

ASTR 1040: Stars & Galaxies



M51 Whirlpool

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Lecture 20 Thur 23 Mar 2017
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Onward to Galaxies, starting with our own!

- Revisit **Our Milky Way Galaxy** in overview, aspects of any **spiral galaxy**
- How spiral galaxy may have been **assembled**
- Examine galaxy components: **stars, gas, dust**
- Look at why **spiral patterns are made in the disk** of galaxies, including our own
- **Homework #9** due today, new **HW #10** out – requires reading **S2** on “special relativity”
- **Read Chap 19 “Our Galaxy”** in detail
- Sorry that Observatory #6 was scrubbed!

Review 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

OVERVIEW

Our Milky Way Galaxy



- **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’**

Artist’s sketch!



Halo stars travel high above and far below the disk on orbits with random orientations.

Bulge stars also have orbits with random orientations.

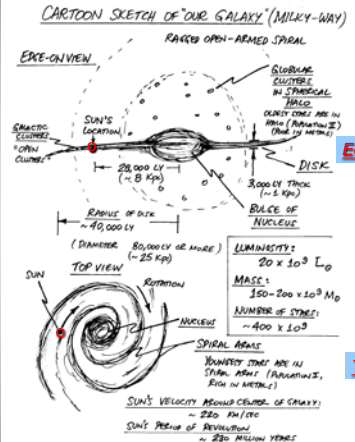
Disk stars orbit in circles with the same orientation, except for a little up-and-down motion.

REVISIT

One-pager: ALL about us!

Sketch of Milky Way

CARTOON SKETCH OF “OUR GALAXY” (MILKY-WAY)



EDGE-ON VIEW

- GALACTIC EQUATOR
- GALACTIC POLE
- SUN'S LOCATION
- 28,000 LY (~ 8 kpc)
- RADIUS OF DISK ~ 40,000 LY
- (DIAMETER 80,000 LY OR MORE)
- RARELY OPEN-ARMED SPIRAL
- GLOBULAR CLUSTER IN SPHERICAL HALO
- OLIVY STARS ARE IN SPIN (BAR/NUCLEUS) (ONLY IN METALS)
- DISK
- 3,000 LY THICK (~ 1 kpc)
- BULGE OF NUCLEUS
- SUN
- ROTATION
- NUCLEUS
- SPIRAL ARMS
- QUANTITY STARS ARE IN SPIN ARM (BAR/NUCLEUS, SPIN IN METALS)
- SUN'S VELOCITY ABOUT CENTER OF GALAXY: ~ 240 km/sec
- SUN'S PERIOD OF REVOLUTION ~ 230 MILLION YEARS

LUMINOSITY: $20 \times 10^9 L_{\odot}$

MASS: $150-200 \times 10^9 M_{\odot}$

NUMBER OF STARS: $\sim 400 \times 10^9$

Edge-on

Top

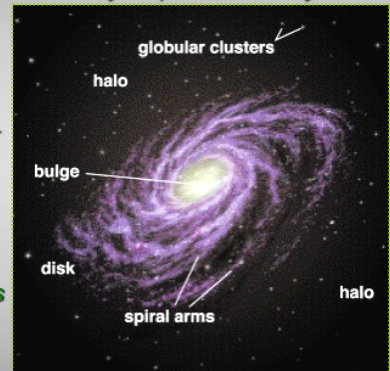
If we might see Milky Way from outside



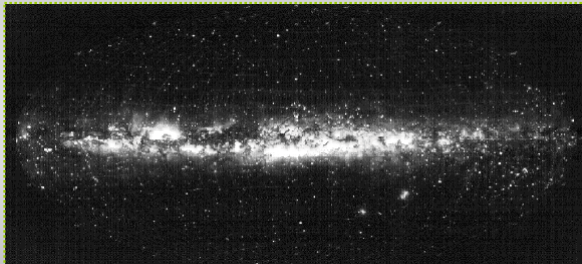
Spiral Sb galaxy NGC 4414

Milky Way Anatomy: Spiral Galaxy

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



The Milky Way (fuzzy ribbon of light across the sky)



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

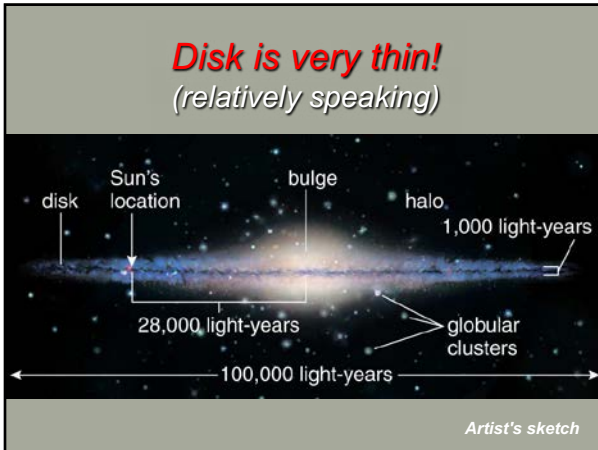
We might prefer to look like this! Prettier?



M101 with more distinctive spiral arms

Composite of M101 – much goes on!





FORMATION OF MILKY WAY

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

- INFALL (COLLAPSE) OF PRIMITIVE GAS**
- HALO STARS FORM**
LOW METALS
RANDOM, HIGH SPEEDS
- ROTATION FLATTENS**
DISK'S BULGE STARS FORM
- DISK STARS FORM**
 - RECYCLING OF MATERIAL BY INCOMING ELEMENTS IN STARS, WINDS, SUPERNOVAE
 - METAL ENRICHMENT IN DISK
 - NOT ENOUGH GAS FOR RECYCLING ELSEWHERE



INVENTORY OF MILKY WAY

Inventory of "stuff" making up our galaxy

Stars

- STARS** FEW HUNDRED BILLION, $\approx 10^{11} M_{\odot}$
 - BULGE** MEDIUM OLD, "METAL POOR"
 - DISK** YOUNG, "METAL RICH" INCLUDES OPEN CLUSTERS, OB ASTEROIDS
 - HALO** OLDEST, METAL POOR INCLUDES GLOBULAR CLUSTERS

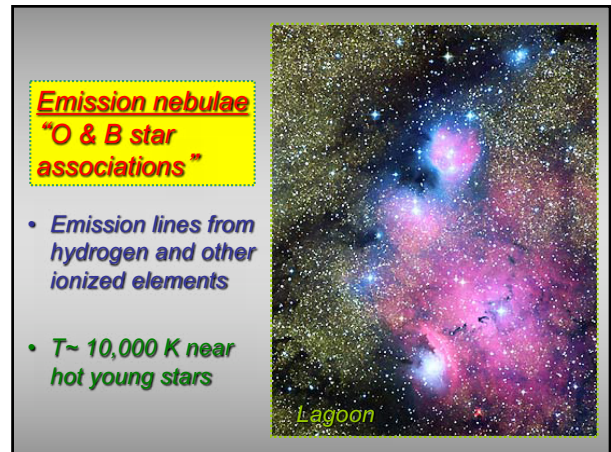
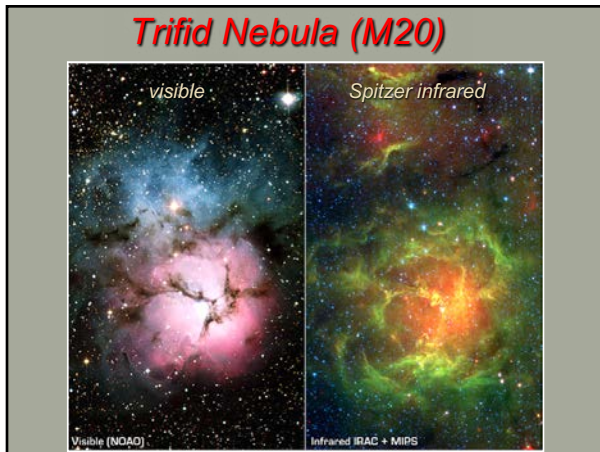
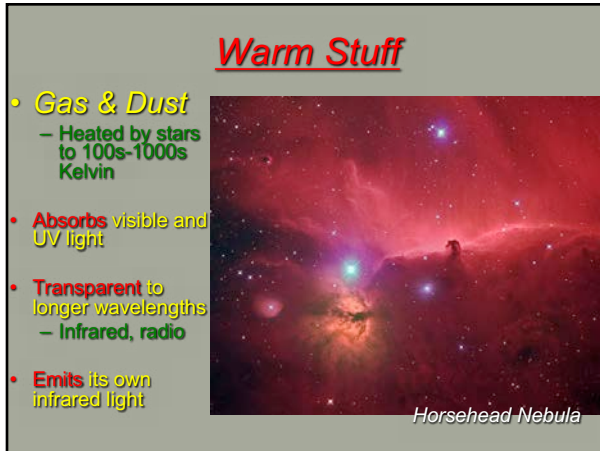
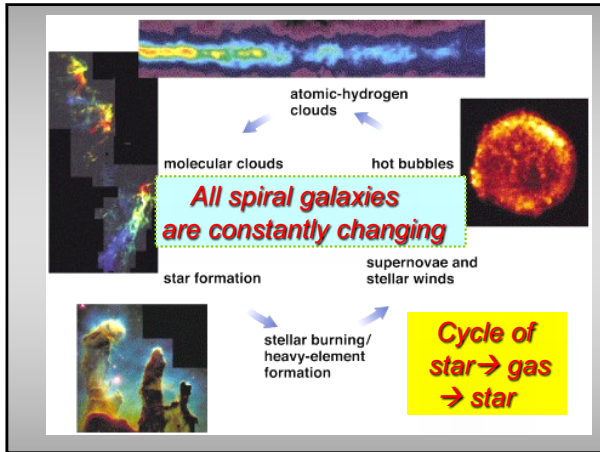
Gas

- GAS** 10% MASS OF STARS
MOSTLY IN DISK INTERSTELLAR MEDIUM
 - VERY COLD GAS IN THIN SHEET SITE OF STAR FORMATION (MOLECULAR CLOUDS)
 - WARM IONIZED H CLOUDS EMISSION NEBULAE (BRIGHT NEBULAE)
 - HOT GAS HEATED BY STELLAR WINDS, SUPERNOVAE VERY HOT GAS BLOWING OUT OF GALAXY

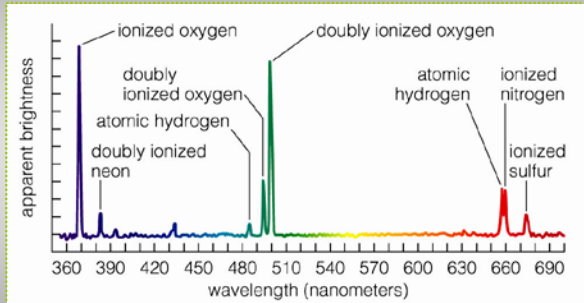
Dust

- DUST** 1% MASS OF GAS, 0.1% MASS OF STARS
MOSTLY IN CLOUDS IN DISK

+ "dark matter"

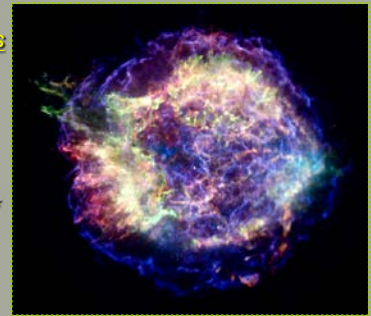


Where the emission colors come from ..



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**



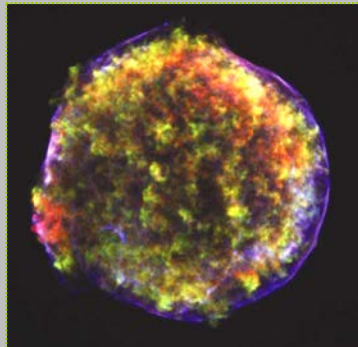
Cass A SN remnant Flamsteed ~1680

26

Fast electrons & magnetic fields

REALLY HOT STUFF

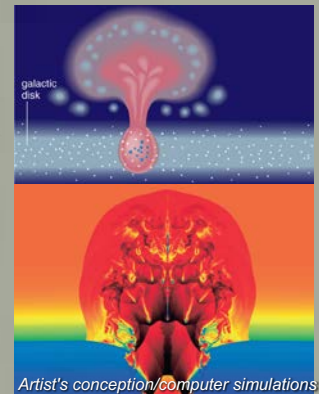
- **Synchrotron emission from SNR**
- **X-ray and radio**
- **Traces very hot gas bubbles (SNR)**



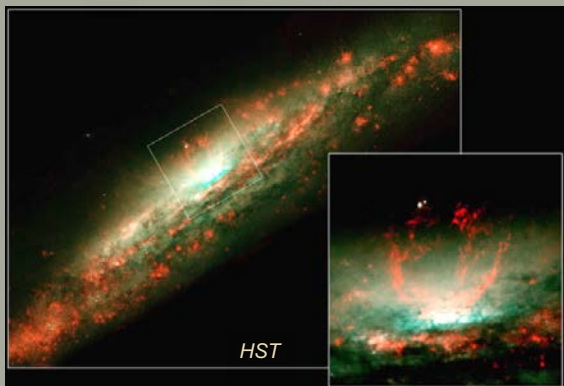
Chandra X-ray image of Tycho Brahe 1572 supernova remnant

Super-bubbles

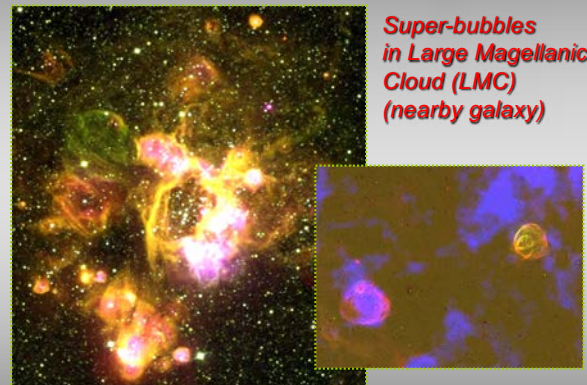
- **When multiple bubbles join (from a cluster) they can create superbubbles.**
- **If the superbubbles reaches the edge of the disk, it can blast hot gas out of the Galaxy!**
 - Some will rain back down and mix into the galaxy

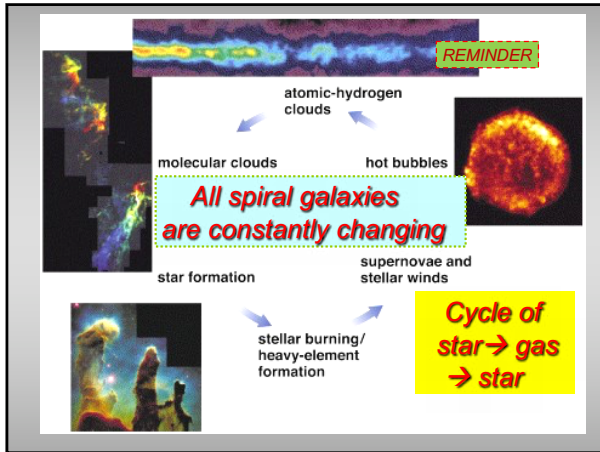


Super-bubbles in spiral galaxy NGC 3079



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





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

COMPONENTS OF INTERSTELLAR MEDIUM

- GIANT MOLECULAR CLOUDS ~ $10^5 M_{\odot}$
 - 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, CYANIDE, CARBON MONOXIDE (CO) ...
 - CO IMPROBANT FOR DOPPLER MEASUREMENTS OF CLOUDS WITH RADIO OBSERVATIONS

Very cold gas: star birth
- DIFFUSE CLOUDS OF GAS (AND SOME DUST)
 - H I REGIONS: CLOUDS OF COOL, NEUTRAL HYDROGEN ATOMS (REFLECTIVE MEDIUM) 21 cm RADIO EMISSION
 - Cool gas: neutral H**
 - H II REGIONS (EMISSION NEBULAE): GLOWING, IONIZED HYDROGEN SURROUNDING YOUNG HOT STARS (O & B STARS)
 - Hot H**

INTERSTELLAR MEDIUM ...

- 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 II (OXYGEN STRONG OF S.E. ELEMENTS)

Really hot gas
- COSMIC RAYS
 - VERY ENERGETIC ATOMIC NUCLEI (PARTICLES)
- INTERSTELLAR DUST
 - NOT MUCH BY MASS, BUT ...
 - REDSHIFTS STARLIGHT, ABSORBS SOME OF IT, POLARIZES THE LIGHT

Dust

More stuff in ISM inventory

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