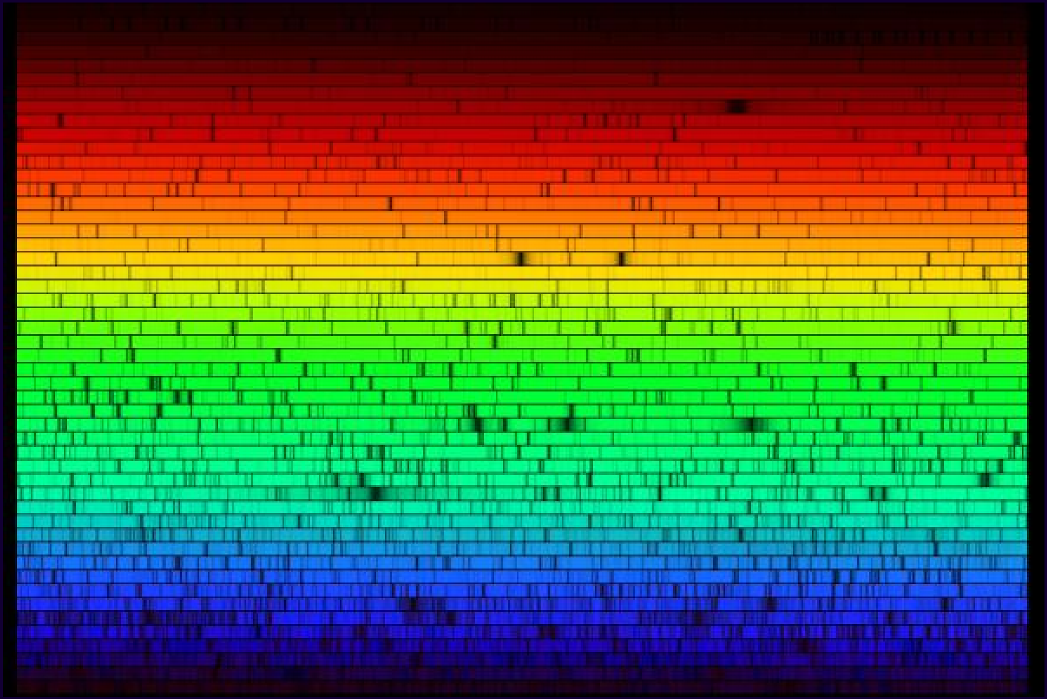
Light

Astronomy 101
Syracuse University, Fall 2018
Walter Freeman

October 23, 2018



This is a “picture” of the Sun. What can we learn from it?

Announcements

- Everyone who took Exam 2 at the normal time should have their grade.
- I still have some Paper 1's to grade; I'll get to those as soon as I can.
- I'll update the textbook pages later today on the website.
- I am way behind on answering email; I will catch up as soon as I can.

How much of the light in this room can you see?

A: All of it

B: Most of it

C: Around a quarter of it

D: Not much of it at all

How much of the sound in this room can you hear?

A: All of it

B: Most of it

C: Around a quarter of it

D: Not much of it at all

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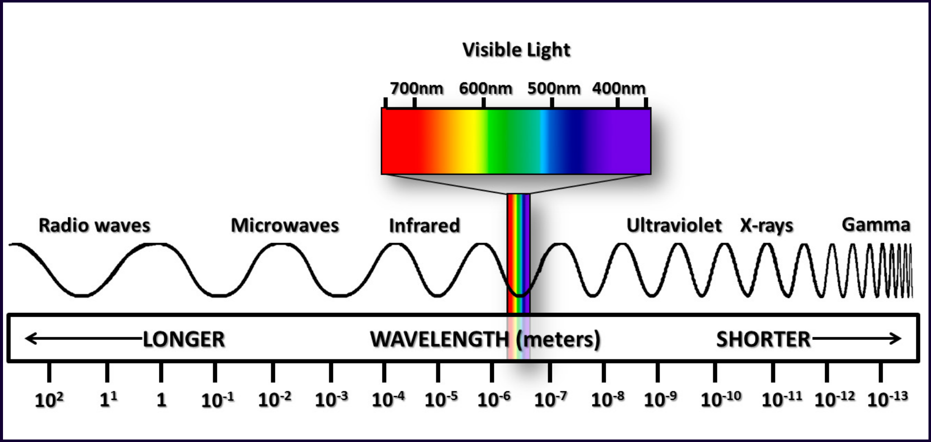
In the same way *light* has a spectrum of frequencies/wavelengths, and our eyes only perceive a tiny fraction of that spectrum.

When we say "light", we mean *all* wavelengths, not just the ones we can see!

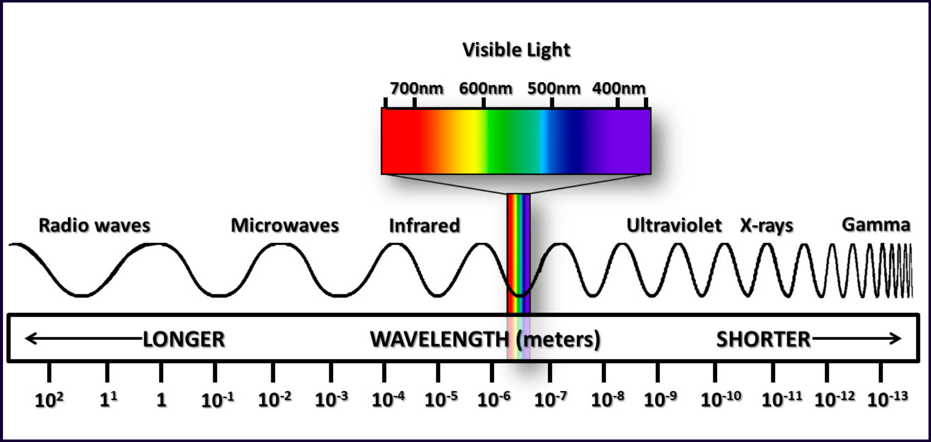
The electromagnetic spectrum



There is an enormous range of “colors” of light out there!

What’s this “sound” like?

The electromagnetic spectrum



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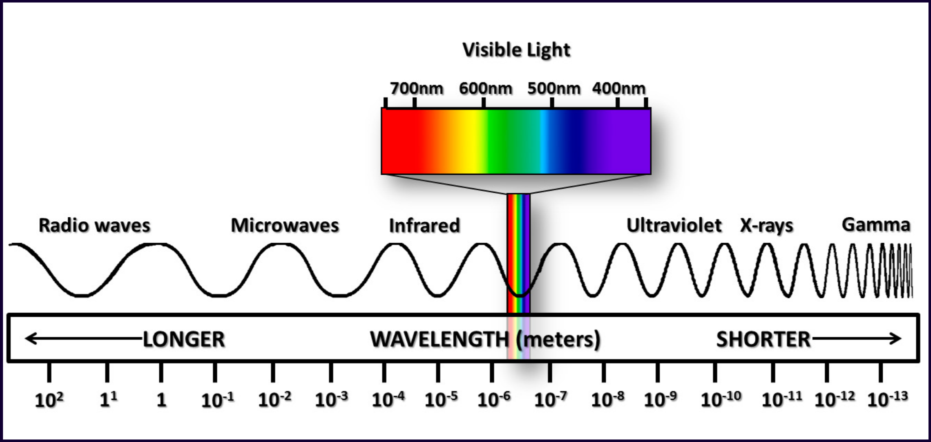

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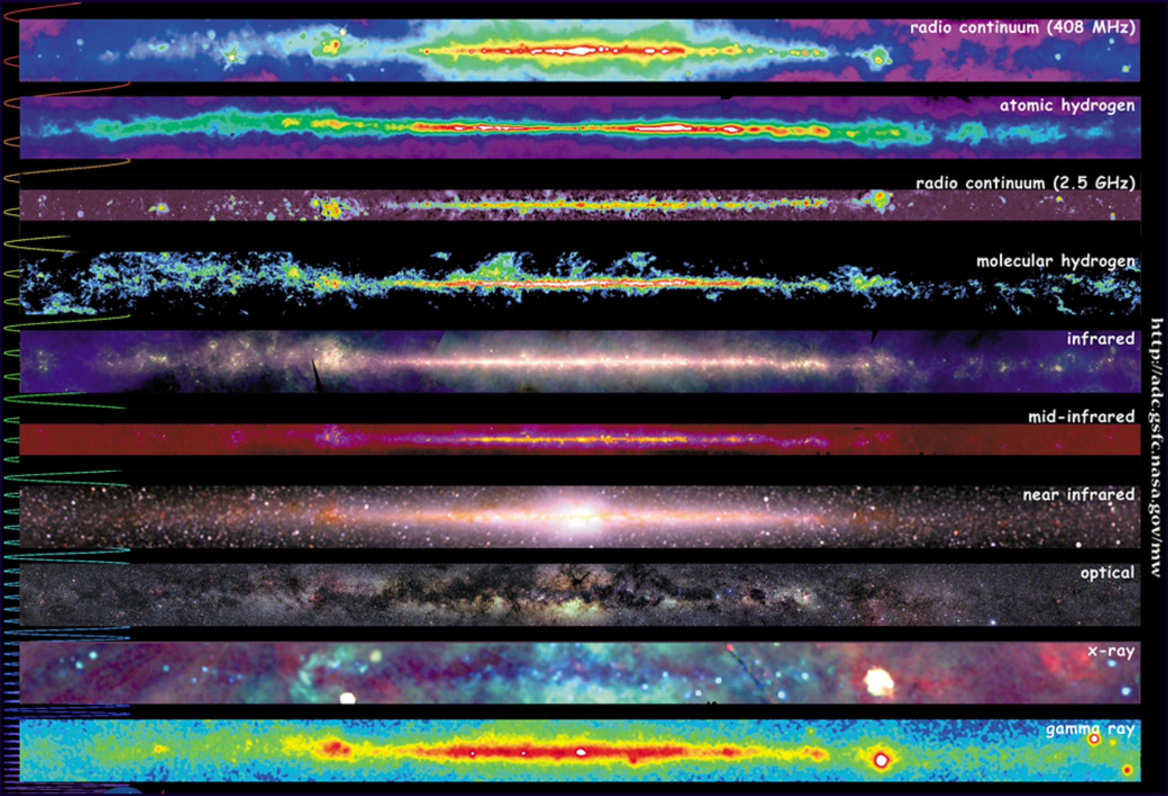
Music: "The Blood of Cu Chulainn", from the soundtrack to *Boondock Saints* (Jeff Danna, 1999)

We can learn far more about what's going on in the orchestra if we have the whole spectrum, rather than just a piece!


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw

An illuminating story

In the late 19th century, the laws of electromagnetism looked like this:

- Electric fields exert a force on electric charges
- Magnetic fields exert a force on *moving* electric charges

We know this thanks in large part to the work of Michael Faraday, who famously wasn't good at algebra and drew pictures of fields.

Where do these fields come from?

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- Moving electric charges make magnetic fields
- Changing magnetic fields make electric fields

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- ... which makes an electric field further away ...

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Last law added by James Clerk Maxwell in the 1860's, and it has a surprising consequence:

- Changing electric field makes a magnetic field
- ... which makes a magnetic field ...
- ... which makes an electric field further away ...
- This leads to a traveling electromagnetic disturbance: an *electromagnetic wave.*

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Independently, light had been measured to travel at 300 million meters per second some years prior.

So ... if this electromagnetic wave travels at the speed of light, perhaps it *is* light?

In the history of science, sometimes theory gets ahead of experiment – like in the discovery of the nature of light.

The properties of waves

Light is a traveling *electromagnetic wave*. This means:

- ... it moves through space at some speed: the speed of light, $c = 3 \times 10^8$ m/s.

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- ... it moves through space at some speed: the speed of light, $c = 3 \times 10^8$ m/s.
- ... these waves have a wavelength: the distance from peak to peak of the electric field. We use the letter λ for wavelength.
- ... and, as an observer holds still, a certain number of waves pass that observer per second. This is called the frequency, f.

How are these things related? Let's look at a simulation...

Three basic wave properties:

- Wave speed: c
- Wavelength: λ
- Frequency: f

If I keep c constant and increase f, then λ will ______________...

If I keep c constant and decrease f, then λ will ______________...

If I keep λ constant and increase c, then f will ______________...

This leads us to the basic relation:

$$c = f\lambda$$

This means:

- Shorter wavelengths have higher frequency
- Longer wavelengths have lower frequency

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... but later experiments (which we'll see soon) showed that it had to come in discrete chunks! What gives?

Is light a wave, or is it a bunch of little particles?

It turns out that, in quantum mechanics, it can be *both*, and everyone gets to be right!

The quantum nature of light

Light has both particle properties and wave properties:

- Particle properties: it comes in discrete chunks called *photons*, each carrying a certain energy.
- Wave properties: it has a wavelength λ and frequency f

It turns out that shorter-wavelength, higher-frequency light has higher energy per photon. The relationship is:

$$E = hf = hc/\lambda$$

You should know:

- Energy per photon is *proportional* to the frequency of the light
- Energy per photon is *inversely proportional* to its wavelength
- Wavelength is inversely proportional to frequency

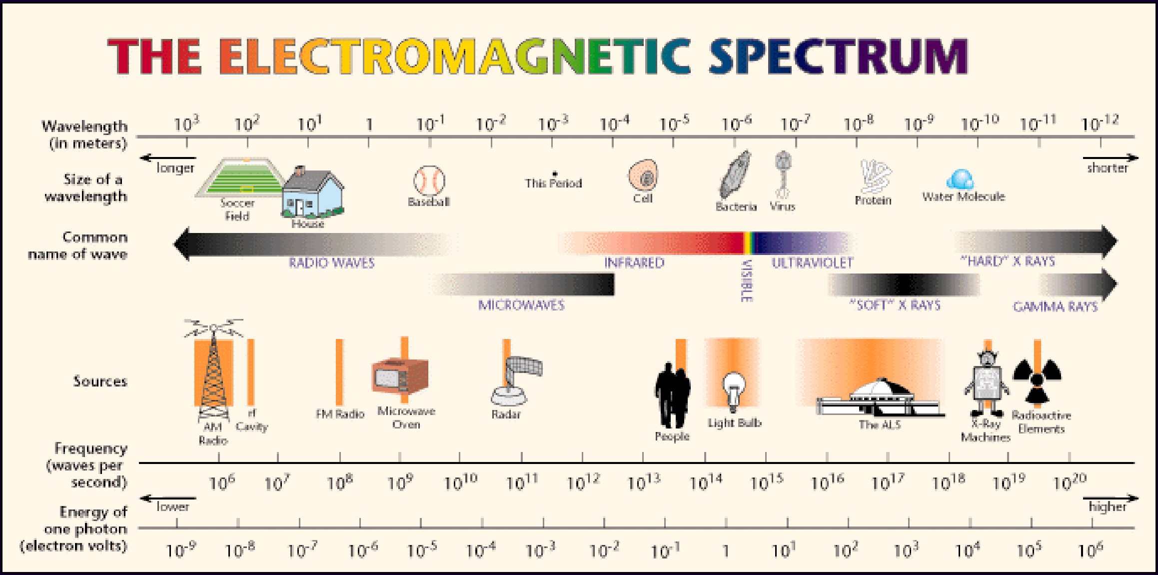
We have lots of names for different sorts of light.

They differ only in wavelength/energy/frequency, and the other things they interact with.

- Radio waves: used to communicate over long distances
- Microwaves: used to communicate over short distances
- "Far infrared": associated with objects with temperatures close to ours
- "Near infrared": much like light, but we can't see it
- Visible light (only a very narrow range!)
- Ultraviolet: enough energy to disrupt atoms
- X-rays: enough energy to penetrate human tissue
- Gamma rays: enough energy to disrupt atomic nuclei!

All of these are "types of light".

They differ only in wavelength/frequency/energy!



Complete *Lecture Tutorials* pp. 47-49.

We will play with some toys after this.