Tools of Astronomy: Telescopes

Lecture 9
Refracting Telescopes

• Large \textit{lens} to gather and focus light.
Problems w/ Refracting Tel’s

- Must make a large piece of glass with no defects (bubbles, impurities, etc.).
- Must suspend the heavy glass by the rim.
- Chromatic aberration.
  - Different wavelengths of light are bent differently (like a prism!)
- Largest refractor is ~1 meter in diameter
Reflecting Telescopes

- Reflect light from an aluminized, curved mirror to a focus.
Mirror shape

- The mirror always has the shape of a conic section:
  - Parabola, hyperbola, or ellipse

Cassegrain Telescope

Major type used in optical astronomy.
Newtonian Telescope

Used by many amateur astronomers
(cheaper to make than Cassegrain)

Advantages of Reflecting Tel’s

• Light is reflected off the surface so it doesn’t pass through the material.

• Can support from the back.

• No chromatic aberration (all light is reflected equally).
What a telescope does -

• “Gathers up” the “flux” from an object
• The amount of light collected (or power collected) depends upon the area of the telescope mirror.

• Thus, bigger telescopes are better.
• They collect more light.

Your eye vs. the telescope

• A dark adapted eye has diameter,
  \( D \sim 7 \text{ mm}. \)
• The Mt. Palomar telescope \( D = 5 \text{ m} \).
  so it collects

\[
\left( \frac{\frac{5 \text{ m}}{7 \text{ mm}} \frac{10^3 \text{ mm}}{\text{ m}}} \right)^2 = 510,000
\]

times more light!
• Thus you could see much fainter with it.
How faint can you go?

- Looking through the Palomar telescope you should see about 14 mags fainter
  - i.e. 20th magnitude
- But Palomar observes objects much, much fainter than this (~25th mag).
- How does it do this?

Photon Detectors

- **Photon detectors** are devices which respond to E-M radiation.
- Photographic film detects photons.
  - Used in the “olden” days of astronomy
- Today **“solid state” detectors** are used, e.g. CCD’s (charge-coupled devices)
  - Used in low light level camcorders and electronic cameras.
Other wavelengths

• Solid state photon detectors in one form or another are used to detect radiation across the E-M spectrum.

• Photography covers a very limited portion of this spectrum
  – Mostly visible,
  – Not very efficient
    (only detecting 1 photon in about 20)

Integration time

• Integration time is the exposure time of the detector.

• The dark adapted eye integrates photons for ~1/8 to 1/4 second.

• CCDs can integrate for hours.

• The long exposure time means many photons can be collected from the source.
Angular Resolution

- **Angular resolution** is the ability to distinguish between nearby objects.
  - Measured in arcseconds or arcminutes

- The eye has a spatial resolution of ~1 arcminute.

Angular resolution (cont’d)

- Measures the clarity with which you can see.
- The following sequences show progressively poorer angular resolution.

  - As the angular resolution gets poorer
    - Images are more blurry
    - Contrast is decreased.
Angular resolution (cont’d)

- Consider two telescopes looking at pairs of stars that are progressively closer together.

<table>
<thead>
<tr>
<th>Pair 1</th>
<th>Pair 2</th>
<th>Pair 3</th>
<th>Pair 4</th>
<th>Pair 5</th>
<th>Pair 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Telescope 1" /></td>
<td><img src="image2" alt="Telescope 2" /></td>
<td><img src="image3" alt="Angular resolution of Telescope 2" /></td>
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</tr>
</tbody>
</table>

- Telescope 2 has better angular resolution than telescope 1.

Empty magnification

- Magnifying the images doesn’t help.

  ![Before magnification](image4) \[\Rightarrow\] ![After magnification](image5)

  - Beyond a certain point, you get “big” fuzzies.
  - The resolution of the system is not improved.
Angular resolution (cont’d)

• The angular resolution, $\theta$, of a telescope (in radians) is given by:

$$\theta \propto \frac{\lambda}{D}$$

where $\lambda = \text{the wavelength}$
$D = \text{telescope diameter}$

- SMALLER angular resolution is BETTER.

Some numbers

• Optical wavelengths ($\lambda \sim 5000 \text{ A}$)

$$\theta'' = \frac{4.9}{D(\text{inches})} = \frac{0.12}{D(\text{meters})}$$

- A dime subtends 1” at 2 km!

• Radio wavelengths (1 mm to 100 m)

$$\theta' = \frac{41\lambda}{D(\text{meters})}$$
Notes on Angular Resolution

• Larger telescopes have better angular resolution.

• But it is the size of the telescope relative to the wavelength that counts.

• Radio telescopes need to be very large to get “good” angular resolution.

If you had radio eyes

• If your eyes operated in the radio (rather than the visible.

• For \( \lambda = 1 \text{ cm} \), \( \theta = 1 \text{ arcminute} \)

\[
D = \frac{41 \times \lambda (\text{cm})}{\theta (\text{')}} \text{ meters}
\]

\[
= 41 \text{ meters}
\]

You would have to have 41 meter pupils to see with the resolution you have now.
Atmospheric blurring

• Telescopes are placed on mountain tops to get better seeing (thinner air).
• But atmospheric blurring limits the angular resolution ~0.5 arcsec (5000 A).
• Adaptive optics corrects the blurring due to the atmosphere in real time
  – Uses a deformable mirror
  – Developed for the military

Interferometers

• Interferometry synthesizes a larger diameter telescope with a set of smaller telescopes spaced a large distance apart.

• Achieves high angular resolution roughly equal to the largest telescope spacing.
Schematic Interferometer

Angular Resolution:
$$\theta = \frac{\lambda}{D_s}$$

Schematic Radio Telescope

Satellite dishes are smaller versions of this.
GBT (Green Bank Telescope)
Features of Interferometers

- **Advantage:** Cheap to build compared to a single large telescope.
- **Disadvantage:** Most photons hit the ground between the dishes.
- Thus interferometers give excellent angular resolution but are much less sensitive than a single “filled aperture” telescope would be.

Radio Interferometers

- Most interferometry is done in the radio.
- The Very Large Array (VLA)
  - 27 radio dishes, each 25 m in diameter spaced in a Y pattern which is 20 km along each leg.
  - Simulates a 40 km diameter telescope
  - At 2 cm the angular resolution is about 0.1”
- Could see a dime in Elmira!
Radio Interferometers (cont’d)

• The Very Long Baseline Array (VLBA)
  – 10 radio dishes, 25 m in diameter located across the world from Hawaii to the Virgin Islands.
  – The baseline is about 16,000 km.
  – The resolution at 2 cm is ~0.0003″ !!

• Could “split a hair” in Elmira!
Telescope Summary

• Reflecting telescopes are the best.
• Larger telescopes collect more photons => larger is better
• Angular resolution: $\theta \sim \lambda / D$ => larger is better
• Interferometry allows a large aperture to be simulated.

Where to put your telescope

• Put on barren mountain tops
  – For best “seeing”
• Keep away from big cities
  – Avoid light pollution
• But not always enough!
  – -- Ain’t no mountain high enough!
Transparency of the Earth’s Atmosphere

Getting rid of the atmosphere

- Put telescopes above the atmosphere!
  - Eliminates “seeing” as a problem.
  - Gets above the absorbing atmosphere.

- Possibilities
  - Airborne Observatories
  - Balloons
  - Spacebased observatories
Kitt Peak National Observatory

Mauna Kea
Keck Mirror

JCMT (James Clerk Maxwell Telescope)
GBT (Size Comparison)

HST
HST Servicing

SQUARE KILOMETER ARRAY