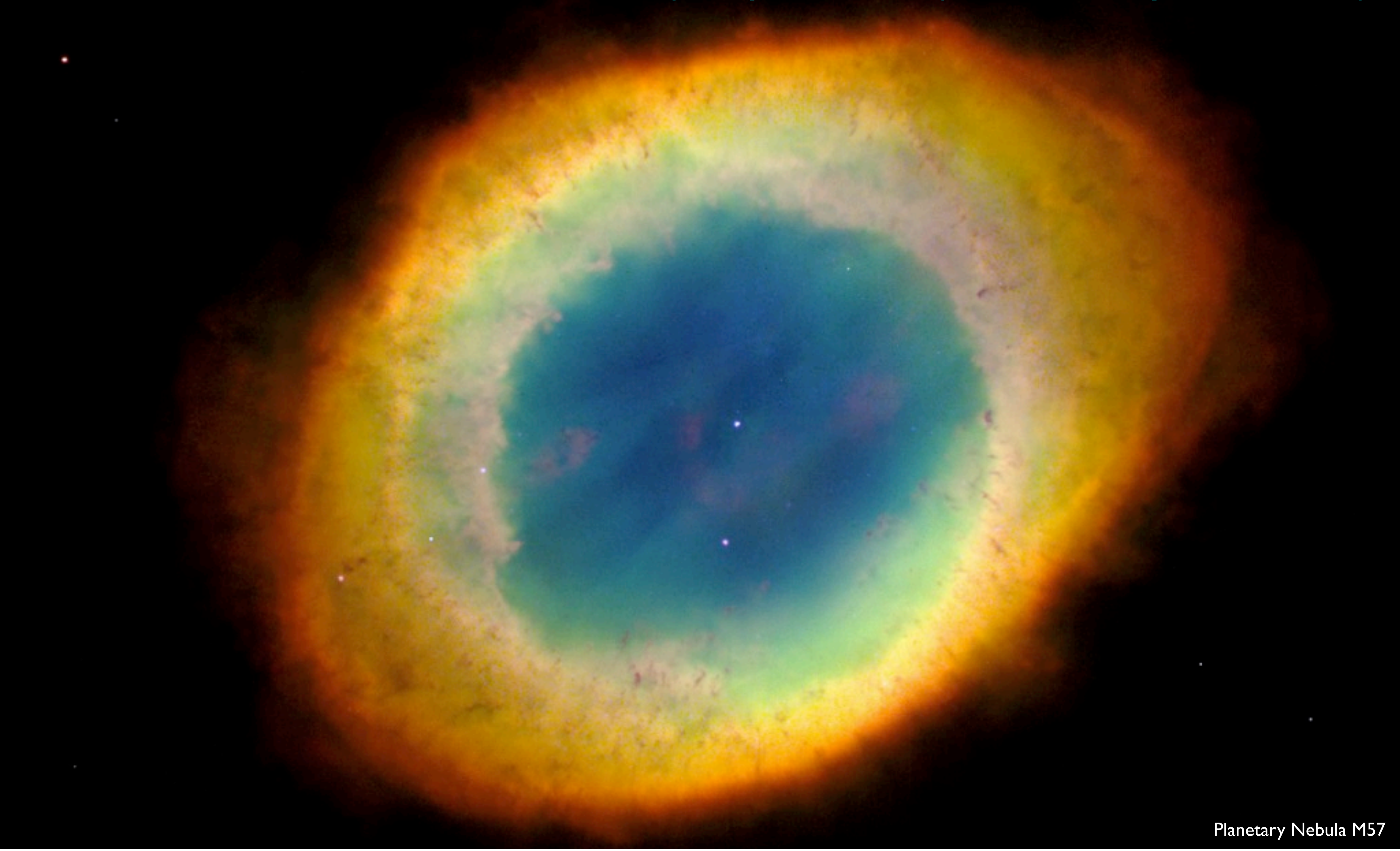
the nature of light

photons are force carriers for electromagnetism. They interact only with charged particles (electrons, protons, ...)



Planetary Nebula M57

There will be two TA office hours the coming week.

1) Charles, MP1203A, Monday Jan 28, 5-6PM
2) Serguei, MP1313, Monday Jan 28, 6-7PM

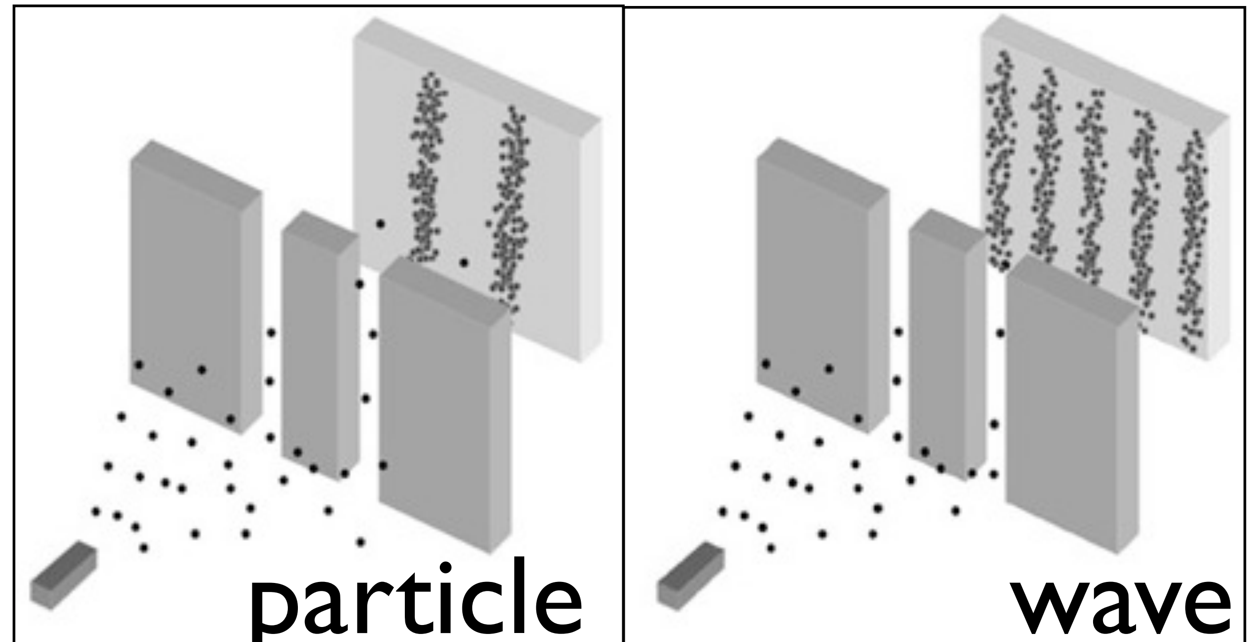
Why light?

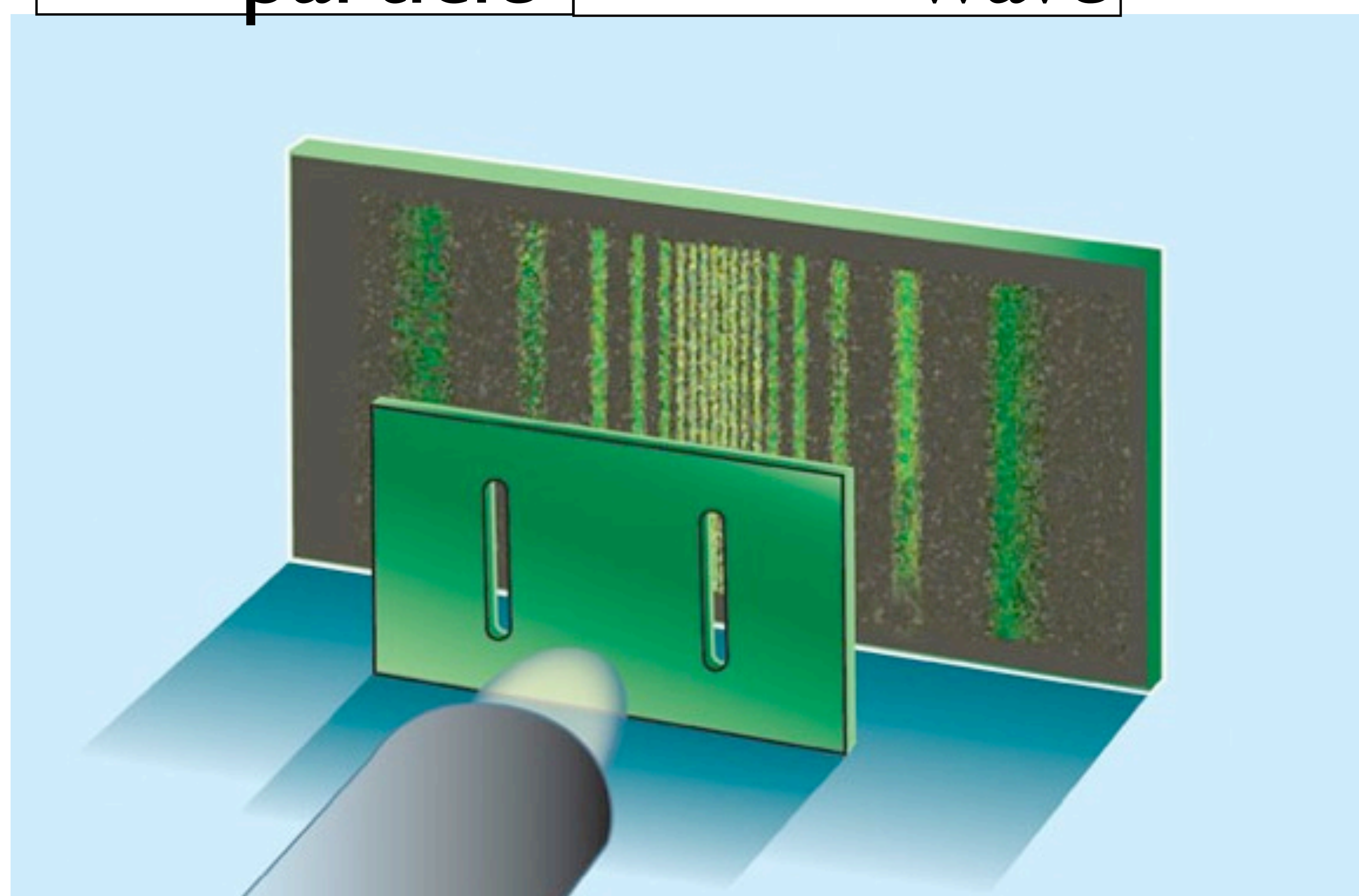
- electromagnetic waves (light -- from radio to gamma rays) are just about the only way we can observe the distant universe

- other ways (cosmic rays, neutrinos, gravitational waves) do exist, at least in principle. At present though they are far more limited and difficult to use. For now (and the foreseeable future), light is the only game in town.

- Light is also interesting in its own peculiar ways.

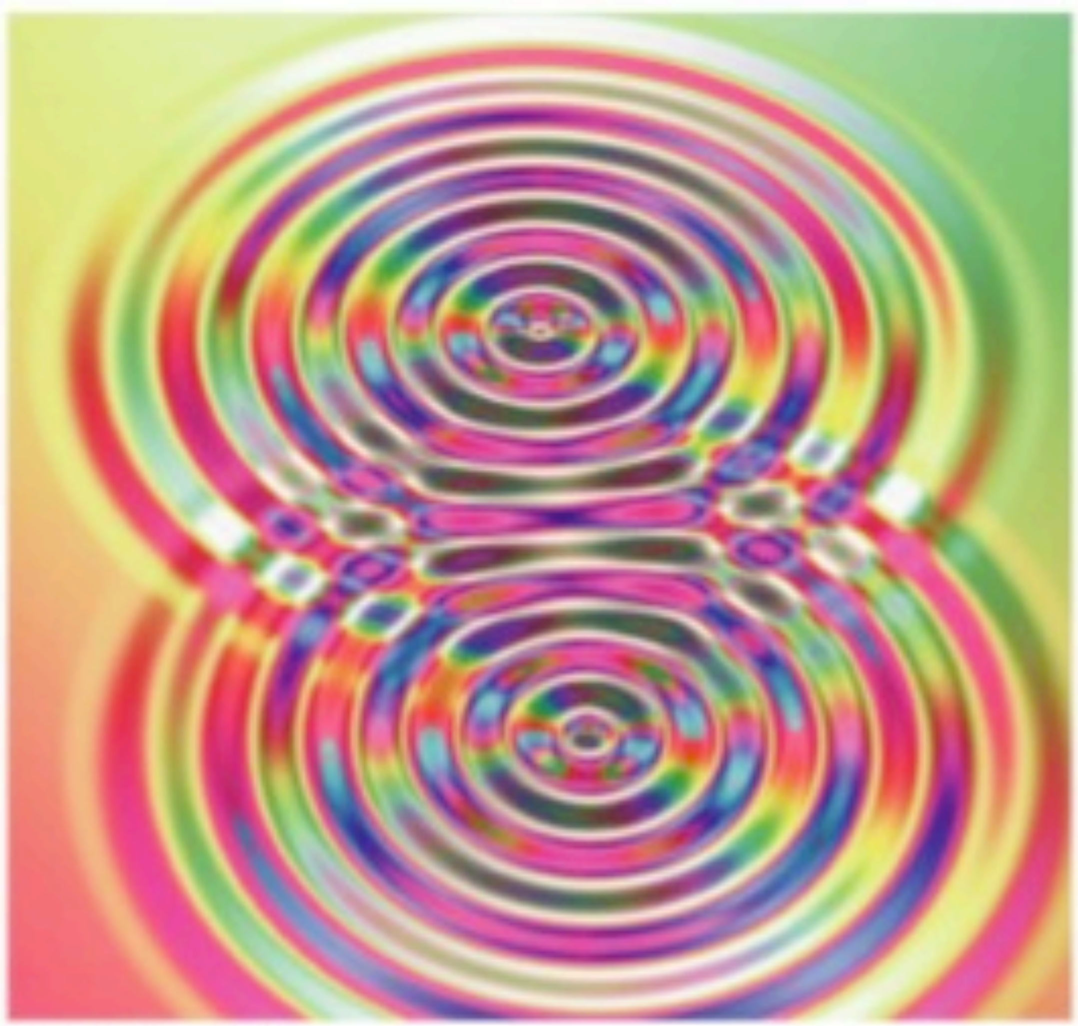
Light as a Wave: Young's Two-Slit Experiment

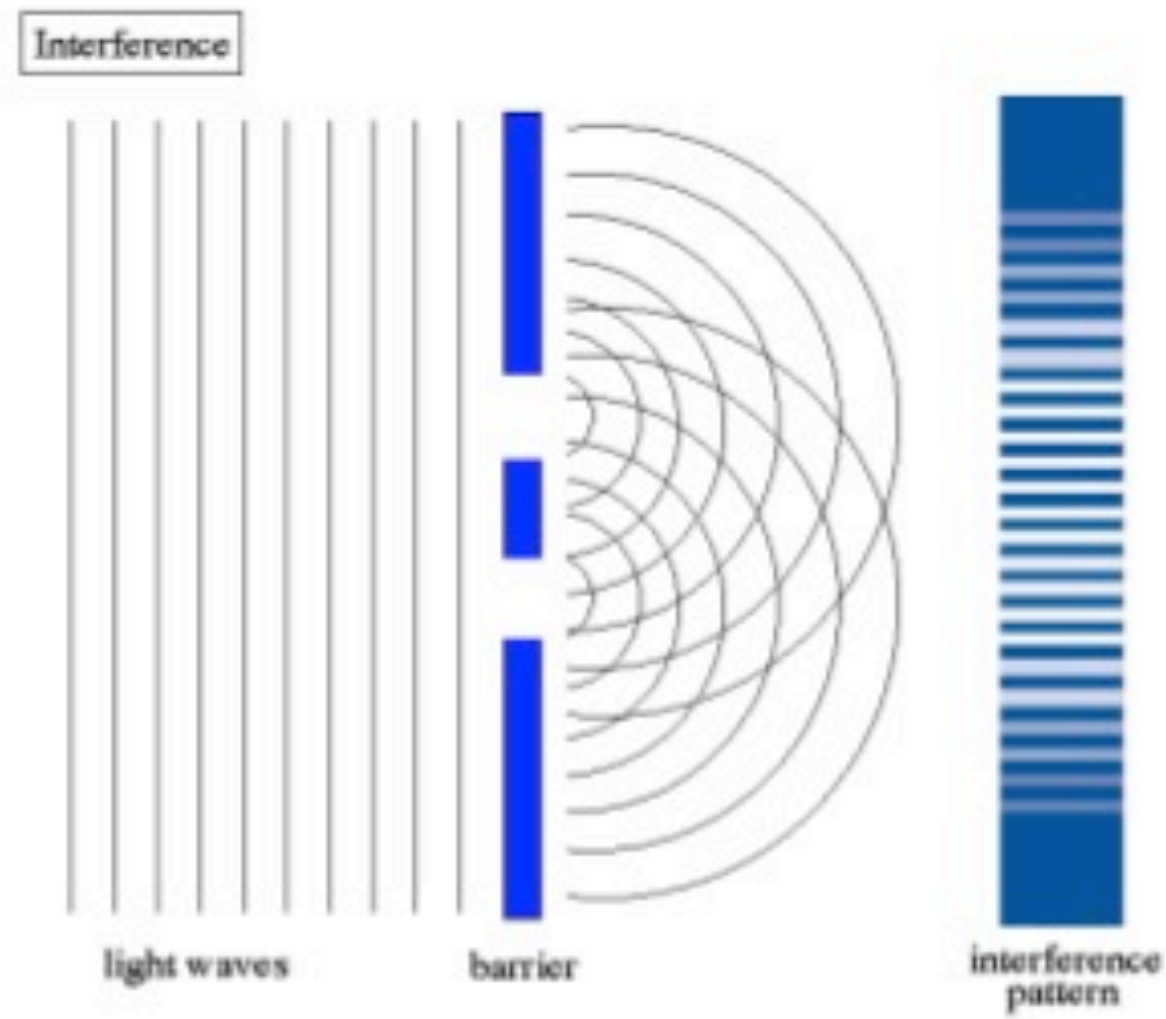




- Ancients believed light was made up of particles emitted by your eyes.
- Newton believed light was made up of particles.
- Thomas Young showed, in his "Two-slit Experiment", that light was a wave. (1800)

It's easy to explain the two-slit experiment





interference pattern

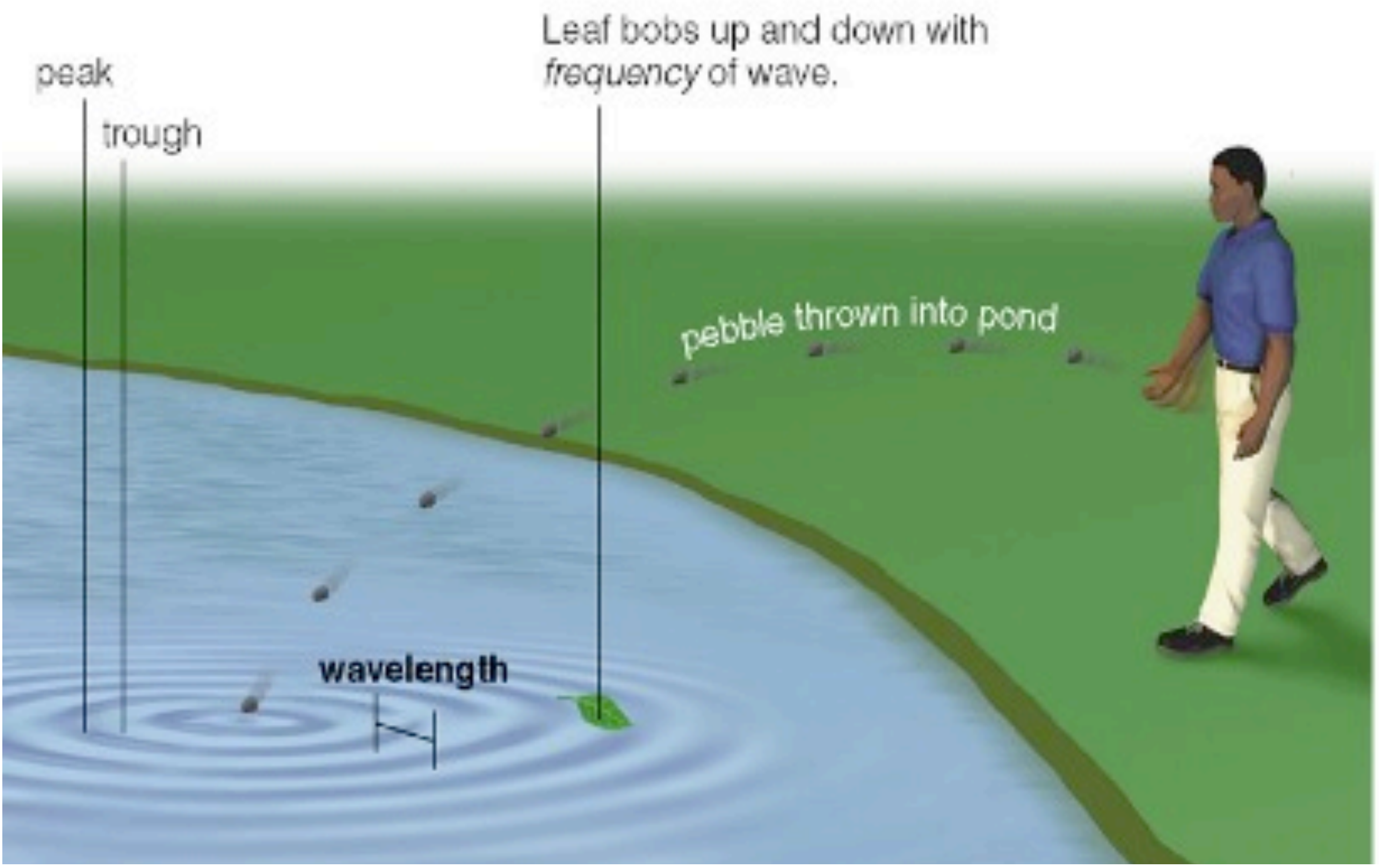
Light as Waves.

$$E = h\nu = hc/\lambda$$

E: energy

λ: wavelength

ν: frequency



shorter wavelength

||

higher energy

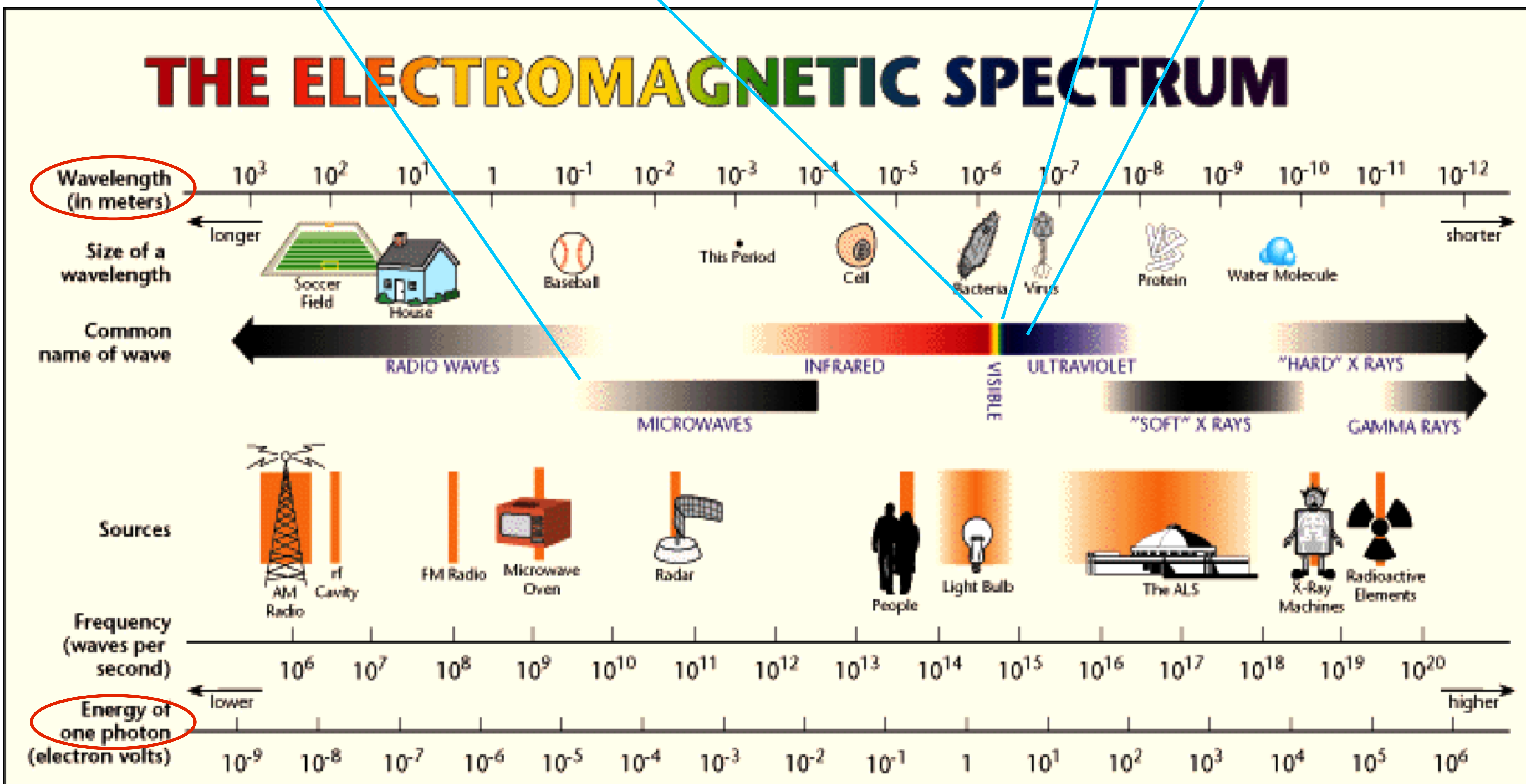
a radio photon (~ metre)
~ 10^{-6} electron volts

visible photon (~ 5×10^{-7} m)
~ 2 electron volts

X-ray photon (~ 10^{-9} m)
~ 1000 electron volts
able to wreak havoc.

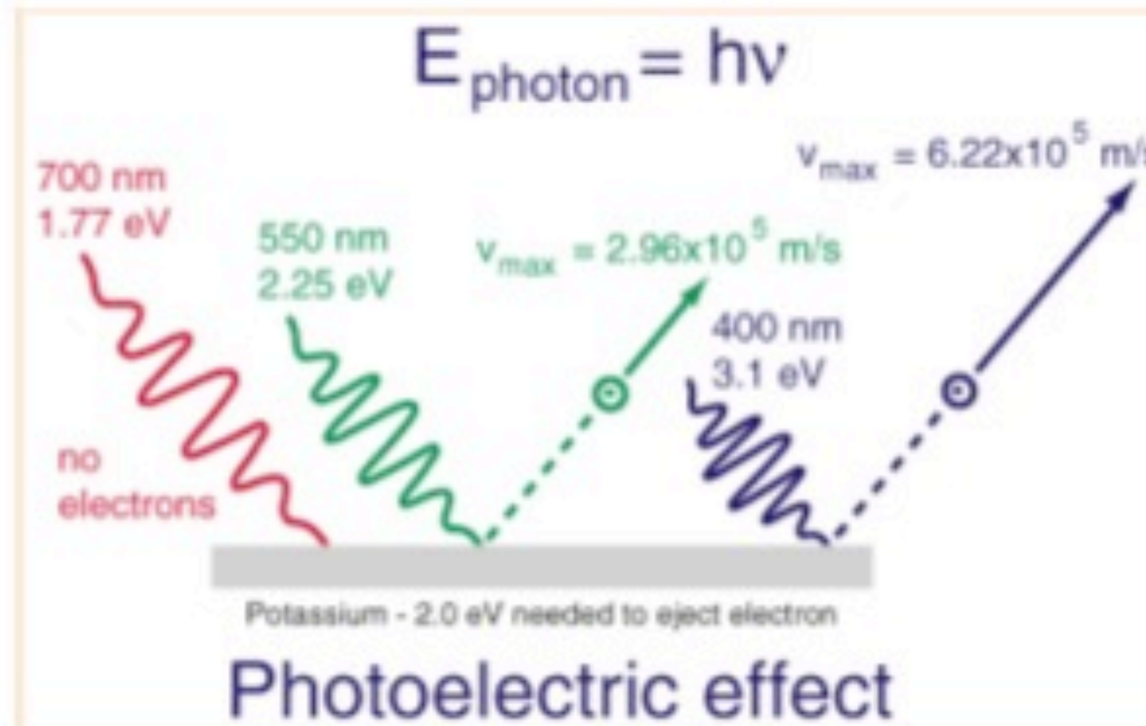
cell phone signal

UV



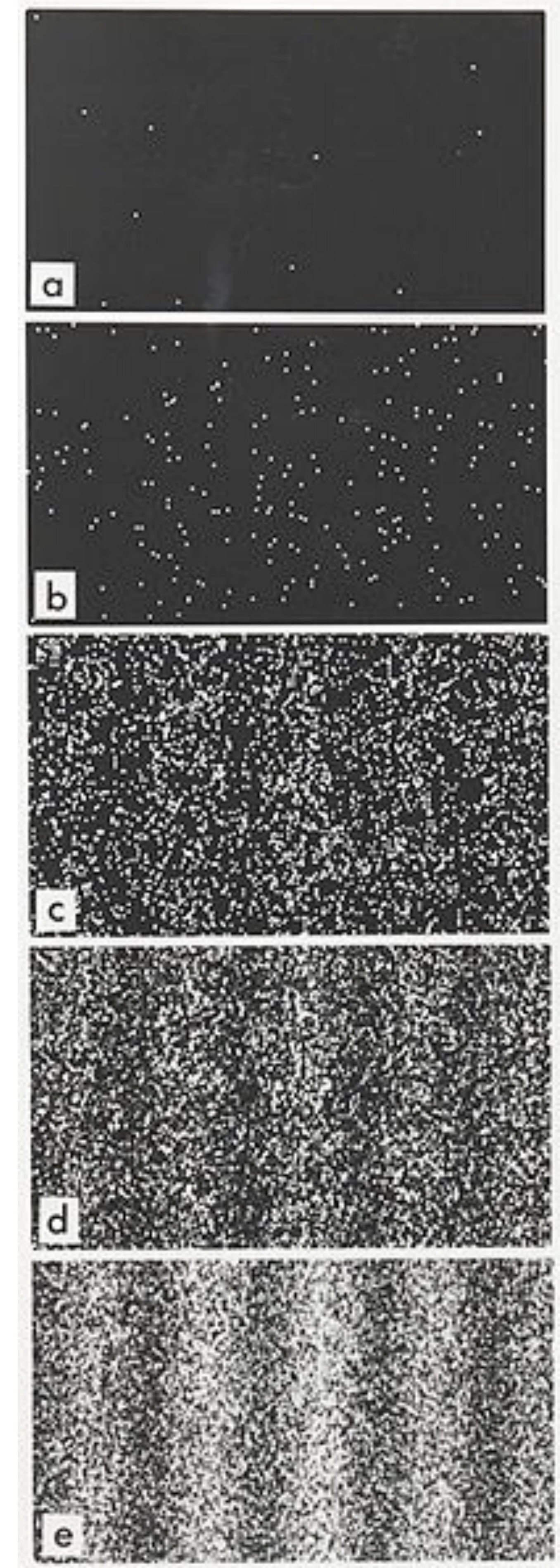
The Wave-Particle Duality

- Light is a particle (photon) and a wave.
  - Evidence: photoelectric effect (Einstein won the Nobel Prize for this)
  - light comes in "packets" of certain energy $E=h\nu$ $=h\,c/\lambda$
    (h=Planck's constant)



- one photon is an individual, quantized wave packet.

Light is a wave. Hence interference pattern in the two-slit experiment. What about an electron?



shooting electrons through the slits, an interference pattern builds up.

The same thing happens for all things in nature. Wave-particle duality. not just to light, but also... you.

The de Broglie Wavelength

- We accept the wave-particle duality
  - In quantum mechanic: everything has a wavelength -- photons, electrons, baseballs, students, elephants etc.

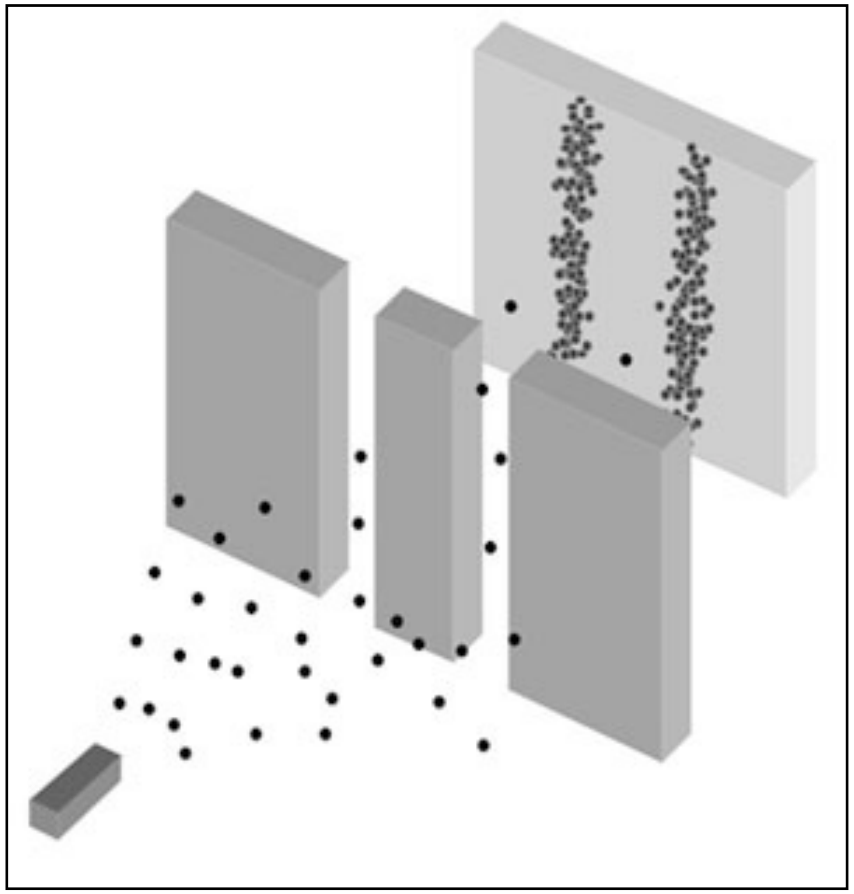
h: the Planck constant

$$\lambda_{de\ B} = h / mv$$

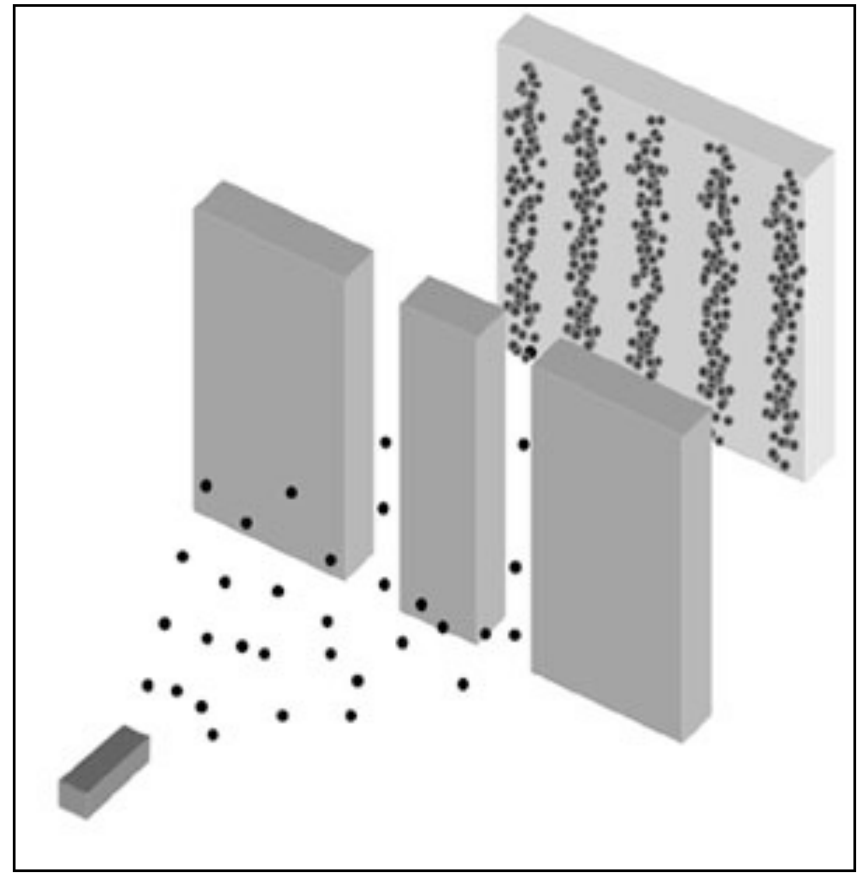
$$p = h / \lambda_{de\ B}$$

  - E.g., a typical electron: $\lambda_{de\ B} \sim 10^{-11}$m, a baseball traveling 10m/s: $\sim 10^{-34}$m, λ indicates how "localized" the object is

What if we shoot photons one by one?

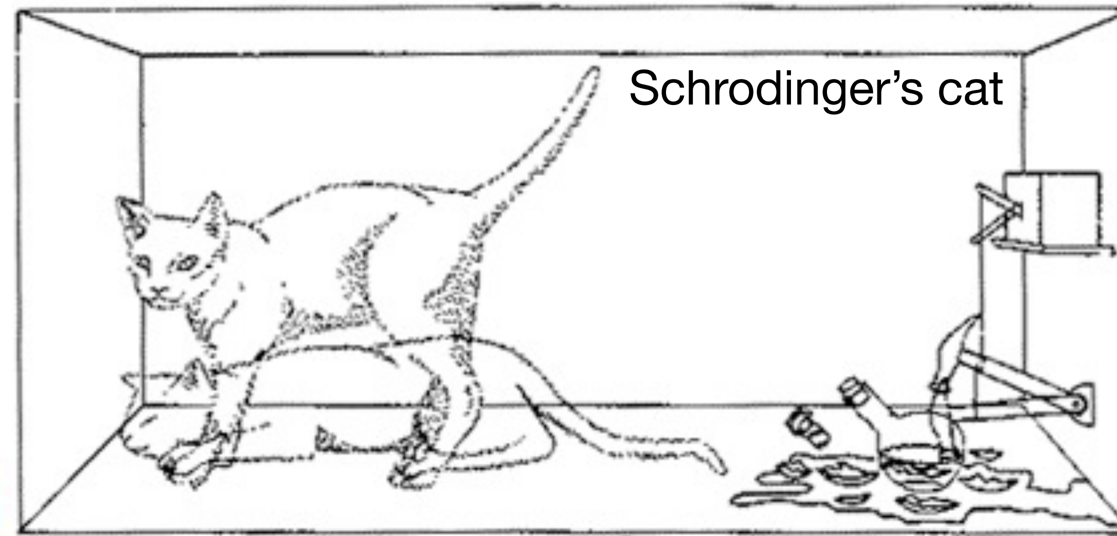


or?



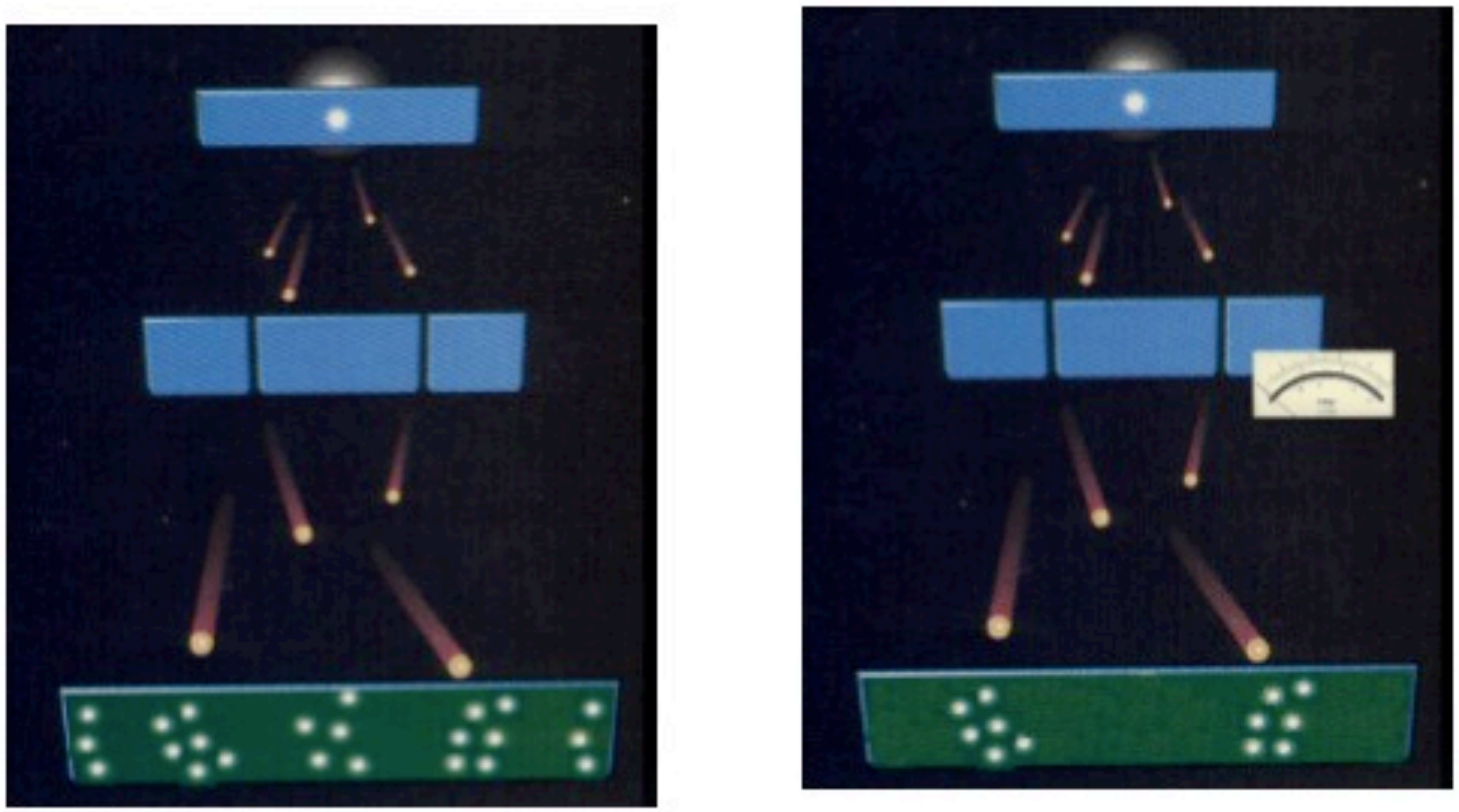
Quantum weirdness:
a single photon (electron, ...
elephant...) can pass through
both slits simultaneously.

what if we put a device to observe the photon's path?

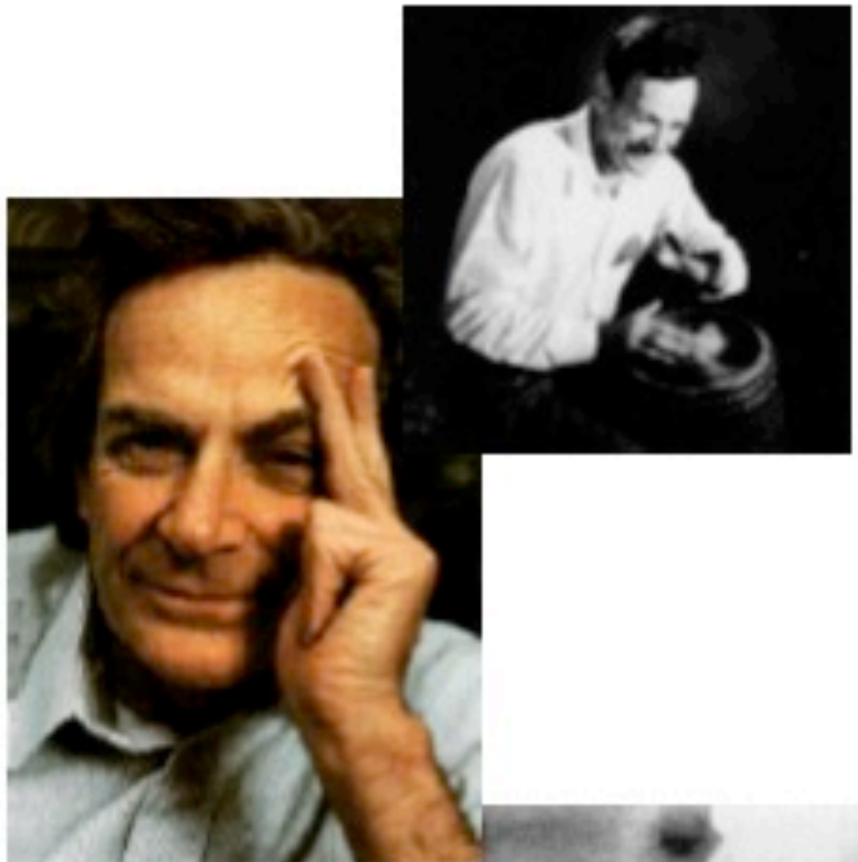


physics colloq.
Thursday 4pm

This is the really weird part



Amazingly, if you add a detector which allows you to figure out which slit a particle goes through, then the interference pattern goes away. This has been confirmed many times in the lab. You cannot just treat a photon (say) as as a "particle with wavelike properties". The quantum world is much stranger than this... the observer is a essential component in the experiment.

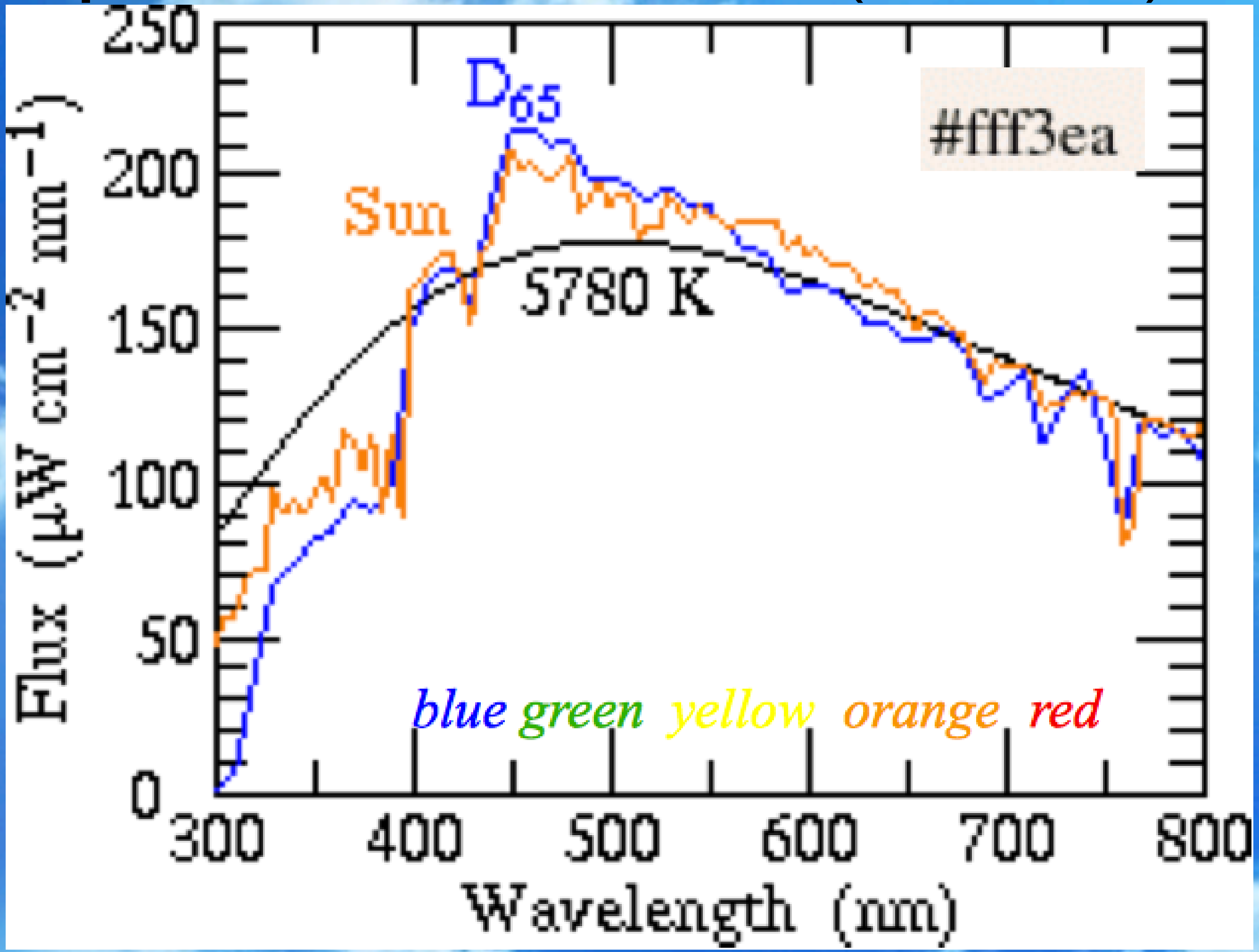


"All of quantum physics is contained in the two-slit experiment. Unfortunately nobody understands the two-slit experiment."

– Richard Feynman

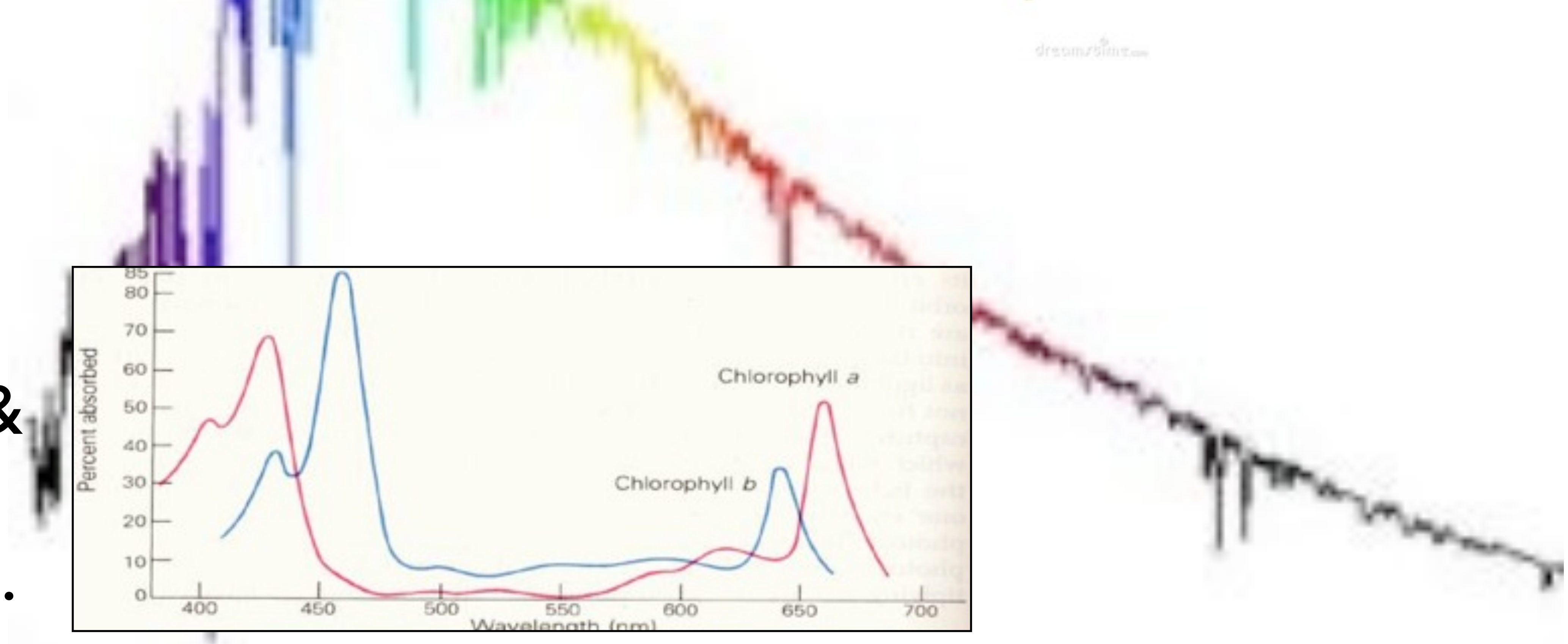
NGC 2266 star cluster:
blue stars T~ 20,000 K
red stars T ~ 2000 K
yellow stars T~6000K
(like the Sun)

Spectrum of the Sun ("white")

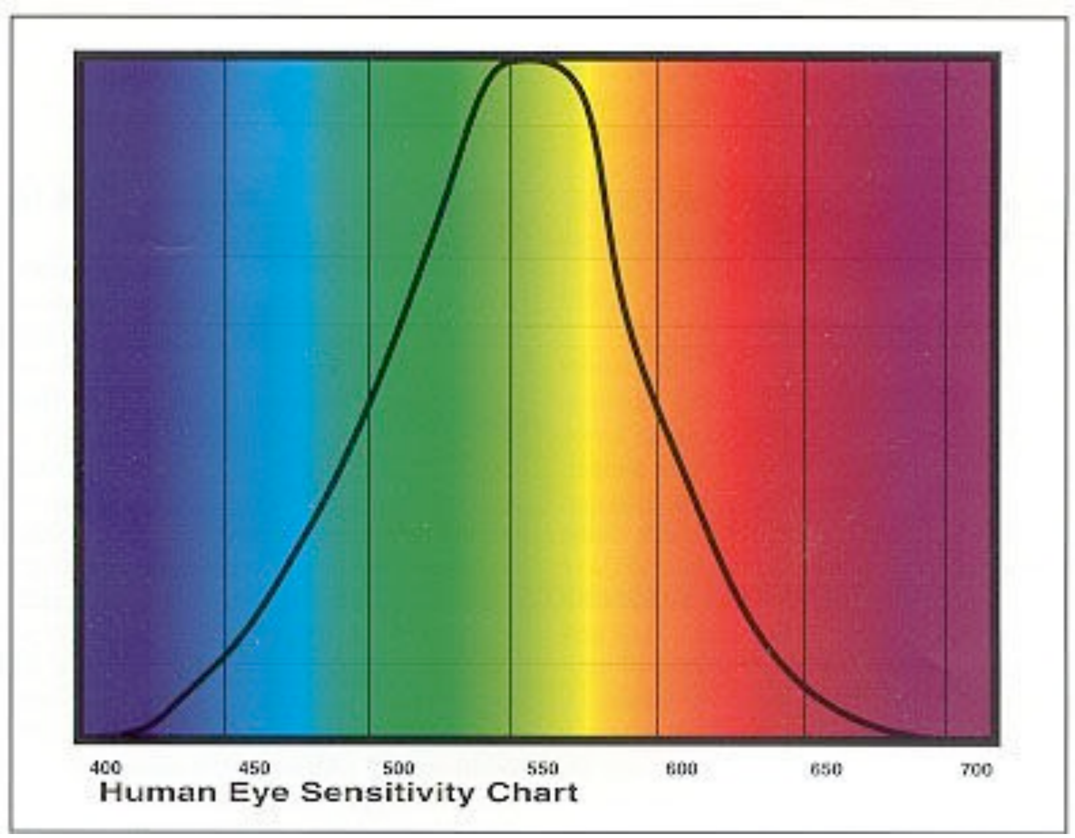


Why are  green?

chlorophyll absorbs blue & red, reflects green.



human eyes most sensitive to different shades of green



evolution at work!

each object around us really has **two** colours.

1) reflection of light. Material property (wood, steel, dye...) determines this color.

2) thermal radiation. All stuff glows (unless it's 0 Kelvin). Temperature determines the colour of this radiation.

Astronomical objects are mostly seen by their own radiation, as opposed to by reflection.

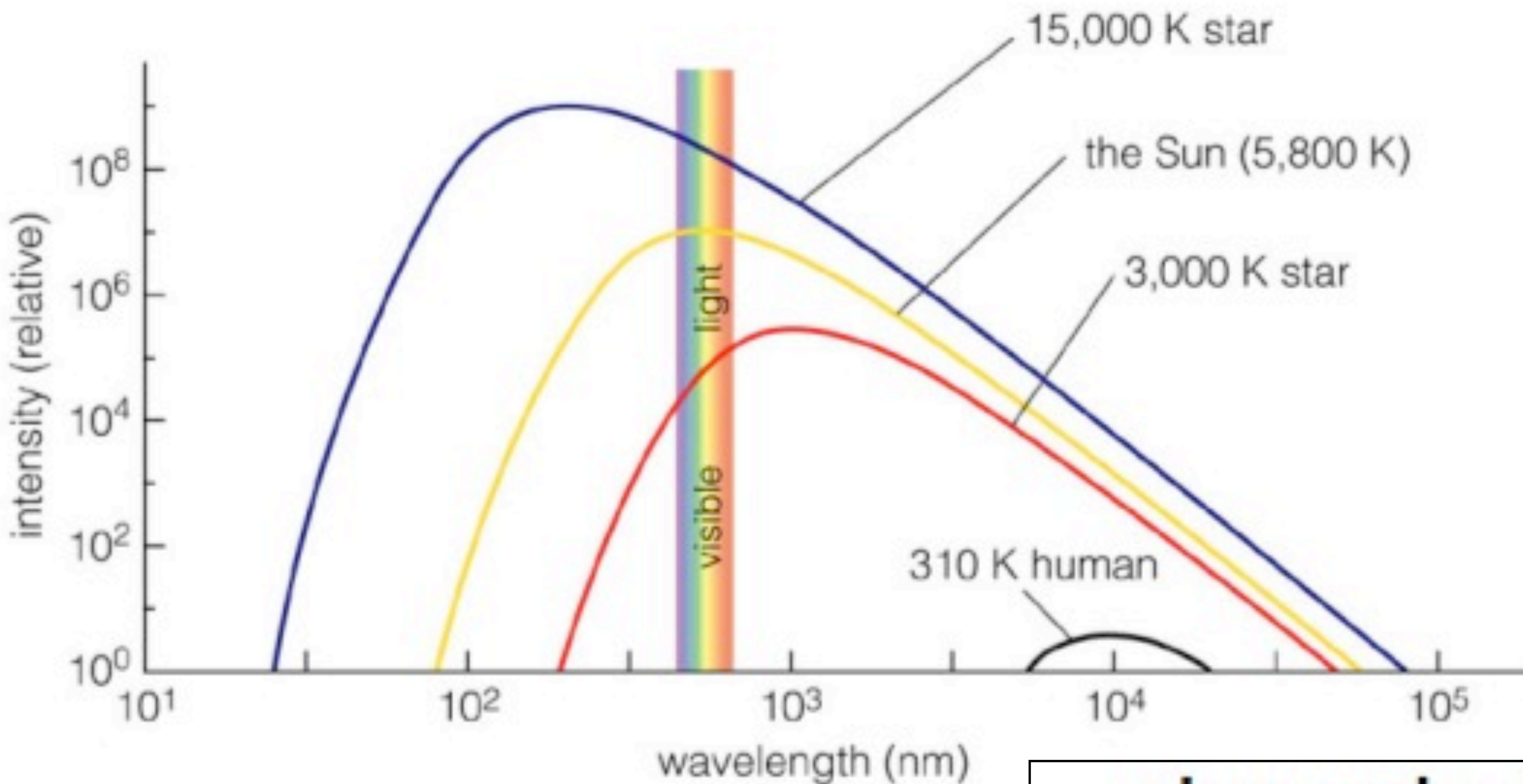
Blackbody Radiation

•All matter emits radiation when its temperature lies above absolute zero (0 K).

•Thermal energy is turned into photons and the body cools -- ‘thermal radiation’.

• the spectrum and intensity of this “thermal radiation” depends only on T (not on who you are) --- ‘blackbody’

Blackbody Spectrum



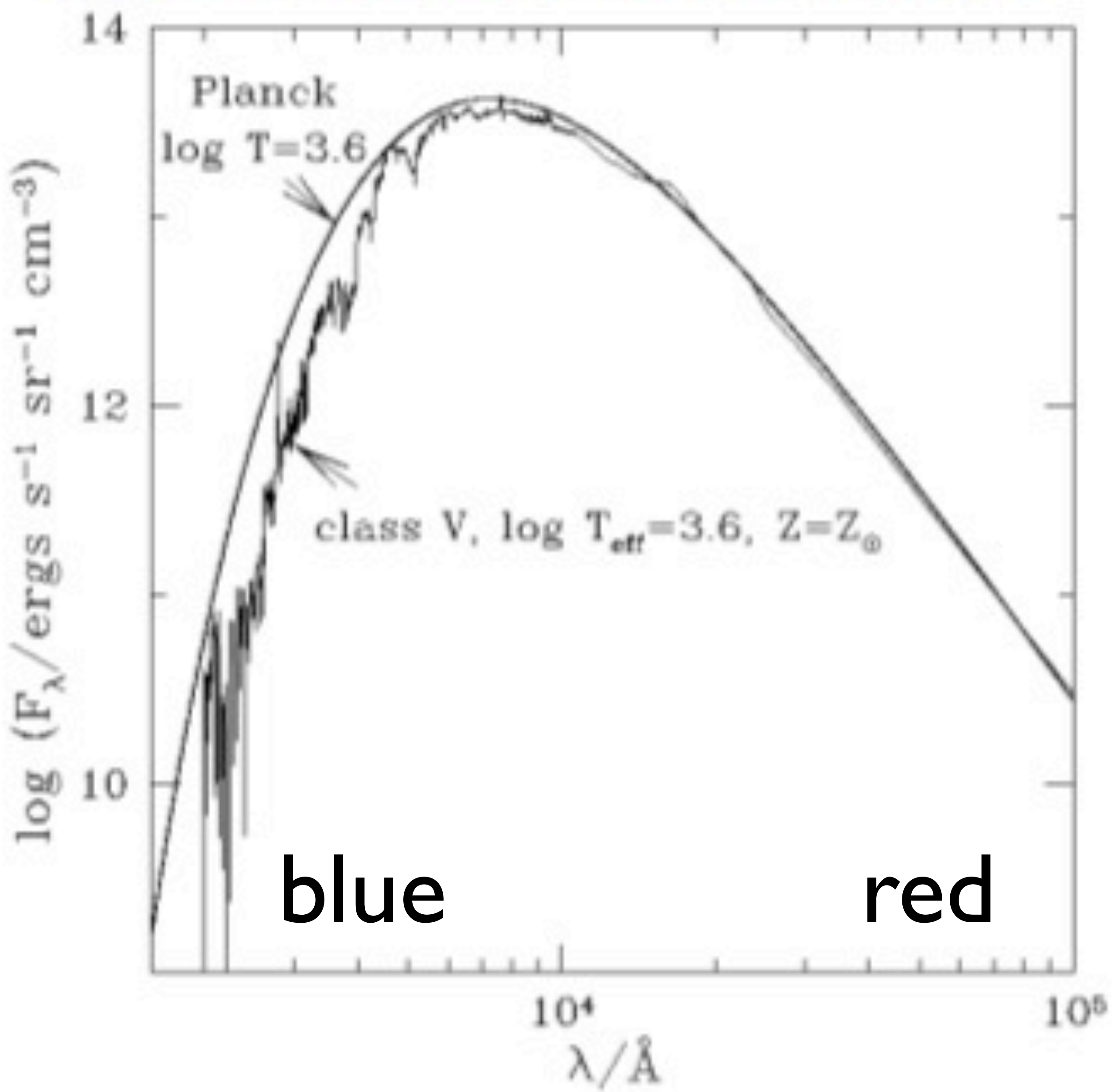
hotter bodies: emit at shorter wavelengths (bluer), and also more luminous

- the peak of the radiation moves to higher freq. for higher T: Wien's Law:
  $\lambda max = 0.0029/T$ m
- the total energy/unit time/unit area: Stefan-Boltzmann Law:
  $E = \sigma T^4$ j/m^{2}s
  where $\sigma = 5.67 \times 10^{-8}$ watt/m^{2}K^4

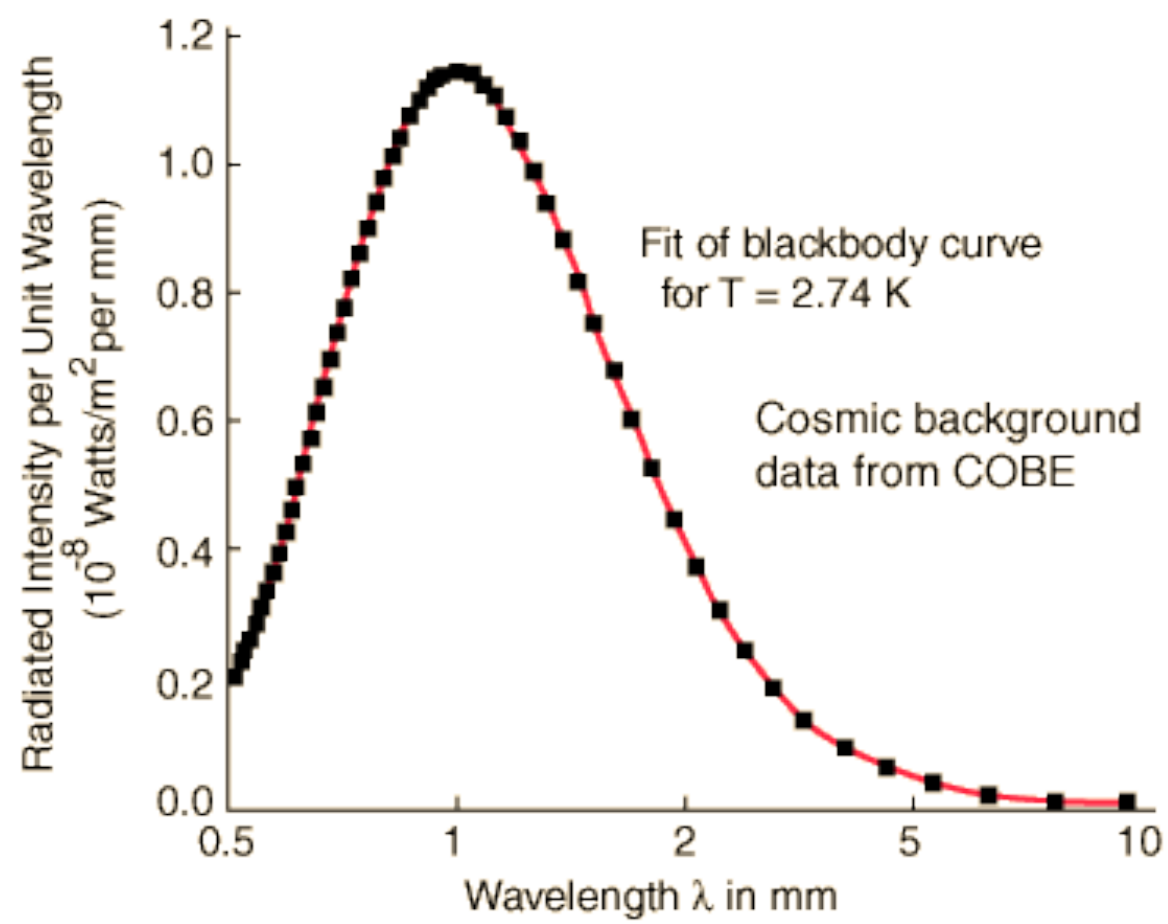
Temperature alone determines
1) 'colour'
2) 'intensity'

Blackbody Curves in Nature

The Sun has T~5760K, λ_{max}~500nm (yellow)

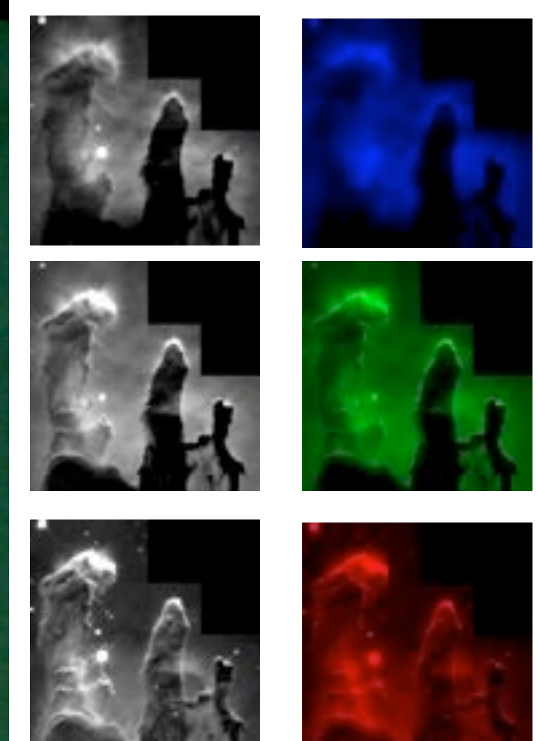


As the stellar spectrum above shows, stellar spectra can be approximated by the Planck curve, but absorption lines prevent them from being perfect blackbodies.



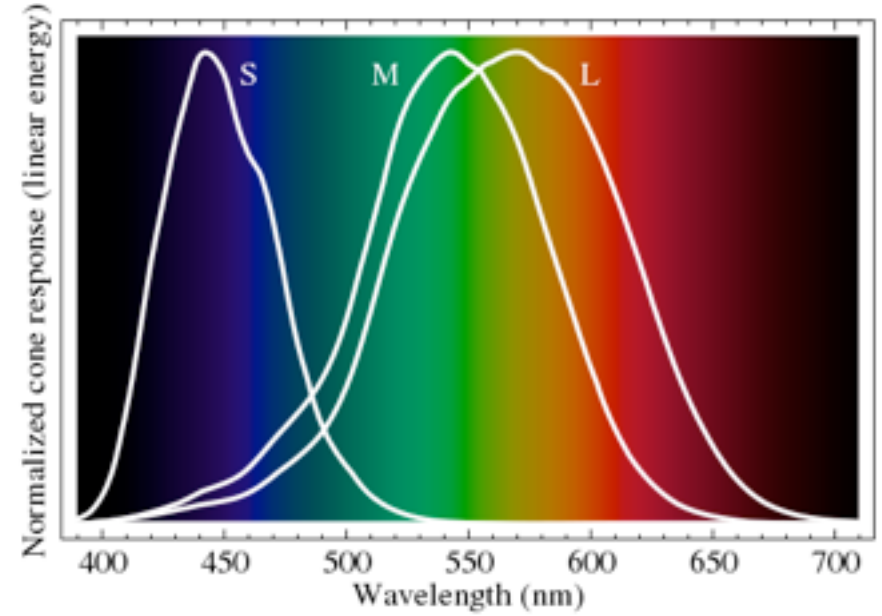
The cosmic microwave background radiation is however, an incredibly perfect blackbody!

Suppose you are to fly out to the Eagle Nebula, is this really what your eyes see?

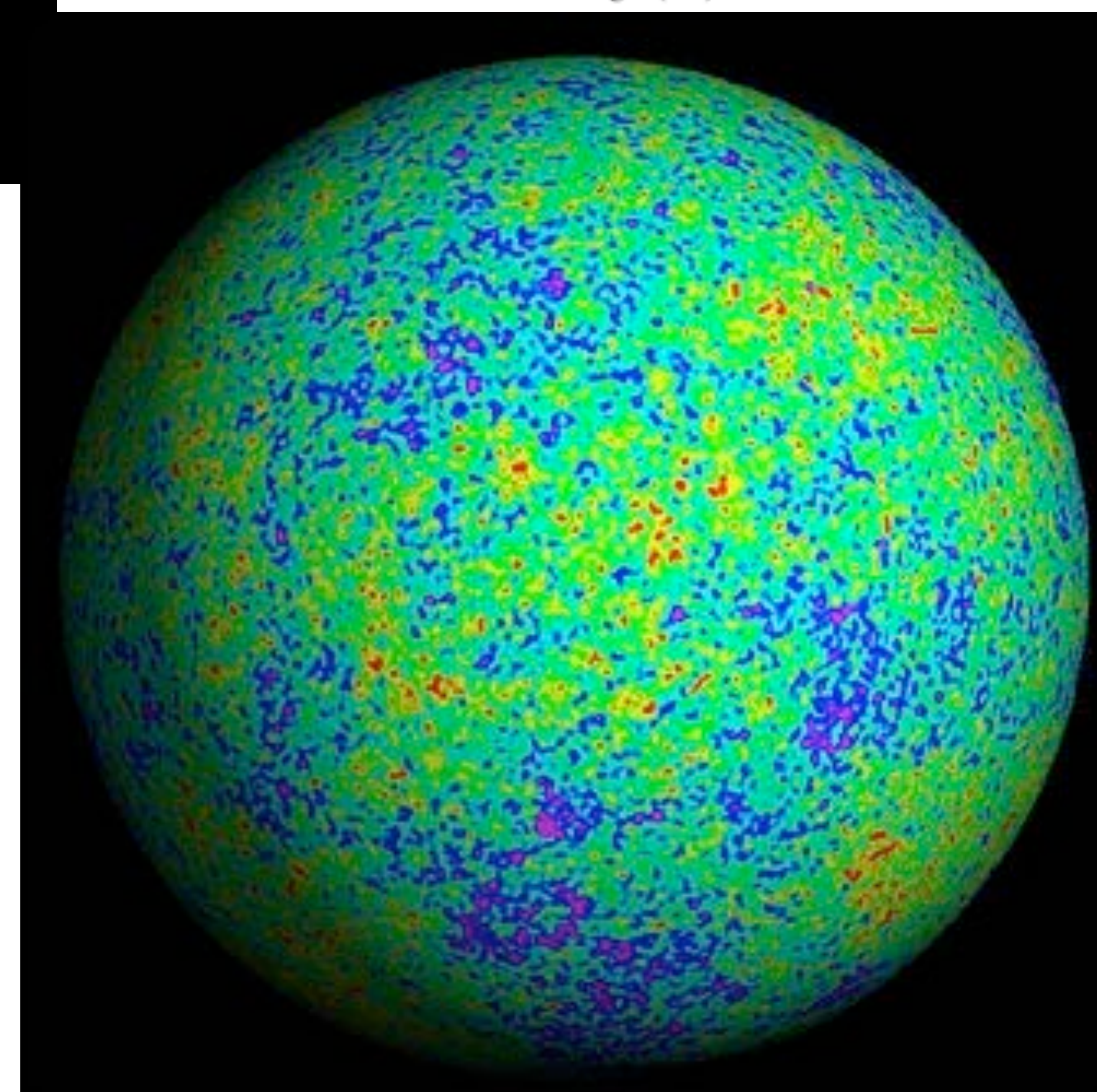


digital images at different λ
each assigned a color
single images combine

human's tri-chromatic colour vision

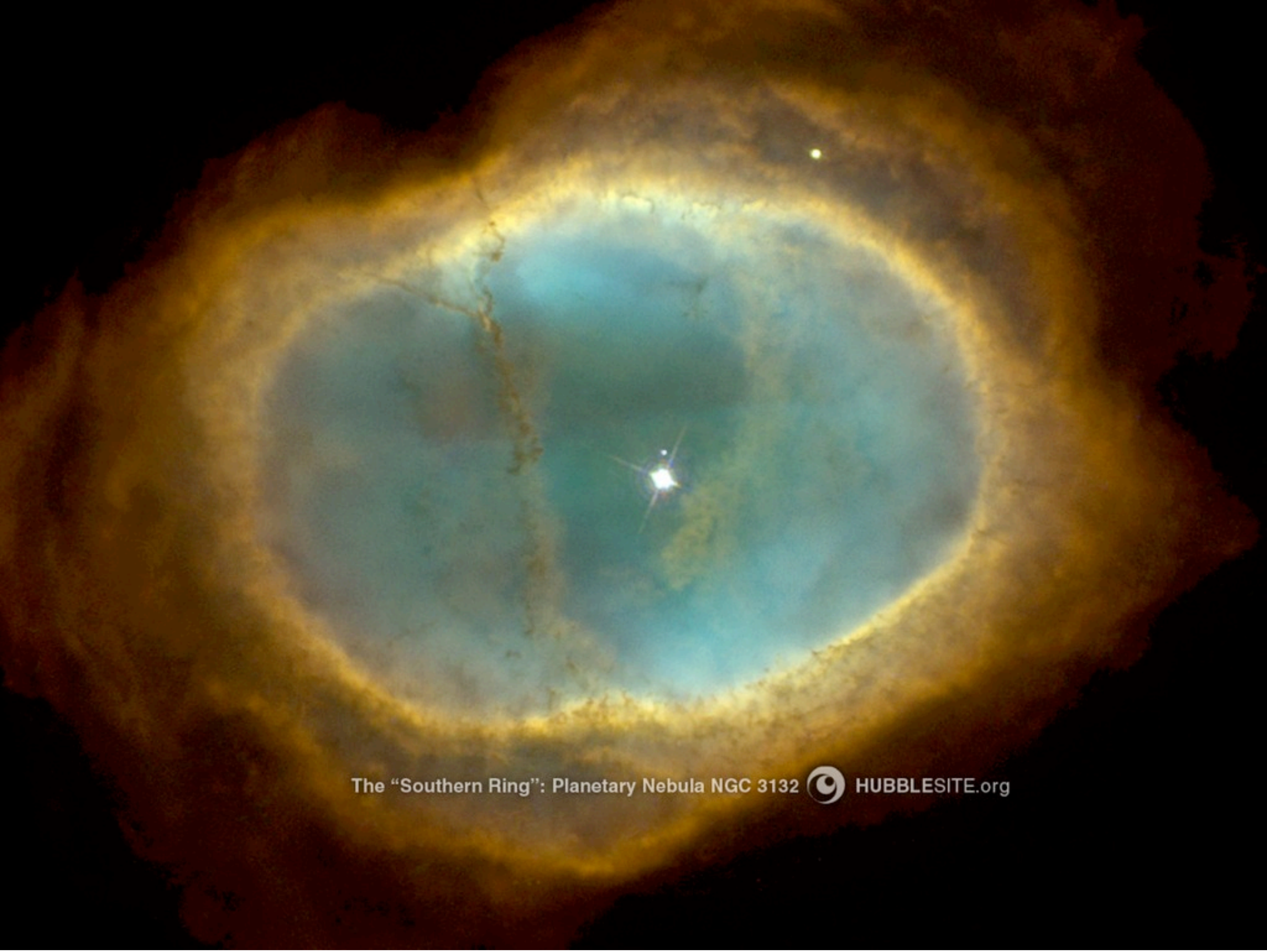


the cosmic microwave background




The Tadpole Galaxy: UGC 10214
HUBBLESITE.org


Star-forming Pillar in the Cone Nebula — NGC 2264
HUBBLESITE.org


The "Southern Ring": Planetary Nebula NGC 3132
HUBBLESITE.org