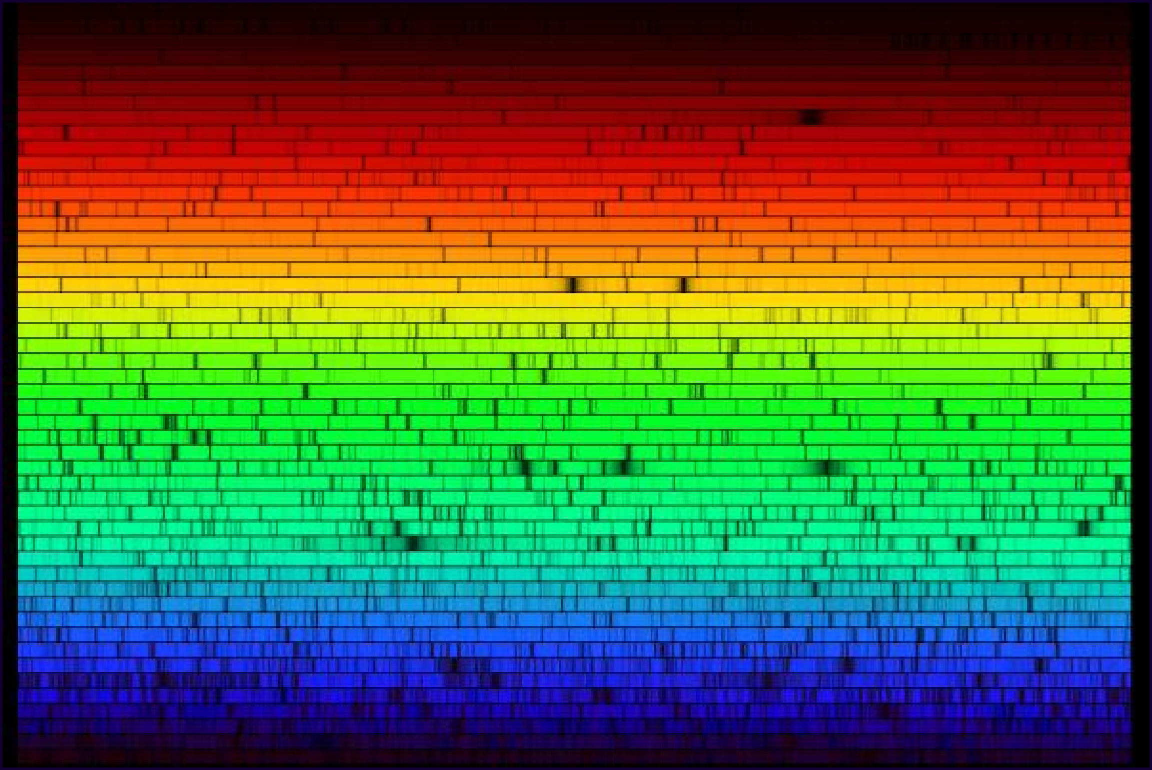
The Sun

Astronomy 101
Syracuse University, Fall 2017
Walter Freeman

November 1, 2017



Announcements

- Exam 3 on Tuesday

Announcements

- Exam 3 on Tuesday
- Study guide and last year's exam posted
- Solutions to last year's exam will be posted on Friday
- Extra study sessions for groups of 4+ only: Friday 2-5, Saturday 10AM-1PM, in the Physics Clinic

Announcements

- Exam 3 on Tuesday
- Study guide and last year's exam posted
- Solutions to last year's exam will be posted on Friday
- Extra study sessions for groups of 4+ only: Friday 2-5, Saturday 10AM-1PM, in the Physics Clinic
- Grade calculator posted on course website
  - Please don't email me about exactly how participation grades are calculated; I've not determined that yet

Chemistry: all I want you to know

- Electrons occupy certain **energy levels**
- The particular energies that these levels have is **unique** to particular elements: hydrogen has different allowed energies than mercury or neon or sodium etc.
- An atom can absorb a photon and jump up to a higher level, conserving energy
- ... an atom in a higher level can emit photons, jumping back down, conserving energy.
- The photon's energy is equal to the *difference* between the two energy levels

... that's it. :)

If I take hydrogen and tear the electrons off of the atoms with an electric current, they'll "fall" back down, going through the energy levels down to $n = 1$.

Sometimes they'll skip energy levels; sometimes they'll go in sequence.

If I do this to hydrogen, what color will we see?

A: UV: we won't see it, since the transitions down to $n = 1$ are in the UV

B: Several shades of red: we'll see the transitions down to $n = 2$, which are red

C: Infrared: the transitions at the top are very low energy, corresponding to infrared light which we can't see

D: UV, IR, and red, all at once: all the transitions happen, but we only see the red photons because of the limits of our eyes

If I take hydrogen and tear the electrons off of the atoms with an electric current, they'll "fall" back down, going through the energy levels down to $n = 1$.

Sometimes they'll skip energy levels; sometimes they'll go in sequence.

If I do this to hydrogen, what color will we see?

A: UV: we won't see it, since the transitions down to $n = 1$ are in the UV

B: Several shades of red: we'll see the transitions down to $n = 2$, which are red

C: Infrared: the transitions at the top are very low energy, corresponding to infrared light which we can't see

D: UV, IR, and red, all at once: all the transitions happen, but we only see the red photons because of the limits of our eyes

E: Orange, because this is Syracuse, darnit!

Complete *Lecture Tutorials* pp.63-69.

After this, we'll talk about another application of this idea.

Emission spectra

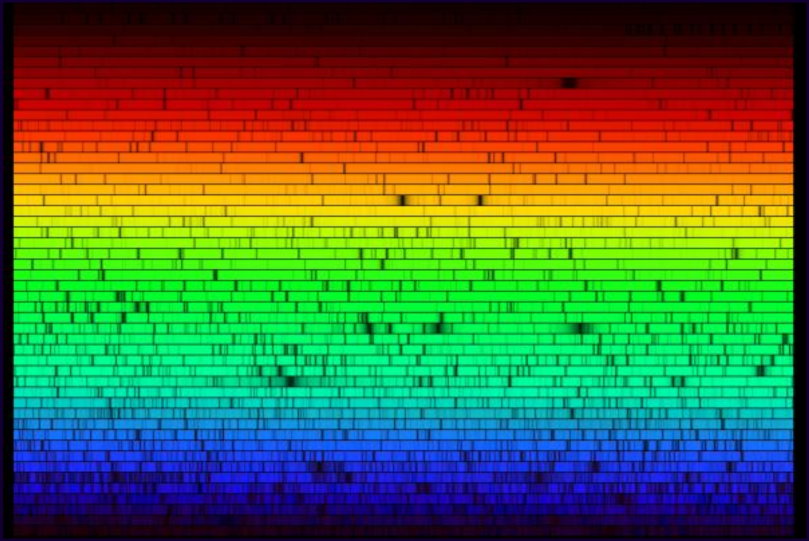
Every chemical element has a unique *spectrum*: the colors of light that it can emit and absorb.

Other colors simply pass through.

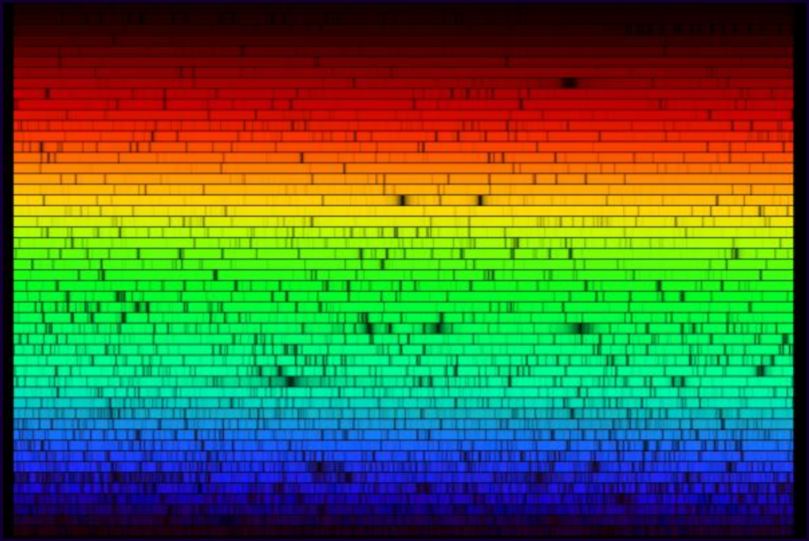
(Molecules have these spectra too: their electron energy levels are more complicated.)

Emission and absorption spectra

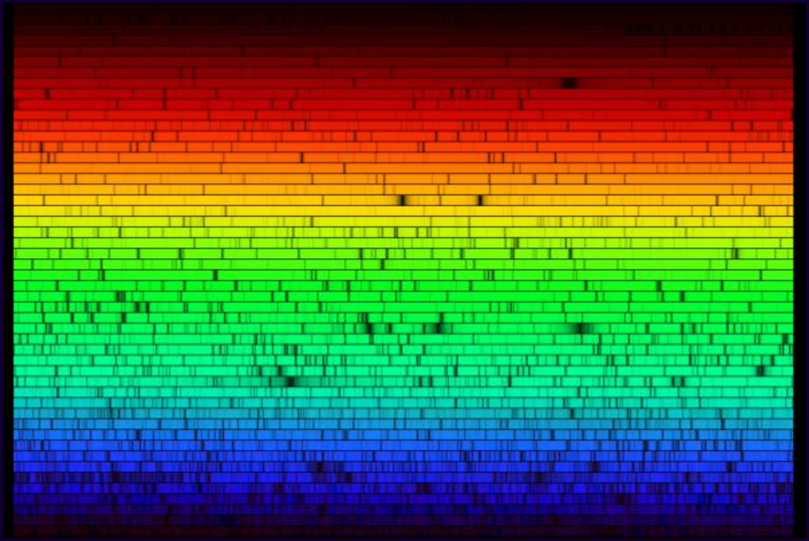
(Demonstration on the document camera, as a reminder of last time)



- The hot core of the Sun emits light of all wavelengths (thermal radiation)



- The hot core of the Sun emits light of all wavelengths (thermal radiation)
- The gases in the cooler atmosphere absorb light of their particular wavelengths



- The hot core of the Sun emits light of all wavelengths (thermal radiation)
- The gases in the cooler atmosphere absorb light of their particular wavelengths

This picture tells us what's in the Sun!

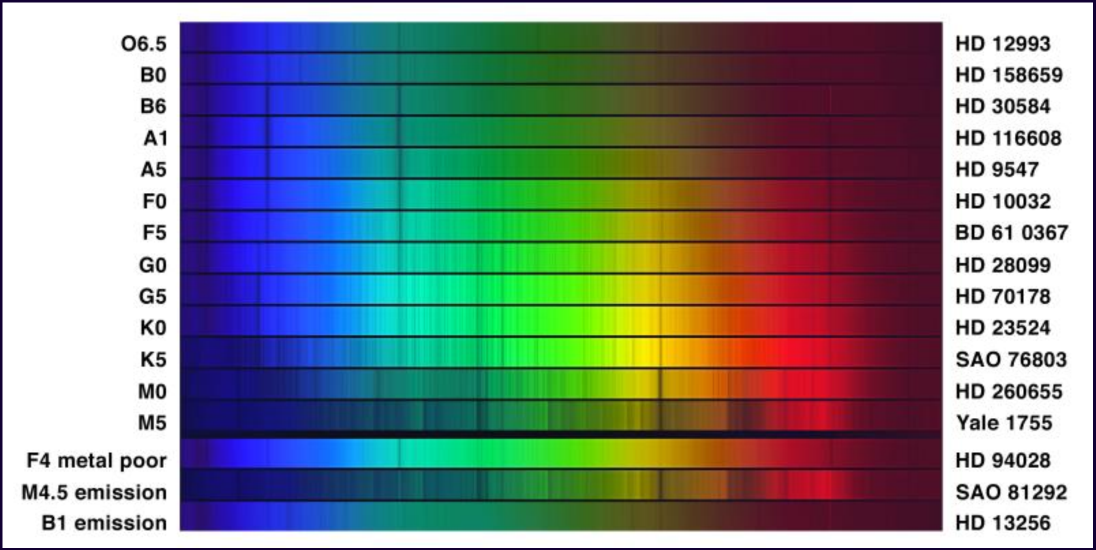
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

A: Something about quantum mechanics is different in the Sun

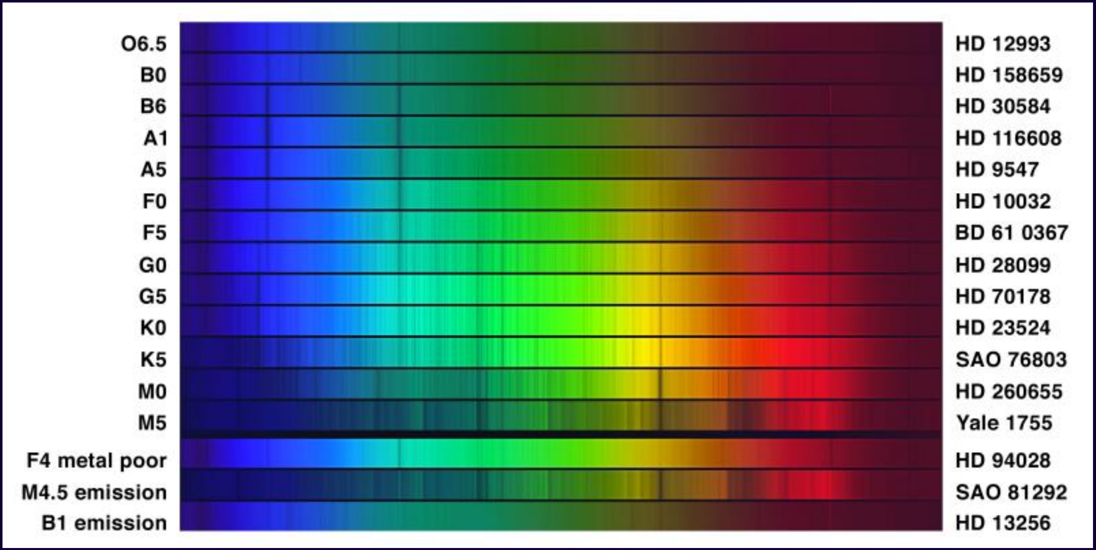
B: Something about light is different in the Sun

C: There's an element in the Sun that's not on Earth – call it **sunium**

D: The extreme temperature of the Sun causes new lines to appear in its gas



All the stars are made of the same stuff – the same stuff as we are.



All the stars are made of the same stuff – the same stuff as we are.

"The cosmos is also within us. We are made of star-stuff. We are a way for the universe to know itself."

–Carl Sagan, *Cosmos*

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!
There are others that are very interesting to astronomers:

- Molecular vibrations: infrared

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!

There are others that are very interesting to astronomers:

- Molecular vibrations: infrared
- Molecular *rotations*: microwave

What a lucky accident!

We're very lucky that atomic transitions happen to lie in our visual range!

There are others that are very interesting to astronomers:

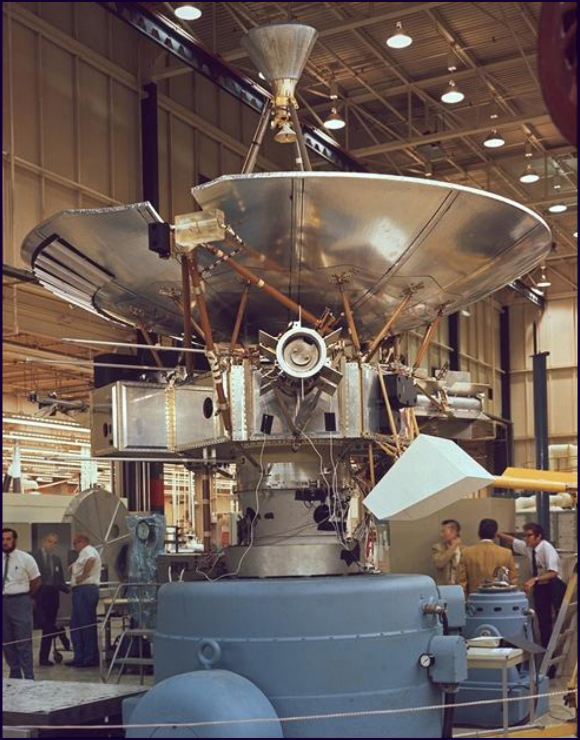
- Molecular vibrations: infrared
- Molecular *rotations*: microwave
- "Hyperfine structure" energy levels in hydrogen: 21 cm radio waves

What a lucky accident!

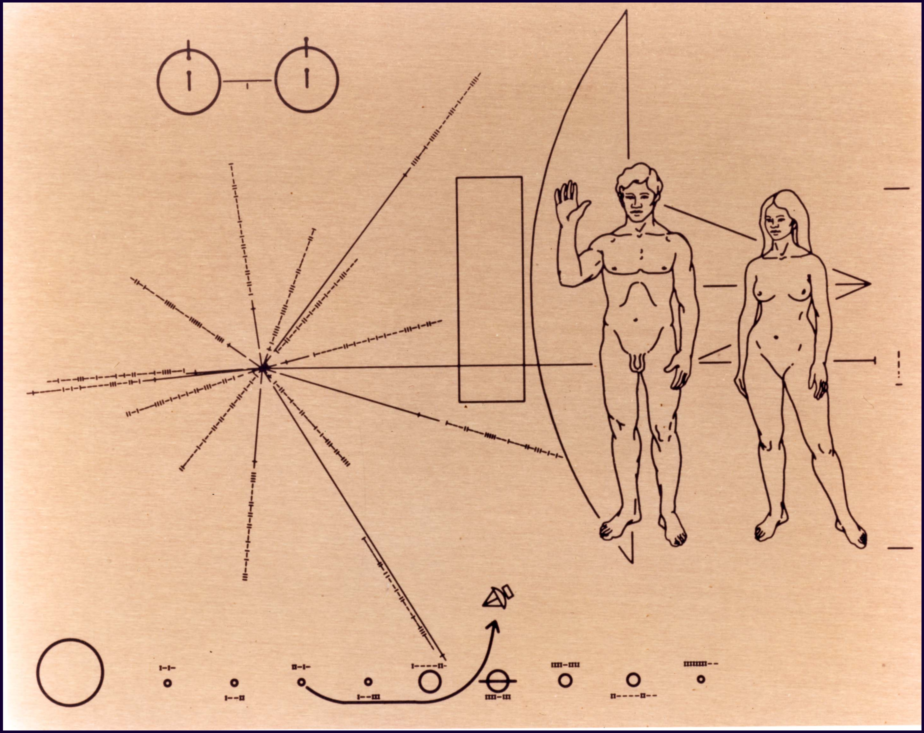
We're very lucky that atomic transitions happen to lie in our visual range!
There are others that are very interesting to astronomers:

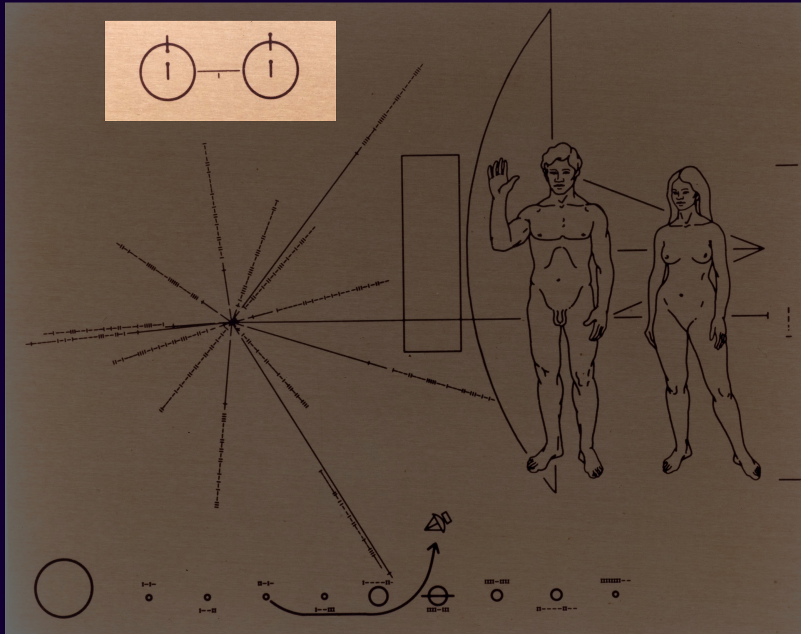
- Molecular vibrations: infrared
- Molecular *rotations*: microwave
- "Hyperfine structure" energy levels in hydrogen: 21 cm radio waves

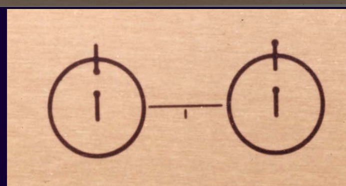
This last is particularly interesting: it is a very particular frequency, echoing out from all corners of the Universe, that says: hydrogen is here. (Hydrogen is 75% of the universe.)



The Pioneer 10 spacecraft (NASA)







The Sun's history and the source of its power

(Hubble Space Telescope image: NASA + ESA / Judy Schmidt)

Clouds of gas – mostly hydrogen but with a few heavier elements – collapse under their own gravity to form stars.

If you smash hydrogen nuclei together hard enough, they fuse to make helium – plus two neutrinos – plus a *lot* of energy.

$$(P) + (P) + (P) + (P) \rightarrow (NNPP) + 2e^+ + 2\nu$$

How much energy? Let's calculate it!

If you smash hydrogen nuclei together hard enough, they fuse to make helium – plus two neutrinos – plus a *lot* of energy.

$$(P) + (P) + (P) + (P) \to (NNPP) + 2e^{+} + 2\nu$$

How much energy? Let's calculate it!

This nuclear fusion process converts hydrogen fuel into helium and a vast amount of energy. Could we harness it here on Earth?

The Sun's fate and the fates of stars

- When the Sun runs out of hydrogen in its core, the core contracts, while the outer layers puff up: it becomes a red giant. (5 billion years in the future, lasting for 1 billion years)
- Eventually the core gets hot enough to fuse helium into carbon, and the core ignites in a "helium flash".
- When the helium is depleted, that's it: the Sun isn't heavy enough to fuse carbon
- The carbon core will be left behind as a white dwarf, slowly cooling – a dying ember in the sky.
- Its outer layers will be blown out into interstellar space, briefly forming a nebula