Cosmology with cosmic voids

Marie Aubert

Ecole d’été France Excellence – 5th July 2018

Outline

- **Cosmology Reminder**
- A bit of LSS history
- Why are you having a cosmic voids class ?
- Void Finding
- Testing cosmology with voids Ω_m

What do we know of the Universe ?

Cosmology is the study of the Universe, it's history, it's evolution and its composition at very large scale.

Our knowledge is based in the framework of Einstein's **General Relativity.**

Universe

Isotropic & Homogeneous

Invariant by rotation : **No privileged direction !**

Invariant by translation: **No privileged position !**

What do we know of the Universe ?

Cosmology is the study of the Universe, it's history, it's evolution and its composition at very large scale.

Our knowledge is based in the framework of Einstein's **General Relativity.**

Universe → Expanding → At an **accelerated rate !**

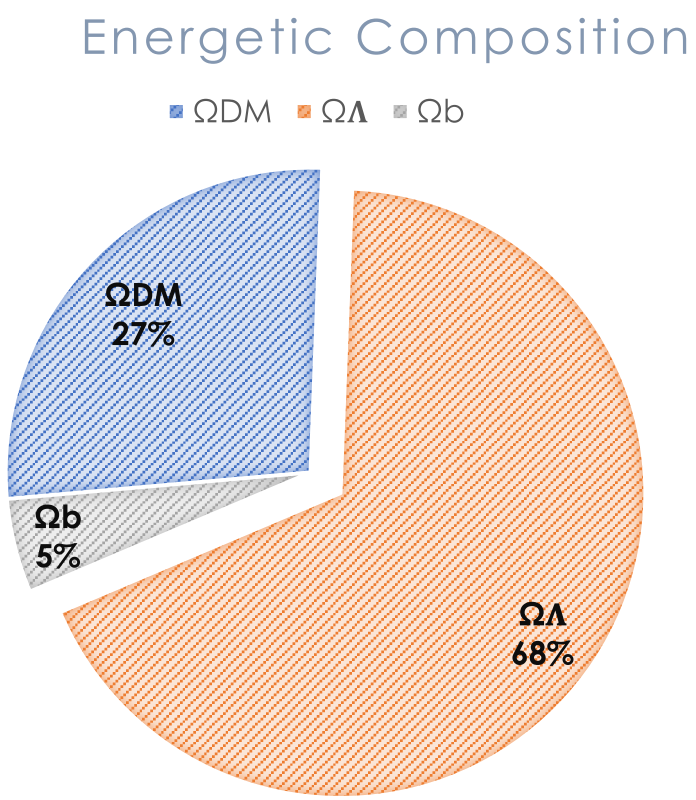
(Riess et al 1998, Perlmutter et al 1998)

What do we know of the Universe ?

Cosmology is the study of the Universe, it’s history, it’s evolution and its composition at very large scale.

Our knowledge is based in the framework of Einstein’s **General Relativity.**

Universe → Its evolution is related to its composition → Dark energy is responsible for the accelerated expansion



What do we know of the Universe ?

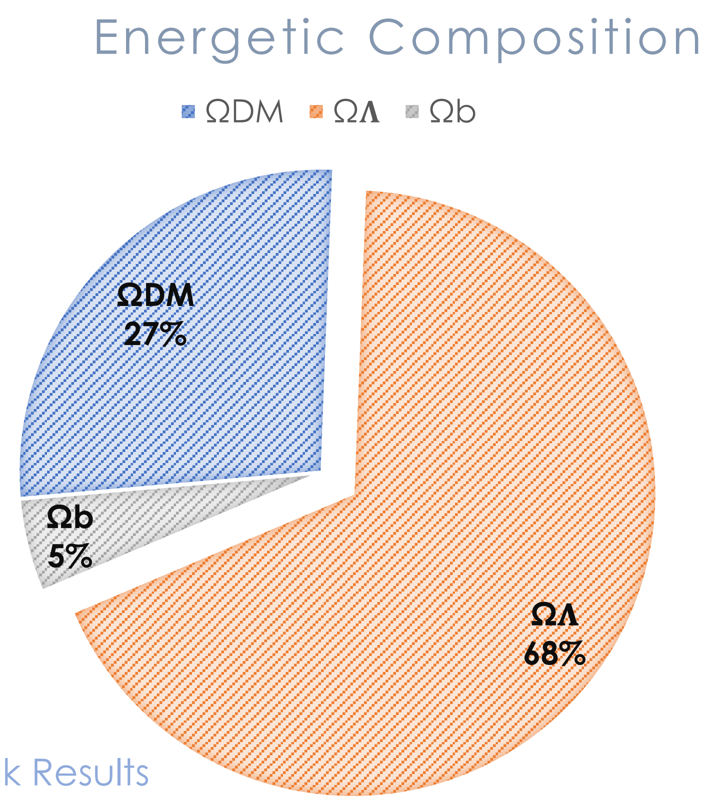
Cosmology is the study of the Universe (very large scale considered). This study relies on Einstein's **General Relativity** theory !

Universe

Flat

Isotropic & Homogeneous

Expanding !
At an **accelerated** rate



Planck Results

Standard Model of Cosmology (ΛCDM)

What are we looking for ?

Two mysteries remains in this framework of the Standard Model of Cosmology :

- What is dark matter ?
- **What is dark energy ?**

In order to explain that we are looking two ways :

- In the framework of the Standard Model : try to constrain dark energy & its equation of state of dark energy
- Testing General Relativity and looking for a modification of its laws ! → **Modified Gravity**

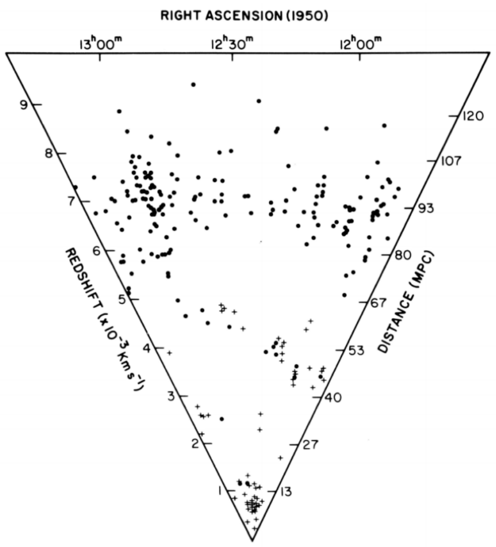
To resarch those effects, we will look in the Large Scales Structures !

Outline

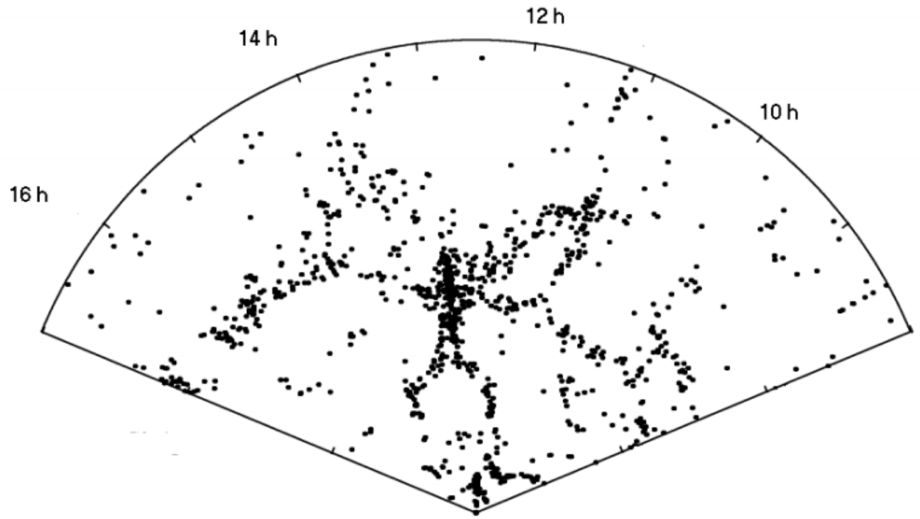
- Cosmology Reminder
- **A bit of LSS history**
- Why are you having a cosmic voids class ?
- Void Finding
- Testing cosmology with voids

Large Scale Structures

- Large Scale Structures are quite a recent discovery !



First Mention of voids surounding the COMA Supercluster.
Gregory & Thomson **(1978)**



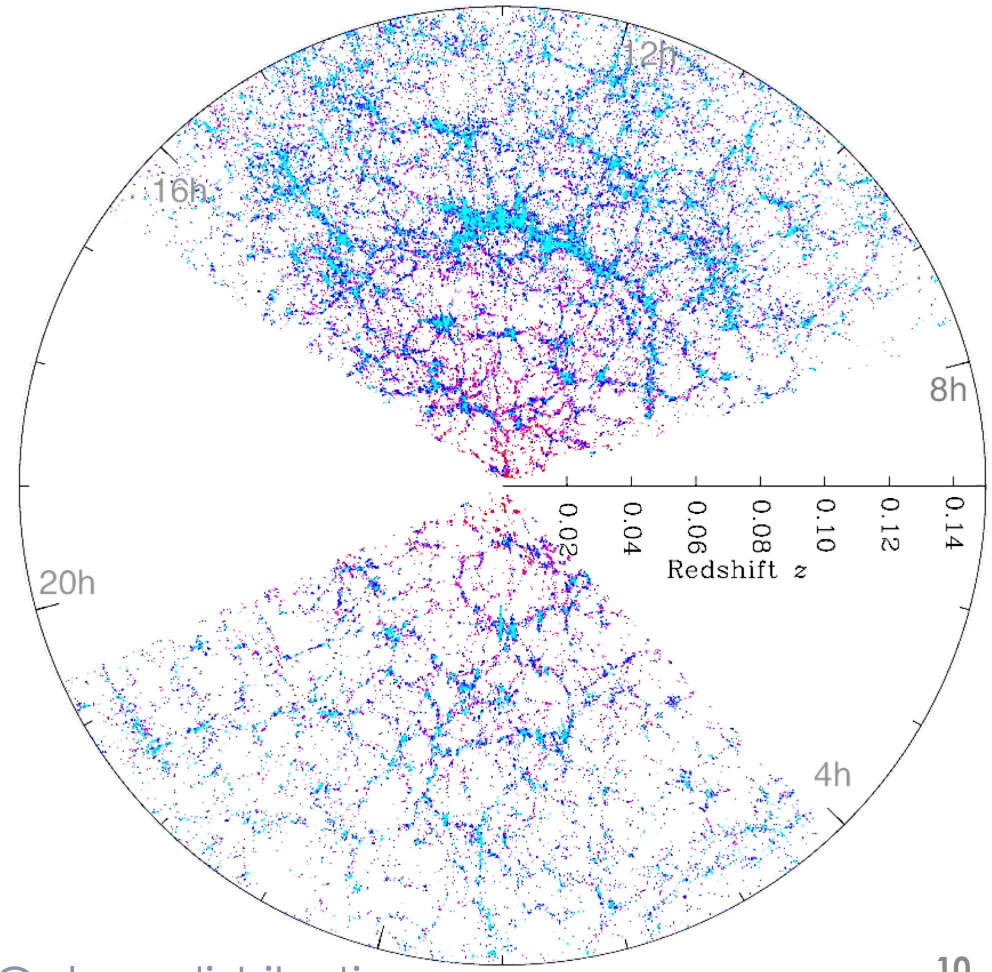
Confirmation of the existence of voids in the cosmic web
de Lapparent et al. **(1986)**

Large Scales Structures

Nowadays, we understand that the LSS :

- Are the remnants of the primordial fluctuations in the early universe.
- Traces the underlying dark matter field
- Are composed as a web of filamentary structures & clusters & **holes**

Voids in the cosmic webs are , by definition, underdensities in the matter field.



SDSS Survey Galaxy distribution

Finding the voids ?

In order to map the large scale structures, **3-D** mapping of the sky is **necessary.**

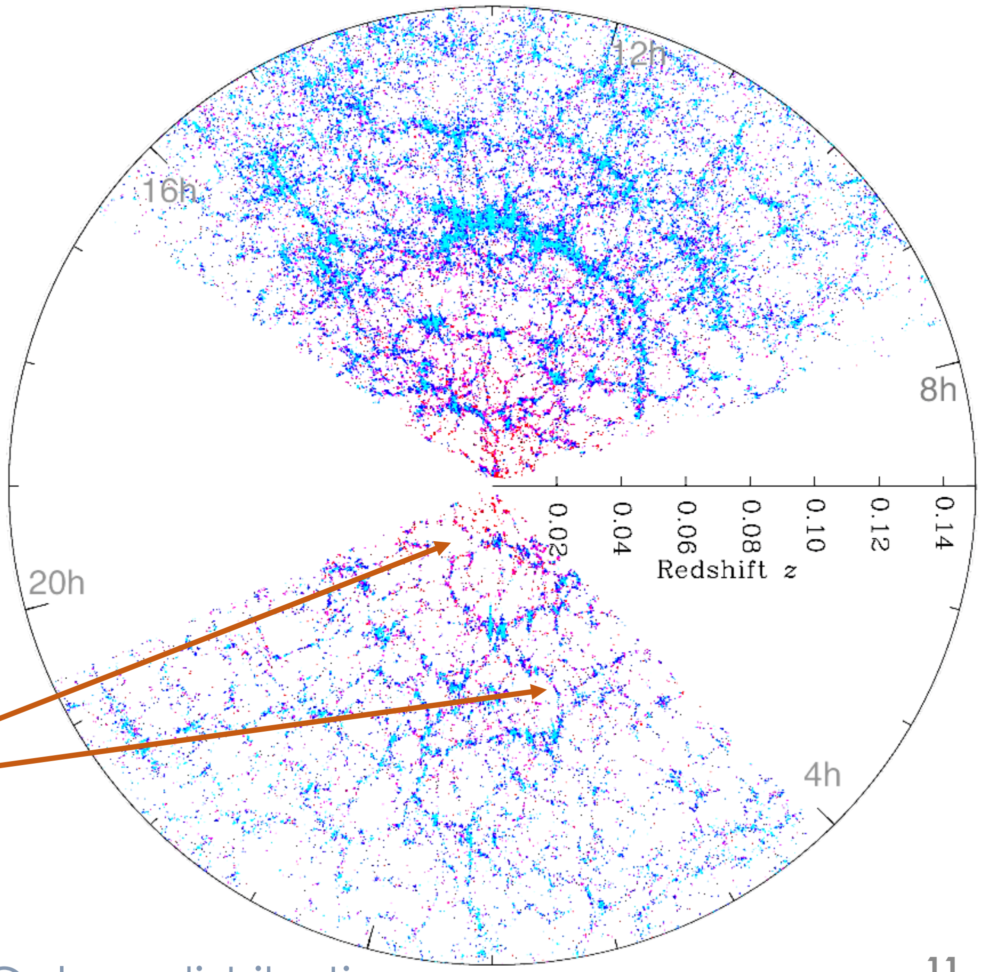
Void science has been rising steadily and the 1st results came out in the 2000's.

A huge volume & a great number of galaxies are needed in order to « observe » them.

→ **How then do we get their properties ?**

It actually depends…

They're here !



SDSS Survey Galaxy distribution

Outline

- Cosmology Reminder
- A bit of LSS history
- **Void Finding (largely inspired from Alice Pisani’s courses)**
- Testing cosmology with voids

Void definition

In order to quantify the void, we use algorithms called **Voidfinders**. Their main goals is to extract the voids from a given galaxy distribution.

- Choosing a certain type of voidfinders is not far from choosing a **void definition**.

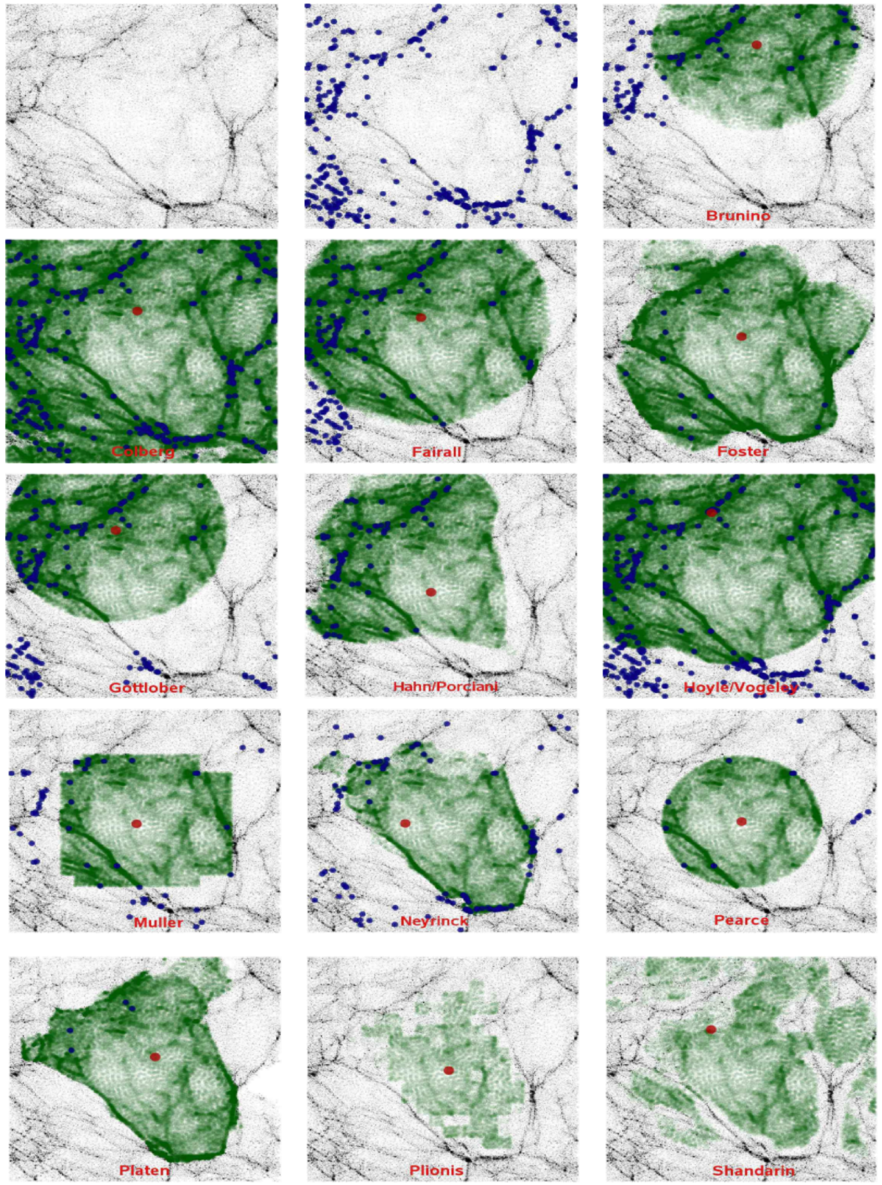
- The VoidFinder that you choose depends on several factors :
  - The survey features
  - The type of analysis you want to make

At the end of the day , you want to choose the best void finder in order to maximize the signal you want to measure

Void Finders

- Void finder based on the density field measurement
  - With/Without a shape assumption (spherical)
  - Throught Tesselation of the field

- Localizing only **empty regions** (devoid of matter/galaxy)



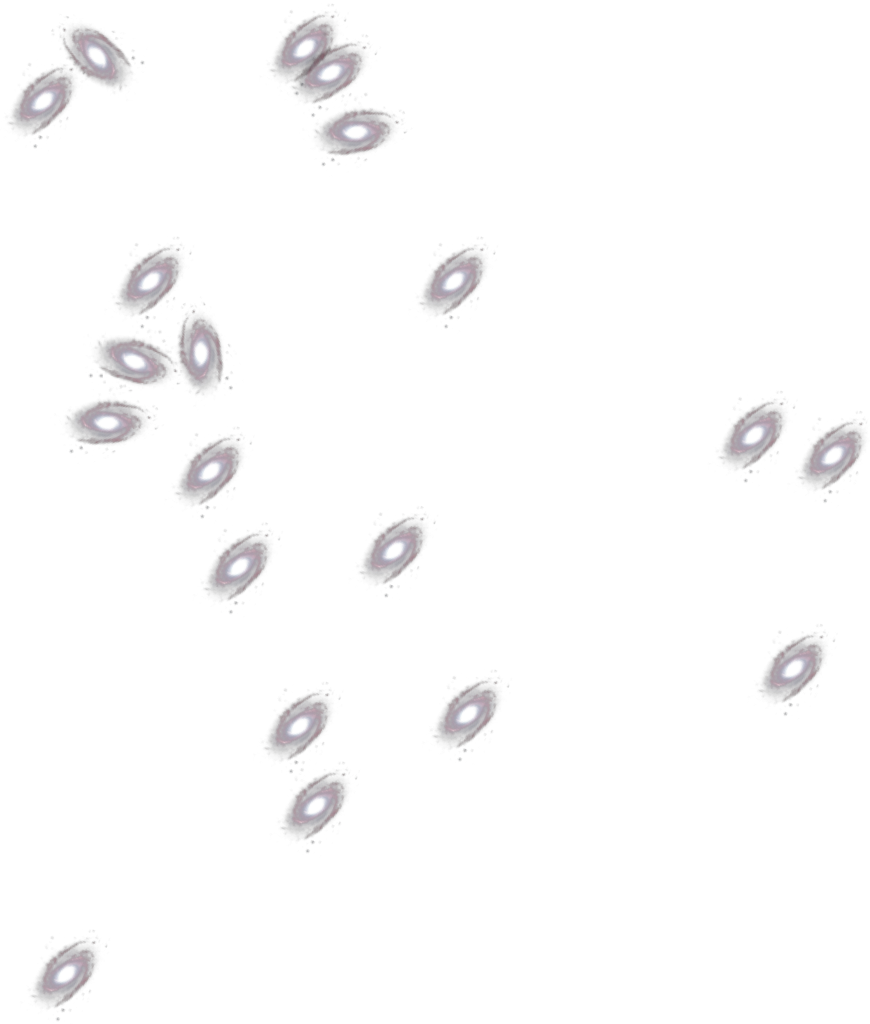
The Aspen–Amsterdam Void Finder Comparison Project (Colberg et al. 2008 , Arxiv: 0803.0918)

VIDE : **V**oid **ID**entification and **E**xamination

Sutter, P. M., Lavaux G., Hamaus N., **Pisani A.**, Wandelt B. D. et al., **Astronomy & Computing** (1406.1191) (ZOBOV, Neyrinck 2008)

- How does it work ? → **With Galaxies position !**

The survey gives us the positions in the sky.



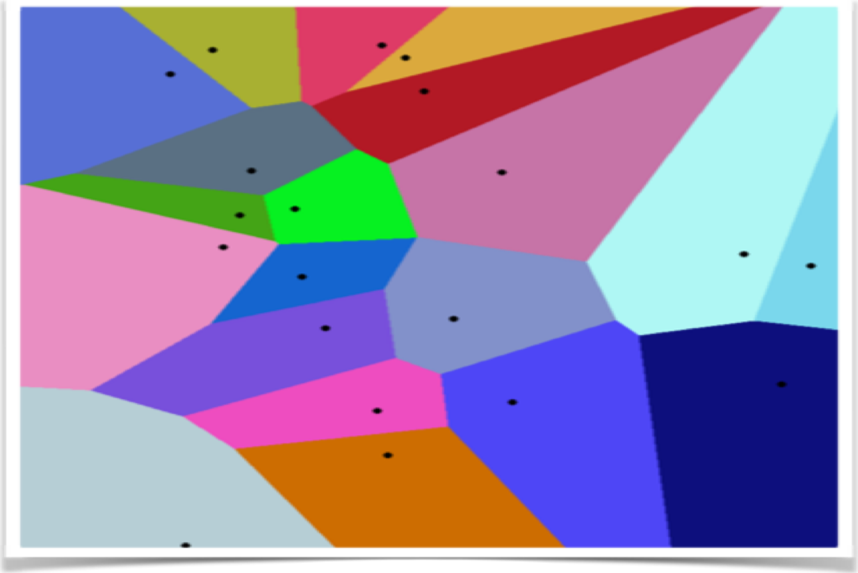
VIDE : **V**oid **ID**entification and **E**xamination

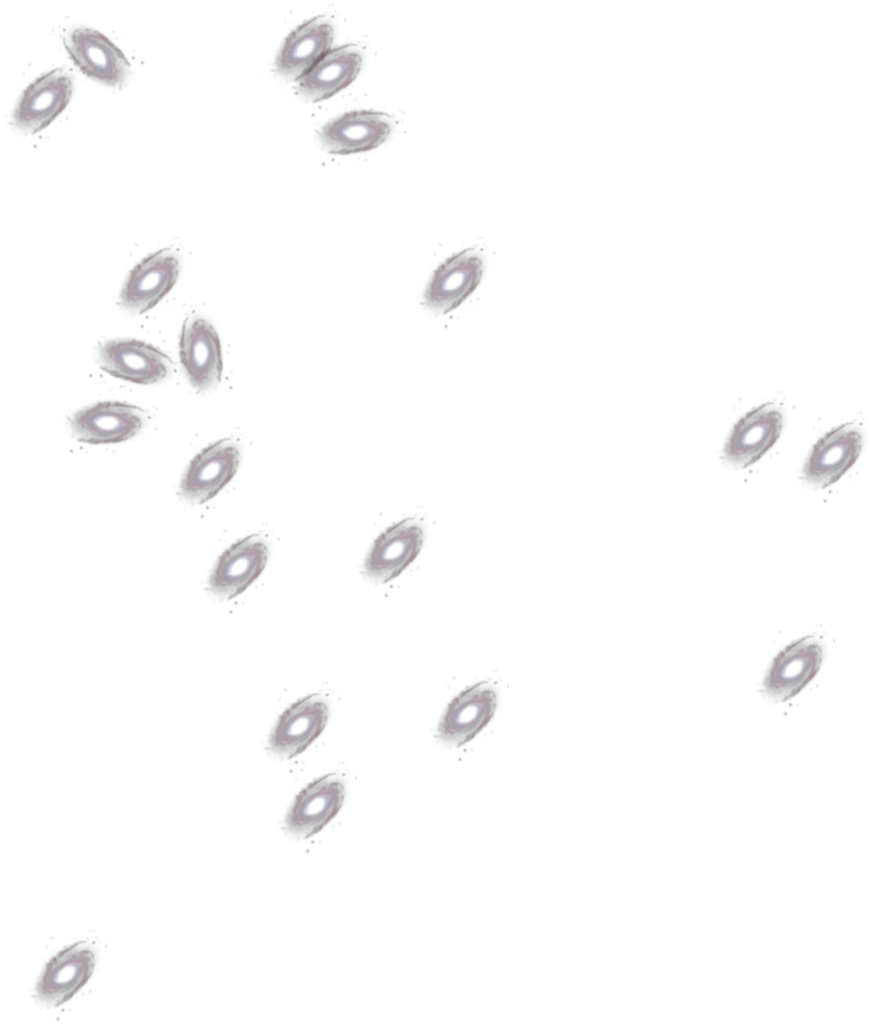
Sutter, P. M., Lavaux G., Hamaus N., **Pisani A.**, Wandelt B. D. et al., **Astronomy & Computing** (1406.1191) (ZOBOV, Neyrinck 2008)

- How does it work ? → **With Galaxies position !**

The survey gives us the positions in the sky.

- Then we practice a Voronoi tessellation.





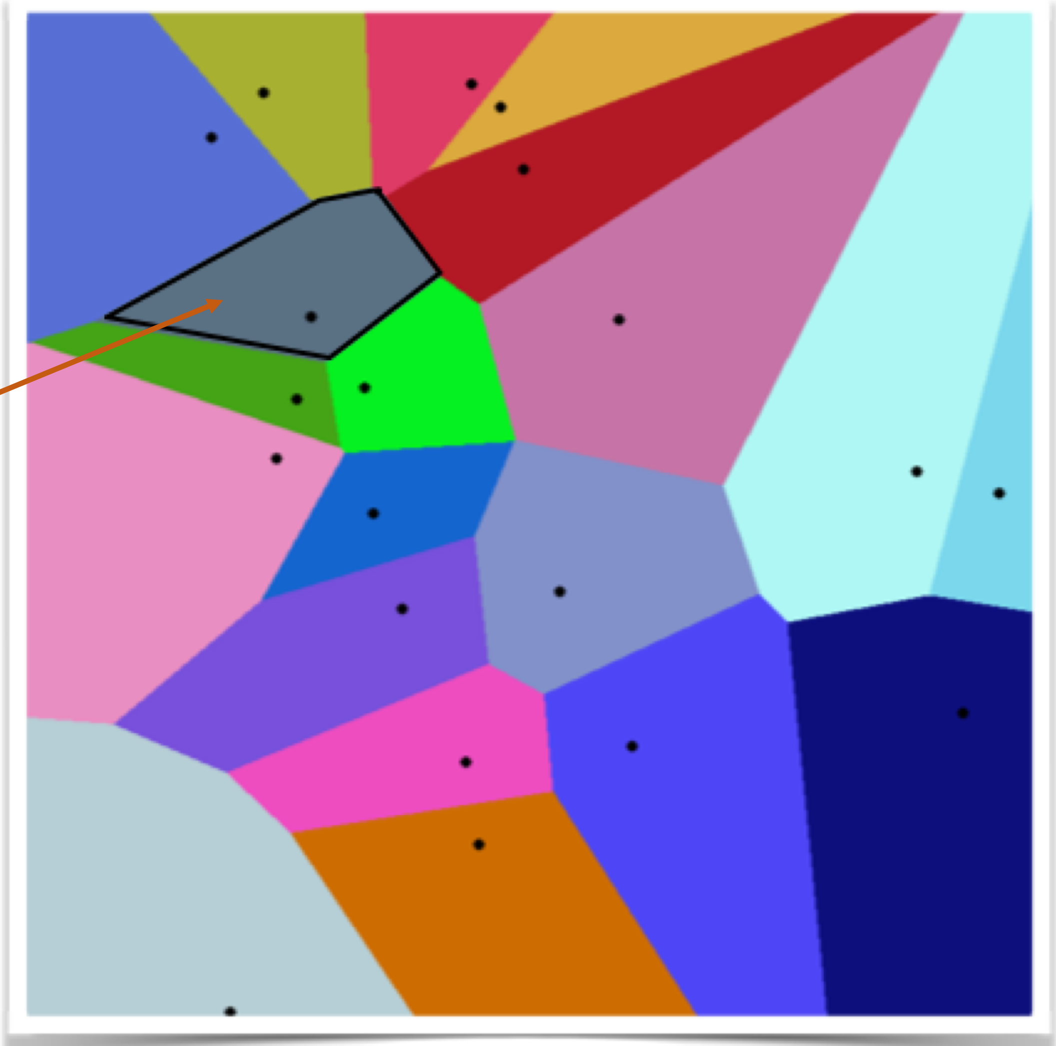
VIDE : **V**oid **ID**entification and **E**xamination

Sutter, P. M., Lavaux G., Hamaus N., **Pisani A.**, Wandelt B. D. et al., **Astronomy & Computing**
(1406.1191) (ZOBOV, Neyrinck 2008)

What is a Voronoi Tessellation ? .

Given a set of points , the Voronoi Tessellation proceed to a partitionning such that :

- All the points closer to the **points considered** point are enclosed in a **Voronoi cell.**
- The boundaries of the cell are the points equidistant to the two tracers defining the cell.
- The volume of the cell allows us to have a local density estimation : **1/V**



VIDE : **V**oid **ID**entification and **E**xamination

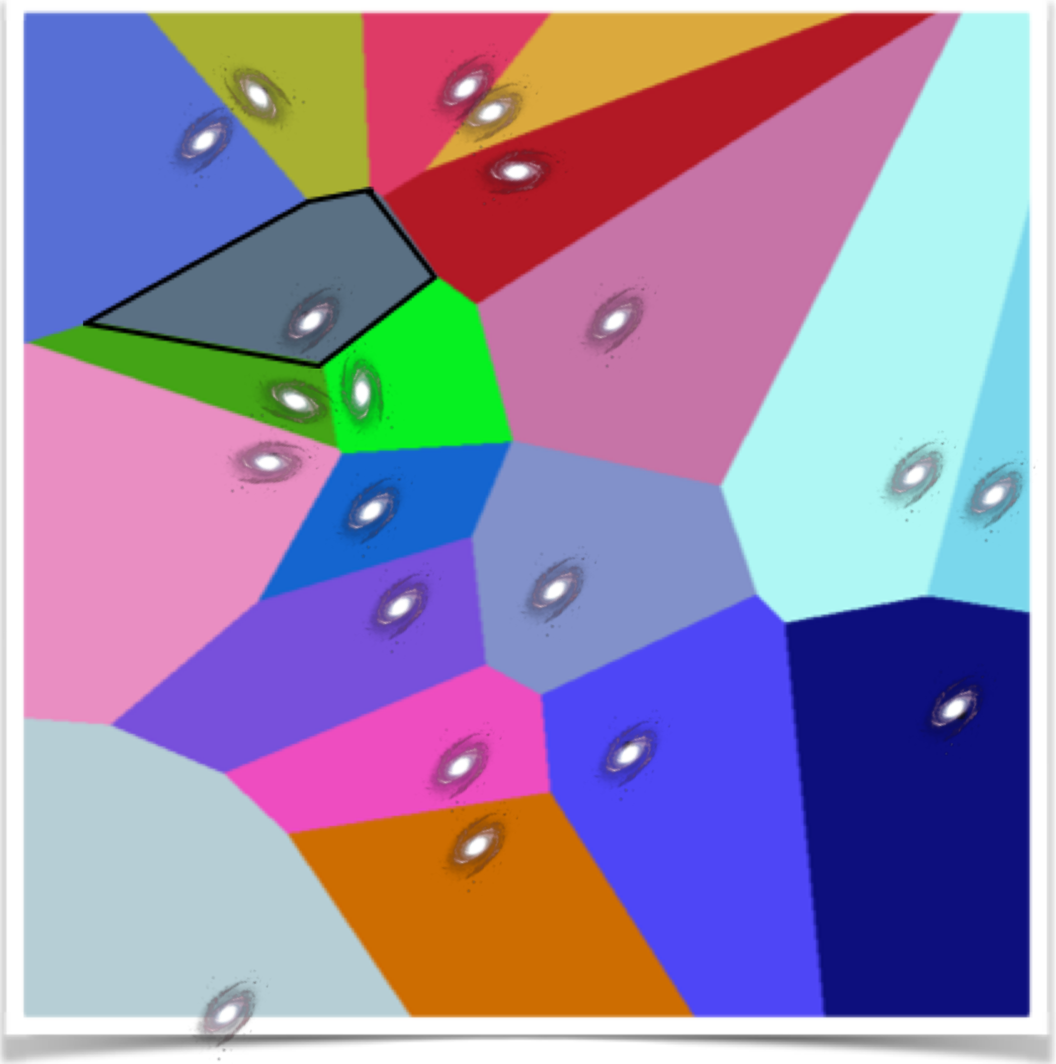
Sutter, P. M., Lavaux G., Hamaus N., **Pisani A.**, Wandelt B. D. et al., **Astronomy & Computing** (1406.1191) (ZOBOV, Neyrinck 2008)

- Applying the Voronoi tessellation allows us to map the galaxy density field, **including :**
  - The density peaks (filaments)
  - The density dips (voids) !

  (Icke & Van de Weygaert , 1987)

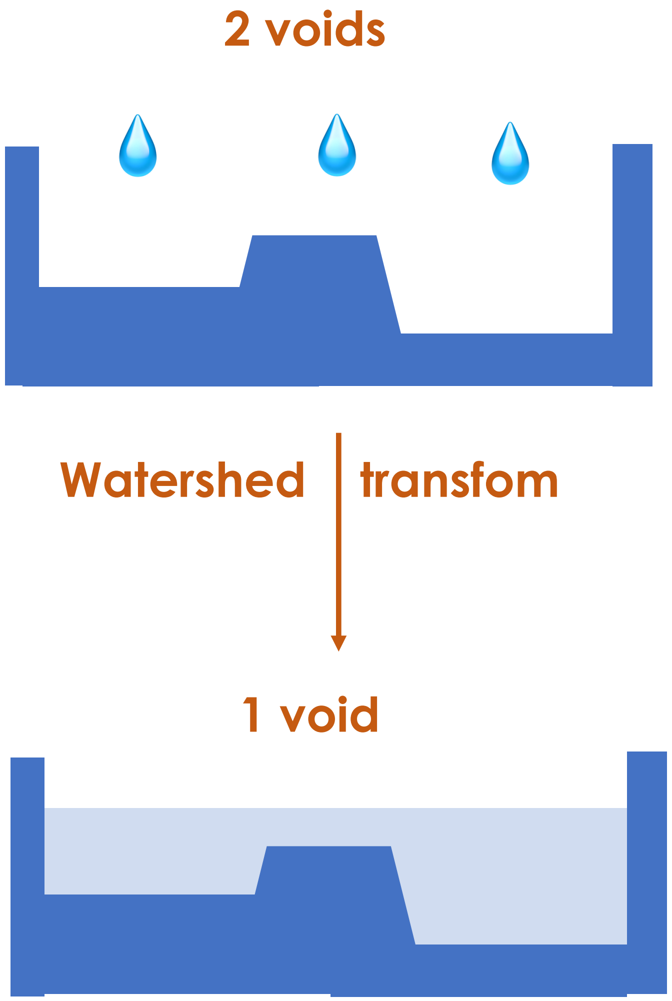
Is the work done then ? (No)

- We have to merge the different cells in order to define our voids.



VIDE : **V**oid **ID**entification and **E**xamination

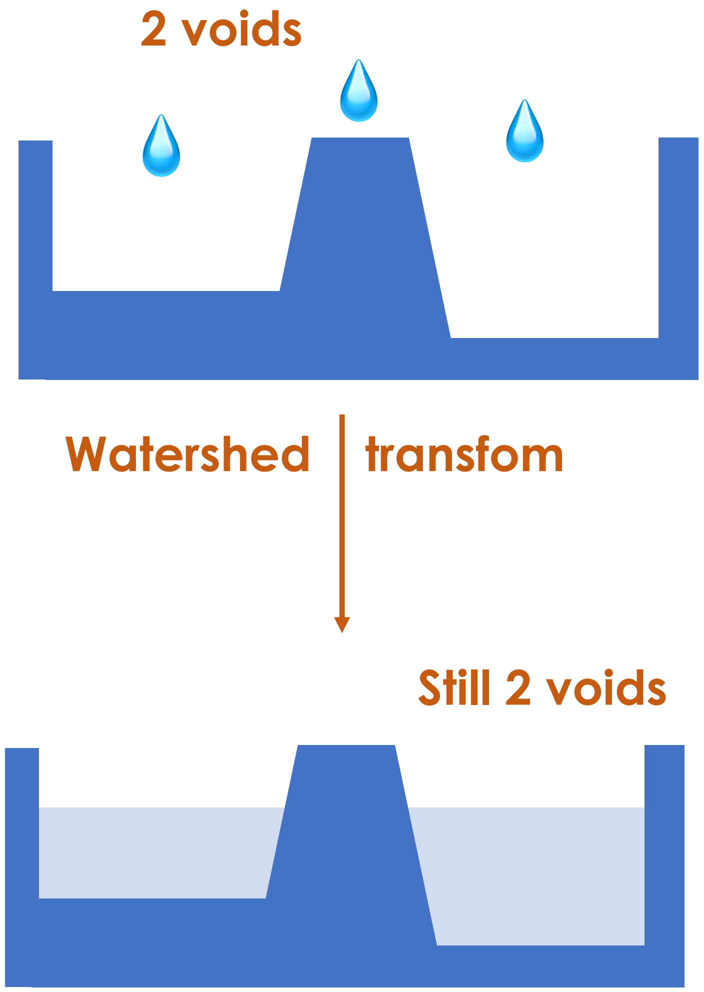
Sutter, P. M., Lavaux G., Hamaus N., **Pisani A.**, Wandelt B. D. et al., **Astronomy & Computing** (1406.1191) (ZOBOV, Neyrinck 2008)



Watershed transform allows us to :

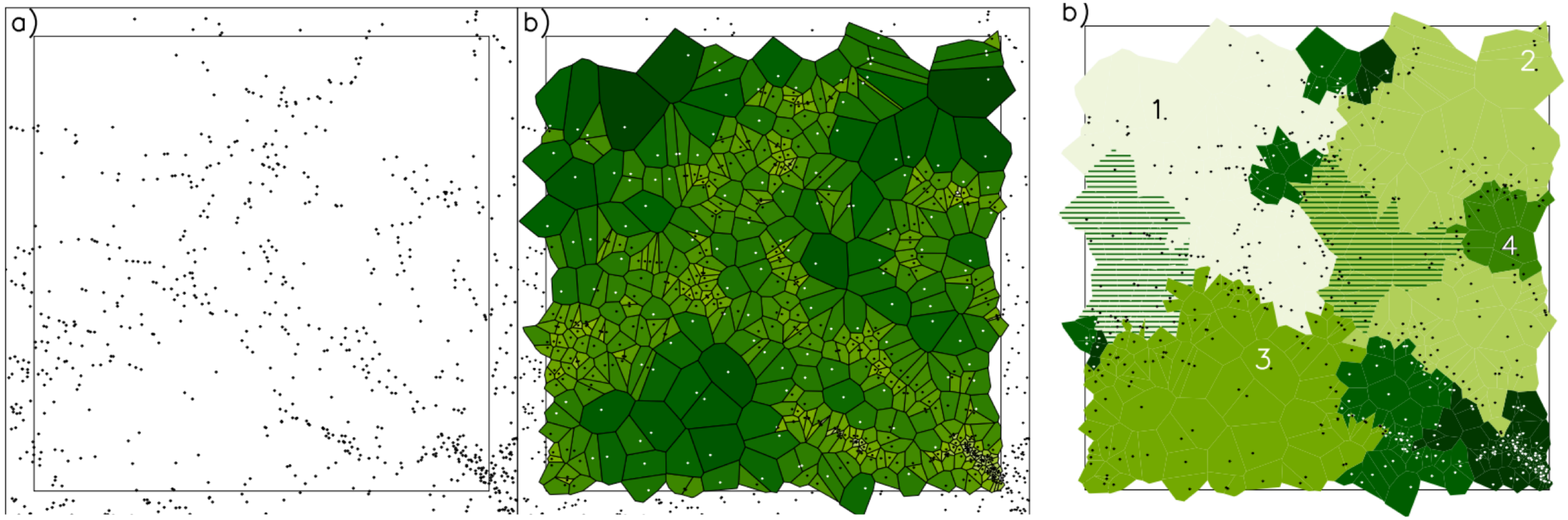
- Merge the different cells into a cluster of low density cells : **a void**
- Capture the hierarchy of the voids structure.

(Platen et al. 2007)



VIDE : **V**oid **ID**entification and **E**xamination

Sutter, P. M., Lavaux G., Hamaus N., **Pisani A.**, Wandelt B. D. et al., **Astronomy & Computing** (1406.1191) (ZOBOV, Neyrinck 2008)

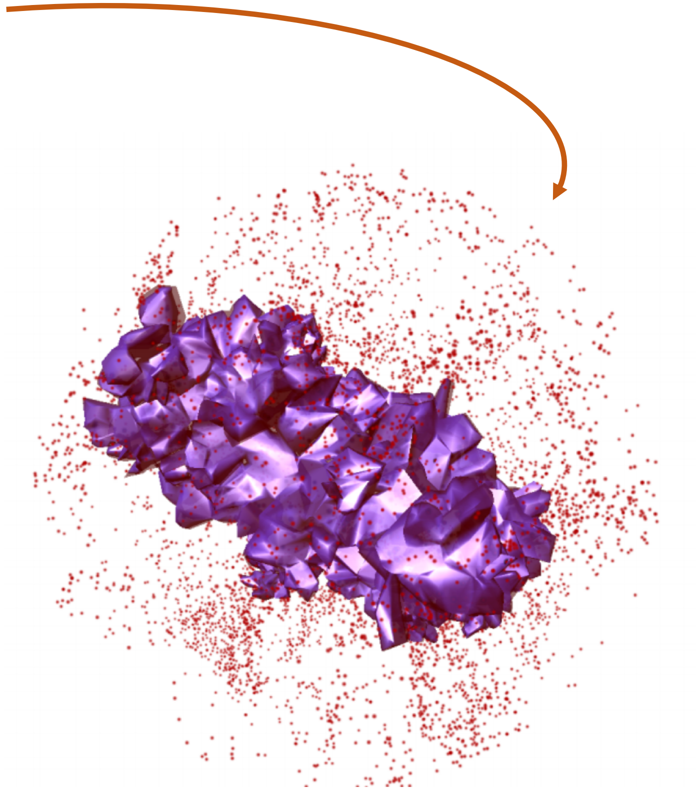


Galaxy distribution

Voronoi tessellation

Watershed Transform

(Neyrinck , 2008)



We obtain :
- The position of the center of the void
- It's radius
- It's member particles **(a void is not necessarily empty)**

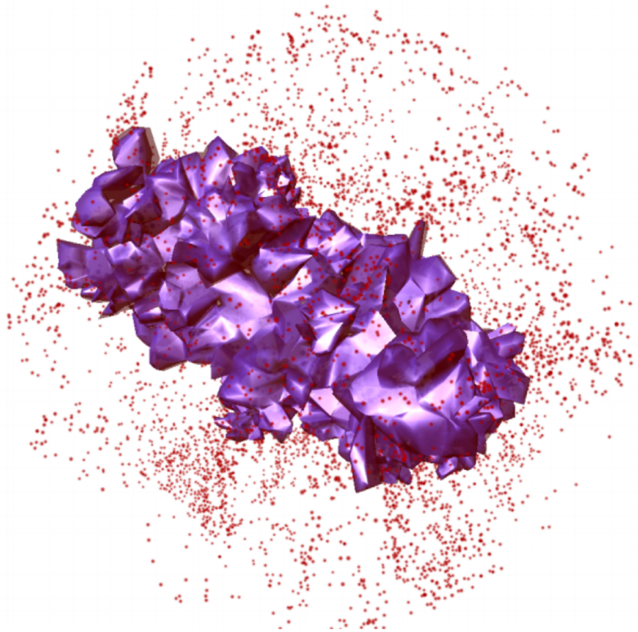
(Sutter, 2012b)

Outline

- Cosmology Reminder
- A bit of LSS history
- Void Finding (largely inspired from Alice Pisani's courses)
- **Testing cosmology with voids**

COSMOLOGY WITH VOIDS

A void → Is empty (-ish) ! → its evolution is not ruled by gravity…



(Sutter, 2012b)

In a ΛCDM scenario :

The evolution of a void & its properties should be more sensitive to dark energy !

In a no- Λ scenario (Modified Gravity) :

After the last cosmological observation, we expect gravity to be modified at very large scales in a low density regime environment !

COSMOLOGICAL PROBES WITH VOIDS

A void in itself is just a tool. But, combined with a specific approach, it can become a very efficient probe !

Most of the cosmological probes that applies to galaxies apply to voids as well !

VOIDS + **BAO, AP TEST, Lensing, RSD, Abundance, iSW** = **6 different ways to Test cosmology !**

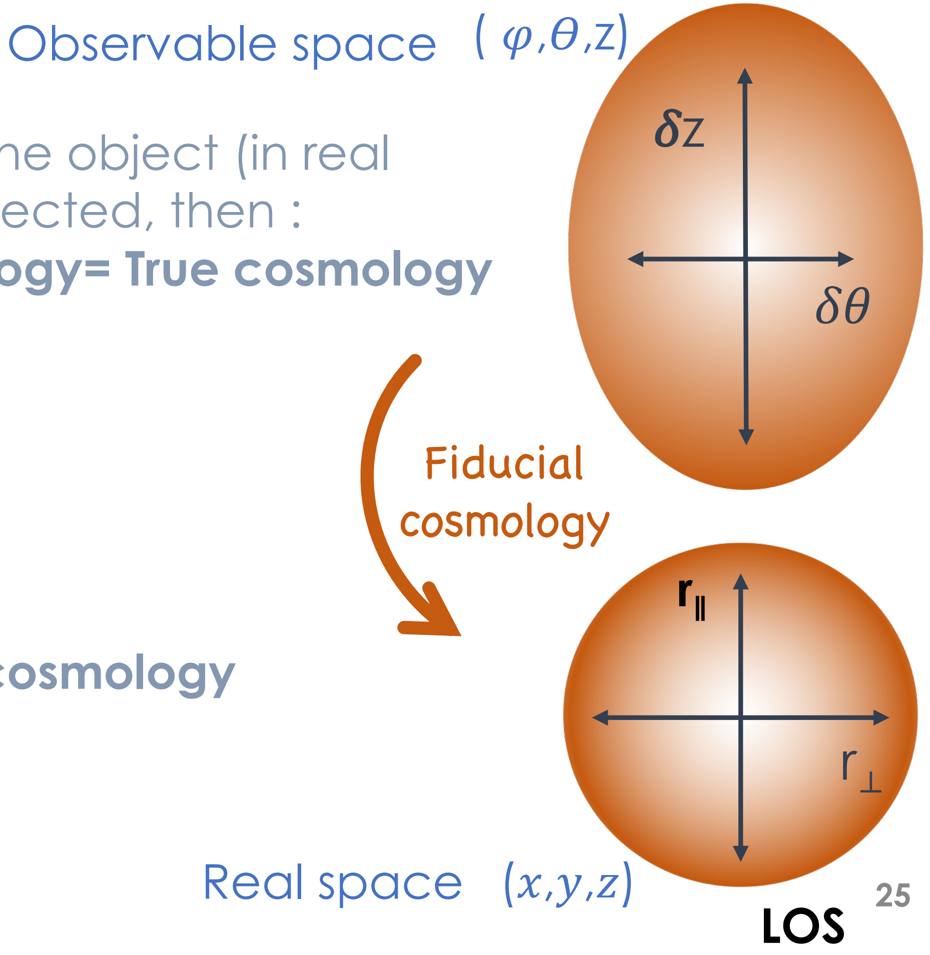
Investigating the shape of the voids

- AP test relies on knowledge of the shape of an object in real space (**ideally with symmetry properties**)

If the shape of the object (in real space) is as expected, then :
Fiducial cosmology= True cosmology

else,
Wrong fiducial cosmology

Iteratively, we are able to deduce information on cosmology.



- AP test relies on knowledge of the shape of an object in real space (**ideally with symmetry properties**)

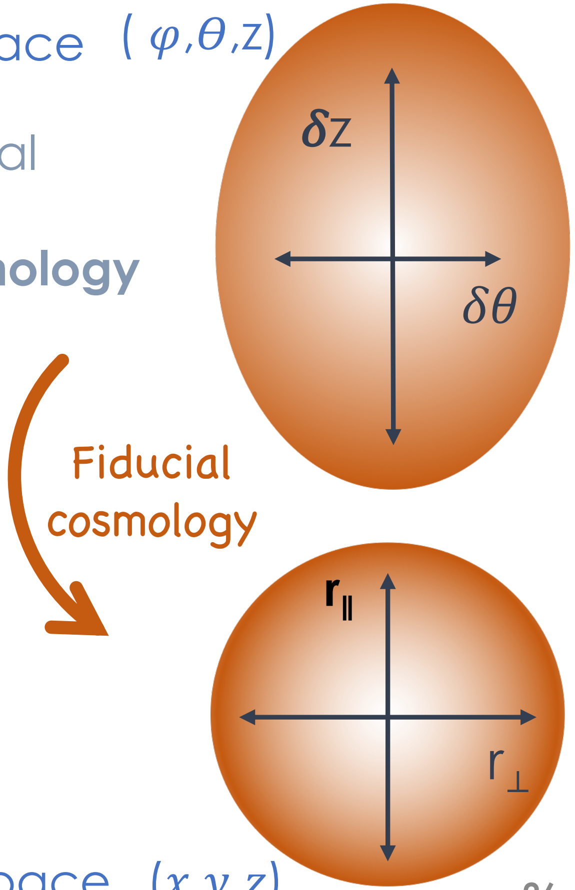
- Cosmic voids have, in average, no favored direction according to the *cosmological principle* (homogeneity et isotropy of the Universe)

Voids can be considered as standard spheres, statistically.

Observable space (φ, θ, z)

If the shape of the object (in real space) is as expected, then :
Fiducial cosmology= True cosmology

else,
Wrong fiducial cosmology



Real space (x, y, z)

LOS

Inverstigation patterns in galaxy – void distribution

Investigating Redshift Space Distortions around voids

Investigating the number of voids