Today in Milky Way

- Look at components of galaxy: stars, gas, dust
- Examine the rotation curve of our galaxy, and the unseen mass (dark matter) that it implies
- Look at why spiral patterns are made in the disk of galaxies, including our own
- Examine the Star-Gas-Star Cycles working in our galaxy disk, and its ingredients
  - Interstellar Medium (ISM) – gas and dust, plus super-bubbles blown by multiple supernovae
- Recycling on a grand scale, and building the heavier atoms
- Complete your reading of 19.4 Mysterious Galactic Center

SECOND MID-TERM EXAM

- Grade boundaries, based on 126 points:
  - If $111/126$ (88%) or over, A's [42%]
  - $96/126$ (76%) or over, B's [36%]
  - $74/126$ (60%) or over, C's [22%]
- Also +, plain, and – within these ranges

Go through answer sheet – and talk to us if do not understand our choices. Keep exam + answers for future review (comp final)

Crib Sheet Awards

Psychic Powers Award
  Jennika Greer
Compact Object Award
  Eric McNeil

Now to Our Milky Way Galaxy

Superbubble
NGC 3079
**The Milky Way** (fuzzy ribbon of light across the sky)

**Size of Milky Way**
- 100-400 billion stars
- 100,000 light years in diameter, or ~30,000 pc = 30 Kpc (kilo-parsecs)
- Sun is located about 8.5 kpc from center, in the ‘Orion Arm’

**If we might see Milky Way from outside**

**We might prefer to look like this! Prettier?**

**Composite of M101 – much goes on!**

**Milky Way Anatomy: Spiral Galaxy**
- **Disk**: includes spiral arms -- young, new star formation
- **Bulge & Halo**: older stars, globular clusters
Clicker – Where are we?

- Why was it so difficult to figure out where in the Milky Way are the Sun and Earth located, and if ours is the only "nebula" (galaxy)?
  - A. We are immersed in a soup of stars, gas and dust, so hard to see far
  - B. In a middle of city of stars, hard to figure shape of overall 'metropolitan area'
  - C. Gas and dust can absorb light, making distance estimates uncertain
  - D. All of the above

Disk is very thin!

- Disk is very thin! Artist's edge-on view

Spiral galaxy NGC 891 – nearly edge-on

- Spiral galaxy NGC 891 – nearly edge-on

Pre-Milky Way: early halo + disk

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How to build a spiral galaxy

- How to build a spiral galaxy
  (or so we think!)
The Star-Gas-Star Cycle

All spiral galaxies are constantly changing, with

star formation
supernovas and stellar winds

Cycle of star → gas
Th → star

Star Cycle

+ “dark matter”

Inventory of “stuff” making up our galaxy

Stars
Gas
Dust

1. Stars
   - Few hundred billions
   - Mostly Hydrogen
   - Mostly Helium
   - Some heavy elements

2. Gas
   - 10% H2
   - Interstellar medium
   - Very cool gas in patches
   - Hot gas in supernova remnants

3. Dust
   - Very cool gas in patches
   - Hot gas in supernova remnants
   - Very cold black cloud

Many views of our galaxy disk

- 21 cm radio emission from atomic hydrogen gas
- Radio recombination from carbon monoxide clouds molecular clouds
- 10 cm radio waves from hydrogen atoms
- Infrared (2.2 micron) star dust from the remains molten meteorites
- Visible light and infrared stars is scattered and absorbed by dust
- X-rays emission from hot gas in between (galaxies) and X-ray emission from black holes
- 21 cm radio emission from clouds of neutral gas with atomic, ionized in interstellar clouds

Reading clicker – mapping our galaxy

We want to map the structures of very cold gas within the dusty disk of the Milky Way. What wavelengths should we be using, and why?

- A. radio
- B. visible light
- C. x-rays

A. Radio
- Dust obscures our vision of much of the galaxy in visible and UV light.
- X-rays only highlight the hottest and weirdest places
- 21 cm radio waves map normal hydrogen gas -- these pass through dust unaffected

Motion of stars in spiral galaxy

- Halo & bulge: swarming in and out
- Disk: circular + bit up/down

MW disk in radio
### Different star motions in disk & halo

1. **Disk Population of Stars (1 Gal & Disk)**
   - **Radius in Highly Circular Orbit (Halo:** **Inner Disk: **“**Globulars**”)
   
   ![Diagram showing star motions in disk & halo](image)

2. **Familiar Patterns**
   - **Stars & Gas** Embedd in Much Larger Dark Matter Halo
   - **Don’t know what dark matter is yet…** probably not baryonic (usual protons, neutrons, electrons)

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### Massive dark matter halo for MW

- Stars and gas are embedded in a much larger dark matter halo ??
- Don’t know what dark matter is yet… probably not baryonic (usual protons, neutrons, electrons)

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### Stars moving in circles: orbital velocity law

\[ M_R = R \times V^2 / G \]

- **mass** in the solar system
- **radius** orbital velocity
- **...faster orbit, more mass**

![MW rotation curve](image)

### Reality for the Milky Way

- Rotation curve is flat or even rising!
- Most of the mass of the galaxy is outside the solar circle!
- But few stars, little gas there…
- **DARK MATTER**!
  - Probably in large halo -- outweights stars+gas by factor of 3 to 10

![MW rotation curve](image)

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### Role of dark matter on rotation profile

- Presence revealed by rotation curves (motions of stars in galaxy)
- Dark matter extends beyond visible part of the galaxy -- mass is ~10x stars and gas!
- Most likely subatomic particles, as yet unidentified (weakly interacting massive particles – WIMPs ?)

![Diagram showing role of dark matter on rotation profile](image)

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### Dark matter halo for galaxies

- Presence revealed by rotation curves (motions of stars in galaxy)
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**Discussion Topic**

“Cycle of Stars and Gas”
-- Does this continue forever in Milky Way – why or why not? And does it depend on your location within MW?

**Why spiral arms?**

“Density waves” – stars move in and out of denser regions
More like ripples in a pond than arms of a pinwheel

In dense regions, star formation is more intense, so “arms” are brighter

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**Push and pull of gravity in disk**

Gas/stars are pulled a little forward or backward toward the high density regions

Such clumping helps create a spiral pattern

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