Lecture Outline: Chapter 5: Telescopes

You don't have to know the different types of optical reflecting and refracting telescopes.

⇒ It is important to understand the difference between "***imaging***," "***photometry***," and "***spectroscopy***" (sec. 5.2) before going any further.

There are really only two topics here:

light gathering power and ***resolution***

The latter involves the most considerations by far. *Most of the variety in design and appearance of telescopes that employ different wavelengths is due to differing needs to attain high resolution at that wavelength.*

First: Make sure you understand what we mean by light gathering power (think of it as how many photons you can collect in a given time) and resolution (you learn resolution, try to put it into everyday language)

Light gathering power—determines how faint an object you can detect. This will be proportional to the area of the collector, so $\propto D^2$ where D is the diameter of the telescope. Read text on largest telescopes, future designs, etc. How much fainter a star can you see with a 6 meter telescope than a 2 meter telescope?

Angular resolution

You must get used to *angular measure* here. Consider these examples: **1 arc sec** is equivalent to the angle subtended by the breadth of a hair view from about 30 ft, or a penny viewed from 3.6 km.

It will help to practice with everyday examples, but word them as an astronomer would: *"At its present distance, that tree subtends about 2 degrees. I cannot resolve the structure of its bark at this distance. Its angular size must be less than my eye's resolution limit. If I decrease my distance from the tree by a large enough factor, I might be able to resolve the structure of its bark.*

The resolution of the human eye is about 60 arcsec. For best telescopes, e.g. adaptive optics or Hubble Space Telescope (HST) $\approx$ 0.05 arc sec, radio interferometer $\approx$ 0.001 arc sec. We return to why these have those values below, but be warned: you will have to be able to explain it.

There are two limits that set how good your resolution is:

1. <u>Diffraction limit</u> ∝ λ / D (just due to the fact that you're using an instrument with edges and boundaries—see text)

(Remember: poor resolution means a large number, like 7 arcsec compared to 2 arcsec.)

So resolution is poorer at radio wavelengths than, say, optical wavelengths for a given telescope diameter D; i.e. D *has* to be huge for radio telescopes.

One way around this, which has almost entirely been used for radio telescopes so far, is to use interferometers—several radio telescopes used to simulate one huge telescope in order to get great resolution. Biggest interferometers can get amazing resolutions of 0.001 arc sec or better! (Read sec. 5.6)

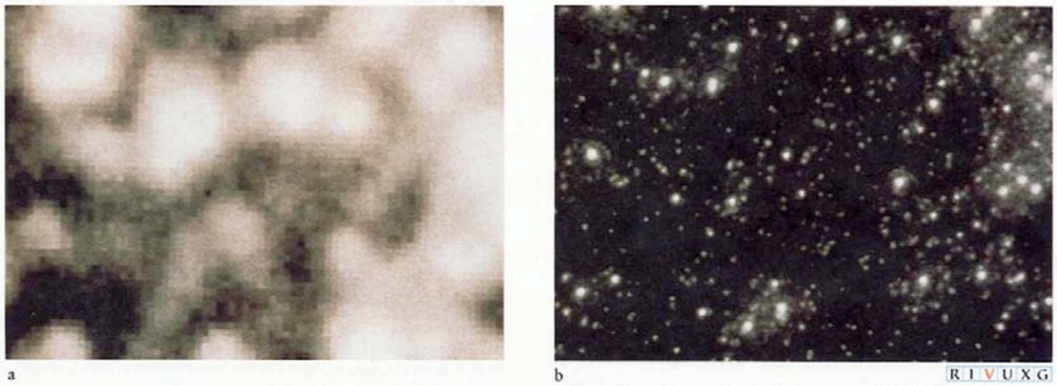
Here are some pictures of present-day large-baseline interferometers:

The Very Large Array (VLA) The 27 radio telescopes of the VLA system are arranged along the arms of a Y in central New Mexico. The telescopes can be moved so that the array can detect either wide areas of the sky (when they are close together, as in this photograph) or small areas with higher resolution (when they are farther apart).

FIGURE 5.18
The Very Long Baseline Array A map showing the distribution of the ten antennas that constitute an array or radio telescopes stretching across the United States. *(National Radio Astronomy Observatory)*

2. ***Seeing* limit** (due to Earth's atmospheric *scintillation*, i.e. "twinkling")

Here is a visual example of how scintillation makes stellar images "fuzzy":



Effects of Twinkling The same star field photographed with **(a)** a ground-based telescope, which is subject to twinkling, and **(b)** the Hubble Space Telescope, which is free from the effects of twinkling.

For a ground-based optical telescope the best res. ≈ **1 arc sec** because of this effect.

Two ways around seeing:

1. Adaptive optics in which the mirror constantly and rapidly adjusts its orientation and shape (sometimes thousands of times per second!) in order to compensate for scintillation. (See discussion sec. 5.4)

2. Space telescopes (Hipparcos, IRAS, HST, Spitzer, Chandra,···Sec. 5.7) (Remember, scintillation is just due to the fact that we have a thick atmosphere.)

Both of these methods to beat the *seeing limit* can get resolutions approaching *0.05 arc* sec or less.

Additional considerations:

1. Atmospheric transmission--Besides being responsible for *seeing*, the Earth's atmosphere also just blocks out light. Visible and radio wavelengths are least affected (recall material from ch.3). For other wavelength regions, need satellite observatories or at least very high mountains (same for visible because of seeing). (Sec. 5.7)

2. CCDs—Photographic plates only capture about 1% of the light, while charge-coupled devices (CCDs) can get about 75% efficiency, *and* extremely accurate. (sec. 5.2 in text). For optical telescopes, photographic plates are no longer used.

3. Infrared telescopes—special problem: must be cold, because the telescope itself emits IR radiation (why?). Also, best when above the Earth's atmosphere to avoid molecular absorption (see 1 above). (Sec. 5.7)

4. X-ray and gamma-ray observations—All must be done far up in Earth's atmosphere because absorption is so strong. Need special telescopes, since these don't reflect off mirrors the way that longer-wavelength light does (why not?). Briefly discussed in class.

See book sec. 5.7 for more details.