The view from the boundary:

a new void analysis method

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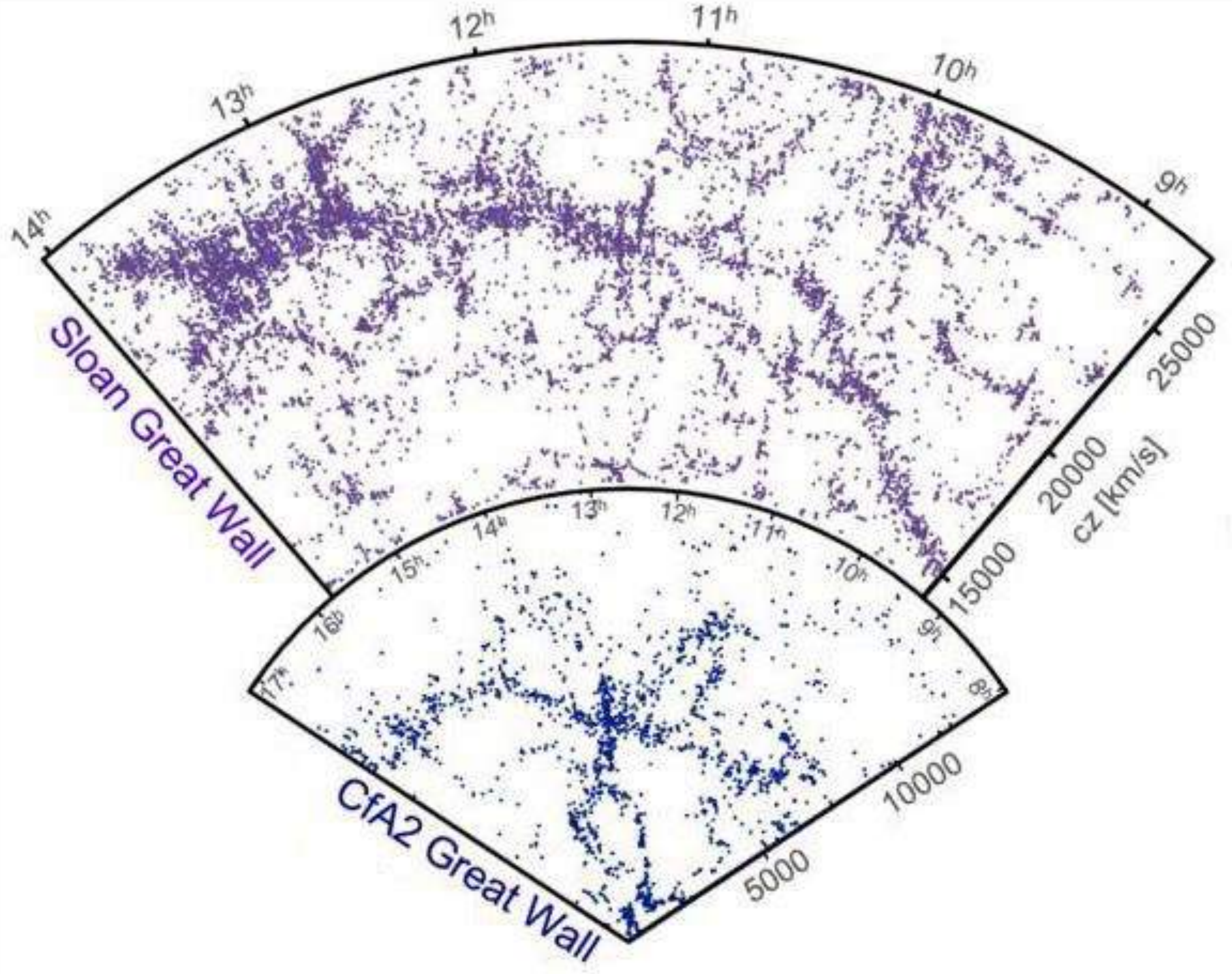
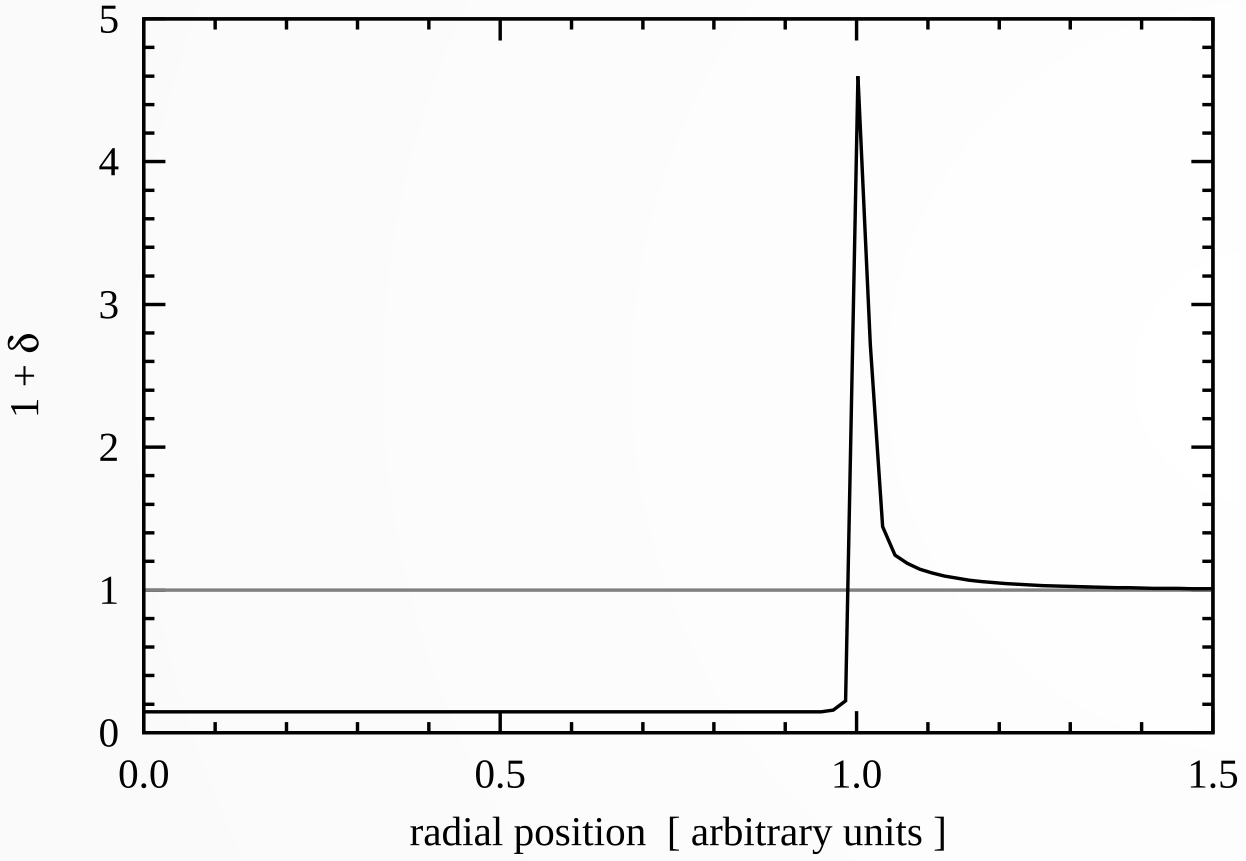
The galaxy distribution



Void structure

Simple analytical model:
expanding spherical underdensity



Fillmore & Goldreich 1984;
Sheth & van de Weygaert 2004

Void structure

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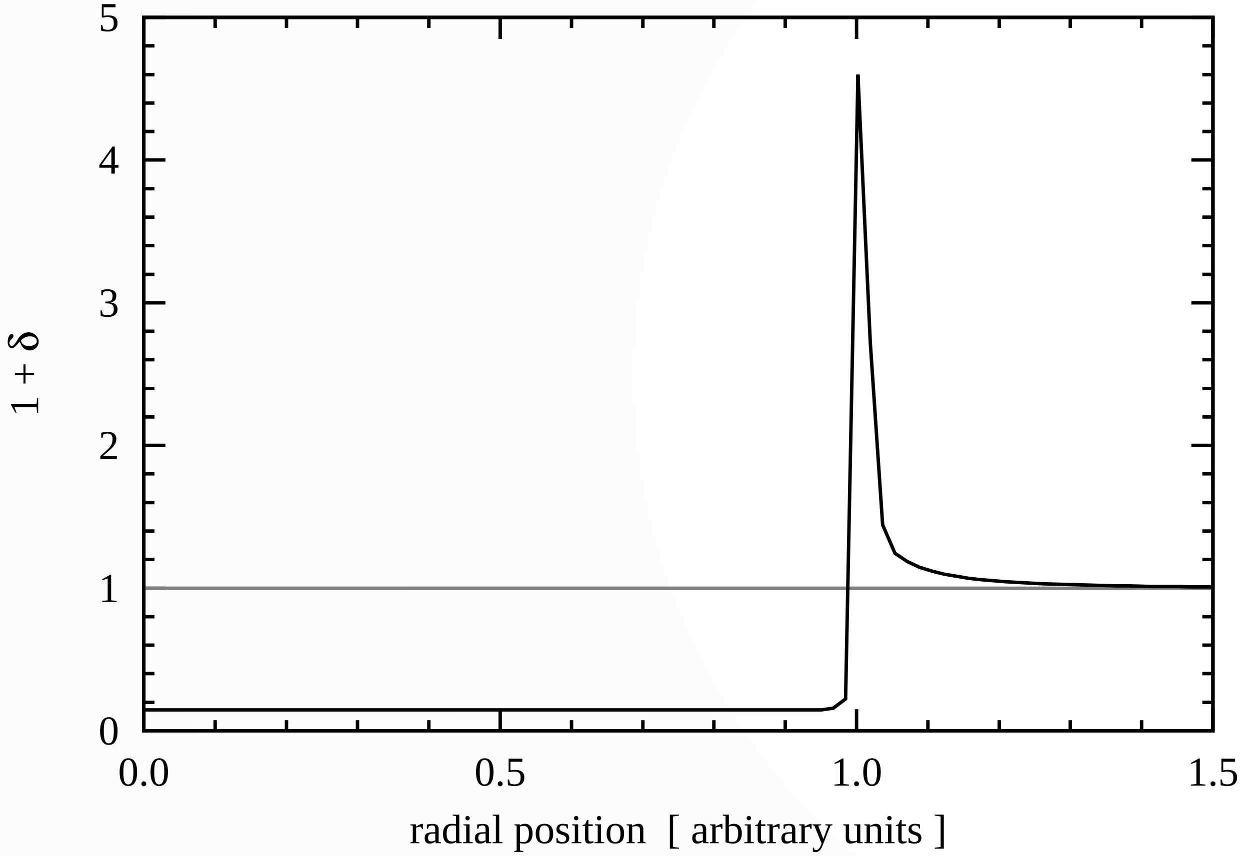
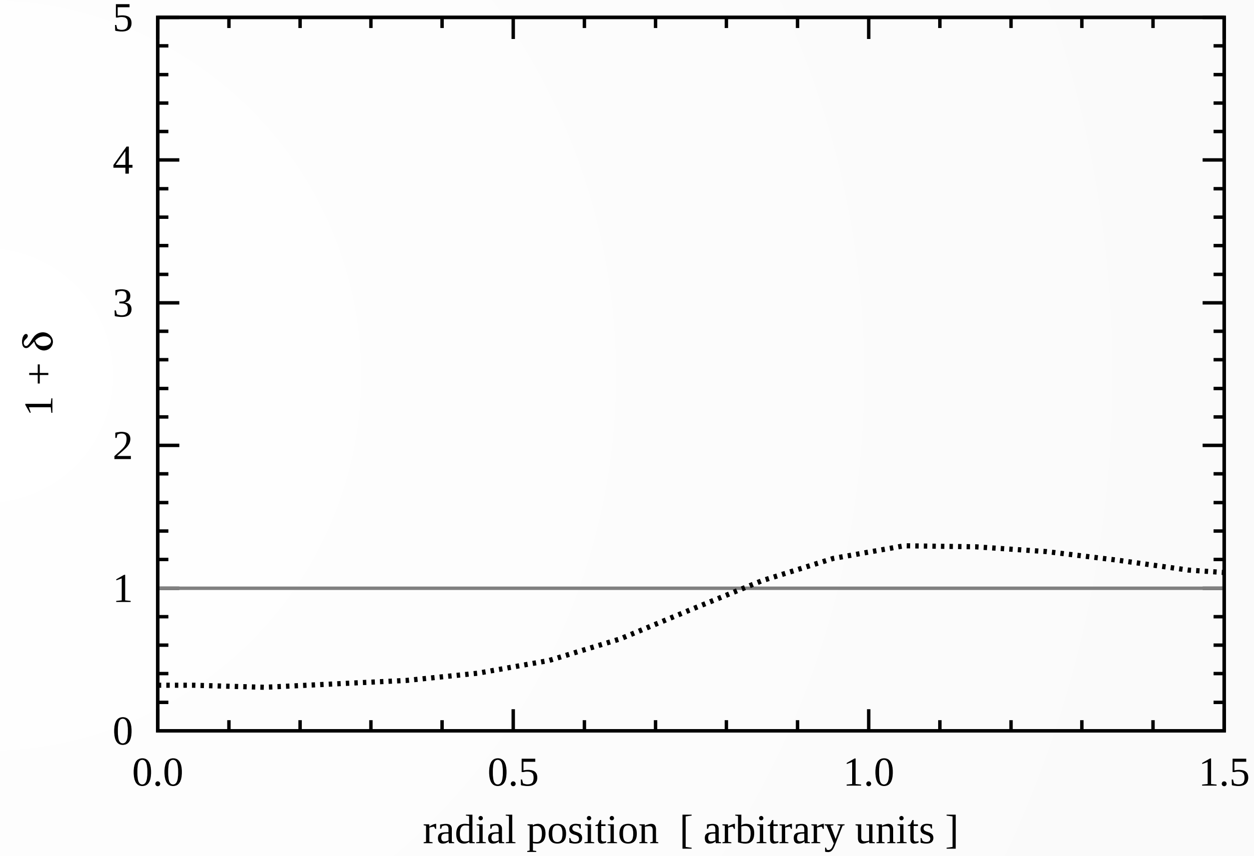


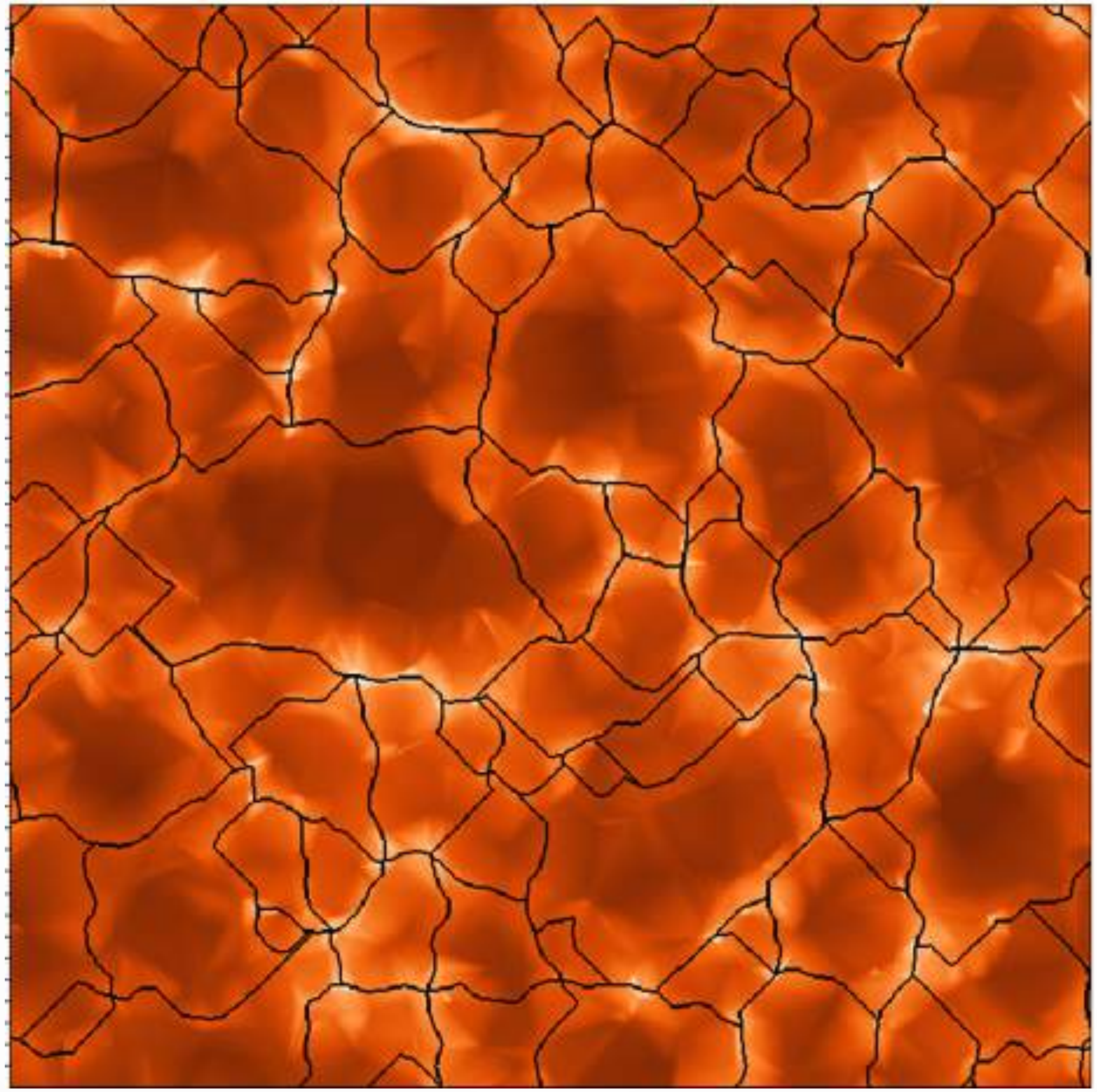
Simulations:
spherically averaged density



Fillmore & Goldreich 1984;
Sheth & van de Weygaert 2004

Hamaus+ 2014; Nadathur+ 2014;
Ricciardelli+ 2014; Cai+ 2015

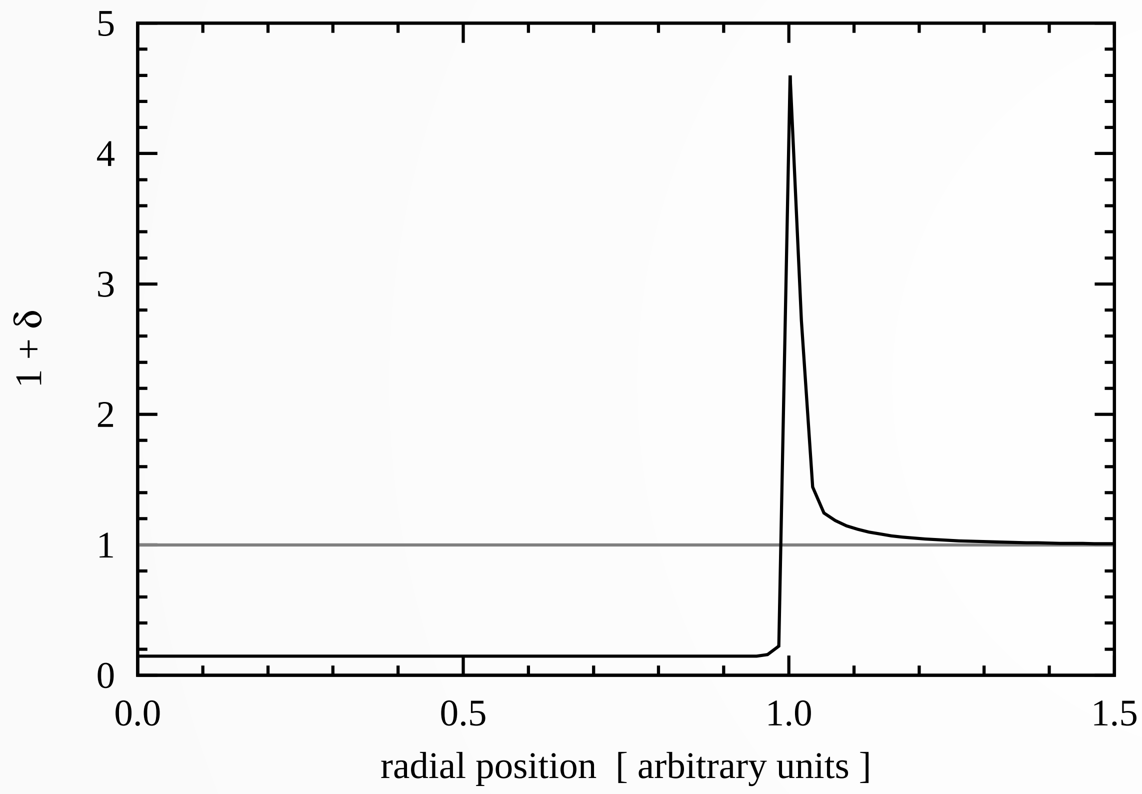
The shape of emptiness

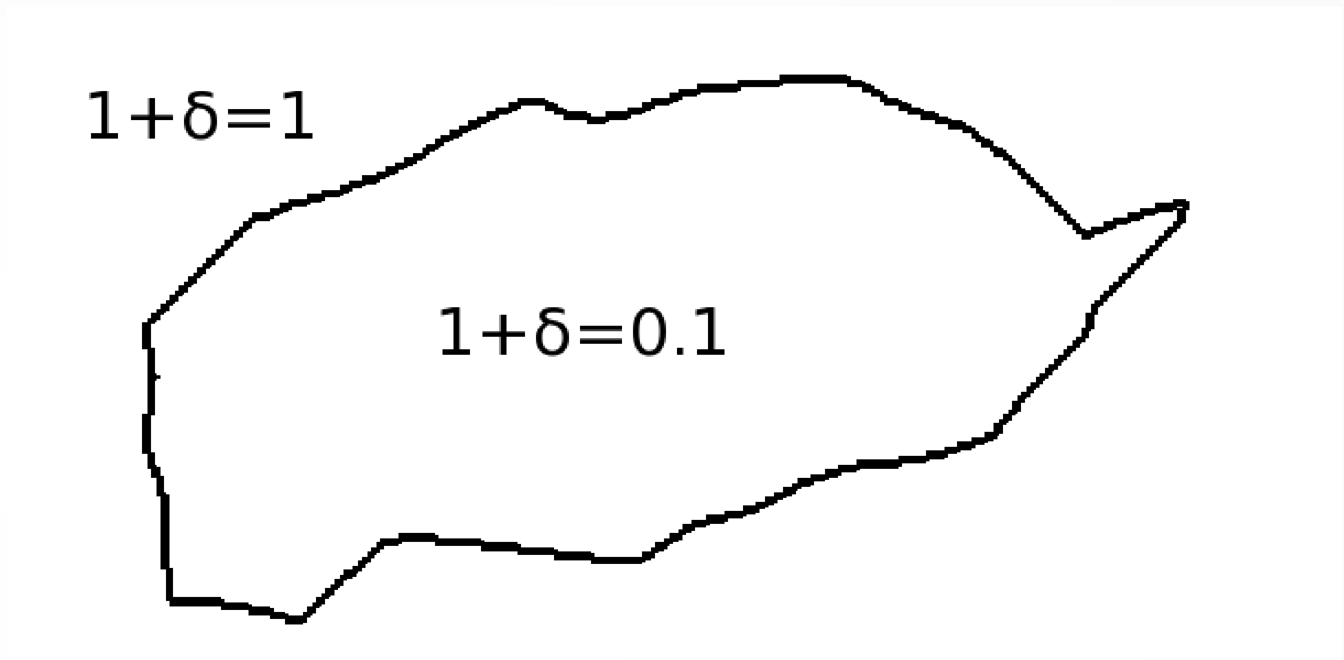


Voids have a diversity of shapes, being distinctly non-spherical.

The boundary profile of voids

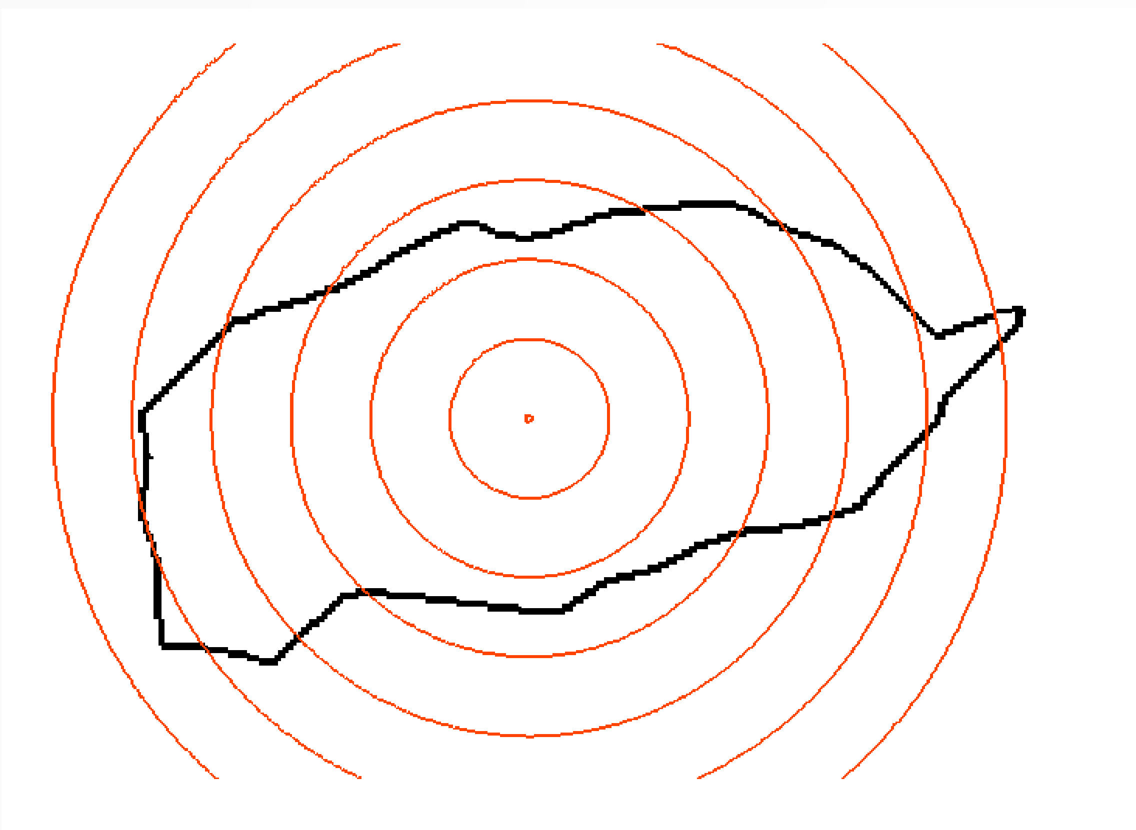
A simple void model

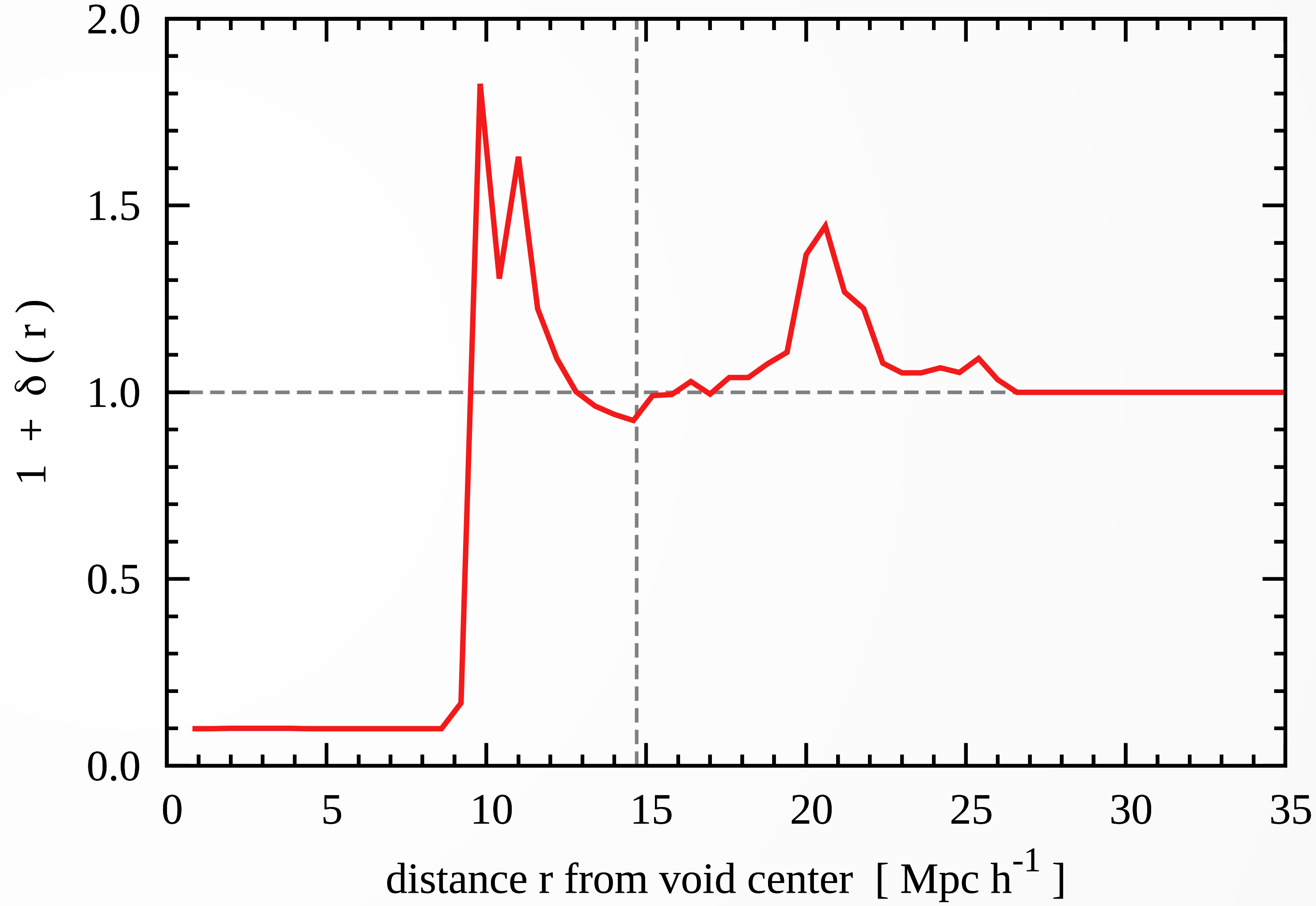




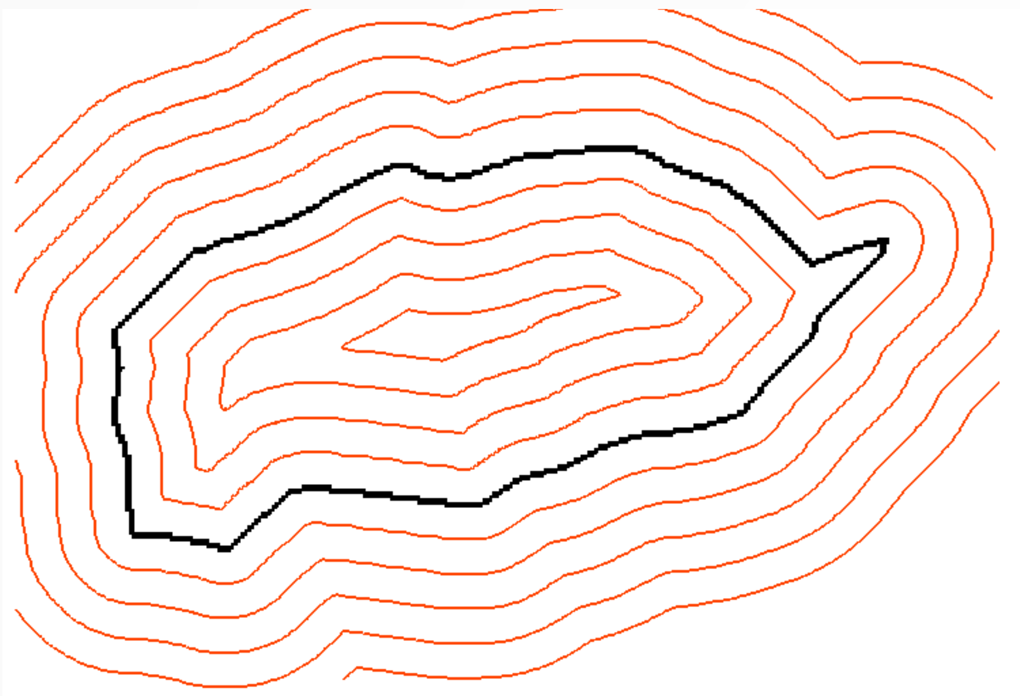
- Void shape taken from a cosmological N-body simulation.
- Density profile based on the expanding spherical underdensity.

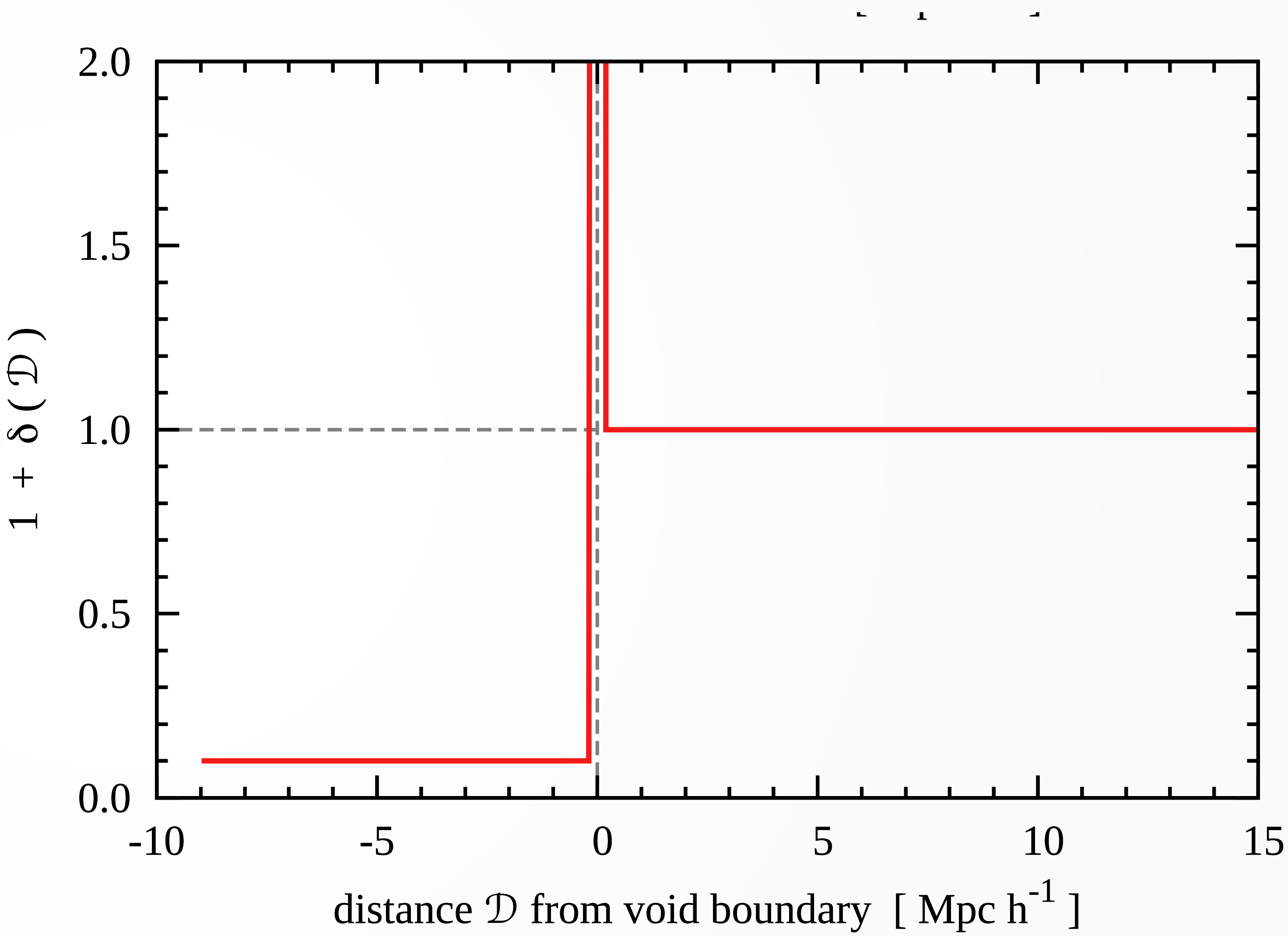
The conventional approach: spherical averaging



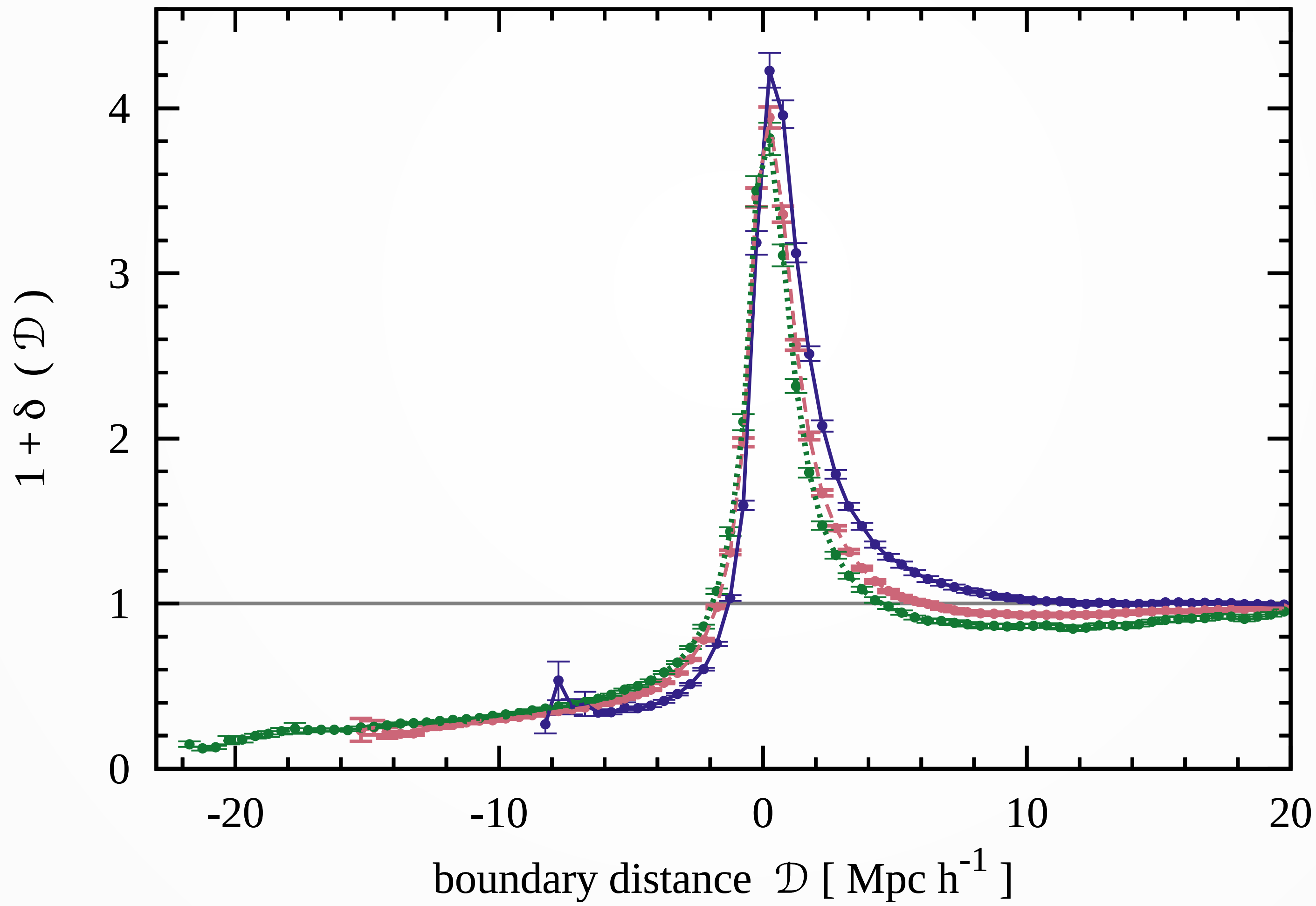


A new method:
boundary profile





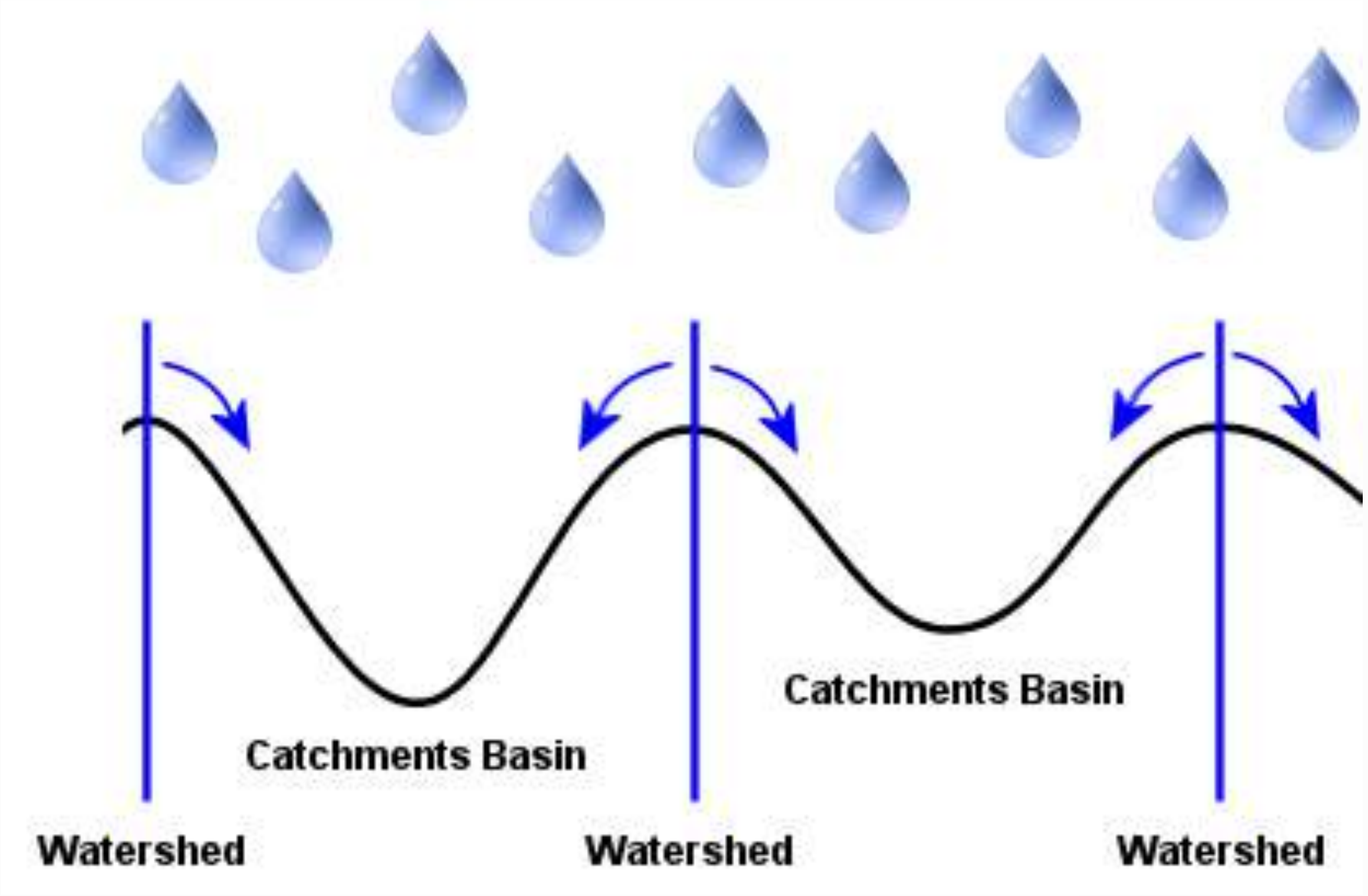
What about realistic voids?



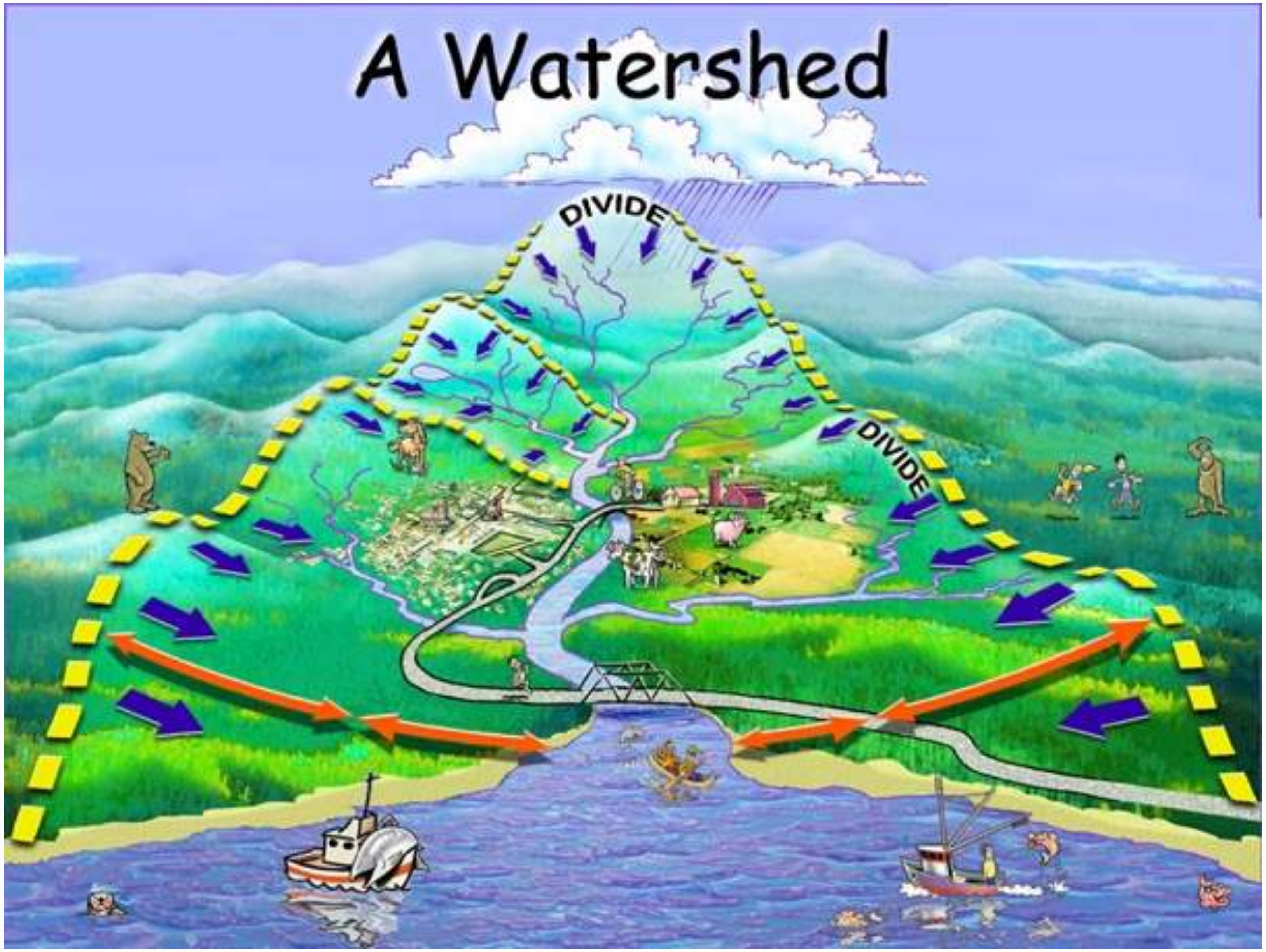
Void detection

- Use the Millennium cosmological simulation (L = 500 Mpc/h).
- Populate the simulation with galaxies using semi-analitycal galaxy formation models (Guo+ 2011).
- Select the most massive galaxies to obtain a number density, $n = 3.2 \times 10^{-3}$ $(\mathrm{Mpc/h})^3$, equivalent to the SDSS main sample ($M_{stellar} > 4 \times 10^{10}$ M_{solar}/h).
- Identify voids using the Watershed Void Finder (Platen+ 2007).

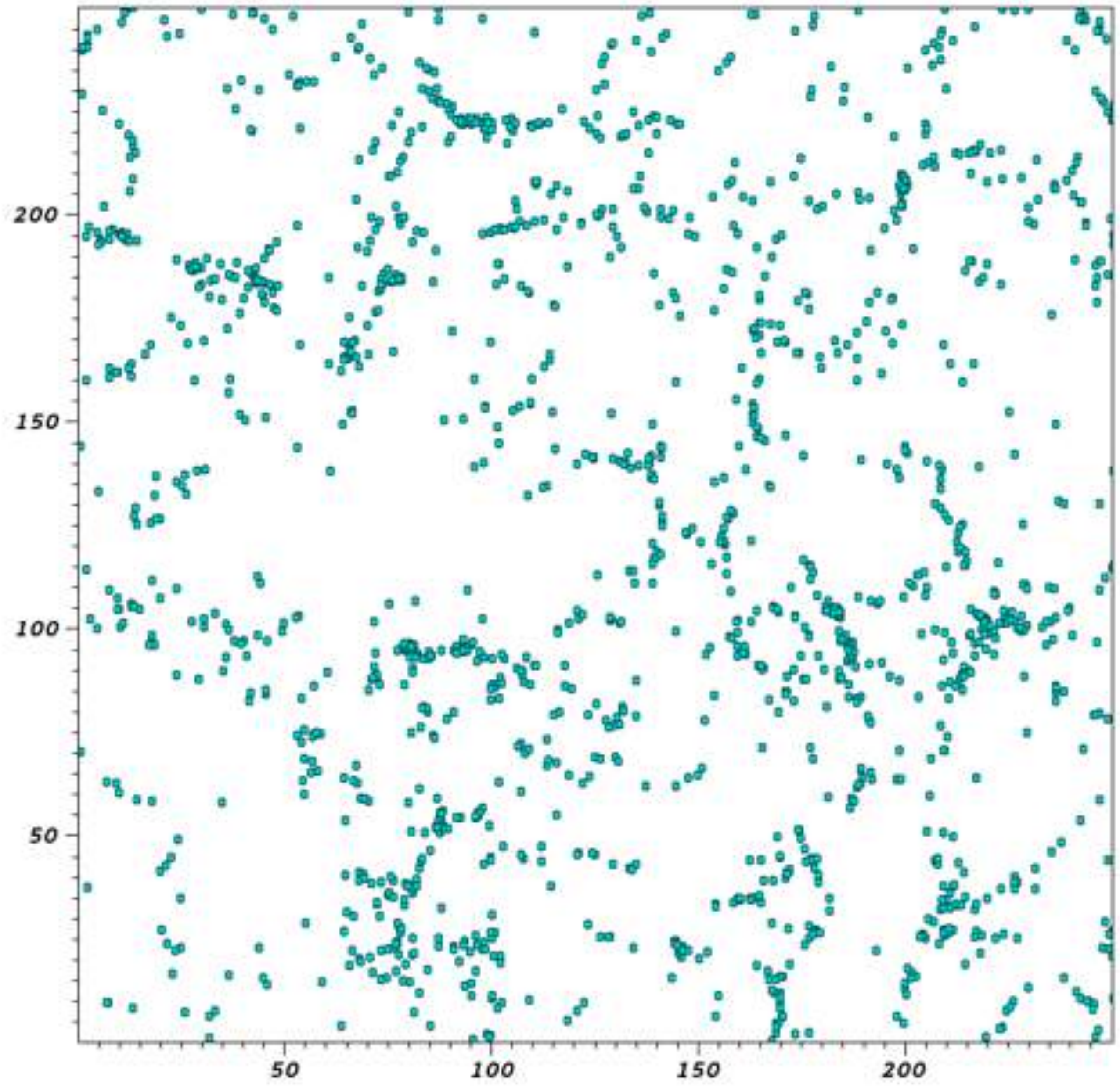
Watershed void finder



Watershed void finder

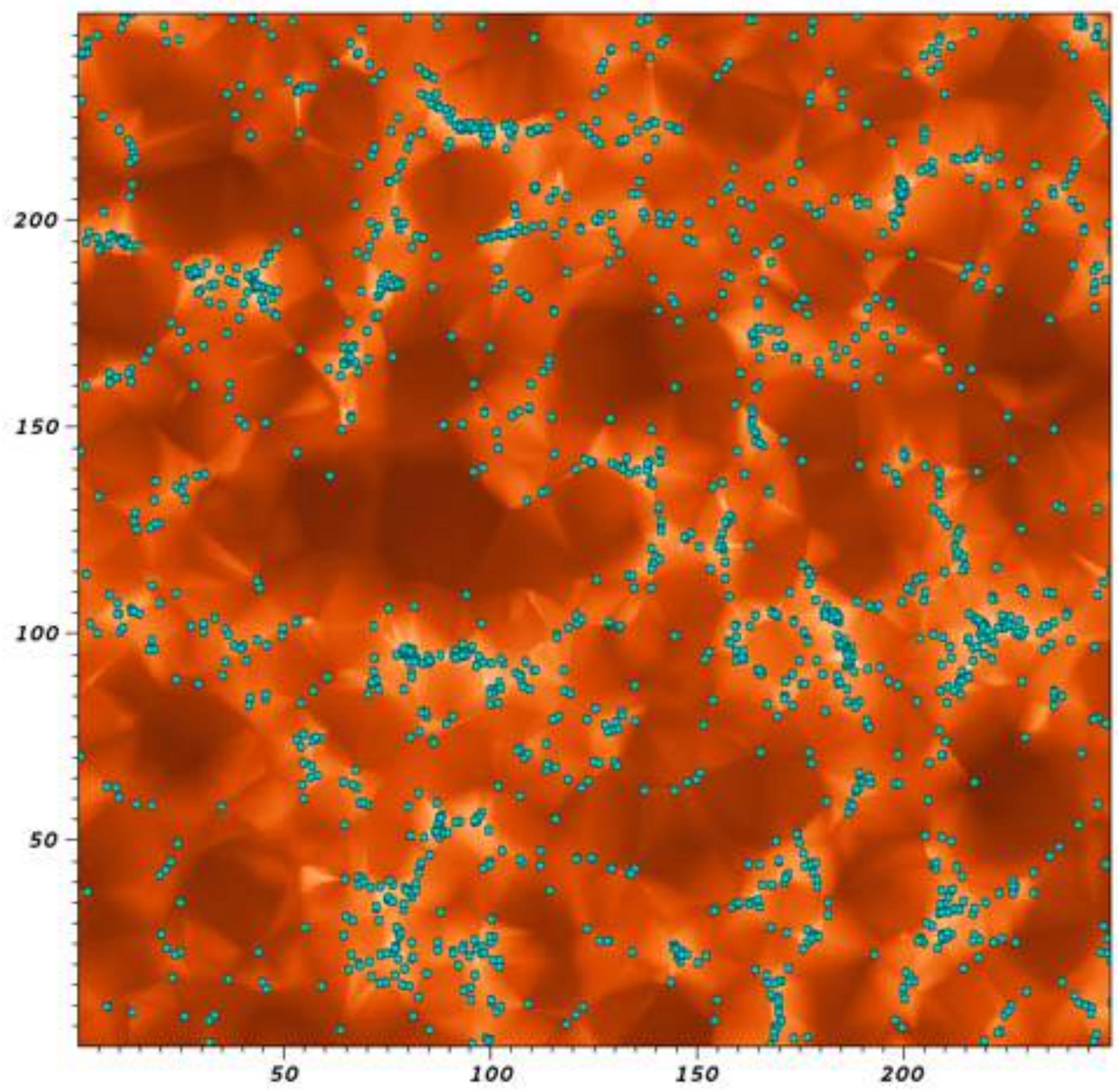


Void identification



Galaxy distribution

Void identification

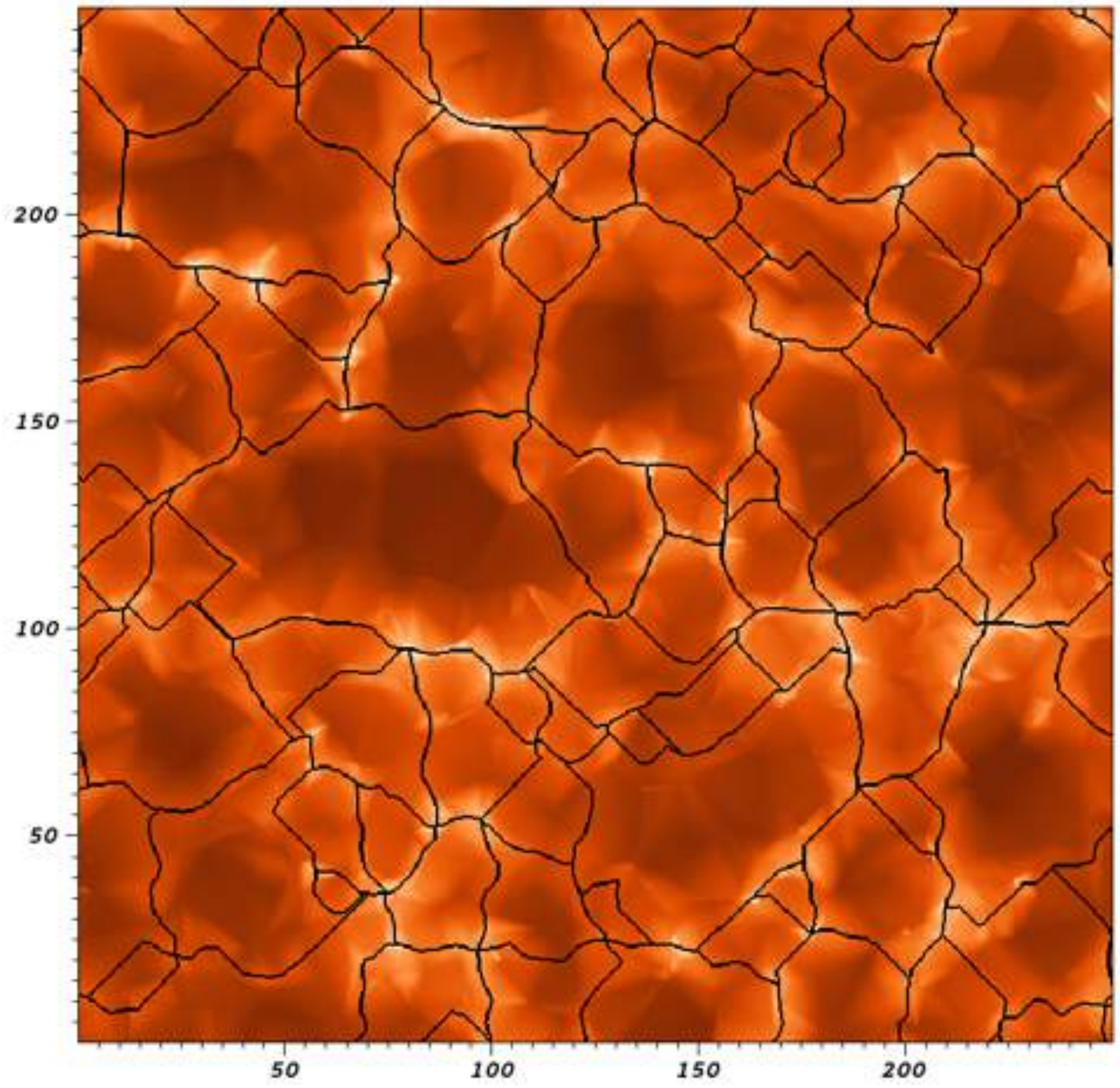


Galaxy distribution

↓

Density field (DTFE; Schaap & van de Weygaert 2000)

Void identification



Galaxy distribution

↓

Density field (DTFE; Schaap & van de Weygaert 2000)

↓

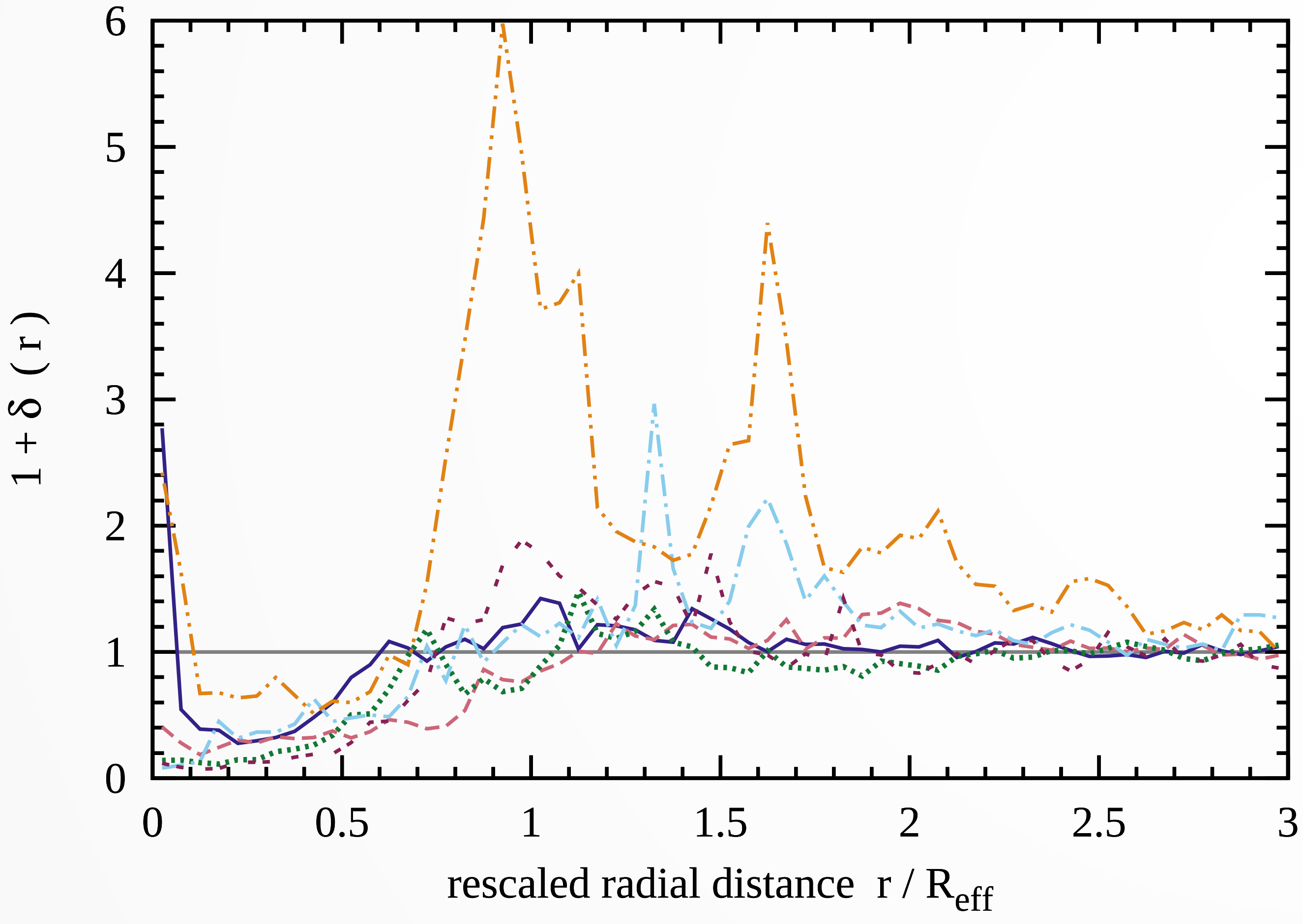
Voids (watershed basins; Platen+ 2007)

Results

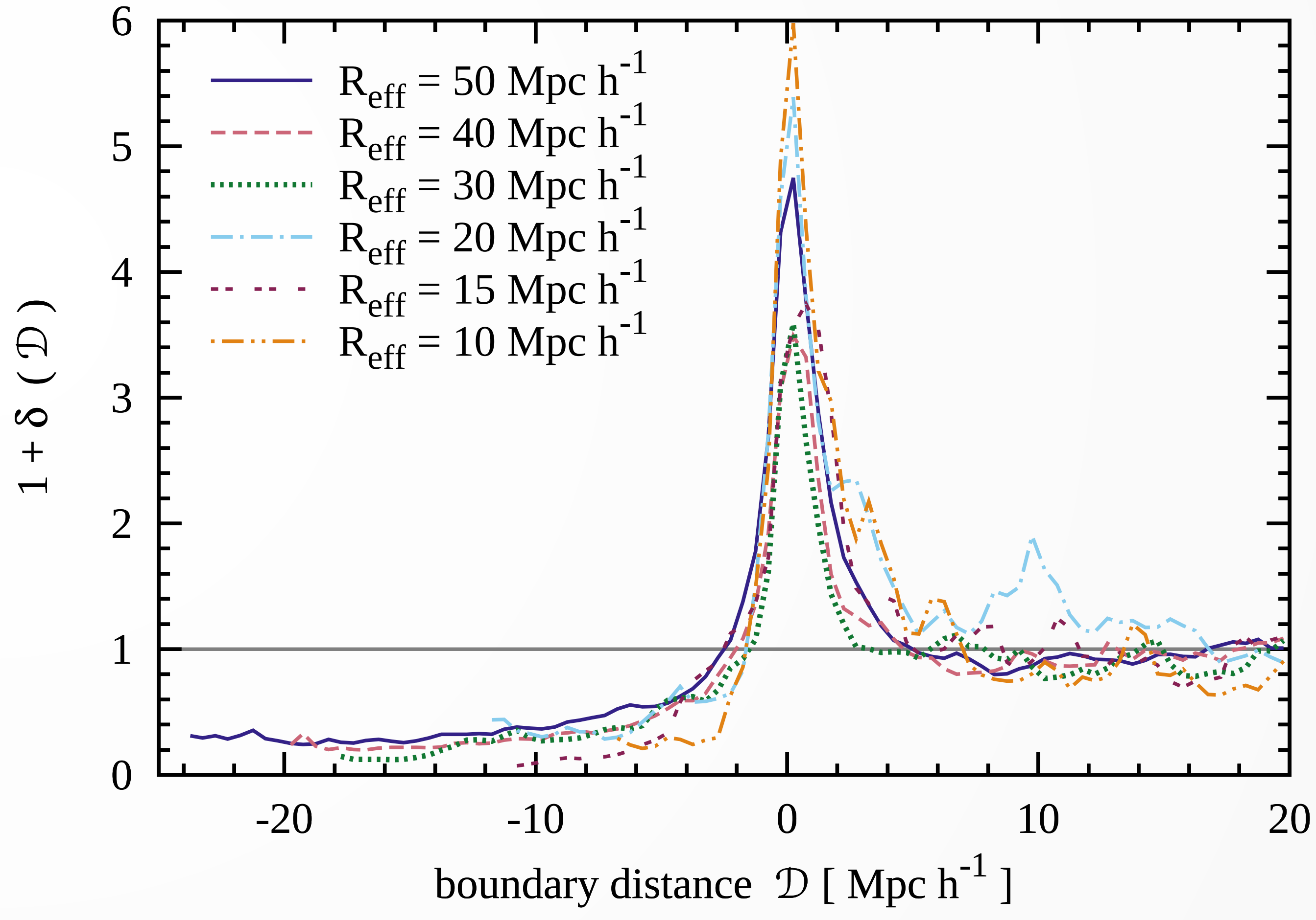
1. Density profiles.
2. Velocity profiles.
3. Weak lensing from voids.

The density profile individual voids

Spherical profile

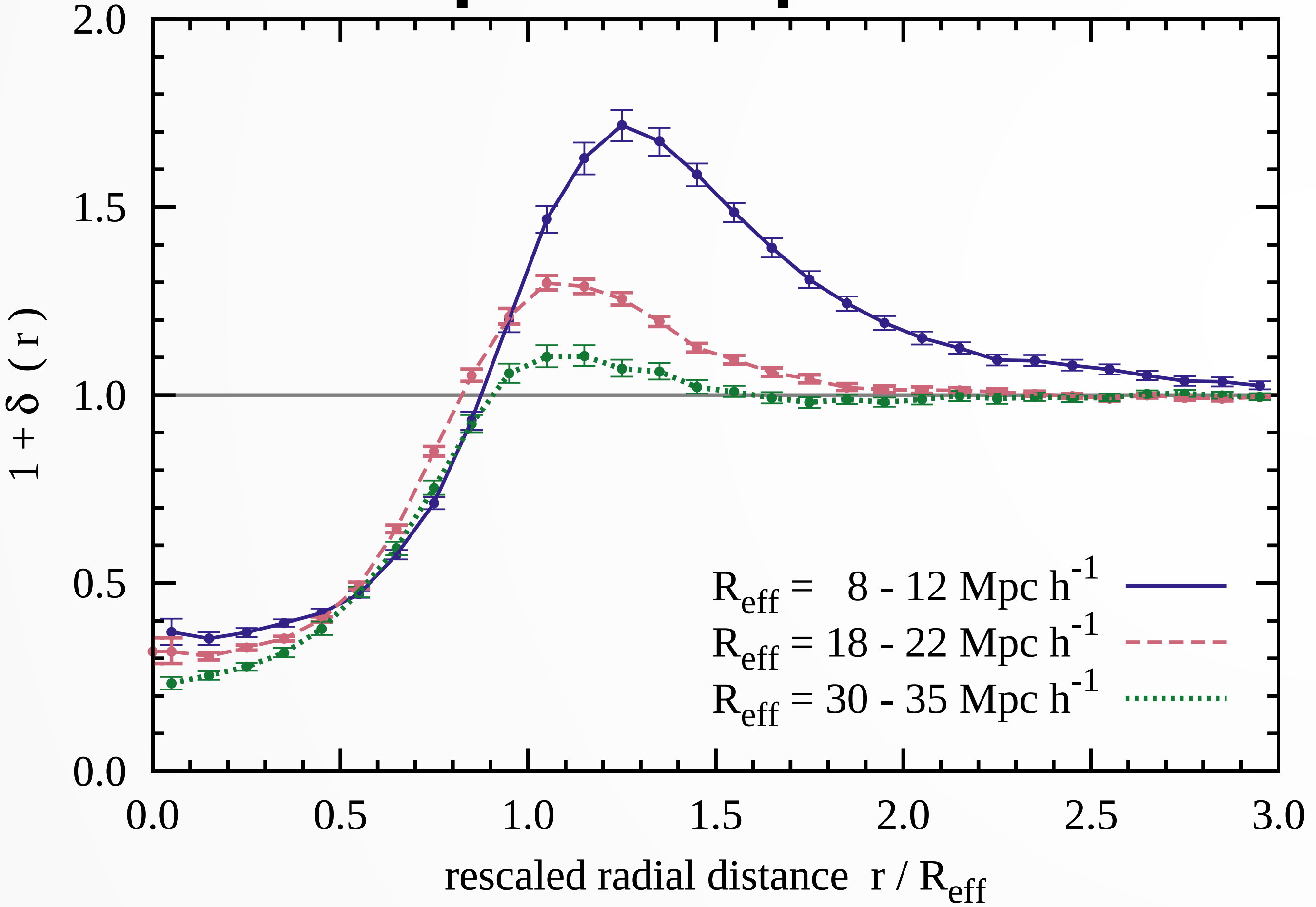


Boundary profile

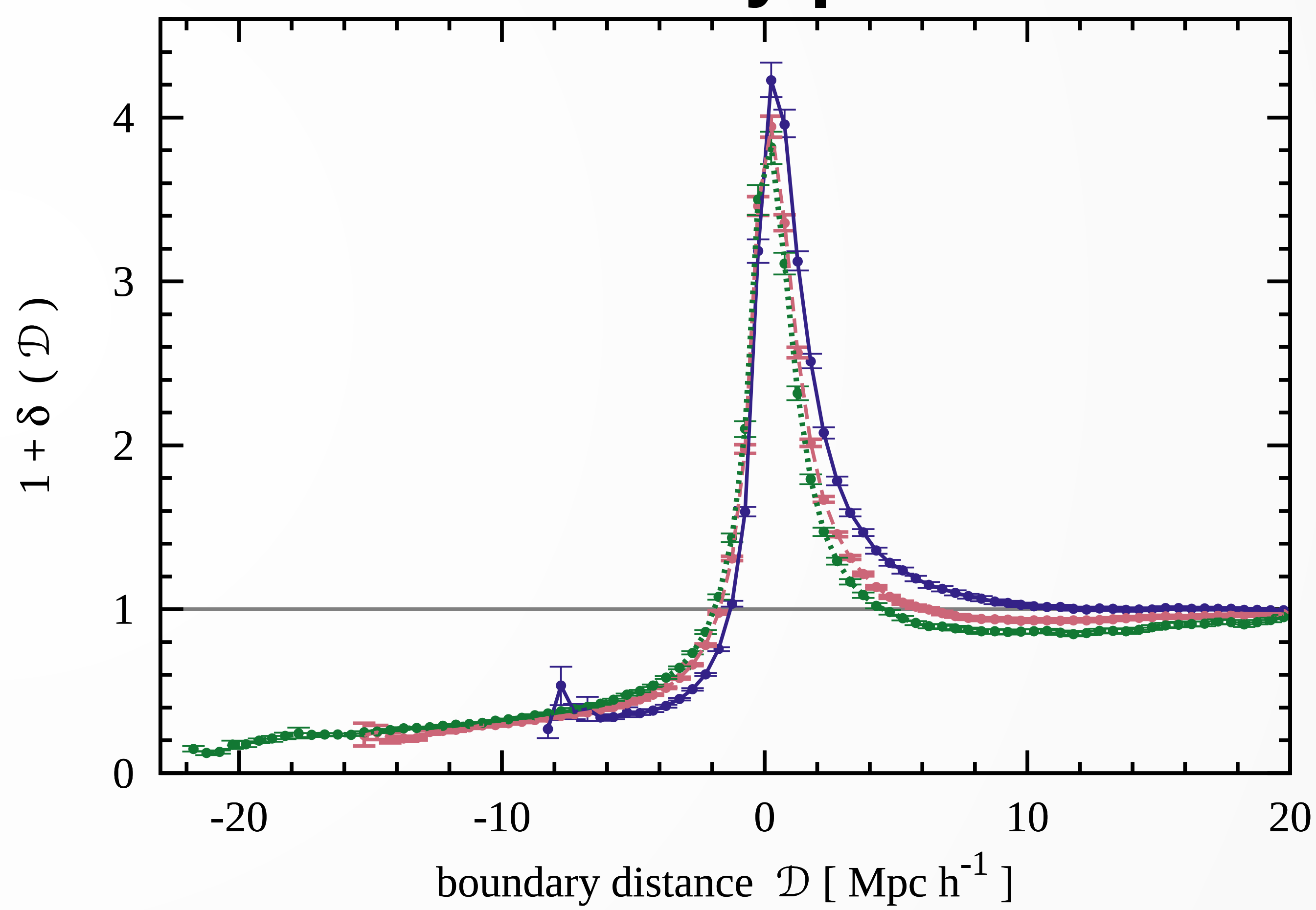


The density profile stacked voids

Spherical profile

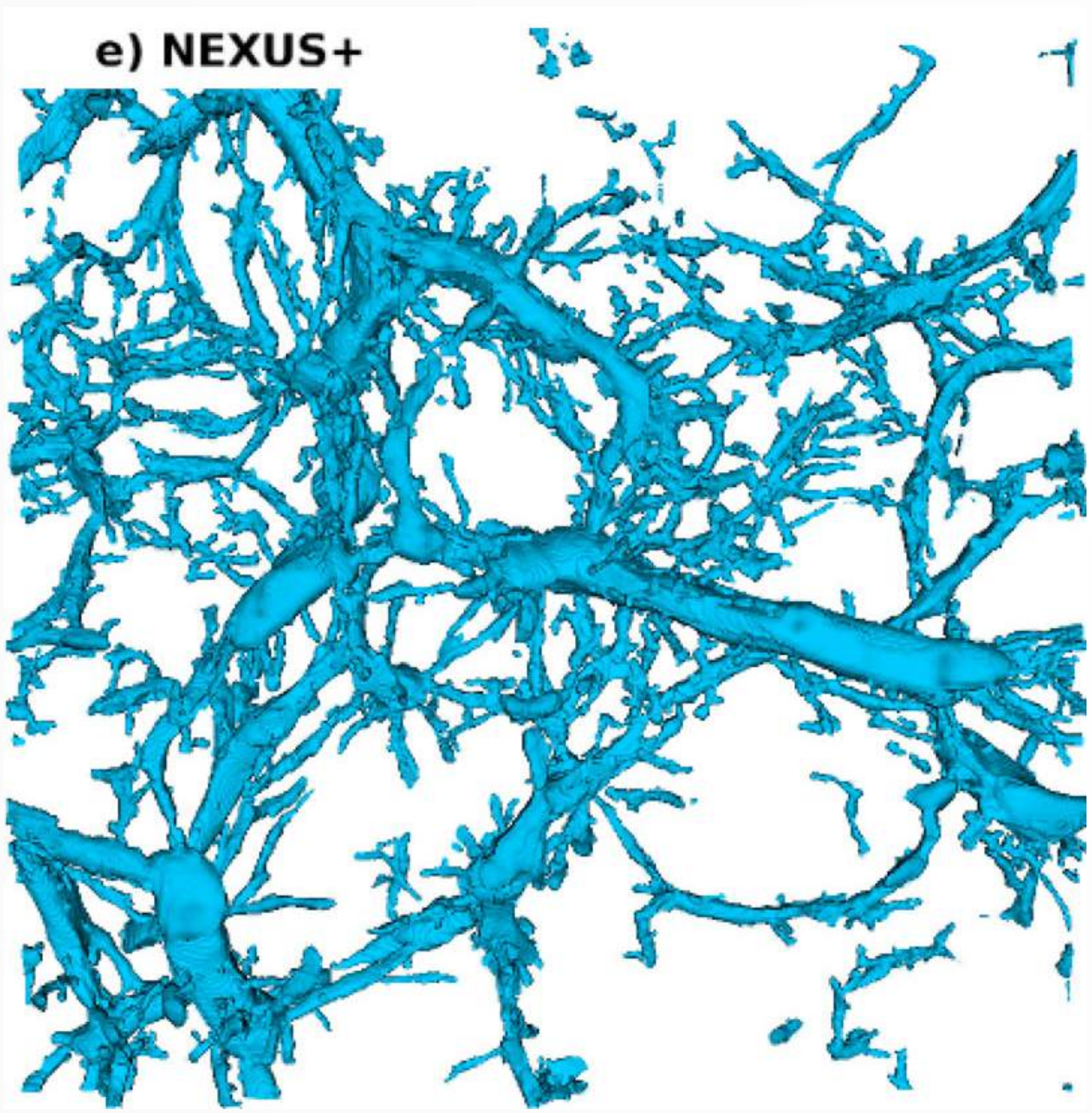


Boundary profile

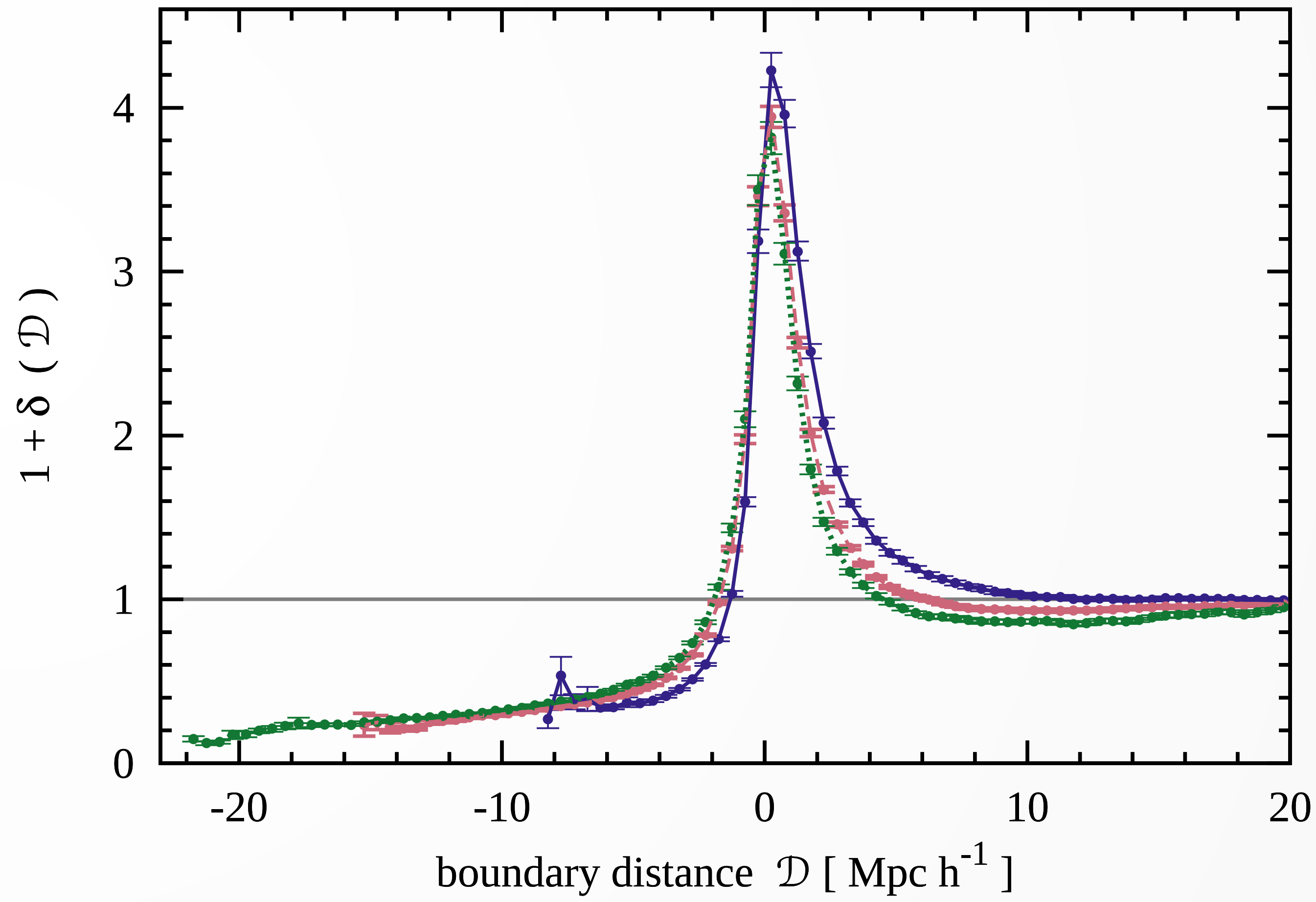


Hamaus+ 2014; Nadathur+ 2014

The density profile
stacked voids



Boundary profile



Cautun+ 2013; Cautun+ 2014

The density profile
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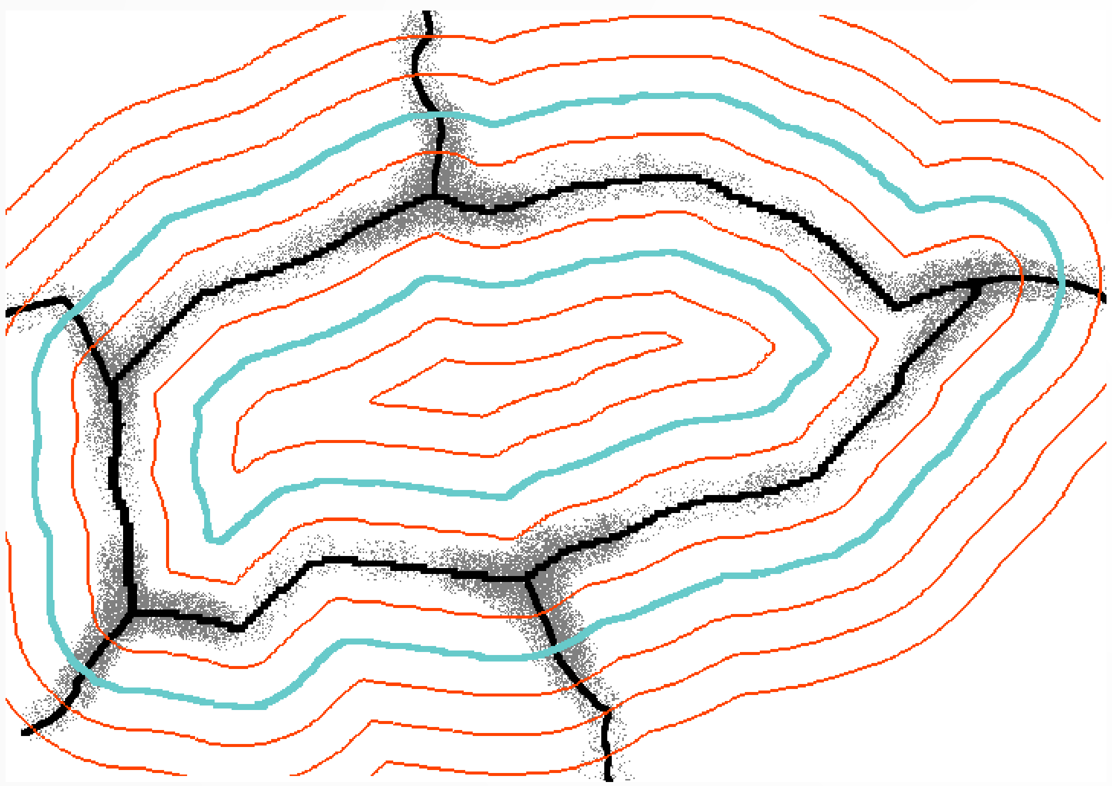
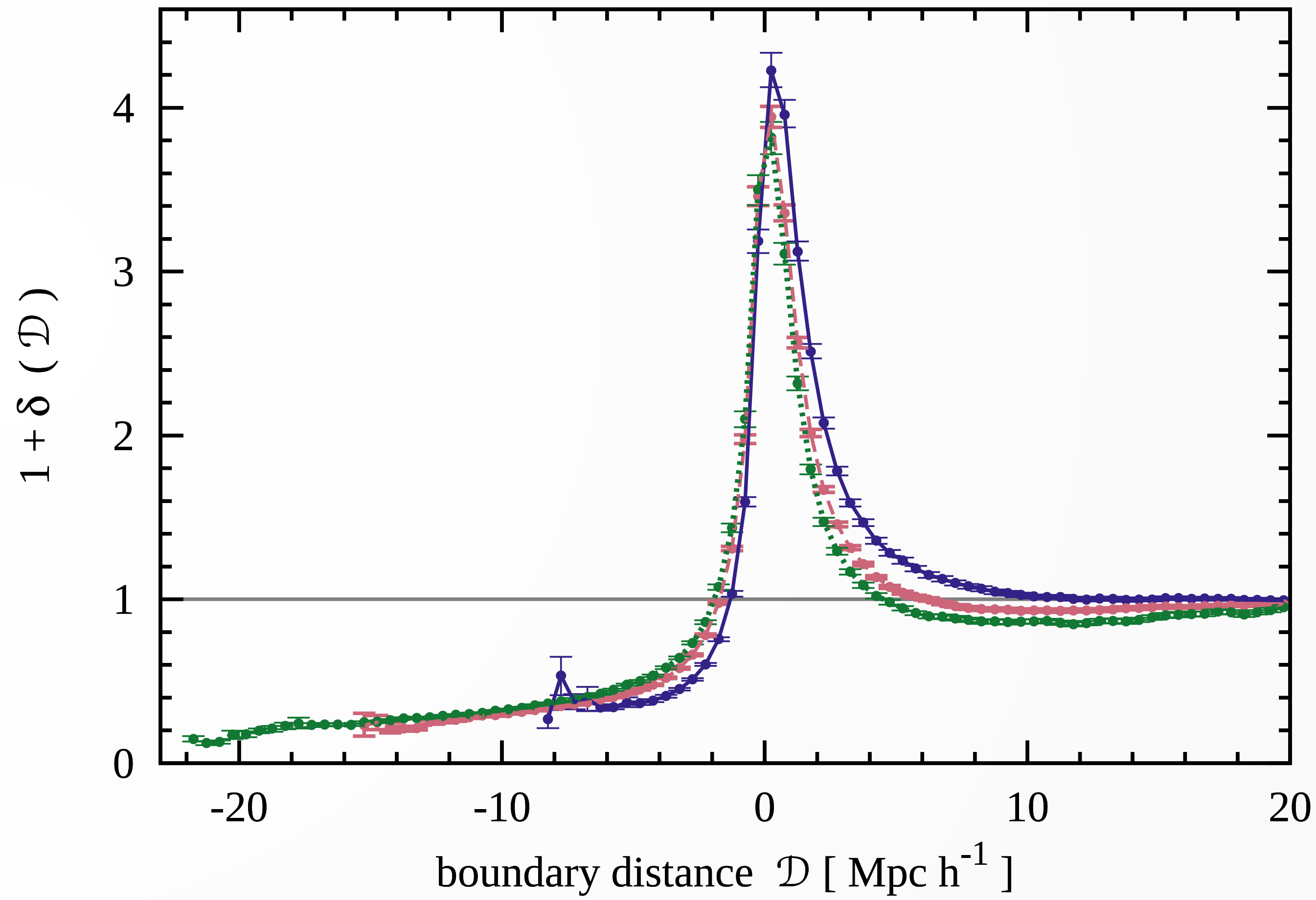
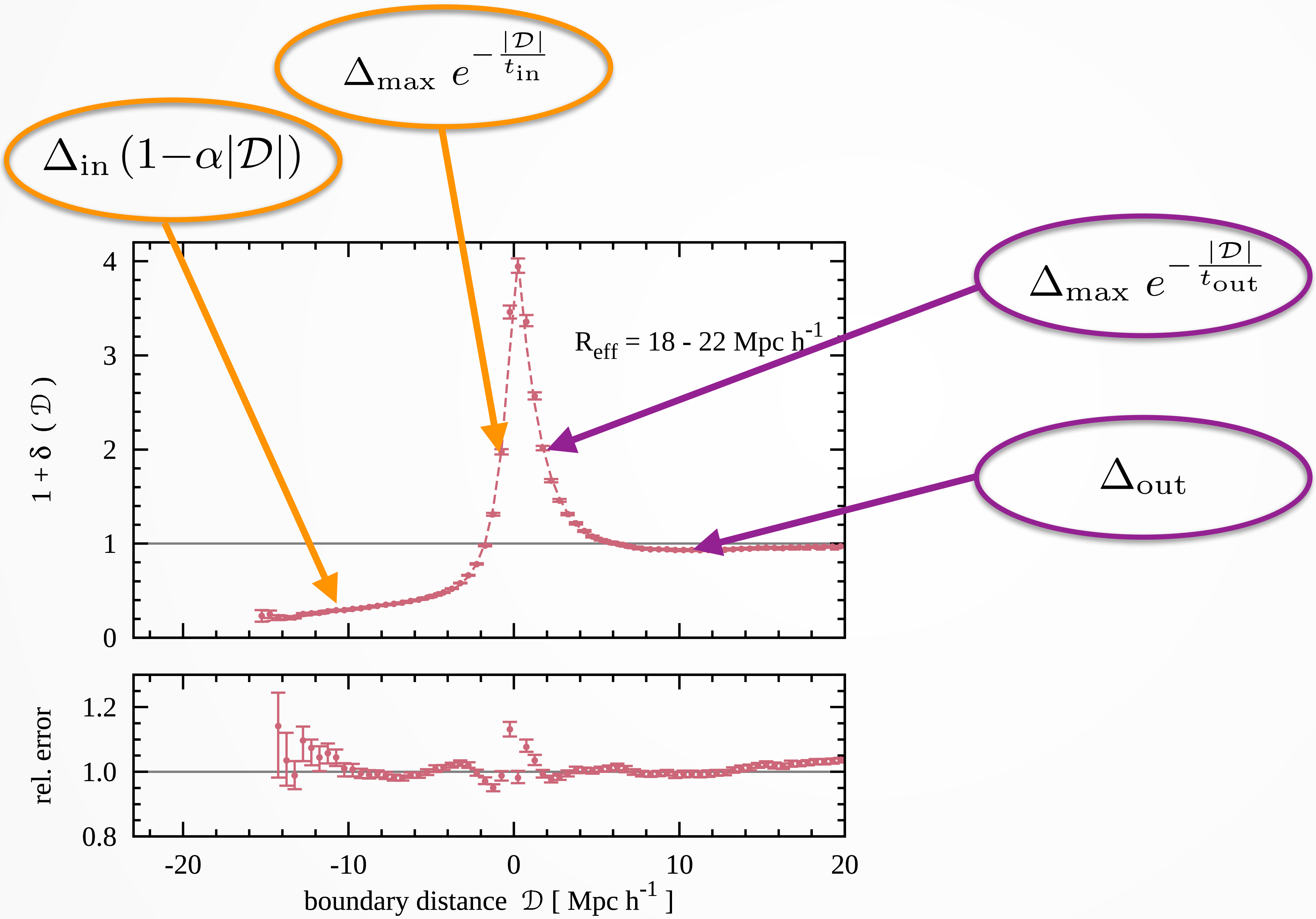


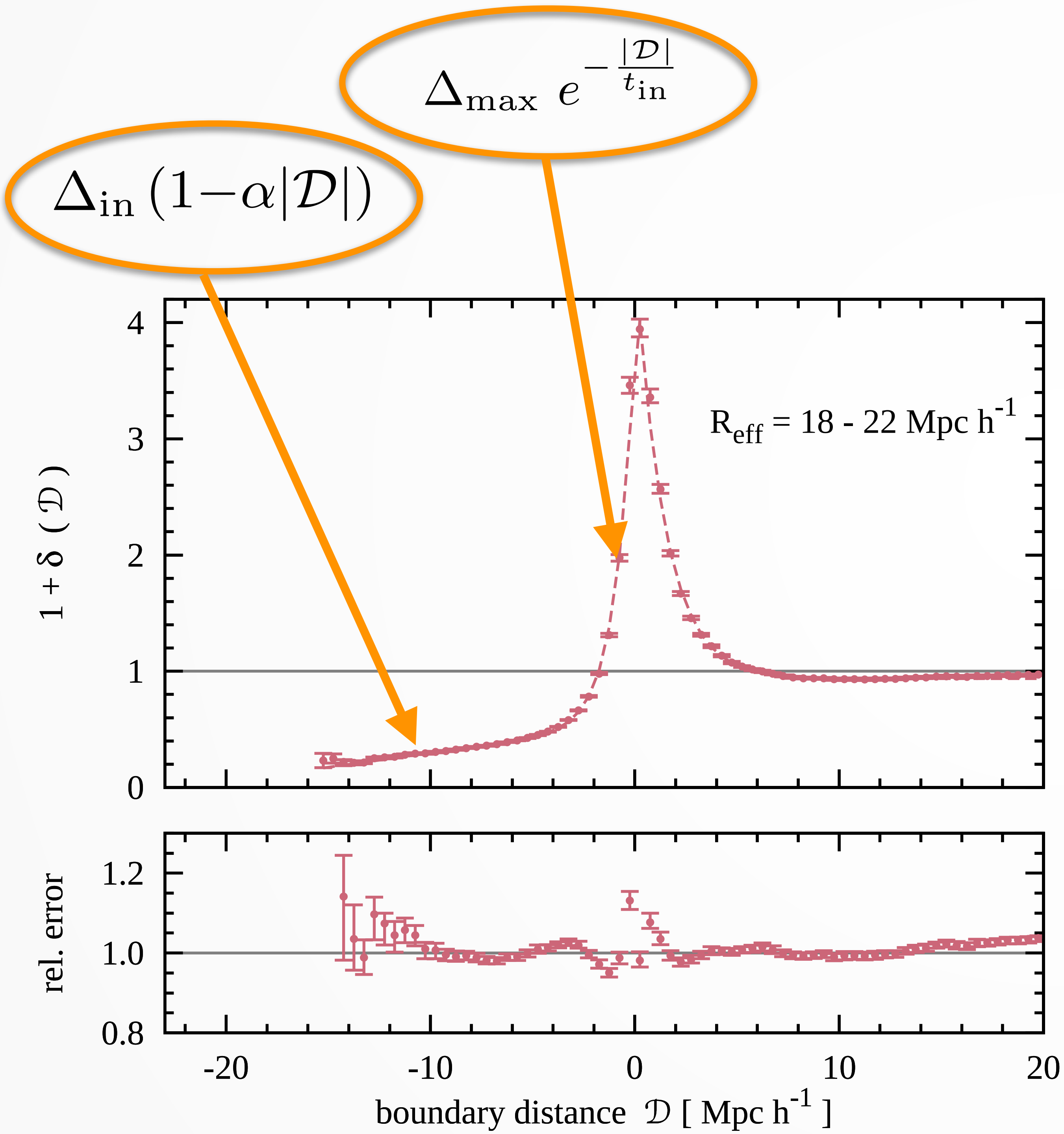
Boundary profile

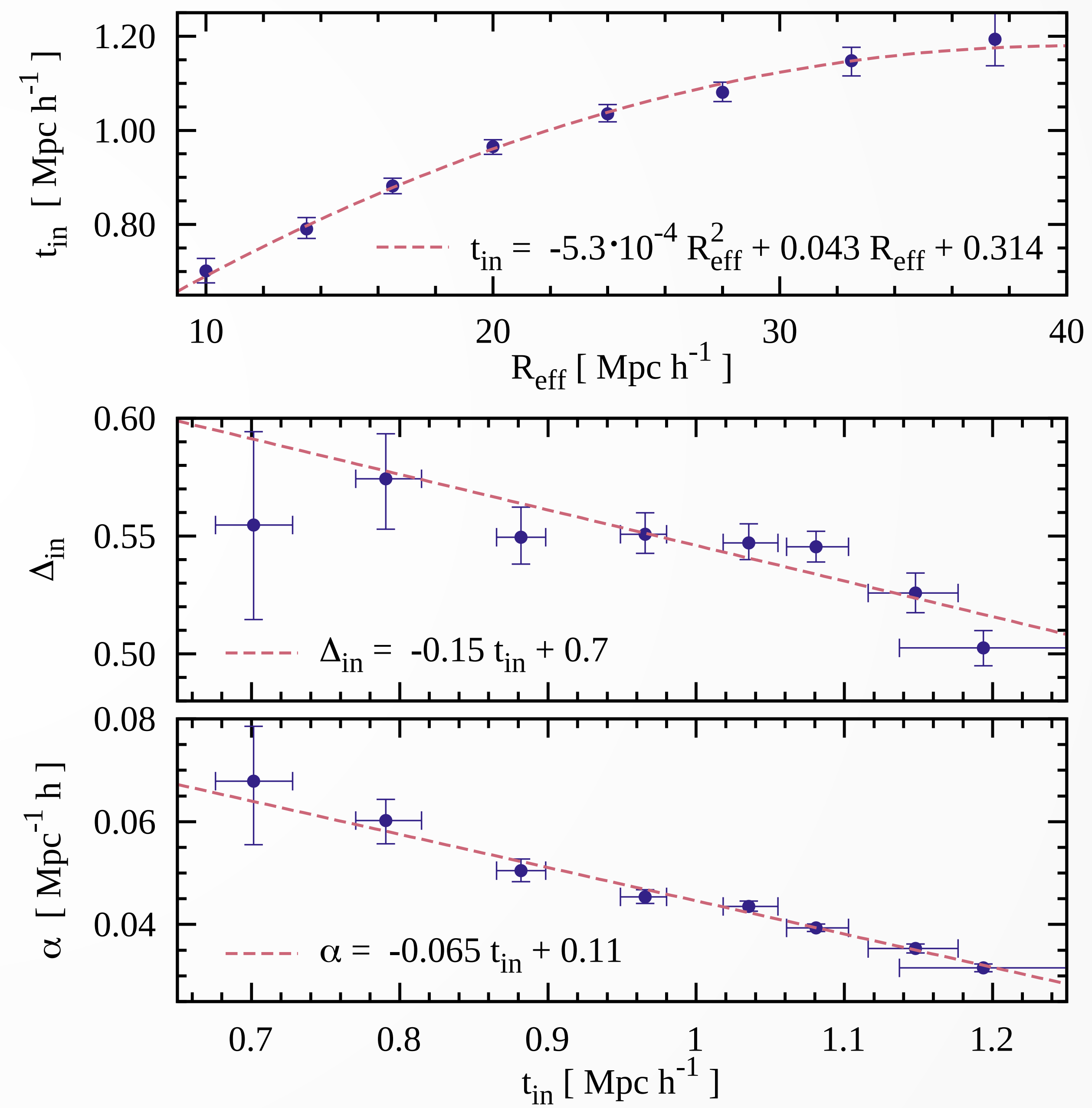


Fit to the boundary profile

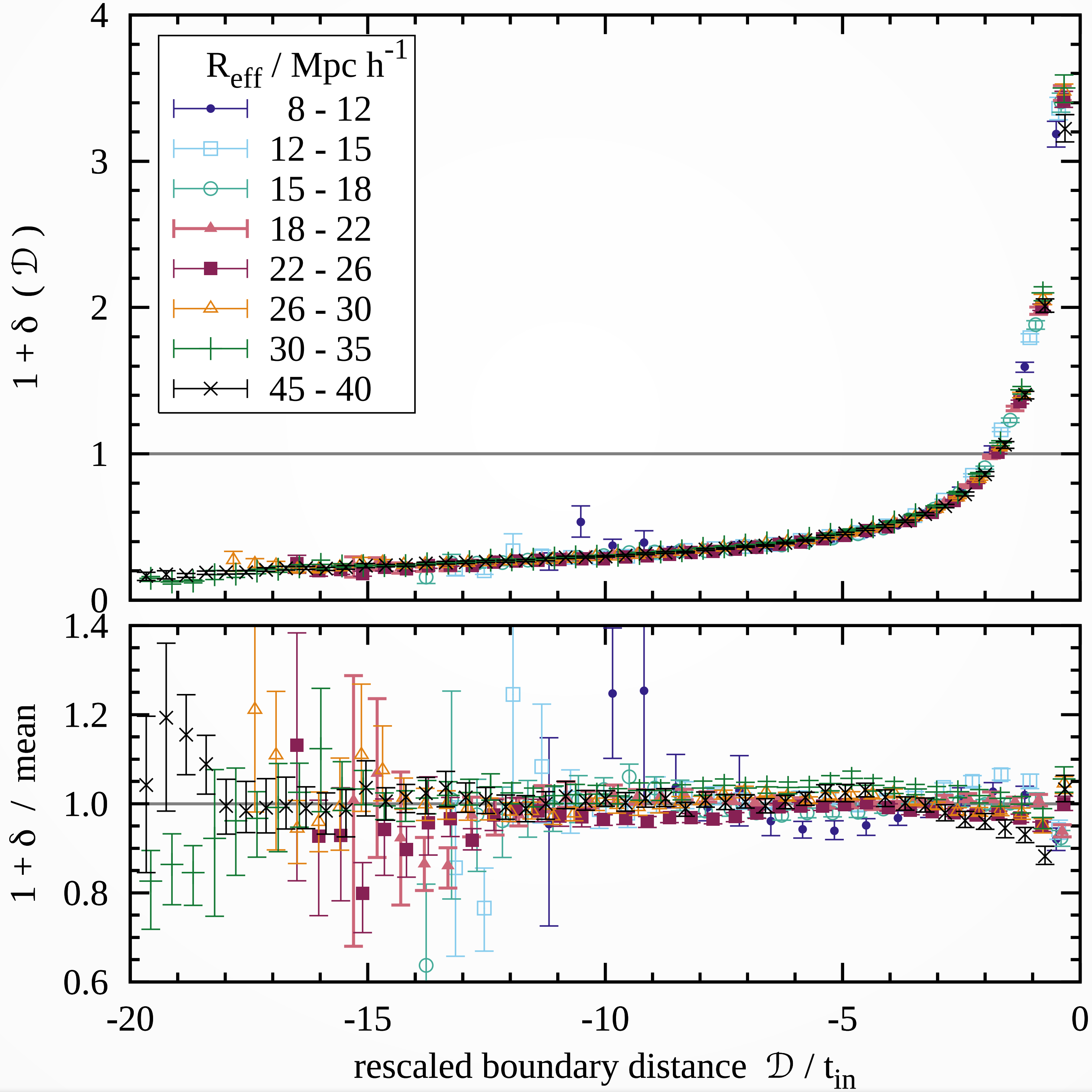


Fit to the boundary profile

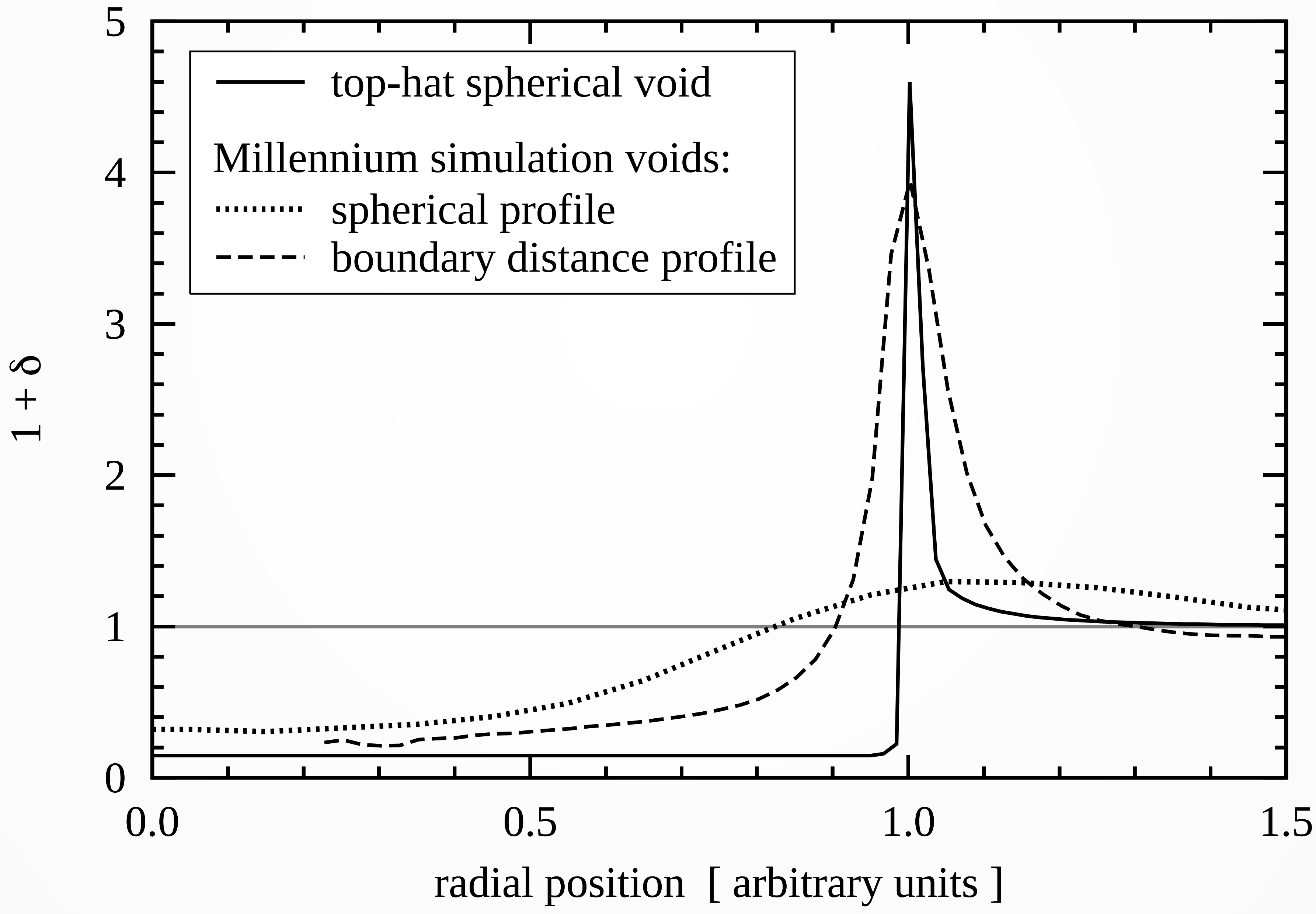




The simplicity of voids: self-similar behaviour

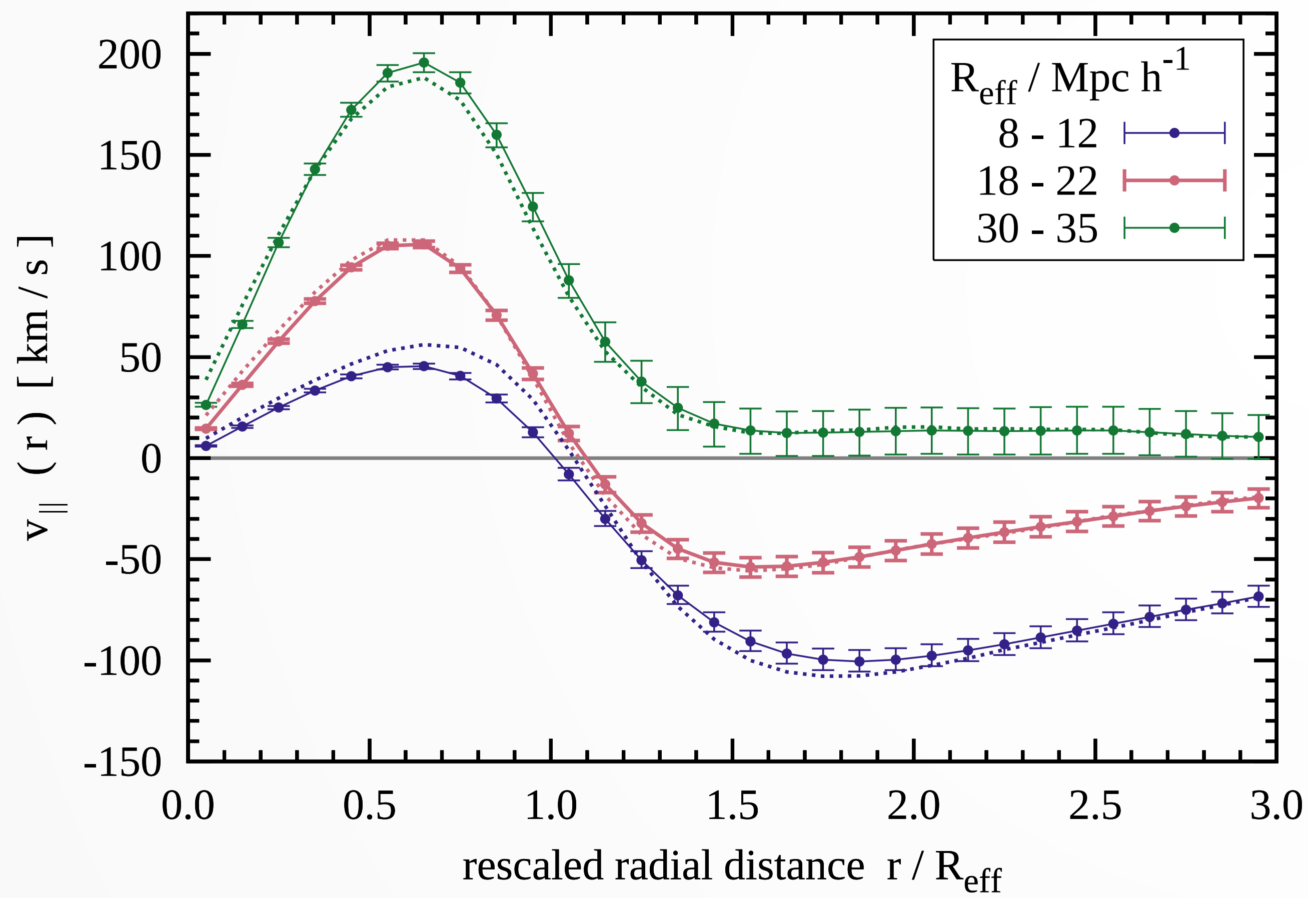


Comparing to analytical models

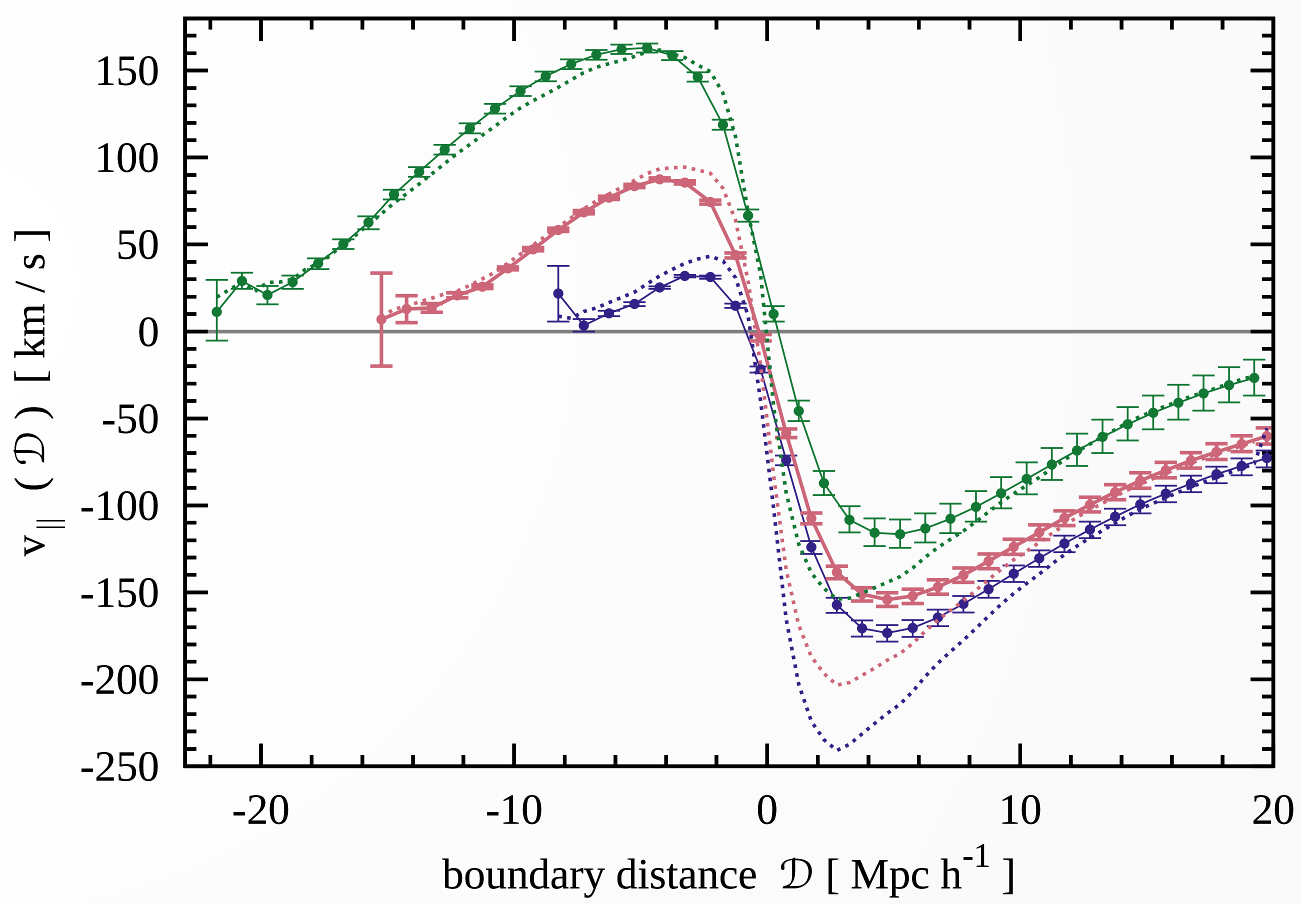


The velocity profile
stacked voids

Spherical profile

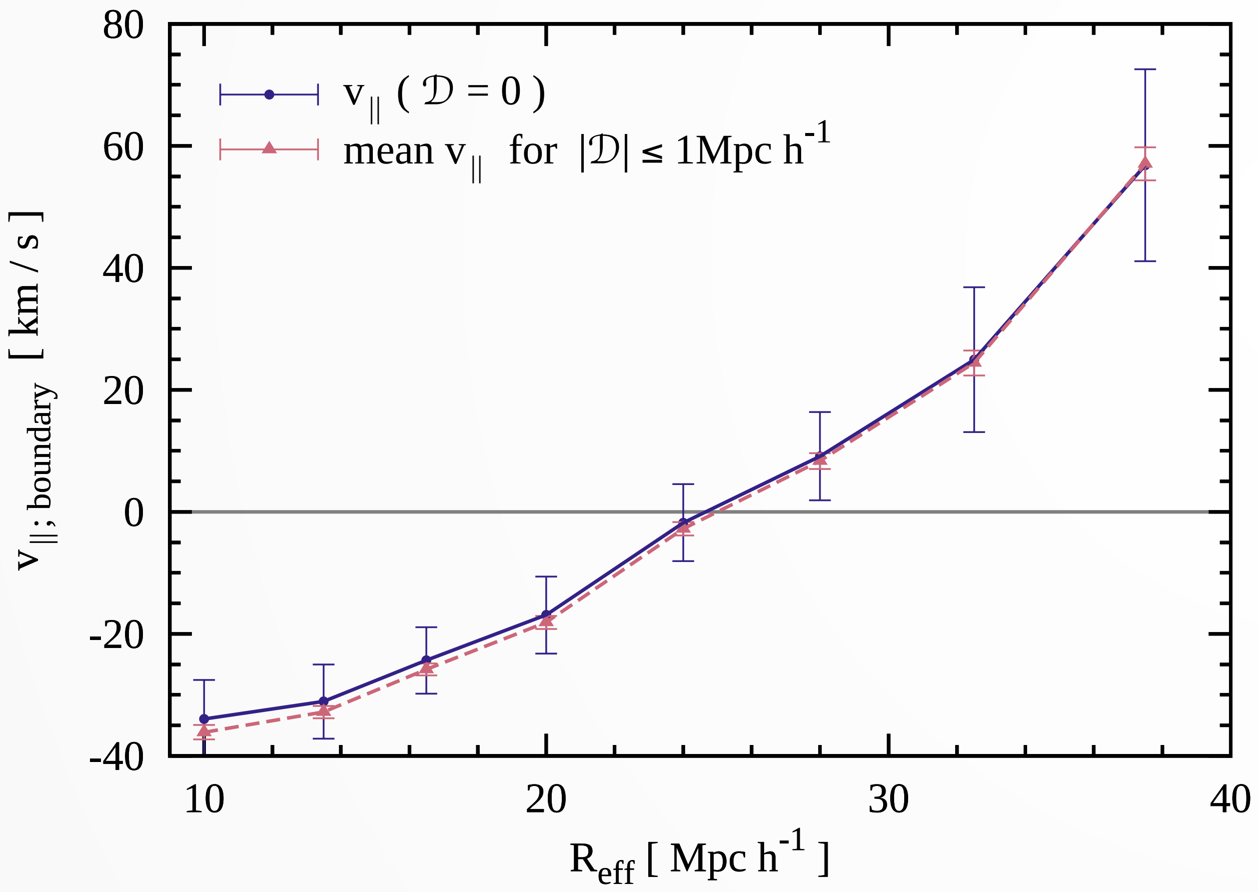


Boundary profile

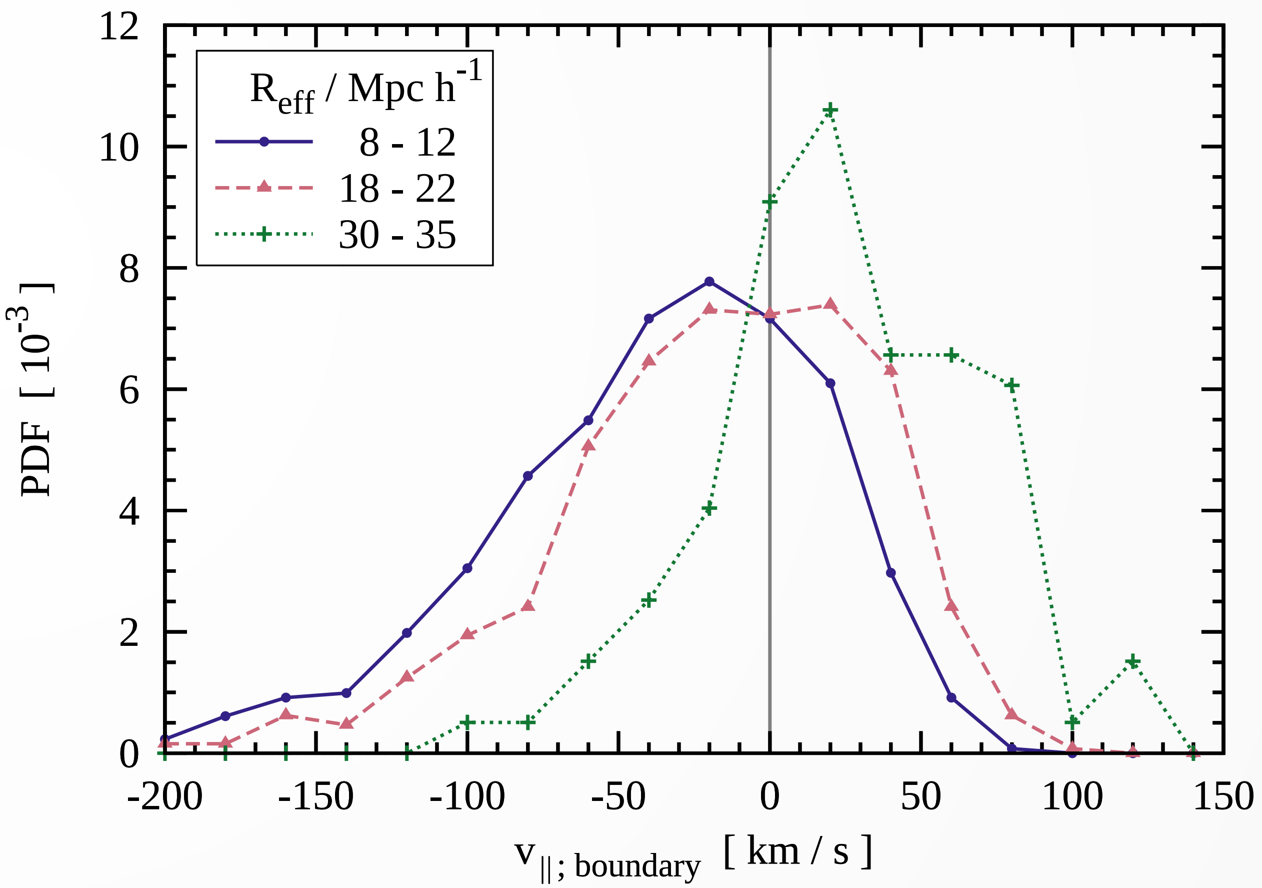


Expanding versus contracting voids

Stacked voids



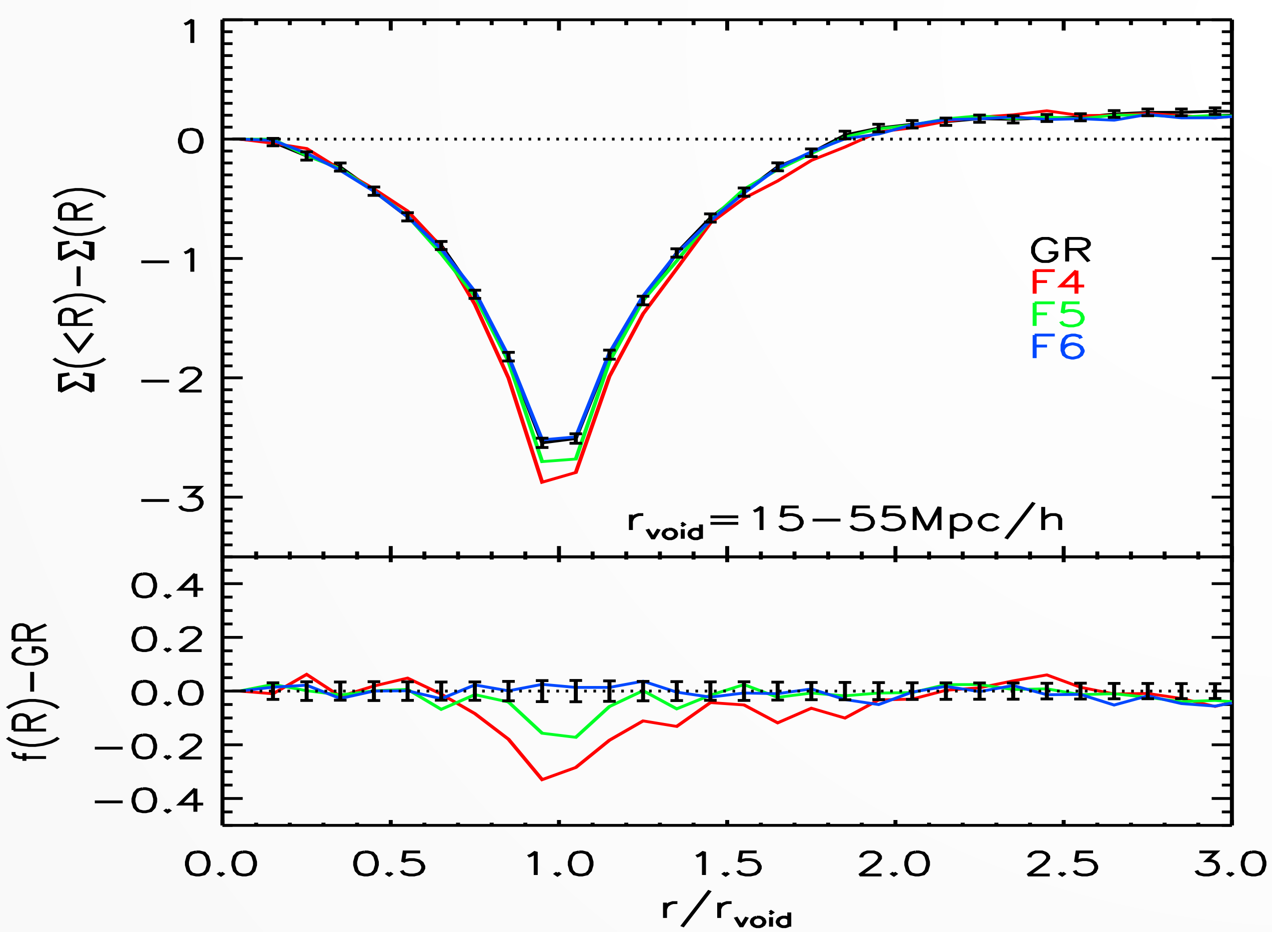
Individual voids



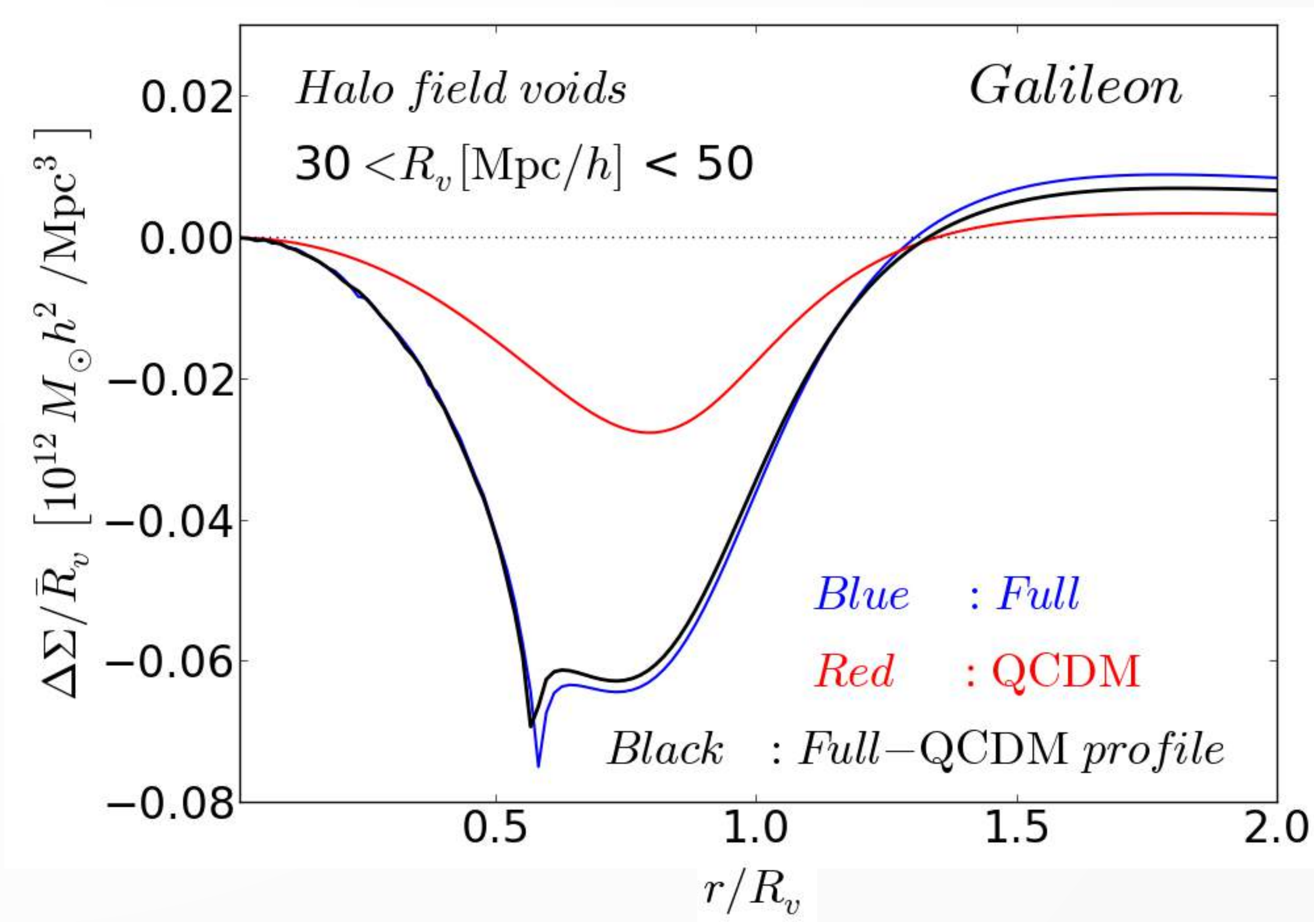
Void weak lensing

- Void density profiles are sensitive to: modifications of gravity (e.g. f(R), Galileon, Nonlocal), neutrino mass (Massara+ 2015); …
- Difference w.r.t. LCDM is small, voids are ~a few percent emptier in some modified theories of gravity.

f(R) - Cai+ 2015

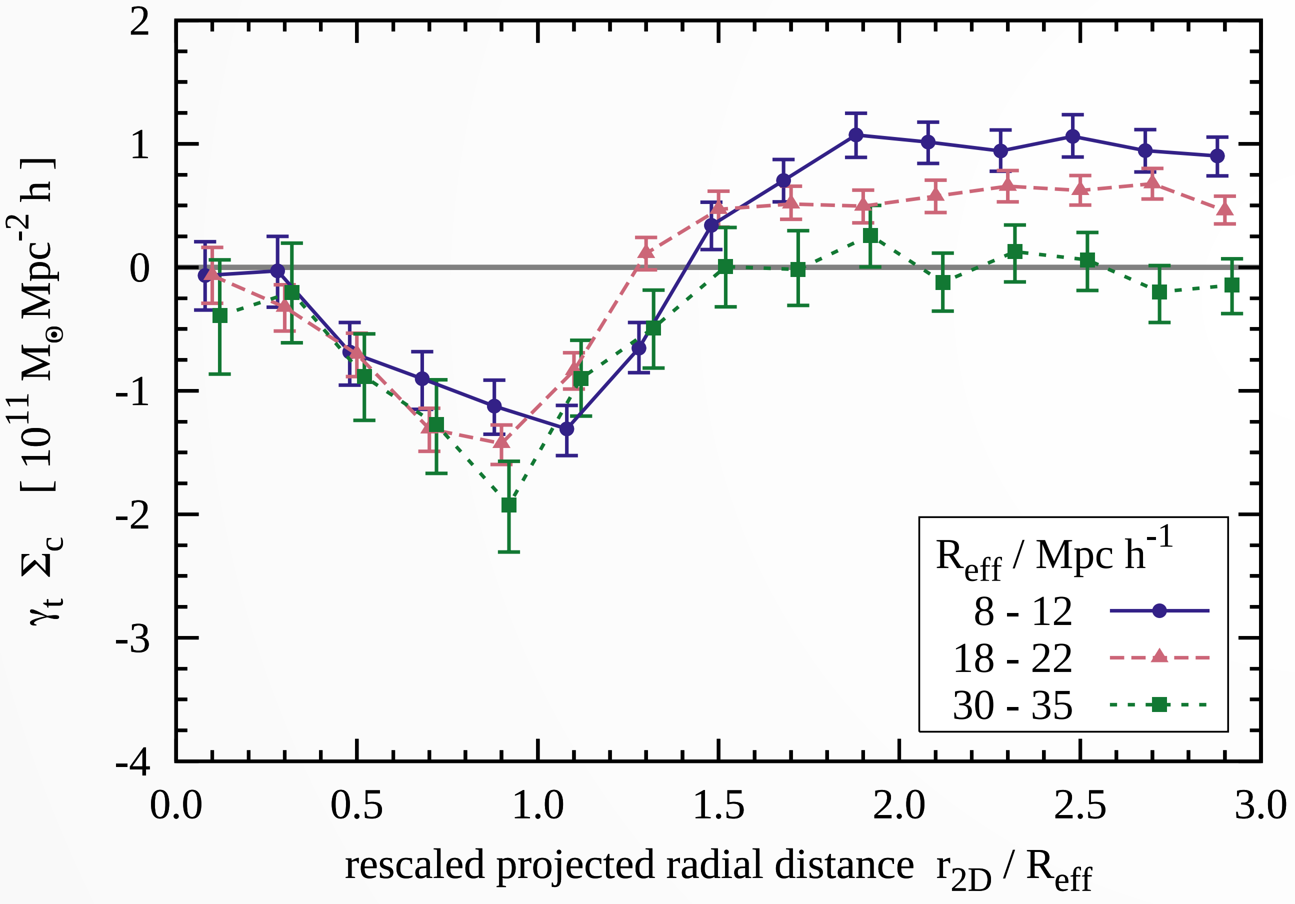


Galileon - Barreira, MC+ 2015

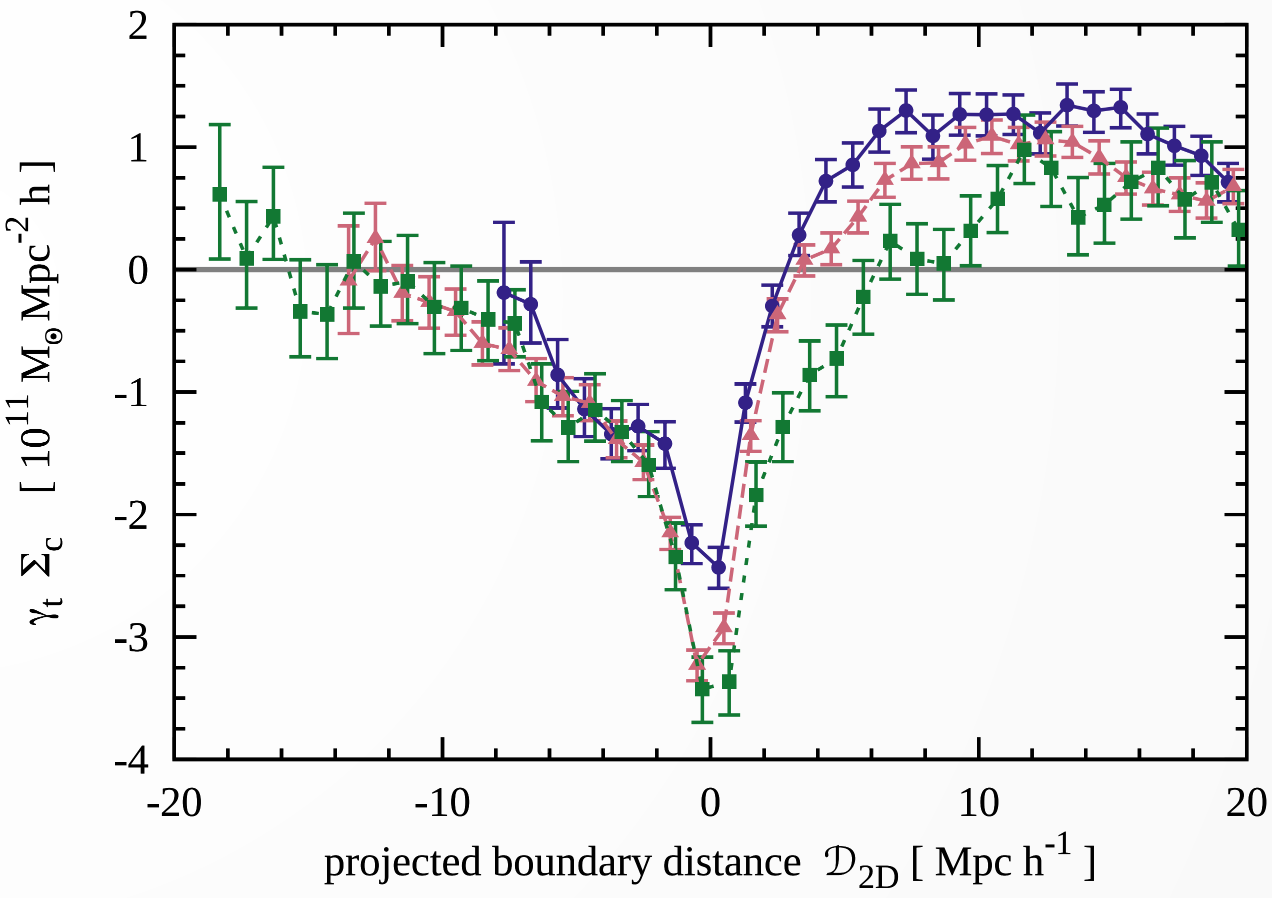


Void weak lensing

Spherical profile



Boundary profile



Summary

- Voids have diverse shape, highly non-spherical, so computing spherical averaged profiles leads to smoothing of their structure.
- The boundary profile separates by construction the inside, boundary and outside of voids, leading to profiles in qualitatively agreement with analytical models.
- The boundary density profile of voids is self-similar when rescaled by the thickness of the void boundary.
- The boundary profile enhances the potential of voids as a cosmological probe by increasing the weak lensing signal by a factor of two.