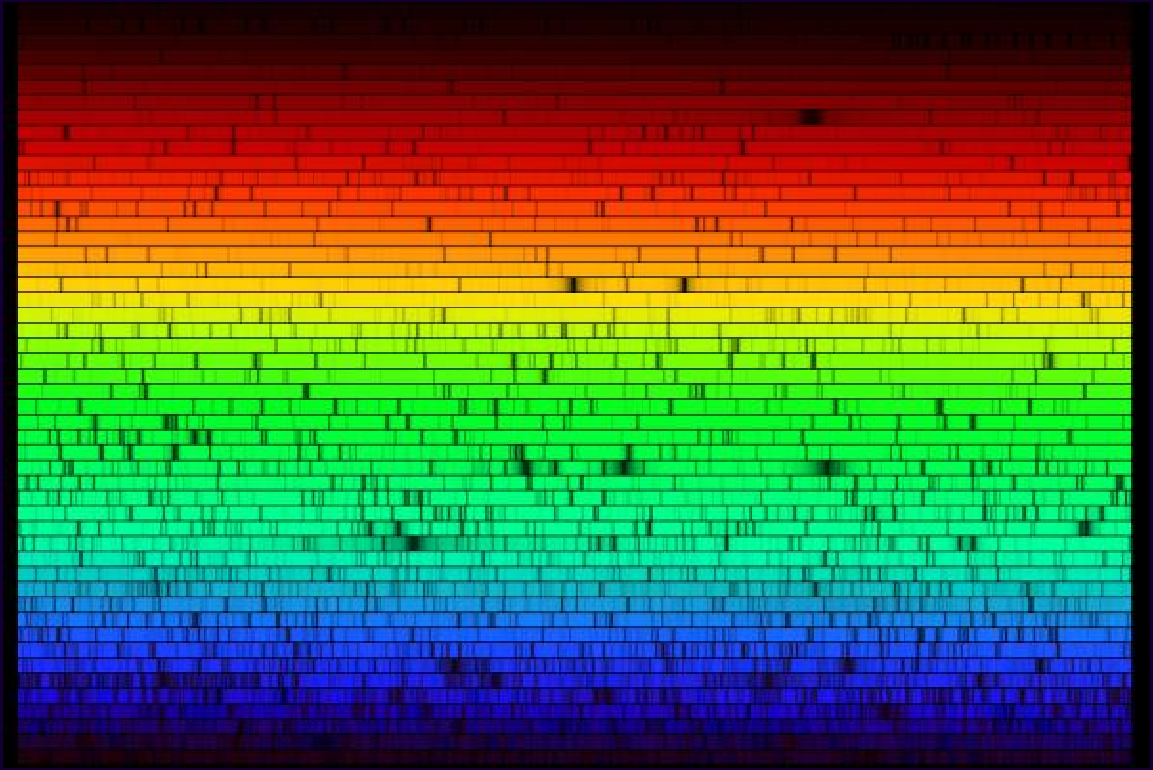
Light and matter

Astronomy 101
Syracuse University, Fall 2016
Walter Freeman

October 30, 2018



Announcements

- Exam 3 two weeks from today

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- Solutions to Exam 2 are posted (had to wait on people to finish)
- Final projects assigned today
- Special warmup question for Thursday for a point of extra credit

Final projects

Find an overlap between astronomy and your other talents...

... create something combining the two ...

... and make it fantastic.

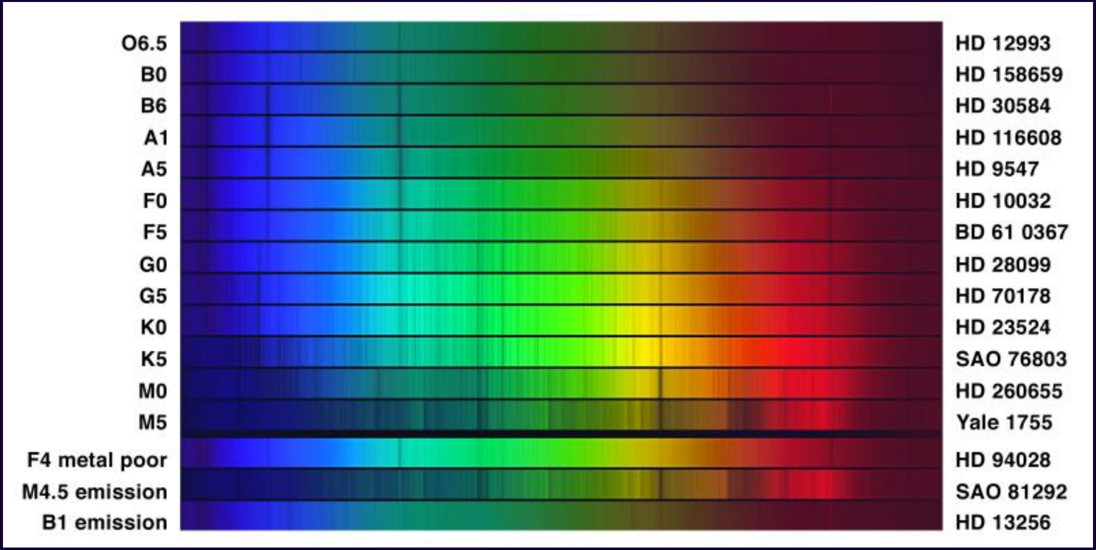
Last time

Last time we saw that all objects with a temperature emit a broad spectrum of light.

As an object gets hotter, the light coming from it:

- … becomes brighter
- … shifts to shorter wavelengths ("becomes bluer")

Which of these stars is hottest?



A: O6.5

B: K5

C: G5

D: F4 "metal poor"

Chemistry done quick†

Electrons in an atom can only have **very particular** amounts of energy!

We measure this energy in "electron volts" (eV).

- Usually all the electrons live in the lowest available levels
- There's a limit to how many electrons can be in each level
- Atoms "fill up" the levels starting from the bottom
- This process leads to the periodic table

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† Does not replace your introductory chemistry class on your transcript

Atomic transitions

Here's a sample atom (on the document camera). These energy levels aren't real; I just made them up for demonstration.

Can the electron in this atom go from $n = 1$ ("ground state") to $n = 2$ (an "excited state")?

A: Yes, since it's just moving from here to there

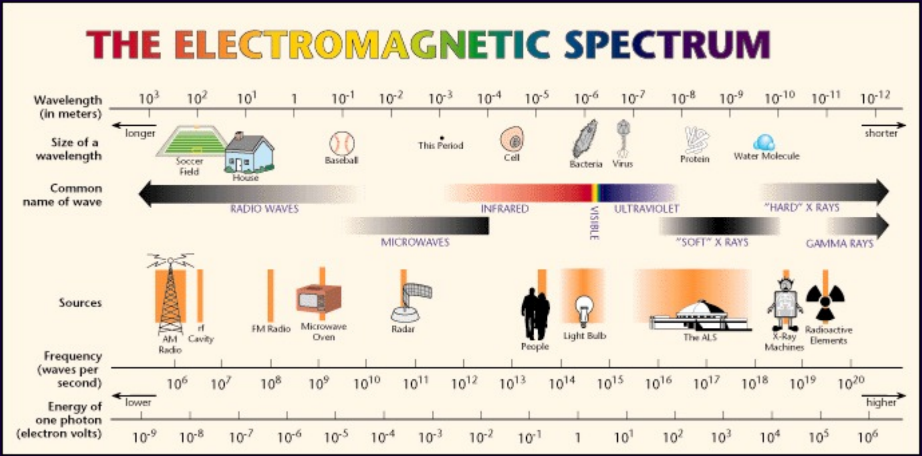
B: Yes, but only if I give it 4 eV of energy from somewhere

C: No, because atoms have a definite state

D: No, because that doesn't conserve energy

Atomic transitions: absorption

This extra energy usually comes from a *photon* – a particle of light. Remember that photons carry energy with them: the shorter the wavelength, the higher the energy.



An atom can absorb a photon with just the right energy, jumping up to a higher energy level in the process.

What energies of photon can our sample atom absorb if it starts in $n = 1$?

A: 4 eV

B: 4 eV, 3 eV, 2 eV, or 1 eV

C: 4 eV, 7 eV, 9 eV, or 10 eV

D: Any value up to 10 eV

E: Any value between 4 eV and 10 eV

Suppose our atom absorbs a photon of 9 eV. What happens?

A: It will emit a photon of 9 eV

B: It will emit a 2 eV photon, then a 7 eV photon

C: It will emit a 5 eV photon, then a 4 eV photon

D: It will emit a 2 eV photon, then a 3 eV photon, then a 4 eV photon

E: It will emit a 3 eV photon, then a 6 eV photon

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.

... 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? (For reference: the visible range is 1.5-3 eV.)

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

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E: Orange, because this is Syracuse, darnit!

Complete *Lecture Tutorials* pp.65-69.

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.)

Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV, and then look at the energies of the photons that come out the other side.

A: Photons with energy 3 and 5 eV

B: Photons with energy 2, 3, and 5 eV

C: Photons of a wide range of energies, *except* 3 and 5 eV

D: Photons of a wide range of energies, *except* 2, 3, and 5 eV

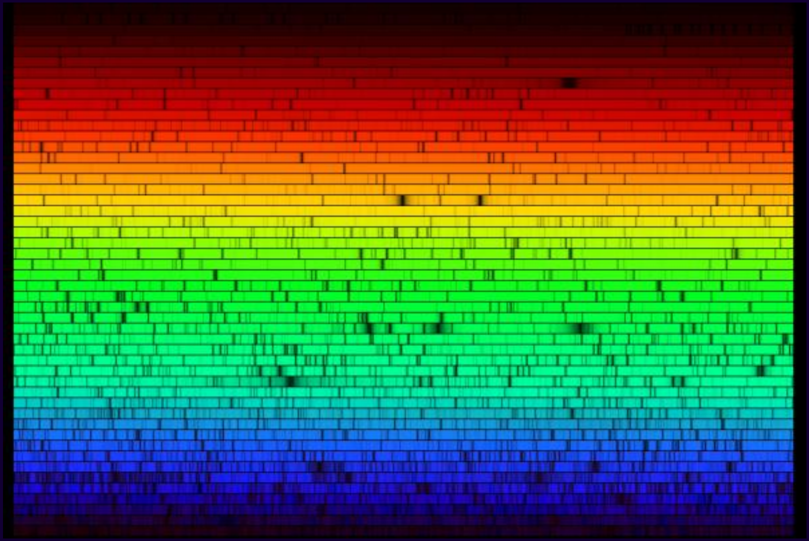
Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV, and then separate its light by color. (Assume that I am a bird and can see ultraviolet light.) What would I see?

A: Only two bright lines

B: Only three bright lines

C: A solid band of color, but with two dark lines

D: A solid band of color, but with three dark lines



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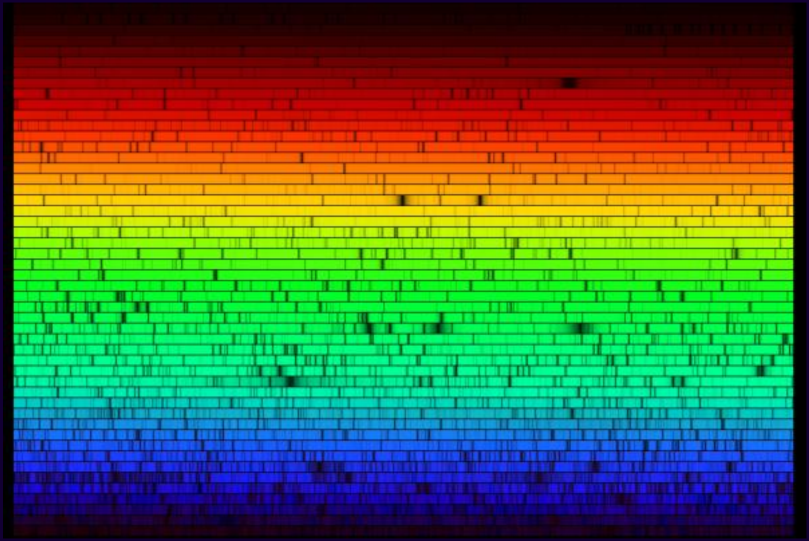

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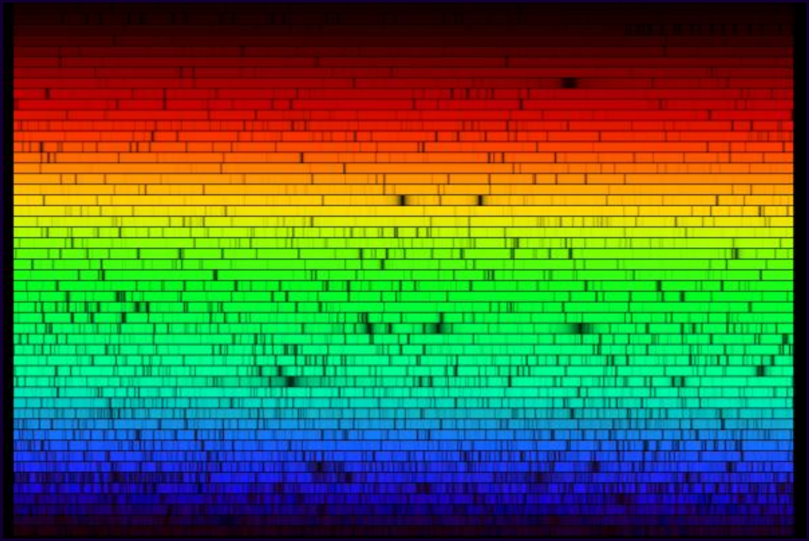

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This picture tells us what's in the Sun!

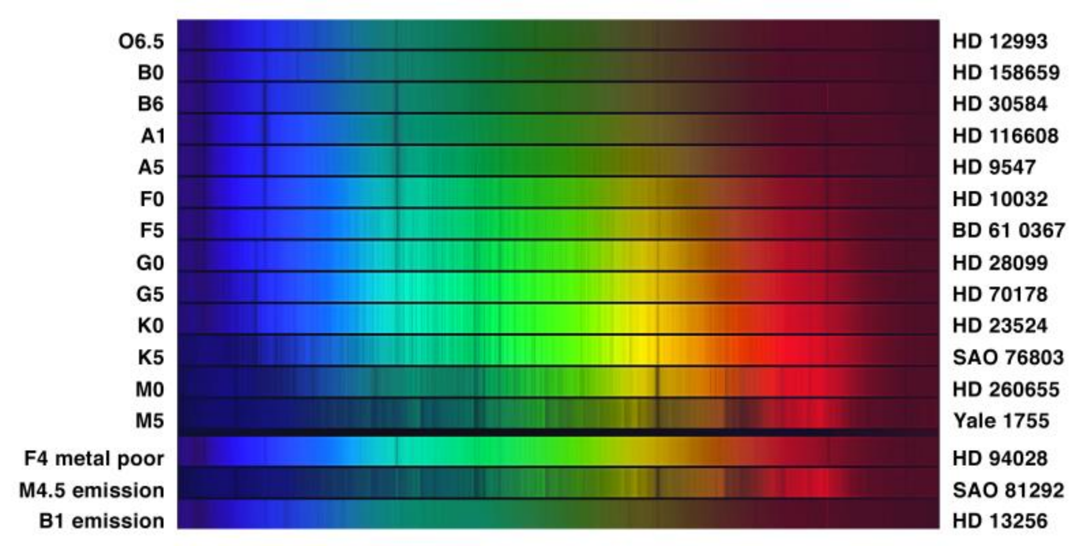
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

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



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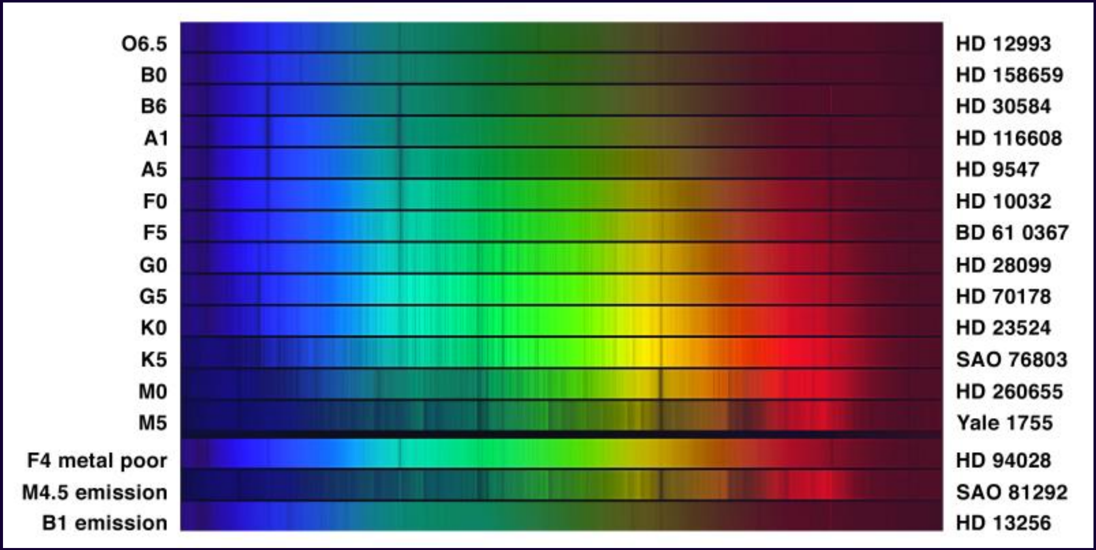

All the stars are made of the same stuff – the same stuff as we are.

"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:

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- 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.)