Lecture 4: Galaxies 1
the Hubble Sequence and Spiral Galaxies

• current astronomical events
• the Hubble sequence
• spiral galaxies
Friday, Jan.21st -- White House directing NASA not to fund a repair mission (manned or robotic) to the **Hubble Space Telescope**. Money directed at a safe de-orbit.
NASA's Mars Exploration Rover "Opportunity" found a basketball-sized meteorite, the first ever found on another planet.
**Huygens** latest imaging: river bed and highlands
nasty solar storm at the end of last week
the Hubble Sequence

galaxy morphology

Hubble's tuning-fork diagram of galaxy types
an evolutionary sequence?

"early-type galaxy"

?  

"late-type galaxy"
Hertzsprung-Russel diagram

“early-type stars”

“late-type stars”
elliptical galaxies: E# galaxies

\[
\# = 10 \times e \\
\text{"ellipticity" } e = 1 - \frac{b}{a}
\]
spiral galaxies

Sa  |  Sb  |  Sc
barred spiral galaxies

SBa

SBb

SBc
“lenticular” galaxies

S0

SB0
irregular galaxies
modifications to the Hubble classification scheme

• van den Bergh: luminosity classes, I thru V
  • I = spirals with well-defined arms
  • V = spirals with least distinct arms
  • “luminosity classes” don't correlate with luminosity

• de Vaucouleurs:
  • added Sd (SBd), Sm (Sbm)
  • changed IrrI/IrrII to Im, Ir
Hertzsprung-Russel diagram

“giants”

“dwarfs”

“early-type stars”

“late-type stars”

O B A F G K M L T

luminosity class:

I

III

V
<table>
<thead>
<tr>
<th>Galaxy type</th>
<th>mass (M_{sun})</th>
<th>M(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ellipticals</td>
<td>1e7 to 1e13</td>
<td>-8 to -23</td>
</tr>
<tr>
<td>spirals</td>
<td>1e9 to 1e12</td>
<td>-16 to -23</td>
</tr>
<tr>
<td>irregulars</td>
<td>1e8 to 1e10</td>
<td>-13 to -20</td>
</tr>
</tbody>
</table>
Spiral Galaxies

“k-corrections”
Spiral Galaxy M51 ("Whirlpool Galaxy")

NASA / JPL-Caltech / R. Kennicutt (Univ. of Arizona)
measuring light distribution:

- “isophotes”
- sky background a problem
- “Holmberg radius”: radius to which isophotal surface brightness $\mu_H = 26.5 \text{ B-mag/arcsec}^2$

- spiral's light distribution as per Milky Way:
  - disks have exponential profiles
  - bulges have de Vaucouleur $r^{1/4}$ profiles
HI (neutral atomic hydrogen) map of Andromeda
Freeman law

• extrapolated central surface brightness of Sa – Sc galaxy disks has a surprisingly small dispersion:

\[ \mu_0 = 21.52 \pm 0.39 \text{ B-mag/arcsec}^2 \]
• flat rotation curves: evidence of dark matter
Tully-Fisher relation

- double-peaked profiles

$$\Delta \lambda / \lambda = v_{\text{rad}} / c = V_{\text{sini}} / c$$
Tully-Fisher relation

- double-peaked profiles

\[ L \sim V_{\text{max}}^\alpha, \quad \alpha \sim 4 \]

- rotation curves can be used to get distances
Tully-Fisher relation

- Gravitational force = centripetal force:
  \[ \frac{GMm}{r^2} = \frac{mv^2}{r} \]
  \[ M = \frac{v^2R}{G} \]

- Assume \( \sim \) constant mass-to-light ratio for spirals:
  \[ C_{ML} = \frac{M}{L} \]

- Assume \( \sim \) constant surface brightness for spirals:
  \[ C_{SB} = \frac{L}{R^2} \]
  \[ L = \left[ \frac{C_{ML}^2}{C_{SB}} \right] \frac{v^4}{G^2} \]
The Tully-Fisher relation is a linear relationship between the luminosity (or apparent magnitude) of spiral galaxies and their rotational velocities. This diagram illustrates the Tully-Fisher relation, where the rotational velocity is plotted against the apparent magnitude. The distance to a galaxy can be estimated by using the Tully-Fisher relation.

TF as a distance indicator
The spiral sequence

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>S0-Sa: Absent/Tight</th>
<th>Sd-Sm: Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral arms</td>
<td>0.3</td>
<td>0.05 (and less)</td>
</tr>
<tr>
<td>$&lt;L_{\text{bulge}}/L_{\text{total}}&gt;_B$</td>
<td>luminous</td>
<td>less luminous</td>
</tr>
<tr>
<td>Luminosity</td>
<td>(1-4)x10^{10}</td>
<td>(&lt;0.1-2)x10^{10}</td>
</tr>
<tr>
<td>Mass</td>
<td>massive</td>
<td>less massive</td>
</tr>
<tr>
<td>$M/M(\text{sun})$</td>
<td>(0.5-3)x10^{11}</td>
<td>(&lt;0.2-1)x10^{11}</td>
</tr>
<tr>
<td>$M/L_B$</td>
<td>~6</td>
<td>~2.6</td>
</tr>
<tr>
<td>Color</td>
<td>red: late G</td>
<td>blue: late F</td>
</tr>
<tr>
<td>$B-V$</td>
<td>0.7-0.9</td>
<td>0.4-0.8</td>
</tr>
<tr>
<td>Young stars</td>
<td>few</td>
<td>many</td>
</tr>
<tr>
<td>HII regions</td>
<td>few, small</td>
<td>many, brighter</td>
</tr>
<tr>
<td>Gas</td>
<td>little gas</td>
<td>much gas</td>
</tr>
<tr>
<td>$M(\text{HI})/L_B$</td>
<td>0.05 – 0.1</td>
<td>0.25 – 1+</td>
</tr>
<tr>
<td>$I(0) = \text{central brightness}$</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>
color gradients

- star formation activity
- metallicity gradients
let $N_{GC} =$ total number of globular clusters in a galaxy:

$$N_{GC} = S_{N} \times (L_{V}/L_{15})$$

where $S_{N} =$ 'specific frequency of GCs'
$L_{V} =$ galaxy absolute magnitude (at V-band)
$L_{15} =$ luminosity of standard galaxy with $M_{V} = -15$

$$S_{N} \approx 1.2 \quad (Sa)$$
$$S_{N} \approx 0.5 \quad (Sc)$$

(ellipticals have even more per luminosity)
BHs: the Magorrian relation
Spiral Structure

“grand-design spiral” (~10%)
Spiral Structure

“multiple-arm spiral” (~60%)
Spiral Structure

“flocculent spiral” (~30%)
Spiral Structure

“ring galaxy”
Spiral Structure

low surface brightness galaxies (LSBs)
Figure 6-6. The appearance of leading and trailing arms. Galaxy A has leading arms, while galaxy B has trailing arms, but both exhibit the same pattern on the sky and the same radial velocity field.
the winding problem

- flat rotation curve implies differential rotation
- arms would get too wound up in a “Hubble time”
SSPSF: stochastic, self-propagating star formation
density-wave theory

- Lin-Shu hypothesis (mid-1960s)
- analogy of a traffic jam
- induced star formation in the denser arms?
- what induces the instability? (and why in only ~10% of galaxies?)
This textbook contains material on evolution. Evolution is a theory, not a fact, regarding the origin of living things. This material should be approached with an open mind, studied carefully, and critically considered.

Approved by
Cobb County Board of Education
Thursday, March 28, 2002
barred spirals
- ~50% of spirals -- WHY?
- not a density wave
- basically 2D (i.e., part of disk, not bulge)
Stephan's Quintet (AKA Hickson 92)

spirals prefer groups; ellipticals prefer clusters
scenes from next class:
• elliptical galaxies

THE END