Milky Way Galaxy

- Milky Way – spiral galaxy - flattened disk 150,000 LY in diameter with about 200 billion stars
- Earth sits in a gas/dust “arm”
  - active star formation
  - absorbs visible light
- Can study its structure using IR/radio/gamma or by looking at other galaxies
Milky Way Structure

- Nucleus
- Disk
- Halo
Galaxy Nucleus

- In Nucleus (observe by radio and IR, some gamma)
  - high density of stars
  - little gas or dust; limited new stars
- Very active star formation in past
  - many black holes
  - super massive BH at center $>1,000,000$ Mass (Sun)
  - tell mass by motion of stars/gas around central region
    (use Doppler shift and measure positions over time)
Galactic center

Study structure using IR/radio/gamma or by looking at other galaxies

measure motion over time → get mass in center (like Kepler)
Milky Way Galaxy - Disk and Halo Stars

• In Disk:
  - lots of bright, young stars
  - lots of gas and dust
  - stars abundant in heavy elements (Type I)
  - active star formation

• In Halo:
  - mostly old red stars
  - no gas/dust
  - no heavy elements (just H and He) (Type II)
  - no current star formation
Globular Clusters \(\rightarrow\) Halo Stars

- Globular clusters have many stars close to each other
  - mostly old red stars
  - no gas/dust
  - no heavy elements (just H and He) (Type II)
- “Fossil” remains of early size and shape of galaxy

M10: 85 LY across, 16,000 LY from Earth
Size and Shape of Galaxy

- Measure distances to globular clusters (and their velocities)
- Outside plane of galaxy so not obscured by gas and dust (and so done early in 20th century)
- Clusters tell us where center of galaxy is
- Orbits give Galaxy mass and shape of early Galaxy
Galaxy Disk

• Our solar system is located about 30,000 LY from galaxy center in “disk”
• Region which has an abundant amount of gas/dust and active star formation
• Earlier generations of stars formed heavy elements with supernovas and giants throwing these into the mix → new generation of stars (like ours) have C, O, Fe, etc
Spiral Arm Formation

Where stars are being formed in spiral arms “moves” over time as gas/dust is compressed by stars in other regions.
Radio Maps of Galaxy

• Visible light absorbed in disk. We can “see” through this using infrared and radio
• Cold gas (H, H$_2$, He, C, water…) emits and absorbs in Radio
• Most important: 21 cm atomic H (also have H II regions where hydrogen is hot/ionized, like in Orion Nebula)
• Gives
  - relative abundance of gas in different regions
  - velocities of gas clouds (from Doppler shift)
• Can be used to determine shape/mass of galaxy, pattern of spiral arms
21 cm line in H (like MRI)

Parallel spins: higher-energy configuration

Opposite spins: lower-energy configuration

21 cm line in H – Doppler Shifts
Radio Maps of Galaxy

Use Doppler shift to get velocity of different regions, identify different arms.
Masses of Galaxies

• Measure mass by:
  – measurements of motion to obtain mass distribution of any Galaxy
  – do as function of distance from galactic center using globular clusters and spiral arms
  – Gravitational Lensing

• Same principles as for planets:
  \[ \text{Dist}^3 = M \times \text{Period}^2 \]
  where
  \[ M = \text{mass inside volume } R < \text{Distance from center} \]

• Results:
  - mass is spread out (most not in central region)
  - most mass isn’t in stars – “dark”
Differential Rotation of Galaxy

If our Galaxy rotated like a solid disk, the orbital speed would be greater for stars and gas in larger orbits.

Because the Sun and stars obey Kepler’s third law, the orbital speed is less for stars and gas in larger orbits.

Stars would remain lined up.

Sun’s orbit

Stars in smaller orbits rapidly overtake those in larger orbits.

Sun’s orbit

Figure 11-17a
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Figure 11-17b
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If there were no material beyond the visible edge of the Galaxy, orbital speeds at large distances would decline as shown by the dashed line; This is not what is observed.
Mass of Galaxy II

- Sun is 30,000 light years from center of galaxy (2,000,000,000 AU) with a period of 200,000,000 years

- Same as for planets:
  \[ \frac{\text{Dist}^3}{\text{Period}^2} = M \text{ (inside)} \]
  giving 200 billion mass(Sun) inside the Sun’s radius

- Repeat for 150,000 LY gives greater than 1000 billion Mass (Sun) for Galaxy mass inside that distance
Spiral Arm Structure

Solar System between two arms – had active star formation (was in “arm”) about 5 billion years ago

structure changes with time
Mass of Galaxy III

• The rotation velocity versus distance doesn’t match the observed amount of matter

• There is unseen “dark matter” whose composition is unknown

• Extends far beyond visible part of Milky Way

• Effect also observed in other Galaxies. Look at orbital velocity vs distance from center. also not in agreement with mass of visible matter (first noticed in 1959)
Visible and Dark Matter

• “Visible” matter - understood objects - stars, gas, dust, neutron stars, black hole
• “Dark” matter - not understood -
  - cooled down white dwarves or very massive black holes leftover from early universe (MACHO study) NO??
  - new physics - neutrinos having enough mass, new particles (SUSY, WIMPS) YES??
• More than 75% of mass is not understood - Dark Matter mystery → possible new physics like Supersymmetry (NIU’s Steve Martin)
Mass of Galaxy: Visible vs Dark

a lot of mass outside where stars are seen
MACHOs vs WIMPS

• Massive Astrophysical Compact Halo Objects – MACHOs
  – not new physics
  – look for by gravitational lensing

• Weakly Interacting Massive Particles – WIMPs
  – new subatomic particles
  – look for in high energy experiments at CERN and Fermilab or ..
  – in ultra cold experiments in deep underground mines
MACHO Search

Figure 11-19
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Other Dark Matter Observations

• Look at velocities of individual galaxies in a cluster about each other and analyze with Newtonian physics → missing mass first observed by Fritz Zwicky in the 1930s (Caltech; he also introduced name “supernova”)

• Look at gravitation lensing by a nearby galaxy of a more distant galaxy (many including NIU students Donna Kubik and Matt Weisner. see their theses at: www.physics.niu.edu/physics/academic/grad/theses1.shtml)
Gravitational Lensing by Galaxies

Massive galaxy and/or dark matter

Apparent location

Actual location

Apparent location
NIU students work with Fermilab astrophysicists. Use Sloan Digital Sky Survey data to find “Einstein” ring candidates. Then use better telescope to improve image. Size of ring tells mass in closer galaxy \( \rightarrow \) amount of dark matter
Composition of the Universe

- Dark Energy: 70%
- Dark Matter: 25%
- Free Hydrogen and Helium: 4%
- Stars: 0.5%
- Ghostly Neutrinos: 0.3%
- Heavy Elements: 0.03%

95% not understood!
Galaxy Formation

• Rotating gas cloud about 13 billion years ago
  - local concentrations give first stars
• Cloud collapses due to gravity
  large rotation $\rightarrow$ spiral
  small rotation $\rightarrow$ elliptical
  near other big galaxy $\rightarrow$ irregular
• Often interacting with other galaxies
• Gas/Dust/Star formation persist in spiral and irregular
Old stars in halo give shape early in formation
Elliptical vs Spiral Galaxy Formation

If less initial rotation easier for early star formation prior to collapse into disk

Sequence of events

a  Formation of a disk galaxy

b  Formation of an elliptical galaxy
Elliptical vs Spiral Galaxy Formation

Elliptical galaxies tend to have older stars
Colliding and Merging Galaxies

Galaxies pull on each other by gravity
→ orbits
→ interact
→ can merge
Happens over billions of years
Colliding and Merging Galaxies

smaller galaxies often consumed by the larger galaxy

nicadd.niu.edu/~macc/162/andromeda.mov   M31-M33