Noam I Libeskind
AIP

High resolution
Environmental
Simulations of
The
Immediate
Area

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MPA: Volker Springel, Rudiger Pakmor, Rob Grand

HUJI: Yehuda Hoffman

UAM: Gustavo Yepes, Alexander Knebe

MIT: Mark Vogelsberger

Lyon: Helene Courtois, Jenny Sorce

Moscow: Sergey Pilipenko

Hestia – Goddess of the home

Aim:
to run *environmentally constrained* simulations of the *Local Group*

Hestia – Goddess of the home

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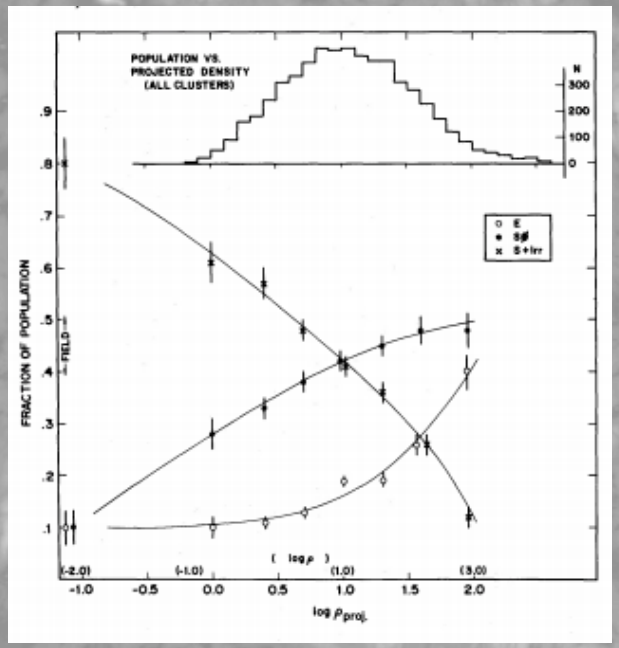
to run *environmentally constrained* simulations of the *Local Group*

Ensure that the environment surrounding the simulated Local Group resembles the real universe

Create a simulated Local Group that resembles the real one

Why bother with constraining the local environment?



Dressler 1980

Galaxy properties are effected by environment

Morphology – density relationship

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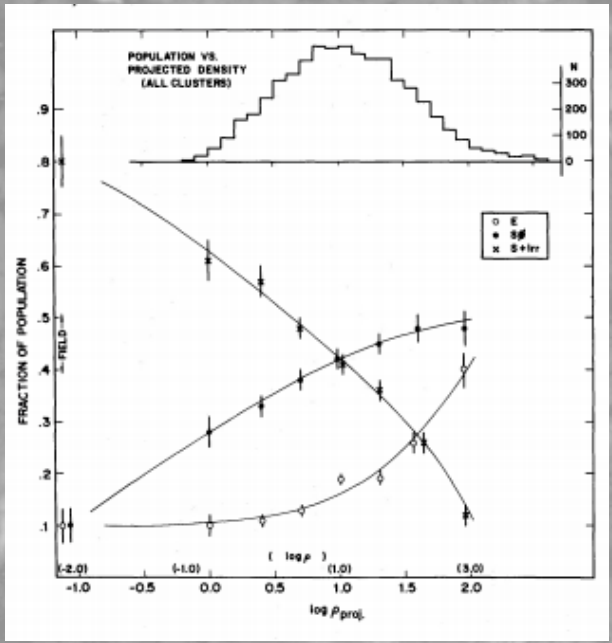

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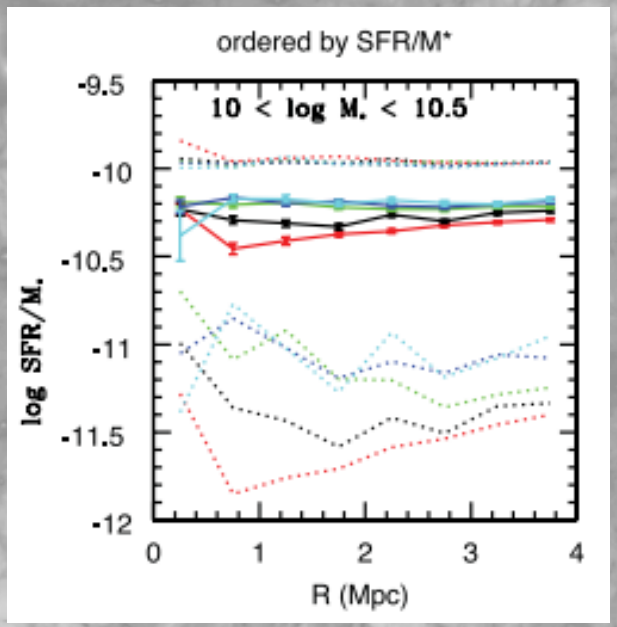

Kauffman et al 2013

Galaxy conformity (Weinman et al 2006)
Neighboring galaxies *conform* to one an other

SSFR conforms out to 4Mpc

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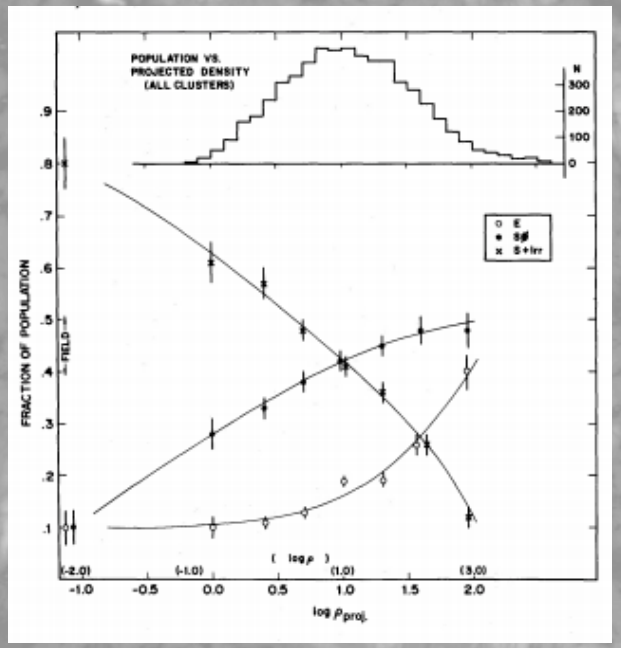

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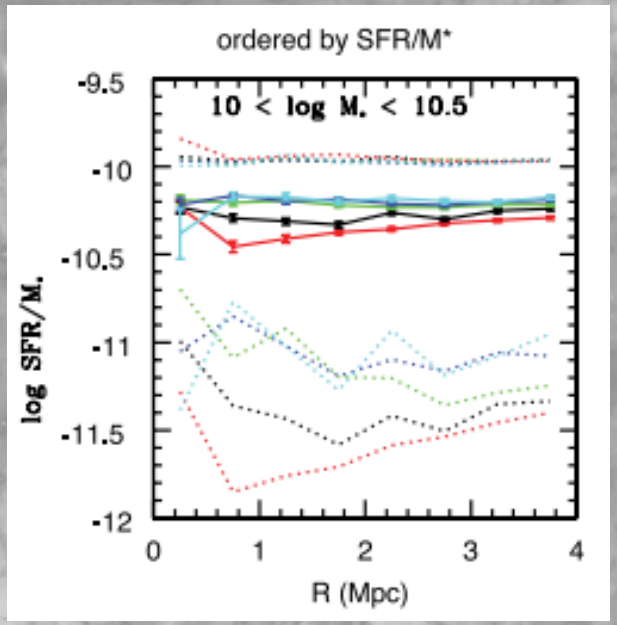

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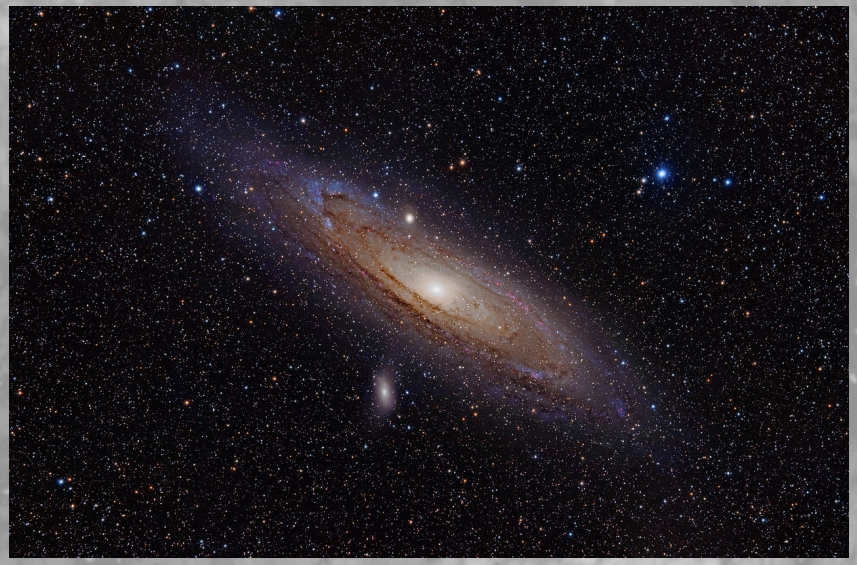
Does the Milky Way look like Andromeda?



Halo mass

M_{200} = **1.3**±0.3 x 10^{12} M_{sol} Posti & Helmi 2018
M_{200} = **1.4**±0.5 x 10^{12} M_{sol} Hattori et al 2018
M_{200} = **1.5**±0.5 x 10^{12} M_{sol} Monari et al 2018,
M_{200} = **1.7**±0.5 x 10^{12} M_{sol} Watkins et al 2018

M_{200} = **0.7**±0.1 x 10^{12} M_{sol} Kafle et al 2018
M_{200} = **1.0** ±0.1 x 10^{12} M_{sol} Tamm et al 2012
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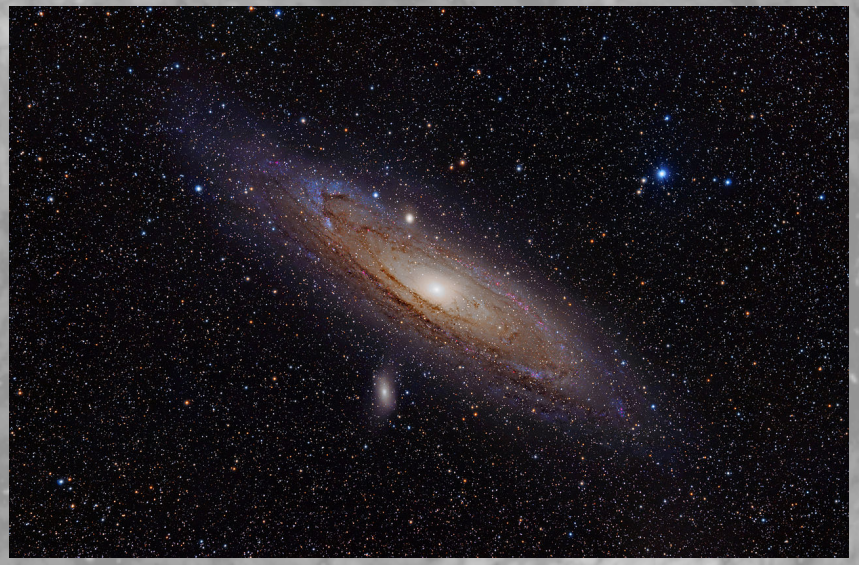

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Stellar mass

M_{star} = 0.5 x 10^{11} M_{sol} Licquia & Newman 2015
M_{star} = 0.6 x 10^{11} M_{sol} McMIllan et al 2017
M_{star} = 1 x 10^{11} M_{sol} Kafle et al 2014

M_{star} = **1.25**±0.25 x 10^{11} M_{sol} Tamm et al 2012
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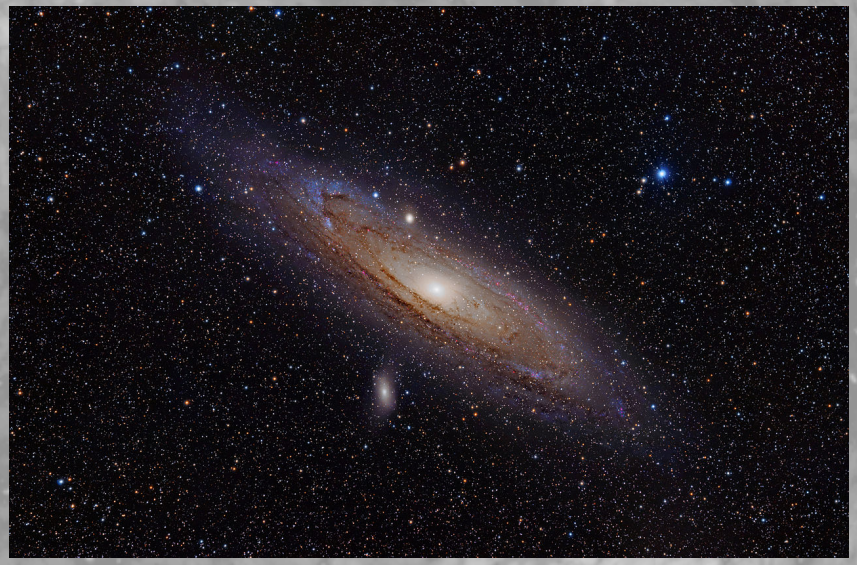

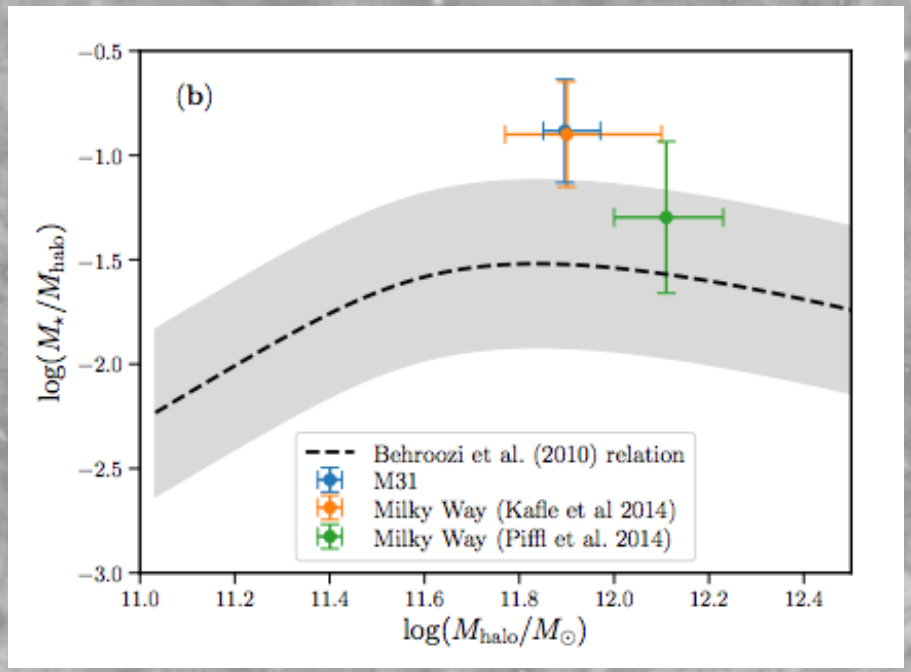

Kafle et al 2018

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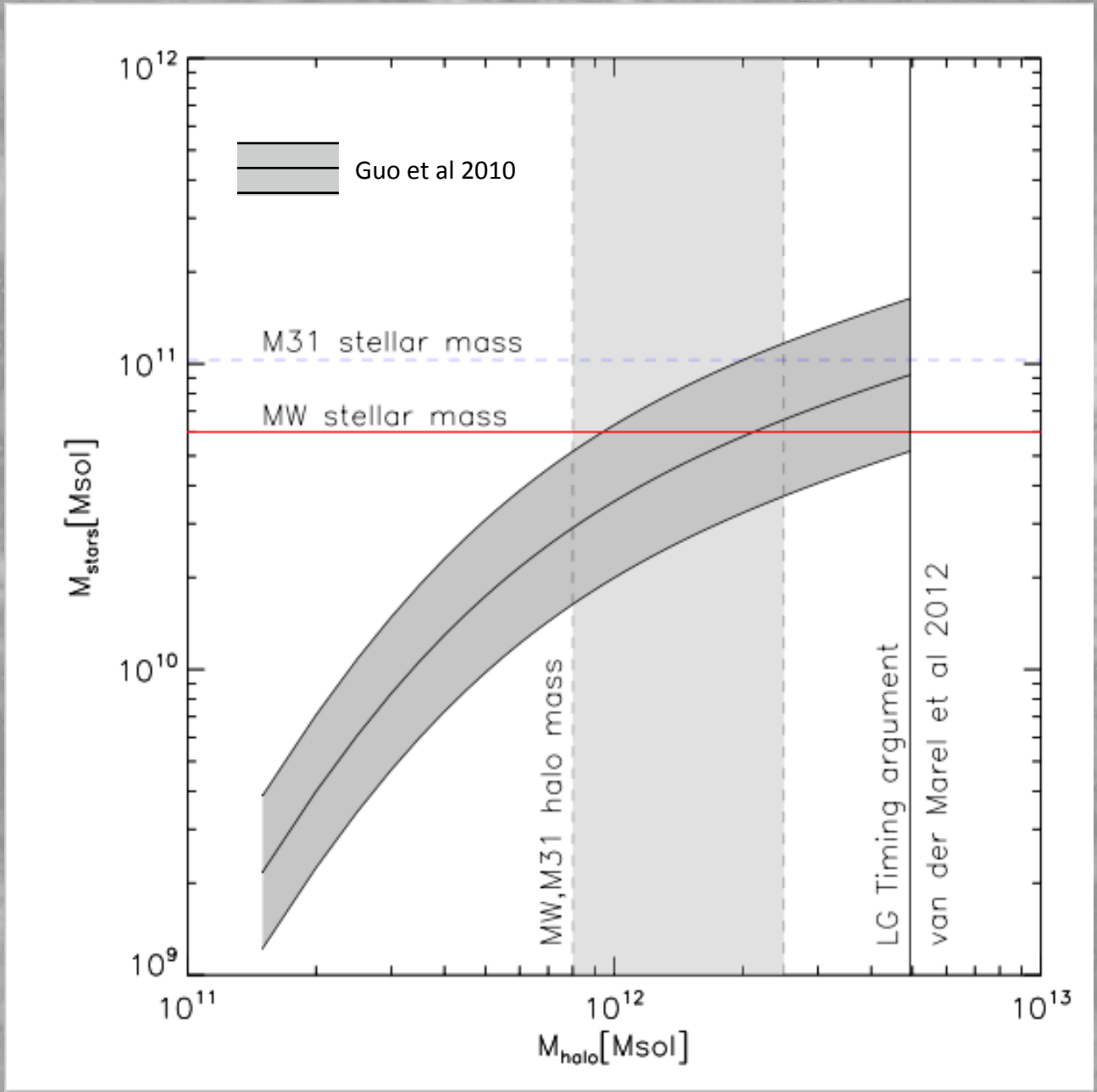
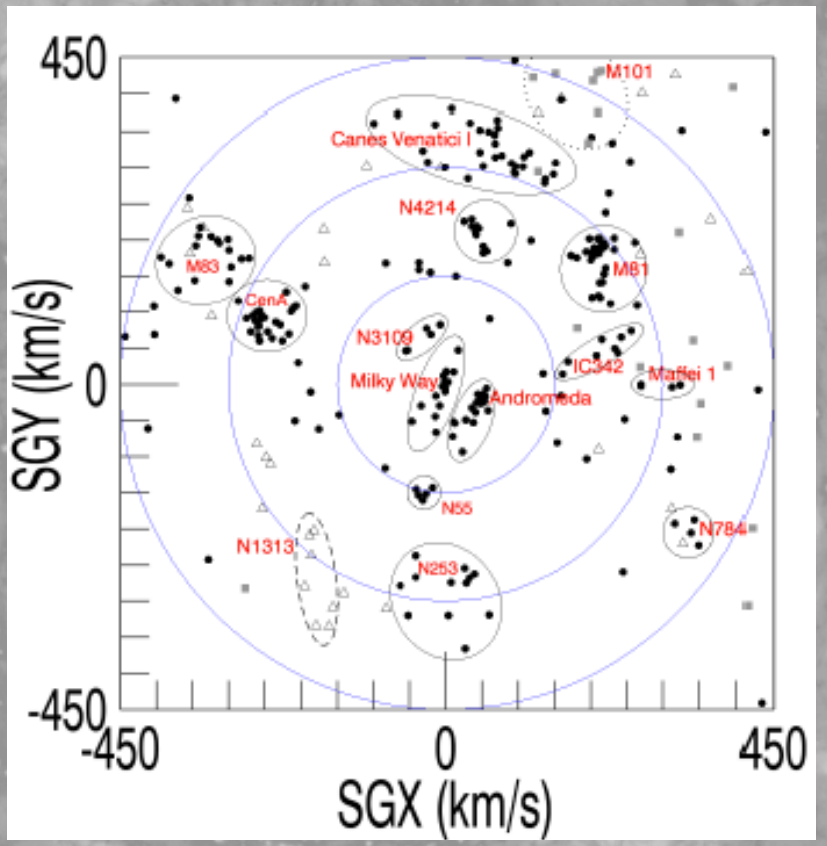


What is our local Environment ?

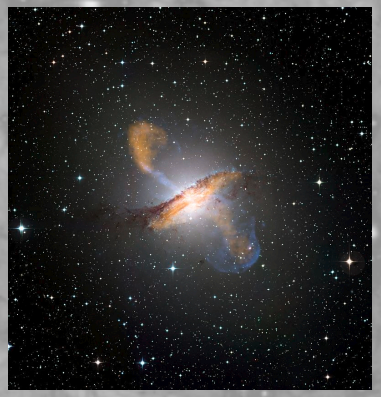
Courtois et al 2013



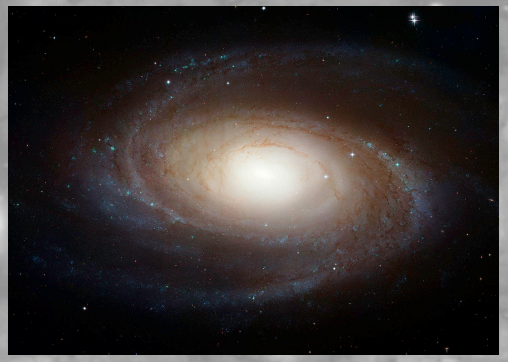
Half a dozen MW sized galaxies within 5Mpc

What is our local Environment ?

M83 ~10^{12}; 4.8Mpc

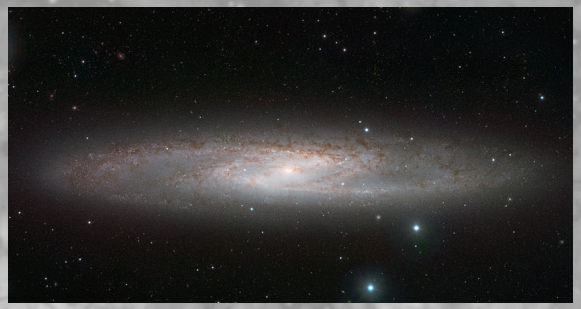


Cen A ~$3x10^{13}$; 3.8Mpc



M81~$3x10^{12}$; 3.6Mpc

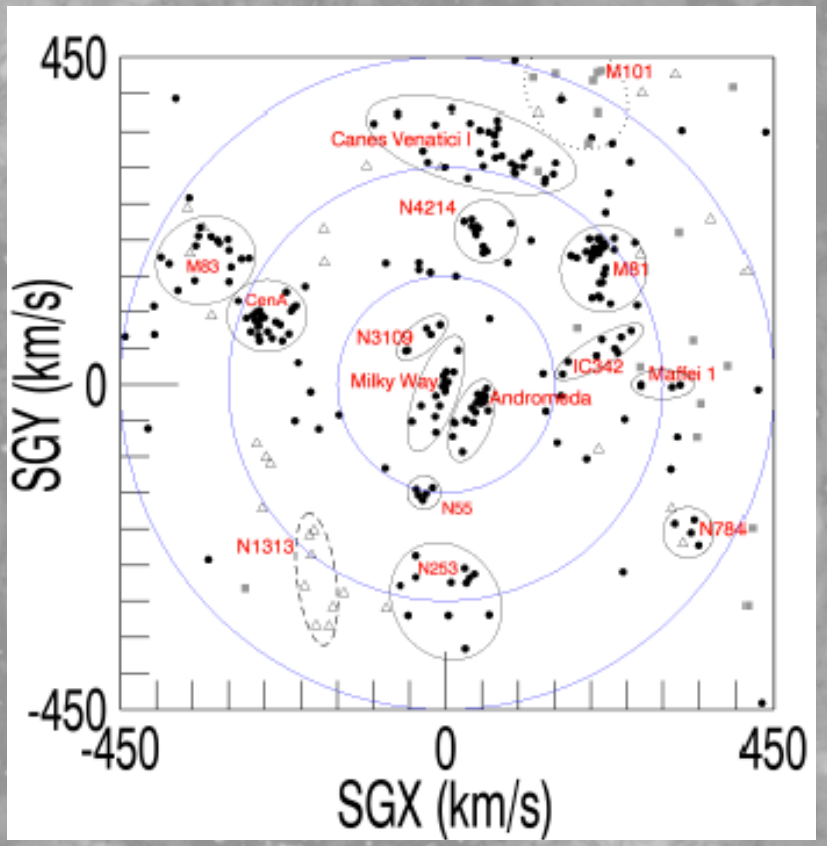
M82 ~10^{12}; 3.7Mpc



NGC 253 ~10^{11}; 3.5Mpc

Maffei-1 ~10^{12}; 3.3Mpc

Courtois et al 2013



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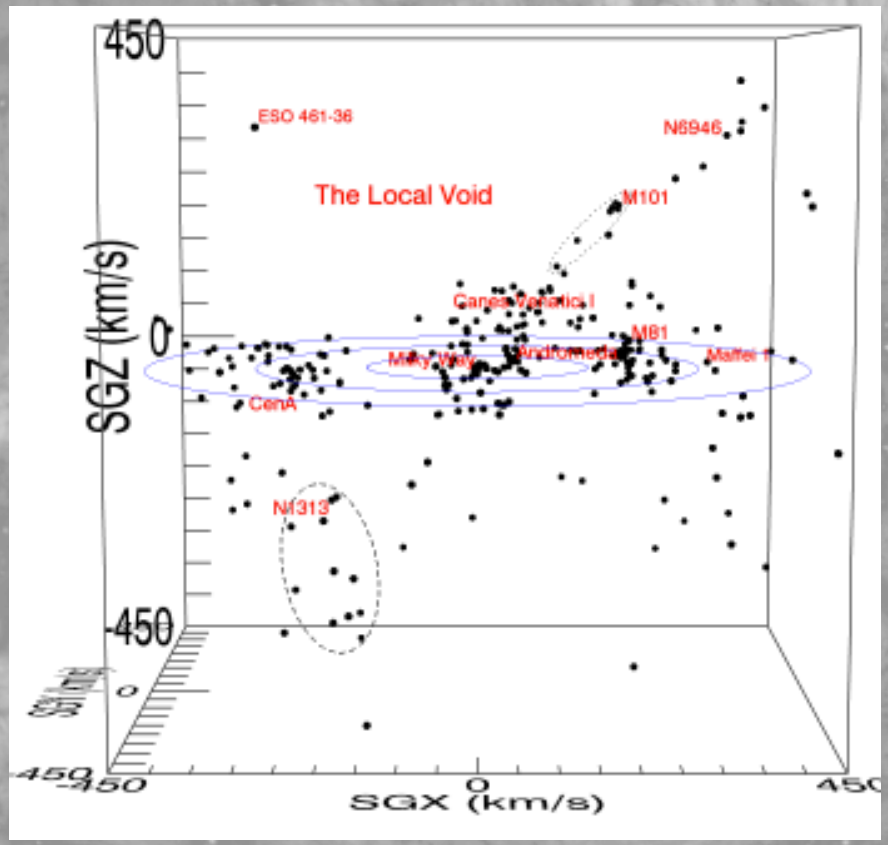
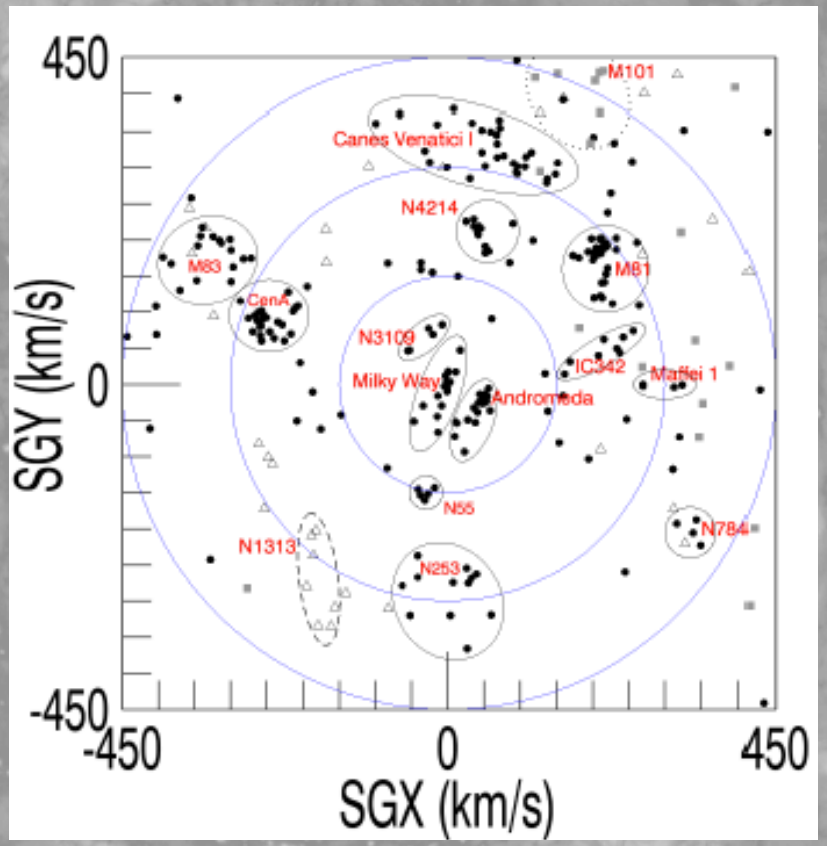


Local Void over us and under us



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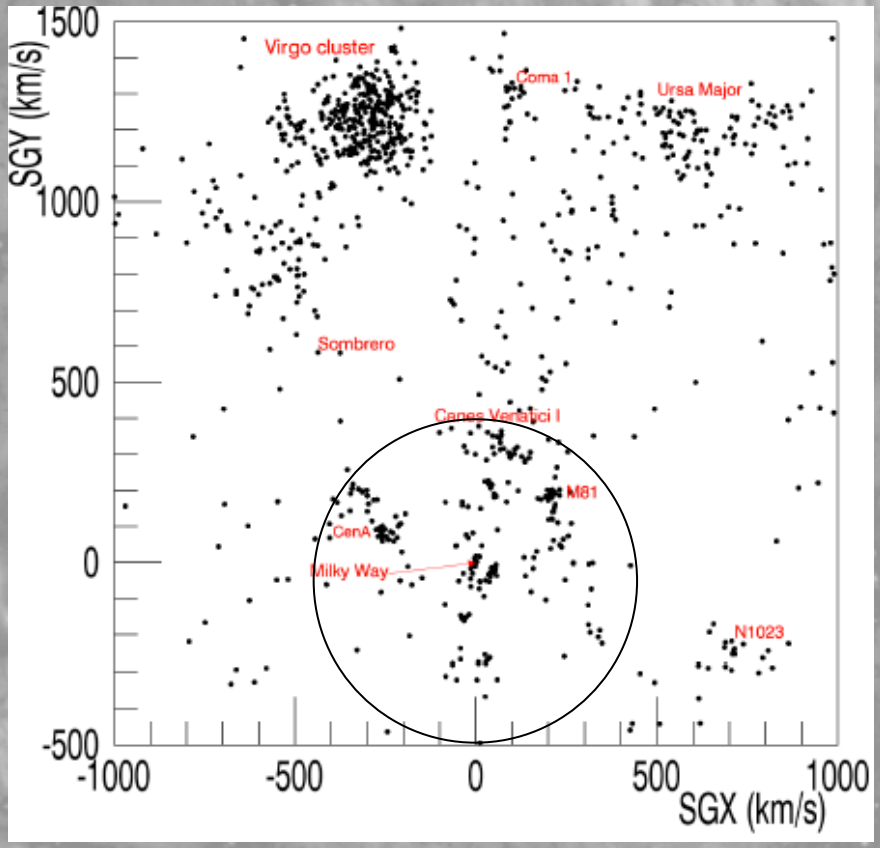
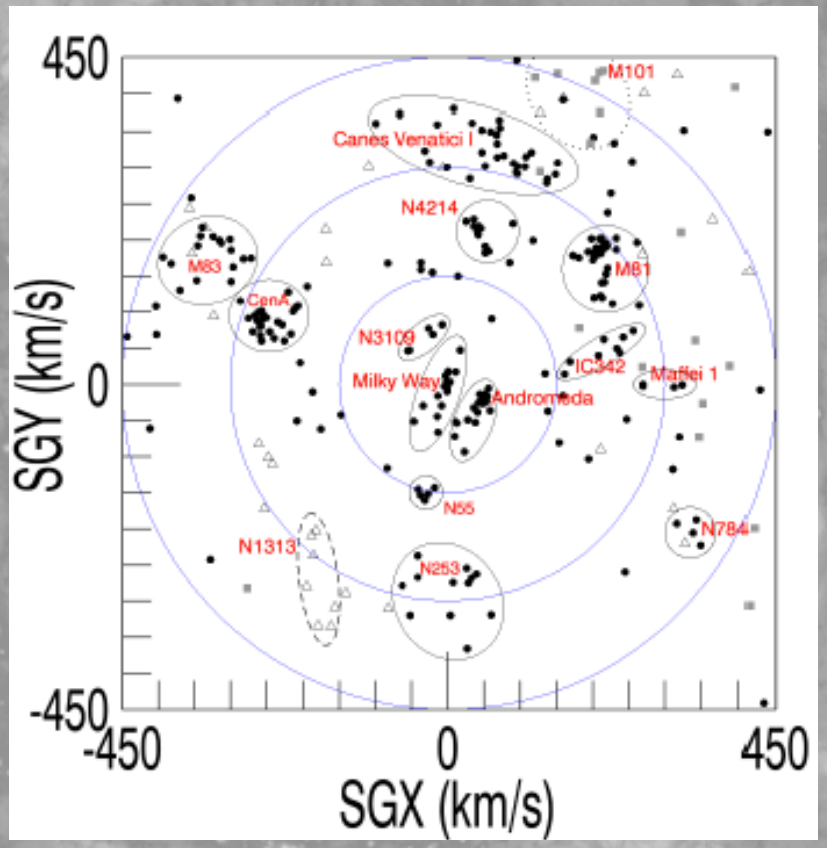


Virgo Cluster on scales of ~15Mpc



Half a dozen MW sized galaxies within 5Mpc

Light is a tracer of the underlying matter distribution

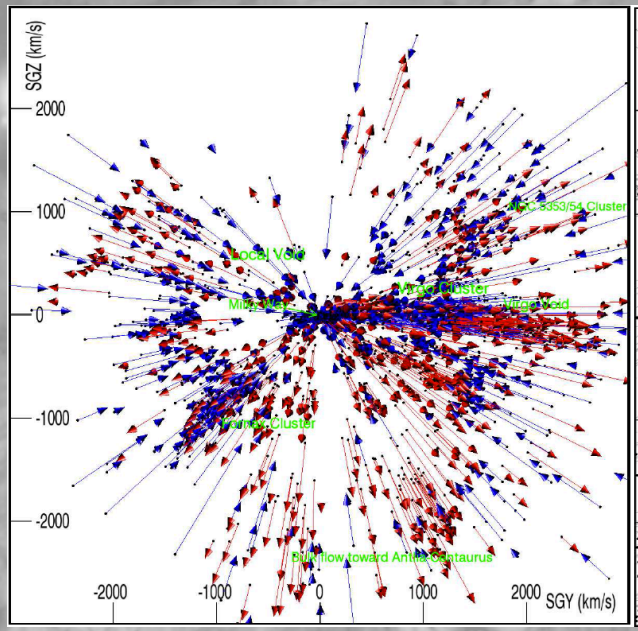
Courtois et al 2013

Reconstructing the underlying matter distribution of the Local universe

$$cz = v_{exp} + v_{pec}$$

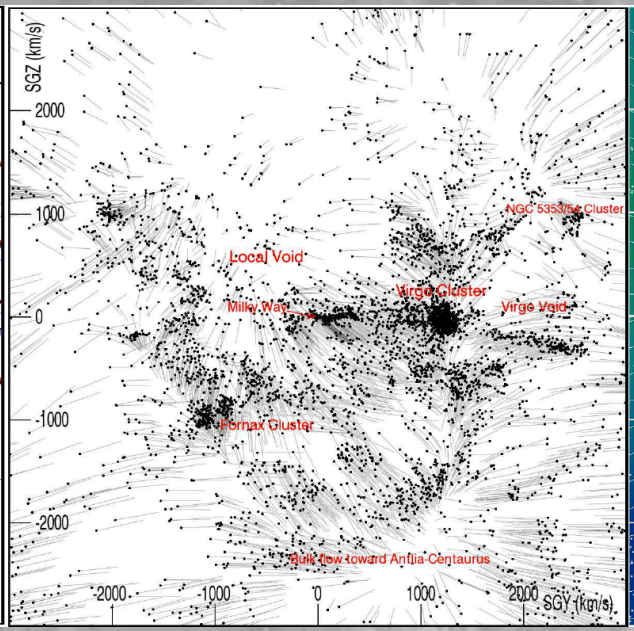
$$v_{exp} = H_0\, d$$

radial peculiar velocity

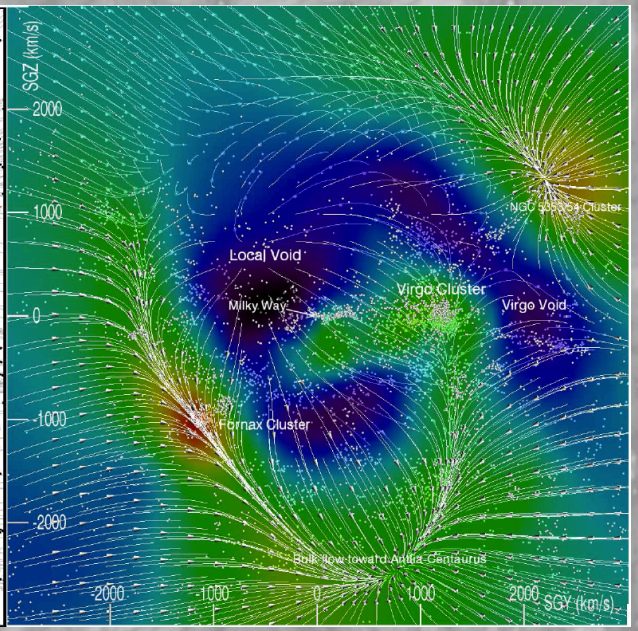


Courtois *et al* 2013

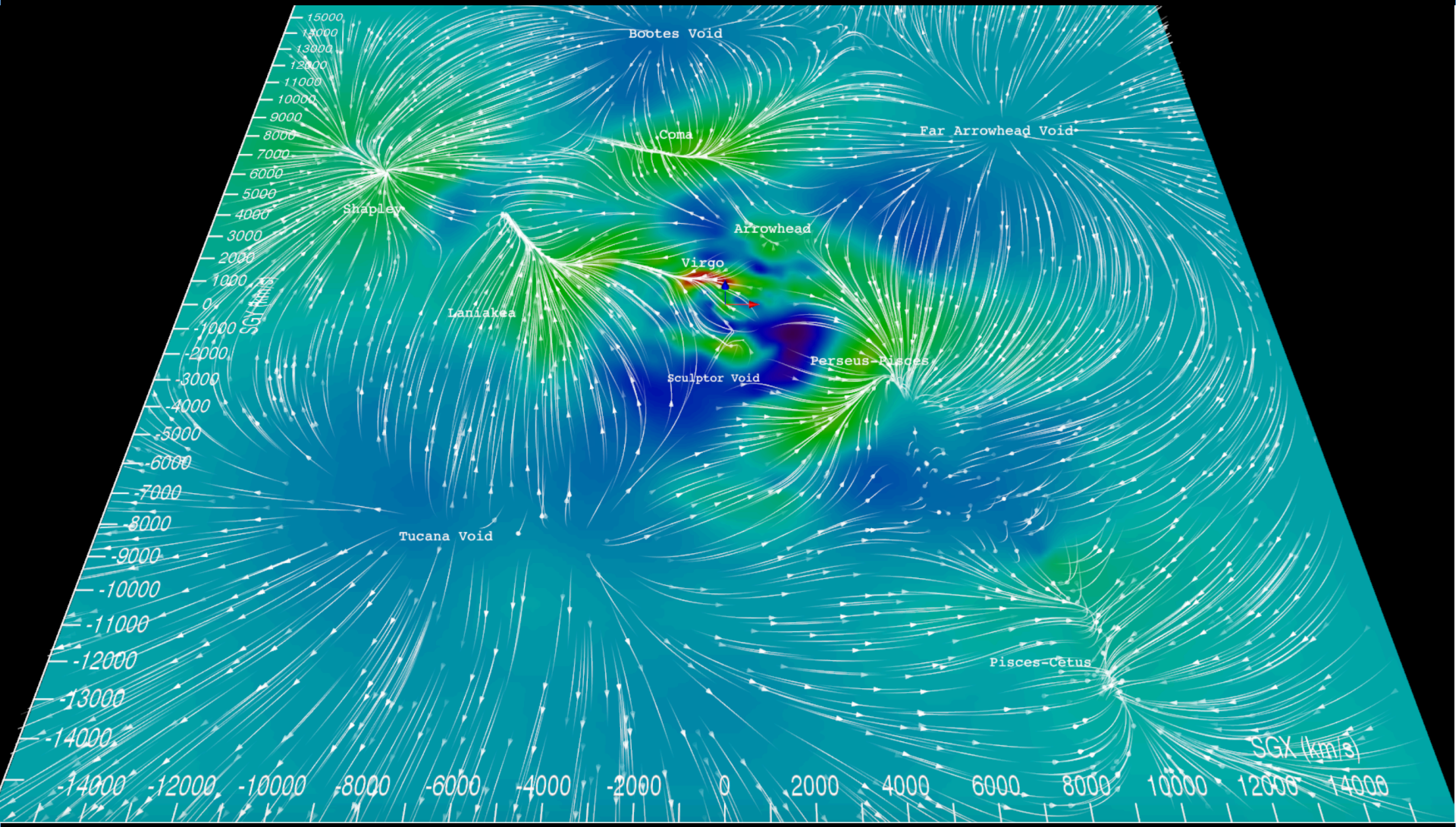
reconstructed 3D peculiar velocity



Corresponding 3D density field

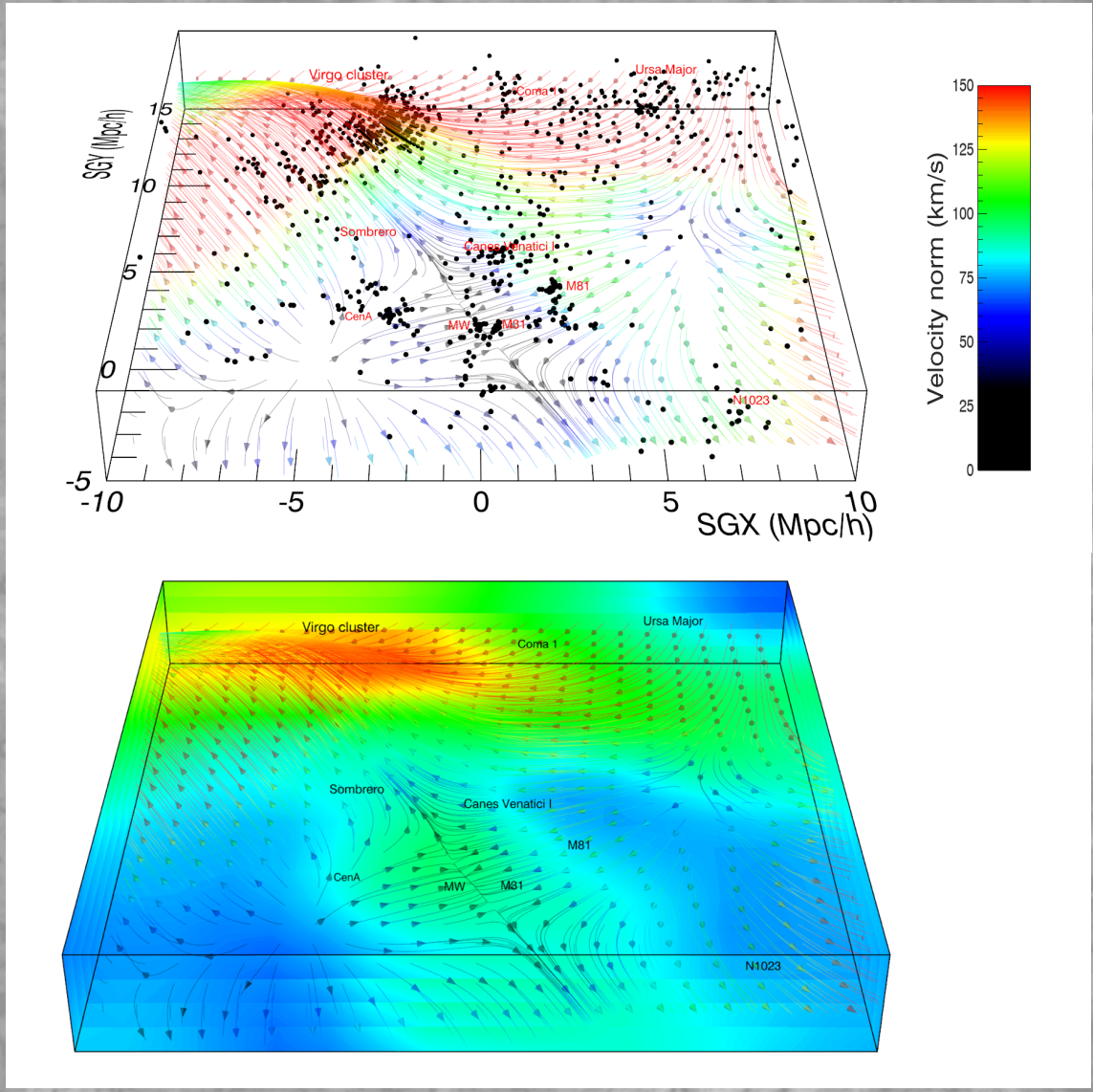


Zaroubi et al 1995



Tully et al 2015

Full underlying matter distribution of the Local universe

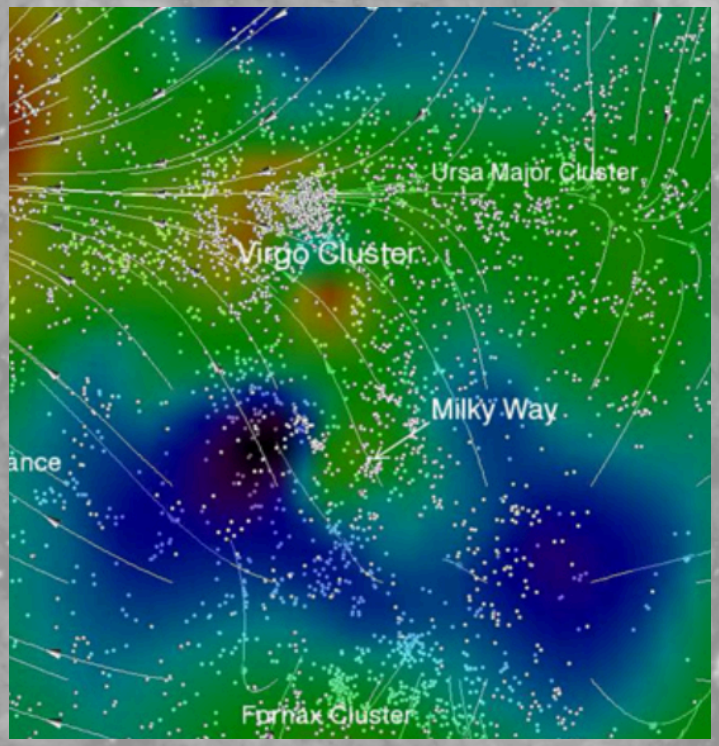


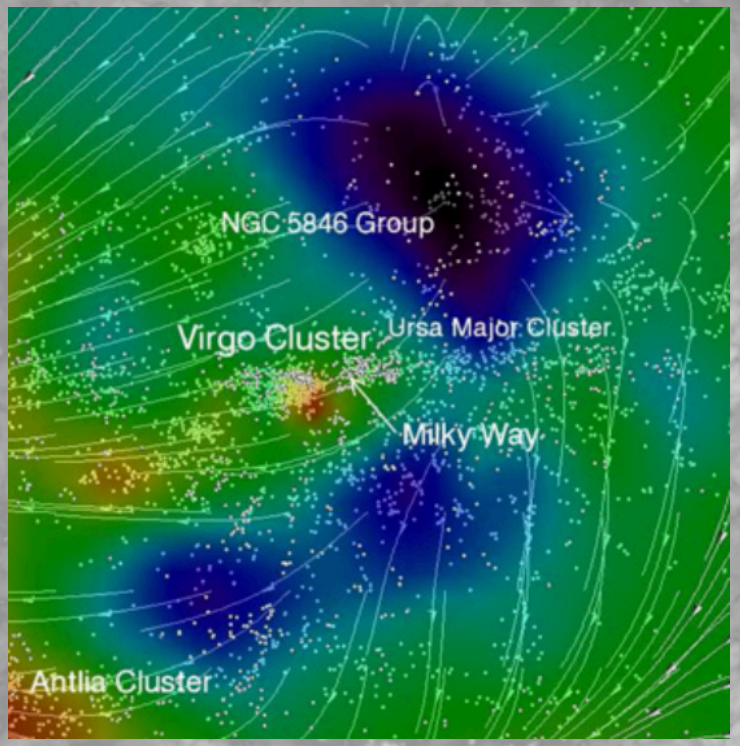
Virgo and the Local Void are the dominant cosmographic features on scales of 5-20Mpc

Libeskind et al 2015

Full underlying matter distribution of the Local universe

50Mpc





Courois et al 2013

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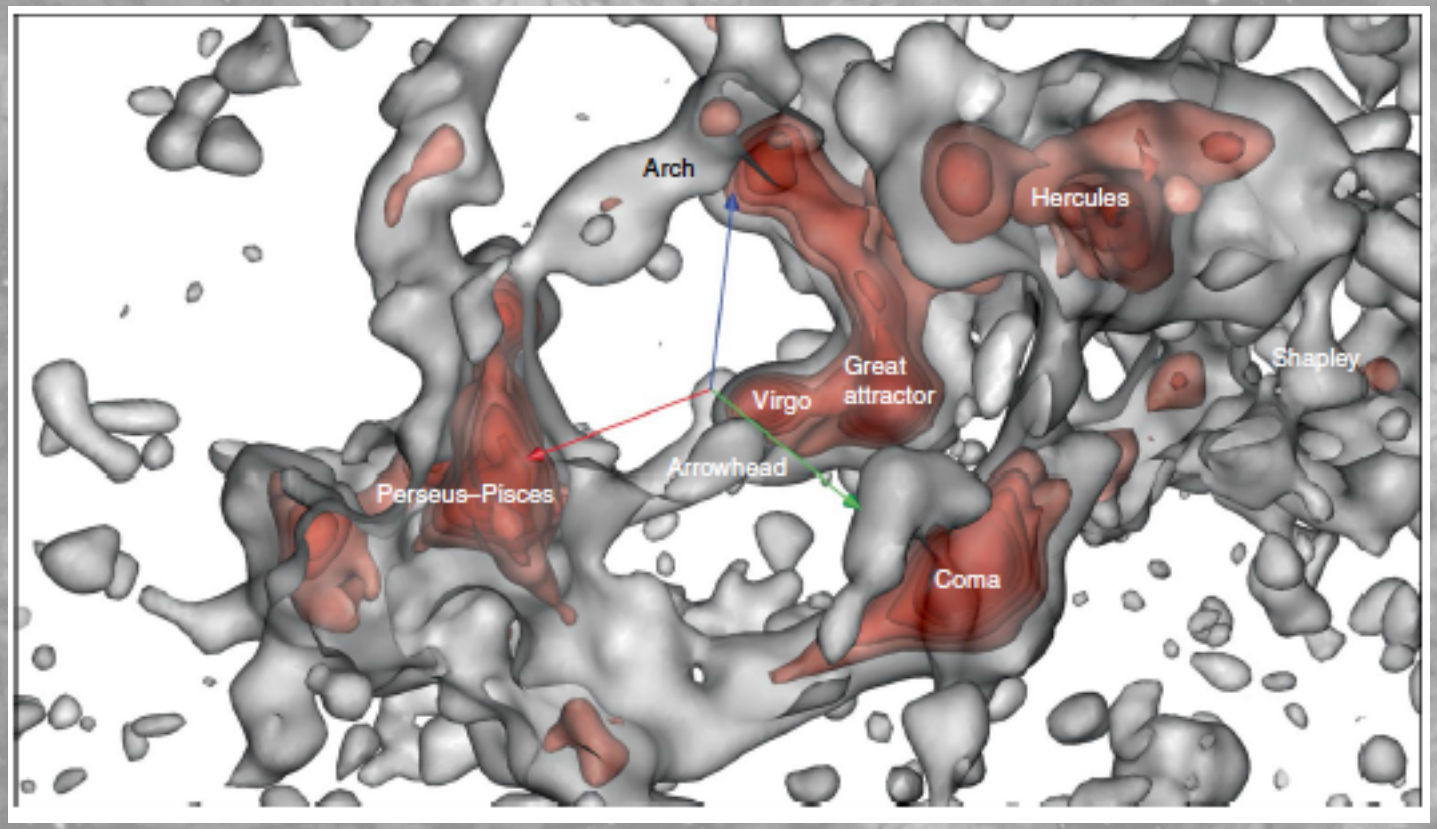


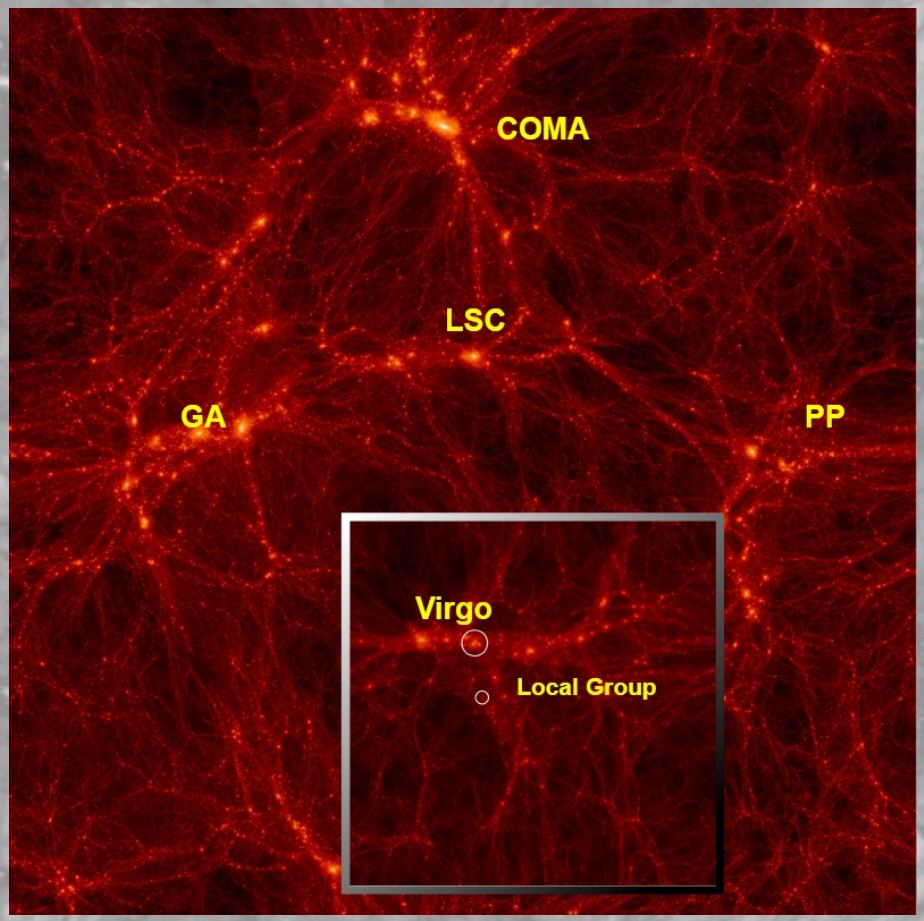
The Local Void is a major contribution to our dynamics and is the anti-pod to the CMBdipole

Hoffman, NL et al 2018

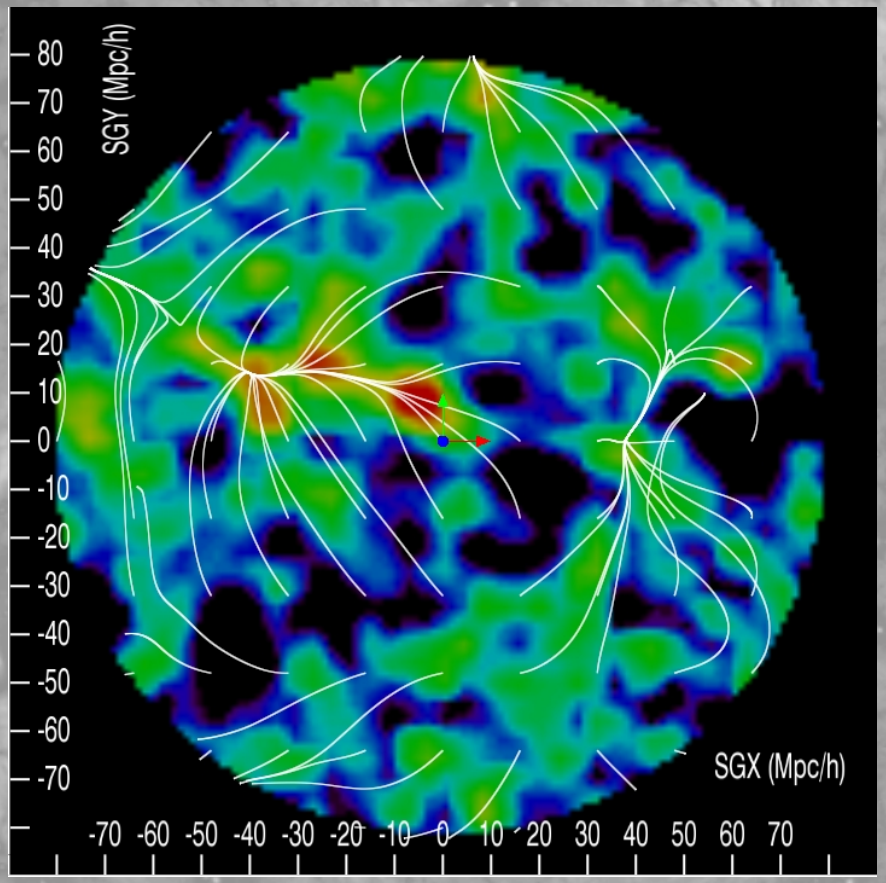
CLUES

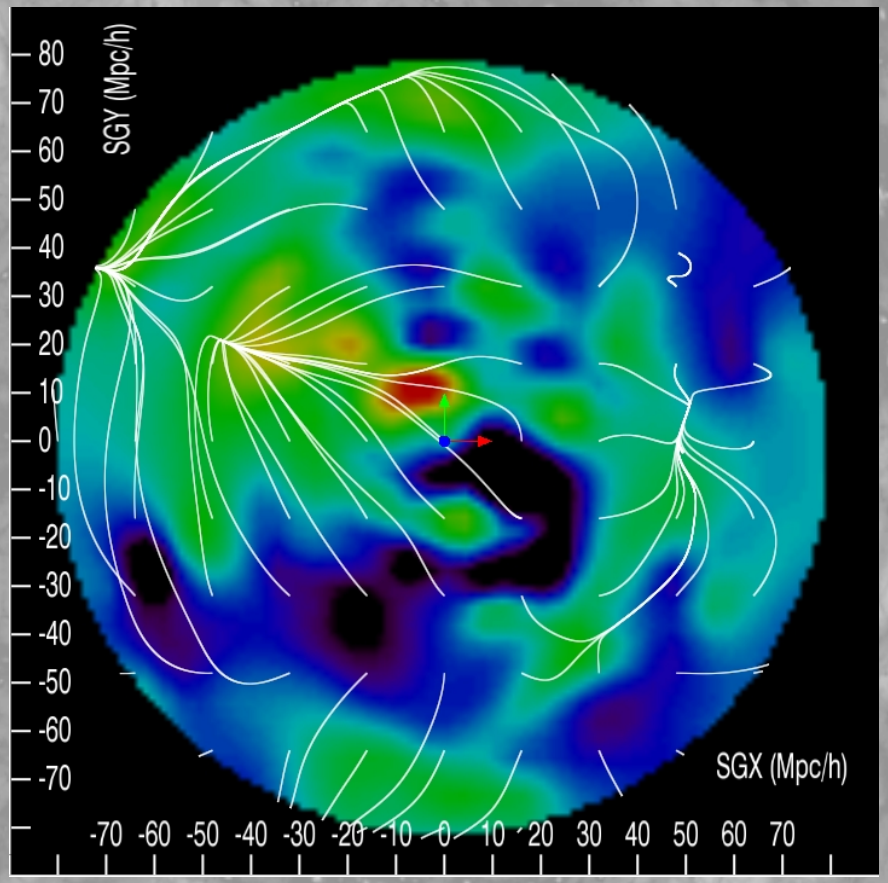
Constrained Local UniversE Simulations

PIs: Helene Courtois (Lyon), Alexander Knebe (UAM),
Noam Libeskind (AIP), Jenny Sorce (Lyon), Gustavo Yepes (UAM)
Emeritus: Stefan Gottlöber, Yehuda Hoffnman



1D peculiar velocity fields can be used to construct *constrained initial conditions* for N body simulations



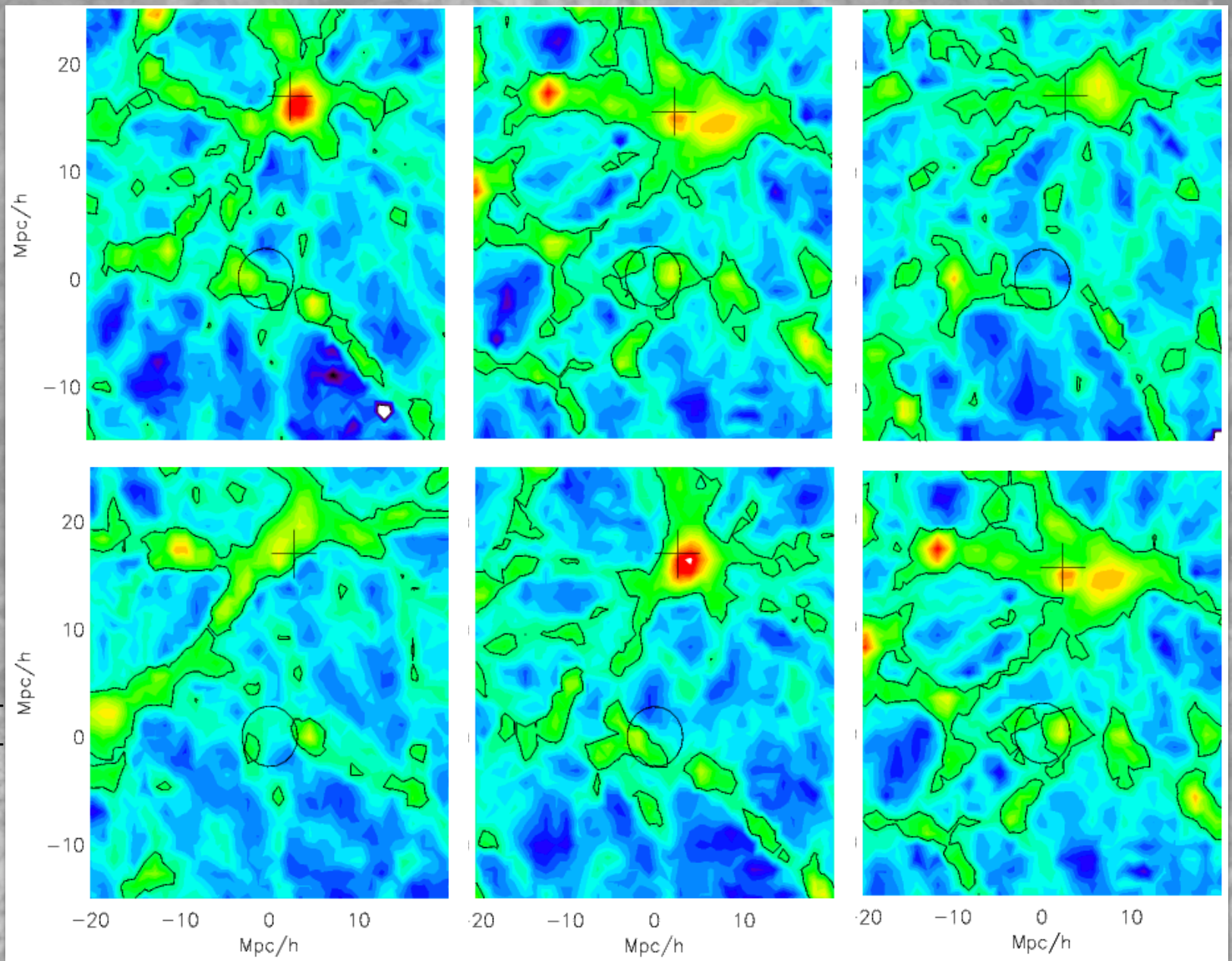


Constrained Simulations Reconstructions

Linear reconstruction, assuming LCDM, gaussian random field prior – small scales are added randomly

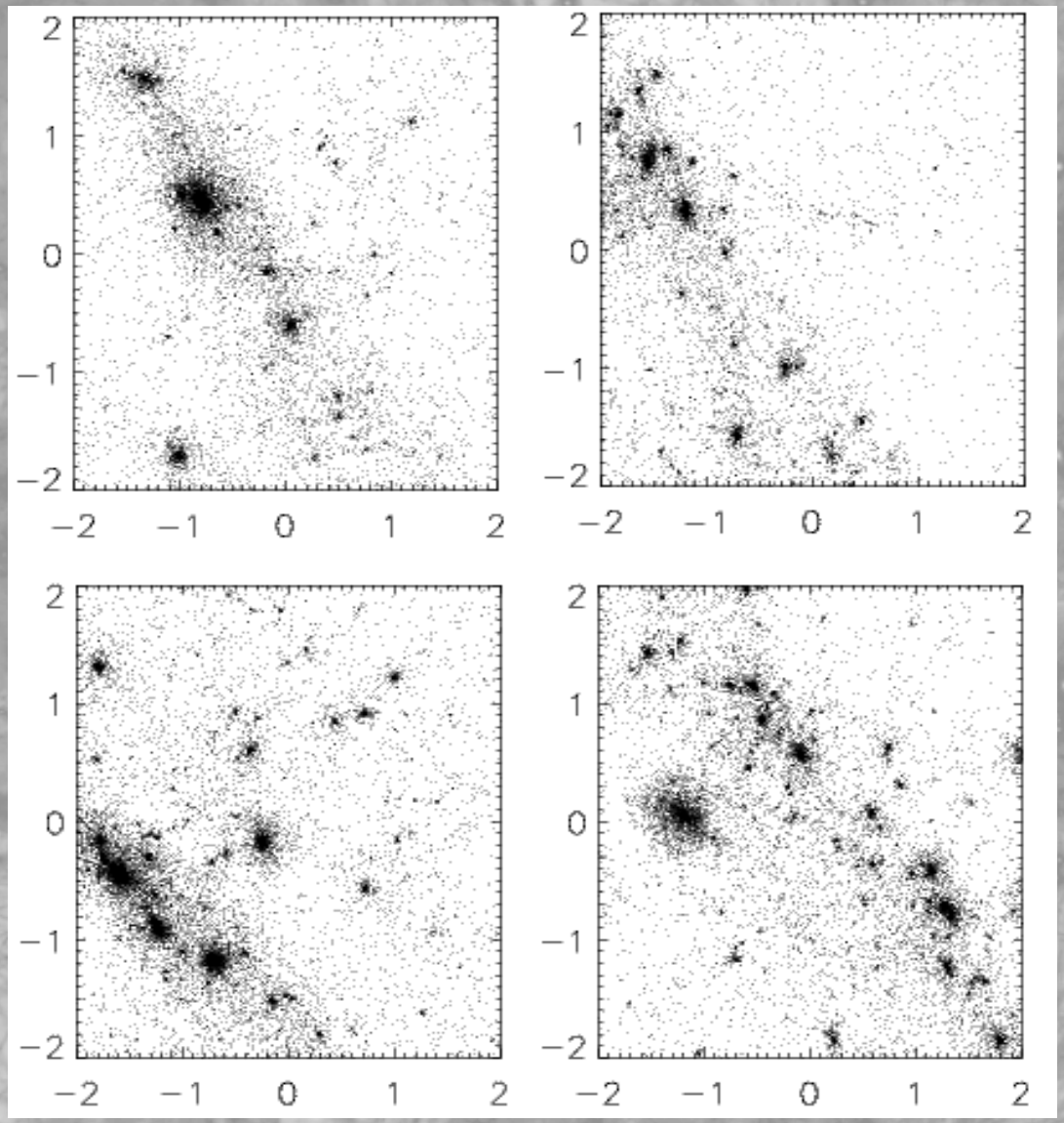
Sorce et al 2016

Hestia:
constrained initial conditions for hydrodynamic simulations of the Local Group

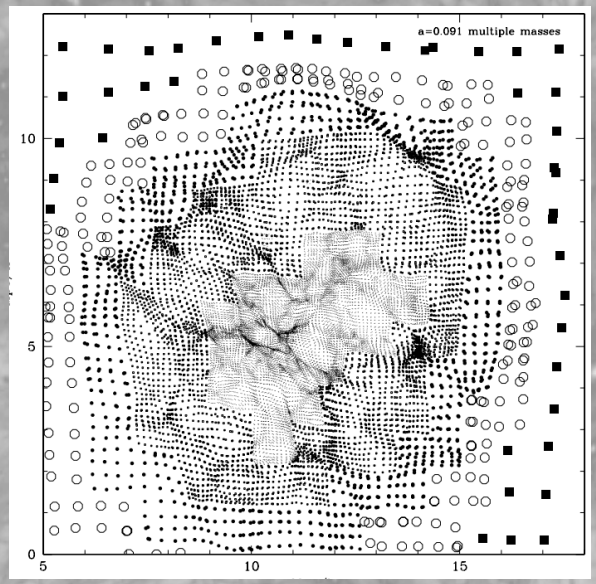


Libeskind et al in prep

Hestia:
Small scales not constrained



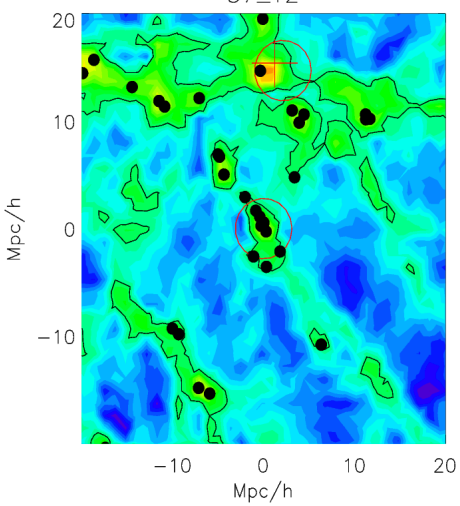
Small scale selection for a LG is done in a “frequentist“ manner. Many low resolution s



Libeskind et al in prep

What is a “GOOD” Constrained simulation

1. Virgo like cluster (> 2 x $10^{14} M_{sol}$) within 5 Mpc of where Virgo should be (in practice $|d_{sim,\ virgo} - d_{obs,\ virgo}| < 3.5$ Mpc)
   1a. No other massive Virgo like cluster closer than the simulated Virgo



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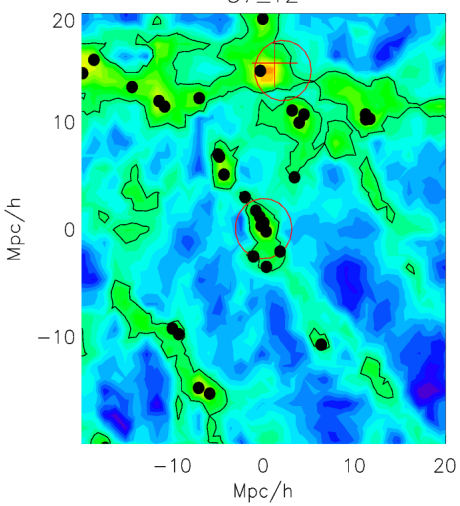
2. LG within 5 Mpc of box center
   2a. LG: 2 halos of mass
   $8 \times 10^{11} < M_{MW} < M_{31} < 2.5 \times 10^{12}$
   2b. $M_{MW}/M_{31} > 1/3$
   2c. Separated by
   $500\ kpc < d_{sep} < 1{,}000 kpc$
   2d. Exclusion: nothing greater than M_{31} within $d_{excl} < 2.5$Mpc of LG c.o.m
   2e. $V_{rad} < 0$ (infalling)



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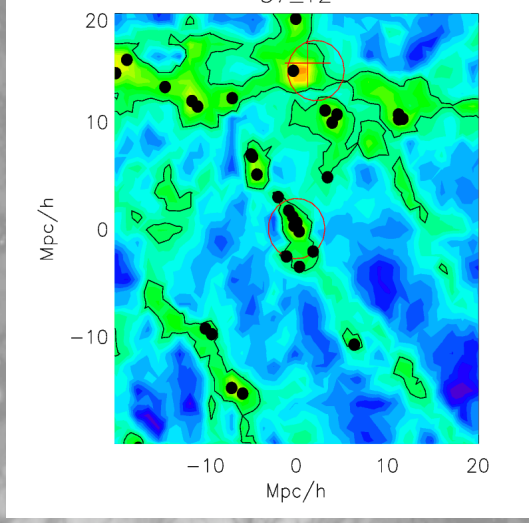
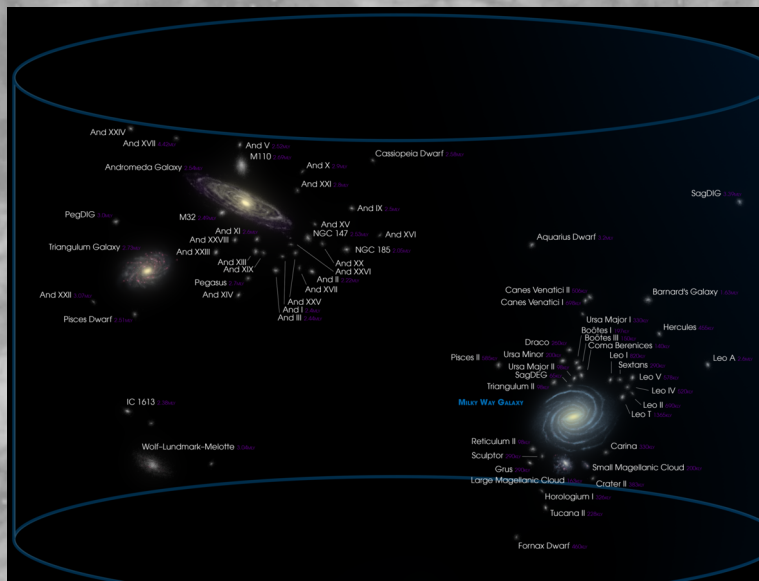
3. $M_{star} > 6 \times 10^{10} M_{sol}$
4. Disky galaxies

Hyrdo criteria

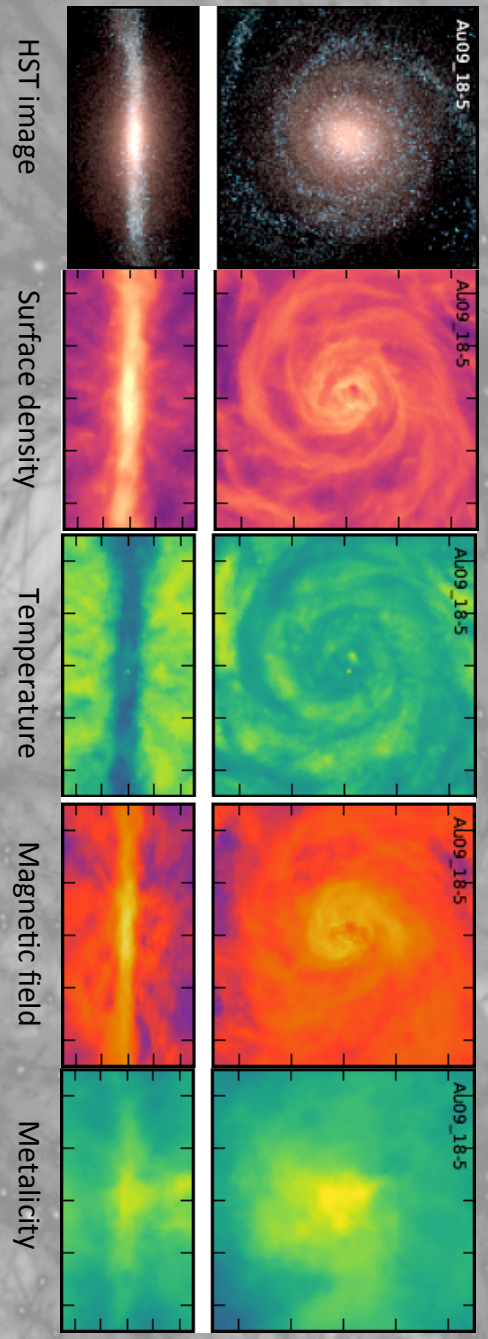




Note on the simulations

Based on the Auriga galaxy formation Model (Grand et al 2017)

L_{box} = 100Mpc/*h*, Plank cosmology



Note on the simulations

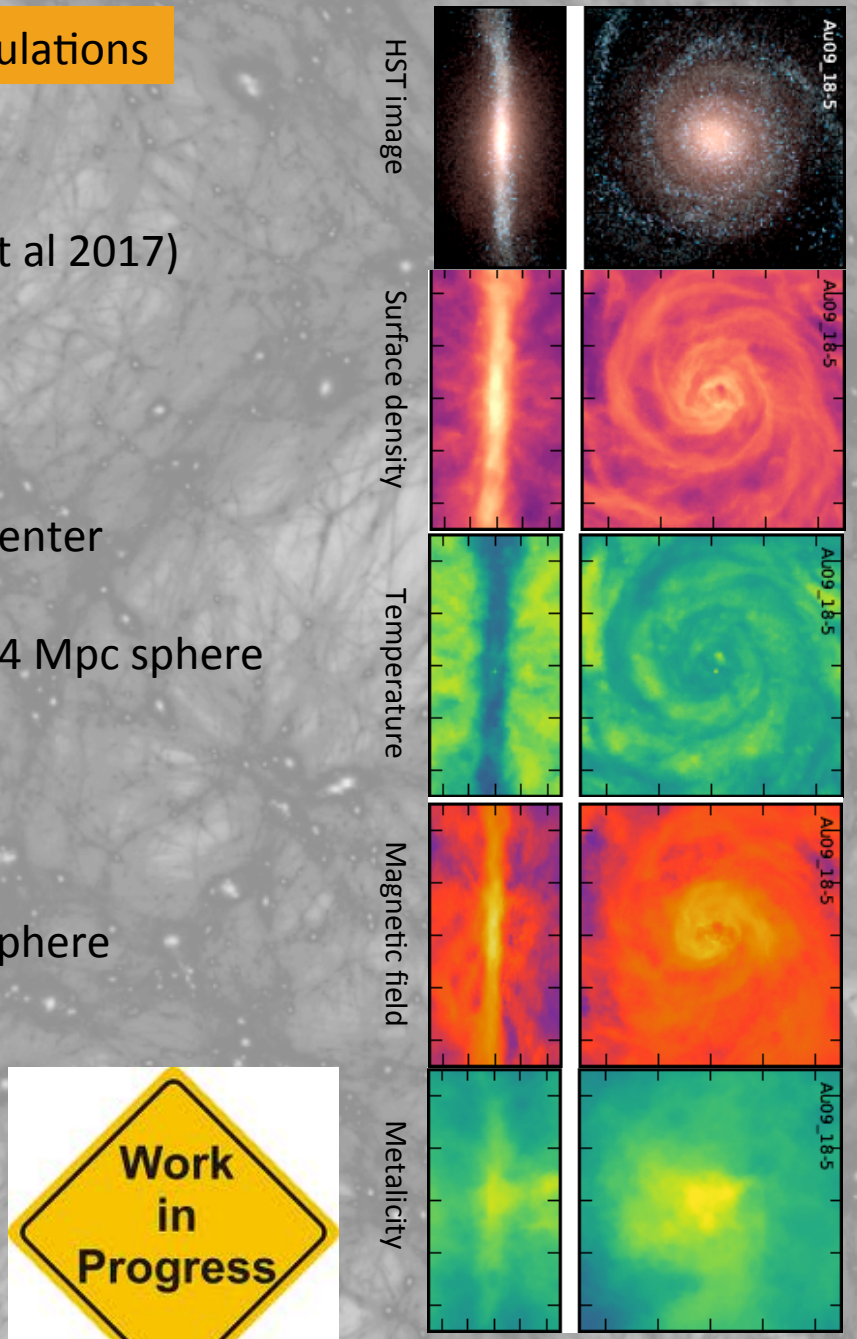
Based on the Auriga galaxy formation Model(Grand et al 2017)

L_{box} = 100Mpc/*h*, Plank cosmology

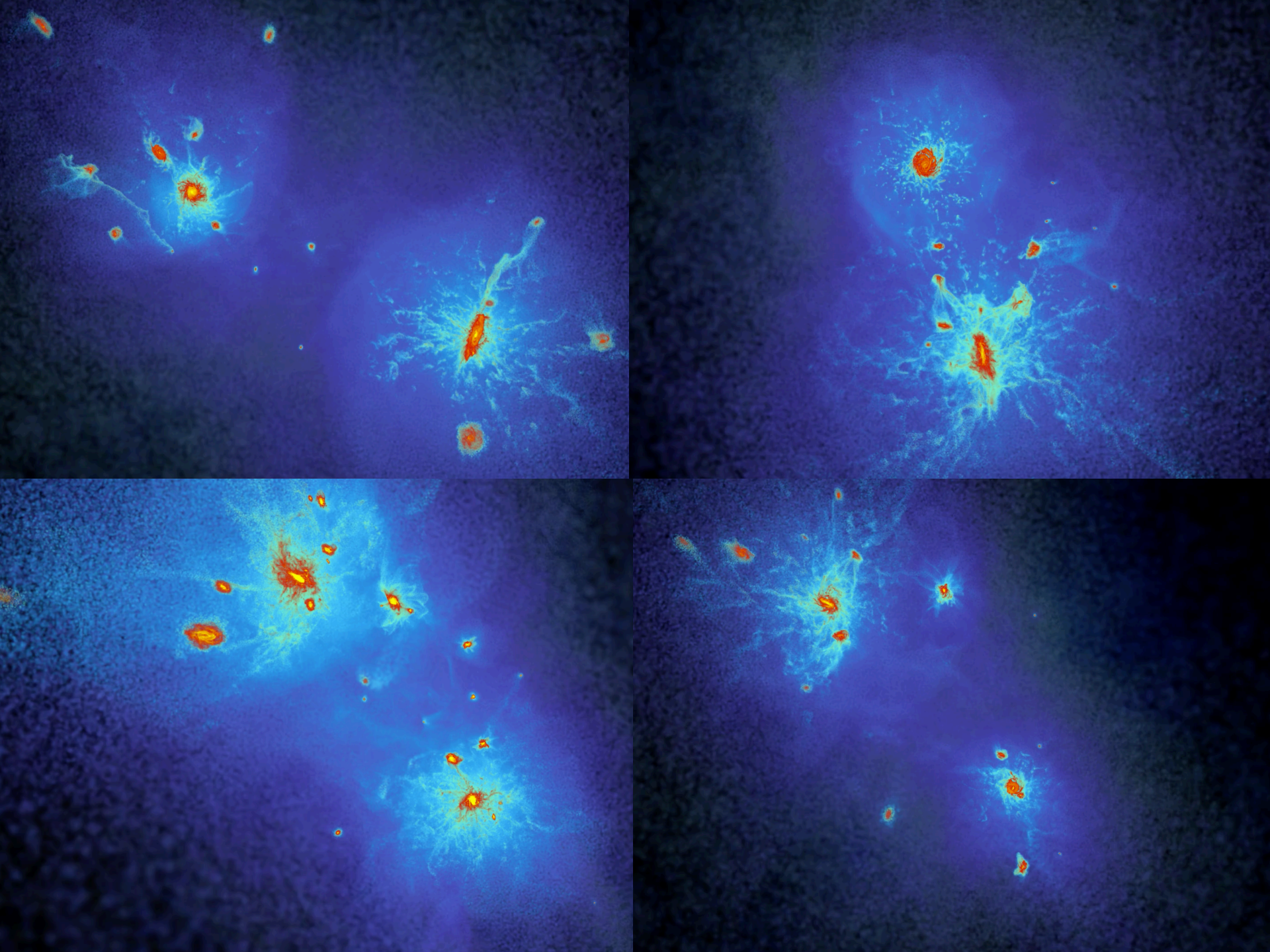
Resimulated region is between 2.5 – 4 Mpc from LG center

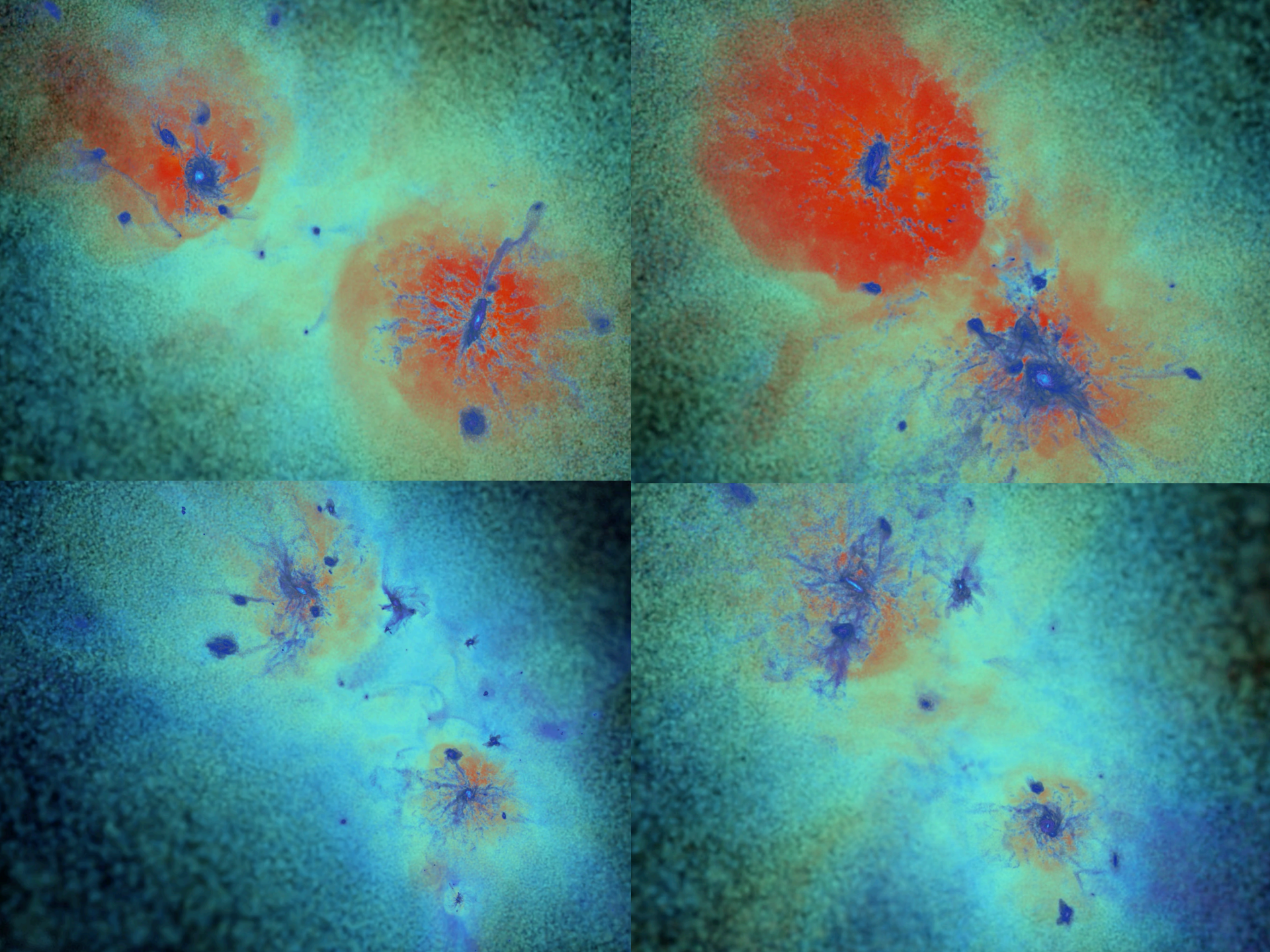
Goal is to have a 10-20 runs at “4096” resolution in a 4 Mpc sphere
$M_{dm} \sim 10^6 M_{sol}$
$M_{baryon} \sim 10^4 M_{sol}$
ε = 350pc

And to have ~5 runs at 8192 resolution in a 2,5 Mpc sphere
$M_{dm} \sim 2.3 \times 10^5 M_{sol}$
M_{baryon} A $10^3 M_{sol}$
ε = 170pc



Grand et al 2017





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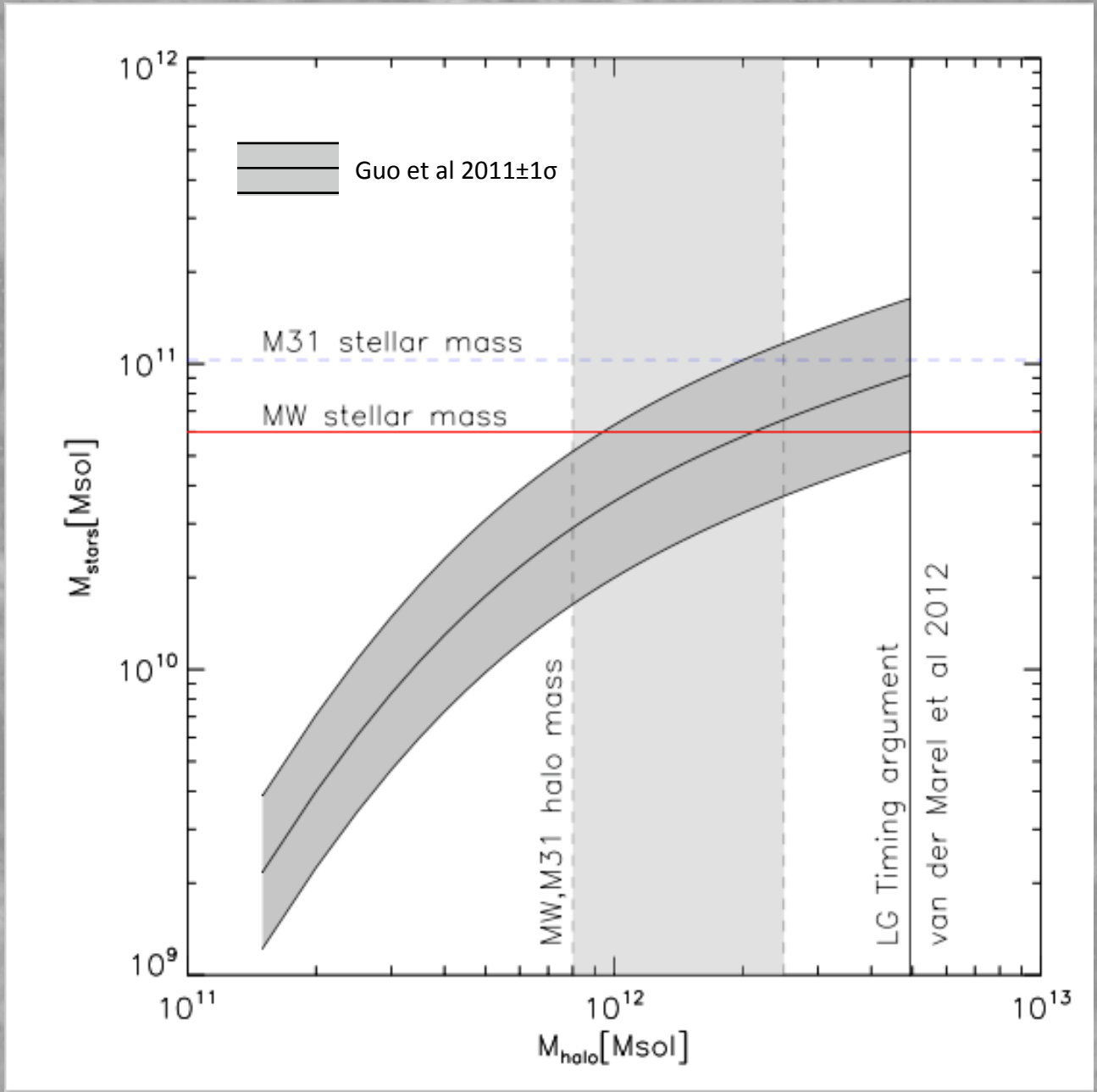
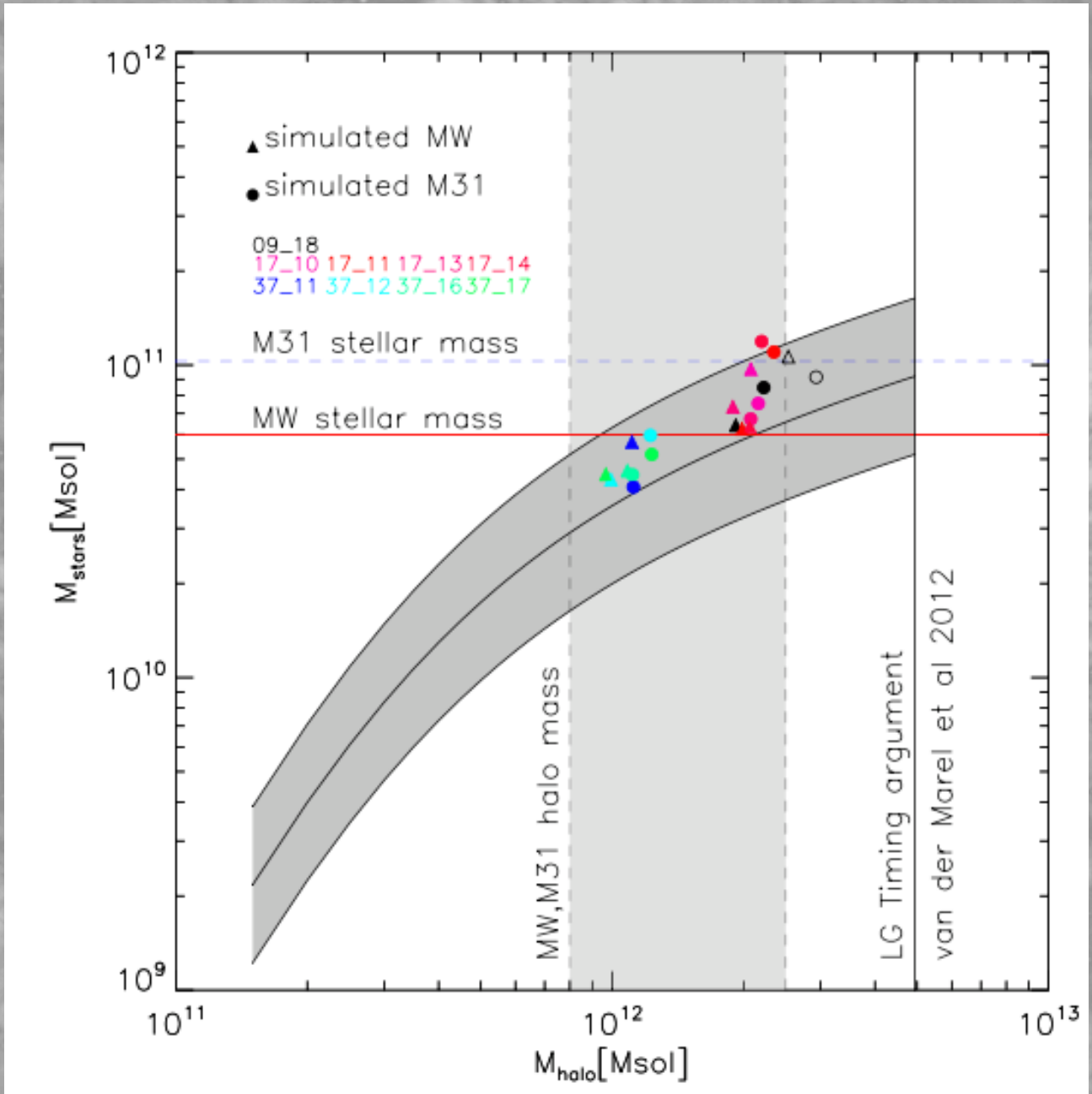
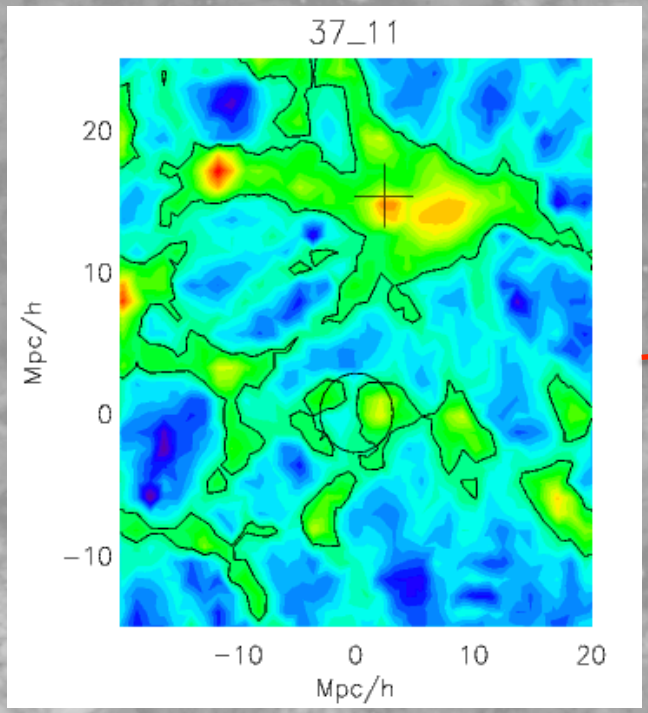
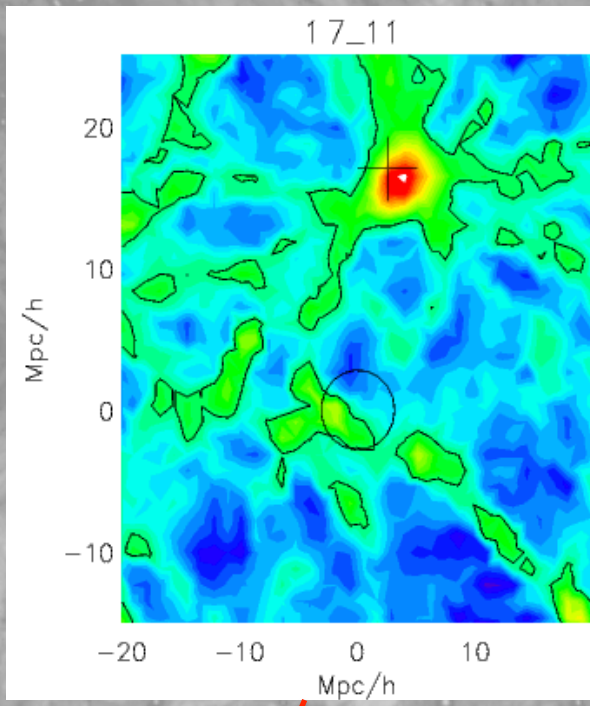


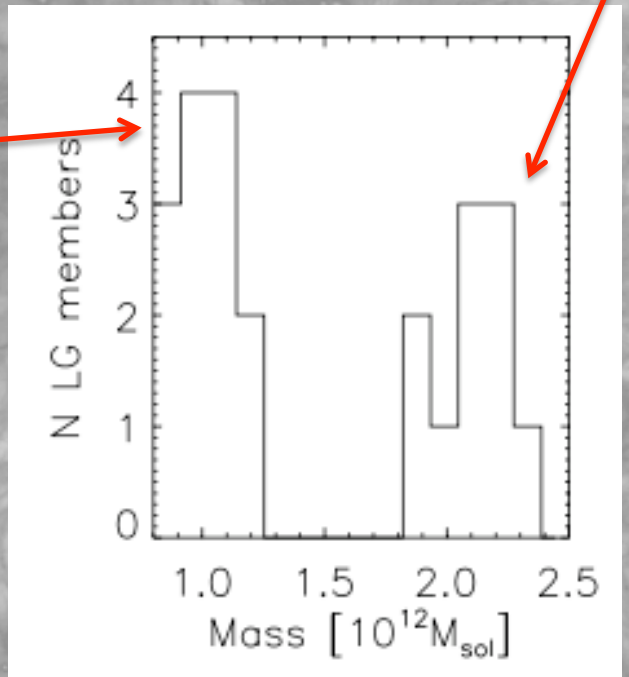
Does the Milky Way look like Andromeda?



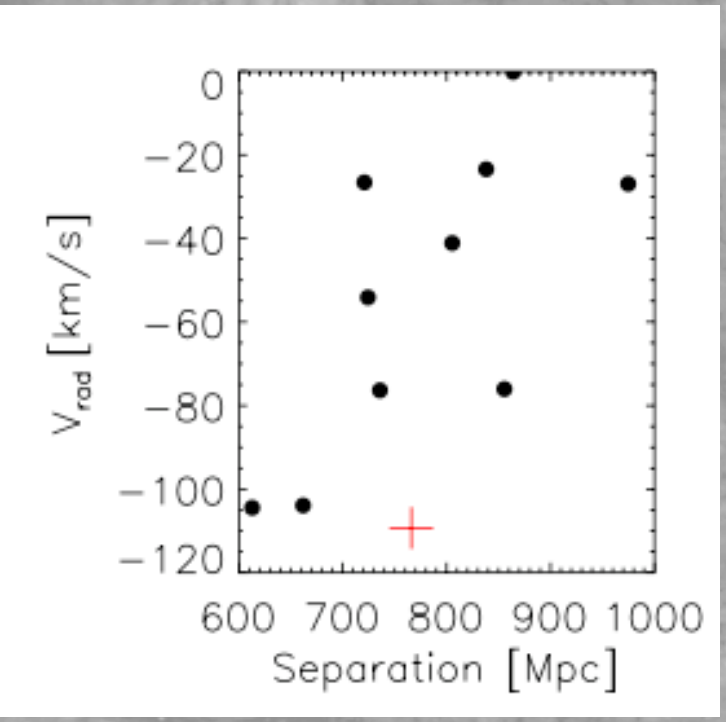
Even though a given realization of the LSS is not guaranteed to produce a "suitable" LG, if it does there's not much variance on the mass of the LG member



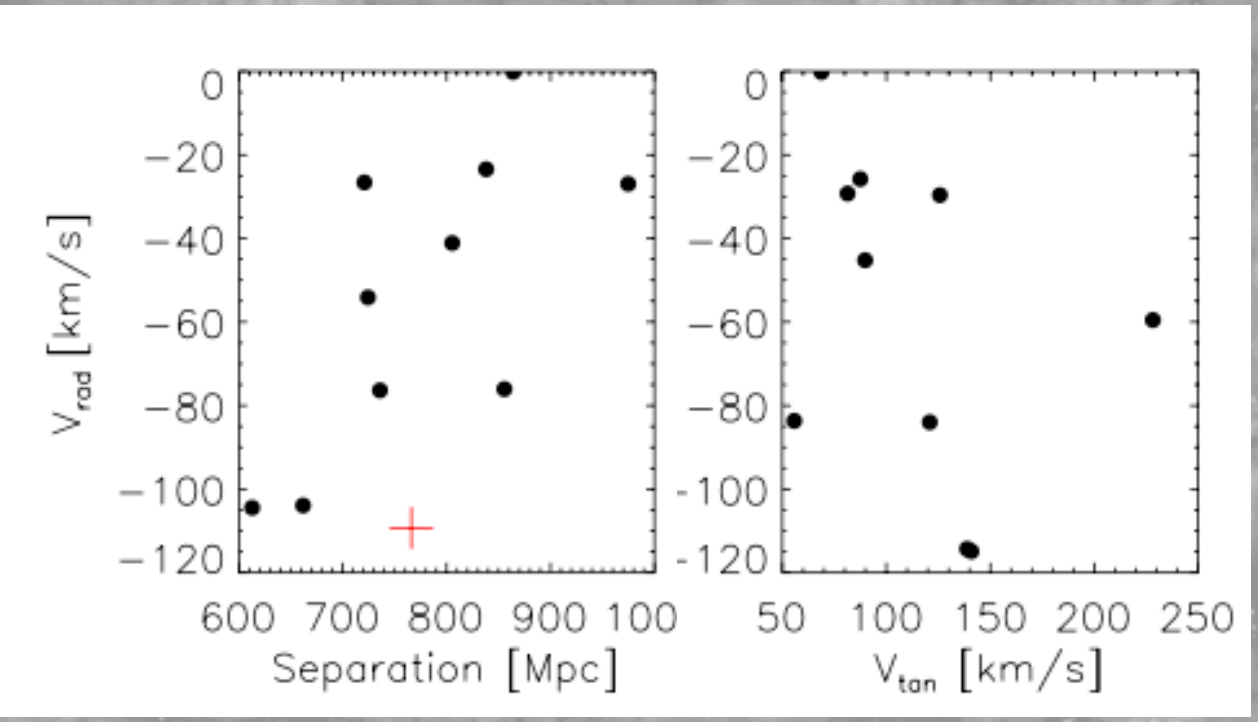




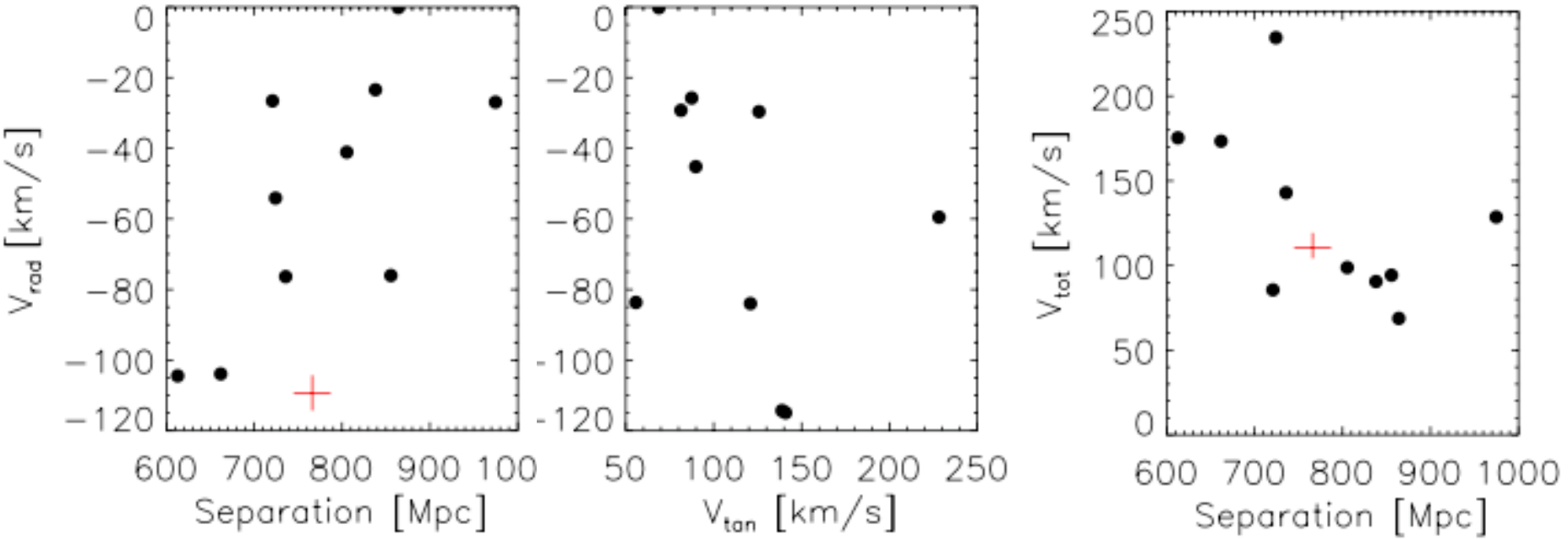
LG dynamics


0
−20
−40
−60
−80
−100
−120
V_{rad} [km/s]
600 700 800 900 1000
Separation [Mpc]

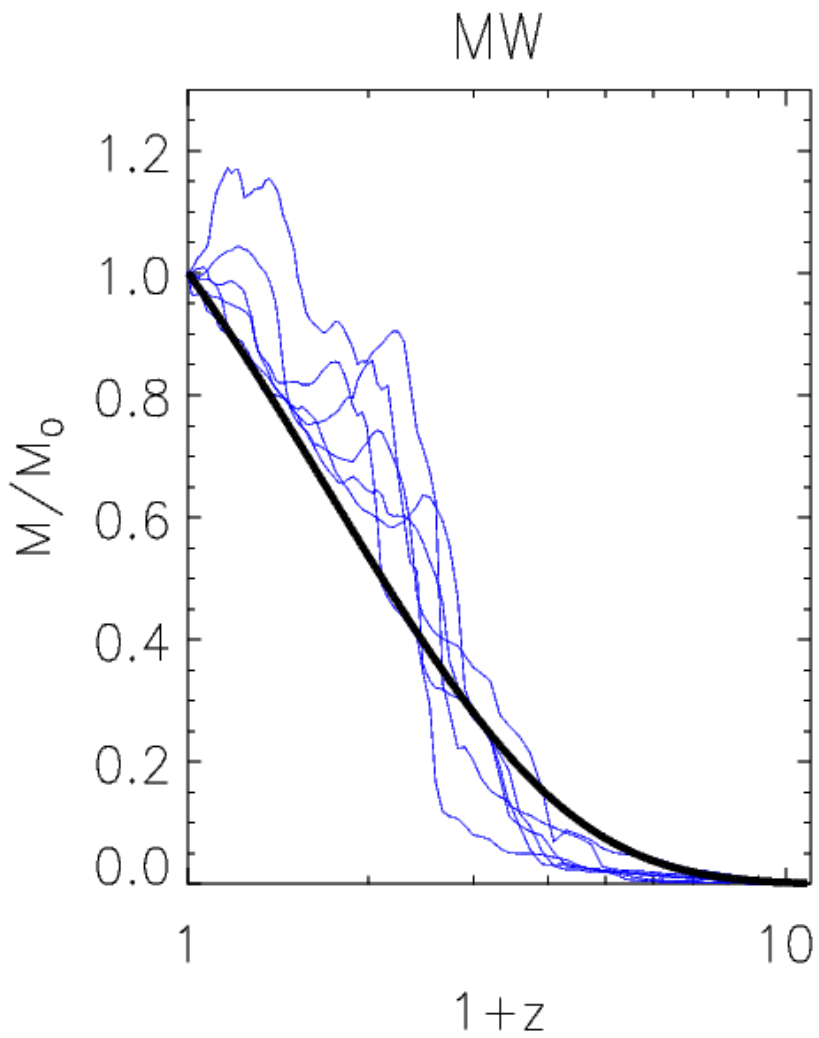
LG dynamics

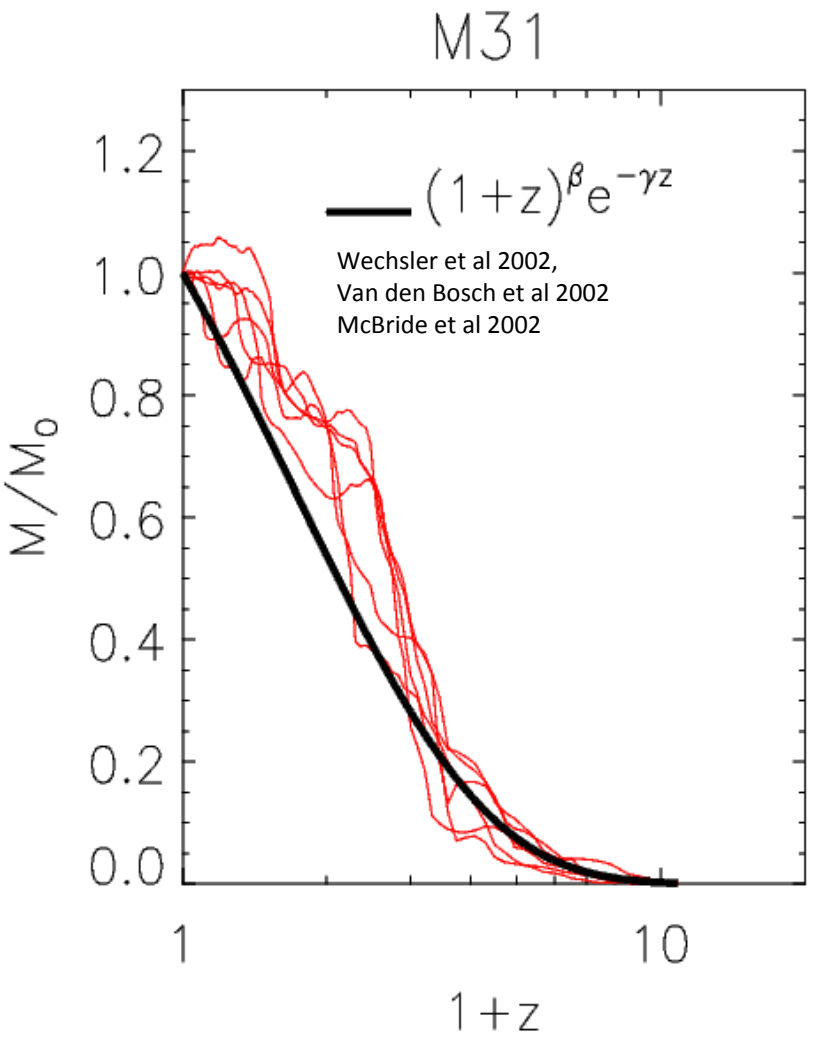

0
−20
−40
−60
−80
−100
−120
V_{rad} [km/s]
600 700 800 900 100
Separation [Mpc]
0
−20
−40
−60
−80
-100
-120
50 100 150 200 250
V_{tan} [km/s]

LG dynamics

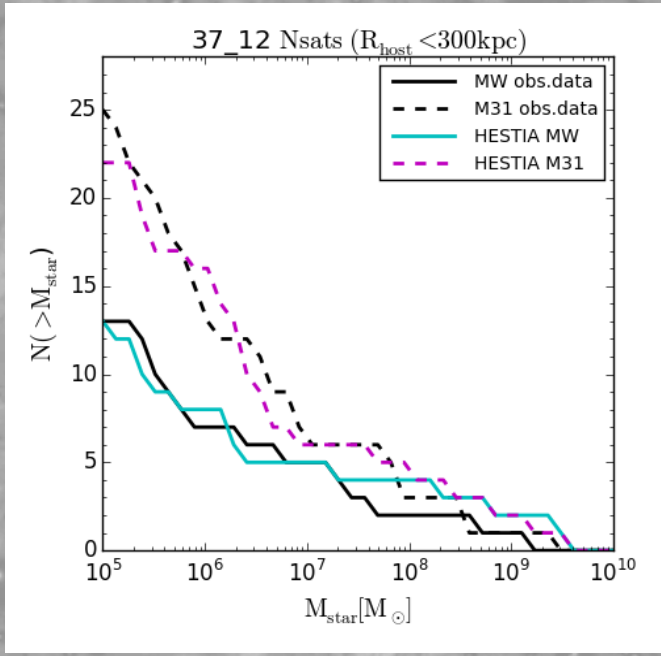

0
−20
−40
−60
−80
−100
−120
V_{rad} [km/s]
600 700 800 900 100
Separation [Mpc]
0
-20
-40
-60
-80
-100
-120
50 100 150 200 250
V_{tan} [km/s]
250
200
150
100
50
0
V_{tot} [km/s]
600 700 800 900 1000
Separation [Mpc]

Halo growth seems a bit faster after z=2





A Note on the Satellites mass function and concentration

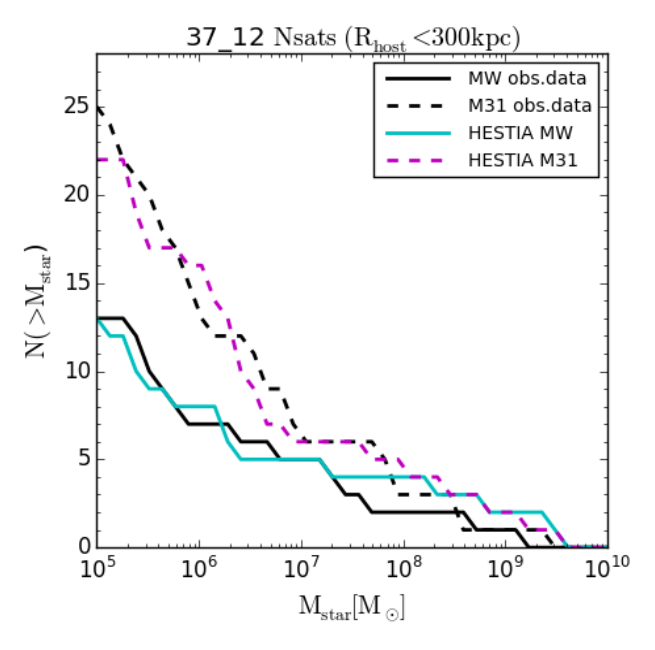


Dwarf galaxy Mass function looks excellent

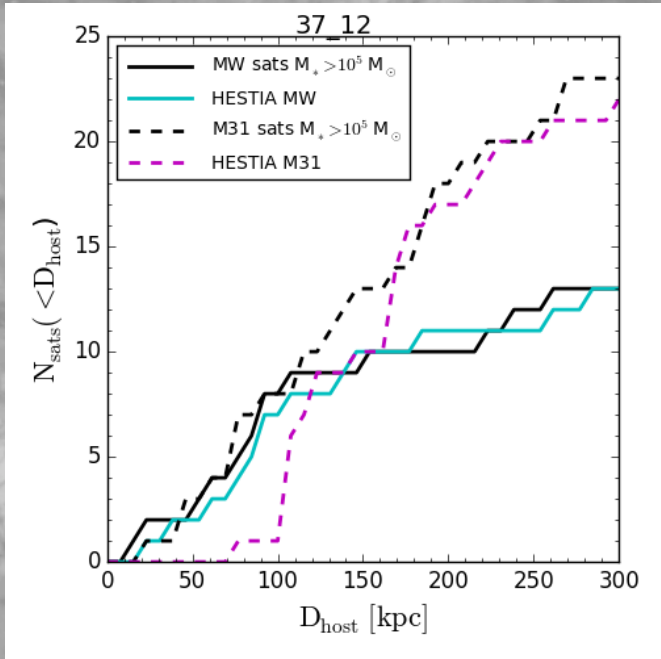
✔

Credit: isabel Santos-Santos

A Note on the Satellites mass function and concentration



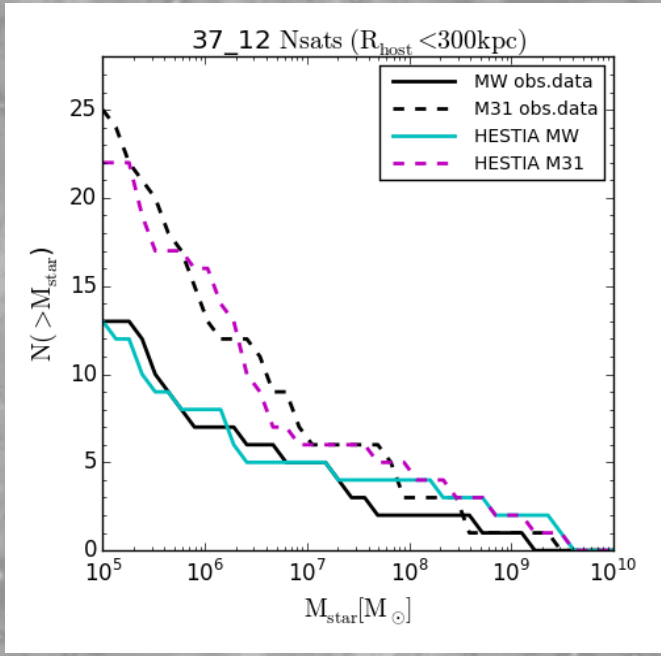
Dwarf galaxy mass function looks excellent

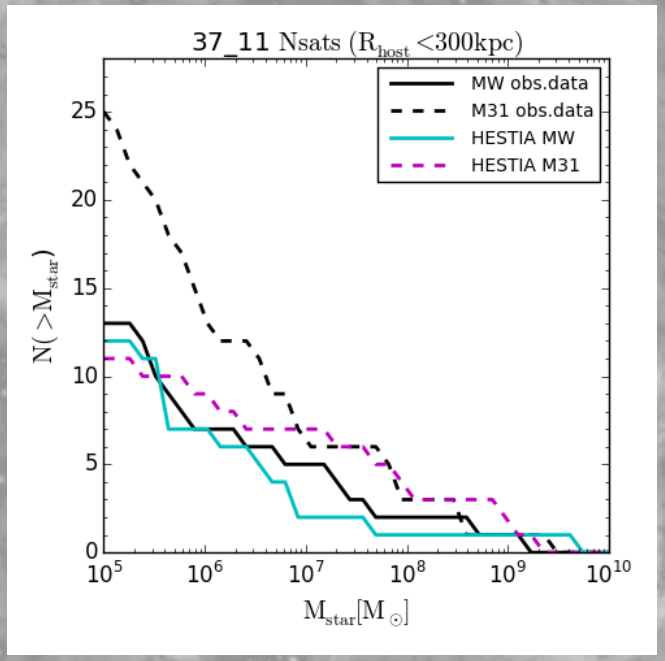


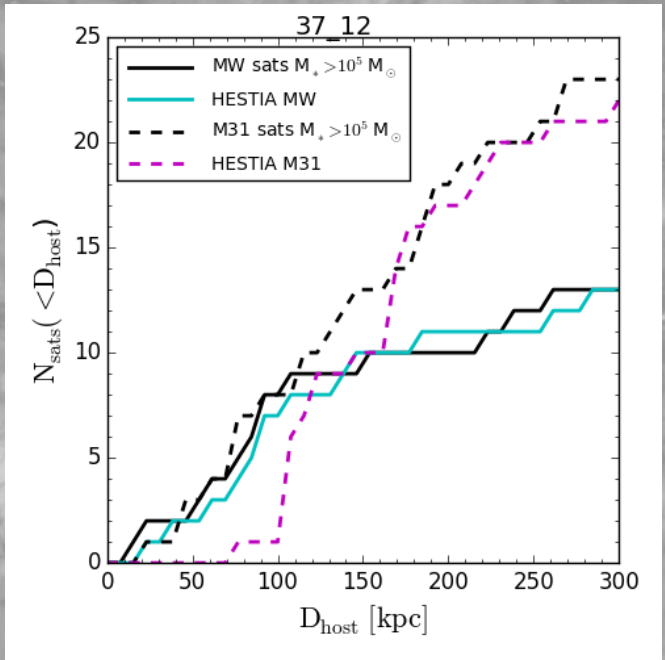
Radial concentration looks good

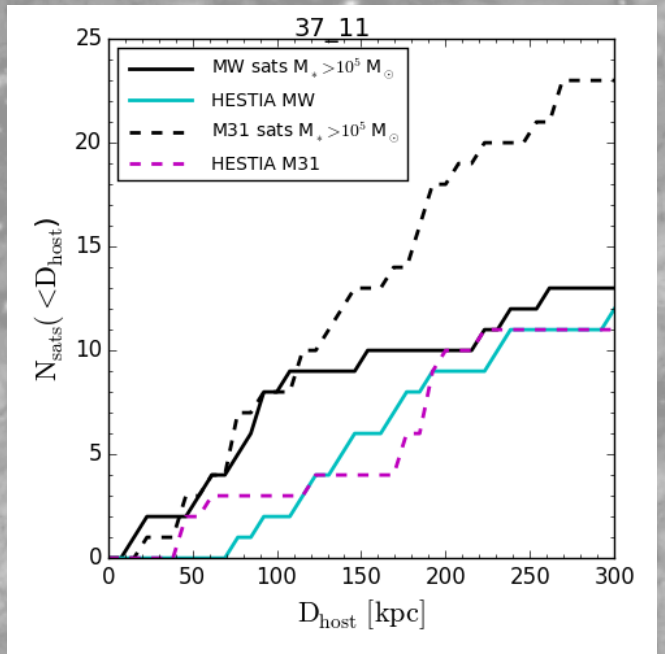
Credit: isabel Santos-Santos

A Note on the Satellites mass function and concentration









Credit: isabel Santos-Santos

Hestia is a suite of Local Group hydro simulations run with AREPO, where the Large Scale Structure has been constrained to mimic the local cosmography.

Although the bulk properties (stellar mass, dm halo mass, etc) conform, the small scale structure (e.g. satellite properties) exhibits variance

The LSS does however seem to affect both the mass accretion history of the Local Group and the mass of the Local Group

Higher resolution runs are under way..