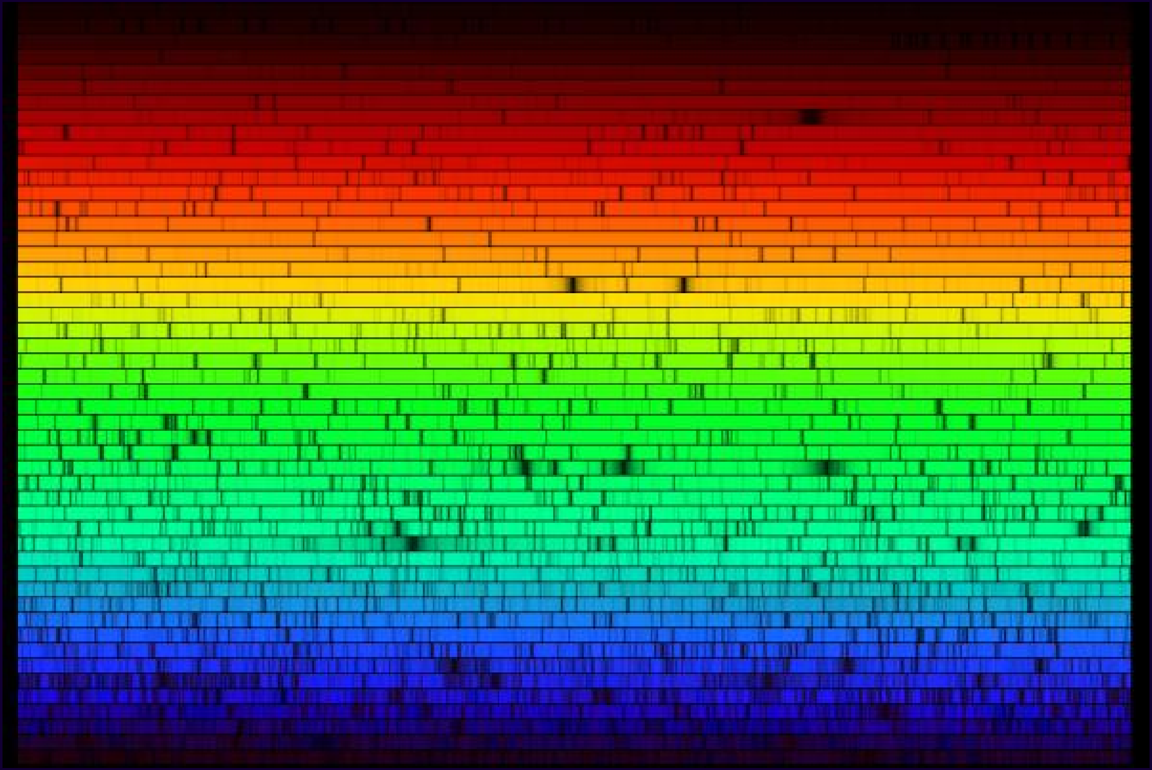
Thermal radiation and spectroscopy

Astronomy 101
Syracuse University, Fall 2022
Walter Freeman

October 25, 2022



Announcements

- Paper due Nov 3 (not Nov 1)
- A few of our coaches have offered to help people with paper drafts:
  - Kiersten Edwards - kedwar03@syr.edu
  - Xinning Li - xli287@syr.edu (bilingual in English and Chinese)

Announcements

Slight modification to the planned homework schedule:

- Just one homework assignment this unit
- It will be assigned Thursday (next class)
- It will be due the following Thursday
- We'll have time for questions, plus a quiz that day

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- (This is also the new date your papers are due – don't do everything at the last minute!)

Exam 2 retrospective

Confession time:

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- We're going to rescale the grades to reflect this
  - Your letter grade will thus be higher than what's written on your exam
  - It will also be worth slightly less

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

We thus have three ways to distinguish different colors:

"Redder" colors (red, infrared, microwave, radio) have:

- Longer wavelengths
- Less energy per photon
- Lower frequencies (we usually don't care)

"Bluer" colors (blue, ultraviolet, x-rays, gamma rays) have:

- Shorter wavelengths
- More energy per photon
- Higher frequencies (we don't care)

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!

Types of light

As you go down the table:

- Wavelength decreases
- Frequency increases (not shown)
- Energy per photon increases

Types of light

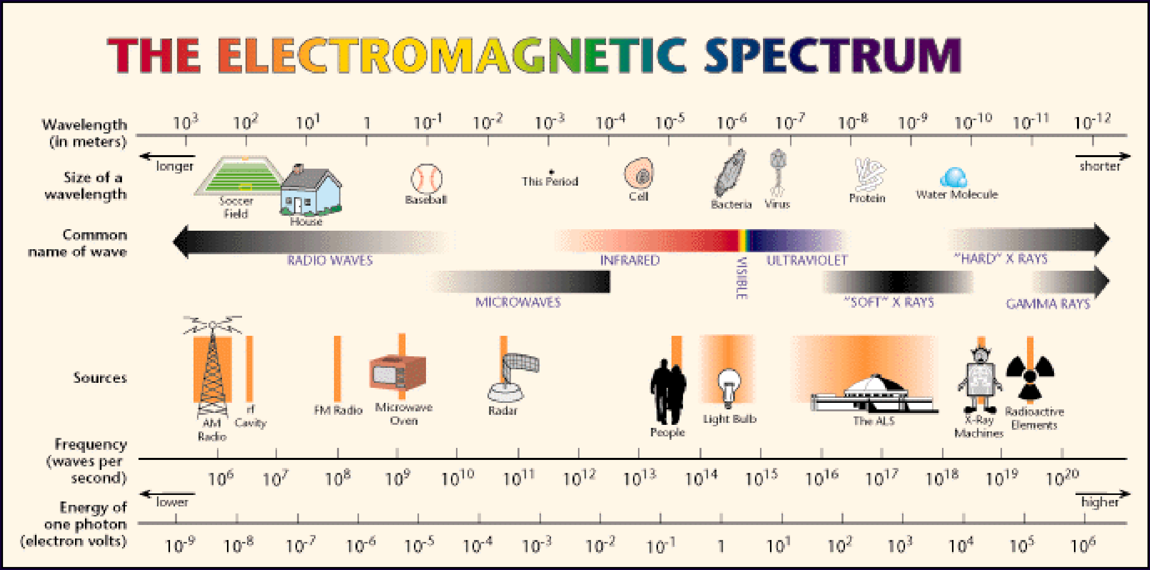
As you go down the table:

- Wavelength decreases
- Frequency increases (not shown)
- Energy per photon increases
- These are just names – all light is really the same kind of thing

	Wavelength	Energy	Application
Radio waves	100 meters - 1 meter		Long distance communication
Microwaves	1 meter - 1 cm	Too small to matter	Short distance communication
"Far infrared"	1 cm - 10 μm	Thousandths of an eV	Radiated by room temp objects
"Near infrared"	750 nm - 10000 nm	Tenths of an eV - 1.6 eV	"Invisible light"
Visible light	380-750 nm	1.6 eV - 3.2 eV	Eyeballs!
Near ultraviolet	100-380 nm	3.2 eV - 10 eV	"Invisible light"
Extreme ultraviolet	1 nm - 100 nm	10 eV - 1000 eV	Etching computer chips
X-rays	Trillionths of a meter	1000 eV - 1 million eV	Medical imaging
Gamma rays	Too small to matter	Millions of eV	Nuclear transitions

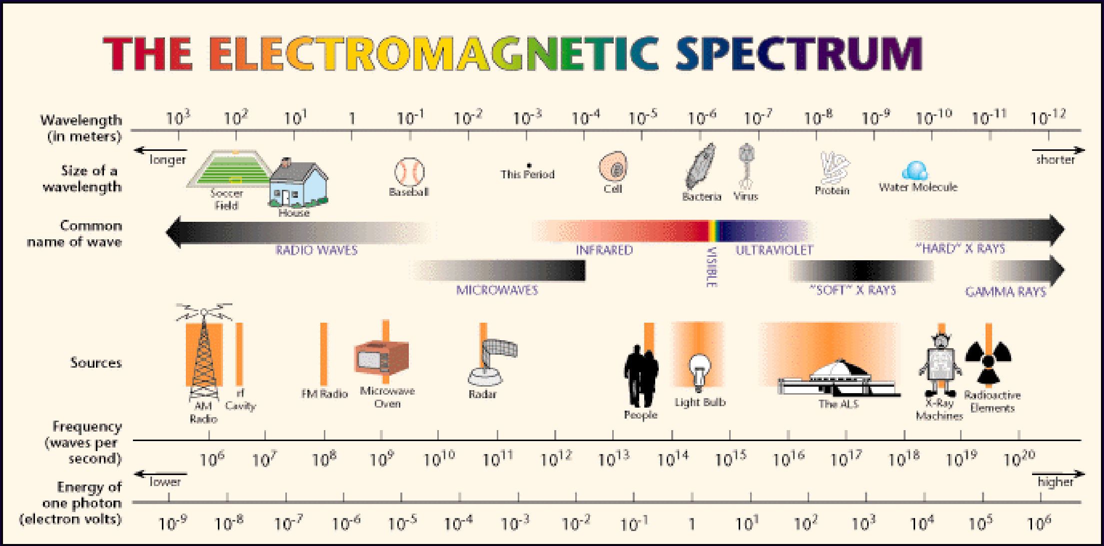
All of these are "types of light".

They differ only in wavelength/frequency/energy!



Lots of folks are curious about different types of “radiation” – in particular, how it can affect human health.

Do you have any questions about this?



Light and spectra

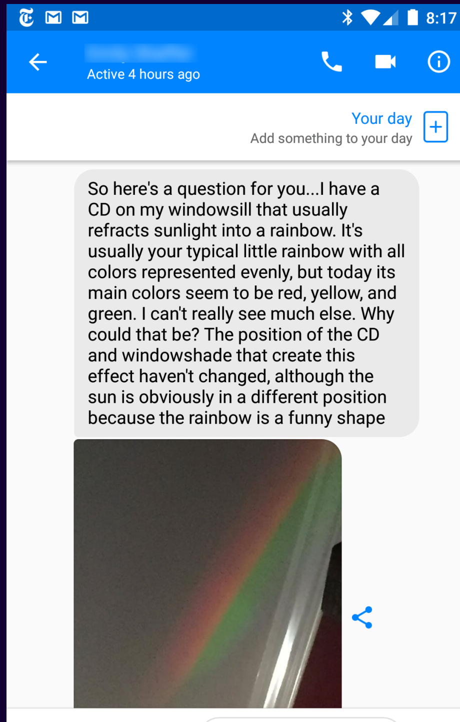
White light isn't really white; it's a mix of many colors (wavelengths).

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 a few years ago, the day before we did 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?

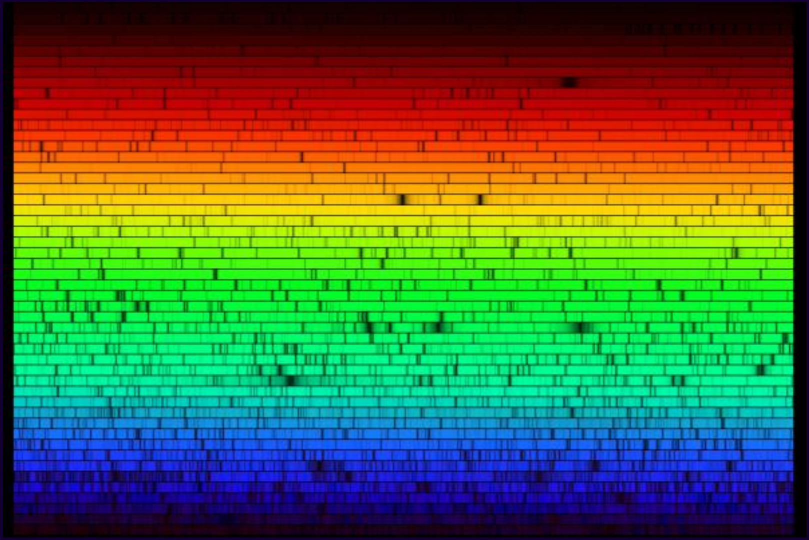
A: There's less blue light right after sunrise because the Sun is different then

B: The colors are in a different order earlier in the day

C: All the colors are fainter right after sunrise

D: There's less blue light right after sunrise because something happened to the light as it was traveling here

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



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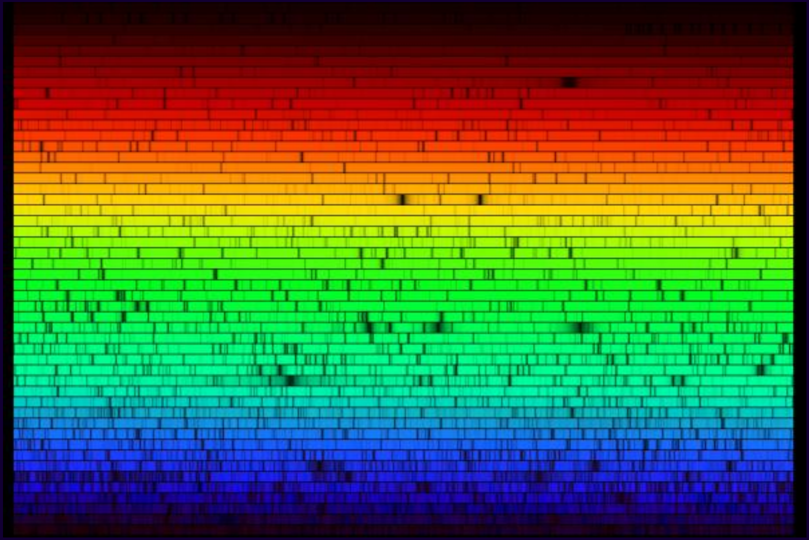

Need to understand:

- Where did all those colors come from in the first place? (today)
- What can we learn about the sizes and temperatures of stars by their colors (next Tuesday)
- Why are there dark lines? (next Thursday)

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 if it's warmed up)

See the simulation to see how this works...

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

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

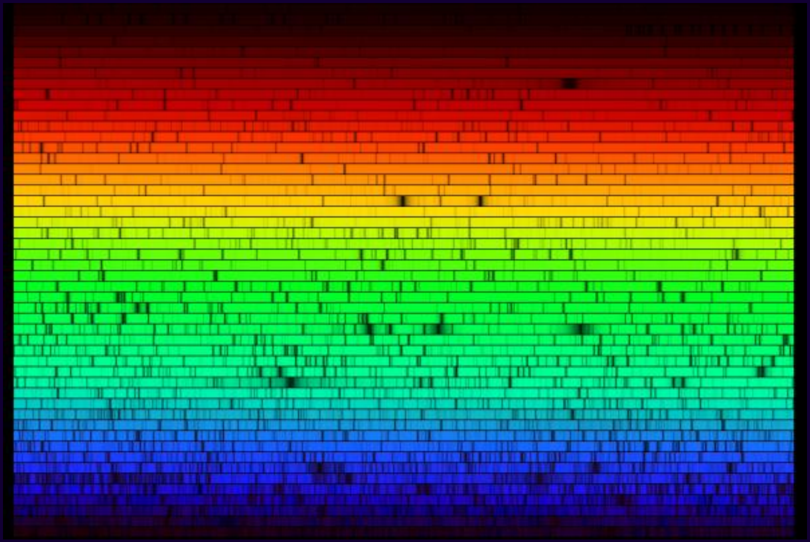
Another table

It's important to know, roughly, what temperature objects emit radiation of what wavelengths (mostly):

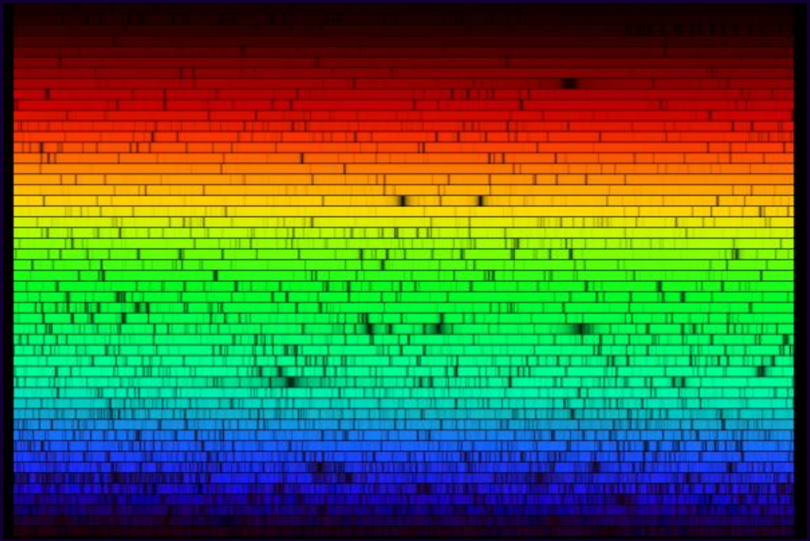
Name	Temp (Kelvin)	Temp (Celsius)	Object
Microwaves	3	-270	The universe itself
Infrared	300	30	Stuff on Earth
Near infrared	1500	1200	A candle flame (mostly IR, some red)
Visible (middle)	5000	5000	A star like the Sun
Ultraviolet	Tens of thousands	Tens of thousands	A very hot star, like Rigel
X-ray	Millions	Millions	Gas falling into a black hole

Let's practice this.

This sort of thing will be on your homework (assigned Thursday) and on the following homework quiz.



- The hot core of the Sun emits light of all wavelengths



- The hot core of the Sun emits light of all wavelengths
- The gases in the cooler atmosphere absorb very particular colors ... but why, and which ones?