1) Large-scale distribution of galaxies

2) Bridging the gap between halos and galaxies:

z = 0

1Gpc

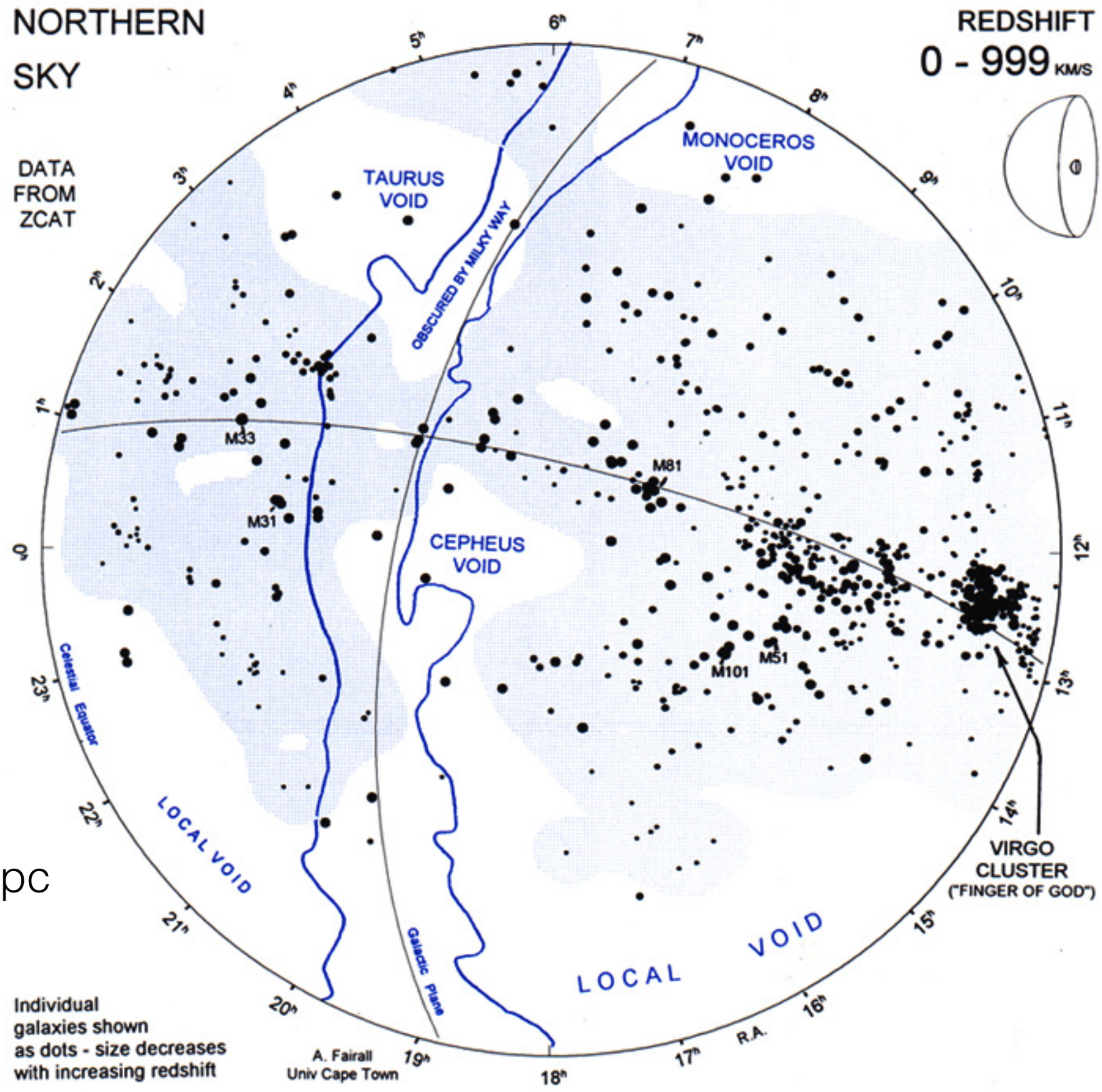
5Mpc slice

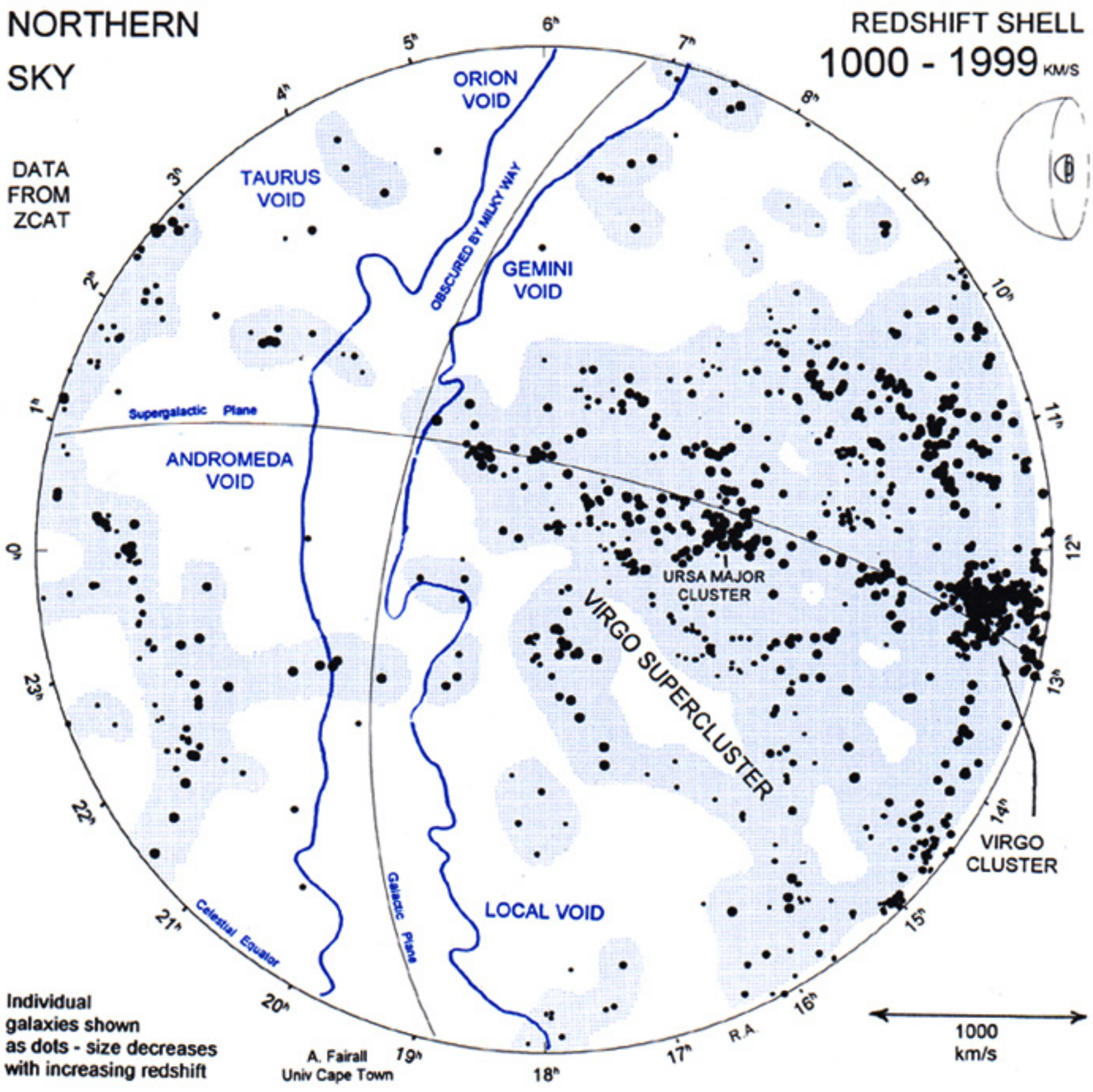
Distribution of galaxies around the Milky Way:

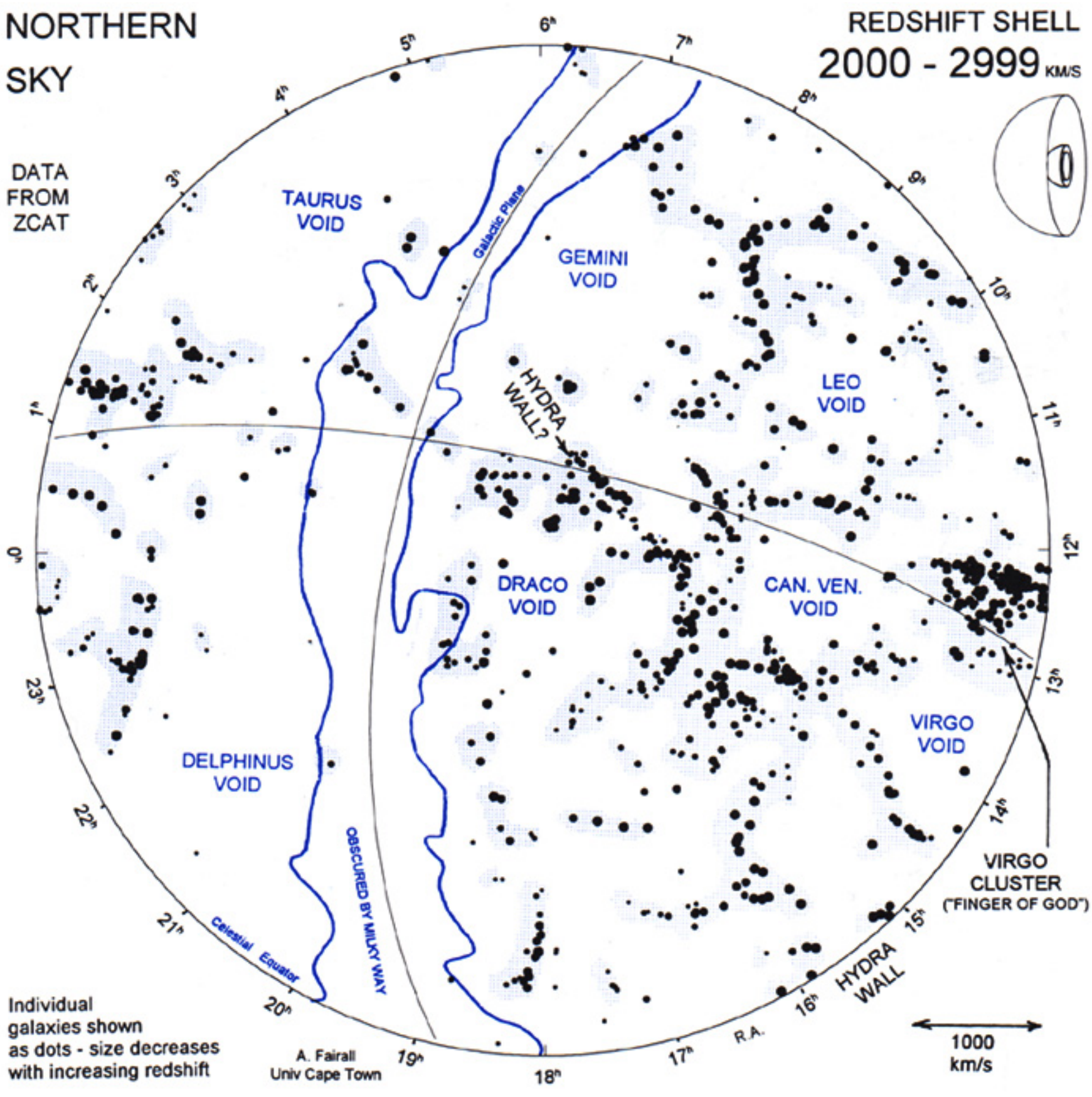
- Messy. Difficult to observe, but
- Shows details that can be missed in large pictures
- Lots of measurements

Projection

Distances <15 Mpc




NORTHERN SKY
REDSHIFT SHELL
1000 - 1999 KM/S
DATA FROM ZCAT
ORION VOID
TAURUS VOID
OBSCURED BY MILKY WAY
GEMINI VOID
Supergalactic Plane
ANDROMEDA VOID
URSA MAJOR CLUSTER
VIRGO SUPERCLUSTER
VIRGO CLUSTER
LOCAL VOID
Celestial Equator
Galactic Plane
R.A.
1000 km/s
Individual galaxies shown as dots - size decreases with increasing redshift
A. Fairall
Univ Cape Town


NORTHERN
SKY
REDSHIFT SHELL
2000 - 2999 KM/S
DATA
FROM
ZCAT
TAURUS
VOID
Galactic Plane
GEMINI
VOID
HYDRA
WALL?
LEO
VOID
DRACO
VOID
CAN. VEN.
VOID
VIRGO
VOID
DELPHINUS
VOID
OBSCURED BY MILKY WAY
Celestial Equator
VIRGO
CLUSTER
("FINGER OF GOD")
HYDRA
WALL
R.A.
1000
km/s
Individual
galaxies shown
as dots - size decreases
with increasing redshift
A. Fairall
Univ Cape Town

REDSHIFT

0 - 999 KMS

SOUTHERN SKY

DATA FROM SRC

MONOCEROS VOID

VOLANS VOID

CETUS VOID

CRATER VOID

LOCAL VOID

LOCAL VOID

CENTAURUS WALL

NGC 253

NGC 300

NGC 5128

M83

Galactic Plane

Supergalactic Plane

Celestial Equator

OBSCURED BY MILKY WAY

6h 7h 8h 9h 10h 11h 12h 13h 14h 15h 16h 17h 18h 19h 20h 21h 22h 23h 0h 1h 2h 3h 4h 5h R.A.

A. Fairall
Univ Cape Town

Large - scale Structures (galaxies closer than 200 km/s to each other) shown by stippling.

A SLICE OF THE UNIVERSE

VALÉRIE DE LAPPARENT,[2,3] MARGARET J. GELLER,[2] AND JOHN P. HUCHRA[2]

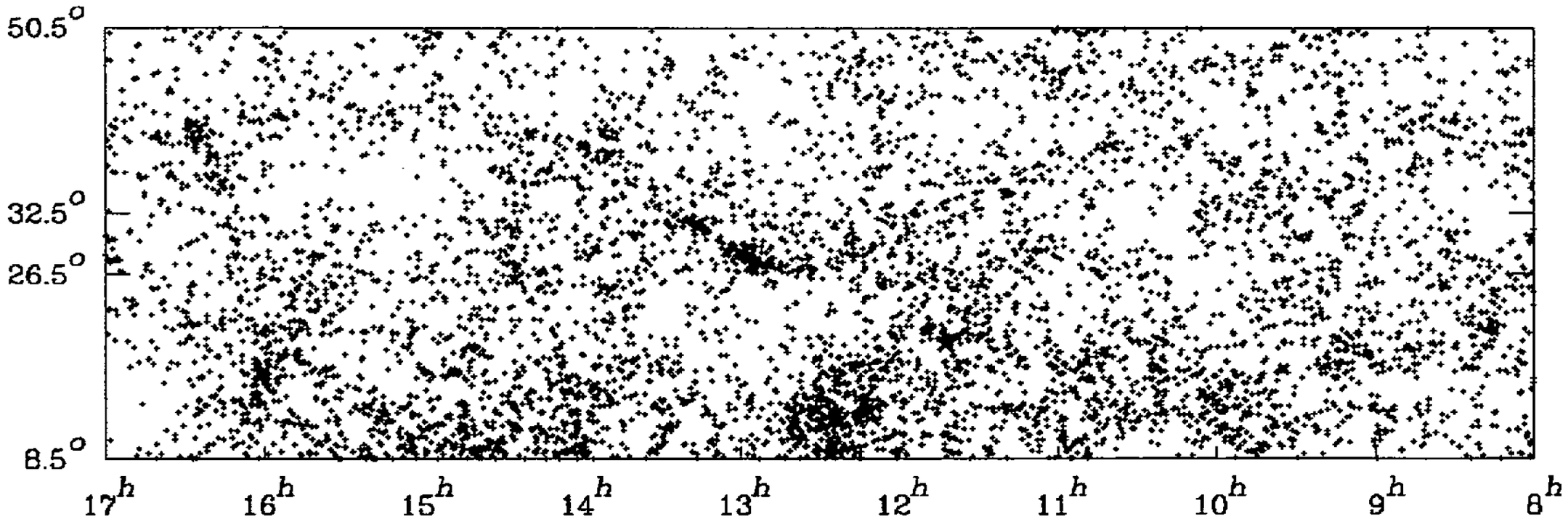
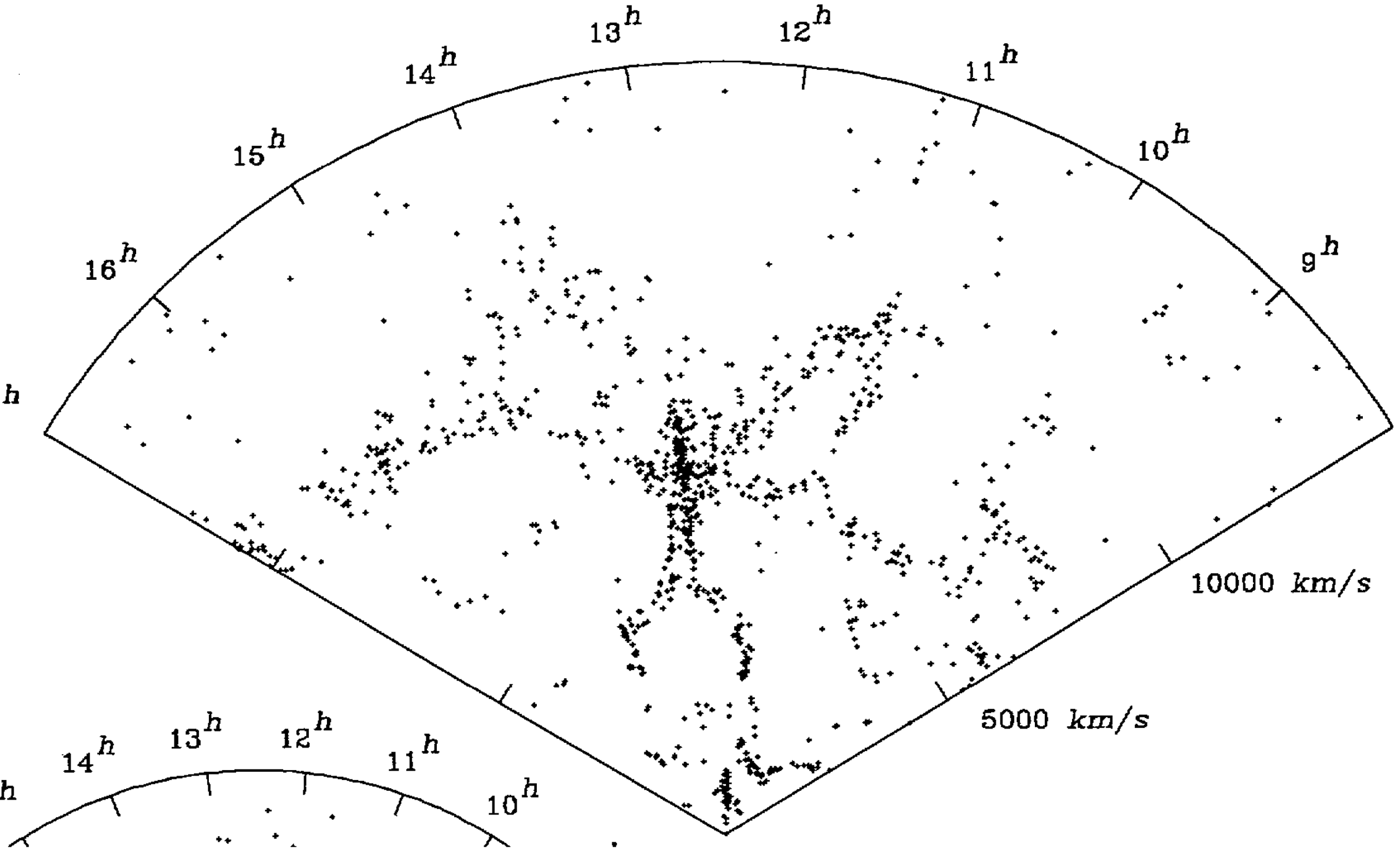


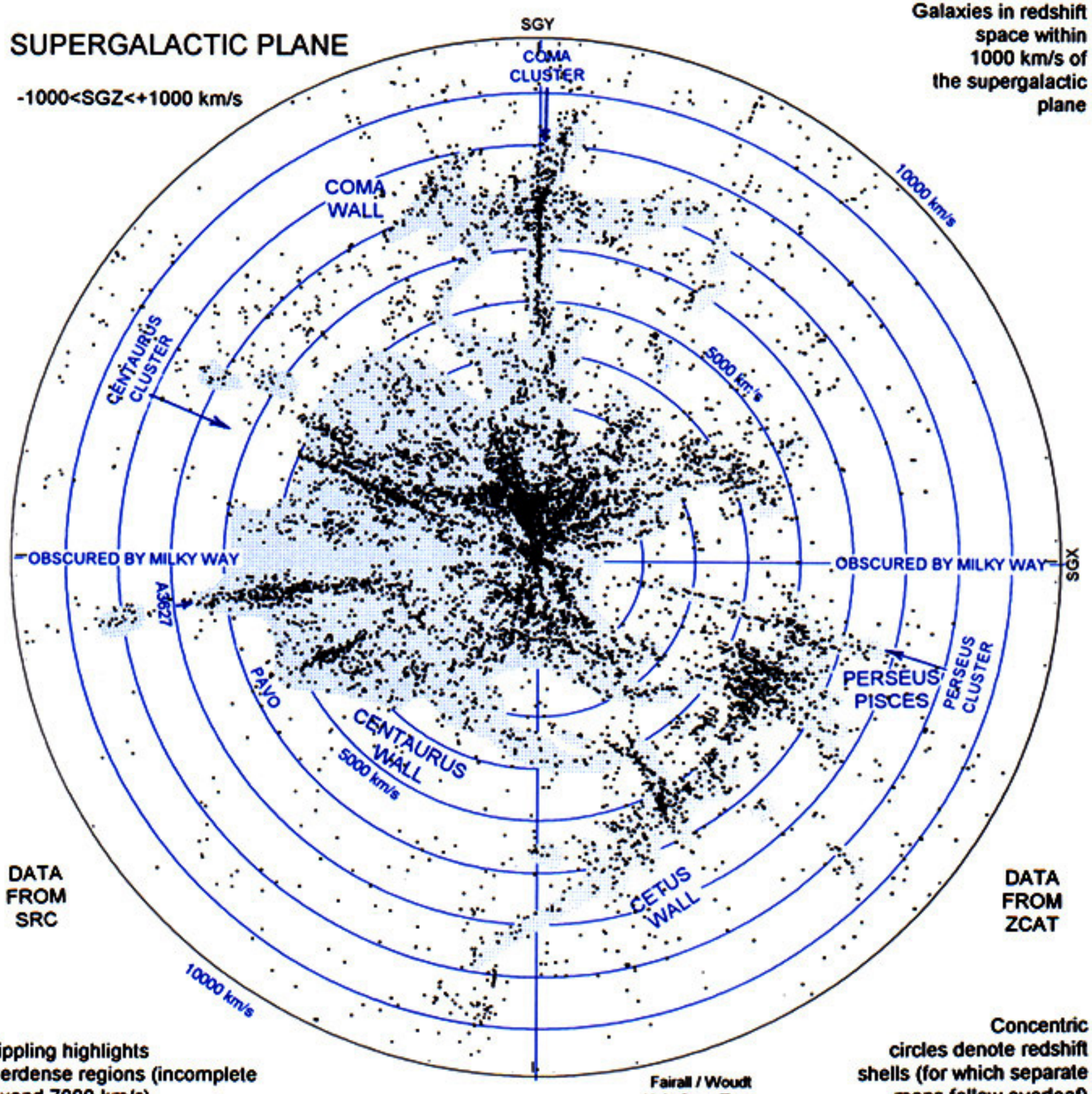
FIG. 1.—(*a*) Map of the observed velocity plotted vs. right ascension in the declination wedge $26°.5 \leq \delta \leq 32°.5$. The 1061 objects plotted have $m_B \leq 15.5$ and $V \leq 15{,}000$ km s^{-1}. (*b*) Same as Fig. 1*a* for $m_B \leq 14.5$ and $V \leq 10{,}000$ km s^{-1}. The plot contains 182 galaxies. (*c*) Projected map of the 7031 objects with $m_B \leq 15.5$, listed by Zwicky *et al.* in the region bounded by $8^h \leq \alpha \leq 17^h$ and $8°.5 \leq \delta \leq 50°.5$.


13^h
12^h
14^h
11^h
15^h
10^h
16^h
9^h
10000 km/s
5000 km/s
14^h
13^h
12^h
11^h
10^h

SUPERGALACTIC PLANE

-1000<SGZ<+1000 km/s

Galaxies in redshift space within 1000 km/s of the supergalactic plane



DATA FROM SRC

DATA FROM ZCAT

Stippling highlights overdense regions (incomplete beyond 7000 km/s)

Concentric circles denote redshift shells (for which separate maps follow overleaf)

Fairall / Woudt
Univ Cape Town

Local Supercluster:

- Distribution of light and mass
- Peculiar velocities (deviations from the Hubble flow)
- Voids

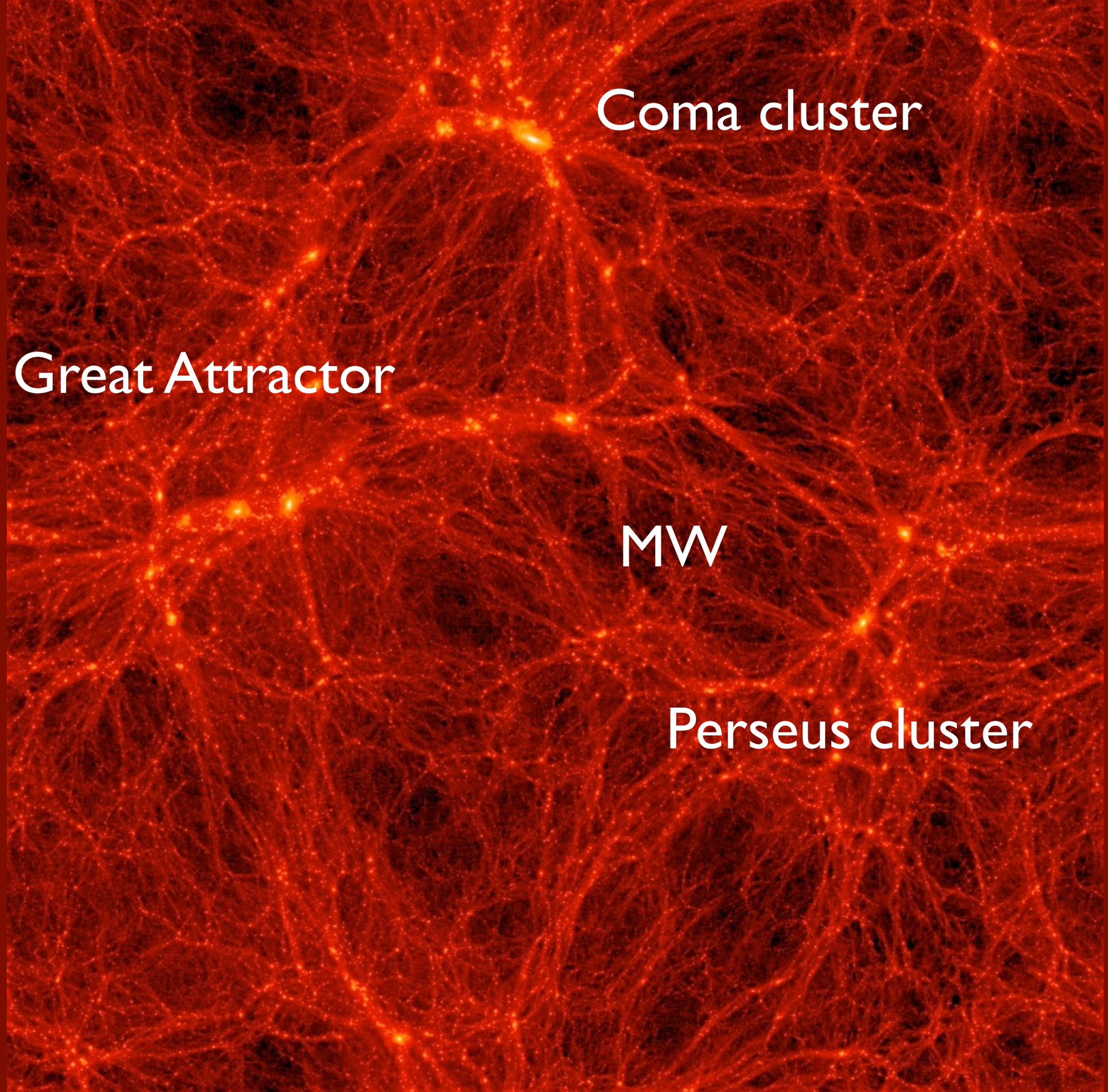
1G particles

Dynamical range 1e5

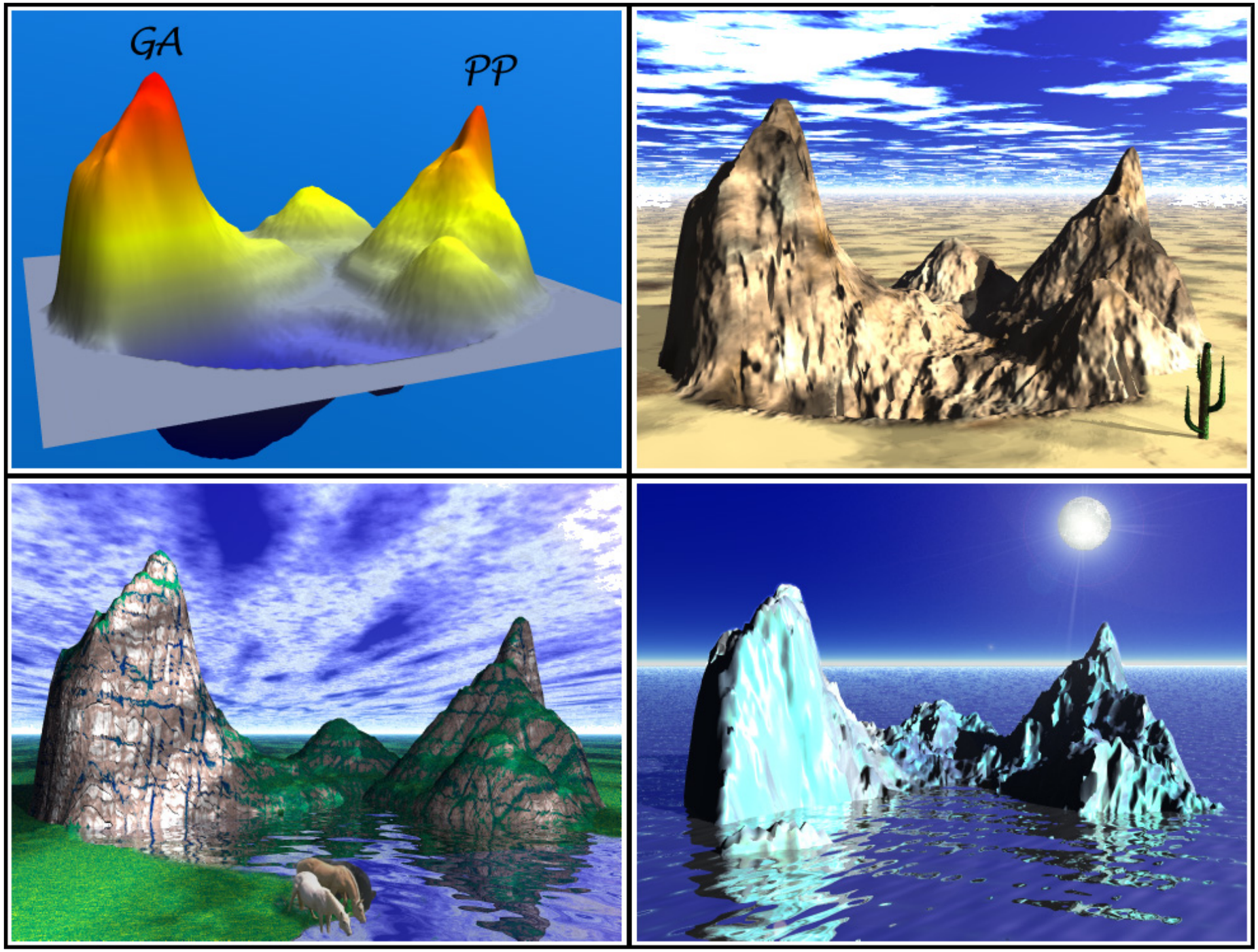
Constrained simulations

160 Mpc

Klypin, Hoffman, Gottlober

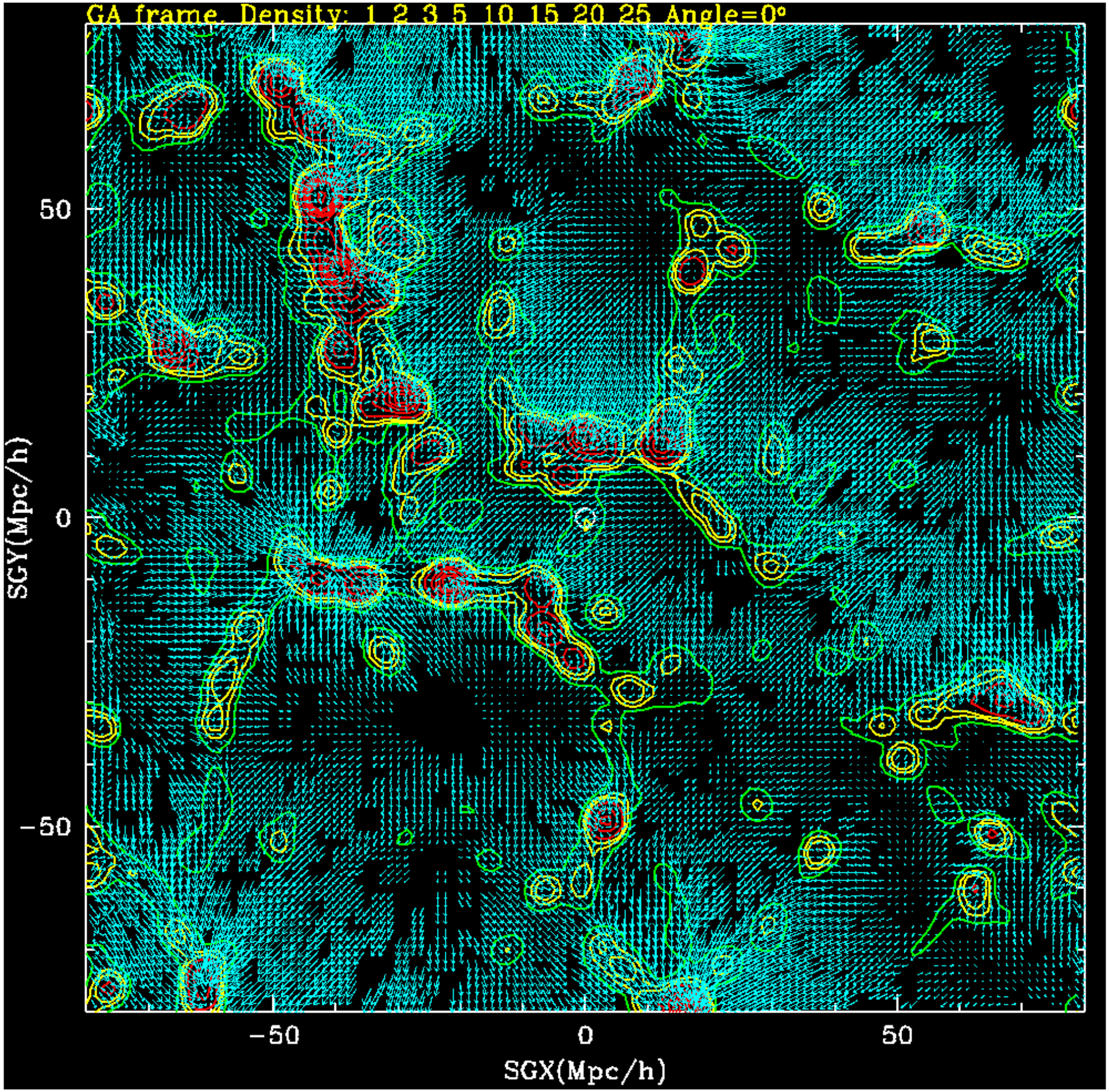


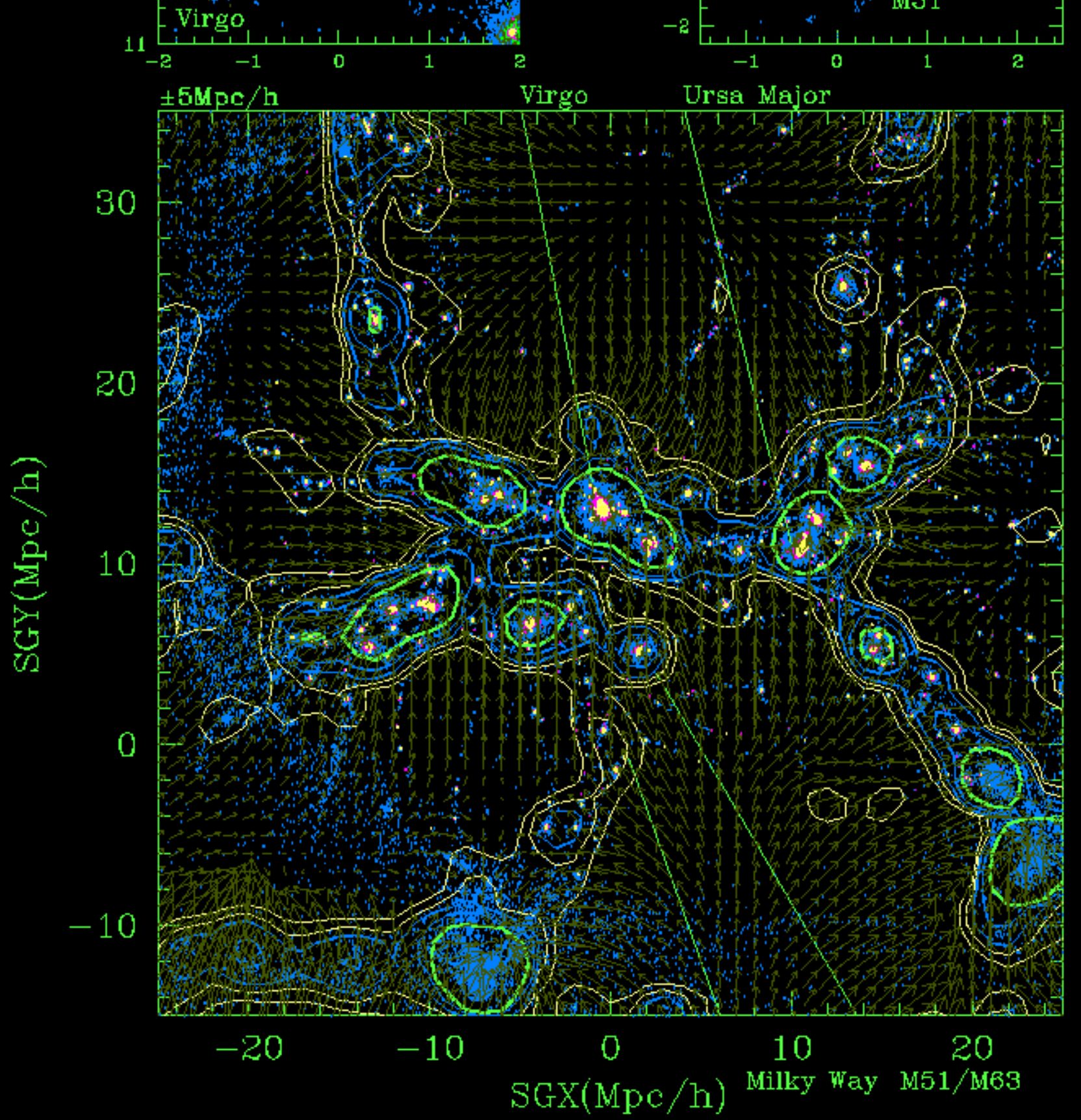
Landscape of the MW neighborhood: 80Mpc



Position of GA, Coma, Virgo, and Perseus-Pices. Our galaxy is a white circle at (0,0)

- Long waves (amplitudes and phases) are taken from observations.
- Small scale-perturbations and dynamics are for LCDM cosmological model
- N-body simulations at z=0




Virgo
M51
±5Mpc/h
Virgo
Ursa Major
30
20
10
0
−10
SGY(Mpc/h)
−20
−10
0
10
20
SGX(Mpc/h)
Milky Way
M51/M63

30
20
10
0
−10
SGY(Mpc/h)
−20
−10
0
10
20

Virgocentric frame. OverDensity: 1 2 3 5 10 15 20 25

30

20

10

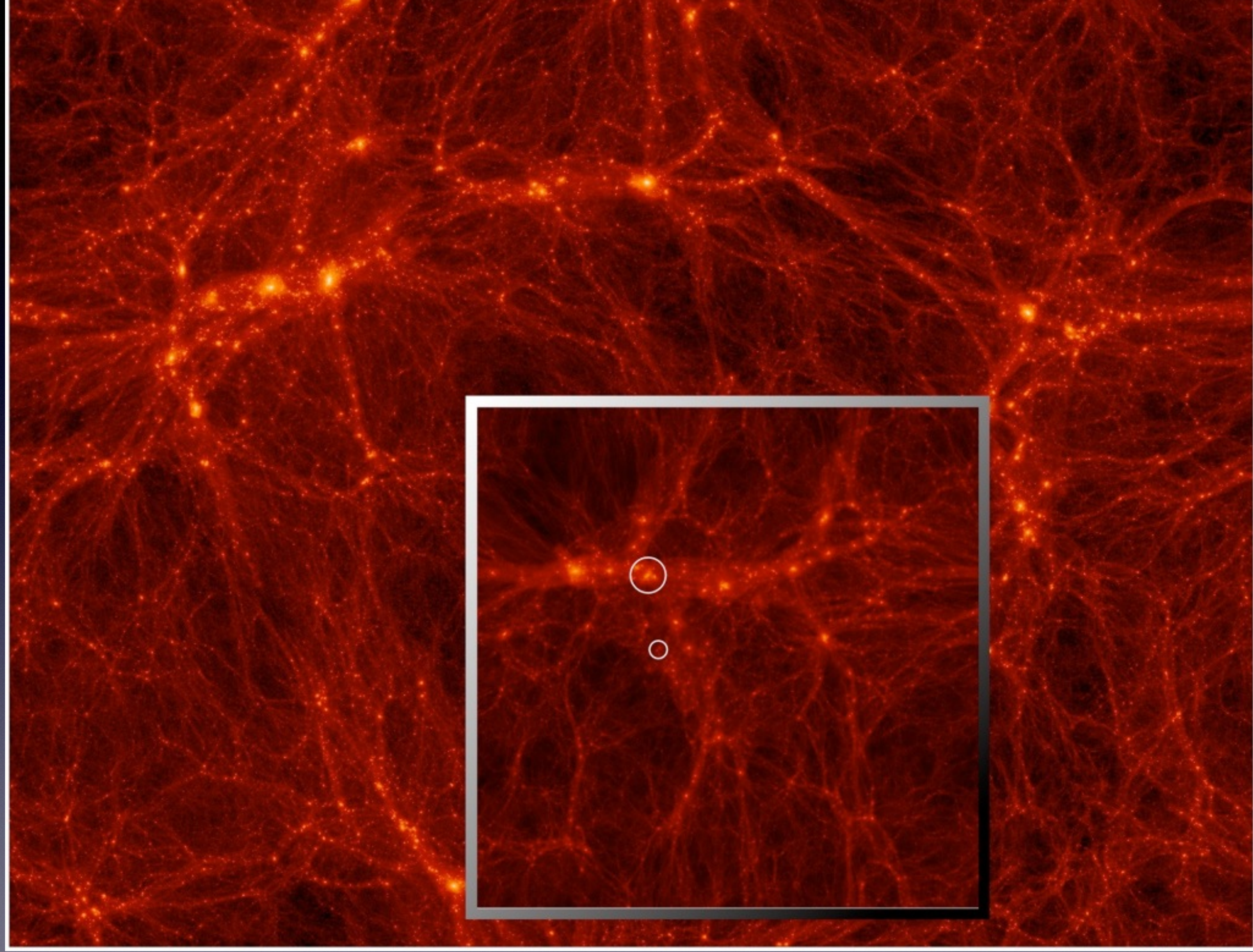
0

−10

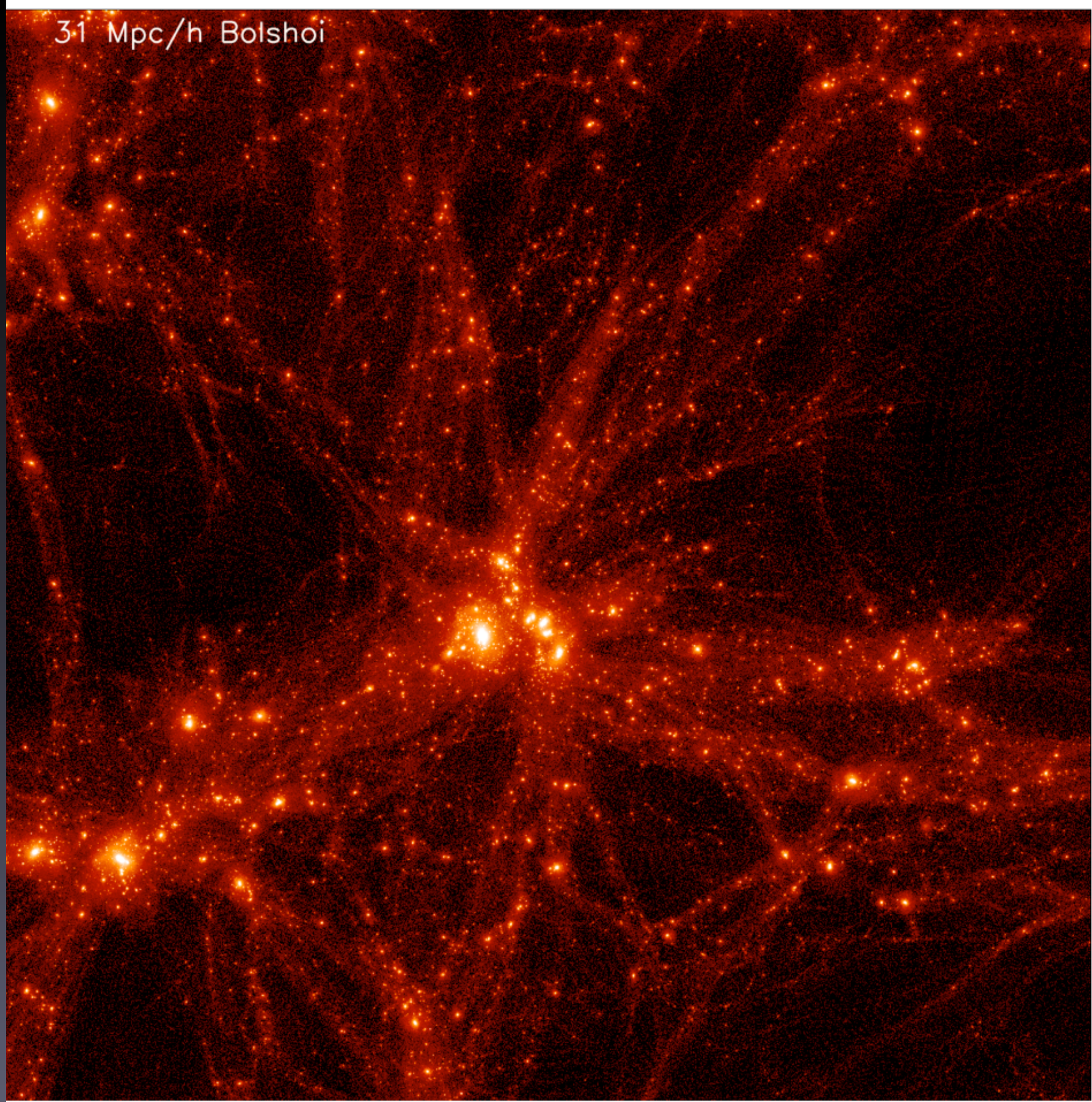
SGY(Mpc/h)

−20 −10 0 10 20

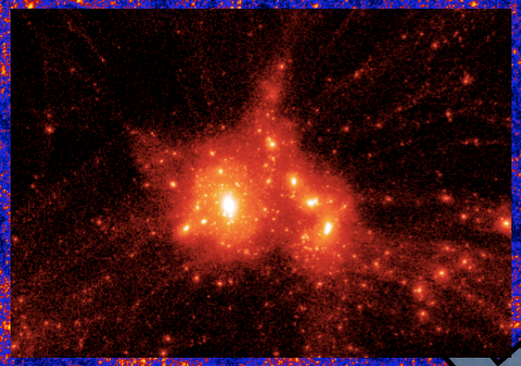
SGZ(Mpc/h)



Bridging the gap between halos and galaxies:


31 Mpc/h Bolshoi

Galaxy Formation and Metals in The Universe



Gas

GMC

SF

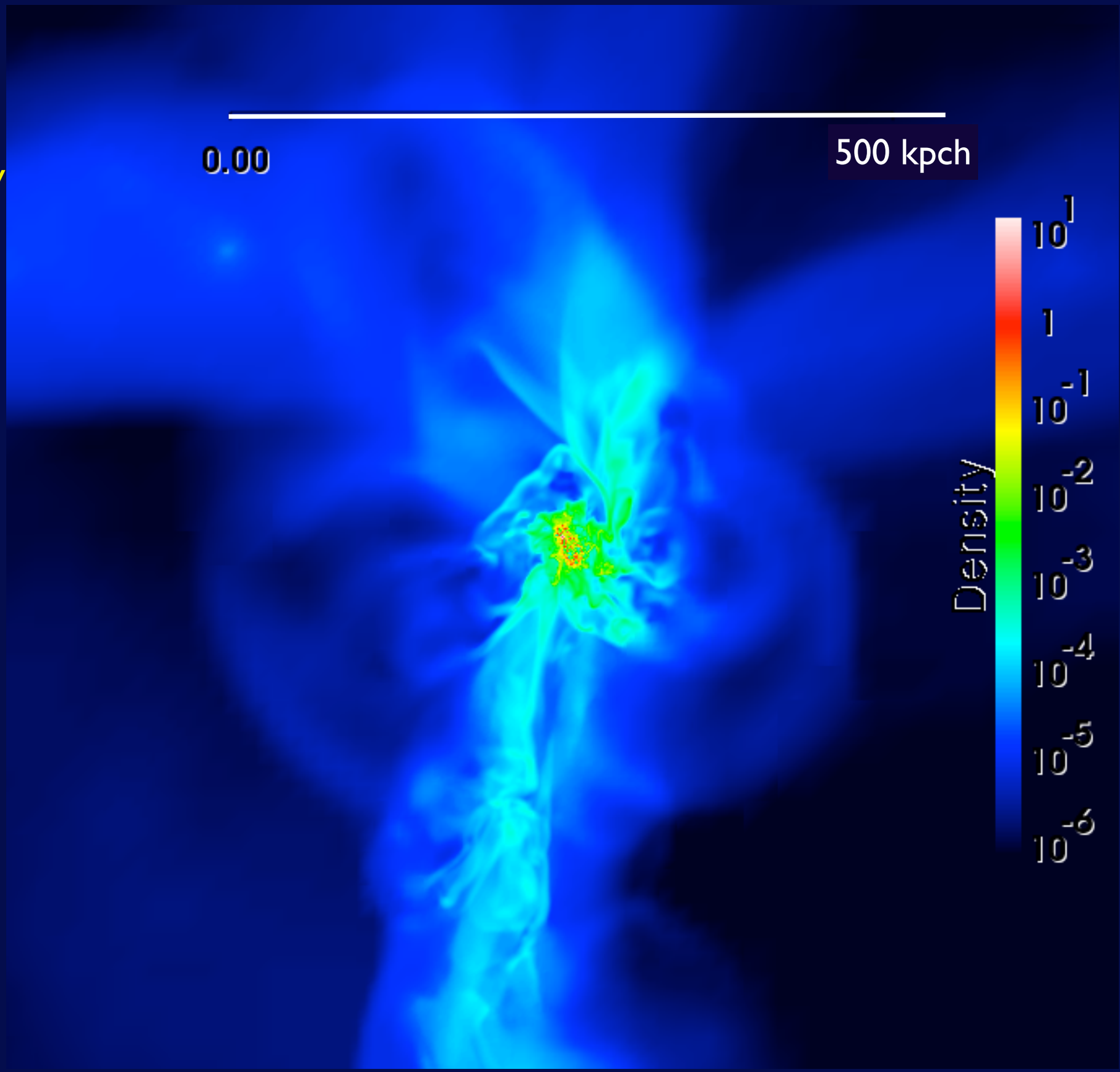
Z=1

Progenitor of M33-size galaxy

Radiation pressure + SN

~50 pc resolution

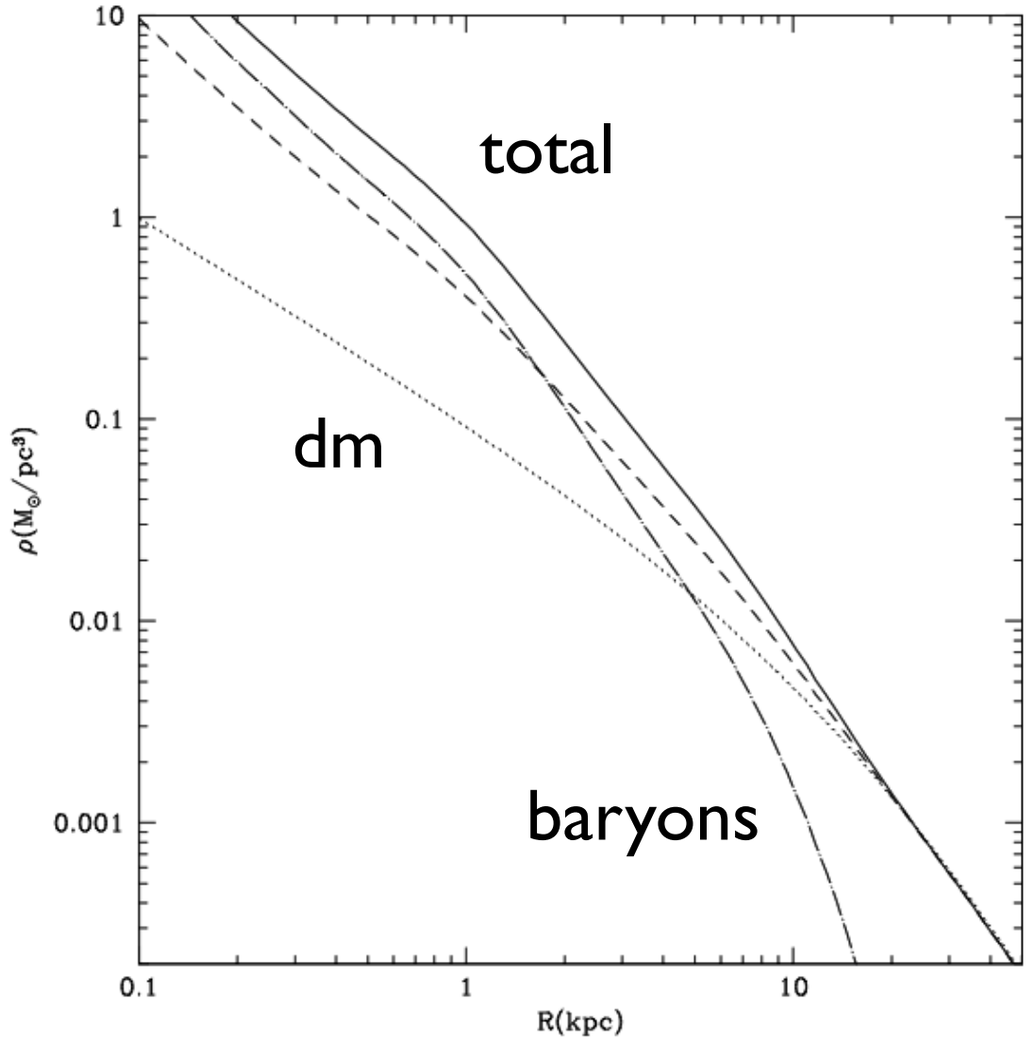
Gas density

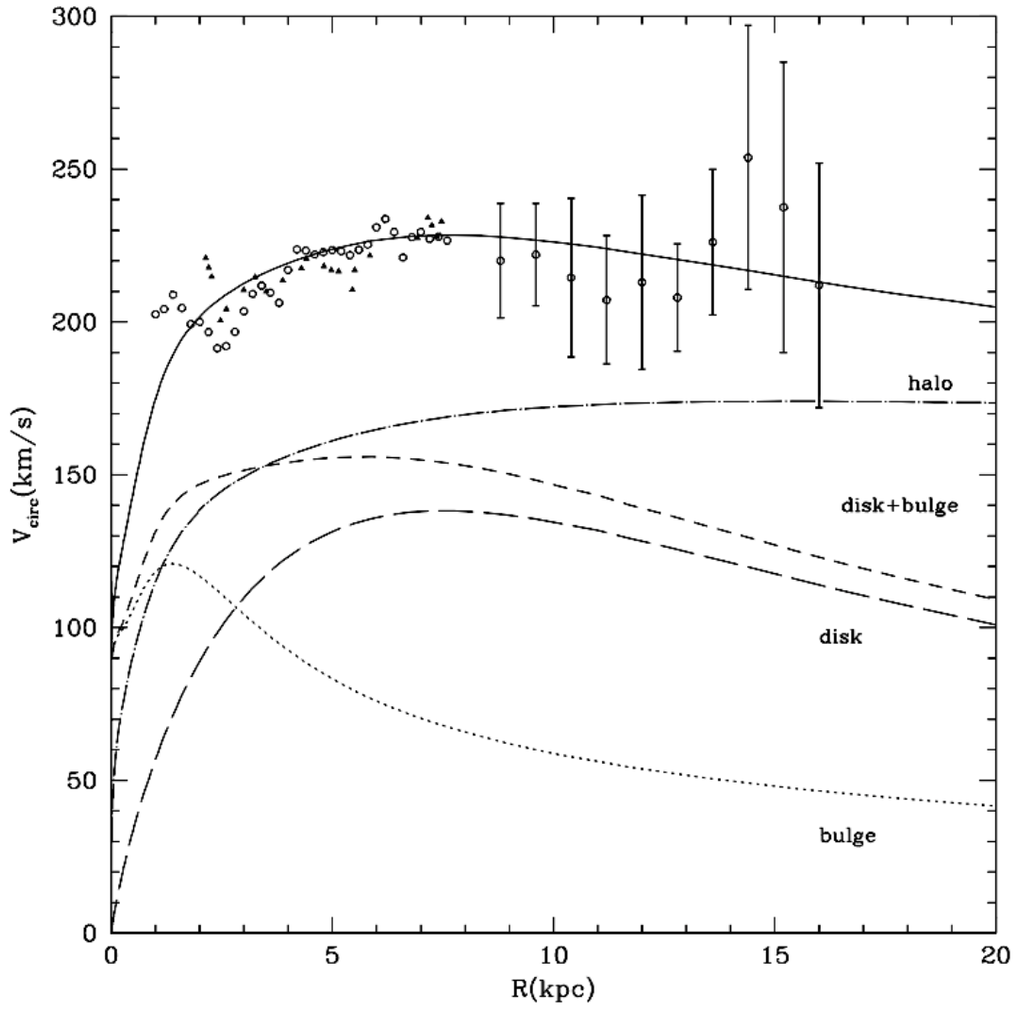


Trujillo-Gomez etal 2013

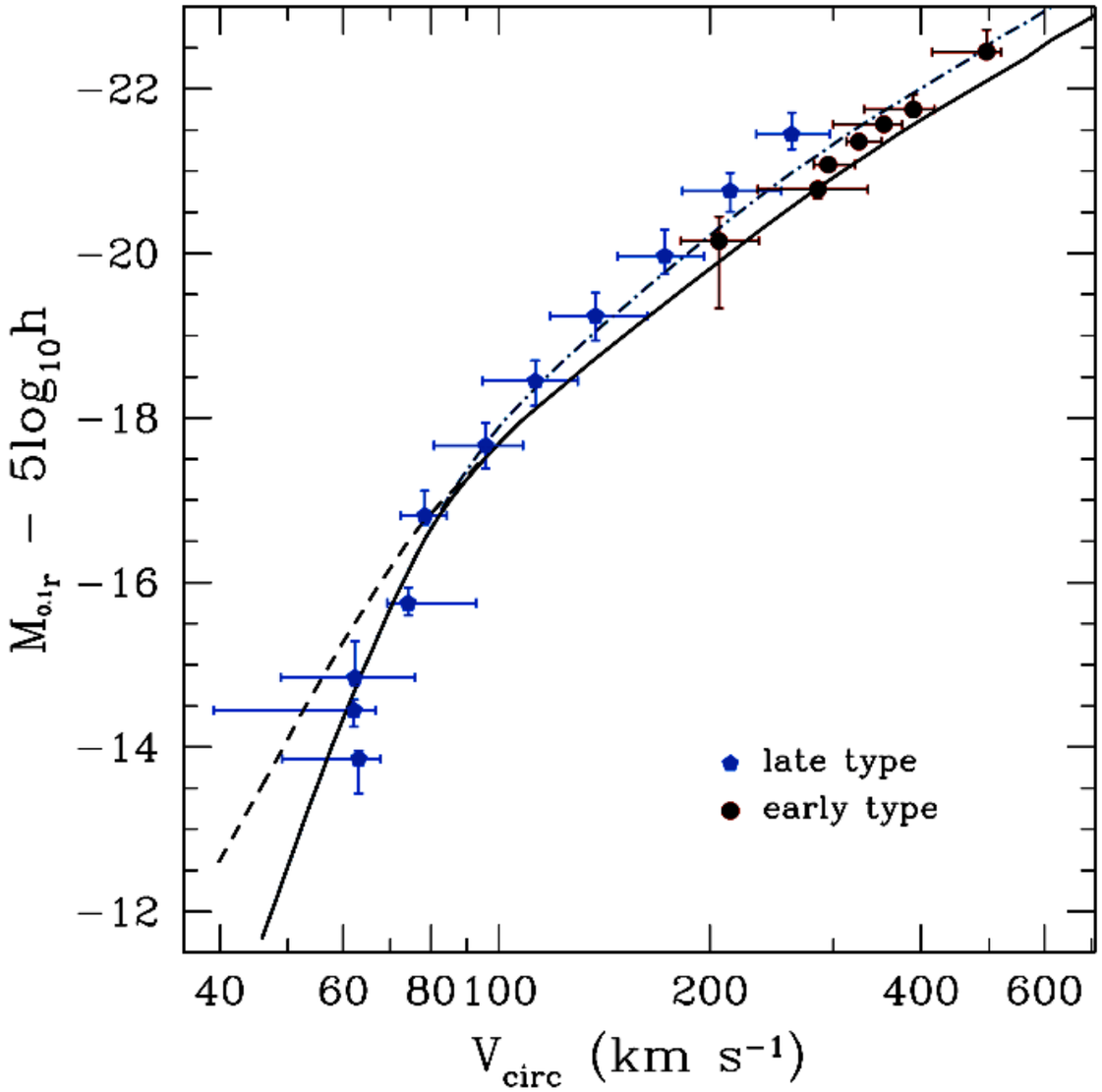
Bridging the gap between halos and galaxies:

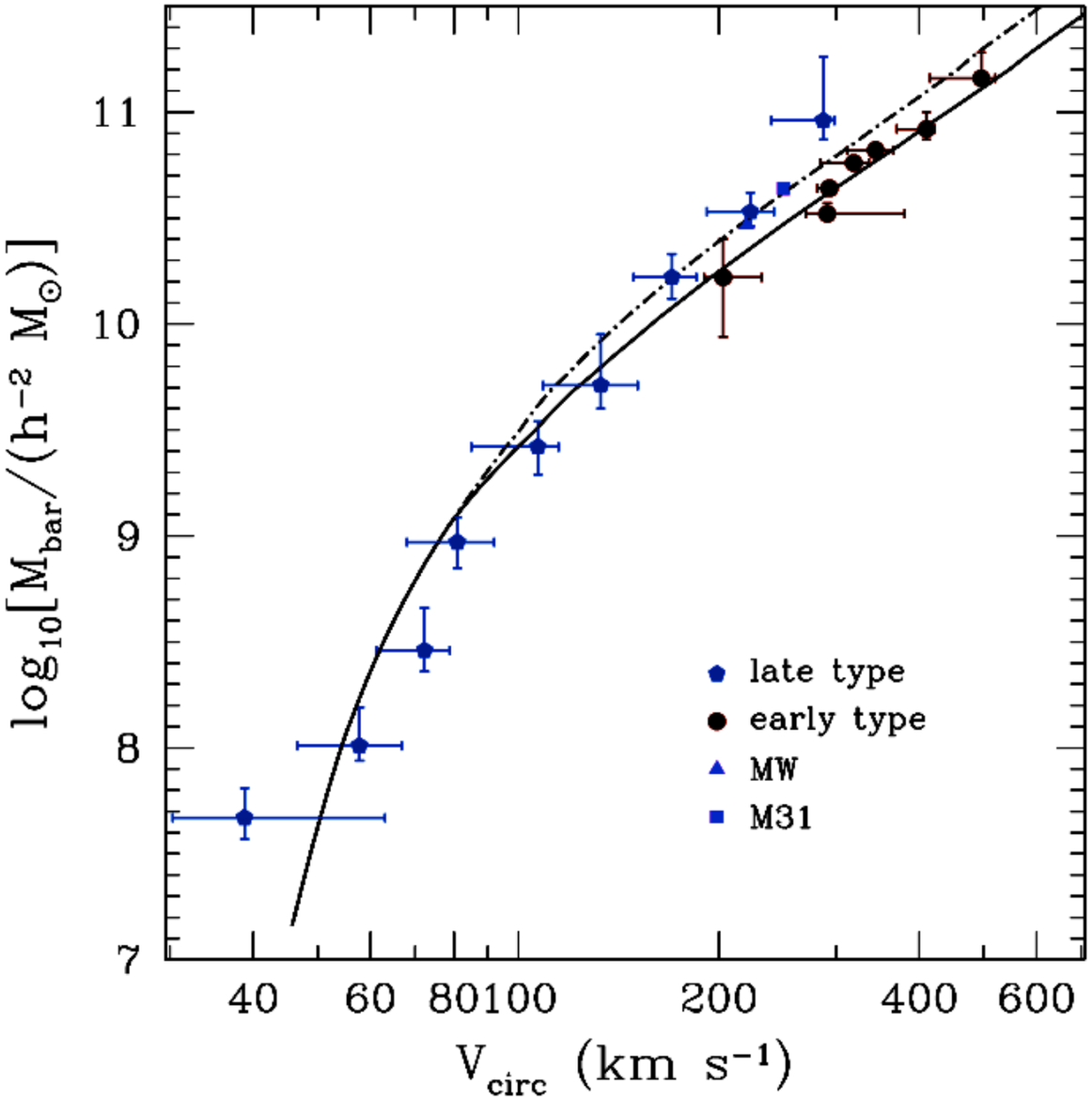
Milky Way: just an example of a dark matter distribution





Internal dynamics of galaxies: TF and BTF



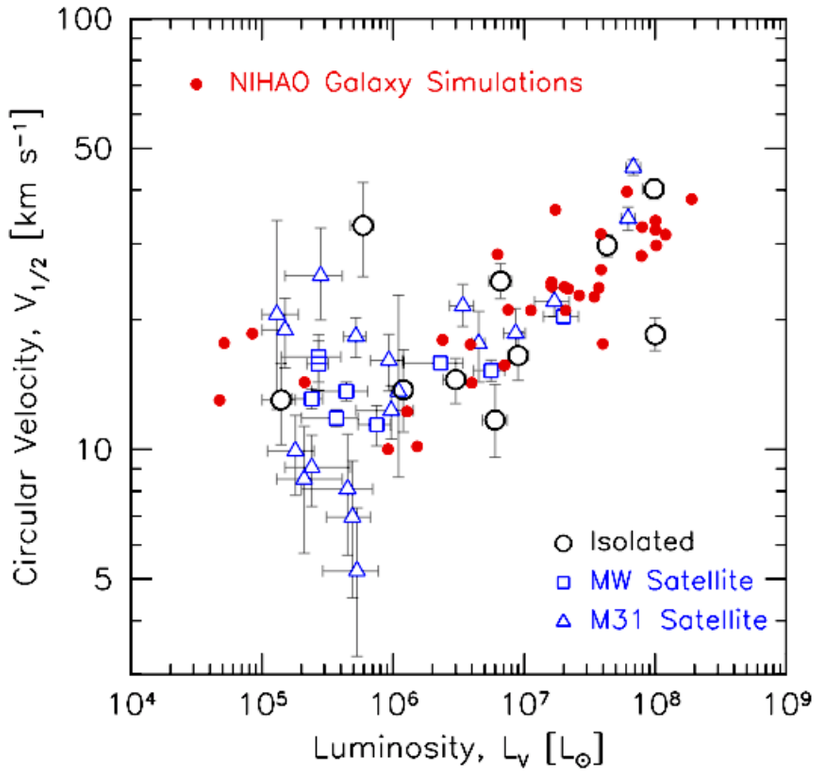


Halo Abundance matching: larger galaxies are hosted by bigger DM halos. No free parameters.

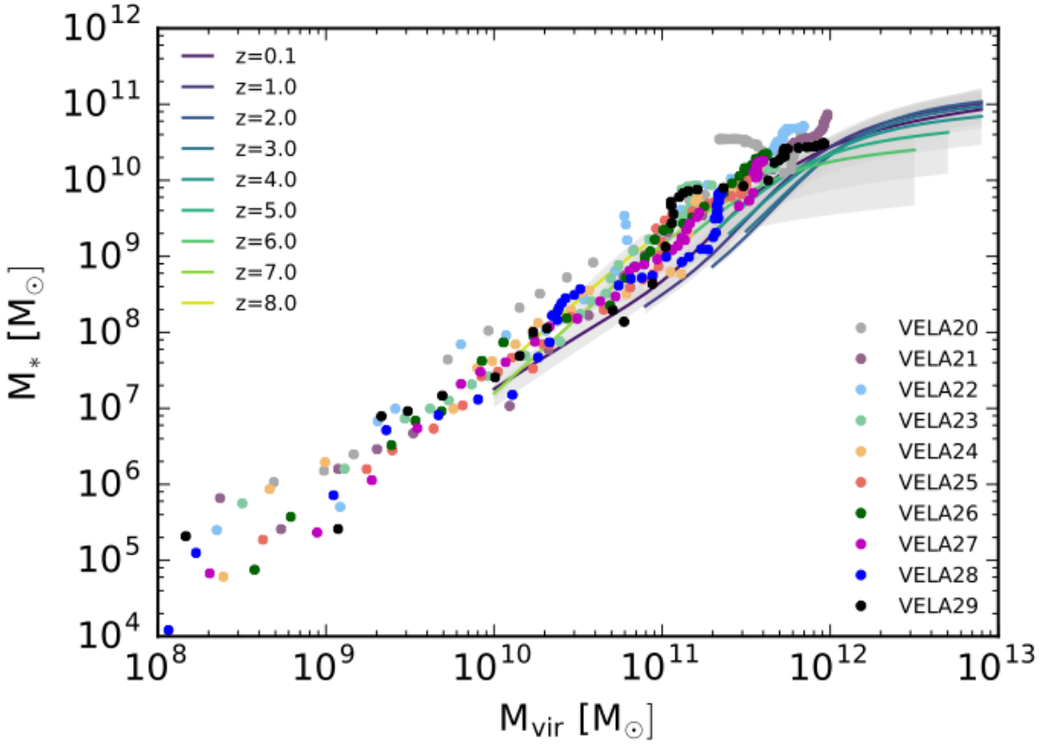
Trujillo-Gomez et al 2011

Too big doesn't fail

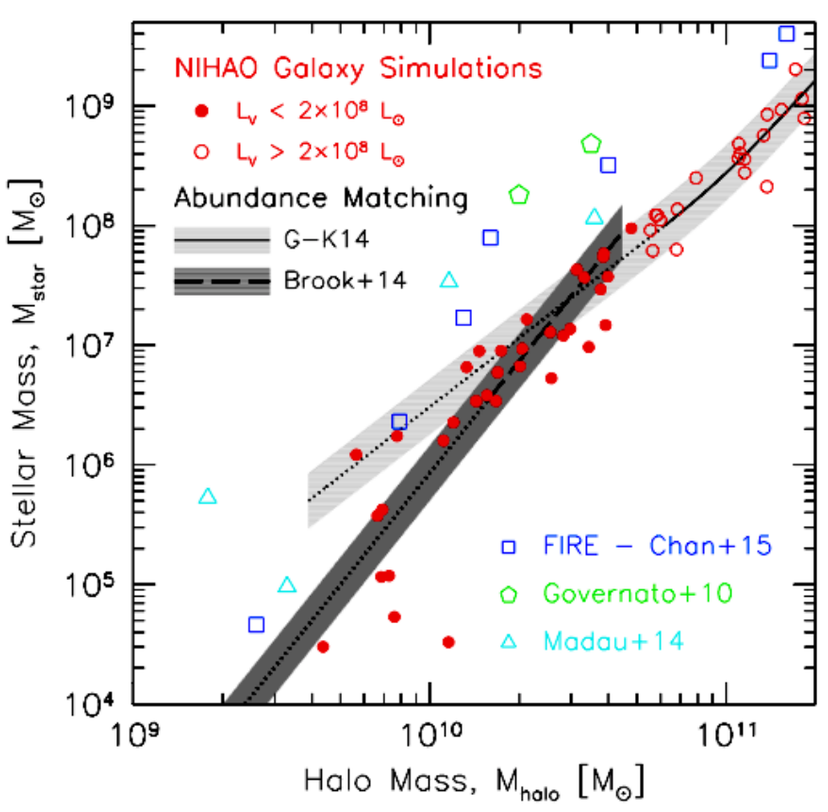
Hydro simulations: stellar mass and dark matter mass tightly correlate



Ceverino et al

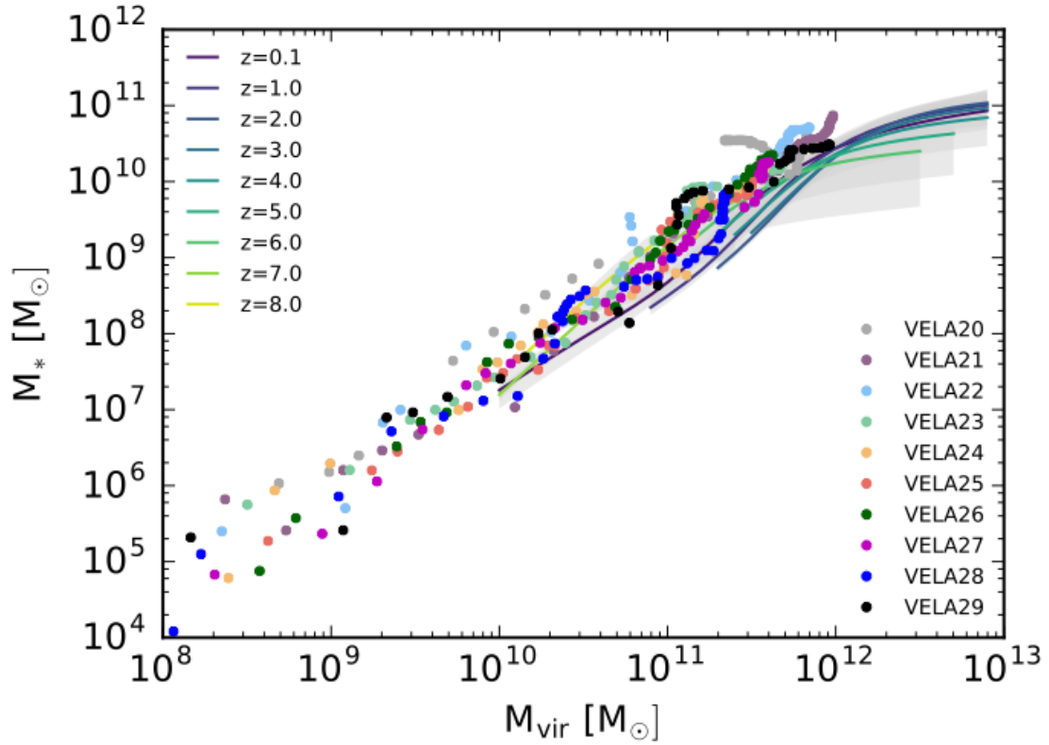


Dutton, Maccio et al



Lessons:

- Every galaxy is a dark matter halo
- No dark halos: if there is a dark matter concentration, it makes stars.



Bridging the gap between halos and galaxies:

Halo Occupation Distribution:

probability to find $N_{galaxies}$ in a distinct halo of mass M: $P(N_{galaxies}|M_{halo})$

- need to know how to get $P(N_{galaxies}|M_{halo})$
- need to know how to place 'galaxies'
- P(N|M) may depend on halo environment and dynamical state (e.g. merging ...)

Halo Abundance Matching (HAM):

- The biggest galaxy is hosted by the biggest halo and so on.
- There is some stochasticity between DM and stellar mass
- Subhalos must be resolved in simulations
- Needs merging trees of halos and subhalos

Bridging the gap between halos and galaxies:

- Halo Occupation Distribution
  - Depending on implementation:
    - tune parameters till clustering matches observations
    - use a simplified model to tidal striping+ dynamical friction
- Halo Abundance Matching
  - Less predictive because it borrows some observational results (luminosity function and stellar mass function).

Clustering: DM halos and L

Conroy, Wechsler, Kravtsov (2005): **N-body only**

- Get all halos from high-res simulation
- Use maximum circular velocity or mass
- Every halo (or subhalo) is a galaxy
- Every halo has luminosity: **LF is as in SDSS**
- No cooling or major mergers and such. Only DM halos

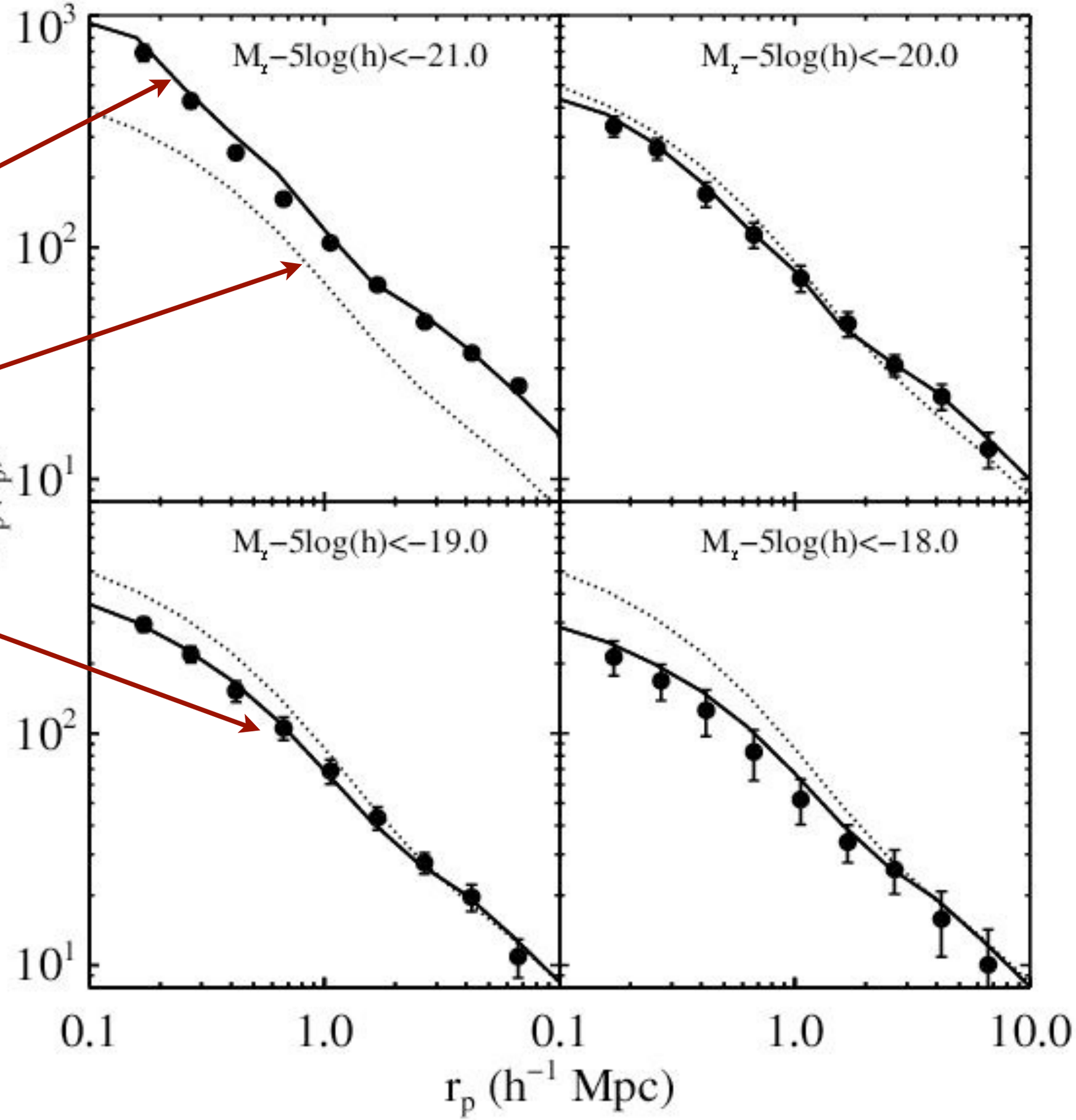
Reproduces most of the observed clustering of galaxies

SDSS: z=0

DM galaxies

DM

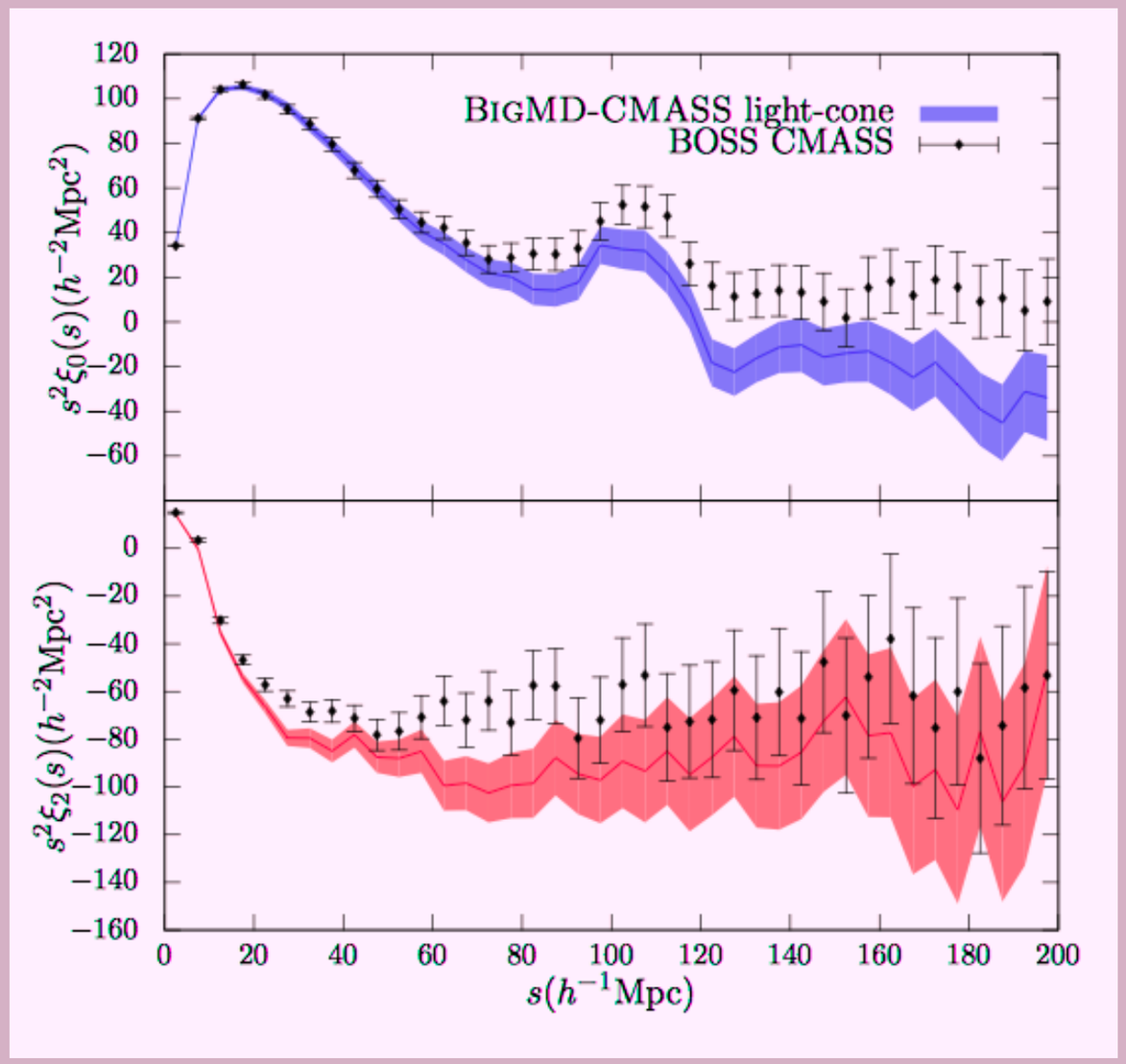
SDSS



Comparing LCDM with BOSS data

Dark Matter ==> galaxies:

Halo Abundance matching: larger galaxies are hosted by bigger DM halos. No free parameters.

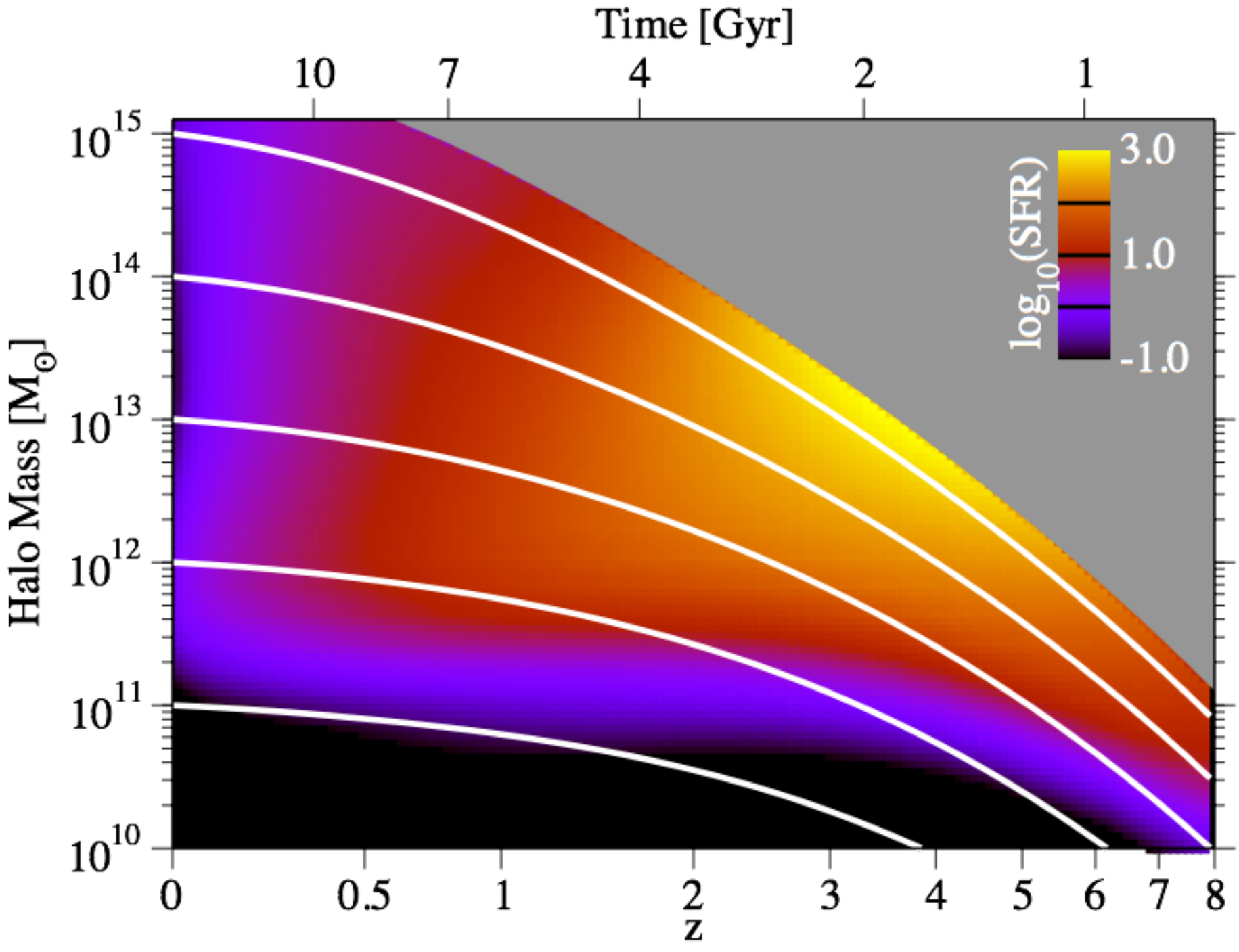


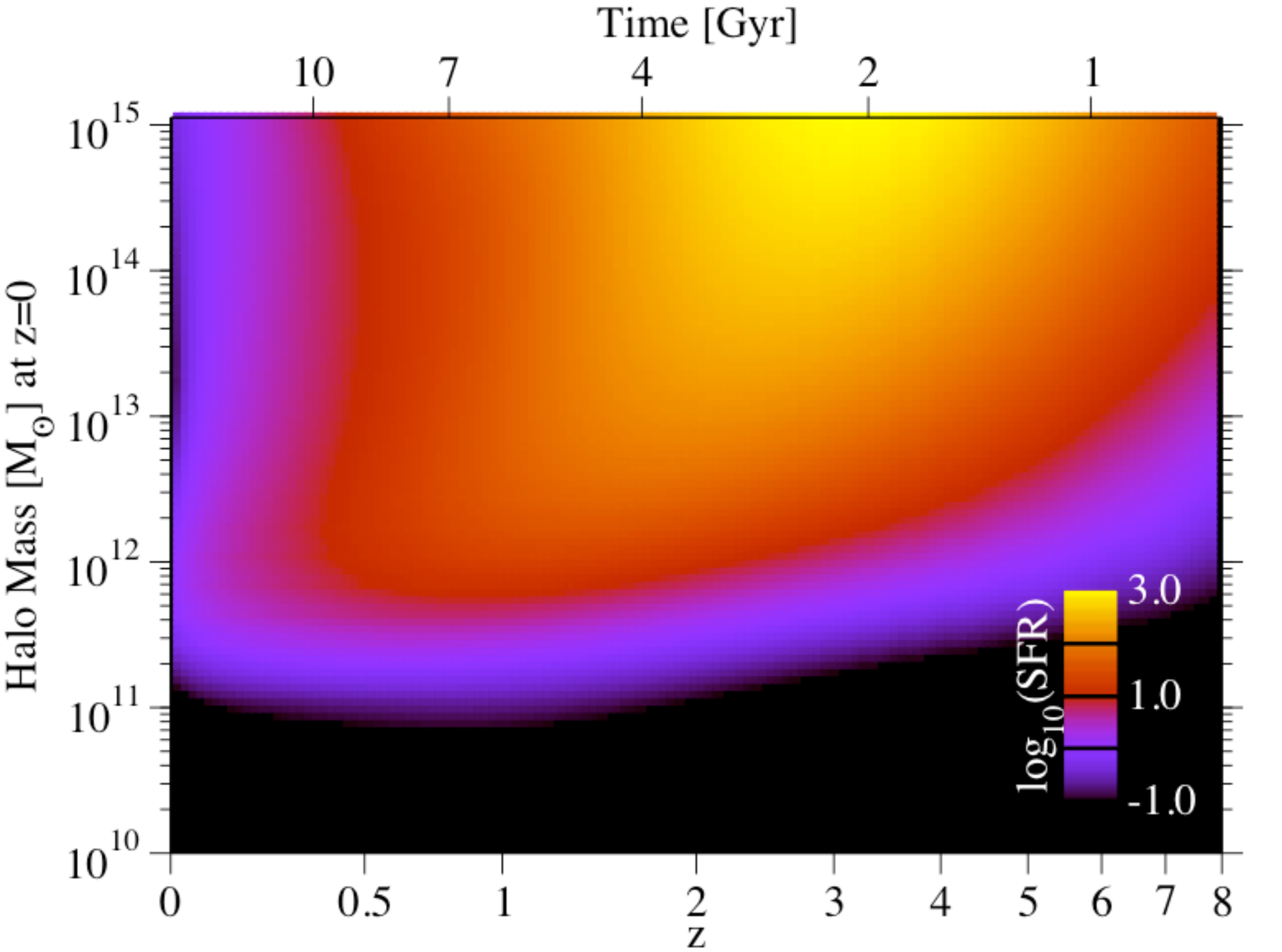
Rodriguez-Torres et al 2015

MultiDark Simulations

star formation history of the Universe:

arXiv:1207.6105




Time [Gyr]
10
7
4
2
1
Halo Mass [M$_\odot$] at z=0
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
log$_{10}$(SFR)
3.0
1.0
-1.0
0
0.5
1
2
3
4
5
6
7
8
z

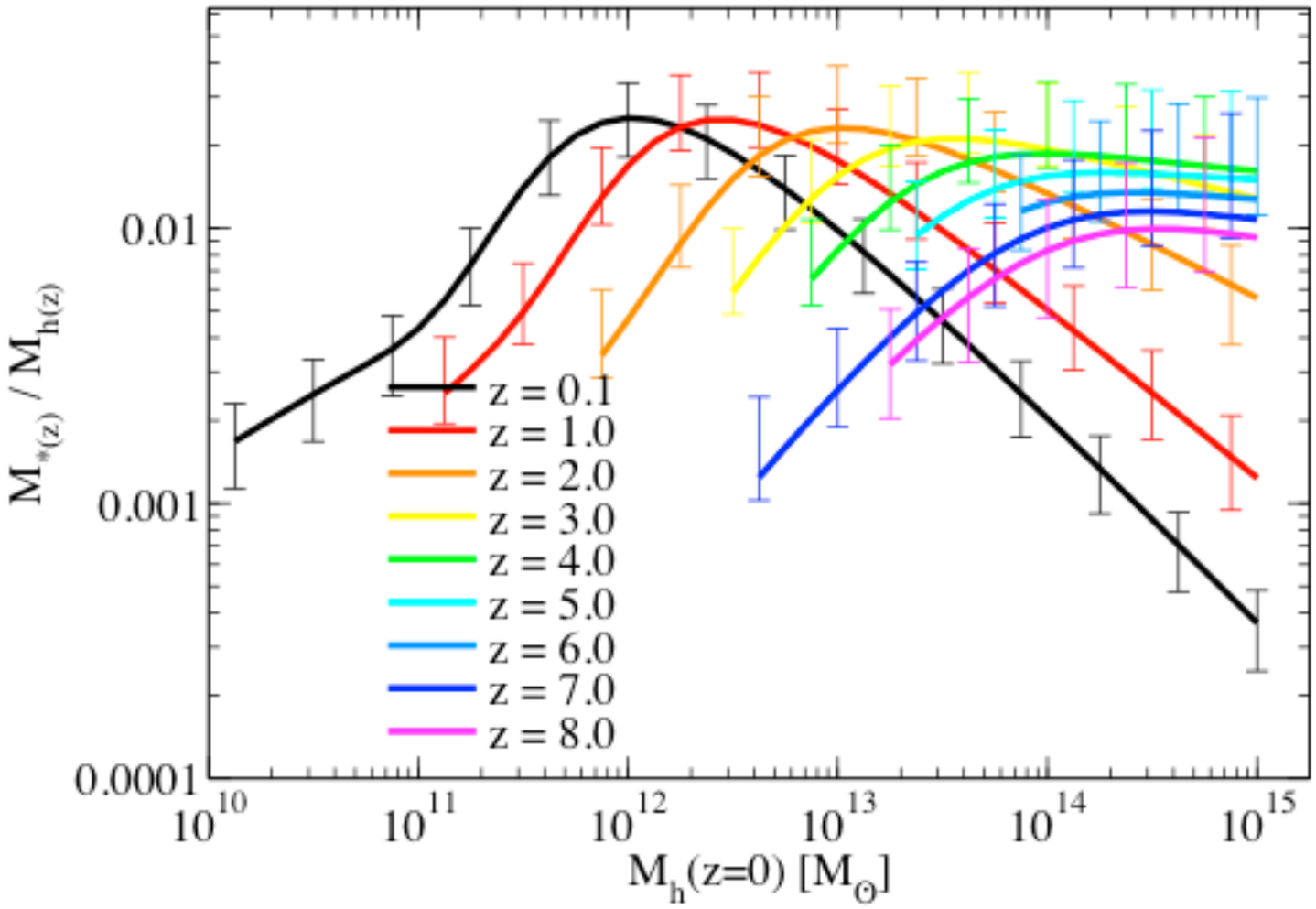
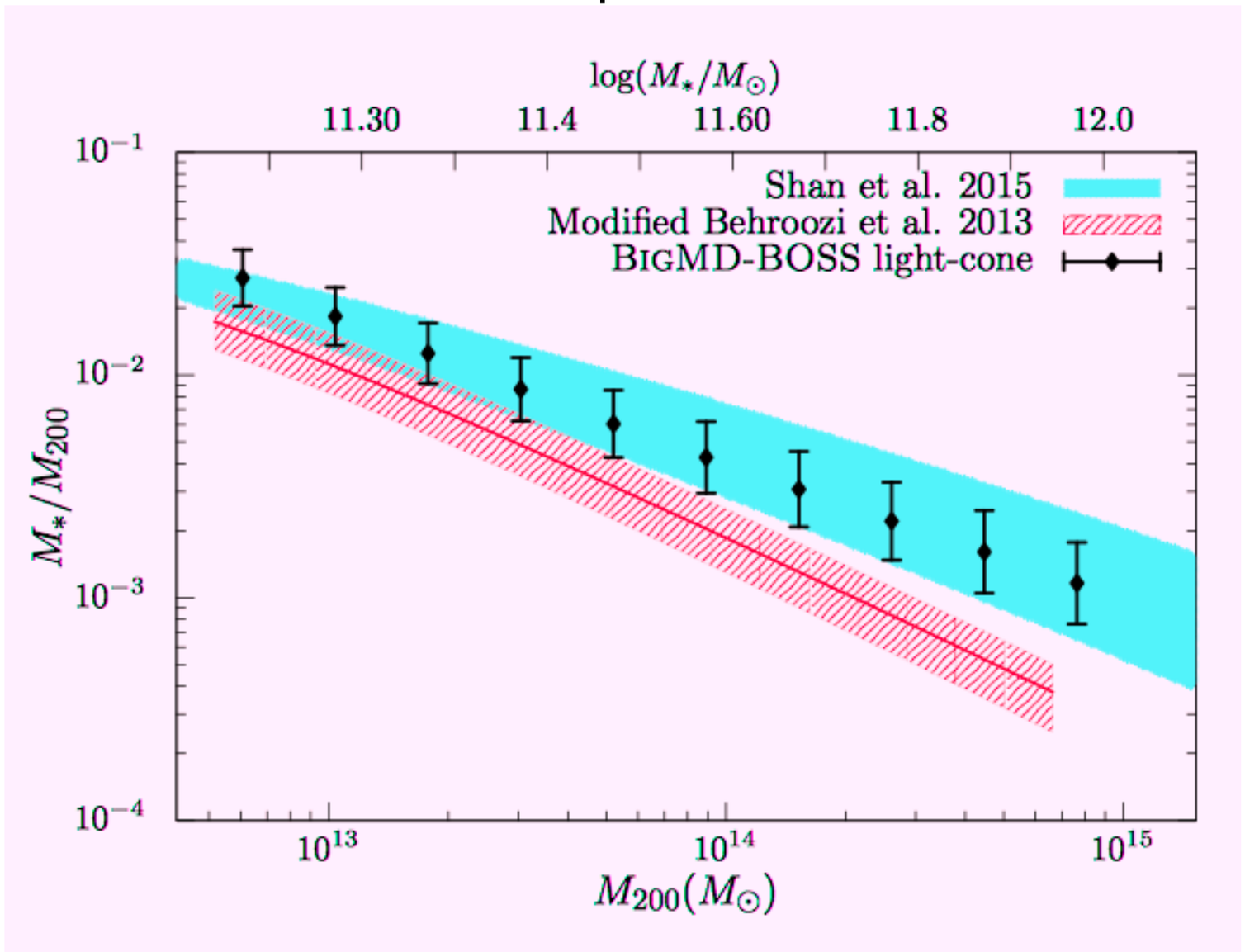


FIG. 8.— Evolution of the derived stellar mass fractions ($M_*(z)/M_h(z)$) as a function of halo mass at the present day. More massive halos used to have a significantly larger fraction of mass in stars, but the peak star formation efficiency has remained relatively constant to the present day.

Comparing LCDM with BOSS data

Dark Matter ==> galaxies:

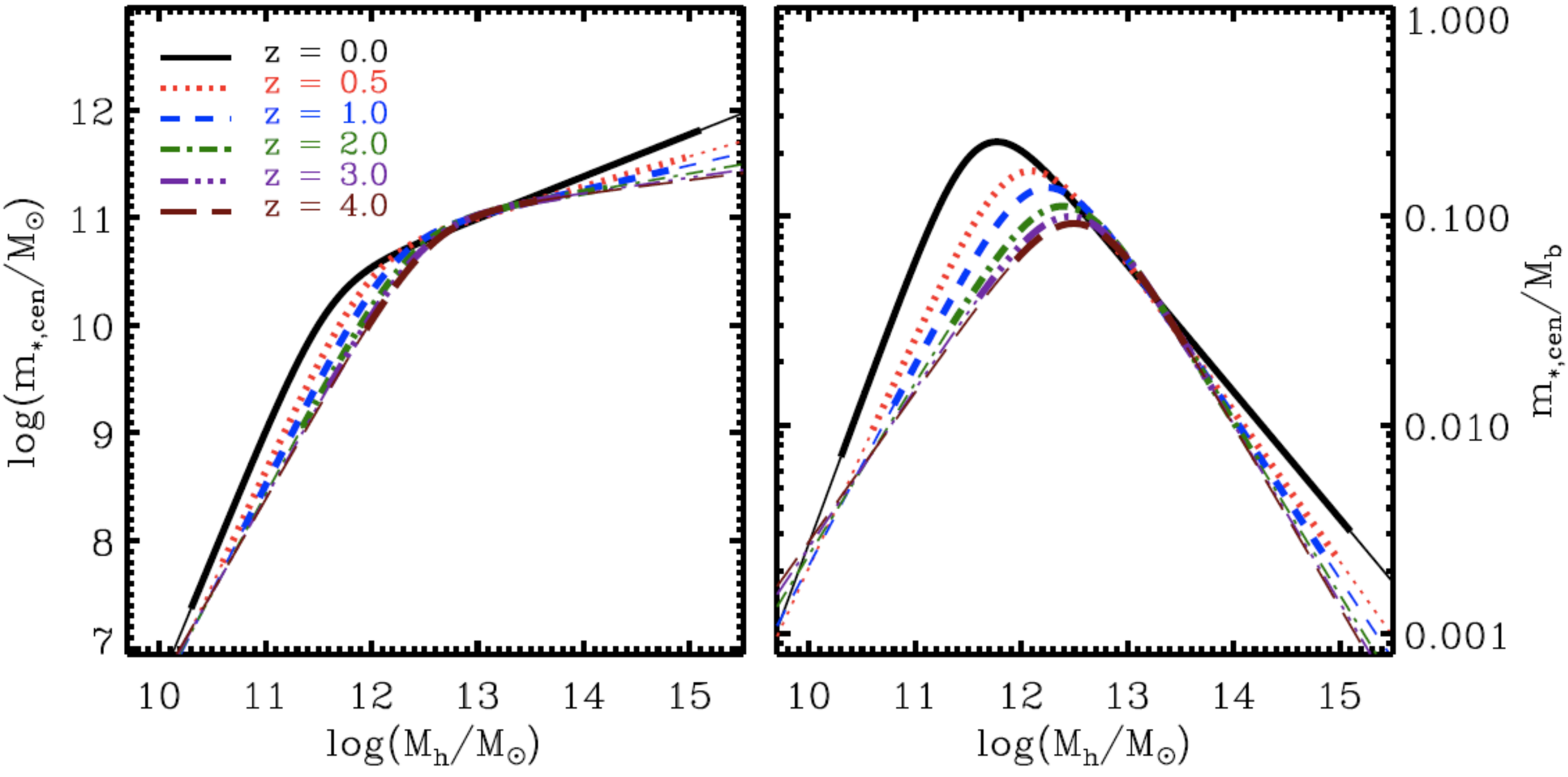
Halo Abundance matching: larger galaxies are hosted by bigger DM halos. No free parameters.



Rodriguez-Torres et al 2015

MultiDark Simulations

Stellar-to-Halo mass relation for central galaxies as a function of redshift.



Moster et al 2012