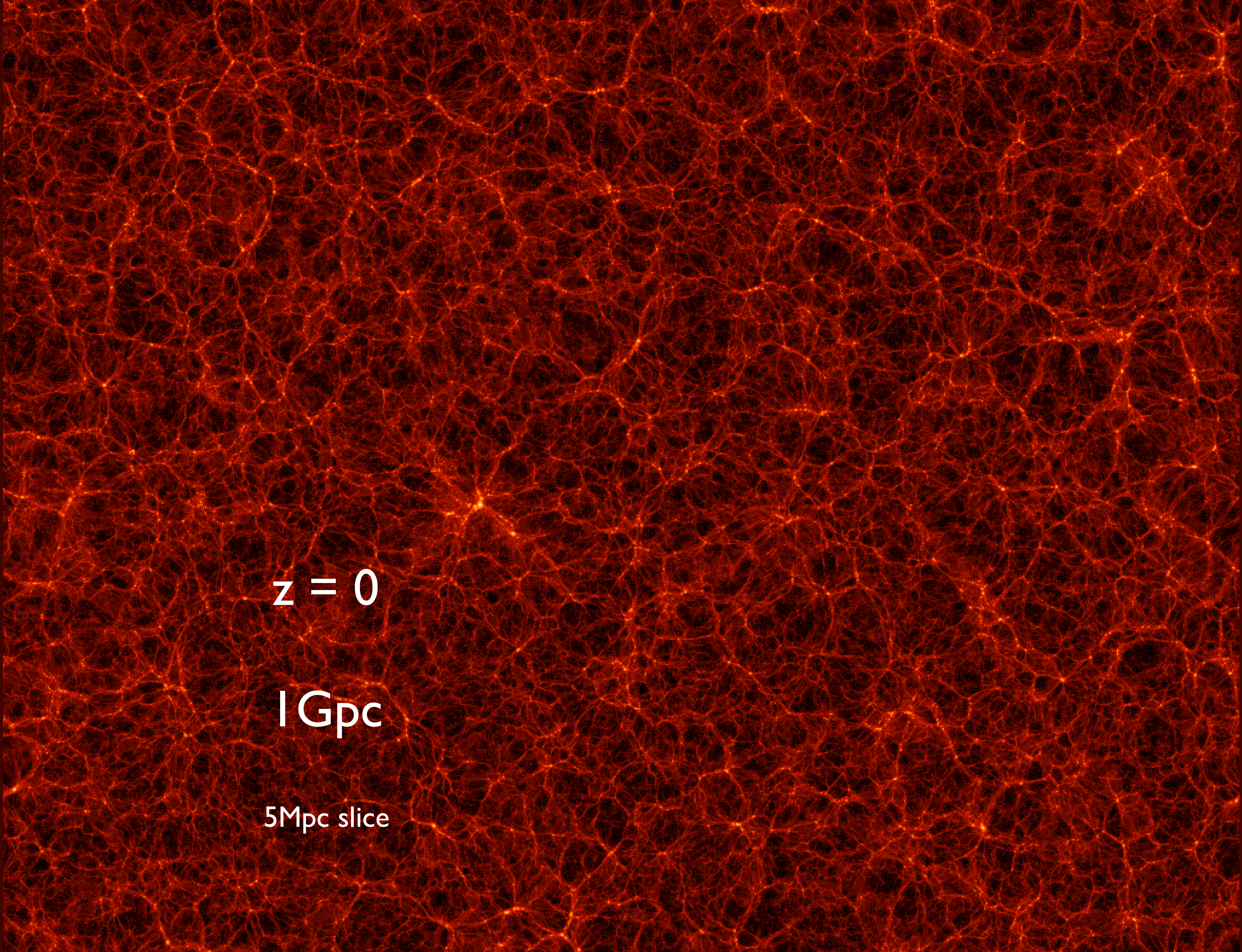
1) Large-scale distribution of galaxies

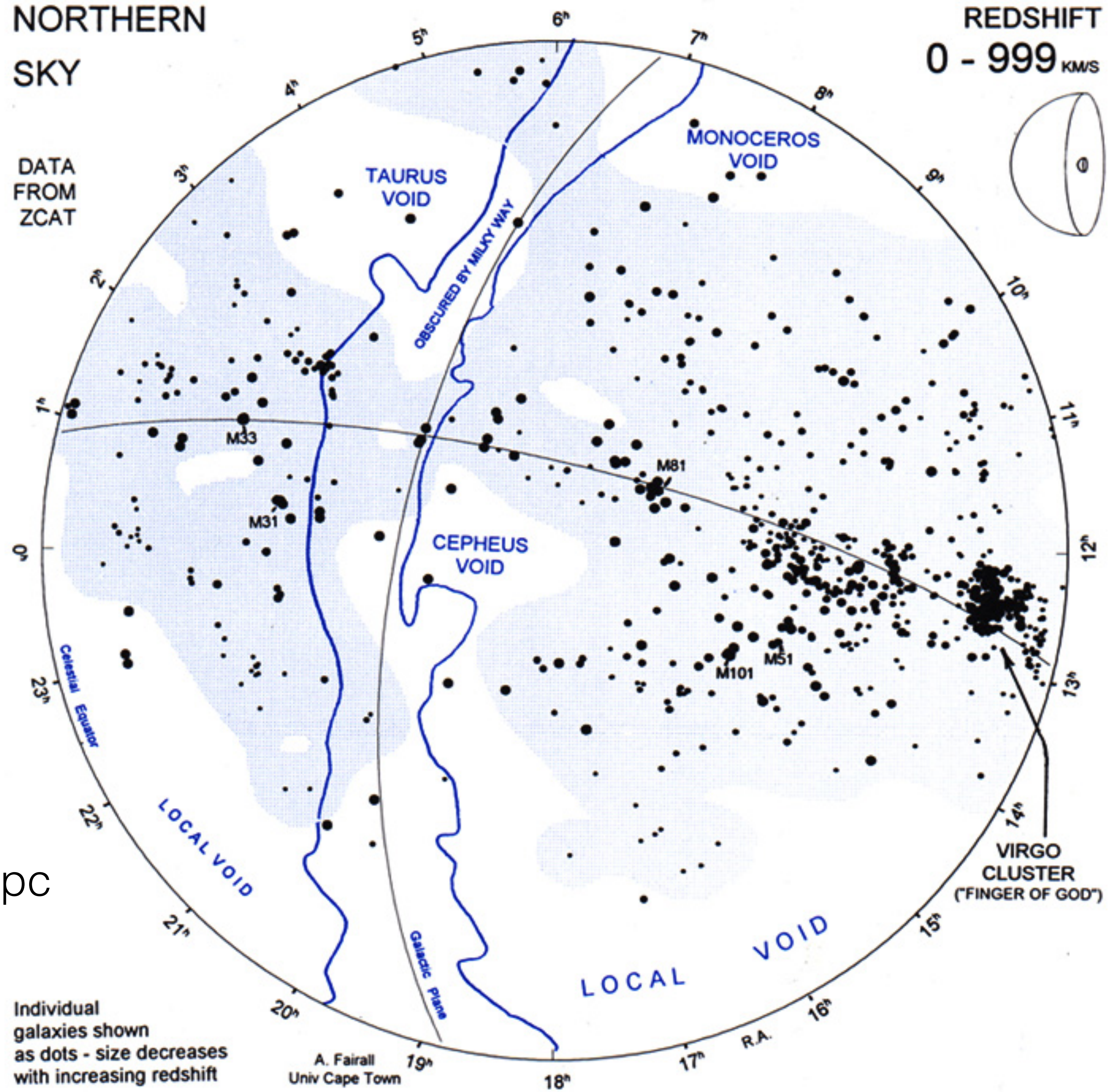
2) Bridging the gap between halos and galaxies:


z = 0
1Gpc
5Mpc slice

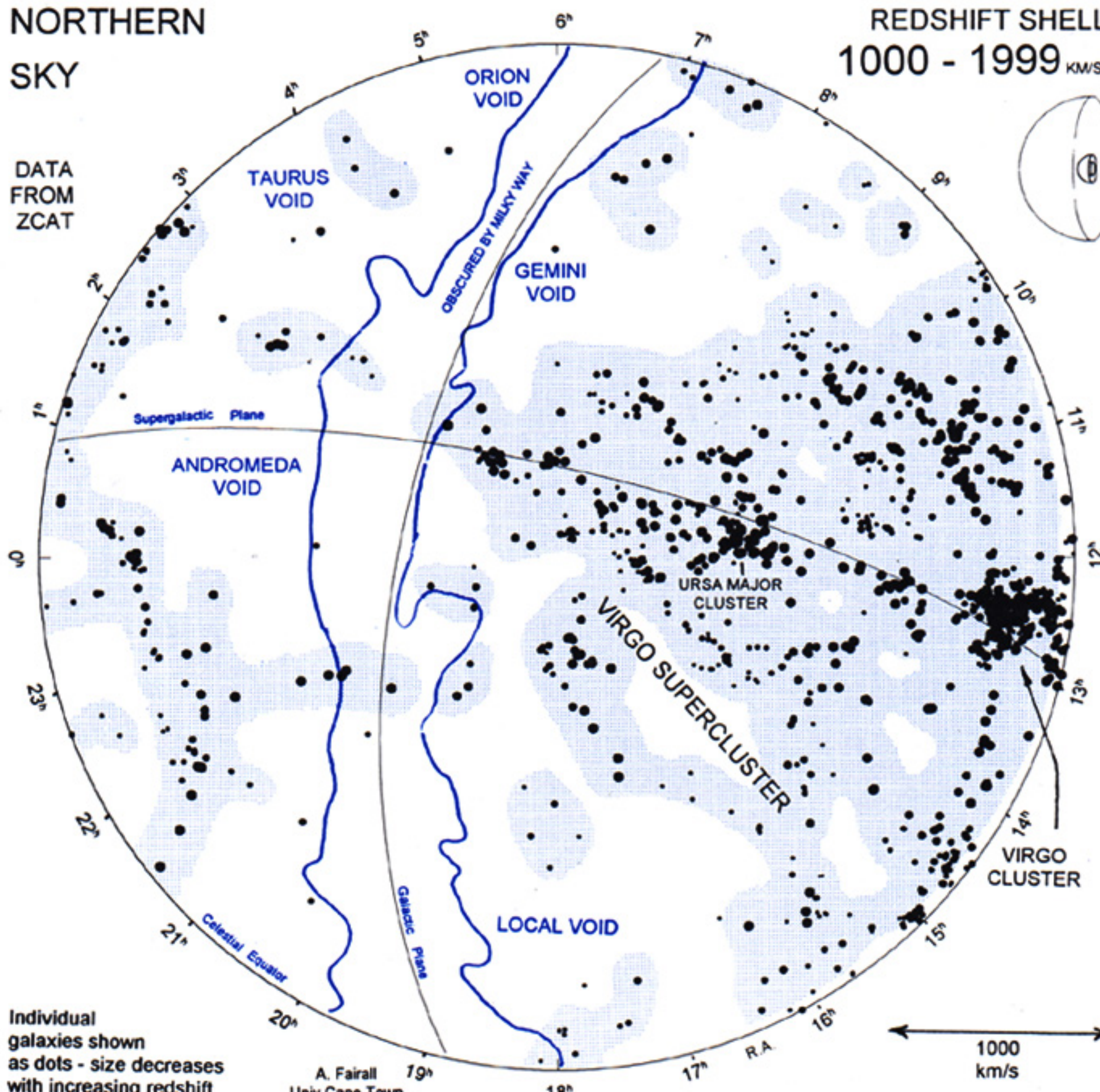
Distribution of galaxies around the Milky Way:

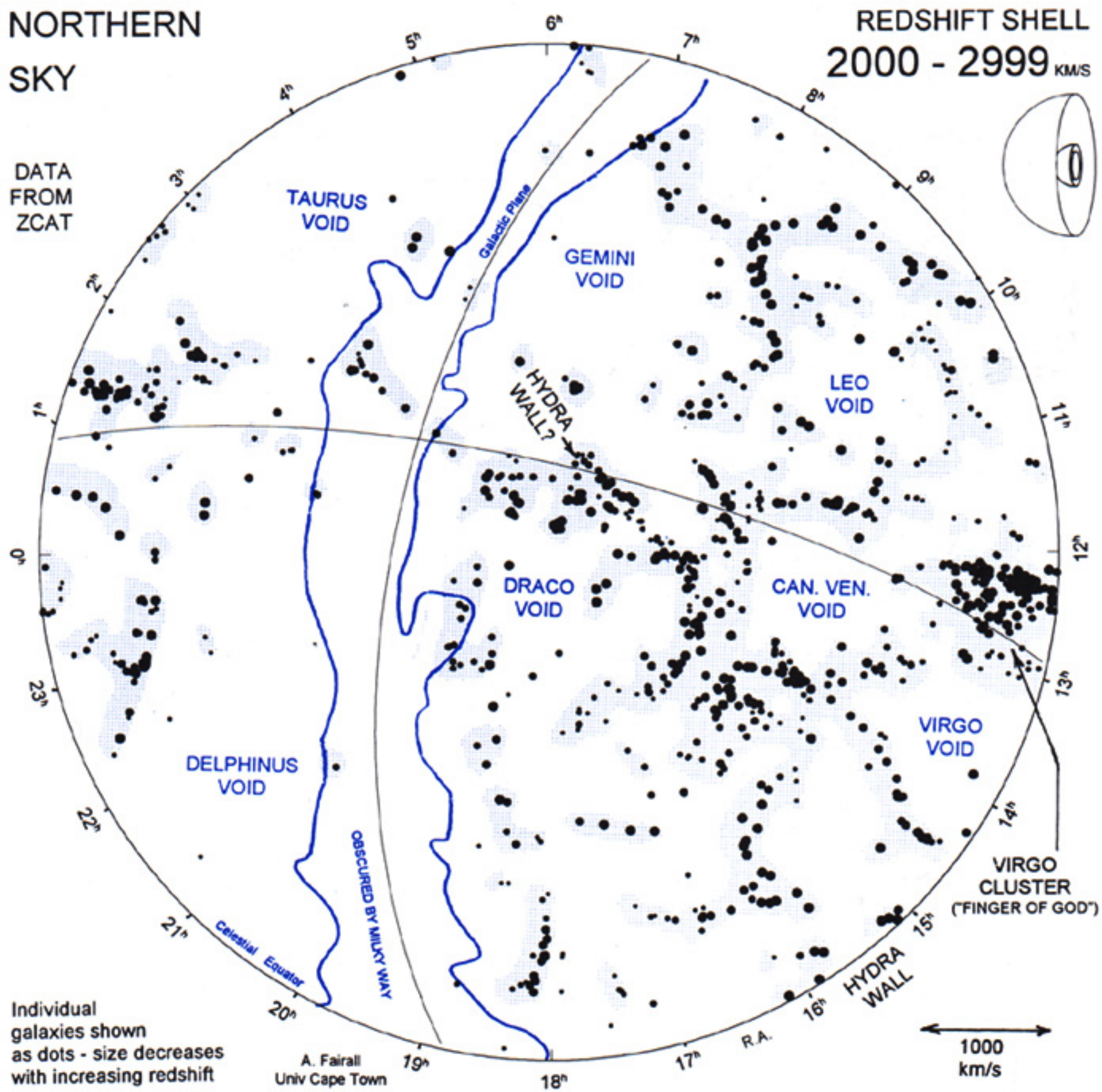
- Messy. Difficult to observe, but
- Shows details that can be missed in large pictures
- Lots of measurements

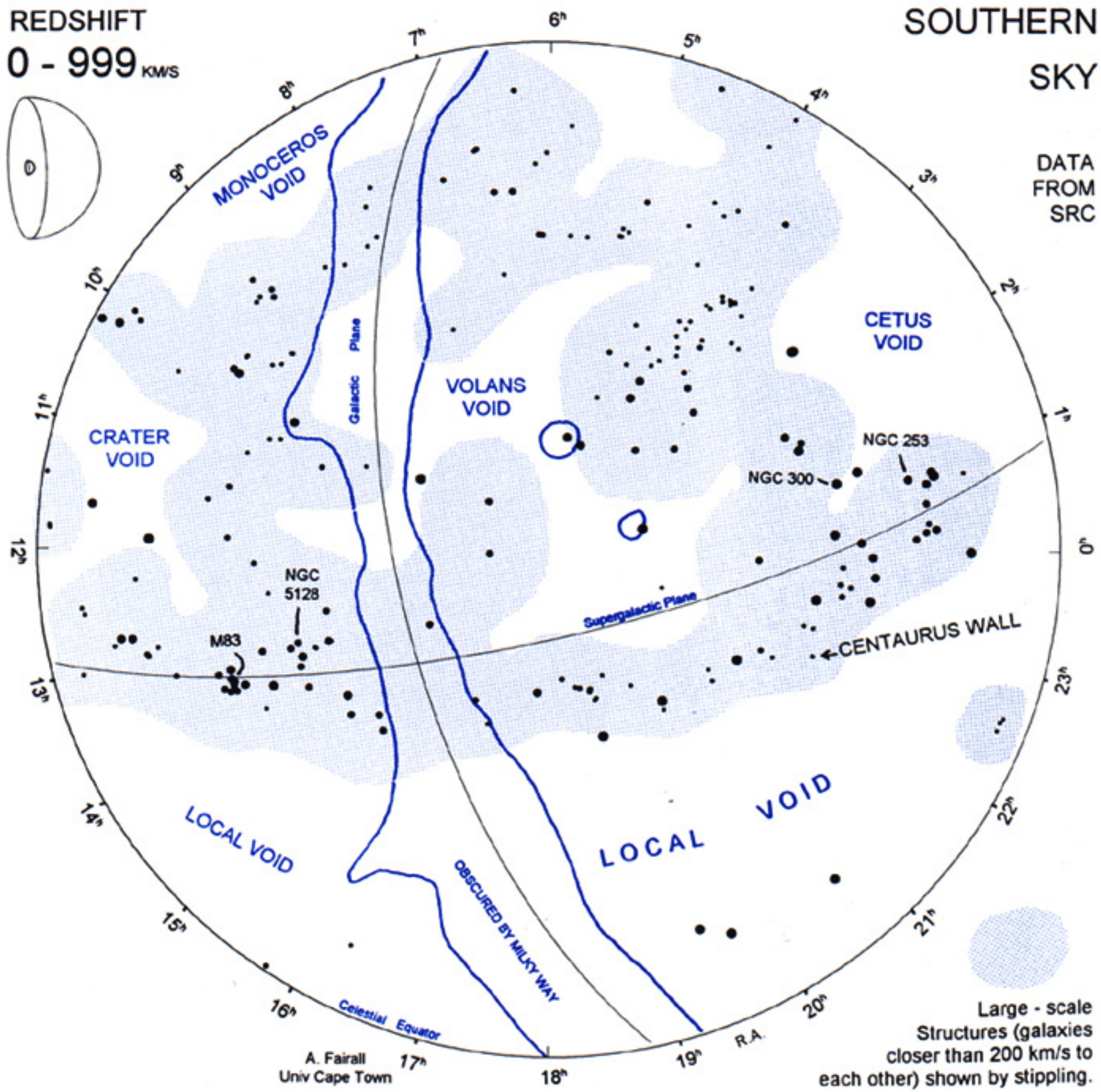
Projection



Distances <15 Mpc


NORTHERN
SKY
REDSHIFT SHELL
1000 - 1999 KM/S
DATA
FROM
ZCAT
TAURUS
VOID
ORION
VOID
OBSCURED BY MILKY WAY
GEMINI
VOID
Supergalactic Plane
ANDROMEDA
VOID
URSA MAJOR
CLUSTER
VIRGO SUPERCLUSTER
VIRGO
CLUSTER
LOCAL VOID
Galactic Plane
Celestial Equator
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 KM/S
SOUTHERN
SKY
DATA
FROM
SRC
MONOCEROS
VOID
CRATER
VOID
VOLANS
VOID
CETUS
VOID
Galactic Plane
NGC 253
NGC 300
NGC
5128
M83
Supergalactic Plane
CENTAURUS WALL
LOCAL VOID
LOCAL VOID
OBSCURED BY MILKY WAY
Celestial Equator
R.A.
0h
1h
2h
3h
4h
5h
6h
7h
8h
9h
10h
11h
12h
13h
14h
15h
16h
17h
18h
19h
20h
21h
22h
23h
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]

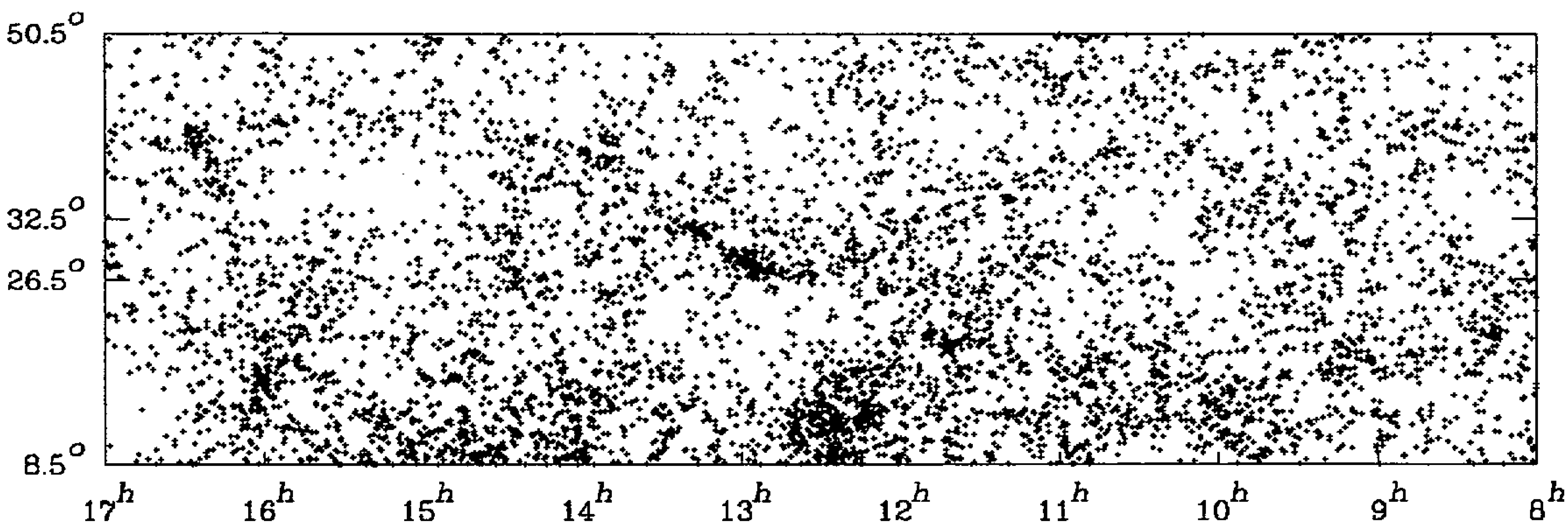
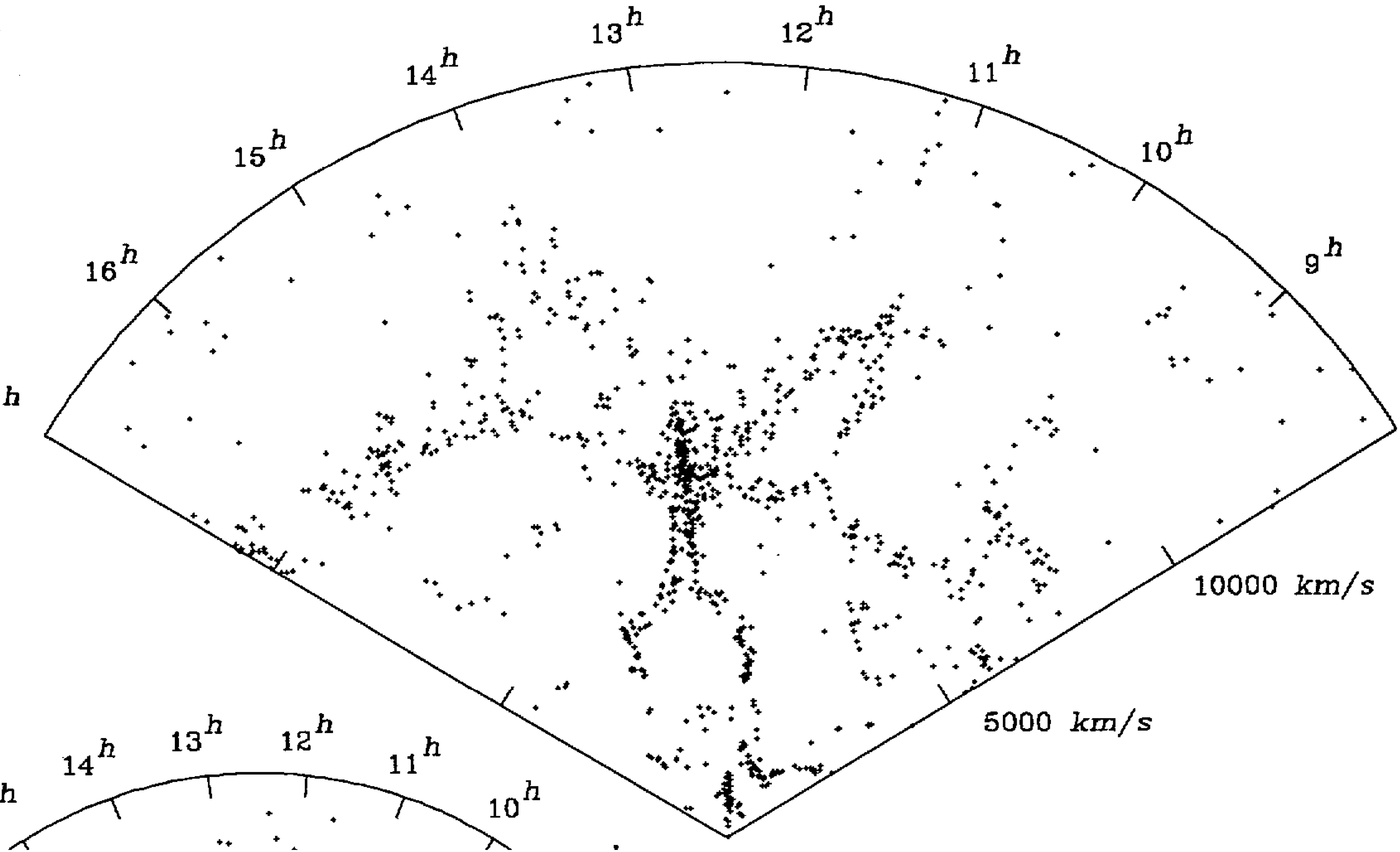
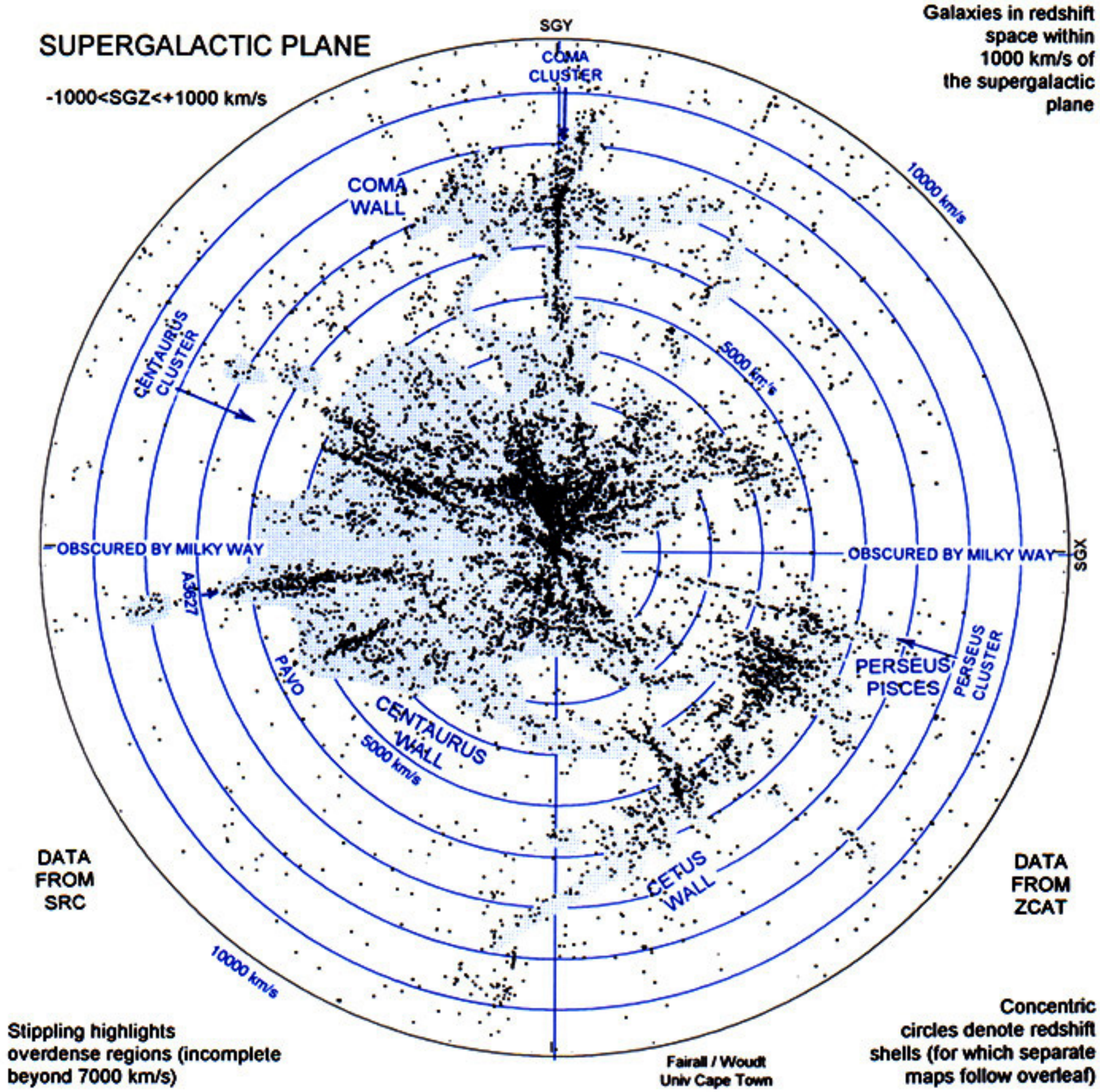


FIG. 1.—(*a*) Map of the observed velocity plotted vs. right ascension in the declination wedge 26°5 ≤ δ ≤ 32°5. The 1061 objects plotted have $m_B \le 15.5$ and $V \le 15{,}000$ km s^{-1}. (*b*) Same as Fig. 1*a* for $m_B \le 14.5$ and $V \le 10{,}000$ km s^{-1}. The plot contains 182 galaxies. (*c*)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



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


SUPERGALACTIC PLANE
-1000<SGZ<+1000 km/s
Galaxies in redshift space within 1000 km/s of the supergalactic plane
SGY
SGX
COMA CLUSTER
COMA WALL
CENTAURUS CLUSTER
10000 km/s
5000 km/s
OBSCURED BY MILKY WAY
OBSCURED BY MILKY WAY
A3627
PAVO
CENTAURUS WALL
5000 km/s
PERSEUS PISCES
PERSEUS CLUSTER
CETUS WALL
10000 km/s
DATA FROM SRC
DATA FROM ZCAT
Stippling highlights overdense regions (incomplete beyond 7000 km/s)
Fairall / Woudt Univ Cape Town
Concentric circles denote redshift shells (for which separate maps follow overleaf)

Local Supercluster:

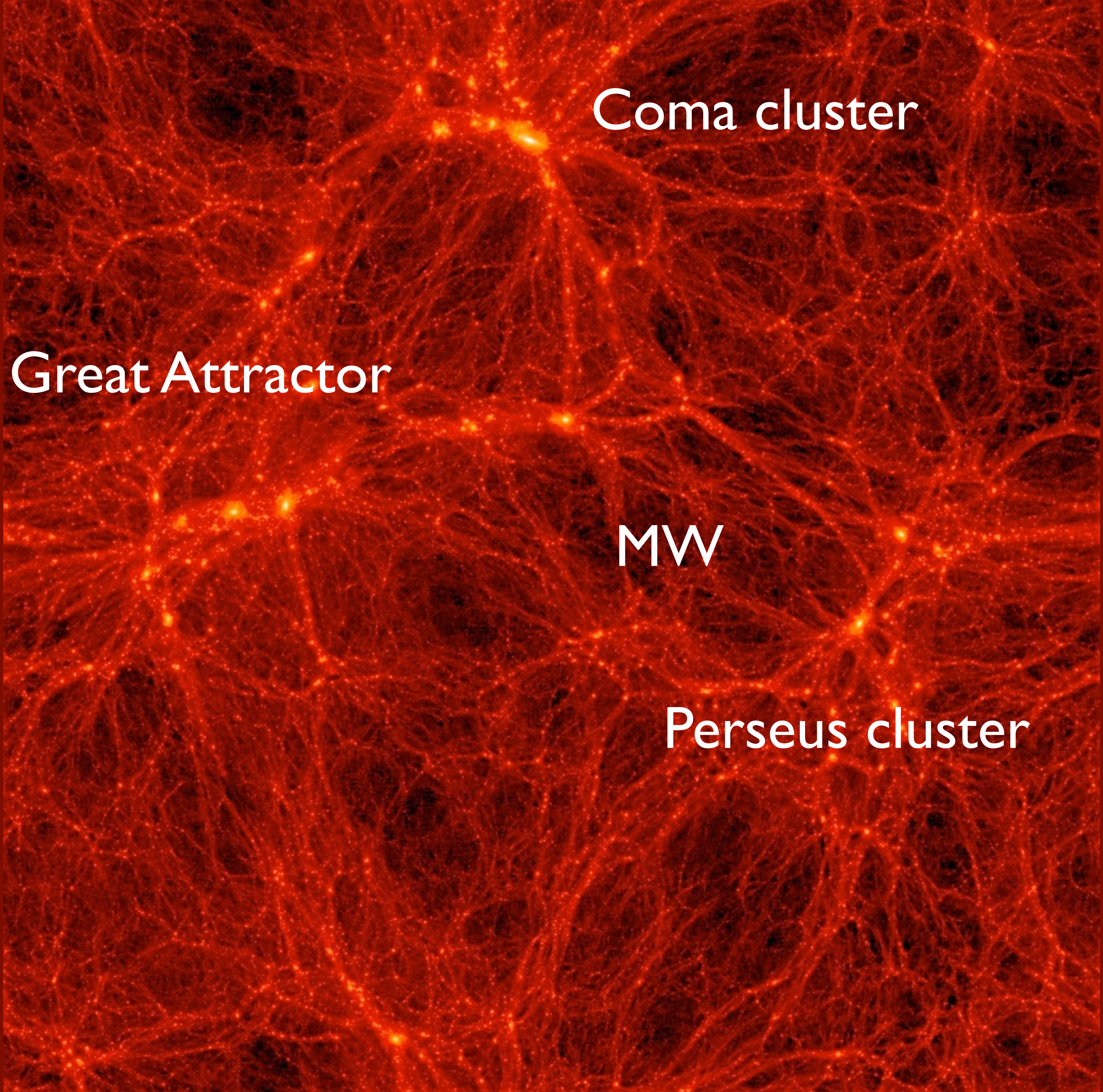
- Distribution of light and mass
- Peculiar velocities (deviations from the Hubble flow)
- Voids

1G particles
Dynamical range 1e5

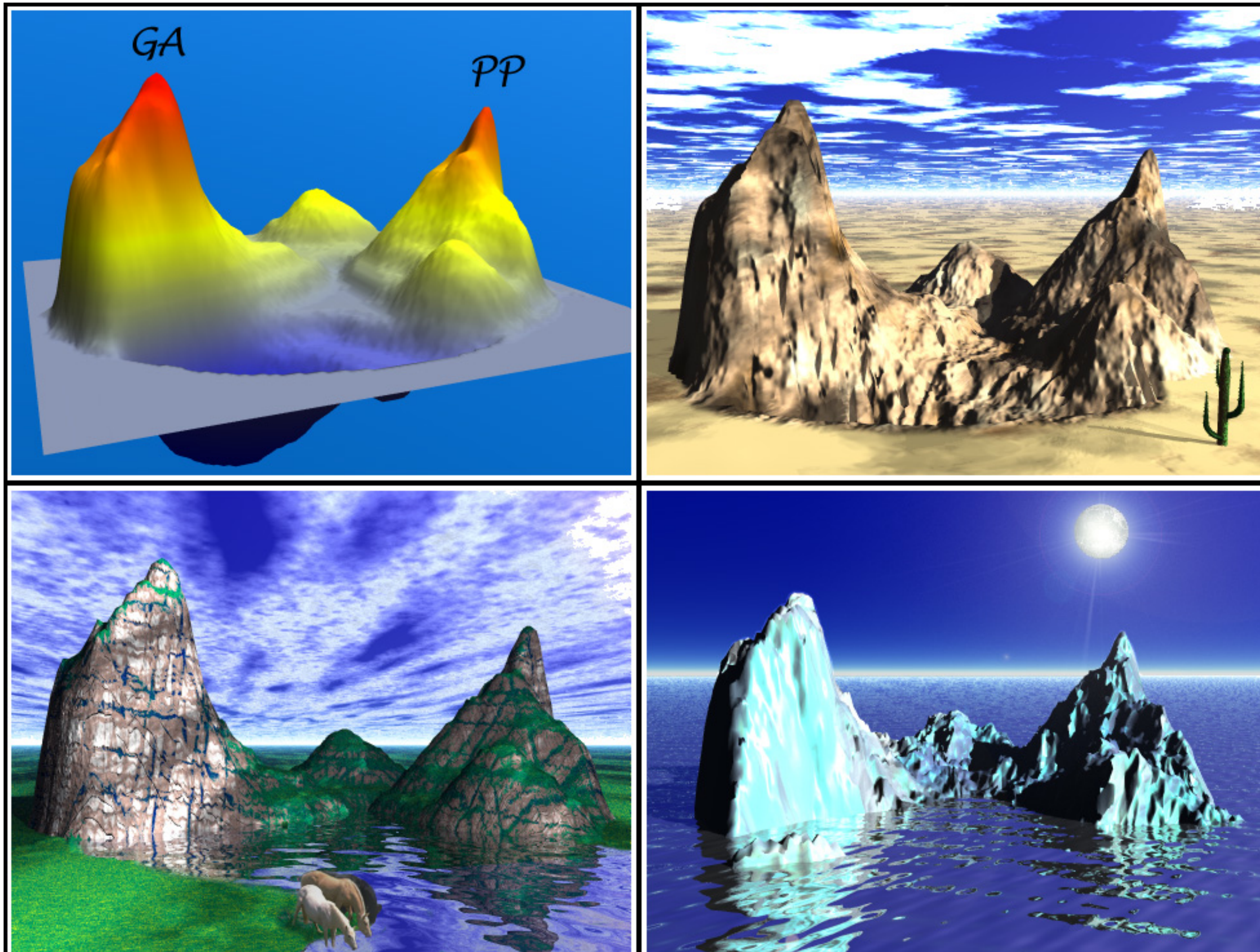
Constrained simulations

160 Mpc

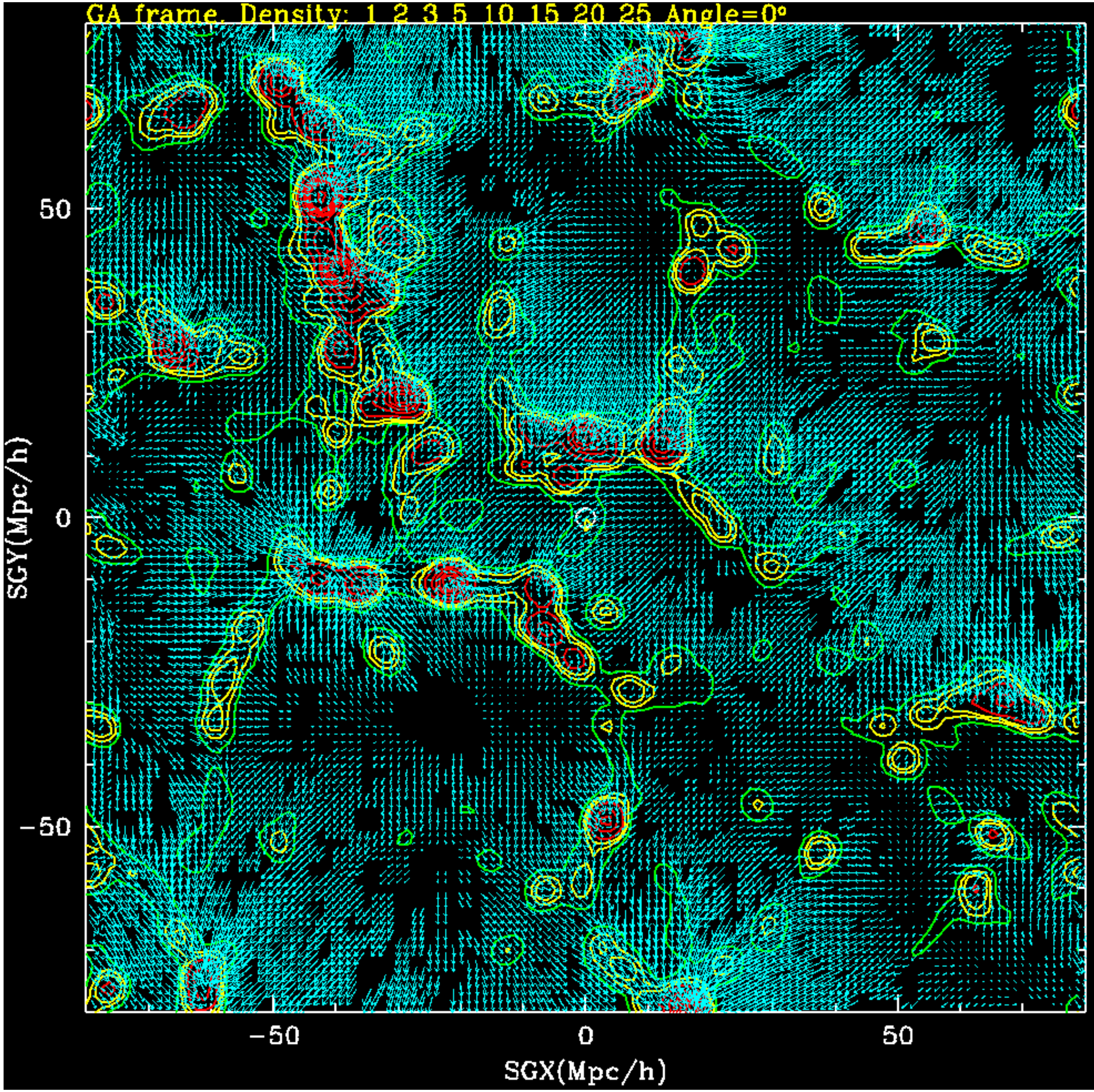
Klypin, Hoffman, Gottlober



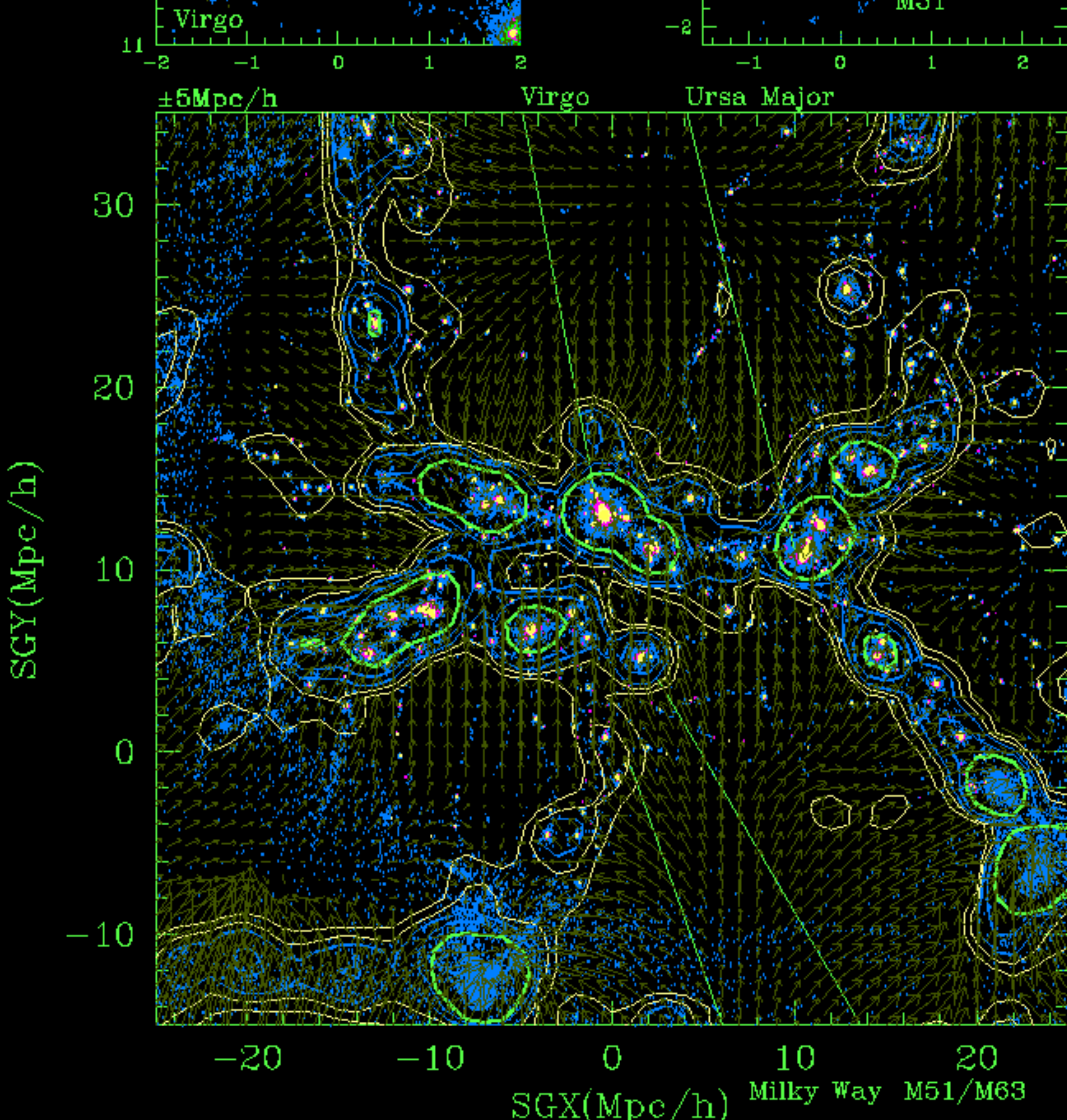
Landscape of the MW neighborhood: 80Mpc



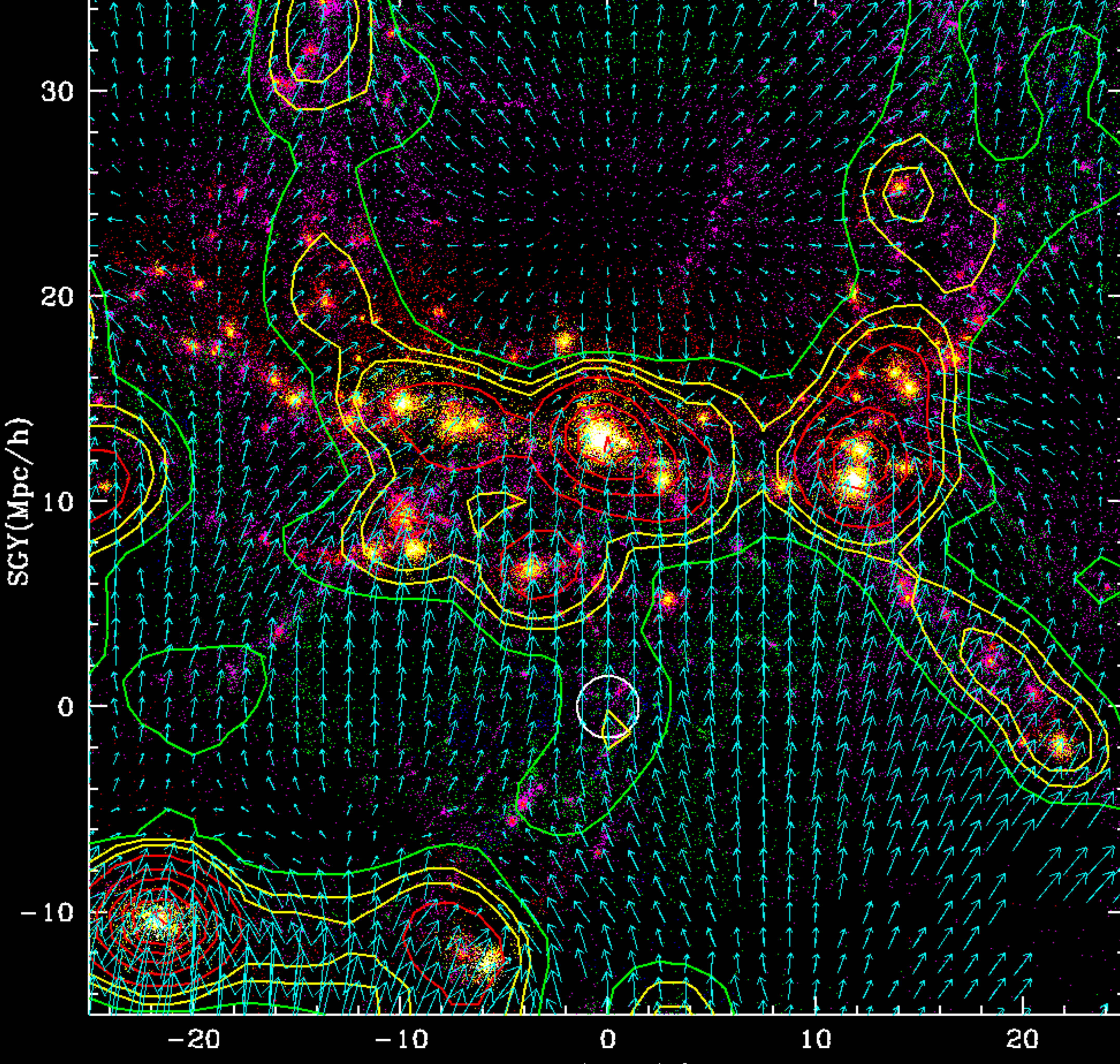
Position of GA, Coma, Virgo, and Perseus-Pices. Our galaxy is a white circle at (0,0)



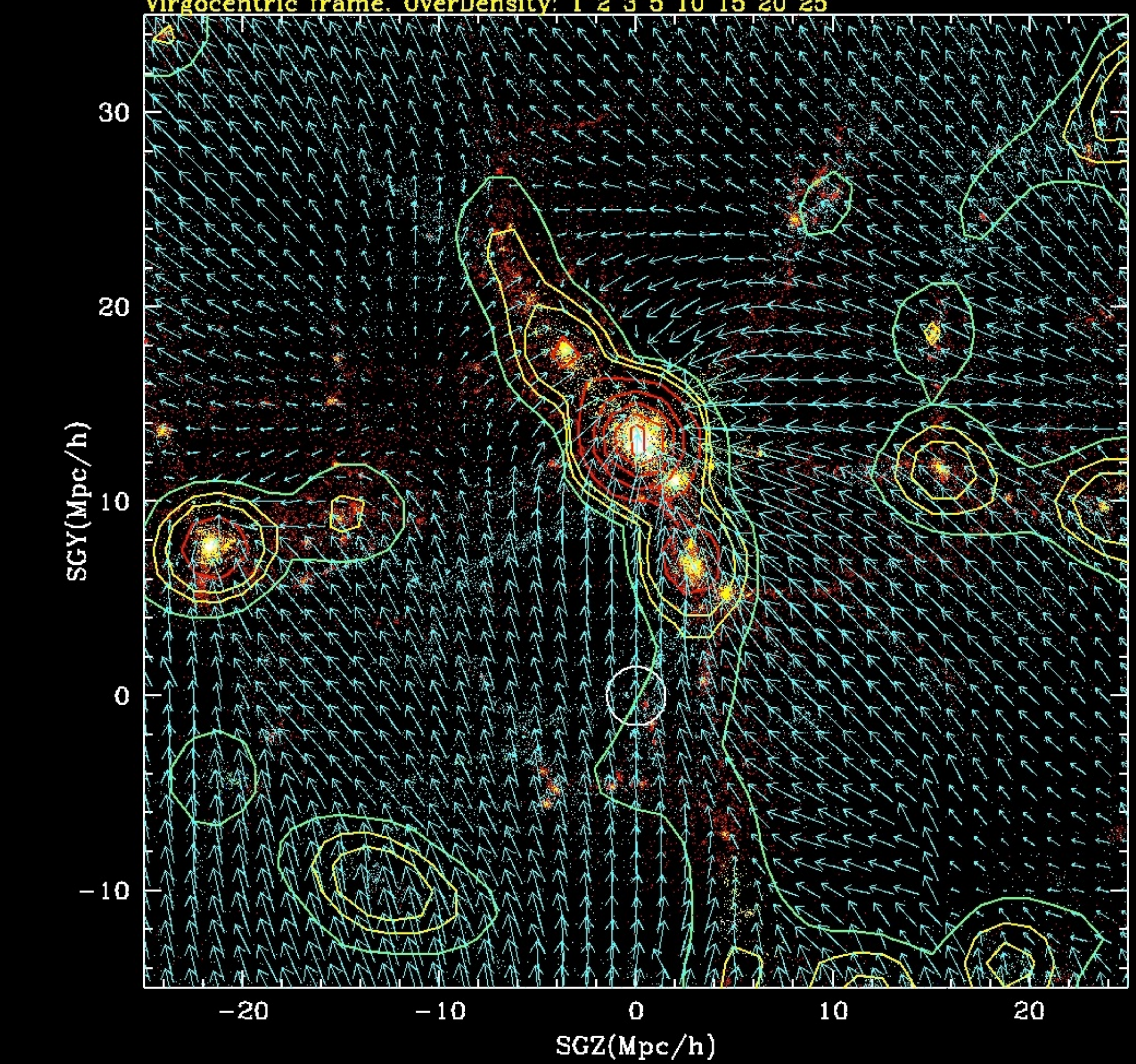
- Long waves (amplitudes and phases) are taken from observations.
- Small scale-perturbations and dynamics are for LCDM cosmological model
- N-body simulations at z=0



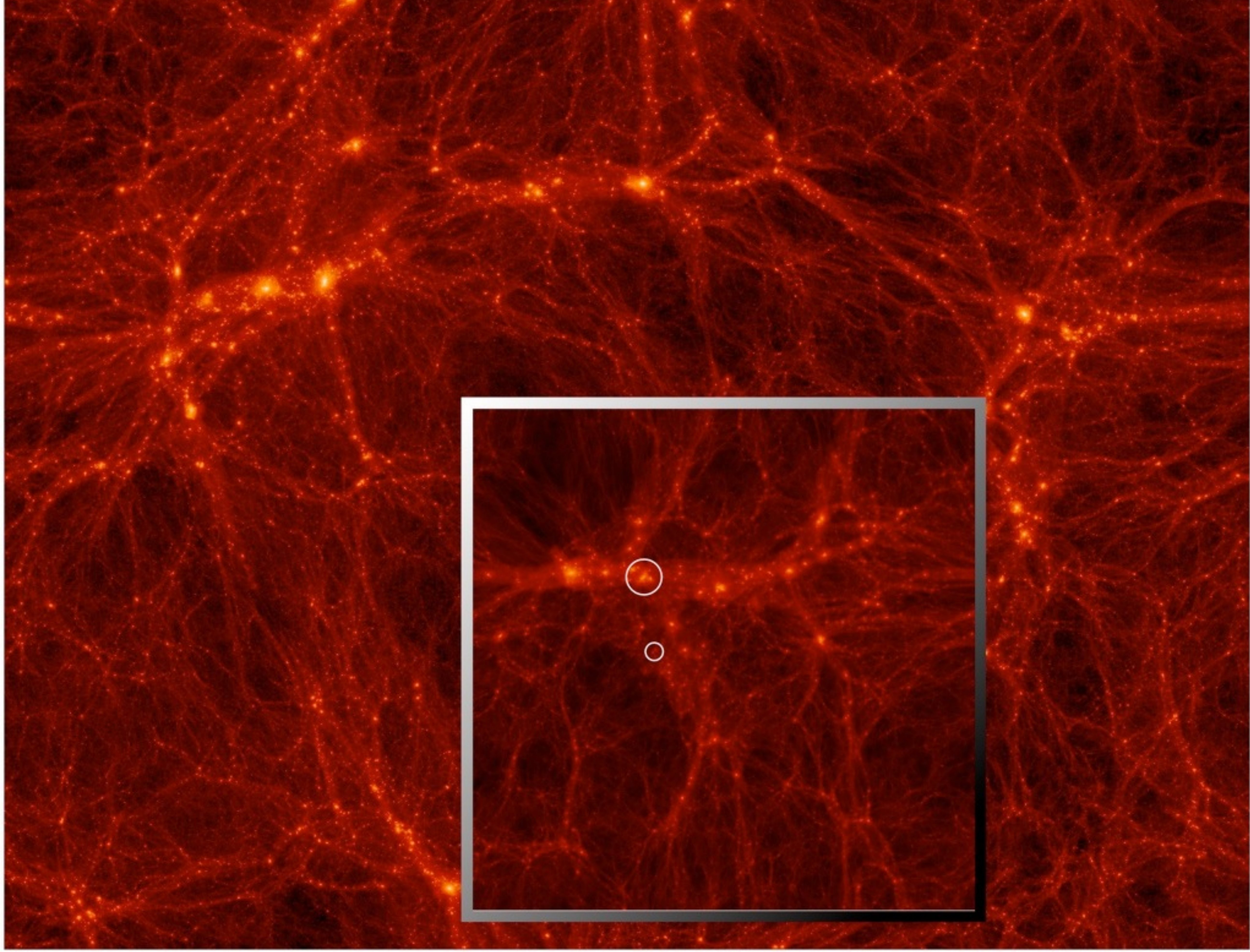
Virgo
±5Mpc/h
Virgo
Ursa Major
30
20
10
0
−10
SGY(Mpc/h)
−20
−10
0
10
20
SGX(Mpc/h)
Milky Way
M51/M63



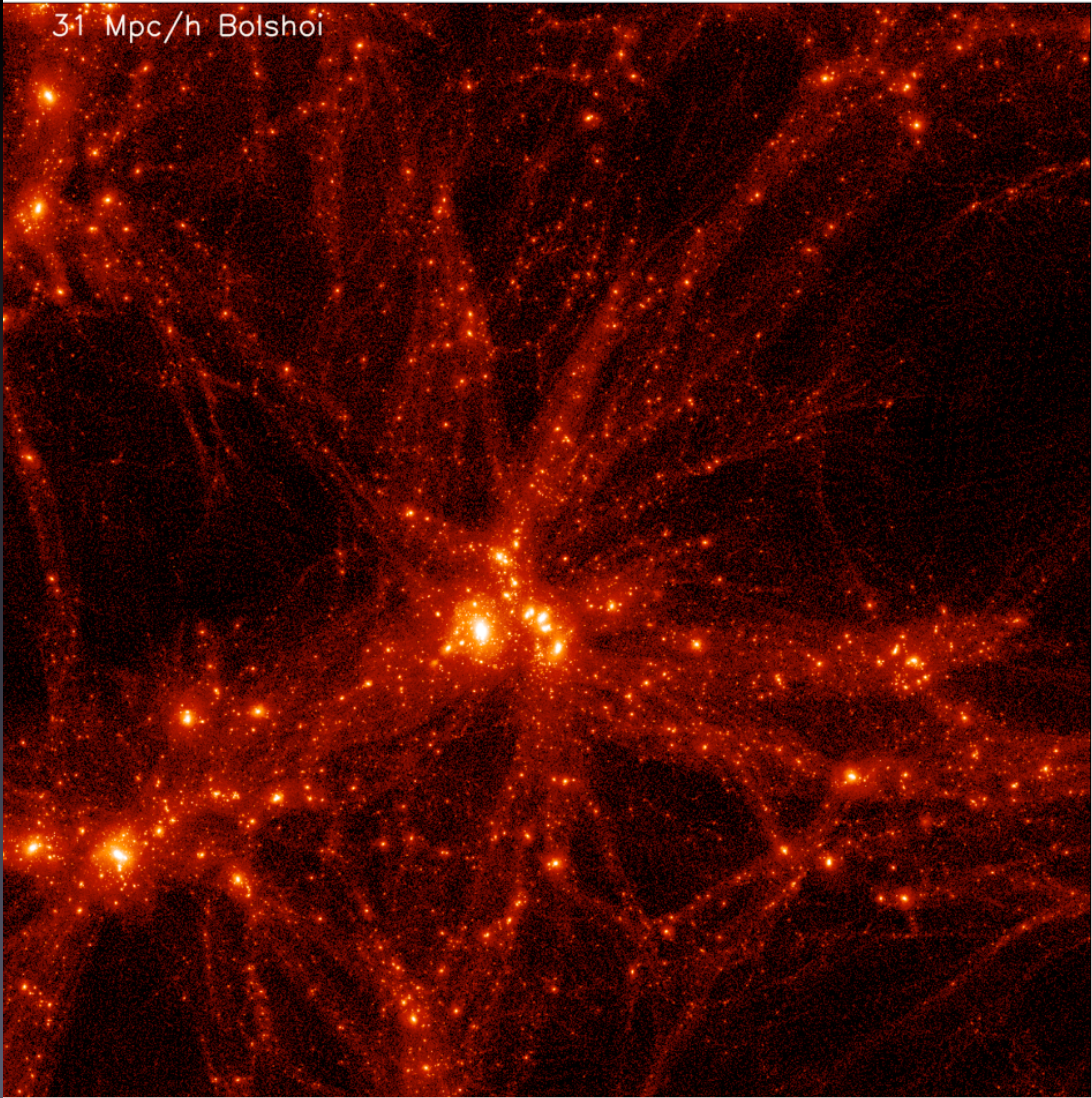
SGY(Mpc/h)
30
20
10
0
−10
−20
−10
0
10
20



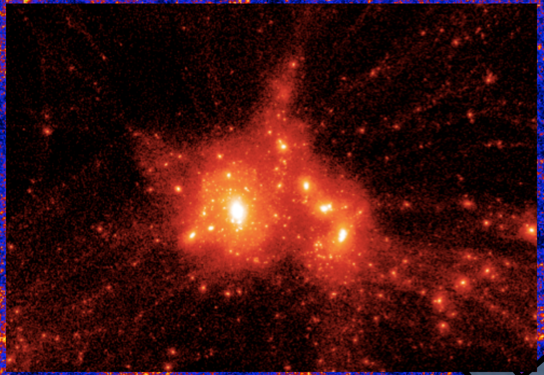
Virgocentric frame. Overdensity: 1 2 3 5 10 15 20 25
SGY(Mpc/h)
SGZ(Mpc/h)
30
20
10
0
−10
−20
−10
0
10
20

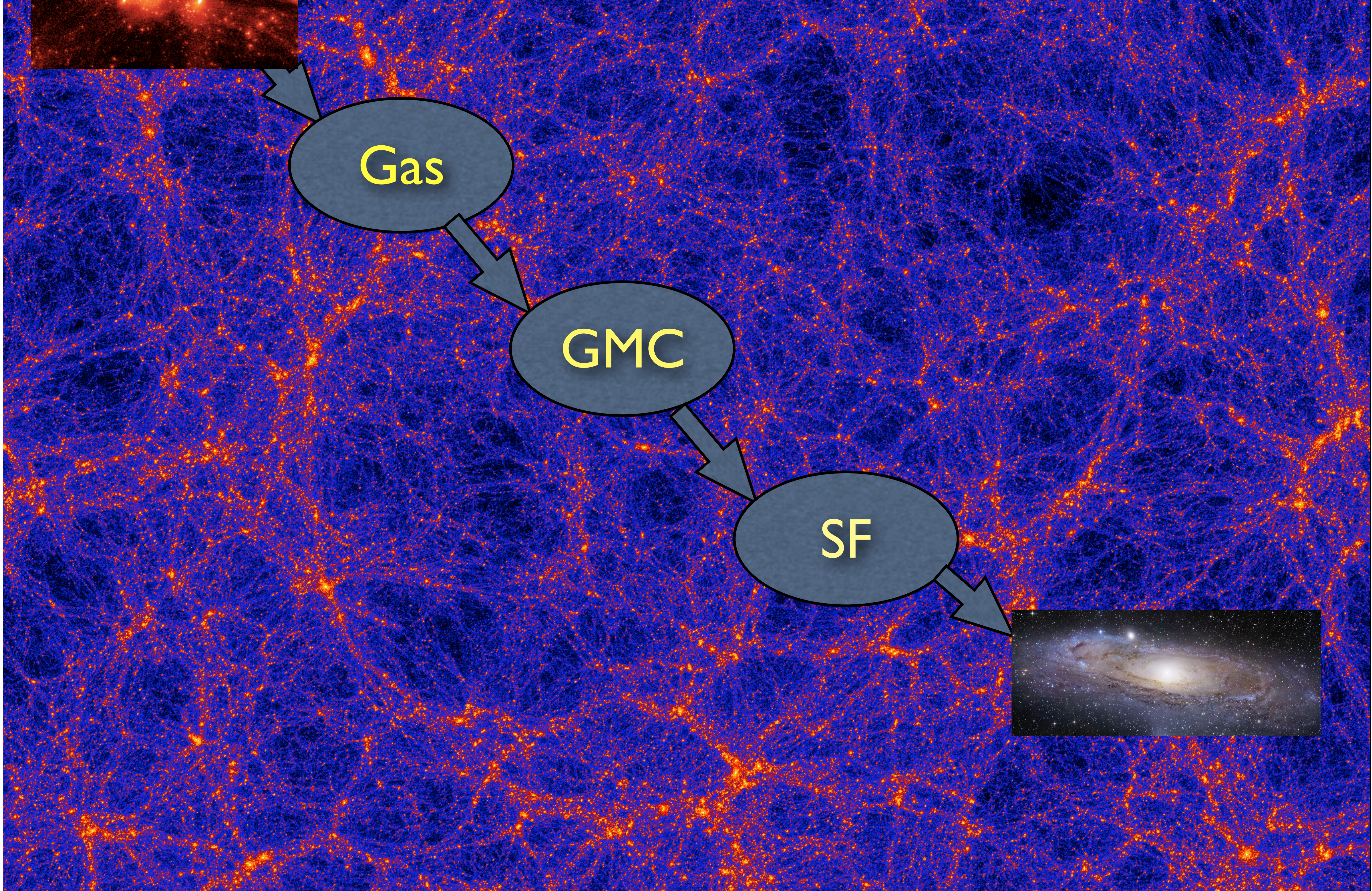


Bridging the gap between halos and galaxies:


31 Mpc/h Bolshoi

Galaxy Formation and Metals in The Universe





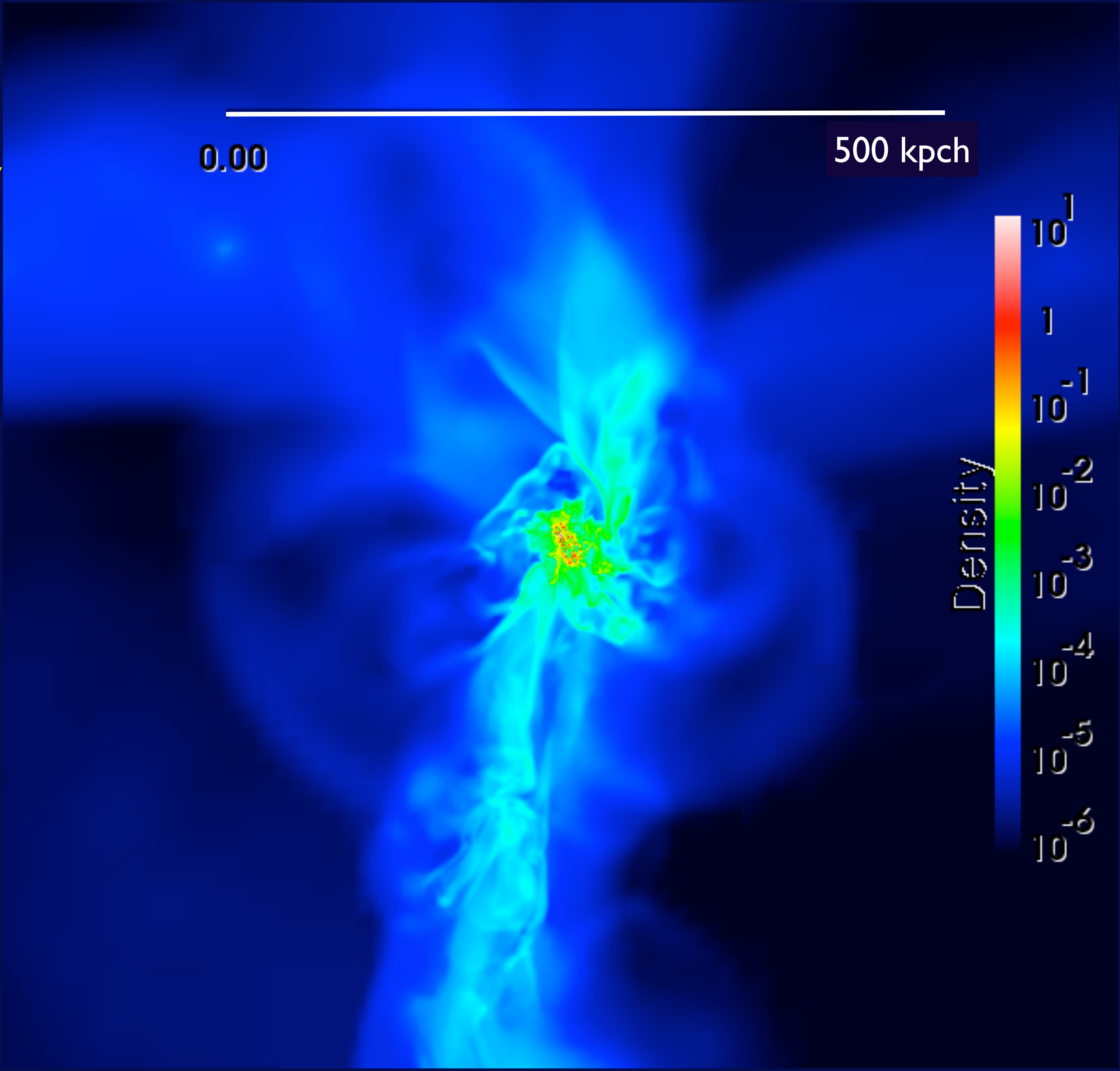
Z=1

Progenitor of M33-size galaxy

Radiation pressure + SN

~50 pc resolution

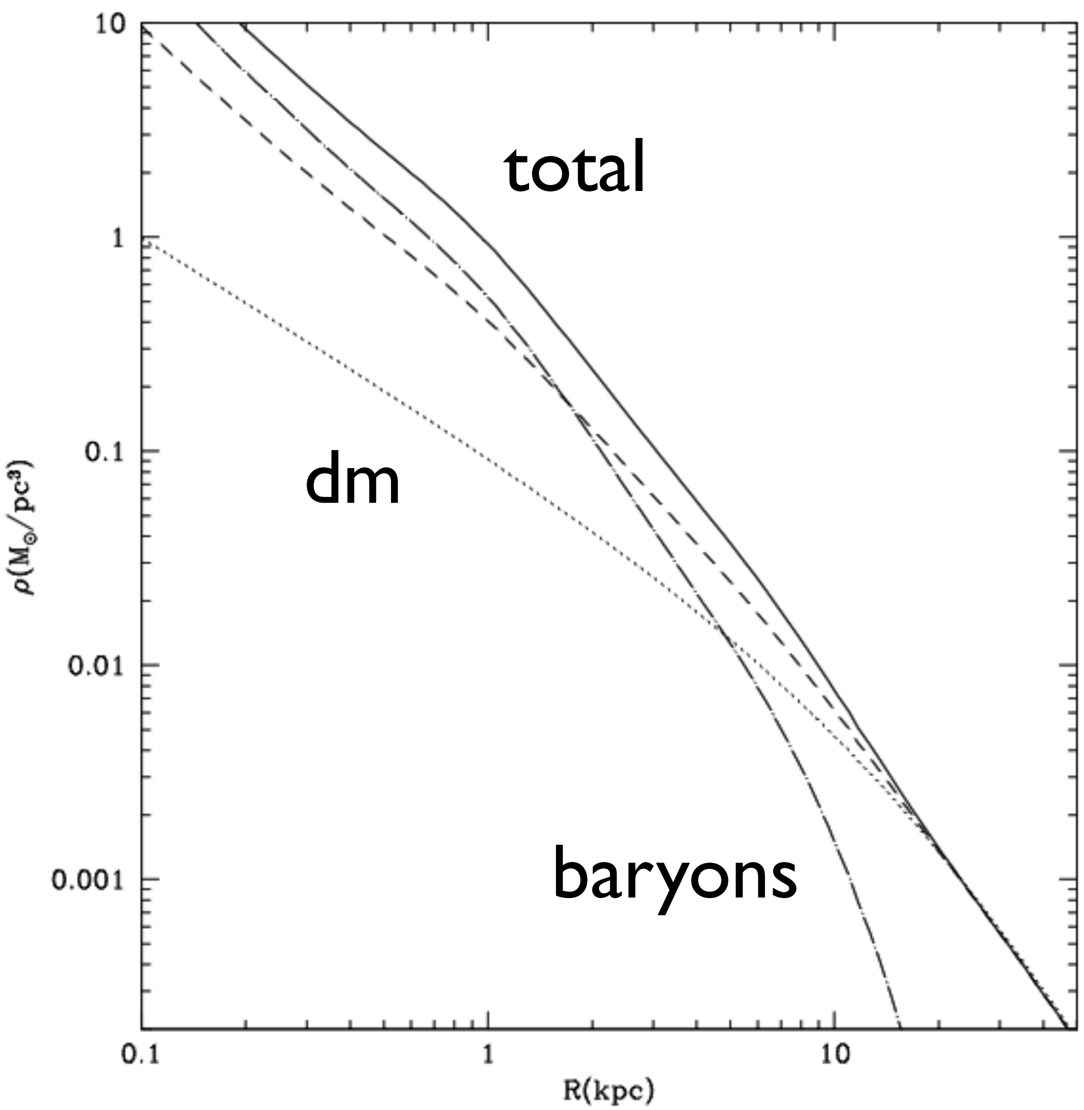
Gas density

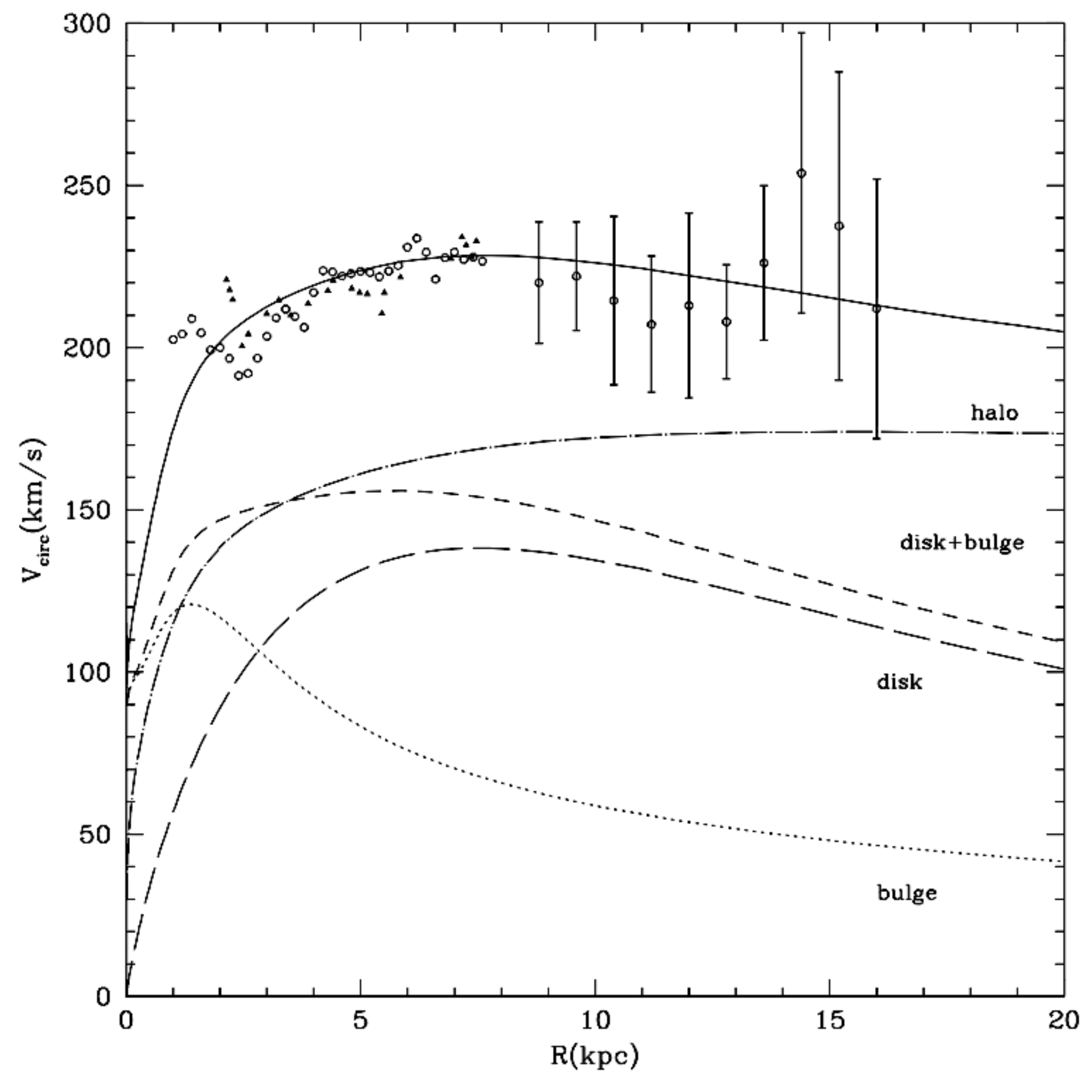


Trujillo-Gomez etal 2013

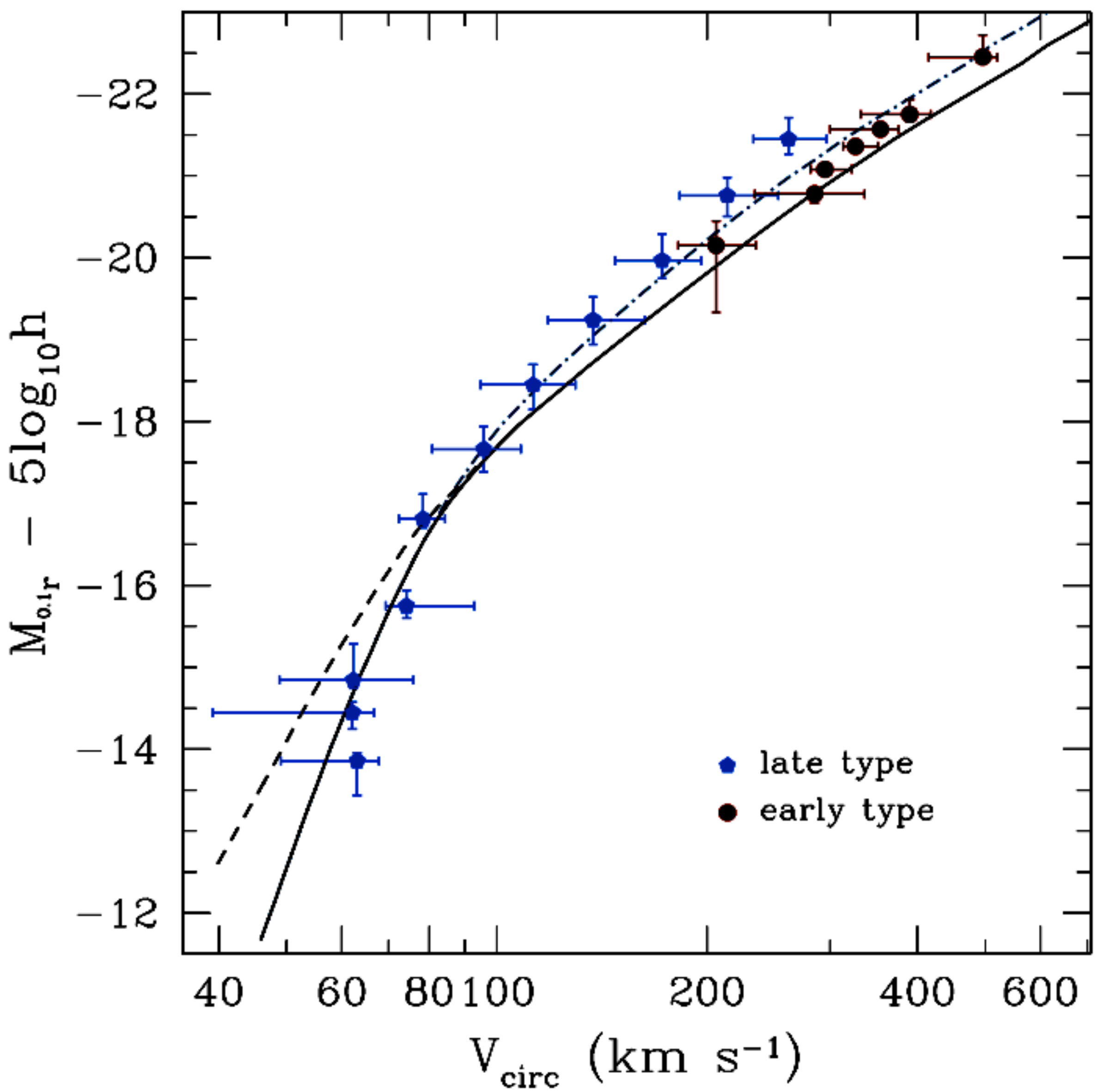
Bridging the gap between halos and galaxies:

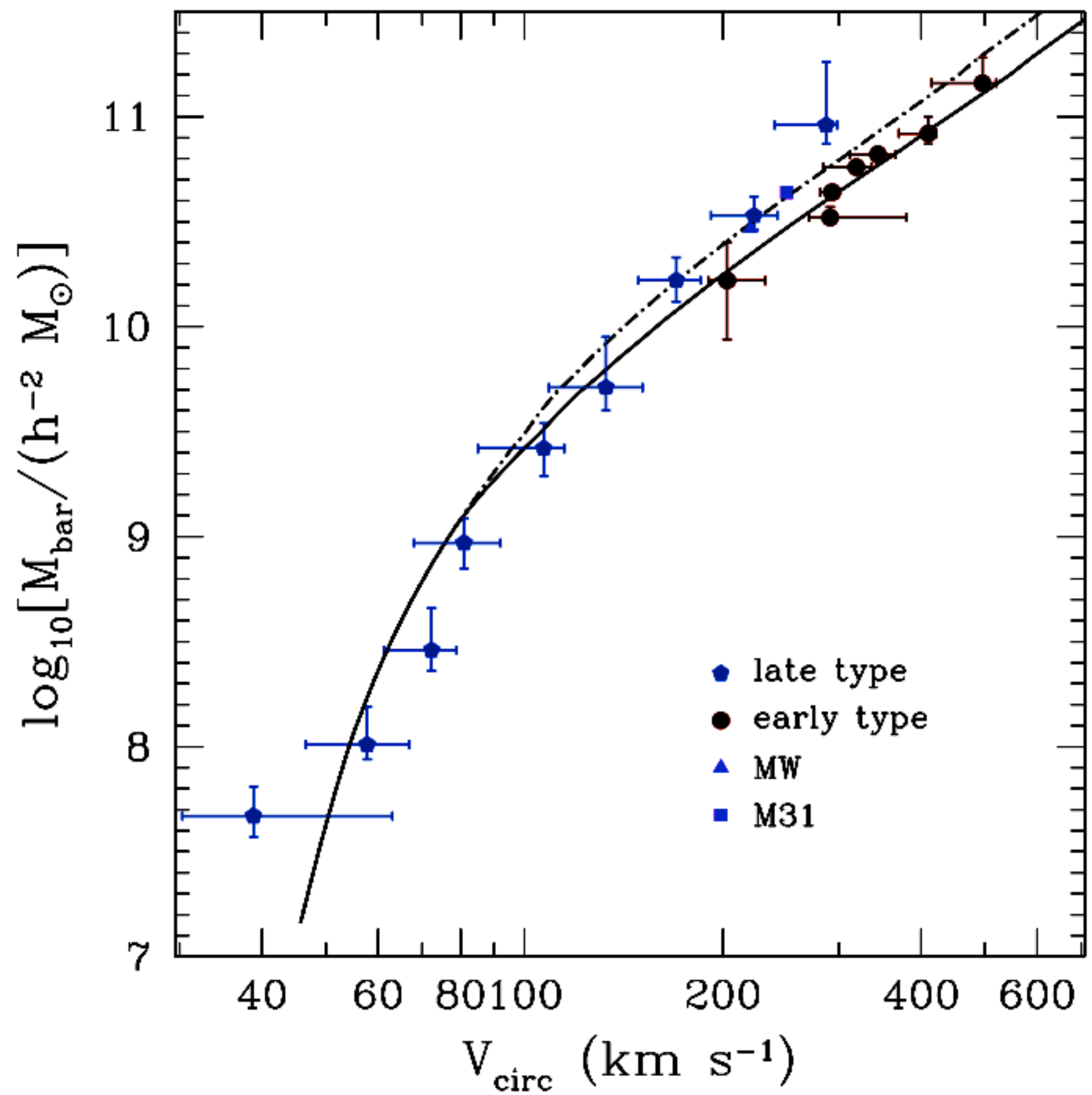
Milky Way: just an example of a dark matter distribution





Internal dynamics of galaxies: TF and BTF

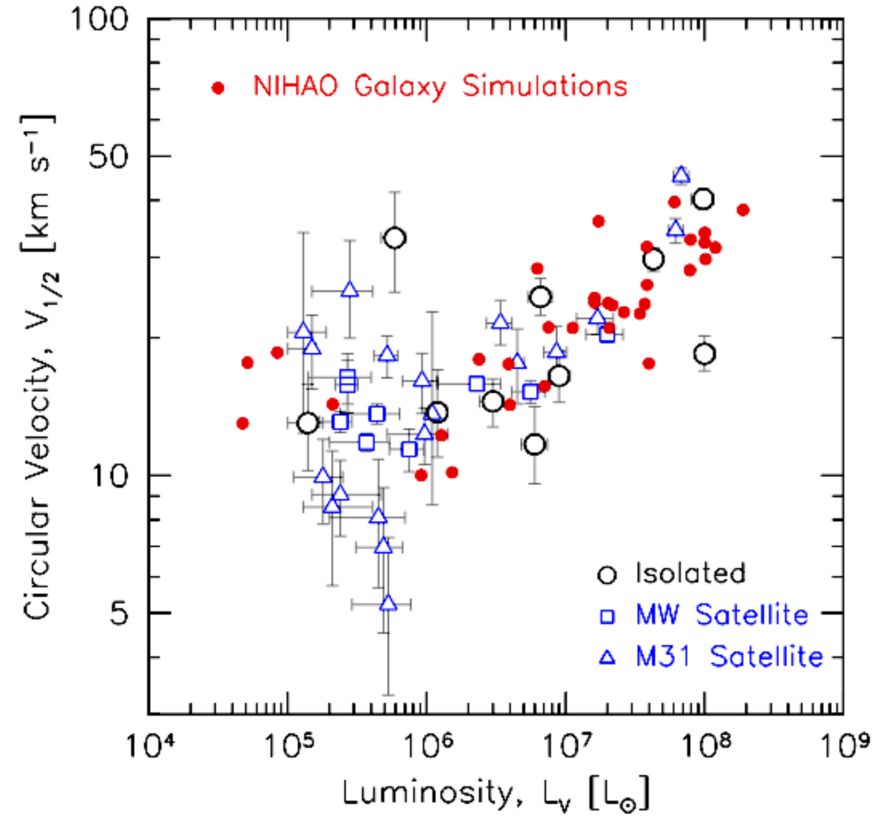




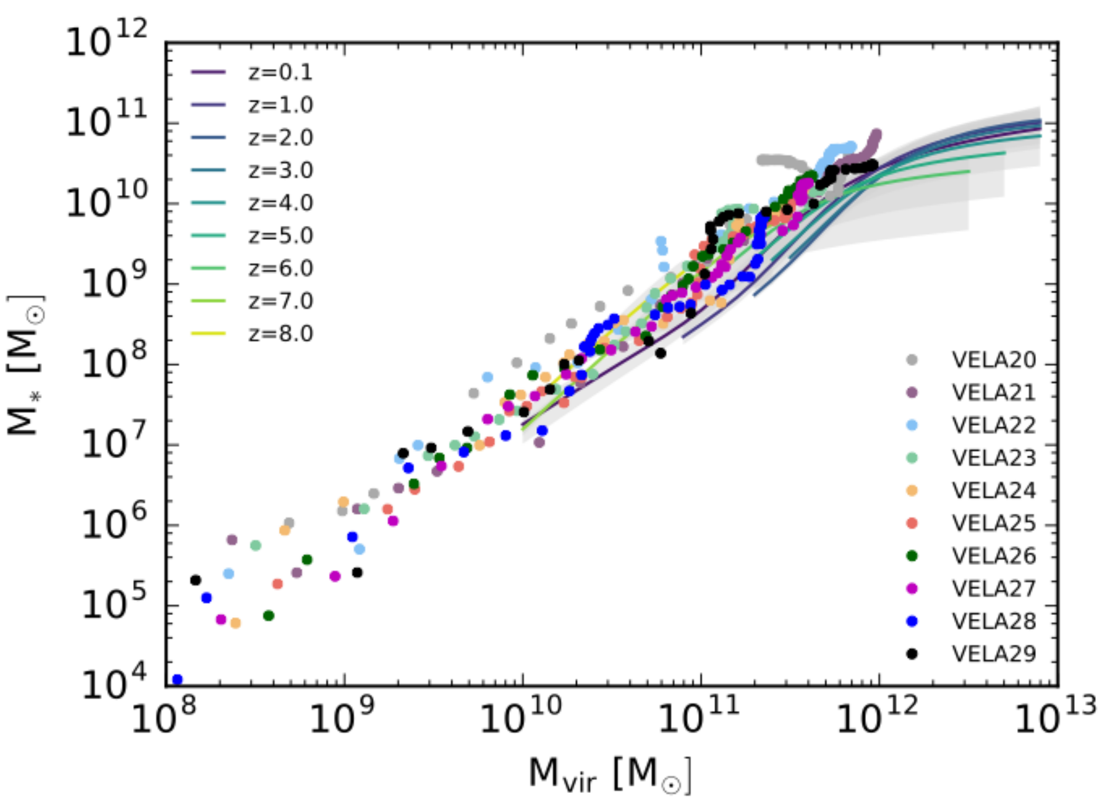
Halo Abundance matching: larger galaxies are hosted by bigger DM halos. No free parameters.

Trujillo-Gomez et al 2011

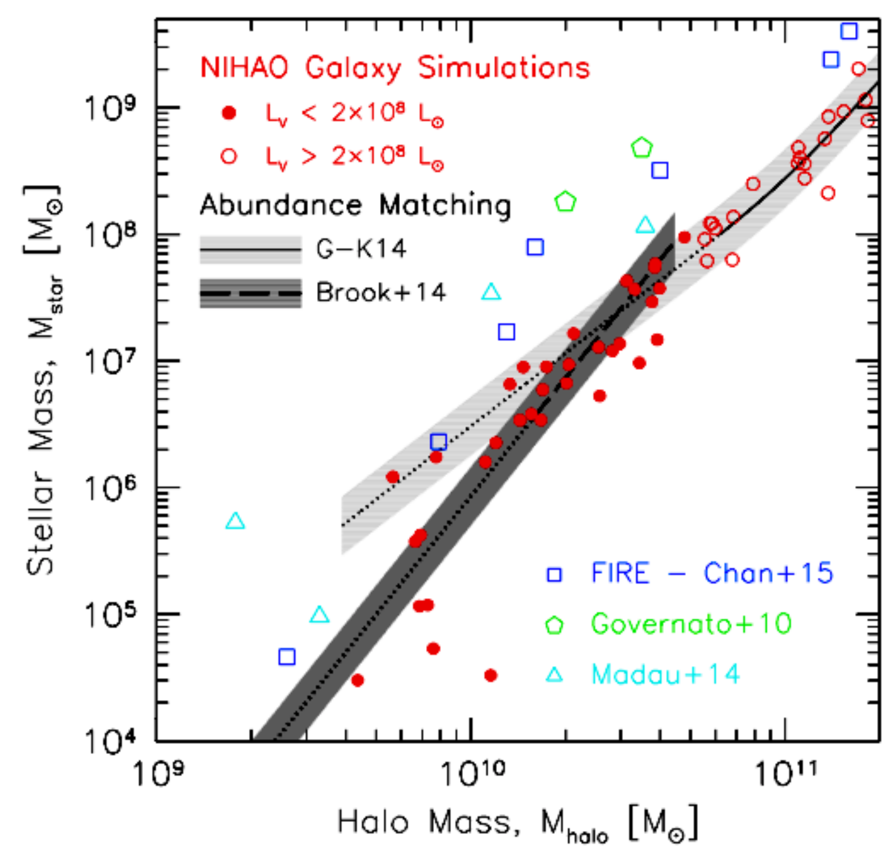
Hydro simulations: stellar mass and dark matter mass tightly correlate



Ceverino et al

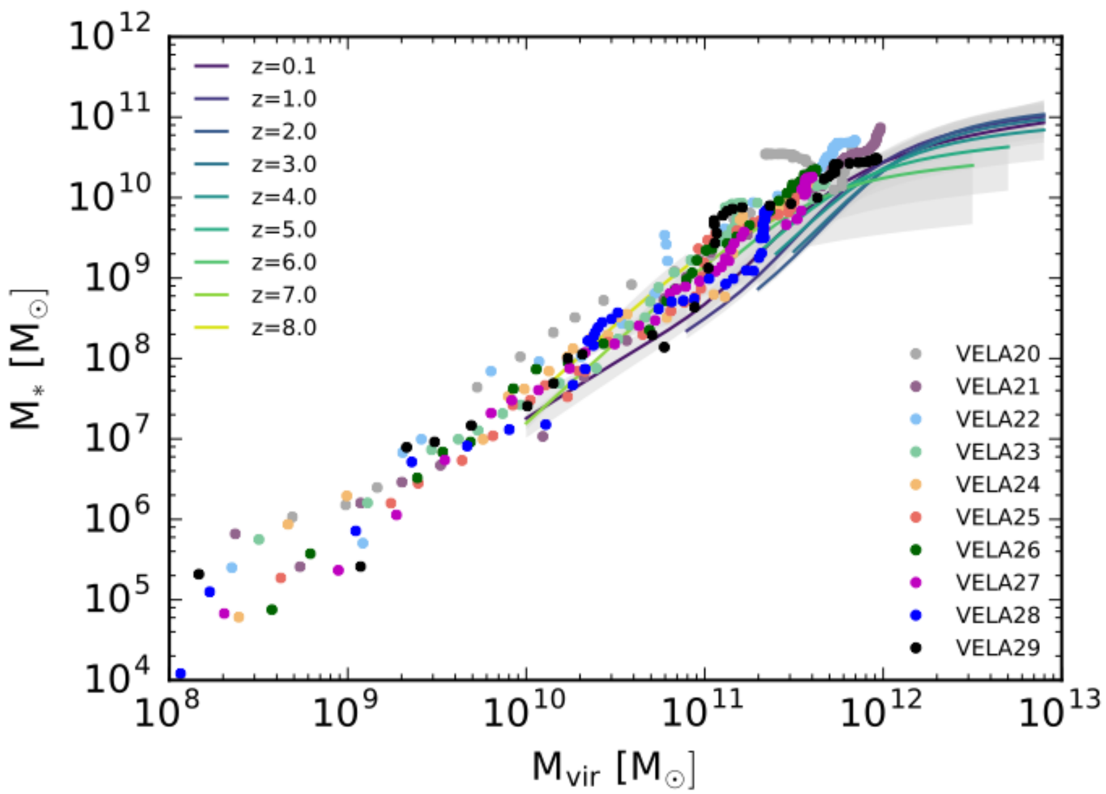


Dutton, Maccio et al



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).

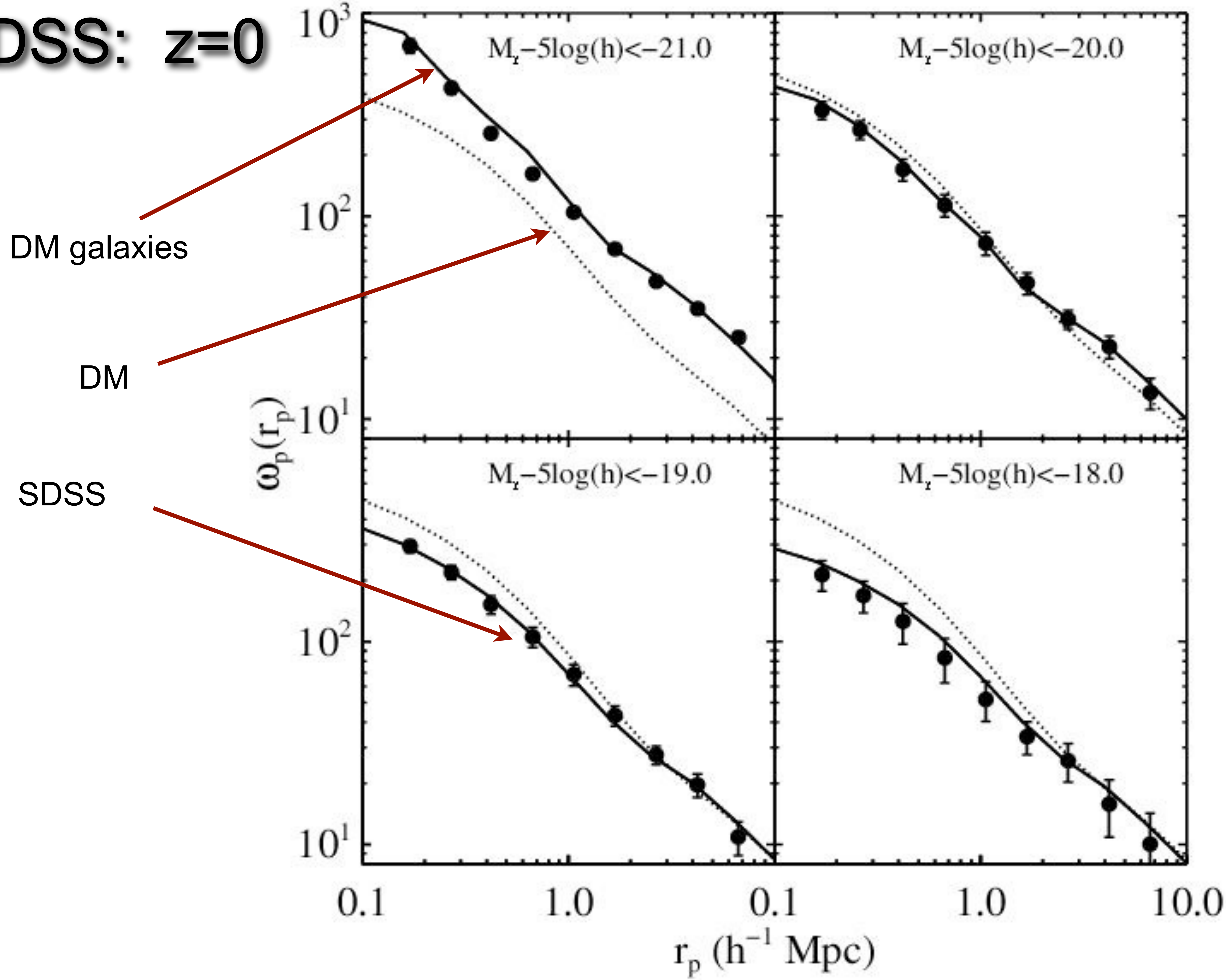
Clustering: DM halos and L

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

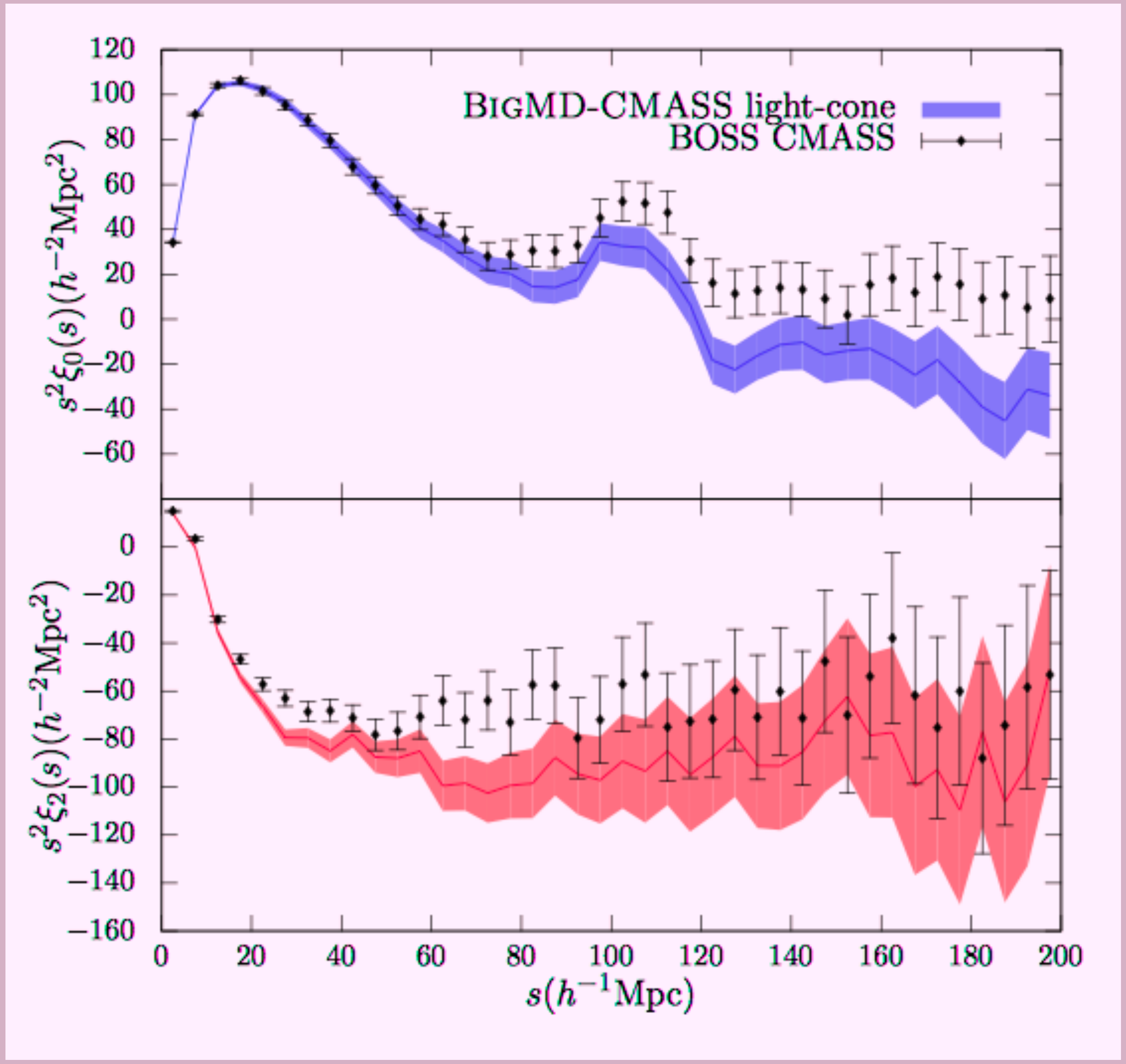


DM galaxies
DM
SDSS
$M_r-5\log(h)<-21.0$
$M_r-5\log(h)<-20.0$
$M_r-5\log(h)<-19.0$
$M_r-5\log(h)<-18.0$
$\omega_p(r_p)$
10^3
10^2
10^1
10^2
10^1
0.1
1.0
0.1
1.0
10.0
r_p (h^{-1} Mpc)

Comparing LCDM with BOSS data

Dark Matter ==> galaxies:

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

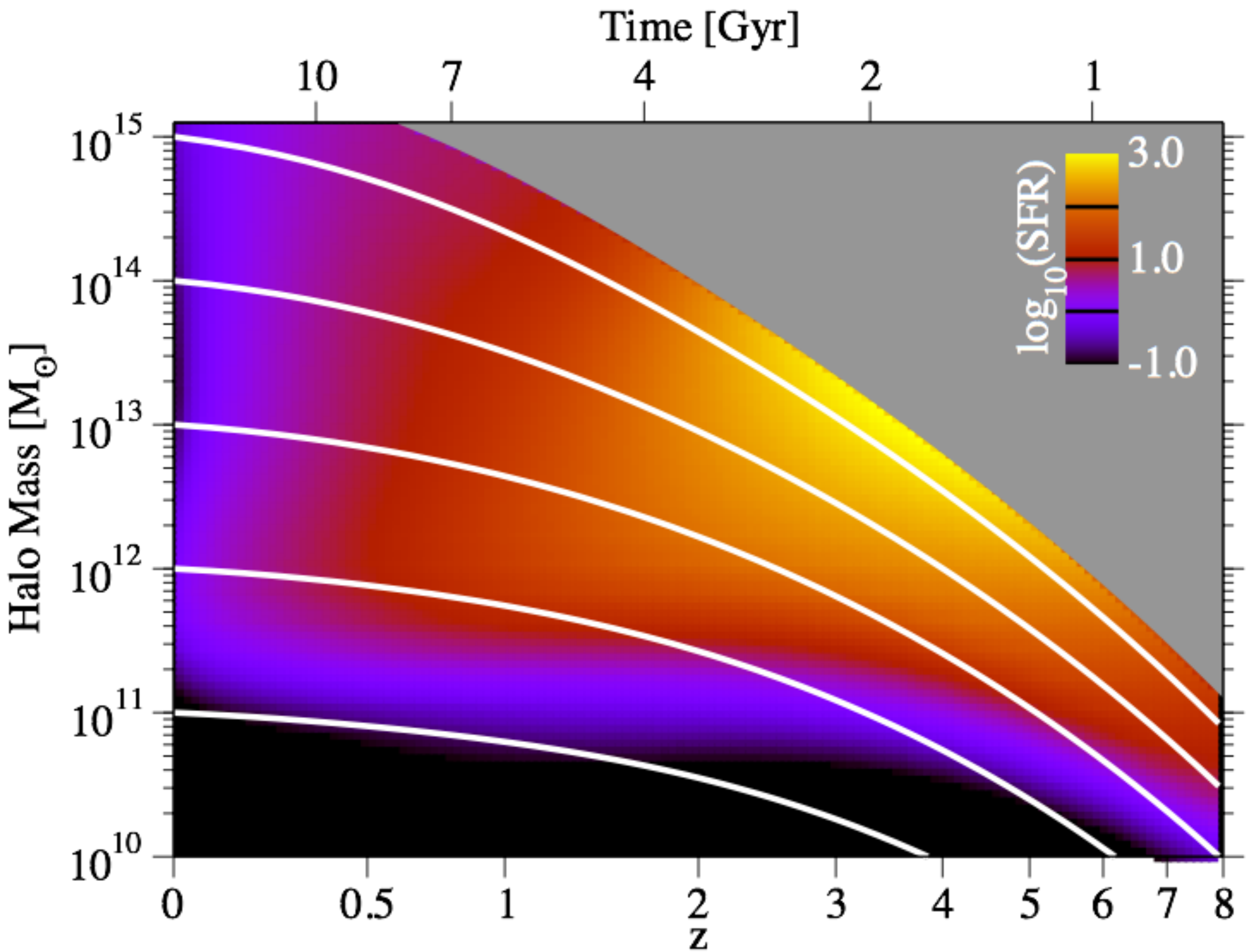


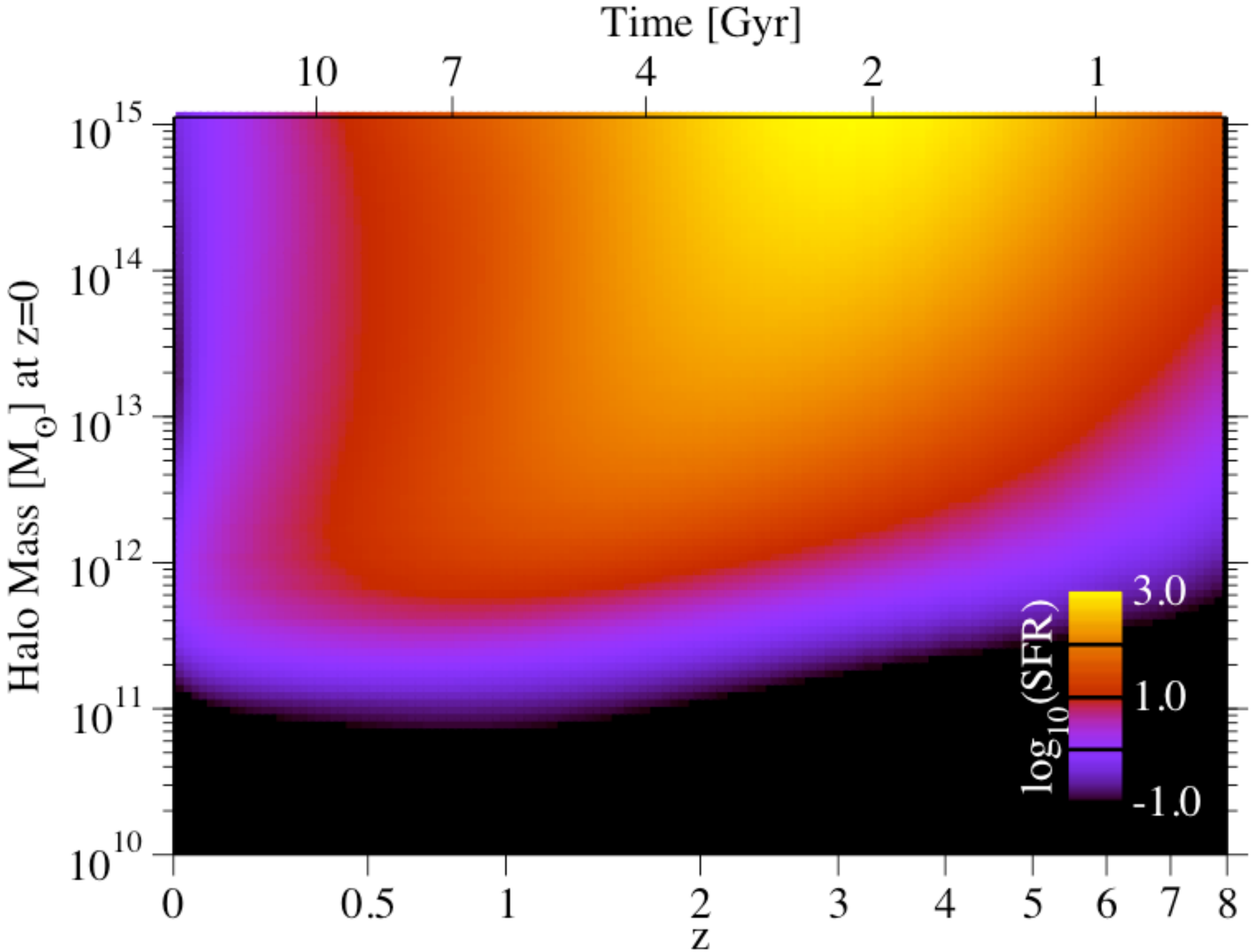
Rodriguez-Torres et al 2015

MultiDark Simulations

arXiv:1207.6105

star formation history of the Universe:





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

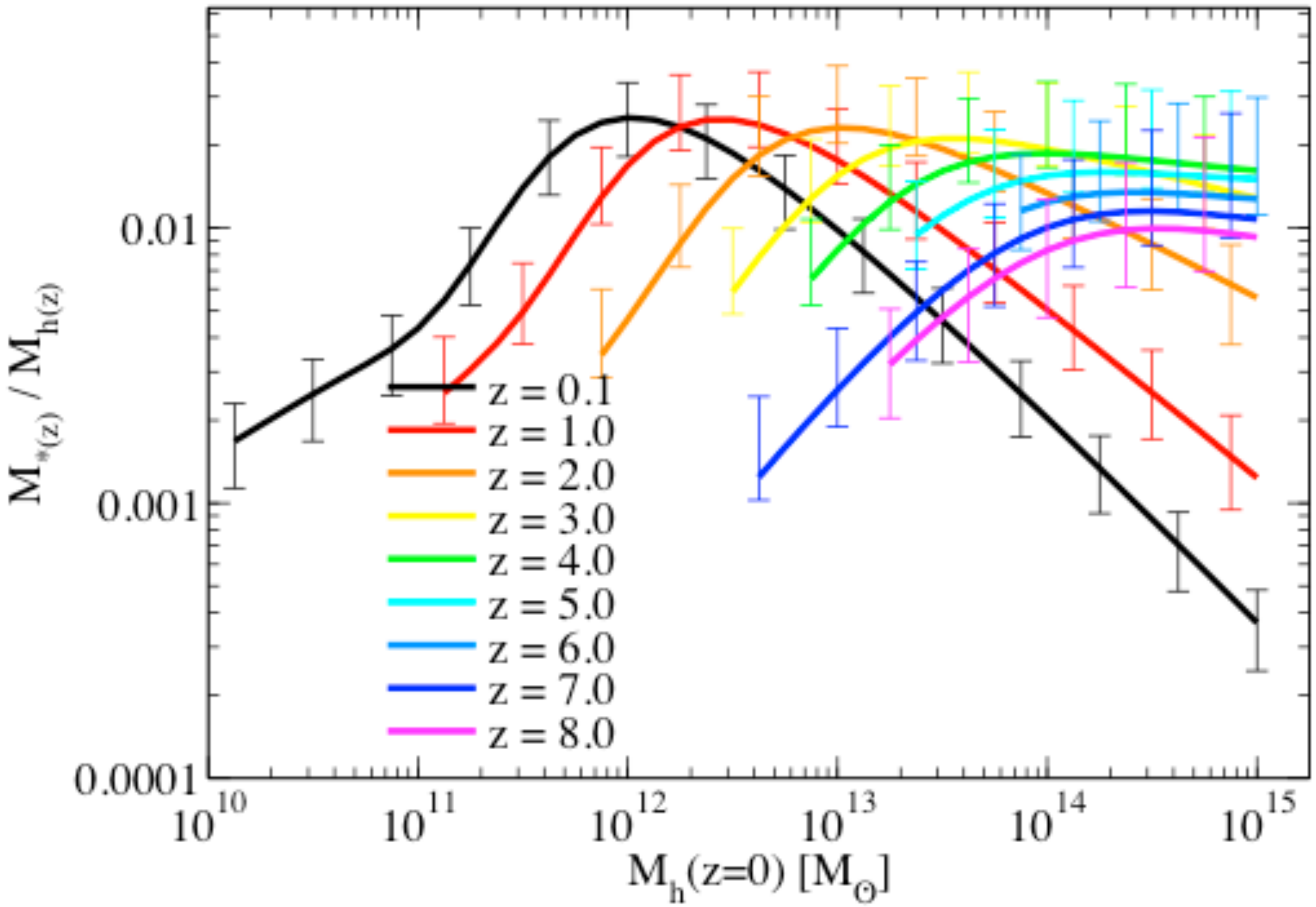
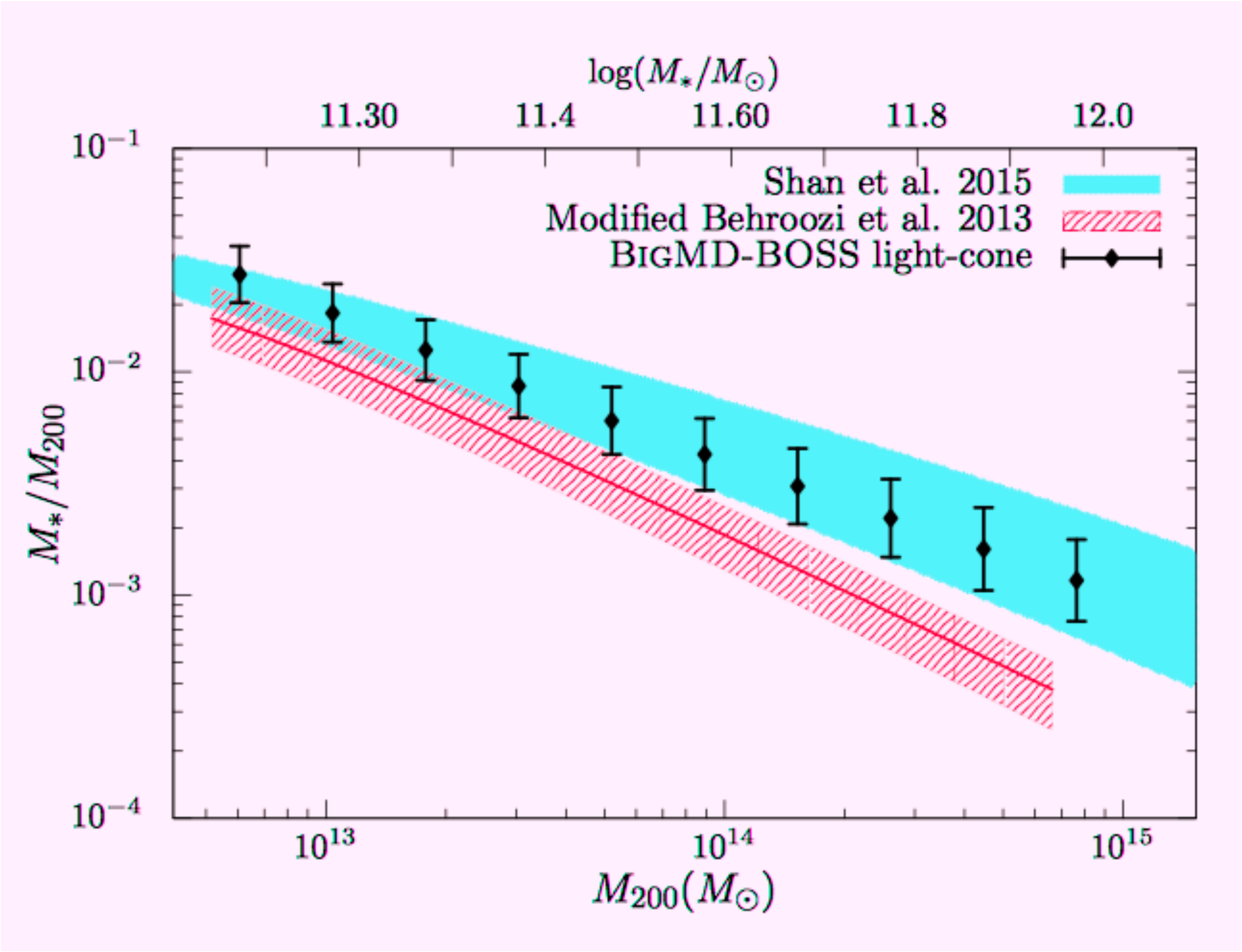


FIG. 8.— Evolution of the derived stellar mass fractions ($M_*(z)/M_h(z)$) as a function of halo mass at the present day. More massive halos used to have a significantly larger fraction of mass in stars, but the peak star formation efficiency has remained relatively constant to the present day.

Comparing LCDM with BOSS data

Dark Matter ==> galaxies:

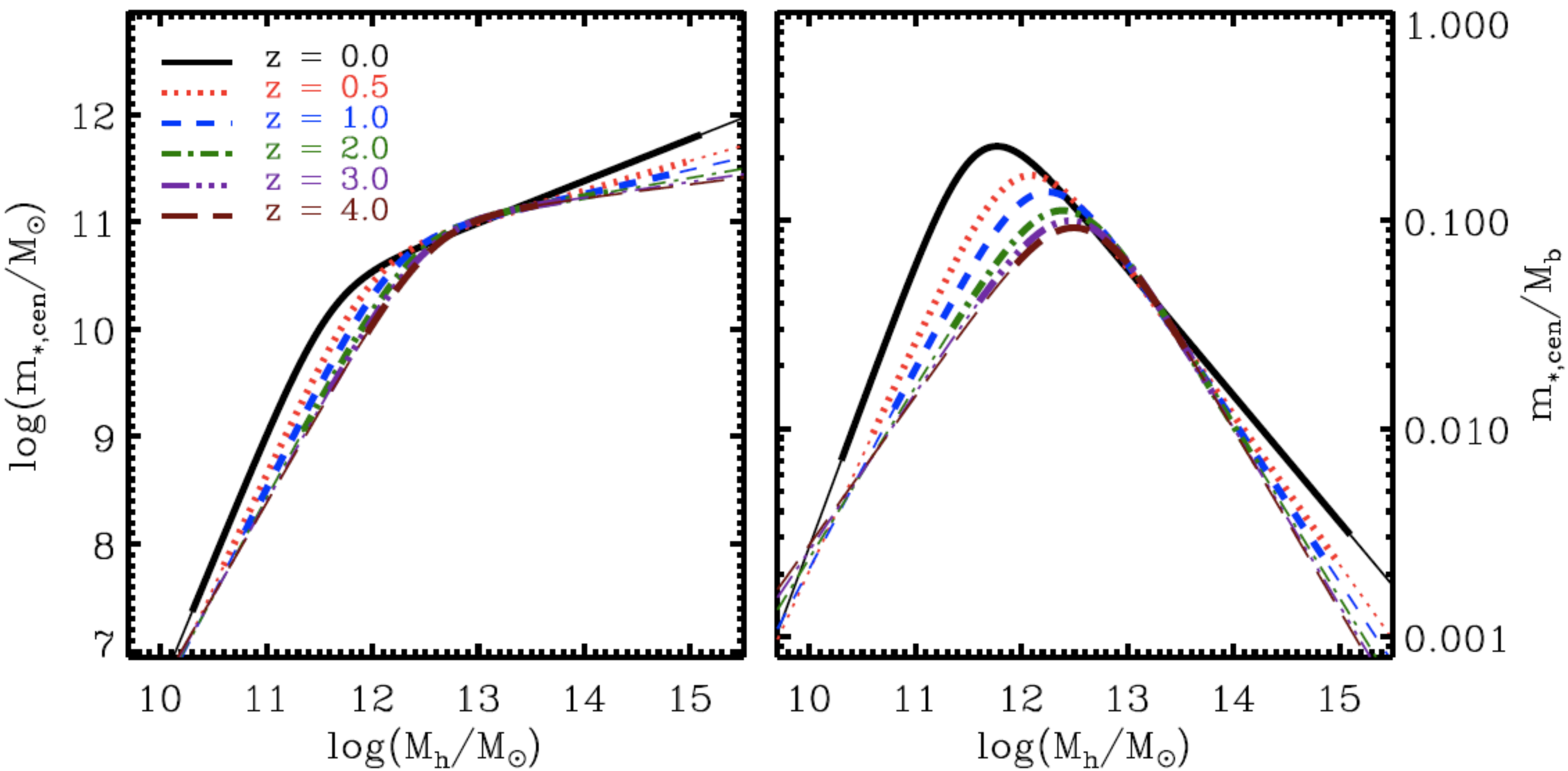
Halo Abundance matching: larger galaxies are hosted by bigger DM halos. No free parameters.



Rodriguez-Torres et al 2015

MultiDark Simulations

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



Moster et al 2012