

Probing the cosmic dark matter
distribution using observations and
simulations of clusters of galaxies

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- Large-scale peaks of Dark Matter

Environment provided by superclusters

Chon, Böhringer, Nowak (2013)

Chon, Böhringer, Krause (2014)

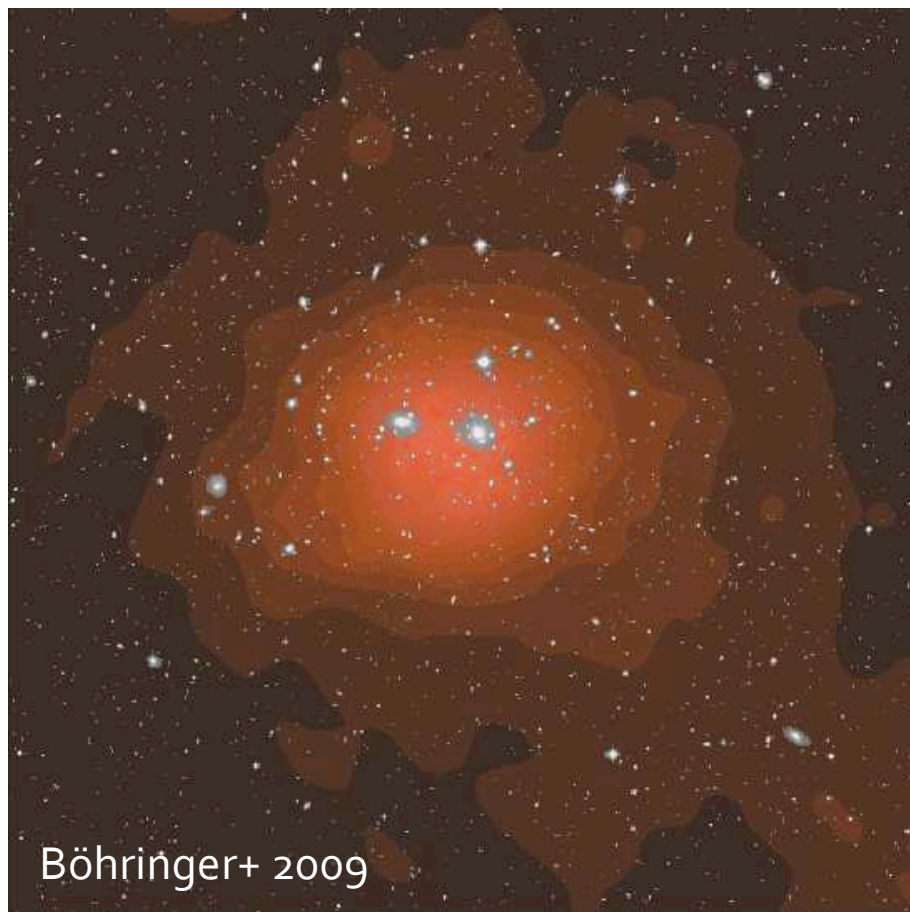
Chon, Böhringer, Zaroubi (2015)

- (In)homogeneous distribution of Dark Matter

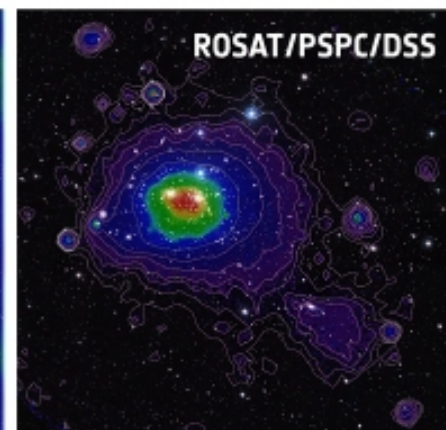
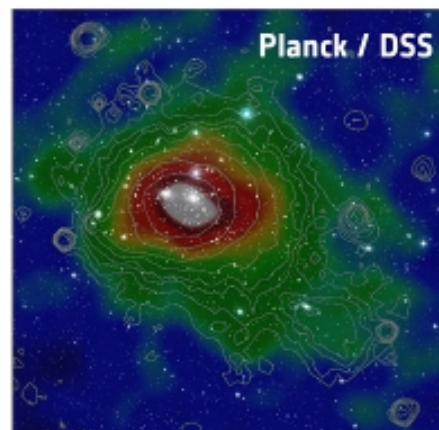
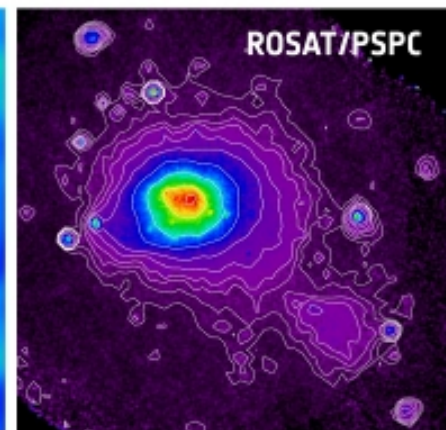
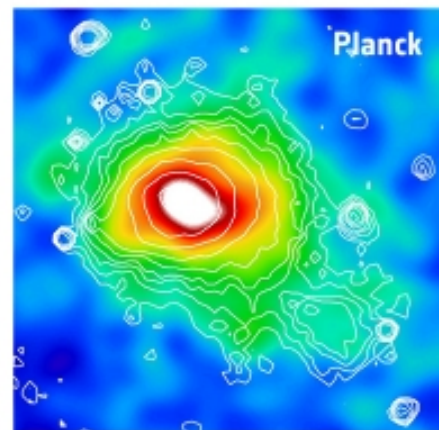
Local cosmography

Böhringer+ (2015)

Cluster constituents



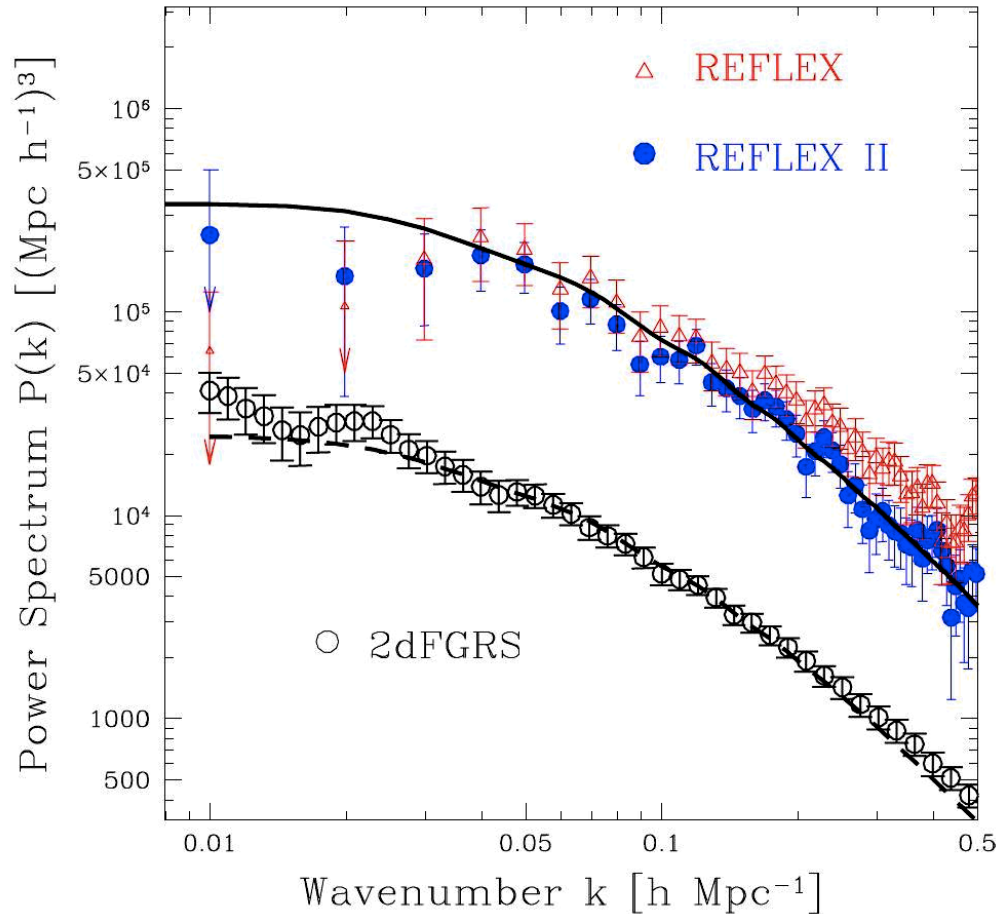
Optical Palomar sky survey (gray)
ROSAT X-ray all-sky survey (red)



DM 82 – 87% Hot gas 11-13 %
Galaxies 2-5%

credit: ESA/LFI & HFI Consortia

Clusters as biased tracers of Dark Matter

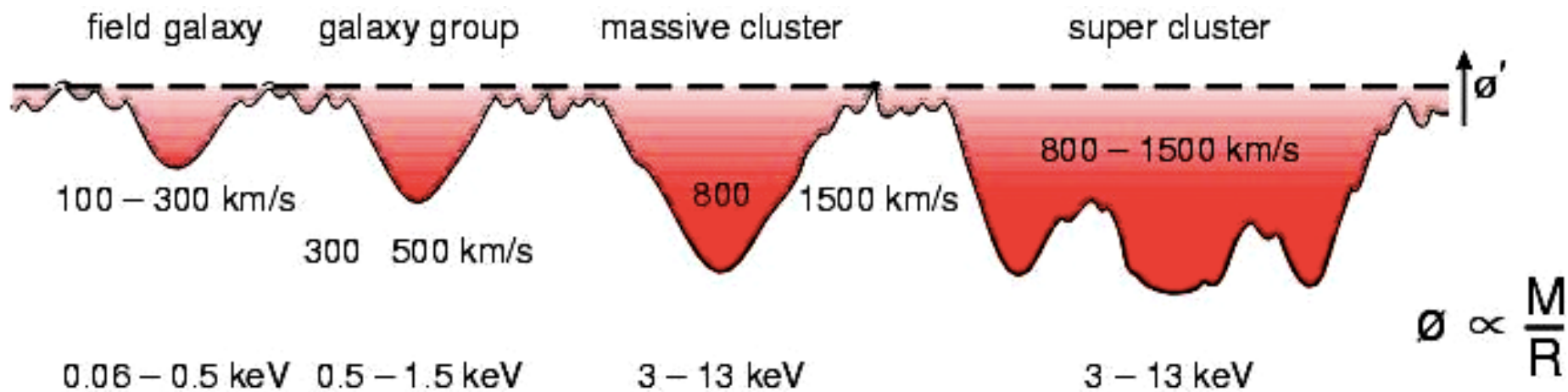


$$\tilde{P}(k) = b^2 \cdot P_{DM}(k)$$

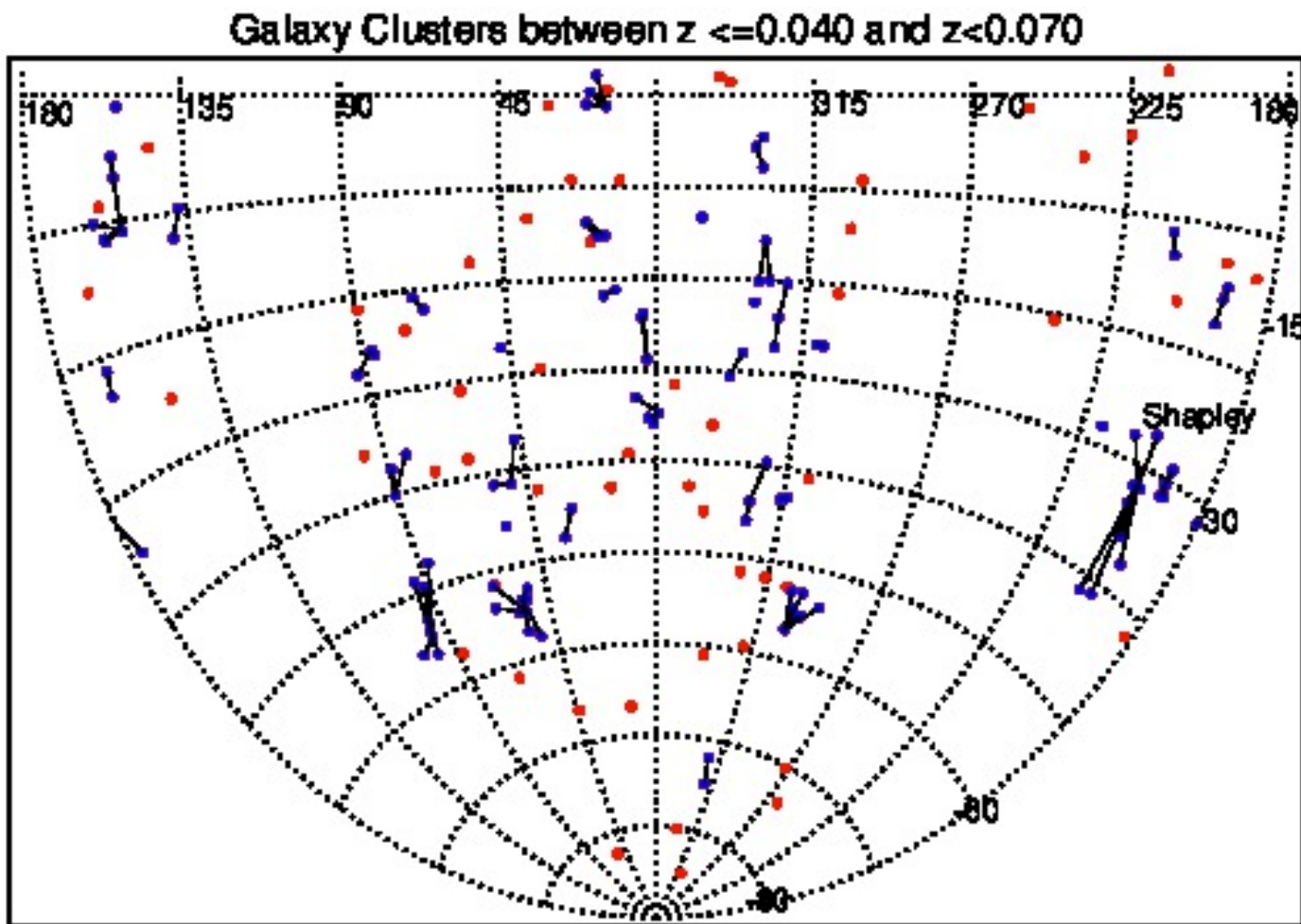
Cluster density traces DM density.

Balaguera-Antolinez+ 2010

Hierarchy of cosmic structures

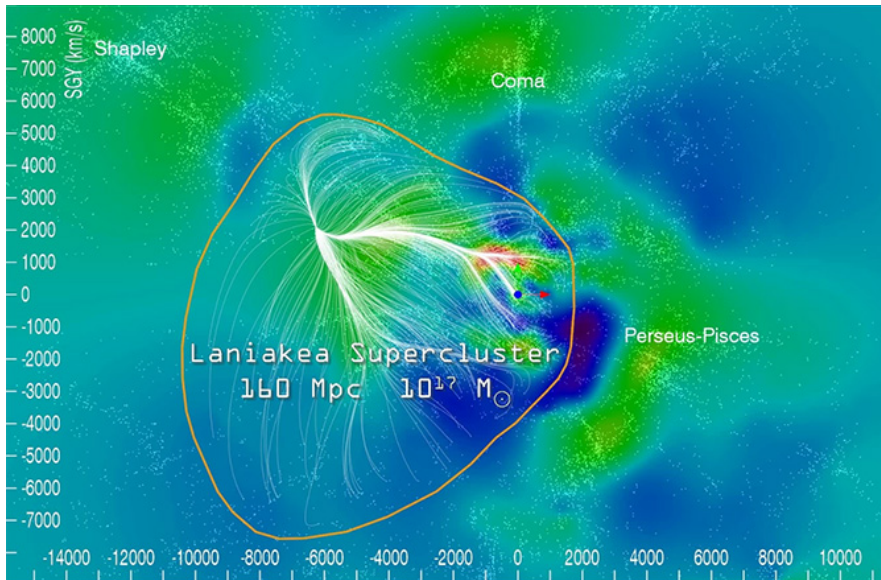


REFLEX supercluster distribution

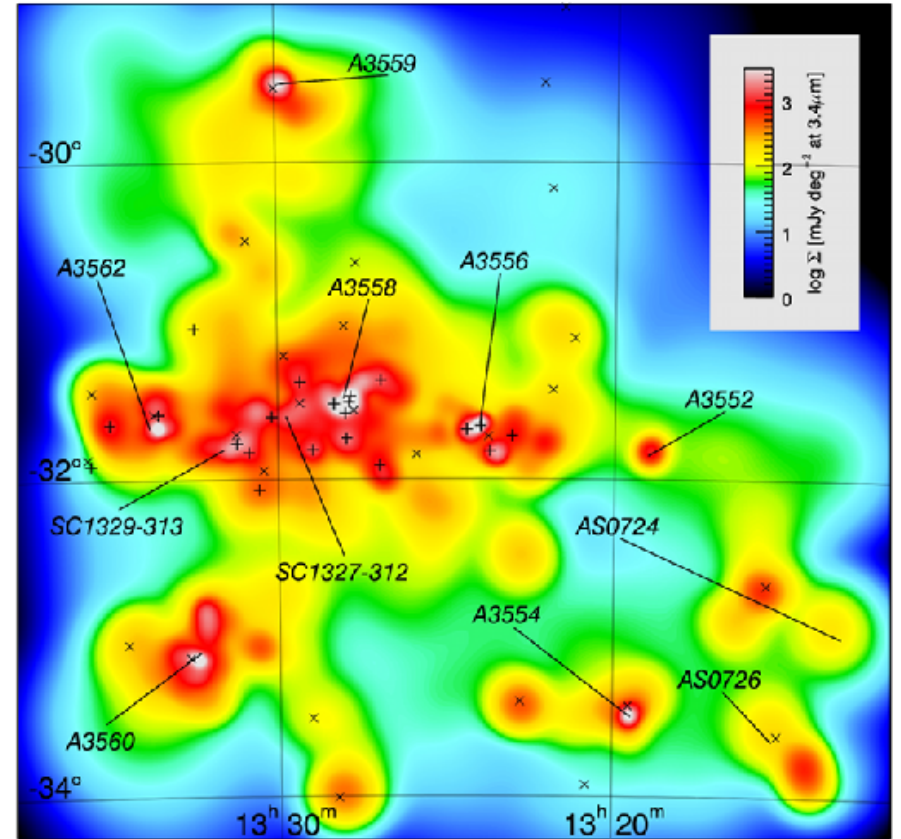


GC+ 2013

Applications

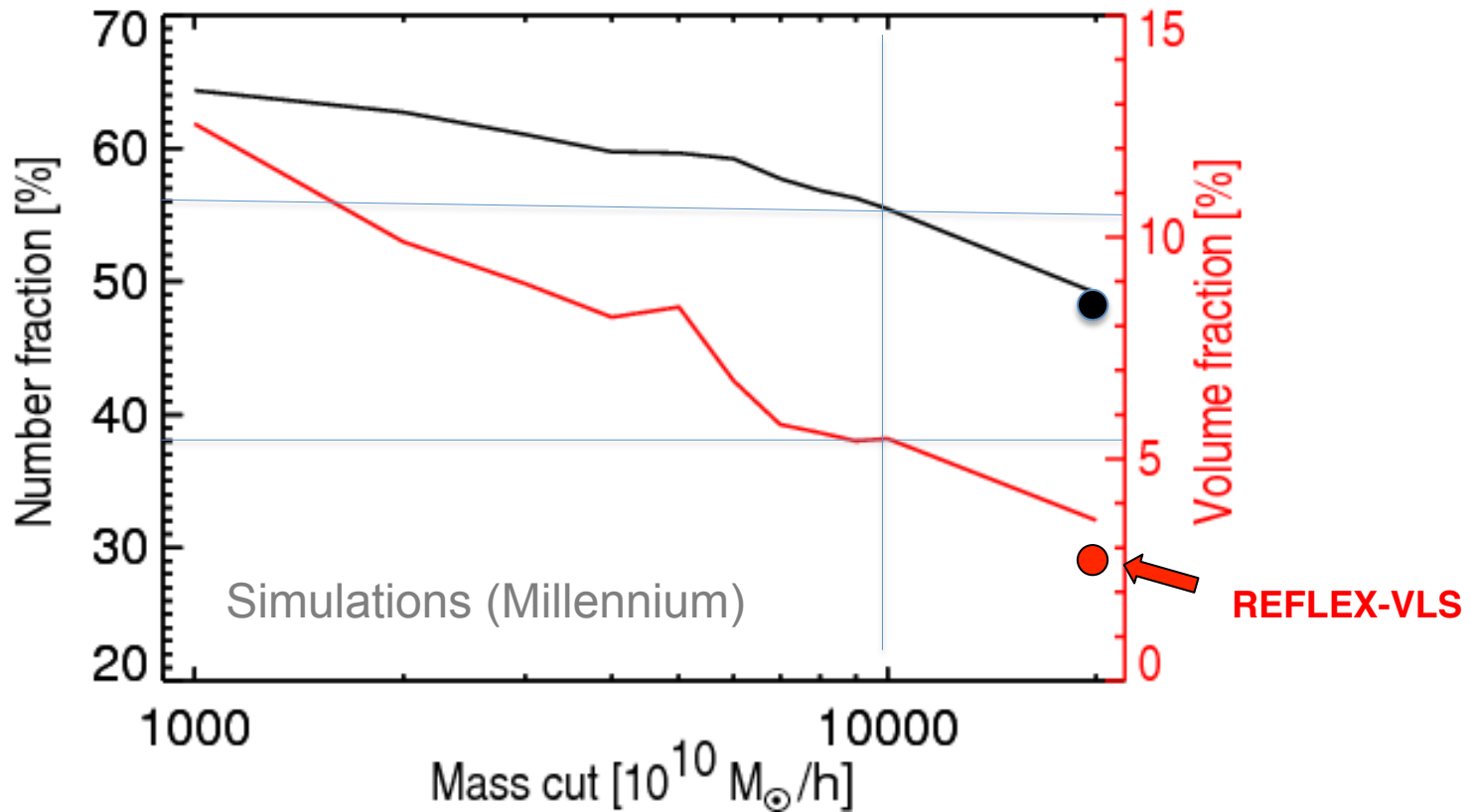


Tully+ 2014



Merluzzi+2014

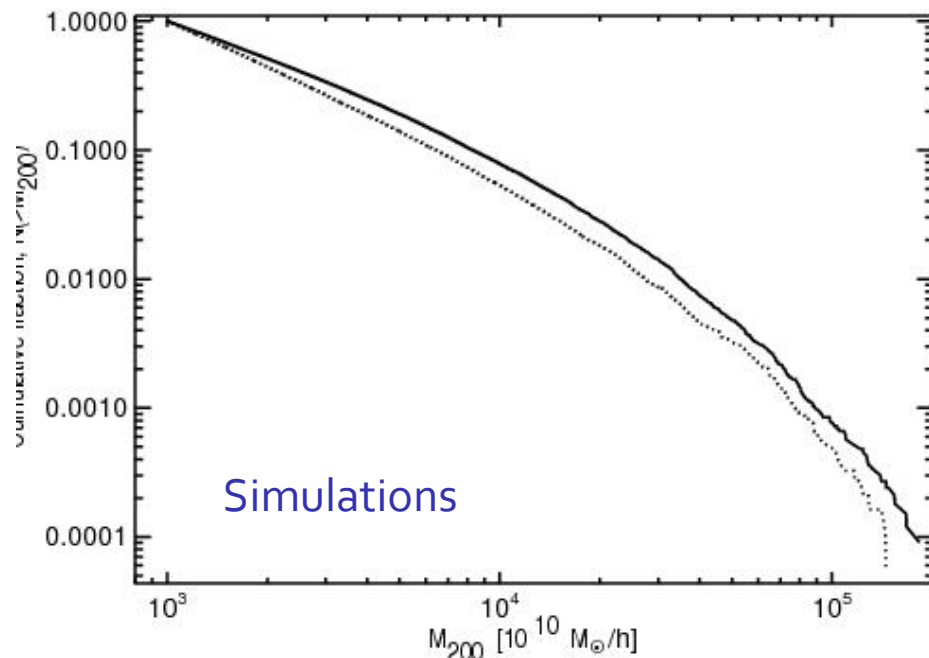
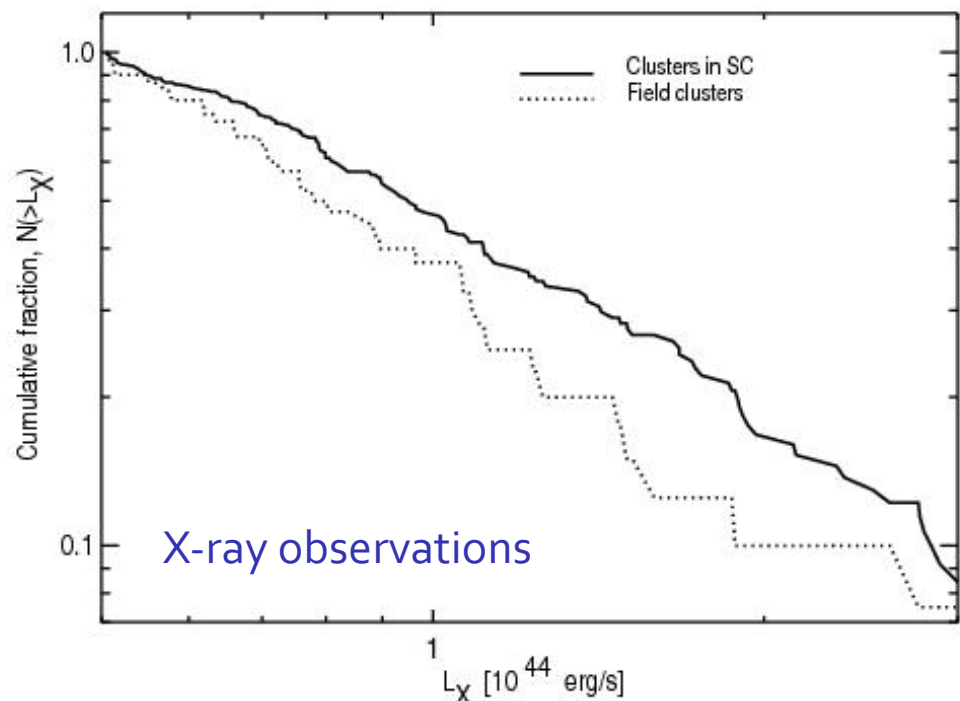
Statistics – number and volume



Superclusters occupy only a small fraction, few %, of the Universe, but they contain more than half of the clusters

Environment

Cumulative X-ray luminosity function (observation)
and cumulative mass function (simulation).
Supercluster clusters (solid)
Field clusters (dotted)



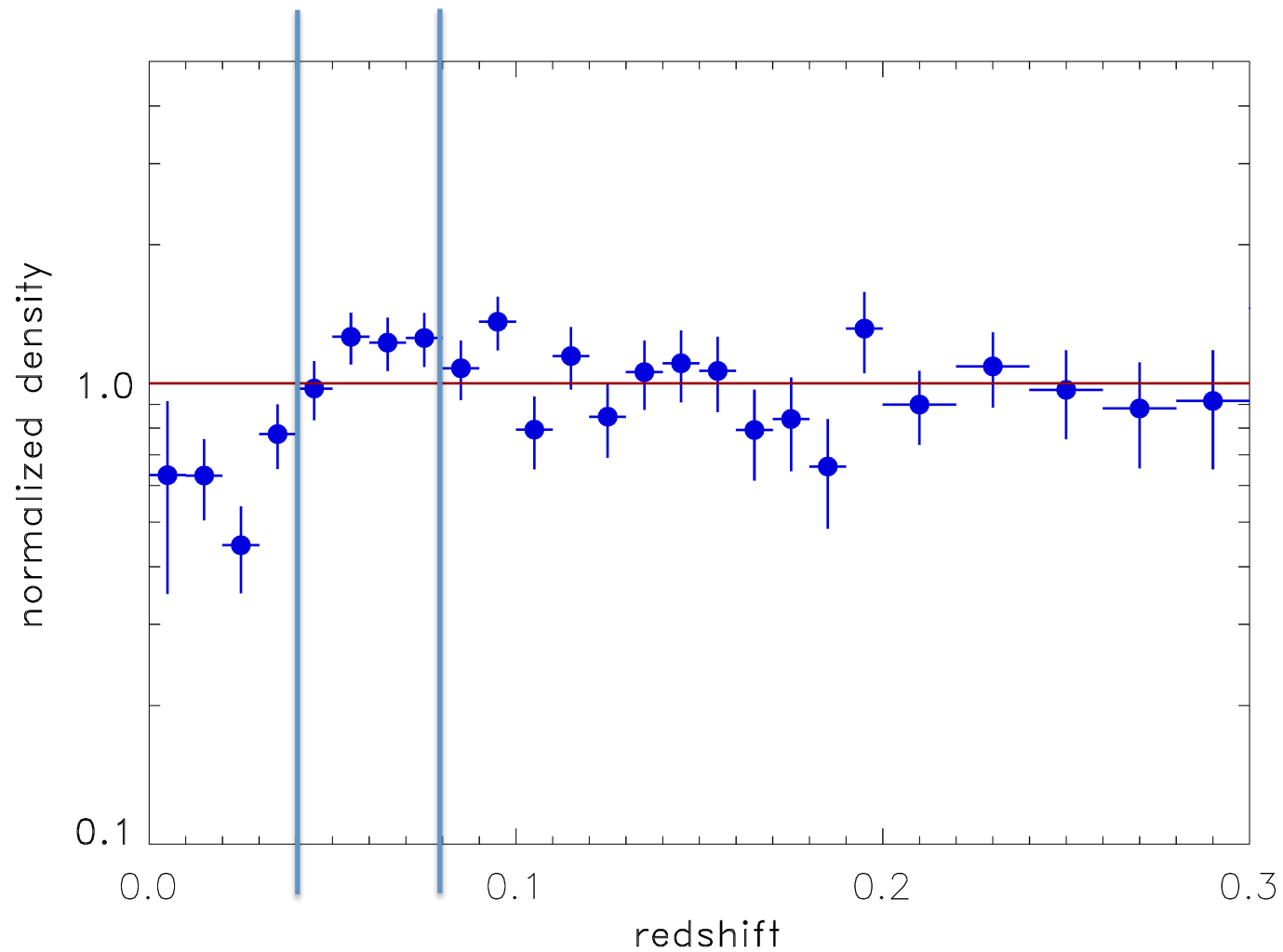
Top heavy X-ray L_X /mass function

GC+ 2014

Local density traced by REFLEX II

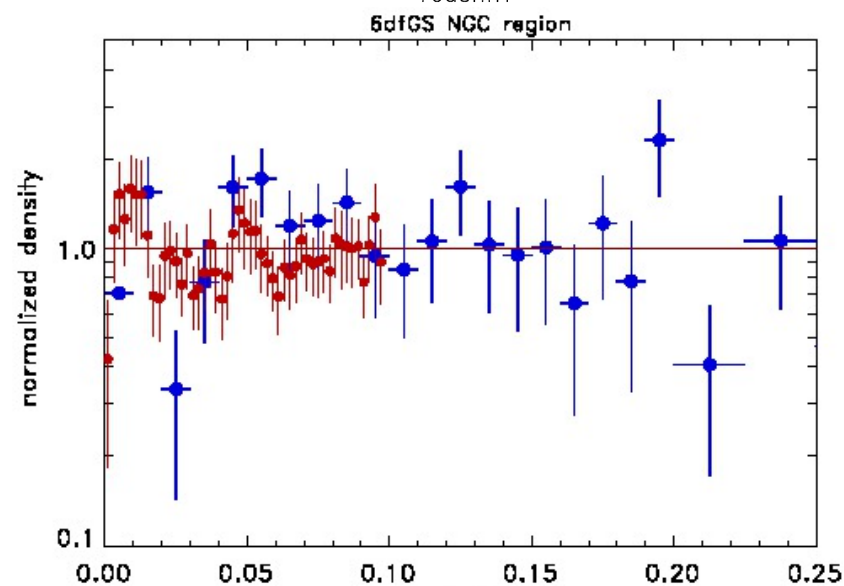
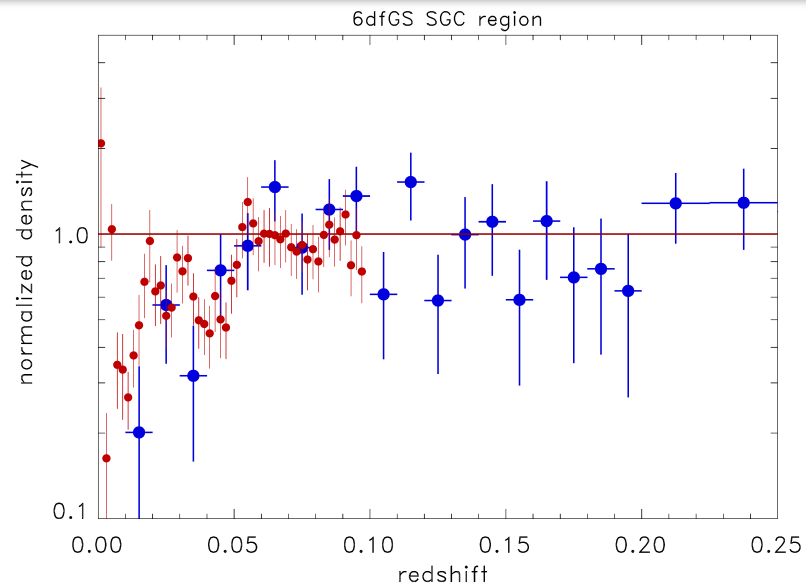
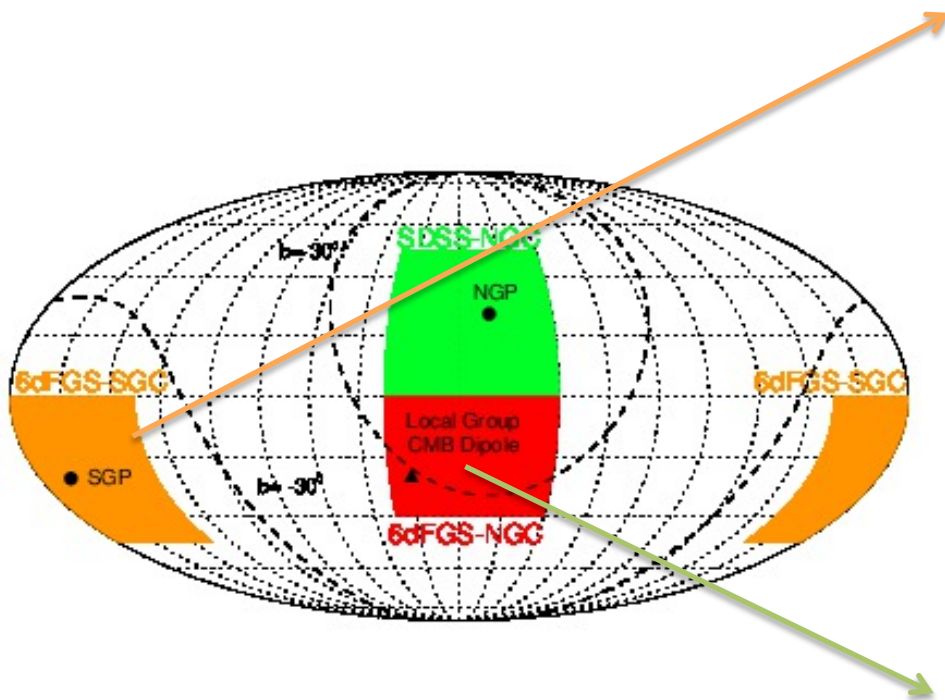
- Conflicting arguments about under-density measurement, e.g. Zehavi+98, Jha+07 vs. Hudson+04, Tonry+03, Conley +07, Giovanelli+99, Whitbourn+14
- Cosmic acceleration observed with SNIa and CMB – by minimum void model, sitting at centre, e.g. Alexander+09, which rules out Lambda Universe
- Implication on the interpretation of the local measurements of cosmological parameters
- REFLEX traces out to a large radius, $z=0.3$, at least.

Underdensity detected in REFLEX II



>3.4 σ detection of local underdensity out to $z \sim 0.04$ (170 Mpc) for $L_x \geq 1e42$ erg/s

Distribution of galaxies vs. clusters



Böhringer+ 2014

Summary

- Exploring LSS with REFLEX cluster sample
- Very large scale distribution of DM
- Clusters of galaxies provide indirect ways to measure distribution of Dark Matter – amplified.
- Superstes-clusters – new way to probe environment of DM overdensities.
- (In)homogeneous distribution of DM – locally underdense in southern sky. Implications on cosmological parameters.
- Consistency between observations and simulations based on CDM structure formation scenario.