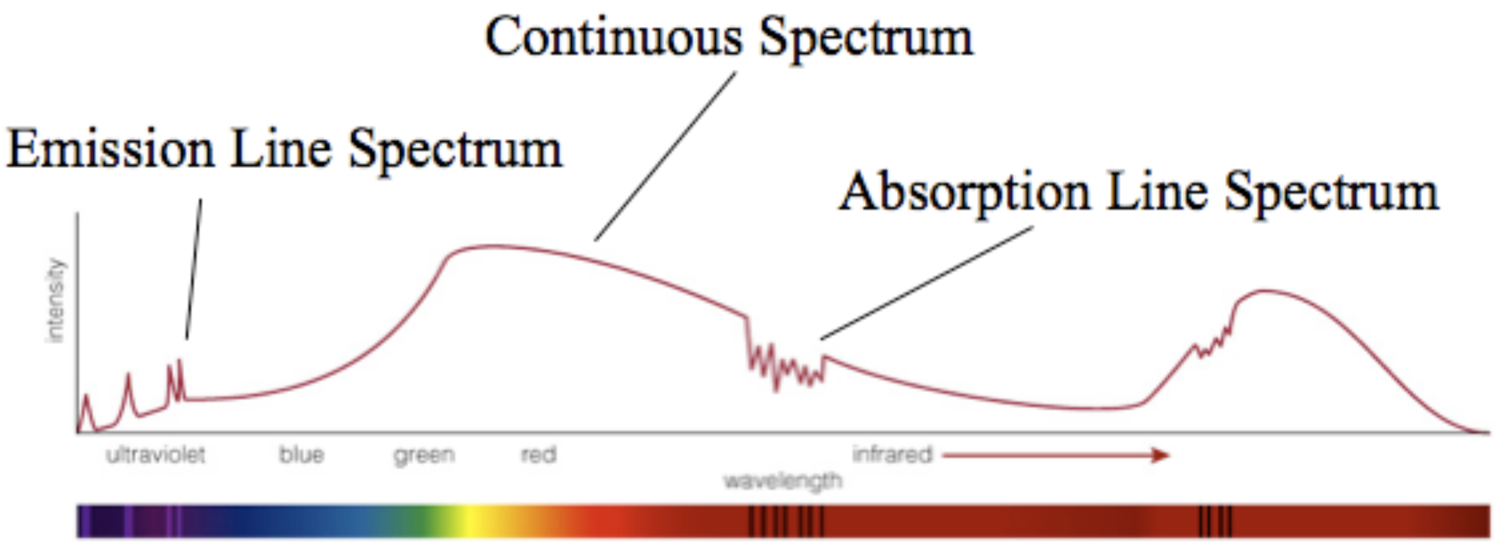
5.4 Learning from Light

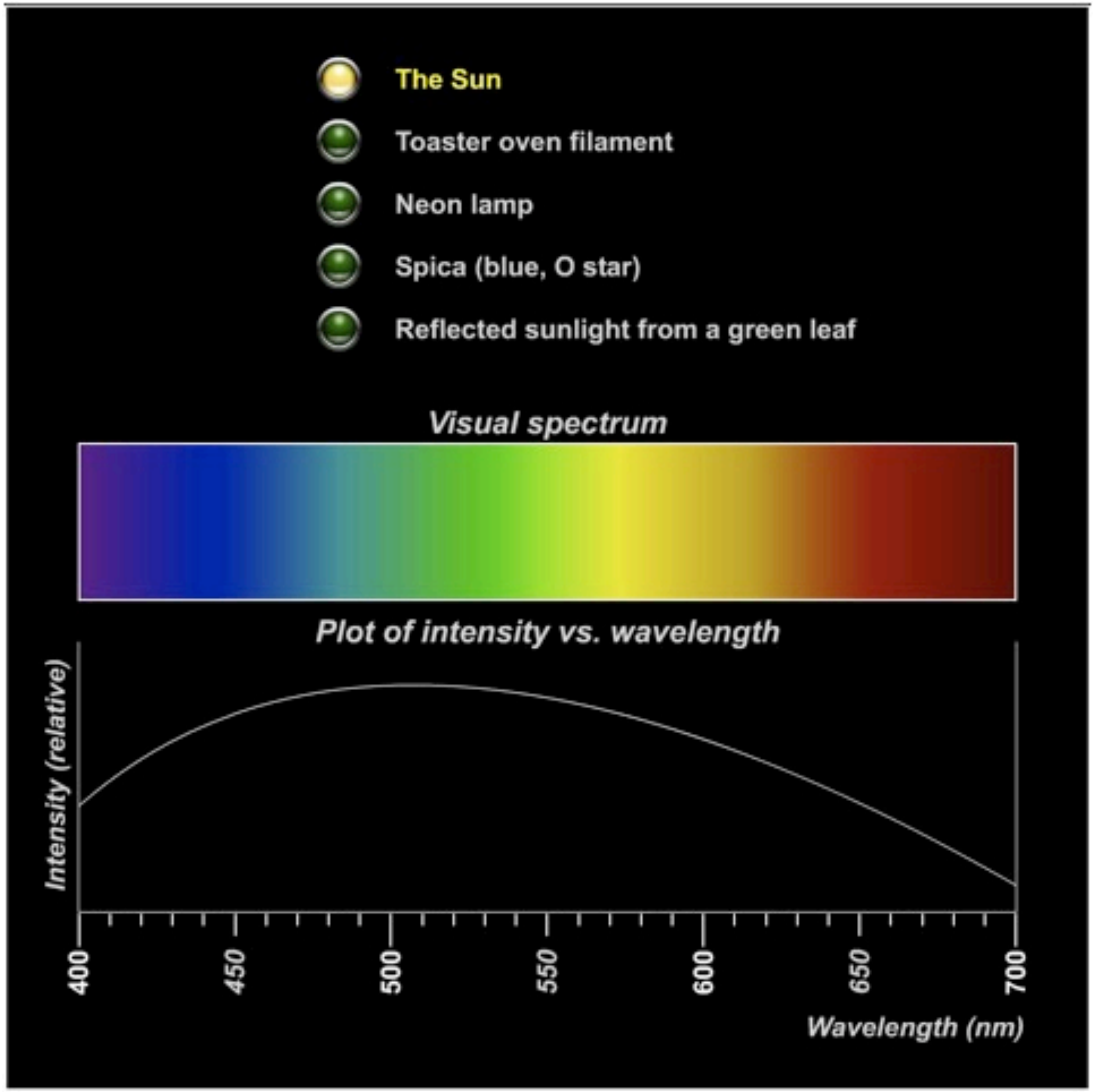
- Our goals for learning:
  - **What are the three basic types of spectra?**
  - **How does light tell us what things are made of?**
  - **How does light tell us the temperatures of planets and stars?**
  - **How does light tell us the speed of a distant object?**

What are the three basic types of spectra?

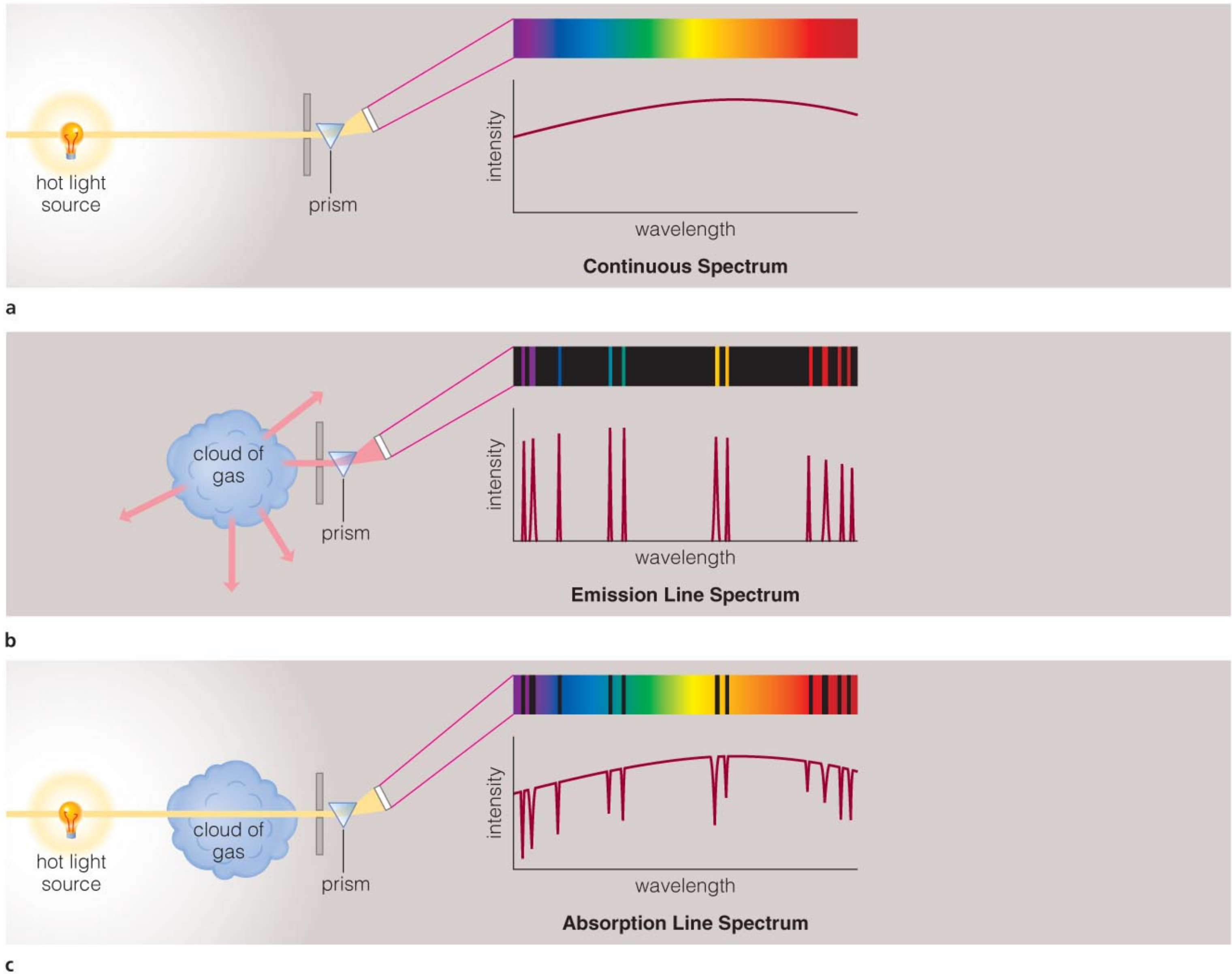


- Spectra of astrophysical objects are usually combinations of these three basic types.

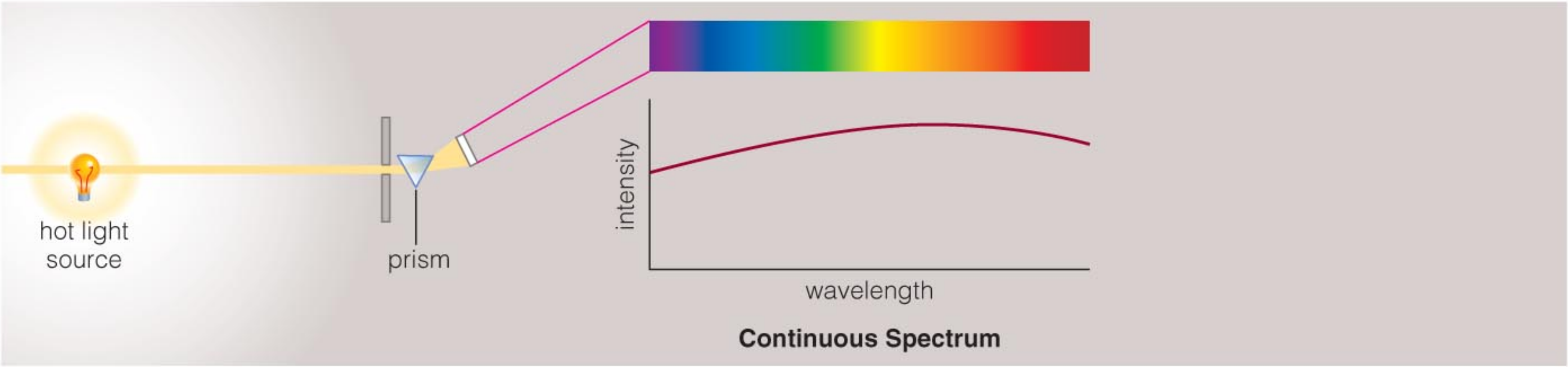
What are the three basic types of spectra?



Three Types of Spectra

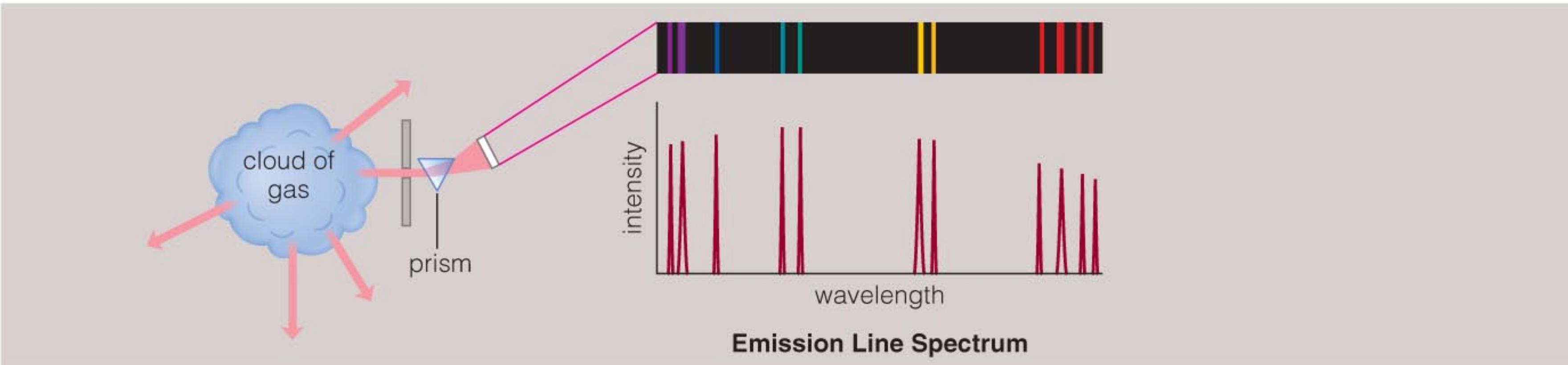


Continuous Spectrum



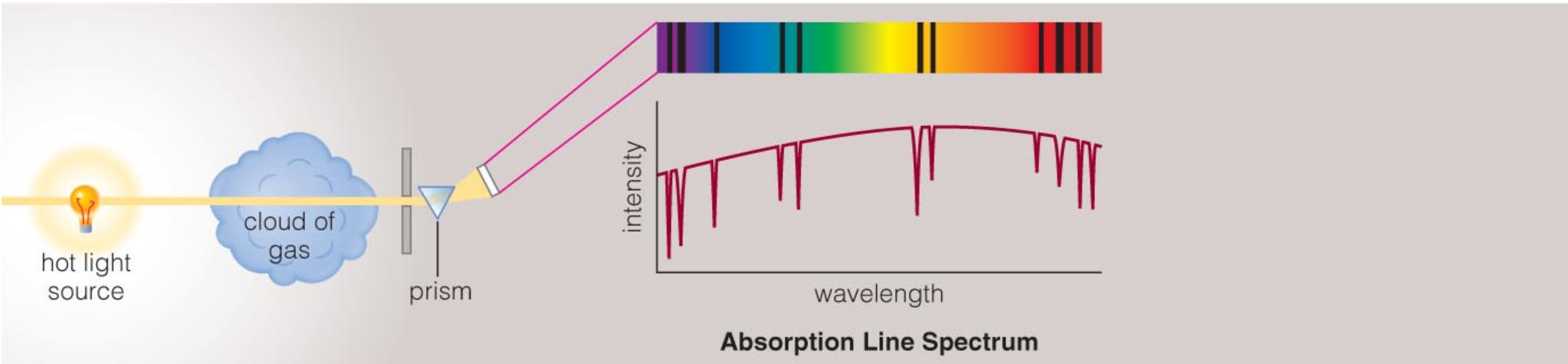
- The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.

Emission Line Spectrum



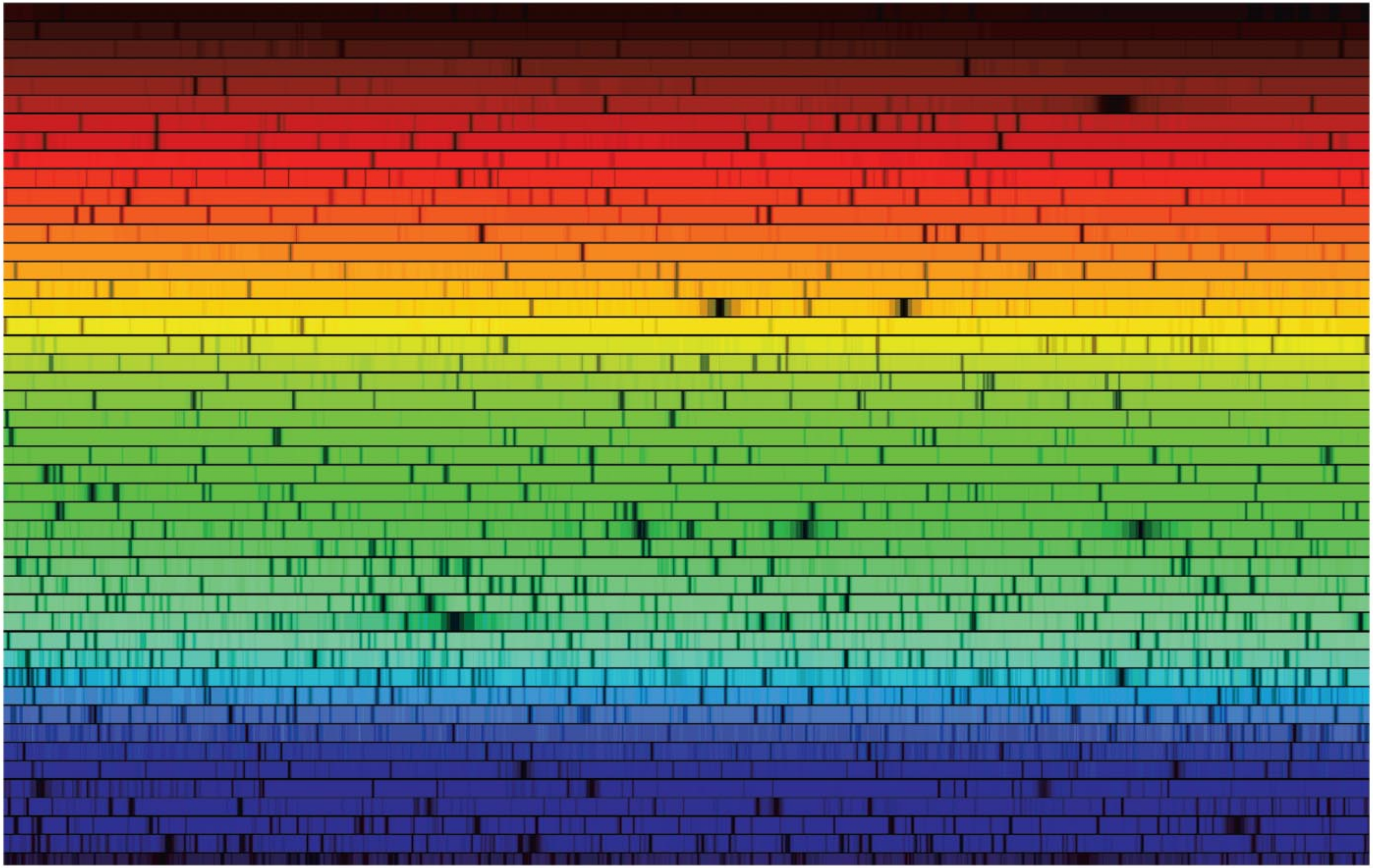
- A thin or low-density cloud of gas emits light only at specific wavelengths that depend on its composition and temperature, producing a spectrum with bright emission lines.

Absorption Line Spectrum

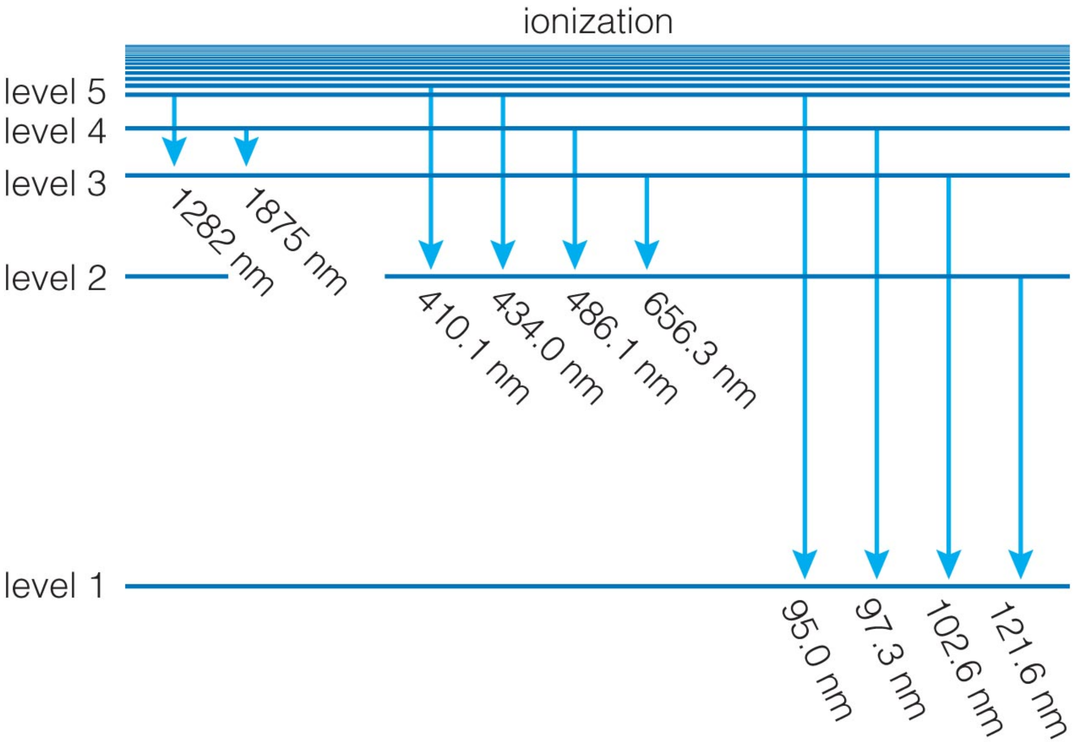


- A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.
- The thin outer atmosphere of a star can also act as the "intervening gas cloud" absorbing light from the star.

How does light tell us what things are made of?



Chemical Fingerprints



a Energy level transitions in hydrogen correspond to photons with specific wavelengths. Only a few of the many possible transitions are labeled.

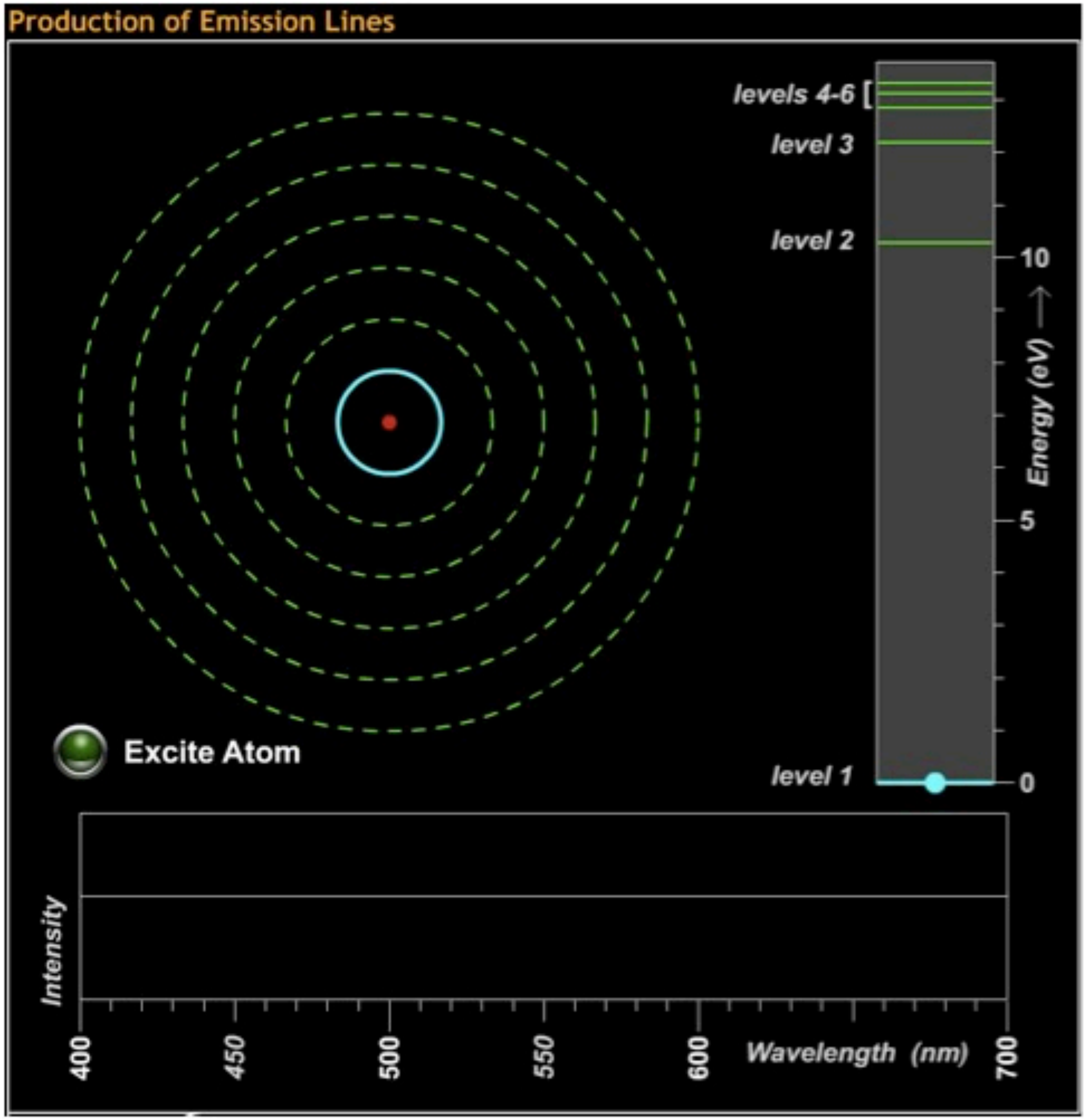
- Each type of atom has a unique set of energy levels.
- Each transition corresponds to a unique photon energy, frequency, and wavelength.

Chemical Fingerprints

- Downward transitions produce a unique pattern of emission lines.

b This spectrum shows emission lines produced by downward transitions between higher levels and level 2 in hydrogen.

Chemical Fingerprints

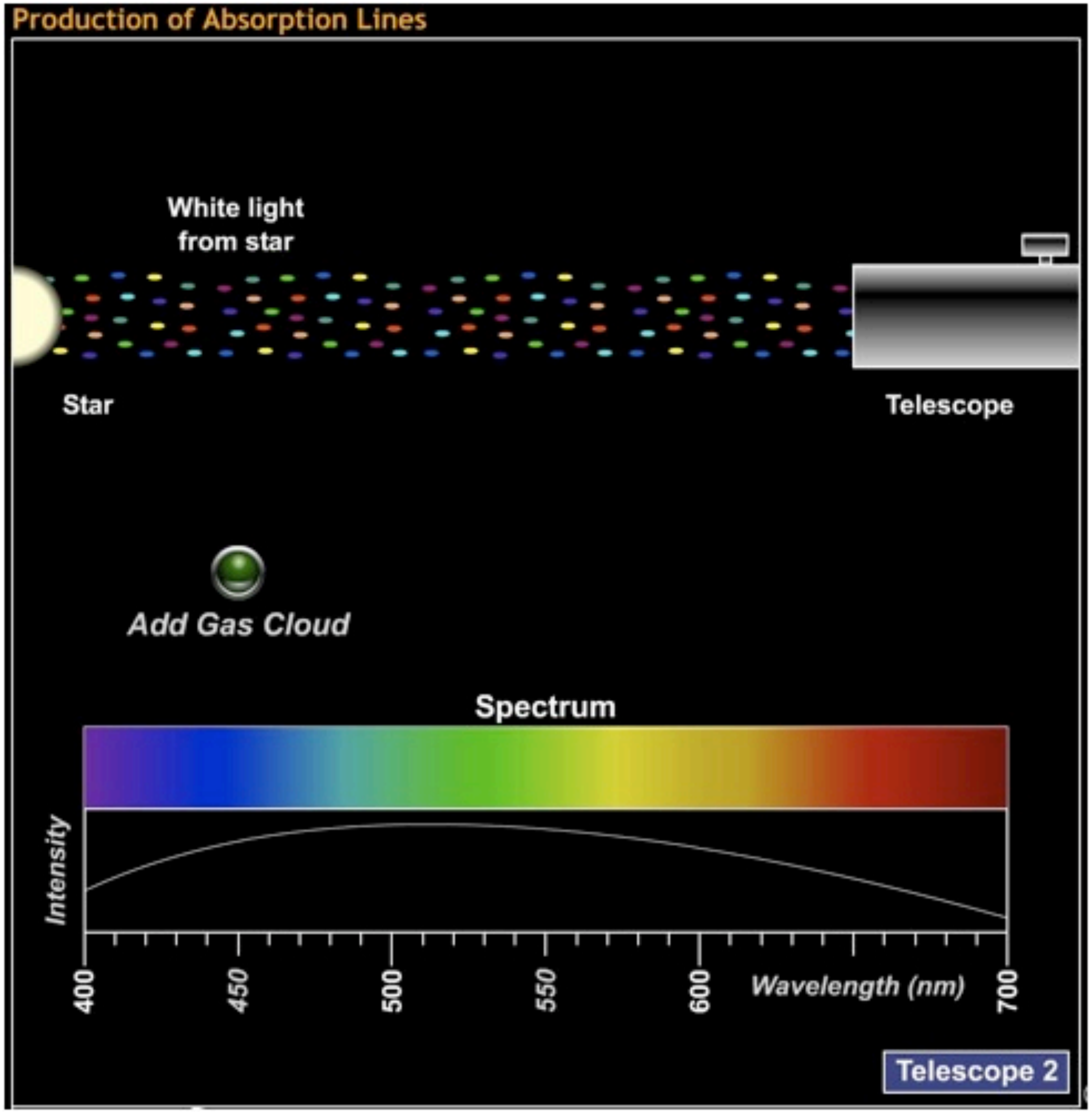


Chemical Fingerprints

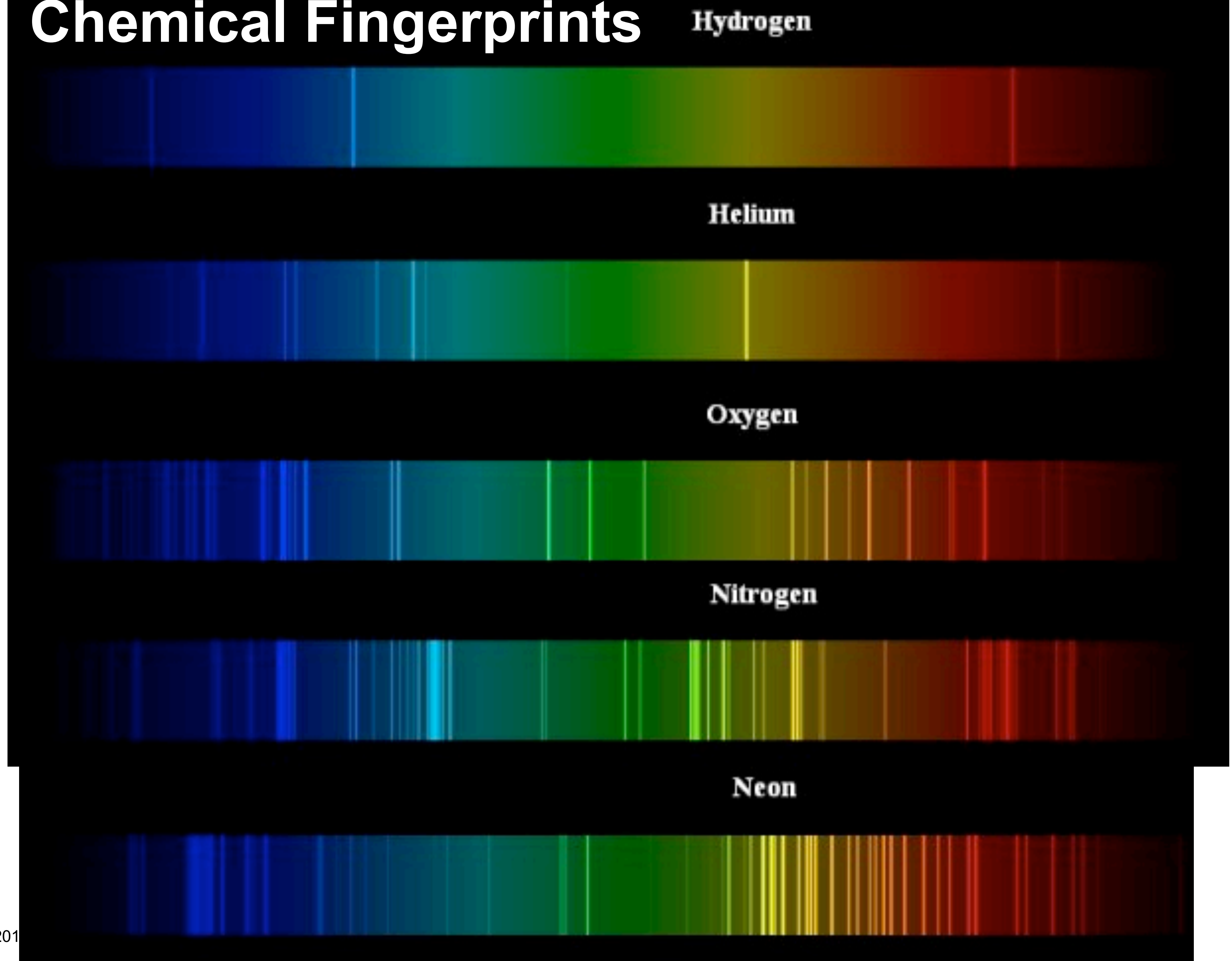
- Because those atoms can absorb photons with those same energies, upward transitions produce a pattern of absorption lines at the same wavelengths.

c This spectrum shows absorption lines produced by upward transitions between level 2 and higher levels in hydrogen.

Chemical Fingerprints



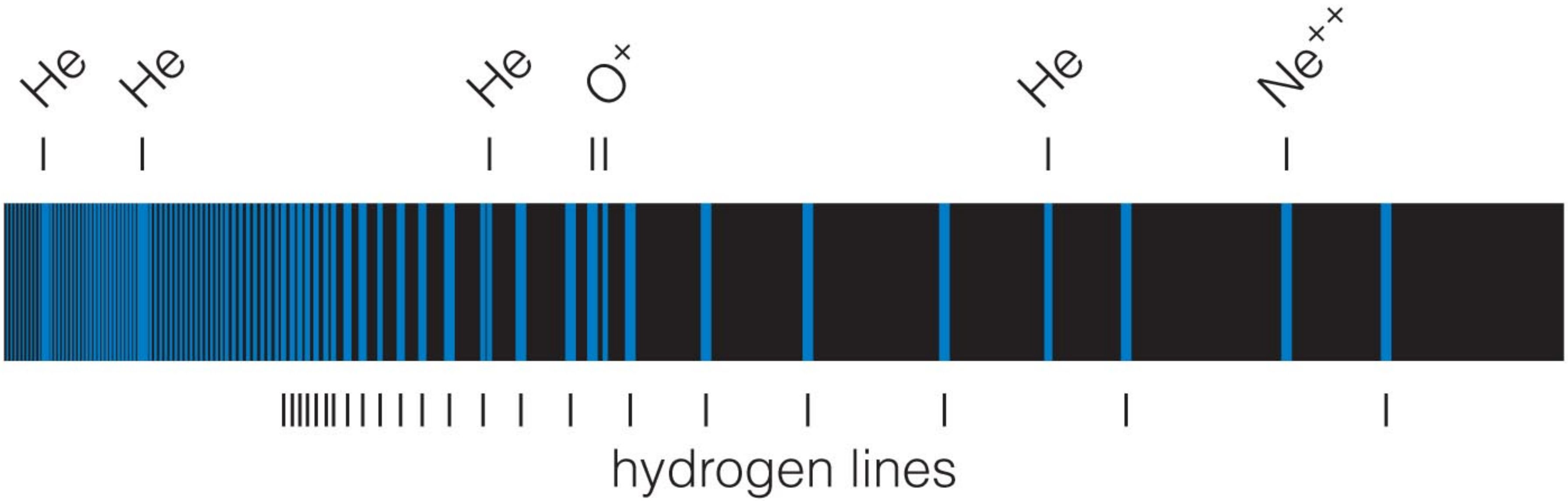
Chemical Fingerprints



Chemical Fingerprints

- Each type of atom has a unique spectral fingerprint.

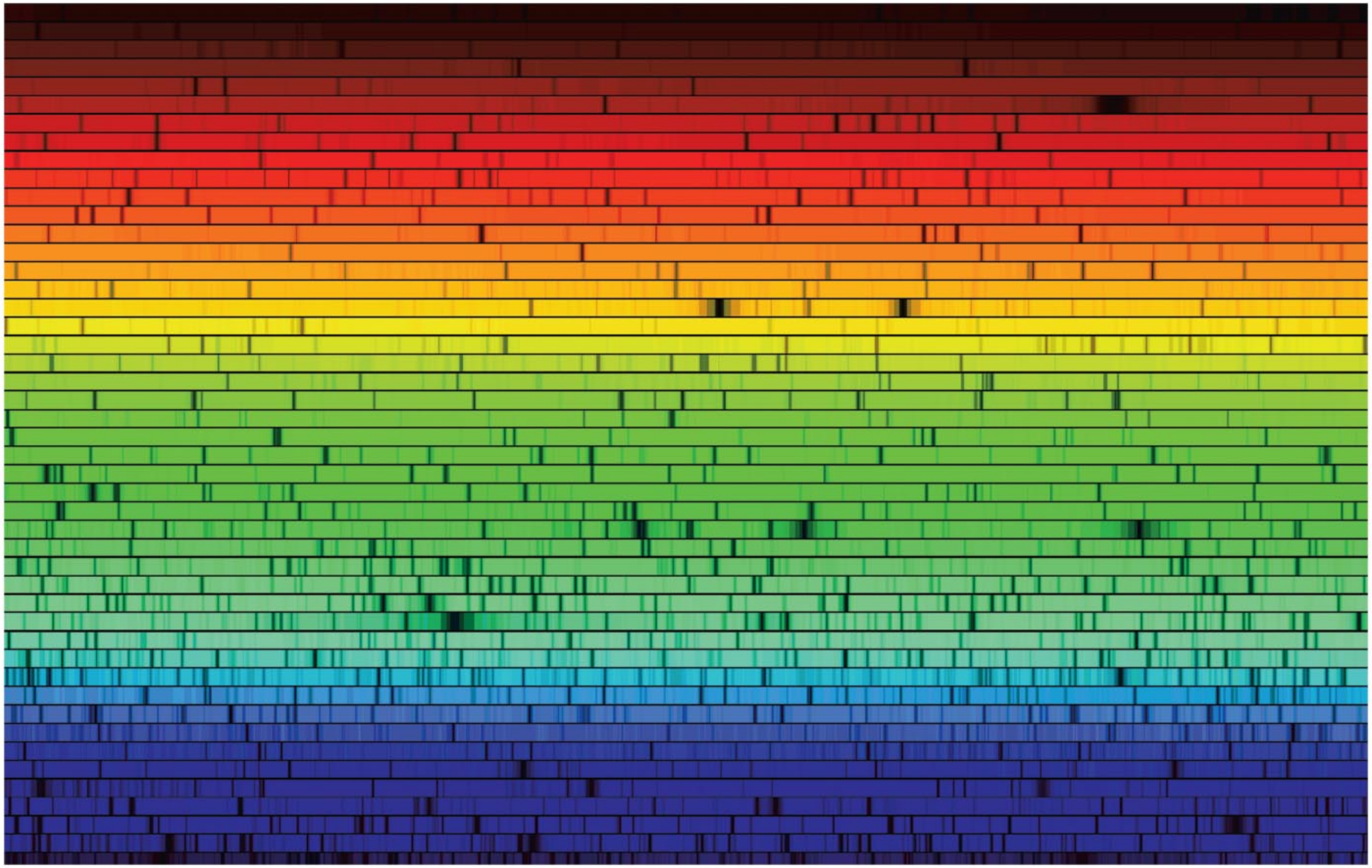
Chemical Fingerprints



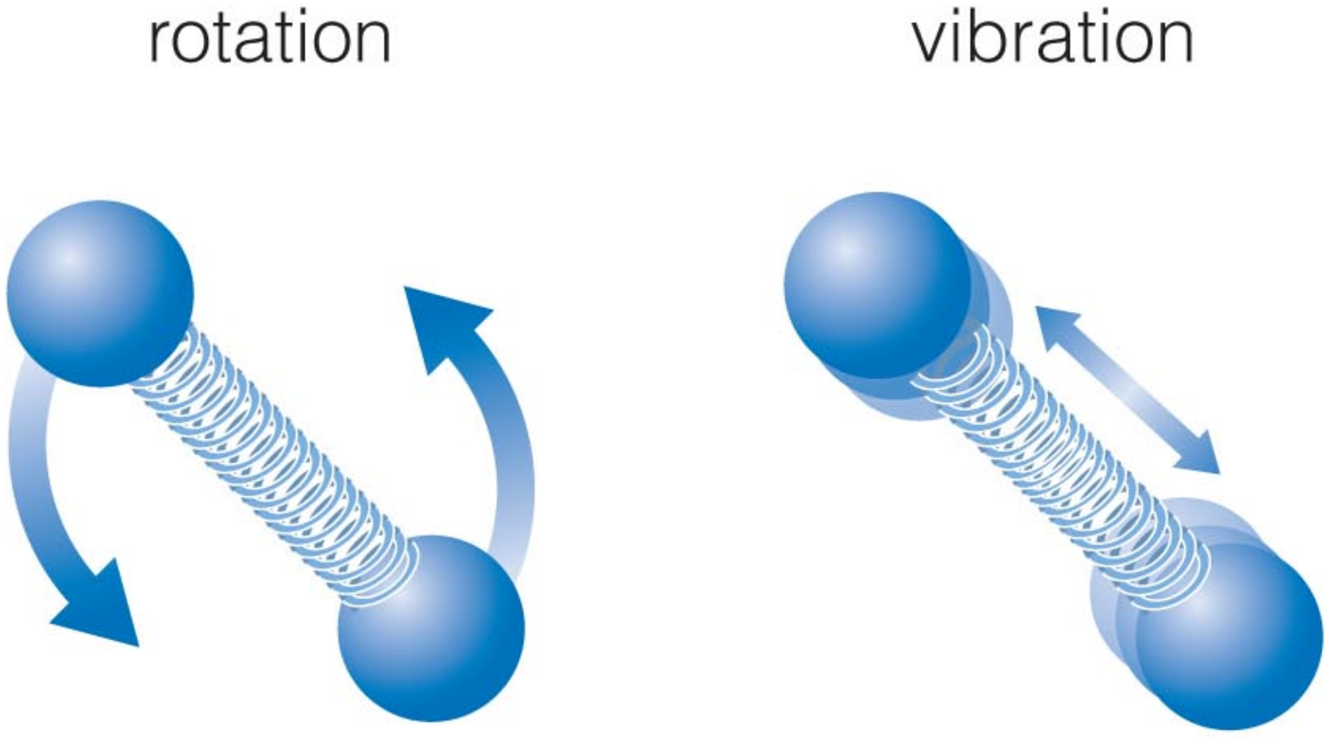
- Observing the fingerprints in a spectrum tells us which kinds of atoms are present.

Chemical Fingerprints

Example: Solar Spectrum



Energy Levels of Molecules

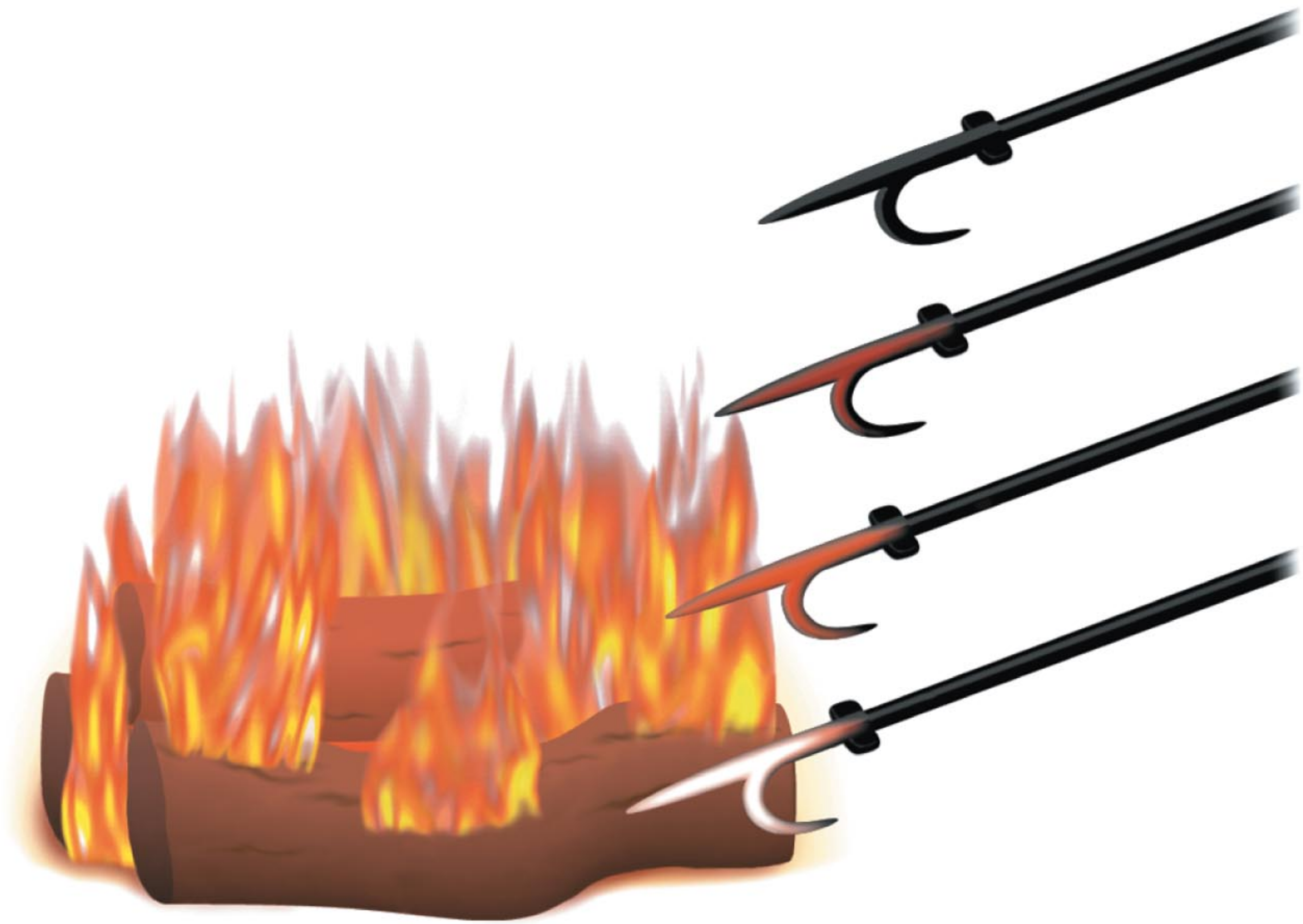


- Molecules have additional energy levels because they can vibrate and rotate.

Energy Levels of Molecules

- The large numbers of vibrational and rotational energy levels can make the spectra of molecules very complicated.
- Many of these molecular transitions are in the infrared part of the spectrum.

How does light tell us the temperatures of planets and stars?



Thermal Radiation

- Nearly all large or dense objects emit thermal radiation, including stars, planets, you.
- An object's thermal radiation spectrum depends on only one property: its **temperature.**

Properties of Thermal Radiation

1. **Wein's Law**: Hotter objects emit photons with a higher average energy (shorter wavelengths, bluer).

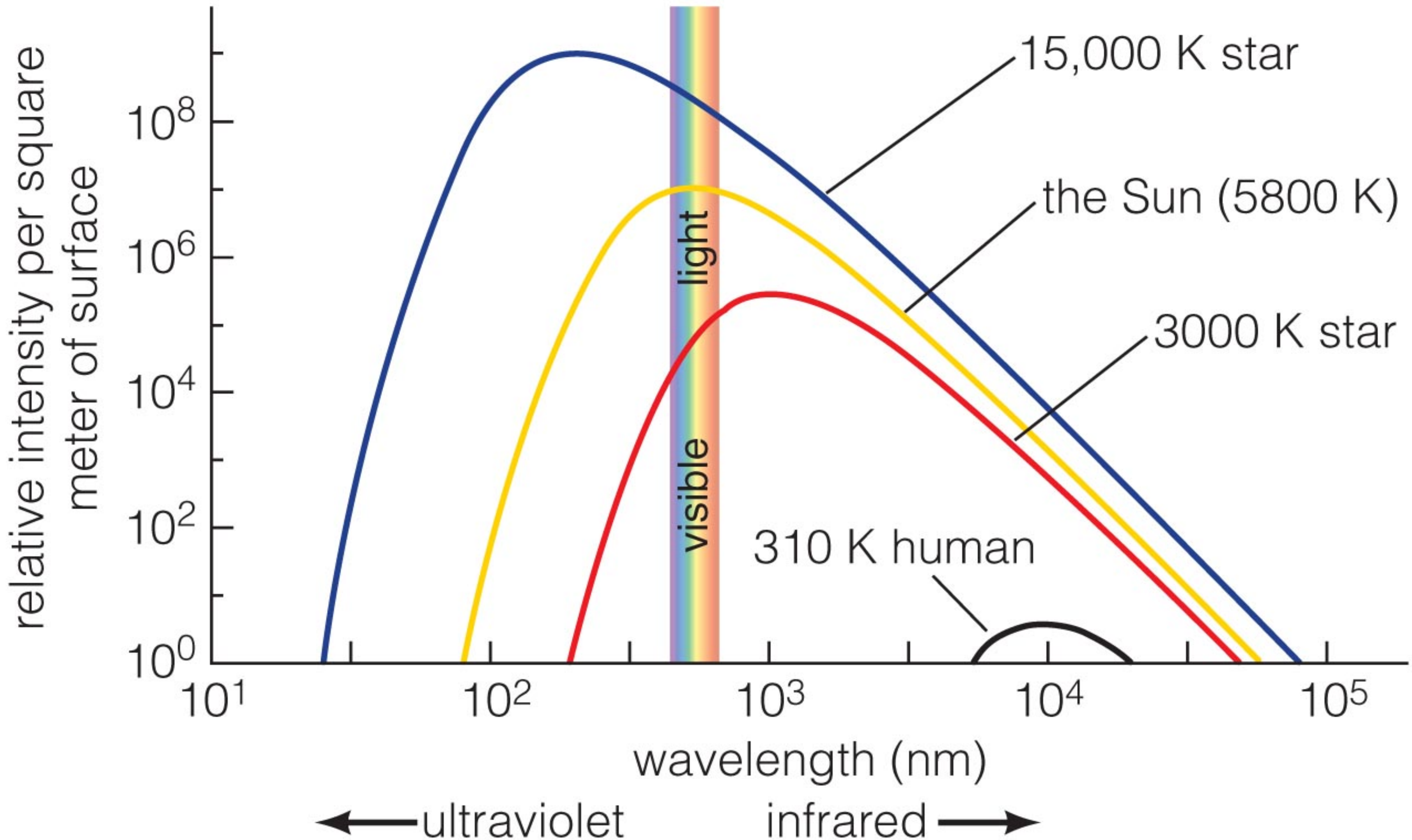
2. Hotter objects emit more light at all frequencies **per unit area**.

   Energy emitted per unit area is proportional to T^4.

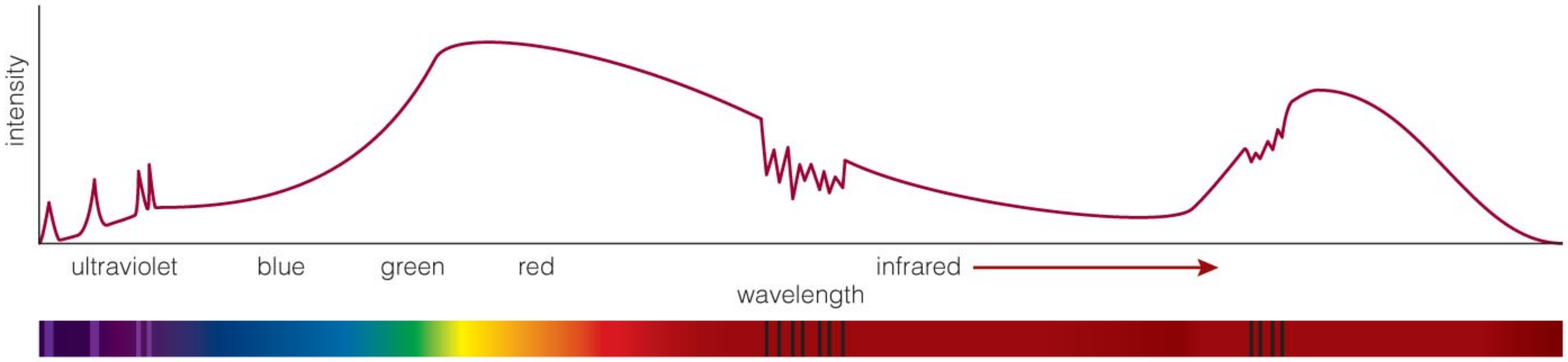
   An object twice as hot will emit 16x more energy!

3. If two objects have the *same* temperature, the *bigger* one will emit more total energy.

Properties of Thermal Radiation

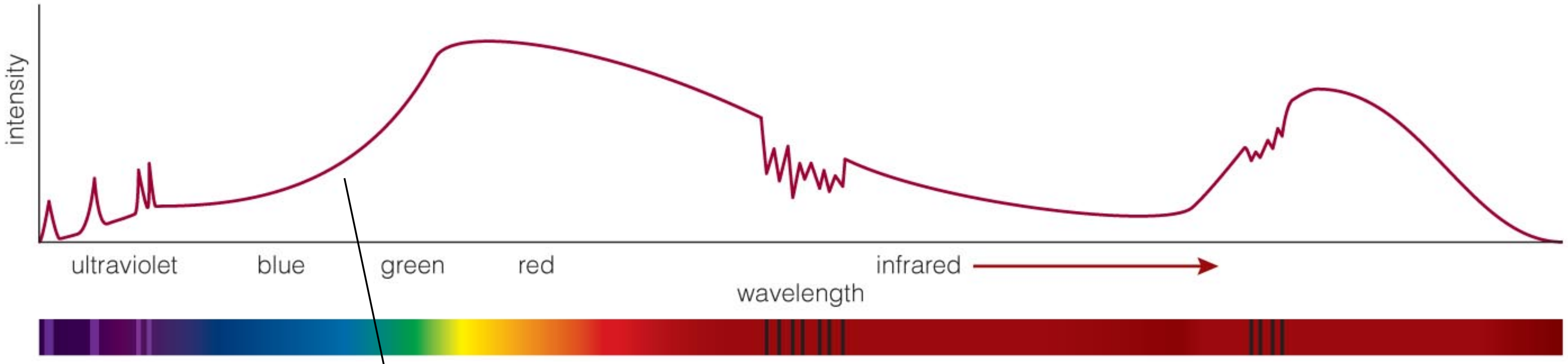


Example: How do we interpret an actual spectrum?



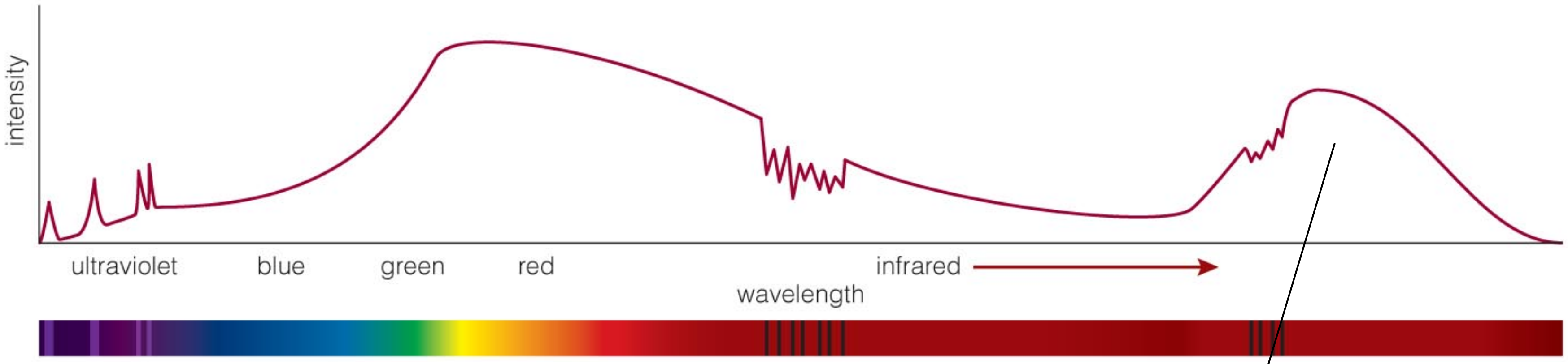
- By carefully studying the features in a spectrum, we can learn a great deal about the object that created it.

What is this object?



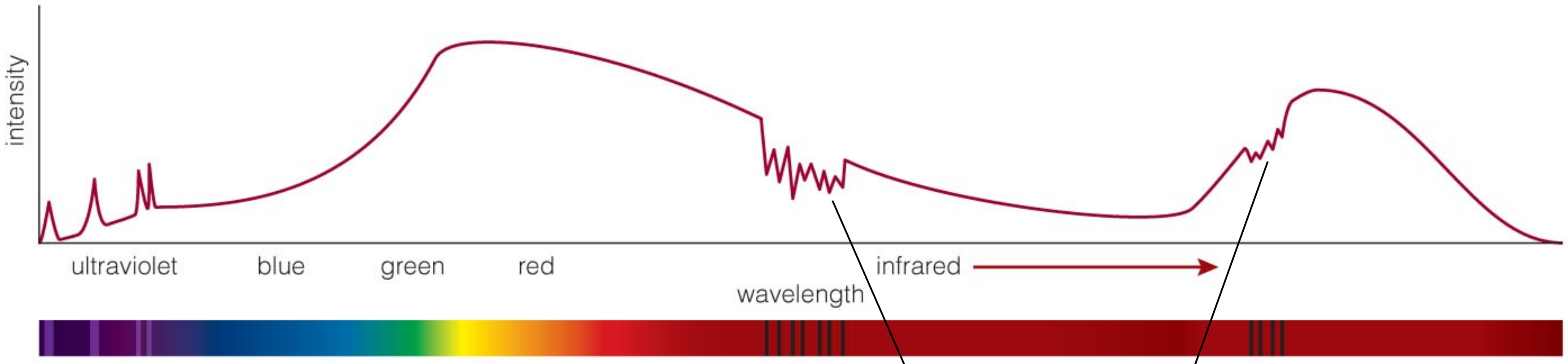
Reflected sunlight: Continuous spectrum of visible light is like the Sun's except that some of the blue light has been absorbed—object must look red.

What is this object?



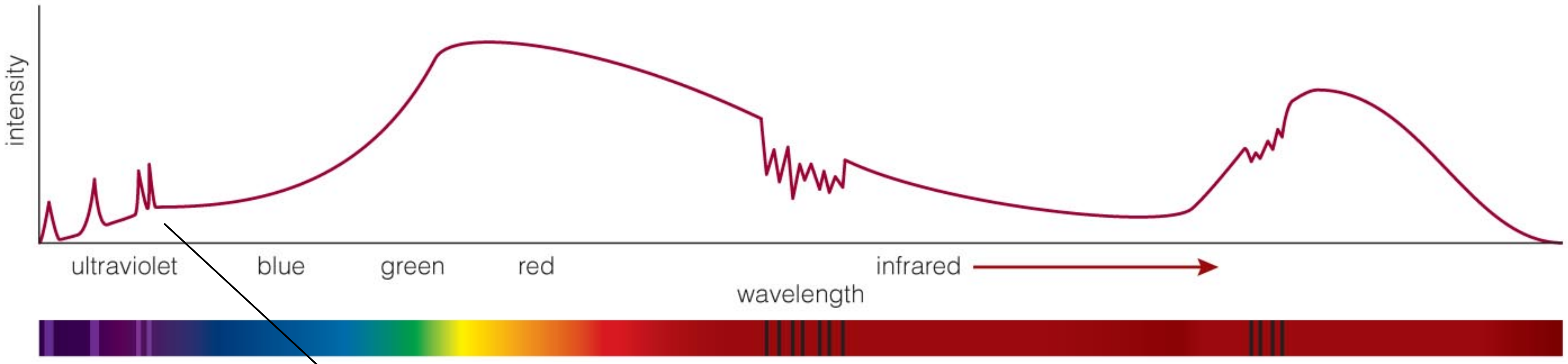
Thermal radiation: Infrared spectrum peaks at a wavelength corresponding to a temperature of 225 K.

What is this object?



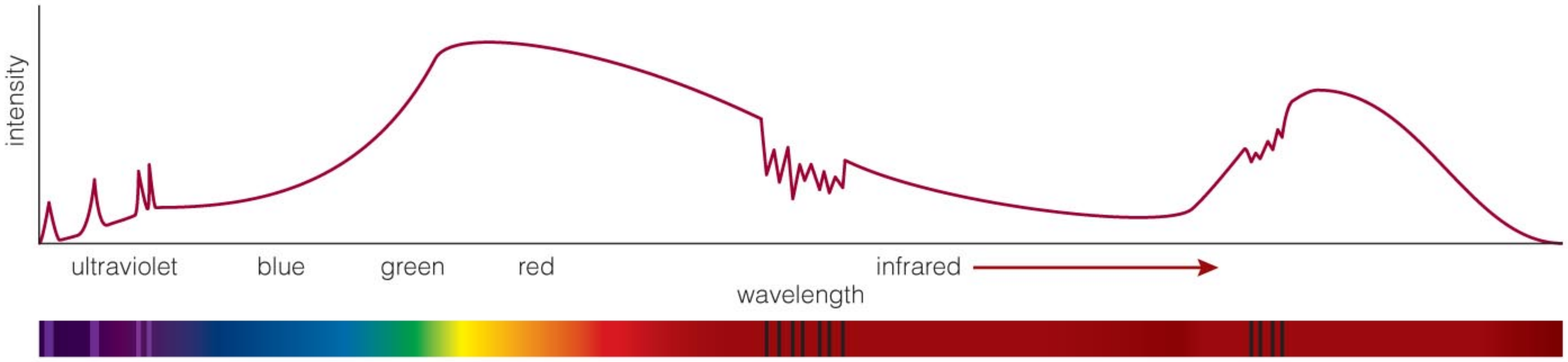
Carbon dioxide: Absorption lines are the fingerprint of CO_2 in the atmosphere.

What is this object?



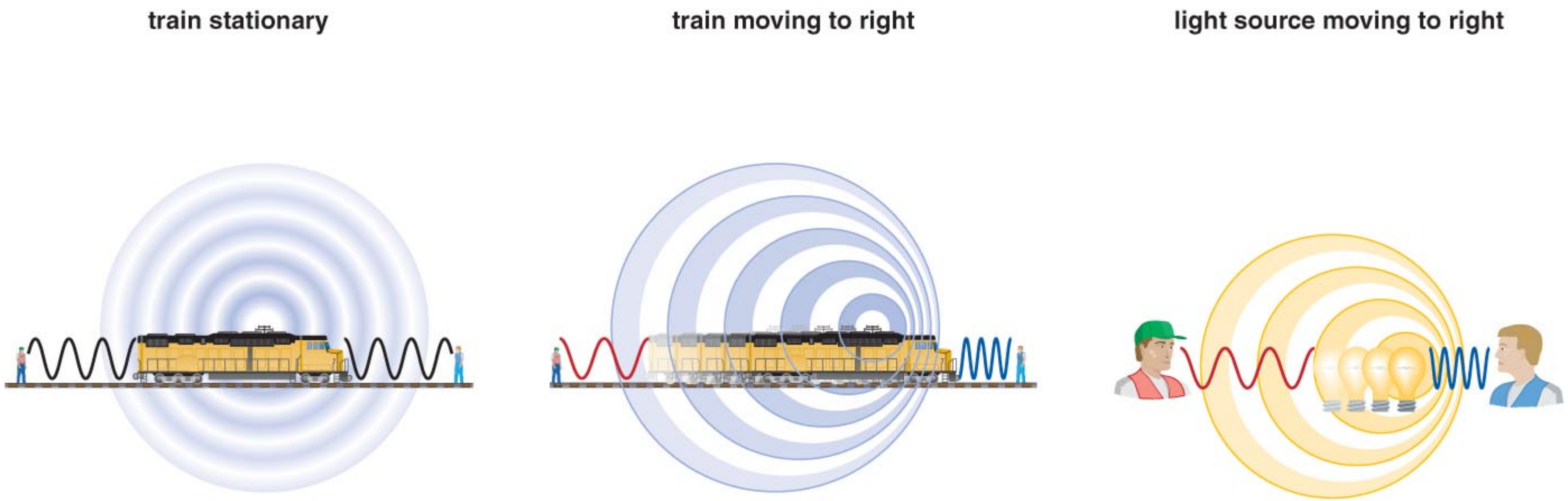
Ultraviolet emission lines: Indicate a hot upper atmosphere

What is this object?

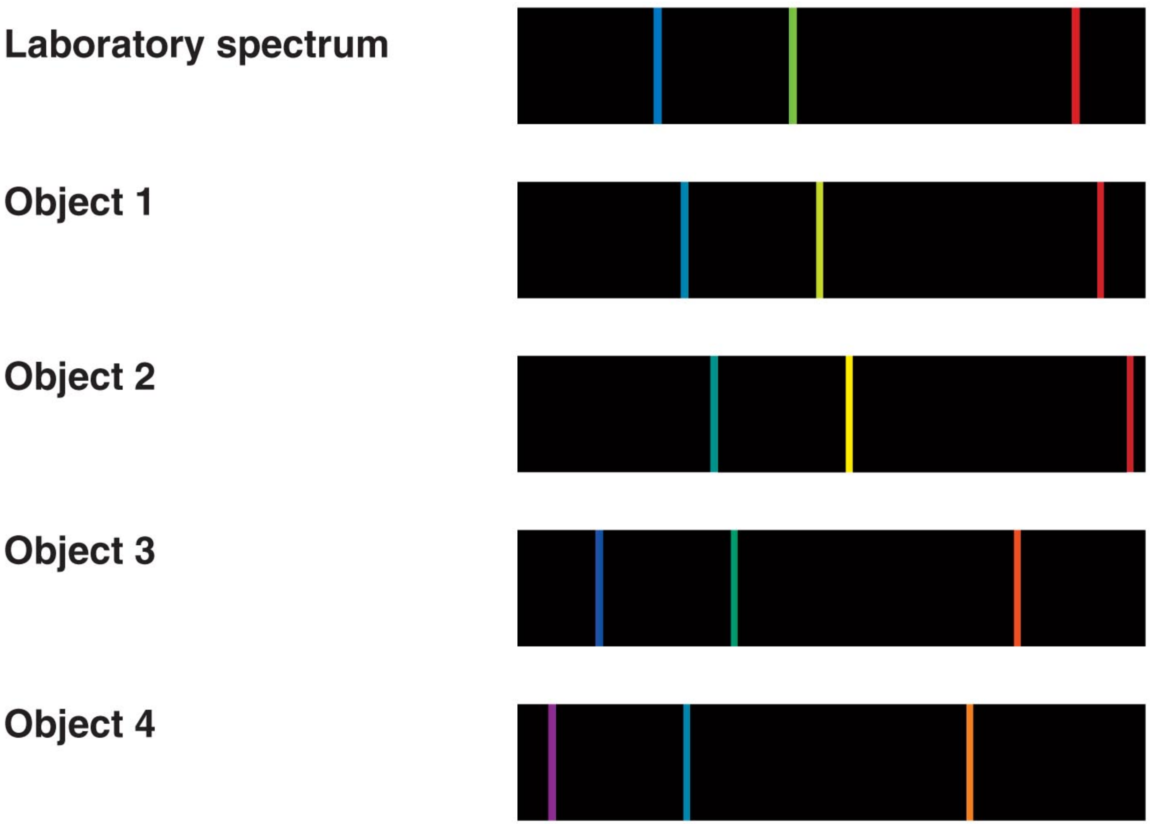


Mars!

How does light tell us the speed of a distant object? The Doppler Effect



Measuring the Shift



Stationary

Moving away

Away faster

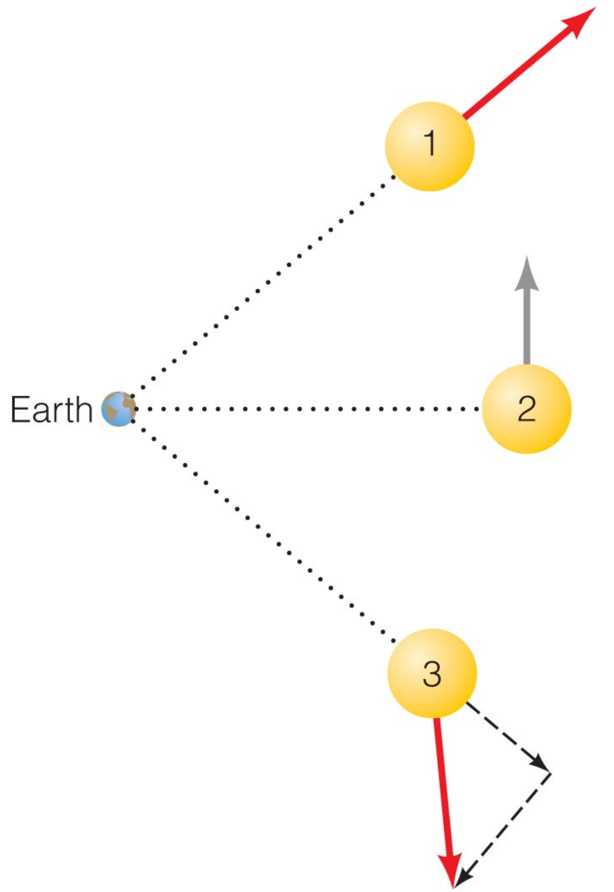
Moving toward

Toward faster

- We generally measure the Doppler effect from shifts in the wavelengths of spectral lines.

Measuring the Shift

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



Interactive Figure

Measuring the Shift

Doppler shift math

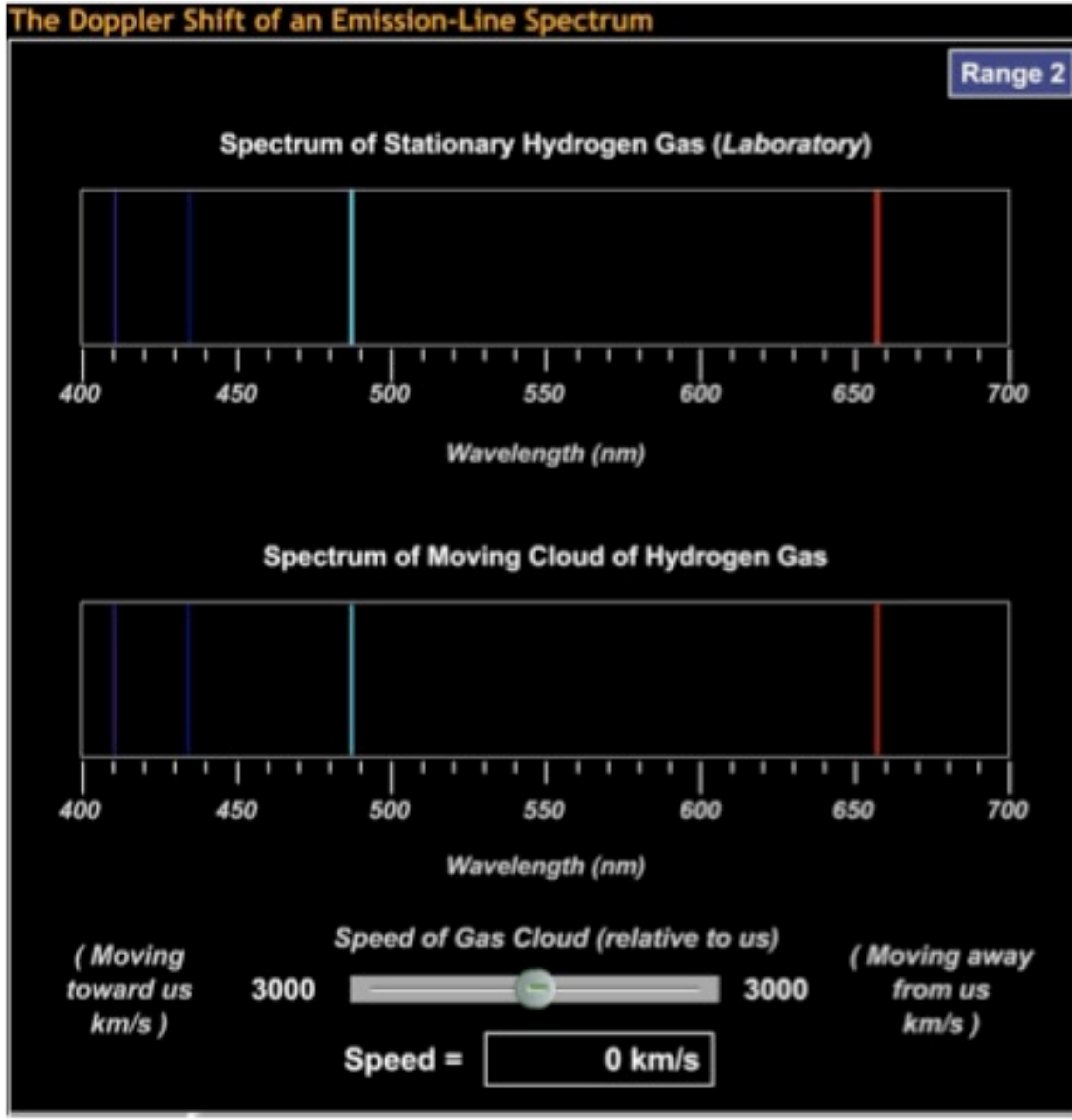
(see also Mathematical Insight 5.3 in textbook)

$$\frac{v_{rad}}{c} = \frac{\lambda_{shift} - \lambda_{rest}}{\lambda_{rest}}$$

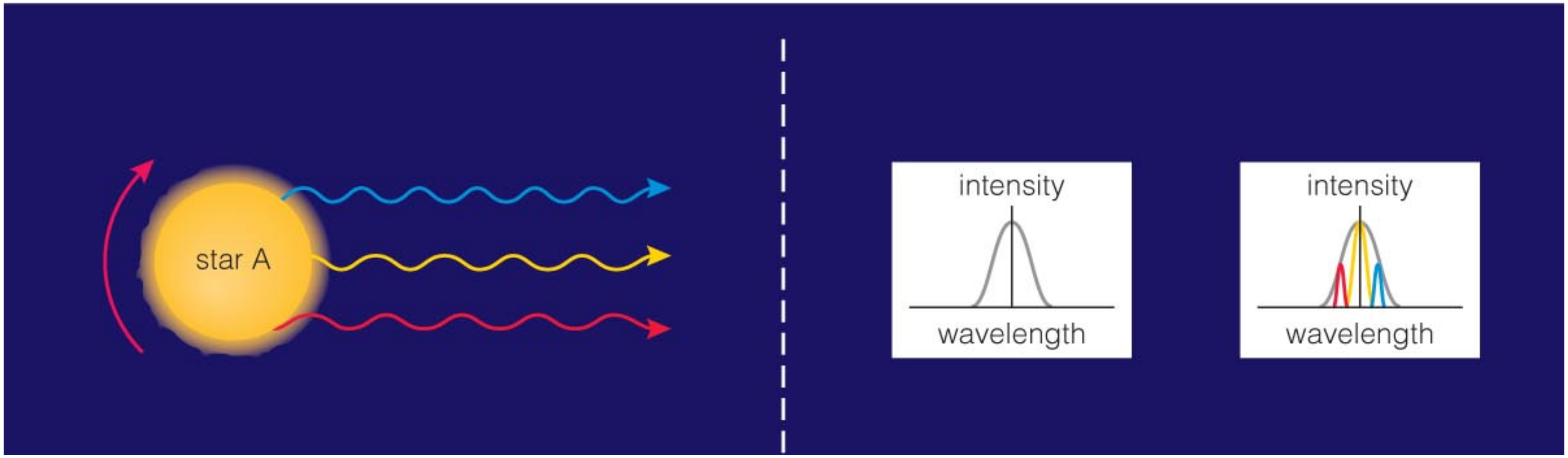
v_{rad}: the velocity towards or away from us
c: the speed of light (300,000 km/s)
λ_{shift}: the Doppler shifted wavelength of light
λ_{rest}: the original ("rest") wavelength of light

Measuring the Shift

- Measuring Redshift

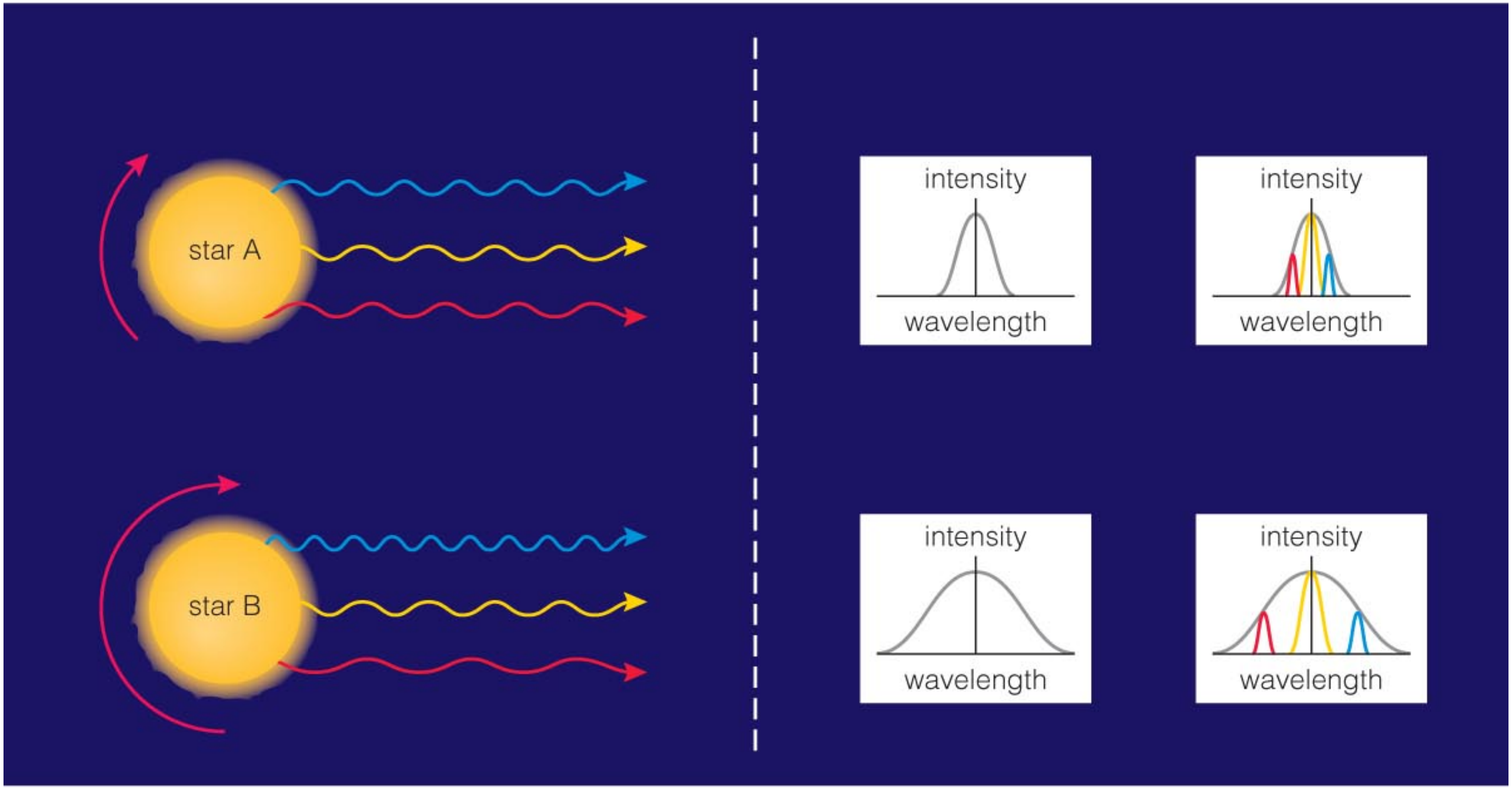


Spectrum of a Rotating Object



- Different Doppler shifts from different sides of a rotating object spread out its spectral lines.
- Since one side moves towards us and other side moves away, the Doppler spread is the measured shift from one side to the other.

Spectrum of a Rotating Object



- Spectral lines are wider when an object rotates faster. Line width measures rotation rate.

What have we learned?

- **What are the three basic type of spectra?**
  - Continuous spectrum, emission line spectrum, absorption line spectrum
- **How does light tell us what things are made of?**
  - Each atom has a unique fingerprint.
  - We can determine which atoms something is made of by looking for their fingerprints in the spectrum.

What have we learned?

- **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.
- **How does light tell us the speed of a distant object?**
  - The Doppler effect tells us how fast an object is moving toward or away from us.