We Discover the Galaxies

The nature of the nebulae
the “island universe hypothesis” ---

The “analogy (of the nebulae) with the system of stars in which we find ourselves ... is in perfect agreement with the concept that these elliptical objects are just island universes – in other words, Milky Ways”

Kant 1755

Galactic or Extragalactic? -- the nature of the “nebulae”

The Shapley – Curtis Debate 1920

Resolution of the controversy -- Cepheid variables in M31 and M33

Hubble 1923 – 24 using the new Mt Wilson 100-inch telescope
Morphological Classification of Galaxies -- Hubble

Spirals, Ellipticals and Irregulars

Spiral Galaxies – normal and barred

Based on size of nuclear bulge and openness of the arms

Sa -- large bulge, tightly wound arms
Spiral Galaxies

Type Sb
Spiral galaxies -- Types Sc and Sd
small bulge, very open fragmented arms
Barred Spirals
Elliptical Galaxies -- giants and dwarfs

Classification based on degree of ellipticity or flattening
Irregular Galaxies
Magellanic Irregulars
Hubble’s Tuning Fork Diagram

- Normal spirals: Sa → Sb → Sc
- Ellipticals: E0 → E4 → E7 → S0
- Barred spirals: SBa → Sbb → Sbc
The Milky Way

Edge-on

Milky Way -- infrared

SBbc type
## Properties of Different Types of Galaxies

<table>
<thead>
<tr>
<th></th>
<th>Spirals</th>
<th>Ell. (dwarf / giant)</th>
<th>Irr.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>$10^9 - 5 \times 10^{11}$</td>
<td>$10^6$</td>
<td>$&gt; 10^{12}$</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>7 – 50 kpc</td>
<td>1</td>
<td>100 kpc</td>
</tr>
<tr>
<td><strong>Lum.</strong></td>
<td>$10^{10} - 10^{12}$</td>
<td>$10^6$</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td>old &amp; young</td>
<td>old</td>
<td>old &amp; young</td>
</tr>
<tr>
<td><strong>ISM</strong></td>
<td>gas, dust</td>
<td>little gas,dust</td>
<td>gas, dust</td>
</tr>
</tbody>
</table>
Galaxy Clustering

Local Group of Galaxies --
3 spirals + > 30 small Irr
and dEll

Virgo Cluster
Rotation Curves and the Missing Mass

![Graph showing rotational speed vs. distance from the galactic center for different galaxies.](image)
Gravitational Lensing

Gravitational Lensing Splits Quasar Light into Five Images

Distant quasar with host galaxy

Light emitted from quasar bends around intervening galaxy cluster, producing lensed images*

*The red crescents represent lensing arcs — smeared images of background galaxies.
Missing Mass in Galaxy Clusters and
missing mass in halos of galaxies?

“cold dark matter” -- CDM

WIMPS (weakly interacting massive particles)
or
MACHOS (massive compact halo objects)
How do we measure distances to Galaxies?

The distance scale or distance ladder

We begin with nearby stars

Parallaxes -- ~ 500pc
   Moving cluster method -- Solar neighborhood ~ 30 pc → lower MS
Cluster main sequence fitting
   calibration of spectroscopic parallaxes -- distance modulus equation 40 pc to 10 kpc
Calibration of Cepheids
   RR Lyrae
   Brightest stars
      → Local Group and nearby galaxies out to 30 Mpc
Supernovae Ia (collapse of WDs) 1 – 1000 Mpc
Distance – Redshift Relation or Hubble Law

Slipher at Lowell Obs first noticed the redshift several years earlier.
A linear relation

\[ \text{Vel} = \text{constant} \times \text{Distance} \]

Constant = slope – km/sec/Mpc (Hubble Constant)

\[ V = H \times D \quad \text{The inverse} \quad \frac{1}{H} \quad \text{Time -- expansion age of the Universe} \]
H = 73 – 75 km/s/Mpc and

\[ \frac{1}{H} \sim 13 – 15 \times 10^9 \text{ yrs} \]

Current best value \( 14.3 \times 10^9 \text{ yrs} \)
Galaxy Clusters, Superclusters and Large Scale Structure
Large Scale Structure of the Universe from redshift surveys