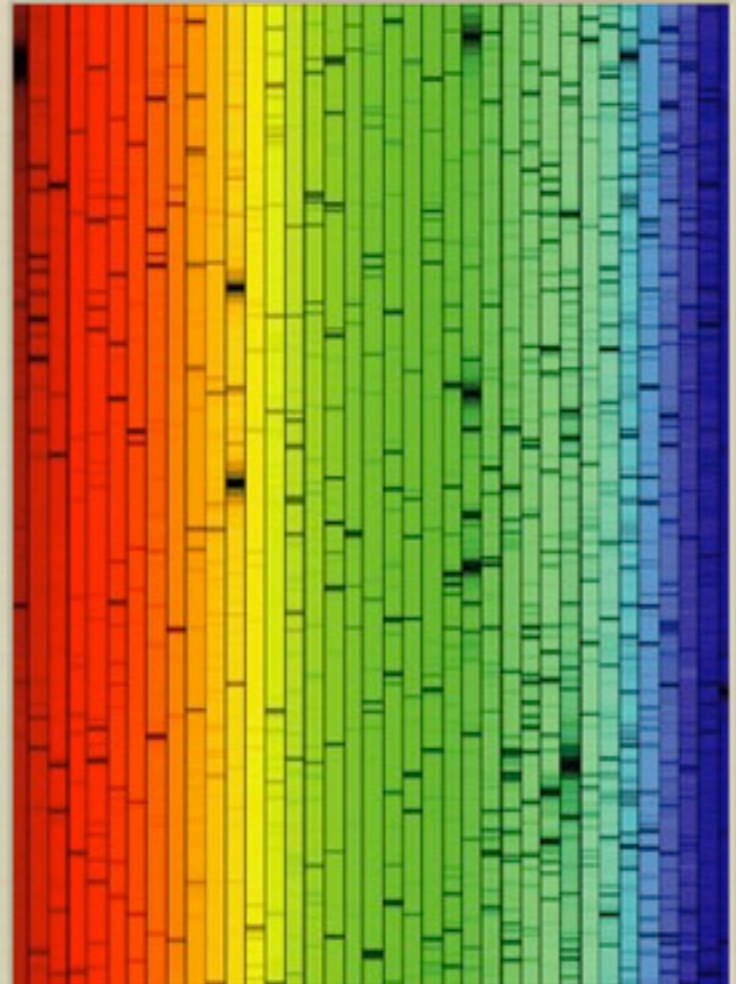
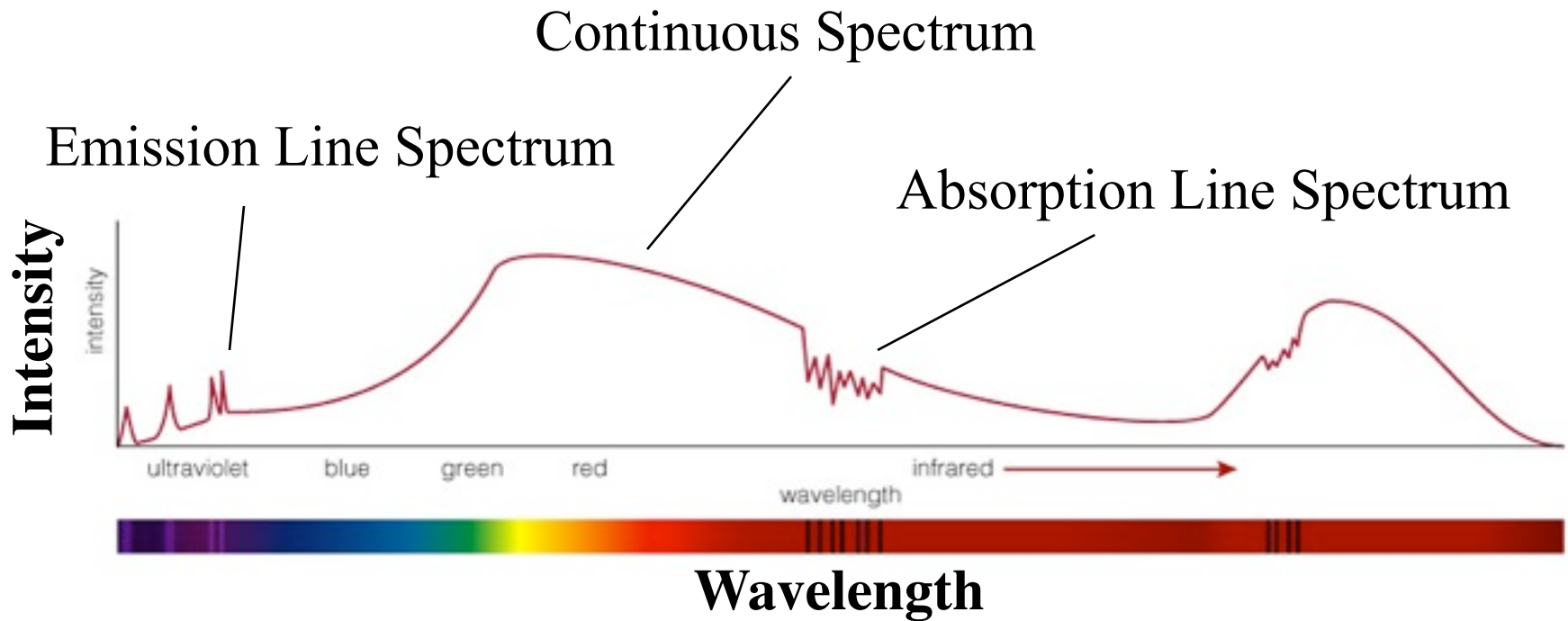


TODAY

- KIRCHOFF'S LAWS
- EMISSION AND ABSORPTION
- STELLAR SPECTRA & COMPOSITION
- DOPPLER EFFECT & MOTION
- EXTRASOLAR PLANETS



Three basic types of spectra

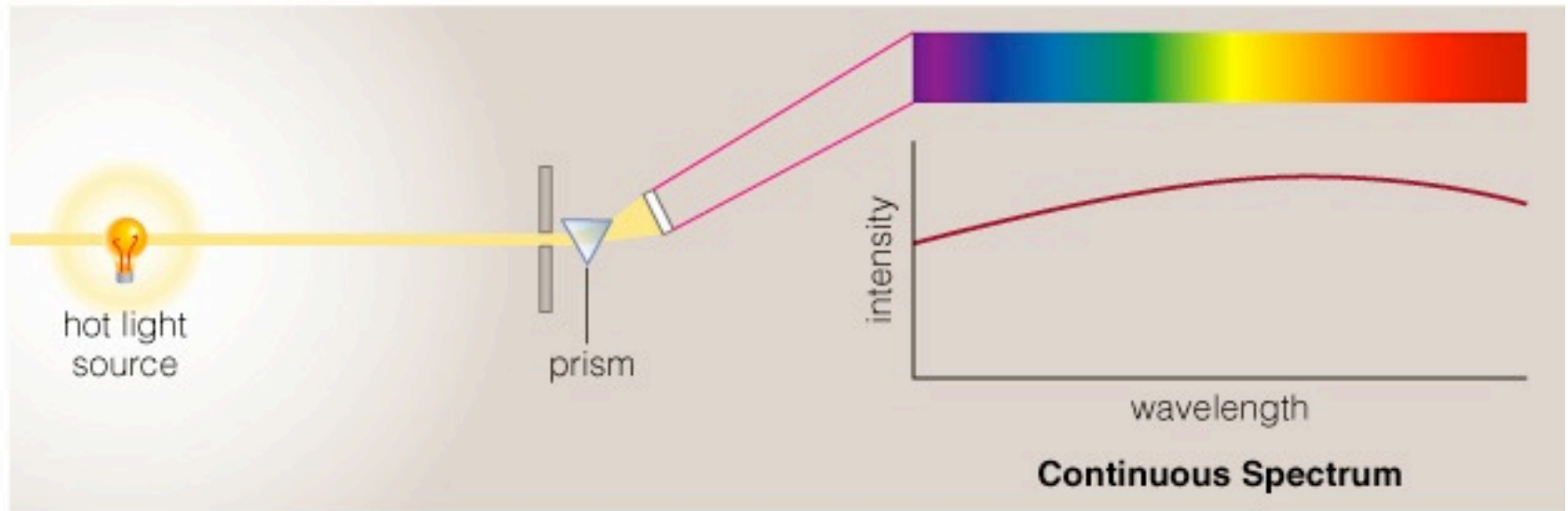


Spectra of astrophysical objects are usually combinations of these three basic types.

Kirchoff's Laws

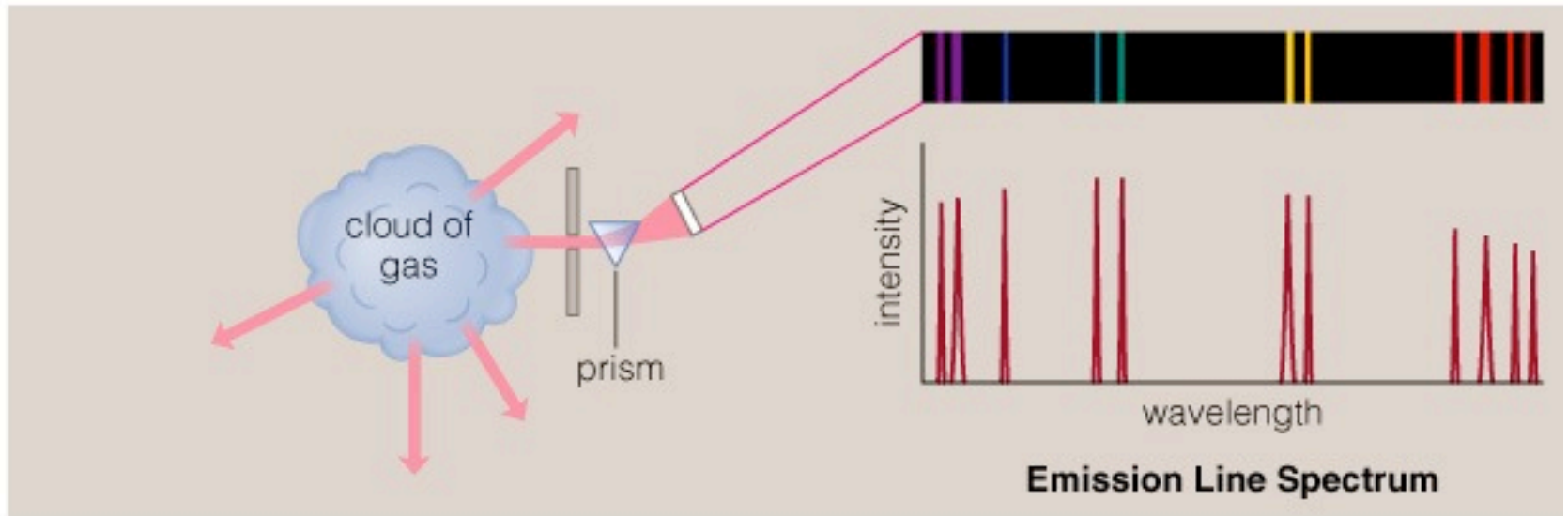
- Hot, dense objects emit a
 - **continuous spectrum** e.g., a light bulb
 - light of all colors & wavelengths
 - follows thermal distribution
 - obeys Wien's & Steffan-Boltzmann Laws.
- Hot, diffuse gas emits light only at specific wavelengths.
 - **emission line spectrum** e.g., a neon light
- A cool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

Continuous Spectrum



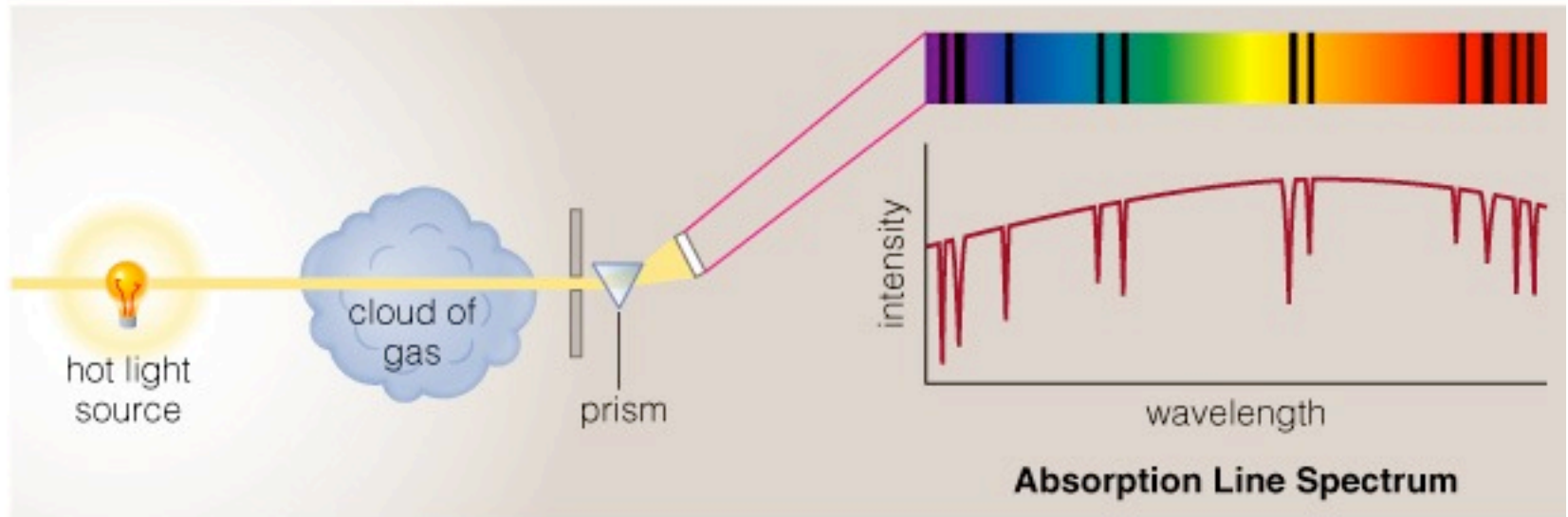
- The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.

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

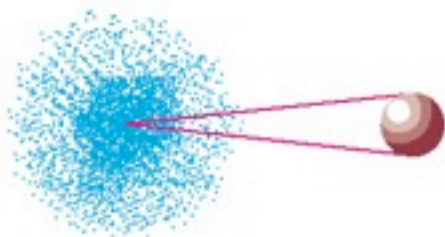


- A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.

Atomic Terminology

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

Hydrogen (${}^1\text{H}$)



atomic number = 1
atomic mass number = 1
(1 electron)

Helium (${}^4\text{He}$)



atomic number = 2
atomic mass number = 4
(2 electrons)

Carbon (${}^{12}\text{C}$)



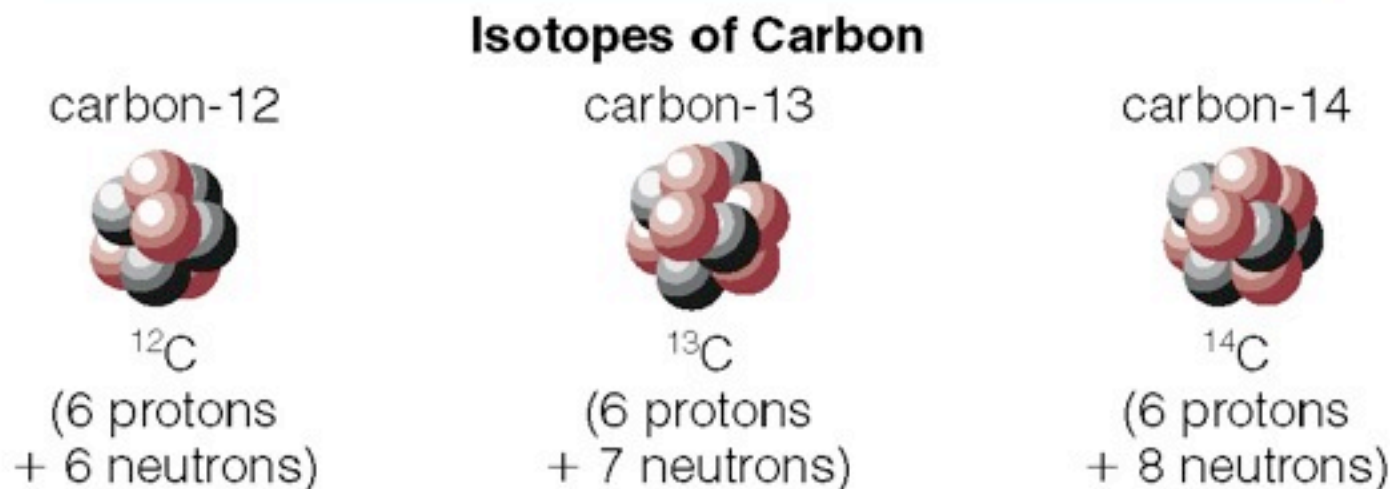
atomic number = 6
atomic mass number = 12
(6 electrons)

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		

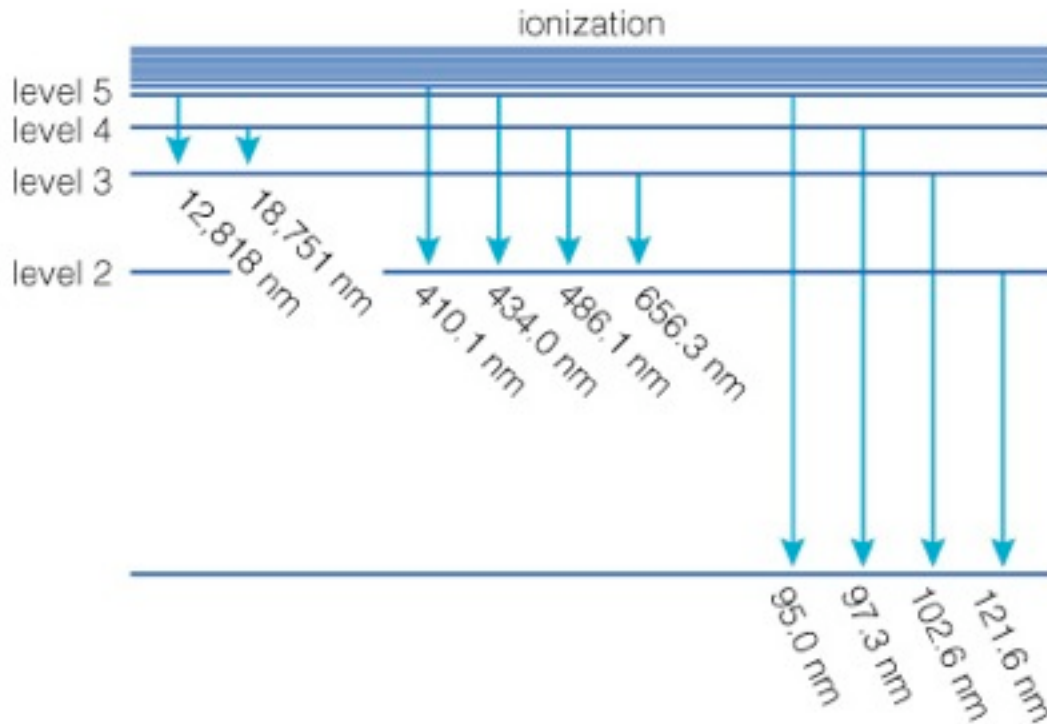
Atomic Terminology

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



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

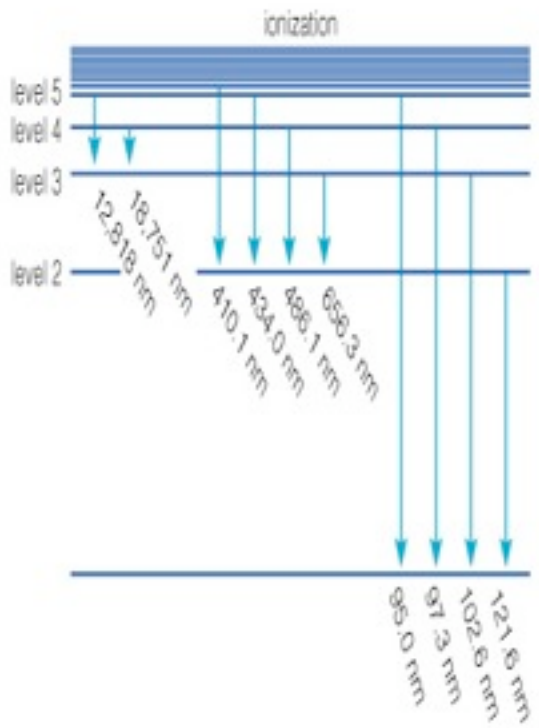
Chemical Fingerprints



Energy levels of hydrogen

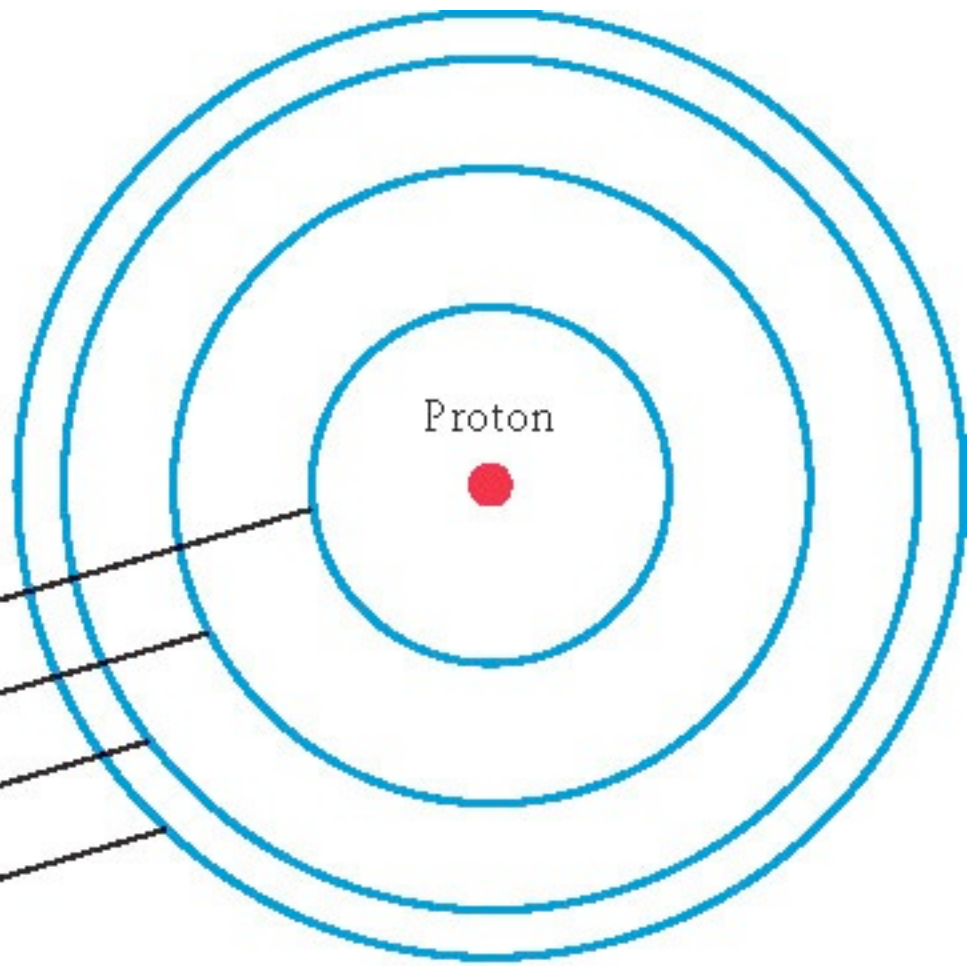
- Each type of atom has a unique set of energy levels.
- Each transition corresponds to a unique photon energy, frequency, and wavelength.

Possible Electron orbits



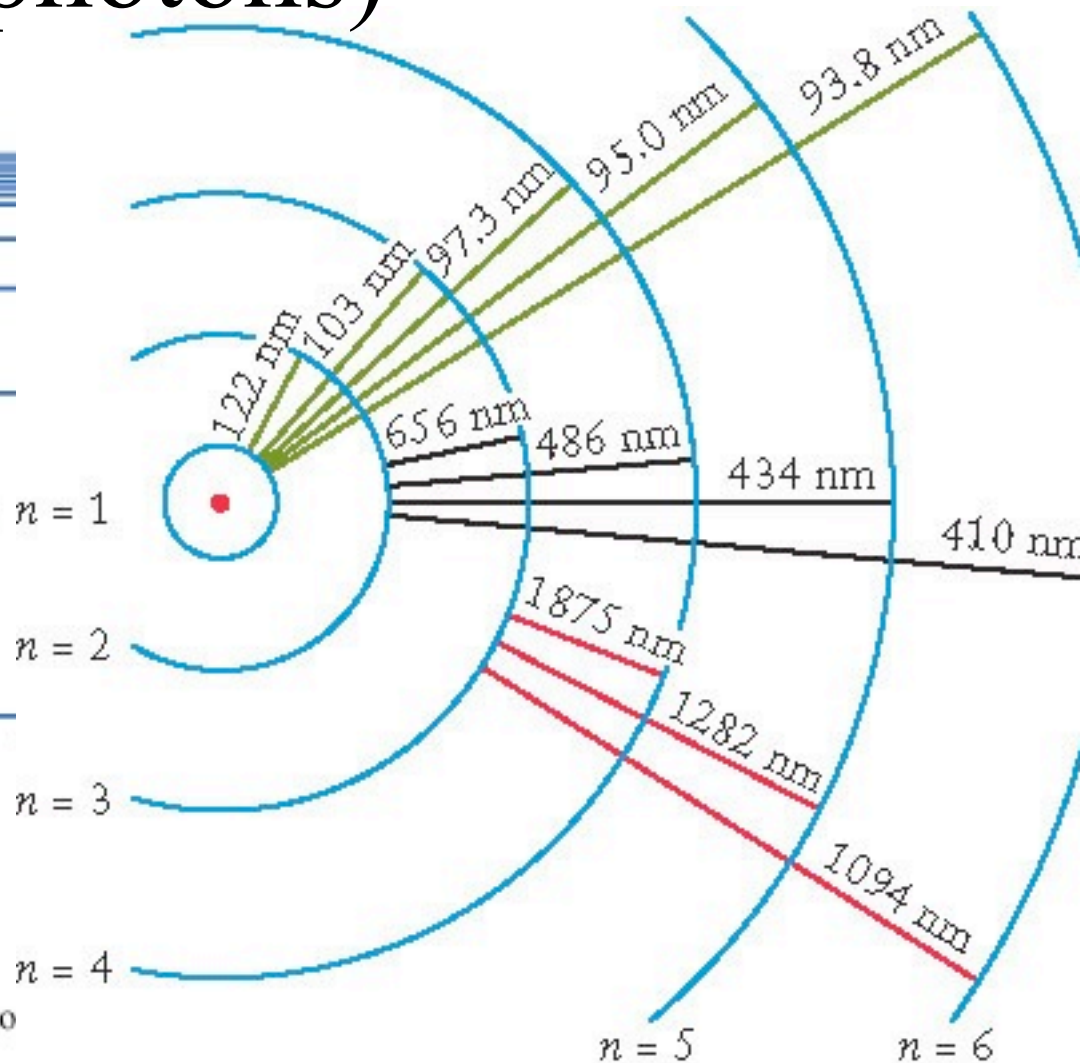
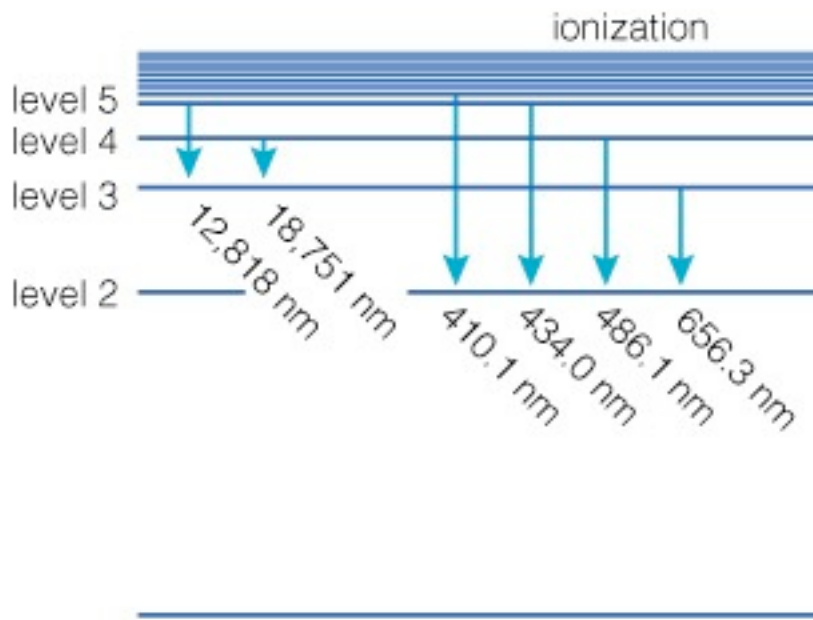
Allowed Bohr orbits:

- $n = 1$
- $n = 2$
- $n = 3$
- $n = 4$
- etc.



Energy levels of hydrogen

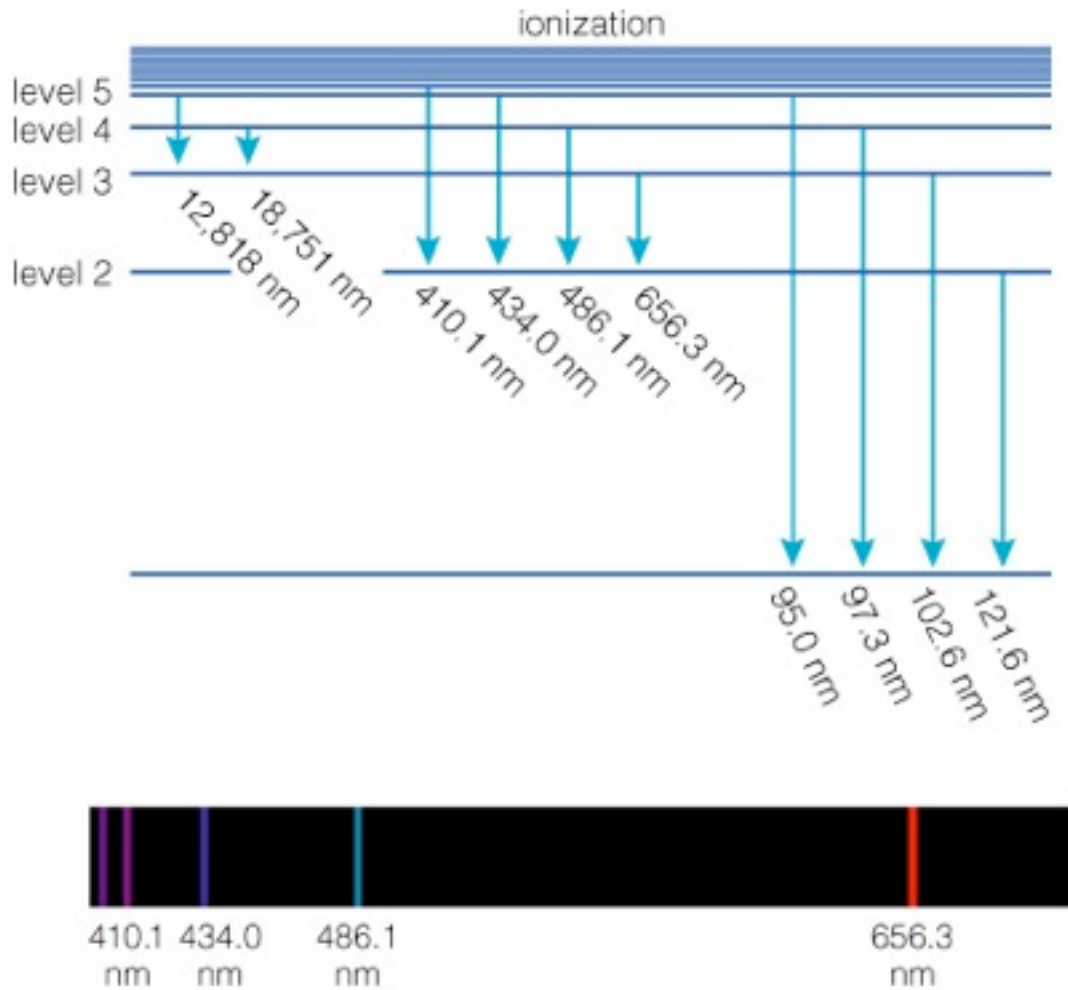
Transitions between orbits release energy (photons)



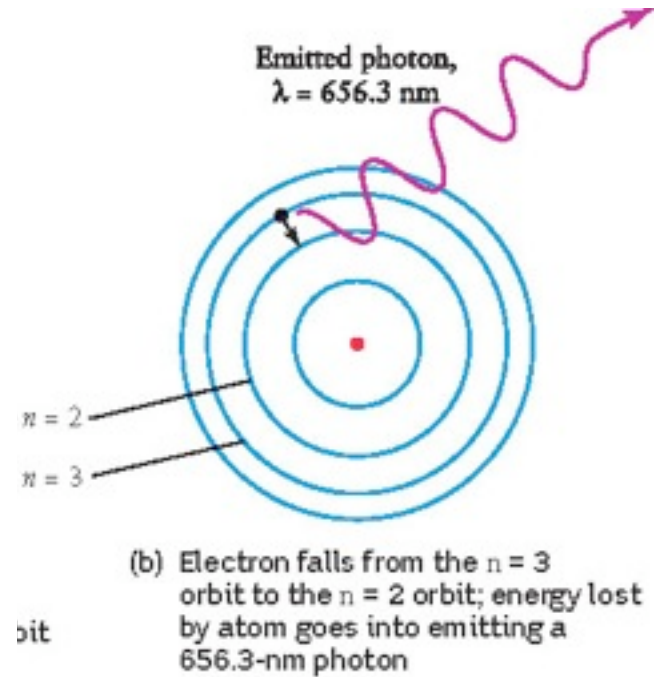
Energy levels of hydrogen

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Chemical Fingerprints

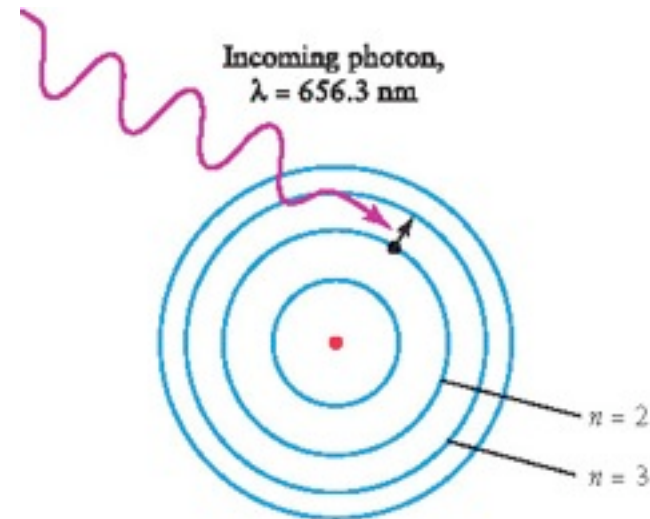
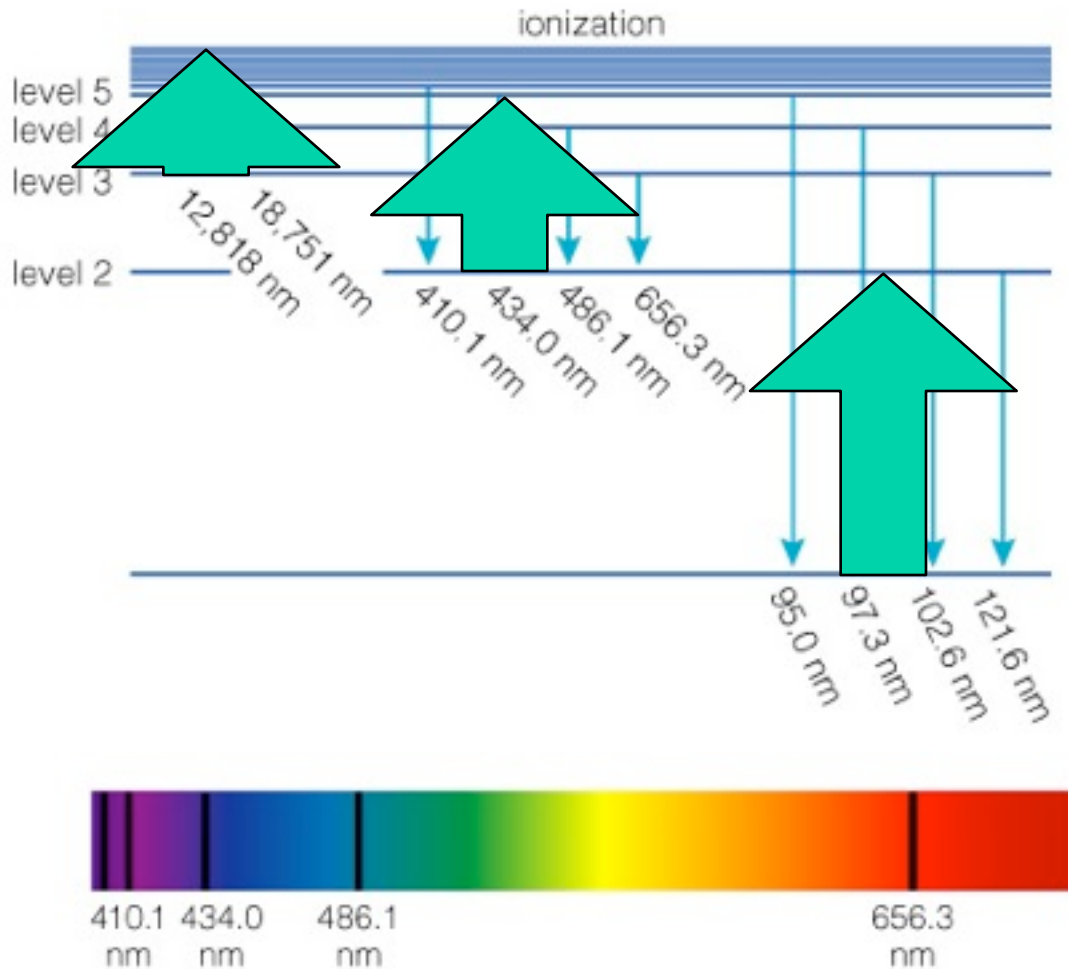


- Downward transitions produce a unique pattern of emission lines.



Chemical Fingerprints

- 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

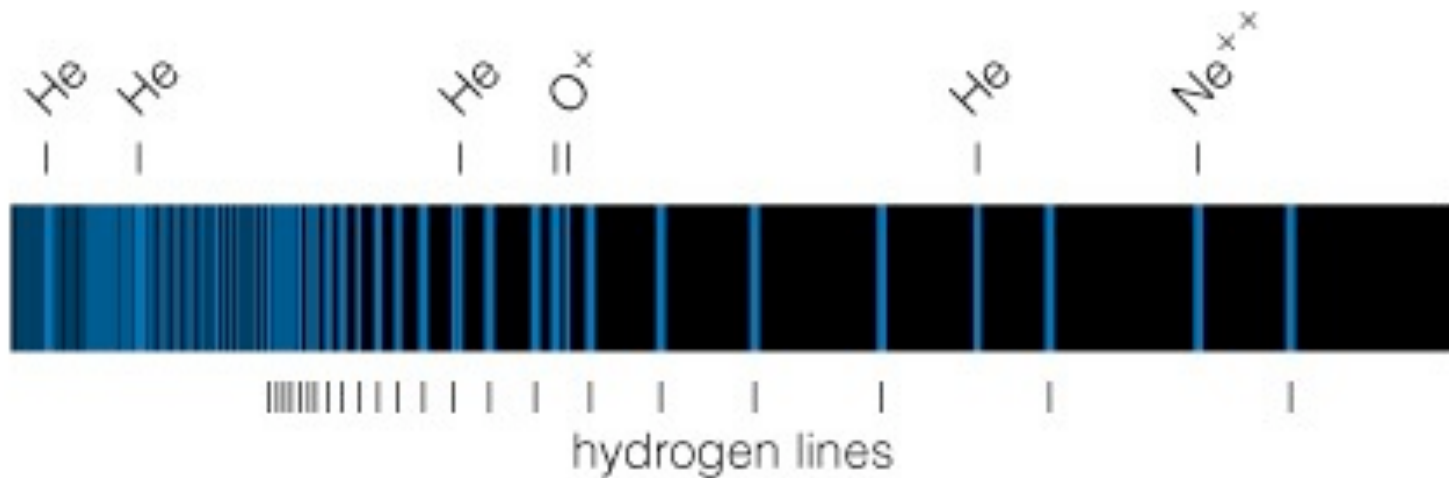
Chemical Fingerprints



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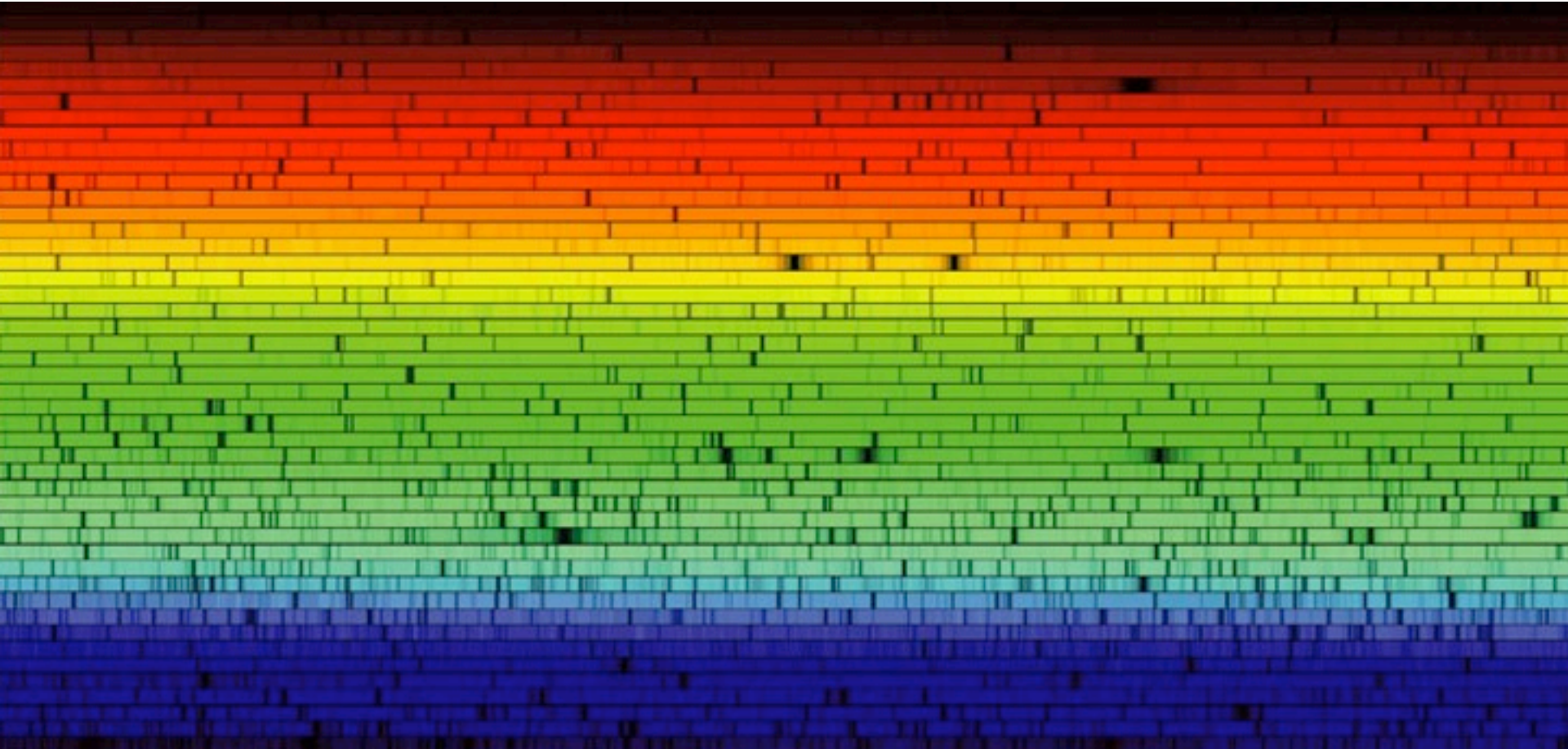
- Each type of atom has a unique spectral fingerprint.

Chemical Fingerprints



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

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

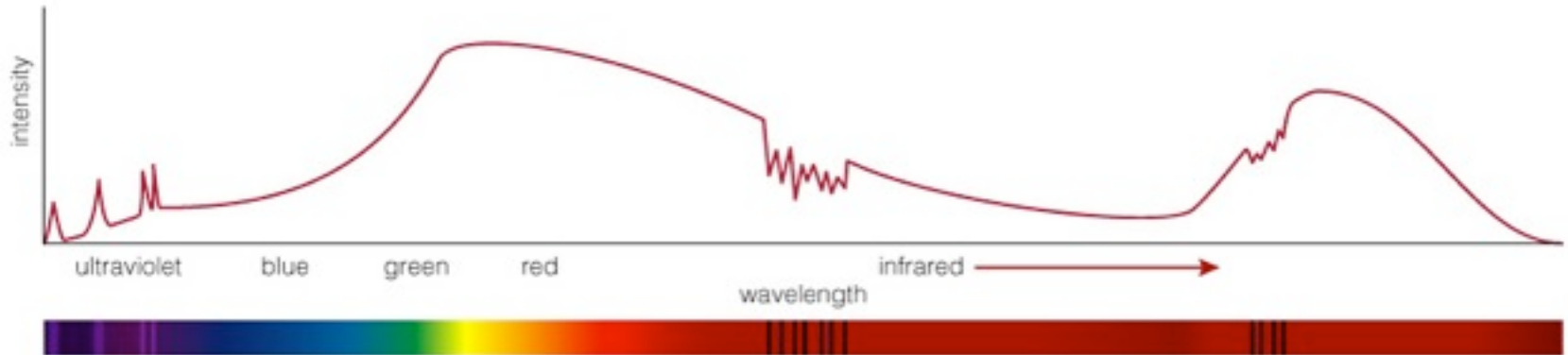
- 73% Hydrogen
- 25% Helium
- 2% everything else
 - “metals”

Periodic Table of the Elements

1 H Hydrogen	2 He Helium																
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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	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		
87 Fr Francium	88 Ra Radium	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		

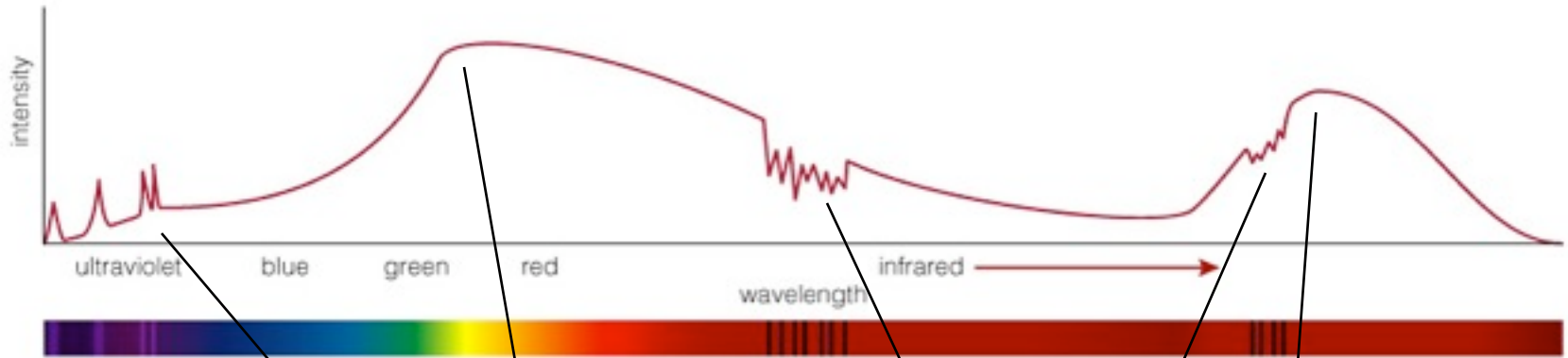
- Other stars similar
 - H & He most common stuff in the universe
 - Helium was *discovered* in the spectrum of the sun

Interpreting 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? Mars!



Hot upper atmosphere

Carbon Dioxide in atmosphere

Reflected Sunlight:
Mars is red

Infrared peak
wavelength tells us
 $T = 225 \text{ K}$

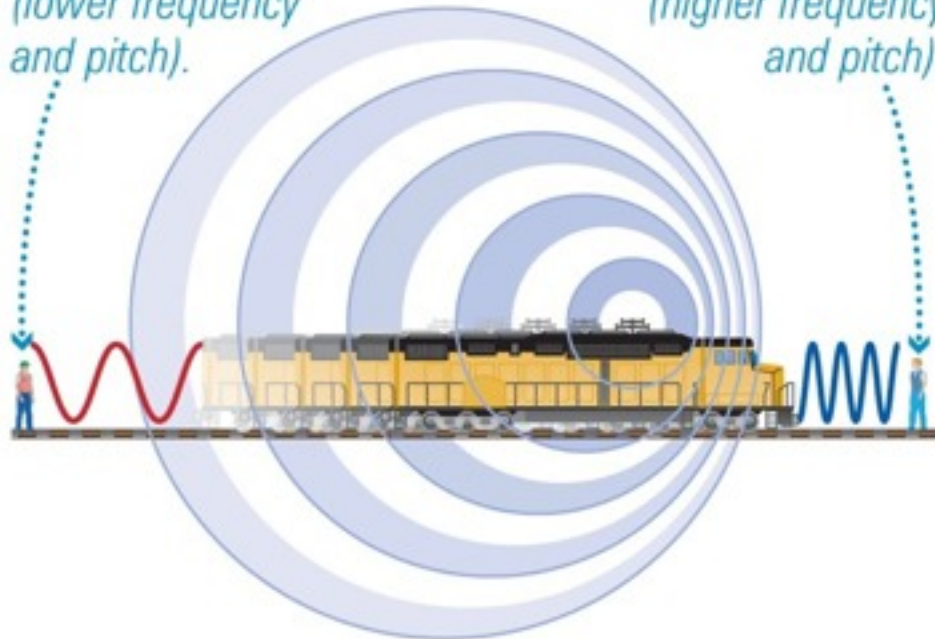
We can learn an enormous amount from spectra!

The Doppler Effect

train moving to right

*Behind the train,
sound waves stretch
to longer wavelength
(lower frequency
and pitch).*

*In front of the train,
sound waves bunch up
to shorter wavelength
(higher frequency
and pitch).*



H2-41

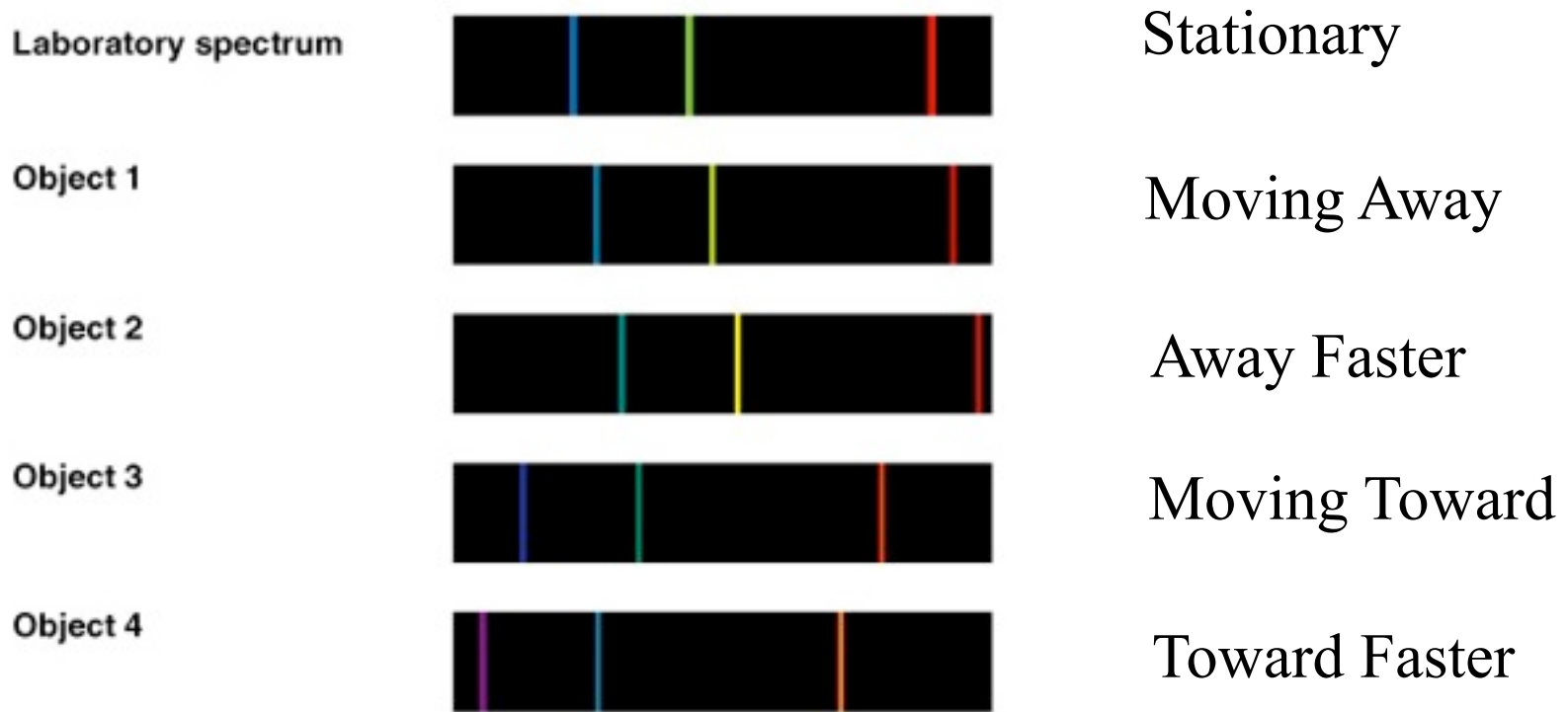
b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

Doppler Effect for Light

- Motion away \rightarrow redshift
- Motion towards \rightarrow blueshift

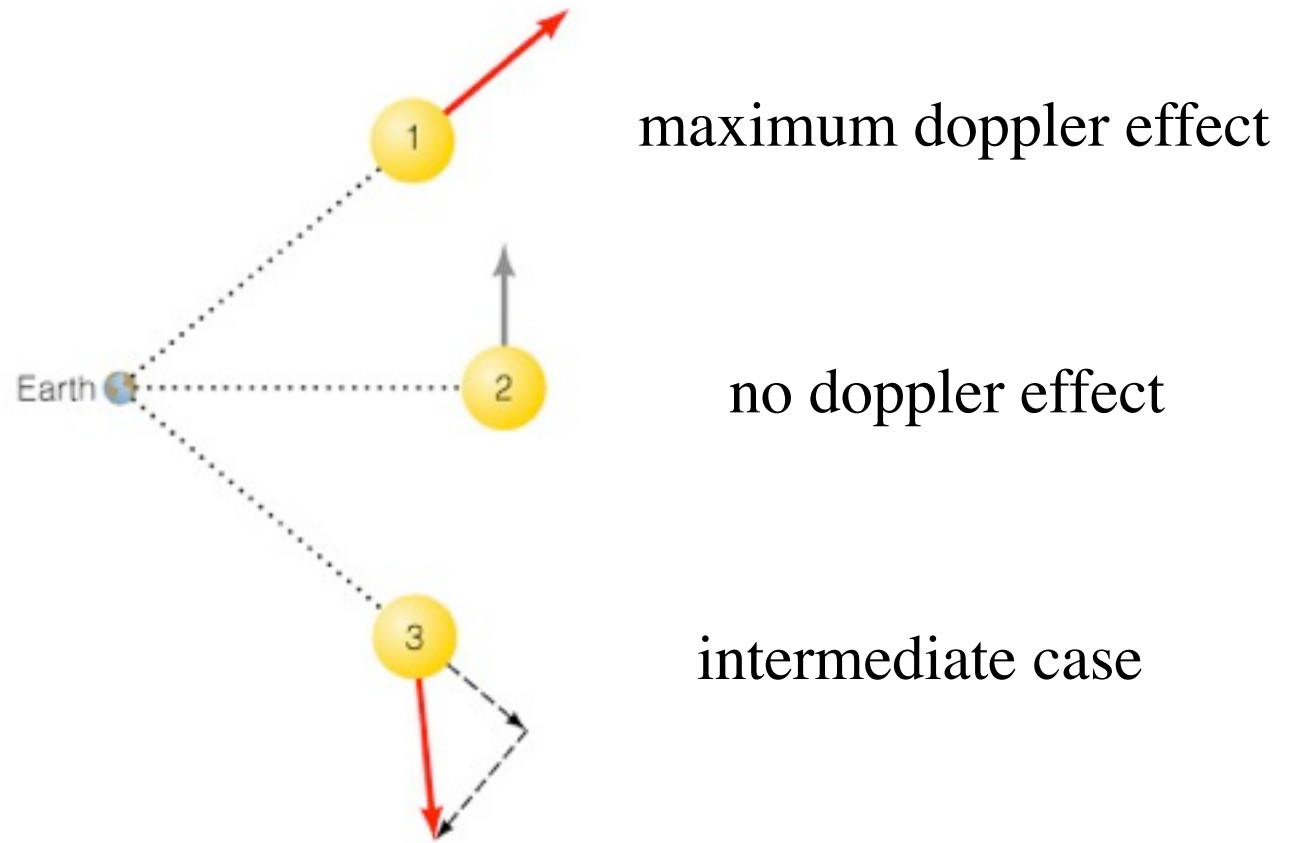
$$\frac{\Delta\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} = \frac{v}{c}$$

Measuring the Shift



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

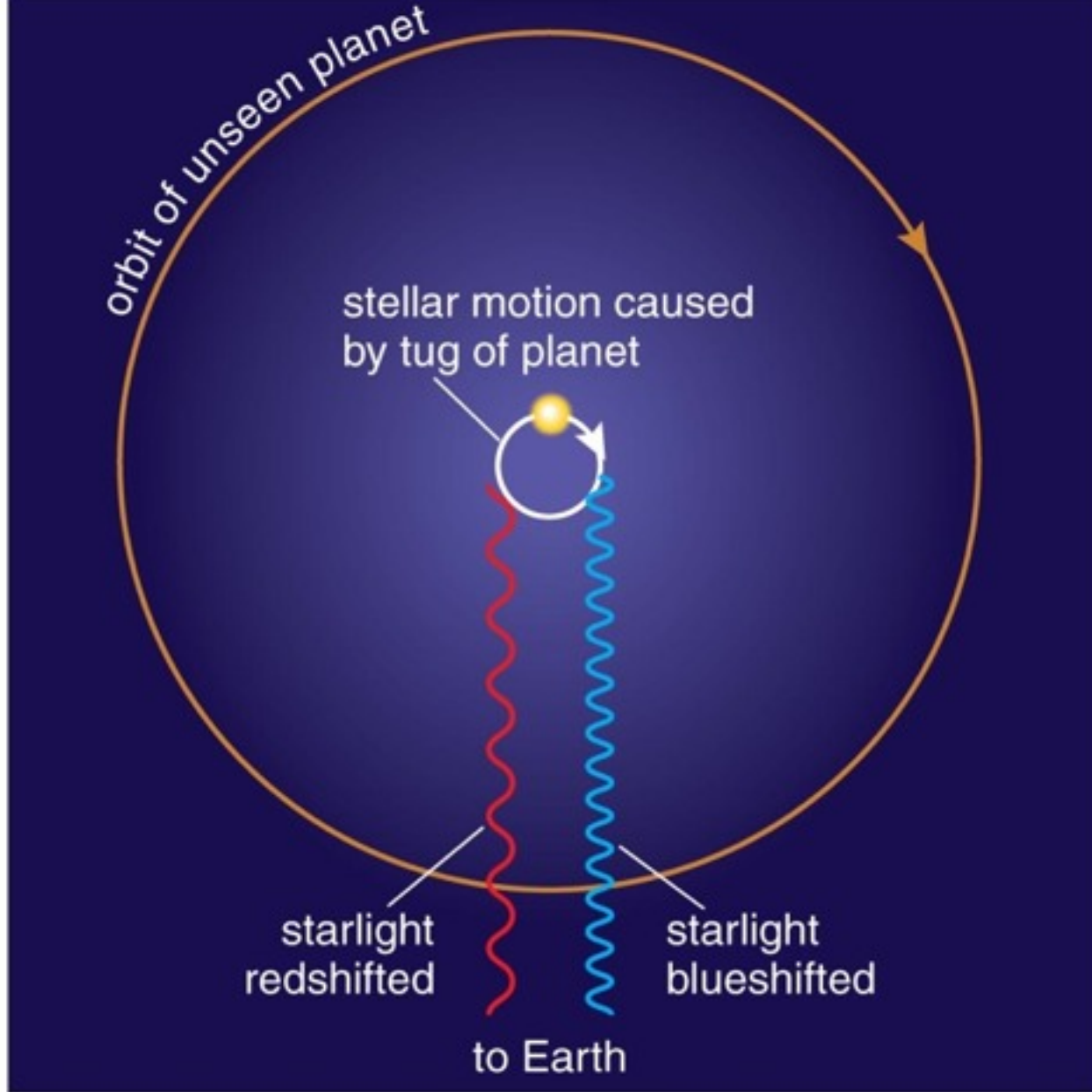
Doppler shift tells us ONLY about the part of an object's motion toward or away from us (along our line of sight).



A futuristic landscape with a large reddish planet in the sky and two bright stars. The foreground is a rocky, yellowish-brown terrain with jagged mountains in the background. The sky is dark blue with stars and a large, reddish planet on the left. Two bright stars are visible in the distance.

Doppler Application

- Extrasolar planets



C1-01

a Doppler shifts allow us to detect the slight motion of a star caused by an orbiting planet. 27

