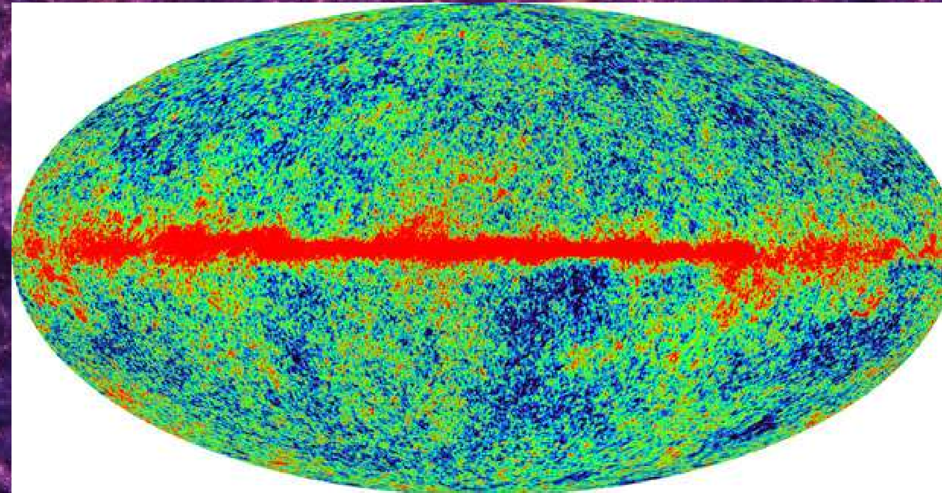
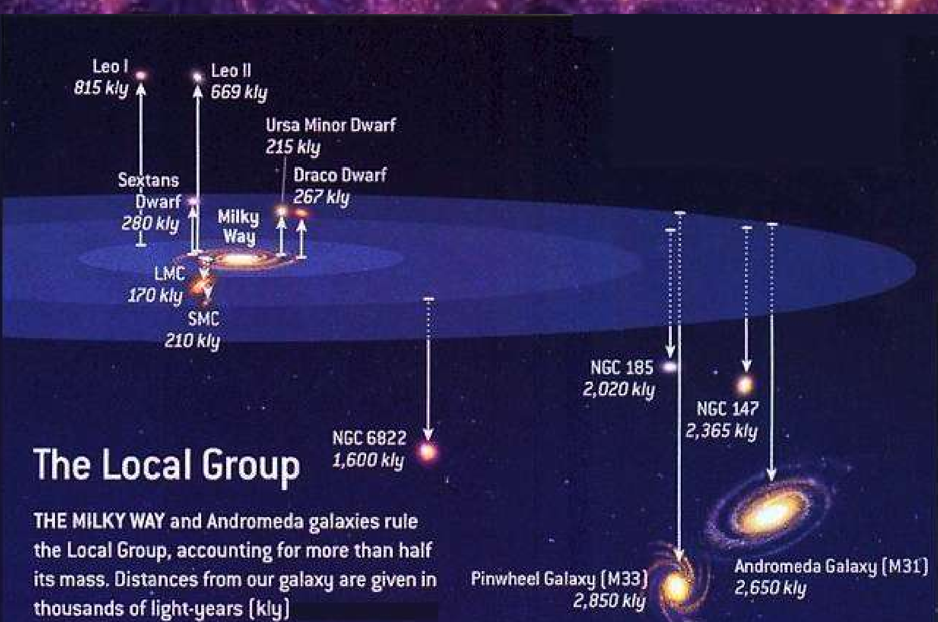
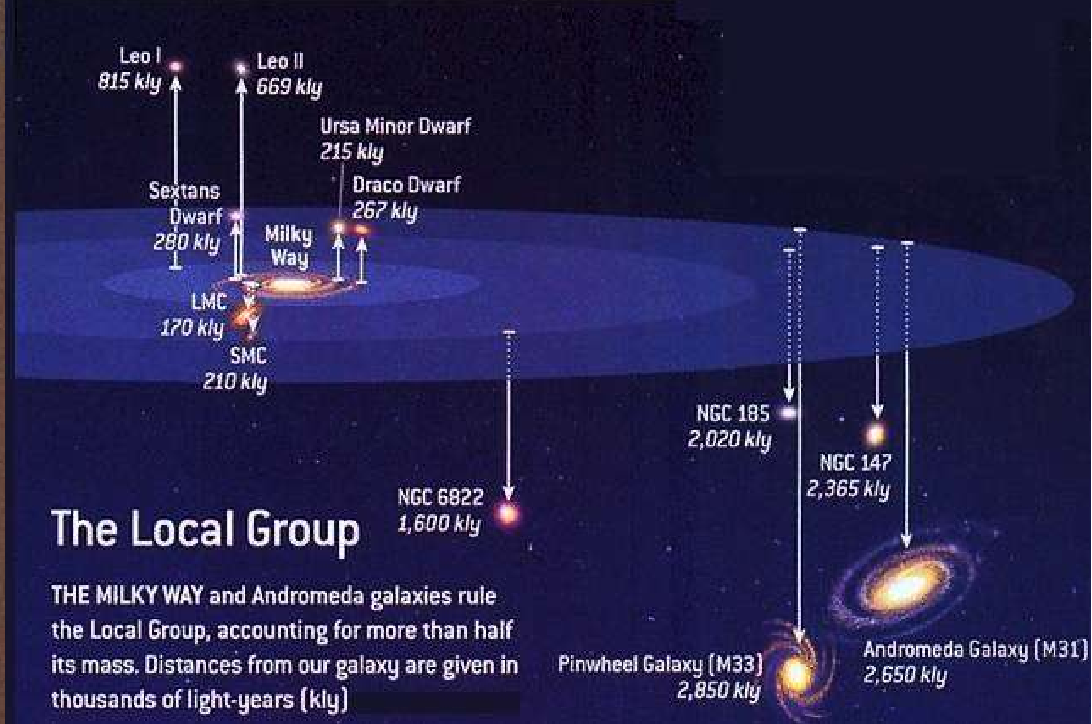


The Millenium Simulation...

...and the Local Group



Simon White
MPI for Astrophysics
Yang-Shyang Li
Kapteyn Lab., Groningen


Leo I
815 kly
Leo II
669 kly
Ursa Minor Dwarf
215 kly
Sextans Dwarf
280 kly
Draco Dwarf
267 kly
Milky Way
LMC
170 kly
SMC
210 kly
NGC 185
2,020 kly
NGC 147
2,365 kly
NGC 6822
1,600 kly
The Local Group
THE MILKY WAY and Andromeda galaxies rule the Local Group, accounting for more than half its mass. Distances from our galaxy are given in thousands of light-years (kly)
Pinwheel Galaxy (M33)
2,850 kly
Andromeda Galaxy (M31)
2,650 kly

Millennium Run Statistics

Springel et al 2005: The Virgo Consortium

- DM particle number: $N = 2160^3 = 10{,}077{,}696{,}000 \approx 10^{10}$
- Box size: $L = 500$ Mpc/h, Softening: $\epsilon = 5$ kpc/h $\longrightarrow$ $L/\epsilon = 10^5$
- Initial redshift: $z_{init} = 127$
- Cosmology: $\Omega_{tot}=1$, $\Omega_m=0.25$, $\Omega_b=0.045$, $h=0.73$, $n=1$, $\sigma_8=0.9$
- 343,000 processor-hours on 512 nodes of an IBM Regatta
  (28 machine days @ 0.2 Tflops using 1 Tbyte RAM)
- Full raw and reduced data stored at 64 redshifts
  $\longrightarrow$ 27 Tbytes of stored data

A testbed for <u>simulating</u> the formation of $\sim 10^7$ galaxies

Simulating galaxies /AGN with the Millennium Run

Springel et al 2005; Croton et al 2005, De Lucia et al 2005

- Build and store merger trees which encode the detailed assembly history of every z=0 halo and of the substructure within it

- Implement models for the formation/evolution of galaxies to follow
  - -- accretion, shock-heating and cooling of diffuse gas into disks
  - -- star formation from the ISM in disks
  - -- stellar evolution
  - -- SN feedback and stellar winds
  - -- chemical enrichment/dust formation
  - -- galaxy merging/morphological transformation

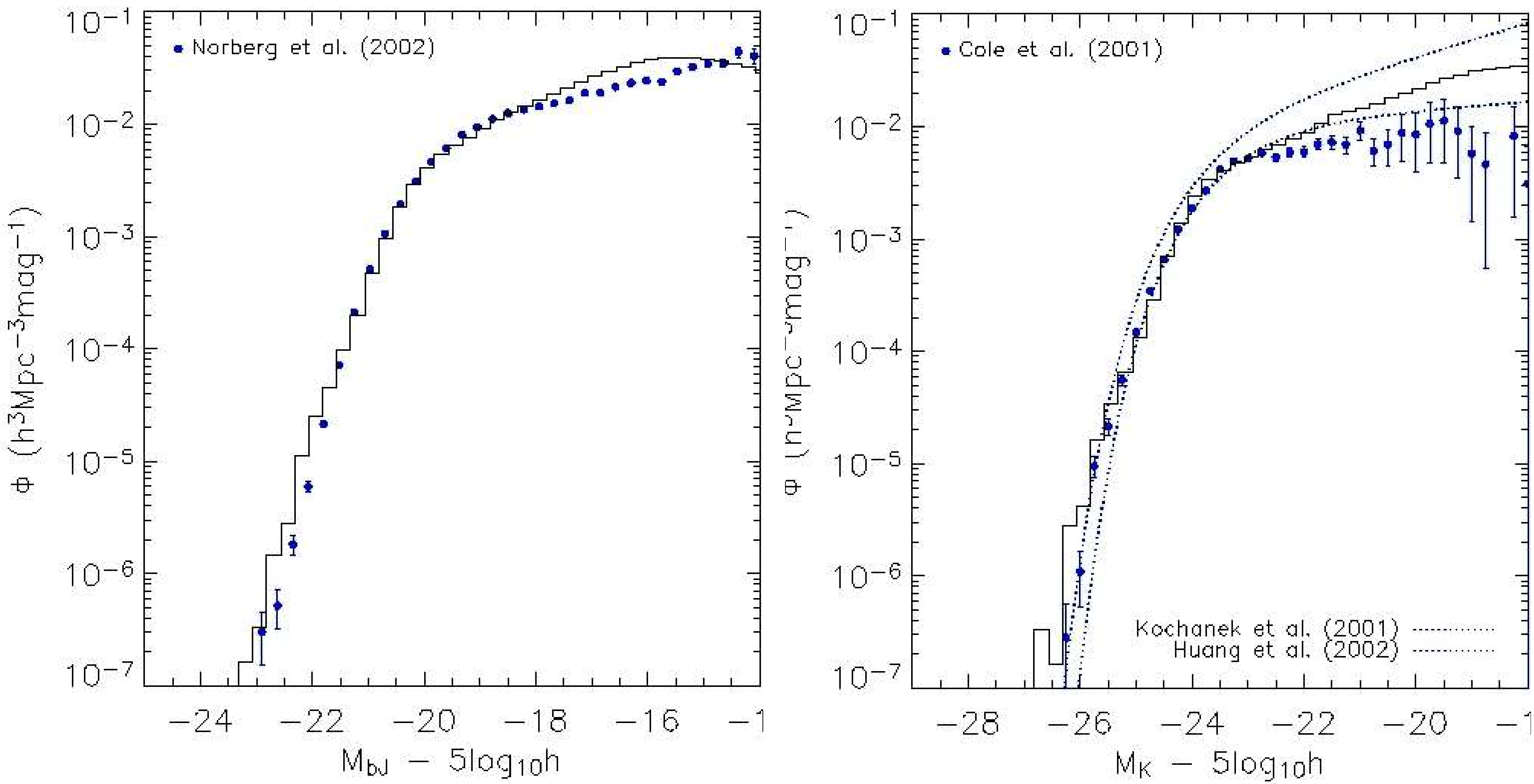
  [After Springel et al (2001) and De Lucia et al (2004)]

- Implement models for the growth of central black holes to follow
  - -- formation and growth from ISM gas during mergers
  - -- black hole mergers following galaxy mergers

  [After Kauffmann & Haehnelt (2000)]

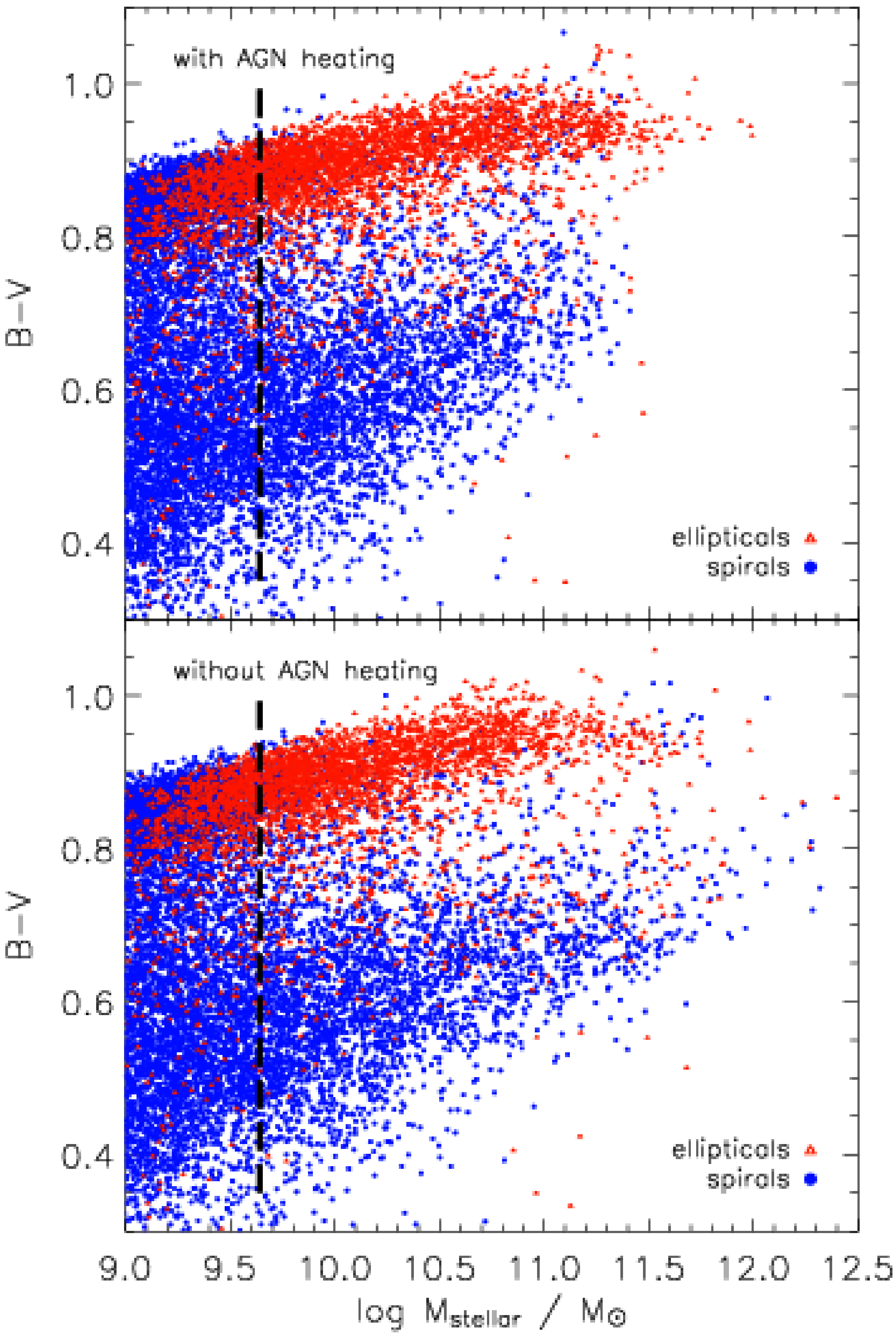
- Include "radio mode" feedback from BH at cooling flow centres
  - -- energy feedback from BH in the central dominant galaxy depends on BH mass, gas temperature and gas mass fraction $\propto f_{gas} \, m_{BH} \, T^{1.5}$

Effect of feedback on the Luminosity Function



Full model with reionisation, AGN and SN feedback

Croton et al 2005

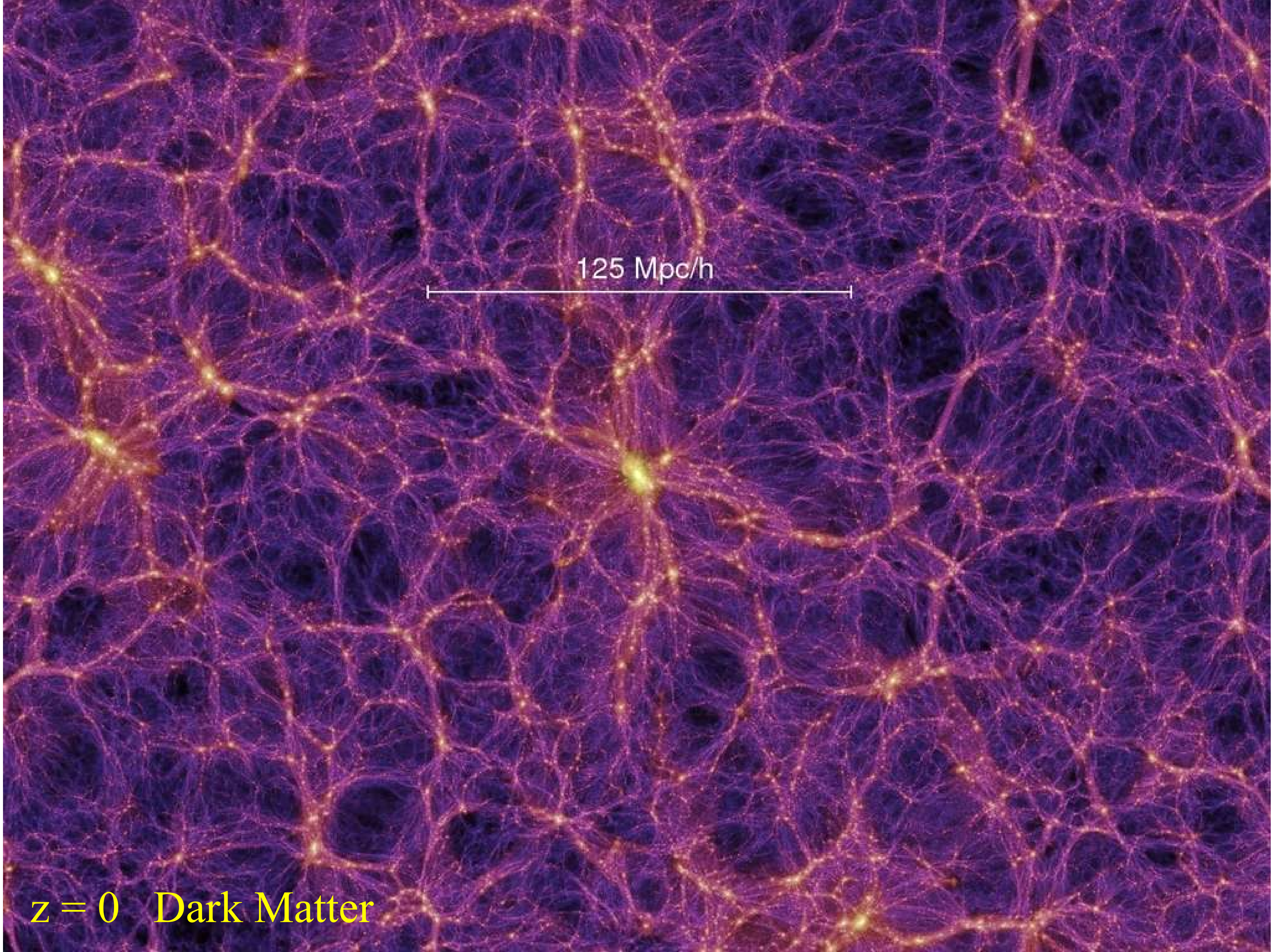


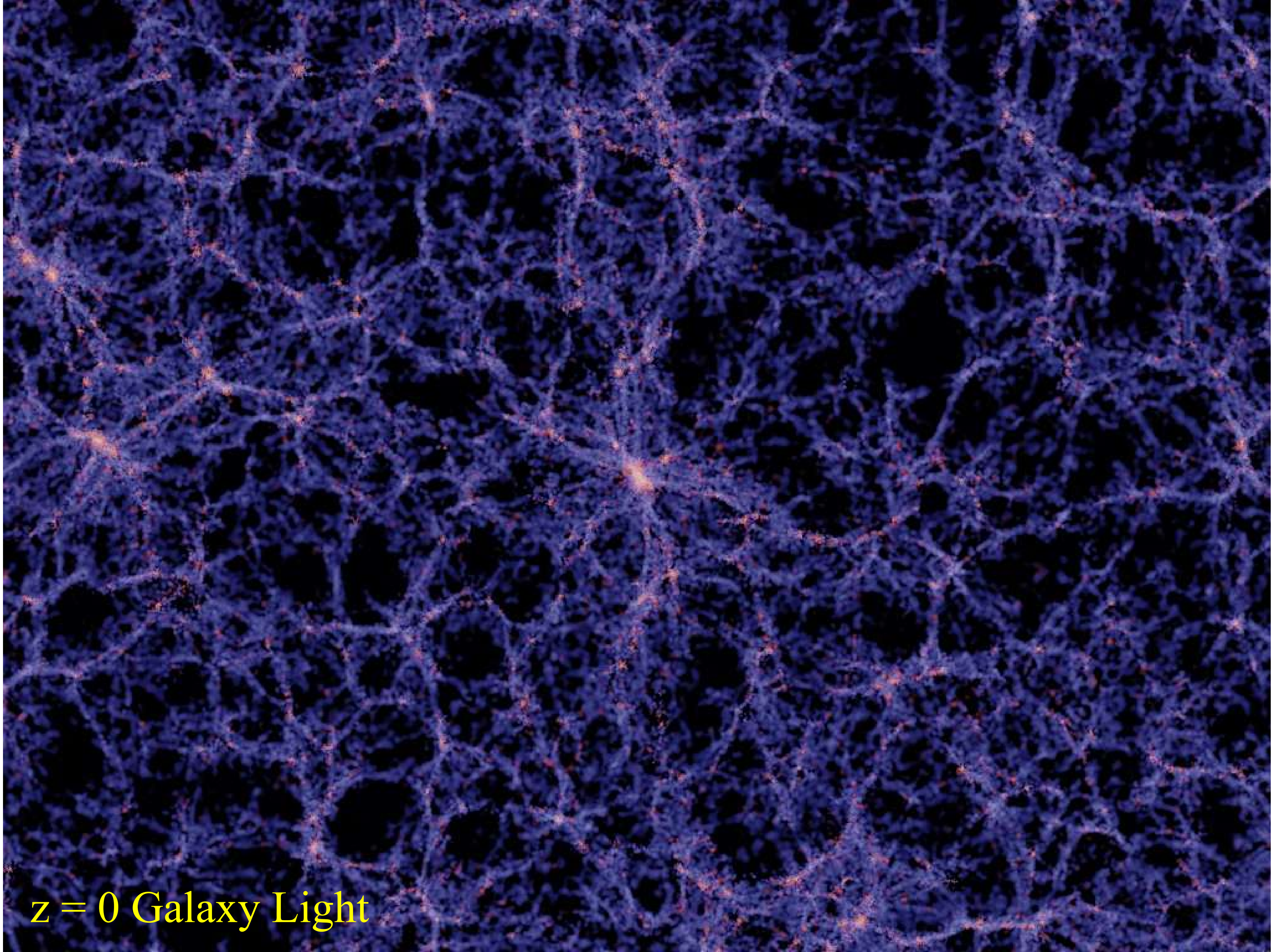
The effects of “radio mode” feedback on z=0 galaxies

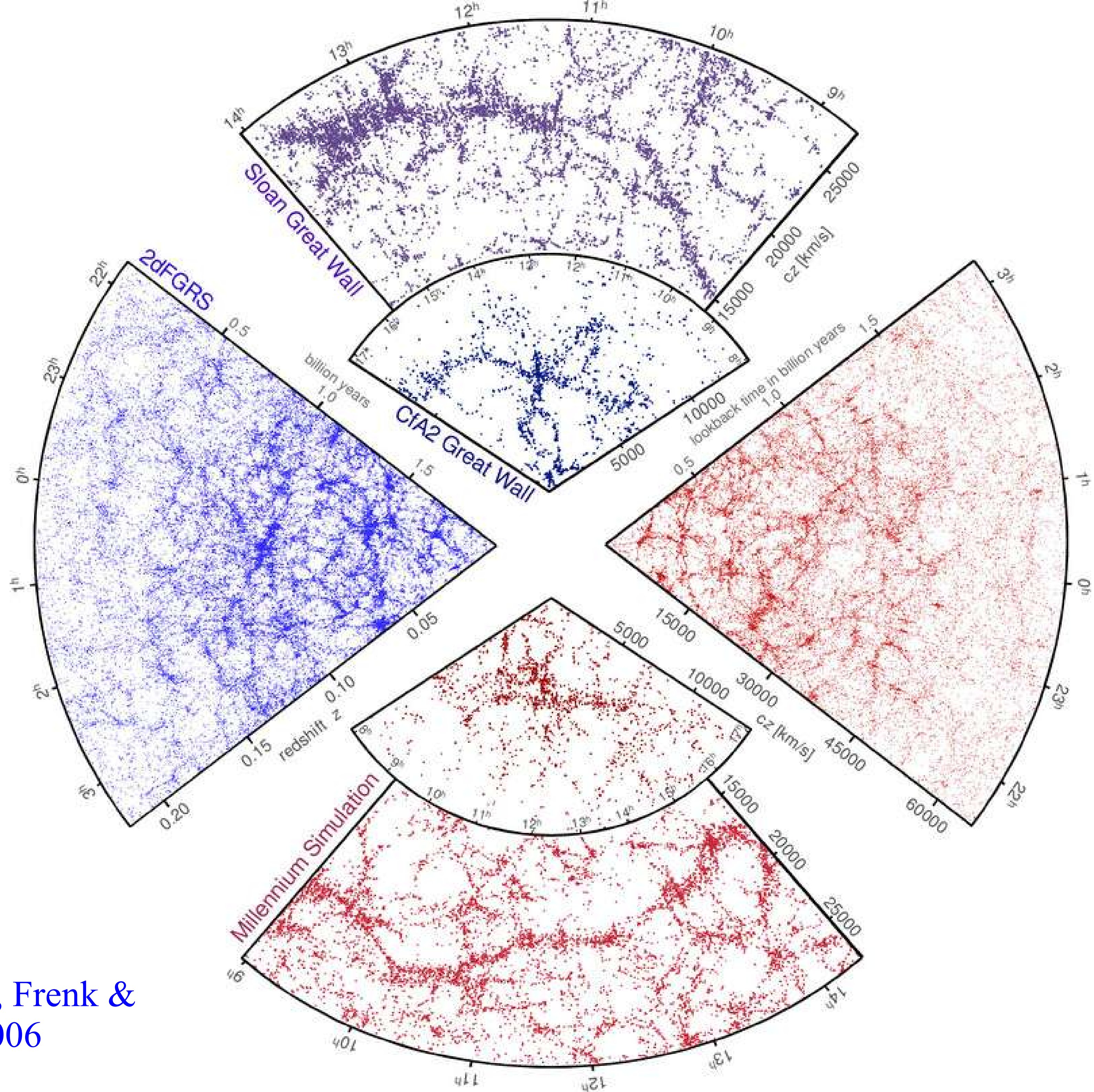
Croton et al 2005

- In the absence of a “cure” for the cooling flow problem, the most massive galaxies are:
  - too bright
  - too blue
  - disk-dominated

- With cooling flows suppressed by “radio AGN” these galaxies are
  - less massive
  - red
  - elliptical

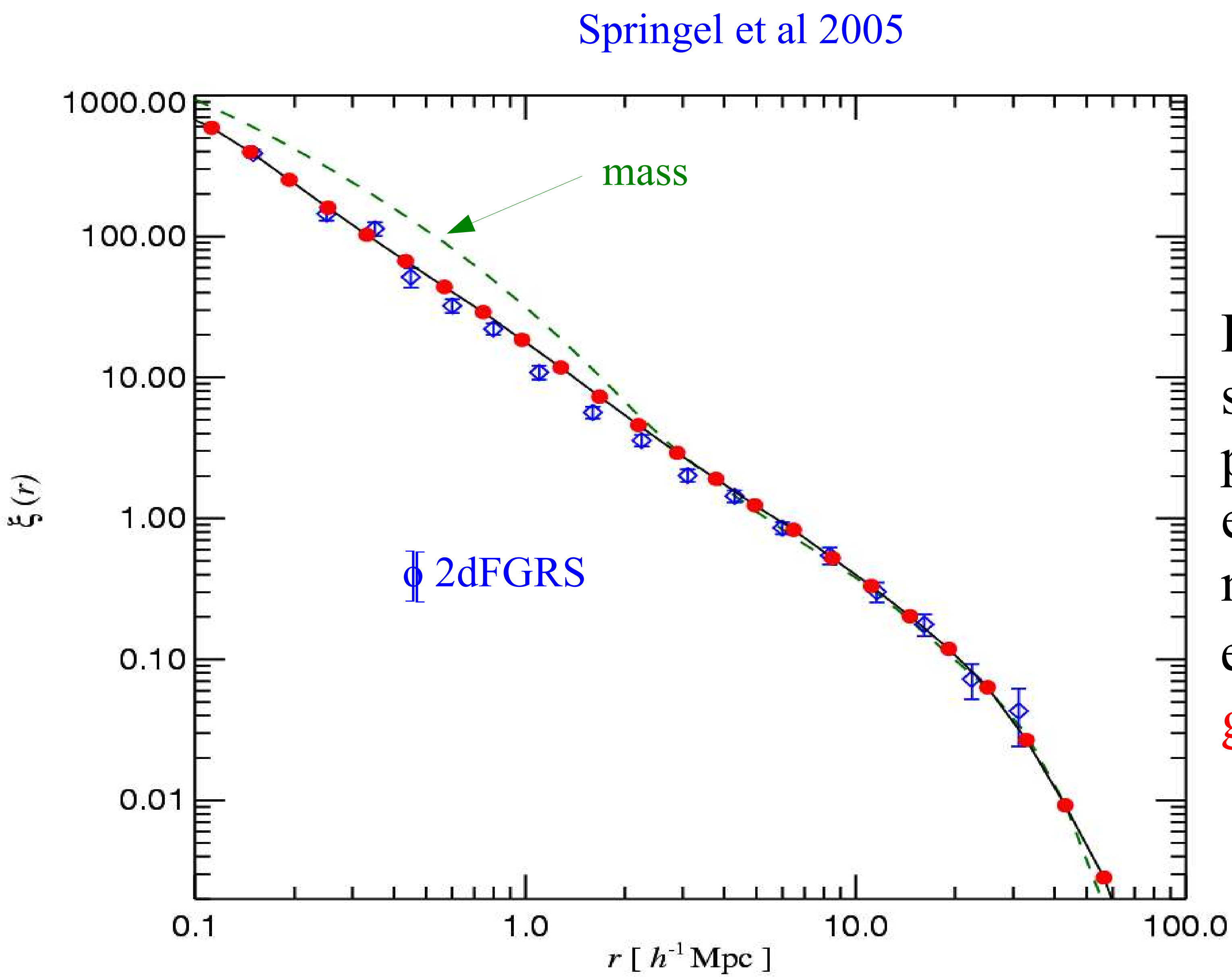

125 Mpc/h
z = 0 Dark Matter


z = 0 Galaxy Light



Springel, Frenk &
White 2006

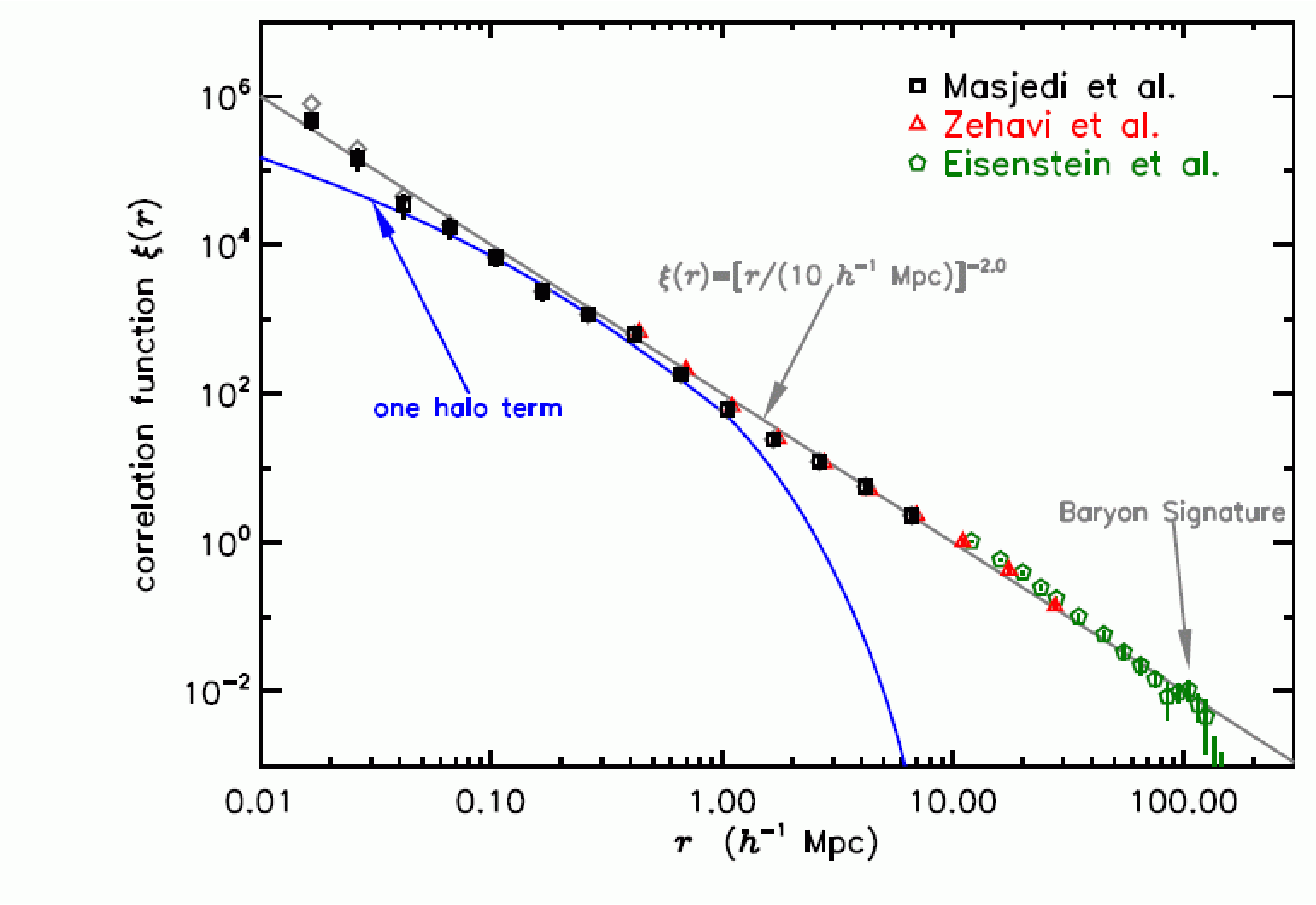
Galaxy autocorrelation function



For such a large simulation the purely statistical error bars are negligible on ξ even for the galaxies

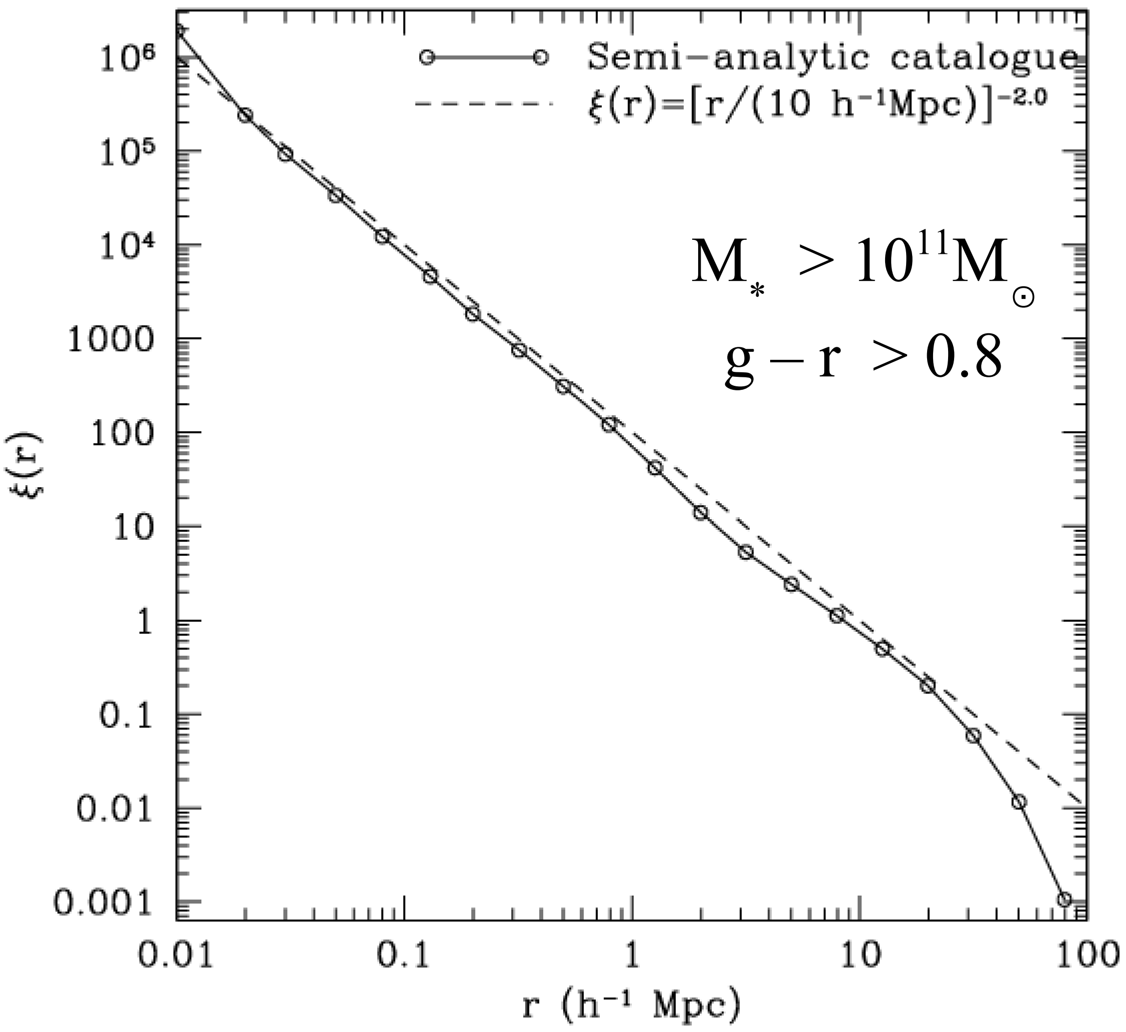
Precise estimates of autocorrelation functions Luminous red galaxies in the SDSS

Masjedi et al 2005

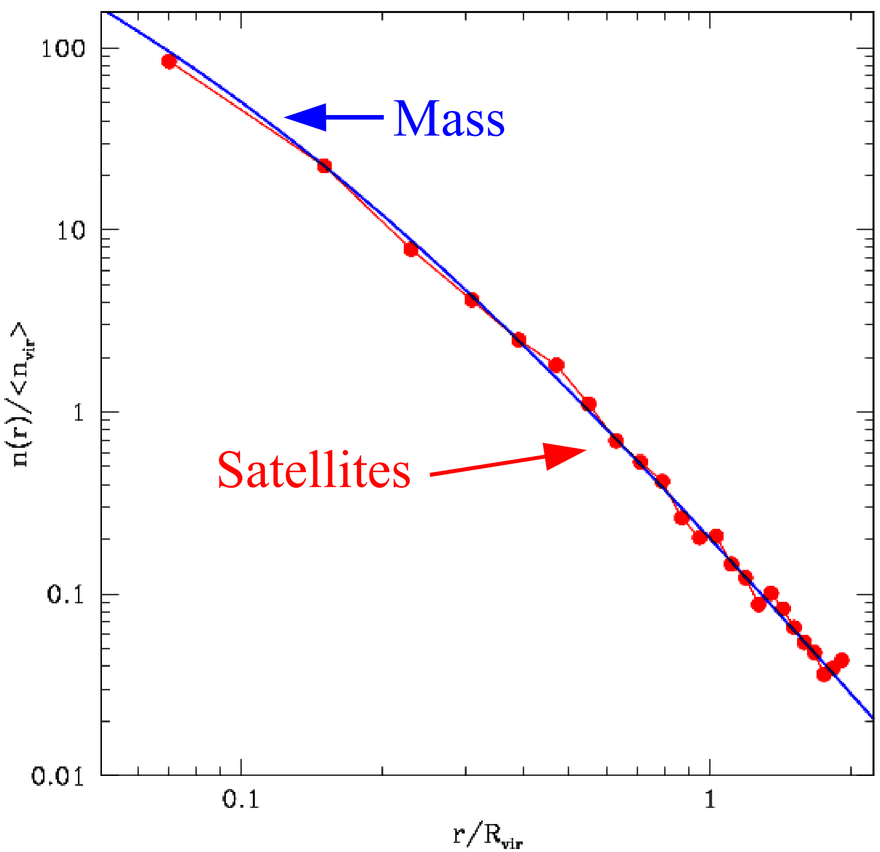


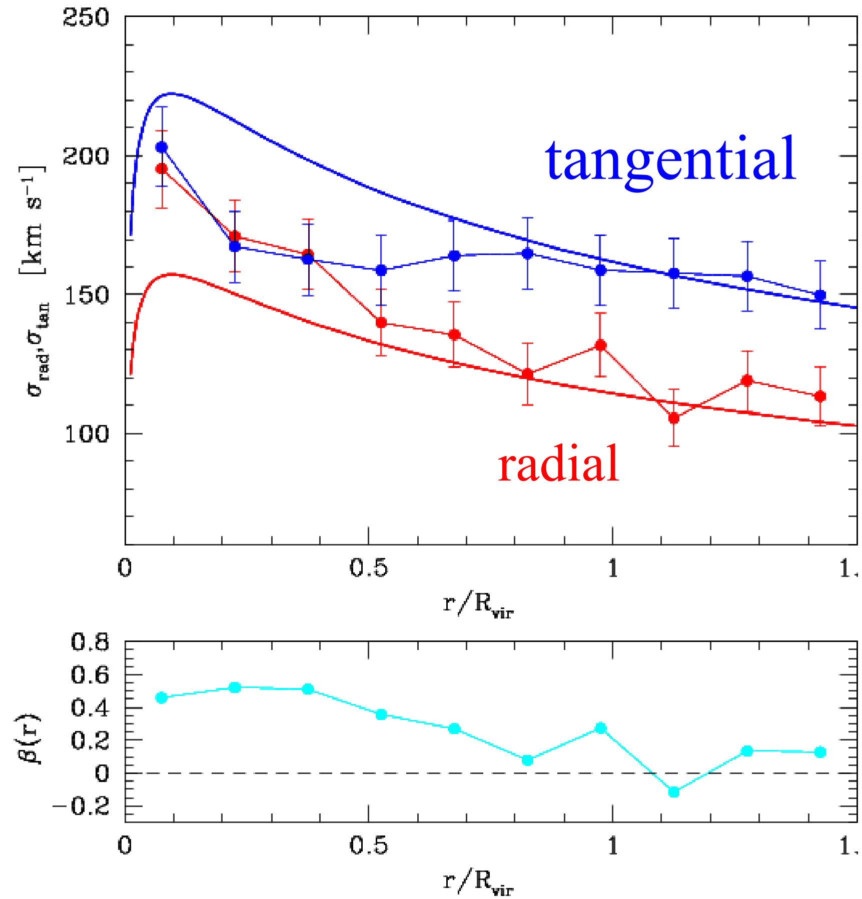
Precise estimates of autocorrelation functions
Luminous red galaxies in the M.S.

From public Millennium Simulation data archive



Satellite distributions around MW-like galaxies



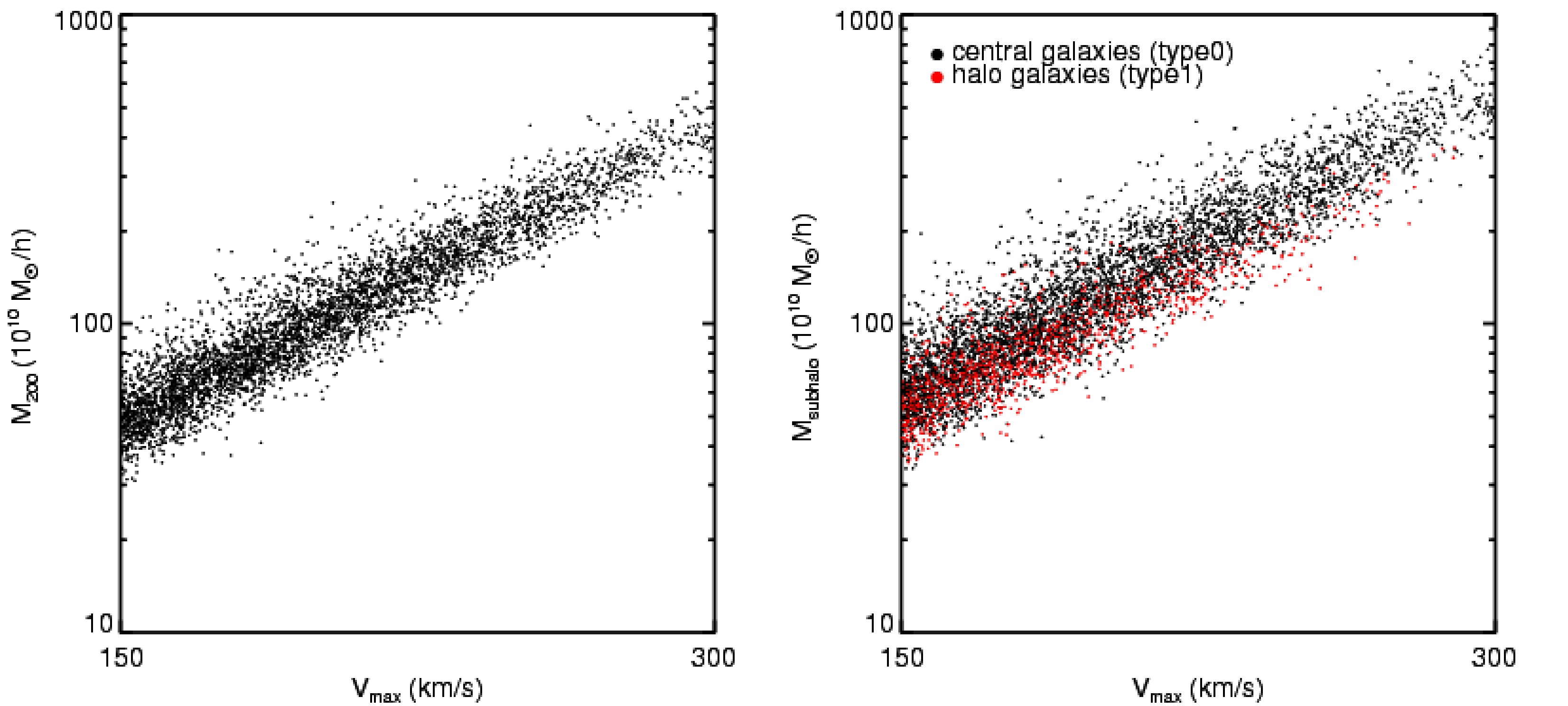


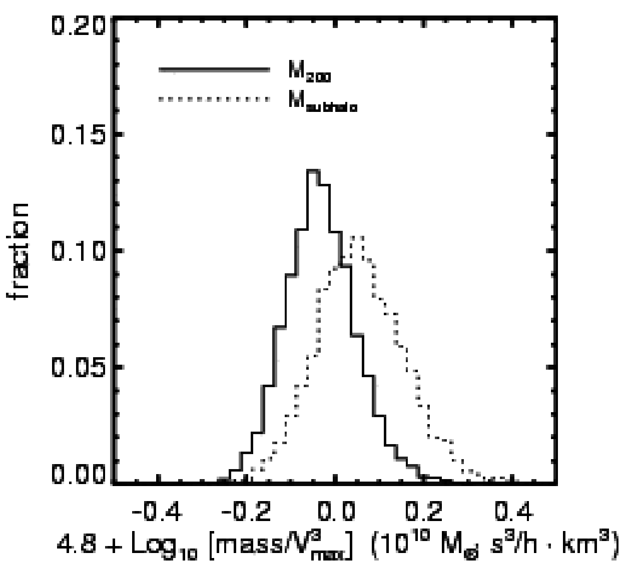
- Host galaxies: $-19.8 > M_B > -20.2$, $B/T < 0.3$, isolated
- Satellites: $-15.6 > M_B > -18.0$, $\langle N_{sat} \rangle = 2.0$ at $r < 2R_{vir}$
- About 20,000 hosts in the Millennium Simulation
- Mass profile mirrored *only* if satellites without subhalos are included

Statistics of "Milky Ways" and "Local Groups"

	$200 < V_{max} < 250$	$150 < V_{max} < 300$
Central galaxies of halos or subhalos		
Number of galaxies	166,090	699,177
$0.3 > B/T > 0.1$	62,605	271,857
Pairs of such galaxies		
500 kpc < D < 1.0 Mpc	1,596	23,429
$0.3 > B/T > 0.1$	241	3,532
Isolated pairs of such galaxies		
D_{next} >1.0 Mpc	1,165	17,276
$0.3 > B/T > 0.1$	181	2,903
Isolated pairs with LG-like separation velocity		
$-60 > V_{sep} > -180$	778	8,814
$0.3 > B/T > 0.1$	118	1,325

Estimating halo masses from V_{max}





- Both the "virial mass" (M_{200}) and the bound subhalo mass correlate tightly with V_{max}
- Scatter is less than 0.1 dex r.m.s.
- V_{max} is close to the level of observed rotation curve at large radii for standard disk models

Does the Timing Argument work?

Kahn & Woltjer's (1959) timing argument treats the MW/M31 system as two point masses on a radial orbit approaching for the first time.

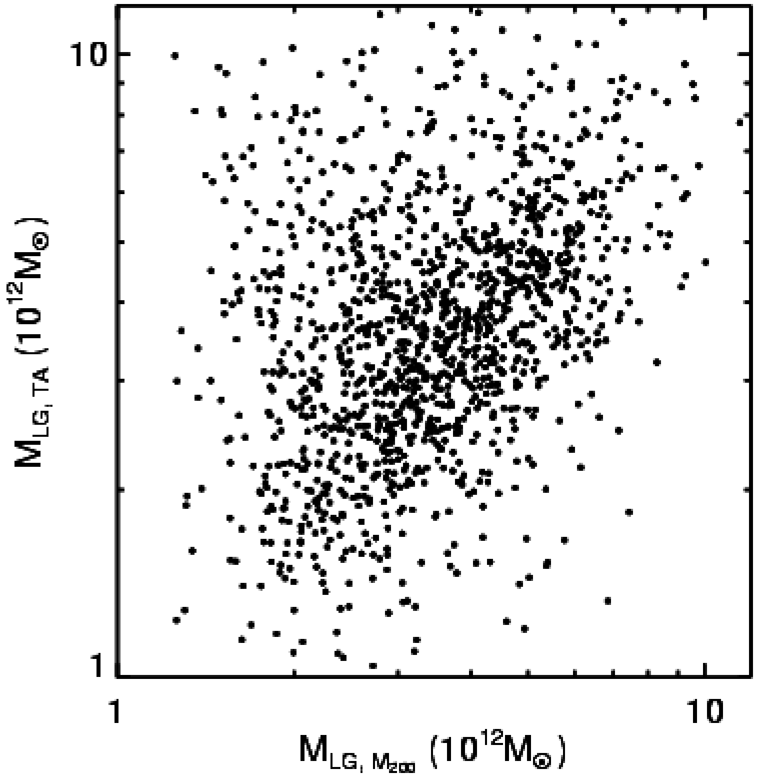
Then observed separation (700 kpc), relative velocity (-120 km/s) and the current time (13.6 Gyr)

→ The orbital phase, semi-major axis and total mass

This gives $M(MW) + M(M31) = 4.1 \times 10^{12}\ M_\odot$

- This is a lower limit if one allows for transverse motion
- The real mass distributions are extended – what mass is measured?
- How well does this work for "realistic" mass distributions?

Mass from the Timing Argument



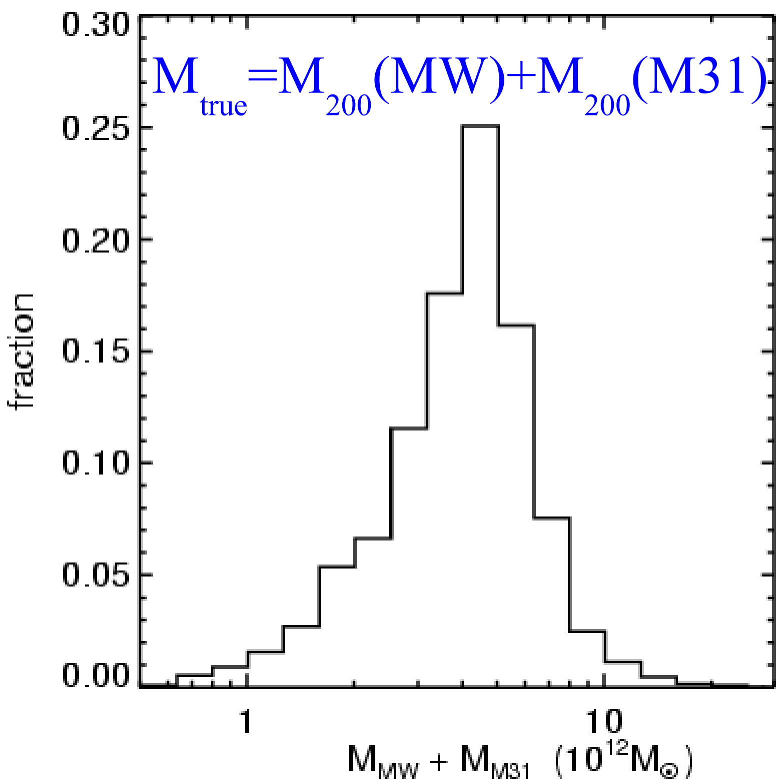
M_{200}(MW) + M_{200}(M31)

Scatter in TA mass vs "true" mass for the LG

- Isolated pairs with 500 kpc < D < 1.0 Mpc
- 0.3 > B/T > 0.1 for both galaxies
- 150 km/s < V_{max} < 300 km/s for both galaxies
- -60 km/s > V_{sep} > -180 km/s

1325 pairs

Local Group "Timing Argument" mass estimates with a ΛCDM prior



Find ratio of the true mass to the "Timing Argument" estimate for each Millennium Simulation pair

Multiply by the TA estimate for the Local Group based on
D = 700 kpc
V = -123 km/s
t = 13.6 Gyr
i.e. $M_{TA} = 4.1 \times 10^{12}\, M_\odot$

$1.49 \times 10^{12}\, M_\odot < M_{true} < 7.82 \times 10^{12}\, M_\odot$ at 90% confidence

Note: M_{200} is measured at radius $R_{200} = 207\, (M_{200}/10^{12}\, M_\odot)^{1/3}$ kpc

How about the Timing Argument for Leo I?

Leo I is at a distance of 230 kpc from the Milky Way and is moving away at 177 km/s. In a simple radial orbit model it must have completed a full orbit and be approaching apocentre for the 2^{nd} time.

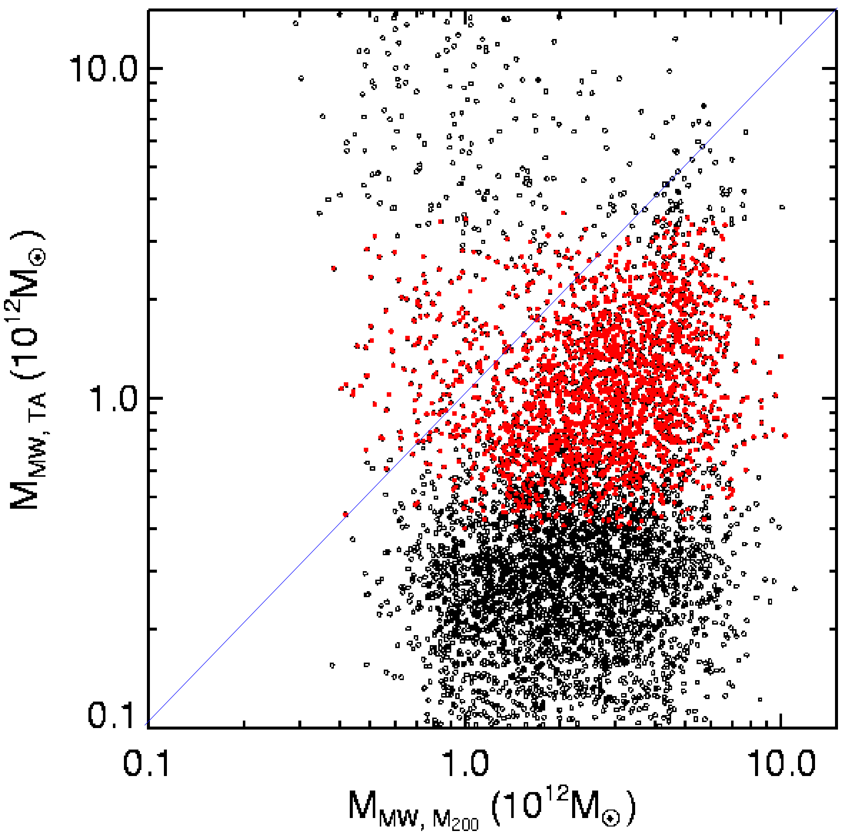
In this case the observed quantities + the system age (13.6 Gyr) $\longrightarrow$ The orbital phase, semi-major axis and MW mass

This gives $M(MW) = 1.4 \times 10^{12}\ M_\odot$

As before --

- This is a lower limit if one allows for transverse motion
- The real mass distributions are extended – what mass is measured?
- How well does this work for “realistic” mass distributions?

Mass from the Timing Argument

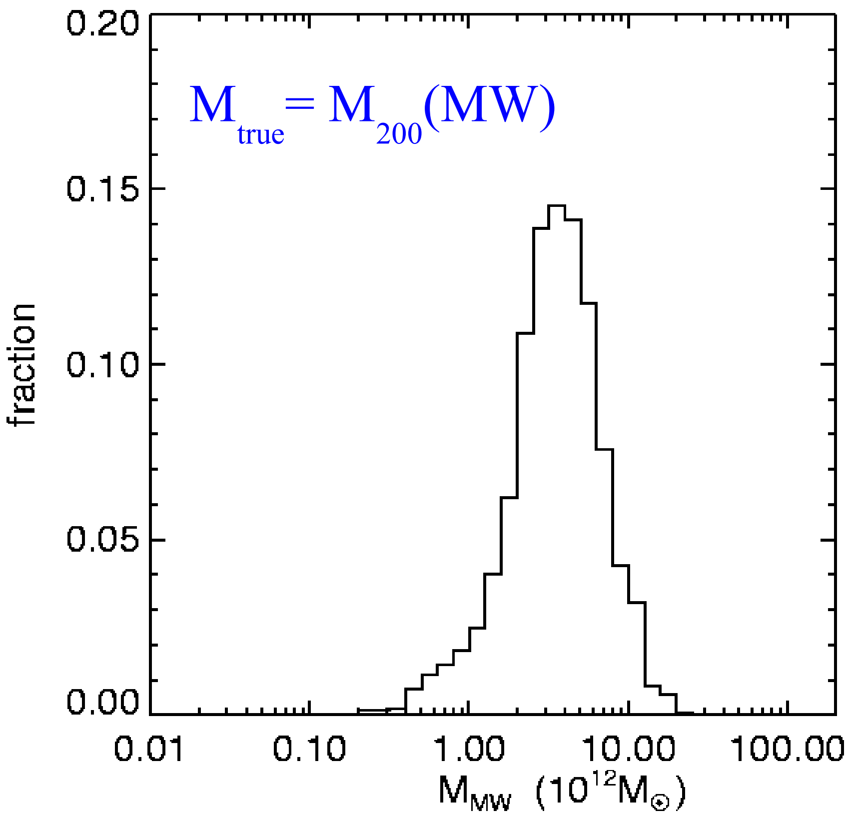


M_{200}(MW)

Scatter in TA mass vs "true" mass for the MW

- Isolated host with no massive companions at D < 700 kpc
- Host 0.3 > B/T > 0.1 and 150 km/s < V_{max} < 300 km/s
- Satellite with V_{max} < 80 km/s and M_B < -16.75
- V_{sep} positive, or 270 km/s > V_{sep} > 90 km/s

Milky Way "Timing Argument" mass estimates with a ΛCDM prior



Find ratio of the true mass to the Timing Argument estimate for each Millennium Simulation "MW"

Multiply by the TA estimate for the real MW based on
D(LeoI) = 230 kpc
V = +177 km/s
t = 13.6 Gyr
i.e. $M_{TA} = 1.4 \times 10^{12} M_\odot$

$0.9 \times 10^{12} M_\odot < M_{true} < 10.0 \times 10^{12} M_\odot$ at 90% confidence

The TA mass estimate is usually a substantial underestimate

GERMAN ASTROPHYSICAL GAVO VIRTUAL OBSERVATORY

Exploring the milli-Millennium simulation with a relational database

Documentation


```
select D.I_HALO,
       D.SNAPNUM,
       D.N_P as D_NP,
       P1.N_P as P1_NP,
       P2.N_P as P2_NP
  from HALO P1,
       HALO P2,
       HALO D
 where P1.SNAPNUM=P2.SNAPNUM
   and P1.I_HALO < P2.I_HALO
   and P1.I_DESCENDANT = D.I_HALO
   and P2.I_DESCENDANT = D.I_HALO
   and P1.N_P >= .2*D.N_P
   and P2.N_P >= .2*D.N_P
   and D.N_P > 1000
```

Execute Query

Clear all

Help

http://www.g-vo.org

Maximum number of rows to return to the query form: 10

Previous queries :

Halo 1 | Galaxy 1 — Find halos/galaxies at a given redshift (SNAPNUM) within a certain part of the simulation volume (X,Y,Z).

Halo 2 — Find the whole progenitor tree, in depth-first order, of a halo identified by its id (I_HALO)

Halo 3 — Find the progenitors at a given redshift (SNAPNUM) of all halos of mass (N_P) greater than 4000 at a later redshift (SNAPNUM). The progenitors are limited to have mass >= 100.

Halo 4 — Find all the halos of mass (N_P) >= 1000 that have just had a major merger, defined by having at least two progenitors of mass >= 0.2*descendant mass.

Halo 5 | Galaxy 5 — Find the mass/luminosity function of halos/galaxies at z=0 using logarithmic intervals.

Galaxy 6 — Find the Tully-Fisher relation, Mag_b/v/i/k vs V_vir for galaxies with bulge/total mass ratio < 0.1. Subsample by about 1% (RANDOM between 20000 and 30000).

Reformat — CSV

Plot (VOPlot) — This button wil attempt to start up VOPlot within an applet, so that the current result can be explored graphically. This clearly requires that the browser has been configured for viewing applets.
DISCLAIMER This functionality has been partially tested only. Any problems are our responsibility, not VOPlot's.
It seems that the applet does not work properly with Konqueror.

Query time (in millisec) = 15623
Number of rows retrieved from database = 12 (Maximum # = 10000)

i_halo	snapnum	d_np	p1_np	p2_np
2576	60	1079	924	222