

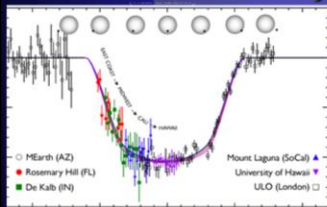
What do we want to know?

What stuff is out there?



What's it made of?

Underlying physics?



Is it changing over time?

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

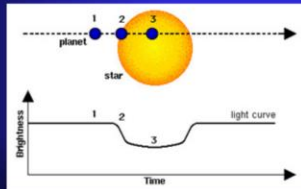
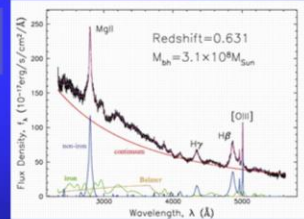
Exoplanet timing: <http://www.personal.psu.edu/ebf11/mystuff/press.html> (Eric Ford, journal article: http://iopscience.iop.org/0004-637X/703/2/2091/pdf/0004-637X_703_2_2091.pdf)

Types of Observations



Imaging

Spectroscopy



Time

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

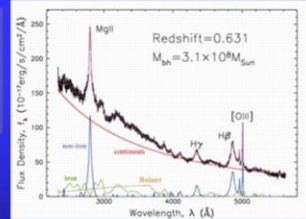
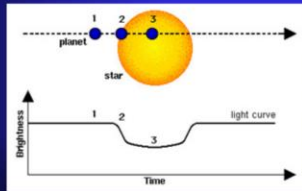
- This can be done with either imaging or spectroscopy
- How an object's brightness changes over time
- How temperature changes over time
- Useful for detecting extra-solar planets, variable stars, etc.

Challenges



Things are really
DIM

Need even more
light to do this



Things are really small
too

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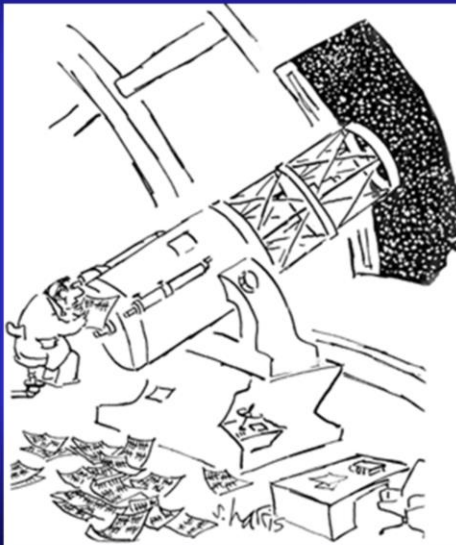
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Telescopes



Light: Why so dim?



Brightness (Intensity)

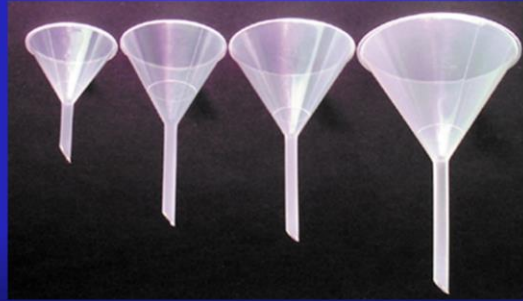
$$\propto \frac{1}{r^2}$$

where r = distance

Further away = Dimmer

Dim things: Gathering Light

$$A = \pi r^2$$



Telescopes are photon funnels

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.

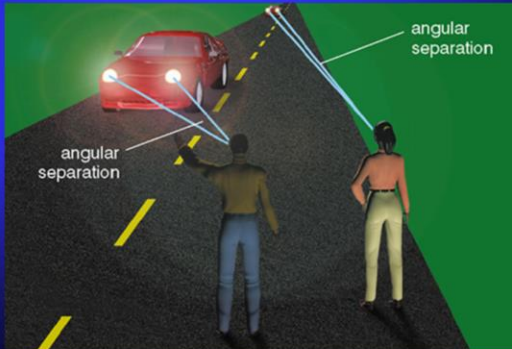
[Note this is a different area than for a star! Stars are spheres, light collecting area is a flat circle]

Small things: Angular Separation

The apparent angle between two distant points

$$1^{\circ} = 60'$$
$$= 3600''$$

$$1' = 60''$$



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

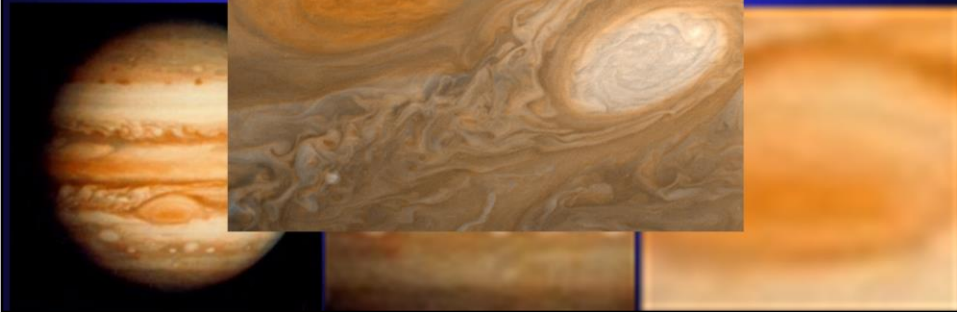
Angles are measured in degrees. There are 360 degrees in a circle. For small angles, we subdivide a degree into 60 arc minutes and each minute into 60 arc seconds. So... There are 3600 arc seconds per degree

Angular Resolution

Rayleigh Criterion

$$\theta \propto \frac{1}{D}$$

The *quality* of the
on
fication



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.

Small things: Magnification



The collage features three main elements: a telescope on a tripod in the top left, a dog's head (resembling a Shiba Inu) in the bottom center, and a microscope in the bottom right. The background is a dark blue gradient.

So Magnify !!!!

Much Excite!

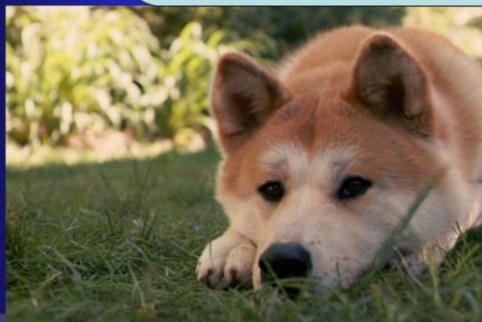
WOW

Three Eyepiece!!!!

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

Small things: Magnification

**You need a
bigger
telescope!**



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

Why Big Telescopes?

We can gather more light

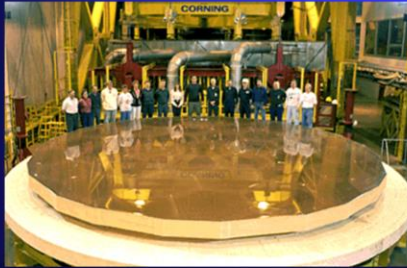
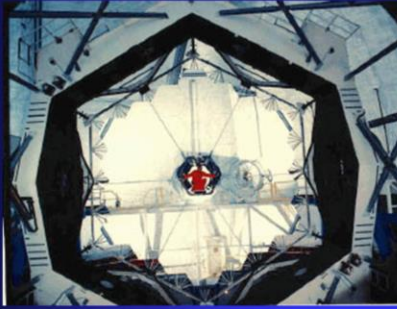
We can see finer detail

~~Incredible magnification~~



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

Mirrors = Big!



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.

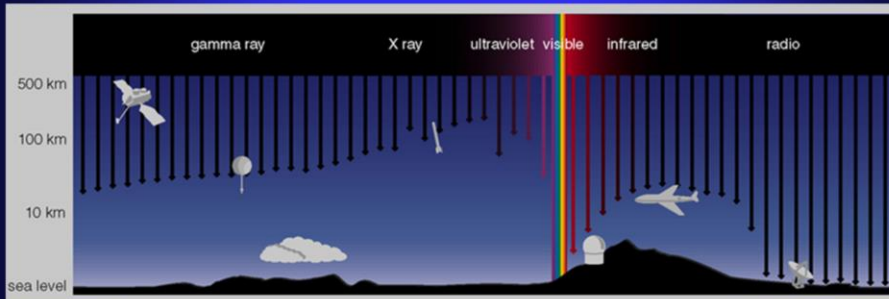
The bottom left picture is the solid 8 meter Gemini telescope primary mirror.

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.

Challenges: Atmosphere

The **opacity** of the atmosphere depends on the wavelength



Opacity: The amount of light that passes through a given material.

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

Solutions

Space!

Advantages

- Takes care of opacity.
- Takes care of seeing

Disadvantages

- Expensive
- Really Really Expensive



We are also still limited by the telescope *diffraction limit*

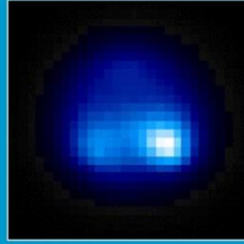
The Hubble mirror is only 2.4 meters. Compare this to Keck's 10 meter mirror.

Solutions: Adaptive Optics

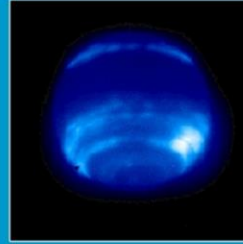
Fixing atmospheric distortions.

Adaptive optics: Neptune

without



with



Center for Adaptive Optics, Univ. of California

Does not fix atmospheric opacity

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 infrared. 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.

Low Energy Telescopes

Glass mirrors are **transparent** at radio frequencies



So we make them out of something else

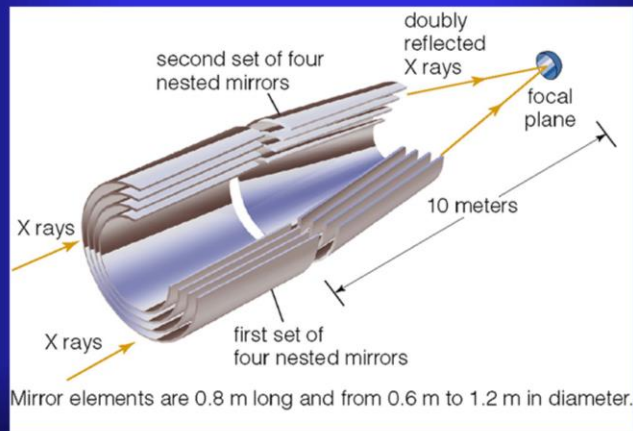
Looooong radio waves require huge dishes (apertures) to overcome the diffraction limits.

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.

High Energy Telescopes

Glass is **opaque** at X-ray frequencies



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