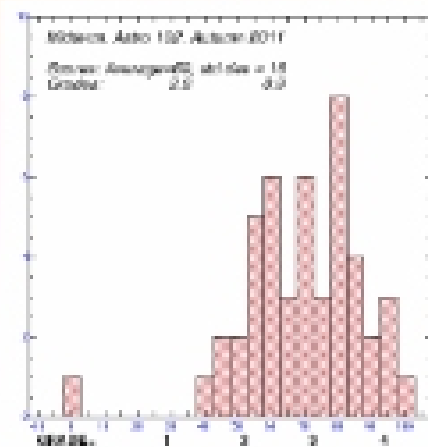
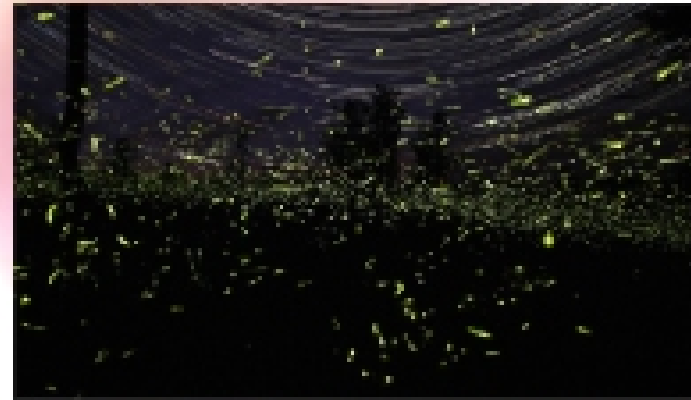


Announcements



Galaxies are Fireflies



Luminous tracers of the structure of space

MEASURING MOTIONS

The key to monitoring large-scale cosmic change

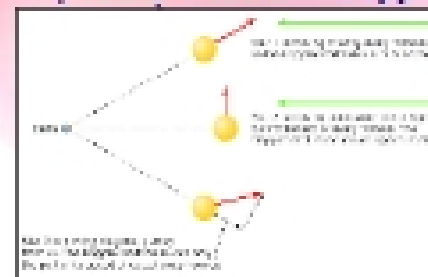
How to measure celestial motions

Across the sky

(**proper motion** - repeated images; difficult!)

Along the line of sight, or radial vector

(**radial motions** - **Doppler shift**; pretty



radial motion

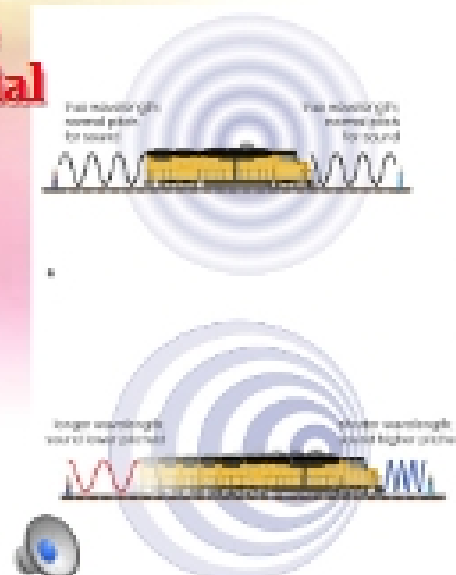
angular or proper motion

General case: both types

How do we measure radial motion???

"Doppler shift"

an apparent shift in the wavelength of a wave related to the relative motion of a source and observer



This stuff is important!

You'll be working with Doppler Shifts in the Hubble lab!

Doppler Shifts

Approaching sources move into the waves that they've emitted.

To you, the wave seems compressed (shorter λ) and its frequency higher

→ **Bluer!**

Doppler Shifts

Receding sources move away from the waves that they've emitted. So the waves have lower frequency (longer λ)

To you, the wave seems stretched (longer)

→ **Redder!**

Stump the Grumps

Do passengers hear a doppler shift?

Dining Car to the Pacific

Doppler movies

Observer & emitter

@ rest

subsonic motion

supersonic motion

Sound yes, light no!

Doppler Shifts: Measurement

Waves appear stretched when emitted by a receding wave source

NOTE! Each spectral feature is found at an observed wavelength 5% larger than the "rest" wavelength

We can measure the recession speeds of things!

Doppler Effect: Measurement

Summary: radial motion of recession or approach, V_r , produces a **Doppler Shift** (redshift blueshift), or change in wave-length $\Delta\lambda$, of light (and sound) :

V_r = recession (+) or approach (-) speed
 c = speed of the light wave
 λ_0 = rest or lab wavelength of light wave
 $\Delta\lambda$ = shift of λ seen by the observer
 $\Delta\lambda = \lambda_0 (V_r / c)$ provided $V_r \ll c$

Redshift = $z = \Delta\lambda / \lambda_0$

A wavelength stretch, not a shift
Wavelengths are multiplied!

Doppler shifts and gravitational or orbital mass

- Parts of a rotating galaxy which are in motion towards you are a bit bluer, and away from you are a bit redder.
- We can measure both orbital radius and speed. From this we derive the galaxy's total MASS (math insight 19.1).

$$M = \frac{r \times v^2}{G} = \frac{2.6 \times 10^{17} \text{ km} \times (200 \text{ km/s})^2}{6.67 \times 10^{-11}} = 2 \times 10^{36} \text{ kg} = 10^{11} M_{\odot}$$

Doppler shifts change apparent colors

visible spectrum

What color do we see in each case?

So what???

We can measure the patterns of motion in the Universe!! *Amazing!*

Is the Universe isn't just sitting around doing nothing but getting older? Or is there a "grand pattern" of Growing? Shrinking (remember, gravity sucks!).

The Universe contains coherent swarms or squadrons of galaxies defined by their common (or very similar) distances and recession speeds. "Clusters"

The "Local Group" of Galaxies

