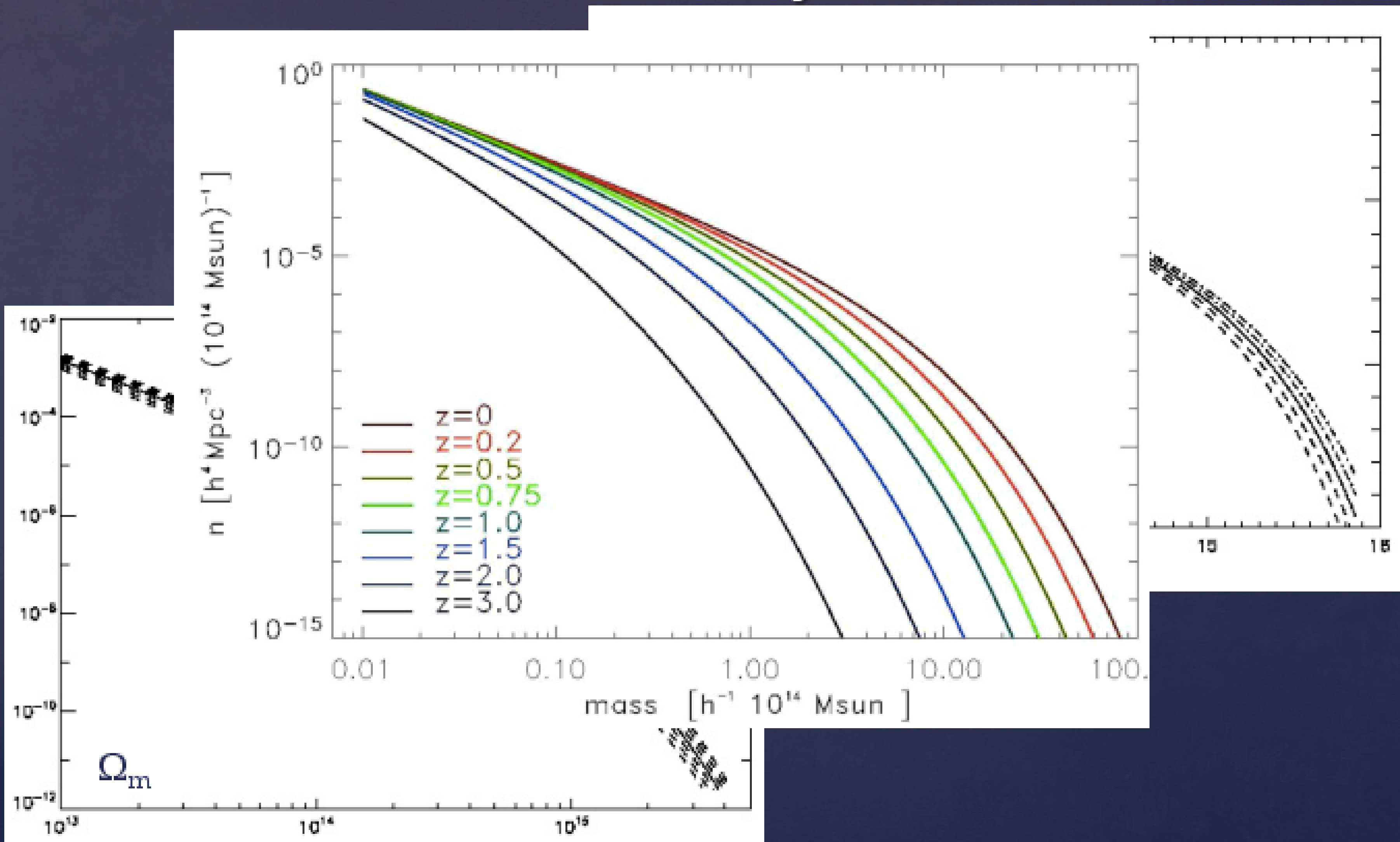
Characterising our Universe with the REFLEX cluster survey

Gayoung Chon @ MPE

Overview

- REFLEX cluster survey
- Testing cosmology
- Large-scale structure with superclusters

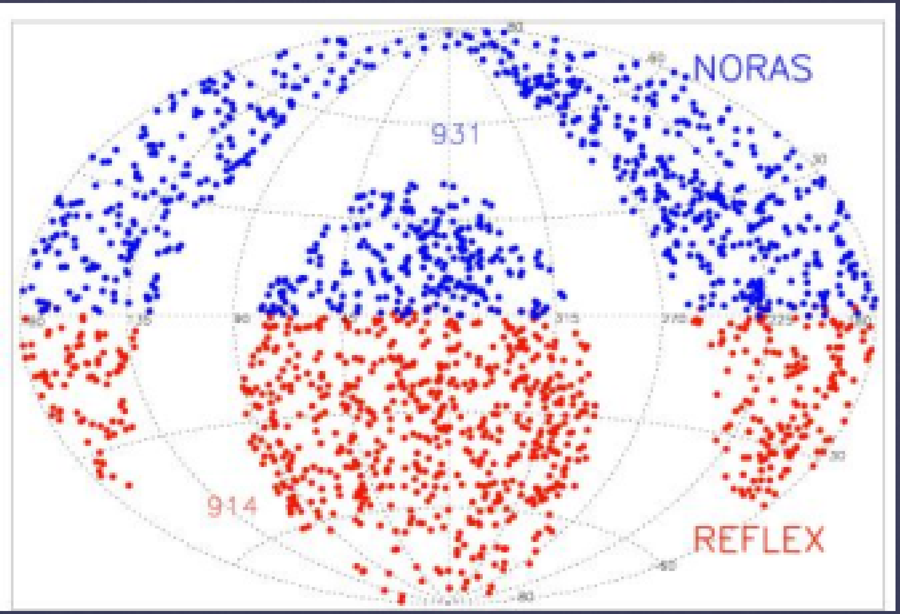
Cluster number density



REFLEX
ROSAT-ESO flux-limited X-ray clusters

- P.I. Hans Böhringer
- Extended REFLEX (REFLEX II) is completed
- Largest, homogenous flux-limited sample of X-ray clusters
- Long-term follow-up with ESO instruments
- Northern counterpart is being completed

REFLEX and NORAS cluster survey



REFLEX II 919 clusters

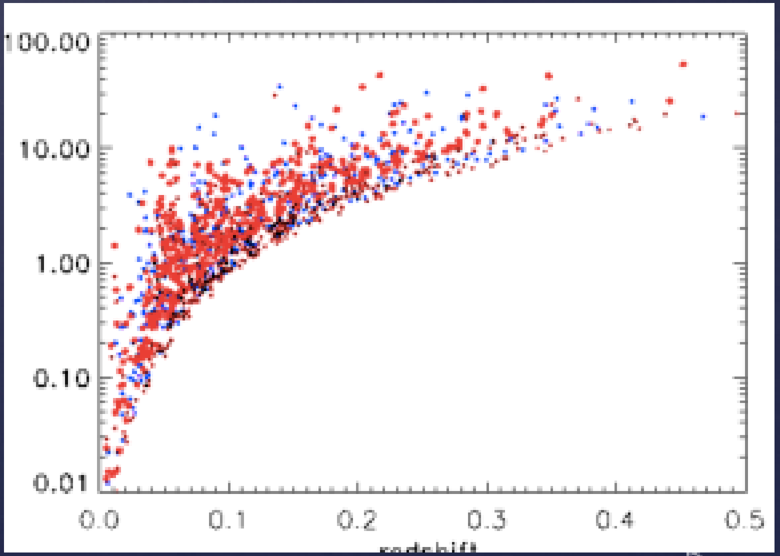
NORAS II 934 clusters

F> 1.8 10^{-12} erg s^{-1} cm^{-2}

REFLEX I: 18 runs La Silla

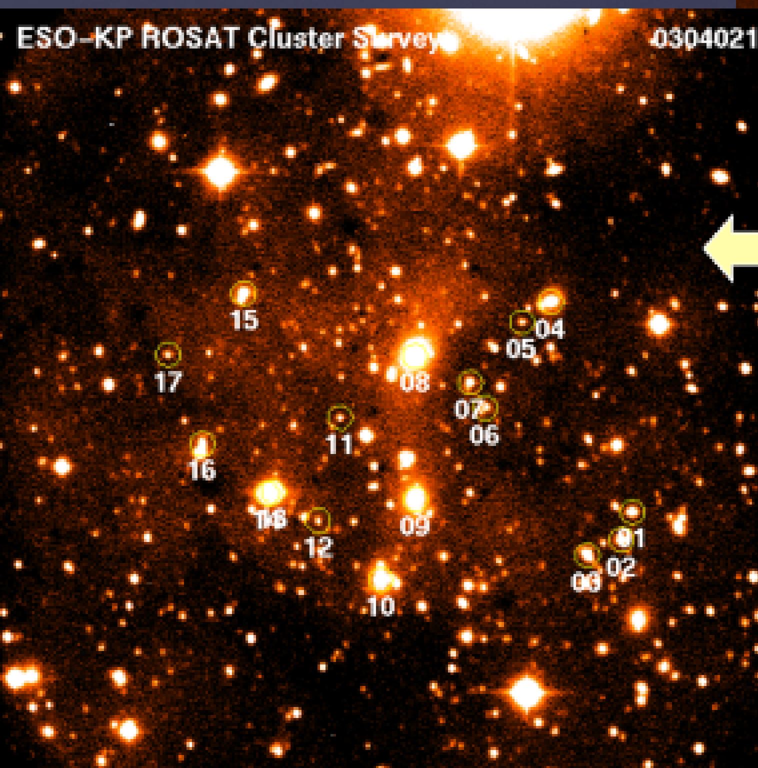
REFLEX II: 9 runs ESO 3.6m/NTT

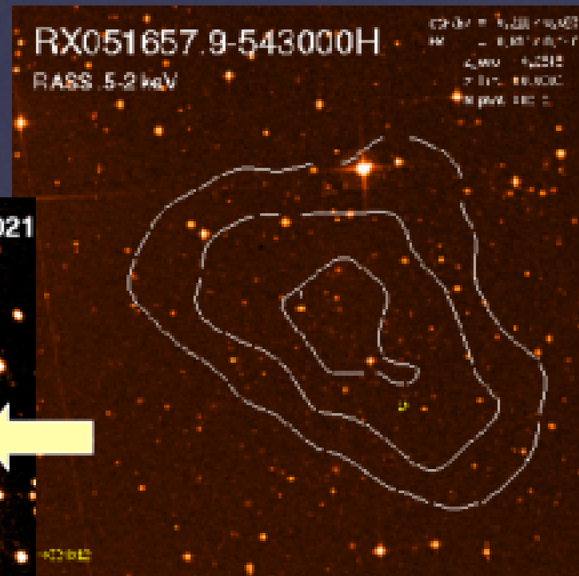
NORAS 10 runs C.A. 2 runs K.P.



Böhringer et al. 2000, 2001, 2004, 2012
Chon & Böhringer, 2012

ESO – Key Program @ La Silla 1992 - 99 (II) - 2011

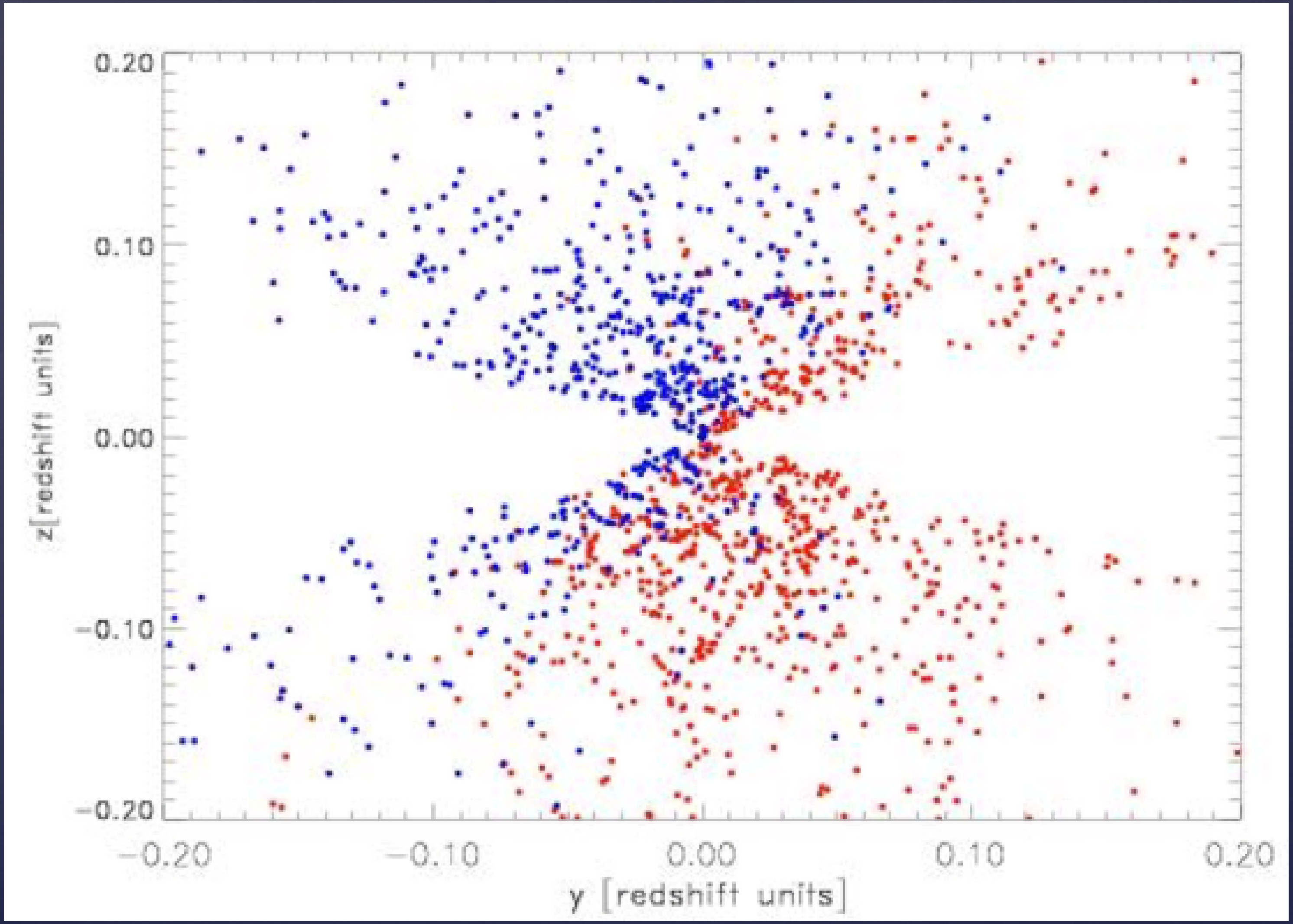




Chon & Böhringer, 2012

ESO 3.6m & NTT

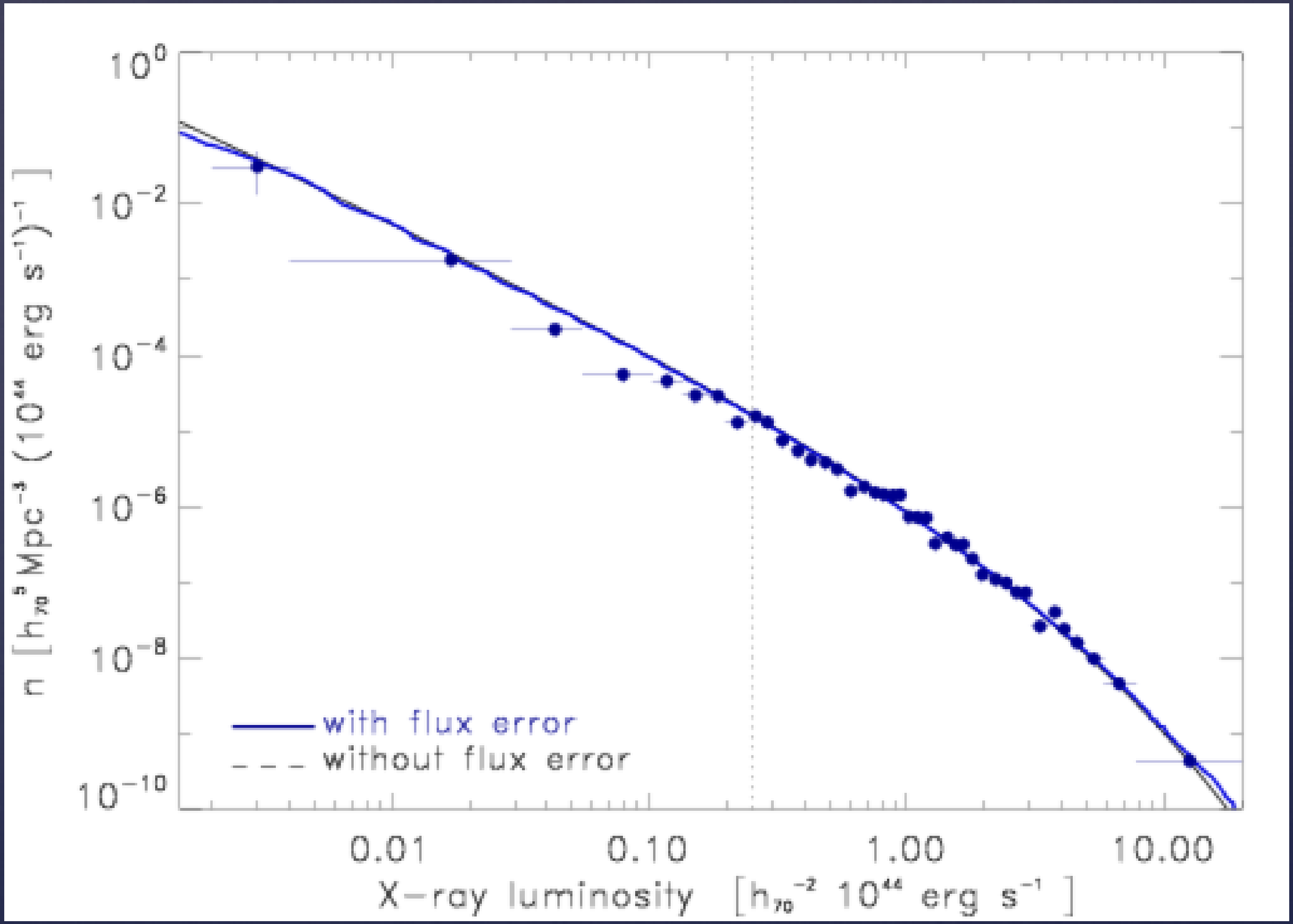
3D distribution of ROSAT clusters



Credit: H. Böhringer

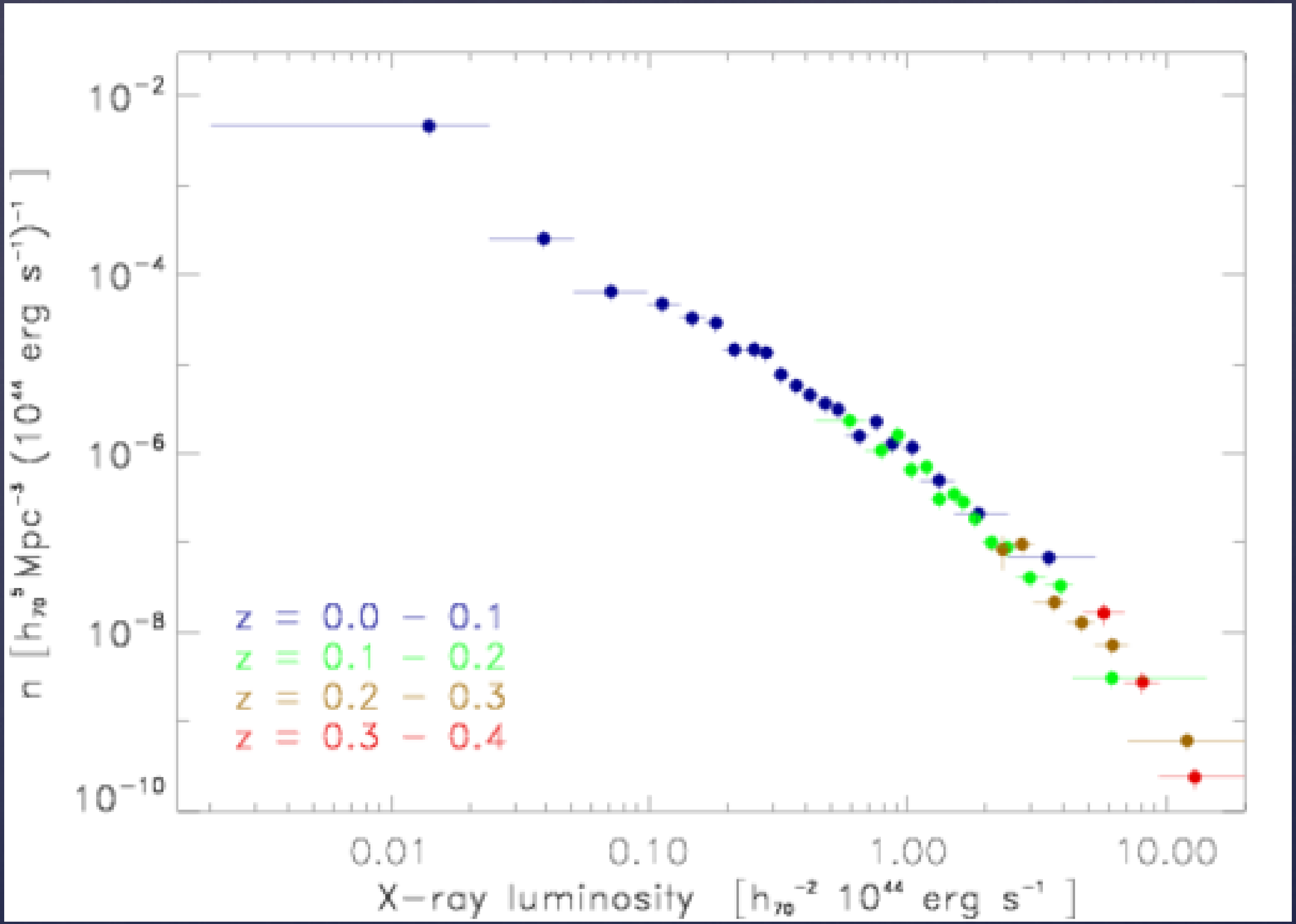
Observed and predicted Lx

Prediction from a flat LCDM model $\Omega_m = 0.27$, $\sigma_8 = 0.8$ and REFLEX II XLF



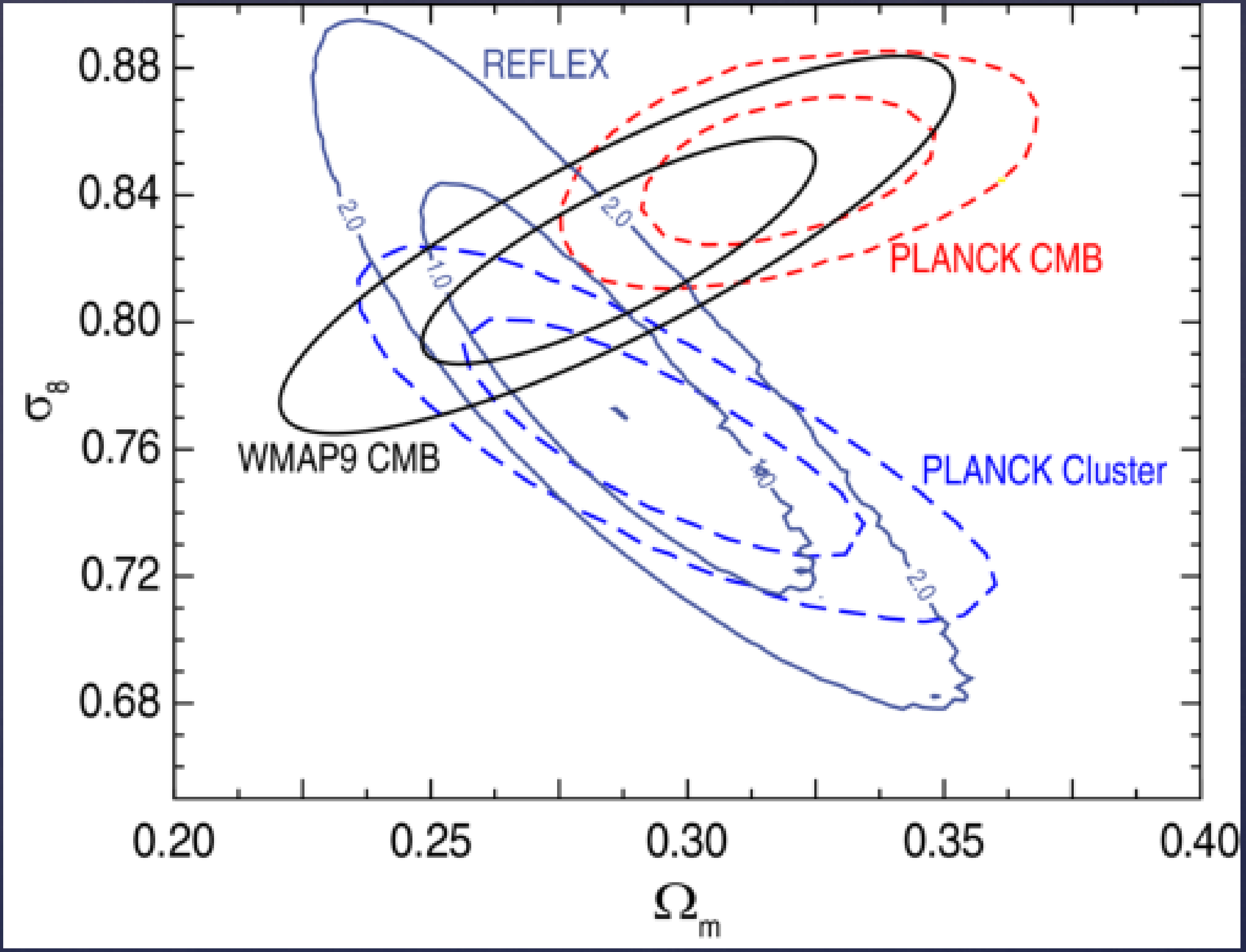
Böhringer et al. 2013

Luminosity function for REFLEX II



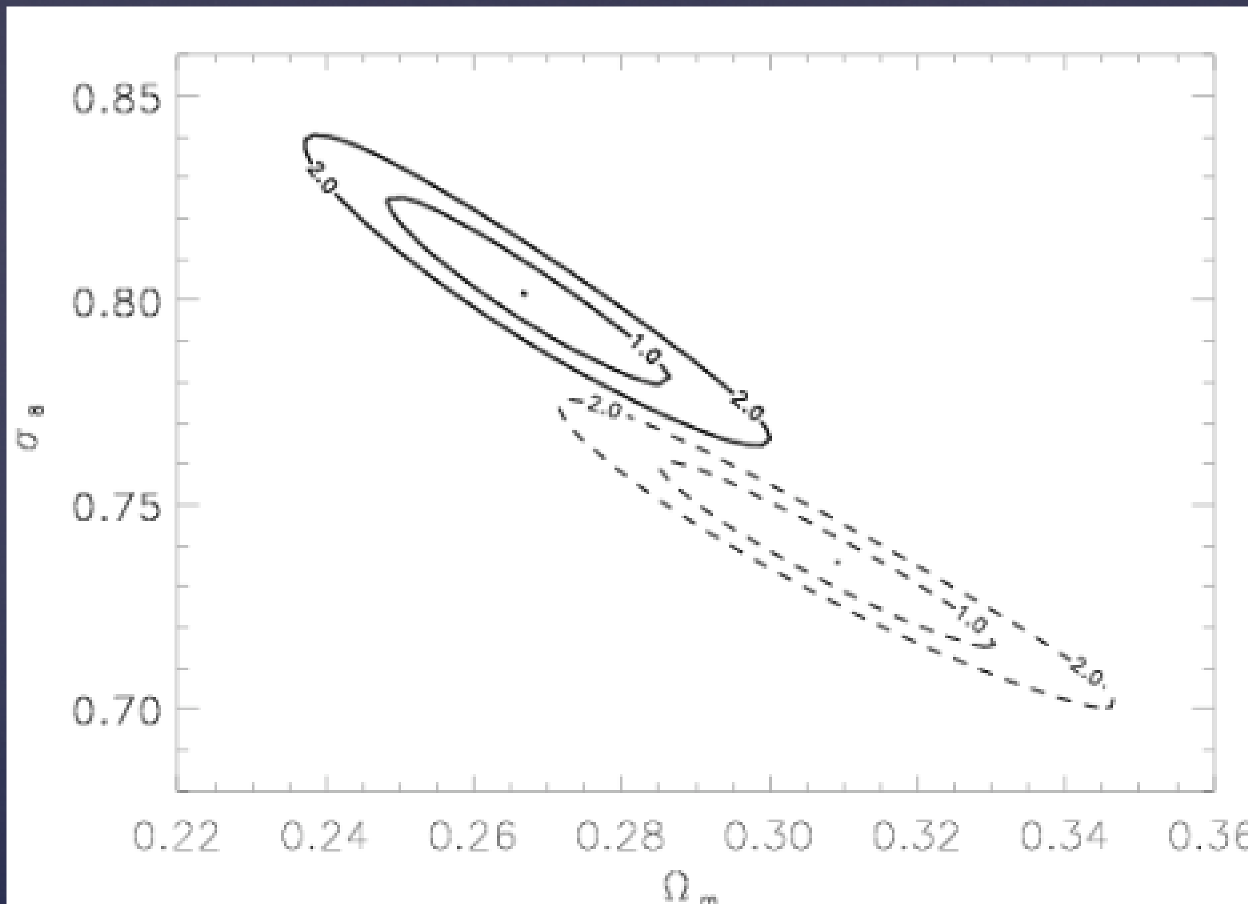
Böhringer et al. 2014

REFLEX II cosmological constraints



Böhringer et al. 2014

REFLEX II : Cosmological constraints for two versions of scaling relation

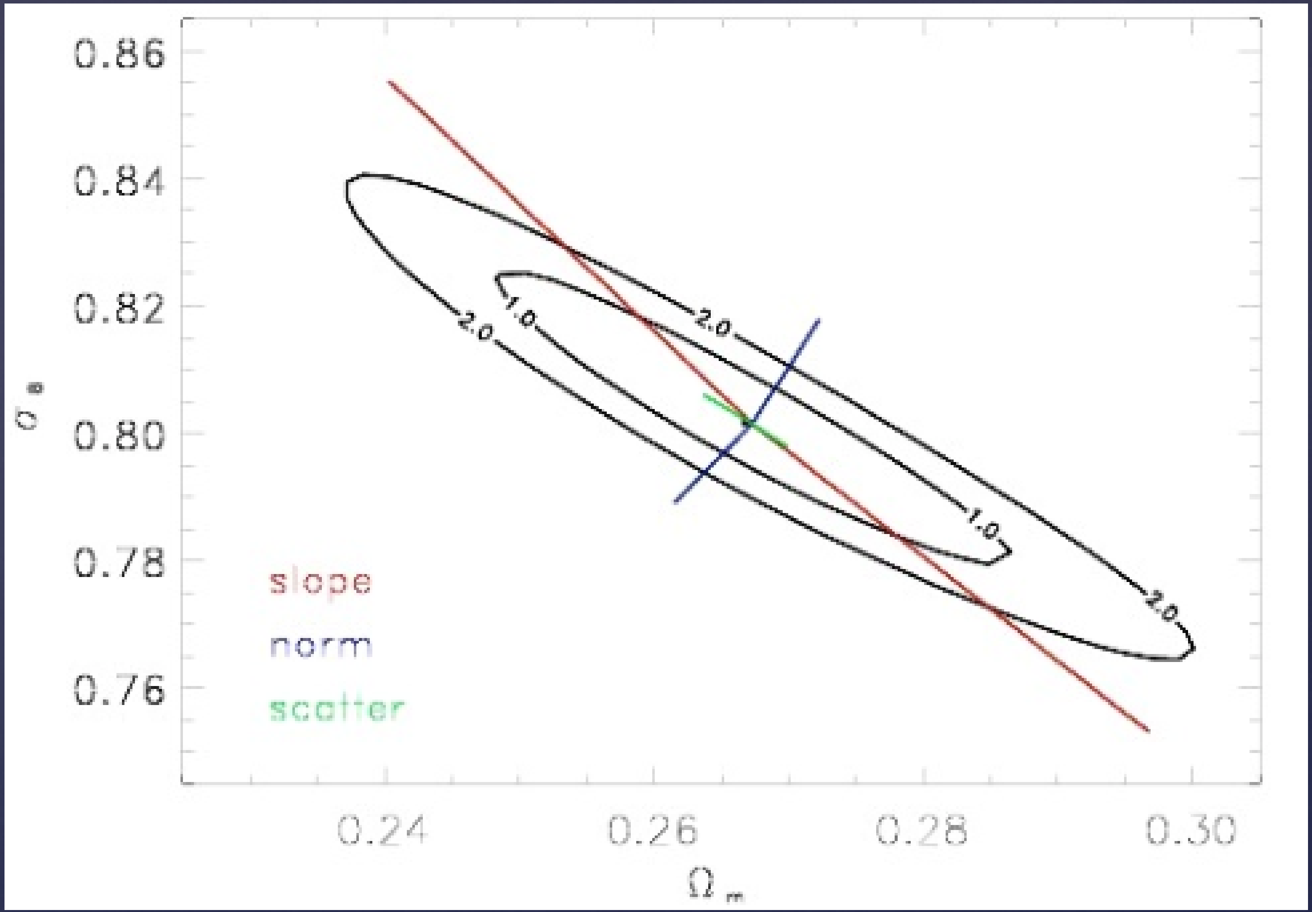


$\Omega m = 0.27 \pm 0.03$
$\sigma 8 = 0.80 \pm 0.03$

$\Omega m = 0.29 \pm 0.04$
$\sigma 8 = 0.77 \pm 0.07$

Böhringer et al. 2013

Influence of scaling relation



slope +- 5%, normalization +- 10%, scatter +- 10%

Böhringer et al. 2013

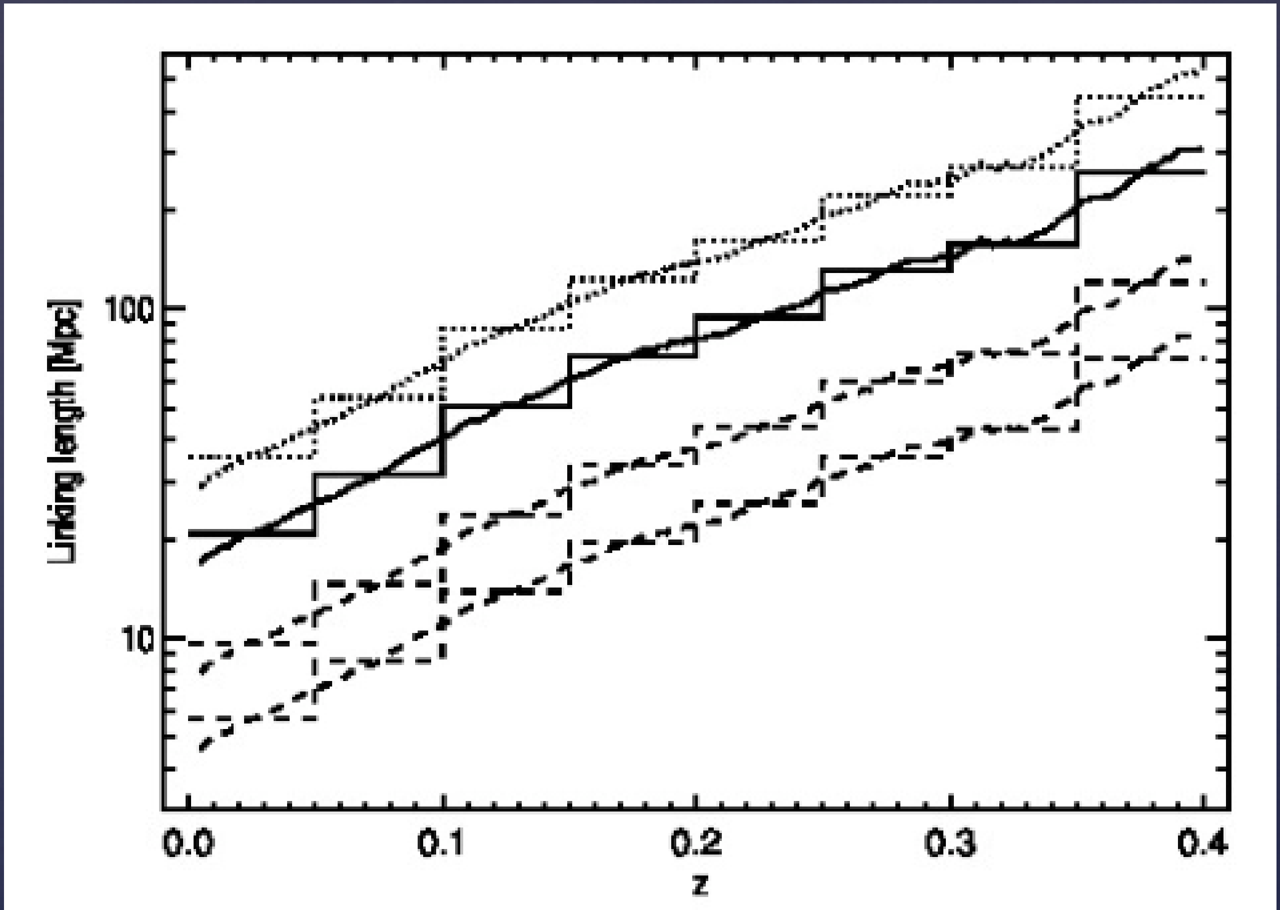
Superclusters as a probe of large-scale structure

Based on
Chon et al. 2013
Chon et al., 2014

Motivation

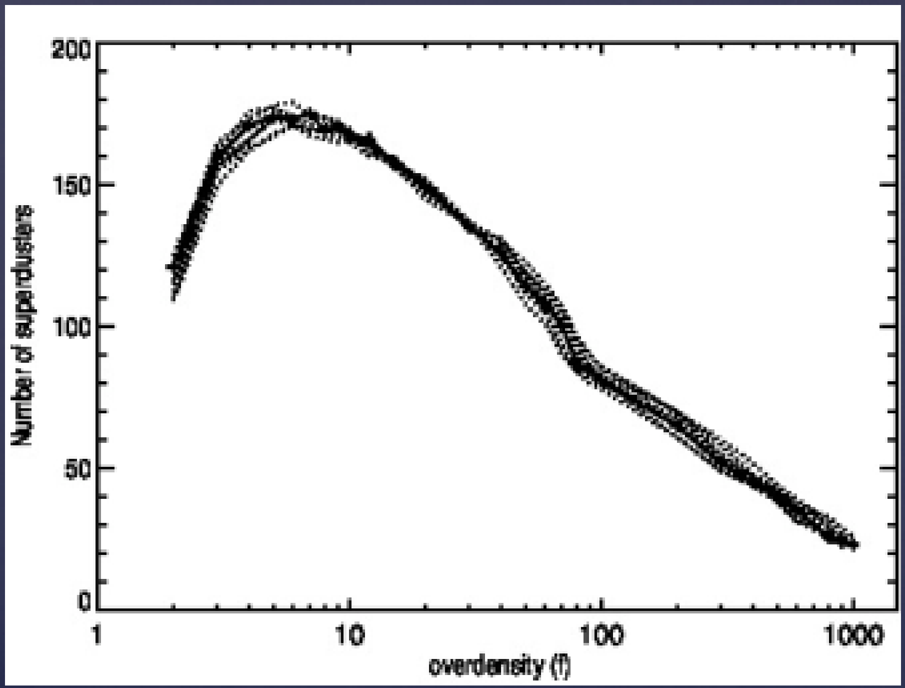
- Characterising largest overdensed structure observed, not collapsed.
- Previous studies with Abell, X-ray selected clusters or galaxy overdensities. Abell richness is not as tightly coupled to mass.
- Well-understood selection of clusters: can address issues quantitatively, e.g. simulations.
- To understand physical properties, and to use them as a laboratory to study cluster properties.
- Testing new concepts

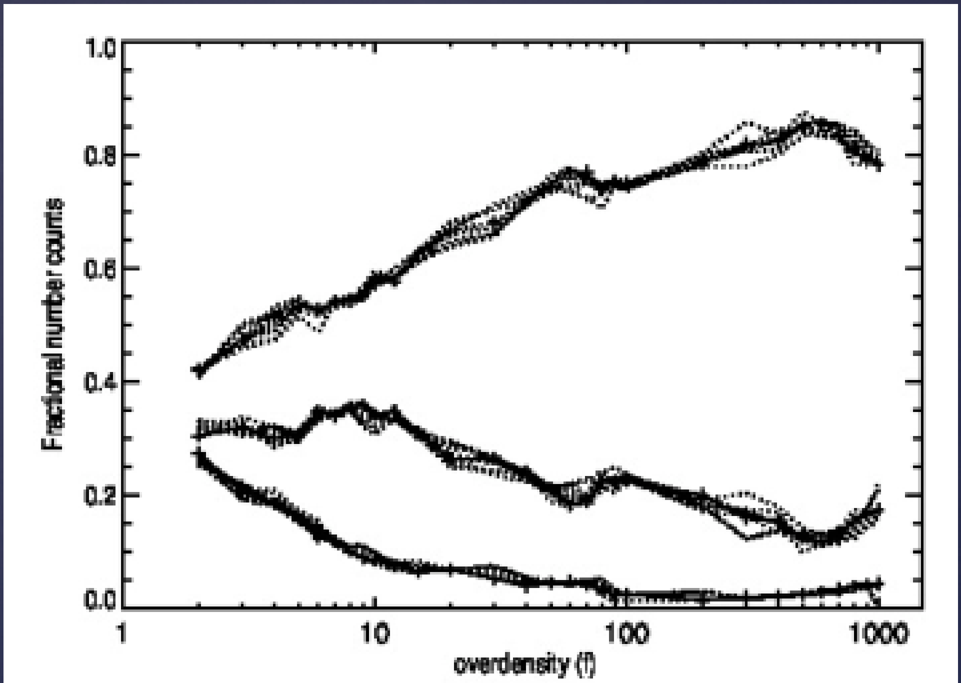
Construction of REFLEX supercluster catalogue via friends-of-friends



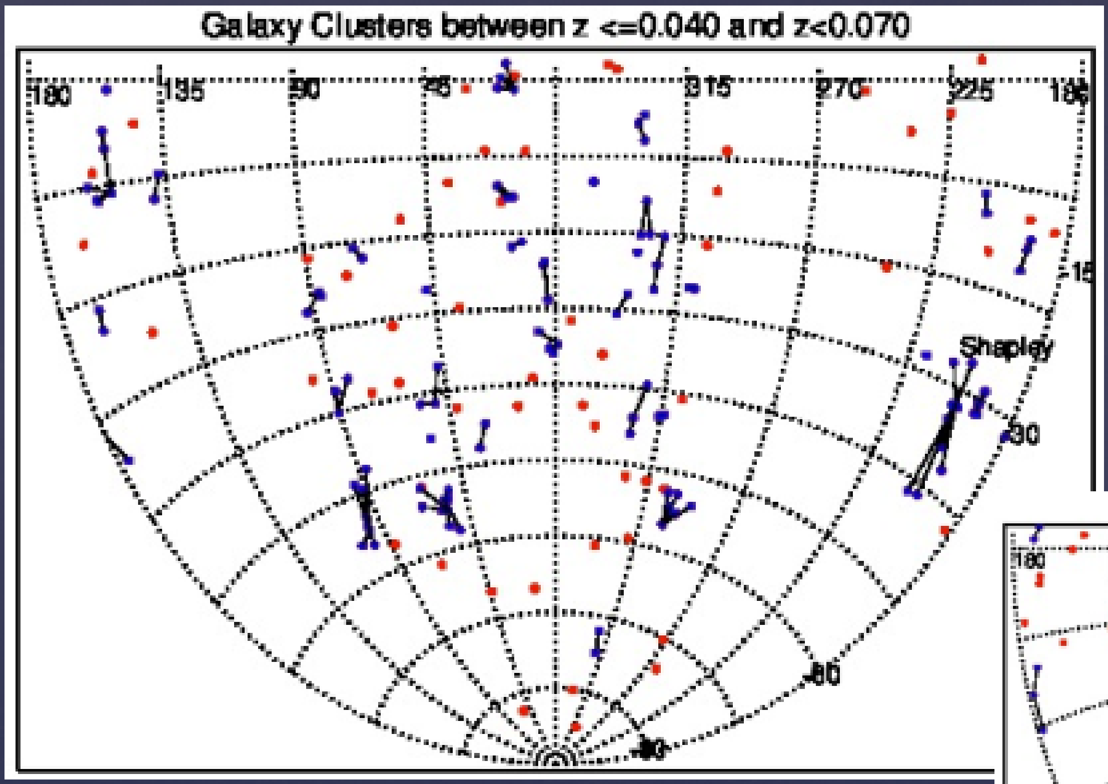
Overdensity, $f=n/n_0$ → linking length proportional to $f^{(-1/3)}$

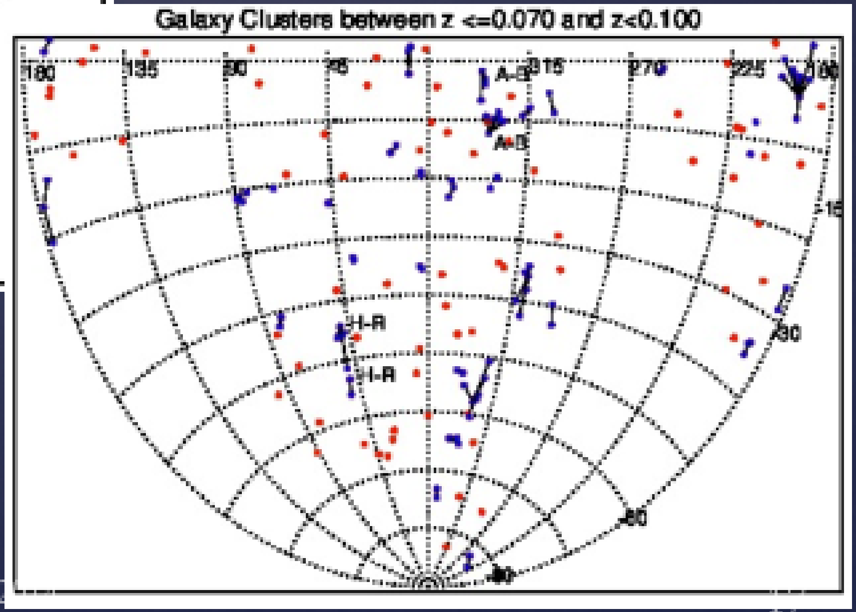
Counts


200
150
100
50
0
Number of superclusters
1
10
100
1000
overdensity (f)

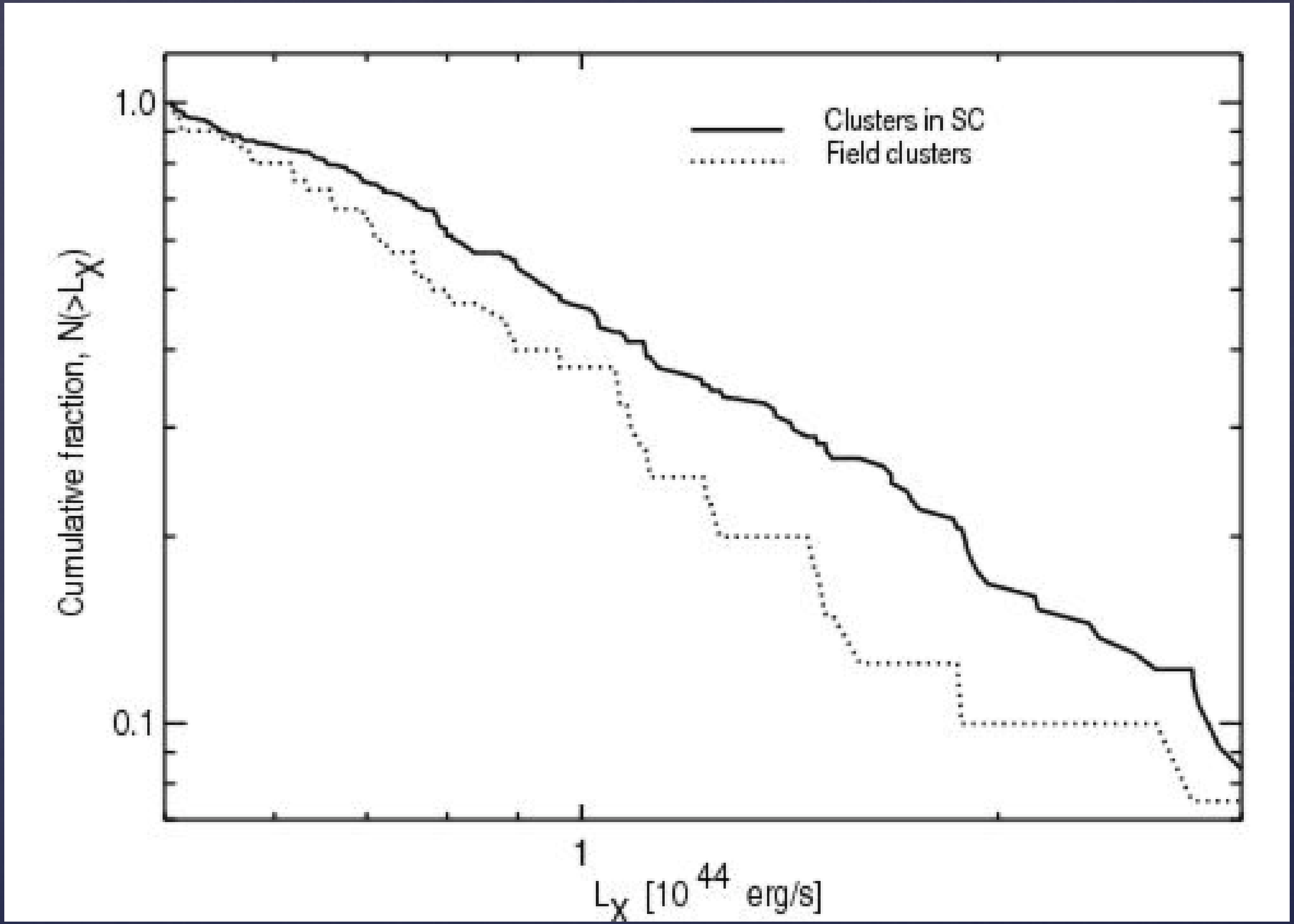

1.0
0.8
0.6
0.4
0.2
0.0
Fractional number counts
1
10
100
1000
overdensity (f)

Distribution of REFLEX II superclusters





X-ray Luminosity function

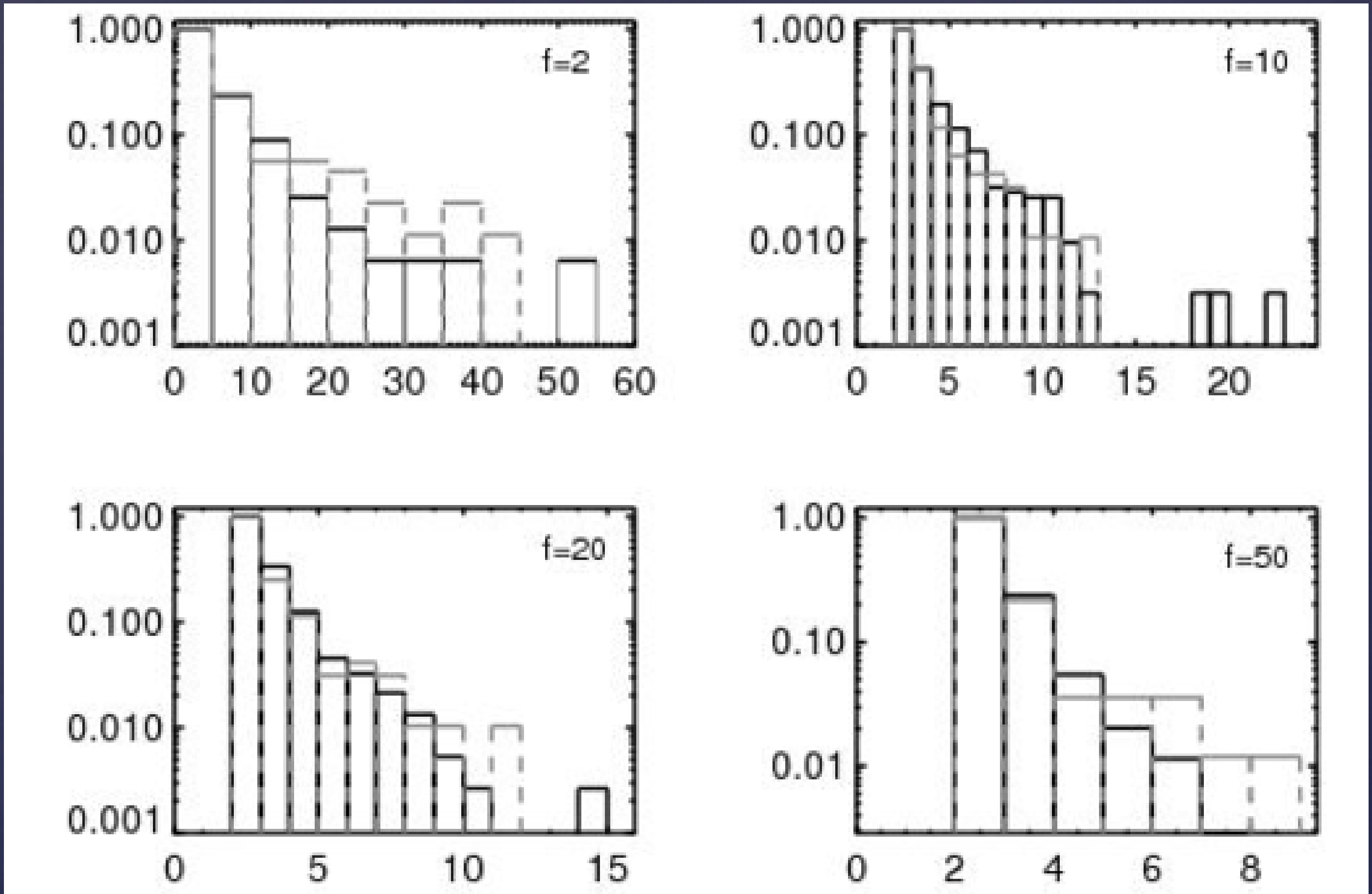


Superclusters in simulations

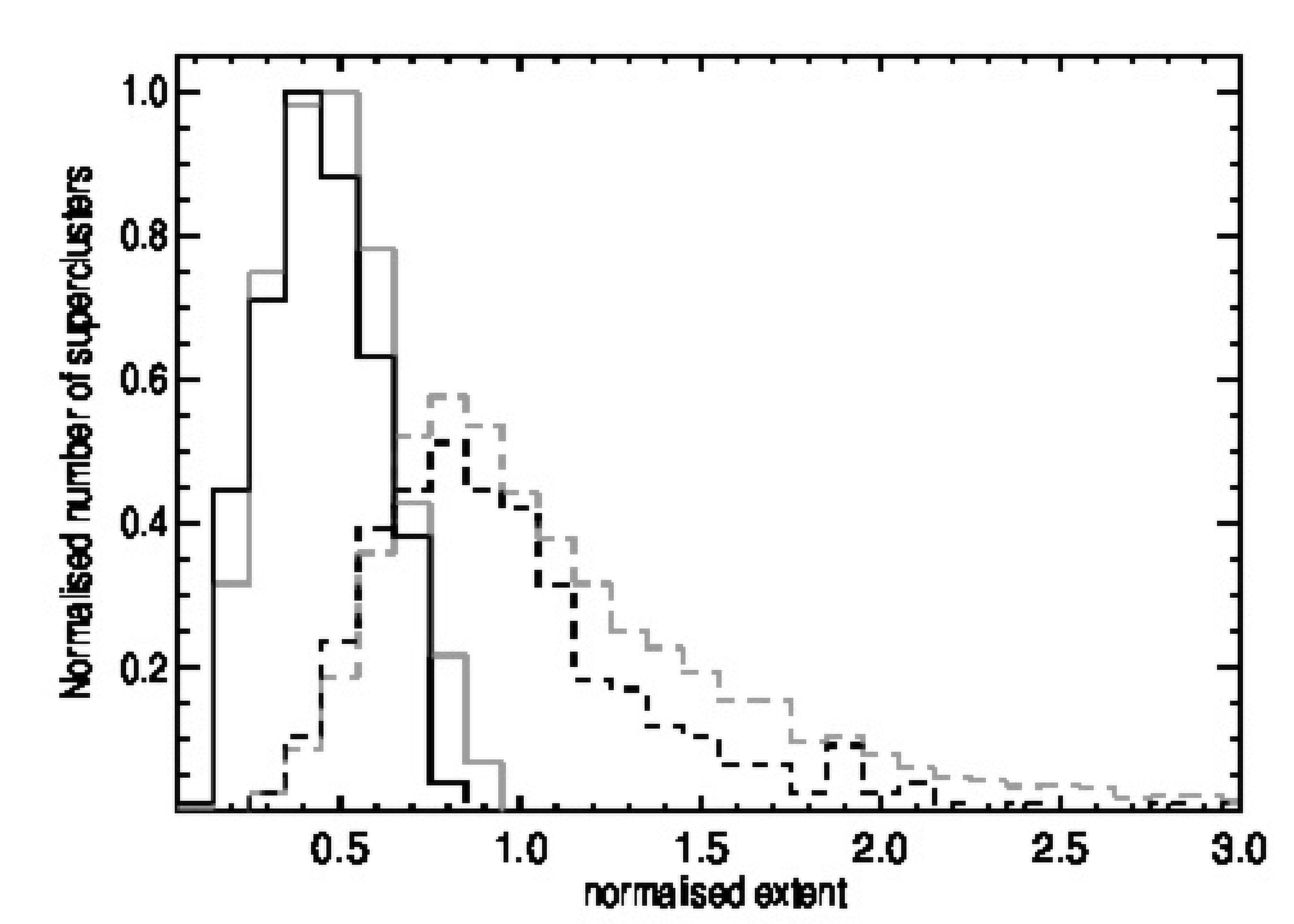
Constructing simulated superclusters

- Millennium simulation – Dark Matter only
- Cluster selection - apply equivalent criteria to build superclusters
- Properties of superclusters and their environment in simulations

Multiplicity

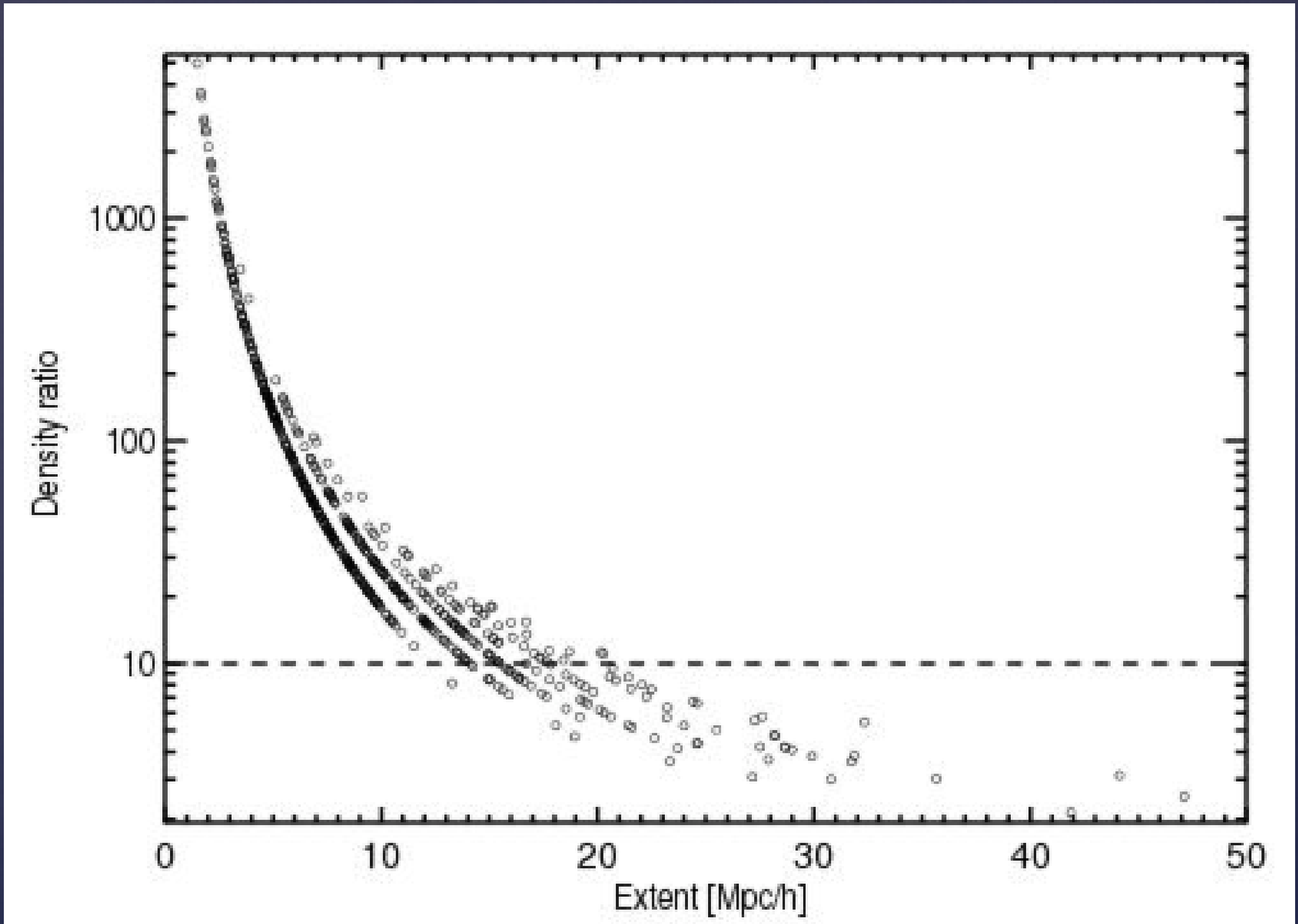


Extent

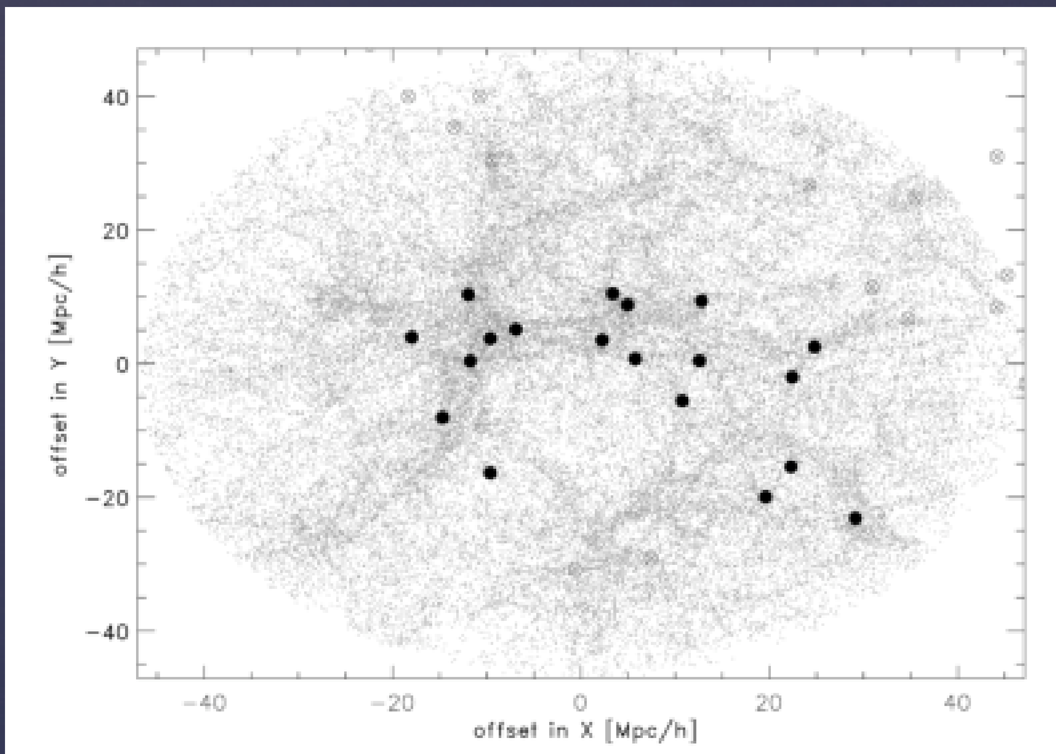


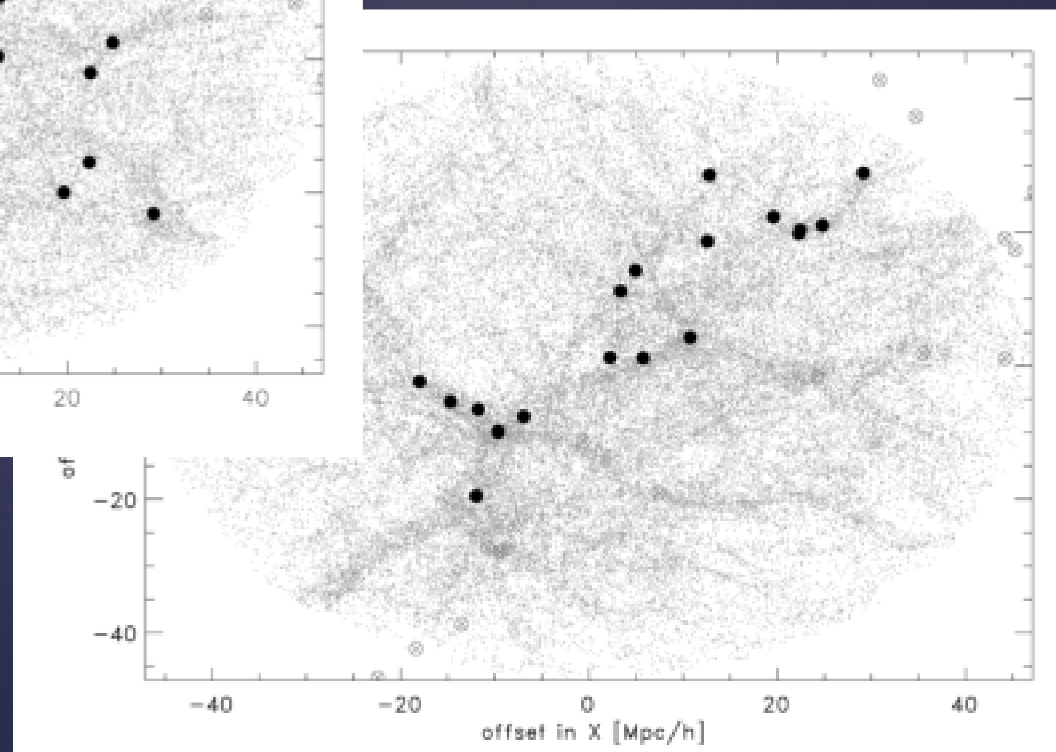
Normalised number of superclusters
1.0
0.8
0.6
0.4
0.2
0.5
1.0
1.5
2.0
2.5
3.0
normalised extent

Density ratio

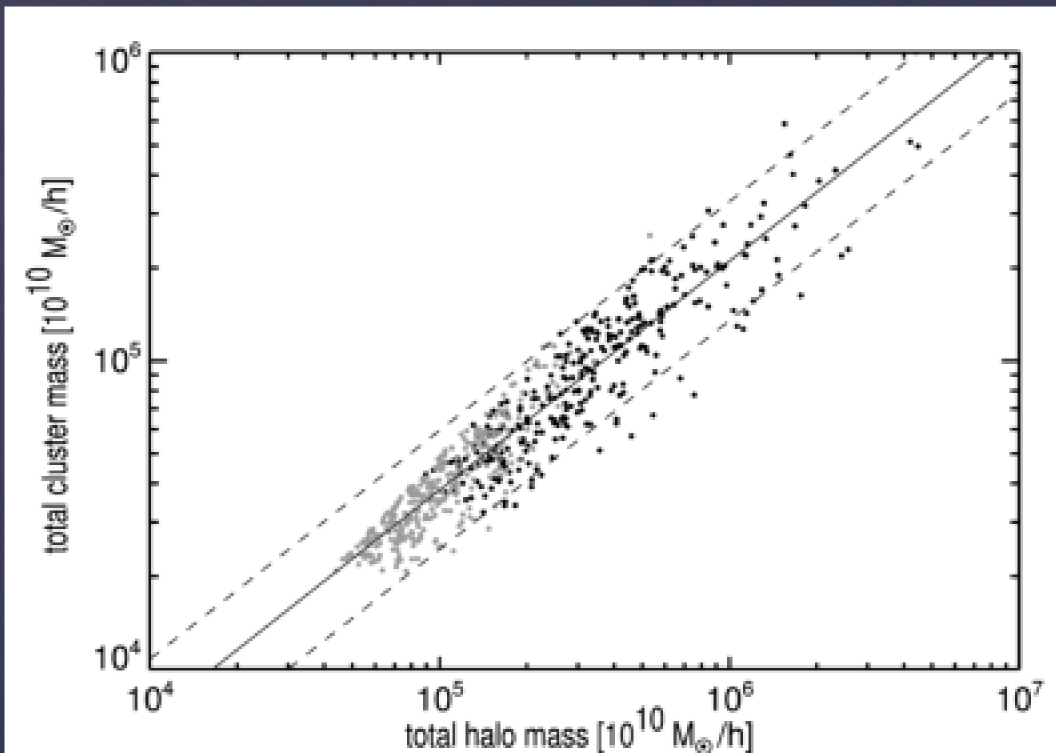


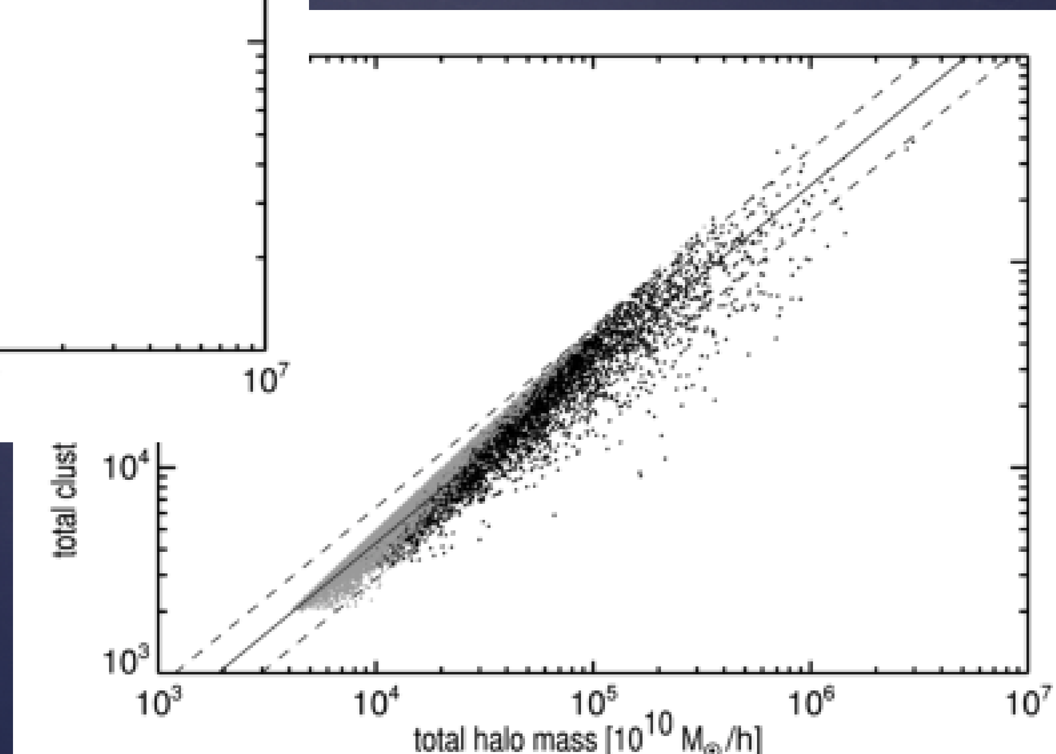
e.g. spatial distribution of clusters



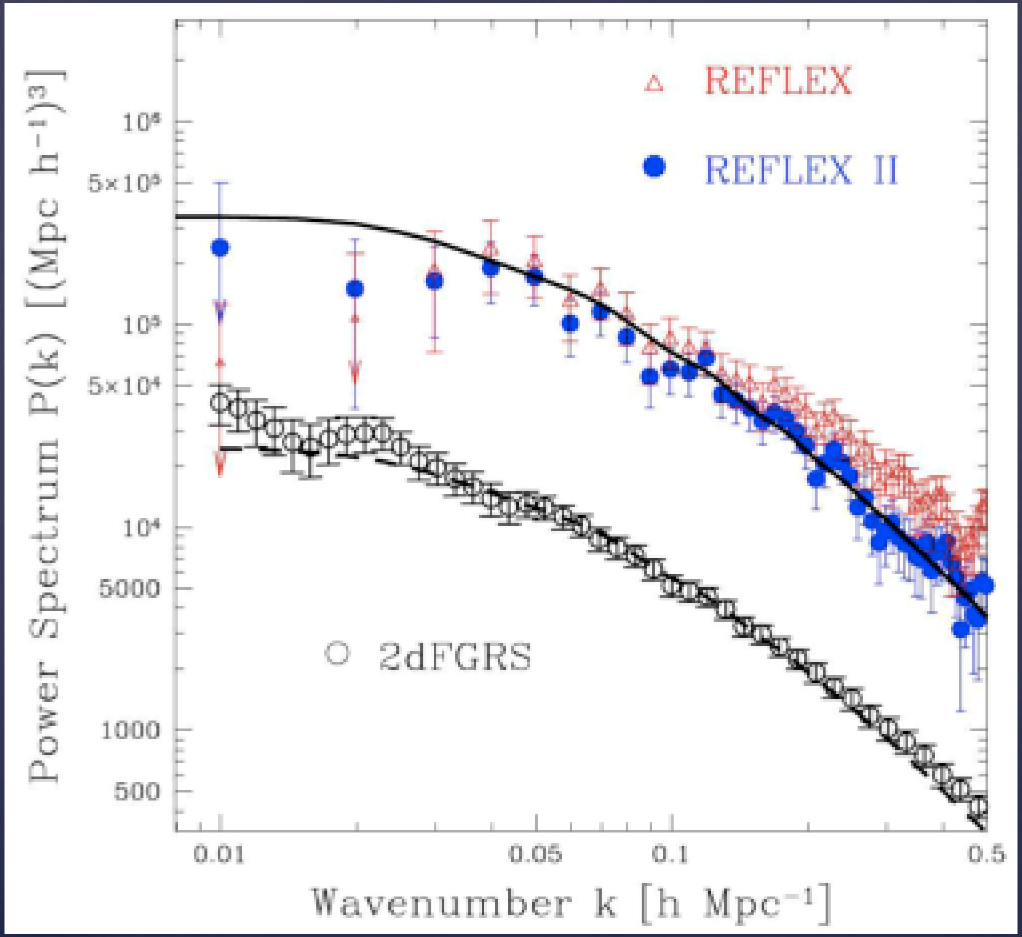


Mass fraction





REFLEX II power spectrum

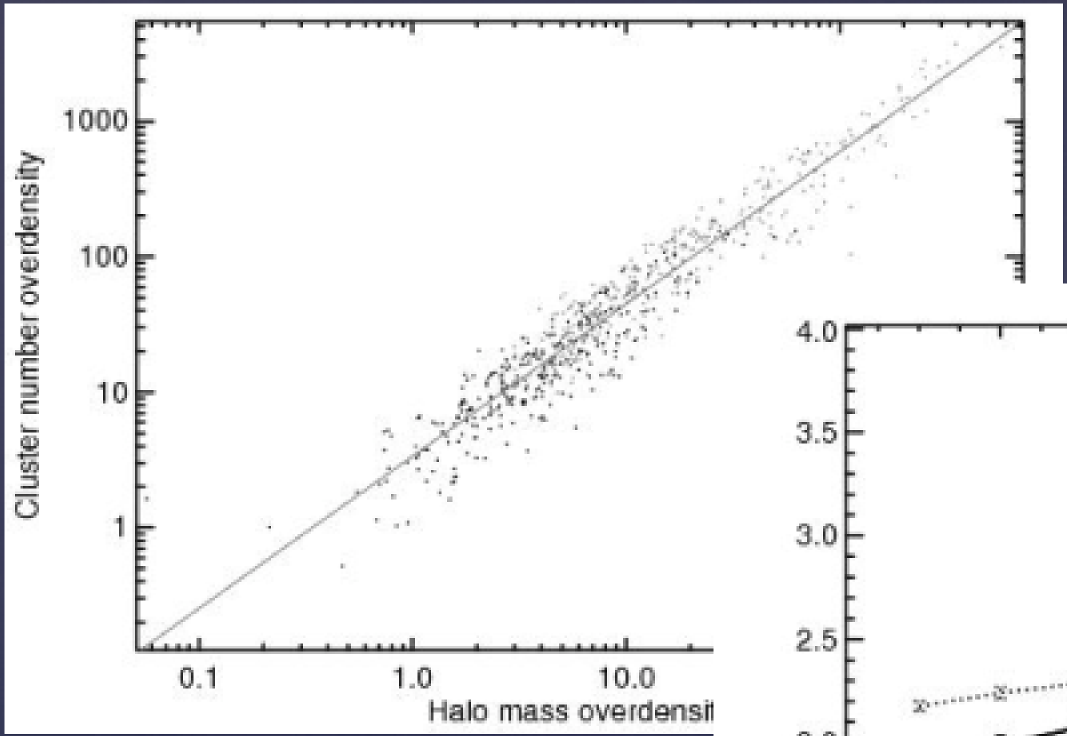


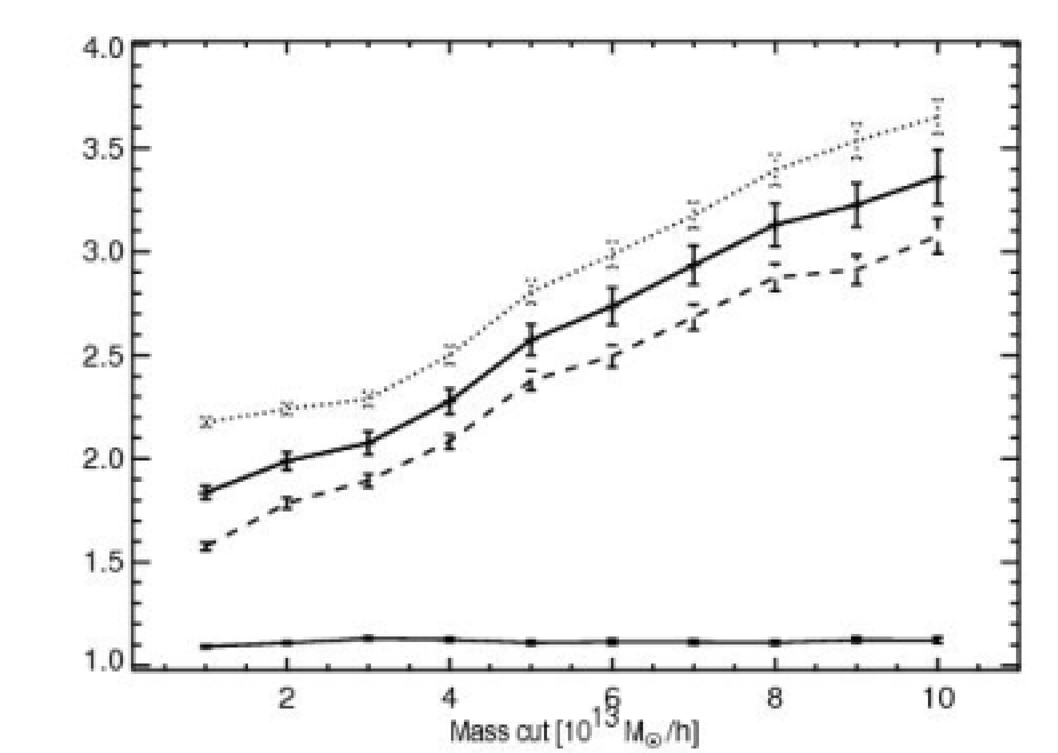
The lines give the prediction of the Concordance Cosmological Model with WMAP 5yr parameters

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

Balaguera-Antolinez et al. 2010

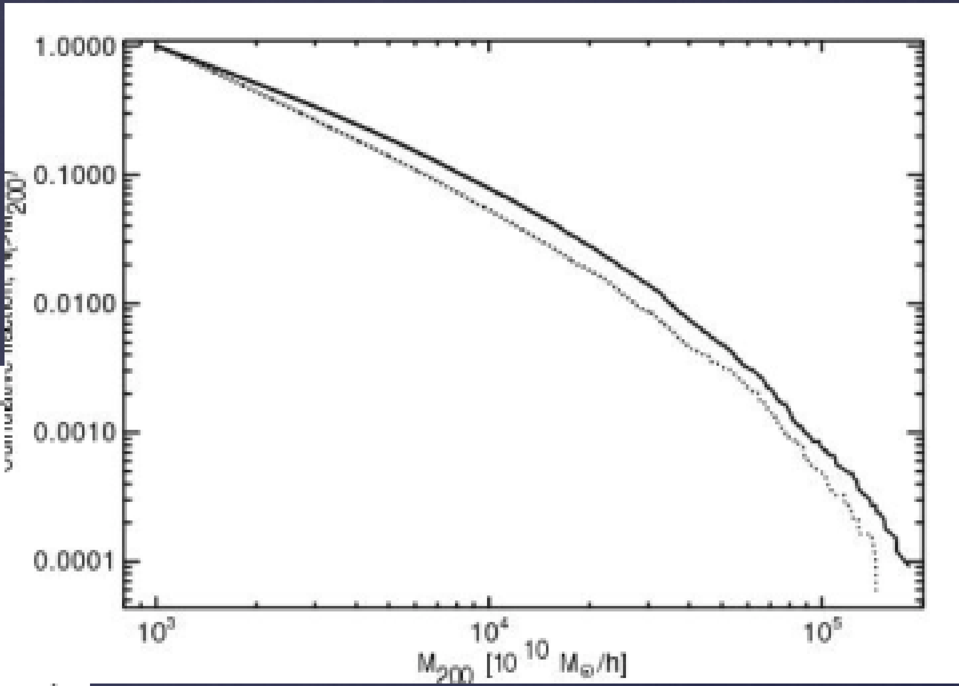
How clusters trace DM-LSS locally

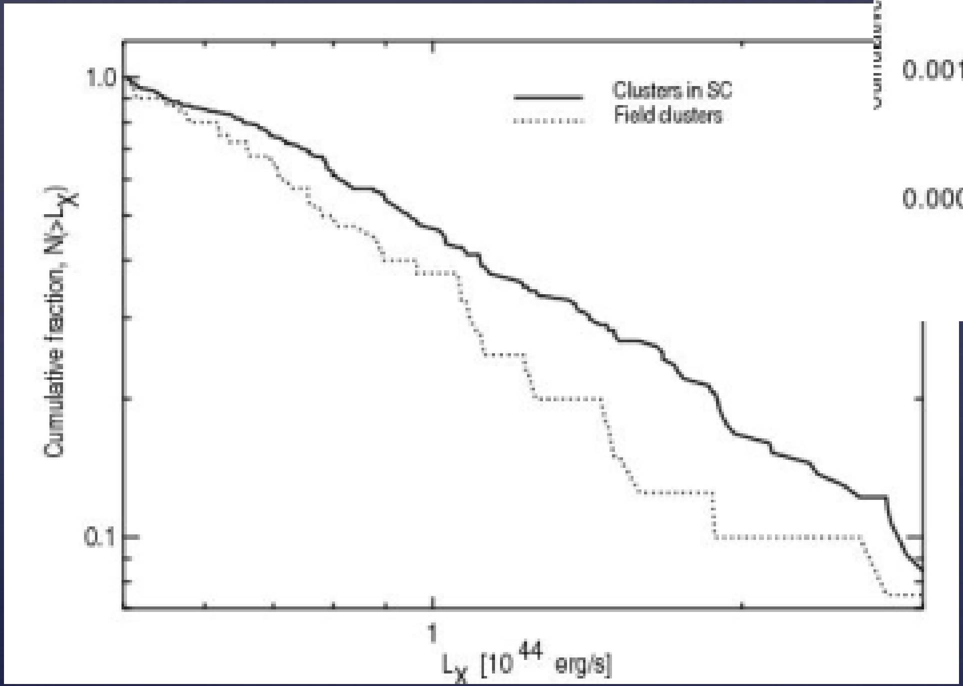




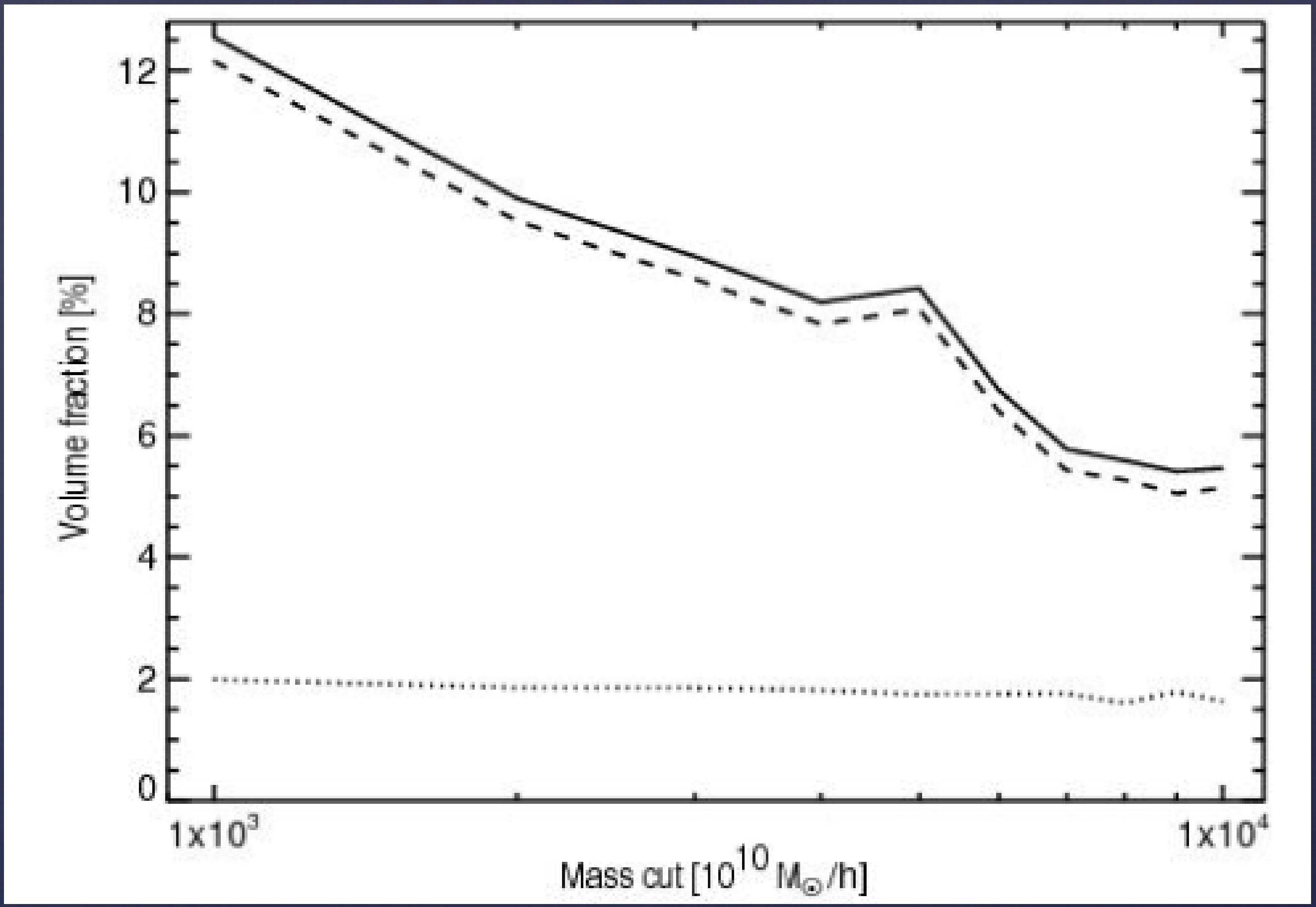
Environment

Mass function comparison : Observation vs. Simulation





Volume fraction



Conclusion

- Cluster of galaxies are useful probes
- X-ray observations provide an efficient way to detect clusters
- Accurate mass determination is necessary for cosmological applications
- REFLEX catalogue has served many purposes successfully, shown among which;
  - Cosmological constraints, Ω_m and σ_8
  - Large scales – superclusters, statistical description of large scale structure.
  - Superclusters provide different environment – supported by observation and simulation for the first time.