Galaxy Types

The Hubble (Sandage) “tuning fork” diagram is the most basic and fundamental system. The periodic table of galaxies.

Spiral classification criteria:

- Bulge size
- Openness of the arms (pitch angle).
- Resolution of ‘stars’ (young associations).
<table>
<thead>
<tr>
<th>Property</th>
<th>Ellipticals</th>
<th>Spirals</th>
<th>Irregulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hubble type</td>
<td>E0-E7 (10(a-b)/a)</td>
<td>Sa-Sc (Sd, Sm)</td>
<td>Irr</td>
</tr>
<tr>
<td>Mass (M(_{\text{sun}}))</td>
<td>(10^6-13)</td>
<td>(10^9-12)</td>
<td>(10^7-10)</td>
</tr>
<tr>
<td>Visible R (kpc)</td>
<td>1-100</td>
<td>3-30</td>
<td>1-10</td>
</tr>
<tr>
<td>Stellar Pops.</td>
<td>II (bulge type)</td>
<td>I &amp; II</td>
<td>I &amp; II</td>
</tr>
<tr>
<td>B-V color</td>
<td>0.9</td>
<td>0.66</td>
<td>0.4</td>
</tr>
<tr>
<td>Spectral type</td>
<td>G-K</td>
<td>A-K</td>
<td>A, F</td>
</tr>
<tr>
<td>ISM (gas/dust)</td>
<td>little (usually)</td>
<td>1-3 %</td>
<td>&gt; 10%</td>
</tr>
<tr>
<td>Bulge/Disk</td>
<td>little disk</td>
<td>~0-90%</td>
<td>formless</td>
</tr>
<tr>
<td>Rot. Support</td>
<td>&lt; 1/3</td>
<td>Disk 1</td>
<td>Little</td>
</tr>
<tr>
<td>Environment</td>
<td>Clusters</td>
<td>Groups,</td>
<td>Field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small clusters</td>
<td></td>
</tr>
<tr>
<td>Fraction</td>
<td>50%</td>
<td>30%</td>
<td>&lt; 20%</td>
</tr>
</tbody>
</table>
Relations between Galaxy Properties

• Galaxies have many properties, even though they have only a few basic components: size, total luminosity, gas fraction, star formation rate, disk/bulge masses, disk/halo ….  

• If all these properties were independent, then we would expect many different types of galaxy. (On other hand, there’s clearly more than a 1-parameter main sequence.)

• The elliptical galaxies live primarily in a fundamental plane (e.g., L, σ or r_e, and metallicity), which suggests that there are 2 primary parameters governing their global structure.

• The Tully-Fisher relation for disk-halo systems is equally important. (Tully-Fisher and the Faber-Jackson relation for ellipticals are essentially the same.)

  - Freeman’s Law for the existence of a maximum central surface brightness in disks may be related.

Theories of galaxy formation must explain these relations.
Galaxy Environments

2 extremes: field vs. dense cluster.

Field Galaxies: Isolated or in small “local groups” well away from other groups. Most Sc galaxies are found in the field.

Dense Clusters: (e.g., Virgo, Coma) contain 1000s of galaxies. Size $\leq 10$ Mpc. Few spirals, but most ellipticals are found there.

- Many clusters contain a cD “giant elliptical” galaxy, which may be a ‘bloated cannibal.’

- Interactions are common in clusters, but are of a different character than those in small groups. Gas commonly stripped out of disks. Formation of S0s?

- The total mass of clusters can be estimated from velocities of members, the distribution of hot X-ray gas, and gravitational lensing.

- Clusters have at least as high a fraction of dark matter as individual galaxies.
Galaxies in View Credit & Copyright: Johannes Schedler (Panther Observatory)
Our local group

FIGURE 23-1 The Local Group. (A) A top view projected on the plane of our Galaxy. (B) A side view. Note the concentrations around our Galaxy and M31.
Dark Matter and Galaxies

We believe that galaxies have dark matter halos of 10 times the mass of the visible contents and several times larger radius. The first line of evidence for this came from rotational motions in galaxy disks.

**Disk Kinematics**

Assume: 1) Circular motion in 2) a very thin disk.

How does the circular velocity vary with radius in the disk? Some simple examples:

1) **Keplerian case**

\[
\frac{v_c^2}{r} = \frac{GM}{r^2},
\]

\[v_c \propto r^{-1/2}.\]
2) Keplerian case

\[ \omega = \frac{v_c}{r} = \text{constant}, \]

\[ M(r) \sim v_c^2 r \sim r^3. \]

Example 2) is only relevant to the inner parts of galaxy disks. (Differential rotation elsewhere!)

Example 1) is of little relevance for most galaxies. Surprise!
3) **Flat rotation curves**

\[ v_c = \text{constant}, \quad M \sim r, \quad \rho \sim \frac{M}{r^3} \sim r^{-2}. \]

This increase of the mass with radius, is not evident in the visible matter, and so implies the existence of dark matter.

**Other evidences of dark matter:**

- velocity dispersions of galaxies in groups and clusters.
- hydrostatic equilibrium of hot gas in clusters.
- gravitational lensing by clusters.
Giant Cluster Bends, Breaks Images

Credit: W. N. Colley (U. Virginia & E. Turner (Princeton), J. A. Tyson (UC Davis), HST, NASA

Explanation: What are those strange blue objects? Many are images of a single, unusual, beaded, blue, ring-like galaxy which just happens to line-up behind a giant cluster of galaxies. Cluster galaxies here appear yellow and -- together with the cluster's dark matter -- act as a gravitational lens. A gravitational lens can create several images of background galaxies, analogous to the many points of light one would see while looking through a wine glass at a distant street light. The distinctive shape of this background galaxy -- which is probably just forming -- has allowed astronomers to deduce that it has separate images at 4, 8, 9 and 10 o'clock, from the center of the cluster. This spectacular photo from the Hubble Space Telescope was taken in October 1994.