Leibniz-Institut für Astrophysik Potsdam

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Simulating our Cosmic Home using Galaxy Flows

Jenny Sorce

Collaborations Cosmicflows & CLUES

Large Scale Structure and Galaxy Flows

Quy Nhon, Vietnam, July 8th 2016

Leibniz-Institut für Astrophysik Potsdam

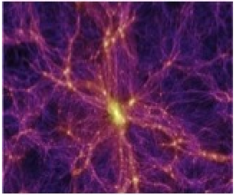
ΛCDM works well on large scales

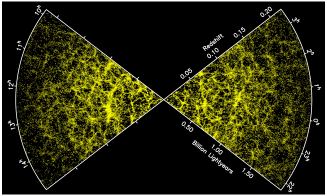
Because the Universe is ‘quite’ **homogeneous** on **large** scales

in order to test ΛCDM, any simulation with:

- a reasonable boxsize to capture the large structures
- a reasonable resolution to resolve the large structures

is enough to show that **ΛCDM works well on large scales** (i.e. that the observed LSS resembles the simulated LSS)





2dF redshift survey, Colless 1999 & Millennium runs, Springel et al. 2005 and 2008
(other recent and on-going surveys presented by Jeremy Mould, Christina Magoulas, Matthew Colless)

But problems...

... on the small scales, e.g.:

• missing satellite galaxies and dwarfs (Klypin et al. 1999 ; Moore et al. 1999 ; Zavala et al. 2009), etc

• size of voids (Tikhonov & Klypin 2009)

• preferential distribution of the Milky Way's satellites in a pancake shape-like rather than an isotropic distribution (Kroupa et al. 2005) (mentioned by Xi Kang)

But problem...

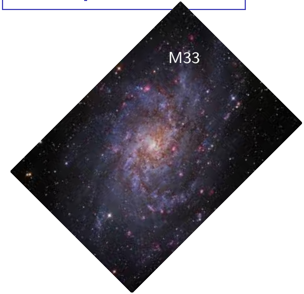
... we reside in a given environment,

thus our **measurements, conclusions, local and far observations** might be **biased** by its characteristics, e.g.:

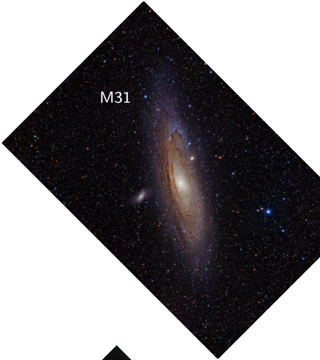
• variation of the 'local' Hubble Constant with density (Wojtak et al. 2014)

• impact of the gravitational redshift due to the local gravitational potential (Wojtak et al. 2015)

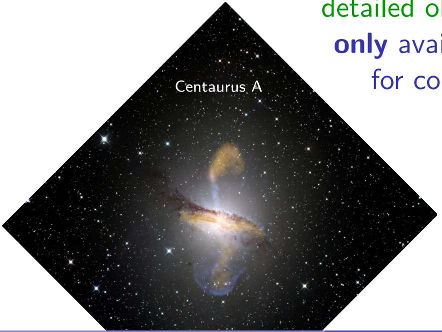
But problem...



Magellanic Cloud



... the best and most detailed observations are **only** available close-by for comparisons!



To summarize

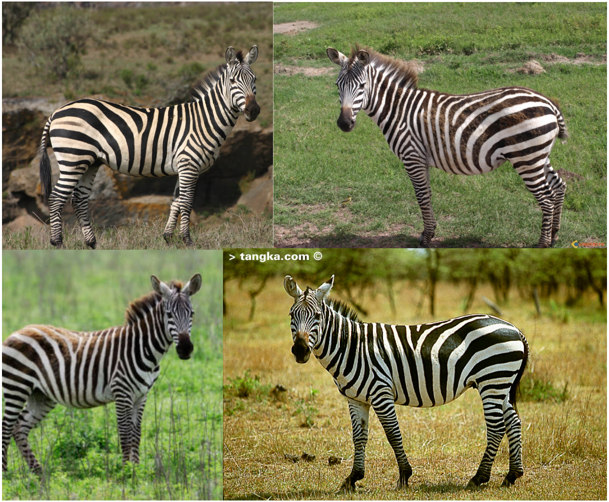
The Universe might well look like this...

To summarize

we have the details only for this one...

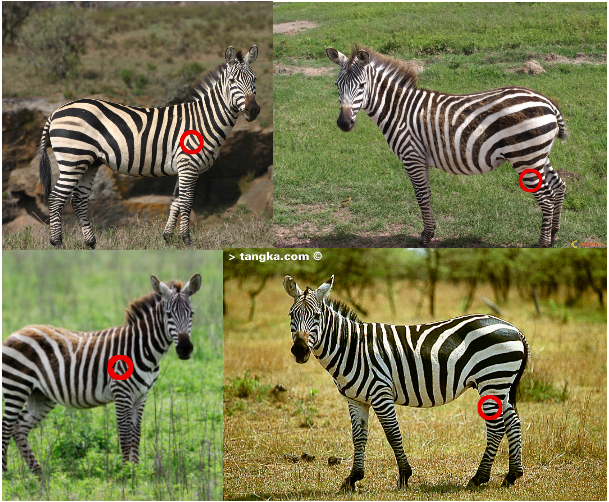
To summarize

and it does not look like the others when looking at the details !



To summarize

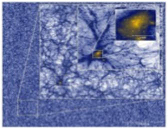
and it does not look like the others when looking at the details !



Two solutions

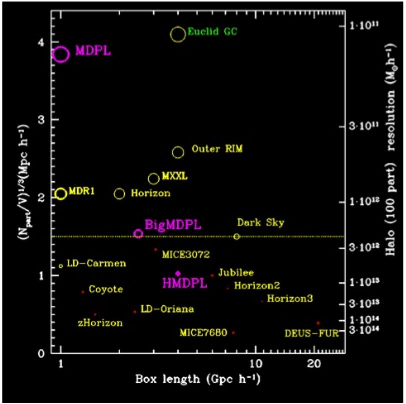
First solution

Very large and high resolution simulations to **select similar** environmental conditions or/and similar objects e.g.



MilleniumXXL, Angulo et al. 2012

$\Longrightarrow$



Courtesy of G. Yepes

First solution

Very challenging / demanding because huge computer resources are required in terms of:

- time
- memory
- storage

Second solution: followed in this talk

"This identical twin of yours... Can you describe him?"

Constrained simulations of the best-observed volume, i.e. our **local environment**

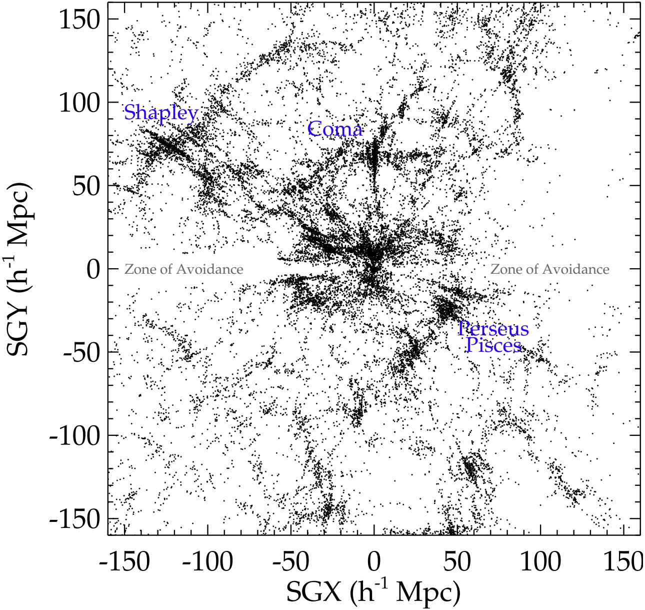
=

Simulations **resembling** the Local Universe to make **direct comparisons** on **multi-scales** (down to the dwarfs)

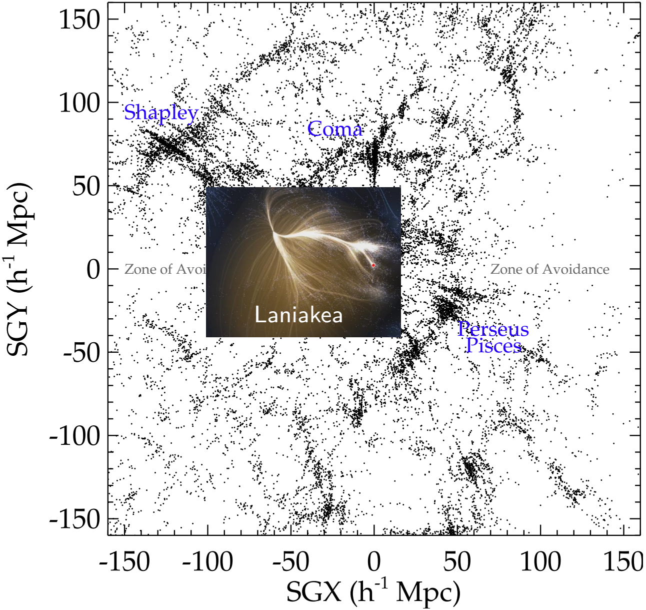
=

Reduction of the **cosmic variance**

The Local Universe



The Local Universe



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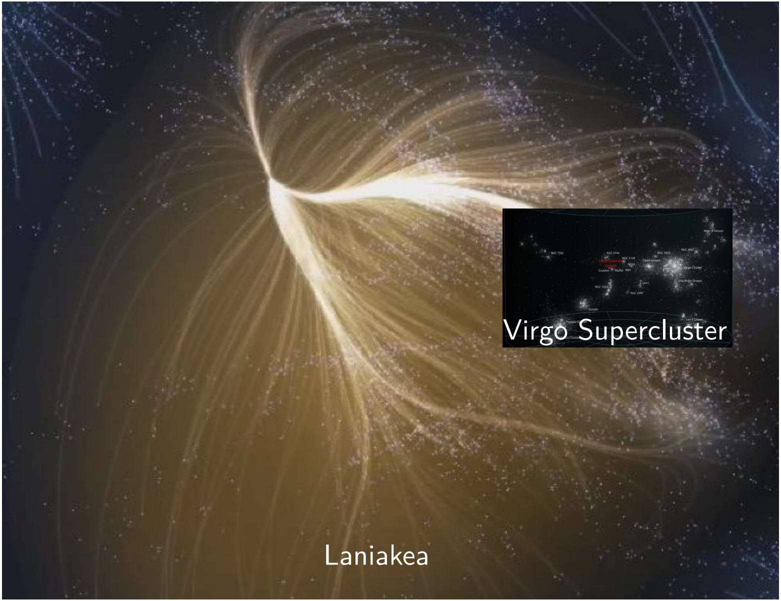
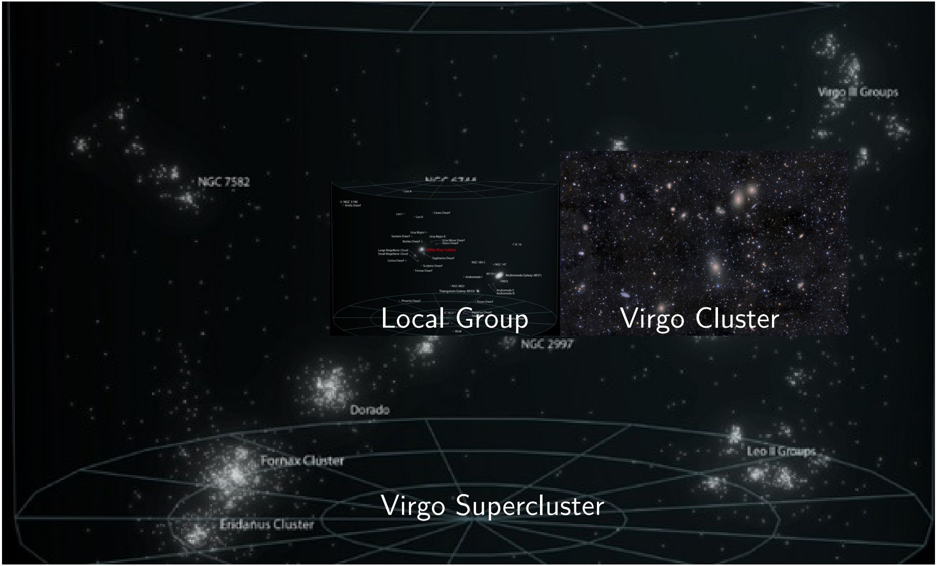
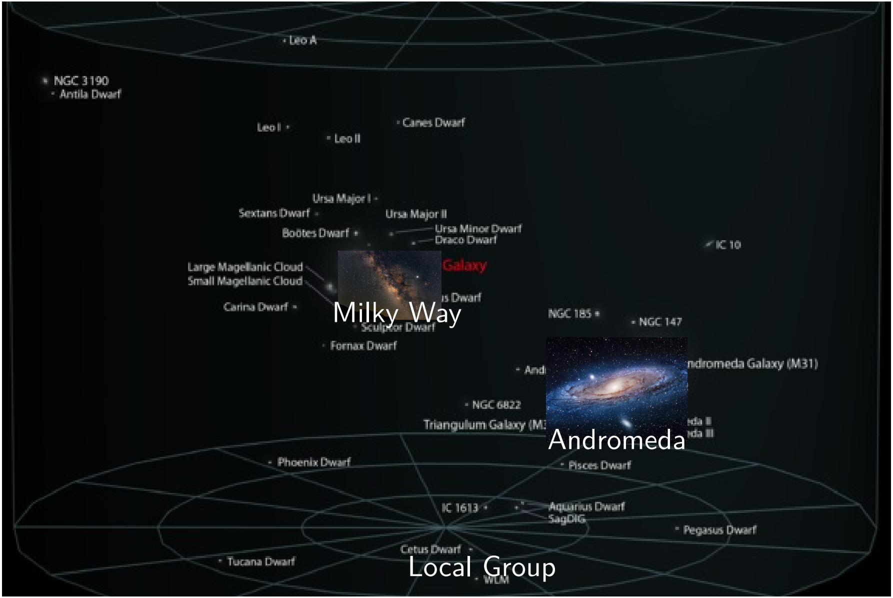


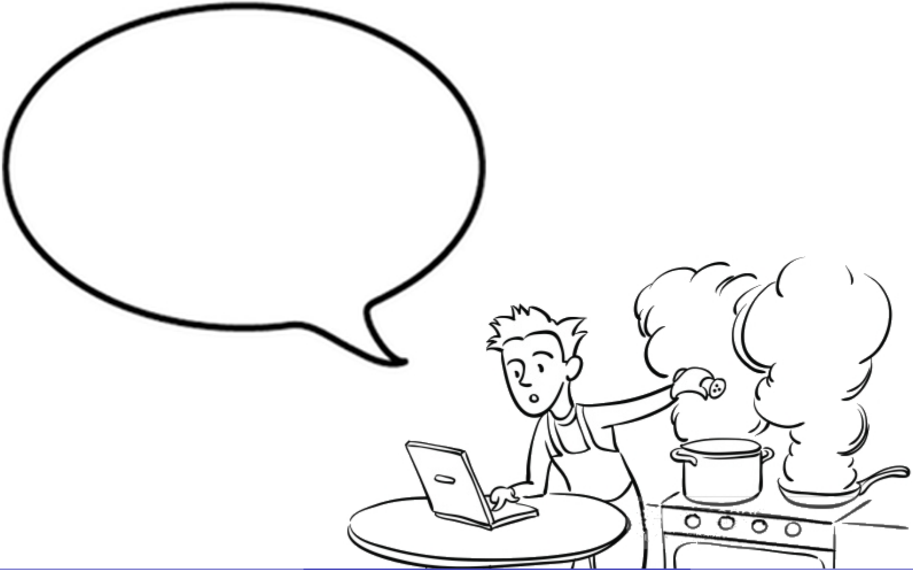
The Local Universe



The Local Universe



Ingredients to get Constrained Simulations



Ingredients to get Constrained Simulations

- observations:

radial peculiar velocities

Brent Tully's talk

Ingredients to get Constrained Simulations

- observations:

radial peculiar velocities

Brent Tully's talk

- simulations:

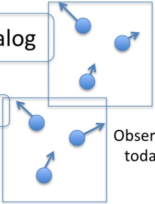
backward method

Yehuda Hoffman's & Stefan Gottlöber's talks

(see Guilhem Lavaux's talk for forward methods)

Summary of the method

Radial peculiar velocity catalog



Observed today!

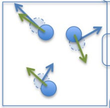
Tully et al. 2013

Minimization of the biases

Observed today!

Tully 2015
Sorce 2015

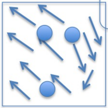
Constrained with positions at z>0!



Reverse Zel'dovich Approximation

Zaroubi et al. 1995 (see Yehuda Hoffman's and Romain Graziani's talks)

Constrained Realization Technique (prior = power spectrum)

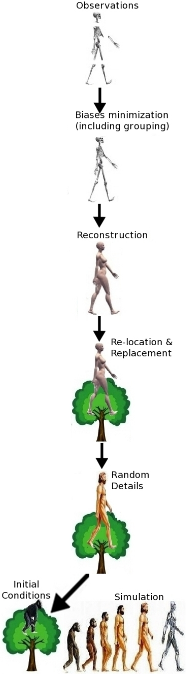


Hoffman & Ribak 1991

Constrained Initial Conditions

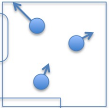
Doumler et al. 2013
Sorce et al. 2014

Simulation run



Summary of the method

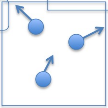
Radial peculiar velocity catalog



Observed today!

Tully et al. 2013

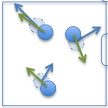
Minimization of the biases



Observed today!

Tully 2015
Sorce 2015

Constrained with positions at z>0!



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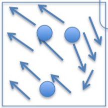

Hoffman & Ribak 1991

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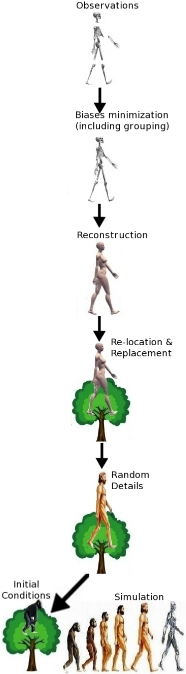
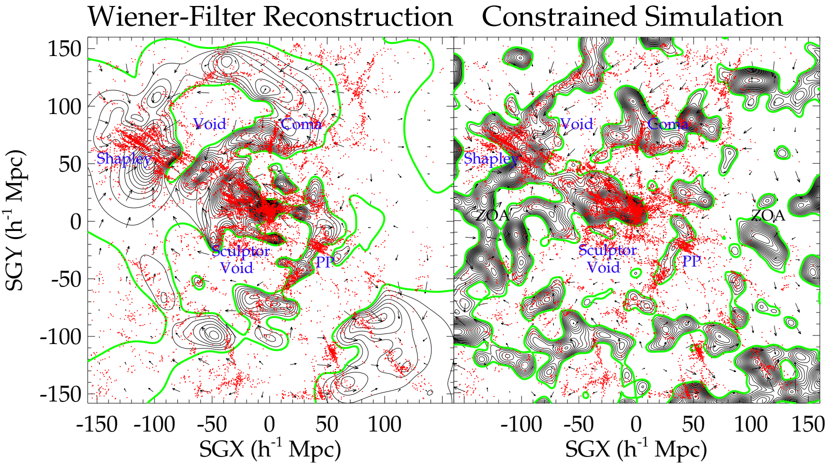


The local LSS: CLUES with CF2

Sorce et al. 2016a

At z = 0



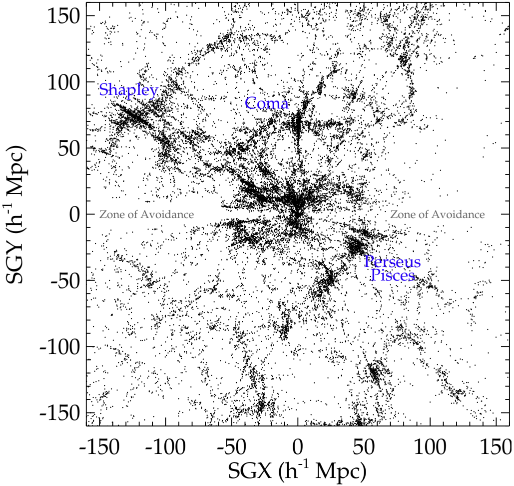
Observations for comparisons: redshift catalog •
Observations to constrain: Peculiar Velocities
Reconstruction: L=500 h^{-1} Mpc, n=256^3, linear field
Simulation: L=500 h^{-1} Mpc, n=512^3, full field)

Structures in the ZOA: Renée Kraan-Korteweg's, Anja Schroeder's and Khaled Said's talks

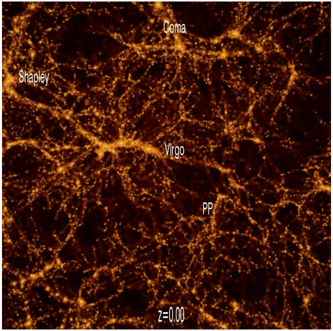
How did the Local Universe form?

Sorce et al. 2016a

Observed



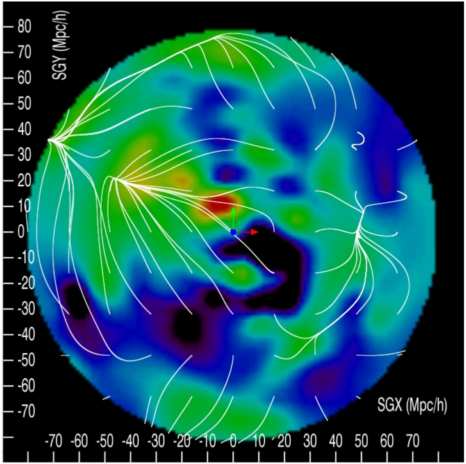
Simulated



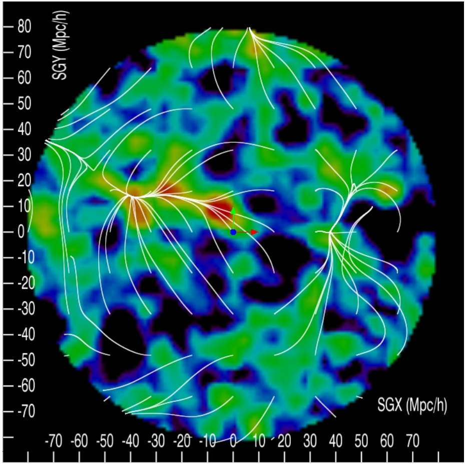
The Laniakea Supercluster, the zero velocity surface

Sorce et al. 2016

Reconstruction



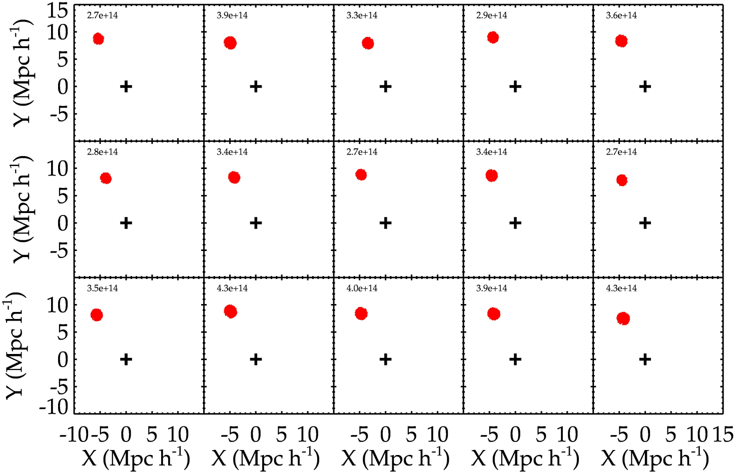
One Constrained Simulation



Plot made with Daniel Pomarède's SDvision software

How did the Virgo cluster form?

Sorce et al. 2016b

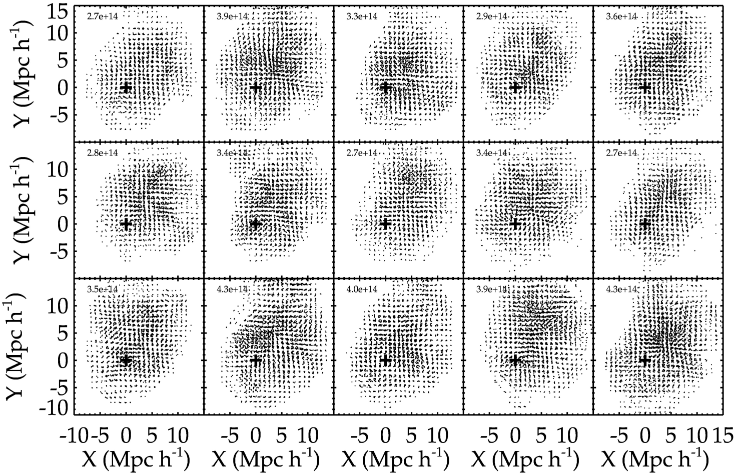


Dark Matter Haloes - Virgo Candidates: Particles at z= 0

- Shift $\sim$ 3-4 h^{-1} Mpc
- Mass within $\sim$ [0.5,2] estimated mass (Ludlow & Porciani 2011) M_{200}

How did the Virgo cluster form?

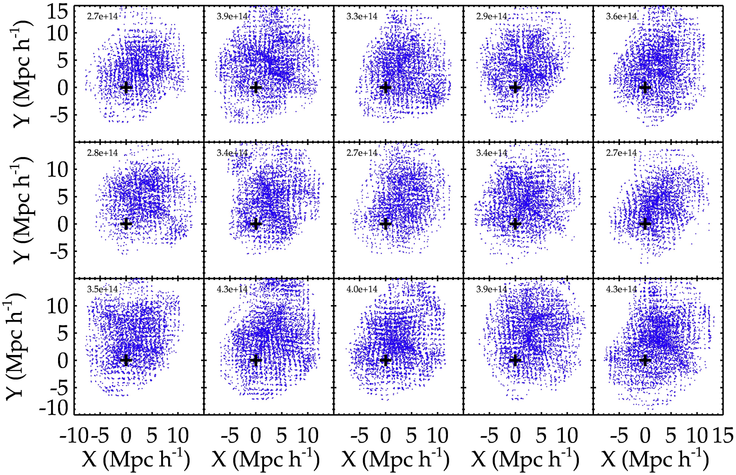
Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates: Particles at z= 10.

How did the Virgo cluster form?

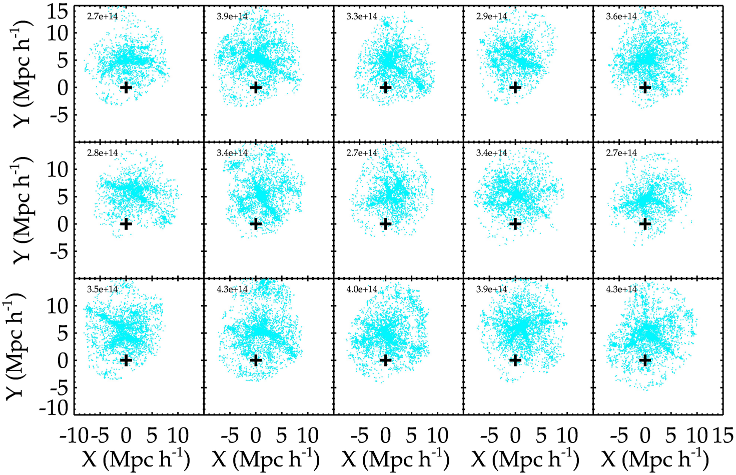
Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates: Particles at z= 5.

How did the Virgo cluster form?

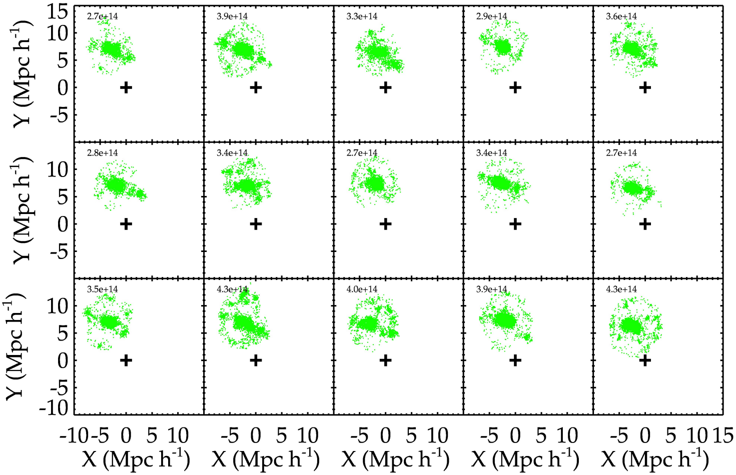
Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates: Particles at $z = 2$.

How did the Virgo cluster form?

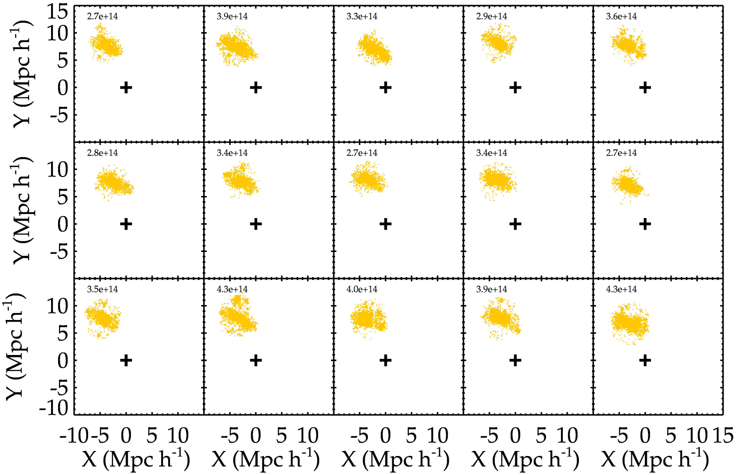
Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates: Particles at z= 0.5

How did the Virgo cluster form?

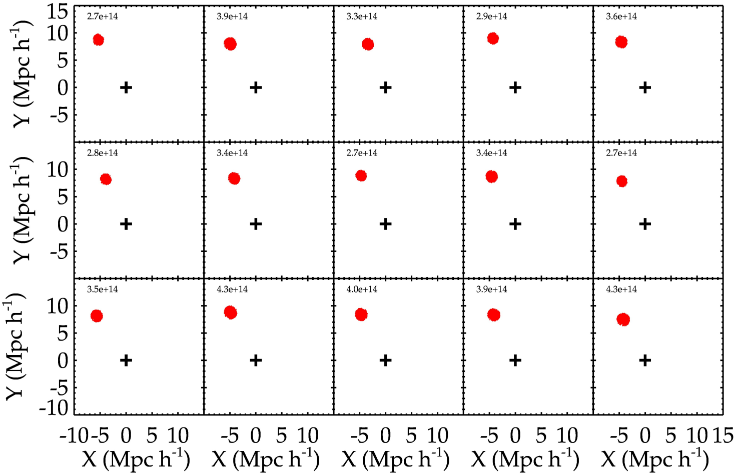
Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates: Particles at z= 0.25

How did the Virgo cluster form?

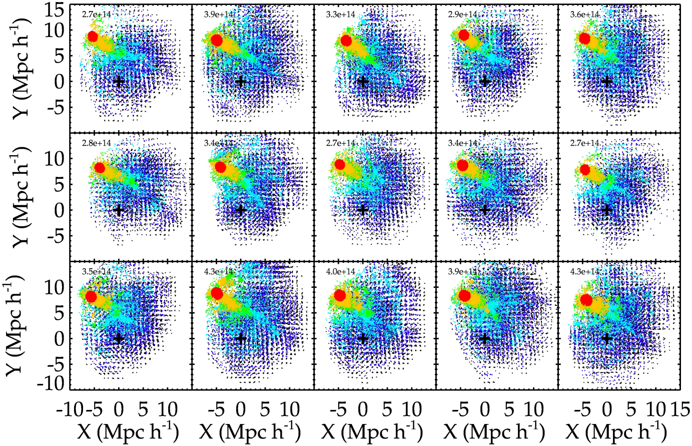
Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates: Particles at z= 0.

How did the Virgo cluster form?

Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates:

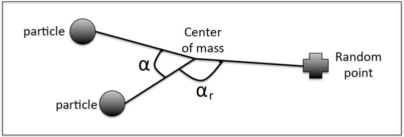
- Similar formation / evolution

One color per redshift:

10, 5, 2, 0.5, 0.25, 0

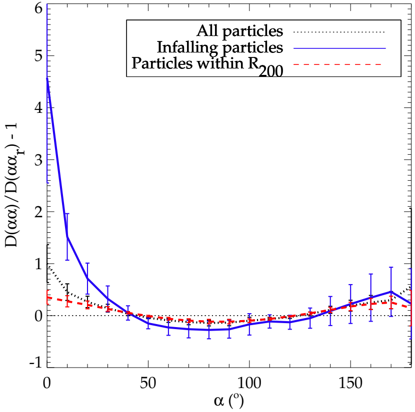
A preferential direction of infall

Sorce et al. 2016b



$D(\alpha\alpha)$: distribution of angle α
$D(\alpha\alpha_r)$: distribution of angle α_r

Autocorrelation function:
$D(\alpha\alpha)/D(\alpha\alpha_r)$ - 1



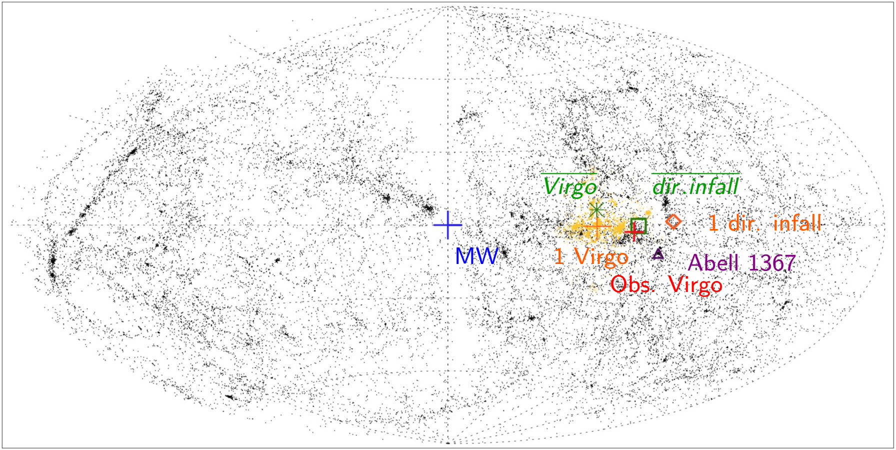
Particles within 6 h^{-1} Mpc at z=0

A preferential infall: Aitoff

Sorce et al. 2016b

In Supergalactic coordinates,

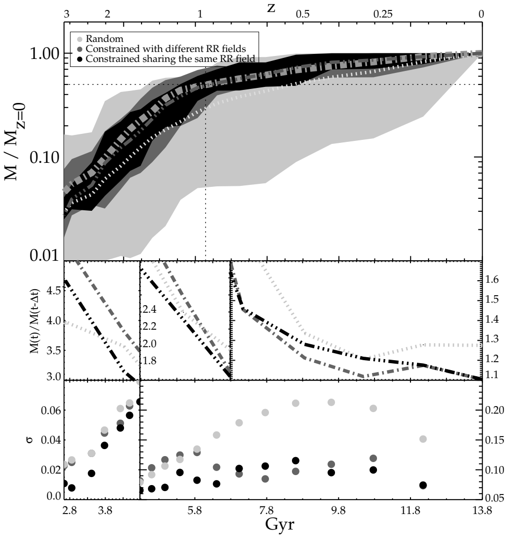
- redshift catalog
- infalling particles



West & Blakeslee (2000)

A quiet formation history over the last gigayears

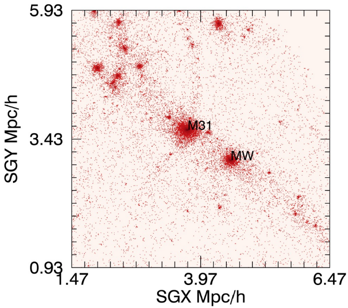
Sorce et al. 2016b

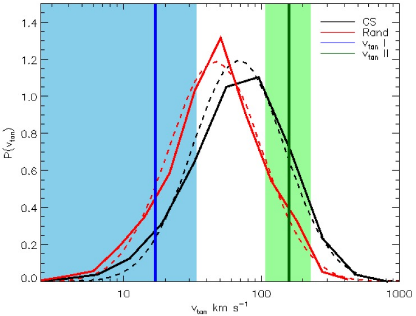


Similar merging histories: a quiet history over the last 7 Gigayears.

The Local Group

See Edoardo Carlesi's talk





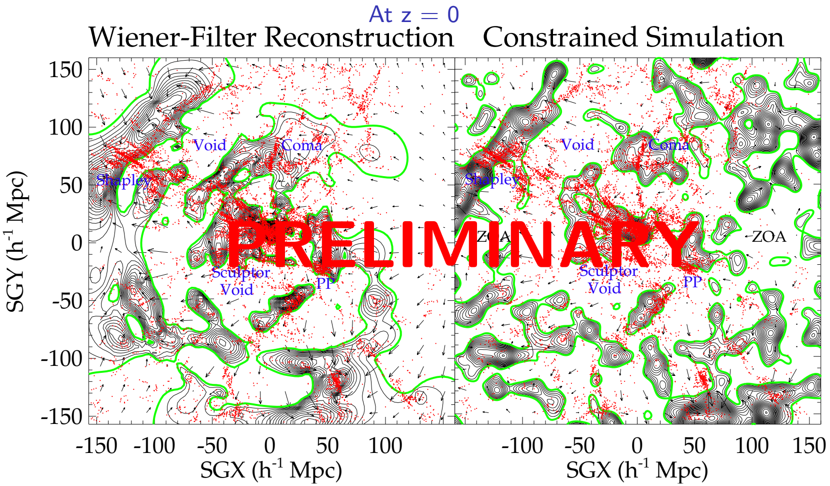
The Local Group factory
Carlesi, Sorce et al. 2016

Higher tangential velocity preferred
Carlesi, Hoffman, Sorce et al. 2016

Sohn et al. 2016: 17 ± 4 km s^{-1}
Salomon et al. 2016: 64 ± 61 km s^{-1}

Preliminary results with CF3

Sorce et al. 2016



Observations for comparisons: redshift catalog •

Observations to constrain = Peculiar Velocities: **CF3** catalog

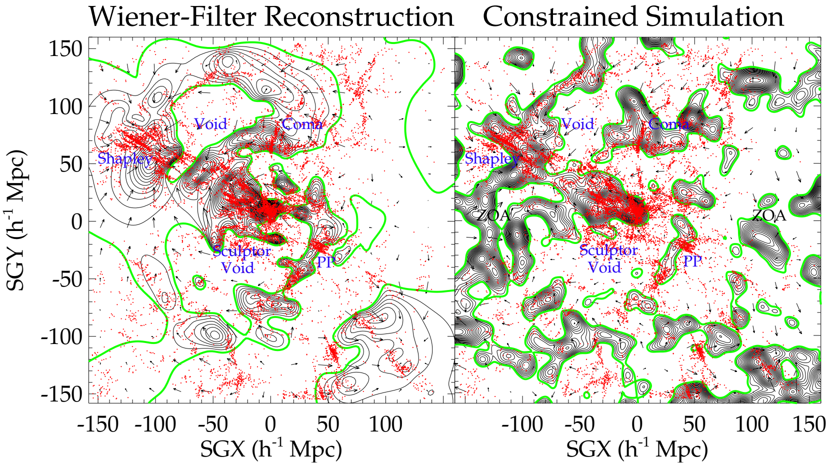
Reconstruction: L=800 h^{-1} Mpc, n=256^3, linear field (contours, arrows)

Simulation: L=500 h^{-1} Mpc, n=512^3, full field (contours, arrows)

CLUES with CF2

Sorce et al. 2016a

At z = 0



Observations for comparisons: redshift catalog •

Observations to constrain = Peculiar Velocities: CF2 catalog

Reconstruction: L=500 h^{-1} Mpc, n=256^3, linear field (contours, arrows)

Simulation: L=500 h^{-1} Mpc, n=512^3, full field (contours, arrows)

Conclusion & Prospectives

"WE FOUND BOTH OF YOU EQUALLY QUALIFIED FOR THE POSITION..."

Problems:

... on the small scales

... we reside in a local environment

... the best and most detailed observations are **only** available close by for comparisons!

Solutions to study, etc them:

Use constrained simulations !

(A lot is, will be or can be available ! Just ask)

Acknowledgements

Thank you, Merci, Danke,

Gracias, Grazie, Spasibo,

Mahalo, Xièxie, Arigatô,

Toda, Tak, Dank u,

Obrigada, Cám Ơn ...