The Local Group in the Cosmic Web

in collaboration with
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arXiv: 1408.3166

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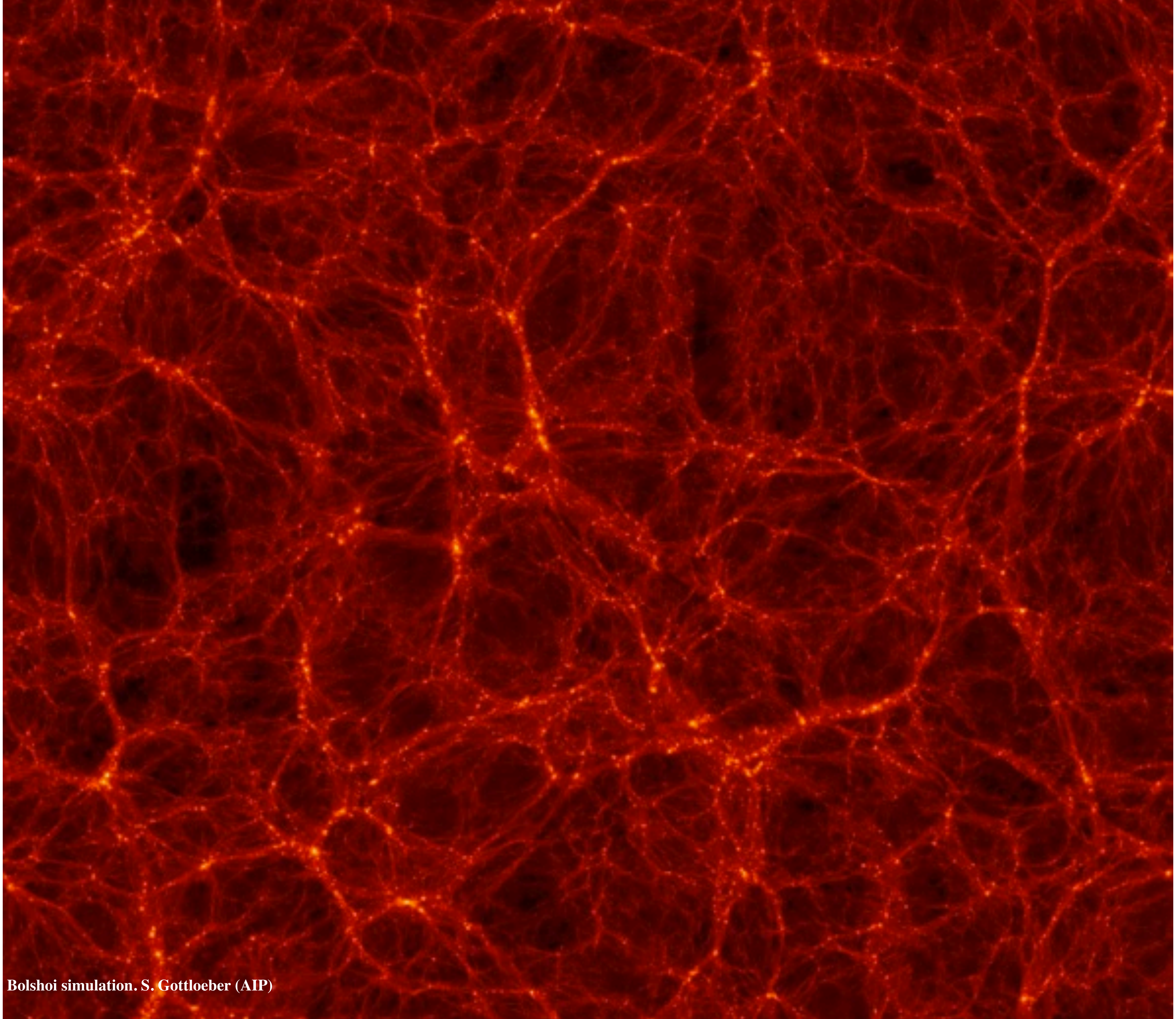
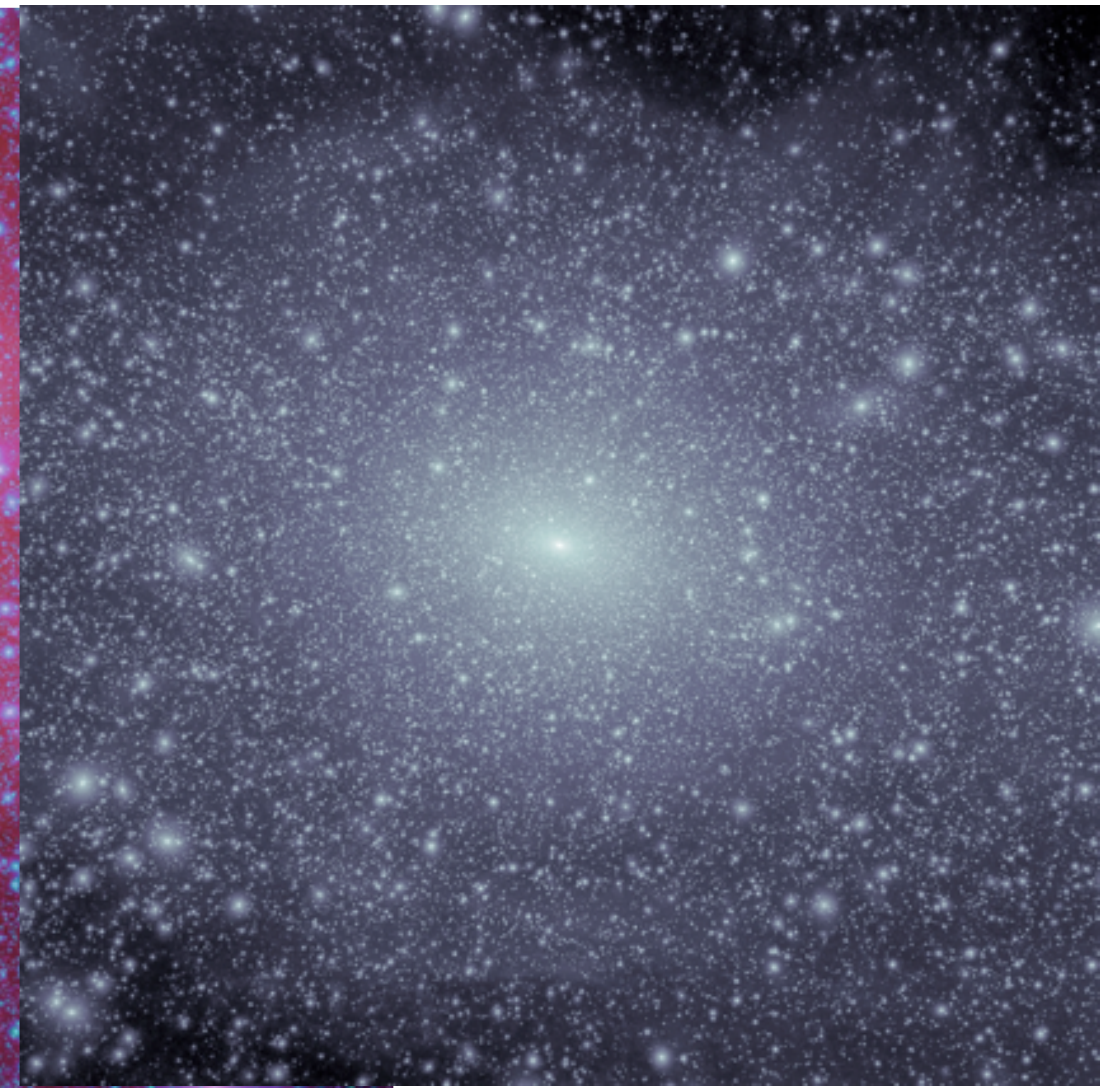

Bolshoi simulation. S. Gottloeber (AIP)

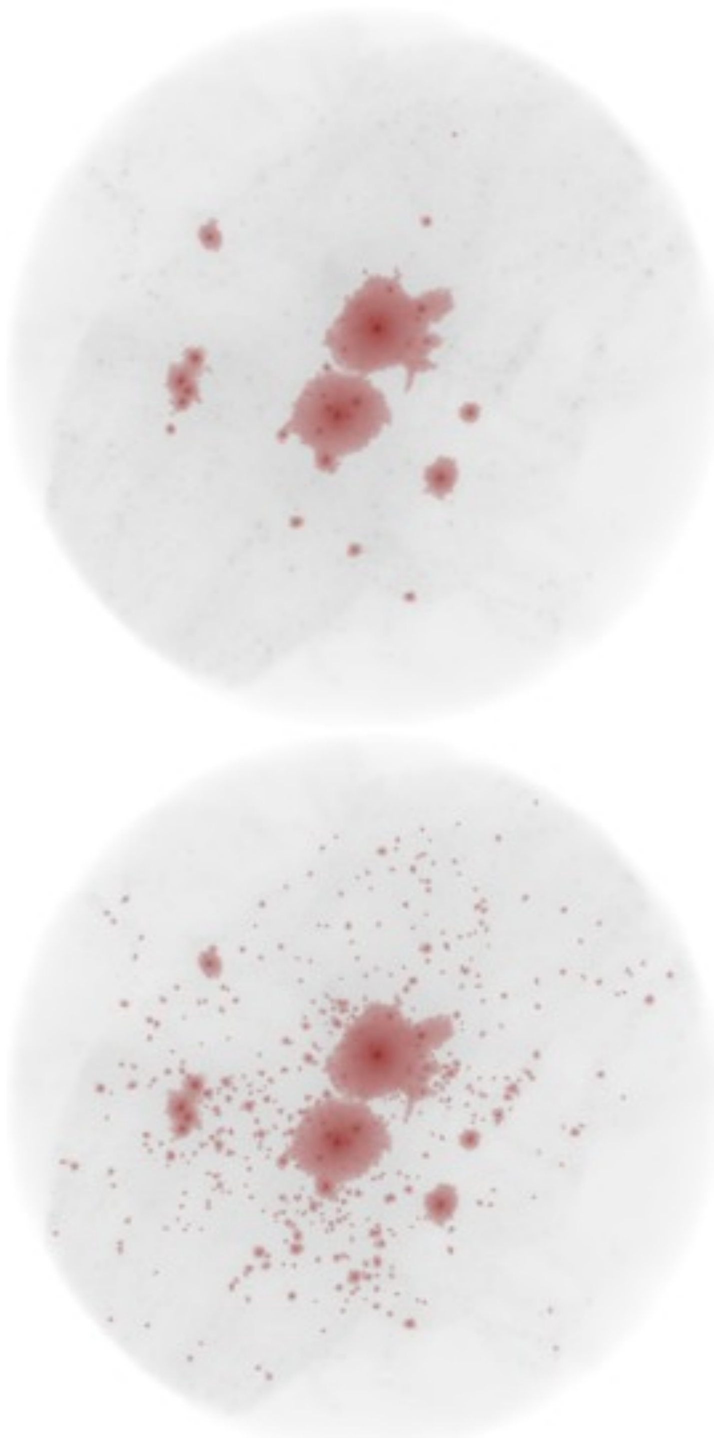
There are large variations if the MW is thought as a random 10^{12} M_{sol} halo

Aquarius Project (Springel et al. 2008)

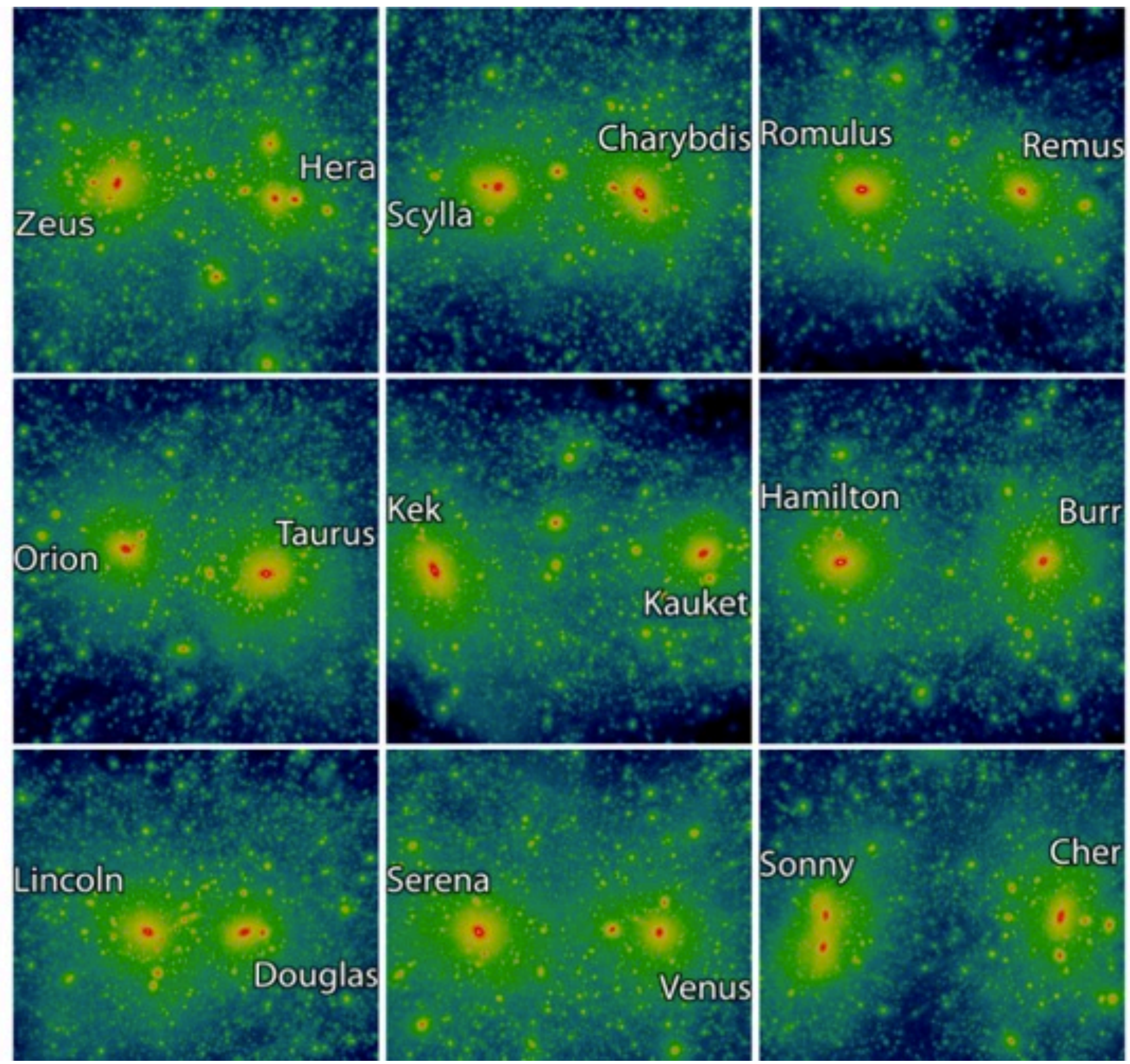


Via Lactea Project (Diemand et al. 2008)

Pairs: the natural way to think about the MW environment



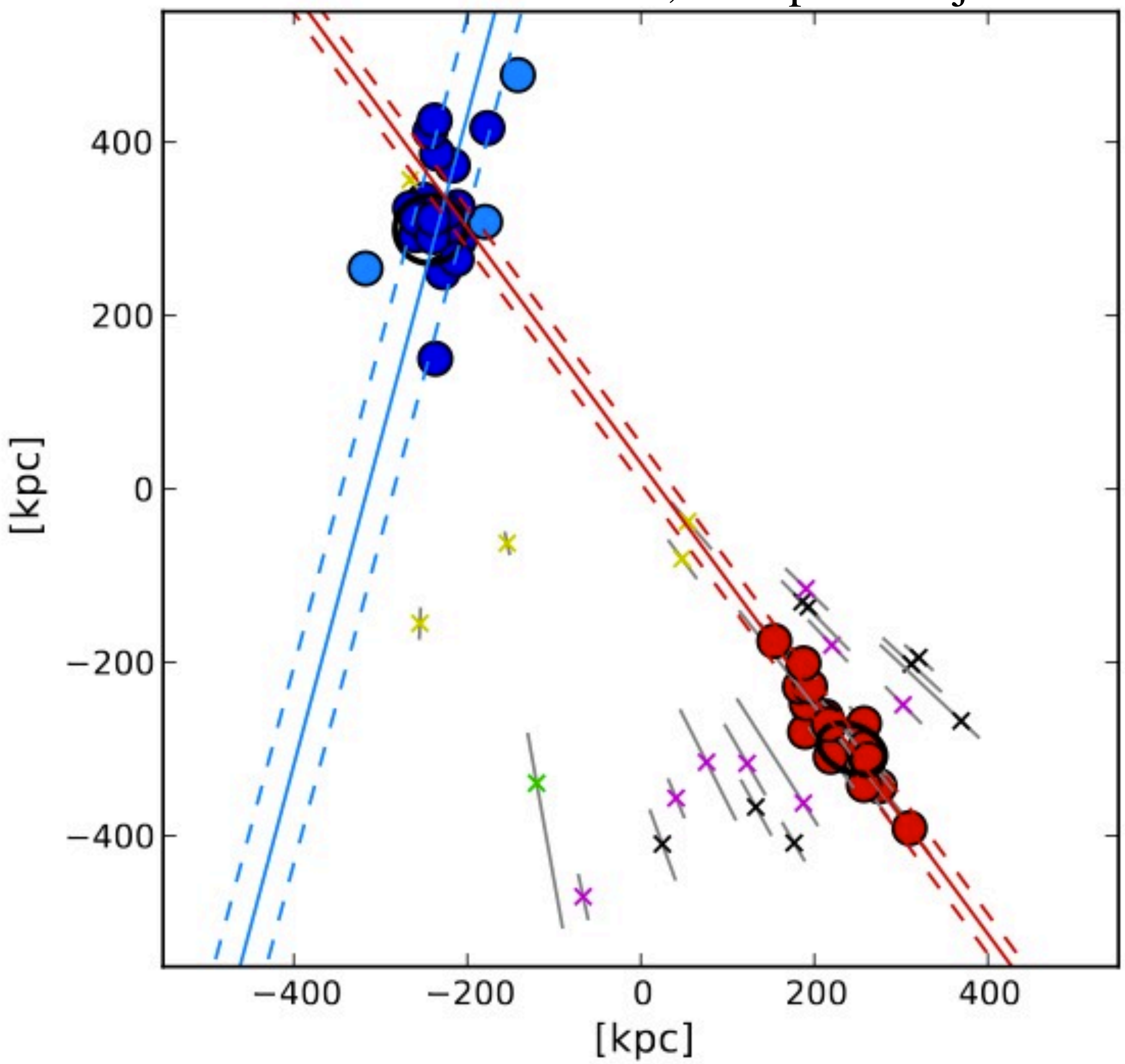
DOVE, Sawala et al., 2014



ELVIS, Garrison-Kimmel et al., 2014

Planes: preferred directions around the LG

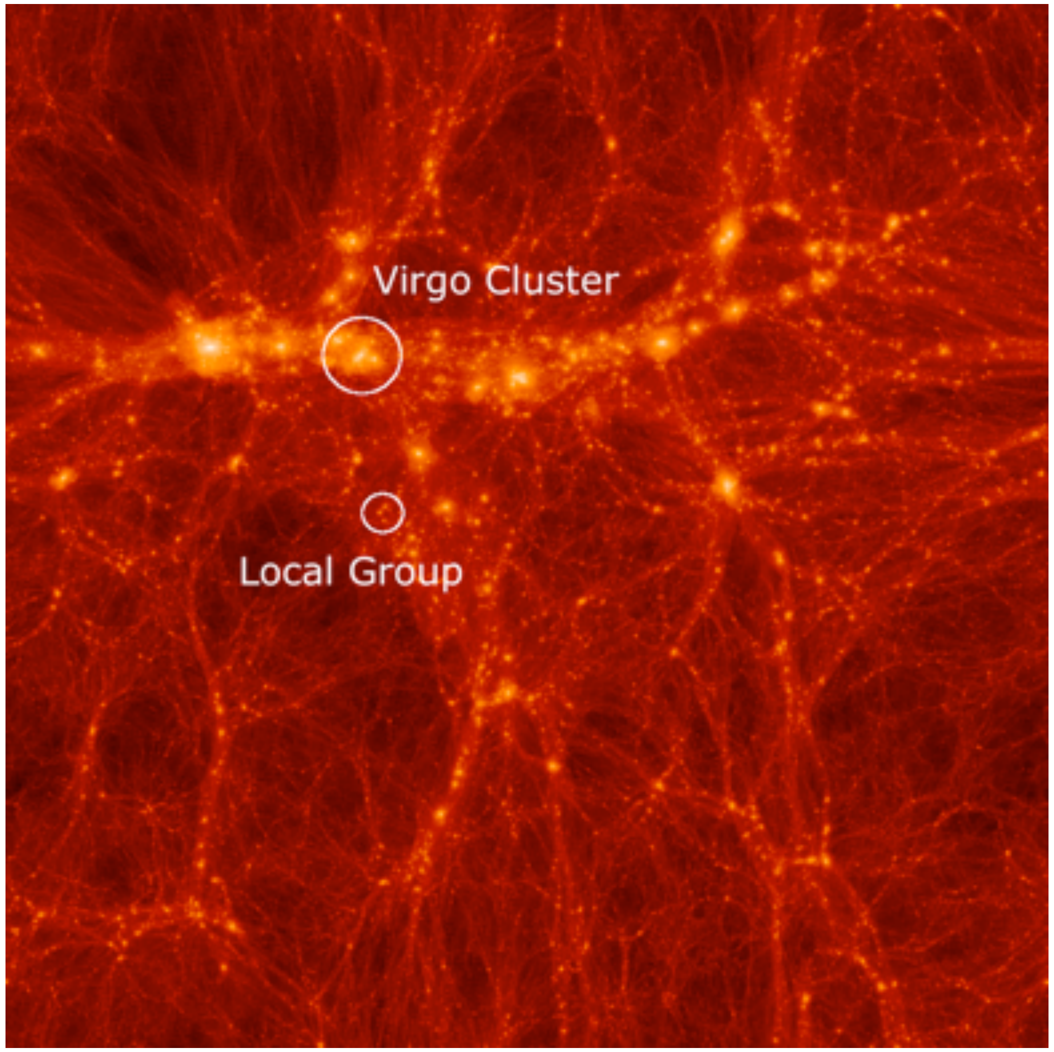
Pawlowski, Kroupa & Jerjen 2013



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

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

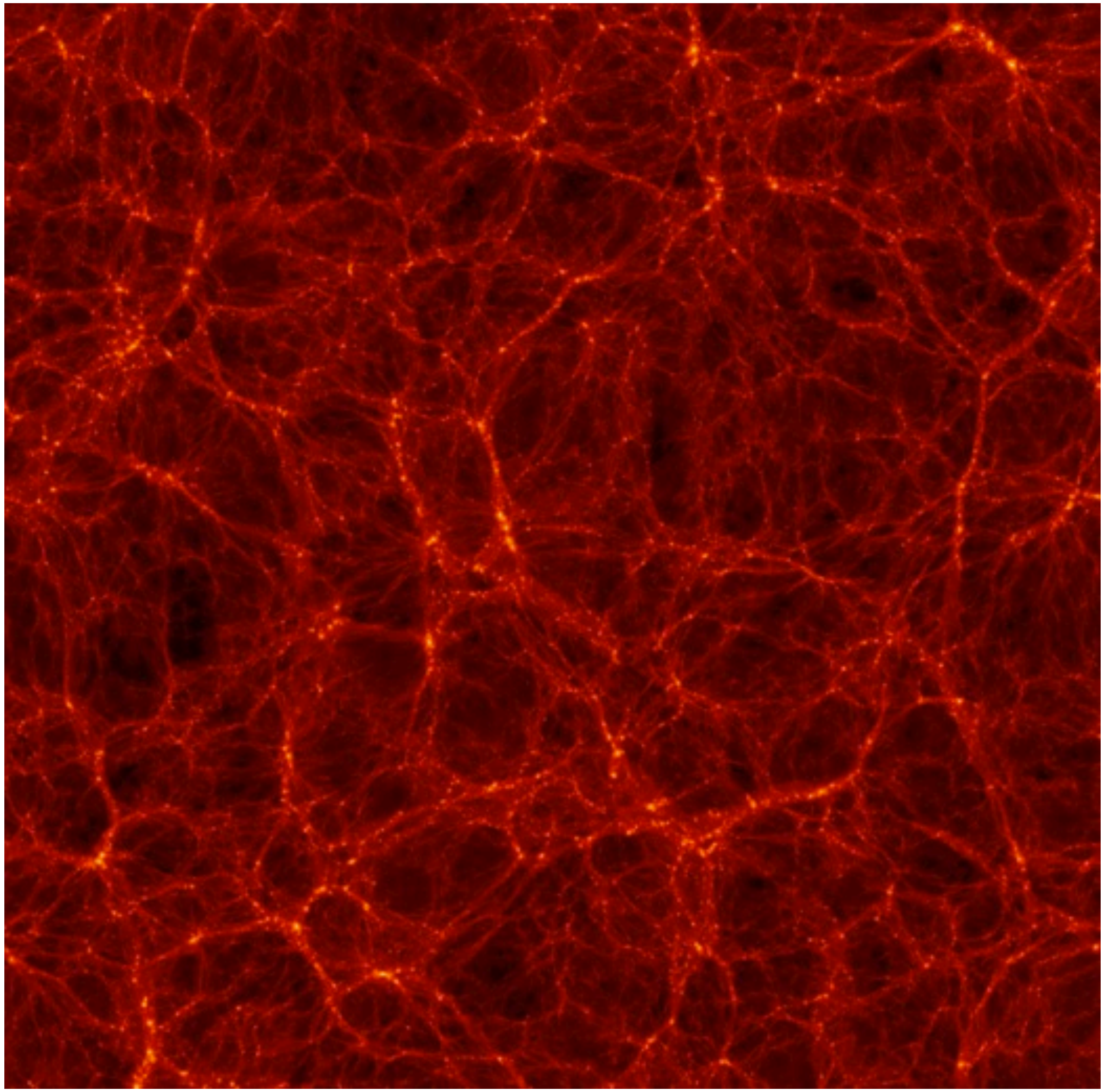
Constrained Local UniversE Simulations (CLUES) as a more sophisticated environment definition



Gottloeber, Hoffman, Yepes 1005.2687

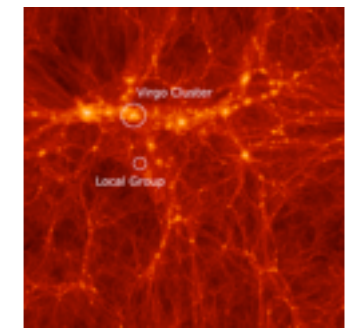
- See Stefan Gottlober's talk.
- Large Scales (5-7 Mpc) are fixed
- Small scales are random.
- 200 low resolution realizations until a LG is found: **found 3** .

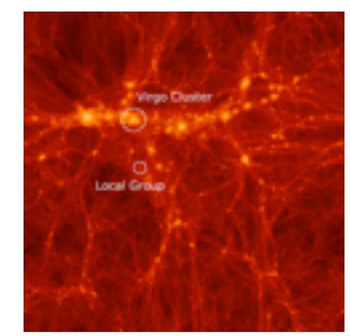
LG in constrained simulations are then compared against LGs in random realizations

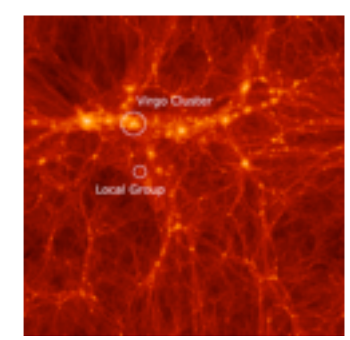


BOLSHOI (250 Mpc/h)

CLUES
(64 Mpc/h)





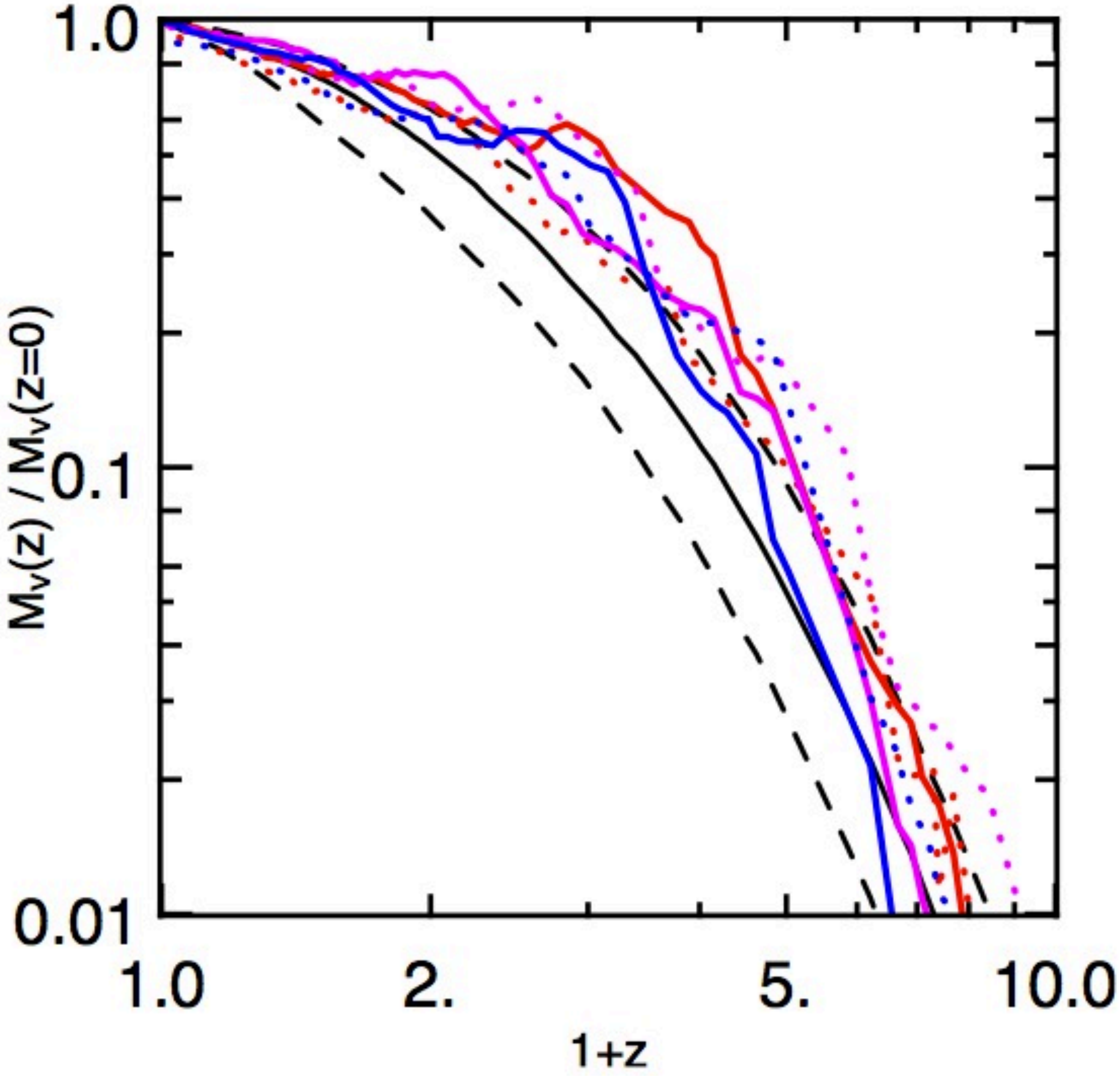


We consider 5 conditions to define a LG in a unconstrained simulation

5

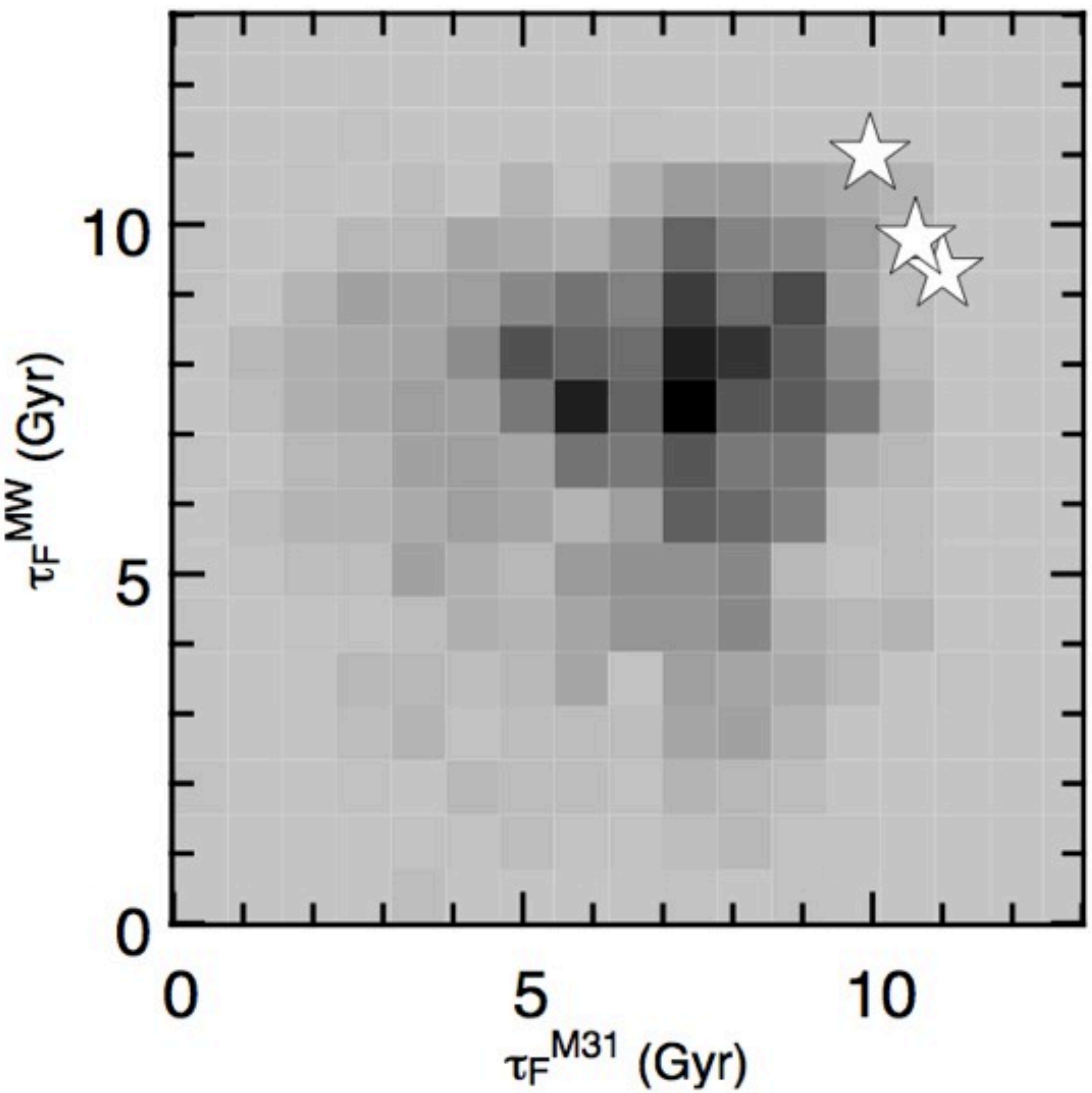
- Individual halo mass
- Halo separation
- Negative radial velocity
- Isolated (3Mpc)
- Isolated (7Mpc) (>5 10^{13} M_{sol})

LGs in the constrained simulations assemble earlier



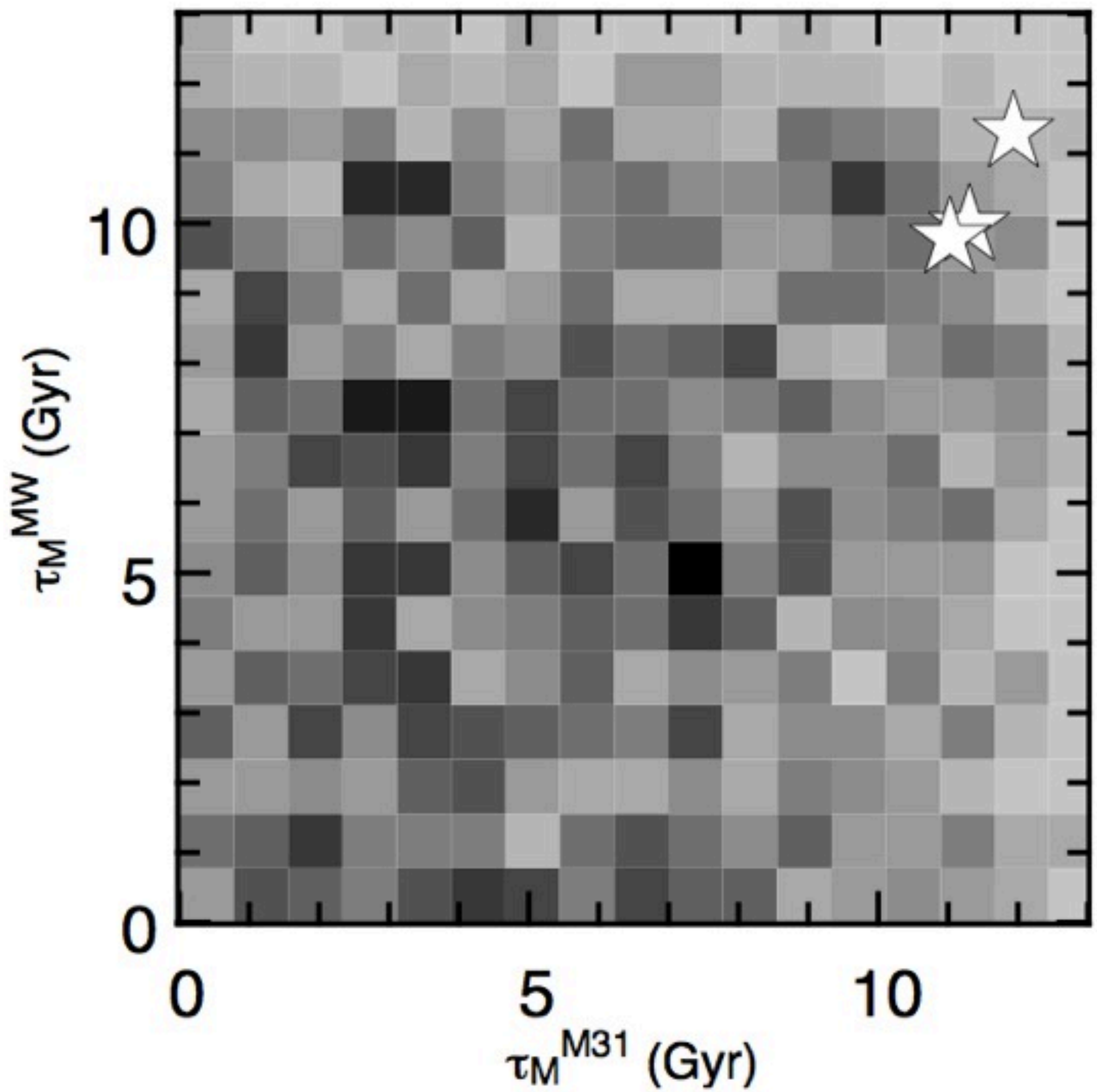
JEF-R, Hoffman, Yepes, Gottloeber, Piontek, Klypin, Steinmetz, MNRAS 2011, 1107.0017

LGs in the constrained simulations assemble earlier



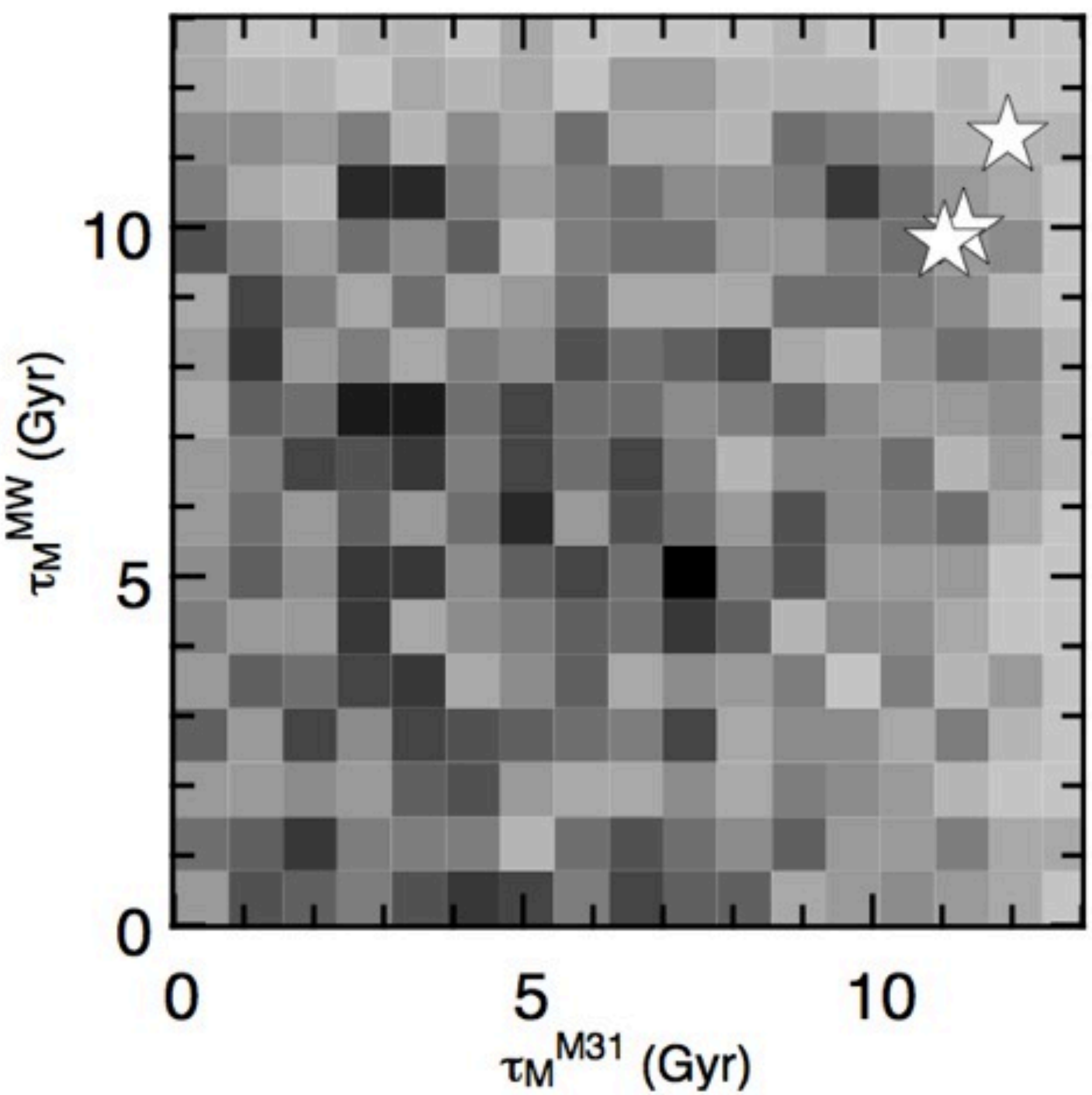
JEF-R, Hoffman, Yepes, Gottloeber, Piontek, Klypin, Steinmetz, MNRAS 2011, 1107.0017

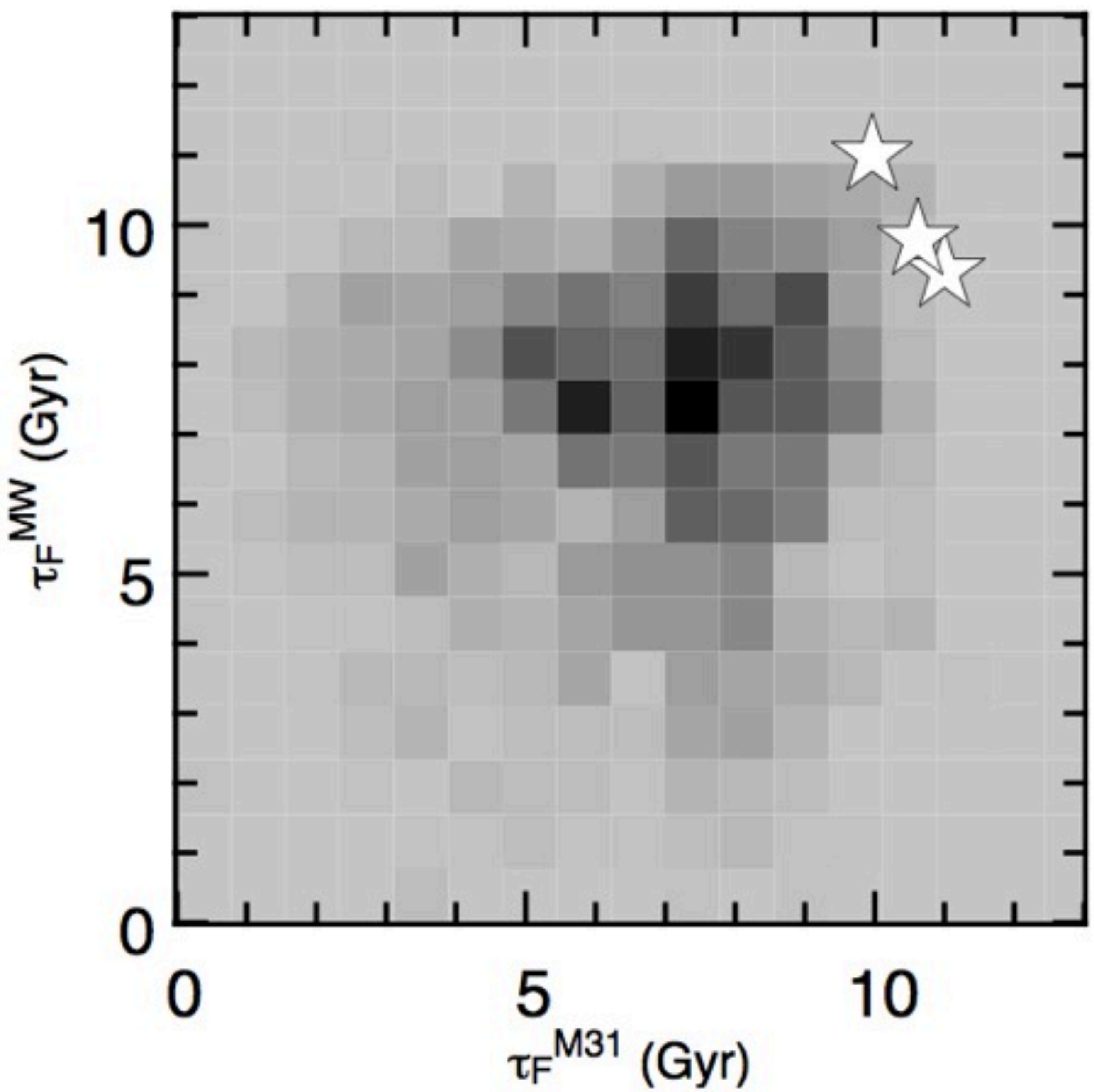
LGs in the constrained simulations live quietly



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

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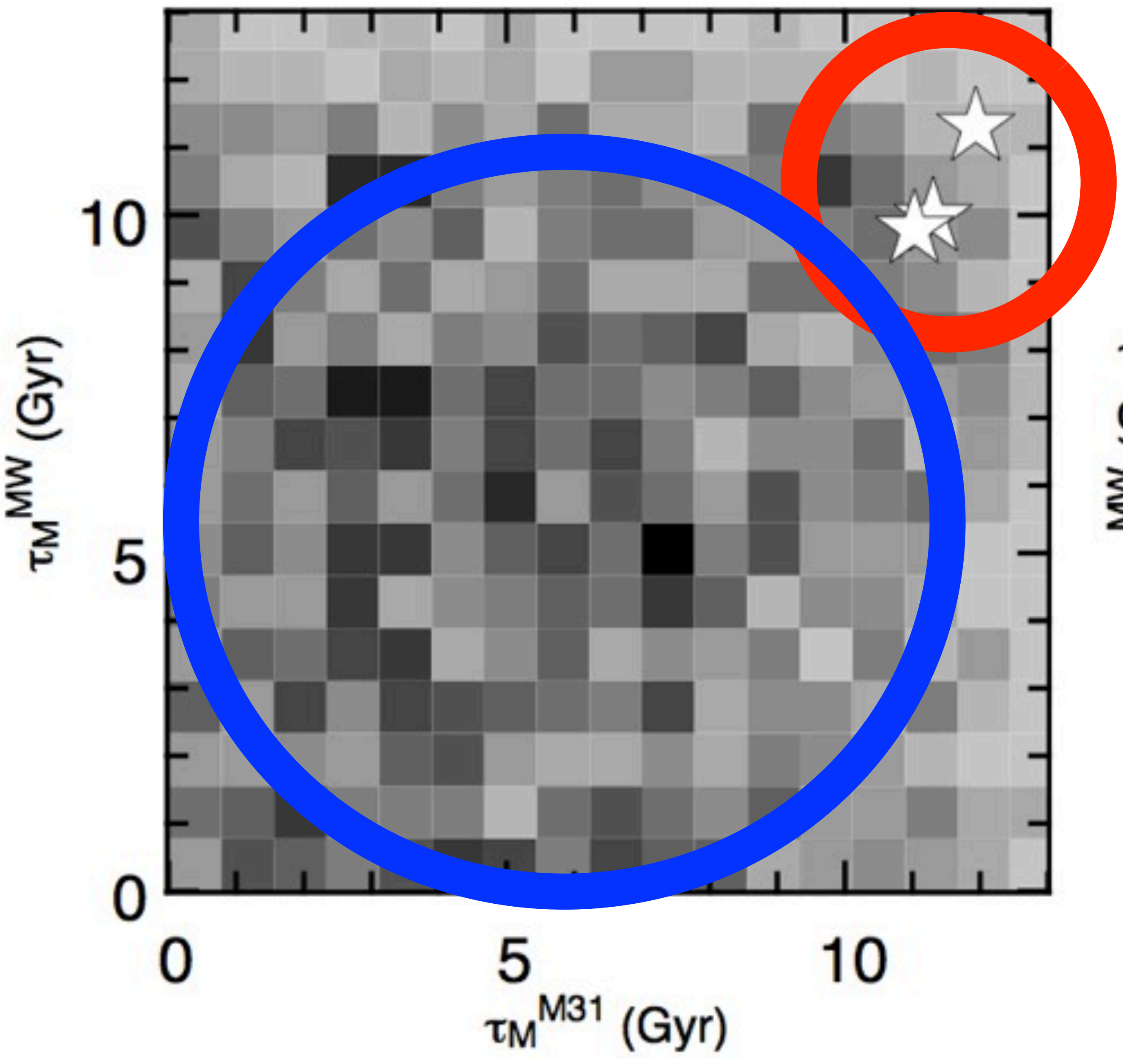
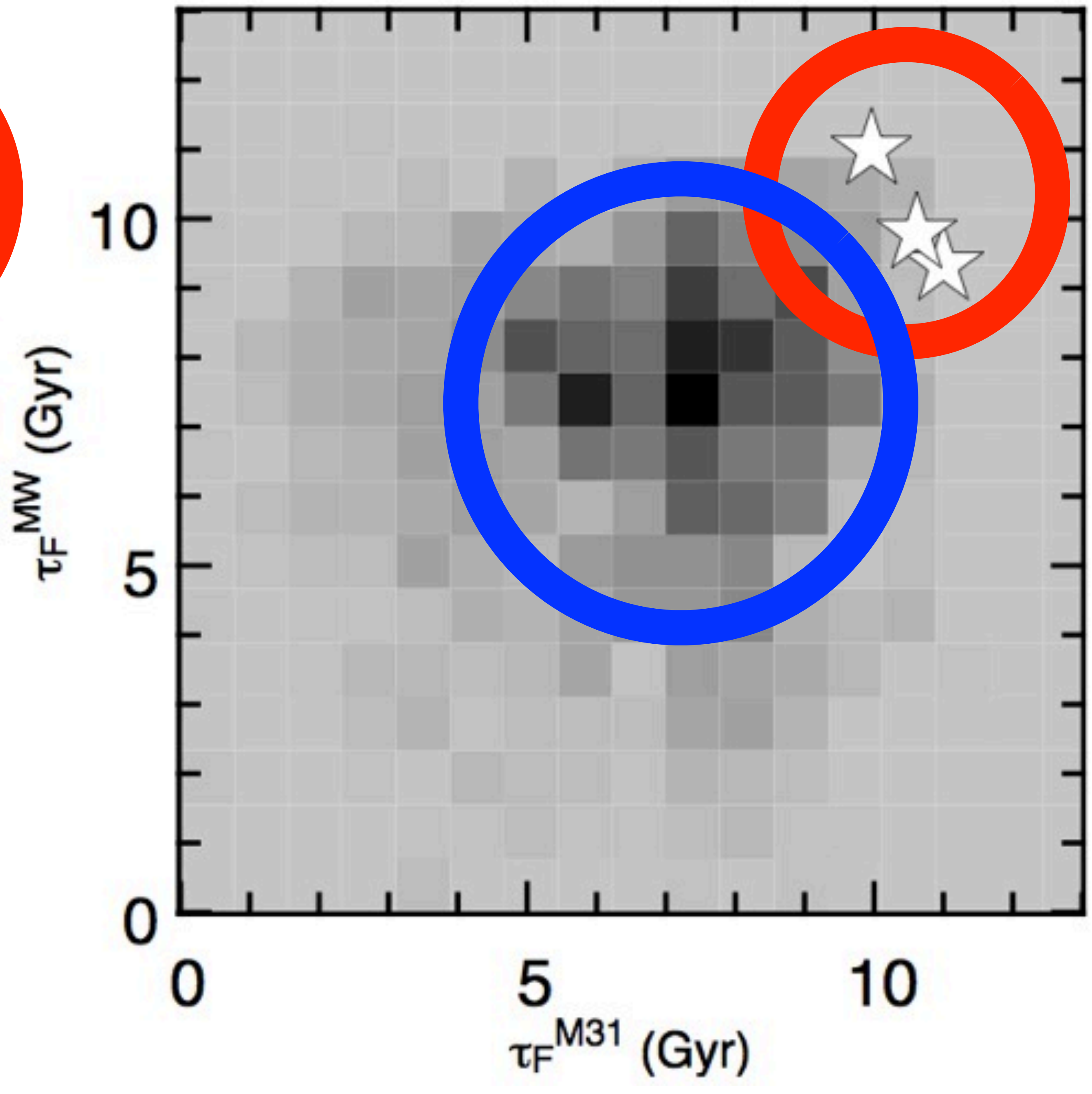




JEF-R, Hoffman, Yepes, Gottloeber, Piontek, Klypin, Steinmetz, MNRAS 2011, 1107.0017

Observation #1

Constraints on large scales (by construction)

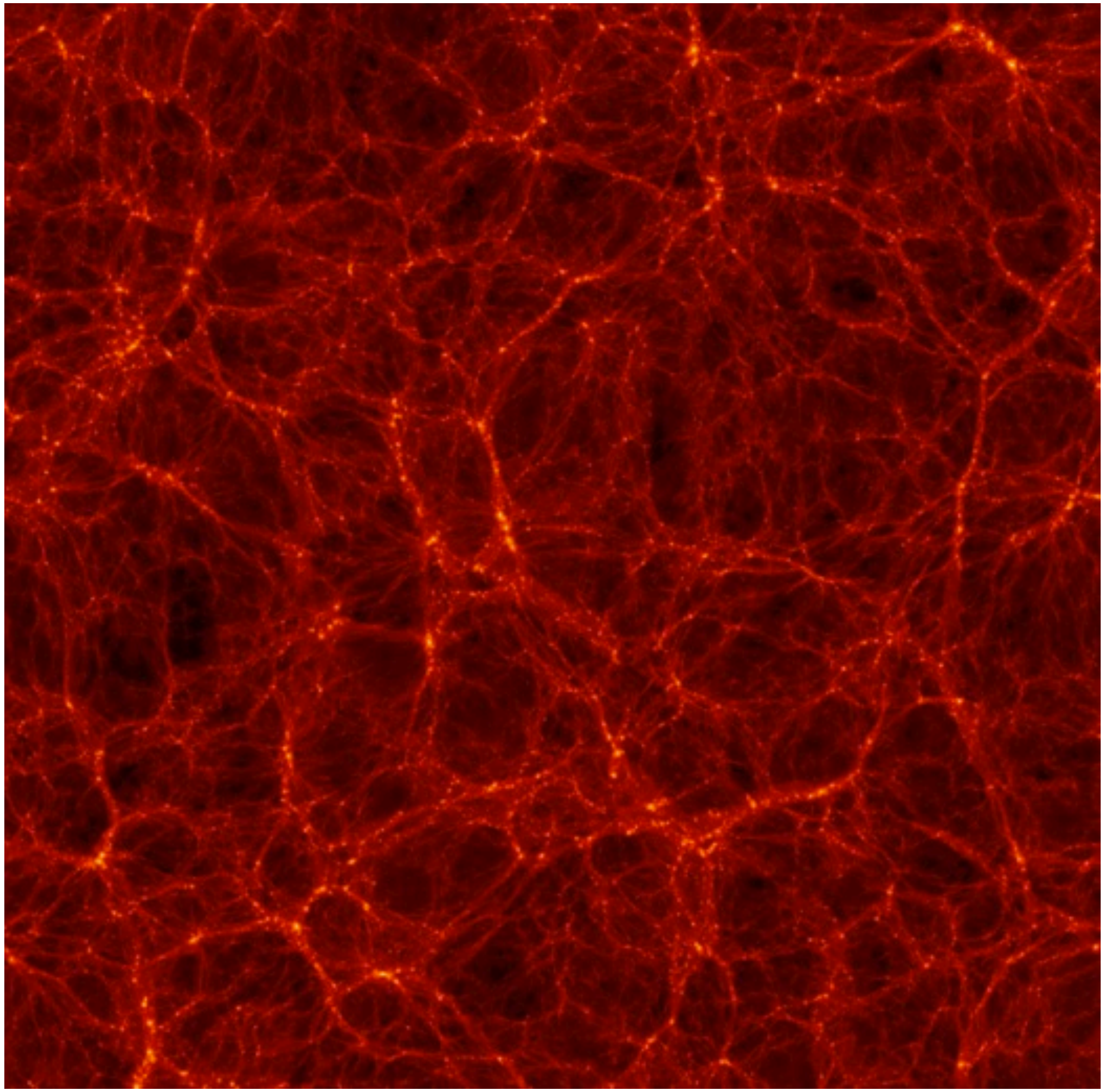
+

Constraints on meso scales (by selection)

=

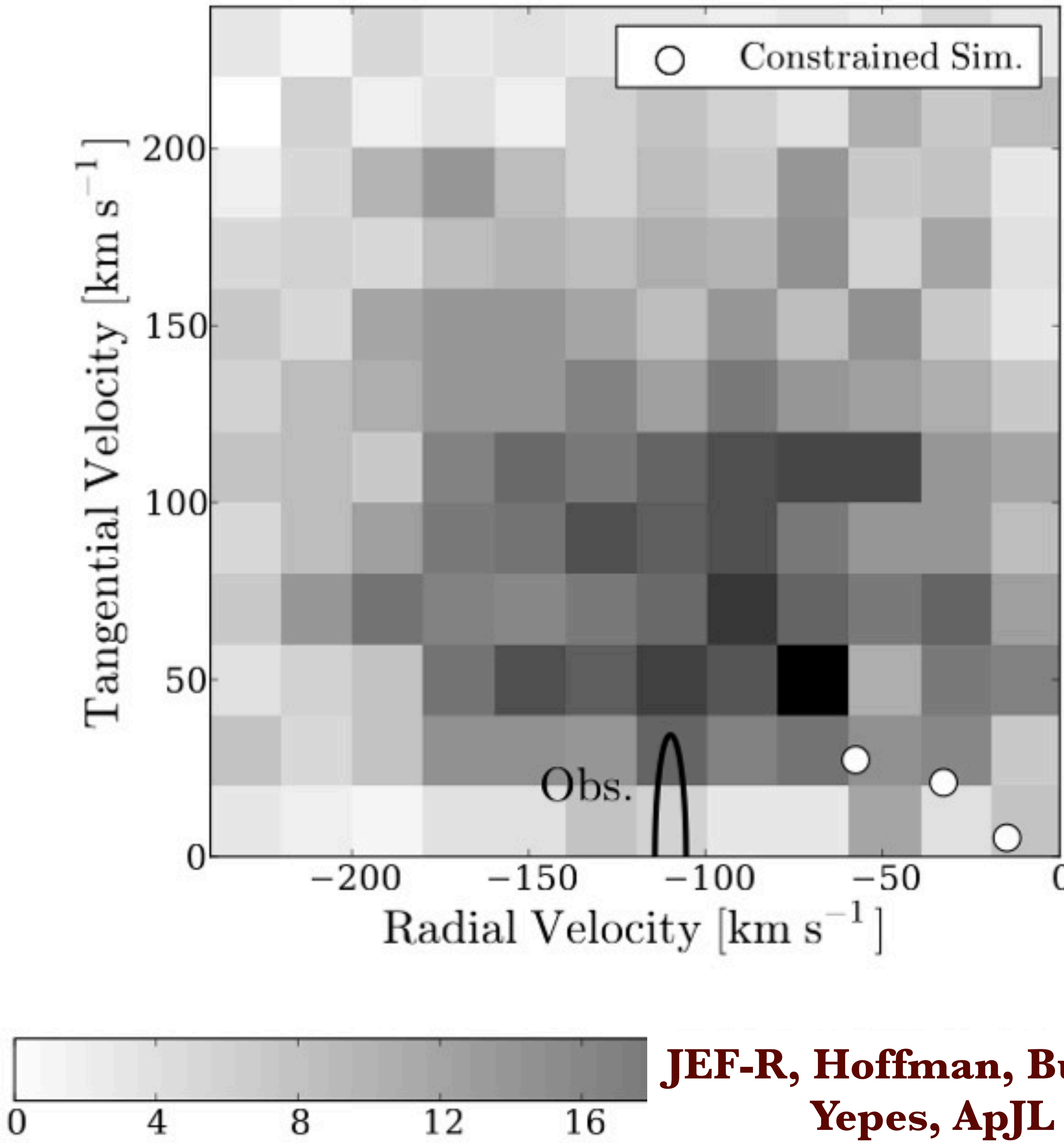
pairs with narrow formation properties

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-σ) (full sample)
$v_{\rm r}$-$v_{\rm t}$	(0.4%) 8/1923
$e_{\rm tot}$-$l_{\rm orb}$	(15%)298/1923
$\log_{10}\lambda$	(13%)257/1923
$r_{\rm t} = v_{\rm t}/v_{\rm r}$	(12%)242/1923

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

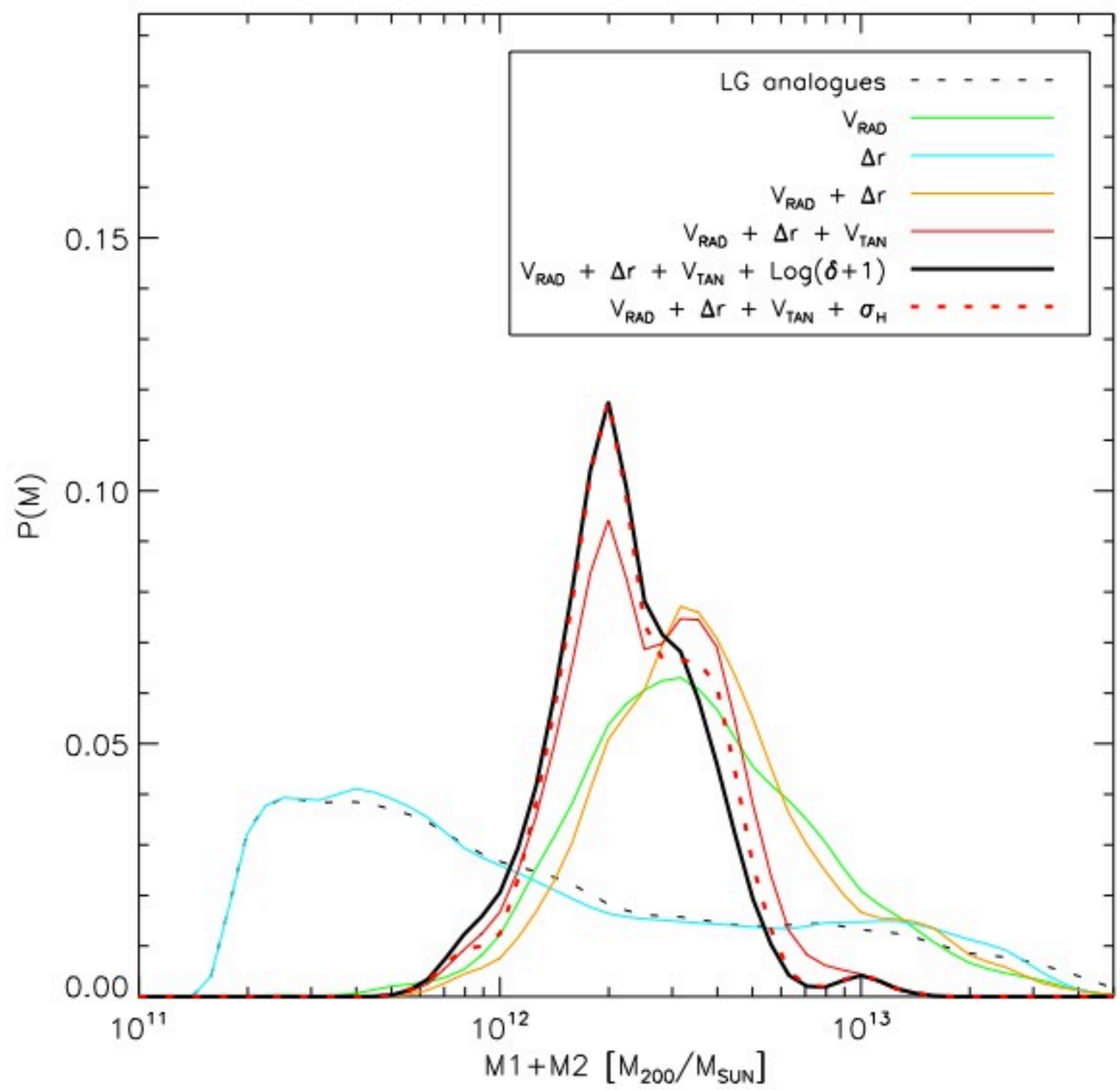
Larger samples can be constructed by looking back in time for the special kinematic configurations

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

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

Gonzalez, Kravtsov, Gnedin, ApJ 2014, 1312.2587

LG kinematics are equivalent to mass selection



Gonzalez, Kravtsov, Gnedin, ApJ 2014, 1312.2587

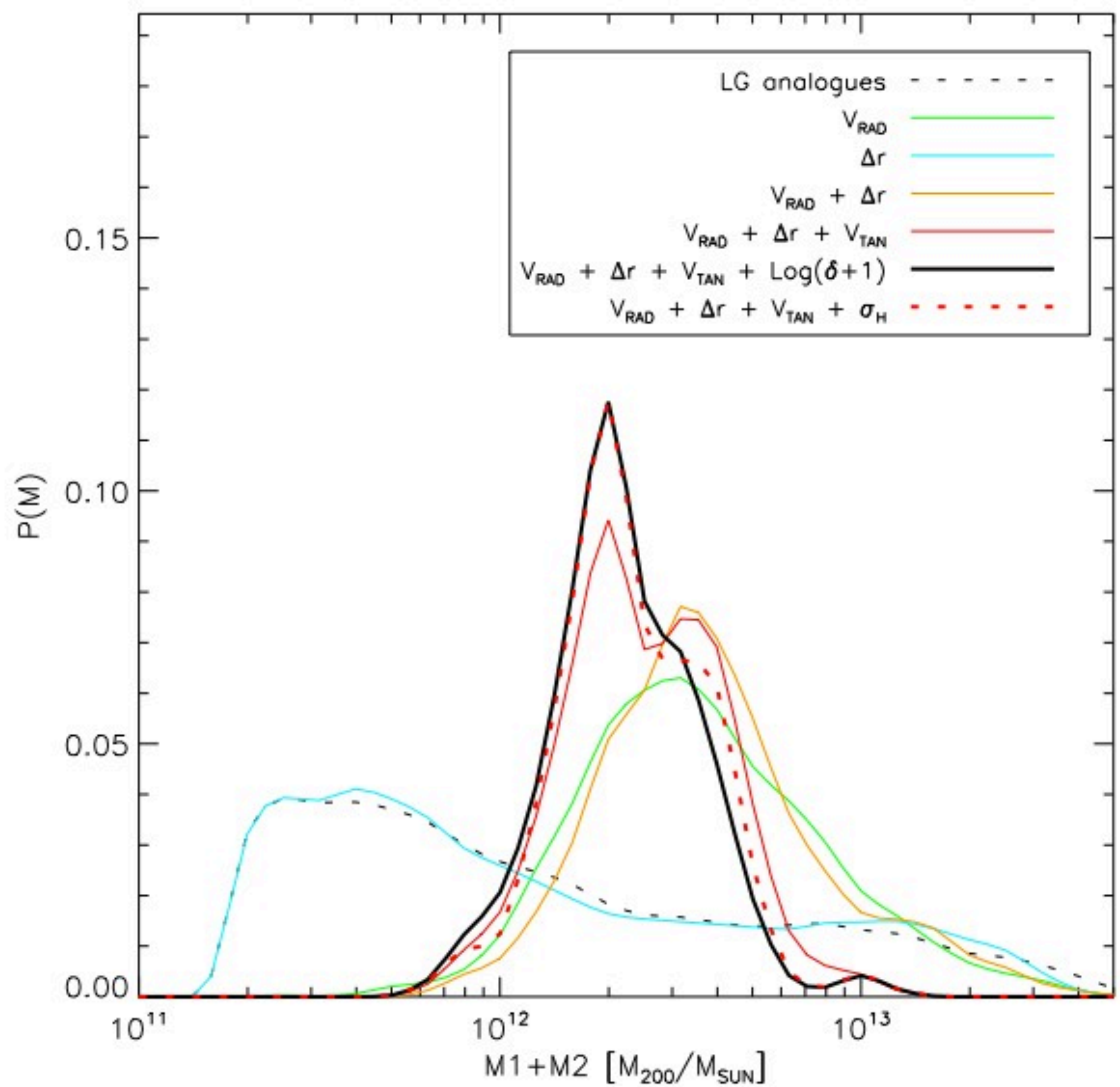
Observation #2

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.

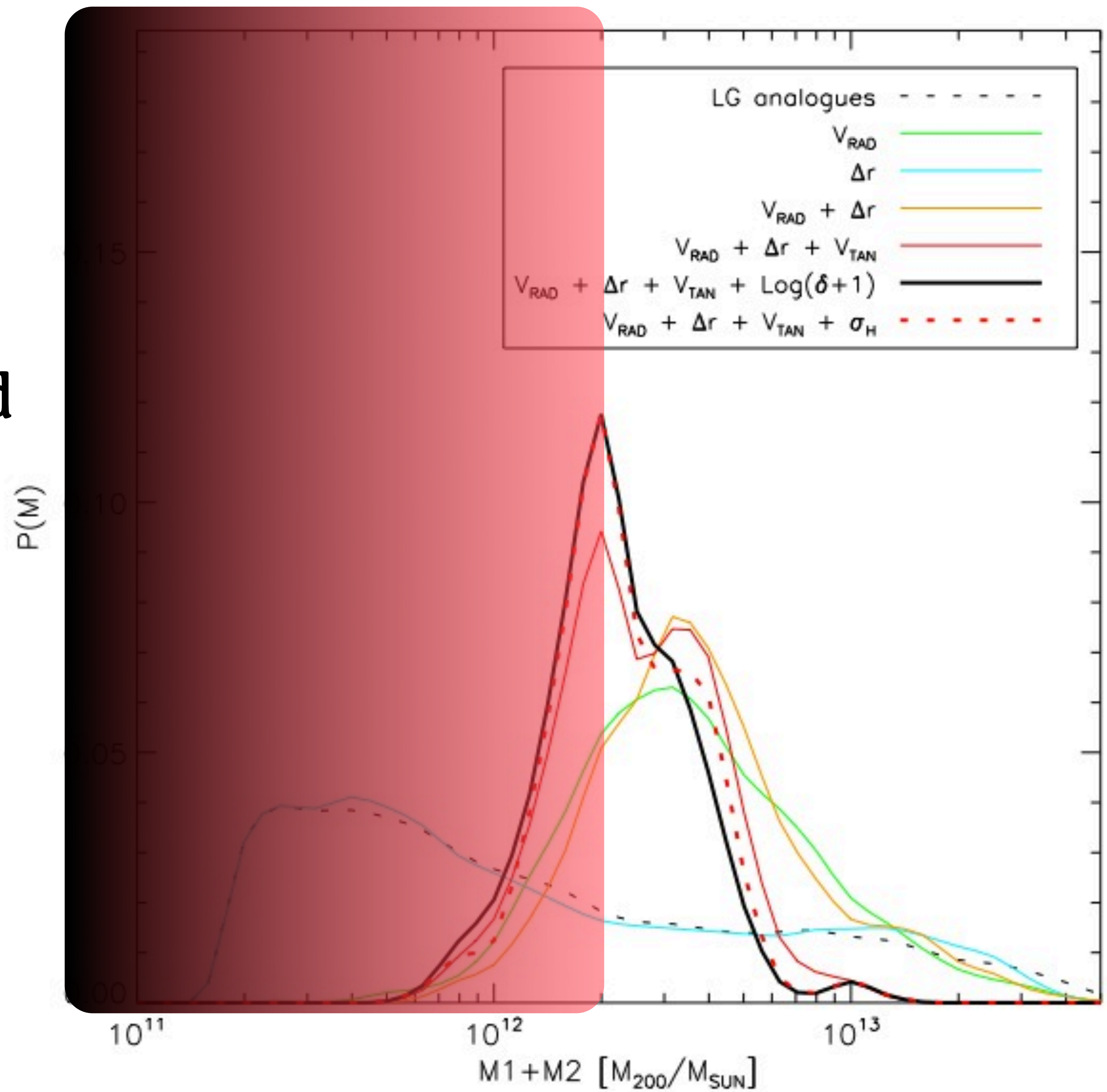
LG kinematics is equivalent to mass selection



Gonzalez, Kravtsov, Gnedin, ApJ 2014, 1312.2587

LG kinematics is equivalent to mass selection

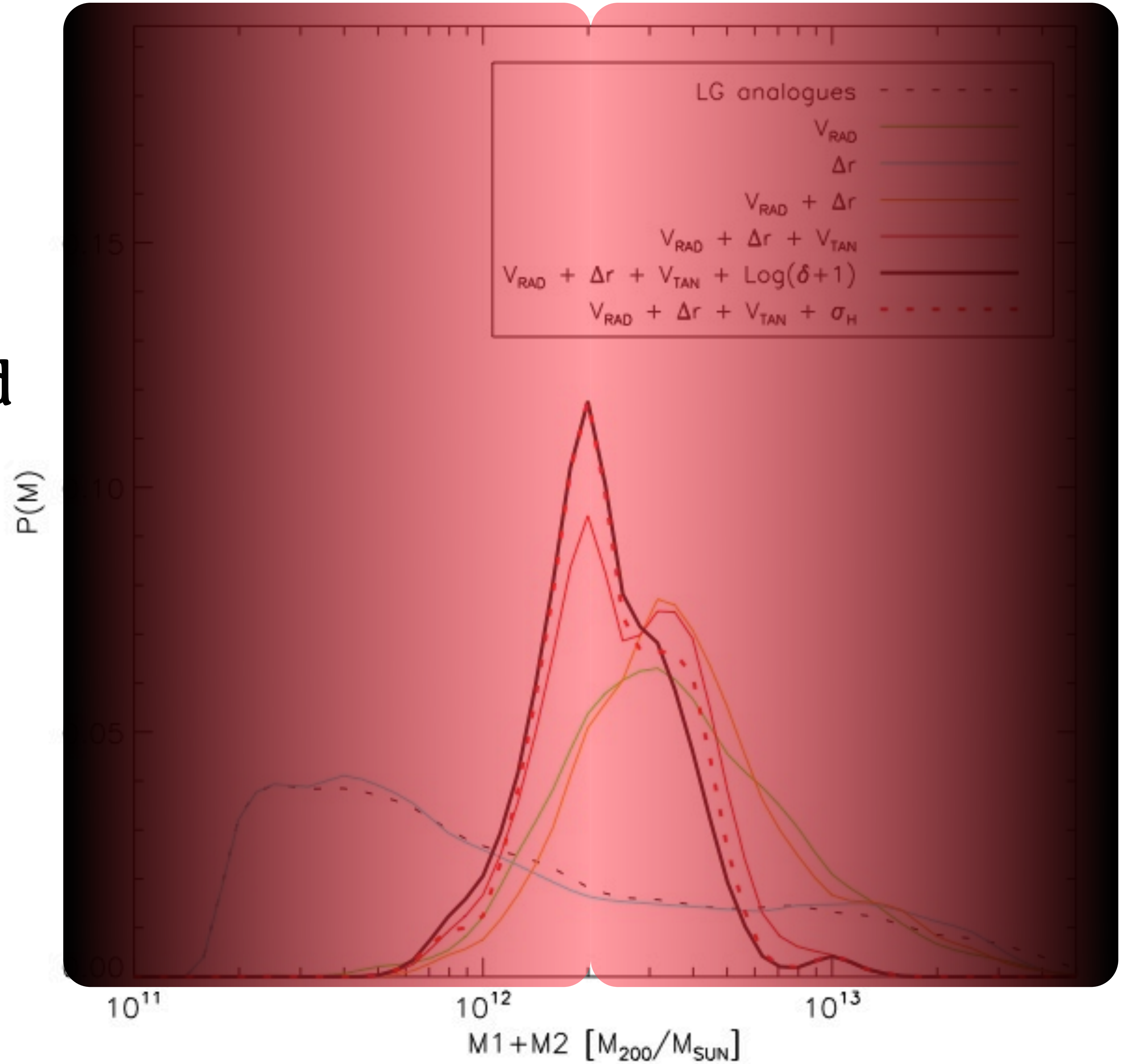
Disfavored
by high
radial
velocities



Gonzalez, Kravtsov, Gnedin, ApJ 2014, 1312.2587

LG kinematics is equivalent to mass selection

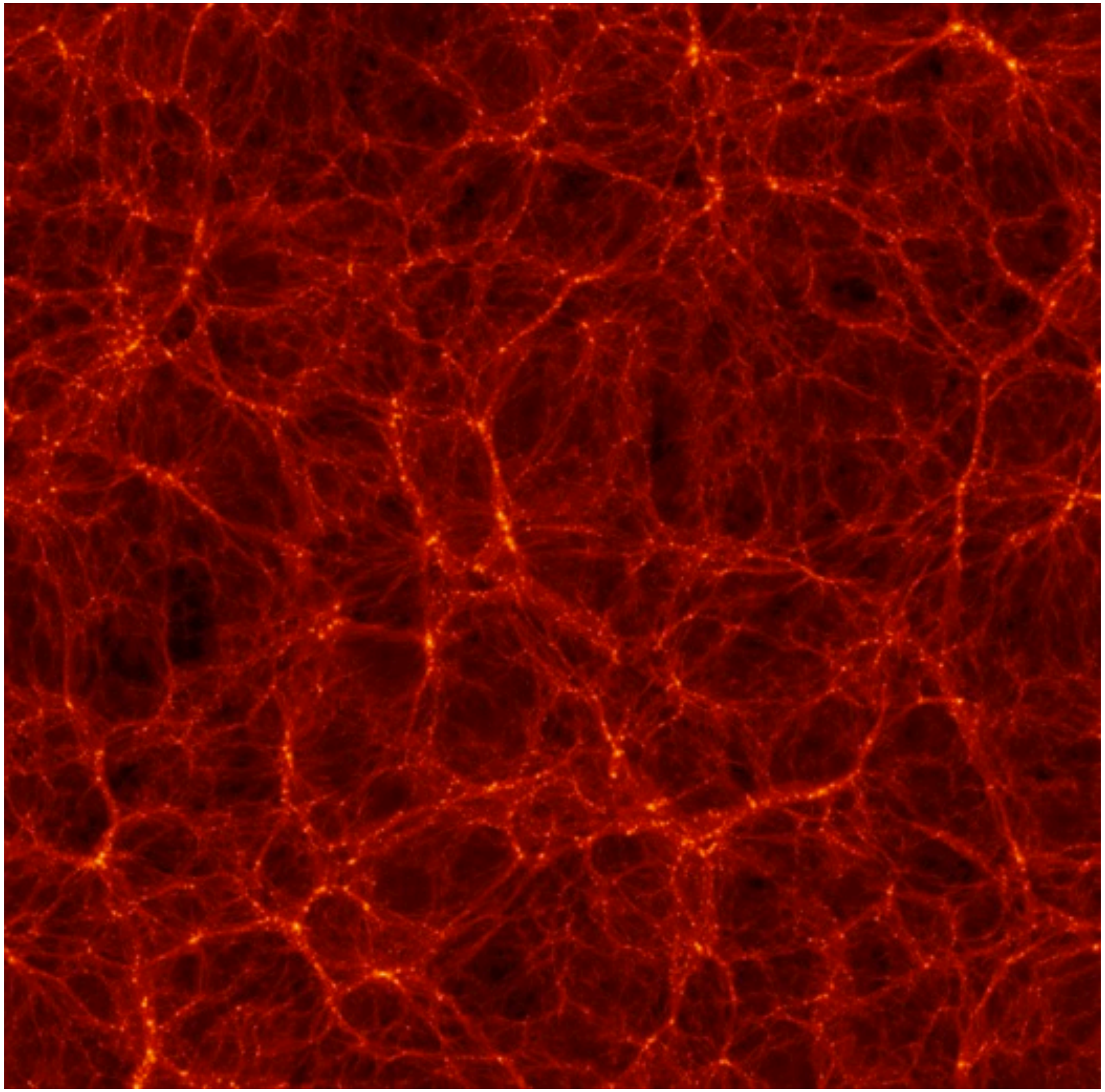
Disfavored by high radial velocities



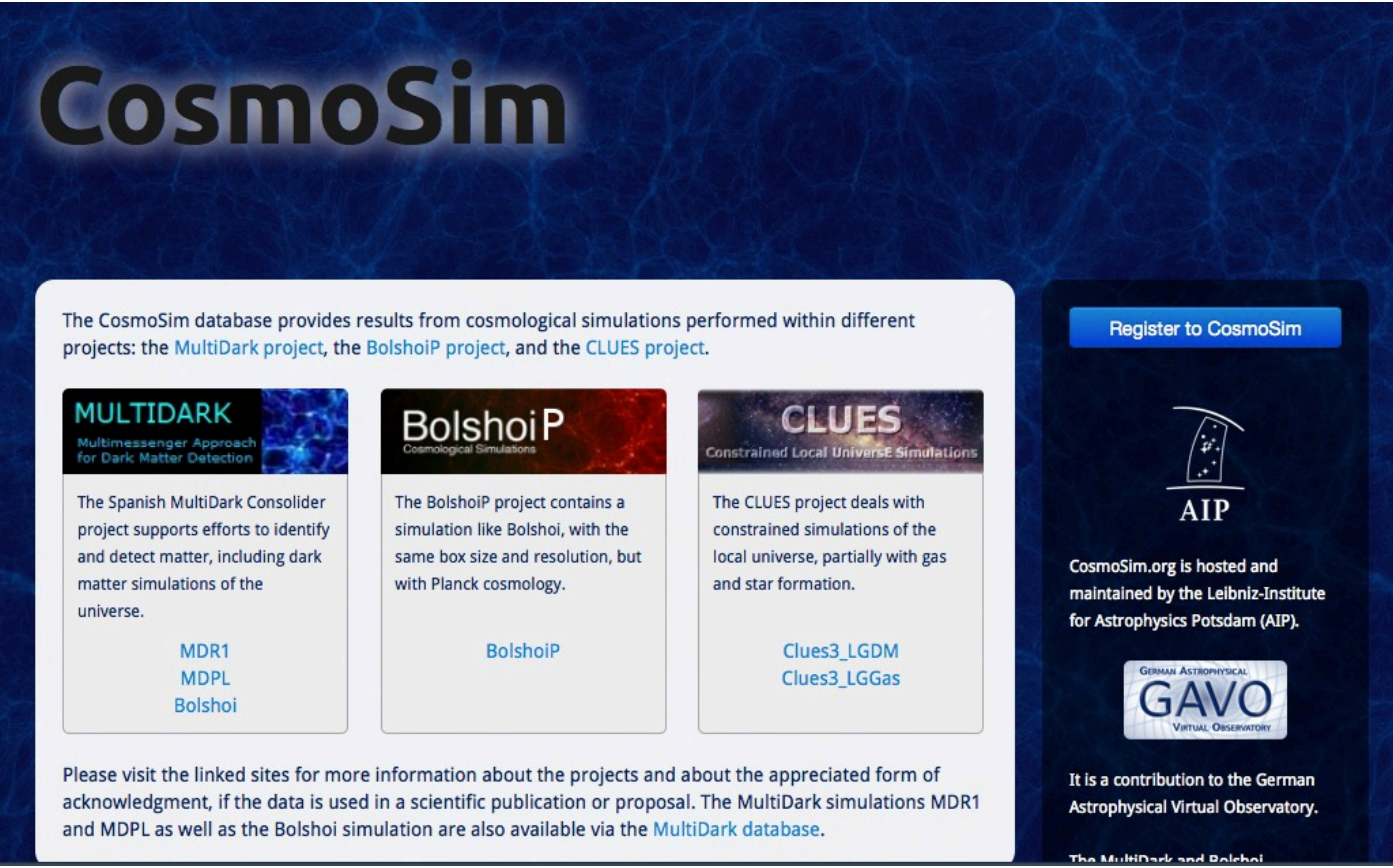
Disfavored by low tangential velocities

Gonzalez, Kravtsov, Gnedin, ApJ 2014, 1312.2587

Use Bolshoi to study in detail the environment of LG pairs

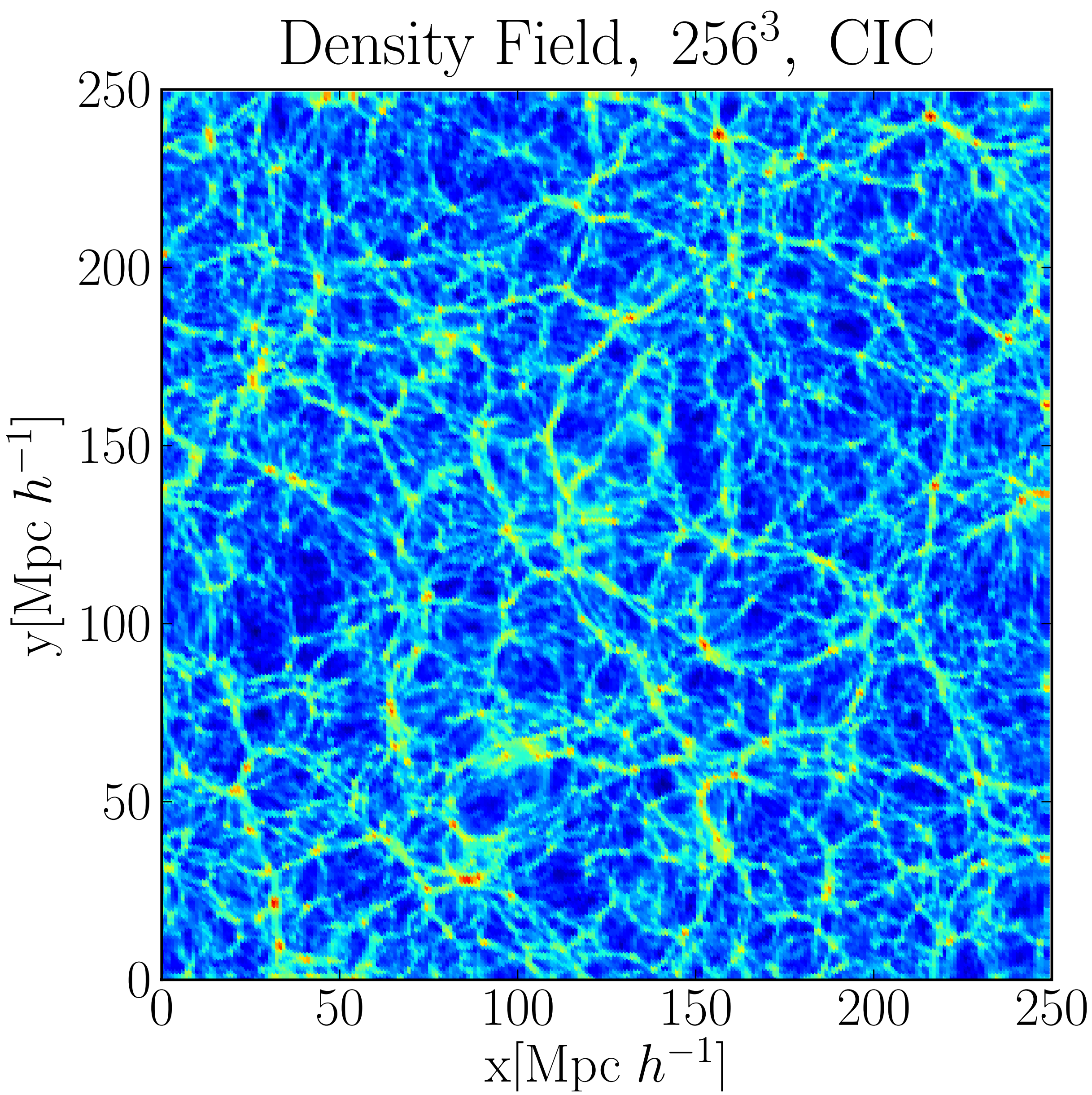


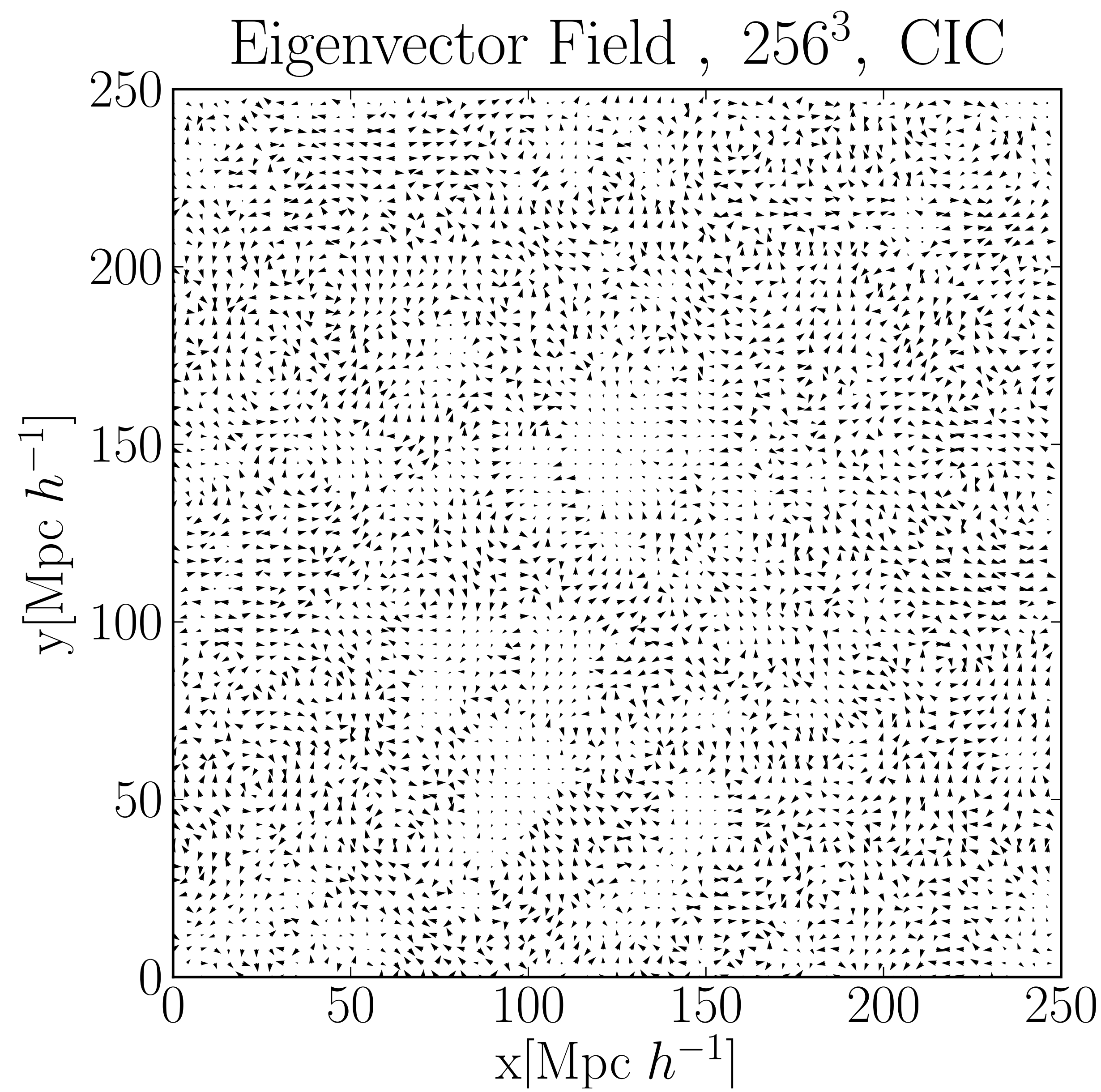
Data publicly available



Environment is defined from the tidal tensor

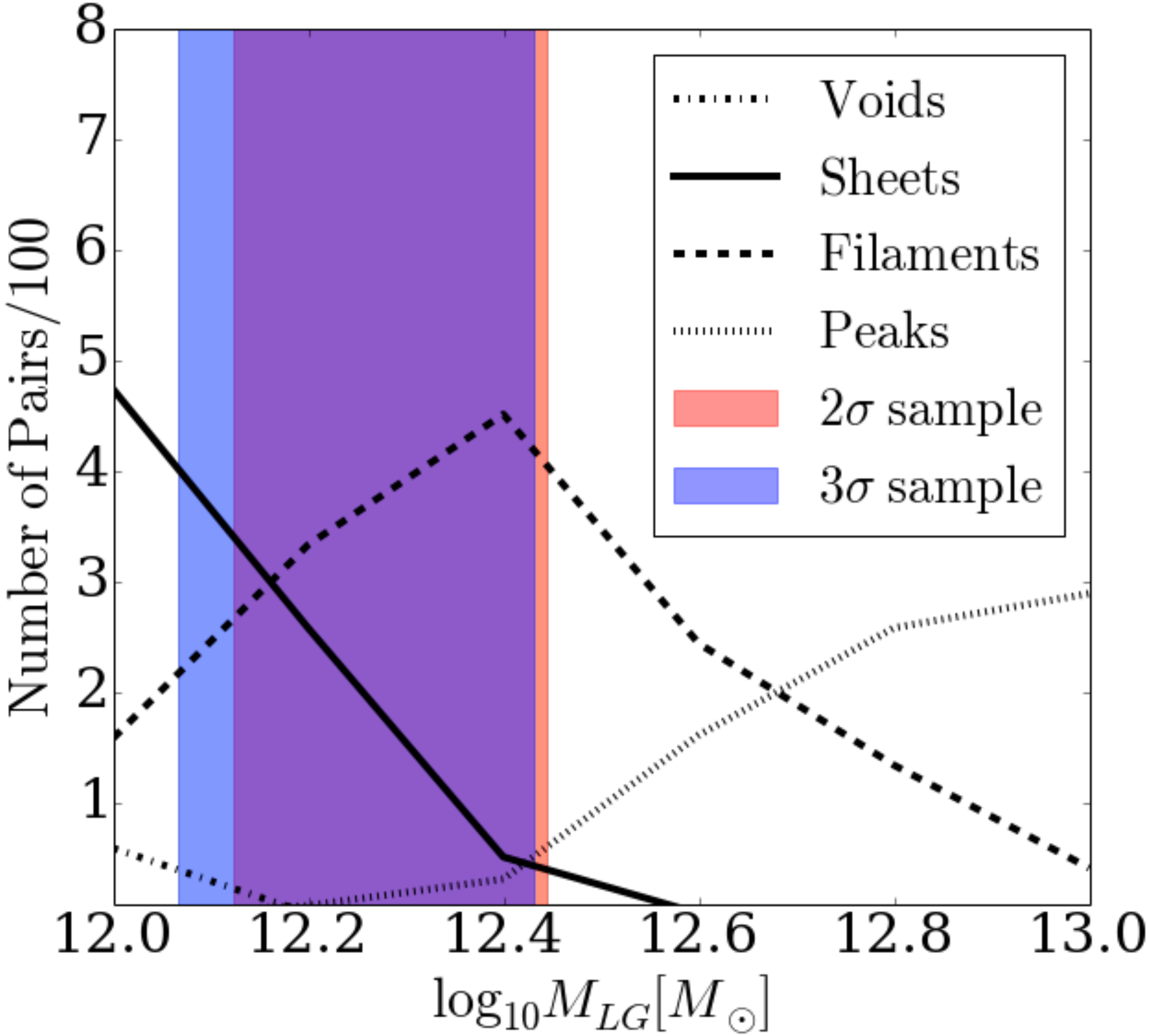
$$T_{ij} = \frac{\partial^2 \phi}{\partial r_i \partial r_j} \qquad \delta = \lambda_1 + \lambda_2 + \lambda_3 \qquad e = \frac{\lambda_3 - \lambda_1}{2(\lambda_1 + \lambda_2 + \lambda_3)}$$





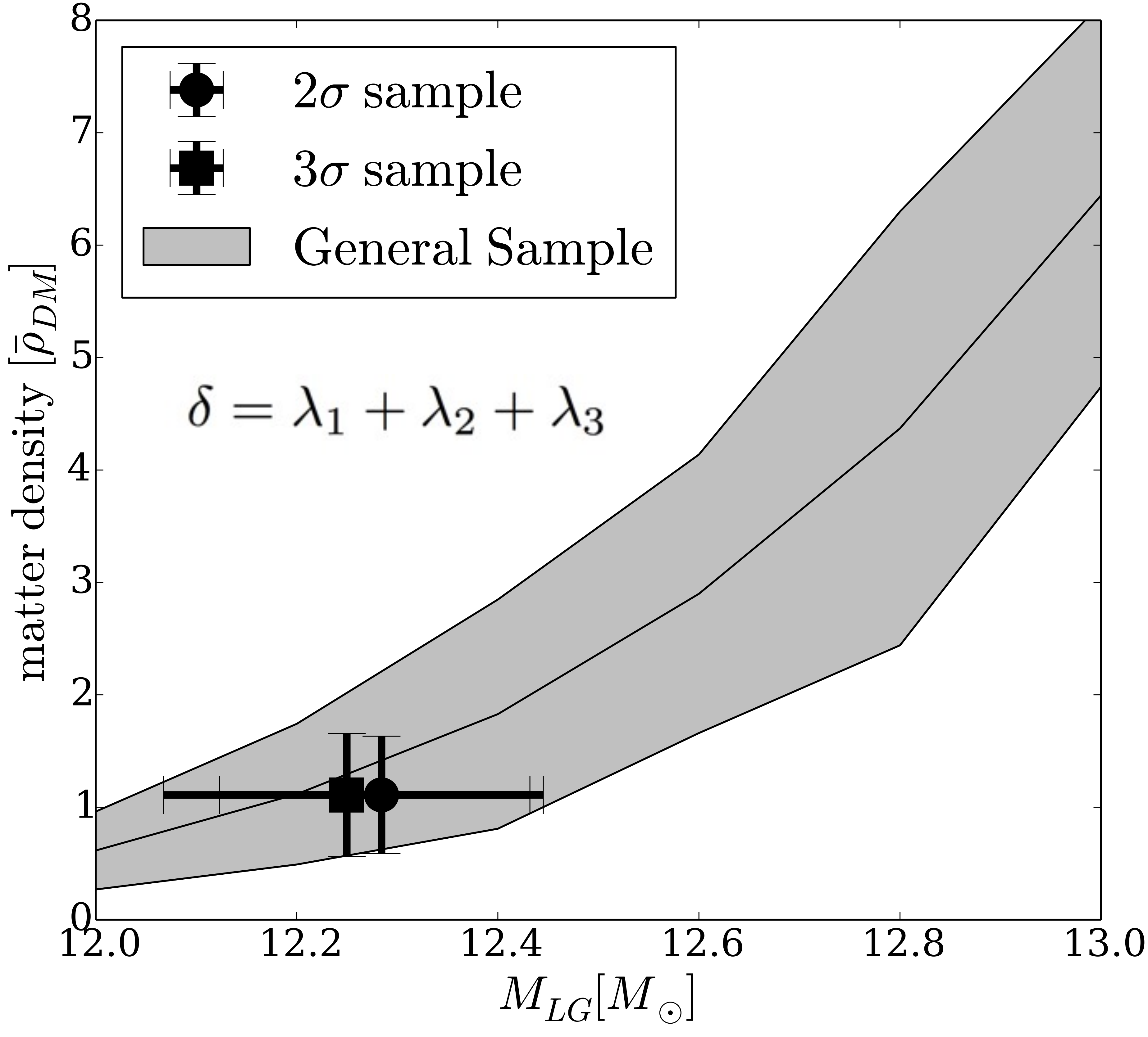
defined over a grid of 1Mpc/h + 1Mpc/h gaussian smoothing

LG mass selects the environment



JEF-R & Gonzalez, ApJ submitted, 1408.3166

LG mass selects the environment



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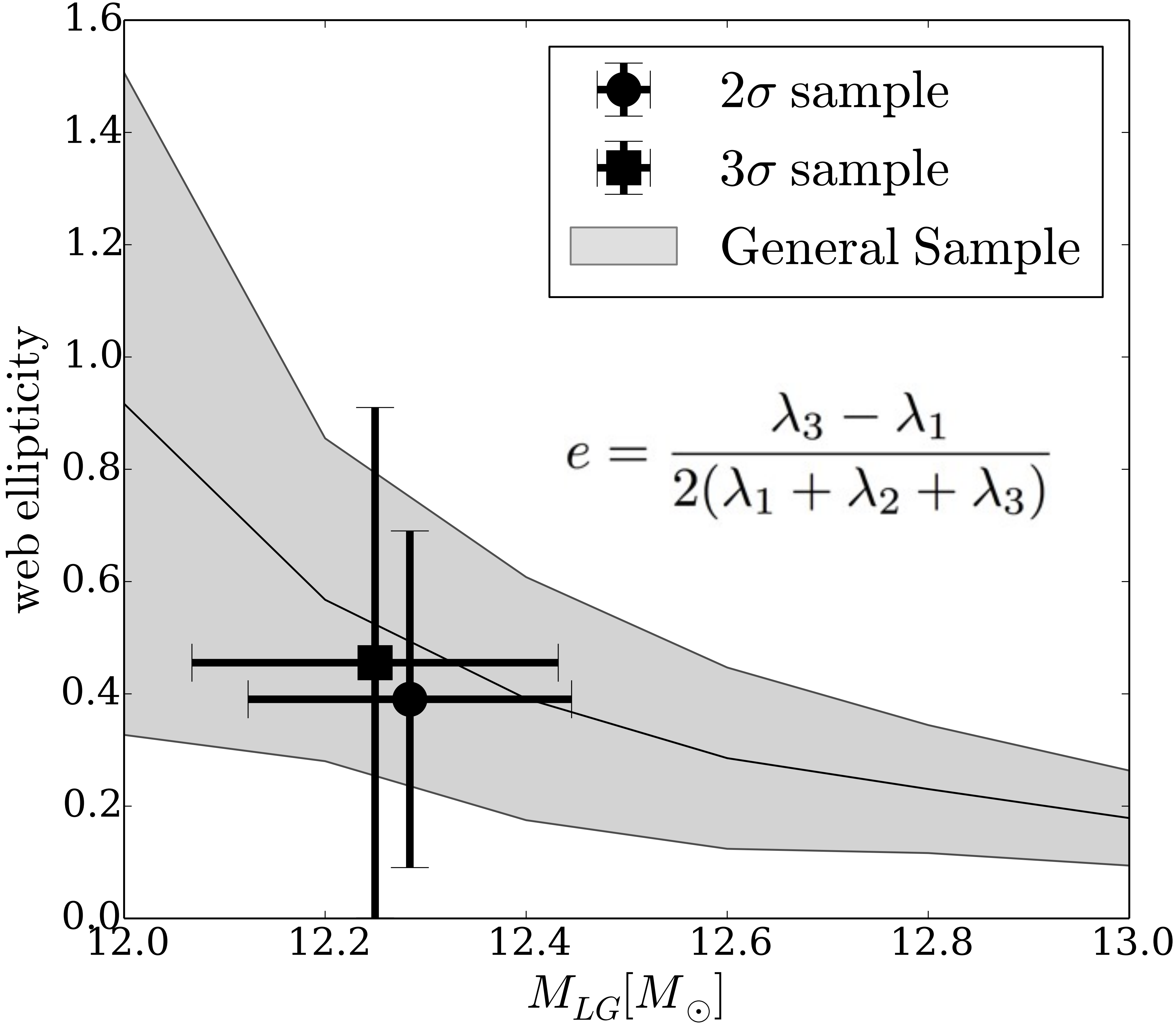
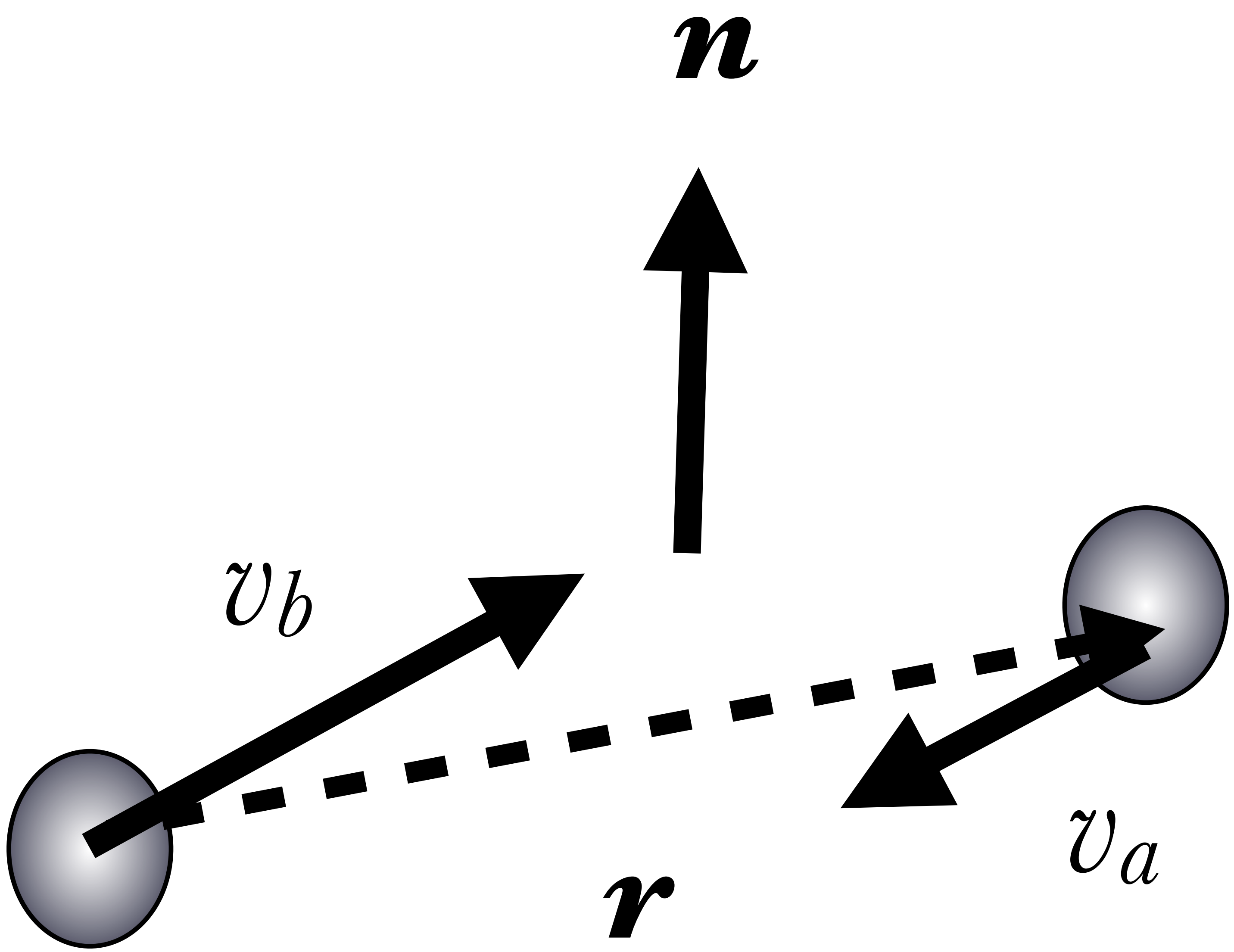


JEF-R & Gonzalez, ApJ submitted, 1408.3166

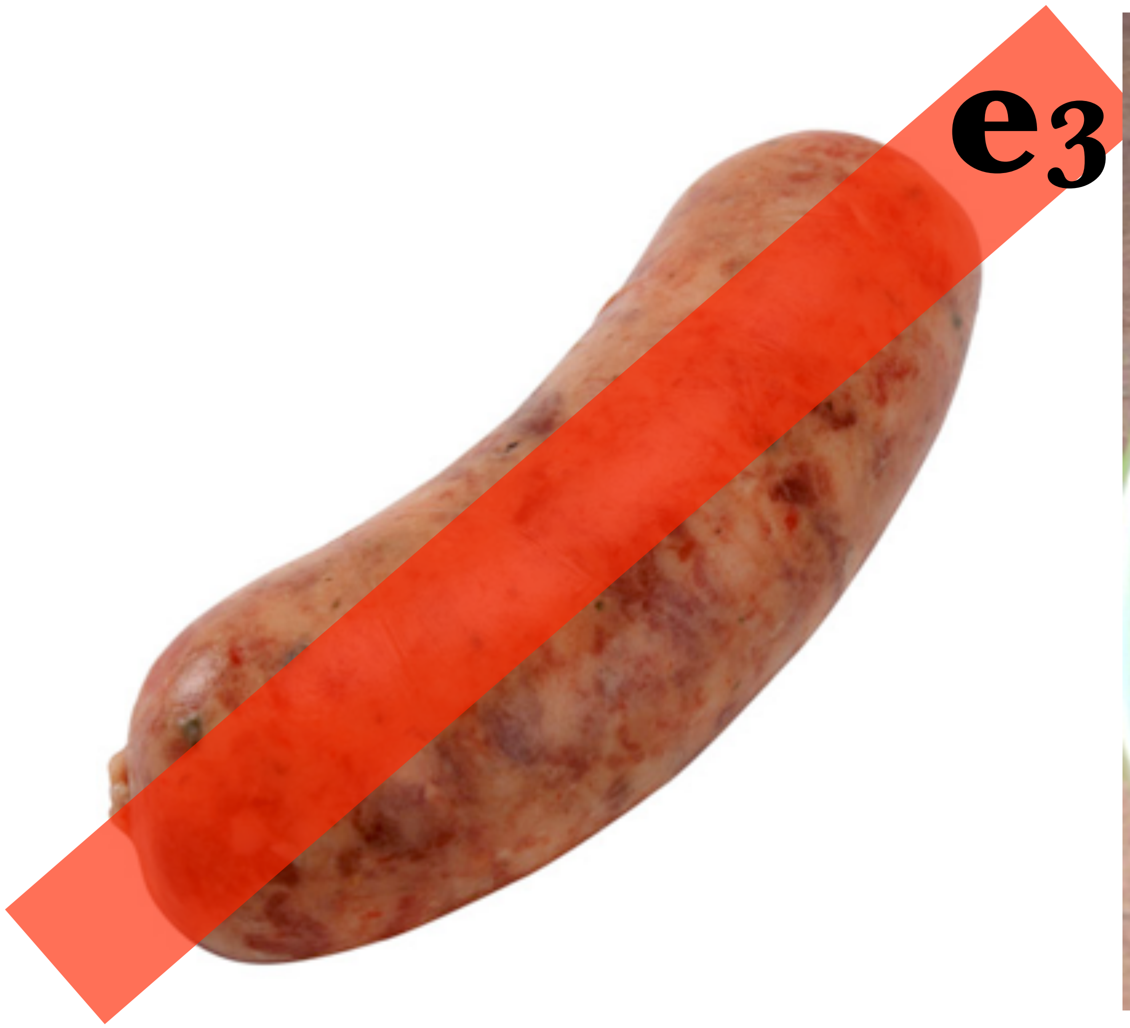
We look for alignments with the cosmic web

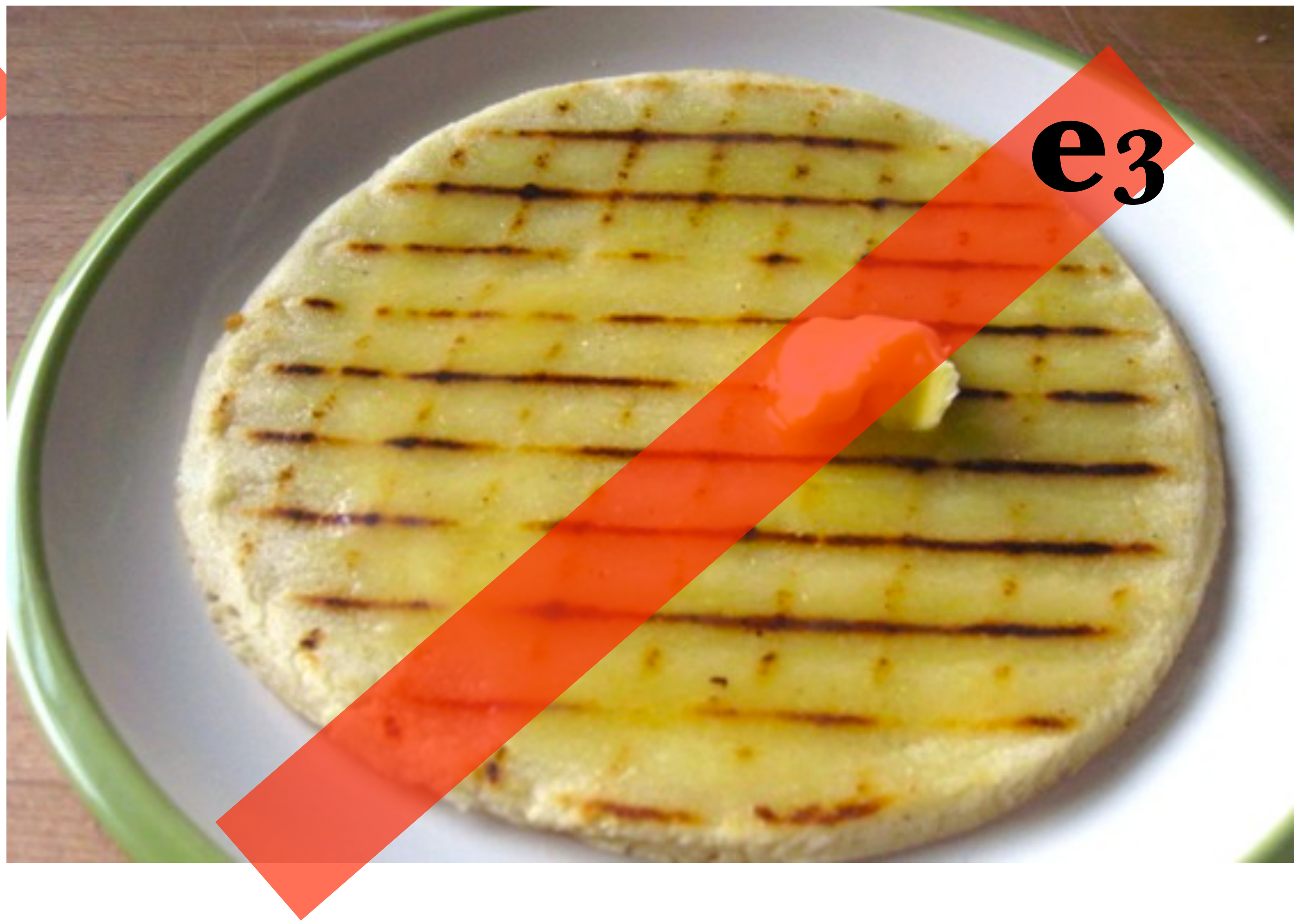


CM Frame

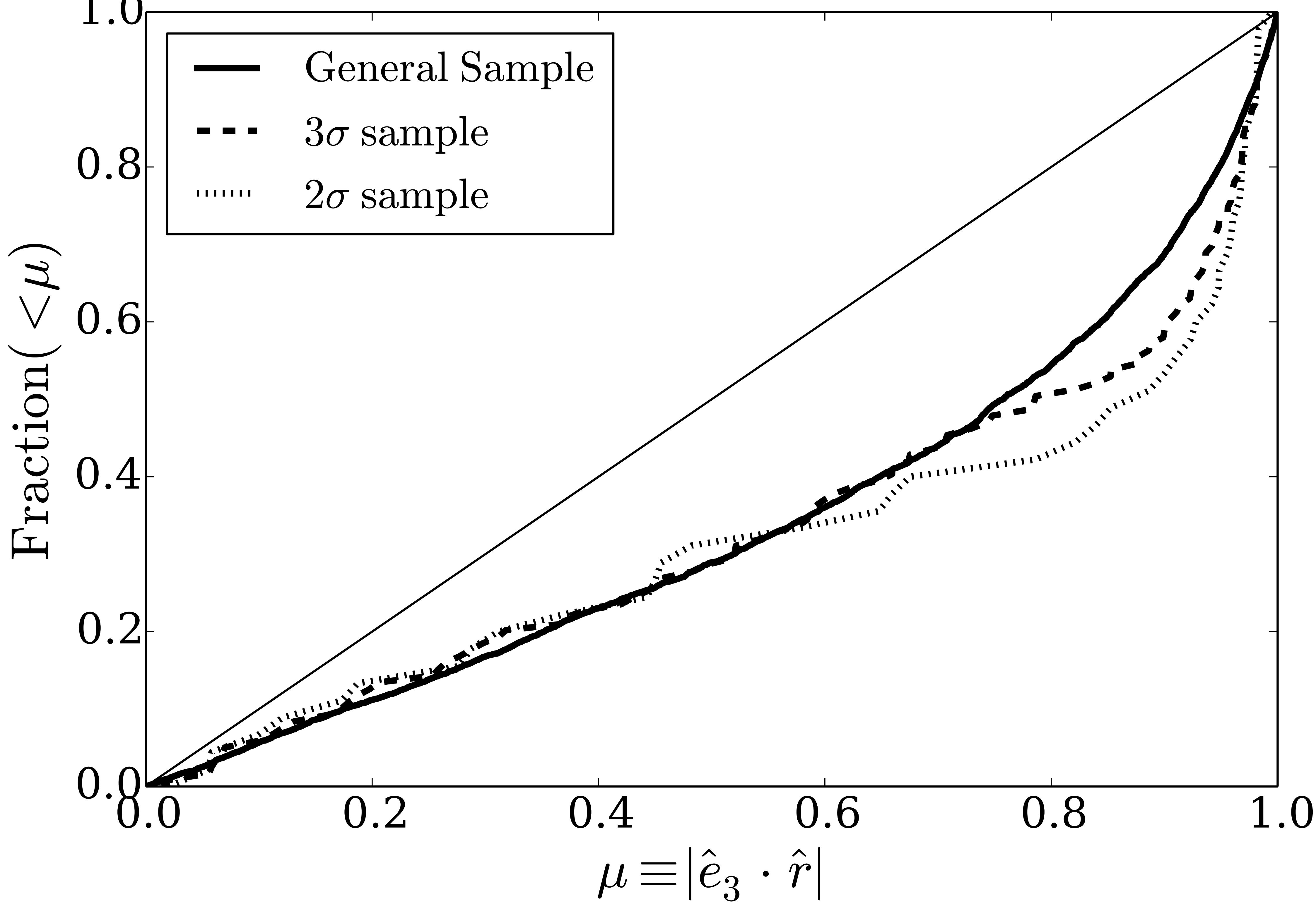
filaments and walls

e_3 goes along filaments and parallel to walls



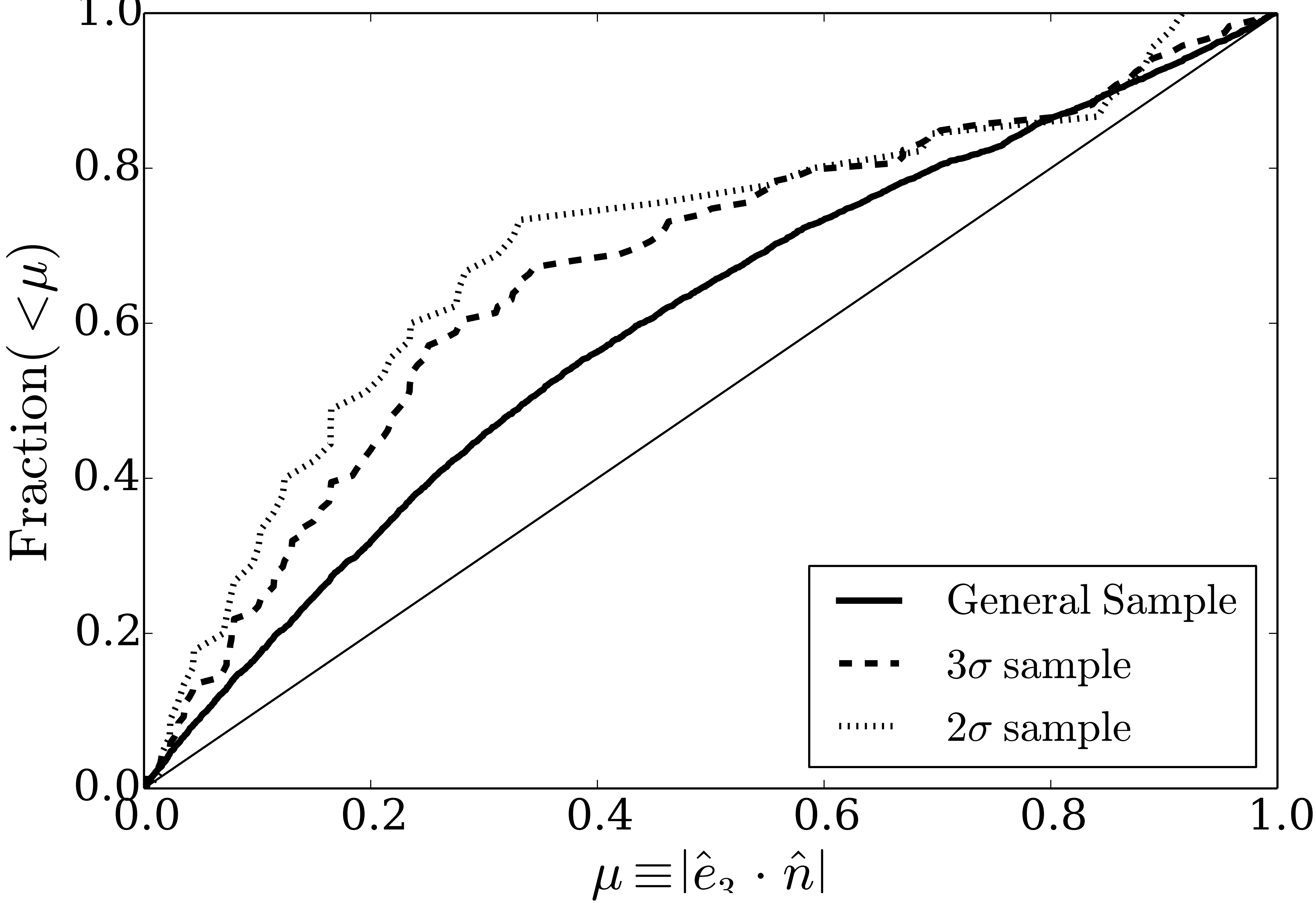


strong alignment of r with e₃



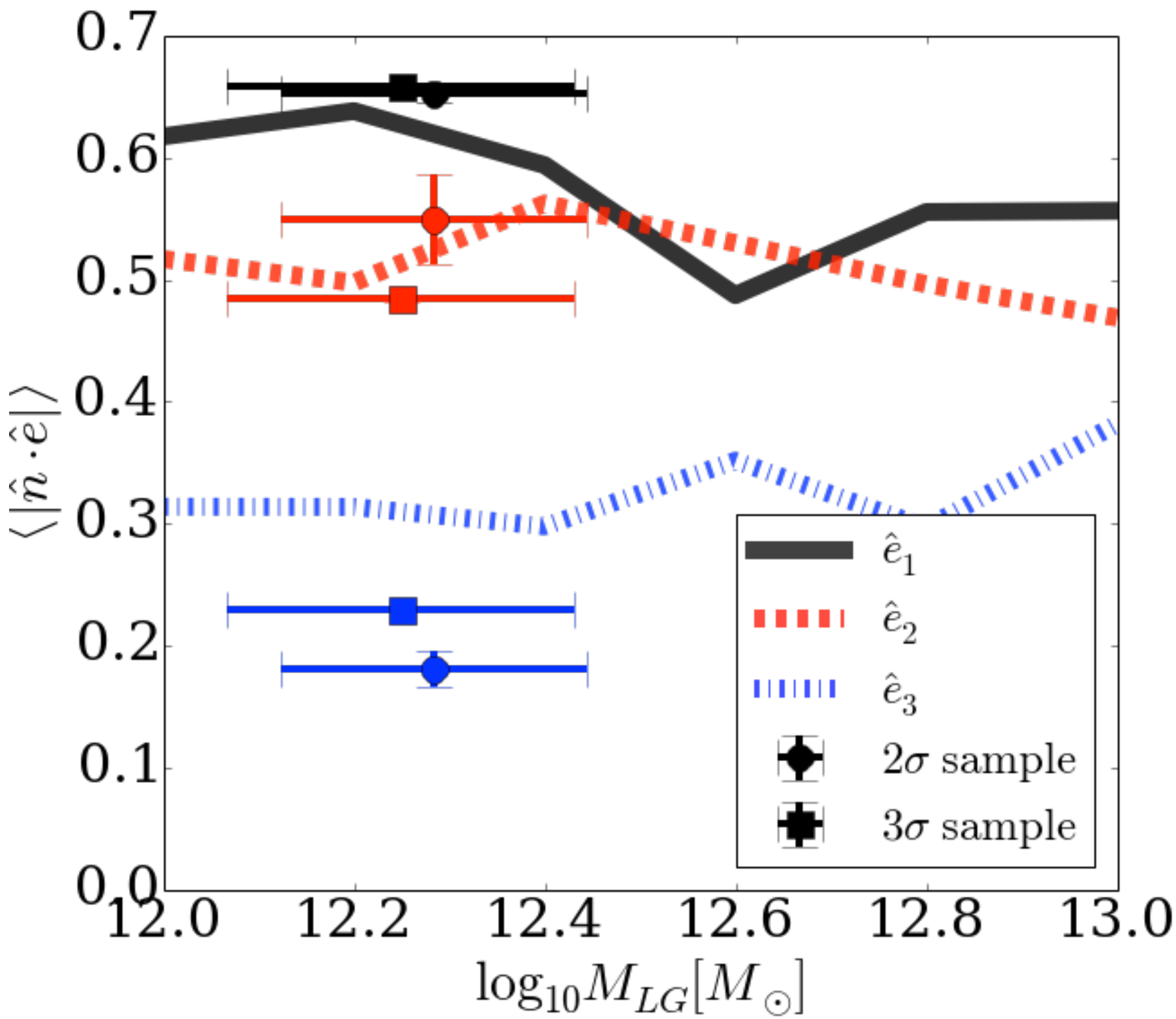
JEF-R & Gonzalez, ApJ submitted, 1408.3166

strong anti-alignment of **n** with e_3



JEF-R & Gonzalez, ApJ submitted, 1408.3166

Strong alignments for pairs are not mass dependent



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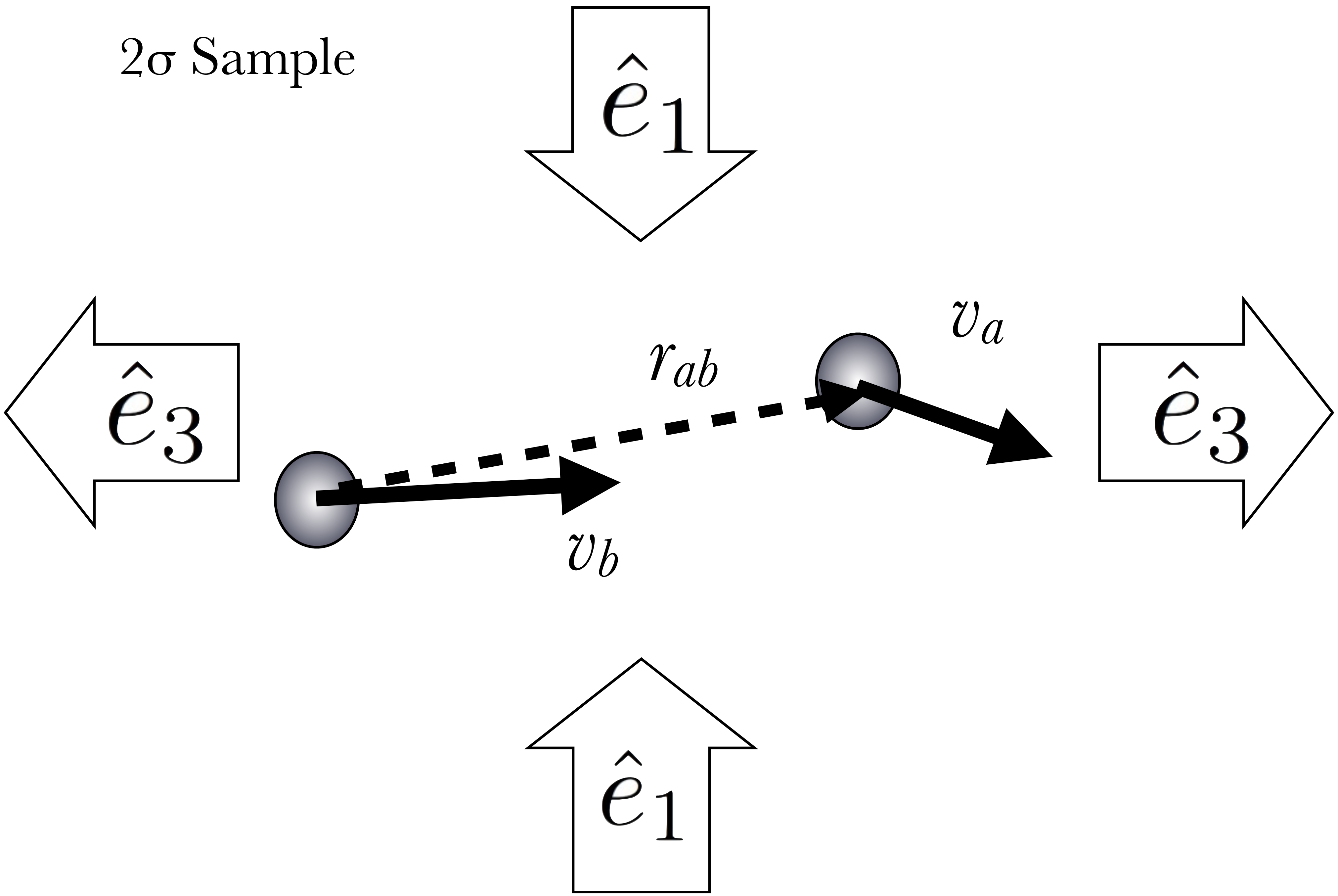
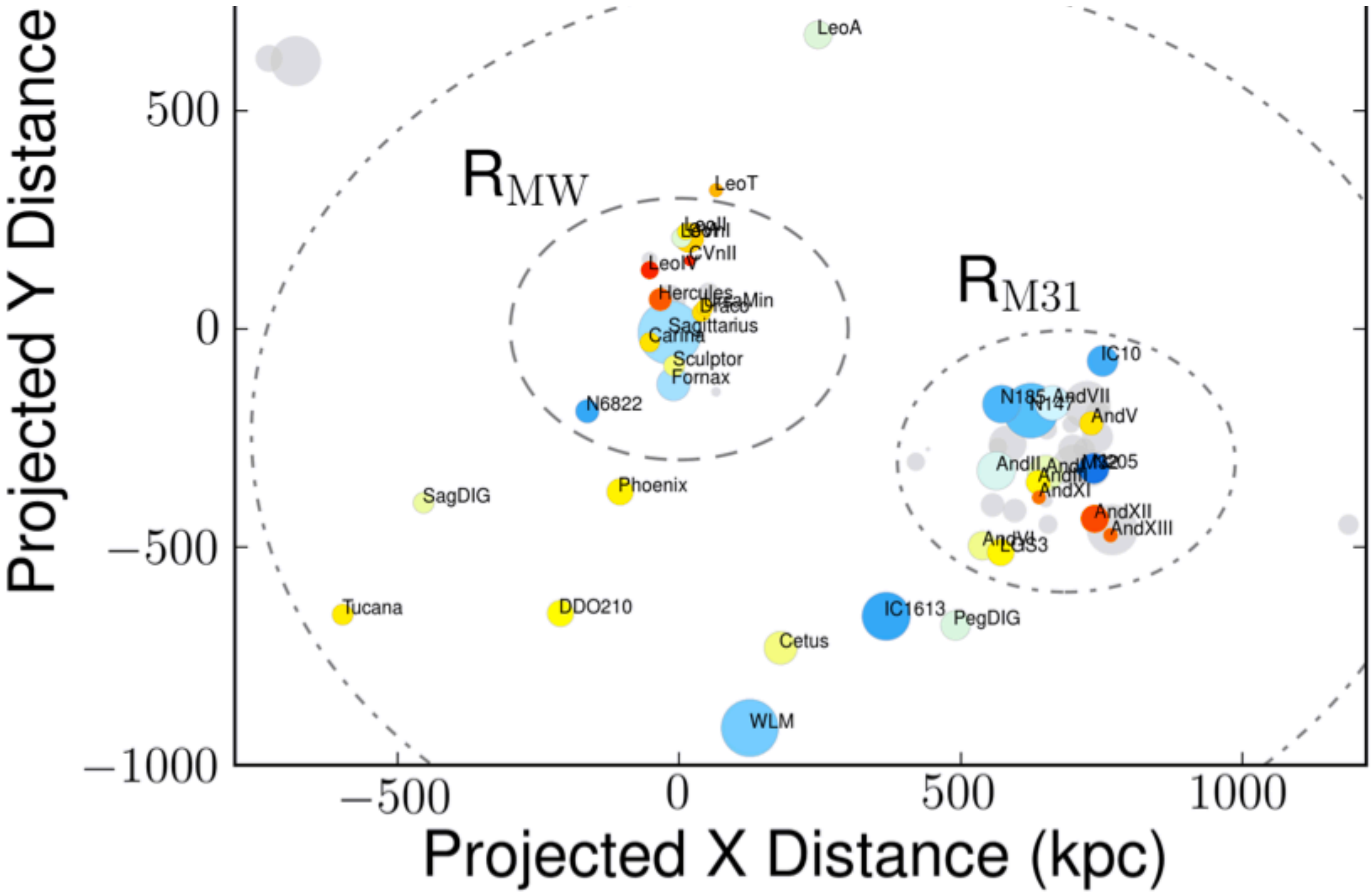
Observation #4

2σ Sample



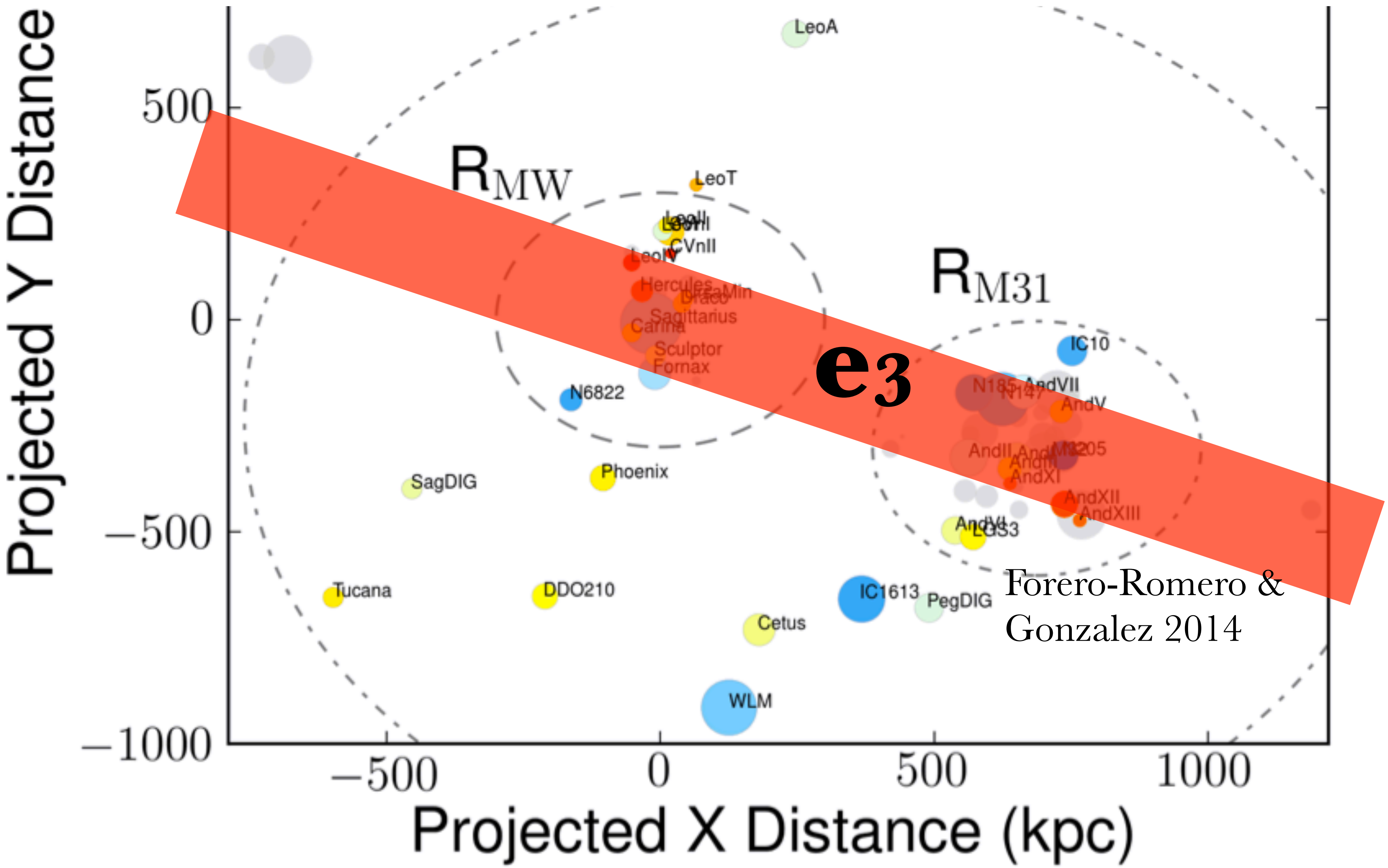
JEF-R & Gonzalez, ApJ submitted, 1408.3166

What is the situation in the observed Local Group?



Weisz et al. 2014

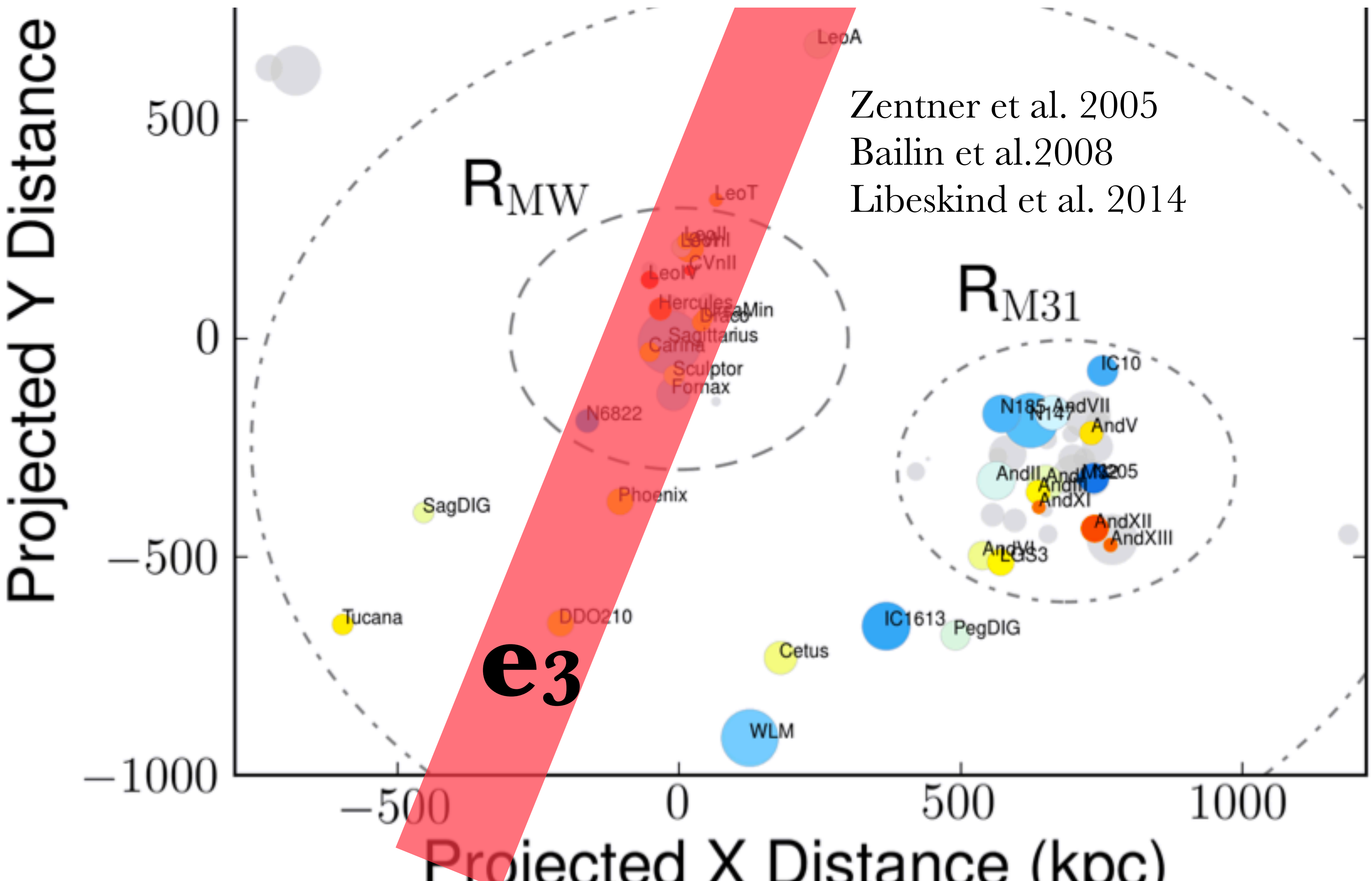
This is the alignment we predict in the local Group



Forero-Romero & Gonzalez 2014

Weisz et al. 2014

Tension with the expected alignment for plane of MW satellites?



Weisz et al. 2014

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?