Galaxies in The Local Universe
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?
A simple calculation: 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 (out to 250 Mpc)
• 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.

\[ cz = H_0 d \]
Distances to nearby galaxies

Tonry, et al. 2000
Galaxies in The Local Universe

Galaxy Morphology
Galaxies across the spectrum

What do galaxies look like?

M81

cz = -34 km/s
**Galaxy Types**

Are all galaxies the same?

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

Galaxies in The Local Universe

Early Type

Late Type
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

M51
\[ cz = 600 \text{ km/s} \]

M33
\[ cz = -179 \text{ km/s} \]
**Dwarf Galaxies**

- **Smaller size** than giant elliptical galaxies
- **Lower surface brightness**
- dE galaxies dominate Virgo

```
cz = -200 km/s
```

```
cz = -79 km/s
```

M32

Sagittarius Dwarf

Galaxies in The Local Universe
Irregular Galaxies

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

\[ cz = 158 \text{ km/s and 278 km/s} \]

LMC and SMC

© Anglo-Australian Observatory
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!

$cz = 203 \text{ km/s}$
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

$cz = 1307 \text{ km/s}$

M87
The Local Group

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

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>H$\alpha$ gas near the Sun</td>
<td>130</td>
<td></td>
<td>$\approx 5$</td>
<td>$\approx 7$</td>
<td>tiny</td>
</tr>
<tr>
<td>Local CO, H$_2$ gas</td>
<td>65</td>
<td></td>
<td>4</td>
<td></td>
<td>tiny</td>
</tr>
<tr>
<td>Disk stars: $Z &gt; Z_\odot/4$</td>
<td></td>
<td>(Fig. 2.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau &lt; 3$ Gyr</td>
<td>$\approx 250$</td>
<td>30</td>
<td>21</td>
<td>16</td>
<td>$-11$</td>
</tr>
<tr>
<td>$3 &lt; \tau &lt; 6$ Gyr</td>
<td>$\approx 300$</td>
<td>36</td>
<td>25</td>
<td>19</td>
<td>$-9$</td>
</tr>
<tr>
<td>$6 &lt; \tau &lt; 10$ Gyr</td>
<td>$\approx 350$</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>37</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>$\sim 1500$</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>$\gtrsim 1$ kpc</td>
<td>$\sim 150$</td>
<td>$\sim 100$</td>
<td>$\sim 100$</td>
<td>$-210$</td>
</tr>
<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
- $M_{\text{tot}} \sim 5 \times 10^{11} M_\odot$
- SFR $\sim 3 M_\odot/\text{yr}$
- Bulge $\sim 3$ kpc in diameter
Around the Milky Way...
Galaxies in The Local Universe

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!

\[ cz = -300 \text{ km/s} \]
The Andromeda Galaxy

- GALEX mission mosaic in the ultraviolet

\[ cz = -300 \text{ km/s} \]
Galaxies in The Local Universe

**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.

\[
cz = -179 \text{ km/s}
\]
• 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!

\[ cz = -179 \text{ km/s} \]
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?
# Galaxies in The Local Universe

## 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(^a)</th>
<th>CVn I(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D_{\text{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>
</tr>
<tr>
<td>(D_{\text{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>
</tr>
<tr>
<td>(SGZ) (Mpc) (^b)</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_{\text{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_{\text{El+Sph}})</td>
<td>10</td>
<td>13</td>
<td>11</td>
<td>18</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</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>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>(V_{\text{in}}(1)) (km s(^{-1}))</td>
<td>220</td>
<td>255</td>
<td>232</td>
<td>398</td>
<td>211</td>
<td>162</td>
<td>163</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>(V_{\text{LG}}(1)) (km s(^{-1}))</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>
</tr>
<tr>
<td>(\langle V_{\text{LG}}\rangle) (km s(^{-1}))</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(^{-1}))</td>
<td>76</td>
<td>77</td>
<td>91</td>
<td>105</td>
<td>71</td>
<td>54</td>
<td>59</td>
<td>54</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^{10} \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_{\text{vir}}(10^{10} \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_{\text{orb}}(10^{10} \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_{\text{vir}}/L) ((\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_{\text{orb}}/L) ((\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_{\text{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>

\(^a\) Scolnic, M., et al. (2018)

\(^b\) Zentner, R. A., et al. (2005)
Groups of galaxies

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution  21 cm HI Distribution

\[ cz = -34 \text{ km/s} \]
Groups of galaxies

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution 21 cm HI Distribution

cz = -34 km/s
Cen A Group

$cz = 547 \text{ km/s}$
M83 Group

Galaxies in The Local Universe

\[ cz = +513 \text{ km/s} \]
Extended HI Disk of a BCD

UGC 5288
Sdm:

cz = 557 km/s
Galaxies in The Local Universe

M66 Group

$cz = 5917 \text{ km/s}$
Galaxies in the Local Universe

M66 Group
Galaxies in The Local Universe
Colliding Galaxies

Galaxies in The Local Universe

$cz = 1706 \text{ km/s}$
Colliding Galaxies

Galaxies in The Local Universe

$cz = 1706 \text{ km/s}$
Colliding Galaxies

$cz = 422 \text{ km/s}$
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

- \(cz \sim 1035\) km/s
- \(\Delta v \sim 1000\) km/s !!
- 1300 catalogued members!!
- Most galaxies are dwarf elliptical type
- Core radius \(\sim 500\) kpc
Virgo Substructure

Galaxies in The Local Universe

Virgo

$-5 \leq \delta < 30$

$m_B \leq 22$

2001
Galaxy distributions

- The E+S0 galaxy distribution are more gaussian in nature.
- The wider dispersion in the late-type galaxies is indicative of the infall/expansion regions.
- Morphology – density relation details that the spiral fraction decreases in higher density regions, such as that of a cluster.

Dressler 1984

Binggeli et al. 1987
Fornax cluster

• $cz \sim 1400$ km/s
Fornax Cluster – Xray view

Galaxies in The Local Universe
View of the Local Universe
Local Universe Overview

- ~9000 redshifts based on HI detections
- Data taken from a variety of radio telescopes…
Galaxies in The Local Universe
References and Acknowledgements

- Hibbard’s Rogue’s Gallery
- Herter, T. Astro 530, Cornell University
- Malin, D. Anglo-Australiian
- Alex Mellinger
- Mateo, et. al.
- APOD
- Haynes, M. P.
- Giovanelli, R.
- J. Sanders, A. Fabian
- KPNO REU Program
- Nigel Sharp, KPNO, WIYN
- Jason Ware
- Sparke and Gallagher, Galaxies in the Universe
- NRAO Image Gallery
- Springob, C.M.
- Spizer Multiwavelength View – M81
- Sarah Maddison