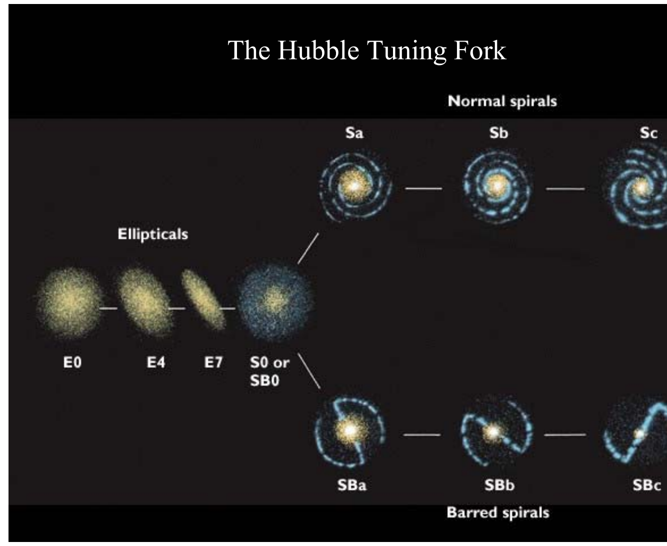
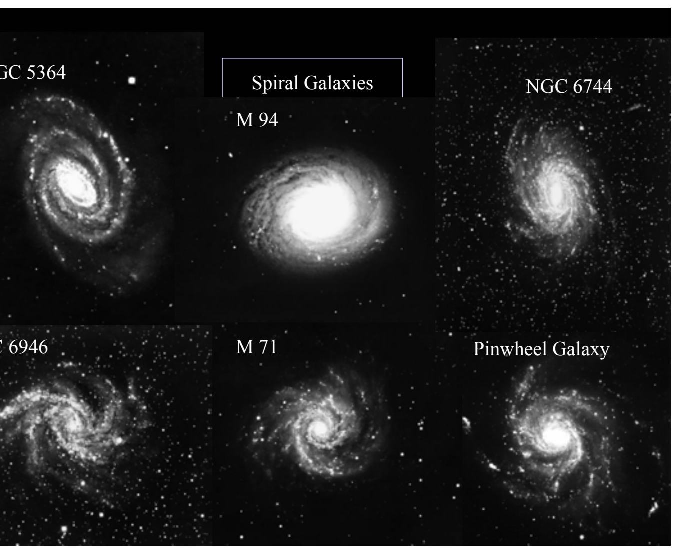
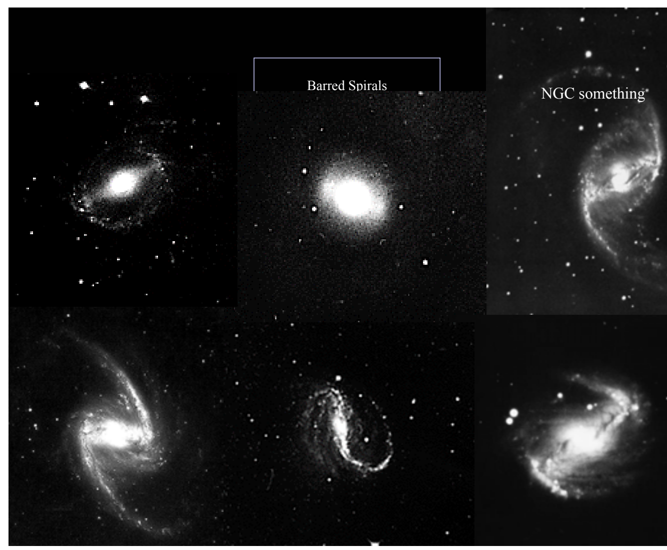
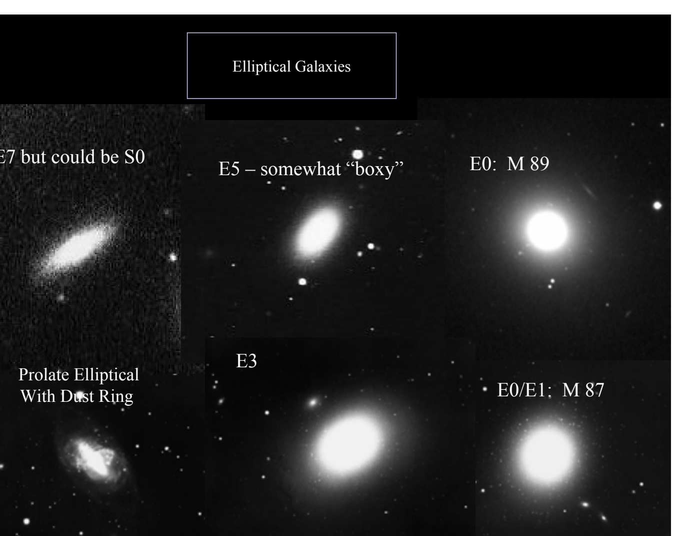
Properties of Ellipticals and Spirals

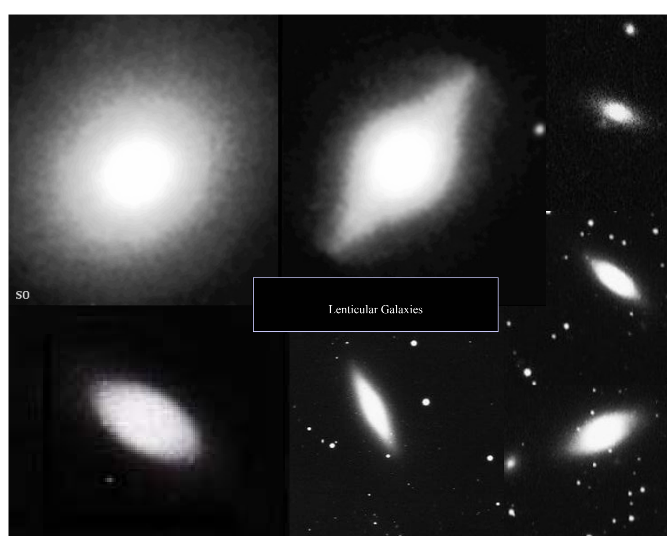
Globular Cluster Evolution
Galaxies in Color and Star Formation
List of Properties of Ellipticals and Spirals
Surface Brightness Profiles
Winding Dilemma
Differences in Kinematics
Hubble Classification Scheme Revisited





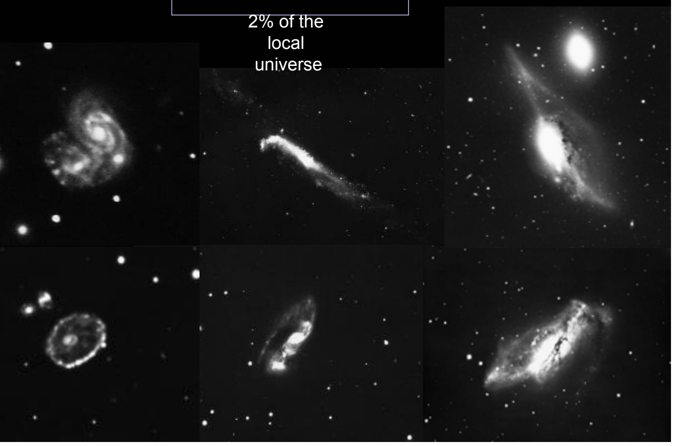






Peculiar Galaxies

2% of the local universe



Understanding Galaxy Formation and Evolution

First Step: Classify Galaxies according to **<u>some</u>** scheme that makes sense.

Possibilities of Grouping Galaxies **just** by **Appearance**:

- By Overall Shape (Elliptical versus Spiral)
- By Details in the Shape (e.g. structure and length of Spiral Arms, or presence of Bars, or Rings)
- By Overall Size or by the Size of the Bulge or the Disk
- By Luminosity

Step II: Galaxy contains

- Stars
- Gas (ionized, atomic molecular)
- Dust
- Stellar remnants
- Dark Matter

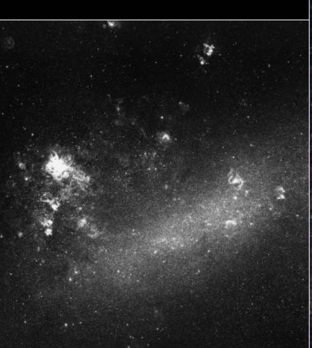
Question: How do these change as galaxies evolve?

Next: Need to know more about stars and gas and dust in galaxies

- To follow– analyzing light of stars
- Crash course on stellar evolution
- Star Formation and the Interstellar Medium
- Continue with discussion on galaxies
  - Evolution and Formation

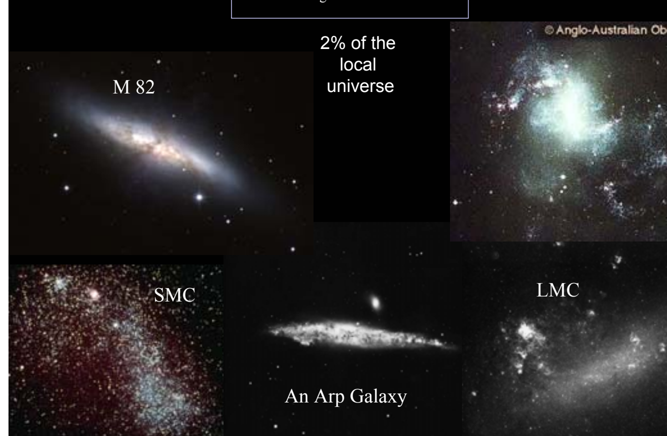
arge Magellanic Cloud

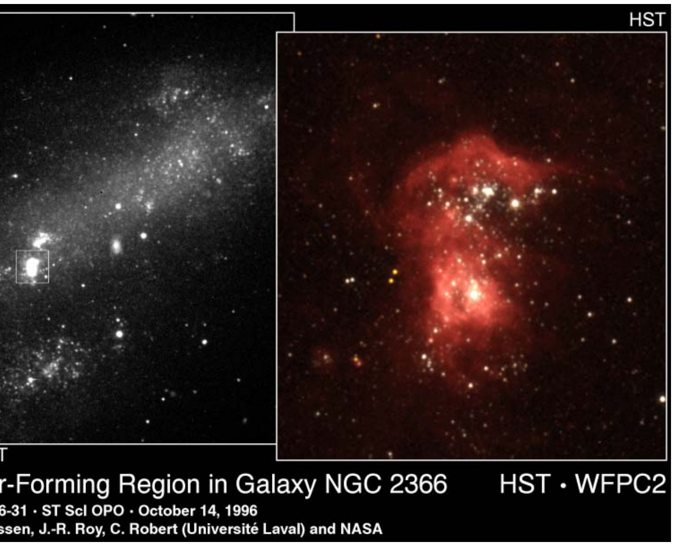
Can see HII-regions, eflection Clouds and Galaxy Light reddened by Dust



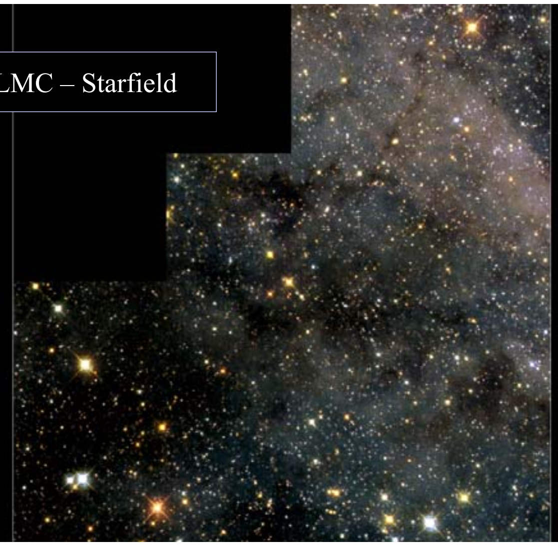
Irregular Galaxies

2% of the local universe





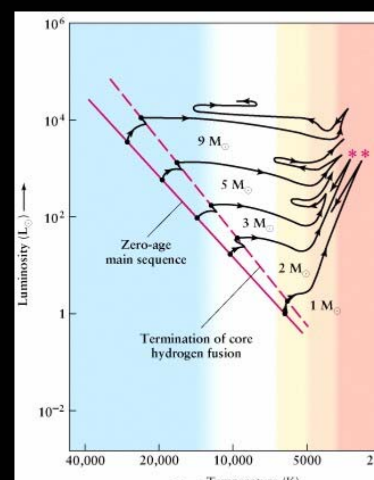
LMC – Starfield



Let globular cluster evolve

- Question 1: How is the overall globular cluster luminosity going to change
- Question 2: How is the overall globular cluster color going to change?
- Question 3: What factors is this evolution going to depend on?

Main Sequence Lifetimes and Evolution



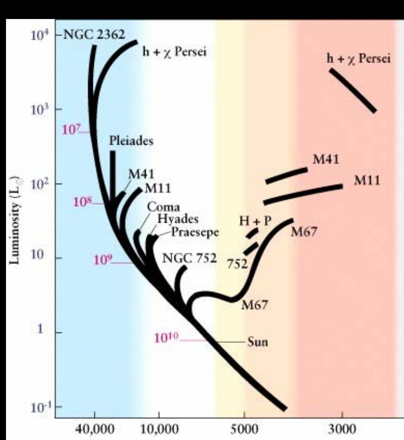
Integrated galaxy luminosity and galaxy colors

Dominated by the **colors** of the **most luminous** stars

Young Cluster: Blue stars are still on main sequence

Old Cluster: The most luminous stars, i.e., the blue, hot, and young stars have evolved off the main sequence and have terminated their lives.

→ Age of Galaxy correlates to the time since the last major star formation epoch.



Galaxy Luminosity -- based on star formation

- A young galaxy compared to an older galaxy can be up to 3 magnitudes brighter
- → galaxies fade as they age
- Question: what other factors affect galaxy luminosities?

Luminosity Evolution

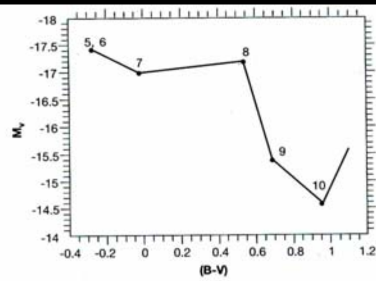
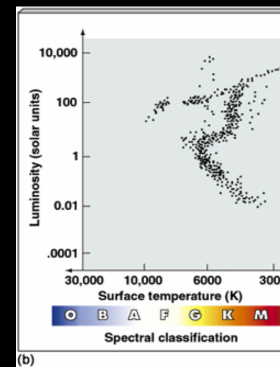


FIGURE 4.13 *Population synthesis model for a Salpeter initial mass function; log (age) is indicated in years above the curve. (Based on Wray 1988.)*

If galaxy colors are blue

a) Upper m.s. stars from recent burst
b) Horizontal branch stars
c) Post assymptotic giant branch stars
d) Non-stellar radiation



Aging galaxy clusters

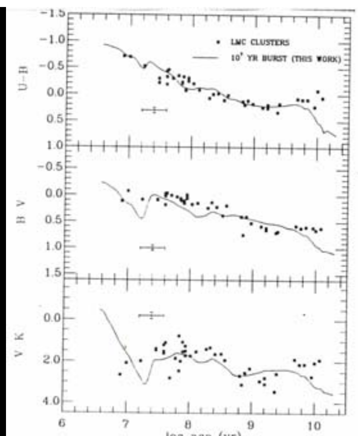


FIG. 10.—Evolution of the $U-B$, $B-V$ and $V-K$ colors of a 10^7 yr burst population computed with the Salpeter (1955) IMF (*solid lines*). The data points are from a representative sample of LMC clusters with infrared photometry from Persson *et al.* (1983) and *UBV* photometry from van den Bergh (1981). The clusters ages are from Elson and Fall (1985, 1988). All observed colors have been dereddened by using the color excesses tabulated by Persson *et al.* (1983). Typical error bars are indicated on the figures. The oldest, blue clusters in the sample are biased toward low metallicities (Cohen 1982).

M87 & M84

Elliptical Galaxies

Elliptical Galaxies are rather different from Spirals:

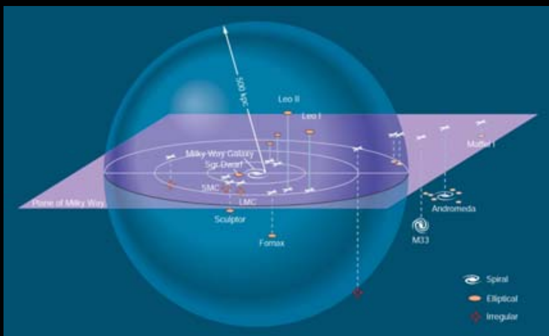
What can you say about the stellar populations of Elliptical Galaxies?

Galaxy Colors

Galaxy type	B-V color	
Elliptical	0.95	red
Sa	0.65	
Sb	0.55	
Sc	0.4	
Irregular	0.3	bluish

Question: What do these colors tell us about the last star formation epoch?

Local Group



- ❖Galaxies are found in groups.
- ❖Shown is the Milky Way's local group.

Spirals in Color

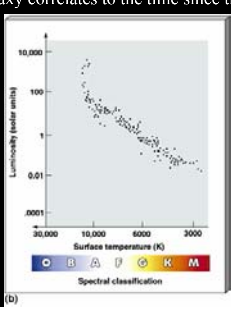
Spiral galaxies display ongoing star formation in the spiral arms. Many stars in the arms are young stars. The most luminous stars dominate the overall color of those regions. These are the young hot (blue!!) stars. Thus the spiral arms tend to have a bluish hue.

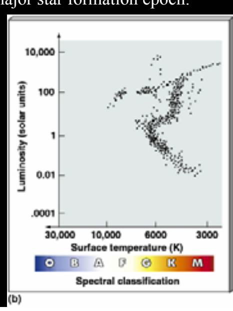
Galaxy Colors

Dominated by the **colors** of the **most luminous** stars

Young Cluster: Blue stars are still on main sequence
Old Cluster: The most luminous stars, i.e., the blue, hot, and young stars have evolved off the main sequence and have terminated their lives.

→ Age of Galaxy correlates to the time since the last major star formation epoch.



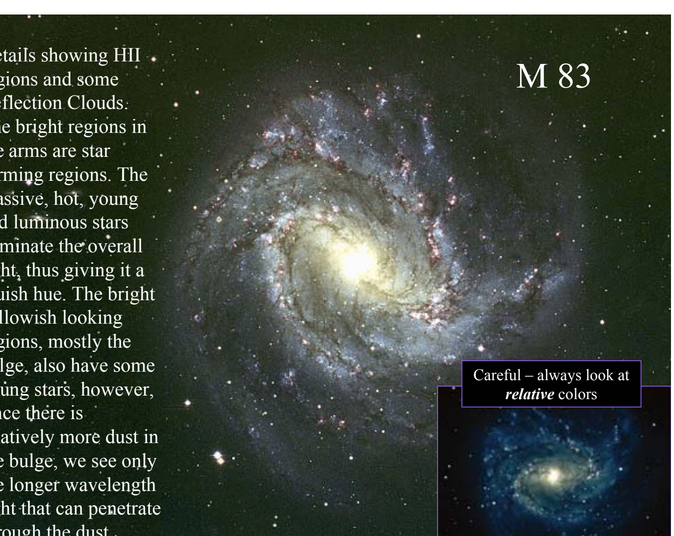


Dust in Spirals

The Light from Regions where Intervening Dust blocks our view are REDDENED (like the Sun at sunset)

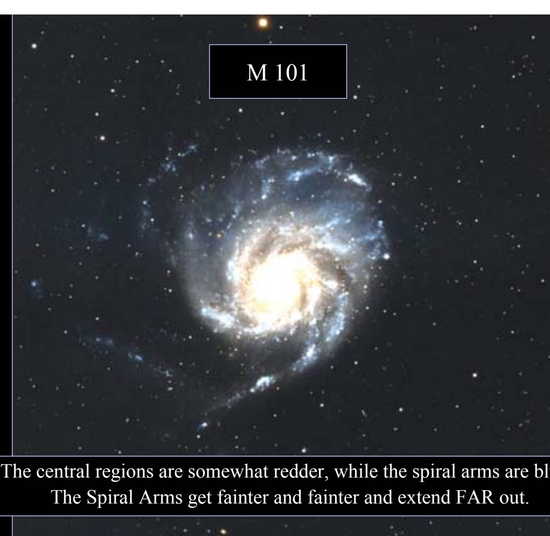
M 83

etails showing HII gions and some eflection Clouds. he bright regions in e arms are star rming regions. The assive, hot, young d luminous stars minate the overall ht, thus giving it a uish hue. The bright llowish looking gions, mostly the lge, also have some ung stars, however, nce there is atively more dust in e bulge, we see only e longer wavelength ht that can penetrate rough the dust.

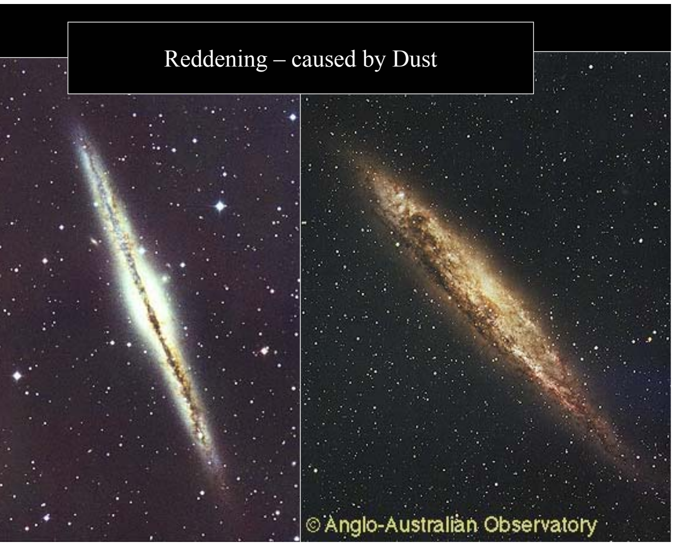


Careful – always look at ***relative*** colors

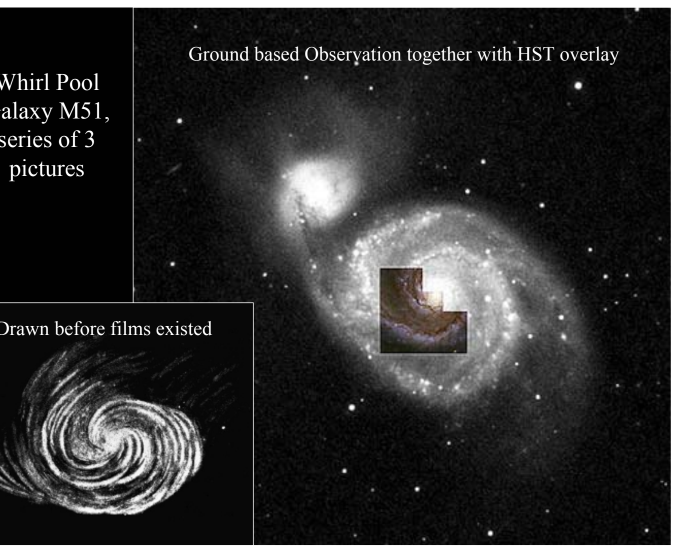
M 101



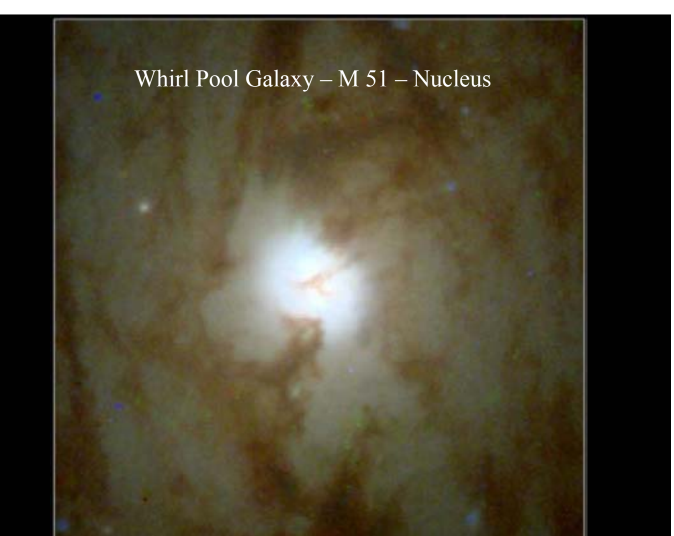
The central regions are somewhat redder, while the spiral arms are bluer. The Spiral Arms get fainter and fainter and extend FAR out.

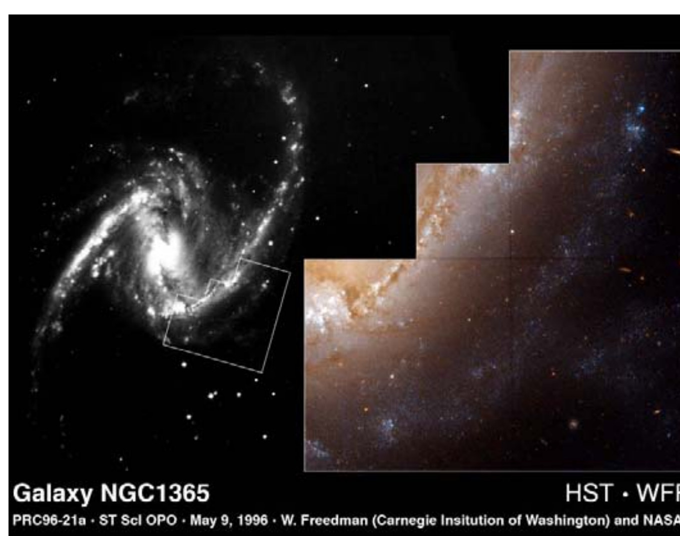

Reddening – caused by Dust
© Anglo-Australian Observatory


NGC 891

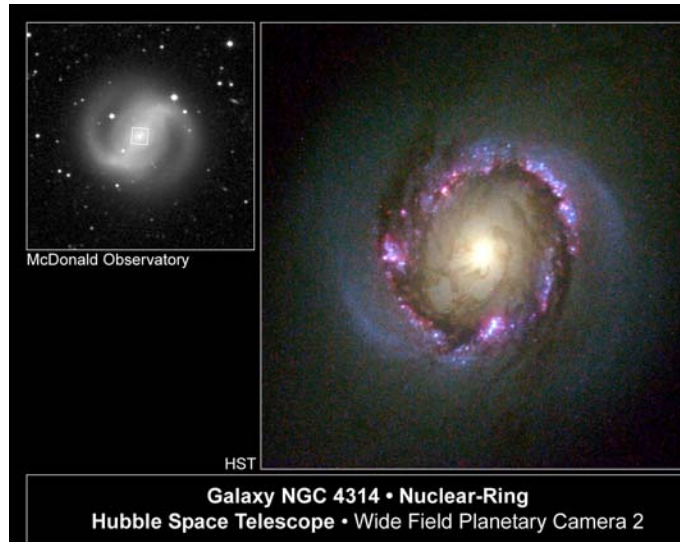

Whirl Pool
alaxy M51,
series of 3
pictures
Ground based Observation together with HST overlay
Drawn before films existed


Whirl Pool Galaxy – M 51 –
series of 3 pictures

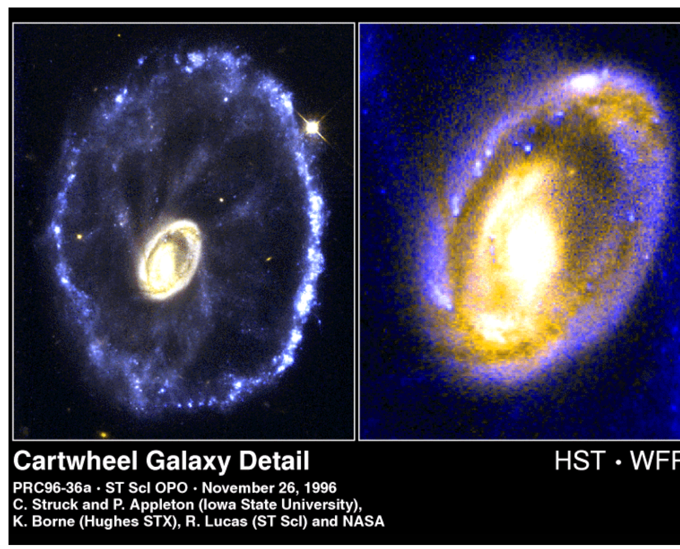

Whirl Pool Galaxy – M 51 – Nucleus

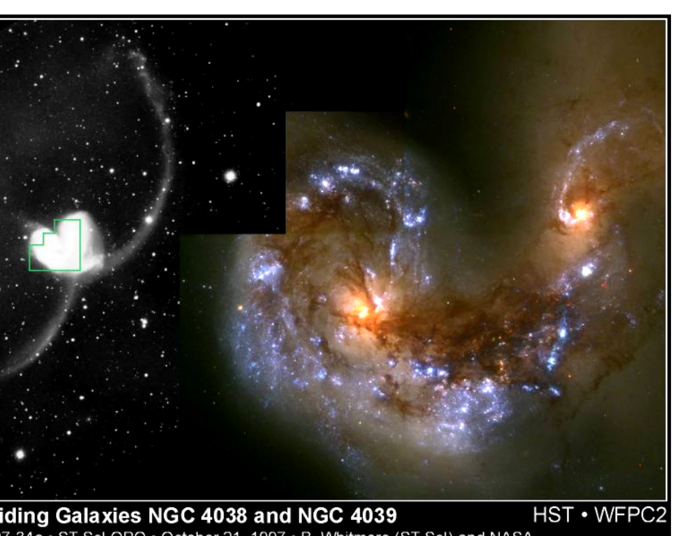

Galaxy NGC1365
HST · WF
PRC96-21a · ST ScI OPO · May 9, 1996 · W. Freedman (Carnegie Insitution of Washington) and NASA

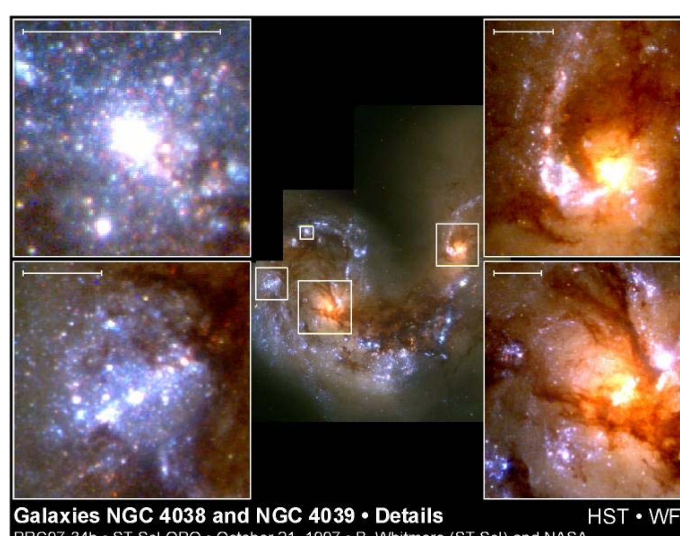

NGC 253
Pretty Details

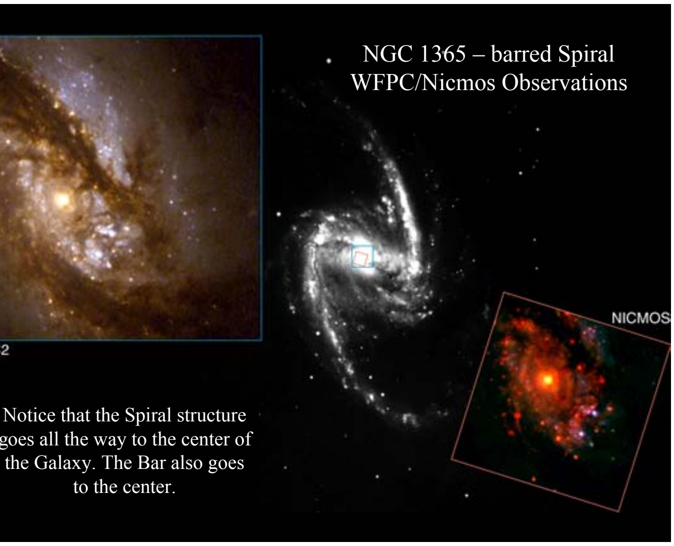

McDonald Observatory
HST
Galaxy NGC 4314 • Nuclear-Ring
Hubble Space Telescope • Wide Field Planetary Camera 2


NGC 7742 – Ring Galaxy


Cartwheel Galaxy Detail
HST • WF
PRC96-36a · ST ScI OPO · November 26, 1996
C. Struck and P. Appleton (Iowa State University),
K. Borne (Hughes STX), R. Lucas (ST ScI) and NASA


iding Galaxies NGC 4038 and NGC 4039
HST • WFPC2
7-34a • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

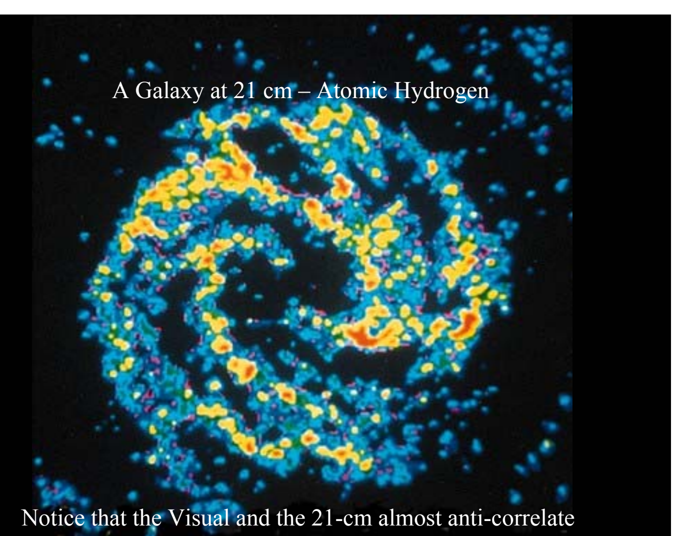

Galaxies NGC 4038 and NGC 4039 • Details
HST • WF
PRC97-34b • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

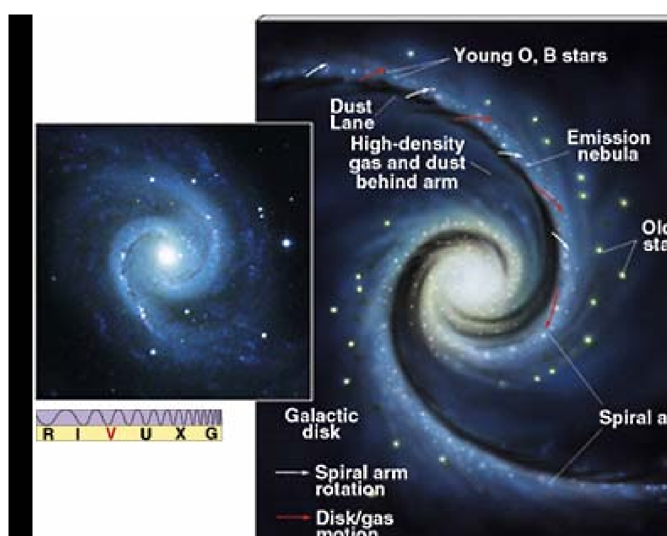


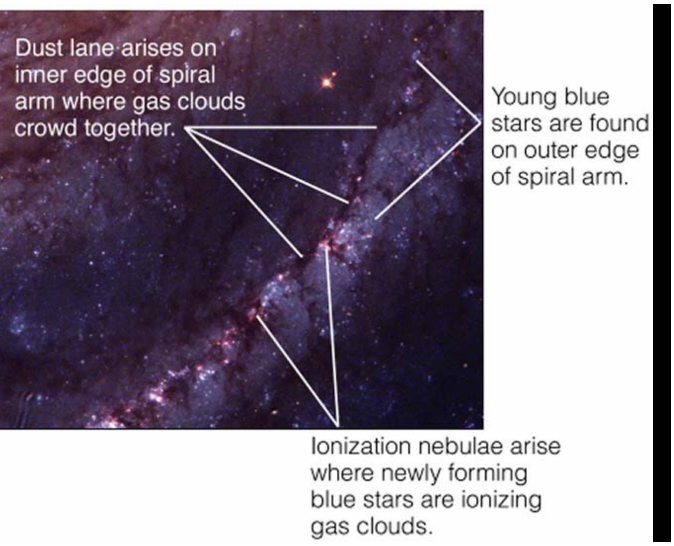
The Spiral Structure

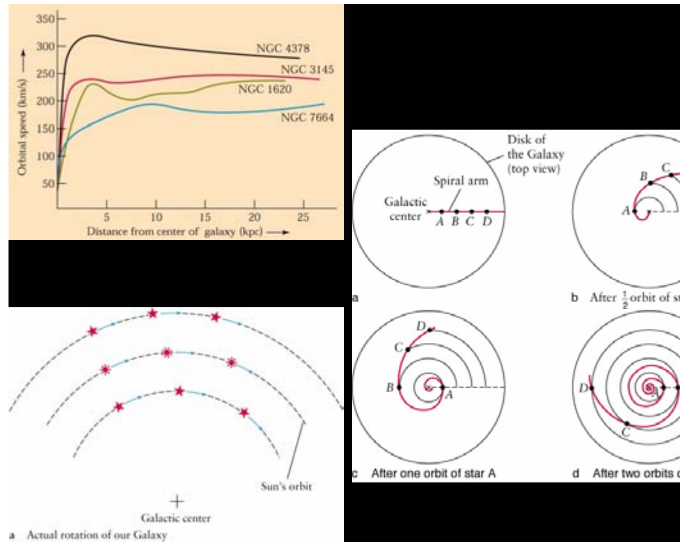
- What causes the spiral structure?

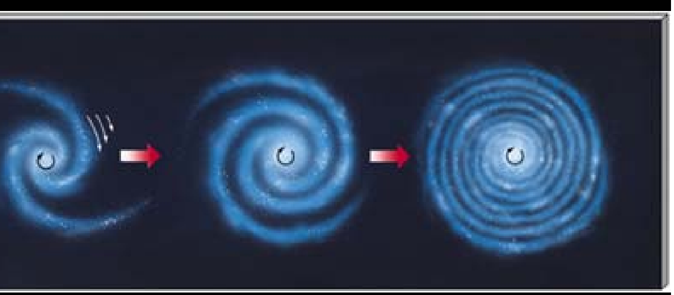
- First look at some characteristics of the spiral arms
- Then determine if spiral arms can "wind up"











The Winding Dilemna

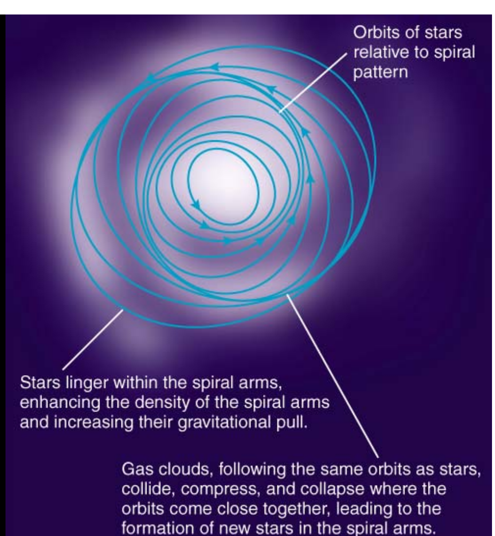
One rotation of the Galaxy takes roughly 200 million years (2 x 10^8 years)
The age of the Galaxy is roughly ~20 billion years (2 x 10^{10} years)

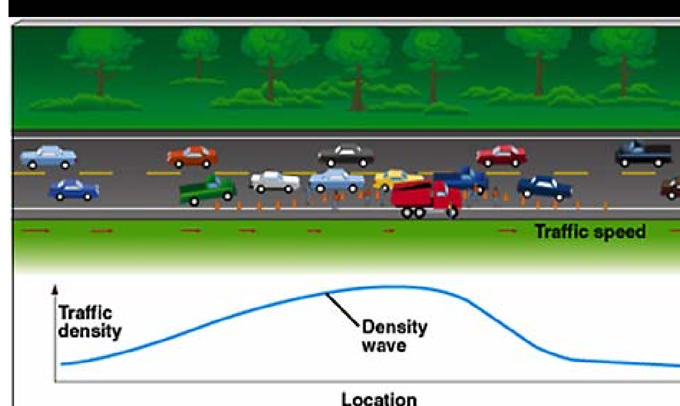
How many revolutions would you have?

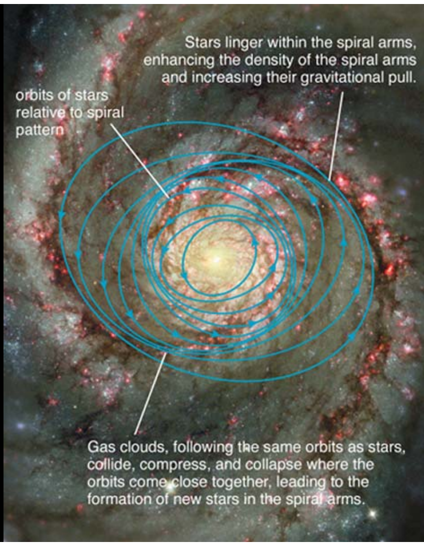
$$\#\ of\ \ revolutions = \frac{age\ of\ universe}{time\ of\ one\ orbit}$$

$$\#\ of\ \ revolutions = \frac{2 \cdot 10^{10}\ yrs}{2 \cdot 10^{8}\ yrs} = 100$$

What would you expect the galaxy to look like after 100 revolutions?







M87 & M84

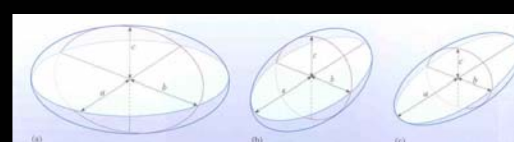
Elliptical Galaxies

Elliptical Galaxies are rather different from Spirals:

They do Not have a Disk;
They are tri-axial (comparable to a football);
They do not have dust;
They do NOT have hot young stars; most stars have formed a long time ago;
Their colors are red not because of reddening by dust, but because mostly old red stars are left.
Ellipticals are believed to be "old", i.e. "evolved" galaxies.

Challenges

- Problems with Orientation
- Biaxial/Triaxial/Boxy



$$EN = 10\left(1 - \frac{b}{a}\right)$$

Minor axis

Major axis

Understanding Galaxy Formation and Evolution

First Step: Classify Galaxies according to **some** scheme that makes sense.

Second Step: Design a more **meaningful** scheme as we learn more…

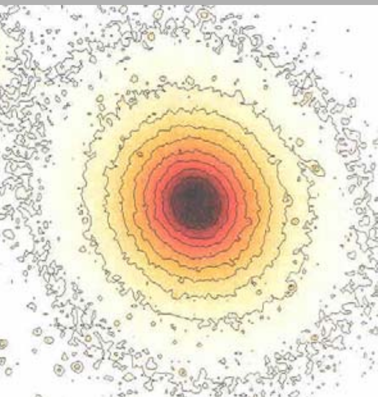
Study galaxy contend in detail and look for **connections**:

- Amounts and Distributions of Stars, Gas, Dust, etc
- Star Formation Histories as related to Stars, Gas, Dust
- Astrophysical Processes responsible for observed colors, spectra, etc
- Presence of a particular type of "Active Nucleus"

Global Properties – Ellipticals ~20 to 25 %

- # of stars 10^5 to 10^{13}
- Masses up to 10^{13} solar Masses
- Magnitudes -9 to -24
- Sizes 1 to 200 kpc
- Dust < 1%
- Hot gas in some ellipticals
- Stars all population II
- Colors B-V ~ 0.95 → "red"
- Metallicity > 2%; hight ~ 3 times solar

Surface Brightness Profile



Light distribution falls off exponentially

Ellipticals can be described by deVaucouleurs $r^{1/4}$ law.

$$I(r) = I(r_o)e^{-\left(r/r_o\right)^{1/4}}$$

Studying Ellipticals

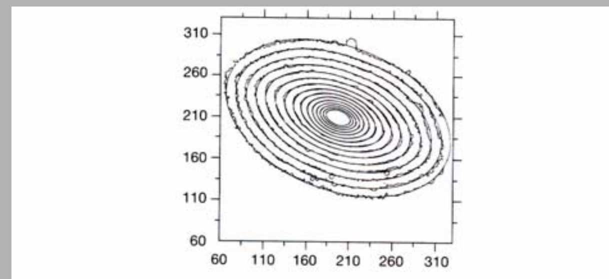


FIGURE 5.2 ***Contours of the elliptical galaxy NGC 4697, with smooth ellipses. (From models, Carter 1987.)***

Surface Brightness Profiles

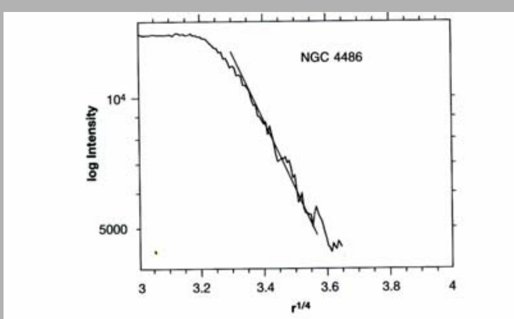


FIGURE 5.1 ***Surface brightness as a function of $r^{1/4}$ for the elliptical galaxy NGC 4486, compared with an $r^{1/4}$ profile (straight line).***

$$I(r) = I(r_o)e^{-\left(r/r_o\right)^{1/4}}$$

How does this profile change, if:

- There is a black hole in the center?
- It is a cD galaxy?

Giant elliptical Galaxy in the center of a cluster that has swallowed up others

Global Properties – Spirals ~ 60 to 70%

- # of stars 10^4 to 10^{12}
- Masses up to 10^{12} solar Masses
- Magnitdes -7 to -22
- Sizes 5 to 50 kpc
- Dust ~ 10%
- Warm gas
- Stars all population II in halo; Population I otherwise
- Colors B-V ~ 0.3 to 0.9 → bluer than ellipticals
- Metallicity varies though roughly solar

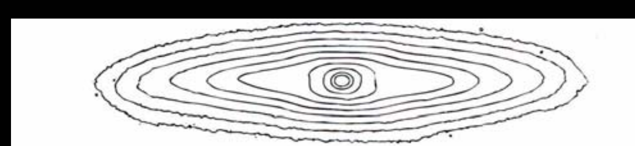


FIGURE 5.6 ***Magnitude contours are shown for the edge-on spiral galaxy NGC 2310, which has a boxy bulge. (From Shaw 1993.)***

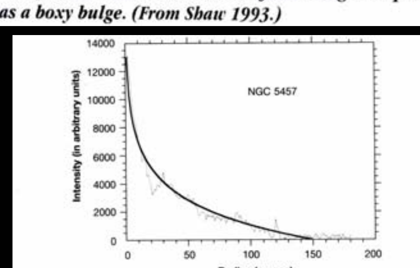
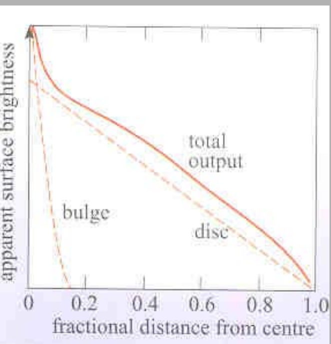


FIGURE 5.7 ***Radial profile for the spiral galaxy NGC 5457, with a solid curve showing an exponential light profile for comparison.***

Surface Brightness Profiles for Spirals



Fit by an exponential disk and a separate bulge component

This is based on empirical models

Mass distribution falls off much more slowly

→ M/L ratio increases with distance

Question:
What happens to spirals if they are stripped of their gas?

- A) cols → redder
- B) arms disappear → SO

Global Properties – Lenticulars ~ 10%

- Spiral galaxies without spiral arms but a disk and a bulge
- # of stars 10^4 to 10^{12}
- Masses up to 10^{12} solar Masses
- Magnitdes -7 to -22
- Sizes 5 to 50 kpc
- Dust ~ 10%
- Warm gas
- Stars all population II in halo & Bulge; Population I otherwise
- Colors B-V ~ mostly 0.9 → "red"
- Metallicity varies though roughly solar to 3 times solar

Global Properties
Irregulars and Peculiar galaxies ~ 3%

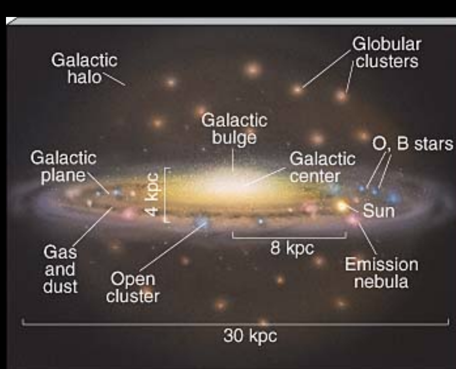
- # of stars 10^4 to 10^{10}
- Masses up to 10^{10} solar Masses
- Magnitudes -7 to -18
- Sizes 1 to 10 kpc
- Dust > 10%
- Warm gas
- Stars population I – active star formation
- Colors B-V ~ 0.3 to 0.7
- Metallicity varies though roughly solar, often less

Dwarf Galaxies

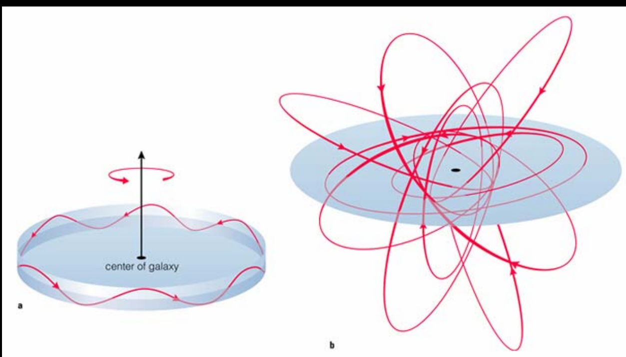
- Do not fit classification scheme
- Not always sure if disk or spheriodal galaxies
- Sometimes irregular
- Low surface brightness

Disk Galaxies

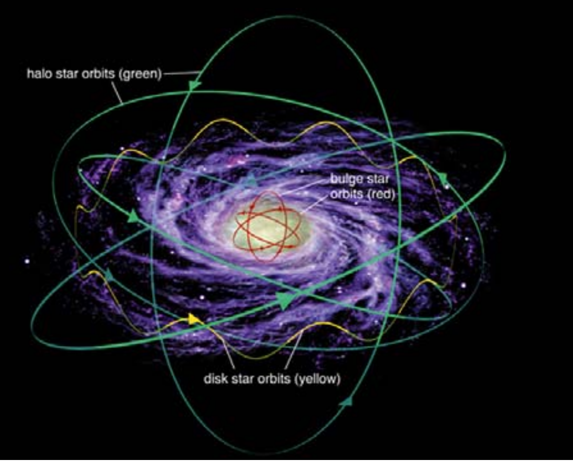
- Bulge
- Disk
- Halo



Kinematics – Spirals versus Ellipticals



Kinematics

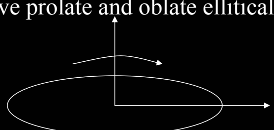


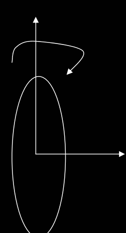
Flatening due to Rotation

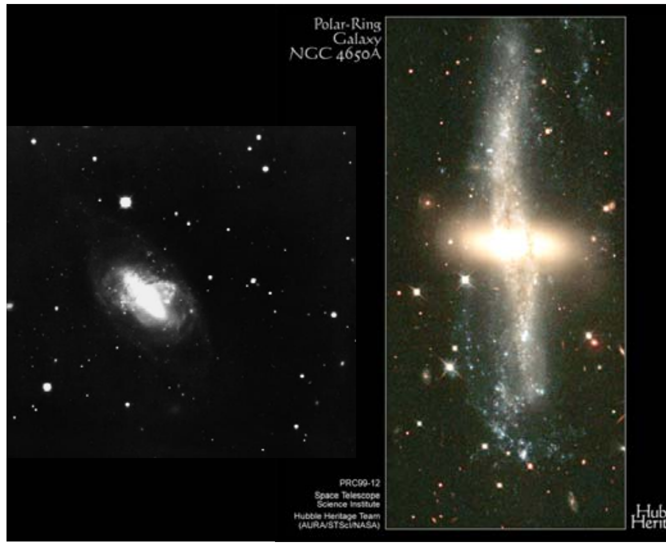
- Disk in Spirals – flattened due to Rotation

- Ellipticals – some rotate far too slowly
- Shape of Ellipticals is kept up by velocity dispersions
- Some Triaxial
- Some are "Boxy"

- Have prolate and oblate ellipticals







Major differences between Ellipticals and Spirals

Shapes:

Ellipticals – biaxial footballs (some may be triaxial)

Spirals: Have a disk with spiral arms, a bulge **and** a halo.

Stellar populations & Ages:

Very efficient Star Formation in Ellipticals

Spirals have Gas and Dust and Young Stars – continual star formation

Ellipicals are devoid of gas and dust and can no longer form young stars

Ellipicals have old stars – but they have high metallicity

Kinematics:

Ellipticals: Velocities of stars in ellipticals are more or less random

Velocity dispersions are responsible for the overall shape of galaxies.

Oblate and Prolate Ellipticals – how that?

Spiral: Velocities of stars in spirals are more ordered. Stars rotate around the galactic center in a disk surrounding it – Halo is random.

Spiral galaxies are flattened by rotation (ellipticals are not).

Hubble's Original Proposal:
There is an evolutionary connection
Could this be correct?

Arguments for & against…

Discussion