Evaluation of the Topological and Morphological Characteristics of the LSS During Evolution Process by Means of Minkowski Functionals

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Millennium Simulations

Springel V. et al., 2005, Nature 432, pp. 629-636

$r = 1.25\ Mpc$  
$r = 2.5\ Mpc$  
$r = 10\ Mpc$
Minkowski Functionals (MF)

Volume:
\[
MF_1(\nu) = \int_{I(\nu)} dV = n_c
\]

Surface:
\[
MF_2(\nu) = \int_{\partial I(\nu)} dS = -6n_c + 2n_f
\]

Integral Mean Curvature:
\[
MF_3(\nu) = \int_{\partial I(\nu)} \frac{1}{2} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) dS = 3n_c - 2n_f + n_e
\]

Gaussian Curvature:
\[
MF_4(\nu) = \int_{\partial I(\nu)} \left( \frac{1}{R_1 R_2} \right) dS = -n_c + n_f - n_e + n_v
\]
Summary

• Gaussian filters with large smoothing radius (r=10 Mpc) destroy filamentary structure of the LSS

• Minkowski Functionals reflect morphological and topological changes in density distribution of the dark matter during time evolution of the LSS

• Starting from the almost random Gaussian density field dark matter evolves into the structure with very sharp onset of the spongious topology with dominant number of tunnels