Lecture 6 recap

- The electromagnetic spectrum

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- Wien's Law
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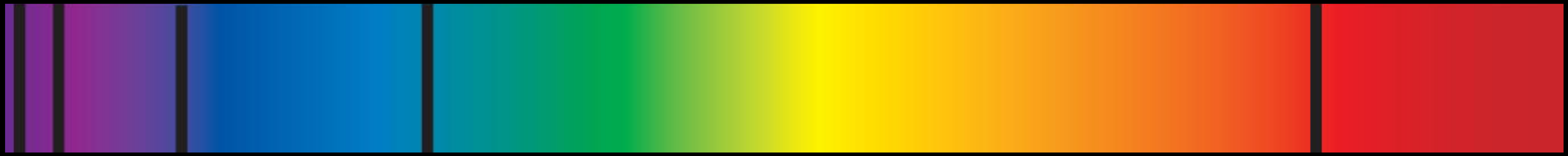
- The electromagnetic spectrum
- A Thermal Spectrum
- Wien's Law
  - $\lambda_{peak} = 2,900,000 / T$
- Stefan-Boltzmann Law
  - Surface Brightness = σT^4

Spectral lines

Spectral lines

You don't always get a perfect thermal spectrum (rainbow)

Sometimes you get "absorption lines"



Sometimes you get "emission lines"

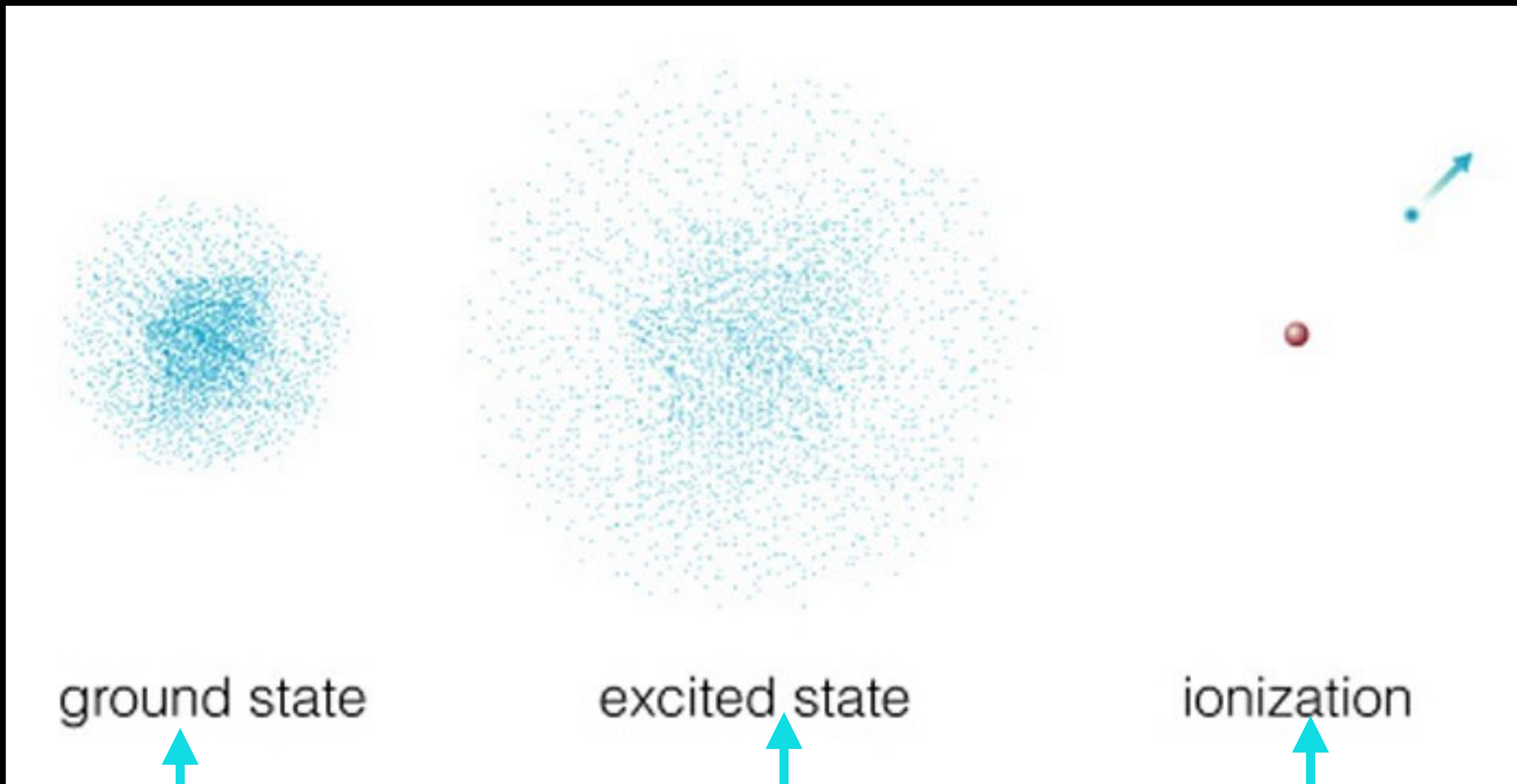
These lines are signatures of specific atoms and molecules.

- If we can understand which atoms produce which lines, we can determine the elements making up what we see in space!

These lines are signatures of specific atoms and molecules.

- If we can understand which atoms produce which lines, we can determine the elements making up what we see in space!
- How does it work?
  - Specific wavelengths correspond to specific energies (Electric potential energy)
  - These energies correspond to characteristic energies within atoms.

Remember that electrons respond to having more energy



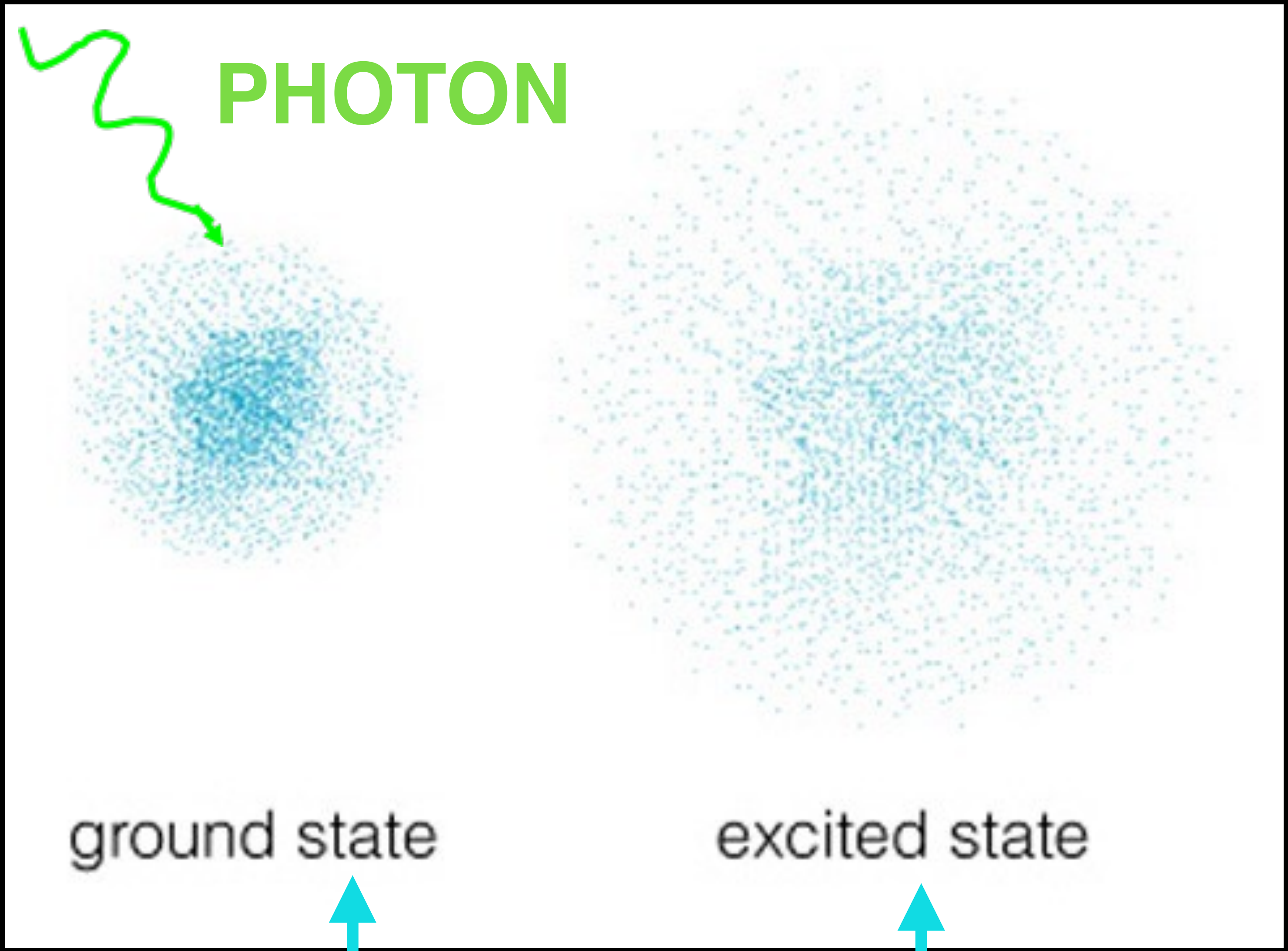
Lowest possible energy

Electron has gained electric potential energy

Electron has gained enough energy to become free.

How do electrons gain and lose electric potential energy?

1. Collisions with other atoms
   Kinetic energy <--> electric potential energy



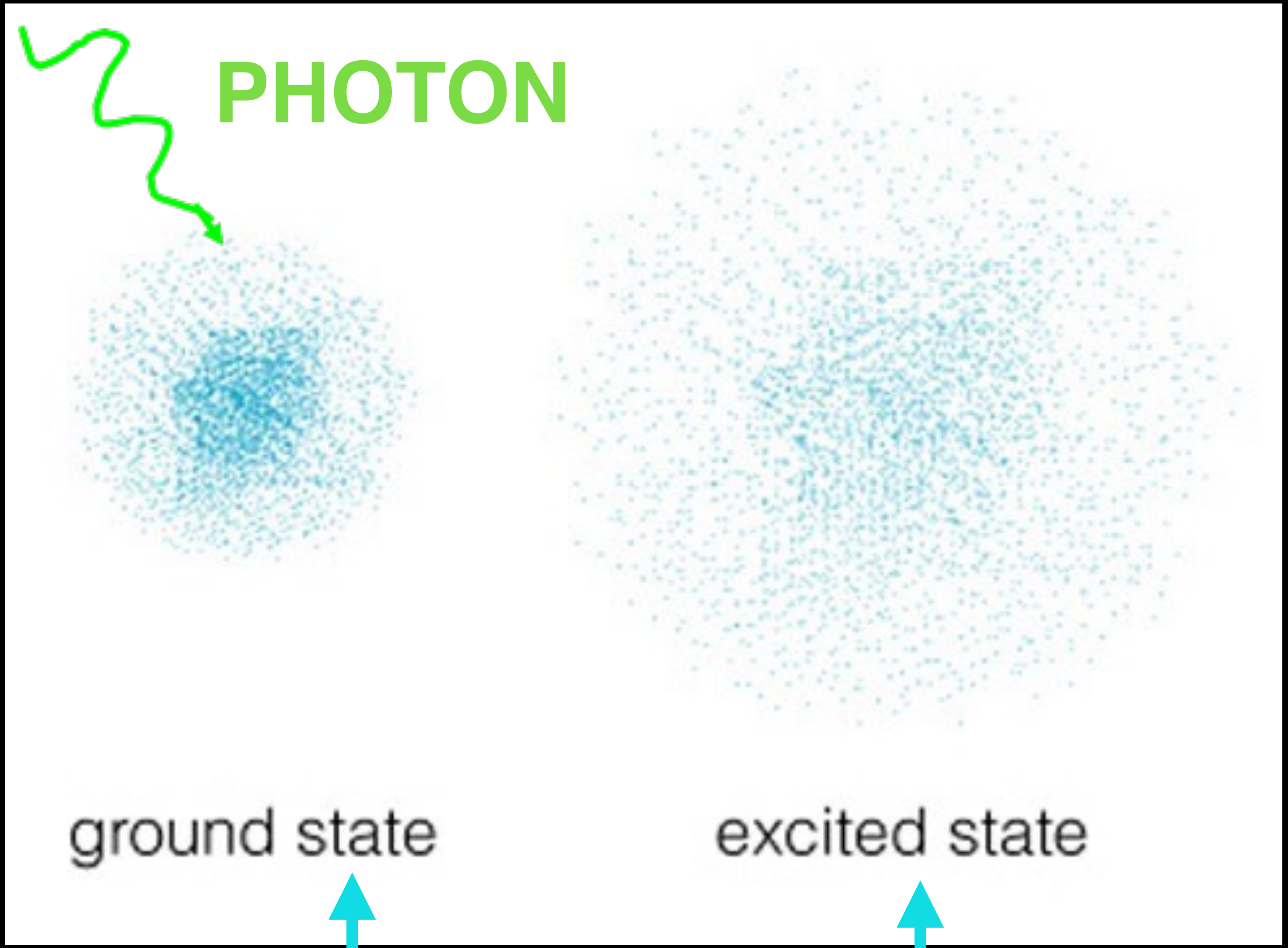
Lowest possible energy

Electron has gained electric potential energy

How do electrons gain and lose electric potential energy?

1. Collisions with other atoms
   Kinetic energy <--> electric potential energy

2. Absorption or emission of PHOTONS
   Radiative energy <--> electric potential energy



Lowest possible energy

Electron has gained electric potential energy

The amount of energy an electron can have is NOT ARBITRARY!

- We say that electrons can occupy different

  ENERGY LEVELS

- The energies of these levels are fixed by the number of protons in the nucleus and by the number of electrons (is the atom neutral or charged?).
- There can be no other possible energies besides these fixed levels!

Energy Levels

Electrons can only absorb or emit very specific photons.

Interacting photons must have energies corresponding to one of the energy differences between levels.

Note that emitted photon is going a different direction than absorbed photon.

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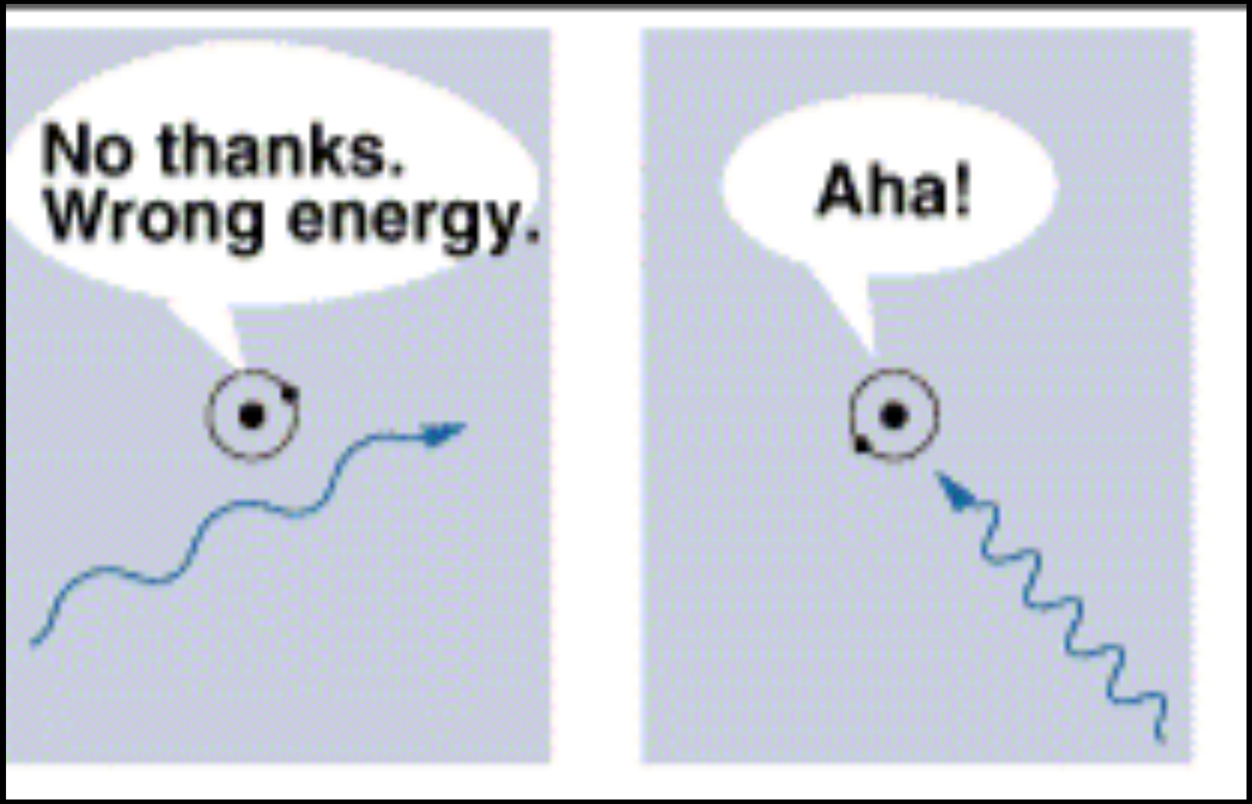

Absorption

Note that emitted photon is going a different direction than absorbed photon.

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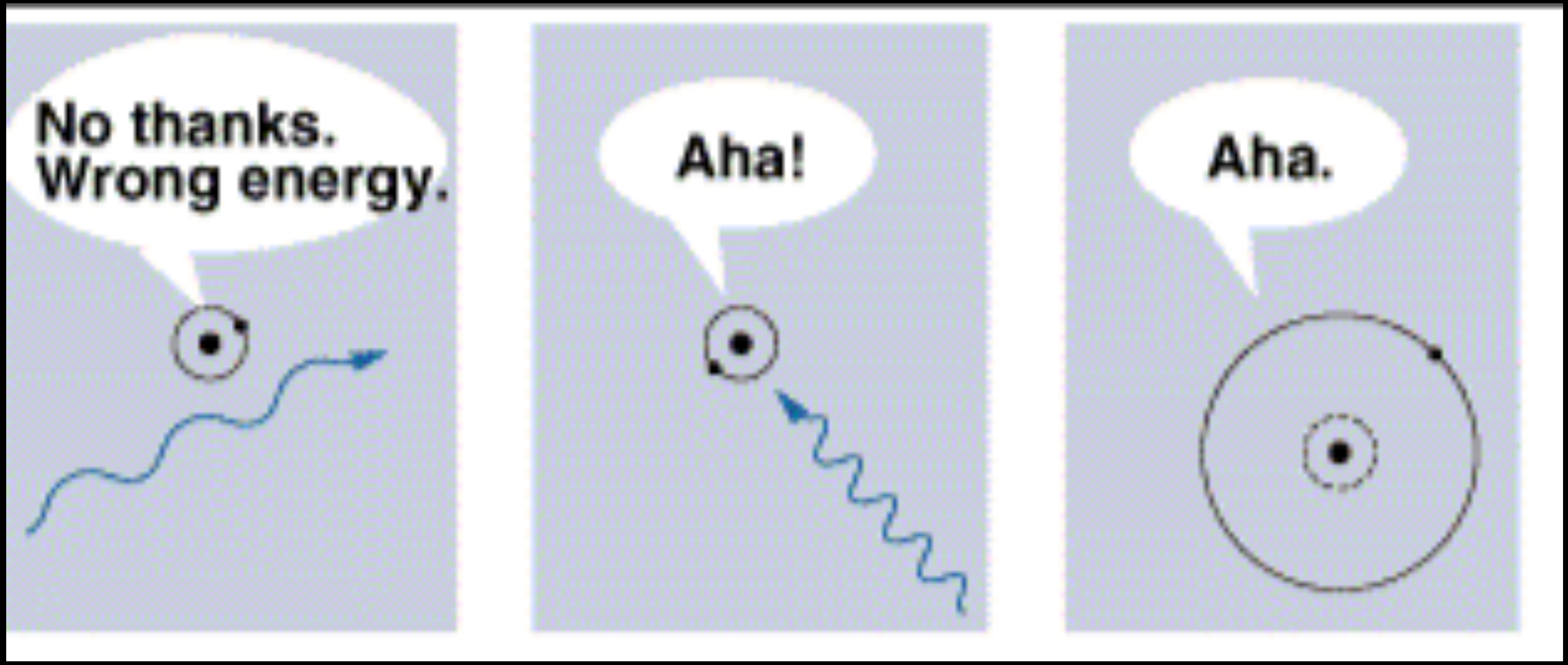

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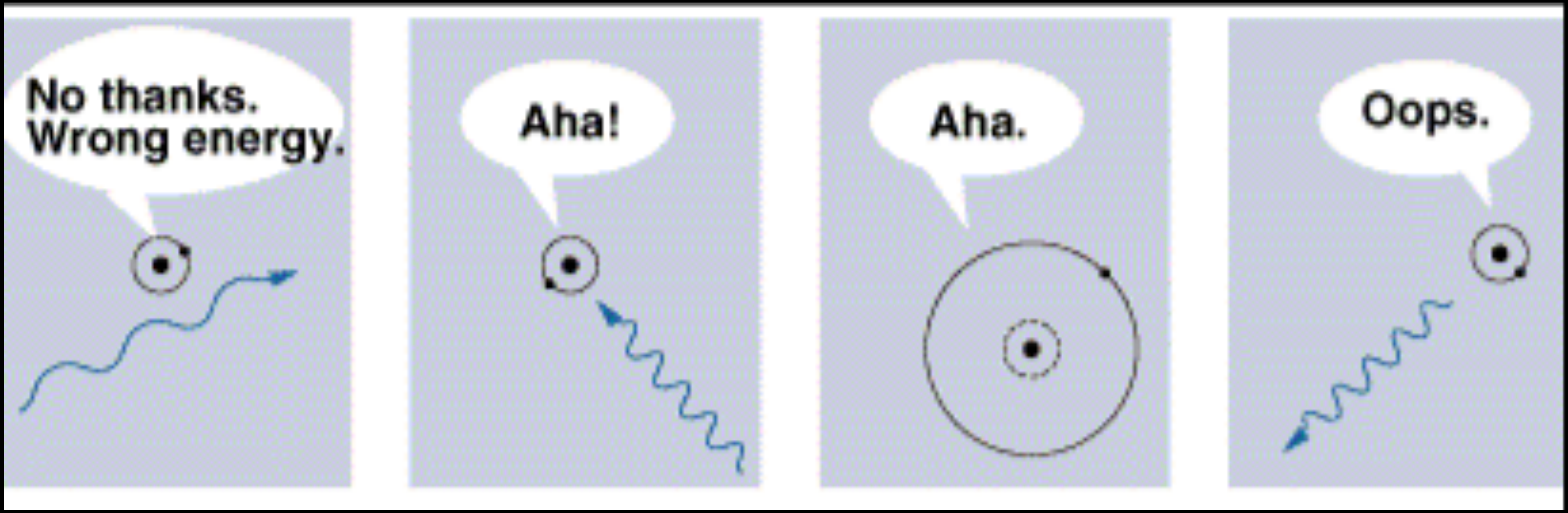
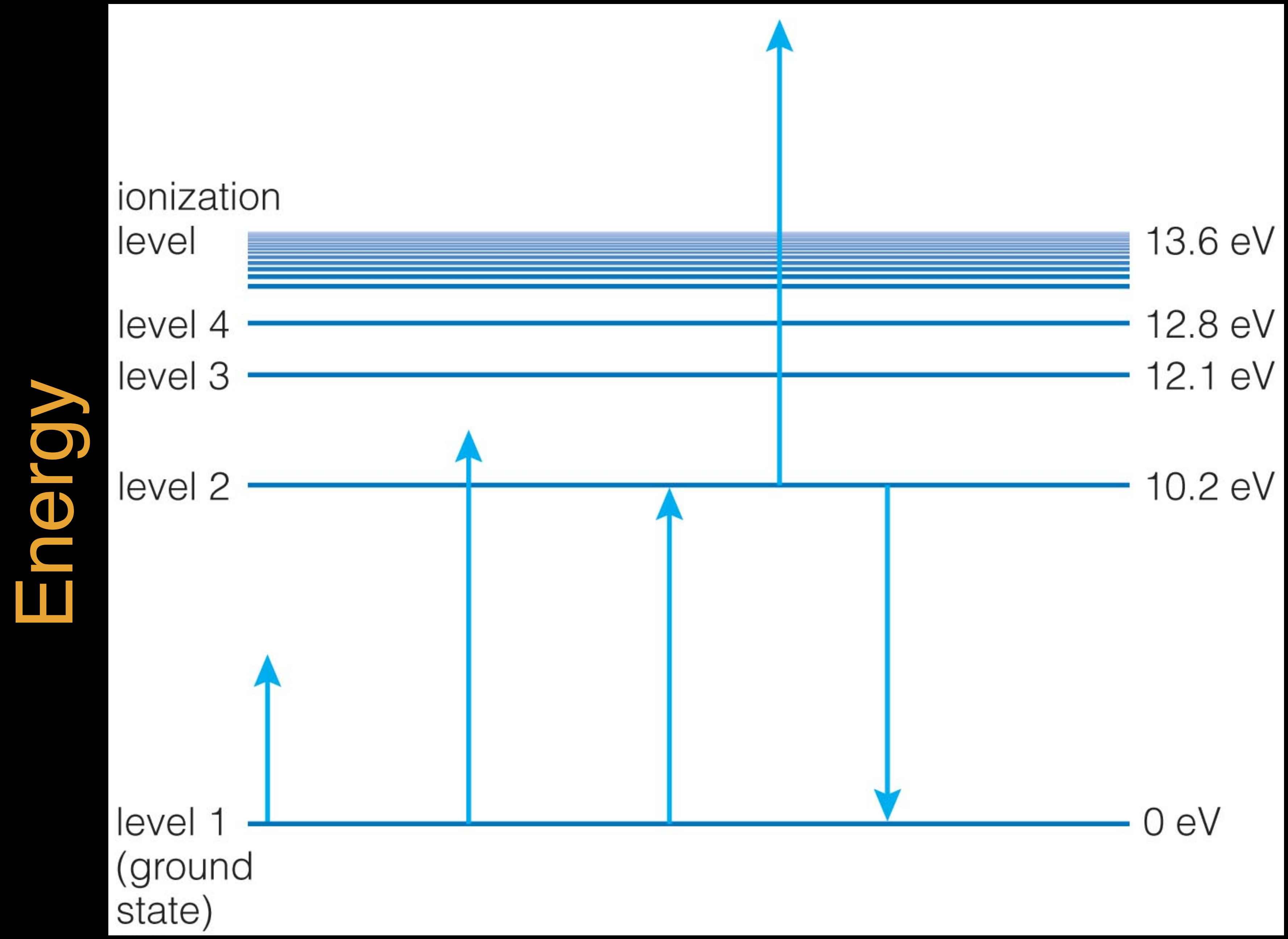
Emission



Note that emitted photon is going a different direction than absorbed photon.

Energy Levels are QUANTIZED

These energy levels are like (uneven) steps in a ladder.



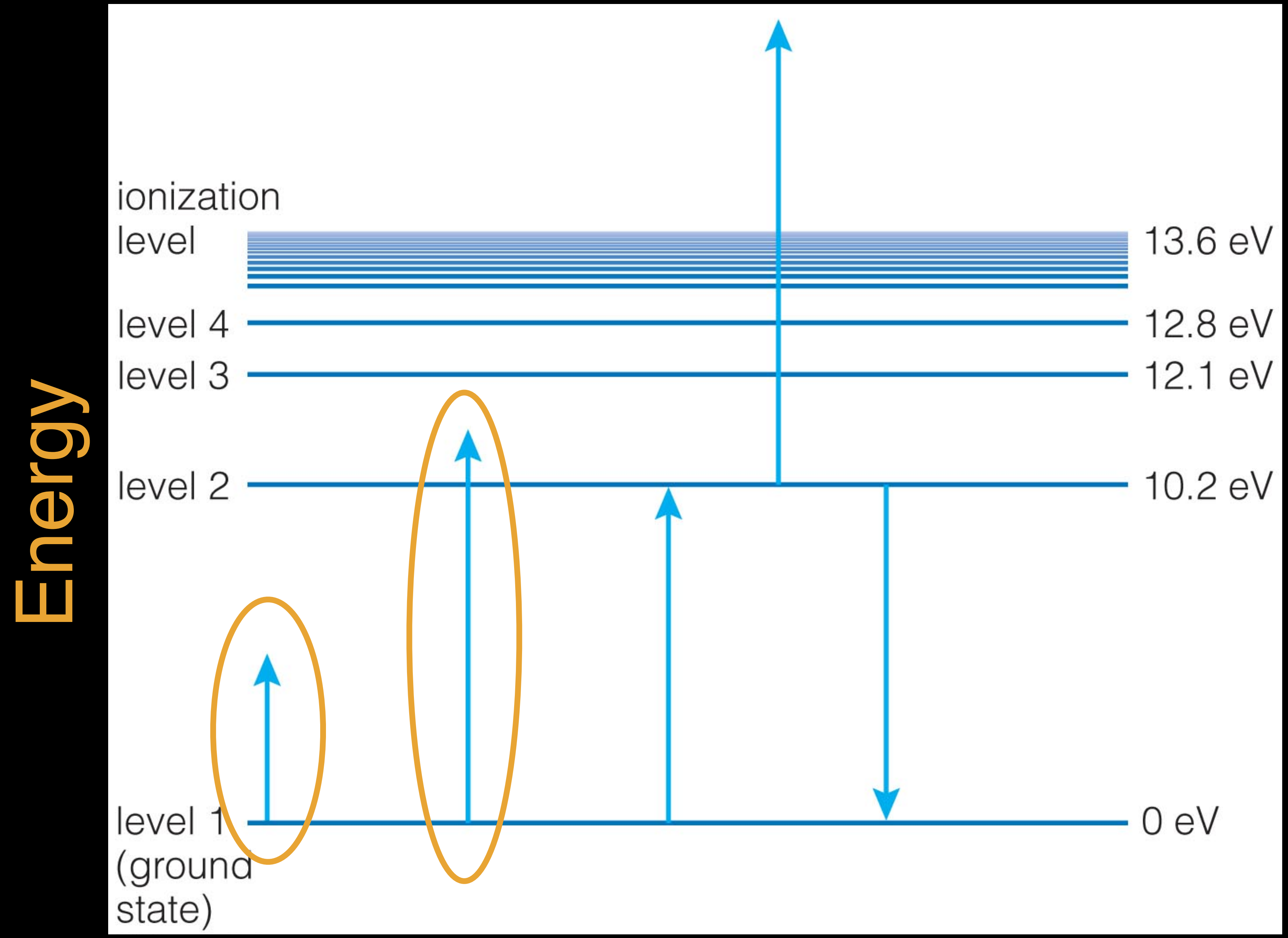
An "eV" is an electron volt" a unit of energy characteristic of electrons in atoms (1 eV = 1.6×10^{-19} Joules).

Energy Levels are QUANTIZED

There are specific energy differences between levels.

The length of each blue arrow represents the energy difference between the two levels it connects.

What happens when an arrow is longer than the difference between the max and min energy levels?



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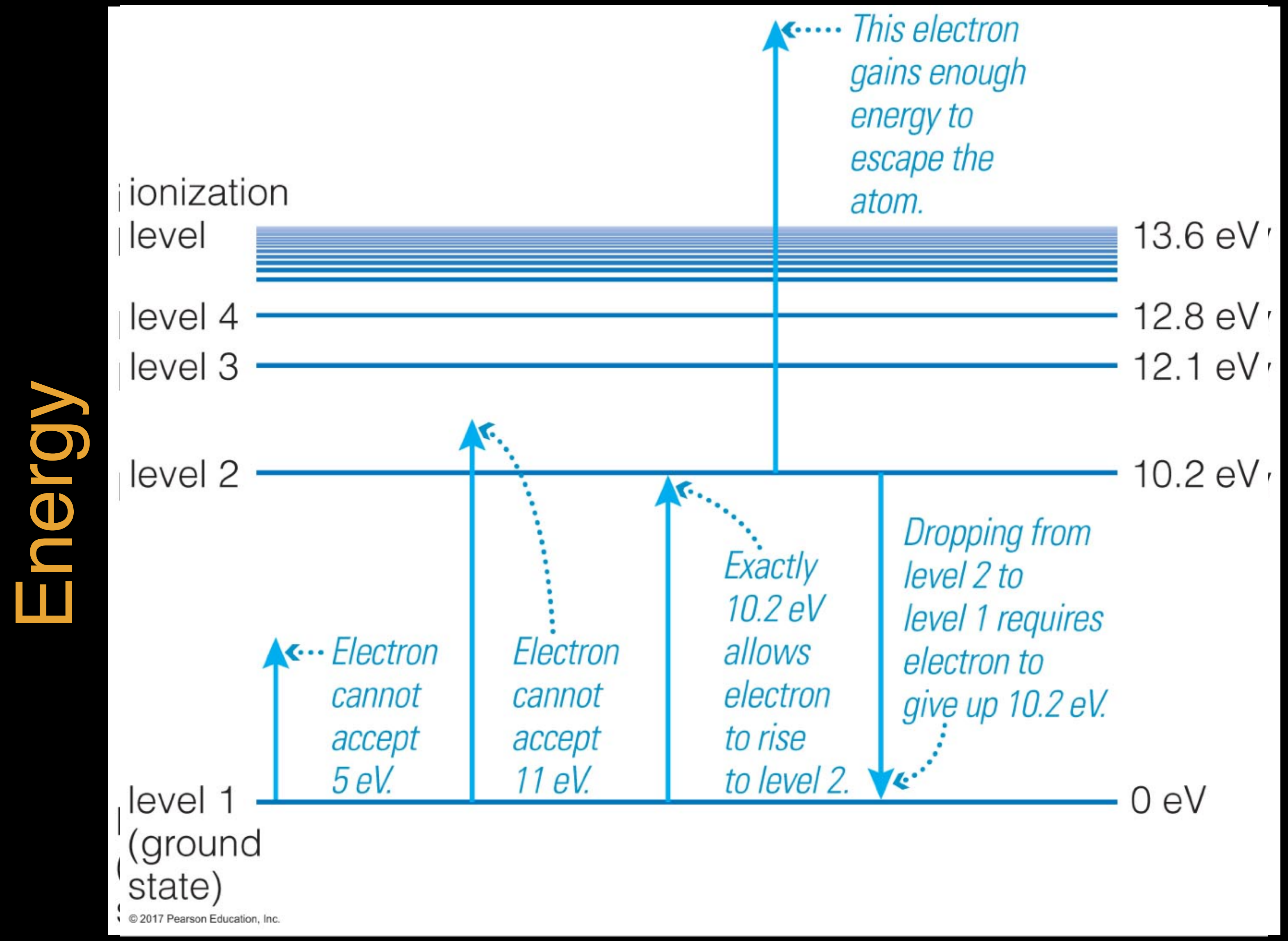
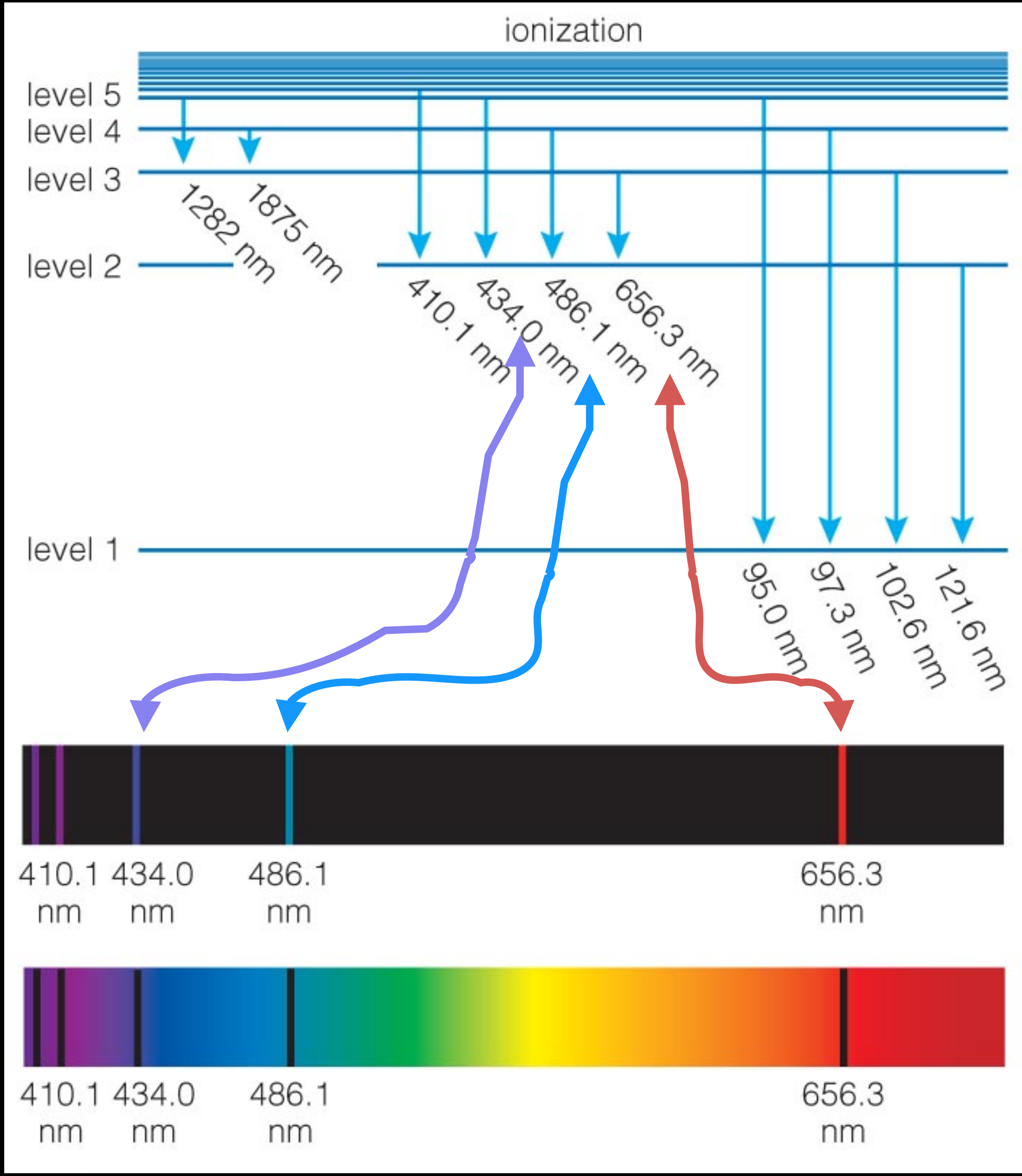
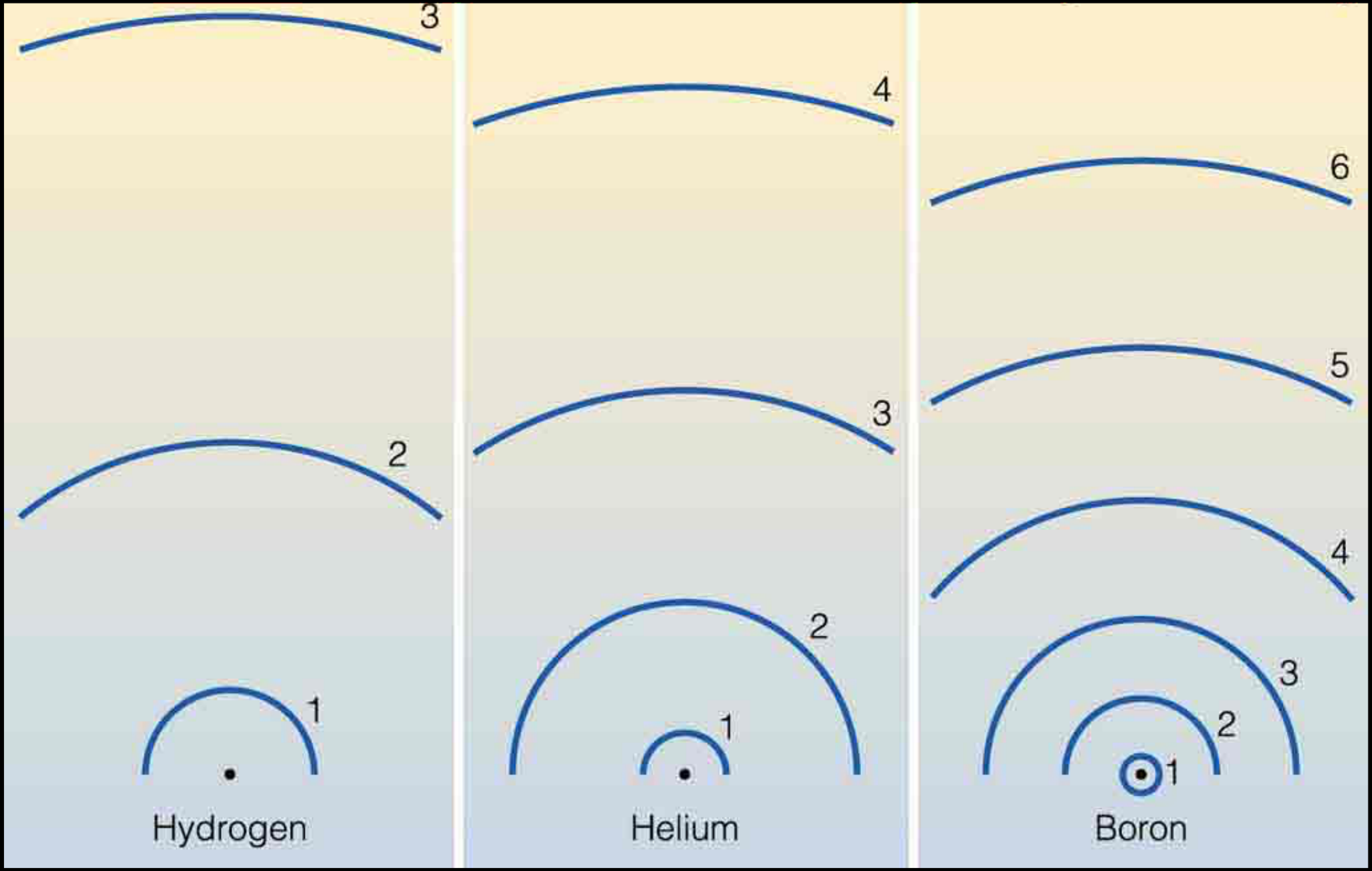


Hydrogen

These special photons with just the right energy are responsible for emission lines and absorption lines.

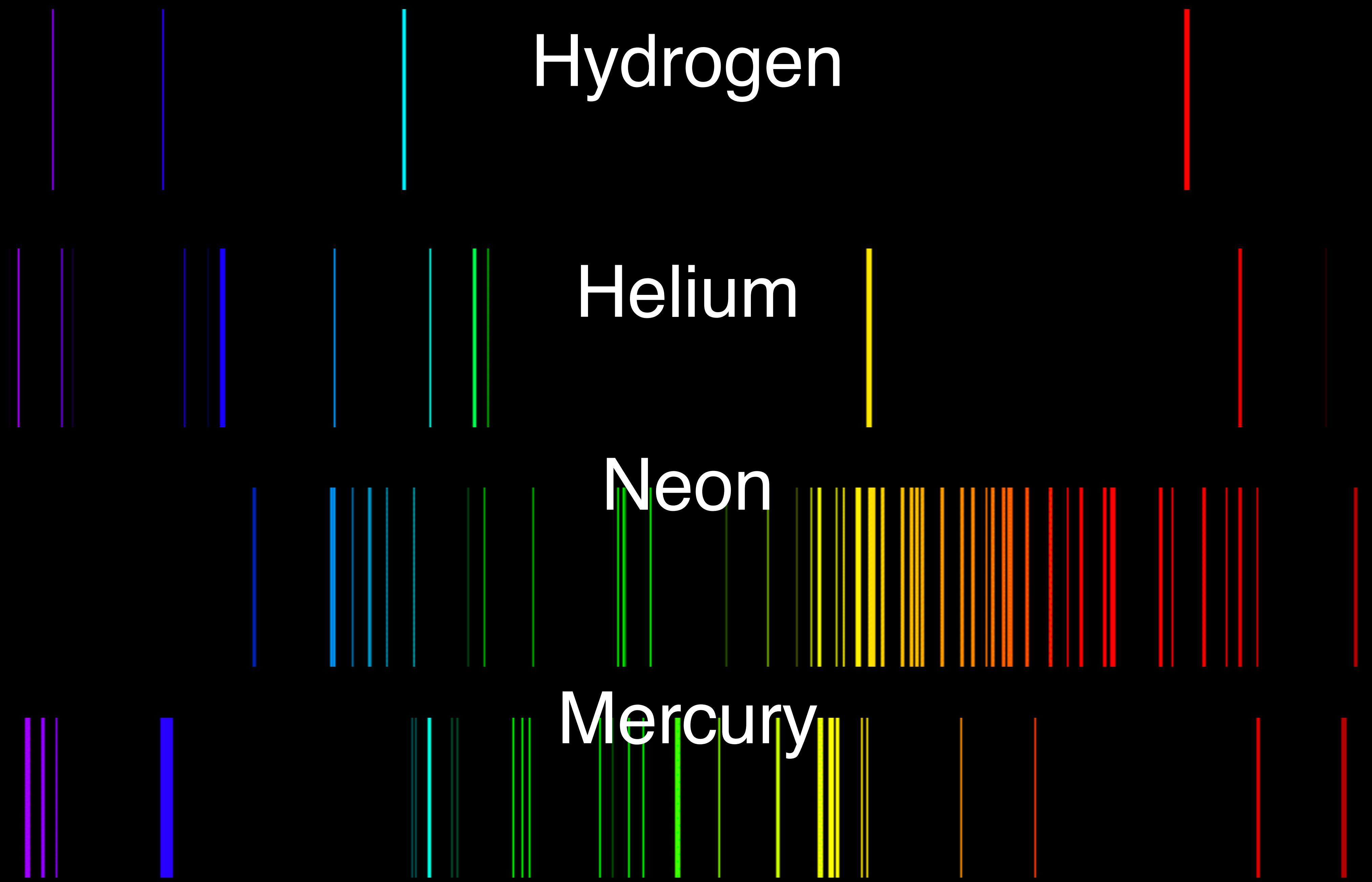


Different elements have different electron energy levels...



These energy levels are sometimes drawn as radii, because more energetic electrons spend more time far away from the nucleus.

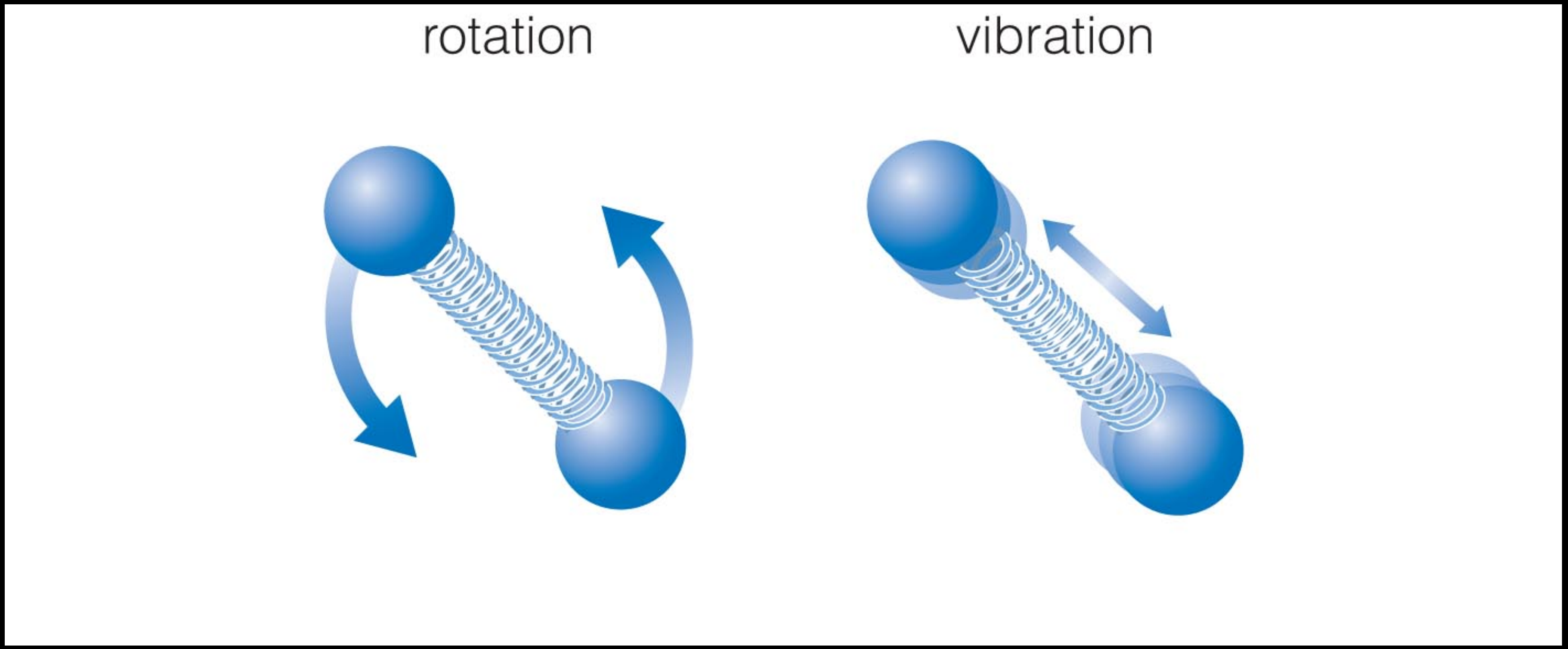
...Therefore, they produce different emission & absorption lines -- spectral “fingerprints”.



P.S. There are many other absorption & emission lines in other parts of the spectrum (i.e. infrared, ultraviolet).

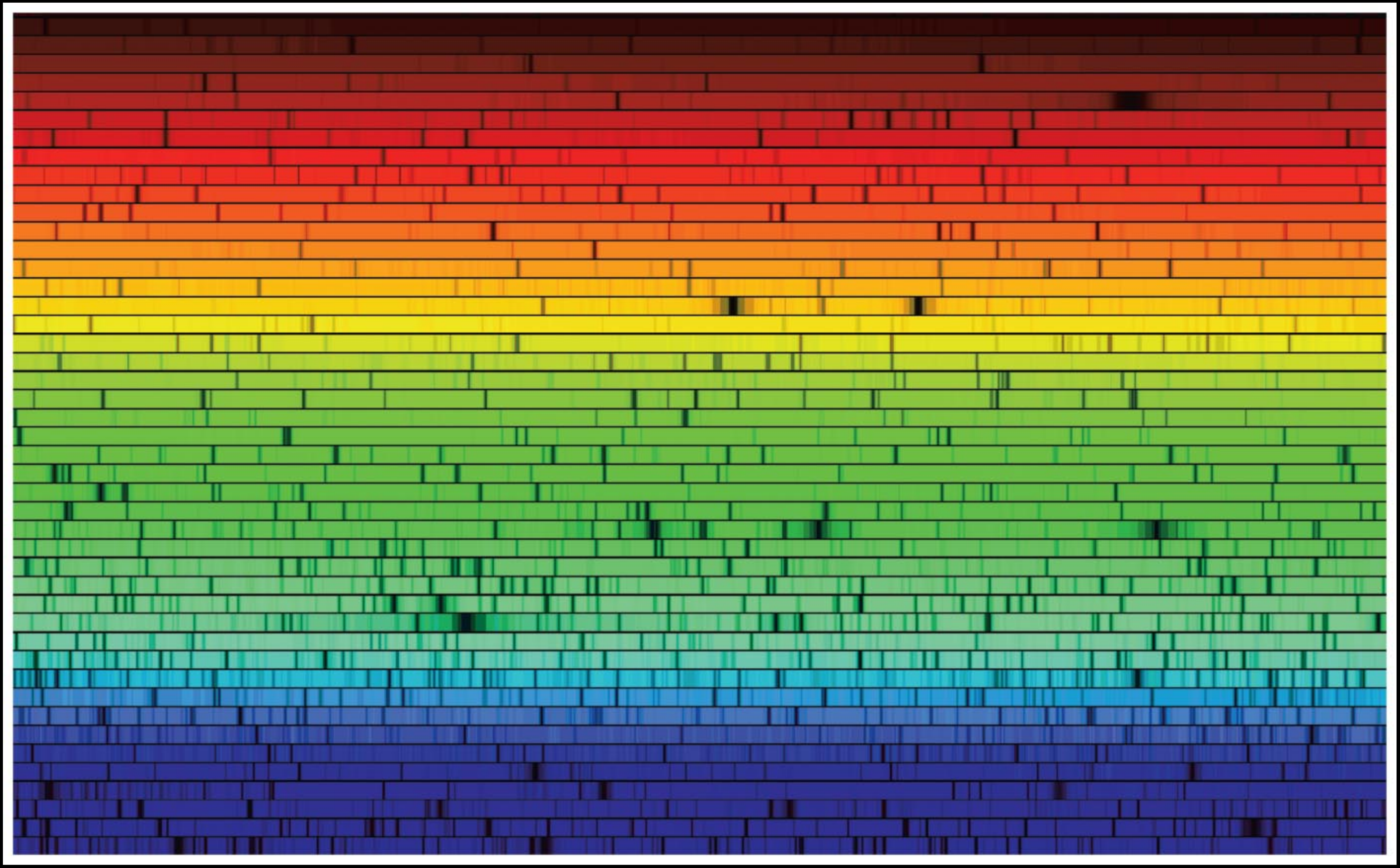
http://chemistry.bd.psu.edu/jircitano/periodic4.html

Energy levels of Molecules



Molecules have additional energy levels because they can vibrate and rotate.

Solar spectrum

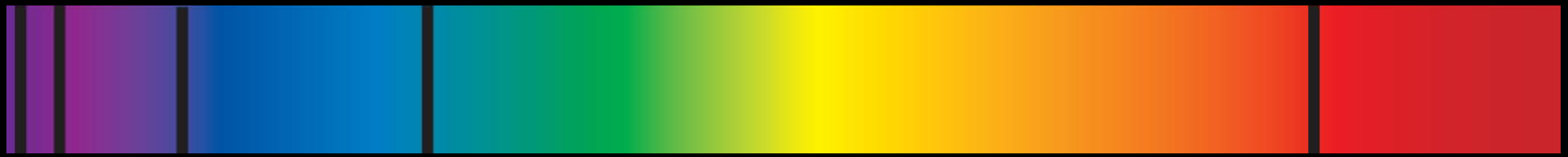


Absorption vs. Emission

- Absorption = taking light away
  - Mostly bright continuum with some dark lines
- Emission = adding light
  - Mostly dark with a few bright lines

Absorption vs. Emission

Absorption Lines?



– Absorption lines come from electrons in a low energy state intercepting and absorbing light in order to transfer to a high energy state.

Need unexcited gas with bound electrons and a background light source

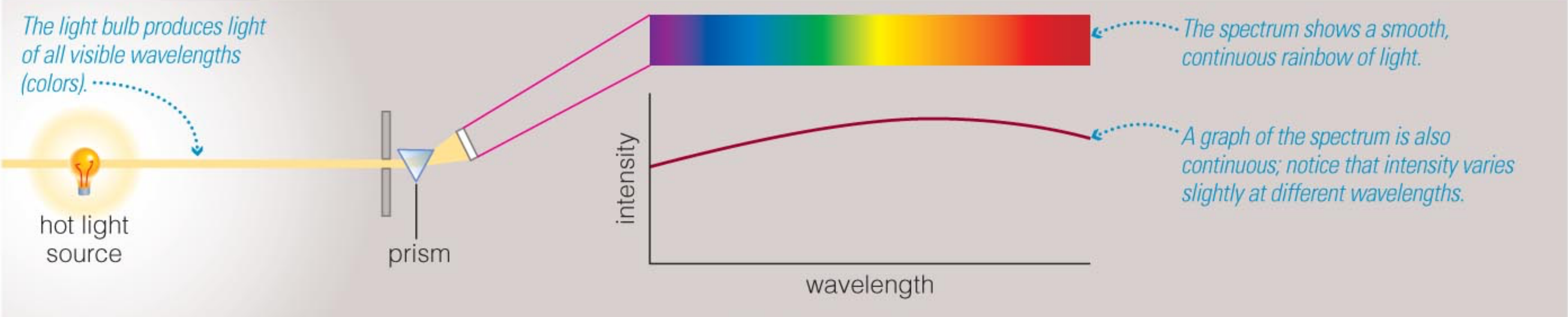
Emission Lines?

– Emission lines come from excited electrons decaying down to a lower energy level.

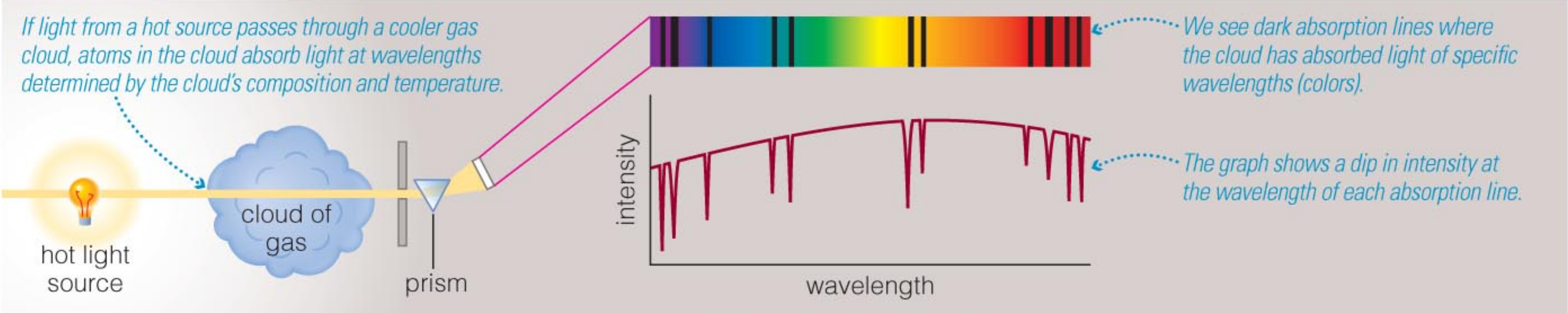
Need an energy source to excite the electrons in the first place

Absorption vs. Emission

http://www.ifa.hawaii.edu/users/lin/ast110-6/applets/production_of_absorp_line.htm

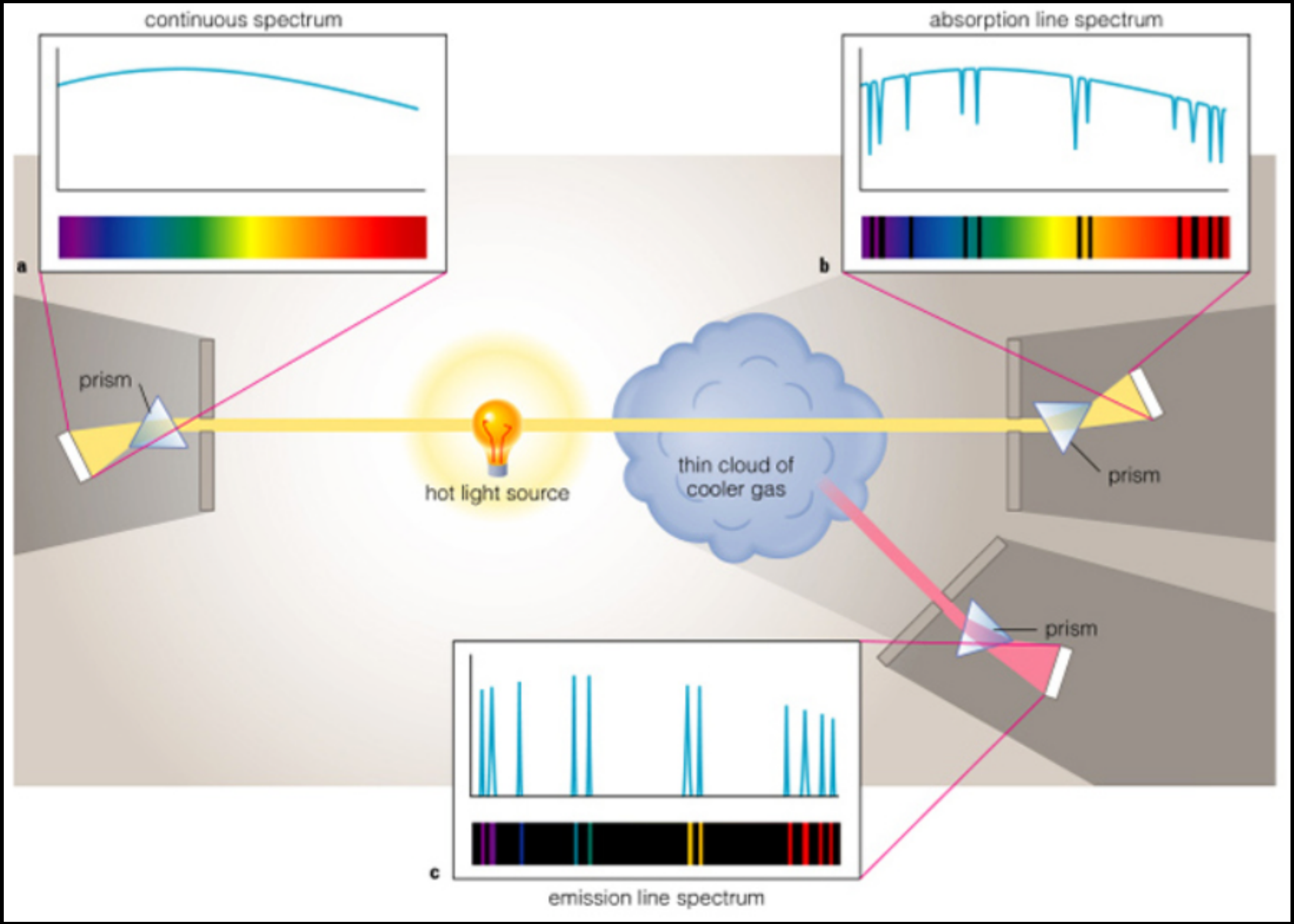


Continuous Spectrum

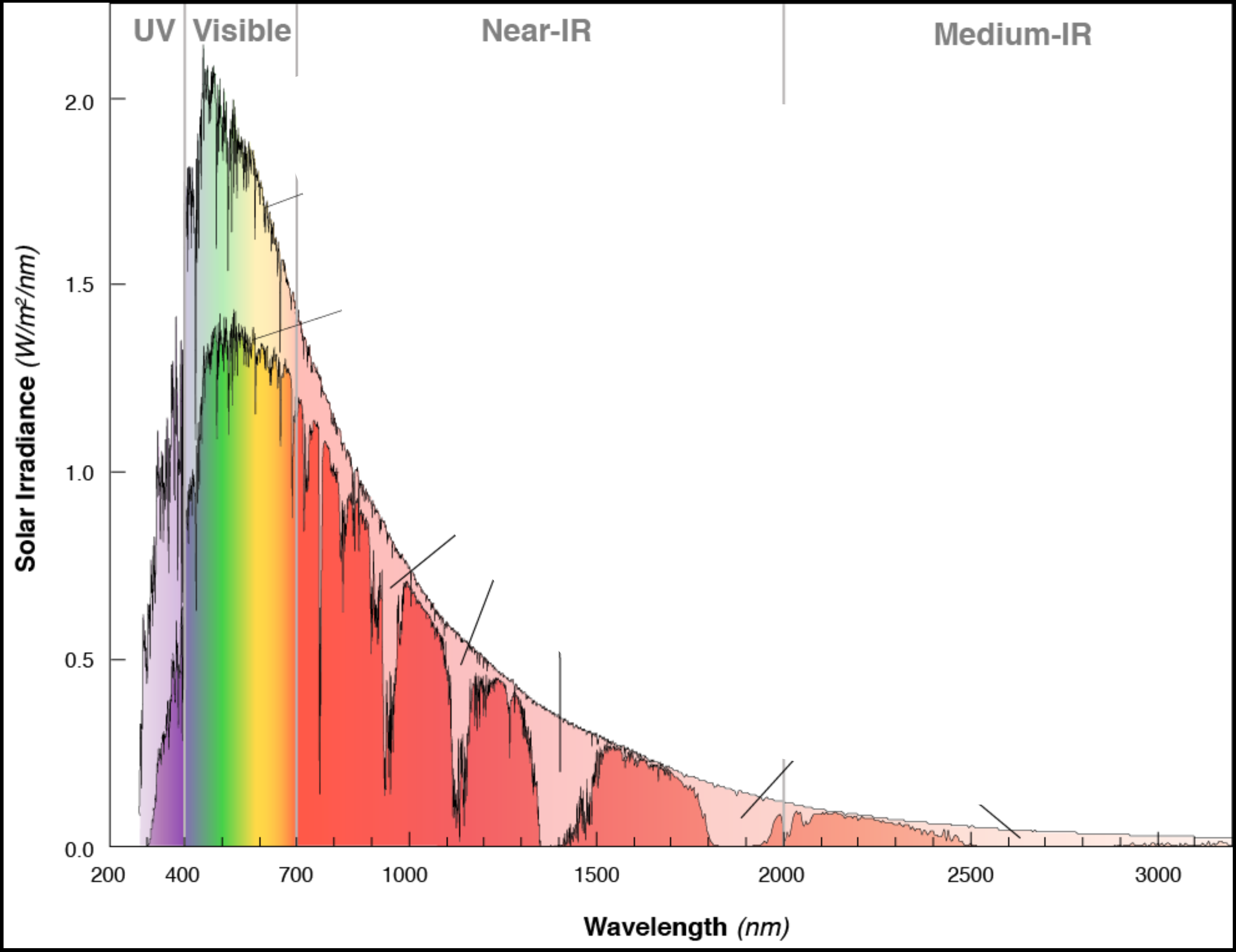


Absorption Line Spectrum

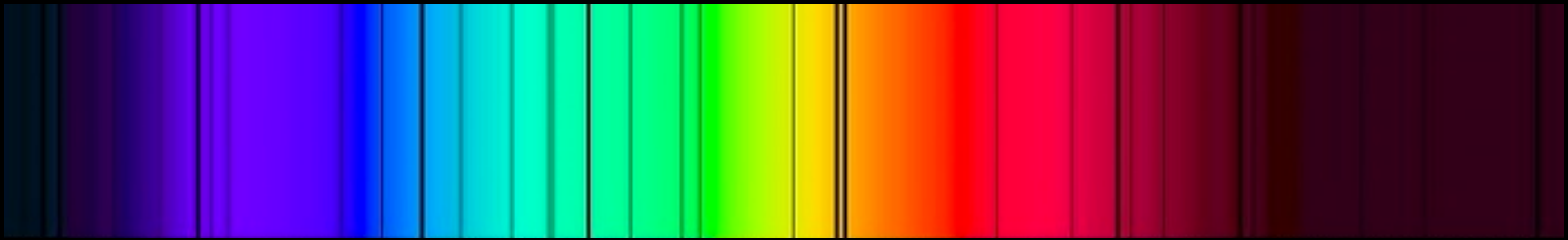
Absorption vs. Emission



What do you see?

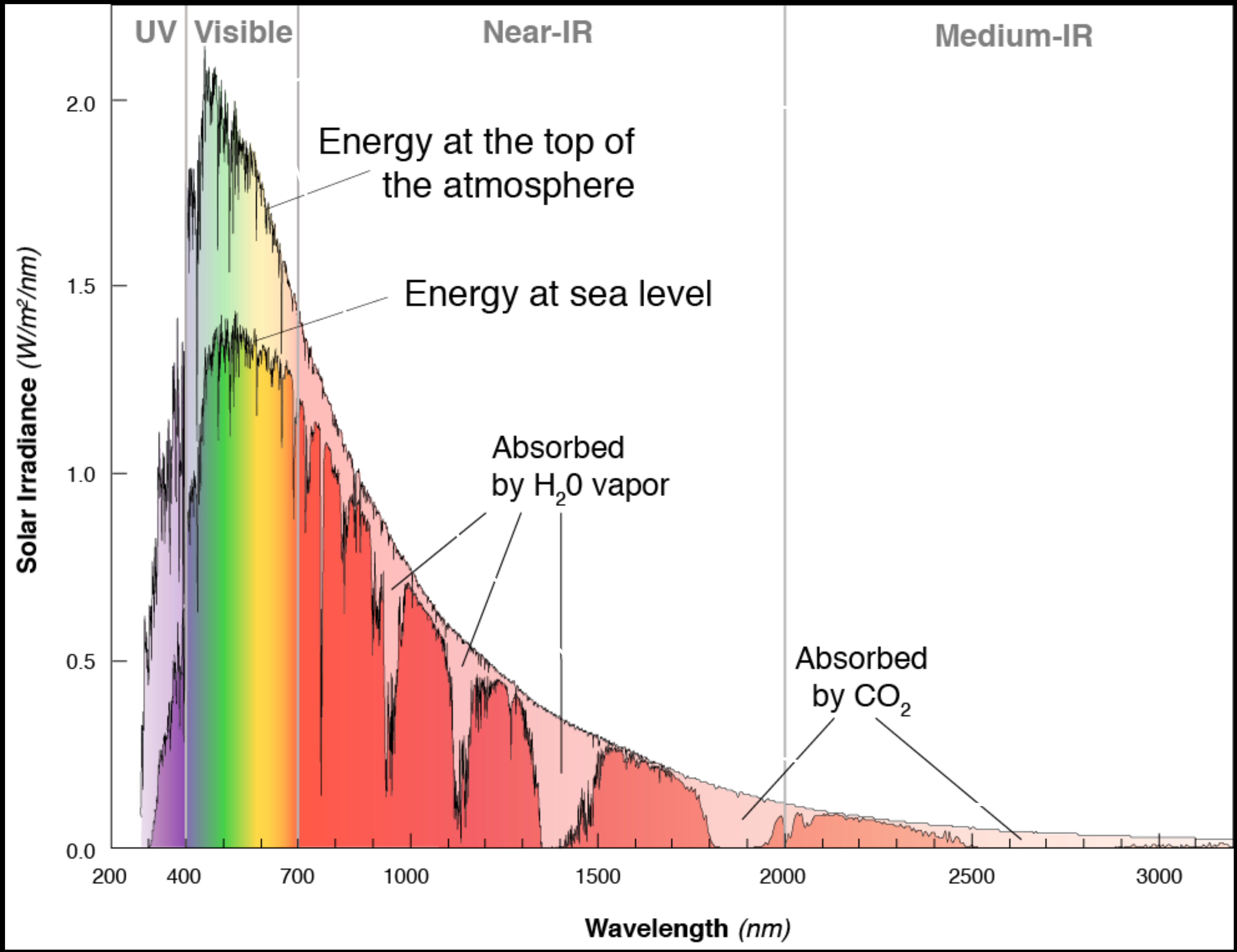


This is a spectrum of a star like the sun



ABSORPTION! Immediately we know:

What do you see?



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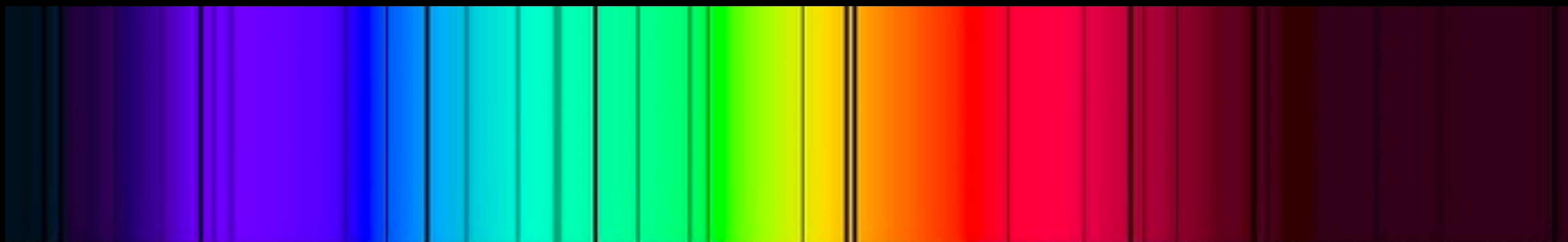
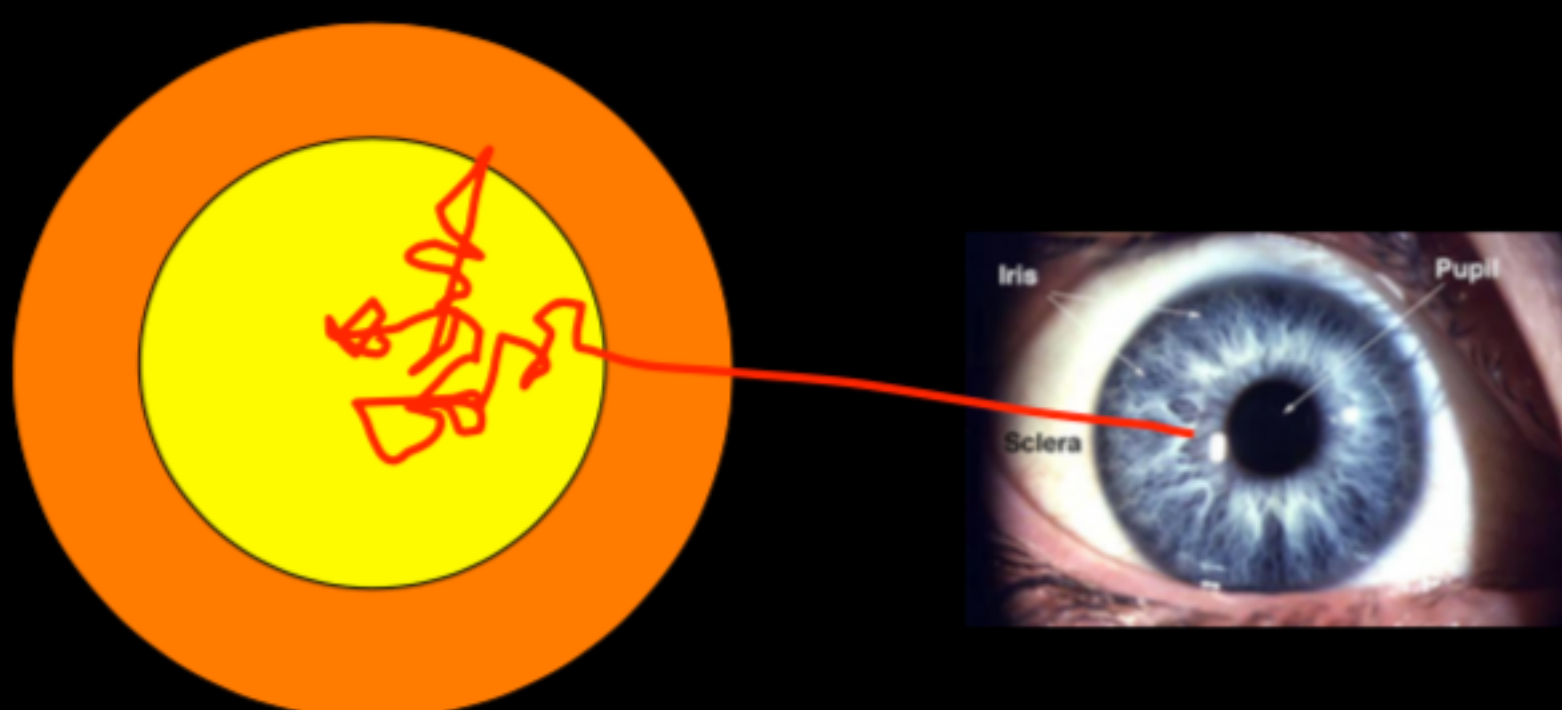


ABSORPTION! Immediately we know:

– There is an opaque source of thermal radiation, with cooler gas in front of it. This tells us immediately about the structure of stars!



What have we learned?

- **What are the three basic type of spectra?**
- **How does light tell us what things are made of?**
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  - We can determine which atoms something is made of by looking for their fingerprints in the spectrum.
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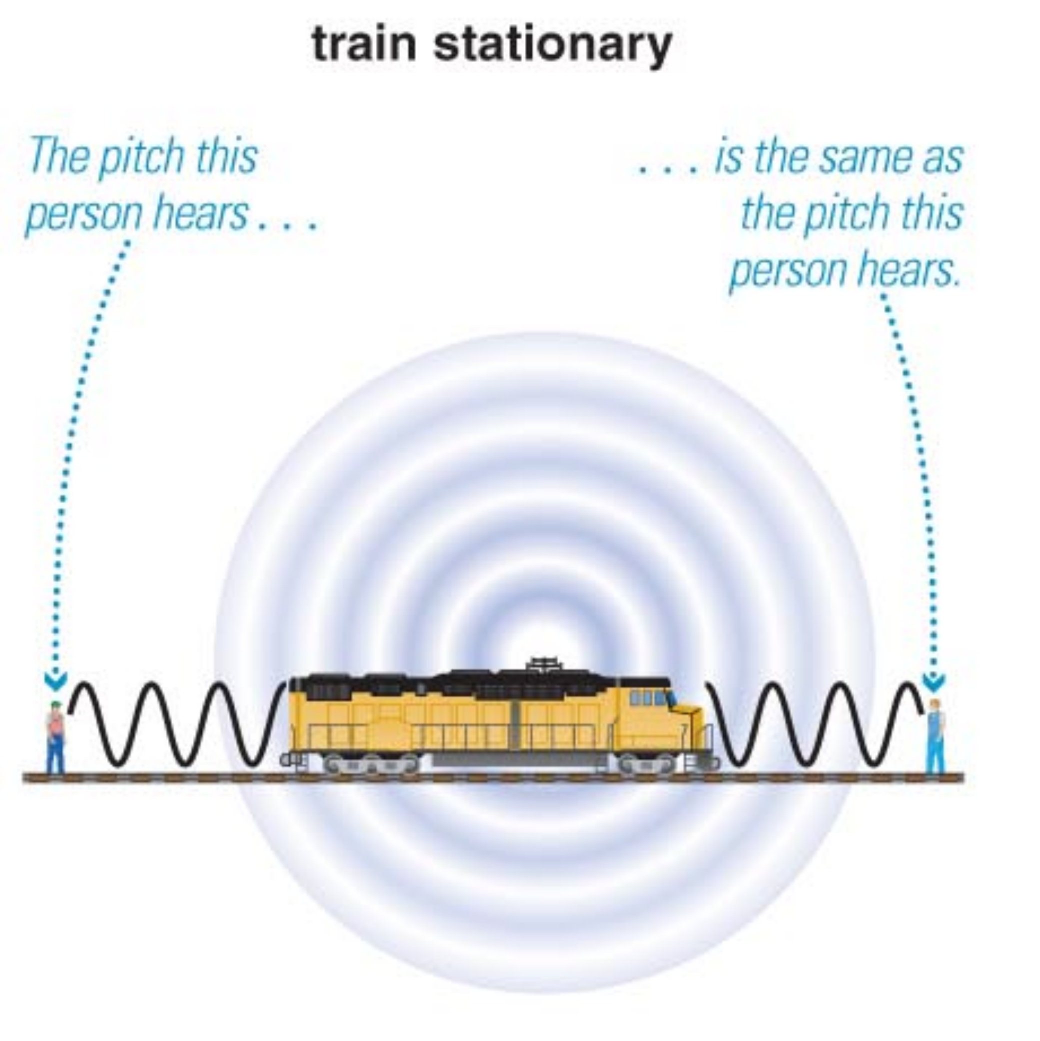
  - We can determine which atoms something is made of by looking for their fingerprints in the spectrum.
- **How does light tell us the temperatures of planets and stars?**
  - Nearly all large or dense objects emit a continuous spectrum that depends on temperature.
  - The spectrum of that thermal radiation tells us the object's temperature.

More fun with spectra: the Doppler shift

More fun with spectra: the Doppler shift

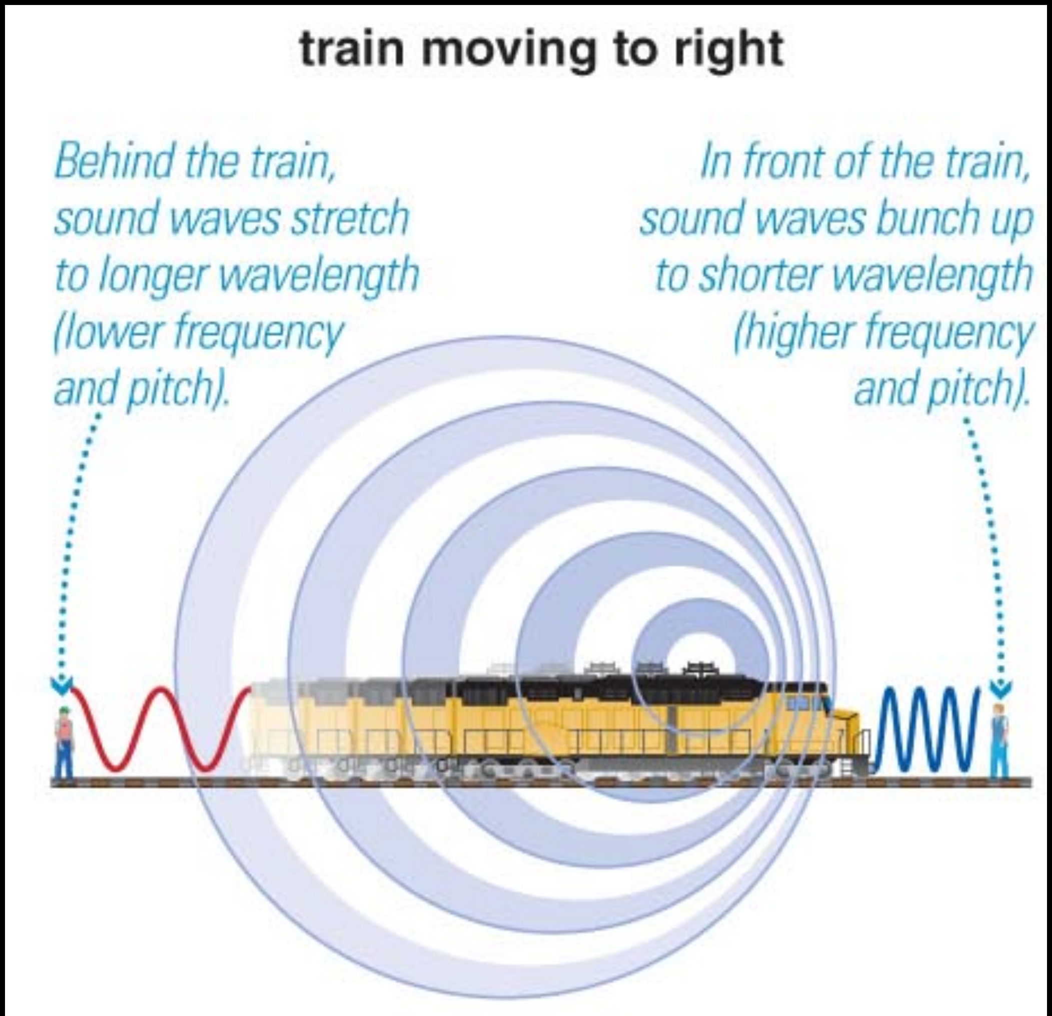
Doppler shift is the change in frequency (or wavelength) of a wave for an observer moving relative to the source of the wave

More fun with spectra: the Doppler shift



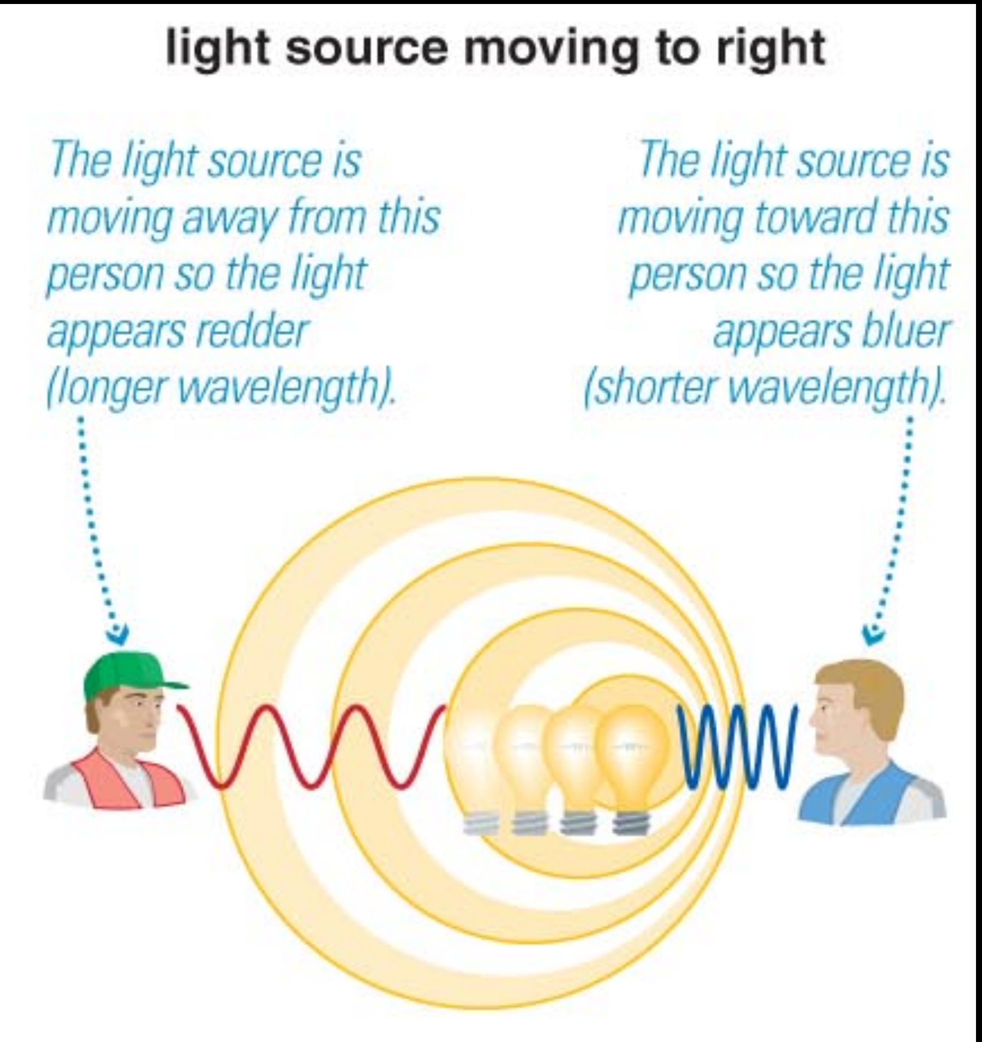
a The whistle sounds the same no matter where you stand near a stationary train.

More fun with spectra: the Doppler shift



b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

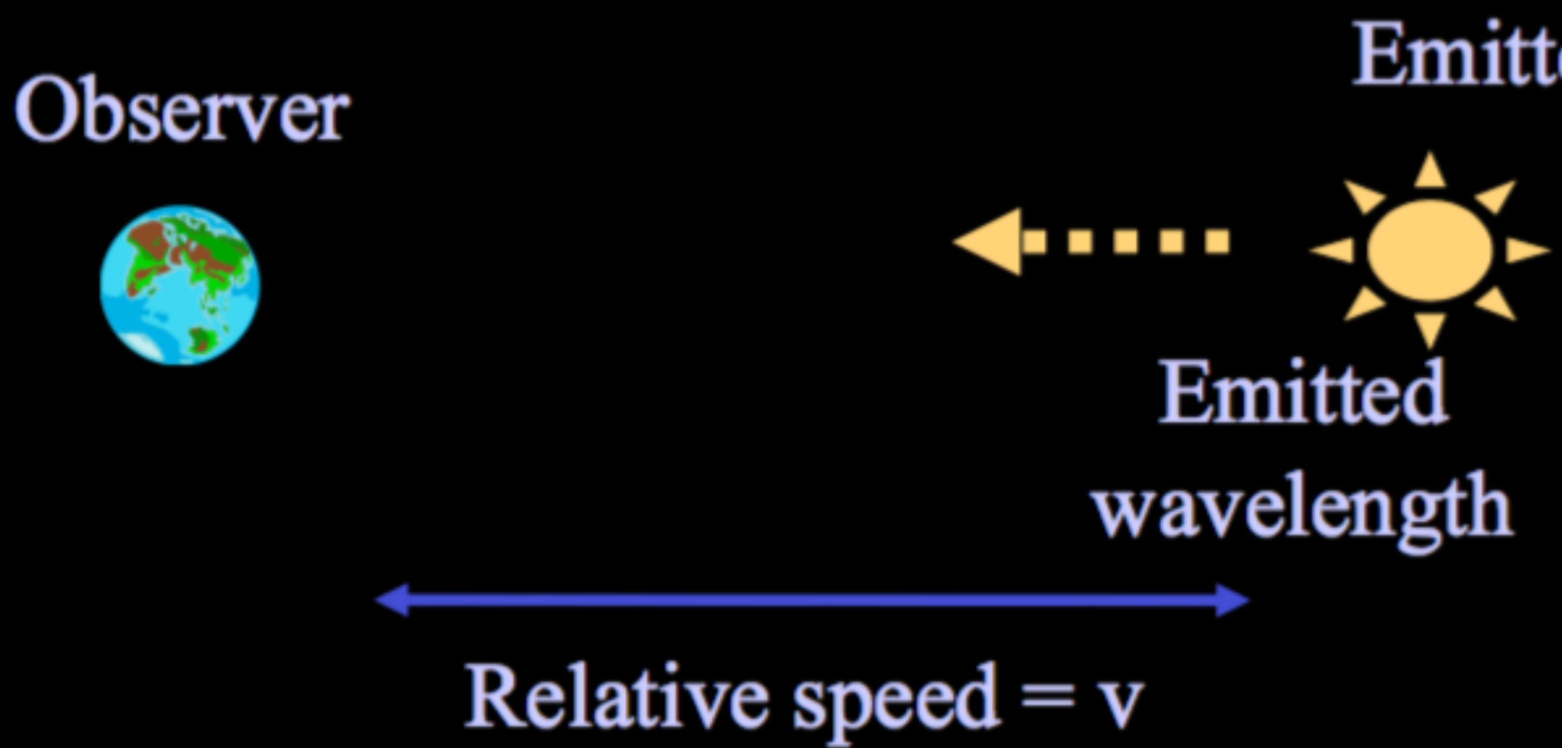
More fun with spectra: the Doppler shift



c We get the same basic effect from a moving light source (although the shifts are usually too small to notice with our eyes).

http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/doppler.htm

More fun with spectra: the Doppler shift



$$\lambda_{Observed} = \lambda_0 + \Delta\lambda$$

$$\Delta\lambda = \frac{v}{c}\lambda_0$$

- λ increases when the object is receding (“redshift”)
- λ decreases when the object is approaching (“blueshift”)

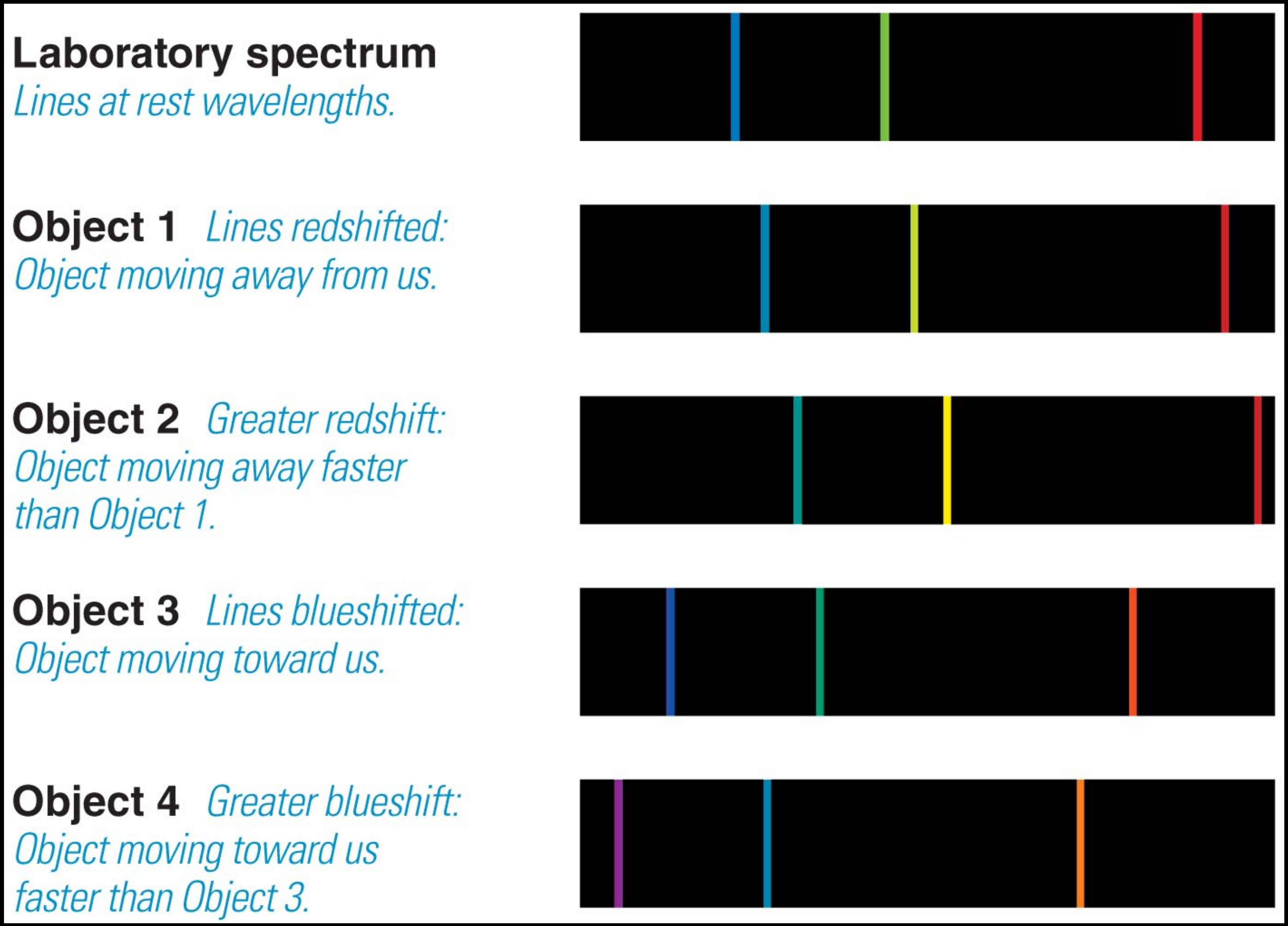
Doppler shifts: How we measure speeds

Look at the shift in the wavelengths of emission and/or absorption lines in the spectrum of an object with respect to their wavelengths in the lab (at rest)

$$\frac{v}{c} = \frac{\Delta\lambda}{\lambda_0}$$

Note: only for **radial** motion and only for v much smaller than c

Using the Doppler Shift



$$\frac{v}{c} = \frac{\Delta\lambda}{\lambda_0}$$

Bigger shift —> Bigger speed!

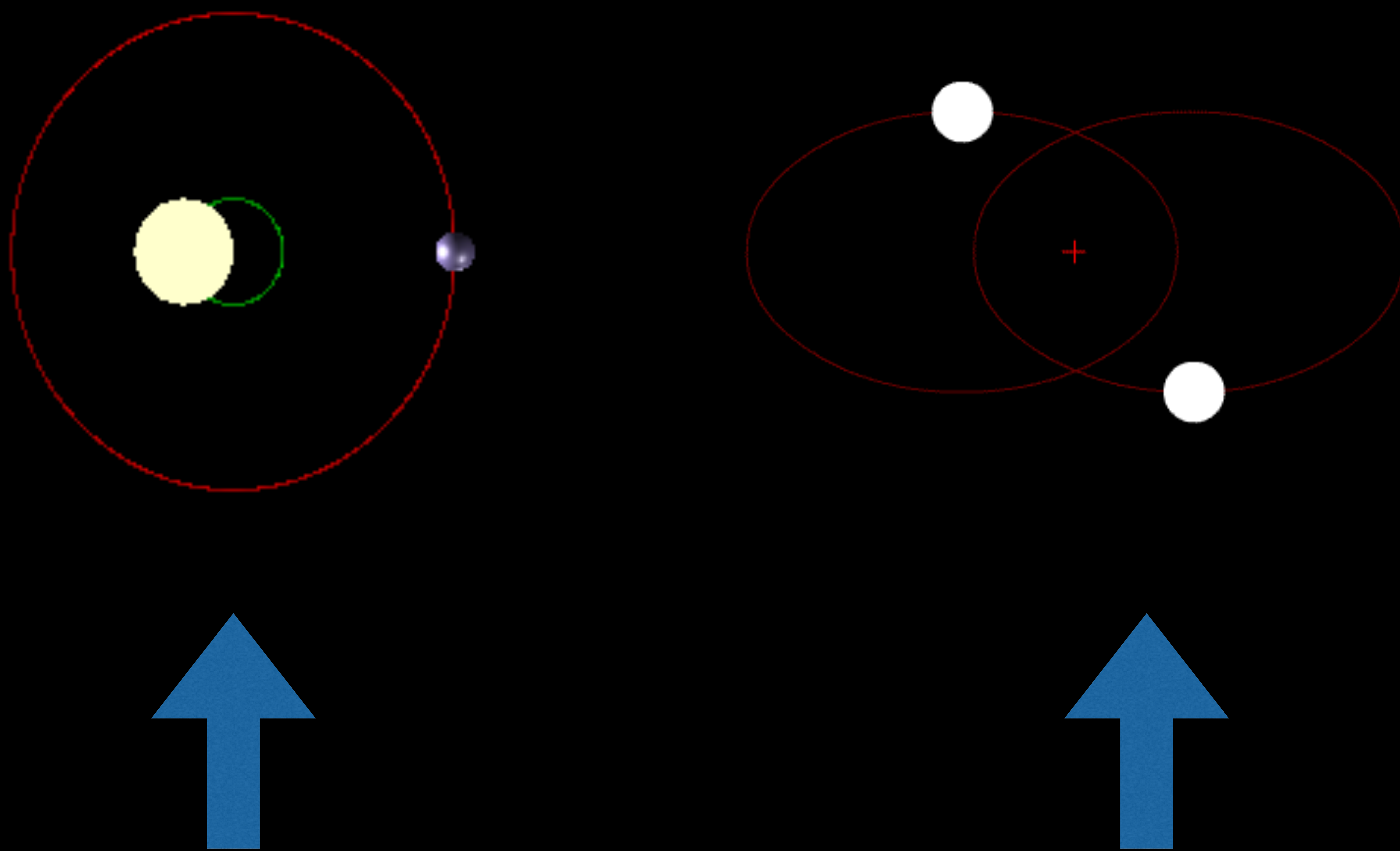
We use the Doppler shift ALL THE TIME in astronomy

For this class:

- Motions of stars when planets are going around them

Measuring the Shift

Doppler shift tells us ONLY about the part of an object's motion toward or away from us



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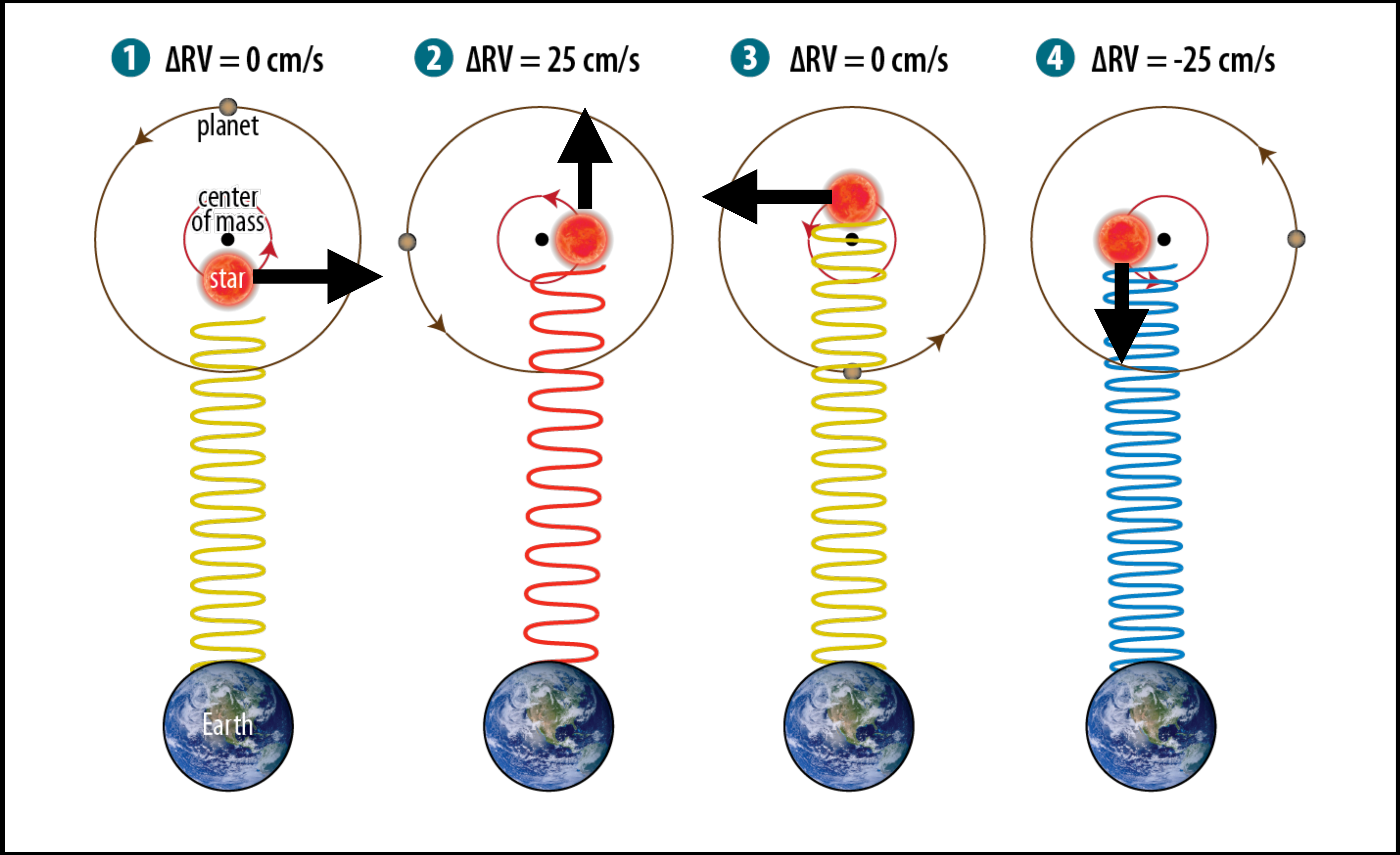

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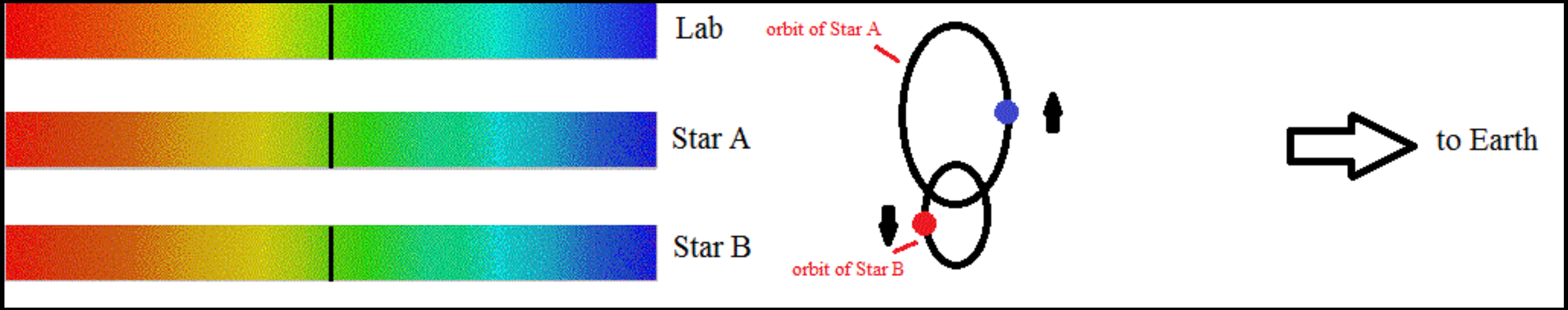
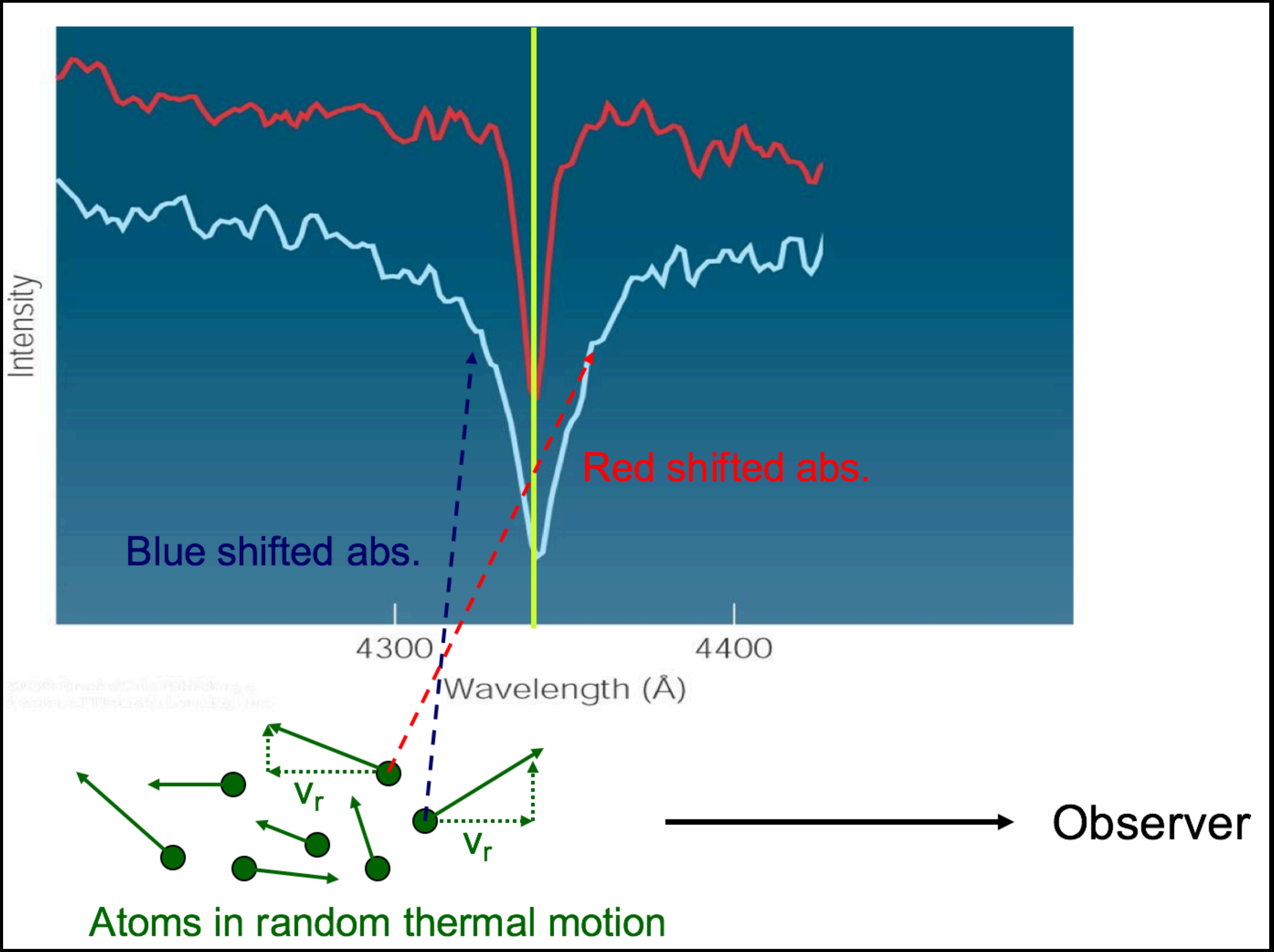


Doppler Broadening



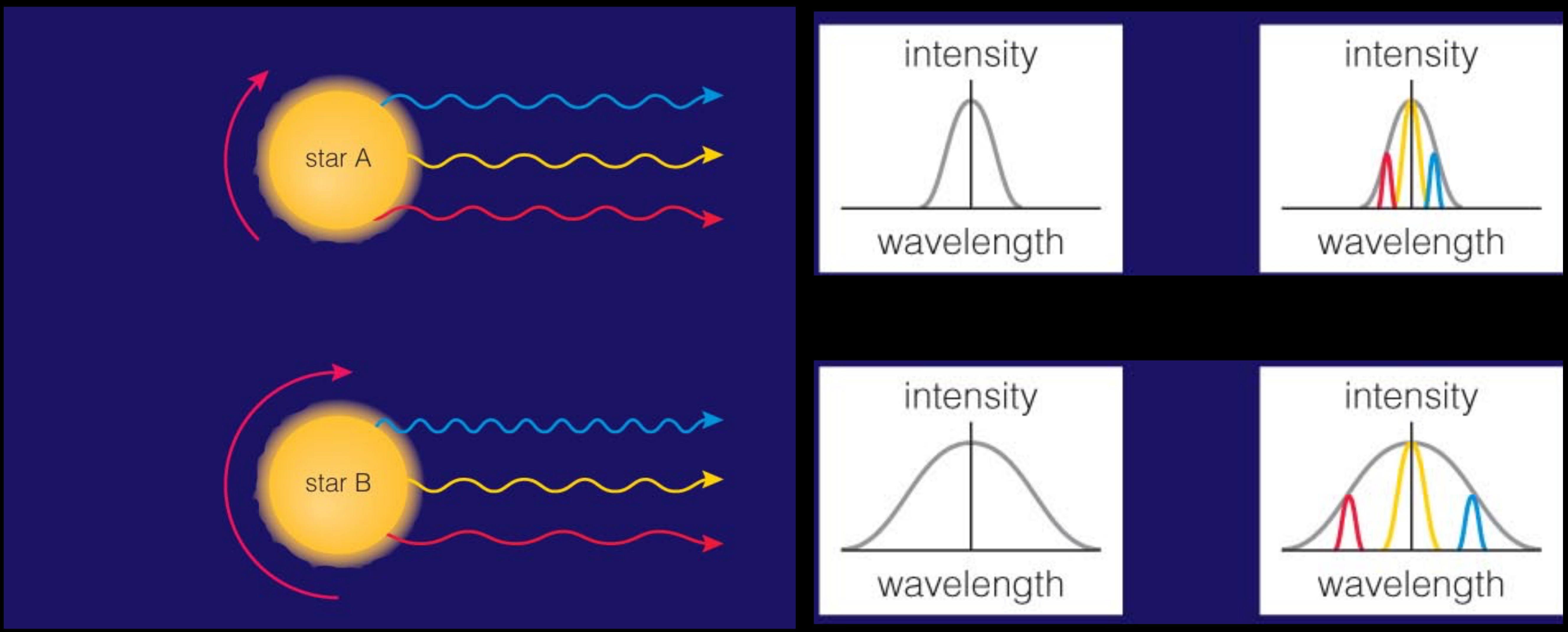
Doppler Broadening

due to the motions of the absorbers. In thermal equilibrium, the atoms in a gas, each of mass m, are moving randomly with a distribution of speed that is described by the Maxwell-Boltzman distribution function.

For the Sun, the photosphere temperature is T = 5777 K and the Doppler broadening is ~ 0.0427 nm, roughly 1000 times grater than natural broadening. Turbulence are particularly important in giant and super giant.

gaussian profile

Rotating stars



A spectrum tell us:

- [redacted] (spectral lines)
- [redacted] (Doppler shift)
- [redacted] (Continuum spectrum)
- [redacted] (line shape)

A spectrum tell us:

- **Composition (spectral lines)**
- **(Doppler shift)**
- **(Continuum spectrum)**
- **(line shape)**

A spectrum tell us:

- Composition (spectral lines)
- How far the object is from us (Doppler shift)
- (Continuum spectrum)
- (line shape)

A spectrum tell us:

- **Composition (spectral lines)**
- **How far the object is from us (Doppler shift)**
- **Temperature of the object (Continuum spectrum)**
- **(line shape)**

A spectrum tell us:

- **Composition (spectral lines)**
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- **How fast is rotating (line shape)**
  or how fast atoms are moving

A spectrum tell us:

- **Composition (spectral lines)**
- **How far the object is from us (Doppler shift)**
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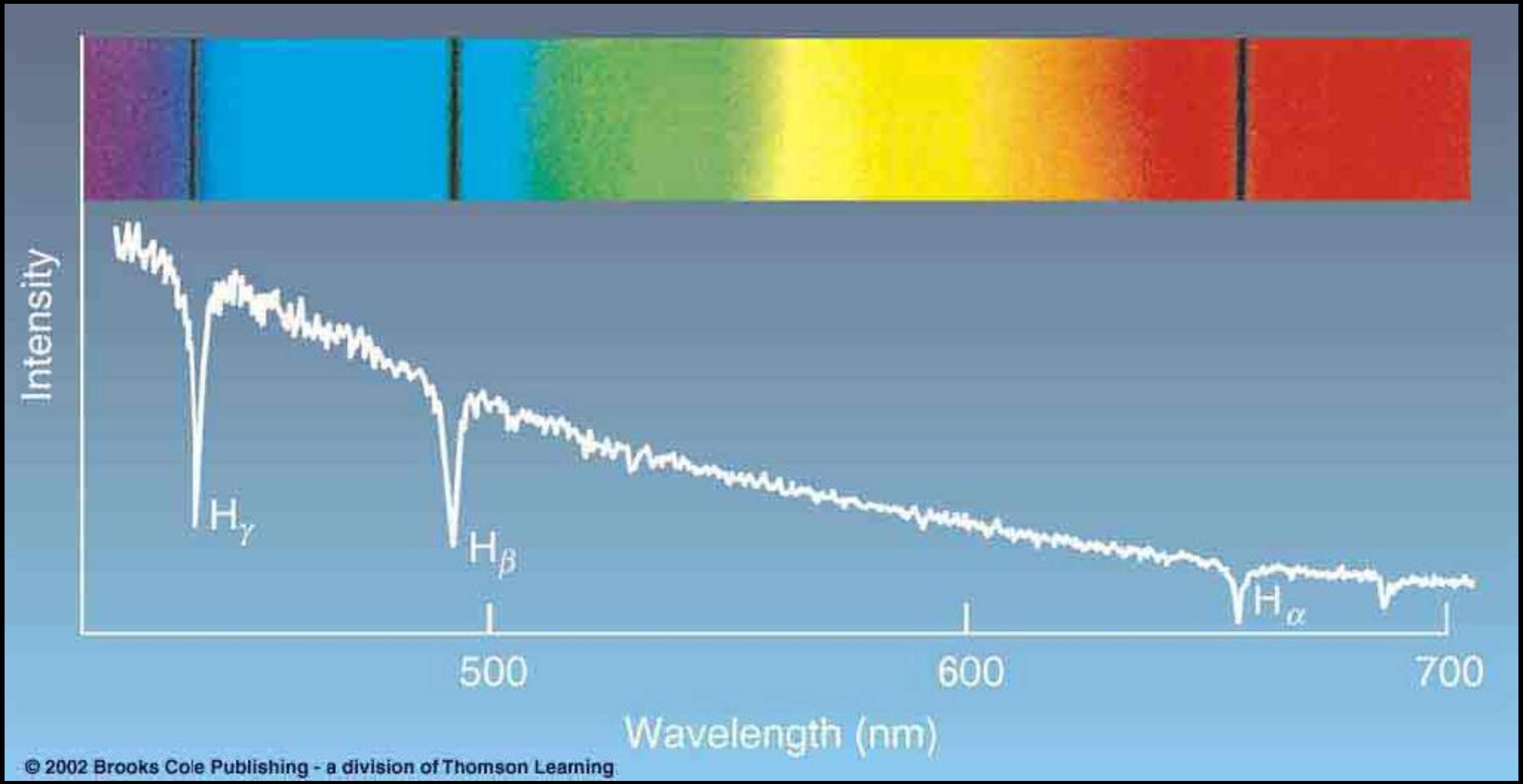
- **How fast is rotating (line shape)**
  or how fast atoms are moving

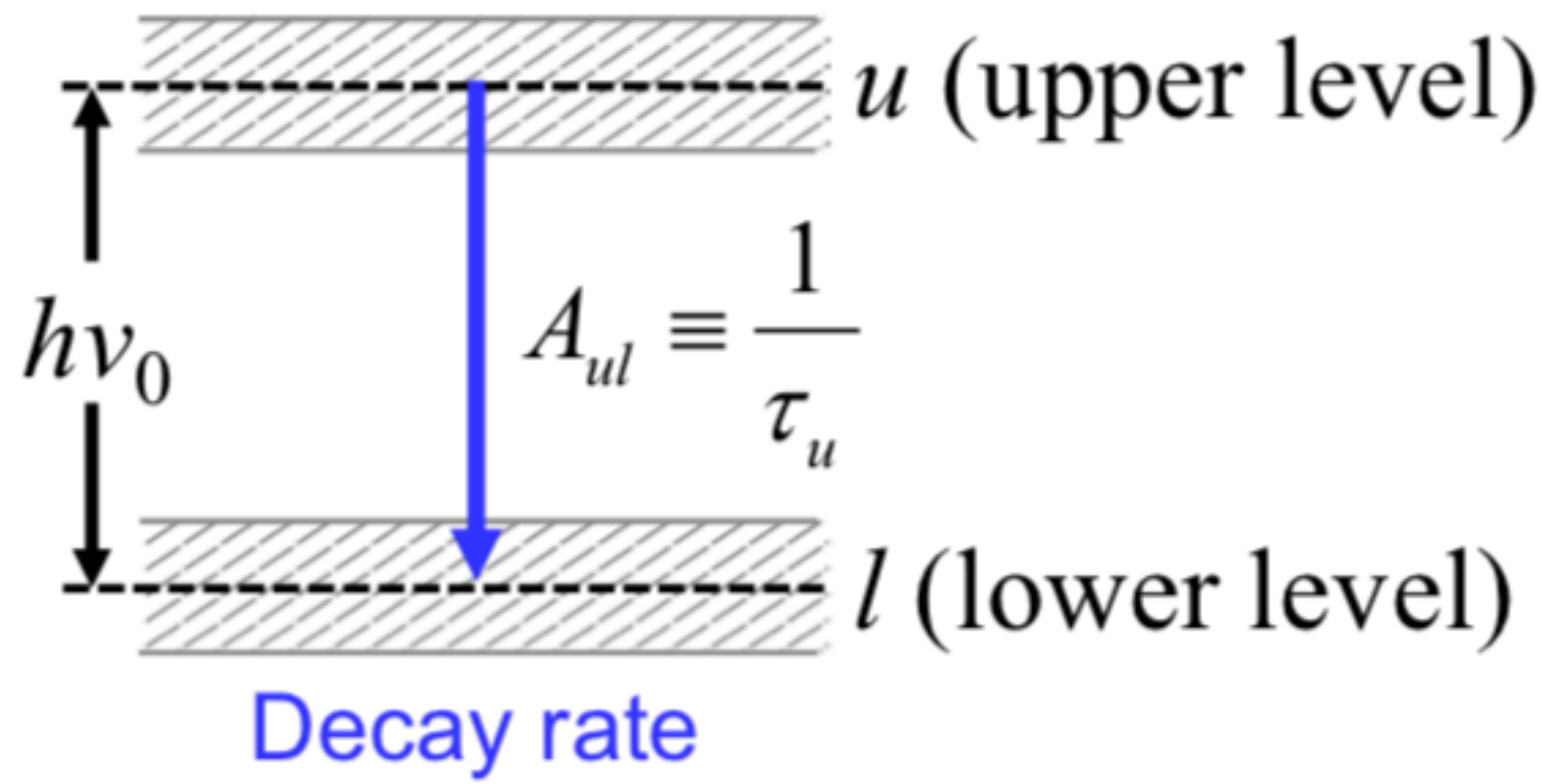
  .. in reality the line shape tell us much more …

Line profile



Natural broadening

Heisenberg uncertainty principle: $\Delta E_u \Delta t_u \geq h/2\pi$



lorentian profile

Pressure Broadening

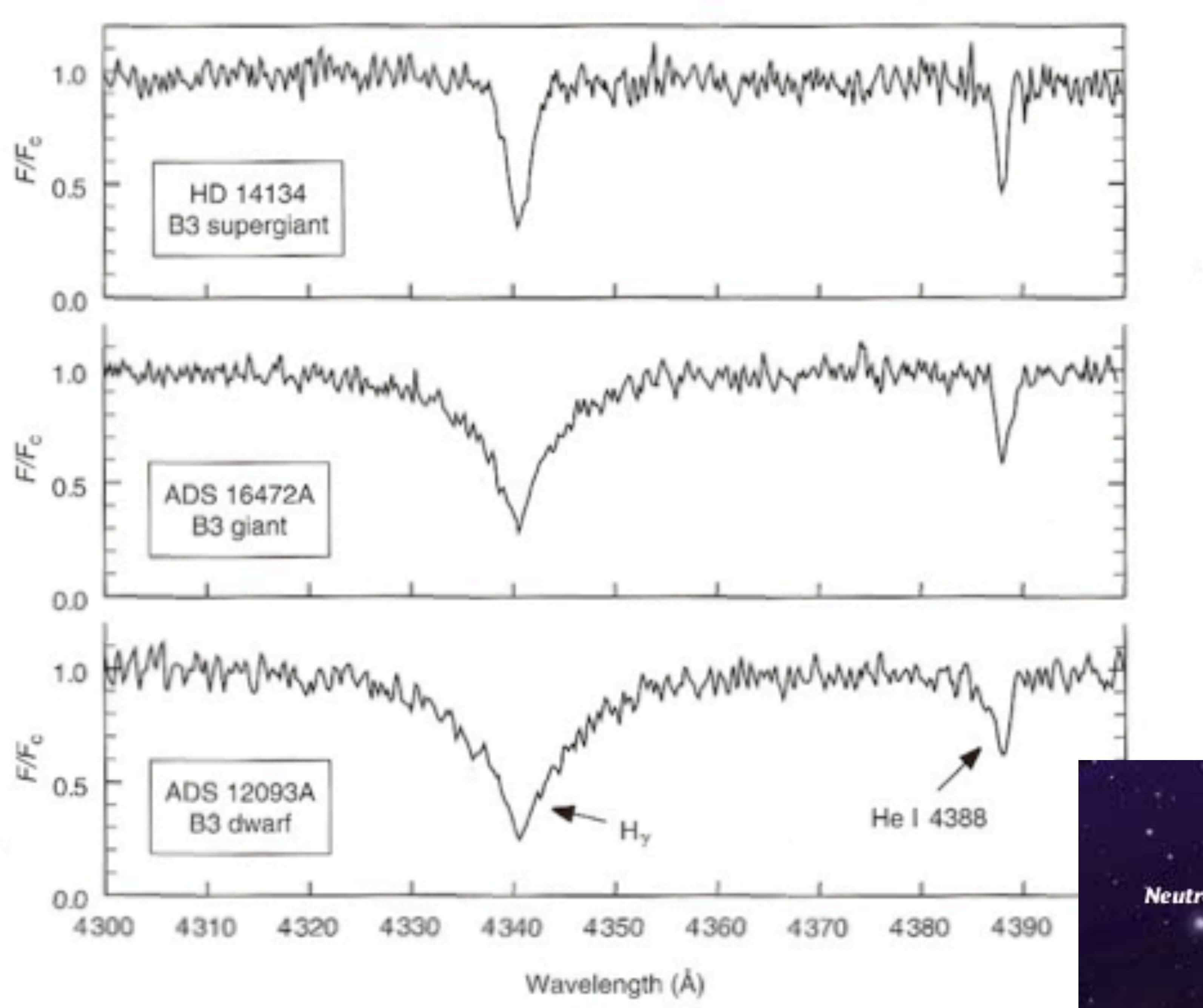
The orbit of an atom can be perturbed by a collision with a neutral atom or by close encounter with a ion.

It is more important for main sequence stars and low mass stars where gravity is stronger

In the case of the Sun, the pressure broadening is of the order of 10^{-5} nm comparable to the natural broadening.

lorentian profile

Pressure Broadening



A spectrum tell us:

- **Composition (spectral lines)**
- **How far the object is from us (Doppler shift)**
- **Temperature of the object (Continuum spectrum)**
- **Pressure, Temperature, density, motion (line width)**