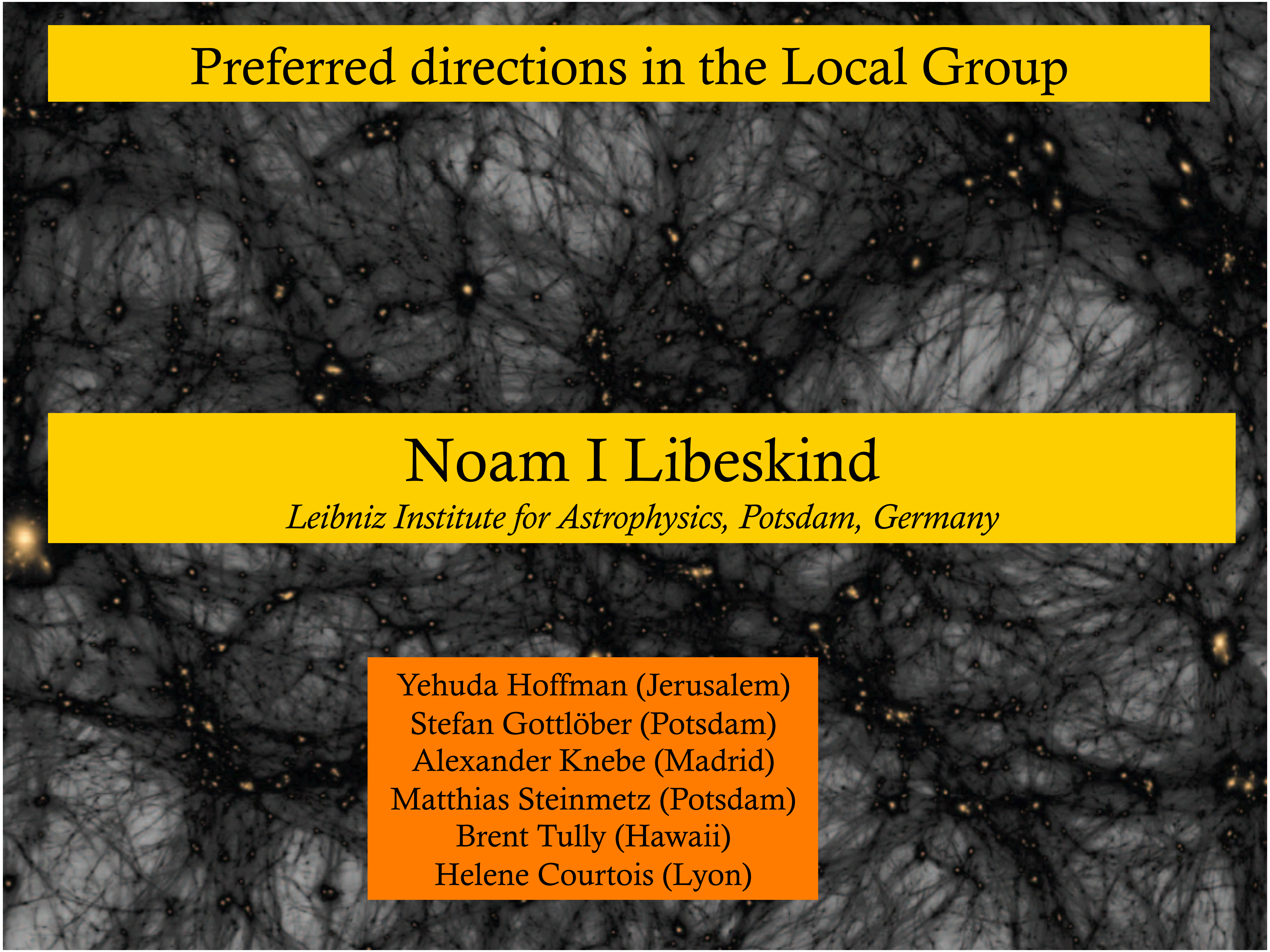
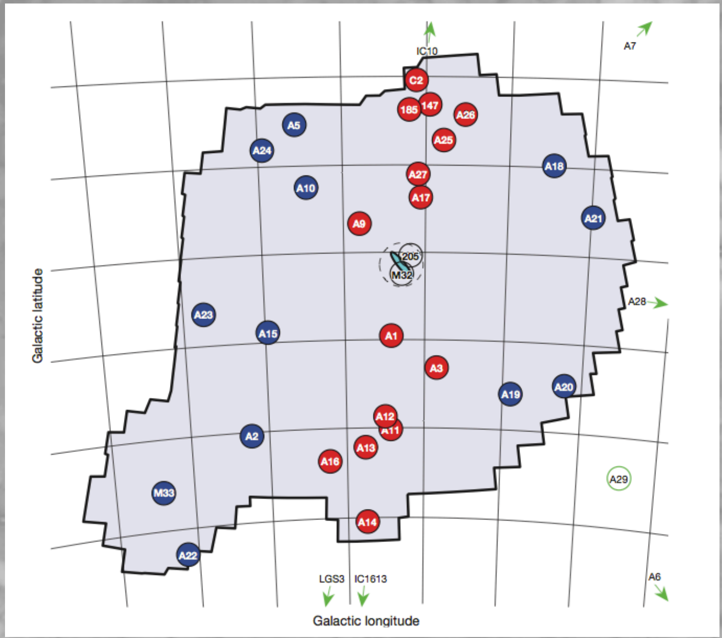


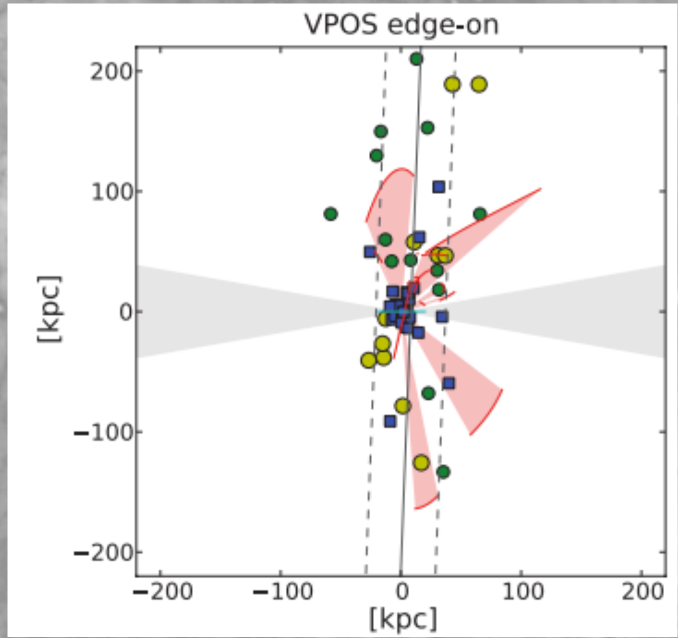
Preferred directions in the Local Group

Noam I Libeskind

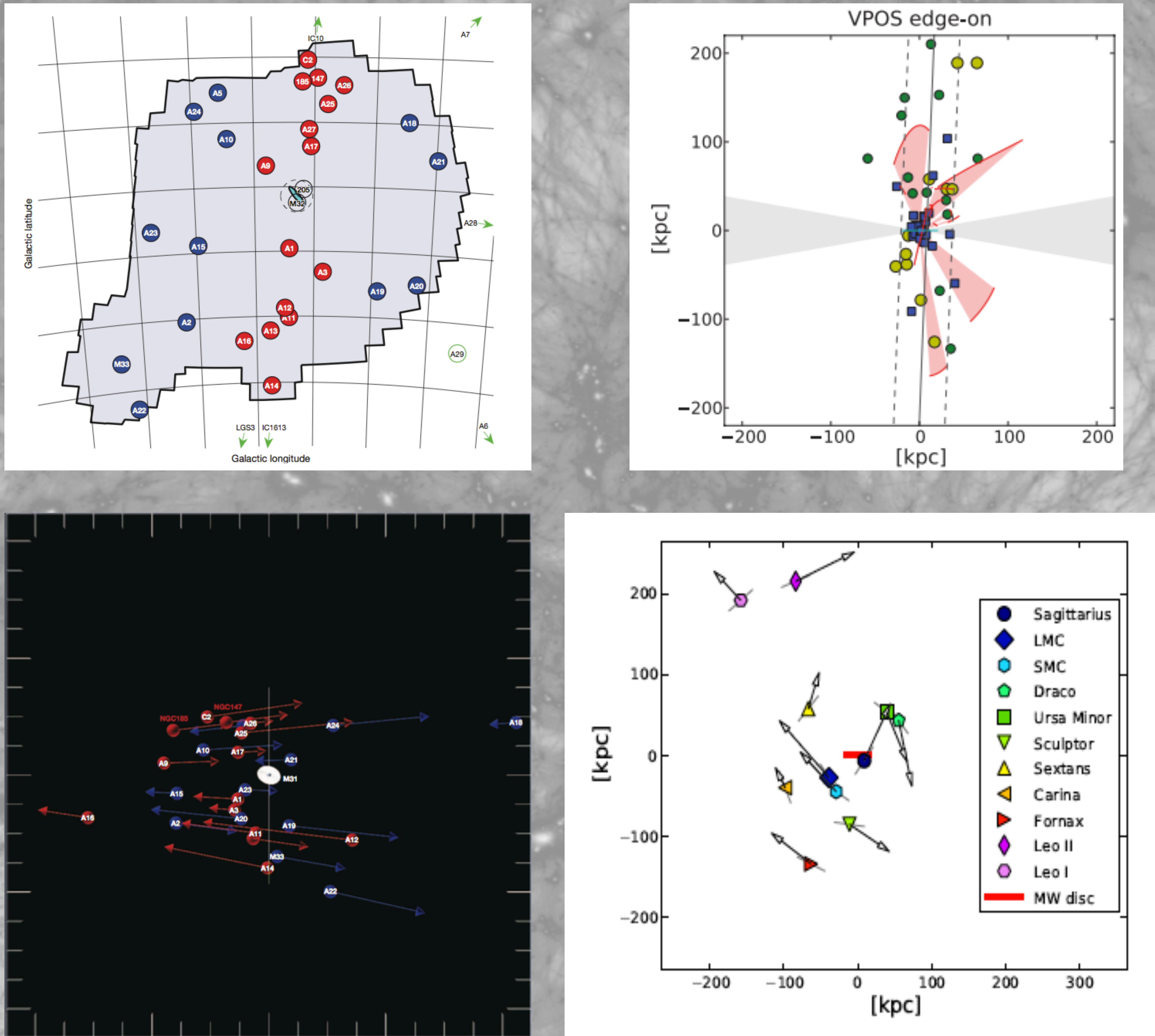
Leibniz Institute for Astrophysics, Potsdam, Germany

Yehuda Hoffman (Jerusalem)
Stefan Gottlöber (Potsdam)
Alexander Knebe (Madrid)
Matthias Steinmetz (Potsdam)
Brent Tully (Hawaii)
Helene Courtois (Lyon)

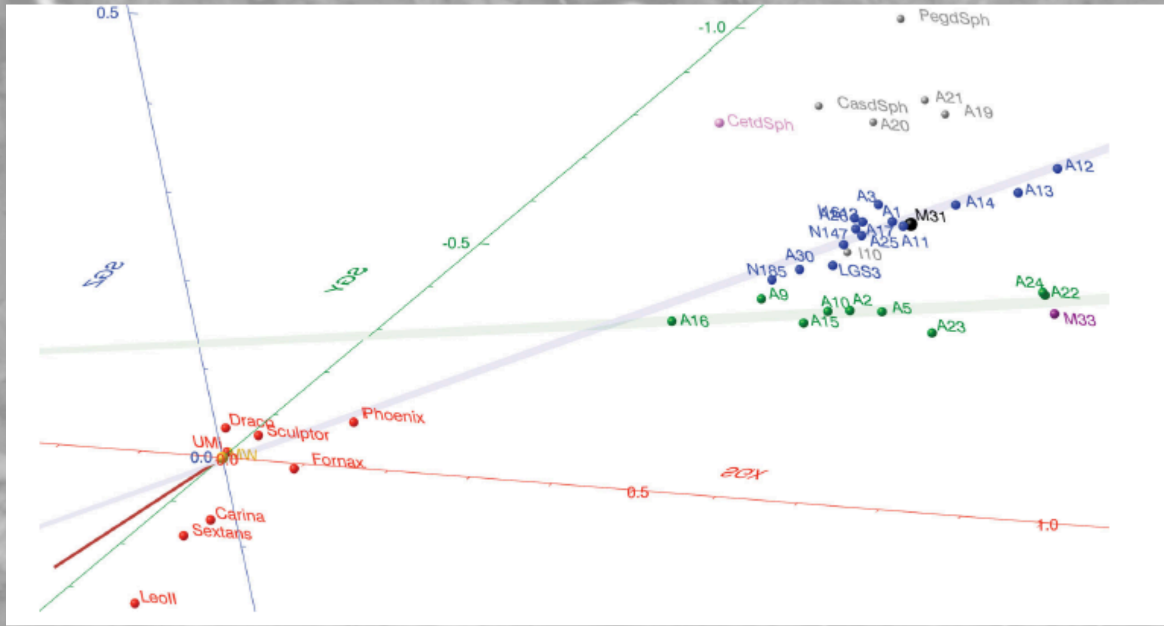




Ibata et al 2013, Conn et al 2013 Kroupa et al 2005, Pawlowski & Kroupa 2013 Metz, Kroupa & Libeskind 2008



Ibata et al 2013, Conn et al 2013 Kroupa et al 2005, Pawlowski & Kroupa 2013 Metz, Kroupa & Libeskind 2008



PegdSph
CasdSph
A21
A19
A20
CetdSph
A12
A13
A14
A3
A1
M31
N147
A17
A25
A11
A30
I10
N185
LGS3
A24
A22
A9
A10
A2
A5
A16
A15
A23
M33
Phoenix
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UMi
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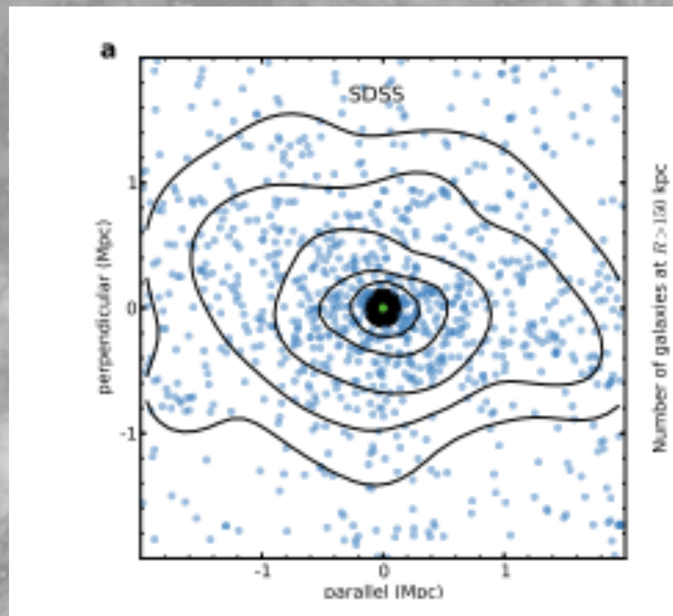
-0.5
0.0
1.0

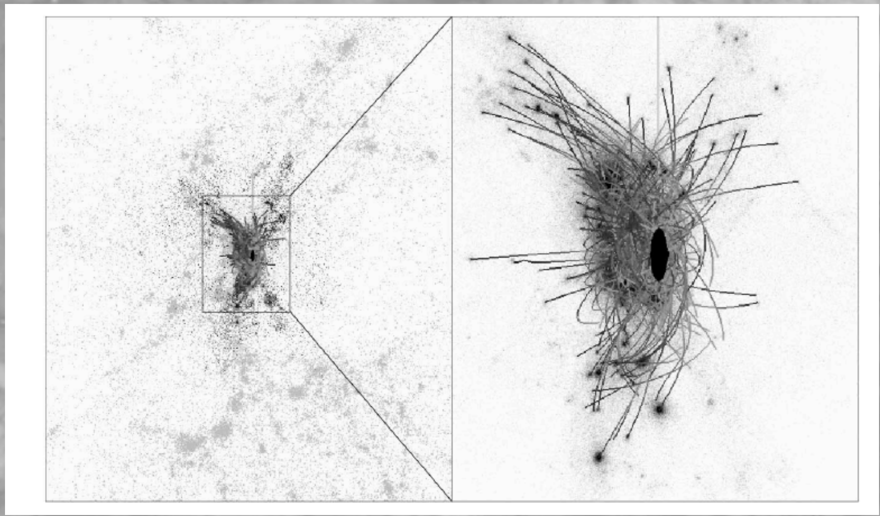


a
SDSS
perpendicular (Mpc)
parallel (Mpc)
Number of galaxies at R > 150 kpc

+ Ibata[2]

+ …

Q: What makes a dwarf a satellite?



Knebe et al 2004

A: Accretion onto larger host

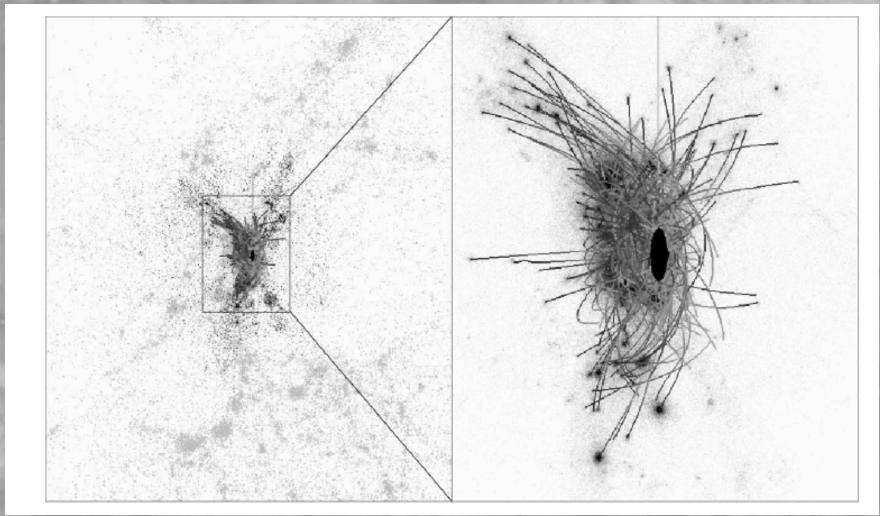
•*Strangulation*

•*Harassment*

• *Stripping*

•*Cannibalism*

Q: What makes a dwarf a satellite?



A: Accretion onto larger host
- *Strangulation* → Satellite can no longer accrete gas
- *Harassment* → Satellite has high speed encounters which perturb it
- *Stripping* → Satellite disintegrates due to tidal encounters
- *Cannibalism* → Mergers

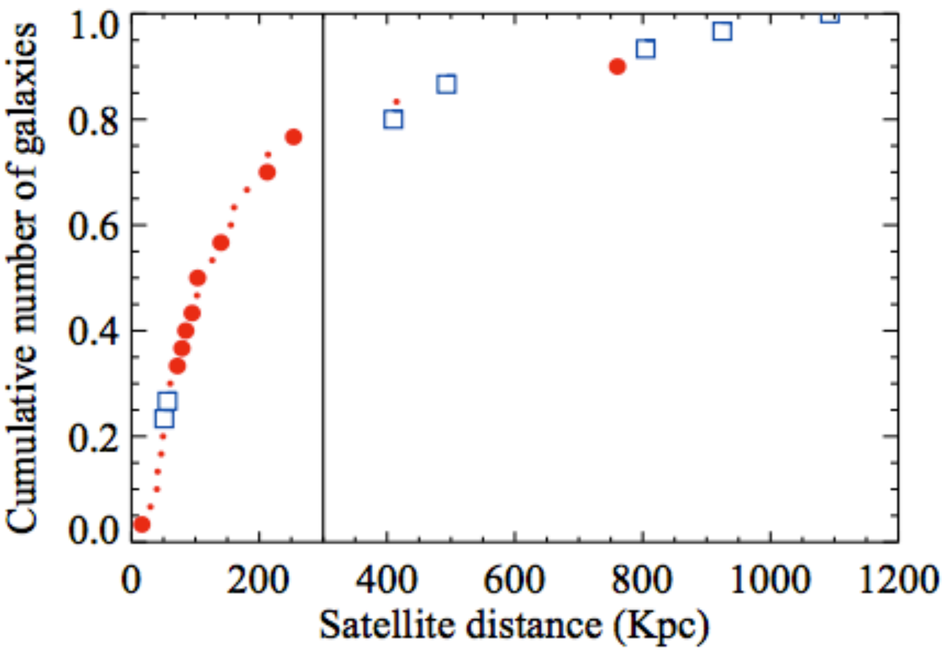
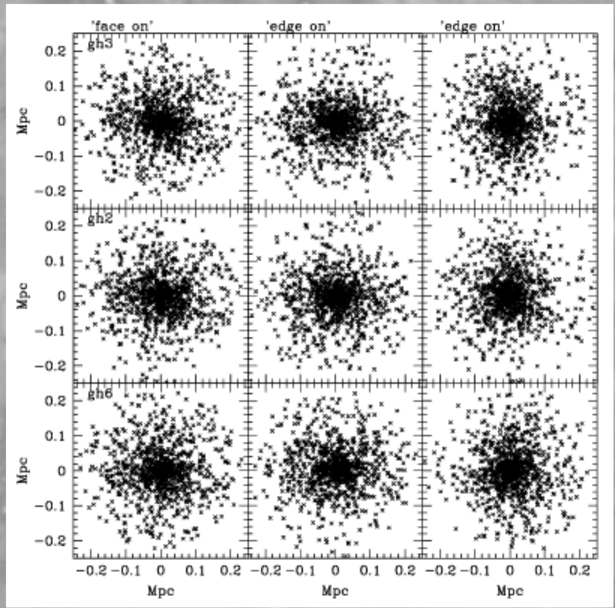
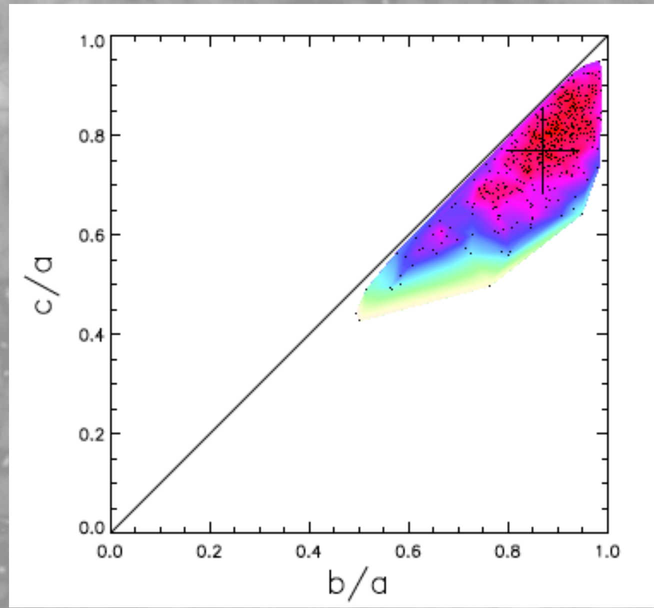


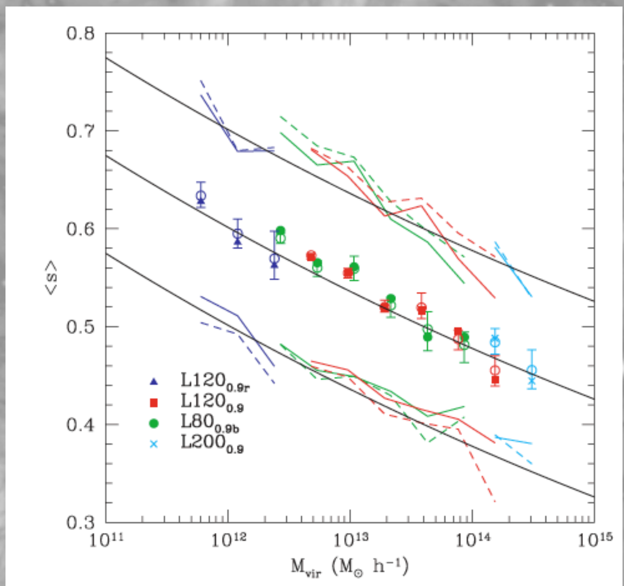
Figure 1. Distribution function of the satellite-MW distances. Large red points represent the dSphs, small red ones the UFDs, while blue squares represent the dIrrs. A line separates the MW companions considered in this study (closer than 300 kpc) from the other dwarf galaxies.

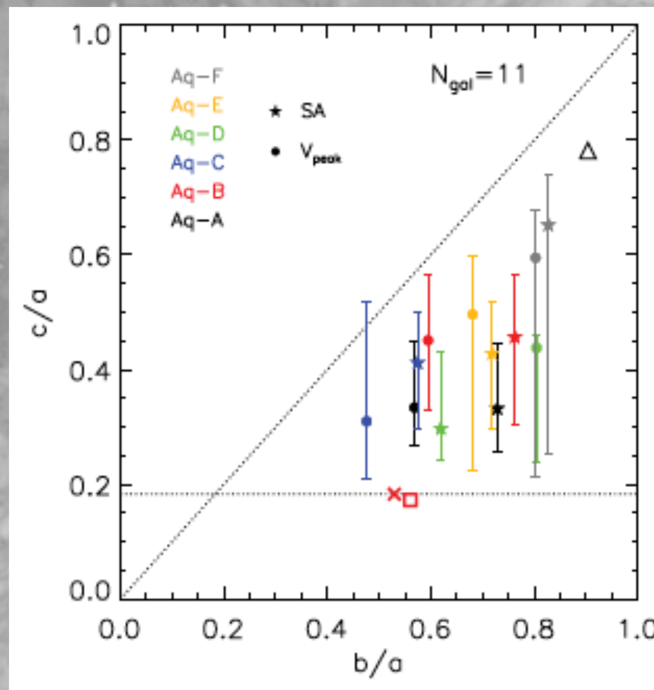
Extreme objects: metalicity, DM content, surface brightness

Foquiet et al 2012

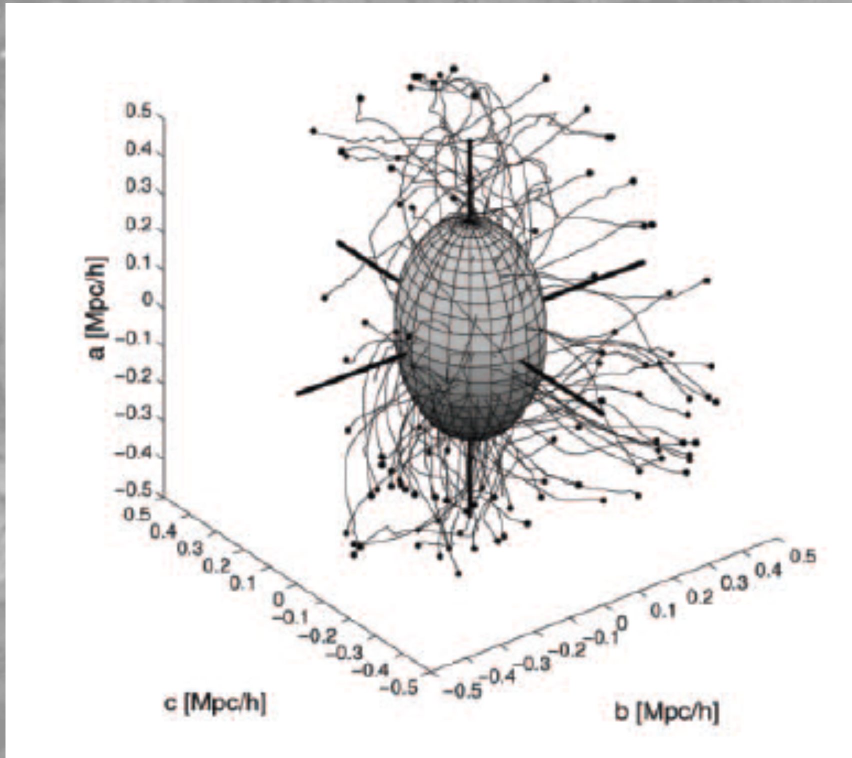


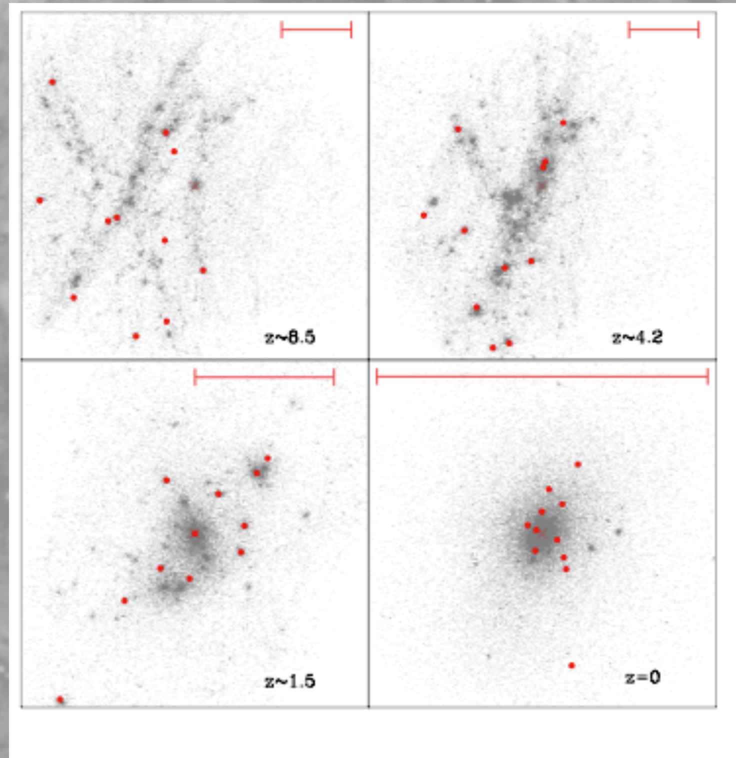






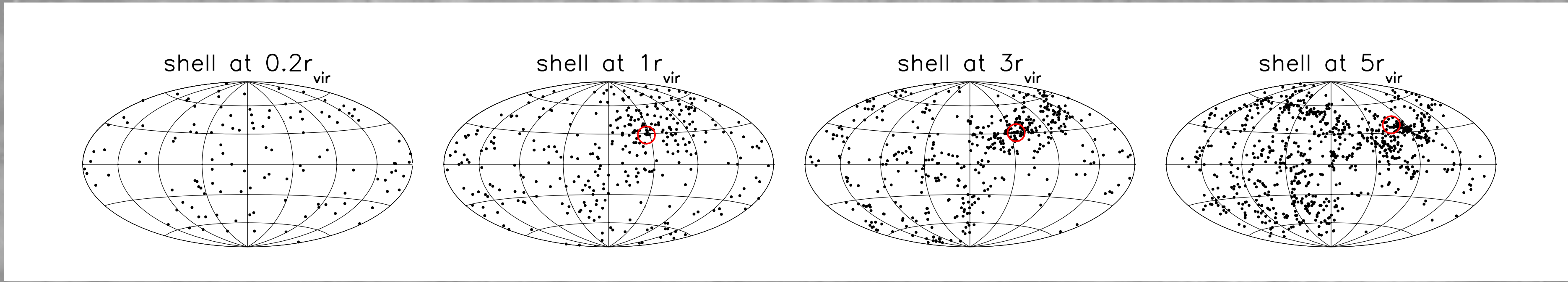
Wang et al 2013, Libeskind et al 2005, Allgood et al 2006

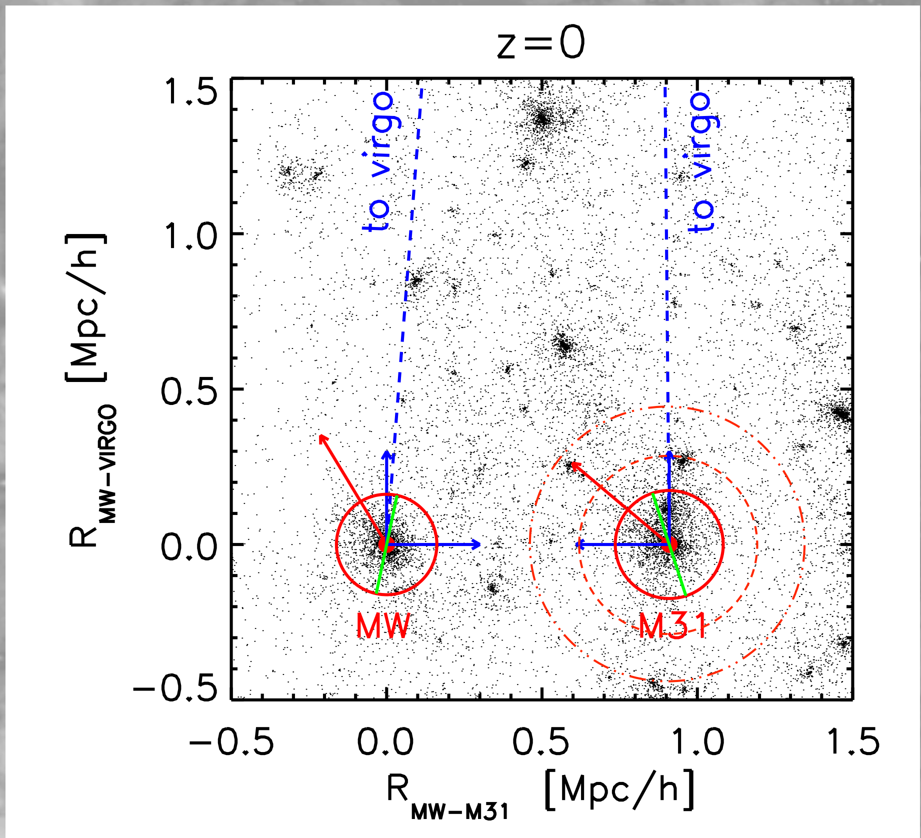


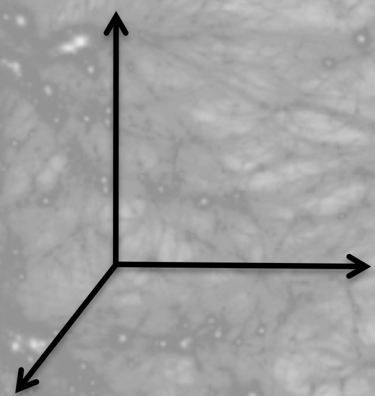


Zentner et al 2005, Libeskind et al 2005

Where do the entry points of accreted satellites lie?





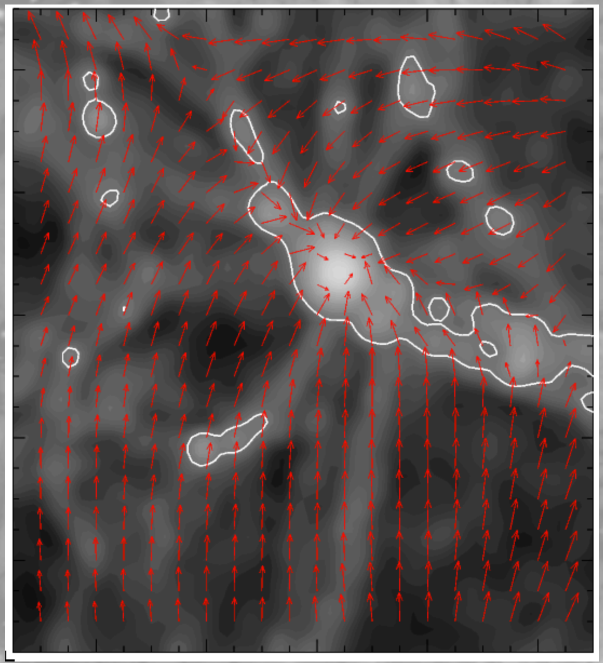


Libeskind et al 2011

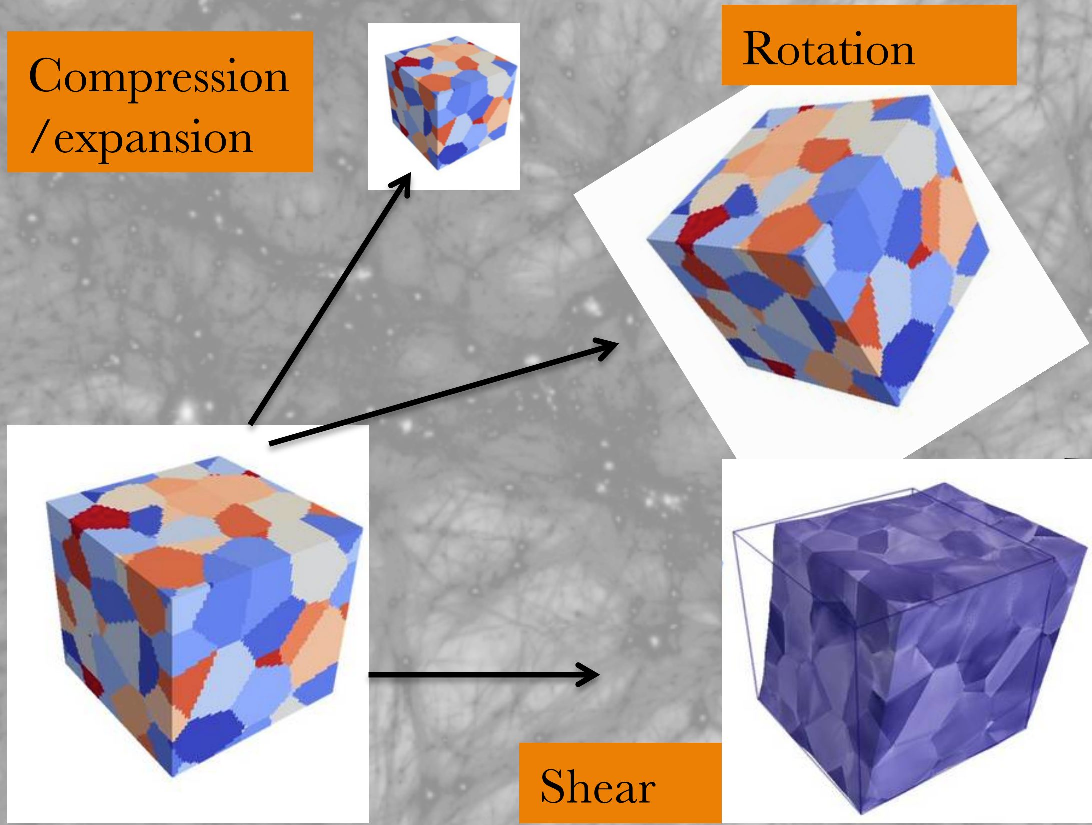
Velocity Shear Tensor

Looking at LSS from the point of view of (*peculiar*) velocity.

Specifically the deformation of the velocity field – shear, compression and rotation:



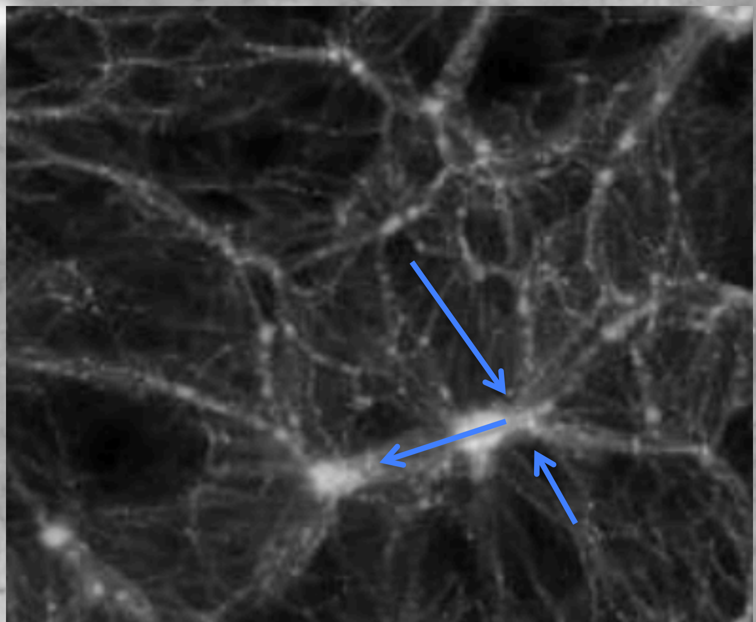
Hoffman et al 2012
Libeskind et al 2012, 2013

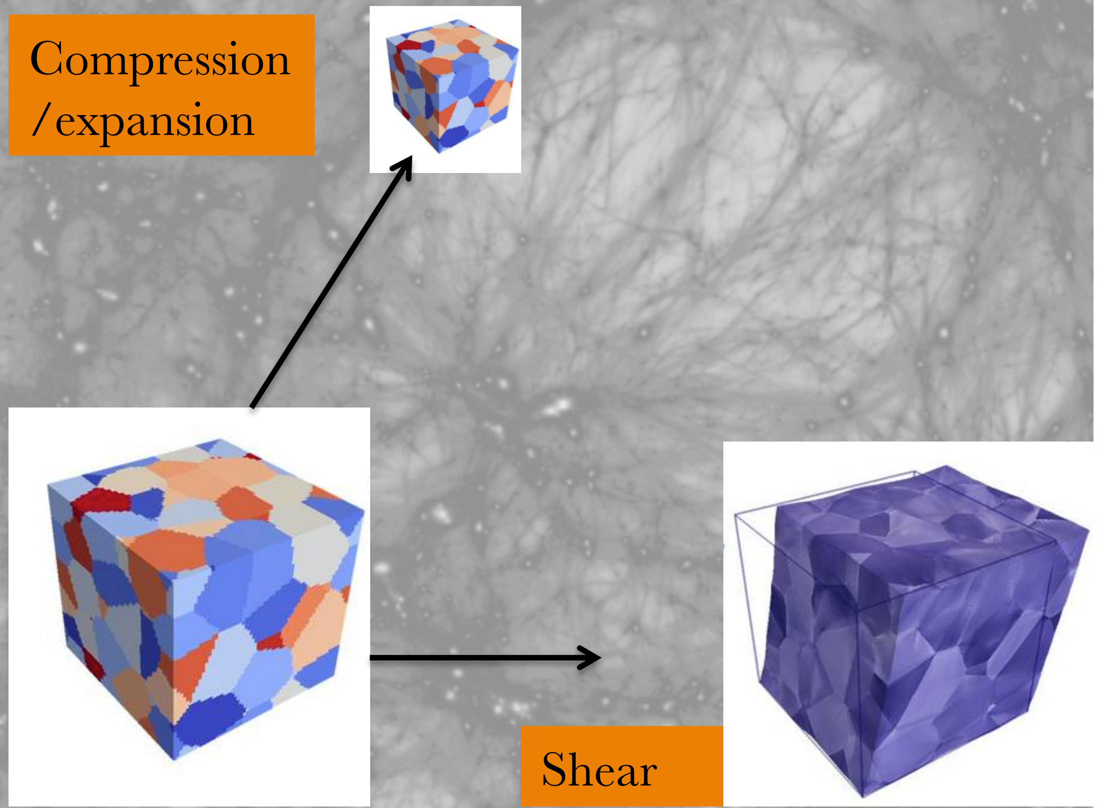


Symmetric part is the "Shear" tensor + Divergence

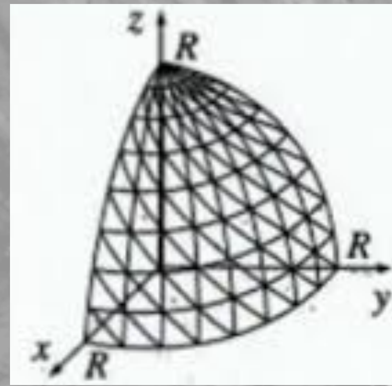
$$\Sigma_{ij} = \frac{1}{2H(z)}\left(\frac{\partial v_i}{\partial r_j} + \frac{\partial v_j}{\partial r_i}\right)$$

The eigenvectors of the shear give the principal axes along which material is collapsing/expanding.

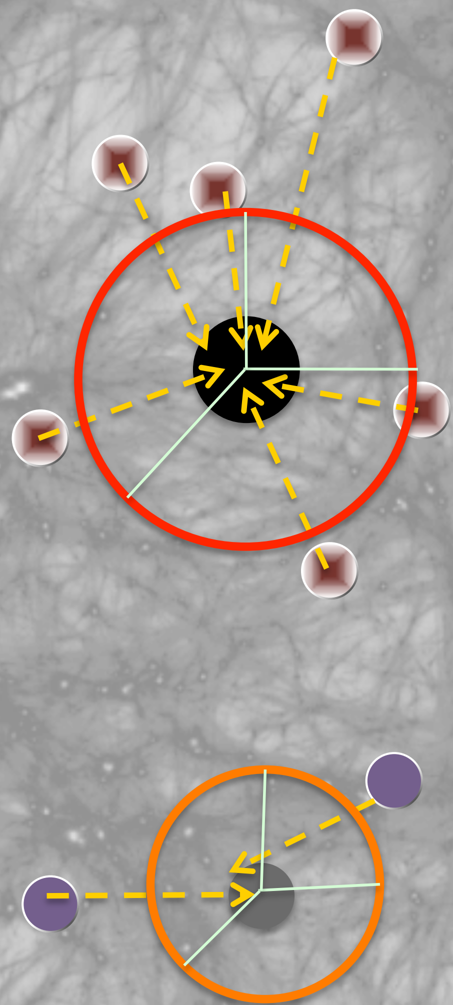


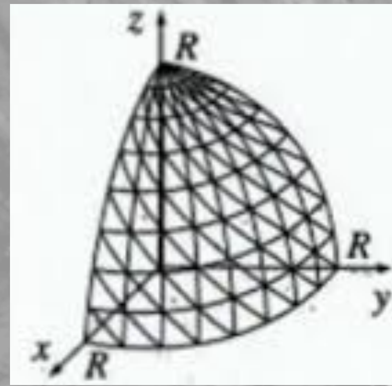


Eigenvectors are degenerate: Only one octant



For each accretion event onto each halo at all *z*, we compute the shear *adaptively* on 4, 8, 16r_{vir} scales





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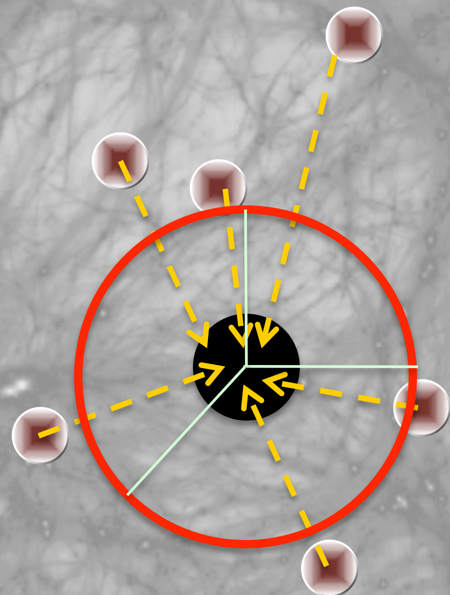


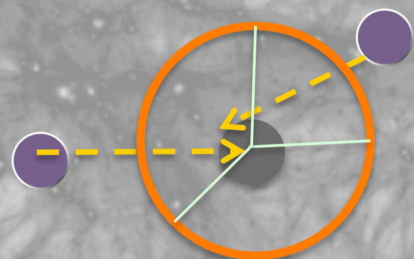
For each accretion event onto each halo at all *z*, we compute the shear *adaptively* on 4, 8, $16r_{vir}$ scales

Scale the mass of each halo

$$\tilde{M} = \frac{M_{vir}}{M_\star}$$

$M_\star$ - Mass scale of collapsing objects at *z*.

Mass in closed by a radius on which the variance σ^2 is equal to the square of the critical density threshold for collapse, δ_c^2



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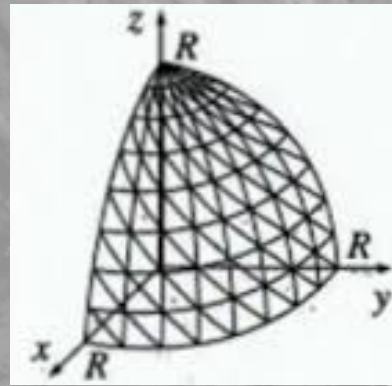

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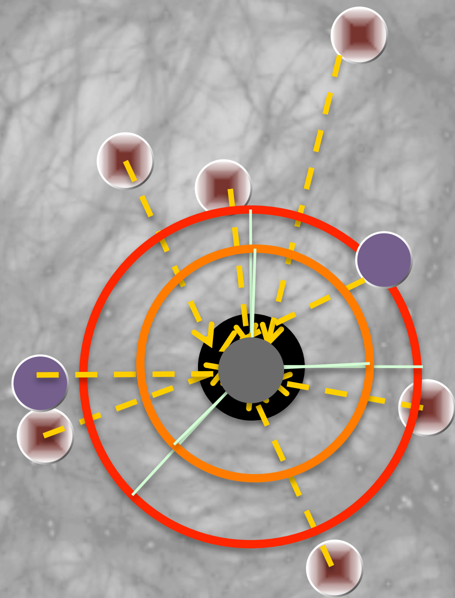


Scale the mass of each halo

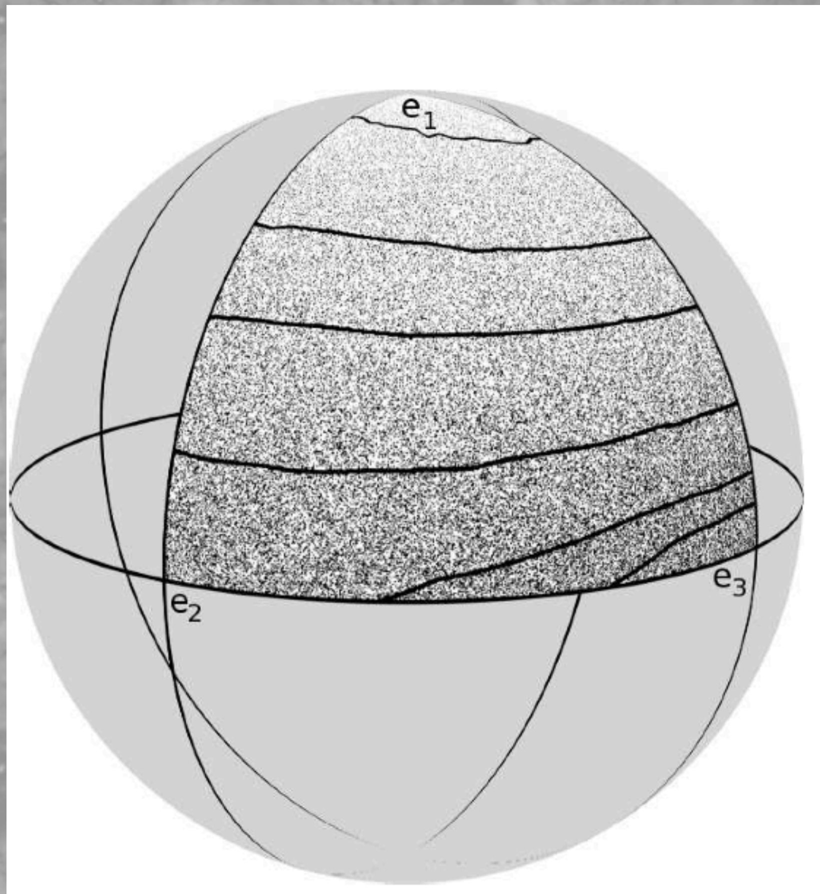
$$\tilde{M} = \frac{M_{vir}}{M_\star}$$

$M_\star$ - Mass scale of collapsing objects at *z*.

Stack, all accretion events, all haloes, all *z*

Infall points of subhaloes in the Shear eigenframe

1024^3 DM only simulation WMAP9
64Mpc box, Mres~ 2e7Msol



Libeskind et al 2014

Infall points of subhaloes in the Shear eigenframe

1024^3 DM only simulation WMAP9
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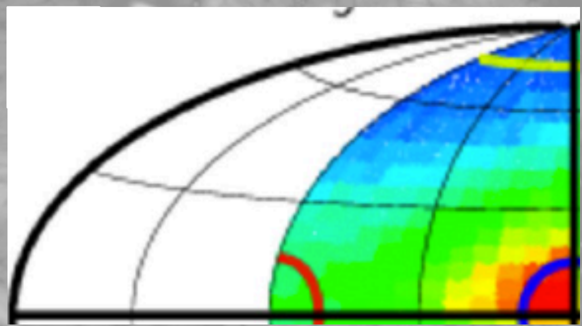
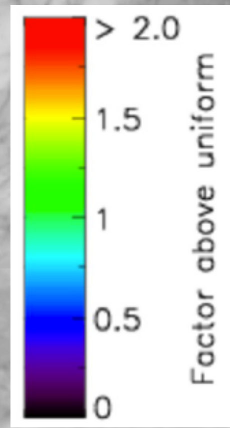


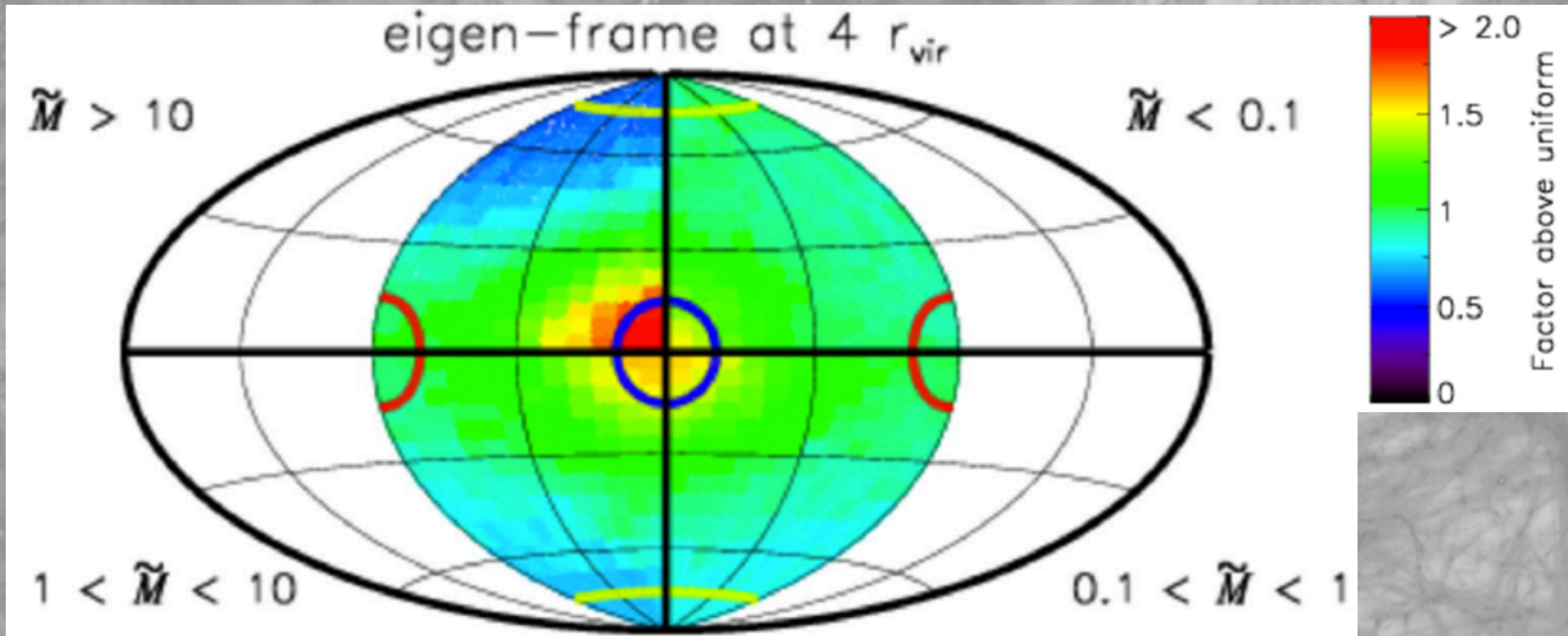


Libeskind et al 2014

All mergers

Infall points of subhaloes in the Shear eigenframe

1024^3 DM only simulation WMAP9
64Mpc box, Mres~ 2e7Msol

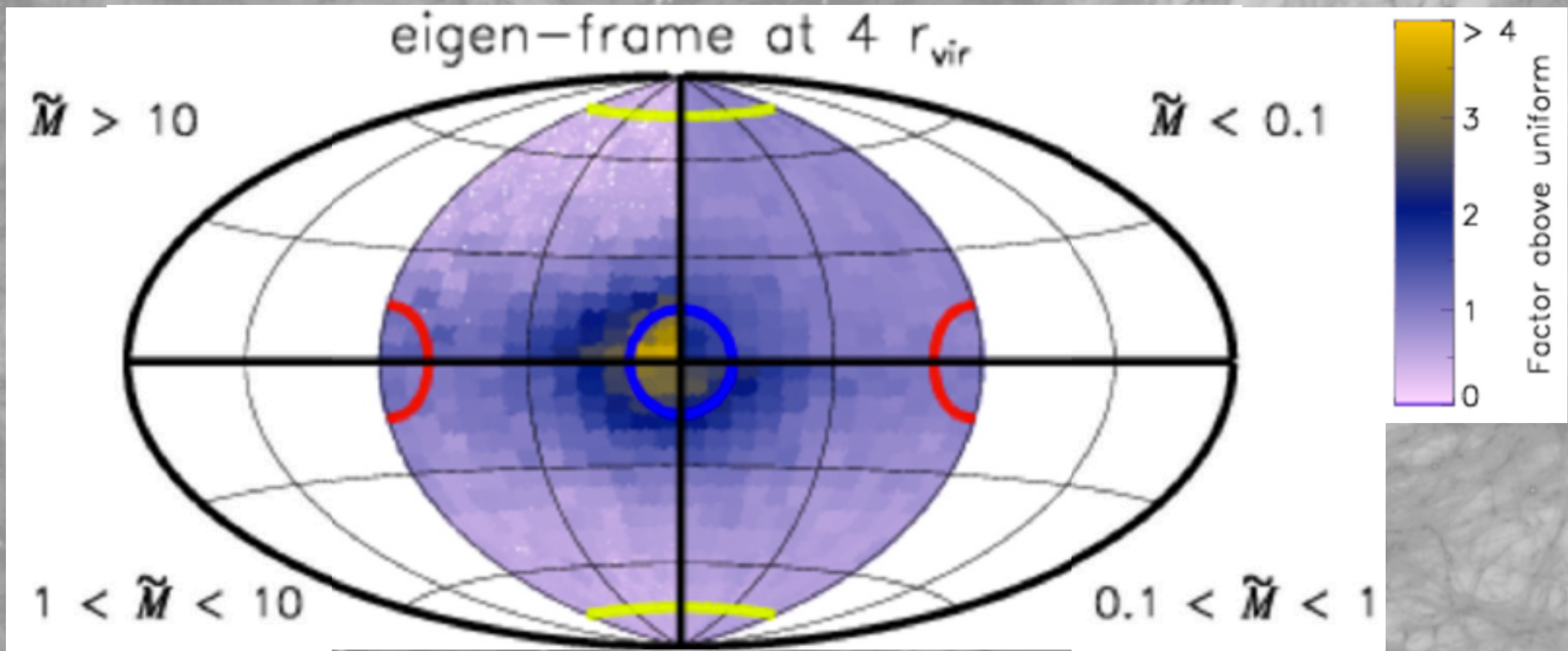


Libeskind et al 2014

All mergers

Infall points of subhaloes in the Shear eigenframe

1024^3 DM only simulation WMAP9
64Mpc box, Mres~ 2e7Msol

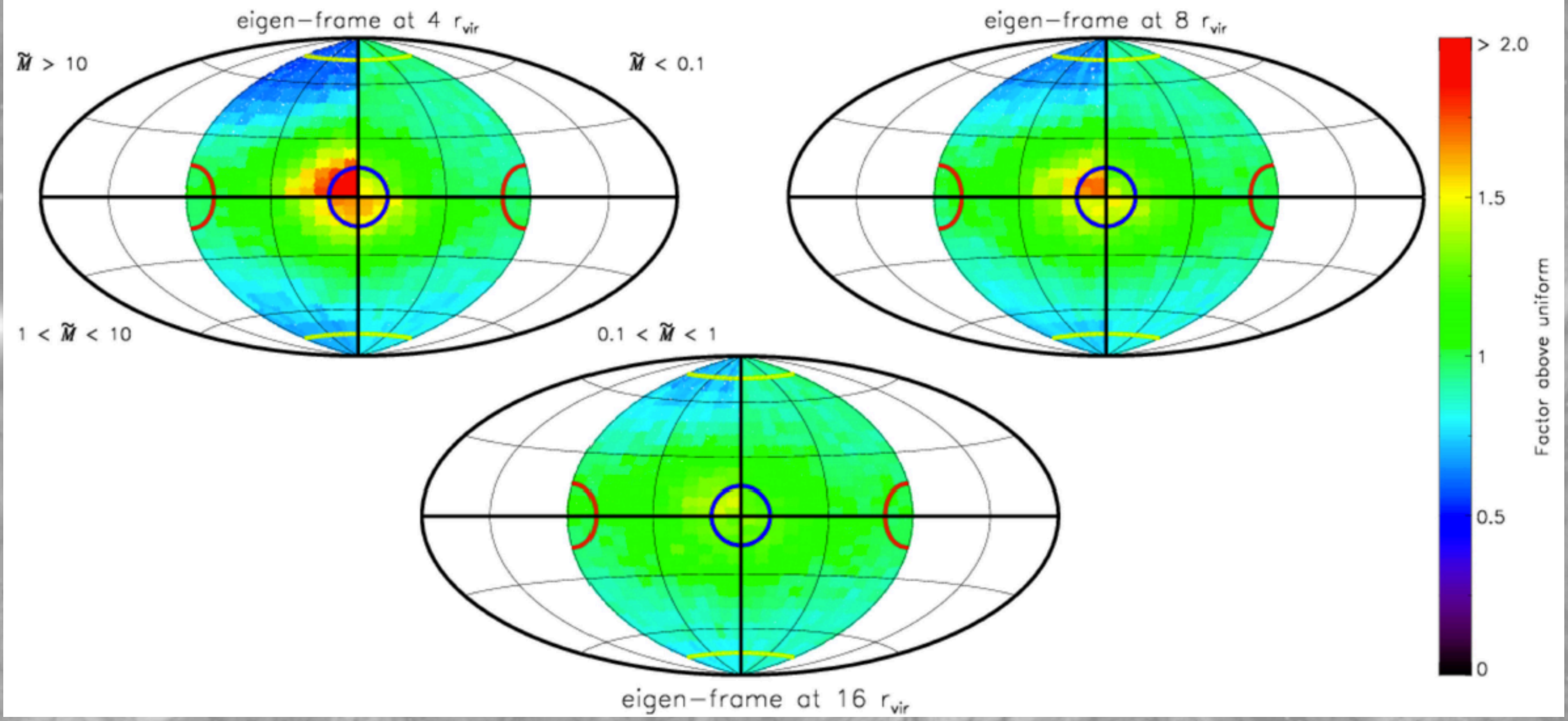


Libeskind et al 2014

“Major” (>10%) mergers

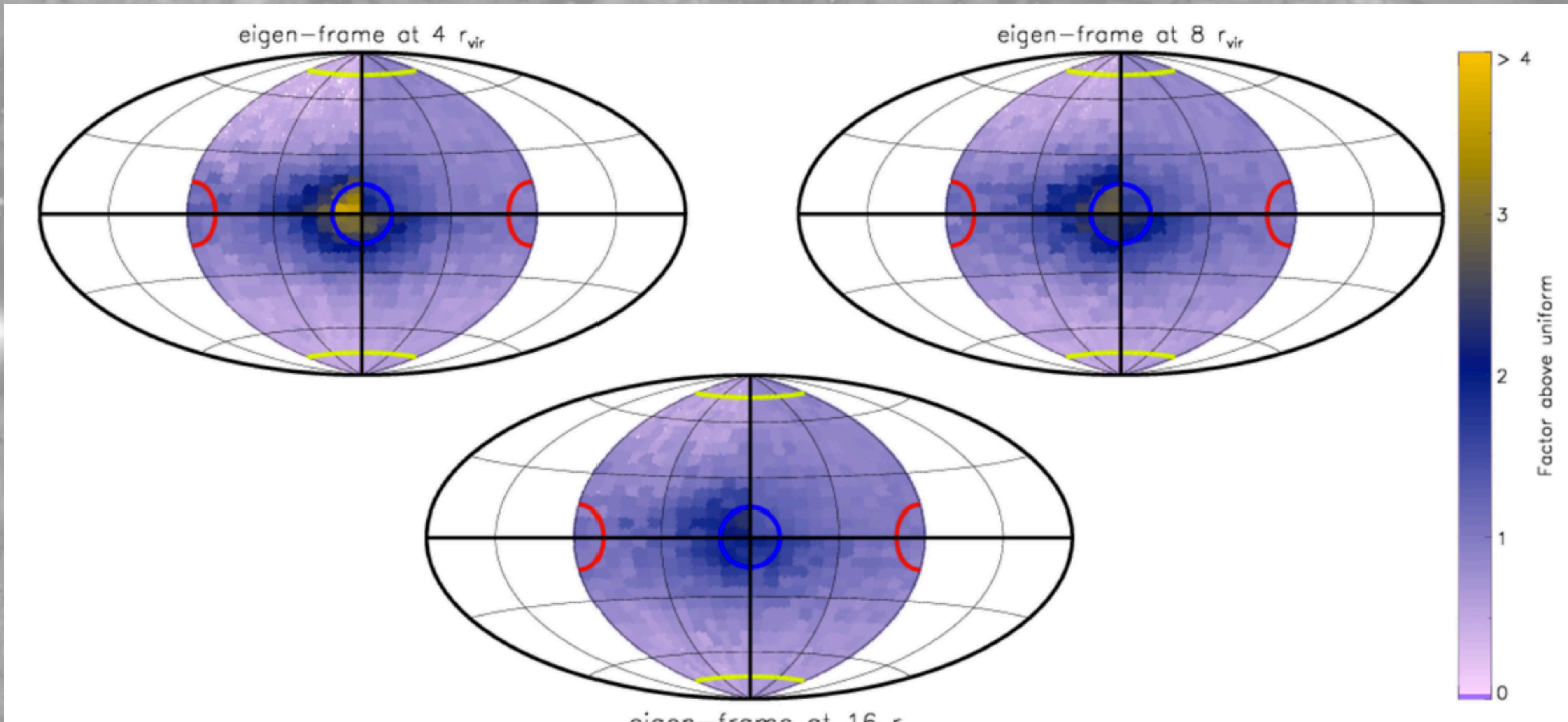
Infall points of subhaloes in the Shear eigenframe

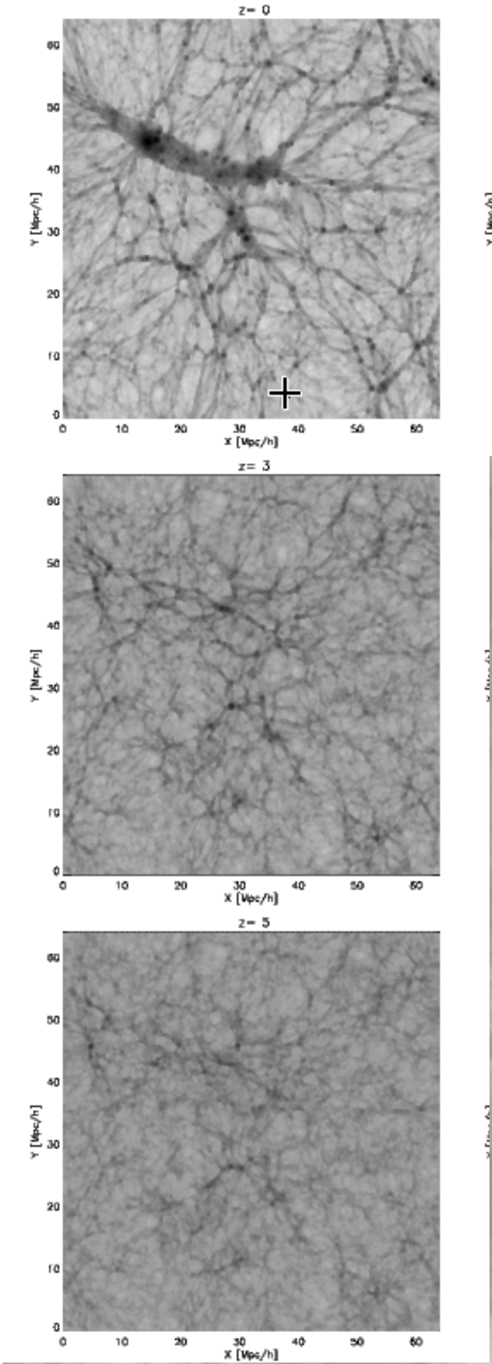
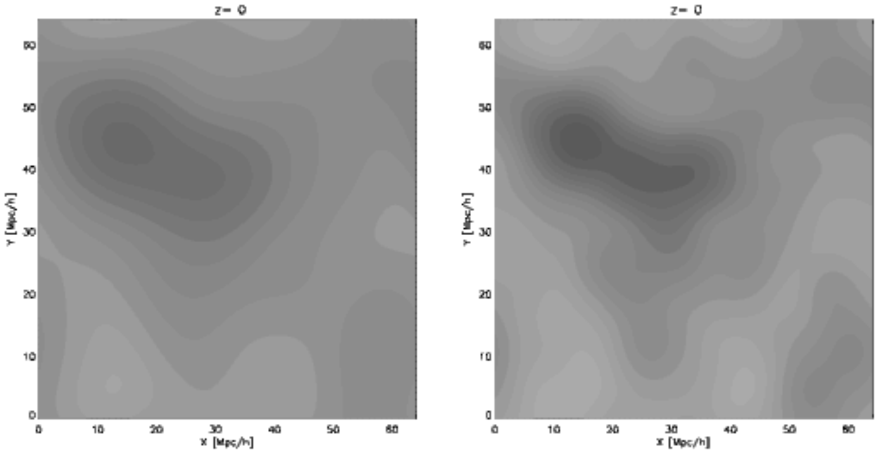
1024^3 DM only simulation WMAP9



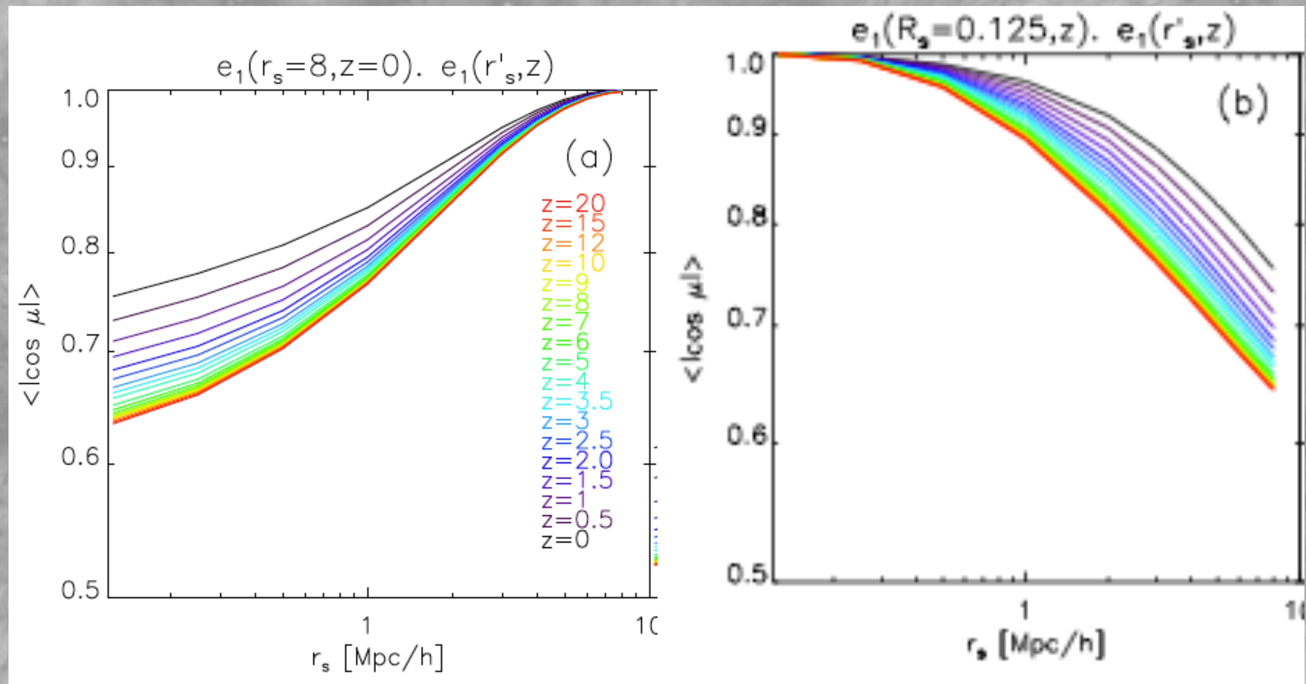
Infall points of subhaloes in the Shear eigenframe

1024^3 DM only simulation WMAP9



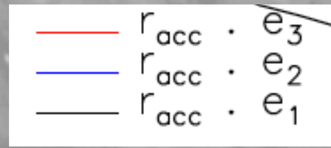



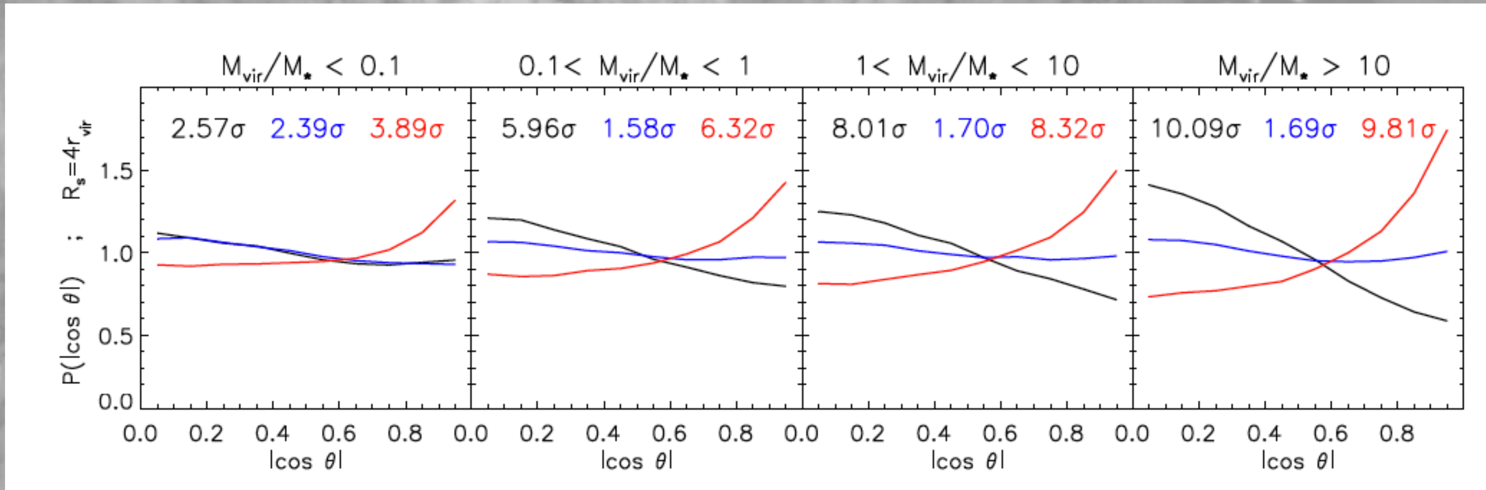
Shear is a remarkable stable quantity –
Large scale structure is “imprinted”



Quantify with Probability distribution:

Divided by masses





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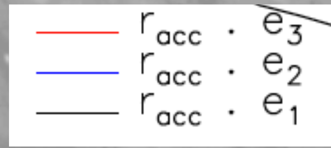
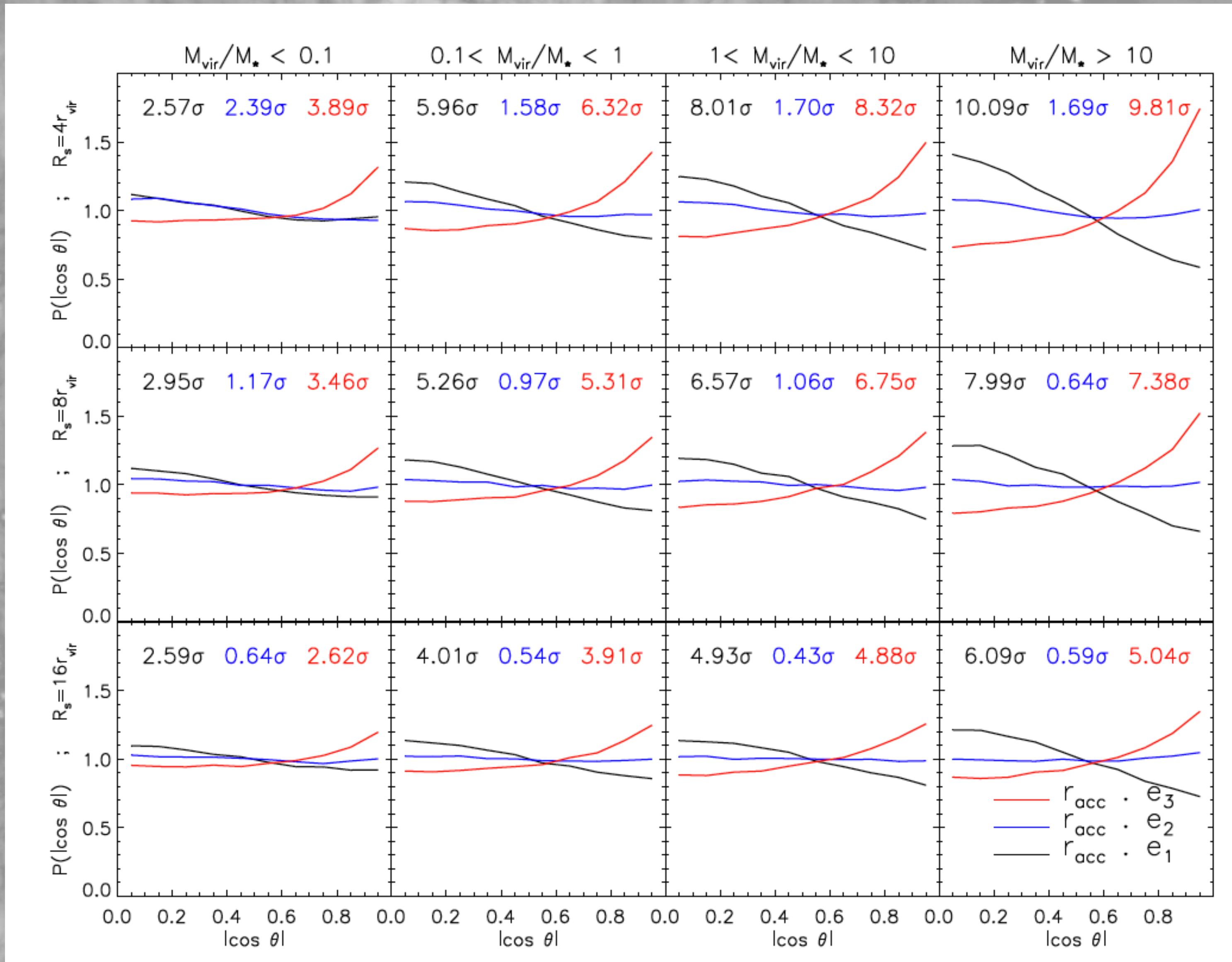
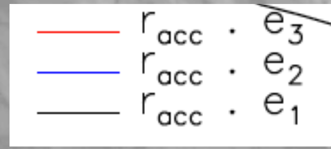
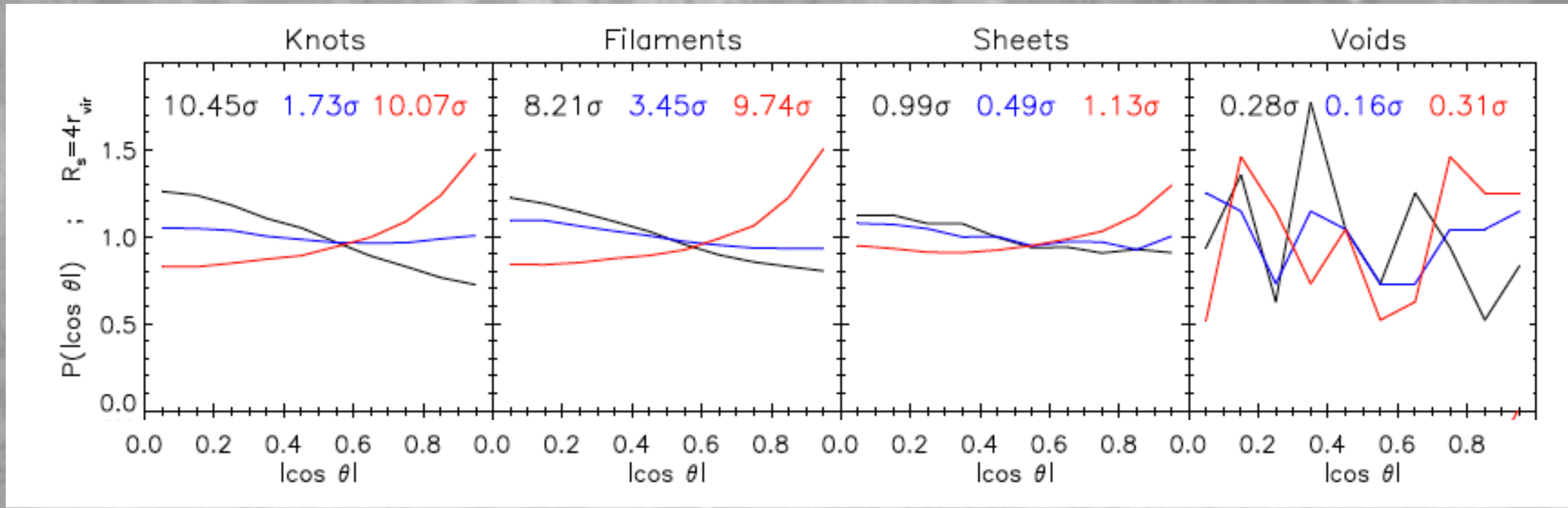




Quantify with Probability distribution:

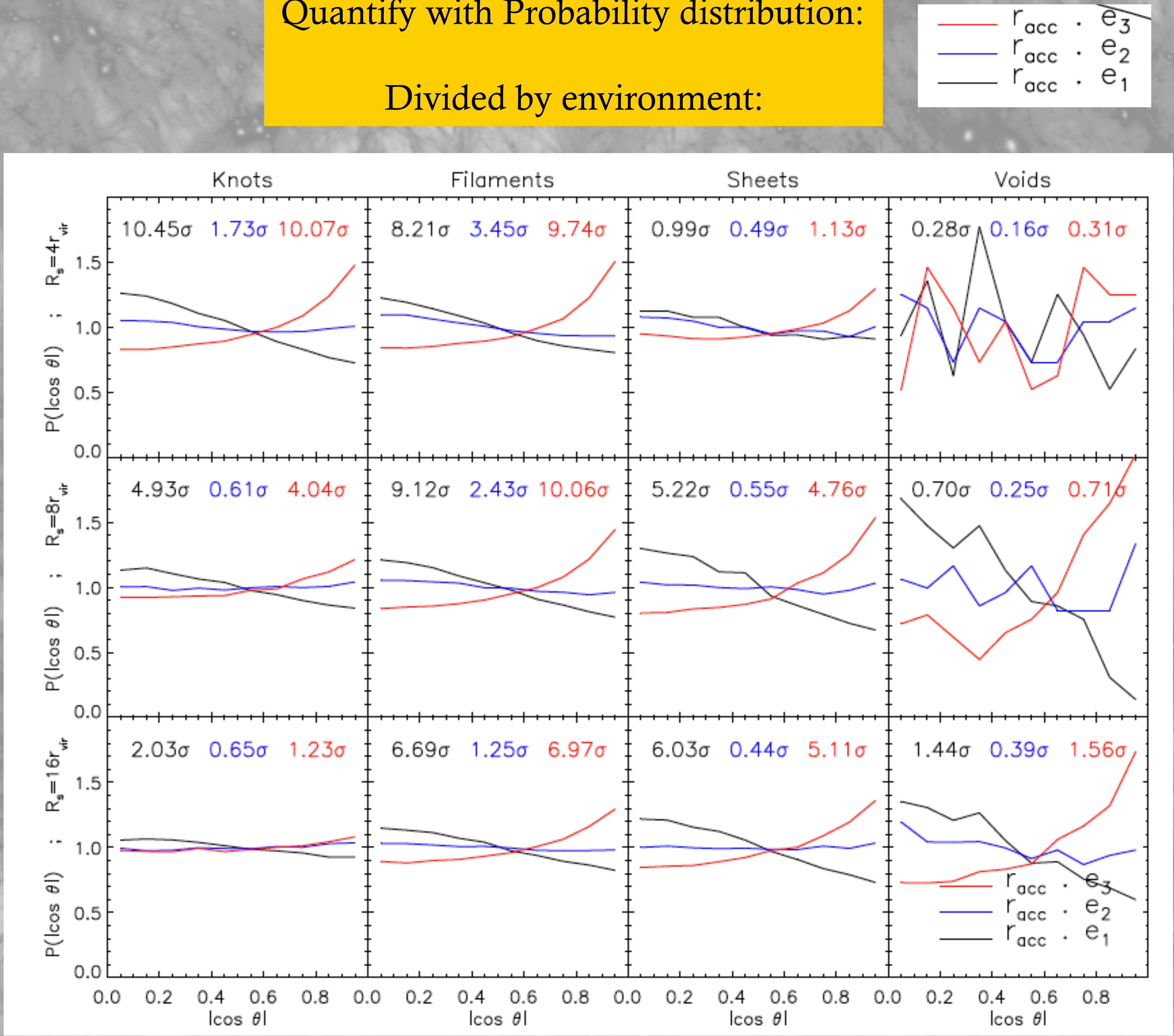
Divided by environment:





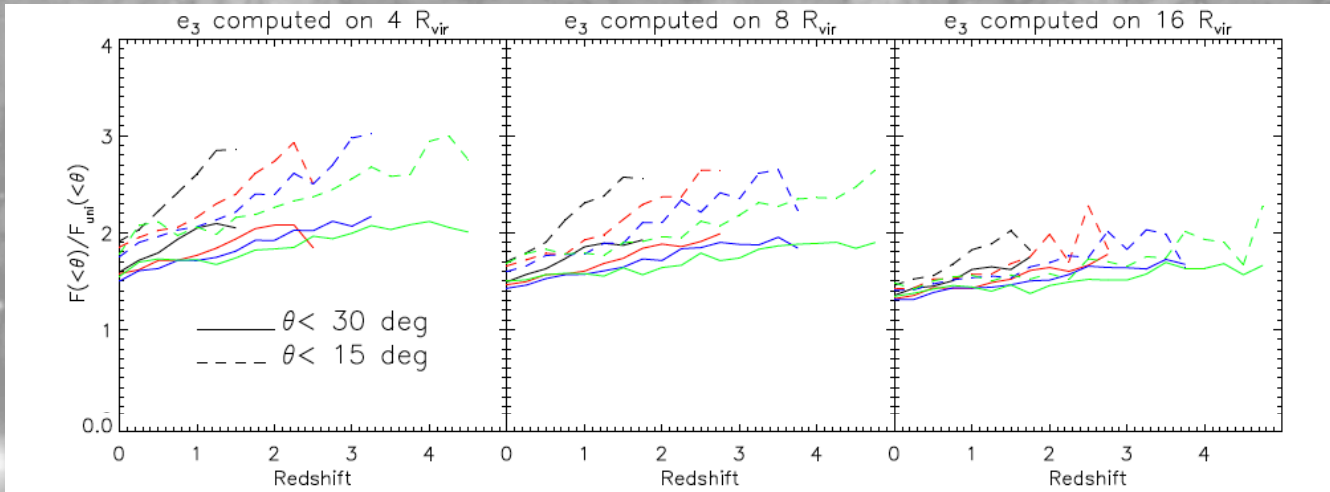
Quantify with Probability distribution:

Divided by environment:



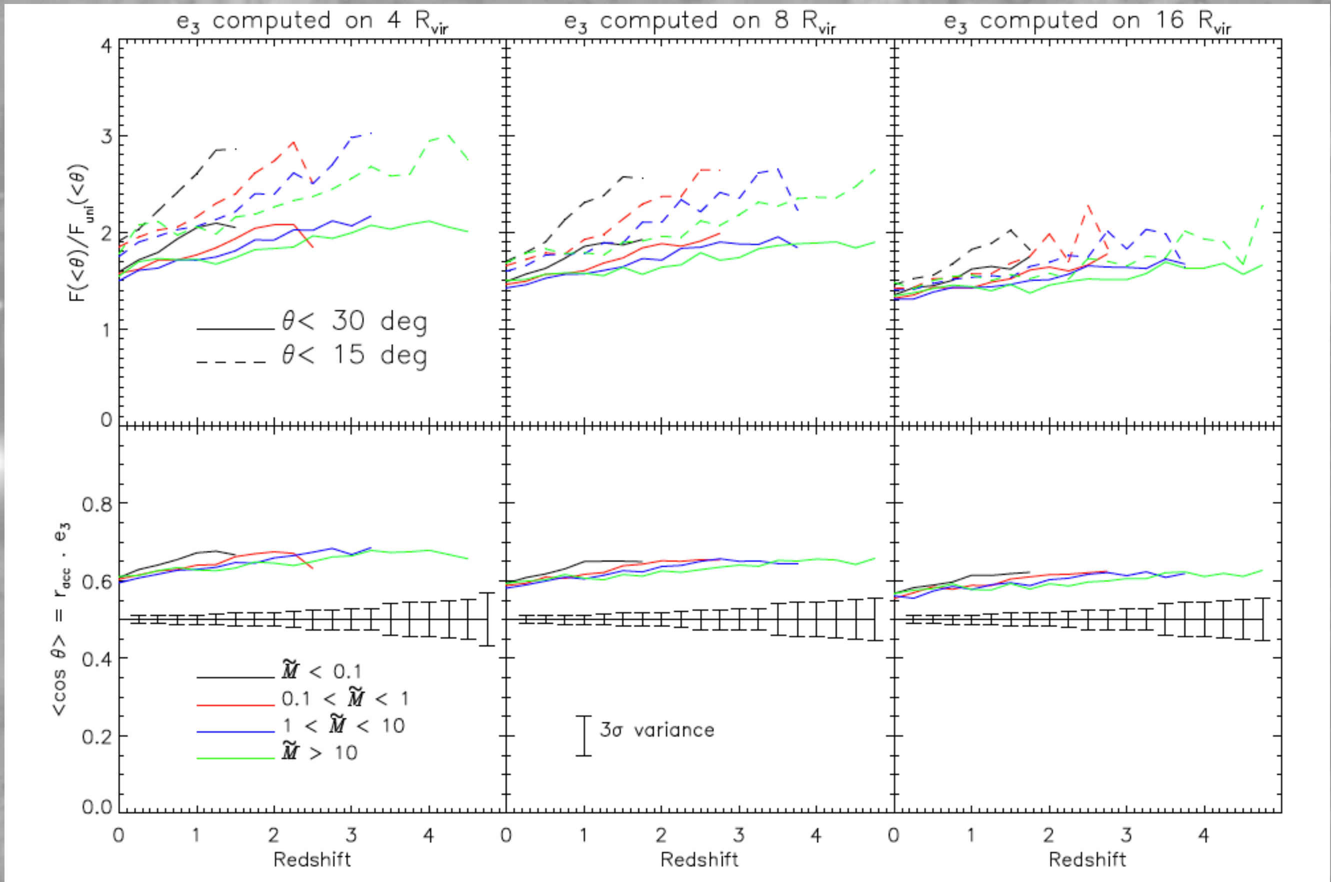
Infall angle as a function of *z*

How many more entry points are there within an opening angle of 15°, 30° than expected from a uniform distribution?

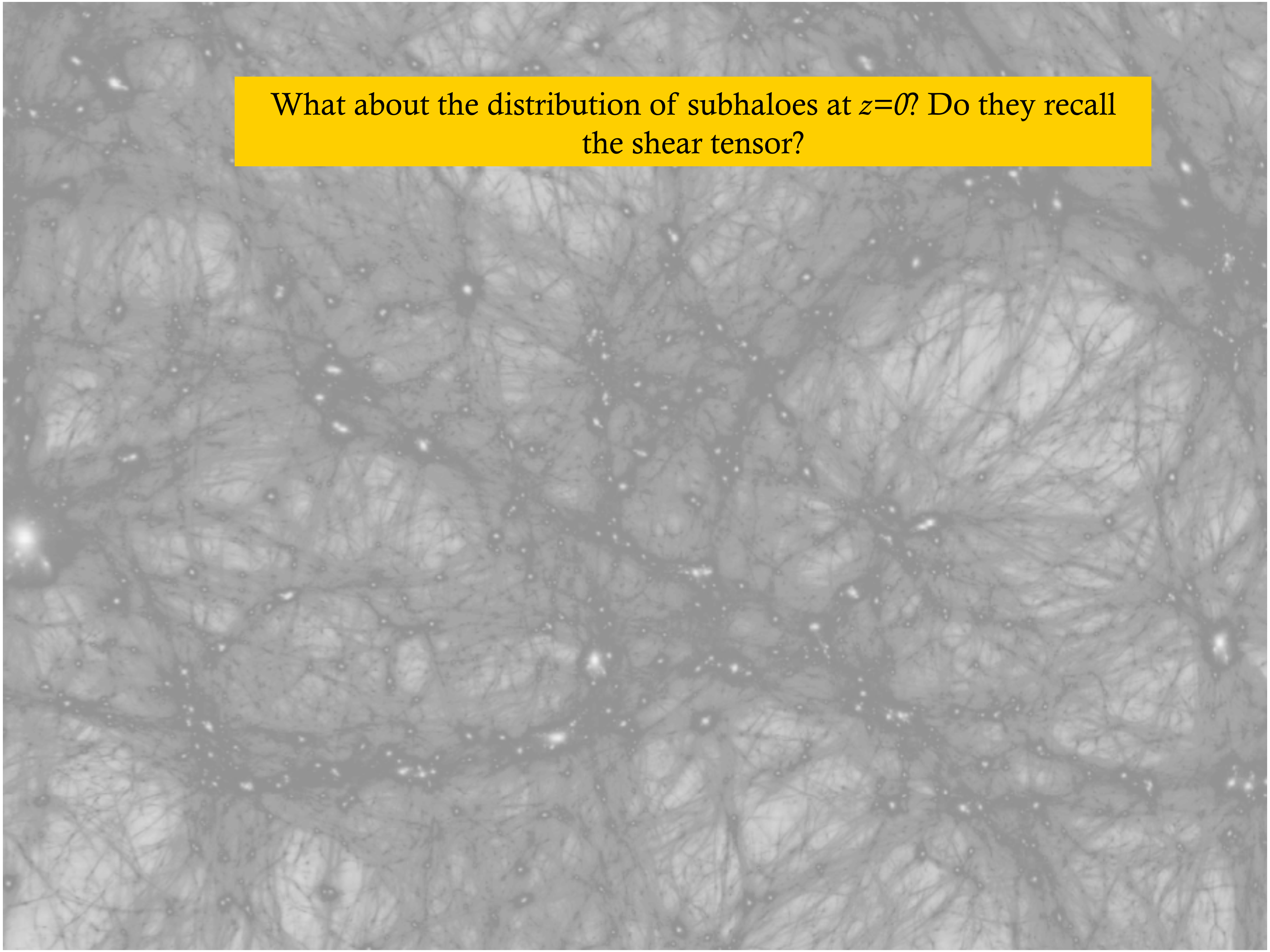


Infall angle as a function of *z*

Median angle of all entry points at a given *z*



What about the distribution of subhaloes at $z=0$? Do they recall the shear tensor?



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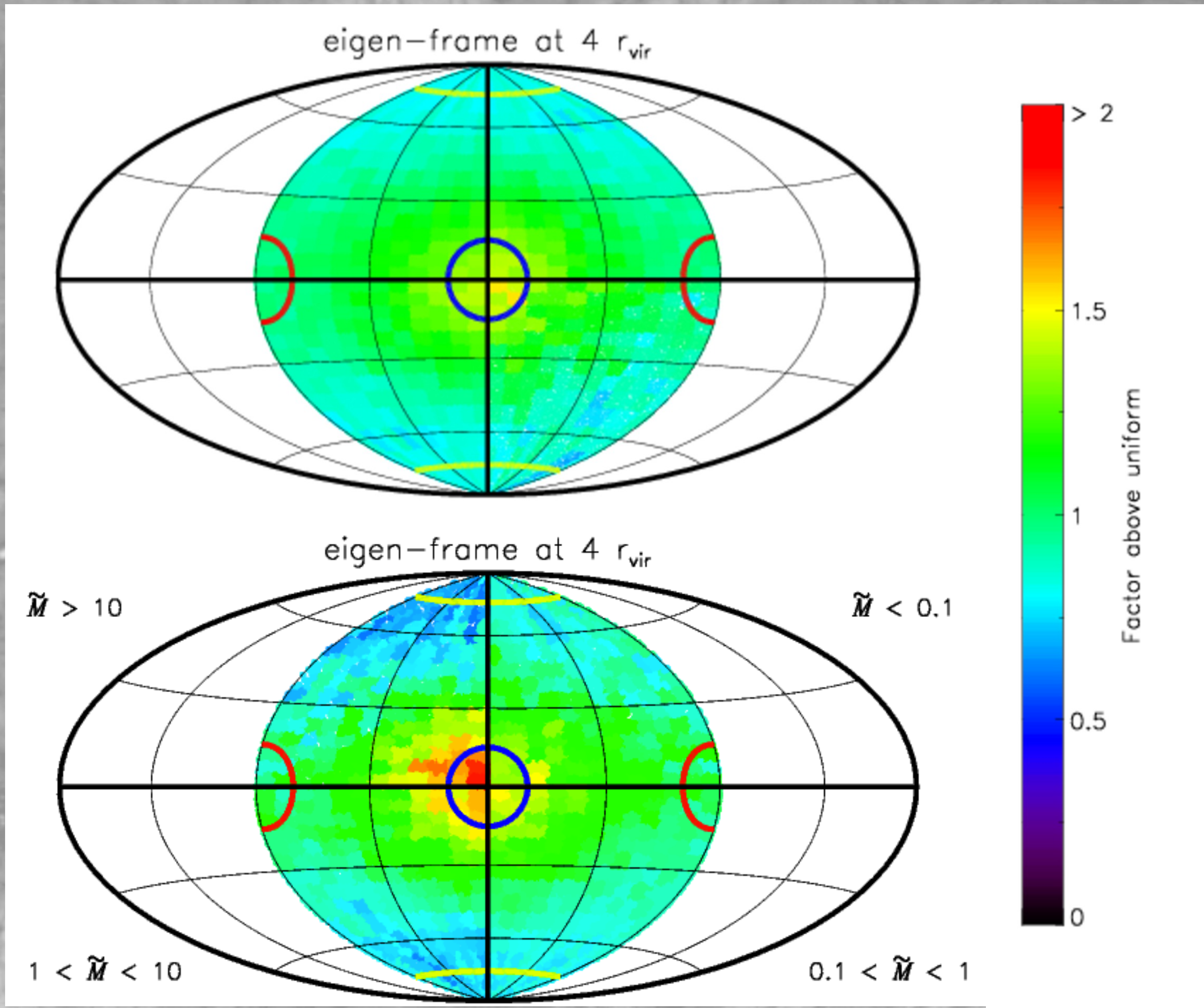
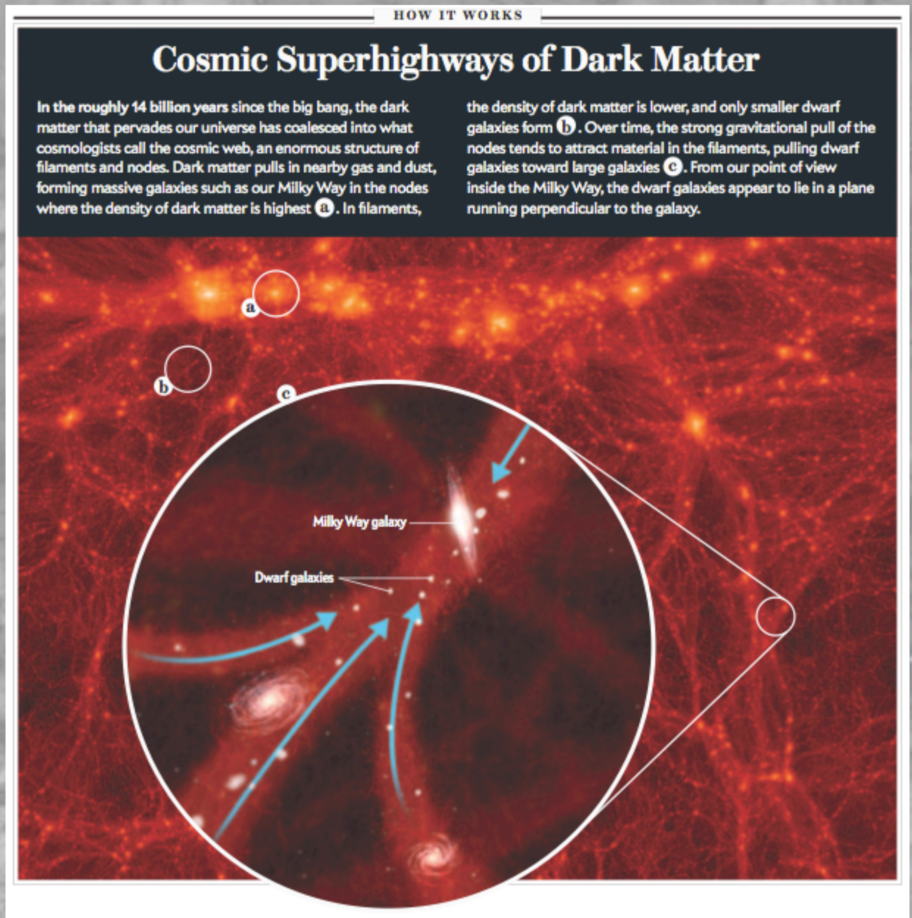


Could the setups seen around M31 be due to the shear field?



Libeskind 2014, *Scientific American*

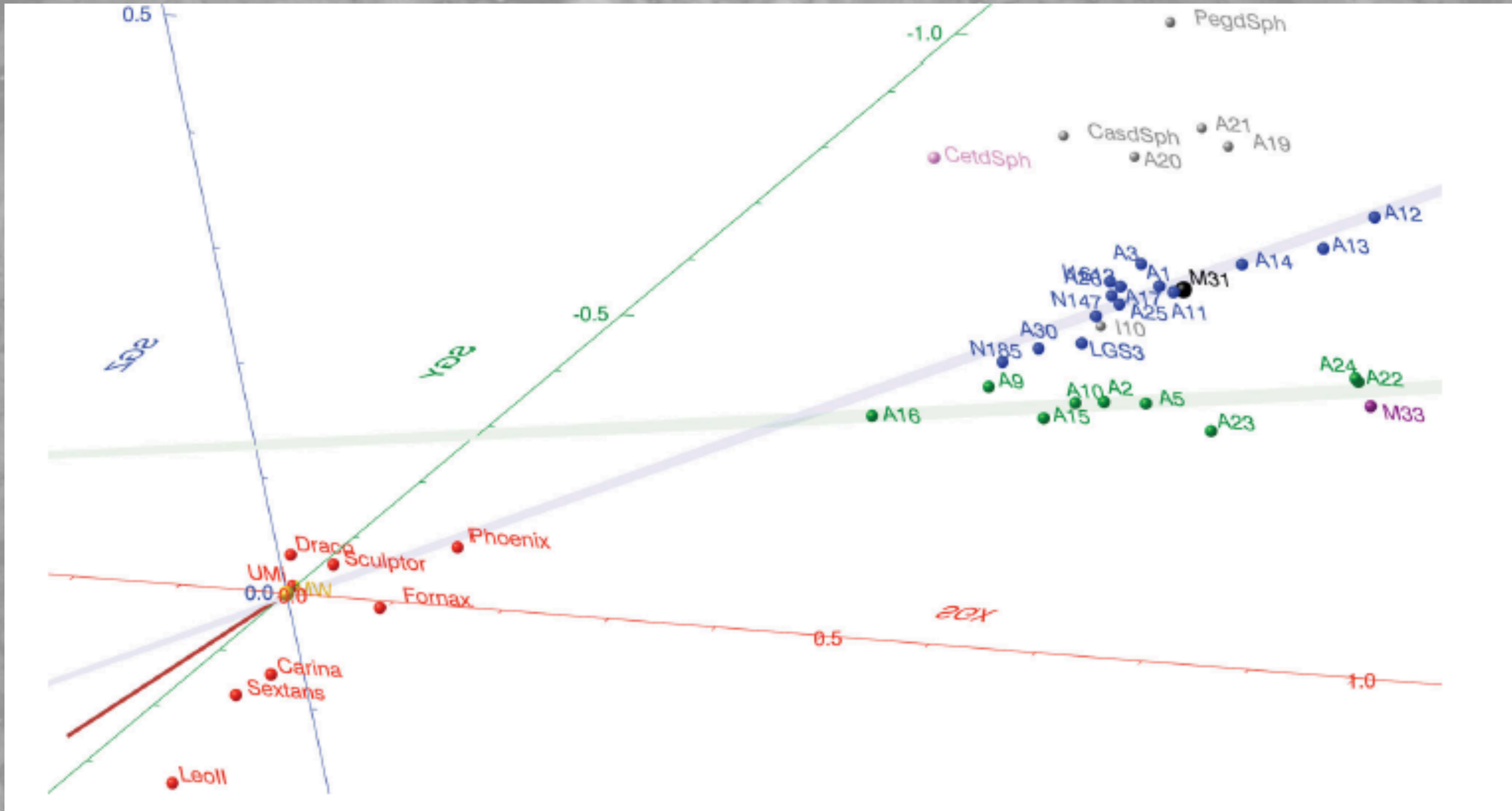
Velocity Field of the LG

Local Shear field

Eigenvectors

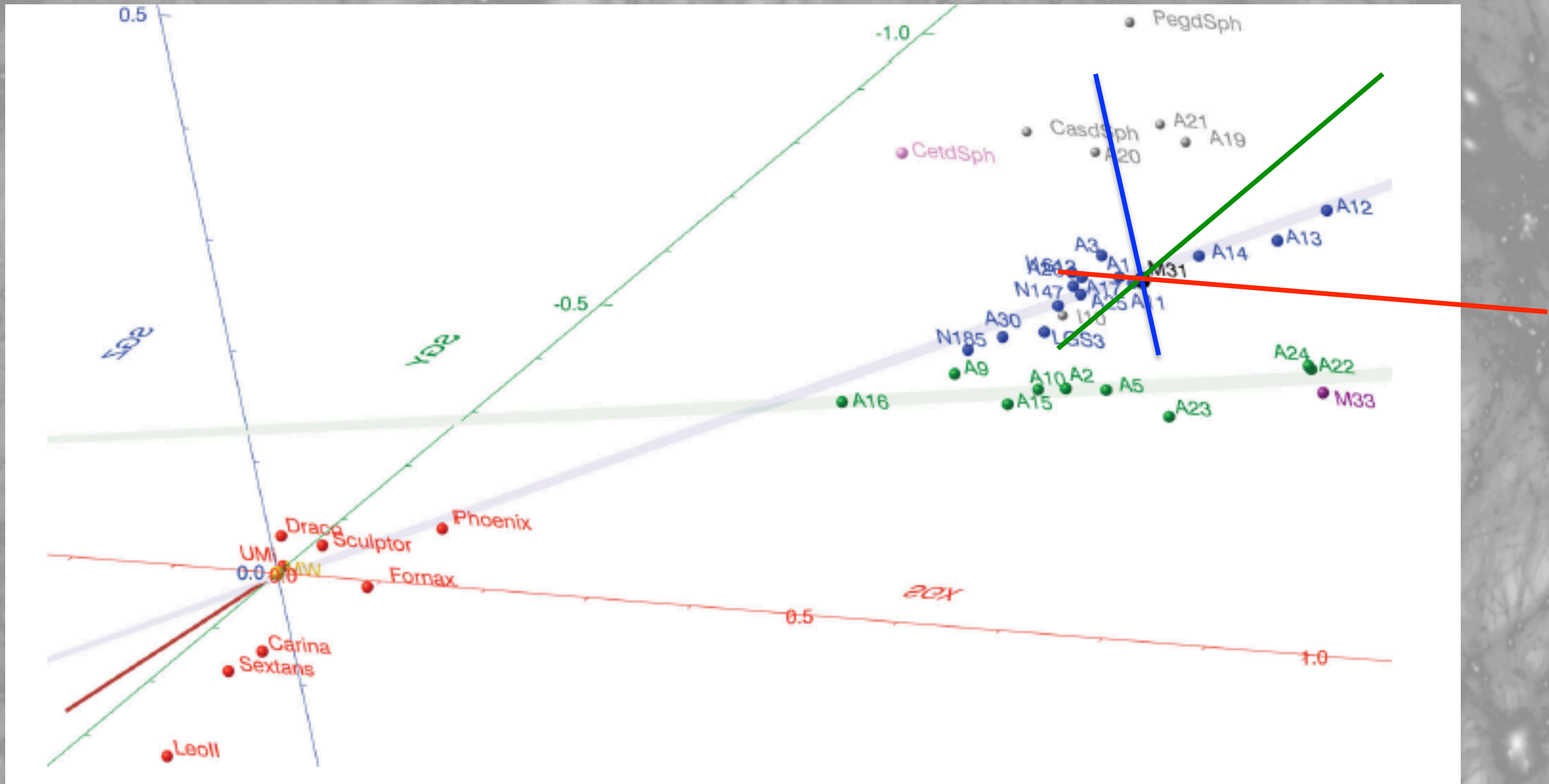
Check satellite galaxies

Examine if there's a signal



Shaya & Tully 2014

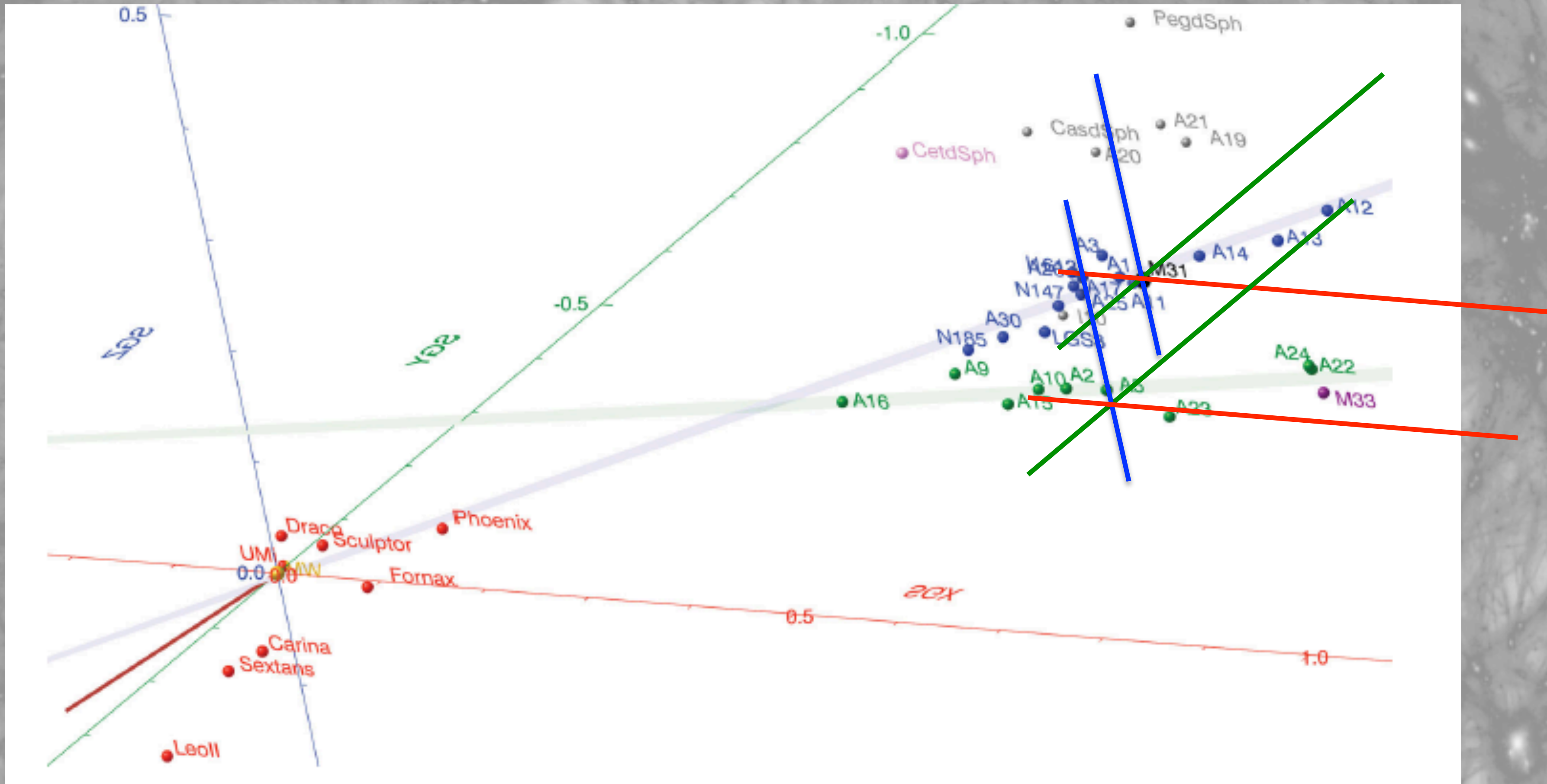
Which system to examine?



Shaya & Tully 2014

“Ibata plane”

Which system to examine?

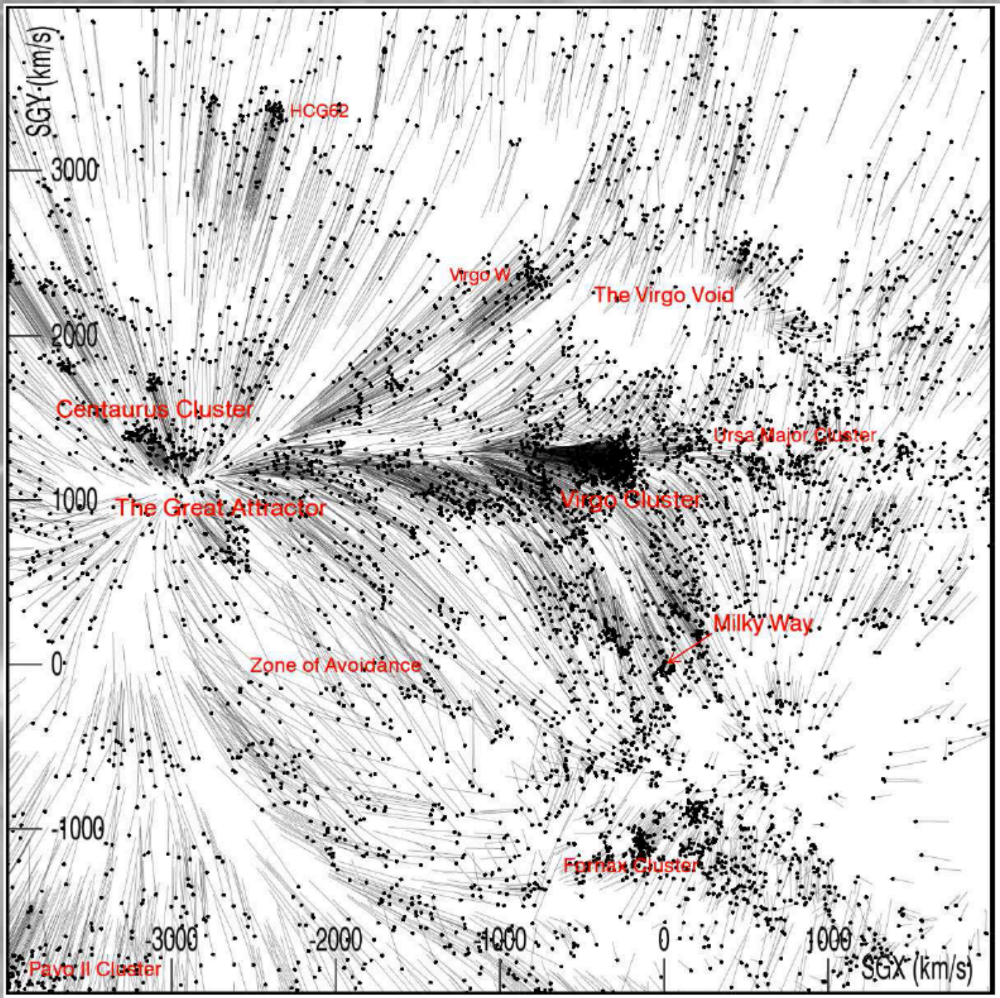


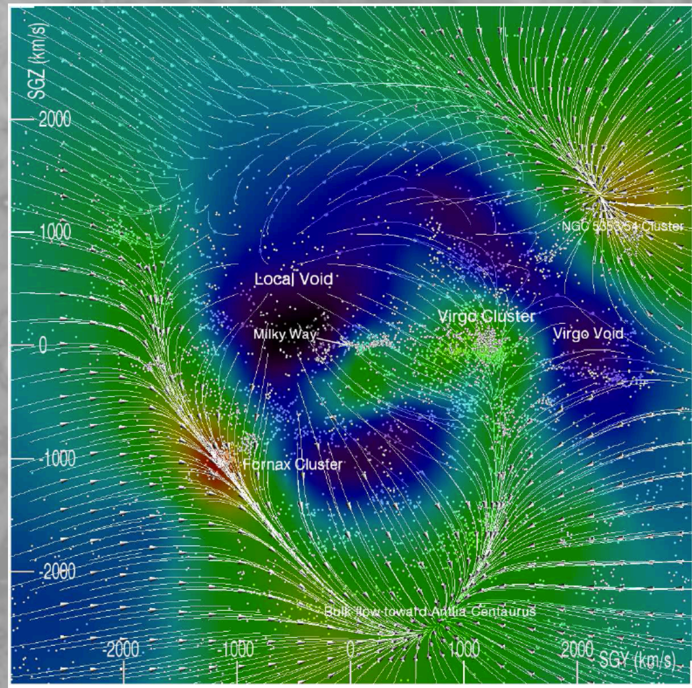
Shaya & Tully 2014

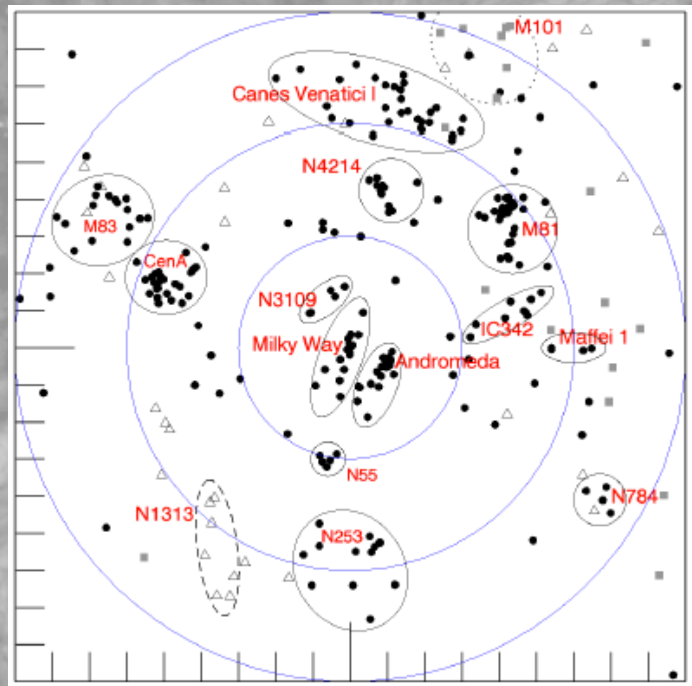
Which system to examine?

"Ibata plane"

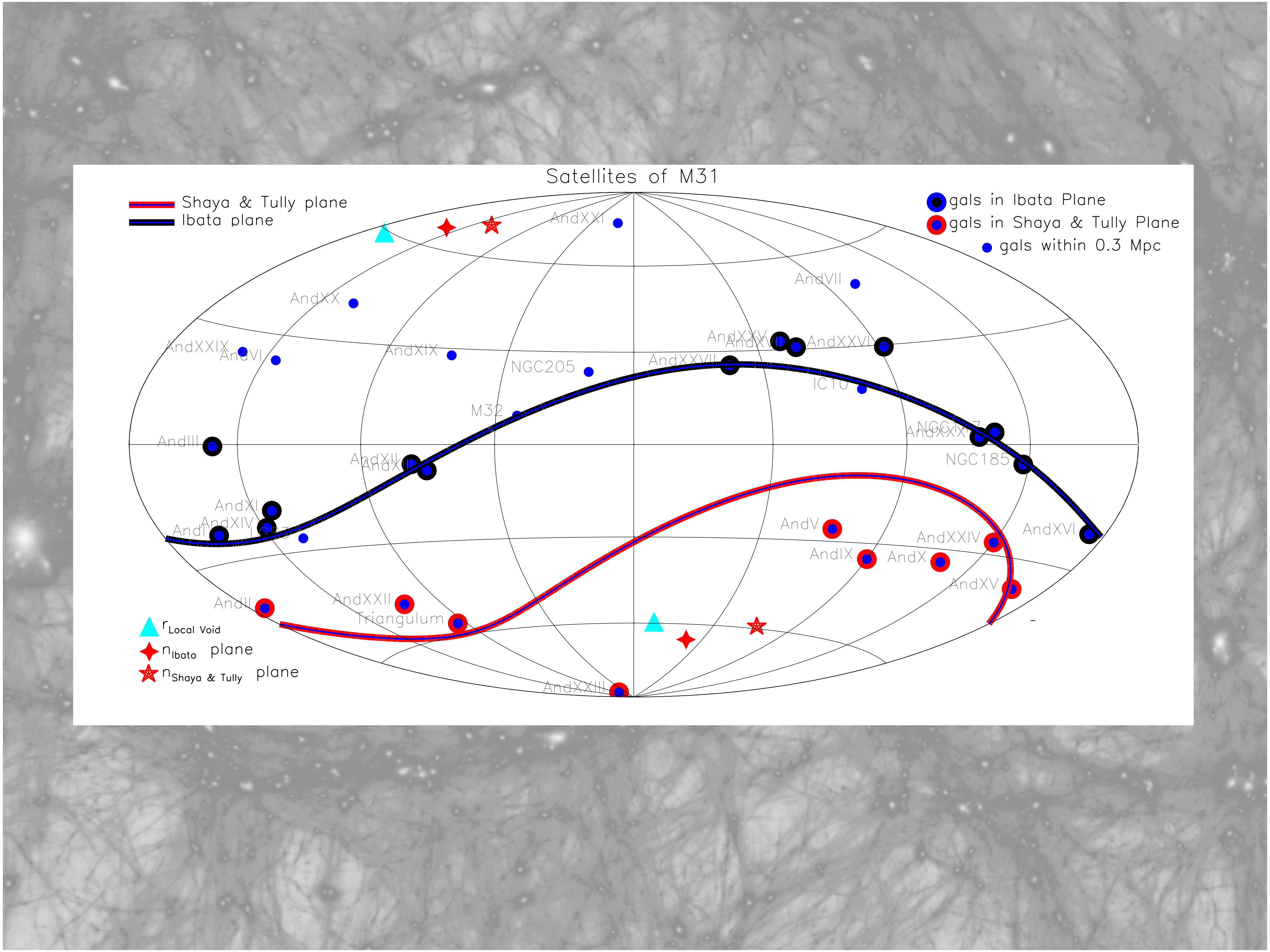
"Shaya & Tully plane"



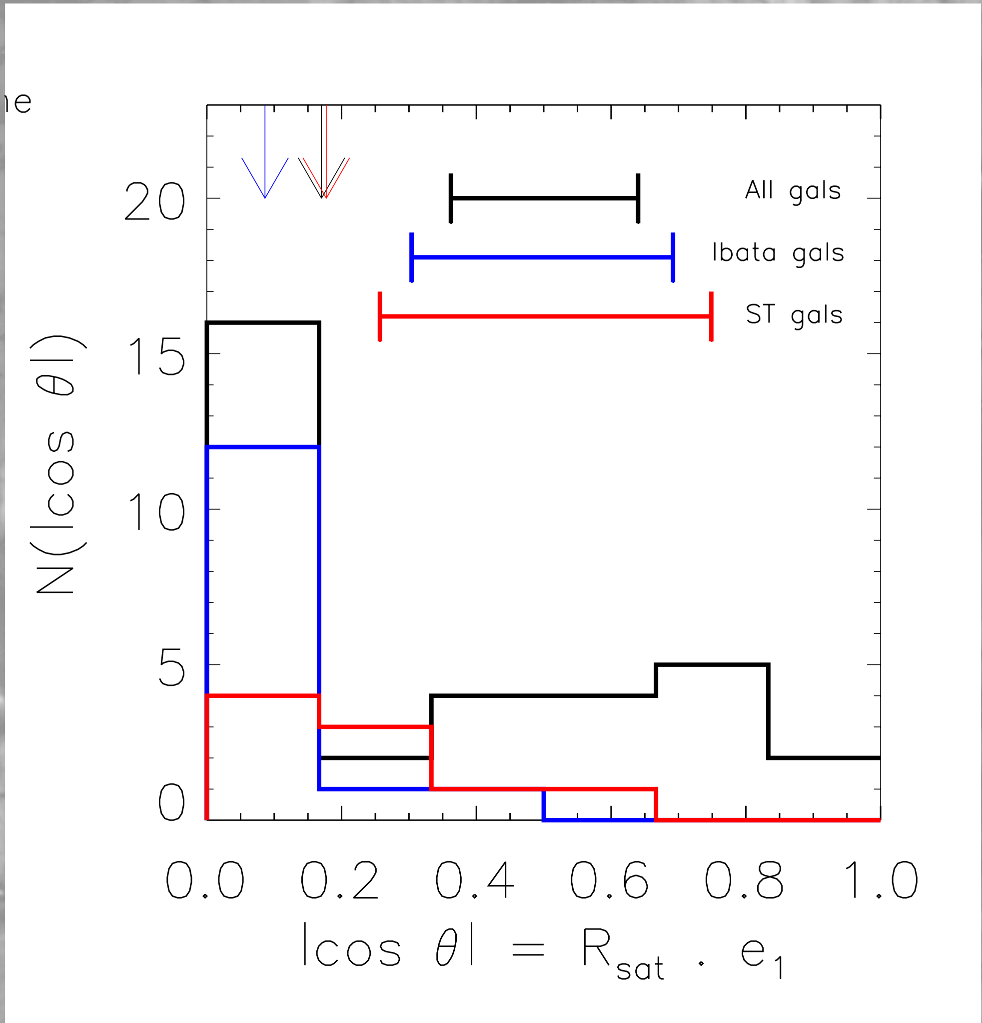




Courtois et al 2013



Satellites of M31
Shaya & Tully plane
Ibata plane
gals in Ibata Plane
gals in Shaya & Tully Plane
gals within 0.3 Mpc
AndXXI
AndVII
AndXX
AndXXIX
AndVI
AndXIX
NGC205
AndXXVI
AndXXVII
IC10
M32
AndIII
NGC185
AndXI
AndXIV
AndI
AndV
AndXXIV
AndXVI
AndIX
AndX
AndXV
AndII
AndXXII
Triangulum
AndXXIII
$r_{Local\ Void}$
n_{Ibata} plane
$n_{Shaya\ \&\ Tully}$ plane



The (flattened) distribution of M31's satellites are aligned with the plane of e_2-e_3 namely *away* from the axis of fastest collapse

Conclusions:

1. The shear tenor is one of the most important drivers structure formation.

2. Subhaloes are beamed towards central galaxies by the principal axes of the shear. Their z=0 distribution is similarly reflective of the Shear tensor

3. This effect is universal in that it happens for

    a. all host masses
    b. all merger ratios (stronger for larger mergers)
    c. all environments
    d. all scales (stronger when the shear is computed on smaller scales)
    e. all redshifts

4. “Cosmic Web” unimportant

5. May explain the origin of peculiar satellite galaxy alignments in the around M31