Halo Properties of Isolated Galaxies

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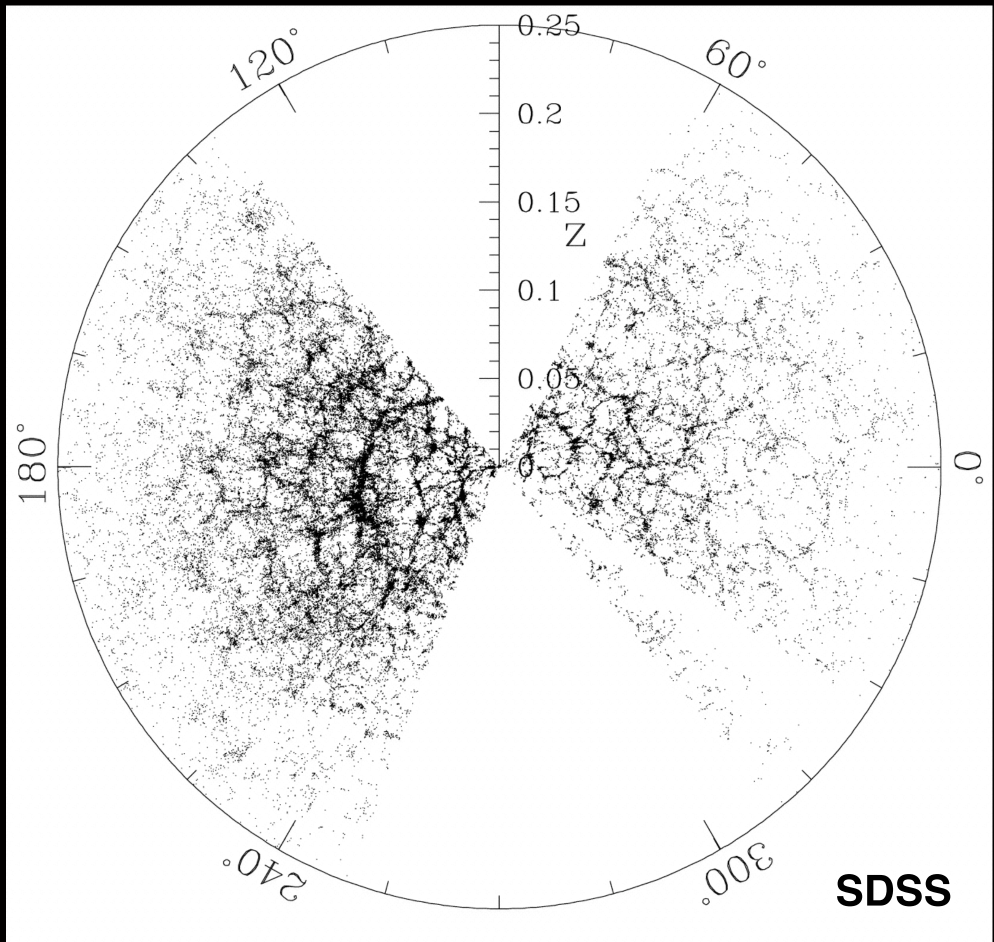
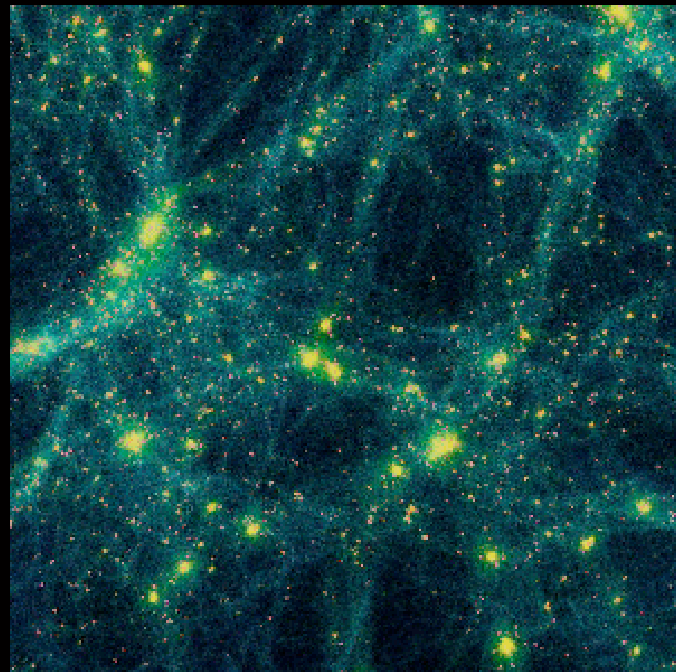
Berkeley, November 10th, 2006

Galaxies - DM halos connection

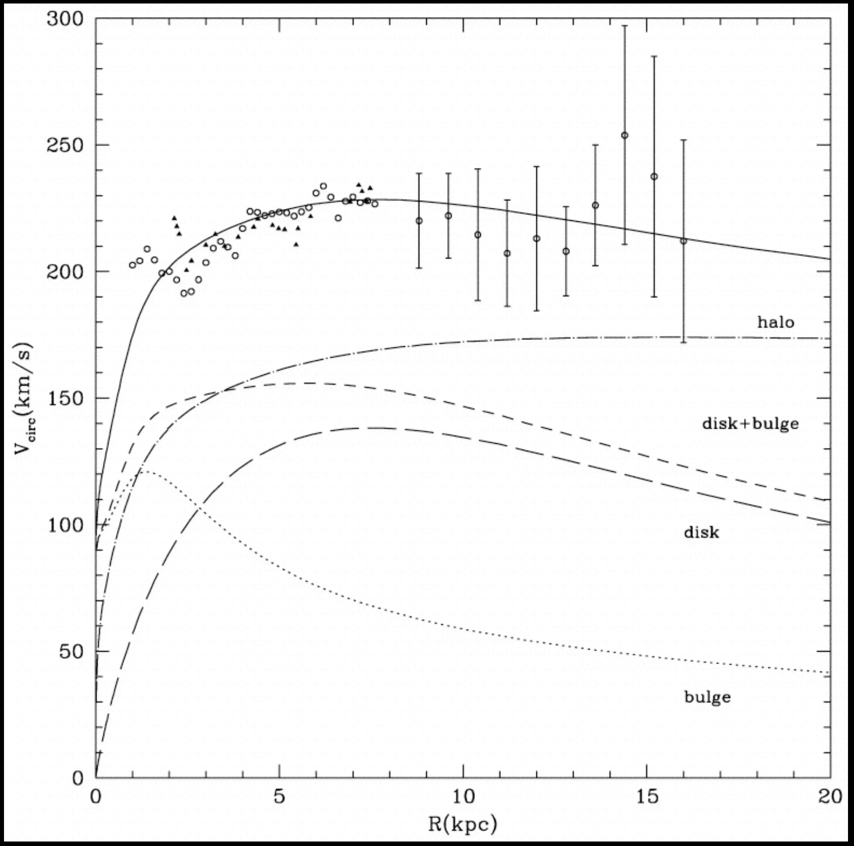


Credits: B. Allgood



The mass distribution of galaxies at large distances (>100 kpc) can be only determined by

- galaxy-galaxy weak lensing
- Satellite dynamics



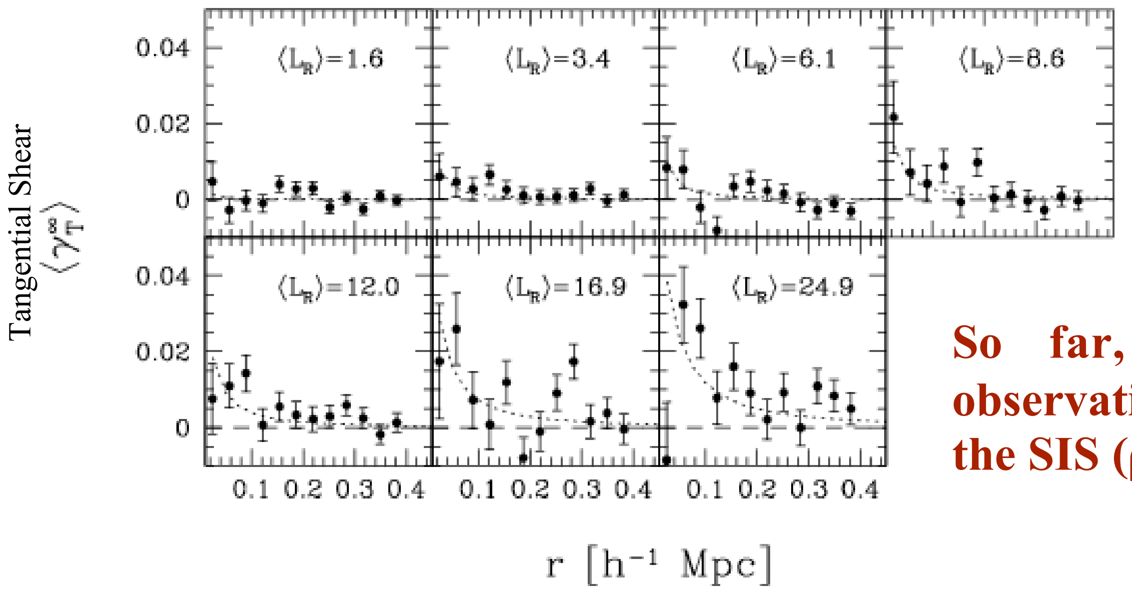
Luminous tracers are needed to probe dark matter halos at large distances

Properties of DM halos from g-g weak lensing

- **Recent developments in weak gravitational lensing have made possible to probe the ensemble mass distribution around galaxies out to large projected distances:**

  - Pioneering efforts by Tayson et al. 84, Brainerd et al. 96
  - Advantage of large surveys: Fischer et al. 00, Smith et al. 01, McKay et al. 01, Guzik & Seljak 02, Hoekstra et al. 04, Sheldon et al. 04, Kleinheinrich et al. 04, Hoekstra et al. 05, Mandelbaum et al. 06)

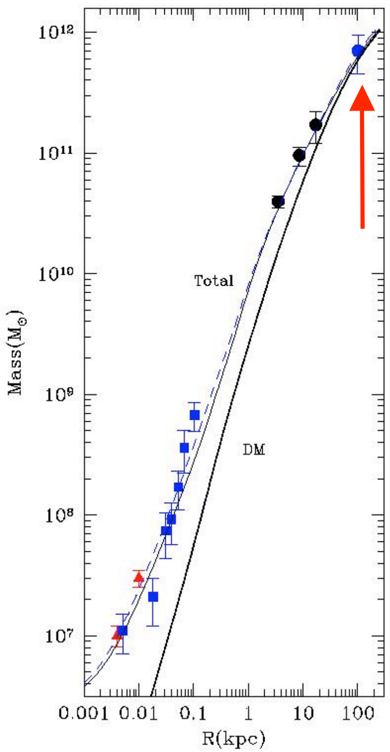
- **Weak lensing signal measurements for isolated galaxies (to minimize the effect of neighbouring bright galaxies, and the contribution of group/cluster halos)**



Hoekstra et al. 05

So far, current g-g weak lensing observations cannot distinguish between the SIS ($\rho \propto r^{-2}$) or LCDM halo model

Motion of satellites as a simple way to probe the connection between galaxies and matter



Klypin et al. 2002

- **The mass of the halo of the Milky Way and Andromeda:**

  - MW (e.g. Zaritsky et al 89, Kochanek 96, Fich & Tremaine 91, Wilkinson & Evans 99, Klypin et al. 02, Battaglia et al. 05)

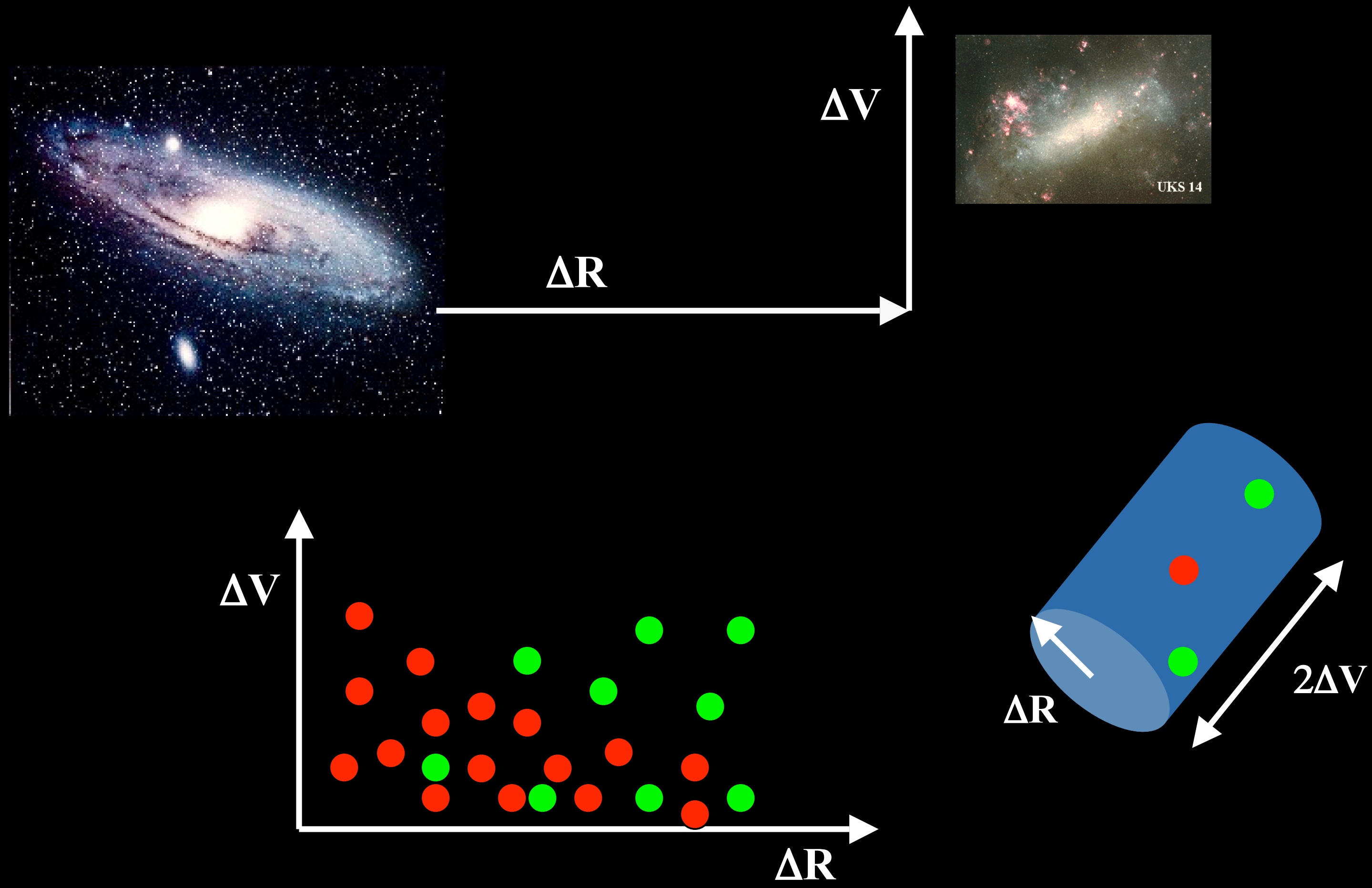
  - M31 (e.g. Evans et al. 00, Klypin et al. 02, Widrow et al. 2003)

- **Ensamble of satellites around external galaxies as dark matter probes:**

  - Pioneering efforts by Erikson et al. 87, Zaritsky et al. 93, Zaritsky & White 94, Zaritsky et al. 97

  - **SDSS, 2dFGRS, DEEP2:** McKay et al. 02, Prada et al. 03, van den Bosch 04, Brainerd 04, Conroy et al. 05

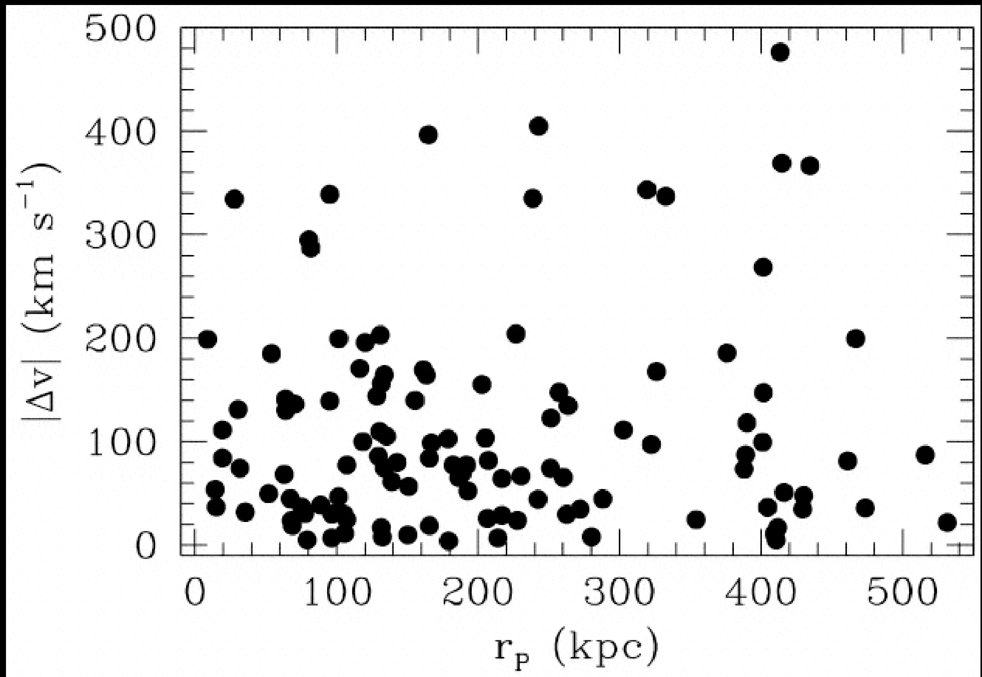
Satellites of external galaxies



Important issues => projection effects (i.e. **Interlopers**)

Extended massive DM halos around spiral galaxies

115 satellites around 69 hosts



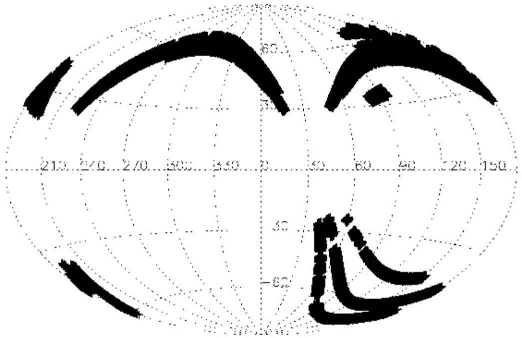
1. Strong indications of dark matter at 200-400 kpc. Their limited statistics did not allow to put accurate constrains on velocity dispersion decline or density profile

2. No correlation between the velocity dispersion of satellites with the host luminosity.

Zaritsky et al. 1993,1997
Zaritsky & White 1994

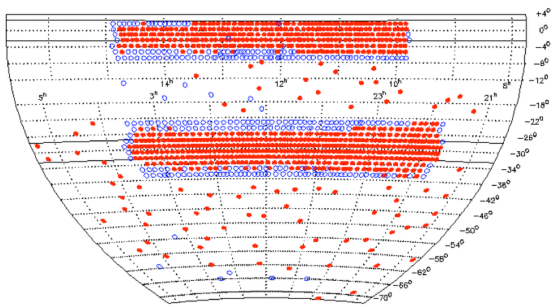
Current observational results

- **McKay et al. 2003, Prada et al. 2003**



2,500 sq. Degrees (DR2)
spectroscopy (< 20km/s)
250,000 galaxies
1,000-2,000 satellites

- **van den Bosch et al. 2004, Brainerd 2004**



2,500 sq. Degrees
spectroscopy (< 120km/s)
221,000 galaxies

Primaries:
(M_B< -19)

$\Delta m = 2$ mag
$\Delta R = 500\ h^{-1}$ kpc
$\Delta V = 1000$ km s^{-1}

Satellites:

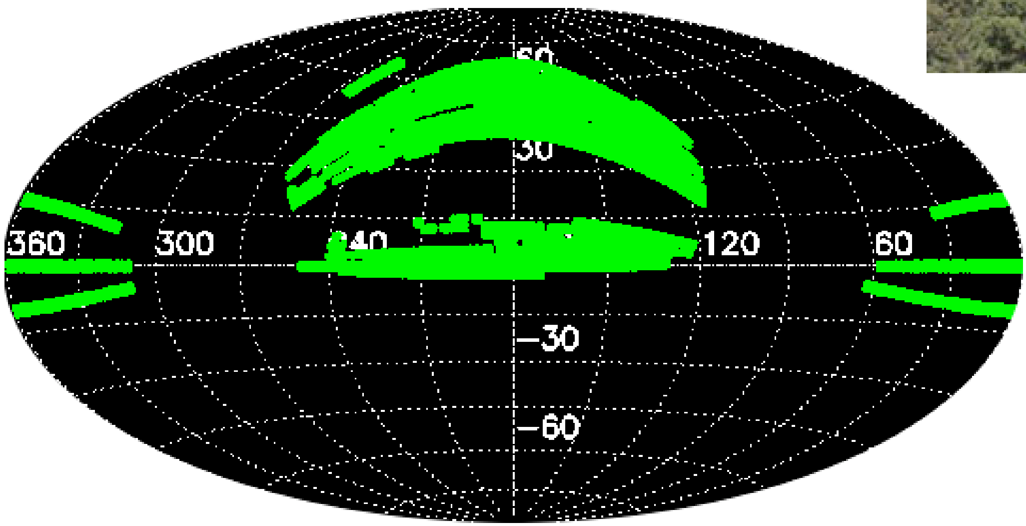
$\Delta m > 2$ mag
$\Delta R < 350\ h^{-1}$ kpc
$\Delta V < 500$ km s^{-1}

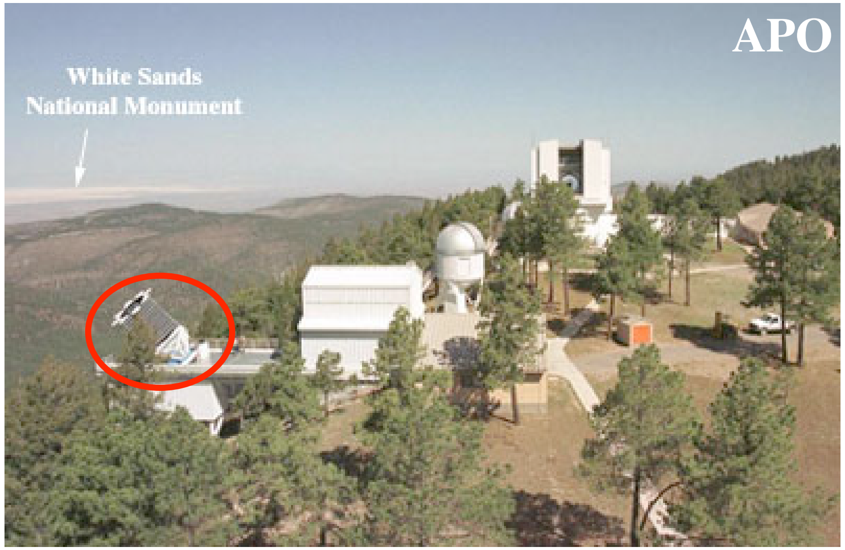
Satellite dynamics: observations and methodology

- SDSS Data Release 4

  (e.g. Abazajian et al. 2004)

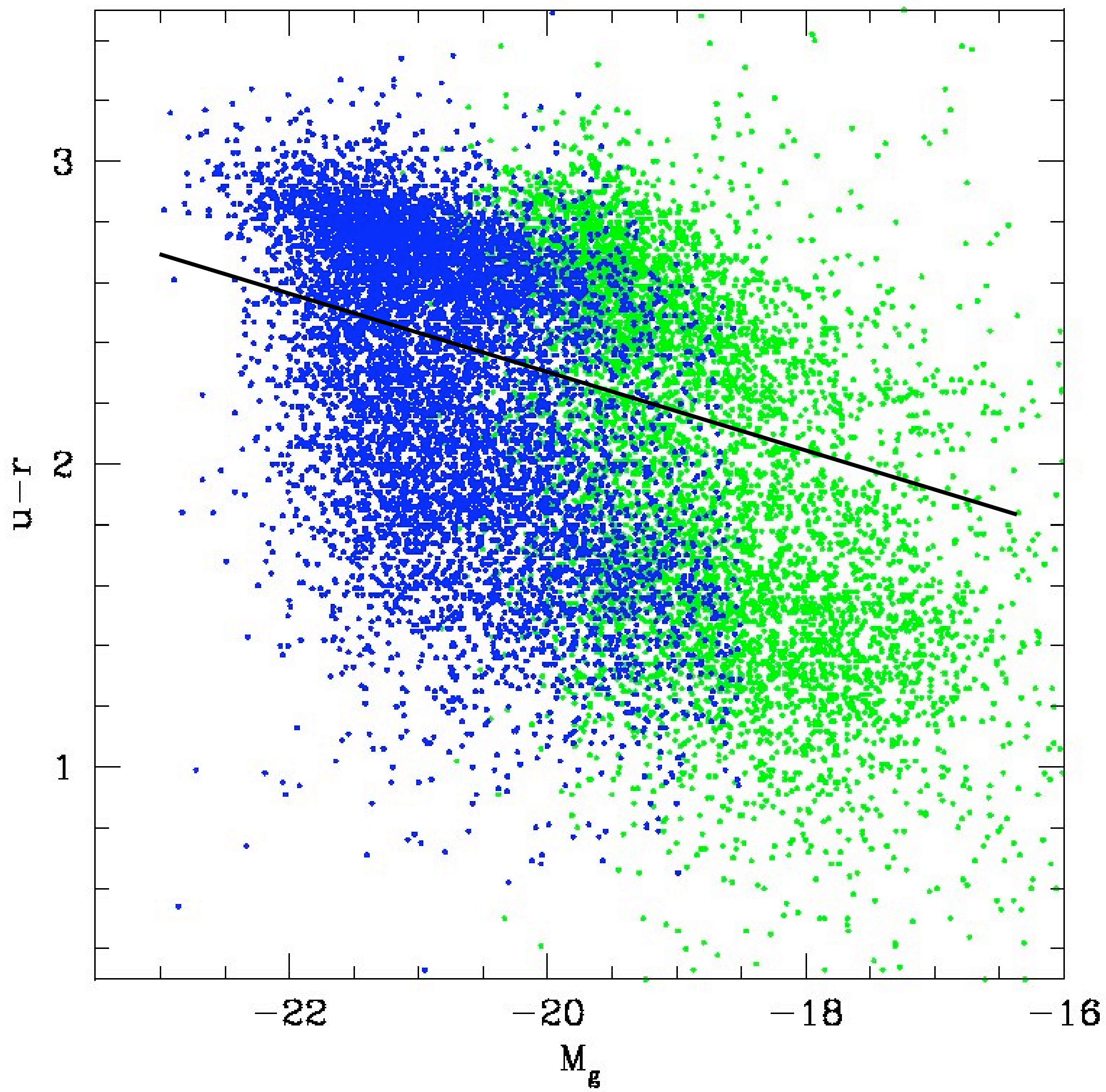
4,780 deg^2
450,000 redshifts (< 20 km/s rms)
R=17.77 limiting magnitude
90% overall completeness





NEW RESULTS

Color-magnitude diagram for host galaxies and satellites



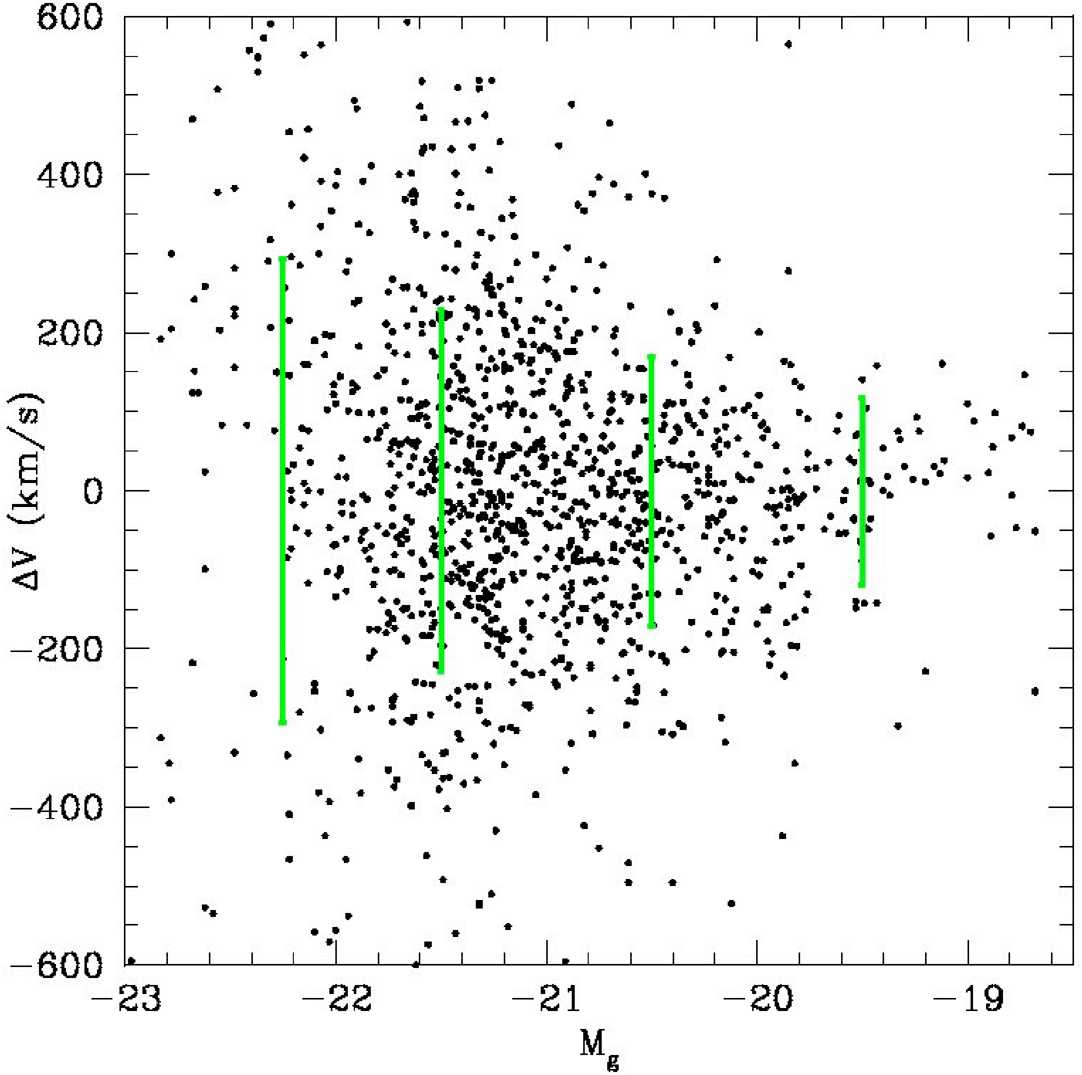
• host

• satellite

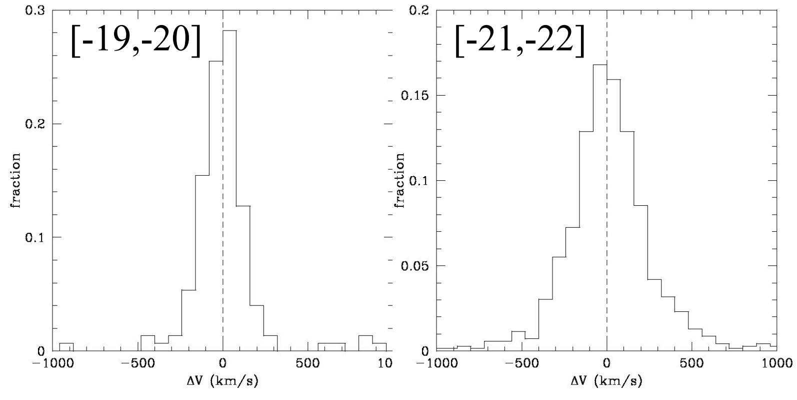
SDSS DR4:

3930 isolated hosts
6472 satellites

The relative l.o.s. satellite velocity within 100 kpc as a function of host luminosity

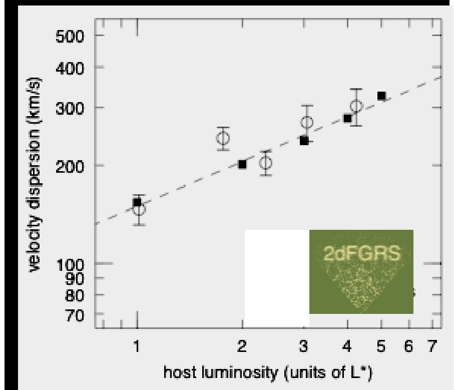


M_g bin	fwhm (km/s)	σ (km/s)
[-19,-20]	235	100
[-20,-21]	340	145
[-21,-22]	460	195
[-22,-23]	590	250

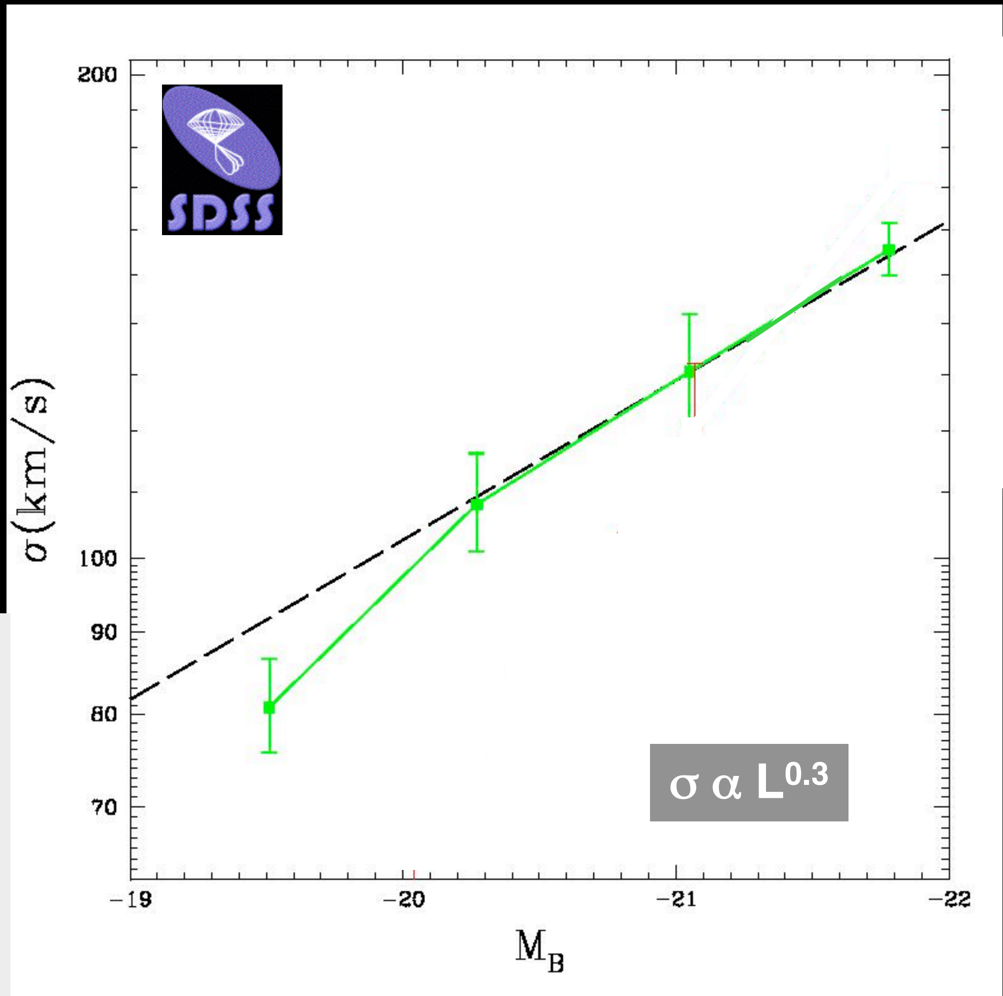


I. Dependence of the satellite velocity dispersion on the host luminosity

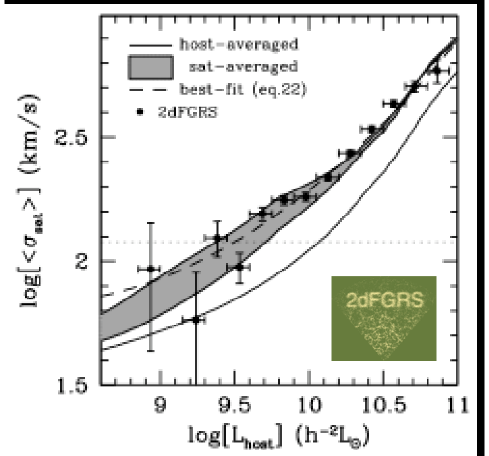
"Tully-Ficher on 100 kpc"



Brainerd 2004

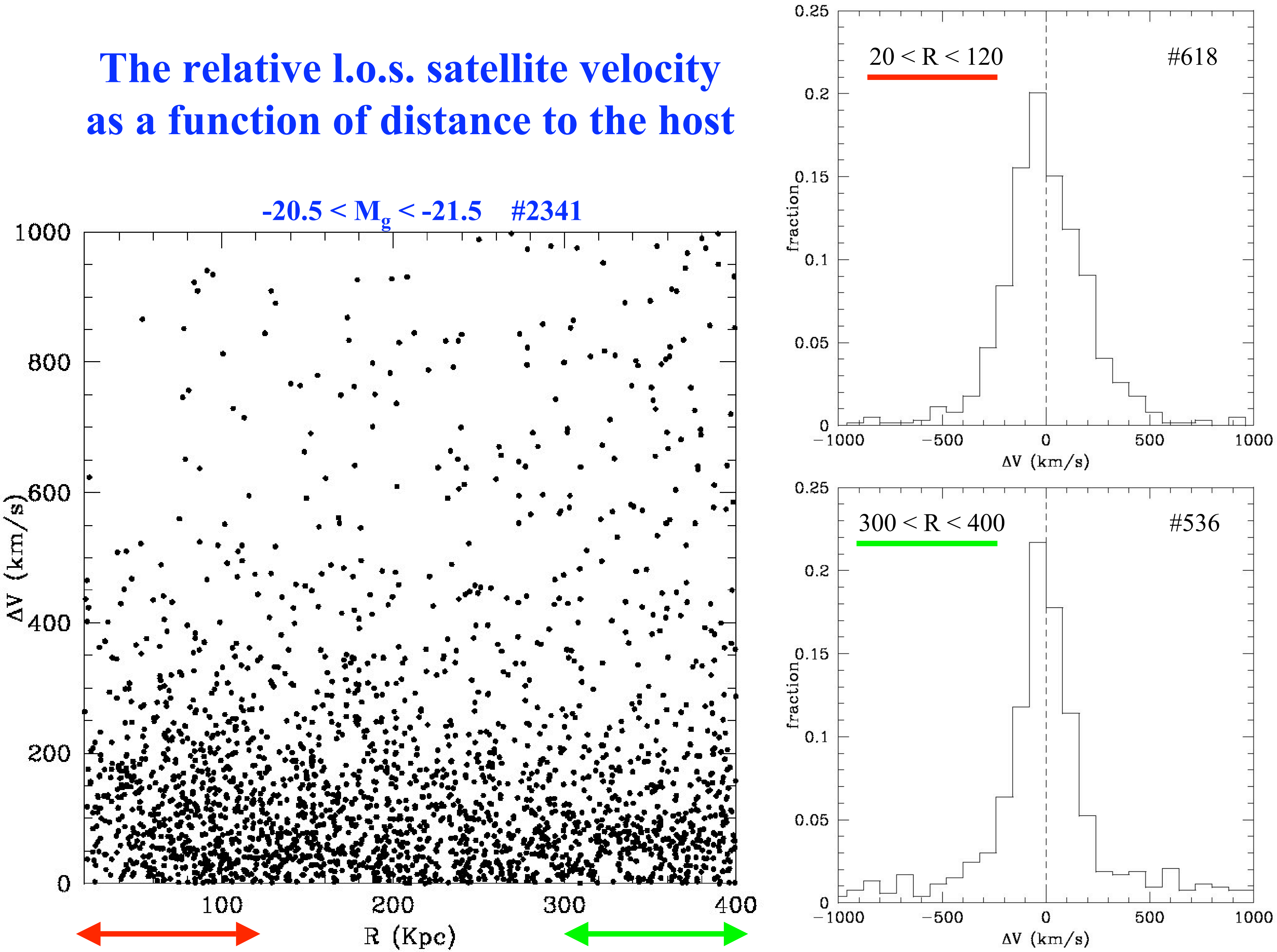


Prada et al. 2003

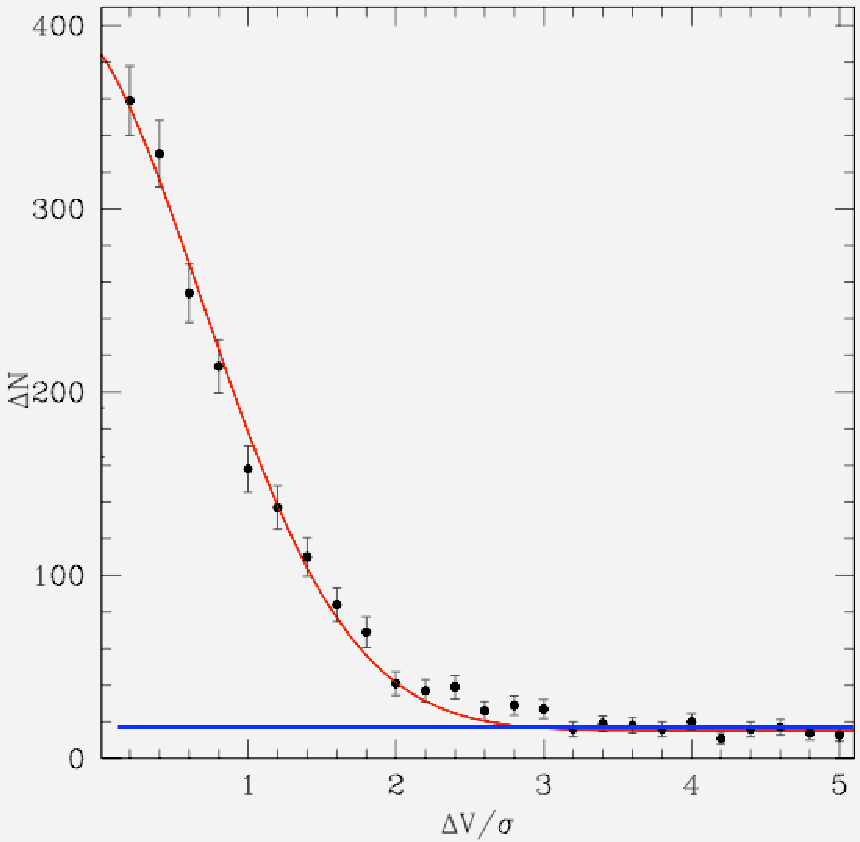


van den Bosch et al. 2004

The relative l.o.s. satellite velocity as a function of distance to the host



Observed distribution of relative velocities of satellites around isolated hosts with $< M_g > = -21$

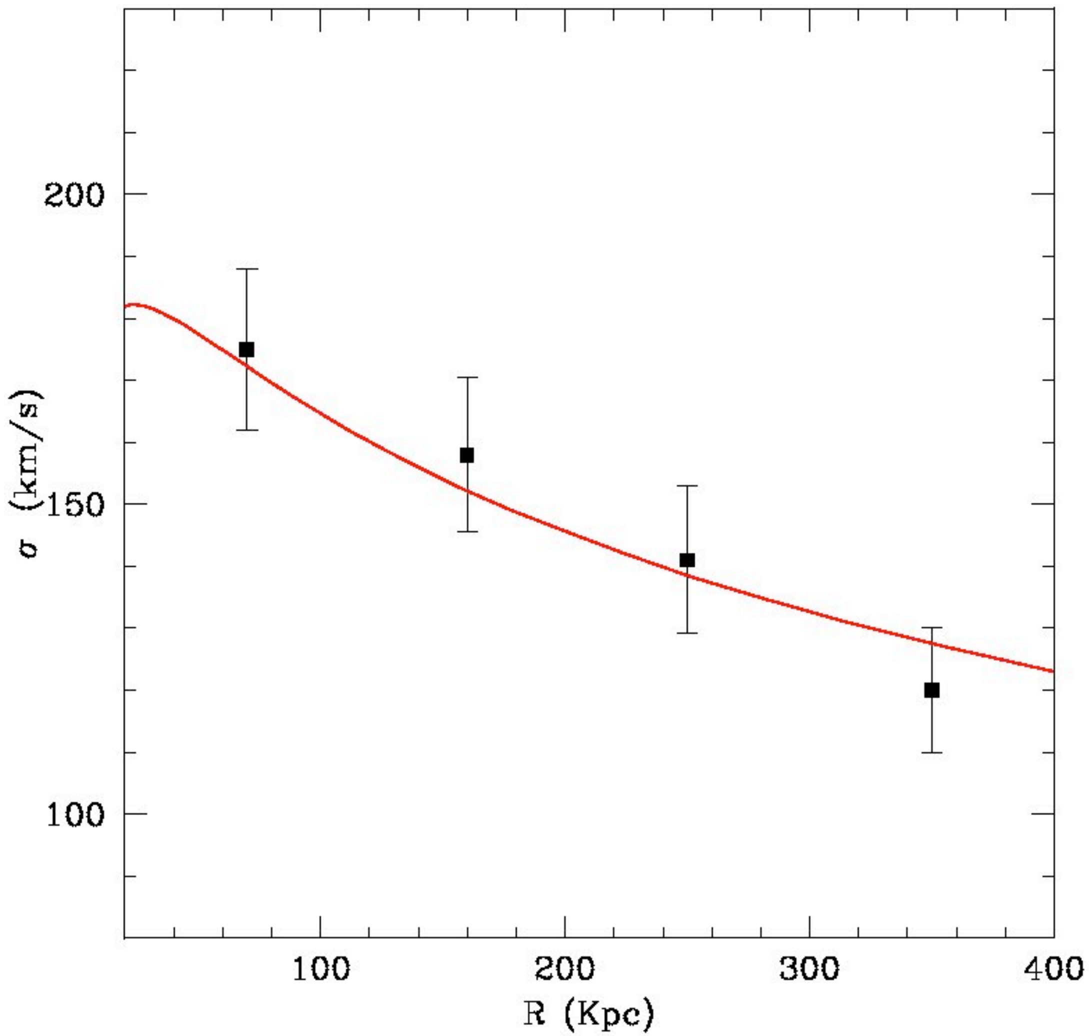


$$D(V) = \eta_{\text{int}} + N_{sat}\frac{2}{\sigma\sqrt{2\pi}}\exp(-\Delta V^2/2\sigma^2)$$

interlopers

satellites

The velocity dispersion profile of satellites around isolated hosts with < M_g> = -21



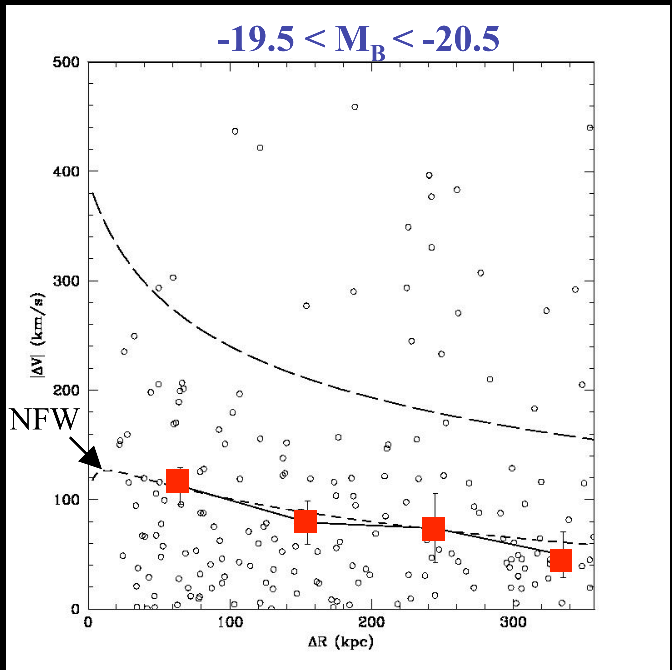
$$L_g = 2.9 \cdot 10^{10} L_\oplus$$

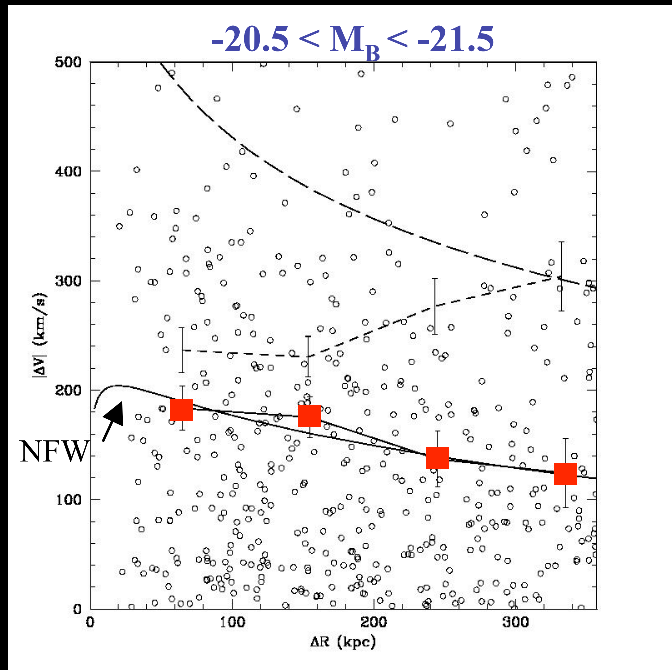
NFW density profile

$$M_{vir} = 5.3 \cdot 10^{12} M_\oplus$$

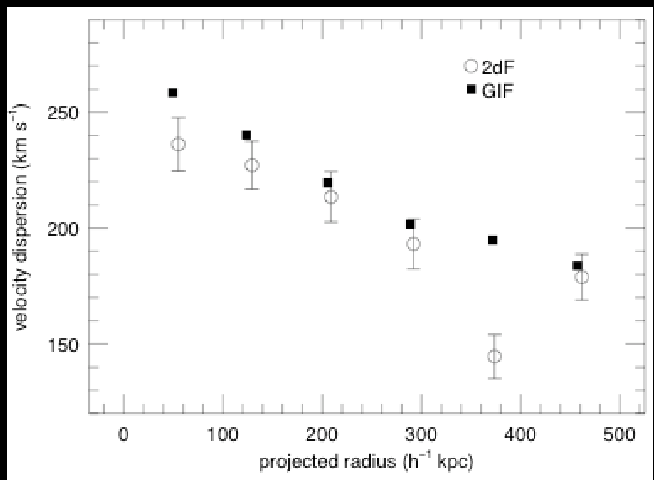
$$\frac{M_{vir}}{L_g} = 180$$

II. The line-of-sight velocity dispersion of satellites declines with distance to the host galaxy





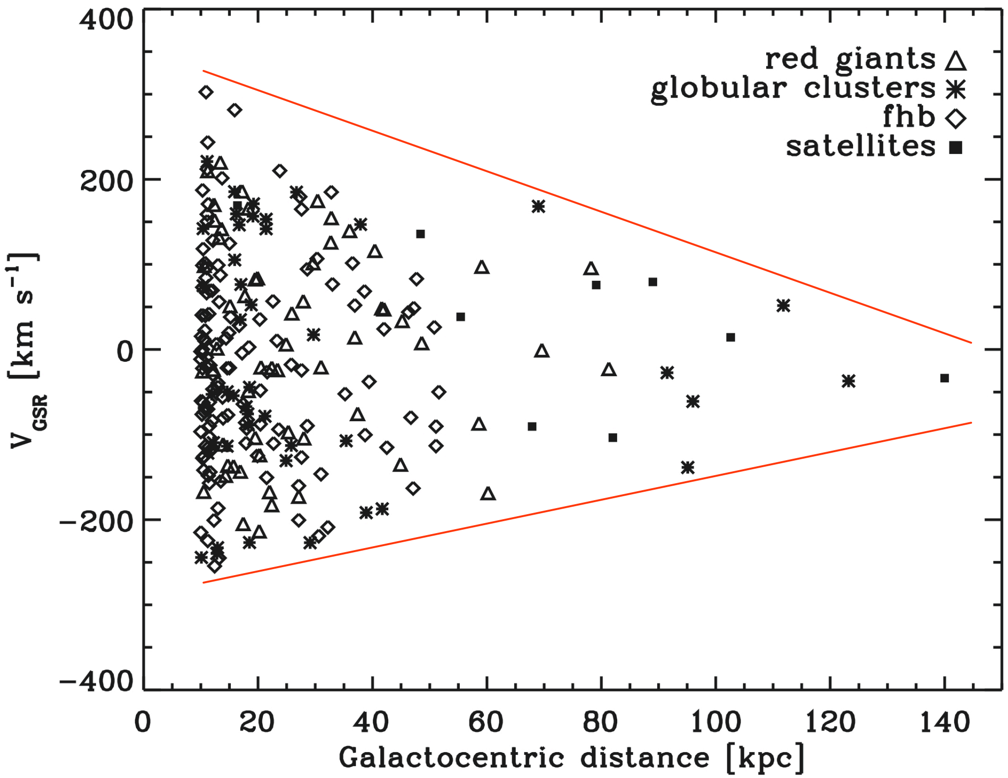
Prada et al. 2003

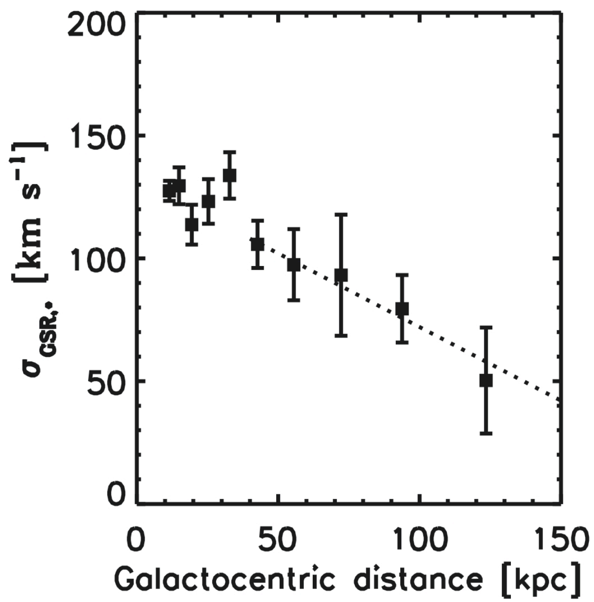


Brainerd 2004

This decline agrees remarkably well with LCDM predictions, $\rho_{cdm} \propto r^{-3}$

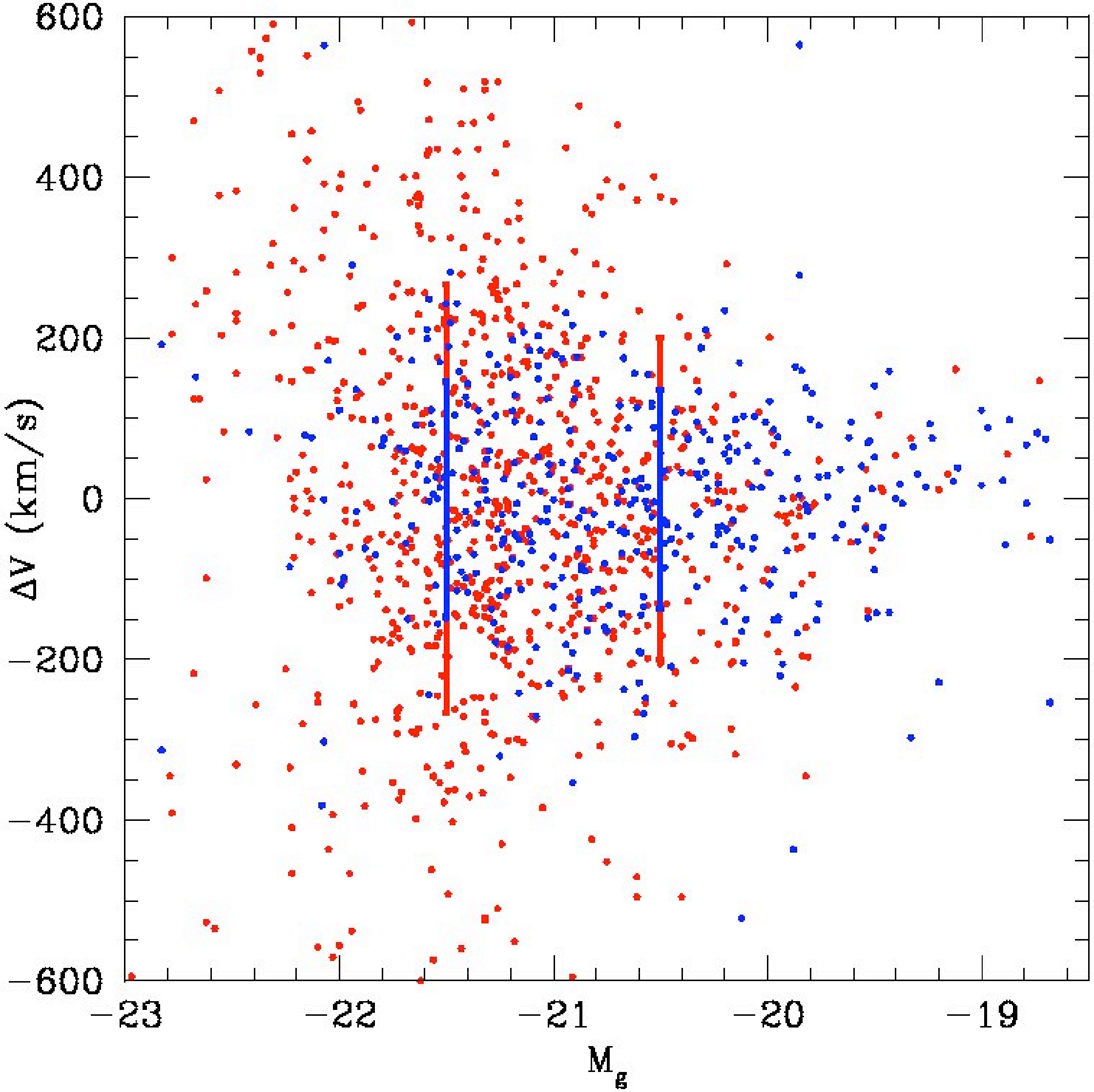
The radial velocity dispersion profile of the Milky Way Halo





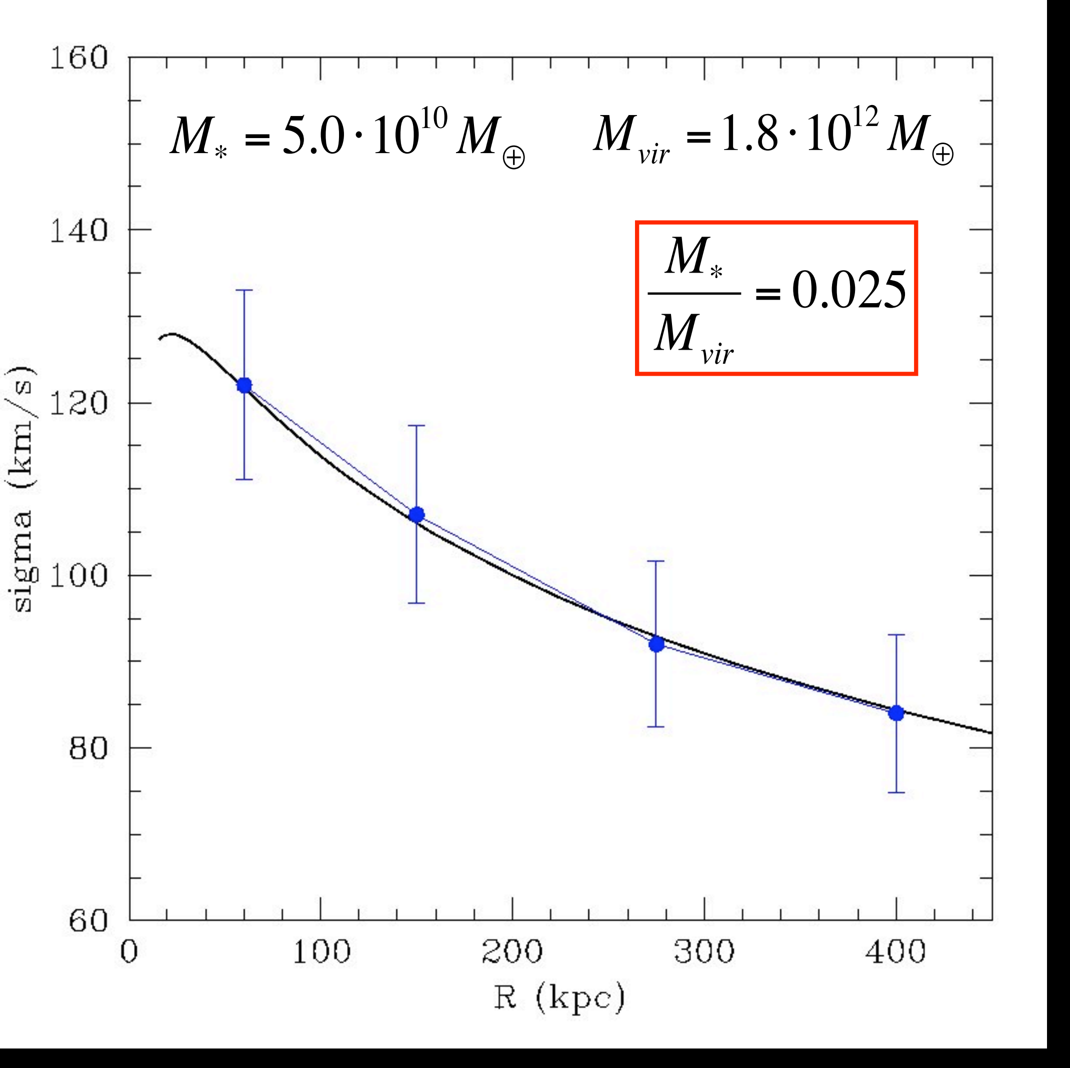
Battaglia et al. 2005

Dependence of the satellite velocity dispersion with the host galaxy color



M_g bin	σ	σ (km/s)	σ
[-20,-21]	145	115	170
[-21,-22]	195	130	230

The stellar content of isolated galaxies



4,500 sq. degrees

SDSS

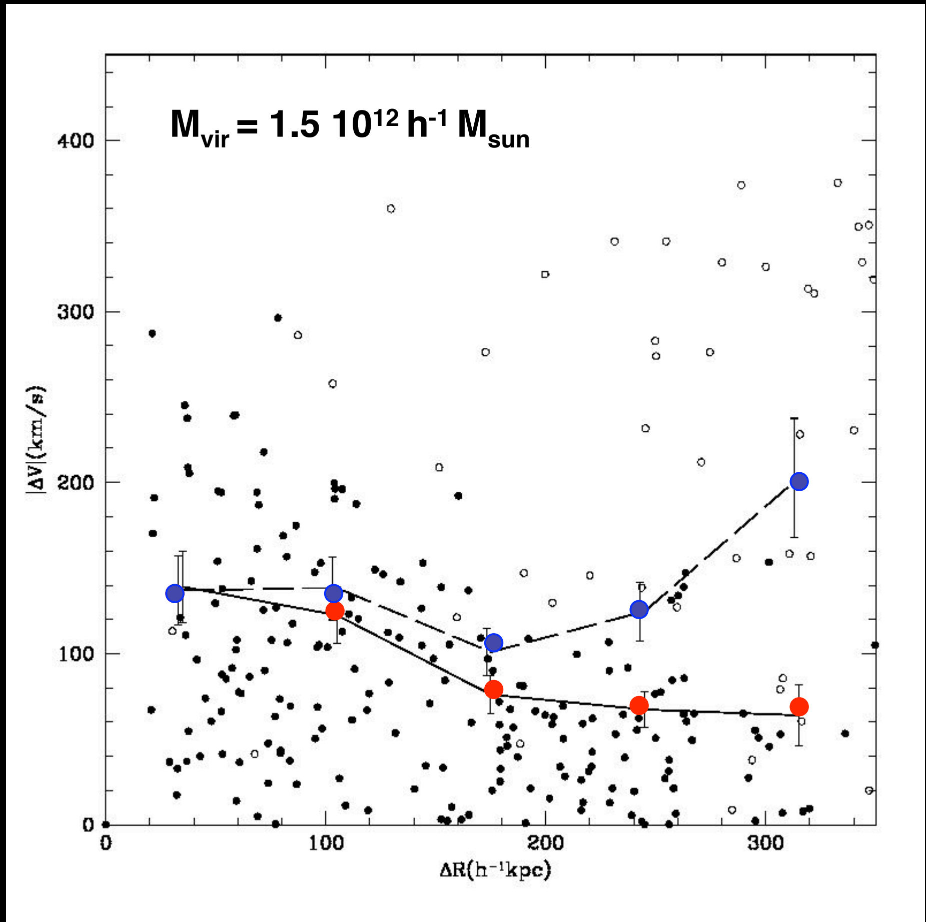
Which one is interloper?

...sds writes...
sdsd

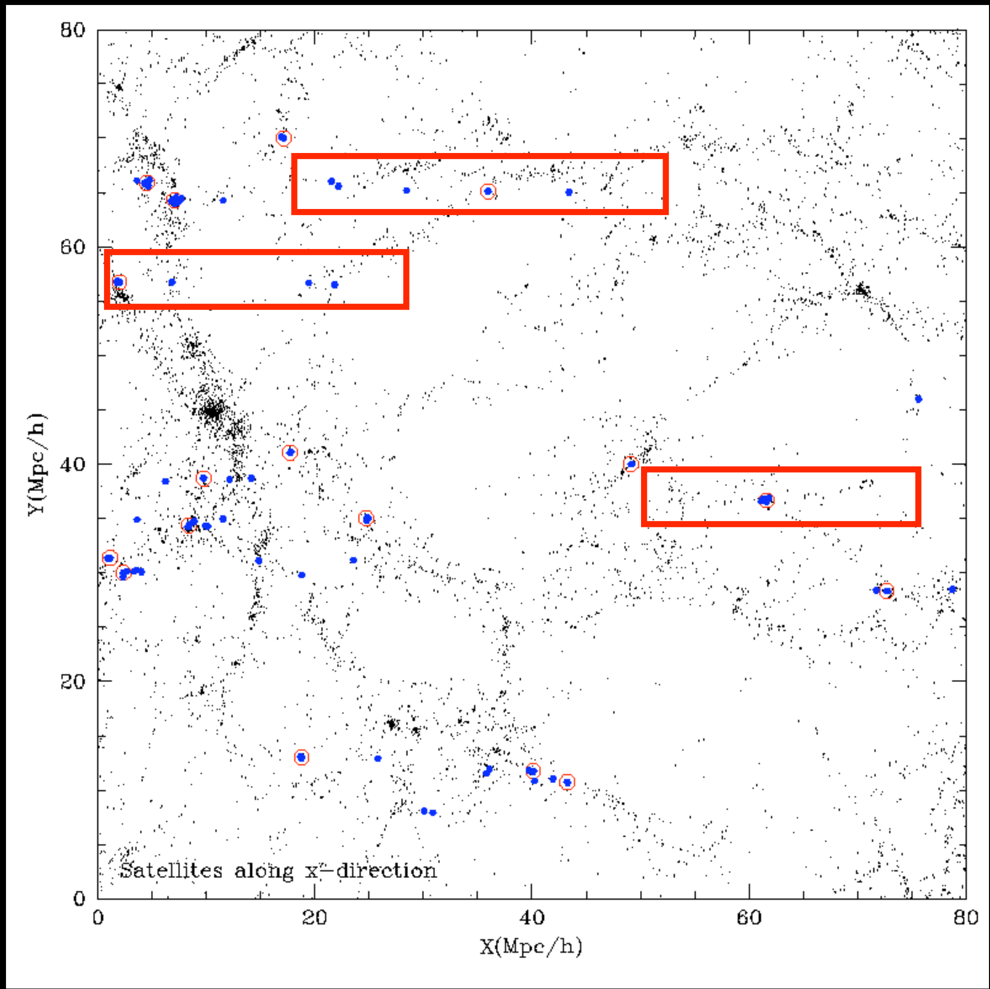
Aardman

The presence of interlopers

Credits: Kravtsov



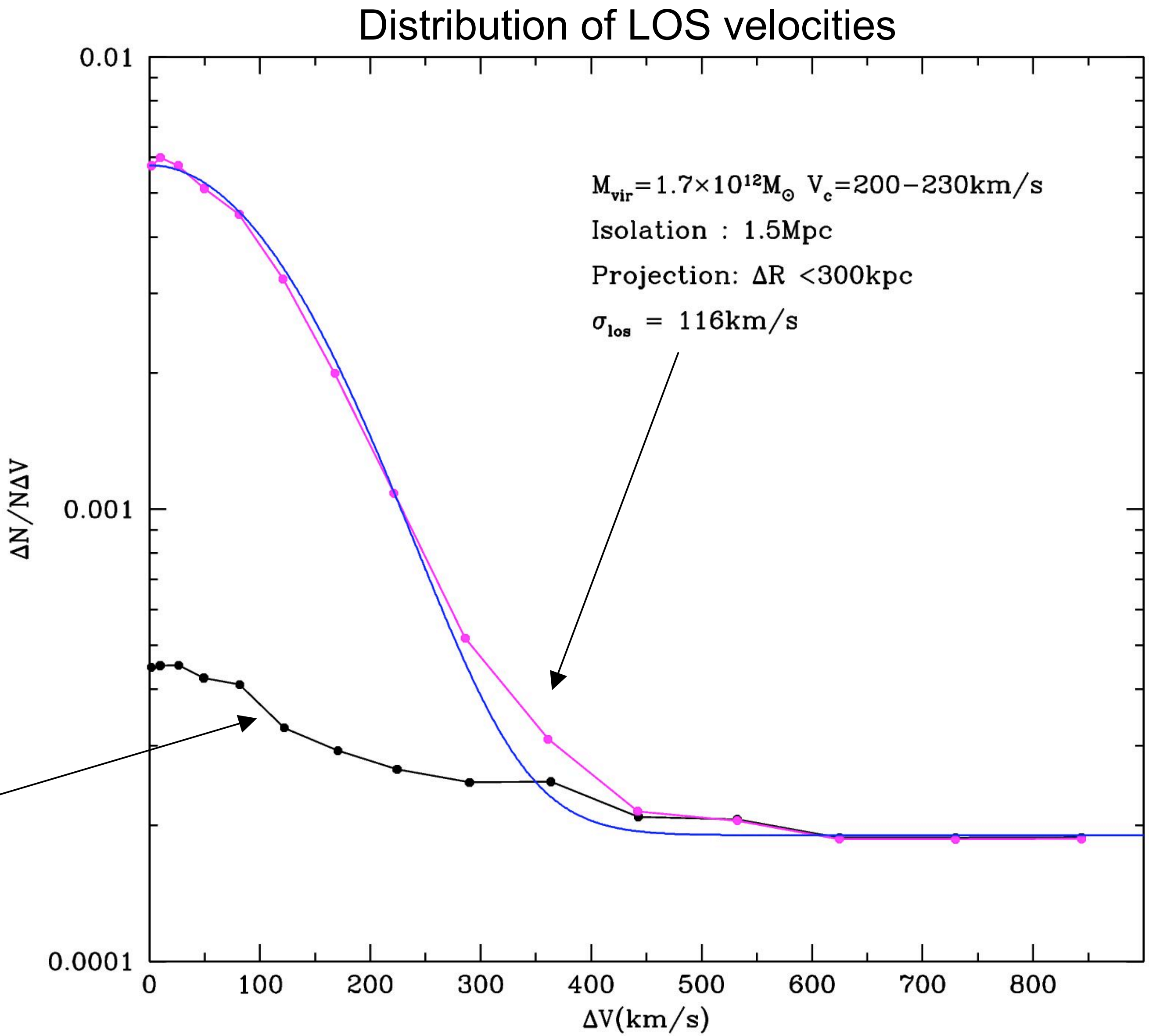
Where are the interlopers ?



Isolated Halo   Satellite/Interlp

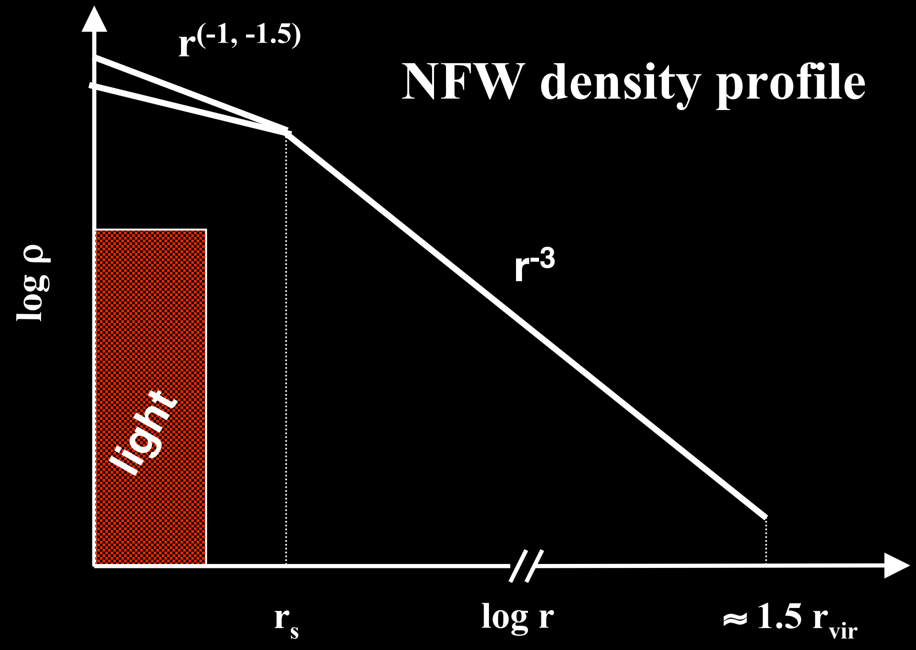
Gaussian + Constant method

McKay et al. 02
Prada et al. 03
Brainerd 04
Van den Bosch et al. 04
Chen et al. 06
Conroy et al. 06

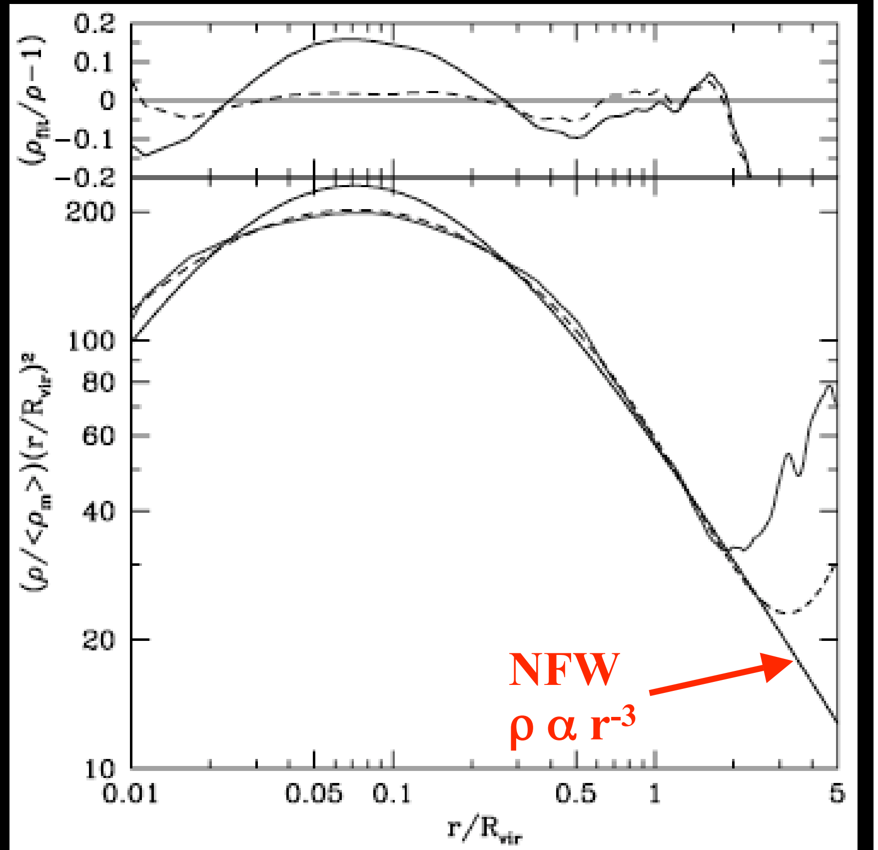


DM outside
500kpch

The mass distribution of isolated LCDM halos



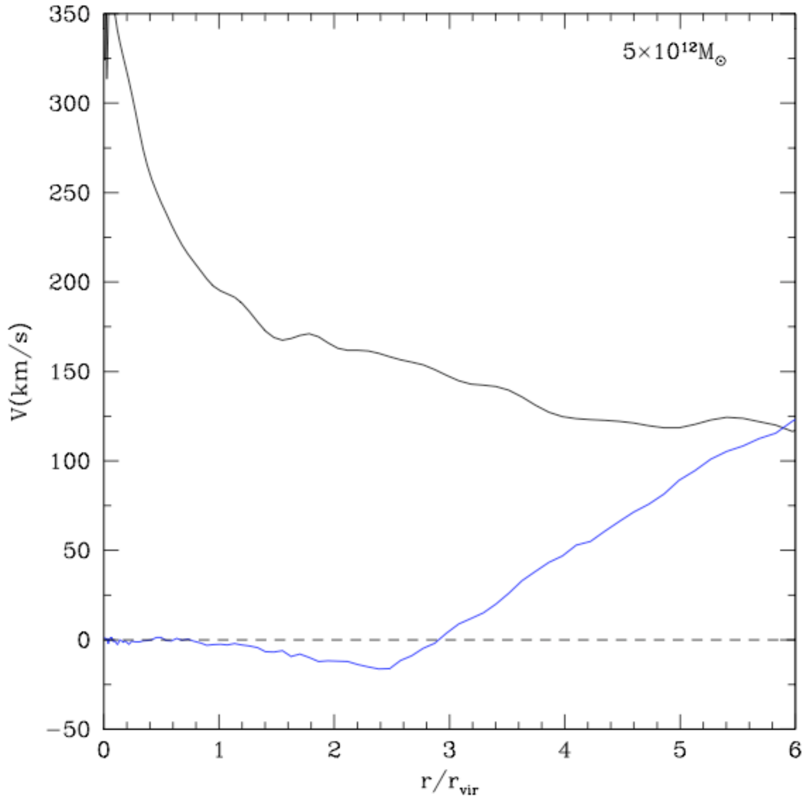
$M_{vir} \approx 10^{12} M_{sun}$
$r_{vir} \approx 250$ kpc
$r_s \approx 20$ kpc

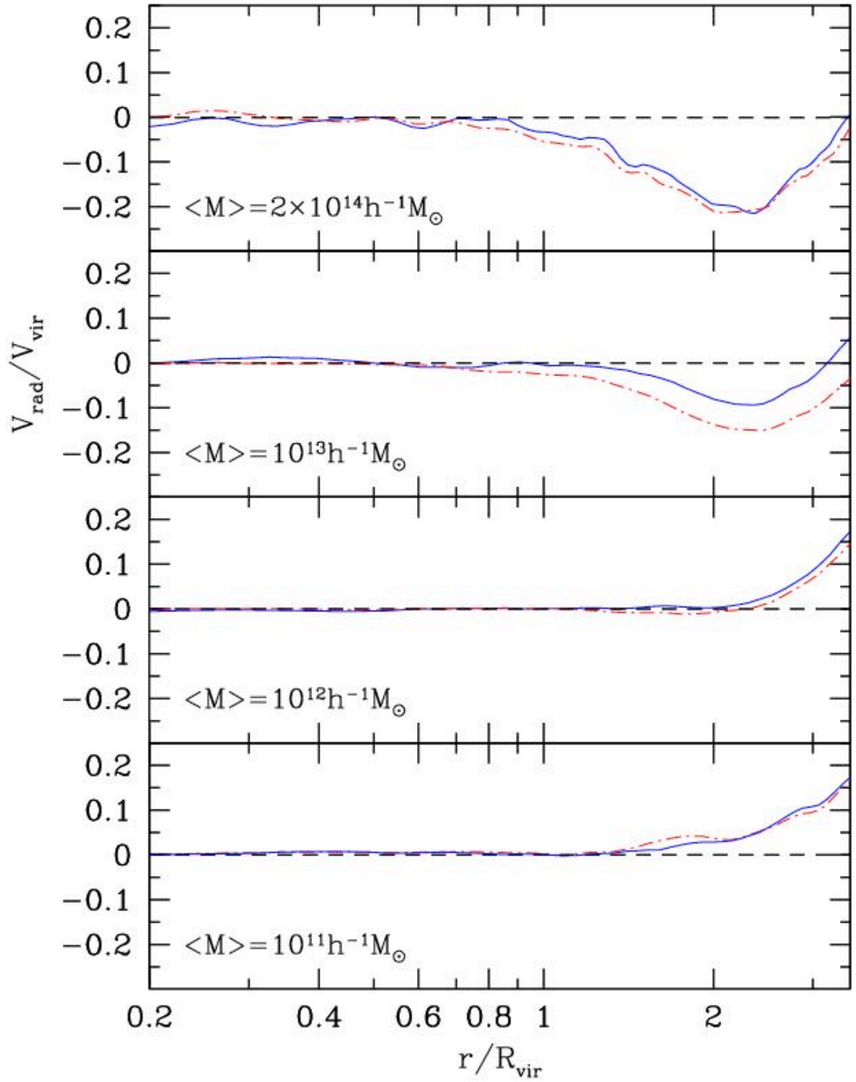


Isolated Milky-Way size halos extend well beyond R_{vir} displaying all properties of virialized objects up to 2-3R_{vir} i.e. relatively smooth density profiles and no systematic infall velocities

Prada et al. 2006

The kinematics of galactic LCDM isolated halos





For galaxy-size halos the virial radius is 2-3 times larger than the formal virial radius. There are no infall velocities on isolated Milky-Way size halos.

Prada et al. 2006

Evolution in the halo masses of isolated galaxies

The evolution in the virial mass-to-light ratio and virial-to-stellar mass ratio for bright isolated galaxies is almost entirely unconstrained:

- Wilson et al. (2001) measured the weak lensing signal for early-type L_* galaxies from z=0.1 to z=0.8. They found little evolution in the halo mass of L_* galaxies (their formal errors on the halo mass at z=0.8 were very large) **(!)**
- Heymans et al. (2006) find no significant evolution in the virial-to-stellar mass ratio of bright galaxies to z=0.8 (though constraints are weak) **(!)**
- Conroy et al. (2005) used the dynamics of satellites to study the evolution of M_{vir}/L from z=1 to present (small sample size and selection effects between DEEP2 and SDSS were not taken into account) **(!)**
- Boehm & Ziegler (2006); Conselice et al. (2005); Kassin et al. (2006) have used the Tully-Fisher relation to constrain the evolution in M_{vir}/M_*. They found no evidence of change in virial-to-stellar mass ratio from z=1 to z=0 **(!)**

Utilizing satellite dynamics we measure the evolution in M_{200}/L_B and M_{200}/M_* for isolated L_* galaxies between z=1 to z=0 by combining data from the DEEP2 and SDSS.

Conroy, Prada + DEEP2 team 2006

The Data. The DEEP2 survey (z ~ 1)

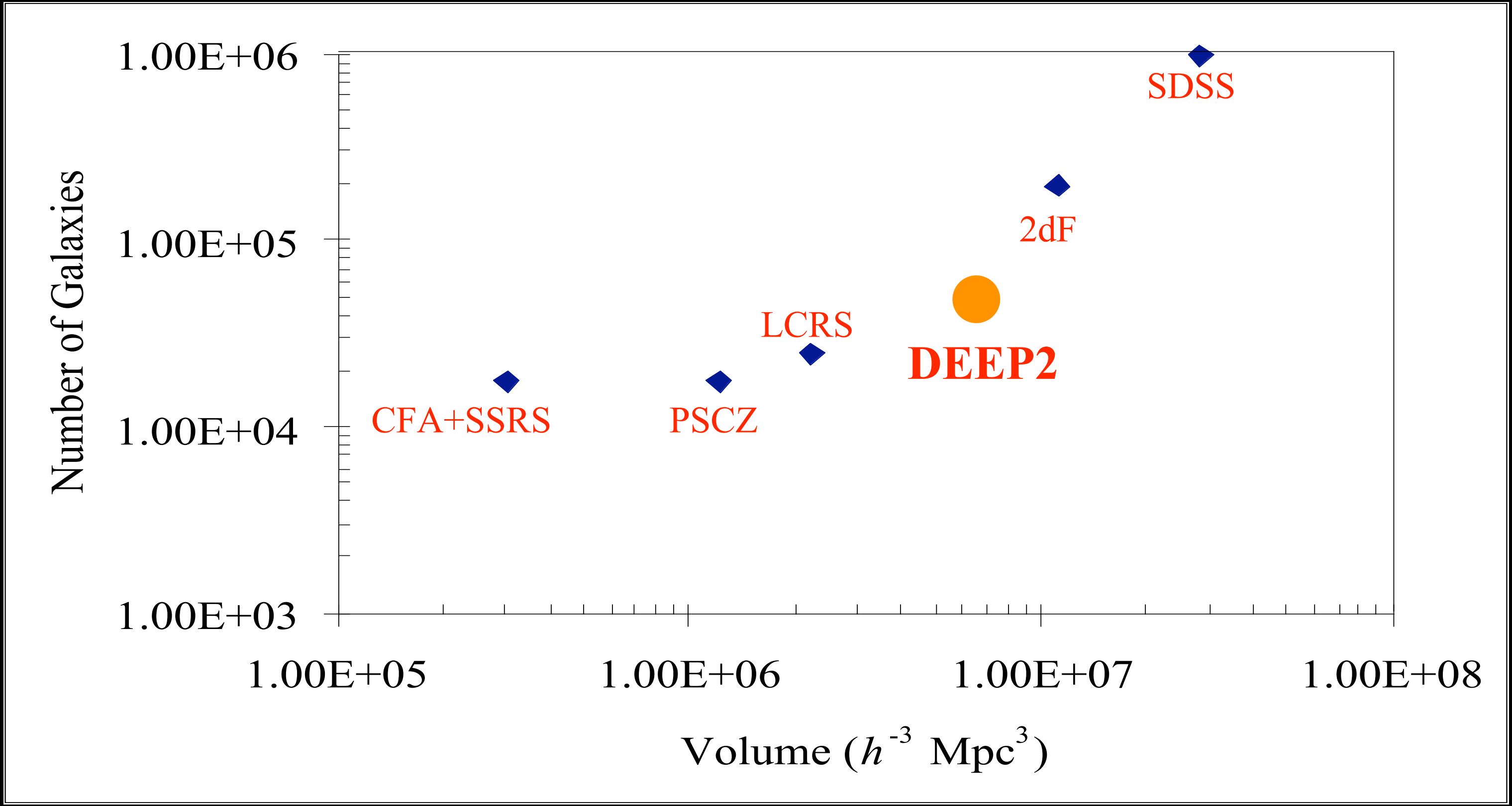
The DEEP2 (= DEEP Extragalactic Evolutionary Probe 2) Galaxy Redshift Survey is studying both galaxy properties and large-scale structure at z=1.

Davis et al. 2003

- **3 square degrees of sky; 4 fields (0.5^o x <2^o)**
- **400 slitmasks observed over 80 Keck nights**
- **1200 l/mm grating: ~6500-9200 Å**
- **1.0” slit: FWHM≈ 68 km/s**
- **Primary redshift range ~0.7-1.4**
  (pre-selected using *BRI* photometry)
- **>40,000 redshifts (< 30 km/s rms)**
- **~$5\cdot 10^6$ h^{-3} Mpc^3 comoving volume**
- **One-hour exposures**
- **R_{AB}=24.1 limiting magnitude**
- **50% overall completeness**

DEIMOS (PI: Faber) and Keck provide a unique combination of wide-field multiplexing (up to 160 slitlets over a 16’x4’ field), high resolution (R~5000), spectral range (2600 Å at highest resolution), and collecting area (Faber et al. 2003).

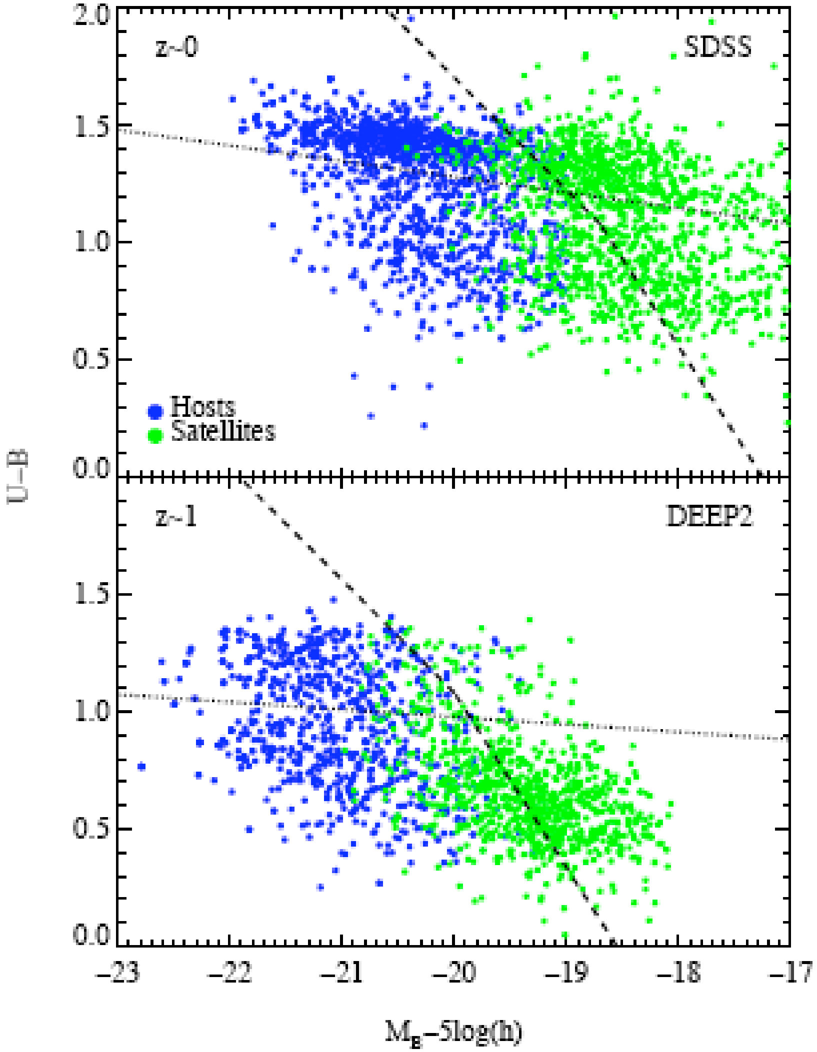
DEEP2 vs. local redshift surveys



A careful handling of the different selection effects of both surveys:

- different completeness: 90% SDSS DR4; 50% DEEP2
- restframe R-band selection in SDSS; restframe B-band selection in DEEP2

Sample of Hosts and Satellites



Color-magnitude diagram for host galaxies and satellites

TABLE 1. SEARCH CRITERIA

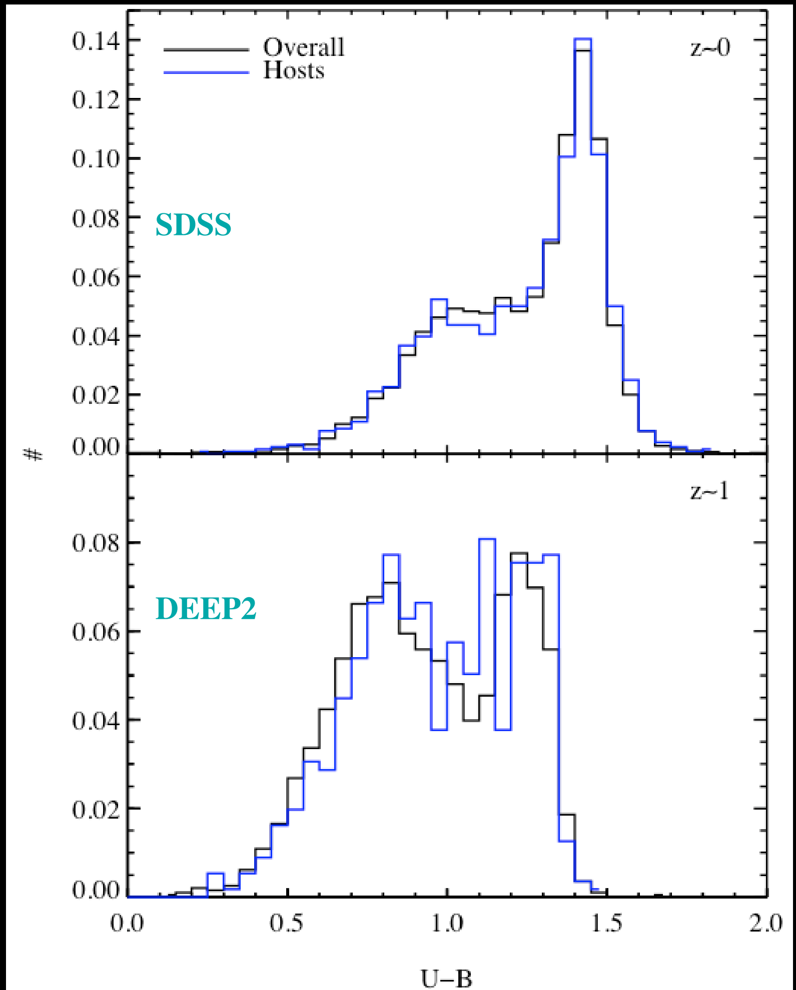
Sample Name	Isolation Criteria ΔM	ΔV km s^{-1}	ΔR_p h^{-1} kpc	Satellite Criteria δM	δV km s^{-1}	δR_p h^{-1} kpc
A	1.0	1000	500	1.0	750	350
B	1.5	1000	500	1.5	750	350
C	1.5	1000	1000	1.5	500	350

TABLE 2
SUMMARY OF SAMPLES

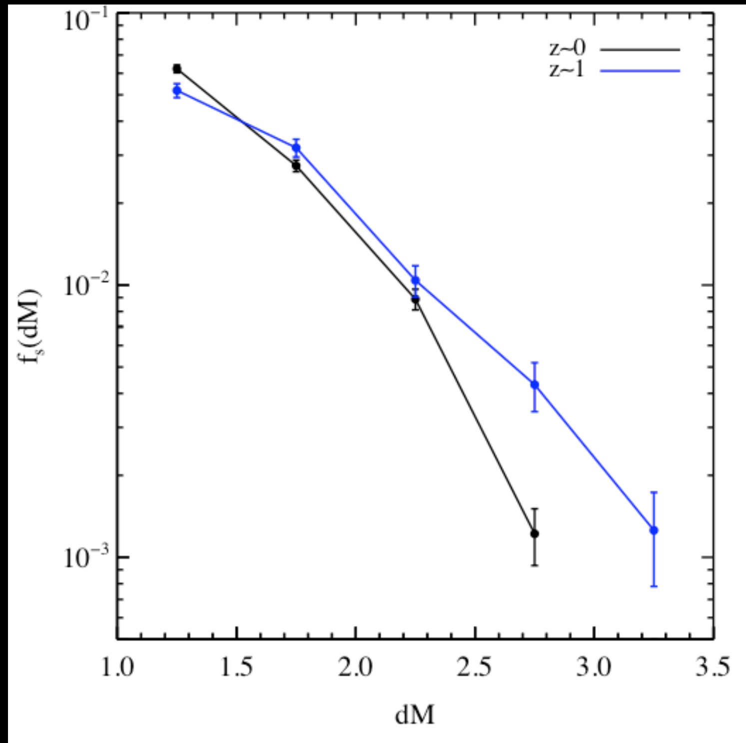
	SDSS	DEEP2
redshift range	$0.01 < z < 0.10$	$0.7 < z < 1.2$
$\langle z \rangle$	0.06	0.84
Host $M_B - 5\log(h)$ range	< -19	< -20
without R-band cut:		
Total Sample Size	102, 656	21, 184
Satellite $\langle M_B - 5\log(h) \rangle$	−18.3	−19.4
N_{sat}	5414	1007
N_{host}	3431	755
with R-band cut:		
Total Sample Size	56, 397	12, 887
Satellite $\langle M_B - 5\log(h) \rangle$	−19.0	−19.6
N_{sat}	1475	554
N_{host}	1283	440

NOTE. — The host and satellite galaxies contained in these samples were obtained using search criteria *A* (cf. Table 1). The total sample size for the SDSS survey refers to the survey after it has been diluted by 40% to match the completeness of DEEP2.

Properties of Hosts and Satellites



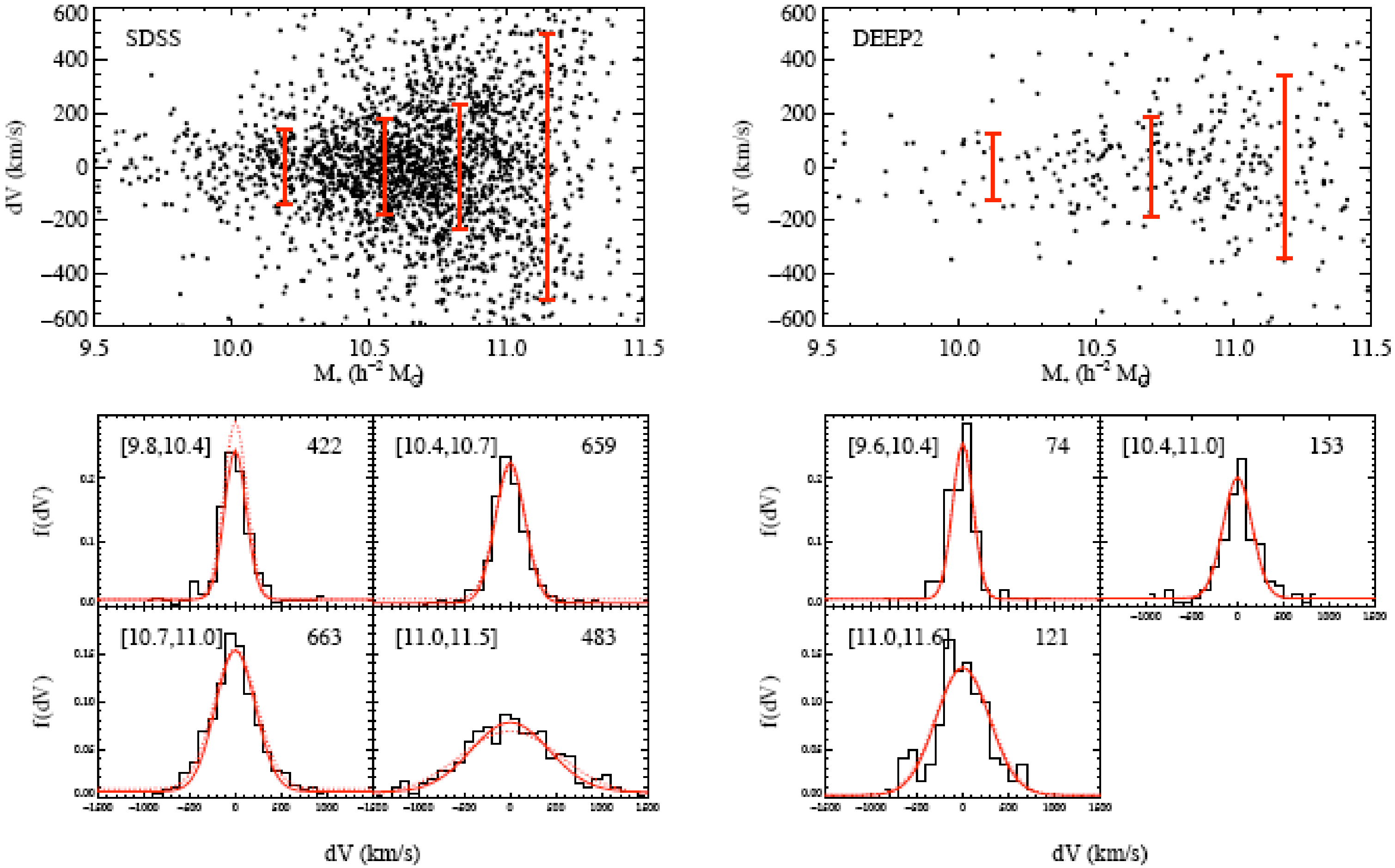
U-B colors for host galaxies compared to the overall galaxy distribution, for galaxies at z ~ 0 and z ~ 1.



Fraction of satellites as a function of $dM=M_b^{sat}-M_b^{hosts}$. We find that satellites at z ~ 1 tend to be comparatively fainter, relative to their host luminosity, than satellites at z ~ 0 .

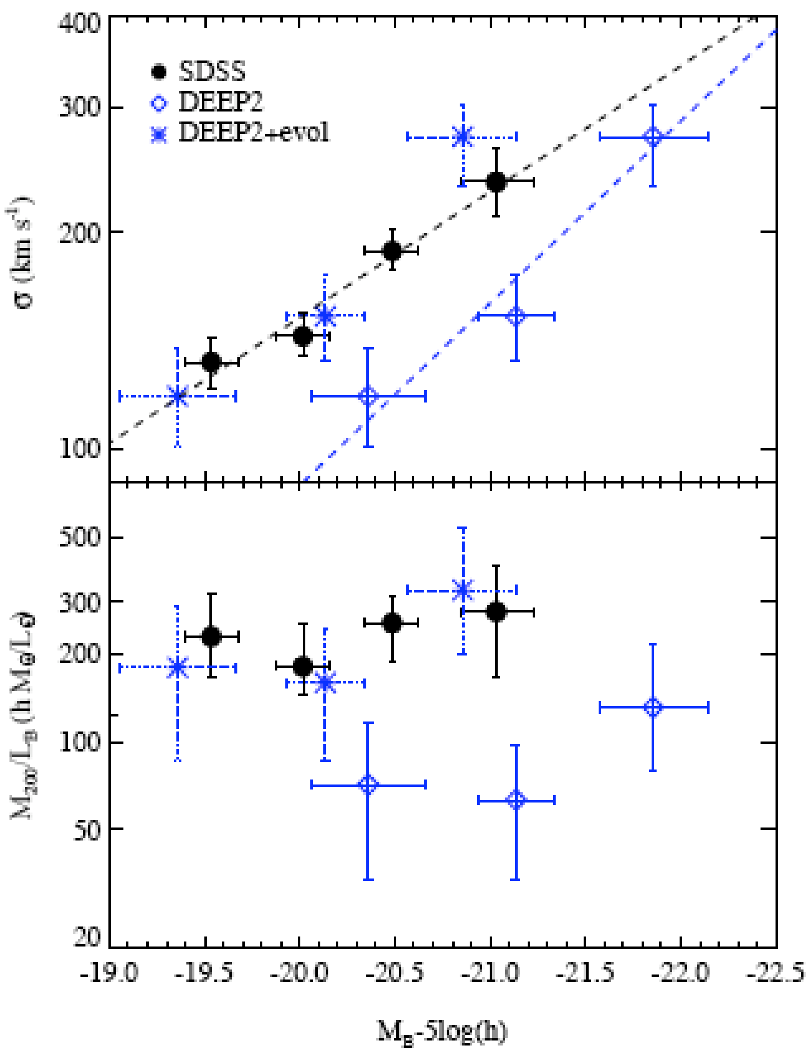
Satellite velocity dispersion measurements

We plot the relative line-of-sight satellite velocity to the host, as a function of host stellar mass, for all satellites within R_p=[20,150] h^{-1} kpc at z ~ 0 (left) and z ~ 1 (right)



Evolution of σ-L_B and M_{200}/L_B

Satellite velocity dispersion, measured within R_p=[20,150] h^{-1} kpc, for host galaxies at z ~ 0 and z ~ 1 as a function of the B-band luminosity of the host galaxy.



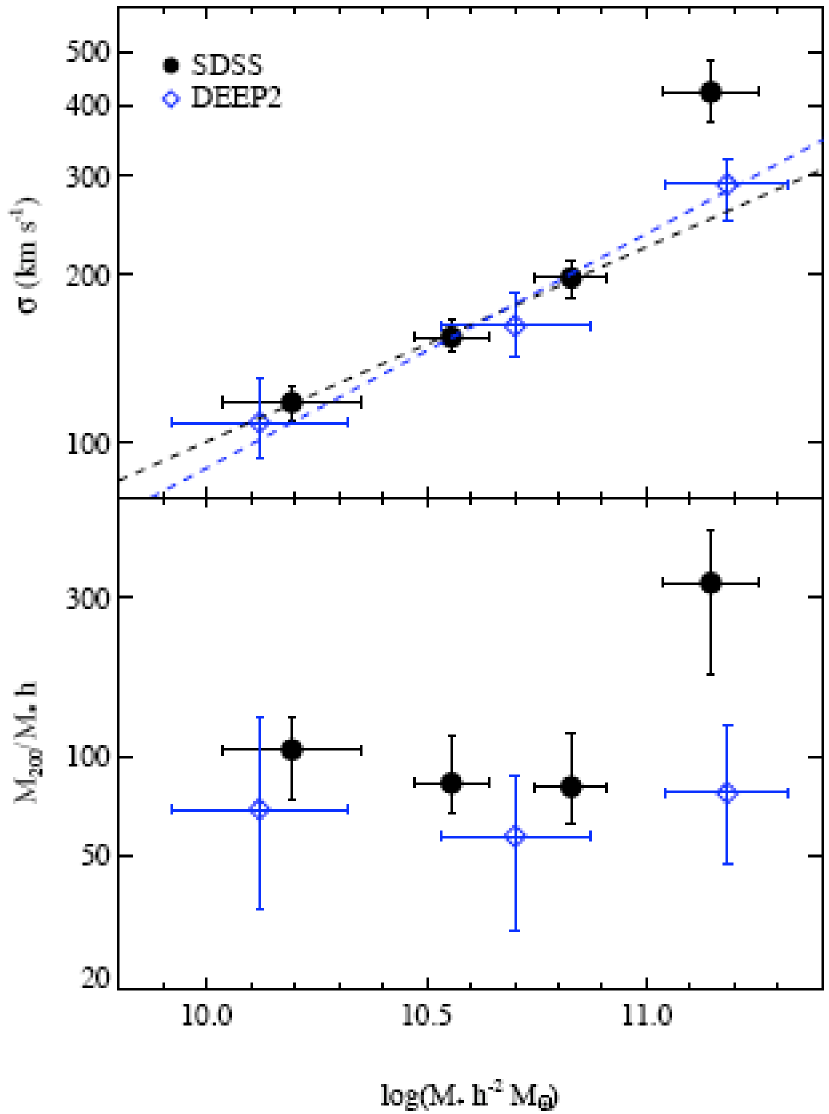
*** DEEP2+evol: measurements with one magnitude dimming in the B-band luminosity, Consistent with evolution in the LF from z ~ 1 and z ~ 0 (Faber et al. 05).**

From the measured satellite velocity dispersion and assuming NFW, we estimate the virial mass of the host galaxies.

Virial mass-to-light ratio as a function of galaxy B-band luminosity.

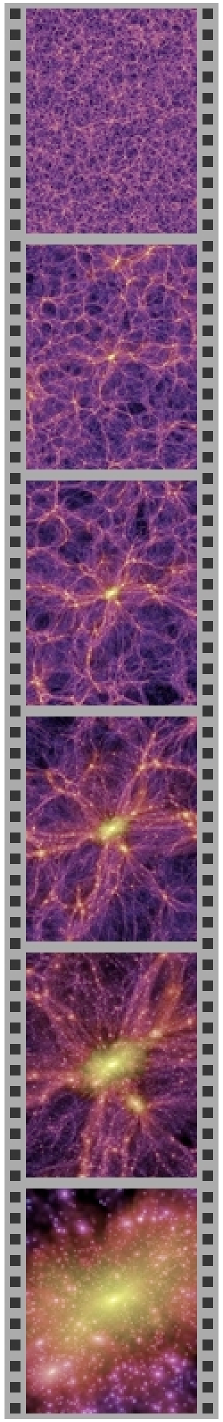
Evolution of σ-M_* and M_{200}/M_*

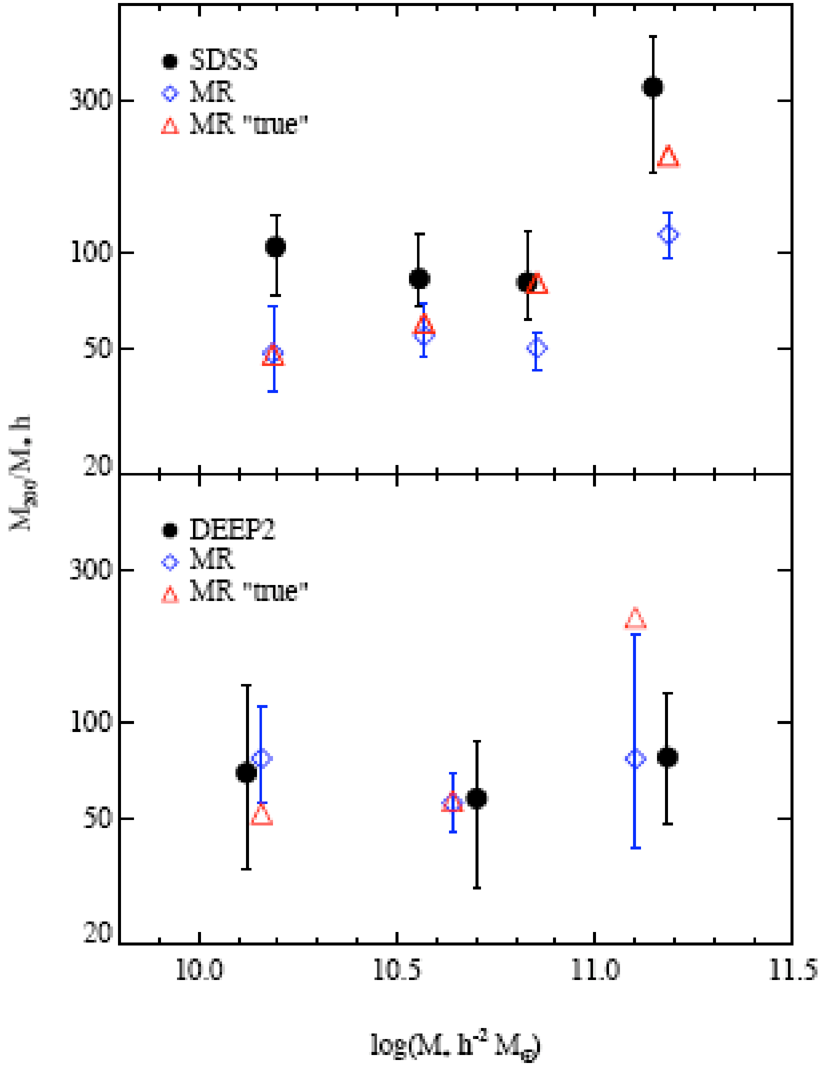
Satellite velocity dispersion, measured within R_p=[20,150] h^{-1} kpc, for host galaxies at $z \sim 0$ and $z \sim 1$ as a function of stellar mass M_* of the host galaxy.



Virial-to-stellar mass ratio as a function of galaxy stellar mass

Comparison to a semi-analytical model of galaxy formation: the MR simulation





Observed and predicted virial-to-stellar mass ratios at z ~ 0 and z ~ 1.

Mock surveys have been created out of the MR that match the geometry and sampling of the SDSS and DEEP2 surveys. We apply exactly the same search criteria and methodology to these mocks as to the data.

Remarks

(Conroy, Prada, Newman,Croton, et al. 2006)

Using the dynamics of satellite galaxies we have obtained direct constraints on the evolution in the virial mass-to-light ratio and virial-to-stellar mass ratio for isolated L_* galaxies from $z \sim 1$ and $z \sim 0$ by combining data from the DEEP2 and the SDSS.

- **The virial mass-to-light ratio does not evolve between these two epochs when we compare galaxies at $z \sim 1$ to galaxies one magnitude fainter (in the B-band) at $z \sim 0$.**
- **Our results suggest that the virial-to-stellar mass ratio of isolated galaxies (with $\sim 10^{12}$ M_{sun} halo mass) does not evolve between $z \sim 1$ and $z \sim 0$. This suggests that any dark matter accreted by these systems between these two epochs is accompanied by a comparable increase in the amount of stellar mass.**
- **At the high stellar mass end, M_{200}/M_* for these galaxies with $\sim 10^{13}$ M_{sun} halo mass increases by a factor of 4 from $z \sim 1$ and $z \sim 0$. For these host galaxies, predominantly red, we expect little increase in the stellar mass between these epochs, but implies a massive increase in the virial mass of the host galaxy dark matter halo.**
- **Our results are compatible with weak lensing measurements and they agree well with predictions from a semi-analytic models of galaxy formation (the Millennium Run)**

Conclusions

• The DM halo properties, mass-to-light ratios and baryonic content of isolated galaxies can be determined from our SDSS satellite analysis. This can help us to constrain galaxy formation models and determine the mass distribution of isolated galaxies.

• Masses of galaxies at high-z can be obtained from satellite dynamics (DEEP2, Conroy, Prada et al.)

• Satellite dynamics is a complementary method to the g-g lensing studies