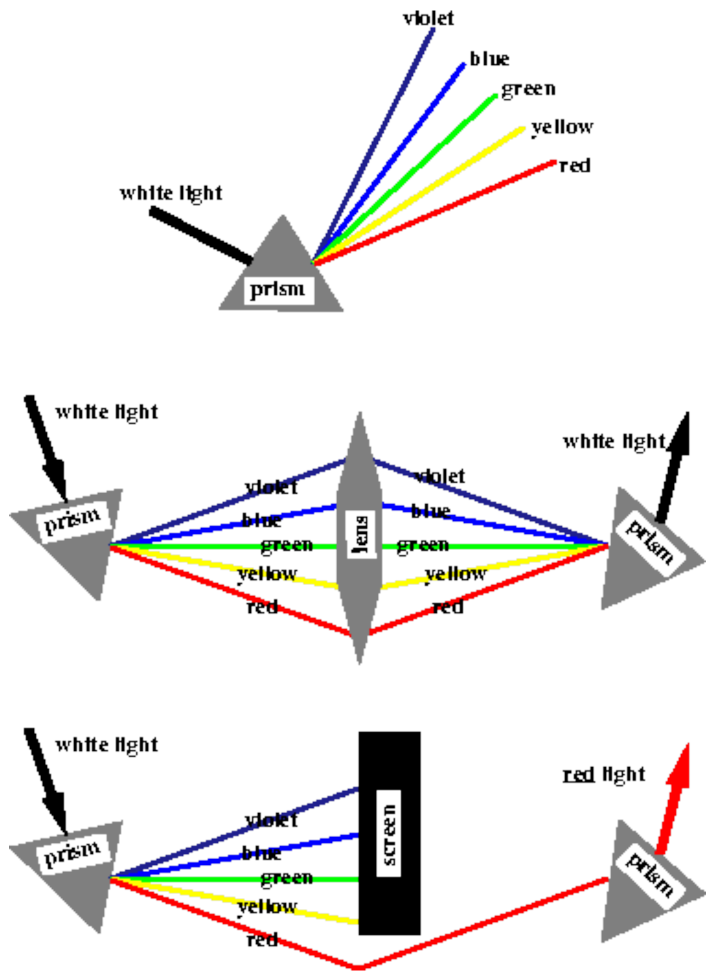
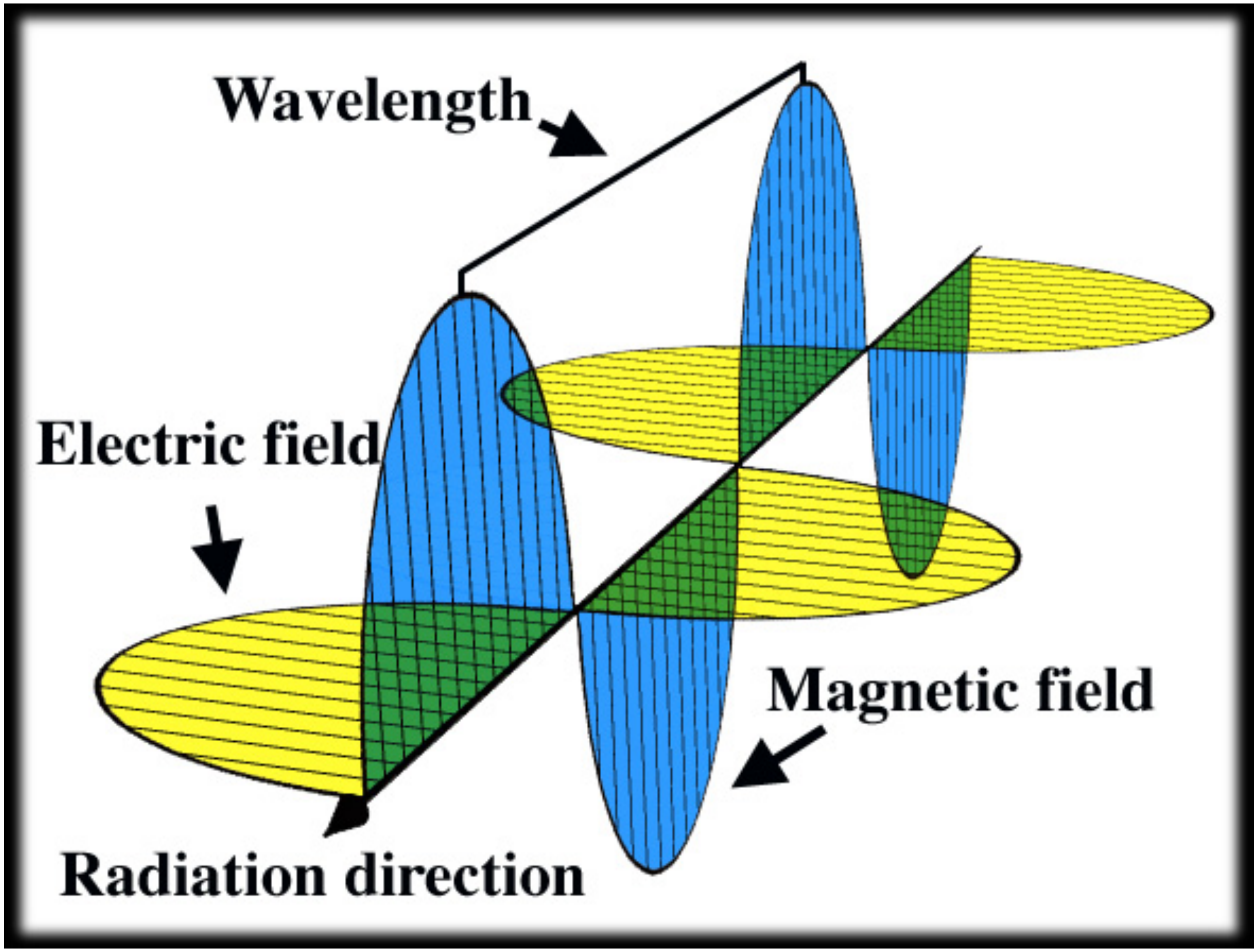
Light as a Tool

- **Gravity is one major tool for astronomy; light is the another.**
- **Topics on Light/Radiation:**
  - Light as a wave
  - Telescopes and observing
  - Brightness
  - Radiation laws and spectra
  - Blackbodies
  - Light as a particle
  - Interaction of matter and light
  - Doppler shift

Newton's Experiments with Light



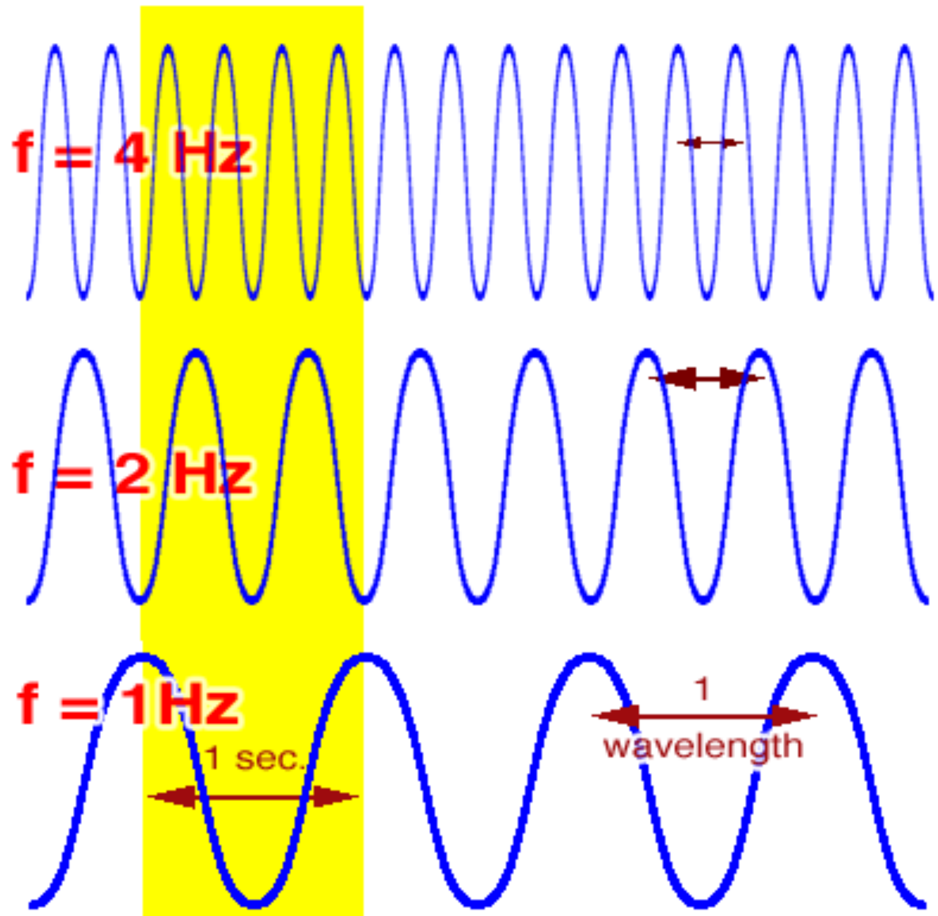
Electromagnetic Waves

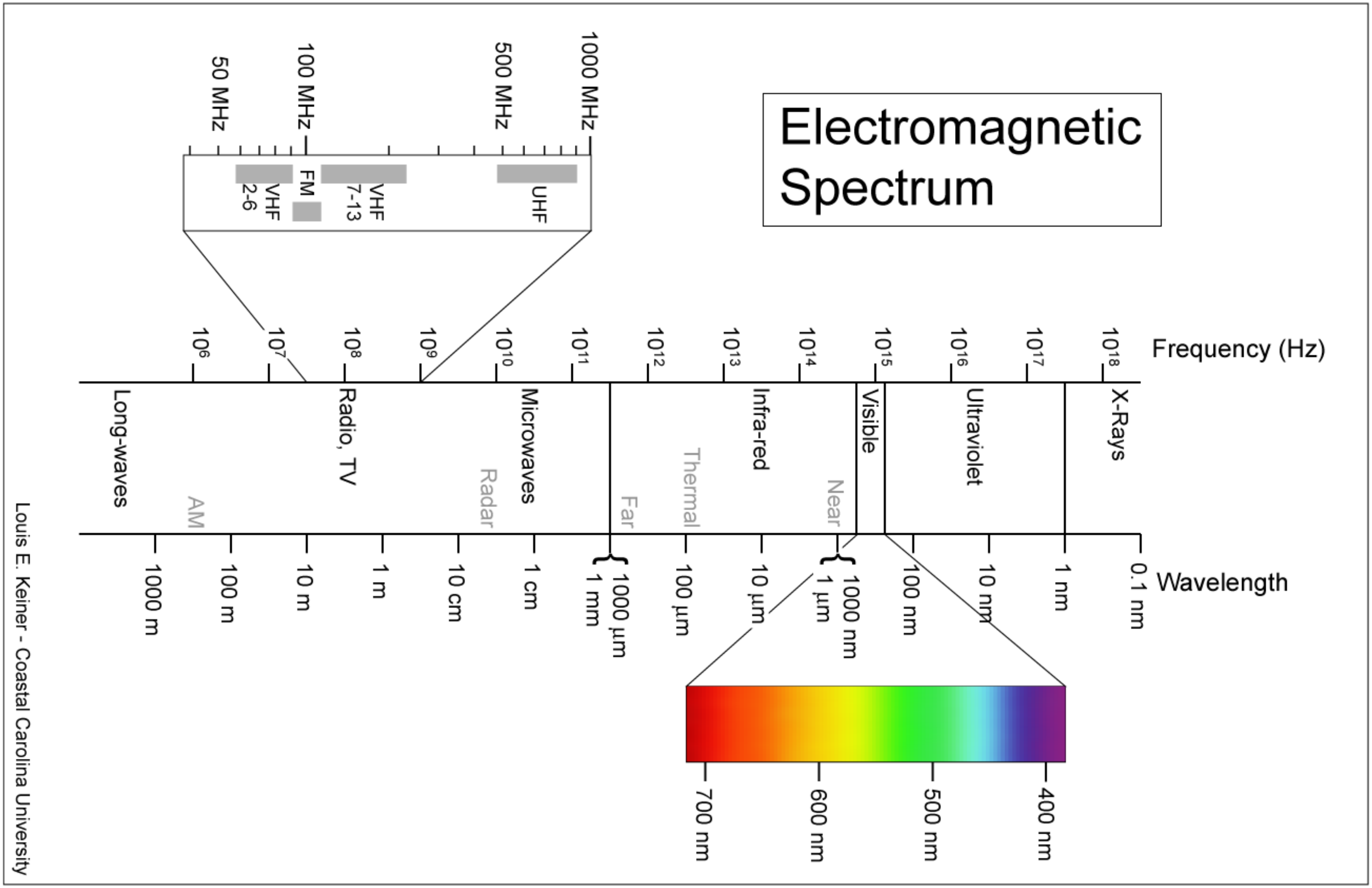


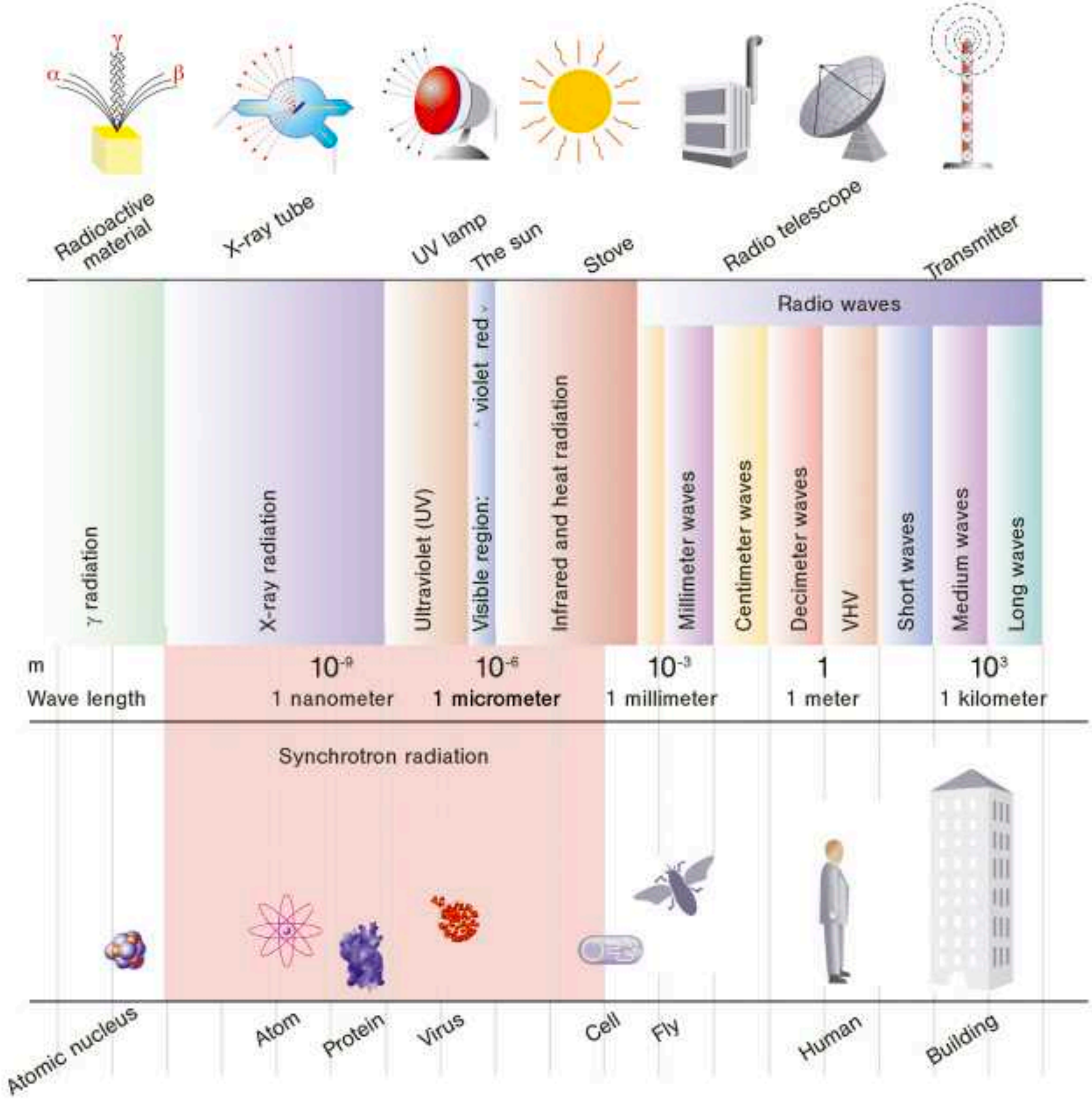
Properties of Waves: Frequency and Wavelength

- Frequency, typically use symbols like f or ν
- For wavelength, usually use symbol λ
- Speed of light is c
- The relationship between these parameters is:

$$\lambda\nu = c$$

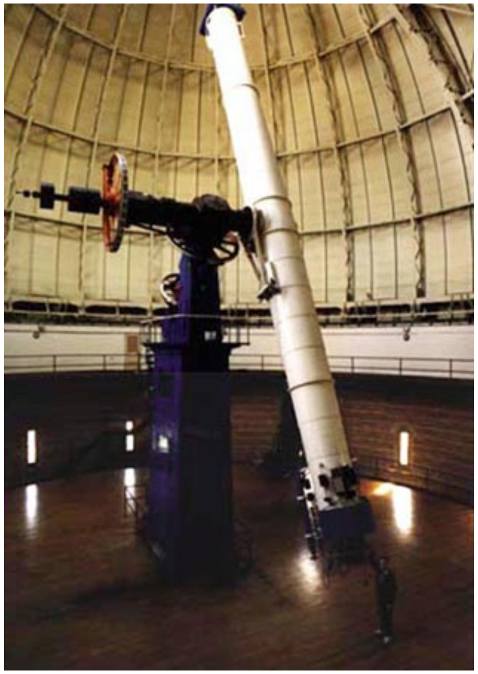



Electromagnetic Spectrum
50 MHz
100 MHz
500 MHz
1000 MHz
VHF 2-6
FM
VHF 7-13
UHF
Frequency (Hz)
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
Long-waves
AM
Radio, TV
Radar
Microwaves
Far
Thermal
Infra-red
Near
Visible
Ultraviolet
X-Rays
Wavelength
1000 m
100 m
10 m
1 m
10 cm
1 cm
1 mm
1000 µm
100 µm
10 µm
1 µm
1000 nm
100 nm
10 nm
1 nm
0.1 nm
700 nm
600 nm
500 nm
400 nm
Louis E. Keiner - Coastal Carolina University

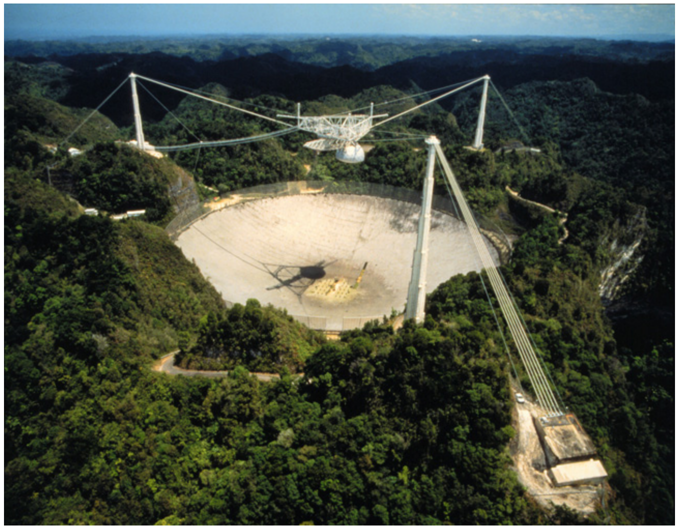


α
γ
β
Radioactive material
X-ray tube
UV lamp
The sun
Stove
Radio telescope
Transmitter
Radio waves
γ radiation
X-ray radiation
Ultraviolet (UV)
Visible region: violet red
Infrared and heat radiation
Millimeter waves
Centimeter waves
Decimeter waves
VHV
Short waves
Medium waves
Long waves
m
Wave length
10⁻⁹
1 nanometer
10⁻⁶
1 micrometer
10⁻³
1 millimeter
1
1 meter
10³
1 kilometer
Synchrotron radiation
Atomic nucleus
Atom
Protein
Virus
Cell
Fly
Human
Building

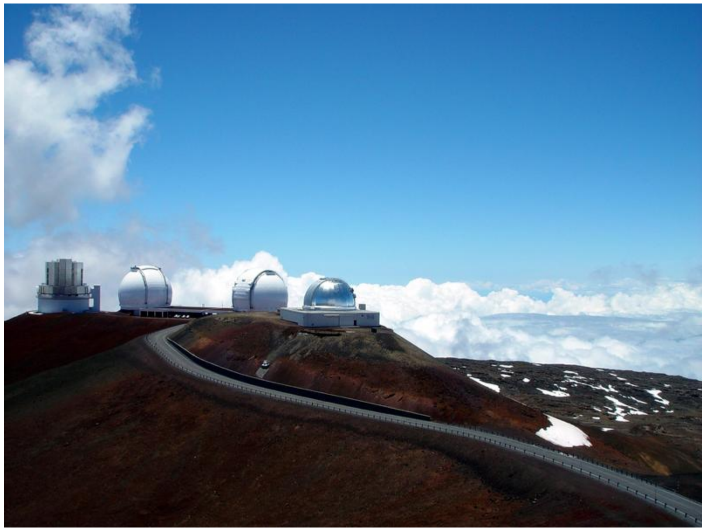
Telescopes



Yerkes Refractor



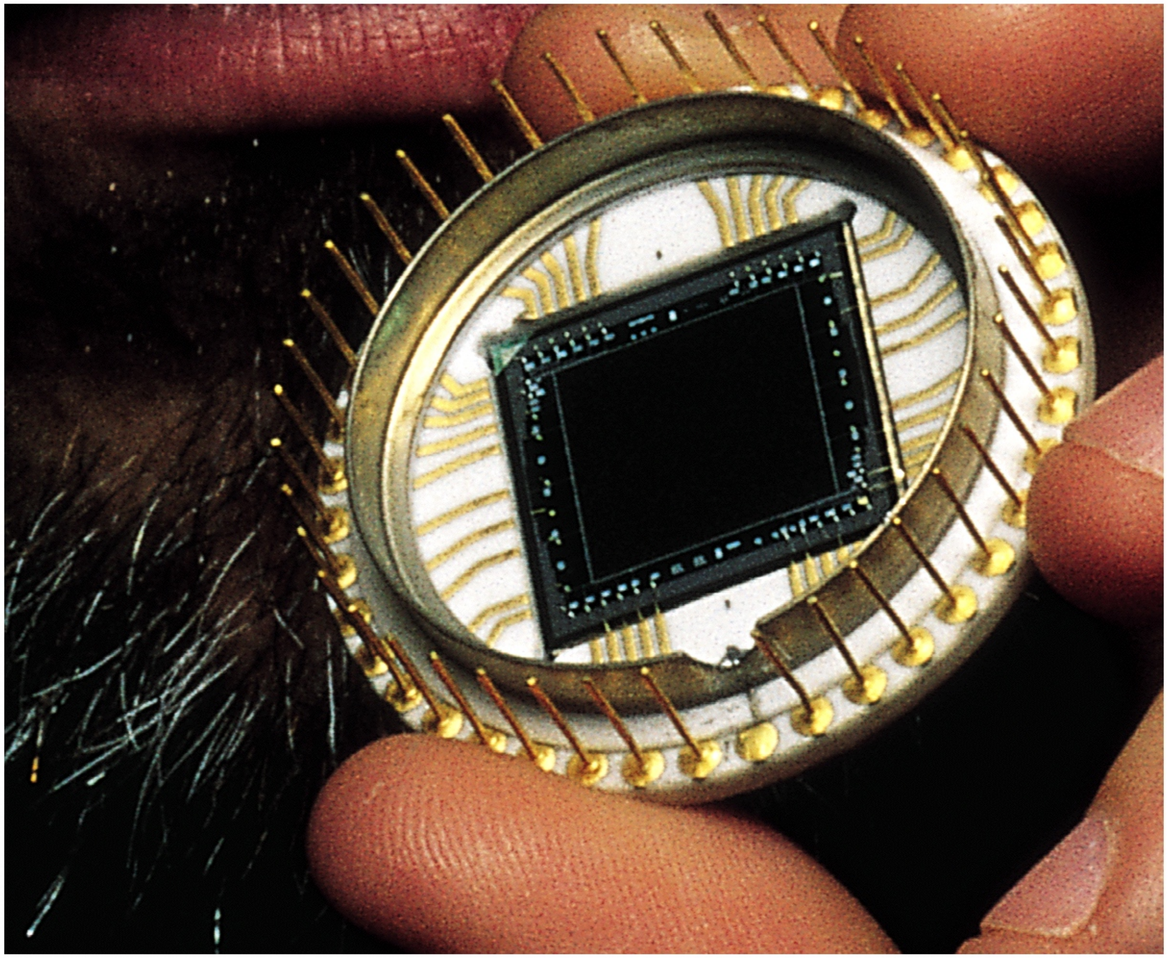
Arecibo Radio Dish

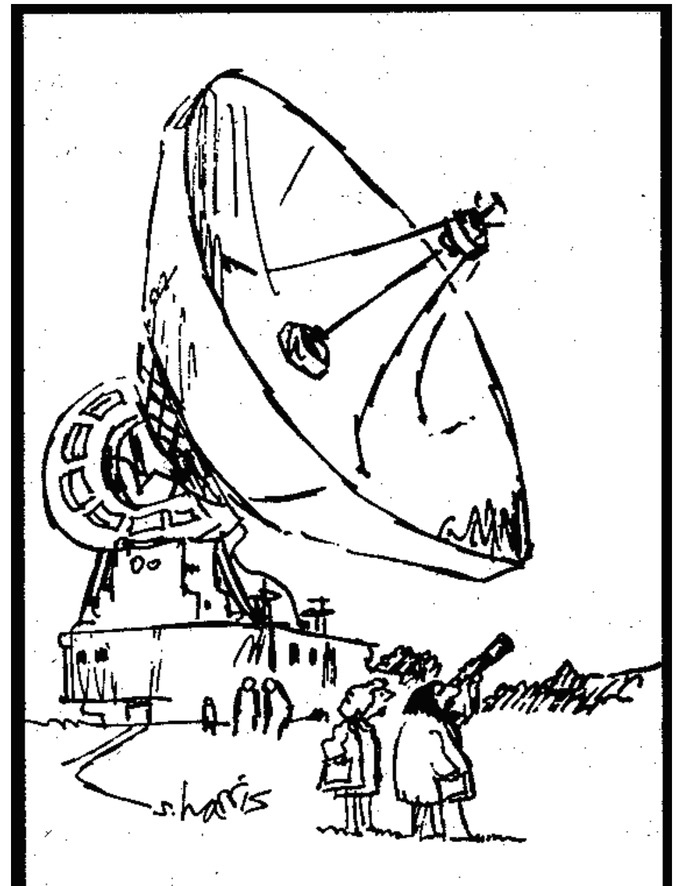


Mauna Kea

Hubble Space Telescope

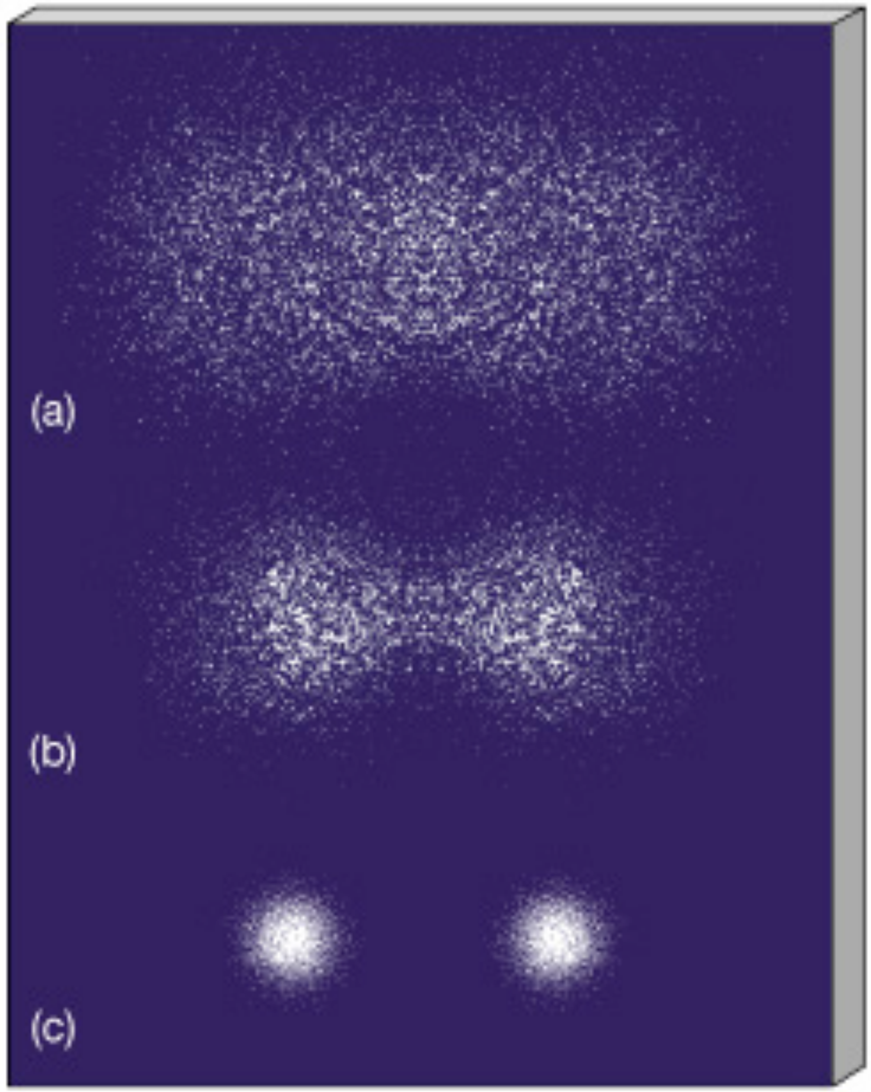
Charged Coupled Device (CCD)





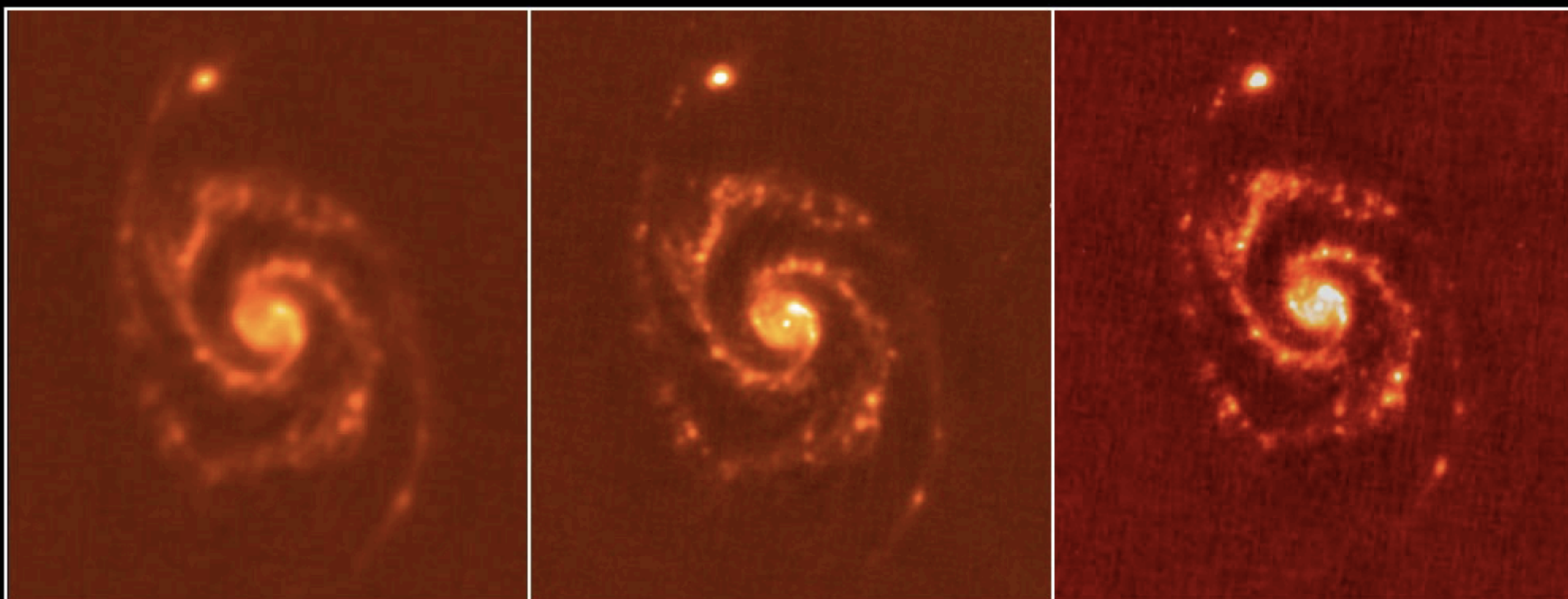
"Just checking."

Spatial Resolution of Telescopes



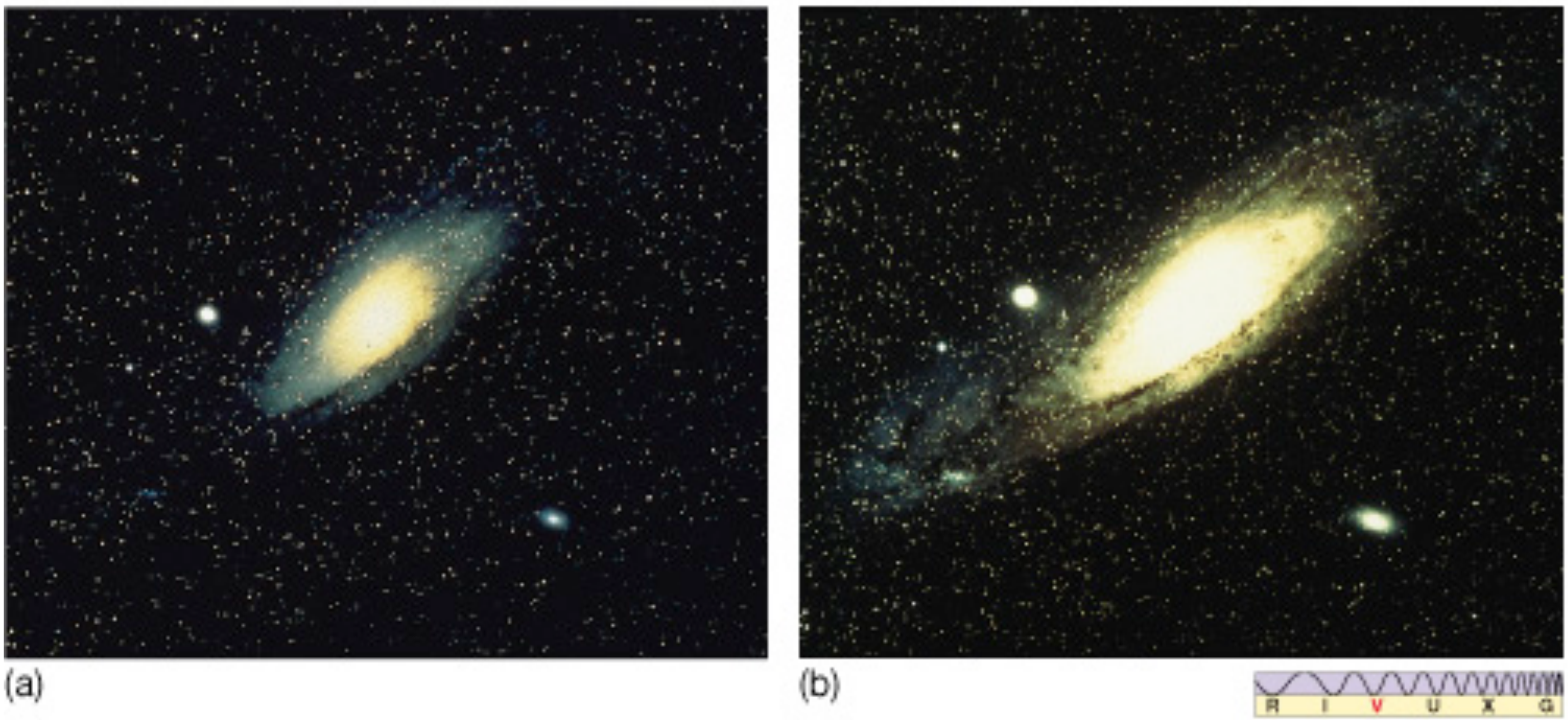
Spatial Resolution Depends on Wavelength (or color)

Herschel/PACS Images of M51 (“Whirlpool Galaxy”)



160 µm 100 µm 70 µm

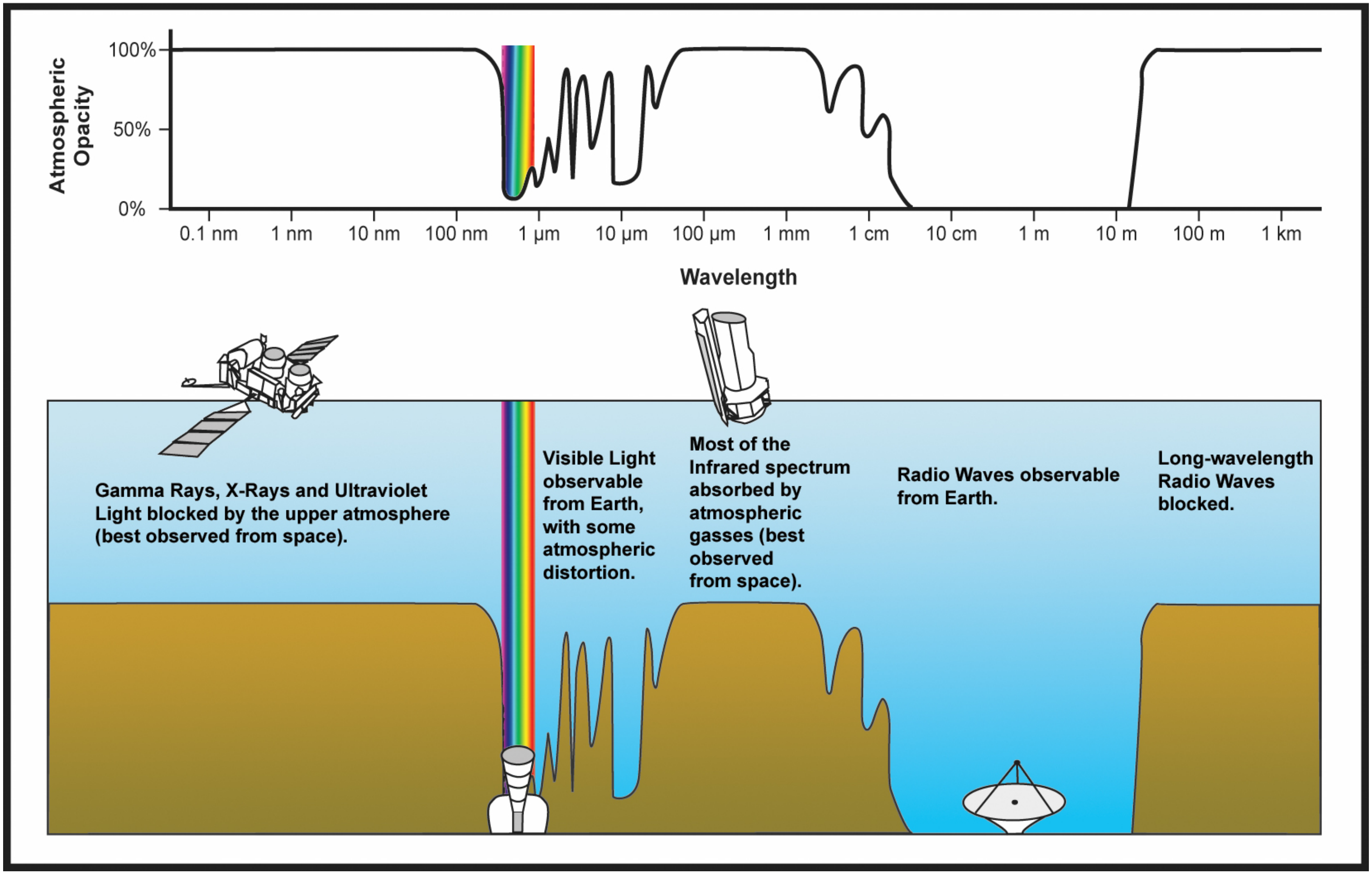
Sensitivity of Telescopes



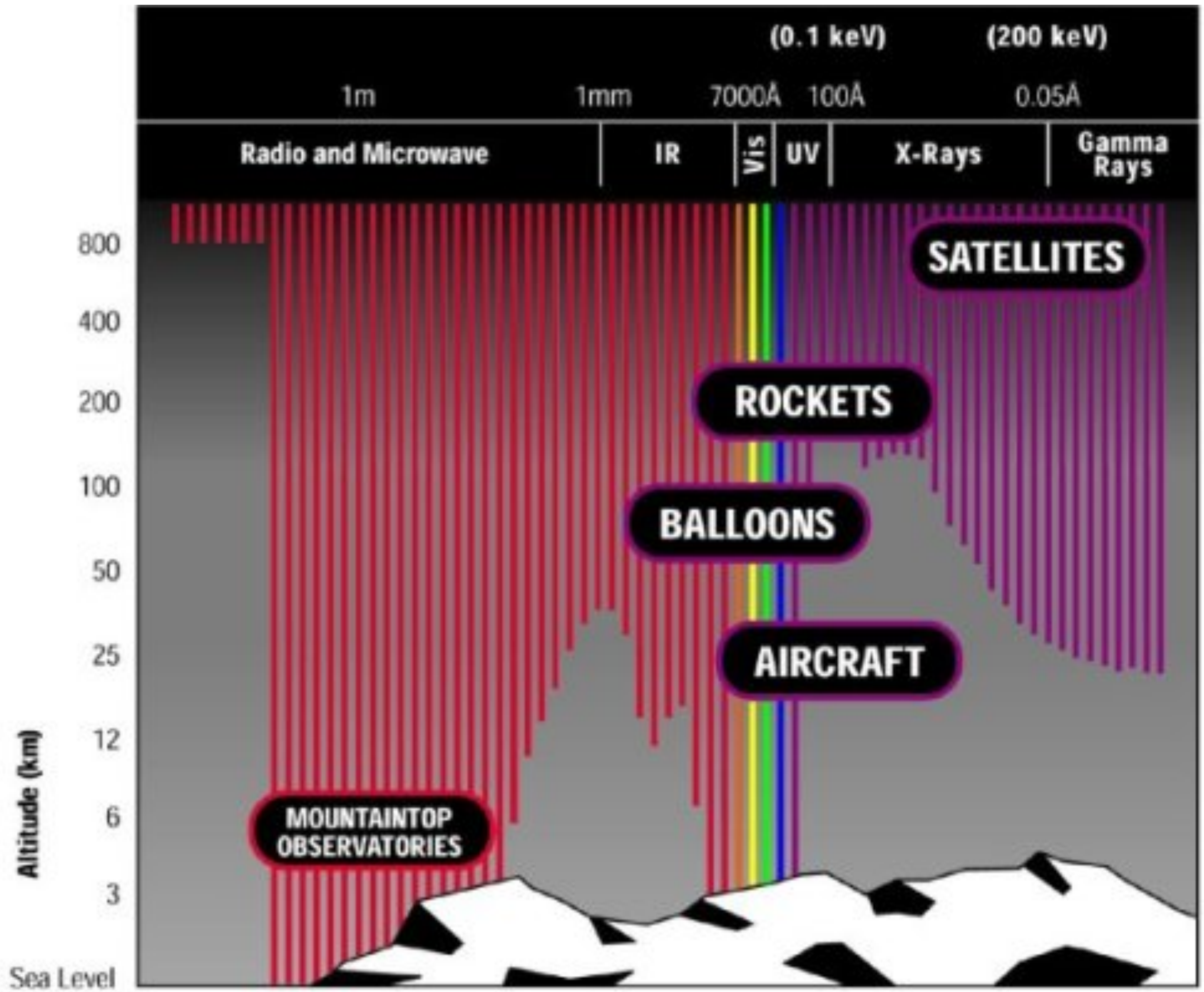
The Earth's Shroud

- The Earth's atmosphere acts to "screen" out certain kinds, or bands, of light.
- Visible light and radio waves penetrate the atmosphere easiest; the IR somewhat. Most other bands are effectively blocked out.
- Consequently, telescopes are built at high altitude or placed in space to access these otherwise inaccessible bands.

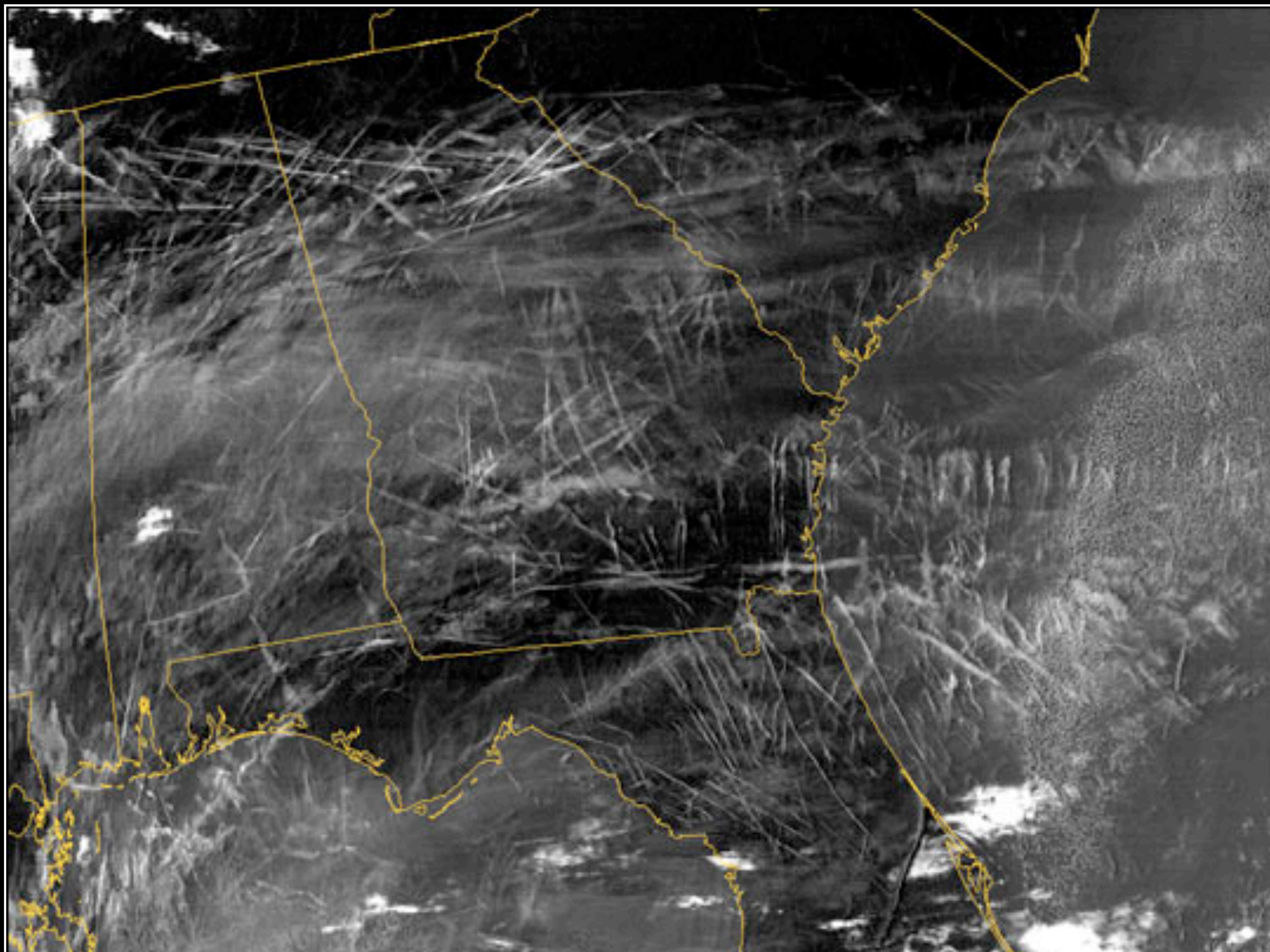
Transparency of the Atmosphere

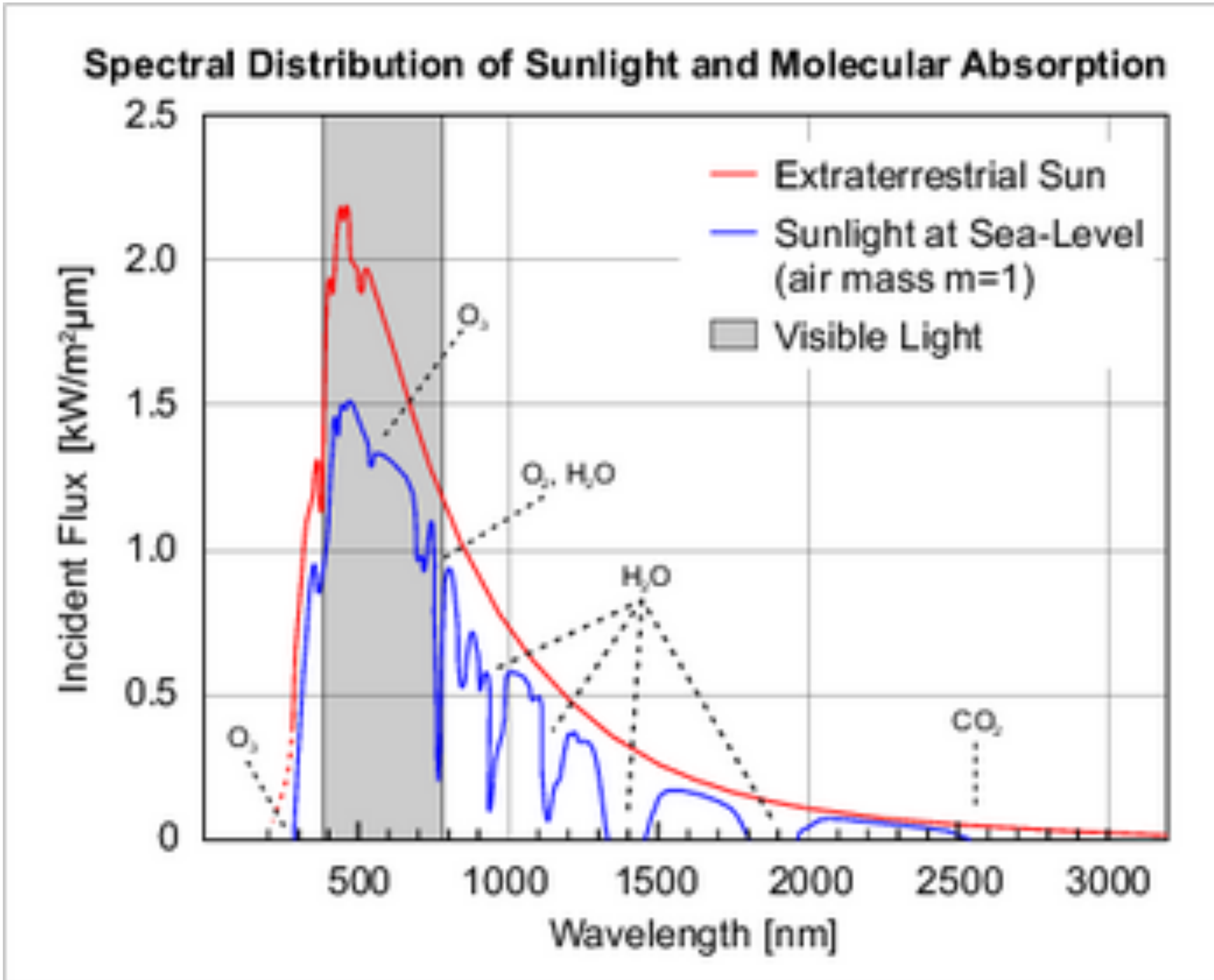


Transmission with Altitude



Contrails from Airplanes

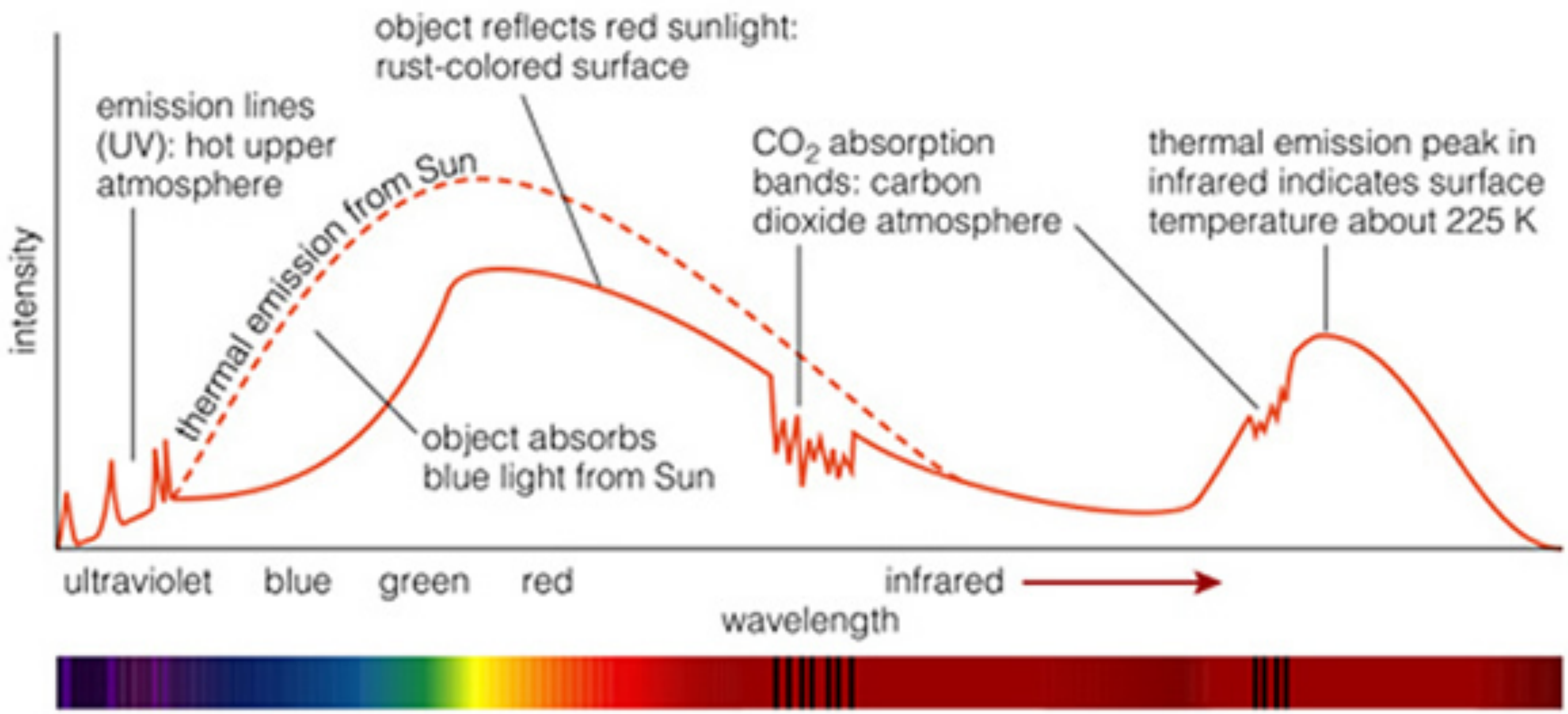




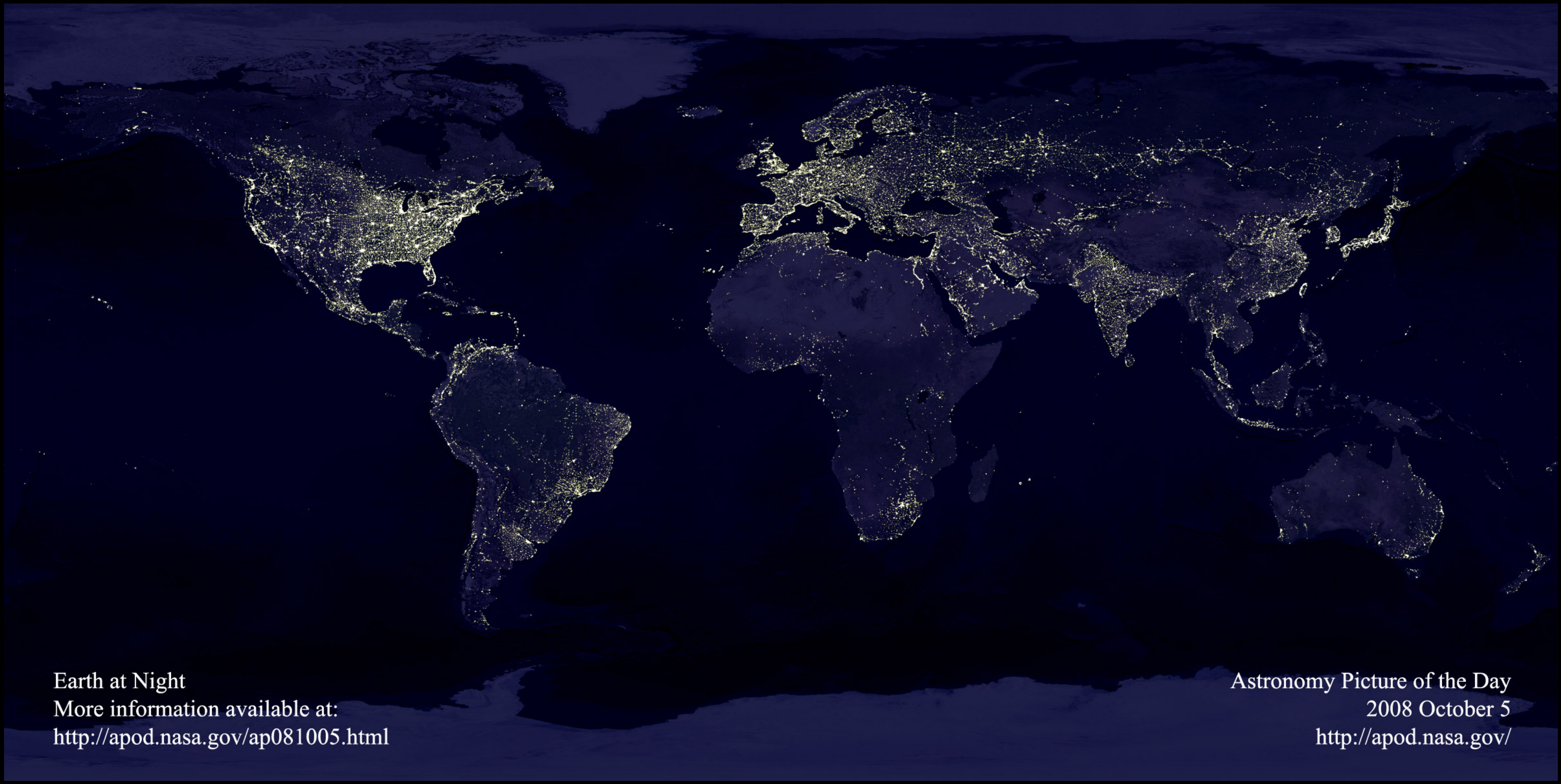
Spectral Distribution of Sunlight and Molecular Absorption
Extraterrestrial Sun
Sunlight at Sea-Level (air mass m=1)
Visible Light
Incident Flux [kW/m²µm]
Wavelength [nm]
2.5
2.0
1.5
1.0
0.5
0
500
1000
1500
2000
2500
3000
O3
O2, H2O
H2O
CO2

The Case of Mars:

Mix of Atmospheric Absorption and Reflection, and Thermal Emission by the Planet



Light Pollution



Flux of Light

Light carries energy (e.g., warmth from sunlight)

How does this energy propagate through space? And how does that relate to the apparent brightness of a source?

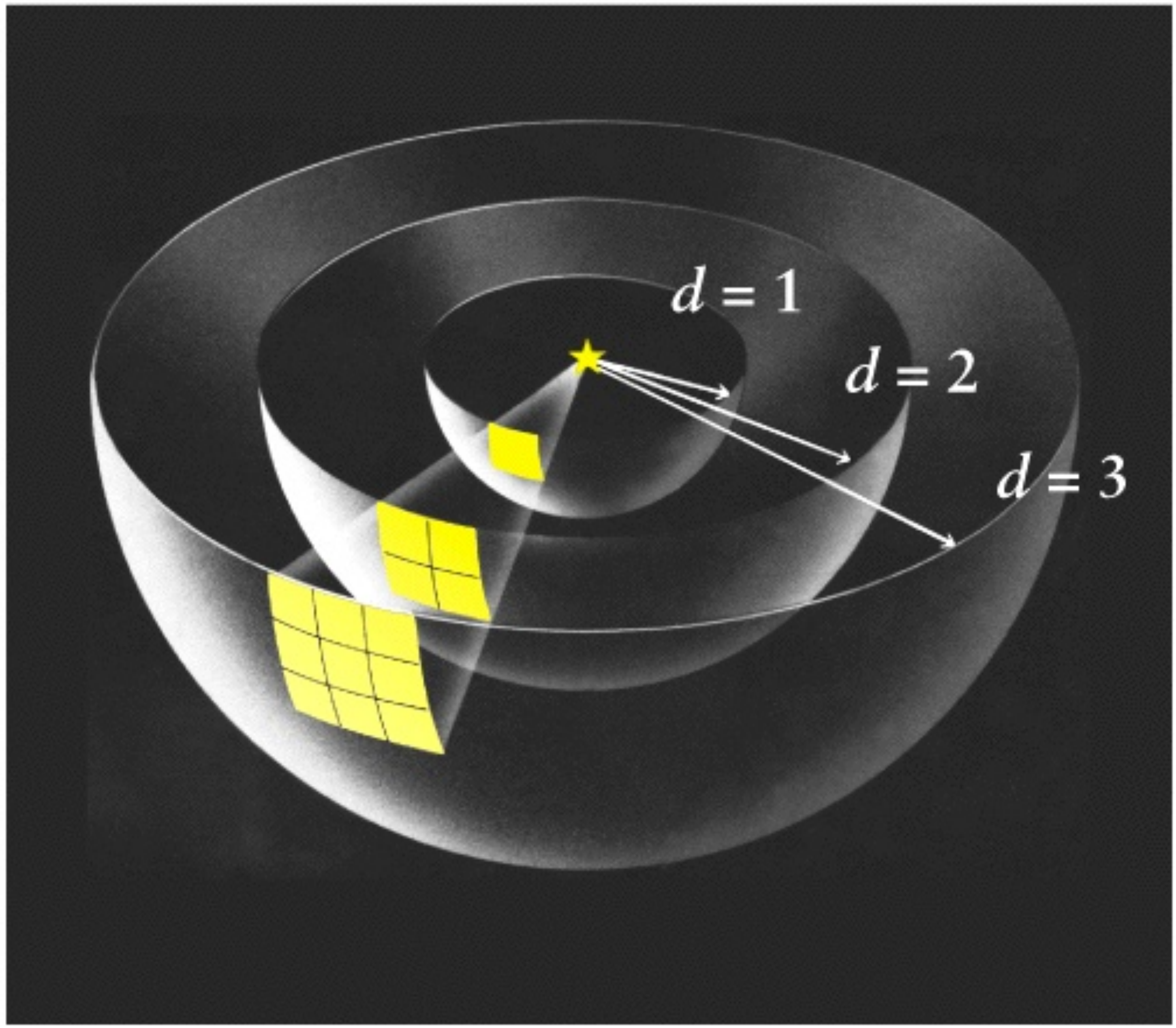
"Flux" describes how light spreads out in space:

with L=luminosity (or power),

and d = distance,

flux is Watts/sq meter = J/s/m^2

$$F = \frac{L}{4\pi d^2}$$



d = 1
d = 2
d = 3

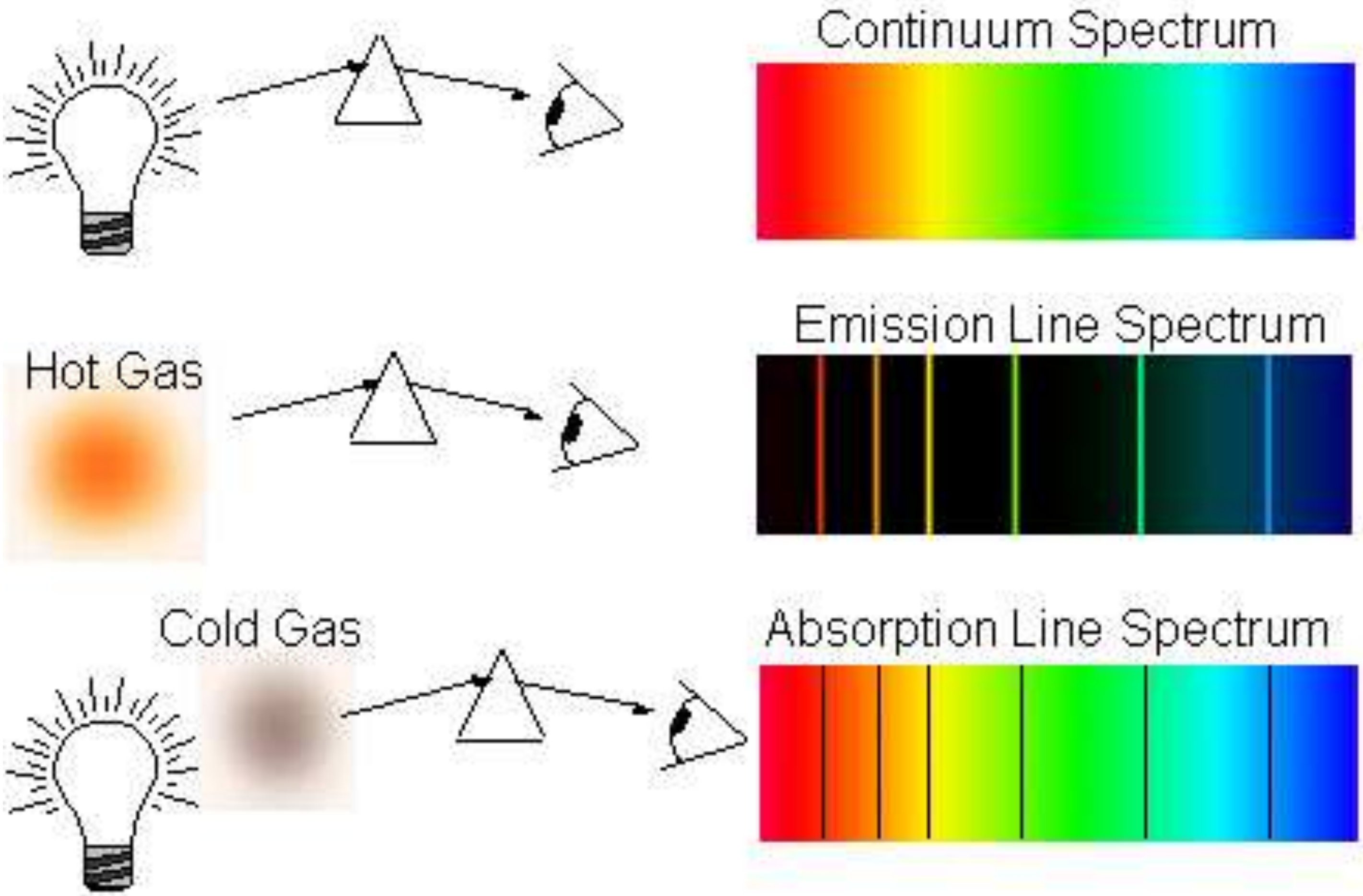
Kirchoff's Laws

I. A hot solid, liquid, or dense gas produces a continuous spectrum of emission.

II. A thin gas seen against a cooler background produces a bright line or emission line spectrum.

III. A thin gas seen against a hotter soure of continuous radiation produces a dark line or absorption line spectrum.

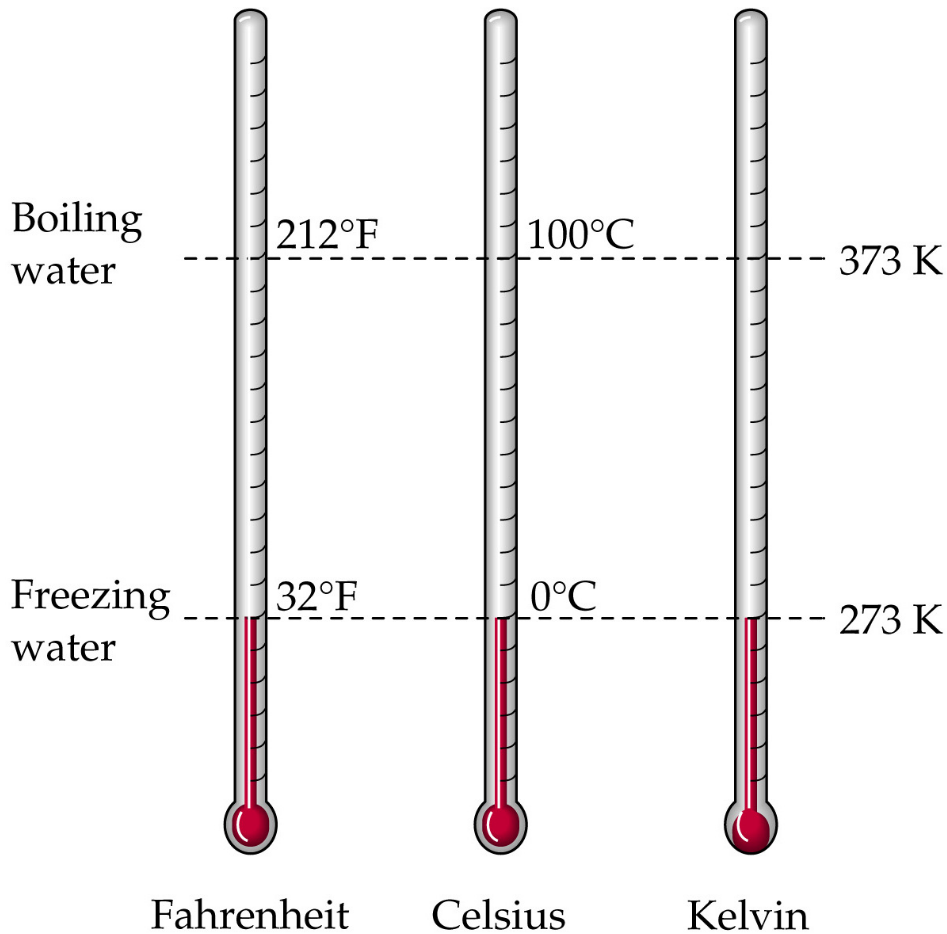
Kirchoff's Laws: Illustrations



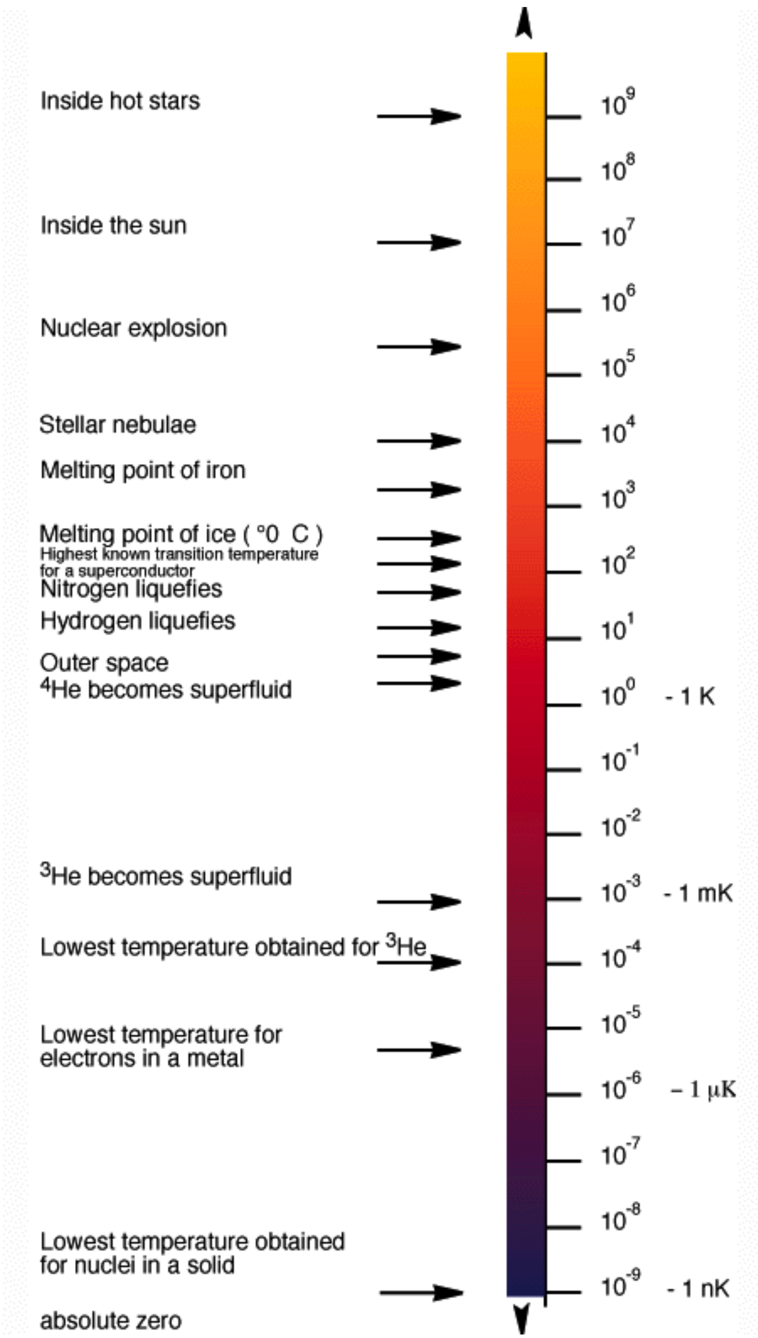
Blackbodies

- A common approximation for the continuous spectrum produced by many astrophysical objects is a blackbody (or "Planckian").
- A blackbody (BB) is a *perfect absorber* of all incident light.
- BBs also emit light!

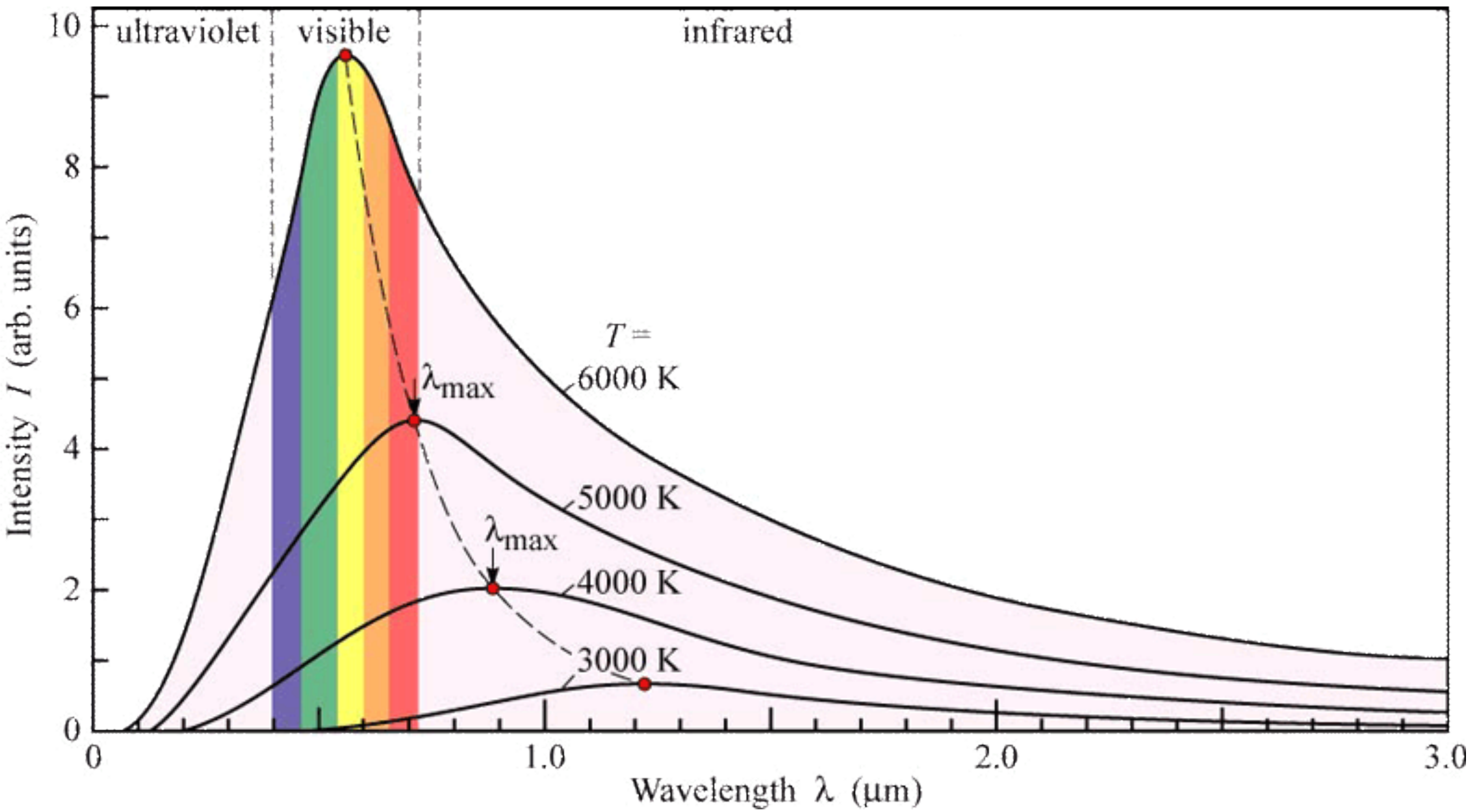
Temperature Scales



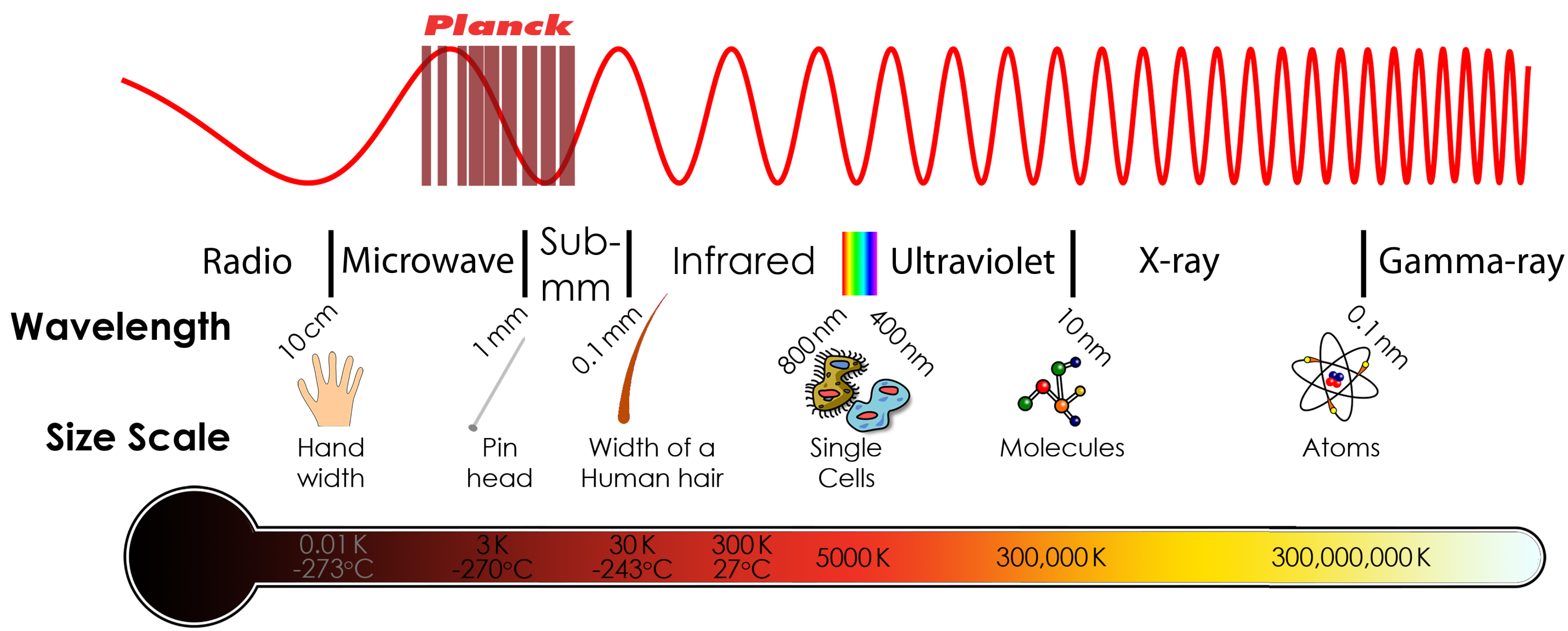
Temperatures of Note



Sample Blackbody Spectra



Graphical Version of Wien's Law



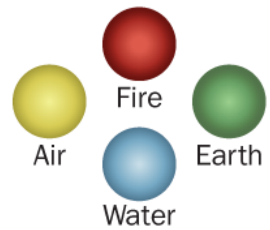
Atomic Physics

- Atoms composed of protons, neutrons, and electrons
- p and n in the nucleus
- e resides in a "cloud" around the nucleus
- m_p/m_n~1
- m_p/m_e~2000

Protons	p	+1	m_p
Neutrons	n	0	m_n
Electrons	e	-1	m_e

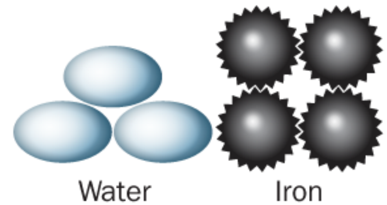
History of the Atom

500 B.C.?



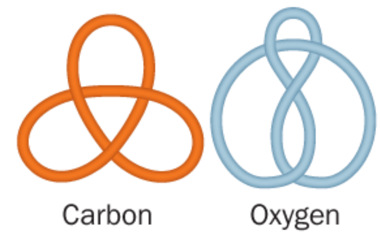
Hindu philosophers discuss atoms as ultimate pieces of the elements earth, air, fire and water. Atoms are round and differ in properties such as color, flavor and odor.

500–400 B.C.



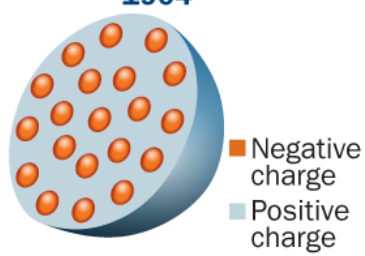
Democritus describes atoms as eternally unchanging and indivisible, all made of the same substance, and differing only in size, shape and arrangement in space.

1867



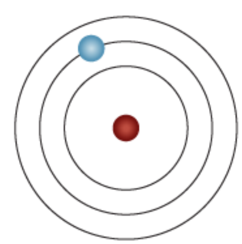
Lord Kelvin proposes a "vortex model" in which atoms are twisted knots, or vortices, in the ether.

1904



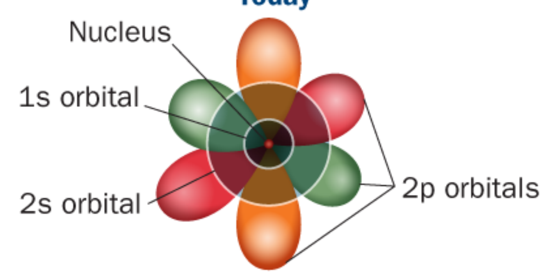
J.J. Thomson proposes the "plum pudding" model of the atom, picturing negatively charged electrons rotating in concentric rings within a sphere of positive electricity.

1913



Bohr's atom model describes a dense, positively charged nucleus, containing nearly all the atom's mass, surrounded by electrons traveling in specific allowed orbits.

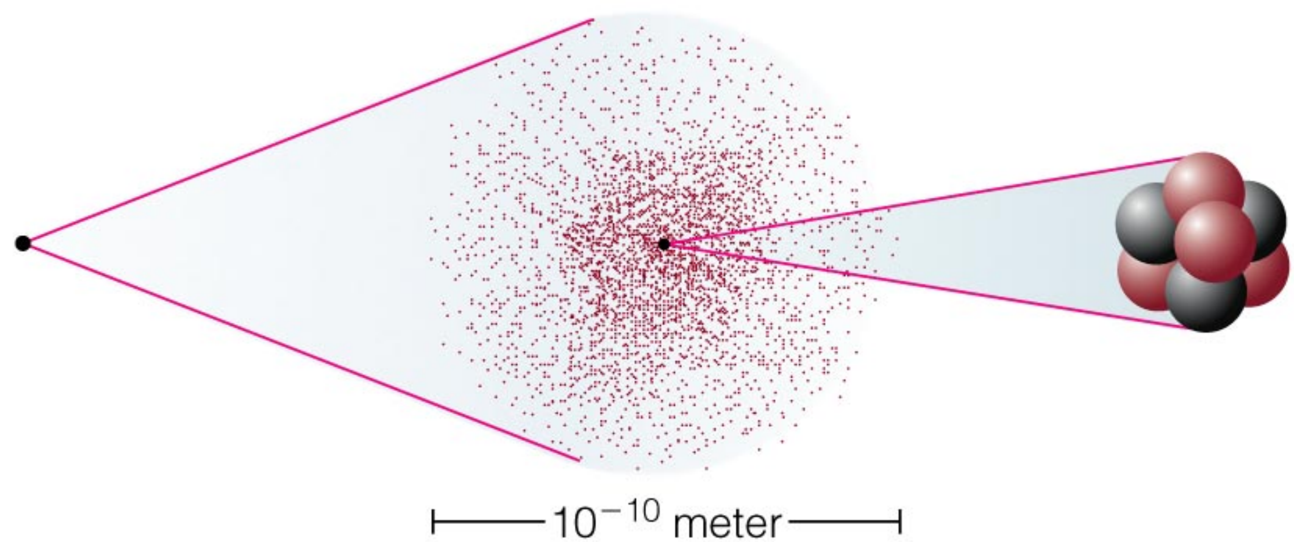
Today



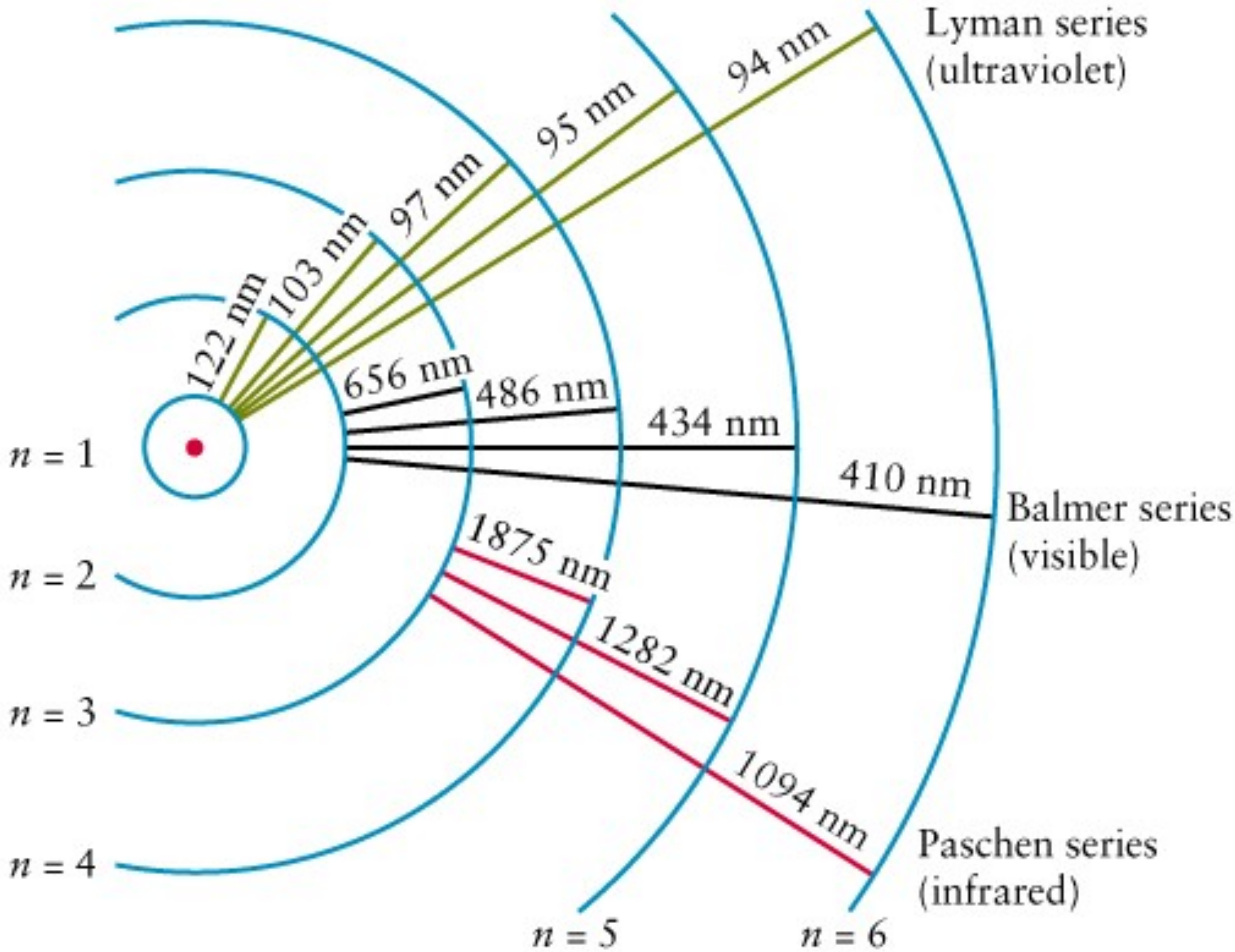
Modern atom Electrons travel not in orbits, but exist as clouds of electric charge within "orbitals" that define regions of space with a high probability of containing the electron.

The Atom:

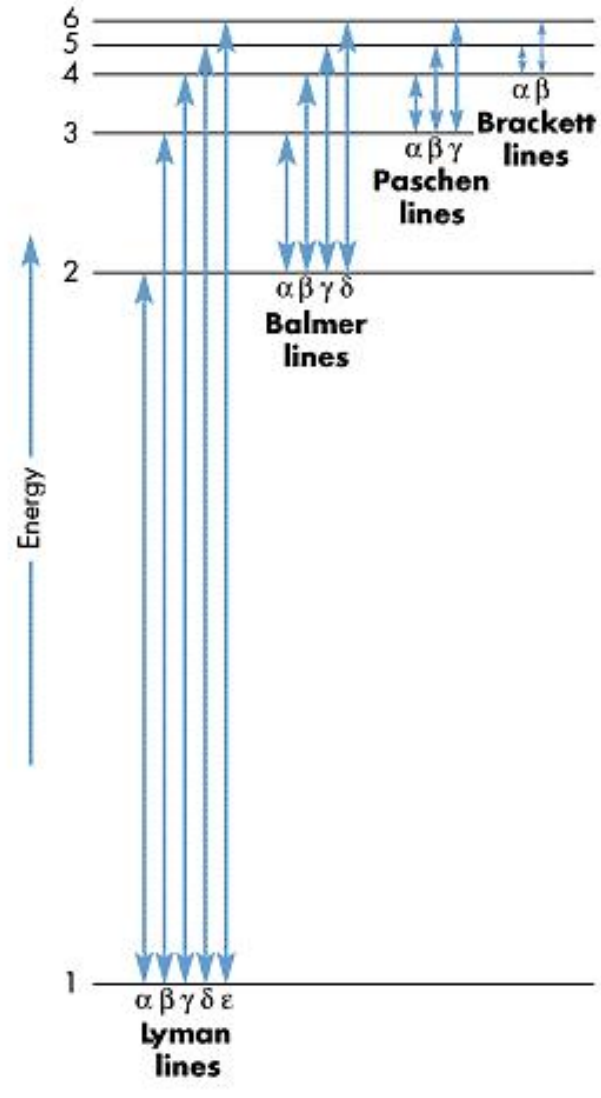
Comparing the "electron cloud" with the nucleus



The Bohr Atom



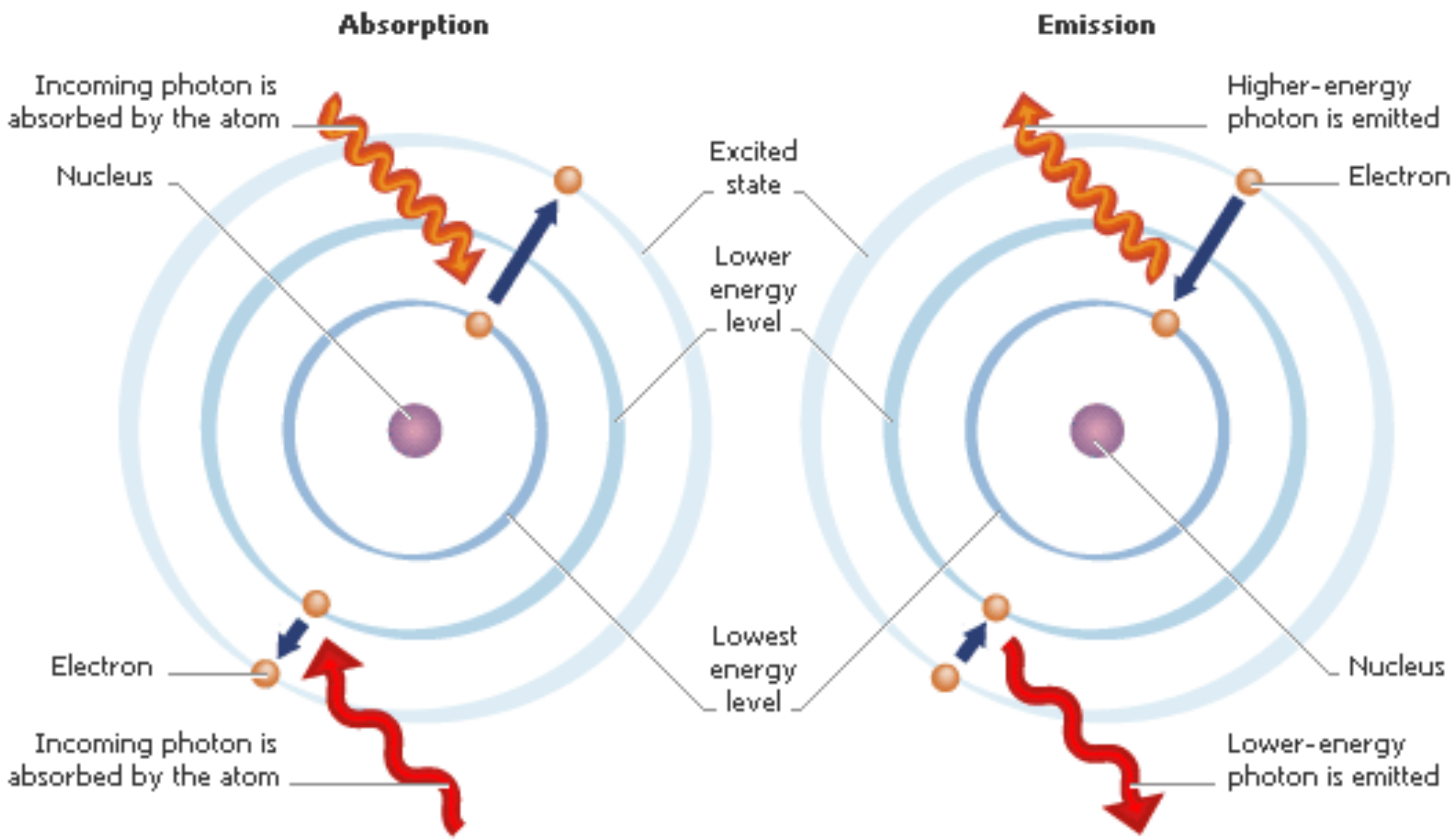
Atomic Energy Level Diagram



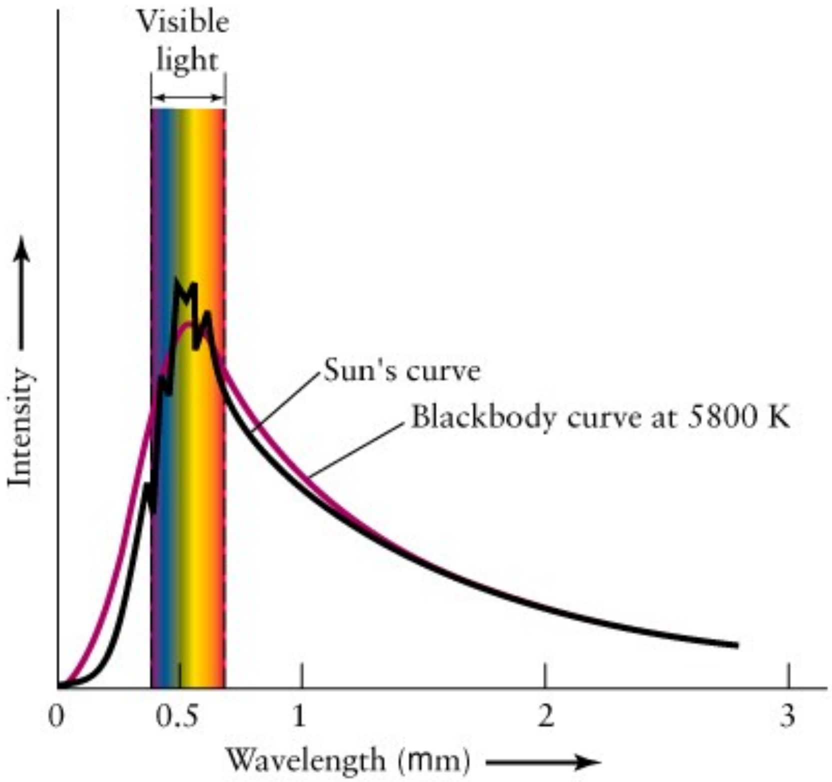
Interaction of Matter and Light

- ***Absorption***: Occurs when a photon of the correct energy moves an e from a lower orbit to an upper orbit.
- ***Emission***: Occurs when an e drops from an upper orbit to a lower one, thereby ejecting a photon of corresponding energy
- ***Ionization***: Occurs when a photon knocks an e free from the atom
- ***Recombination***: Capture an electron

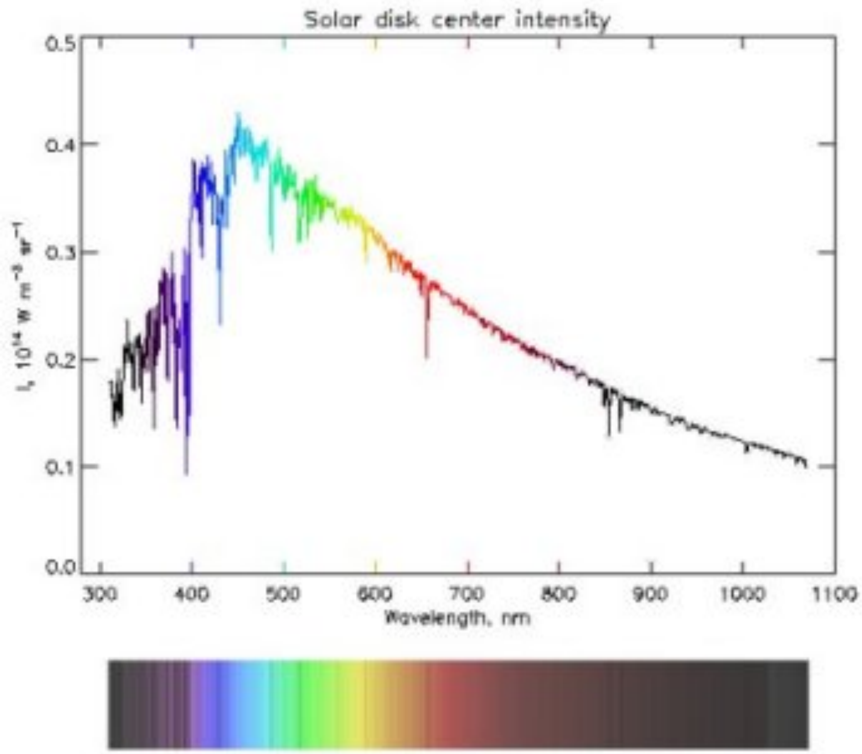
Absorption and Emission



The Gross Solar Spectrum

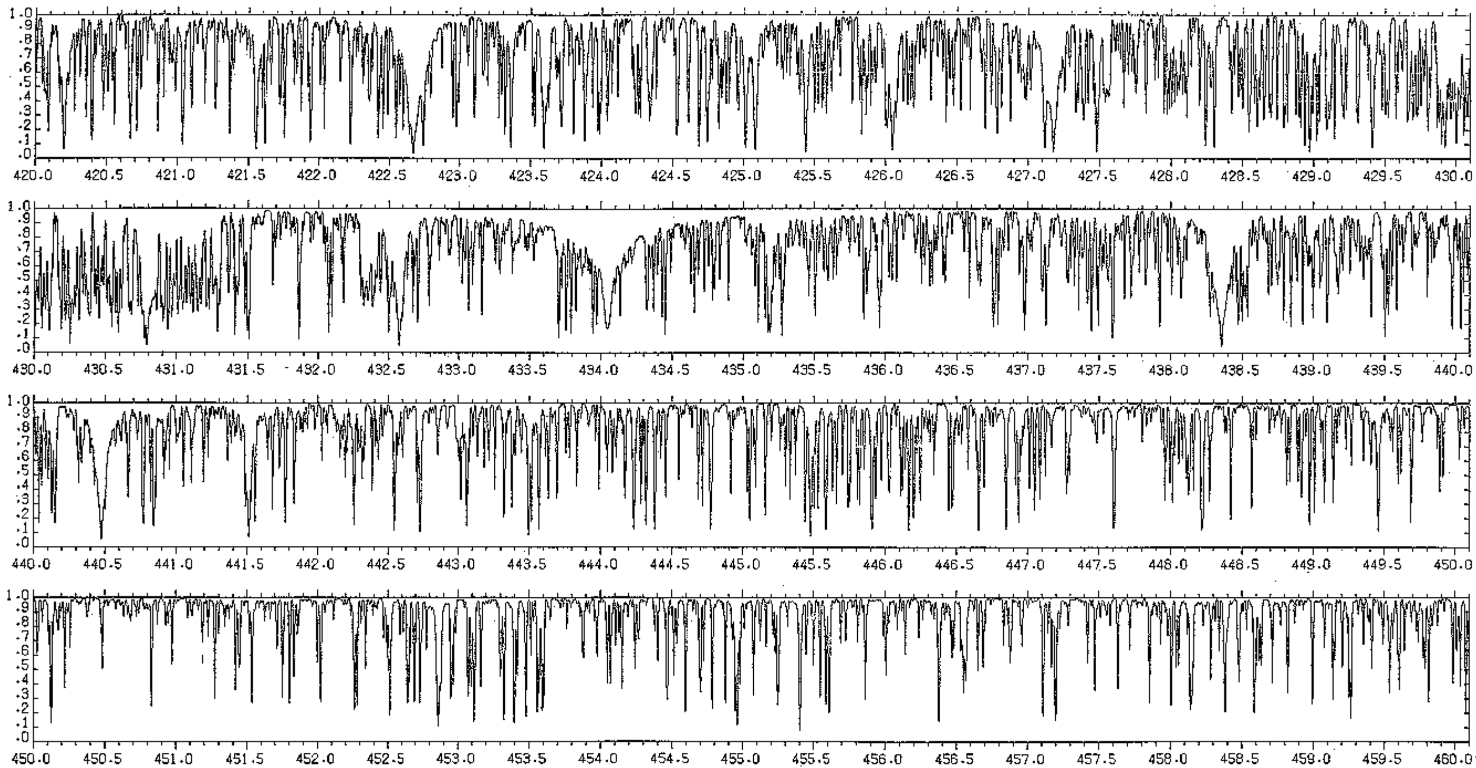


Blackbody-like

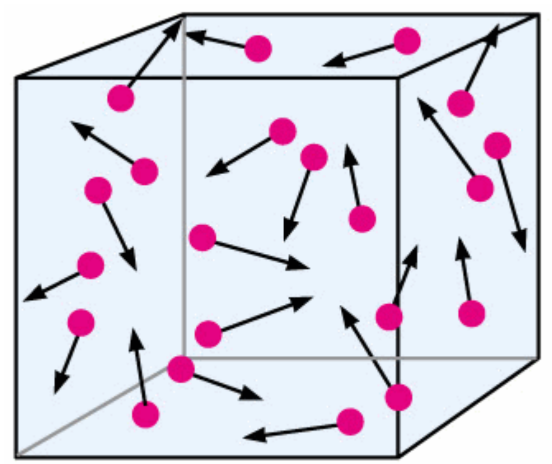


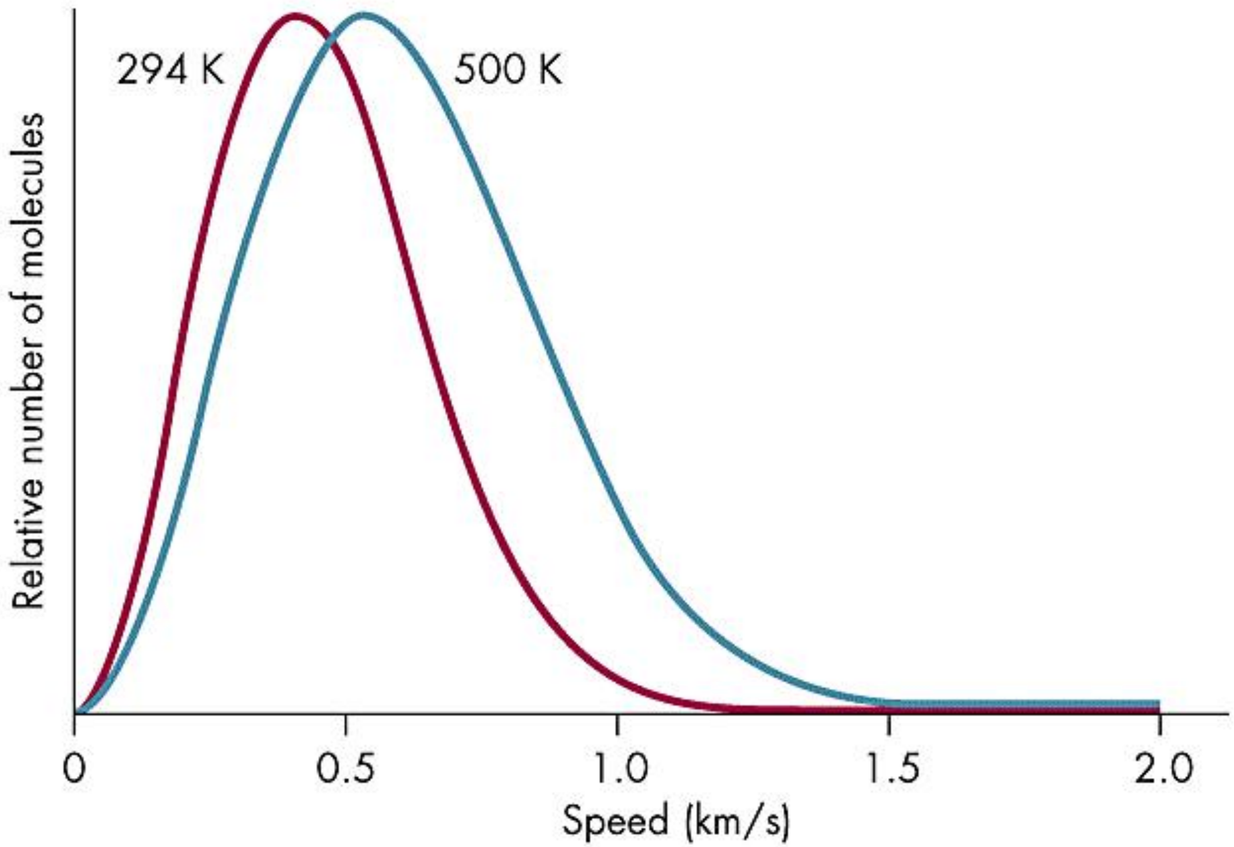
Blackbody deviations

Solar Fingerprint



Thermal Motions of Particles in Gases





Doppler Shift

The Doppler effect is a change in λ, ν, E of light when either or both the source and detector are moving *toward* or *away* from one another. So, this is a relative effect.

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v_{rad}}{c}$$

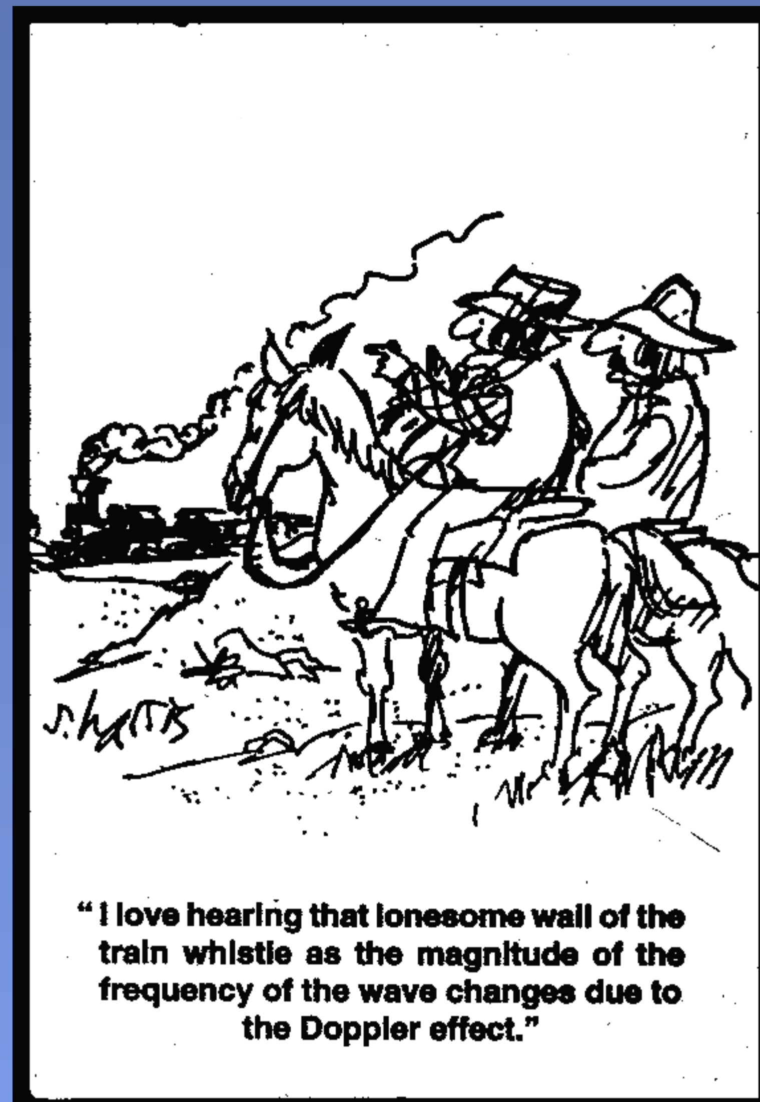
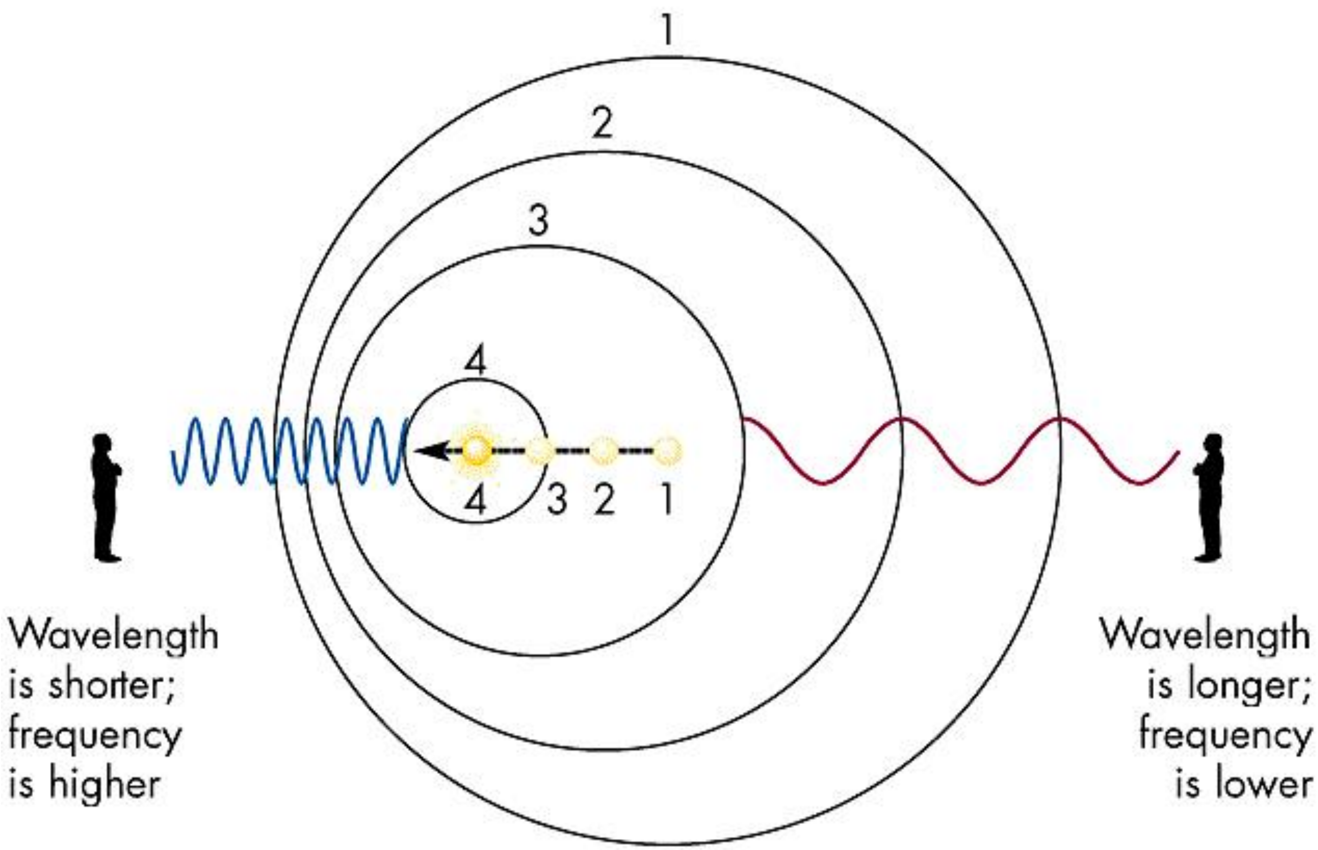
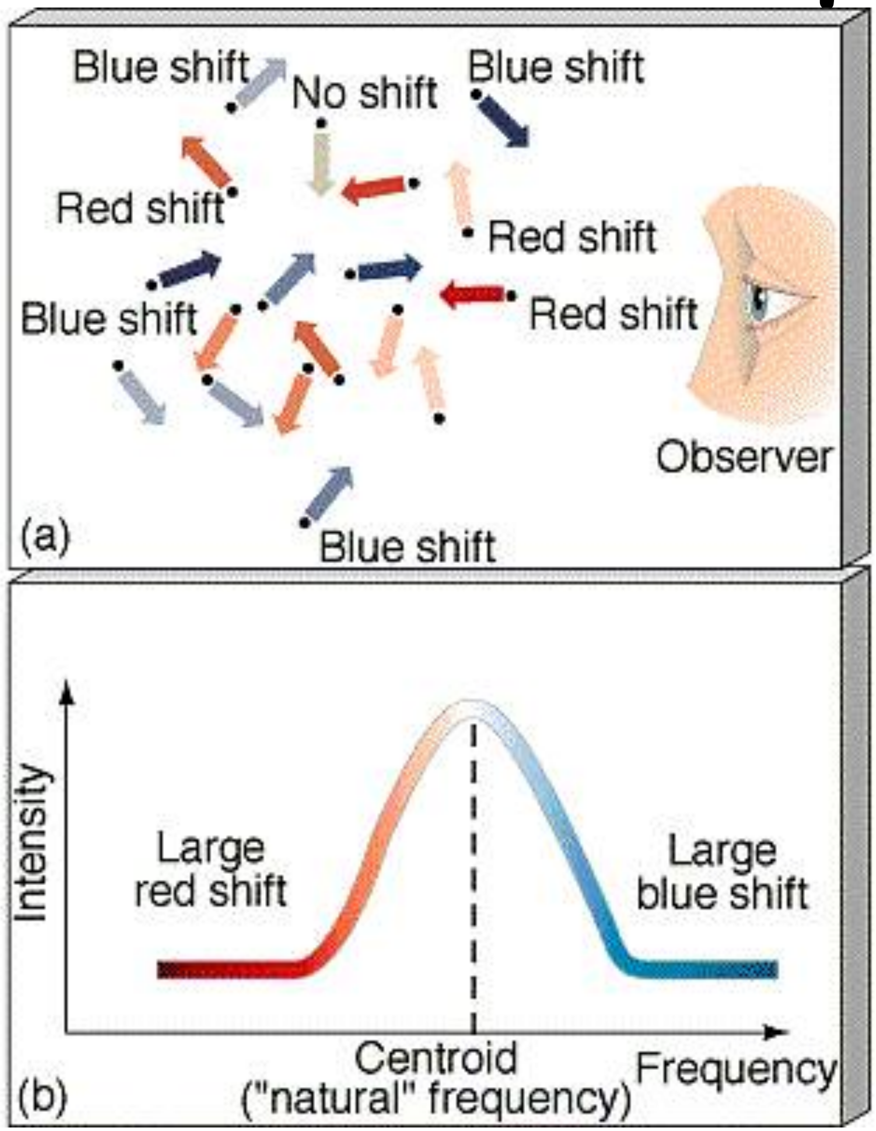


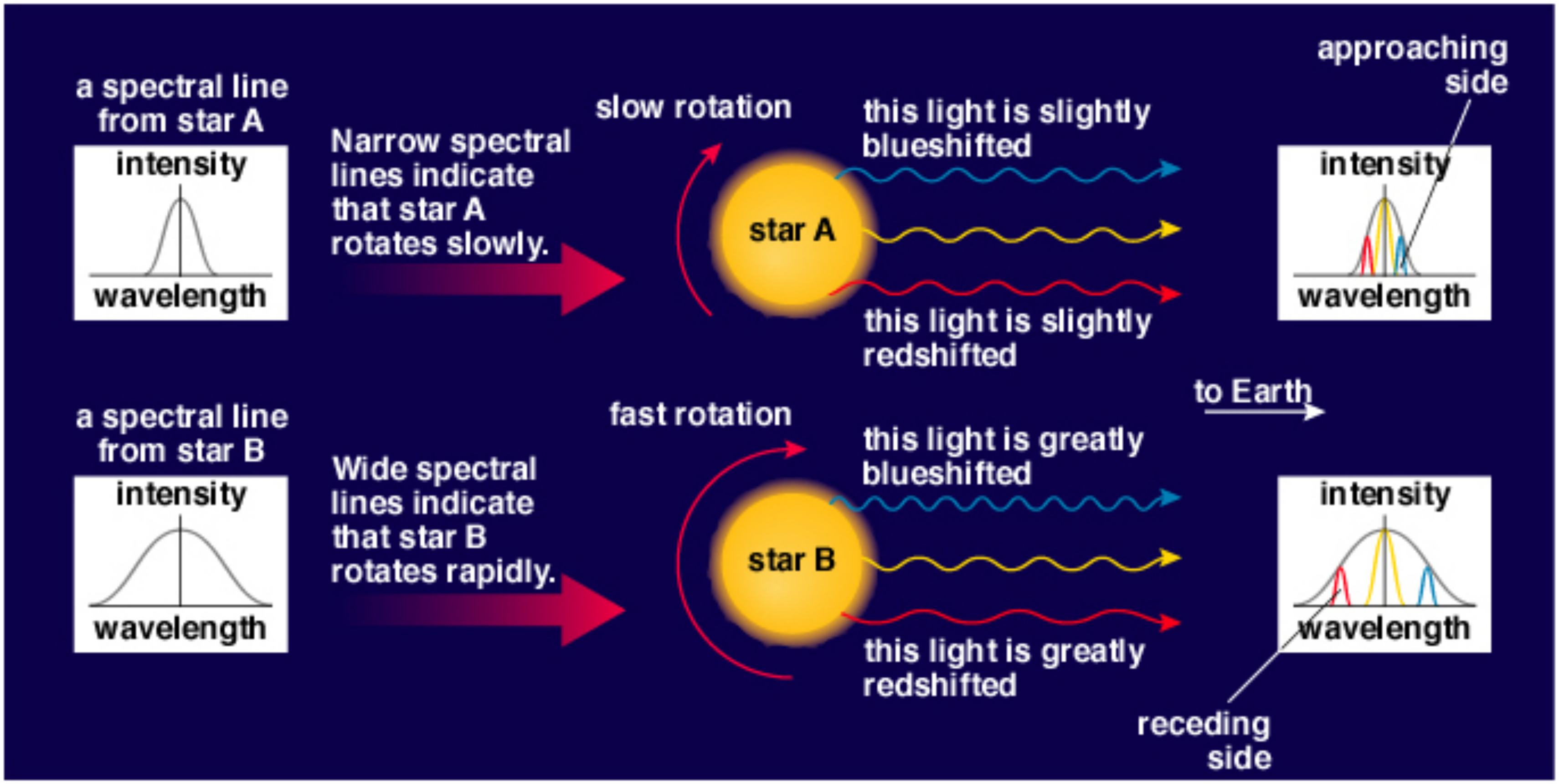
Illustration of the Doppler Effect



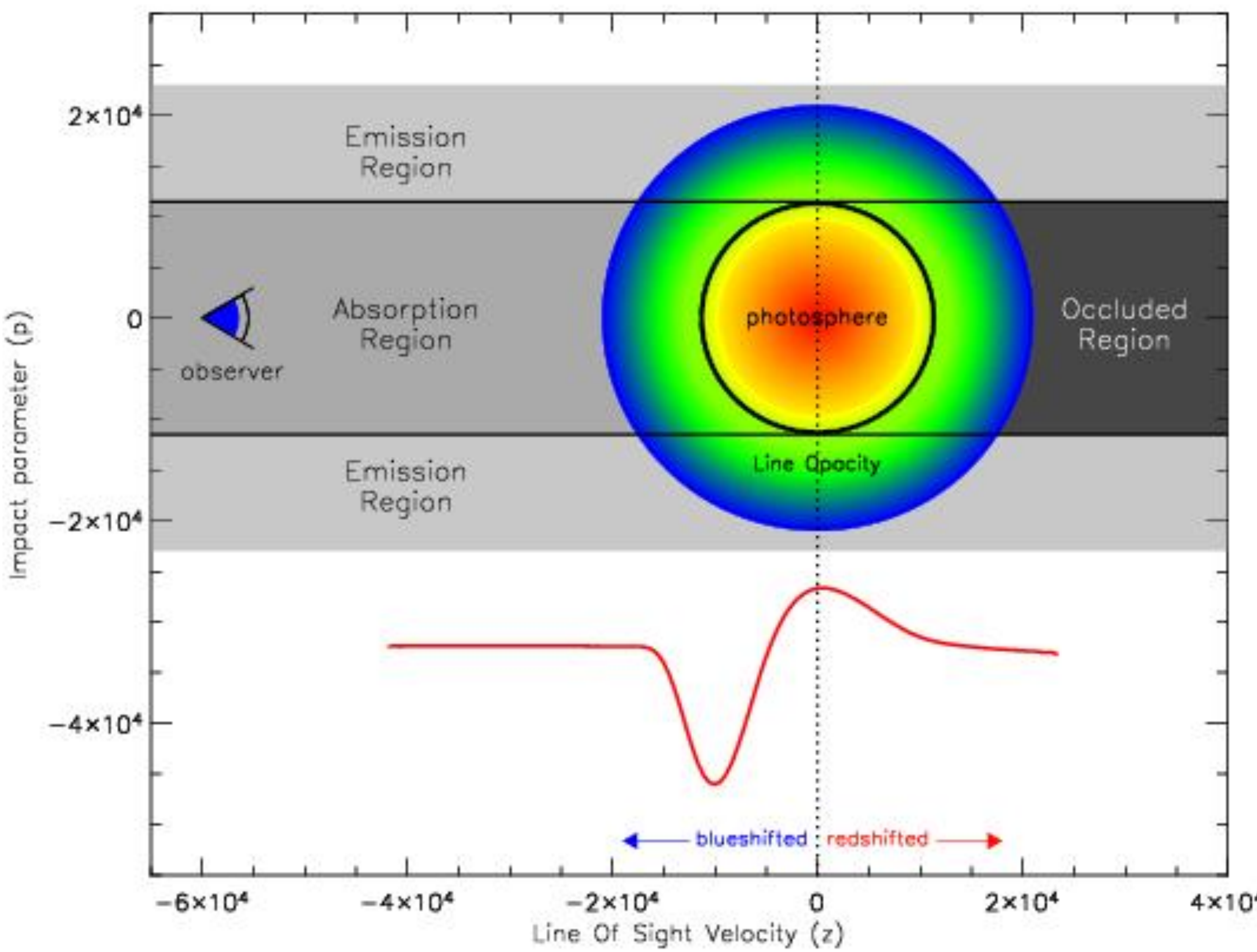
Doppler Effect: Application to Gas Temperature



Doppler Effect: Application to Rotation



Stellar Winds and the Doppler Effect



Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII	VII	VII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	O
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Composition of the Universe