Astronomy 404

August 30, 2013

Review of last lecture:

- Planck function

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1}.$$

- Wien's displacement law

$$\lambda_{\max} T = 0.00289775 \text{ m K}$$

- Stefan-Boltzmann Equation

$$L = A \sigma T^4 = 4 \pi R^2 \sigma T^4$$

- Color indexes

U-B, B-V, V-I, J-K, V-K, etc.

- Stars with different spectral types have different colors

We have a 300 ks Chandra X-ray observation of a region in the Large Magellanic Cloud (DM = 18.5). Many point sources are detected, and some have optical counterparts as stars. Are these stars in the LMC or the Galaxy?

Star 54	Star 145	Star109
U=20.959	U=17.78	U=20.11
B=22.031	B=18.23	B=19.77
V=21.023	V=18.30	V=19.30
I=18.075	I=18.35	I=18.42
J=16.61	J=18.50	J=17.66
H=16.07	H=18.22	H=17.15
K=15.86		K=17.09

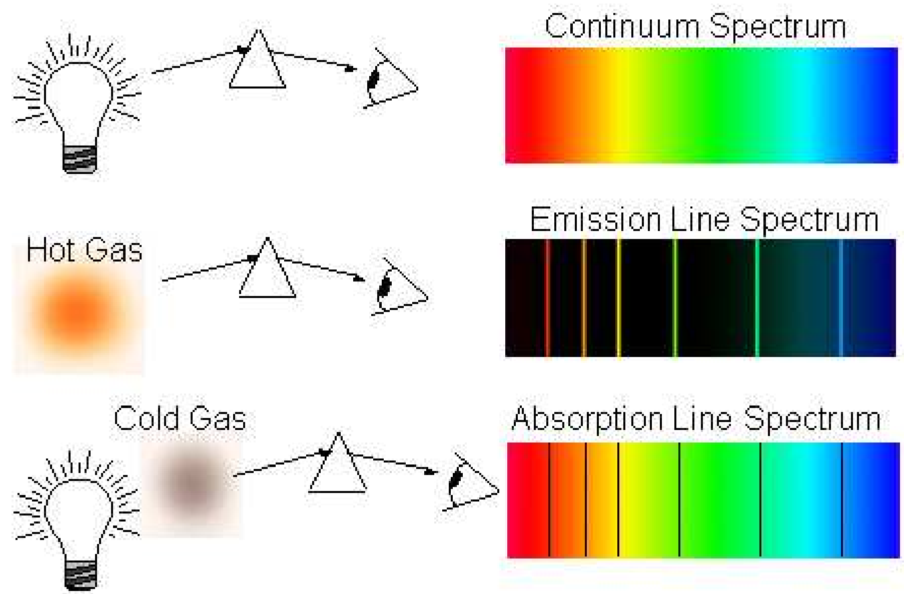
Chapter 5. The Interaction of Light and Matter

Spectral Lines

1766-1828	William Wollaston	dark lines in solar spectrum
1787-1826	Joseph von Fraunhofer	cataloged 475 dark lines
1811-1899	Robert Bunsen	burner produced colorless flame
1824-1887	Gustav Kirchhoff	spectra of flames, identified 70 dark lines in solar spectrum

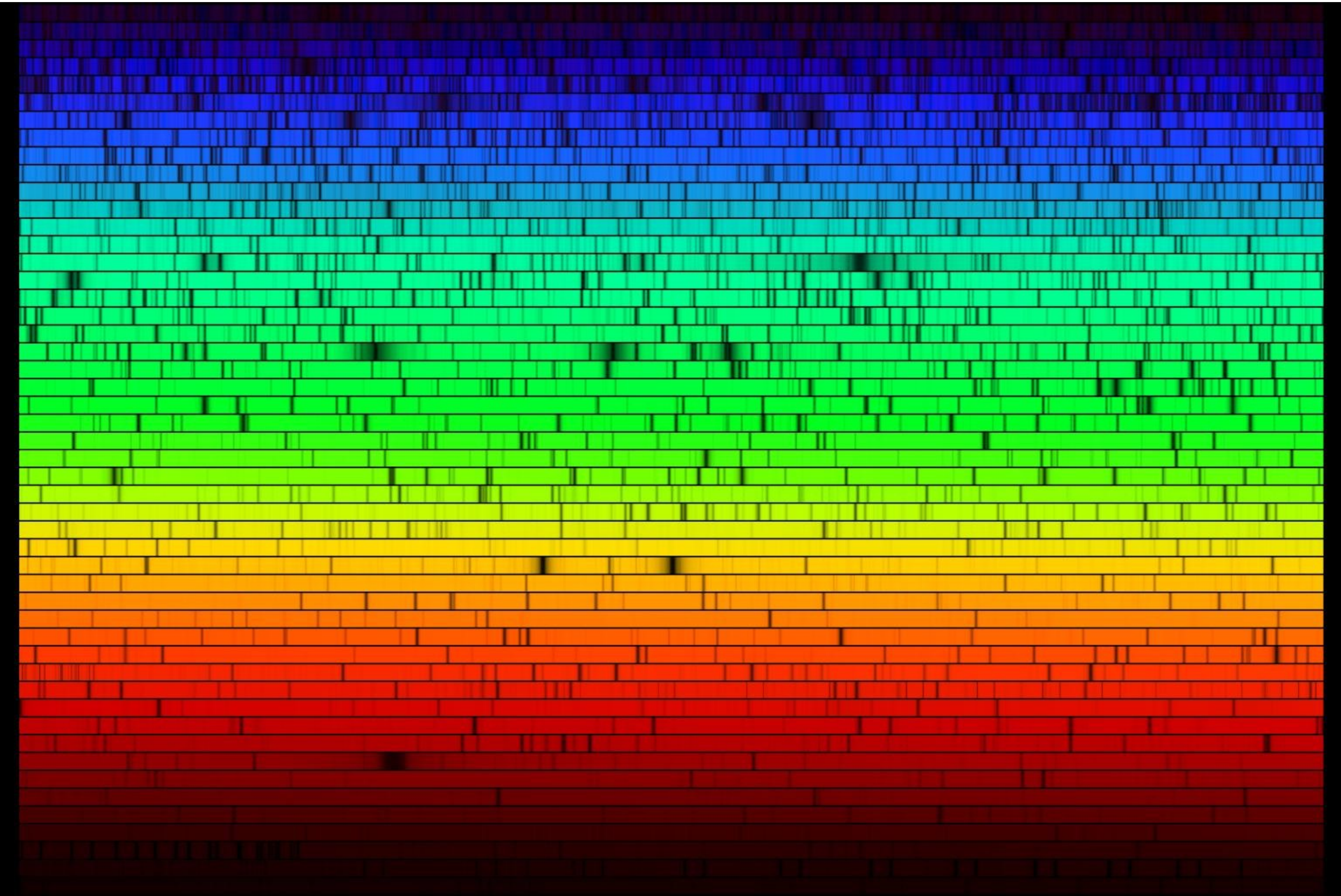
Kirchhoff's laws of spectral analysis

1. **Hot, dense gas or solid**
   => continuum emission
2. **Hot, diffuse gas**
   => emission lines
3. **Cool, diffuse gas in front of a continuum source**
   => absorption lines



Star: photosphere produces continuum, atmosphere produces absorption lines

High-Resolution Solar Spectrum (NOAO/NSO)



Applications of Stellar Spectra

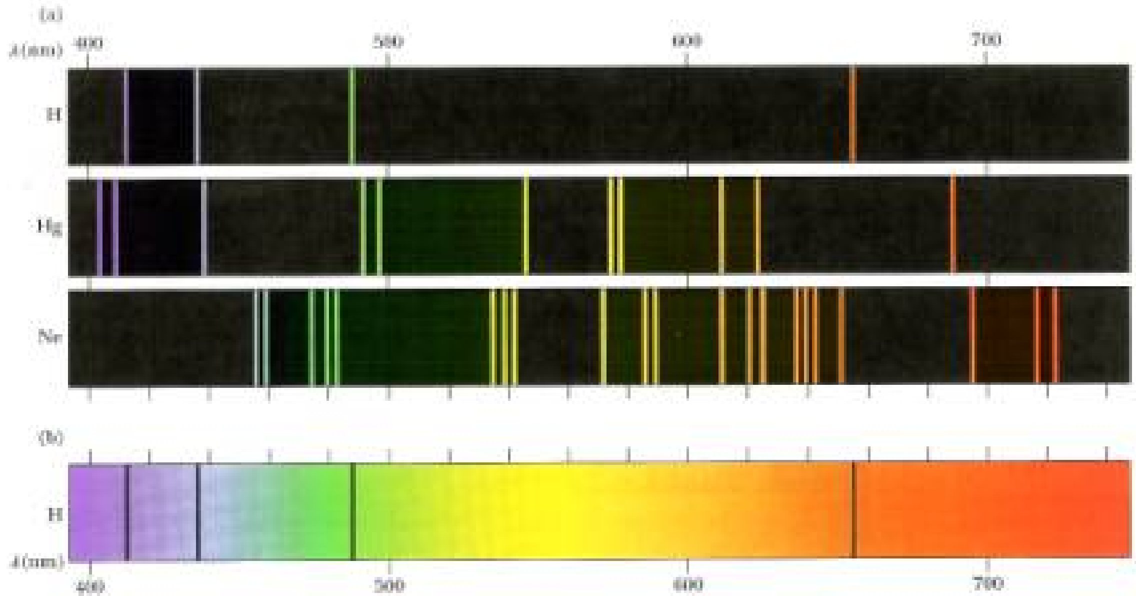
1. **Elemental composition - e.g. H, He, Na, Fe, Mg, etc. in solar spectrum**

H

Hg

Na

H



2. **Radial velocity** $\Delta\lambda / \lambda_{rest} = v_r / c$
3. **Temperature, density, and pressure of the stellar atmosphere (Chap. 9)**
4. **Magnetic field on stellar surface - Zeeman splitting.**

How do we interpret the spectra?

We need to understand the nature of light itself, especially when it interacts with matter.

Photons

**Dual nature of light - propagates through space like *waves*,
interacts with matter like *particles*.**

Photoelectric effect

Light shines on metal surface and kicks out electrons. The kinetic energy of the electrons does not depend on the intensity of light.

Einstein suggested that light consists of a stream of massless particles called "photons" and the energy of a photon is $E_{\text{photon}} = h\,\nu = h\,c\,/\,\lambda$.

$$h = 6.626 \times 10^{-34}\ \text{J s} = 4.135 \times 10^{-15}\ \text{eV s}$$

$$\boxed{K_{\text{max}} = E_{\text{photon}} - \phi = h\,c\,/\,\lambda - \phi}$$

ϕ **the minimum binding energy of an electron**

K_{max} **the maximum kinetic energy of the ejected electron**

Cutoff frequency $\nu_c = \phi\,/\,h$; cutoff wavelength $\lambda_c = hc/\,\phi$

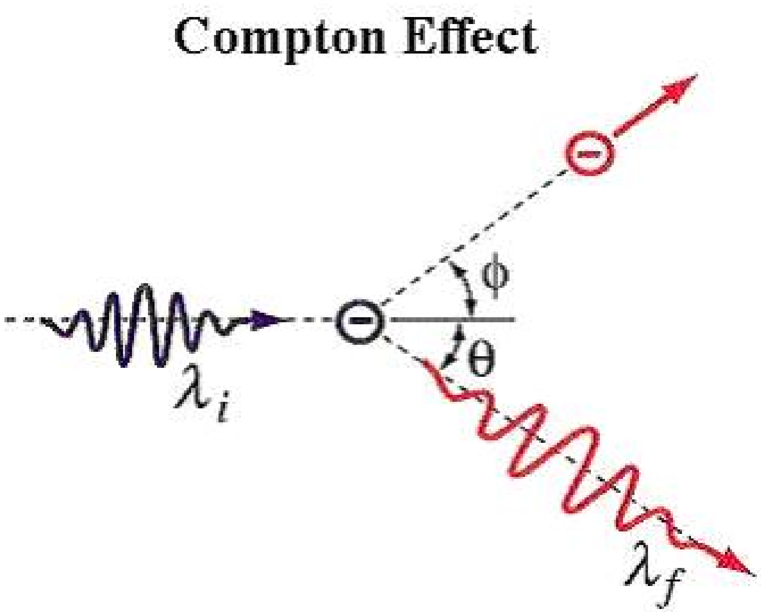
Einstein was awarded the 1921 Nobel Prize for the photoelectric effect.

Compton Effect (1892-1962 Arthur Compton)

A photon collides with an electron like a particle with

$$E_{\text{photon}} = h\,\nu = h\,c\,/\,\lambda \quad = \quad p\,c\ ,$$

where p is the momentum of the photon.



Conservation of (relativisitic) momentum and energy ⇒

$$\boxed{\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{m_e\,c}(\,1 - \cos\theta\,)}$$

Compton wavelength $\lambda_C = h\,/\,m_e c$

= 0.00243 nm

~ 30 times smaller than the X-ray photons used

The Bohr Model of the Atom

Emission lines and absorption lines are apparently associated with interactions between light and matter => how are they formed?

Johann Balmer (1825-1898) found that the series of hydrogen lines at

656.3 nm	**red**	**Hα**	**Balmer series**
486.1 nm	**teal**	**Hβ**	**Balmer lines**
434.0 nm	**blue**	**Hγ**	
410.2 nm	**violet**	**Hδ**	

can be reproduced by the formula:

$$1 / \lambda = R_H \left(1/4 - 1/n^2 \right)$$

where R_H is the experimentally determined Rydberg constant

$$R_H = 1.096 \times 10^7 \text{ m}^{-1}$$

n = 3 gives Hα ; n = 4 gives Hβ ; n = 5 gives Hγ …

$$\boxed{1 / \lambda = R_H \left(1/m^2 - 1/n^2 \right)}$$

m = 1 Lyman (ultraviolet)
2 Balmer (visible)
3 Paschen (infrared)

It was known that an H atom has a positively charged nucleus and a negatively charged electron. If the electron orbits around the nucleus like a planet around a star, the electron would lose energy through radiation and spiral into the nucleus in 10^{-8} s.

Niels Bohr (1885-1962)

- **The dimensions of Planck's constant, J × s , are equivalent to kg × m s^{-1} × m, the units of angular momentum.**
- **Perhaps the angular momentum or the orbiting electron was quantized…** $L = n\,h/2\pi = n\hbar$
- **Electon orbits around the nucleus like a planet around a star, except that the gravitational force is replaced by the electric force.**
- **Energy levels of a hydrogen atom are:**

$$E_n = -13.6 \text{ eV } n^{-2}$$

What do Kirchhoff's laws mean?

Kirchhoff's laws of spectral analysis

1. **Hot, dense gas or solid**
   => blackbody radiation
2. **Hot, diffuse gas**
   => downward transition between energy elevels
3. **Cool, diffuse gas in front of a continuum source**
   => upward transition between energy levels