learned from last lecture and readings would you rely on? Can you “MacGyver” it together with household items or only things you have on hand?
Lenses: How do they work?

- Important components of any type of telescope (glasses, ..)

- They are refractive, so they transmit light, bending (changing the angle of) an incident light ray by means of having refractive indices (‘n’) different (greater) than that of air (n ~ 1)

- An individual lens also varies in thickness from end to end, so light is not just re-directed, it is focused in some way

- There are converging, diverging lenses. (All types of) telescopes more commonly use the former, which focuses light onto a point to create a real, inverted image, but can also magnify (virtual)
Curved mirrors

- Specular reflectors: light comes, bounces off at same angle
- If not polished enough, a “bad” mirror becomes a diffuse reflector: tiny surface imperfections create seemingly random-angle reflections (a question of rough vs. smooth)
- Surface imperfections at some microscopic scale are unavoidable, so their size relative to the wavelength of the incoming light is what matters: similar is bad
- Flat (planar) or curved (convex and concave): concave useful for focusing purposes, creating real (and inverted) images
The 2 main telescope types

- **Refracting:** invented first, in the early 17\textsuperscript{th} century
  - Galileo is often credited as being the first to point a telescope upward to study the heavens
  - Sealed design advantageous: no dirt or moving air inside
  - Heyday ended in the 1890s. Yerkes Observatory in Wisconsin has largest in world. No new being built

- **Reflecting:** invented soon after, in the late 17\textsuperscript{th} century
  - Couple different designs. Making more compact possible with more reflections. Cheaper, originally open tube
Galileo’s discoveries (1600s)

- Imperfections on the Moon’s surface
- Secondary light of Moon (light reflected off Earth)
- The four largest moons of Jupiter
- The phases (just like Earth’s Moon) of Venus
- Sunspots, and fact the sun rotates
- New stars too faint to see with naked eye
Refracting telescope

- **Simple design:** light ~straight through two lenses on tube
  - Objective (larger in diameter) and eyepiece (smaller)
  - In fancier design can reflect rays off mirror at 90 degrees (right angle) and thus also make image right side up
- **Suffers from “chromatic aberration”:** unique colors will bend at slightly different angles (n is a function of wavelength). This leads to annoying rainbow halos
- **Can’t keep building them bigger:** lenses start to sag under their own weight at the center. Glass not 100% rigid
Reflecting telescope

- Mirrors are one-sided optical devices. Can be propped up from the rear with sturdy metal plates, so limitation of telescope size bypassed. Gather more light from faint objects, the most distant.

- Maybe not as easy for today’s amateur astronomer to build, but …

- No chromatic aberration, because operating principle is reflection not refraction. First built by Newton (studied optics not just gravity)

- Can make mirrors so well polished that specular across multiple wavelengths. Can have gap in objective and have straight design

- Sealing with an extra lens on end keeps dust out, also corrects for spherical aberration (rays not all focusing to same point)
The Hubble Space Telescope

- Space-based is good (but expensive) because gets you out of earth’s atmosphere: no twinkling!
- Disadvantage when you need to fix it, but we managed. (Telescope received “glasses”)
- Many important discoveries made with Hubble, which we will go through as semester progresses
- In one giant leap took us farther than ever before in distance, and so also farther back in time, closer to the beginning of the universe. Launched back in 1990
Adaptive optics can compensate very well for atmospheric effects

- Laser used as reference to subtract them
- So ground-based telescopes will do more than compete, they’ll do much better than at least old space ones (also cheaper)

- Like all modern telescopes, a reflector
- Largest mirrors (segmented) on planet

Sources: GMTO, University of Arizona
Special telescopes

- **Radio**: The Very Large Array (VLA), the Arecibo Observatory
- **Microwave**: Cosmic Microwave Explorer (COBE), Wilkinson Microwave Anisotropy Probe (WMAP), Planck
- **Infrared**: Spitzer Space Telescope (SST), formerly the Space Infrared Telescope Facility (SIRTF)
- **Ultraviolet**: International Ultraviolet Explorer (IUE), Extreme Ultraviolet Explorer (EUVE)
- **X-rays**: The Chandra X-ray Observatory
- **Gamma rays**: The Fermi Gamma-ray Space Telescope (LAT)
The Charge-Coupled Device

- The CCD is the technology of choice for most modern digital cameras
- "Real-time" (unlike photograph film needing exposure)
- Utilizes silicon, which is a "semiconductor." Has a "conduction band"
- Outer electrons get knocked up into it (photons impart energy – remember last time about photons as energy packets, and about energy levels). Pulled out by voltage
Photomultiplier Tube (PMT)

- *1-photon* sensitive (~5-50% quantum efficiency) with photoelectric effect
- PMTs not for creating object “images”
  - Just know you’ve got a hit, and can often tell how many photons (some noise), but not position within window
- Can have many PMTs in array, but these are not really good “pixels” (few inches in diameter); not all λ detected
- Electron cascade/avalanche caused by increasing electric fields, leading to “gain” in millions (1 photo-electron)
Homework Assignments

- Scaling Activity [http://www.astro.princeton.edu/~dns/teachersguide/ScActBkgd.html](http://www.astro.princeton.edu/~dns/teachersguide/ScActBkgd.html) [Will not be doing this activity next class. Table is just for your own edification and concept reinforcement for now.]
- Shorter articles than usual, and fewer. Focus on written homework due on Monday, catch up on any earlier readings you haven’t done yet, and re-read any lectures on topics you didn’t quite understand the first time around