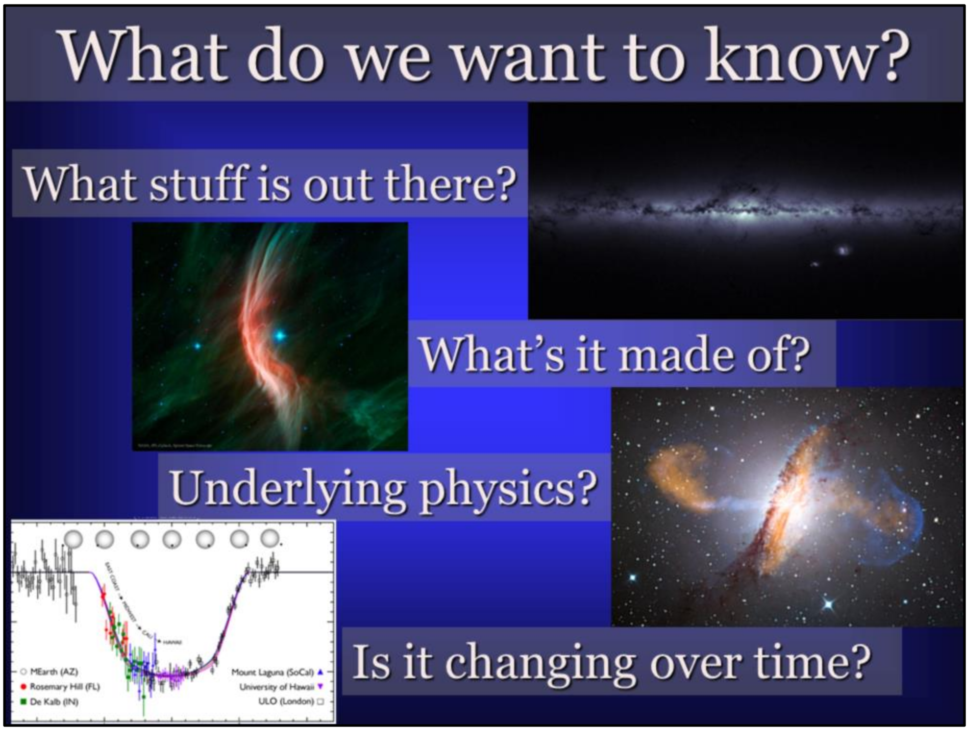
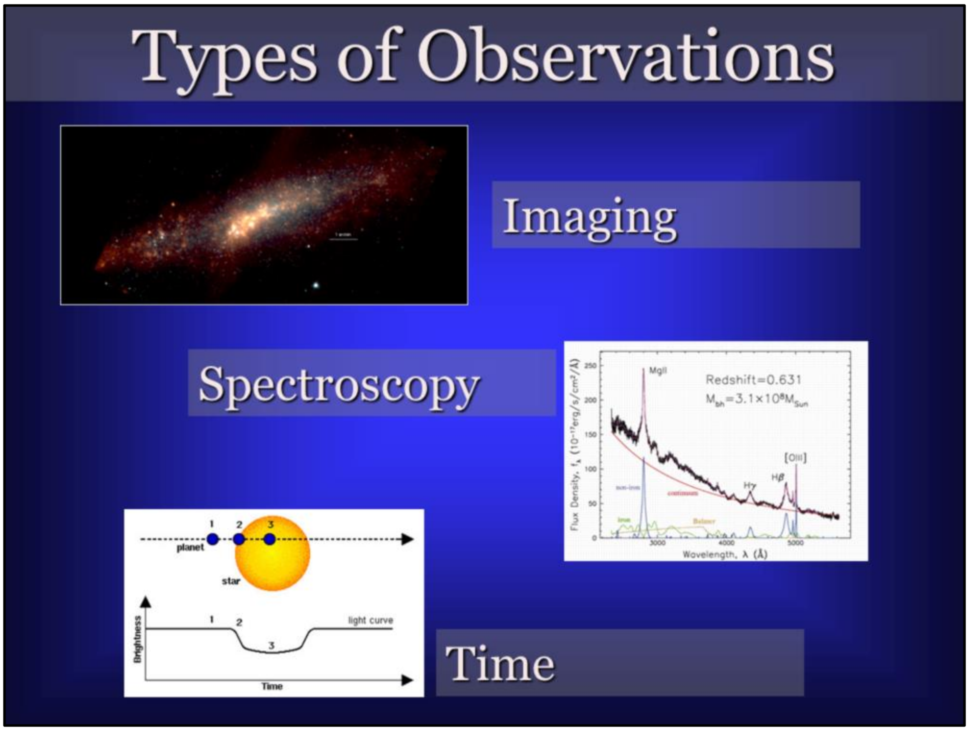


How do we answer these questions?

Images:
Milky way: http://www.cosmos.esa.int/web/gaia/iow_20150703 *ESA/Gaia-CC*
Zeta Oph: http://apod.nasa.gov/apod/ap150705.html (NASA/JPL/Spitzer)
Centaurus A: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)
https://en.wikipedia.org/wiki/File:ESO_Centaurus_A_LABOCA.jpg
Exoplanet timing: http://www.personal.psu.edu/ebf11/mystuff/press.html (Eric Ford, journal article: http://iopscience.iop.org/0004-637X/703/2/2091/pdf/0004-637X_703_2_2091.pdf)

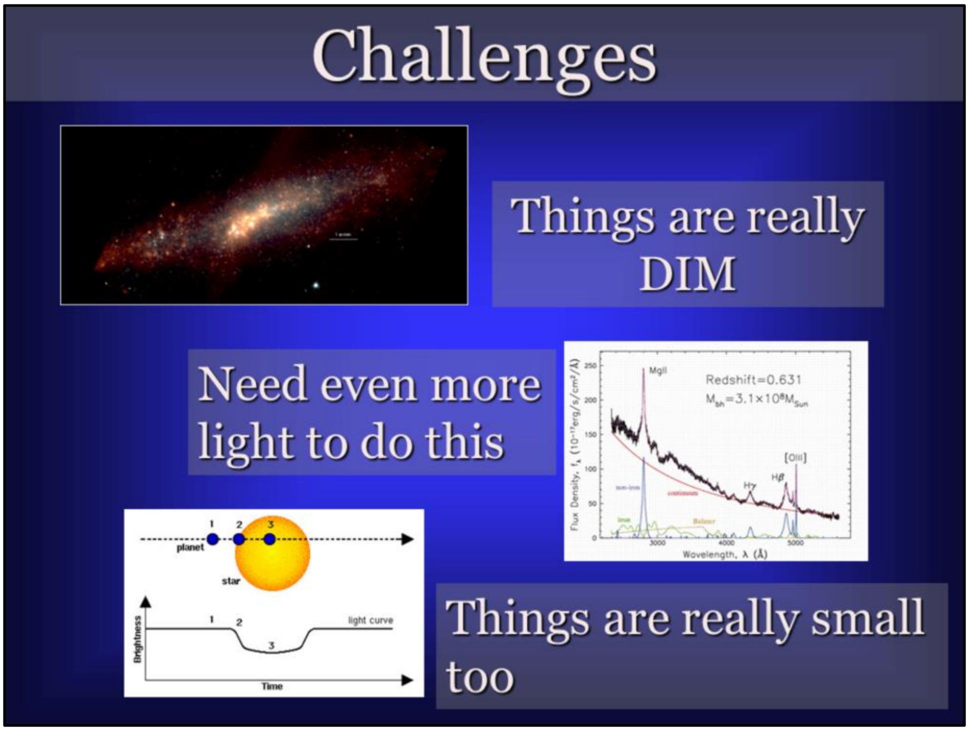


When we make observations, what are the things we can find out? What are we trying to do?

Imaging can tell us a lot about the object we are looking at
- Components (stars, gas, dust, etc.)
- Morphology (size and shape)
- Brightness
- Rough colors from different filters

Spectra tell us more about the physics that is taking place
- Composition
- Temperature
- Radial motion
- Rotation

Timing tells us how an object is changing over time
- This can be done with either imaging or spectroscopy
- How an object's brightness changes over time
- How temperature changes over time
- Useful for detecting extra-solar planets, variable stars, etc.



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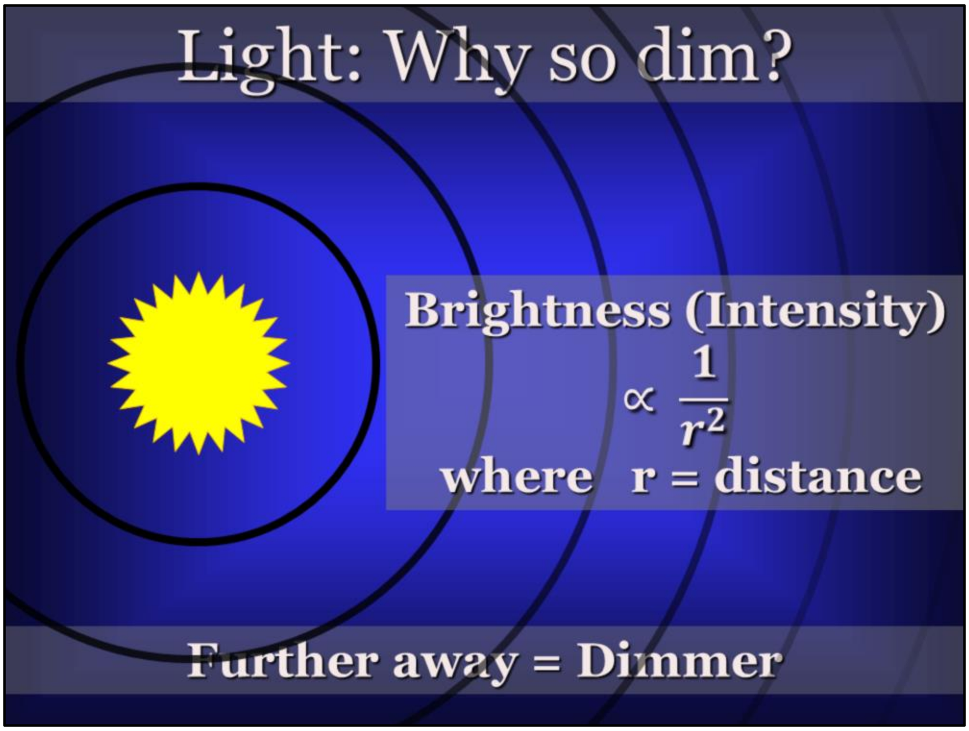
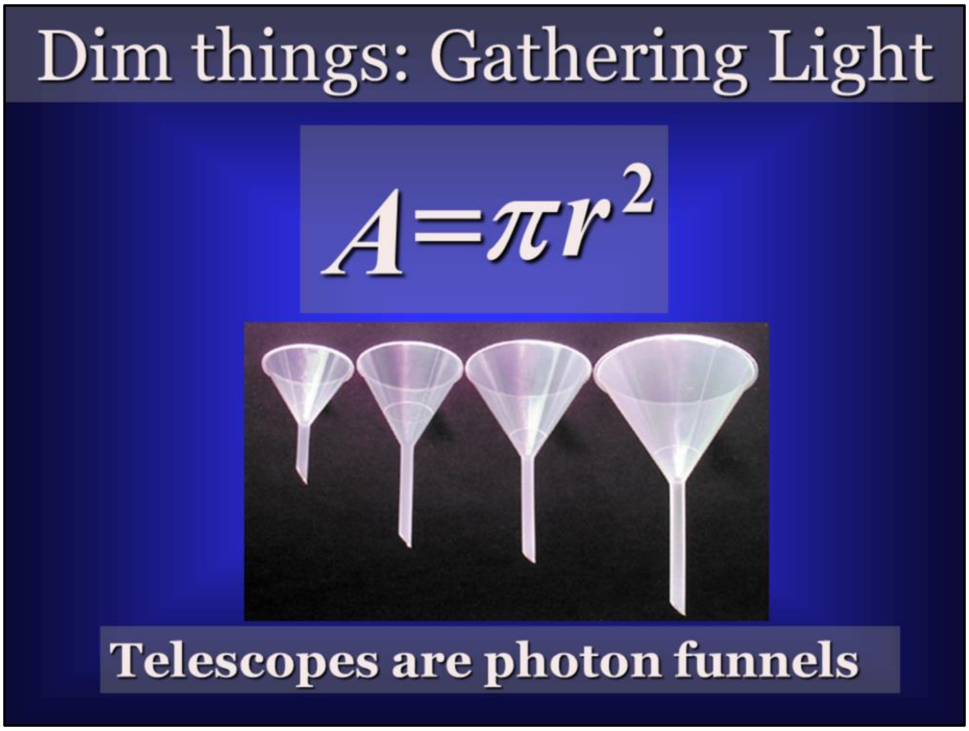
Telescopes

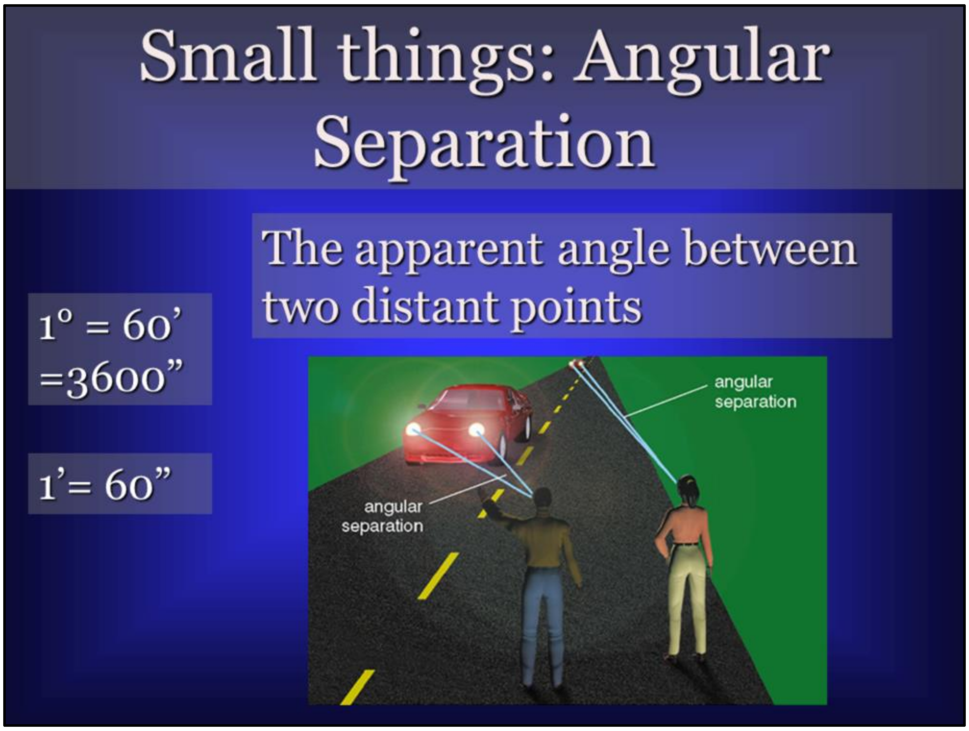

Light: Why so dim?
Brightness (Intensity)
$\propto \frac{1}{r^2}$
where r = distance
Further away = Dimmer



If I want to catch more rain… I should use a bigger funnel.
If I want to catch more photons, I should use a bigger mirror. This lets us see really faint things, like far away galaxies or very small dim planets.

If I double the telescope diameter, I quadruple the collection area.

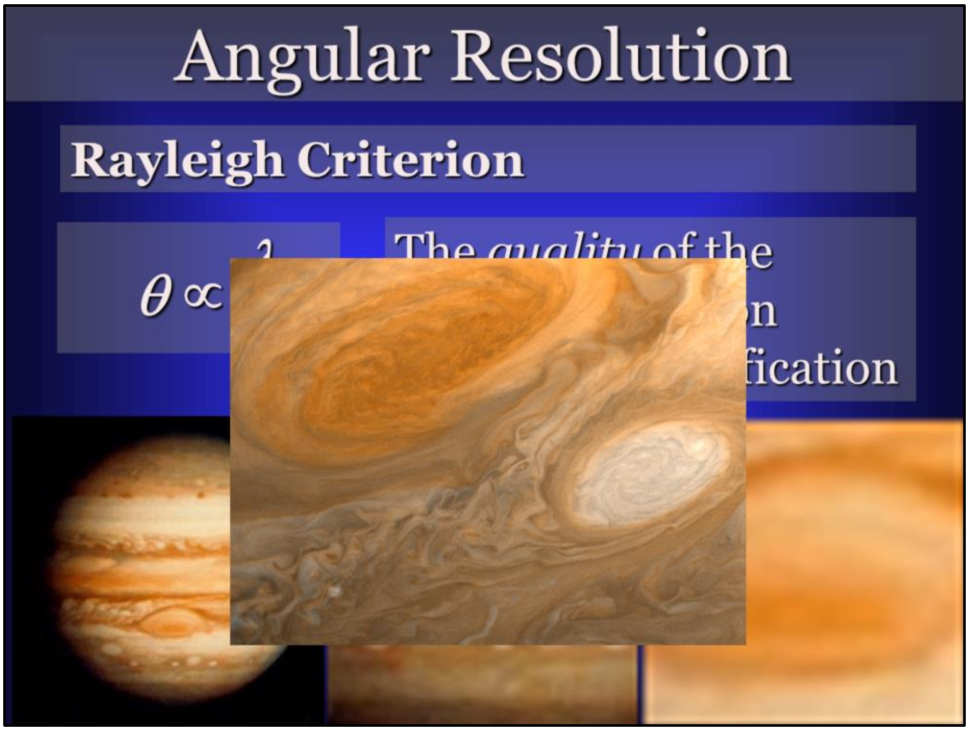
[Note this is a different area than for a star! Stars are spheres, light collecting area is a flat circle]



Imagine two long lines extending from your eye, one to each distant point. The angle between the lines is the angular separation.

Objects appear smaller (have a smaller angular separation) as they are moved further away

Angles are measured in degrees. There are 360 degrees in a circle.
For small angles, we subdivide a degree into 60 arc minutes and each minute into 60 arc seconds.
So… There are 3600 arc seconds per degree



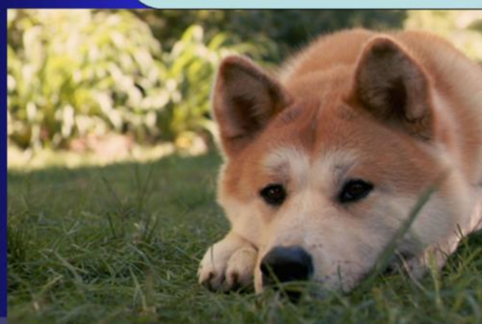
Less fuzziness! You see things bigger AND better!

Our ability to distinguish one point from another depends on the angular resolution which in turn depends on the size of the telescope mirror or lens.

Magnification: don’t buy any telescope where this is the selling point. You can change magnification by changing eyepieces.

Small things: Magnification

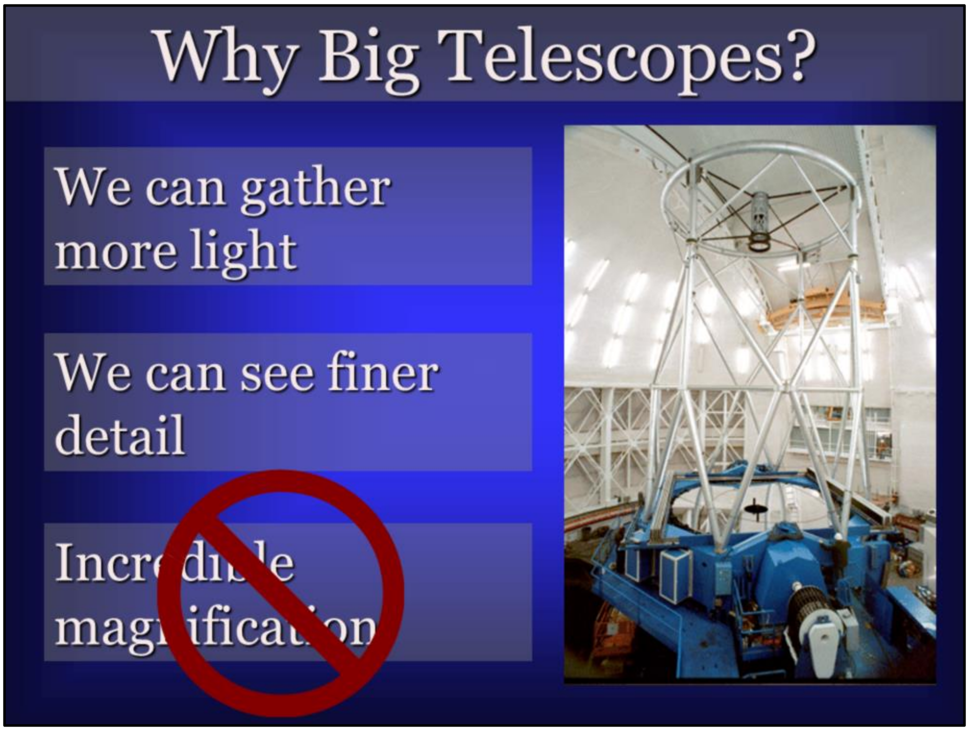
No, Doge, this is not what you need



Such sad

Many cry

With a BIG telescope you get magnification for free -- AND….

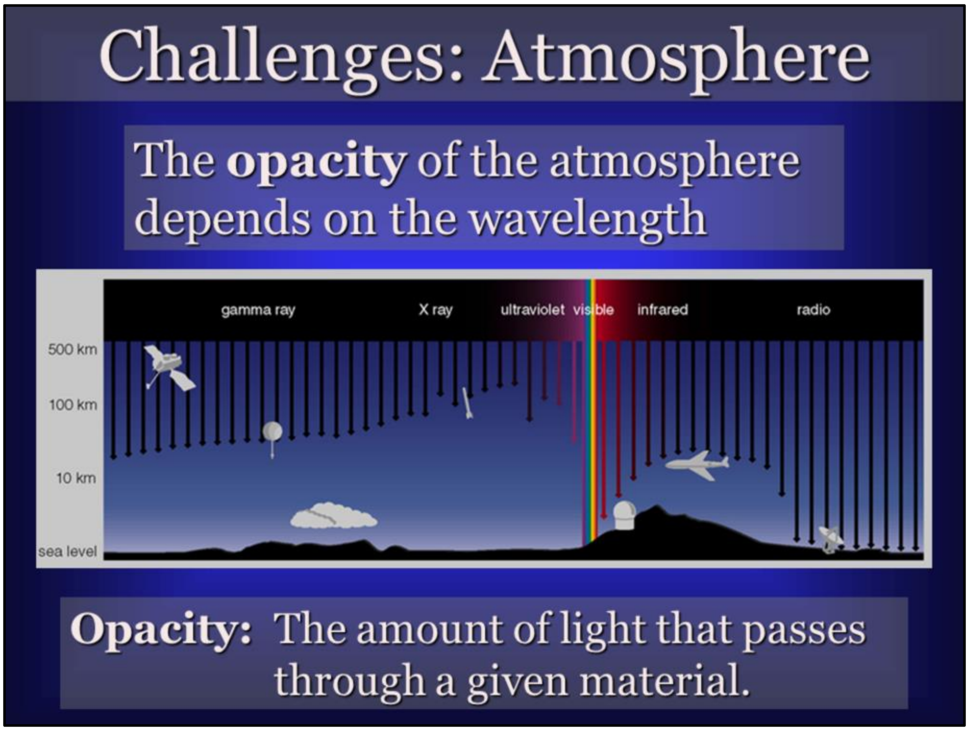


You do get magnification for free, with larger telescopes, but that's not the *reason* to do it

Most modern telescopes use mirrors.

The top left mirror is from one of the twin Keck telescopes on Mauna Kea in Hawaii.
At 10 meters, it is currently the largest optical telescope in the world (approximately 845 square feet of glass)
It is not a single piece of glass, it is made up of 36 hexagonal segments.

The bottom left picture is the solid 8 meter Gemini telescope primary mirror. The There are hexagonal pockets on the back of the mirror to make it lighter. The picture on the right is the fully assembled Gemini telescope. Notice that it doesn't have a tube.

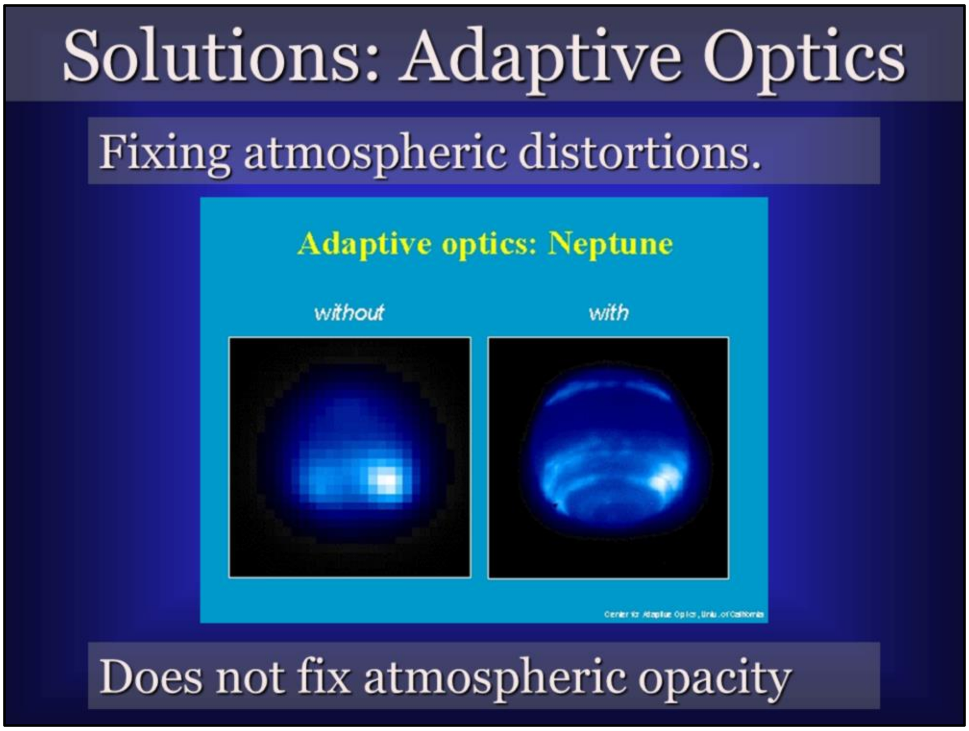


The atmosphere happens to be transparent at optical wavelengths.
This is not so at other wavelengths.

If we can't catch photons of a particular wavelength on the ground, we have to get above the atmosphere.

Lecture tutorial: Telescopes & Atmosphere, pg. 51

We are also still limited by the telescope *diffraction limit*
The Hubble mirror is only 2.4 meters. Compare this to Keck's 10 meter mirror.

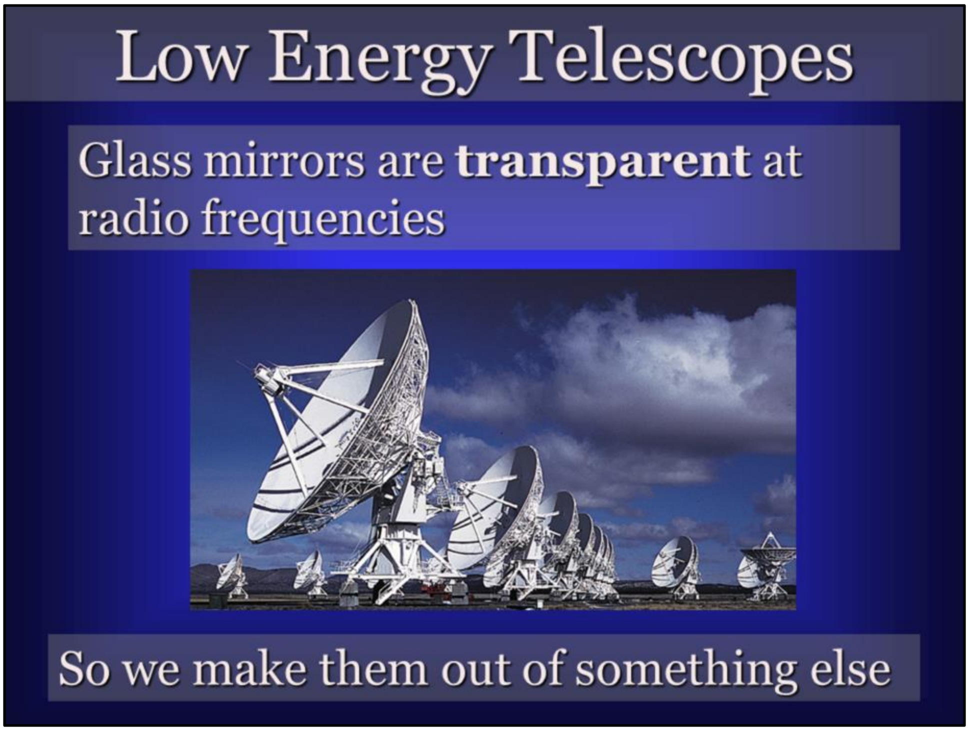


Adaptive optics systems actively measure and correct for atmospheric turbulence in real time.

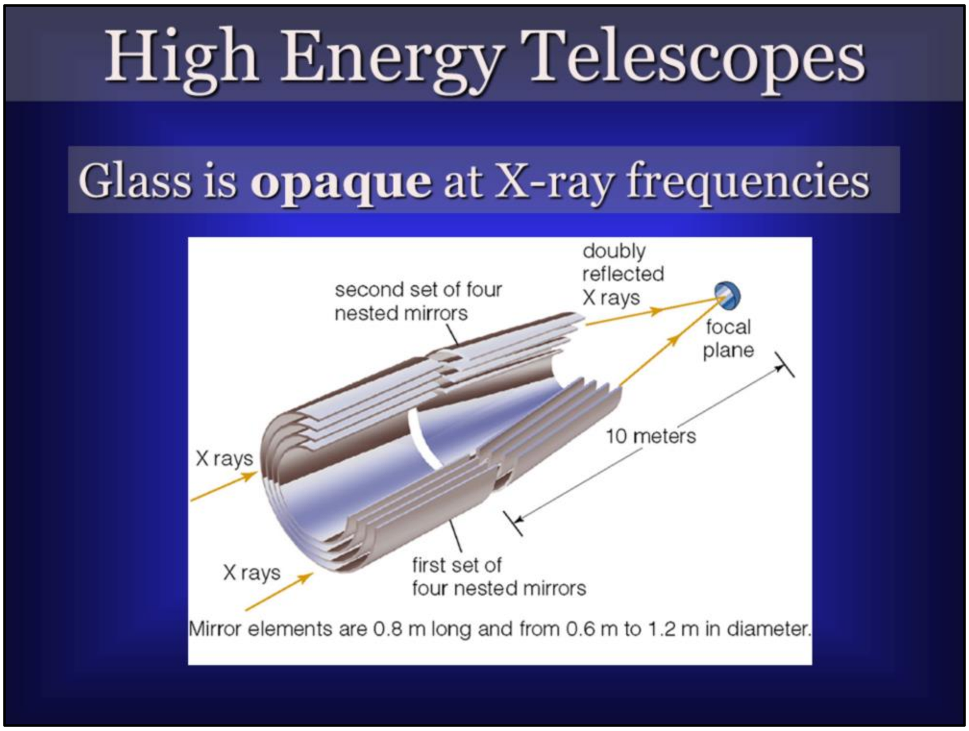
There are mid-level solutions as well, such as balloon observatories and observatories on airplanes.
For some wavelengths, these are valid solutions to the absorption problem.

Actually we can use more than one telescope in other wavelengths too – both the large binocular telescope and Keck observe at visible wavelengths. Keck also observes in the infared. LBT has an effective diameter of meters, and Keck has an effective diameter of .

Hubble operates on its own, above the atmosphere, observing primarily in the optical and near infrared. Hubble's diameter is 2.4 meters.



Loooong radio waves require huge dishes (apertures) to overcome the diffraction limits.
We can cheat a little bit by placing two dishes a long way away.
Then (in terms of diffraction anyway) it’s like having one really big dish.



And it’s hard get big reflection angles with x-rays
So we build our mirrors with grazing reflection angles.