ASTR 1040: Stars & Galaxies

M51 Whirlpool

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Lecture 20 Thur 1 Nov 2018

zeus.colorado.edu/astr1040-toomre

Onward to Galaxies, starting with our own!

Our Milky Way Galaxy in overview, aspects of any spiral galaxy – and a fine SONG

- 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, Chap 20 "Galaxies ..Cosmology" in overview

OVERVIEW

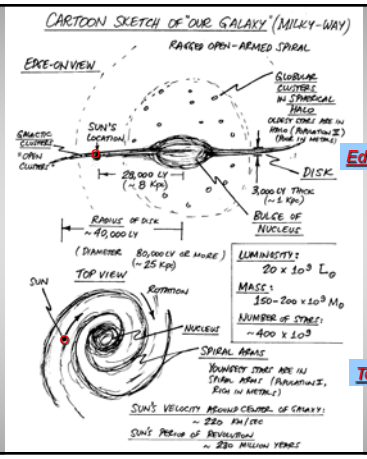
Our Milky Way Galaxy

- 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!

One-pager: ALL about us!

Sketch of Milky Way



Edge-on

Top

Stars and gas are all moving!

THIS INSPIRES A SONG!

Sing our way to the Milky Way

THE GALAXY -- LIGHTEN UP

Whenever life gets you down, Mrs. Brown,
And things are hard and tough,
And people are stupid, obnoxious and down,
And you feel that you've had quite enough...

Just remember that you're standing on a planet that's evolving
And revolving at 900 miles an hour.
It's orbiting at 90 miles a second, so it's reckoned,
From the sun that is the source for all our power.
The sun and you and me and all the stars that we can see
Are moving at a million miles a day
In an outer spiral arm at 40 thousand miles an hour
In the Galaxy we call the Milky Way.

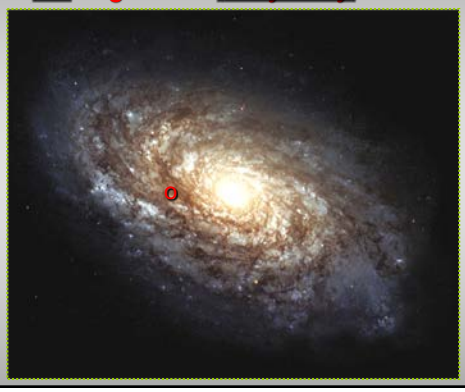
Now the Galaxy itself contains a hundred billion stars.
It's a hundred thousand light-years side from side.
It bulges in the middle 16 thousand light-years thick,
But out by us it's just 3 thousand light-years wide.
We're 30 thousand light-years from galactic central point.
It'll go round every 200 million years.
And our galaxy is only one of millions and billions
In this amazing and expanding Universe.

Now the Universe itself is still expanding and expanding
In every direction it could wish
As fast as it can go, the speed of light we know,
12 million miles a minute and that's the fastest speed there is.
So remember when you're feeling very small and insecure
How amazingly unlikely was your birth,
And pray that there is intelligent life somewhere up above,
For there isn't any down here on Earth.

Lighten up, there are stars in the sky,
Lighten up, it's a good question why,
But you don't know the answer and neither do I,
So meanwhile let's just all lighten up.

And remember that you're standing on a planet that's evolving ...

If we might see Milky Way from outside

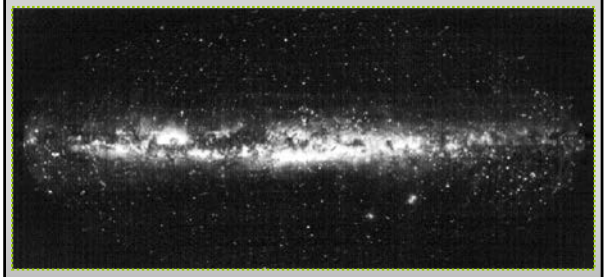


Spiral
Sb galaxy
NGC 4414

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

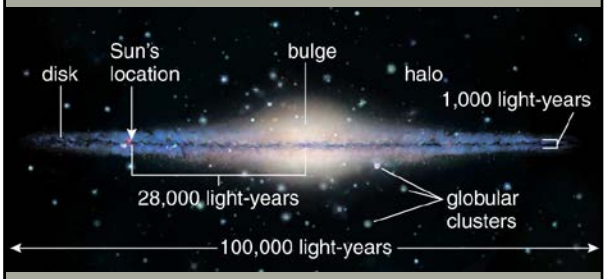
D.

We might prefer to look like this! Prettier?

M101
with more distinctive spiral arms

Composite of M101 – much goes on!

Disk is very thin!
(relatively speaking)



Artist's sketch

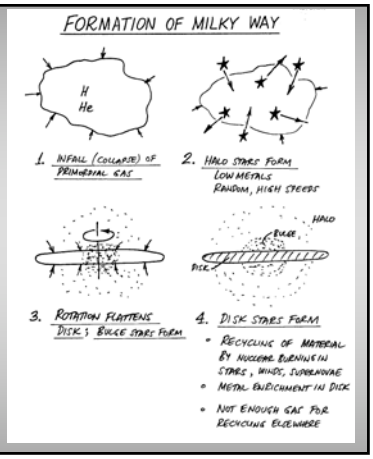
Galaxy NGC 4565 → nearly edge-on

REAL IMAGE!

Pre-Milky Way: early halo + disk

How to build a spiral galaxy

(or so we think!)



What are galaxies made of?

M104 Sombrero Galaxy

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
2. DIFFUSE CLOUDS OF GAS (AND SOME DUST)
   - HI REGIONS: CLOUDS OF COOL, NEUTRAL HYDROGEN ATOMS (REFLECTION NEBULAE) 21 cm RADIO EMISSION
   - HII REGIONS (EMISSION NEBULAE): GLOWING, IONIZED HYDROGEN SURROUNDING YOUNG HOT STARS (O & B ASSOCIATIONS)

Very cold gas: star birth

Cool gas: neutral H

Hot H

More stuff in ISM inventory

Really hot gas

Dust

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

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!)
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

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

Cold Stuff

Dark Molecular clouds (10's of Kelvin)

Horsehead in close-up

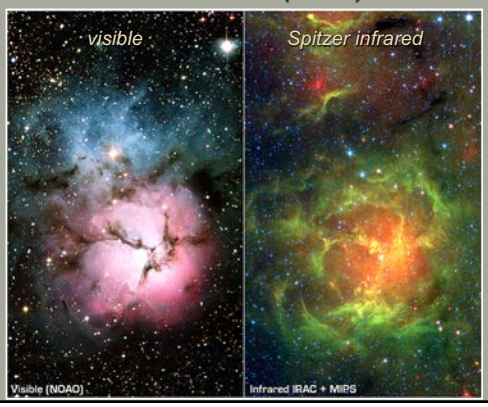
Warm Stuff

- 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*

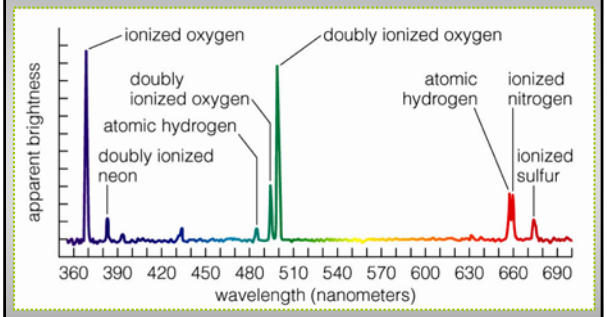
Trifid Nebula (M20)



Emission nebulae "O & B star associations"

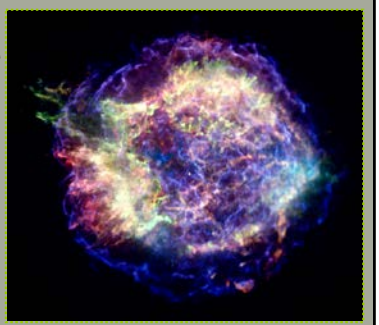
- *Emission lines from hydrogen and other ionized elements*
- *T~ 10,000 K near hot young stars*

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*



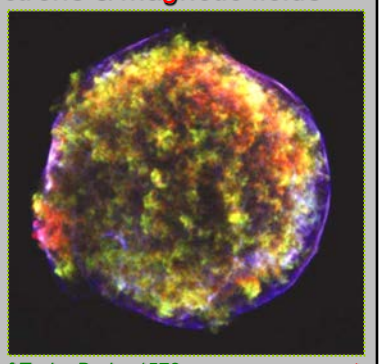
Cass A SN remnant Flamsteed ~1680

29

Fast electrons & magnetic fields

REALLY HOT STUFF

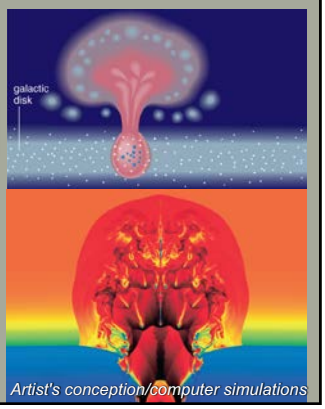
- *Synchrotron emission from SNR*
- *X-ray and radio*
- *Traces very hot gas bubbles (SNR)*



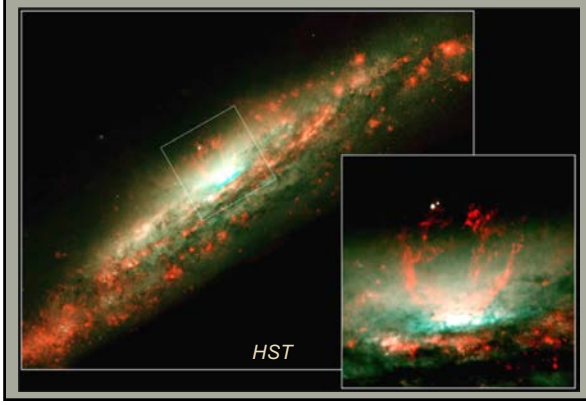
Chandra X-ray image of Tycho Brahe 1572 supernova remnant

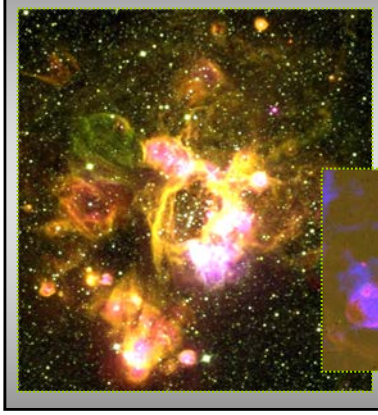
Super-bubbles

- 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

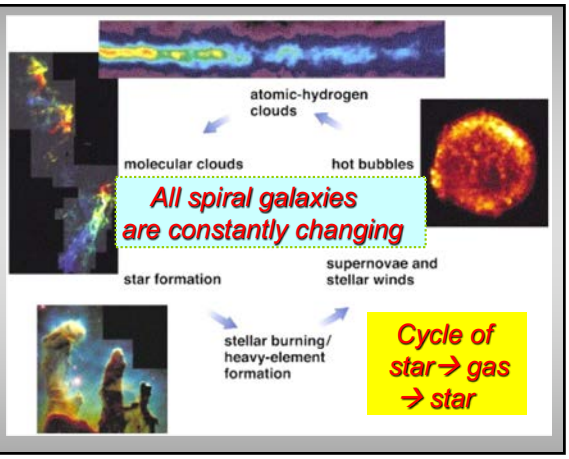




Super-bubbles in Large Magellanic Cloud (LMC) (nearby galaxy)

Clicker Poll of Advice

- How do you take notes (or listen) during lectures?
- A. I get most of it by just listening
- B. I write down some notes, then go back to book to look things up
- C. I listen, take some notes, then get copies of lecture slides from course website
- D. I enjoy talking with my buddies, and they tell me later if I missed anything
- E. I try to read the subject in advance, and then listen, taking some notes in class



Reading ahead 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?

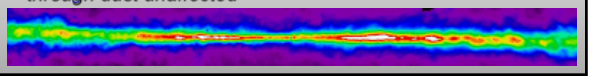
A.

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

A. Radio

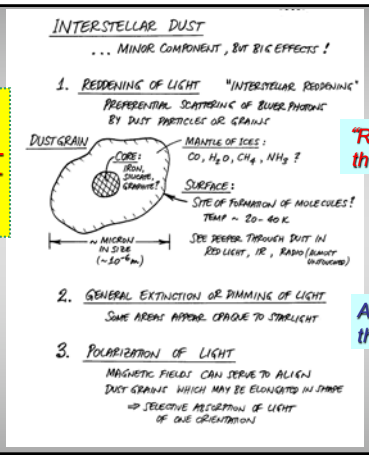
- Dust obscures our vision of much of the galaxy in visible and UV light.
- X-rays only highlight the hottest and weirdest places
- 21 cm radio waves map normal hydrogen gas -- these pass through dust unaffected

MW disk in radio



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