The Local Group as a Cosmological Training Sample

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Why study the Local Group?
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For cosmology, of course!
Local Group studies and cosmological questions

(Cold) Dark Matter Issues
- Measures of the total mass of the big galaxies
- Measures of the density profile and flattening of the halo
- Constraints on substructure in the halo
- Possible insights into the nature of dark matter

Galaxy Formation/Evolution Issues
- Star formation/enrichment histories of diverse galaxies
- Gaseous structures in galaxies
- Dynamical processes modifying galaxy structure
- Assembly history of big galaxies
WMAP Map of the Cosmic Microwave Background

Bennett et al 2003
- $>10^5$ near-independent $5\sigma$ temperature measurements
- Gaussian map: PS fit by a CDM model with parameters consistent with other data
- Extrapolation fits the Ly-\(\alpha\) forest power spectrum
  Confirms standard model to scales well below those of clusters and bright galaxies

Bennett et al 2003

Spergel et al 2003

Halo mass
Weighing galaxy halos

- The massive and extended galaxy halos expected in CDM theories can weighed only by
  -- gravitational ('galaxy-galaxy') lensing
  -- static X-ray halos (for massive central ellipticals)
  -- satellite galaxy dynamics

- In the Local Group halo mass information comes from
  -- the Kahn-Woltjer (1959) timing argument
  -- the Zaritsky et al (1989) timing argument for Leo I
  -- proper motions and radial velocities of satellites
  -- the kinematics of tidal streams

Odenkirchen et al 2003
Dark Matter within Satellites

- Flat stellar velocity dispersion out to the tidal radius
  - rising $V_c$ curve
- Extended DM halos?
- High DM phase density? $\sim$ WDM?
- $V_{c,\text{max}} \geq 25$ km/s?
- Critical observation: extratidal stars?
High quality rotation curves for local dwarfs

Blais-Ouellette, Amram & Carignan 2001

'NFW' halo is not as concentrated as expected in ΛCDM

NGC3109
Too many satellites for CDM?

Kauffmann, Guiderdoni, White 1993

- In hierarchical models like CDM the Milky Way's halo formed out of many smaller halos.
- If all progenitors made stars with *reasonable* efficiency too many satellites result.
- Star formation must be strongly suppressed in low mass progenitors.
  Reionisation effects?
The number of observed satellites with circular velocity $V = (GM/r)^{1/2}$ (inferred from the mean velocity dispersion) exceeding 10 km/s is at least 10 times smaller than the number expected in a $\Lambda$CDM halo.
Inconsistency with observed satellite kinematics?

- Inconsistency is much less dramatic when one uses the *limiting* circular velocity inferred from the velocity dispersion profiles
Consider a *known* (*i.e.* observed) density distribution of stars \( \rho(r) \) in a *given* (*i.e.* simulated) potential well \( \Phi(r) \)

- For gas in a spherical potential: 
  \[
  \frac{dp}{dr} = -\rho \frac{d\Phi}{dr} = -\rho \frac{V_c^2}{r}
  \]

- For a spherical stellar distribution
  \[
  \frac{d(\rho \sigma_r^2)}{dr} + 2 \rho (\sigma_r^2 - \sigma_t^2) / r = -\rho \frac{V_c^2}{r}
  \]
  \[\langle \sigma_{\text{l.o.s.}}^2 \rangle = \frac{\langle V_c^2 \rangle}{3} \text{ independent of anisotropy}\]
  where \( \langle \ldots \rangle \) denotes an average over all stars in the dwarf

- For an isotropic velocity dispersion \( (\sigma_r = \sigma_t \text{ at all } r) \)
  \[
  \sigma_{\text{l.o.s.}}^2(r_p) = \int dr \rho \frac{V_c^2 (r^2 - r_p^2)^{1/2}}{r} / \int dr \rho \frac{r}{(r^2 - r_p^2)^{1/2}}
  \]
Satellite circular velocity curves

Stoehr et al 2003

- Circular velocity curves for 11 of the 30 most massive subhalos in a $10^7$ particle 'Milky Way' halo
- The NFW and 'main halo' curves are scaled to the $(r_m, V_m)$ of largest subhalo
- All curves are narrower than NFW or 'main halo'
- Many profiles approach a constant density core in their inner regions
- The most massive of these potentials could host the observed satellites
Effects of CDM substructure

- Dynamical heating of Galactic substructures
  -- the disk? globular clusters? halo streams?
  -- effects dominated by most massive objects -- LMC, SMC

- Differential image magnification in multiply imaged QSOs
  -- dominant substructures have lensing scale smaller than image separation but larger than image size
  intermediate masses

- Relation to high-velocity clouds?

- Visible in annihilation radiation at $\gamma$ frequencies?
Local Group Constraints on the Nature of DM

- Microlensing signals are measured for the Galactic bulge, the Magellanic Clouds and for M31 stellar mass DM?

- If DM particles have Majorana masses then they have a finite cross-section for annihilation $\gamma$ emission

- Most WIMPS have a finite cross-section for elastic collision with baryons detection by calorimeters?

Helmi & White 2002
$\gamma$-rays from the annihilation of DM particles

Stoehr et al. 2003

Image of a 'Milky Way' halo in annihilation radiation

Distributions of mass and of smooth and subhalo luminosity
γ-rays from the annihilation of DM particles

- The annihilation luminosity is \( L \propto \int \rho^2 \, dV \propto \int \rho^2 \, r^2 \, dr \) for a spherical system \( \rho \propto r^{-1.5} \) the dominant contribution comes from regions where \( \rho \propto r^{-1.5} \).
- The simulated ΛCDM Milky Way halo has half its luminosity coming from within 8.6 kpc of the centre.
- The luminosity/mass of substructures is independent of mass extra luminosity comes from most massive substructures.
- The total luminosity exceeds that of a smooth spherical halo with the same \( V_{\text{circ}}(r) \) by:
  + 25% due to substructure
  + 15% due to flattening
  + 8% due to unbound substructure
- Annihilation radiation from \( R < R_{\text{sun}} \) may be detectable with next generation γ-ray telescopes.
How was the Milky Way assembled?
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Monolithic collapse of a protogalaxy
How was the Milky Way assembled?

- Monolithic collapse of a protogalaxy
- Slow aggregation of fragments
Streams -- fossils of galaxy assembly

Ibata et al 2001

- Which progenitors produced streams? When?
- How many mergers were there?
- How many streams from each?
- Streams near the Sun? In the disk? In DM detectors?
- Did the metal-poor halo form this way? the bulge?
- Relation to globular clusters?
- Enrichment history of the progenitors?
The lowest mass galaxies

- What limits star formation?
  -- breakdown of L - \( \sigma \) relation (cf Draco, Fornax)
  -- star formation in widely separated bursts
  -- reionization effects?
  -- galactic wind effects?

- What is the relation of DwSph to DwIrr?

- What is the role of tidal limitation?
  -- do satellites differ from the field? from cluster dwarfs?
Star formation issues in the Local Group

- Which processes regulate star formation?
  - molecule formation (and dust)?
  - magnetic fields and cosmic ray densities?
  - turbulence and shocks?
  - radiative and hydrodynamic feedback?

- What initiates star formation bursts in dwarfs?
  - tidal effects?
  - interactions with halo gas?
  - internal latency/activity cycles?

- How active are winds in dwarfs?
  - only during bursts?
  - heavy element loading?
  - differential loss of elements (α/Fe/CNO, dust...)

- Is IMF or binary fraction variable?
  - low metallicity, low dust conditions?
  - low escape velocity?
Understanding the Galactic gas supply

- Does satellite accretion refuel the galactic disk?
- Is satellite gas lost by ram-pressure stripping on a hot halo?
- Are some high velocity clouds stripped from satellites?
- Are the HVC the 'missing' satellites?
- How is the Galactic fountain/Galactic wind functioning?
Dynamical processes in the Local Group

- Generation of the Galactic warp/flare
- Origin of the thick disk/thin disk dichotomy
- Origin of the Milky Way and M31 bulges
- Connections between element abundance and structure
- Stellar dynamics around central black holes (MW, M31, M32)
And so.....
And so.....

On to the \textit{real} meeting

Thank you!