2nd Thinkshop
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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

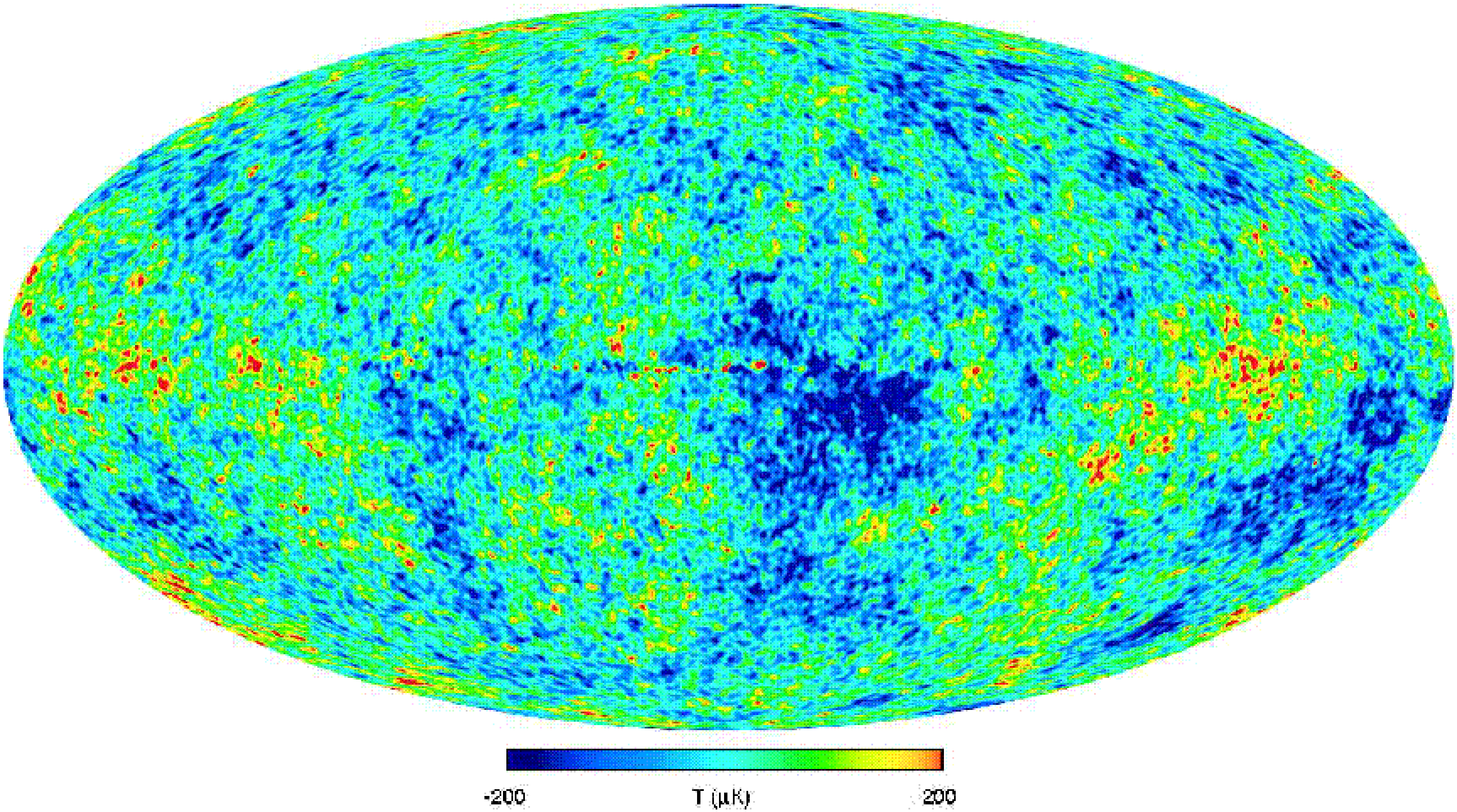
(Cold) Dark Matter Issues

- 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

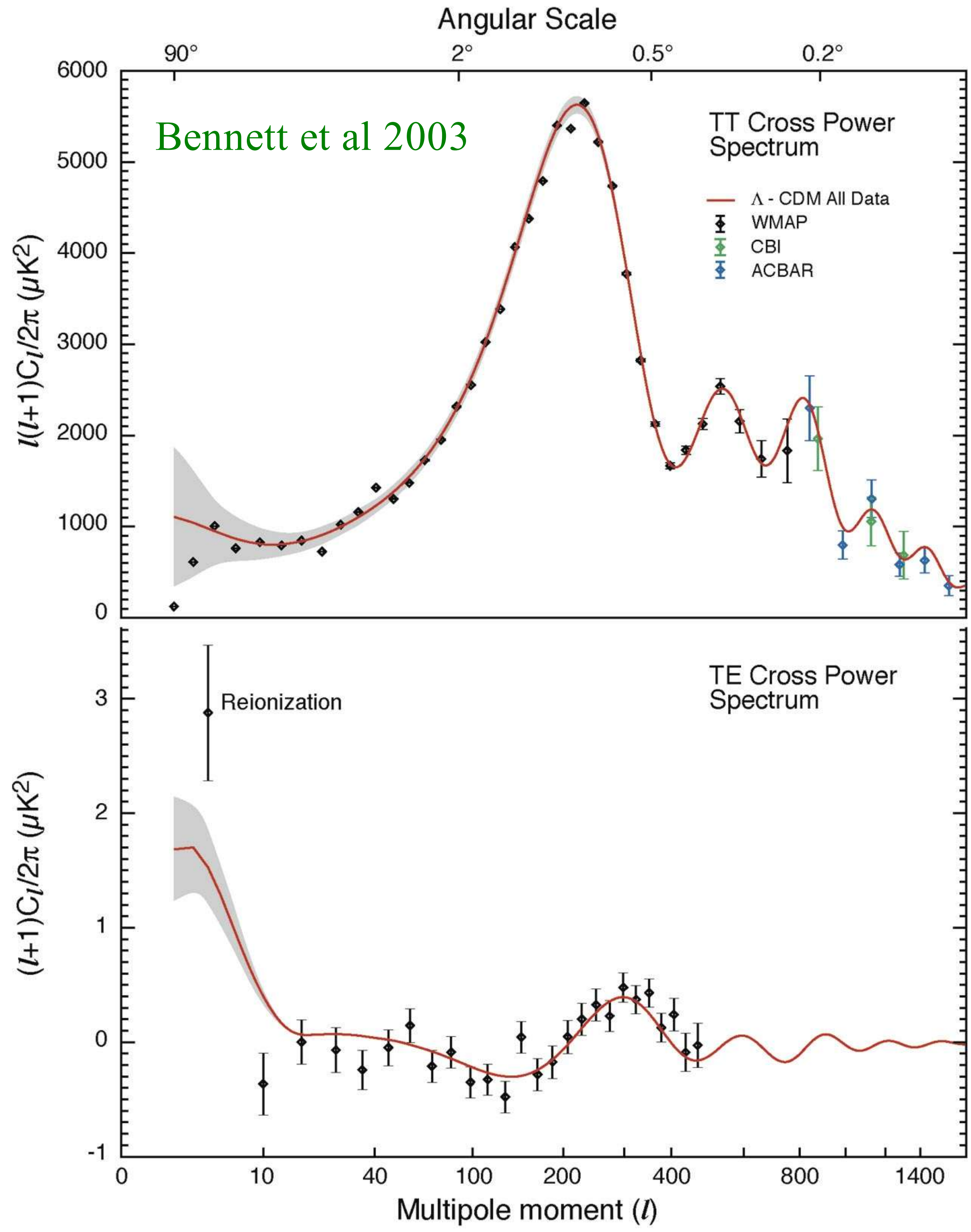
Galaxy Formation/Evolution Issues

- 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

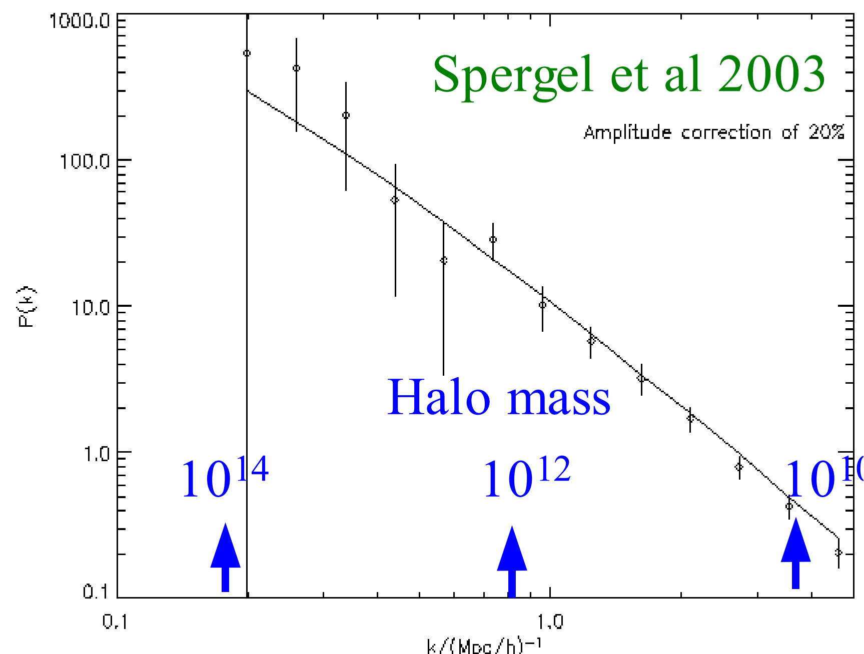


Bennett et al 2003



- > 10^5 near-independent 5σ temperature measurements
- Gaussian map: PS fit by a CDM model with parameters consistent with other data
- Extrapolation fits the Ly-α forest power spectrum

Confirms standard model to scales well below those of clusters and bright galaxies

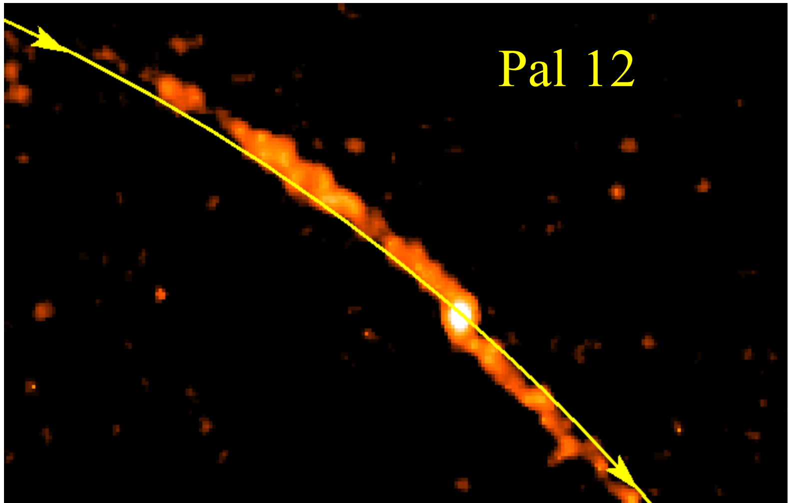


Weighing galaxy halos

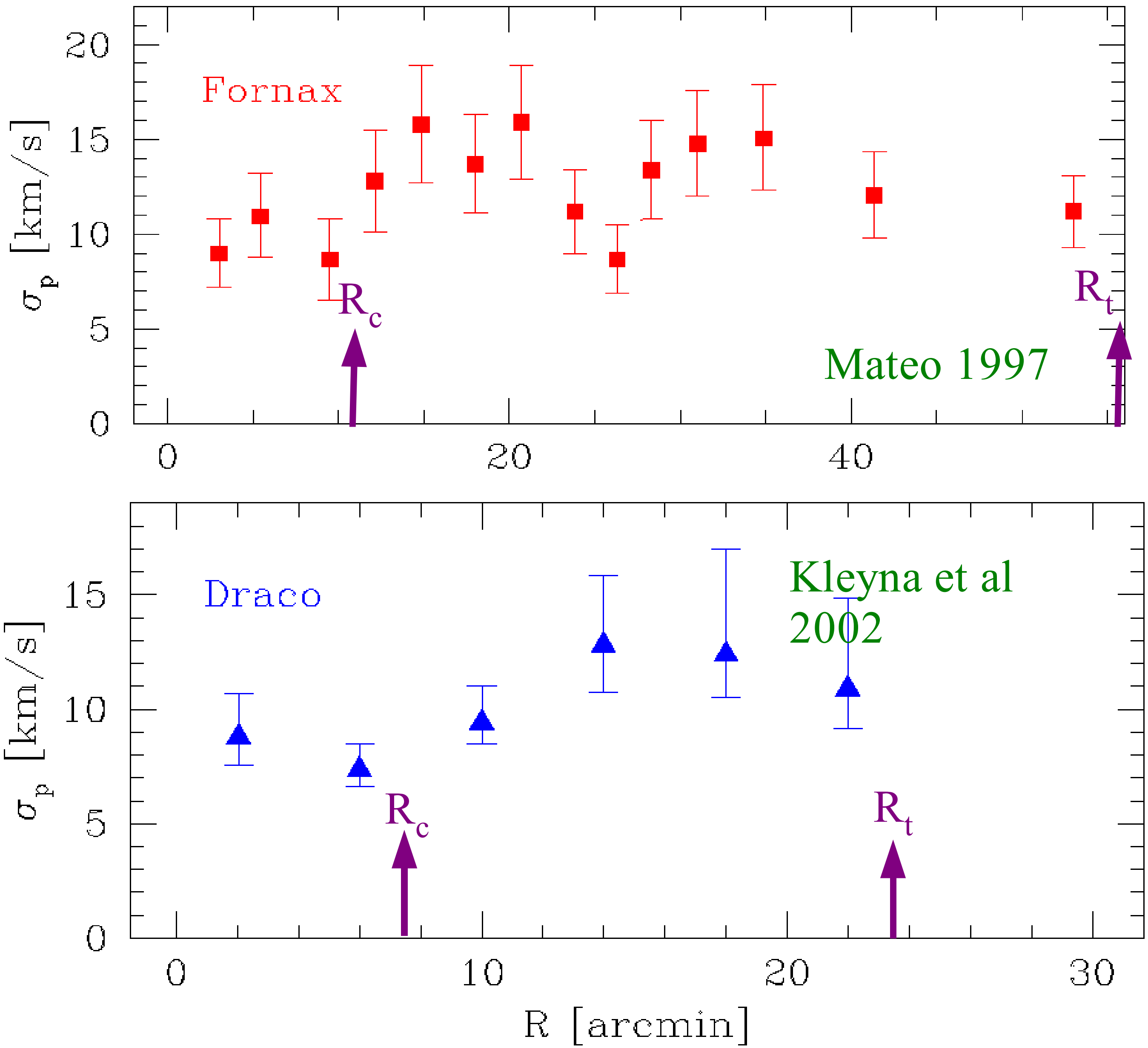
- The massive and extended galaxy halos expected in CDM theories can weighed only by
  - -- gravitational ('galaxy-galaxy') lensing
  - -- static X-ray halos (for massive central ellipticals)
  - -- satellite galaxy dynamics

- 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

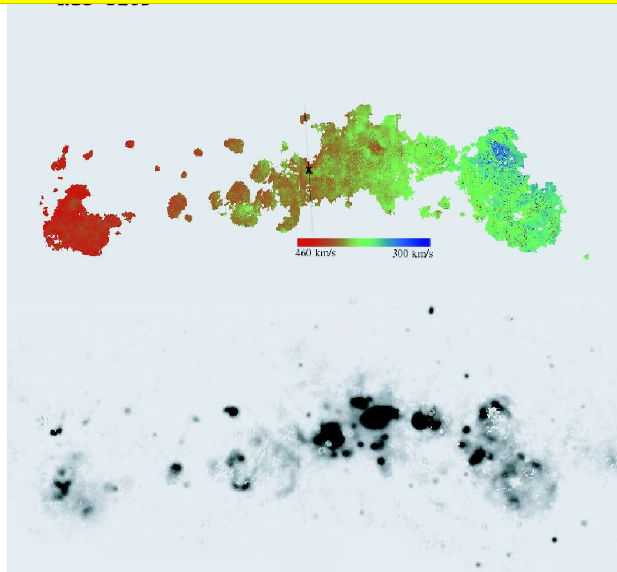


Dark Matter within Satellites

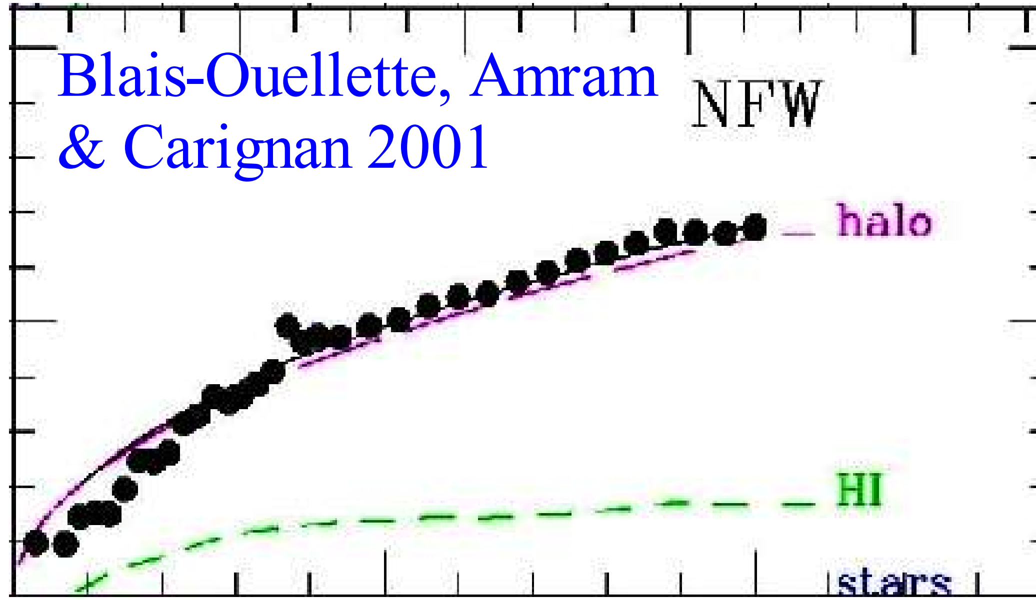


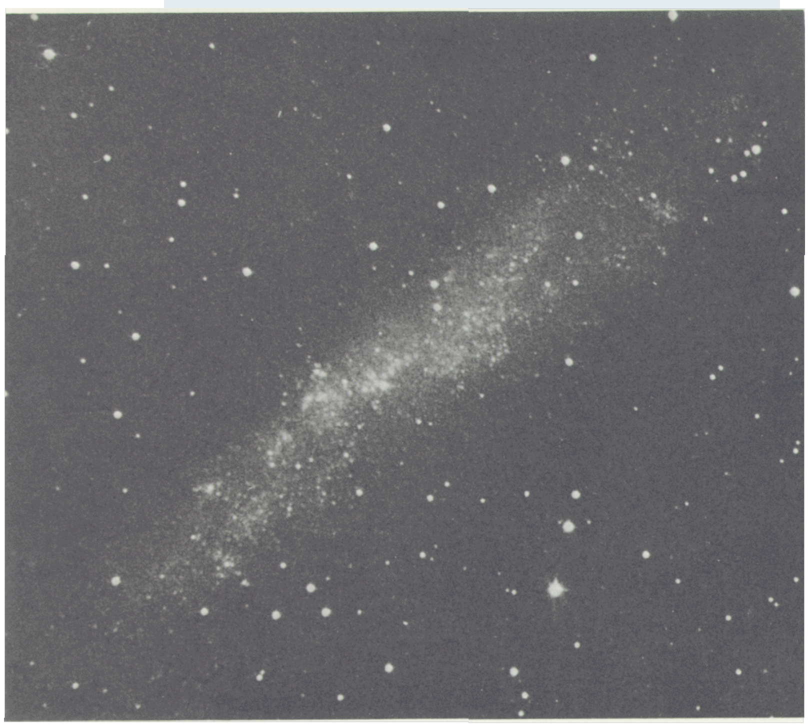
- Flat stellar velocity dispersion out to the tidal radius
  → *rising* V_c curve
- Extended DM halos?
- High DM phase density? ~~*WDM*~~ ?
- $V_{c,max} \gtrsim$ 25 km/s ?
- Critical observation: extratidal stars?

High quality rotation curves for local dwarfs

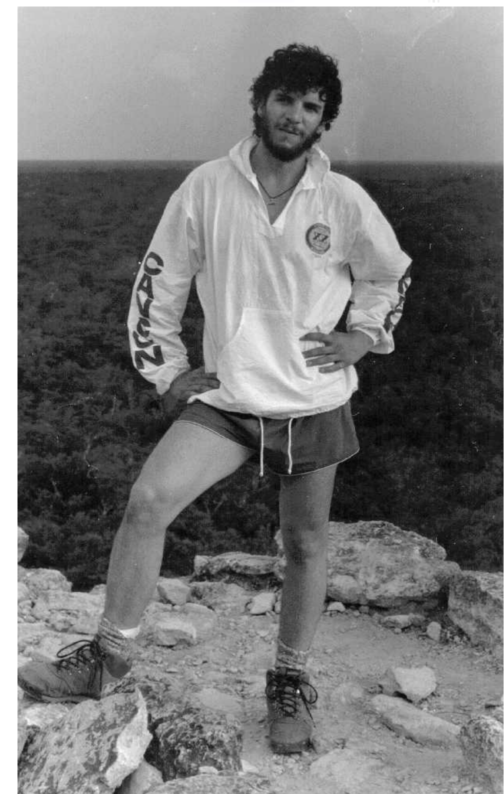


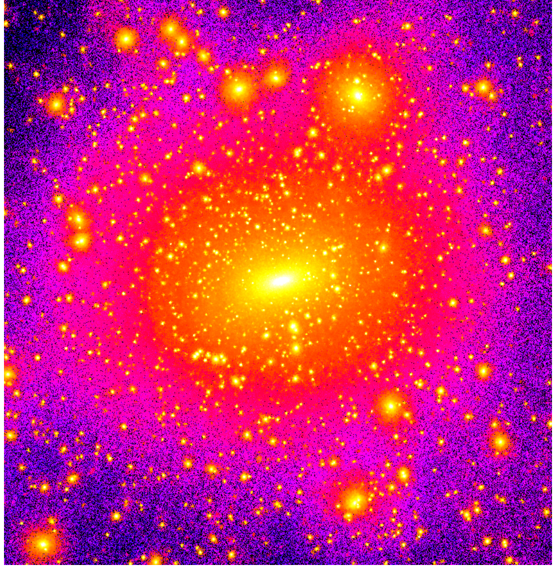
NGC3109





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



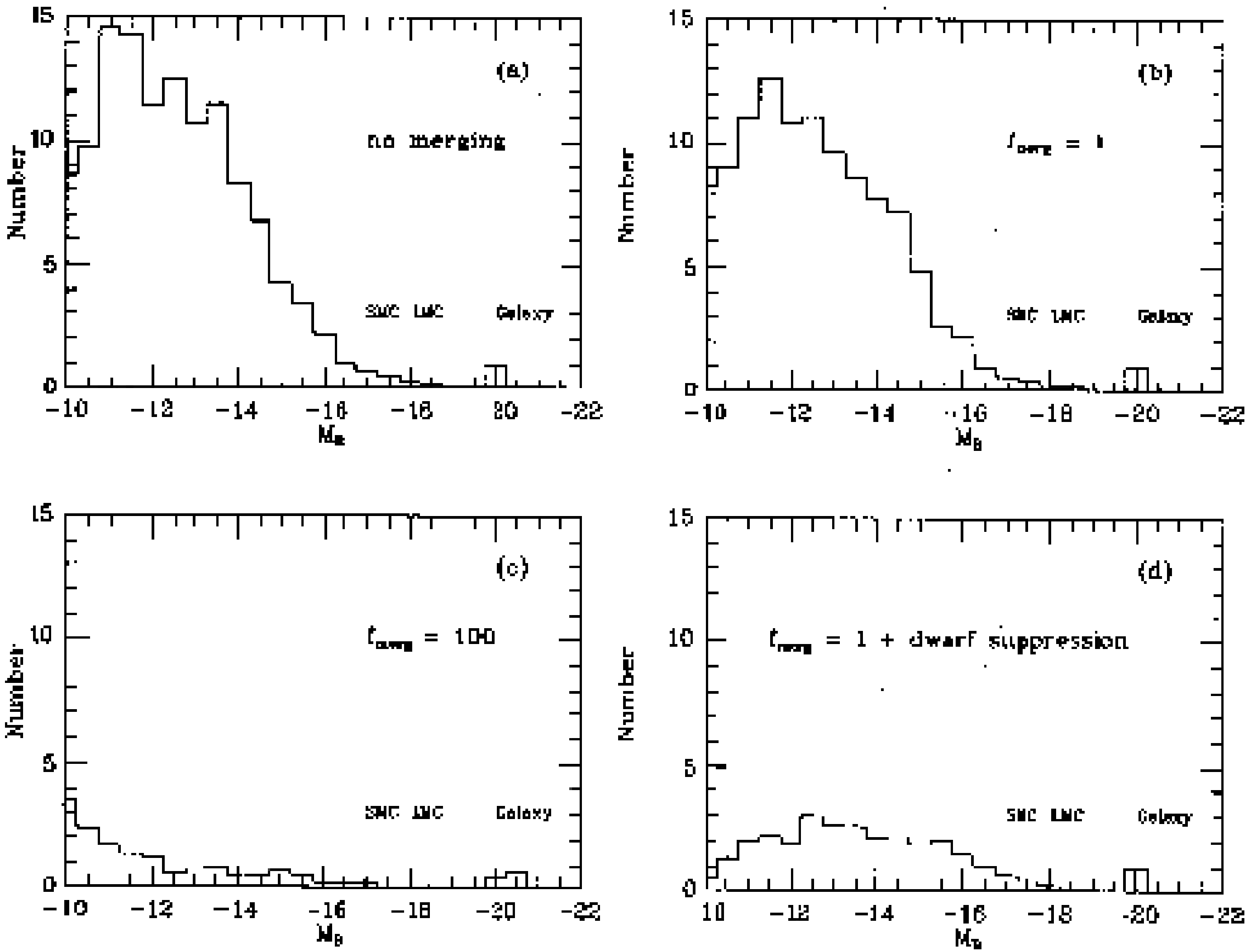


Too many satellites for CDM?

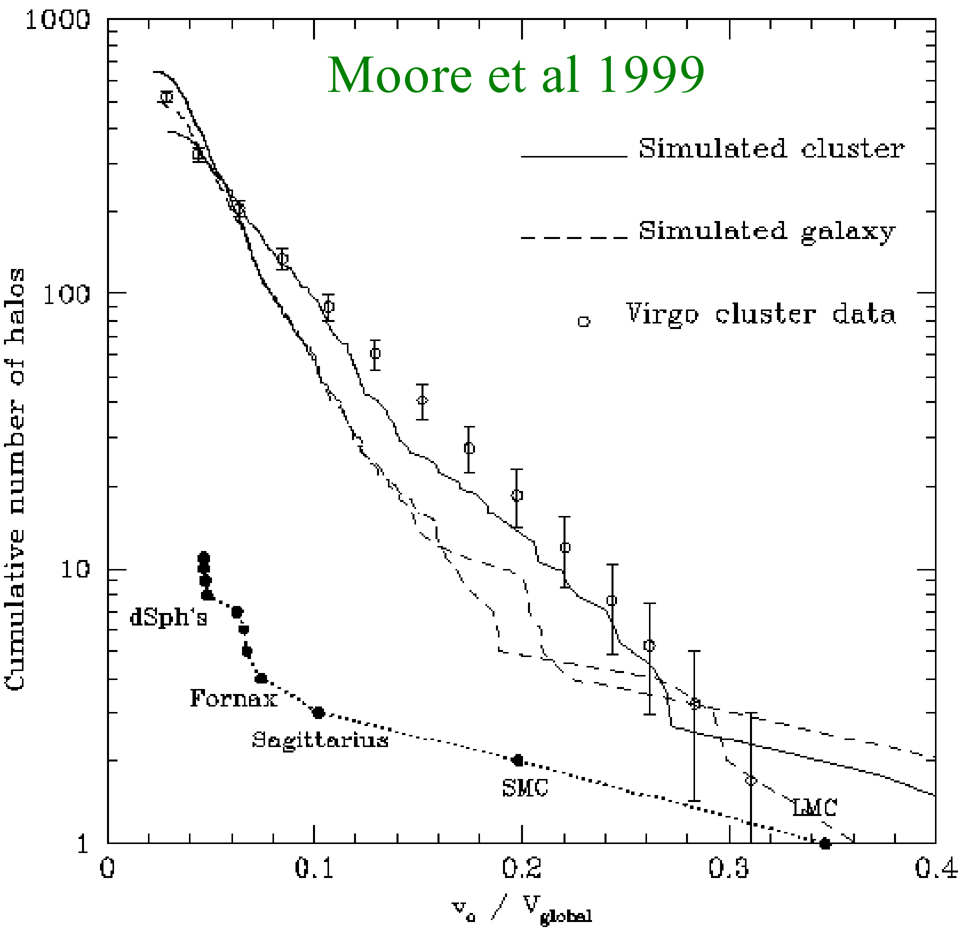
- In hierarchical models like CDM the Milky Way's halo formed out of many smaller halos
- If all progenitors made stars with *reasonable* efficiency too many satellites result
- Star formation must be strongly suppressed in low mass progenitors

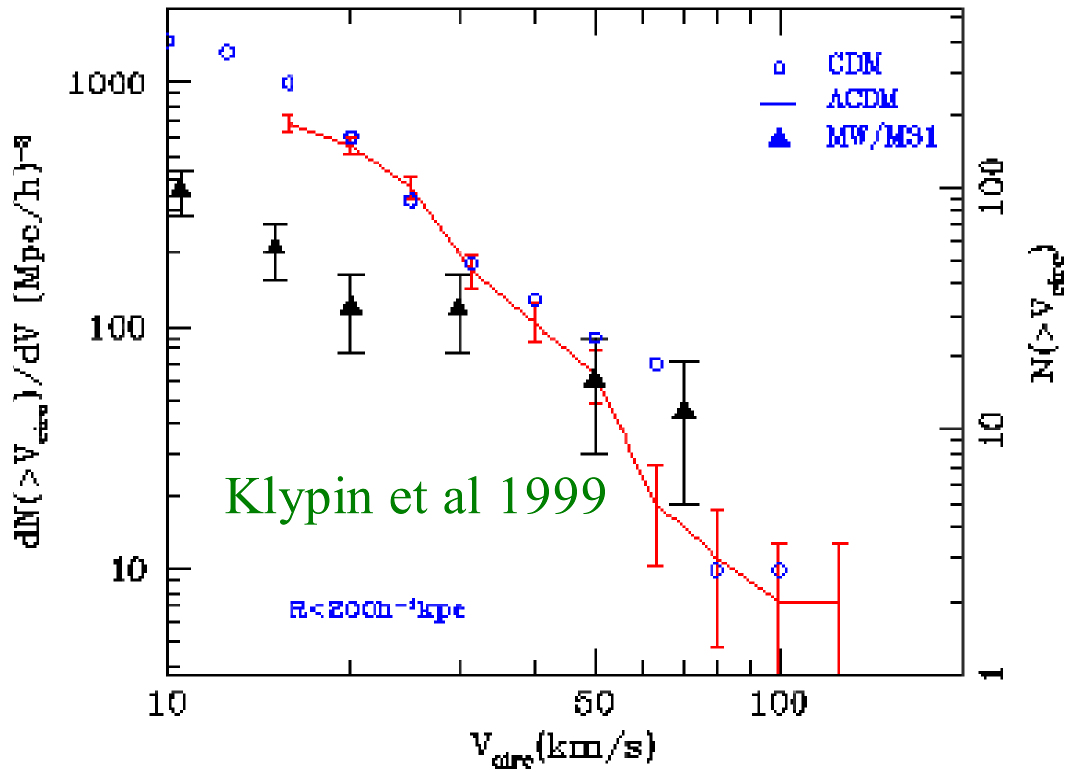
Reionisation effects?

Kauffmann, Guiderdoni, White 1993



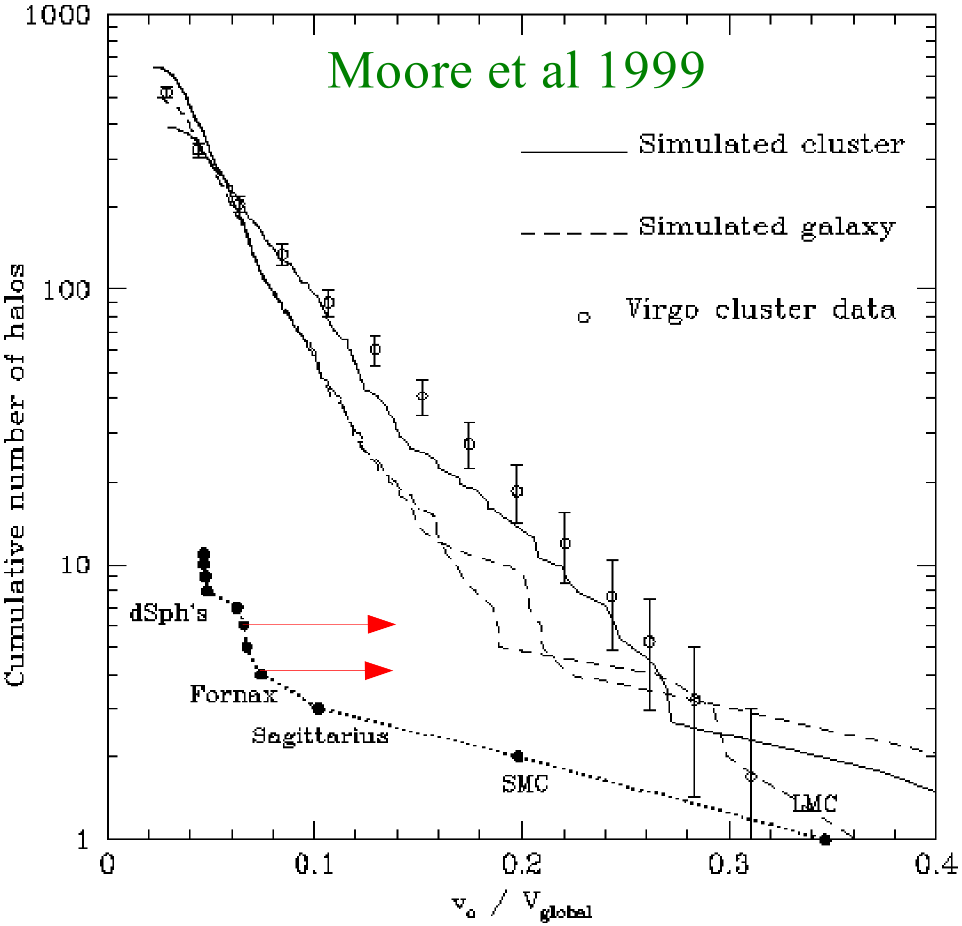
Inconsistency with observed satellite kinematics?

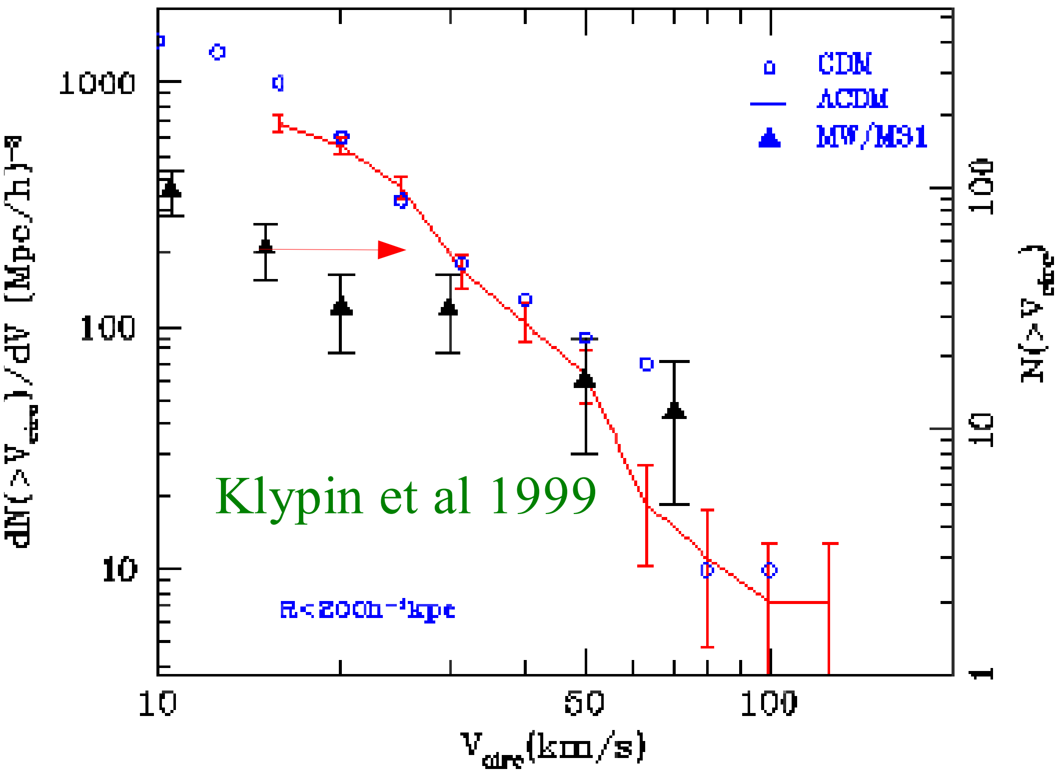




- The number of observed satellites with circular velocity V = (GM/r)$^{1/2}$ (inferred from the *mean* velocity dispersion) exceeding 10 km/s is at least 10 times smaller than the number expected in a ΛCDM halo

Inconsistency with observed satellite kinematics?





- Inconsistency is much less dramatic when one uses the *limiting* circular velocity inferred from the velocity dispersion profiles

Observed velocity dispersion versus potential well depth

Consider a *known* (*i.e.* observed) density distribution of stars ρ(r) in a *given* (*i.e.* simulated) potential well Φ(r)

- For gas in a spherical potential: $\mathrm{d}\,p/\mathrm{d}\,r = -\rho\,\mathrm{d}\Phi/\mathrm{d}\,r = -\rho V_c^2 / r$

- For a spherical stellar distribution

$$\mathrm{d}\,(\rho\sigma_{\mathrm{r}}^2)/\mathrm{d}\,r + 2\,\rho\,(\sigma_{\mathrm{r}}^2 - \sigma_{\mathrm{t}}^2)/r = -\rho\,V_c^2/r$$

$$\longrightarrow \langle\sigma_{\mathrm{l.o.s.}}^2\rangle = \langle V_c^2\rangle \,/\, 3 \quad \textit{independent of anisotropy}$$

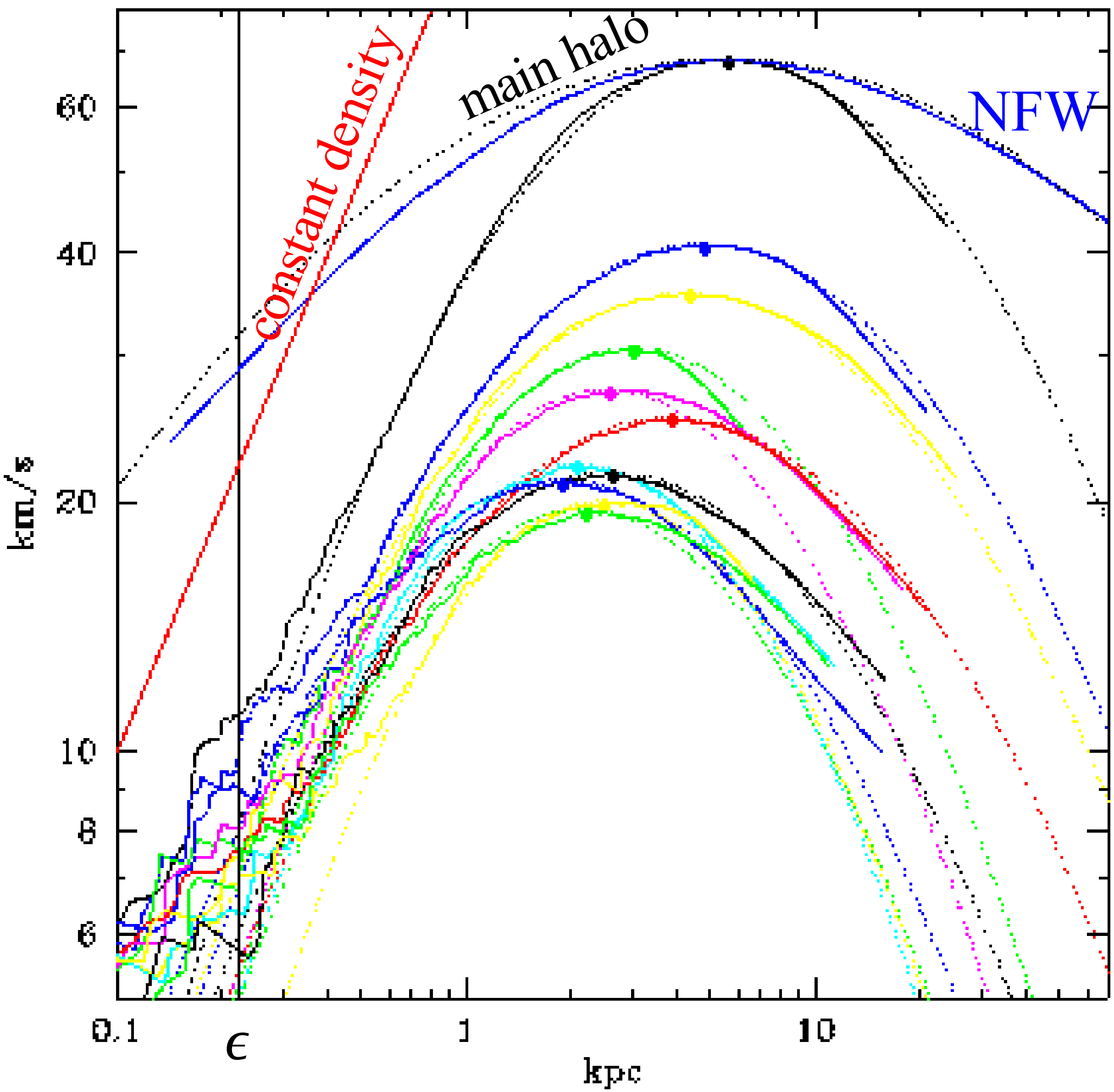
where $\langle....\rangle$ denotes an average over all stars in the dwarf

- For an isotropic velocity dispersion ($\sigma_{\mathrm{r}} = \sigma_{\mathrm{t}}$ at all r)

$$\sigma_{\mathrm{l.o.s.}}^2(r_{\mathrm{p}}) = \int \mathrm{d}\,r\;\rho\,V_c^2\,(r^2 - r_p^2)^{1/2}/r \;\Big/\; \int \mathrm{d}\,r\;\rho\,r/(r^2 - r_p^2)^{1/2}$$

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?

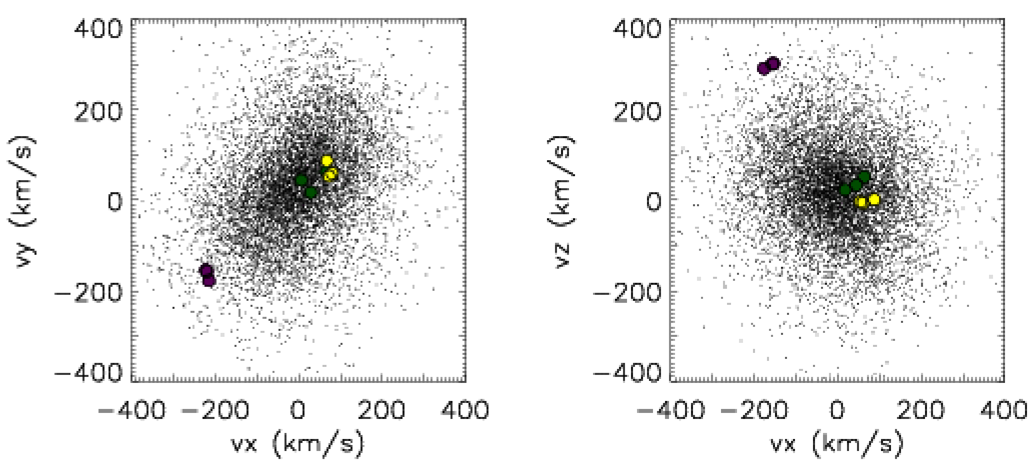
- Visible in annihilation radiation at γ frequencies?

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 ⟶ γ emission

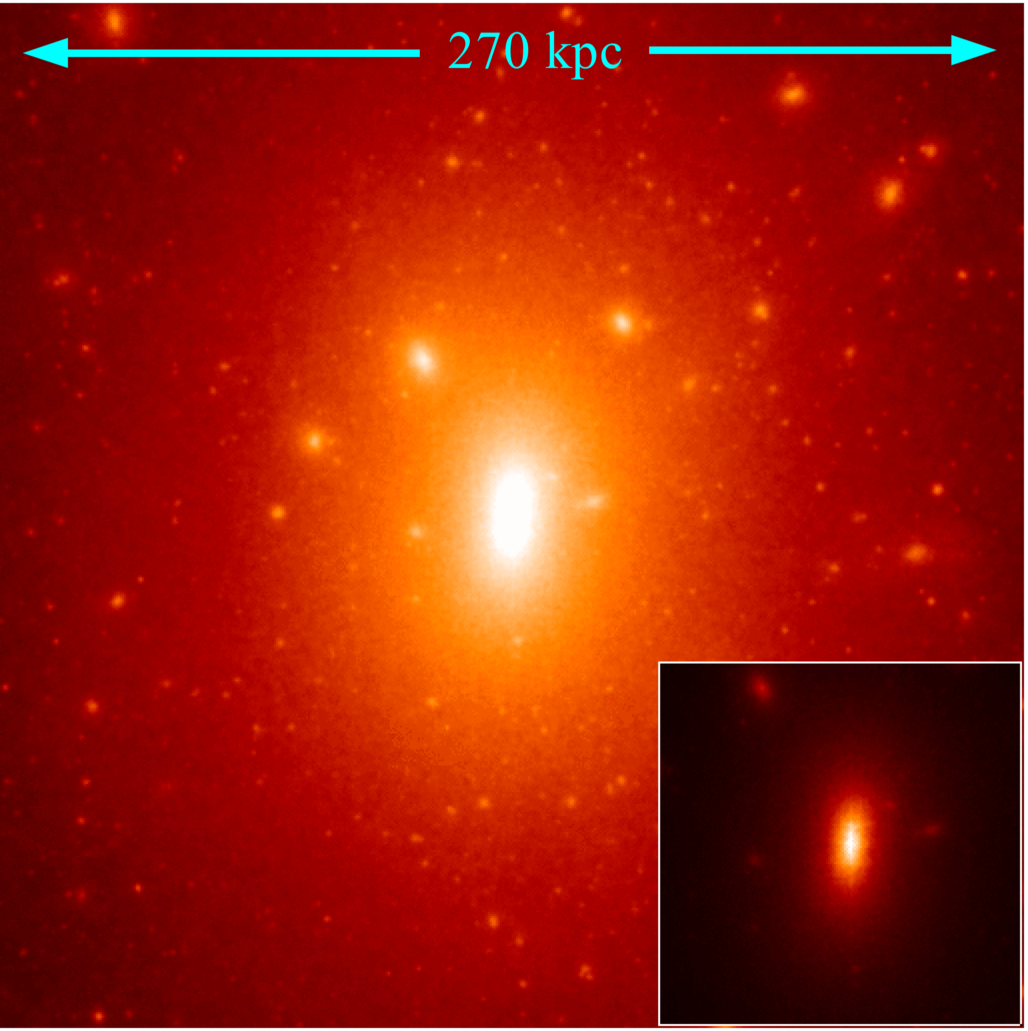
- Most WIMPS have a finite cross-section for elastic collision with baryons ⟶ detection by calorimeters?



Helmi & White 2002

γ-rays from the annihilation of DM particles

Stoehr et al 2003



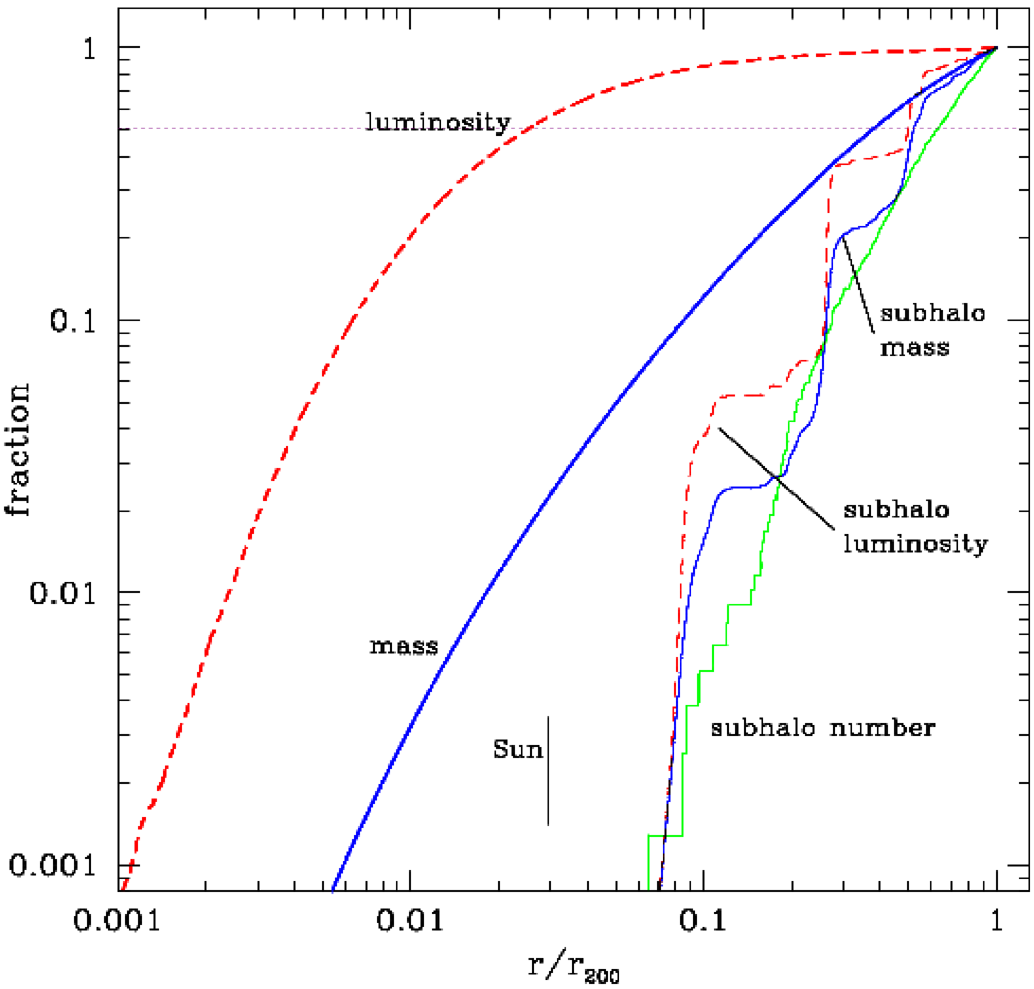


Image of a 'Milky Way' halo in annihilation radiation

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 $\longrightarrow$ 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 $\longrightarrow$ extra luminosity comes from most massive substructures
- The total luminosity exceeds that of a smooth spherical halo with the same $V_{circ}(r)$ by:

  +25% due to substructure
  +15% due to flattening
  + 8% due to unbound substructure

- Annihilation radiation from $R < R_{sun}$ may be detectable with next generation γ-ray telescopes

How was the Milky Way assembled?

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Monolithic collapse of a protogalaxy

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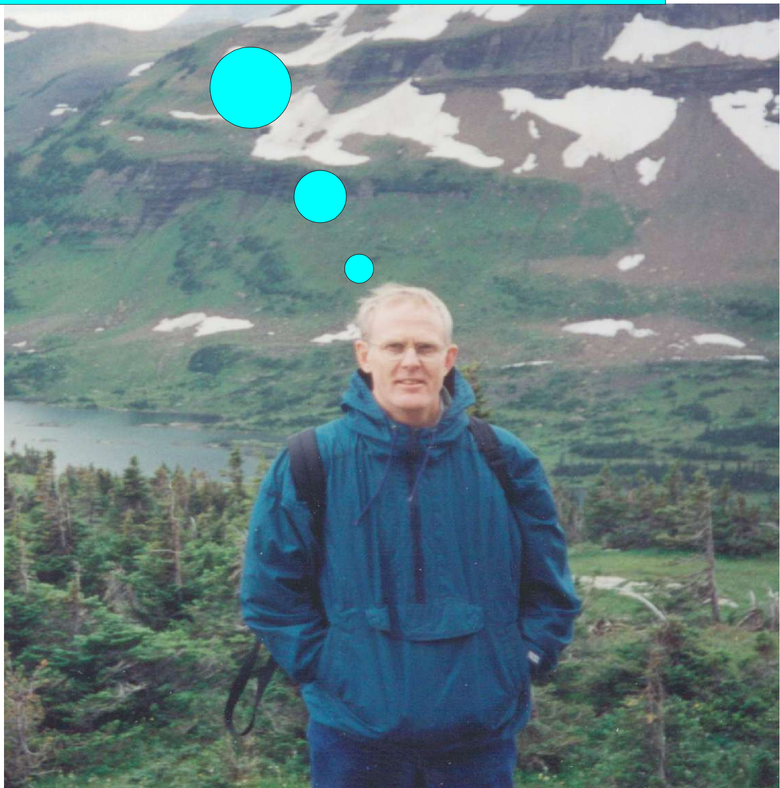
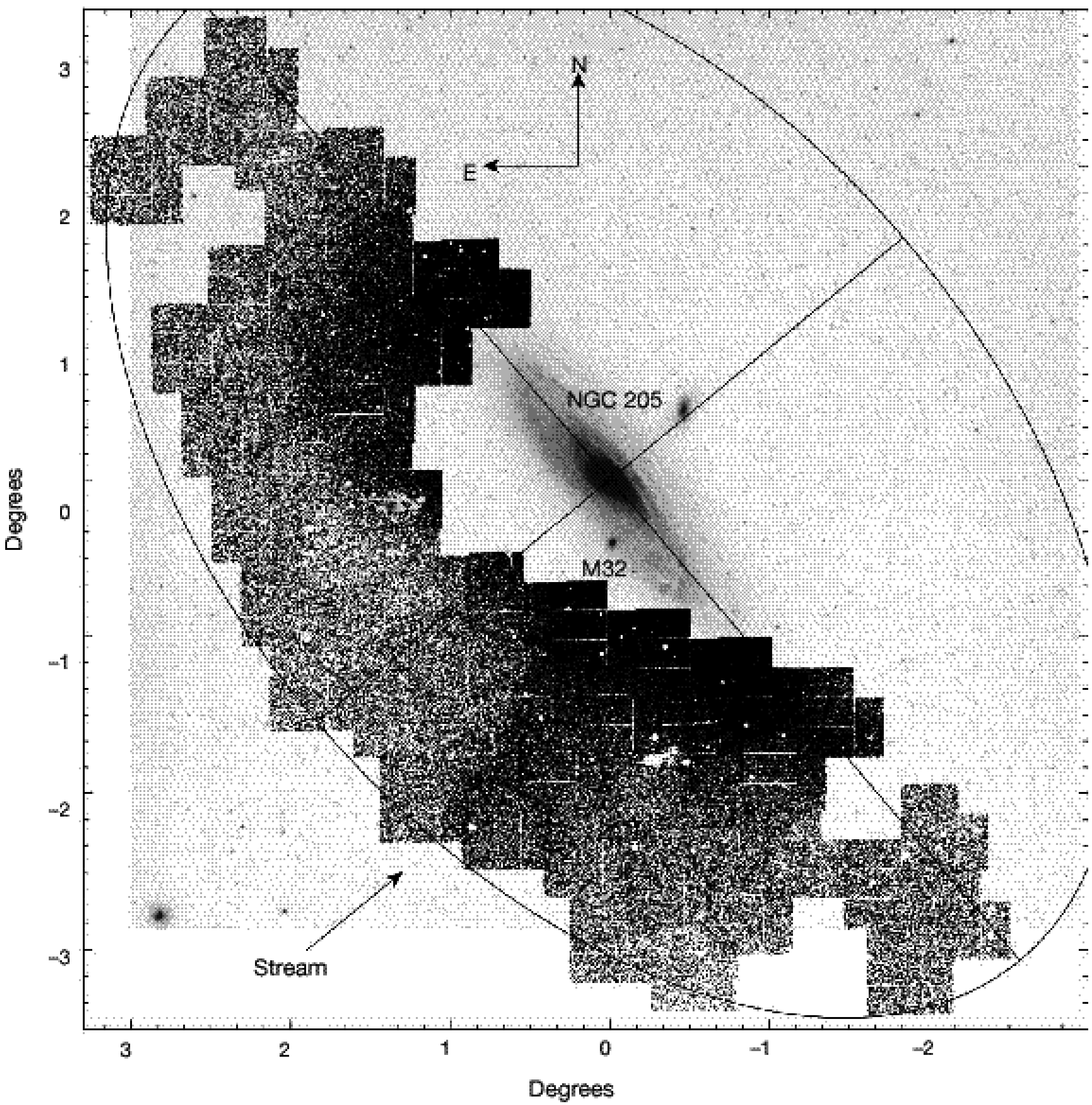
Monolithic collapse of a protogalaxy

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 - σ 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 hydrodyamic 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 *real* meeting

Thank you!