Today in Our Galaxy

- Our Milky Way Galaxy in overview, seeing various components of any spiral galaxy – and a fine SONG
- Consider why spiral patterns are made in the disk of galaxies, including our own
- Examine the rotation curve of our galaxy, and the unseen mass (dark matter) that it implies

- Complete your reading of 19.2 Star-Gas-Star Cycle, provide discussion response by 5 Apr
- Observatory Night 5 on Wed 4 Apr 8:30pm

Cygnus X-1: Blue supergiant (strong winds) pours H + He onto accretion disk of black hole

Cygnus X-1: Most famous black-hole candidate
- X-ray binary (strong x-ray source)
- Eclipses by giant star, every 5.5 days
- Dramatic X-ray variations of HB component (orbital periods: 10 days)
- "Prominent" blue supergiant ~ 25 M☉
- "Companion" ~ 10 M☉
- "Prominent" to the north, "Companion" to the south
- Stellar wind feeds matter into near-black hole
- "Prominent" star becomes a superwind star in that time before a black hole of similar size

Cygnus Loop SNR – Home of Cyg X-1

Eagle Nebula

How to "detect" a black hole?

(VERY CAREFULLY!)

... Only through effects on nearby matter

- Mostly look at gas near black hole
- Studied for nearby x-ray sources

Criteria:
1. "Prominent" star in binary system is
   "eclipsed" by black hole in
   "eclipsing binary zone" ≈ 10 M☉
2. The same as must be suspected
   in a similar star.
Clicker – Size of Black Hole

- What does the Schwarzschild radius of a black hole (BH) depend on?  **C.**
- A. Both mass and chemical composition of the BH
- B. Radius of BH, as measured by careful observations of its size
- C. Only the mass of BH
- D. Whether BH formed in massive star supernova or in some other way

Now to Our Milky Way Galaxy

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
  \( \sim 30,000 \text{ pc} = 30 \text{ Kpc} \) (kilo-parsecs)
- **Sun** is located about 8.5 kpc from center, in the "Orion Arm"

If we might see Milky Way from outside

Milky Way Anatomy: Spiral Galaxy

- **Disk**: includes spiral arms -- young, new star formation
- **Bulge & Halo**: older stars, globular clusters

If we might see Milky Way from outside

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)?
  - **D.** All of the above

Disk is very thin!

- **Disk** is very thin!
Spiral galaxy NGC 891 – nearly edge-on

Stars and gas are all moving!

Pre-Milky Way: early halo + disk

One-pager:
ALL about us!

Sing our way to the Milky Way

How to build a spiral galaxy
(or so we think!)

THE GALAXY LIGHTEN UP

FORMATION OF MILKY WAY

1. Make (Orbit) of Protoparticle(s)
2. Gas & Clouds

4. Disk & Outer Planets

- Collection of Nebulae
- Protoparticles
- Sun and Planets
- Milky Way: Our Galaxy

- PROTECTED BY STELLAR BUBBLES
- Nebulae: Stars (for Galaxies)
- SUN: MILKY WAY'S CENTER
All spiral galaxies are constantly changing. Inventory of "stuff" making up our galaxy:

- **Stars**: Made of hot hydrogen gas. 
- **Gas**: Mostly hydrogen, some helium and heavier elements. 
- **Dust**: Made of carbon, iron, and other heavy elements. 
- **Dark Matter**: Unable to be seen directly, inferred from gravitational effects.

**Cycle of Star ± Gas ± Star Cycle** includes:
- Star formation
- Supernovas and stellar winds
- Stellar burning / heavy-element formation

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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: swirling in and out
- Disk: circular + bit up/down

**MW disk in radio**

**Confused visible image**
Different star motions in disk & halo

1. Disk population of stars (incl. dark matter):
   - compact disk
   - barred disk
   - normal disk
   - warped disk

2. Bar and spiral arms
   - spiral arms: open to disk, close to central bulge
   - warped disk: "disk warp"......

Stars moving in circles: orbital velocity law

\[ M_R = R \times \frac{V^2}{G} \]

- mass inward
- radius orbital velocity
- ...faster orbit, more mass

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

Role of dark matter on rotation profile

- 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)

Massive dark matter halo for galaxies

- 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 ?)
Magnificent spiral galaxy – M51 Whirlpool

Why the two-armed SPIRAL PATTERN?