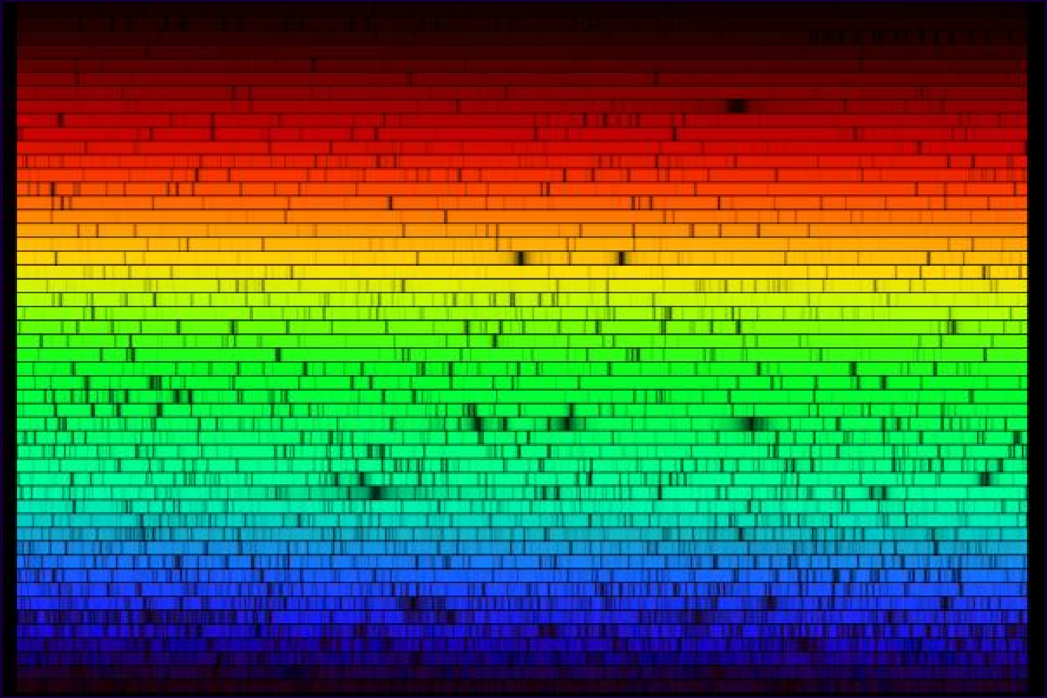
Light

Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

October 15, 2020



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

Announcements

- We are trialling a new system for playing audio over Zoom today (it turns out there are several severe bugs in the Linux version of Zoom)
- ... this means I can *FINALLY* play music during class!
- Please let me know how it goes and if there are any problems

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Paper 2

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  - It is due October 26 if you don't participate in peer review
  - First draft due October 23 if you do; final draft due November 1
  - More details about peer review, and how to sign up, coming later

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  - First draft due October 23 if you do; final draft due November 1
  - More details about peer review, and how to sign up, coming later
- 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!

A few slides we didn't get to last time

Two things are both true:

- Some scientific findings can dramatically change our lives and our perspective on the world, and are compelling and exciting
- Whether a scientific claim is true or not doesn't depend on whether it's exciting or not (objectivity)

Scientists thus have twin duties:

- They should engage with society in sharing the excitement and interest of their findings. Science communication is vital (and many of us are bad at it; the astronomers do better than the physicists!)
- They should separate this excitement from the task of evaluating the validity of claims

Sensationalism

Beware of any sort of scientific claim that conflates the evidence that it is true with why you should be excited by it, or that seems to be hyped by its claimant.

Good scientists do hold press conferences, because many discoveries are exciting!

But these happen only in the context of:

- a vast amount of self-skepticism applied to their results first
- objective, sober presentation of the *evidence* for their conclusions

On grades

If there is something wrong with your grades:

- **Don't** send an email cc: everyone telling us that there is something wrong, without details
- **Do** help us fix it: find the original email where you submitted your work and *forward* it to your lab TA.
- If you don't know who your lab TA is, see the Blackboard announcement / email
- I can post the schedule on the website, too

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- I can post the schedule on the website, too
- ... but you really do need to know who your TA is (they're there on Collaborate during lab every week, and you likely met them in person earlier)

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.

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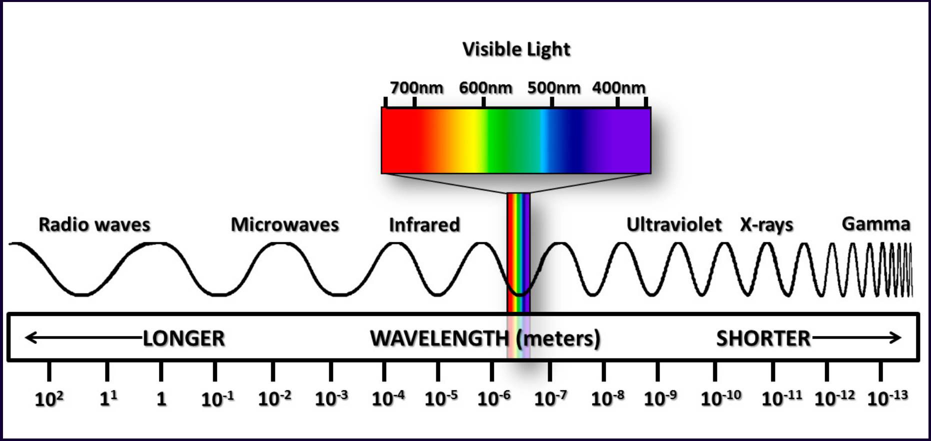
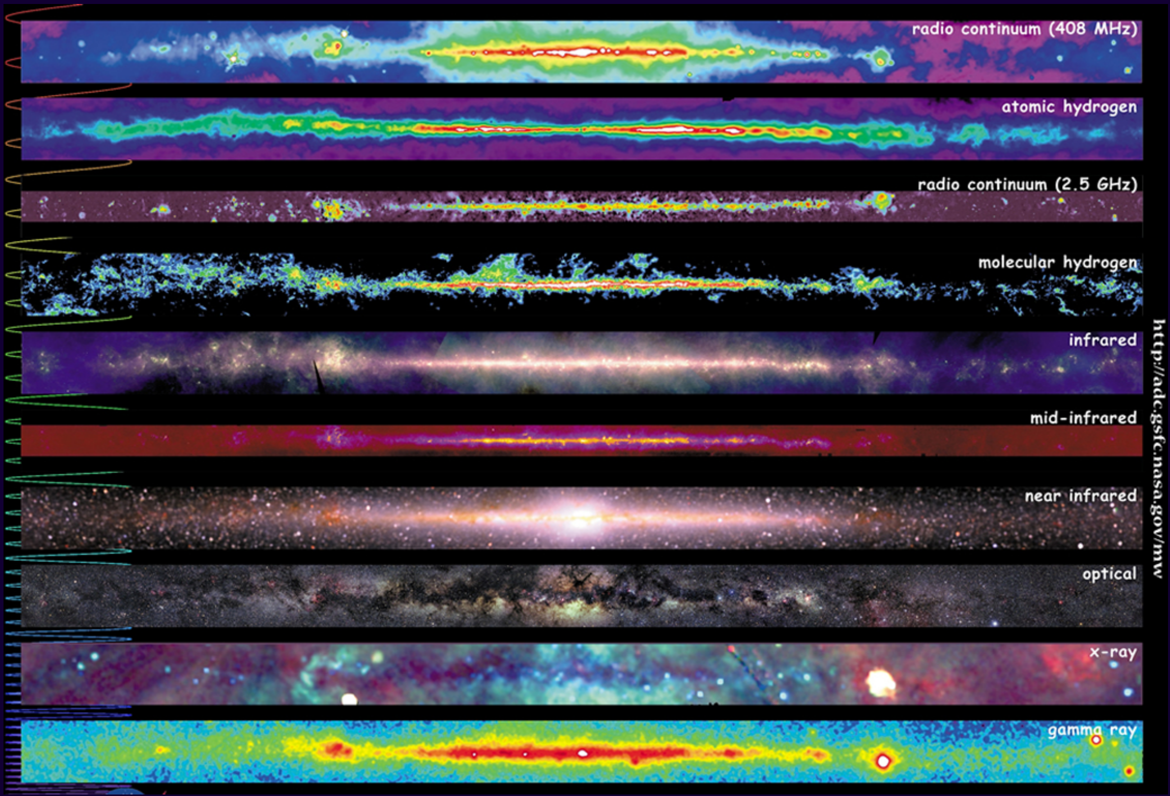
In the same way *light* has a spectrum of frequencies/wavelengths, and our eyes only perceive a tiny fraction of that spectrum.
When we say "light", we mean *all* wavelengths, not just the ones we can see!

The electromagnetic spectrum



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

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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- Changing magnetic fields make electric fields

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

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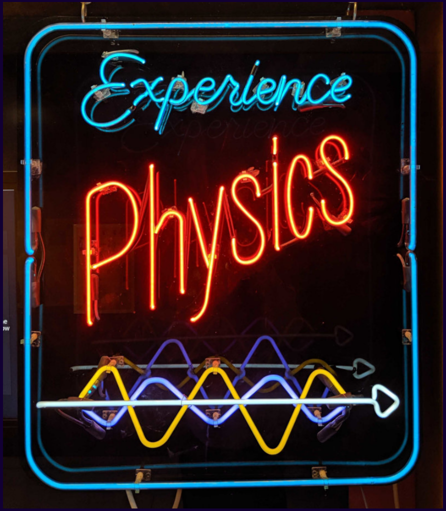
Last law added by James Clerk Maxwell in the 1860's, and it has a surprising consequence:

- 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

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- ... 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!