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

The Hubble Tuning Fork

Spiral Galaxies
Pinwheel Galaxy
M 71
NGC 6744
NGC 5364

Barred Spirals
NGC something

Elliptical Galaxies
M 85
E0:  M 89
E7 but could be S0 E5 – somewhat “boxy”

Prolate Elliptical With Dust Ring
E3

E0:  M 89
E0/E1:  M 87

Lenticular Galaxies
Understanding Galaxy Formation and Evolution

First Step: Classify Galaxies according to some 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

Large Magellanic Cloud
Can see HII-regions, Reflection Clouds and Galaxy Light reddened by Dust

Irregular Galaxies

2% of the local universe
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

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

If galaxy colors are blue

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

Aging galaxy clusters

M87 & M84

Color is roughly right – reddish tint

Elliptical Galaxies

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

Elliptical Galaxies are rather different from Spirals:

Galaxy Colors

<table>
<thead>
<tr>
<th>Galaxy type</th>
<th>B-V color</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elliptical</td>
<td>0.95</td>
<td>red</td>
</tr>
<tr>
<td>Sa</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Sc</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Irregular</td>
<td>0.3</td>
<td>bluish</td>
</tr>
</tbody>
</table>

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

M 83

Details showing HII regions and some Reflection Clouds. The bright regions in the arms are star forming regions. The massive, hot, young and luminous stars dominate the overall light, thus giving it a bluish hue. The bright yellowish looking regions, mostly the bulge, also have some young stars, however, since there is relatively more dust in the bulge, we see only the longer wavelength light that can penetrate through the dust.

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

NGC 891

Whirlpool Galaxy M51, series of 3 pictures

Ground based observation together with HST overlay

Whirlpool Galaxy – M 51 – Nucleus

Galaxy NGC1365

HST - WFPC2

PRC99-23a - ST ScI OPO - May 9, 1999 - W. Freedman (Carnegie Institution of Washington) and NASA
Notice that the Spiral structure goes all the way to the center of the Galaxy. The Bar also goes to the center.

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”

Notice that the Visual and the 21-cm almost anti-correlate.
The Rotation of Galaxies and the Spiral Structure

What causes the Spiral Structure?

Is this observed?

What is the age of the galaxy?

How often has it rotated around its axis during its lifetime?

The Winding Dilemma

One rotation of the Galaxy takes roughly 200 million years \((2 \times 10^8\ \text{years})\)

The age of the Galaxy is roughly \(\sim 20\) billion years \((2 \times 10^{10}\ \text{years})\)

How many revolutions would you have?

\[
\text{# of revolutions} = \frac{\text{age of universe}}{\text{time of one orbit}}
\]

\[
\text{# of revolutions} = \frac{2 \times 10^{10}\ \text{yrs}}{2 \times 10^{8}\ \text{yrs}} = 100
\]

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

Elliptical Galaxies

- Color is roughly right – reddish tint

Challenges

- Problems with Orientation
- Biaxial/Triaxial/Boxy

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%; height ~ 3 times solar

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 content 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”
Surface Brightness Profile

- Light distribution falls off exponentially
- Ellipticals can be described by deVaucouleurs $r^{1/4}$ law.

$$I(r) = I(r_0)e^{-rac{r}{r_e}}$$

Studying Ellipticals

- Ellipticals can be described by the deVaucouleurs $r^{1/4}$ law.
- The profile changes if:
  - There is a black hole in the center?
  - It is a cD galaxy?

Global Properties – Spirals ~ 60 to 70%

- # of stars $10^4$ to $10^{12}$
- Masses up to $10^{12}$ solar Masses
- Magnitudes -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
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) colsprerdder
• 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
• Magnitudes -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 spheroidal galaxies
• Sometimes irregular
• Low surface brightness

Disk Galaxies

• Bulge
• Disk
• Halo
Kinematics – Spirals versus Ellipticals

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