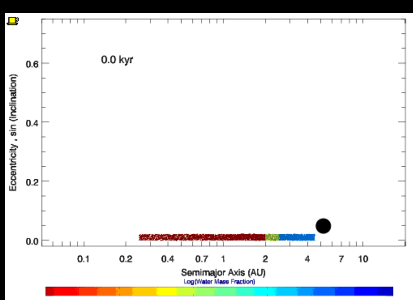
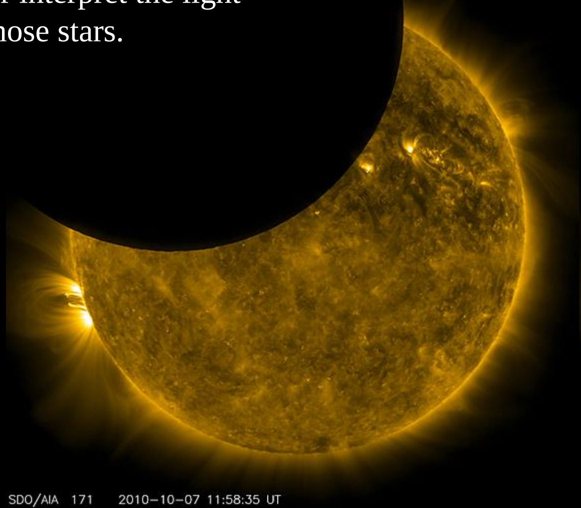
Upcoming Astronomy-themed Talks and Events

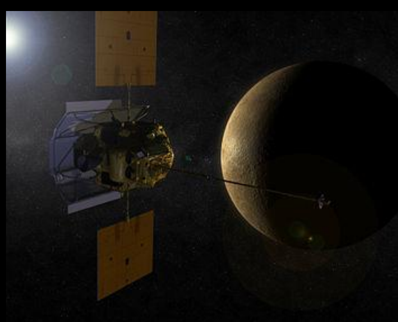
Thursday, 1/30, 3:45-5:00p Astronomy Colloquium – Phys-Astr A102 – Adrian Liu (McGill) – “The Past, Present, and Future of 21cm Cosmology”.

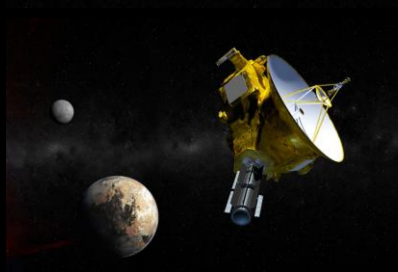


We finished our exploration of planetary formation last time by noting how dramatic orbital encounters aren’t such odd events after all – in fact, they’re a ***critical*** component in determining the overall layout and character of the planets in a planetary system. That level of historical contingency is something we did not fully appreciate until we looked to the more distant stars!

That’s where we’ll turn our full attention now – though we’ll need to start closer to home, with a quick exploration of how to better interpret the light coming from those stars.

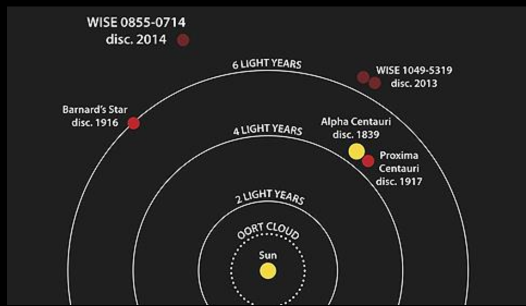






So far in our study of astronomy, we have focused on objects within humankind’s direct reach. We’ve seen images from dozens of probes and satellites sent to observe the planets and other Solar System objects in detail, some that even landed on those worlds and collected direct physical evidence from them.

These missions are hard because planets in our Solar System are so far apart – but those worlds are *millions* of times closer to us than even the ***nearest*** star. Even to those inspired by the Newtonian revolution, such extreme distances – first revealed in the 18th and 19th century – initially seemed to rule out our knowing anything about stars other than their location and brightness.

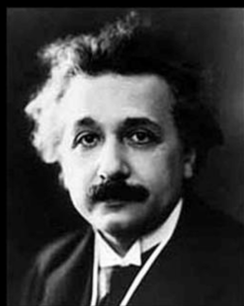


The distance to the nearest half-dozen stars – note that Voyager I, the farthest thing humans have sent *anywhere*, would still be near the exact center of the yellow dot that represents the Sun in this graph.

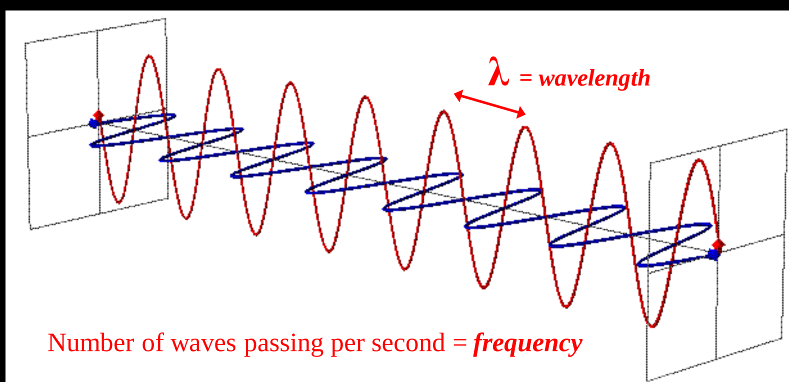
But it turns out that there ***are*** ways to answer many more physical questions about distant objects – they just require us to understand more about the nature of light!



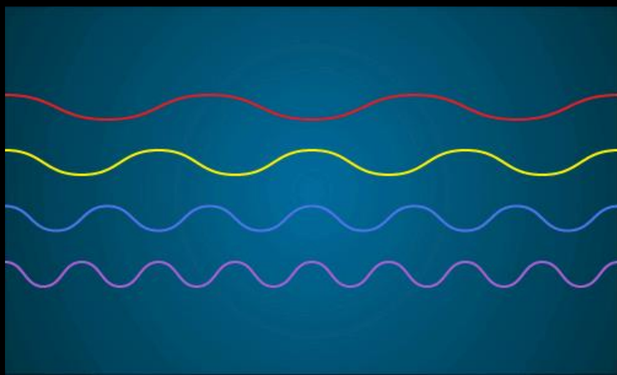




The physics of light has been studied for centuries, by some of the greatest minds of all time – Alhazen, Newton, Herschel, Maxwell, Einstein, and many others.



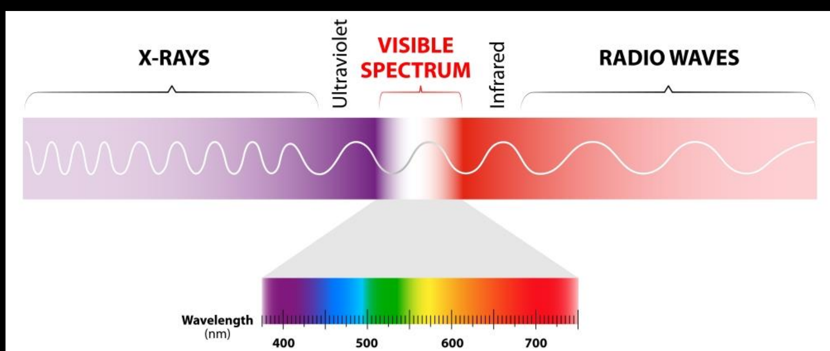
Research over the last 300 years has revealed that light is related to ***electromagnetism*** – in particular, light moves through the universe in the form of propagating ‘waves’ of electric and magnetic fields.



Red light = fewer waves per second, lower energy

Purple light = more waves per second, higher energy

All forms of light move at the same speed, but because they have different wavelengths, they have different frequencies and different energies – the longer the wavelength, the lower the frequency and energy of the light. Short wavelengths have more waves passing per second, and are more energetic.

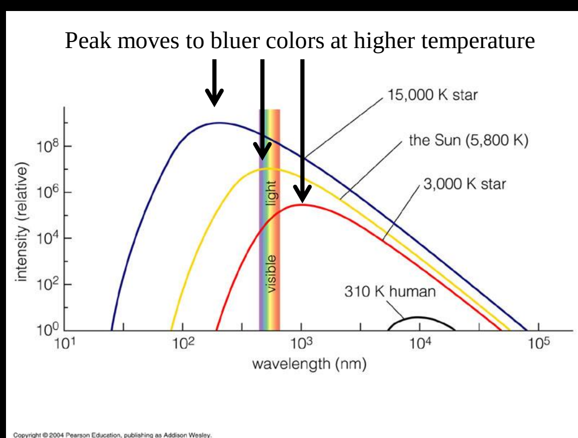


Most forms of light are 'invisible' to your eyes, which are only sensitive to a small range of wavelengths between about 400 and 800 nanometers. But many objects in the universe give off radiation at other wavelengths – short wavelength, high energy light like UV, X-rays, and Gamma Rays – and longer wavelength, low energy light like Infrared, Microwave, and Radio waves.

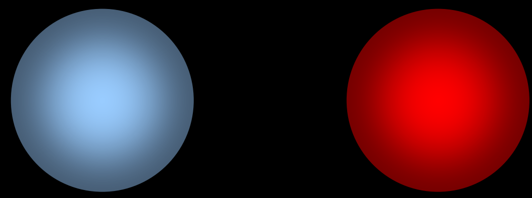
Image Credit – NASA Spitzer Infrared Telescope team

The light you see from most objects around you is *reflected* light, produced originally by the Sun or other visible light sources. But all objects dense enough to interact strongly with light – even you – *produce* light in the form of Thermal (or *continuous*) Radiation. This image shows the differences between the reflected light you see and the infrared light actually produced by ordinary things around you.

Examples of thermal or "continuous" ***spectra*** from objects of a few different temperatures. We'll see many such graphs in coming days!

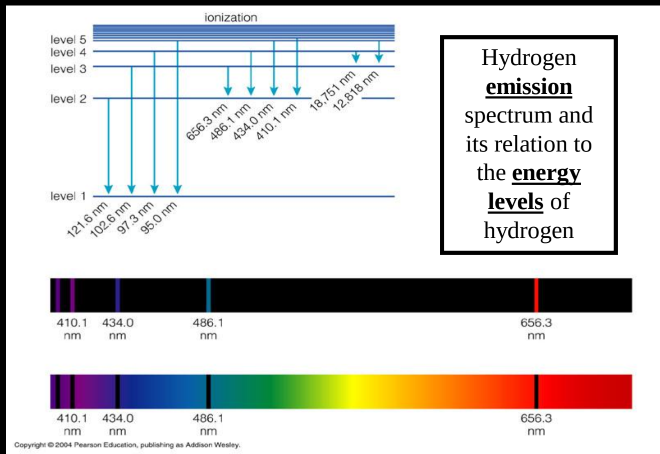


Hotter objects emit more light (per unit surface area) compared to colder objects at <u>all wavelengths</u>. Further, the 'peak' of light production from hotter objects lies at ***shorter*** wavelengths – and therefore at higher frequencies and higher energies!



So… just by looking at the location of the 'peak' emission of an object, we can tell something about that object's temperature – without ever touching it!

But there's more to this – it turns out that electrons in any atom respond in a predictable way to ***very particular*** energies. This means electrons in atoms interact preferably with some types of light, absorbing ***and*** producing photons of those energies. You likely saw this in a chemistry class at some point – heated gases produce different colors of light because of this effect.

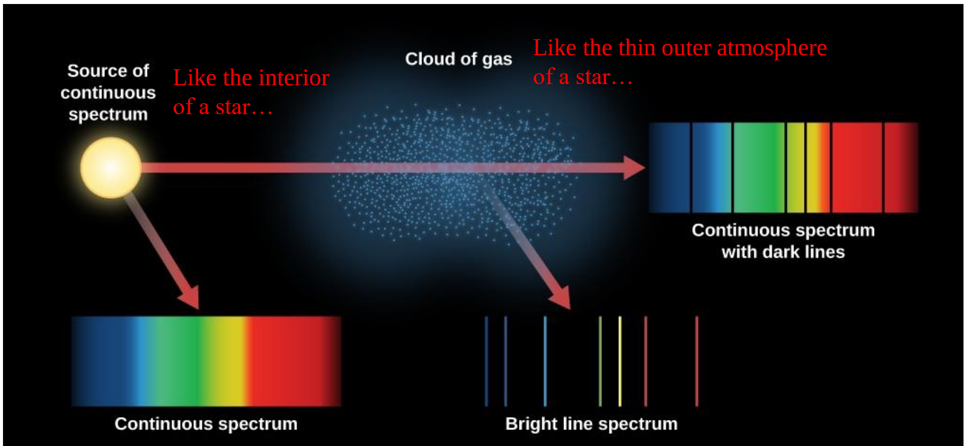


Hydrogen **emission** spectrum and its relation to the **energy levels** of hydrogen

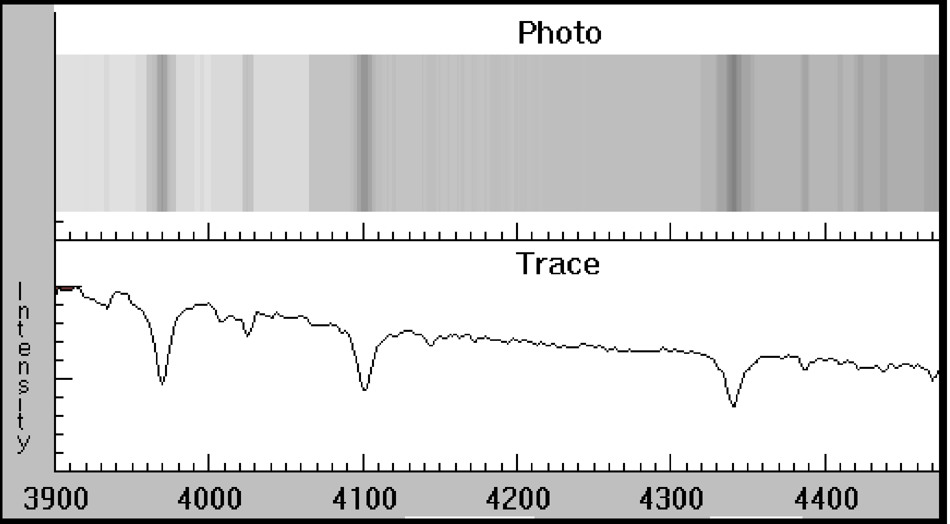
By carefully studying different elements here on Earth, in controlled laboratories, we can determine the unique pattern of energies – and therefore the unique wavelengths of light – that any particular atom or molecule will interact with.

Emission Spectra of Some Other Gases

Every element produces a unique "barcode" when exposed to light! How handy is that?!

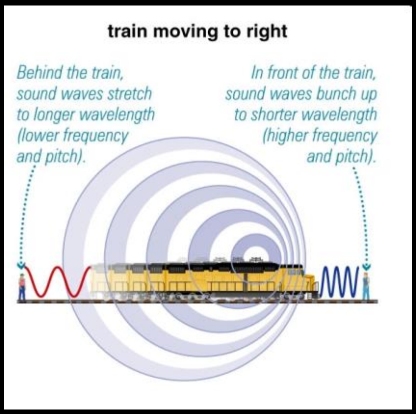


The physical phenomena that produce the two types of spectra we've discussed so far – opaque hot objects making thermal (continuous) spectra, and transparent, heated gases making emission (bright line) spectra – often interact to produce a third type of spectra, called absorption spectra.



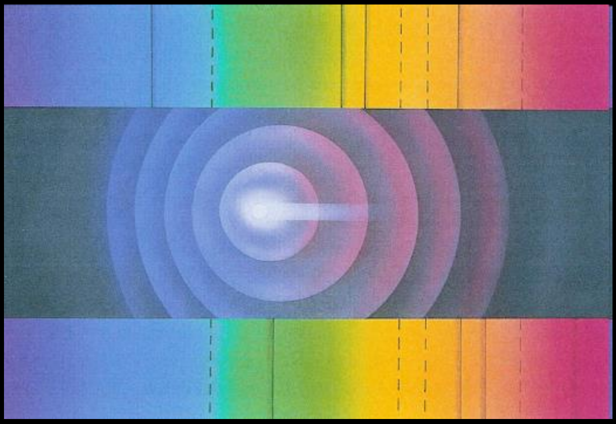
Two ways of looking at the same absorption spectra.
(The bottom image is ***extremely*** typical of modern astronomical data!)

Spectral Features and the "Doppler Shift"

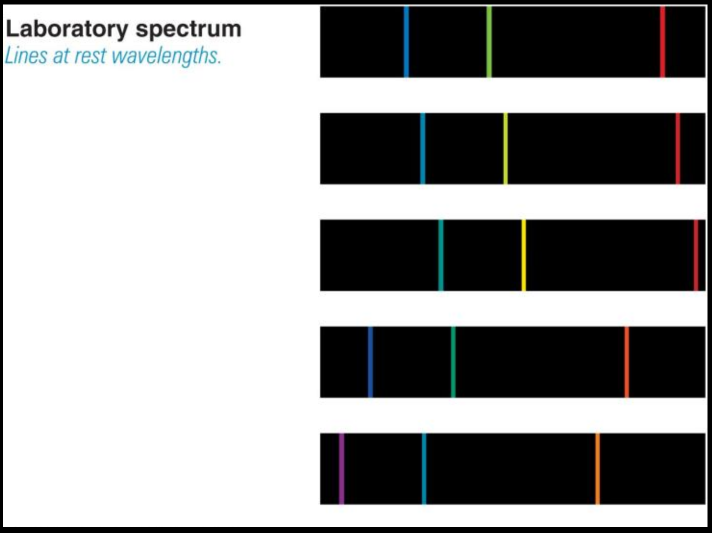


Doppler shifting of sound waves

Because light is a wave-like phenomenon, it shares some properties with other physical waves, like sound waves. A very useful property is that light waves are affected by relative motion between the source of the waves and an observer – the "Doppler Shift".



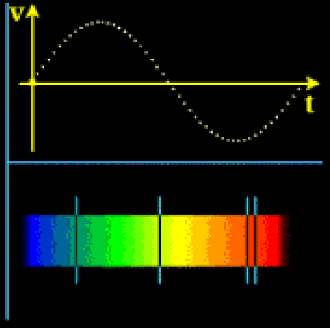
Similarly, light waves can also be "compressed" or "stretched out", changing the wavelength – and therefore the frequency and energy – of the light one observes coming from a moving object. That said, it takes quite a lot of velocity to get grossly visible changes such as the one illustrated above!



Most Doppler shifts are instead detected when the pattern of spectral features in an object – its absorption or emission lines – are shifted to the blue or red.

We've seen the Doppler shift in action already – it's how we measure the motions of stars to find their hidden planets!

Telescope on Earth…



…sees this sort of repeated, back-and-forth Doppler shift.

Measuring all this neat stuff about light from the stars requires specialized equipment – in the form of both ***telescopes*** and ***light detectors***.

The Two Major Telescope Types

Refractor

– focuses light using lenses

Reflector

- focuses light using mirrors
- used exclusively in professional astronomy today

Because they can be made much larger than refractors, all modern major telescopes are reflectors.

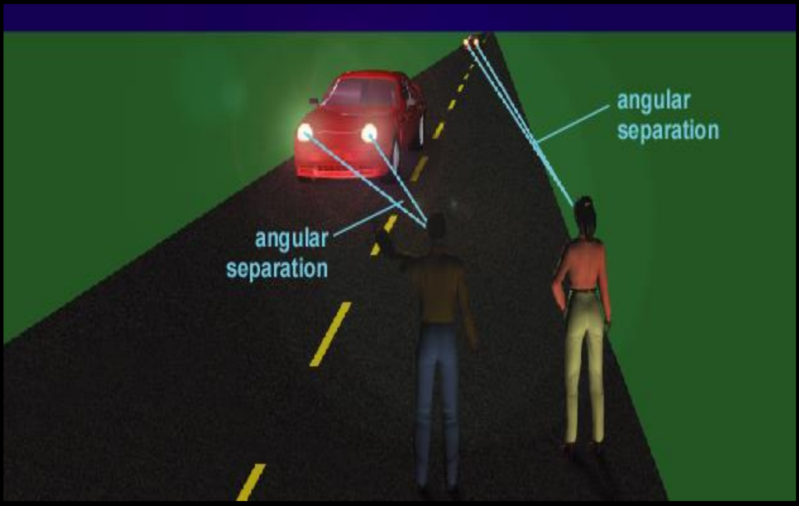
The Gran Telescopio CANARIAS, current holder of the "biggest mirror" title amongst optical telescopes, at 10.4m in diameter.

Why does size matter when it comes to telescopes?
What real advantages do big telescopes have over smaller ones?

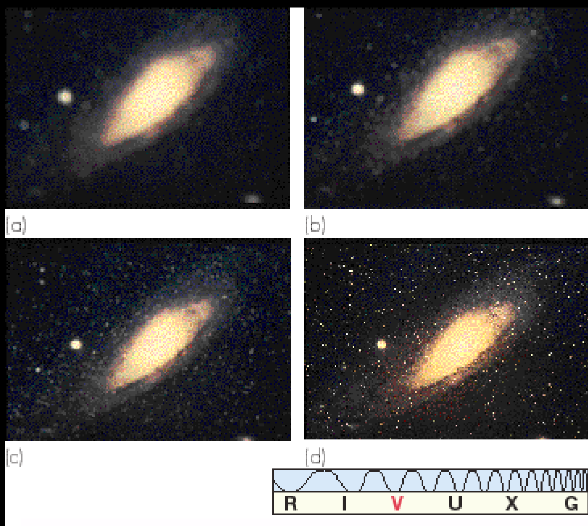
First, bigger telescopes have more "Light-Collecting Area" available. In general, all telescopes are like "photon buckets" – and because they are much bigger than your eye, the lenses or mirrors of telescopes gather many more photons per second than pass through the tiny opening of your pupil!

"I see better in the dark than humans coz' I got such freaky big eyes!!"

This means that telescopes with larger mirrors (or lenses) can collect ***more light*** in the same amount of time as smaller telescopes – as a result they can see ***fainter objects*** than smaller telescopes are able to.



The second advantage of telescopes is that they improve the ***Angular Resolution*** of images, a measure of the smallest angle (or level of detail) which can be detected.

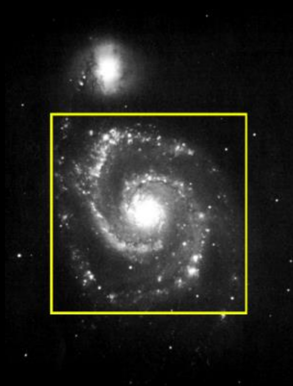


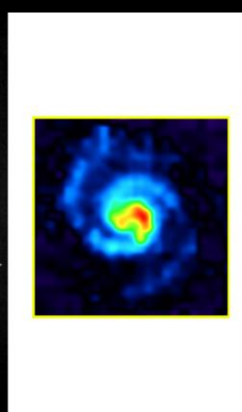
The Andromeda Galaxy, imaged at increasing angular resolution from (a) to (d)

The larger the main telescope mirror (or lens), the smaller this “angular resolution” is – that is, the ***greater the level of detail*** you can see! Note that this is <u>not</u> the same thing as greater magnification (which is more like “zooming in”)!

Furthermore, it turns out that the angular resolution of a telescope also depends on the wavelength of light you are looking at – for the same-sized telescope mirror, you get less detail at longer wavelengths, and equivalently more detail at shorter wavelengths.

Optical image from a ~ 5 meter telescope





Radio image from a ~ 45 meter telescope

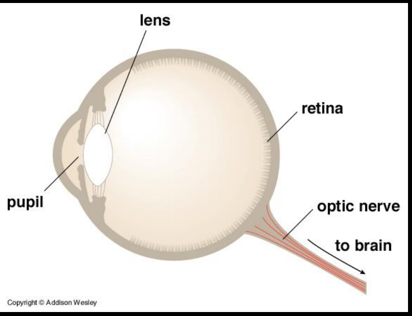
This is why Radio Telescopes are especially big!

The wavelengths of radio waves are long, so the dishes which reflect them must be very large to achieve any reasonable angular resolution! Fortunately they don't have to be as smooth as reflectors for visible light do, so they're much easier to build!

305-meter radio telescope at Arecibo, Puerto Rico – more than occasionally used in the movies!

But "big eyes" are only part of the story – the advantages of telescopes are enhanced by the use of modern light detectors.

Your eyes are pretty darn sophisticated light detectors, but the information they collect is effectively erased every 0.03 seconds or so – an important thing to do in a rapidly changing environment! But this means you can only ***see*** objects bright enough to make an impression on your eye in that short period of time!



Schematic of the Human Eye

The development of photography in the late 1800's allowed astronomers to take 'exposures' much longer than the 0.03 seconds their eyes allowed for. This permitted ever fainter, previously unseen objects – both near and far – to be discovered!

Daguerrotype Camera, ca. 1845

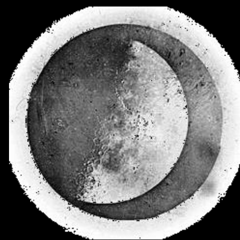
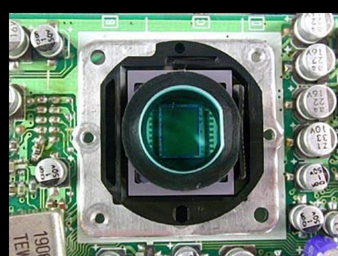
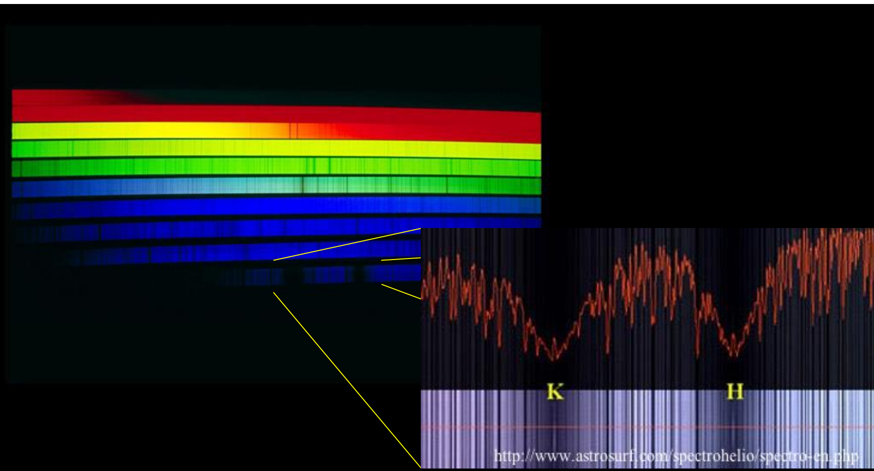


Image of the Moon by H. Draper, 1840

Astrophotography also made it possible to make precise, accurate, and permanent records of astronomical observations – allowing observations from different nights to be compared reliably.

Modern astronomical cameras look much like the CCDs (charge-coupled devices) in consumer digital cameras, using a grid of 'pixels' on a thin piece of silicon treated to interact with light. Each pixel in this 'film' records the number of photons that strike it during the exposure – and in a much more precise manner than photographic film.





Often we 'take pictures' of the emission and absorption spectra of stars and other objects, which contains a wealth of information that we've just begun to explore!

It's not always clear skies at Mauna Kea's Keck Observatory!

However, there's a big problem that we have not yet addressed – the fact that we take all of our images ***through*** the Earth's atmosphere! While it's good for breathing, the air causes a multitude of problems for astronomers on the ground – bad weather, for example makes it impossible to observe the night sky.