

Distribution of real X-ray clusters in the Universe and model clusters in simulations

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Abstract: We investigate the large-scale distribution of galaxy clusters taken from several X-ray catalogs. Different statistics of clustering like the conditional correlation function (CCF) and the minimal spanning tree (MST) as well as void statistics were used. Clusters show two distinct regimes of clustering: 1) on scales of superclusters ($\sim 40 h^{-1}$ Mpc) the CCF is represented by a power law; 2) on larger scales a gradual transition to homogeneity ($\sim 100 h^{-1}$ Mpc) is observed. We also present the correlation analysis of the galaxy distribution taken from DR6 SDSS main galaxy database. In case of galaxies the limiting scales of the different clustering regimes are 1) $10-15 h^{-1}$ Mpc; 2) $40-50 h^{-1}$ Mpc. The differences in the characteristic scales and scaling exponents of the cluster and galaxy distribution can be naturally explained within the theory of biased structure formation. We compared the density contrasts of inhomogeneities in the cluster and galaxy distributions in the SDSS region. The value of the density contrast should be taken into account to reconcile the observed gradual transition to homogeneity with the apparent presence of structures on the corresponding scales. The estimation of the relative cluster-galaxy bias (comparing number of clusters in different SDSS regions with corresponding number of galaxies) gives the value $b=5 \pm 2$. The distribution of real clusters is compared to that of simulated (model) clusters (the MareNostrum Universe simulations). We selected a cluster sample from $500 h^{-1}$ Mpc simulation box with WMAP3 cosmological parameters and $\sigma_8 = 0.8$. We found a general agreement between the distribution of observed and simulated clusters. The differences are mainly due to the presences of the **Shapley supercluster** in the observed sample.

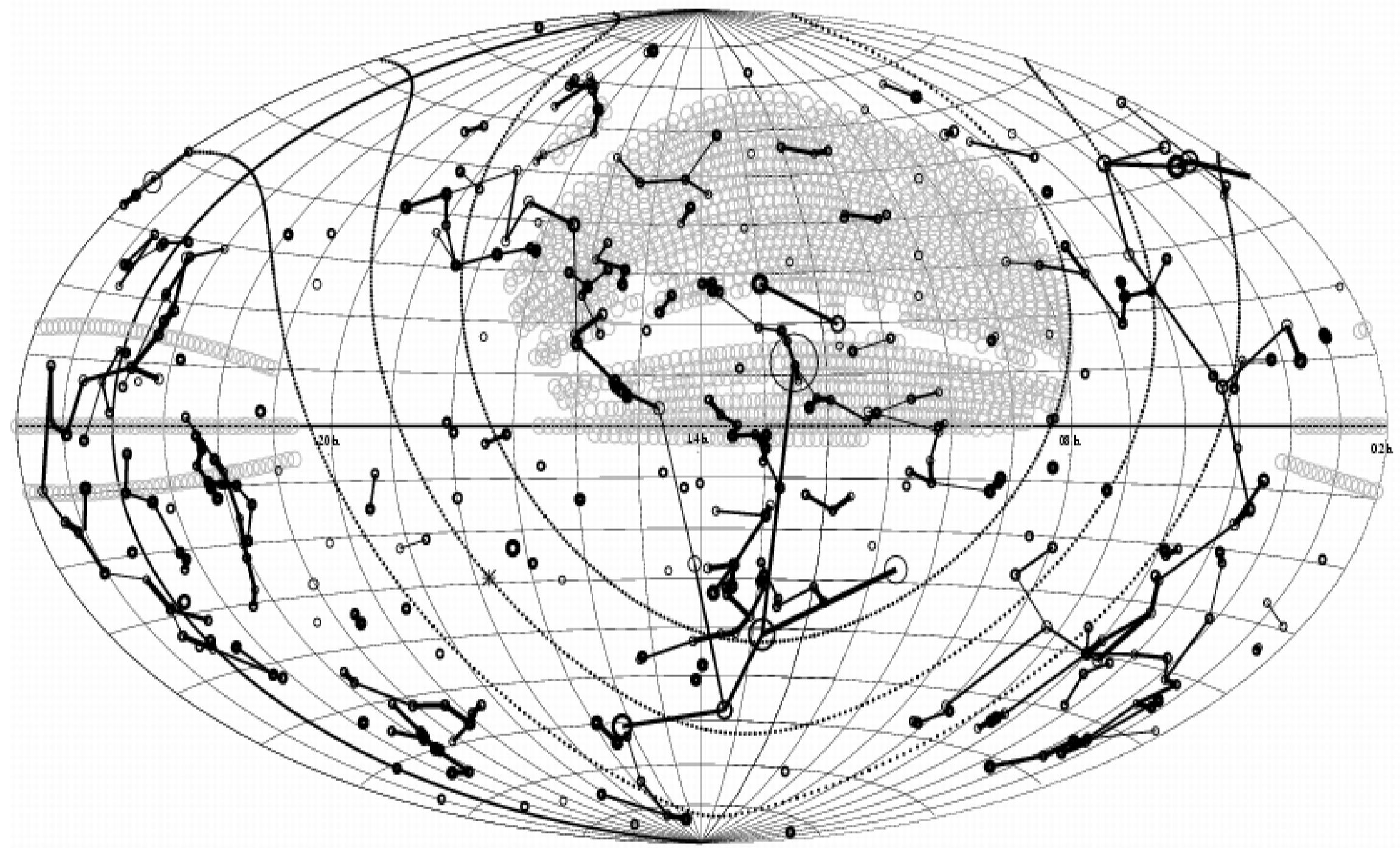


Fig. 1. Distribution in equatorial coordinates of 400 X-ray clusters with $z < 0.1$ and $L_x (0.1-2.4 \text{ keV}) > 1.25 10^{43} h^{-2} \text{ erg/s}$. The edges of minimal spanning tree (MST) shorter than $45 h^{-1}$ Mpc are shown by solid lines. Circles of constant galactic latitude ($b = -20^\circ, 0^\circ, +20^\circ$) are plotted by dotted lines. Gray circles represent the spectral plates of the SDSS-DR6.

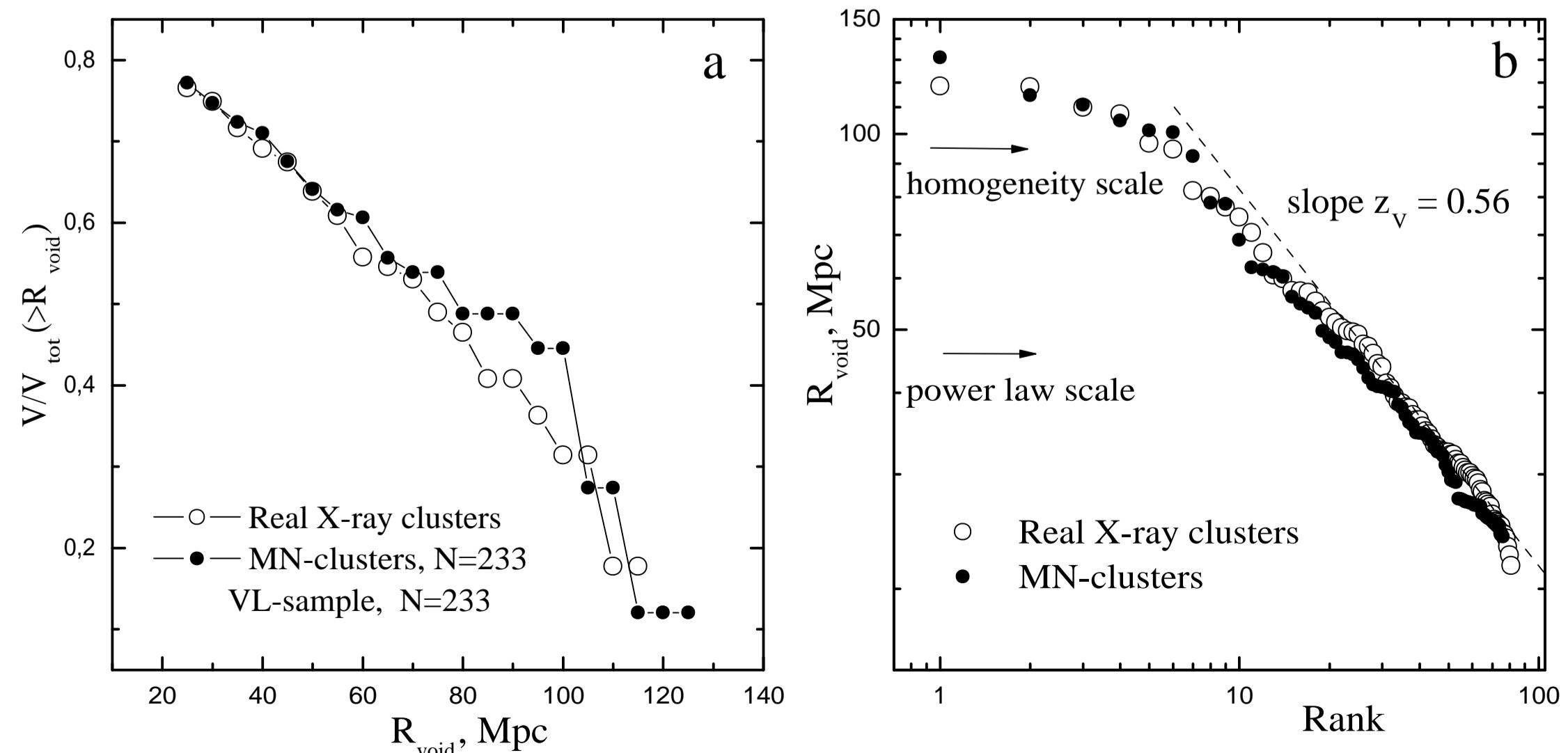


Fig. 4. a) Cumulative Void Function for X-ray and MareNostrum clusters; b) Size - Rank dependence of voids in distributions of real X-ray and MareNostrum-clusters.

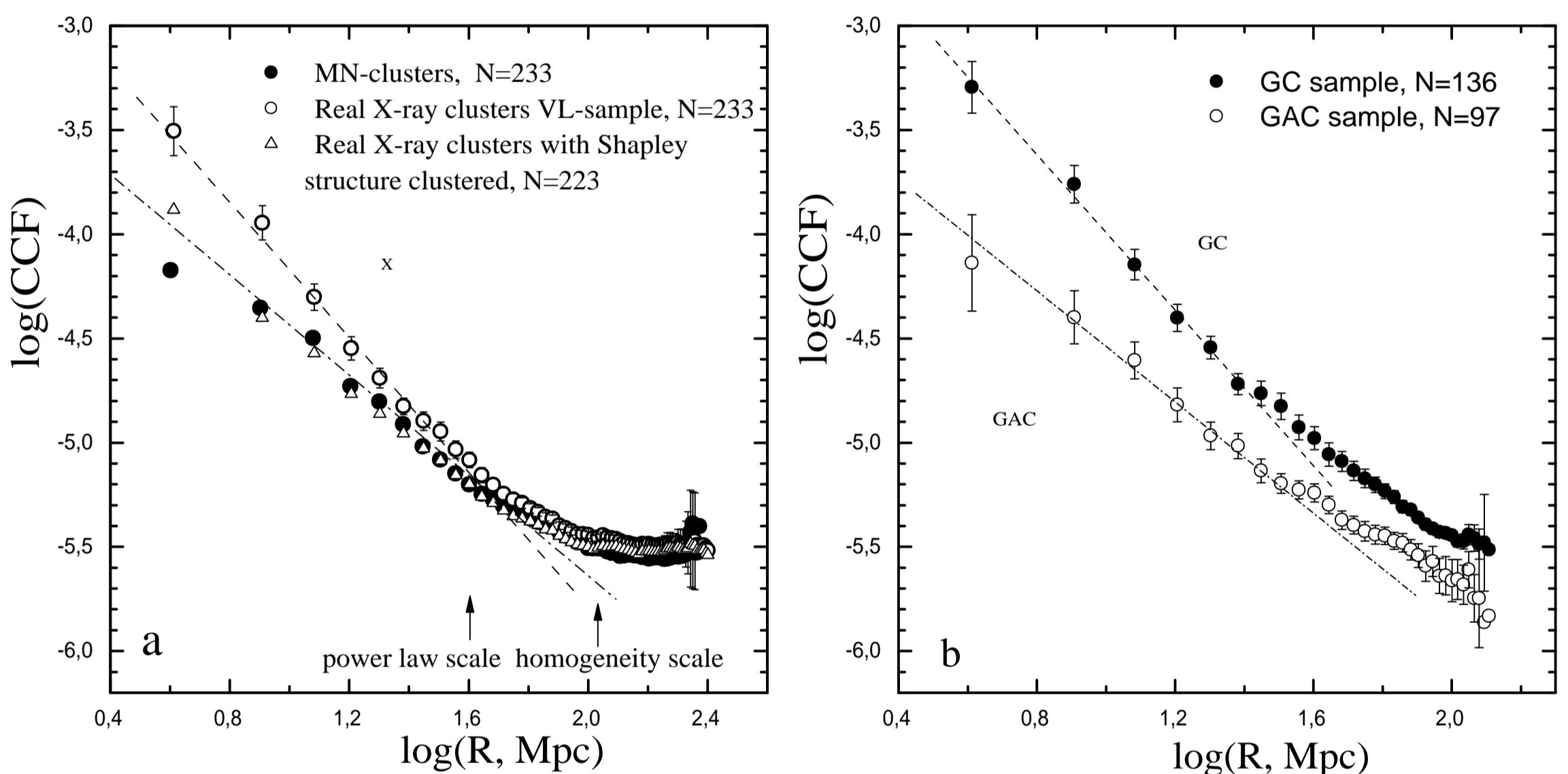


Fig. 3. a) Comparison of CCFs for X-clusters and MN-clusters; b) CCFs for VL cluster sample in 2 hemispheres: GAC ($123^\circ < l_{\text{gal}} < 303^\circ$) and GC ($303^\circ < l_{\text{gal}}$ and $l_{\text{gal}} < 123^\circ$). The volume-limited sample (VL) extracted from our compilation contains 233 X-clusters with redshifts limited by $Z_{\text{VL}} = 0.09$, $L_x > 2.5 h^{-2} 10^{43} \text{ erg/s}$. For comparison with observations we extracted the 233 most massive clusters with positions converted to redshift space from the MareNostrum (MN-clusters) $500 h^{-1}$ Mpc simulation box in a sphere of real cluster VL sample radius $265.3 h^{-1}$ Mpc (we slightly expanded the simulation box using the box periodicity)

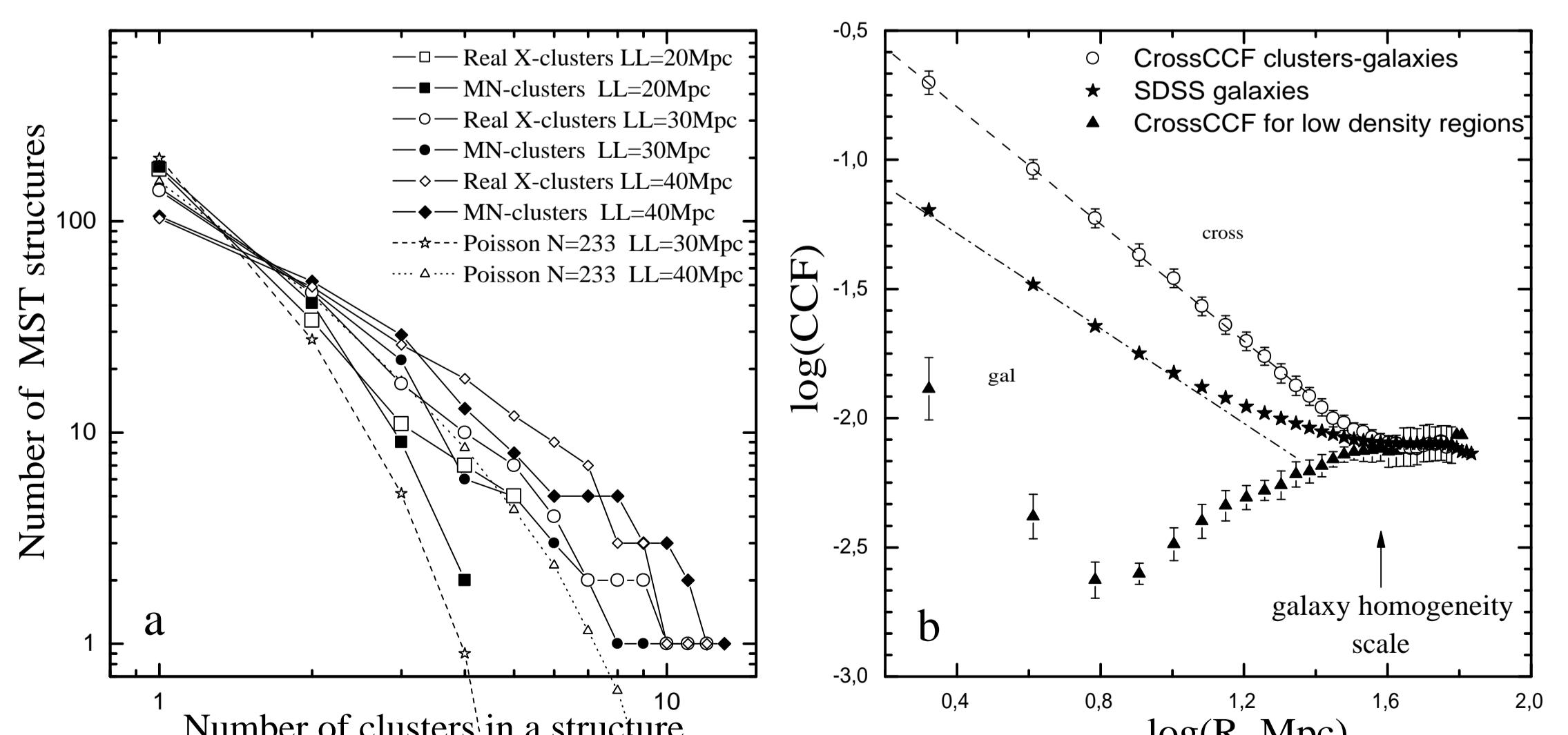


Fig. 5. a) MST analysis for X-ray and model MN-clusters; b) CrossCCF clusters-galaxies (open circles), CCF of SDSS galaxies (stars; error bars are smaller than symbol size), galaxies-in-voids crossCCF (triangles, 10 realizations).