Stars, Galaxies & the Universe Announcements

- **Reading Quiz #10** – today
  - Mix of questions from Monday's lecture & reading for today on galaxies
- **HW#9 in ICON** – due Friday (11/5) by 5 pm
  - available as of this morning (Wed)
- **Bonus Points!! From clickers in class that are not quiz questions** (they are in ICON under "Bonus"; there are 4 sets now)
- **Observing Trip** - next week! Any interested lecture or lab students, please sign up after class. I can take up to 12 students. Will likely be Monday, Tuesday or Wednesday next week (leaving around 8 pm from VAN).

Stars, Galaxies & the Universe Lecture Outline

Our Milky Way Galaxy

(1) Spiral Arms of the Milky Way

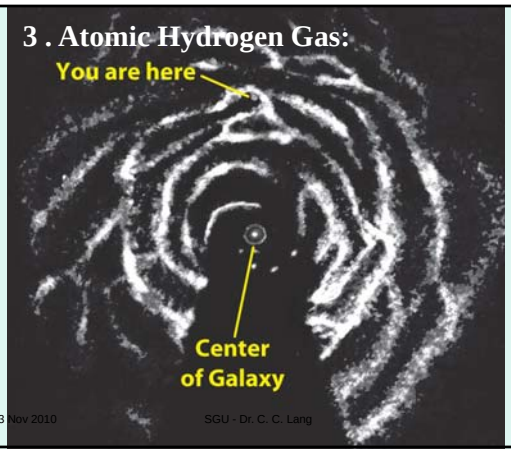
(2) Galactic Center!

The Variety of Galaxies in the Universe

(1) A few very nearby galaxies

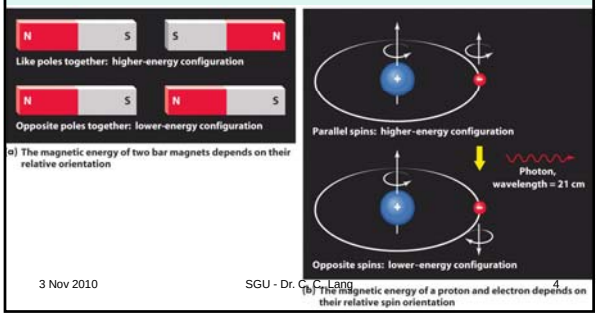
(2) Types of galaxies: spiral, elliptical, irregular

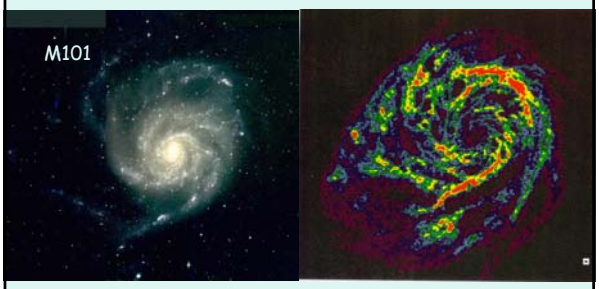
(3) Galaxy collisions



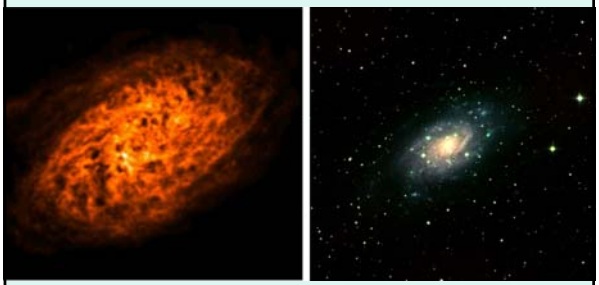
3 . Atomic Hydrogen Gas: Detection!

Atomic Hydrogen emits 21 cm radio waves

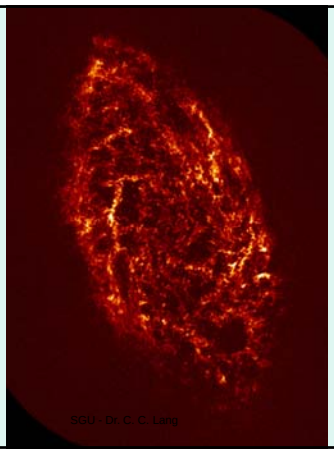




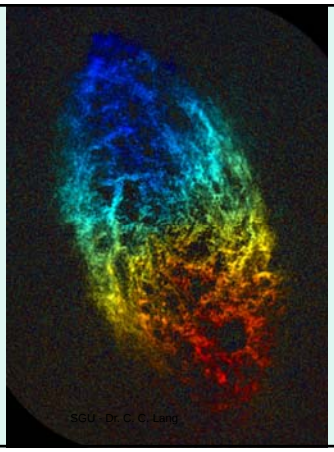
Distribution of HI emission in NGC 2403



Distribution of HI emission in M33



Distribution of HI emission in M33 – color represents velocity of HI line

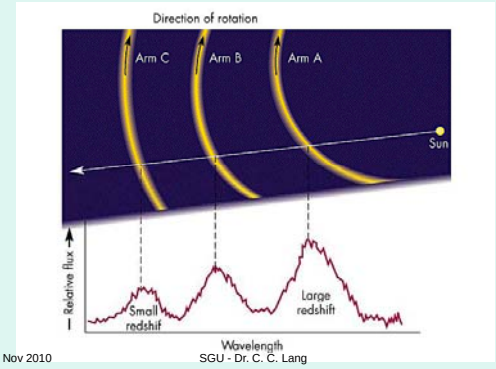


Spiral Structure

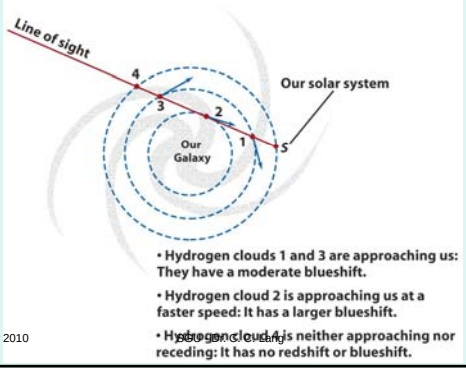
M 51

- The Galactic disk does not appear solid.
  - it has spiral arms, much like we see in other galaxies like M51
- These arms are <u>not</u> fixed strings of stars which revolve like the fins of a fan.
- They are caused by compression waves which propagate around the disk.
  - such waves increase the density of matter at their crests
  - we call them **density waves**
  - they revolve at a different speed than individual star orbit the Galactic center

Tracing spiral arms



Spiral arms can be traced from the positions of clouds of atomic hydrogen



- Hydrogen clouds 1 and 3 are approaching us: They have a moderate blueshift.
- Hydrogen cloud 2 is approaching us at a faster speed: It has a larger blueshift.
- Hydrogen cloud 4 is neither approaching nor receding: It has no redshift or blueshift.

Formation of the Milky Way Galaxy

→ Galaxy ~10 billion years old (globular clusters in the bulge)
→ Halo may be older ~12 million yrs
→ Halo may have formed first from clouds as well as already-formed clusters

Halo may be made up of stars and clouds

How can we better understand the centers of galaxies?

By looking at the heart of our own Galaxy – only 24,000 light years away from Sun!

- **Does our Galaxy have a *supermassive* black hole at its core?**
- **What physical conditions exist at the Galaxy center and are they different than rest of Galaxy?**
- **Is the Milky Way center strongly magnetized?**
- **Are there new stars forming in the Galactic center?**

Our Galactic center lies behind obscuring clouds of dust

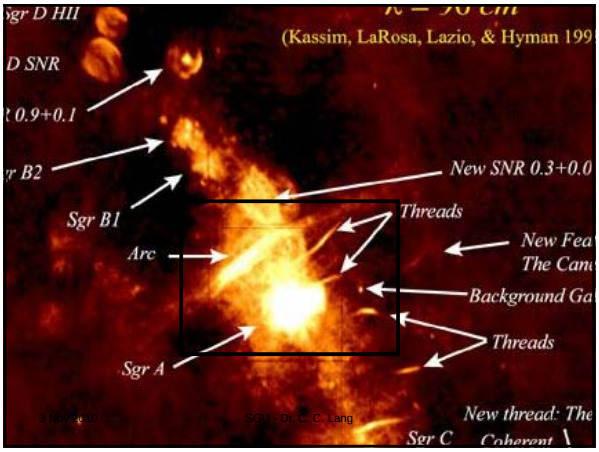
→ interstellar dust completely blocks out visible light from the GC!
→ we can observe **IR, radio, X-ray, and gamma-ray** from GC

The "Great Observatories" View of the Galactic Center

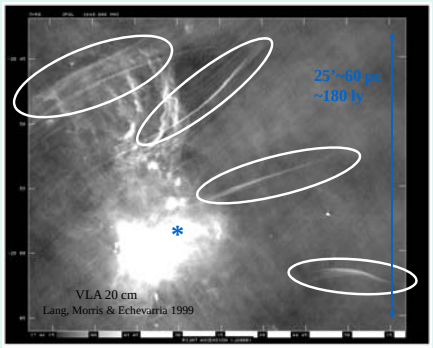
http://apod.nasa.gov/apod/ap091111.html

Why study our Galactic Center?

- our GC has a d = 24,000 ly
- GC is a much more extreme lab than the solar neighborhood
- GCs are known to have dense concentrations of
  - massive stars
  - molecular clouds
  - ionized gas
  - magnetic fields
  - hot ISM
  - SMBH
- the *interplay* between these components which gives rise to ENERGETIC EPISODIC activities



Magnetic Fields and Clouds of Hot Gas



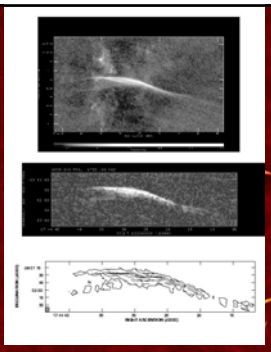
Magnetic Filaments

Magnetic Field in Galactic Center may play important role

- vertical field is unusual

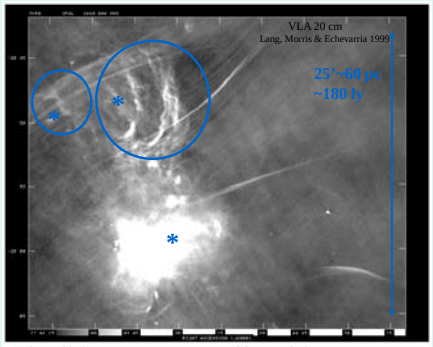
-strength is much higher

- may help direct hot plasma gas up and out of GC in large chimneys



- New survey underway here at U Iowa to reveal the complex magnetic structure (Lang et al., in prep.)

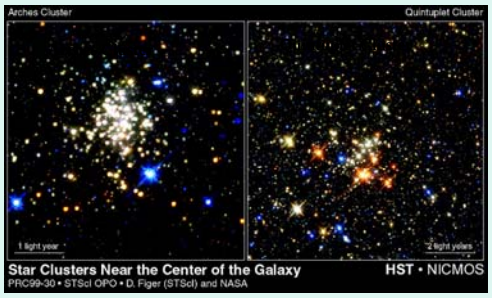
Clouds of Hot Gas and Star Formation



Clouds of Ionized Hydrogen T~10,000 K

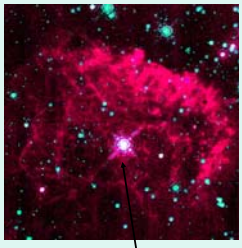
Gas ionized by groups of massive stars

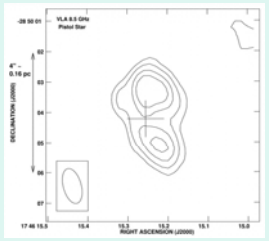
Stars in the Galactic Center: the most massive!



- densest clusters of stars in Galaxy
- some of the most massive stars in Galaxy (20-50 M_{sun})
- powerful radiation and winds heat plasma gas to 10 million K!

Pistol Star: one of the most massive stars in our Galaxy!





Thought to have had an initial mass > 150 Msun
May be a binary star (need better resolution)
Nebula is previous mass-loss event (burp); LBV star

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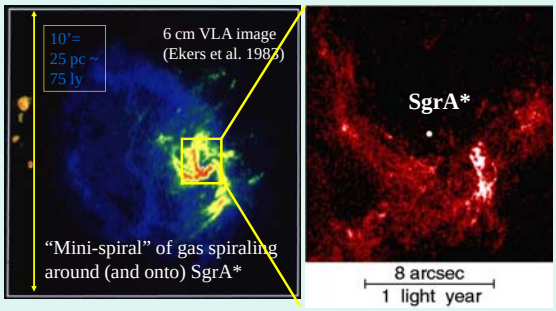
Lang et al. (2005)

Radio telescopes reveal supermassive black hole!



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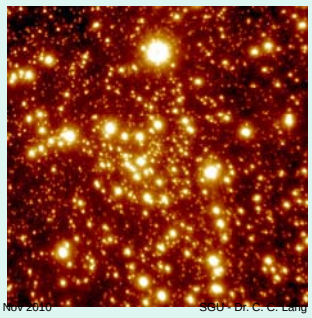
IR Radiation can reveal motions of the stars near SgrA*



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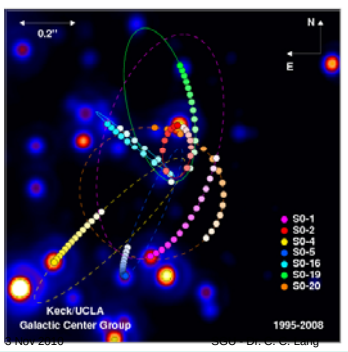
Near-IR motions: stars orbit SgrA* very quickly



0.2" = 1600 AU
R_s = 0.06 AU

Velocites of ~1500 km/s
SO-2 has velocities of ~5,000 km/s

Using Kepler's Law, With $M_2 << M_1$

$M_1 = 4\pi^2 a^3 / GP^2$
a = 5.5 light days!
P = 15.2 years

=> M = 3 x 10^6 M_o

Galactic Center Mysteries

Is our Galaxy an "active galaxy"? How does its luminosity compare to active galaxies?

Does our Galaxy have huge jets of emission? What does it sup on? (Many think it only 'snacks').

How does SgrA* affect the rest of the GC environment? i.e., how close can stars form near SgrA* BH?

How do such massive star clusters form near the GC?

What role does the magnetic field play in the GC?

"Spiral Nebulae"

- early observers could distinguish between stars & fuzzy things (nebulae)
- Andromeda galaxy (M31) – fuzzy patch seen with naked eye from here
- Magellanic clouds – two fuzzy patches seen clearly in Southern Hemisphere

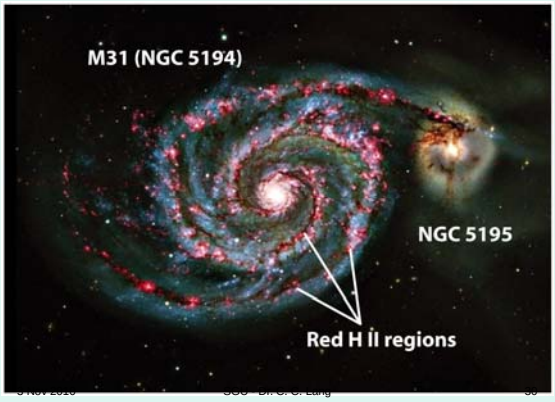
- "island universes" became a popular term in the 1800's
- novas and other variable stars were discovered in many of these "island universes" making them like our own Milky Way

• Immanuel Kant (1755) – a philosopher - suggested that there should be "island universes" like our own Milky Way galaxy

• 1845 in Birr, Ireland, Lore Rosse had the world's largest telescope built – the mirror was 6 ft in diameter with elaborate engineering

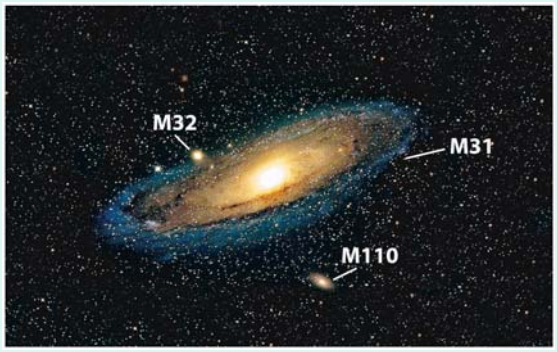
Rosse's "Leviathan of Parsonstown"

M51 as viewed through the "Leviathan"



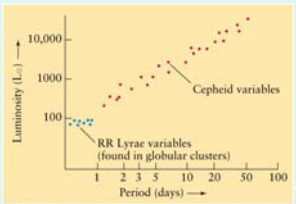
The Andromeda Galaxy (M31)

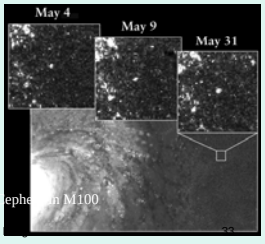
- Milky Way twin
- Distance of ~2.5 million ly discovered by Edwin Hubble
- Cepheid variables used to find the distance



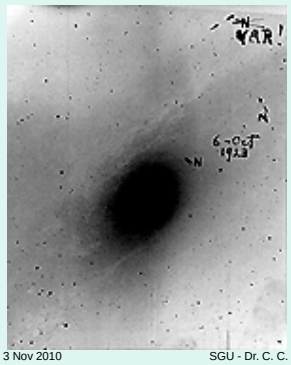
Cepheid variables discovered in Andromeda galaxy by Edwin Hubble in 1923

- noticed a number of dim stars which varied on a timescale of days
- identified these stars as being Cepheid variables
- measured their FLUX and PERIOD
- used the P-L relationship to derive their Luminosities (as high as $L \sim 2 \times 10^4 L_\odot$)
- then calculated their distances to be **2.5 million light years away!!**





Cepheids in M100

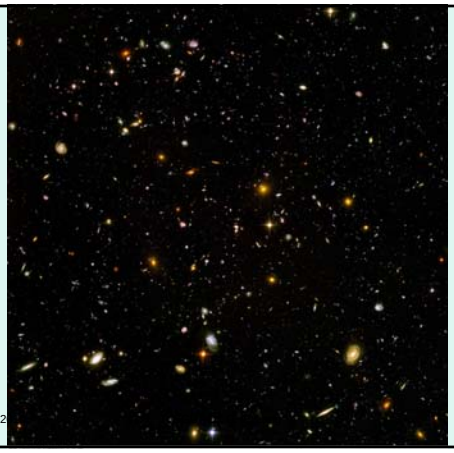


Edwin Hubble's discovery of a Cepheid in Andromeda Galaxy in 1923 (Mt. Wilson Observatory)

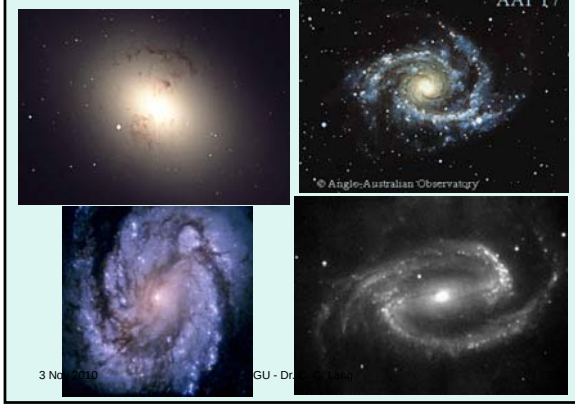
this picture shows the photographic plate identifying a Cepheid as "VAR!"

The Large & Small Magellanic Clouds

- closest galaxies – LMC: 180,000 ly; SMC: 210,000 ly
- do not have the spiral pattern that Andromeda does
- "irregular, dwarf" galaxies



Different types of galaxies



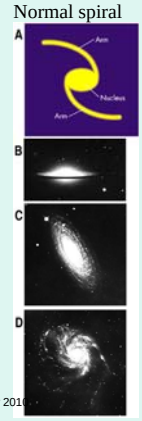
Different types of galaxies

Types of galaxies:

1. **Spiral galaxies**

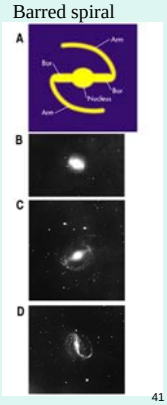
- 80% of all galaxies have flattened disks
- spiral arms
- divided into two subtypes:
  Normal spirals
  Barred spirals
- contain vast reservoirs of gas and dust like the Milky Way

Normal spiral

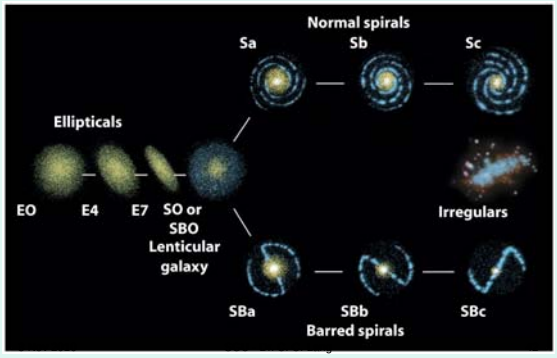


further classified on the ratio of bulge to arms

Barred spiral



Hubble classification of galaxies



Types of galaxies:

2. Elliptical galaxies

- nearly featureless galaxies
- look like giant starballs
- can have a variety of shapes
- thought to be rotating (and flattened), but not

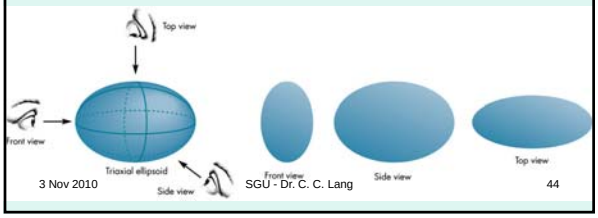
- sizes range from a few kilo-pc to 2 million-pc
- masses range from a million solar masses to 100 times the mass of the milky way

Types of galaxies:

2. Elliptical galaxies

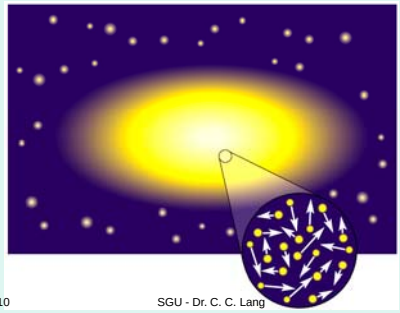
- nearly featureless galaxies
- look like giant starballs
- can have a variety of shapes

cigar shape to football shape to spherical shape
depends on how you view the galaxy

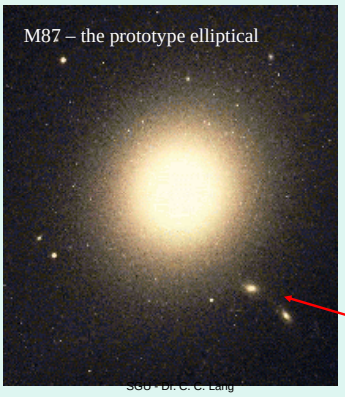


The shape of elliptical galaxies results from

→ the motions of billions of stars



M87 – the prototype elliptical



jet-like feature

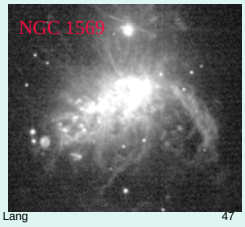
Types of galaxies:

3. Irregular galaxies

- neither elliptical or spiral galaxies
- LMC and SMC are good examples of irregular types
- often have MORE gas, dust than spirals do!

LMC

NGC 1569

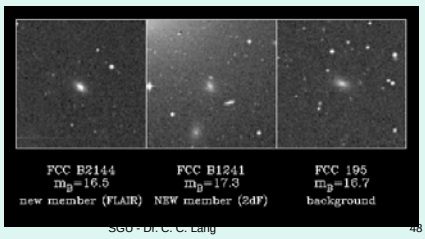


Types of galaxies:

4. Dwarf galaxies

- much smaller galaxies
- often visible because of intense star formation
- there may be a very significant number of dwarf gals.

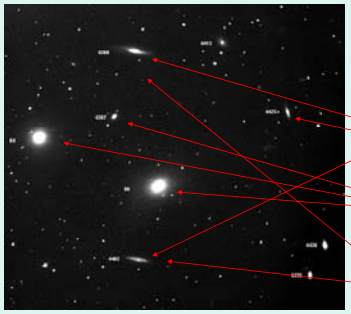
Fornax cluster of dwarf galaxies



			
1. Size	5-50 kpc	1-200 kpc	1-10 kpc
2. Mass	10^9-10^{12} M_o	10^5-10^{13} M_o	10^6-10^{11} M_o
3. Luminosity	10^8-10^{11} L_o	10^6-10^{12} L_o	10^6-10^9 L_o
4. Rotation	yes	no, motions of stars	chaotic motions
5. Gas/star content	gas, dust in disk	little gas, dust	much gas, dust
6. forming stars?	yes!	no	YES!

Check your knowledge --

The Virgo Cluster of galaxies



which galaxies:

- have more young stars?

spiral galaxies

- are redder?

elliptical galaxies

- have large rotations?

spiral galaxies

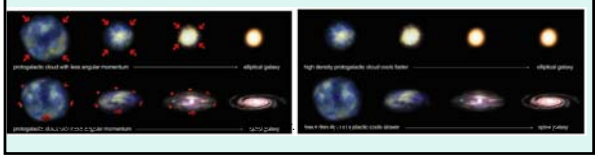
Galaxies are organized into clusters, like stars

- galaxy clusters are gravitationally bound systems
  - members stay in the cluster due to gravity
  - members orbit around center of mass

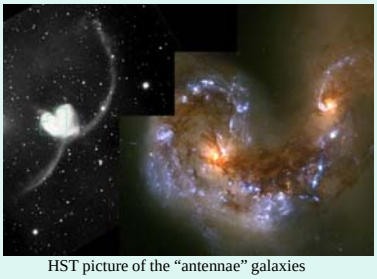
- galaxy clusters are classified as "rich" or "poor"
  - "rich" clusters have many BRIGHT members
  - "poor" clusters have mostly dim, elliptical galaxies

What Determines Galaxy Type?

- We can explore two options:
  - the initial conditions of the protogalactic cloud; i.e. destined from birth
  - later interactions with other galaxies; i.e. a life-altering conversion
- Two plausible explanations regarding the birth properties of the protogalactic cloud:
  - Protogalactic spin…the initial angular momentum determines how fast the cloud will form a disk before it is completely turned into stars
  - Protogalactic cooling…the initial density determines how fast the cloud can form stars before it collapses into a disk



What happens with two galaxies collide?



HST picture of the "antennae" galaxies

→ we can observe galaxies in process of colliding

→ slow process, orbits of stars are disrupted

→ repeated collisions become MERGERS of two galaxies

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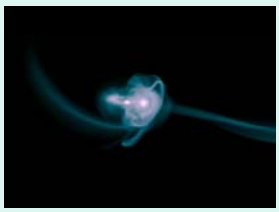
Galaxy collisions cause galaxies to be "tidally disrupted"

- effects due to gravitational pull between the two galaxies



simulation of a galaxy "encounter"

Andromeda (M31) and the MW

also, the MW and the Magellanic clouds will collide within a few billion years

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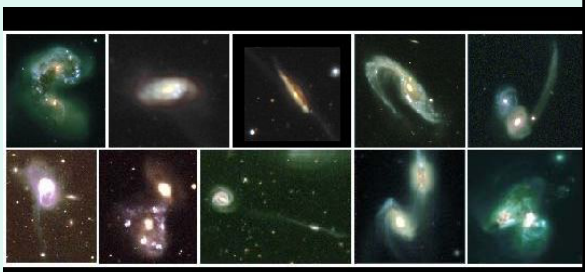
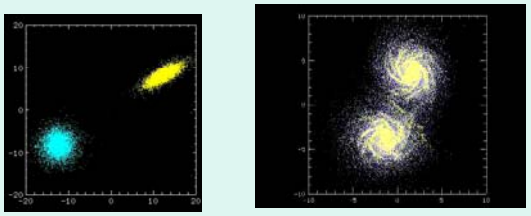
Galaxy collisions result in peculiar galaxies

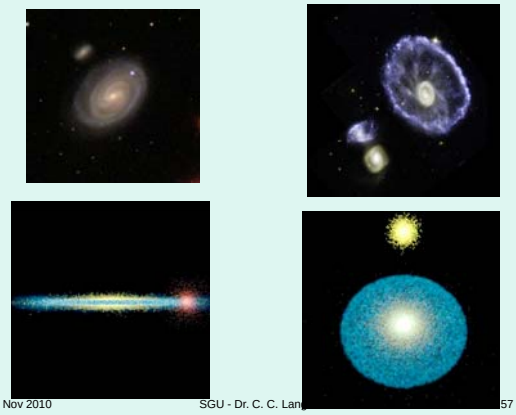


Some Peculiar Galaxies

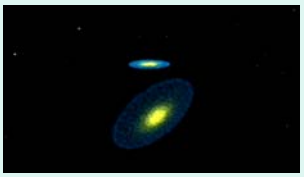
When Spirals Collide

Model of Galaxy Interaction



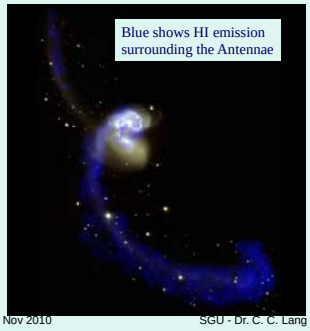


"The Mice"
Interacting galaxies



Streamers of atomic hydrogen (HI) are often leftover after a collision

Blue shows HI emission surrounding the Antennae



HI cloud set to collide with the Milky Way