

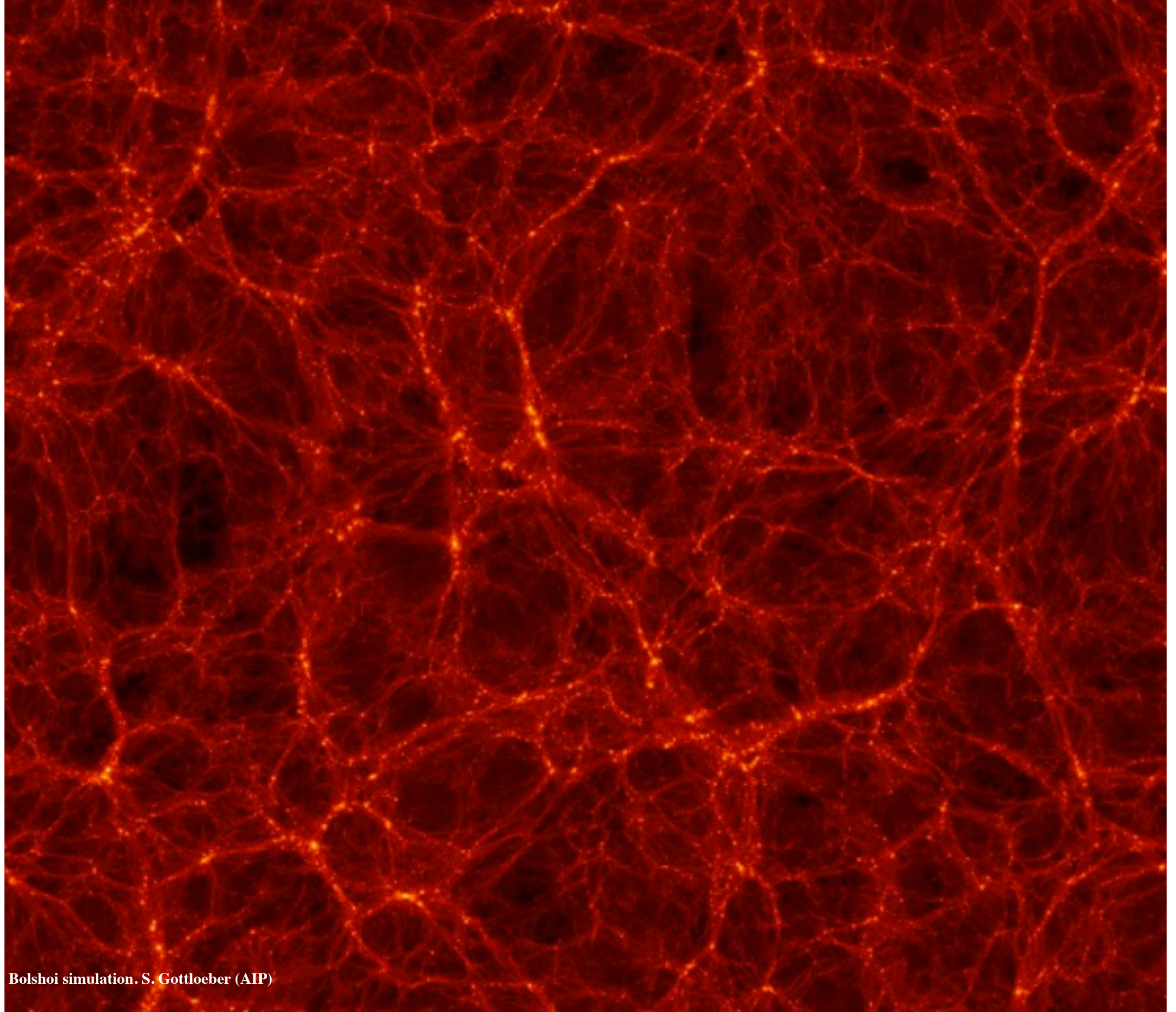
# The Local Group in the Cosmic Web

in collaboration with  
**Roberto González (PUC)**

Stefan Gottloeber (AIP), Yehuda Hoffman (Jerusalem), Gustavo Yepes (UAM), Sebastian Bustamante (UdeA), Anatoly Klypin (NMSU), Rob Piontek, Matthias Steinmetz (AIP)

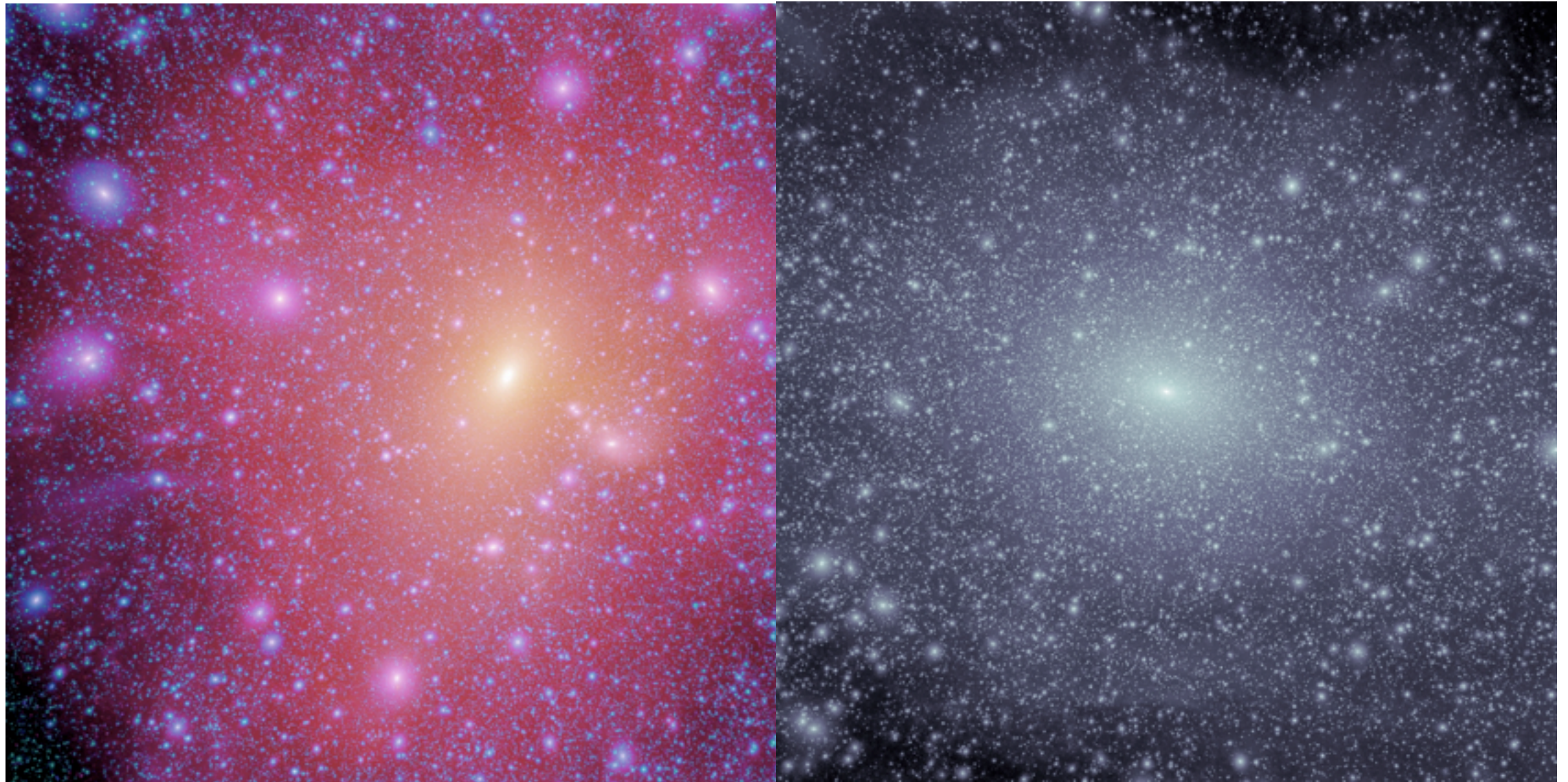
**arXiv: 1408.3166**

Jaime E. Forero-Romero - Universidad de los Andes (Colombia)  
je.forero@uniandes.edu.co





There are large variations if the MW is thought as a random  $10^{12} M_{\text{sol}}$  halo

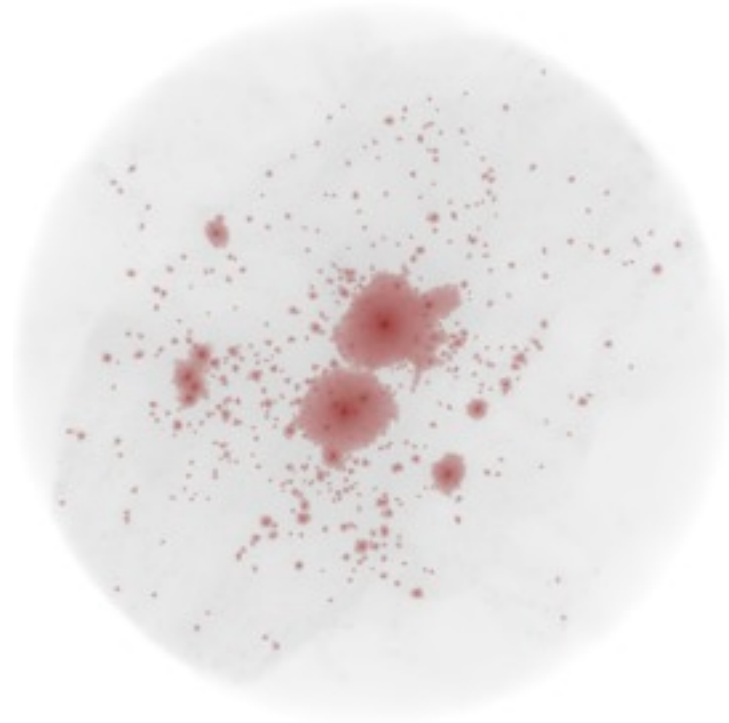
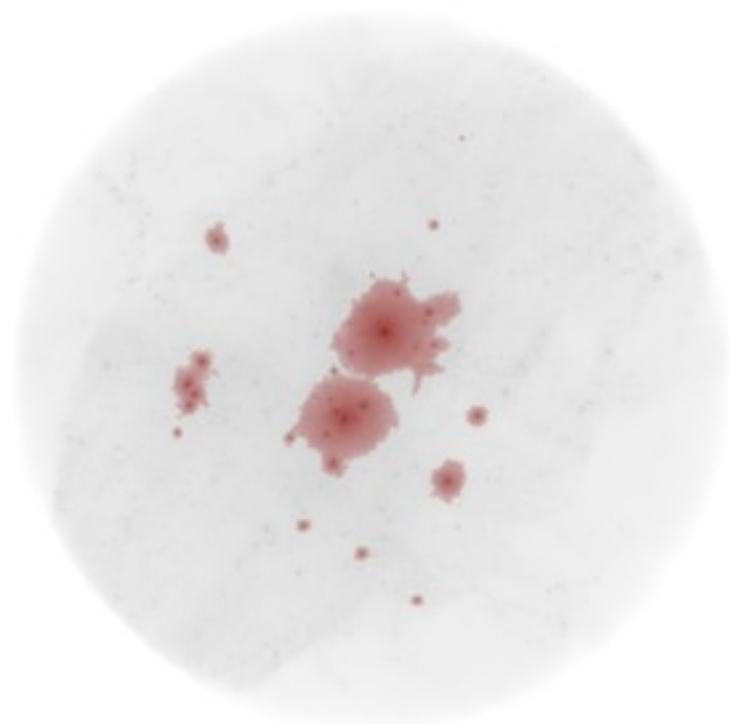


Aquarius Project (Springel et al. 2008)

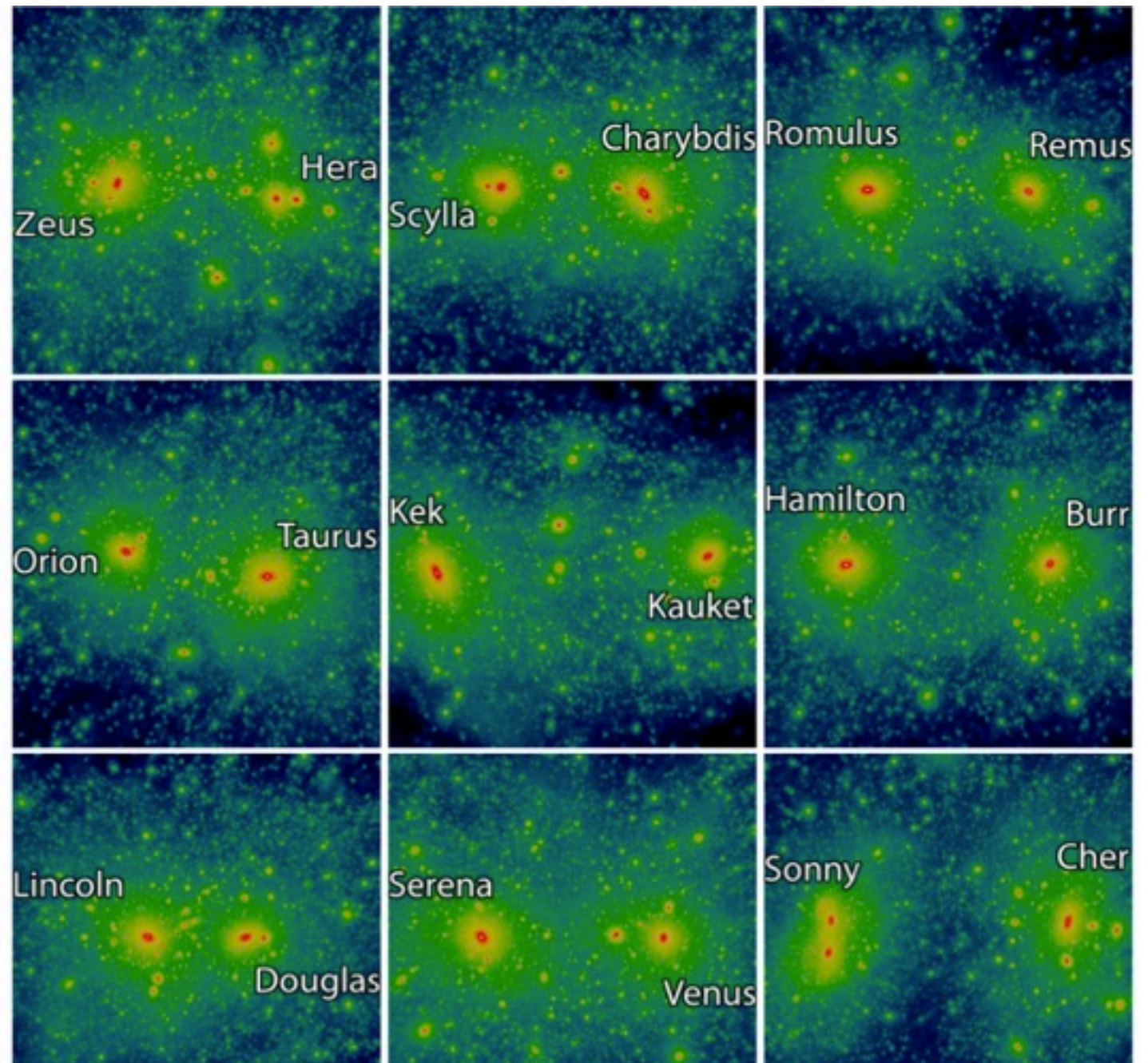
Via Lactea Project (Diemand et al. 2008)



# Pairs: the natural way to think about the MW environment



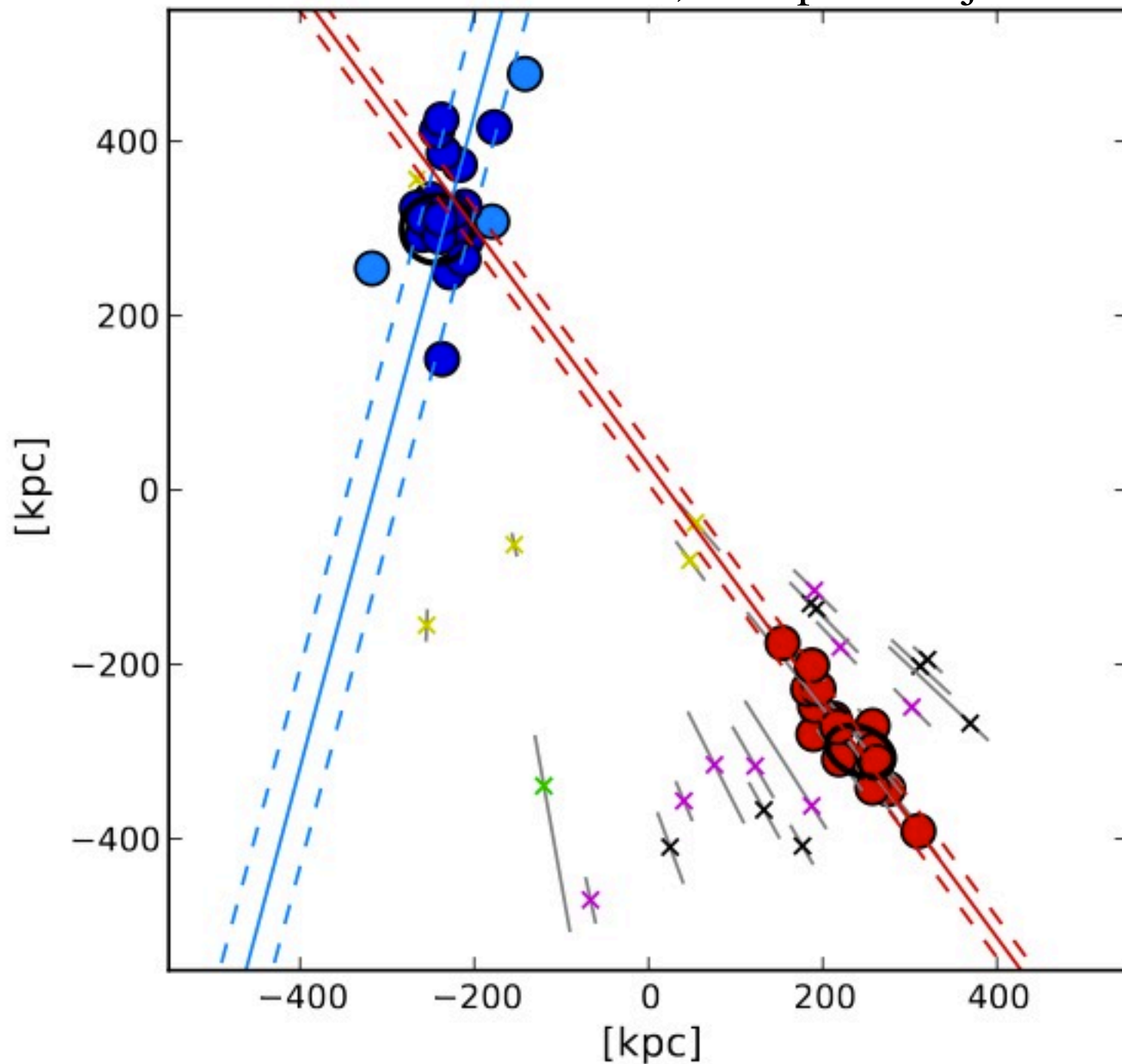
DOVE, Sawala et al., 2014



ELVIS, Garrison-Kimmel et al., 2014

# Planes: preferred directions around the LG

Pawlowski, Kroupa & Jerjen 2013

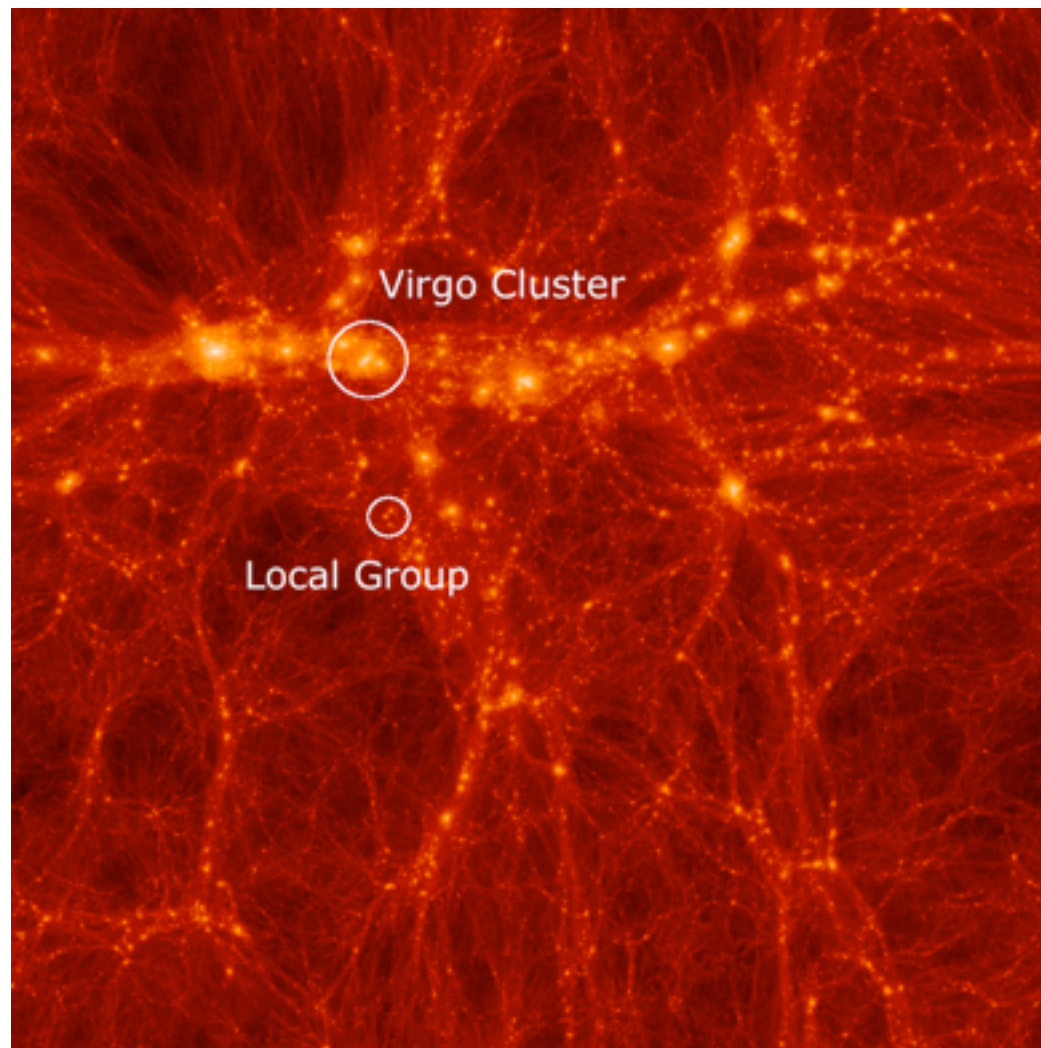


Talks by:  
Tully, Ibata,  
Pawlowski, Rix,  
Libeskind, Willman,  
Hellwing

Kroupa et al. 2005,  
Pawlowski, Kroupa & Jerjen 2013;  
Ibata et al. 2013, 2014.



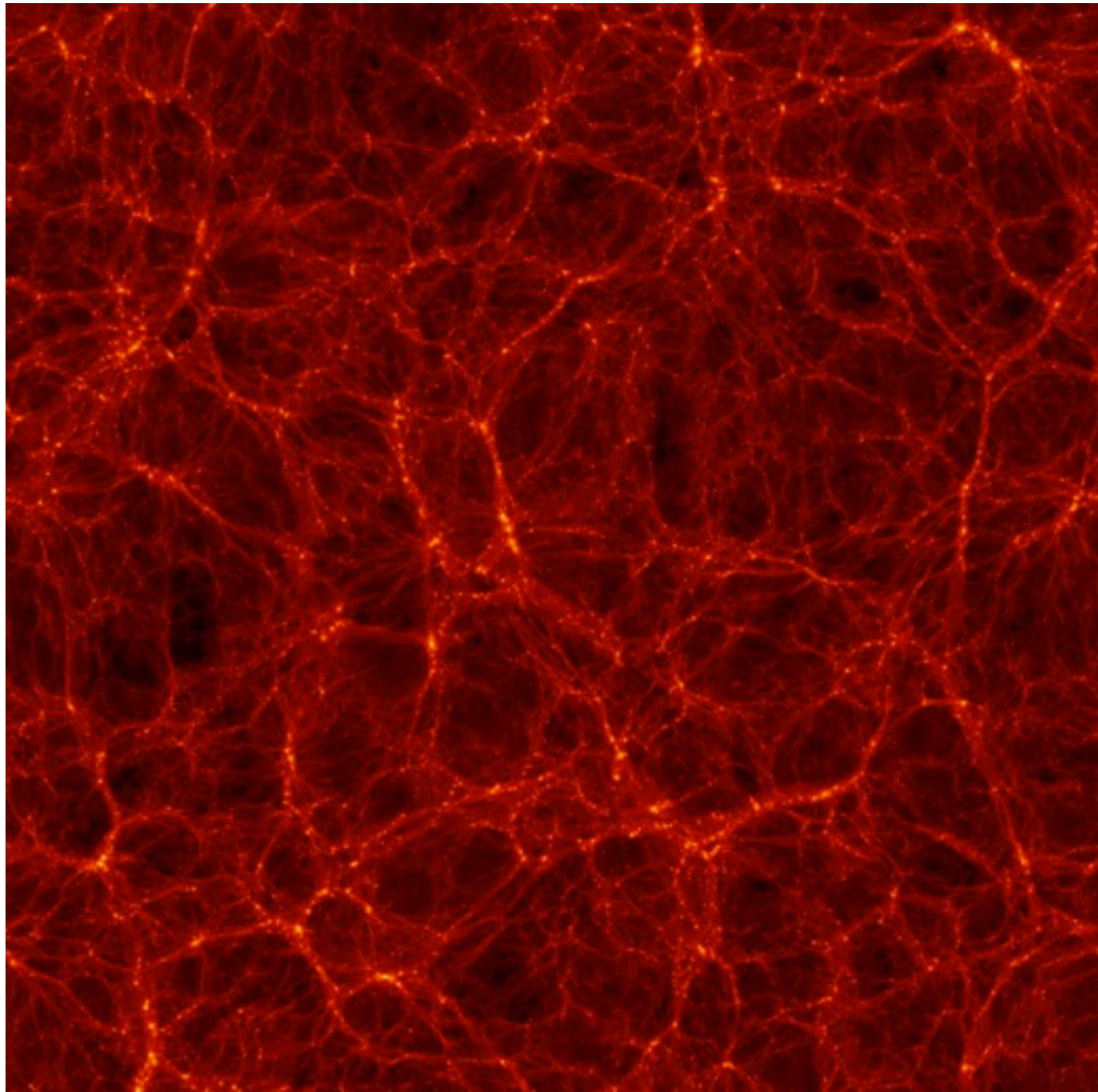
# Constrained Local Universe Simulations (CLUES) as a more sophisticated environment definition



Gottloeber, Hoffman, Yepes 1005.2687

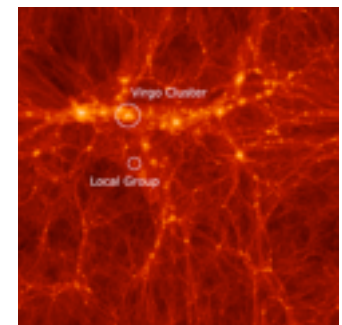
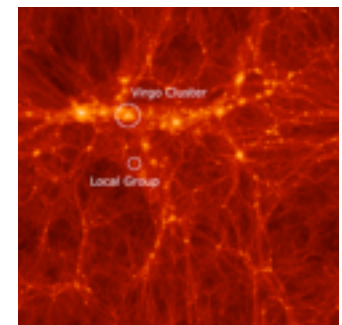
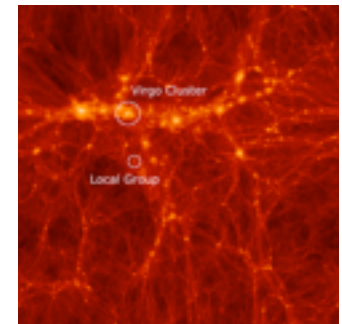
- See Stefan Gottlober's talk.
- Large Scales (5-7 Mpc) are fixed
- Small scales are random.
- 200 low resolution realizations until a LG is found: **found 3**.

**LG in constrained simulations are then compared  
against LGs in random realizations**



**BOLSHOI (250 Mpc/h)**

**CLUES  
(64 Mpc/h)**



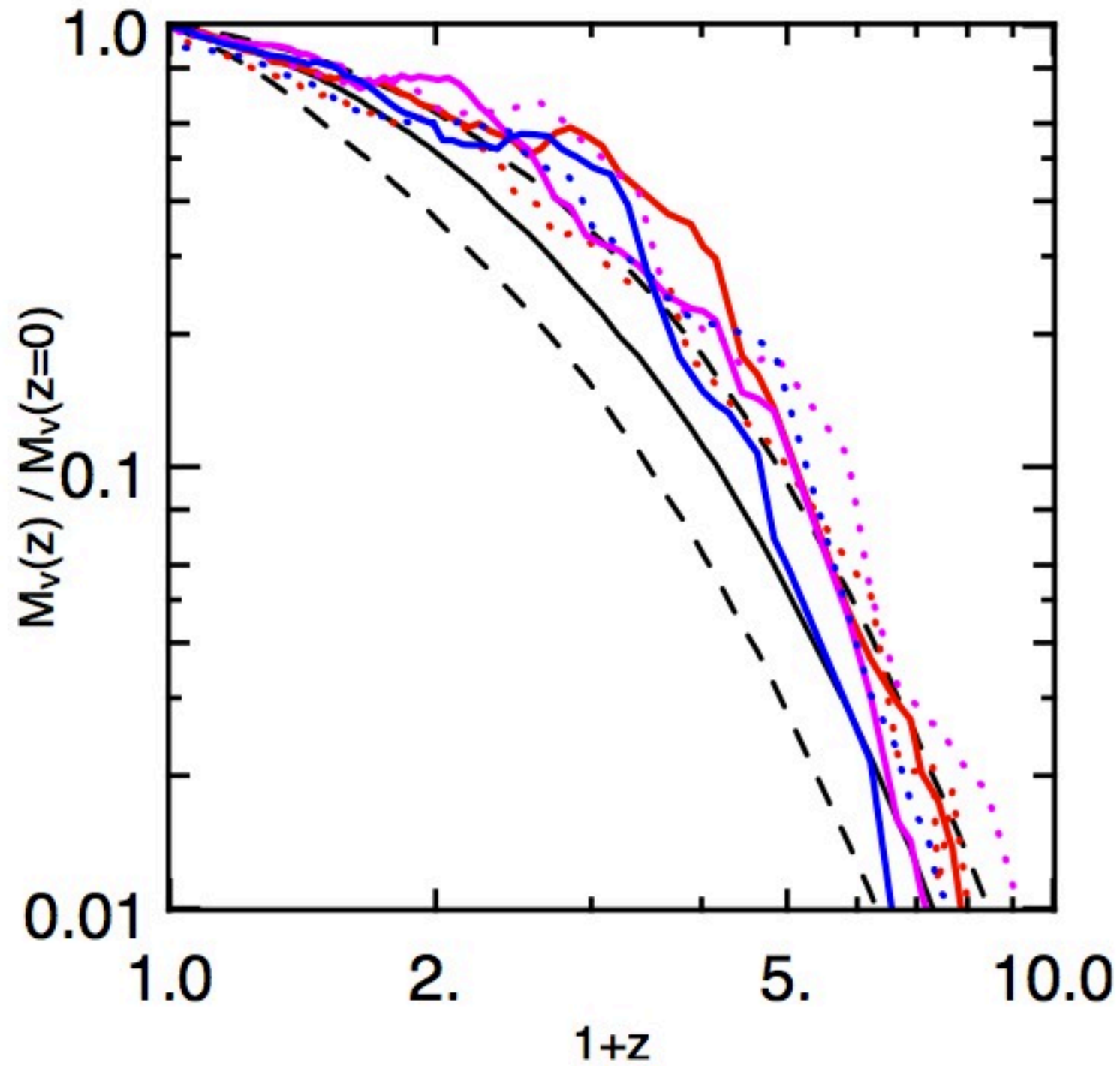
# We consider 5 conditions to define a LG in a unconstrained simulation



- Individual halo mass
- Halo separation
- Negative radial velocity
- Isolated (3Mpc)
- Isolated (7Mpc) ( $>5 \cdot 10^{13} M_{\text{sol}}$ )

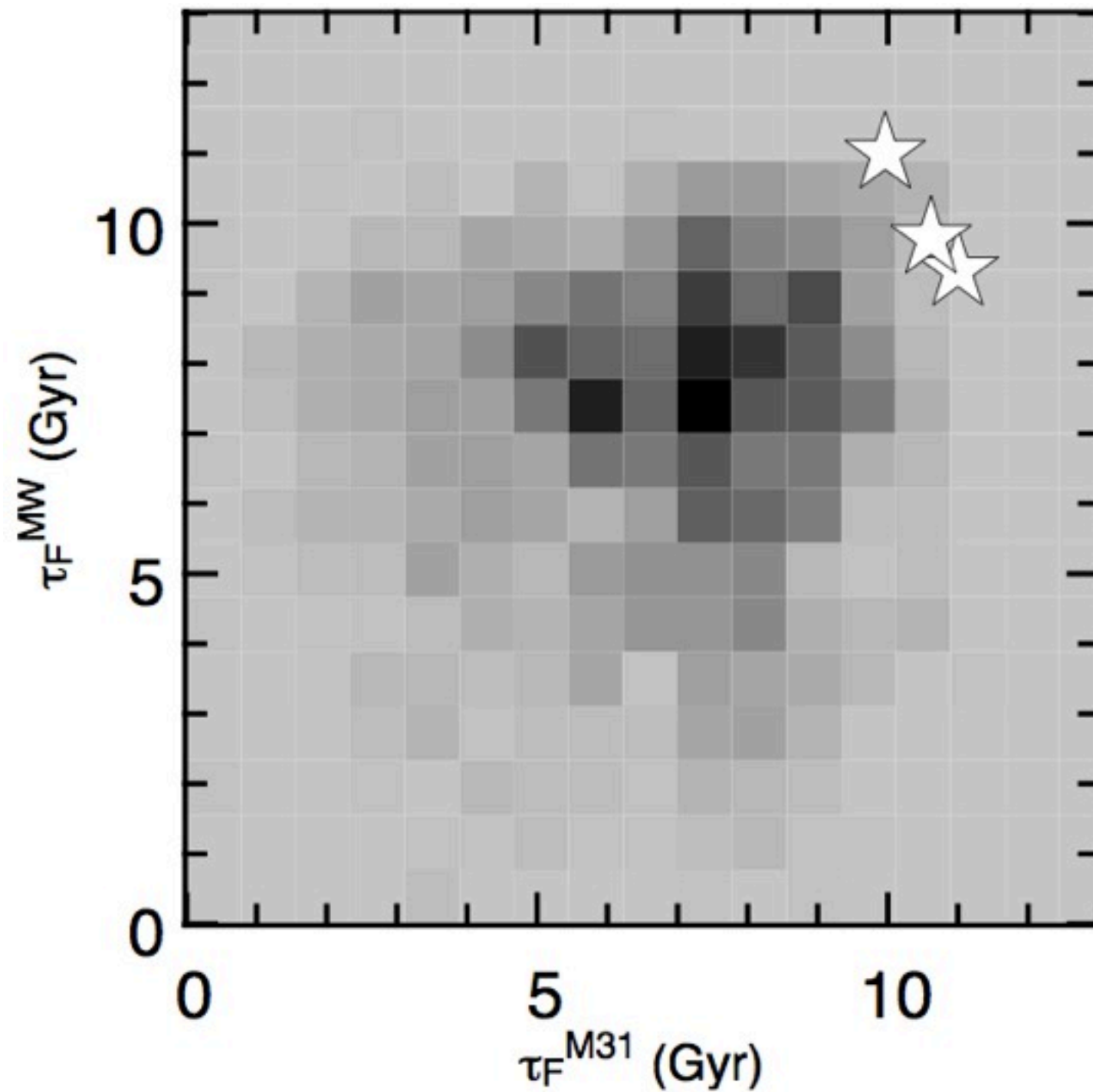


# LGs in the constrained simulations assemble earlier



**JEF-R, Hoffman, Yepes, Gottloeber, Piontek,  
Klypin, Steinmetz, MNRAS 2011, 1107.0017**

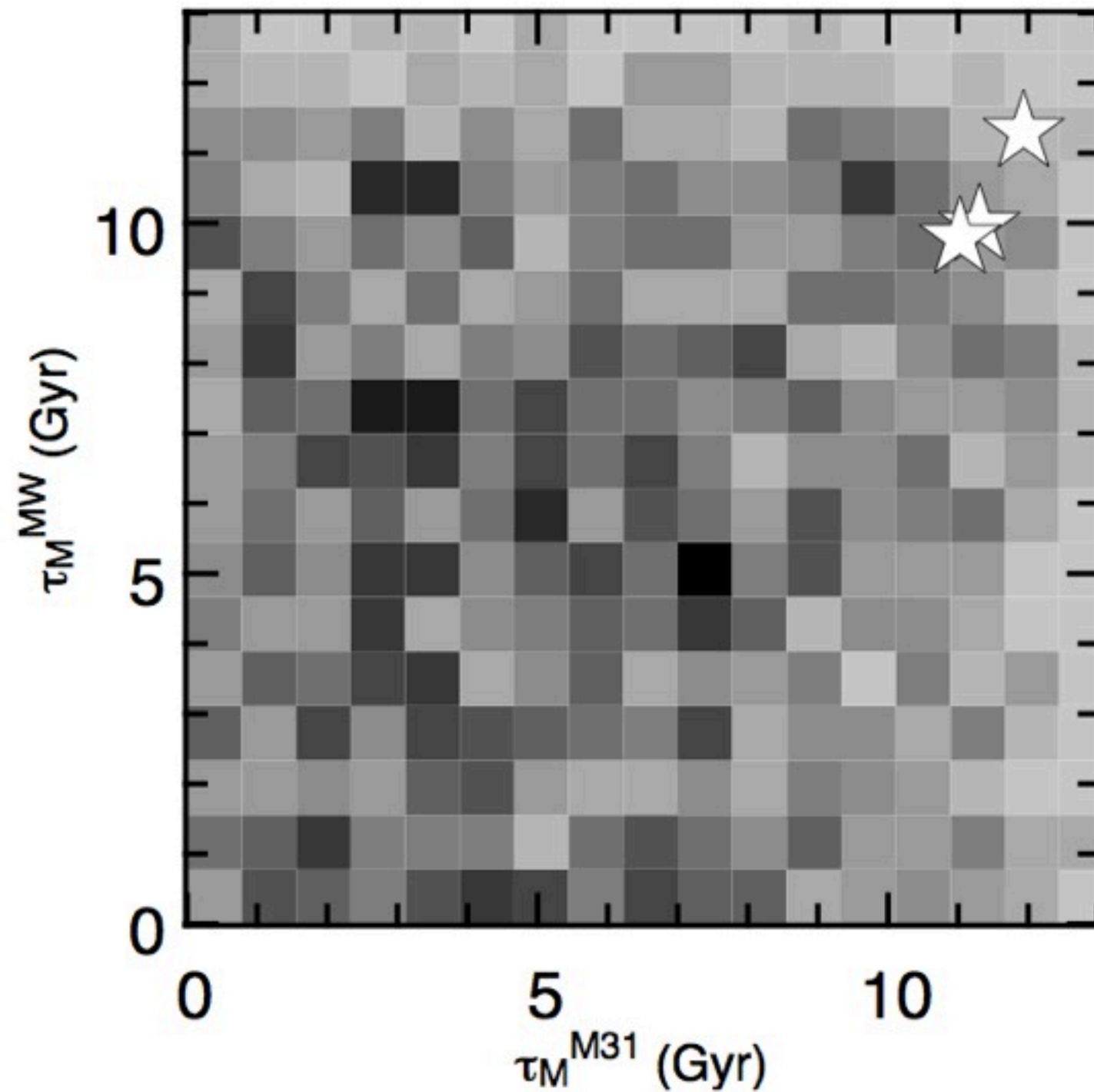
# LGs in the constrained simulations assemble earlier



**JEF-R, Hoffman, Yepes, Gottloeber, Piontek,  
Klypin, Steinmetz, MNRAS 2011, 1107.0017**

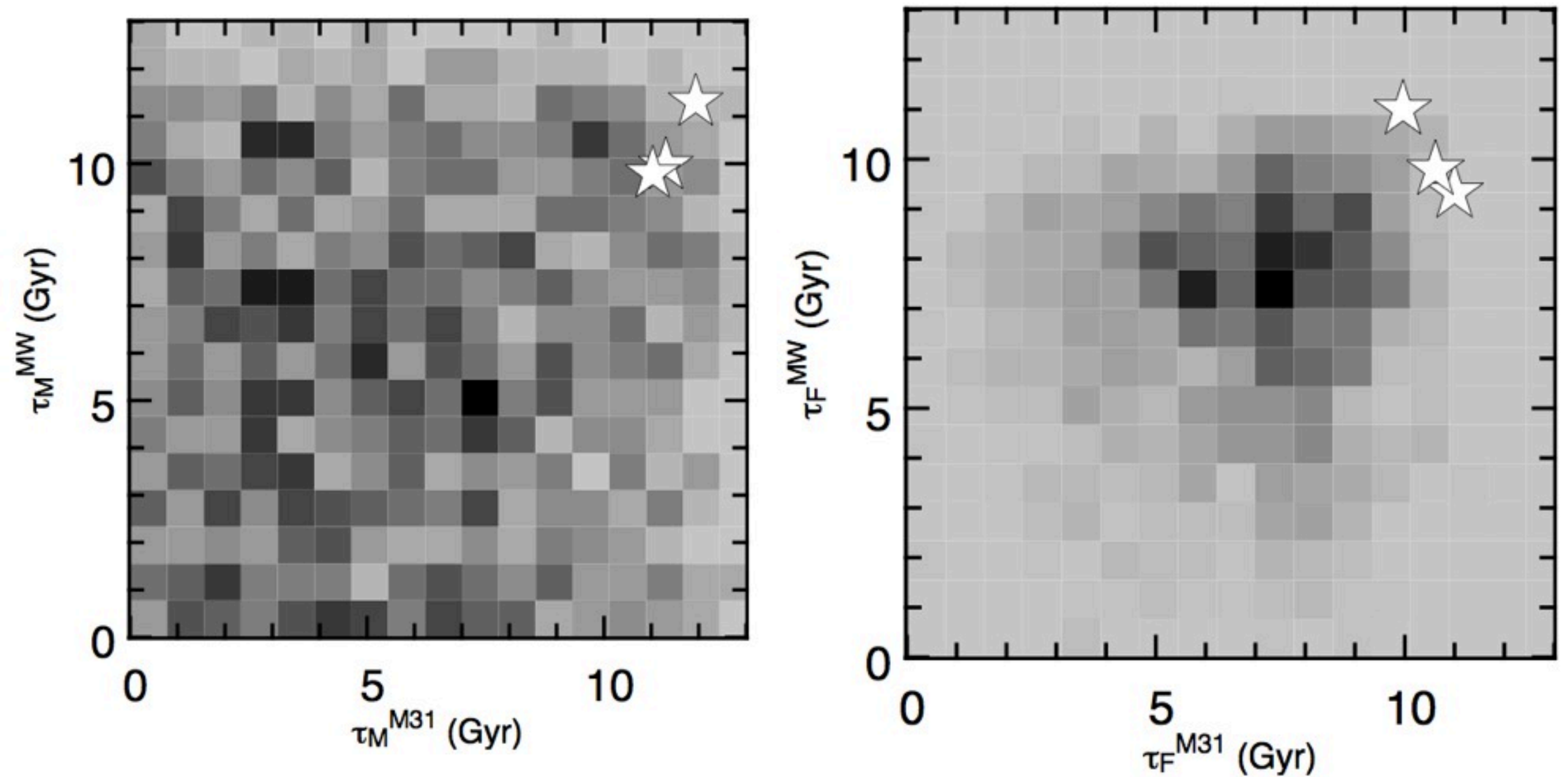


# LGs in the constrained simulations live quietly



**JEF-R, Hoffman, Yepes, Gottloeber, Piontek,  
Klypin, Steinmetz, MNRAS 2011, 1107.0017**

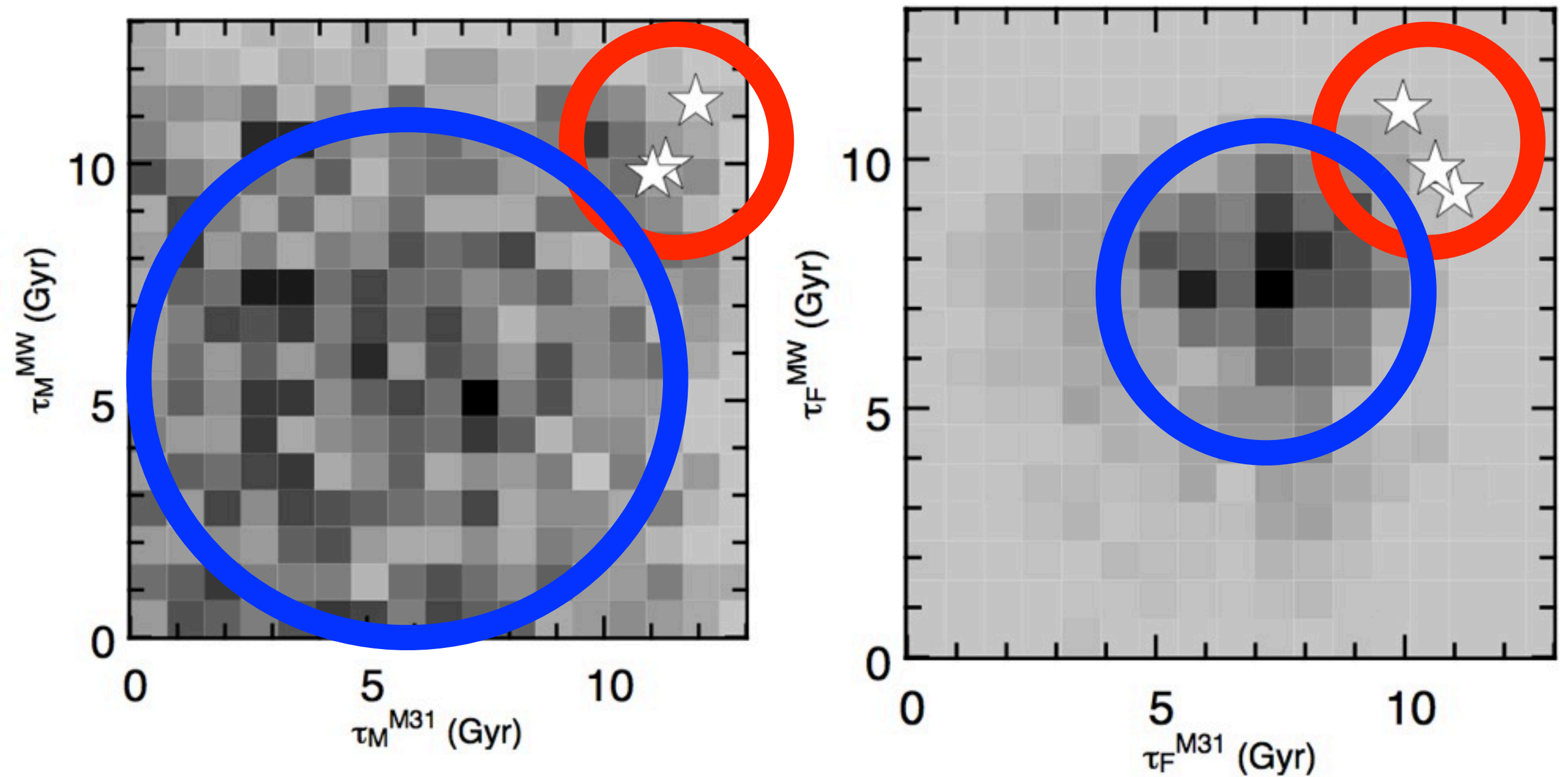
The LGs in constrained simulations are in a narrow region of parameter space



**JEF-R, Hoffman, Yepes, Gottloeber, Piontek,  
Klypin, Steinmetz, MNRAS 2011, 1107.0017**



The LGs in constrained simulations are in a narrow region of parameter space



**JEF-R, Hoffman, Yepes, Gottloeber, Piontek,  
Klypin, Steinmetz, MNRAS 2011, 1107.0017**

# Observation #1

Constraints on large scales (by construction)

+

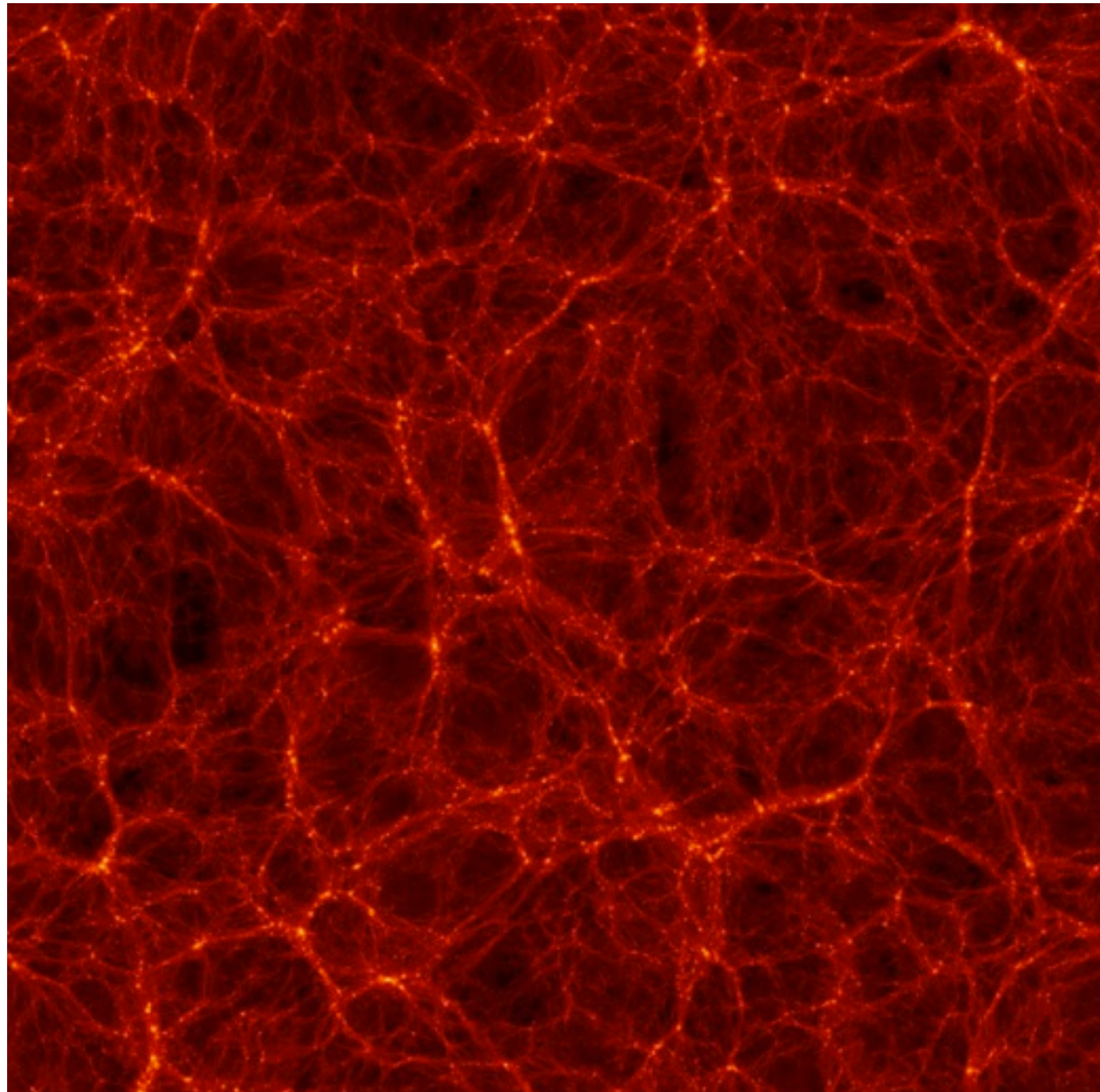
Constraints on meso scales (by selection)

=

pairs with narrow formation properties

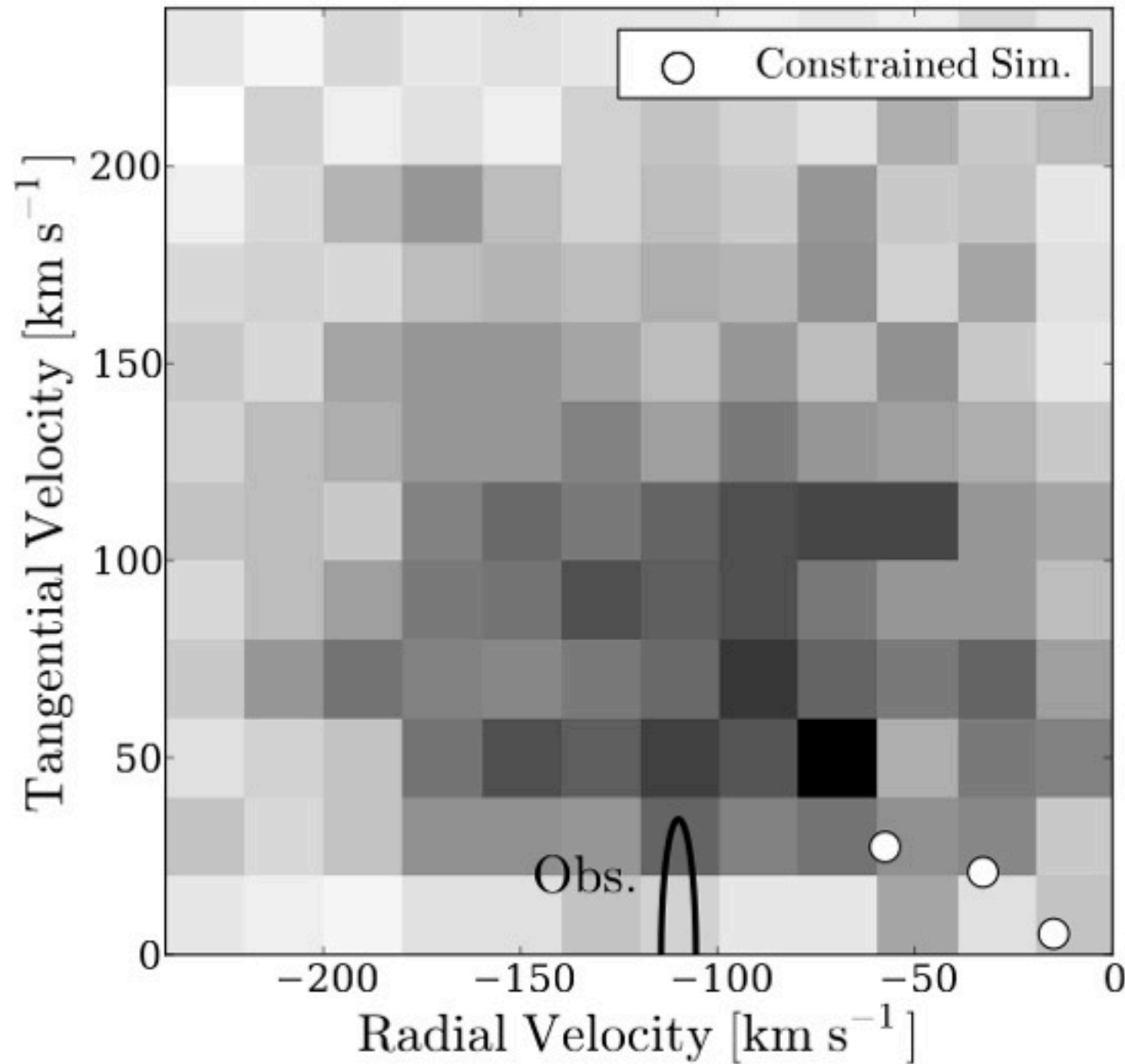


# Use Bolshoi to study in detail the Isolated Pairs



Kinematics from Sohn, Anderson & van der Marel (2012)

# LG kinematics is not so common in LCDM



**JEF-R, Hoffman, Bustamante, Gottloeber,  
Yepes, ApJL 2013, 1303.2690**



Because it is uncommon, it is difficult to build large samples

| Physical property                 | (%) Pairs consistent with observations ( $1-\sigma$ ) (full sample) |
|-----------------------------------|---|
| $v_r - v_t$                       | (0.4%) 8/1923   |
| $e_{\text{tot}} - l_{\text{orb}}$ | (15%) 298/1923  |
| $\log_{10} \lambda$               | (13%) 257/1923  |
| $r_t = v_t / v_r$                 | (12%) 242/1923  |

**JEF-R, Hoffman, Bustamante, Gottloeber, Yepes, ApJL 2013, 1303.2690**

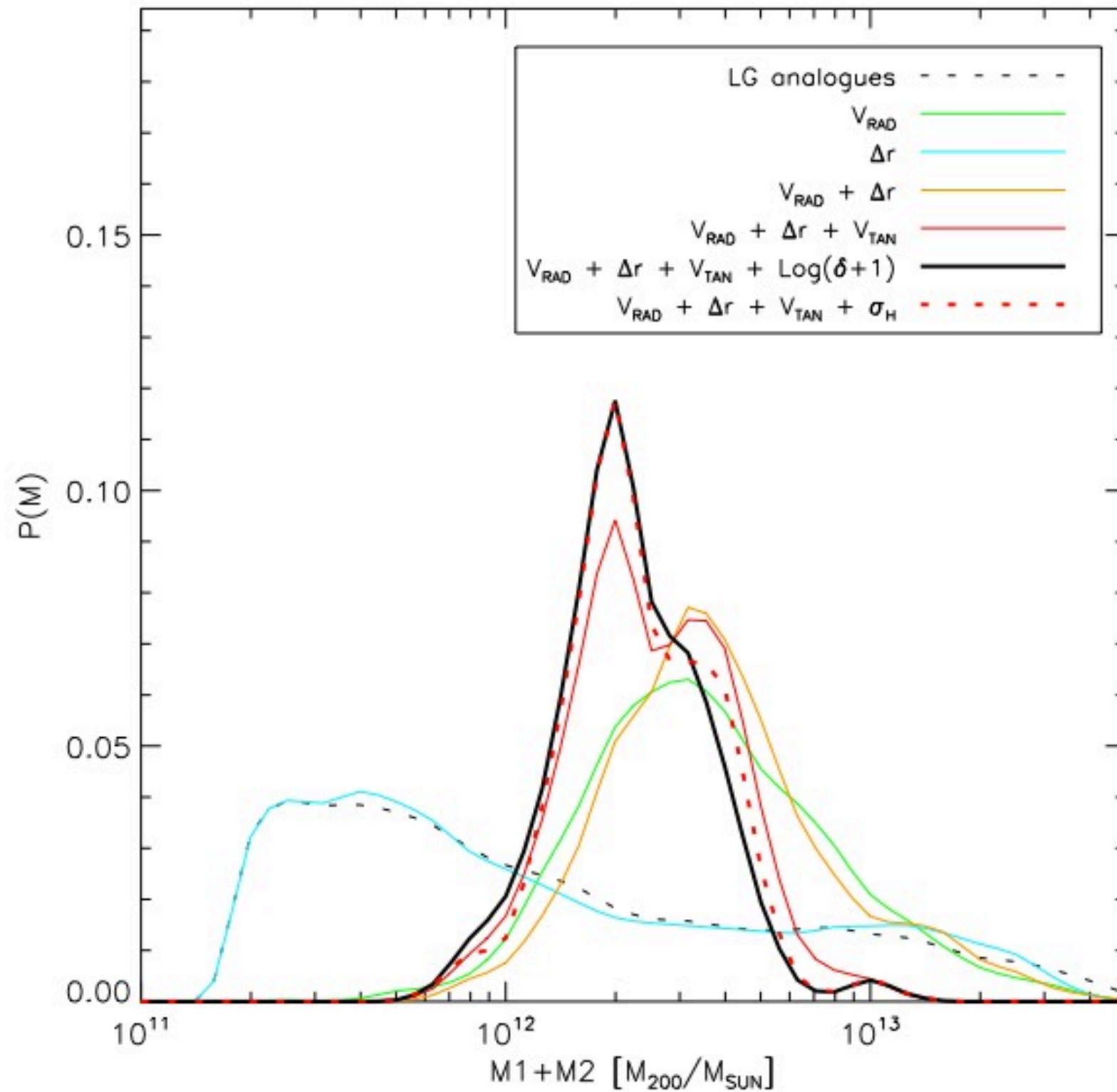
# Larger samples can be constructed by looking back in time for the special kinematic configurations

TABLE 1  
MASS LIKELIHOOD OF MW+M31 PAIRS IN LG ANALOGUES

| Constraints   | $\log(M_{200c}/M_{\odot})$ | 68% conf. interval | 90% conf. interval | $N$ pairs |
|---|----------------------------|--------------------|--------------------|-----------|
| $V_{\text{RAD}} + \Delta r$   | 12.60                      | -0.10 +0.12        | -0.31 +0.45        | 347       |
| $V_{\text{RAD}} + \Delta r + V_{\text{TAN}}$                                      | 12.45                      | -0.12 +0.11        | -0.25 +0.25        | 88        |
| $V_{\text{RAD}} + \Delta r + V_{\text{TAN}} + \log(1 + \delta)$                   | 12.38                      | -0.07 +0.09        | -0.25 +0.24        | 66        |
| $V_{\text{RAD}} + \Delta r + V_{\text{TAN}} + \sigma_{\text{H}}$                  | 12.39                      | -0.07 +0.13        | -0.19 +0.27        | 64        |
| $V_{\text{RAD}} + \Delta r + V_{\text{TAN}} + \log(1 + \delta) + 1 \text{ Mpc}^a$ | 12.62                      | -0.11 +0.13        | -0.28 +0.26        | 66        |
| $V_{\text{RAD}} + \Delta r + V_{\text{TAN}} + \sigma_{\text{H}} + 1\text{Mpc}$    | 12.62                      | -0.11 -0.13        | -0.28 +0.27        | 64        |



# LG kinematics are equivalent to mass selection



**Gonzalez, Kravtsov, Gnedin, ApJ 2014, 1312.2587**

## **Observation #2**

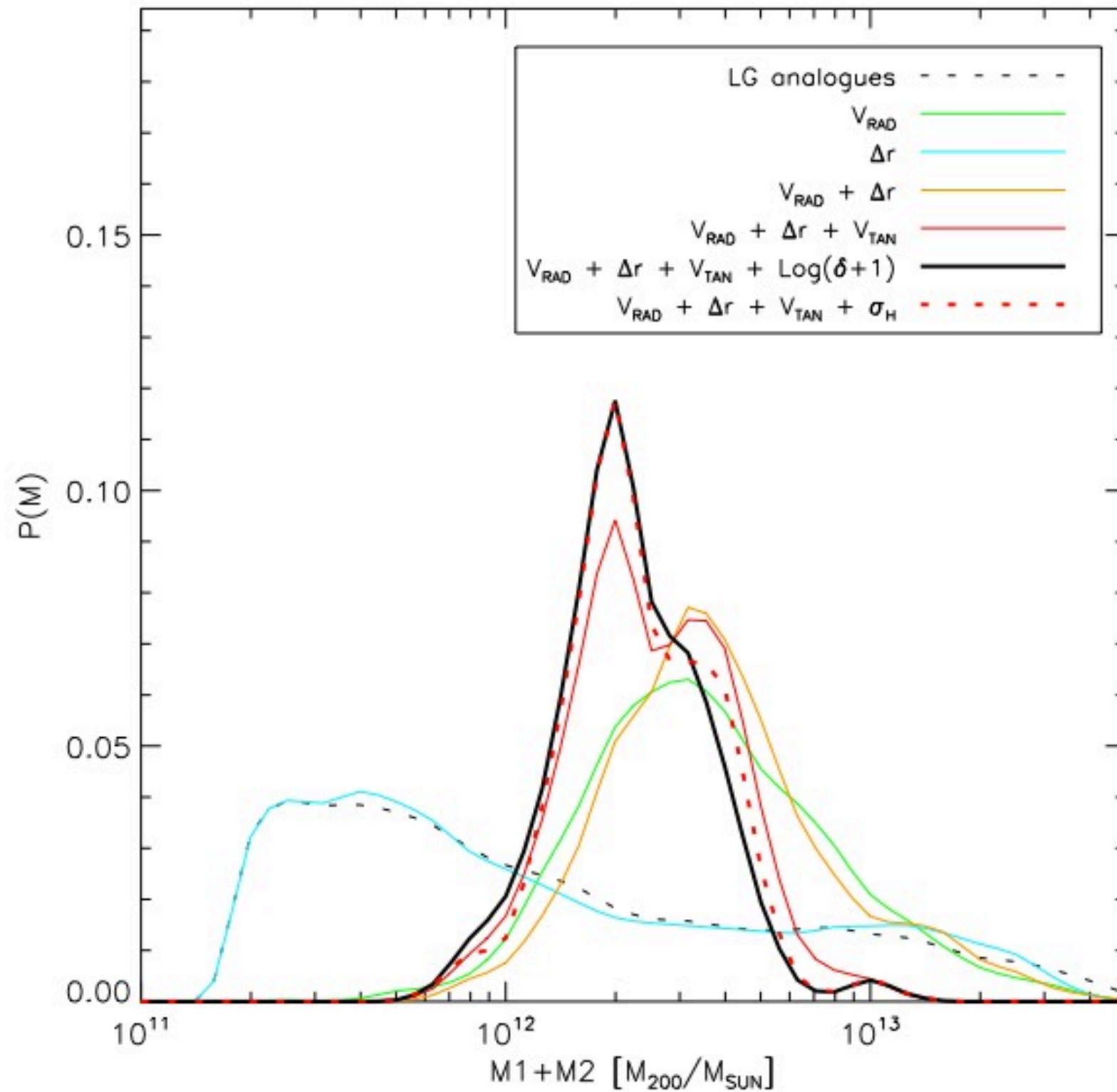
**The observed LG kinematics does not correspond to the expectation of the average pair in LCDM.**

## Observation #3

Requiring kinematics consistent with observations can constraint the LG mass.

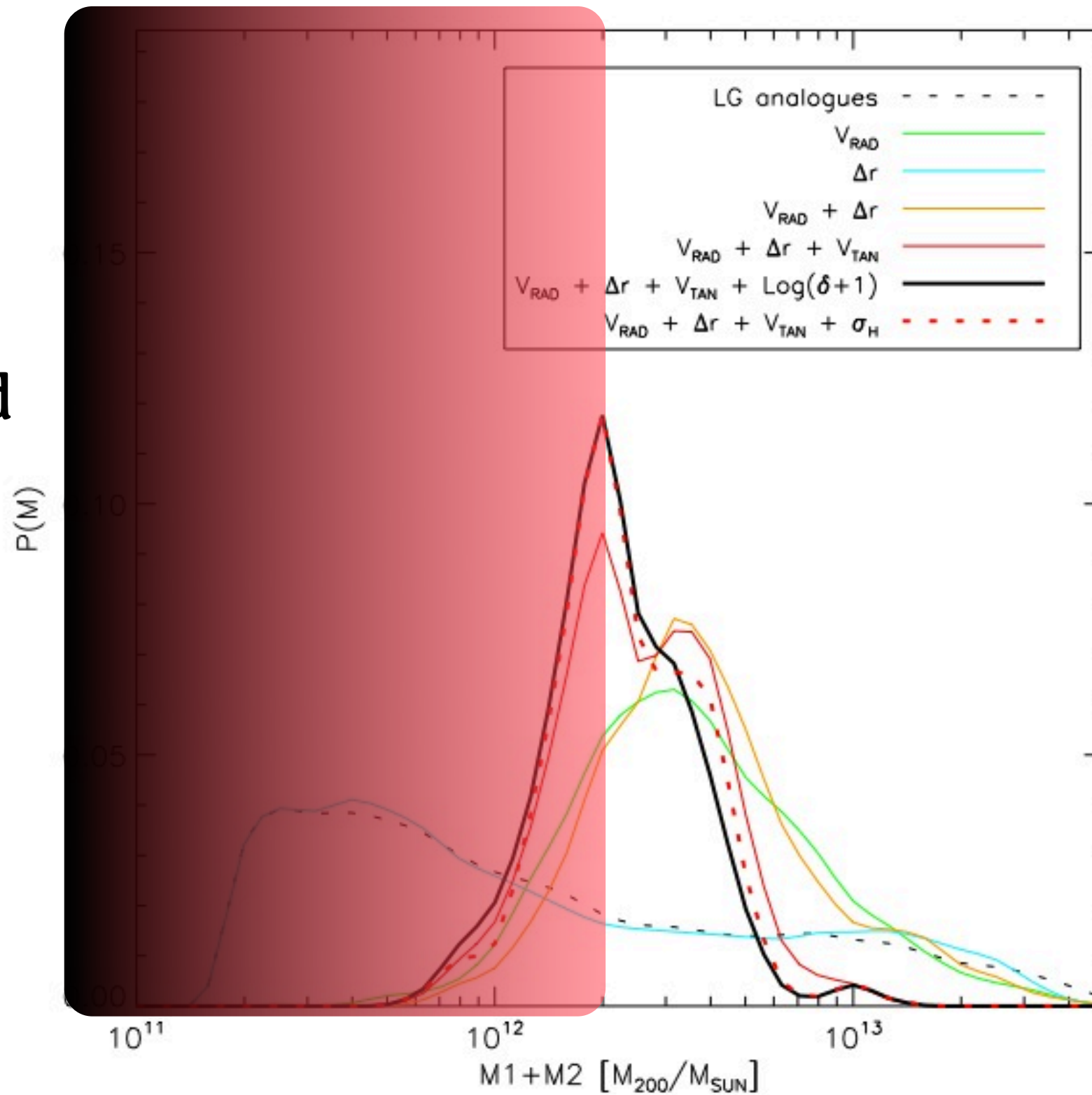


# LG kinematics is equivalent to mass selection



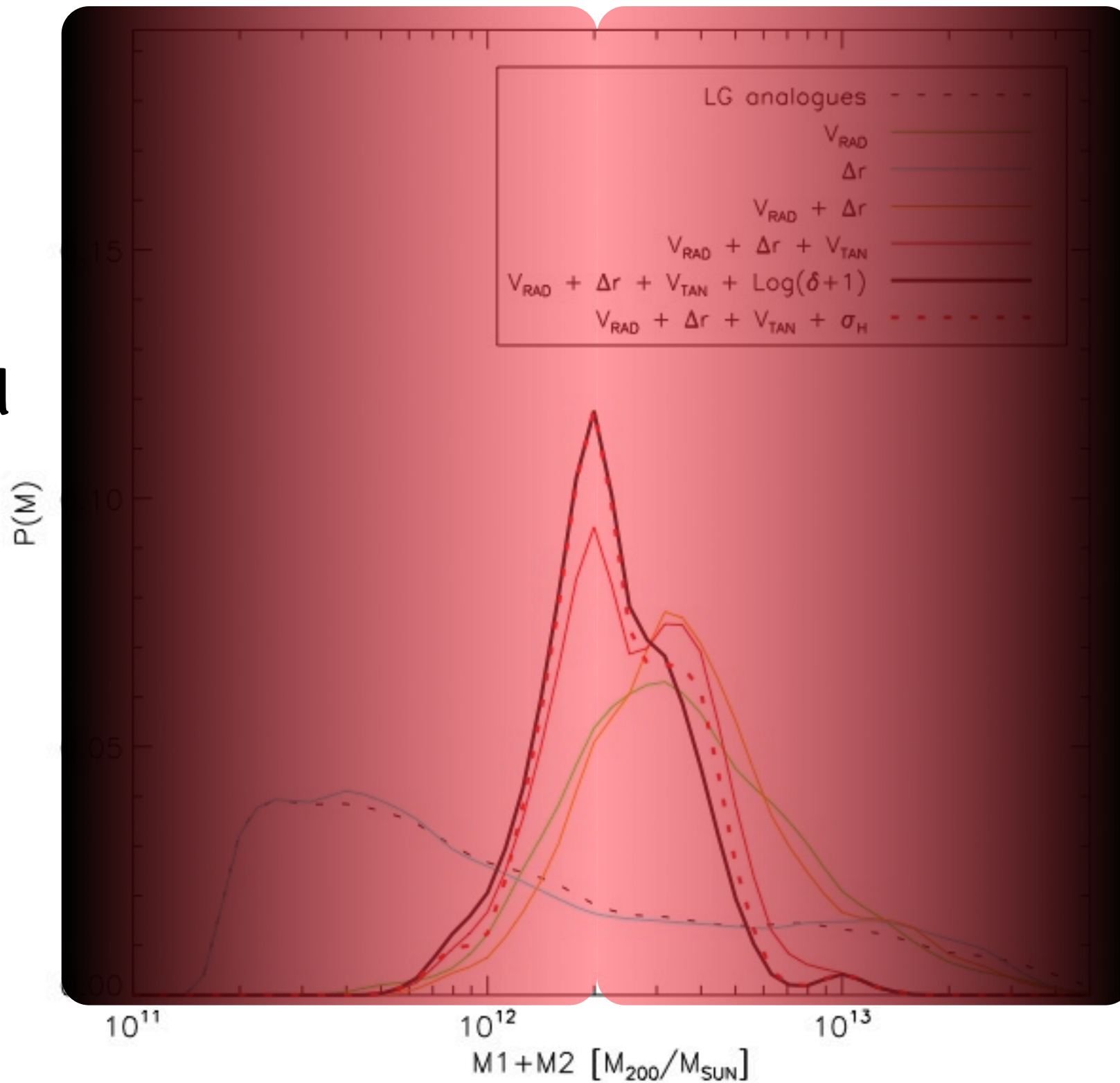
# LG kinematics is equivalent to mass selection

Disfavored  
by high  
radial  
velocities



# LG kinematics is equivalent to mass selection

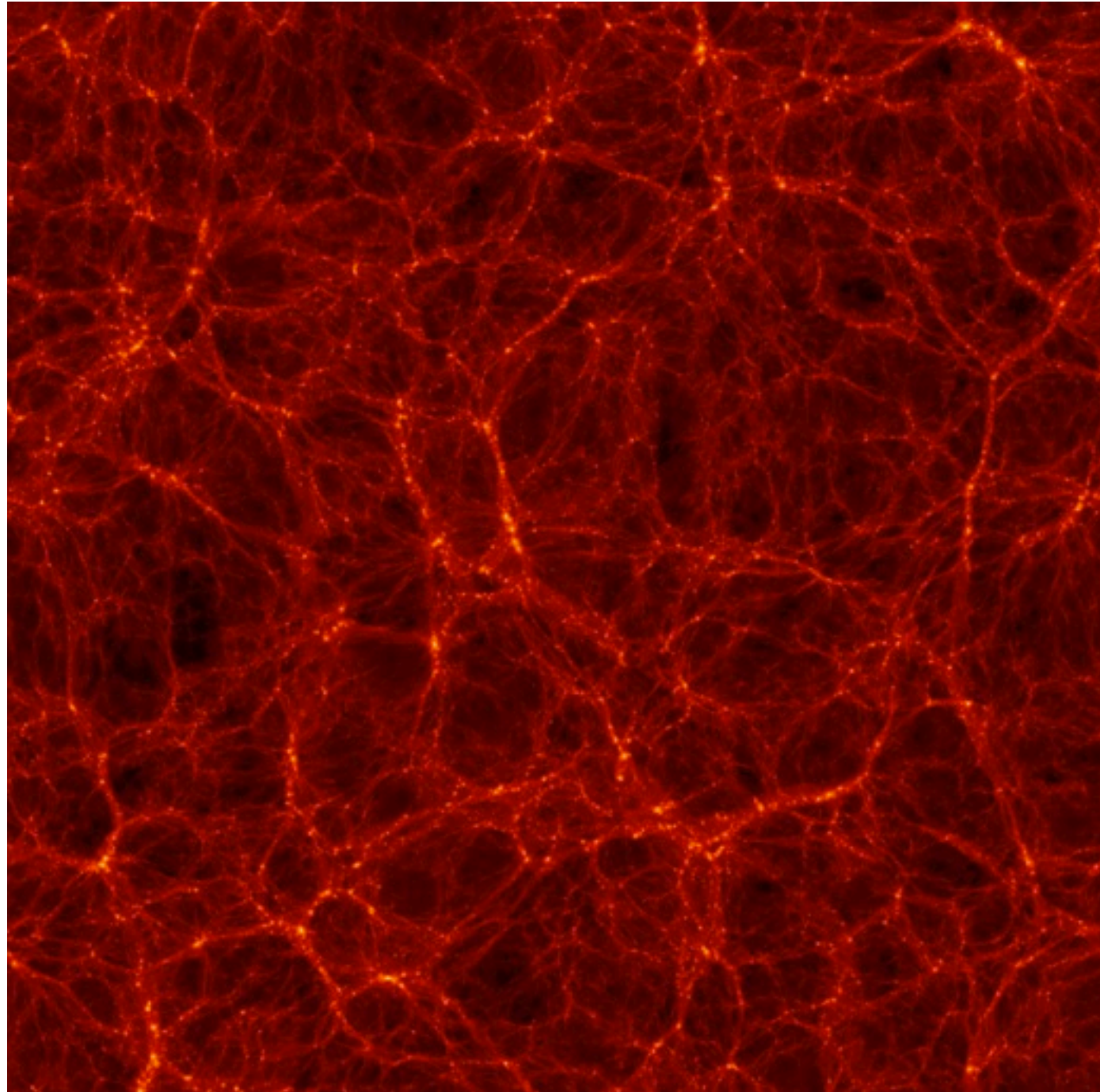
Disfavored  
by high  
radial  
velocities



Disfavored  
by low  
tangential  
velocities



# Use Bolshoi to study in detail the environment of LG pairs





# Data publicly available

# CosmoSim

The CosmoSim database provides results from cosmological simulations performed within different projects: the [MultiDark project](#), the [BolshoiP project](#), and the [CLUES project](#).

## MULTIDARK

Multimessenger Approach  
for Dark Matter Detection

The Spanish MultiDark Consolider project supports efforts to identify and detect matter, including dark matter simulations of the universe.

[MDR1](#)  
[MDPL](#)  
[Bolshoi](#)

## BolshoiP

Cosmological Simulations

The BolshoiP project contains a simulation like Bolshoi, with the same box size and resolution, but with Planck cosmology.

[BolshoiP](#)

## CLUES

Constrained Local Universe Simulations

The CLUES project deals with constrained simulations of the local universe, partially with gas and star formation.

[Clues3\\_LGDM](#)  
[Clues3\\_LGGas](#)

Please visit the linked sites for more information about the projects and about the appreciated form of acknowledgment, if the data is used in a scientific publication or proposal. The MultiDark simulations MDR1 and MDPL as well as the Bolshoi simulation are also available via the [MultiDark database](#).

[Register to CosmoSim](#)



CosmoSim.org is hosted and maintained by the Leibniz-Institute for Astrophysics Potsdam (AIP).



It is a contribution to the German Astrophysical Virtual Observatory.

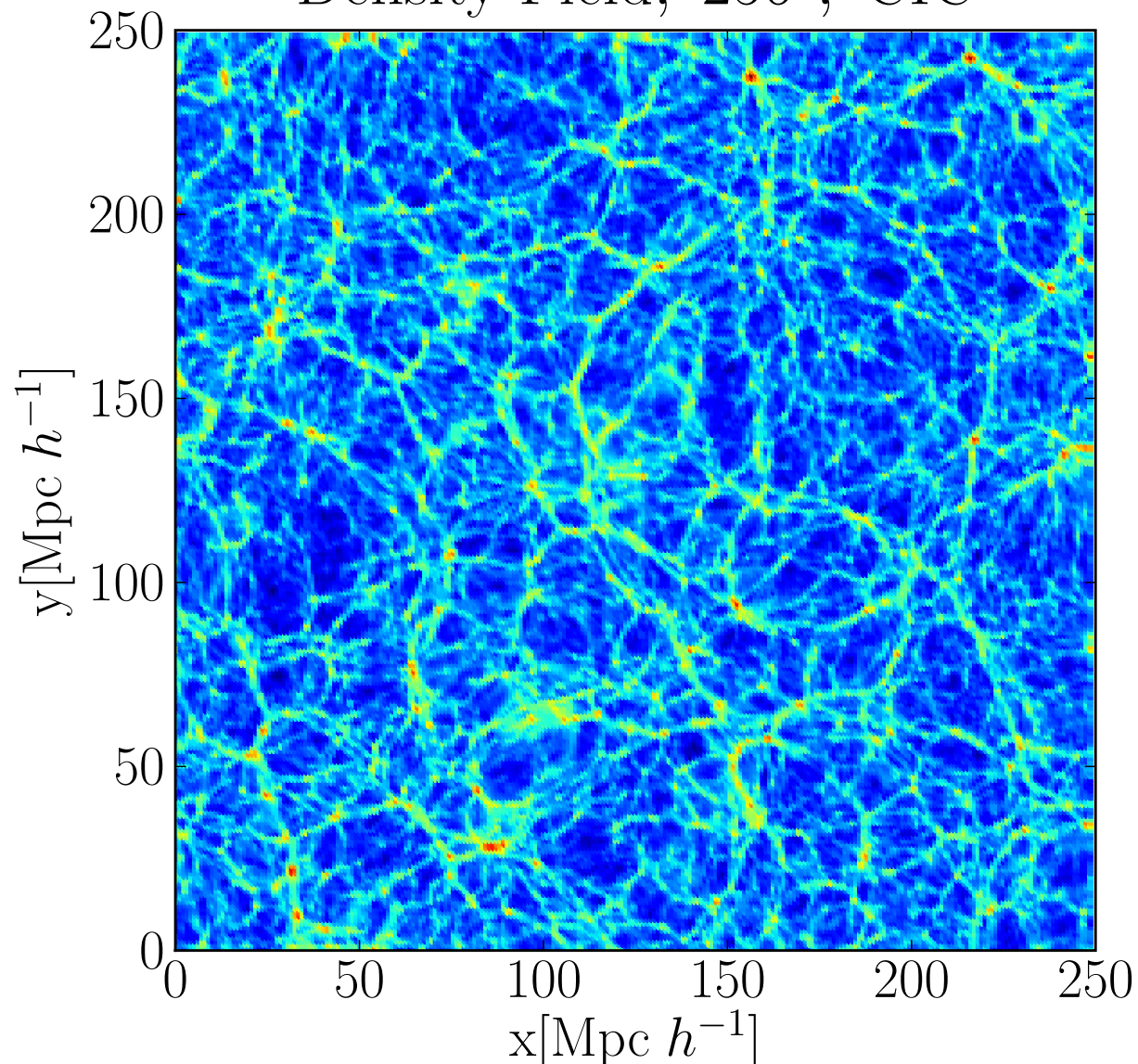
The MultiDark and Bolshoi



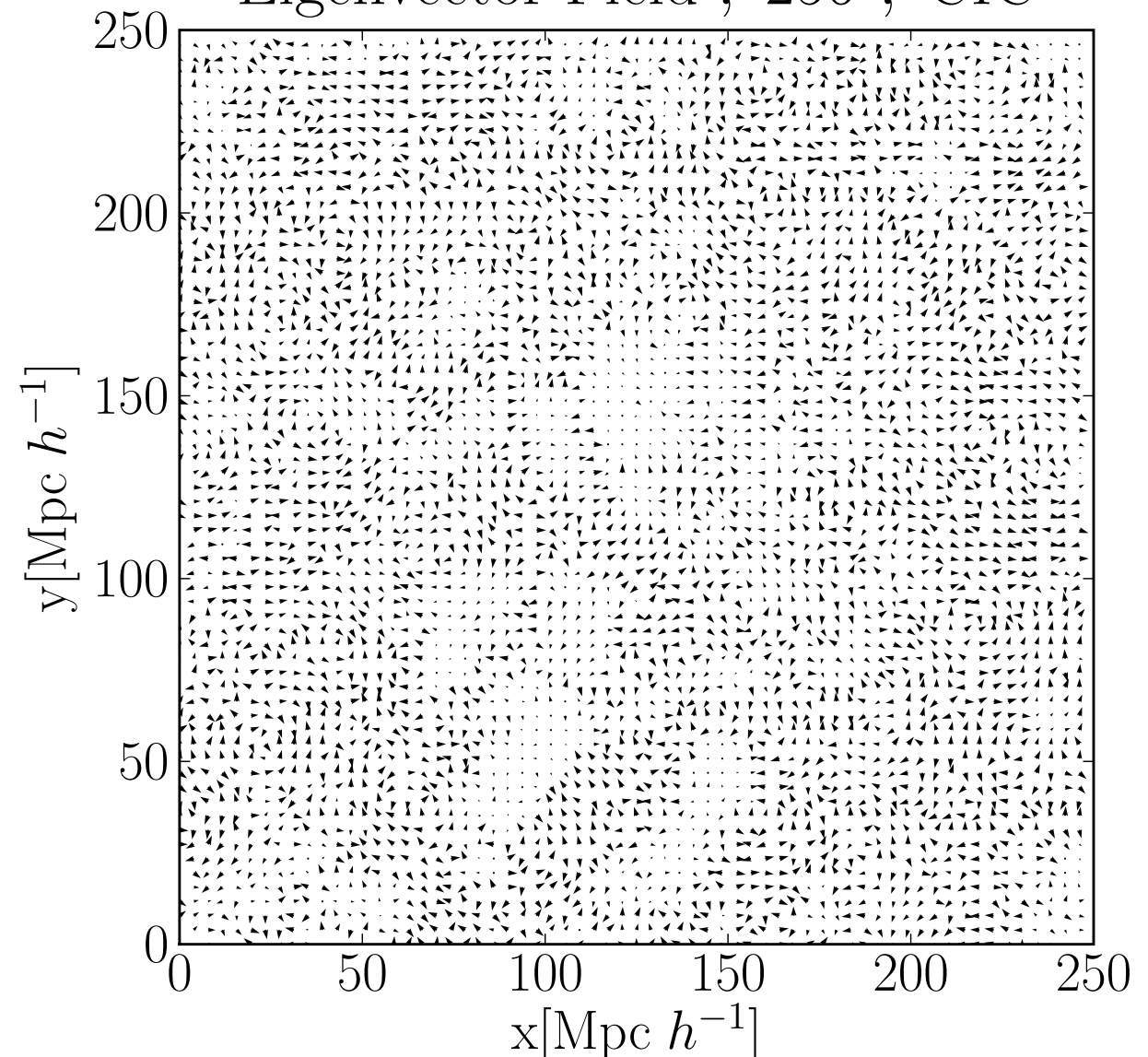
# Environment is defined from the tidal tensor

$$T_{ij} = \frac{\partial^2 \phi}{\partial r_i \partial r_j} \quad \delta = \lambda_1 + \lambda_2 + \lambda_3 \quad e = \frac{\lambda_3 - \lambda_1}{2(\lambda_1 + \lambda_2 + \lambda_3)}$$

Density Field,  $256^3$ , CIC



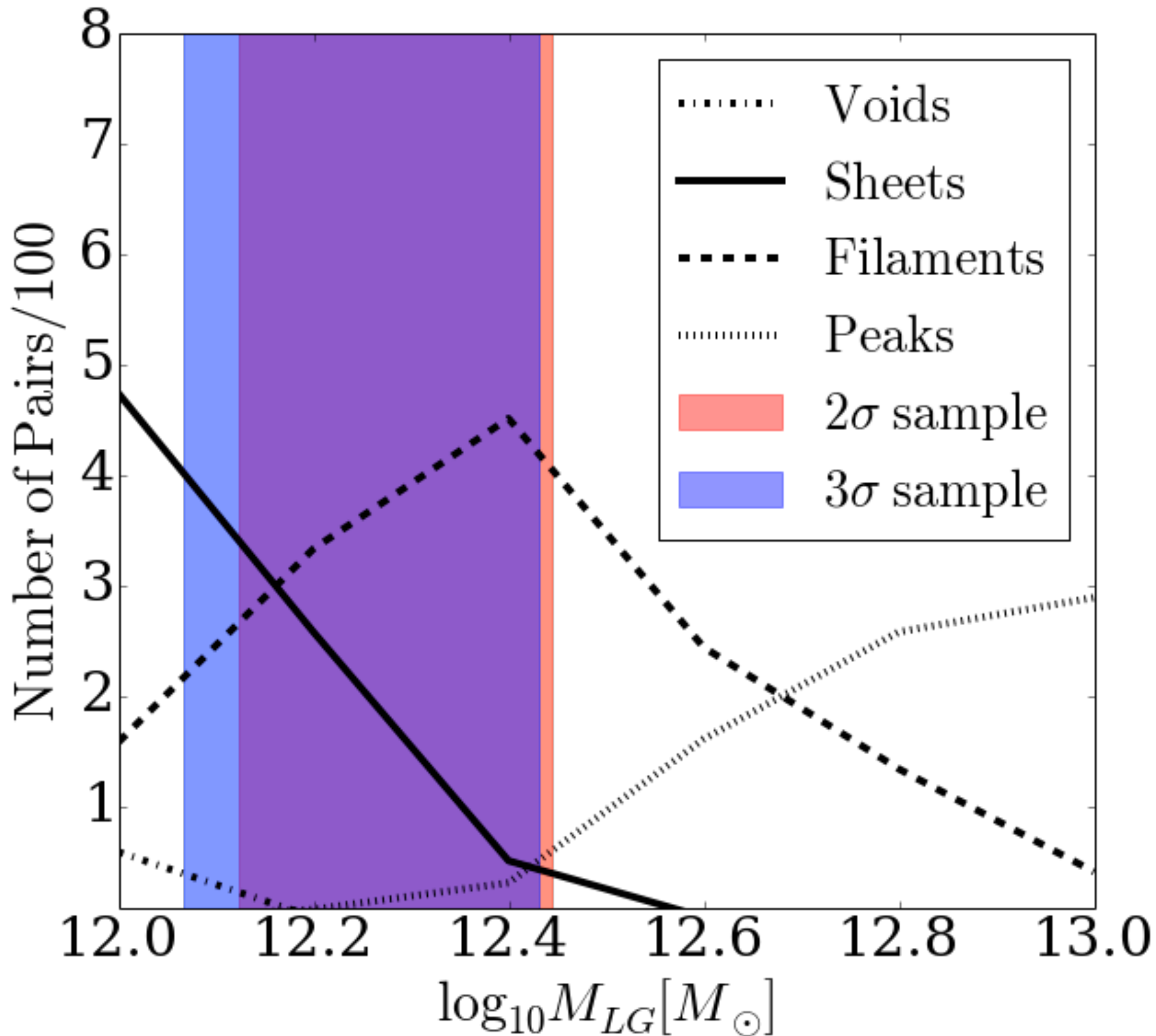
Eigenvector Field,  $256^3$ , CIC



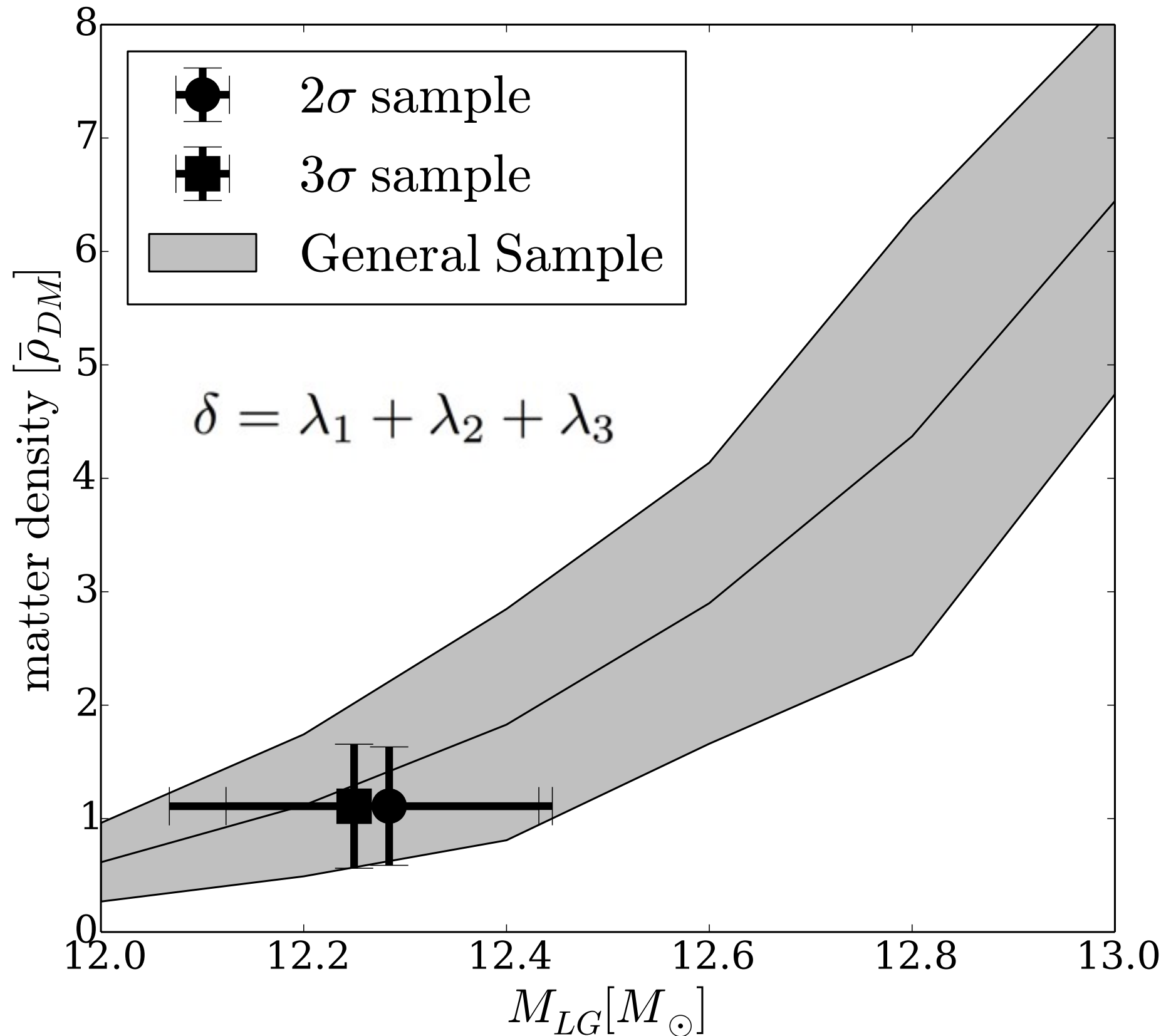
defined over a grid of  $1\text{Mpc}/h + 1\text{Mpc}/h$  gaussian smoothing



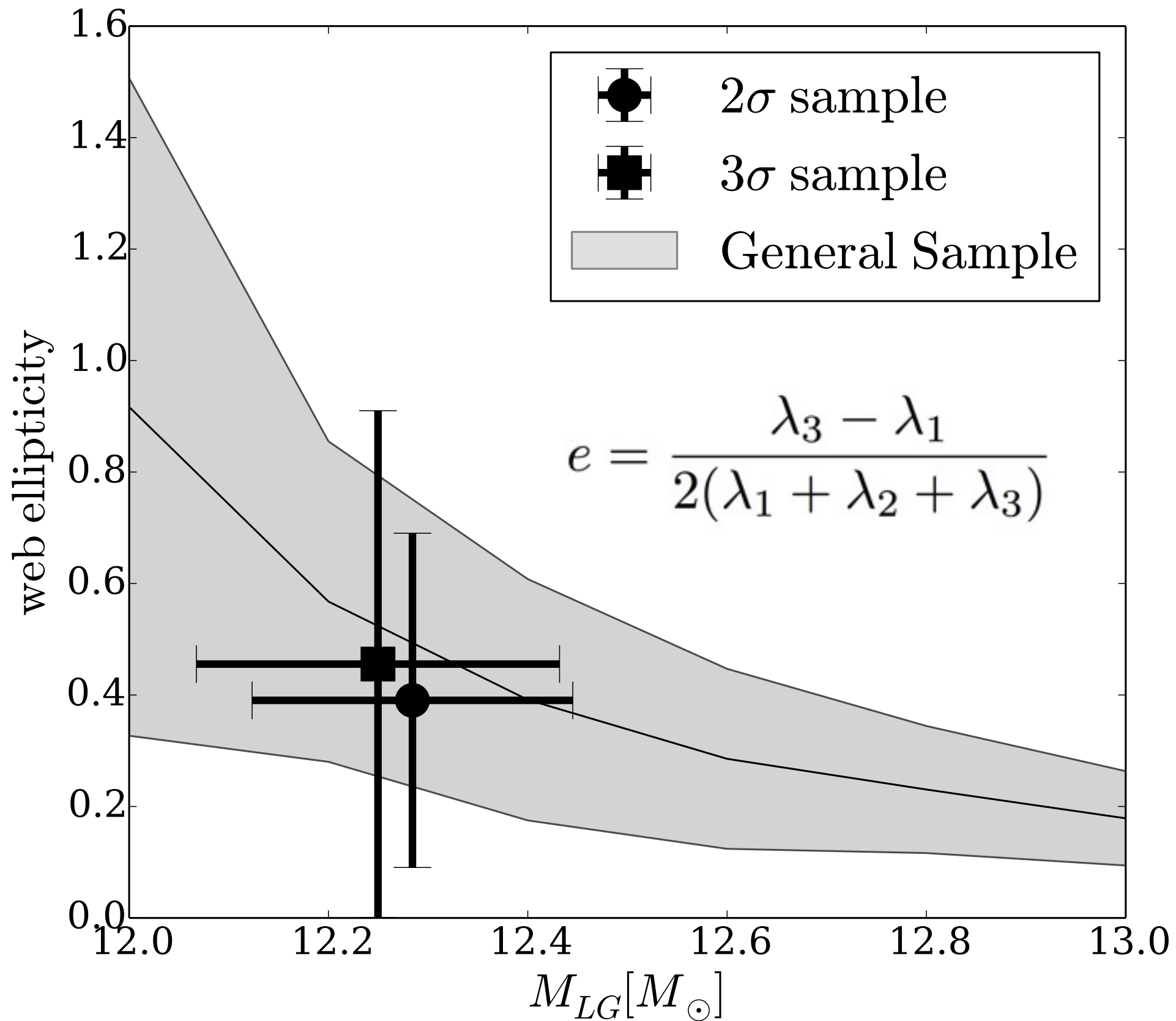
# LG mass selects the environment



# LG mass selects the environment

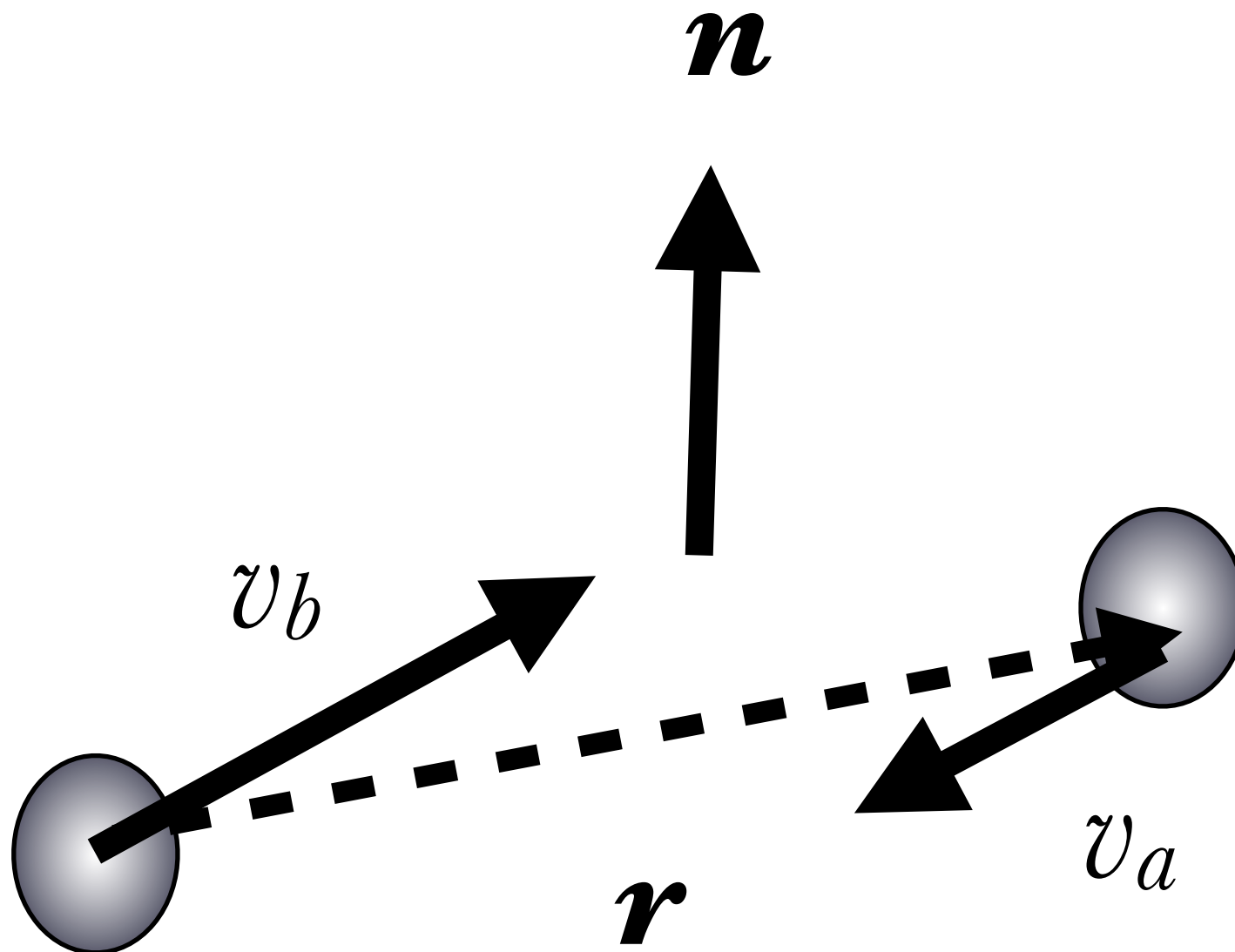


# LG mass selects the environment



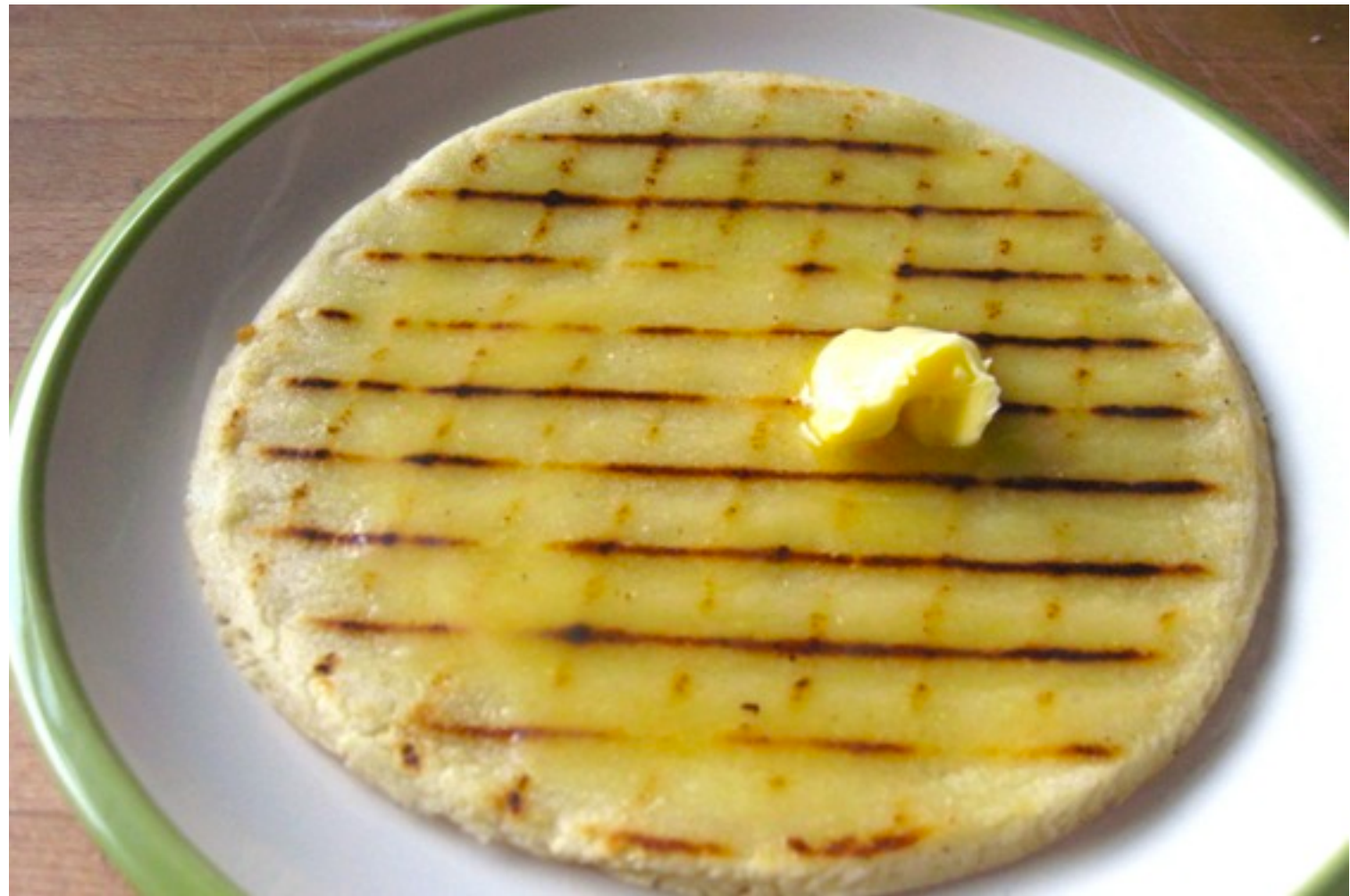


We look for alignments with the cosmic web

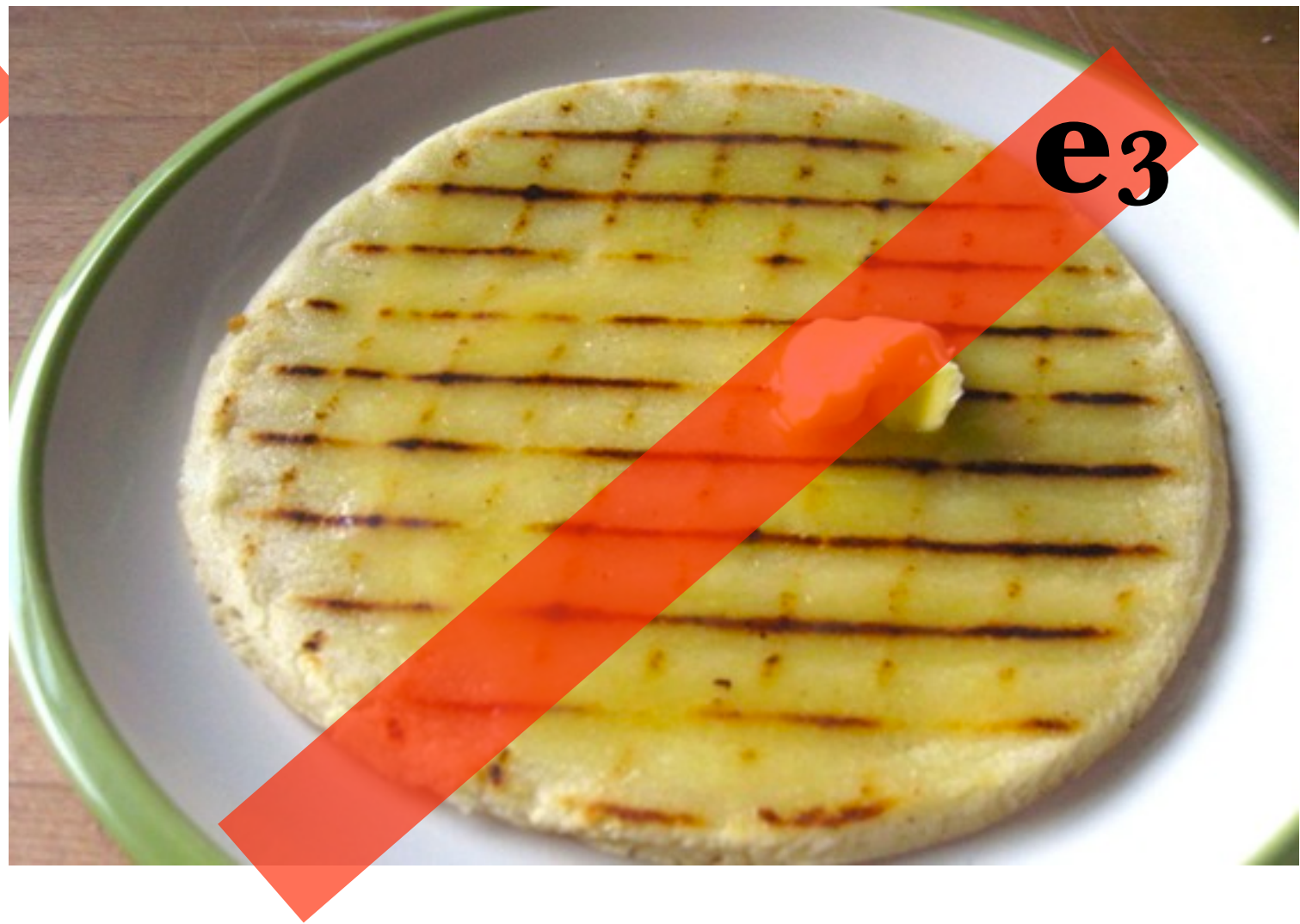
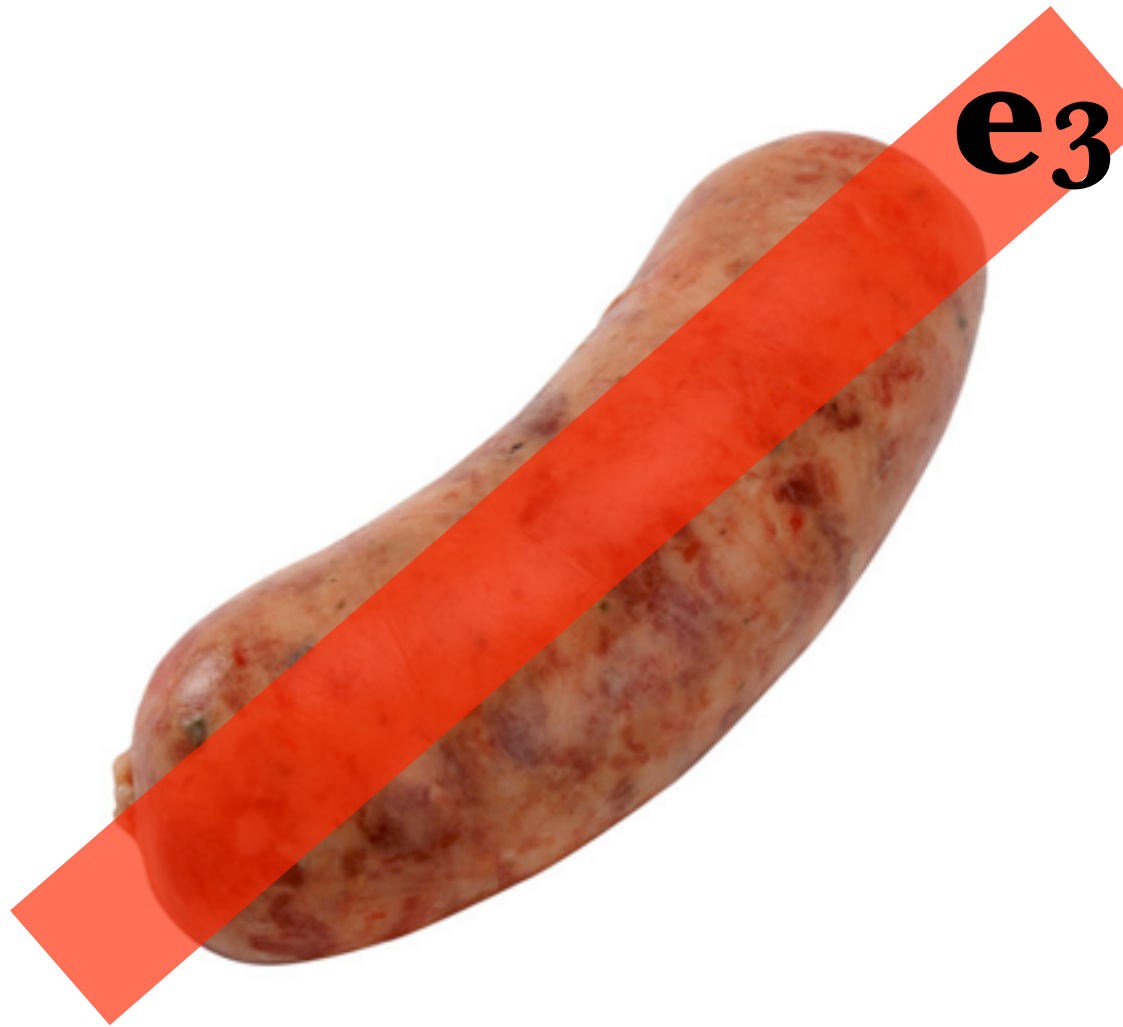


CM Frame

# filaments and walls

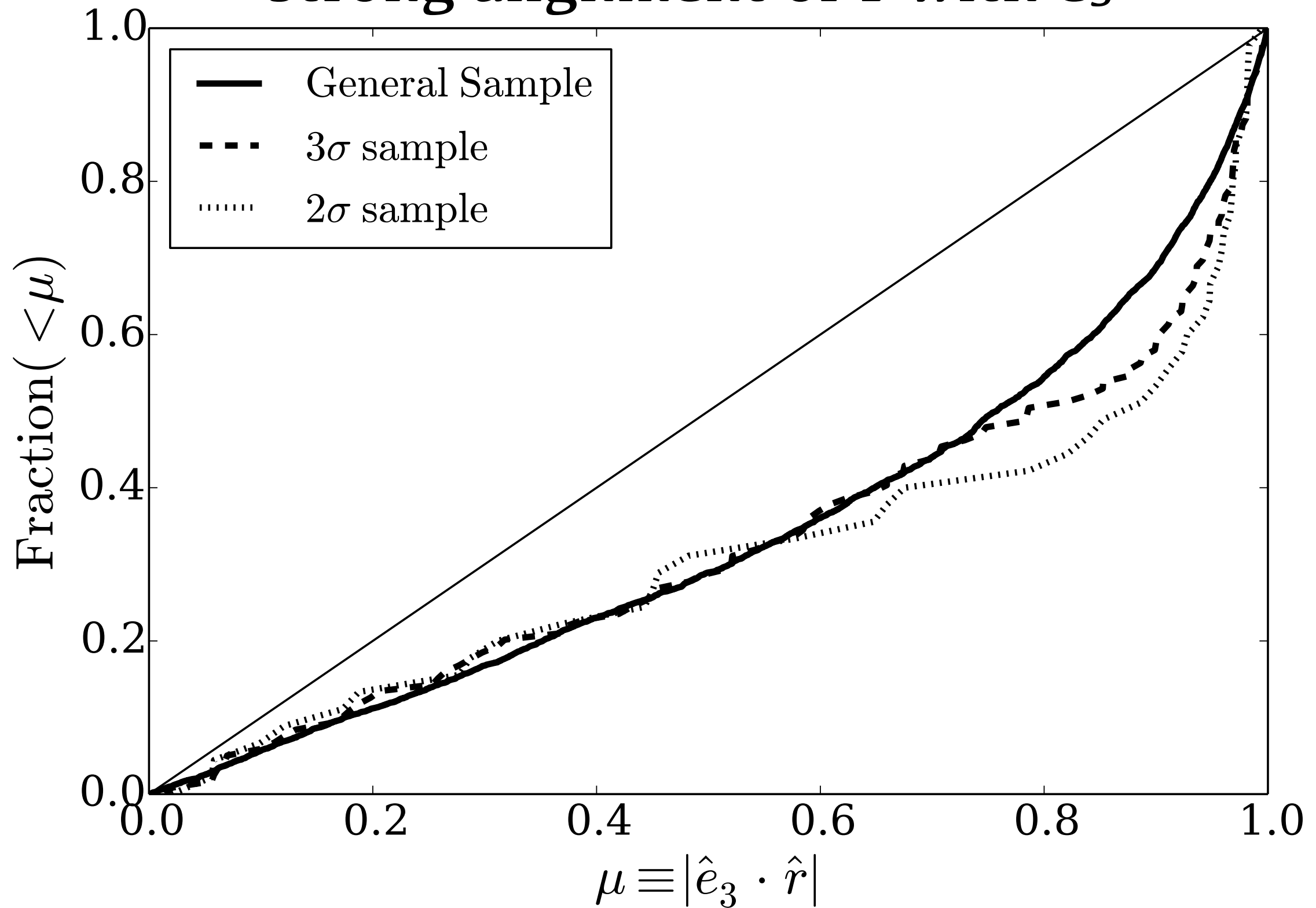


$e_3$  goes along filaments and parallel to walls

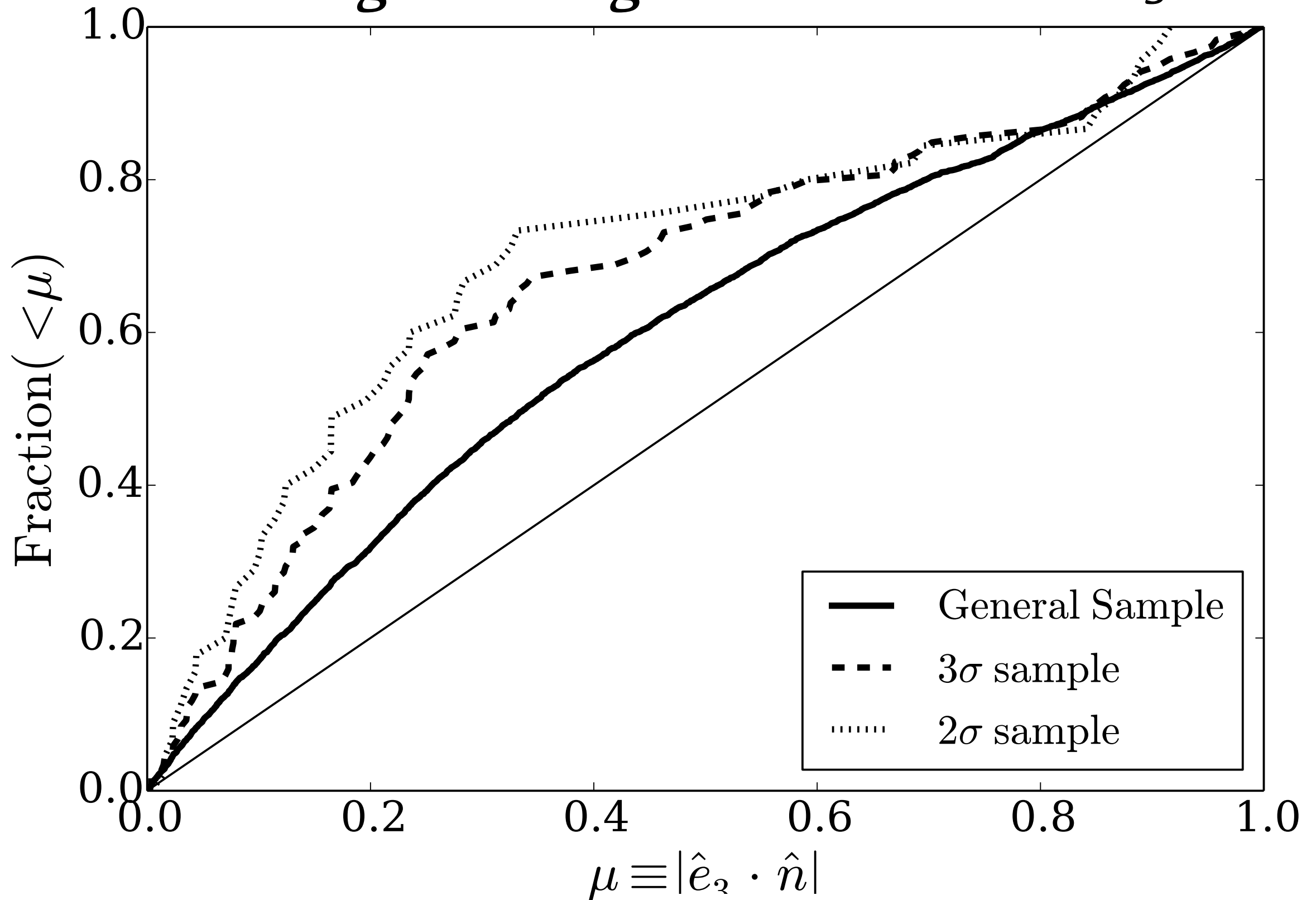




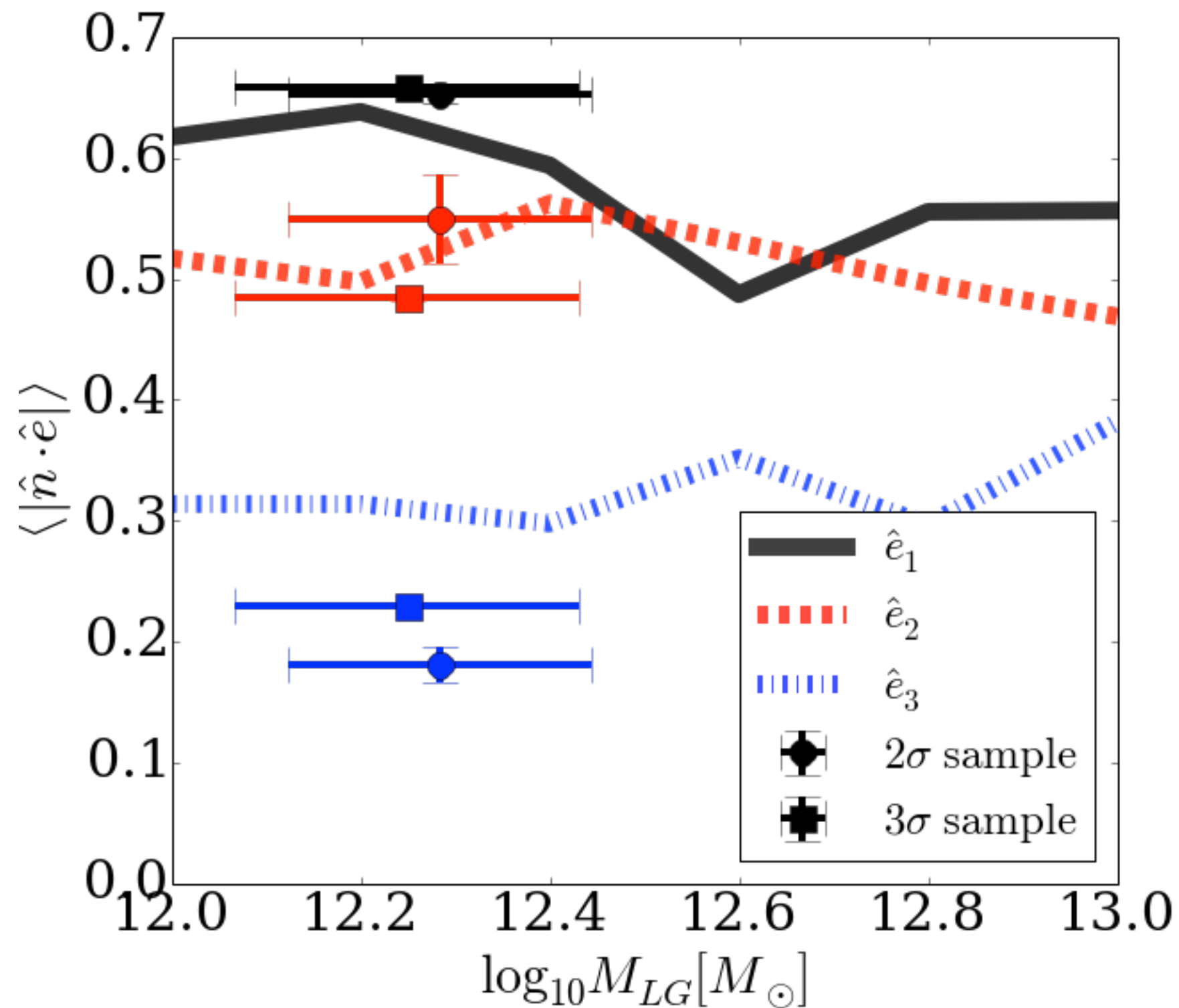
# strong alignment of $\mathbf{r}$ with $\mathbf{e}_3$



# strong anti-alignment of $\mathbf{n}$ with $\mathbf{e}_3$

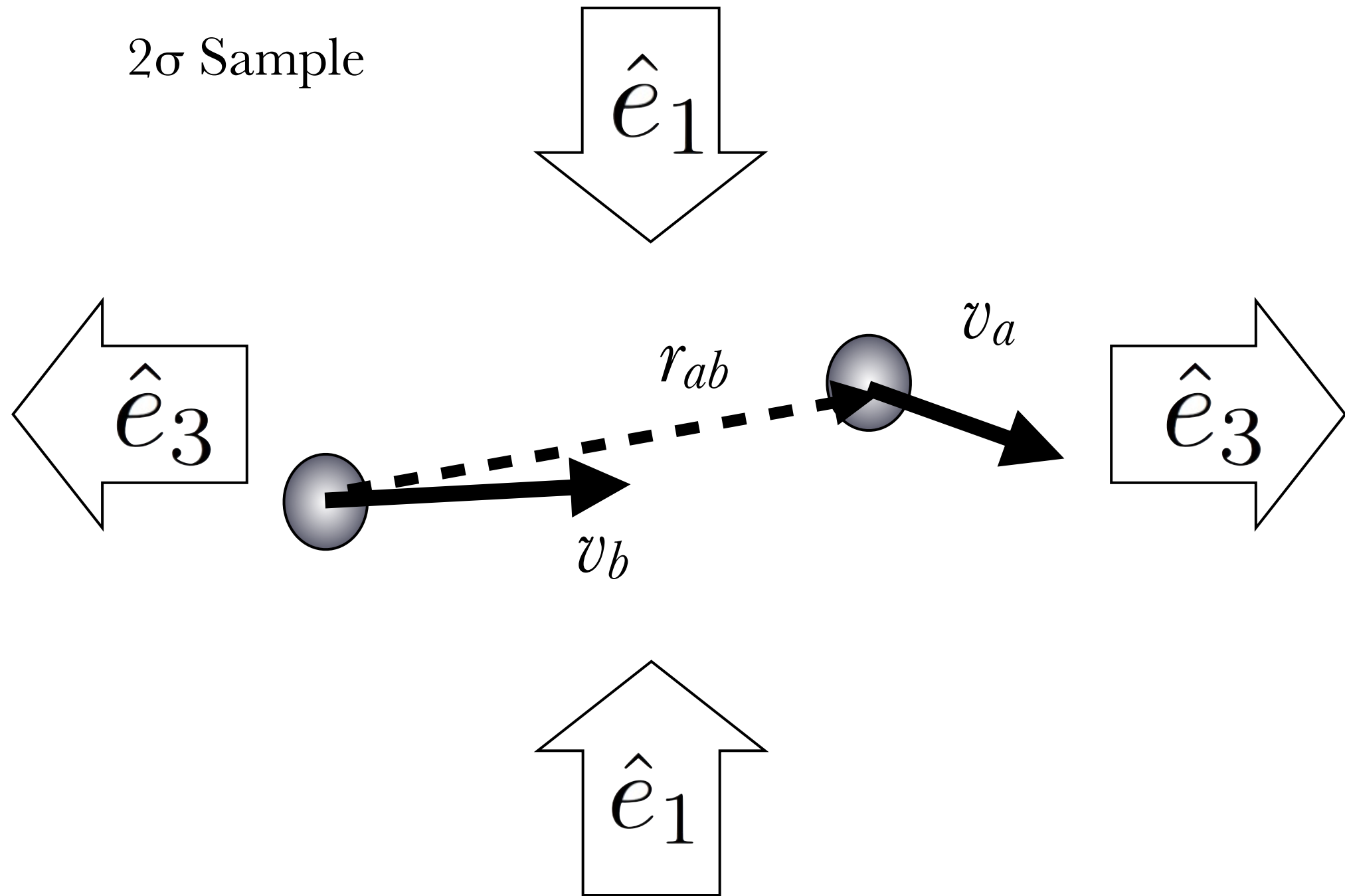


# Strong alignments for pairs are not mass dependent

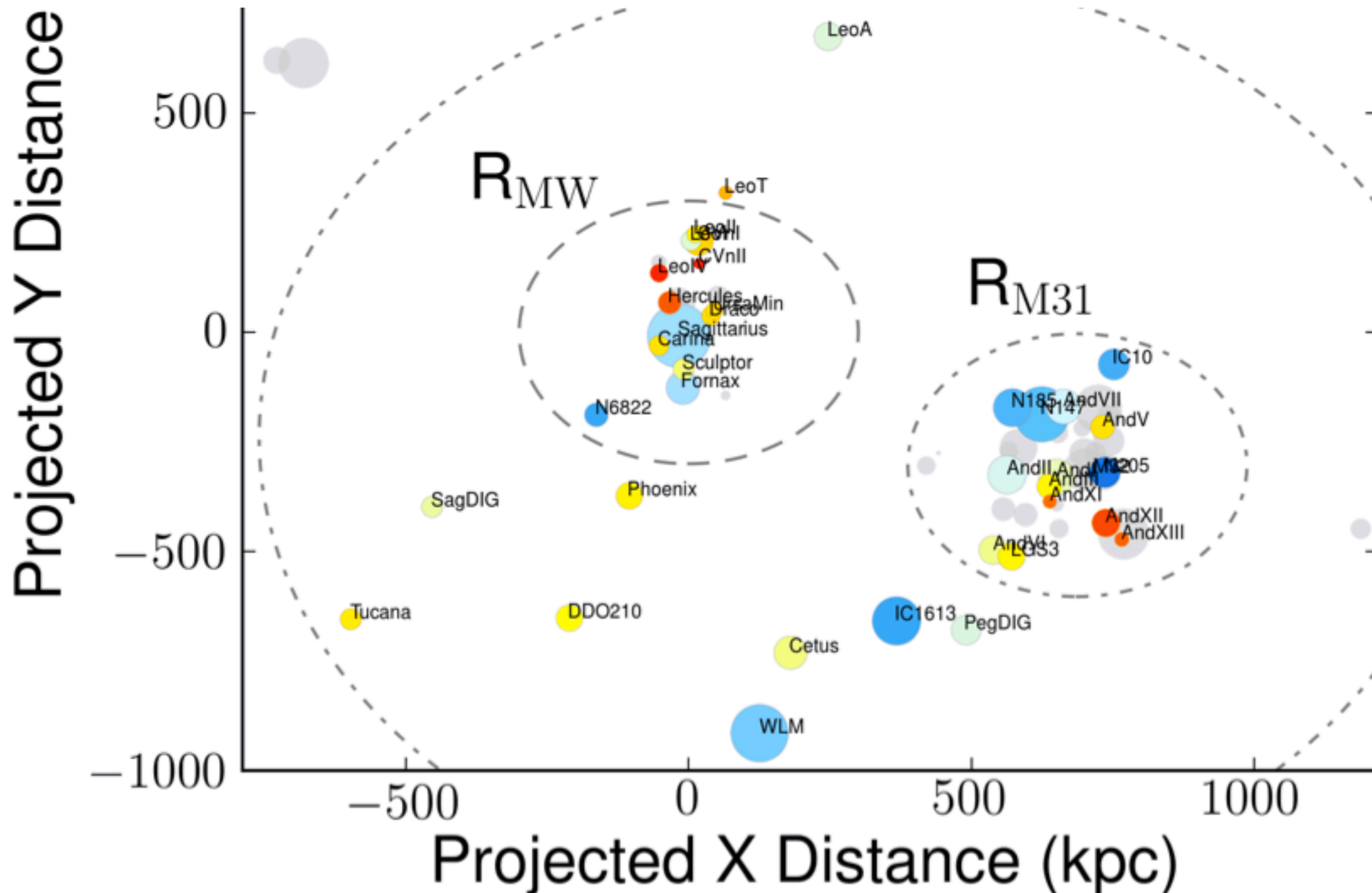




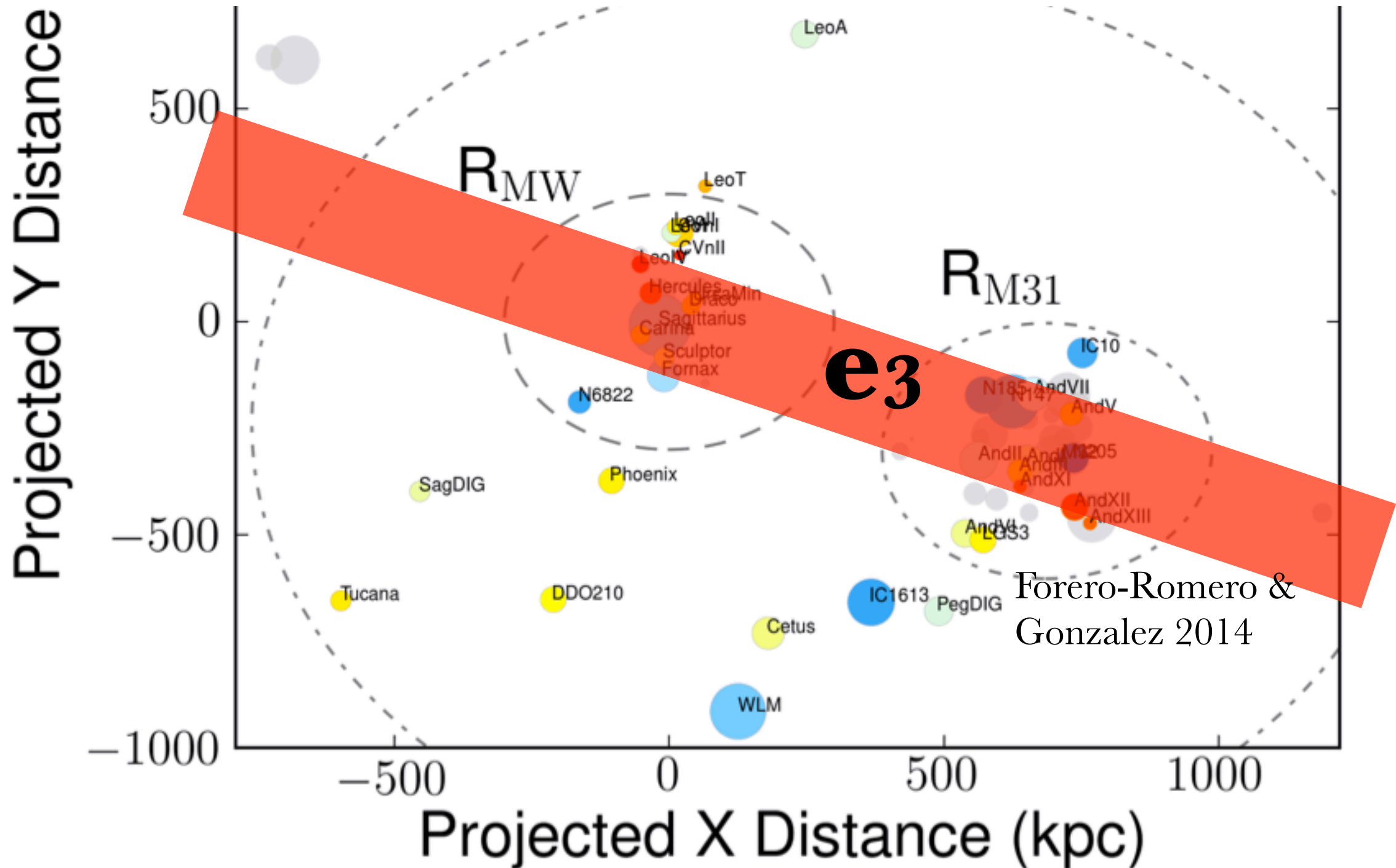
# Observation #4



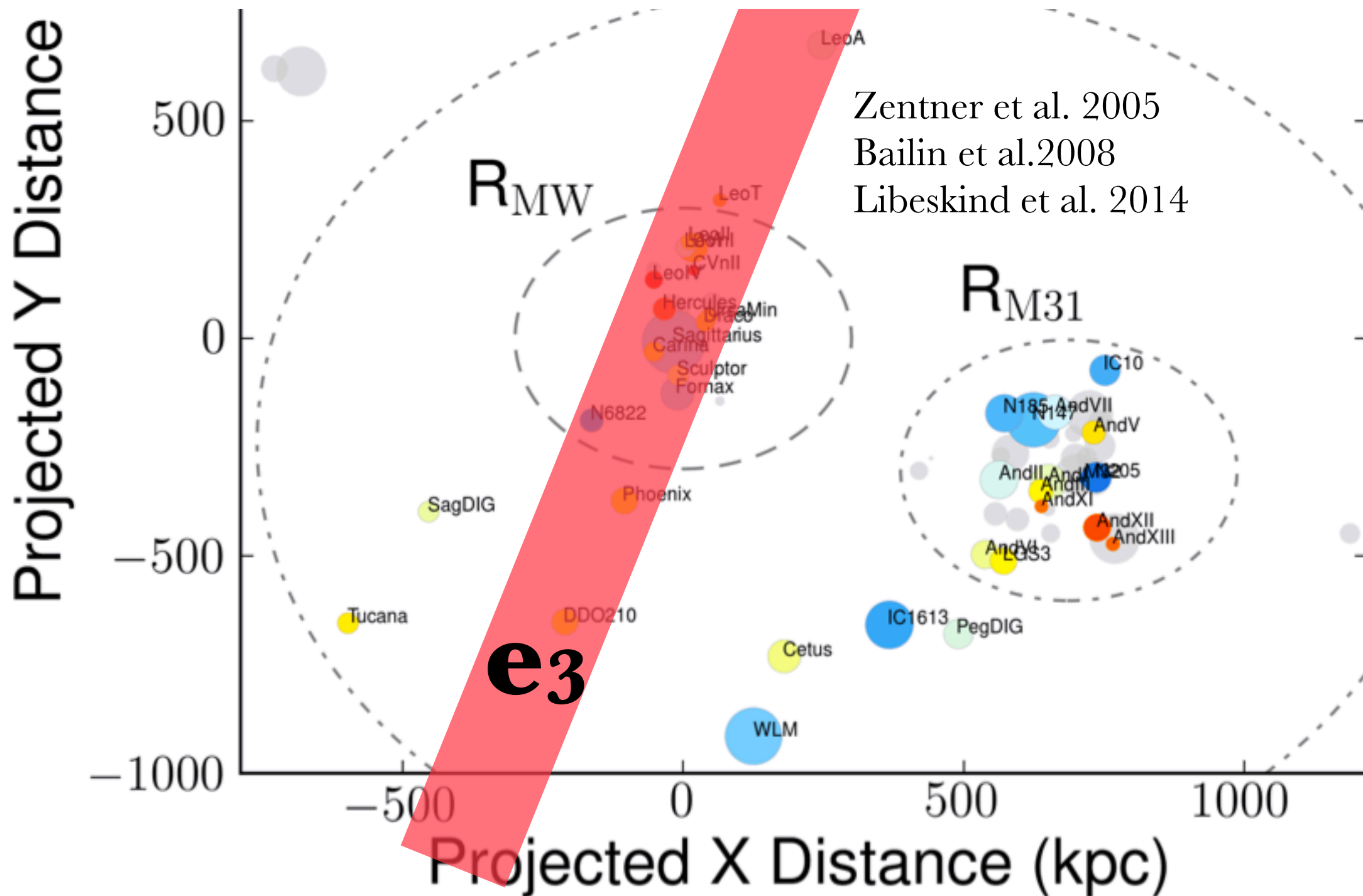
# What is the situation in the observed Local Group?



# This is the alignment we predict in the Local Group



# Tension with the expected alignment for plane of MW satellites?





# Summary

- Density field constraints (large scales + meso scales) narrows down halo formation properties.
- LG kinematics does not correspond to the expectations from the average pair in LCDM
- LG kinematics imposes constraint the LG mass.
- The vector connecting MW-M31 is strongly aligned with filament/wall.
- Is this alignment in tension with the MW plane of satellites?