• Hand out the first assignment!
• Using Arecibo for ALFALFA
• Survey design:
  • Defining the science goals
  • Balancing technological capability and science goals
• Complementary observations
The hunt for low mass halos requires that we survey a lot of sky area (solid angle)

- They have low HI mass, so their HI signals are weak.
- Therefore, we can only detect them nearby.
- Therefore, we have to cover a wide solid angle to sample enough volume.
- We need to integrate long enough at each point in the sky to detect a typical low mass object out to some (desired) distance.
- Arecibo is part of NAIC; it is a national observatory and serves many scientific users. Alas, we cannot have all the telescope time.
- ALFALFA is a trade-off between ambition and practicality.
ALFALFA: Spring Sky

2005: Tiles at $+10^\circ$ and $+14^\circ$
- Leo to Virgo region
- Leo Group
- Virgo cluster core

Virgo cluster
D=$16.7$ Mpc

Leo I group
D=$10$ Mpc

Supergalactic plane
The Virgo Cluster

RA = 12h, Dec = +12°
\( \langle V \rangle = 1035 \text{ km/s} \)

- The Spring 2005 ALFALFA dataset includes a 7 degree wide band across the center of the Virgo cluster.
- Much of this region is also included in the Sloan Digital Sky Survey (optical).
- The nearest rich cluster, Virgo is dynamically young.
The Virgo Cluster

- Virgo Cluster Catalog (BST85)
- ~2000 objects
- Based on morphological appearance
- Largely confirmed by redshift measurements

Binggeli, Sandage & Tammann 1985, AJ 90, 1681
Structure in the Virgo Cluster

- Extended X-ray emission implies hot ICM
- Redshift distribution implies substructure including main cluster around M87, secondary one around M49, plus infalling spiral groups
Dwarf galaxies in Virgo

- BST in the VCC identified some 1000 dwarfs in Virgo
- 90% are dE’s
- The remainder are dIs and BCDs

- dEs are the dominant population in Virgo
- Some of them rotate!
- How are they like/unlike dwarfs in the Local Group?
dIs in Virgo

- dIs form a widely dispersed population
- dIs not preferentially stripped as might be expected due to shallower potential wells

Hoffman et al. 1987, 1989
Morphological Alterations

Morphological segregation:

- Spirals avoid cluster cores; Ellipticals favor cores.
- Spirals in Virgo core are HI deficient.
- In loose groups, tidal tails can be traced by HI where galaxies have interacted in the recent past.
- The ratio of the number of dwarfs to the number of giants seems to vary from place to place.
- Dwarfs around MW and M31 are dE/dSph; dI’s are widely dispersed in Local Group.
How and when do galaxies form?

Numerical simulations predict the existence of lots of low mass halos, but so far, we have not observed them.

Do they exist?

Movie by M. Steinmetz
Credit: Virgo collaboration (MPIfAp)
Dark Matter Dominated

Arecibo map outer extent [Hoffman et al. 1993]

Carignan & Beaulieu 1989
VLA D HI

Extent of Optical image
Leo I: An interesting region

- Quite nearby: \( D=10 \) Mpc
- Leo I is dominated by early types
- Velocity dispersion is very small \( \sim 112 \) km/s
- Leo I contains the “Leo ring” of HI

Figure 1. The Leo Ring System.
HI: Arecibo single dish map, 3.3’ resolution, contour: \( 2 \times 10^{18} \) cm\(^{-3} \times 2^n \).
Optical: DSS, FOV=70’ \times 100’.
Notes: Labeled galaxies have redshifts similar to the HI ring.
Reference: Schneider, S.E., Skrutskie, M.F., Hacking, F.B., Young, J.S.,
Dirkman, R.L., Claussen, M.J., Salpeter, E.E., Houck, J.R., Terndrup, Y.,
HI deficiency in Virgo

Galaxies embedded in the hot X-ray gas are deficient in their HI relative to isolated galaxies of the same size and morphology.

Dots: galaxies w/ measured HI
Contours: HI deficiency
Grey map: ROSAT 0.4-2.4 keV

Solanes et al. 2002
Ram pressure sweeping

- Spirals in Virgo are HI deficient.
- Hydrodynamical simulations show effectiveness of ram pressure stripping

Vollmer et al. 2001
Stripping in Groups/Clusters

- ALFALFA clues:
  - Asymmetric/peculiar HI distribution
  - No HI in optically “gassy” galaxy
- Better definition of group/cluster structure and substructure.
- What is the X-ray environment in groups/clusters?
  - Chandra data (archival and new)
- Other evidence for interactions?
  - Active nuclei
  - Star burst indicators
  - Radio continuum emission
HI Tidal Remnants

Figure 1. The Tidal Sequence merger NGC4038/9.

**HI:** VLA C+D array, 40\" resolution, contours=4 \times 10^{19} \text{ cm}^{-2} \times 2\".

**Optical:** DSS, FOV=20\" \times 24\".

**Notes:** The HI concentration at the end of the southern tail is associated with a putative Tidal Dwarf Galaxy. For a close-up of the companion galaxy ESO 572-G95 see Fig. 77.

Blind search for tidal remnants

In loose groups, slow tidal encounters lead to disruption of disks and the formation of bridges and tails.

Simulation by Josh Barnes
Leo Triplet

Single ALFALFA drift
Galaxy harassment

Multiple rapid encounters in a cluster may also seriously impact galaxy evolution.

Animation courtesy of G. Lake
Extragalactic databases

NED: http://nedwww.ipac.caltech.edu
NASA Extragalactic Database

Sloan Digital Sky Survey

Skyview: http://skyview.gsfc.nasa.gov/
NASA database of multiwavelength surveys