

# The void size function in dynamical dark energy cosmologies

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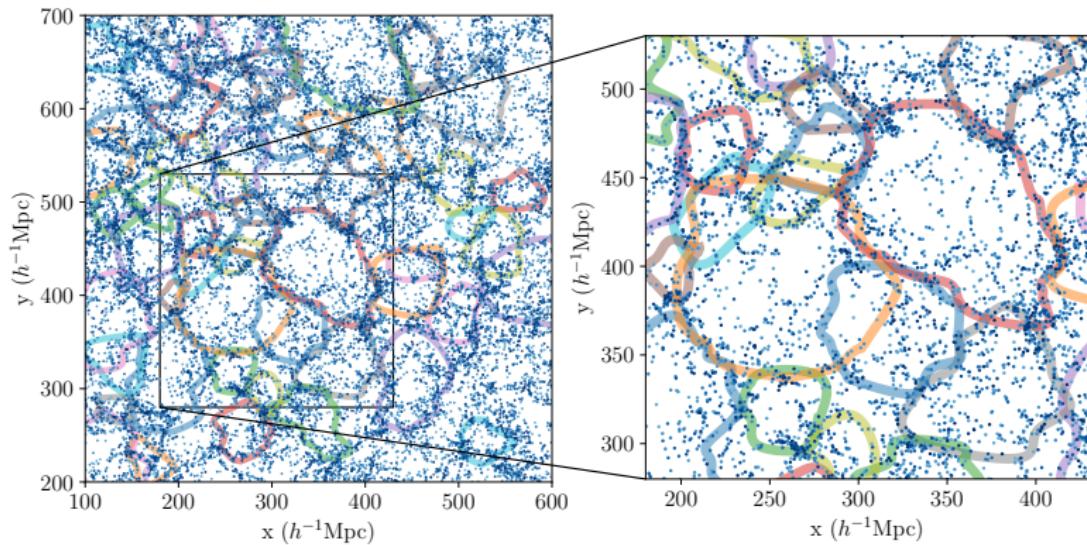
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# Cosmic Voids in the Large-Scale Structure: ID & motivation

Cosmic voids are vast under-dense regions filling most of the volume of the present-day Universe. With sizes spanning from tens to hundreds of Mpc, they are the largest observable structures in the cosmic web.

Voids constitute a unique cosmological probe: their interiors, spanning large scales and featuring low matter density, make them particularly suited to study dark energy and modified gravity, massive neutrinos, primordial non-Gaussianity, etc.



# Dark Energy: background evolution and growth of structures

Equation of state:  $P = w(a)\rho$ ,  $d(\rho a^3) = -3Pa^2 da$  :

$$\rho_{\text{DE}}(a) = \rho_0 \exp \left[ -3 \int_a^1 \frac{da'}{a'} (1 + w(a')) \right]$$

- $w(a) = -1 \quad \forall a \Rightarrow$  cosmological constant
- Evolving  $w(a)$  with  $w(a) < 0 \Rightarrow$  dynamical dark energy

Dark energy effect:

1. Background Evolution:  $H^2 = \left( \frac{\dot{a}}{a} \right)^2 = \frac{8\pi G}{3} [\rho_{m,0} a^{-3} + \rho_{\text{DE}}(a)]$

2. Growth of perturbation (linear theory):

$$\frac{d^2 \ln \delta}{d \ln a^2} + \left( \frac{d \ln \delta}{d \ln a} \right)^2 + \frac{d \ln \delta}{d \ln a} \left\{ 1 - \frac{1}{2} [ \Omega_m(a) + (3w(a) + 1)\Omega_{\text{DE}}(a) ] \right\} = \frac{3}{2} \Omega_m(a)$$

where:  $\Omega_m(a) = \frac{8\pi G}{3} \frac{\rho_m(a)}{H^2}$ ,  $\Omega_m(a) = \frac{8\pi G}{3} \frac{\rho_{\text{DE}}(a)}{H^2}$

# The theoretical void size function

$$\frac{dn(M, z)}{d \ln M} = \frac{\rho}{M} f_{\ln \sigma}^v(\sigma, \delta_v, \delta_c) \frac{d \ln \sigma^{-1}}{d \ln M}$$

- Number density ←
- The multiplicity function ←  
(fraction of fluctuations that become voids,  
Sheth & Van de Weygaert 2004)

- Jacobian: from  $\sigma(M)$  to mass interval ←
- Redshift dependence: extrapolation to  $z = 0$ :

$$\begin{aligned}\delta_{v,c} &\rightarrow \delta_{v,c}/D(z), \\ \sigma(z) &\rightarrow \sigma(z = 0)\end{aligned}$$

$$\left\{ \begin{array}{l} \sigma(M) = \sigma(r_L(M)) \\ M = \frac{4\pi}{3} \bar{\rho} r_L^3(M) \end{array} \right.$$

Mass to radius conversion

$$M \rightarrow r$$

Volume conservation  
(from linear to non-linear)

$$V(r)dn = V(r_L)dn_L$$

$$\frac{dn(r, z)}{d \ln r} = \frac{f_{\ln \sigma}^v(\sigma, \delta_v, \delta_c)}{V(r)} \frac{d \ln \sigma^{-1}}{d \ln r_L} \Big|_{r_L=r_L(r)}$$

(Jennings et al. 2013)

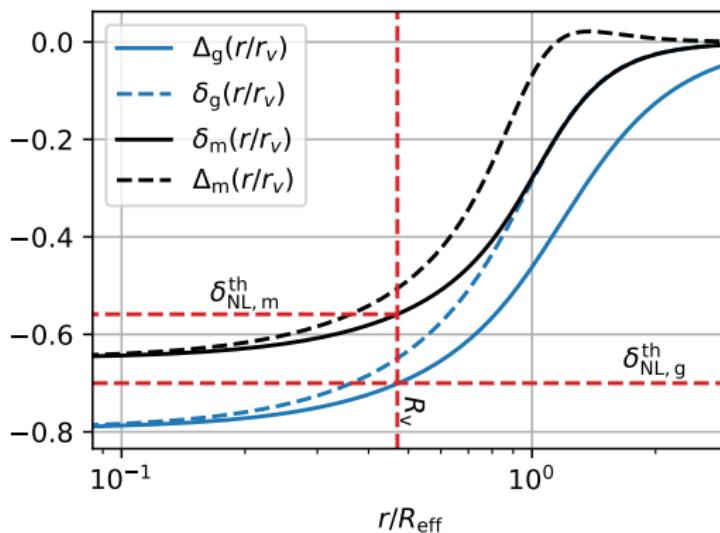
# Cosmic voids in galaxy distribution

## Observed voids

Depressions in the galaxy distribution.

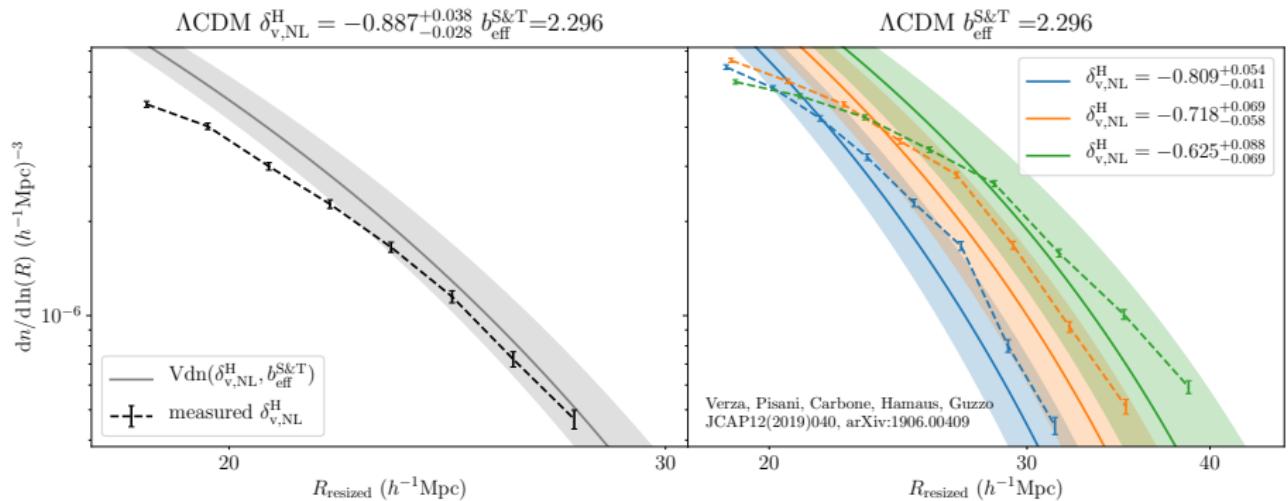
## Theoretical objects

Fluctuations in the matter field that reaches a given depth  $\delta$  at radius  $R_v$

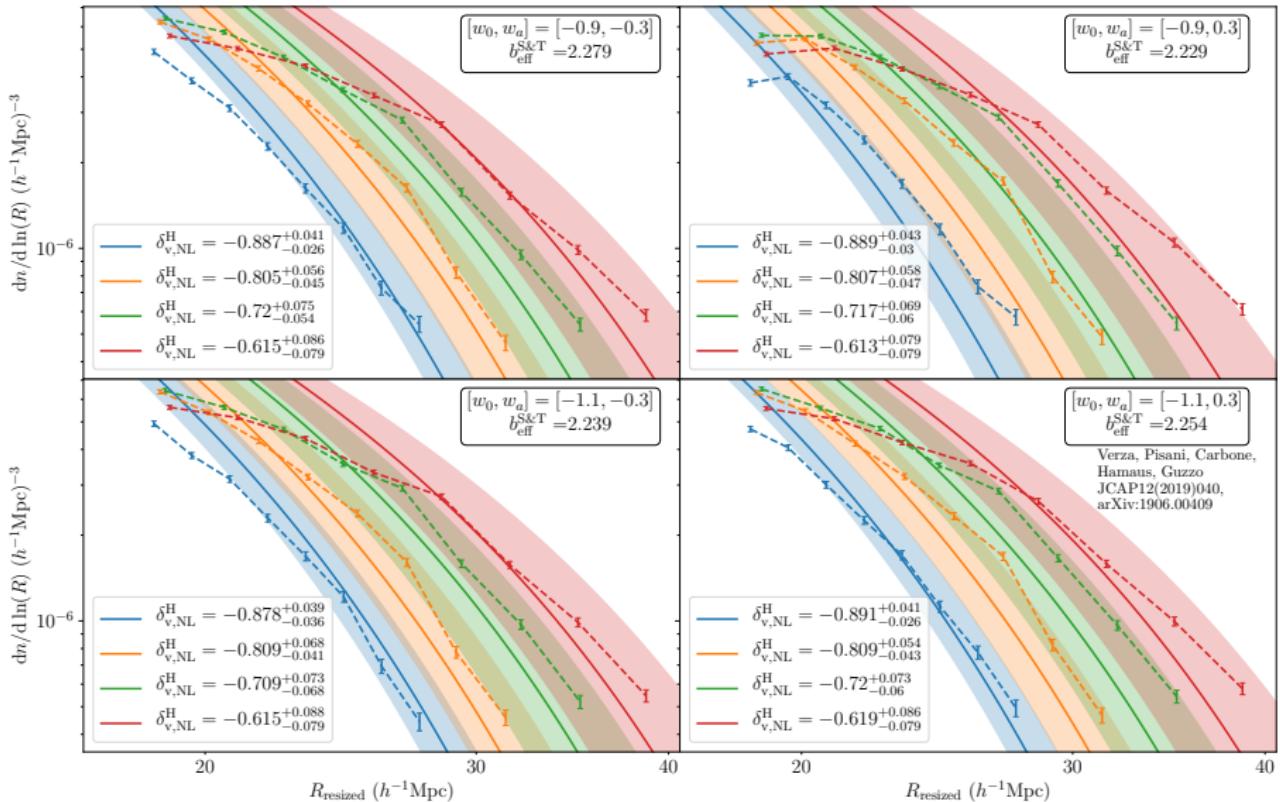


Galaxy bias can be theoretically modeled to recover voids in matter distribution.

# Void abundance in standard cosmological model



# Void abundance in dynamical dark energy cosmologies



Verza, Pisani, Carbone,  
Hamano, Guzzo  
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Thank you for your attention