CHAPTER 03: TELESCOPES

3.1: OPTICAL TELESCOPES

**Buckets of Light**
- Whole point of any telescope, any type, is to gather light
- Light = information: More light = more information
- “Light” might be any portion of the e·m spectrum

**Reflecting and Refracting Telescopes**

**Refractors**
- Original type of telescope used by Galileo
- Telescope uses lenses to form image
- Light passes through primary lens, is refracted (bent) to a focus
- Focus is where image is formed: This is fixed by design of primary lens
- Second lens, eyepiece: This can be changed to alter magnification or field of view (FOV)

**Reflectors**
- Invented by Newton (but there are several different types of configuration)
- Instead of primary lens, uses a curved mirror to focus incoming light
- Focus is fixed by mirror
- Also uses an eyepiece lens to change magnification and/or FOV

**Which One Is Better?**
- Refractors are limited because of lens parameters
- Much harder to machine a high-quality lens than high-quality mirror
- Lens disadvantage: Chromatic and spherical aberrations require painstaking correction
- Size/weight: Large lenses are heavy, and can only be supported at the edge (glass can literally sag under its own weight, creating distortion)
- Cheaper and easier to design/build larger reflectors

**Types of Reflecting Telescopes**

**Newtonian Reflectors**
- Light reflects off primary mirror
- Secondary mirror located in front of primary focus
- Secondary mirror tilted to divert light through aperture on side of telescope tube, to eyepiece

**Cassegrain Reflector**
- Secondary mirror not tilted: Light reflects back toward primary mirror
- Aperture located at center of primary mirror
- Eyepiece, camera, or electronic detector mounted behind primary, at base of telescope tube

**The Hubble Space Telescope**
- Hubble is a Cassegrain because this is most compact configuration and gravity is not an issue
- Launched 1990, corrective optics (COSTAR) in 1993
- Subsequent service missions: Replace/renew (new devices build in corrections)
- Service Mission 4: May 2009 (probably last service mission)
- Install Wide Field Camera and Cosmic Origins Spectrograph, remove the COSTAR

**Coudé Configuration**
- Combine the Newtonian with the Cassegrain: Cassegrain secondary mirror, Newtonian tertiary
- The point is to get the beam out of the telescope and into a detector
- The detector may be too big (or too delicate or too sensitive to motion) to mount anywhere on the scope itself
Keck Observatory
✦ Largest ground-based reflectors: Two telescopes, 10-m primary mirrors
✦ Can be used in either Cassegrain or Coudé mode
✦ Large mirror possible only because of compound section design: Mirror is segmented

Detectors and Image Processing
How Do You See What’s There?
✦ Once upon a time, you had to use an eyepiece...and your eye
✦ You had to look, then draw what you saw...at night...in the dark...in the freezing dome
✦ Then there were cameras: Mount a camera at the eyepiece, then snap away (at night...in the dark...in the freezing dome)
✦ Now there are CCD chips: Electronic detector lets you sit in a warm control room and record data at the touch of a button

What Is A CCD Chip?
✦ CCD = charge-coupled device
✦ Analogous to old-fashioned film, but the ccd pixels are smaller and more sensitive than the silver halide grains on film
✦ Every time a photon strikes a pixel, it transfers energy to that pixel
✦ Image forms as a composite of pixels: more energy (more photon strikes), brighter pixel
✦ Faster and more sensitive than film, increasingly small pixels for better resolution

3.2: Telescope Size
Light Gathering Power
✦ To collect more light: Use a longer exposure time (this is directly proportional: Twice the time = twice the light)
✦ Amount of light gathered in a given amount of time depends on area of primary mirror
✦ Compare a 1m mirror with a 2m mirror: Double the diameter means 4x the area (area = \( \pi r^2 \))
✦ 4x the area means 4x the light-gathering power
✦ Express in terms of time: Twice as big only needs \( \frac{1}{4} \) the exposure time to get the same amount of light
✦ In the same amount of time, twice as big collects 4x as much light: Therefore, it can see dimmer (or farther) objects

Resolving Power
✦ Resolution: Ability to distinguish detail
✦ Human eye example: How far away is car before you can resolve two headlights (as opposed to seeing a single blur of light)
✦ A typical eye can resolve about 2 minutes of arc \( (2' = \frac{2}{60}° = 0.033°) \)
✦ You could resolve two headlights at a distance of about 1500 yards

Diffraction and Telescope Resolution
✦ Resolution is limited by diffraction (tendency of light to bend through apertures)
✦ Larger primary, less diffraction (less diffraction, better resolution)
✦ Angular resolution = \( \frac{1}{4} \)/wavelength/diameter
✦ Notice that better resolution means a smaller number: Smaller the angle, the higher the resolution
✦ Shorter wavelengths will have better resolution (red diffracts more, blue diffracts less)
✦ A telescope may be blurry in the IR, but razor-sharp in the UV
3.3: High-Resolution Astronomy

Atmospheric Blurring

Twinkle, Twinkle

✦ Step outside and view the sky: Stars twinkle
✦ The twinkling is a result of the atmosphere (air molecules are always moving)
✦ If your eyes see twinkle, so do telescopes
✦ This means that in reality, you cannot get resolution as clear as the diffraction limit predicts

The Seeing

✦ Seeing = actual angular resolution obtained
✦ Theoretically, resolution might be 0.01" (for Keck 10m), but actual resolution = 1"
✦ The seeing depends on stillness of the air: Less turbulence = better seeing
✦ Put telescopes on mountaintops to reduce amount of atmospheric blurring

New Telescope Design

Active Optics

✦ Control and compensate
✦ Adjust position of mirror (or individual mirror segments) to compensate for gravity (sag), wind, etc.
✦ Control temperature: Want dome, mirror, to match outside temperature
✦ Dome design: Want aerodynamic dome (even though it's stationary) to prevent turbulence

Adaptive Optics

✦ Use a known guide star as a reference (you could also use a planet, or a laser to make your own)
✦ Fine-tune mirror(s) in real time, using guide star (take the twinkle out)
✦ This corrects for atmospheric turbulence while you are busy observing something else in the FOV
✦ Do this carefully, and you can get really close to diffraction limit resolution

3.4: Radio Astronomy

Essentials of Radio Telescopes

✦ You need a really big dish: Radio waves have long wavelength
✦ You need a really big dish: Radio waves have low energy
✦ You need a really big dish: There are not many of them

The Value of Radio Astronomy

✦ Radio is on 24/7: Does not depends on weather or dark sky conditions
✦ Strong radio emitters are not necessarily strong emitters at shorter wavelengths
✦ Radio transparency: Radio can penetrate where shorter wavelengths are scattered or absorbed

Interferometry

Interference

✦ Two waves occupy the same place at the same time (any kind of waves, any wavelengths)
✦ Constructive: Waves in phase, waves reinforce (combined signal is twice as strong as individual signals)
✦ Destructive: Waves out of phase, waves cancel (combined signal is null)
✦ Partial: Waves do not match up perfectly, resulting signal could be anywhere between 0 and 2x
Interferometry
✦ Overlap (interfere) simultaneous signals from two (or more-the more the better) telescopes
✦ Make sure you are pointed at the same object at the same wavelength at the same time
✦ Remember that resolution is inversely proportional to aperture (diameter of dish): Any array increases the aperture
✦ You need an array of very many dishes: The Very Large Array (VLA) combines 27 radio dishes to improve resolution
✦ You need an array with widely separated dishes: The Very Long Baseline Array (VLBA) only uses 10 dishes, but spans over 5000 miles

Limits on Interferometry
✦ Actually, limits are expanding into shorter wavelengths
✦ Optical interferometry will be getting very exciting very soon, if SIMLite ever launches...the limit here is money, not technology

3.5: Space-Based Astronomy

Infrared and Ultraviolet Astronomy
✦ Some IR and UV penetrate the Earth's atmosphere, but most frequencies do not
✦ Space telescopes to the rescue
✦ Satellite scopes orbit the earth: IRAS, Hubble, EUVE, GALEX
✦ Spitzer Space Telescope: Does not orbit Earth, orbits the sun in the same orbit as Earth (for now)

High-Energy Astronomy
✦ Again, opaque atmosphere means you need orbiting observatories
✦ High energy X-rays need different telescope design, since these are penetrating rays
✦ Gamma rays are so penetrating that you can't really "image," you have to just count

Full-Spectrum Coverage
✦ Important to observe across the e·m spectrum, not just in visible portion
✦ See Table 3.1: Not everything there is to know can be gleaned from visible light