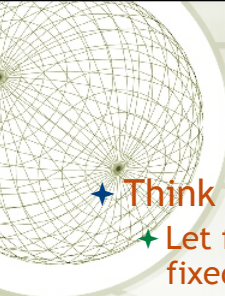


Lecture 7 : The extragalactic universe II

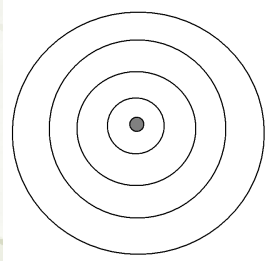
- ✦ Doppler effect
- ✦ Measuring velocities of galaxies
- ✦ Hubble's discovery of the expansion of the Universe


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I : THE DOPPLER EFFECT

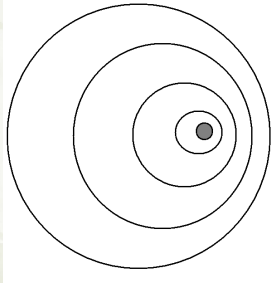

- ✦ Think about sound waves
 - ✦ Let f =frequency (number of waves passing certain fixed point in one second)
 - ✦ Let L =wavelength (distance between two "crests" of the wave)
 - ✦ Let c_s =speed of the wave

$$c_s = Lf$$


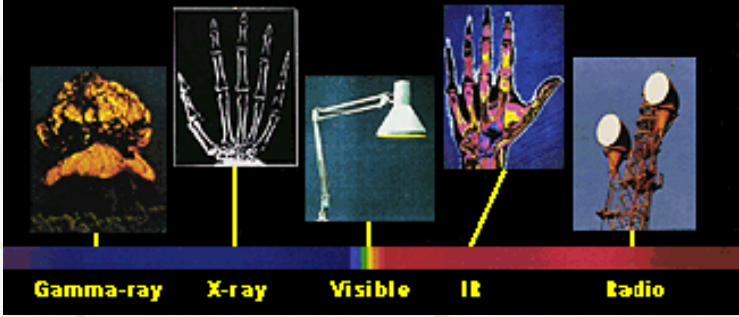


✦ Suppose source is moving towards you with speed V

- ✦ Waves get squeezed in direction of motion (i.e., L decreases)
- ✦ c_s stays same (i.e. speed of sound fixed)
- ✦ So, frequency must go up

$$\frac{L_{moving}}{L_{still}} = \frac{c_s - V}{c_s}$$



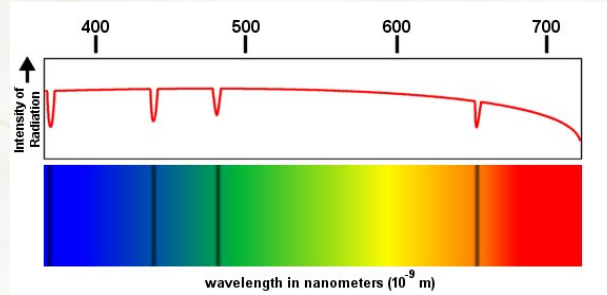
✦ The Doppler effect works on any wave - including light waves!



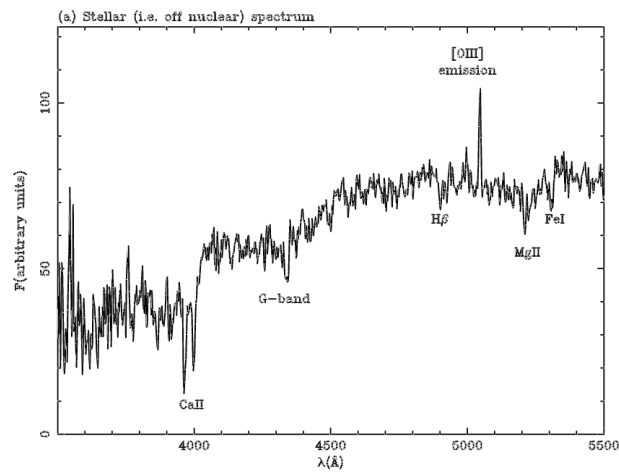
Gamma-ray X-ray Visible IR Radio

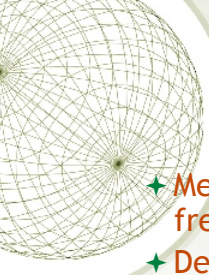
II : MEASURING APPARENT VELOCITIES OF GALAXIES

- ★ Technique for measuring a galaxies velocity:
 - ✦ Measure the spectrum of light from the galaxy
 - ✦ Look for characteristic features in the spectrum

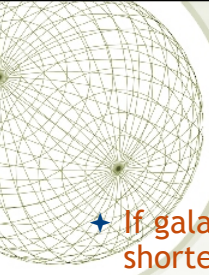


Example of a real galaxy spectrum...





- ✦ Measure the wavelength (or, equivalently the frequency) of the features, L_{gal}
- ✦ Determine where the features “should be” if the galaxy was stationary (either by calculation or laboratory experiment), L_{rest}
- ✦ Then use the Doppler formula to compute the velocity V of the galaxy.
- ✦ “Non-relativistic formula” (V much less than c) is

$$\frac{L_{gal}}{L_{rest}} = \frac{c - V}{c}$$


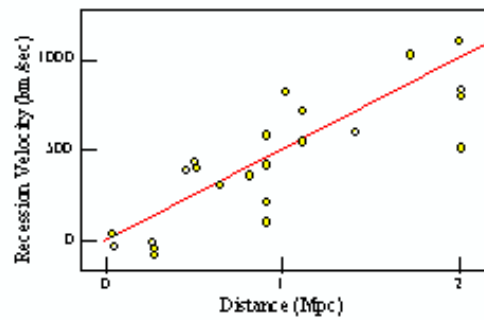
Blueshifts and Redshifts

- ✦ If galaxy is moving towards us, wavelengths are shortened ⇒ **spectrum blueshifted**
- ✦ If galaxy is receding from us, wavelengths are lengthened ⇒ **spectrum redshifted**
- ✦ Slipher measured velocities of nearby galaxies - by 1922, he found that 36 out of 41 were moving away from us!
- ✦ The first hint of Hubble’s remarkable result

III : HUBBLE'S RESULTS

- Hubble measured distance and plotted it against velocity...

Hubble's Data (1929)



Hubble & Humason (1931)

