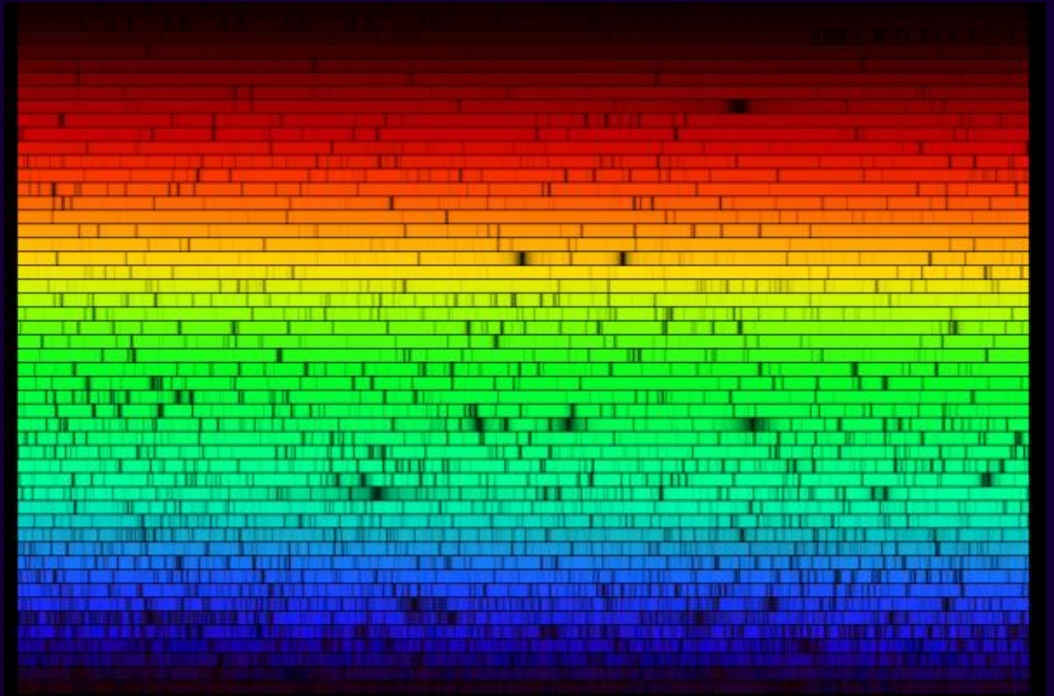


Light

Astronomy 101
Syracuse University, Fall 2019
Walter Freeman

October 14, 2020



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

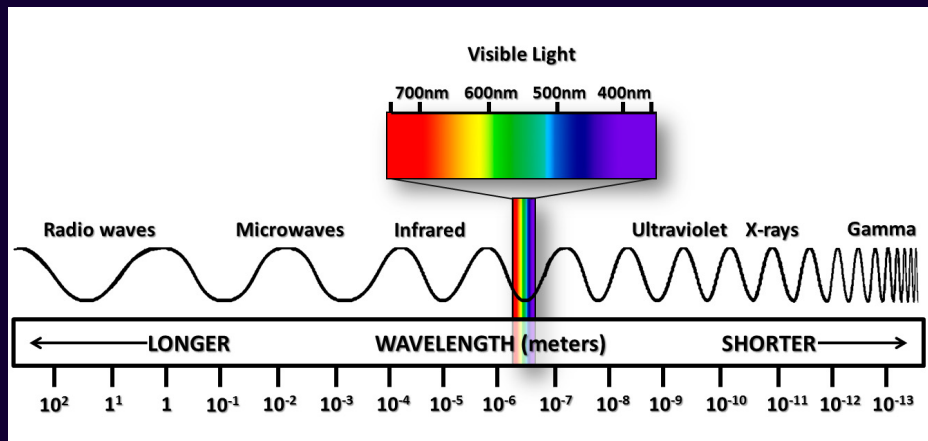
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In the same way *light* has a spectrum of frequencies/wavelengths, and our eyes only perceive a tiny fraction of that spectrum.

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

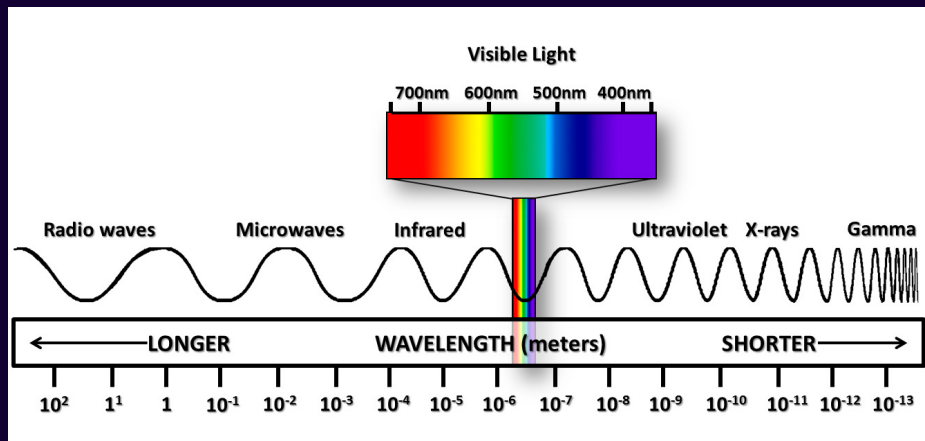
The electromagnetic spectrum



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

What’s this “sound” like?

The electromagnetic spectrum

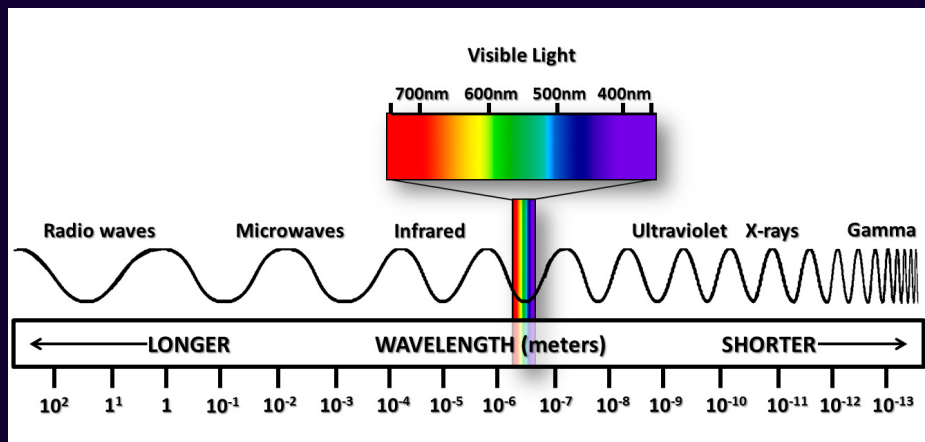


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Music: “The Blood of Cu Chulainn”, from the soundtrack to *Boondock Saints* (Jeff Danna, 1999)

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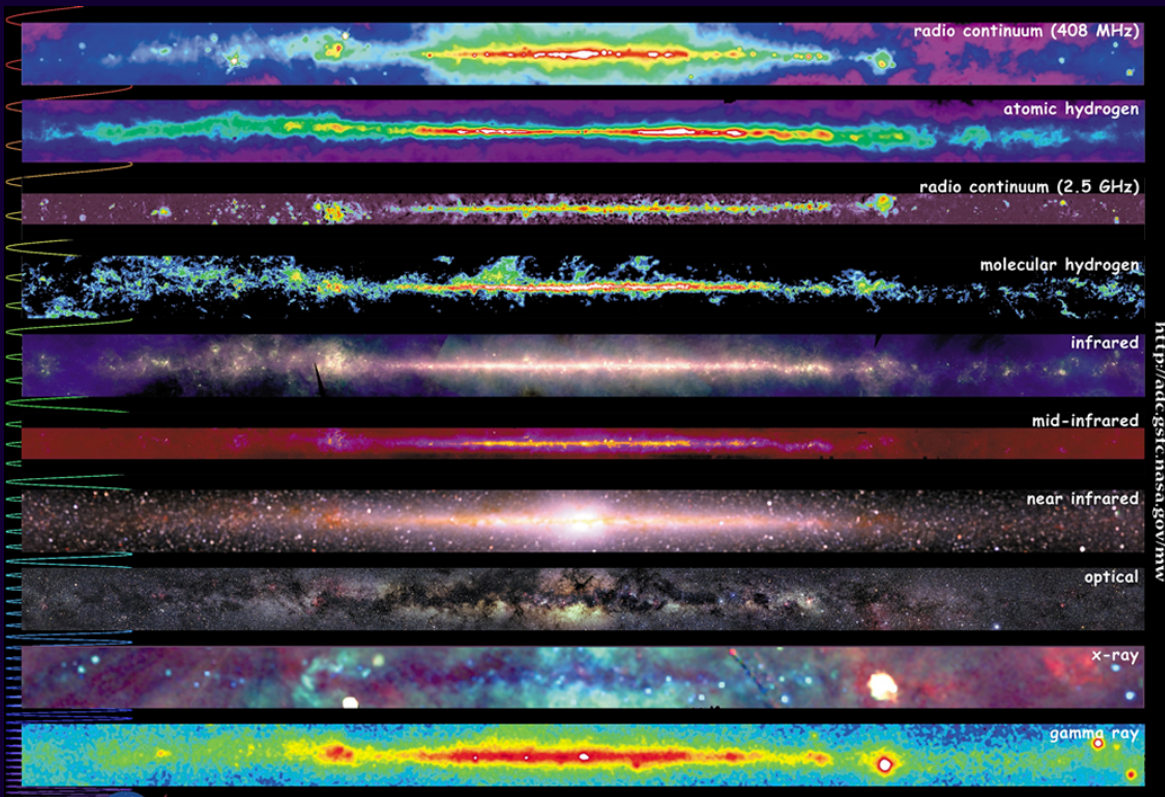


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What’s this “sound” like?

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.

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

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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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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.
- ... 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:

$$c = f\lambda$$

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** λ and **frequency** f

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

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

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

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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.

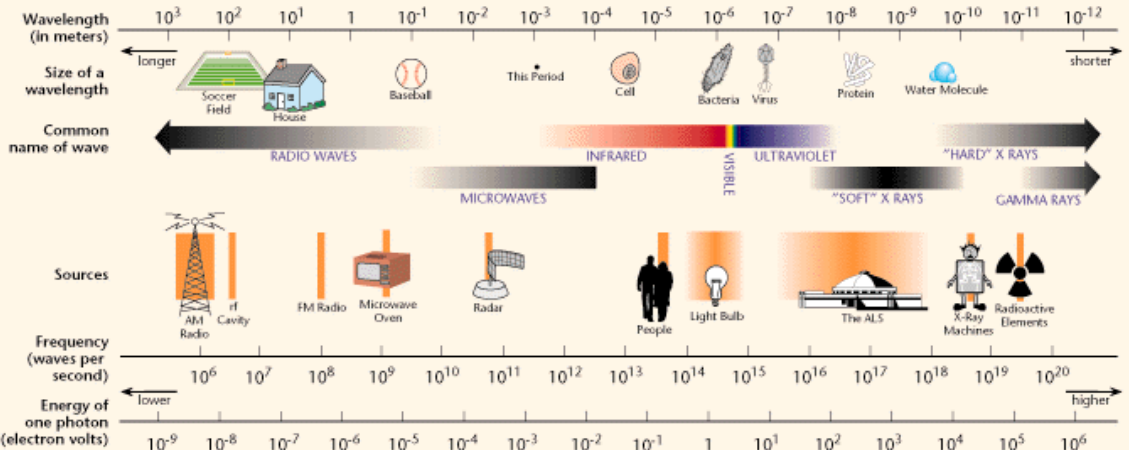
They differ only in wavelength/energy/frequency, and the other things they interact with.

- 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.