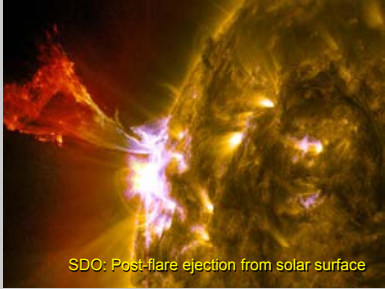


ASTR 1040
Stars & Galaxies



SDO: Post-flare ejection from solar surface

Prof. Juri Toomre TAs: Piyush Agrawal, Connor Bice
Lecture 3 Tues 24 Jan 2017
zeus.colorado.edu/astr1040-toomre

REMINDER

Your account on "Mastering Astronomy"

- Some confusion at CU Bookstore on the use of 8th edition of *Cosmic Perspectives*
- It is essential to have **your account established on Mastering Astronomy (MA) tied into our course "ASTR1040TOOMRE2017"**
- We will help replace any incorrect book versions, and get MA access codes corrected
- **Be sure to work through MA Homework #0, and Homework #1, due Thur Jan 26**

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
- Observatory Night # 1 (this Thur 26 Jan) by signup (7:00pm; 7:45pm; 8:30pm)
- Hope you completed HW #0 on MA, now well underway with HW #1 (due Thur classtime)

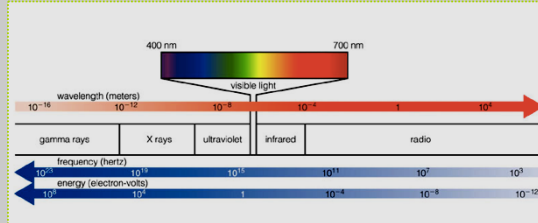
Light: The Cosmic Messenger

CONTINUING TOPIC



Barred Spiral Galaxy NGC 1672

Electromagnetic Spectrum



gamma-rays x-rays ultraviolet visible infrared radio

$c = \lambda \cdot f$

ATOMS

NUCLEUS: POSITIVELY CHARGED PROTONS AND UNCHARGED NEUTRONS

OUTER SHELL(S): POSITIVELY CHARGED ELECTRONS

ATOMS
protons, neutrons, electrons
(and quarks ..)
Building blocks for everything

HYDROGEN
ONE PROTON, NO NEUTRONS
ONE ELECTRON
[BUT ELECTRONS CAN BE IN ONE OF MANY DIFFERENT ORBITS, WITH DIFFERENT ENERGIES]

HELIUM
TWO OF EACH
(ALSO ISOTOPES WITH DIFFERENTIAL NEUTRONS)

CARBON
SIX OF EACH
NUCLEUS REALLY VERY SMALL (10^{-6} Å)

Nucleus and its electron cloud

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

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

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

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

The number of electrons in a neutral atom equals its atomic number.

Isotopes of Carbon

carbon-12 (¹²C): (6 protons + 6 neutrons)
carbon-13 (¹³C): (6 protons + 7 neutrons)
carbon-14 (¹⁴C): (6 protons + 8 neutrons)

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

Atoms Involve Big Empty Spaces

Ten million atoms could fit end to end across this dot.

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

(or 1 Angstrom)
10⁻¹⁰ meter

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

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

"ORBITS" OF ELECTRONS

POSSIBLE ORBITS FOR ELECTRON IN HYDROGEN ATOM (CORRECT)

TRANSITIONS (USUALLY) EMIT OR ABSORB PHOTON

PROTON (NUCLEUS)

1, 2, 3, 4, 5, 6 (ORBIT)

ELECTRON ON ORBIT

ORBITAL SHAPE

SPECTRAL LINES

ONLY LIGHT OF CERTAIN COLORS (ENERGIES) CAN BE ABSORBED OR EMITTED

EACH CHEMICAL ELEMENT HAS ITS OWN UNIQUE NUMBER AND PATTERN OF ELECTRON ORBITS => UNIQUE PATTERN OF COLORS (SPECTRAL LINES ARE LIKE A FINGERPRINT!)

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!

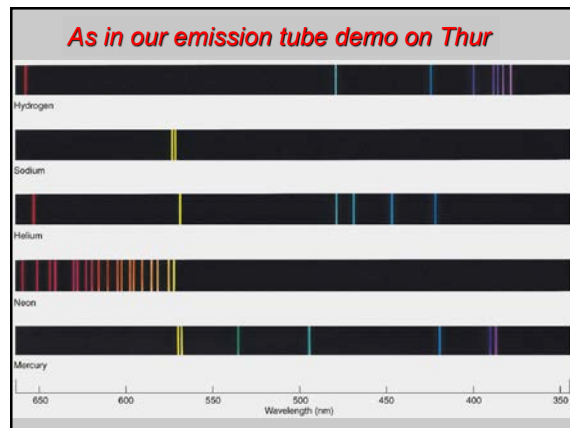
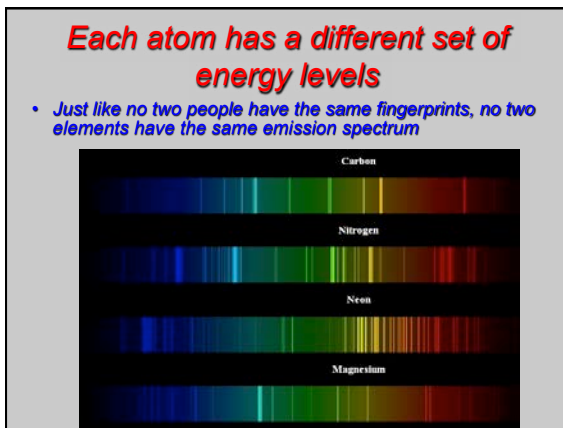
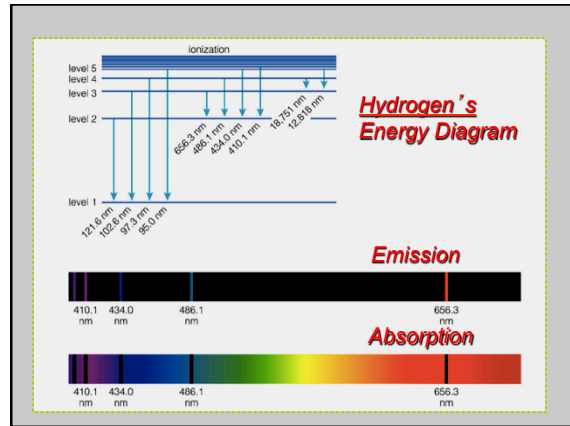
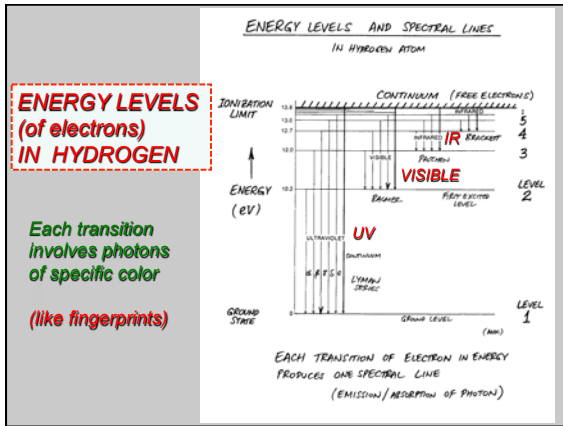
Electron in Hydrogen Atom (S4.3)

s, p, d

1, 2, 3

Orbital solutions from Schroedinger wave equation

- 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)



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 ($3 \times 10^{-6} \text{ m}$) and a frequency of $1.0 \times 10^{14} \text{ Hz}$. What is the wavelength of light that has a frequency of $0.5 \times 10^{14} \text{ Hz}$? (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

SPECTRA (KIRCHOFF'S LAWS)

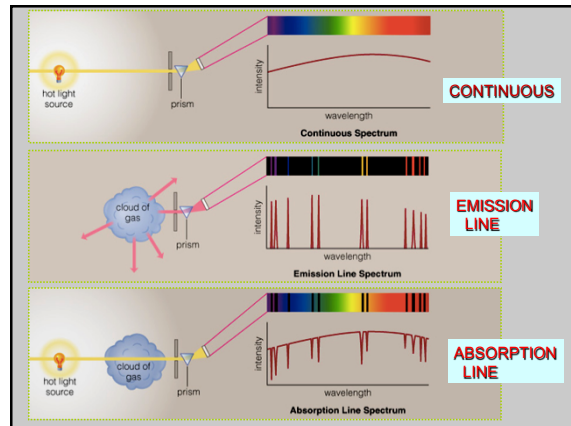
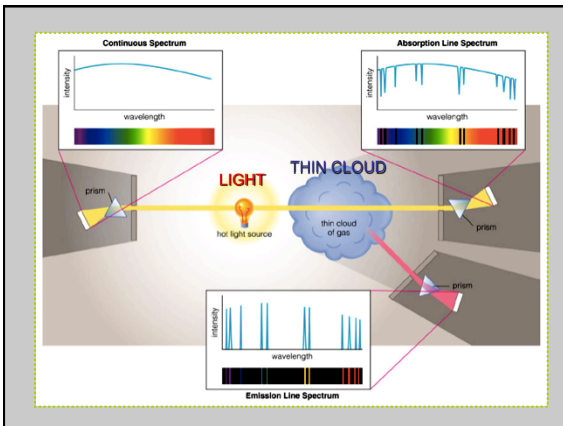
NATURE OF SPECTRA

A. RADIATING SOLID, LIQUID, OR HIGH-PRESSURE GAS (USUALLY THICK) \Rightarrow CONTINUOUS SPECTRUM

B. HOT (THIN) RADIATING RARIFIED GAS (LOW DENSITY) \Rightarrow BRIGHT-LINE SPECTRUM (EMISSION) **Emission**

C. COOL \Rightarrow LIGHT OF CONTINUOUS SPECTRUM VIEWED THROUGH A COOLER GAS \Rightarrow DARK-LINE (ABSORPTION) SPECTRUM **Absorption**

Kirchoff's laws



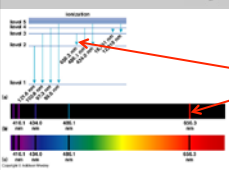
Emission Spectra

- 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!!

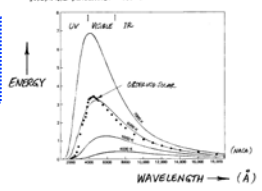
All-sky map of H Alpha emission



CONTINUOUS SPECTRUM OF EMISSION BY "BLACK BODY"

PLANCK'S RADIATION LAW: BEHAVIOR OF THERMAL RADIATION AS TEMPERATURE IS VARIED

"BLACK-BODY" (THERMAL) SPECTRUM



Planck

Peak emission and total energy VARY with temperature

TOTAL ENERGY EMITTED \sim (TEMPERATURE)⁴

$\epsilon = \sigma T^4$ STEFAN-BOLTZMANN LAW

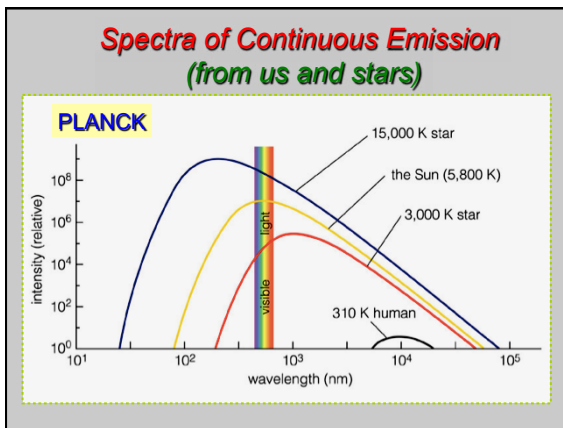
WAVELENGTH OF PEAK EMISSION $\sim 1 / \text{TEMPERATURE}$

$\lambda_{\text{max}} \sim \frac{1}{T}$ WIEN'S LAW

IF INCREASE T FROM 3000 K TO 6000 K, E INCREASES BY FACTOR $6 \times 6 \times 6 \times 6 = 1296!$

"Law 1" Stefan-Boltzmann

"Law 2" Wien



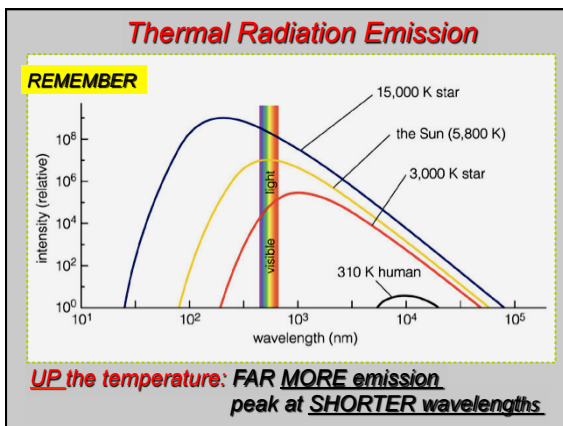
Thermal radiation spectrum

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

$$\epsilon = \sigma T^4$$

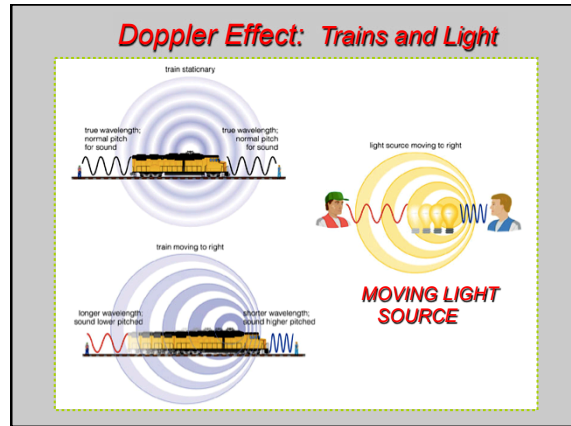
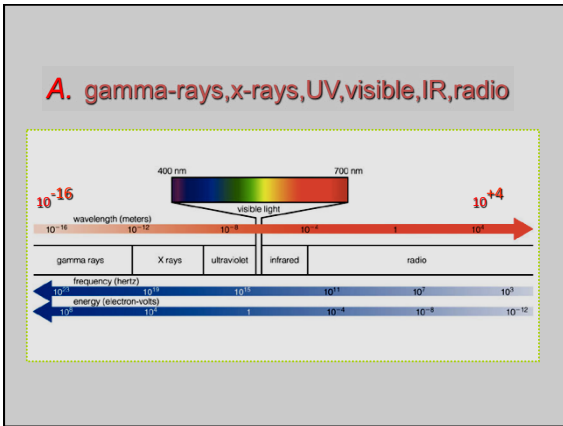
"Luminosity" = "Law 1" x Surface Area of star

Law 2: Wavelength of peak emission

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


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



DOPPLER EFFECT

RECEDING SOURCE IS RED SHIPPED
 LIGHT FROM APPROACHING SOURCE IS BLUE

CRESTS FURTHER APART
 LONGER WAVELENGTH

WAVECRESTS CLOSER TOGETHER
 SHORTER WAVELENGTH OR HIGHER FREQUENCY

CHANGE IN WAVELENGTH $\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$ = VELOCITY OF SOURCE / SPEED OF LIGHT

CAN USE TO CALCULATE LINE-OF-SIGHT VELOCITY OF SOURCE:
 "DOPPLER VELOCITY" v

$v = \frac{\Delta \lambda}{\lambda} c$ IF ABSORPTION LINE AT 5000 Å REDSHIFTED BY 0.5 Å

$v = \frac{(+0.5 \text{ \AA}) (300,000 \text{ km/sec})}{5,000 \text{ \AA}}$
 $= + 30 \text{ km/sec}$

Applied to positions of spectral lines

Doppler Demo

Measuring the Line Shift

Laboratory spectrum

Object 1

Object 2

Object 3

Object 4

Stationary

Moving Away (redshifted)

Away Faster

Moving Toward (blueshifted)

Toward Faster

• Measure the Doppler effect from shifts in the wavelengths of spectral lines

How does Doppler shift tell us the ROTATION RATE of a star?

slow

star A

fast

star B

Doppler shifts from different portions of star broaden the spectral line

Black hole in the center of galaxy M84 was detected using Doppler shifts!

- Big blueshift just above center, big redshift just below
 - gas whirling at incredible velocities around the core

