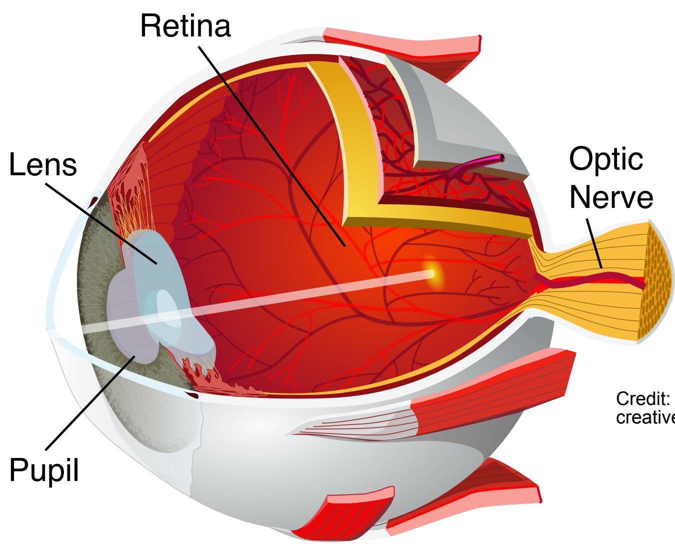
Yeah we all shine on,
like the moon, and the stars, and the sun.
John Lennon

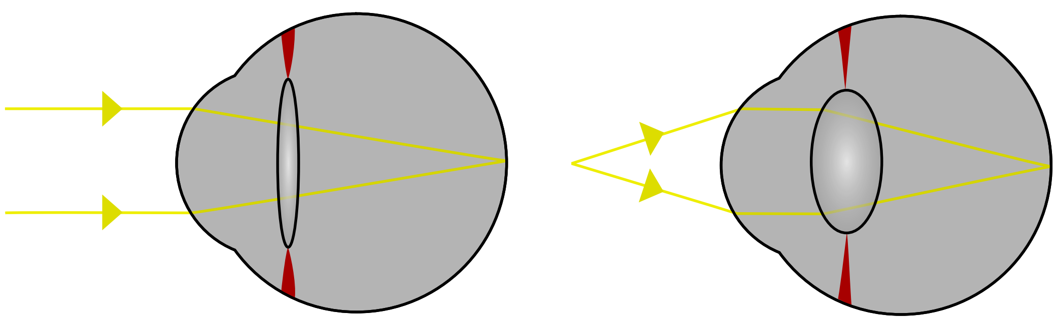
How We See

Hi AST 111/113. In this module we'll explore how astronomy has and does record the photons that come out of the barrel of a telescope.

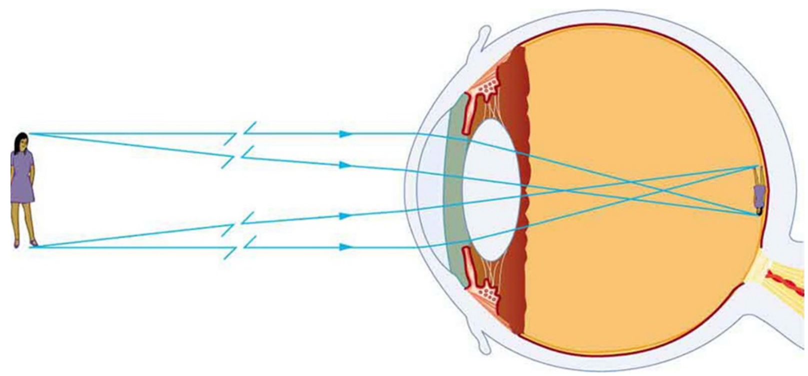


Credit: Wikipedia, creative commons

The human eye was the first astronomical detector. Your eye lens brings light to a focus on your retina. While being a relatively crude lens, your eye is attached to the most fantastic image processing system on the planet - your brain - which corrects for all kinds of stuff.



Credit: Wikipedia, creative commons



Credit:OpenStax, creative commons

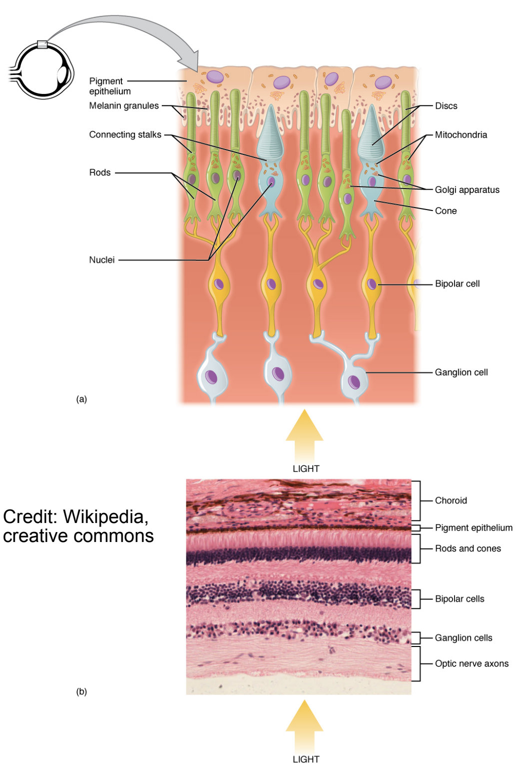
For example, your eye lens is adaptive, flexible. As shown in the first image above for more distant objects the light rays are coming in nearly parallel and your lens stretches into a thinner more elongated configuration. For more nearby images, the eye's lens takes on a squatter more compact configuration. The image processing system between your ears takes care of that. In addition, like any lens, the image that forms on the retina is upside-down. Like a shown in the second image above. Again, your image processing system comes to the rescue by inverting the upside-down image to right size the world for you. And of course with two eyes, two angles of view, the brain does a parallax calculation to give us depth perception, to give us the third dimension of our world.

This said, as an astronomical detector, the eye has several deficiencies. For every 1,000 photons that goes into your eyeball, only about one of them is captured. In other words, 99.9% of the light that goes into your eye is wasted. That's not good for astronomy because you work so hard and spend so much money to gather and control the captured light. You don't want any of it wasted.

Our eyes also sees in the optical only. It's good for us. But we don't see in the infrared. We don't see in the ultraviolet. We don't see in any of the other electromagnetic bands. That's bad for astronomy because other wavelengths often can say much more about an object.

Our eyes also have a logarithmic sensitivity. This is good for you because it allows you see in very dim light and in very bright light as your pupil opens and closes in order to adjust to the amount of eyes. But its not good for astronomy. What astronomy wants is a linear detector. So that if I double the number of photons going in, I double the signal going out. That's not what happens with your eye. You double the number of photons going in your eye, and you only see about a factor of 1.3 times brighter.

And, of course, your eye is no permanent recording device. You have to sketch what you see, which is what early astronomers did. Or you have to remember what you saw. Gasp.

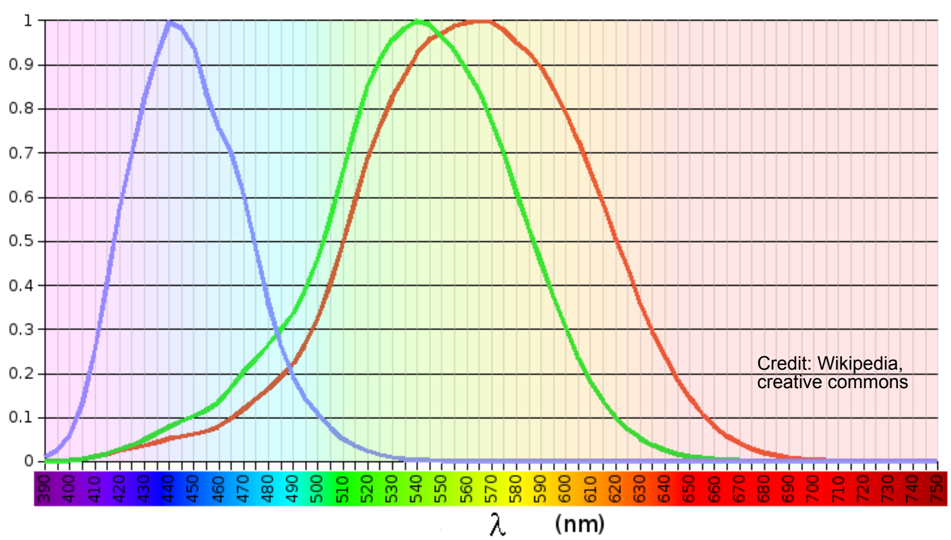


Credit: Wikipedia, creative commons

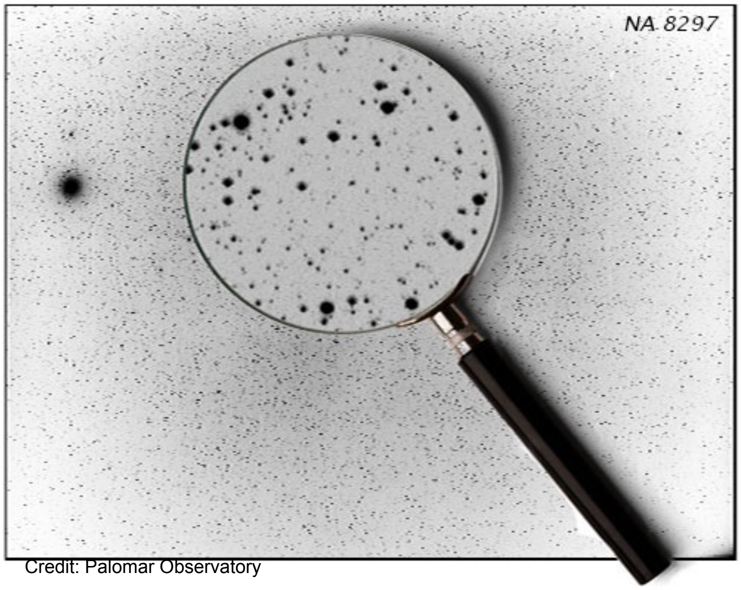
As small aside. On our retina what actually catches that 0.1% of the light coming are about 120 million rods and 10 million cones. Rods are sensitive to motion and dim light. Cones are sensitive to color. You can probably guess why from an evolutionary survival perspective why its advantageous to have many more rods than cones.

Your eye is also not an integrating device. Stare at an object for as long as you want, but the object doesn't get brighter. It stays the same brightness. That's because our eye's integration time is about 1/20 of a second. After 1/20 of a second it refreshes. This is why movies run at 24 to 30 frames per second, slightly faster than the eye's integration time. Although you know a movie is a just series of still images, it's run at a speed a little bit faster than what your eye can integrate. Therefore, motion comes across as a smooth. What astronomy wants though is an integrating device - the longer one looks the brighter is gets as it adds up the photons coming it.

Finally, the rods and cones in our eyes have relatively large pixel sizes, if you'd like to express it in the digital age. They're about a tenth of a millimeter or so, so they're relatively large. And the image there shows the response curve of the cones in the back of our eye.



Another small aside. Of those 10 million cones, about 65% are devoted to red, 33% to green, and 2% to blue. Our brain takes care of mixing to get all the other colors. Although we don't have many blue rods, they are the most sensitive of the ones, which is what the plot to the right shows.



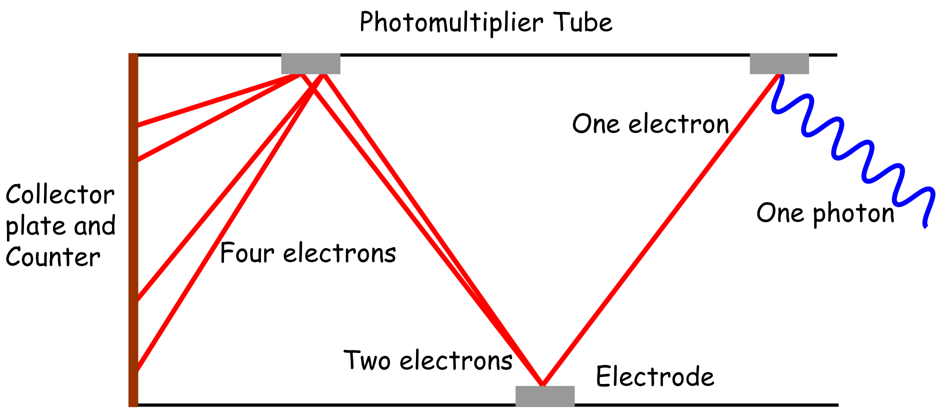
Credit: Palomar Observatory

Credit:Victoria Museum, creative commons

Astronomy's second detector was photographic, first glass plates (left image above) and then plastic film (right image above). This technological revolution came in in about 1840 or so. Now 1 in every 50 photons is detected. Better but still wastes 98% of the light. Film, of course, has the advantage of giving a permanent record. It is an integrating device. You can overexpose film! If you open the shutter long enough, the image will be all black.

The pixel sizes in photographic film are fantastic. They're on the order of the size of molecules, silver nitride, about 10^{-7} meters. If you're looking for maximal resolution, film is king. Although, as technology marches on, the pixel sizes of digital devices is getting smaller and starting to approach what film can do.

Film, unfortunately, is still a non-linear sensitivity. It's not as bad as your logarithmic eyeball. But it's still not linear. Film is also better in that you can capture infrared and ultraviolet wavelengths in addition to visual light wavelengths.



Credit: F.X. Timmes

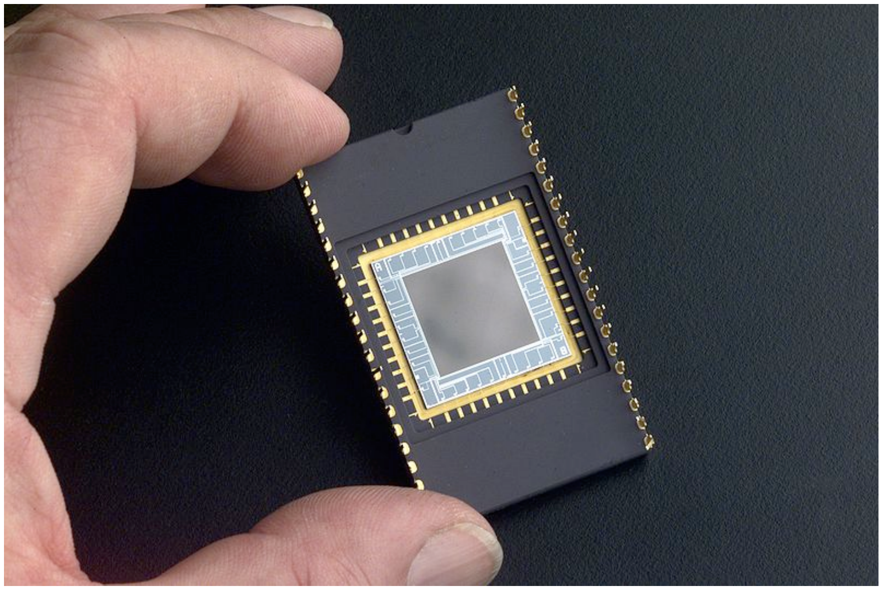
Credit: Wikipedia, Creative Commons

Astronomy's third detector was the photomultiplier tube, which came in circa the 1940’s. It's a better detector in that for every five photons that goes in, one of them is captured. So only now about 80% of the light is wasted.

How a photomultiplier works is shown in the image above. A photon that comes in with a certain amount of energy. It hits an metal electrode. Say there's enough energy in that photon to knock an electron off that electrode. There's also a potential difference, a voltage across the device. The freed electron now accelerates and hit another electrode. Since you've accelerated it, the electron has more energy. Now it can knock two electrons off that second metal electrode. And so on. You can multiply the number of electrons arbitrarily two, four, eight, 16, whatever it happens to be. Ultimately, these freed electrons hit your collector plate where you count how many electrons you got. Finally astronomy has a linear detector. If you double the number of photons that go into the tube, you double the number of electrons coming out. Hurray!

A photomultiplier gives a permanent record. and it's an integrating device. Like Ffilm you can over expose it.

A disadvantage of a photomultiplier tube is that it's a point detector. You're essentially taking a very thin tube and getting one pixel. So if you want to make an image of something, you have to sweep the photomultiplier tube across the object You have to move the photomultiplier tube in order to build up an image. And that takes some time.



Credit: Wikipedia, creative commons

Astronomy's fourth detector came in the 1980s. And that's the Charge-Coupled Device, the CCD. Each pixel in a charge-coupled device acts like a miniature photo multiplier tube. The principle of operation is similar; a photon goes into one of the cells of the CCD. It multiplies the number of electrons that are coming off the silicon. Those electrons and collected and then counted.

CCDs are fantastically efficient devices. They only waste about 10 percent of the light going in. So for every 1.1 photons coming in, you capture one photon. They are also linear detectors; double the light doubles the electrons collected.

They are, of course, digital. So that comes with a price tag. Now you have to have some fancy electronics to create and read those images. And the pixel sizes, as we mentioned above are starting to approach that of film photographic film.

What will astronomy's next detector be?!

Shine on! Bye Bye.