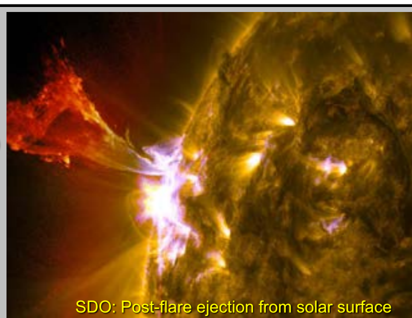


SDO: Post-flare ejection from solar surface

ASTR 1040 Stars & Galaxies

Prof. Juri Toomre TAs: Max Weiner, Daniel Sega, Loren Matilsky

Lecture 3 Tues 21 Jan 2020

zeus.colorado.edu/astr1040-toomre

Reading for today's and Thur class:

- Read Chap 5, carefully (*Light and Matter*)
- *This chapter covers a lot – read it at least twice!*
- Start reading Chap 6, *telescopes*

Continuing Topics for Today

- Electromagnetism: Light as waves and photons
- Coupling of atoms and light
- Yields "spectral lines" that are fingerprints unique to each atom
- How gas can emit or absorb light
- Hope you completed *HW #0* on MA, now well underway with *HW #1* (due Thur classtime)
- Recitations / AHR office hours can help

Light: The Cosmic Messenger

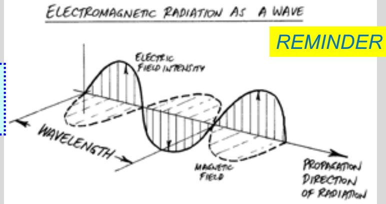
CONTINUING TOPIC

Barred Spiral Galaxy NGC 1672

E-M (LIGHT) AS WAVES

REMINDER

ELECTROMAGNETIC RADIATION AS A WAVE



$\lambda \times f = c$

WAVELENGTH × FREQUENCY = SPEED OF "LIGHT"

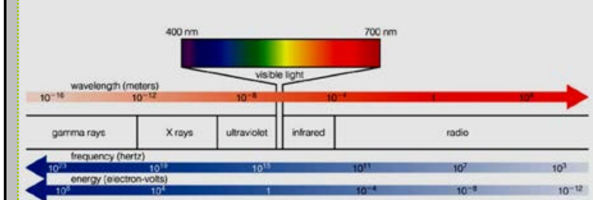
$\lambda = c/f$, $f = c/\lambda$

PROPAGATION SPEED OF ALL EM WAVES IS THE SAME!

C IS A CONSTANT ≈ 300,000 Km/sec = 3×10^{10} cm/sec

Speed of light SAME for all wavelengths

Electromagnetic Spectrum



gamma-rays x-rays ultraviolet visible infrared radio

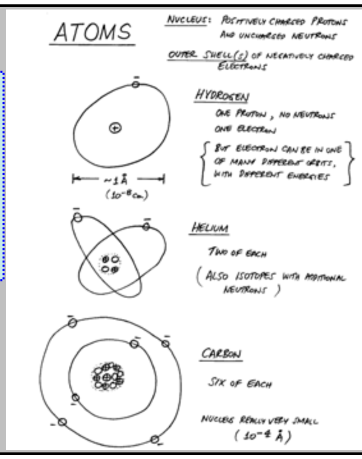
$$c = \lambda \cdot f$$

ATOMS

protons,
neutrons,
electrons

(and quarks ..)

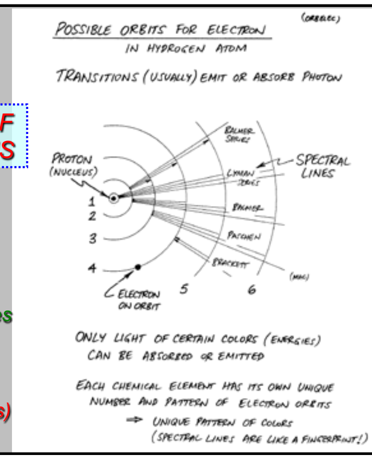
Building blocks for everything



"ORBITS" OF ELECTRONS

Popping from one orbit to another involves particular PHOTONS

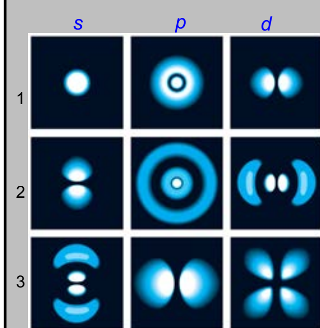
(like DNA prints)



Revolution of "Quantum Mechanics"

- Discrete spectral lines and electron energy levels go hand in hand, but WHY?
- Classical physics had no real explanations, even if Bohr's model of electron orbits for H looked good
- A new mathematics/physics had to be invented in the 1920s, with solutions of the "Schroedinger wave equation" giving *probabilities (orbitals)* of where electrons could be located
- Such "quantum mechanics" also explained why light (photons) act both like waves and particles, and so too electrons!

Electron in Hydrogen Atom (S4.3)



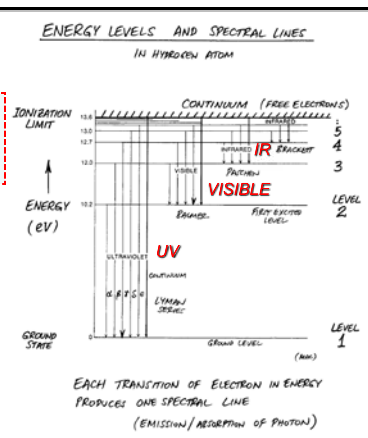
- In ***quantum mechanics***, an electron in an atom does not orbit in the usual sense
- We can know only the *probability* of finding an electron at a particular spot (orbital)

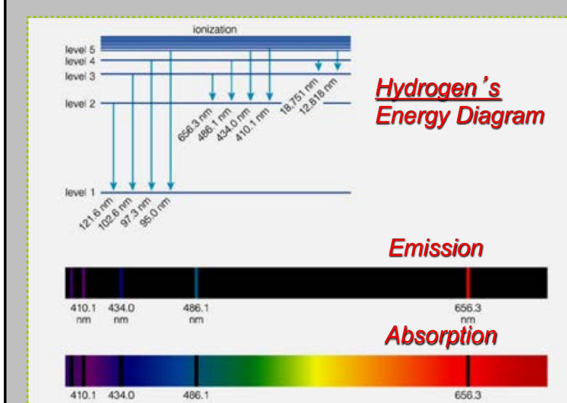
Orbital solutions from Schroedinger wave equation

ENERGY LEVELS (of electrons) IN HYDROGEN

Each transition involves photons of specific color

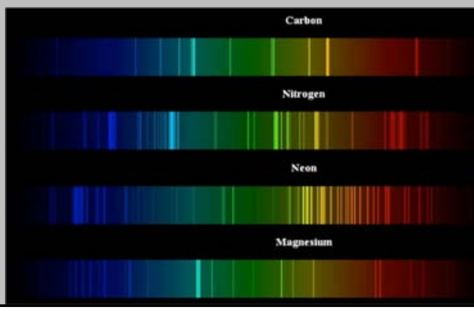
(like fingerprints)



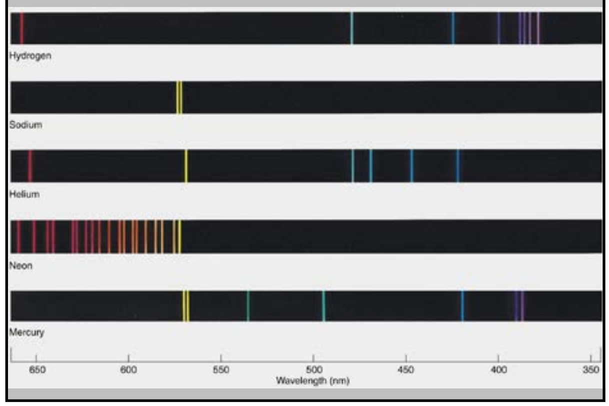


Each atom has a different set of energy levels

- Just like no two people have the same fingerprints, no two elements have the same emission spectrum



As in our emission tube demo last Thur



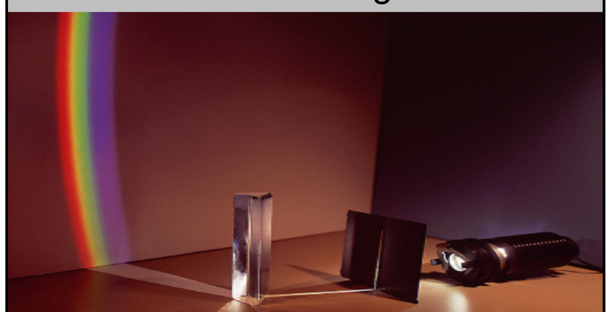
Very important Idea #2

$$E = h \times f$$

Photon's Energy =
Planck's constant x Photon's Frequency

Idea #1 $c = \lambda \cdot f$

Colors of Light



- Newton showed: White light is made up of many different colors

Clicker Question

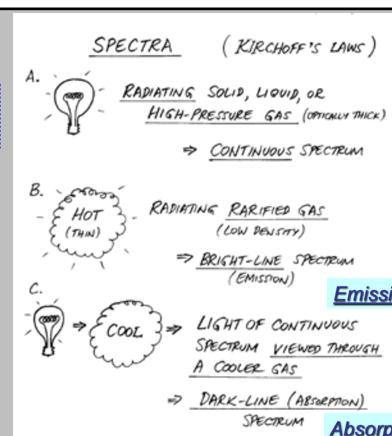
Infrared light can have a wavelength of 3 microns (3×10^{-6} m) and a frequency of 1.0×10^{14} Hz. What is the wavelength of light that has a frequency of 0.5×10^{14} Hz?

(Hint: What is the relationship between wavelength and frequency?)

A. 1.5 microns
B. 2.0 microns
C. 2.5 microns
D. 3.5 microns
E. 6.0 microns

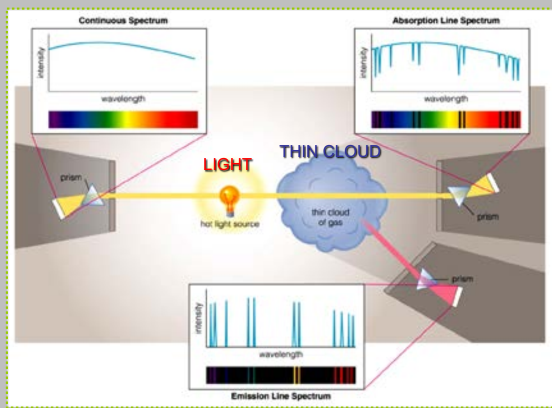
NATURE OF SPECTRA

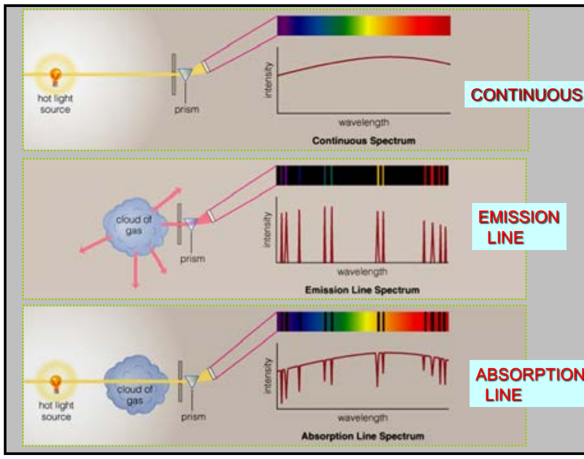
Kirchoff's laws



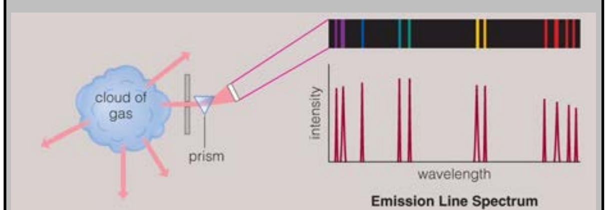
Emission

Absorption

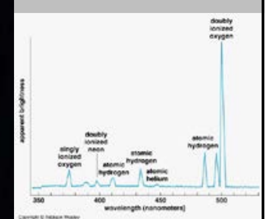




Emission Spectra



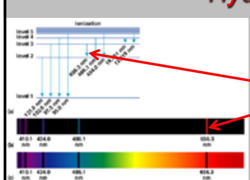
- *Emission for thin, hot gas: Gas glows in specific colors.*



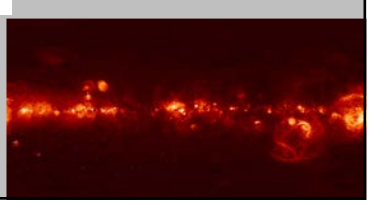
The Crab nebula: remains of an exploded star (supernova, 1054 AD)

Spectrum shows bright emission lines from various elements

Most common visible light emission line: Hydrogen Alpha

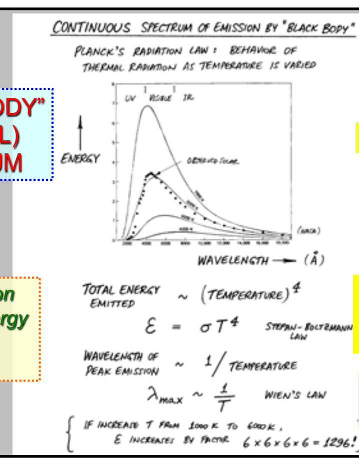


- *Hydrogen Alpha*
- *Level 3 to level 2 energy jump at 656.3 nm*
- *The universe is mostly red!!*



All-sky map of H Alpha emission

"BLACK-BODY" (THERMAL) SPECTRUM



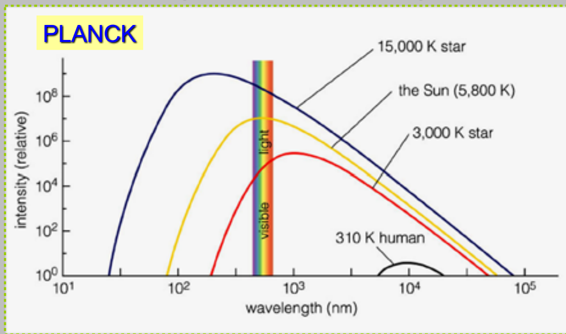
Planck

Peak emission and total energy VARY with temperature

"Law1" Stefan-Boltzmann

"Law2" Wien

Spectra of Continuous Emission (from us and stars)



Thermal radiation spectrum

Law 1: *Power emitted* (per square meter surface area)

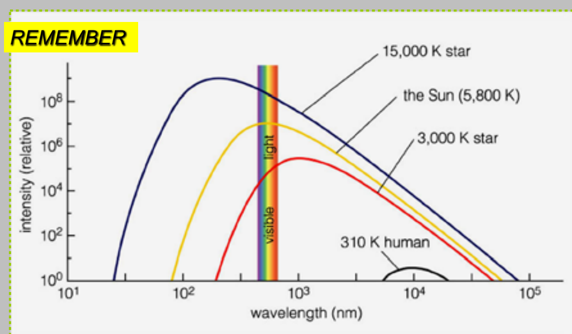
$$\varepsilon = \sigma T^4$$

"Luminosity" = "Law 1" x Surface Area of star

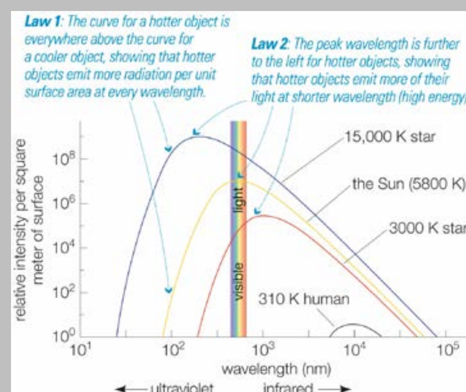
Law 2: *Wavelength* of peak emission

$$\lambda_{\max} \sim 1/T$$

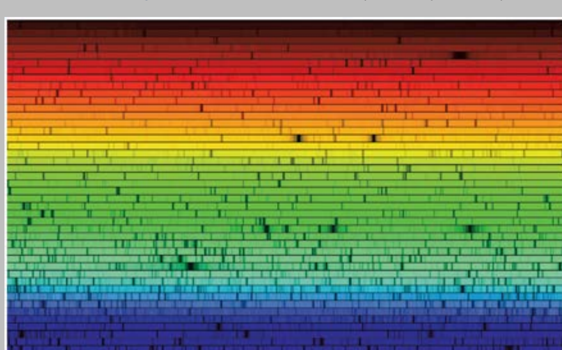
Thermal Radiation Emission



UP the temperature: FAR MORE emission
peak at SHORTER wavelengths



Visible light spectrum of the Sun (optically folded)

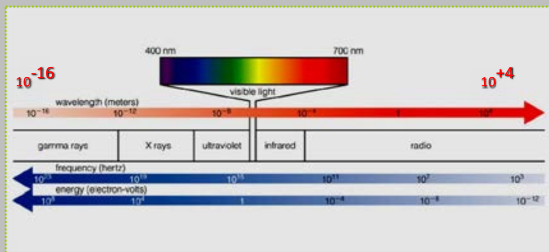


Clicker Q – EM Waves

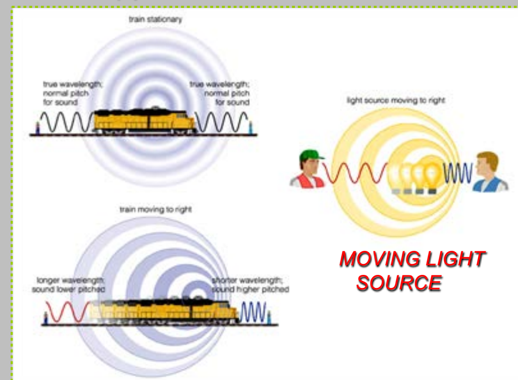
- From *shortest to longest wavelength*, what is the correct sequence of EM radiation?

- *A.* gamma-rays, x-rays, UV, visible, IR, radio
- *B.* gamma-rays, x-rays, visible, UV, IR, radio
- *C.* IR, visible, UV, x-rays, gamma-rays, radio
- *D.* radio, IR, visible, UV, x-rays, gamma-rays

A. gamma-rays,x-rays,UV,visible,IR,radio

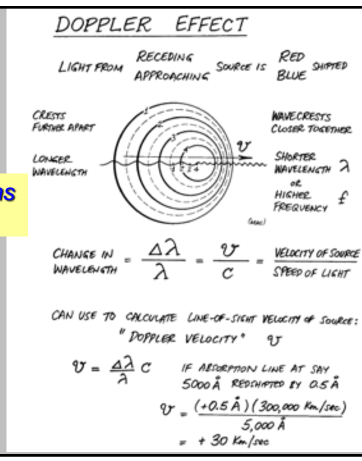


Doppler Effect: Trains and Light



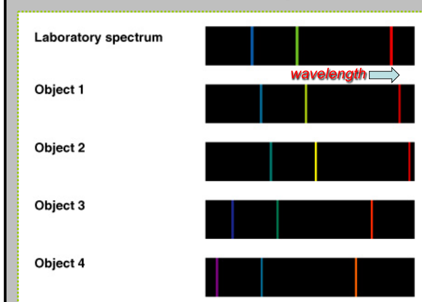
DOPPLER EFFECT

Applied to positions of spectral lines



Doppler Demo

Measuring the Line Shift



Stationary

Moving Away (redshifted)

Away Faster

Moving Toward (blueshifted)

Toward Faster

- *Measure the Doppler effect from shifts in the wavelengths of spectral lines*