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

NOTES AND SKETCHES

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 = πr^2)
- 4x the area means 4x the light-gathering power
- Express in terms of time: Twice as big only needs ¼ 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 ($2' = (2/60)° = 0.033°$)
- 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 = (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

NOTES AND SKETCHES

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

NOTES AND SKETCHES

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

NOTES AND SKETCHES