Simulating objects of the local Universe: The Virgo galaxy cluster, a case study

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in collaboration with lots of people mainly Jérémy Blaizot (CRAL), Yohan Dubois (IAP) for today's work presentation

CRAL
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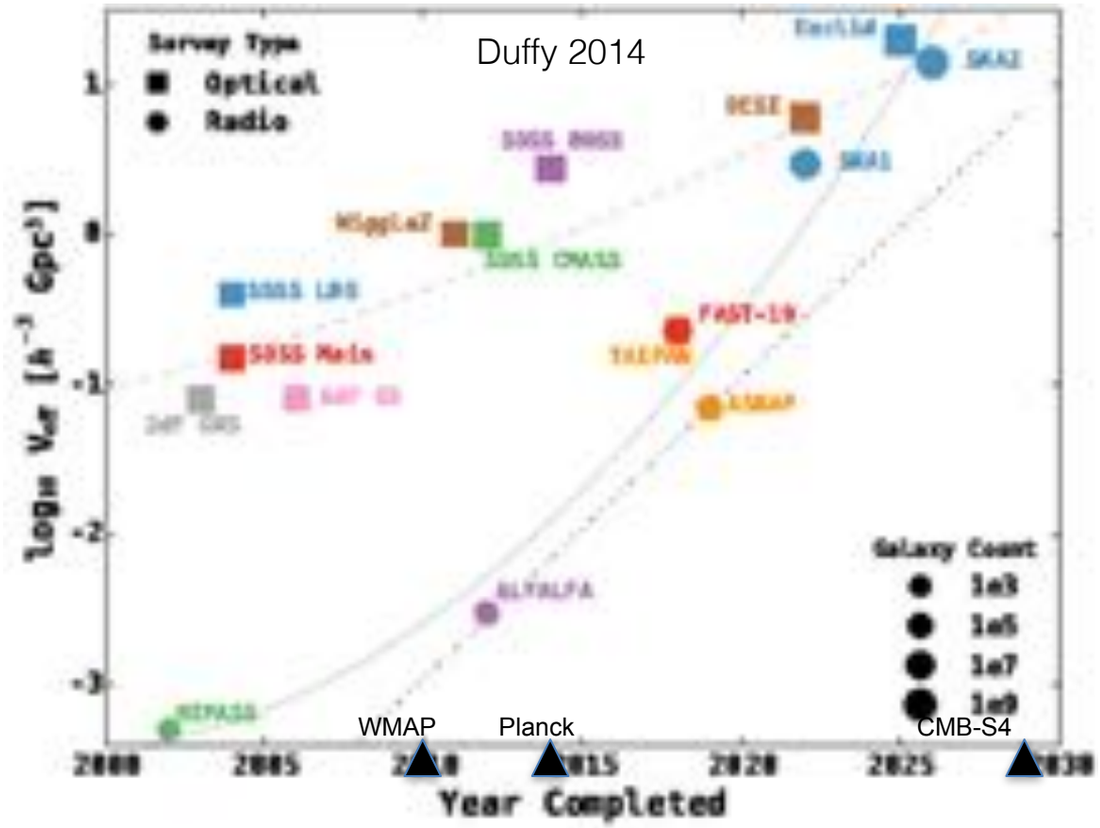
Motivations

Galaxy clusters: powerful cosmological probes

- largest virialized structures in the Universe
- last step of a hierarchical formation process (ΛCDM model)
- excellent tracers of large-scale structures

➙ density & properties sensitive to cosmological parameters (σ_8, Ω_m)
➙ joint analysis to control systematics (CMB, SN, BAOs, etc.)

Statistical study



Motivations

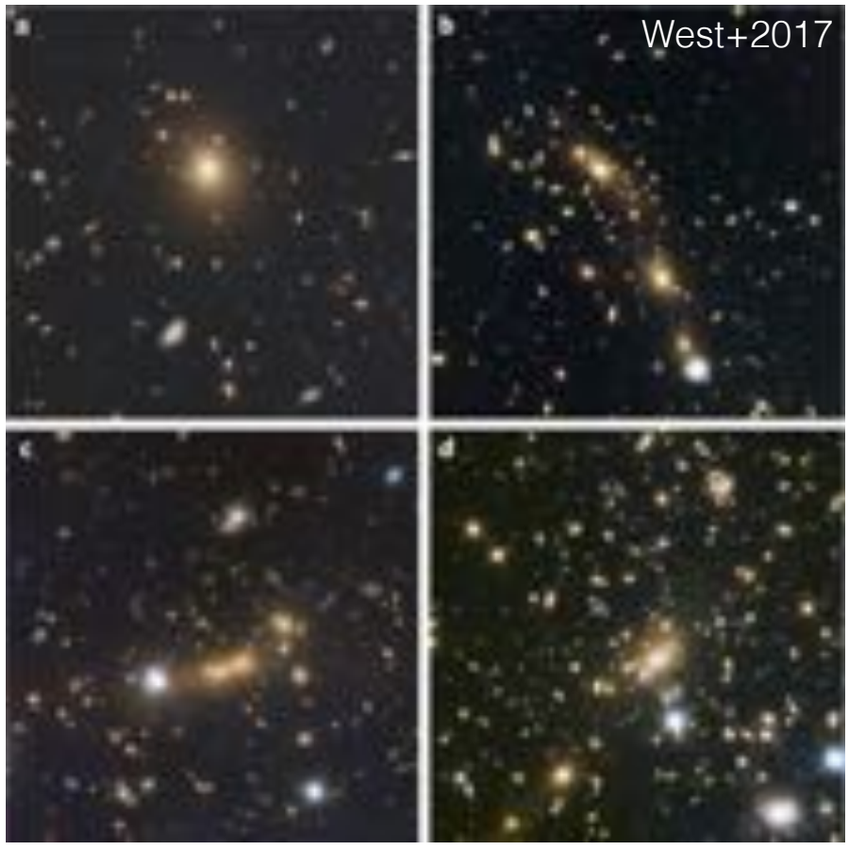
A wide diversity of clusters

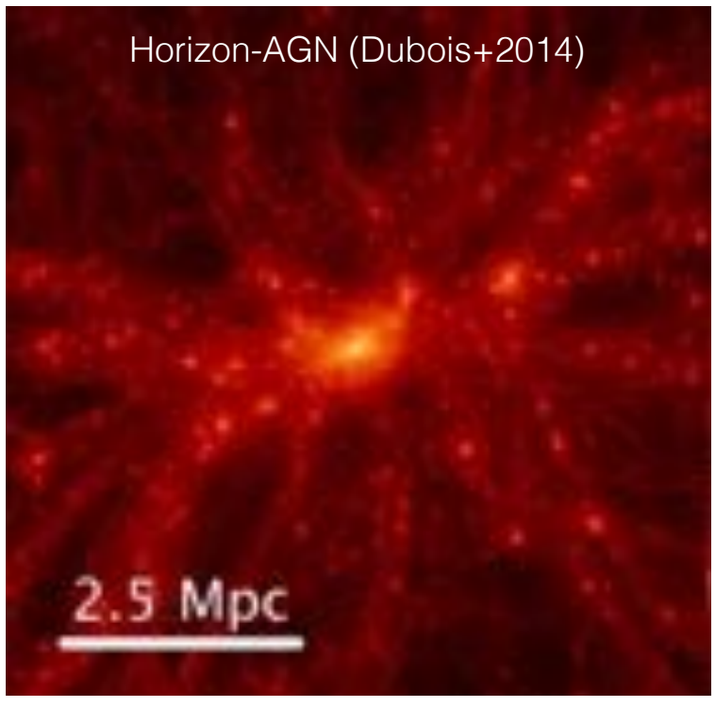
- challenging aspects of cluster physics (e.g. mass determination) = limitation to applications

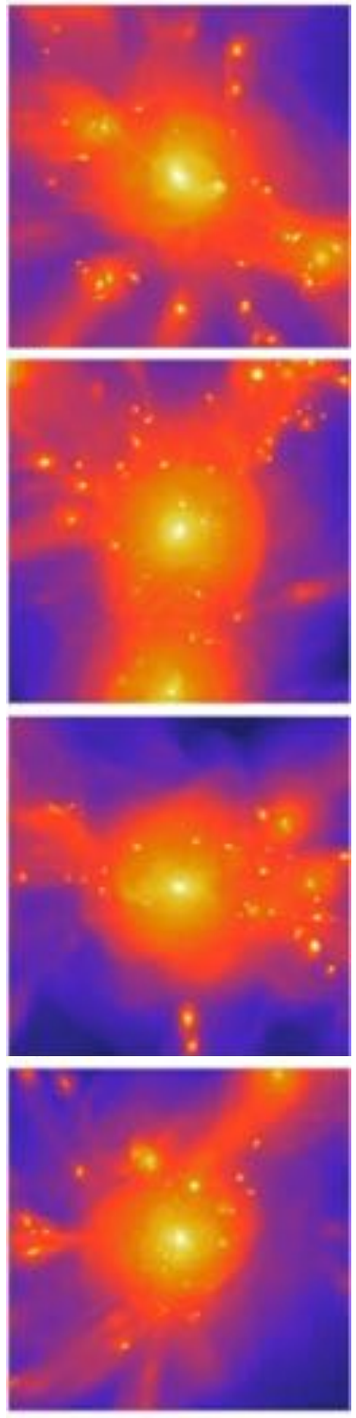
➙ modeling of cluster physics in general

Motivations

A wide diversity of clusters







Rhapsody (Hahn+2017)

One to one comparison

Great for statistical purposes but one to one matching is challenging: properties to match are uncertain, difficult to measure, only predictable…

➙ limitation of the comparison (in particular galaxy population is affected by history)

Ideally, simulated lookalike for

- direct comparisons
- determination of properties
- checking observational ‘predictions’
- studying past history & galaxy population

➙ calibration of formation & evolution modeling, measurement techniques…

Direct lookalikes

Direct lookalikes with constrained simulations

PATH INTEGRAL METHODS FOR PRIMORDIAL DENSITY PERTURBATIONS: SAMPLING OF CONSTRAINED GAUSSIAN RANDOM FIELDS

EDMUND BERTSCHINGER
Center for Theoretical Physics, Center for Space Research, and Department of Physics, Massachusetts Institute of Technology
Received 1987 August 17; accepted 1987 September 10

ABSTRACT

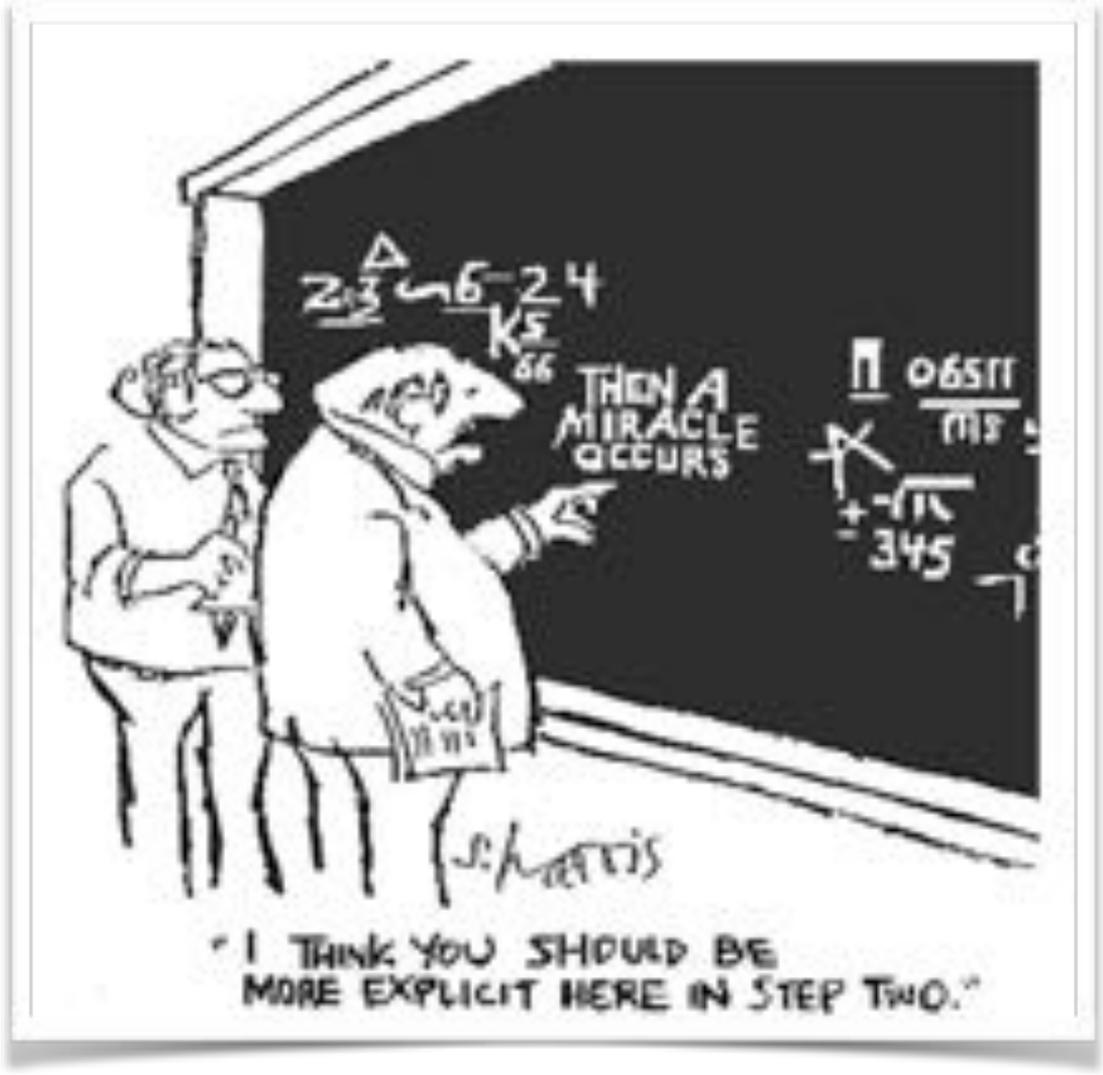
Path integrals may be used to describe the statistical properties of a random field such as the primordial density perturbation field. In this framework the probability distribution is given for a Gaussian random field subjected to constraints such as the presence of a protovoid or supercluster at a specific location in the initial conditions. An algorithm has been constructed for generating samples of a constrained Gaussian random field on a lattice using Monte Carlo techniques. The method makes possible a systematic study of the density field around peaks or other constrained regions in the biased galaxy formation scenario, relevant for generating initial conditions for *N*-body simulations with rare objects in the computational volume.

Bayes1761 Wiener1942 Hoffman & Ribak 1991 Zaroubi+1995 van der Weijgaert & Bertshinger 1996

Work \ Constraints	Redshift surveys	peculiar velocities + density	peculiar velocities
Kitaura2008,2012, 2013 Hess+2013	☑		
Lavaux2010, Jasche+2013-tdy	☑		
Wang+2014-tdy	☑		
Klypin+2003		☑	
Sorce+2014-tdy			☑

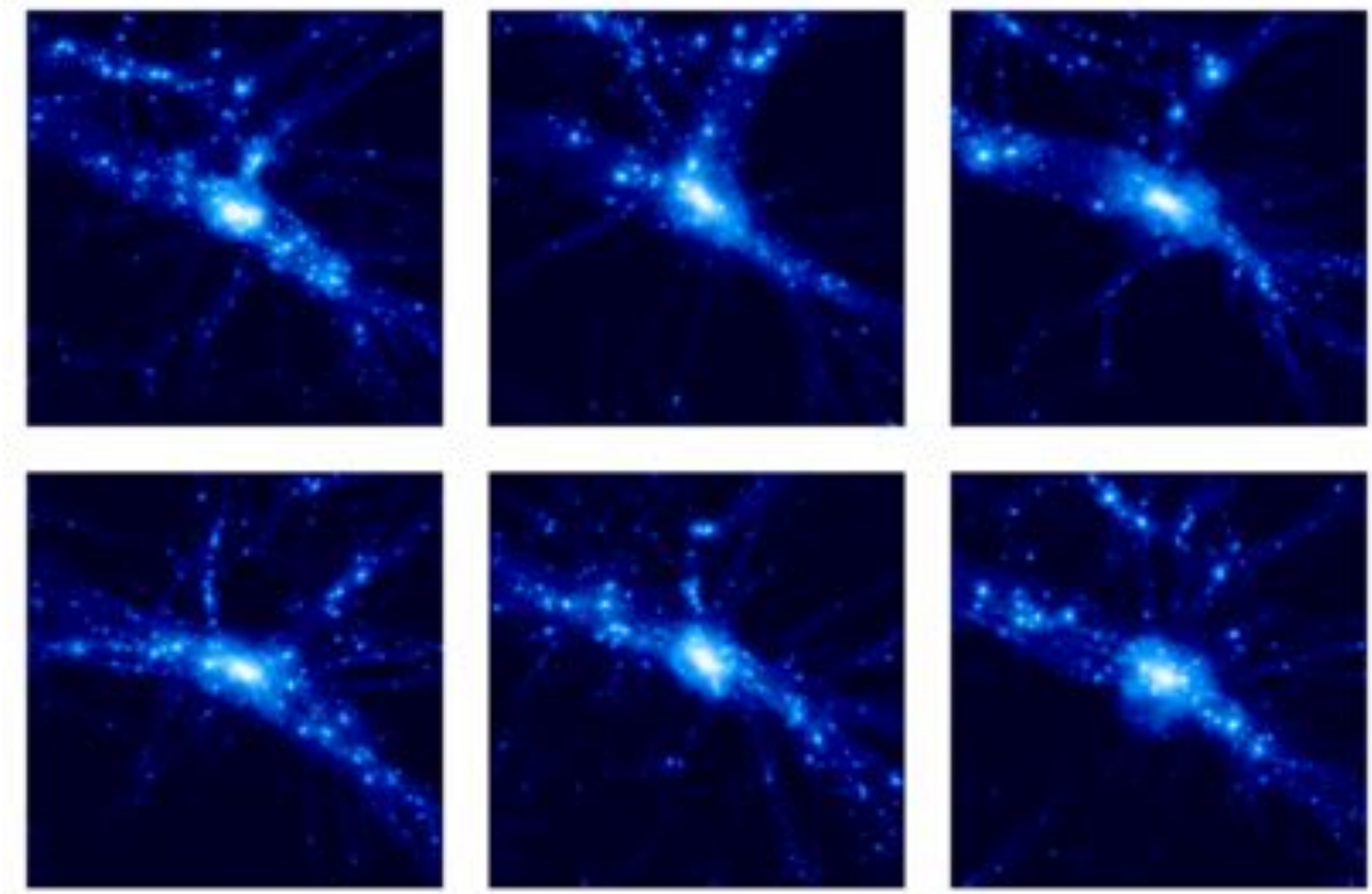
no luminosity bias

Dark matter only



Dark matter only

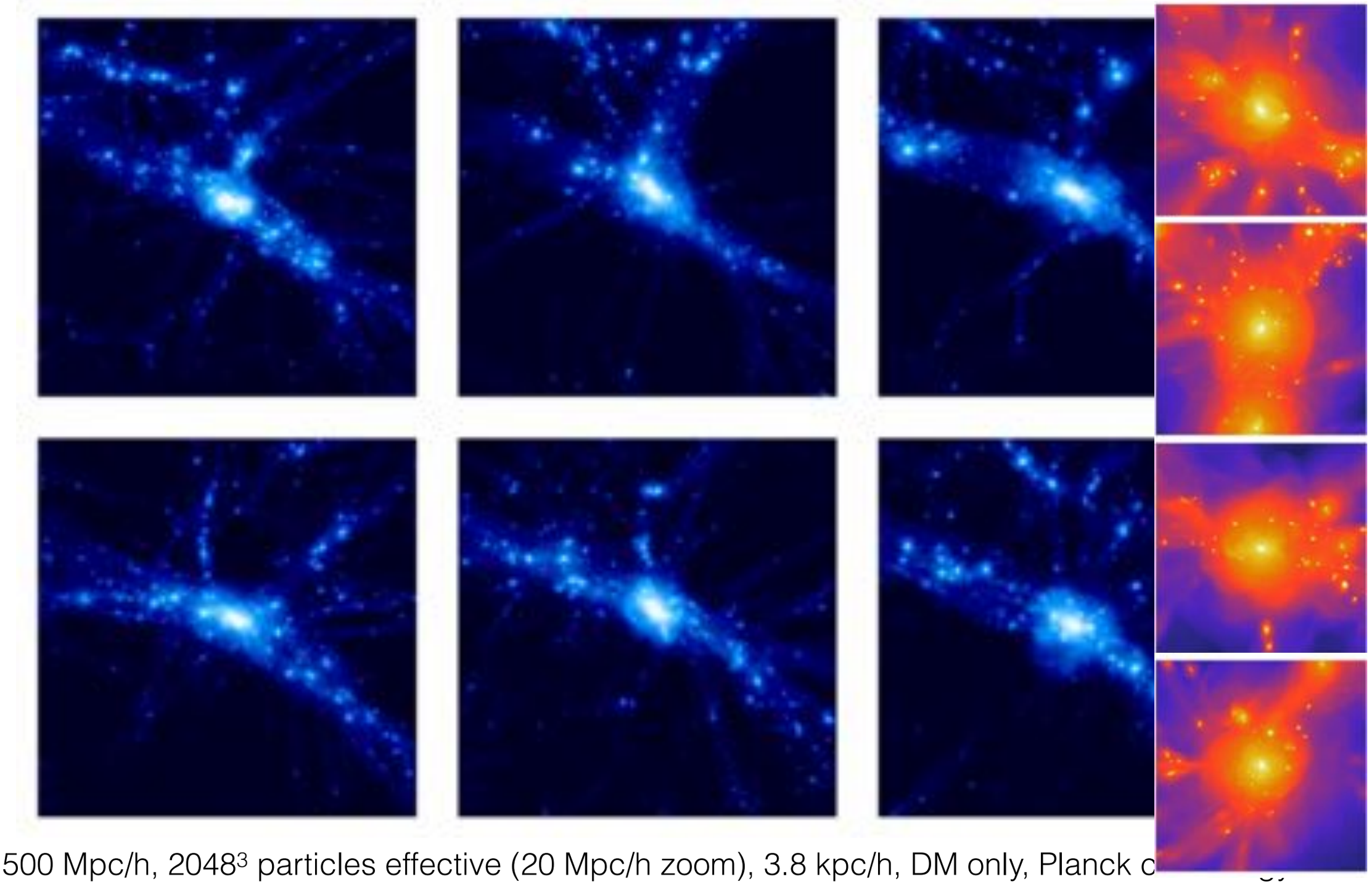
small residual cosmic variance



500 Mpc/h, 2048^3 particles effective (20 Mpc/h zoom), 3.8 kpc/h, DM only, Planck cosmology

Dark matter only

small residual cosmic variance



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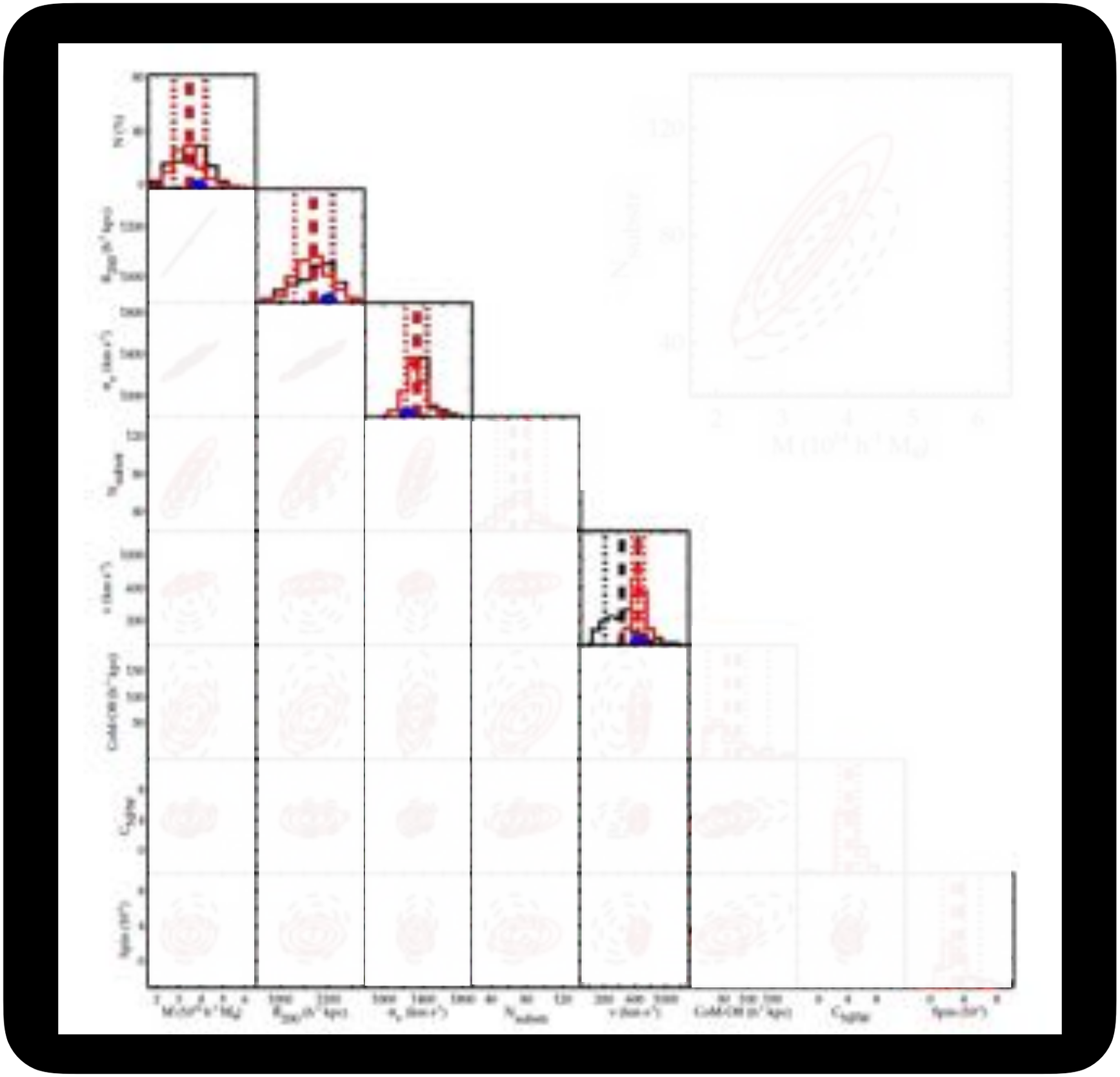
Rhapsody (Hahn+2017)

Dark matter only

Observed vs. Simulated Virgo cluster

Dark matter only

Overall agreement with observations



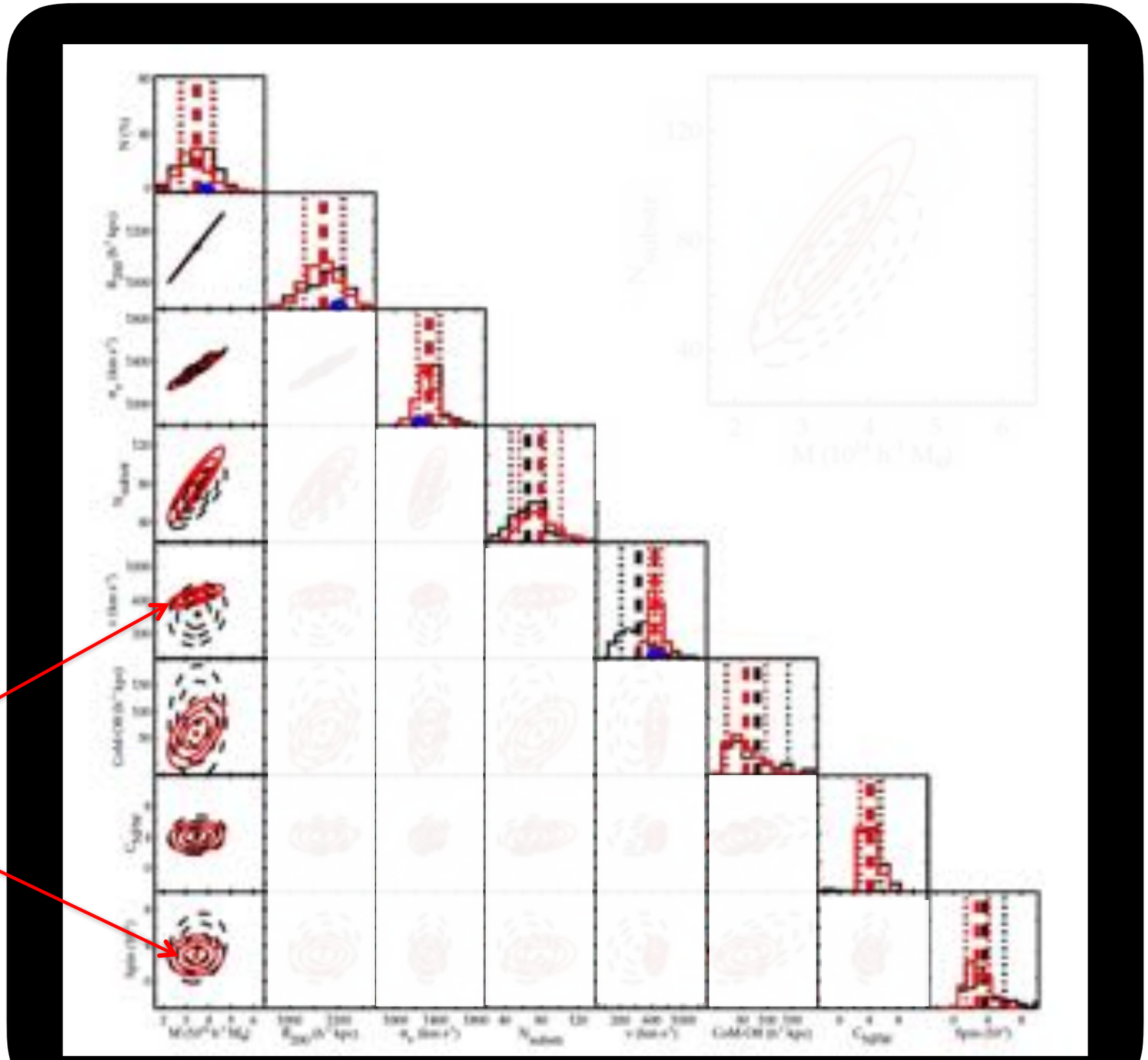
Sorce, Blaizot,
Dubois to be submitted

Dark matter only

Simulated Virgo cluster vs. Random clusters

Dark matter only

Different from an average random cluster



Velocity

Spin

→ Environment

Sorce, Blaizot,
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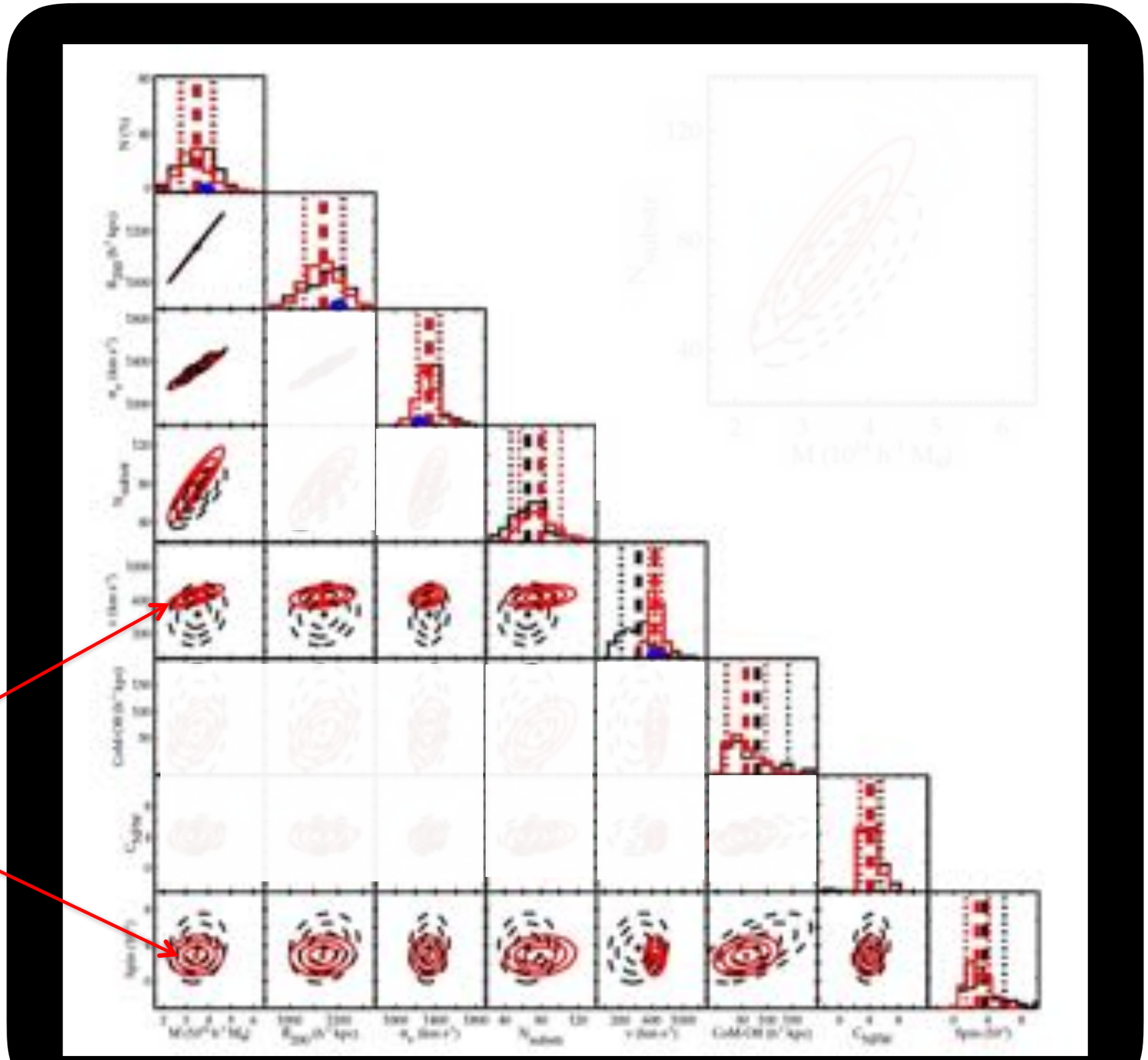
Dark matter only

Different from an average random cluster



Velocity

Spin

→ Environment

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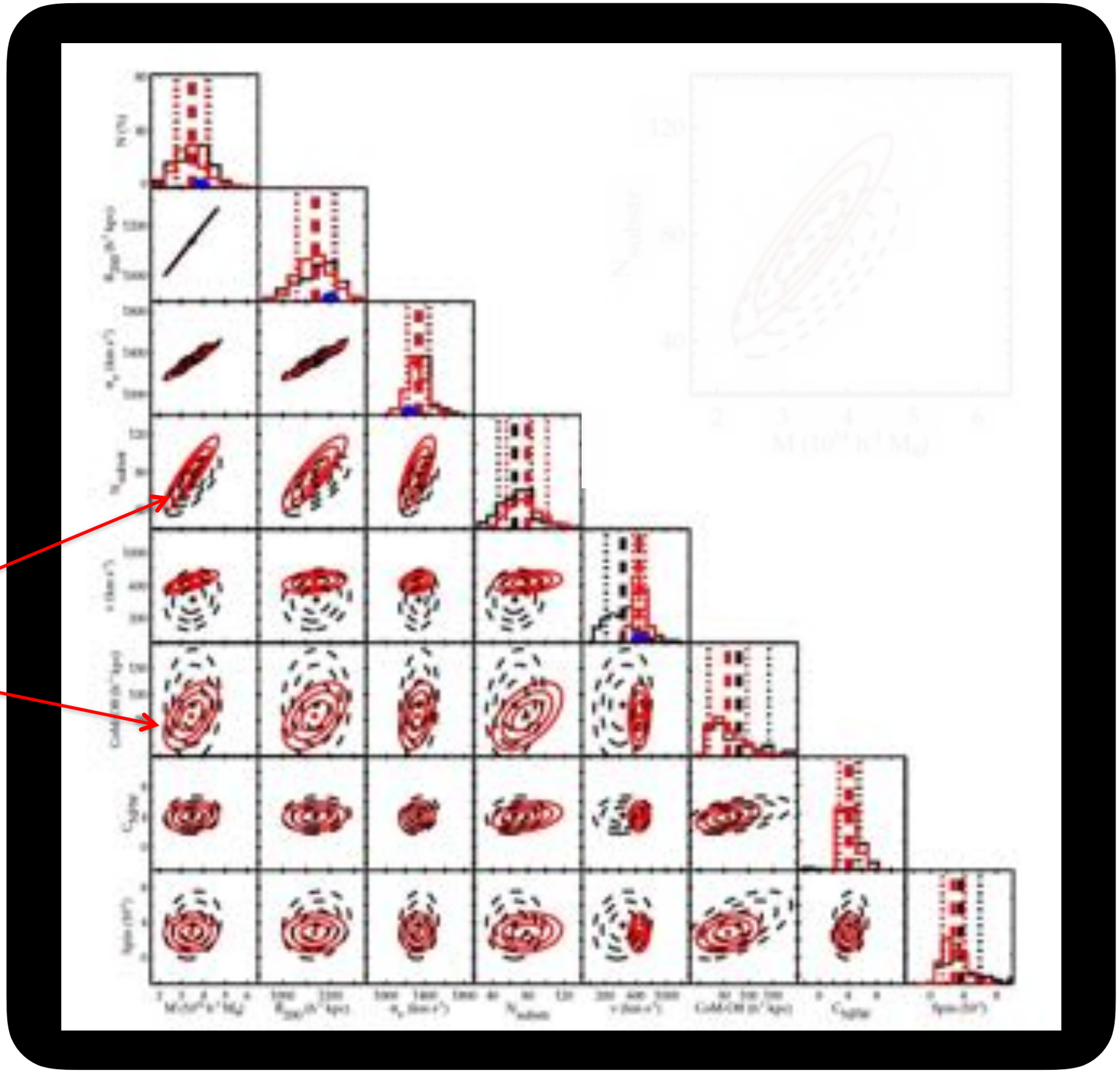
Dark matter only

Different from an average random cluster

Number of substructures

Center of mass offset wrt spherical center

➙ History



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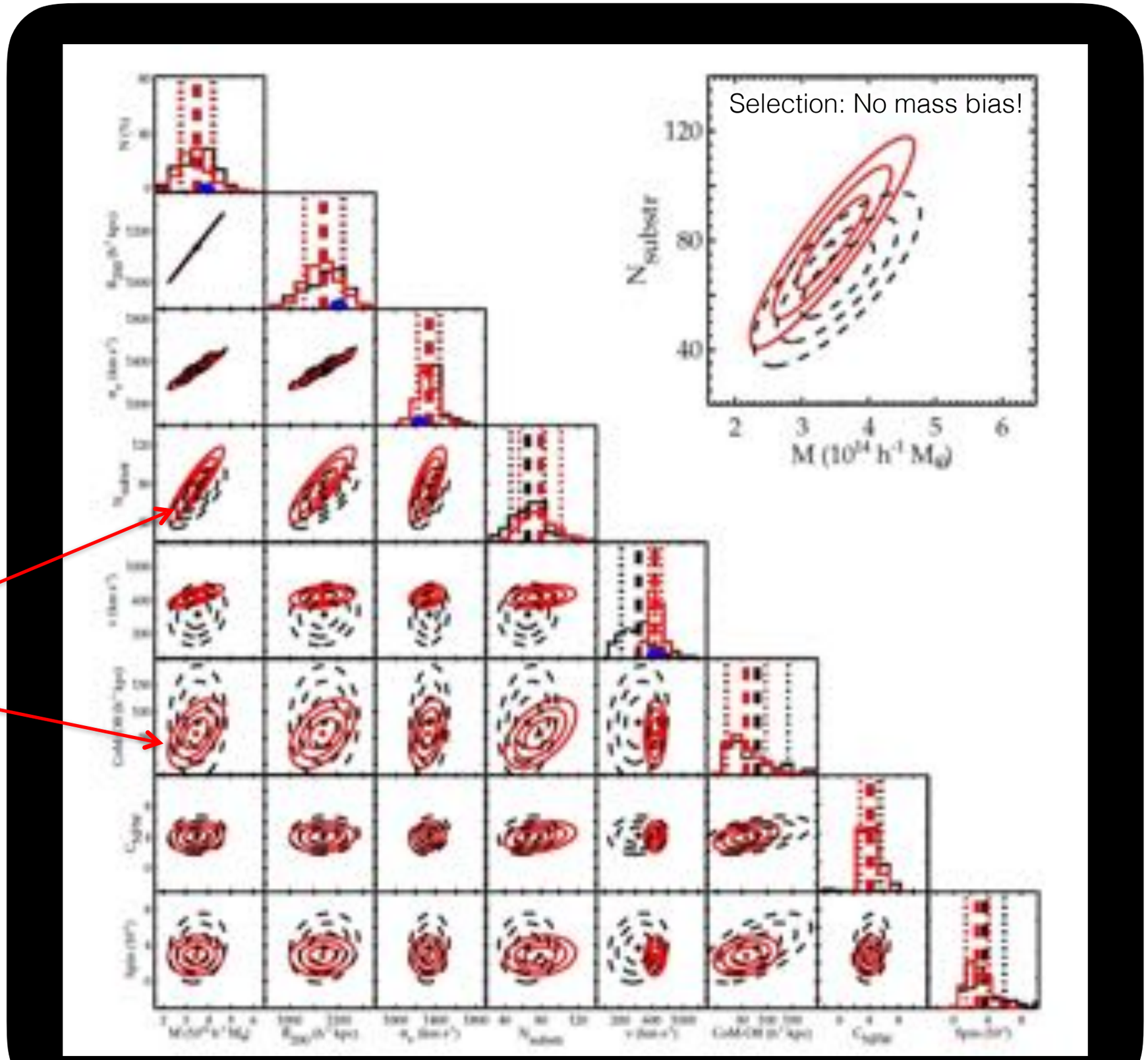
Different from an average random cluster



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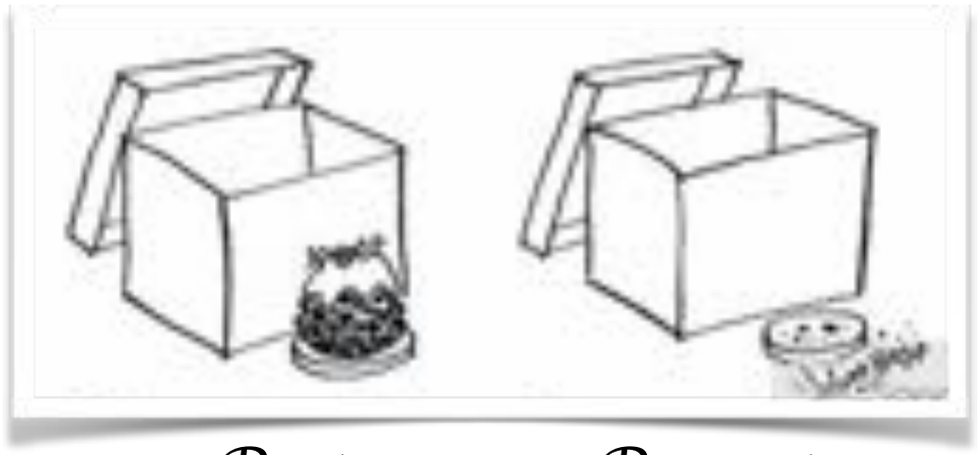


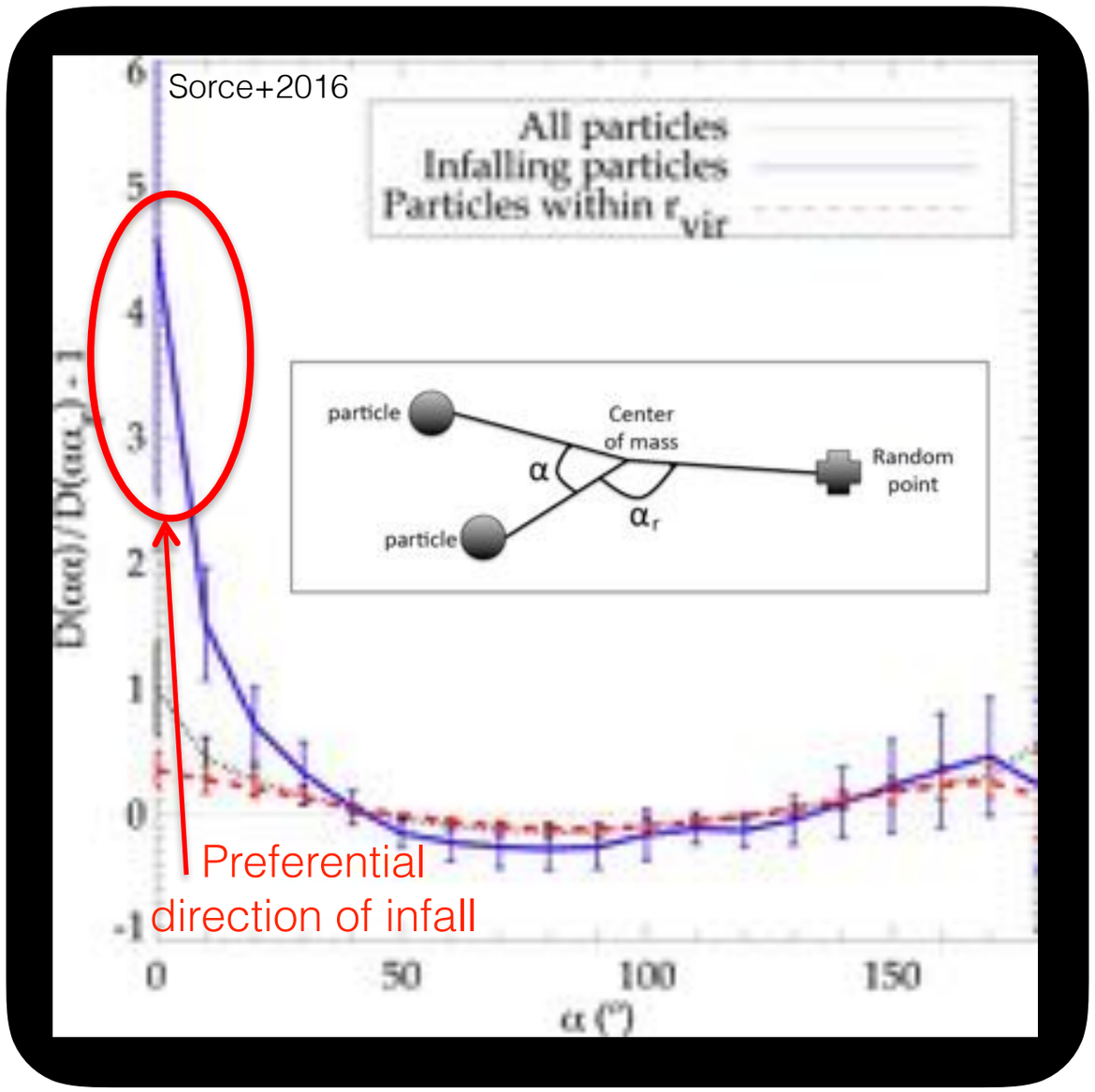
Past *Present*

Dark matter only

Agreement with observational predictions

West & Blakeslee 2000 : from observation, formation along a filament

From simulation, preferential direction of infall = filament



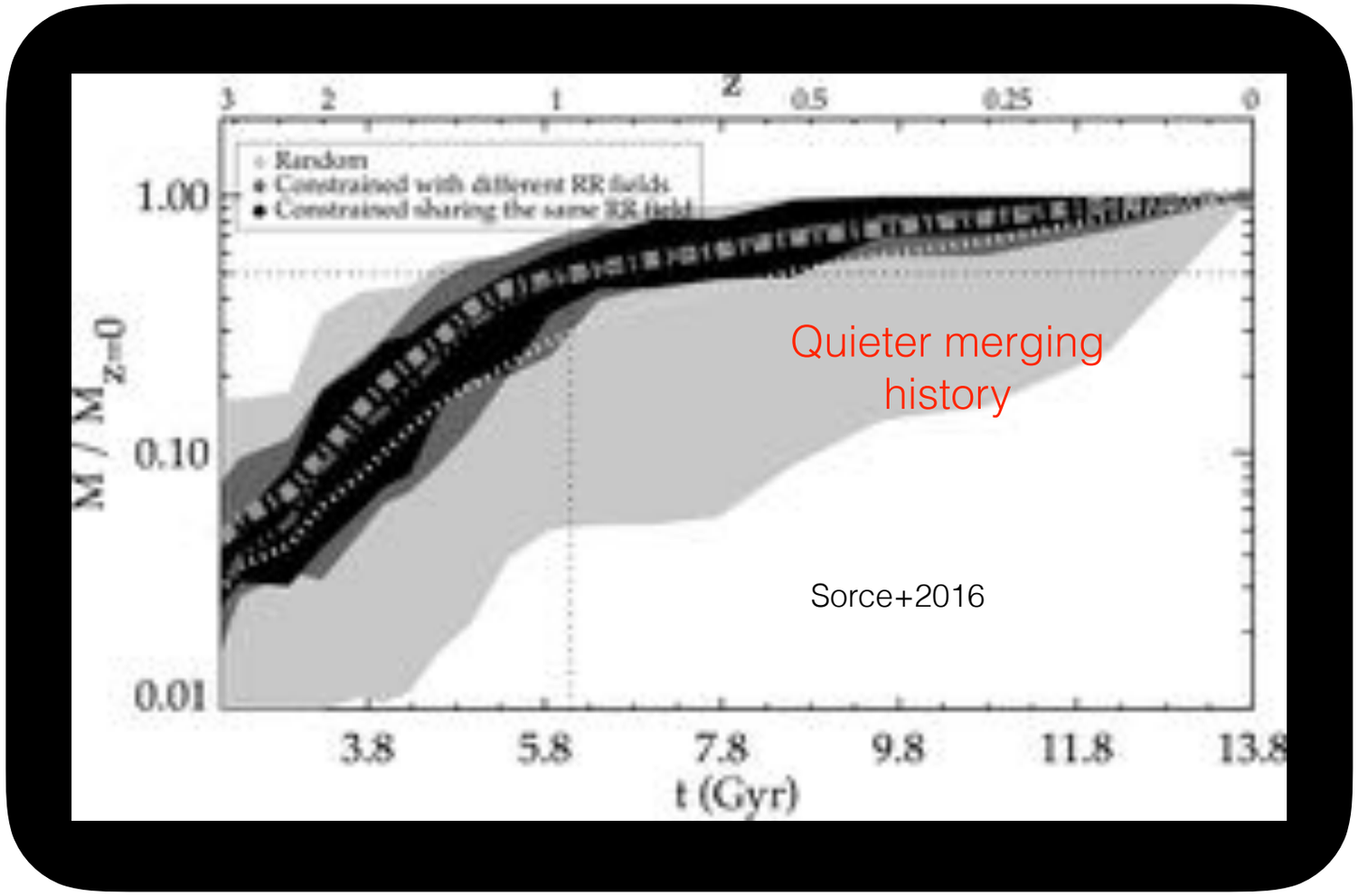
500 Mpc/h, 512^3 particles, DM only, Planck cosmology

Dark matter only

Agreement with observational predictions

Boselli+2008,2014: from observation, only small mergers within the past few Gyrs

From simulation, quieter merging history within the last few Gyrs = no major merger



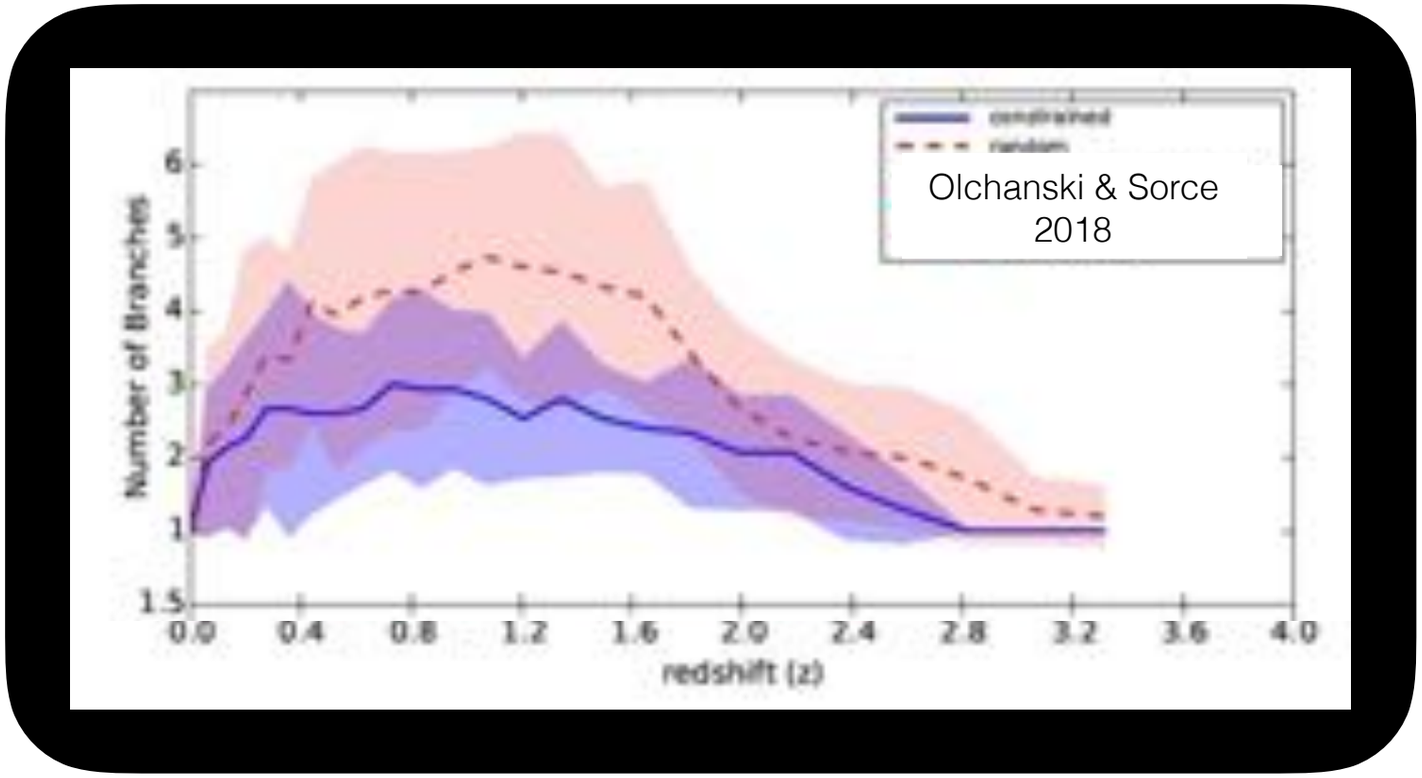
500 Mpc/h, 512^3 particles, DM only, Planck cosmology

Dark matter only

Agreement with observational predictions

Lisker+2018: from observation, remnant of a group of ~10% $m_{cluster}$ than infall 2-3 Gyr ago

From simulation, only one merger of ~10% $m_{cluster}$ within the past 4 Gyr



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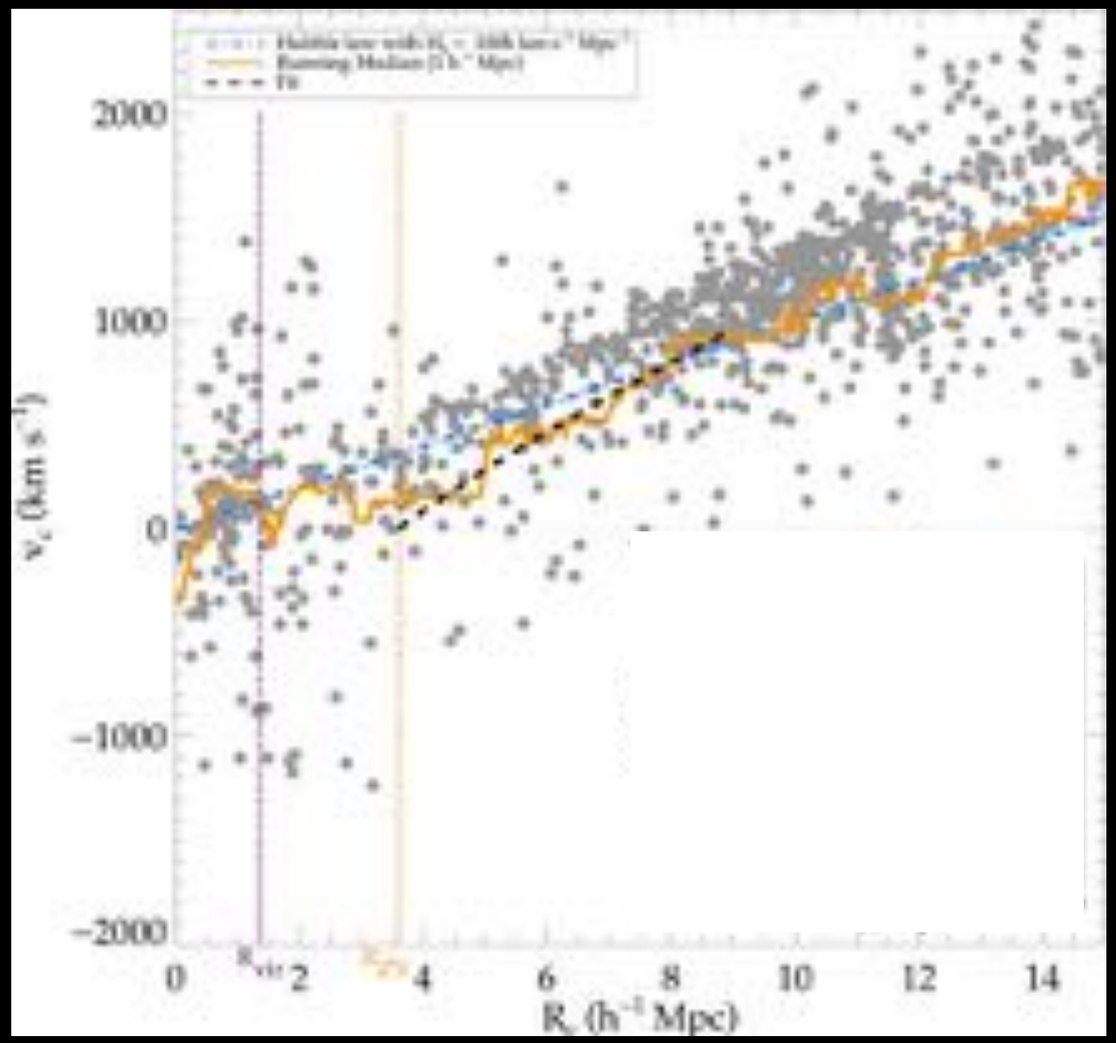
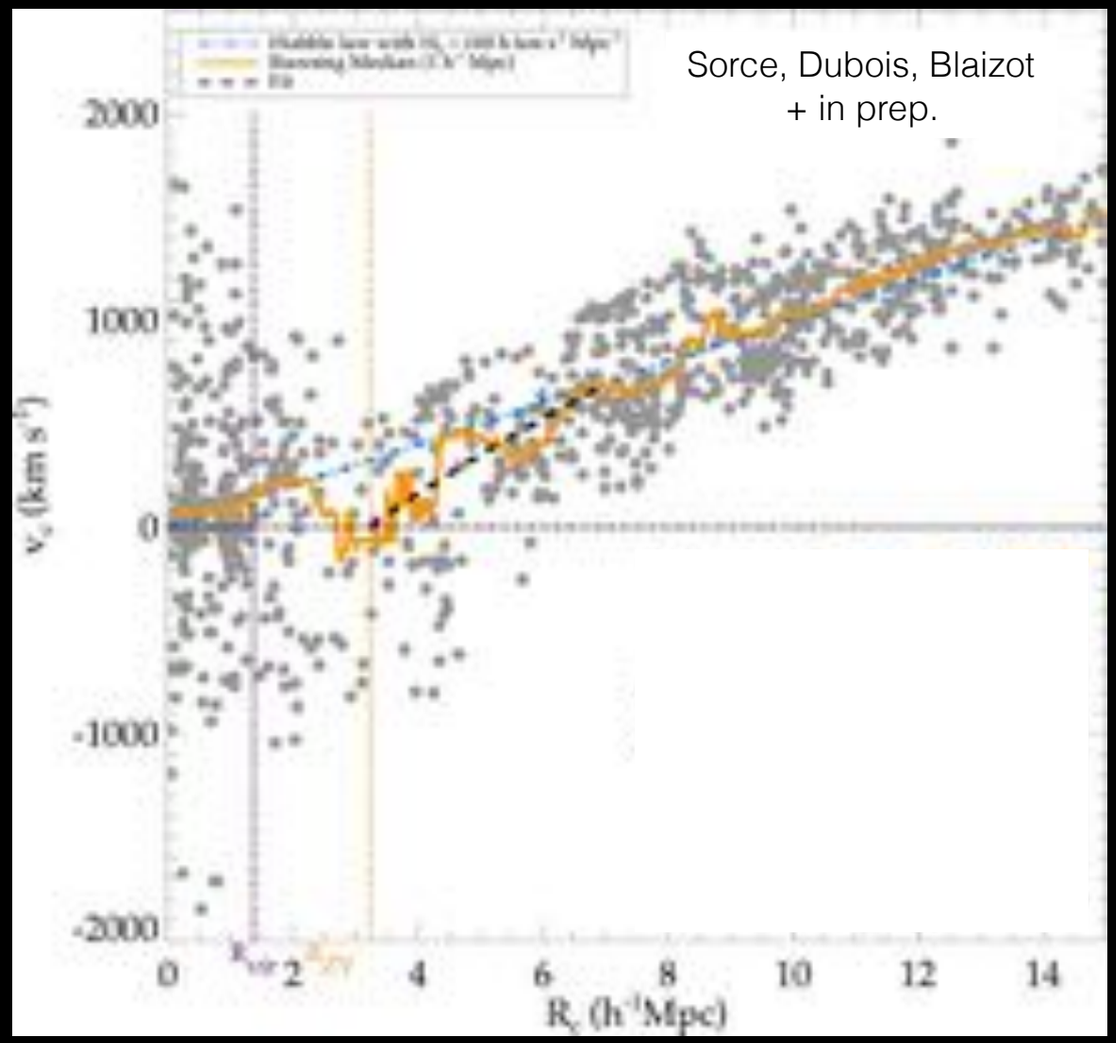
Hydrodynamical simulation

Observed vs. Simulated Virgo galaxy population

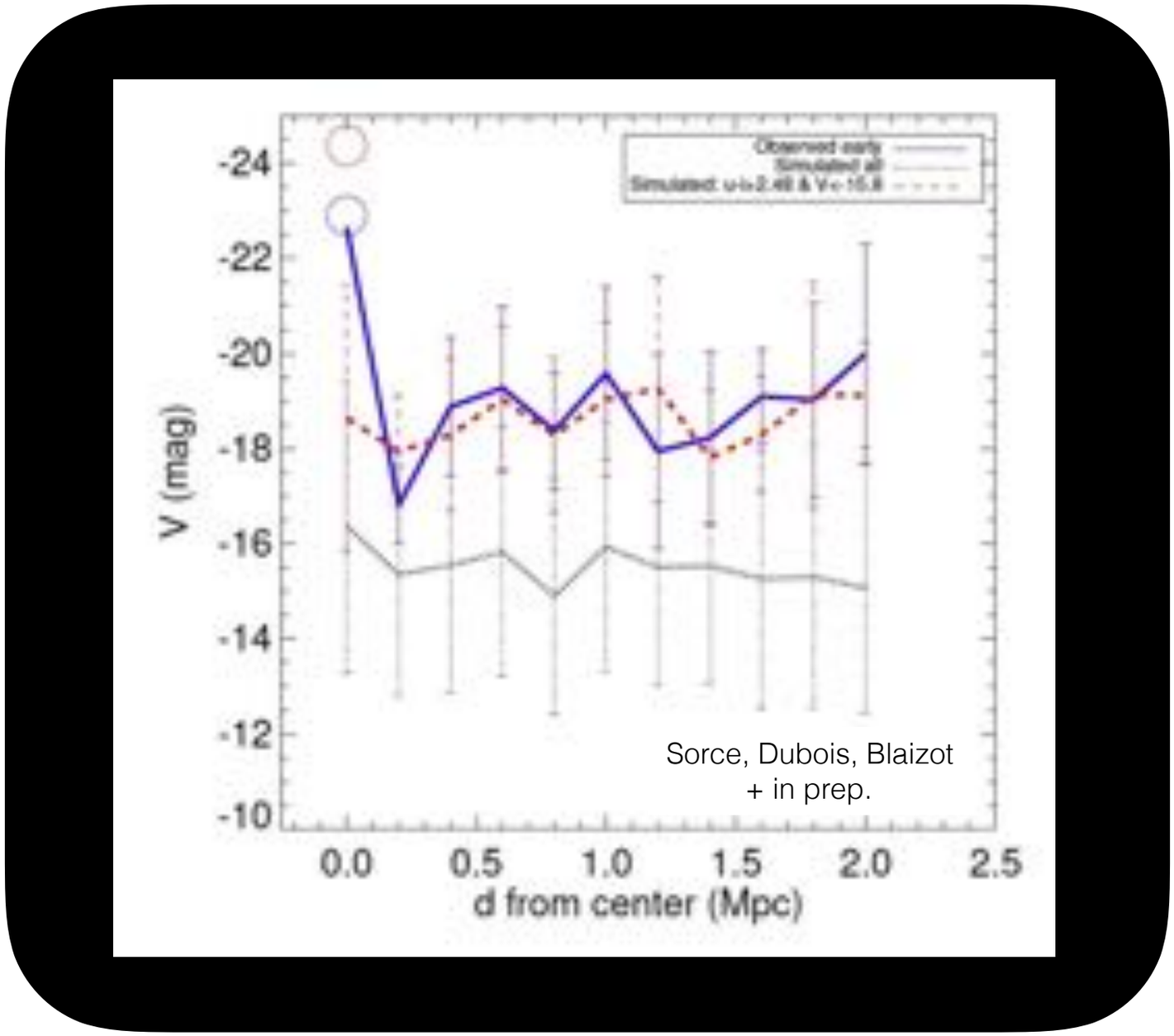
Hydrodynamical simulation

Comparison with observations





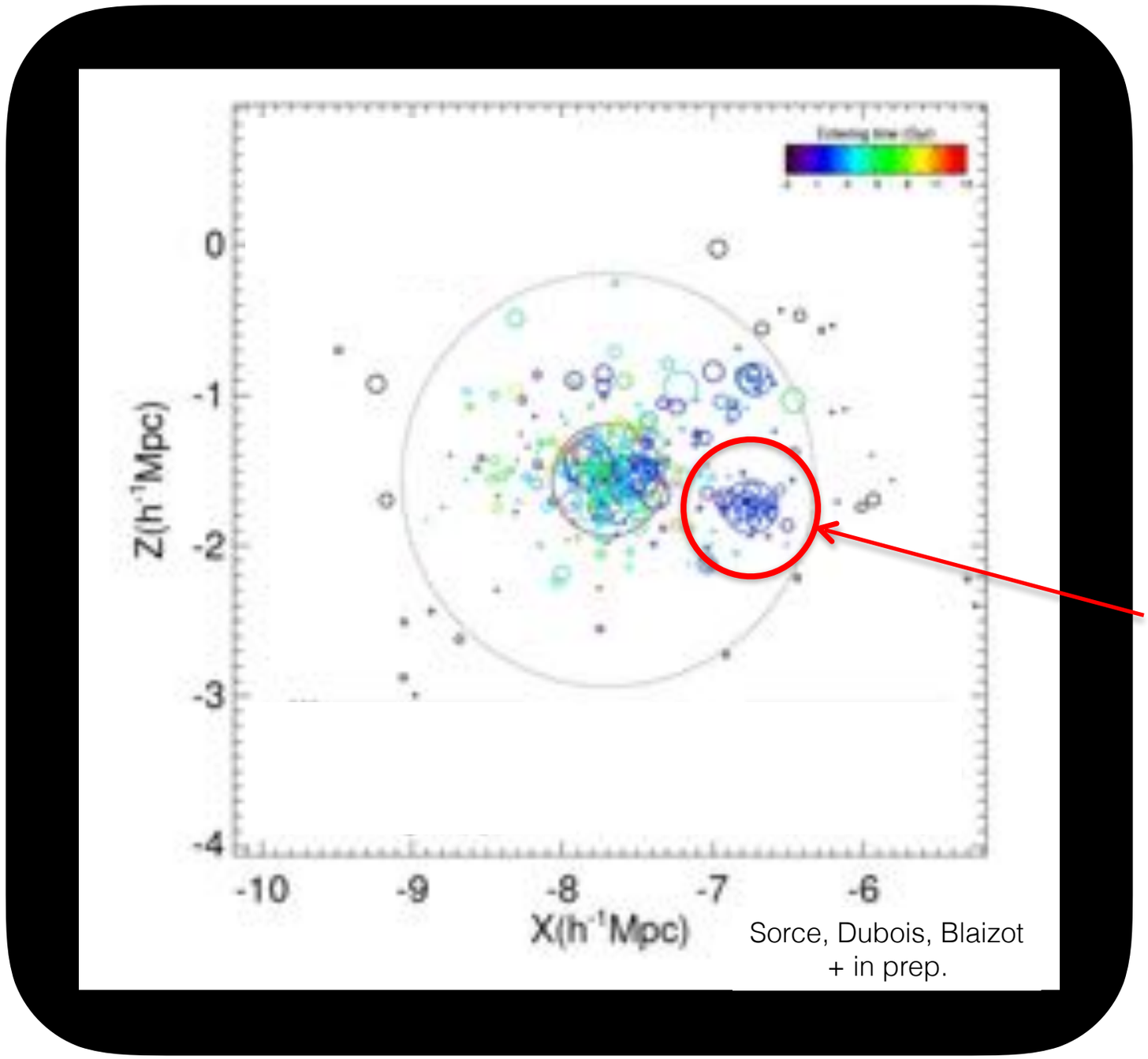
500 Mpc/h, 8192^3 particles effective (20 Mpc/h zoom), 0.24 kpc/h
hydrodynamics: SN and AGN feedback, Planck cosmology



Sorce, Dubois, Blaizot
+ in prep.

Hydrodynamical simulation

Comparison with observations

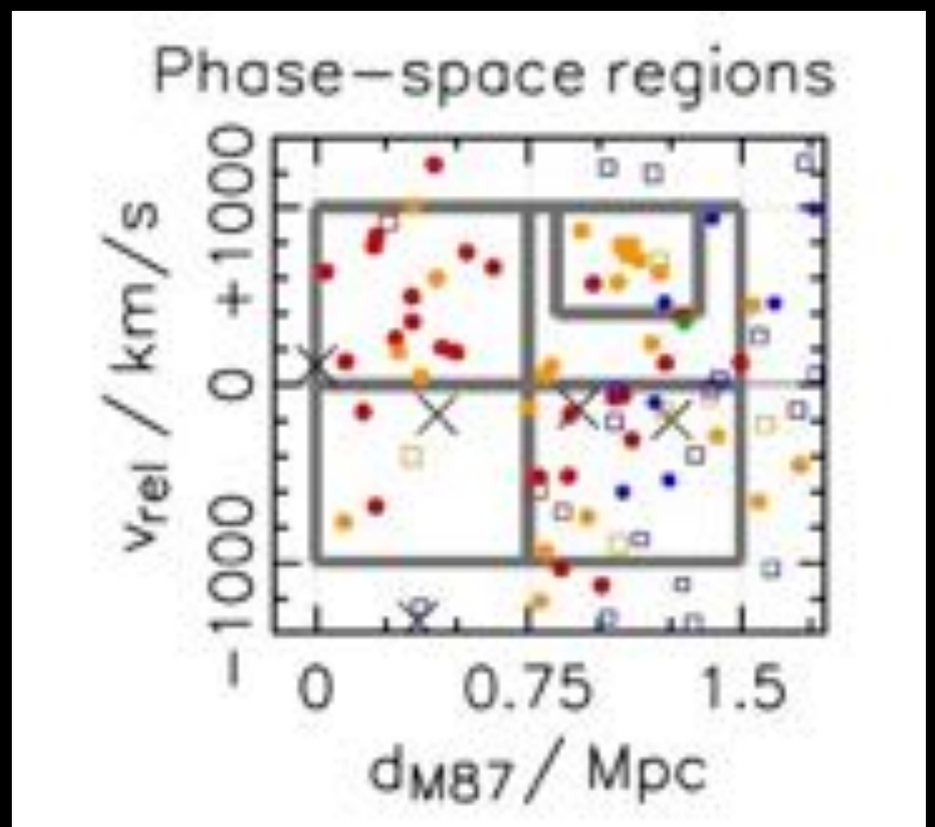


Small group that merged within the last few Gyrs

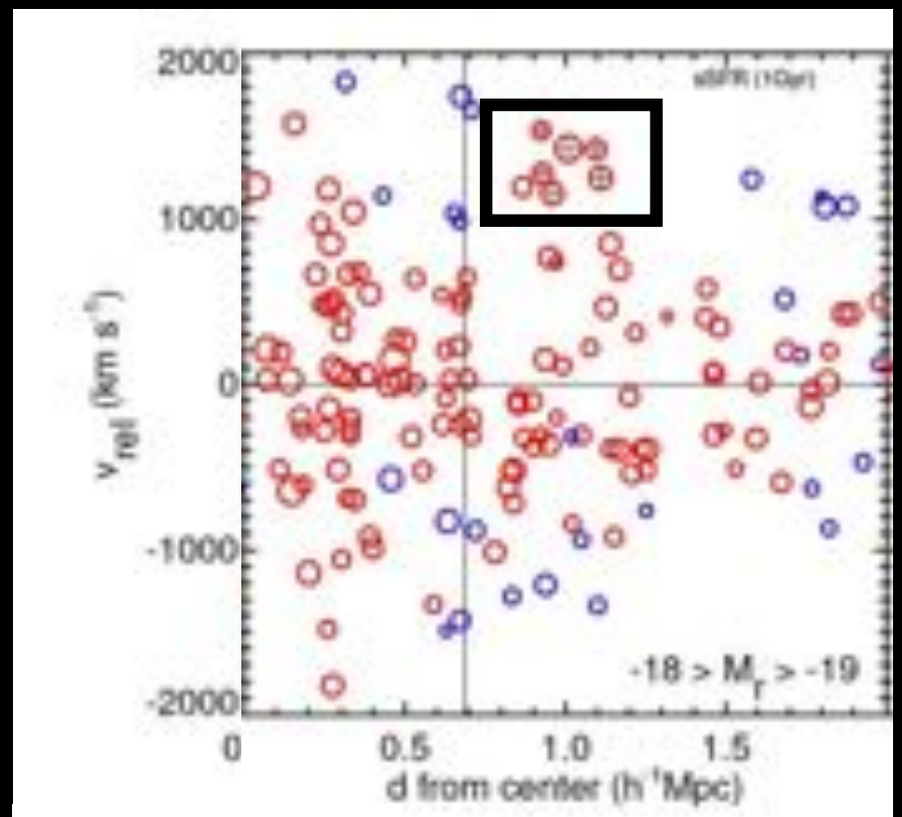
Sorce, Dubois, Blaizot + in prep.

Hydrodynamical simulation

Comparison with observations



Lisker+2018



Sorce, Dubois, Blaizot
+ in prep.

Summary & Prospectives

Excellent lookalikes

- small residual cosmic variance
- agreement with current observations at z=0: both overall and galaxy population
- agreement with observational ‘predictions’ for past history

➙ calibration of formation and evolution modeling, measurement techniques possible, etc

Acknowledgements

Thank you, Merci, Grazie,
Gracias, Danke, спаси́бо,
Mahalo, 谢谢, ありがとう,
תודה, Obrigada, Dank u,
Tak, Cảm ơn, Dziękuję , …