Illuminating the Future: The Arrival of Solid State Lighting

Science and Technology Council Presentation

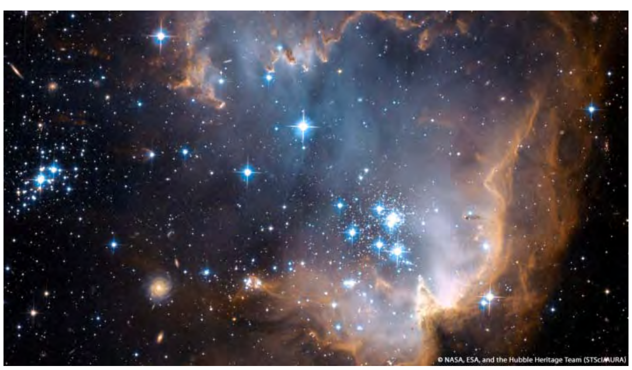
May 22, 2010

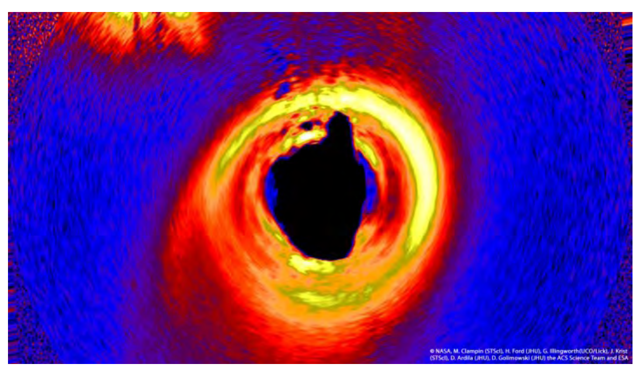
The Science of Colour

by

Jonathan Erland

We’re looking at the birth of stars. These are images from the Hubble and Herschel space telescopes and they're showing us a time and place very close to the beginning of the universe, and we’re very grateful to both NASA and the European Space Agency for having them.



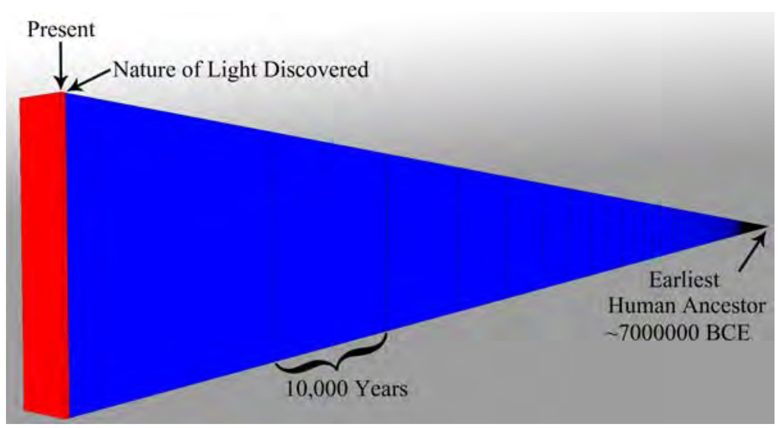


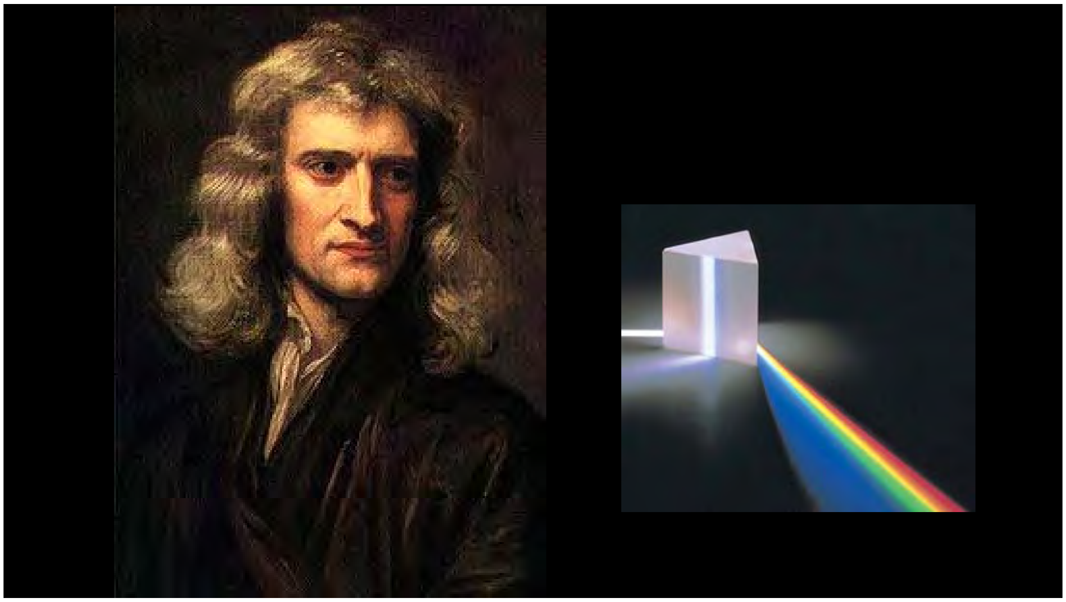
We’re seeing energy in the form of electromagnetic radiation: The stuff of life.

The essential ingredient of actinism, of photosynthesis. Energy, transformed and translated from one form to another in a roiling, boiling universe.

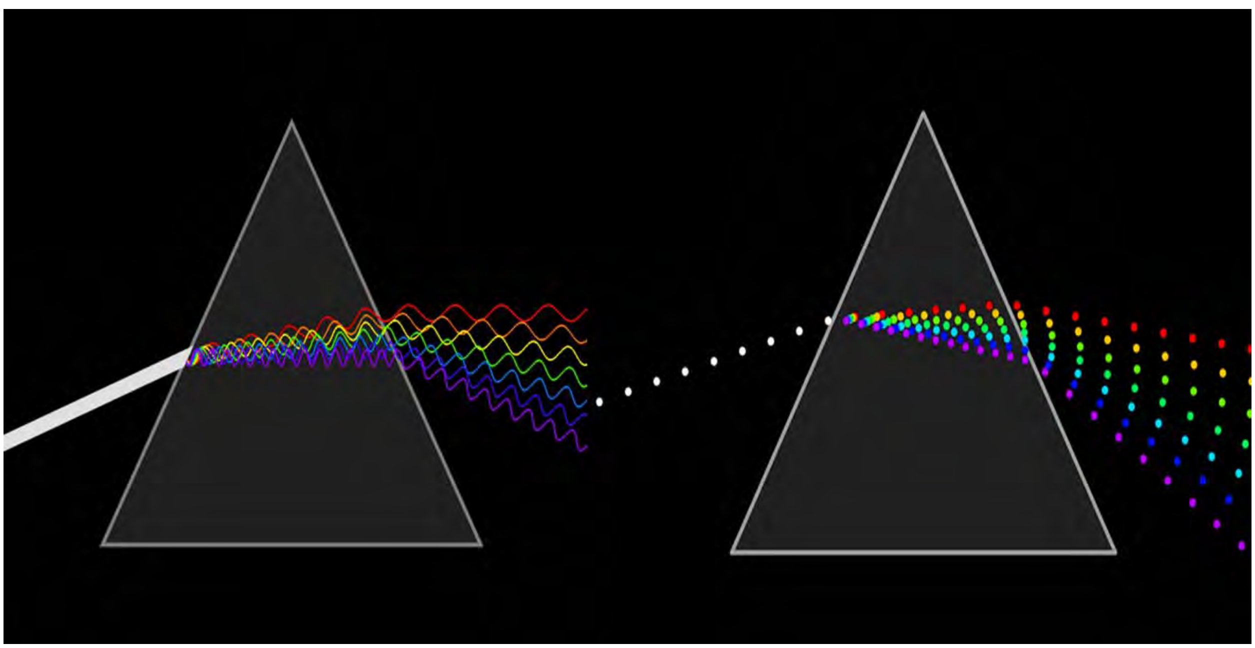
Responsible for everything there is, that we are, or can see or touch.

It's astonishing, given humans have been around for some seven million years, that it's only been for the last hundred and sixty five years that we've comprehended this. Seems we just woke up in time to say goodbye. By the way nothing in this discussion represents an official Academy view. This is my very personal perspective on the subject of human vision.





The portion of all this radiation that we call “light” was described in some detail by Sir Isaac Newton some three hundred and fifty years ago.



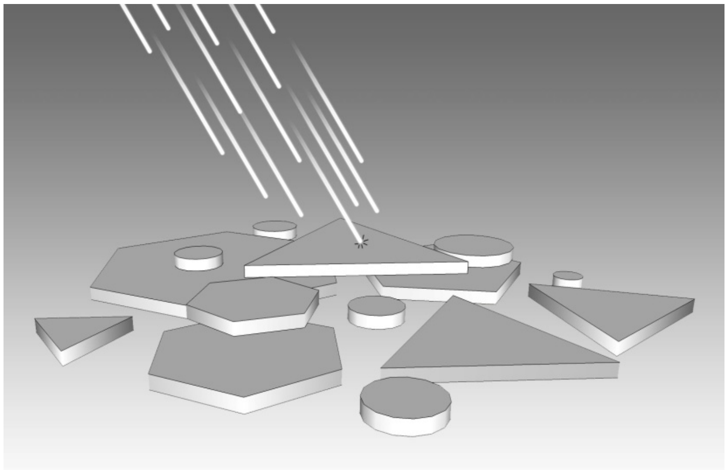
Newton argued that light is composed of particles or corpuscles and today we’ve adjusted to light being simultaneously a particle and a wave. And it needs to be both for us to understand how it works for us.

Light performs an “actinic” function. Which means it causes a chemical reaction . . .

Indeed, a photochemical reaction. A particle of light, a “photon” will fall upon the leaf of a plant, be absorbed, and through “photosynthesis,” allow the plant to perform most of the chemical functions it needs to grow. We do the same thing when our skin absorbs light to form Vitamin D. In our art form that same light particle or “photon” creates the images without which we would be, well, - radio theatre.

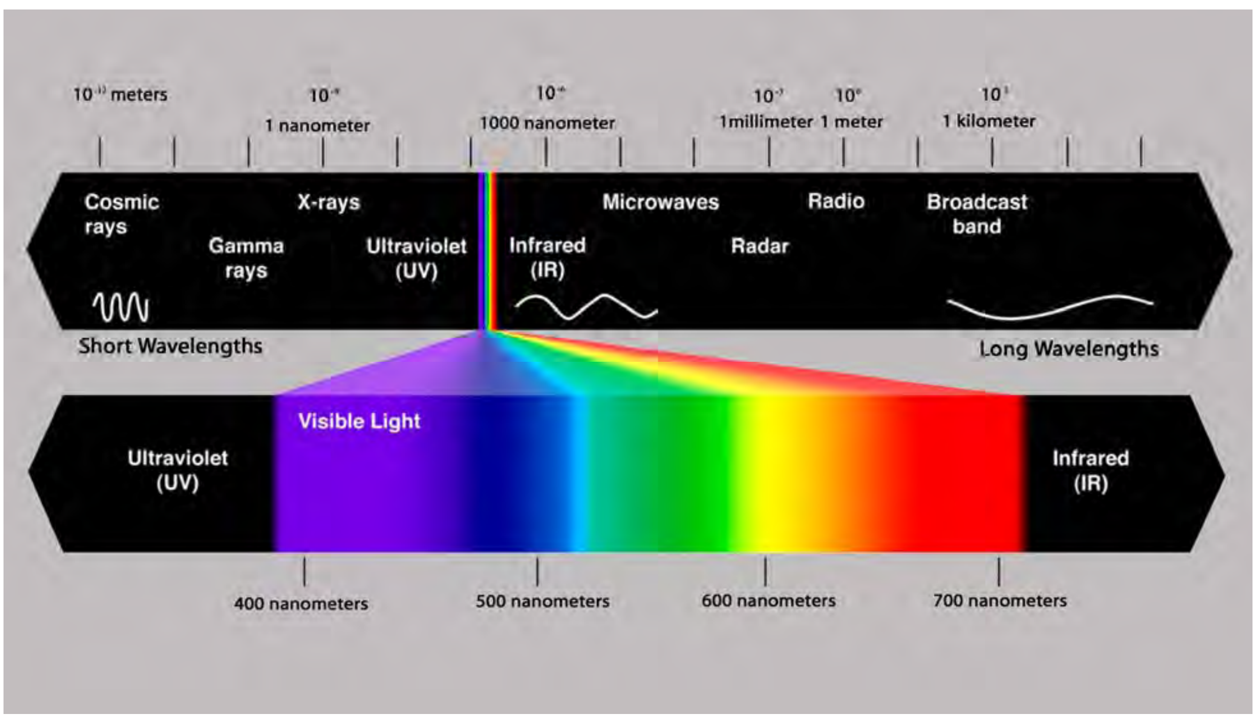
In our case the photon has bounced off Ingrid Bergmans face and made a bee line for the camera lens and onto a silver halide film emulsion.

Landing on a silver halide crystal it magically becomes an electron (photons and electrons are very, very close relatives) and adds its weight to others causing the crystal to change its “energy state” and become “exposed,” another actinic function.



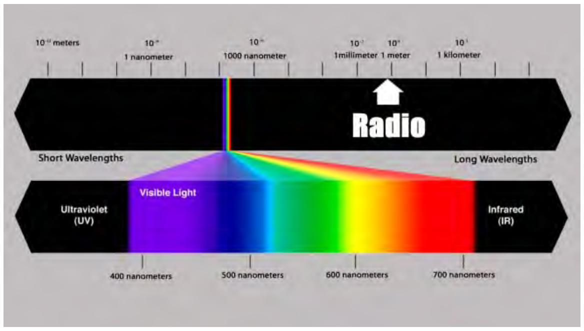
At the time of “Casablanca” that little phenomenon was all that was needed. That’s because this 1942 Warner classic was a Black and White film. With colour films it got a little more complicated than that but we’ll come back to colour film in a moment.

Right now we need to perform the admittedly tricky task of thinking of our “particle” of light as a “wave” that is both “undulating” and “vibrating” at different rates.

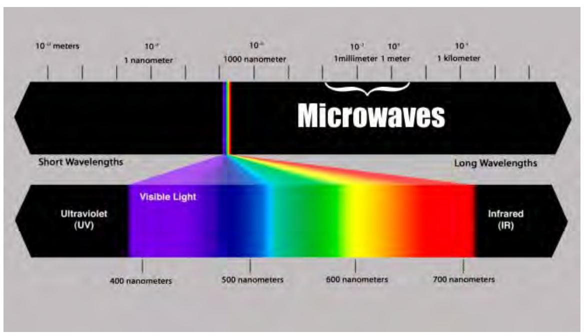


And the range of these wavelengths is astonishingly huge, from as long as the universe to smaller than an atom.

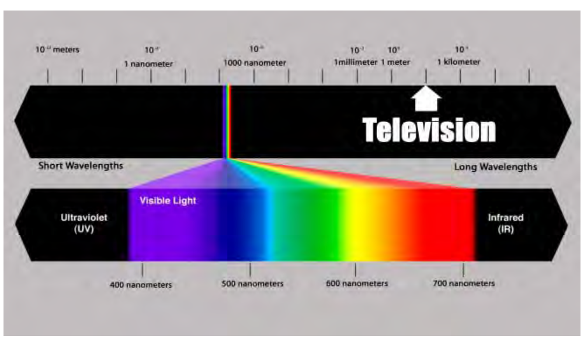
It encompasses heat, over here,

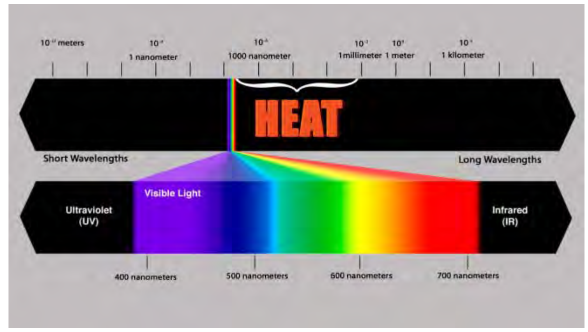


over here we find x-rays that make pictures of our bones,

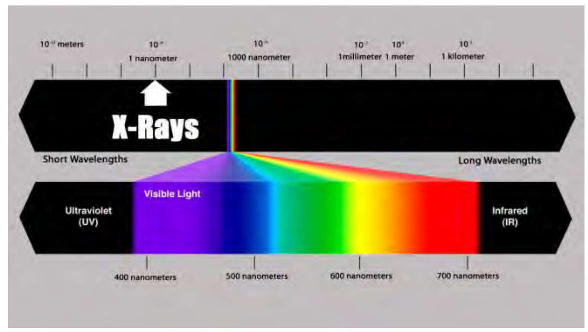


Your cell phone is here,

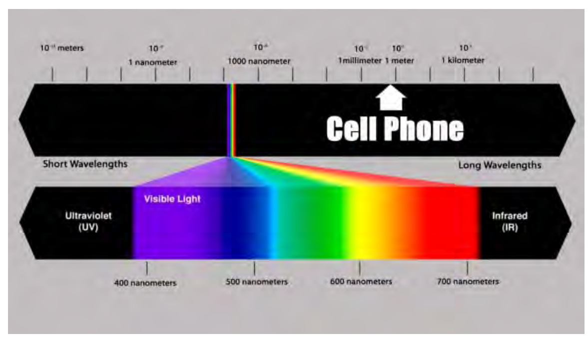




and radio waves here,



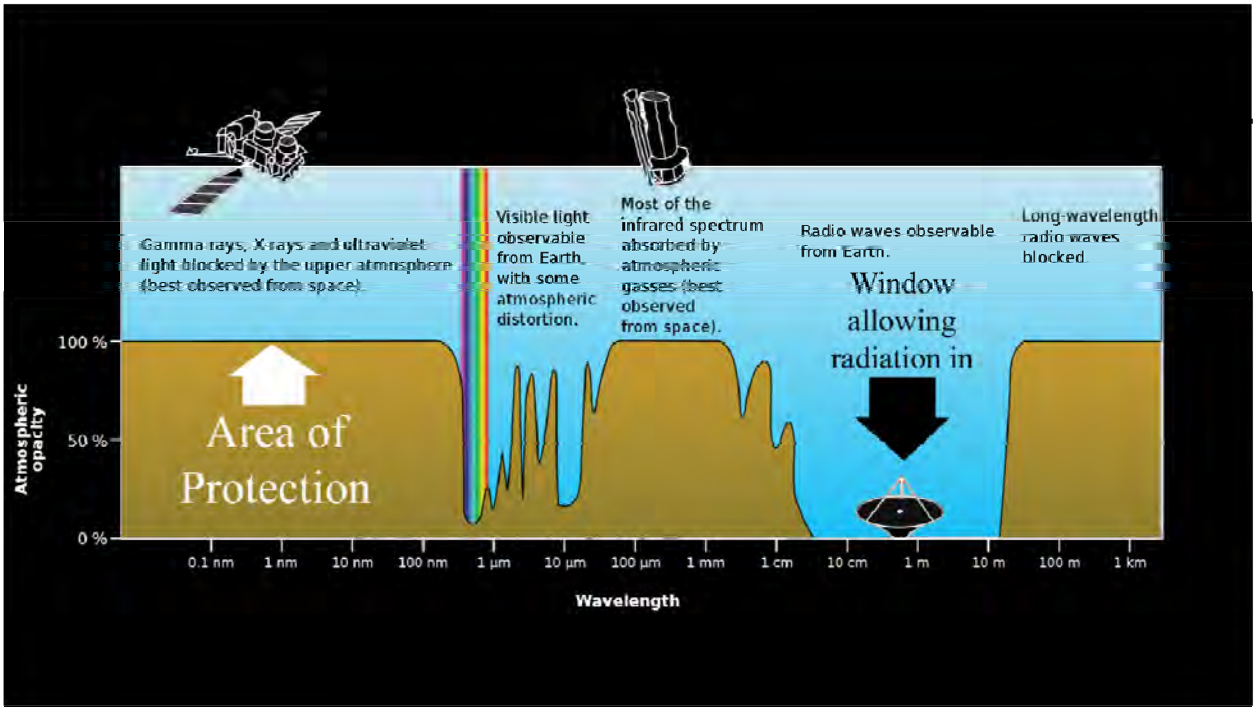
here is where we micro-wave our food,



television and so on.

In short a very busy “spectrum” of electromagnetic radiation.

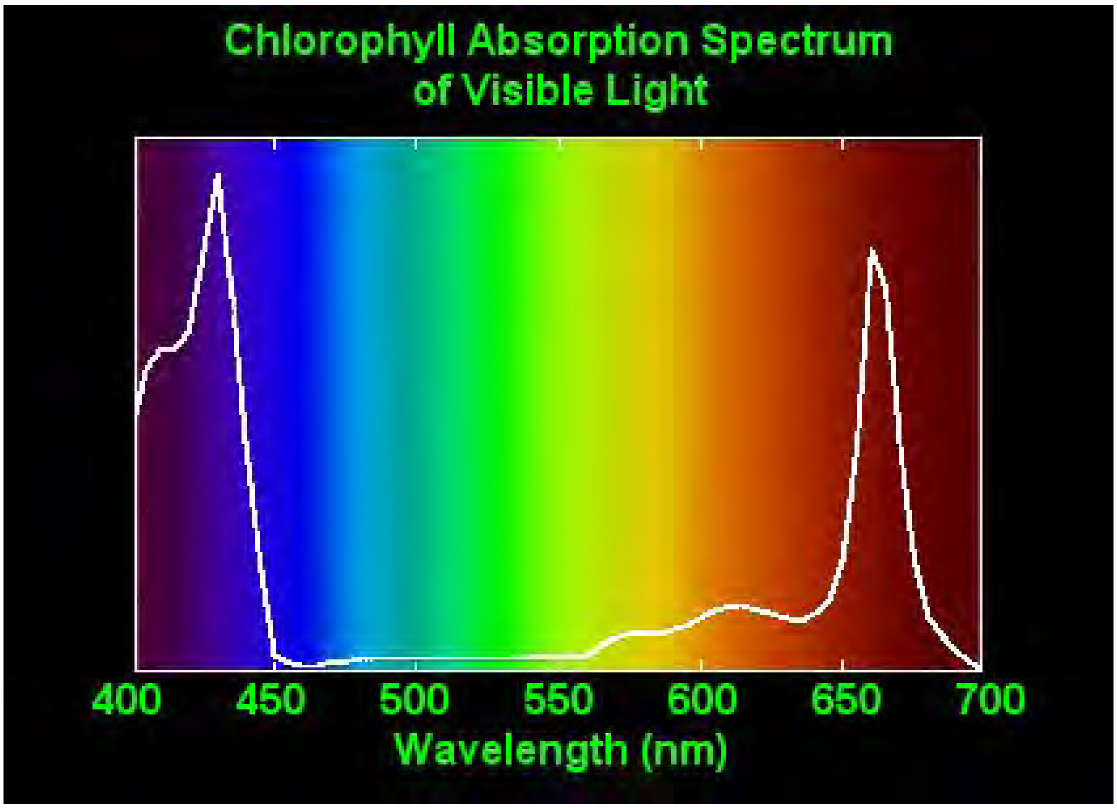
Fortunately for us, the full range of the radiation that permeates the universe never reaches us here on the surface of the earth because it's blocked by our atmosphere.



That's a very good thing, because some of the actinic reactions that would occur would be literally lethal to us. Here we can see areas where we're protected and some of the windows in our atmosphere that let radiation in. The fact that we humans can exist at all depends upon a myriad set of very precise circumstances with little tolerance for deviation.

So the radiation that reaches us is accomplishing a lot of work.

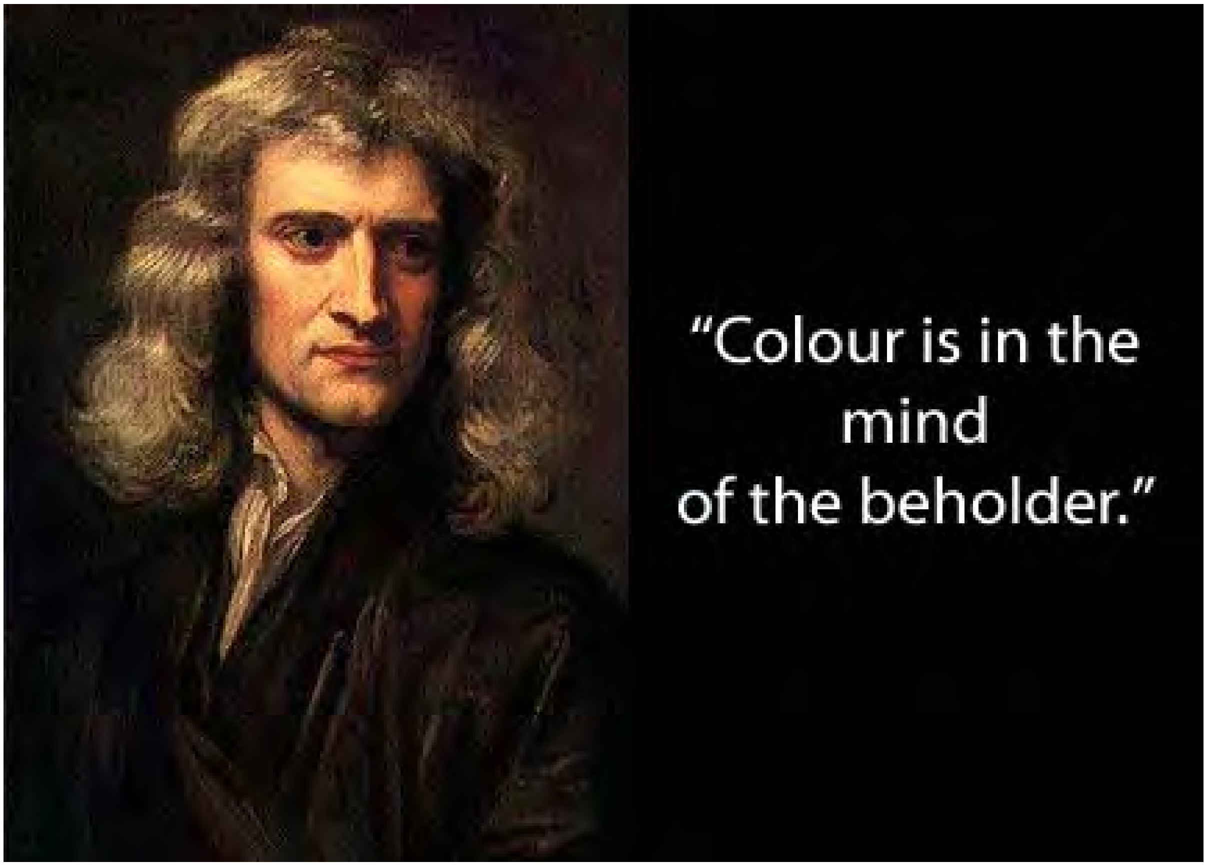
The leaf we mentioned earlier that's using this radiant energy is also quite selective about which of those wavelengths it's going to use. And there's a clue about which wavelengths that's immediately apparent. The leaf is almost always green, to us.



The Green, which is Chlorophyll of course, corresponds to certain wavelengths around five hundred to five hundred fifty nanometers. Those are wavelengths the leaf doesn't actually want. So it reflects them away, which is why we see them. What it really wants, it absorbs and doesn't reflect, and so we don't see those wavelengths when we look at a leaf. Those wavelengths, of course, are the opposite of Green, in other words, Magenta, a combination of Blue and Red.

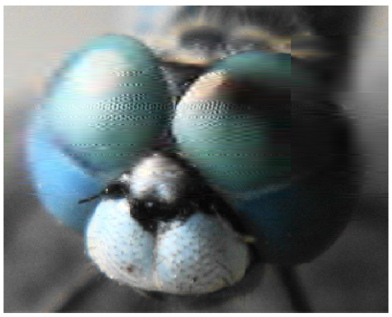
Which is why your “grow light” is a Magenta colour. To us. I keep saying, “to us” because, of course, the leaf doesn’t know it’s Green. It doesn’t know colour at all. In fact, out here in the world and universe surrounding us, there is no colour.

I have no less authority than Sir Isaac Newton for my being able to say, “Color, like beauty, is in the mind of the eye of the beholder.”

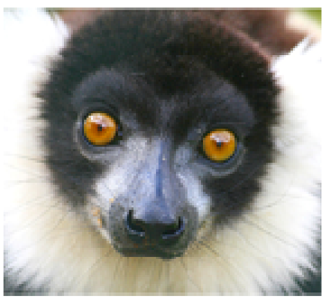


Because the only place color exists is in your mind, as a sensation, an interpretation of the radiant energy your eyes detected.

Ah, the Eye.
That's the other astounding thing this is all about.

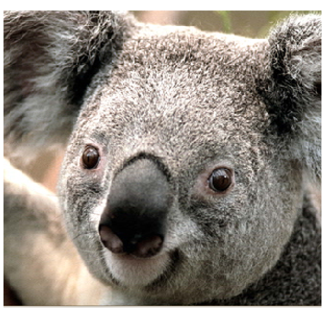


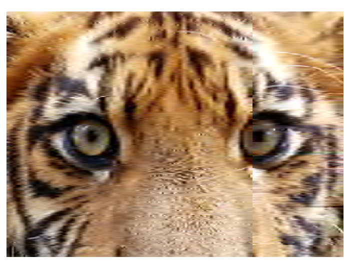
Eyes and the tiny sliver of the vast electromagnetic spectrum that the eyes can work with.



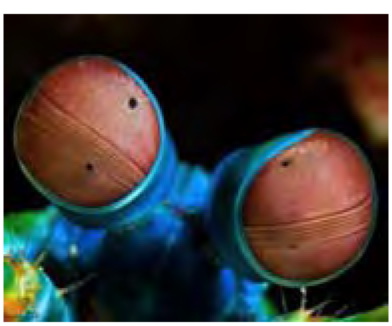
And there are many of them.

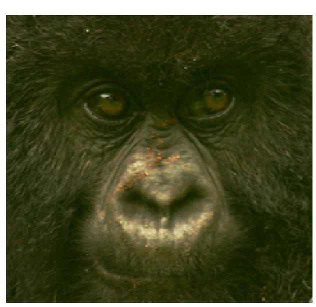
Most of our fellow inhabitants of this planet have some form of eye.





And we all see the world quite differently.





We've all heard how a Red rag infuriates a bull. Really? Anybody ever ask the bull about that?

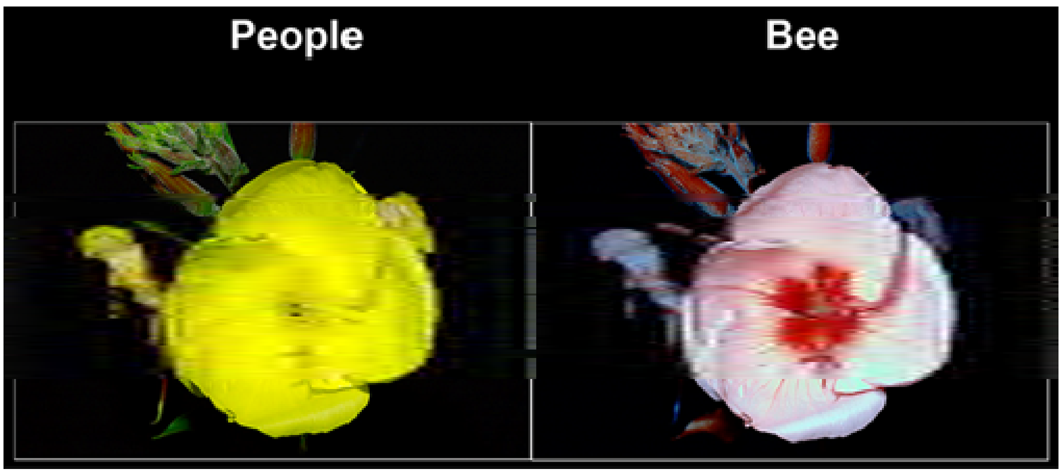
Well, this is how we see the scene in the bullring,

and here's how the bull sees it.

Quite different.

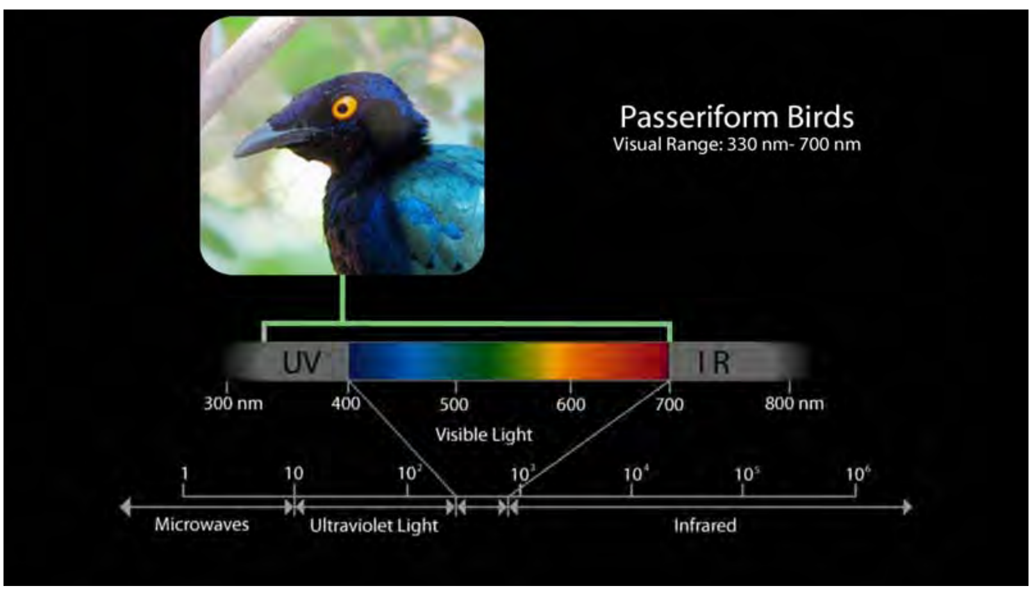
.

And here is how a cat sees the world,



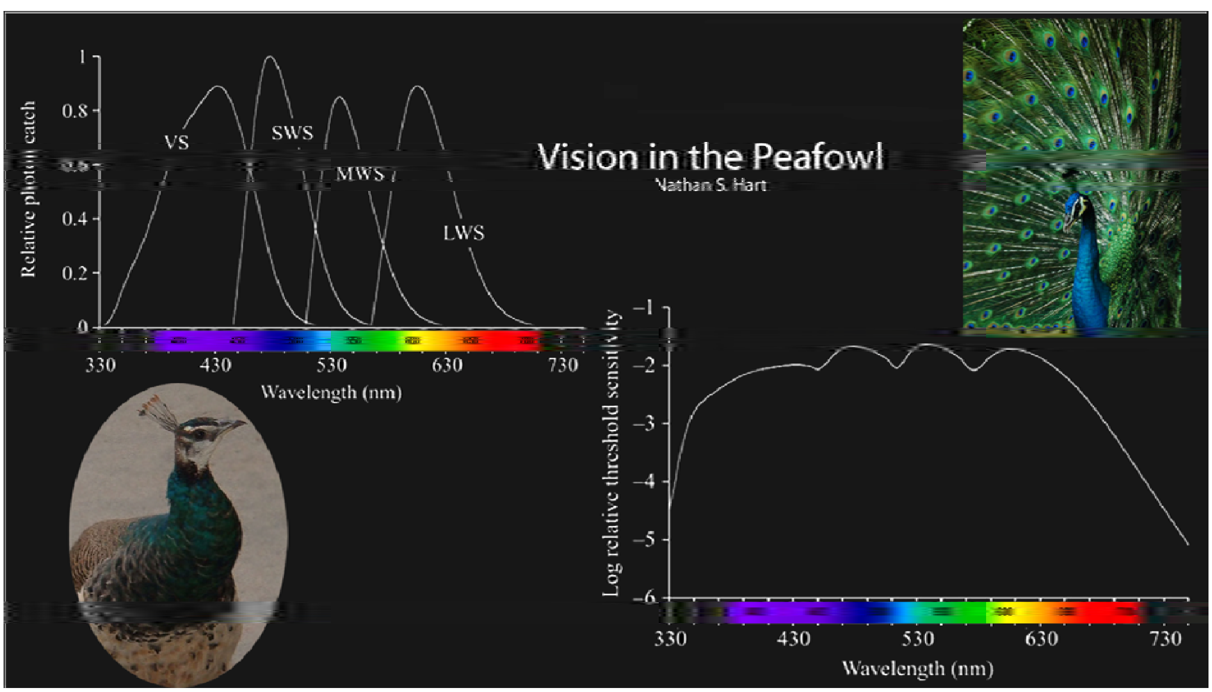
A bee,

This is the range visible to a bird.

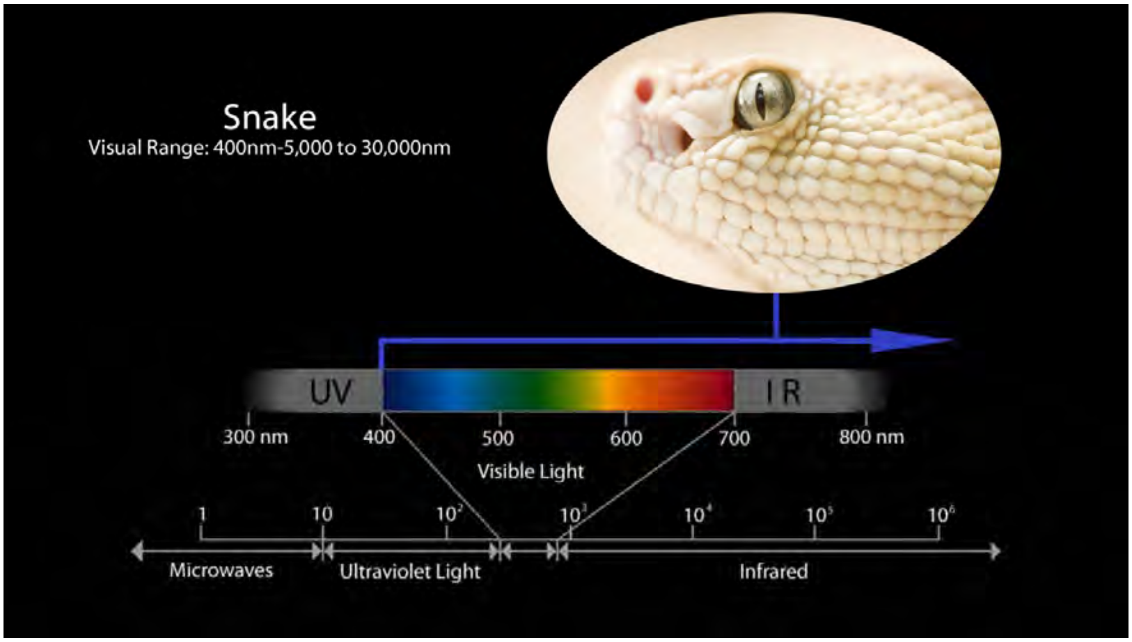


We’re impressed by the colorful display a Peacock can present when courting,

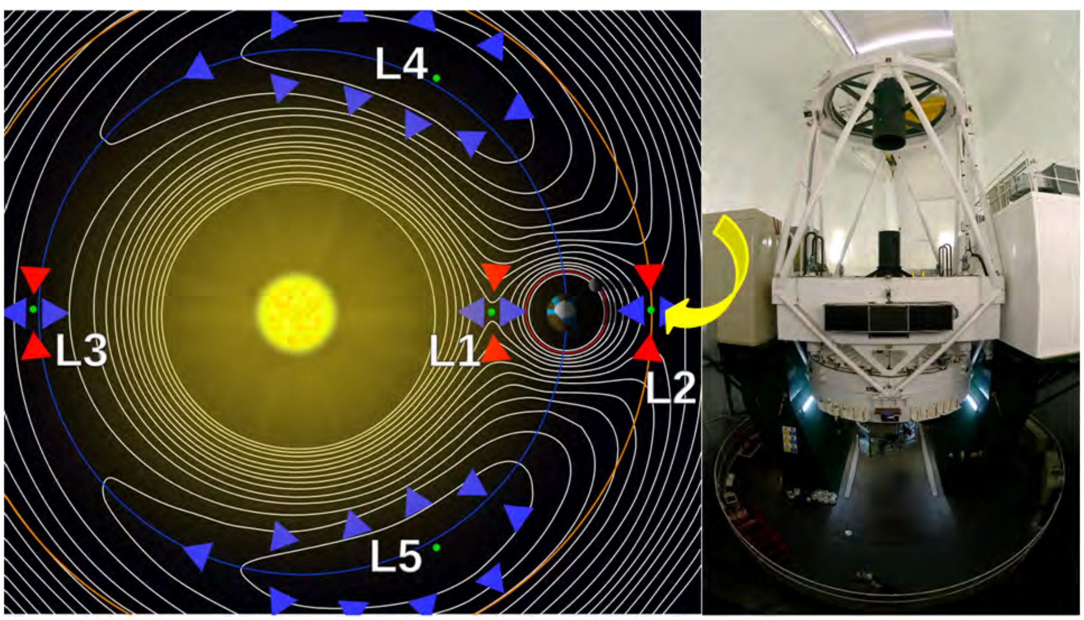
so how does it appear to the peahen? Well, we humans can eat our hearts out, because it turns out she probably gets a much better show than we do. The cones in a peahen’s eye, and she’s got four types instead of our three, can discern wavelengths from 330nm to 740 nm.



And those Hubble and Herschel images we were just looking at?



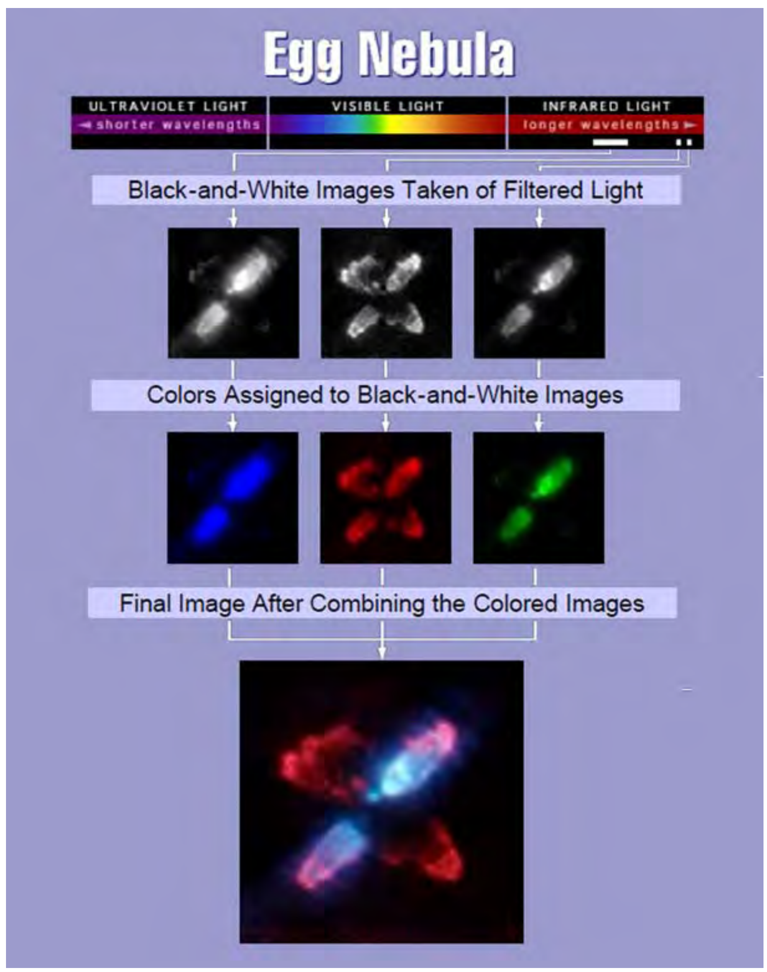
Of all the creatures including us, only a snake could probably see them directly, and the snake would have to be in space to do so. That's because the snake sees very deep into the infra red portion of the spectrum and our atmosphere interferes too badly for the snake to "see" through it.



The Herschel telescope, in orbit some nine-hundred and thirty thousand miles in space, far beyond the moon, is designed to see deep into the infra red, an area that would appear completely black to our unaided vision.

It was named after the astronomer Sir William Herschel who discovered infra red. He was also a photography pioneer and gave us the photographic terms "positive" and "negative."

Anyway, we can "see" what the Herschel scope can see because we transpose the images it records from infra red to our more familiar visible spectrum so that our eyes and our minds can work with.



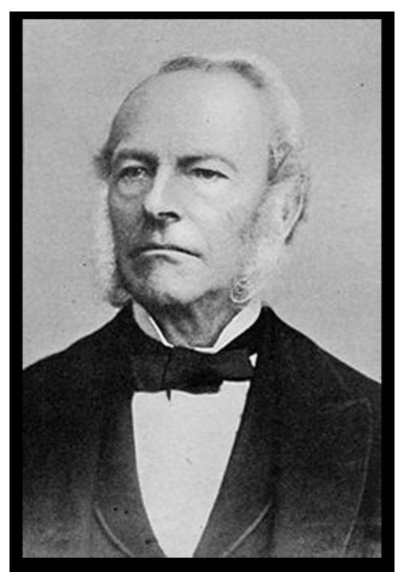
These Herschel images show us the birth of stars. Our solar system, our planet, was created just this way, out of what's called "space dust" though I prefer the term "Stardust."

Everything was made from stardust. And if, at the time of the Garden of Eden, the atmosphere was not so opaque, that snake may have been able to look up at the stars, and back through space-time and actually observe the birth of the universe, while Adam and Eve could not.

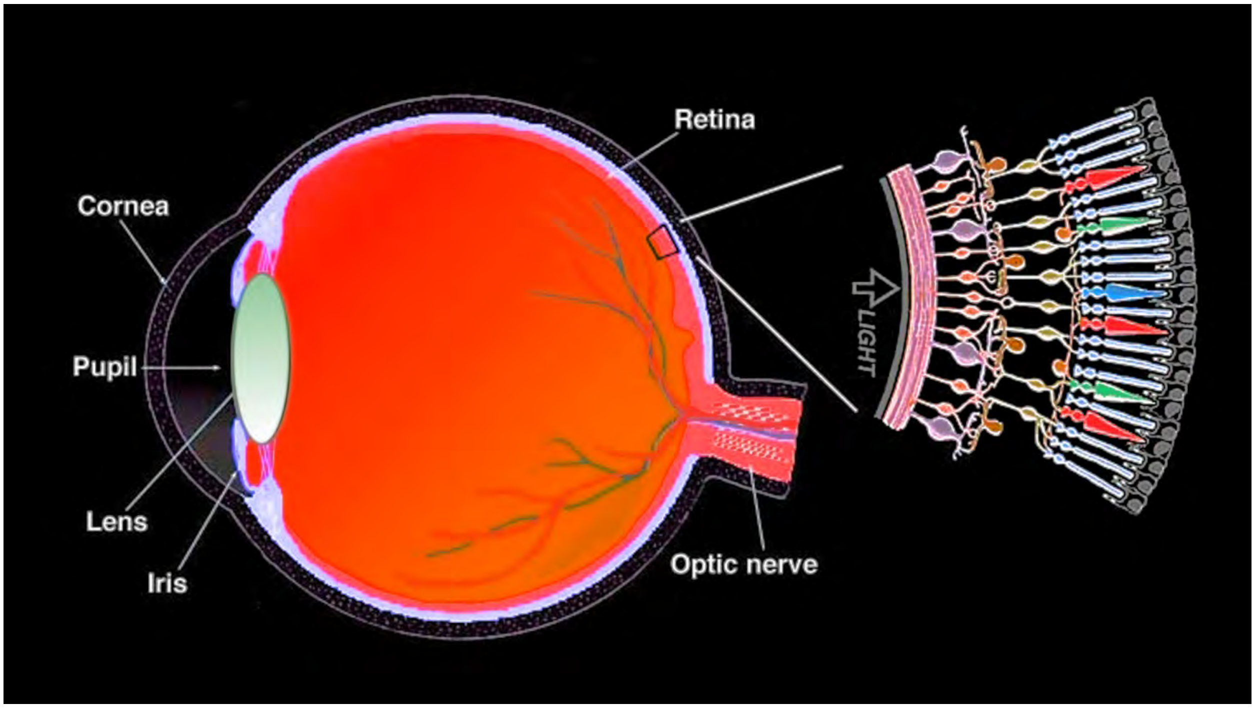
The transfer of energy from one wavelength to another happens in nature, by the way. Among the actinic, or photochemical reactions that occur is fluorescence. Where light energy is absorbed and then re-emitted at a longer wavelength.

The famous “brighter than white” laundry detergent ad is referring to the fact that “optical brighteners” or fluors, have been added to your clothes. Day-Glo colours work this way.

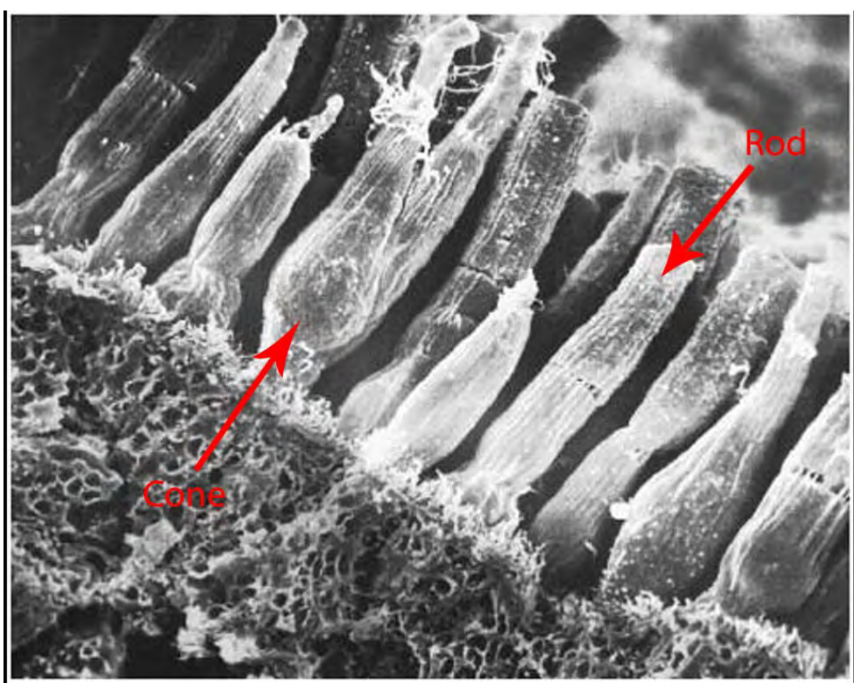
It’s called the “Stokes shift” after the discoverer of the phenomenon of fluorescence, Sir George Stokes, a contemporary of James Clerk Maxwell and Lord Kelvin. We’re still trying to comprehend it completely but the process can cascade down from higher to lower frequencies, absorbing, releasing, re-absorbing and building energy like a snowball to produce - well, the familiar emergency clothing like this.



It may be awhile since some of us last looked at this,

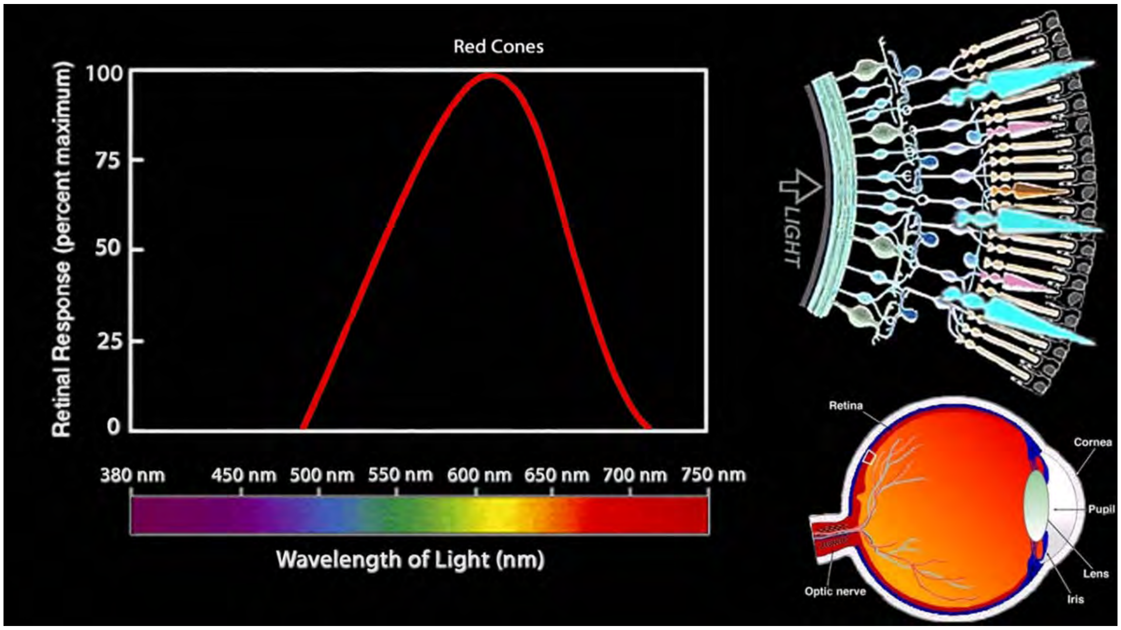


…so we'll very briefly review some of how the eye does the wonderful job of enabling us to experience colour. Note, I didn't say "see colour" because there's none to see. So in this view of an eye, we can see that light travels into the eye via the lens and is focused onto the retina. The retina, we recall, contains rods and cones, the actual sensors of light.

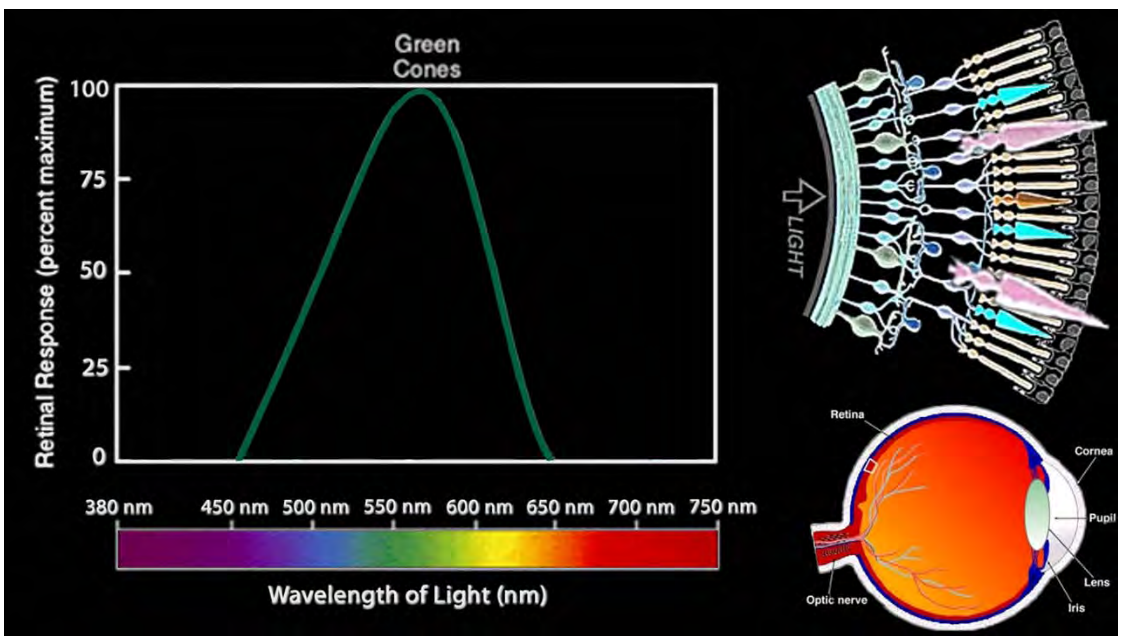


The rods work mainly at night or in dim light and don't help with colour, but the cones are what interest us.

Recall the discussion about the green leaf using chlorophyll to enable it to absorb certain wavelengths of light? And reject others? Well, the cones in our eyes contain pigments that do the same thing.

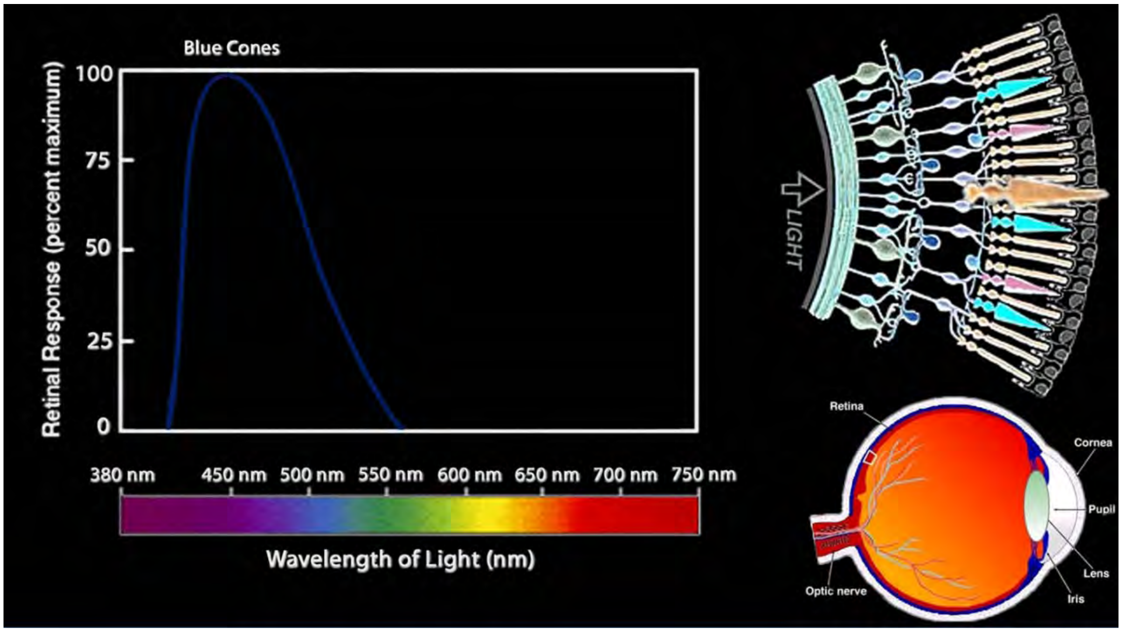


Thus some cones select this region of the visible spectrum which we'll label Red (inferentially a Cyan pigment).

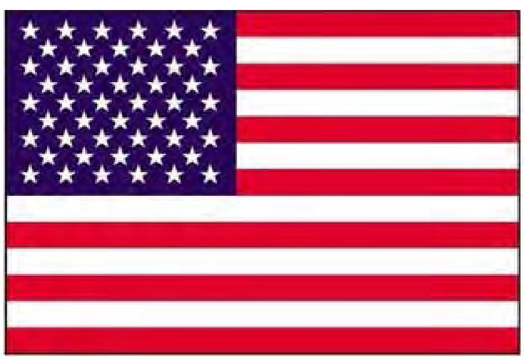


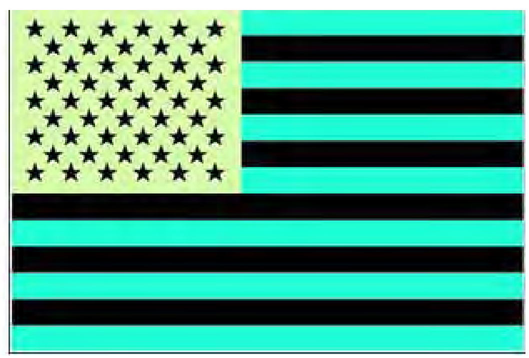
..

Others, the Green (inferentially a Magenta pigment), and still others,



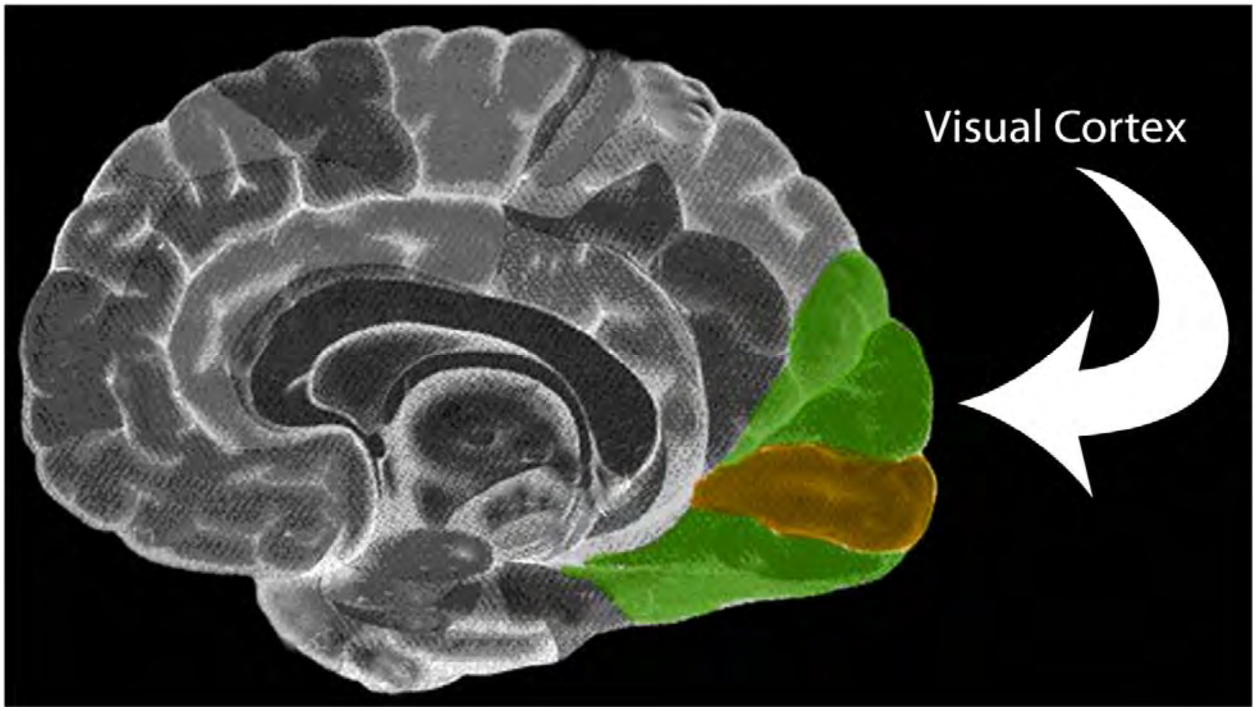
the Blue (inferentially a Yellow pigment). This process is a little difficult to study, as it's an actinic photochemical reaction; the eyes pigments are actually consumed in the process of detecting the light, and have to be constantly replenished.





There are parlor tricks like staring at the U.S, flag for a minute and then looking at a blank white surface, where you will see the colours inverted because the cone pigments have become exhausted, red becomes green, etc.

All these signals are conveyed to a section of the brain called the visual cortex where they are processed by the Grandaddy of all da Vinci Color Correctors and, viola, you enjoy the experience of colour!



And because of the particular construction of your eyes and your brain you can experience literally millions of colours, possibly ten million of them. (And remember the pea-hen? With her four cones? How many more millions of colours can she see? We poor humans will never know, it's beyond our comprehension.) But it's all in your head, mind, out in the world there's nothing but a vast array of radiation emitted by the sun, being bounced around and off of things, some absorbed some not until this jumble of radiation at different wavelengths enters your eye to be decoded.

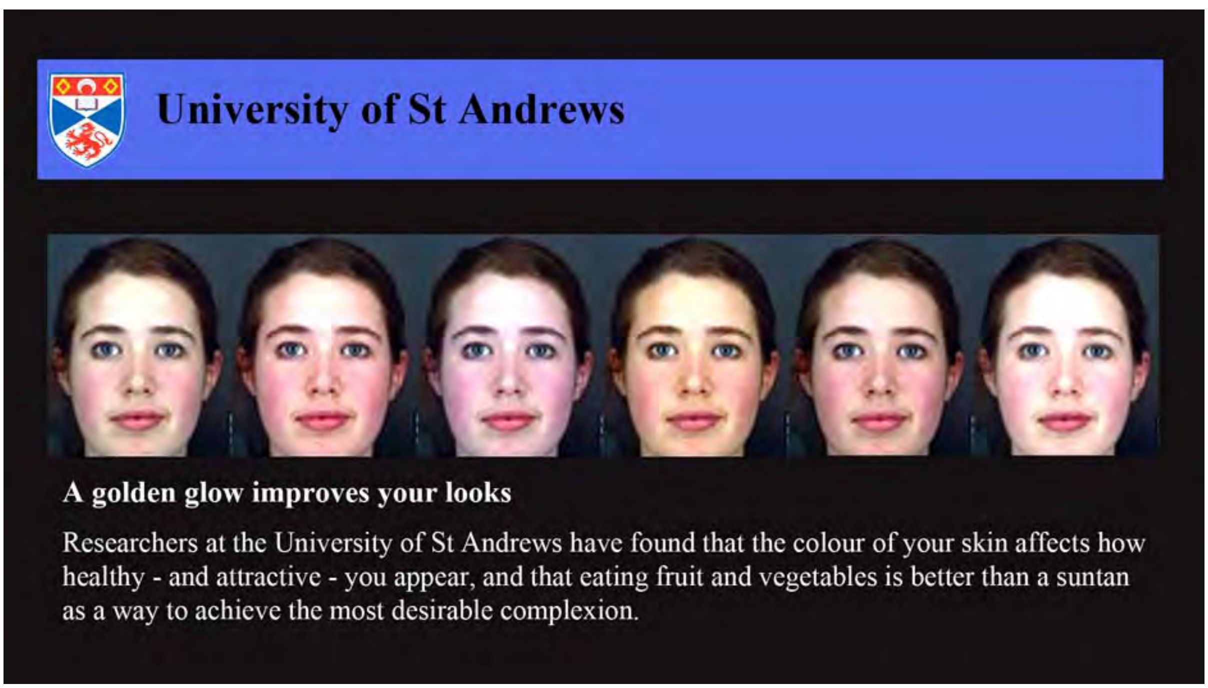
That decoding and "image forming" is what allows us to form a very comprehensive conception of the world around us. Creatures less blessed than us have a rudimentary notion of the world surrounding them. By comparison we're able to create a superb picture, and because we've got two of these eyes, we model our world in both colour and three dimensional space.

No, no, we're not going there--wrong show. And anyway we don't have the anaglyph glasses. Sorry. I just figured if Dr. Hans Kiening can do this sort of thing, I could too.

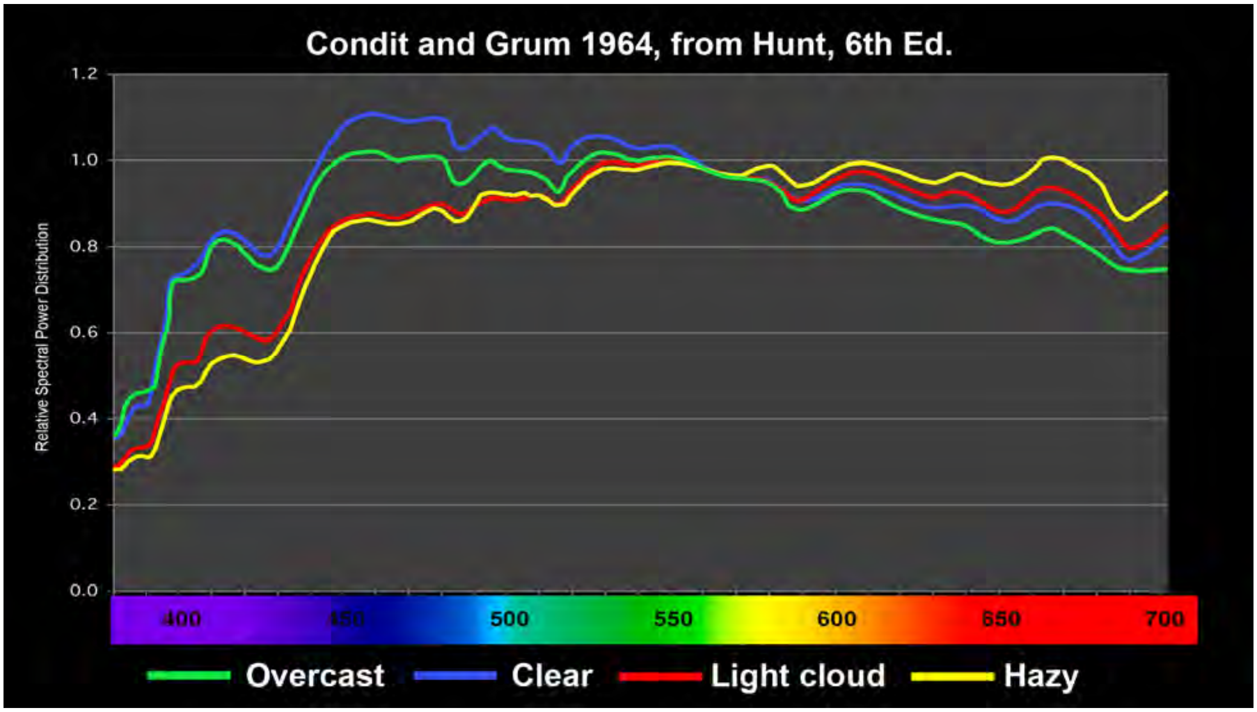
Anyway, that same mind can also effect what we call “hand and eye co-ordination.”

We can throw a ball to another human and catch it coming back from them, all because of our ability to model the world around us in exquisite and colourful detail.

Armed with our ability to distinguish many millions of colours, we are also capable of detecting the extremely subtle changes in the colour of a human’s skin which can alert us to their state of health.



Our eyes, of course, took millennia to evolve to this level of sophistication, and throughout almost the entirety of that time they worked in perfect harmony with the visible radiation our world provided, for the most part daylight, which even in its myriad forms provides a fairly constant spectral trace. Here are various forms of daylight:



When we were able to banish the dark of night (and, by the way, that darkness, just like colour, is solely a function of our visual system. Night or day, our world is crackling with radiant energy.)

But, when we were able to banish our dark by the use of firelight,

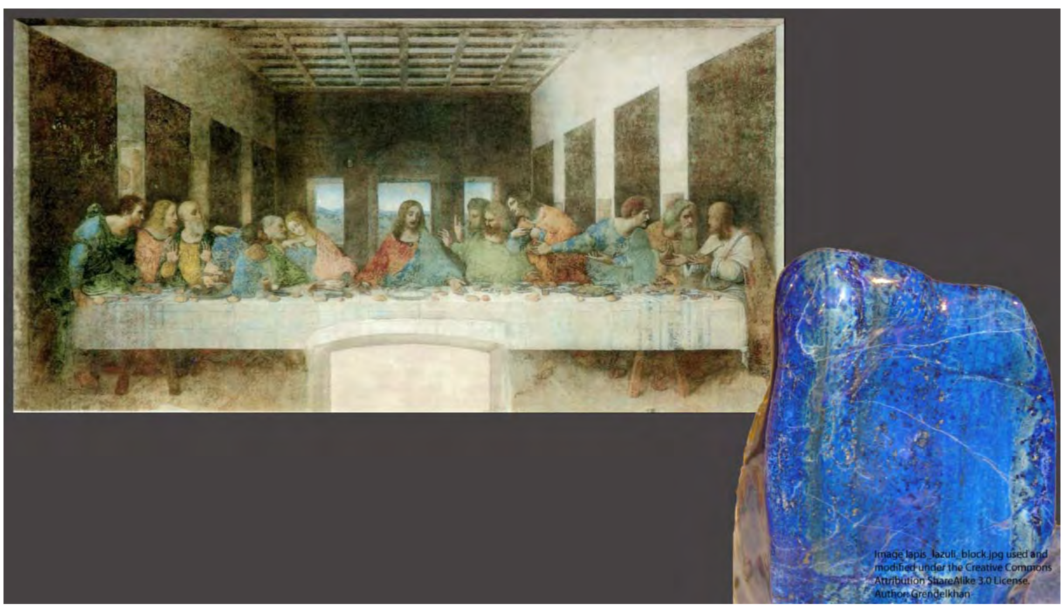
and then candles,

and oil lamps,

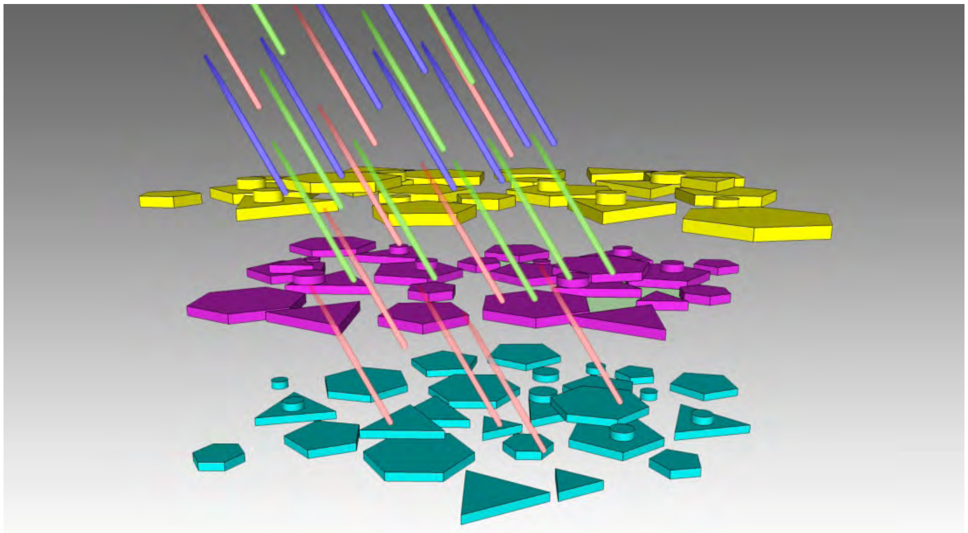
and eventually
incandescent light,

each of these lights also provided an essentially continuous spectrum. And this complete and continuous spectrum of light was, of course, necessary if we were to make those infinitely subtle distinctions about the state of someone's health or the safely of something we wished to eat.

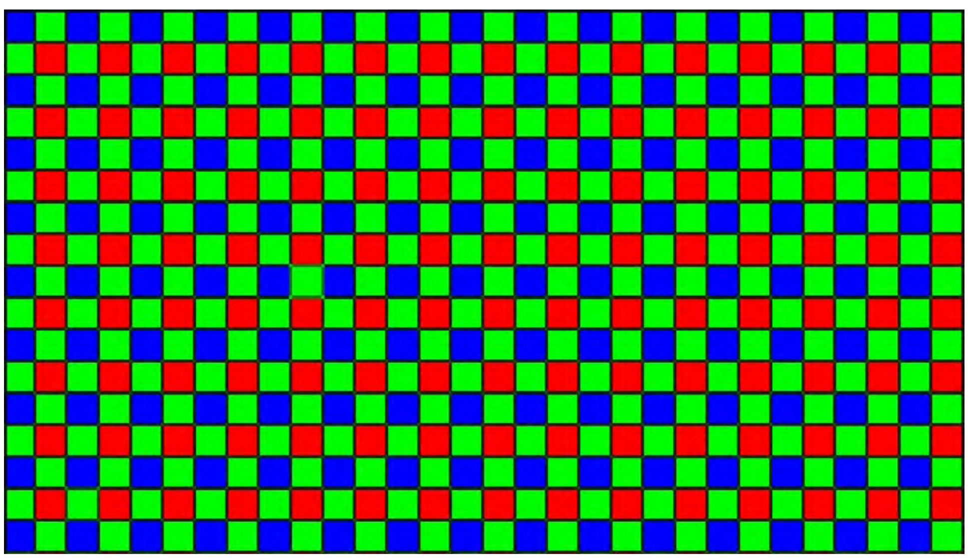
And, as we evolved and sought to capture representations of our world we found ways to paint pictures of our world that conjured the same experience we had when we viewed the original scene.



Artists fought hard to be faithful in their depiction, so that, to reproduce Blue in a painting, for many years it was necessary to grind up the semi precious stone Lapis Lazuli and turn it into a pigment, as da Vinci did here in, "The Last Supper." And the use of this much hugely expensive blue in the painting tells us this was not a trivial commission. This was a big deal even when he painted it. They also sought to paint by a "north light" as that was more constant through the day.

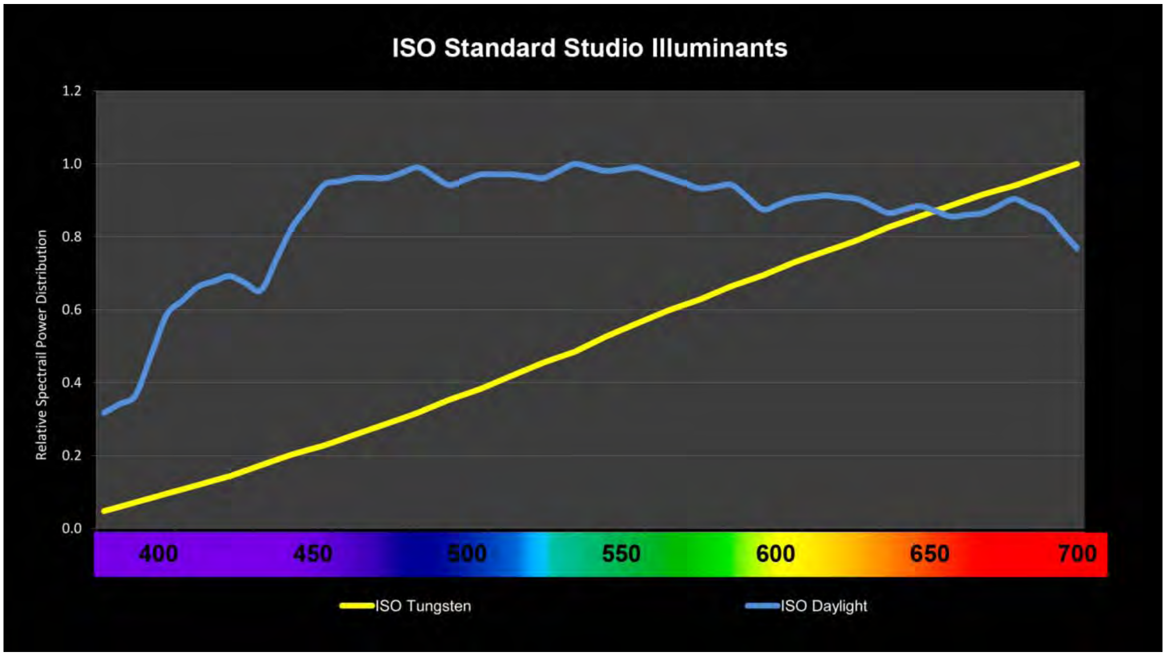


And when we came to reproduce our colourful world in the medium of film, again we sought to be as faithful as we could to life itself and built a system remarkably analogous to the way our own eyes work. Like the cones in our eyes, film contains detectors, sensitive to Blue, Green and Red regions of the spectrum.



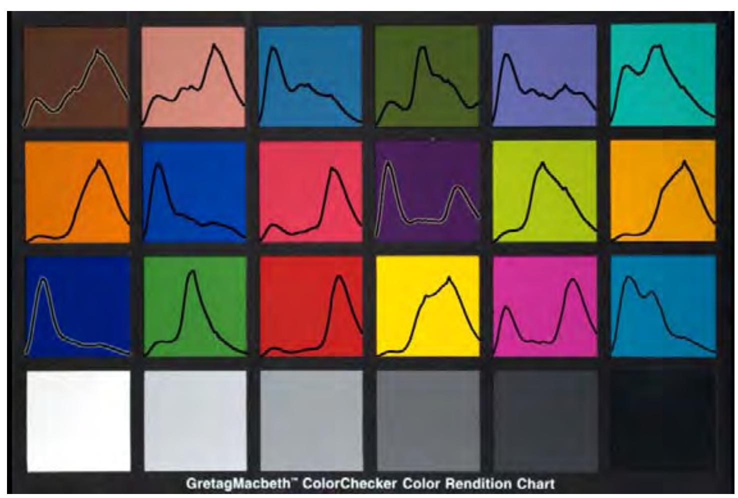
A digital cinema camera likewise has Blue Green and Red sensitive detectors. Both the film camera and the digital camera were, like the eye, designed to work with a broad, continuous spectrum of light either Daylight or Tungsten.

So here we see a graphic representation of Studio Tungsten light and Studio Daylight.



The builders of both filmstocks and digital cameras (each carefully striving for a unique and particular “look” for their own product) all assume ISO standard studio illuminants as the basis on which to build their sensitivity curves, as do the builders of various ancillary products such as camera and lighting filters, photographic meters and the like.

In recent years we have begun to adopt “artificial” simulator light forms such as fluorescent, discharge and LED.



These new lamps endeavor to emulate our traditional continuous lights by providing enough luminance to our Red, Green and Blue sensitive cones to create the sensation of “white” light. However, illuminating an industry standard colour matching Macbeth chart with such “white light” simulators will, as we shall show you, produce colour shifts with varying degrees of severity.