Cosmology with voids

A look at the underdense side of the Large Scale Structure

Tommaso Ronconi

September 26, 2017

SISSA - International School for Advanced Studies

Outline

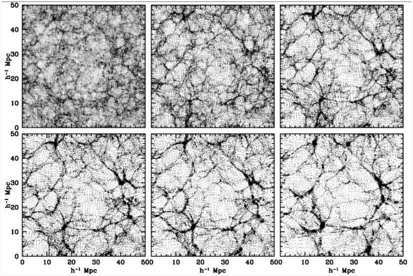
1. Cosmic voids in the Large Scale Structure
2. Towards a reliable cosmic void statistics
3. Conclusions & future developments

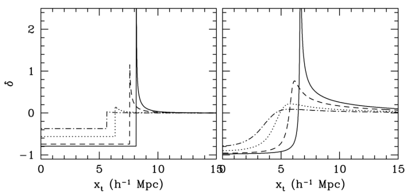
Cosmic voids in the Large Scale Structure

Cosmic Voids

Theoretical definition:

- $\approx$ spherical top-hat shape (Icke, 1984)
- faster than Hubble flow $v_{exp} \propto \overline{\rho}(< r_{shell})$
- $v_{inner} > v_{outer} \Rightarrow$ shell crossing: $\delta_v = -2.71$
- formed void $\Rightarrow$ Hubble expansion





- simple structure/shape
- spherical expansion
- $\delta_{min} = -1 \Rightarrow$ mildly non-linear

Potential cosmological probes:

AP-test, ISW, DE equation of state, theories of gravity, coupled DE, nature of DM, redshift space distortions...

Cosmic void size function

Linear theory

$$\frac{dn_L}{d\ln r_L} = \frac{\rho}{M} f_{\ln\sigma}(\sigma, \delta_c, \delta_v) \frac{d\ln\sigma^{-1}}{d\ln r_L} = \frac{f_{\ln\sigma}(\sigma, \delta_c, \delta_v)}{V(r_L)} \frac{d\ln\sigma^{-1}}{d\ln r_L}$$

$$\delta_v = -2.71 \rightarrow \delta_v^{NL} = -0.8 \rightarrow r/r_L = 1.71$$

SvdW (Sheth & van de Weijgaert,2004)

$$\frac{dn}{d\ln r} = \left.\frac{dn_L}{d\ln r_L}\right|_{r_L = r/1.7}$$

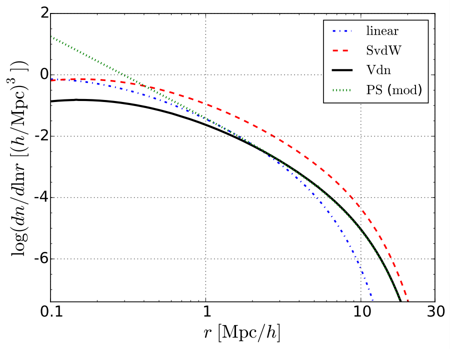
Vdn (Jennings et al.,2013)

$$V(r)dn = V(r_L)dn_L\big|_{r_L(r)}$$

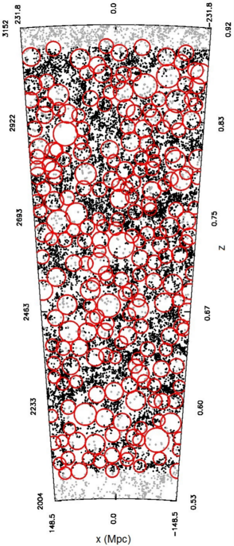
$$\frac{dn}{d\ln r} = \frac{V(r_L)}{V(r)} \left.\frac{dn_L}{d\ln r_L}\right|_{r_L(r)}$$

Modified halo-mass function

$$\frac{dn_L}{d\ln r_L} \equiv \frac{d\ln M}{d\ln r}\left(M\frac{dn}{dM}\right) = 3M\frac{dn}{dM}$$



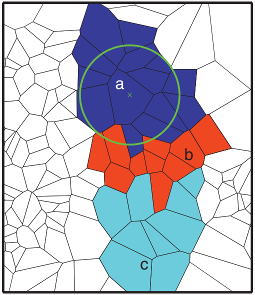
Void finders

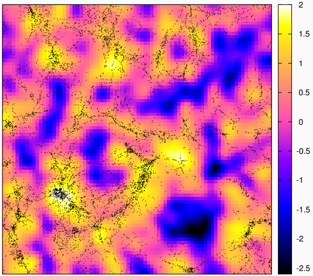


density regions with no tracers or $\rho < \rho_{\text{lim}}$
(Elyiv et al., 2013, Micheletti et al., 2014)

geometry Voronoi tessellation field estimator
(ZOBOV-Neyrinck, 2008; VIDE-Sutter et al., 2014)

dynamics recover underlying velocity field
(Lavaux & Wandelt, 2010; Elyiv et al., 2015)





Is this the end of the story?

Models + measured distribution $\longrightarrow$ NO MATCH

GAP between theory & observations

- are the models reliable?
  - calibrate δ_v with simulations
- are the void finders doing their job?
  - search for objects coherent with models

Towards a reliable cosmic void statistics

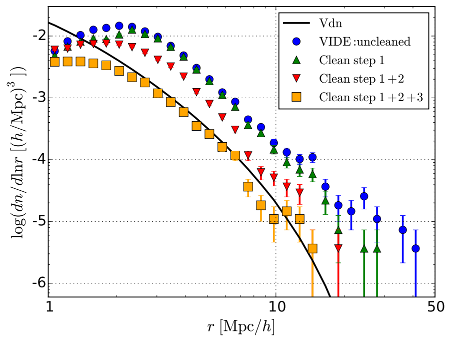
Algorithm

input: **void-centre catalogue** (optional: scale radius, central density, density contrast)

tracer positions (DM-particles, halo/galaxy mock catalogues, galaxy surveys)

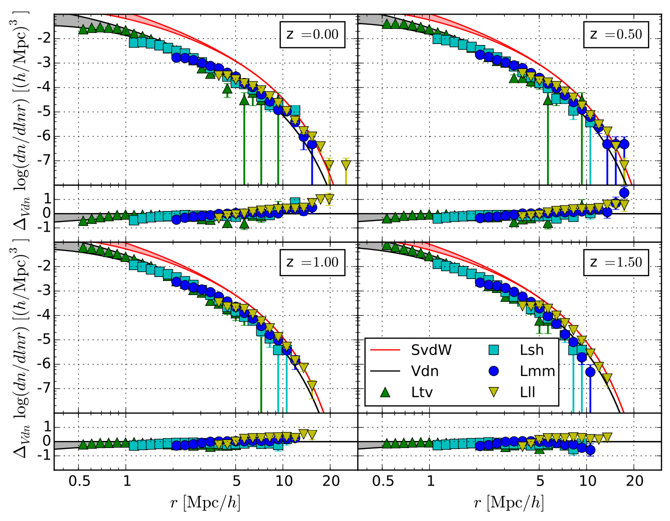
output: **new void catalogue** (spherical, shell-crossed, not overlapping)

1. clean the catalogue
   - $r \in [r_{\text{min}}, r_{\text{max}}]$
   - $\delta_{\text{in}} < \delta_v^{\text{NL}}$
2. find shell-crossing radius
   - get density profile
   - find r; $\delta(r) \equiv \delta_v^{\text{NL}}$
3. remove overlapping voids



(Ronconi & Marulli, 2017)

Validation on unbiased tracers



(Ronconi et al., *in prep.*)

When it comes to bias...

Void-catalogue in a biased sample

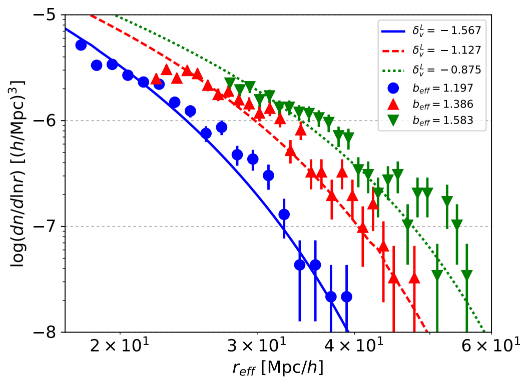
- fix threshold: $\delta^{\rm NL}_{h,v} \equiv \delta^{\rm NL}_{v}$
- find radius: $r_{eff,h} \neq r_{eff,\rm DM}$

Void size-function

Underdensity threshold: $\delta^{\rm NL}_{v,\rm DM} = b_{eff}\, \delta^{\rm NL}_{v,\rm tr}$ (Pollina et al., 2016)

Vdn model:

$$\frac{{\rm d}n}{{\rm d}\ln r} = \frac{f_{\ln\sigma}(\sigma, \delta_c, \delta_v)}{V(r)} \frac{{\rm d}\ln\sigma^{-1}}{{\rm d}\ln r_L}\bigg|_{r_L(r)}$$



(Ronconi et al., *in prep.*)

Conclusions & future developments

Summary

- Developed an algorithm capable of
  - finding cosmic voids as coherent as possible with the theoretical definition (spherical, gone through shell-crossing, not overlapping)
  - allow comparison between different void-catalogues
- Validated the Vdn model without free parameters
- Extended the formalism to biased samples

Future developments:

- Parameters extraction from cosmic void number counts (Fisher information matrix)
- Void detection in HI intensity mapping (M.Viel, A.Lapi)
- Growing interest for the Euclid mission (In preparation: White paper on voids from the Euclid Void Group)