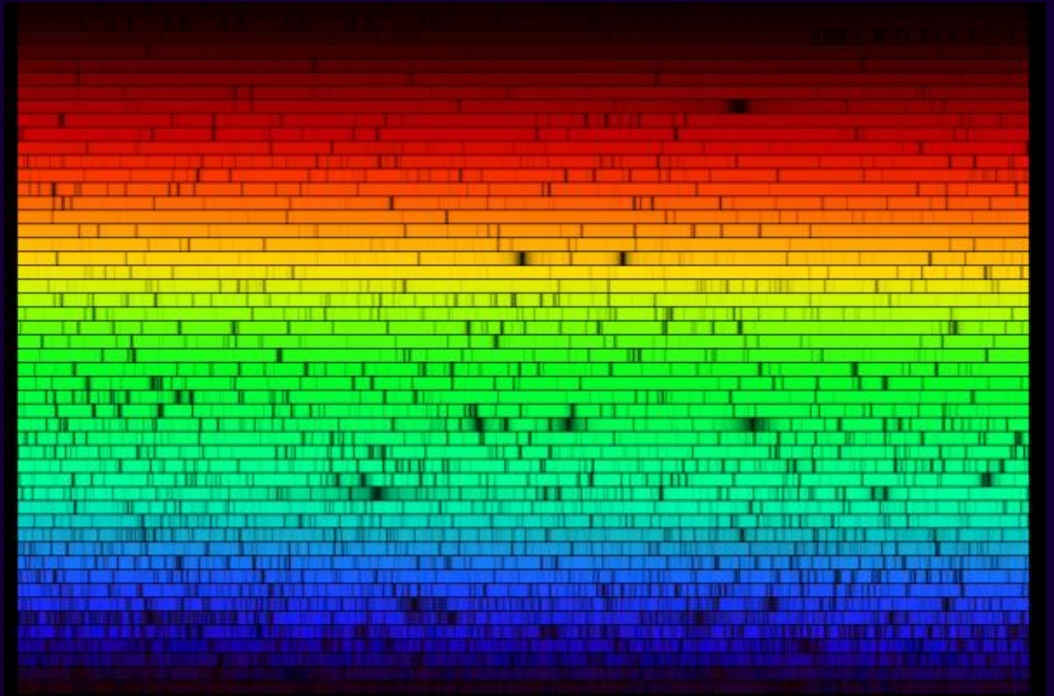


# Light

Astronomy 101  
Syracuse University, Fall 2019  
Walter Freeman

October 20, 2021



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

# Announcements

- I'm catching up after being out sick for a while
- I am way behind on answering email and messages because of this
- The Scantron folks closed early on Friday because of sportsball and I was out sick Monday
- You should have your Exam 2 grades late tomorrow
- I'll post an answer key with the exam tomorrow as well

# Paper 2

- Paper 2's assignment is posted
- It is due three weeks from tomorrow.

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- This paper is an argumentative paper:
  - You're telling us that someone else is wrong
  - You can be bold in making these claims, as long as you argue your point well!

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

Sounds can have a spectrum of frequencies and wavelengths, and we can only perceive a piece of that spectrum.

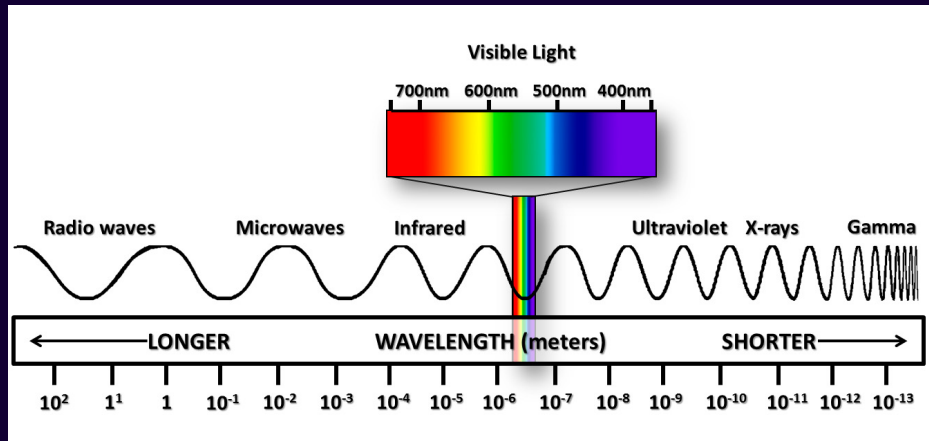


Sounds can have a spectrum of frequencies and wavelengths, and we can only perceive a piece of that spectrum.

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!

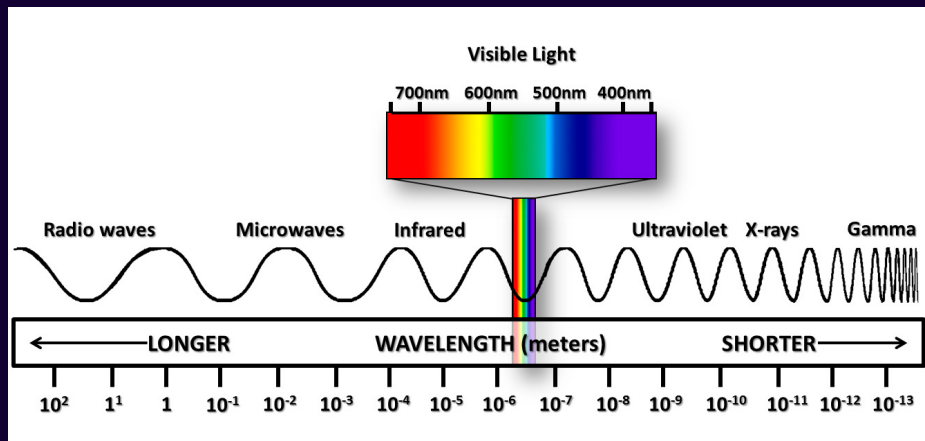
# The electromagnetic spectrum



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

What’s this “sound” like?

# The electromagnetic spectrum

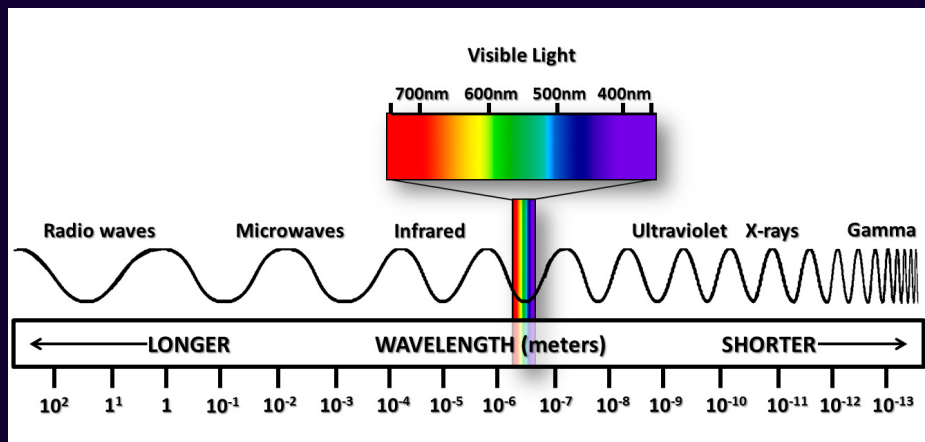


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Music: “The Blood of Cu Chulainn”, from the soundtrack to *Boondock Saints* (Jeff Danna, 1999)

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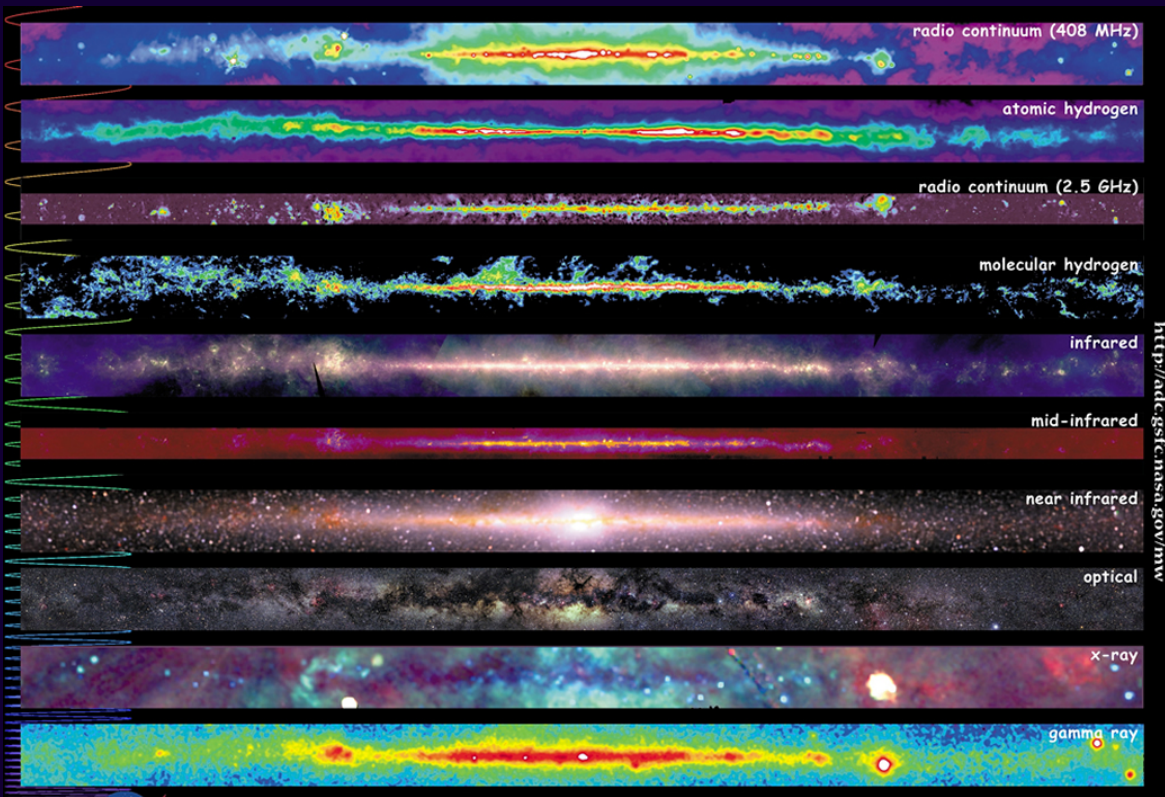


There is an enormous range of “colors” of light out there!

What’s this “sound” like?

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!



# 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?

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

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- ... which makes a magnetic field ...

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- ... which makes a magnetic field ...
- ... 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

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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  $\lambda$  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:  $\lambda$
- Frequency:  $f$

If I keep  $c$  constant and increase  $f$ , then  $\lambda$  will \_\_\_\_\_...

If I keep  $c$  constant and decrease  $f$ , then  $\lambda$  will \_\_\_\_\_...

If I keep  $\lambda$  constant and increase  $c$ , then  $f$  will \_\_\_\_\_...

This leads us to the basic relation:

$$c = f\lambda$$

Or in words:

$$(\text{speed of light}) = (\text{frequency}) \times (\text{wavelength})$$

This is easy to remember by thinking about how each quantity is measured:

$$\frac{\text{meters}}{\text{second}} = \frac{\text{waves}}{\text{second}} \times \frac{\text{meters}}{\text{wave}}$$

This means:

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

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Maxwell deduced that it was a **wave**, and experiments confirmed that.

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

... 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**  $\lambda$  and **frequency**  $f$

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

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

This value  $h$  is called Planck's constant. It is baked into the fabric of the Universe, like  $G$  and  $c$ :

- $G$ , the universal gravitational constant: tells us how strong gravity is
- $c$ , the speed of light: tells us how fast light goes

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- $G$ , the universal gravitational constant: tells us how strong gravity is
- $c$ , the speed of light: tells us how fast light goes
- $h$ , Planck's constant: tells us how “lumpy” light is: how much energy do photons of a given frequency have?

## Things you should know:

Light is both a particle and a wave.

- All light travels at the same speed,  $c = 300$  million m/s, in vacuum
- Light comes in little lumps called *photons*
- 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.

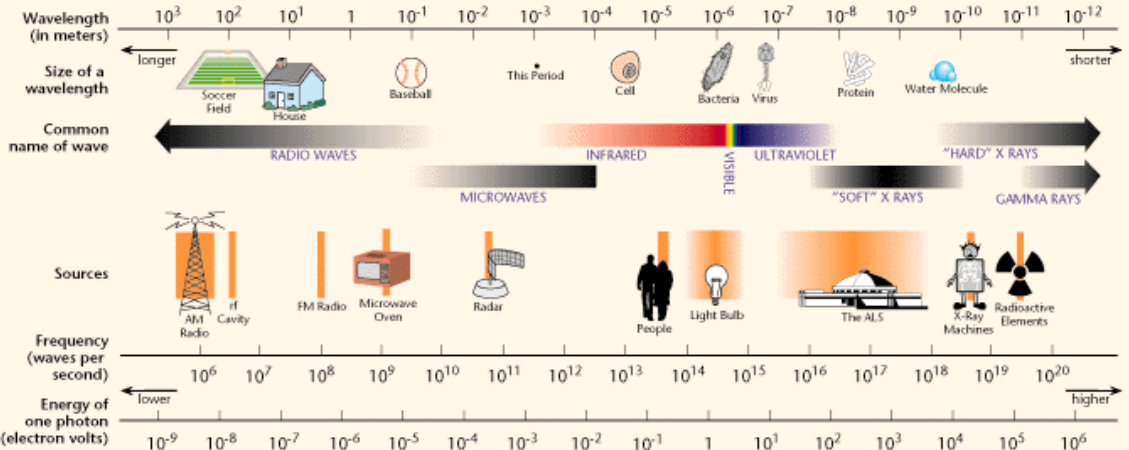
- Radio waves: used to communicate over long distances
- Microwaves: used to communicate over short distances
- “Far infrared”: associated with objects with temperatures close to ours
- “Near infrared”: much like light, but we can’t see it
- Visible light (only a very narrow range!)
- Ultraviolet: enough 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!

# THE ELECTROMAGNETIC SPECTRUM



Complete *Lecture Tutorials* pp. 47-49.

We will play with some toys after this.