Leibniz-Institut für
Astrophysik Potsdam

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Simulating the Local Universe

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SF2A

Lyon, June 17th 2016

Leibniz-Institut für Astrophysik Potsdam

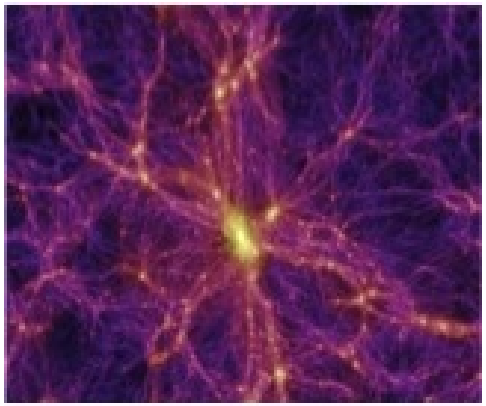
ΛCDM works well on large scales

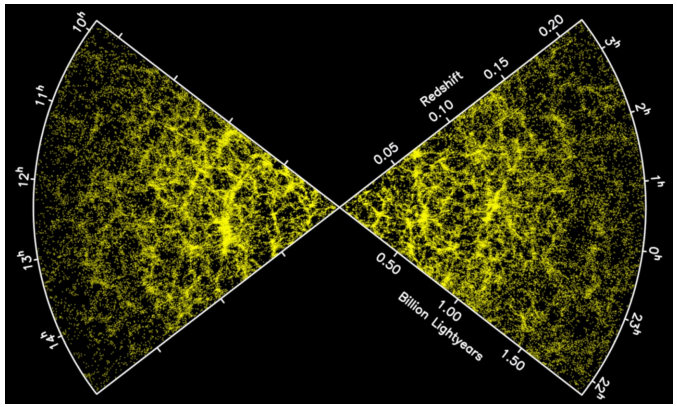
Because the Universe is 'quite' **homogeneous** on **large** scales

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

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)

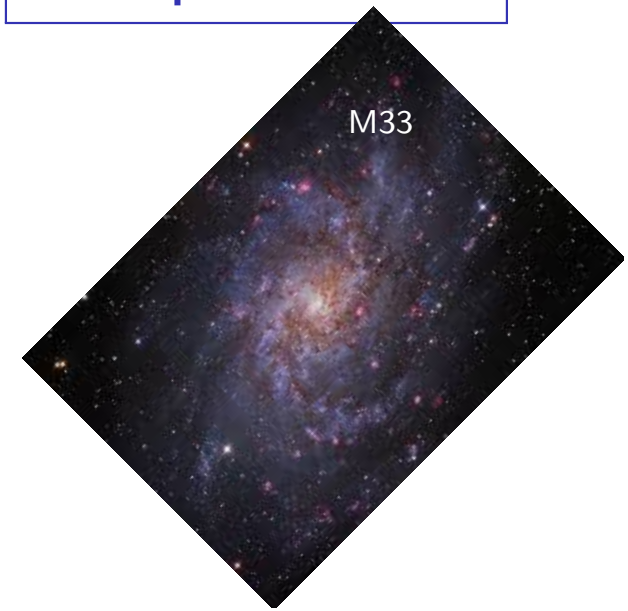
But problem...

... we reside in a given environment,

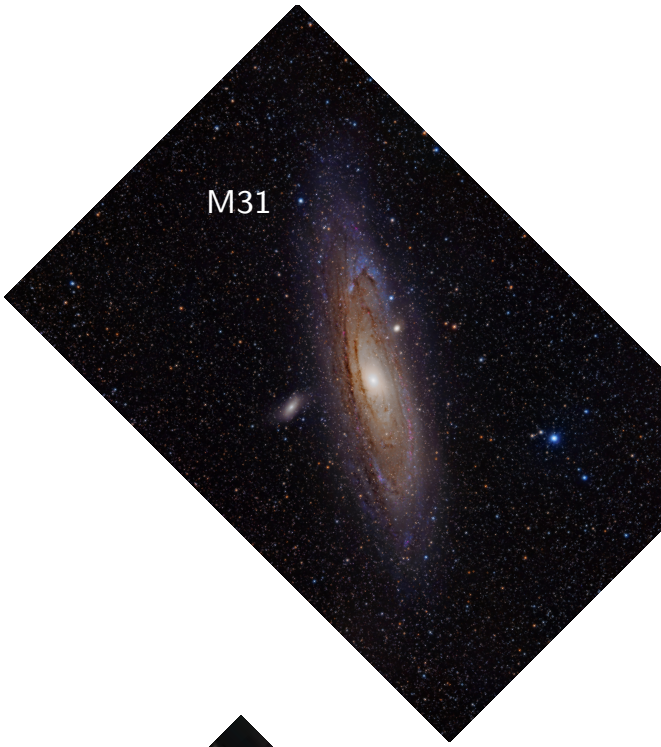
thus our **measurements, conclusions, local and far observations** might be **biased** by its characteristics, e.g.:

- 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)

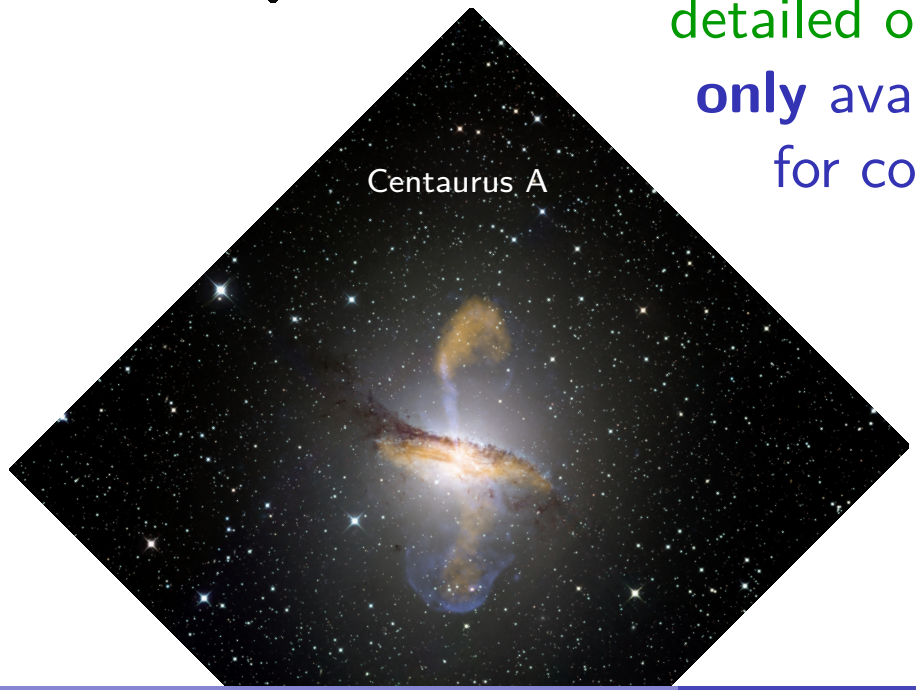
But problem...

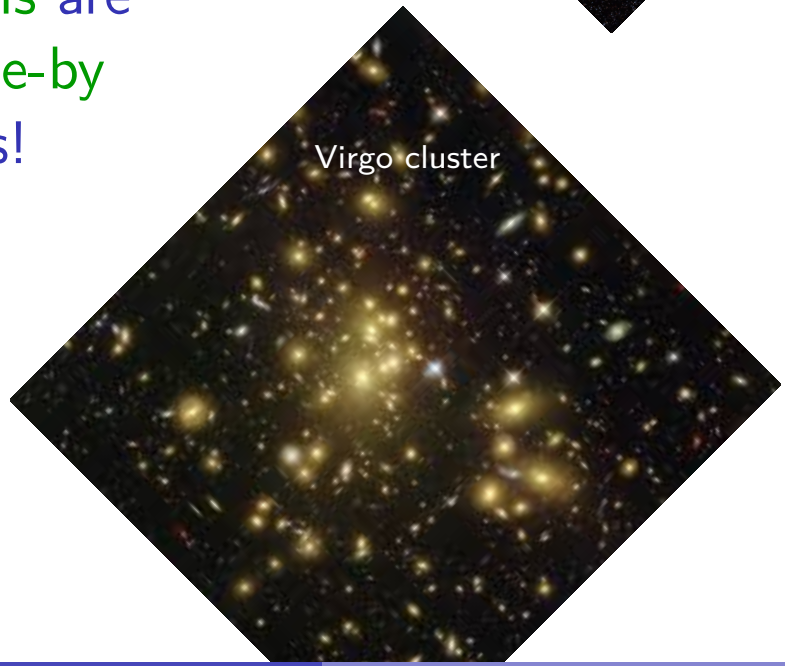


Magellanic Cloud



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





To summarize

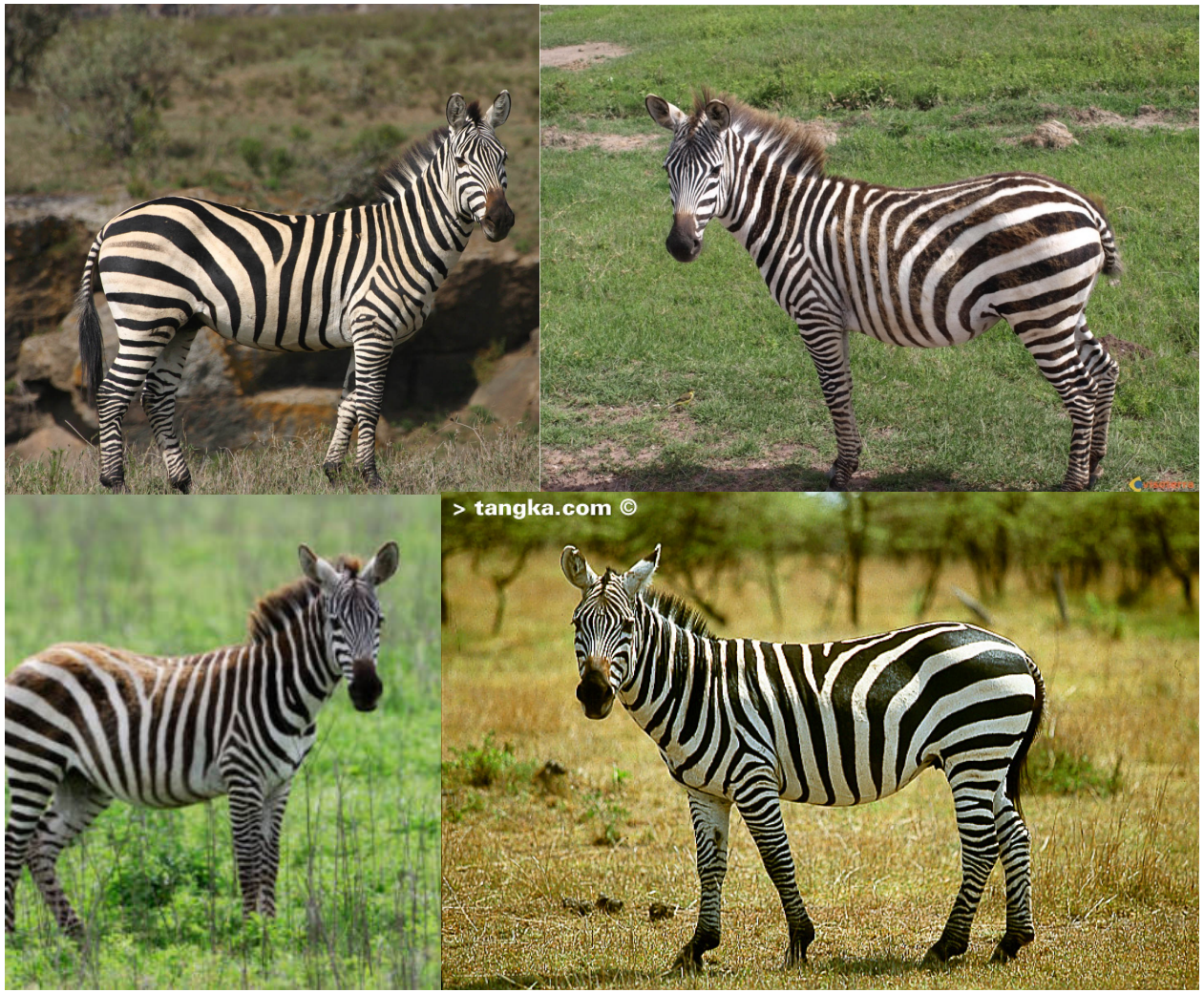
The Universe might well look like this...

To summarize

we have the details only for this one...

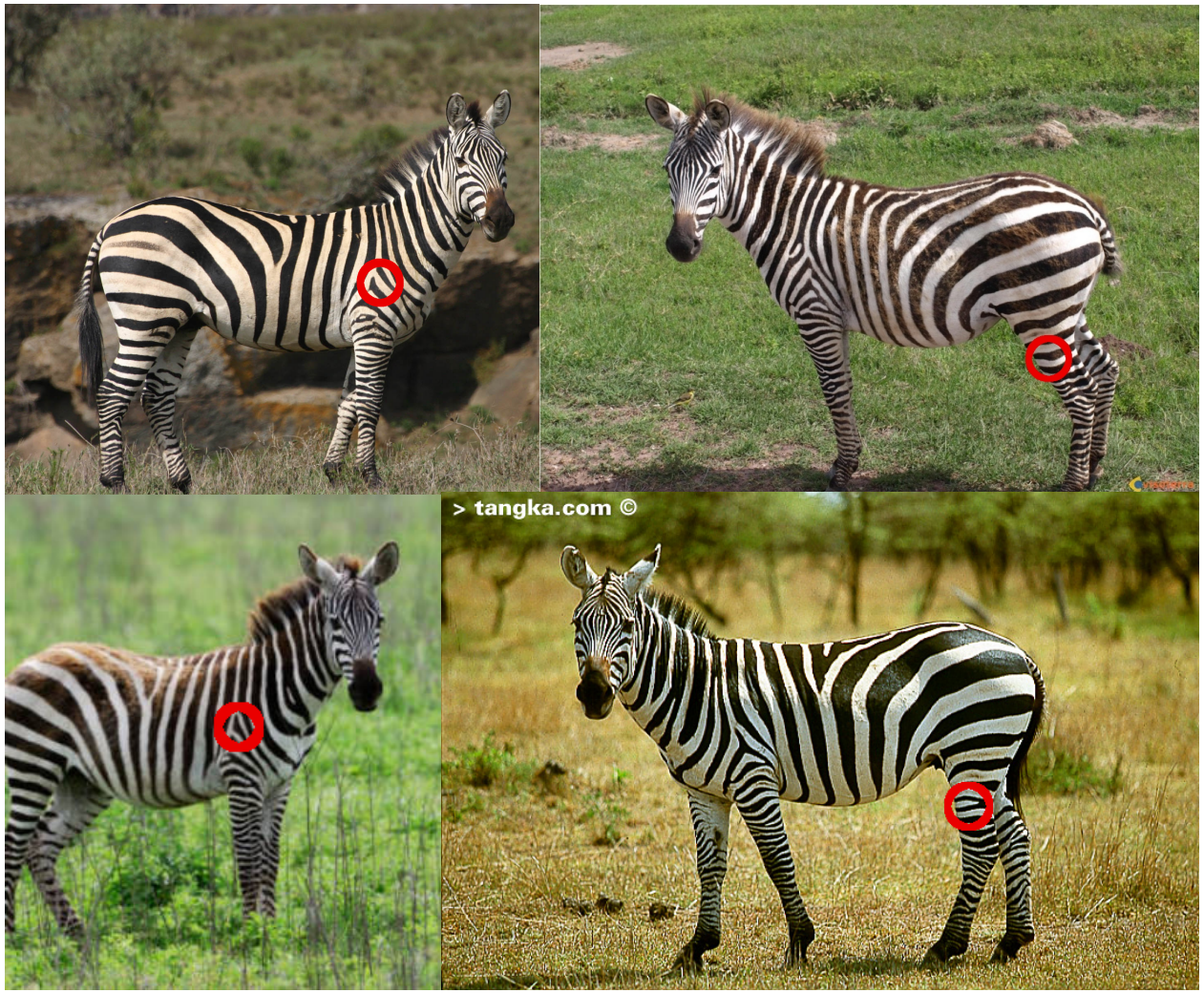
To summarize

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



To summarize

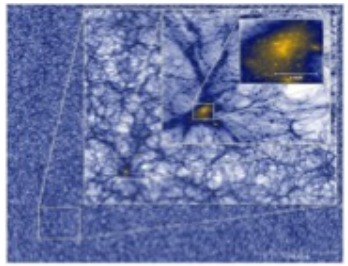
and it does not look like the others when looking at the details !



Two solutions

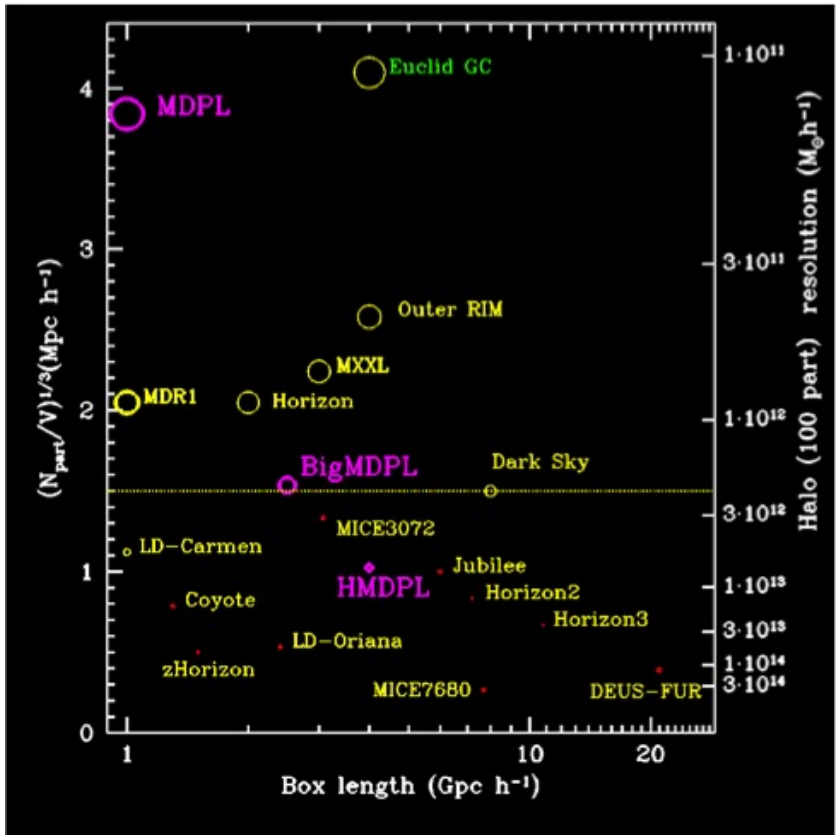
First solution

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**

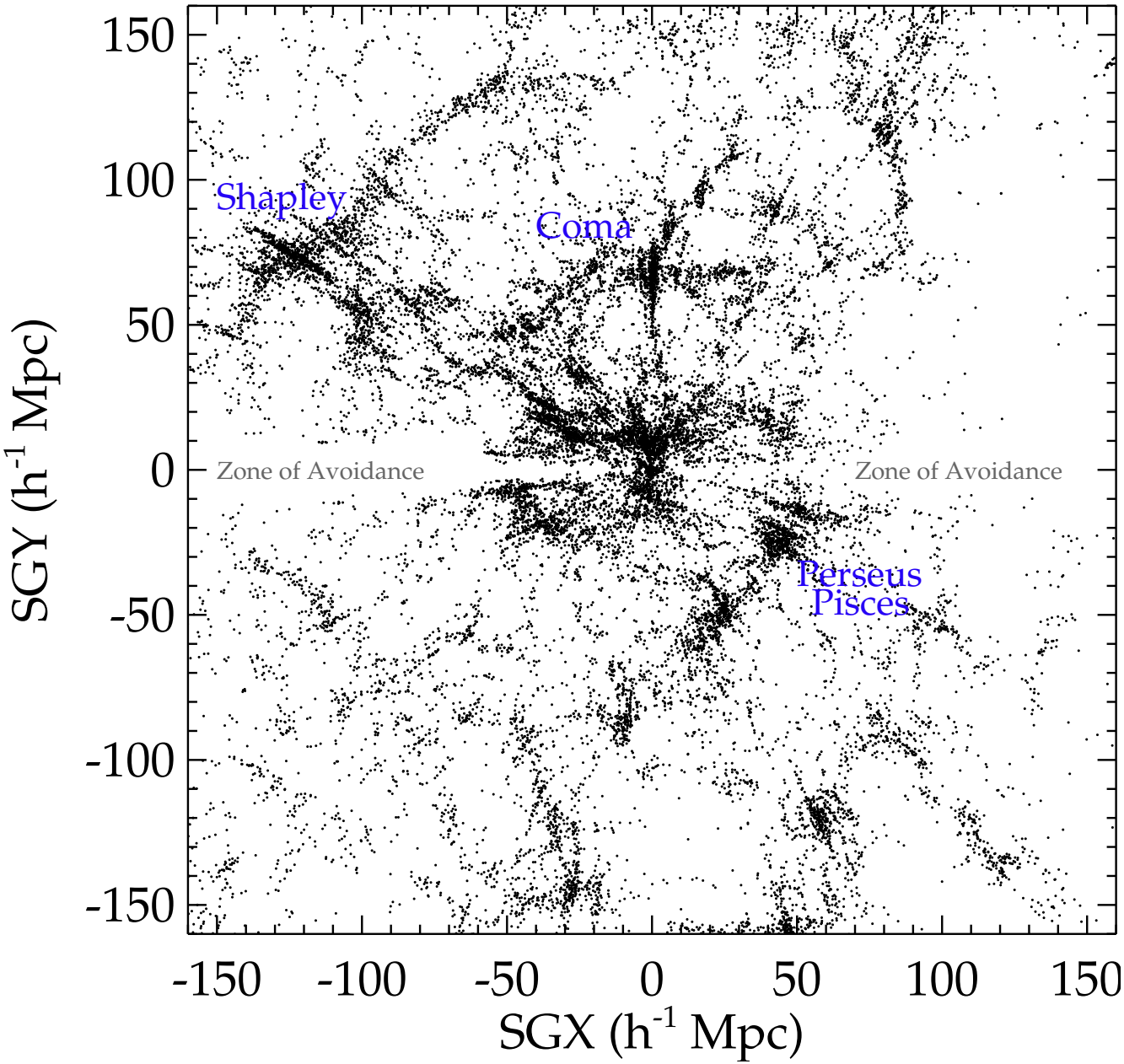
=

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

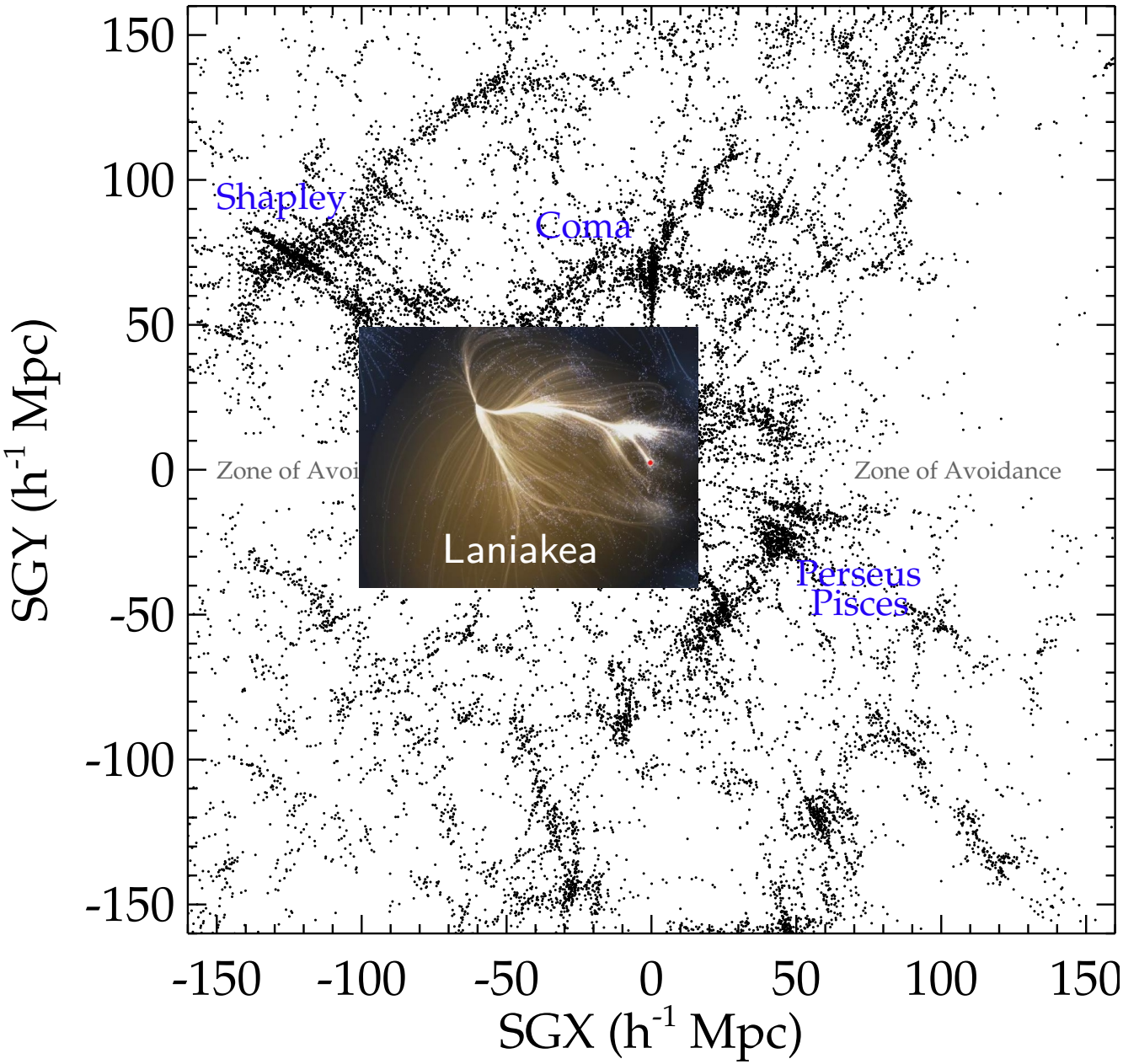
=

Reduction of the **cosmic variance**

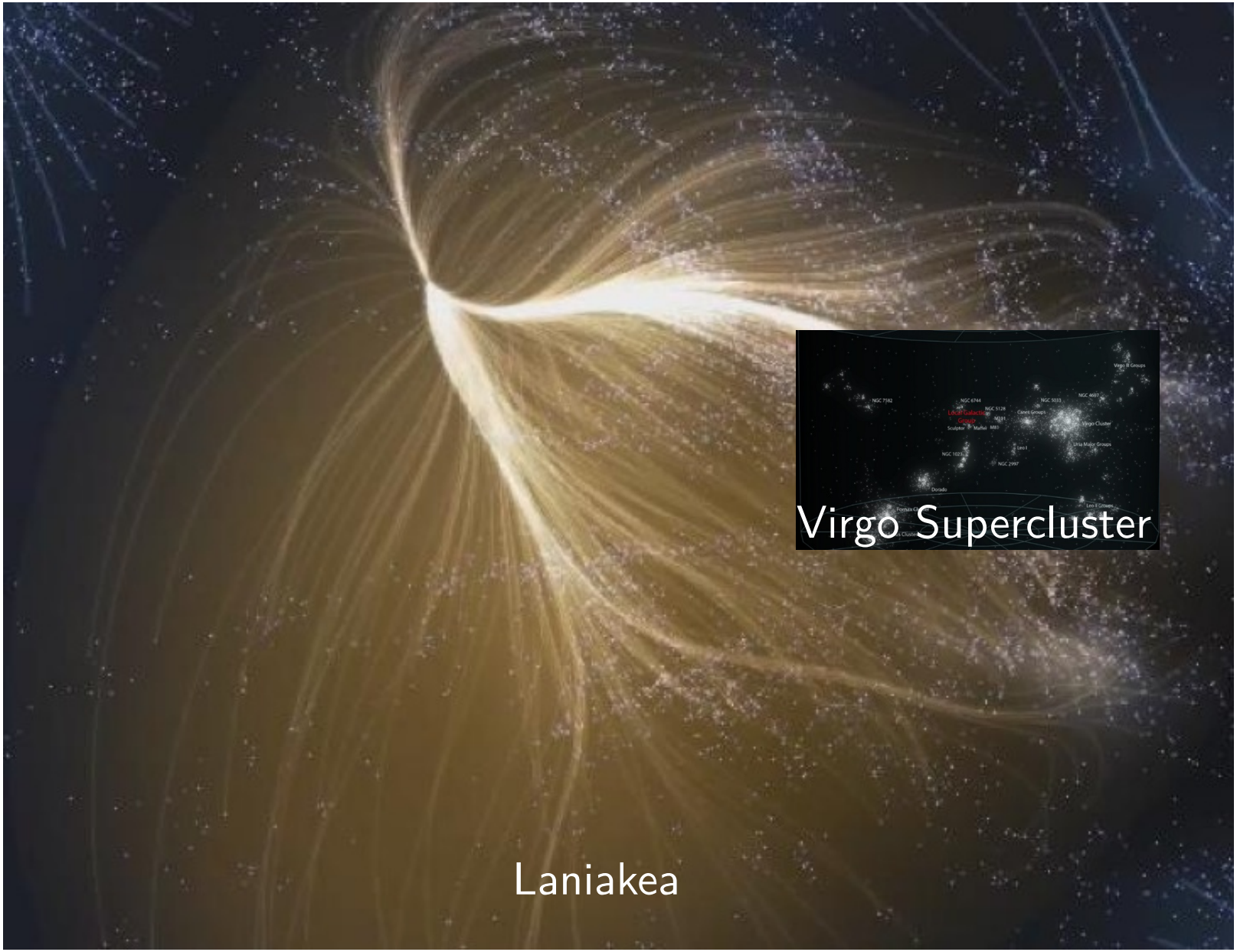
The Local Universe



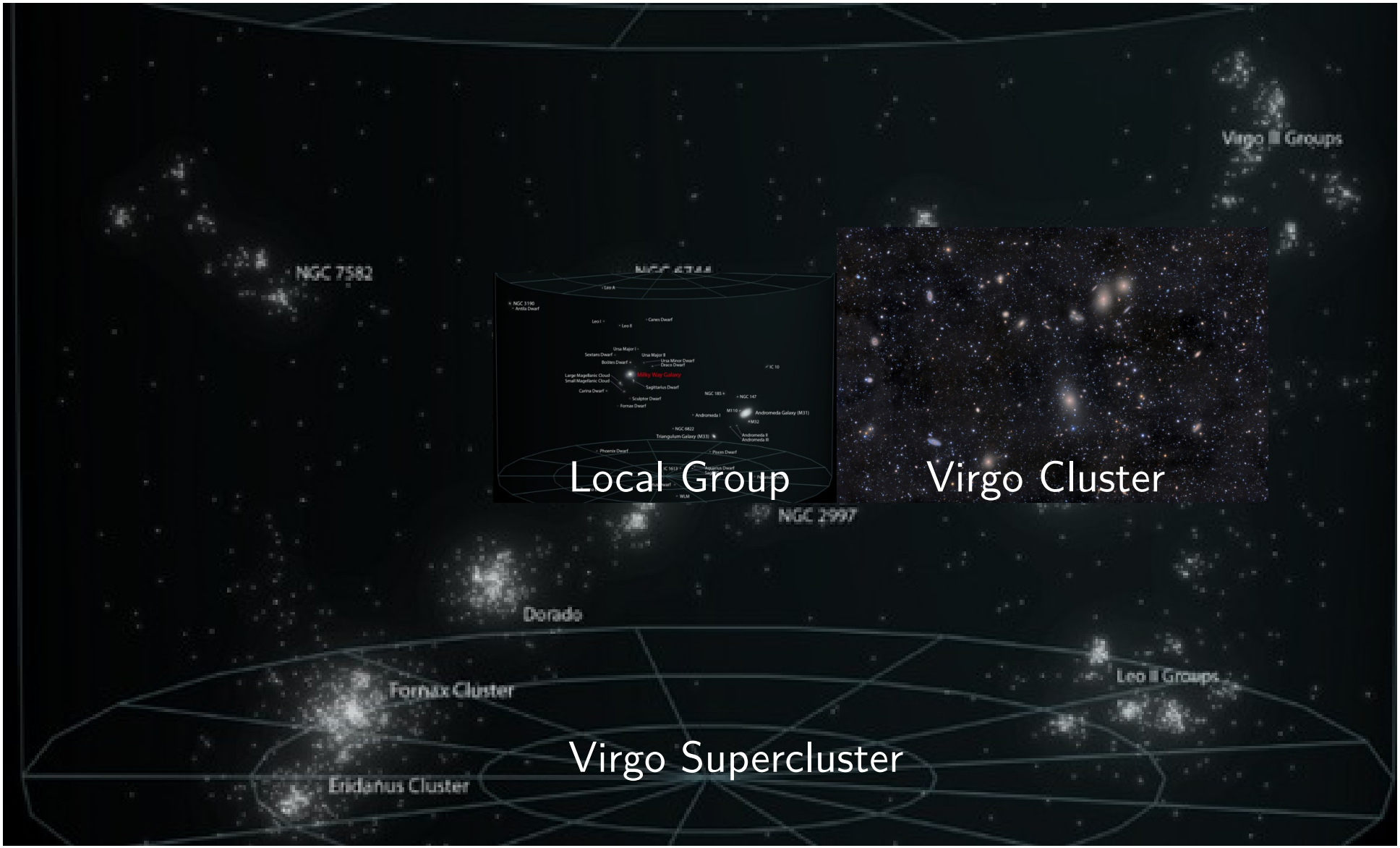
The Local Universe



The Local Universe



The Local Universe



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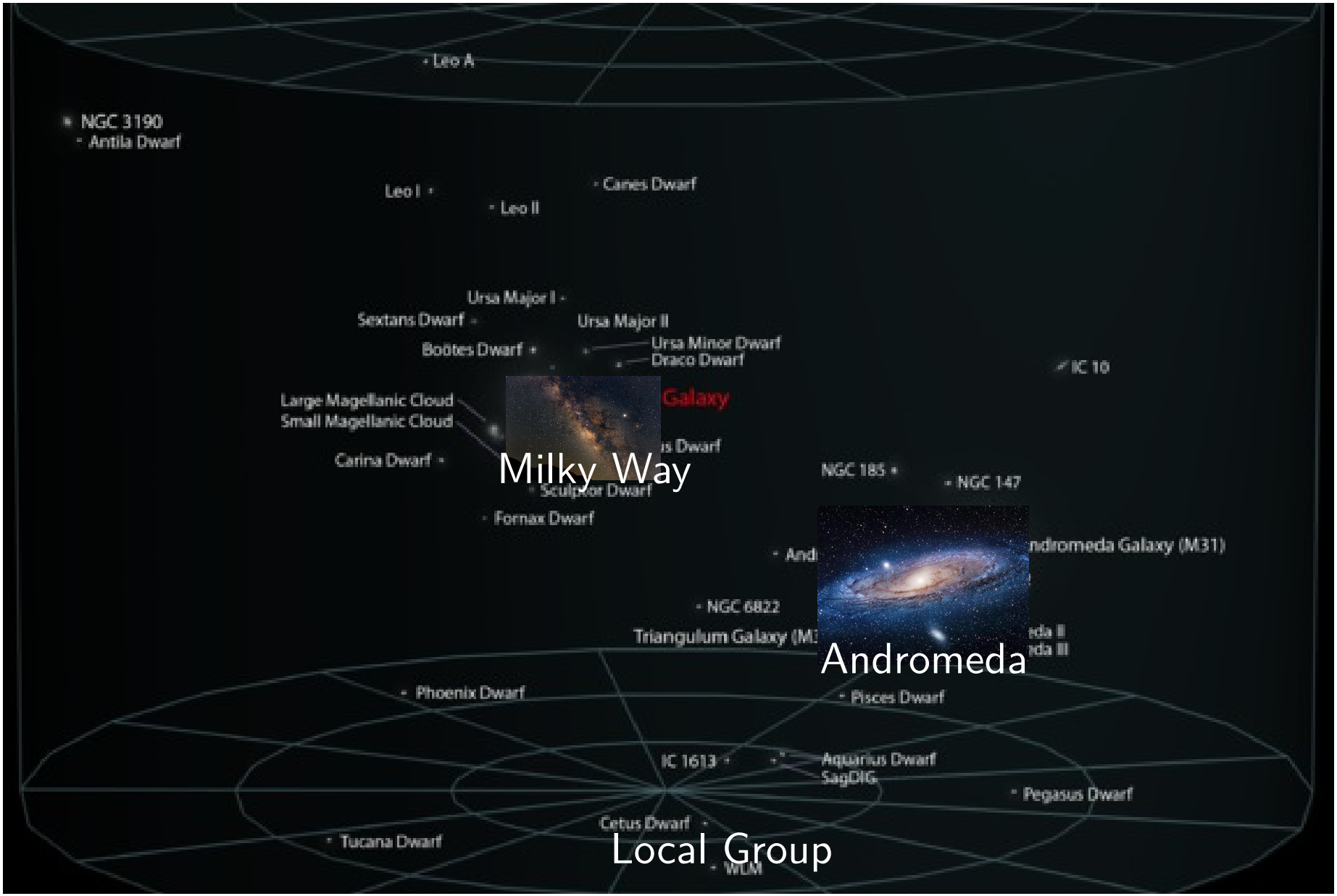
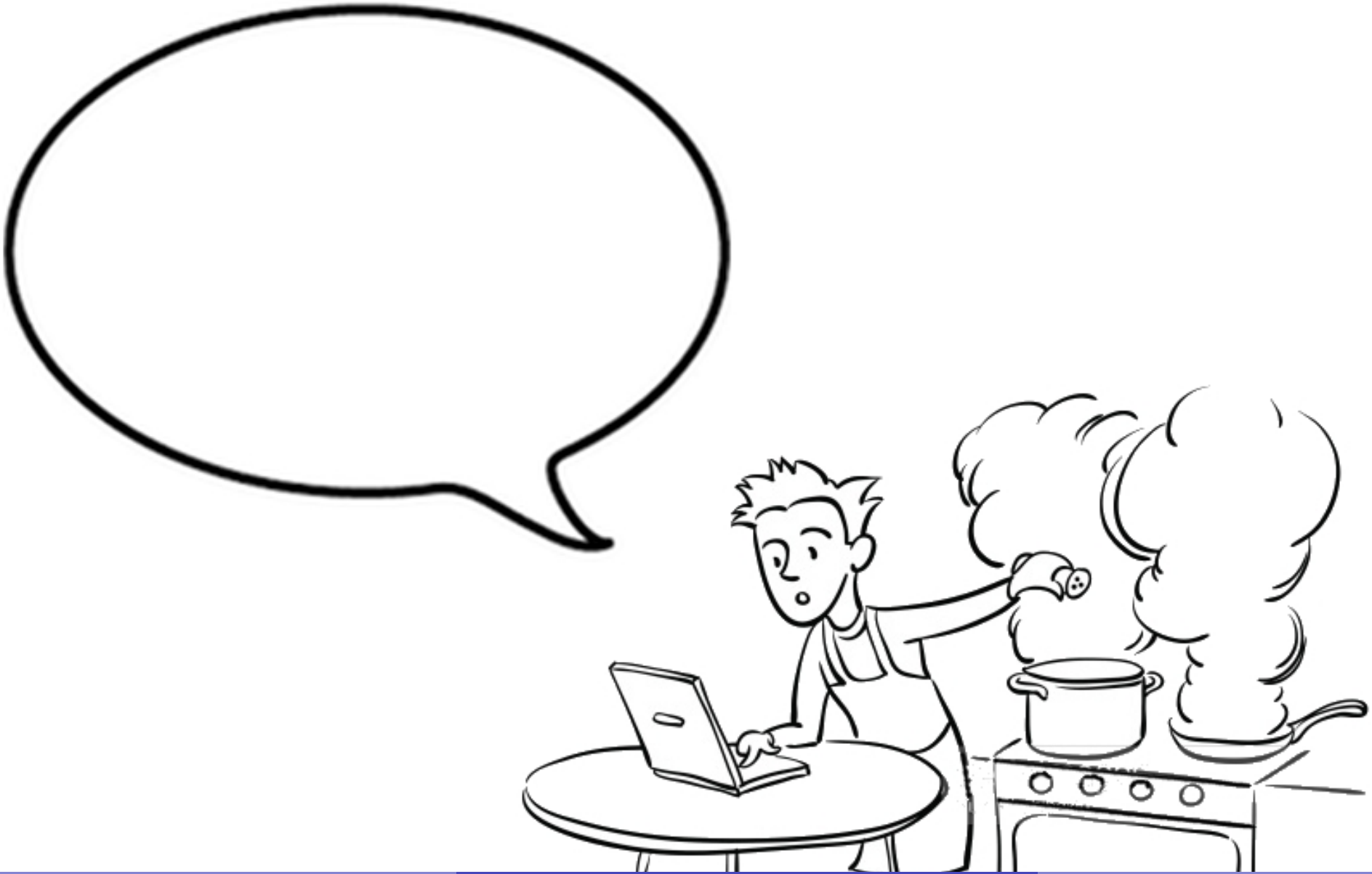


Ingredients to get Constrained Simulations



Ingredients to get Constrained Simulations

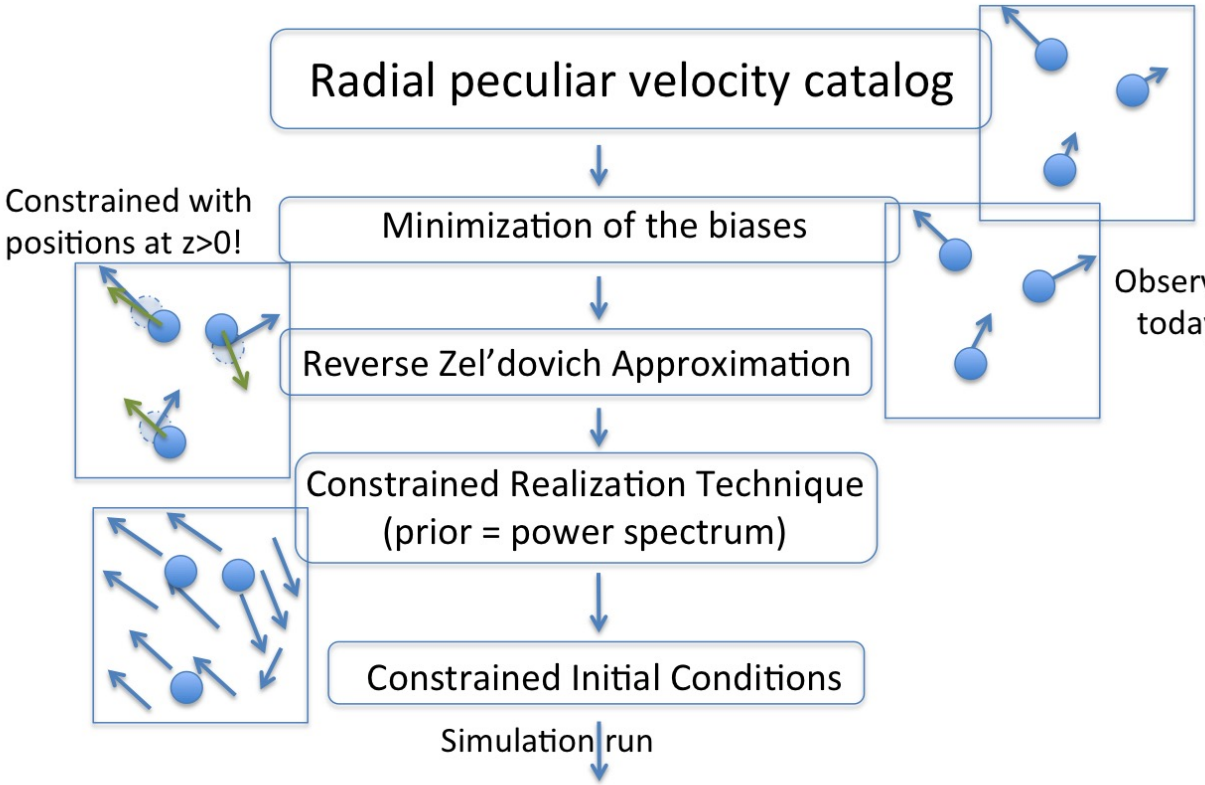
- observations:
radial peculiar velocities

Ingredients to get Constrained Simulations

- observations:
radial peculiar velocities

- simulations:
backward method

Summary of the method



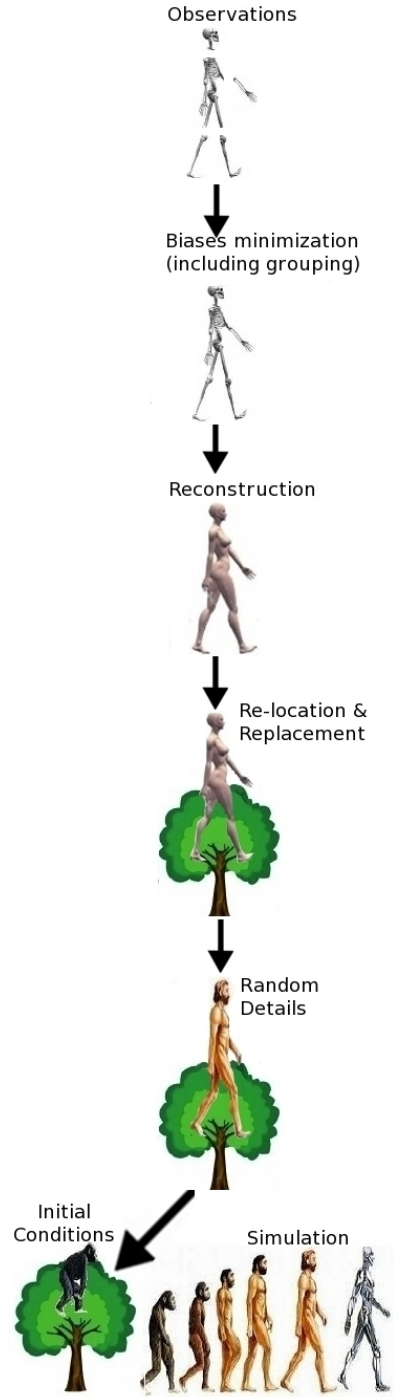
Tully et al. 2013

Tully 2015
Sorce 2015

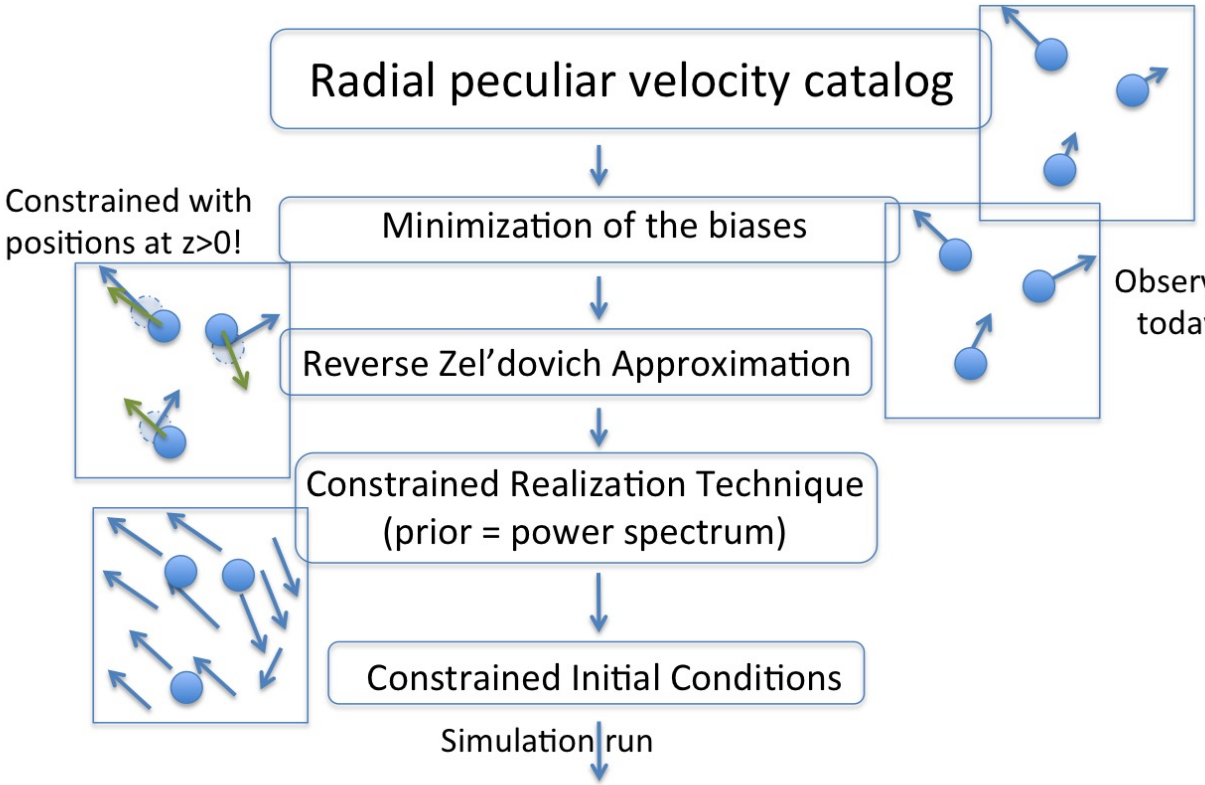
Zaroubi et al. 1995

Doumler et al. 2013
Sorce et al. 2014

Hoffman & Ribak 1991



Summary of the method



Tully et al. 2013

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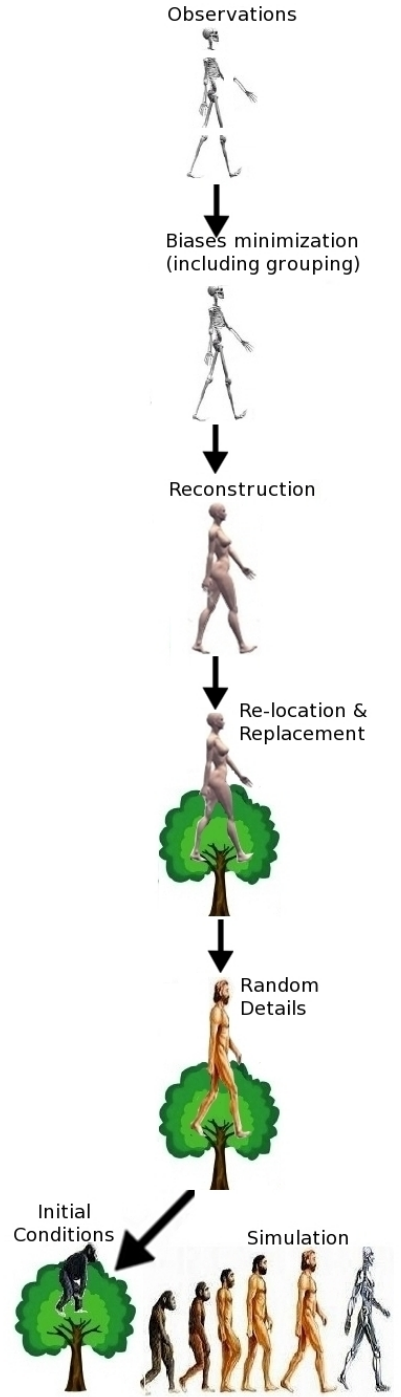
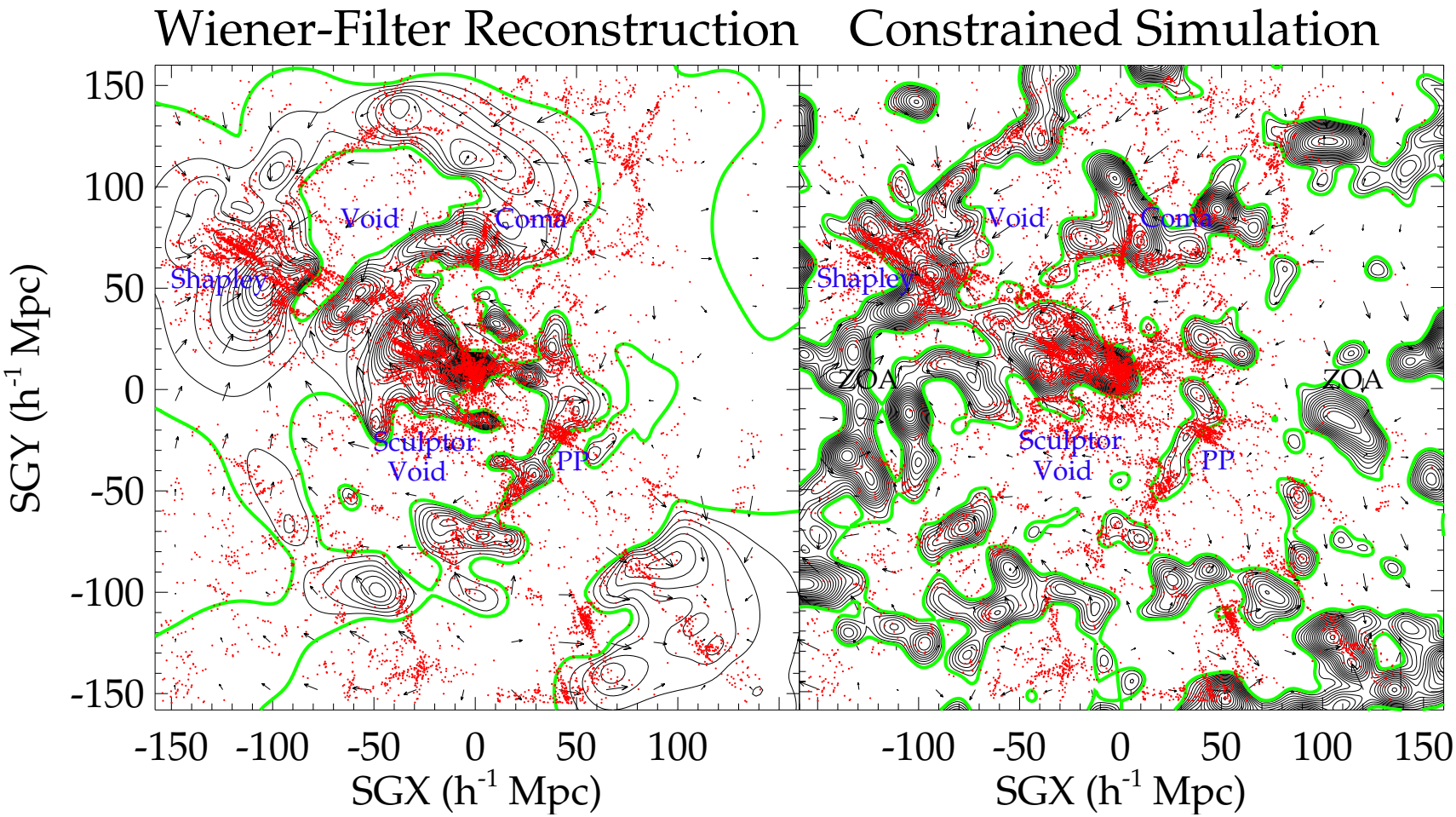


The local LSS: CLUES with CF2

Sorce et al. 2016

At z = 0



Observations for comparisons: redshift catalog •

Observations to constrain = Peculiar Velocities: CF2 catalog

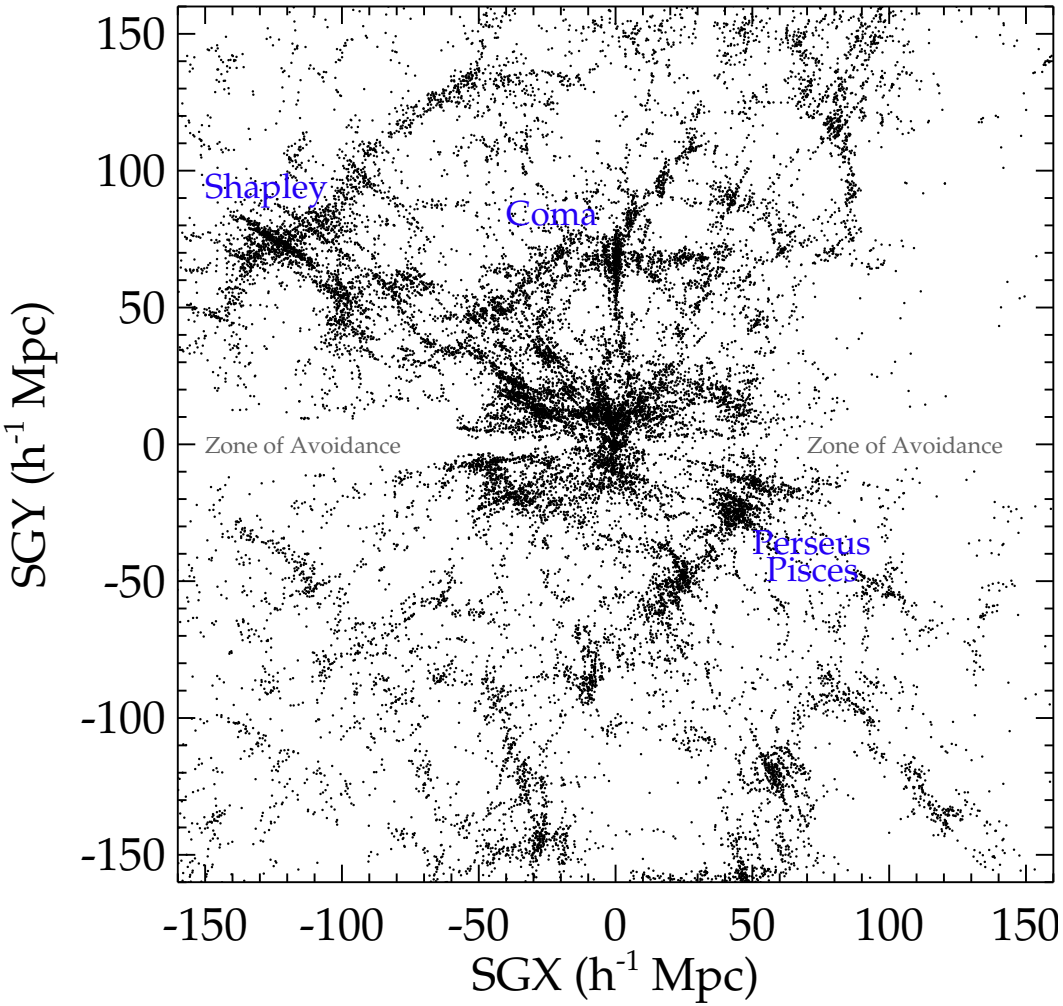
Reconstruction: L=500 h^{-1} Mpc, n=256^3, linear field (contours, arrows)

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

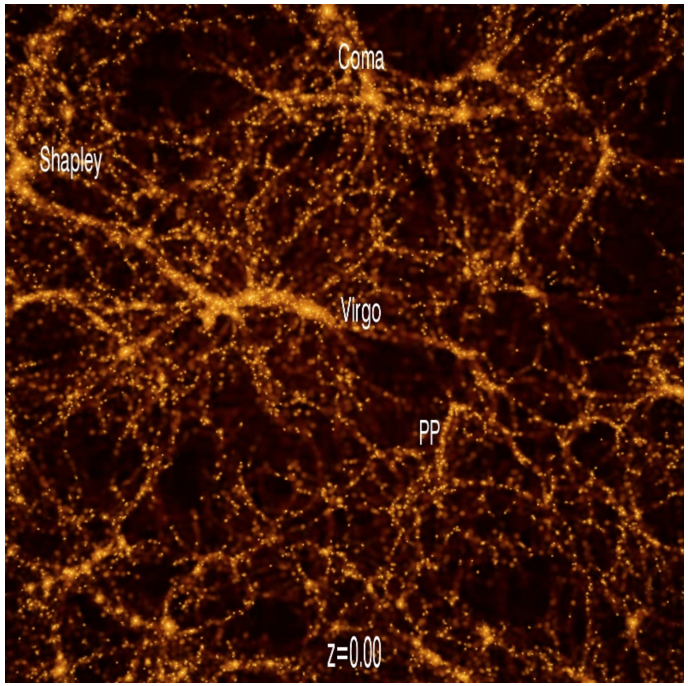
How did the Local Universe form?

Sorce et al. 2016

Observed



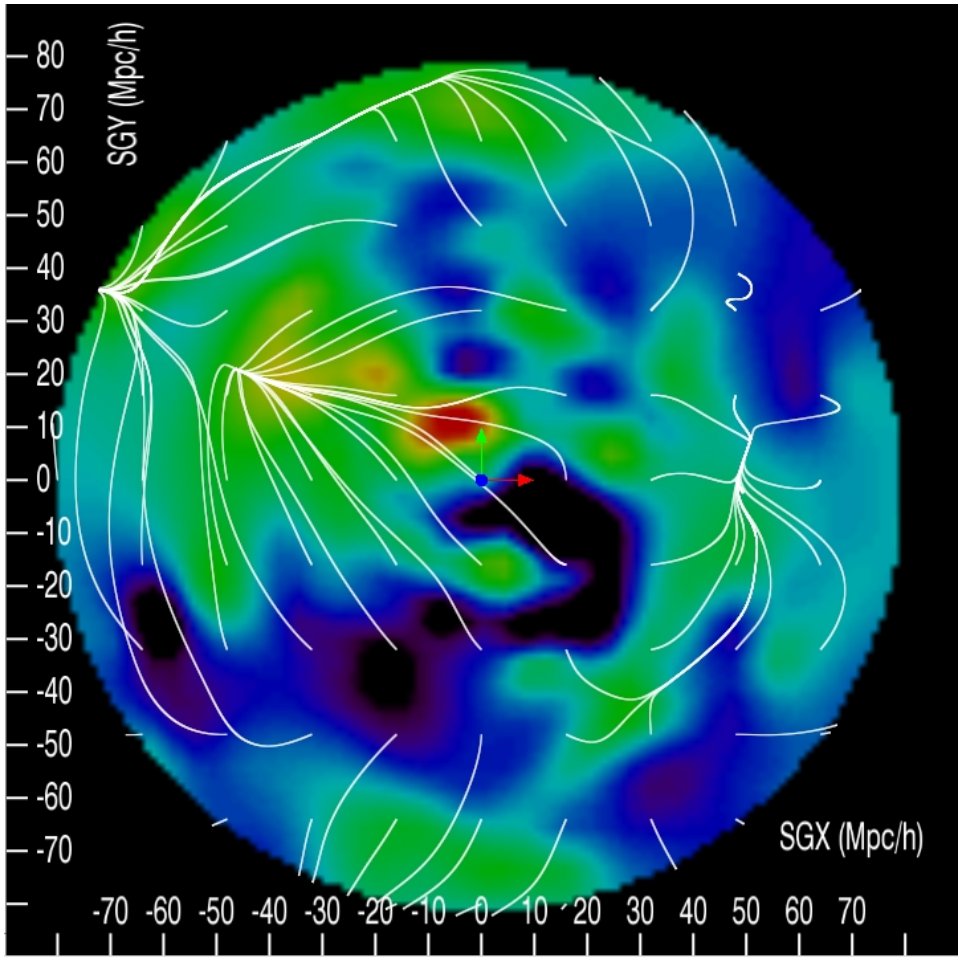
Simulated



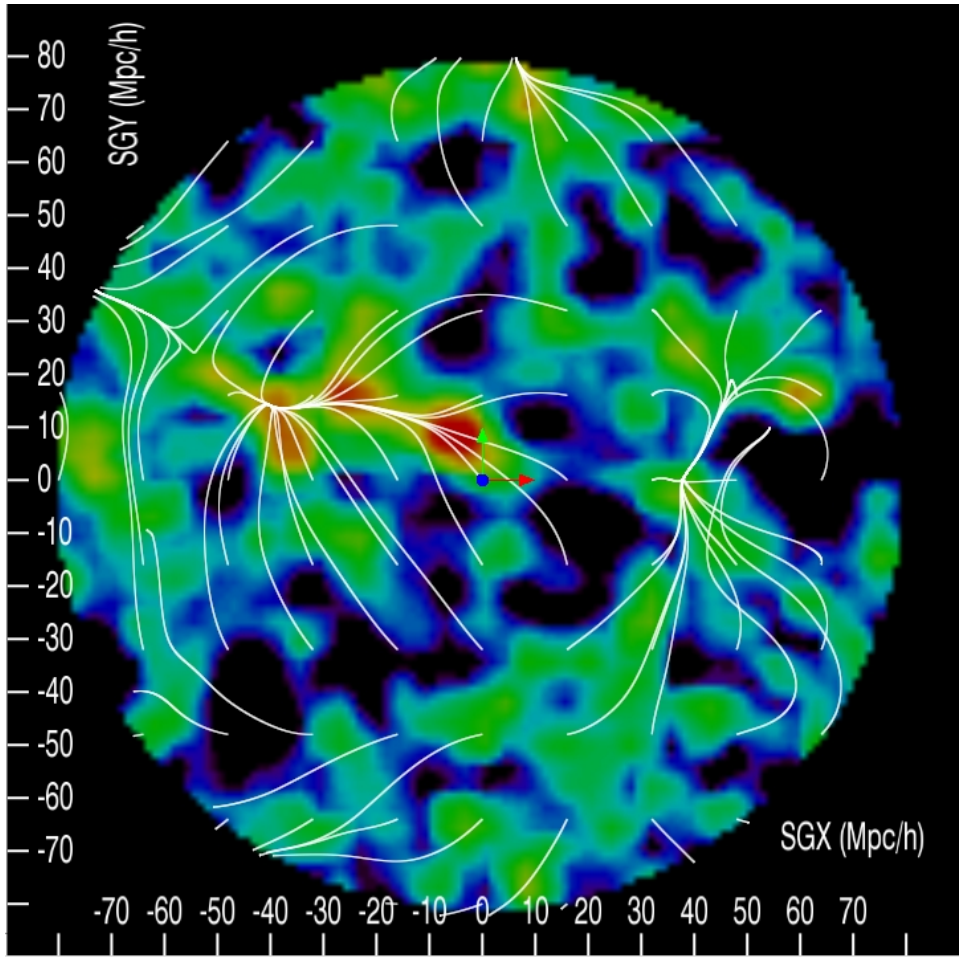
The Laniakea Supercluster, the zero velocity surface

Sorce et al. 2016

Reconstruction

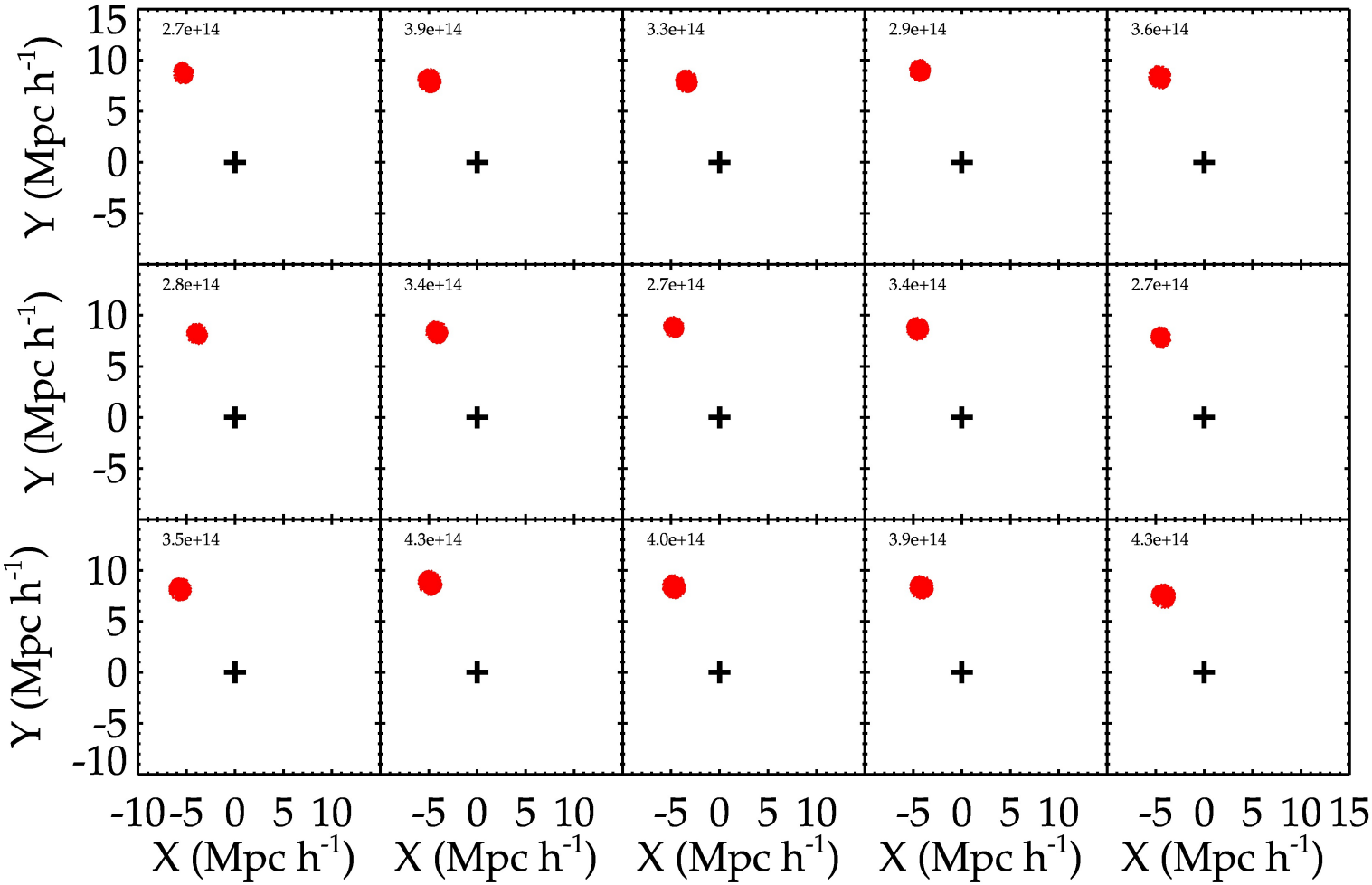


One Constrained Simulation



How did the Virgo cluster form?

Sorce et al. 2016b

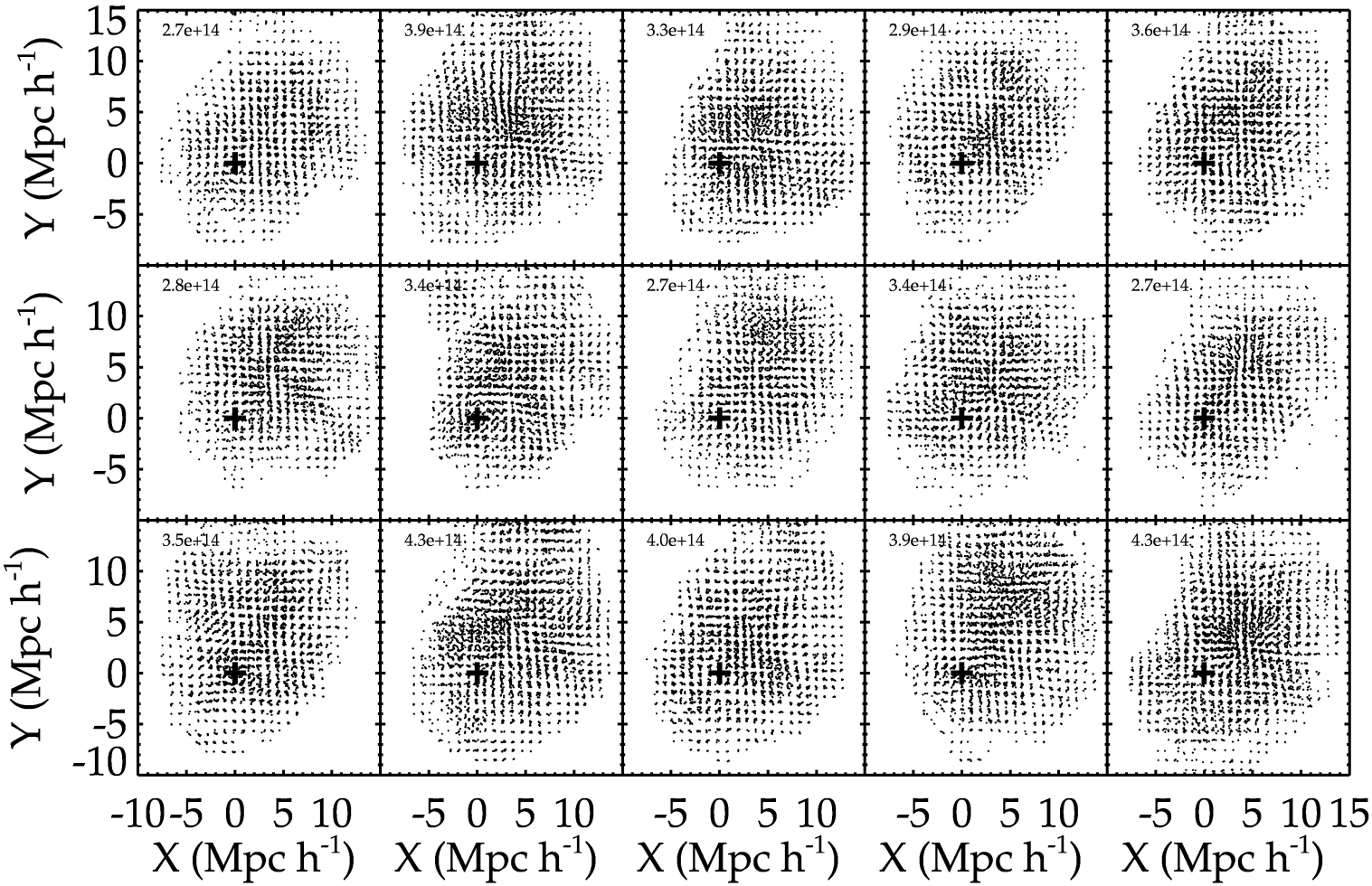


Dark Matter Haloes - Virgo Candidates: Particles at z= 0

- 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?

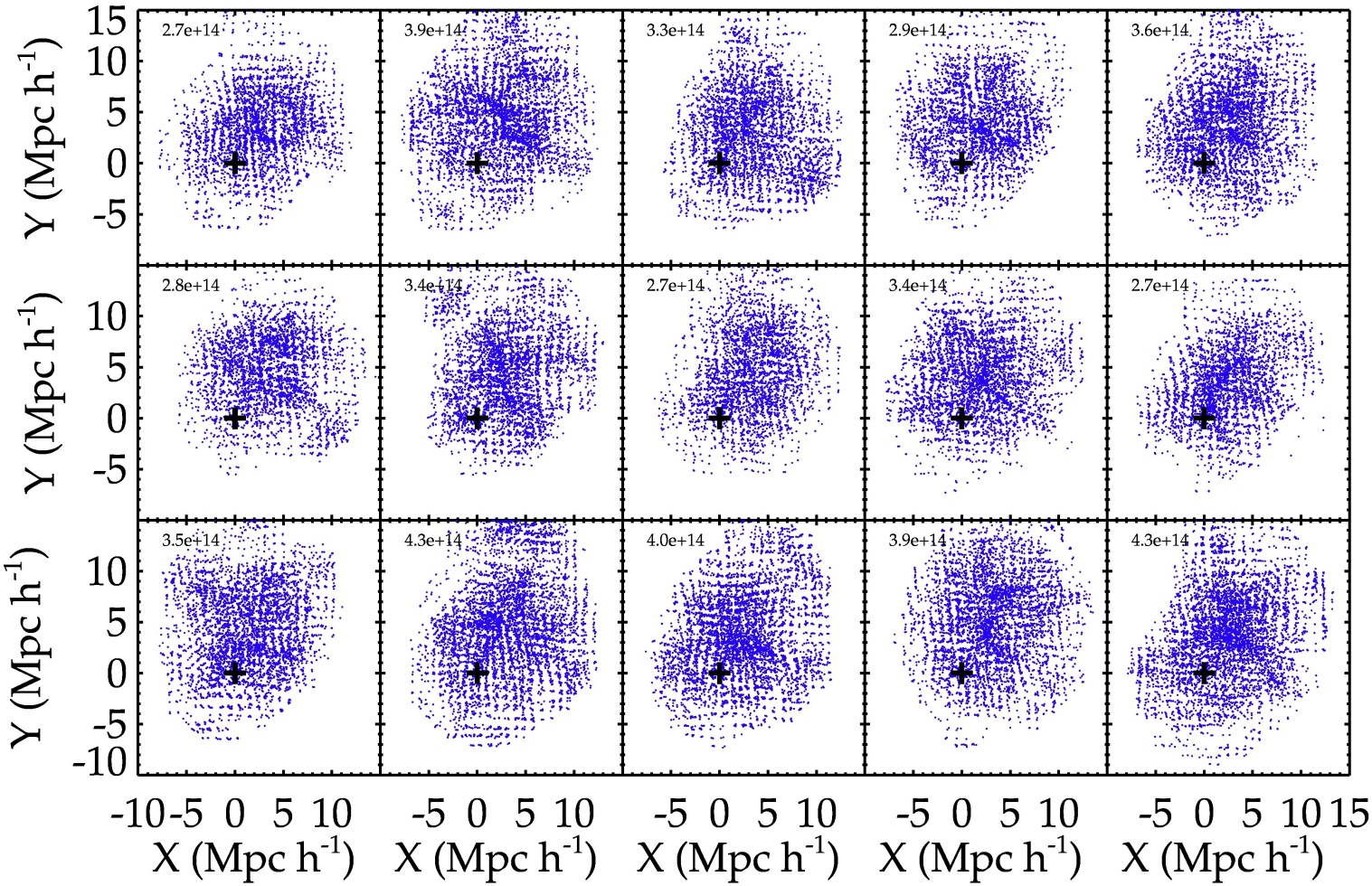
Sorce et al. 2016b



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

How did the Virgo cluster form?

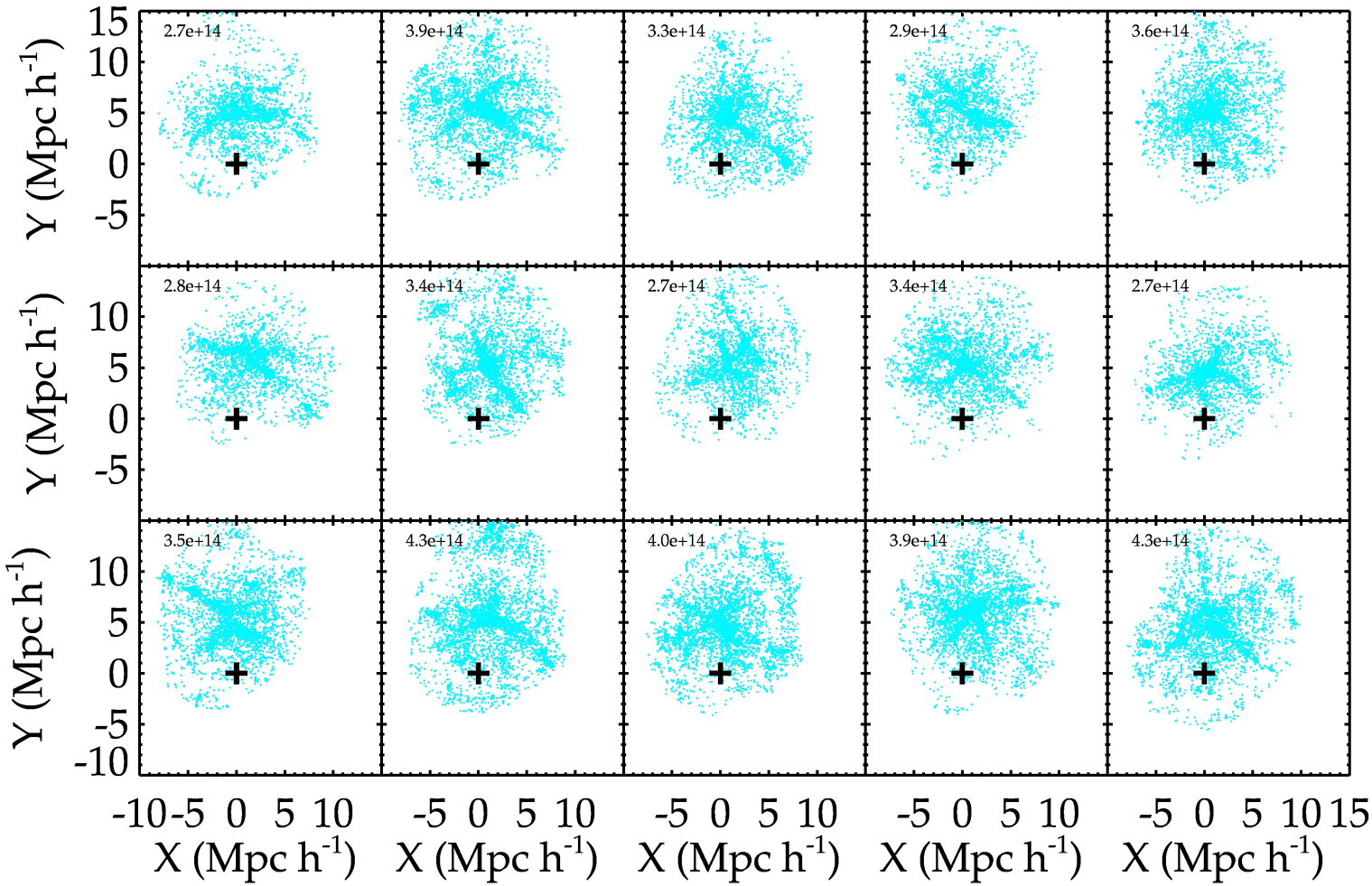
Sorce et al. 2016b



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

How did the Virgo cluster form?

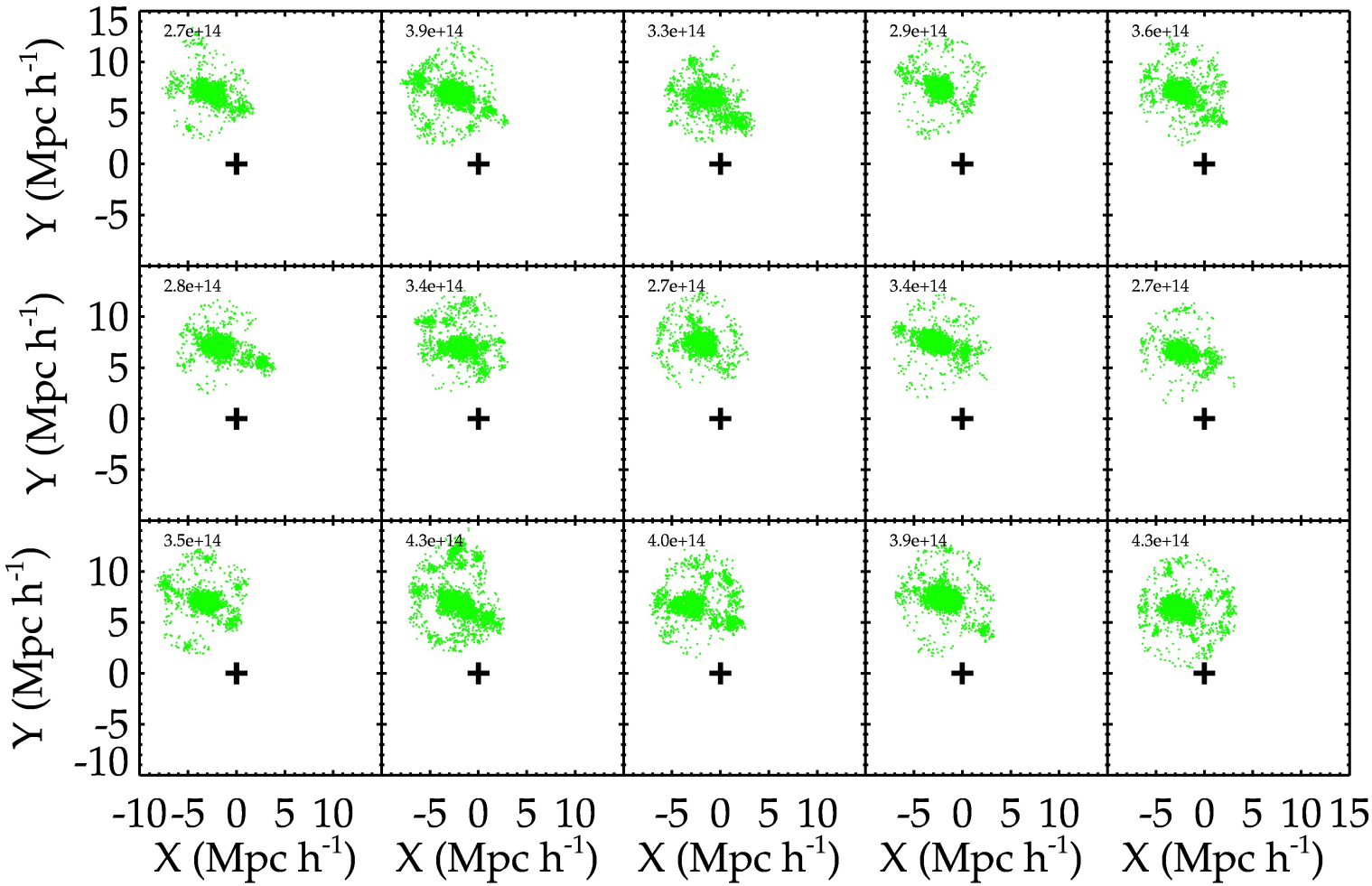
Sorce et al. 2016b



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

How did the Virgo cluster form?

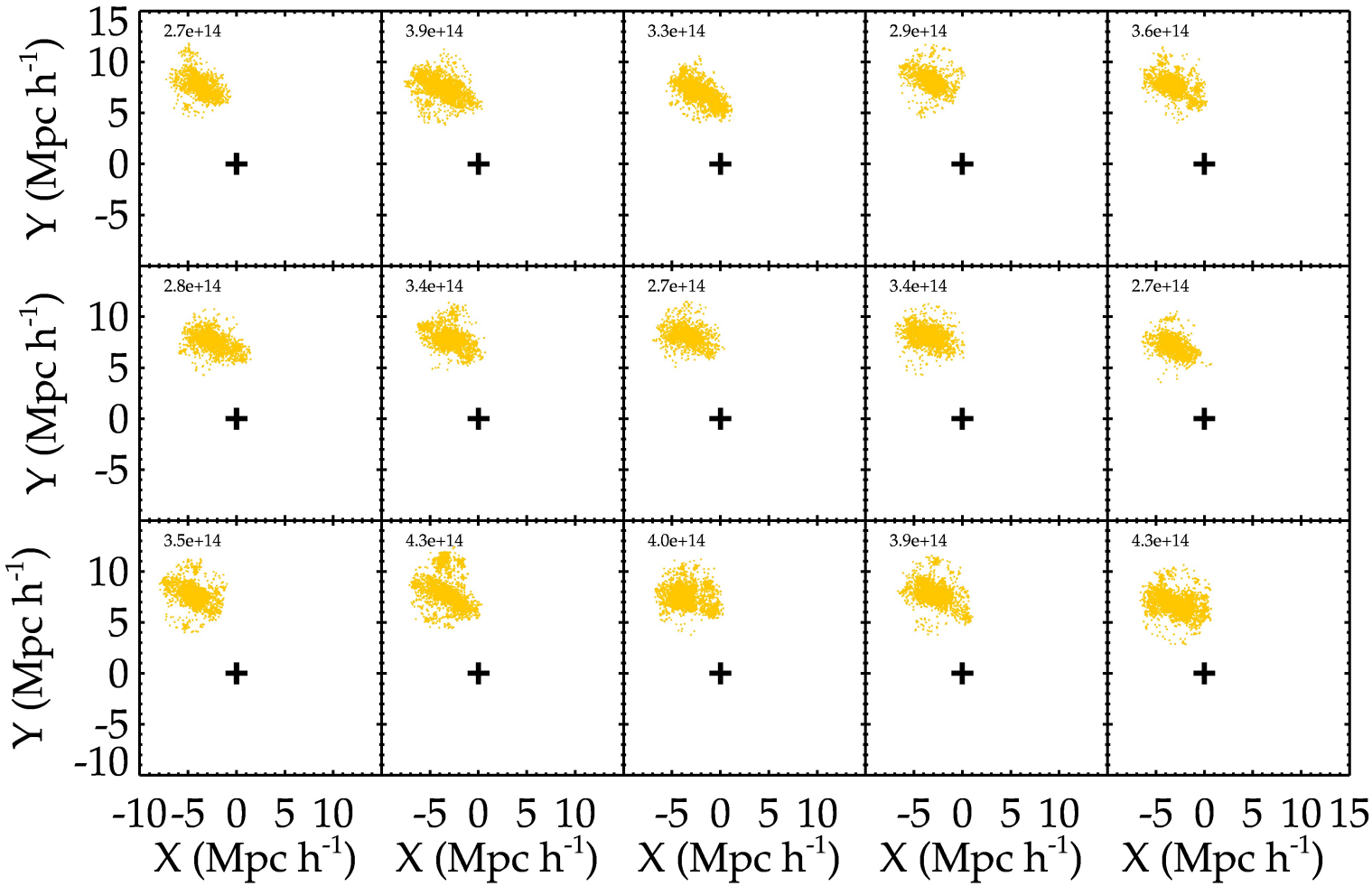
Sorce et al. 2016b



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

How did the Virgo cluster form?

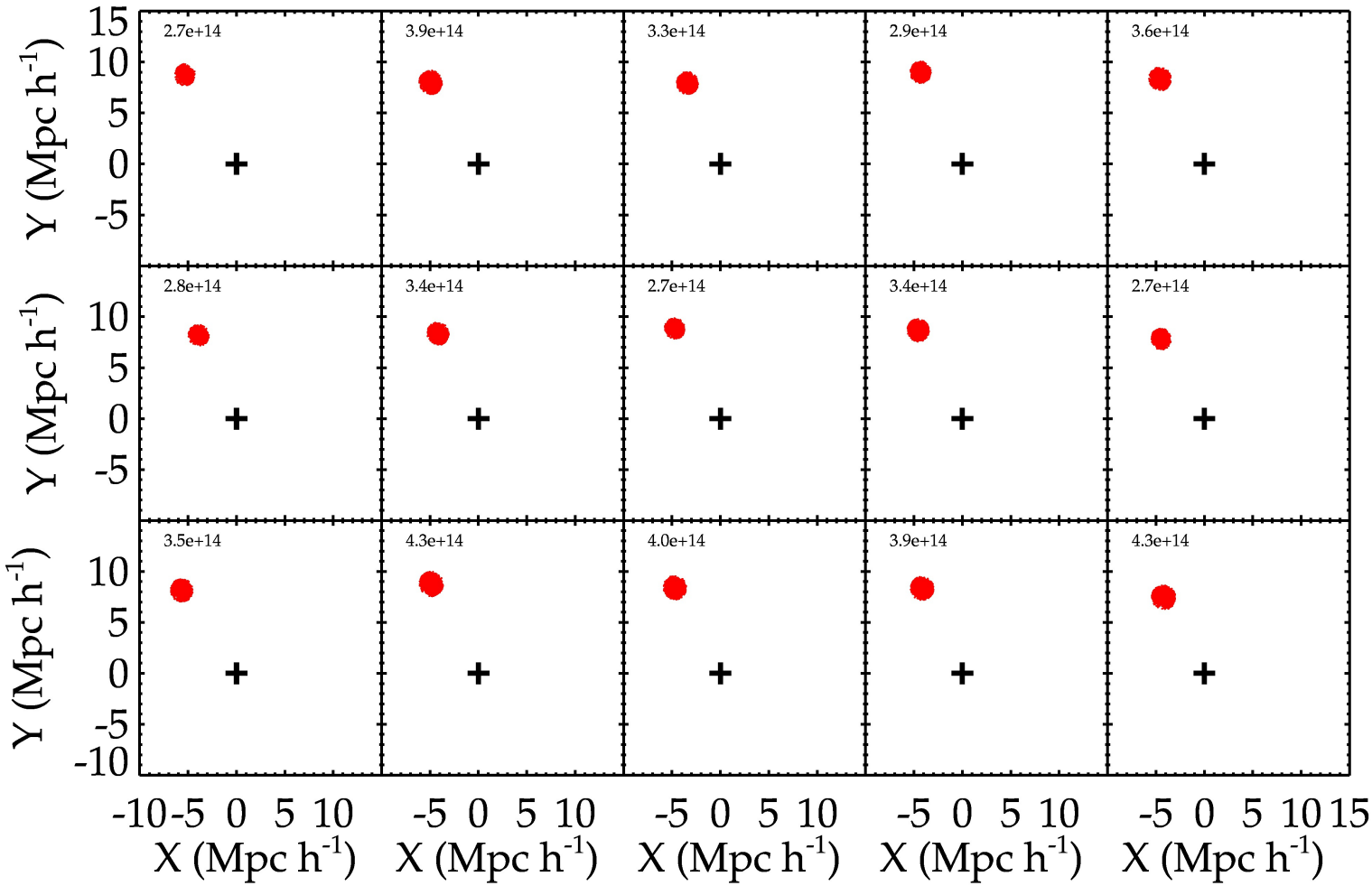
Sorce et al. 2016b



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

How did the Virgo cluster form?

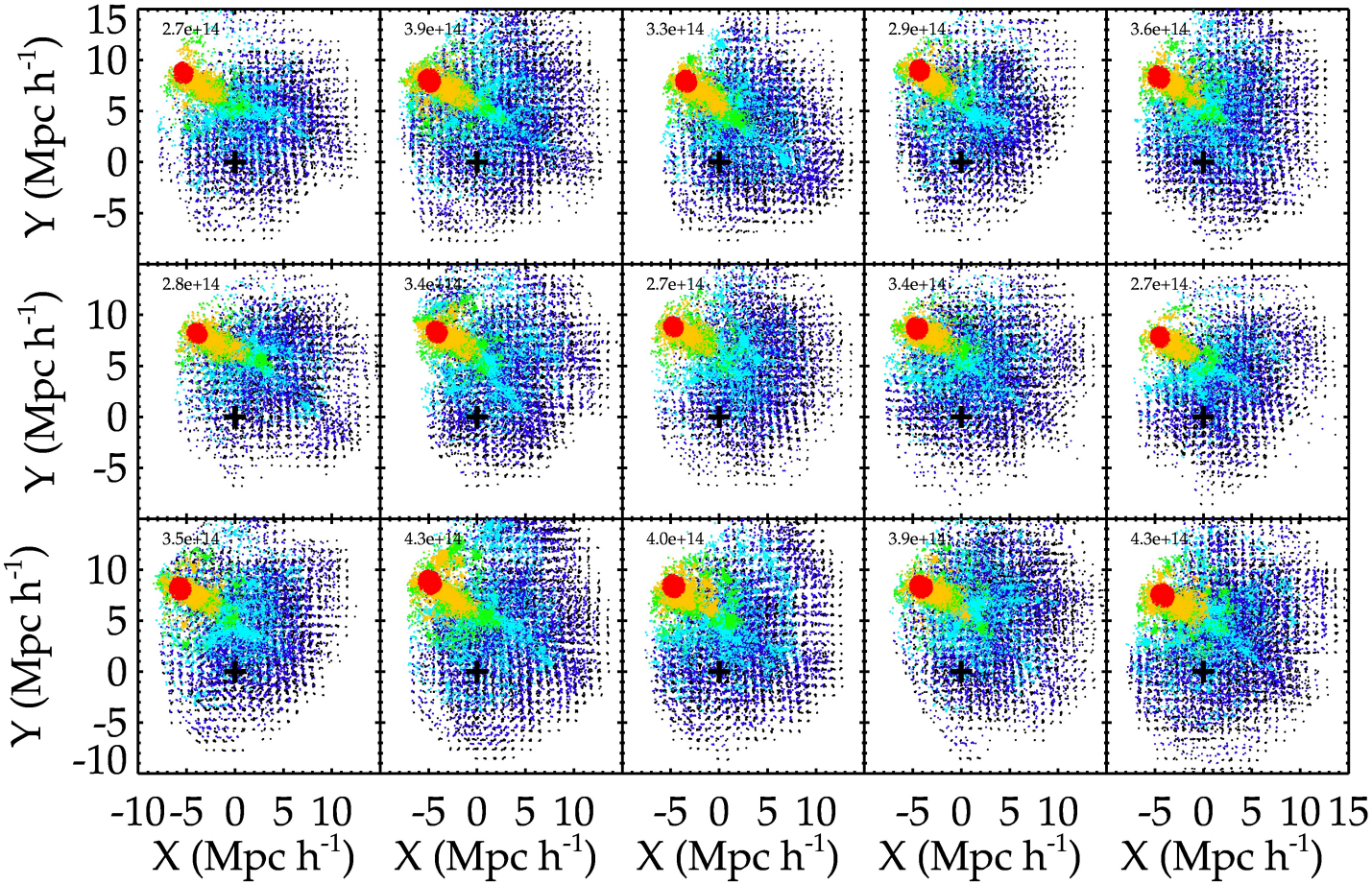
Sorce et al. 2016b



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

How did the Virgo cluster form?

Sorce et al. 2016b



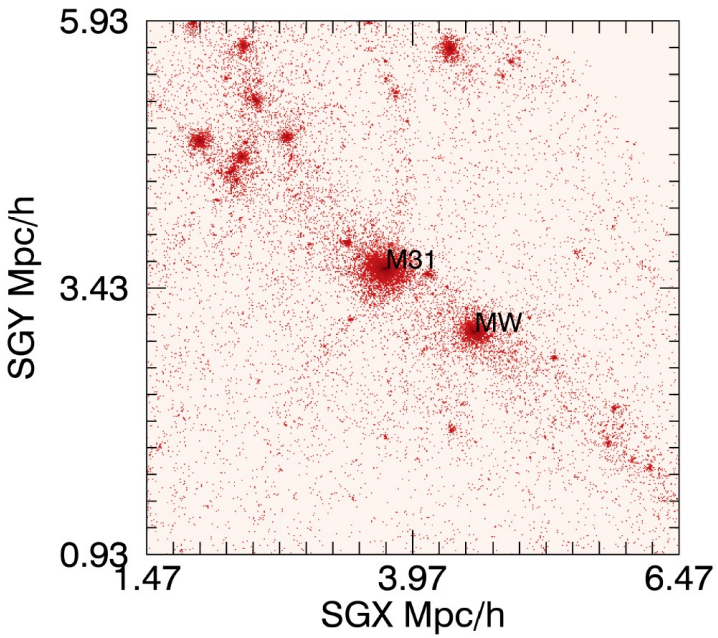
Dark Matter Haloes - Virgo Candidates:

- Similar formation / evolution

One color per redshift:

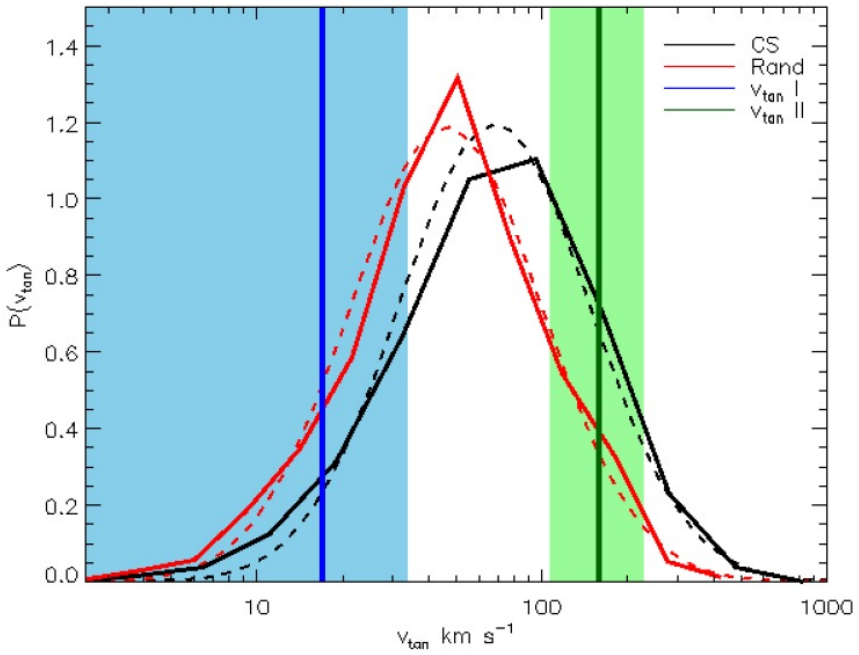
10, 5, 2, 0.5, 0.25, 0

The Local Group



The Local Group factory

Carlesi, Sorce et al. 2016



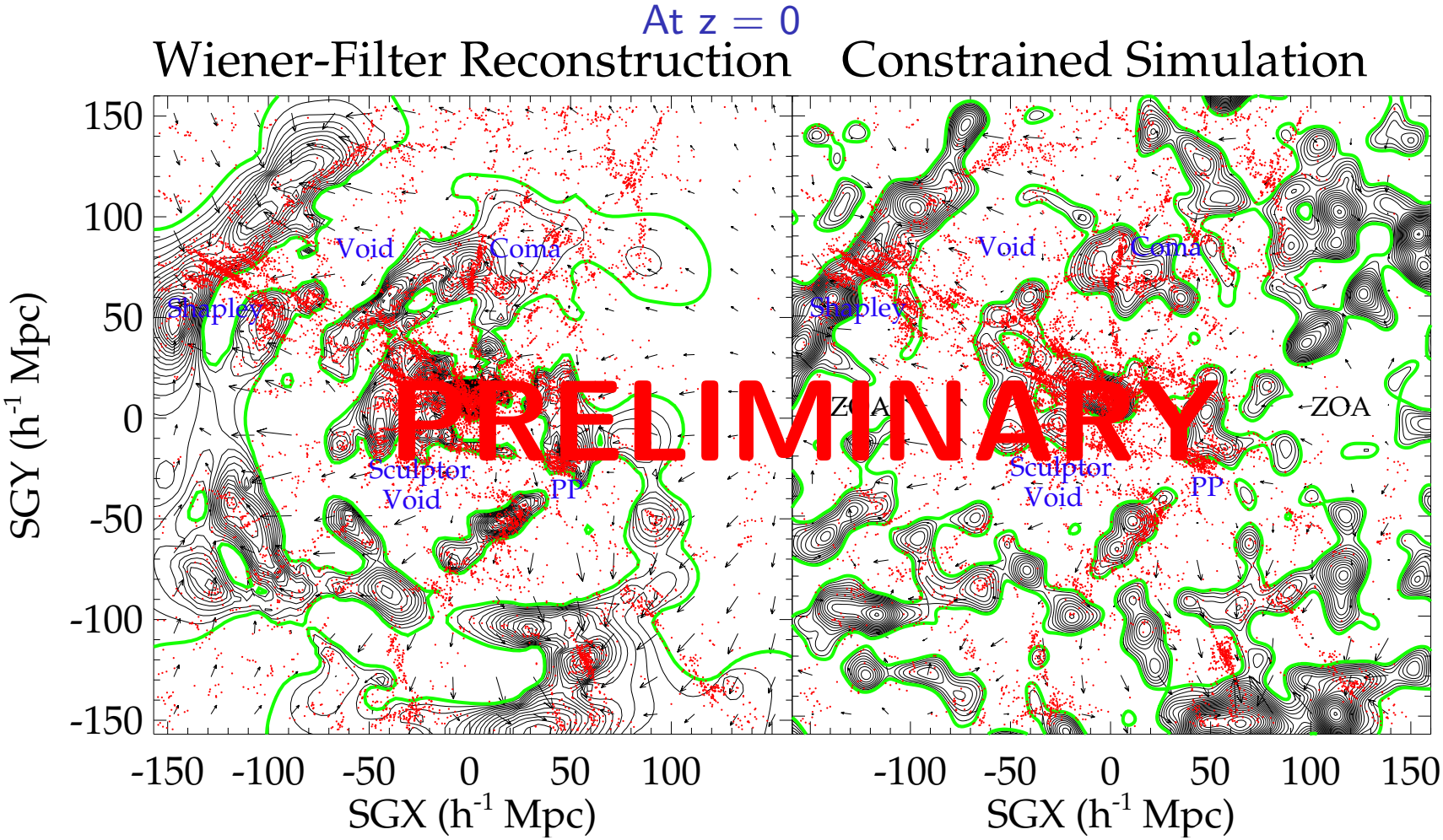
Higher tangential velocity preferred

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

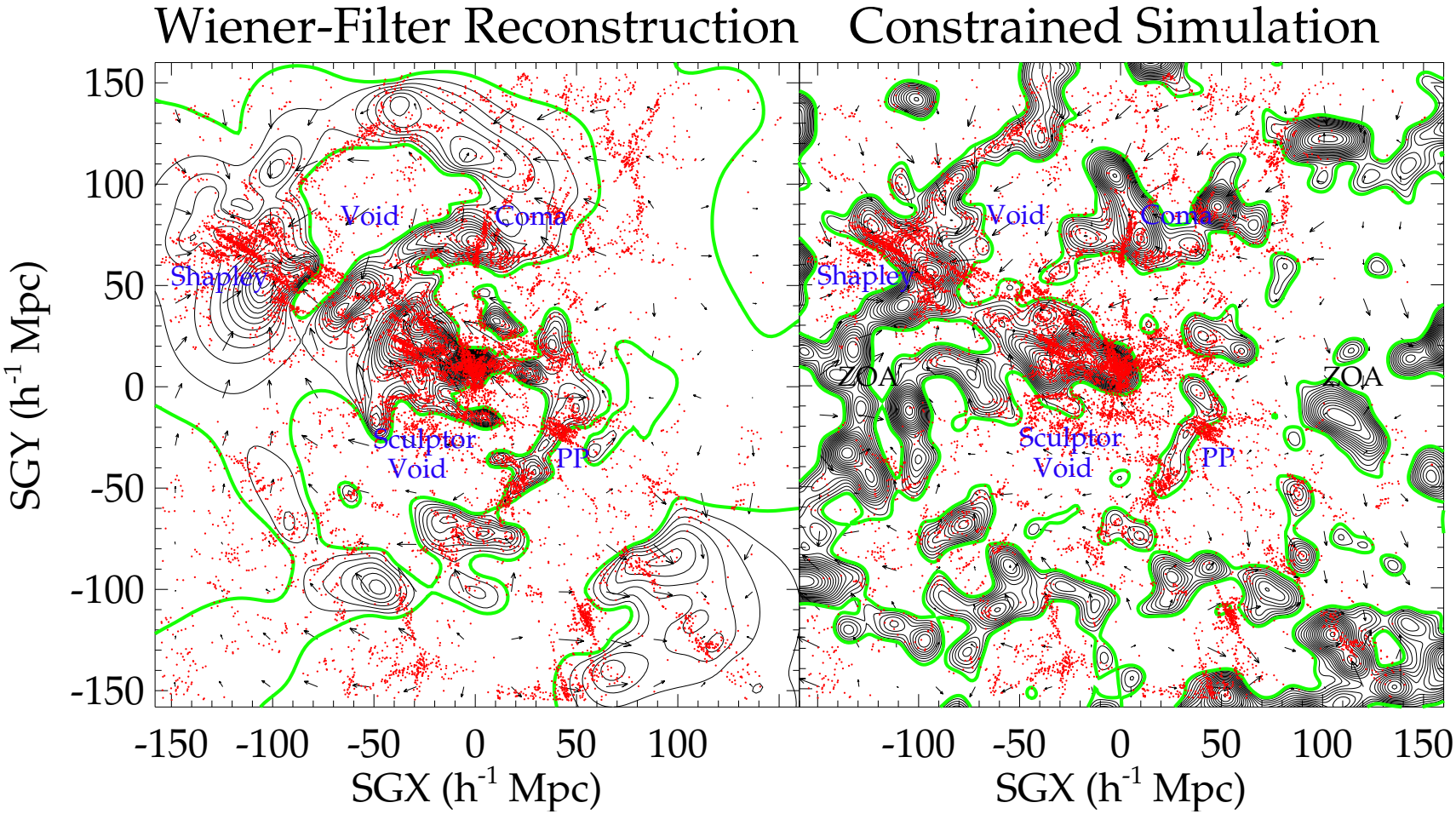
Reconstruction: L=800 h^{-1} Mpc, n=256^3, linear field (contours, arrows)

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

CLUES with CF2

Sorce et al. 2016

At z = 0



Observations for comparisons: redshift catalog •

Observations to constrain = Peculiar Velocities: CF2 catalog

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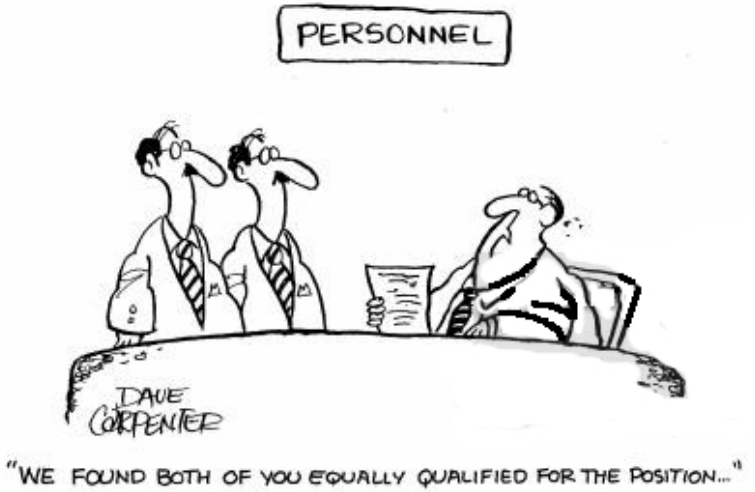
Conclusion & Prospectives



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 ...