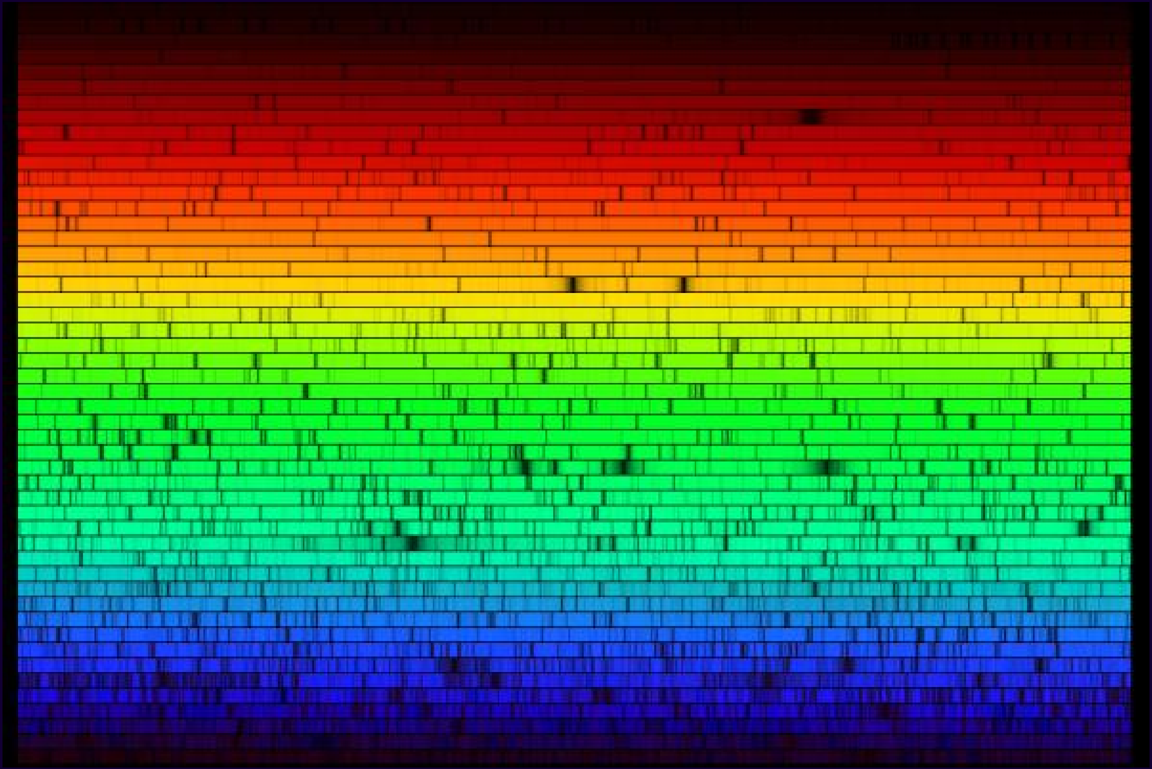
Spectroscopy

Astronomy 101
Syracuse University, Fall 2018
Walter Freeman

November 1, 2018



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- A note on "special-case" grading

What we know so far

Hot objects emit light (thermal radiation):

- This light is a broad spread of wavelengths
- The hotter the object, the shorter ("bluer") they are

Atoms have energy levels that the electrons occupy. Electrons can:

- Absorb a photon whose energy is equal to the difference between energy levels, and move up
- Emit a photon whose energy is equal to the difference between energy levels, and move down

The pattern of energy levels is specific to each atom, but in general, the higher ones are closer together.

The first few energy levels of hydrogen are: 0 eV, 10.2 eV, 12.1 eV, and 12.8 eV.

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 $n = 1$.

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!

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

Absorption spectra

If you excite a diffuse gas, it will *emit* light of particular colors that correspond to its transitions. (We do this electrically in lamps.)

H + electricity

Emission spectrum

But that same gas can *absorb* those same colors, too.

Hot object

Continuous spectrum

Light from hot object passing through H gas

Absorption spectrum

Complete *Lecture Tutorials* pp.63-69.

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

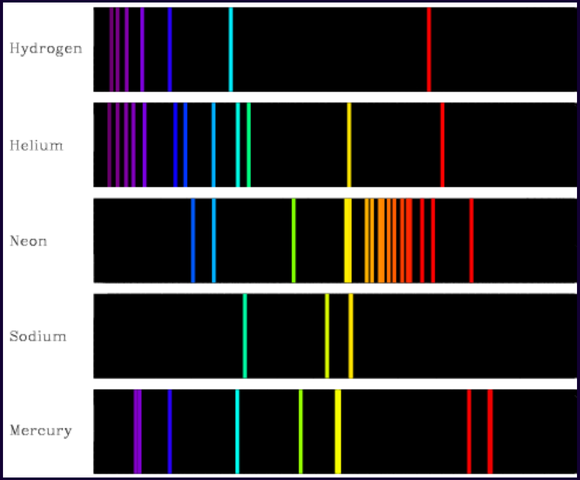
Spectroscopy

How do we use this to learn about astronomy?

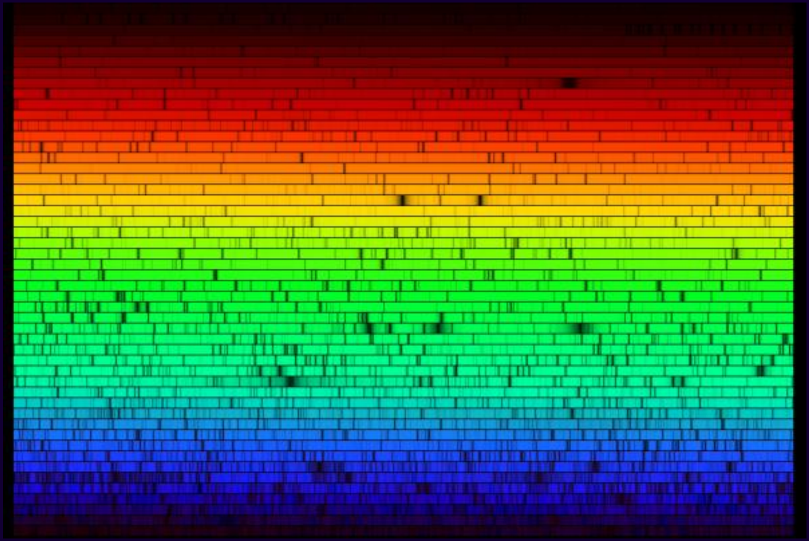
Every element has its own “fingerprint”, based on its unique energy levels.

We can measure those fingerprints easily on Earth with emission lamps.

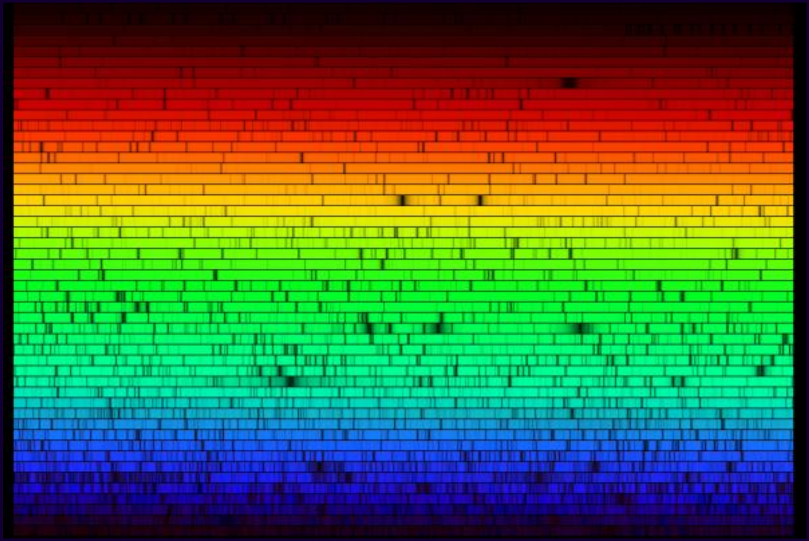
Then, if we see them in the sky – either in emission or absorption – we know where they came from!



We can figure out what chemicals are in anything in the sky by looking for lines in its spectrum!



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



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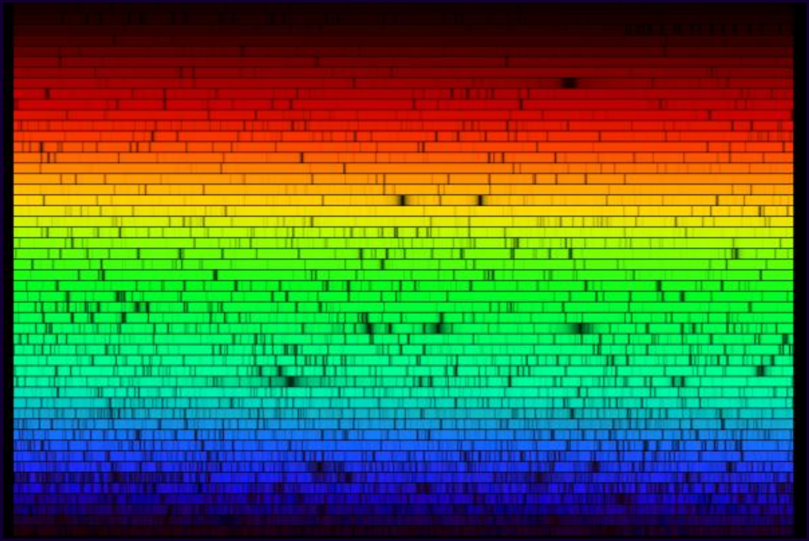
- The gases in the cooler atmosphere absorb light of their particular wavelengths



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This picture tells us what's in the Sun!

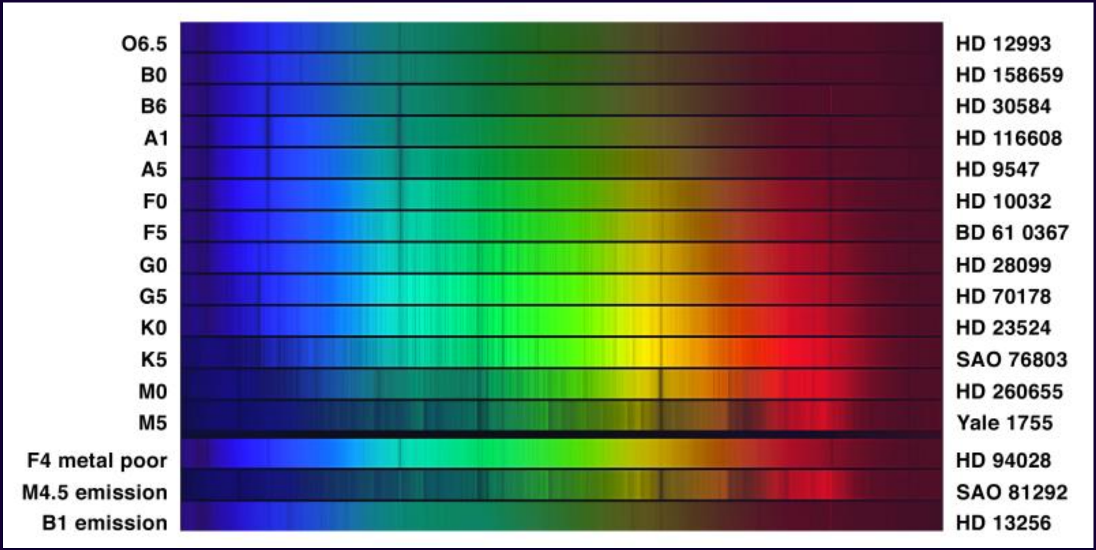
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

A: Something about quantum mechanics is different in the Sun

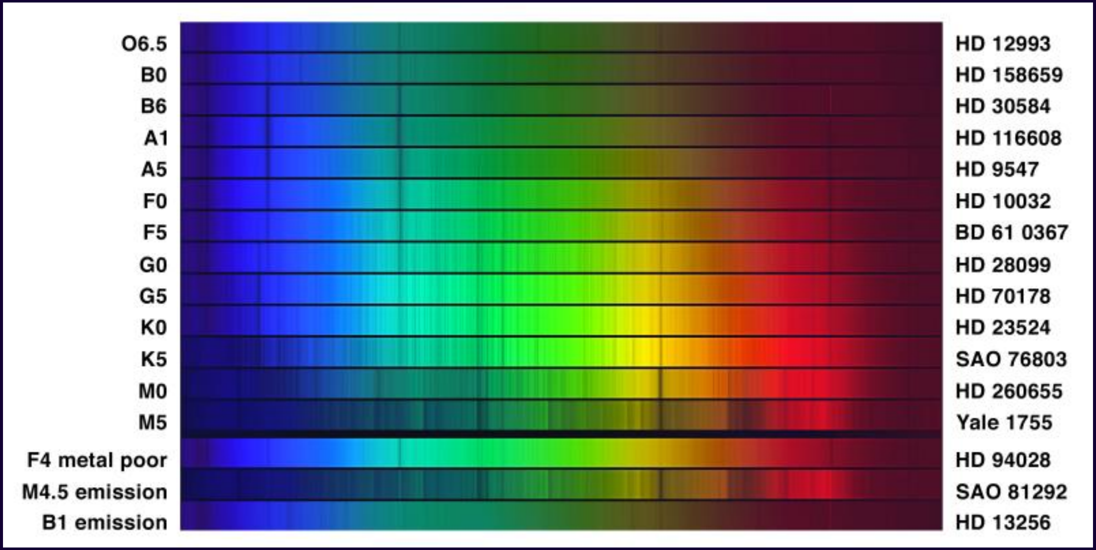
B: Something about light is different in the Sun

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



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

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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.)