ASTR 1040: Stars & Galaxies

Edge-on spiral galaxy NGC 4013

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Lecture 21 Tues 31Mar 2020

zeus.colorado.edu/astr1040-toomre

- *Today+ in Our Galaxy (Chap 19)*

- Visit *"inventory"* of our galaxy: *stars, gas, dust,* and all in constant motion and recycling
- Look at *dust* in absorbing / reddening light
- Why *spiral patterns are made in the disk* of galaxies, including our own

- *Mr. Einstein's work S.2* (special relativity), *S.3* (general relativity) *in recitation*
- *HW #9* now graded, *answer sheet* on canvas

How we will be zoom-interactive

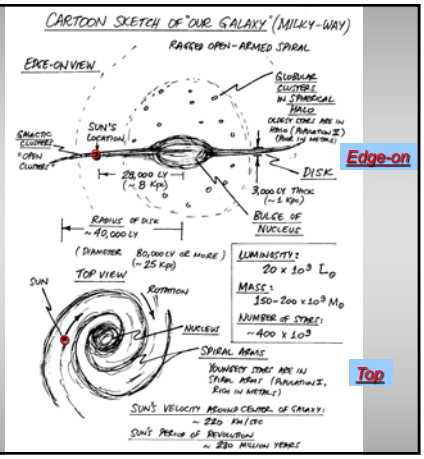
- "*Raise Hand*" *(Max monitors "Participants")*
- *"Send Chat" Message (Max will act)*
- In both cases, Juri will get to your question or comment within at most a few minutes
- *Or if pressing, Unmute your mike and ask question*

- *We can adjust "how to interact", with your advice and experience*

REVISIT

One-pager: ALL about us!

Sketch of Milky Way



Edge-on

Top

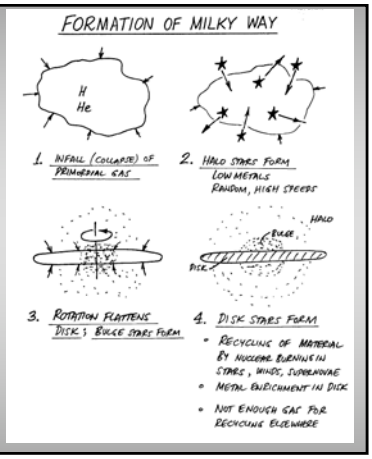
If we might see Milky Way from outside

REVISIT

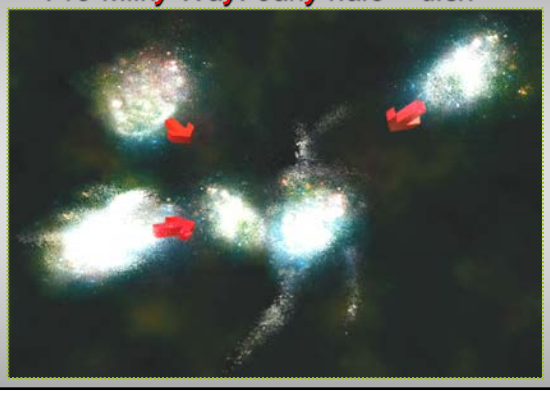
Spiral Sb galaxy NGC 4414

How to build a spiral galaxy

(or so we think!)



Pre-Milky Way: early halo + disk



What are galaxies made of?

Inventory of "stuff" making up our galaxy

Stars

Gas

Dust

+ "dark matter"

INVENTORY OF MILKY WAY

1. STARS — FEW HUNDRED BILLION, $\geq 10^{11} M_\odot$
   - BULGE — MEDIUM TO OLD, "METAL POOR"
   - DISK — YOUNG, "METAL RICH" INCLUDES OPEN CLUSTERS, OB ASSOCIATIONS
   - HALO — OLDEST, METAL POOR INCLUDES GLOBULAR CLUSTERS
2. GAS — 10% MASS OF STARS
   - MOSTLY IN DISK — INTERSTELLAR MEDIUM
     - A. VERY COLD GAS IN THIN SHEET — SITE OF STAR FORMATION (MOLECULAR CLOUDS)
     - B. WARM ATOMIC AND IONIZED H CLOUDS — EMISSION NEBULAE (BRIGHT NEBULAE)
     - C. HOT GAS — HEATED BY STELLAR WINDS, SUPERNOVAE
   - HALO — VERY HOT GAS BLOWING OUT OF GALAXY
3. DUST — 1% MASS OF GAS, 0.1% MASS OF STARS — MOSTLY IN CLOUDS IN DISK

Ingredients of Interstellar Medium (ISM) (stuff between the stars)

COMPONENTS OF INTERSTELLAR MEDIUM

1. GIANT MOLECULAR CLOUDS — $\sim 10^5 M_\odot$
   - SITES OF INTENSE STAR FORMATION
   - NEARLY 50 MOLECULES DISCOVERED BY EMISSION LINES OBSERVED IN RADIO
     - COMBINATIONS OF H, C, N, O FORM MOLECULES (AS MANY AS 11 ATOMS!)
     - ⇒ AMMONIA, WATER, FORMALDEHYDE, METHYL & ETHYL ALCOHOL, CYANOGEN, CARBON MONOXIDE (CO) ...
     - CO IMPORTANT FOR DOPPLER MAPPING OF CLOUDS WITH RADIO OBSERVATIONS

Very cold gas: star birth

2. DIFFUSE CLOUDS OF GAS (AND SOME DUST)
   - HI REGIONS: CLOUDS OF COOL, NEUTRAL HYDROGEN ATOMS (REFLECTION NEBULAE) 21 cm RADIO EMISSION

Cool gas: neutral H

   - HII REGIONS (EMISSION NEBULAE): GLOWING, IONIZED HYDROGEN SURROUNDING YOUNG HOT STARS (O, B ASSOCIATIONS)

Hot H

More stuff in ISM inventory

INTERSTELLAR MEDIUM ...

3. HOT INTERCLOUD GAS — $> 10^6$ K
   - HEATED BY SUPERNOVAE, STELLAR WINDS
   - FILLS HALO, GALACTIC WIND?
   - HIGHLY IONIZED GAS, NO DUST
     EMITS X-RAYS, YIELDS UV EMISSION ... LIKE OXYGEN VII (OXYGEN STRIPPED OF 5 ELECTRONS!)

Really hot gas

4. COSMIC RAYS
   VERY ENERGETIC ATOMIC NUCLEI (PARTICLES)
5. INTERSTELLAR DUST
   NOT MUCH BY MASS, BUT ....
   REDDENS STARLIGHT, ABSORBS SOME OF IT, POLARIZES THE LIGHT

Dust

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

States of gas in ISM

State of Gas	Primary Constituent	Approximate Temperature	Approximate Density (atoms per cm^3)
Hot bubbles	Ionized hydrogen	1,000,000 K	0.01
Warm atomic gas	Atomic hydrogen	10,000 K	1
Cool atomic clouds	Atomic hydrogen	100 K	100
Molecular clouds	Molecular hydrogen	30 K	300
Molecular cloud cores	Molecular hydrogen	60 K	10,000

Questions or Comments

Cold Stuff

Dark Molecular clouds (10's of Kelvin)

Horsehead in close-up

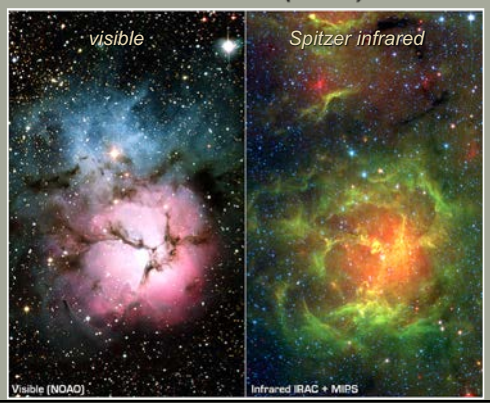
Warm Stuff

- *Gas & Dust*
  - Heated by stars to 100s-1000s Kelvin
- Absorbs visible and UV light
- Transparent to longer wavelengths
  - Infrared, radio
- Emits its own infrared light

Hot Stuff

- Ionization nebulae
- Hot (young) stars ionize hydrogen and other elements in the gas
- *T~ 10,000 K near hot young stars*

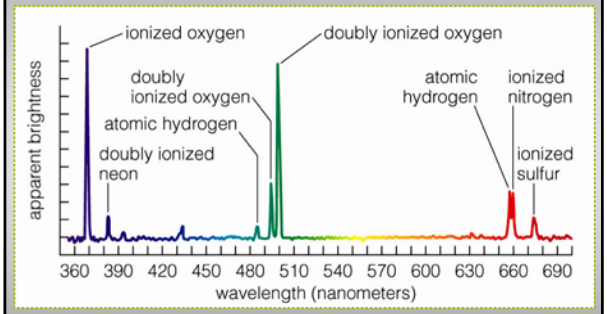
Trifid Nebula (M20)



Emission nebulae "O & B star associations"

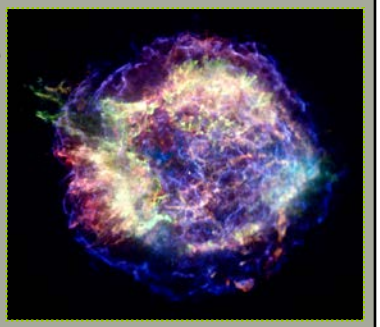
- *Emission lines from hydrogen and other ionized elements*
- *T~ 10,000 K near hot young stars*

Where the emission colors come from ..



Really Hot Stuff

- Bubbles of hot gas blown out by SUPERNOVAE
- T = millions of degrees K
- Mixing with rest of galactic gas → enrichment with heavy elements



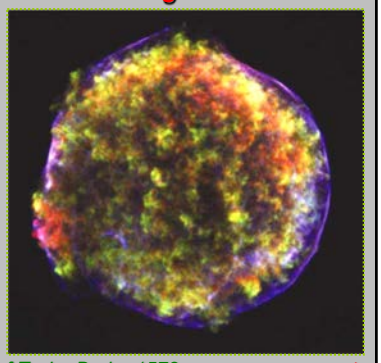
Cass A SN remnant Flamsteed ~1680

20

Fast electrons & magnetic fields

REALLY HOT STUFF

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



Chandra X-ray image of Tycho Brahe 1572 supernova remnant

Questions or Comments

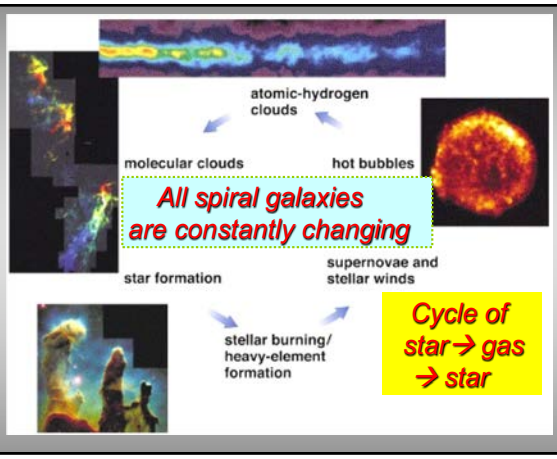
For Break-Out Room:

Meet & Greet with video/sound on

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) ?

Poll 1 – 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



Infrared light reveals stars whose visible light is blocked by gas clouds

Infrared

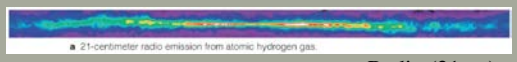
Visible

X-rays are observed from hot gas above and below the Milky Way's disk

We also see "point" sources – these are binaries

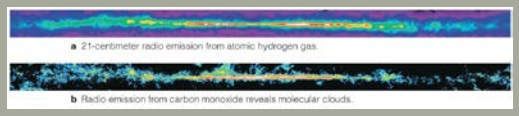
X-rays

21 cm radio waves emitted by atomic hydrogen show where gas has cooled and settled into disk



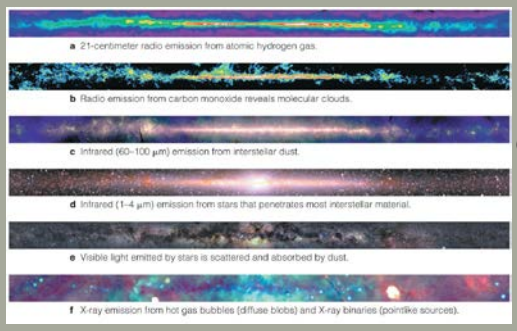
Radio (21cm)

Radio waves from carbon monoxide (CO) show locations of molecular clouds



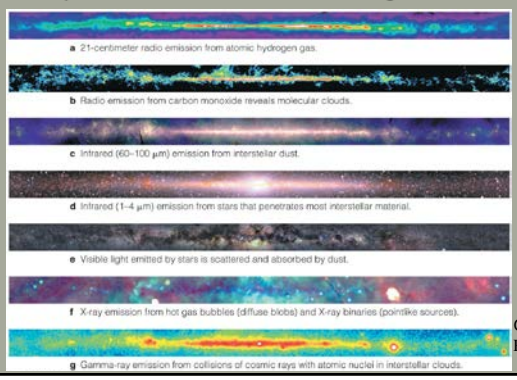
Radio (CO)

Long-wavelength infrared emission shows where young stars are heating the dust



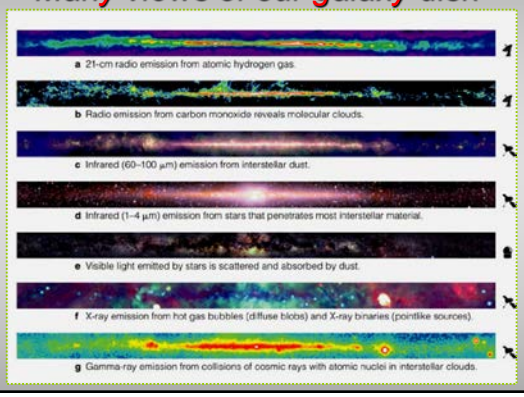
IR (dust)

Gamma rays show where cosmic rays from supernovae collide with atoms in gas clouds



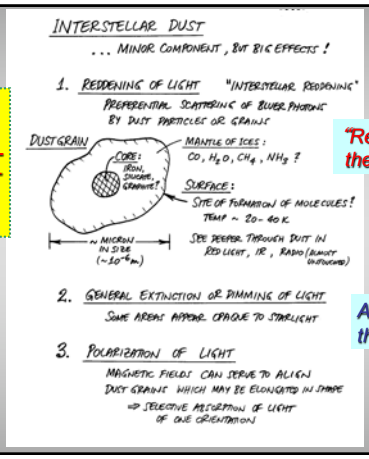
Gamma-Rays

Many views of our galaxy disk



ISM:

A little DUST goes a long way!



"Reddens" the light

Absorbs the light

SEMI-WARM stuff: dust

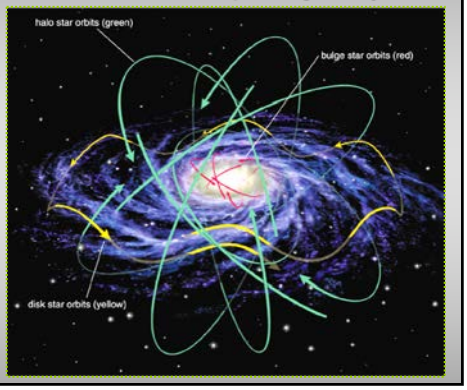
- **DUST: absorbs** visible and UV light
- **Transparent** to long wavelengths (red, IR, radio)
- Emits IR light

Questions or Comments

Motion of stars in spiral galaxy

Halo & bulge: swarming in and out

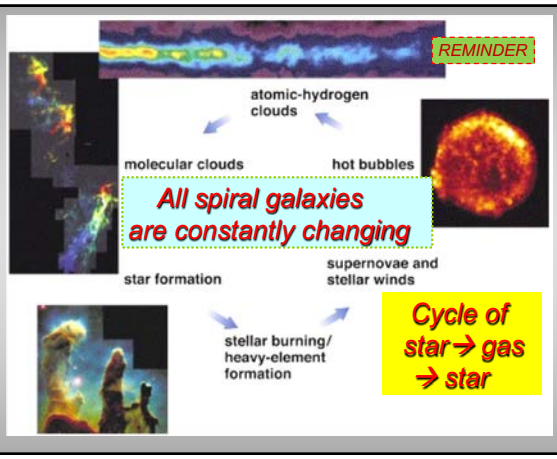
Disk: circular + bit up/down



Poll 2 – 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)?
- **A.** Halo and bulge stars
- **B.** Disk stars
- **C.** No difference

- **B.** Disk stars are continually forming out of gas that is more and more "polluted" by heavy metals.
- The OLD globular clusters in the halo were formed a long time ago before the galaxy was so polluted – they have very low "metallicities"

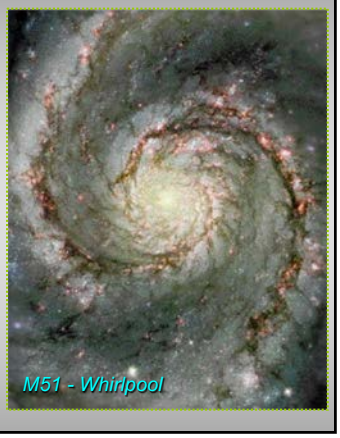


Why spiral arms?

"Density waves" – stars move in and out of denser regions

More like ripples in a pond than arms of a pinwheel

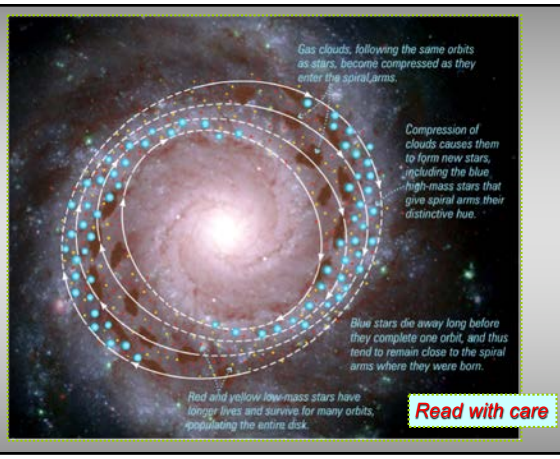
In dense regions, star formation is more intense, so "arms" are brighter



Push and pull of gravity in disk

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

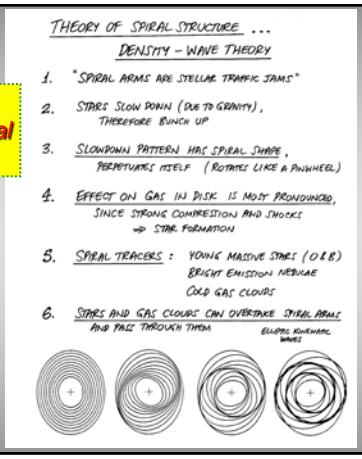
Such clumping helps create a spiral pattern "traffic jam"



Read with care

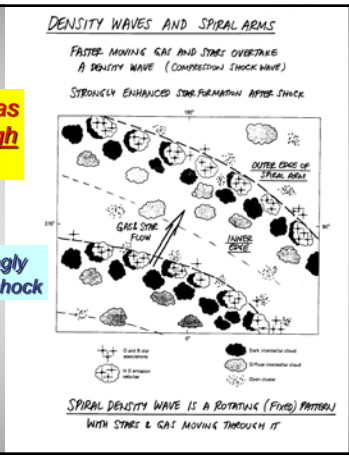
"Density wave" story – how spiral structure is built

Gravitational instability of disks (gentle)



Stars and gas move through spiral wave

Star birth strongly enhanced by shock



Crash/bang of star birth and recycling: rotating through the spiral arms in the disk

Bright O & B stars mark the spiral pattern

M51 Whirlpool Galaxy HST