The Local Universe

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Ask yourself...

How do you define a galaxy?
What is the Milky Way Galaxy, and how does it compare to other galaxies?
What is the Local Group?
Do all galaxies have close neighbors?
What happens when galaxies collide?
Redshift

\[ z = \frac{\lambda_{\text{obs}} - \lambda_0}{\lambda_0} = \frac{f_0 - f_{\text{obs}}}{f_{\text{obs}}} \]

- Measure the shift in a spectral line – \( f_0 \) is the rest frequency (\( \lambda_0 \) the rest wavelength)
- **Extragalactic objects** often identified by their \( cz \) measurement.
- ALFALFA will cover \( cz = -2000 \) to 17000 km/s
- \( cz \) indicator™
Expansion of the Universe

- Edwin Hubble showed the Universe was expanding!
- However, there are other factors to take into account in the local Universe – peculiar velocities! Deviations can be quite large depending on the galaxy, and whether it is part of a group or a field galaxy.

\[ cz = H_0 d \]
Galaxy Morphology
What do galaxies look like?

Well, it depends…
Galaxies across the spectrum
# Galaxy Types

<table>
<thead>
<tr>
<th>Galaxy Type</th>
<th>Hubble</th>
<th>de Vaucouleurs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spiral</strong></td>
<td>S, Sa, Sb…</td>
<td>1 through 6</td>
</tr>
<tr>
<td><strong>Elliptical</strong></td>
<td>E</td>
<td>-6 through –4</td>
</tr>
<tr>
<td><strong>Dwarf</strong></td>
<td>dE, dSph</td>
<td></td>
</tr>
<tr>
<td><strong>Lenticular</strong></td>
<td>S0, SB0</td>
<td>-3, -2, -1</td>
</tr>
<tr>
<td><strong>Irregular</strong></td>
<td>Irr</td>
<td></td>
</tr>
</tbody>
</table>
Hubble’s Tuning Fork
Spiral Galaxies

- Thin disks
- Most have some form of a bar – arms will emanate from the ends of the bars
- Other classification:
  1. Relative importance of central luminous bulge and disk in overall light from the galaxy
  2. The tightness of the winding of the spiral arms
  3. Degree to which spiral arms are resolved into stars and individual HII regions

M33

M51

M33
Dwarf Galaxies

- Smaller size than giant elliptical galaxies
- Lower surface brightness

M32

Sagittarius Dwarf
Irregular Galaxies

- LMC and SMC are satellite galaxies of our own – disrupted by gravitational interaction with the Milky Way…
Irregular Galaxies

- M82 – irregular starburst galaxy
- Star formation rate at 10 times the rate of our galaxy
- Chandra X-ray image reveals hot gas flowing out of the galaxy – hot spots indicate x-ray binary stars – some of the brightest known!
Elliptical Galaxies

- **Smooth** and very little structure; varying in shape
- Classified by $E_N$ where $N=10(1-b/a)$
- Large populations in clusters.
- Little gas – don’t see spectral HI lines

M87
The Local Group

- The Local group has 41 members, ranging from large spiral galaxies to small dwarf irregulars. Most galaxies are dwarf spheriodals...
The Local Group

Giant spirals
dSph (+dEII)
dIrr
dIrr/dSph
The Milky Way Galaxy

• An Sbc galaxy that is 30 kpc in diameter
## Anatomy of the Milky Way

<table>
<thead>
<tr>
<th>Galactic component</th>
<th>$h_z$ (pc)</th>
<th>$\sigma_R$ (km s$^{-1}$)</th>
<th>$\sigma_\phi$ (km s$^{-1}$)</th>
<th>$\sigma_z$ (km s$^{-1}$)</th>
<th>$\langle v_y \rangle$ (km s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ht gas near the Sun</td>
<td>130</td>
<td>≈5</td>
<td>≈7</td>
<td>tiny</td>
<td></td>
</tr>
<tr>
<td>Local CO, H$_2$ gas</td>
<td>65</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disk stars: $Z &gt; Z_\odot/4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau &lt; 3$ Gyr</td>
<td>≈250</td>
<td>30</td>
<td>21</td>
<td>16</td>
<td>$-11$</td>
</tr>
<tr>
<td>$3 &lt; \tau &lt; 6$ Gyr</td>
<td>≈300</td>
<td>36</td>
<td>25</td>
<td>19</td>
<td>$-9$</td>
</tr>
<tr>
<td>$6 &lt; \tau &lt; 10$ Gyr</td>
<td>≈350</td>
<td>38</td>
<td>25</td>
<td>24</td>
<td>$-16$</td>
</tr>
<tr>
<td>$\tau &gt; 10$ Gyr</td>
<td>62</td>
<td>52</td>
<td>52</td>
<td>37</td>
<td>$-21$</td>
</tr>
<tr>
<td>Thick disk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$[\text{Fe/H}] &gt; -0.8$</td>
<td>≈1500</td>
<td>52</td>
<td>37</td>
<td>40</td>
<td>$-35$</td>
</tr>
<tr>
<td>Halo stars near Sun</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$[\text{Fe/H}] &lt; -1.6$</td>
<td>≥1 kpc</td>
<td>150</td>
<td>100</td>
<td>100</td>
<td>$-210$</td>
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<tr>
<td>Halo stars at 2.5$R_0$</td>
<td>few kpc</td>
<td>80–100</td>
<td>130–150</td>
<td>130–150</td>
<td>$-220$</td>
</tr>
</tbody>
</table>
Anatomy of the Milky Way

- $R_0 \sim 8$ kpc
- 200 billion stars
- $5 \times 10^{11} M_\odot$
- SFR $\sim 3 \, M_\odot/yr$
- Bulge $\sim 3$ kpc in diameter
Around the Milky Way...
Around the Milky Way...
Around the Milky Way...
The Andromeda Galaxy

- Sb galaxy 770 kpc from the Milky Way.
- Larger, more luminous, with a larger disk scale length than the Milky Way – it even rotates faster at 260 km/s!
- At least 9 known satellite galaxies – dwarf elliptical and spheroidals!
The Andromeda Galaxy

- GALEX mission mosaic in the ultraviolet
M33

- **Late-type spiral** galaxy ~850 kpc from the Milky Way and ~200 kpc from Andromeda
- Disk scale length is around 1.7 kpc, rotating around 120 km/s.
• **Richer in HI gas** than M31 or the Milky Way – VLA doppler image show movement of the HI gas towards and away.

• The **HI disk** extends out to 30 kpc, enough for M31 to cause **tidal effects** and warp the outer disk!
Galaxy Groups
Groups of galaxies

- Galaxies can be gravitationally bound to each other, and undergo interactions and collisions.
- Separations across intergalactic distances range from 50 kpc up to 1 Mpc.
- Groups are important because one can determine a dynamical mass for the system.
- ALFALFA science goals include studying the effects within the group environment –
  - What is HI mass function?
  - How do unseen HI clouds/starless galaxies effect dynamics?
  - Are their unseen tidal remnants or debris?
  - What are sizes of HI disks?
# Neighboring Galaxy Groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Milky Way</th>
<th>M31</th>
<th>M81</th>
<th>Cen A</th>
<th>M83</th>
<th>IC 342</th>
<th>Maffei</th>
<th>Sculptor&lt;sup&gt;a&lt;/sup&gt;</th>
<th>CVn I&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{MW}$ (Mpc)</td>
<td>0.01</td>
<td>0.77</td>
<td>3.63</td>
<td>3.66</td>
<td>4.56</td>
<td>3.28</td>
<td>3.01</td>
<td>3.94</td>
<td>4.09</td>
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<tr>
<td>$D_{LG}$ (Mpc)</td>
<td>0.43</td>
<td>0.34</td>
<td>3.47</td>
<td>4.10</td>
<td>4.98</td>
<td>2.94</td>
<td>2.67</td>
<td>3.79</td>
<td>4.17</td>
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<tr>
<td>SGZ&lt;sup&gt;b&lt;/sup&gt; (Mpc)</td>
<td>0.00</td>
<td>0.07</td>
<td>0.04</td>
<td>-0.33</td>
<td>0.08</td>
<td>0.02</td>
<td>0.08</td>
<td>-0.34</td>
<td>0.77</td>
</tr>
<tr>
<td>$N_{tot}$</td>
<td>15</td>
<td>19</td>
<td>29</td>
<td>28</td>
<td>14</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>$N_{EndSph}$</td>
<td>10</td>
<td>13</td>
<td>11</td>
<td>18</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Type(1)</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>-2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>$V_{in}(1)$ (km s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>220</td>
<td>255</td>
<td>232</td>
<td>398</td>
<td>211</td>
<td>162</td>
<td>163</td>
<td>199</td>
<td>164</td>
</tr>
<tr>
<td>$V_{LG}(1)$ (km s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>-88</td>
<td>-35</td>
<td>107</td>
<td>301</td>
<td>304</td>
<td>245</td>
<td>212</td>
<td>274</td>
<td>353</td>
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<tr>
<td>$\langle V_{LG} \rangle$ (km s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>-79</td>
<td>-16</td>
<td>193</td>
<td>312</td>
<td>308</td>
<td>229</td>
<td>302</td>
<td>279</td>
<td>306</td>
</tr>
<tr>
<td>$\sigma_v$ (km s&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>76</td>
<td>77</td>
<td>91</td>
<td>105</td>
<td>71</td>
<td>54</td>
<td>54</td>
<td>59</td>
<td>56</td>
</tr>
<tr>
<td>$\langle R_p \rangle$ (kpc)</td>
<td>155</td>
<td>254</td>
<td>211</td>
<td>290</td>
<td>164</td>
<td>322</td>
<td>104</td>
<td>359</td>
<td>385</td>
</tr>
<tr>
<td>$L_B$ (10&lt;sup&gt;10&lt;/sup&gt; $L_\odot$)</td>
<td>3.28</td>
<td>6.83</td>
<td>6.11</td>
<td>5.55</td>
<td>2.31</td>
<td>3.21</td>
<td>2.69</td>
<td>5.58</td>
<td>2.00</td>
</tr>
<tr>
<td>$M_{vir}$ ($10^9$ $M_\odot$)</td>
<td>93</td>
<td>57</td>
<td>117</td>
<td>489</td>
<td>109</td>
<td>57</td>
<td>65</td>
<td>332</td>
<td>267</td>
</tr>
<tr>
<td>$M_{orb}$ ($10^9$ $M_\odot$)</td>
<td>96</td>
<td>111</td>
<td>197</td>
<td>288</td>
<td>100</td>
<td>95</td>
<td>135</td>
<td>153</td>
<td>322</td>
</tr>
<tr>
<td>$M_{vir}/L$ ($M_\odot$ $L_\odot^{-1}$)</td>
<td>28</td>
<td>8</td>
<td>19</td>
<td>88</td>
<td>47</td>
<td>18</td>
<td>24</td>
<td>60</td>
<td>133</td>
</tr>
<tr>
<td>$M_{orb}/L$ ($M_\odot$ $L_\odot^{-1}$)</td>
<td>29</td>
<td>16</td>
<td>32</td>
<td>52</td>
<td>43</td>
<td>30</td>
<td>50</td>
<td>28</td>
<td>161</td>
</tr>
<tr>
<td>$T_{cross}$ (Gyr)</td>
<td>2.1</td>
<td>3.3</td>
<td>2.3</td>
<td>2.8</td>
<td>2.3</td>
<td>5.9</td>
<td>1.8</td>
<td>6.6</td>
<td>6.9</td>
</tr>
</tbody>
</table>
Neighboring Galaxy Groups
Groups of galaxies

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

21 cm HI Distribution
Cen A Group
M83 Group
Extended HI Disk of a BCD

UGC 5288
Sdm.
M66 Group

NGC 3628  SAB pec

Arp 16
M 66
NGC 3627  SAb pec
Sy 2

M 65
NGC 3623  SAB pec
M66 Group
Colliding Galaxies
Colliding Galaxies
Colliding Galaxies
Galaxy Clusters
Clusters of Galaxies

- Around half the galaxies in the Universe are found in clusters or groups.
- Cluster have a higher density than “loose” groups – brightest galaxies are S0s and ellipticals instead of spirals
- Abell Catalog contains 4073 rich clusters
- Gravity binds the members, as well as hot intracluster gas (seen in the X-ray)
Clusters of Galaxies

• Some well known clusters:
  – Virgo
  – Fornax
  – Eridanus
  – Coma
  – Perseus
  – Hercules
  – Leo
  – Centaurus
Virgo Cluster

- \( cz \sim 1050 \text{ km/s} \)
- \( \Delta \nu \sim 1000 \text{ km/s} \)
- 1300 catalogued members!!
- Most galaxies are dwarfs
- Core radius \( \sim 500 \text{ kpc} \)
Coma Cluster

- At $cz = 6900$ km/s
- Four times the size of Virgo!!
- Core contains only ellipticals.
Fornax cluster

- $cz \sim 1400 \text{ km/s}$
Fornax Cluster – Xray view
Fornax – optical + radio
Hercules Cluster

\[cz \sim 11,000 \text{ km/s}\]
Perseus Cluster

\[ \text{cz} \sim 5000 \text{ km/s} \]
Leo Cluster

- $cz \sim 6400 \text{ km/s}$
Centaurus Cluster

- $cz \sim 3000 \text{ km/s}$
- X-ray image shows gas expelled from the central member
Superclusters

The largest structures in The Universe
Superclusters in the Universe

The Local Universe

Superclusters

Capricornus Supercluster
Sculptor Void
Virgo
Centaurus Supercluster
Fornax/Perseus Supercluster
Hydra
Horologium Supercluster
Columba Supercluster

Corona Borealis Supercluster
Boötes Superclusters
Eccles Void

0 3500 6000 2000 1000 4000 5000

0 1000 2000 3500 4000 5000 6000
Overview of the Local Universe
Local Universe Overview

• ~9000 redshifts based on HI detections
• Data taken from a variety of radio telescopes…
cz = 0
References

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