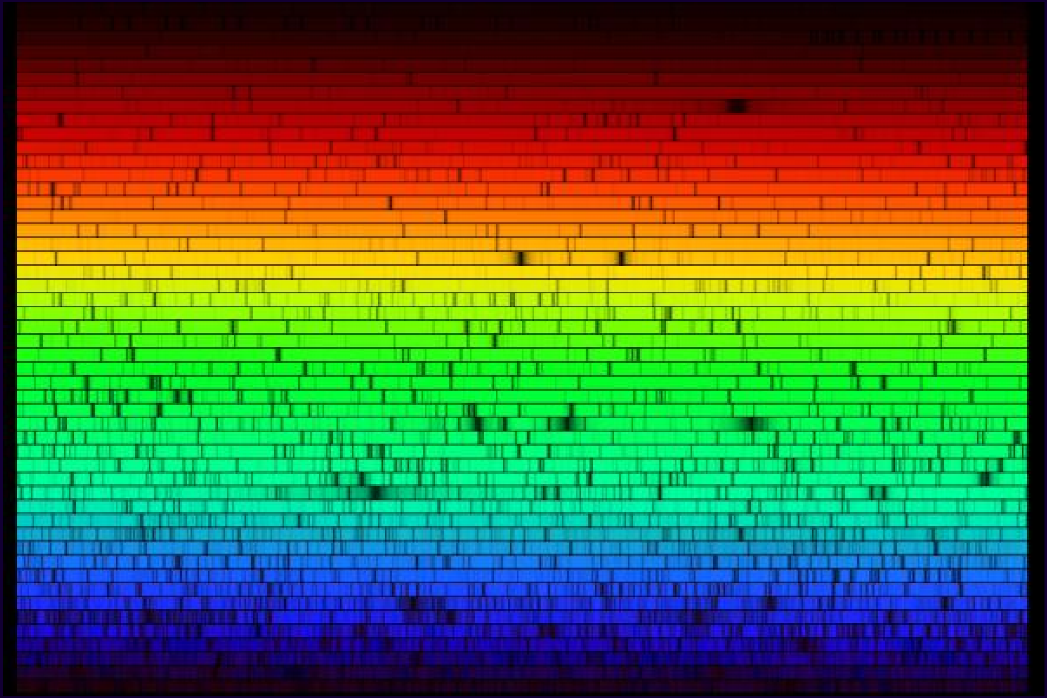
Light

Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

October 20, 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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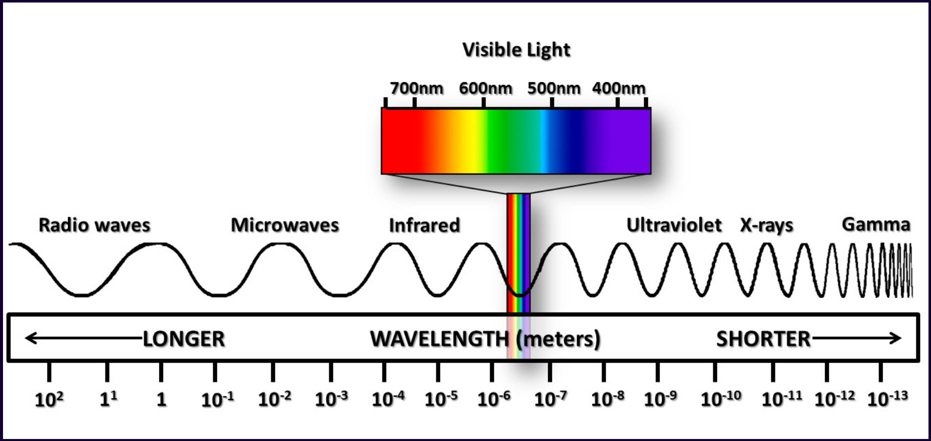
  - It is due October 26 if you don't participate in peer review
  - First draft due October 23 if you do; final draft due November 1
  - More details about peer review, and how to sign up, coming later
- This paper is an argumentative paper:
  - You're telling us that someone else is wrong
  - You can be bold in making these claims, as long as you argue your point well!

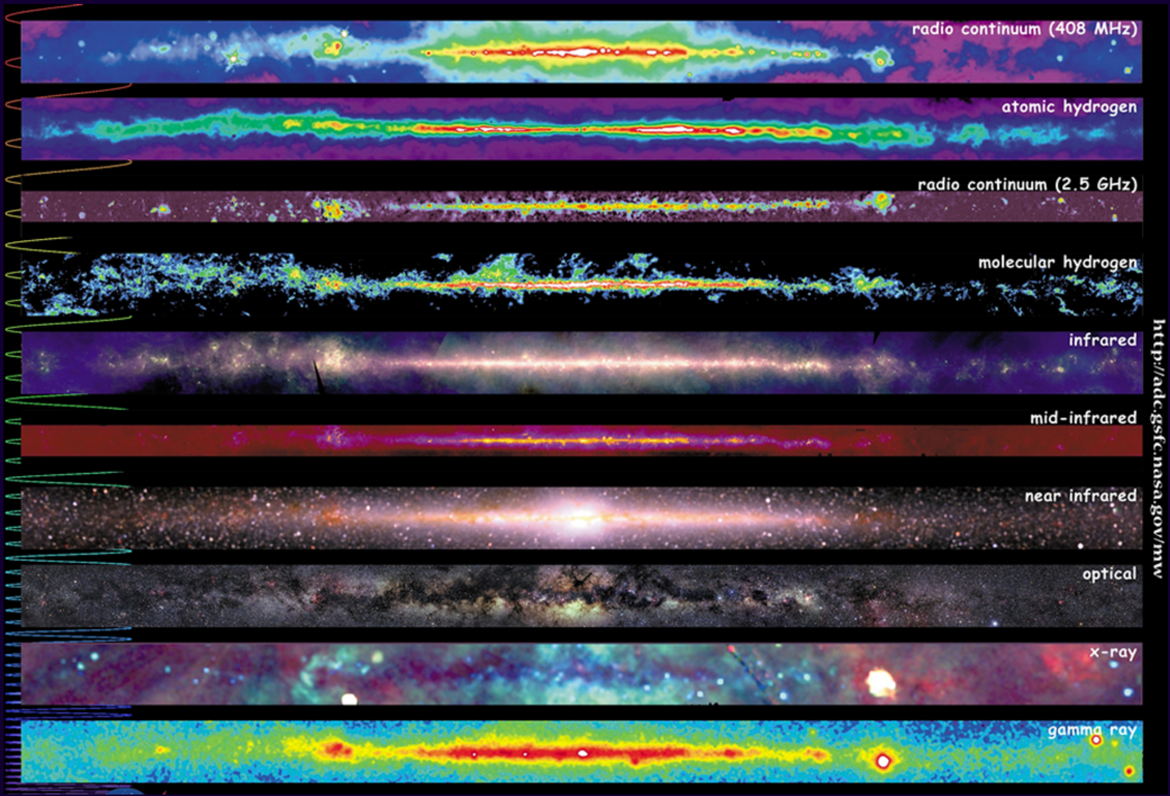
The electromagnetic spectrum



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

When we talk about “light”, we mean them *all!*

If I mean only the light we can see, I’ll say “visible light”.


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

Last time

Last time we saw that:

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

But we know that different wavelengths of light have very different *properties*:

- Radio waves pass through nearly everything without much effect
- "Far infrared" light is associated with heat on Earth
- "Near infrared" and visible light can be associated with different chemicals (and causes chemical change in our eyes)
- Ultraviolet light can cause skin cancer
- X-rays pass through our bodies
- Gamma rays are associated with nuclear reactions

... why?

Particles vs. waves

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Which model is right? How do you know?

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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

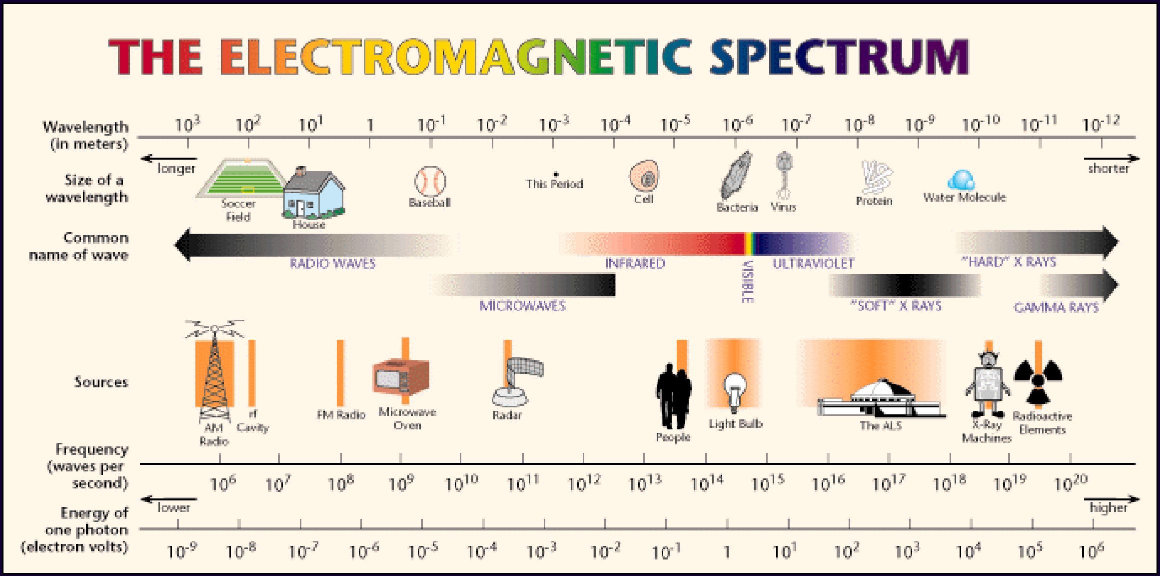
We have lots of names for different sorts of light.

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!): produced by very hot objects
- 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!



Light and spectra

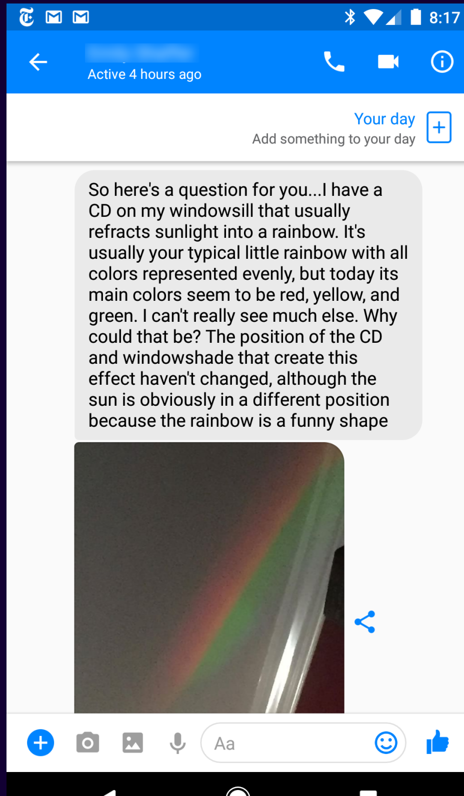
White light isn't really white; it's a mix of many colors (wavelengths).

Our eyes are very limited; we can only distinguish between three colors.

We can learn a lot about an object by the colors of light it emits, but we have to be able to see them first!

We do that by spreading them out. Then we can see what colors are there in great detail.

A friend sent me this three years ago, the day before this topic:



The two pictures:

Shortly after sunrise:

Later in the day:

The two pictures:

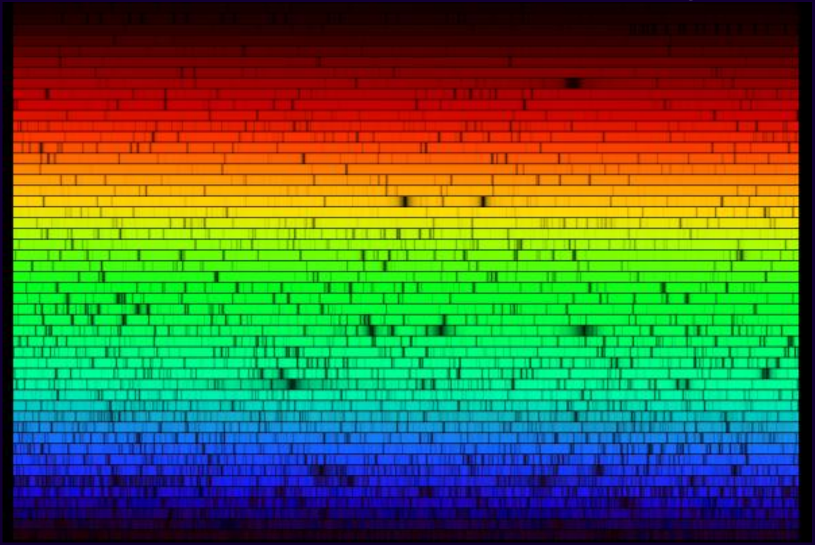
Shortly after sunrise:

Later in the day:

What is different?

What happened here?

Let's look at that picture of the Sun again:



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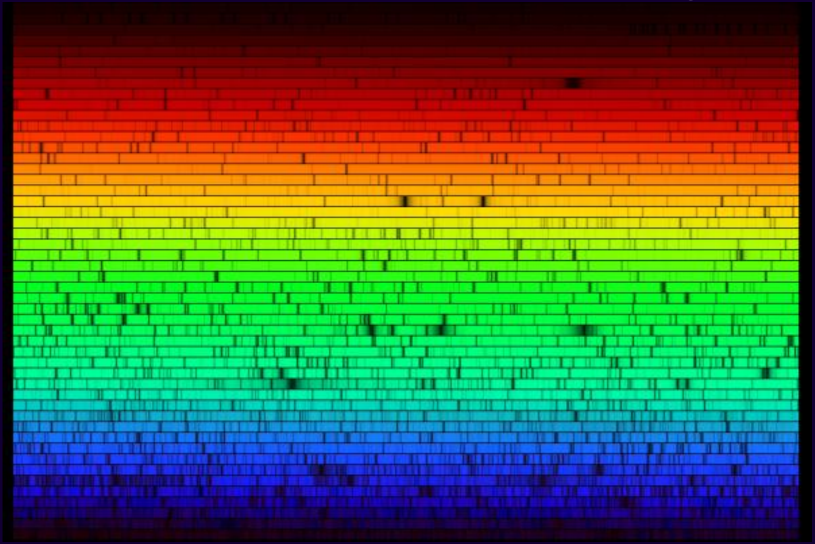
Let's look at that picture of the Sun again:



Need to understand:

- Where did all those colors come from in the first place? (today)
- Why are there dark lines? (next Tuesday)

Why does the sun shine?

A: Chemical reactions make light!

B: Nuclear reactions make light!

C: It's really hot, so it glows

D: That's just what stars do

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E: Google to the rescue!

Incandescence

"The sun is a mass of incandescent gas" – what does that mean?

Objects glow because they're hot. This is called *thermal radiation*.

- Any object with a temperature emits electromagnetic radiation ("light").
- For objects as warm as we are, this is in the "far infrared".
- As objects heat up, the peak wavelength decreases (the average photon energy increases)
- As objects heat up, the total intensity emitted goes up *rapidly* (proportional to T^4)
- This is also called "blackbody radiation" (since even a black object glows because of its temperature)

What will happen if I turn the power up on the lamp?

A: The height of the graph will go up

B: The graph will shift left

C: The graph will shift right

D: The height of the graph will go down

Takeaways: thermal radiation

- Any object with a temperature glows
- Hotter objects glow "bluer" (shorter wavelengths) and brighter
- Hotter objects emit more light per unit area (of all wavelengths)
- A larger object that is cold (large red star) may emit more total light than a small object that is hot (small yellow star)
- This glow is a *broad spread of wavelengths* – there aren't narrow bright or dark lines in it

See the simulation to see how this works...

Measuring temperature

Physicists measure temperature using the Kelvin scale, where 0 K is absolute zero, and the "degrees" are the same size as Celsius:

Temperature	Celsius (approx)	Object	Thermal Radiation
0 K	-273 C	Absolute zero	N/A
3 K	-270 C	The universe	Microwave
273 K	0 C	Melting ice	Far infrared
300 K	27 C	Room temperature	Far infrared
310 K	37 C	Body temperature	Far infrared
373 K	100 C	Boiling water	Far infrared
2500 K	2200 C	Incandescent lightbulb; cool star	Near infrared / red
5800 K	5500 C	Star like the Sun	Visible
15000 K	15000 C	Hot star	Blue / UV
60000 K	60000 C	Extraordinarily hot star	UV
Millions	Millions	Gas spiraling into black hole	X-ray

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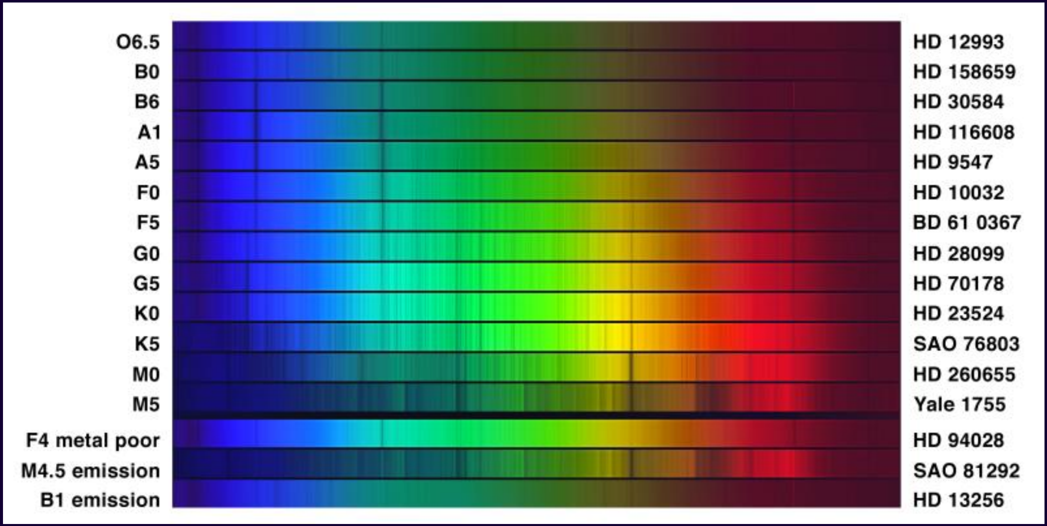
Would it work if objects in the room had temperatures of a few Kelvin rather than a few hundred Kelvin?

What will happen to the image from the visible-light camera if I turn out the lights in the room?

What will happen to the image from the infrared camera if I turn out the lights in the room? How does the infrared camera work?

Would it work if objects in the room had temperatures of a few Kelvin rather than a few hundred Kelvin?

What if they had temperatures of a few thousand Kelvin rather than a few hundred Kelvin?



Here are spectra from a lot of stars.
What can we conclude from them?