Today before Spring Break-Away

- 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 19.5 Mysterious Center of our Galaxy
- Second Mid-Term Exam + answers still available for retrieval
- Problem Set 7 due in class today

Clicker reading Q: Where are we?

- The Sun’s location in the Milky Way is ________.
  - A. in galactic disk, about halfway between center and outer edge of disk
  - B. in halo of galaxy, about 28,000 light years above galactic disk
  - C. at very outer edge of galactic disk
  - D. very near the galactic center
Ingredients of Interstellar Medium (ISM) (stuff between the stars)

1. **Very cold gas:** star birth
   - Bubbles of hot gas
   - Blown out by supernovae
   - \( T = \text{million degree K} \)
   - Mixing with rest of galactic gas → enrichment with heavy elements

2. **Cool gas:** neutral H
   - HII regions (regions where ionized hydrogen exists)

3. **Hot gas:**
   - > 10^6 K
   - Heated by supernovae, stellar winds
   - \( T \) in billion degree
   - Light enriched with elements

4. **Mixing with rest of galactic gas → enrichment with heavy elements

Now let us look at them in turn....

**ISM Contents:** some stuff is HOT

- Bubbles of hot gas blown out by supernovae
- \( T = \text{million degree K} \)
- Mixing with rest of galactic gas → enrichment with heavy elements

**Super-bubbles & Fountains**

- Supernovae can burst hot gas even out of the galaxy!
- "Enriches" gas between galaxies
- Some will rain back down and mix into galaxy

Artists' conceptions!

**Edge-on view of spiral galaxy NGC 4013**

- Dust/gas in disk obscures light
- Plumes and fuzz sticking out are "fountains" & "superbubbles" from supernovae

Super-bubbles in Large Magellanic Cloud (LMC) (nearby galaxy)
Super-bubbles in spiral galaxy NGC 3079

Fast electrons & magnetic fields

- Synchrotron emission from SNR
- X-ray and radio
- Traces very hot gas bubbles (SNR)

Chandra X-ray image of Tycho Brahe 1572 supernova remnant

Kepler’s SNR (1604) latest SN in MW

Kepler SNR (1604) Chandra X-ray

Really HOT: Cass A Supernova Remnant

Supernova Remnant N49B in LMC

Chandra x-ray images reveal ~one solar mass of magnesium blasted into space by SN
Clicker – stars and “heavy metals”

- The ages of stars suggest that the bulge and halo of the Milky Way formed before many of the stars in the disk. Which would you expect to have more heavy metals (higher metallicity)?
  
  **B.**

- A. Halo and bulge stars
- B. Disk stars
- C. No difference

---

**Some stuff is WARM**

- Gas & dust heated by stars
- GAS -- emission lines from hydrogen and other elements (ionization nebulae)

\[ T \approx 10,000 \text{ K near hot young stars} \]
\[ T \approx 100 \text{ K between star forming regions} \]

---

**Emission nebulae**

- “O & B star associations”
- Emission lines from hydrogen and other ionized elements
- \[ T \approx 10,000 \text{ K near hot young stars} \]

---

**ISM – hot gas:**

- **Emission nebula** (H II region)
- UV radiation from hot O or B stars ionizes a big cavity

---

**O & B star associations**

- many cluster stars join in to blow "big bubbles"
**Trifid emission nebula "O & B star associations"**

ISM:

A little DUST goes a long way!

**SEM I - WARM stuff: dust**

- **DUST**: absorbs visible and UV light
- Transparent to long wavelengths (red, IR, radio)
- Emits IR light

**Where are we in MW?**

Dust makes it hard to estimate distances (stars dimmed)

Globular clusters on COBE IR sky image

Shapley's (1920) distances to globular clusters: Sun at 18 kpc from center (twice too far!)
**COLD stuff: dark clouds**

- Molecular CLOUDS
- Dark, dusty, cold (10 - 30 K)
- Emit molecular emission lines in far IR, radio
- Orion image here in carbon monoxide (CO) -- colors are Doppler shifts

**ISM is a pretty violent place**

"Life cycle" in a molecular cloud

**Dark and dusty stellar nurseries**

- Nebula RCW 49
- Stellar jewels Spitzer IR

**Stellar nursery (Sharpless 140)**

- Spitzer IR image shows three deeply embedded O-type stars within dark dust cloud encasing them

**COLD hydrogen throughout**

- Even the coldest hydrogen emits faint emission line in the RADIO
- Wavelength 21 cm
- Emission from flip of electron from spinup to spindown state

**Disk is busy!**

Cycle of stars $\rightarrow$ gas $\rightarrow$ stars