ZTF-COSMO DR2 : Exploring SNIa properties in the vicinity of underdense environments.

Marie Aubert – PostDoc @ LPCA

Aubert et al 2024 ; Arxiv:2406.11680

Laboratoire de Physique de Clermont

Marie Aubert @ Action Dark Energy - 30/10/2024

The Large Scale Structure of the Universe

→ *Intricate network of matter shaped by gravity*

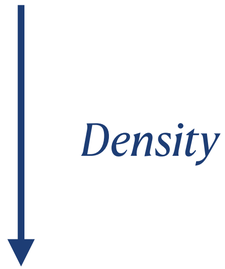
- Matter is structured at large scale (LSS) :

Cluster

Filaments

Wall

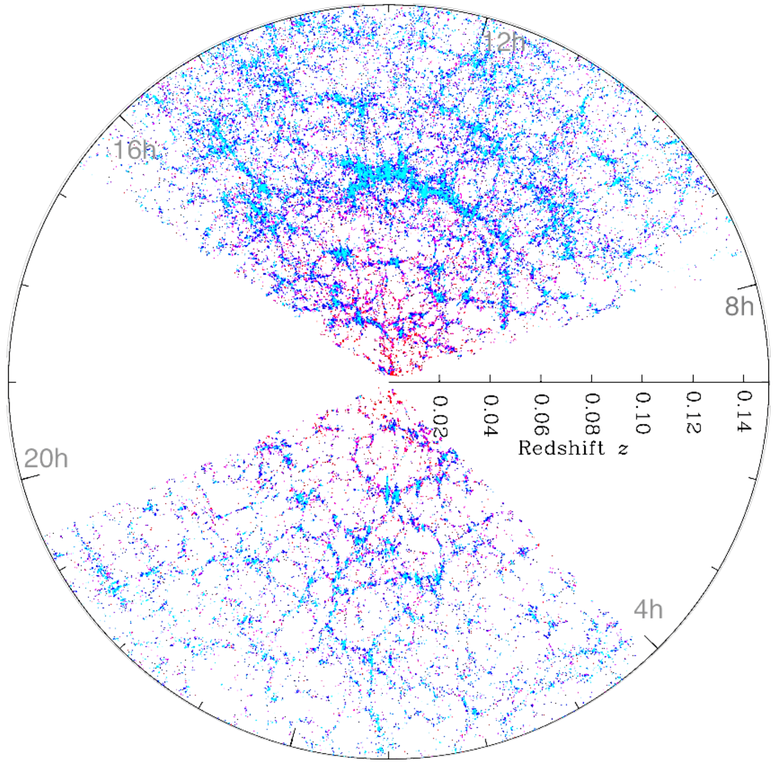
Voids



Density

Voids : Under-dense environment of LSS → Large **extended** objects

Less matter than average of all LSS combined



©SDSS Collaboration | Blanton 2005

Introductory remarks

LSS and SNe Ia

SNe Ia properties assumed to be independent of Large Scale Structure.

New era

Wide field survey (e.g ZTF now, LSST in the future)
→ large statistics allowing us to test this hypothesis.

Work presented today is a first exploratory study of the interplay between low density environments in the LSS and the ZTF-DR2 SNe Ia

The ZTF-COSMO DR2 sample

Rigault, Smith et al. subm. 2024, Arxiv:2409.04346

Zwicky Transient Facility (ZTF) :

- Large field-of-view camera : 47 $\deg^2$
- High cadence
- 20 000 $\deg^2$ of the sky.

→ detect and sample SNIa light-curve efficiently.

- About 3600 spectroscopically classified SNe Ia :
  → detected between **March 2018 to December 2020.**

All SNe Ia with redshift. $\sigma_z \sim [10^{-3}, 10^{-5}]$:

→ from SNe Ia spectra

→ from SNe Ia hosts.

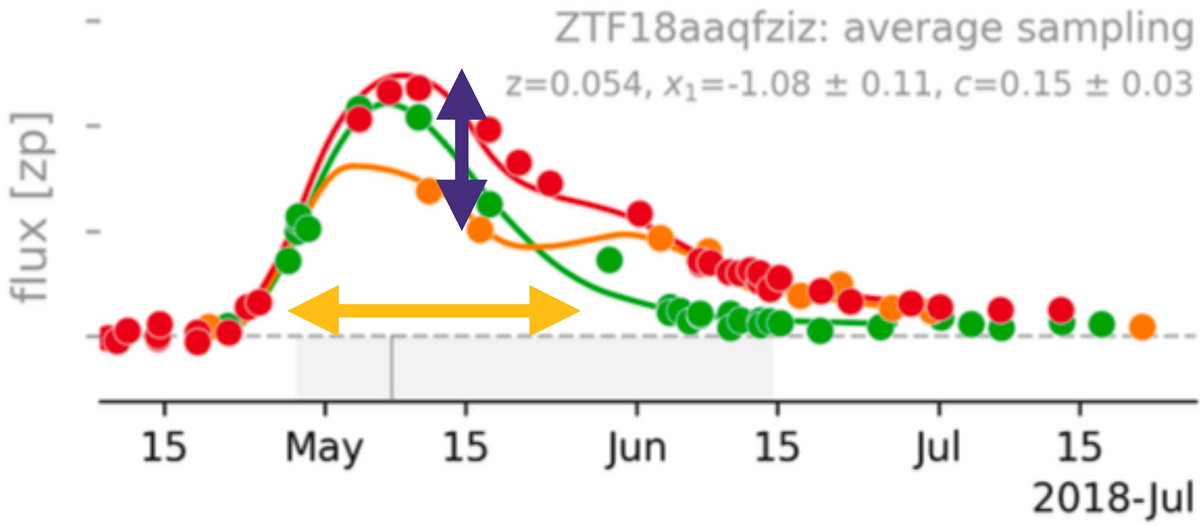
~ 1000 volume-limited SNe Ia of cosmological quality, $z \leq 0.06$.

The ZTF-COSMO DR2 sample

Rigault, Smith et al. subm. 2024, Arxiv:2409.04346

Testing the dependency of the SNe Ia

→ SNe Ia are not all the same:
Properties of their light curve can change.



- **Stretch x_1 :**
  → How long the SNe Ia light-curve evolves in time.

- **Colour c :**
  → the difference between the light-curves in the respective bands (zg, zi, zr)

Tracing the low redshift LSS with SDSS

SDSS-DR7 Main Sample

(Blanton 2005)

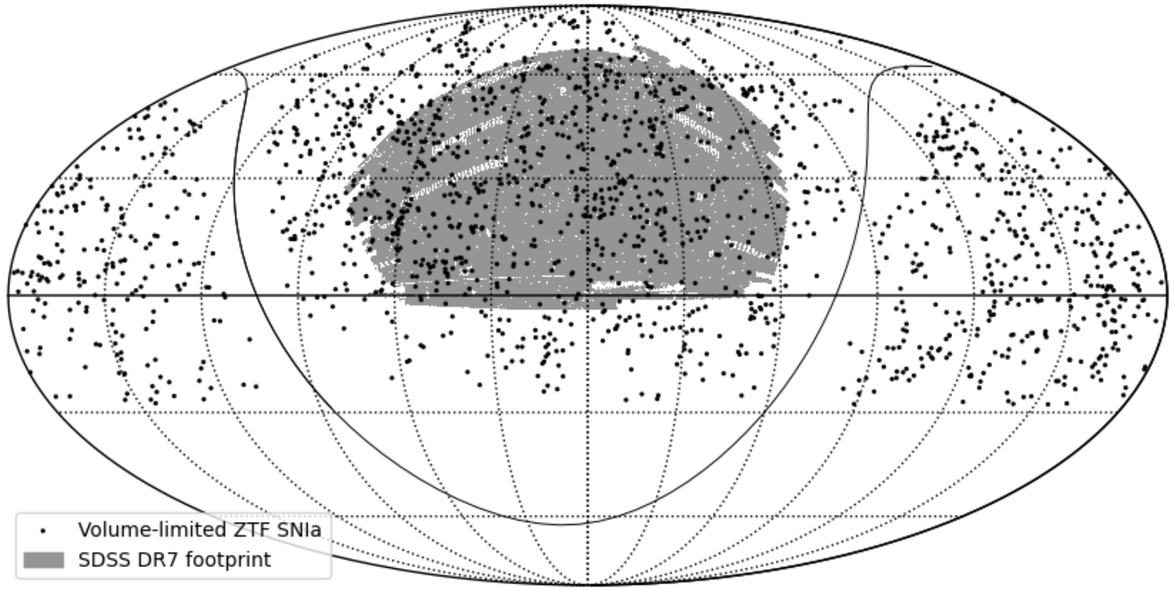
(Abazajian 2009)

Widest LSS spectroscopic sample available at low redshift, $z < 0.1$

Selection of 341433 Galaxies

- Contiguous footprint in the North Galactic Cap.

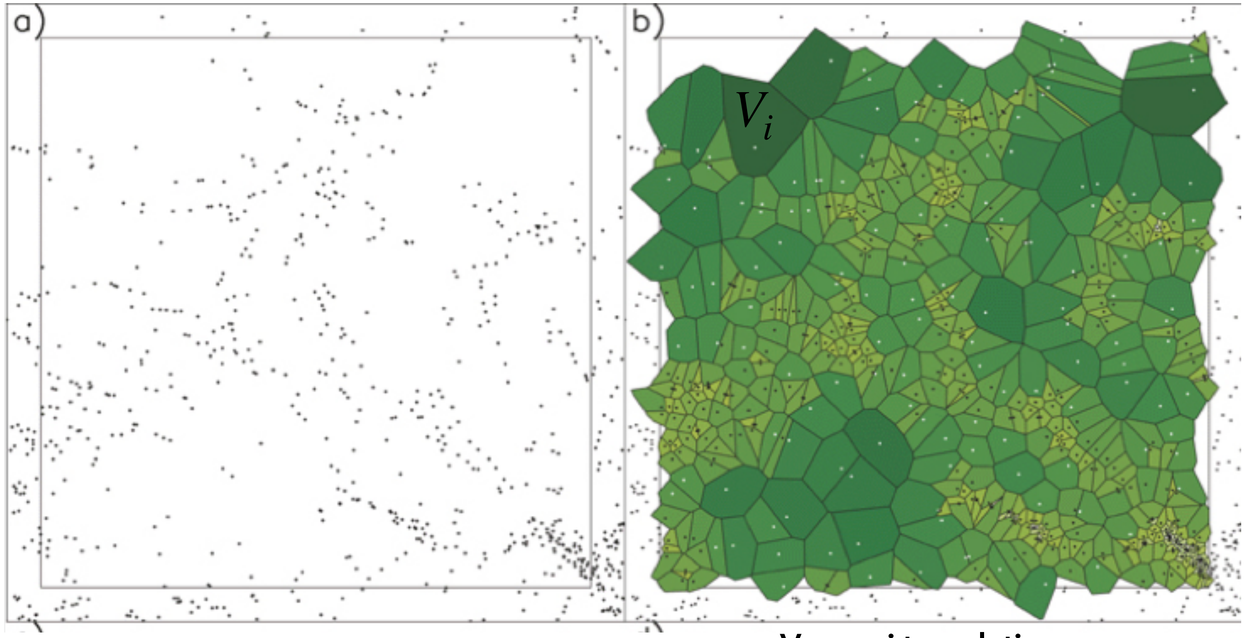
- Galaxy redshift in $z \in [0.018, 0.11]$



Aubert et al 2024 ; Arxiv:2406.11680

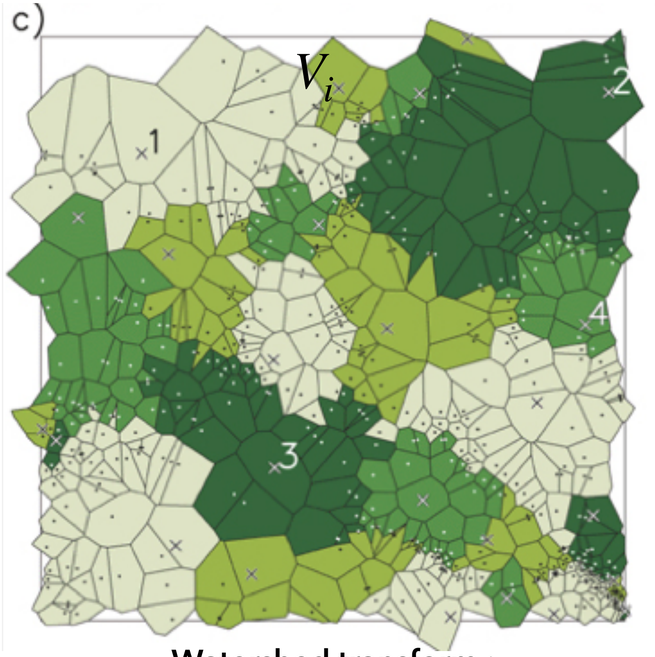
Void properties extraction

Fiducial cosmology : Flat ΛCDM $\Omega_m = 0.31$ → **Revolver** Nadathur et al 2019



Tracer distribution

Voronoi tesselation :
Identify local density minima



Watershed transform :
delineates void extents around the minima

Based on ZOBOV

Neyrinck, 2008

Arxiv:0712.3049

$\rightarrow \rho_{loc} = 1/V_i$

Void centre definition

$$X_v = \frac{\sum_i V_i X_i^g}{\sum_i V_i}$$

Radius

$$R_v = \left(\frac{3}{4\pi} \sum_i V_i \right)^{1/3}$$

Byproduct :

V_i : local volume around each galaxies

Voids → R.A , Dec, z with fiducial cosmology

Final void and SNe Ia samples selection

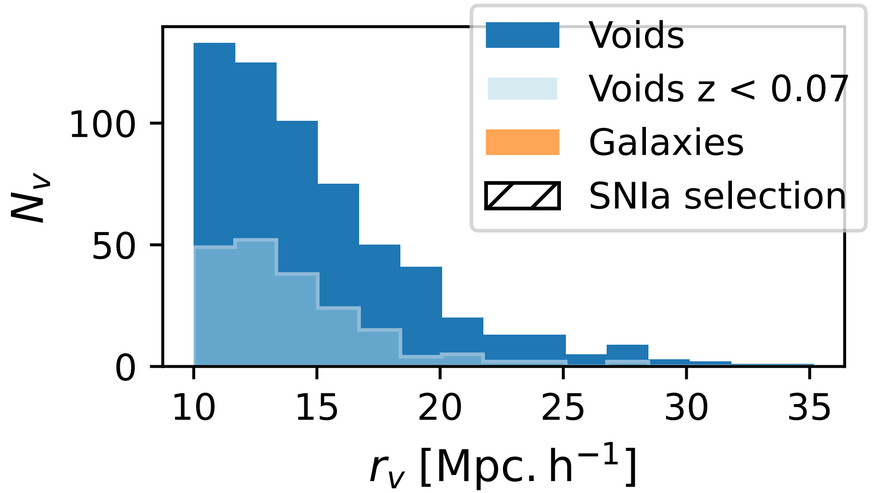
Void sample selection

— **Use voids distinct from the edges**

— $R_v \geq 10$ Mpc . h^{-1}

— **Redshift max :** $z = [0.018, 0.07]$

193 Voids

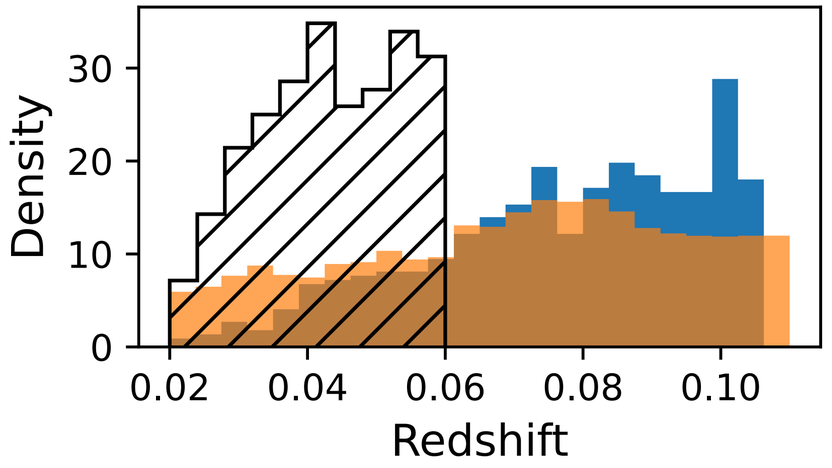


SNe Ia sample selection

— **ZTF SNIa DR2 overlapping with SDSS**

— **Volume-limited** $z = [0.02, 0.06]$

281 Cosmo SNe Ia



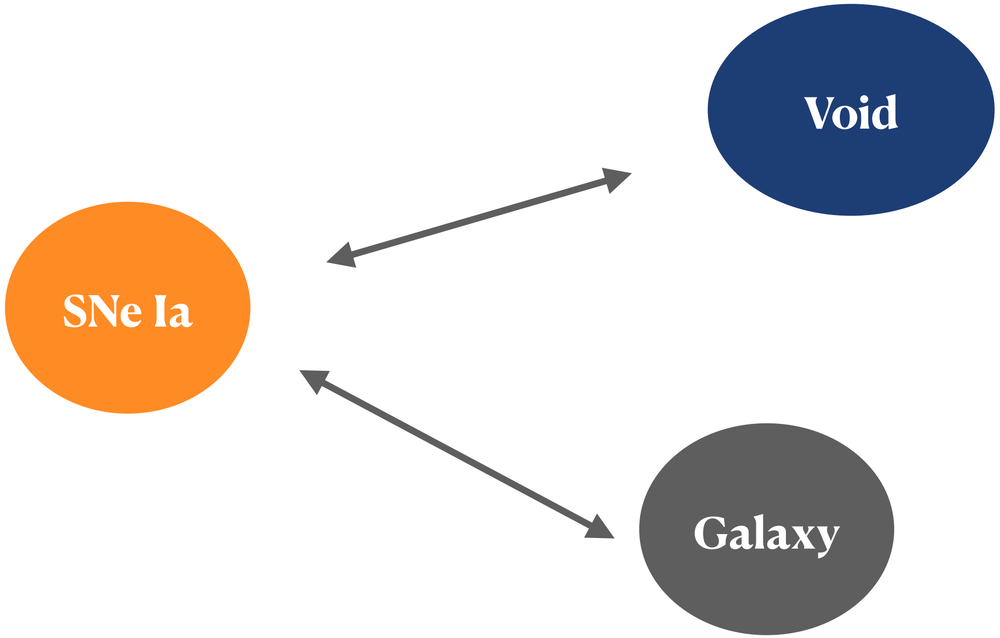
Aubert et al 2024 ; Arxiv:2406.11680

Matching SNe Ia in pairs

Fiducial cosmology : Flat ΛCDM $\Omega_m = 0.31$

Available information :

- SN Ia positions in R.A, Dec, z with $\sigma_z = [10^{-5} - 10^{-3}]$
- Void positions and radius (r_v).
- Galaxies positions.



Nearest 3D distance matching
Comoving coodinates (Mpc . h^{-1})

A single SNe Ia is matched to :

- Nearest neighbouring void
- Nearest neighbouring galaxy

Matching SNe Ia in pairs

Fiducial cosmology : Flat ΛCDM $\Omega_m = 0.31$

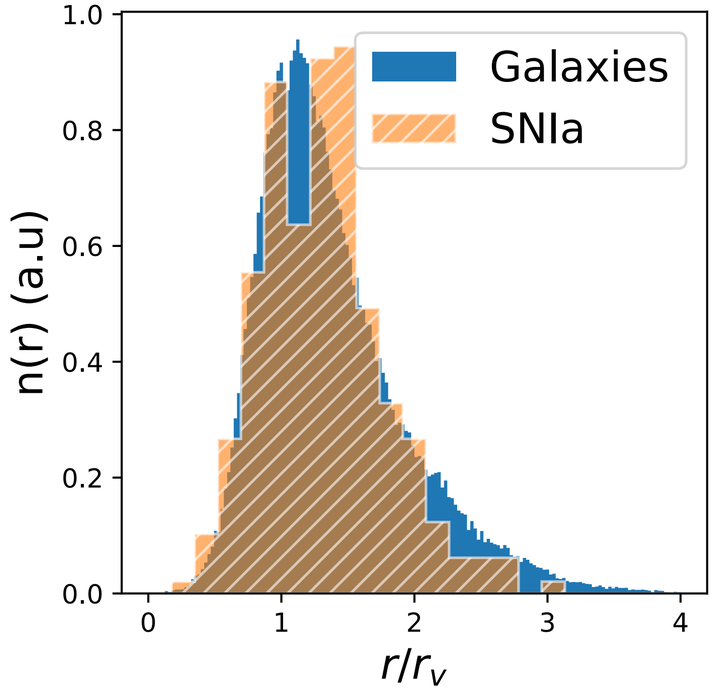
Available information :

- SN Ia positions in R.A, Dec, z with $\sigma_z = [10^{-5}, \sim 10^{-3}]$
- Void positions and radius (r_v).

Nearest 3D distance matching
Comoving coodinates (Mpc . h^{-1})

SNe Ia distance from void centre distribution overlaps properly with that of the galaxies distribution.

→ They do not singularly sample a zone in the LSS.



Aubert et al 2024 ; Arxiv:2406.11680

Matching SNe Ia in pairs

Fiducial cosmology : Flat ΛCDM $\Omega_m = 0.31$

Available information :

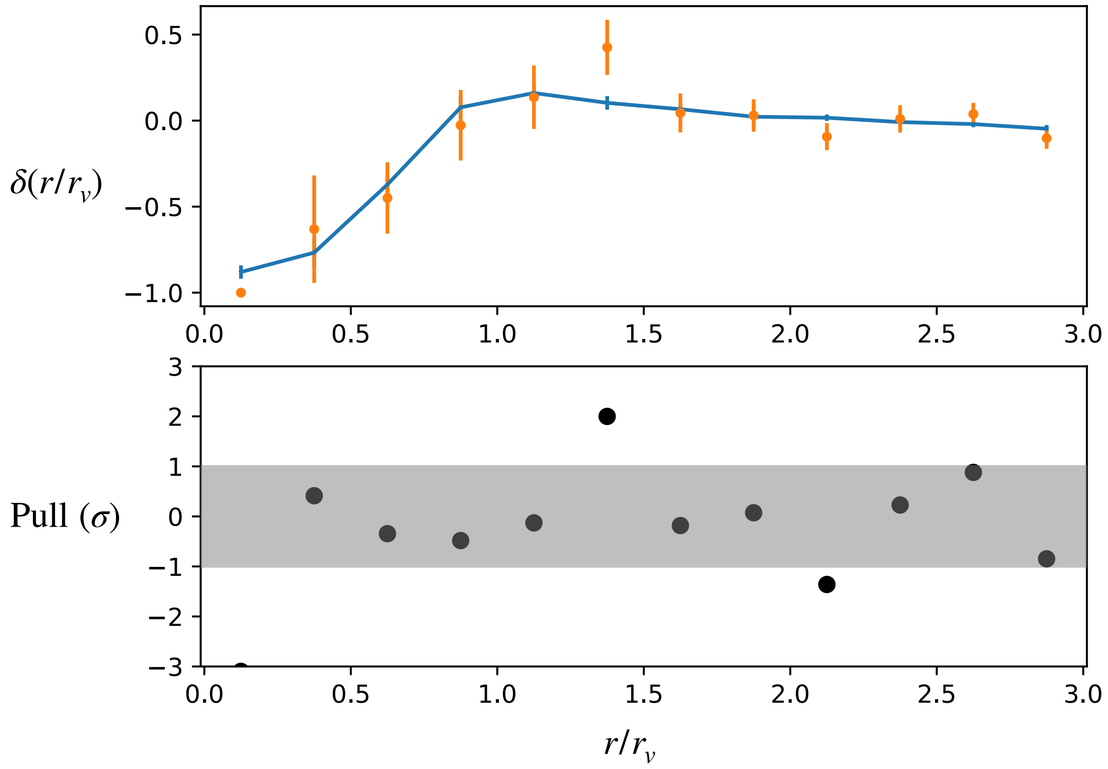
- SN Ia positions in R.A, Dec, z with $\sigma_z = [10^{-5}, \sim 10^{-3}]$
- Void positions and radius (r_v).

Nearest 3D distance matching
Comoving coodinates (Mpc . h^{-1})

Confirmation with the void density profile from SNe Ia and galaxies.

→ SNe Ia sample pretty well the LSS as traced by SDSS galaxies.

→ No sampling « bias ».



Aubert et al 2024 ; Arxiv:2406.11680

Light curve properties around voids

Property scatter & median of light-curve properties as function of normalized distance to the nearest voids

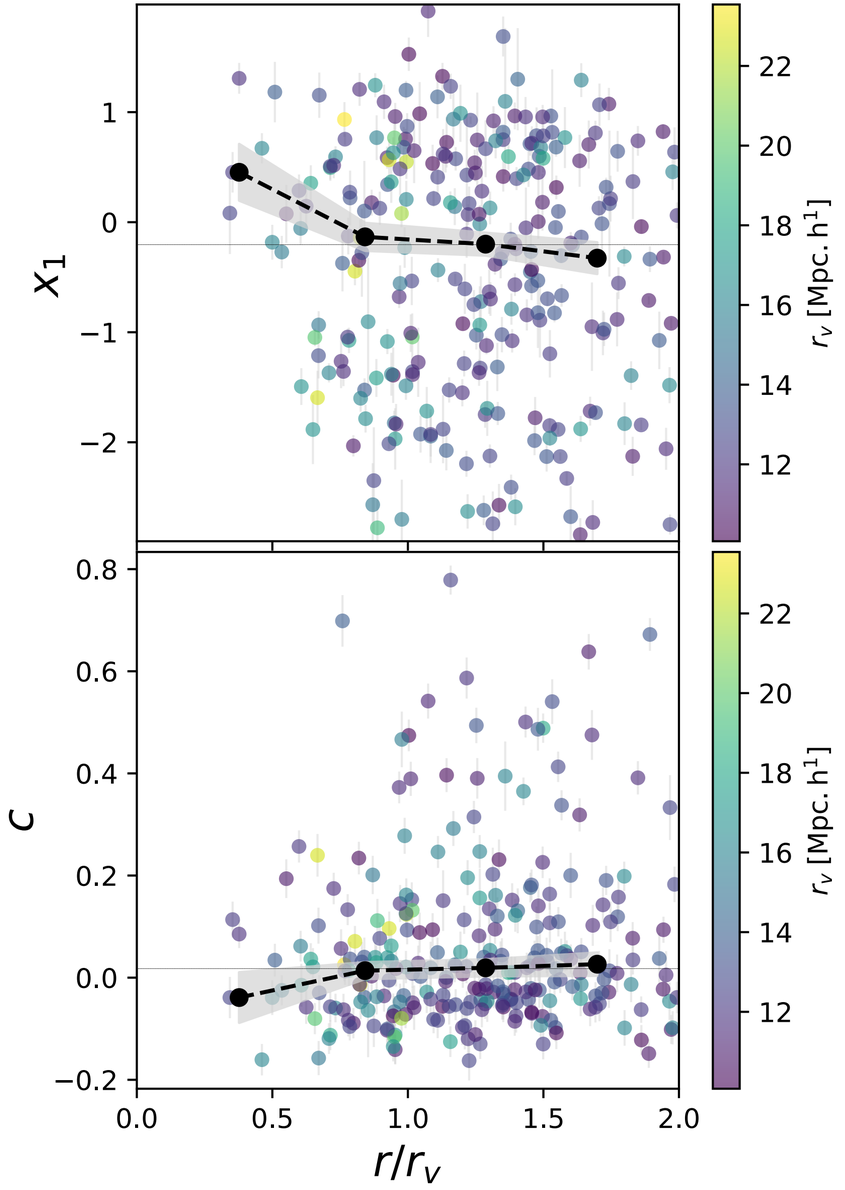
Global description of the repartition of properties around voids.

Colour No significant behavior w.r.t distance to the centre of the nearest void.

Stretch Signal in the innermost part of the voids with higher median stretch compared to the larger distance.

However, limited statistic within the core of the void.

5 SNIa
$r/r_v < 0.5$



Aubert et al 2024 ; Arxiv:2406.11680

Additional tracer of density : Voronoi volumes

Available information :

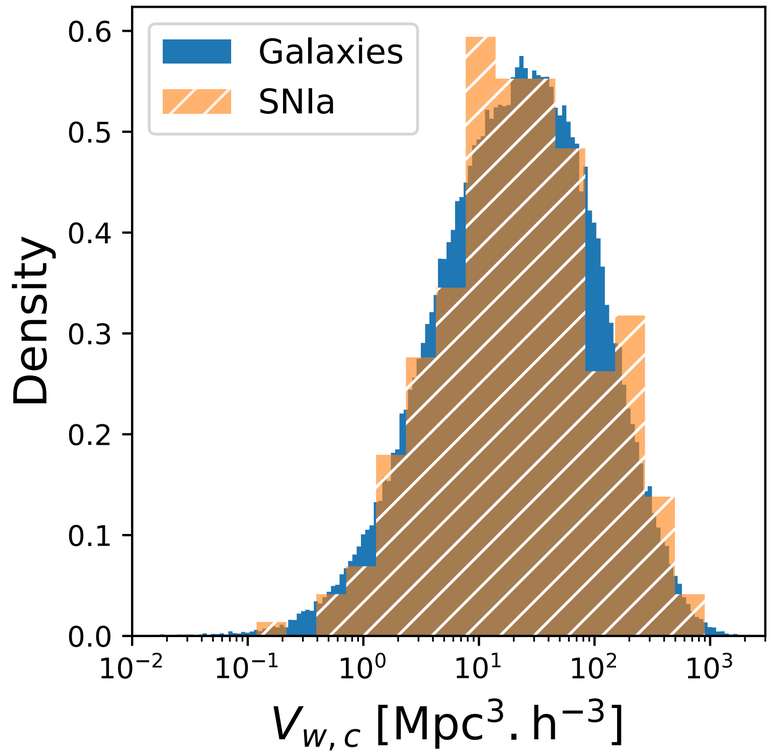
- SN Ia positions in R.A, Dec, z with $\sigma_z = [10^{-5}, \sim 10^{-3}]$
- Galaxies positions $+\mathbf{V_c}$ **(Voronoi volumes)**

By definition : $V_c = 1/\rho_{loc}$

Each SN Ia is paired with its nearest neighbouring galaxy.

→ We match the SNe Ia to the corresponding Voronoi volume.

→ Again no local density environment is favoured.



Aubert et al 2024 ; Arxiv:2406.11680

Properties w.r.t matched volume

Scatter properties w.r.t their matched Voronoi volume.

Large Voronoi volume → Low local density

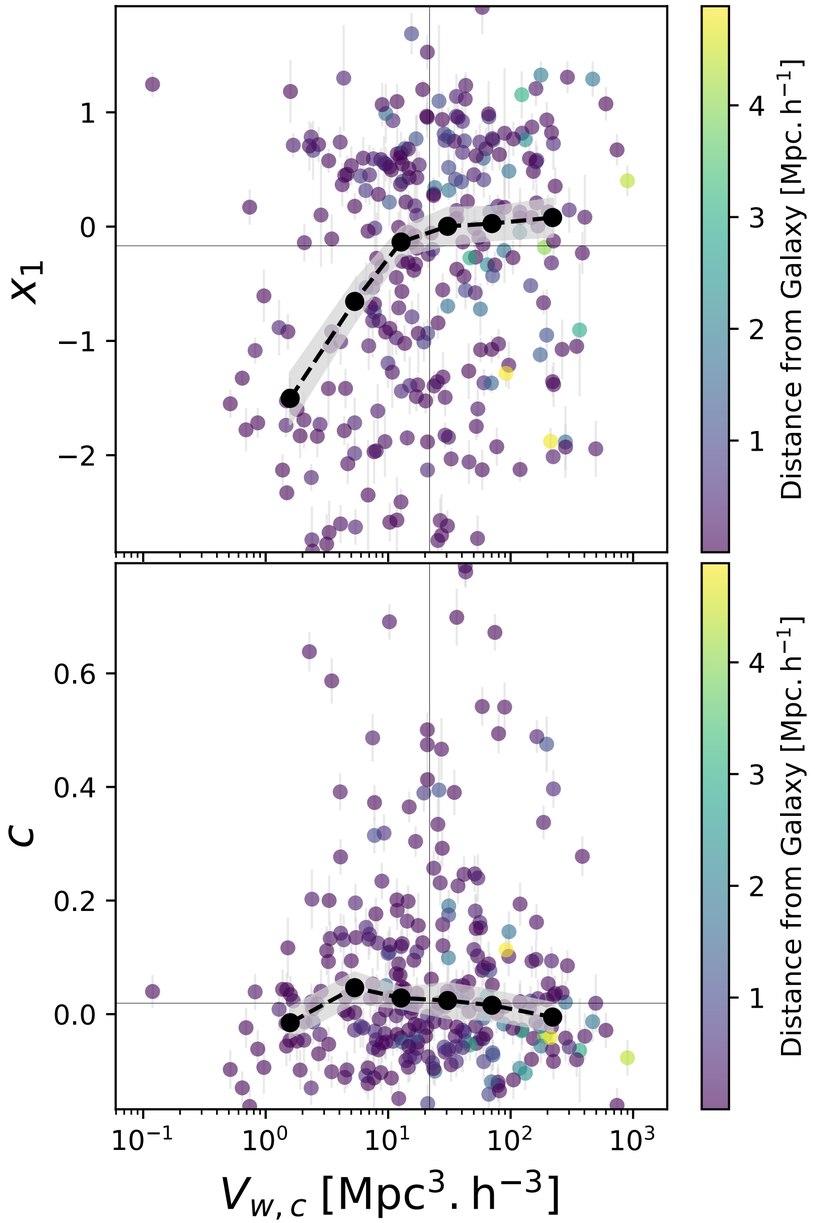
Small Voronoi volume → High local density

Colour

No significant behavior w.r.t local density

Stretch

- Two stretch regimes : 'high density' / 'low density'
- Locally dense environment leads to low stretch *(cf. Florian Ruppin)*
- Voronoi volumes probe intermediate scales as well.



Aubert et al 2024 ; Arxiv:2406.11680

Stretch distribution comparison

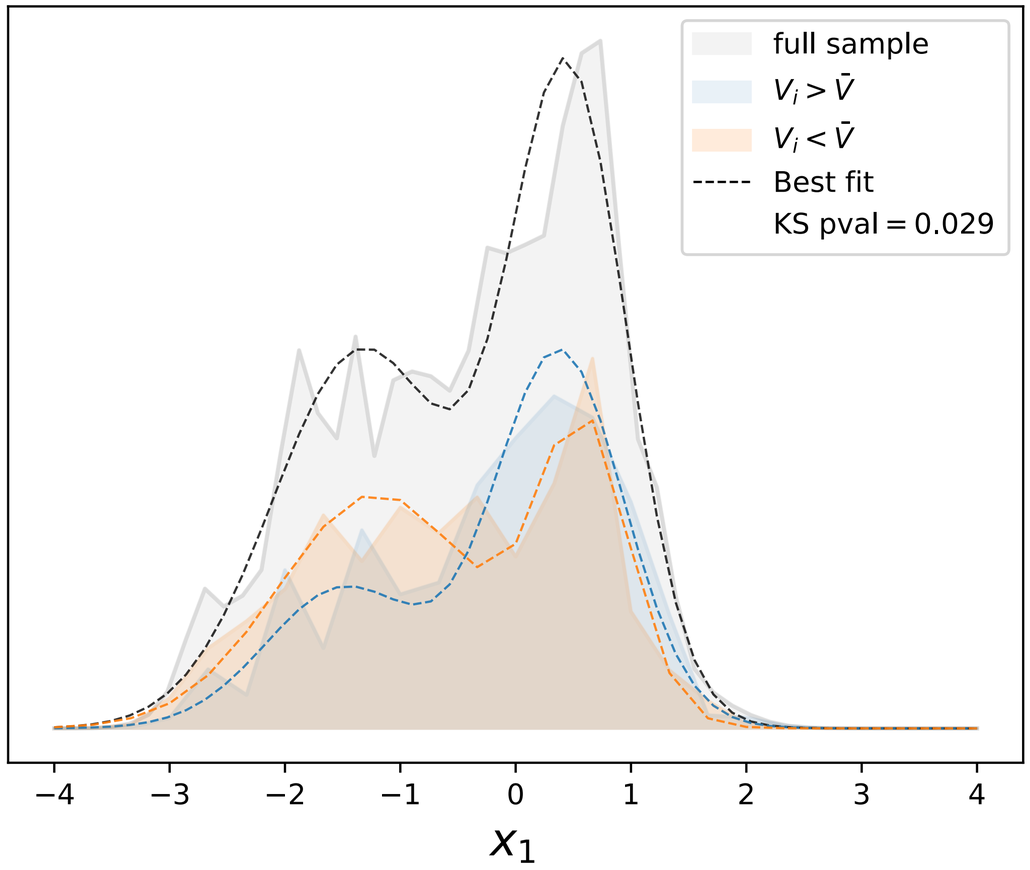
The sample is separated into 'low density' stretch sample ($V <$ med V) and 'high density' stretch sample ($V >$ med V).

One can characterize the PDF of x_1 as :

$$\mathscr{P}(x_1) = r\mathcal{N}(x_1 \,|\, x_1^{high}) + (1-r)\mathcal{N}(x_1 \,|\, x_1^{low})$$

Fraction r of SNe Ia in the high/low modes is affected by the density environment. (2.52σ)

→ Similar results to Ruppin et al, 2024, Arxiv:2406.01108



$\bar{V} = \text{median}(V)$

Aubert et al 2024 ; Arxiv:2406.11680

Conclusion :

SNe Ia properties are affected by their large scale environments

→ Impact of high-to-moderate density environment is stronger than low density environment.
Consistency between analyses with clusters and voids/voronoi volumes.

→ Probably a consequence of galaxy properties dependency on LSS.

Despite limiting factors :

For voids & SNe Ia → Limiting factor is the statistics. Especially within void core.
→ Need wider overlap of low redshift galaxy sample with ZTF.
→ Need denser SNe Ia sample. (LSST ?)

Food for thoughts :

- Relevant for velocity/density field reconstruction methods
- What kind of new test can we devise from SNe Ia X Voids ?

Thanks !

Voidfinding in the DR7 sample

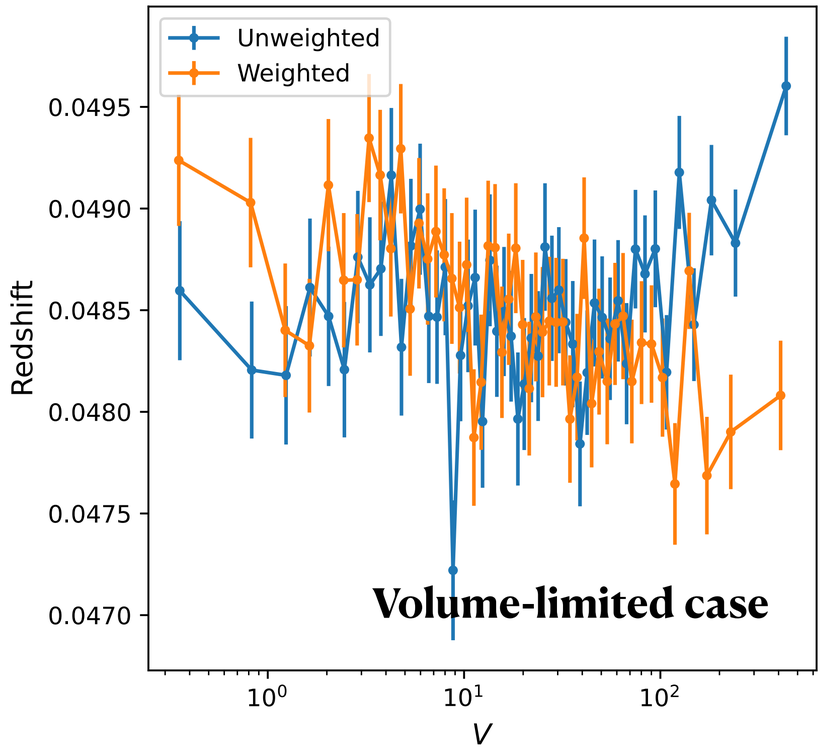
Fiducial cosmology : Flat ΛCDM $\Omega_m = 0.31$

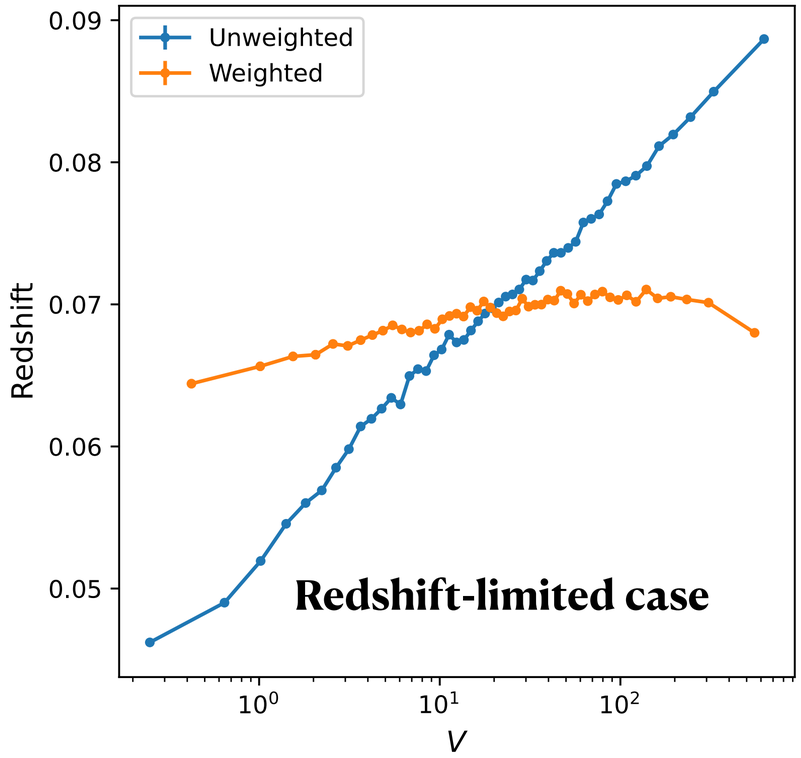
Corrective weights based on $n(z)$: w_z applied in VF.

$$V_i^w = w_z V_i$$

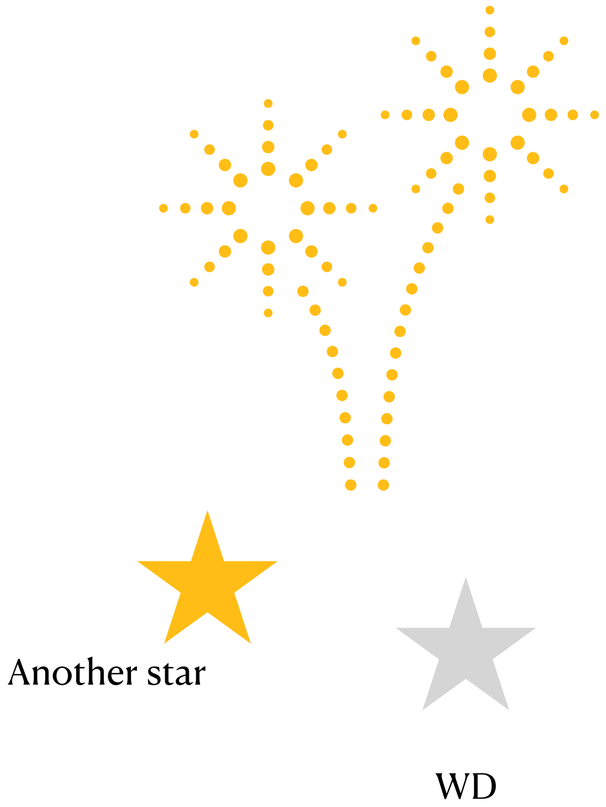
→ Correct the natural growth of void volumes with redshift.

If the galaxy is near to edge or masked areas → V_i^w = Flag

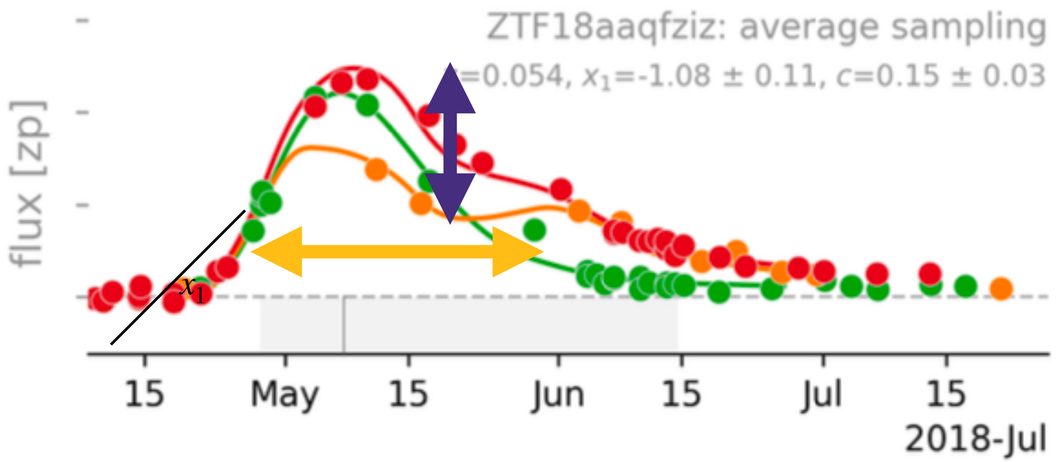




Type Ia Supernovae



— **Observed Flux of photons evolves in time.**



$$\mu = m_B - M_B + \alpha x_1 - \beta c$$

m_B : *Observed Magnitude at peak luminosity in B band*

x_1 : ***Stretch of the light-curve***

c : ***Colour differential between light-curves in different bands***

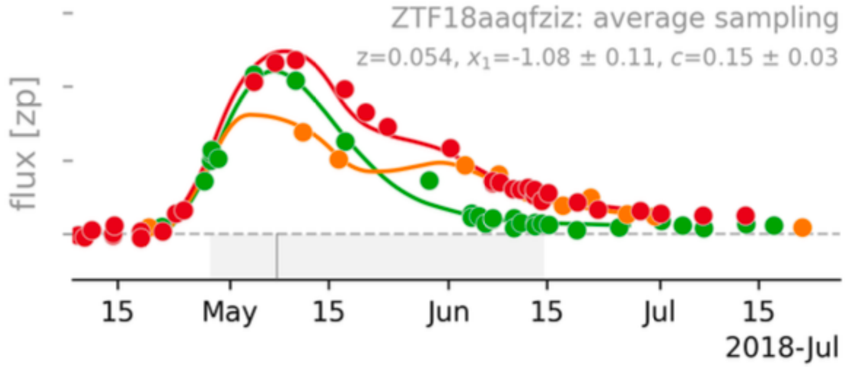
The ZTF-COSMO DR2 sample

Rigault, Smith et al. 2024

Large field-of-view camera : 47 deg^2

Scan the sky every night which enables us to :

→ detect and sample SNIa light-curve



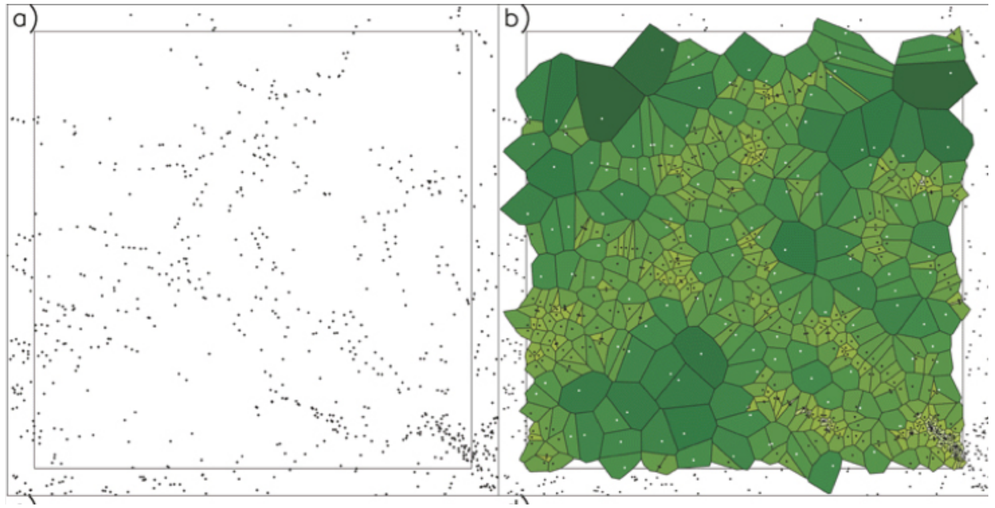
SNIa between 2018-2020 - DR2 Overview paper

Cuts	n targets	removed	% removed
Master list	3795	–	–
+ ZTF lightcurve	3778	17	0.4
+ a spectrum	3668	110	2.9
+ confirmed “Ia”	**3628**	40	1.1
Basic cuts			
good l.c. sampling	2959	669	18.4
$x_1 \in [-3, +3]$	2898	61	2.1
$c \in [-0.2, 0.8]$	2861	37	1.3
$\sigma_{t_0} \leq 1$	2836	25	0.9
$\sigma_{x_1} \leq 1$	2822	14	0.5
$\sigma_c \leq 0.1$	2809	13	0.4
“fitprob”$\geq 10^{-7}$	**2666**	143	5.1
Subsample examples			
volume ltd ($z \leq 0.06$)	989	1677	63.0
non-peculiar SNe Ia	2628	38	1.5

Revolver and the Zobov algorithm

Voronoi tesselation

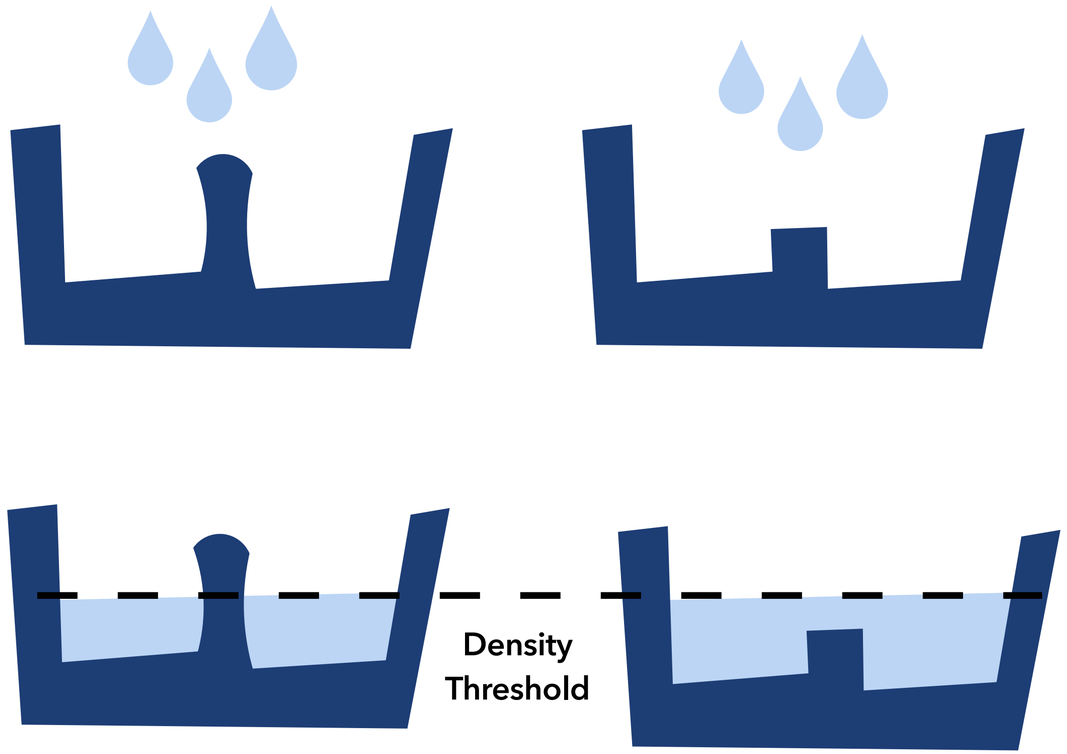
- Each galaxy is enclosed within a Voronoi cell.
- $\rightarrow \rho_{loc} = 1/V_i$



Tracer distribution Voronoi tesselation

Neyrinck 2008

Watershed transform



Distinct voids Single voids