Leibniz-Institut für
Astrophysik Potsdam

How did the Virgo cluster form?

Jenny Sorce

IAP, Paris, October 7th 2016

RUM 2016

Observatoire de Strasbourg / Leibniz-Institut für Astrophysik Potsdam

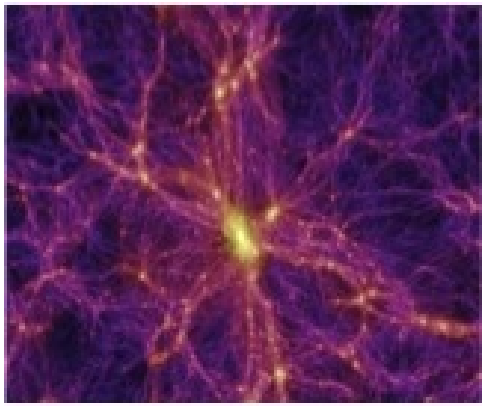
ΛCDM works well on large scales

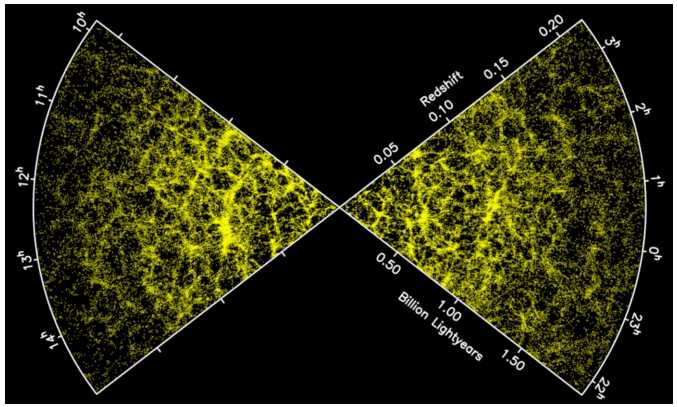
Because the Universe is 'quite' **homogeneous** on **large** scales

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)

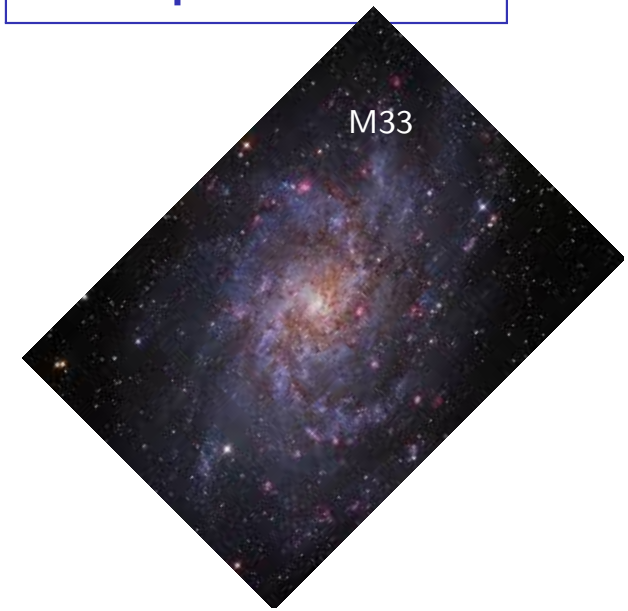
But problem...

... we reside in a given environment,

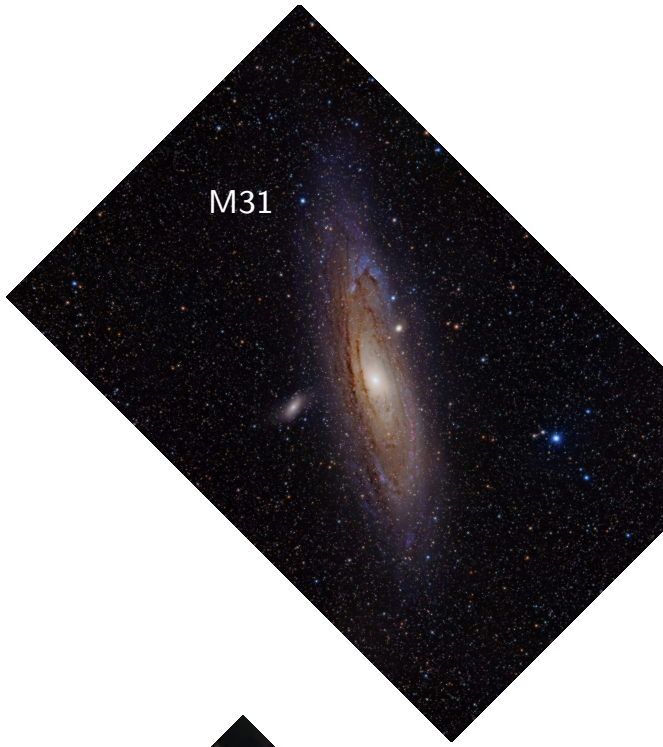
thus our **measurements, conclusions, local and far observations** might be **biased** by its characteristics, e.g.:

- 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)

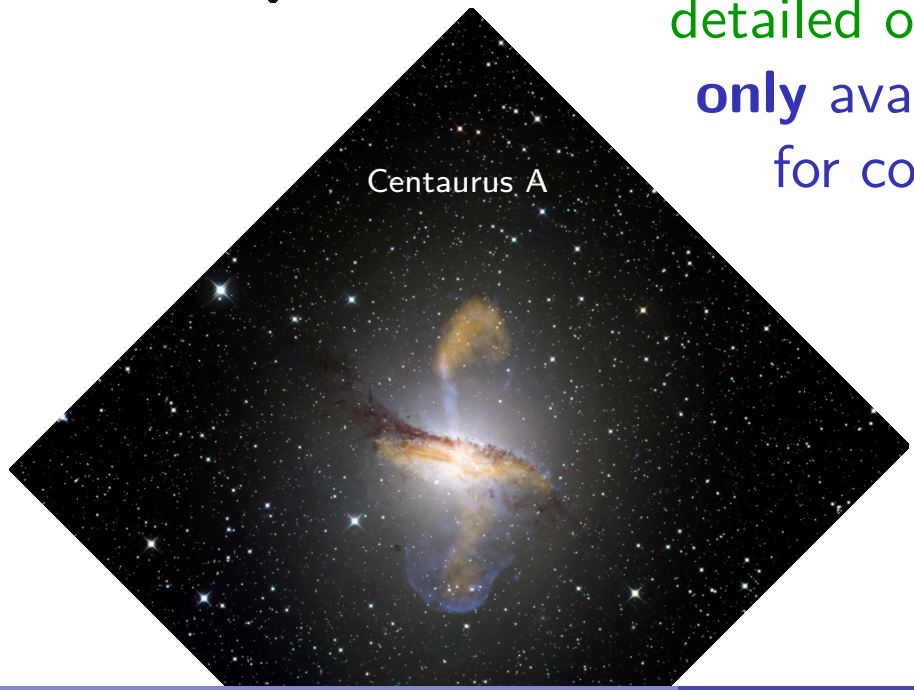
But problem...

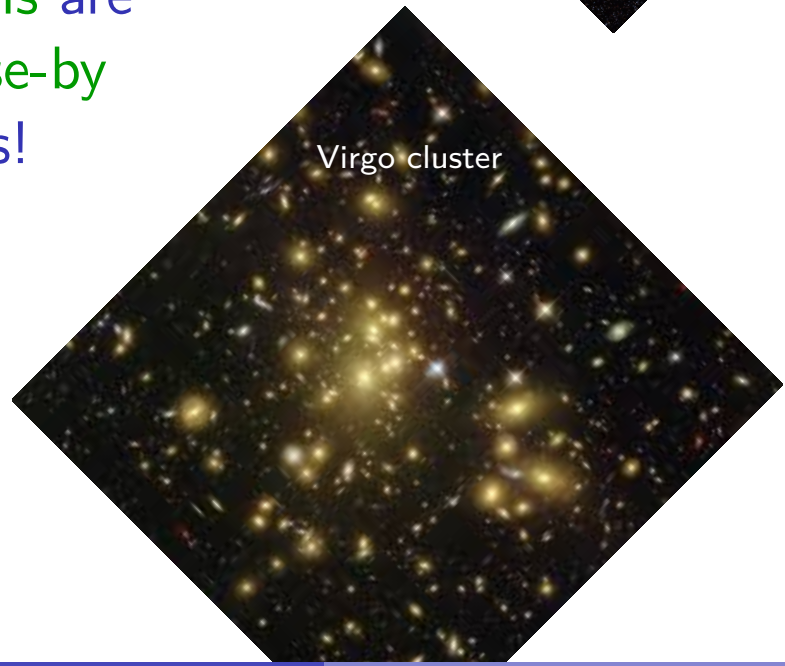


Magellanic Cloud



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

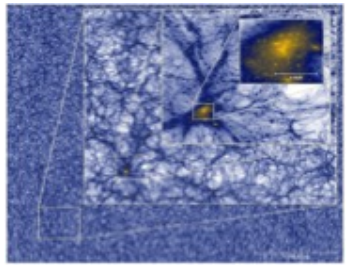




Two solutions

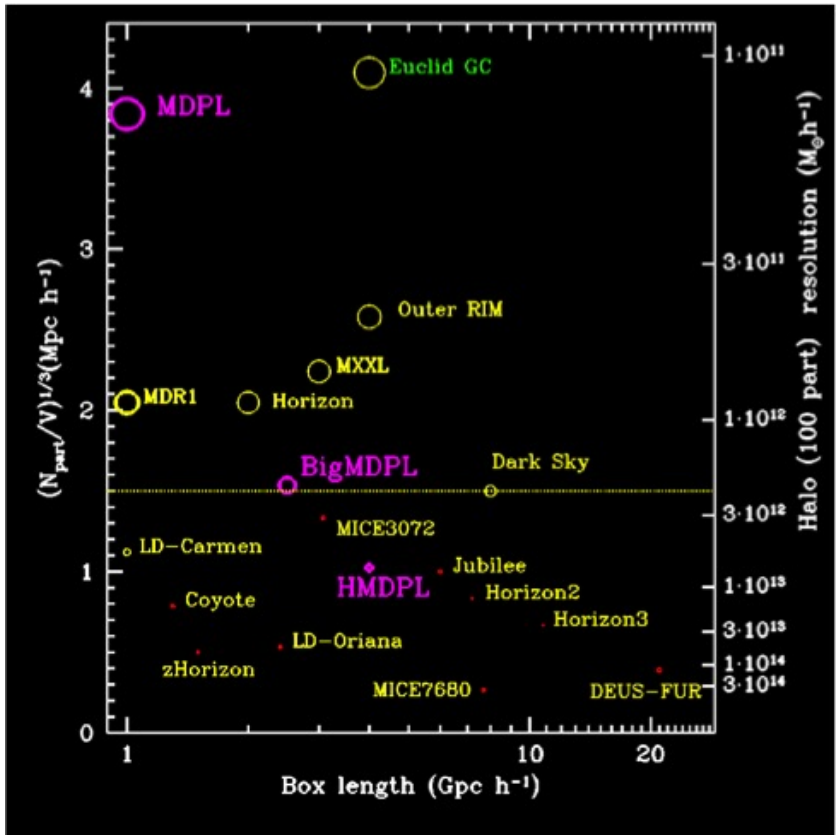
First solution

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

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**

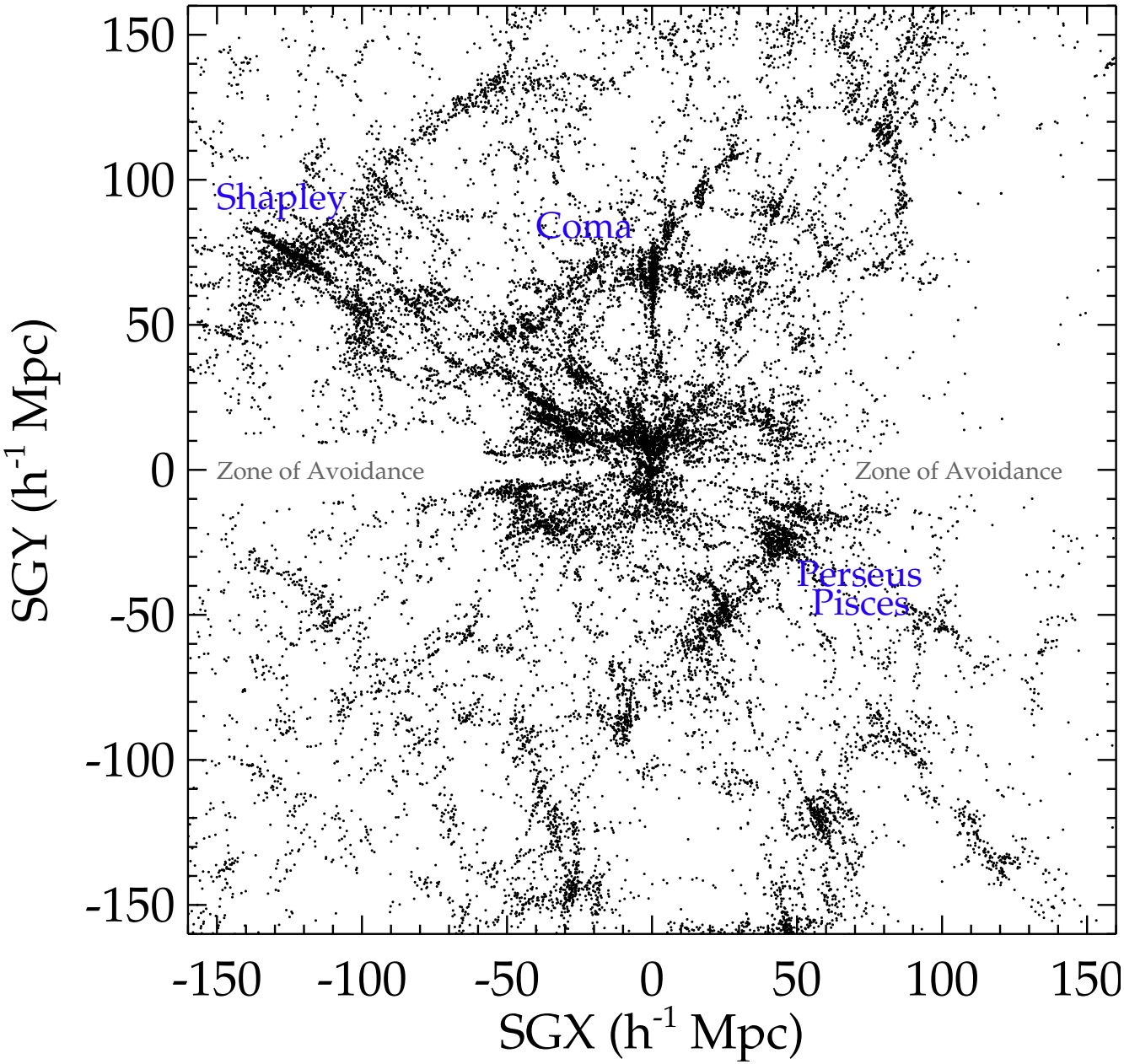
=

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

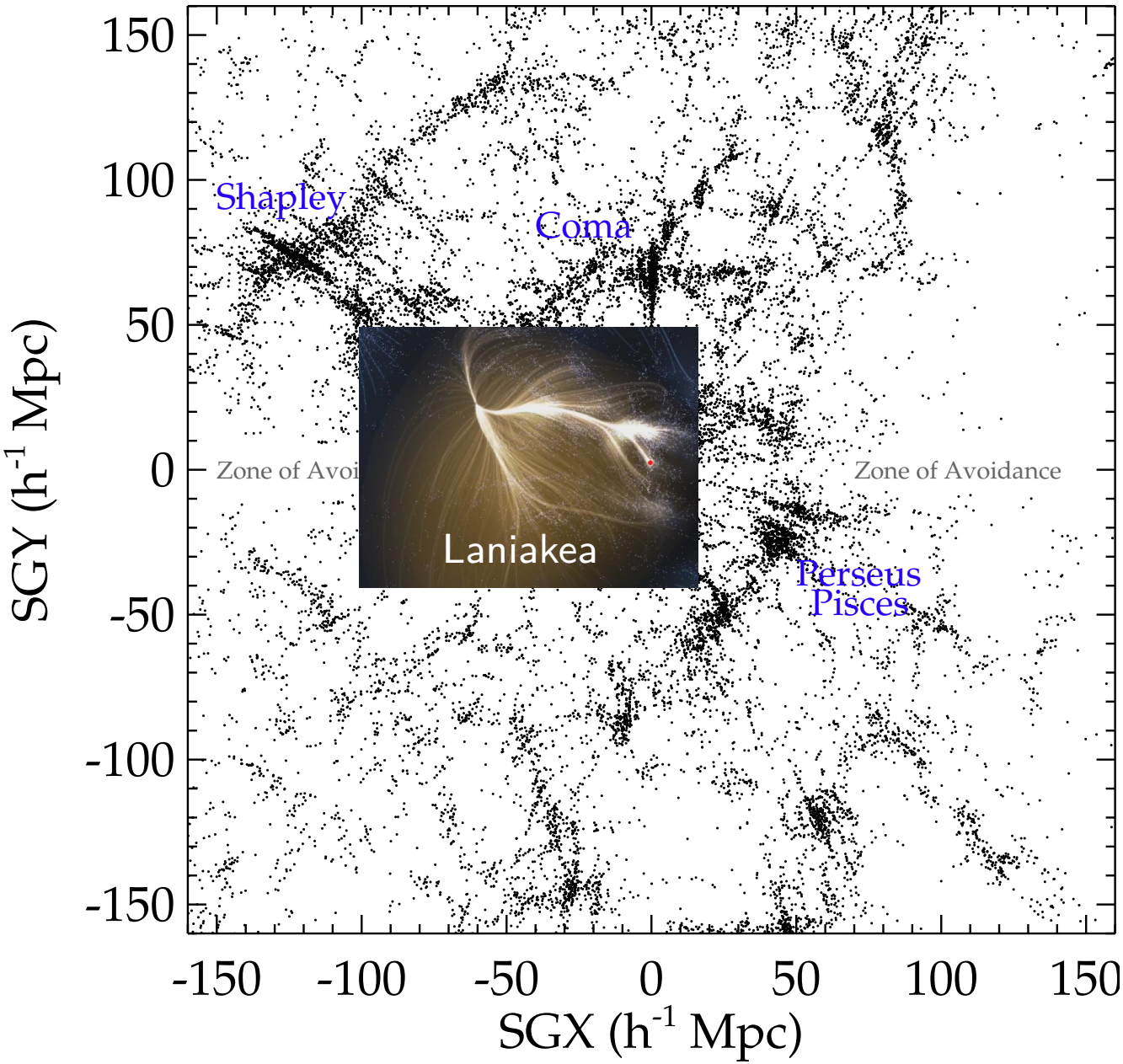
=

Reduction of the **cosmic variance**

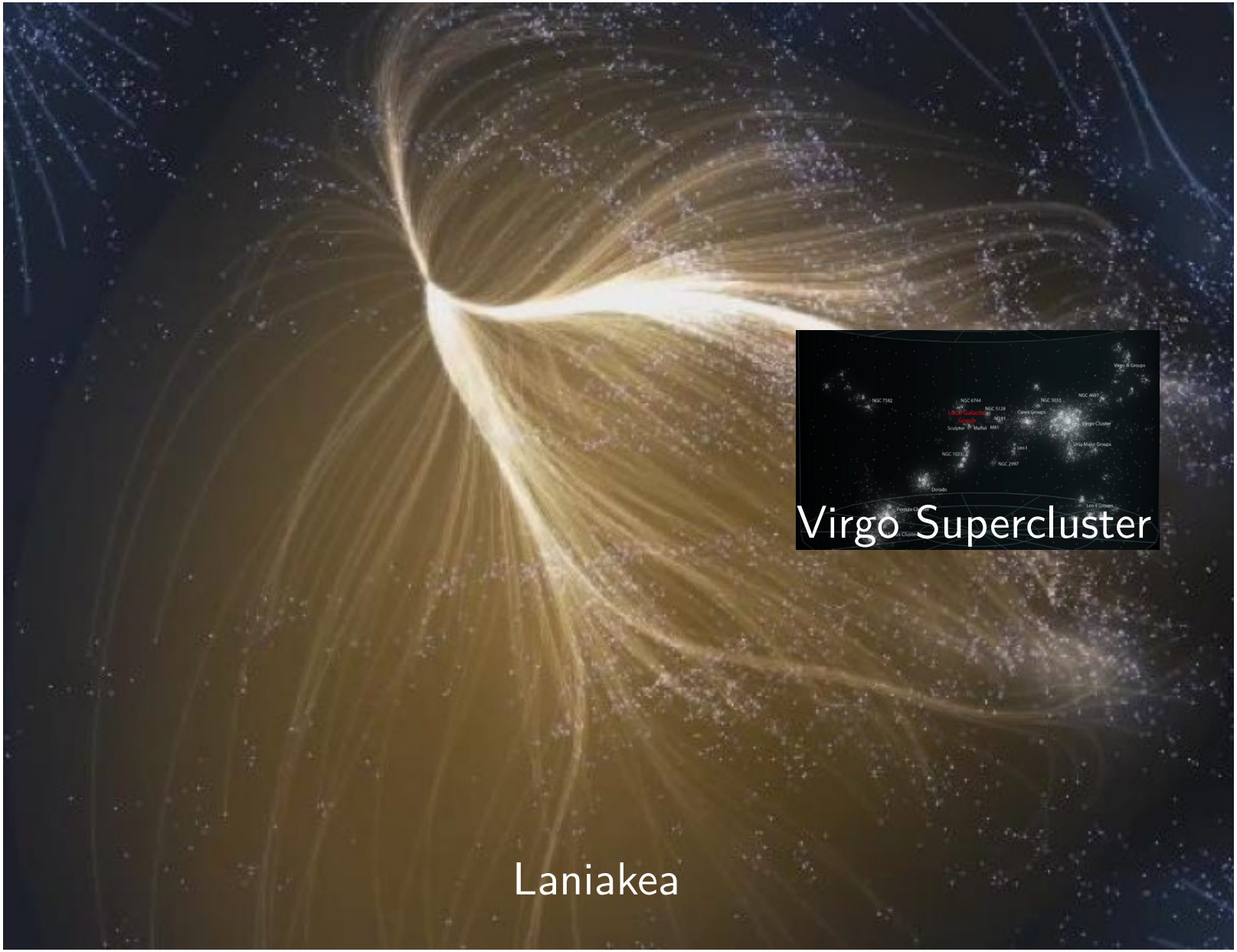
The local Universe



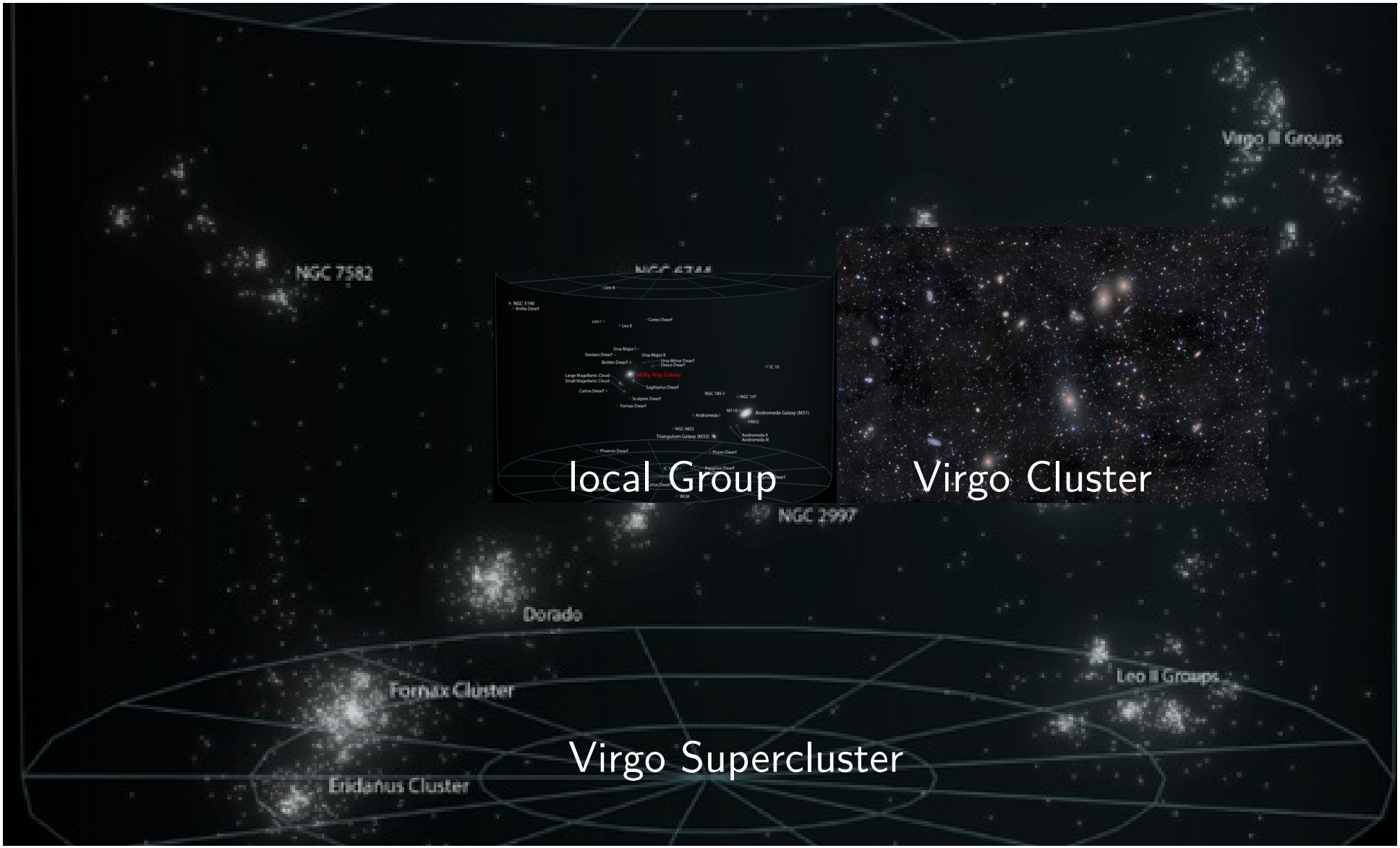
The local Universe



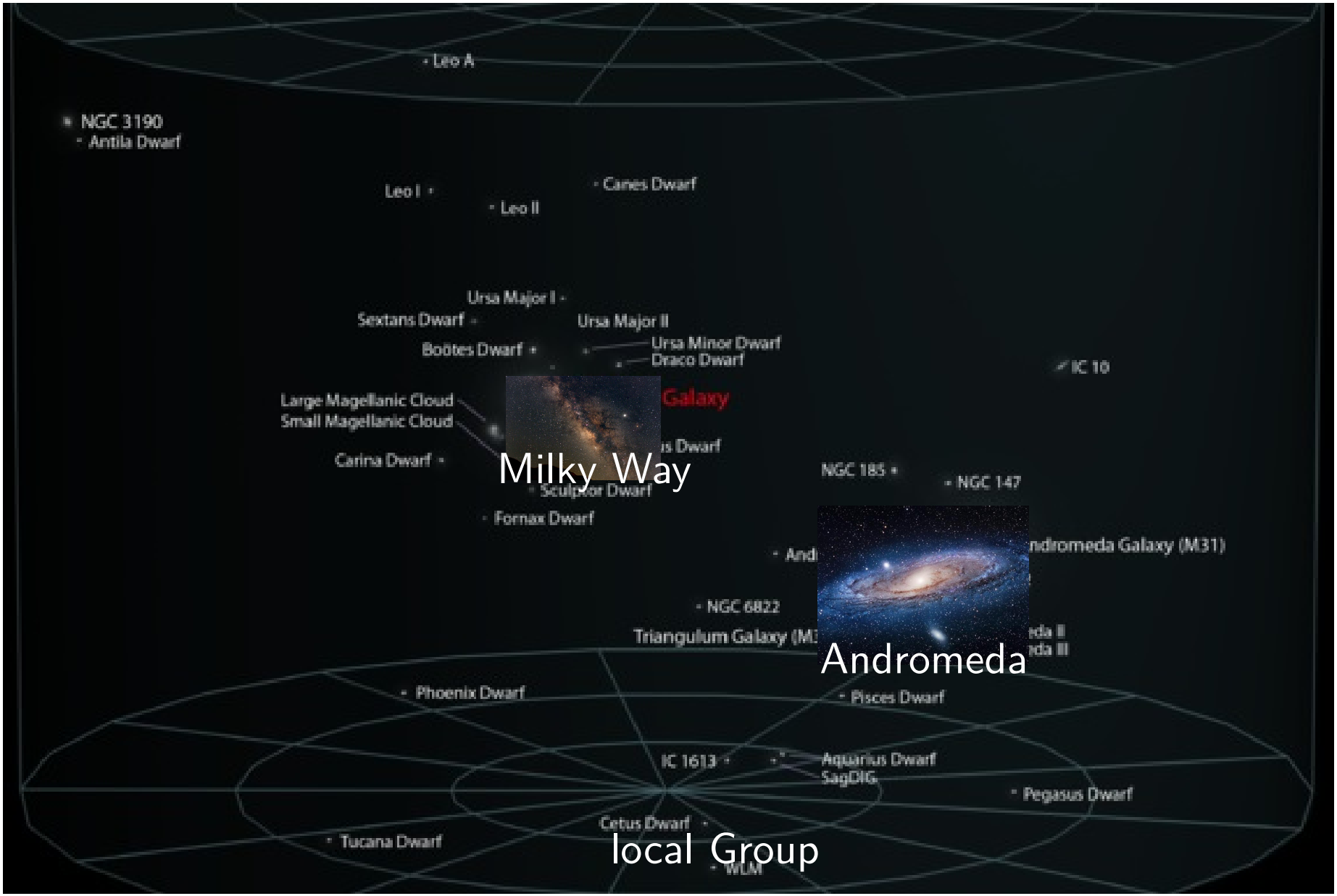
The local Universe



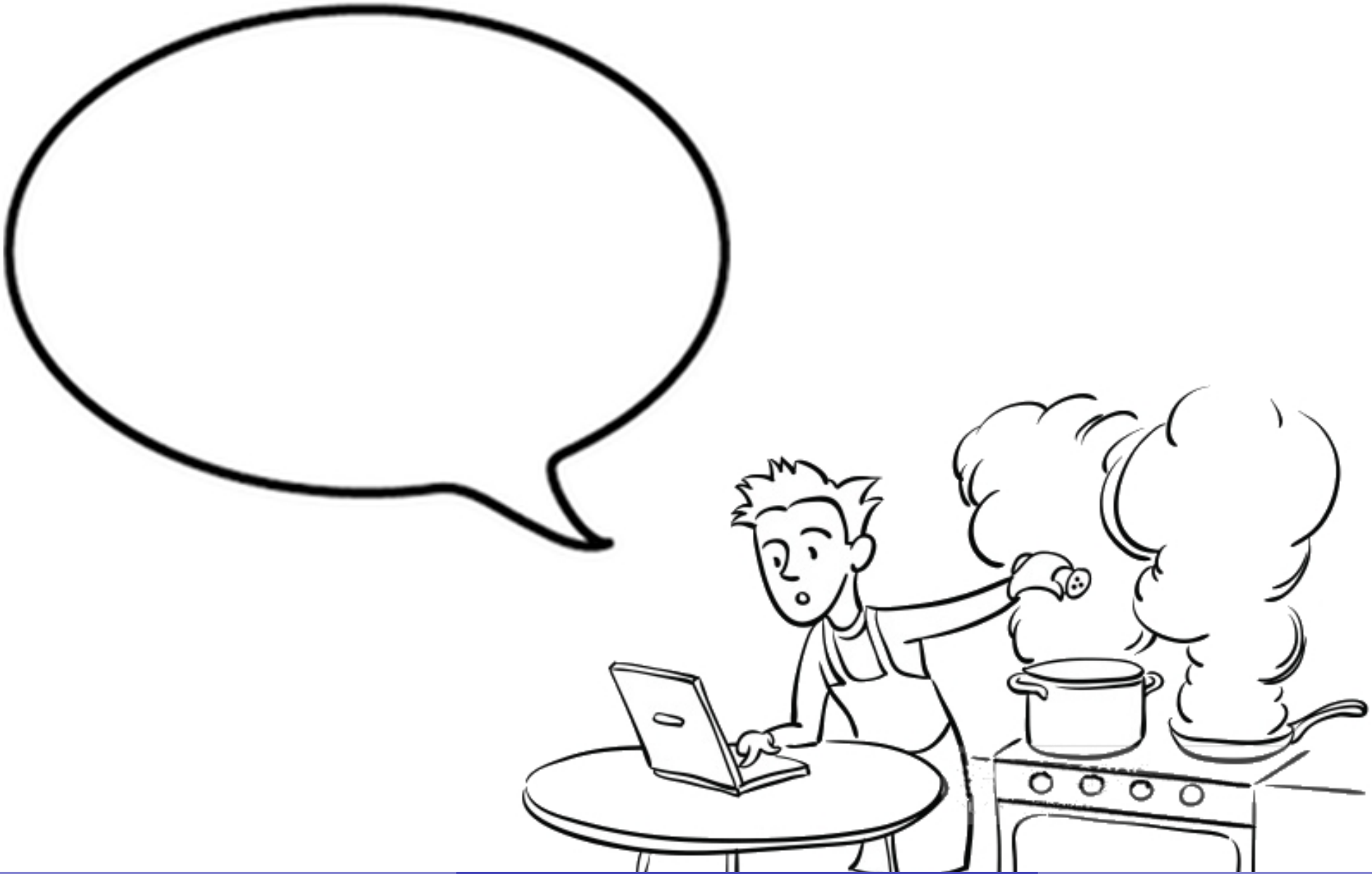
The local Universe



The local Universe



Ingredients to get Constrained Simulations



Ingredients to get Constrained Simulations

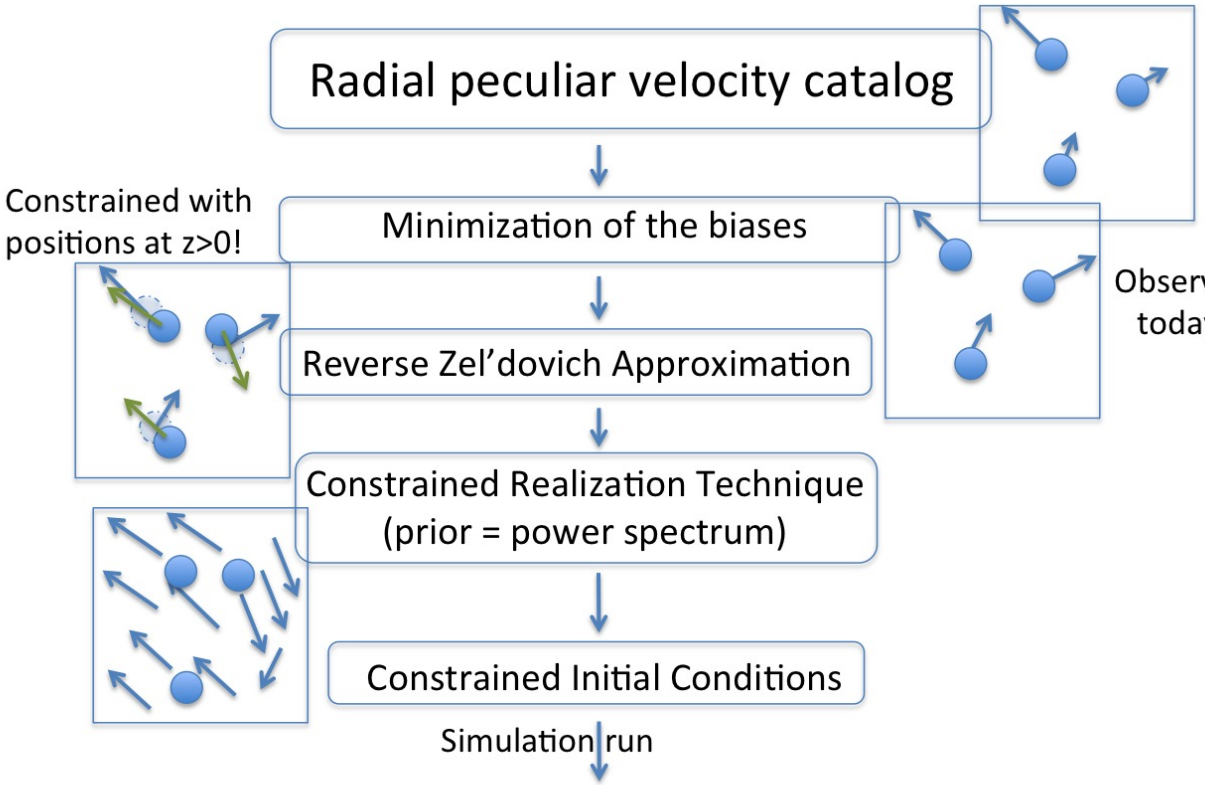
- observations:
radial peculiar velocities

Ingredients to get Constrained Simulations

- observations:
radial peculiar velocities

- simulations:
backward method

Summary of the method



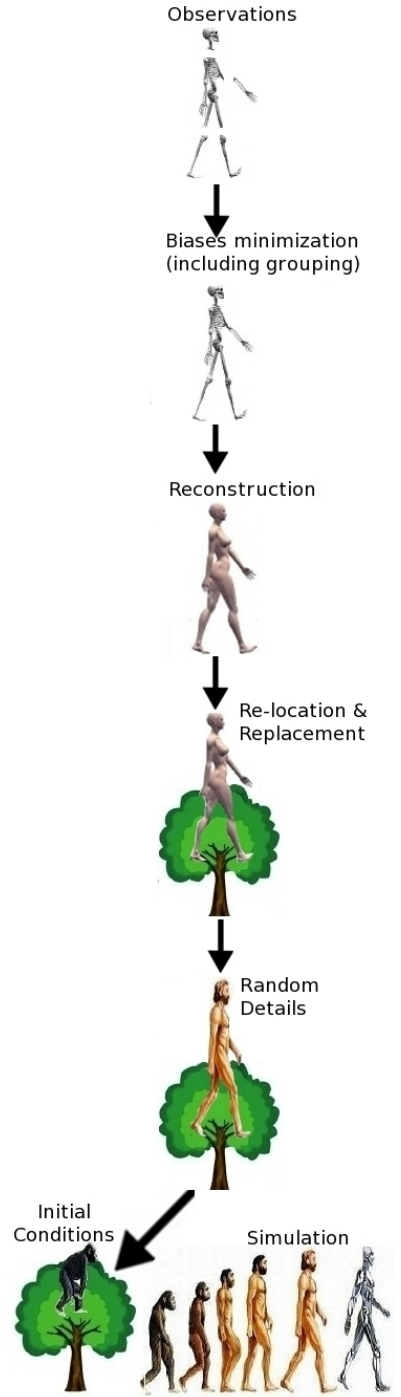
Tully et al. 2013

Tully 2015
Sorce 2015

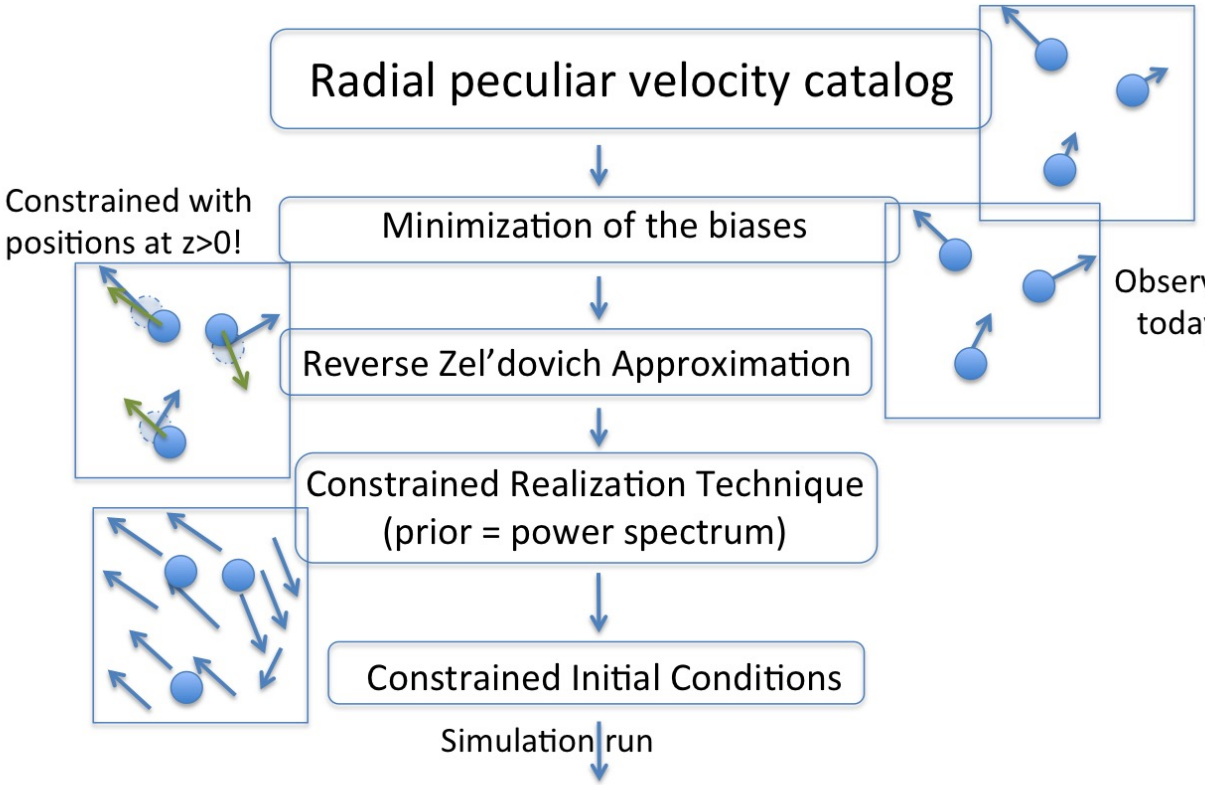
Zaroubi et al. 1995

Doumler et al. 2013
Sorce et al. 2014

Hoffman & Ribak 1991



Summary of the method



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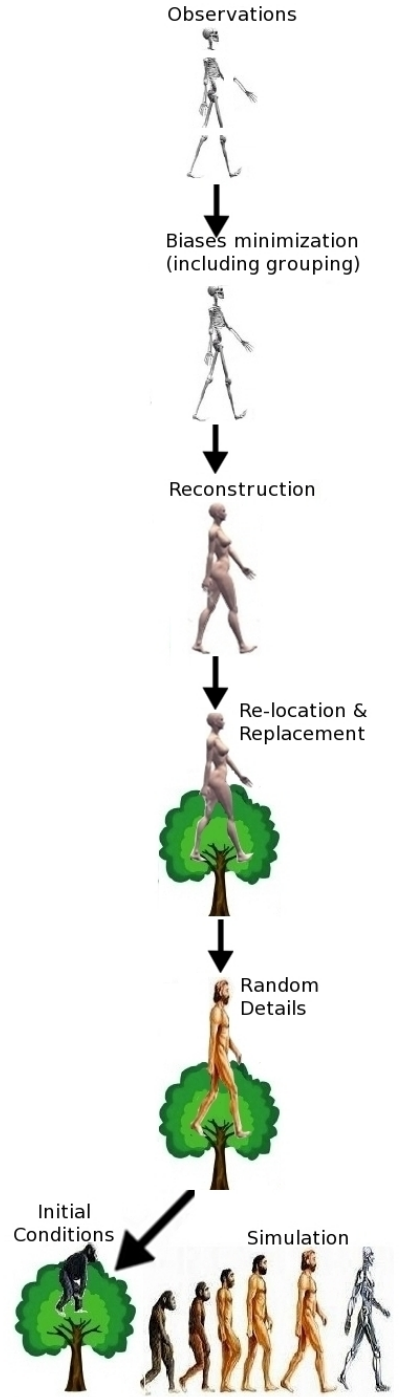
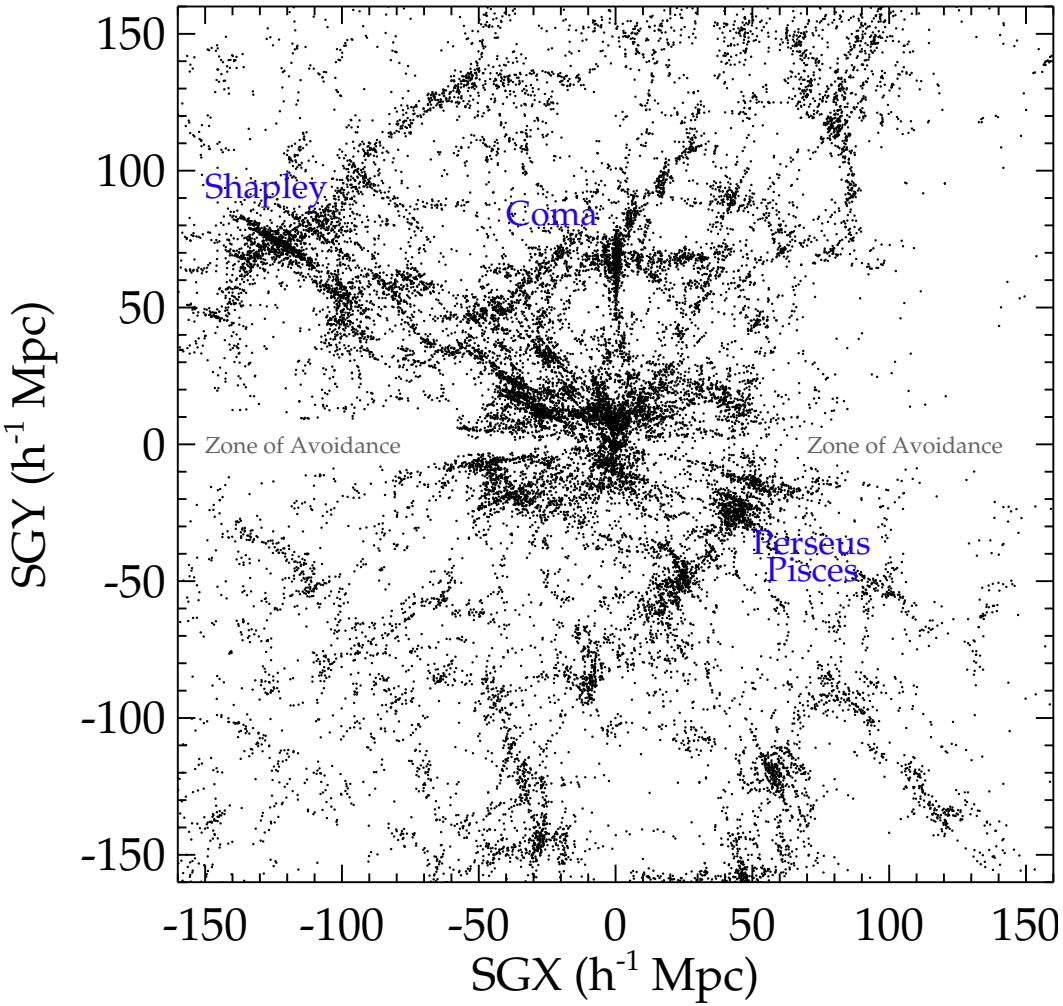


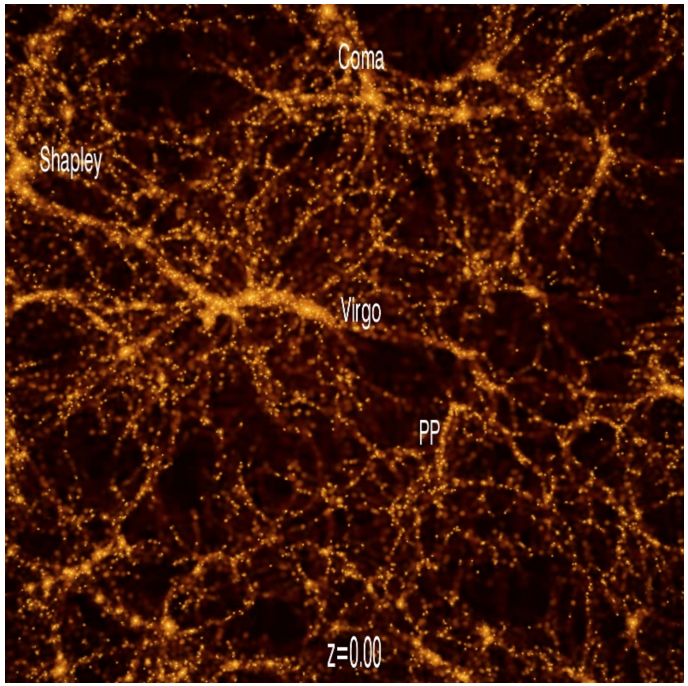
Simulations of the local Universe

Sorce et al. 2016

Observed



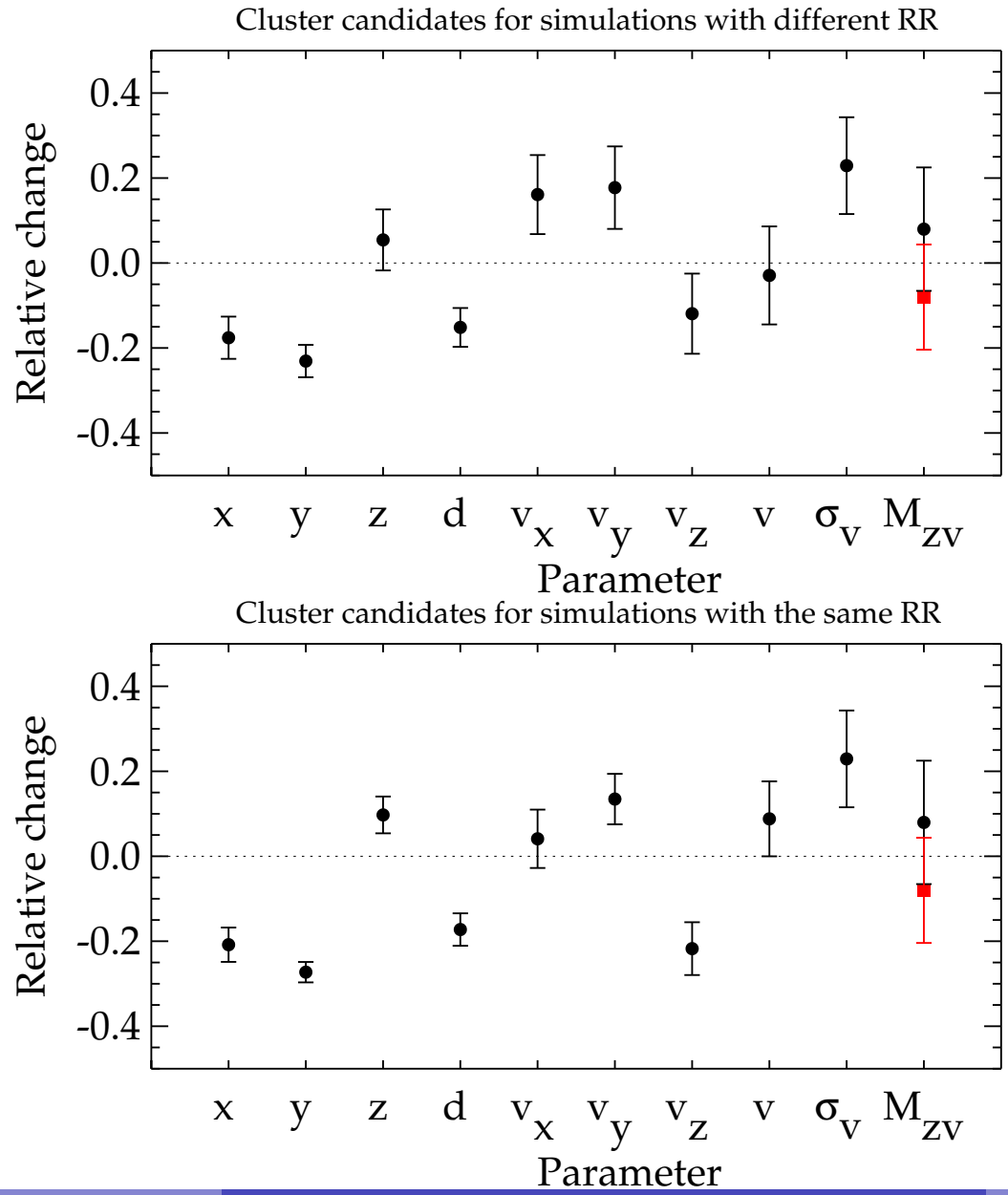
Simulated



Focus on the Virgo cluster

Virgo candidates at z=0

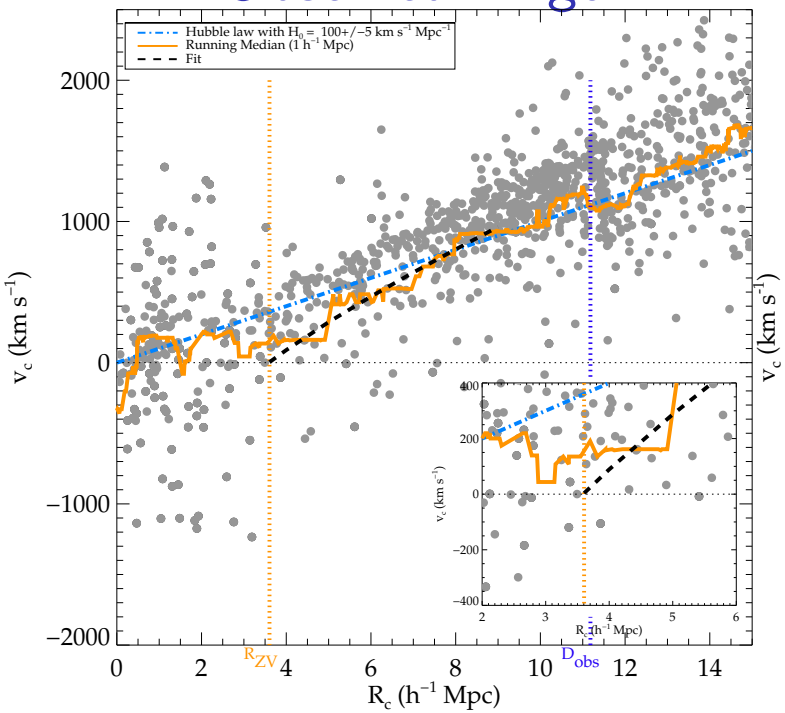
Sorce et al. 2016b



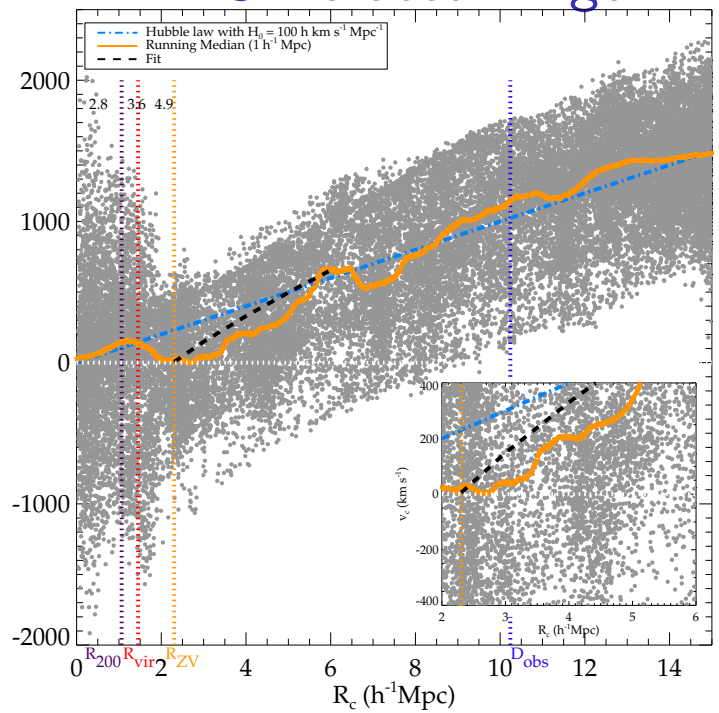
Zero velocity masses of Virgos at z=0

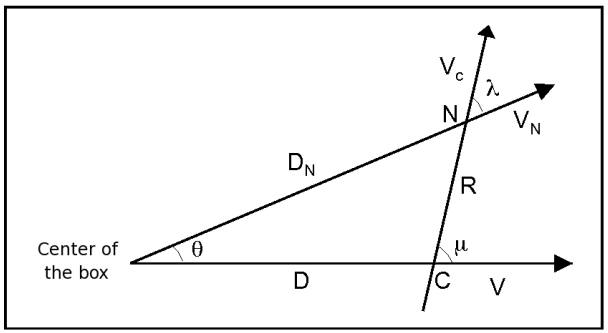
Sorce et al. 2016b

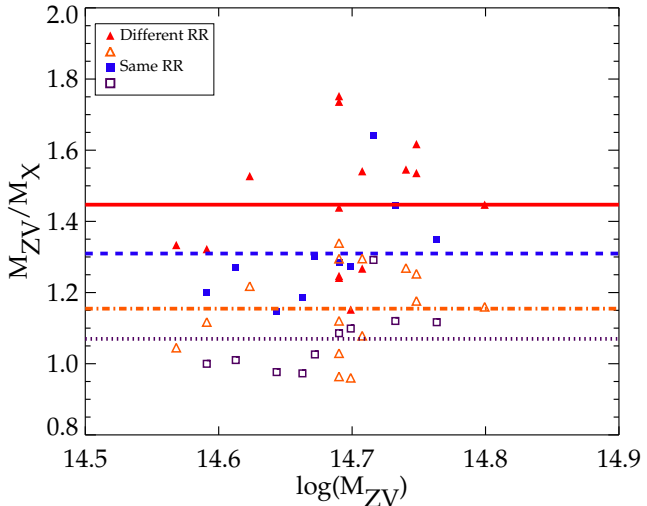
Observed Virgo



Simulated Virgo

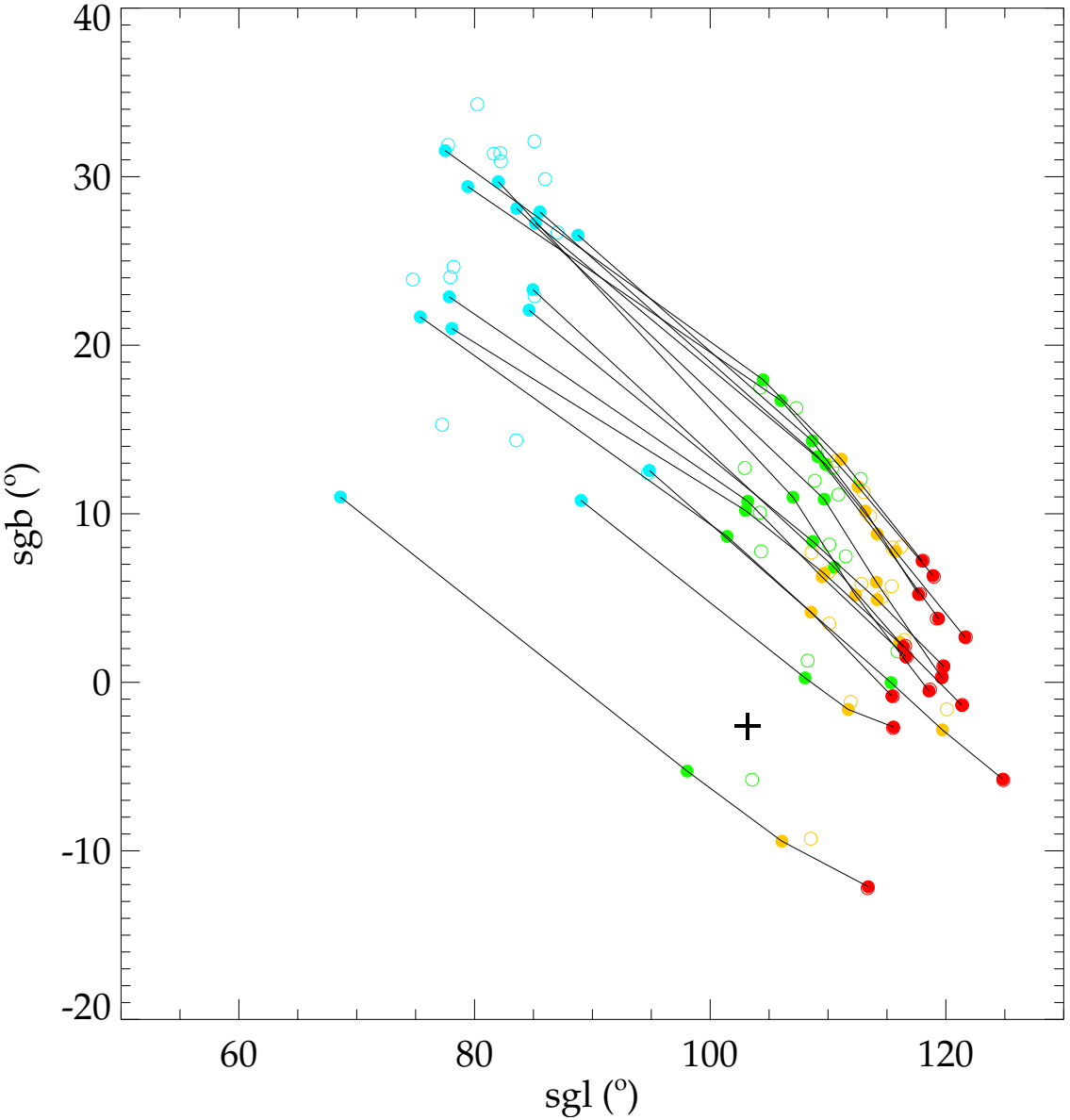






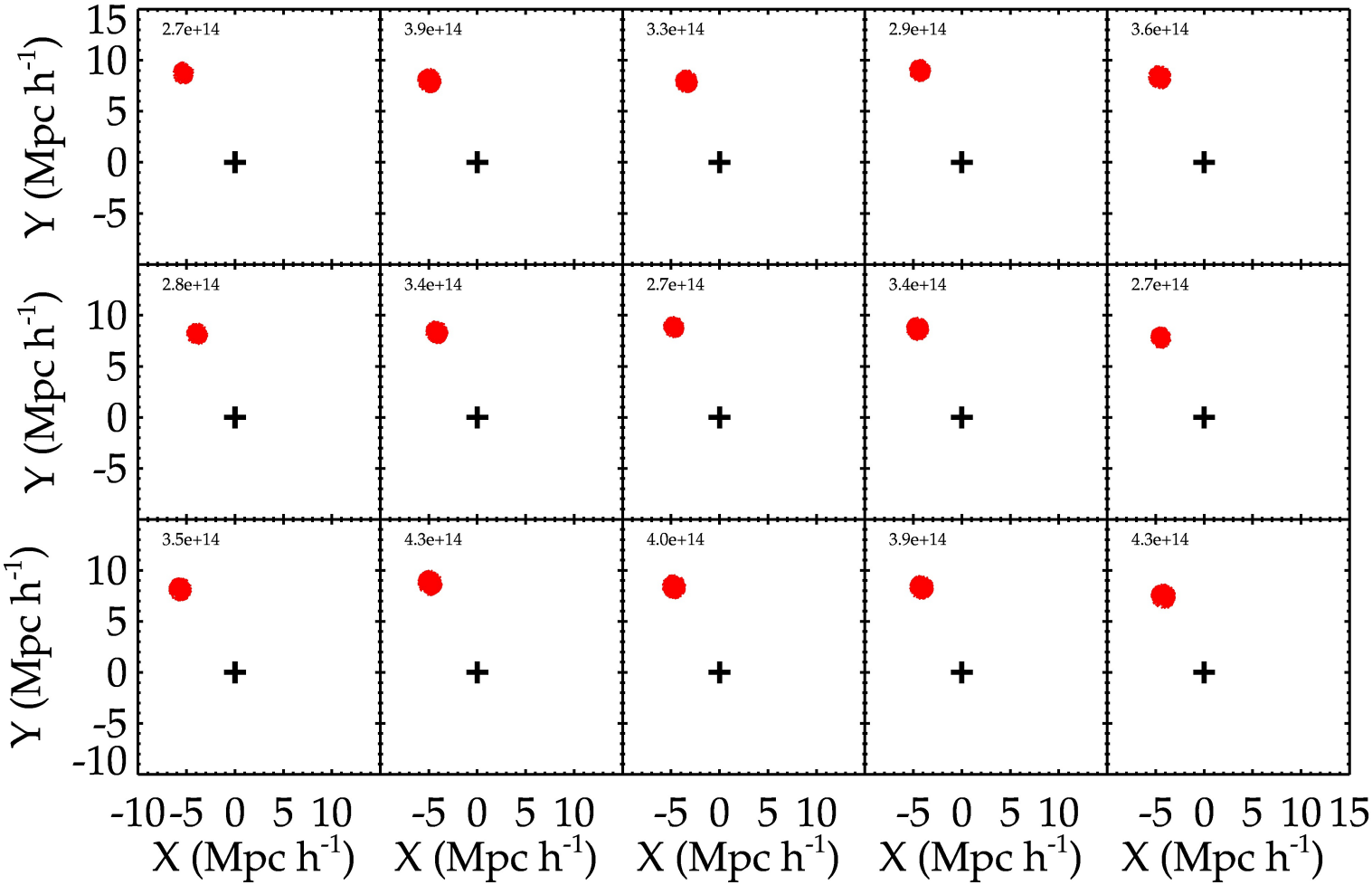
Progenitors (z>0): Particles' center of mass

Sorce et al. 2016b



How did the Virgo cluster form?

Sorce et al. 2016b

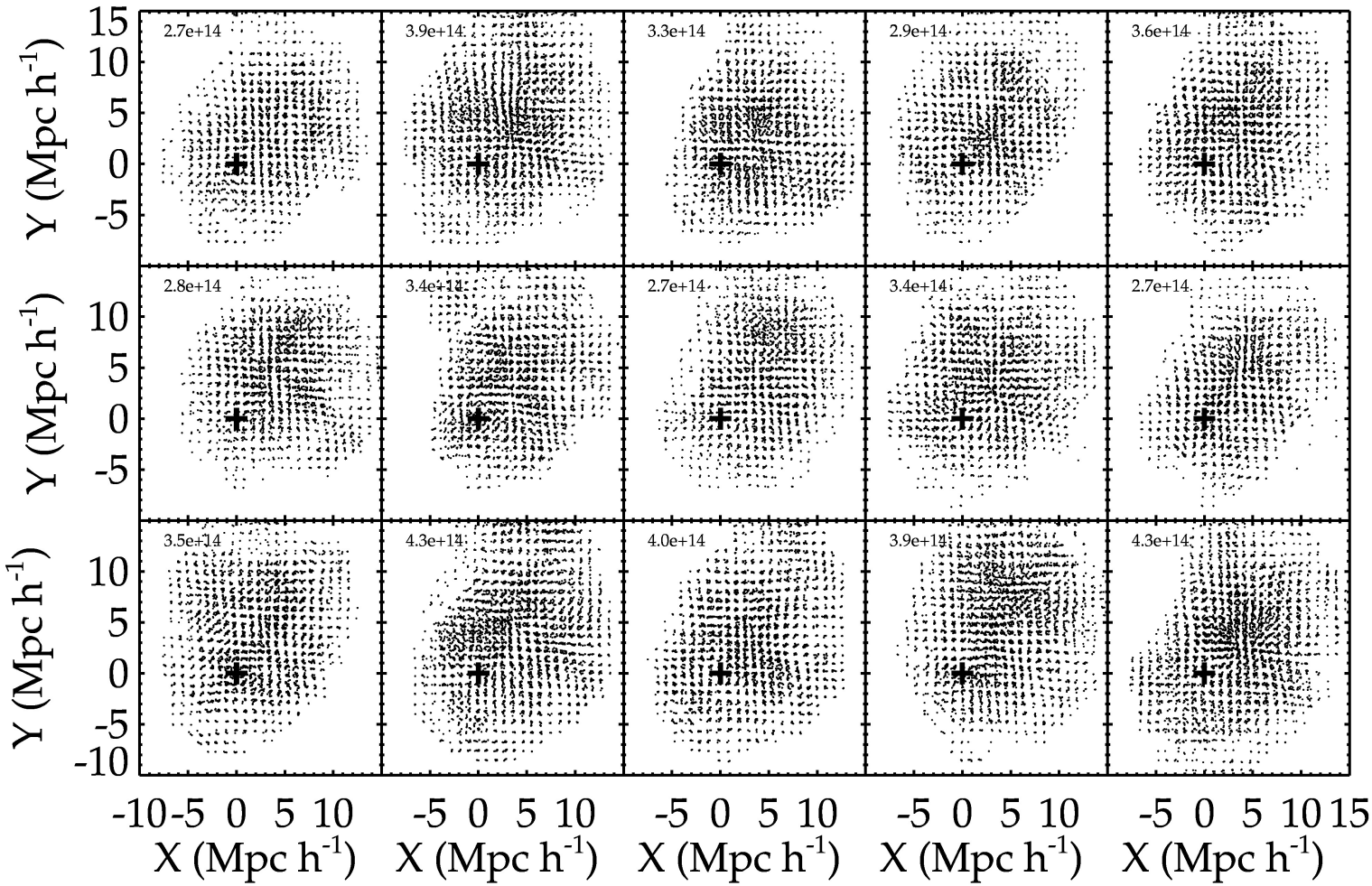


Dark Matter Haloes - Virgo Candidates: Particles at z= 0

- 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?

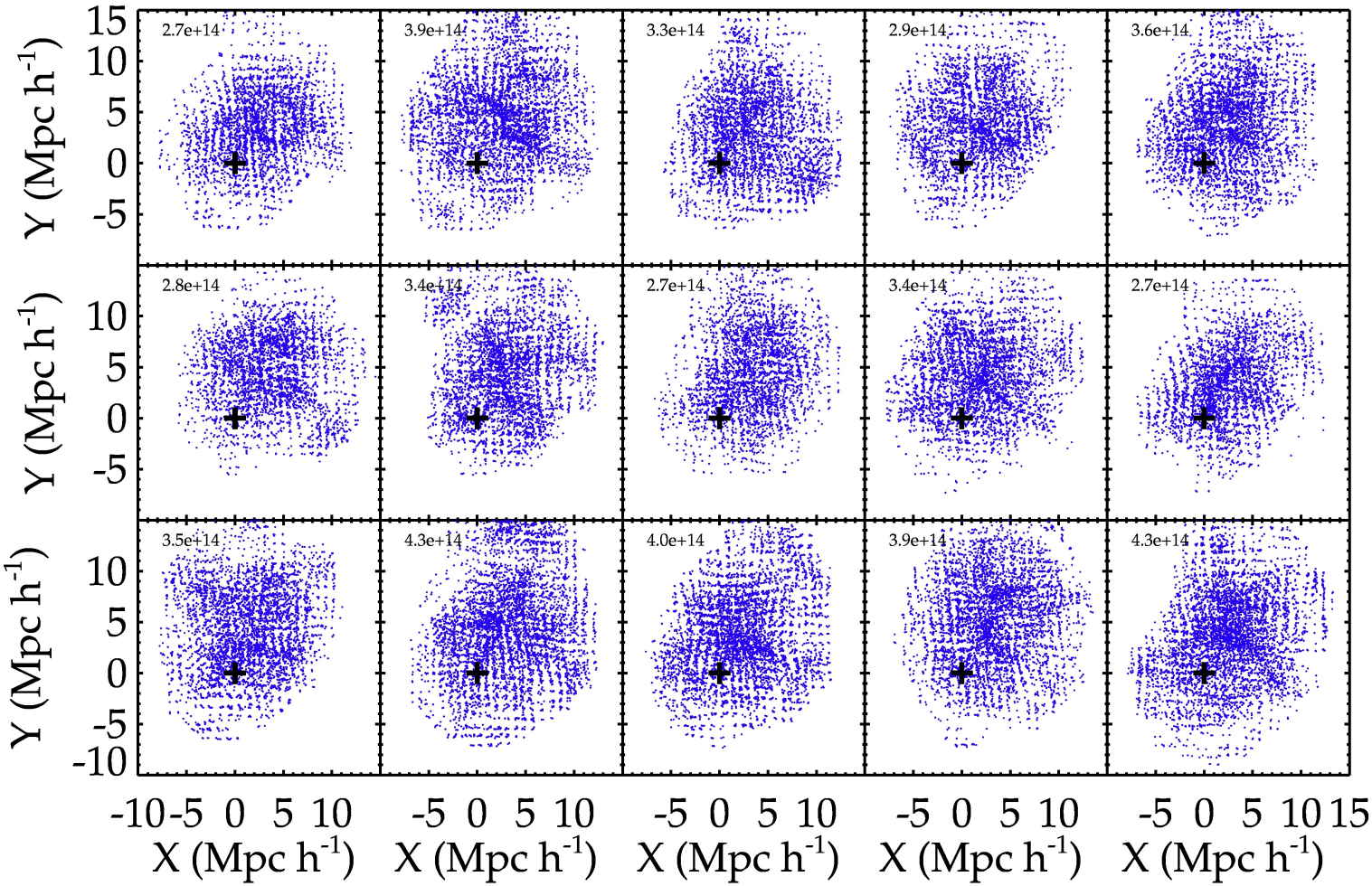
Sorce et al. 2016b



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

How did the Virgo cluster form?

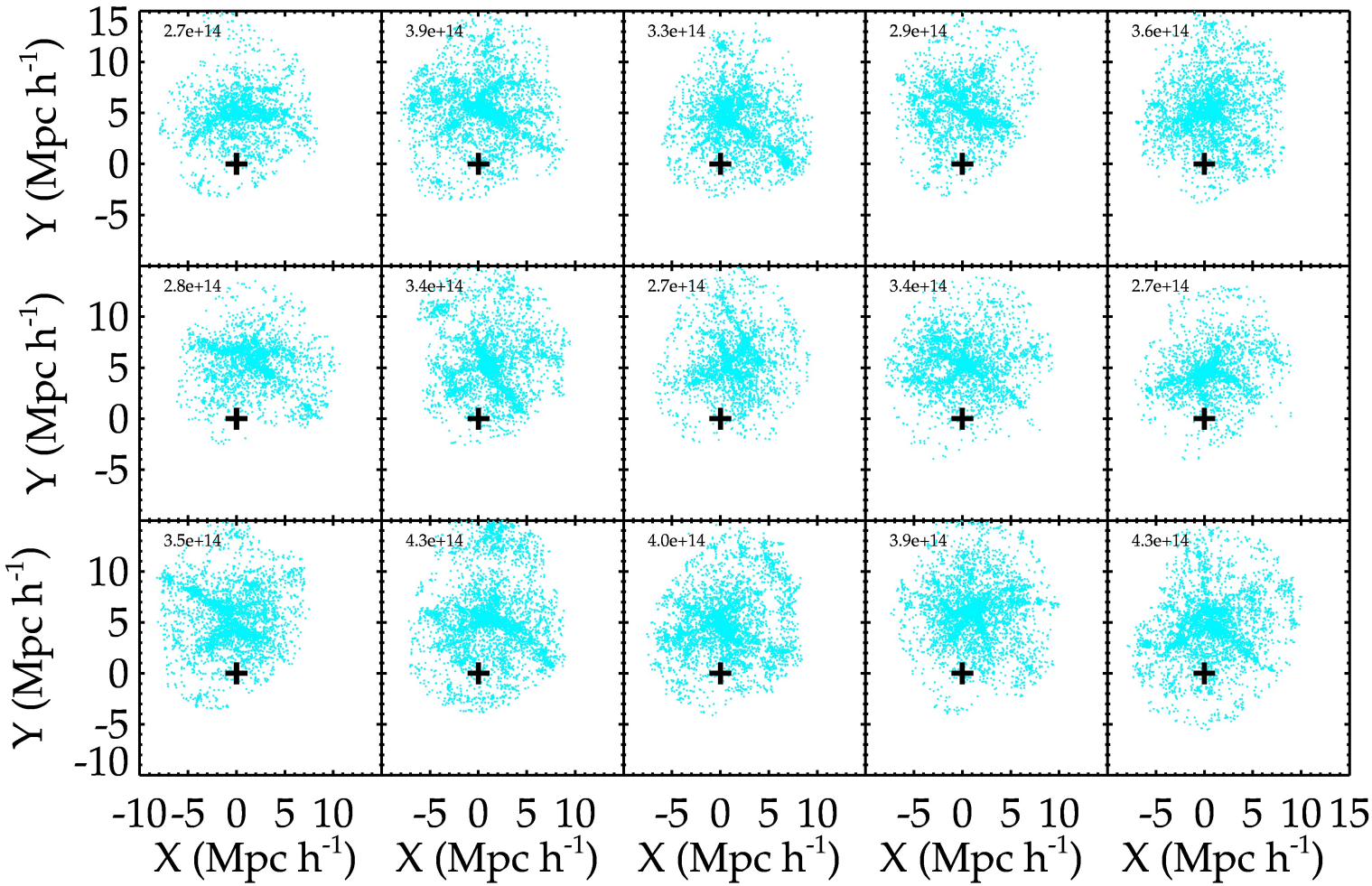
Sorce et al. 2016b



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

How did the Virgo cluster form?

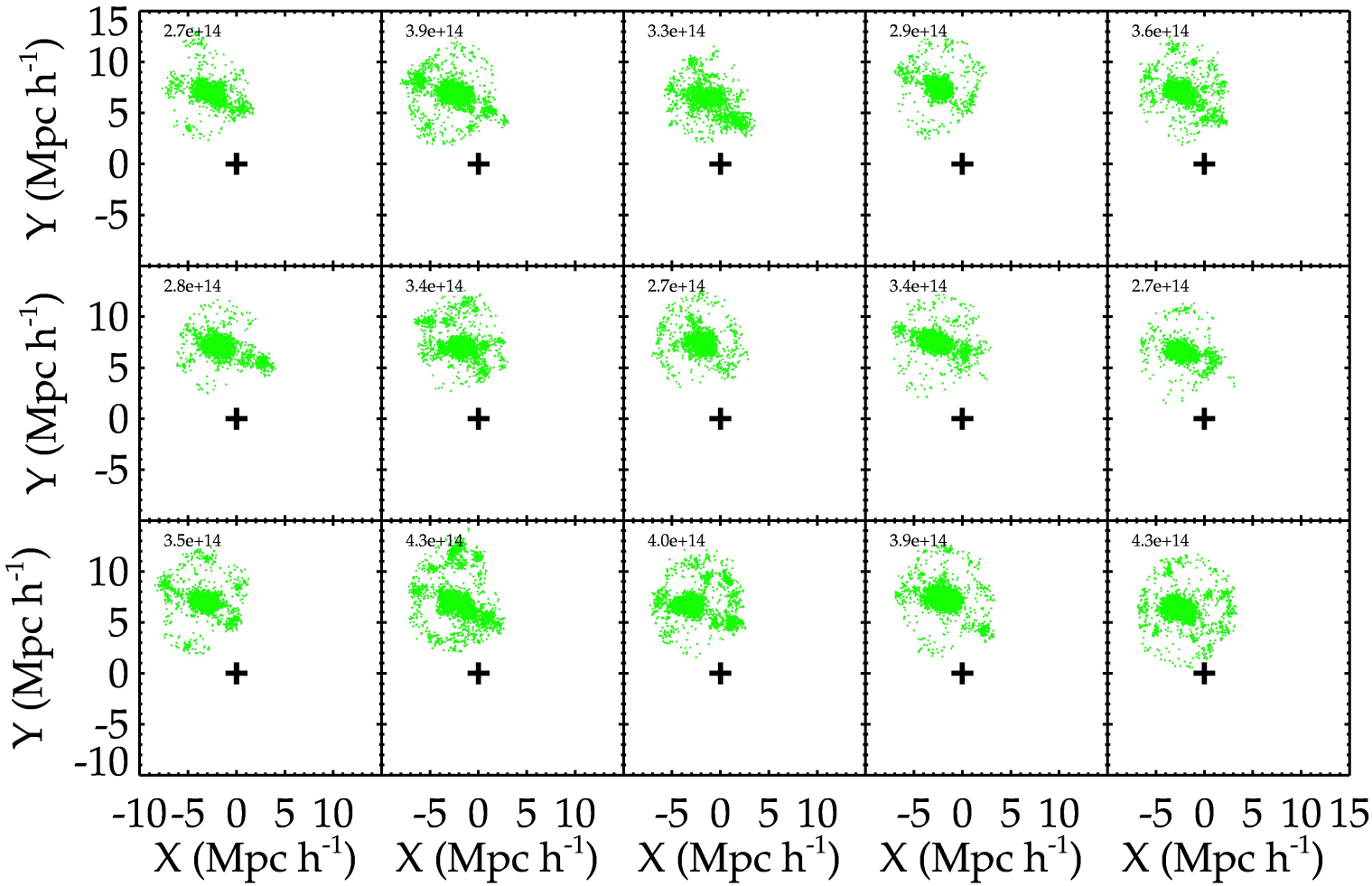
Sorce et al. 2016b



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

How did the Virgo cluster form?

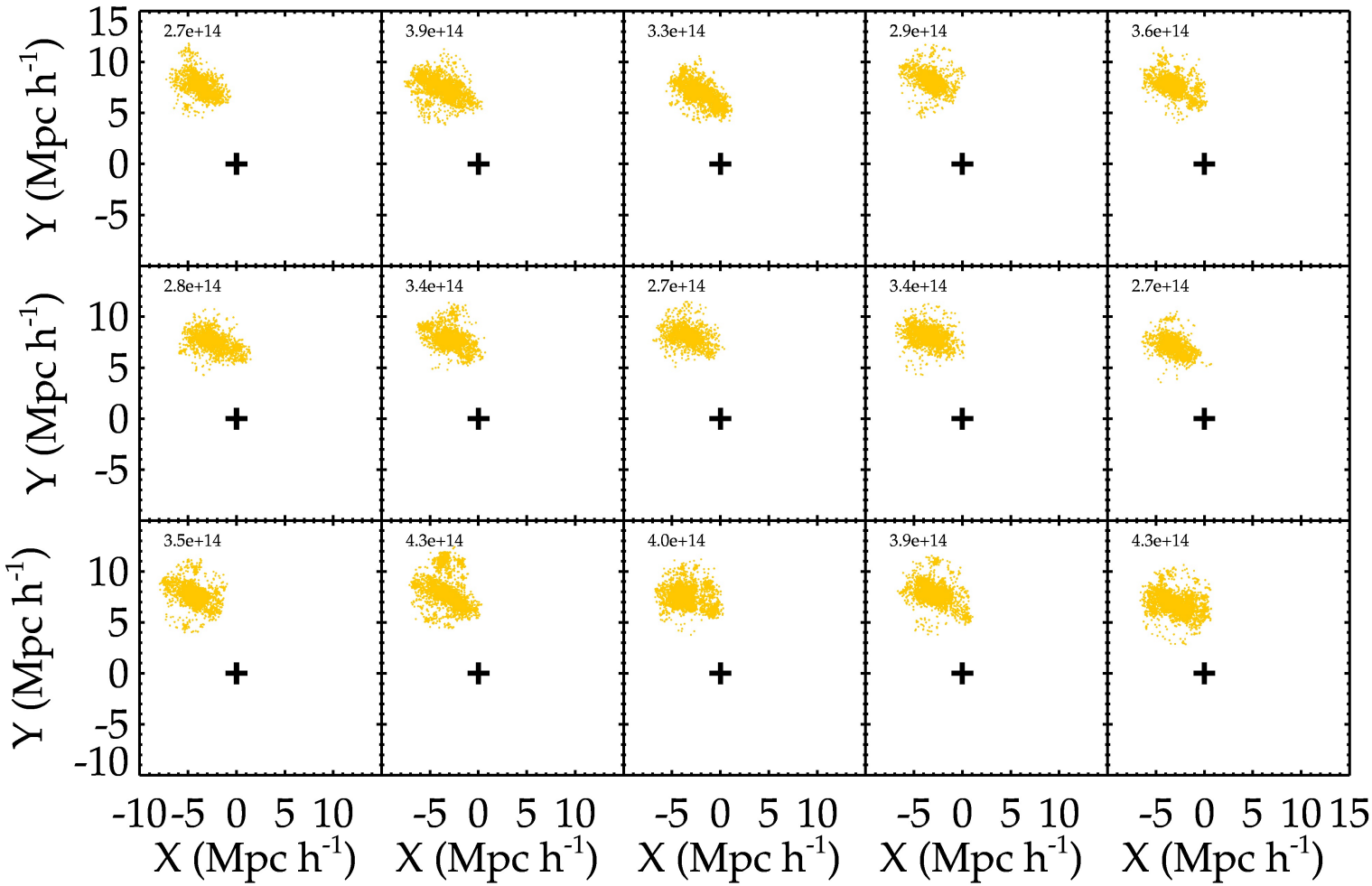
Sorce et al. 2016b



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

How did the Virgo cluster form?

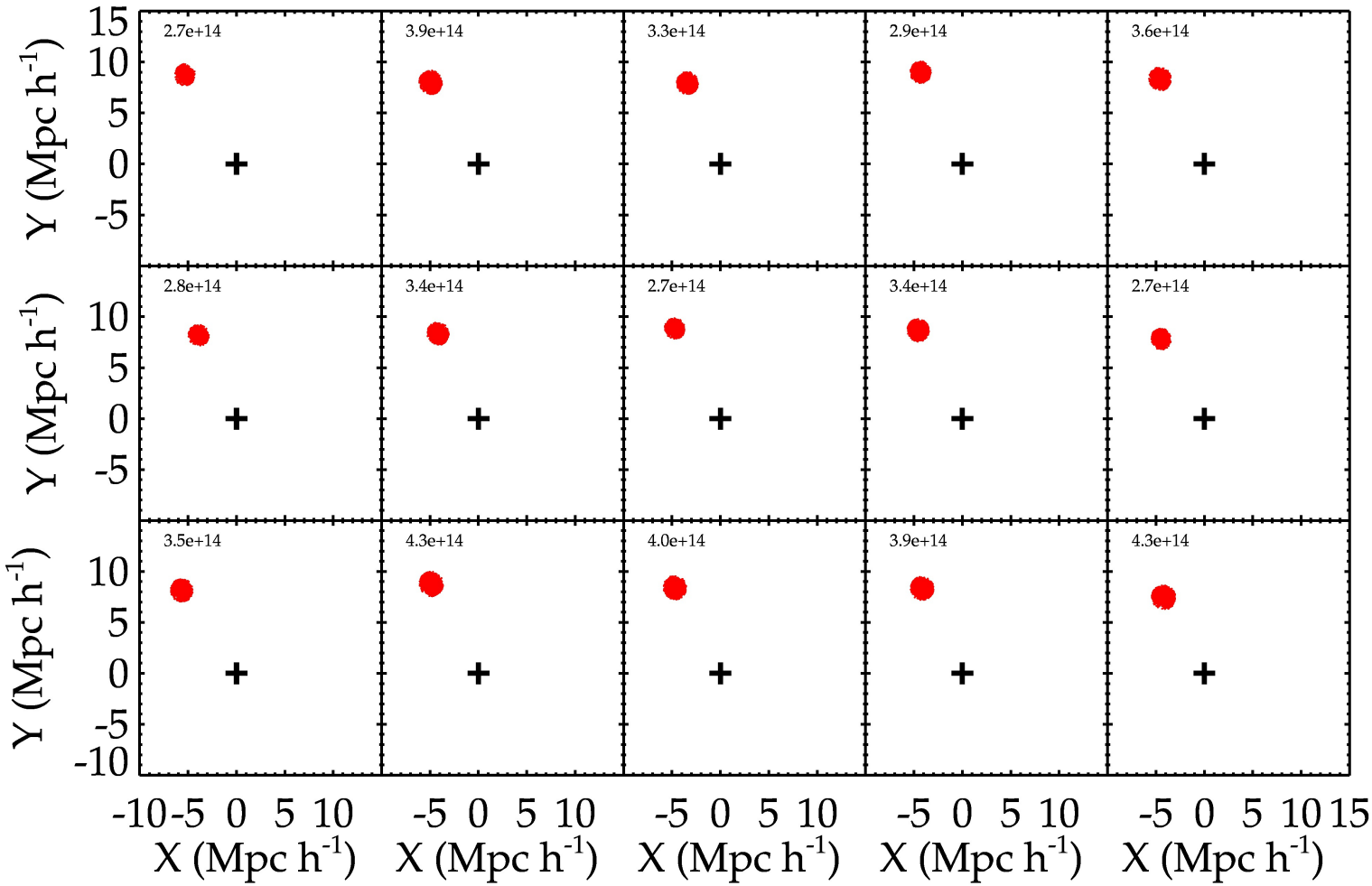
Sorce et al. 2016b



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

How did the Virgo cluster form?

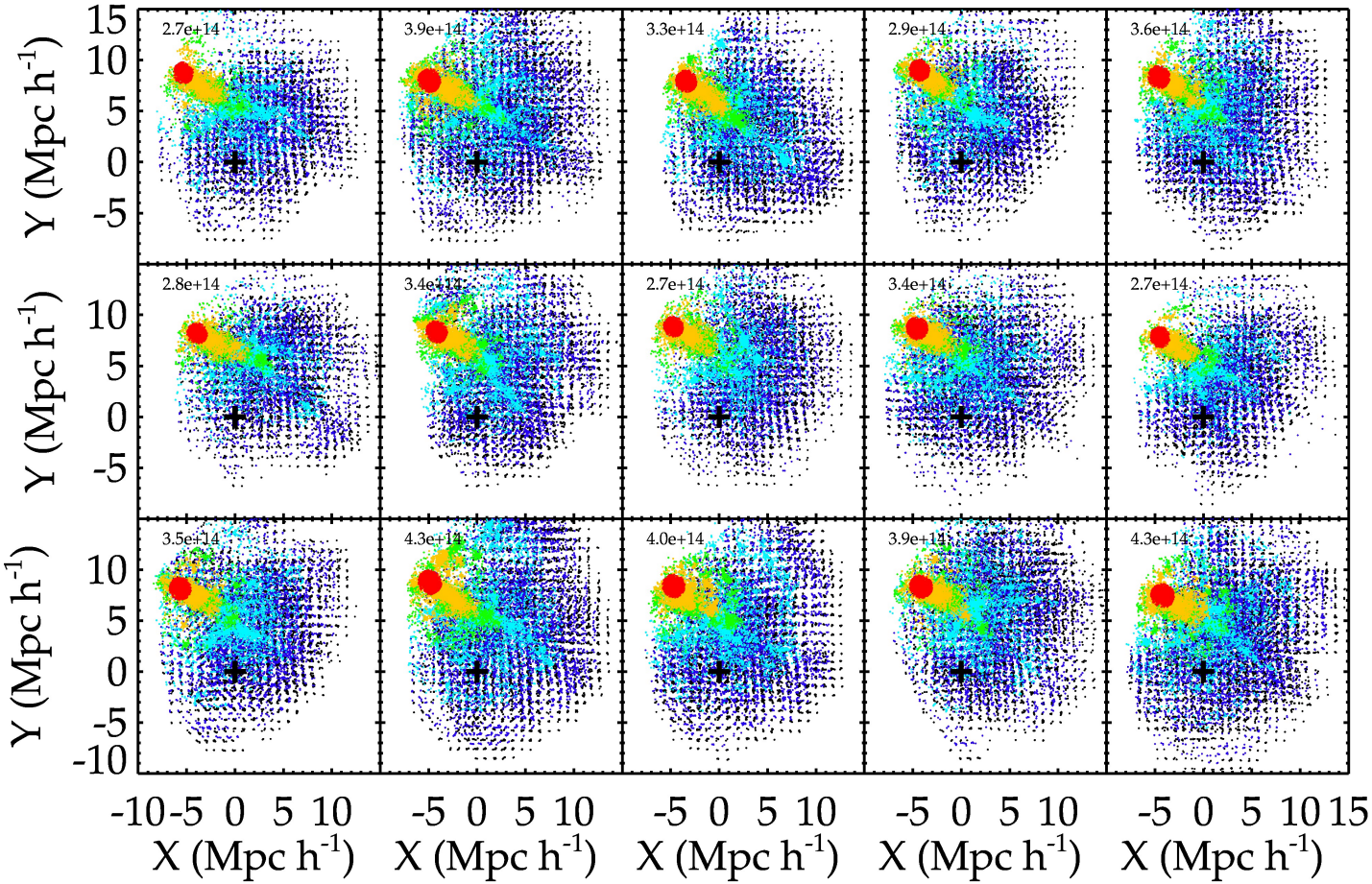
Sorce et al. 2016b



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

How did the Virgo cluster form?

Sorce et al. 2016b



Dark Matter Haloes - Virgo Candidates:

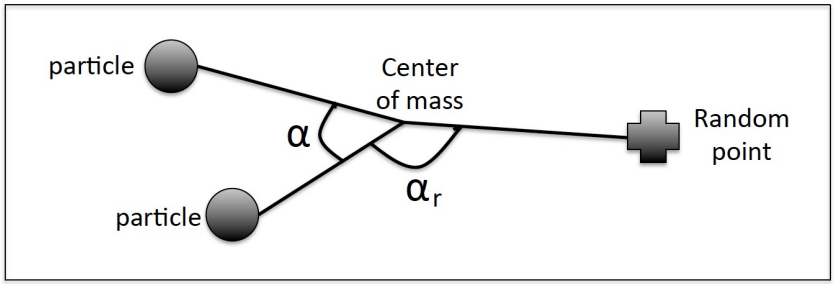
- Similar formation / evolution

One color per redshift:

10, 5, 2, 0.5, 0.25, 0

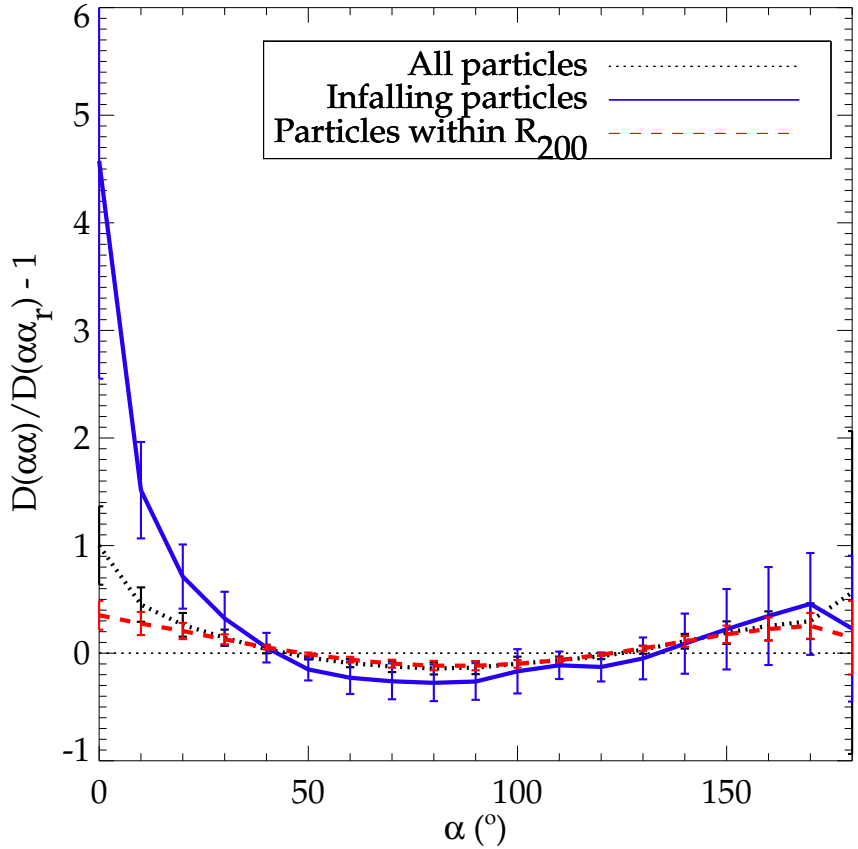
A preferential direction of infall at z=0

Sorce et al. 2016b



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

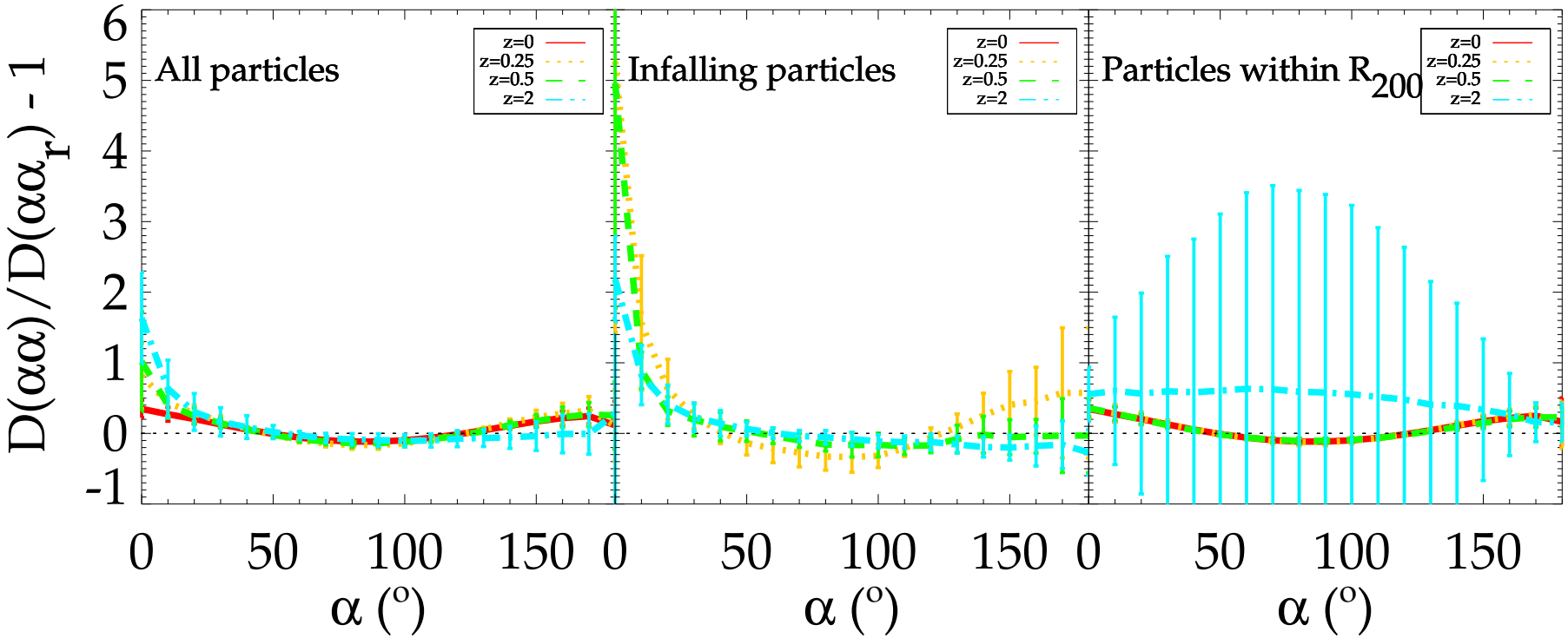
Autocorrelation function:
D($\alpha\alpha$)/D($\alpha\alpha_r$) - 1



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

A preferential infall at z>0

Sorce et al. 2016b

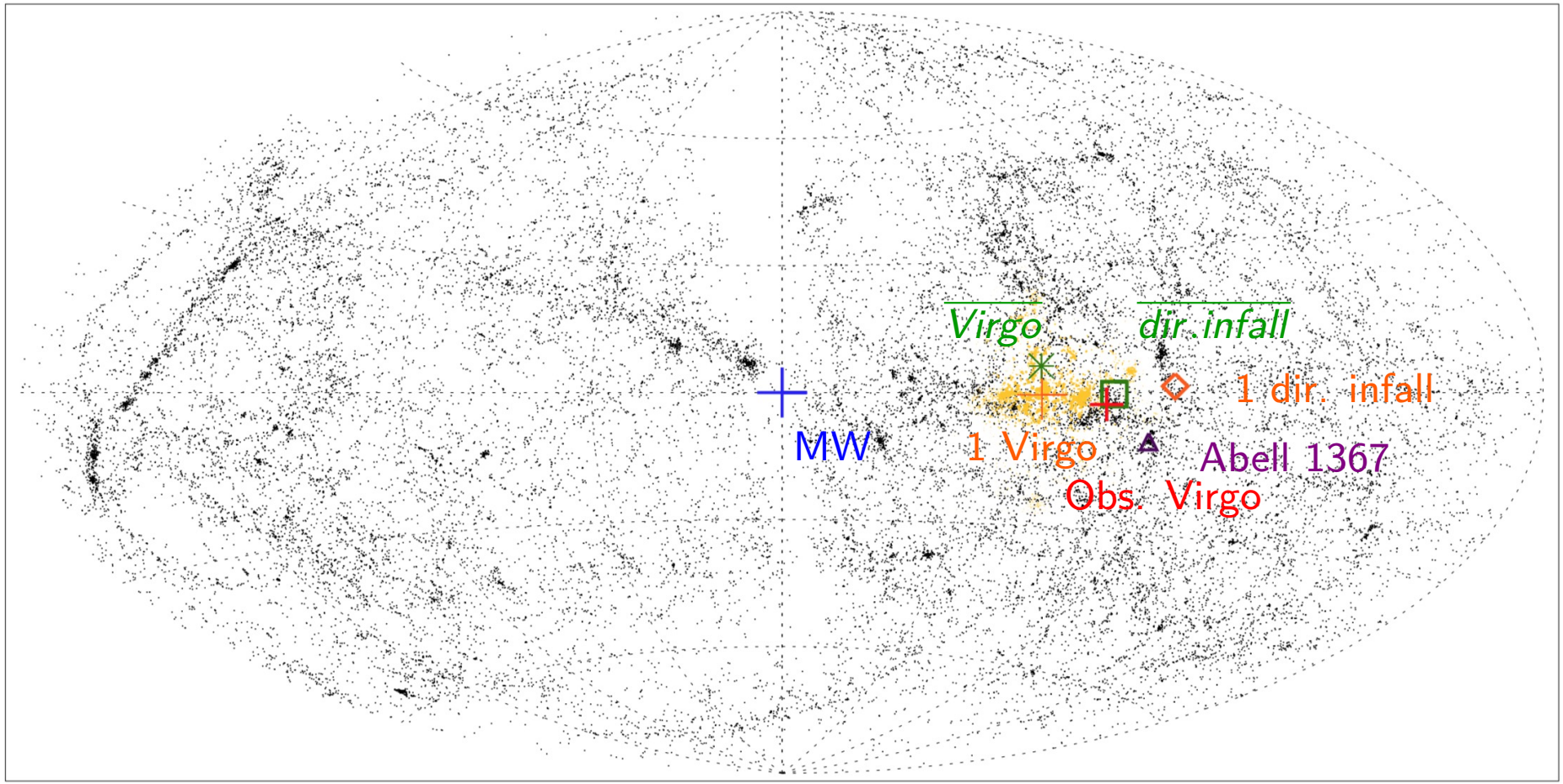


A preferential infall: Aitoff

Sorce et al. 2016b

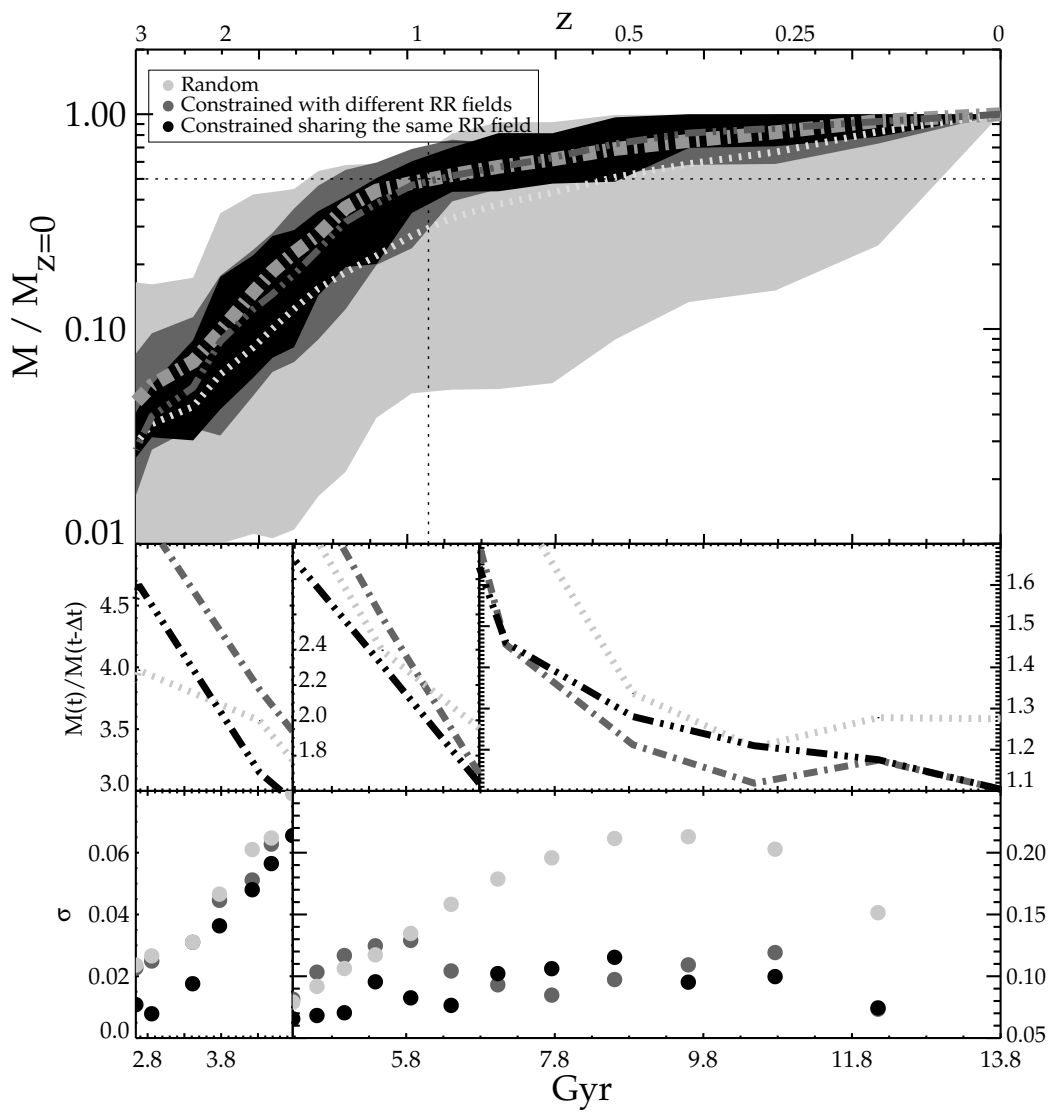
In Supergalactic coordinates,

• redshift catalog • infalling particles



West & Blakeslee (2000)

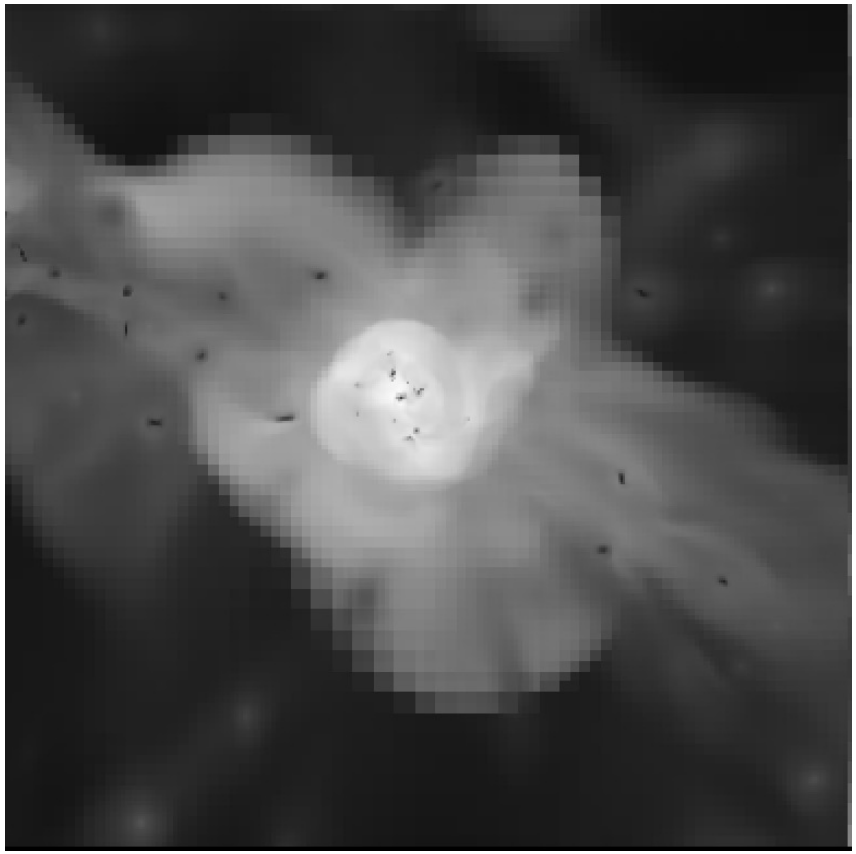
A quiet formation history over the last gigayears



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

What next?

Zoom-in + Hydro (MUSIC + Ramses): 200 zoom-in DM only runs, 6 selected for hydro runs



First tests and next step: Supernova and AGN feedbacks

in collaboration with Yohan Dubois and Jérémy Blaizot

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,

Obrigada, Cám Ơn ...