Interactions

- Dynamical friction
  - Dwarf/globular cluster moving through stellar distribution governed by shape of the potential/density distribution

- Impulsive/high velocity encounters
  - Velocity of encounter $\gg$ internal velocities of galaxies involved $\rightarrow$ galaxy “harassment”
  - Clusters/dwarfs plunging through the disk

- Tidal effects
  - Dissolution of clusters/dwarfs

- mergers
Mergers

- Two galaxies of roughly equal mass
- Velocities ~ internal velocity → mergers tend to occur if orbital energy is negative (i.e. galaxies are bound to one another)
- Difficult to do analytically → requires simulations
Toomre & Toomre
<table>
<thead>
<tr>
<th>Time</th>
<th>Image 1</th>
<th>Image 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.375</td>
<td><img src="image1.png" alt="Image" /></td>
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<tr>
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<tr>
<td>1.5</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<tr>
<td>3.0</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Mergers → angular momentum decreases (gas)

Resulting pile has almost $r^{1/4}$ distribution
Why Galaxy Groups?

- ~70% of nearby galaxies reside in groups
  ➔ What is the impact of the group environment on galaxy evolution?
  ➔ What is the impact of galaxy evolution on the group environment?

- Groups may hold the key to the baryon budget of the Universe
  ◦ What is the density of the intragroup medium?

- Groups define the large scale structure
  ➔ What can groups tell us about the formation of large scale structure?
What are Galaxy Groups?

- 3–10 members with $M_V < -19$ within a radius of 0.5 Mpc (Zirbel 1997)
- “poor cluster” (Bahcall 1980)
  - ~30 members with $m$ such that $m_3 < m < (m_3+2)$
  - $m_3$ is the magnitude of the 3rd brightest member
- $N > 4$ with $200 \text{ km s}^{-1} < \sigma < 400 \text{ km s}^{-1}$ (Carlberg 2001)
- $M_{\text{halo}} \sim 10^{12}–10^{14} \text{ M}_\odot$ (Eke 2004)
- Compact groups $\rightarrow$ “few” galaxies with separations of a “few” galactic radii
Simulation of the formation of the Local Group

B. Moore
http://nbody.net
What are galaxy groups?

- GEMS Sample (Brough et al. 2006)
  - $N \sim 3-20$
  - $\sigma \sim 28-430 \text{ km s}^{-1}$
  - $R_{500} \sim 0.22-0.56 \text{ Mpc}$
    - Radius at which density $= 500 \times \rho_{\text{crit}}$
  - $\log L_X (\text{erg s}^{-1}) \sim 40.7-42.11$
    - 2/16 with upper limits $\sim 40.5$

Groups have been defined by the luminosity and extent of their X-ray emission
Groups aren’t clusters…. 

- Group velocity dispersion ~ internal velocity dispersion of individual galaxies
  - Galaxy–galaxy mergers more likely in groups than clusters
  - Ram pressure stripping & “harrassment” less likely
  - Galaxies more likely to be falling into a “dense” environment for the first time
Why Galaxy Groups?

- Galaxy properties vary with environment
  - Luminosity function (Eke et al. 2004)
  - Color/morphology
    - Morphology–density relationship
  - Star formation rate
HI Content of The Local Group

- Gas–rich spirals
  - M31 (log $M_{HI} \sim 9.76$)
  - MWG (log $M_{HI} \sim 9.60$)
  - M33 (log $M_{HI} \sim 9.18$)
  - LMC (log $M_{HI} \sim 8.85$)
HI Content of The Local Group

- Gas–rich spirals
- Gas–rich irregulars
  - SMC (log M$_{HI}$ ~ 8.81)
  - IC 10 (log M$_{HI}$ ~ 8.18)
  - WLM (log M$_{HI}$ ~ 7.90)
  - Sextans A (log M$_{HI}$ ~ 7.90)
  - IC 1613 (log M$_{HI}$ ~ 7.78)
  - Leo A (log M$_{HI}$ ~ 7.30)
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- Gas–rich irregulars tend to lie at large distances
HI Content of The Local Group

- Gas–rich spirals
- Gas–rich irregulars
- Tidal Debris/HVCs
  - Magellanic Stream
  - M31/M33 bridge (Braun & Thilker 2004)
  - HVC system
Milky Way/Local Group  High Velocity Clouds

courtesy B. Wakker
Gas Content of The Local Group

- Gas–rich spirals
- Gas–rich irregulars
- Tidal Debris/HVCs
  - Magellanic Stream
    - ($\log M_{\text{HI}} \sim 8.69$ – Bruens et al. 2005)
  - M31/M33 bridge (Braun & Thilker 2004)
  - HVC system ($\log M_{\text{HI}} \sim 8$)

Total HI Mass of Local Group $\sim 10.13$ ($\log M_{\text{HI}}$)
$\sim 10\% M_{\text{stellar}}$, $\leq 1\%$ of $M_{\text{dynamical}}$
Morphology, Gas Content, and the Dynamical State of Galaxy Groups

- **Morphology–Dynamics**
  - Optical surveys indicate that dynamically evolved groups have high elliptical fractions (0.6–1.0), while dynamically young groups have small elliptical fractions (0.0–0.2)
  - Corresponding relationships between velocity dispersion, $L_X$, and early-type fraction (Brough et al. 2006)
    \[
    F = 0.27 \log_{10} L_X - 10.8
    \]
    \[
    F = 0.76 \log_{10} \sigma - 1.2
    \]

- **Gas Content vs Dynamics**
  - Evolved groups have extended X-ray halos
  - The gas content of dynamically young groups is largely in neutral gas \(\rightarrow\) **no group with \(f=0\) has a detected X-ray halo.**
Morphology, Gas Content, and the Dynamical State of Galaxy Groups

- **The Role of Interactions**
  - Evolution traced by interactions
  - Interactions produce ellipticals & enhance star formation
    - Tidally remove neutral gas from galaxies
    - Star formation induced ejection of hot gas from individual galaxies

- **Tracing the Evolution with 21 cm line HI observations**
  - Measure the interaction/merger rate
  - Measure the total amount and distribution of neutral gas
Two trends
- Spiral rich → elliptical dominated
- Cool, neutral → hot, ionized
  - None of the groups observed with $F_{\text{spiral}} = 1$ have detectable X-ray halos

Possible Scenarios
- Tidally stripped neutral gas is heated in the intragroup medium
- Galaxy mergers
- Heating of intergalactic medium
- Compact groups are transient phenomena within larger loose groups → development of common HI envelopes
X-ray properties

Mulchaey et al. 2003
X-ray Properties

Mulchaey & Zabludoff 1998
Comparison with X-ray emission

n2563 overlaid with n2563 and n2563final.tothi.fits:Ext[1] and NGC2563→rosat.fits

HI detections
All members
X-ray emission
HCG 58 & Environ

Freeland et al 2008
~30% of the total HI is in the tidal material.
NGC 664

Freeland et al 2007

Mulchaey & Zabludoff
~4–5 galaxies

$R_{\text{separation}} \sim 50$ kpc

$\sigma < 200$ km s$^{-1}$

Crossing times $<<$ Hubble time
VLA 21 cm Line Observations of a HCG

Wilcots & Prescott 2004
HCG 58 & Environs

Freeland et al 2007
HCG 79

HCG 79b1 (Tidal debris)
HCG 79b (S0)
HCG 79c (S0)
HCG 79e (Scd)
HCG 79a (EO)
HCG 79d (Sdm)

HCG 79 Continuum
HCG 79 Continuum + Hα
HCG 79 Hα
The Evolution of the Gas Content of Groups

- Interaction rate much higher in “intermediate” groups.
  - Almost all HI detected galaxies are interacting or show signs of recent tidal encounters
  - “significant” amounts of tidally stripped neutral gas

- HI detected galaxies remain outside of the X-ray halo in X-ray luminous groups
- No evidence of a population of pure HI halos (except tidally stripped material)
- Growth of common HI envelopes in HCGs
- Not enough HI to account for baryon budget
The Distribution of CDM halos & HVCs

from Klypin et al. (1999)

from Ben Moore http://nbody.net
There is no indication of a population of pure HI clouds (HVCs) in the intragroup medium.

The HI mass function in the group environment is flat at the low mass end.

Intragroup medium in “intermediate” groups is populated with tidally stripped HI as groups evolve.