Grupo de
Física y Astrofísica
Computacional
Instituto de Física - Universidad de Antioquia

The Place of the Milky Way and Andromeda in the Cosmic Web

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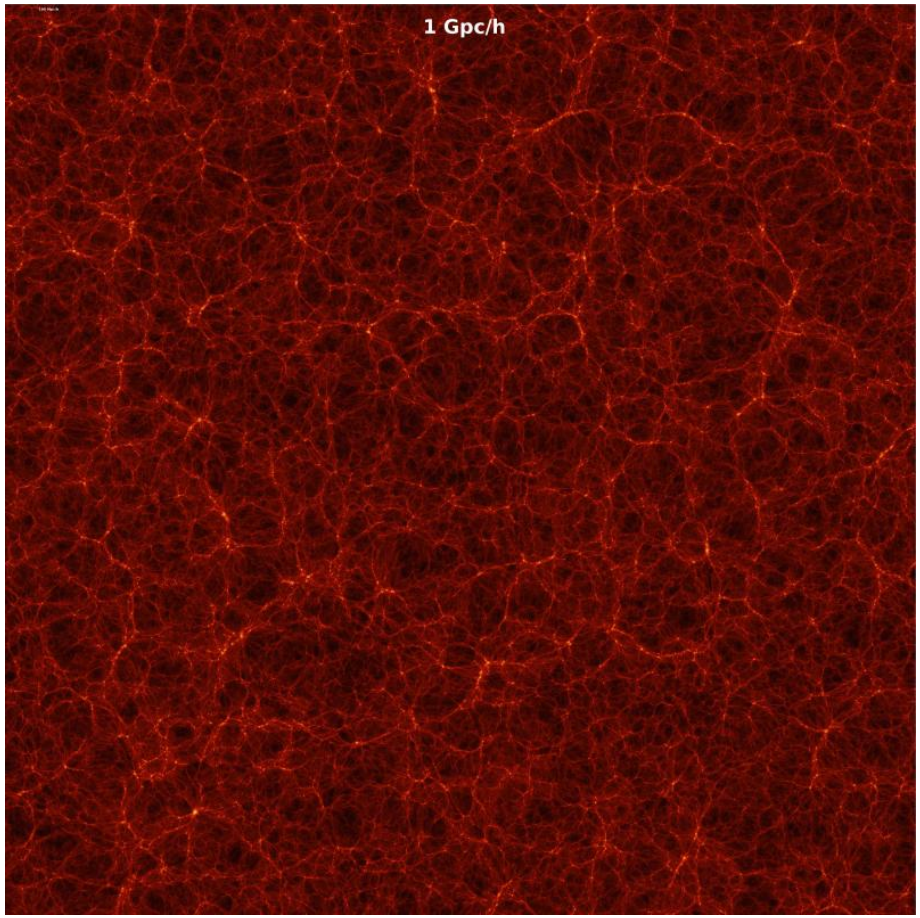
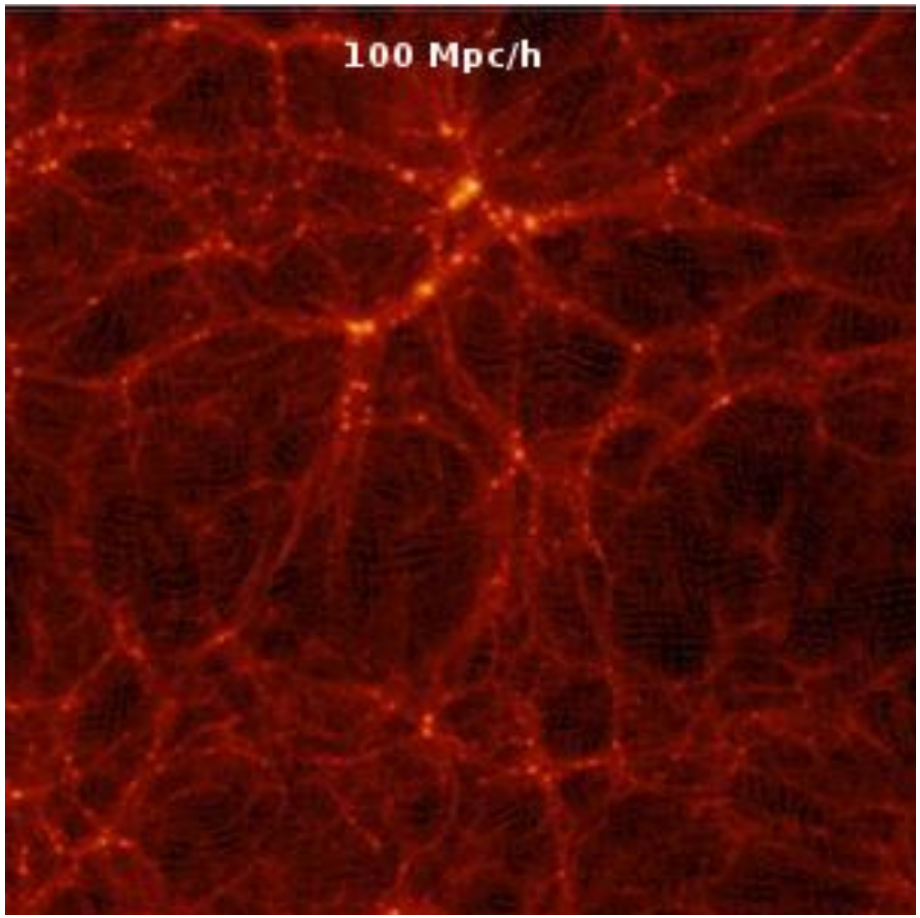
febrero de 20

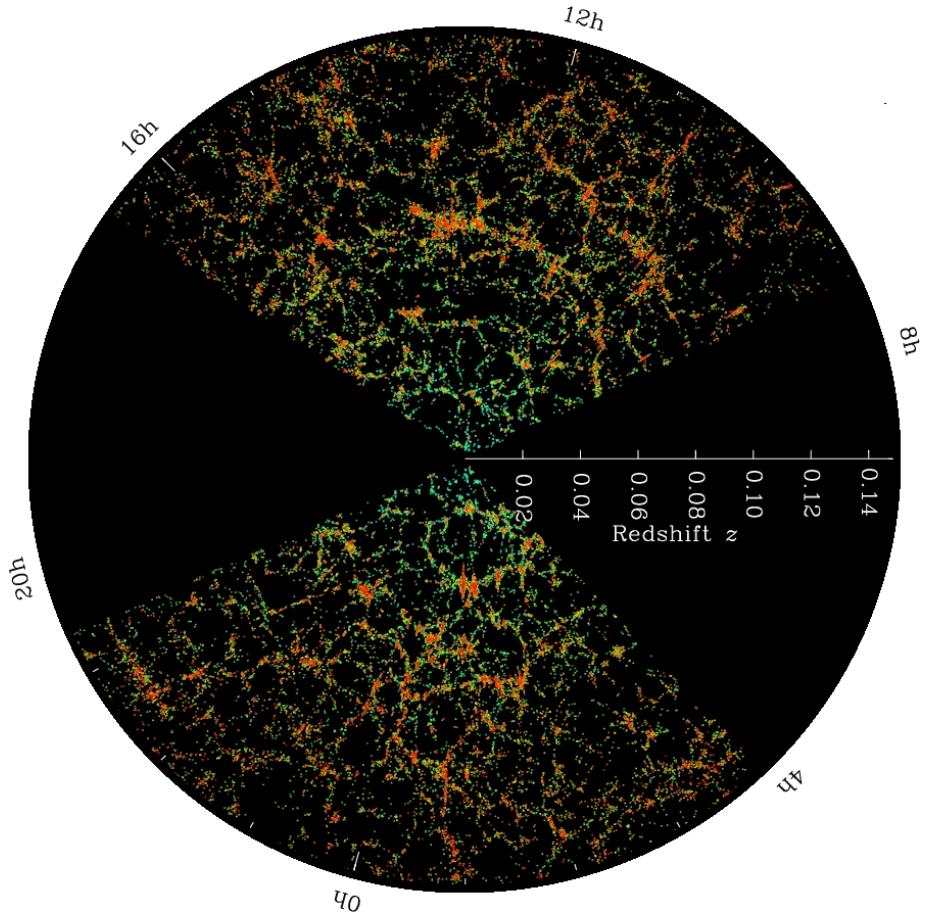
Cosmic Web



Cosmic Web



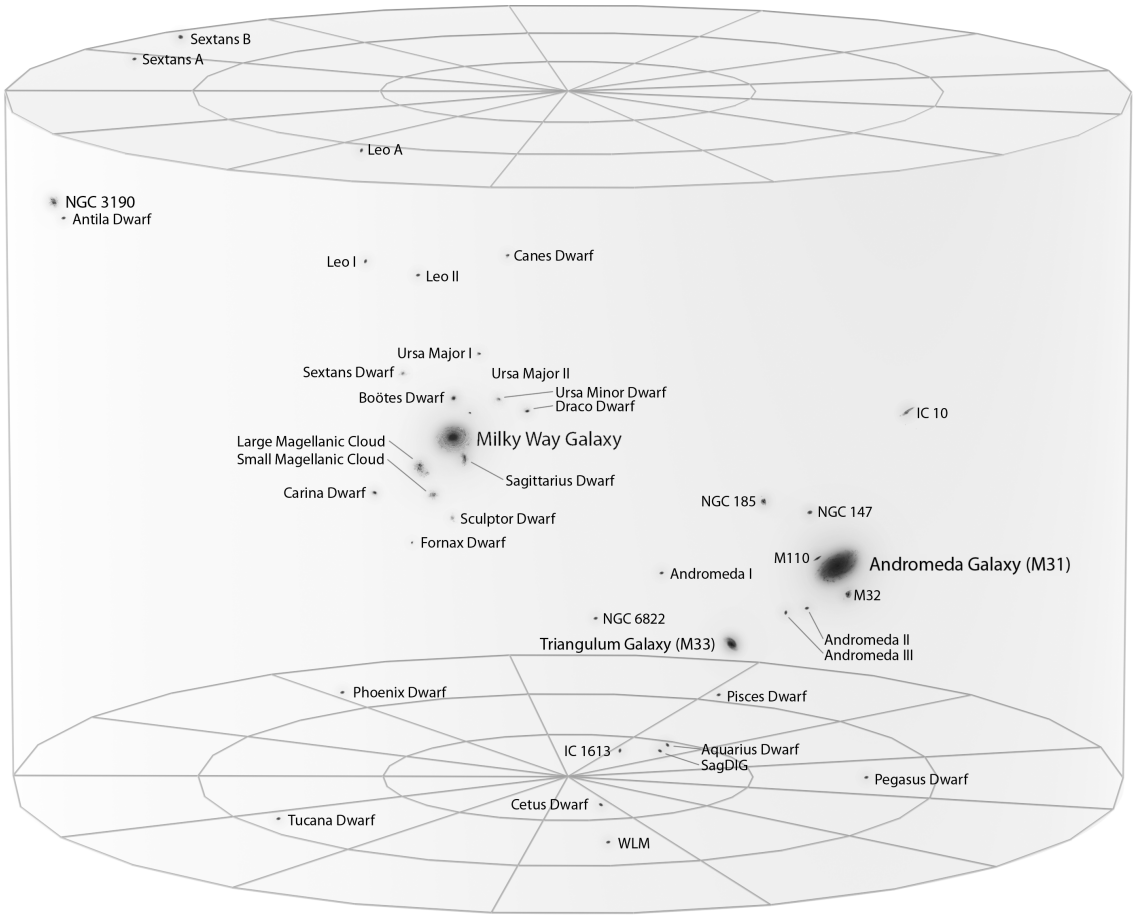
Observed Cosmic Web (SDSS)



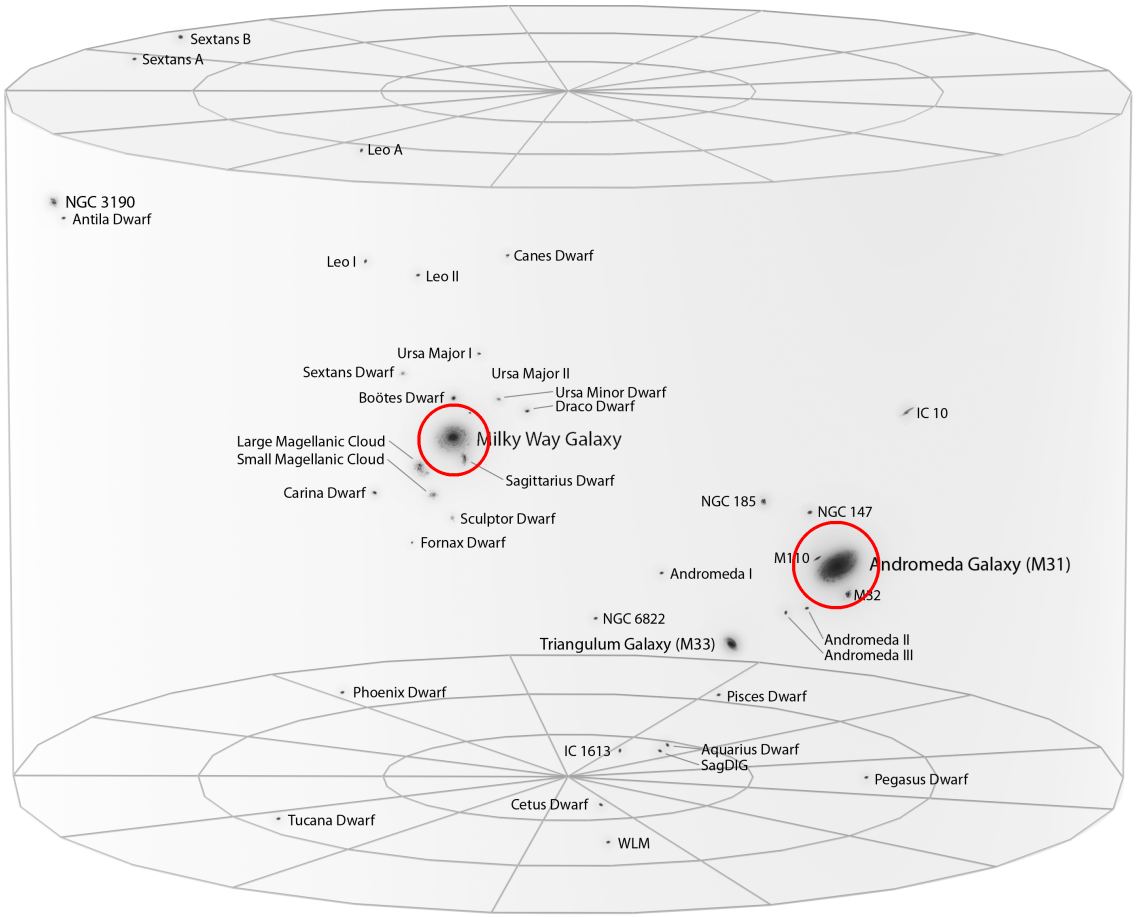
Motivation

1. Quantify the structure of the Cosmic Web.

Local Group


Sextans B
Sextans A
Leo A
NGC 3190
Antila Dwarf
Leo I
Canes Dwarf
Leo II
Ursa Major I
Sextans Dwarf
Ursa Major II
Ursa Minor Dwarf
Boötes Dwarf
Draco Dwarf
IC 10
Large Magellanic Cloud
Small Magellanic Cloud
Milky Way Galaxy
Sagittarius Dwarf
Carina Dwarf
NGC 185
NGC 147
Sculptor Dwarf
Fornax Dwarf
M110
Andromeda Galaxy (M31)
Andromeda I
M32
NGC 6822
Triangulum Galaxy (M33)
Andromeda II
Andromeda III
Phoenix Dwarf
Pisces Dwarf
IC 1613
Aquarius Dwarf
SagDIG
Pegasus Dwarf
Cetus Dwarf
Tucana Dwarf
WLM

Local Group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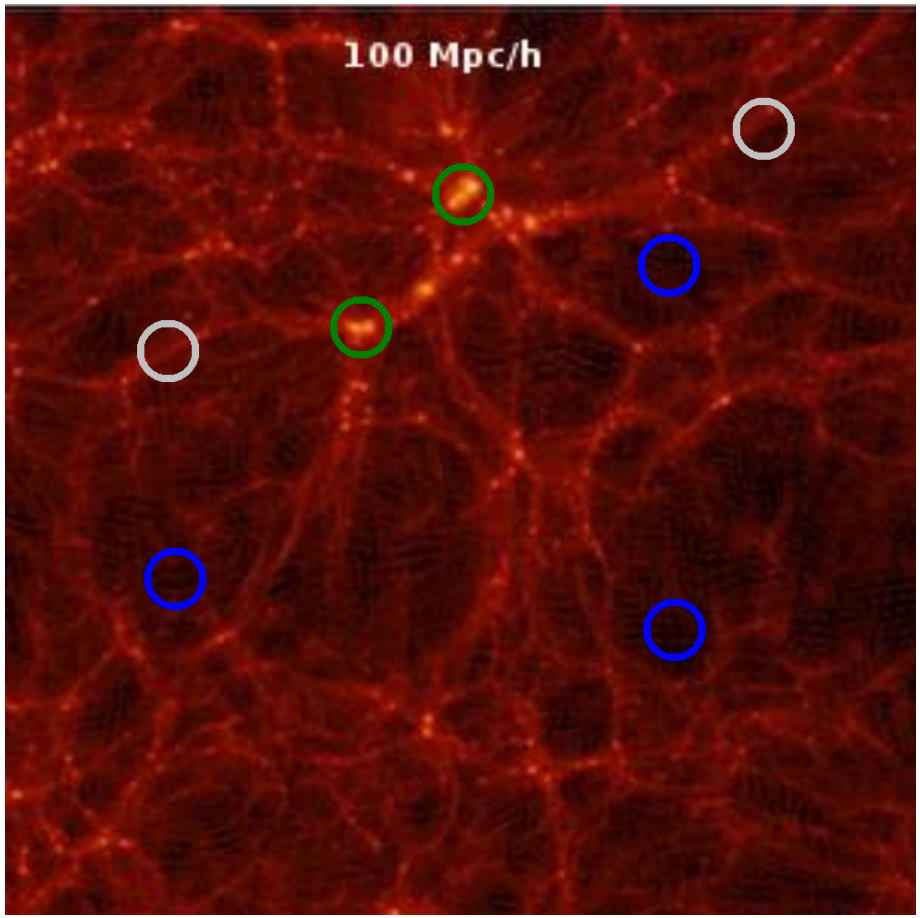
Motivation

1. Quantify the structure of the Cosmic Web.
2. Construct samples of LG-like systems in (unconstrained) cosmological simulations.

Cosmic Web

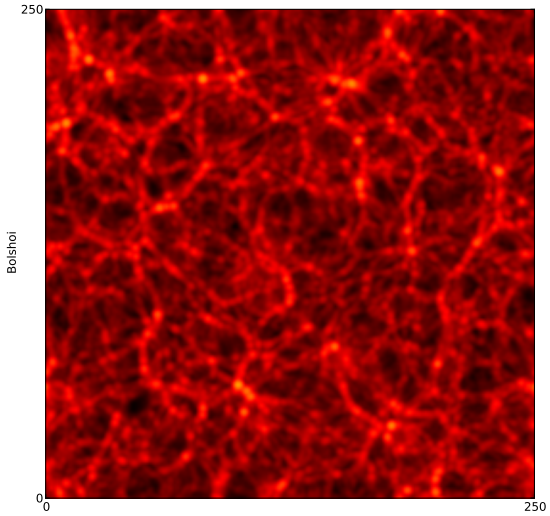


Motivation

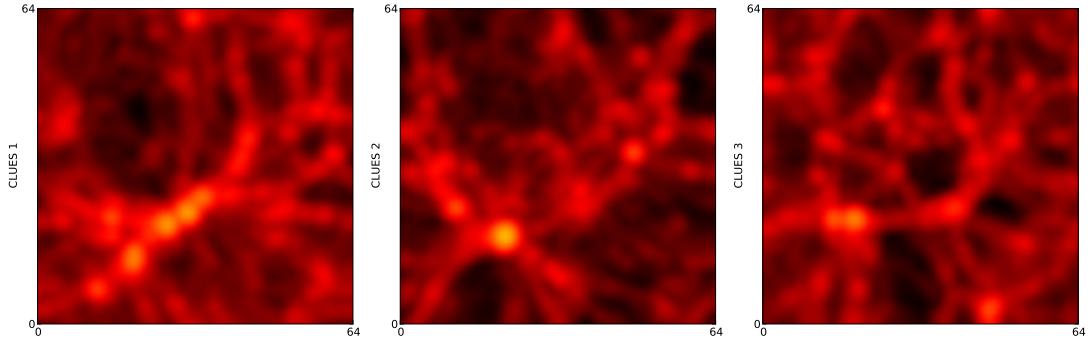
1. Quantify the structure of the Cosmic Web.
2. Construct samples of LG-like systems in (unconstrained) cosmological simulations.
3. Find possible effects of the local environment on the physical properties of LG-like systems
4. What is the most likely host environment of LG-like systems?

Simulations

- **Unconstrained Simulation (Bolshoi project)**
  - $250h^{-1}$Mpc
  - ΛCDM
  - WMAP7
  - 2048^3 particles
  - $1{,}35\times10^8 M_\odot/h$



- **Constrained Simulations (CLUES project)**
  - $64h^{-1}$Mpc
  - ΛCDM
  - WMAP7
  - 1024^3 particles
  - $1{,}83\times10^7 M_\odot/h$



Classification of the Cosmic Web

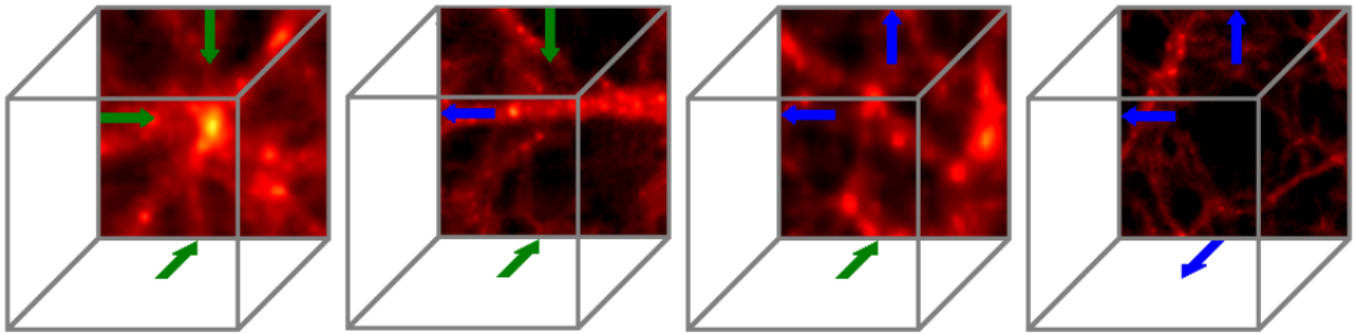
V-web Scheme
Dynamical classification scheme based on the shear velocity tensor (Hoffman et al. 2012)

$$\Sigma_{ij} = -\frac{1}{2H_0}\left(\frac{\partial v_i}{\partial r_j} + \frac{\partial v_j}{\partial r_i}\right) \tag{1}$$

This scheme is more adequate to classify the cosmic web at smaller cosmological scales ($\gtrsim 5h^{-1}$ Mpc) compared to schemes based on the density field.

Classification of the Cosmic Web

Significant improvement by introducing a threshold parameter λ_{th} (Forero-Romero et al. 2009).

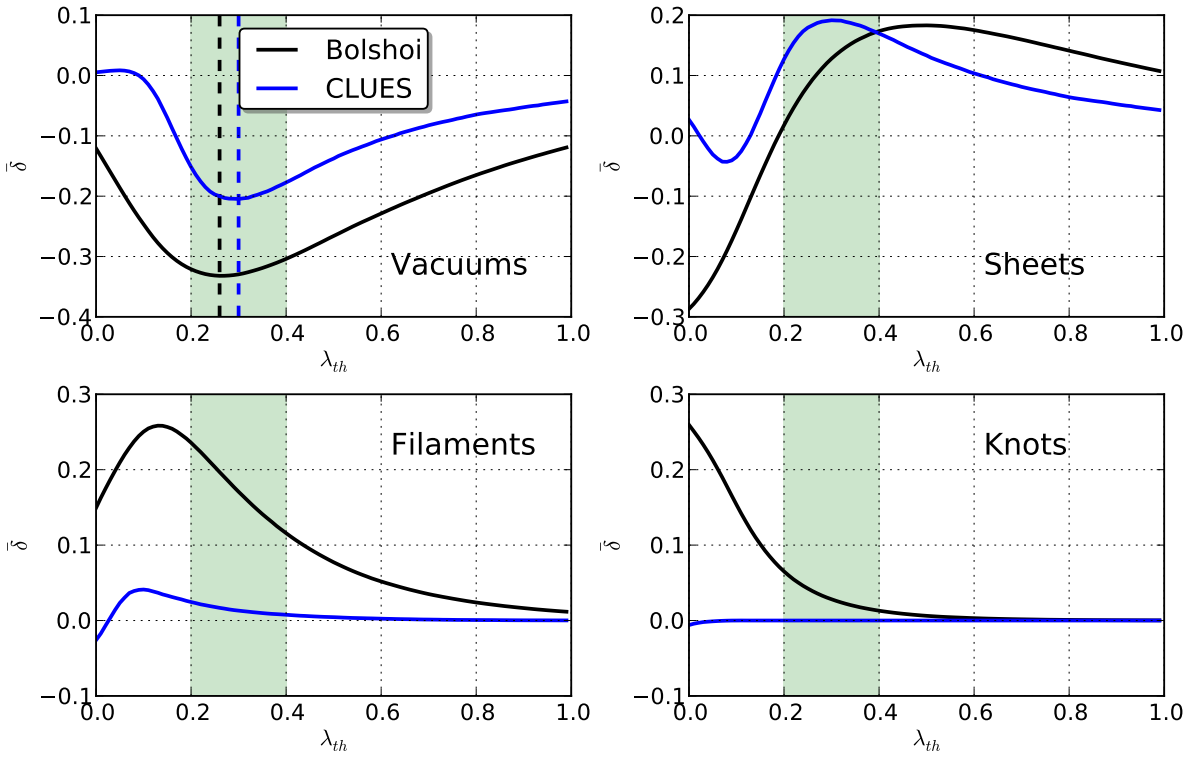


knots	filaments	sheets	vacuums
$\lambda_1 > \lambda_{th}$	$\lambda_1 > \lambda_{th}$	$\lambda_1 > \lambda_{th}$	$\lambda_1 < \lambda_{th}$
$\lambda_2 > \lambda_{th}$	$\lambda_2 > \lambda_{th}$	$\lambda_2 < \lambda_{th}$	$\lambda_2 < \lambda_{th}$
$\lambda_3 > \lambda_{th}$	$\lambda_3 < \lambda_{th}$	$\lambda_3 < \lambda_{th}$	$\lambda_3 < \lambda_{th}$

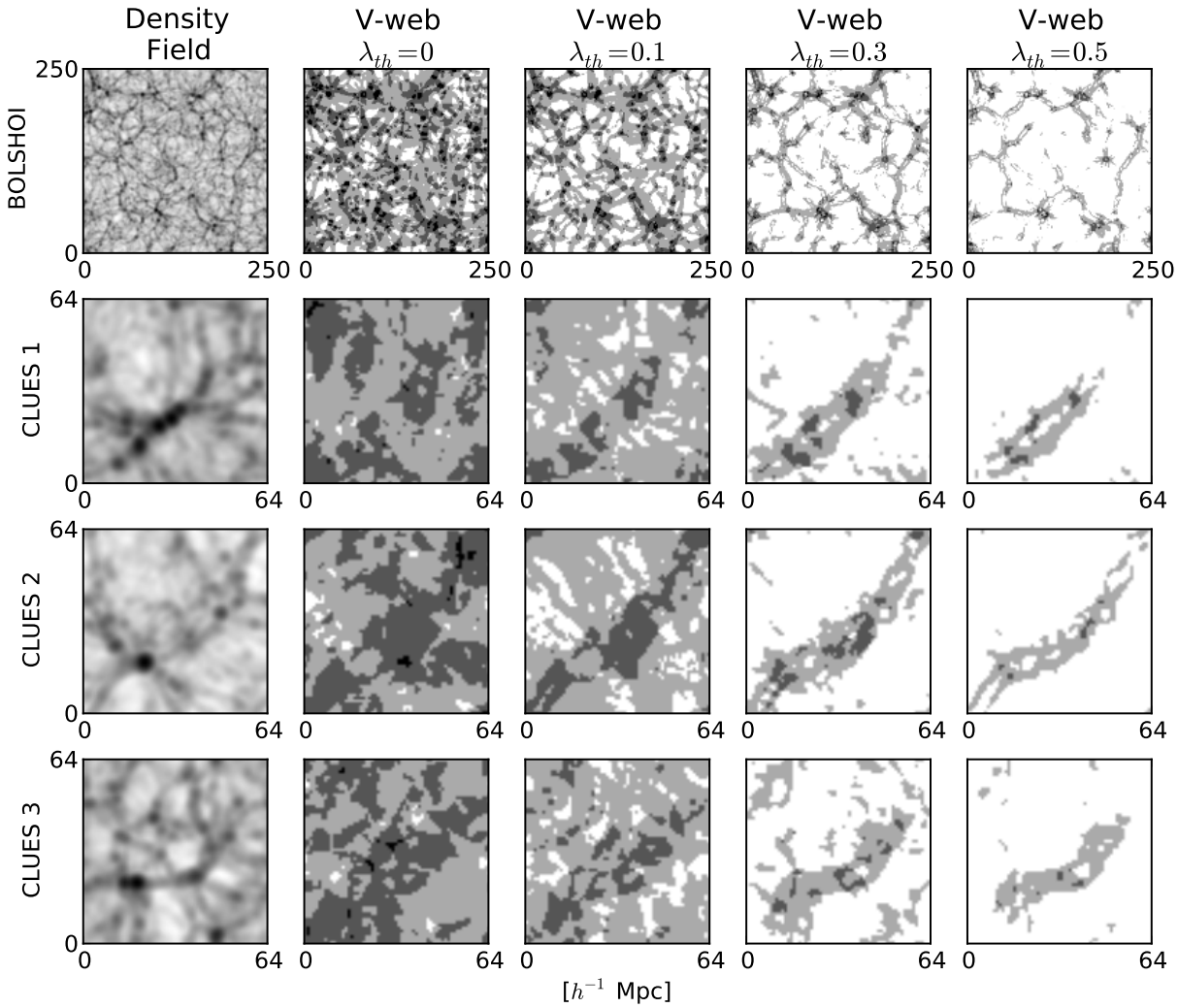
Nevertheless, λ_{th} is still a free parameter, chosen manually in order to reproduce the visual impression of the cosmic web.

Classification of the Cosmic Web

The proposed scheme is based on the minimization of the mean density of vacuums, since this type of region dominates the visual appearance.



Classification of the Cosmic Web



Defining the Samples

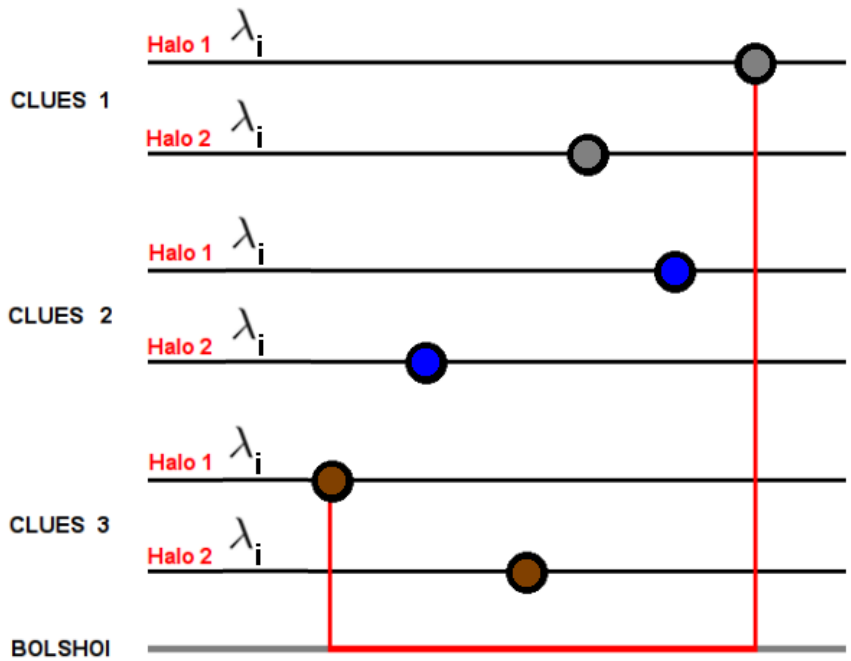
From FOF catalogues of dark matter halos of each simulations, it is built the next samples of halo pairs:

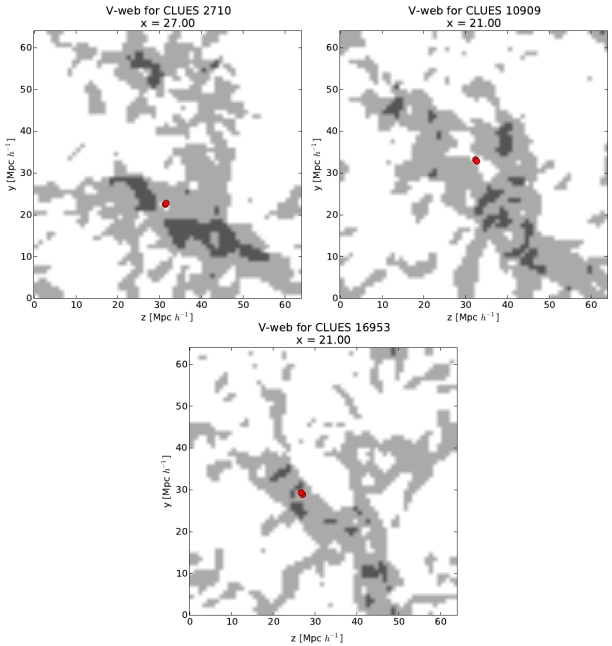
- **Pairs (P):** all halo pairs that satisfy the criterion to be the closest neighbour to each other. Defined in Bolshoi, CLUES.
- **Isolated Pairs (IP):** all halo pairs that besides, satisfy having a relative distance less than $0{,}7h^{-1}$ Mpc, negative radial velocity, and being relatively isolated from more massive halos and other cosmological structures. Defined in Bolshoi, CLUES.
- **LG-like pairs (LG):** the three LG systems defined in each one of the three CLUES simulations, respectively. By construction, they are embedded into a cosmological environment compatible with observations. Defined in CLUES.

Defining the Samples

In order to obtain a faithful sample of LG-like systems in unconstrained simulations regarding the local environment, it is proposed the next scheme.

- **Constructed Local Groups (CLG):** all halos pairs of the *IP* sample whose eigenvalues (host cell) are within the range defined by the LG-like systems in the constrained simulations. Defined in Bolshoi.





Defining the Samples

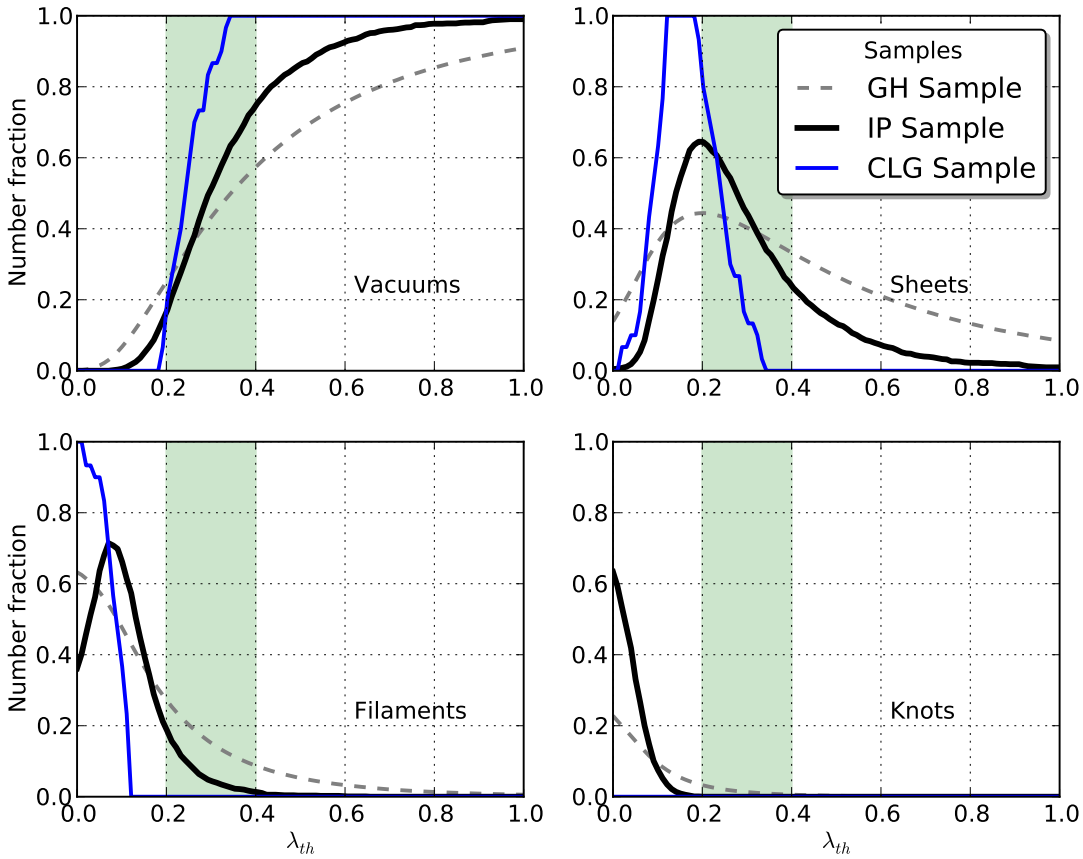
The size of each sample scales approximately as the volume of the simulations.

Sample	CLUES 1	CLUES 2	CLUES 3	Bolshoi
GH	56632	57707	56799	432000
IH	1493	1490	1493	88068
P	386	380	387	23037
IP	20	12	18	1256
LG	1	1	1	–
CLG	1	2	3	30

Taking into account the number of systems in each simulation, the *CLG* sample in Bolshoi is a more faithful sample than the *IP*.

Environment of LG-like Systems

The proposed method to construct the *CLG* sample biases the host environment to low density regions, so these LG-like systems lie preferentially in vacuums and sheets.



Fractional Anisotropy

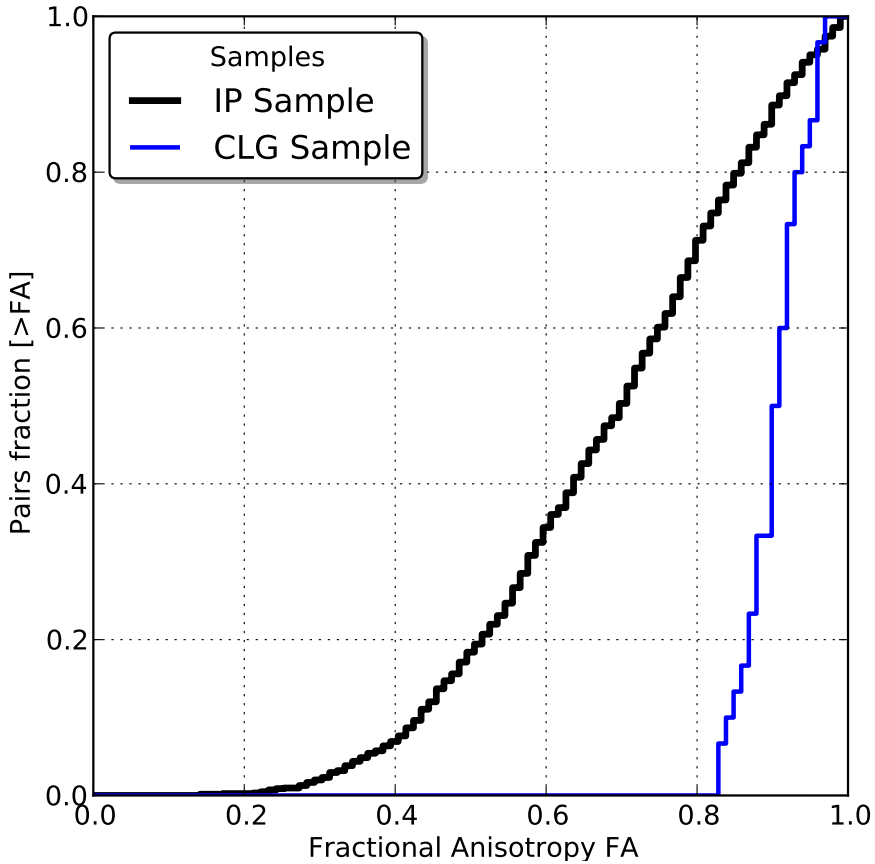
Another more convenient way to quantify the cosmological environment is the fractional anisotropy, defined as (Libeskind et al. 2013)

$$FA = \frac{1}{\sqrt{3}} \sqrt{\frac{(\lambda_1 - \lambda_3)^2 + (\lambda_2 - \lambda_3)^2 + (\lambda_1 - \lambda_2)^2}{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}} \tag{2}$$

This quantity quantifies the anisotropy degree of a region. Vacuums are biased to low FA values ($FA \sim 0$), whereas Knots to high values ($FA \sim 1$). Filaments and Sheets are distributed over middle values, even so, there are a slight tendency towards lower values for Filaments and higher values for Sheets.

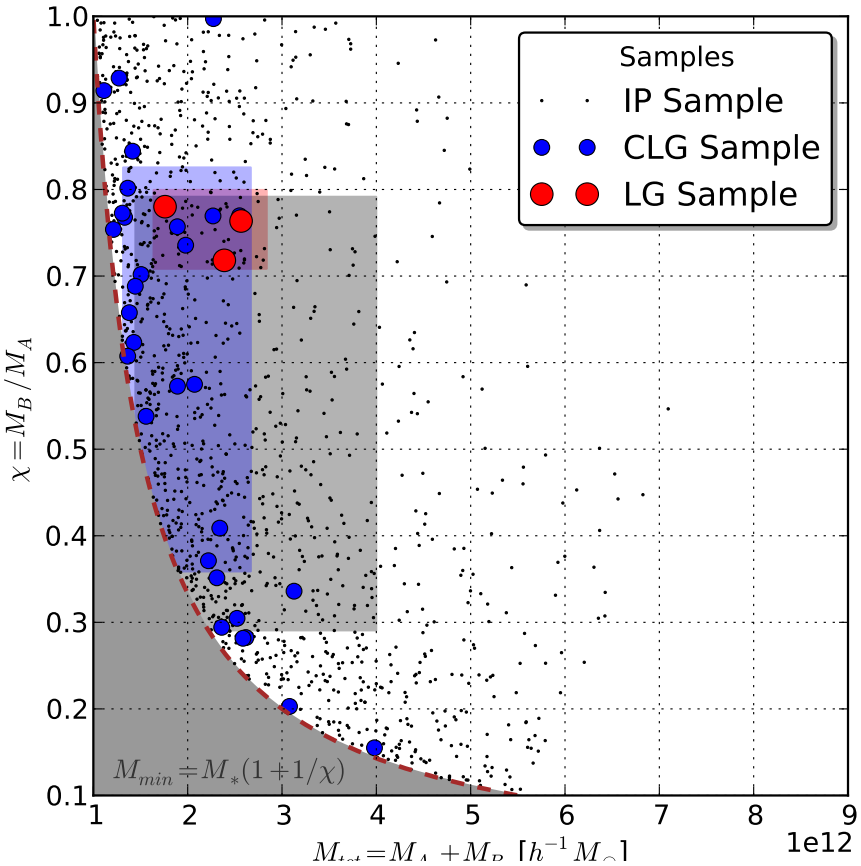
Fractional Anisotropy

The distribution associated to *CLG* systems is biased again compared with the *IP* sample, confirming the preferred environment.



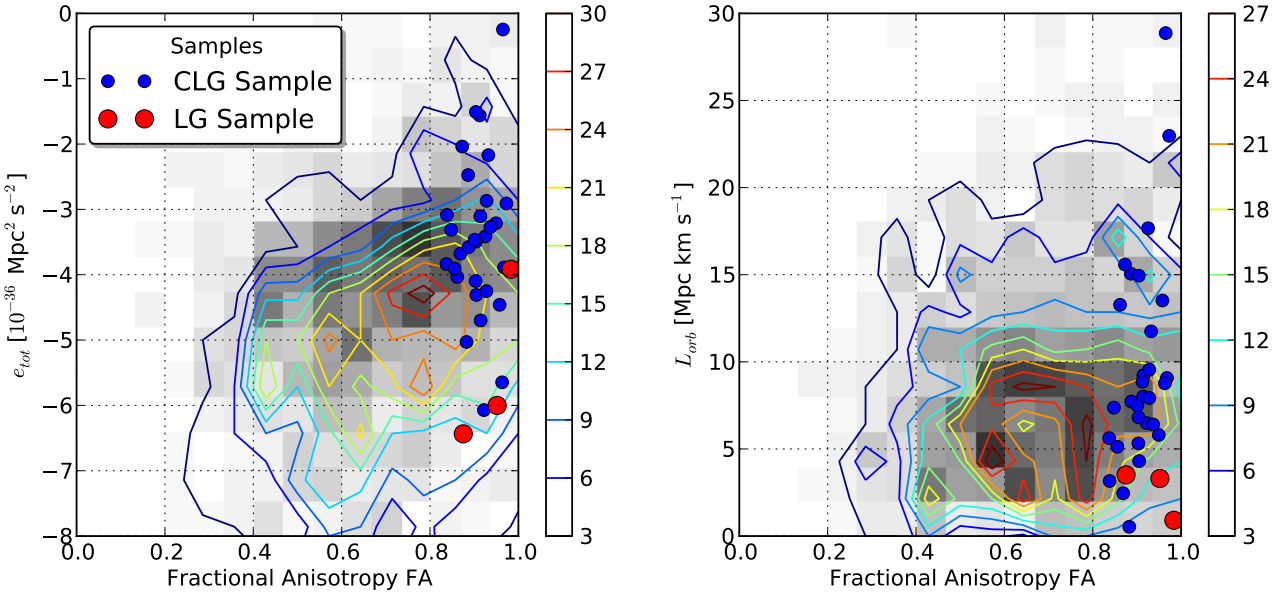
Mass of LG-like systems

It has been found an environmental bias with respect to the total mass of *CLG* systems, but not for the mass ratio.



Energy and Angular Momentum of LG-like systems

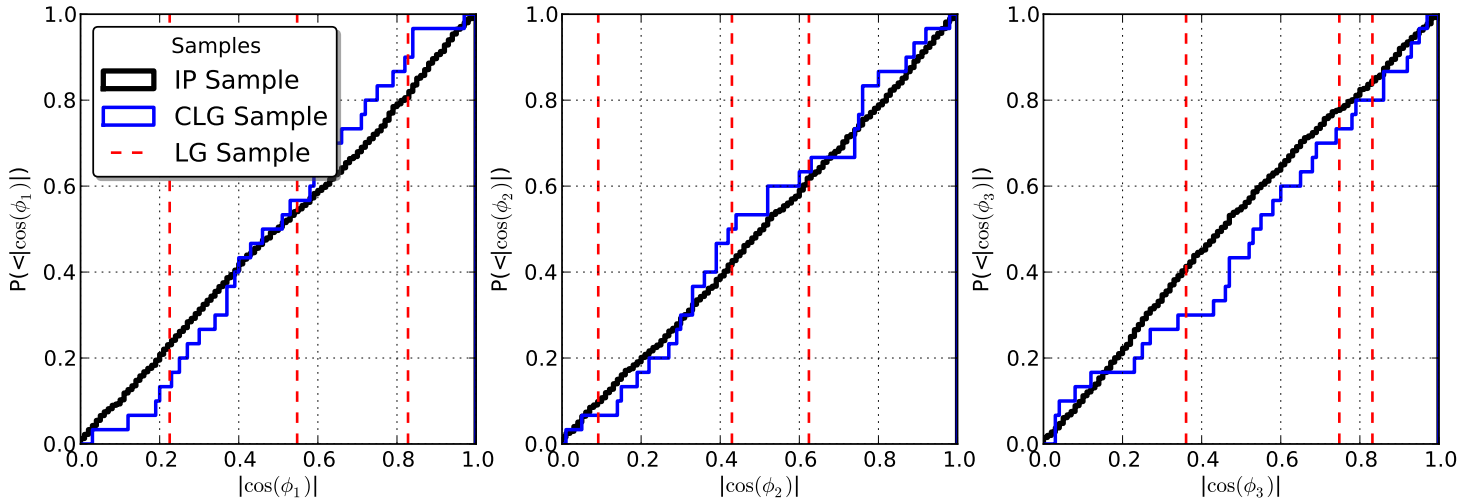
Considering each pair system as a isolated system, it is calculated the specific energy and the specific orbital angular momentum.



It can be noticed a bias for the energy but not for the angular momentum. Higher values of energy are more abundant in high anisotropic regions, whereas lower values are distributed over middle anisotropic zones.

Alignment of LG-like systems

Finally, it is calculated the alignment of the angular momentum with each one of the eigenvector of the V-web.



No preferred alignments have been found, although further data are necessary to conclude.

Conclusions

- The proposed method to set the threshold parameter of the V-web scheme reproduces properly the visual appearance of the cosmic web, and works fine for both simulations, obtaining similar values.
- The numbers of samples in each simulation scales approximately as their volumes.
- The proposed method to construct LG-like systems in the Bolshoi simulation biases the environment, being preferred high anisotropic and low density regions, like sheets and vacuums.
- The criterion to select CLG systems according to the environment of the LG sample in CLUES, biases the total mass distribution, but not the mass ratio.
- There is an environmental bias in the specific energy of *IP* systems, but not for the angular momentum. Furthermore, any preferred alignment has been found for the orbital plane.

Further Work

- Look for other possible correlations for other physical properties.
- Compare with classification schemes based on the density field.
- Use BDM catalogues instead of FOF.
- Look for possible effects of near voids (large-scale voids).
- Use observational constrains in a direct way instead of using constrained simulations.

And finally

Thank you!

Further information and the corresponding bibliography can be found in the next github repository
`https://github.com/sbustamante/Thesis`