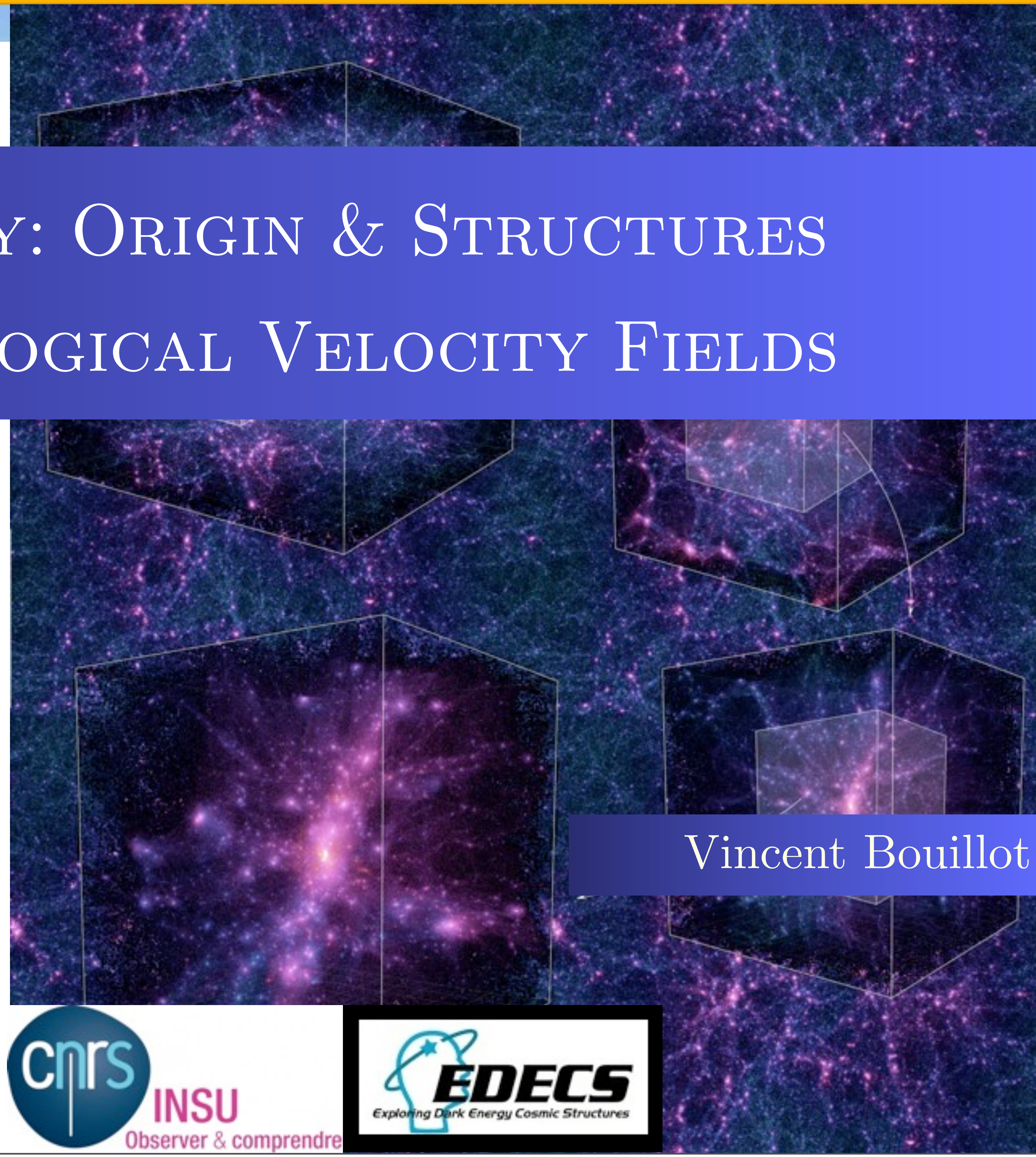
Cosmology: Origin & Structures

On cosmological Velocity Fields



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EDECS Exploring Dark Energy Cosmic Structures

AGENDA

I. Introduction

II. Large-scale cosmological velocity fields

III. Statistical interpretation of high velocity cosmic flows

IV. Large-scale asymmetry: origin of high velocity cosmic flows

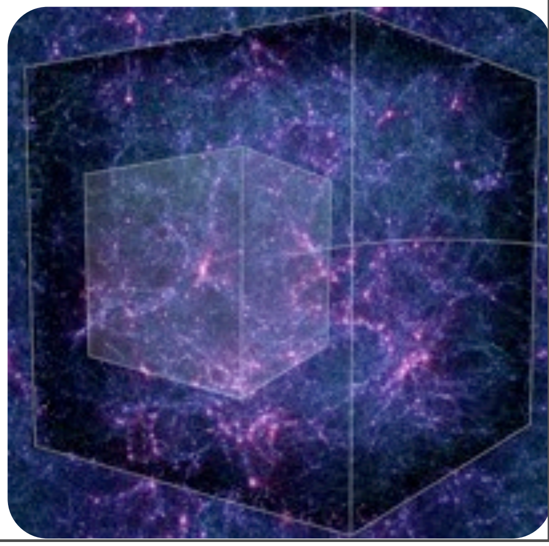
V. Spatial distribution of high velocity cosmic flows

VI. Bullet Cluster: A challenge to standard cosmology?

VII. Conclusion

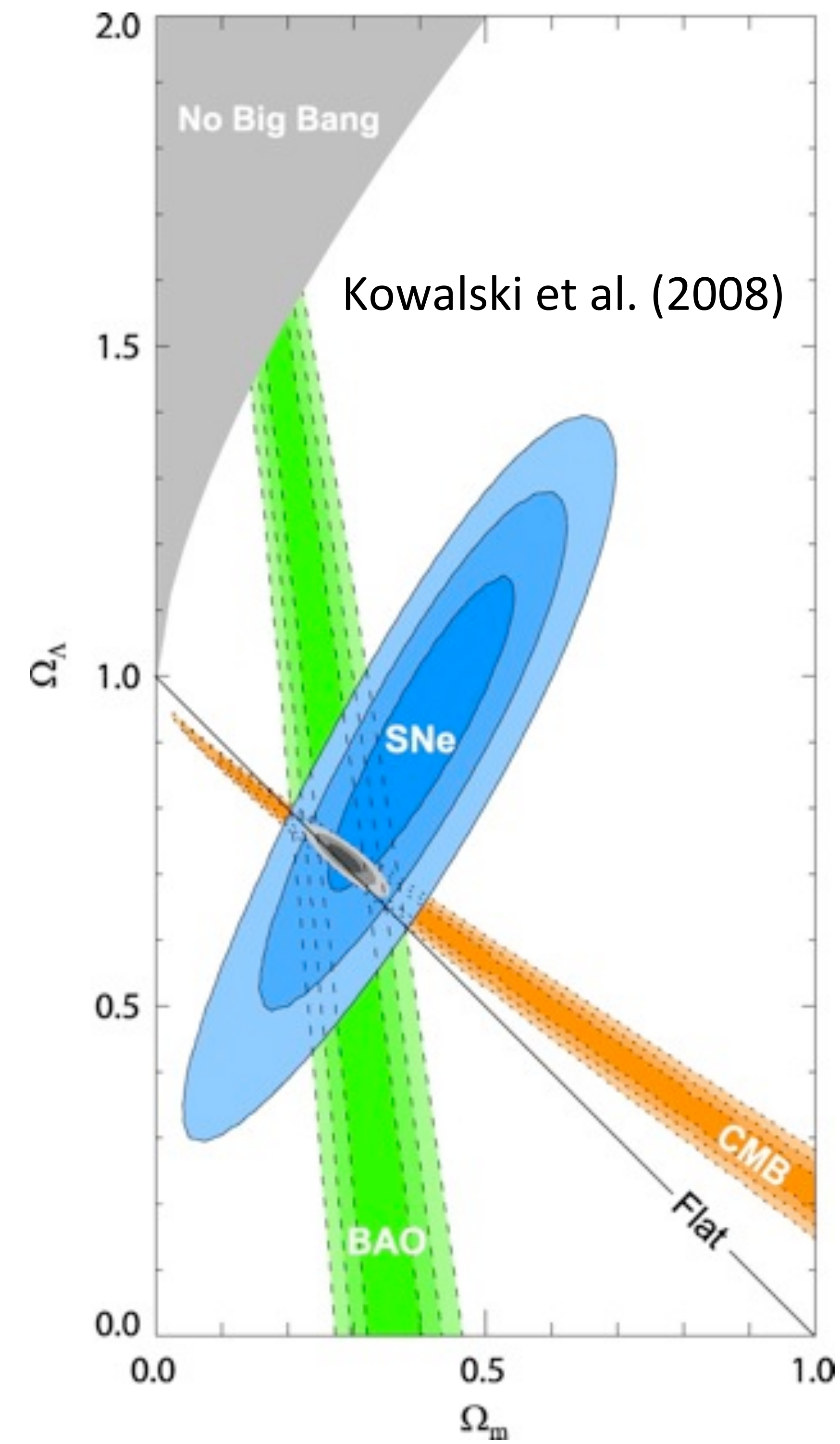
I.Introduction

1) Discovery of a Dark Sector
2) Dark Energy - Structure formation
3) N-body simulations
4) Cosmological velocity fields



DISCOVERY OF A DARK SECTOR

- The Universe is a dynamical physical system.
- Cosmic expansion is accelerated:
  - This acceleration is driven by an unknown form of energy.
  - What is the amount of Dark Energy?
- Supernovae Ia, Cosmic Microwave Background, Baryonic Acoustic Oscillations.



Kowalski et al. (2008)

Dark Energy - Structure formation

- What is the nature of Dark Energy?
  - Numerous concurrent Dark Energy models
- How can we distinguish various Dark Energy models?
- Solution: use of structure formation and gravitational non-linear clustering.
  - What can we learn on Dark Energy from structure formation?
  - Conversely, what is the impact of Dark Energy on structure formation?

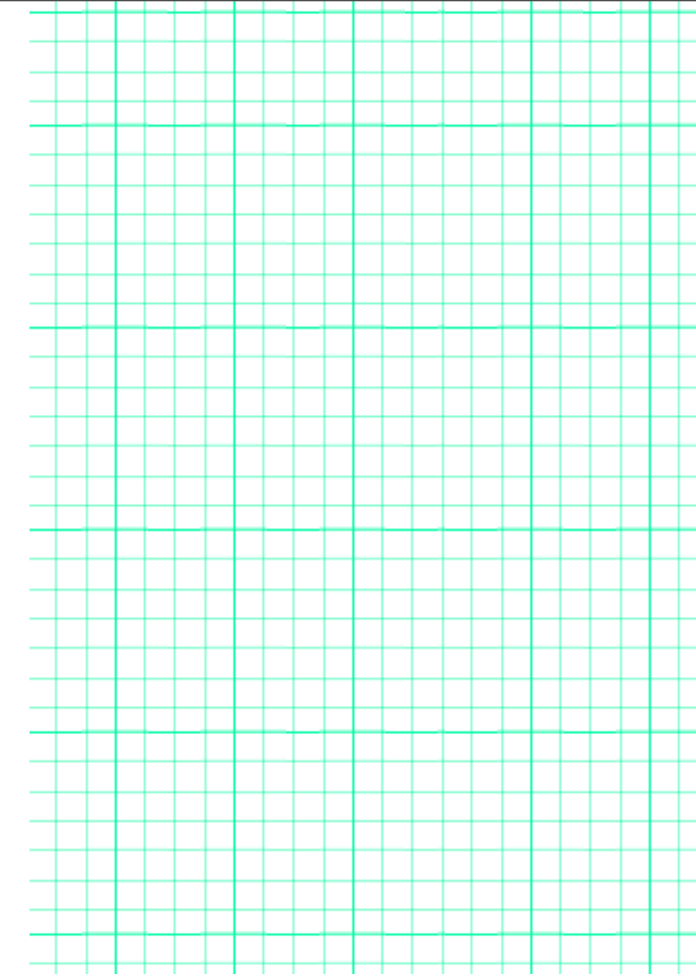
STRUCTURE FORMATION

- Structure formation and gravitational clustering are non-linear processes.
- No analytic theories to fully describe the gravitational collapse from a linear to a non-linear phase, which is very important to understand structure formation:
  - Unavoidable use of the numerical tool.
- How should we proceed to perform numerical simulations of structure formation in Dark Energy models?
  - N-body simulations to follow gravitational clustering in realistic (i.e. in agreement with SNIa, CMB...) cosmological models.

N-Body simulations

- «Not too high» number of bodies: the main difficult part is the resolution of the Vlasov-Poisson equations.
- The DEUS consortium:
  - An highly scalable application called AMADEUS emcompassing the whole simulation chain.
    - Initial conditions: realistic models.
    - Gravity solver (Vlasov-Poisson solver) - RAMSES-DEUS.
    - Post-processing (Slicing, Friends-of-Friends structure detection, filing of generated data...).

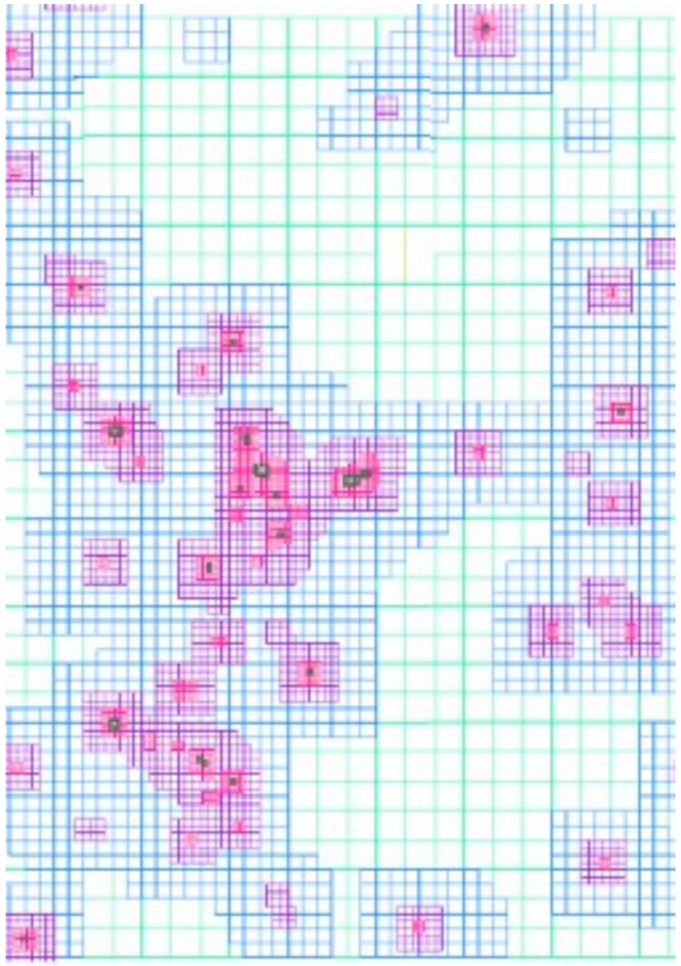
N-BODY SIMULATIONS



❖ The PM method in a nutshell:

1. Compute the mass density ρ on the **mesh** using an interpolation scheme from the position of **particles**.
2. Compute the potential ϕ on the **mesh** using the field equation.
3. Compute the acceleration on the **mesh**.
4. Compute each **particle** acceleration using the inverse interpolation scheme used in step 1.
5. Update each **particle** velocity and position - check energy conservation equation - modify the time-step.

N-BODY SIMULATIONS



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Simulations done with my collaboration

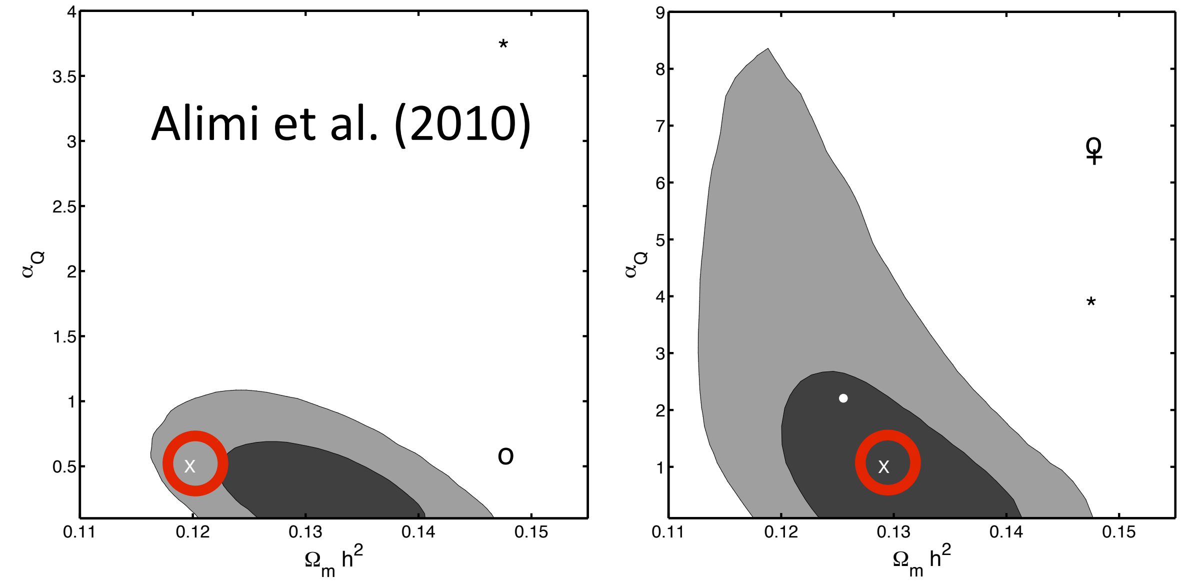
N-Body simulations

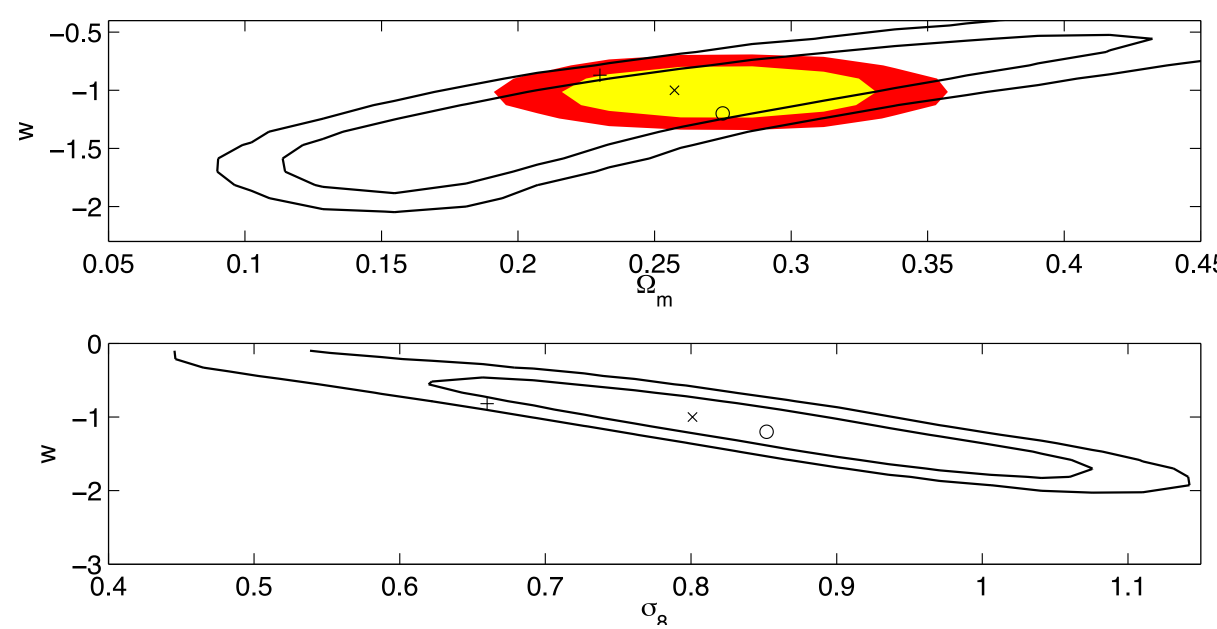
❖ Set of 31 cosmological simulations covering a large range of science topics (scales and cosmological models):

Boxlength (h^{-1} Mpc)	Resolution (h^{-1} kpc)	Mass resol. (h^{-1} $M_\odot$)	Number of particles	Initial redshift	Cosmological model	Computer (# of cores)
162	2.5	2.10^9	512^3	90	Λ, SU, RP	Titane (64)
162	2.5	$2.5.10^8$	1024^3	130	Λ, SU, RP	BlueGene/P (4096)
648	20	$1.5.10^{11}$	512^3	55	Λ, SU, RP	-
648	10	$1.7.10^{10}$	1024^3	90	Λ, SU, RP	BlueGene/P (4096)
648	5	2.10^9	2048^3	90	Λ, SU, RP	BlueGene/P (32768)
1296	40	10^{12}	512^3	40	Λ, SU, RP	-
2592	40	10^{12}	1024^3	55	Λ, SU, RP	BlueGene/P (4096)
2592	20	$1.5.10^{11}$	2048^3	55	Λ, RP	BlueGene/P (24576)
5184	40	10^{12}	2048^3	40	Λ, RP	BlueGene/P (24576)
10368	40	10^{12}	4096^3	100	Λ, RP, w	Curie Thin (9504)
21000	40	10^{12}	8192^3	100	Λ, RP, w	Curie Thin (76032)

N-BODY SIMULATIONS

- DEUS cosmological models:
  - Standard ΛCDM model.
  - Quintessence models:
    - Find the potential parameters:
      - Ratra-Peebles: $V_{RP}(\varphi) = \frac{\lambda^{4+\alpha_Q}}{\varphi^{\alpha_Q}}$
      - Supergravity: $V_{SU}(\varphi) = \frac{\lambda^{4+\alpha_Q}}{\varphi^{\alpha_Q}} e^{\frac{\kappa^2}{2}\varphi^2}$
  - Phantom model:
    - Find the equation of state: w





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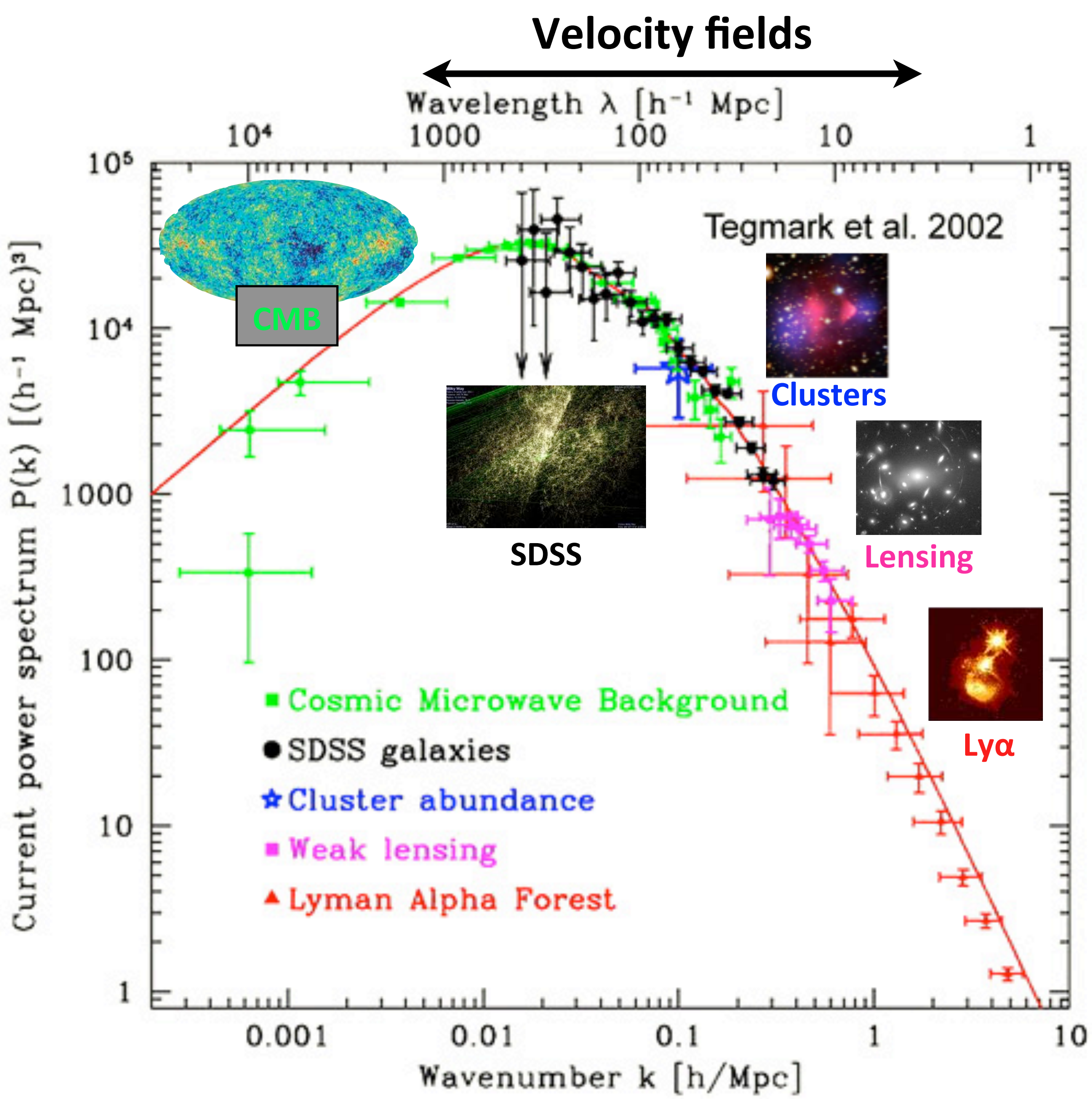
COSMOLOGICAL VELOCITY FIELDS

❖ Cosmological velocity fields:

- Probe from small to large scales.
- Sensitive to the total mass (not only the luminous baryons).
- More sensitive to large scales than density fields.

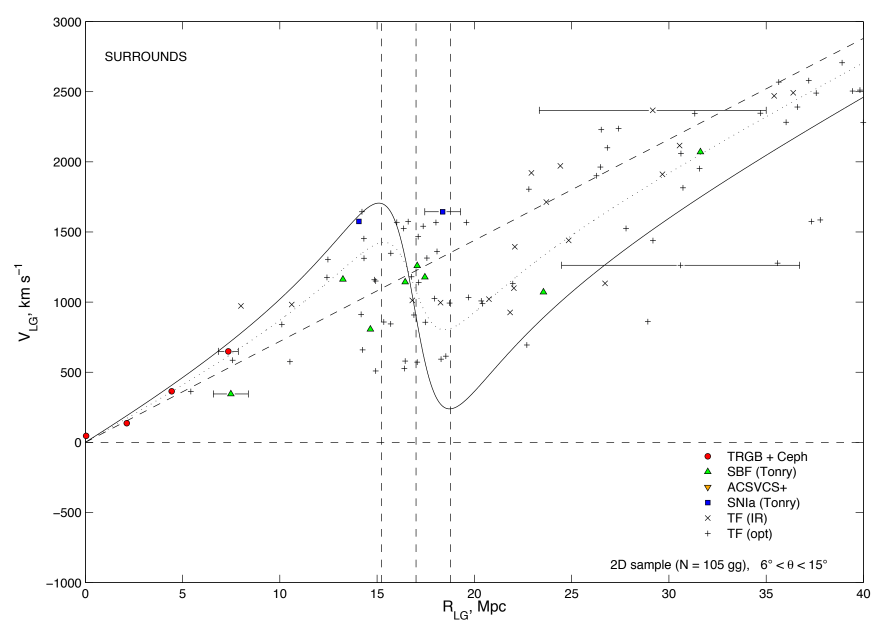


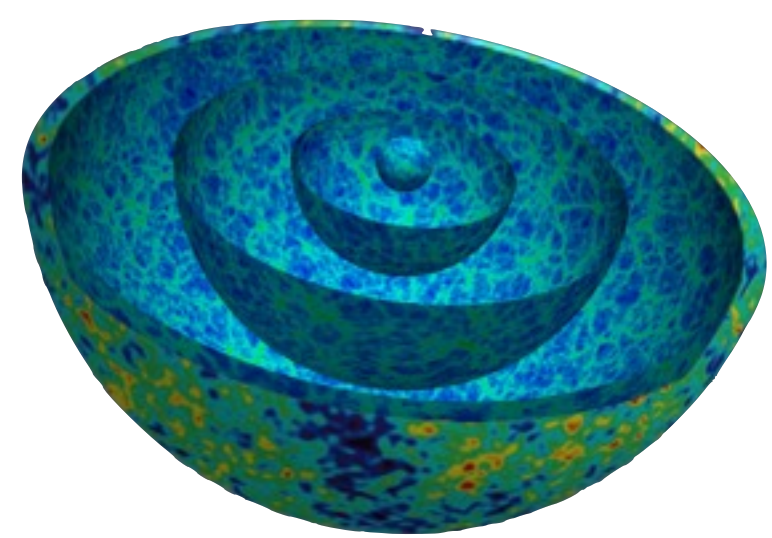
Cosmological velocity fields

- Cosmological velocity fields:
  - Small scales: 1E0657-56 (Bullet cluster)
  - Intermediate scales: Virgocentric infall
  - Large scales: Bulk (spherically averaged) cosmic motion

Markevitch et al. (2002)

Karachentsev, Nasonova (2010)





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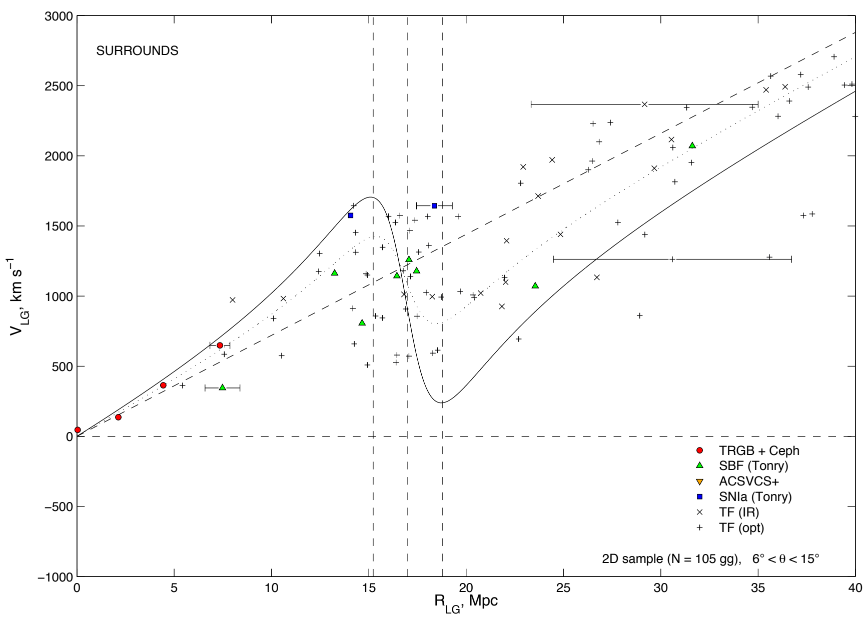
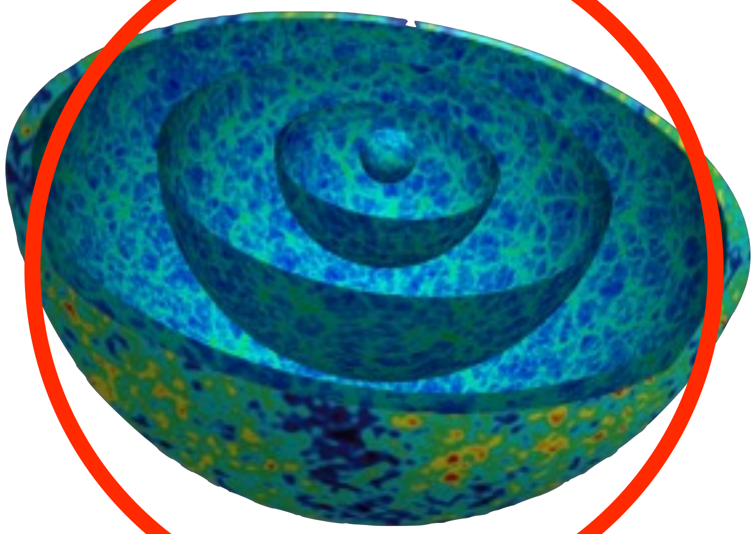




VI.Bullet Cluster: a challenge to standard cosmology

1) Bullet clusters
2) Occurence of bullets
3) Probability of bullets

BULLET CLUSTERS

- 1E0657-56 (BC) is the most famous bullet system:
  - Main cluster mass $10^{15}\ h^{-1}\ M_\odot$.
  - Ratio 10:1 at z=0.296.
  - The gas of the main cluster is ripped off the gravitaional potential!
  - Velocity of the shock front is 4700 km/s.
  - Doesn't mean the dark matter velocity is so high.

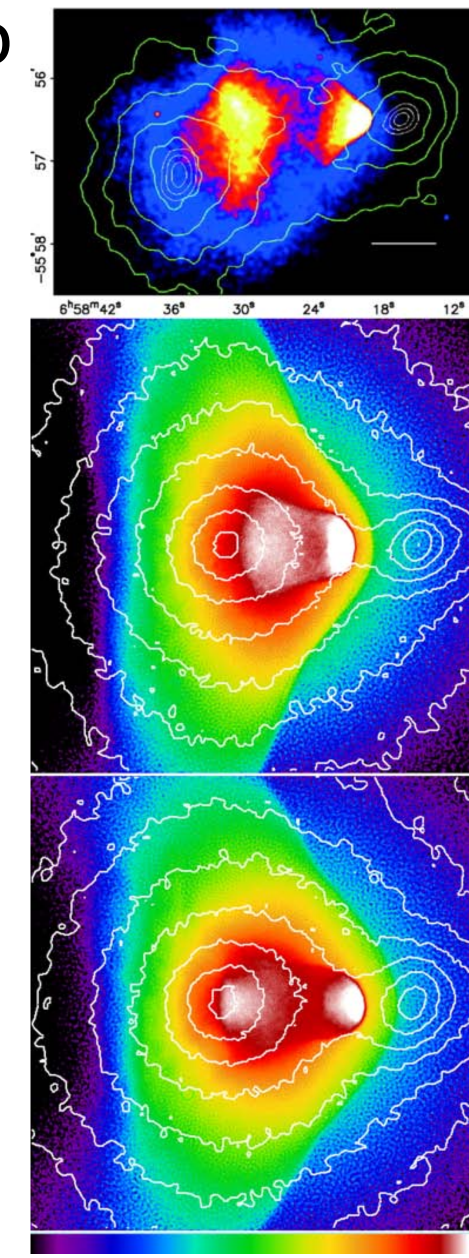
Bullet clusters

- Other bullet systems:
  - El Gordo (ACT-CL J0102-4915) (mass ratio 2:1 z=0.87)

  - MACS J0025.4-1222 (mass ratio 1:1 z=0.586)

BULLET CLUSTERS

- How such galaxy cluster pairs form?
  - Mastropietro & Burkert (2008) pave the initial parameters space to understand how the gas of the main halo can be ripped of the potential (3D hydro simulation)
  - Initial conditions:
    - Initial redshift: z=0.486.
    - Mass ratios: 6:1 better than 10:1.
    - Initial relative (pairwise) velocities: 3000 km/s.
  - Careful: non-cosmological simulations.

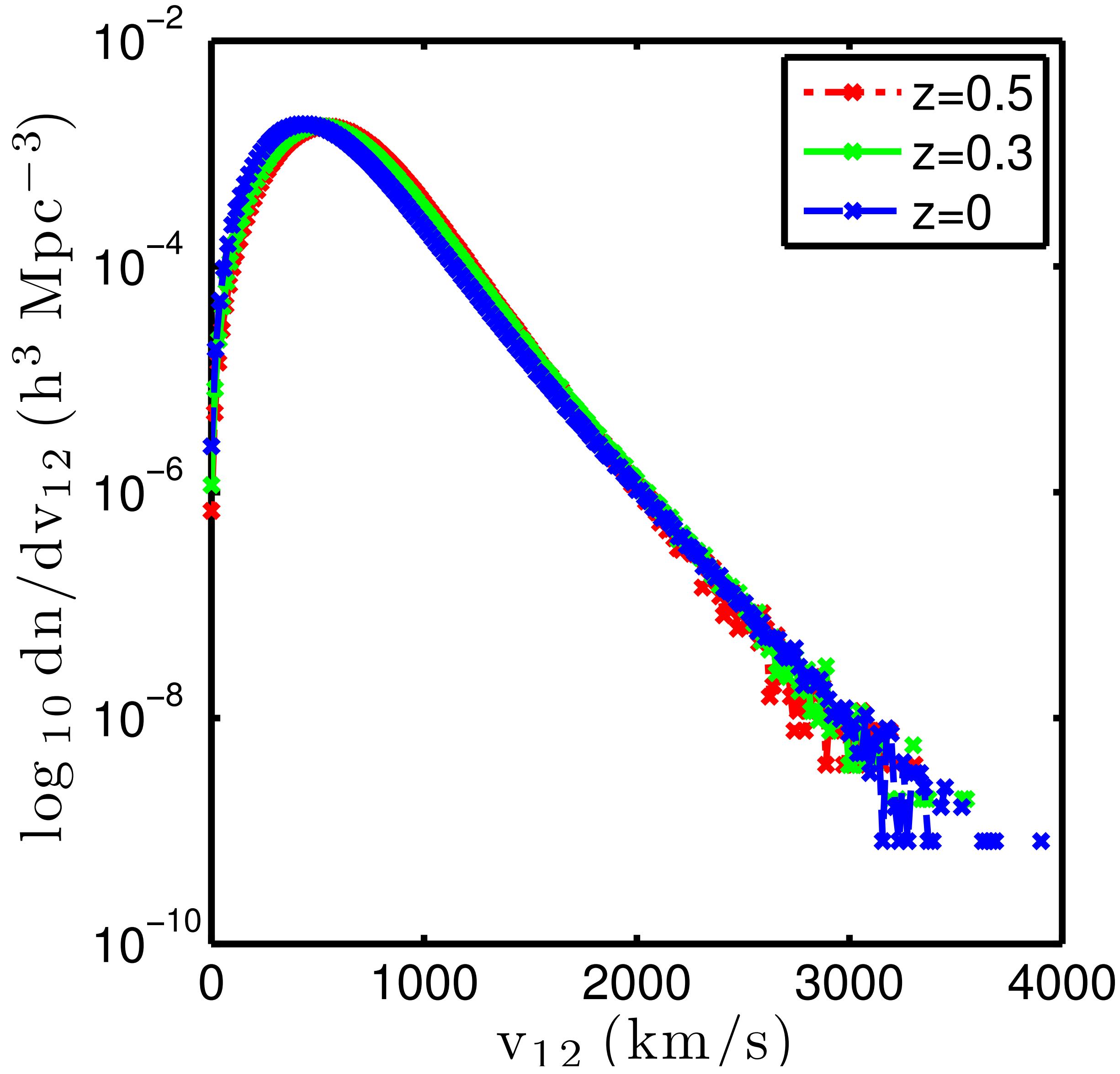


Occurence of bullets

- ❖ Is this a problem for the standard picture of cosmology?
- ❖ Such an event can rule out an entire cosmological model!
- ❖ Use very large numerical simulations to look for the initial conditions of Mastropietro & Burkert (2008).
  - DEUS: Full Universe Run is the perfect simulation:
    - High mass resolution.
    - Large volume to get extreme events and high halo abundance.

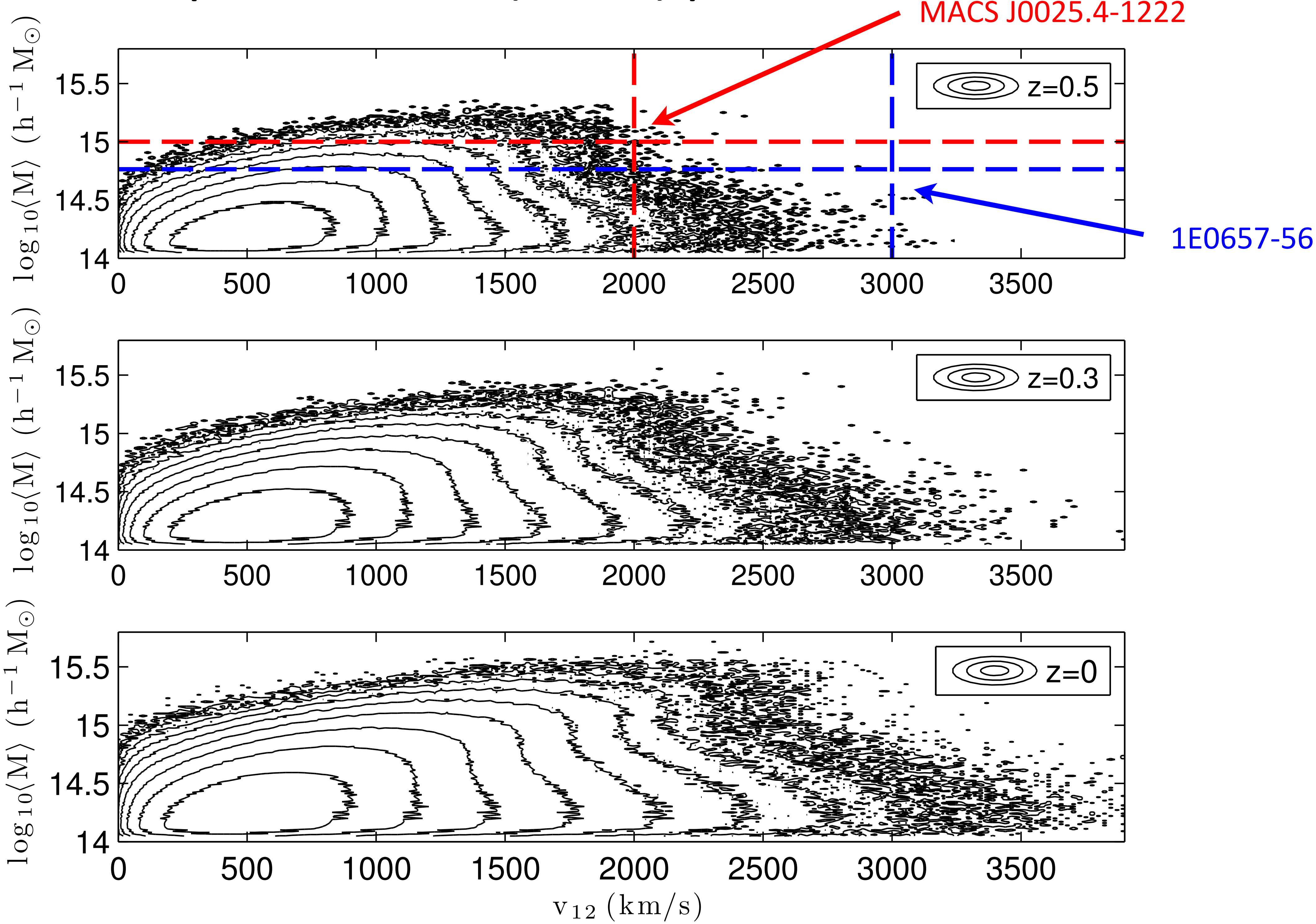
OCCURENCE OF BULLETS

- Distribution of v_{12} to know if some objects may have the good initial velocity:
  - Large pairs velocity are definitely there.
  - But, the BC initial conditions require a given average mass.
- Distribution in (M,v_{12}) plane to know if some objects may match the good initial condition.



Occurence of bullets

❖ Redshift dependence of (M, v_{12}) plane:



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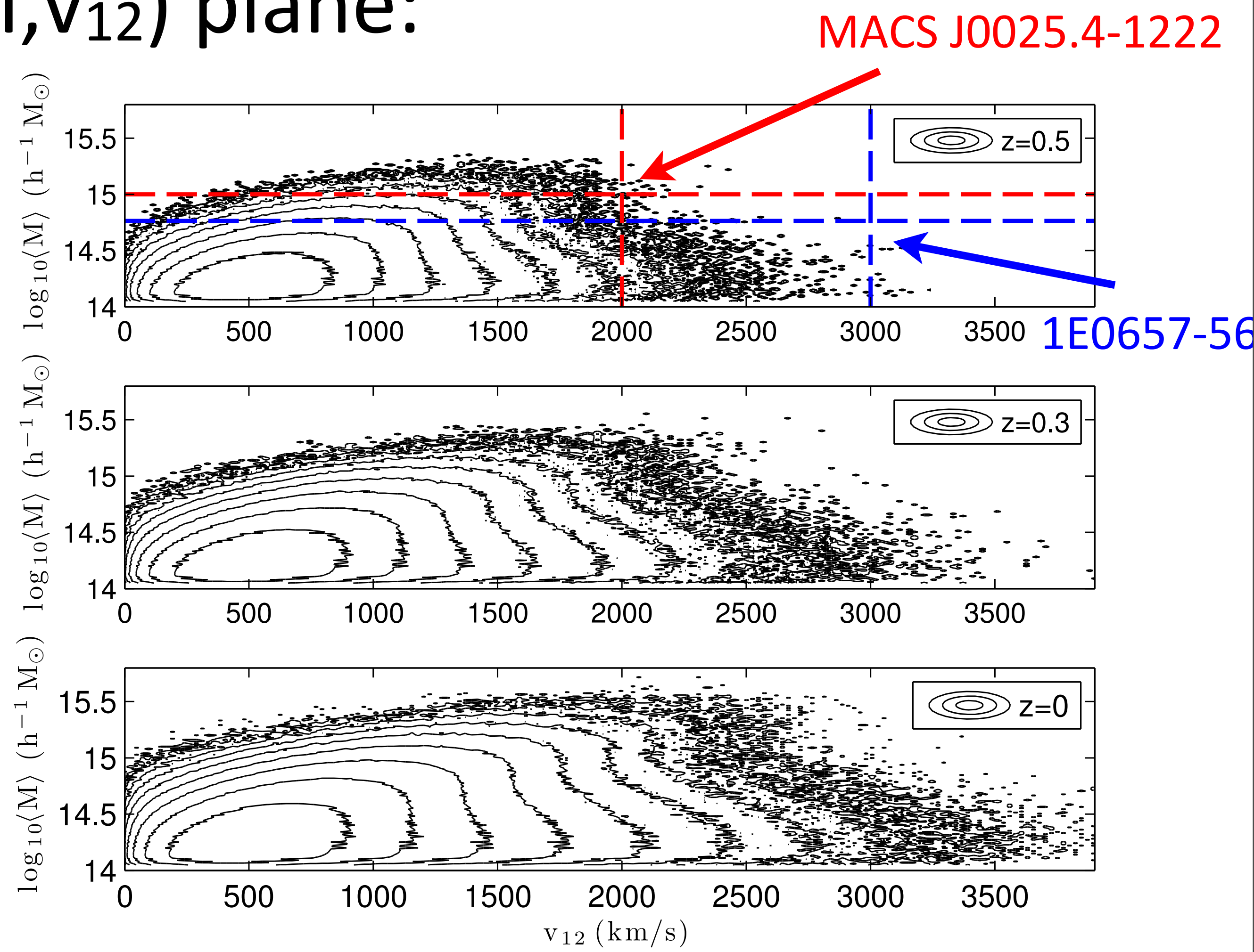
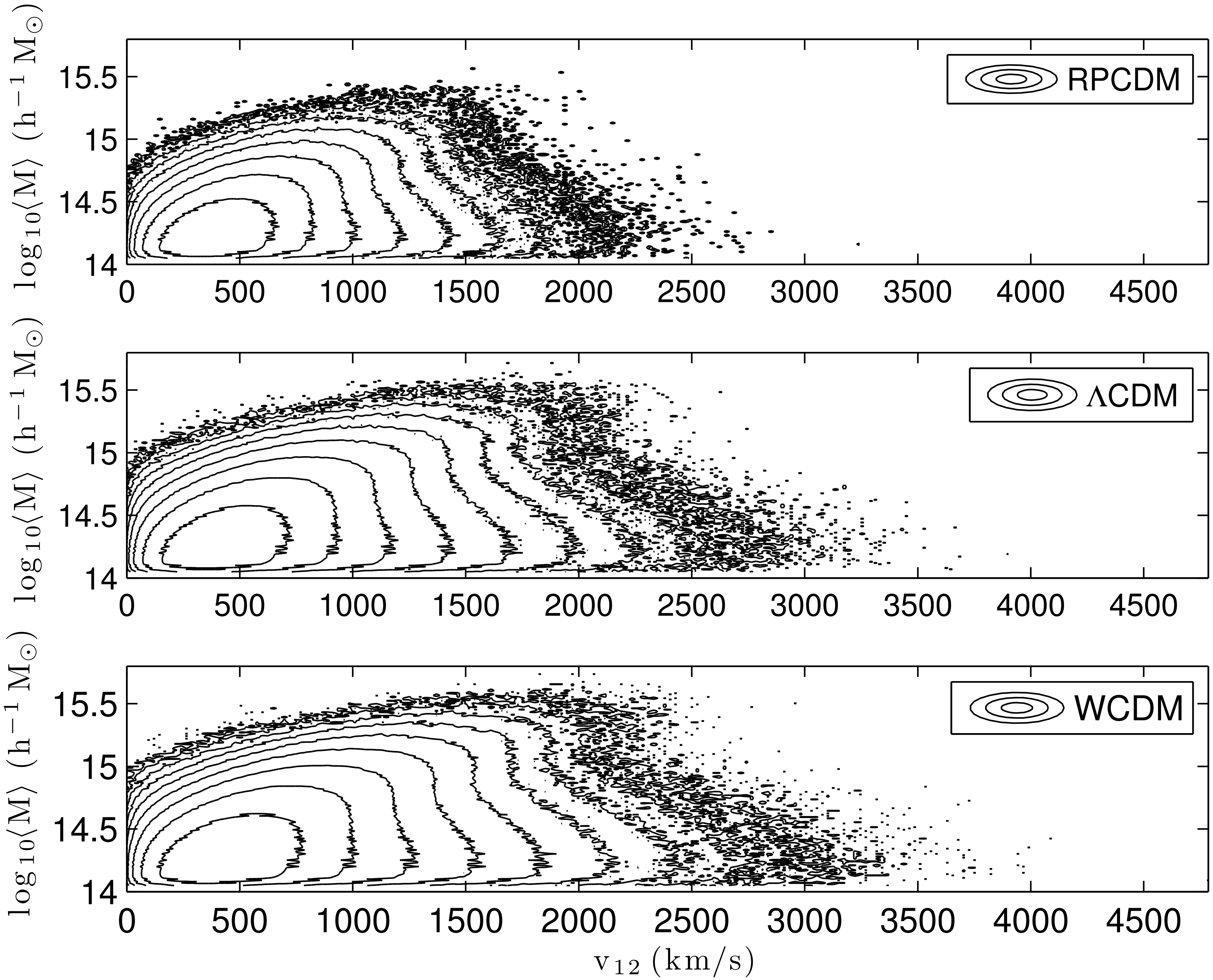
OCCURENCE OF BULLETS

- Redshift dependence of (M, v_{12}) plane:
  - Due to our large statistics, two regions appear in the simulations.
  - In blue, standard BC: a cluster-subcluster collision.
  - In red, MACS J0025.4-1222, a cluster-cluster interaction.
  - Not a lot of BC candidates around blue lines...



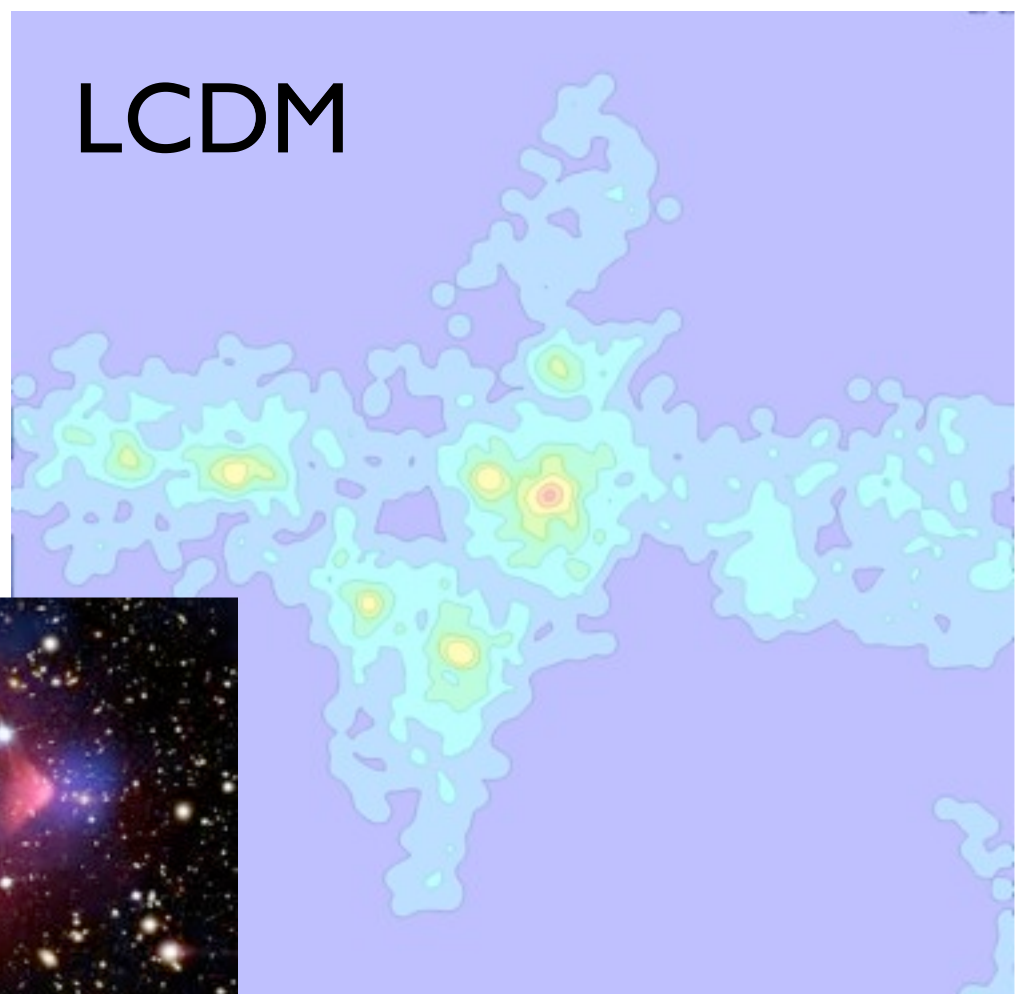
Occurence of bullets

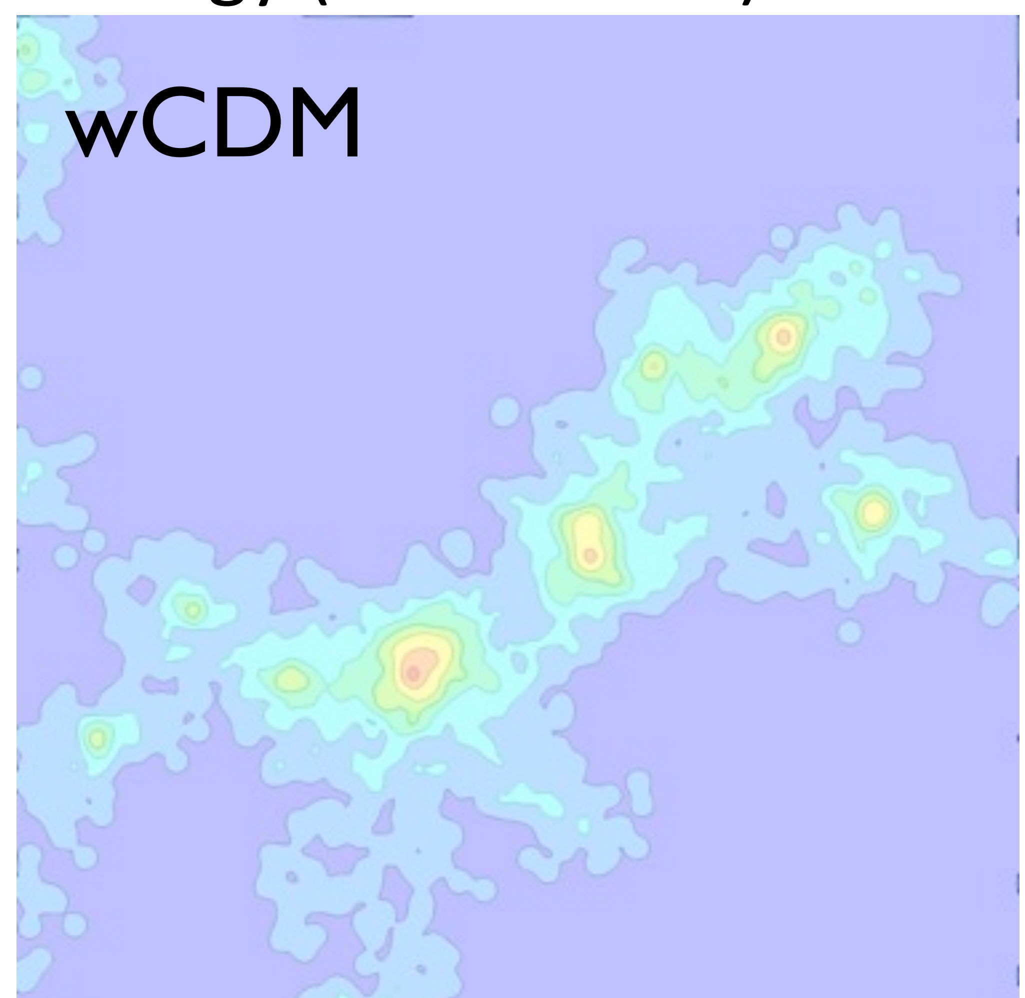
- Cosmology dependence of (M, v_{12}) plane (@ z=0):



OCCURENCE OF BULLETS

- Cosmology dependence of (M, v_{12}) plane (@ z=0):
  - In the Ratra-Peebles model, it is NOT possible.
  - In a phantom cosmology, it is possible (many candidates).
  - The limit case is the standard cosmology (1 candidate)...





PROBABILITY OF BULLETS

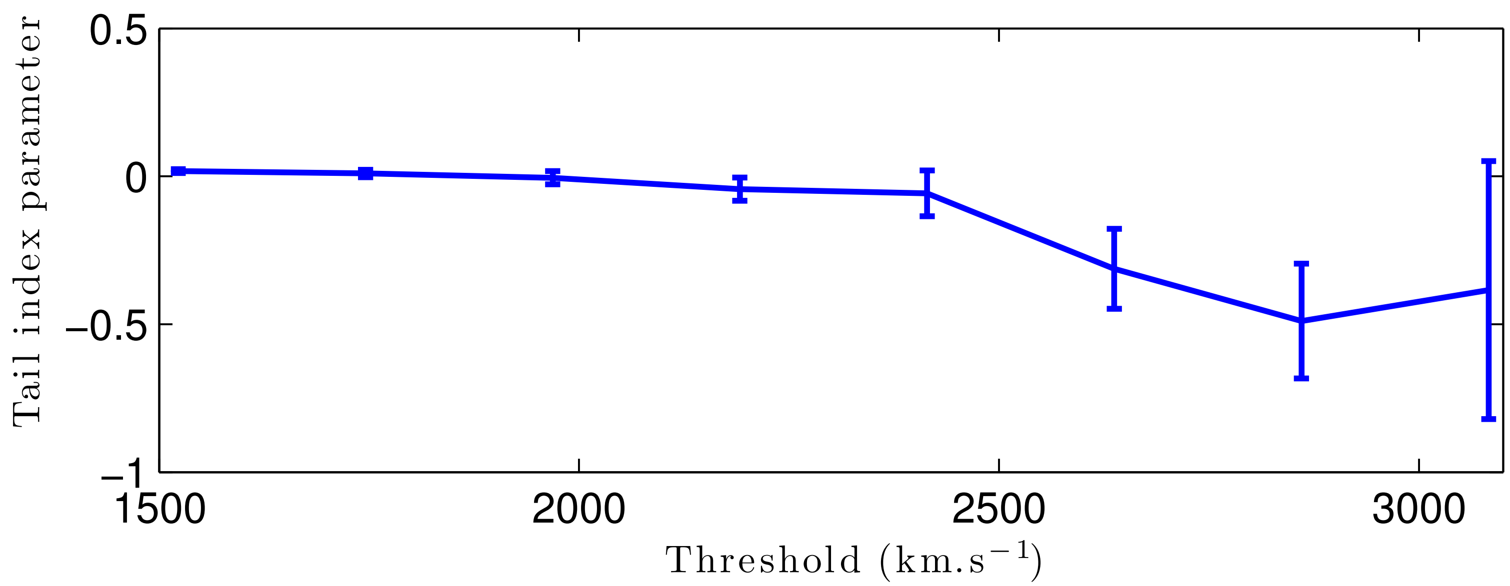
- Usual approach is to model the tail of the pairwise velocity PDF as a gaussian.
- However, we already know it is not!
  - Tails of distribution have something to do with Pareto function.
  - A gaussian modeling can lead to an under-(over-)estimation of the probability of occurence.
- Previous studies (Hayashi et al., Lee et al., Thompson et al.) use gaussians:
  - Their conclusions: the BC is impossible (10^{-9}) in LCDM model.

PROBABILITY OF BULLETS

- Extreme value approach:
  - Define an extremal event: choose of threshold
  - Tail of our velocity distribution is a generalized Pareto function:

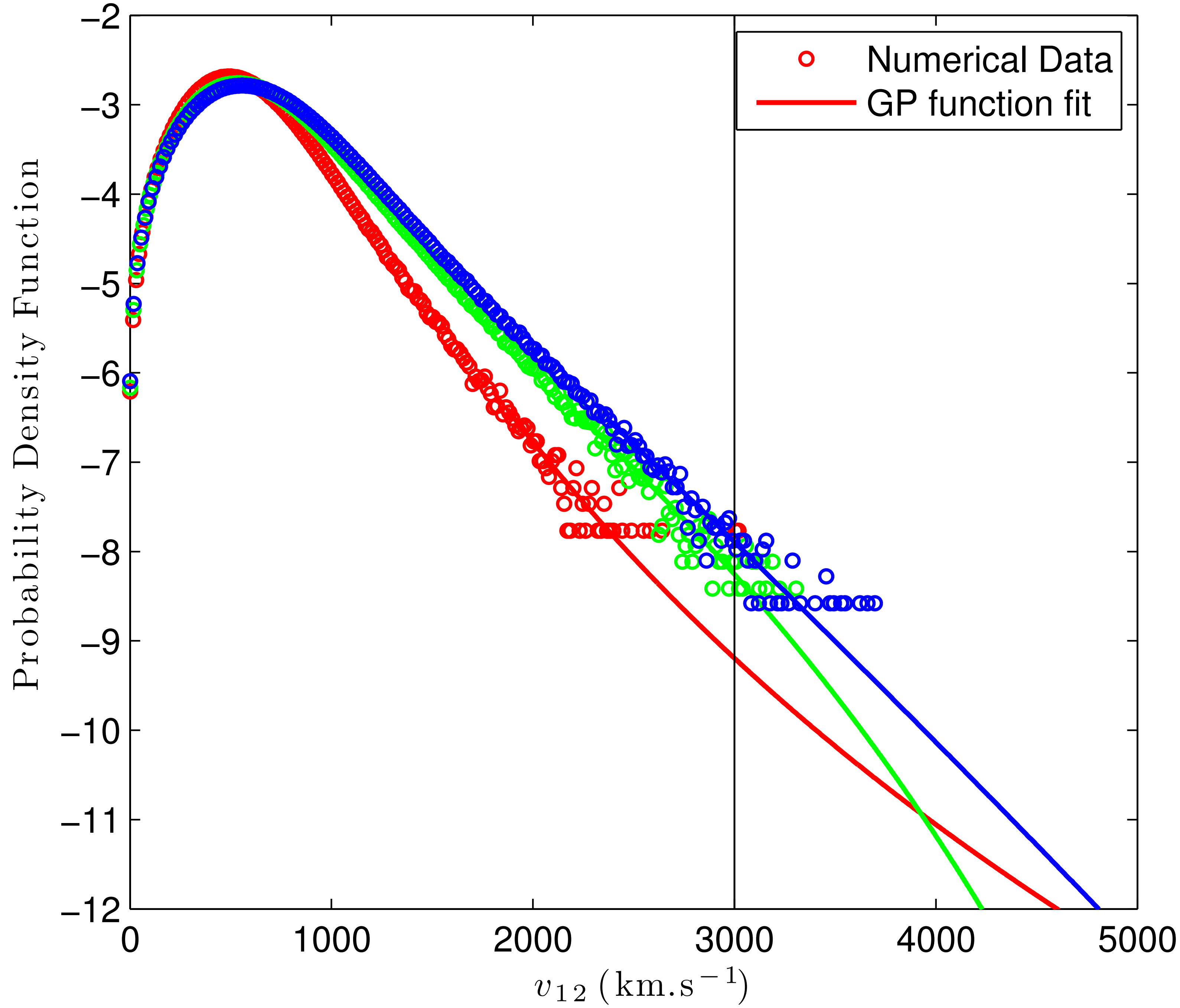
$$F_{(\xi,\mu,\sigma)}(x) = 1 - \left[1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right]_{+}^{-1/\xi}$$

  - What is the evolution of the tail index with the threshold?



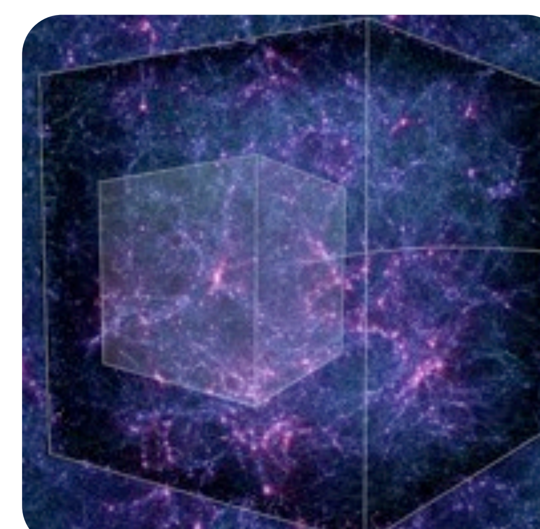
PROBABILITY OF BULLETS

- The tail index is close to zero (gaussian case) but not exactly zero (10^{-2}).
- Higher proba of BC (v>3000):
  - RPCDM: 3.10^{-8}
  - LCDM: 9.10^{-7}
  - wCDM: 3.10^{-6}



II. Large scale cosmological velocity fields

1) Local Universe measurements
2) Numerical catalogs
3) Link with initial conditions



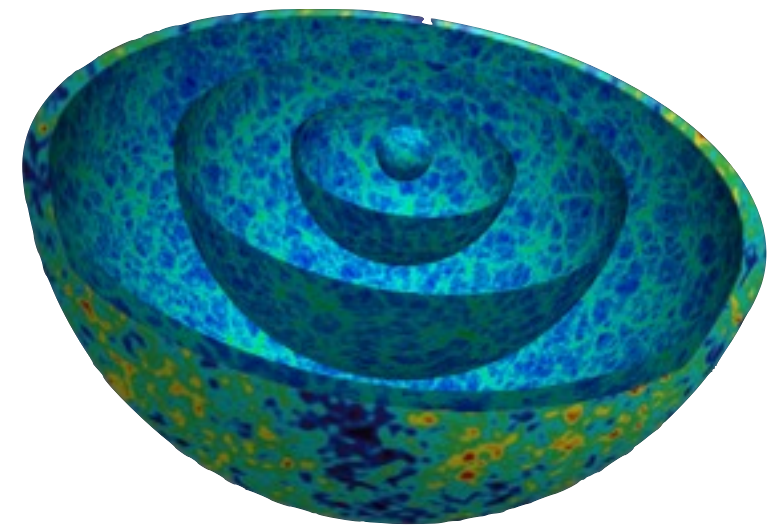
LOCAL UNIVERSE MEASUREMENTS

❖ Observational state:

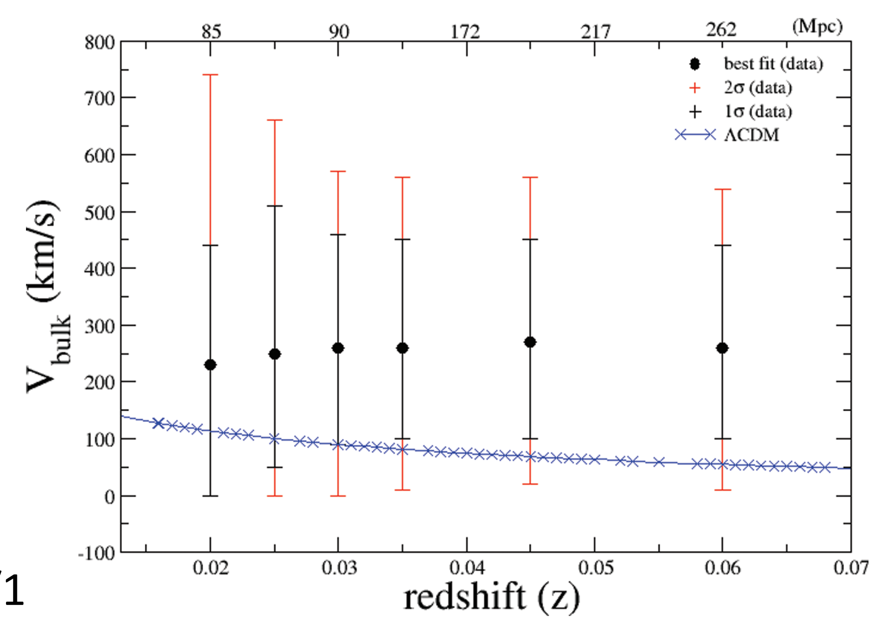
◆ COMPOSITE (SFI++, SBF...), 2MRS, 6dF...

❖ Two measured facts:

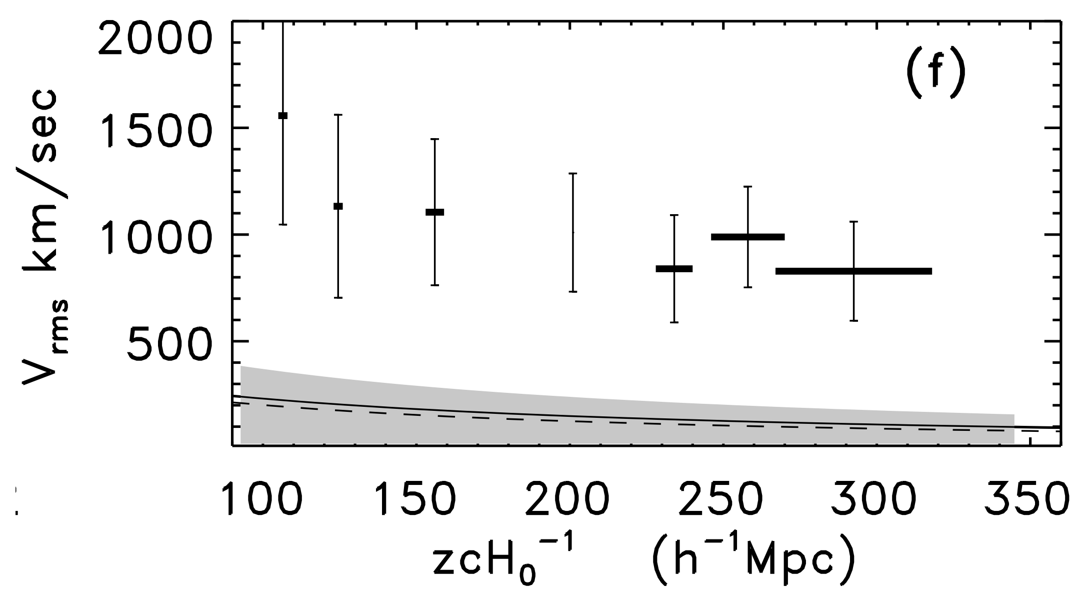
◆ Non-reconvergence of the spherical mean of the velocity fields at large scales towards the CMB dipole.



Référentiel CMB
$\vec{v}_{CMB} = \vec{0}$



Colin et al. (2011)



Kashlinsky et al. (2008)

Local Universe Measurements

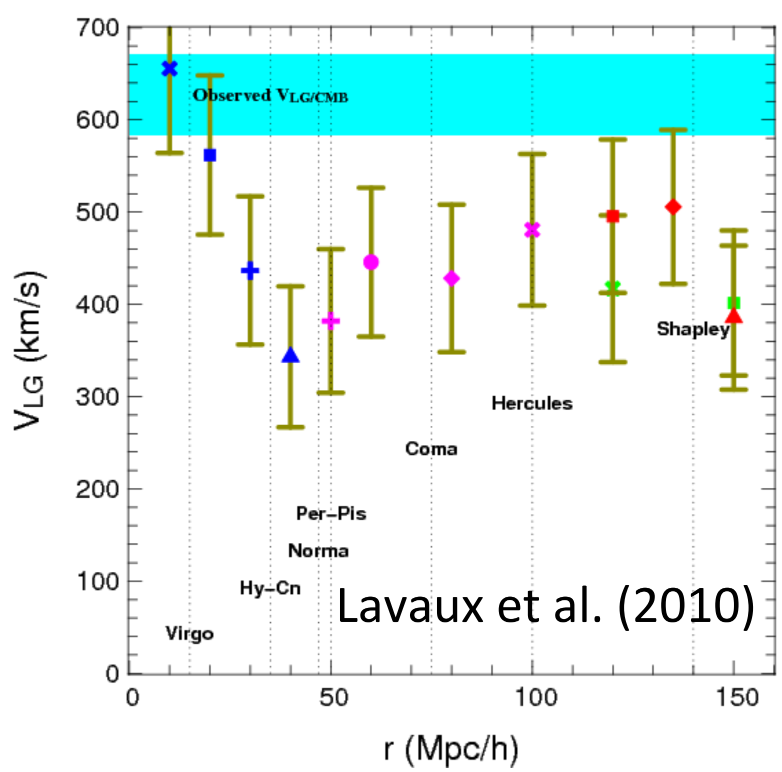
❖ Two measured facts:

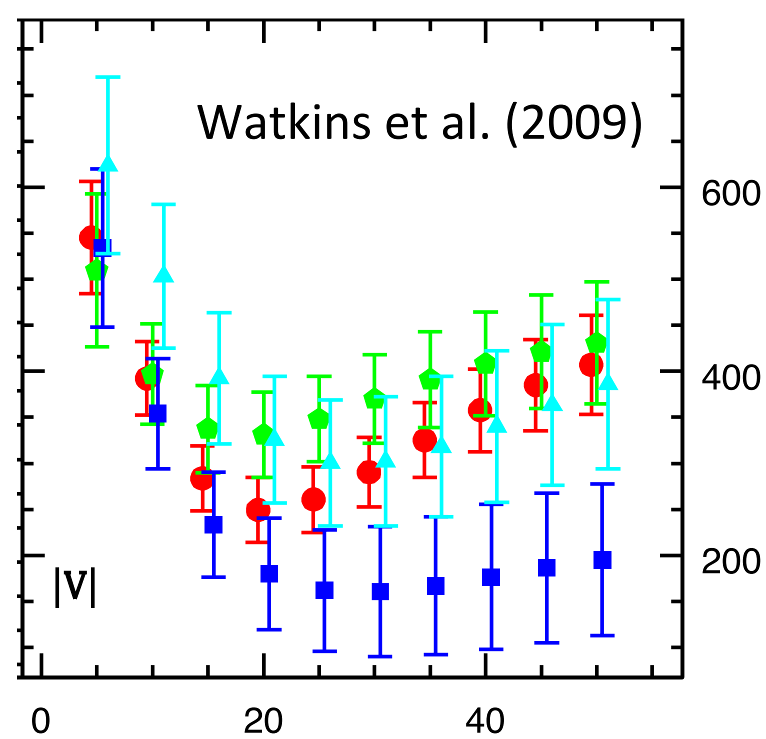
◆ Maximum of cosmic flows at intermediate scales.

❖ Is this an issue for ΛCDM?

◆ Is there a problem with hierarchical models?

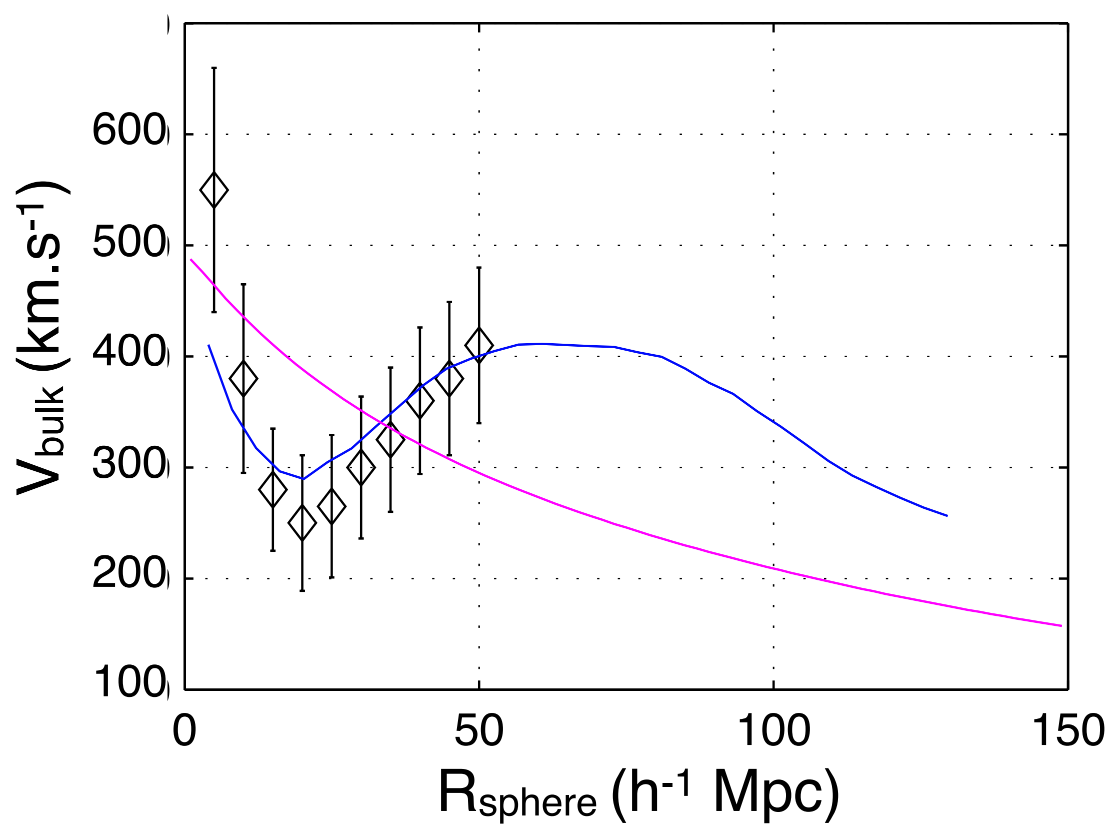
◆ Explanation with dynamical or statistical arguments?

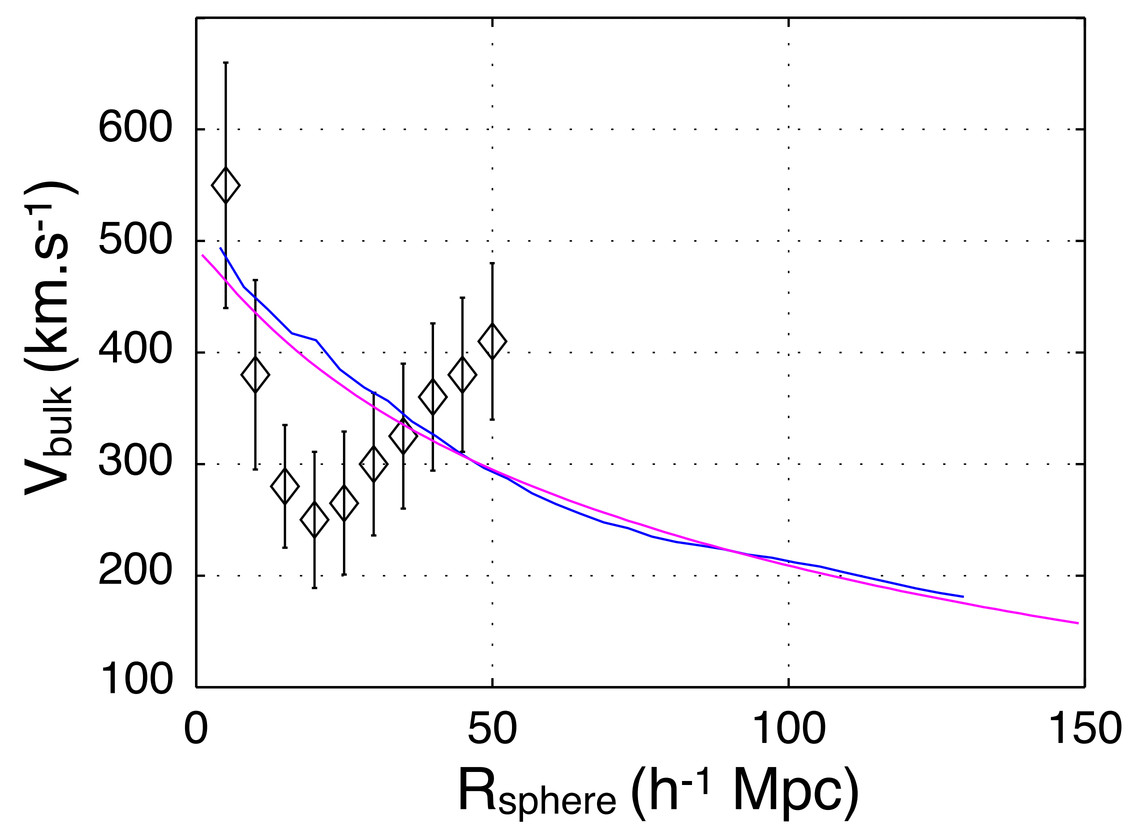




NUMERICAL CATALOGS

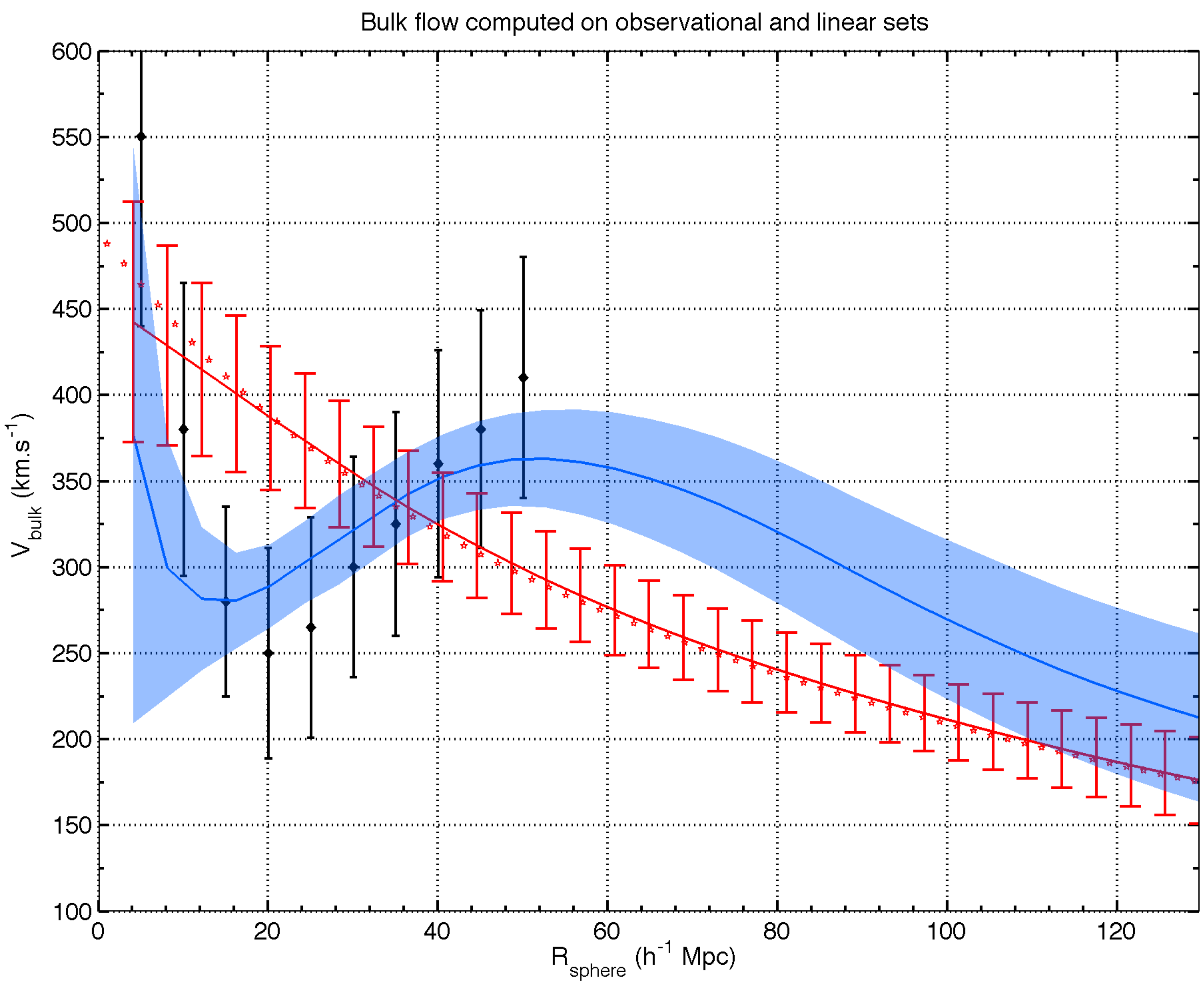
- Statistical behaviour on bulk flows: build numerical catalogs in DEUSS simulations:
  - Realistic catalog: Extrema in agreement with obs.
  - Linear catalog: profile in agreement with lin. prediction.





NUMERICAL CATALOGS

❖ Catalogs mean trend (σ_R & bulk flow):



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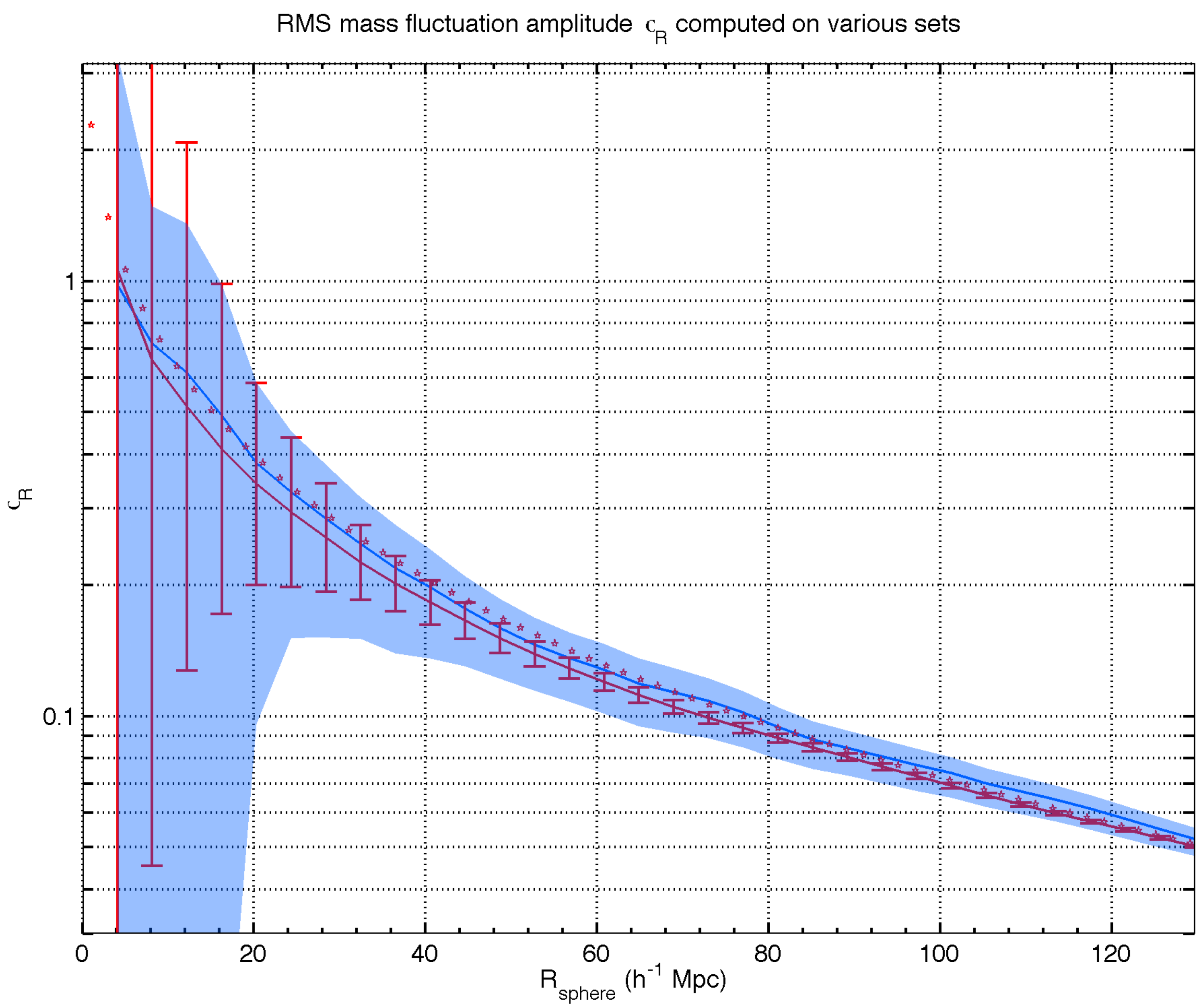
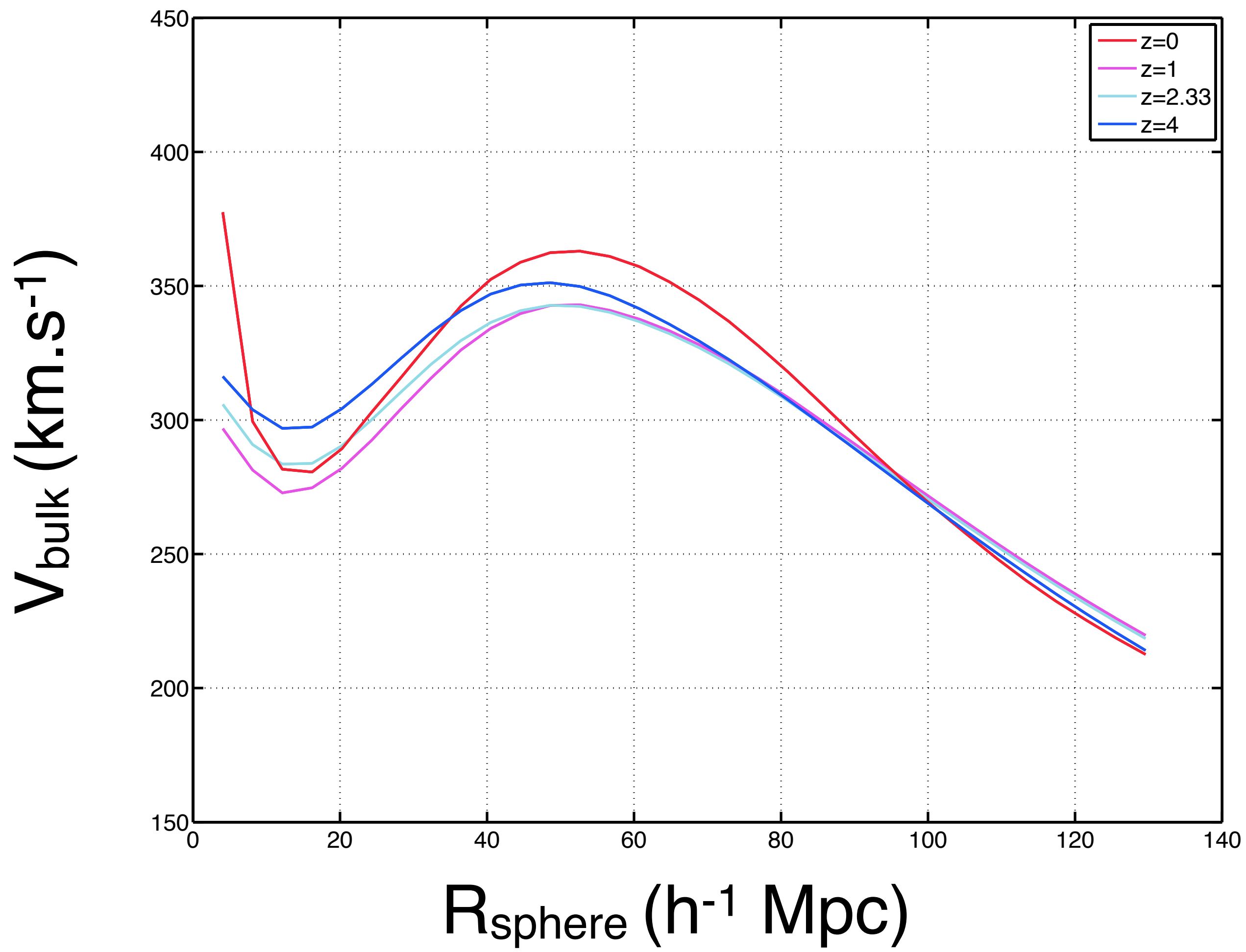


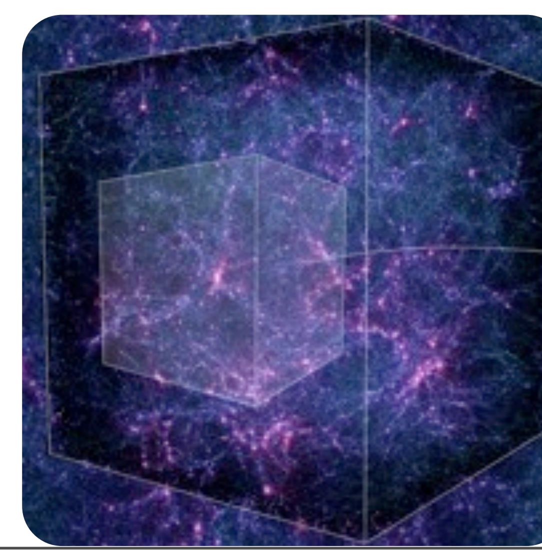
LINK WITH INITIAL CONDITIONS

- An initial condition issue:
  - Follow the evolution backward in time of each member of catalogs.
  - Compute mean bulk flow renormalized by linear evolution factors.
  - The bulk flow stays the same through time: it results from a linear evolution.



III. Statistical interpretation of a high velocity cosmic flows

1) Bulk flow prediction: 1-point pdf
2) Bulk flow: N-point pdf
3) Bulk flow linear deviation: 2-point pdf
4) Retrieving cosmology: 3-point pdf



BULK FLOW: 1-POINT PDF

- Gaussian initial conditions in a given model: what is the probability to have a bulk flow v_1 in a sphere of radius R_1?

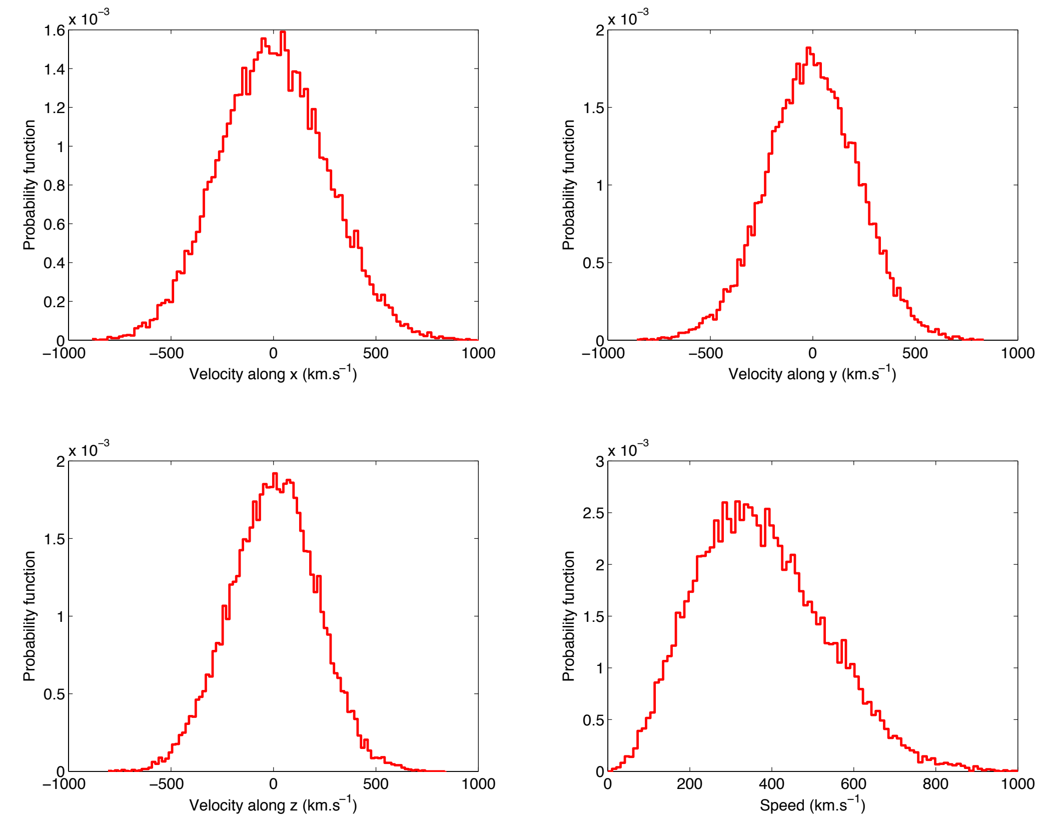
- Standard issue in the kinetic theory of gases:

$$
\begin{aligned}
P(\vec{v}_1)\mathrm{d}^3\vec{v}_1 &= P(v_{1,x}, v_{1,y}, v_{1,z})\mathrm{d}v_{1,x}\mathrm{d}v_{1,y}\mathrm{d}v_{1,z} \\
&= P(v_{1,x})\mathrm{d}v_{1,x}P(v_{1,y})\mathrm{d}v_{1,y}P(v_{1,z})\mathrm{d}v_{1,z}
\end{aligned}
$$

  - $\mathrm{v}_{1,\mathrm{j}}$ is gaussian: its norm is a Maxwell-Boltzmann distribution:

$$P(v_1) = 4\pi\left(\frac{1}{\sigma_R\sqrt{2\pi}}\right)^3 v_1^2 \exp\left(-\frac{1}{2}\frac{v_1^2}{\sigma_R^2}\right)$$

$$\sigma_R^2 = \frac{1}{6\pi^2}\int_0^\infty k^3 P_v(k)\hat{W}(kR_1)^2\frac{\mathrm{d}k}{k}$$



Bulk Flow: N-point PDF

- Let $\vec{V} = (\vec{v}_1, \vec{v}_2, \ldots, \vec{v}_N)$ a set of bulk flows at N radii.
  - What is the probability to get a particular set of bulk flows in a given cosmology $\mathcal{C}$?
- Quantification of correlations between scales:

$$< \vec{v}_{k,i} \cdot \vec{v}_{k',i} > = \delta^{k,k'} \sigma_i^2$$

$$< \vec{v}_{k,i} \cdot \vec{v}_{k',j} > = \delta^{k,k'} \gamma_{i,j} \sigma_i \sigma_j$$

- Gaussian initial conditions:

$$\sigma_i^2 = \frac{1}{6\pi^2} \int_0^\infty k^3 P_v(k) \hat{W}(kR_i)^2 \frac{\mathrm{d}k}{k}$$

$$\gamma_{i,j} = \frac{1}{6\pi^2 \sigma_i \sigma_j} \int_0^\infty k^3 P_v(k) \hat{W}(kR_i) \hat{W}(kR_j) \frac{\mathrm{d}k}{k}$$

BULK FLOW: N-POINT PDF

- Simplification: reduced variables $\vec{U}_i = \vec{V}_i/\sigma_i$.
  - For the k-th component of the bulk flow vector:

$$P(V_k \mid \mathcal{C}) = \frac{1}{(2\pi)^{N/2}\sqrt{|C|}} \prod_i \left(\frac{1}{\sigma_i}\right) \exp\left(-\frac{1}{2} U_k^{\dagger} C^{-1} U_k\right)$$

with C the covariance matrix linking scales:

$$C = \begin{pmatrix} 1 & & \gamma_{j,i} \\ & \ddots & \\ \gamma_{i,j} & & 1 \end{pmatrix}$$

  - Independence of the x, y, z components:

$$P(\vec{V} \mid \mathcal{C}) = \frac{|C^{-1}|^{3/2}}{(2\pi)^{3N/2}} \prod_i \left(\frac{1}{\sigma_i}\right)^3 \exp\left(-\frac{1}{2} \sum_{k=1}^{3} U_k^{\dagger} C^{-1} U_k\right)$$

BULK FLOW: N-POINT PDF

- Quantify the norm of the bulk flow:
  - Introduce the relative angle α_{ij} between directions i and j of the bulk flow in spherical coordinates ($M=C^{-1}$):

$$\mathrm{d}P(v_1,...,v_i,...,v_N|\,\mathcal{C}) = \frac{|C^{-1}|^{3/2}}{(2\pi)^{3N/2}} \prod_i \left(\frac{1}{\sigma_i}\right)^3 \exp\left(-\frac{1}{2}\sum_i m_{i,i}U_i^2\right)$$

$$\times \exp\left(-\frac{1}{2}\sum_{\substack{i,j\\ i\neq j}} m_{i,j}U_iU_j\cos(\alpha_{ij})\right) \times \prod_i \sigma_i^3 \sin(\theta_i) U_i^2 \mathrm{d}U_i \mathrm{d}\theta_i \mathrm{d}\phi_i$$

Bulk Flow: N-point pdf

- What is the probability to get a given cosmic flows profile?
  - To marginalize on the angles, we need to know the link between spherical coordinates of v_i and α_{ij}:

$$\cos\alpha_{ij} = \sin\theta_i \sin\theta_j \left(\cos\phi_i \cos\phi_j + \sin\phi_i \sin\phi_j\right) + \cos\theta_i \cos\theta_j$$

  - A simplification is possible under axes rotation in some cases:
    - 2-point pdf:

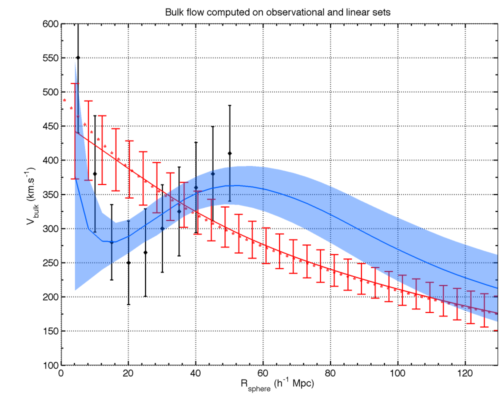
$$\theta_1 = 0 \quad \text{any } \phi_1 \qquad \theta_2 = \alpha_{12} \quad \text{any } \phi_2$$

    - 3-point pdf:

$$\theta_1 = \phi_3 = 0 \qquad \text{any } \phi_1$$
$$\cos\alpha_{12} = \cos\theta_2$$
$$\cos\alpha_{13} = \cos\theta_3$$
$$\cos\alpha_{23} = \sin\theta_2 \sin\theta_3 \cos\phi_2 + \cos\theta_2 \cos\theta_3$$

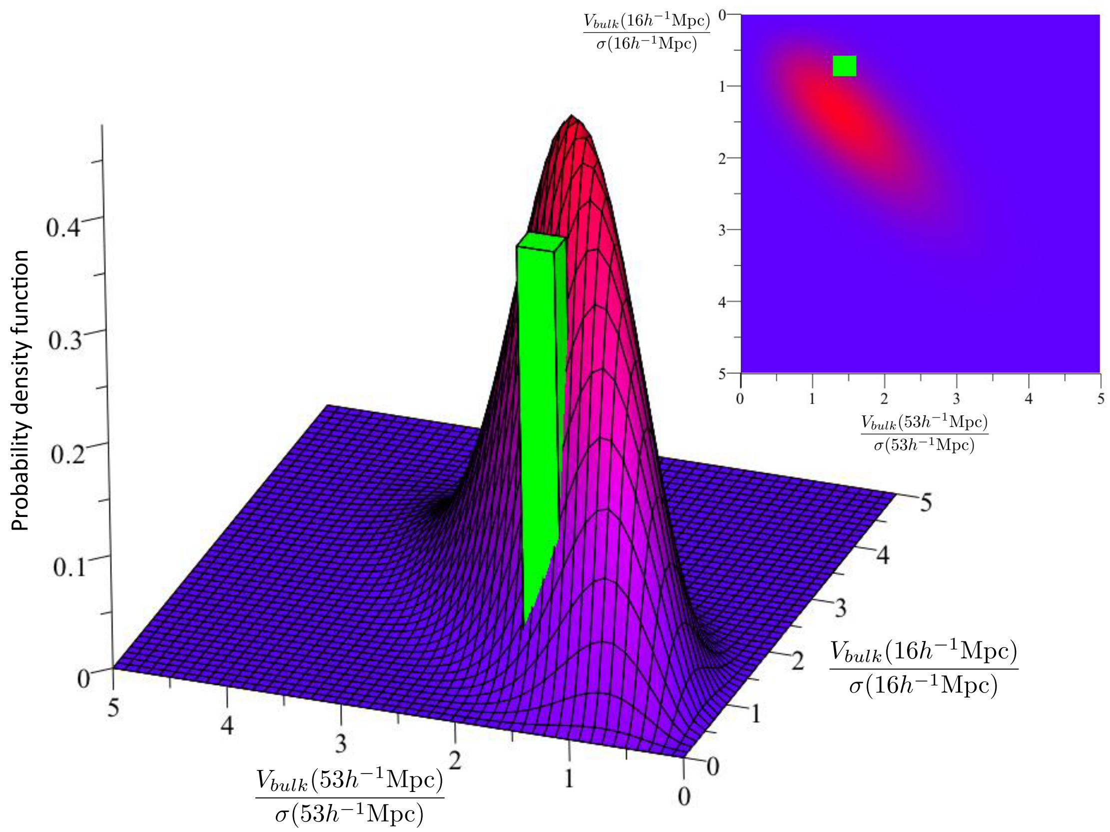
(+circ. perm)

Bulk Flow: 2-point PDF



❖ What is the probability to observe a given bulk flow profile as Watkins et al.?

$$P(v_1, v_2|\, \mathcal{C}) = \frac{2}{\pi}\frac{1}{\gamma_{1,2}}\frac{1}{\sqrt{1-\gamma_{1,2}^2}}U_1 U_2 \exp\left(-\frac{U_1^2+U_2^2}{2(1-\gamma_{1,2}^2)}\right)\sinh\left(\frac{\gamma_{1,2}U_1U_2}{1-\gamma_{1,2}^2}\right)$$



	Proba th.	Proba num.
ΛCDM	1.58%	1.56%
SUCDM	1.27%	1.17%
RPCDM	0.95%	0.82%

BULK FLOW: 2-POINT PDF

- The probability to observe such a bulk flow is low:
  - This is a rare event in a given cosmology.
  - Coherent picture between numerical and statistical points of view.
- In all cosmological models, such observations are predicted by linear theory but are proved to be rare.
- How can we retrieve the cosmological information?

BULK FLOW: 3-POINT PDF

- Have to do deeper survey until a scale R_3: the scale of reconvergence to the linear prediction is a cosmological probe.
- Method: this hypothetic scale of reconvergence is varying.
- Probability of 3 bulk flows at 3 scales: 3-point pdf.
  - Strong correlation between 3 bulk flow vectors.
  - 3 relative angles: non-separable integration.
- Hypothesis: two relative angles are small.

BULK FLOW: 3-POINT PDF

- 3-point PDF:

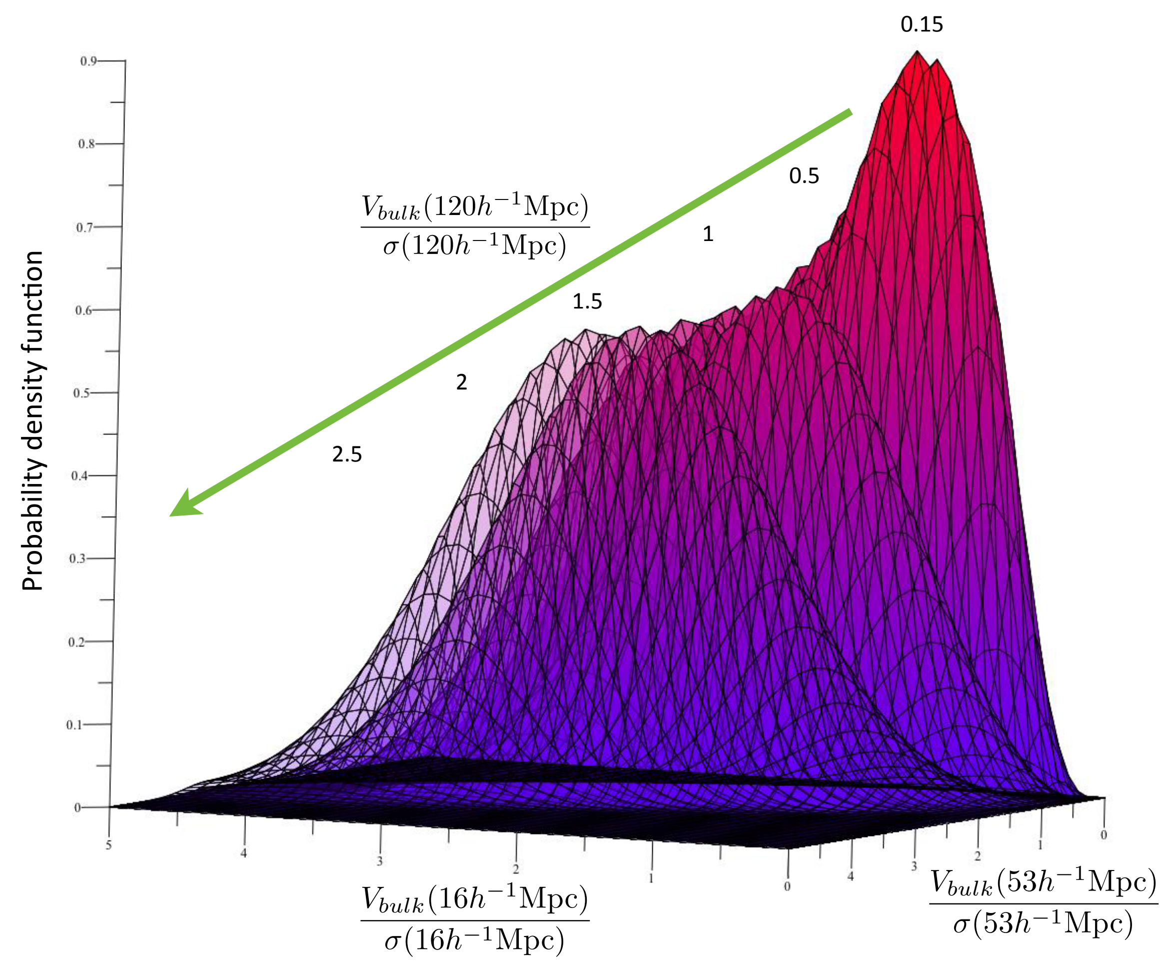
$$P(v_1, v_2, v_3|\,\mathcal{C}) = \frac{2\sqrt{2}}{\pi^{3/2} m_{1,2} m_{1,3}} U_2 U_3 |C^{-1}|^{3/2} \exp\left(-\frac{1}{2}\left(m_{1,1}U_1^2 + m_{2,2}U_2^2 + m_{3,3}U_3^2\right)\right)$$
$$\times \sinh(U_1 U_2 m_{1,2}) \sinh(U_1 U_3 m_{1,3}) \times \mathcal{I}_0(U_2 U_3 m_{2,3}) + \text{perm. circ.}$$

- The differential probability of reconvergence is given by:

$$P(v_3|v_1, v_2) = \frac{P(v_1, v_2, v_3)}{P(v_1, v_2)}$$

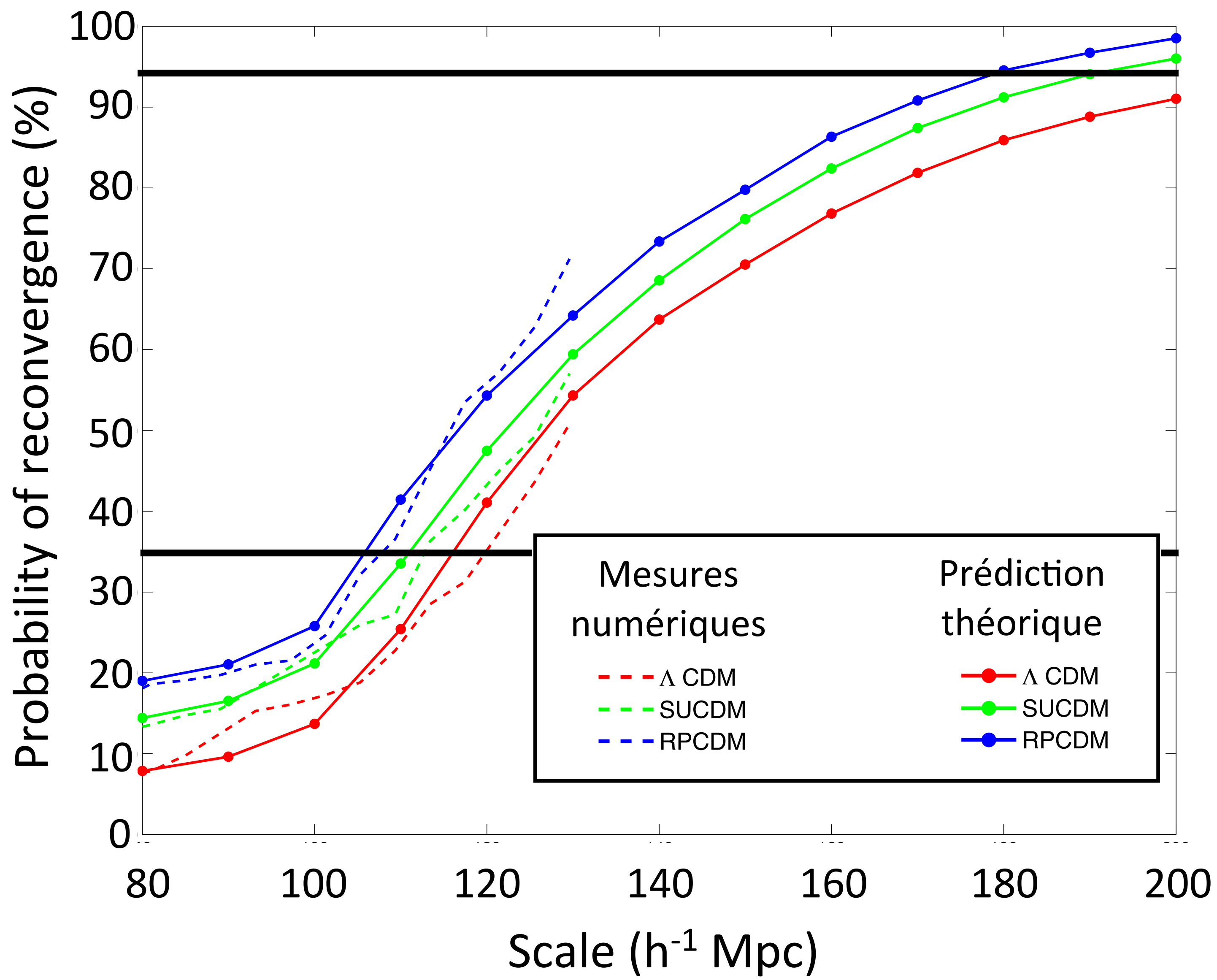
- The probability of reconvergence is given by:

$$Q(v_3|v_1, v_2) = \int_0^{v_3} \frac{P(v_1, v_2, u)}{P(v_1, v_2)} \mathrm{d}u$$



Bulk Flow: 3-point PDF

- An original cosmological probe:
  - The scale of reconvergence to linear theory @ 95%.



Conclusions (so far)

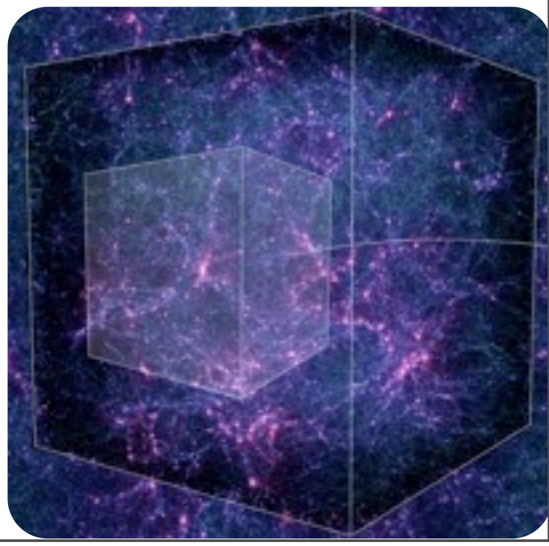
- Large bulk flows in apparent disagreement with linear theory at large scales: a problem for hierarchical CDM models?

- High cosmic flows come from a statistically rare event (~ %) in agreement with the linear theory and consistent with numerical simulations.

- This rare feature gives birth to an original cosmological probe.

IV. Large-scale asymmetry: origin of high velocity cosmic flows

1) Qualitative approach of density field
2) Quantitative approach: asymmetry index
3) A characteristic scale

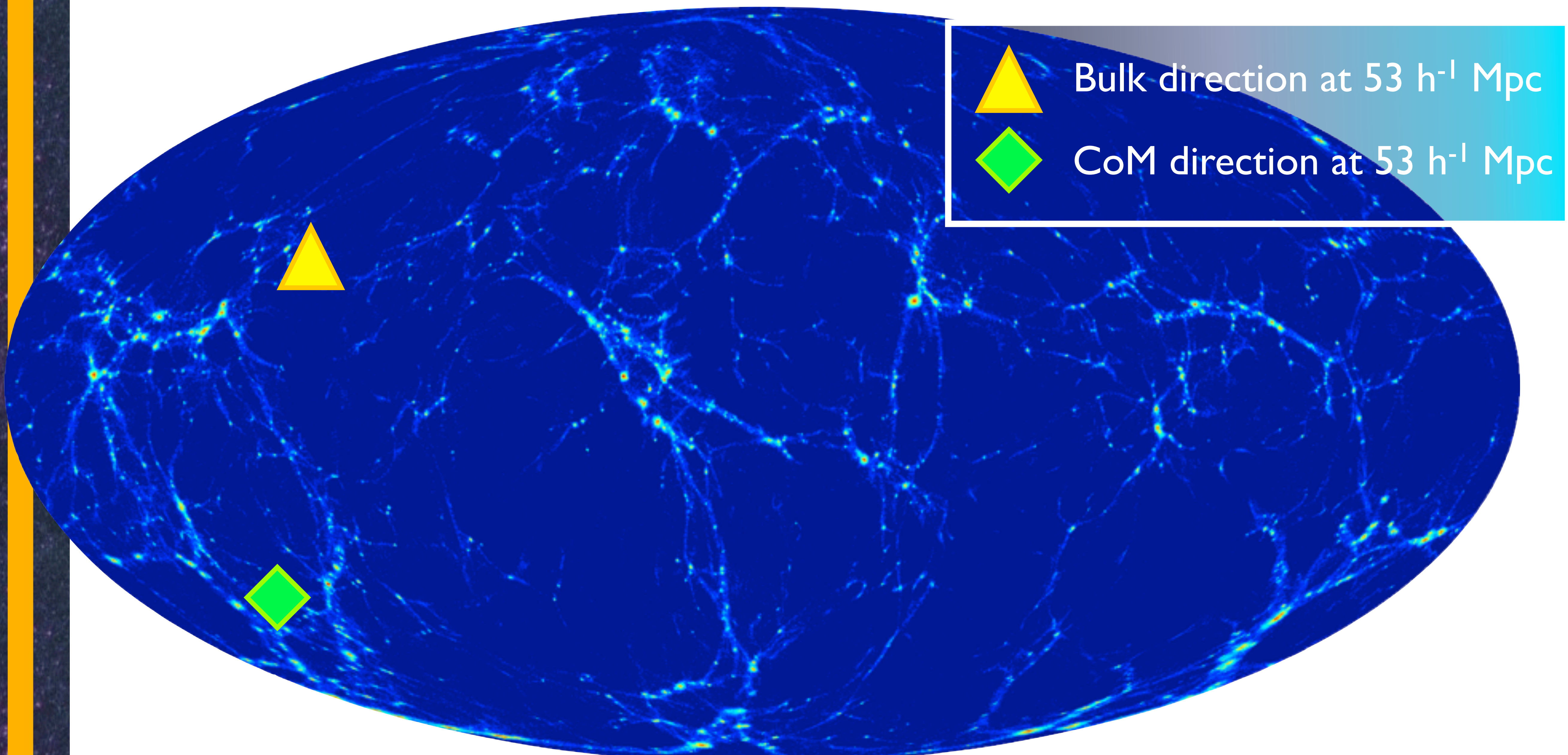


QUALITATIVE APPROACH

- Reconvergence of the bulk flow intuitively linked with an homogenization of the density field at higher scales:
  - What is the dynamical origin of the high velocity bulk flow at intermediate scales in a rare environment?
  - How to characterize the density field to find this origin?
- Bulk flow is a vector (i.e. a directional quantity):
  - For the density field, a direction can be introduced: the center of mass of a sphere.

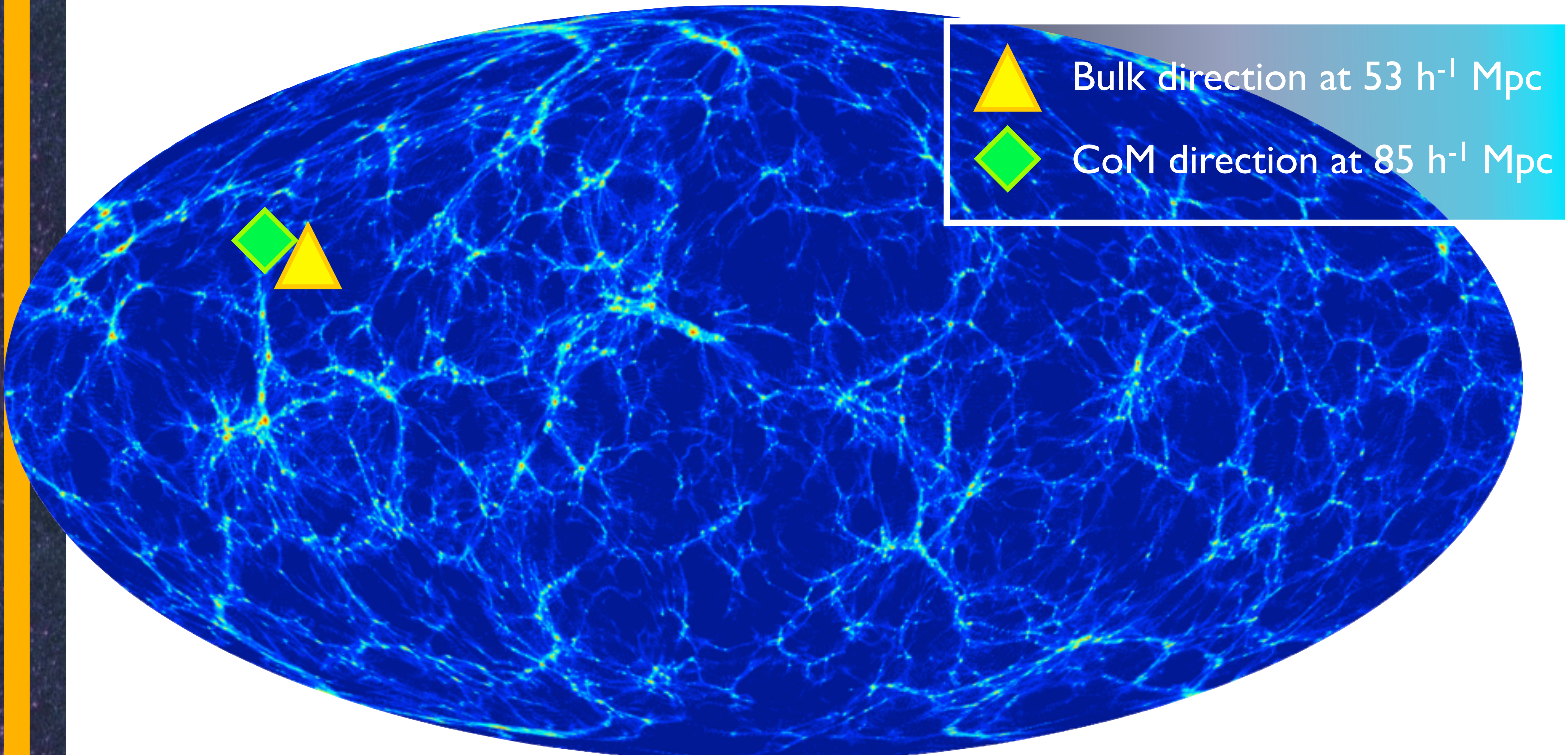
Qualitative approach

❖ <u>Example</u>: Mollweide projection (53 h^{-1} Mpc)



QUALITATIVE APPROACH

❖ <u>Example</u>: Mollweide projection (85 h^{-1} Mpc)



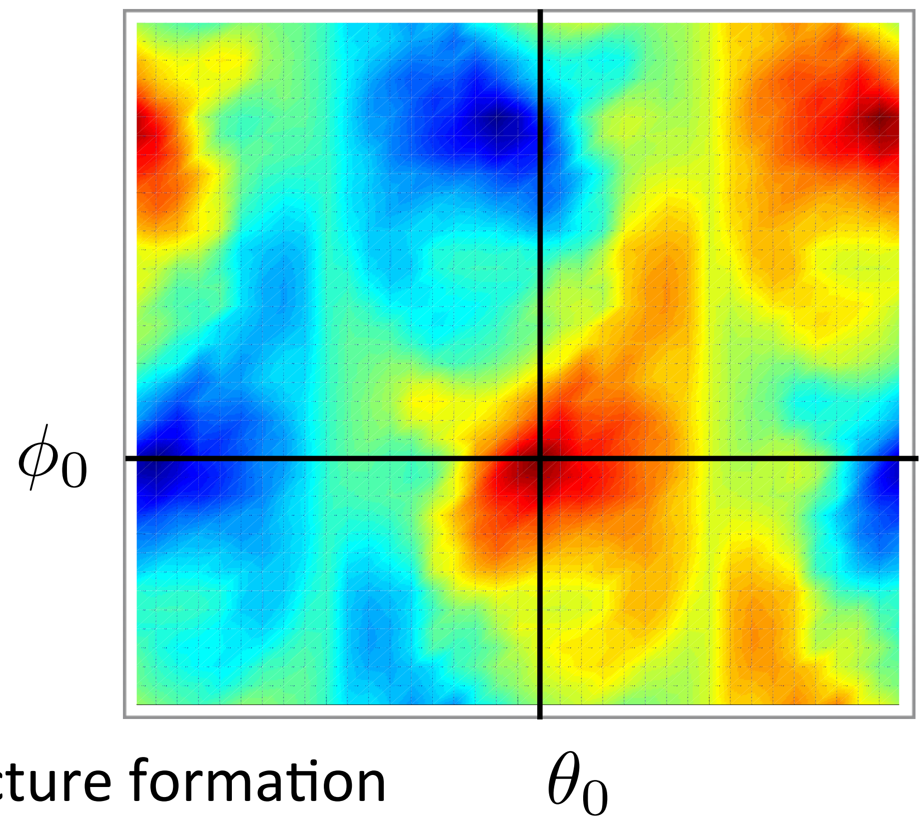
QUANTITATIVE APPROACH

- The center of mass approach suffers from many issues (e.g. normalisation problem).
- More accurate and efficient tool: an estimator of asymmetry of spheres (or shells).

$$F_R(\theta_0, \phi_0) = \frac{1}{\rho_{tot}} \iint_{\mathbb{S}^2/2} \rho_R(\theta + \theta_0, \phi + \phi_0) - \rho_R(\pi - (\theta + \theta_0), \pi + (\phi + \phi_0)) d\Omega$$

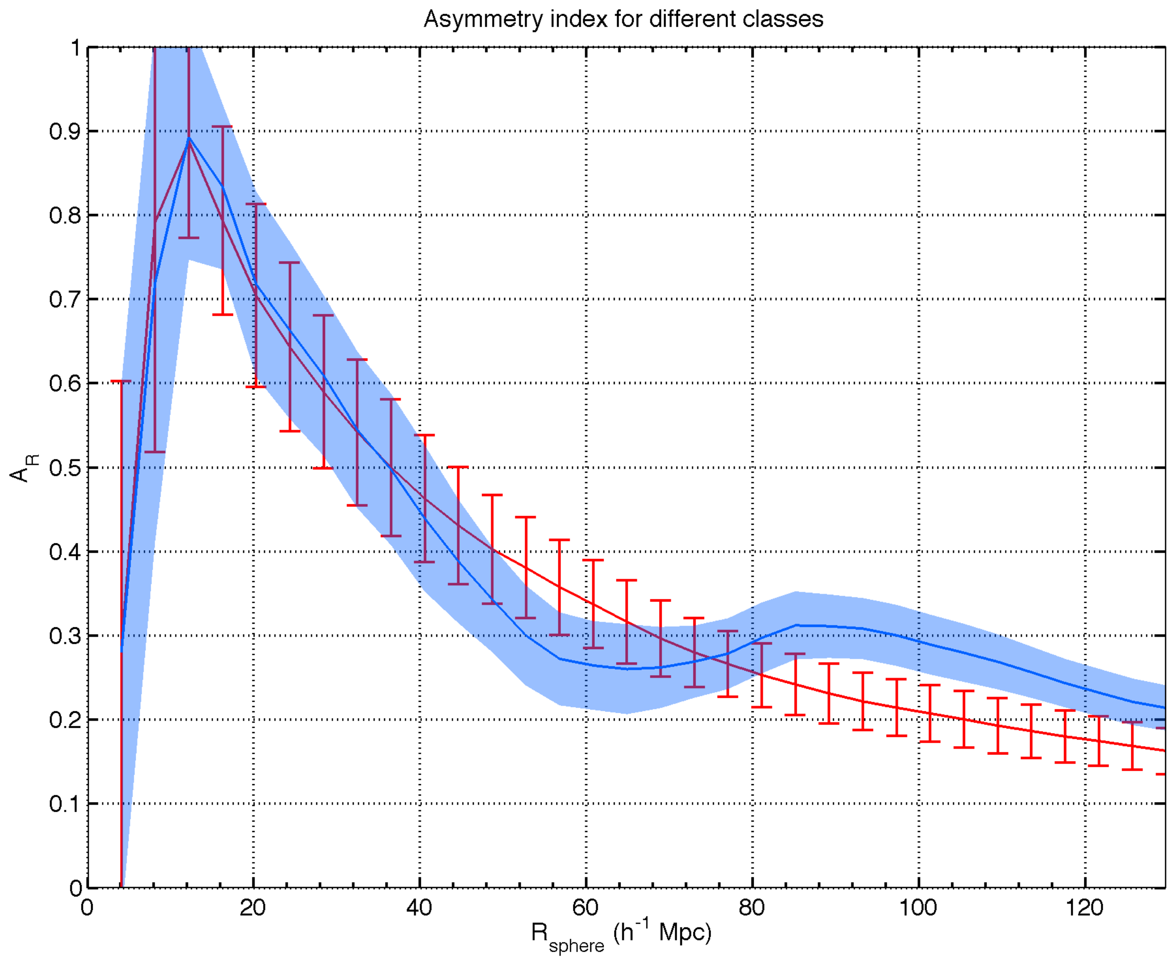
$$A_R = \max_{\phi_0 \in [0,2\pi], \theta_0 \in [0,2\pi]} F_R(\theta_0, \phi_0)$$

- Direction of the asymmetry $\mathrm{A_R}$ given by (ϕ_0, θ_0).



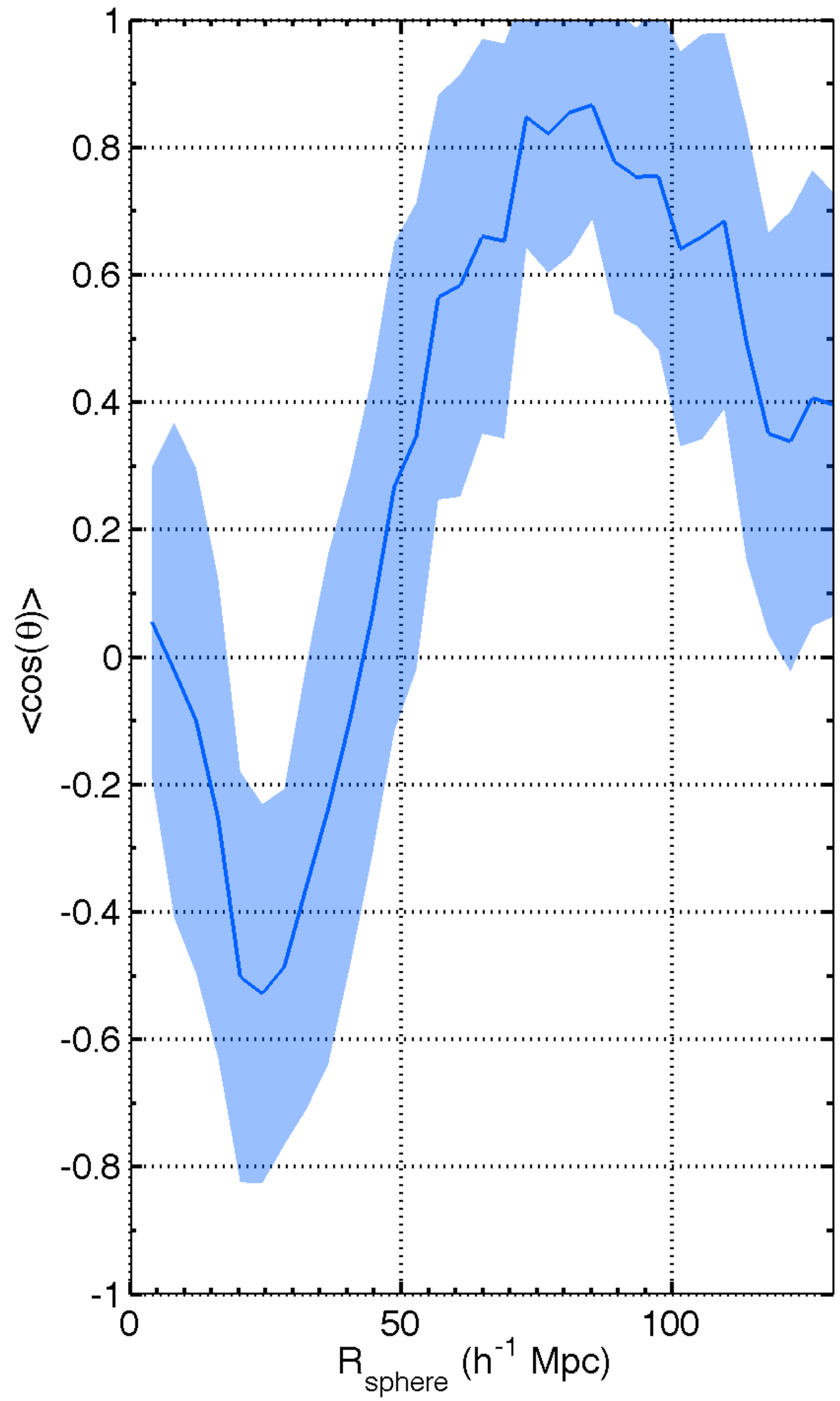
QUANTITATIVE APPROACH

- Mean of asymmetry indexes on linear (red) and realistic (blue) numerical catalogs in spheres.
- Two particular scales for the realistic catalog:
  - Depletion @ 60 h^{-1} Mpc.
  - Bump @ 85 h^{-1} Mpc.
- Link between this bump of asymmetry and the bump of bulk flow?



A CHARACTERISTIC SCALE

- Alignment between the bulk flow at 53 h^{-1} Mpc and the asymmetry vector in shells at radius R?
  - Realistic catalog: scales between 60 and 100 h^{-1} Mpc, peaking at 85 h^{-1} Mpc.
  - Linear catalog: no particular scales.
- Perfect alignment of the bulk flow at 53 h^{-1} Mpc and the asymmetry in shells at radius 85 h^{-1} Mpc.

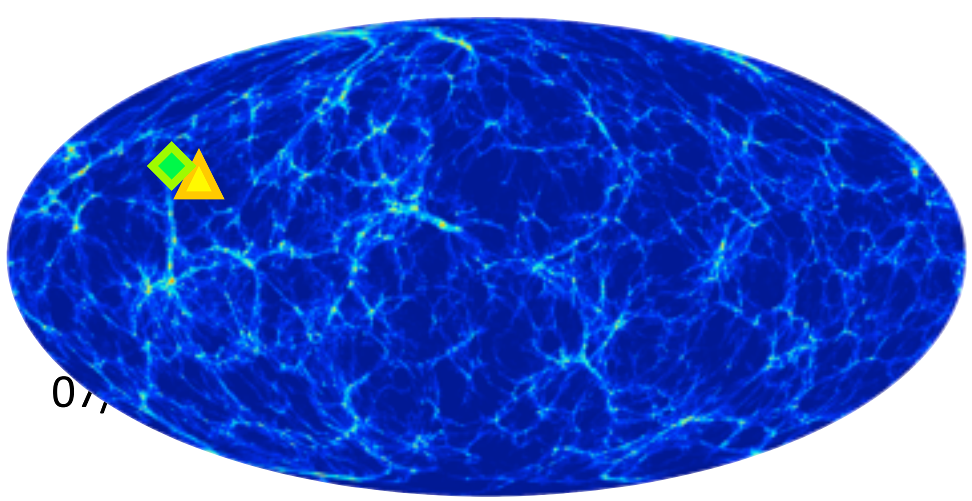


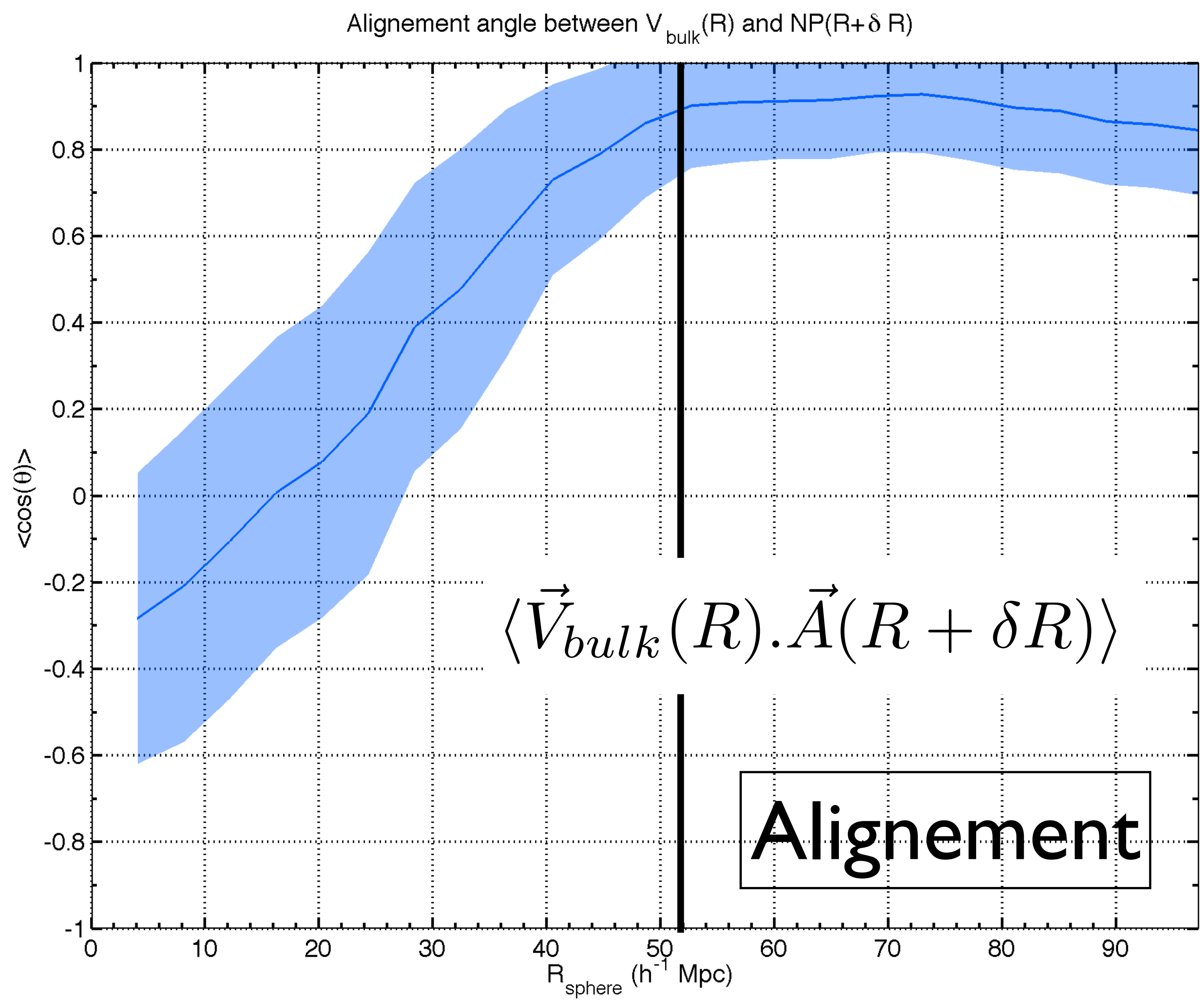
$$\langle \vec{V}_{bulk}(53\text{Mpc}).\vec{A}(R)\rangle$$

A CHARACTERISTIC SCALE

- Asymmetry integrated in spheres:
  - Scalar product of the bulk flow vector at radius R with the asymmetry in spheres of larger radius R+δR.
- The mean shift δR between the velocity and the density fields is:

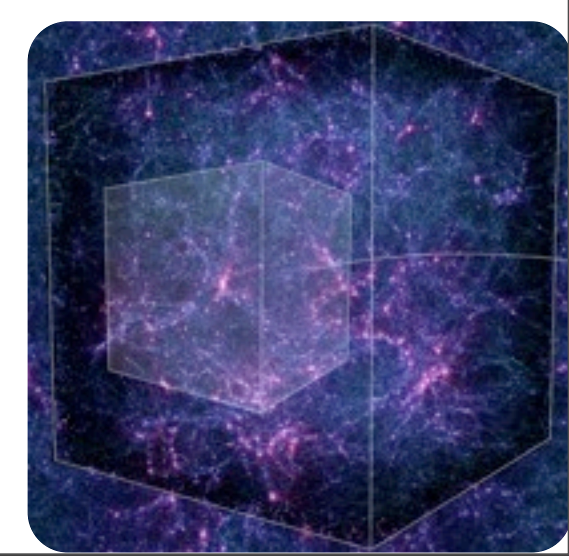
  $\delta R = 32 \pm 4.1\ h^{-1}$ Mpc.





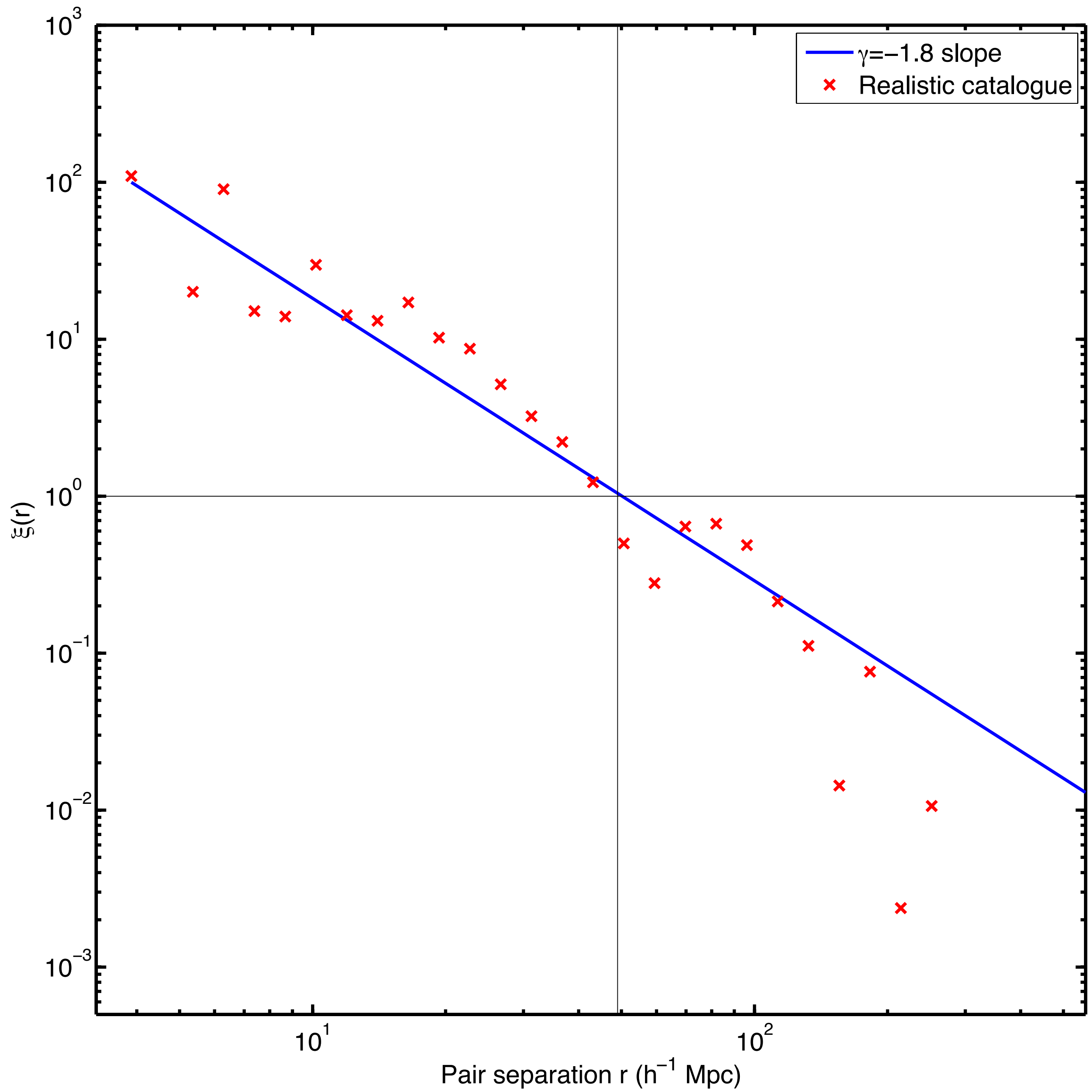
V.Spatial distribution of high velocity cosmic flows

1) Origin of asymmetry
2) Density peak reconstruction
3) Distance to neighboring density peaks



ORIGIN OF ASYMMETRY

- The centers of the realistic catalog are not randomly distributed.
- What structures (voids, filaments, clusters...) can trigger such an asymmetry?
- Characterize neighbors density peaks.



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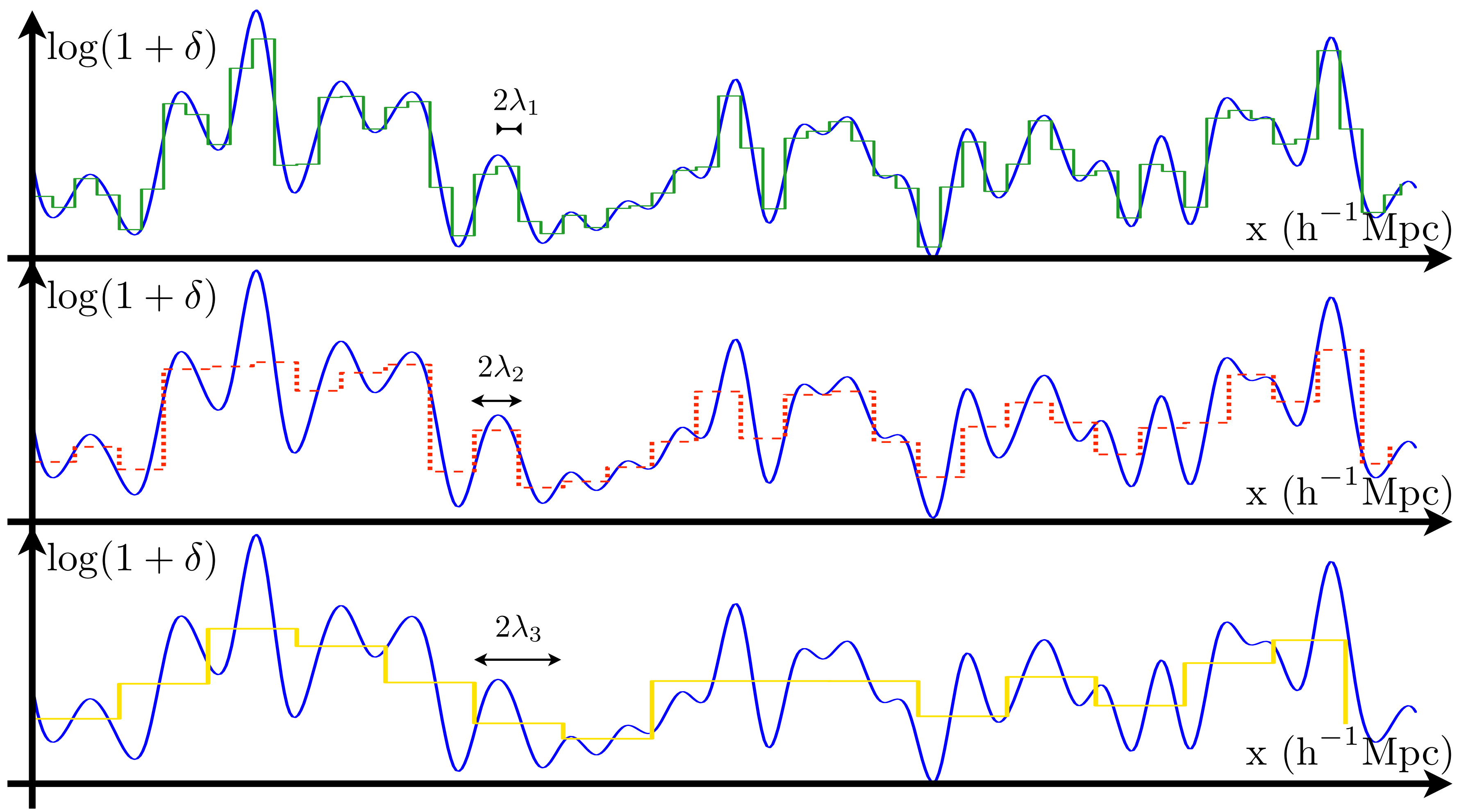
DENSITY PEAK RECONSTRUCTION

- Compute accurate density field from a set of particles using SPH smoothing:

$$\rho_i = \rho(\vec{r}_i) = m \sum_j W\left(|\vec{r}_i - \vec{r}_j|, \lambda\right)$$

- One free parameter: kernel λ.

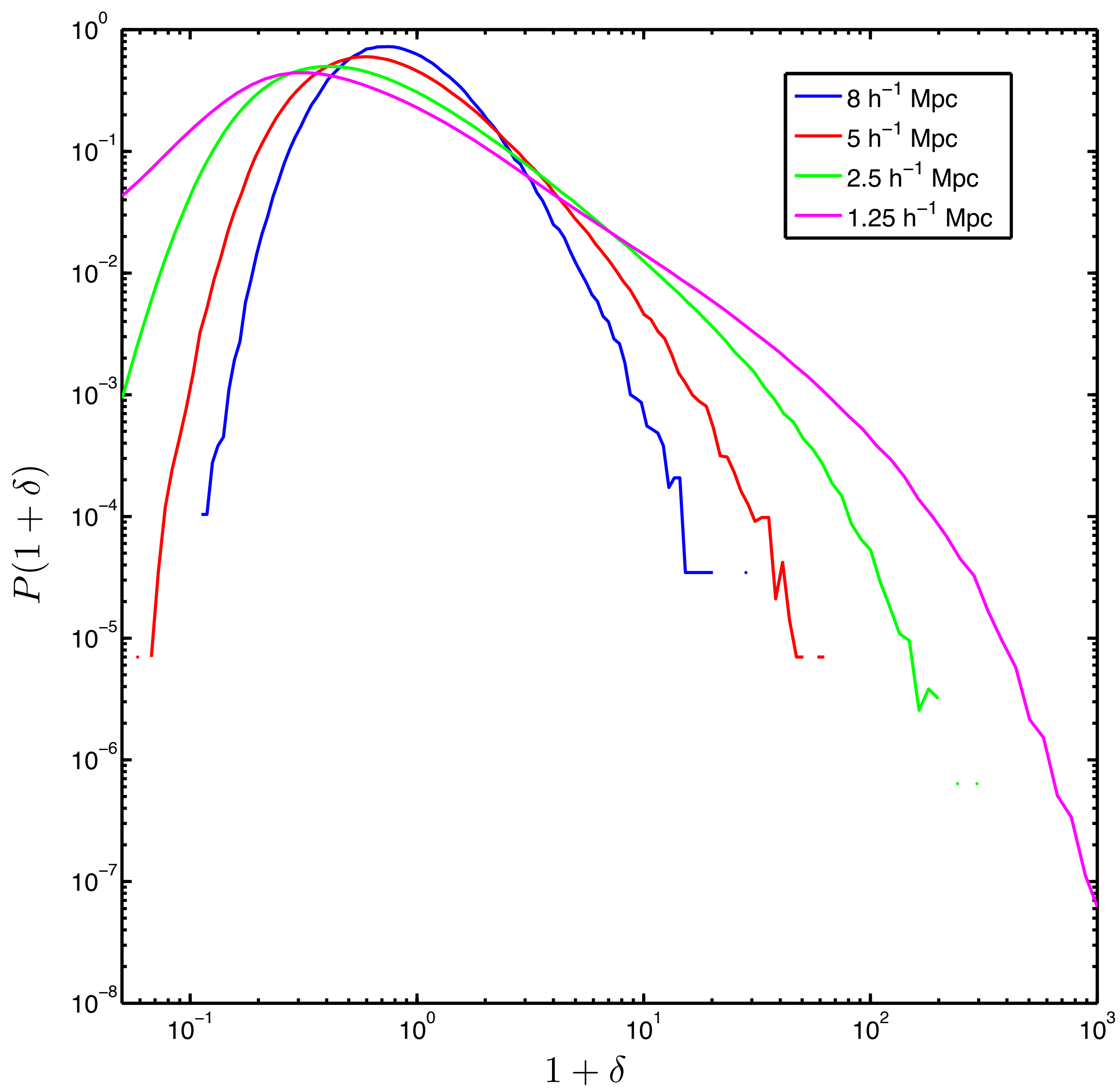


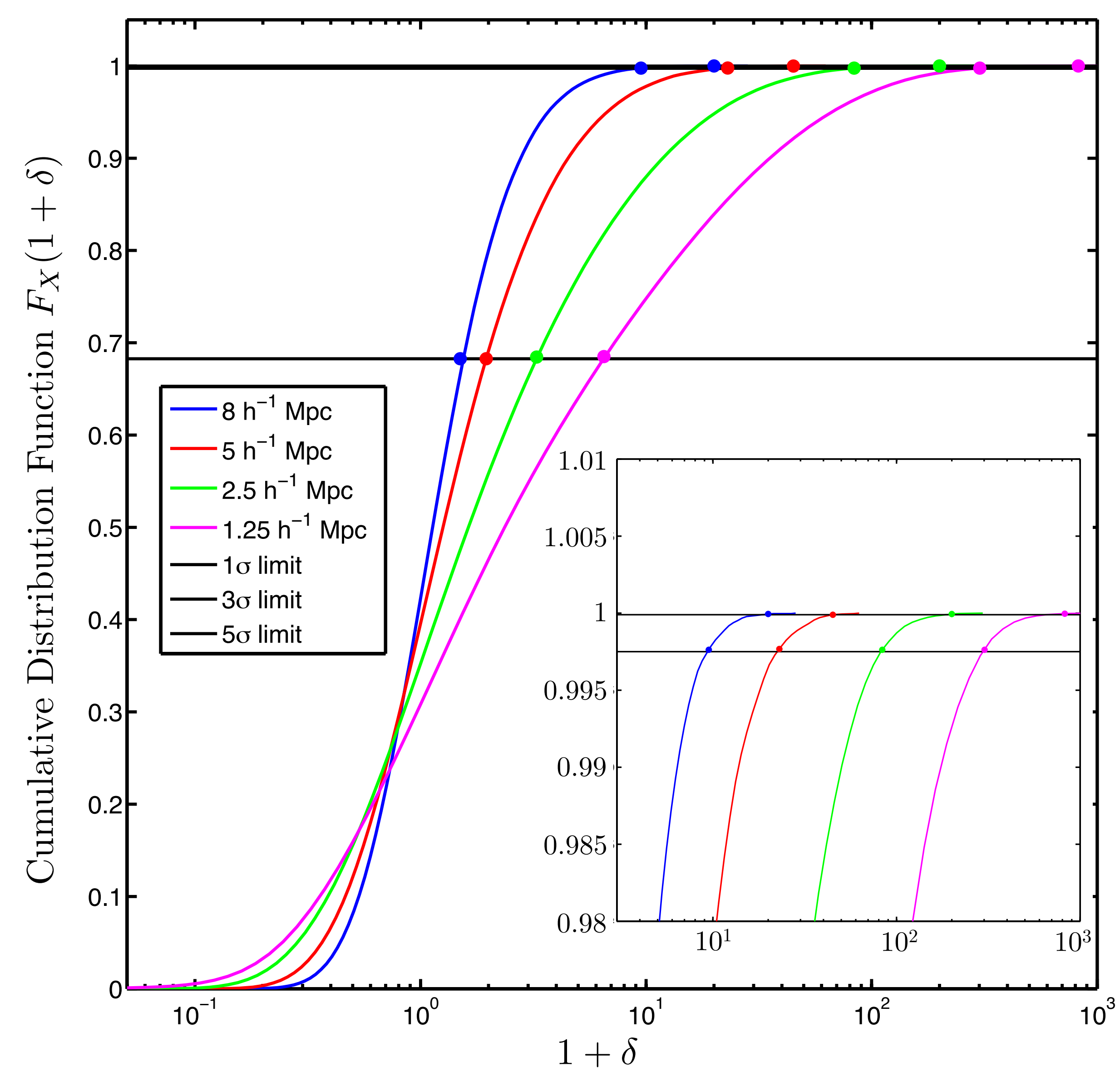
DISTANCE TO NEIGHBORING PEAKS

- The mean mass contained in a SPH bubble of mean density δ is: $$\bar{M} = \frac{4}{3}\pi\lambda^3\bar{\rho}(1+\delta)$$
- Compute separations between closest density peaks and centers of the realistic catalog:
  - Clear definition of centers of the realistic catalog.
  - What closest density peaks?
- Second free parameter: peak height threshold Δ.
- Remaining issue: determine the (λ,Δ) parameters.

Distance to neighboring peaks

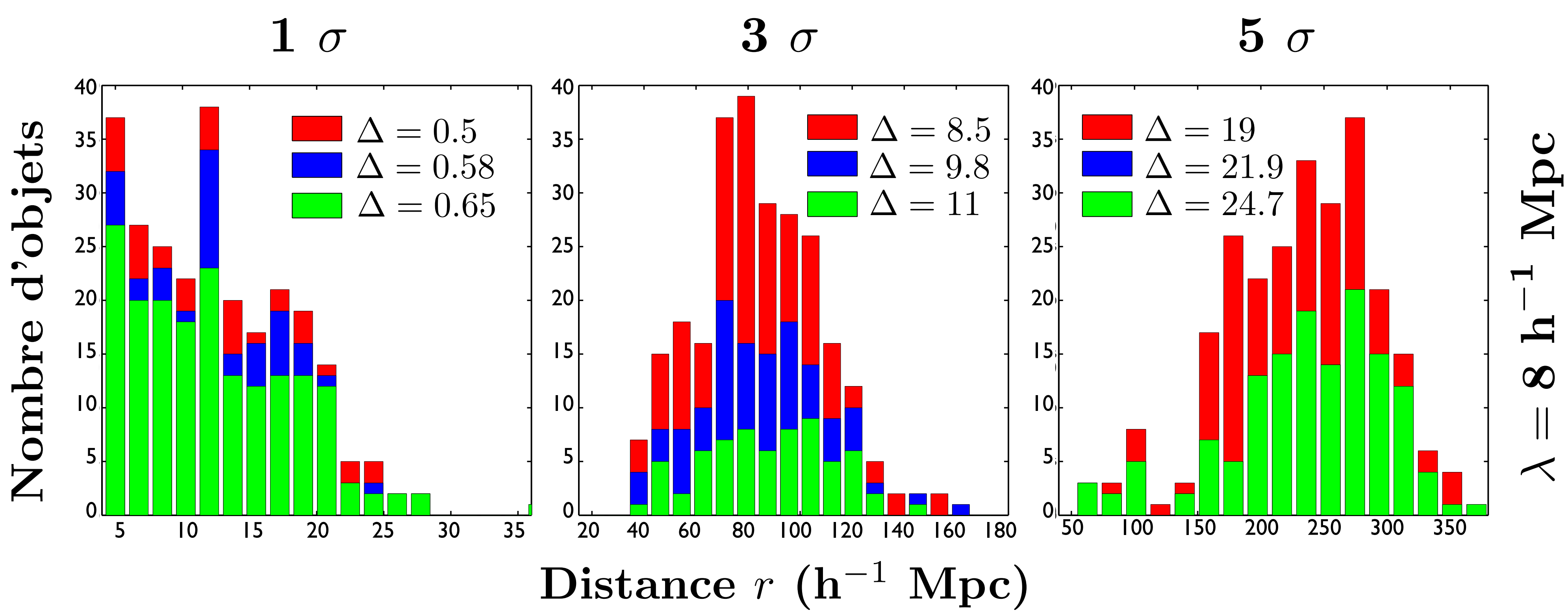
- A univocal way to set the free parameters (λ, Δ):
  - Statistical criterion on the cdf of overdensities: 1σ, 3σ, 5σ confidence levels.





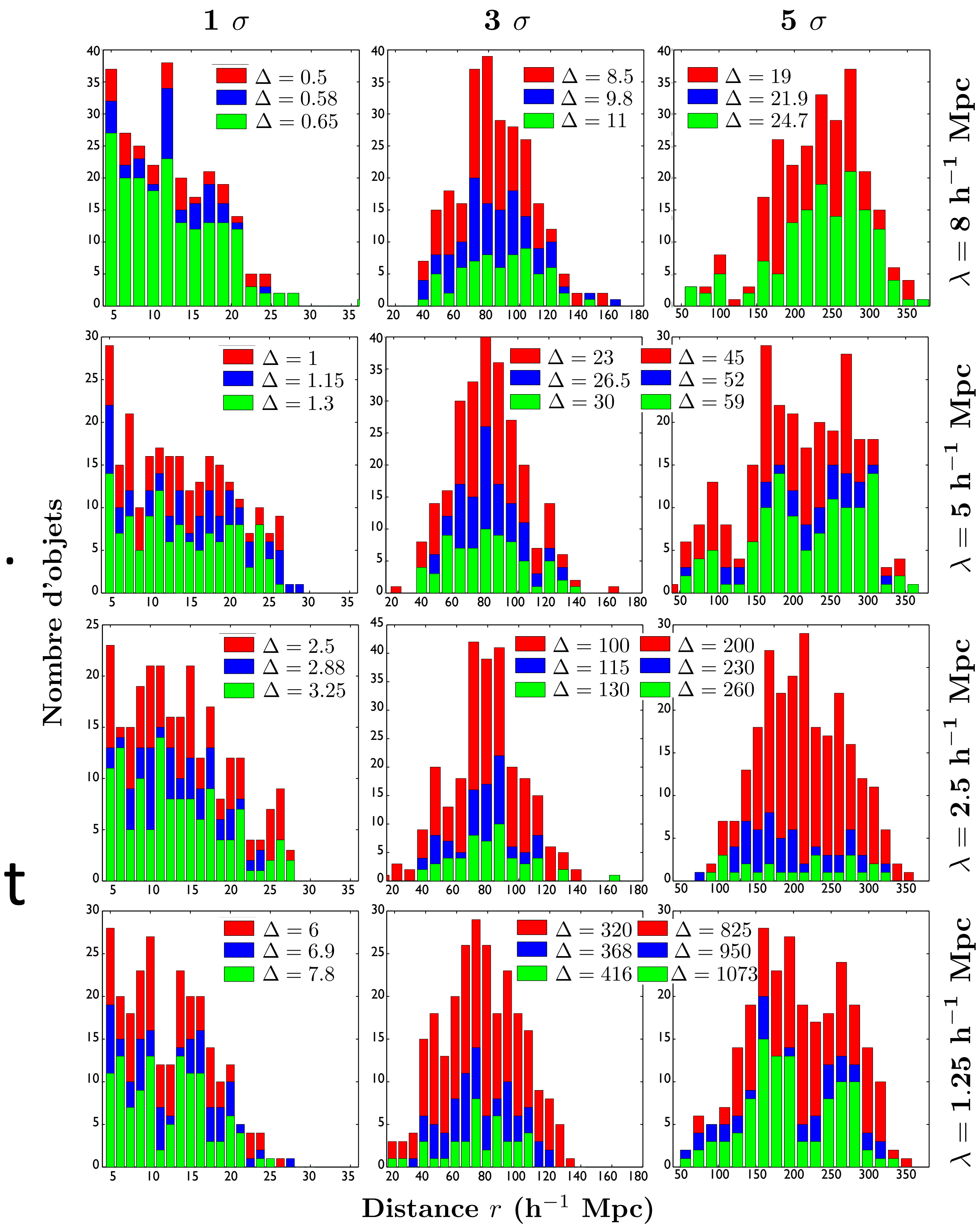
Distance to neighboring peaks

- Histogram of the distance between an observer with high velocity cosmic flows and a density peak smoothed at radius λ and above threshold Δ.
- Colors indicate various thresholds based on the σ one.



Distance to neighboring peaks

- Variation with the kernel:
  - 1 σ density peaks: plateau + quick decrease.
  - 3 σ density peaks: gaussian (similar moments).
  - 5 σ density peaks: depends on the kernel.
- Whatever λ, peak height at 3 σ gives $M=7.10^{14}\ h^{-1}\ M_\odot$ at 80 h^{-1} Mpc.



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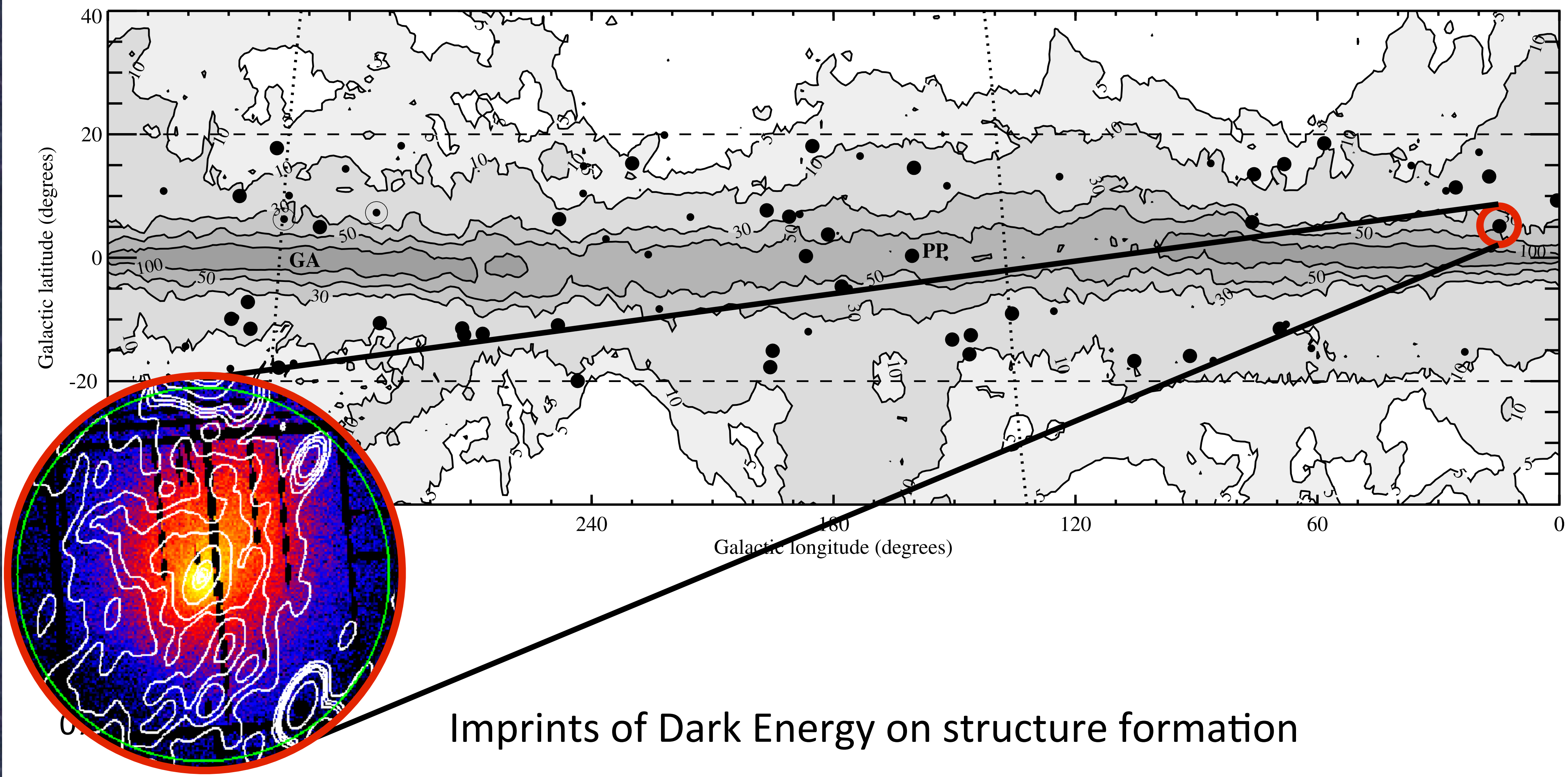
Distance to neighboring peaks

- ❖ A cluster candidate in the Zone of Avoidance (Ebeling et al. 2002, Kocevski et al. 2005)
- ❖ Ophiuchus cluster, mass $5.10^{14}\ h^{-1}\ M_{\odot}$, at $80\ h^{-1}$ Mpc.



CONCLUSION

- ❖ Observations of a high velocity bulk flow at intermediate scales are due to a statistically rare event.
- ❖ The reconvergence of the bulk flow towards the linear amplitude at large scales is an new original cosmological probe.
- ❖ The dynamical origin of a high velocity bulk flow is linked with the asymmetry of the three-dimensional matter field at higher scales (~85 h^{-1} Mpc).
- ❖ Those observers are occupying particular over-dense places at ~80 h^{-1} Mpc from a high density peak.

CONCLUSION

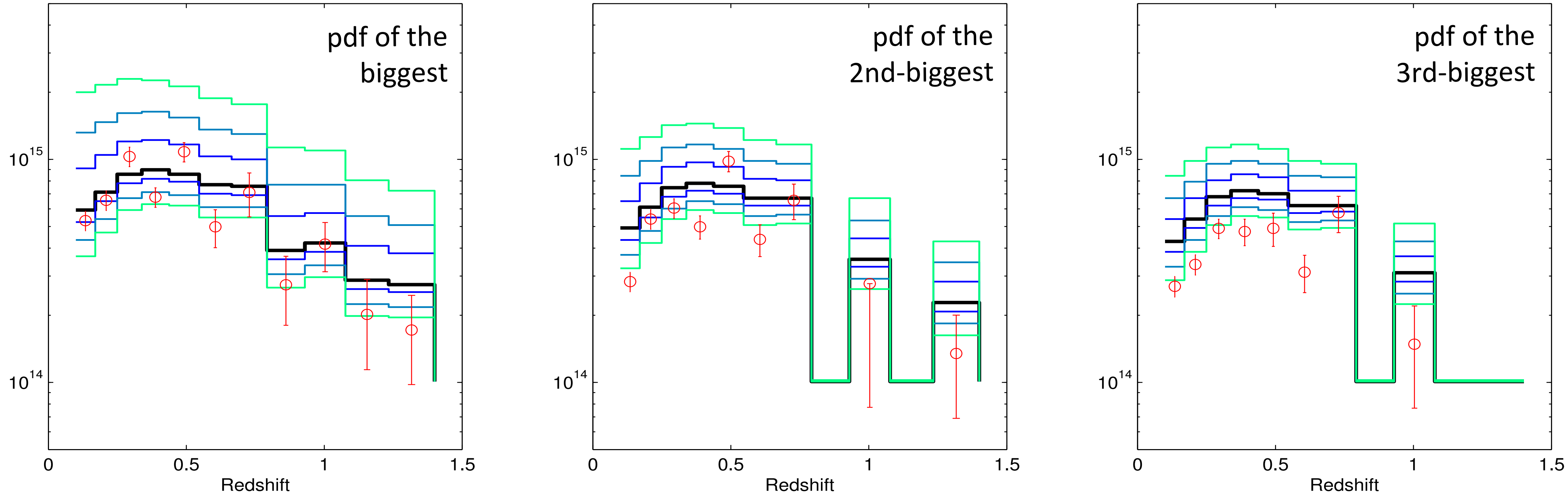
- This presentation: cosmological velocity fields.
- Density field can give information on different aspects:
  - Power spectra.
  - Correlation functions and Haloes-Dark-Matter biases.
  - Mass functions in redshift and comoving space.
  - Covariant perturbations theory in general multi-fluids cosmology.

CONCLUSION

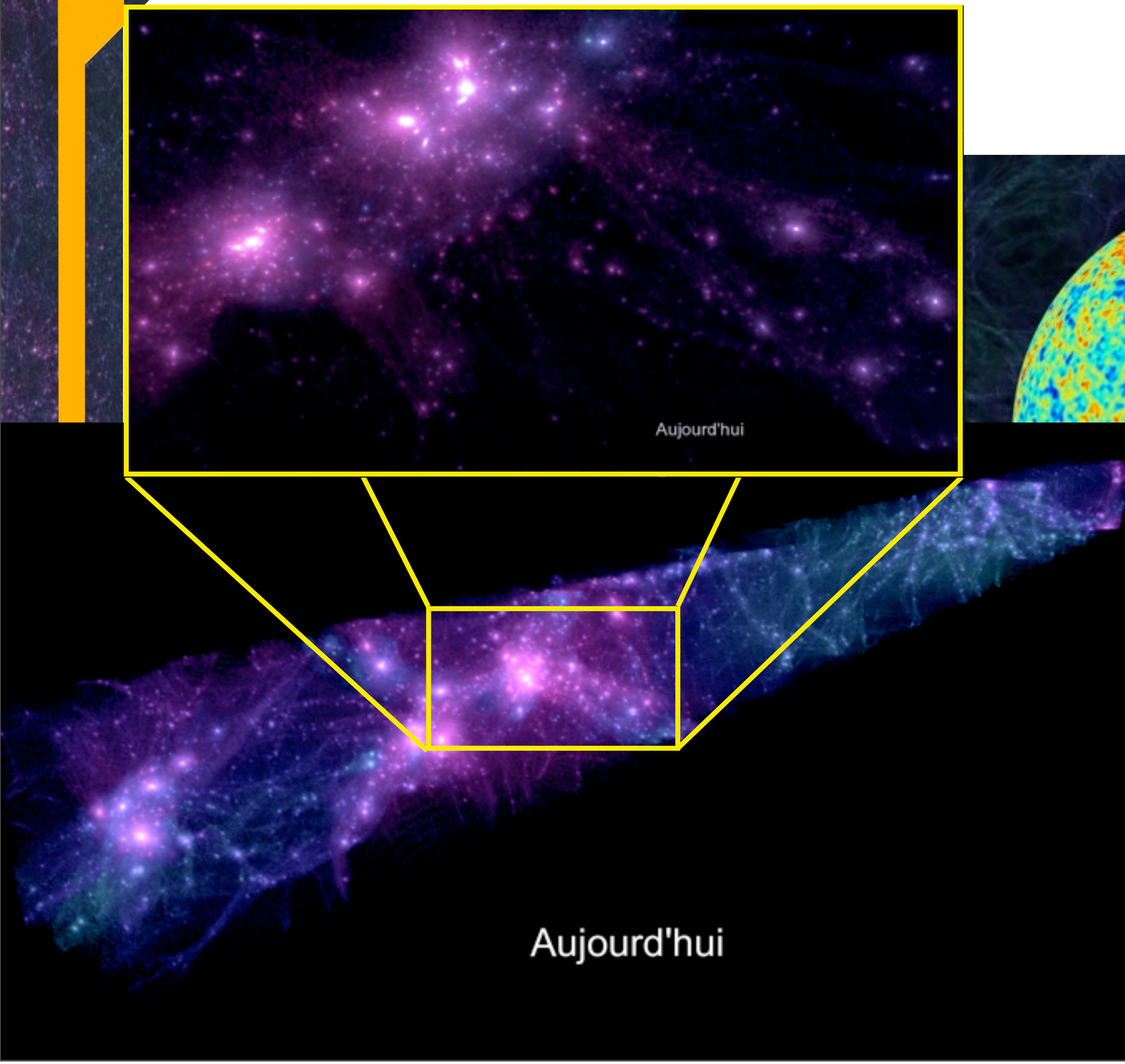
- Importance of efficiency to get new simulations to tackle new scientific problems:
  - Optimization of the communication scheme (BlueGene vs Bullx) of the RAMSES dynamical code.
  - Various optimization of the pFoF halo finder code.
- Fast correlation function computation methods.
- Population of Dark Matter haloes with galaxies (e.g. Markov chains).

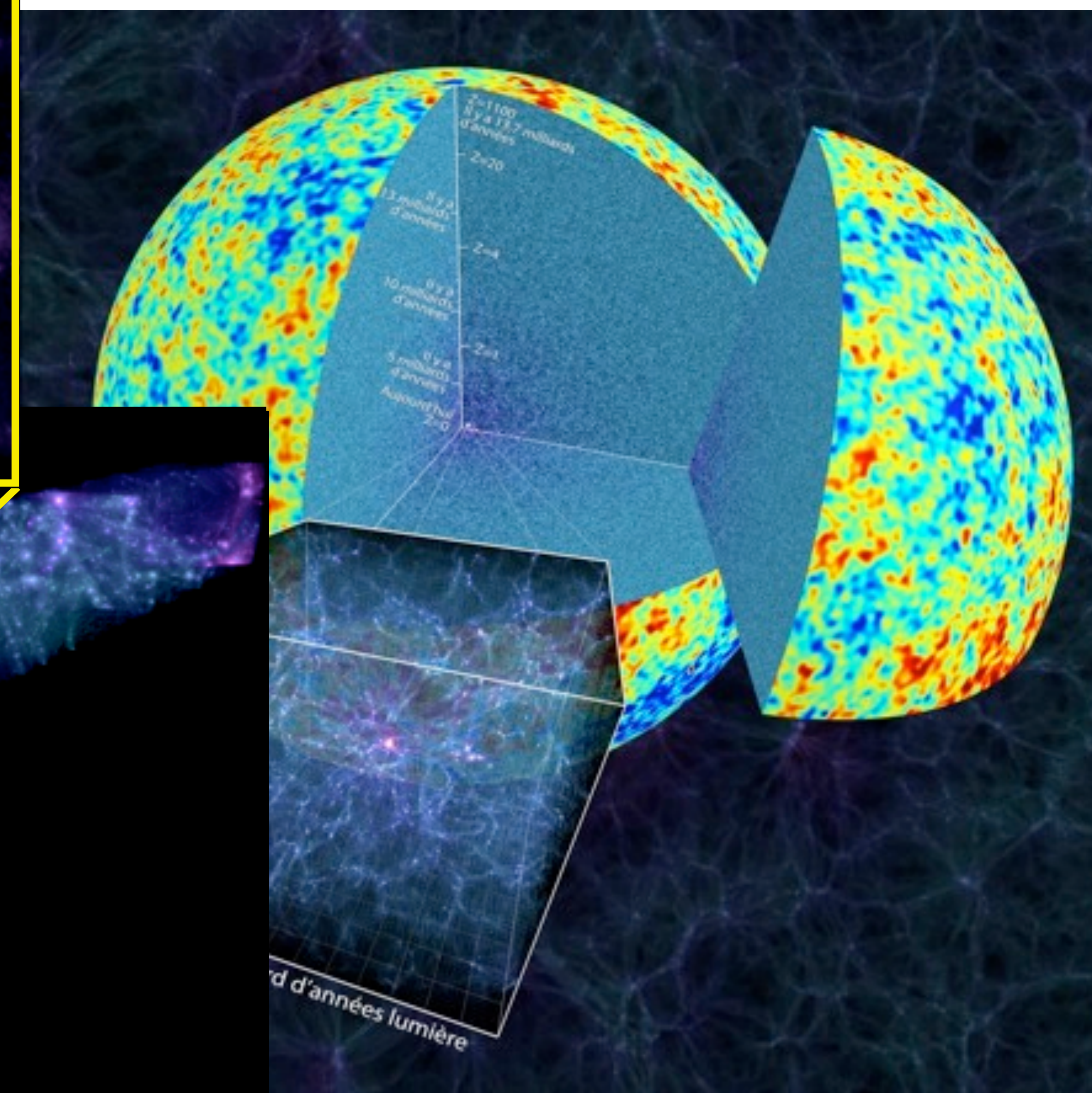
CONCLUSION

- How can we populate Dark Matter haloes from HOD?
- Extreme value statistics:
  - What is the distribution of the most massive Dark Matter haloes at a given redshift in a given cosmology?
  - What is the distribution of the mass of the *kth*-biggest Dark Matter haloes at a given redshift in observations?



QUESTIONS & COMMENTS !





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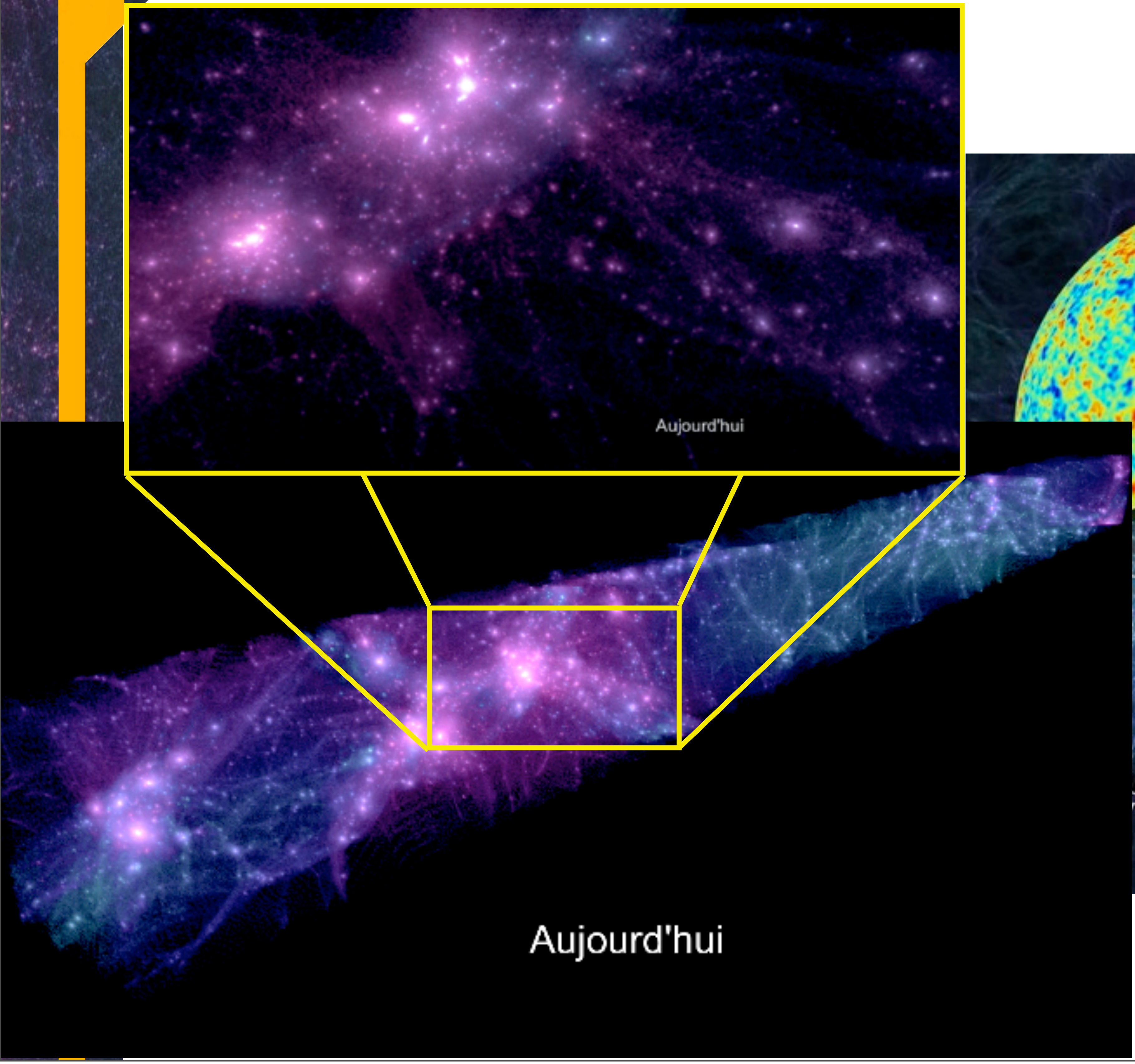
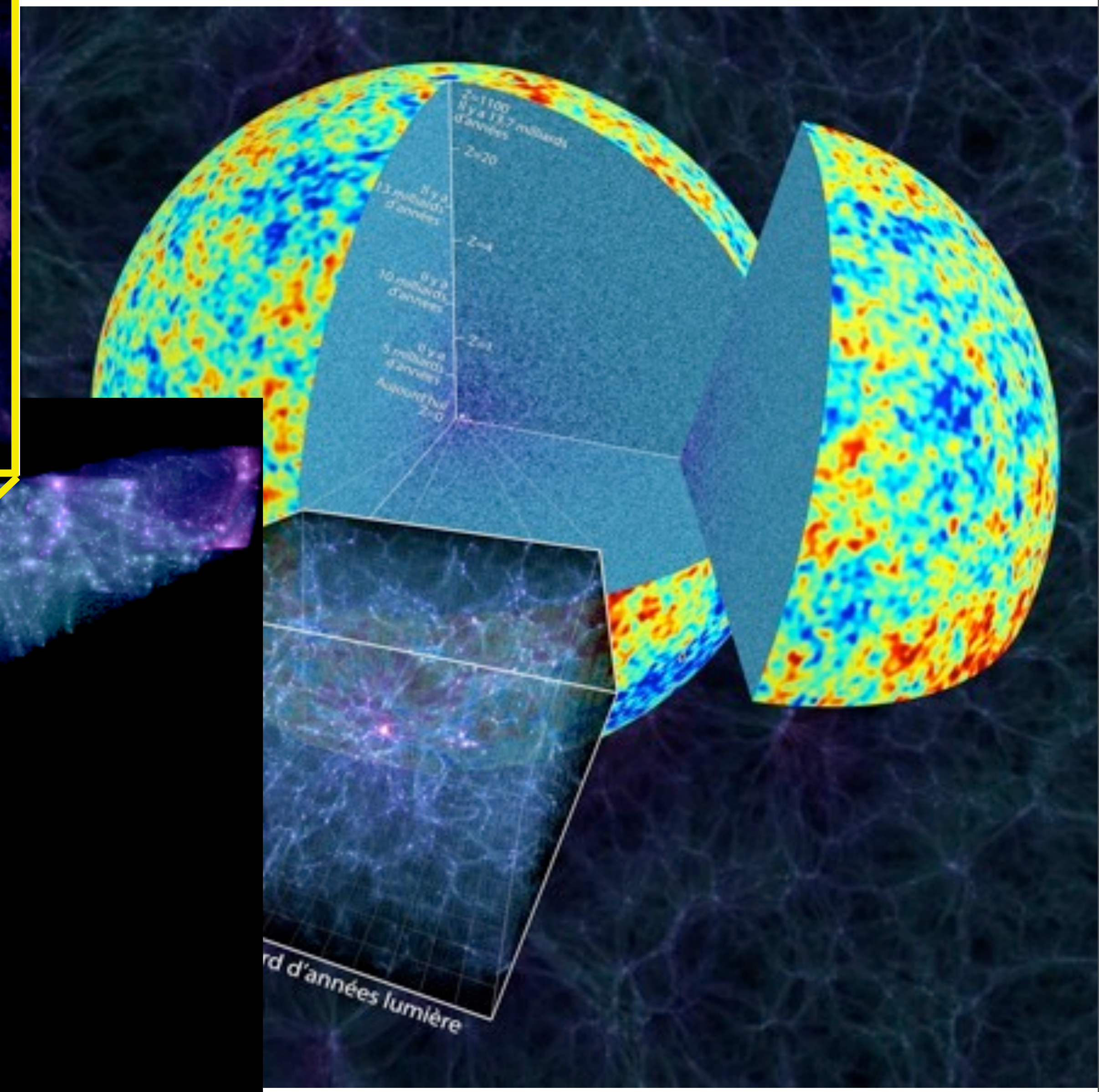
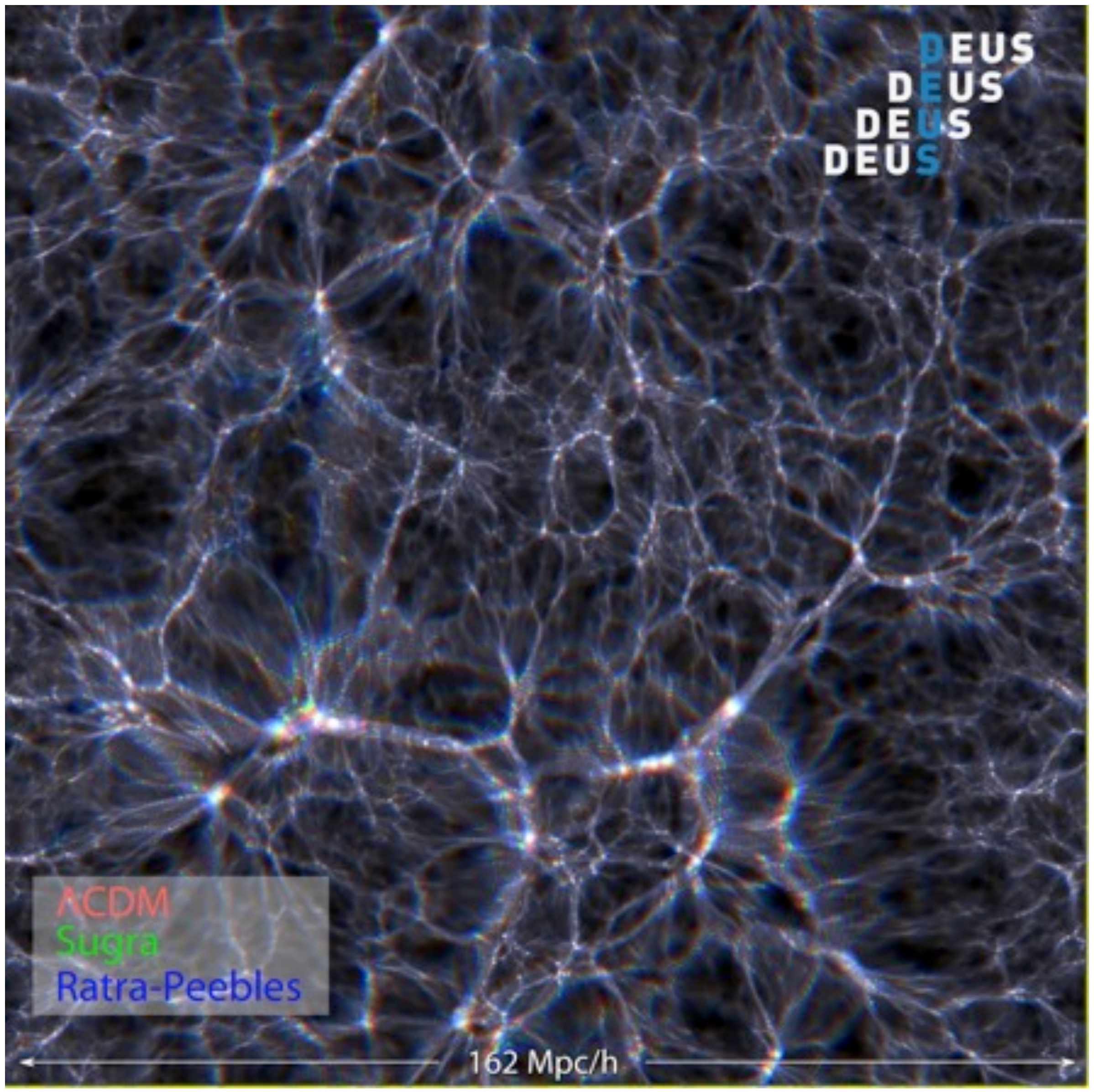
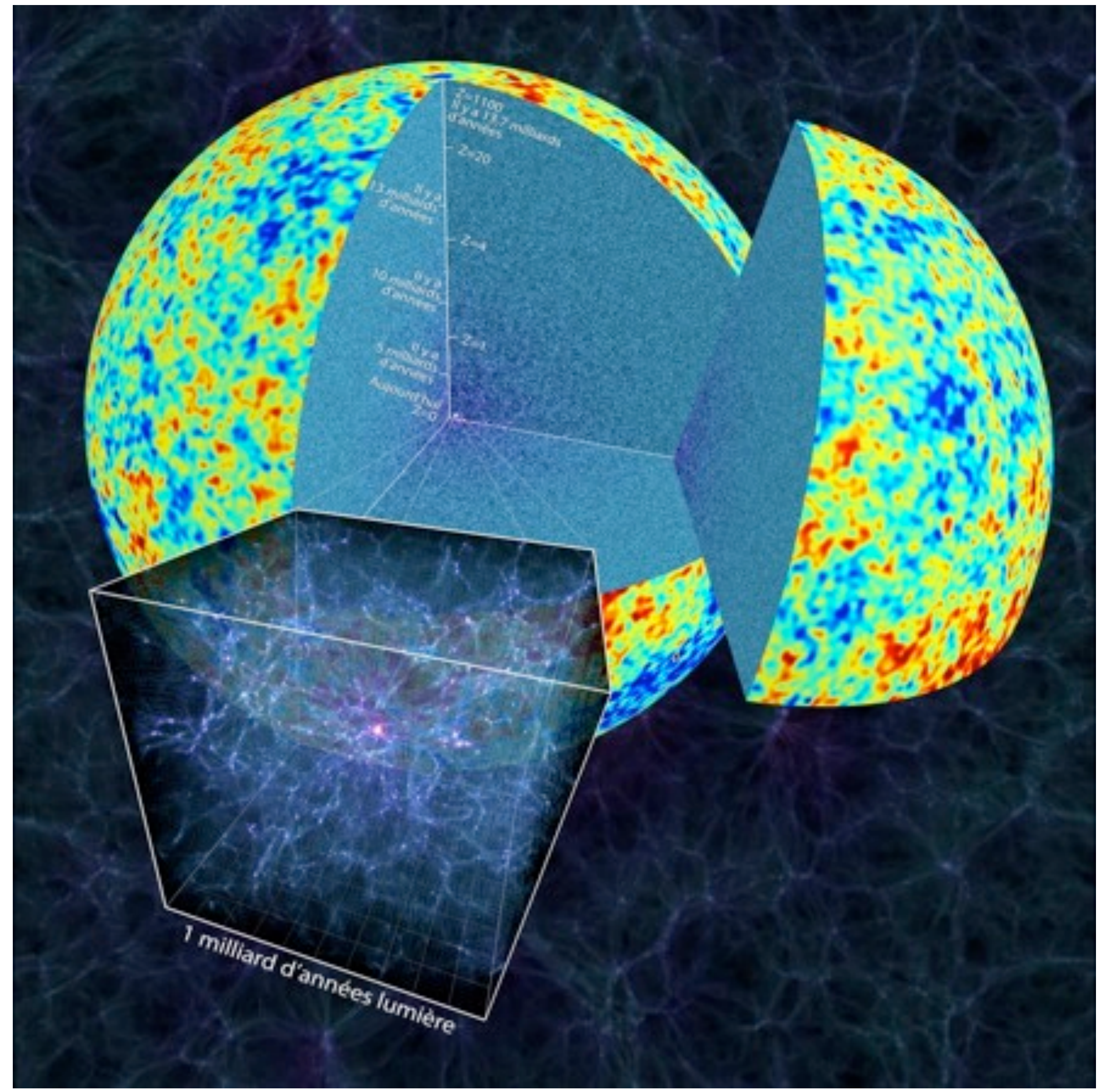




Questions & Comments !





TOOLBOX

- ❖ Toolbox:
  - Malquist bias - In brightness-limited survey
    The average measured lum. of a survey will be higher than the true one since only the brightest object can be seen at large distance.
  - Octree structure at the right
  - Ophiuchus:Détecté par le survey
    CIZA de Ebeling et Kocevski
    (2002-2005-2007).