III. Galaxy Groups

1. The Local Group

Figure 1. The heliocentric velocities of nearby galaxies plotted as a function of cos(vφ), where v is the angle between the plane of the sky and the line of sight to the observer. The data points are from the catalog by Sandage (1969), and the fitted line is given by: v = 100 cos(vφ) + 200. The error bars represent the uncertainties in the velocity measurements. The upper plot shows the distribution of velocities for the Local Group, while the lower plot compares the velocities of nearby galaxies in a similar manner. The fitted lines in both plots are given by: v = 100 cos(vφ) + 200, with the error bars showing the uncertainties in the velocity measurements.
1.1. The LG Galaxy Distribution

The Milky Way and M31 will merge within the next 12 Gyrs.
1.2. Gas Bridge between M31 and M33

Fig. 9: Integrated H I emission from the subset of detected features apparently associated with M31 and M33. The grey-scale varies between log(N_HI) = 17–18, for N_HI in units of cm^-2. Contours are drawn at log(N_HI) = 17, 17.5, 18, ..., 19.5.

Fig. 10: Azimuthally averaged H I column density in the vicinity of M31 as function of radius. The secondary peak near 200 kpc projected distance is due to M33. A Gaussian of 8 kpc dispersion and peak log(N_HI) = 20.05 provides an adequate description of the central disk. The extended circum-galactic component can be well fit with a modified Bessel function of 25 kpc scale-length and peak log(N_HI) = 17.7 as discussed in the text.
1.3. Tidal Disruption of Gaseous Satellites

During the passage of two bodies containing stars and/or gas on eccentric orbits at a distance \( b \) (= impact parameter) the bodies achieve orbit energy due to dissipative effects and are heated up.

\[
\Delta E = \frac{4GM_2M_1}{3b^4v^2}r_n^2
\]

1.4. The Magellanic Stream

Fig. 5. Integrated H\textsc{i} emission image highlighting the Magellanic Clouds and Stream. The HIPASS data of Putman et al. (2003) is combined with the wide-field WSRT survey data (in the region 90 < \( \ell < 160 \), -40 < \( b < 40 \)). The grey-scale varies between \( \log(N_{\text{HI}}) = 17 \) and \( \log(N_{\text{HI}}) > 18.3 \). Kinematic evidence of association with the Magellanic Stream only applies to a subset of the illustrated features (see the text and Fig. 3).
Interaction of Milky Way with Magellanic Clouds: Magellanic Stream

Tidal and ram-pressure stripping exhaust the gas from the main body!

1.5. Sag dSph Satellite

- Tidal stream of stars
- Orbits around Milky Way <1 Gyr
- About 10 orbits so far
- Dark matter prohibits disruption of satellite

Ibata et al. 1996, AJ 113, 634
Fig. 15 - A line of sight projection in equatorial coordinates of our Sgr model. Black dots represent particles that are still bound to the Sgr galaxy; the yellow particles become unbound during the last Gyr; the green particles become unbound between 1.0 and 2.0 Gyr ago; the blue particles, between 2.0 and 3.0 Gyr ago; the purple particles, between 3.0 and 5.0 Gyr ago; and the red particles, more than 5.0 Gyr ago. Symbols represent observational data whose metallicity has been measured (see Sec. 6 for a detailed description).

1.6. Canis Majoris dwarf galaxy

Close to galactic plane, 7.5 kpc distance to sun

Distribution of M giants in direction of Canis Majoris at different galactocentric distances

Martin et al. 2004, MNRAS 348, 12
2.1. Loose Group: Telescopium (NGC6861 & 6868)

2.2. Loose Group: Pavo (NGC6872 & 6876)
3. Compact Groups

Defined and catalogued by Paul Hickson 1982ff.:
- number criterion:
  \[ N_{\text{gal}} \leq 4 \]
- magnitude criterion:
  \[ m_i \leq m_{i+3} \]
- isolation criterion:
  \[ \theta_i \geq 3*\theta_g \]
  \( \theta_g \): group radius, \( \theta_i \): isolation radius
- compacity criterion:
  \[ \mu_g < 26 \text{ mag/arcsec}^2 \]

Compact Groups

Hickson 82
- Compact: \( \mu_R < 26 \)
- Rich: \( N \geq 4 \) within \( R_1, R_1+3 \)
- Isolated: empty ring within \( R_1, R_1+3 \)

100 HCGs

Hickson et al. 92

Accordant velocities: \( |v - \langle v \rangle| < 1000 \text{ km/s} \)
A direct test

Virgo cluster CG = chance alignment!

The nature of CGs from simulations

Díaz, Ragone, Muriel & Mamon 08, MNRAS subm.

- Millennium dark matter simulation: 10G particles!
- 3 different galaxy formation codes: 7M galaxies
  - Croton et al. 06 \[ M_r < -17.4 \]
  - Bower et al. 06
  - De Lucia & Blaizot 07
- mock samples in redshift space: 1M galaxies \[ R < 17.44 \]
- mock projected CGs: 12k mpCGs
- mock velocity-accordant CGs: 7k mvCGs
- mock velocity-accordant CGs with HCG biases 350 mvHCGs
3.1. The M81/M82 Group

Gas bridges within the M81 Group feed the high star formation in M82 by gas infall.

3.2. Stephan’s Quintett

Stephan’s Quintet = HCG 92 = Arp 319 = VV 228

1877 first observation by Édouard Stephan with 80cm Foucault telescope (4 galaxies identified)
3.3. Compact Galaxy Groups (Hickson Compact Groups)

  - 4-5 galaxies < 17.5, ρ_{Group} < 1000 ρ_{Field}
  - 170 triplets, 33 quartets, 2 quintets

- Hickson 1994 Atlas of compact groups of galaxies:
  - 4 galaxies within 3 mag
  - „compactness“-criterium: mean surf. brightness of the group $\mu_G < 26$ mag/arcsec$^2$
  - POSS survey: ca. 100 HCGs
  - 70% of HCGs associated with poor galaxy groups
What are HCGs?

- transient galaxy associations
- isolated, bound galaxy groups
- projection of a poor group
- edge-on filaments of galaxy clusters
- compact structures in poor groups

Stephan's Quintett
HCG 92

Chandra

Spitzer

Stephen’s Quintet
3.4. HCG 79, Seyfert’s Sextet

HST/WFPC2
UBVI
Palma+02
Seyfert’s Sextet = NGC 6027 = HCG 79 = VV 115

Seyfert 1951, PASP, 63, 371

Seyfert’s Sextet • NGC 6027
HST • WFPC2
C. Palma (PSU)

More Distant
Tidal Tail

48,000 light-years
15,000 parsecs
3.5. Question: what happens with such dense galaxy systems?

Stephen’s Quintett: simulation by Barnes
3.6. Merger - Remnants

Massive, elliptical field galaxies with X-ray halos characteristic of galaxy groups

Remnants of HCGs?

Expectation 15 yrs ago from CDM simulations:

Merger Tree

“small systems form first, larger ones via merging & accretion”

4. The hierarchical Merger Tree

Lacey & Cole 1993
4.1. Characteristics of Galaxy Groups

- **Poor groups:** pairs, triplets, multiplets of galaxies

- **Compact groups:**
  \[ \geq 4 \text{ galaxies within 3 mag (} \mu_{\text{group}} < 26 \text{ mag arcsec}^{-2} \) \]

- **Fossil groups:** isolated elliptical with hot diffuse gas component associated (merger remnant of a group?)

<table>
<thead>
<tr>
<th></th>
<th>poor</th>
<th>compact</th>
<th>cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of galaxies</td>
<td>( \approx 20 )</td>
<td>( \approx 5 )</td>
<td>( &gt; 100 )</td>
</tr>
<tr>
<td>Density respective to field</td>
<td>( 20 \times )</td>
<td>( 10^6 \times )</td>
<td>( 10^6 \times )</td>
</tr>
<tr>
<td>Velocity dispersion</td>
<td>( \approx 150 \text{ km s}^{-1} )</td>
<td>( \approx 150 \text{ km s}^{-1} )</td>
<td>( \approx 700 \text{ km s}^{-1} )</td>
</tr>
<tr>
<td>Temperatur of hot gas</td>
<td>&lt; 1 keV</td>
<td>&lt; 1 keV</td>
<td>&gt; 1 keV</td>
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4.2. Clustering Scales

<table>
<thead>
<tr>
<th>unit</th>
<th>scale</th>
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</thead>
<tbody>
<tr>
<td>field galaxies</td>
<td></td>
</tr>
<tr>
<td>pairs, triplets ...</td>
<td>&lt; 0.1 Mpc</td>
</tr>
<tr>
<td>groups</td>
<td>≈ 1.5 Mpc</td>
</tr>
<tr>
<td>associations</td>
<td></td>
</tr>
<tr>
<td>clouds</td>
<td></td>
</tr>
<tr>
<td>clusters</td>
<td>&gt; 10 Mpc</td>
</tr>
<tr>
<td>super clusters &amp; voids</td>
<td>≈ 50 Mpc</td>
</tr>
<tr>
<td>(Hubble bubbles)</td>
<td></td>
</tr>
</tbody>
</table>

4.3. Groups (of Galaxies)

First catalogue by Brent Tully (1987)

“Nearby Groups of Galaxies”:

- hierarchical clustering
- Attractive force as criterion: $L/R_{ij}^2$
  - $L$: Luminosity, $R_{ij}$: 3d distance
- Members are defined by density: $\rho = L/R_{ij}^3$
- Group: $\rho > 10^9 \, L_\odot/\text{Mpc}^3$ virialized and collapsing
Small velocity dispersions ($\approx 150$ km s$^{-1}$) in galaxy groups favour interactions between group members:

- tidal arms (in pairs and multiplets)
- collisions (ring galaxies)
- merging (transformation of morphological type)

Galaxy groups are a transient phenomenon in the context of the hierarchical formation scenario, in which most of the evolution of a galaxy takes place in group environments.
>70% of the galaxies in the local Universe are located in galaxy groups with typical sizes of \( \approx 1 \text{ Mpc}^3 \)

Fig. 1—Spectrum of group sizes. The percentage of galaxies that are part of groups with memberships \( N_g \) are plotted as a function of membership \( N_g \). Thirty percent of the sample are singles, and roughly 10% are in each of the seven other membership intervals identified along the top of the figure.


CfA Redshift Survey

Galaxies in Groups

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>CLUSTERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0.5 \leq m &lt; 1.5 )</td>
<td>( 0.5 \leq m &lt; 1.5 )</td>
</tr>
<tr>
<td>( 1.5 \leq m &lt; 2.5 )</td>
<td>( 1.5 \leq m &lt; 2.5 )</td>
</tr>
<tr>
<td>143 entries</td>
<td>193 entries</td>
</tr>
</tbody>
</table>

Groups & Clusters (X km/s)

Fig. 4b—(a) Cone diagram for group members in the declination range \( 30.0 \leq \delta \leq 40.0 \). There are 778 galaxies. (b) Cone diagram for groups; each pc represents one of the 129 groups in the catalog with mean velocity \( \geq 12,000 \text{ km/s} \). The crosses indicate the locations of Abell clusters. Compare Fig. 4.
Figure 5. The lower half of this figure plots the critical equipotentials of $-\psi$, the gravitational potential of the Local Group in comoving coordinates. The rampart or ridge line off which the galaxies will fall is the dotted line. The eyes are M31 on the left and the Galaxy on the right. Several orbits starting near the ridge line are plotted in the upper half. The two $\times$ mark the triangular Lagrangian points.

Fig. 5.— Bolometric X-ray luminosity vs temperature. Filled circles indicate compact groups, open circles indicate X-ray selected groups (Henry et al 1995) and squares indicate clusters. X-ray data for the compact groups and clusters are taken from Ponman et al (1996). A single relation is consistent with clusters, groups and compact groups.
5. Fossil Groups

5.1. Fossil group NGC 1132

![Fig. 3. The radial surface density profile of faint galaxies in the NGC 1132 field (open circles) compared with the composite profile of the X-ray groups (filled circles). We include only galaxies with estimated absolute magnitudes between $-17 + 5 \log h_{75}$ and $-15 + 5 \log h_{75}$. At large radii (i.e., greater than 100 $h_{75}$ kpc), the estimated galaxy counts in both NGC 1132 and the composite X-ray group are consistent with the rather uncertain background counts expected from R-band galaxy-count surveys (Koo & Koo 1992). However, there is a statistically significant excess of galaxies in this magnitude range near the centers of both NGC 1132 and the composite group. This excess suggests that many of the faint galaxies within 60 $h_{75}$ kpc of the center of NGC 1132 are dwarf ellipticals associated with NGC 1132. The error bars plotted for the NGC 1132 data are based on the Poisson counting statistics. The error bars for the composite group data are considerably smaller (on average by a factor of ~2.6) and are not plotted.

Jones et al. 2003 MNRAS 343, 627

5.2. Merging of galaxies

Merging depends on velocity dispersion:

$$\frac{\sigma_{\text{group}}}{\sigma_{\text{galaxy}}} < 2$$

Dynamical time scale depends on interaction with environment (dynamical friction):

$$T_{\text{dyn}} \sim \frac{1}{M_{\text{galaxy}}} \times \frac{1}{\text{density of environment}}$$

→ small galaxies take longer to merge


6. Intra-group Light

The galaxies in a group are embedded into diffuse group light.
Wavelet multi-resolution method decomposes image into characteristic sizes: noise, sky, extended, point sources (Da Rocha et al.)

**E.g. the NGC 4410 group**

**NGC 4410A:**
RA(2000): 12h 26m 03.8s
Dec(2000): +9° 14' 11.8''
D = 97 Mpc ($H_o = 75$ km s$^{-1}$ Mpc$^{-1}$)
15"x15"

R band image (DSS)

Same in the NGC 4410 Group

in HI, X, Radio