Lecture 27: Ingredients for a Galaxy
Readings: Sections 25-2, 25-3 and 25-6

Key Ideas: The Parts of a Galaxy
Stars
Gas
- Ionized – optical/UV emission lines
- Neutral – 21 cm emission for H
- Molecular – radio and mm emission

Dust
Central Supermassive Black Holes
Dark Matter

What are “*Galaxies*”?
Large assemblies of stars, gas, dust and dark matter, held together by gravity
Sizes:
- Largest ~ 1 Trillion stars (or more)
- Smallest ~ 10 Million stars
- Milky Way & Andromeda ~ 200 Billion stars

By way of comparison, Nabisco has baked ~ 400 billion Oreos since 1913….

Stars
Arranged in different shapes: Spiral, Elliptical, & Irregular

Hubble Classification of Galaxies
All <u>bright</u> galaxies fall into one of three broad classes according to their <u>shape:</u>
- Spiral Galaxies (~75%)
- Elliptical Galaxies (20%)
- Irregular Galaxies (5%)

Basic classification system was developed by Edwin Hubble in the 1930s, and refined in later decades.

Detecting Gas
Gas can be detected by its emission lines
- Hot gas has emission lines in the visible

Cool gas has emission lines in the millimeter and radio

Different atoms will emit different wavelengths/frequencies of light

Neutral hydrogen at 21-cm

Molecules are found in coolest gas and they also have distinctive spectra.

Kirchoff's Laws/Atomic Fingerprint Reminders

Hot Gas

Hot gas (10,000K) radiates in the visible. We see ionized H as a red color.

Cool Gas

In cool regions, the hydrogen is neutral.
Electrons do not jump between orbits.
Change of *spin* changes the energy.
Photon with a wavelength of *21-cm* produced.

Neutral Hydrogen Gas in the Galaxy

Radio waves are not affected by dust.
We can view 21-cm emission from neutral hydrogen from across the Galaxy.
Distance to H^0 clouds a problem (see Section 25-3 and Figure 25-11)
Spiral arms clearly visible

We see neutral hydrogen gas in other galaxies as well. Example: M 83

Cold Gas

The coldest gas is in the form of molecules.
H_2 is difficult to detect
Other molecules, such as CO and NH_3, detected more easily.
Changing vibration or rotation of the molecules=emission/absorption lines.
Not much energy is needed=millimeter/radio wavelengths
Molecules can be distinguished by their spectra.

Molecules in Space

There are lots of interesting molecules out there, from the simple to the complex.

Examples:

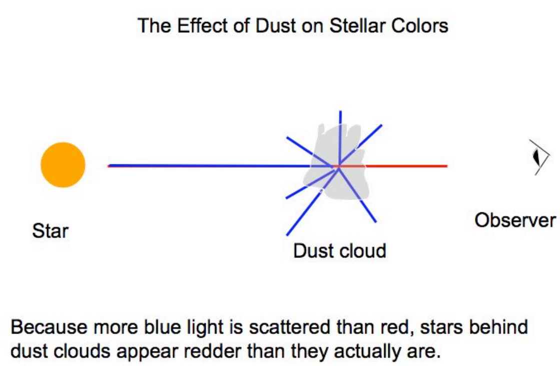
CO: carbon monoxide
NH_3: ammonia
$C_2H_4O_2$: glycine
CH_3CH_2OH: ethanol
c-C_2H_4O: ethylene oxide
CH_2CHOH: vinyl alcohol
$HC_{11}N$

The Pillars of Creation

Hot & cold gas are often close to each other.
Stars born out of cold gas and start shining.
Photons ionize and heat some of the surrounding gas.
Example: Eagle Nebula from Hubble

Dust

Small particles (like smoke or soot)
Found mixed with gas
Dust has MUCH less effect at infrared wavelengths



Hearts of Darkness

Deep in the centers of the Milky Way and Andromeda are supermassive black holes.

Masses > 1 Million M_{Sun}!

Found by the effects of their gravity on the innermost stars:

Stars orbiting much faster than expected from the number of stars present.

Evidence of excess X-ray and radio emission
Use the orbital speeds and sizes to estimate the mass of the central dark object.

Presence of Black Hole in the Center of the Milky Way detected by motions of stars.

See the movie at
boojum.as.arizona.edu/~jill/EPO/Movies/MilkyWayBlackHole.swf

Supermassive Black Holes

Such black holes are extremely large:
Stellar-mass black holes are expected to be at most a few x 10 M_{Sun}

Questions
What are such large black holes doing at the centers of our Galaxy?
How could such large black holes form?
Do other galaxies harbor similarly large black holes in their centers?

Detecting Black Holes in Other Galaxies

In the Milky Way, we detected the black hole by the motions of stars near the Galactic Center.

In the nearest galaxies, we can measure the motions of individual stars as well, but for the vast majority of galaxies we cannot distinguish individual stars.

We have to rely on the *integrated light.*

Integrated Light

For most galaxies outside the Milky way, we need to study their integrated properties.

The light from many stars is blended together, so that the color and spectrum that we observe are average properties.

More luminous stars contribute more light to the color/spectrum. A few O&B stars can emit more light than thousands of M dwarfs.

Black Hole's Effect on Stellar Motions

Stars in the centers of galaxies move faster when there's a black hole. We measure this as a **velocity dispersion**. This broadens the lines in the integrated spectrum as some stars' lines are Doppler-shifted to the blue and some to the red.

Many black hole masses in the centers of galaxies have been measured. Almost all galaxies have them in their centers.

Black Holes—Bulge Relation

The larger the bulge, the larger the black hole
Why? Related to how both bulges and supermassive black holes form?