General Outlook on Galaxies

- Basic concepts
- Important ideas about galactic structure
Basic Concepts

- **Galaxies are the “ultimate synthesis” of astronomy**
  - Look down to smaller structures: stars, gas, atoms, energetic particles, BHs
  - Look up to larger structures: clusters, superclusters, cosmology
  - Conclude: no subject for specialists!

- **Galaxies exhibit regularity of structures**
  - Scaling laws: $T \text{ vs } M$, $L \text{ vs } M$, $R \text{ vs } M$
  - Stars wipe out all signs of their initial conditions – they obey rules given by their present state only \(\Rightarrow\) makes studies of stellar structure “easy”, but studying star formation is very difficult
  - Galaxies have preserved evidence of their initial conditions: scaling laws. Once you decode these laws, galaxy formation becomes “easy”...

- **Galaxies are “living structures”: they can change and they are still changing now**
  - Moving, colliding, merging, ram-pressure stripping...
  - Must get used to the idea that we are looking at a process, not an end-result
Galaxy Interactions
Galaxy Interactions
Galaxy Interactions
Galaxy Mergers
Galaxy Interactions in the Distant Universe
Important Ideas about Galactic Structure

- **Galaxies are two-part structures (visible region)**
  - Disks: flattened, near-circular rotation
  - Spheroids: ellipsoidal, slow rotation, eccentric orbits
  - Relative amount of two components varies – but internally the structure of each component shows remarkable regularity from galaxy to galaxy
Important Ideas about Galactic Structure

- **Galaxies consist of two kinds of matter**
  - Baryonic (mostly luminous) & Non-baryonic (dark)
  - Iceberg effect: 90% is hidden (dark)
  - Profound consequences for our picture of galaxy formation and evolution!

- **Two kinds of matter are separated radially**
  - Condensed baryons, diffuse dark-matter halo
  - How did this separation occur?
    - Thermal radiation by baryons (dissipation) \(\rightarrow\) radial collapse
    - DM is non-interacting, dissipationless material \(\rightarrow\) can’t collapse

- **So, baryons once filled a greater volume than now**
  - Collapse is accompanied by star formation and build-up of heavy elements
  - Positions and motions of stars contain some information about where and when they were born
  - Conclude: there are correlations between positions, motions, and composition of stars that contain a sort of code about galaxy formation and history
  - Our job is to analyze and decode these!
Important Ideas about Galactic Structure

- **Supermassive ( > \(10^6 \, M_{\odot}\))** black holes in galaxies
  - All galaxies with a spheroid contain a SMBH
  - Correlation between spheroid mass and BH mass

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**Correlation Between Black Hole Mass and Bulge Mass**

- **Mass of central bulge**
- **Black hole mass**

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**Black Hole Mass Scales with Galaxy Size**

- **Ground**
  - NGC 4649 (2 billion suns)
  - NGC 4291 (200 million suns)
  - NGC 2775 (20 million suns)
  - NGC 7457 (3 million suns)

- **HST**
  - Diameter of Earth’s Orbit (186 million miles)
Basic aims of a classification scheme

- **Complete:** every galaxy is included under the scheme
- **Unambiguous:** no conflicting criteria; no question as to where each galaxy belongs
- **Illuminate the evolutionary processes:** hope that an underlying theory will emerge (e.g., stellar structure)
- No classification system today really satisfies these requirements. There are particular problems in each category:
  - Peculiar galaxies: when are they physically important and when are they merely interesting side shows?
  - Ambiguities: e.g. bulge-disk ratio vs appearance of arms and disk (e.g., NGC 4932 – smooth arms but no large central bulge)
  - Physical insight: as yet, relatively little...
Hubble Classification (1936 – 1st version; “Tuning-fork diagram”)

- **Primary discriminant:** small-scale light distribution (i.e. “lumpiness”)
  - En – S0: where $n = 10/[1 - b/a]$ where $b/a =$ apparent axial ratio
  - Spirals: Sa $\rightarrow$ Sc  Along this sequence, arms become more prominent and galaxy looks lumpier due to HII regions
- Hubble sequence is basically a sequence of star formation rate (per stellar mass)
- **Secondary discriminant:** relative importance of bulge (spheroid) and disk
  - This is the difference between E’s and S0’s
  - Plays a role in S’s as well
- **Role of S0’s:** a true transition class, not a parallel class
- **Irr. II and S0 pec.:** a wastebasket for strange objects
De Vaucouleurs’ Classification (1959)

- What it does:
  - Improve resolution for late-type systems (Sd, Sdm, Sm) and S0’s (S0+, S00, S0+)
  - Add interesting but not very fundamental detail about internal and external rings
- Fundamental philosophy is the same as Hubble’s, otherwise
- Morphological type T: -5 = E, -2 = S0, 0 = S0/a, 1 = Sa, 3 = Sb, 5 = Sc, 7 = Sd, 9 = Sm
Classification summary (Fig. 1.11 S&G)

Using: \( L^* = 8 \times 10^9 \, \text{h}^{-2} \, L_{\odot} = L_{\text{MW}} \) (if \( H_0 = 75 \, \text{km/s/Mpc} \))

<table>
<thead>
<tr>
<th>CLASS</th>
<th>LUMINOSITY</th>
<th>“V/σ”</th>
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<tbody>
<tr>
<td>cD</td>
<td>~10 ( L^* )</td>
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<td>(0.05) – 10 ( L^* )</td>
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<td>Sa – Sc</td>
<td>1 – 5 ( L^* )</td>
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<tr>
<td>dE</td>
<td>0.002 – (0.05) ( L^* )</td>
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<tr>
<td>dSph</td>
<td>&lt; 0.002 ( L^* )</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>dIrr</td>
<td>&lt; 0.01 ( L^* )</td>
<td>~ 1</td>
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Groups & Clusters

- Effects of the environment on galaxy classification
  - Galaxy mergers in groups
  - Galaxy harassment in clusters
  - Morphological “segregation”
  - Ram-pressure stripping
  - Falling rotation curve
  - Butcher-Oemler effect at $0.4 < z < 1$
  - ...

Local Group

- Bound group of about 36+ galaxies to which the MW belongs
- Size: ~ 1 Mpc in radius
- Members:
  - 3 spirals: MW, M31, M33 (~90% of visible light of LG)
  - 1 elliptical: M32 (companion of M31)
  - 4 Irregulars: LMC, SMC (companions to MW), NGC 6822, IC 10
  - 3 dE’s: NGC 205, NGC 147, NGC 185 (companions to M31)
  - 25+ dIrr + dSph: all other galaxies!
Galaxy Clustering: Local Supercluster
Galaxy Clustering

The Perseus-Pegasus supercluster

The Hydra-Centaurus supercluster, containing the Virgo cluster.

We are here!
Review:
Stellar Atmosphere
Stellar Evolution

Material to be handed out at next lecture…
II. Our Galaxy