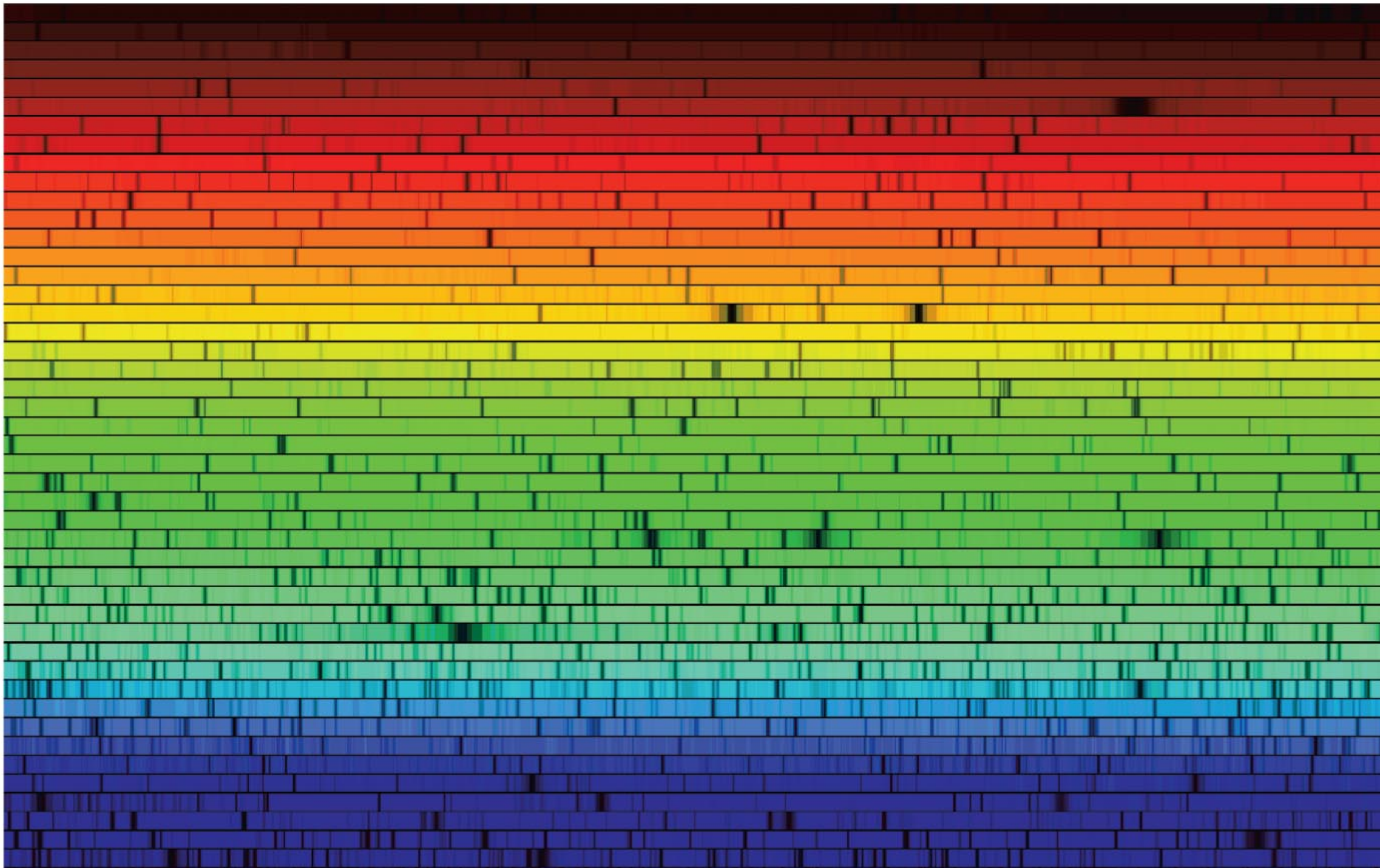
Electromagnetic Radiation



Particles of Light

- Particles of light are called **photons.**
- Each photon has a wavelength and a frequency.
- The energy of a photon depends on its frequency.

Wavelength & Frequency

λ = wavelength (separation between crests)

f = frequency (rate of oscillation)

c = speed of light $= 3 \times 10^8$ m/s

$$\lambda f = c$$

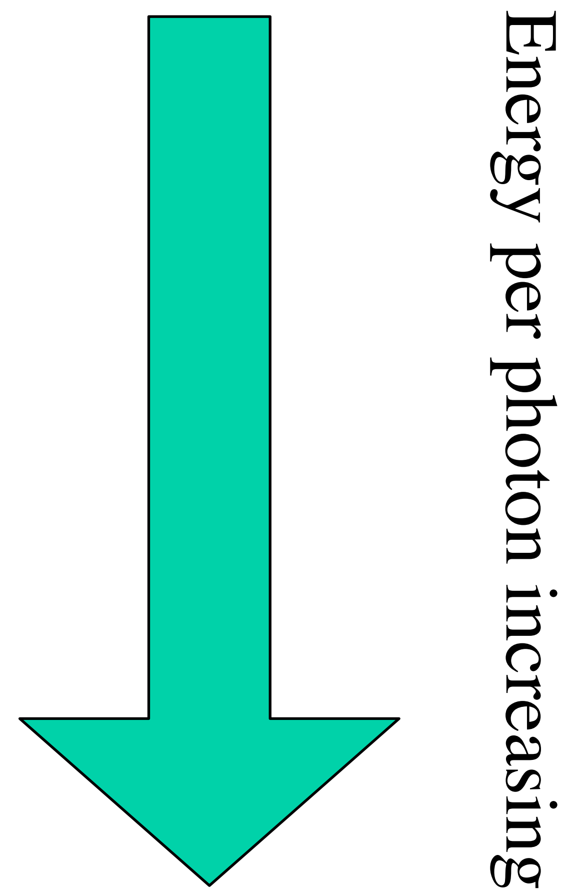
photon energy: $E = hf$ where h is Planck's constant

Same stuff, different Energy:

<u>Electromagnetic Radiation</u>

- radio
- microwave
- infrared
- visible light
- ultraviolet
- X-ray
- gamma ray

long wavelength
low frequency
low energy

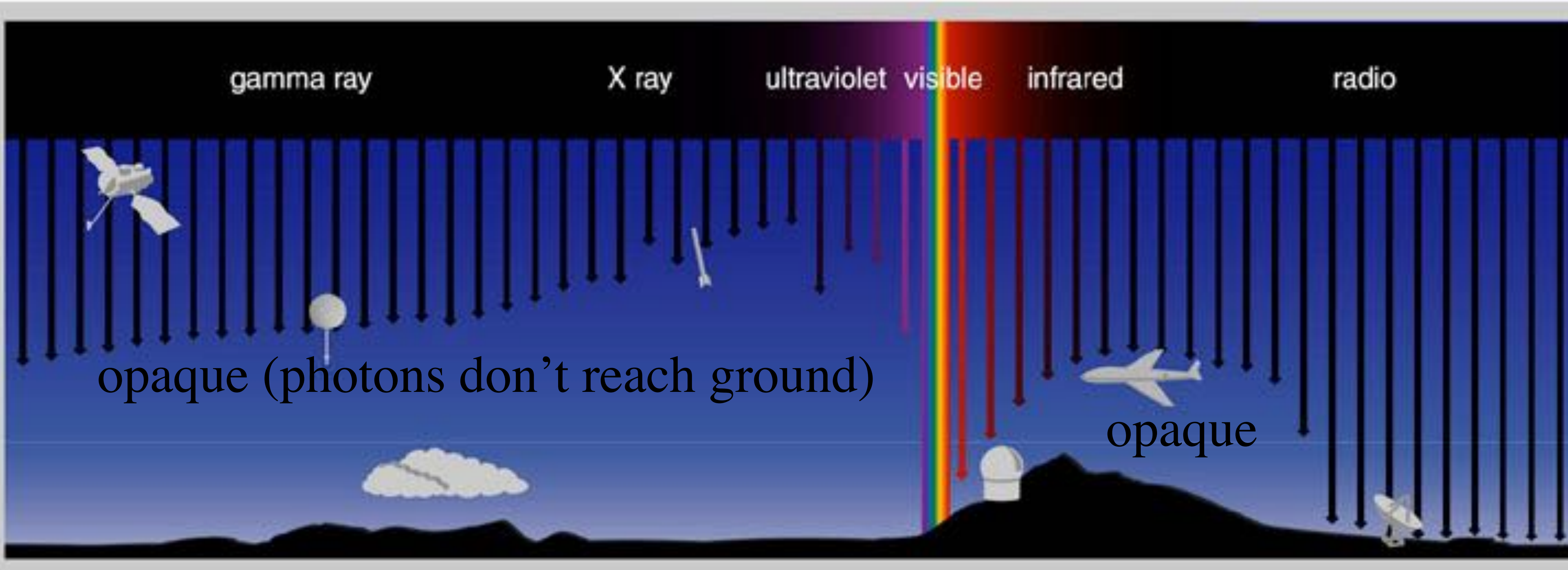


short wavelength
high frequency
high energy

How do light and matter interact?

- Emission
- Absorption
- Transmission:
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection or scattering
  - we see by scattered light

transmission & absorption



Earth’s atmosphere is opaque to light at most wavelengths.
It is transparent only to visible light and radio waves.

Production of light

Thermal Radiation

- Nearly all large, dense objects emit thermal radiation, including stars, planets, and you.

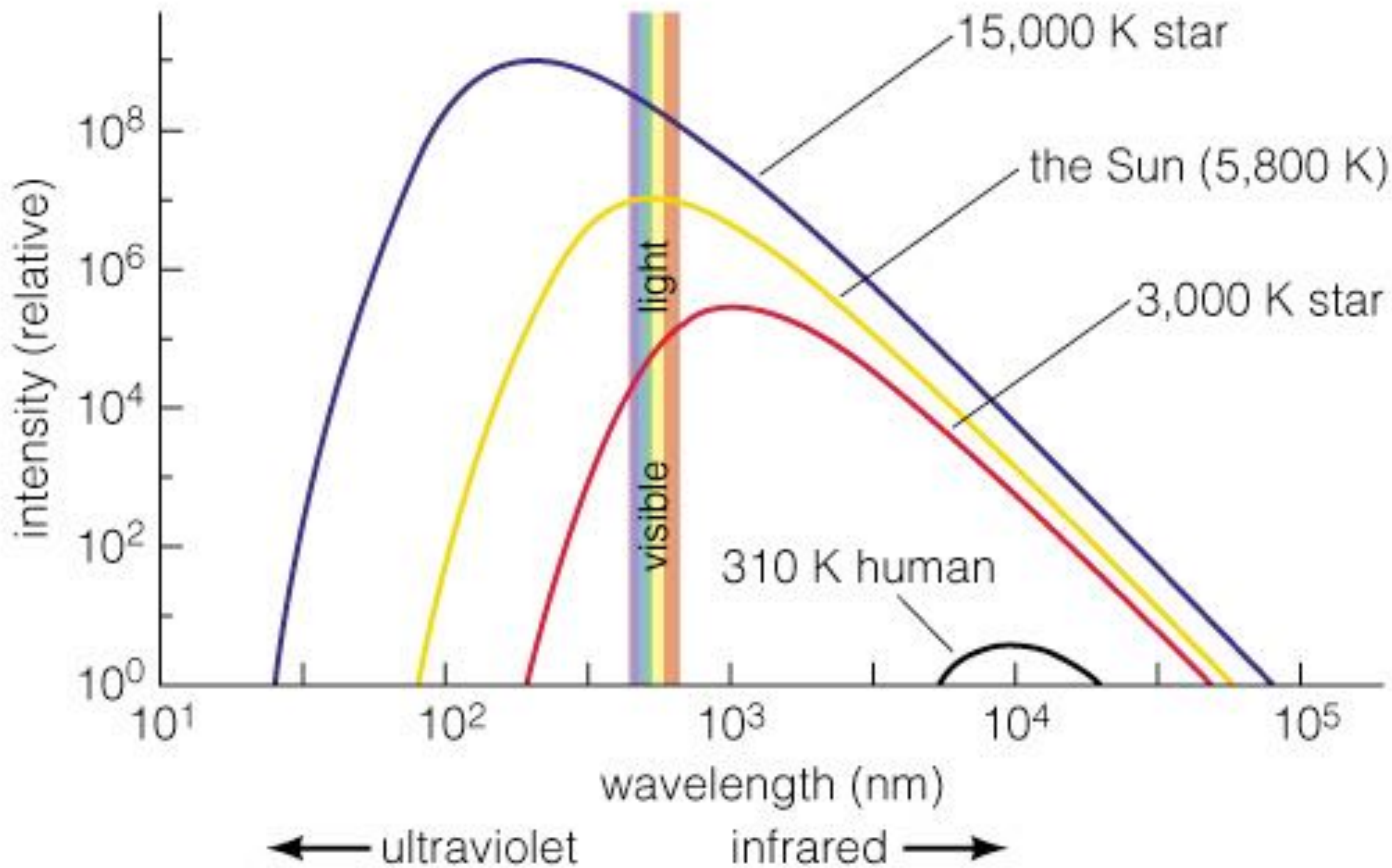
- An object's thermal radiation spectrum depends on only one property: its **temperature.**

Properties of Thermal Radiation

1. Hotter objects emit more light at all frequencies per unit area.
2. Hotter objects emit photons with a higher average energy.

Spectrum:

Intensity



Wavelength λ

Wien's Law

- $\lambda_p T$ = constant = 2.9 x 10^6 nm K

- λ_p is the wavelength of maximum emission (in nanometers   nano = 10^{-9})
- T is temperature (in degrees Kelvin)

As **T** increases, wavelength decreases.
So hot object blue; cool objects red.

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Properties of Thermal Radiation

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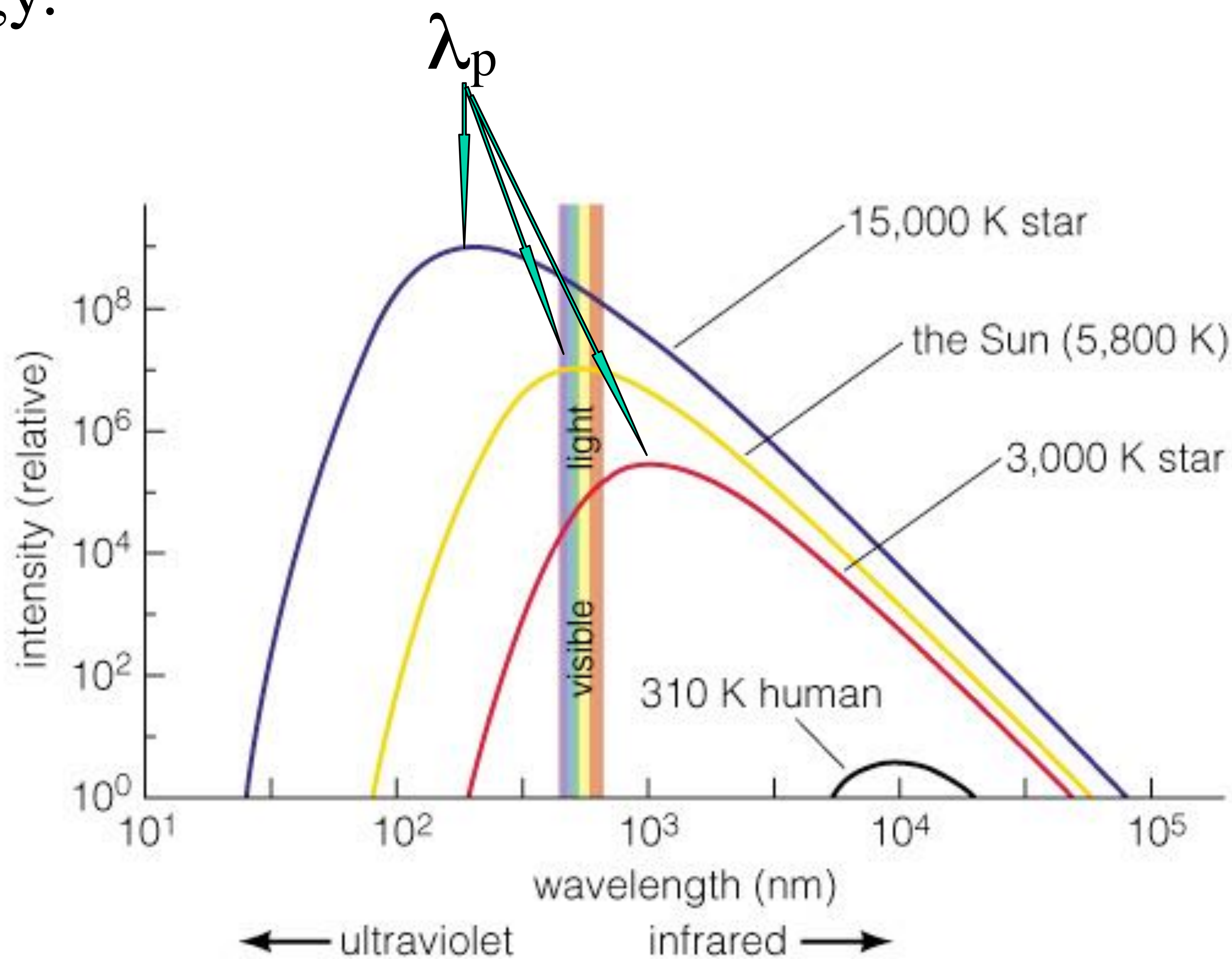


Stefan-Boltzmann Law

$$L = 4\pi R^2 \sigma T^4$$

surface area of a sphere

- **L** = Luminosity (power radiated)
- **R** = Radius (e.g., of a star)
- **T** = Temperature (of radiating surface, in K)
- **σ** = Stefan-Boltzmann constant
  – just a number to make units work right

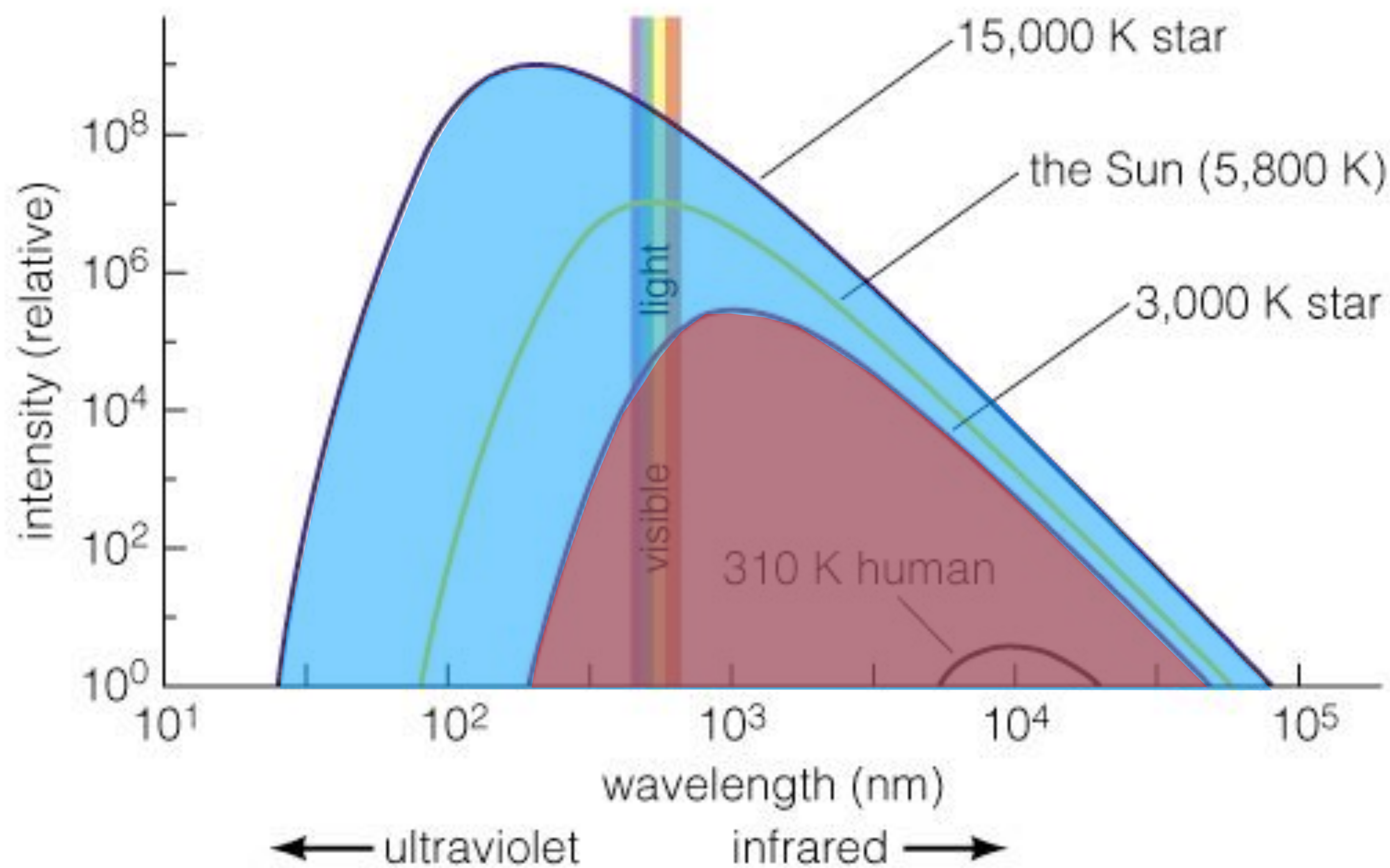
$$L \propto R^2 T^4$$

The absolute brightness of a star depends on its size (**R**) and temperature (**T**).

Properties of Thermal Radiation

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

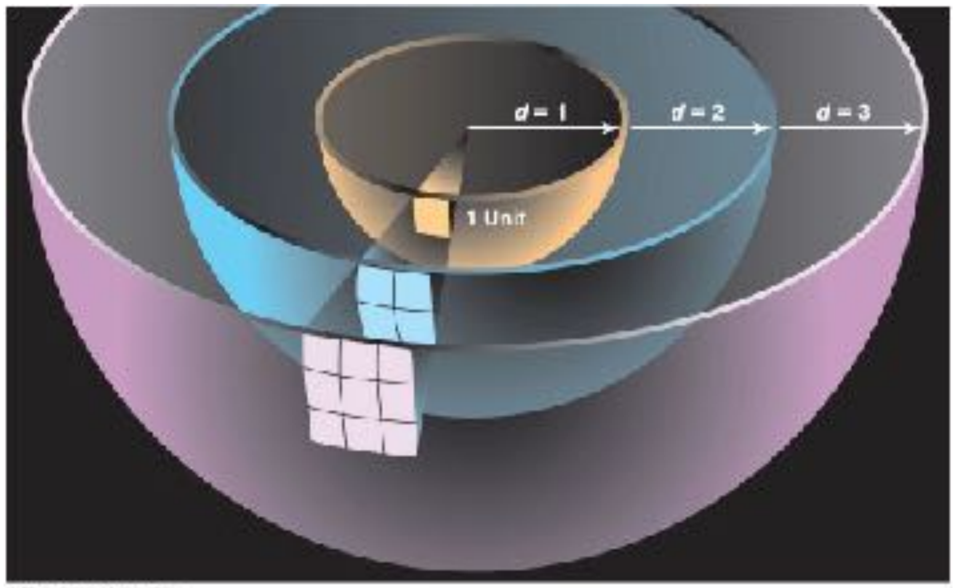
Total luminosity is the area under the curve



Inverse square law

- A simple geometrical effect
  - Light from a point source (e.g., a light bulb or a star) gets spread out in all directions.
  - diminishes by the surface are of the sphere is fills

apparent brightness $$b = \frac{L}{4\pi d^2}$$

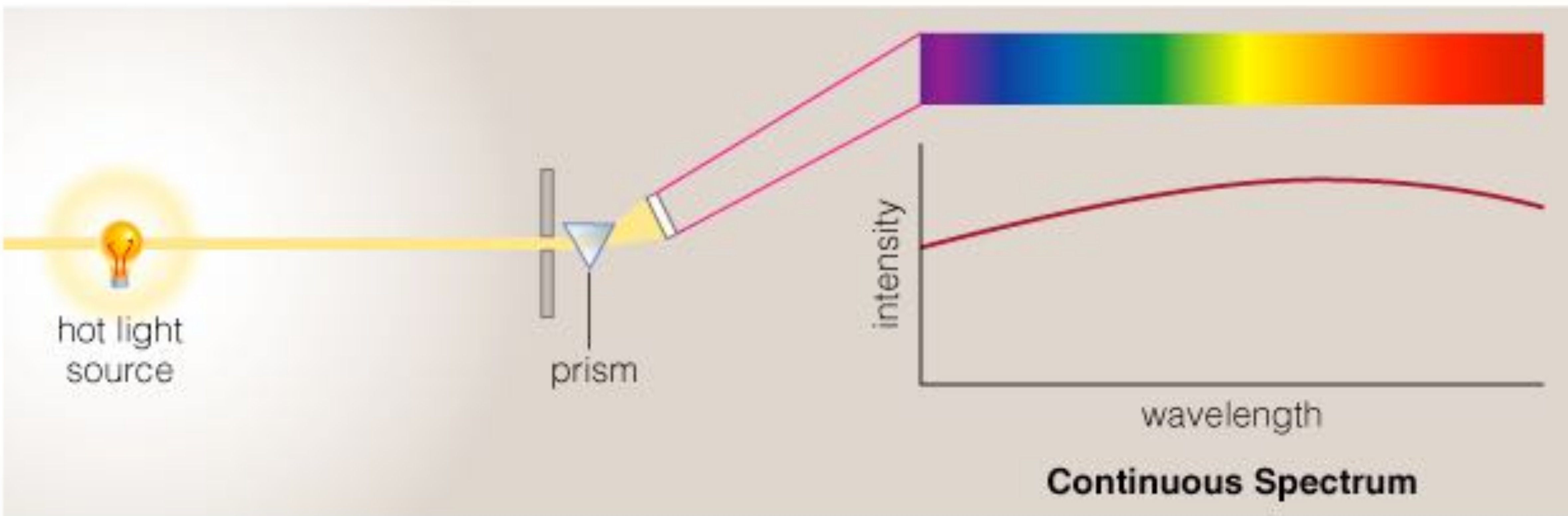


How bright we perceive a star to be depends on both its intrinsic luminosity and its distance from us.

Kirchoff's Laws

- Hot, dense objects emit a
  - **continuous spectrum** e.g., a light bulb
    - light of all colors & wavelengths
    - follows thermal distribution
    - obeys Wien's & Steffan-Boltzmann Laws.
- Hot, diffuse gas emits light only at specific wavelengths. e.g., a neon light
  - **emission line spectrum**
- A cool gas obscuring a continuum source will absorb specific wavelengths
  - **absorption line spectrum** e.g., a star

Continuous Spectrum



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

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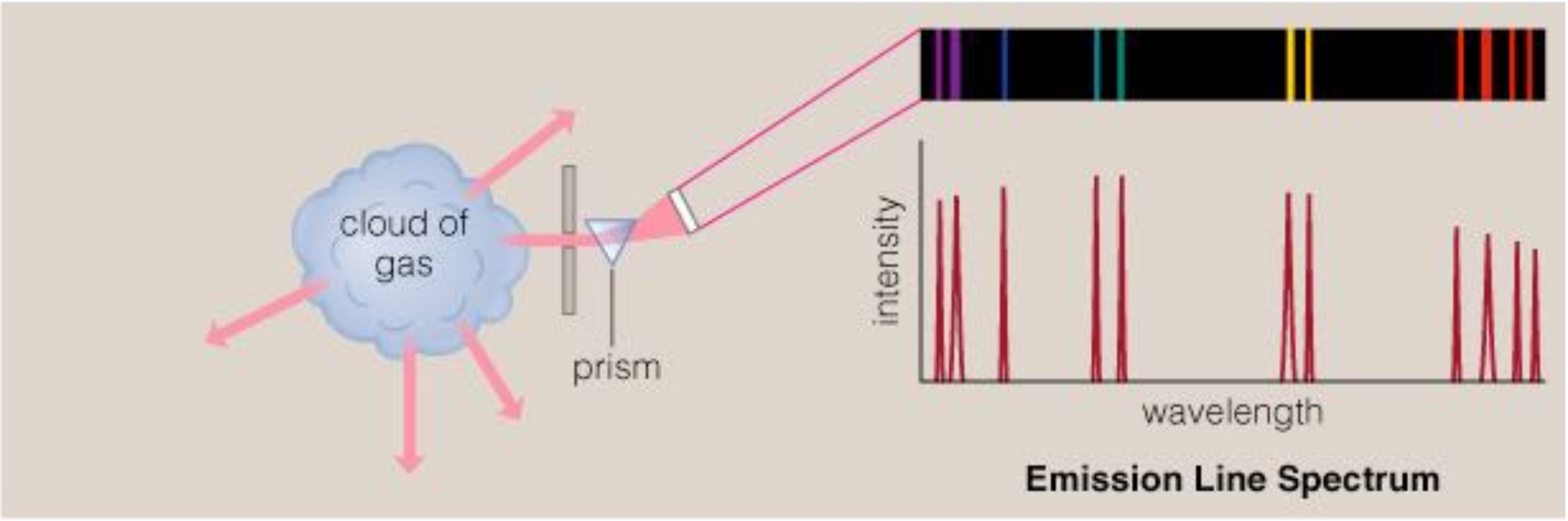
Emission Line Spectrum



- 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.

Kirchoff's Laws

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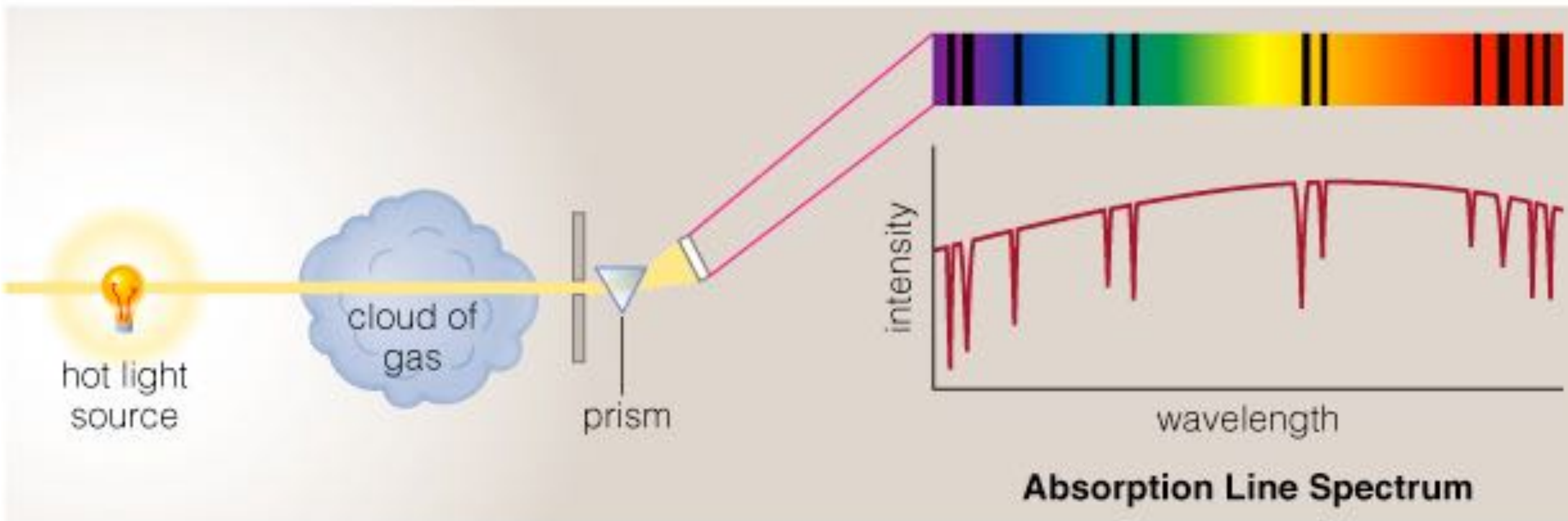
Absorption Line Spectrum



- A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.

Kirchoff's Laws

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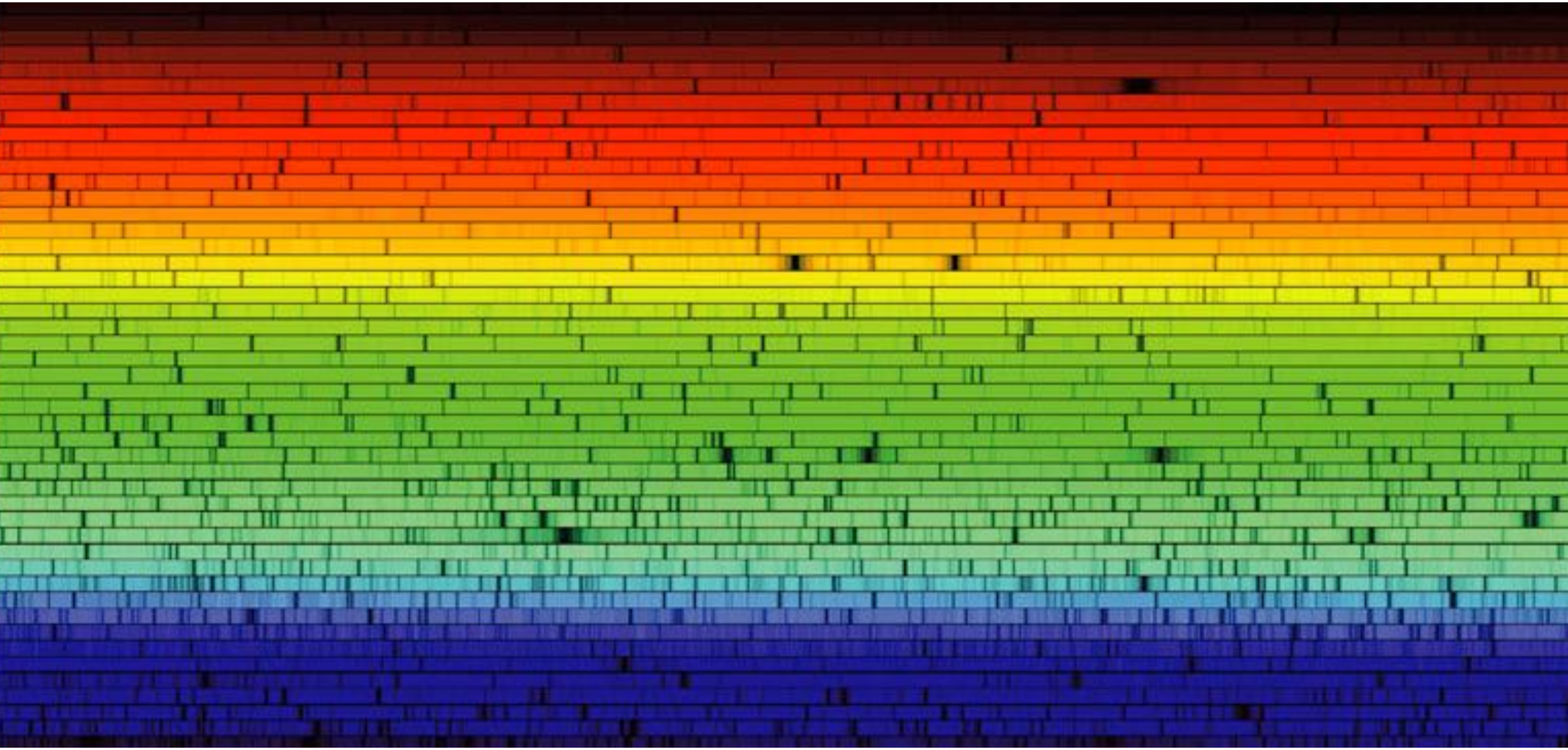
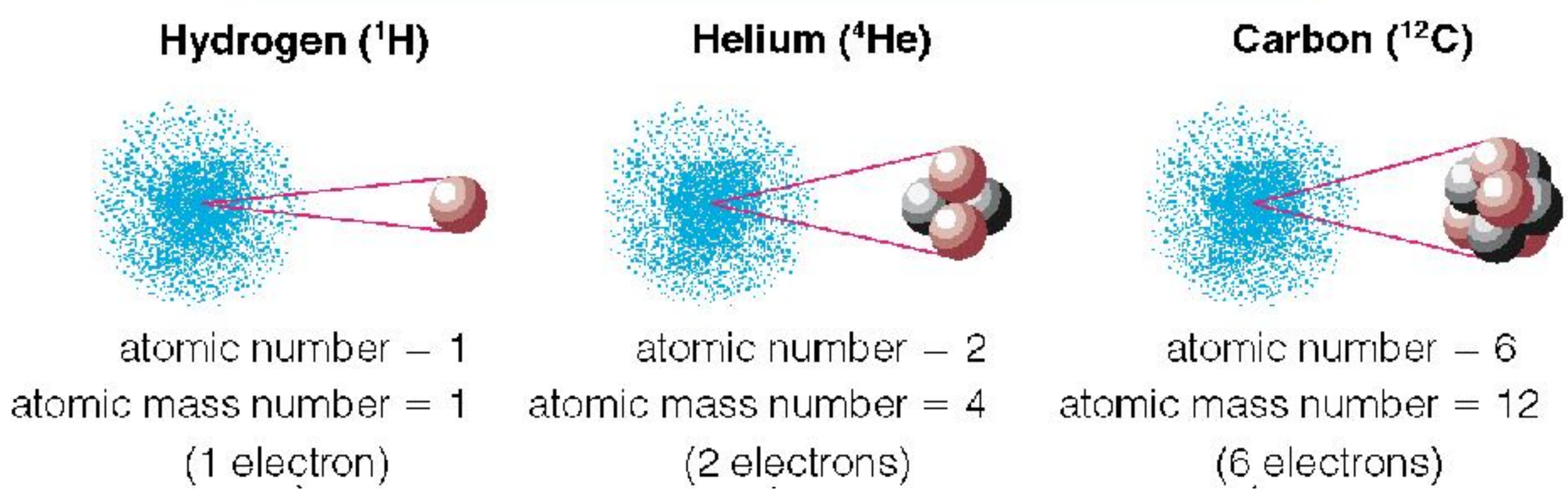
How does light tell us what things are made of?



Spectrum of the Sun

Atomic Terminology

- Atomic Number = # of protons in nucleus
- Atomic Mass Number = # of protons + neutrons



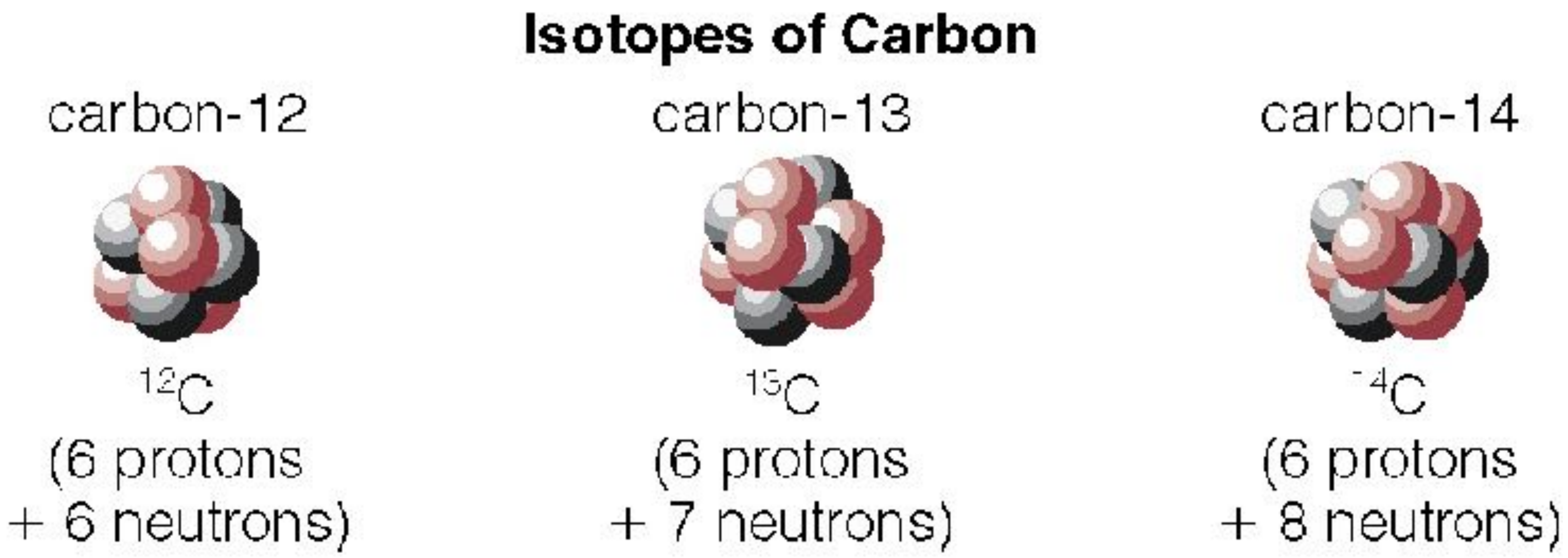
Periodic Table of the Elements

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111	112	113	114	115	116	117	118

57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium

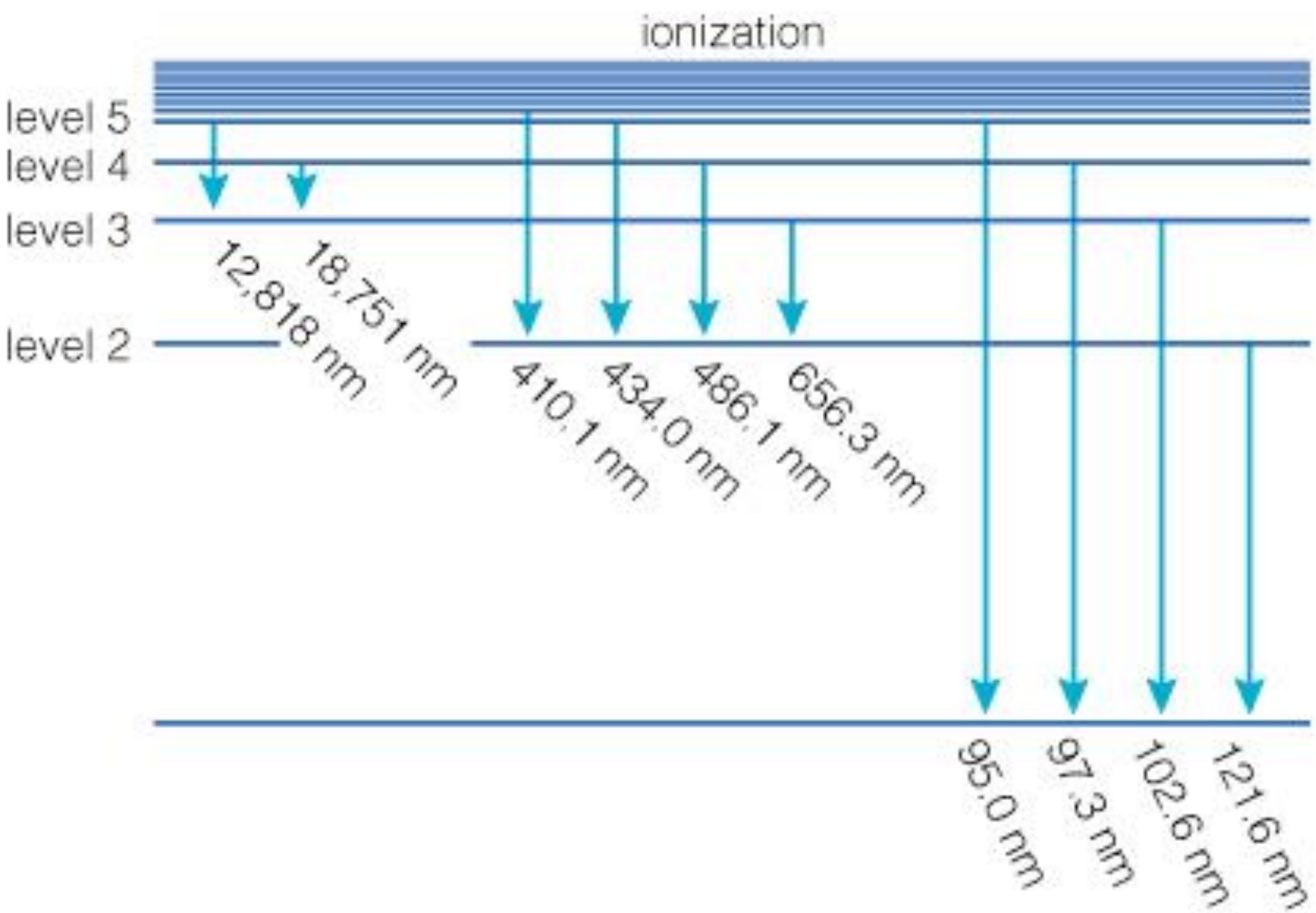
Atomic Terminology

- Isotope: same # of protons but different # of neutrons (^4He, ^3He)



- Molecules: consist of two or more atoms (H_2O, CO_2)

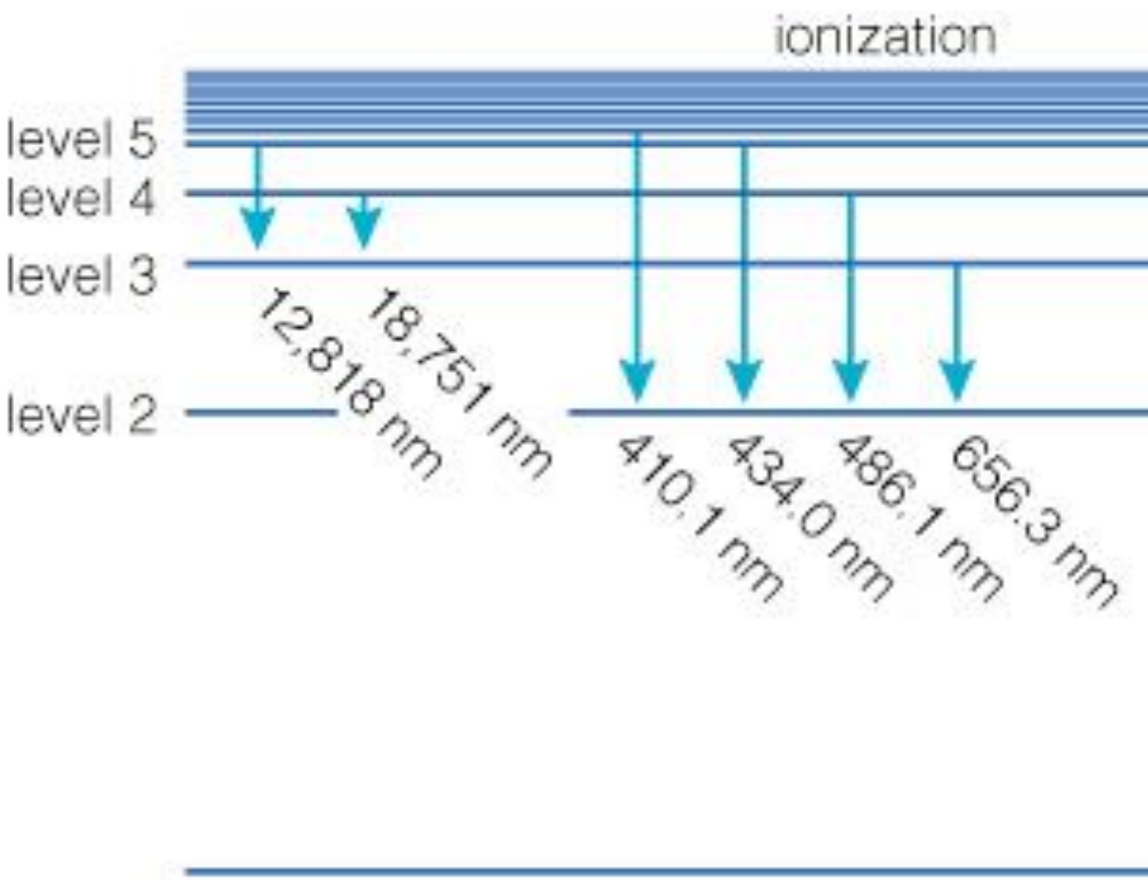
Chemical Fingerprints

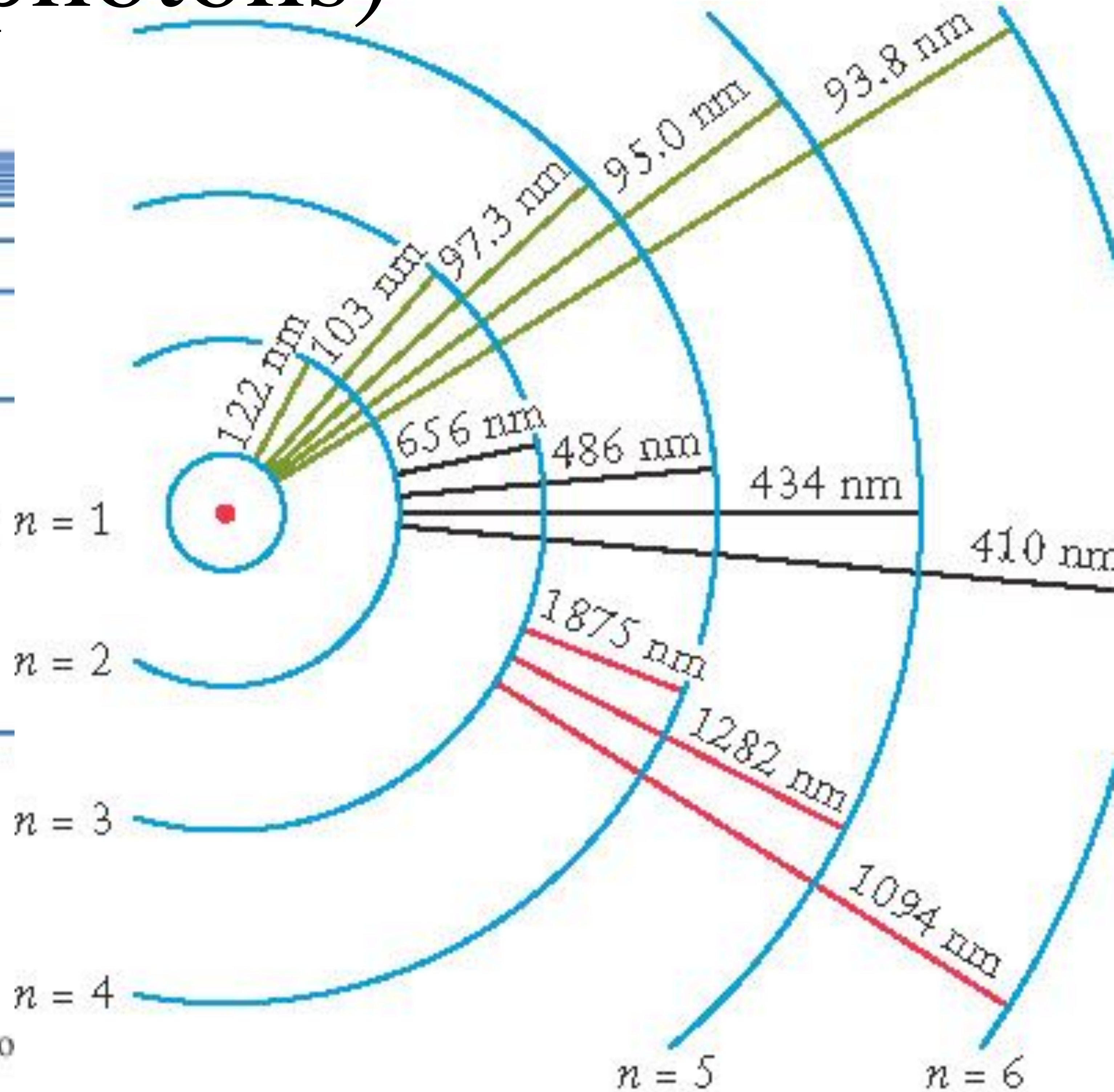


Energy levels of hydrogen

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

Transitions between orbits release energy (photons)

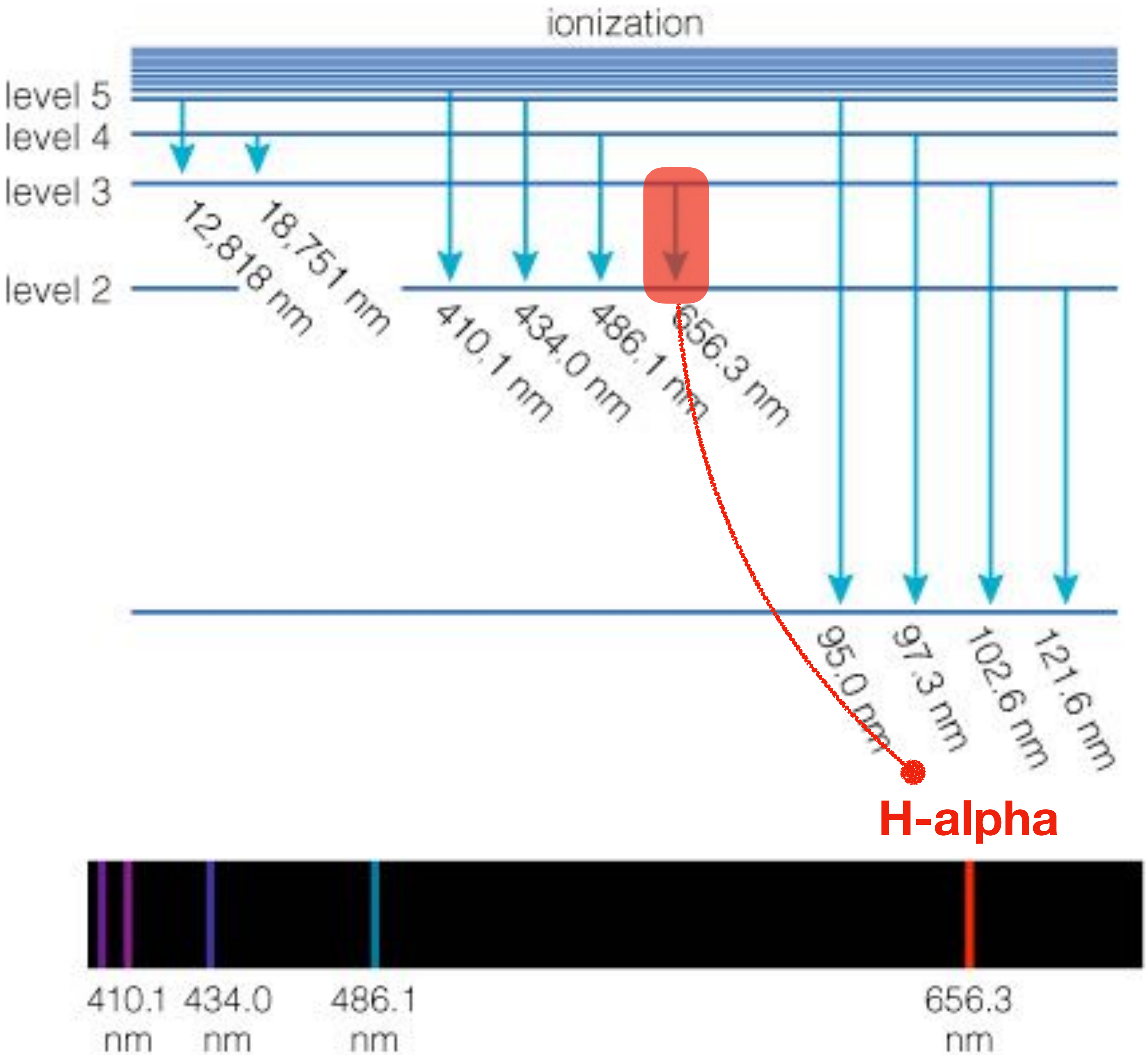




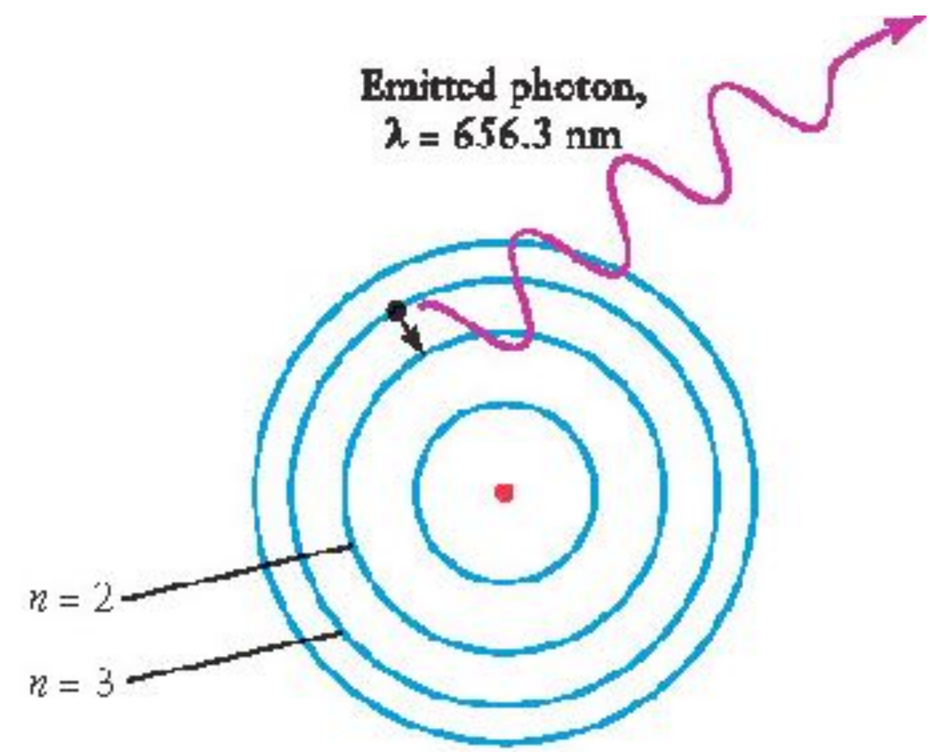
Energy levels of hydrogen

Chemical Fingerprints

Seen in emission



- Downward transitions produce a unique pattern of emission lines.

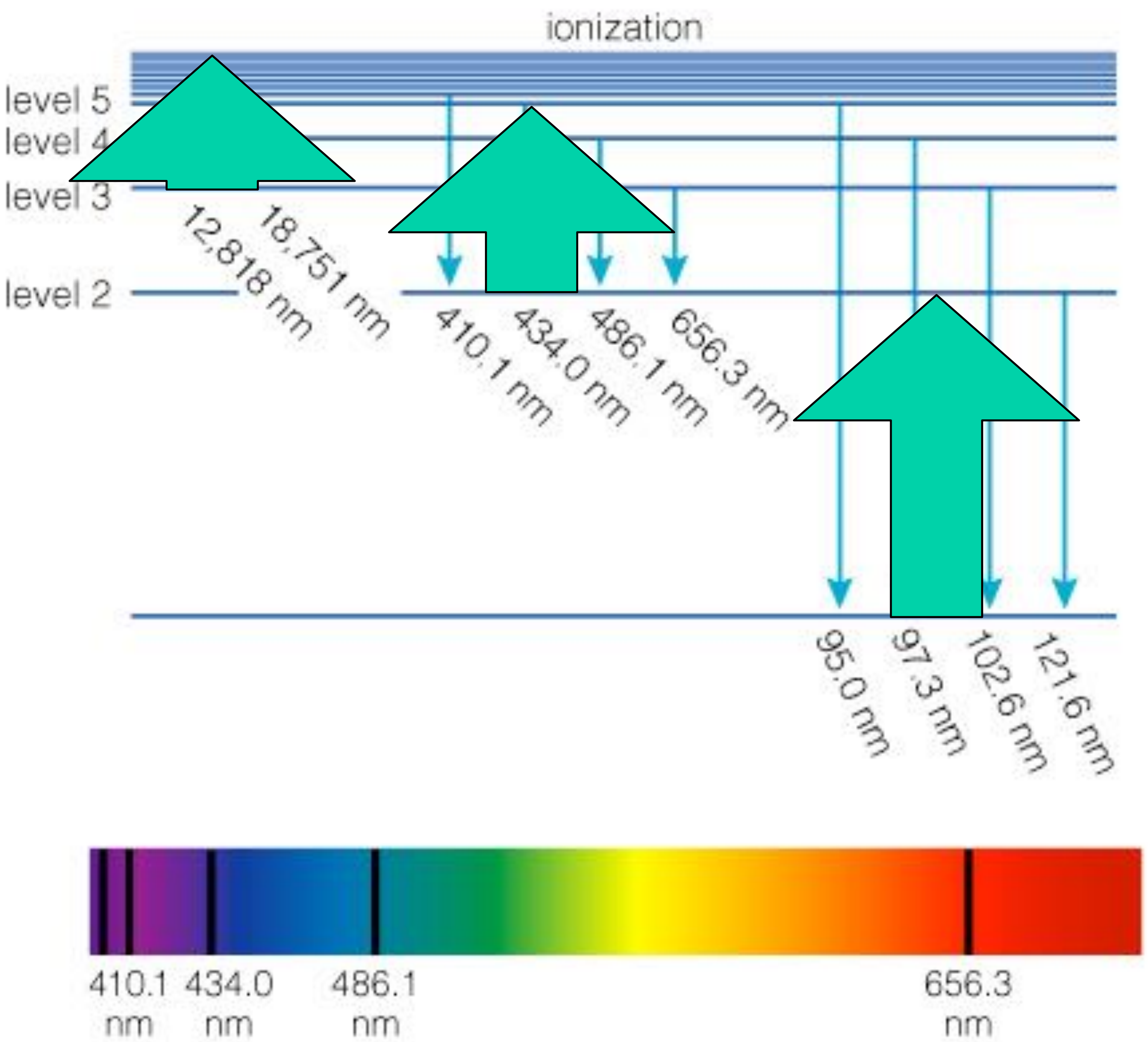


(b) Electron falls from the n = 3 orbit to the n = 2 orbit; energy lost by atom goes into emitting a 656.3-nm photon

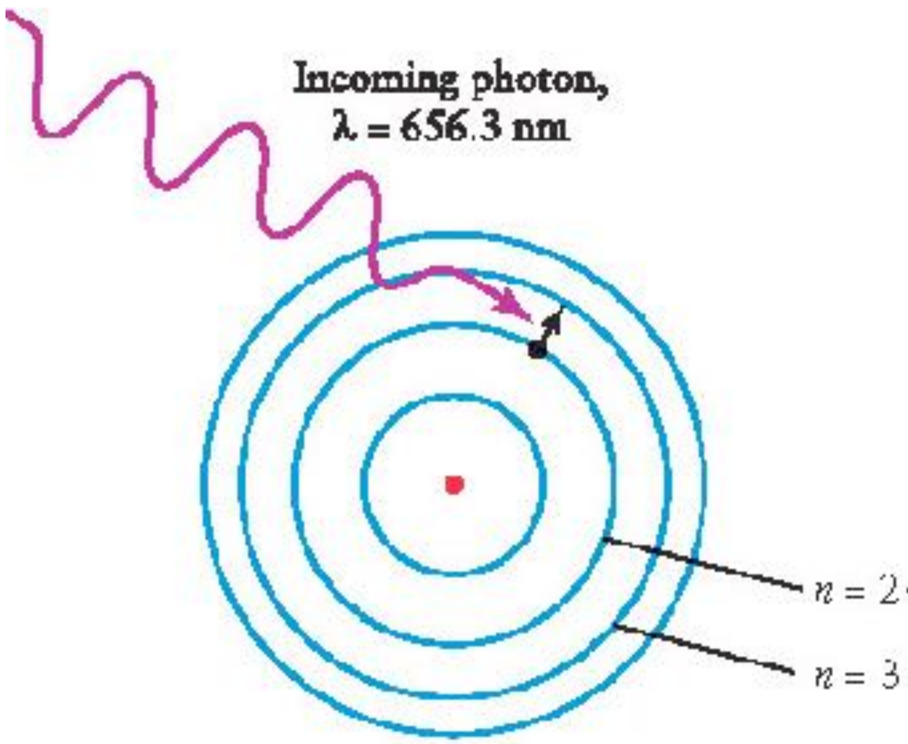
Pink areas are from nebulae glowing with the red “H-alpha” line of Hydrogen

Chemical Fingerprints

Seen in absorption



- Atoms can absorb photons with those same energies, so upward transitions produce absorption lines.



(a) Atom absorbs a 656.3-nm photon; absorbed energy causes electron to jump from the n = 2 orbit up the n = 3 orbit

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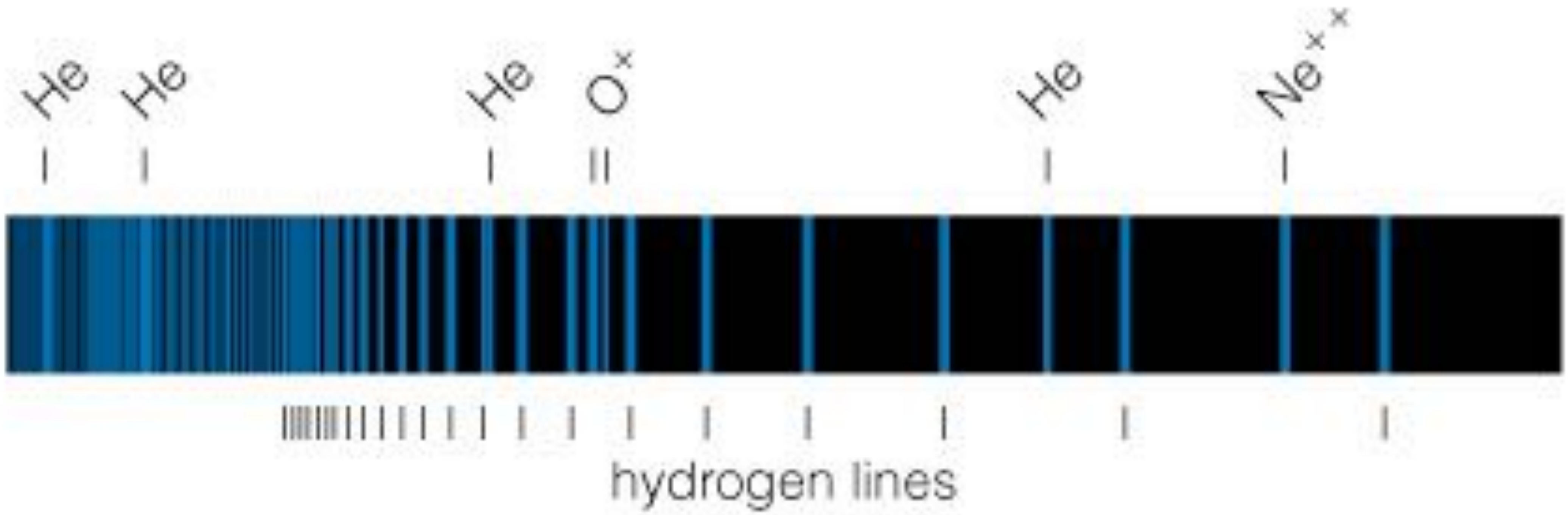
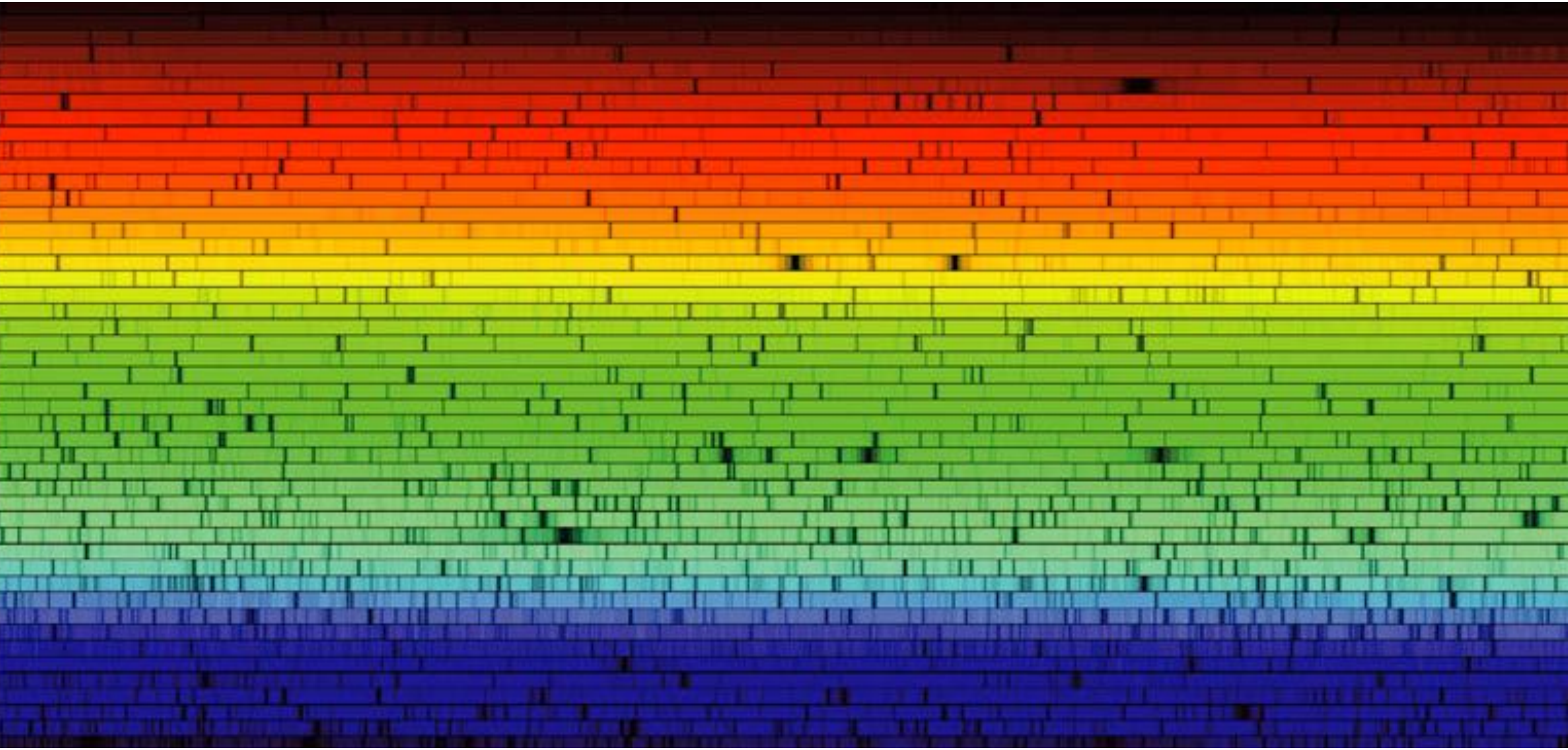
Chemical Fingerprints



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

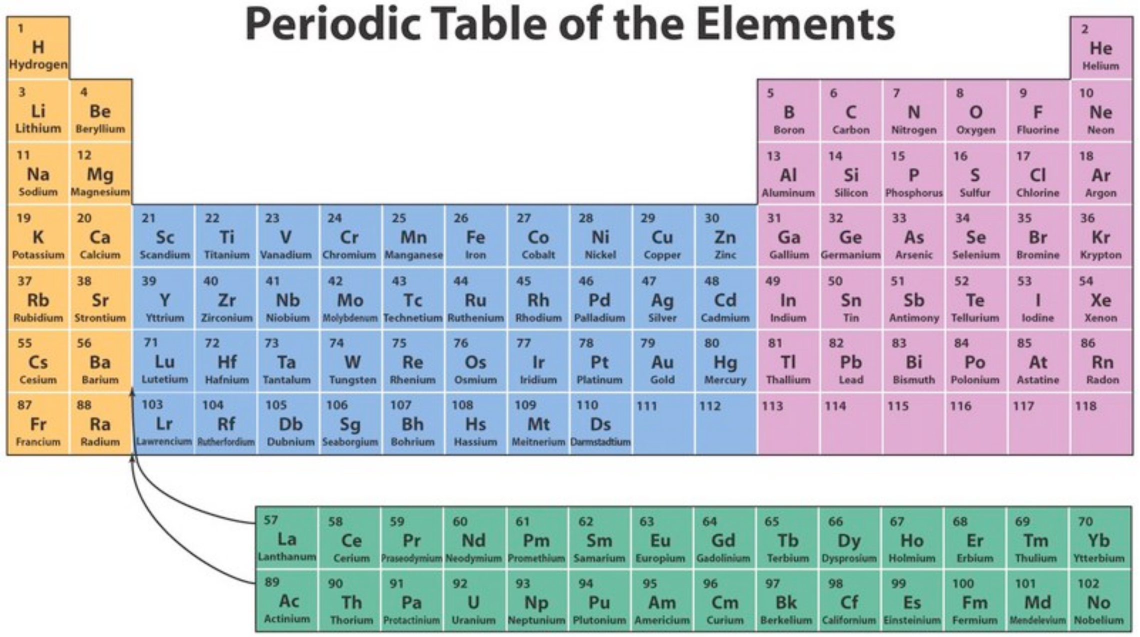
Example: Solar Spectrum



All the dark regions are absorption lines due to all the elements in the sun's atmosphere. The strengths of the lines tell us about the sun's composition and other physical properties.

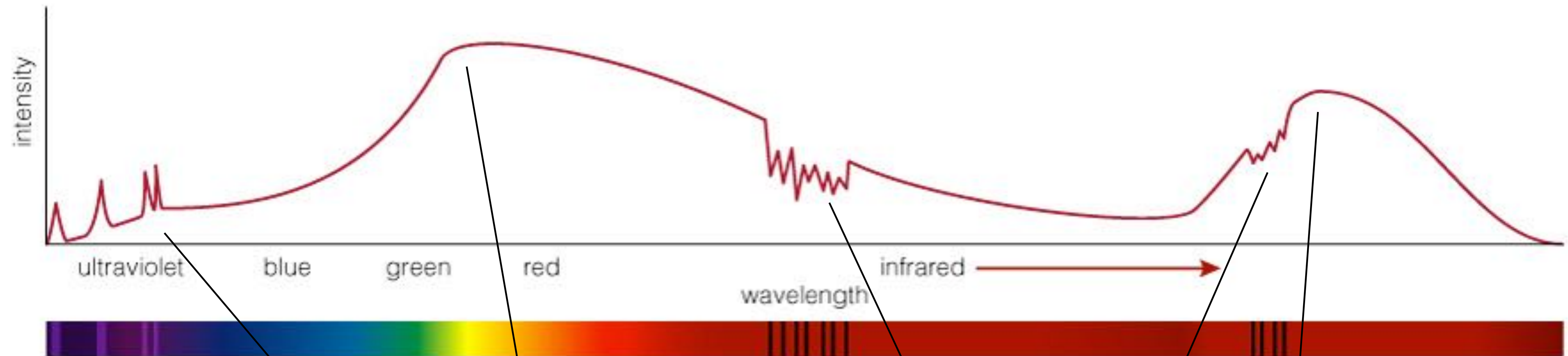
Solar composition

- 73% Hydrogen
- 25% Helium
- 2% everything else
  - "metals"



- Other stars similar
  - H & He most common stuff in the universe
  - Helium was *discovered* in the spectrum of the sun

What is this object? Mars!



Hot upper atmosphere

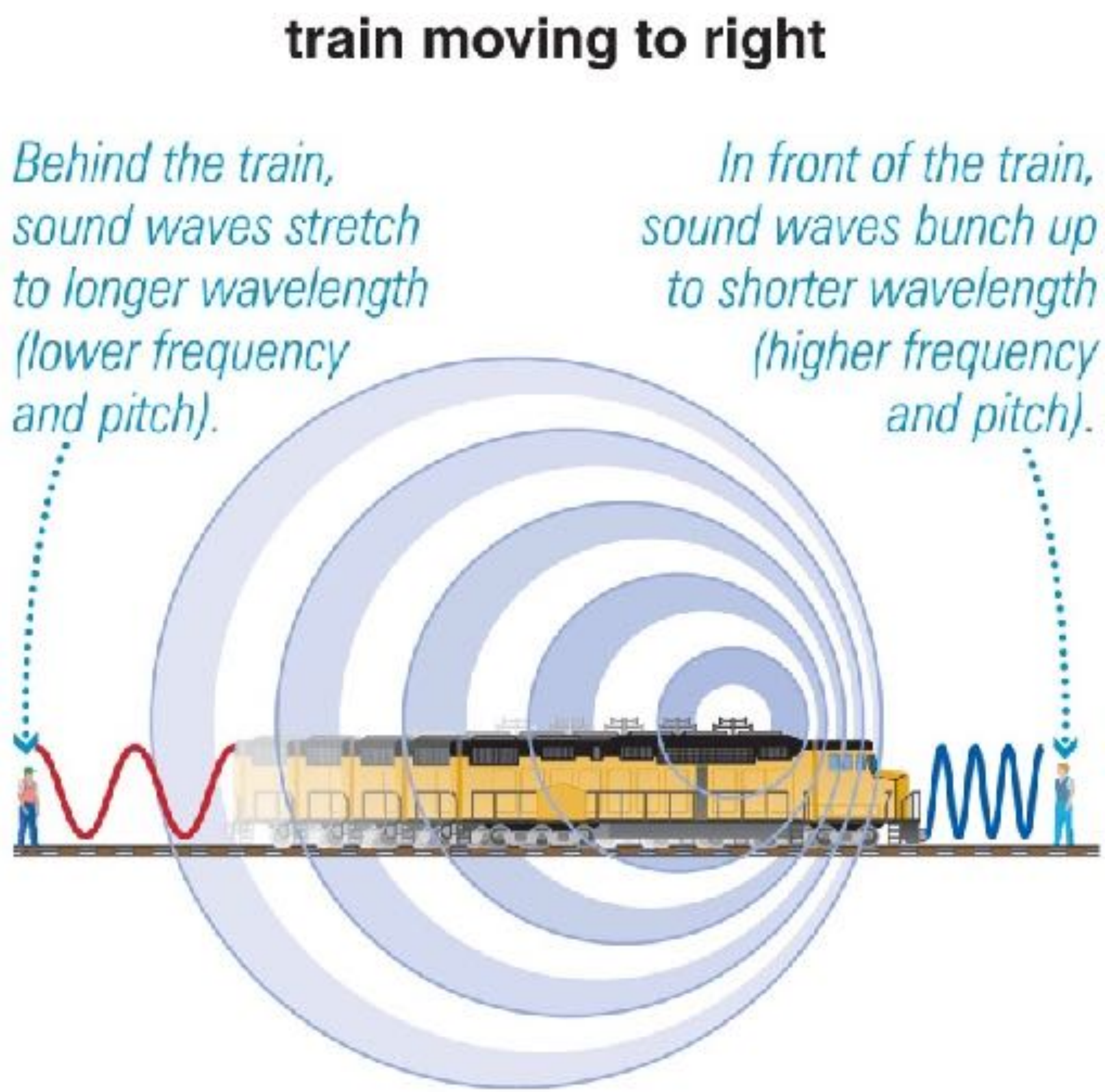
Carbon Dioxide in atmosphere

Reflected Sunlight:
Mars is red

Infrared peak
wavelength tells us
T = 225 K

We can learn an enormous amount from spectra:
temperature, density, and composition

The Doppler Effect



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

Doppler ball

Doppler Effect for Light

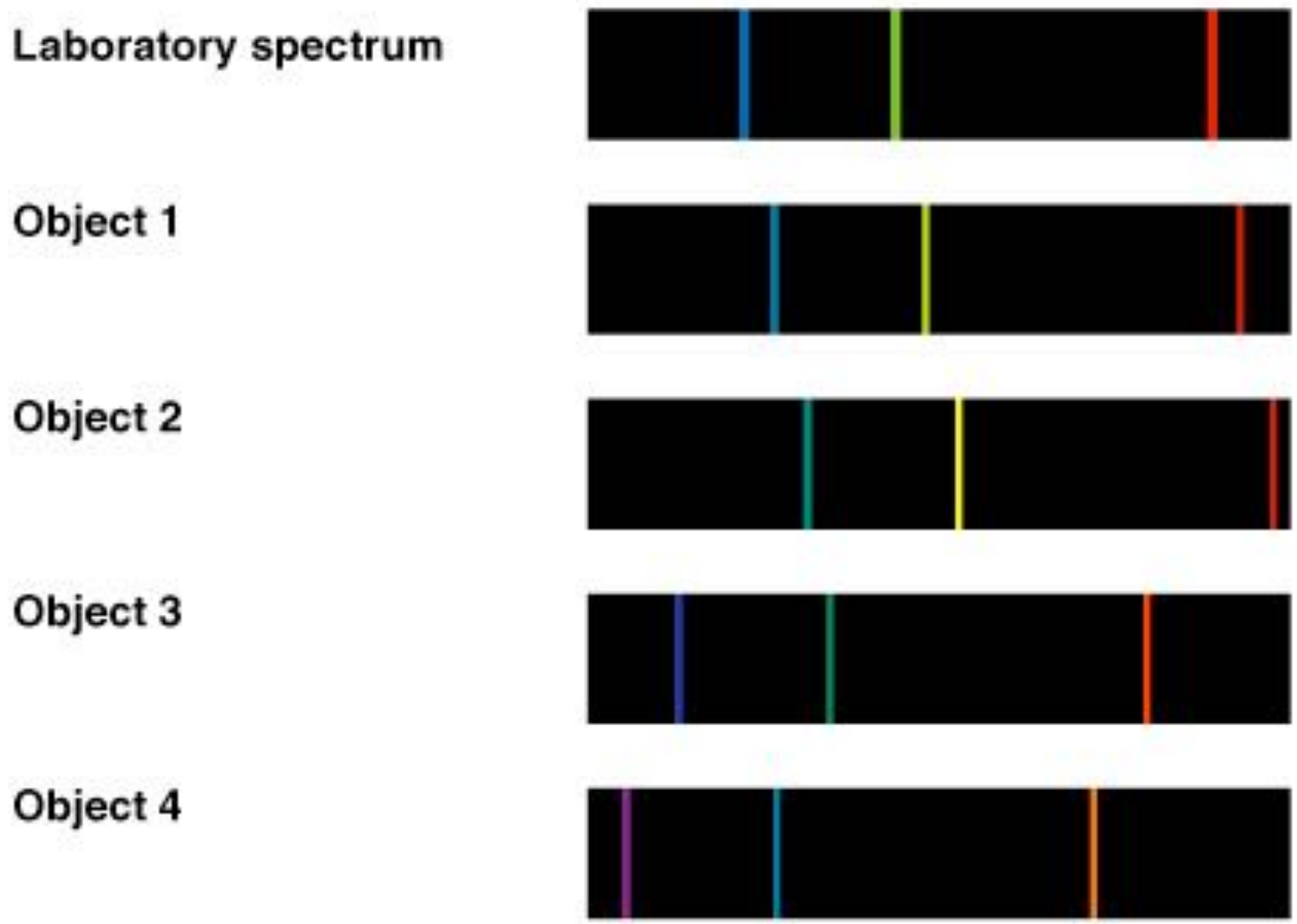
- Motion away -> redshift
- Motion towards -> blueshift

$$\frac{\Delta\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} = \frac{v}{c}$$

wavelength shift ($\Delta\lambda$) / wavelength (λ)

speed (v) / speed of light (c)

Measuring the Shift



Stationary

Moving Away

Away Faster

redshift

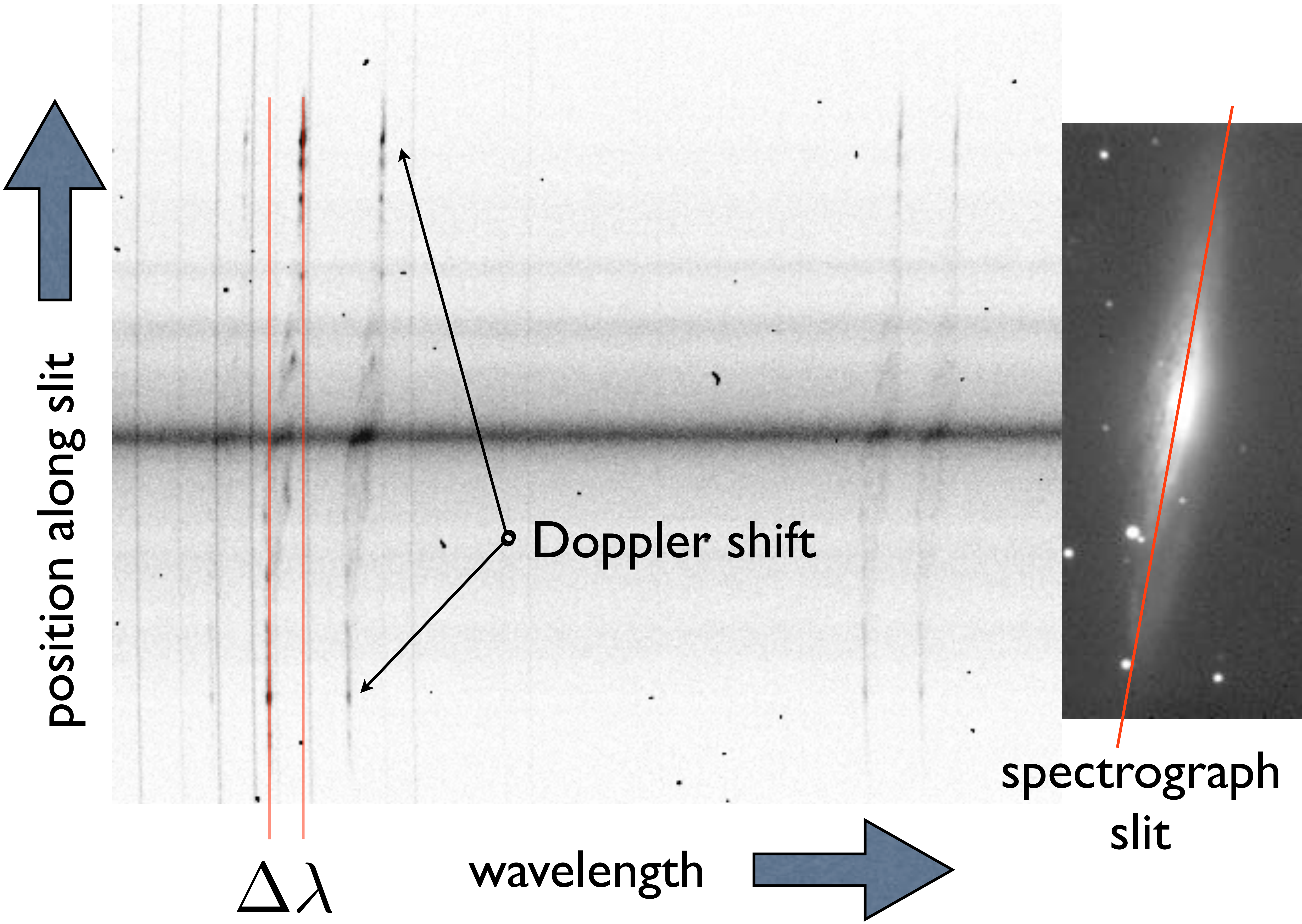
Moving Toward

Toward Faster

blueshift

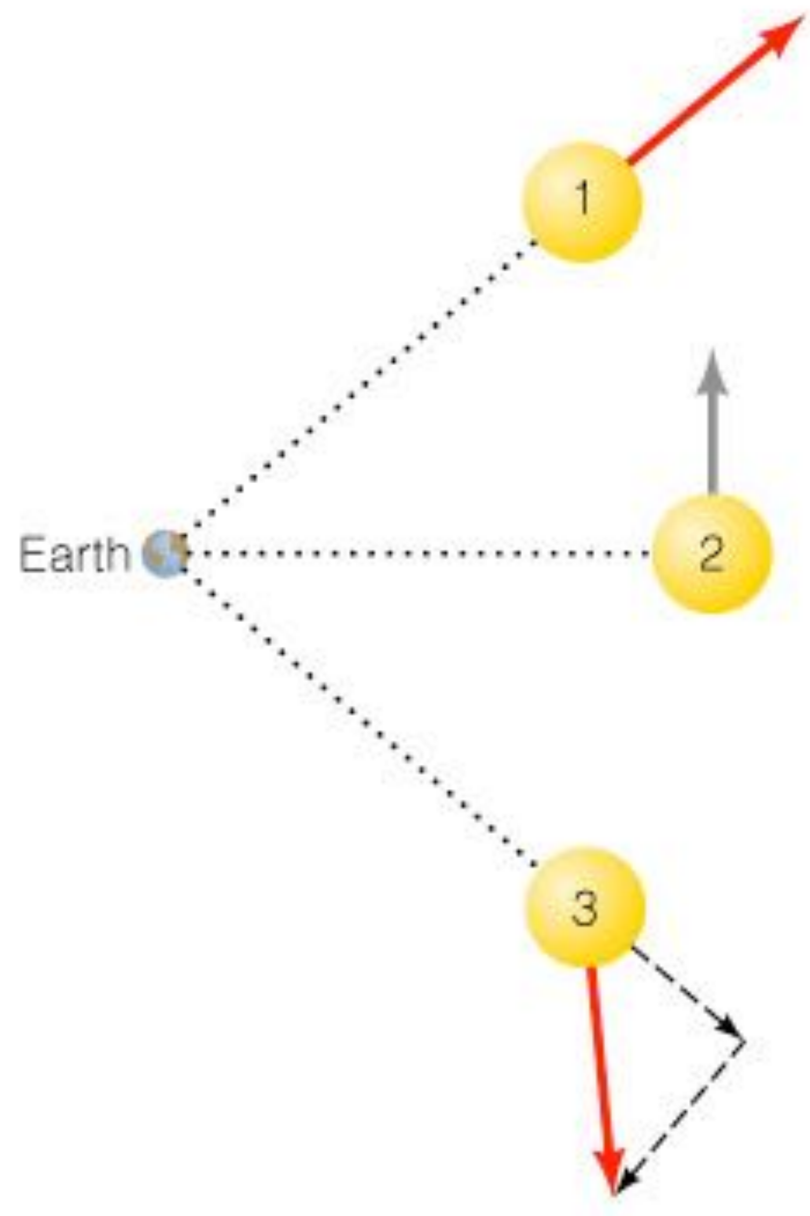
- We generally measure the Doppler effect from shifts in the wavelengths of spectral lines.

Spectrum



position along slit
Doppler shift
Δλ
wavelength
spectrograph slit

Doppler shift tells us ONLY about the part of an object's motion toward or away from us (along our line of sight).



maximum doppler effect

no doppler effect

intermediate case