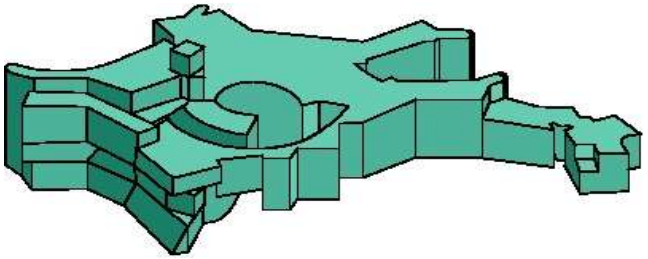


Satellites and Tidal Streams
ING–IAC joint Conference
La Palma, May, 2003

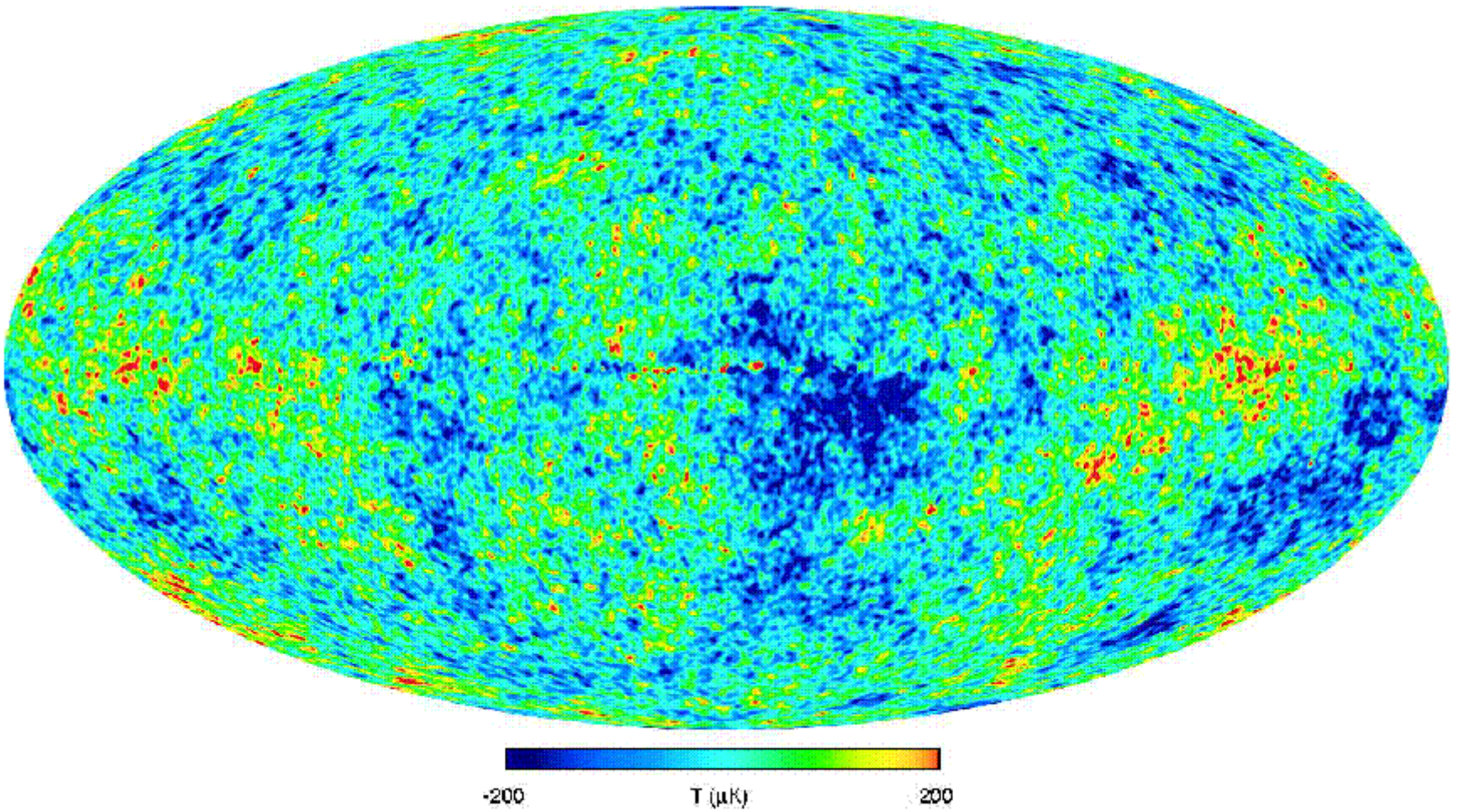
Use and abuse of satellite galaxies

Simon D.M. White
Max Planck Institut für Astrophysik

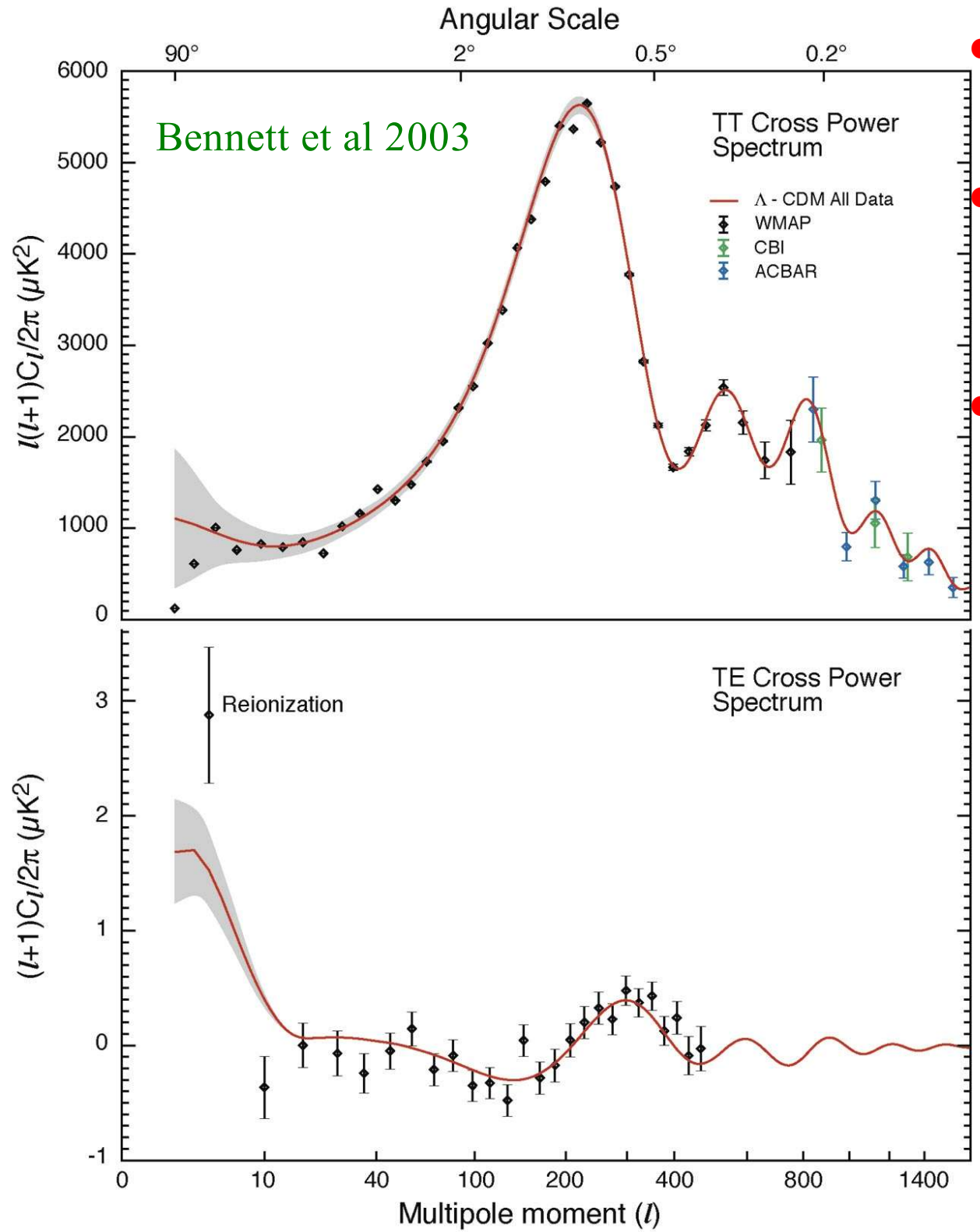
Why study satellites/streams?

- Probes of the nature and distribution of dark matter
- Accessible examples of the lowest mass galaxies
- Fossils of galaxy assembly
- Progenitors of the Milky Way's stellar halo? bulge?
- Laboratories for star formation, feedback and enrichment
- Perturbers/suppliers of the Galactic disk

WMAP Map of the Cosmic Microwave Background

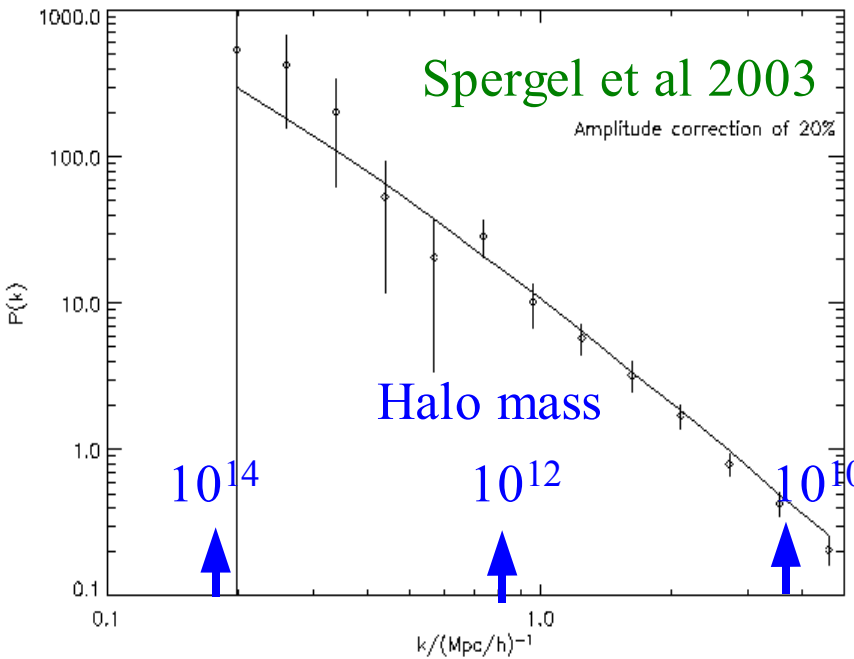


Bennett et al 2003



- $> 10^5$ 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

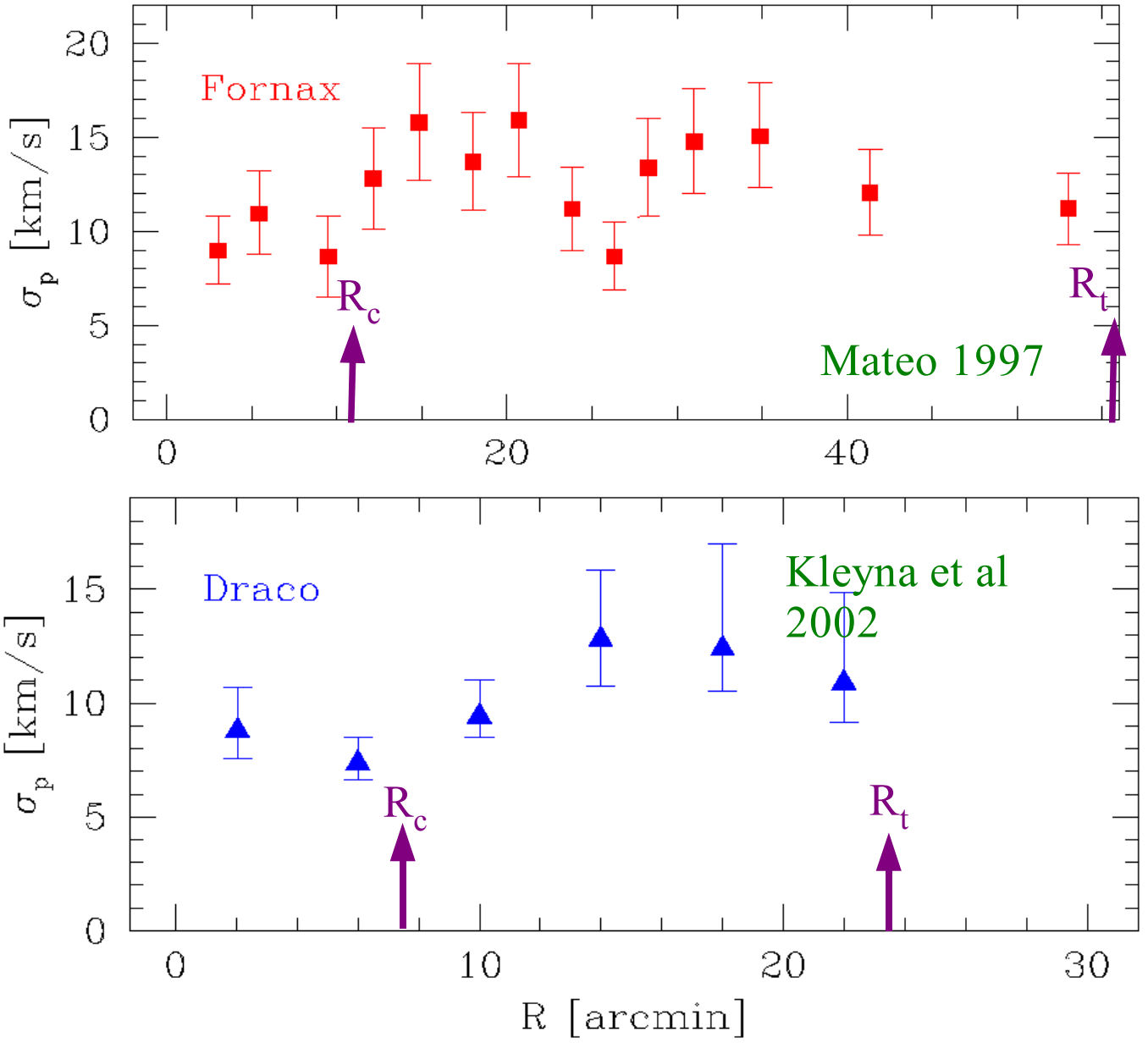
- The massive and extended galaxy halos expected in CDM theories can weighed only by
  - -- gravitational ('galaxy-galaxy') lensing
  - -- static X-ray halos (for massive central ellipticals)
  - -- satellite galaxy dynamics

- Analysis of satellite dynamics is complicated by
  - -- need to stack many 'similar systems' (external galaxies)
  - -- small number of satellites (Milky Way)
  - -- lack of information about orbital eccentricity
  - -- orbital times comparable to the Hubble time

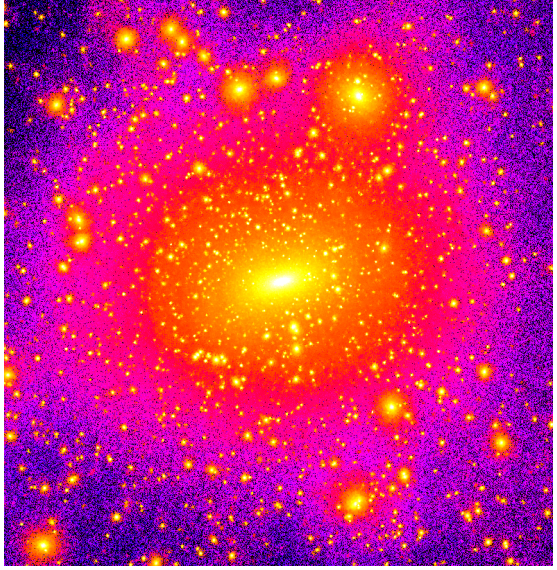
- Data can explore relation of halo mass to galaxy type

Insights into galaxy formation

Dark Matter within Satellites

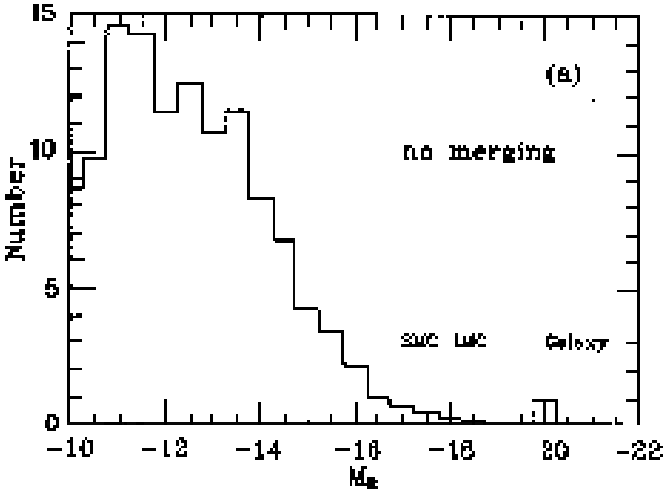


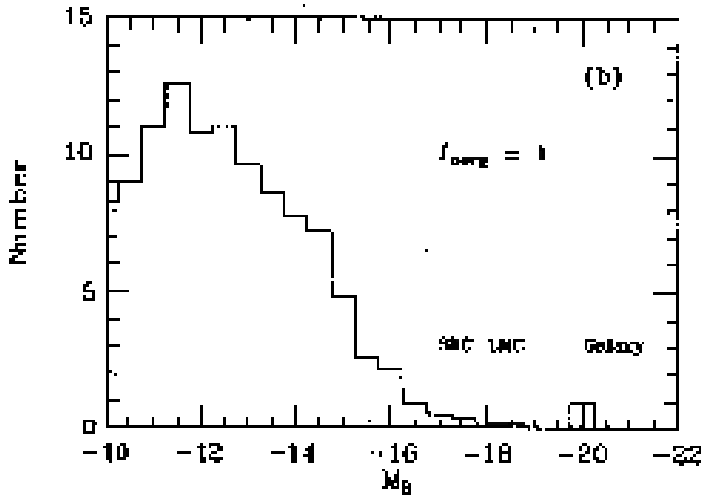
- Flat stellar velocity dispersion out to the tidal radius
  → *rising* V_c curve
- Extended DM halos?
- High DM phase density? ~~*WDM*~~ ?
- $V_{c,max} \gtrsim 25$ km/s ?
- Critical observation: extratidal stars?

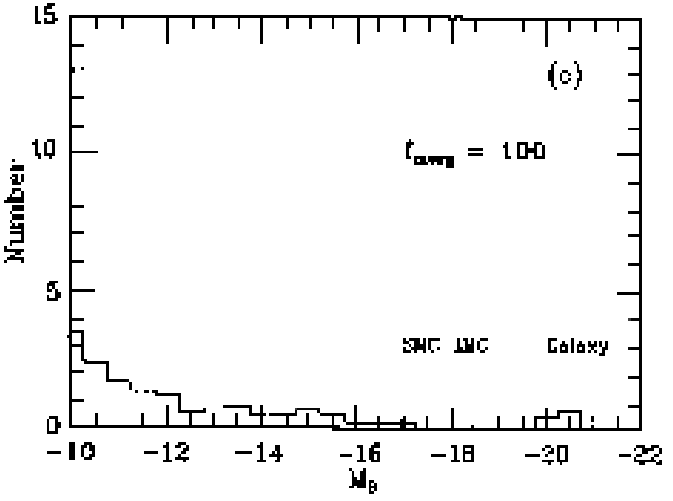


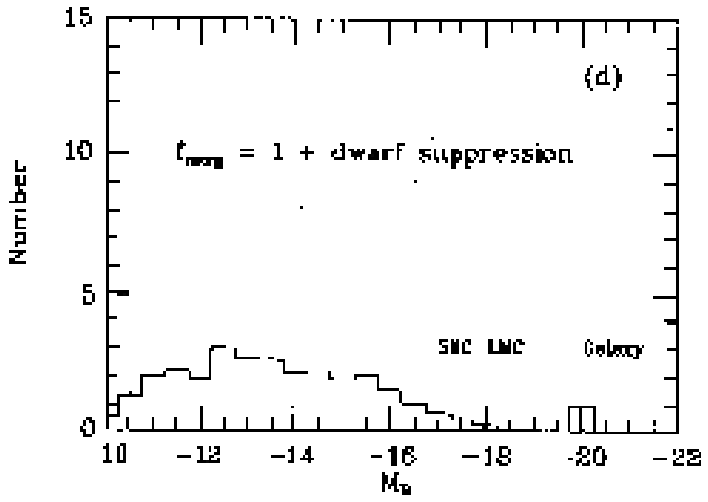
Too many satellites for CDM?

Kauffmann, Guiderdoni, White 1993





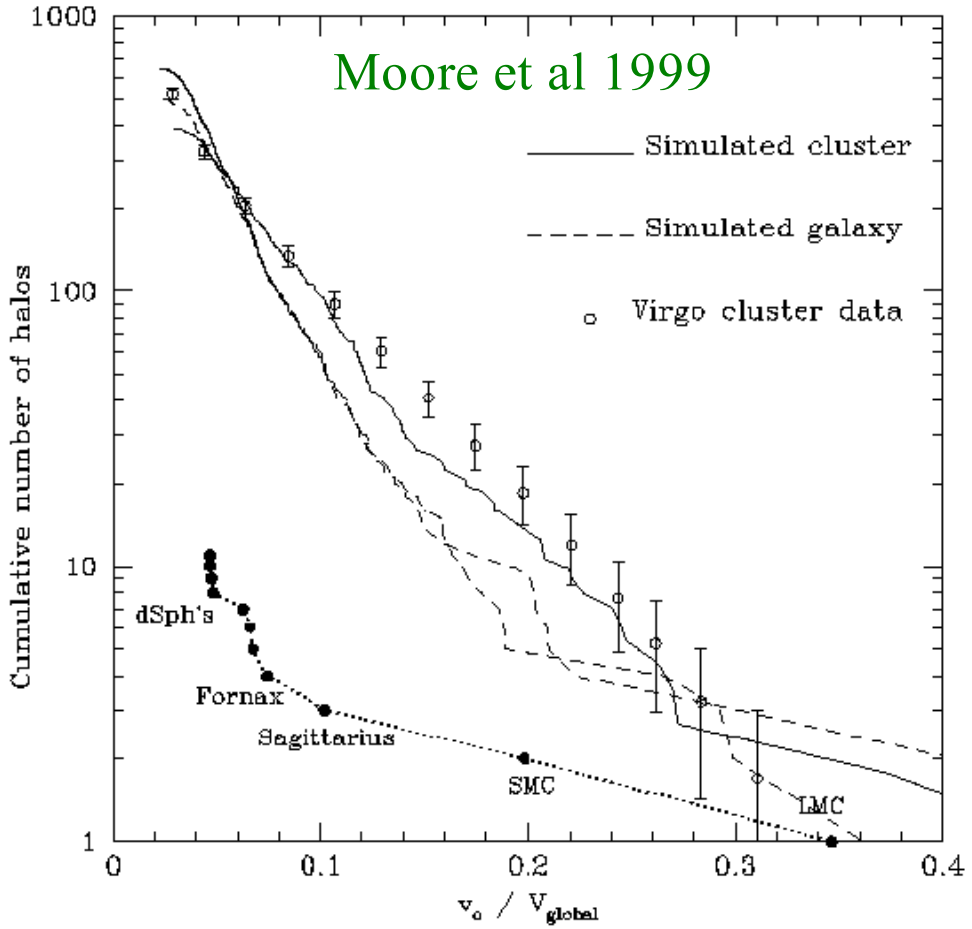


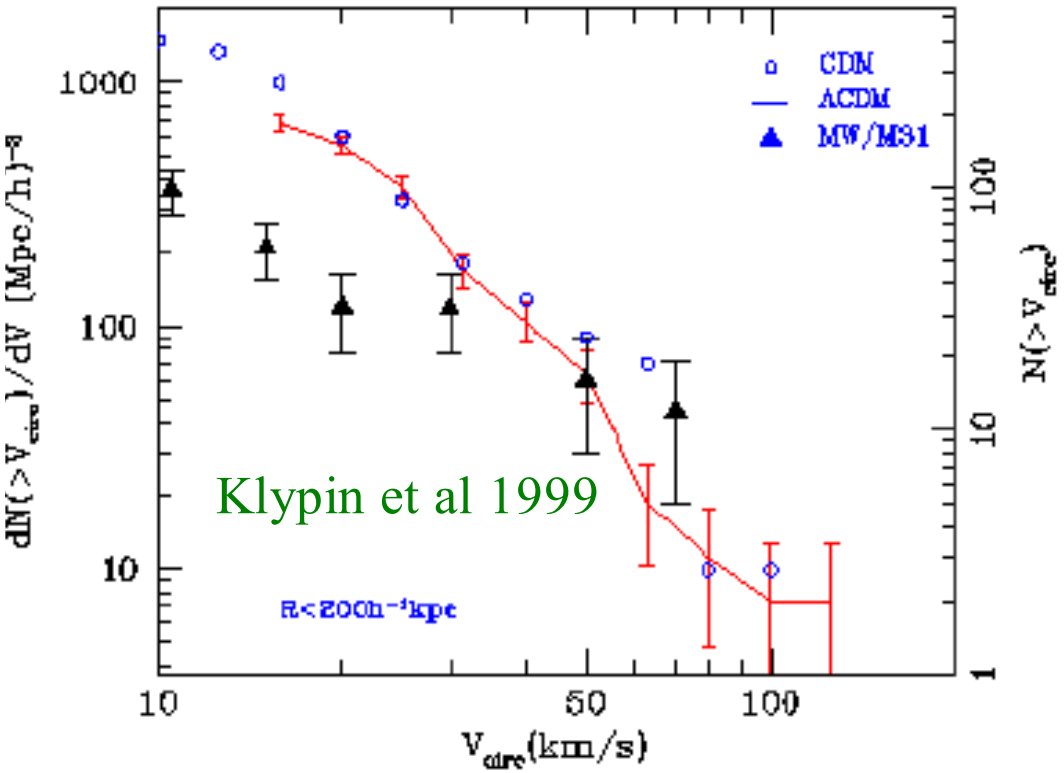


- In hierarchical models like CDM the Milky Way's halo formed out of many smaller halos
- If all progenitors made stars with *reasonable* efficiency too many satellites result
- Star formation must be strongly suppressed in low mass progenitors

Reionisation effects?

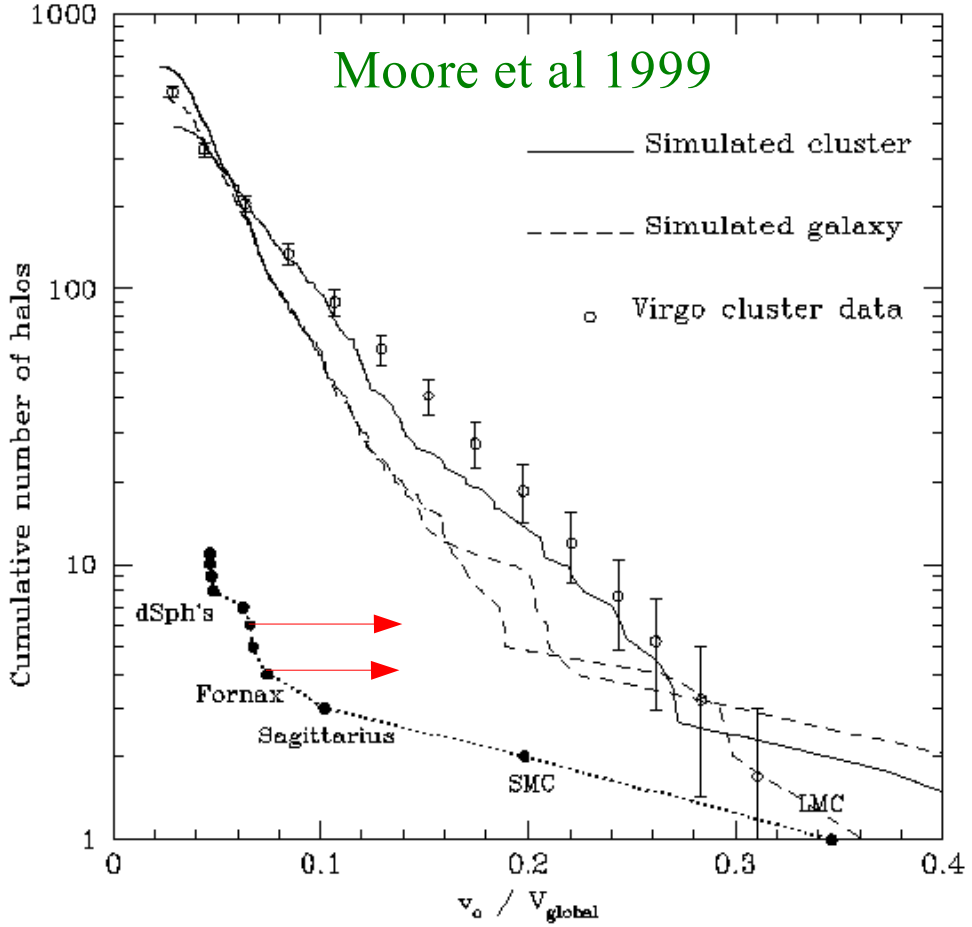
Inconsistency with observed satellite kinematics?

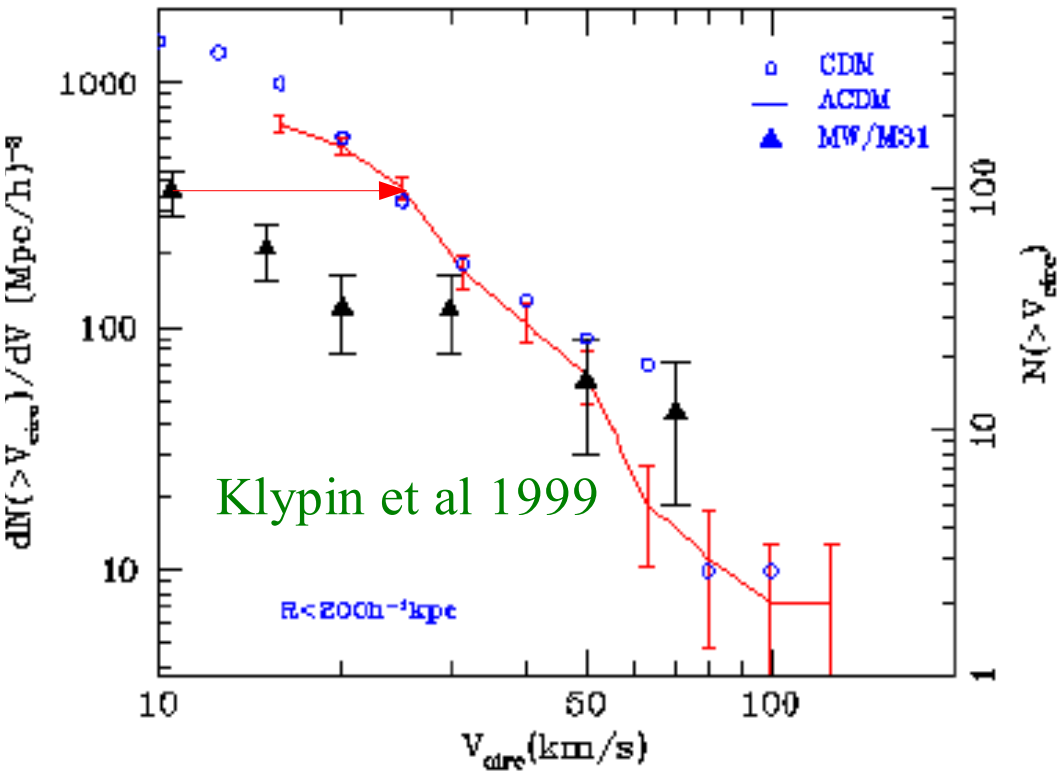




- The number of observed satellites with circular velocity $V = (GM/r)^{1/2}$ (inferred from the *mean* velocity dispersion) exceeding 10 km/s is at least 10 times smaller than the number expected in a ΛCDM halo

Inconsistency with observed satellite kinematics?





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

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?

The lowest mass galaxies

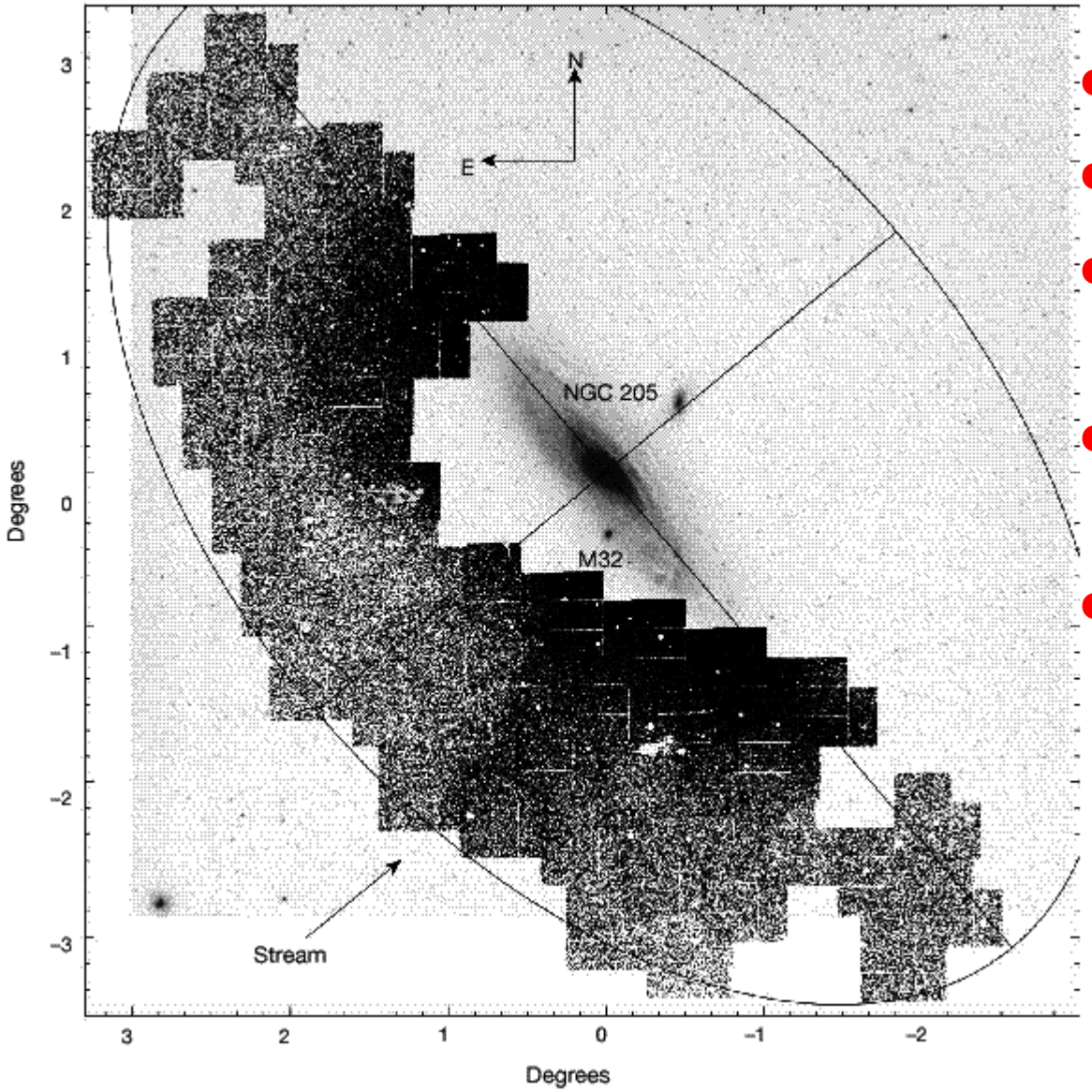
- What limits star formation?
  - -- breakdown of L - σ relation (cf Draco, Fornax)
  - -- star formation in widely separated bursts
  - -- reionization effects?
  - -- galactic wind effects?

- What is the relation of DwSph to DwIrr?

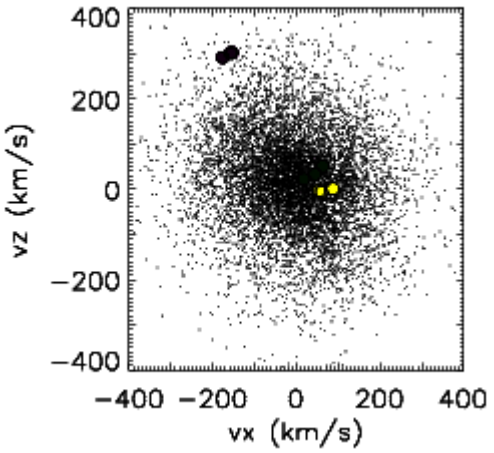
- What is the role of tidal limitation?
  - -- do satellites differ from the field? from cluster dwarfs?

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?



Helmi & White 2002

Uses of streams

- To measure the *shape* of the Galactic halo
- To detect the effects of substructure
- To characterise the accretion history of the Milky Way
- To characterise element abundances in early dwarfs

Star formation issues and satellites

- What initiates star formation bursts?
  - -- 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

Satellites and 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 some satellites stripped out of disks? tidal dwarfs?