Telescopes . . . Light Buckets

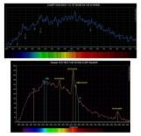
Now that we have an understanding of what light is, and why it's important to astronomy, **what tools are required to study light from distant objects?**

- The **telescope** is the tool used to gather or collect light, hence the name *"Light Buckets"*
- Once the light is collected, digital cameras and spectrometers analyze the light

What information do we want from this light? *(what happens when you're arrested?)*

- **Images,** i.e. pictures or mugshots; can provide lots of information

- **Spectra,** i.e. the intensity of light at different wavelengths, a fingerprint



A spectrum usually has a lot more information than an image; it can tell us: temperature, chemical composition, relative velocity, and more.

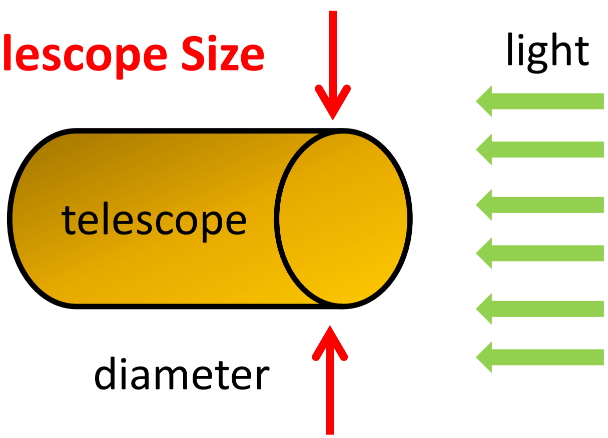
Performance Characteristics of Telescopes

Telescopes that work at different wavelengths can be quite different, but there are **two characteristics of any telescope that determine its performance**:

1. **Light Gathering Power (LGP):** Ability of a telescope to gather light; **Rule:** ***The more light the better!***

Factors that influence a telescope's LGP:

- **Telescope Size**



$$LGP \propto \text{cross sectional area}$$

$$\text{or } LGP \propto (\text{diameter})^2$$

We usually talk about **Relative LGP**, i.e. how much more light is gathered by one instrument than another: **e.g. how much more light is gathered by a 12'' telescope than the naked human eye (d ~ 0.2 '')?** (LC)

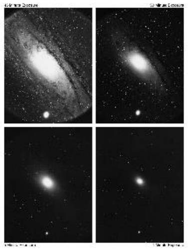
$$\frac{LGP_{12''}}{LGP_{eye}} = \frac{(12'')^2}{(0.2'')^2} = 60^2 = 3600$$

Performance Characteristics of Telescopes

So, in terms of LGP, we have the **First Rule of Telescope Design**:

The Bigger, the Better!

Another aspect that isn't LGP, but is used to gather more light is:



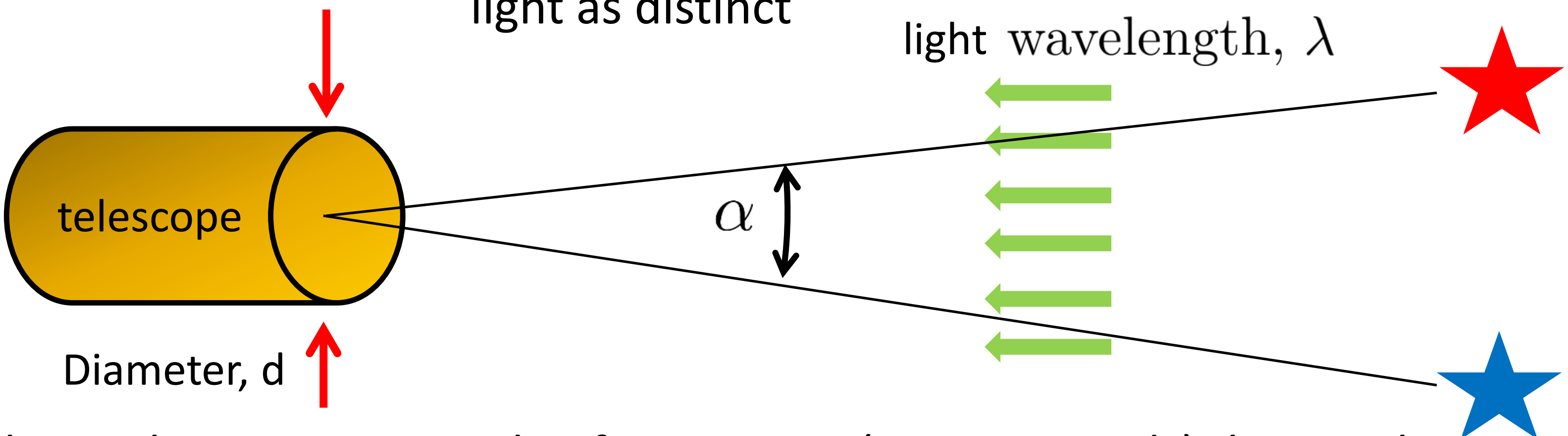
Exposure Time: the length of time that the telescope gathers light

The exposure time of the human eye is about 1/30 of a second. Cameras and other instruments used with a telescope can gather light for as long you want. This is why it can be disappointing sometimes to actually look through a telescope. **What you see with your eyes can never match the wonderful images in books and online that most likely used a long time exposure**

- - but it's still fun to see something with your own eyes!

Performance Characteristics of Telescopes

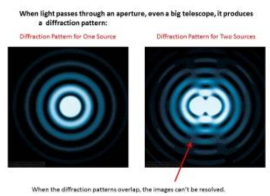
2. Angular Resolution: the ability to distinguish two nearby sources of light as distinct



What is the minimum angle of separation (in arc-seconds) that can be resolved by a telescope?

$$\alpha_{\min}(\text{in arcsec}) = \frac{(250,000)\lambda}{d}$$

where does this come from?



What is the 2nd Rule of Telescope Design? (LC) **The Bigger the Better!**

e.g. the Keck Telescope has a diameter of 10m, so in the middle of the visible band at a wavelength of 550nm:

$$\alpha_{\min} = \frac{(250,000)(550 \times 10^{-9})}{10} = 0.014''$$

But atmospheric thermal turbulence limits this to ~ 0.5 " ***"Bad Seeing"***

A comparison of Angular Resolution (LC)

Optical Telescopes

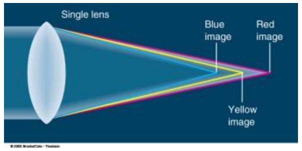
Optical telescopes operate in the visible part of the spectrum (400nm to 700nm); the kind that you can actually look through; there are two basic designs.

1. **Refracting Telescopes:** use a lens as principle component to bring light to a focus. Size is the diameter of the primary lens

Invented in Holland in 1608 by Hans Lippershey. Galileo heard about it and built his own.

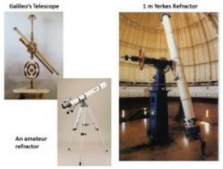
Problems with Refractors:

- **Chromatic Aberration:** different wavelengths come to a different focus; can minimize, but not eliminate.



- The lens must be supported around its rim **(Why?, LC)**, and the the glass can "flow" ruining the optics of the lens.

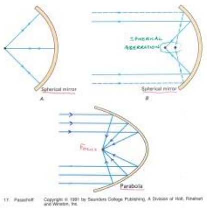
- The largest refractor ever built is the **1 m Yerkes Telescope** in Chicago. Small refractors (3'' to 5'') are widely used.



Optical Telescopes

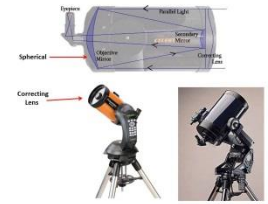
2. Reflecting Telescope: As we saw in the video, Newton thought of using a curved mirror to bring light to a focus.

What shape must the mirror be?



Parabolic - - a spherical shape suffers from spherical aberration where the light doesn't come to a focus.

Most large research telescopes use a parabolic mirror, but the **Schmidt design** uses a **spherical mirror** with a thin correcting lens to counter the spherical aberration. Since spherical mirrors are easy to make and cheap, these are widely used in small telescopes.



Advantages of Reflecting Telescopes:

- No Chromatic Aberration – the light does not pass through glass
- Objective (primary) mirror can be supported from the back (why?)

Optical Telescopes

How big do optical telescopes get?

For a long time, the largest was the 5m Hale telescope in California. The two 10m Keck multiple mirror telescopes in Hawaii are now the largest. Many larger ones (~30m diameter) are under construction

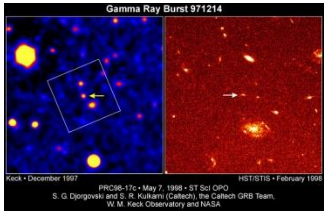

5m Hale at Mt. Palomar

Two 10m Kecks on Mauna Kea


The Hubble Space Telescope

Hubble is an effort to get an optical telescope above the Earth's distorting atmosphere. There's an excellent NOVA episode on Hubble's 25th anniversary. **It's posted on our calendar as an optional video.** ***You'll meet Nancy Roman, The Mother of Hubble!***

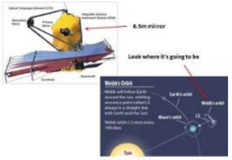
Just one quick image to show how well Hubble works after they fixed it. The 2.4m Hubble mirror is not huge, but look at the resolution in this image. This is because it's above the Earth's atmosphere.



Hubble really has revolutionized observational astronomy – we'll be seeing many of its images throughout this course.

Optical Telescopes

The James Webb Telescope - the next generation space telescope



Since it operates in the near-IR, the Webb telescope is not really an optical telescope, but many really interesting objects emit primarily in the IR. Was scheduled to be placed in orbit in ~~October 2018.~~ **~~March 2021!~~** **(sunshield ripped during practice deployment)**

October 2021 **(Covid Delay, finally launched 12/25/21)**

Cost: many billions $$.

Were you worried about this? I certainly was!

During the next class, we'll see the NOVA video, **The Ultimate Space Telescope,** so we won't talk too much about Webb now, but here are some images comparing the performance of The Hubble and The Webb

– Hubble on the left, and Webb on the right.

Telescopes for other Wavelengths

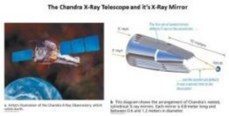
- We've been concentrating on optical telescopes, what about telescopes that can see at other wavelengths?
- For any wavelength, the two characteristics of telescope design are still important: **Light Gathering Power and Angular Resolution**.
- UV and IR telescopes are very similar to optical telescopes but they do have to be in space above the atmosphere.

- Telescopes at both short and long wavelengths have some special issues.

Short Wavelength

Both x-ray and gamma-ray telescopes have to be flown on satellites.

X-Rays are absorbed instead of reflected by most materials at normal incidence angles – **only grazing reflections are possible**.



Gamma-Ray telescopes are really just high energy particle detectors very similar to what are used in particle accelerators.

Radio Telescopes

After World War II, some radar scientists pointed their newly developed radar detectors to the heavens and found there was an enormous amount of long wavelength radiation coming from out there.

Radio telescopes are large metallic dishes that focus radio waves to a common point; like the 100m Green Bank telescope in WV.

But all radio telescopes suffer from a common problem: remember:

$$\text{Minimum angle of resolution, } \alpha_{\text{min}} \propto \frac{\lambda}{d}$$

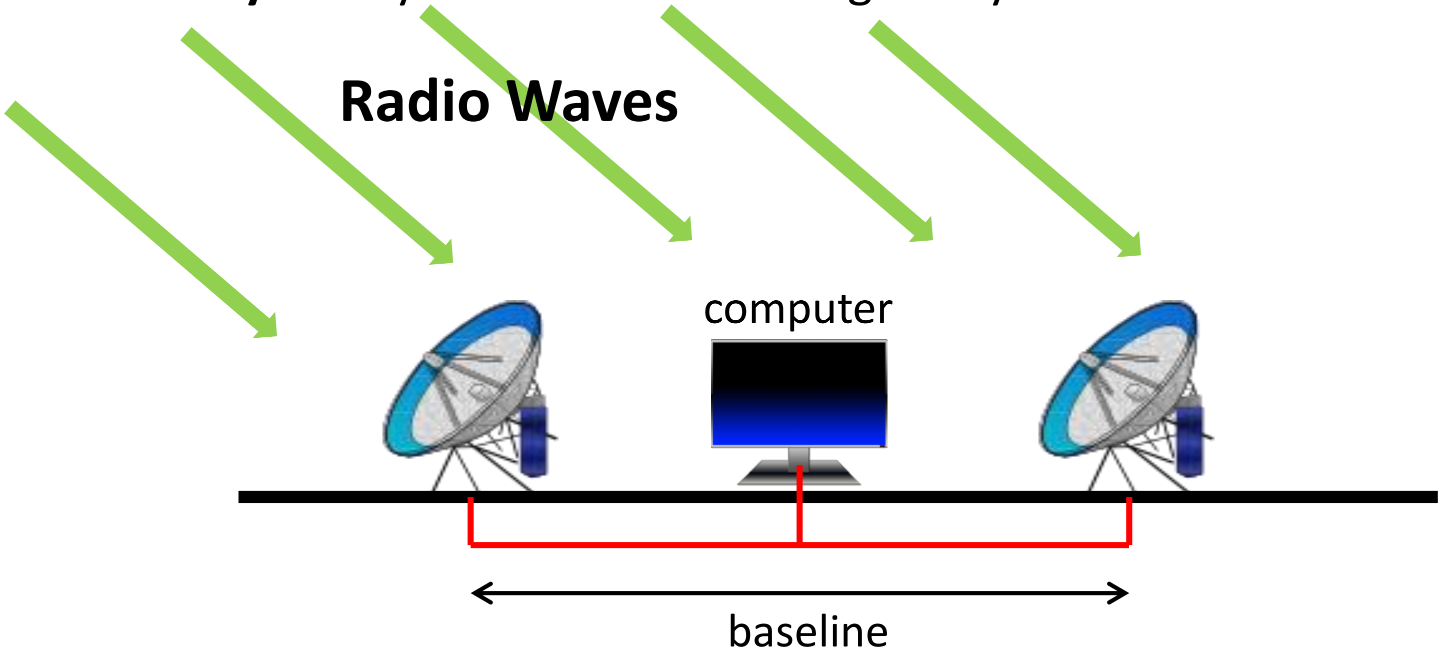
For radio waves, the wavelengths can be several meters; so even for very large dishes, your minimum angle of resolution might be 10^{o}-20^{o}, i.e. you have no idea where the signal is coming from!

The Solution to this problem: <u>Interferometry</u>.

Interferometry

(LC)

Interferometry is very similar to something that you use all the time



The computer combines the signals into an interference pattern; this allows the direction of the signal to be determined very accurately.

Effective diameter for angular resolution = baseline

In practice, more than two telescopes can be arrayed, **e.g. the VLA**:

What could you do if you used radio telescopes all over the Earth as an Interferometer – *maybe take a picture of a black hole in a distant galaxy?*