



Leibniz-Institut für
Astrophysik Potsdam

Constrained Local Universe Simulations

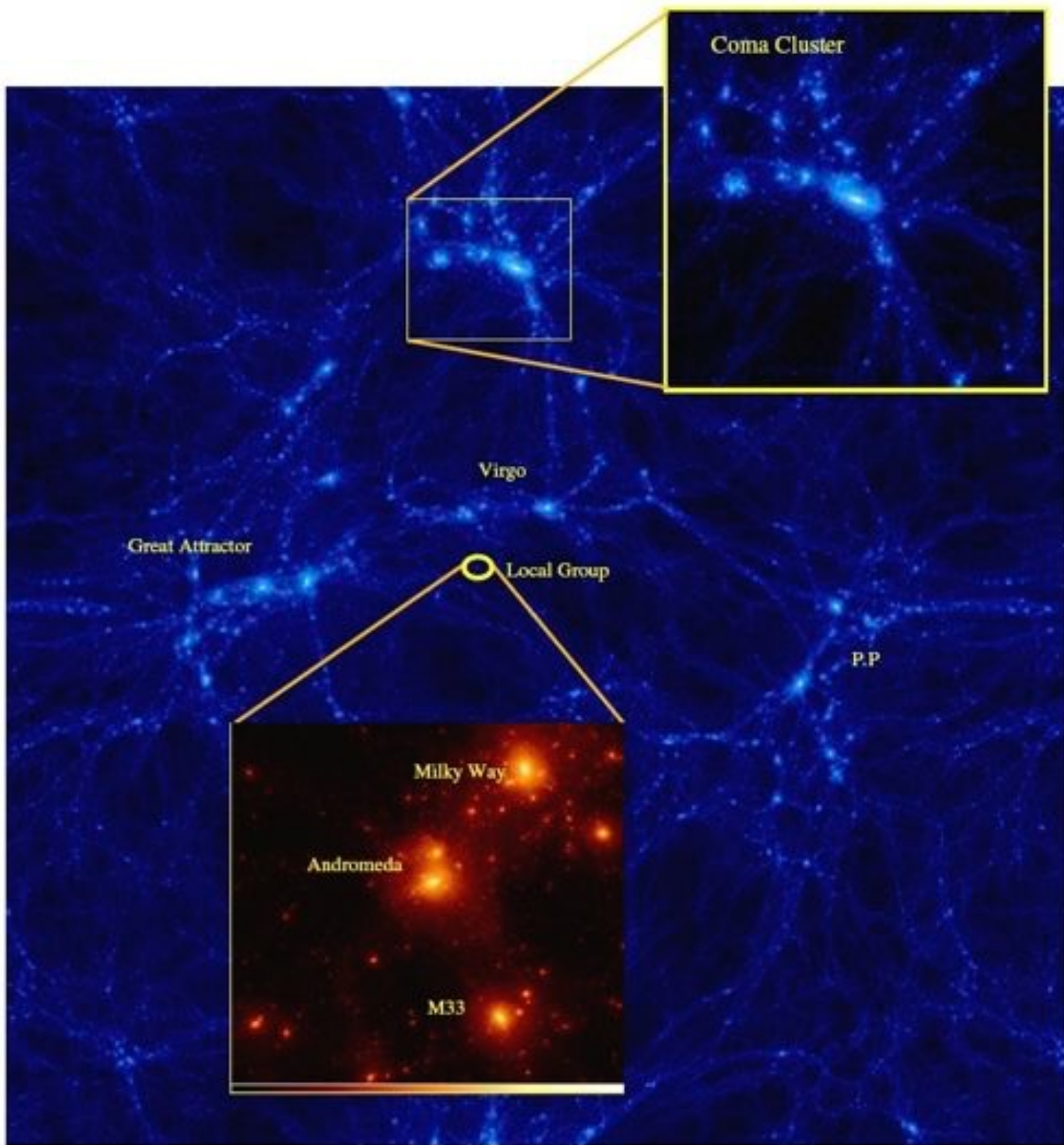
Matthias Steinmetz

(thanks to Alejandro Benitez-Llambay, Stefan Gottlöber, Yehuda Hoffman, Noam Libeskind, Julio Navarro, Jenny Sorce, Brent Tully, Gustavo Yepes)



Modelling the Local Group in a LCDM environment

- How to set up constrain Gaussian Random Fields
- Constrained Local Universe Simulations (CLUES)
 - HI distribution in the (simulated) Local Group
- Applications
 - Effects of environment
 - Vast Planes of Satellites
 - Cosmic web stripping



Coma Cluster

$160h^{-1}$
Mpc

Virgo

Great Attractor

Local Group

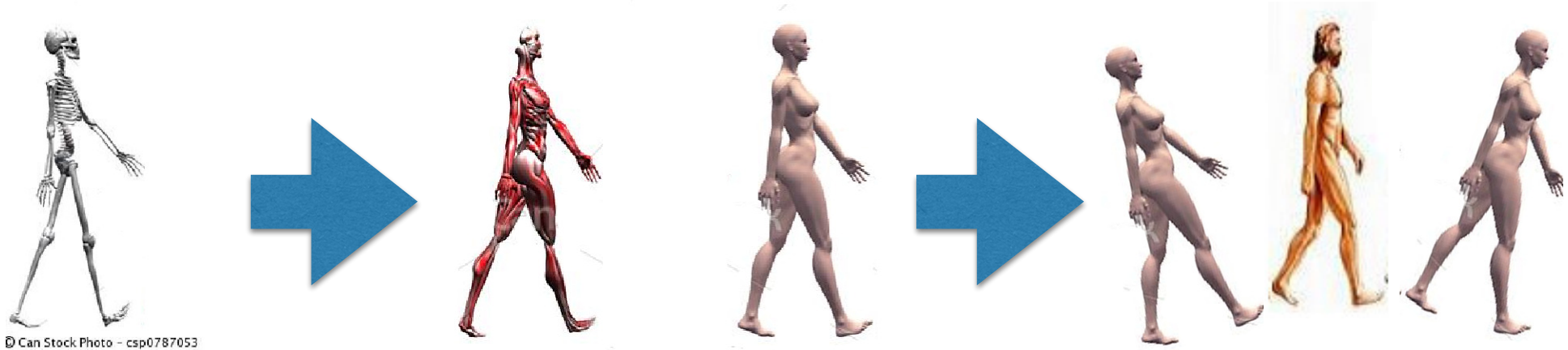
P.P.

Milky Way

Andromeda

M33

Constrained Simulations (from thesis J. Sorce)



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Constraints from Observations

Reconstruction

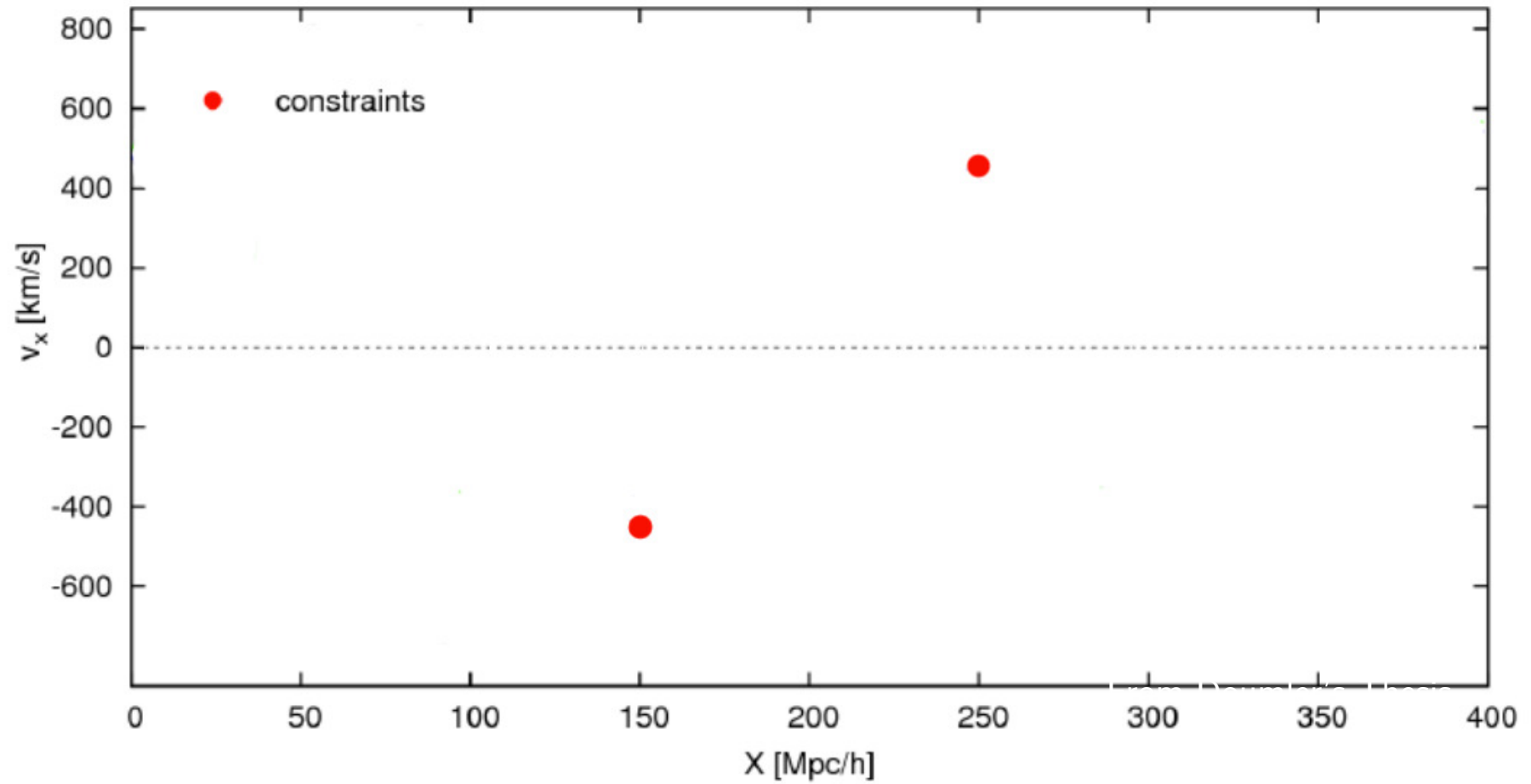
Realizations



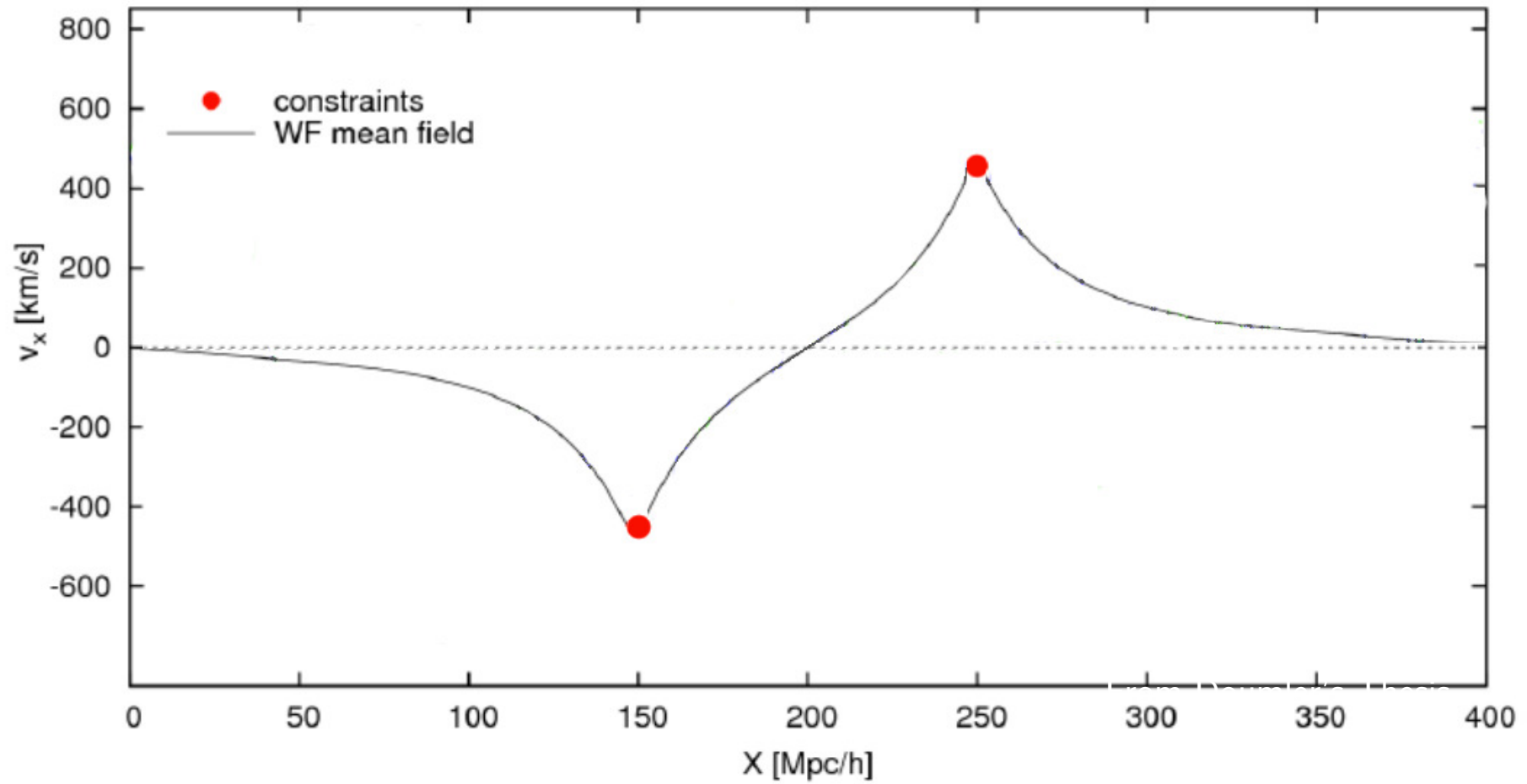
Initial Conditions

Constrained Simulation of Evolution

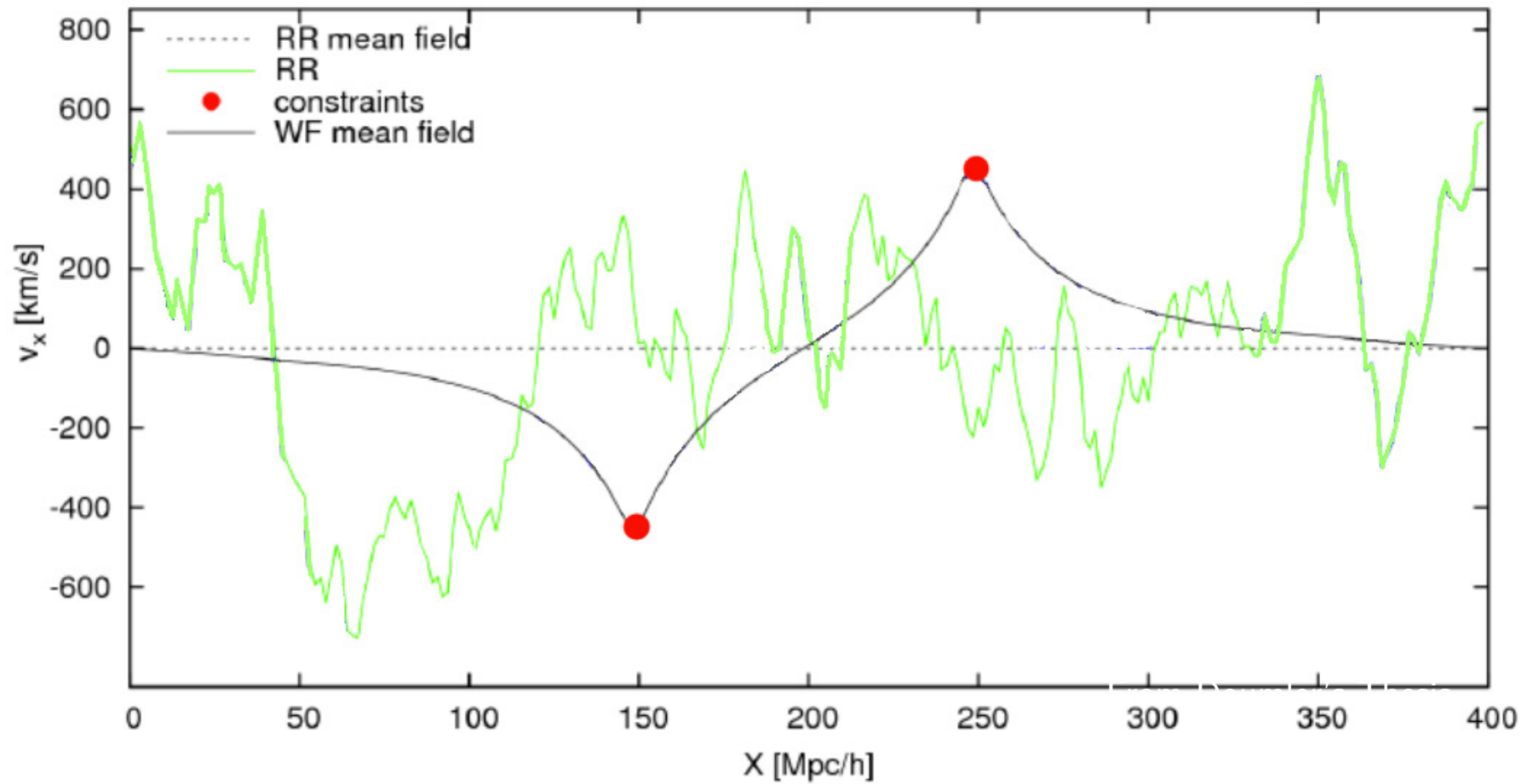
1D example - constraints



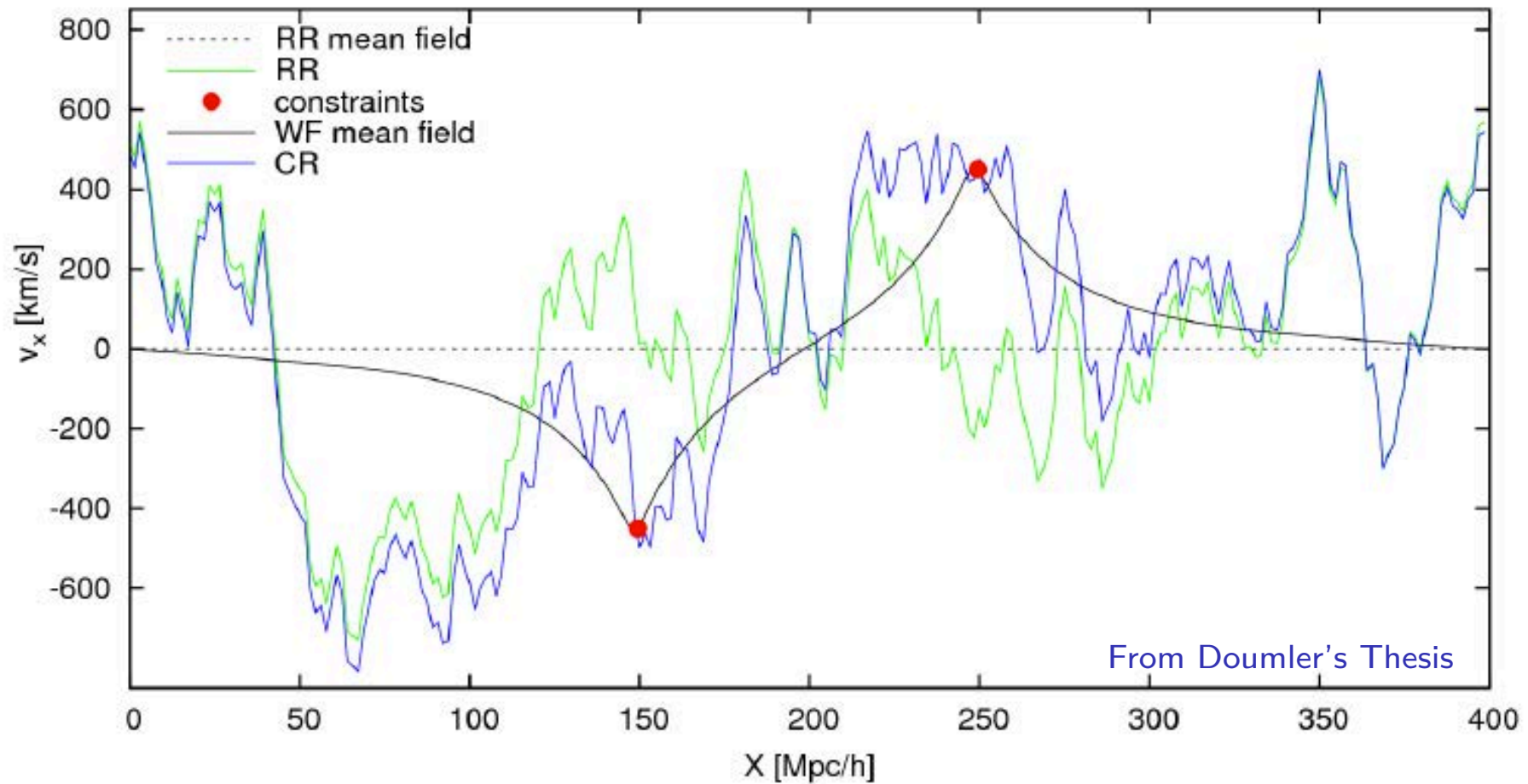
1D example - mean field



1D example - reduced power spectrum realization

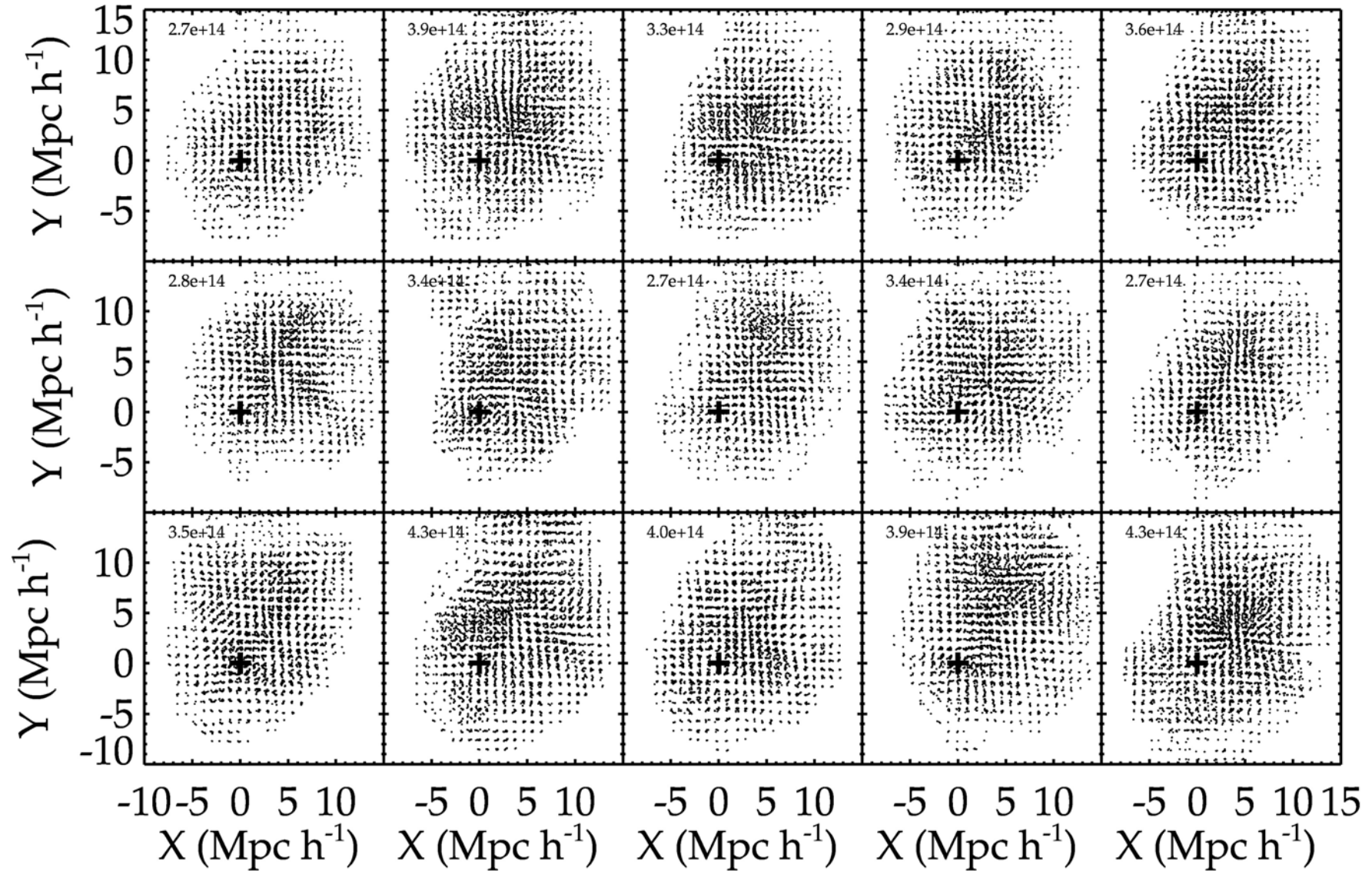


1D example - constrained random field



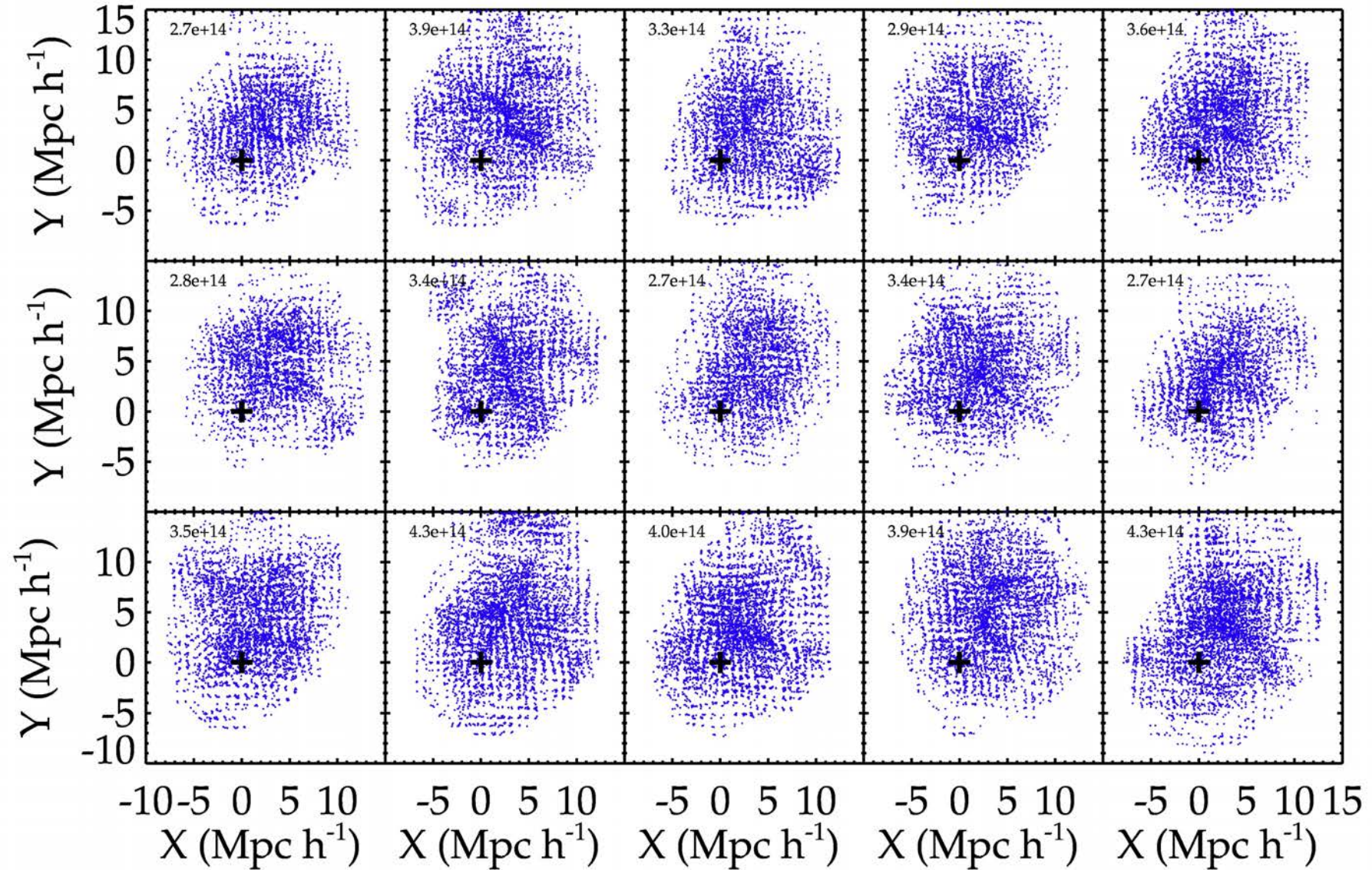
Example Virgo (12 realizations)

$z=10$



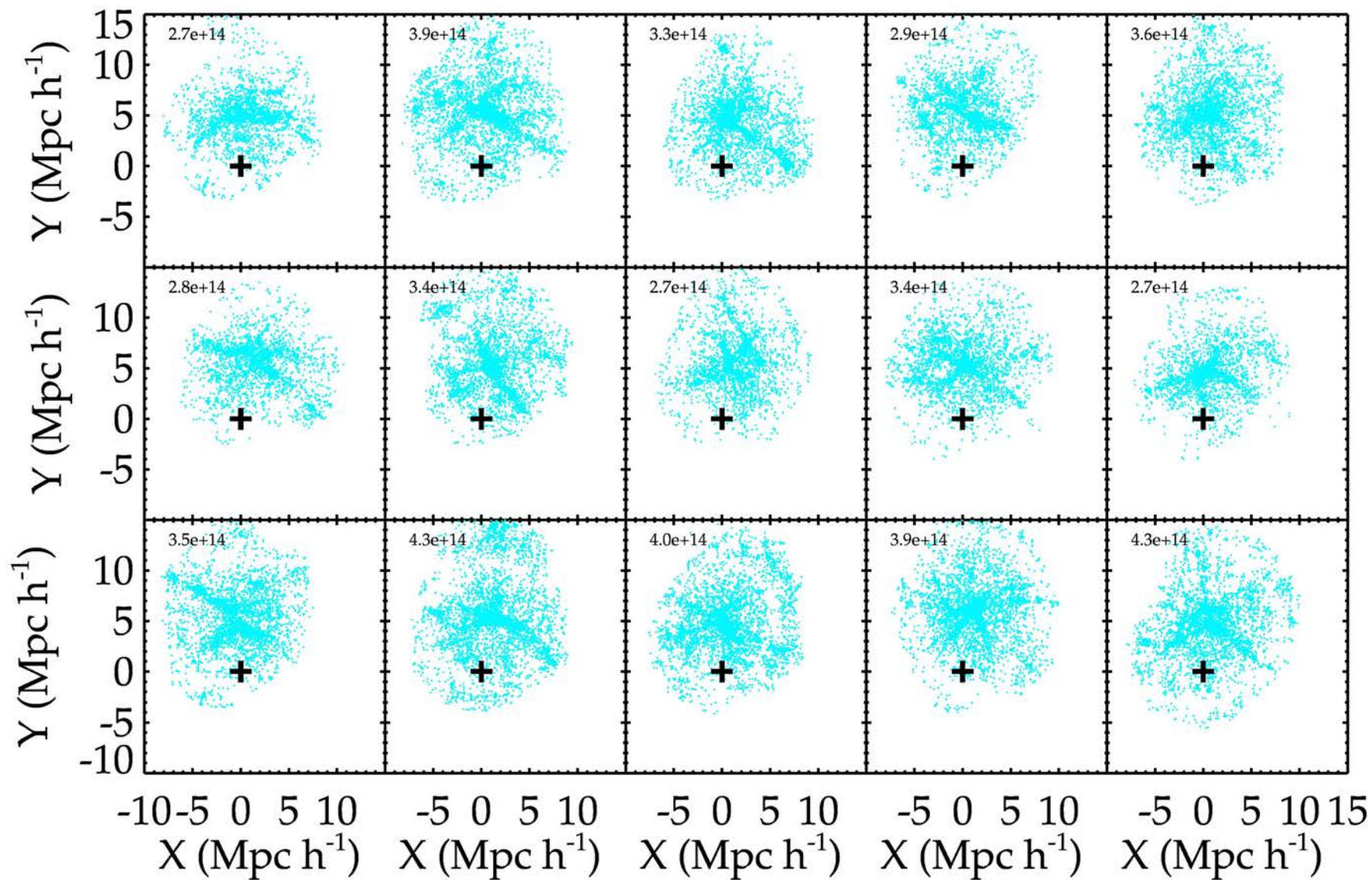
Example Virgo (12 realizations)

$z=5$



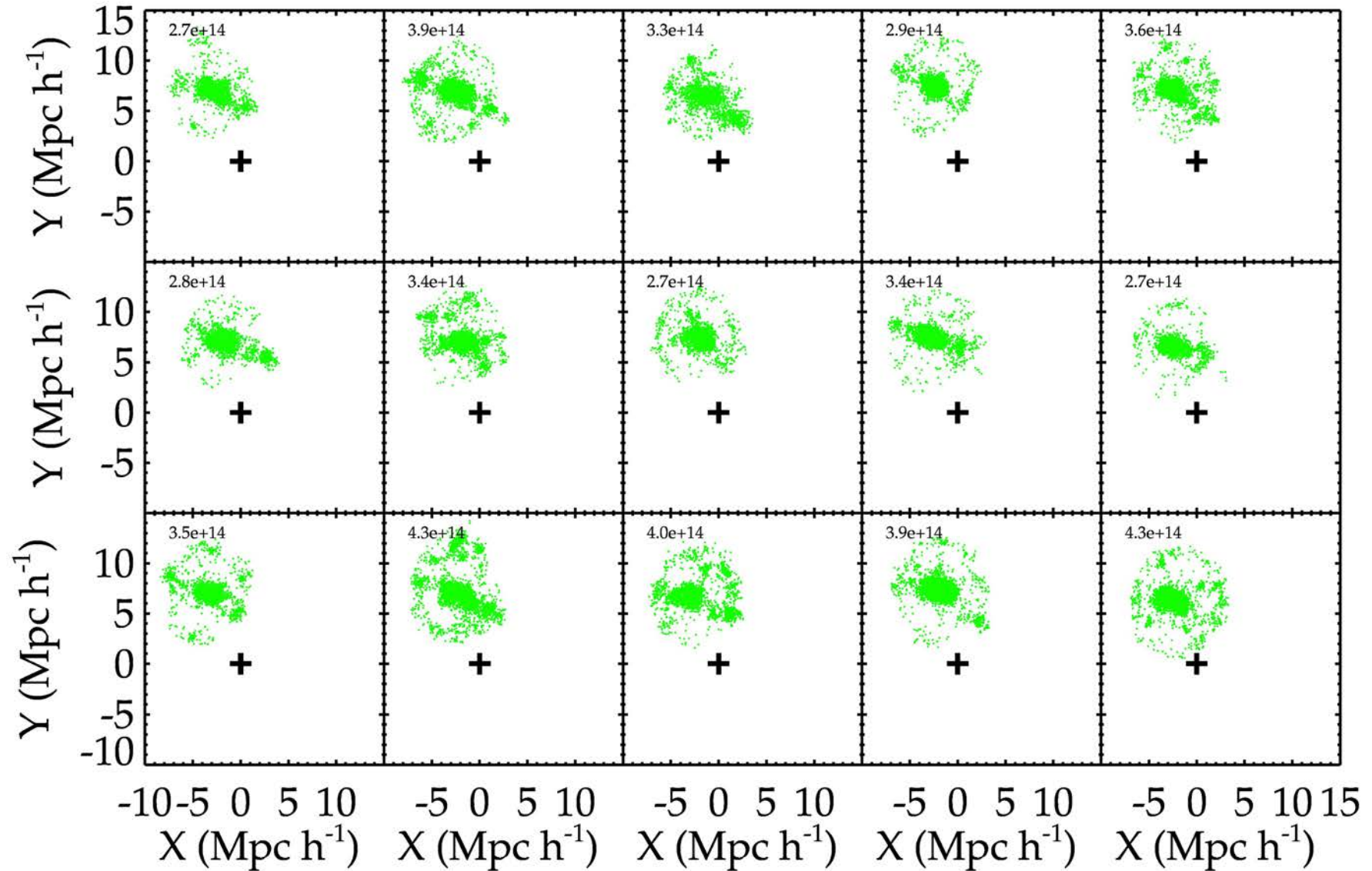
Example Virgo (12 realizations)

$z=2$



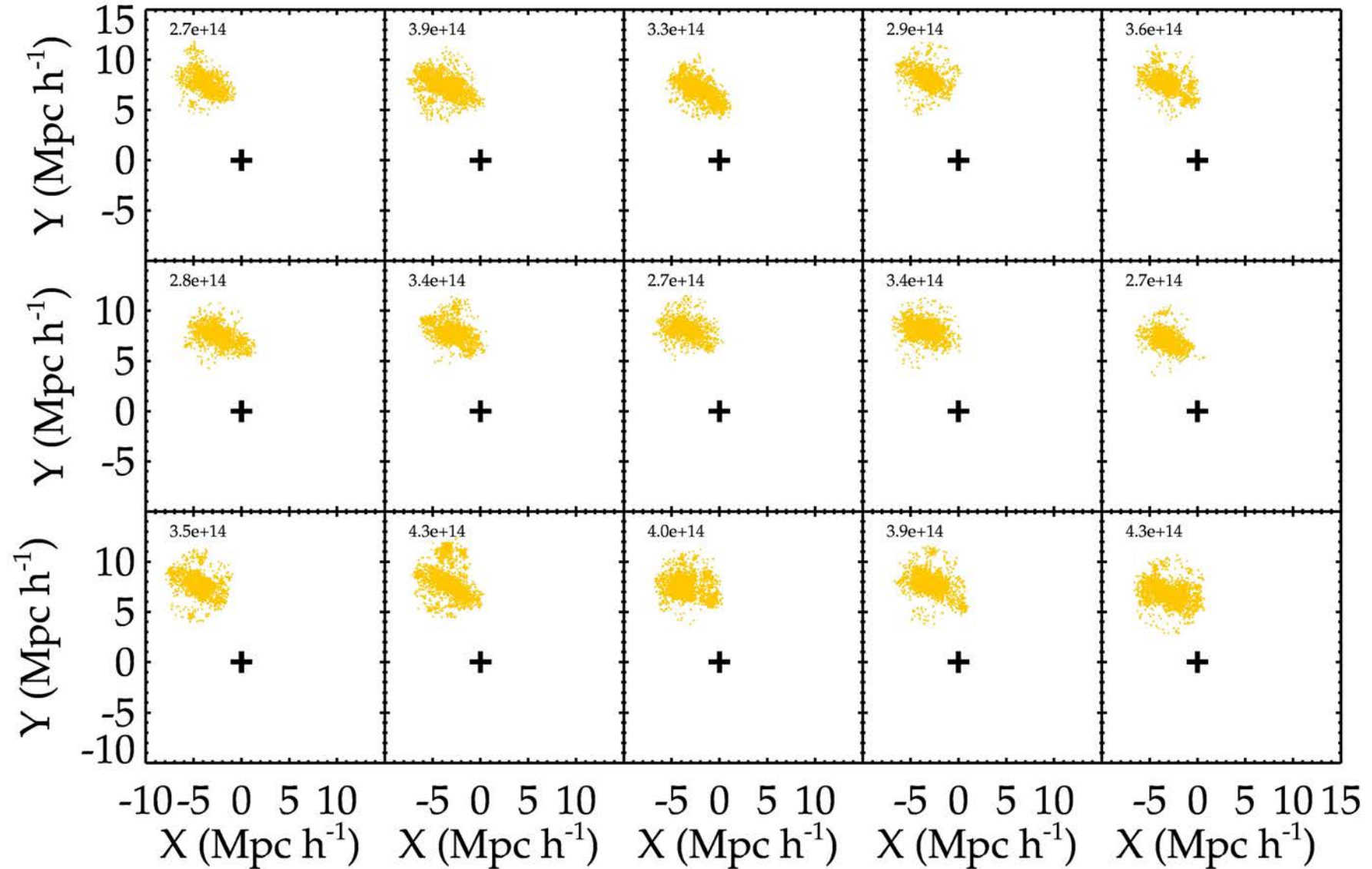
Example Virgo (12 realizations)

$z=0.5$



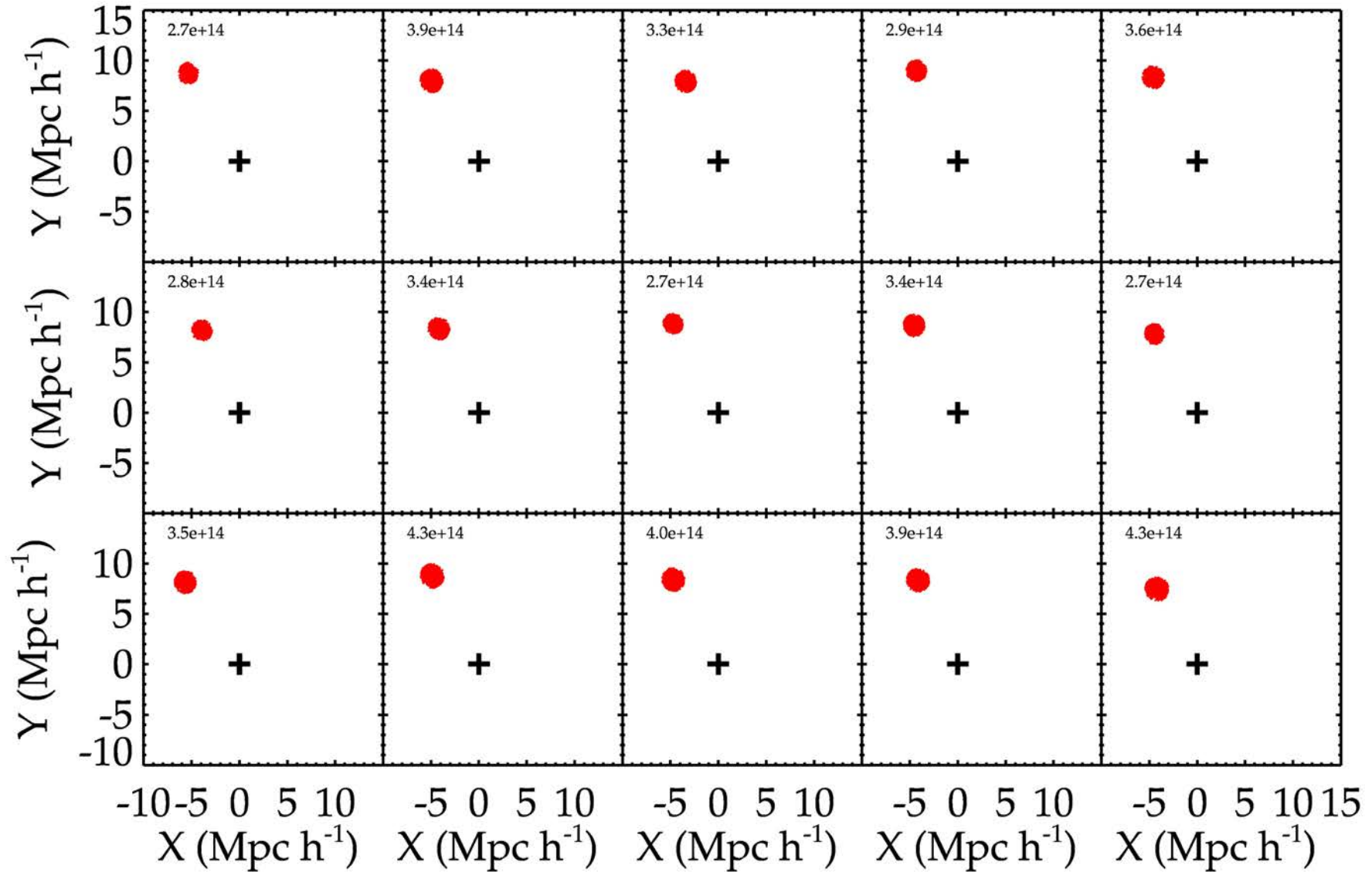
Example Virgo (12 realizations)

$z=0.25$

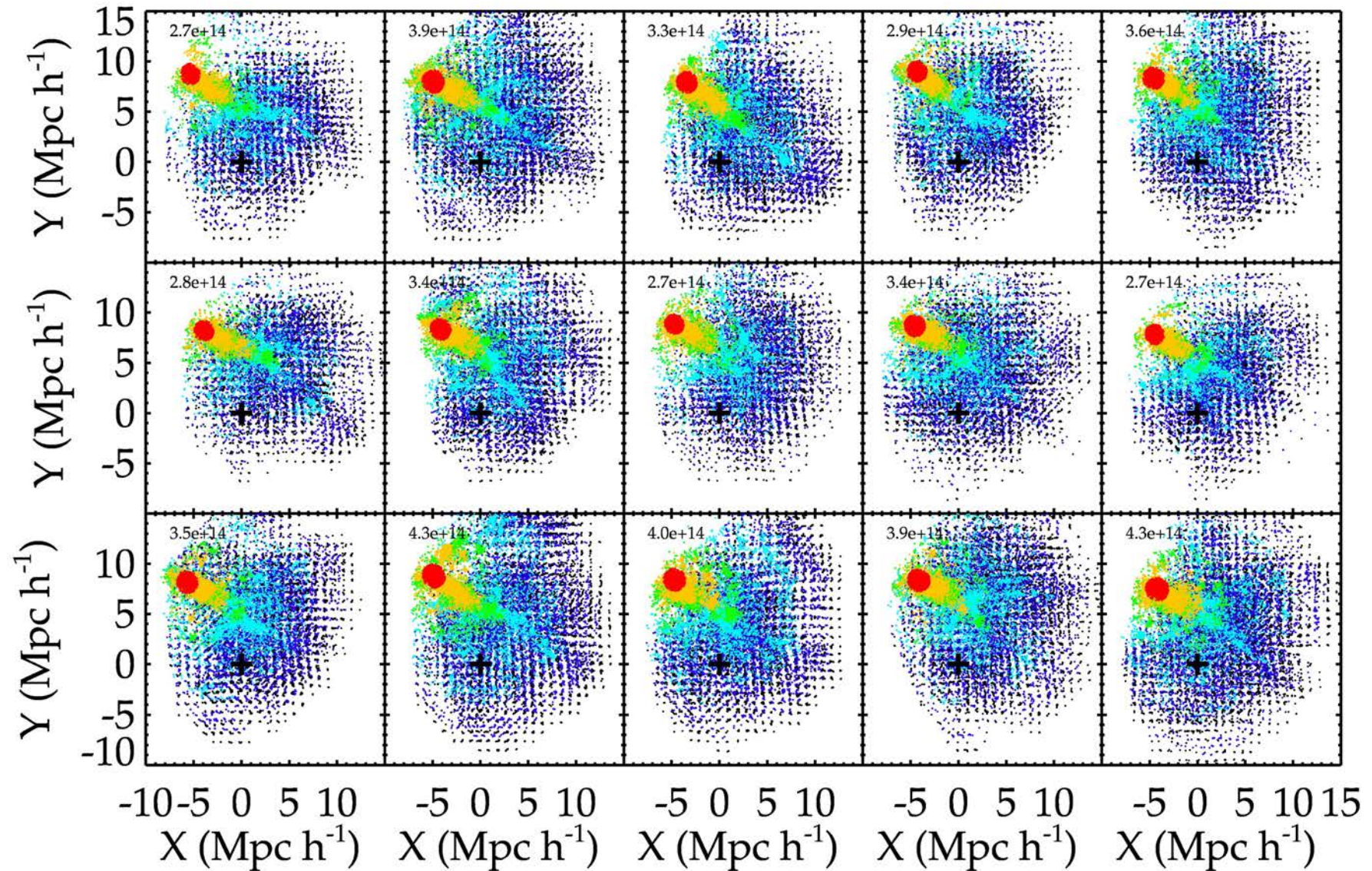


Example Virgo (12 realizations)

$z=0$



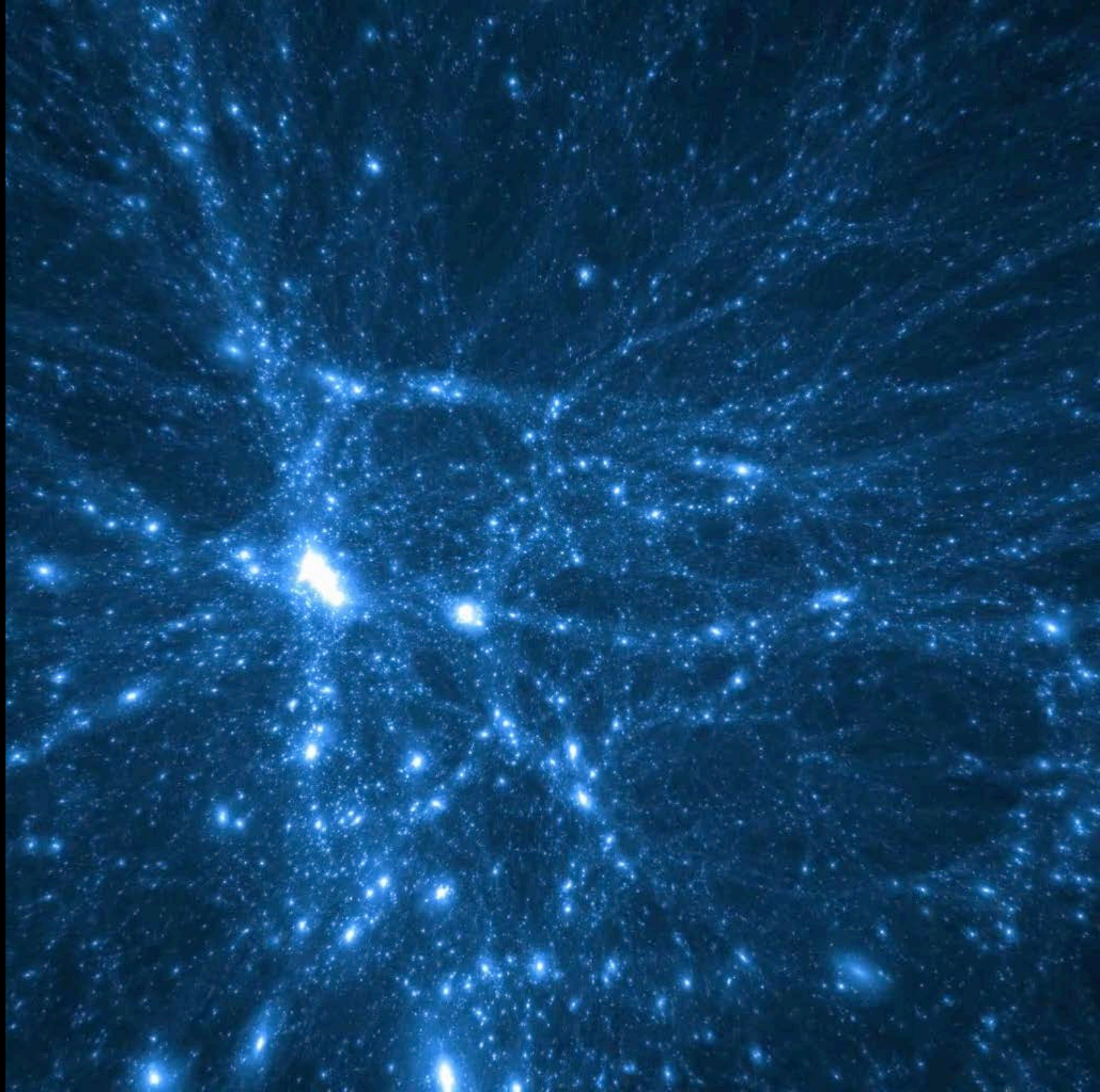
Example Virgo (12 realizations)



Reconstruction and Resampling of Density Fields

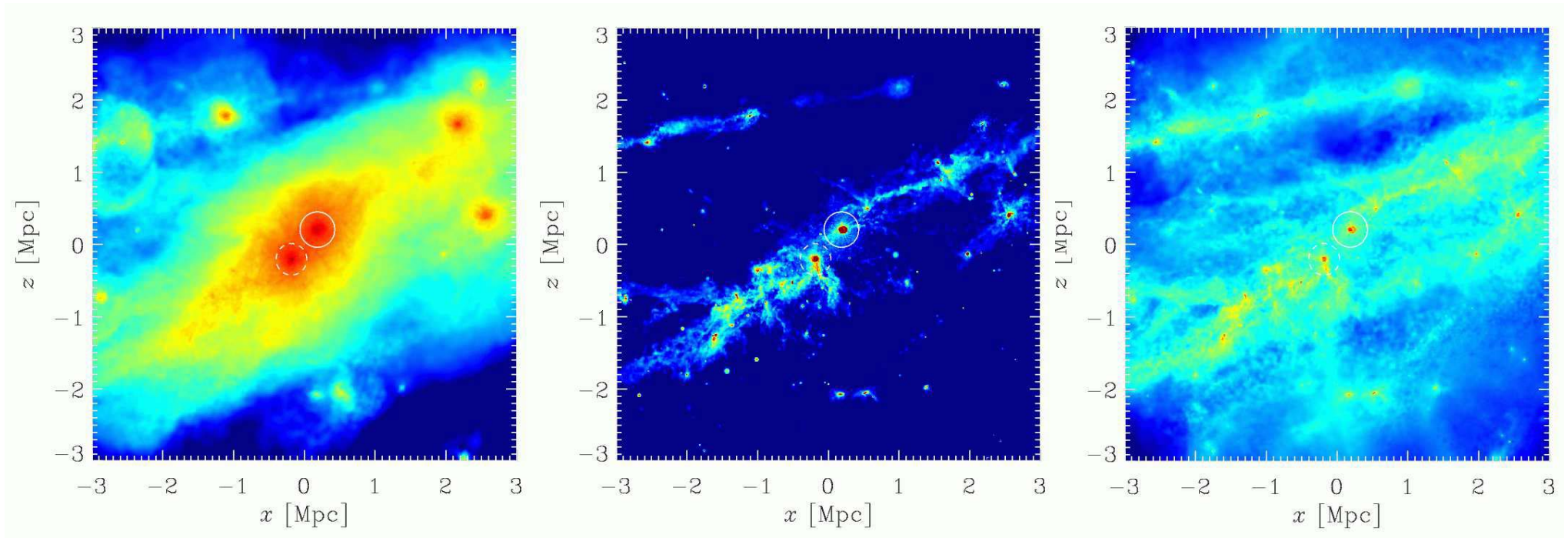
- constraining Gaussian random fields (Hoffman & Ribak, 1991)
- radial velocity field (MARK III, Willick et al., 1997, Tonry 2001, Karachentsev 2004, Tully+Courtois 2013)
- nearby cluster positions (Reiprich & Böhringer, 2002)
- 2MASS galaxy distribution
- reconstruct the underlying density field
- create a Gaussian representation of this density field







Distribution of Phases

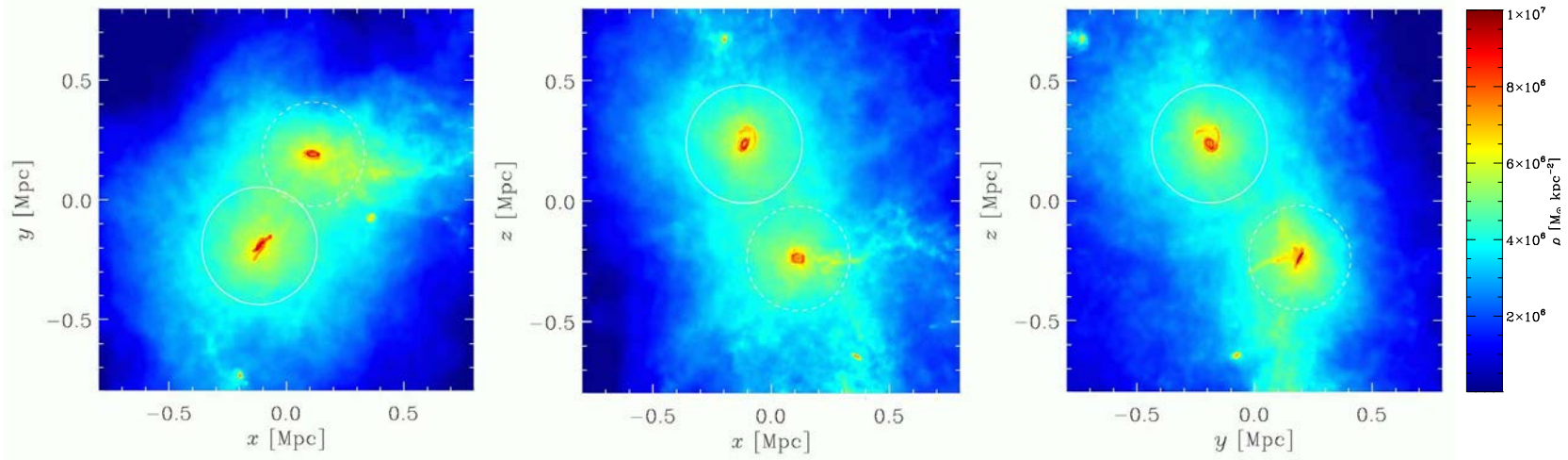


Hot Gas
 $T > 10^5 \text{K}$

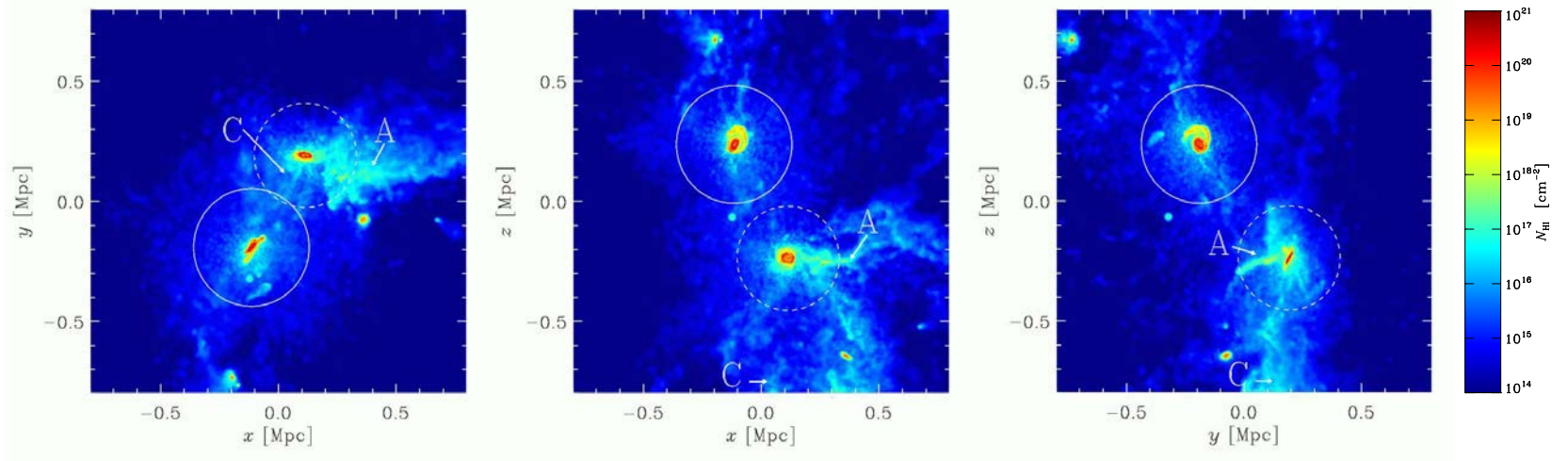
Cold Gas
 $T < 10^5 \text{K}$

HI

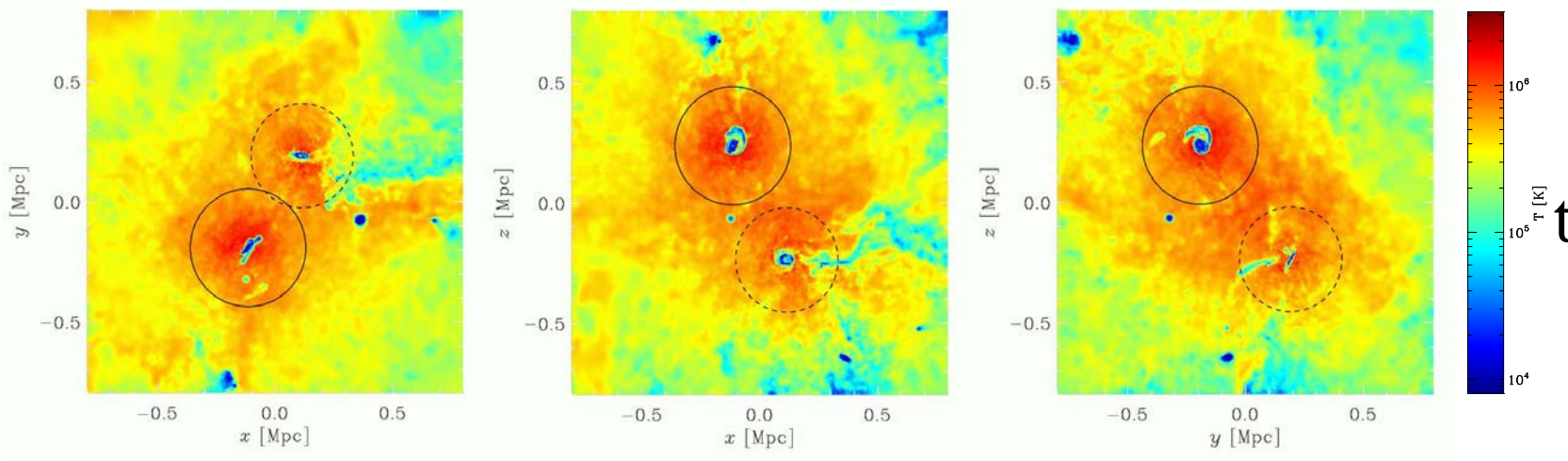
2-phase model by
C. Scannapieco



density

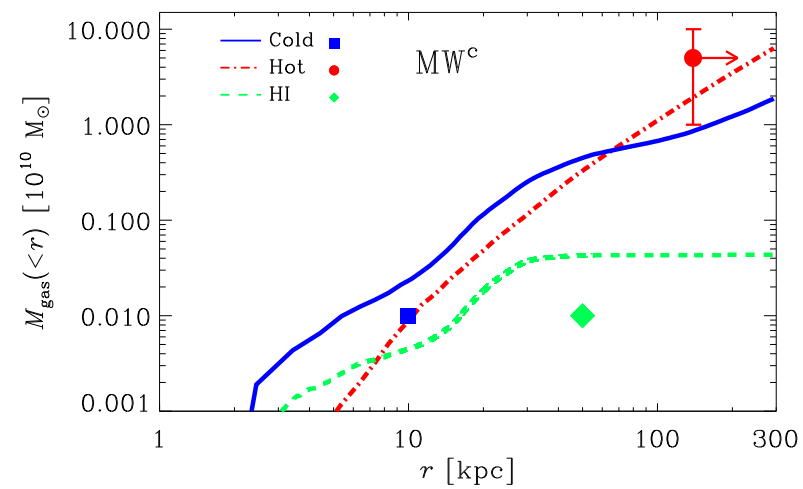
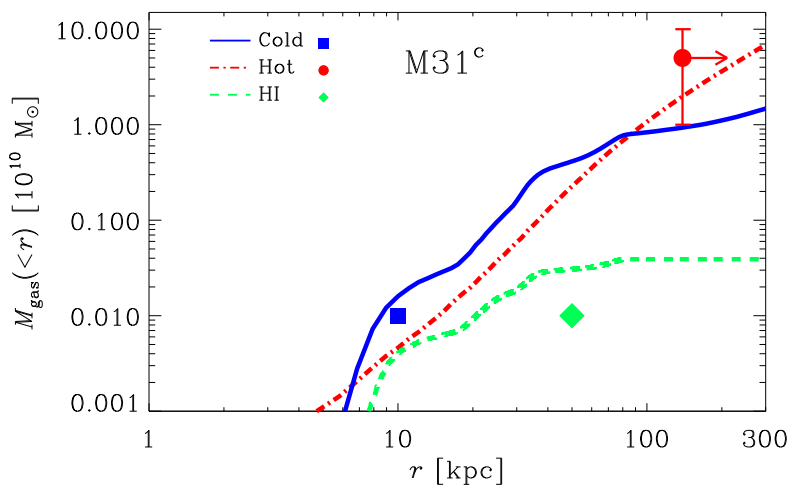
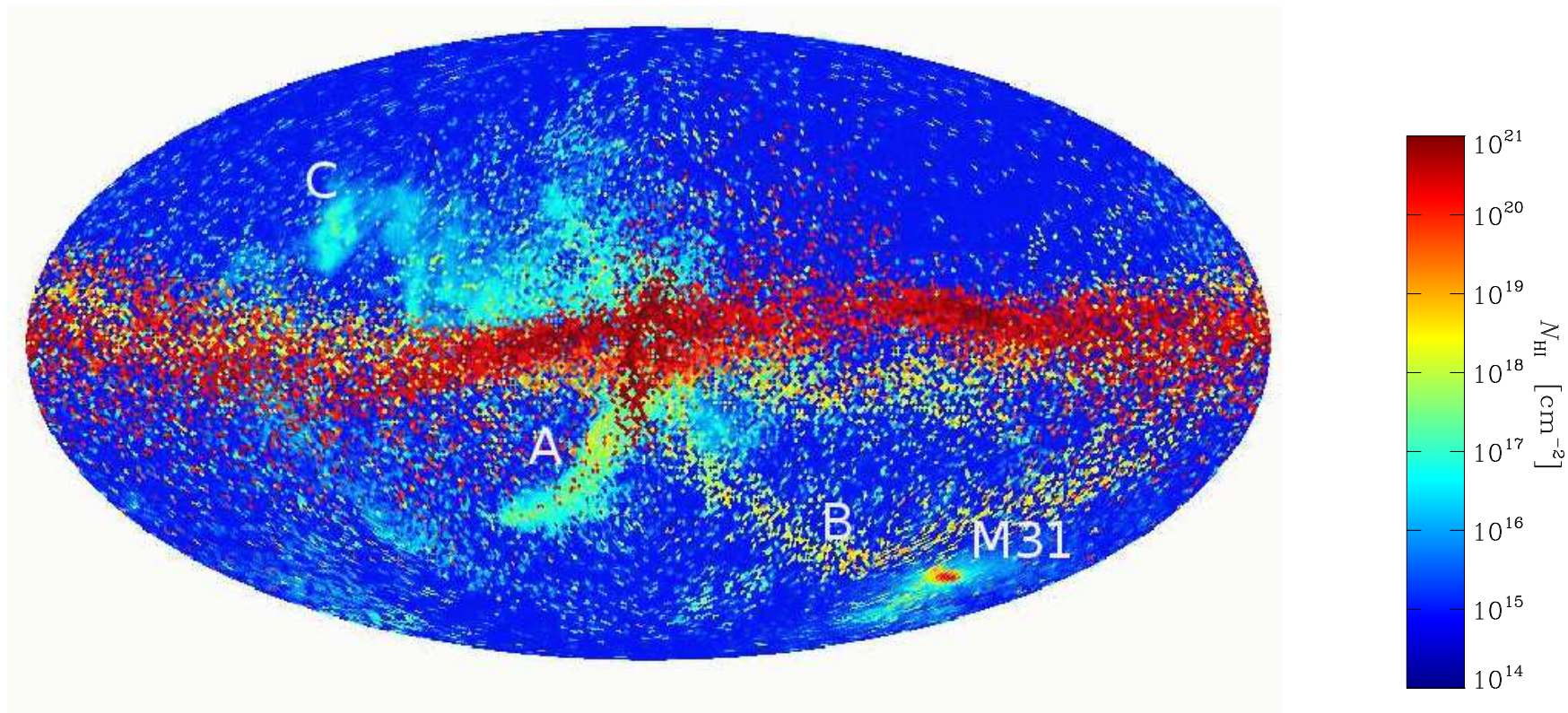


HI



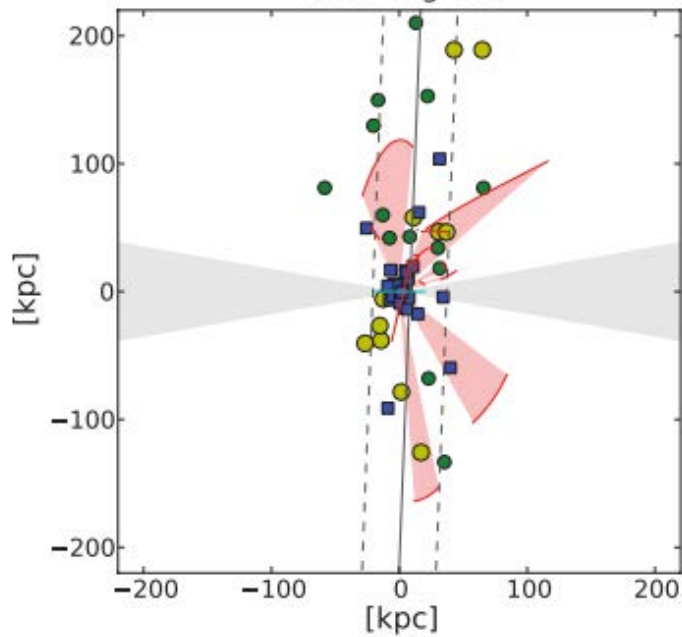
temperature

HI column density as seen from the quasi-Sun

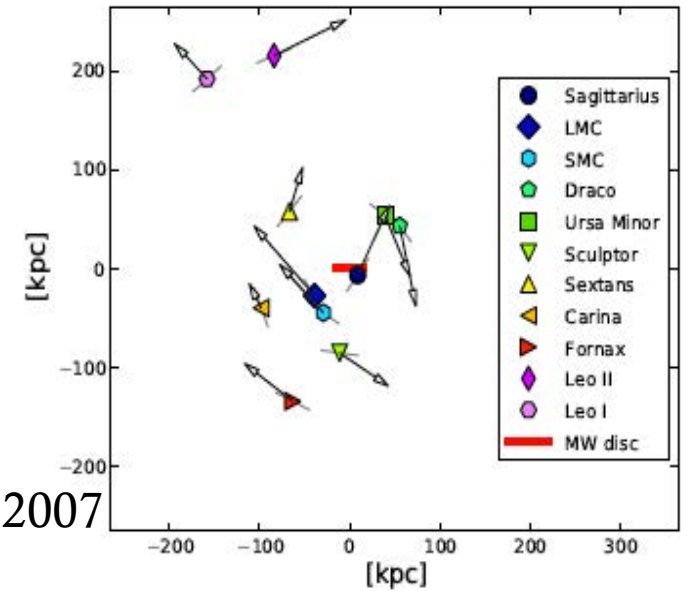


Planes of Satellites

Milky Way – Vast Polar Orbiting structure (VPOS)



$c/a \sim 0.15$
 $\Delta_{rms} = 24 \text{ kpc}$

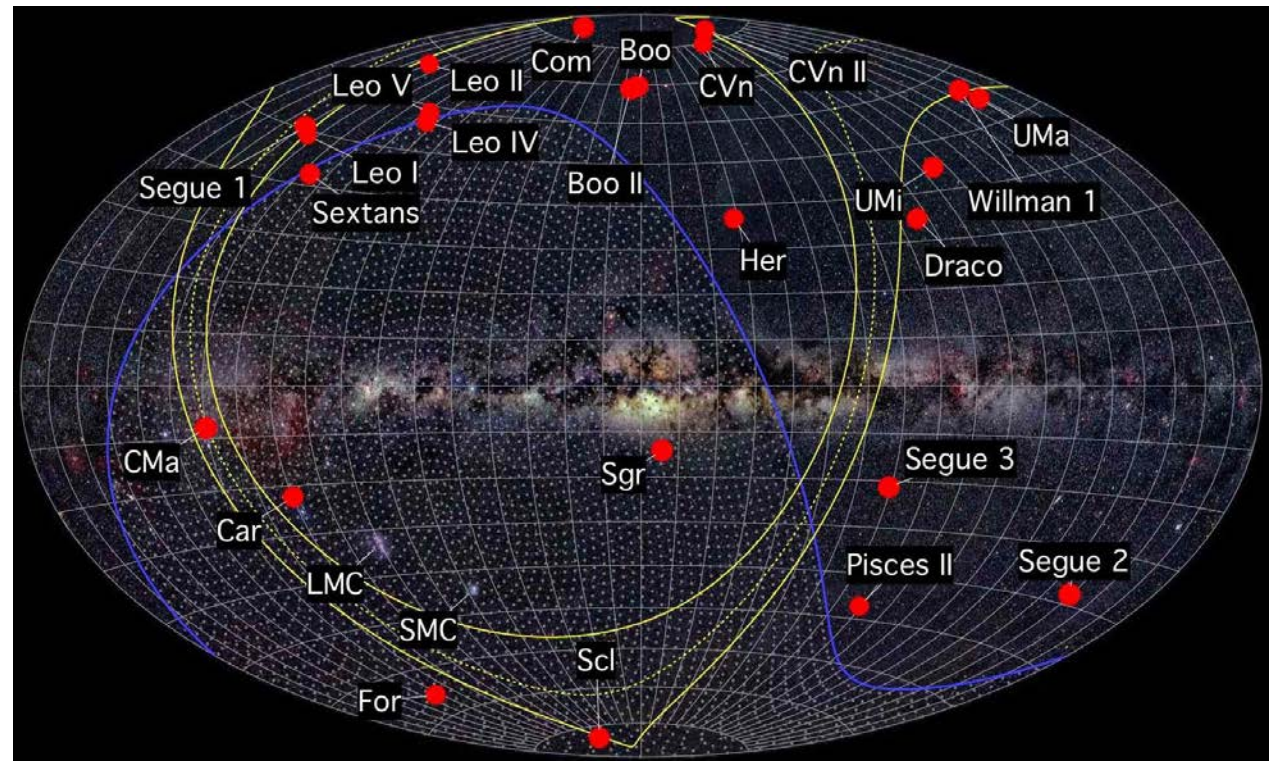


Metz, Kroupa & Libeskind 2007
 Pawlowski & Kroupa 2013

Pawlowski et al 2012
 Metz, Kroupa & Jerjen 2007
 Kroupa, Theis, Boily 2005

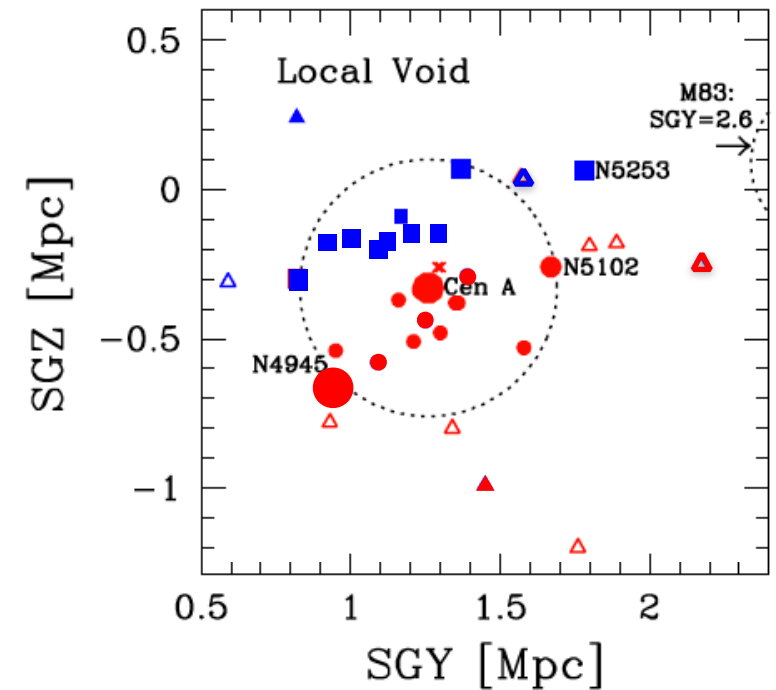
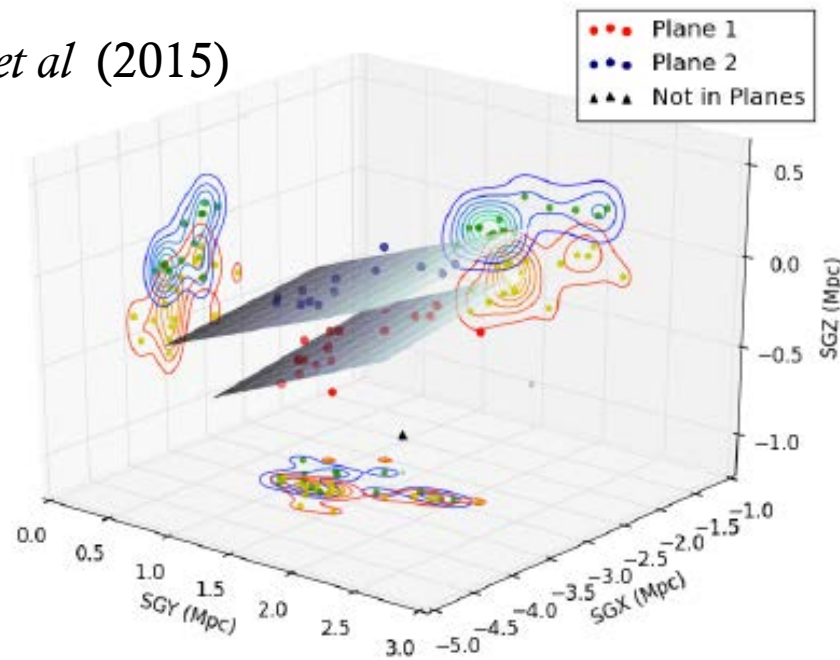
Kunkel & Demers 1975
 Lynden-Bell 1976, 1982
 Lynden-Bell & Lynden Bell 1982

Sloan Digital Sky Survey (SDSS)



Centaurus A Planes

Tully *et al* (2015)



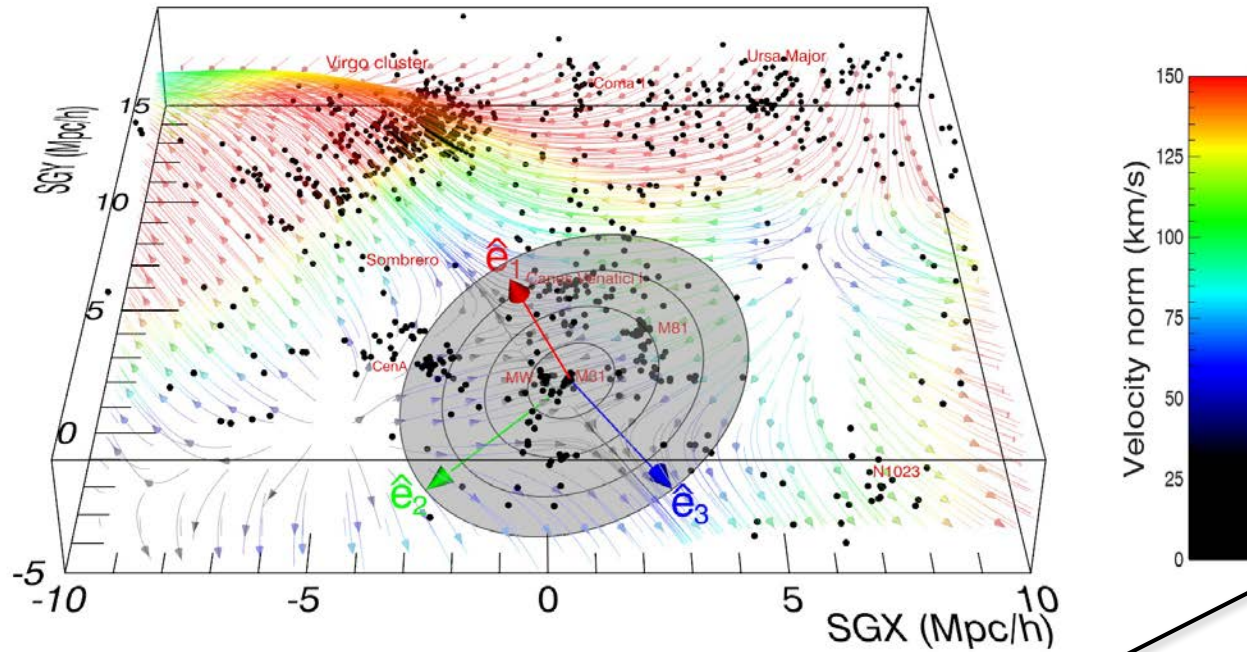
36 galaxies in total, 29 with distances

16 in plane 1
11 in plane 2
2 not in either

7 without distances of which
+4 could be Plane 1 and
+2 in plane 2

	Plane 1 (all)	Plane 1 (good)	Plane 2 (all)	Plane 2 (good)
a_{rms}	397 kpc	346 kpc	413 kpc	250 kpc
b_{rms}	287 kpc	203 kpc	200 kpc	236 kpc
c_{rms}	79 kpc	73 kpc	48 kpc	47 kpc
c/a	0.2	0.21	0.12	0.19
b/a	0.72	0.60	0.50	0.95
c/b	0.28	0.36	0.24	0.2

“Local” velocity field, from cosmic-flows-2

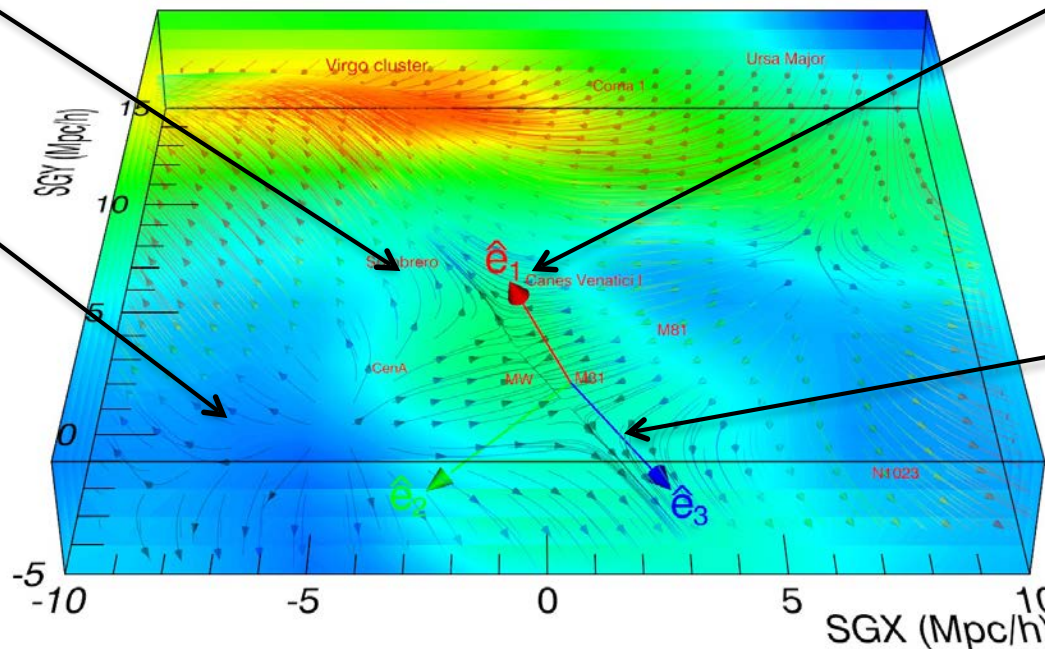


“Local Filament” stretched by Virgo

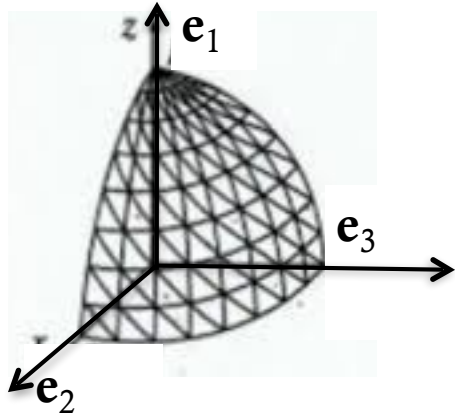
\hat{e}_1 sheet normal, points to the local void

Laterally squashed by a “mini-repeller”

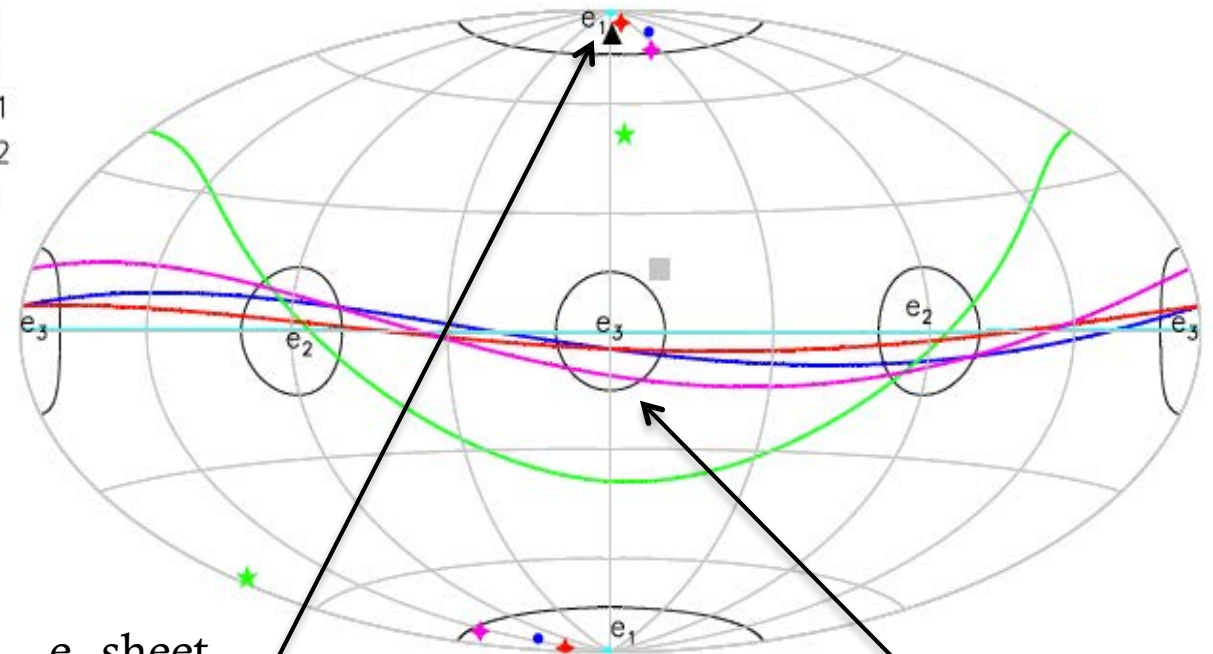
\hat{e}_3 filament axis, points to Virgo



Alignment of satellite planes w.r.t. the shear field

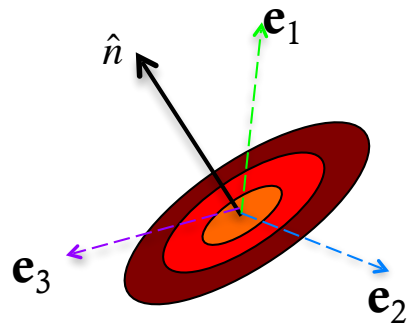


- ◆ π_{M31P1} to M31 plane 1
- ◆ π_{M31P2} to M31 plane 2
- π_{CAP1} to Cen A plane 1
- π_{CAP2} to Cen A plane 2
- ★ π_{MWP} to MW sat plane
- ▲ $r_{Local Void}$
- r_{Virgo}
- M31 Plane 1
- M31 Plane 2
- Cen A Plane 1
- Cen A Plane 2
- MW satellite plane



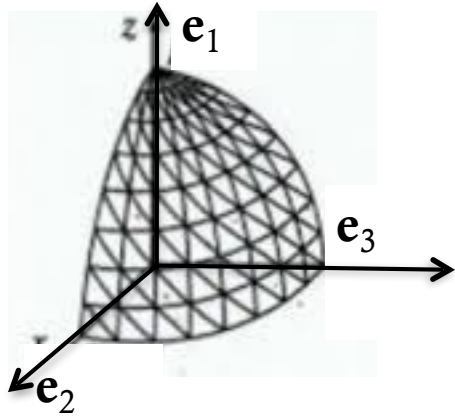
e_1 sheet normal, points to the local void

e_3 filament axis, points to Virgo

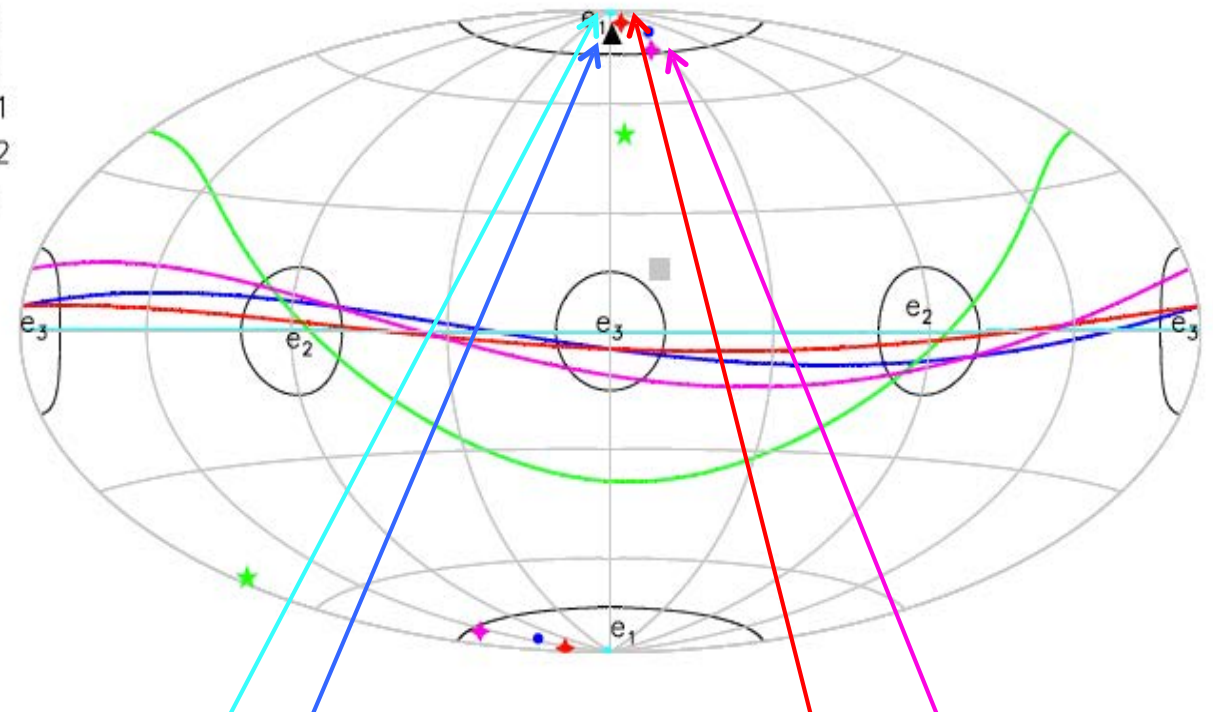


$$\begin{bmatrix} 0 & \frac{1}{2} \left(\frac{\partial v_x}{\partial y} - \frac{\partial v_y}{\partial x} \right) & \frac{1}{2} \left(\frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x} \right) \\ -\frac{1}{2} \left(\frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y} \right) & 0 & \frac{1}{2} \left(\frac{\partial v_y}{\partial z} - \frac{\partial v_z}{\partial y} \right) \\ -\frac{1}{2} \left(\frac{\partial v_z}{\partial x} - \frac{\partial v_x}{\partial z} \right) & -\frac{1}{2} \left(\frac{\partial v_y}{\partial z} - \frac{\partial v_z}{\partial y} \right) & 0 \end{bmatrix}$$

Alignment of satellite planes w.r.t. the shear field

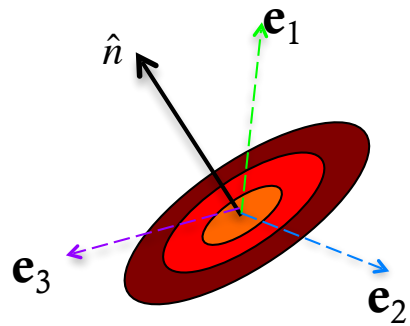


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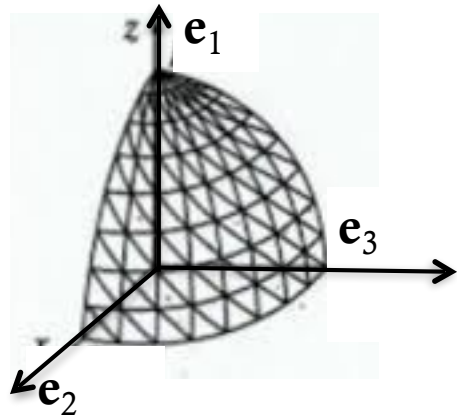
2 planes in CenA
are well aligned

2 planes in M31
are well aligned

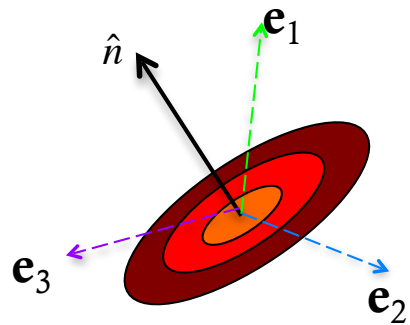
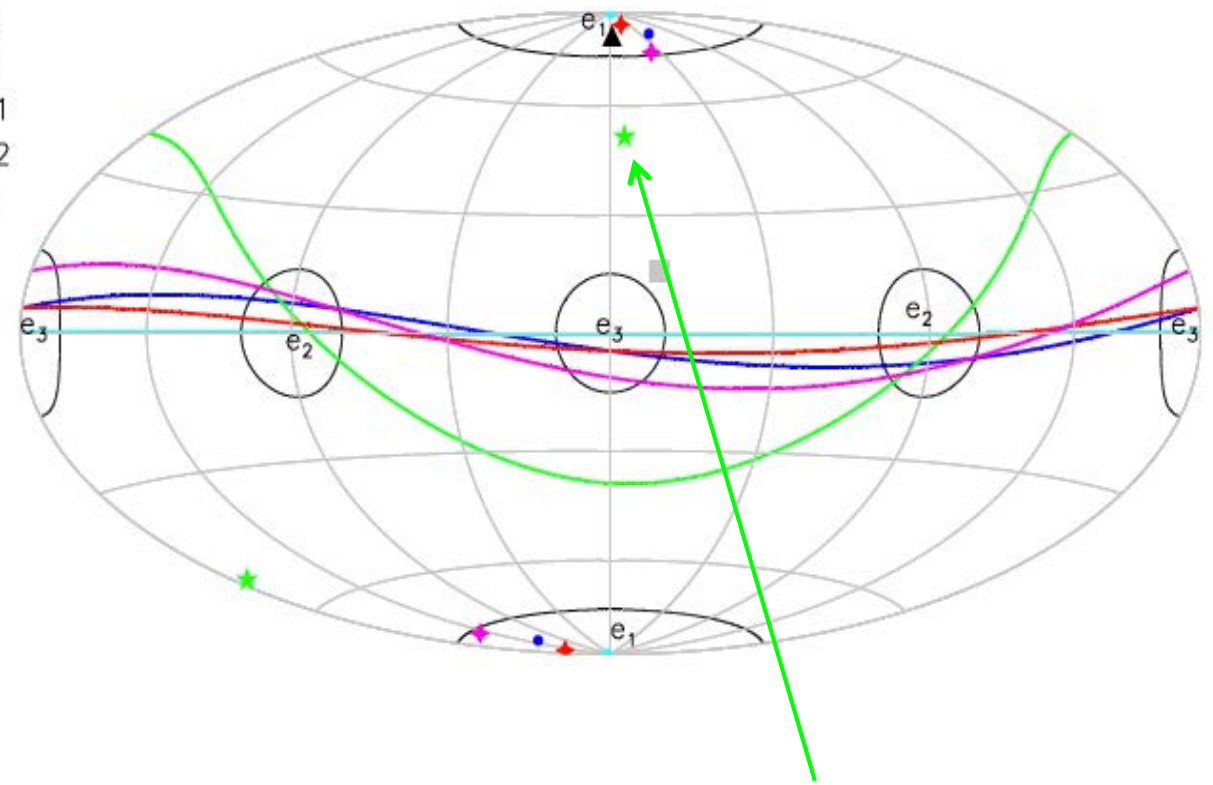


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Alignment of satellite planes w.r.t. the shear field



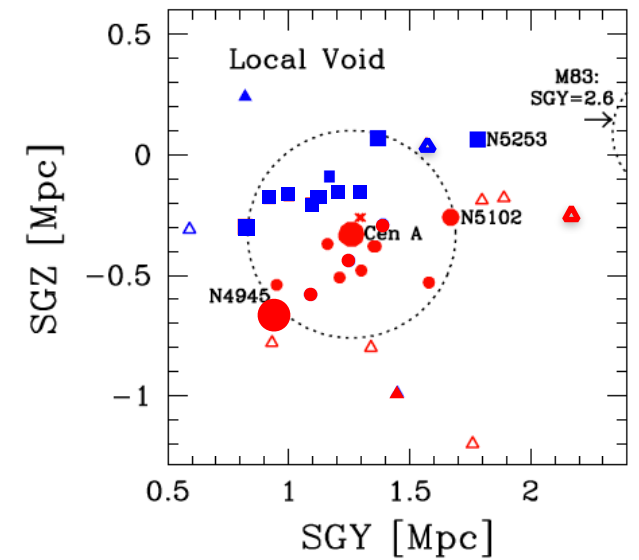
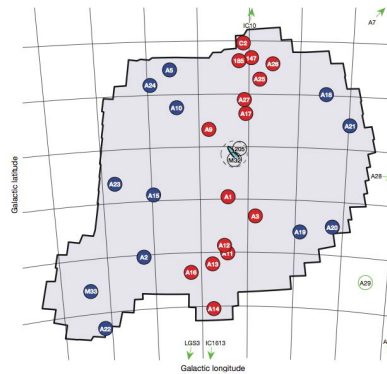
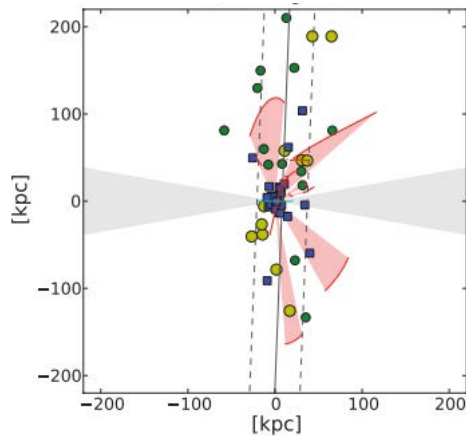
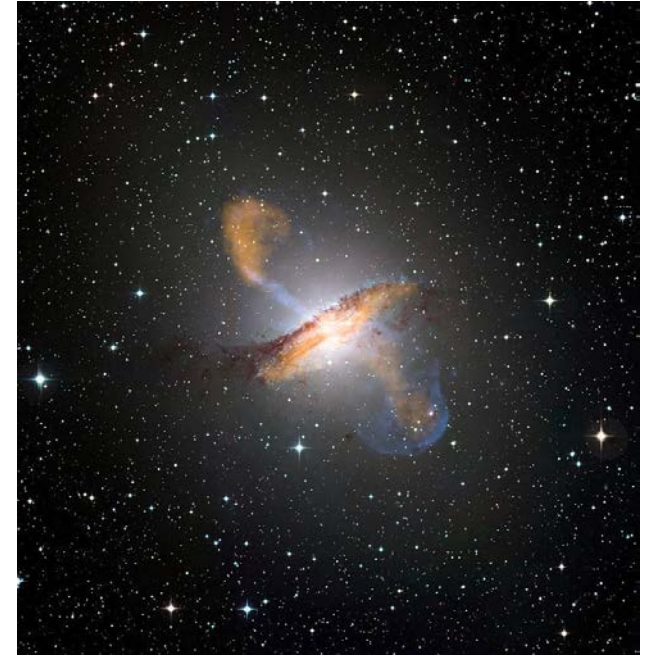
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- MW satellite plane



MW plane is off by ~ 38 deg, appears to have been torqued about the e_2 axis

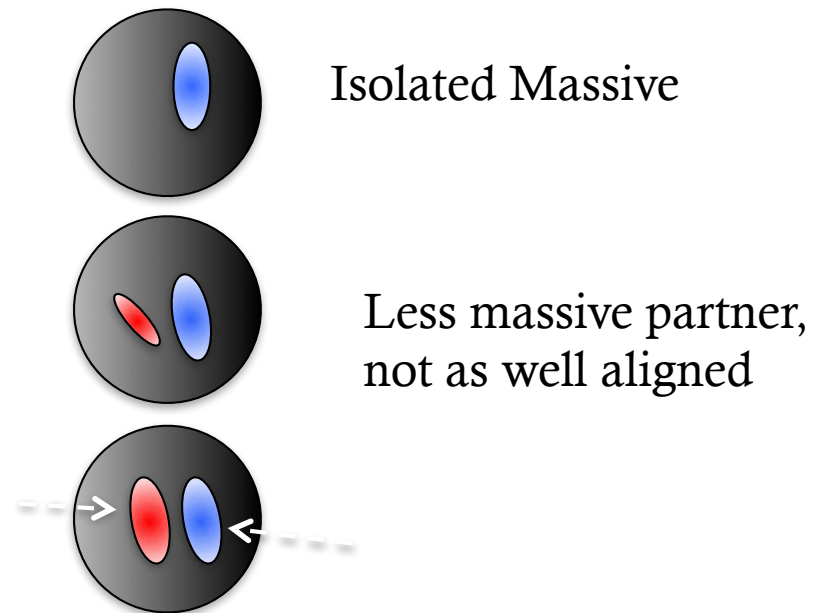
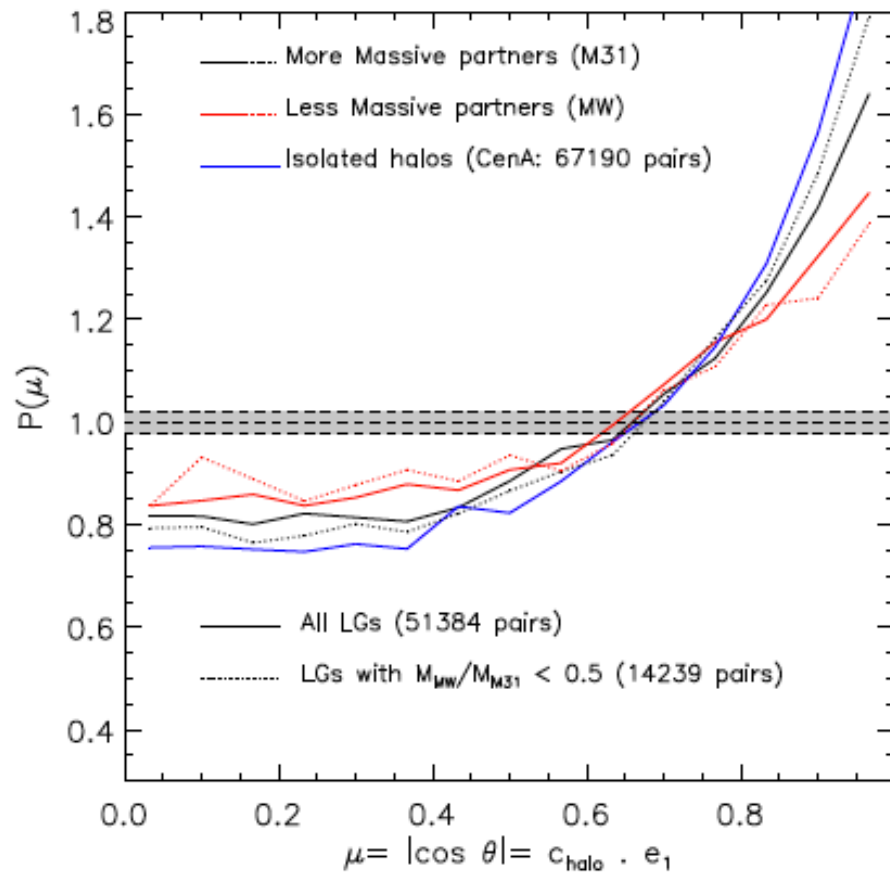
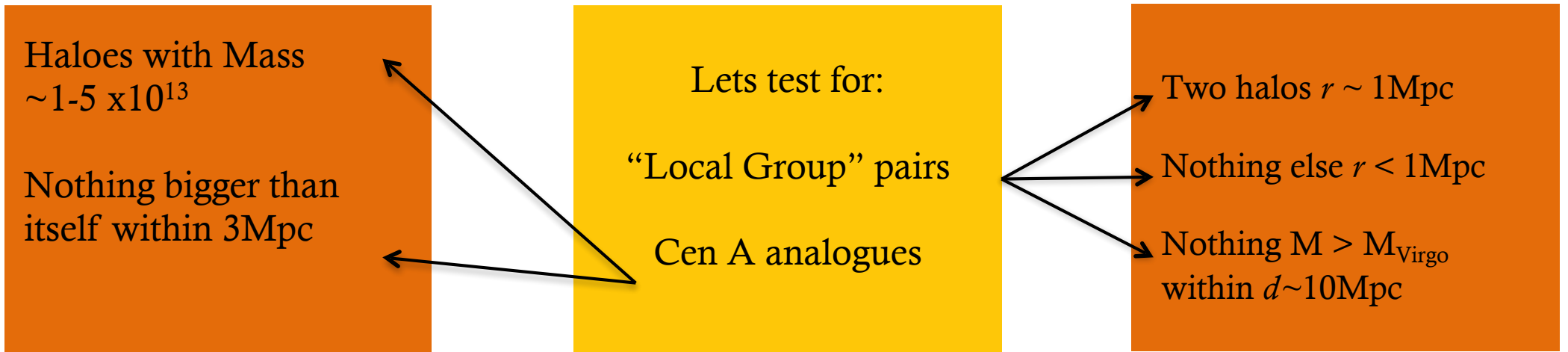
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Summary of Local Volume Planes



4 out of 5 satellite planes are well aligned with shear field!

$\sim 1-9^\circ$



Summary

- Considerable progress in the recent years w.r.t formation of disk galaxies/Hubble sequence
 - Realistic subgrid models of ISM + feedback are crucial
- CLUES: cosmological simulations of the Local Group environment
 - Properties of Milky Way and nearby galaxies may be substantially affected by the special local environment
 - Cosmic web may provide a natural explanation for alignments of satellites