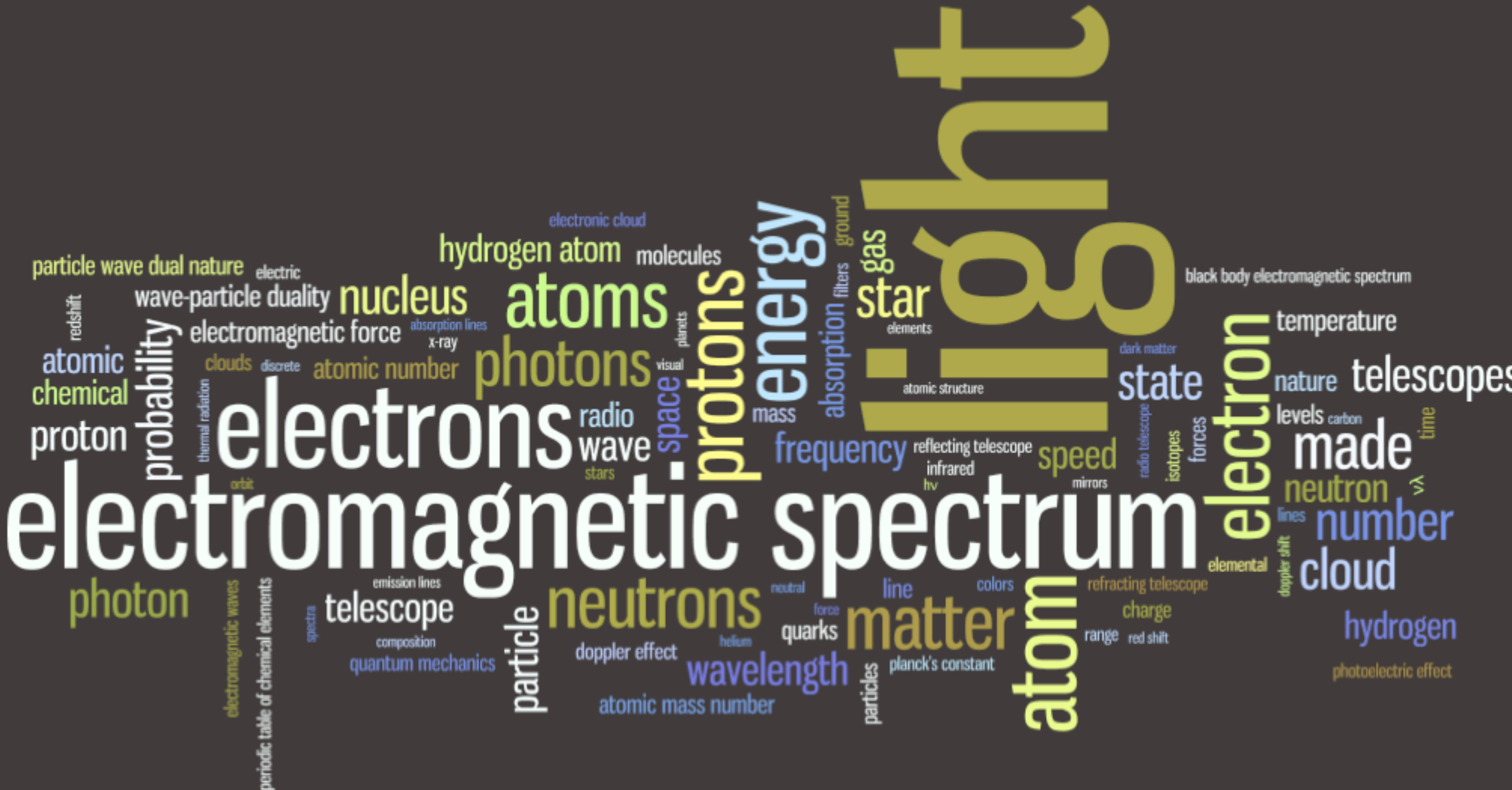
Light & Matter and their Interaction

Chapter 5


light
electromagnetic spectrum
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elemental
doppler shift
cloud
photon
electromagnetic waves
periodic table of chemical elements
emission lines
telescope
spectra
composition
quantum mechanics
particle
neutral
force
line
colors
refracting telescope
charge
quarks
helium
doppler effect
range
red shift
hydrogen
wavelength
particles
planck's constant
atomic mass number
photoelectric effect

Natural Forces

* Last lecture, you saw the Force of Gravitation, one of Nature's four forces
* In this lecture, you will be introduced to the other three:

1) Electromagnetic force

2) Strong Nuclear Force

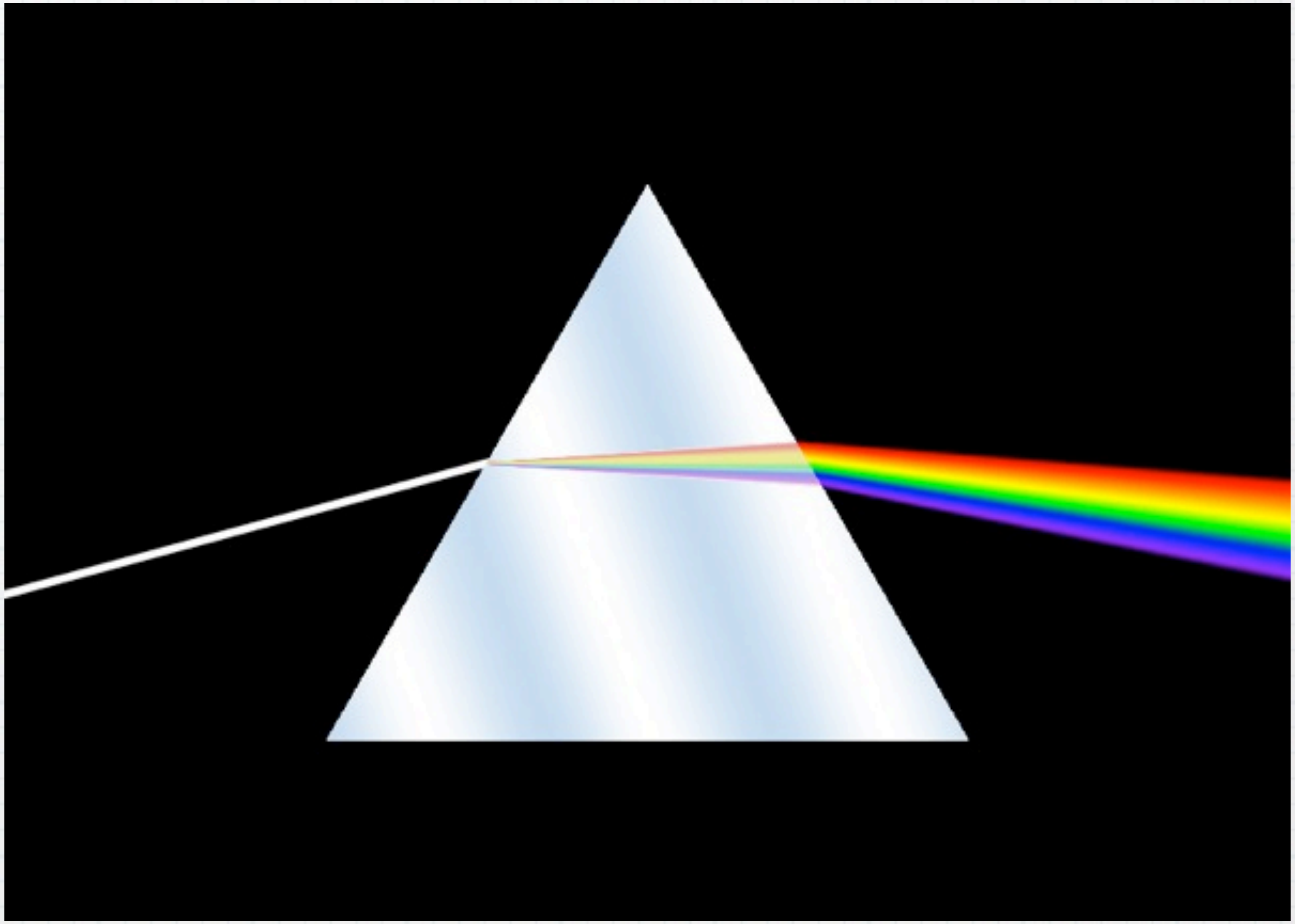
3) Weak Nuclear Force

Natural Forces...

1) Electromagnetic force: light! magnets! and much more: such as providing friction
2) Strong Nuclear Force: keeps nuclei of atoms together
3) Weak Nuclear Force: responsible for radioactivity (or the decay of nuclei of atoms) - radioactivity = instability

* White light can be dispersed when going through a prism: from indigo to red
* The rainbow on the right is called a spectrum

Newton demonstrated that white light was the sum of many other colored lights



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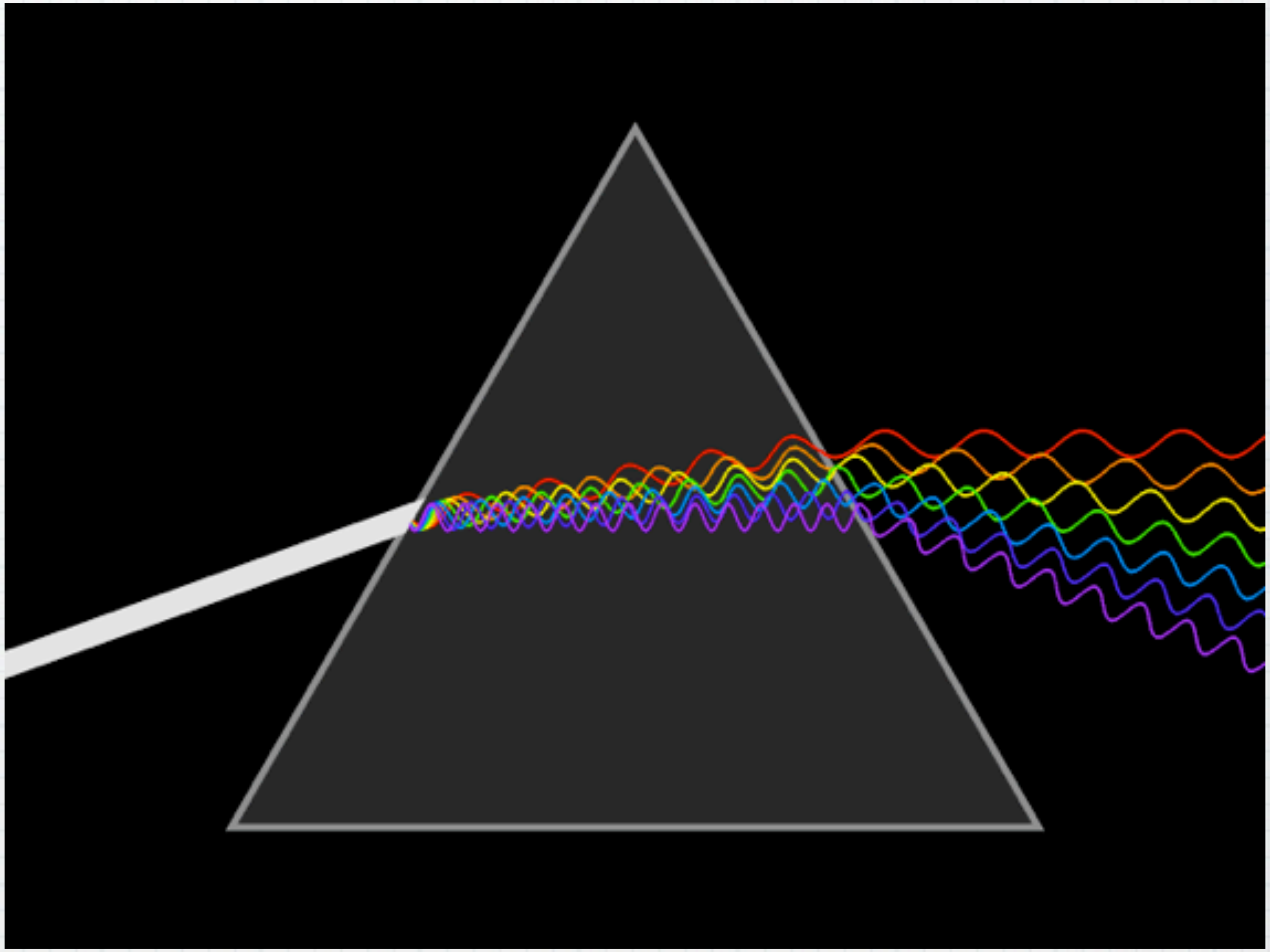
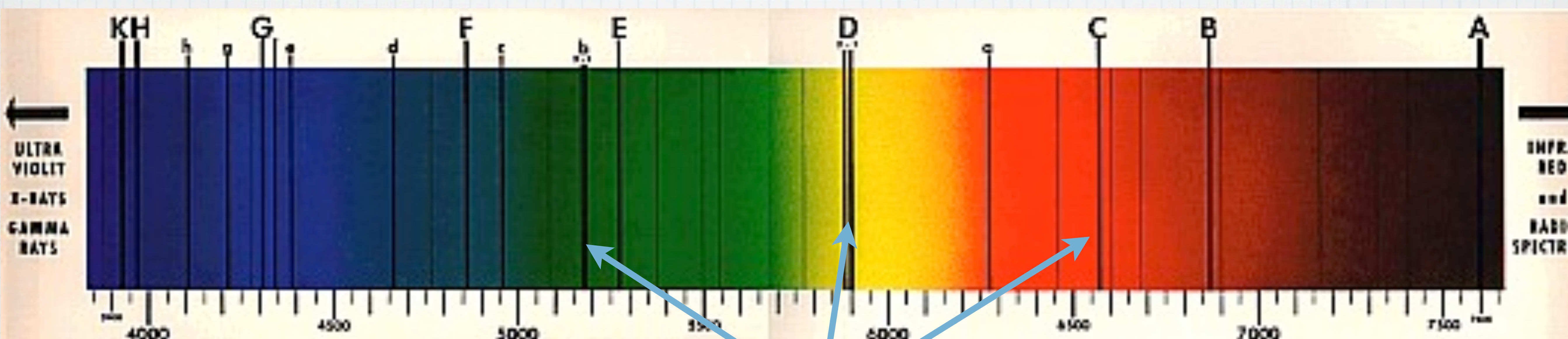


The Solar spectrum

It looks like a dirty spectrum!

Note the brightest part of the spectra: the yellows



Spectral (absorption) lines

* The vertical dark lines are called absorption lines

* Their positions tell us many things about the Sun: they are a chemical fingerprint of what is shining

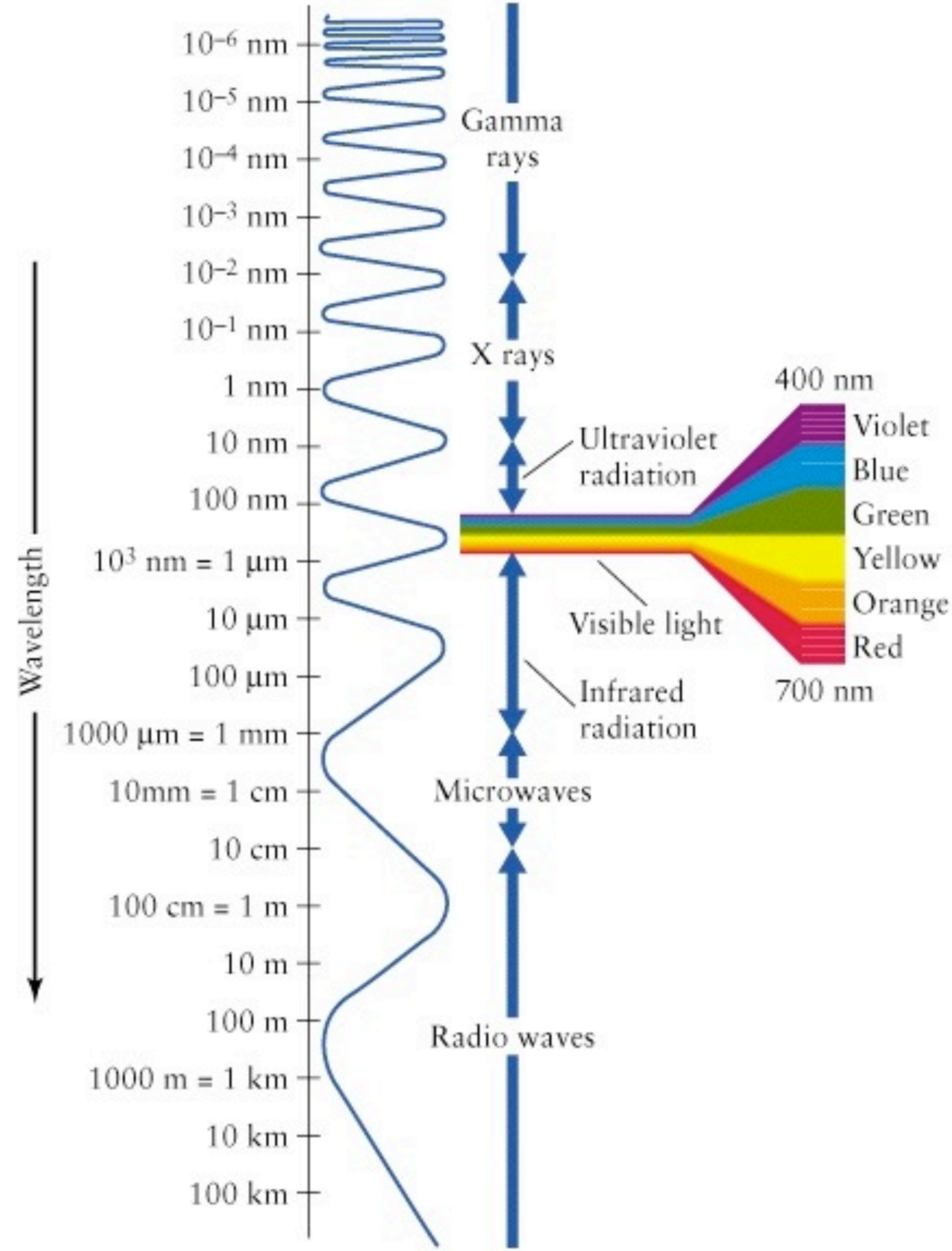
  * indicating temperature and chemical composition of the shining material

* Those lines appear because light and matter interact. Let's see how/why this happens

The Electromagnetic Spectrum

* The light we see is just a small part of a much bigger domain
* X-ray machines, radars, microwave ovens, cell phones, radio and televisions, etc. all work by capturing or emitting "light" that we do not see
* Our eyes are not sensitive to these frequencies (colors)

The Electro-magnetic Spectrum

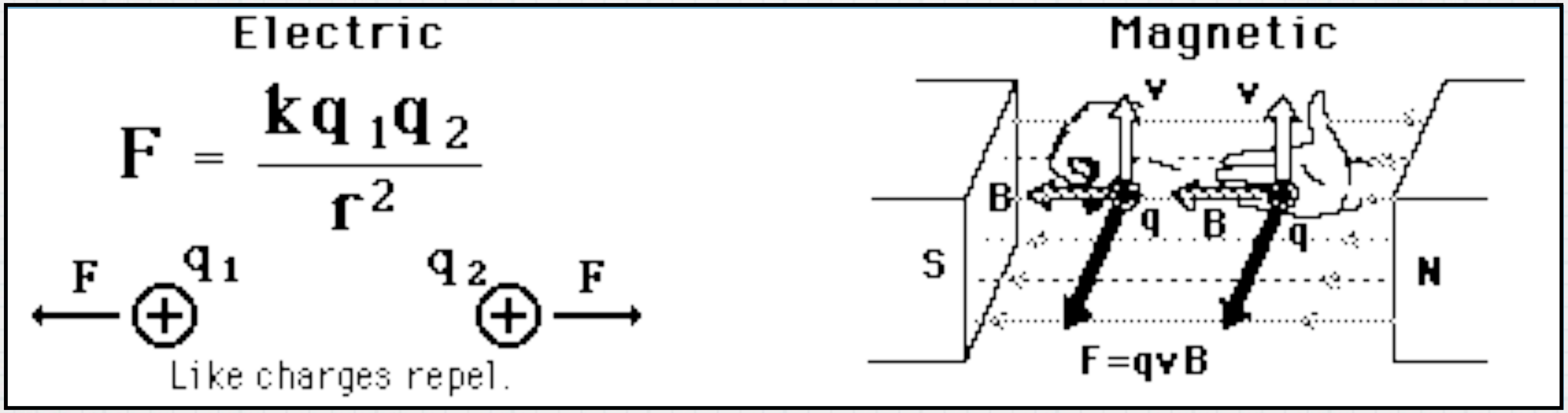


The Electromagnetic Force

* The Electromagnetic Force is one of the four known Fundamental Forces of Nature
* Its range is infinite (like gravity)
* It is propagated by photons (the force carrier)
  * photons have no mass and no charge
  * they travel at the speed of light, c
  * c ≈ 300,000 km/s ≈ 187,000 mi/s in the vacuum

The Electromagnetic Force...

* the electromagnetic force manifests itself through the forces between charges and the magnetic force by an exchange of photons ("light")

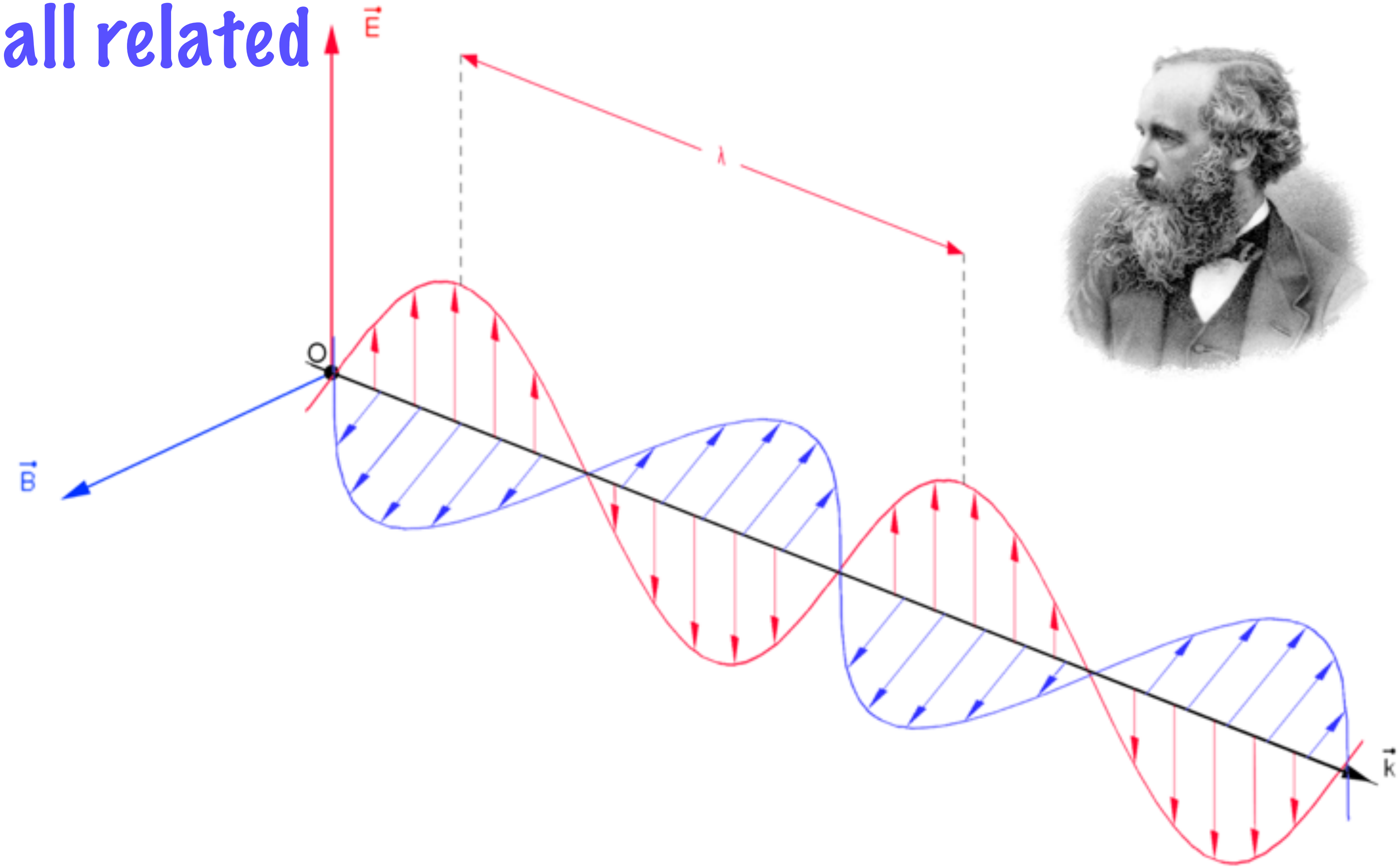


Electromagnetic Waves

An electromagnetic wave consists of two waves that are oscillations of the electric and magnetic fields

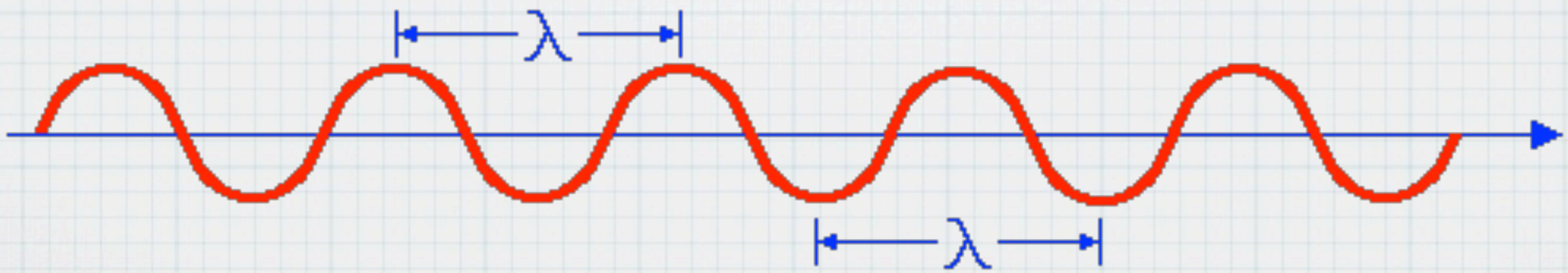
In 1865, James Clerk Maxwell discovered the equations that govern the phenomena

From this emerged the idea that electricity, magnetism and optics were all related



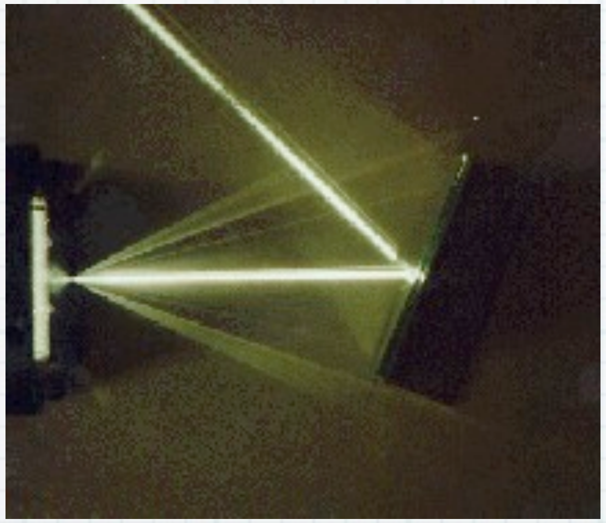
Light as a Wave

* The distance between peaks is called the wavelength and is represented with the greek letter lambda: λ
* Light radiates (travels) with a constant speed and is represented with the letter: c
* c ≈ 300,000 km/s is the speed of light in the vacuum of space

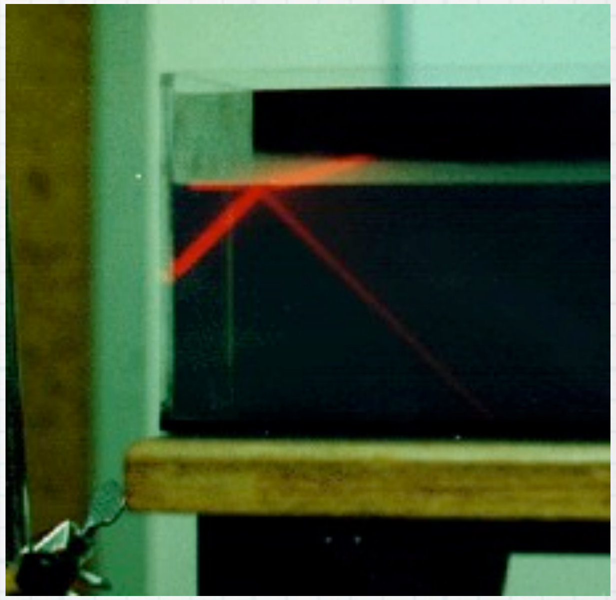


We know light is a wave because...

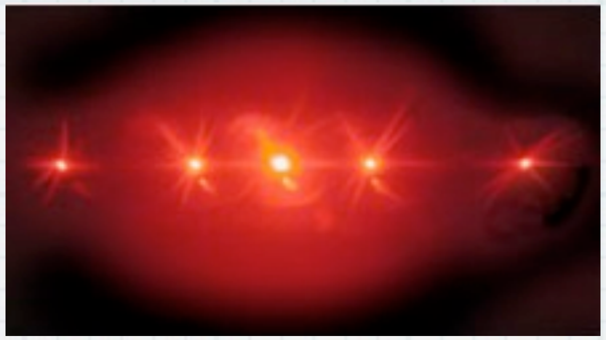
It reflects



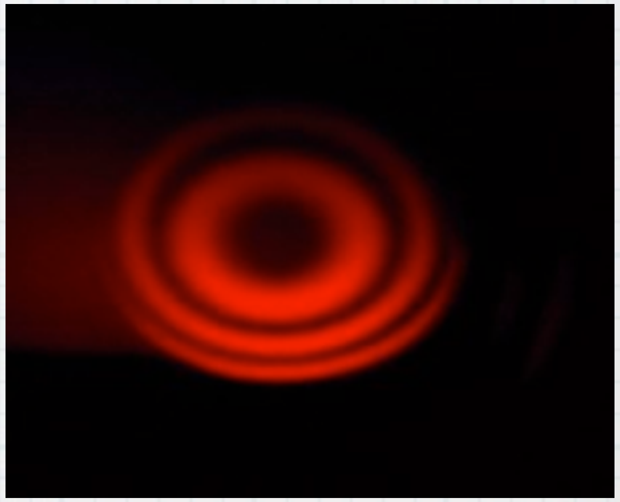
It refracts



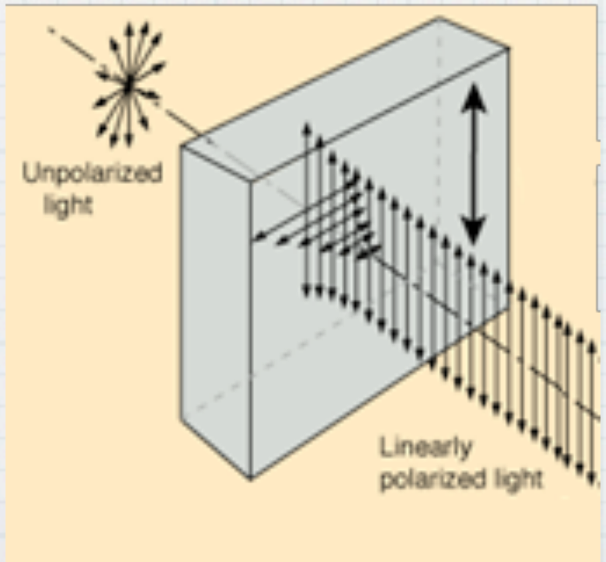
It diffracts



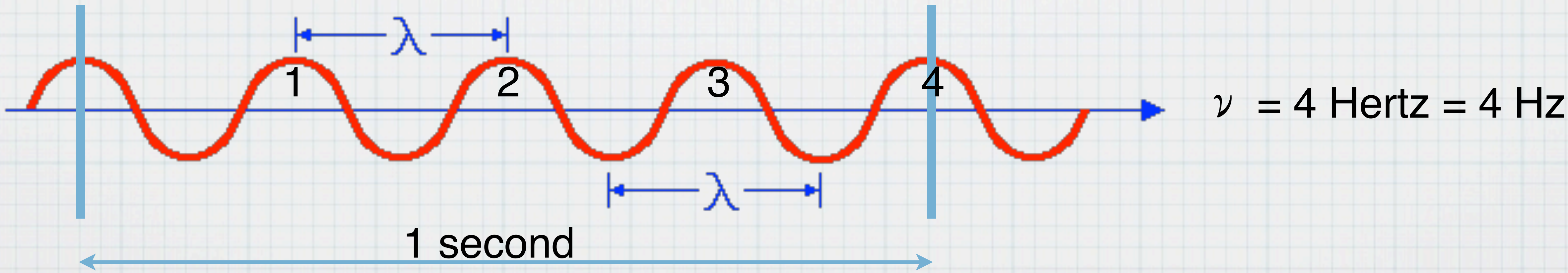
we can get interference waves



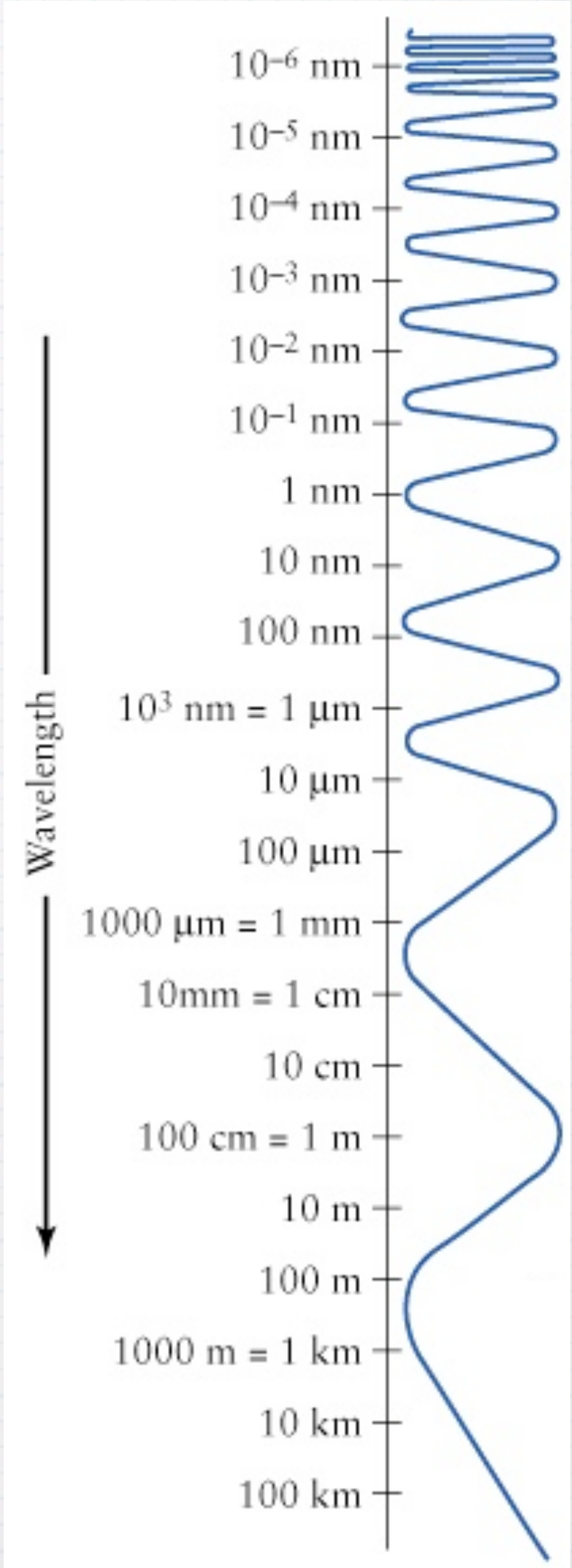
It can be polarized



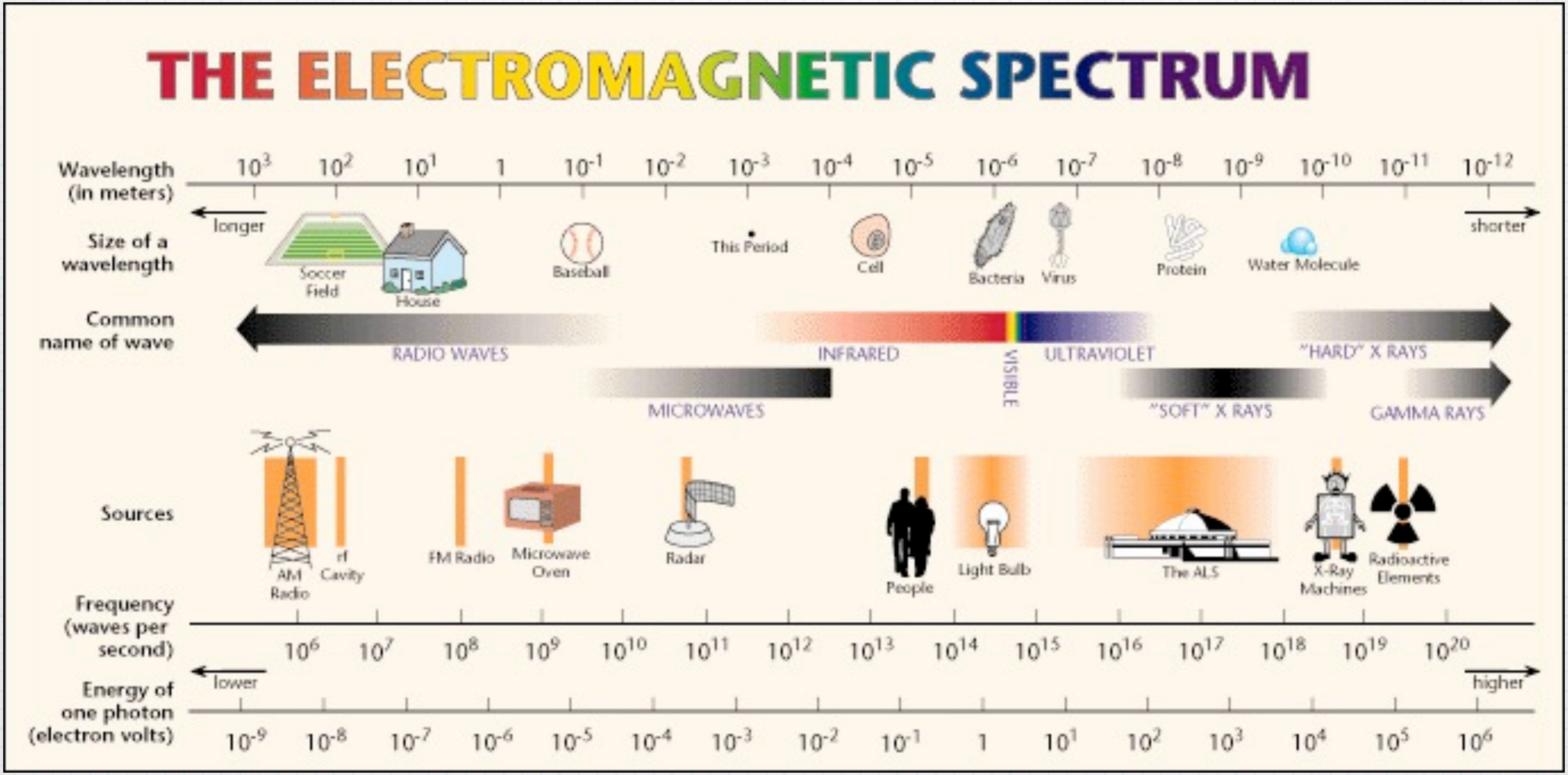
* A light wave consists of energy in the form of electric and magnetic fields and does not need a medium made of matter to travel
* The frequency, ν (the greek letter nu) of the wave is the number of cycles of the waveform that occur in each second of time
* Frequency, wavelength and the speed of light are all very nicely related: $c = \nu \lambda$



* The longer the wavelength, the less energy light has
* Conversely, the shorter the wavelength, the more energy light has
* And because of $\nu = \frac{c}{\lambda}$
* Long wavelength -> short frequency
* Short wavelength -> long frequency



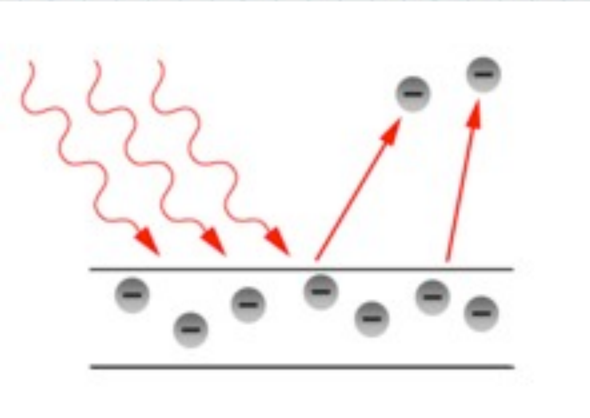
Putting all of this together



Light as a Particle

* Wait! What? Light is a wave! Isn't it?
* Experiments have shown that light, an electromagnetic wave, can also behave as a particle we call a photon
* This is referred to the dual nature of light, aka the wave-particle duality
* A photon, because it travels at the speed of light, has no mass
* A photon is not affected by time!

More on that later

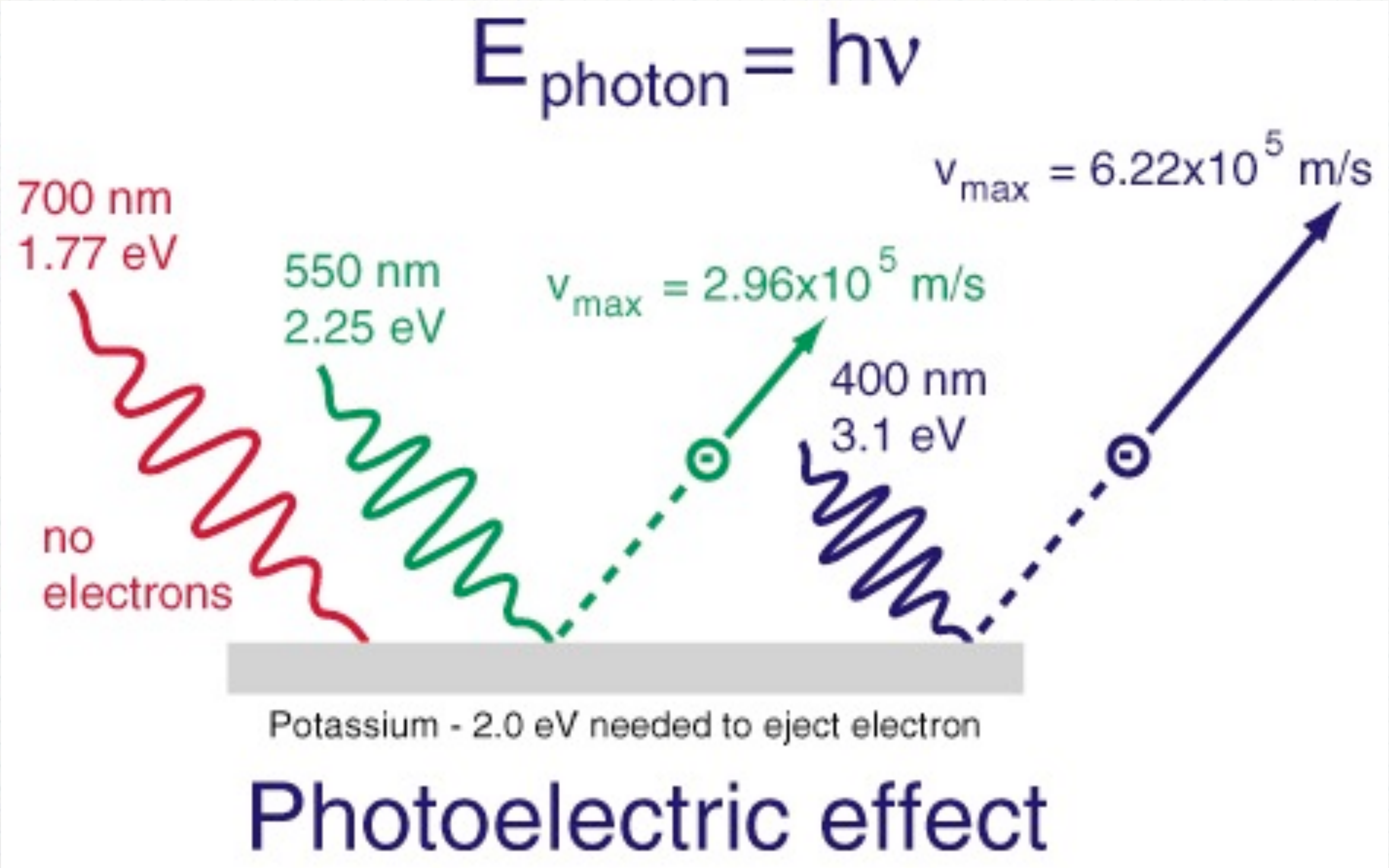


Photoelectric effect

Energy as a Discrete Quantity

* Energy **quanta** (discrete packets) were discovered by Planck (1900)
* **Einstein proved that** light was made of energy quanta (1905)
* $E = h\nu$, where ν is the frequency of light
* **h = Planck's Constant**: one of several fundamental constants of Nature; it represents the smallest amount of energy which can exists in Nature

We know light is a particle because of the photoelectric effect. Basically, a photon with enough energy can ionize (kick an electron out of) an atom



The simplest element of "Light", then, can be thought of as

- a single photon, (a particle)
- traveling at the speed of light, c and
- characterized by
  - a wavelength λ,
  - a frequency ν all related by $c = \nu\ \lambda$
  - carrying a specific energy $E = h\,\nu$
  - and having no mass

Particle versus Wave

* Experiments show that while light has a dual nature (particle & wave) it NEVER displays both at the same time
* If an experiment is designed to show that light is a wave, then light behaves as a wave
* If an experiment is designed to show that light is a particle, then light behaves as a particle

Snapshot

* What is light?
* Light is an electromagnetic wave that also comes in individual "pieces" called photons. Each photon has a precise wavelength, frequency and energy
* Forms of light are: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays

What is Matter?

* In Astronomy, the light we see usually comes from galaxies, stars, planets, ...
* They are all made of matter
* So we need to understand the nature of matter as well

Historically...

* The Greeks thought at first that matter was made of four elements:
  * fire, water, earth, and air
* By 470 B.C. they thought that each of these "elements" eventually became indivisible as they got smaller.
* They called these: atoms
* They are not the same atoms that we know today, but the idea was good

Atomic Structure

* A **chemical element** is a substance that **cannot be decomposed or transformed by a chemical process**
* **All matter consists of these elements**
* As of 2007, there are 118 unique elements but only 92 are found in Nature (26 others have been created by us and are unstable - they exist for a fraction of a second)

Periodic Table of Chemical Elements

Element Groups (Families)		
Alkali Earth	Alkaline Earth	Transition Metals
Rare Earth	Other Metals	Metalloids
Non-Metals	Halogens	Noble Gases

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H																	He
	1																	2
2	Li	Be											B	C	N	O	F	Ne
	3	4											5	6	7	8	9	10
3	Na	Mg											Al	Si	P	S	Cl	Ar
	11	12											13	14	15	16	17	18
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
6	Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	55	56		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
7	Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
	87	88		104	105	106	107	108	109	110	111	112						
			*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
			**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
				89	90	91	92	93	94	95	96	97	98	99	100	101	102	103

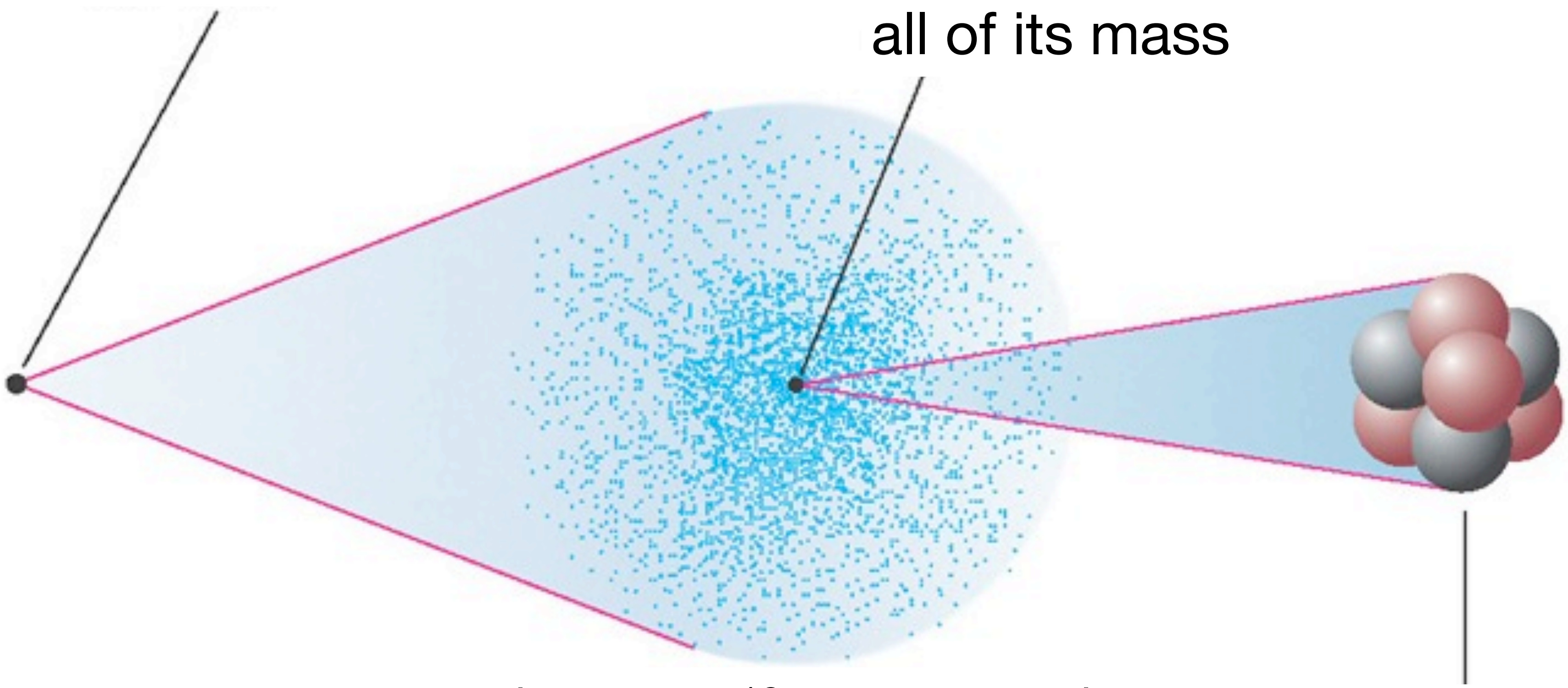
Atoms: some facts

1. The smallest particle of a chemical element is called an atom
2. An atom is made of electrons that are centered around a nucleus made of neutrons and protons
3. An atom which is stripped of some or all of its electrons is said to be ionized (charged)
4. The nucleus of an atom is about 100,000 times smaller than the atom itself
5. A single drop of water contains about 10^{22} atoms

Atom

Ten million atoms could fit end to end across this dot (made by a pencil on paper)

The nucleus is nearly 100,000 times smaller than the atom but contains nearly all of its mass

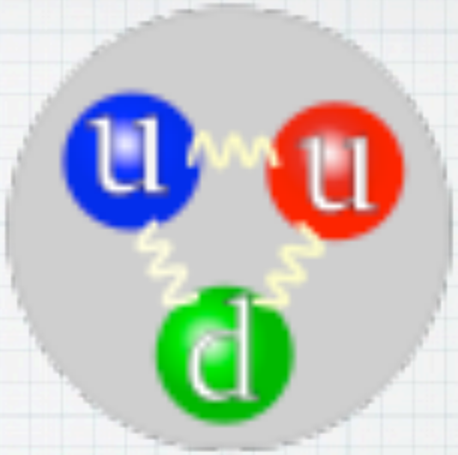


|----- 10^{-10} meter -----|

Atom: Electrons are "smeared out" in a probability cloud around the nucleus

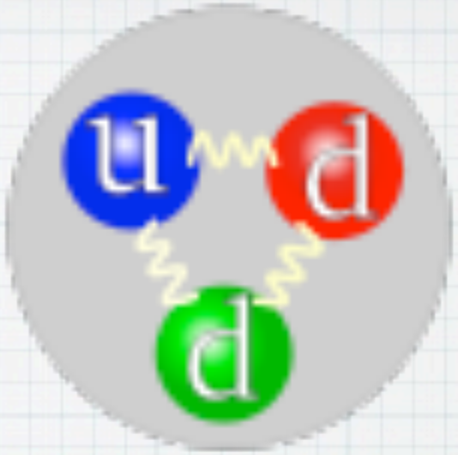
Nucleus: Contains positively charged protons (red) and neutral neutrons (gray)

A Proton



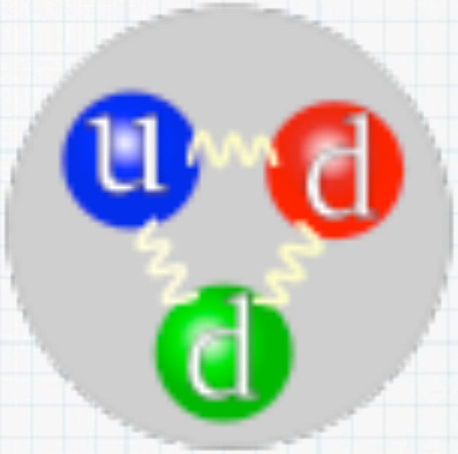
* Made of 3 quarks (elemental particles)
  * 2 "up" quarks and 1 "down" quark
* and held together by 3 gluons (elemental particles) also called the "color force" (which is related to the "strong nuclear force") Gluons have zero mass and zero charge (like photons)
* Has a basic electric charge of +1 (in atomic units) [+2/3 +2/3 -1/3 = 1]

A Neutron

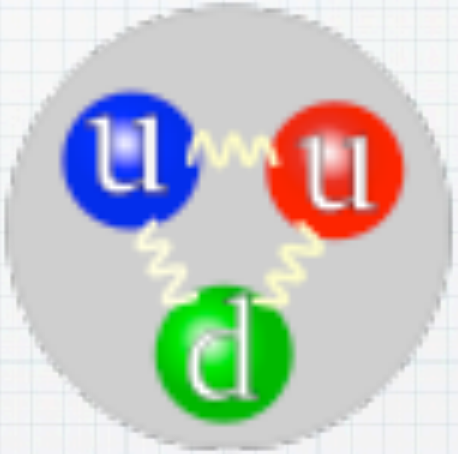


* Made of 3 quarks
  * 1 "up" quark and 2 "down" quarks
* and held together by 3 gluons (elemental particles)
* Has no electric charge [+2/3 -1/3 -1/3 = 0]
* Is unstable when not located in an atom (15-minute mean lifetime)

A Neutron



A Proton



* Far from being elemental particles, both a neutron and a proton "house" 6 particles each: 3 quarks (with mass) and 3 gluons (massless)

An Electron

* Elemental particle
* Has a basic electric charge of -1 (in atomic units)
* Its mass is over one thousand time smaller than a proton
* When in an atom, electrons are responsible for chemical bondings with other atoms
* The electromagnetic force (photons) binds electrons to the nucleus of an atom

More Atomic Facts

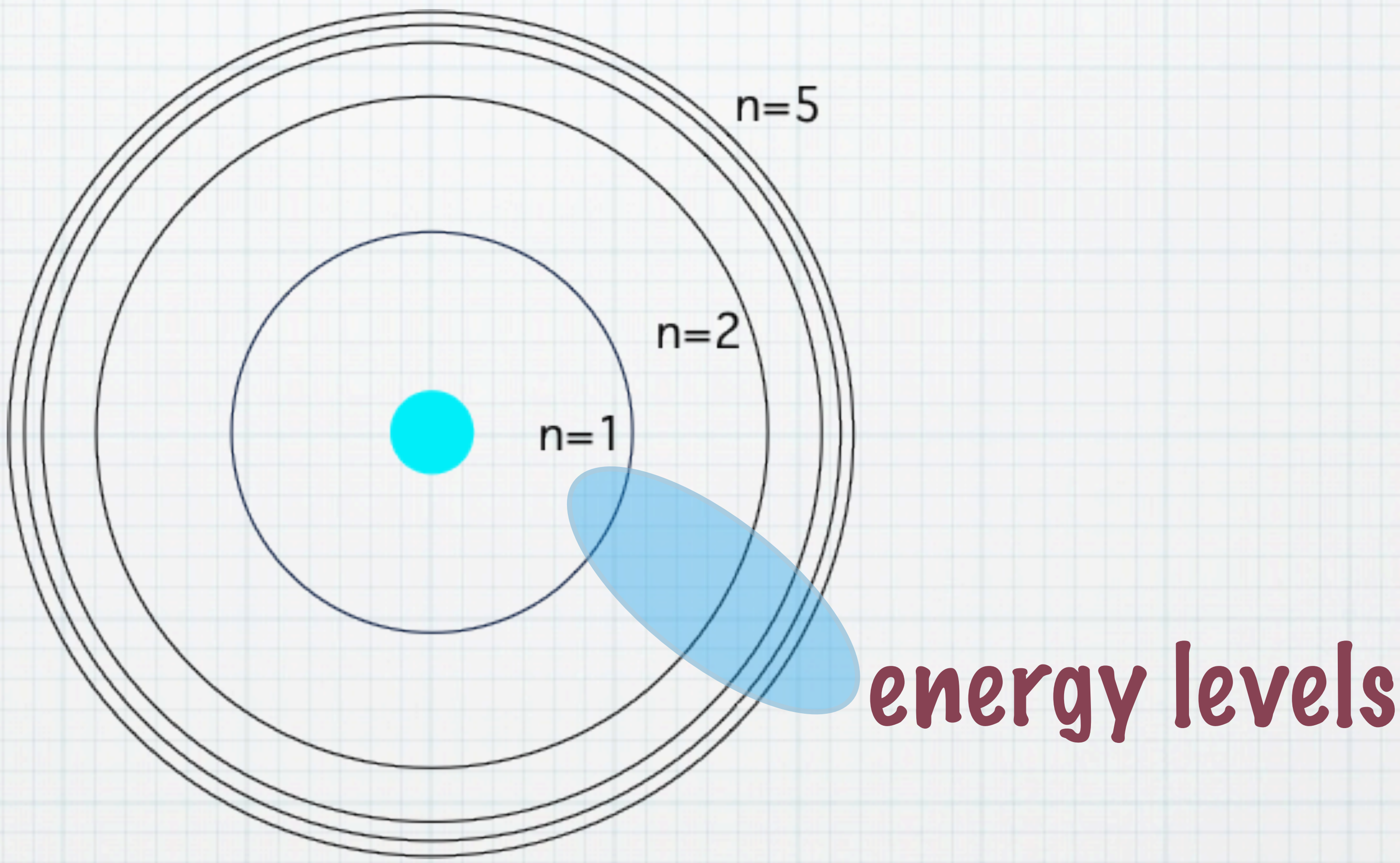
* A proton and a neutron have almost the same mass with the neutron just a bit heavier
* A neutron can also be thought of a proton which has absorbed an electron
  * this explains why
    1. a neutron is heavier than a proton
    2. a neutron has 0 charge [+1 + (-1) = 0]

More Atomic Facts...

* Ordinary atoms have a 0 electric charge: (electrically neutral)
  - ➡ They have the same number of electrons than they have of protons
* Electrons orbit the nucleus of an atom in a "probability cloud" made of discrete energy levels

Ionization levels of an atom of hydrogen

An electron can be found around a proton only at specific energy levels



The higher the level, the more energy the electron has

Atomic Properties

* **Atomic Number:** the number of protons in the nucleus
  - ➡ This dictate the position of an atom in the periodic table
* **Atomic Mass Number:** the number of protons and neutrons in a nucleus
* The **strong force** is responsible for confining protons (and neutrons) together in the nucleus of an atom

atomic number = number of protons
atomic mass number = number of protons + neutrons

Hydrogen (^{1}H)

atomic number = 1
atomic mass number = 1
number of electrons = 1

Helium (^{4}He)

atomic number = 2
atomic mass number = 4
number of electrons = 2

Carbon (^{12}C)

atomic number = 6
atomic mass number = 12
number of electrons = 6

The number of electrons in a neutral atom
equals its atomic number (number of protons)

Atomic Properties...

* The number of neutrons in a specific element can vary:
  - ➡ different versions of an atom are called isotopes
* Carbon, for example has 6 protons and 6 neutrons aka C-12 or ^{12}C
* Other isotopes of Carbon exist: ^{13}C and ^{14}C

Isotopes

Different isotopes of a given element contain the same number of protons but different numbers of neutrons

Isotopes of Carbon

carbon-12

^{12}C

(6 protons
+ 6 neutrons)

carbon-13

^{13}C

(6 protons
+ 7 neutrons)

carbon-14

^{14}C

(6 protons
+ 8 neutrons)

Periodic Table of Chemical Elements

Element Groups (Families)

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Rare Earth	Other Metals	Metalloids
Non-Metals	Halogens	Noble Gases

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H																	He
	1																	2
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	3	4											5	6	7	8	9	10
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	11	12											13	14	15	16	17	18
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
6	Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	55	56		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
7	Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
	87	88		104	105	106	107	108	109	110	111	112						
			*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
			**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
				89	90	91	92	93	94	95	96	97	98	99	100	101	102	103

# of protons →

↖ layers of electrons

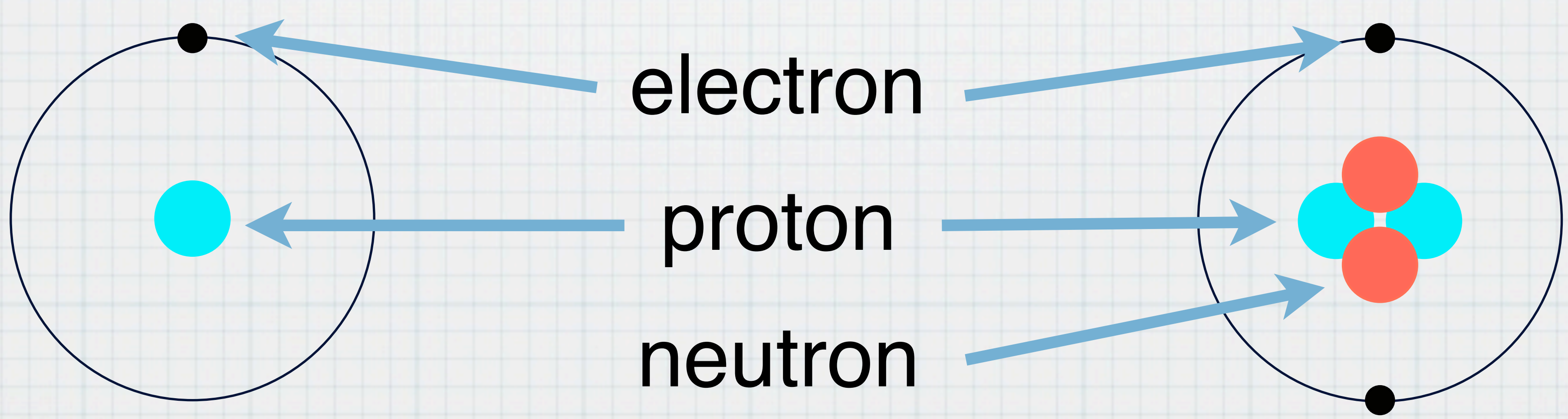
So far...

* 2 Forces we talked in this lecture
  1. color, strong (within the atomic nucleus)
     * color: glues quarks together
     * strong: glues protons together (and neutrons too)
  2. electromagnetic: binds electrons to the charged atomic nucleus

Checking our Understanding

Hydrogen atom
1 proton
0 neutron
1 electron
^{1}H
atomic number=1
atomic mass number=1

Helium atom
2 protons
2 neutrons
2 electrons
^{4}He
atomic number=2
atomic mass number=4



Back to Matter

* Atoms group together to form molecules
* There are 6 known forms of matter
    * 3 are very common: gas, liquid, solid
    * 1 is a special form of a gas: plasma
    * 2 are very very rare: the Bose-Einstein condensate (bosonic condensate - very cold), and the fermionic condensate (quark-gluon soup) - very hot

* Gases, liquids and solids are made of molecules that are made of atoms that are made of protons, neutrons and electrons, and protons and neutrons are made of quarks
* Protons, neutrons and electrons can be found bound in atoms and they can be found by themselves: they are then called "free"
* And protons and neutrons and electrons are particles ... yes?

Wave-Particle Duality

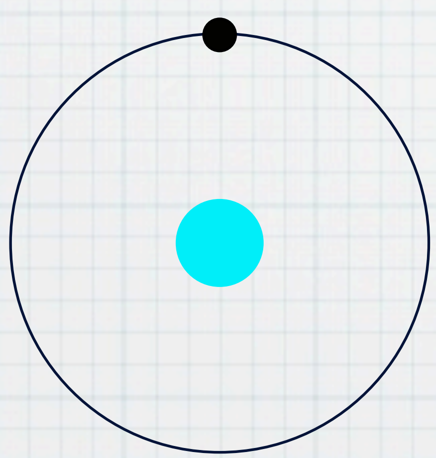
* Just like photons have an "identity crisis" (am they a particle or a wave?)
* Neutrons, protons and electrons exhibit the same wave-particle duality as photons do!
* But you need to look at **atomic scales** to detect that
* And that is the realm of **Quantum Mechanics**

Quantum Mechanics

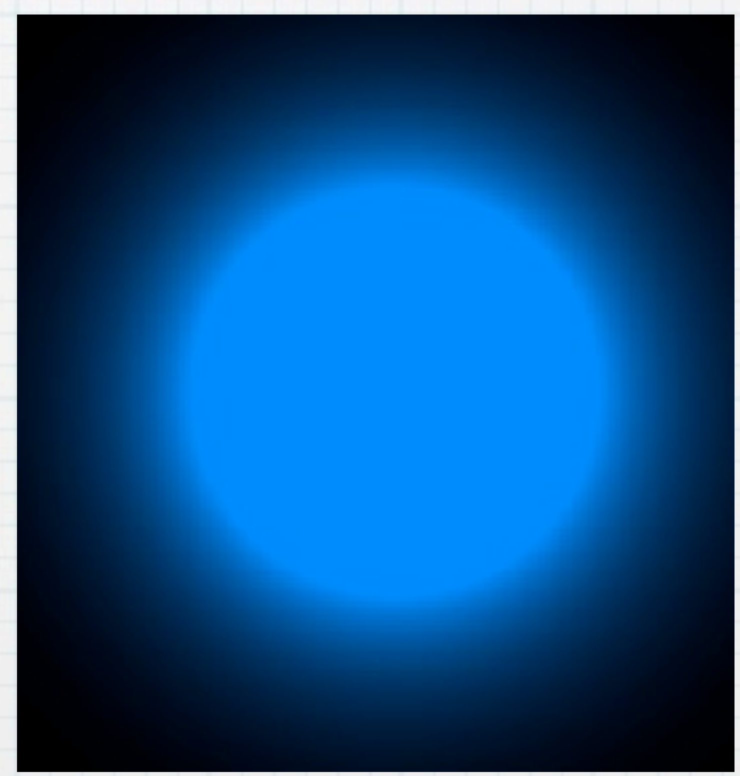
* The location of a particle is expressed as a probability distribution function
* We can't tell what speed a proton, neutron or electron has and know where it is at at the same time
* Many more strange rules apply in QM but most are beyond the scope of this class but we'll see a bit more when we study how stars work

The Hydrogen Atom

Instead of a nicely defined graph, an hydrogen atom is better represented as a fuzzy region: **a probability cloud**

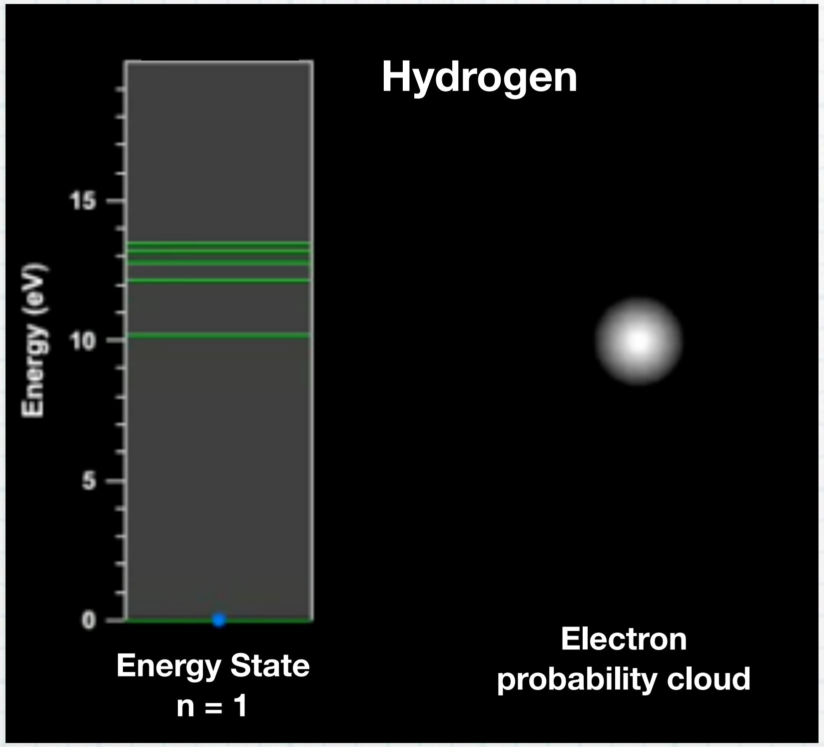


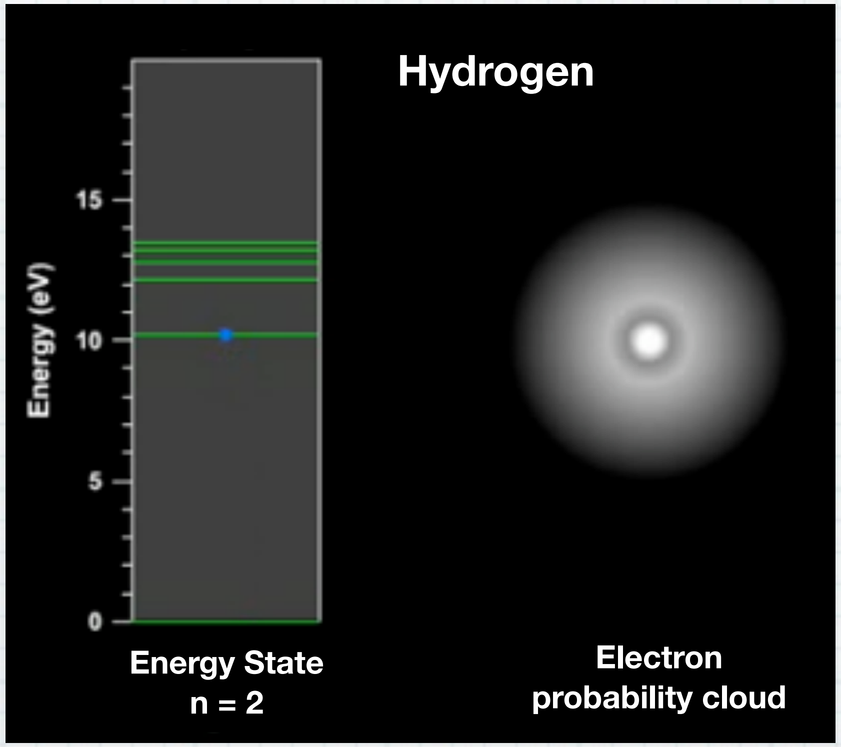
old model

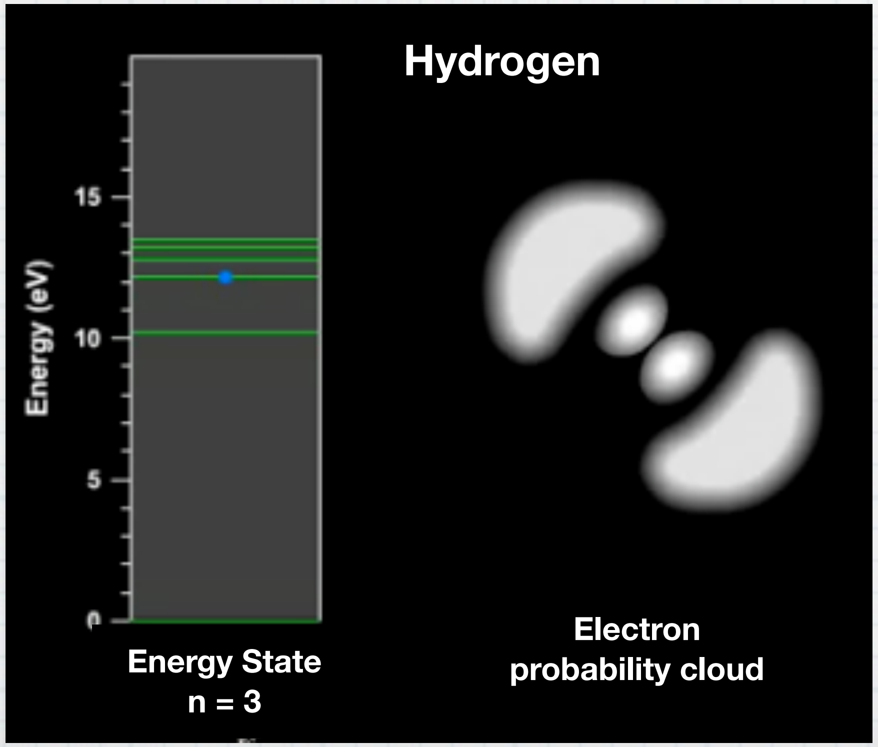


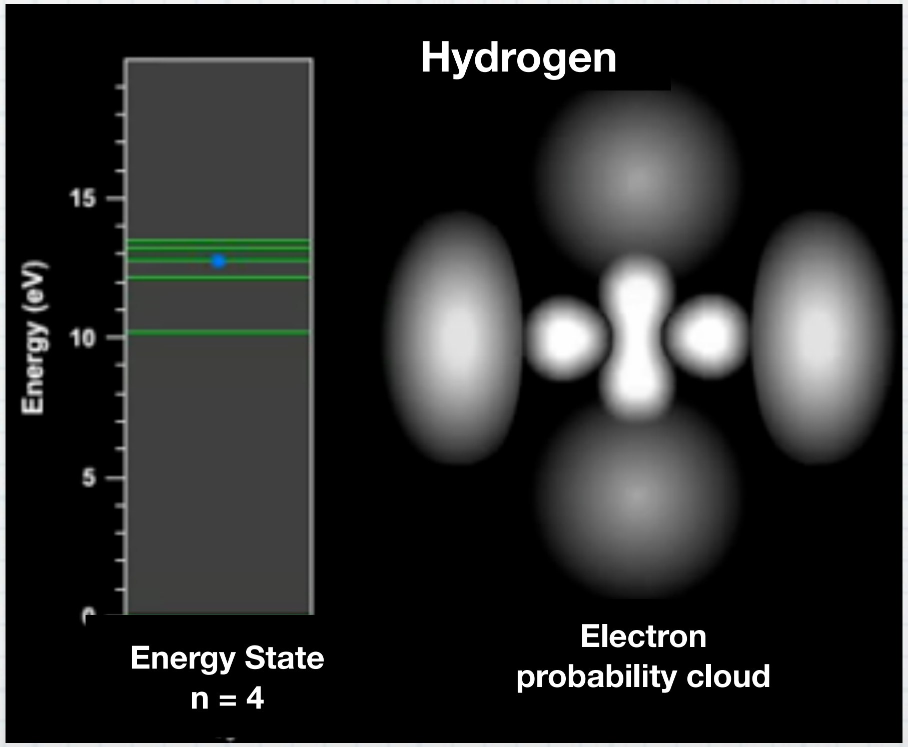
new model

The electronic probability cloud: the electron, which is orbiting the proton (nucleus), is most likely to be found in it. The electron's location is a probability function









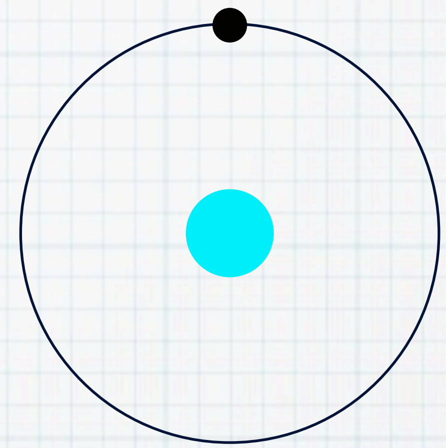
Chemistry 0.001

(a little bit of chemistry)

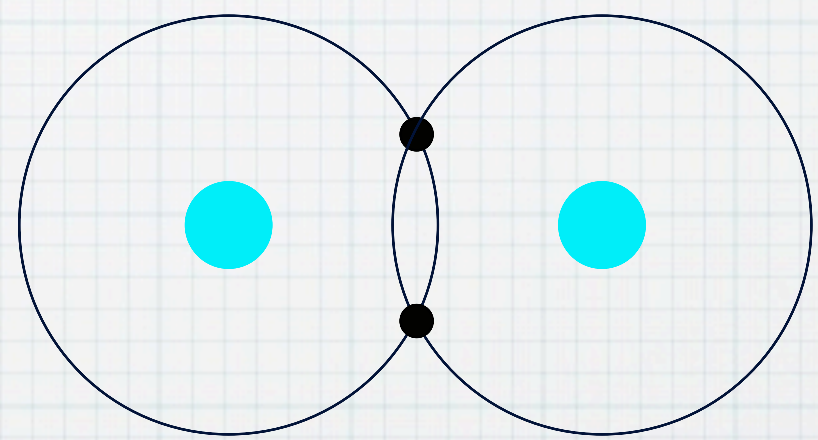
* Molecules form because some atoms are attracted to other atoms
* The attraction is not the electromagnetic force (since electrons repel others)
* The attraction is due to the sharing of electrons (called covalent bonding)
* Ionic bonding and metallic bonding are two other types of bonding (to be ignored in this lecture)

Back to Hydrogen

Hydrogen atom:

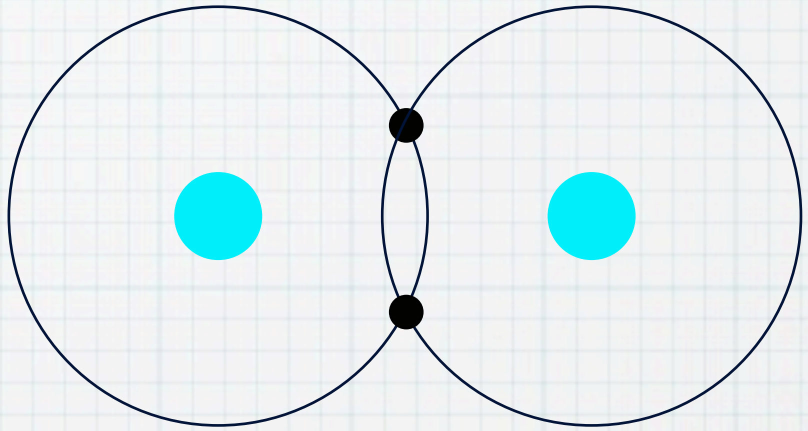


Hydrogen molecule:



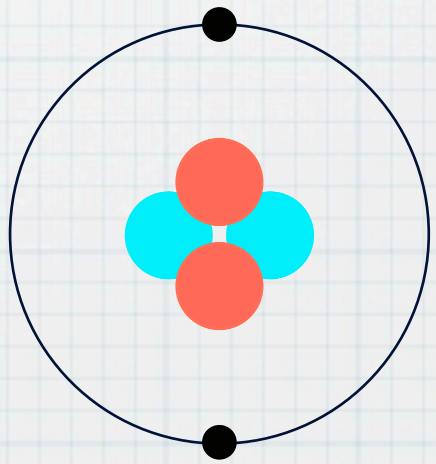
A hydrogen molecule forms because the first electron shell is “complete” (more stable) with two electrons

H-H and He



Two electrons in
the first shell!
Happy Joy Joy!

With two electrons in the first shell, a hydrogen molecule and an atom of helium are chemically stable (non-reactive)

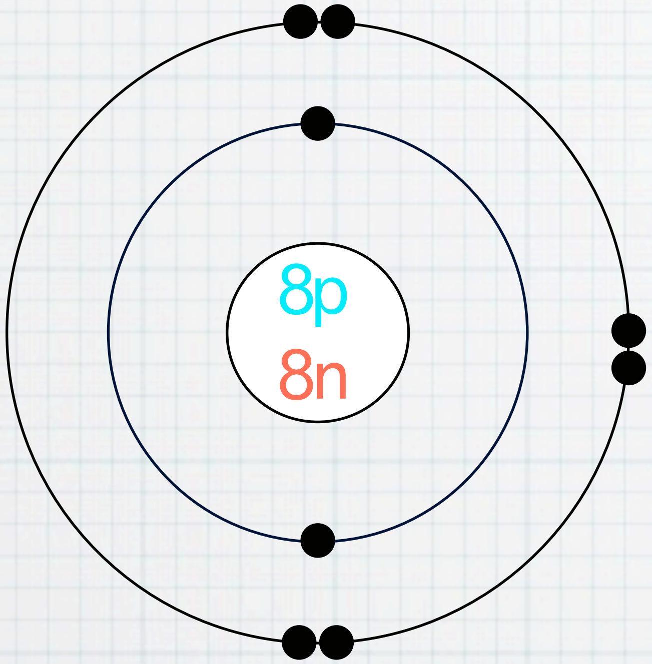


Water or H_2O

* Oxygen has 8 protons, 8 neutrons and 8 electrons.
* Oxygen has 2 electron shells
  * first layer is complete with 2 electrons
  * second layer has 6 electrons
  * but second layer needs 8 electrons to be complete
* Hydrogen has 1 proton and 1 electron

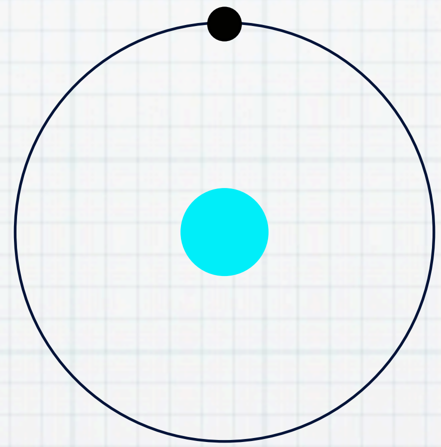
Water or H_2O

one of these



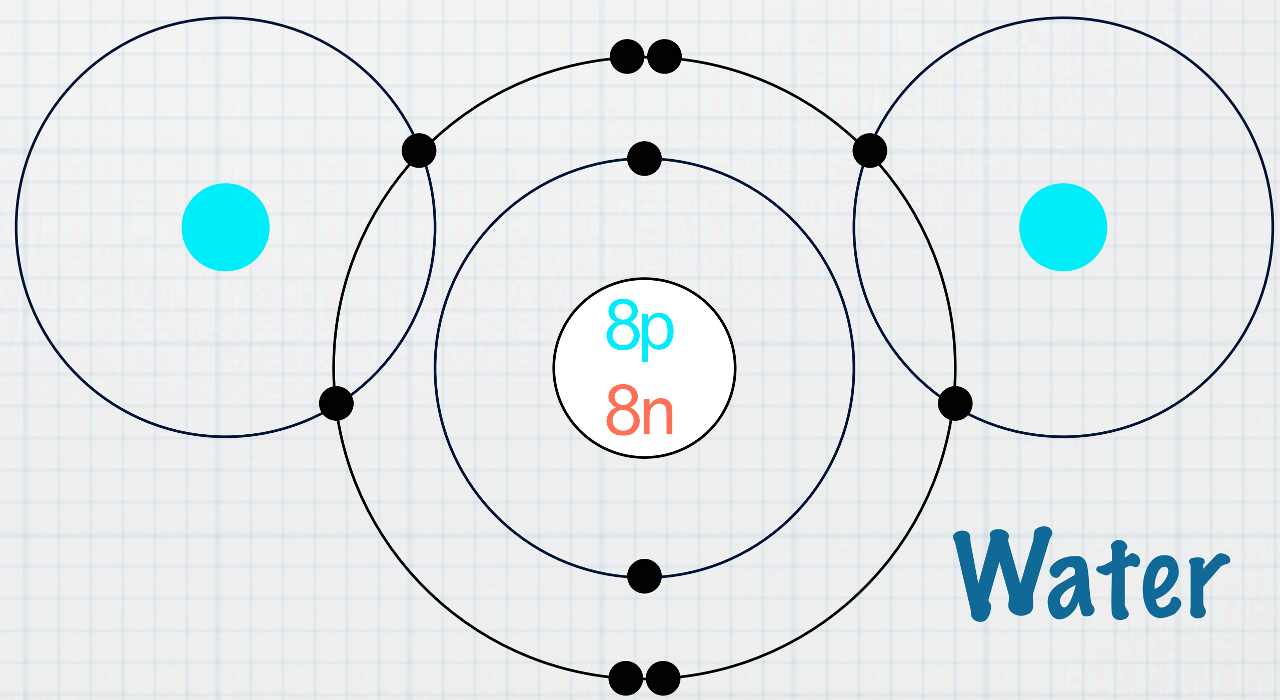
Oxygen

plus two of these



Hydrogen

makes water



Water

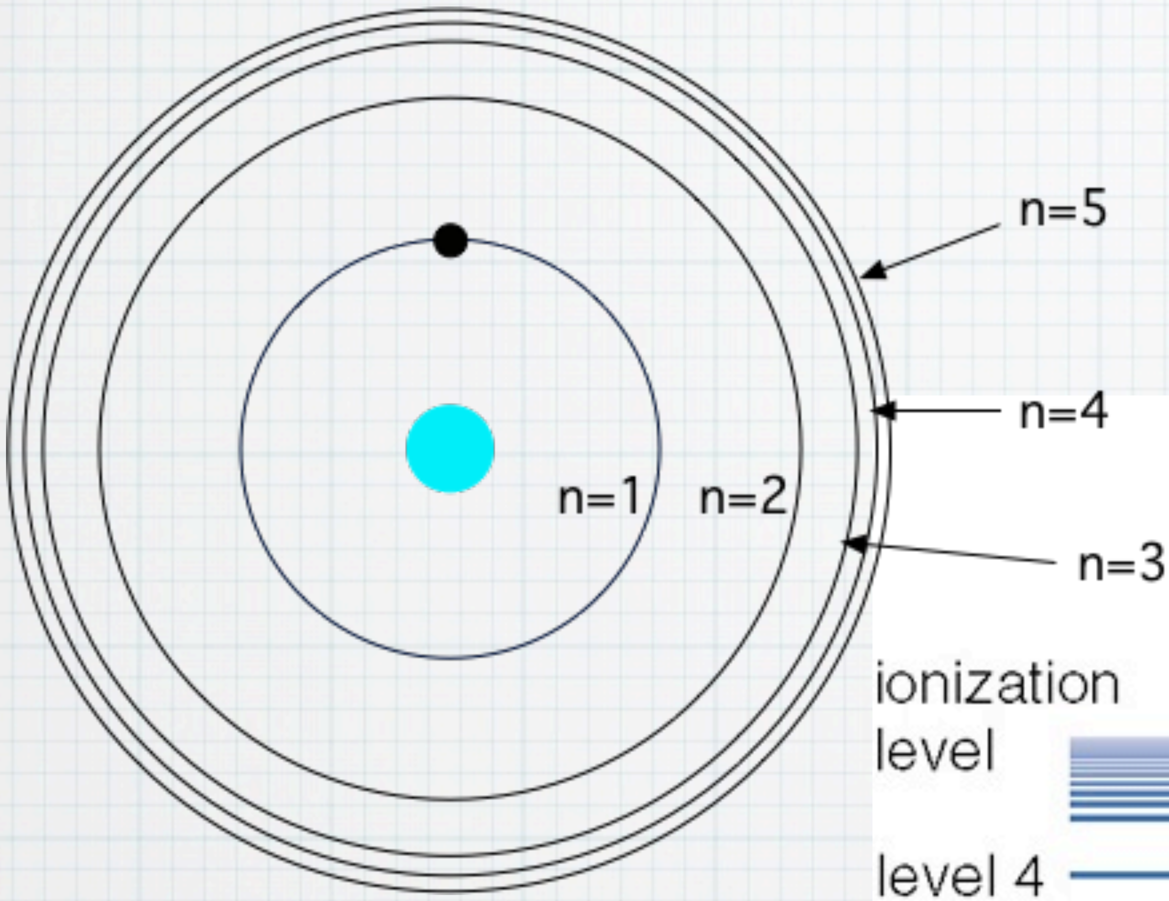
Summary of Chemistry

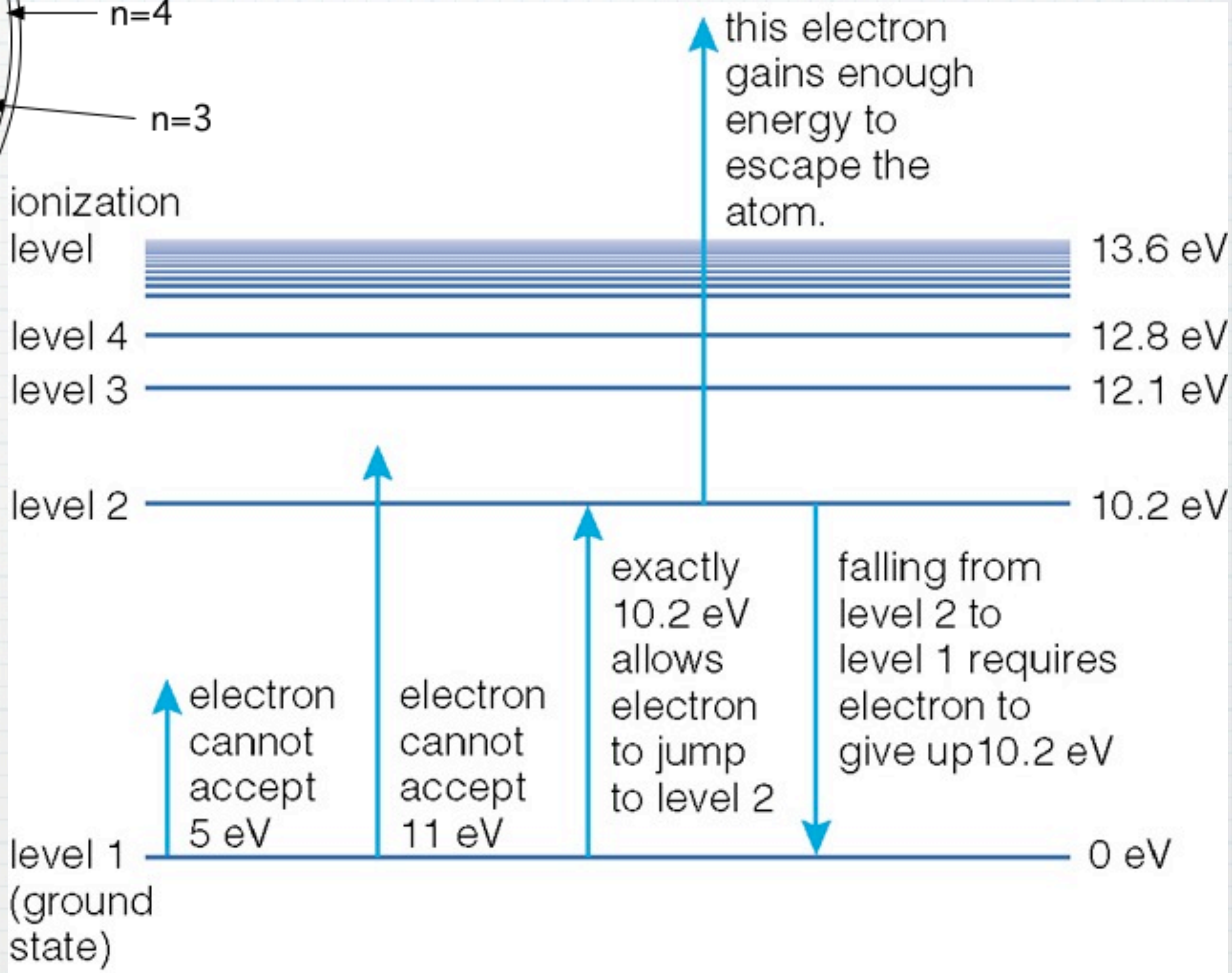
* What to remember
  * Molecules form because some atoms are attracted to others
  * These atoms will co-share electrons via covalent bonding [ionic and metallic bonding too]
  * They can only co-share so many electrons, the rules are dictated by the number of electron shells these atoms have

Atoms can get excited!

* Atoms & molecules have energy levels
* These levels are dictated by the electrons surrounding that atom or molecule
* These levels are quantized (discrete)
* The first level is called the ground state (n=1)
* An atom is in its ground state when all of its electrons are in the lowest possible energy levels

The electronic cloud orbits the nucleus at higher positions when excited





Energies of Matter

* Matter has these different kind of molecular/atomic energies
  * **kinetic** (it is moving)
  * **rotational** (it is spinning)
  * **electronic** (electrons in orbiting shells)
  * **vibrational** (it vibrates/oscillates)
  * but for kinetic, the other 3 are quantized

Matter-Light Interaction

Finally, we are now ready to discuss what happens when light and matter interact!

* All interactions between light and matter are described as a series of

  1. absorption, and
  2. emission of photons

This info is important for when we'll talk about "dark matter"

* Transmission and reflection/scattering are variations/combinations of these two effects

Question

Why is this rose red?

A) the rose absorbs red light

B) the rose transmits red light

C) the rose emits red light

D) the rose reflects red light

Question

Why is this rose red?

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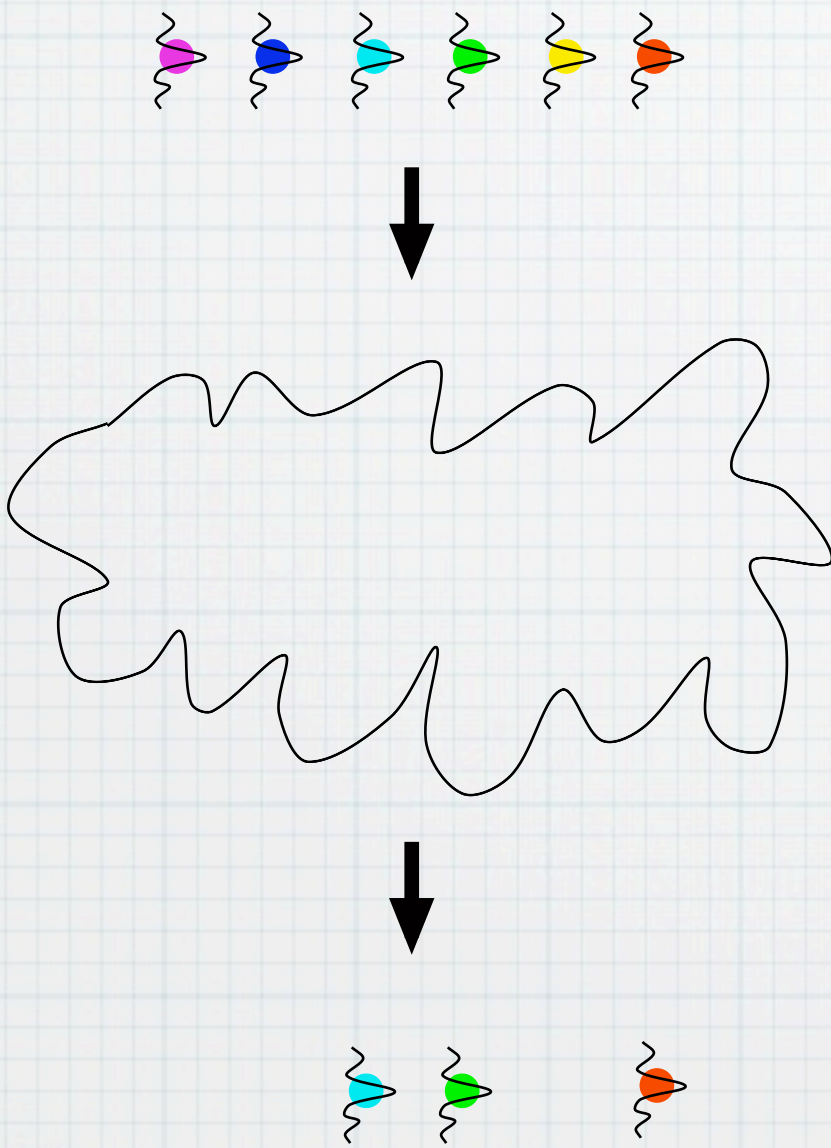
Absorption & Transmission

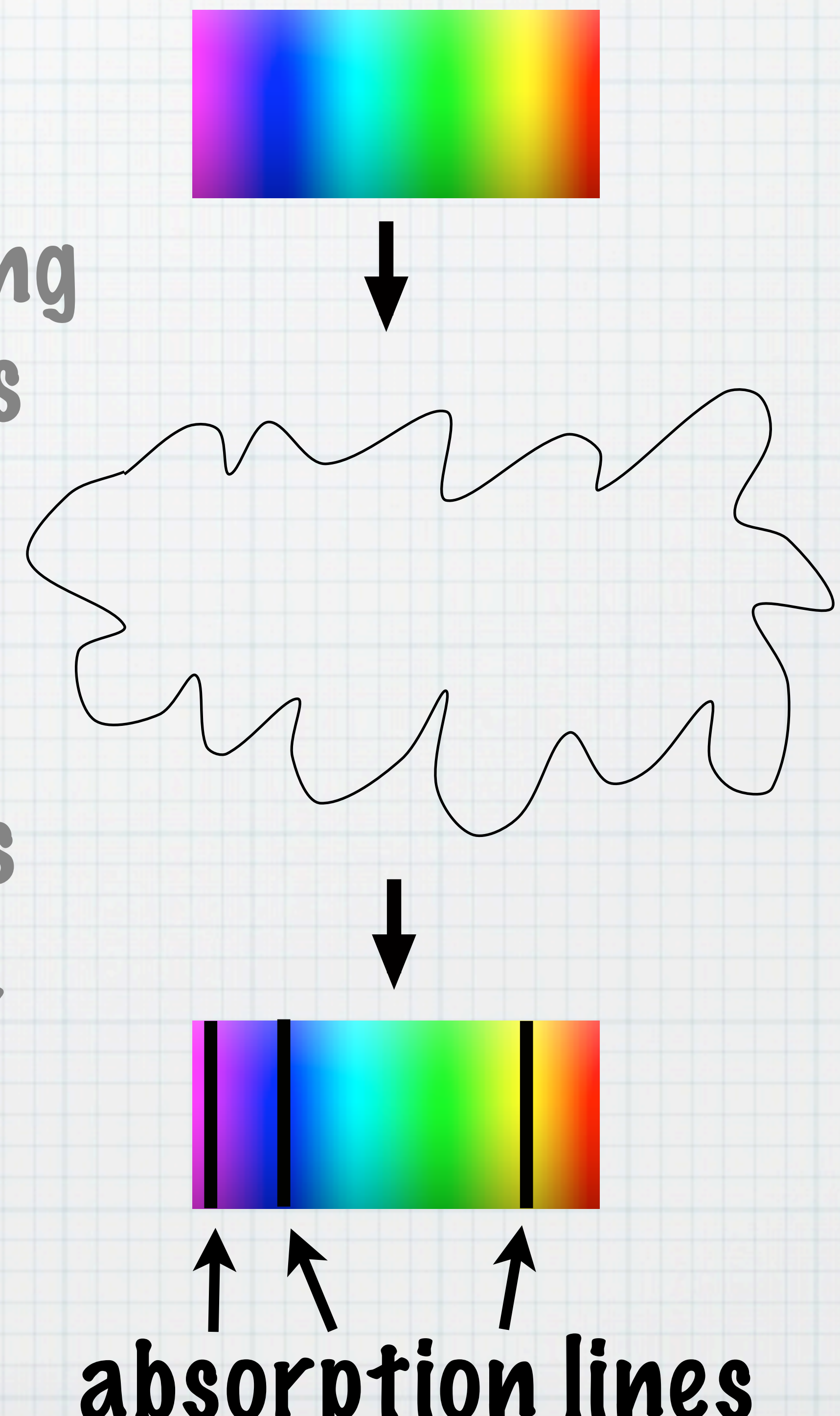
* When a photon hits an atom and it has the right amount of energy, one electron of that atom can jump to a higher orbit
    - ➡ The photon gets absorbed
* If the photon's energy does not precisely match the energy difference of the atom's electronic shells, it passes through

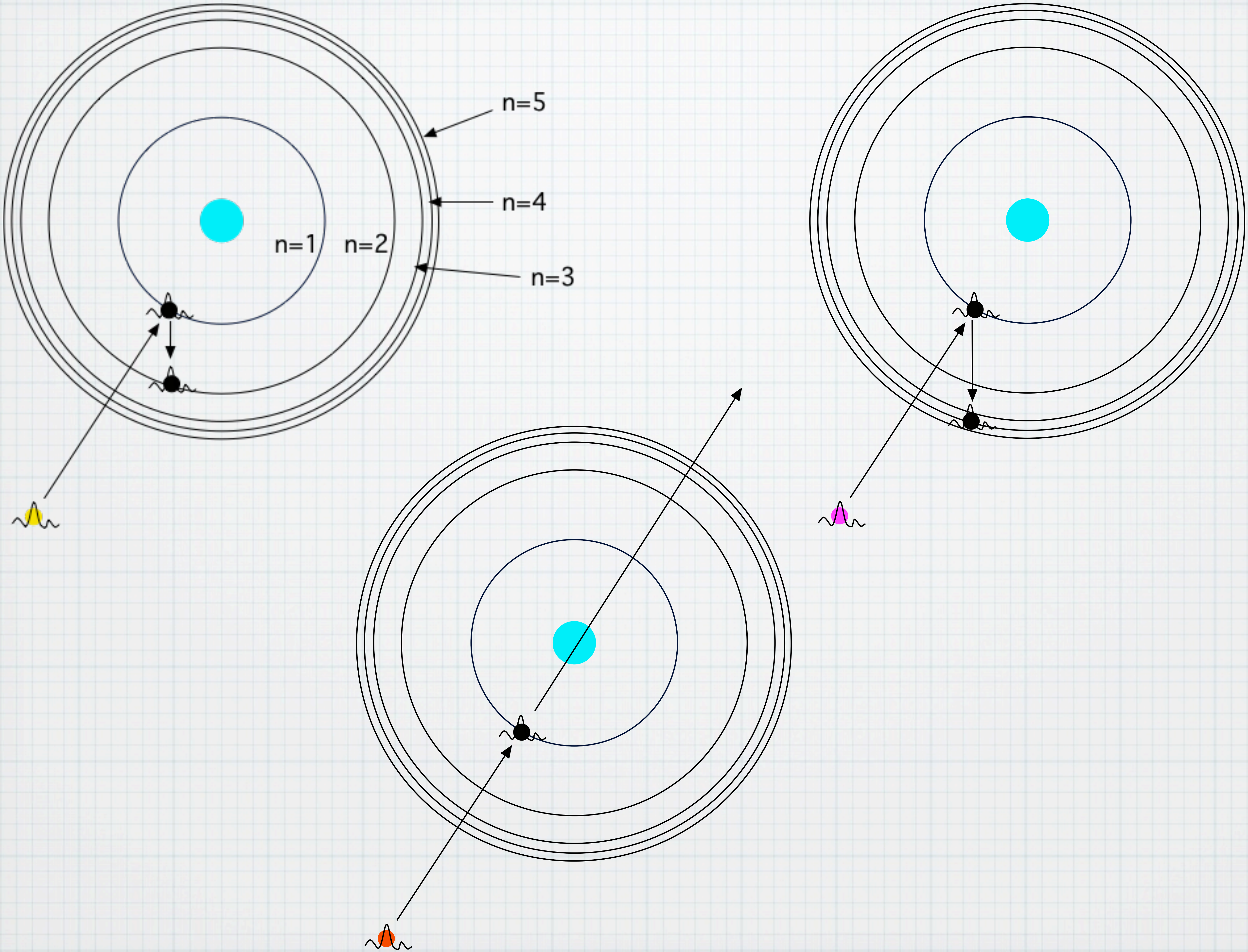
Absorption Line Spectrum



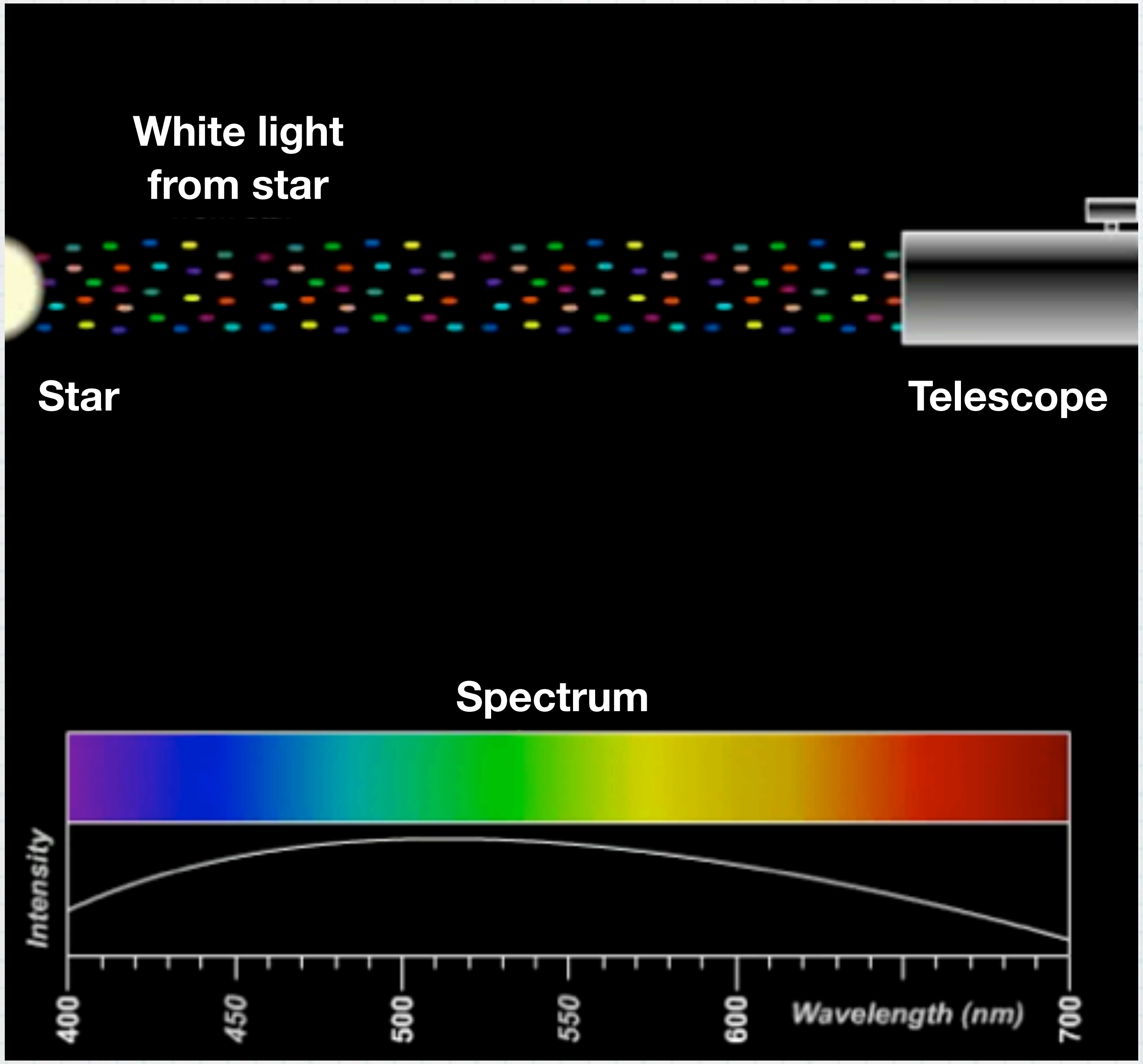
Photons passing through a gas cloud

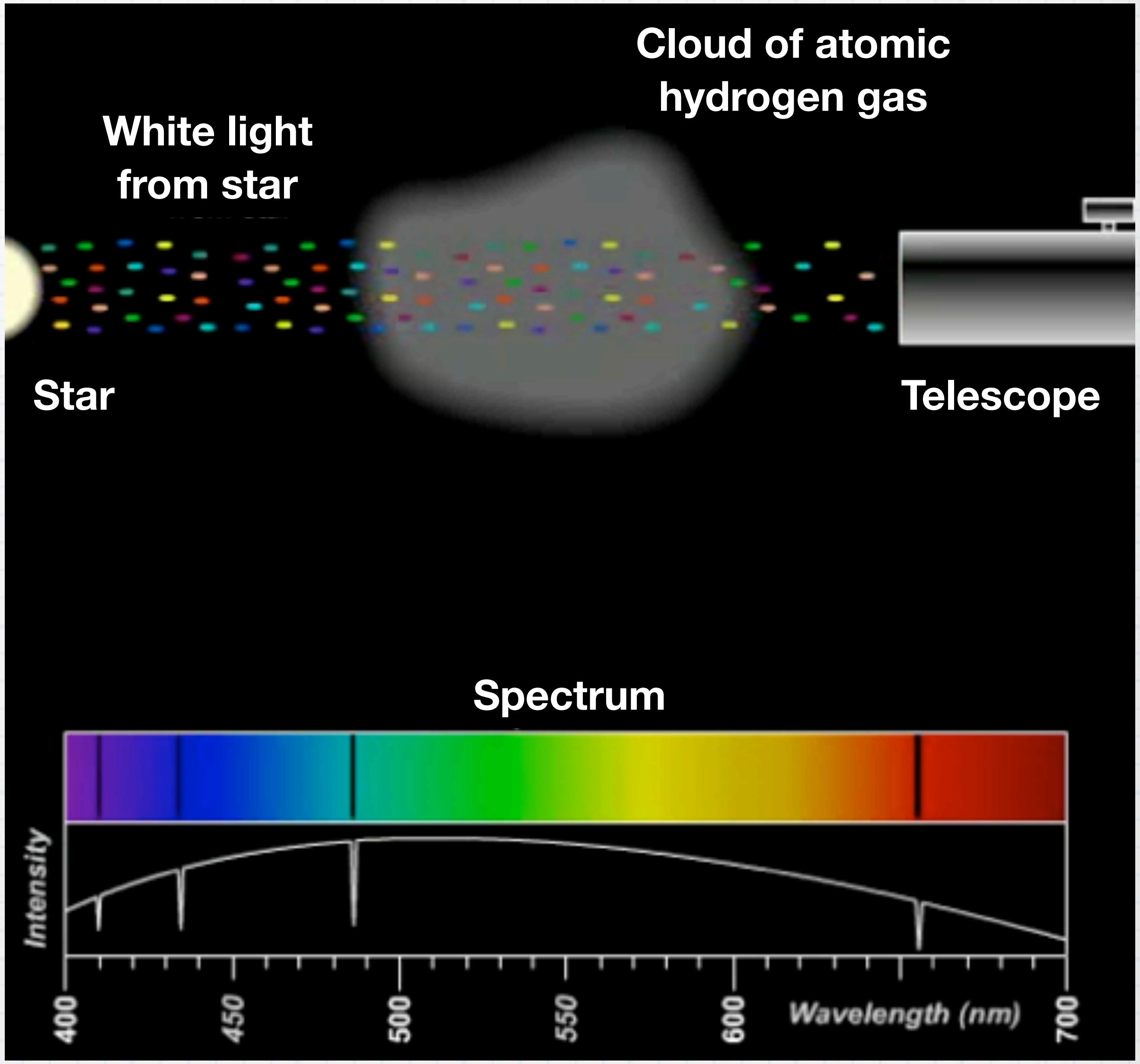
Some photons get absorbed, others pass through




n=5
n=4
n=1
n=2
n=3

Absorption Lines Spectrum





Absorption Examples

* A hand placed near an incandescent light will get warm due to its absorption of the infra-red light
* A X-Ray picture does not show muscles as they are “transparent” for these high-energy photons but bones do absorb them
* A car radio antenna will absorb radio waves (low-energy photons)

More on Absorption and Transmission

* Matter is transparent for some photons and yet absorbs others
* It is not all based on high-energy versus low-energy photons
* To be absorbed, a photon's energy must match the energy that is required for an electron to jump from one orbit to a higher one of the atom/molecule it is part of

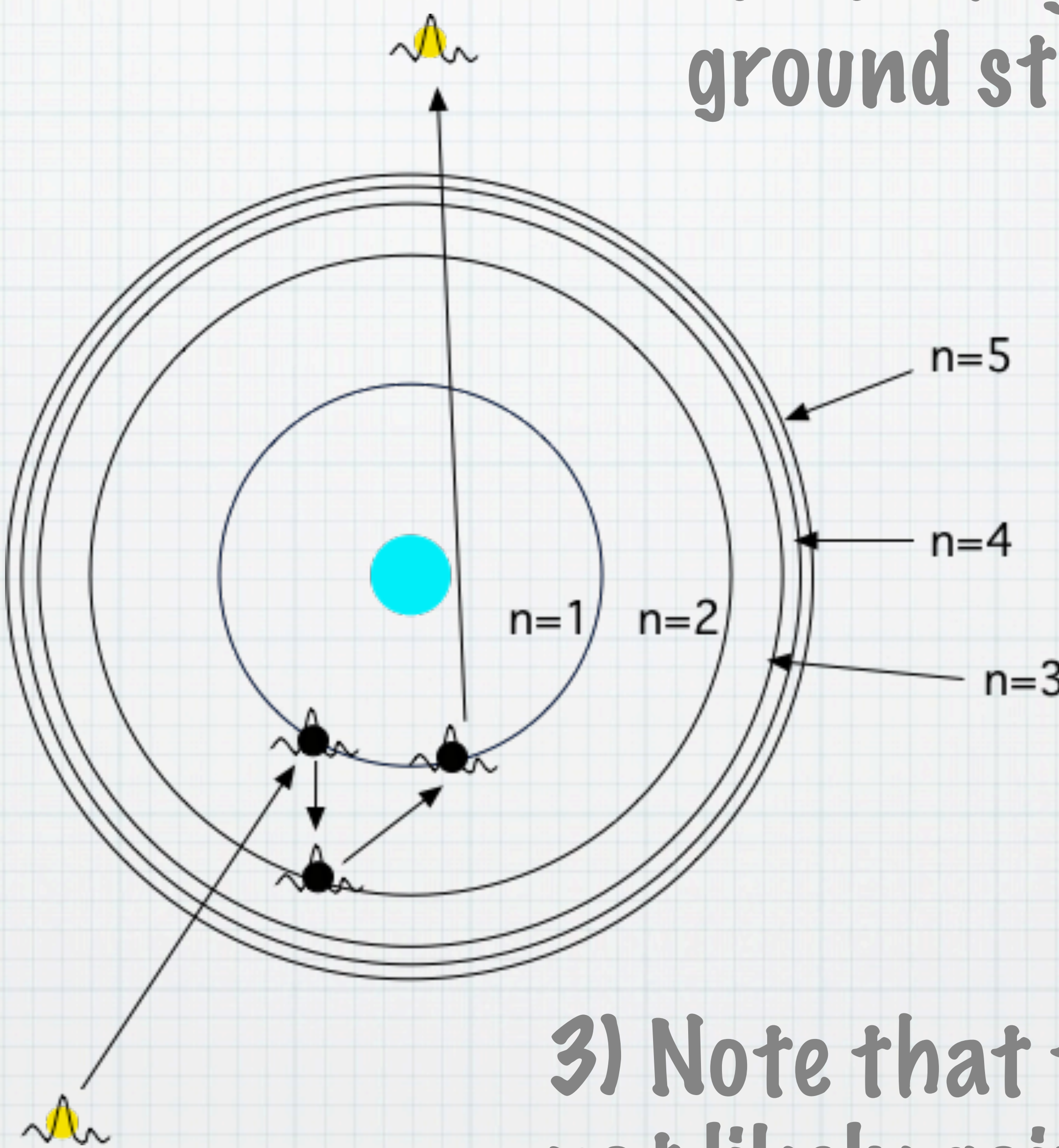
Snapshot

* What is matter?
* Ordinary matter is made of atoms, which are made of protons, neutrons and electrons
* How do light and matter interact?
* Matter can emit light, absorb light, transmit light or reflect light

Emission Line Spectrum

* An atom does not like to be excited (it wants to be at ground-state)
  - ➡ the electron jumps back to a lower orbit and emits a photon
* the photon has no guarantee to be emitted in the same direction as the original one: this is called scattering

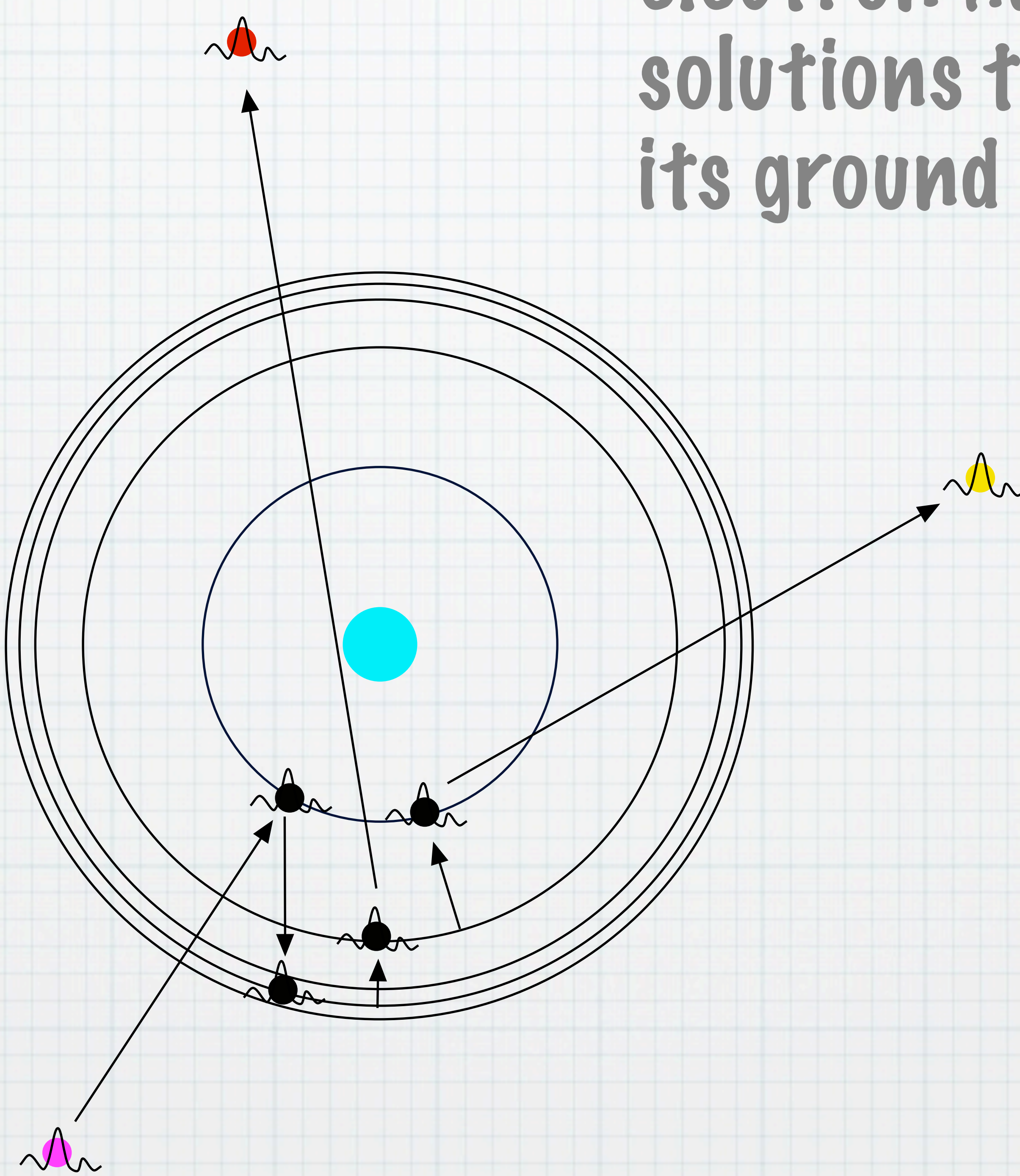
2) A photon with the exact same energy is emitted when the electron goes back to its ground state



1) A photon gets absorbed as it kicks an electron from its ground state to its second lowest orbital state

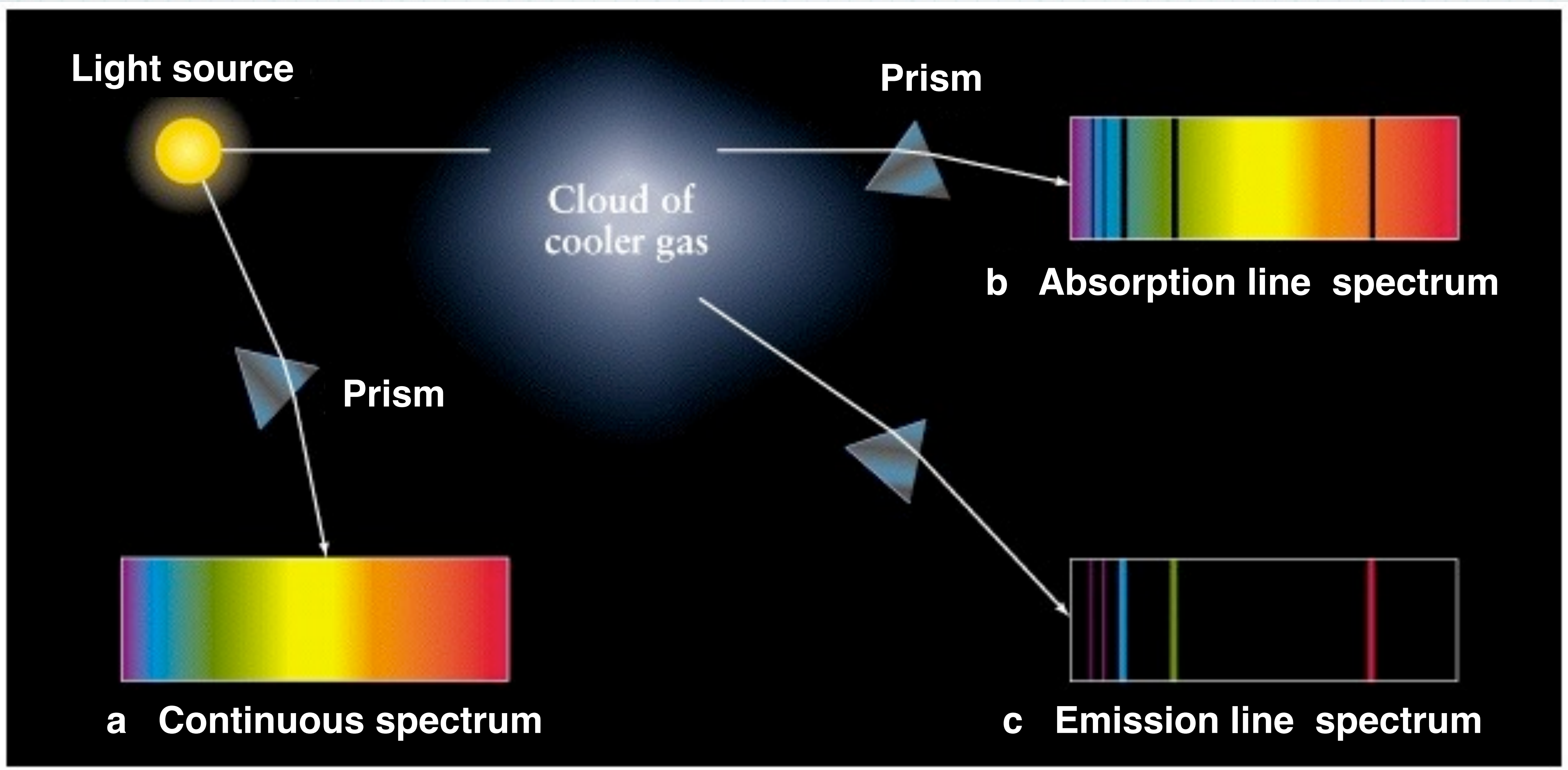
3) Note that the photon is not likely going in the same direction as the original one

2) More than one photon can get emitted as the electron has different solutions to get back to its ground state



1) A photon gets absorbed as it kicks an electron from its ground state to its fourth orbital state

Absorption & Emission Line Spectrum



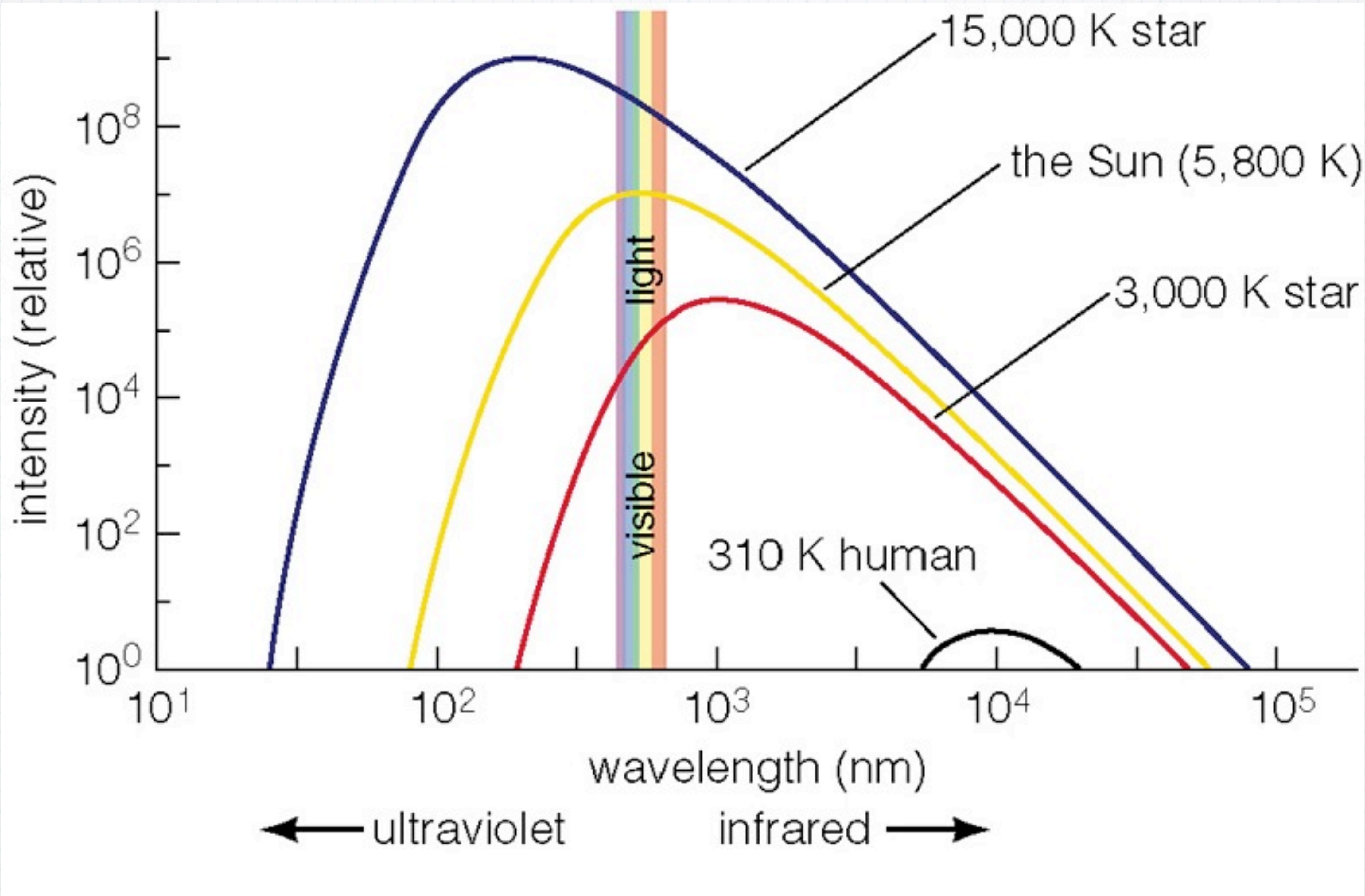
Thermal Radiation

* Thermal radiation is a continuous spectrum due to a block of matter having a temperature
* When atoms and molecules are close enough to collide with one another they emit a continuous spectrum due to their natural vibrations
* It is also called a Black Body Spectrum

Black Body Spectrum

* It is dependent only of the temperature of the matter it is in
* The hotter, the more energetic (more toward high frequencies)
* The hotter and a higher number of photons sent at all frequencies
* Anything that has a temperature emits a Black Body spectrum
* The Black Body curve's shape is well understood

Black Body Spectrum...



Putting This Together!

* An object's thermal (black body) radiation spectrum tells us its temperature
  * stars, planets, clouds of gas, people, ..., even empty space!
* An object absorption or emission spectrum tells us its chemical composition (fingerprint)
* Now you understand why we can learn a lot from capturing "light"

Question

Which is hotter?

A) a blue star

B) a red star

C) a planet that emits only infrared light

Question

Which is hotter?

A) a blue star

B) a red star

C) a planet that emits only infrared light

Question

Why don't we glow in the dark?

A) People do not emit any kind of light

B) People only emit light that is invisible to our eyes

C) People are too small to emit enough light for us to see

D) People do not contain enough radioactive material

Question

Why don't we glow in the dark?

A) People do not emit any kind of light

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C) People are too small to emit enough light for us to see

D) People do not contain enough radioactive material

Complications

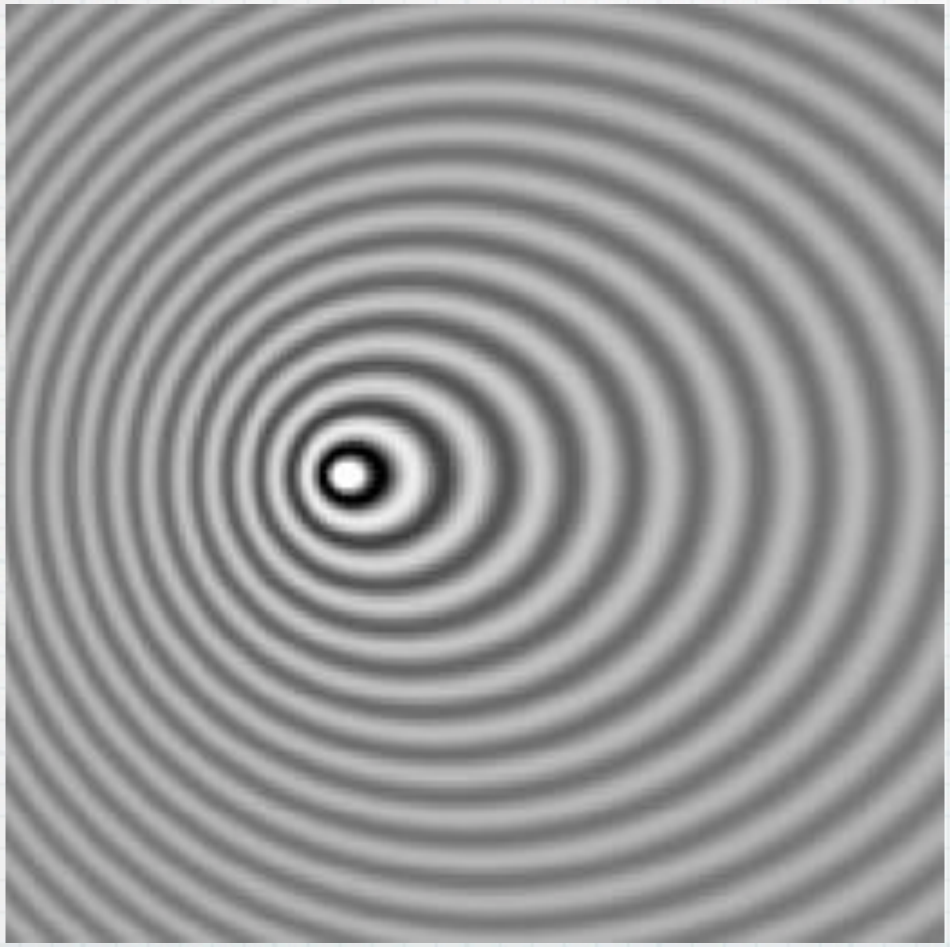
* Life, however, is more complicated
* Before we can determine precisely the temperature and chemical composition of a remote object, added complexities need to be removed, such as
  * the relative velocity between the remote object and us (Doppler Effect)
  * clouds of gas between the object and us
  * the clouds' velocities relative to us

Complications...

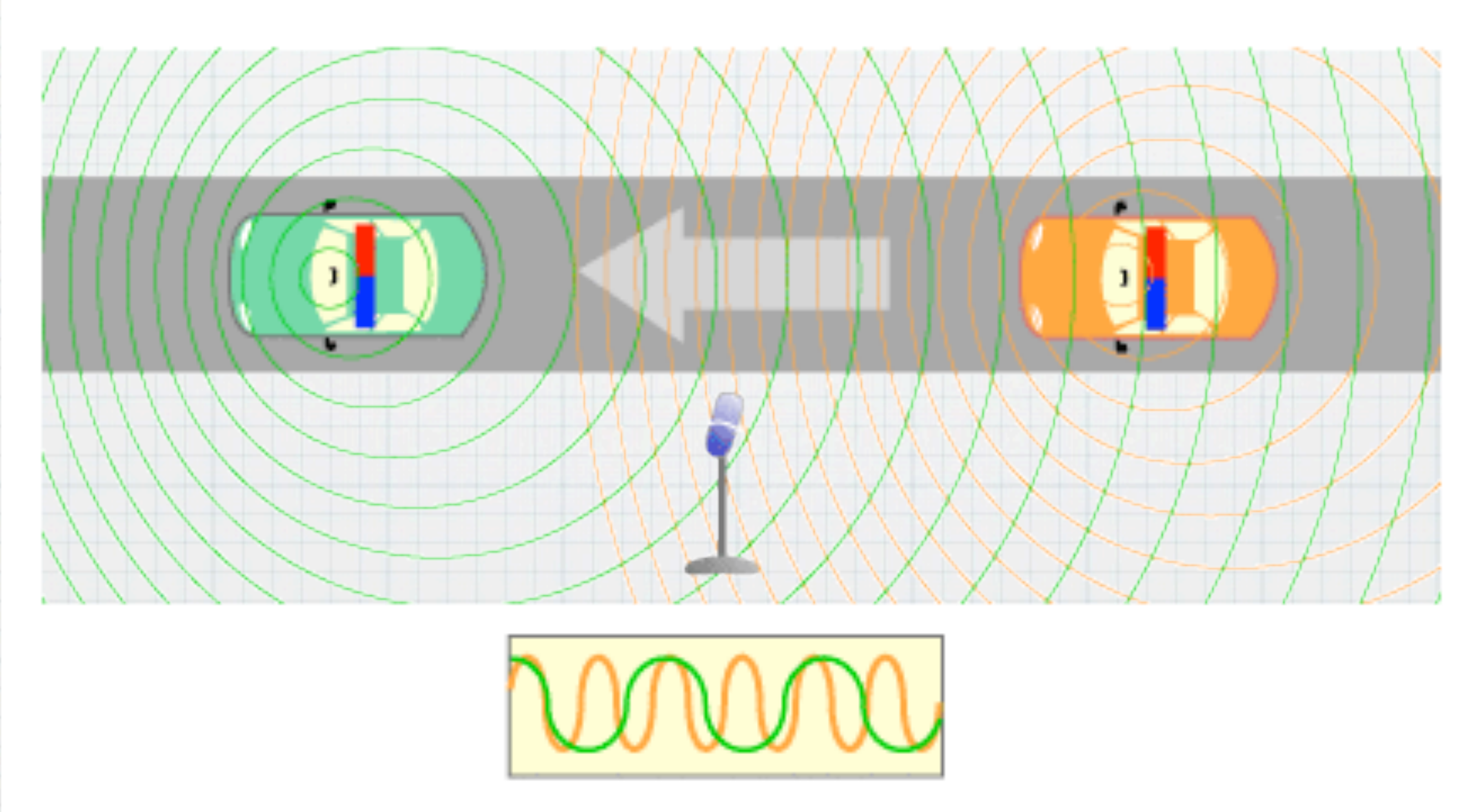
* For example, when we analyze the spectrum of a distant object we need to, at the very least, eliminate the contamination of the spectrum generated by our atmosphere
* We also need to evaluate whether or not the photons went through additional clouds of gas on the way from the object to us

Doppler Effect

* For sound
  * On Earth, if you are standing and a train is blasting its horn and moving toward you and then away from you, you know that the pitch of the horn changes (gets higher as it went toward you and lower as it went past you)



A siren is moving to the left. Note that the frequency of the note is higher on the left and lower on the right. The frequency heard depends on the speed of the object emitting the sound and your relative position to it.

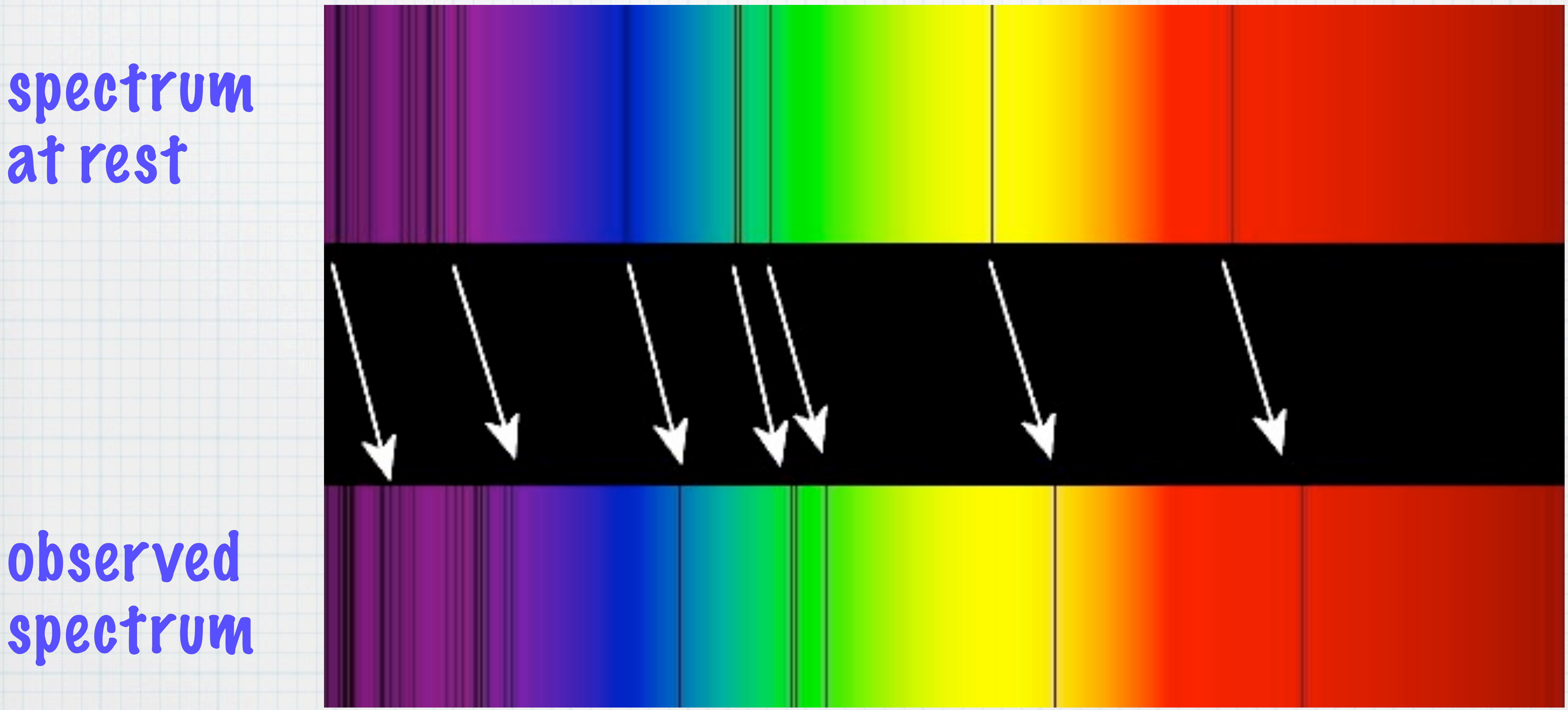


Doppler Effect...

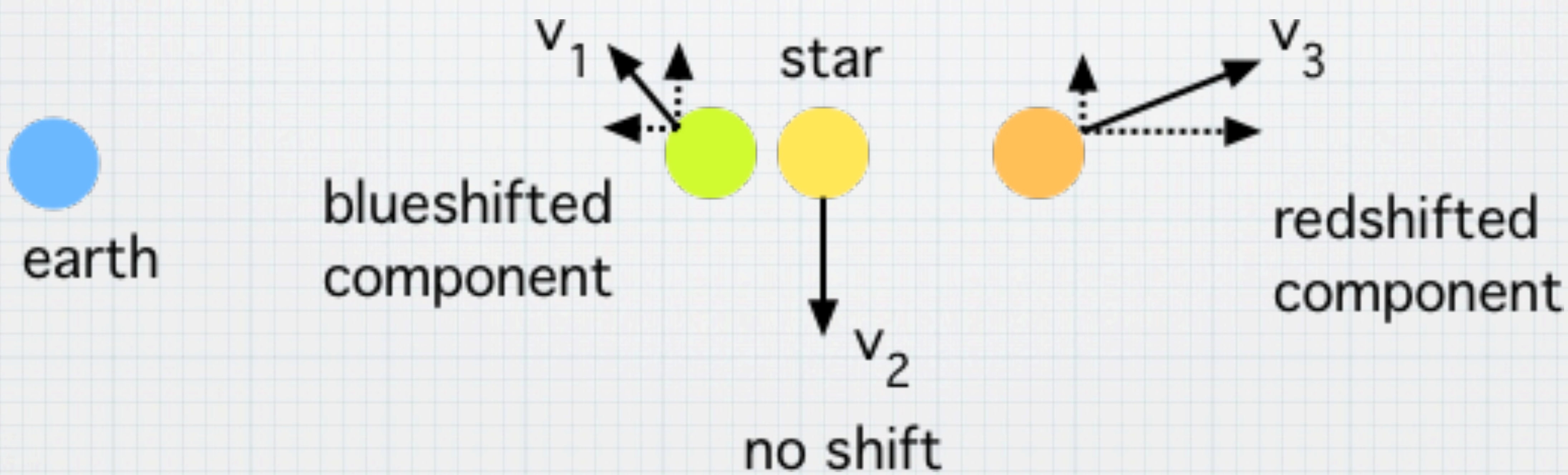
- For electromagnetic waves
  - The Doppler effect causes frequency shifts as well
  - If the object is moving toward us, its entire spectrum is shifted toward shorter wavelengths ("bluer" aka blueshift)
  - If it is moving away from us, its entire spectrum is shifted toward longer wavelengths ("redder" aka redshift)

The bottom spectrum has been **shifted toward the red**. Hence the object emitting it is **moving relatively away from us**

We call this effect (in this case) a **redshift**



* The spectrum shift depends on the relative velocity the object has with respect to us
* It does not depend on the object absolute velocity



Doppler Effect...

* In summary, a doppler shift tells us another important piece of information, that is, the relative line-of-sight speed the object whose spectrum we have captured has
* Of course, we must first be able to recognize what lines of what atoms got shifted

Question

A spectrum line is measured in the lab at 500.7 nanometer. The same line in a star has a wavelength of 502.8 nm. Hence

A) the star is moving away from me

B) the star is moving toward me

C) I cannot tell which

Question

A spectrum line is measured in the lab at 500.7 nanometer. The same line in a star has a wavelength of 502.8 nm. Hence

A) the star is moving away from me

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C) I cannot tell which

Doppler Effect (one more thing...)

* To complicate matter, two other phenomena can alter the shifting of a spectrum

  a. the gravitational redshift

  b. the cosmological redshift

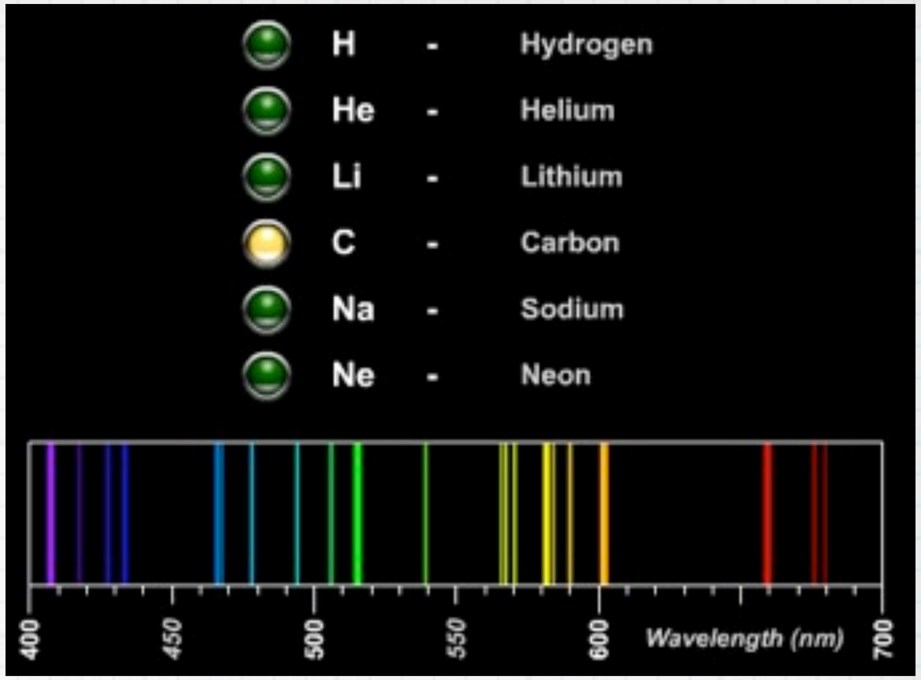
* We'll talk about those later on in class

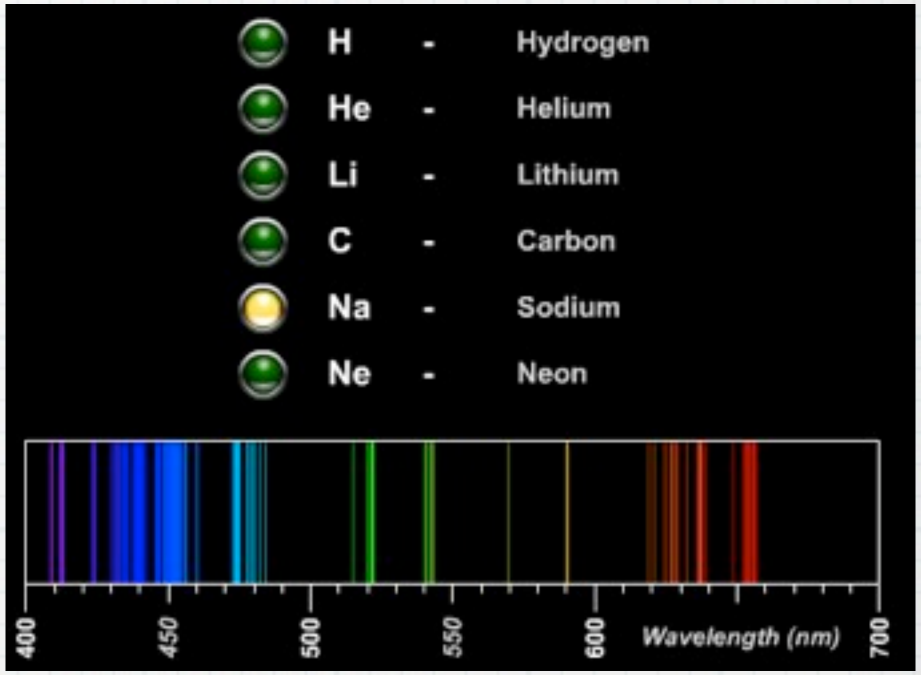
Snapshot

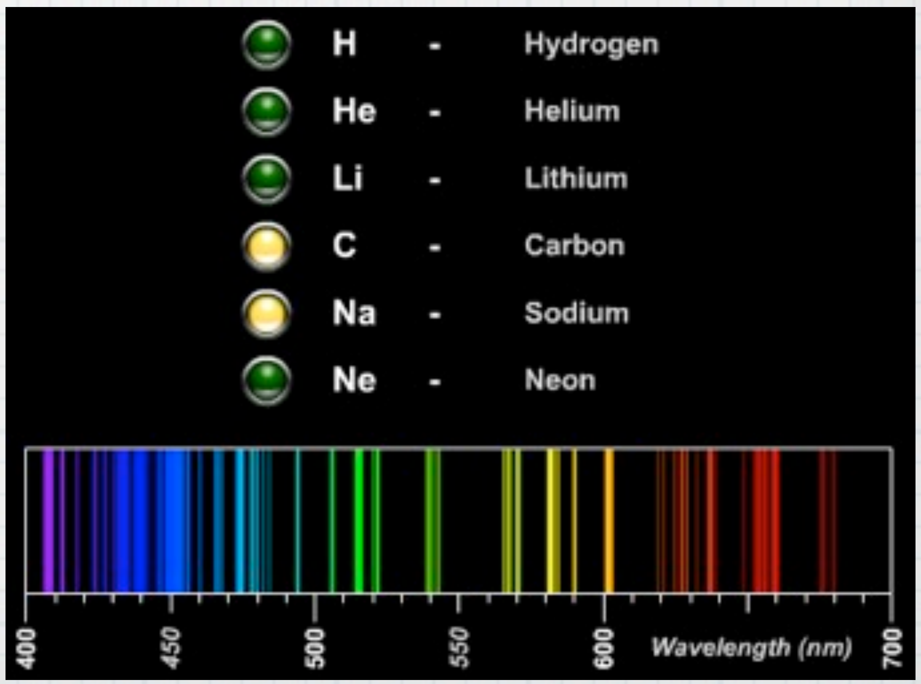
* What types of light spectra are there?
  1. thermal spectrum (continuous)
  2. absorption line spectrum (some missing colors)
  3. emission line spectrum (only see a few colors)

Snapshot

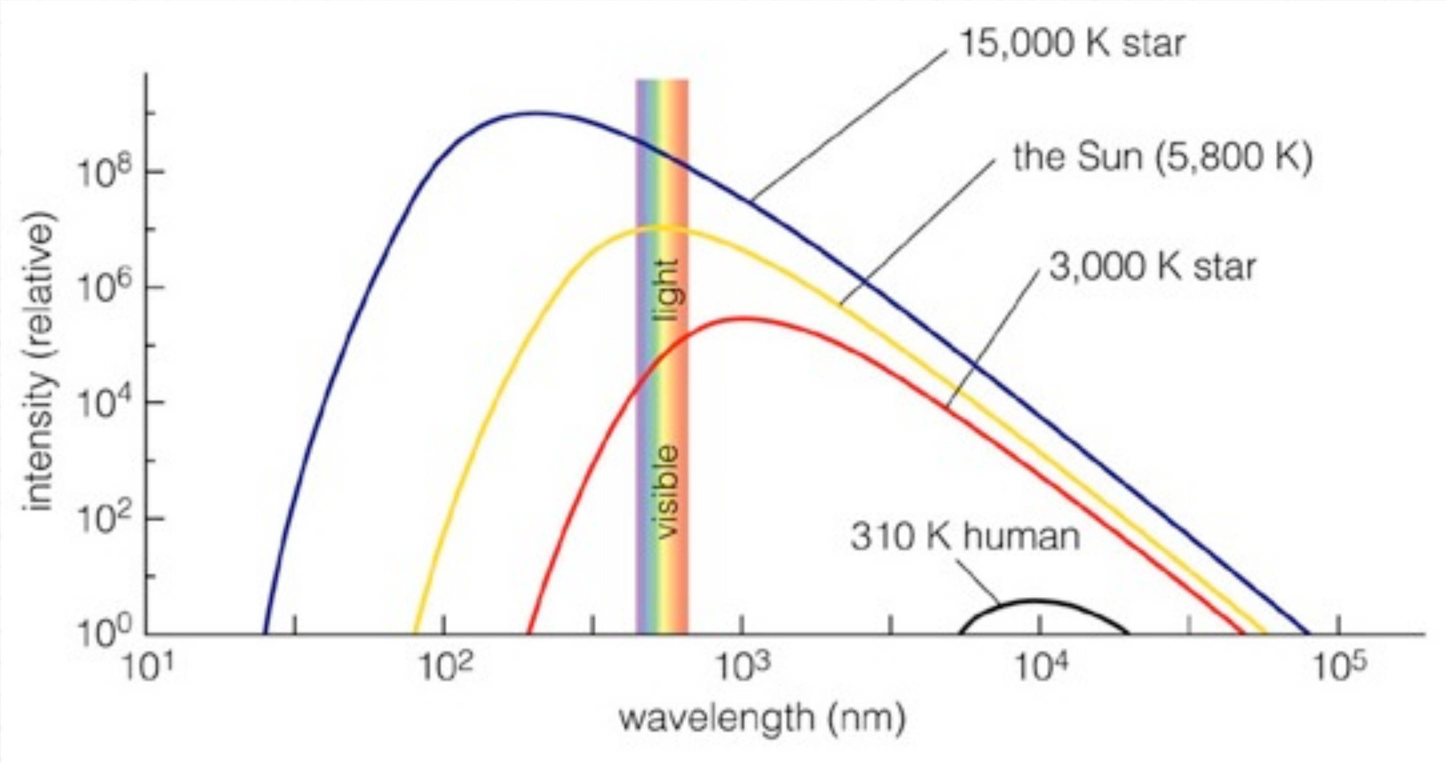
- How does light tell us what things are made of?
- Every kind of atom, ion, and molecules produces a unique set of spectral lines







Snapshot



* How does light tell us the temperatures of planets, stars and even space itself?
* We can determine temperatures from the thermal radiation spectrum

Snapshot

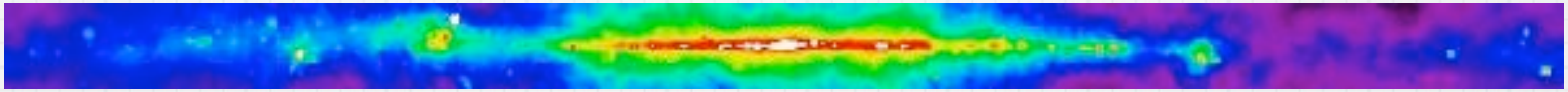
* How does light tell us the speed of a distant object?
* That object's spectral lines will be shifted. A blueshift means the object is moving toward us and a redshift means it is moving away from us

Collecting "Light"

* Astronomers collect different parts of the electromagnetic spectrum with specialized telescopes
    * radio telescopes
    * infrared telescopes
    * optical telescopes
    * ultra-violet telescopes
    * x-ray telescopes
    * gamma ray telescopes

The Milky Way seen in many lights

radio

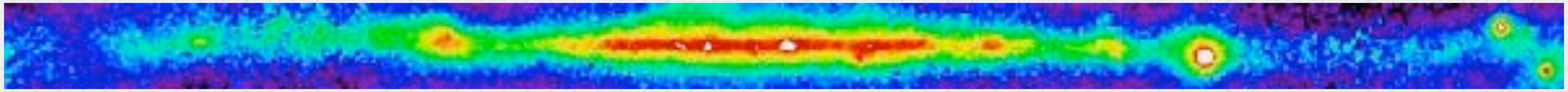


IR

optical

x-ray

ϒ-ray



Telescope placement

* Some telescopes are based in space because
  1. the Earth atmosphere absorbs particular wavelengths
  2. it also distorts light (turbulence effect)
  3. city light pollution contaminate light from space
  4. night time is 24-hour a day in space
* But a space-based telescope is lot more expensive than an Earth-based brother

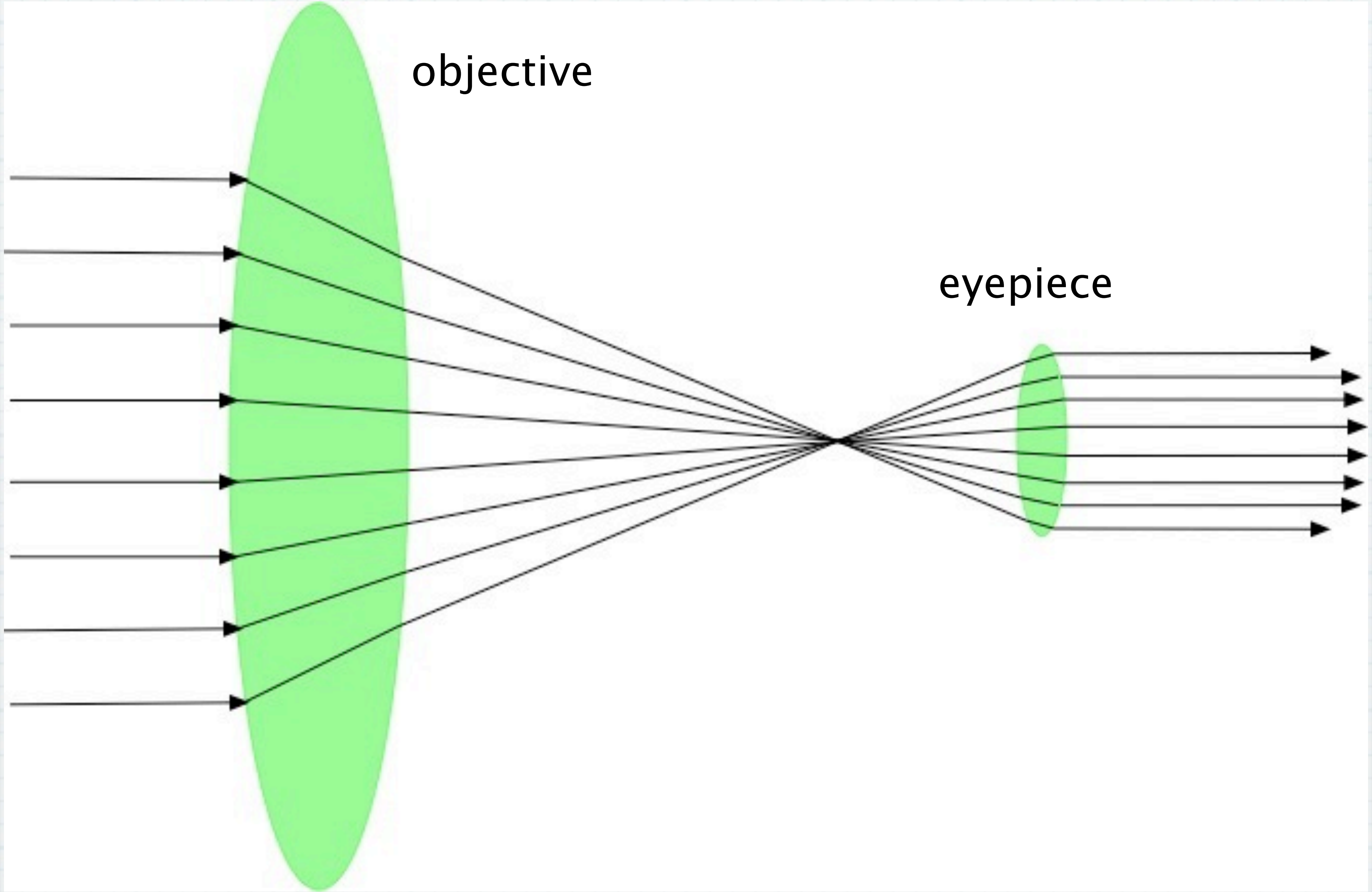
Telescope Basic Properties

* Light collecting area
  * like an eye, just a lot bigger!
  * a 10-meter telescope collects 25 times more light than a 2-meter one
* Angular resolution
  * how close can 2 stars be to each other and not be seen as one?
  * dependent on length of telescope (and the quality of the lenses/mirrors...)

Visual Telescope Designs

* Refracting telescope (only use lenses)
* Reflecting telescope (use mirrors and lenses)
  * Newtonian
  * Cassegrain

Refracting Telescope



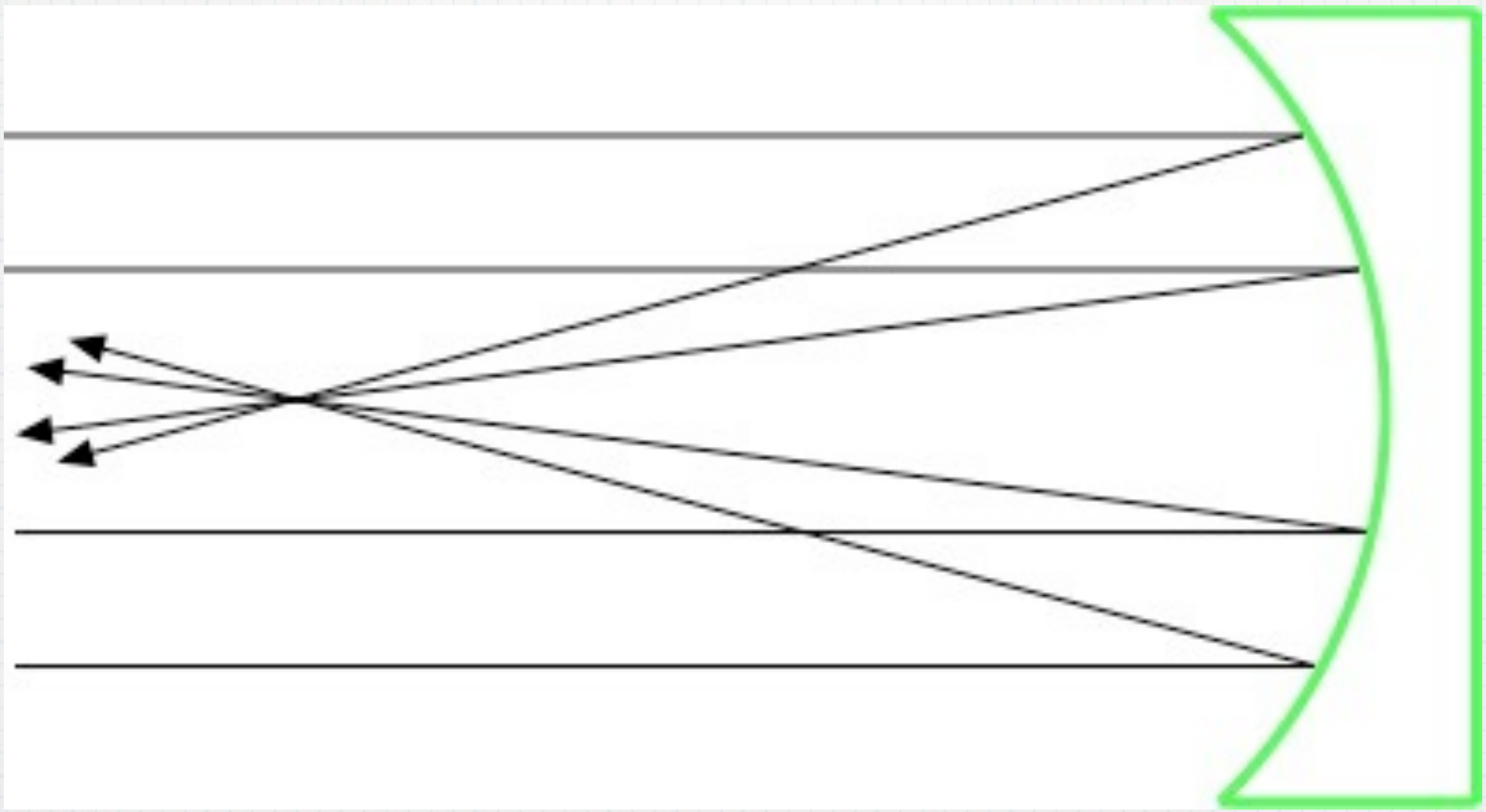
Observatory of Nice, France

∅=76 cm or 30", f=17.9m or 58.8', 1887

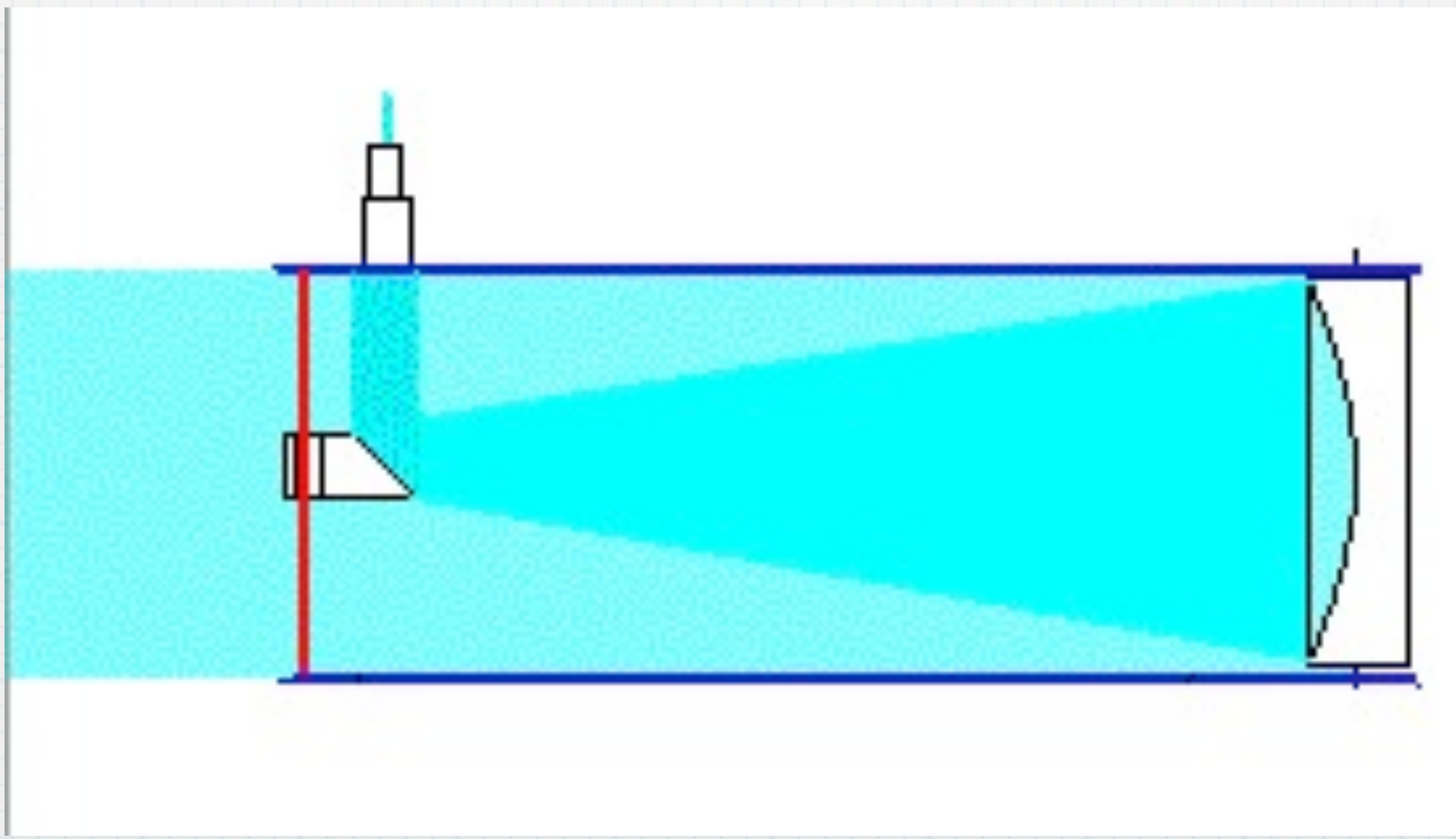
Observatory of Yerkes, Chicago

∅=101.6 cm or 40", f=18.9m or 63', 1897

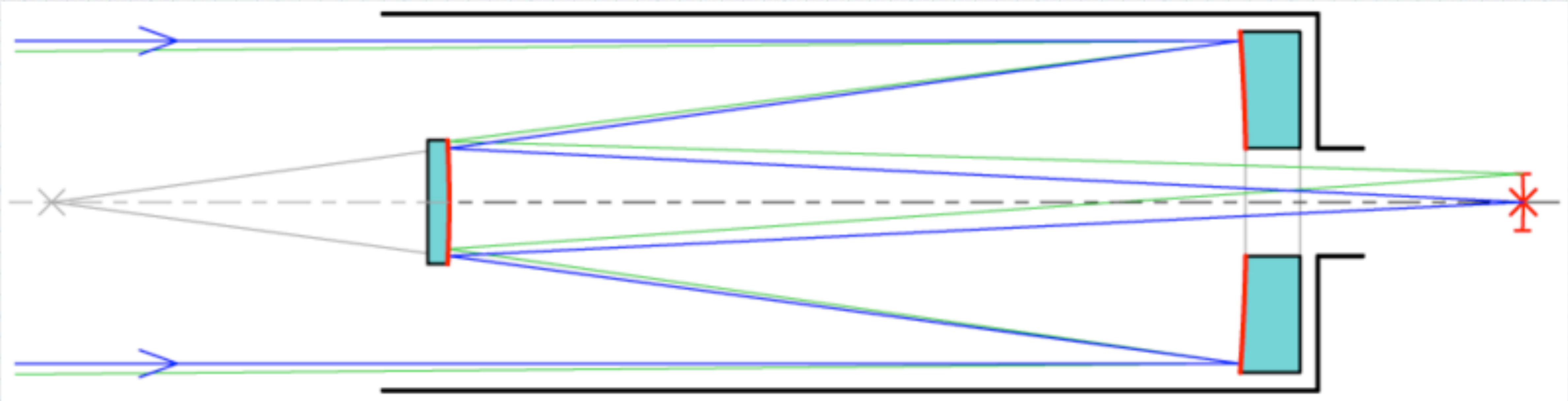
Reflecting Telescope



Newtonian focus

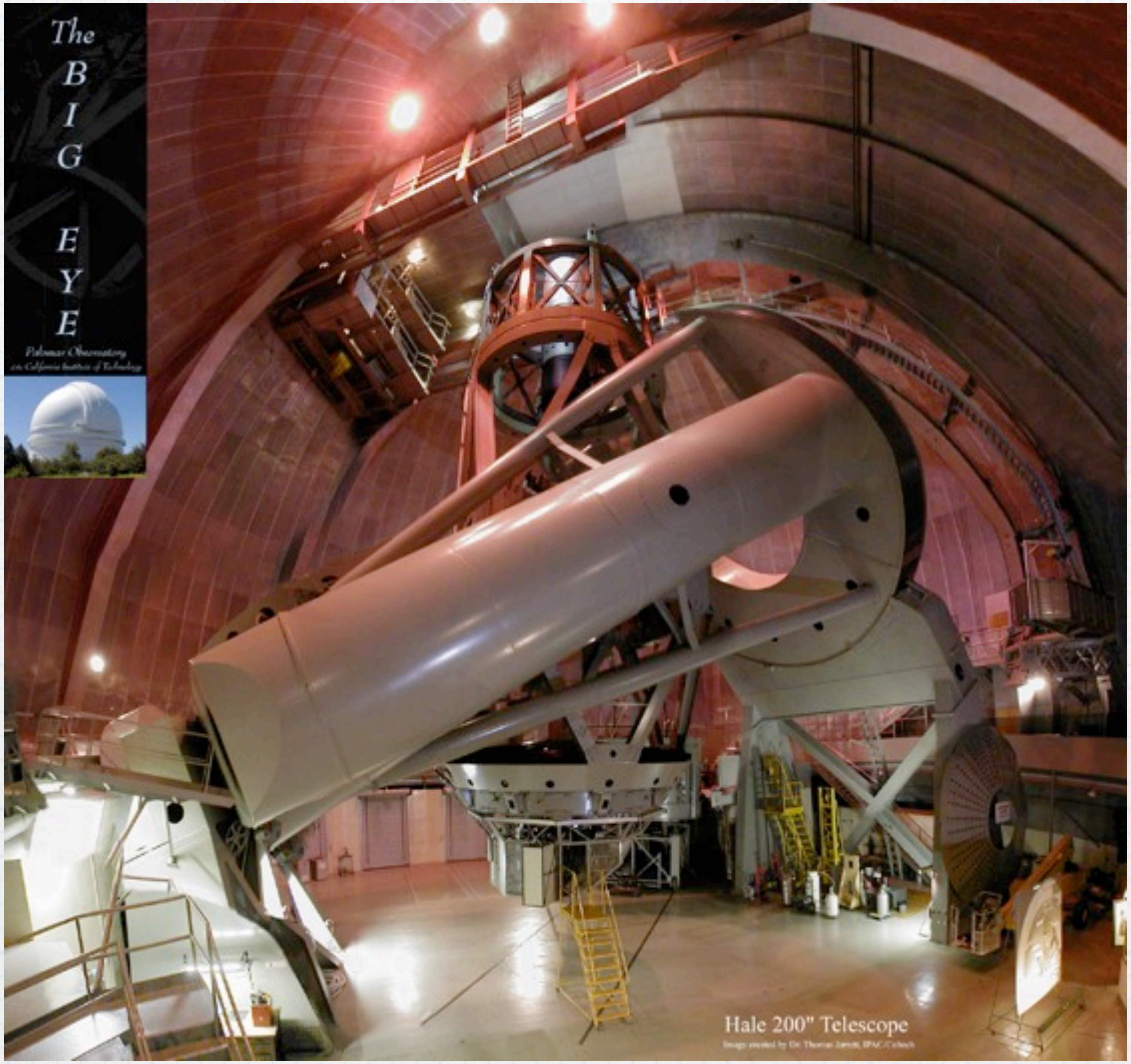


Cassegrain focus



Hale, Mount Palomar, California

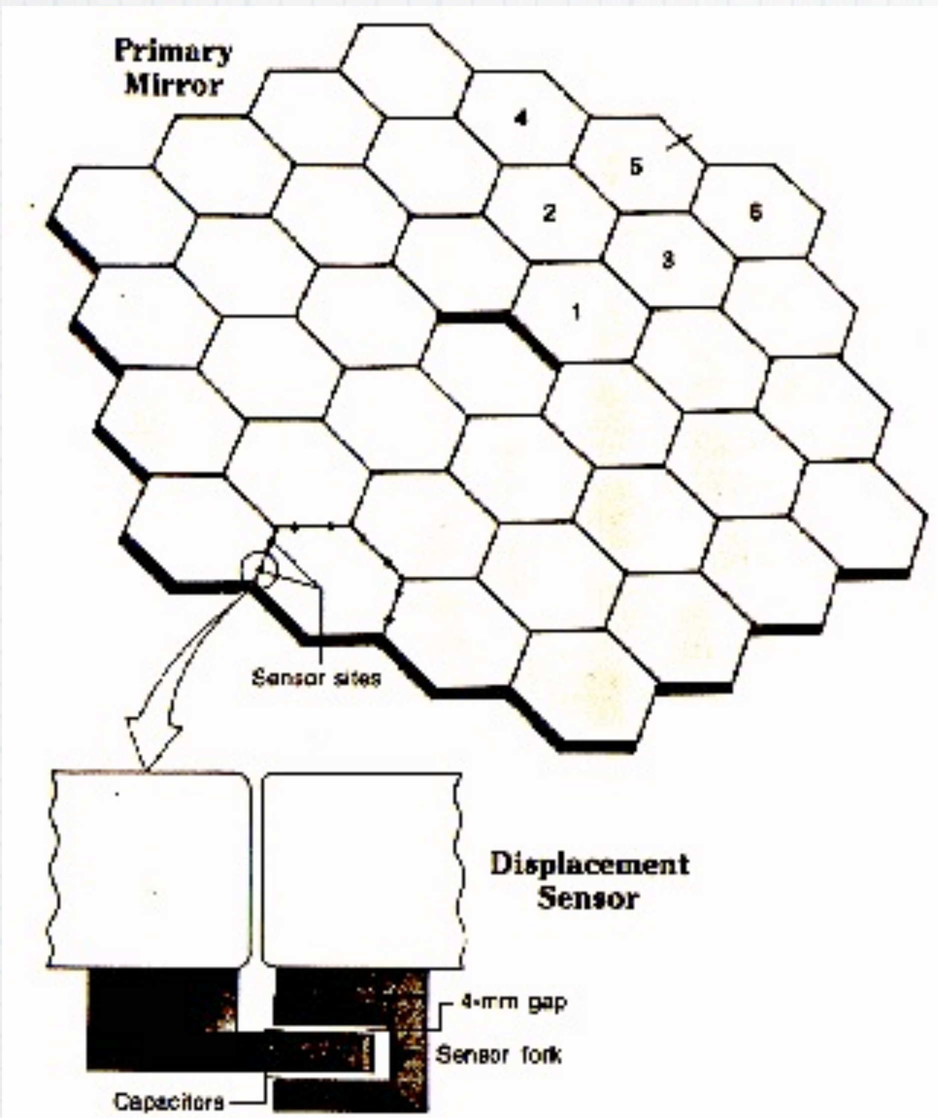
∅=508 cm or 200", f=16.8m or 55', 1948

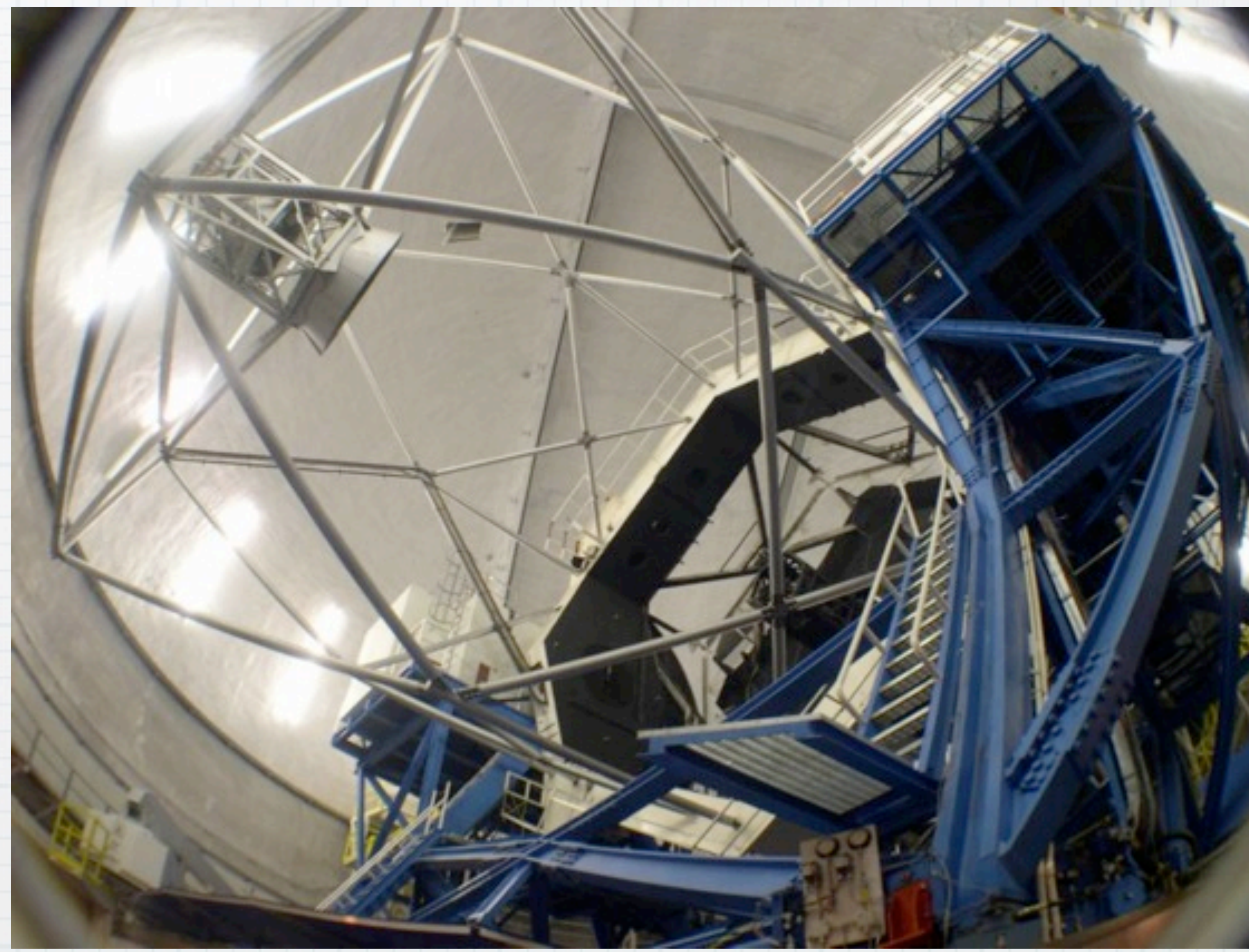


Keck, Mauna Kea, Hawaii

∅=1000 cm or 2540", f=17.5m or 57', 1993

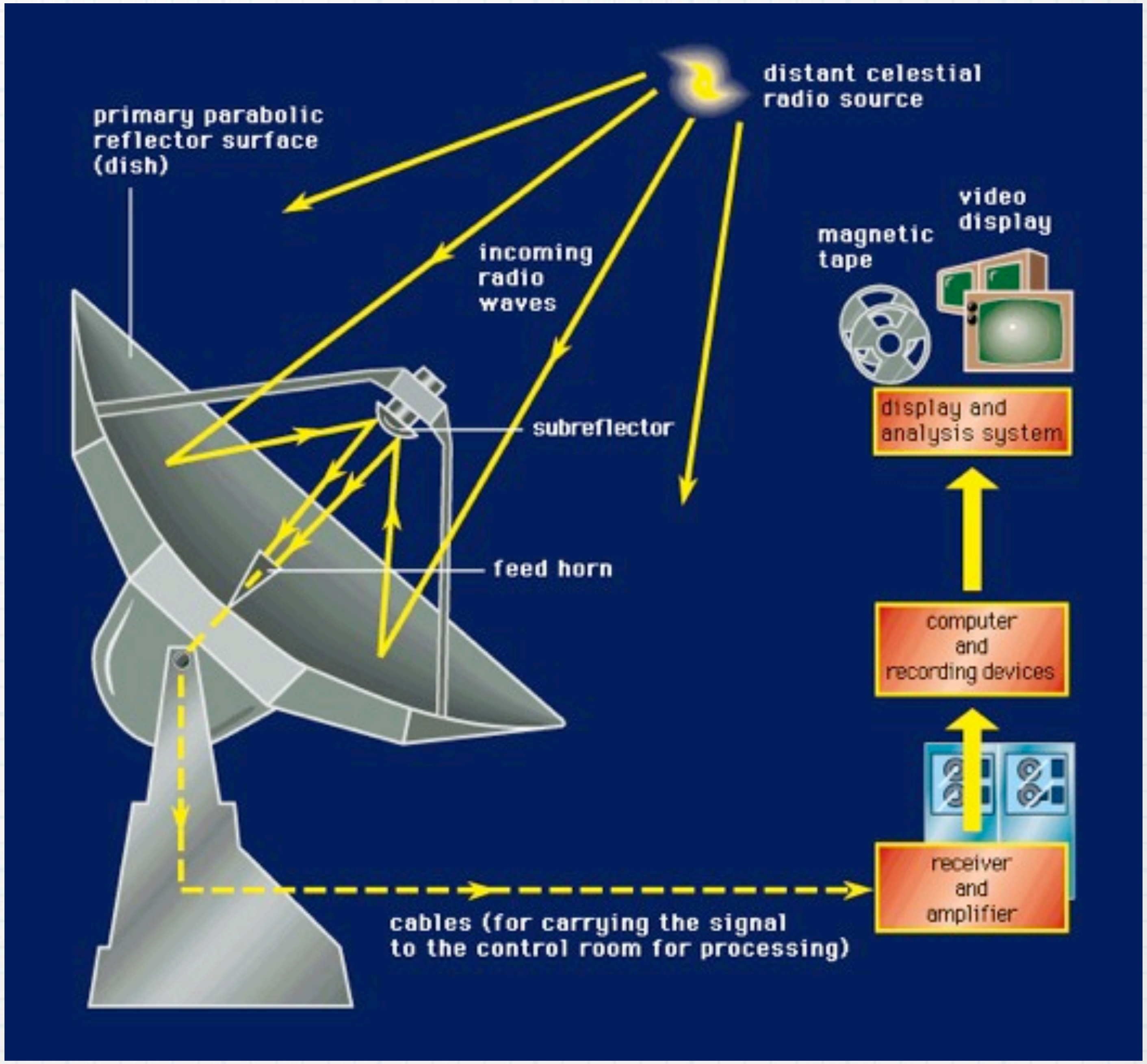
36 mirrors make the effective 10-meter diameter





Radio Telescopes

* They focus radio waves at specific wavelength (e.g. Hydrogen @ 21 cm which is used to map clouds of neutral hydrogen found in interstellar space)



* A single dish makes a blurry image however

Robert C. Byrd Green Bank Telescope, West Virginia

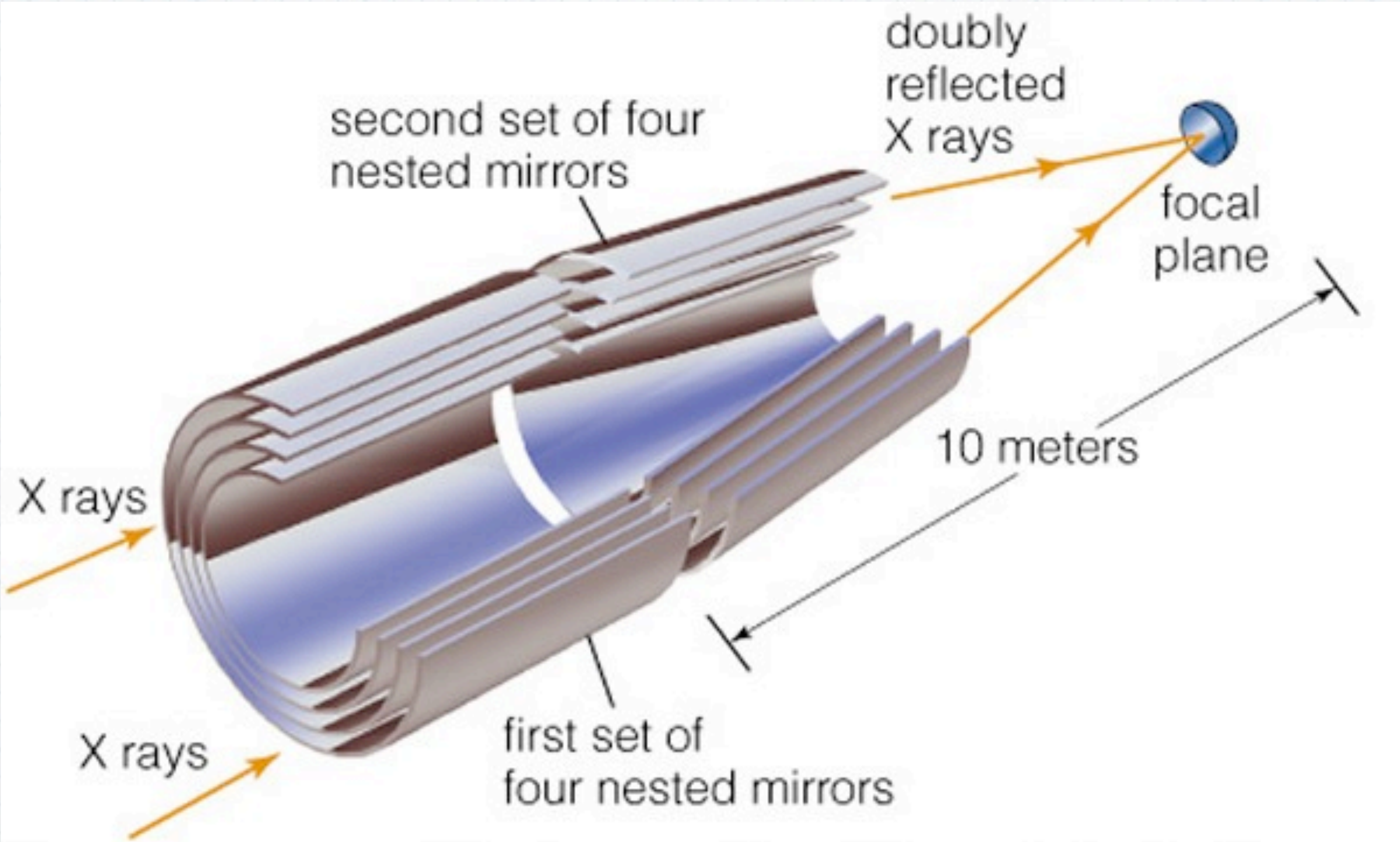
∅=100m

Radio Telescopes...

A radio telescope can be used with many other radio telescopes in **long-baseline interferometry** which simulates a much bigger dish diameter to produce sharp "radio" images

X-Ray Telescopes

* Based in space!
* Focussing X-rays is not like focussing visual light or radio waves



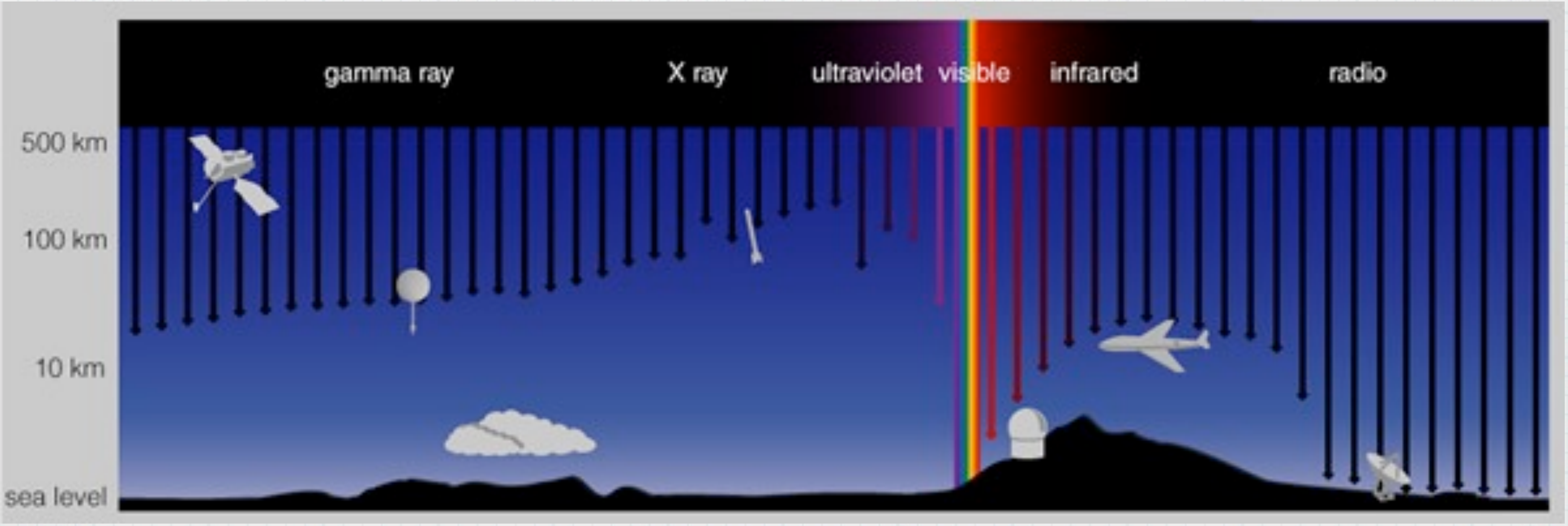
Mirror elements are 0.8 m long and from 0.6 m to 1.2 m in diameter.

Space based telescopes are a necessity as the Earth's atmosphere blocks all energetics photons

This is a good thing - for life on Earth!

Other less energetic photons are absorbed too (IR)

Compton Integral Chandra Hubble Spitzer WMAP



Why look beyond our visual range?

Because we cannot hope to understand Nature
if we do not perceive her range of operation

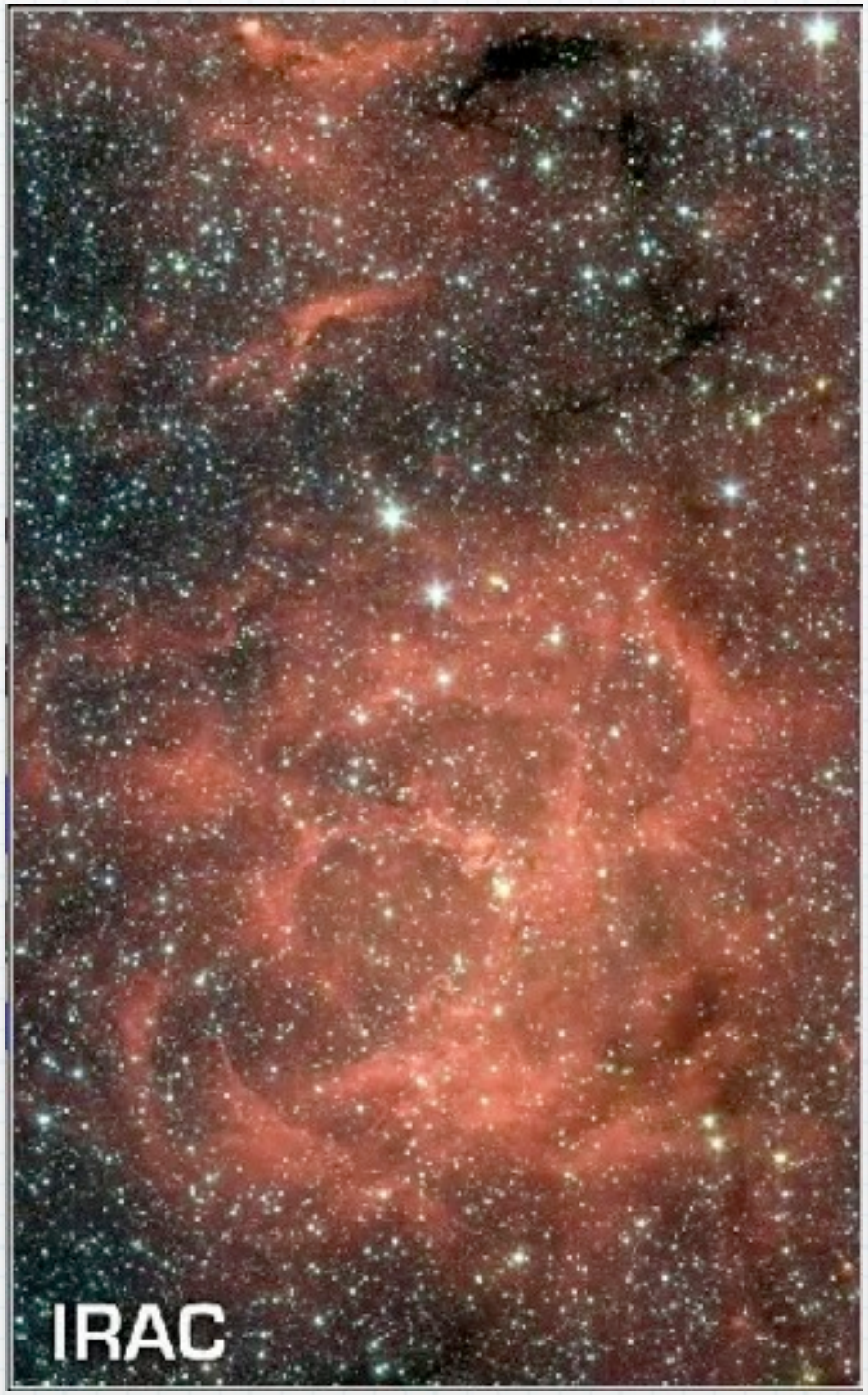
visible

Trifid nebula

Why look beyond our visual range?

Because we cannot hope to understand Nature if we do not perceive her range of operation

near IR



Trifid nebula

Why look beyond our visual range?

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far IR

Trifid nebula

Why look beyond our visual range?

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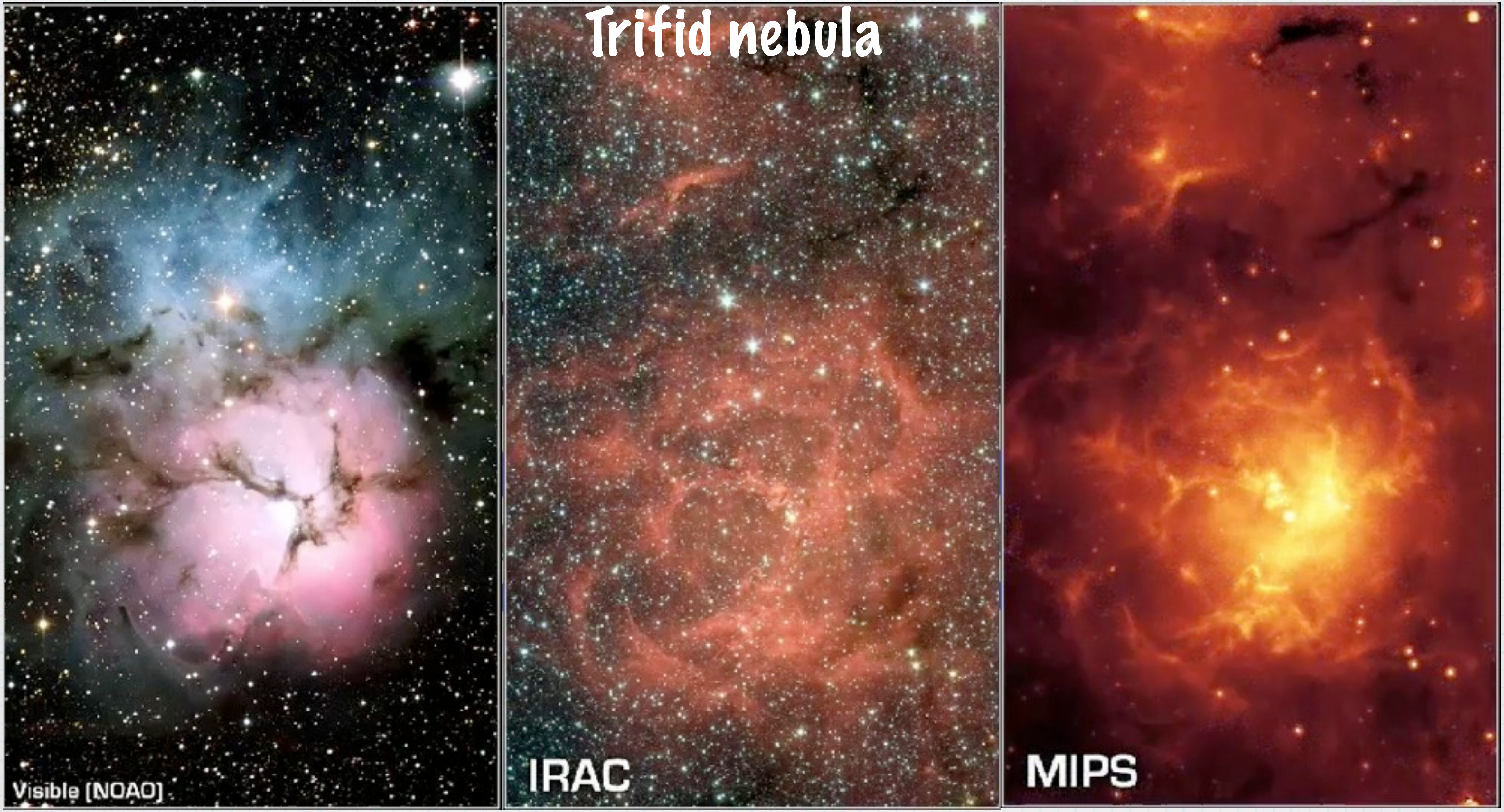
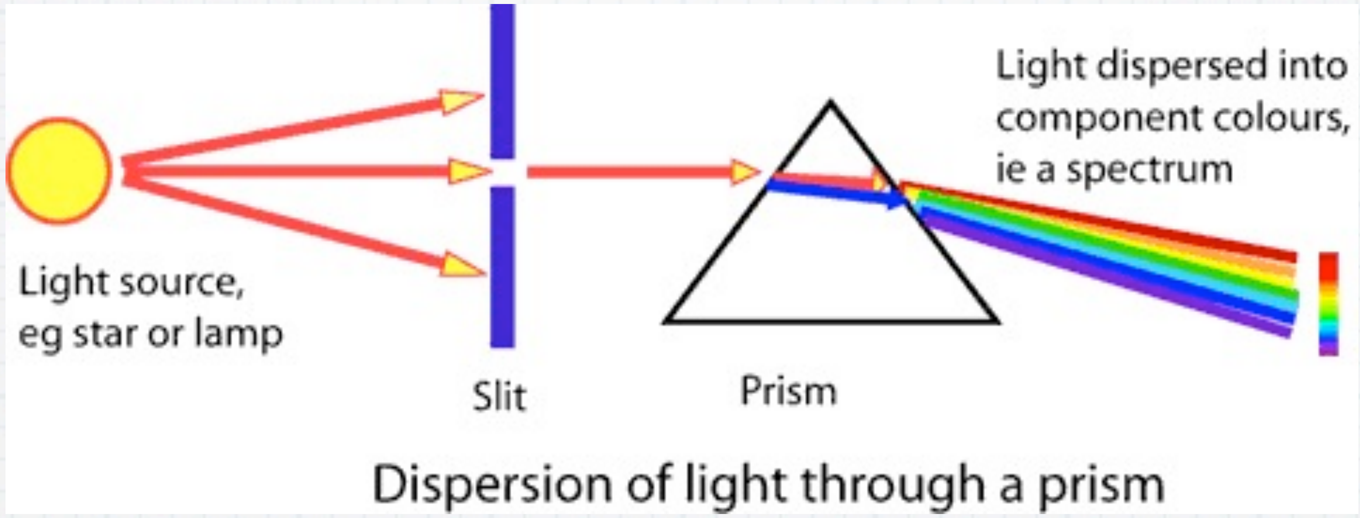


visible near IR far IR

Tools & Filters used by Astronomers: spectrograph



* to identify the chemical makeup of distant objects
* their temperature
* their speed with respect to us

Tools & Filters used by Astronomers: H-alpha filter

* when a hydrogen electron falls from its third to second lowest energy level
    * Wavelength is in the red (656.28 nm)
    * To study the surface of the Sun
    * And to study nebulae, the interstellar cloud of gas expelled by a star

Tools & Filters used by Astronomers...

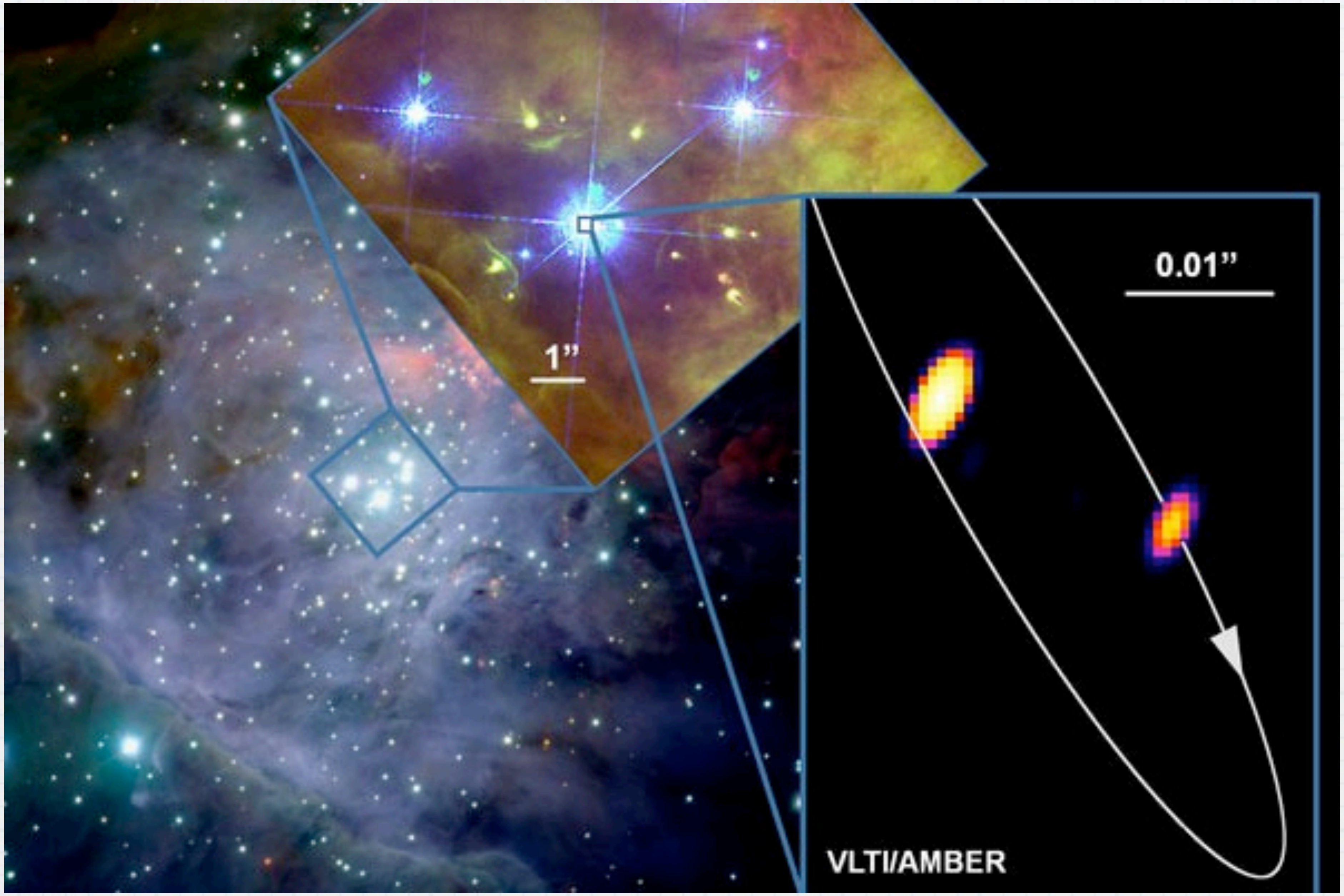
* CCD cameras
  * To take pictures!
* Photoelectric sensors
  * To specifically capture the brightness changes of a particular frequency (or range) of an object such as
  * planets, stars, regions of space, ...

Tools & Filters used by Astronomers...

* Adaptive optics
  * Telescope mirrors which change shape to compensate for atmospheric disturbances
* Interferometry
  * To simulate very large mirrors
  * Used in radio-astronomy and the visual range

Binary star Theta 1 Orionis C

The results show the fascinating new possibilities of high-resolution stellar imaging achievable with infrared interferometry



Provided by Max Planck Institute, Bonn, Germany

Snapshot

* How do telescopes help us learn about the universe?
* We can see fainter objects and more detail than we can see by eye. Specialized telescopes allow us to learn more than we could from visible light alone

Snapshot

* Why do we put telescopes in space?
* They are **above earth's atmosphere** and therefore **not subject to light pollution**, **atmospheric distortion**, or **atmospheric absorption of light**

Snapshot

* What is the role of technology in Astronomy?
* Telescopes (light gathering) and cameras (light capturing) are made more sensitive and precise
  * Adaptive optics
  * Interferometry
* Mathematical analyses play a big role too