Real-space density profile reconstruction of stacked voids

XXVII Texas Symposium on Relativistic Astrophysics

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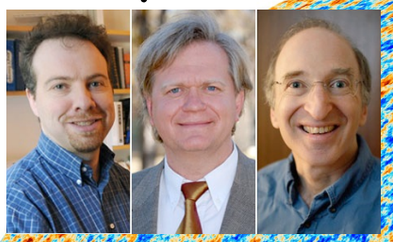
Institut d'Astrophysique de Paris (France)

Dallas, TX
10/12/2013

Credit: Millennium simulation

The standard cosmological model

Physics Nobel Prize 2011 Perlmutter, Riess, Schmidt



Supernova I a

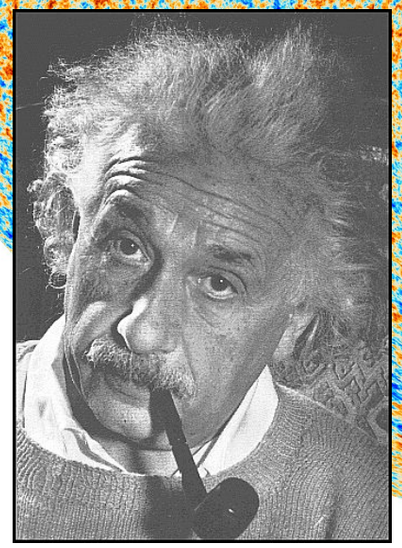
Vera Rubin

Dark matter 27%

Dark energy 68%

Ordinary matter 5%

CMB-Planck collaboration



Albert Einstein

Λ

Fritz Zwicky

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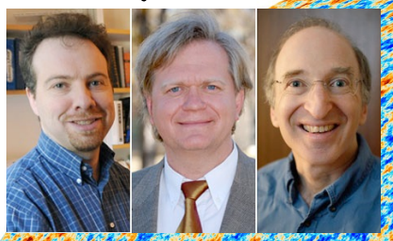

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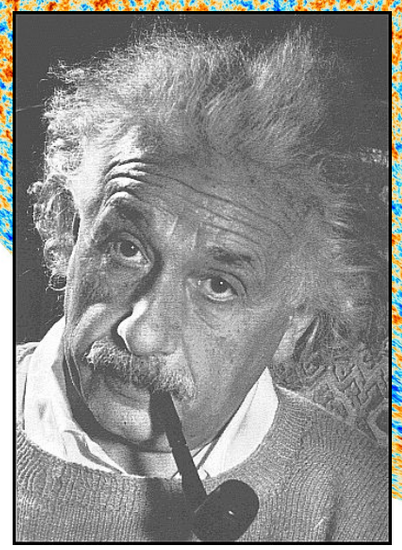
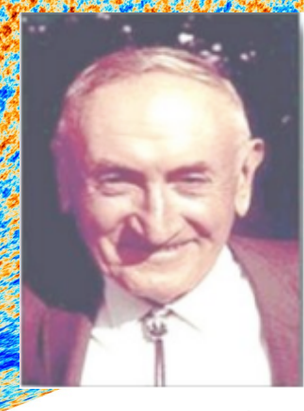


Albert Einstein

Λ

We don't understand most of our universe!



Fritz Zwicky

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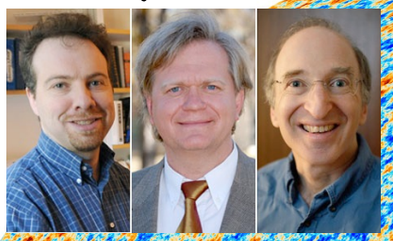

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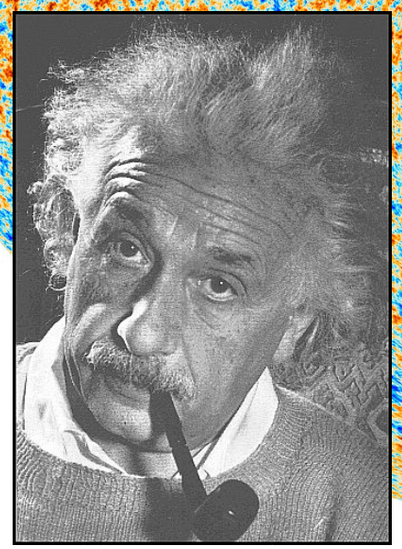

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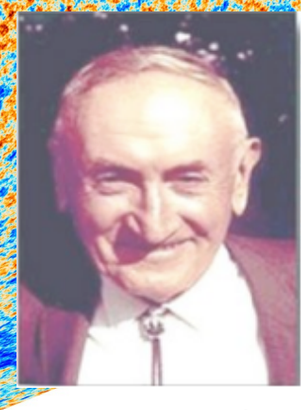
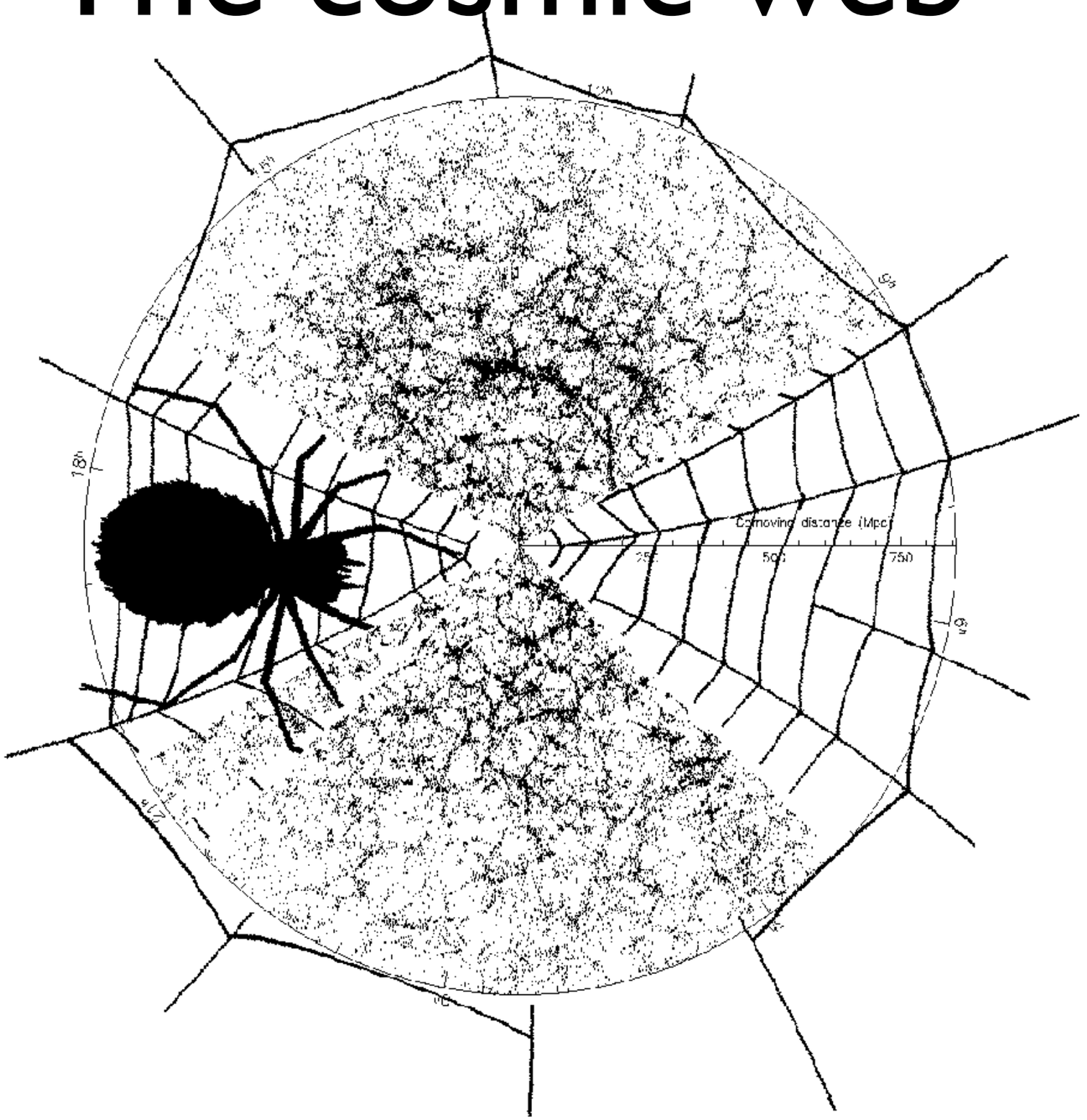


Fritz Zwicky

Albert Einstein

The study of large scale structures is a powerful tool to understand the composition of the universe.

The cosmic web



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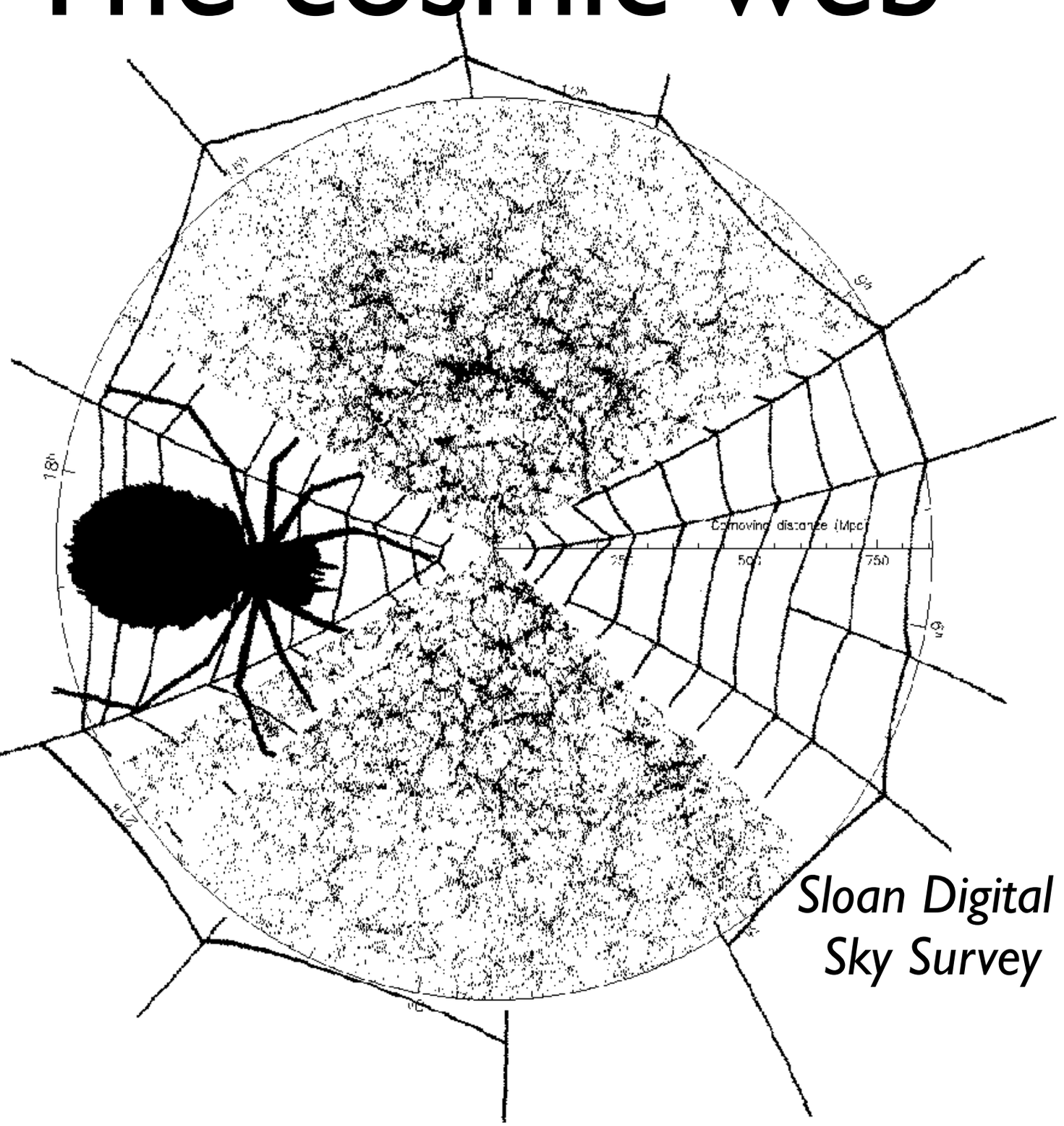
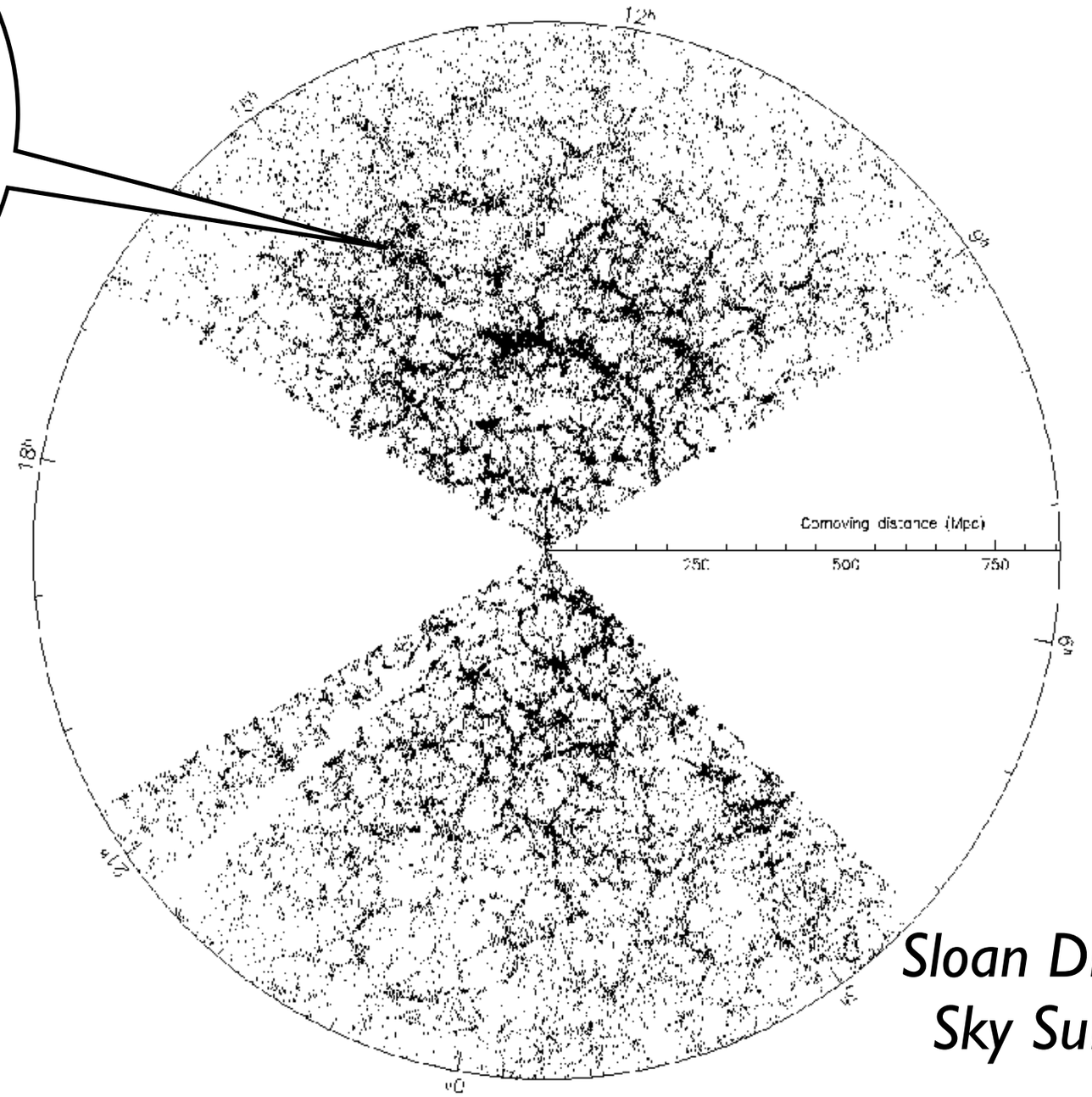


Sloan Digital Sky Survey

The cosmic web

complex
filamentary
supercluster
structures



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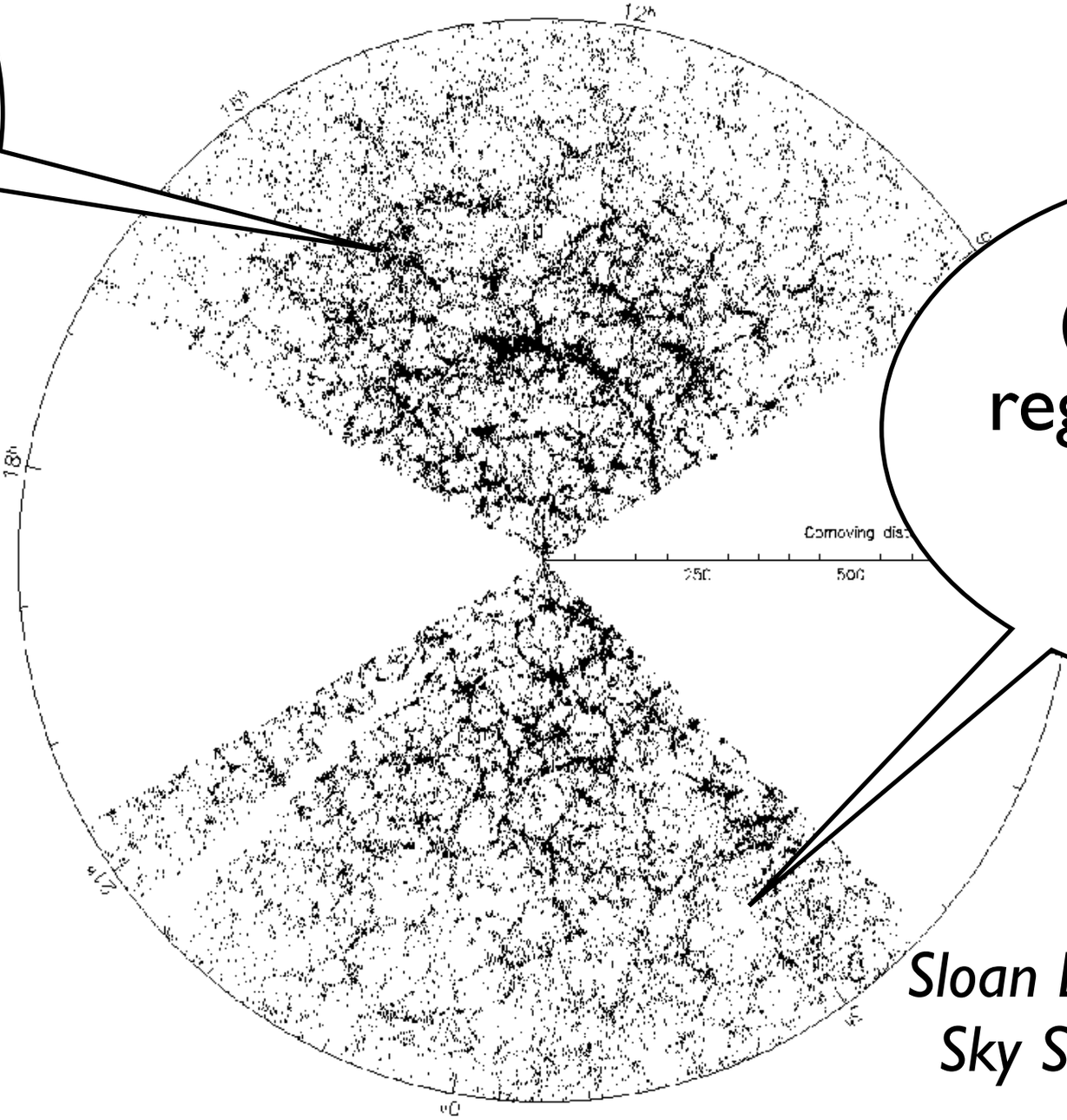

emptier
(not empty!)
regions from 10 to
100 of Mpc/h:
VOIDS

Sloan Digital Sky Survey

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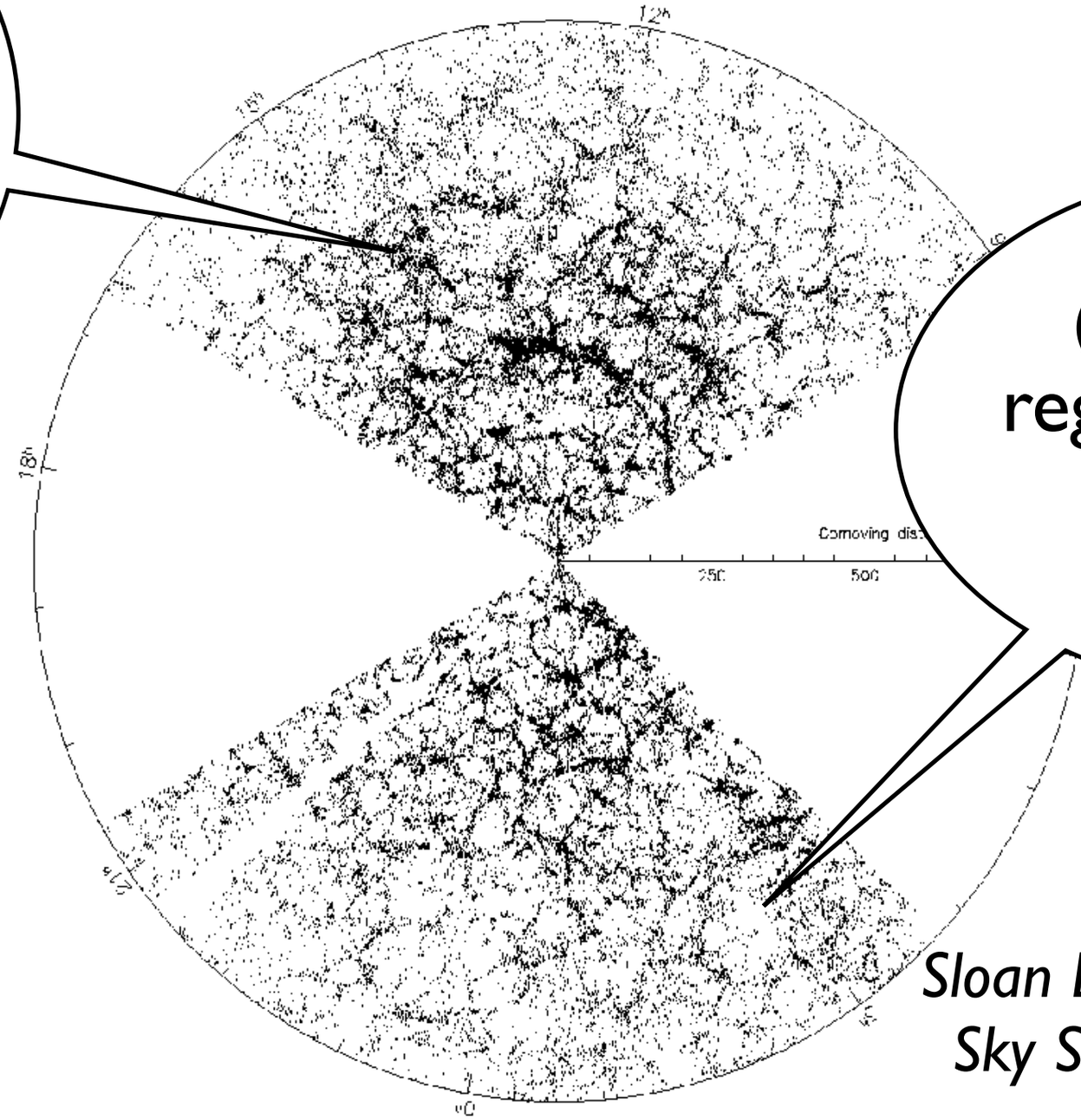


emptier
(not empty!)
regions from 10 to
100 of Mpc/h:
VOIDS

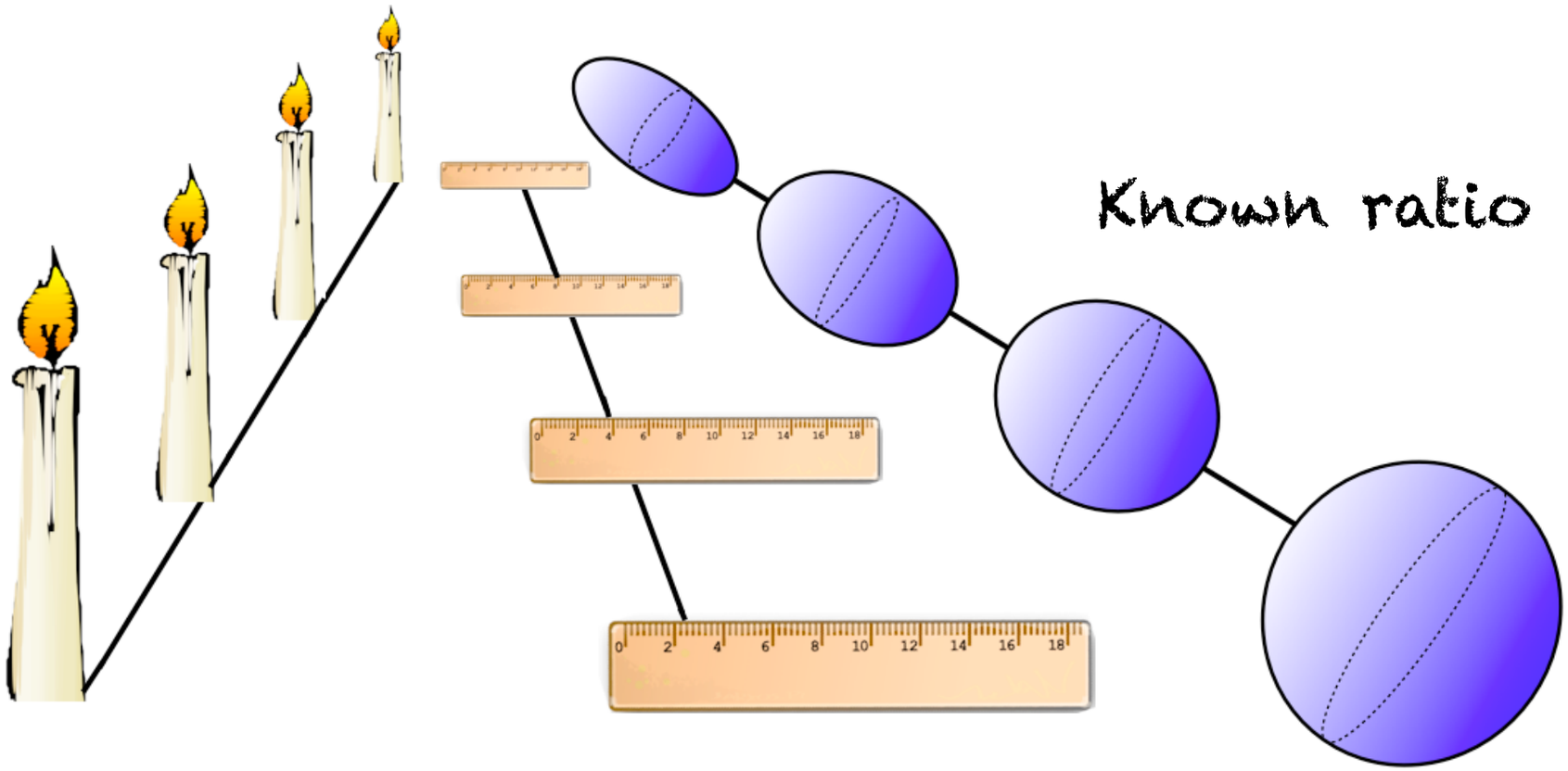
Sloan Digital Sky Survey

Voids =>different shapes but **spherical** average shape in an isotropic and homogeneous universe!

Sphericity is the key feature!

Alcock-Paczyńnski test

The test uses the apparent stretching of spheres in the redshift space coordinates to estimate the local geometry of expansion by comparing the angular size to the radial/redshift size that is affected by cosmology.



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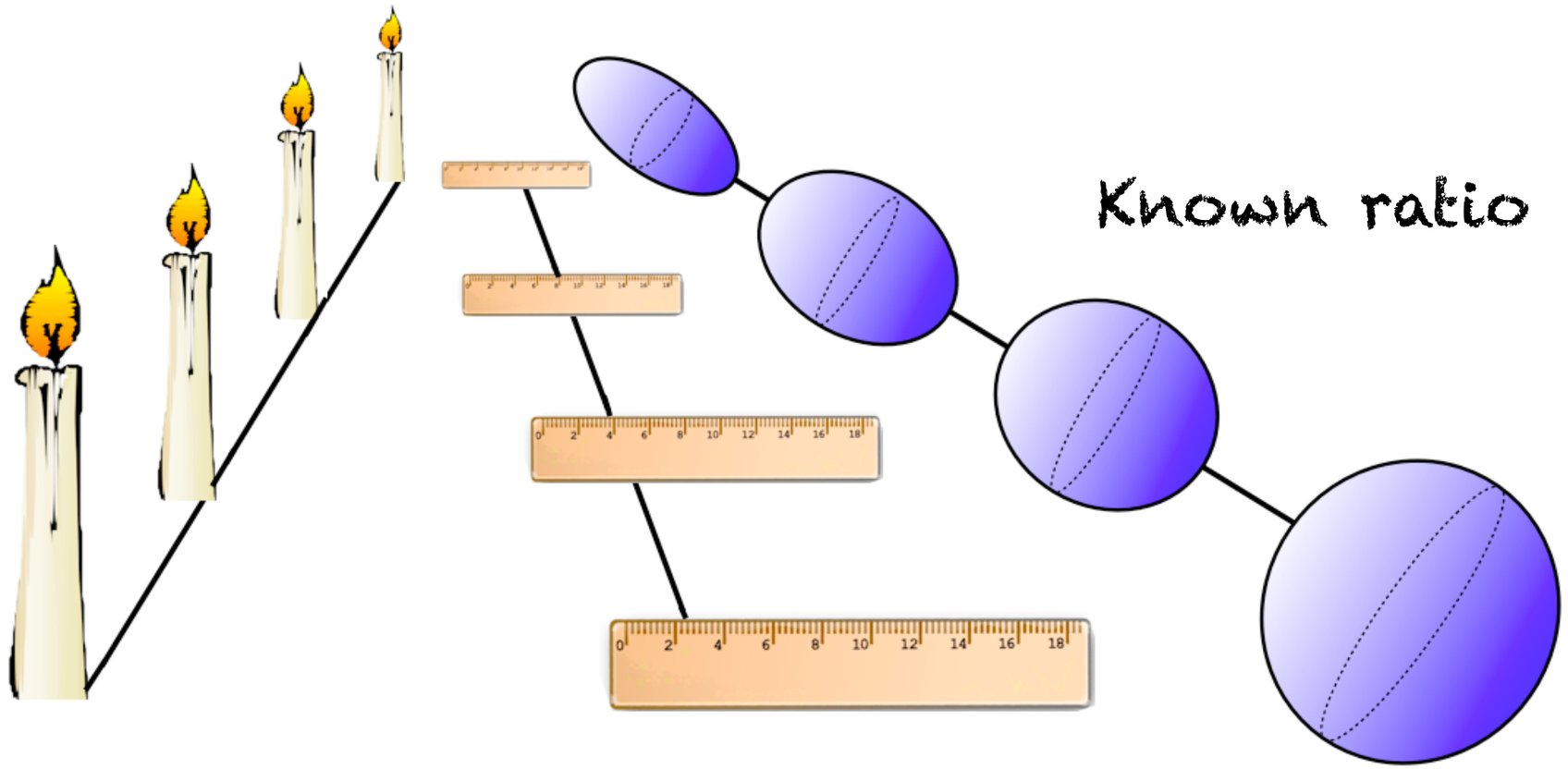

This test can be applied to VOIDS !!

Voids: Dark Energy-dominated objects

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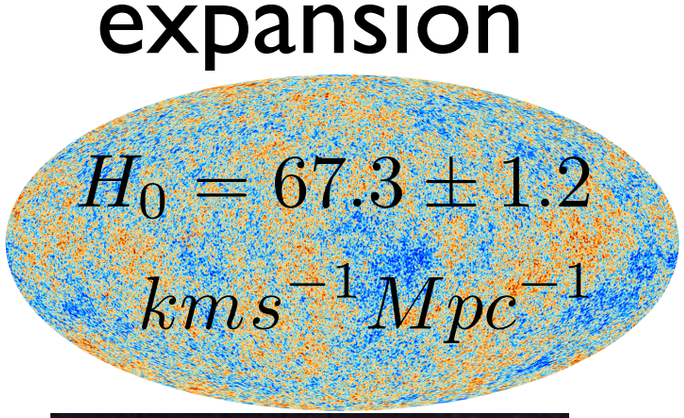
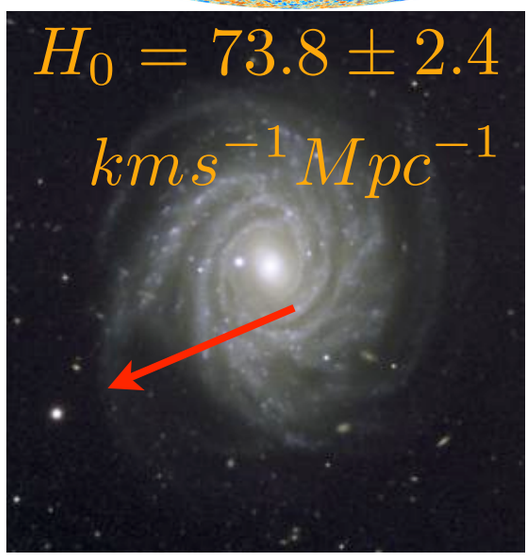
universe accelerated expansion





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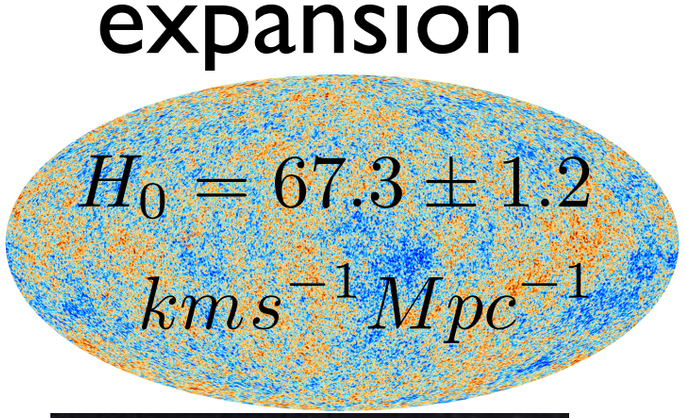

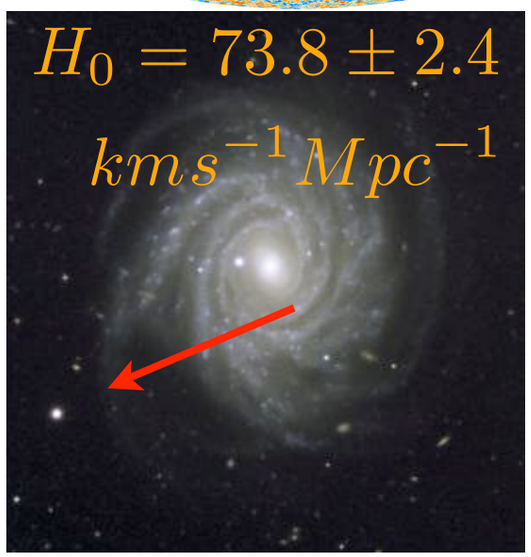

local measure BREAK TENSION

cosmological parameters/ models

Voids: Dark Energy-dominated objects

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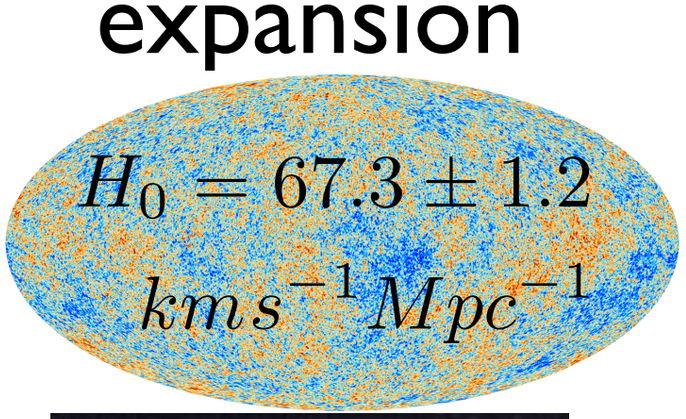

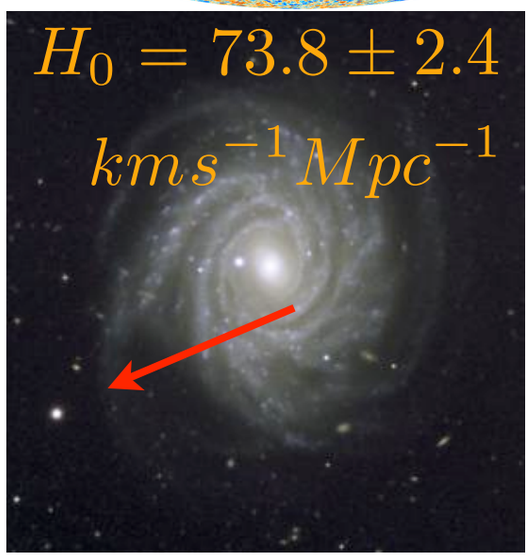

local measure

BREAK TENSION

cosmological parameters/ models

neutrinos and fundamental physics

Voids: Dark Energy-dominated objects

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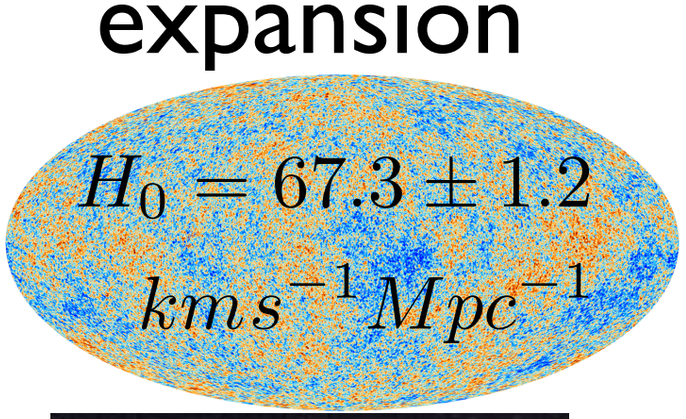

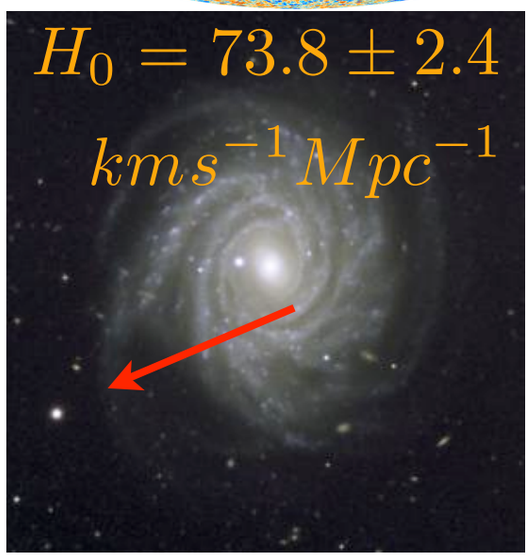

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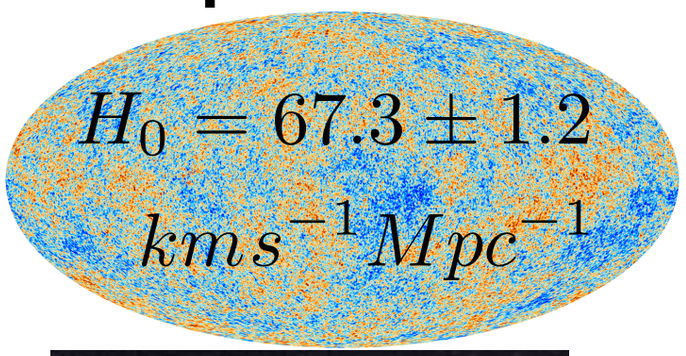
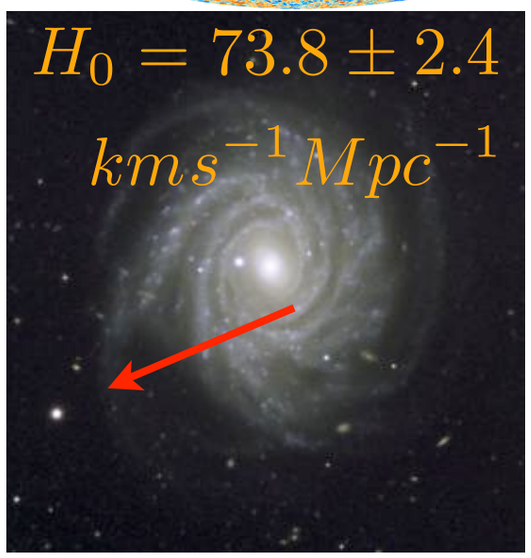
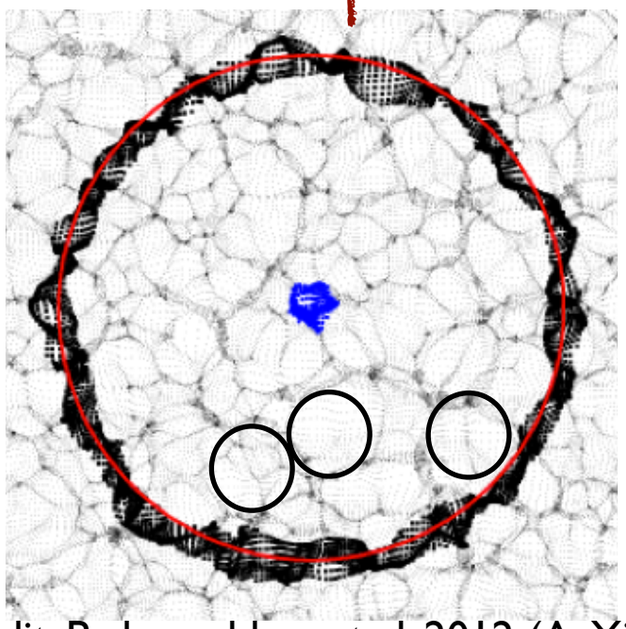




local measure BREAK TENSION

DE (FOM one order of magnitude higher than BAO)

BAO compared to void



More modes!

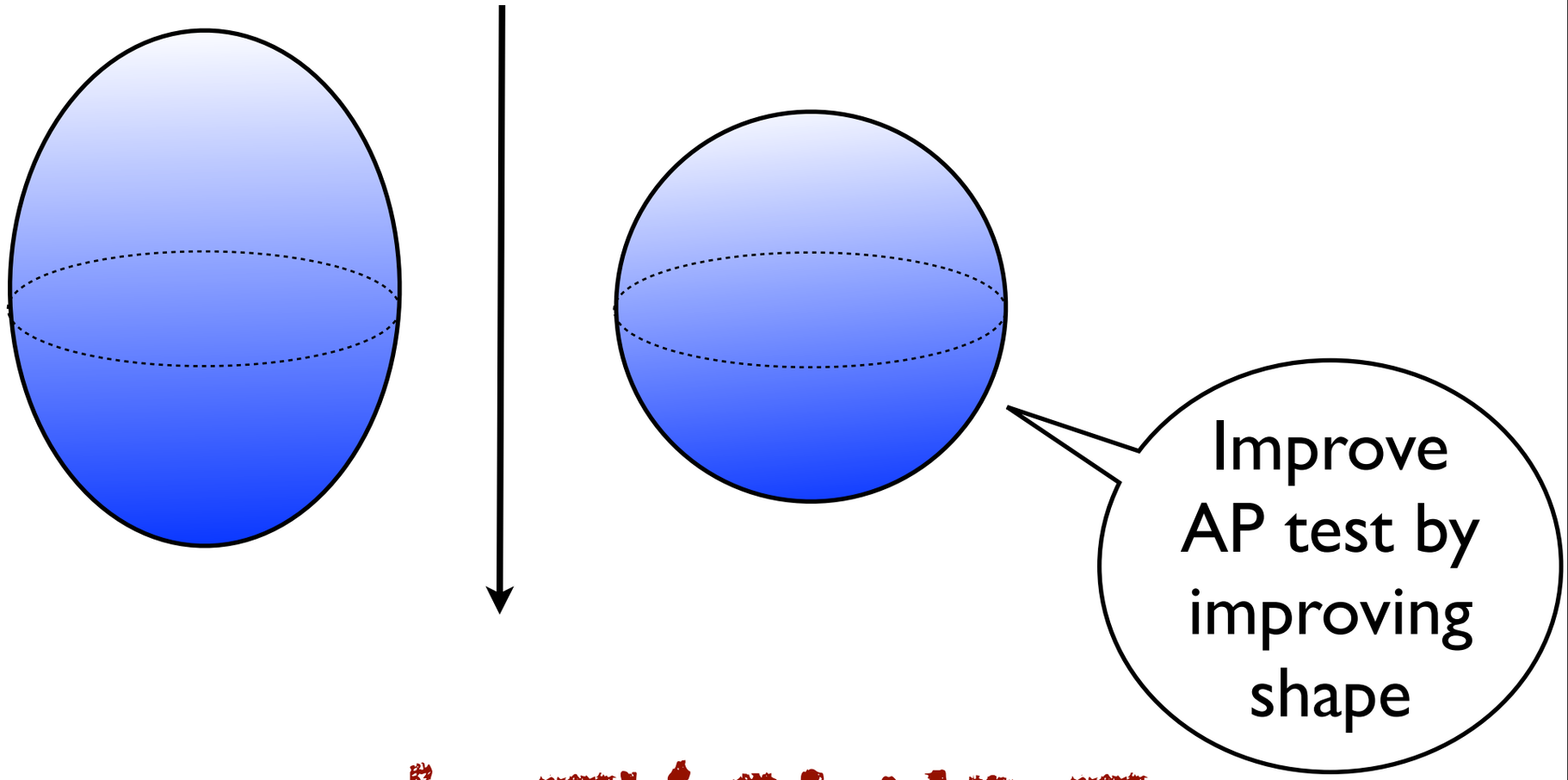
Credit: Padmanabhan et al. 2012 (ArXiv: 1202.0090)

How to determine the void spherical density profile?

Line of sight

Peculiar velocities contribute to redshift

DISTORT the void density profile.

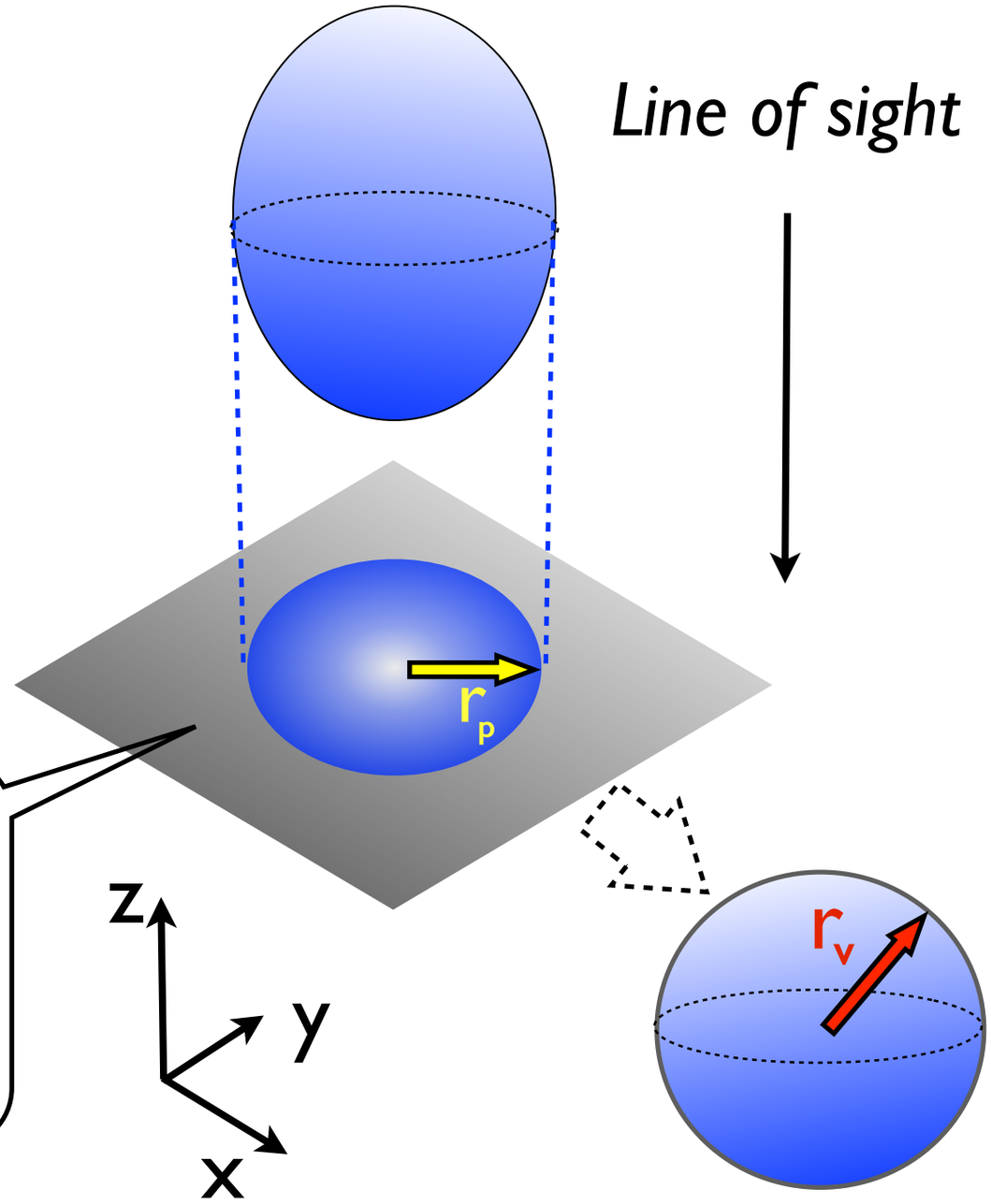


→ We must EXCLUDE distortion!

The method to get the spherical profile

Key idea

Projecting the 3D distribution along the line of sight, the contribution of peculiar velocities disappears.



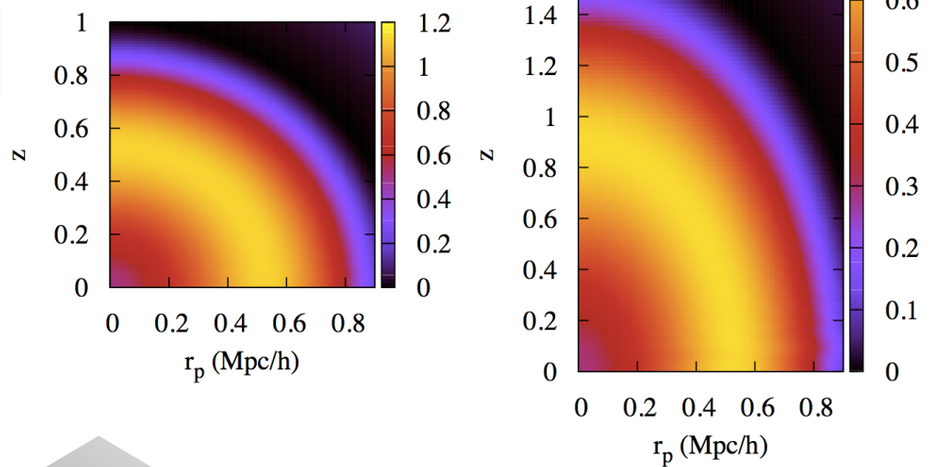
From this projection we reconstruct a 3D profile without the contribution of peculiar velocities.

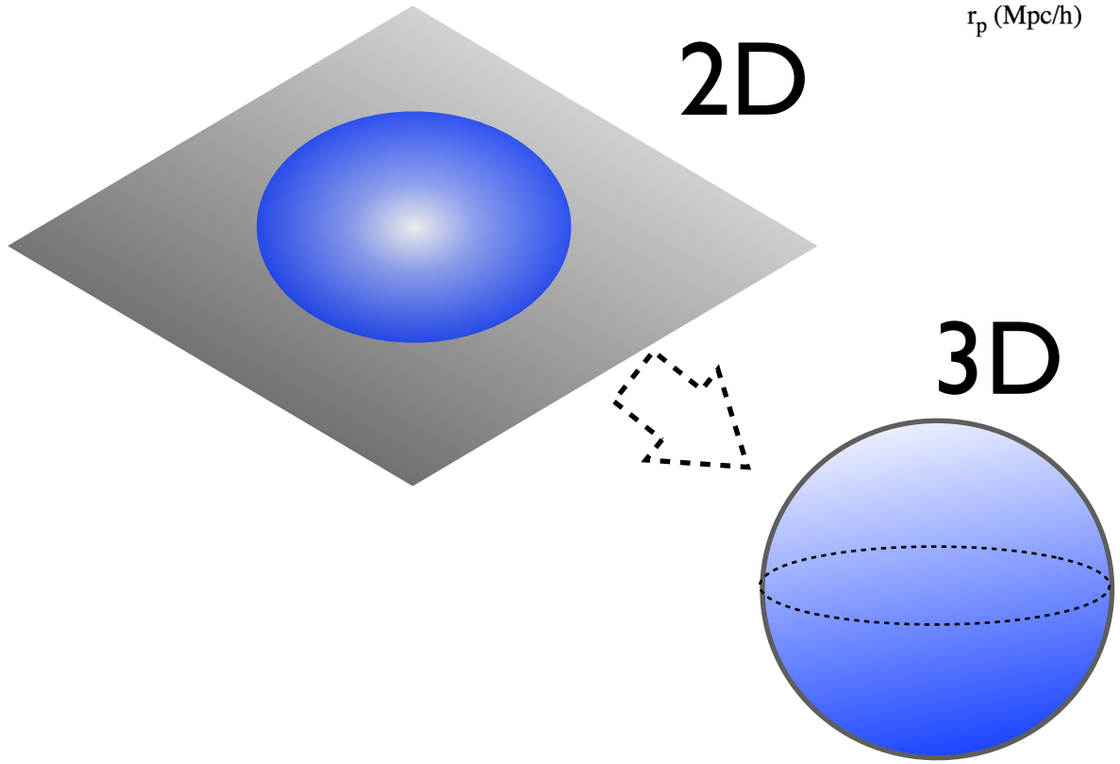
We can obtain the SPHERICAL density profile of stacked voids in real space.

Result I

The toy model

$$g(r) = -\frac{1}{\pi}\int_r^1 \frac{I'(y)}{\sqrt{y^2 - r^2}}dy$$





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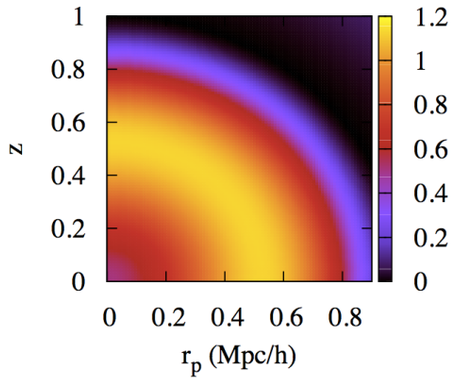
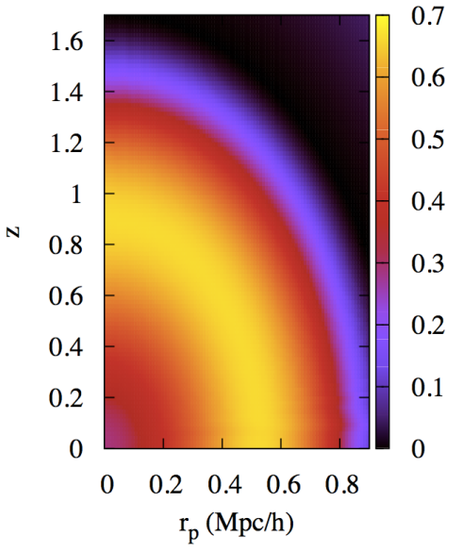
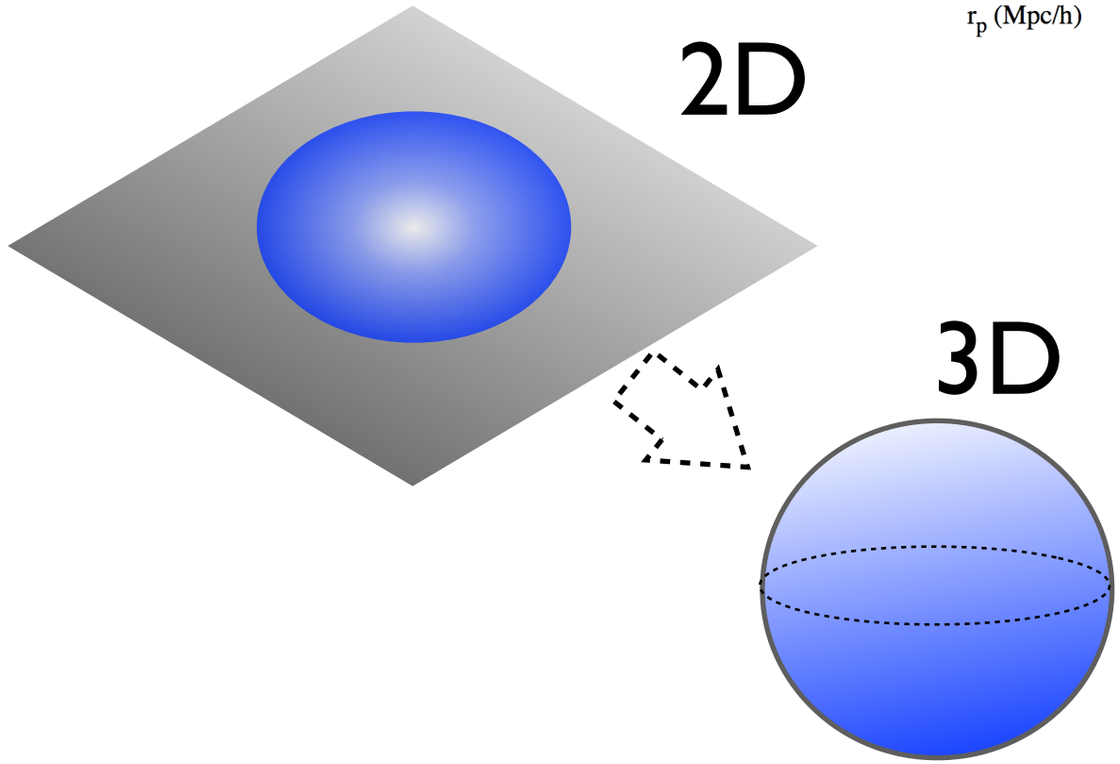




$$g(r) = -\frac{1}{\pi}\int_r^1 \frac{I'(y)}{\sqrt{y^2 - r^2}}dy$$

Abel inverse transform:
mathematically well-defined
but ill-conditioned!



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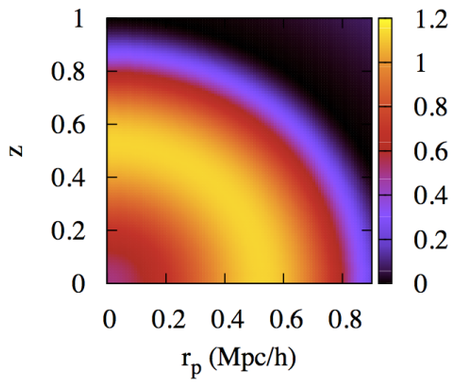

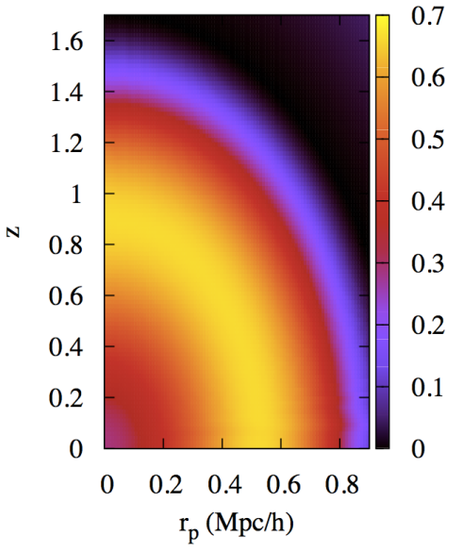

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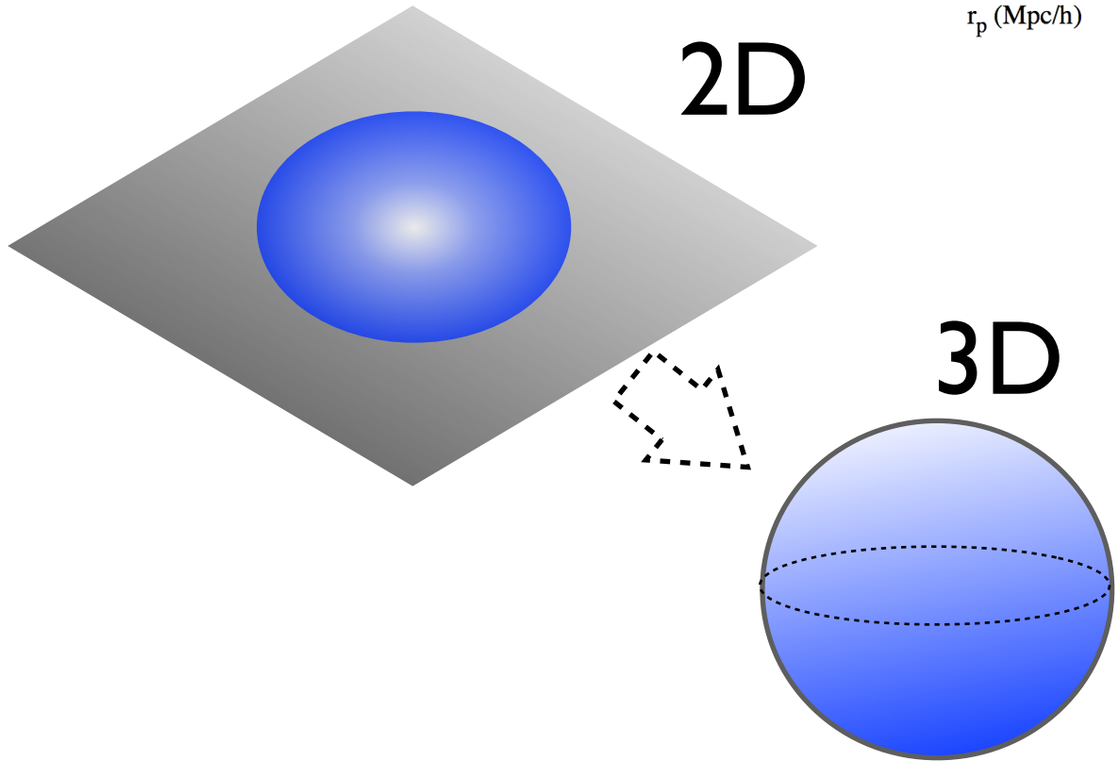

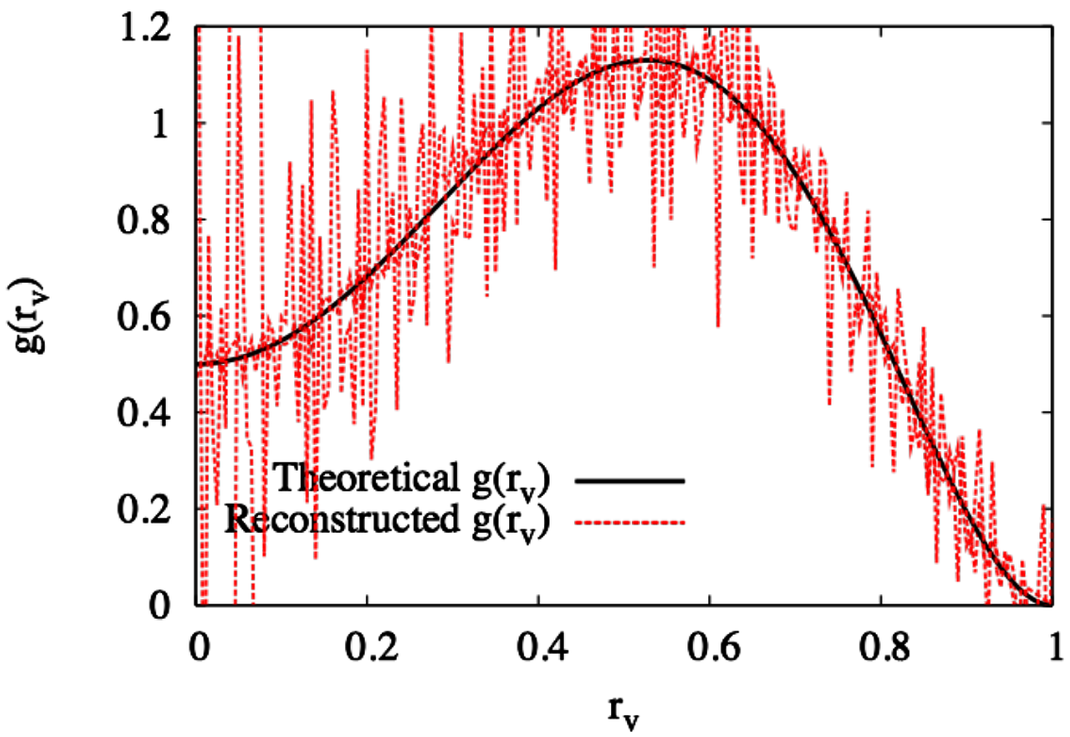

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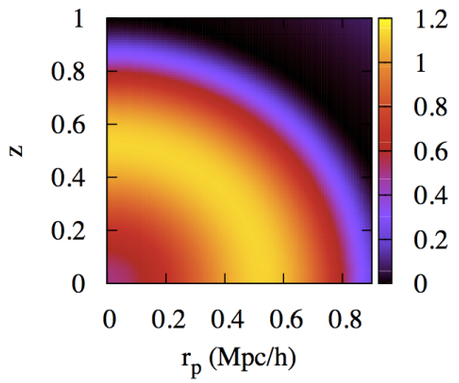

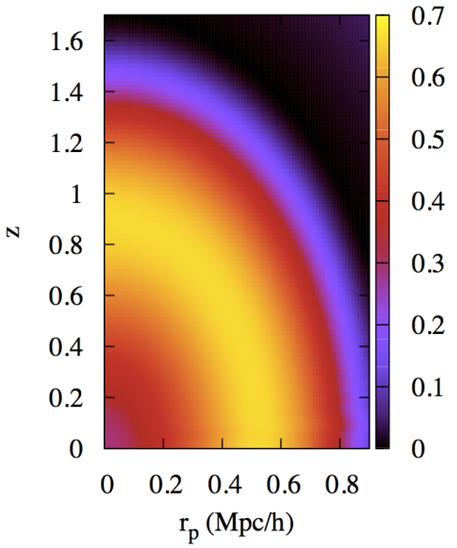

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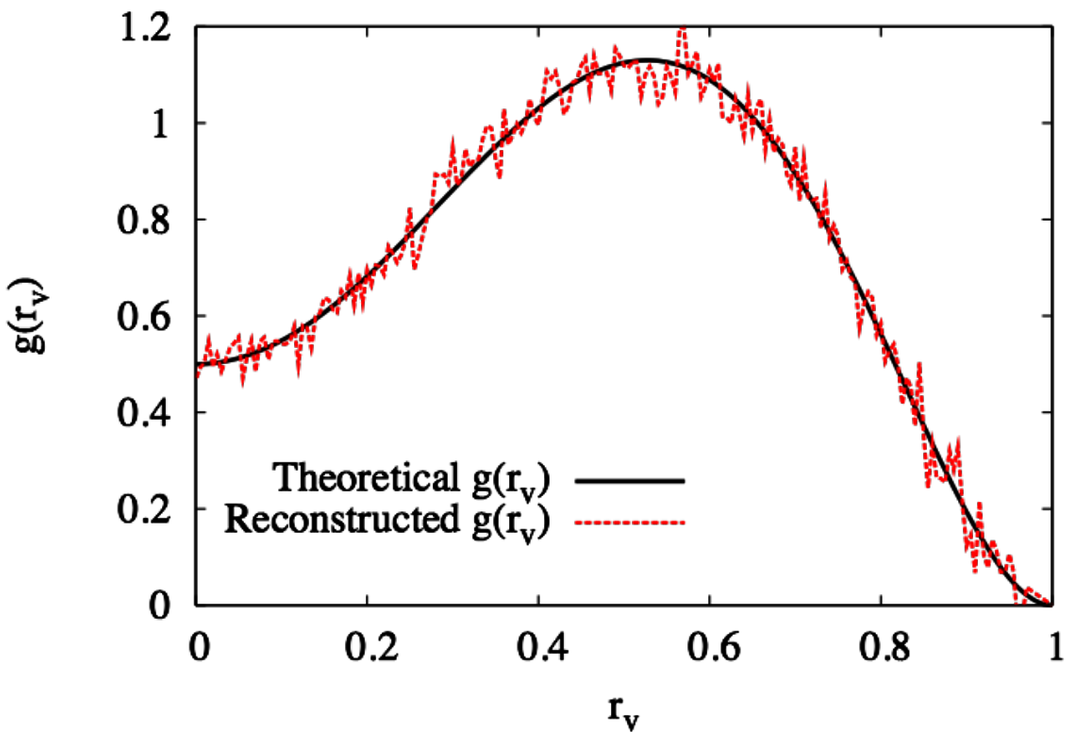
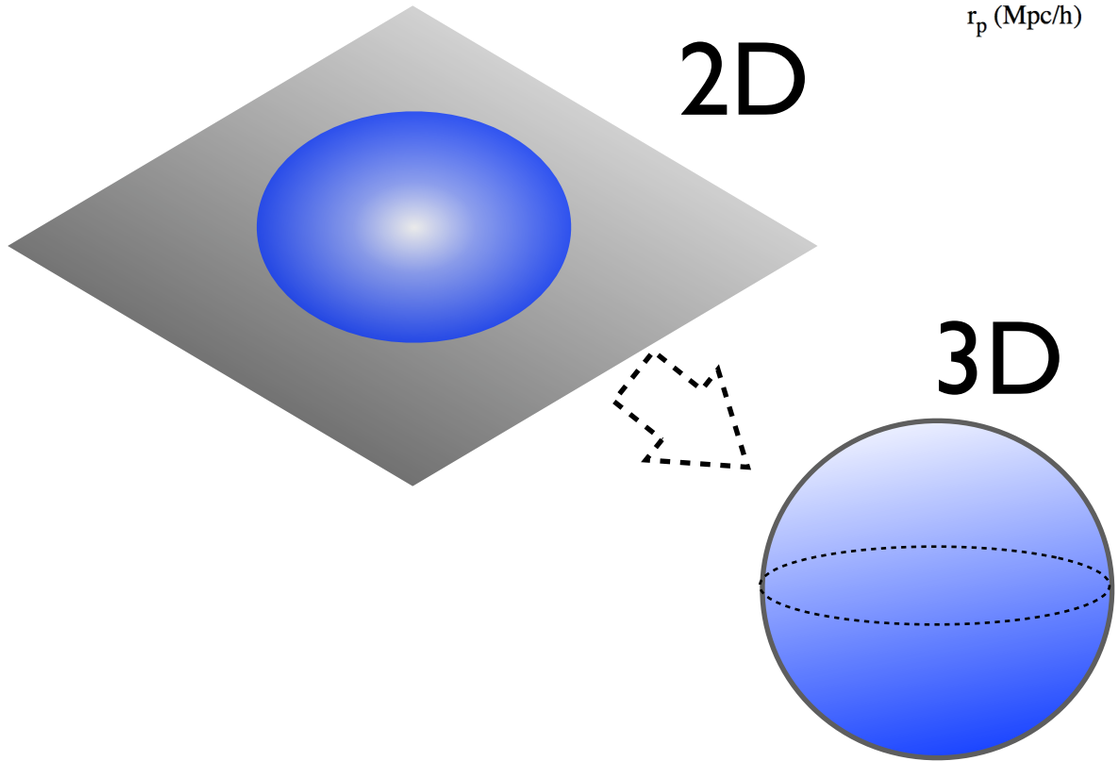
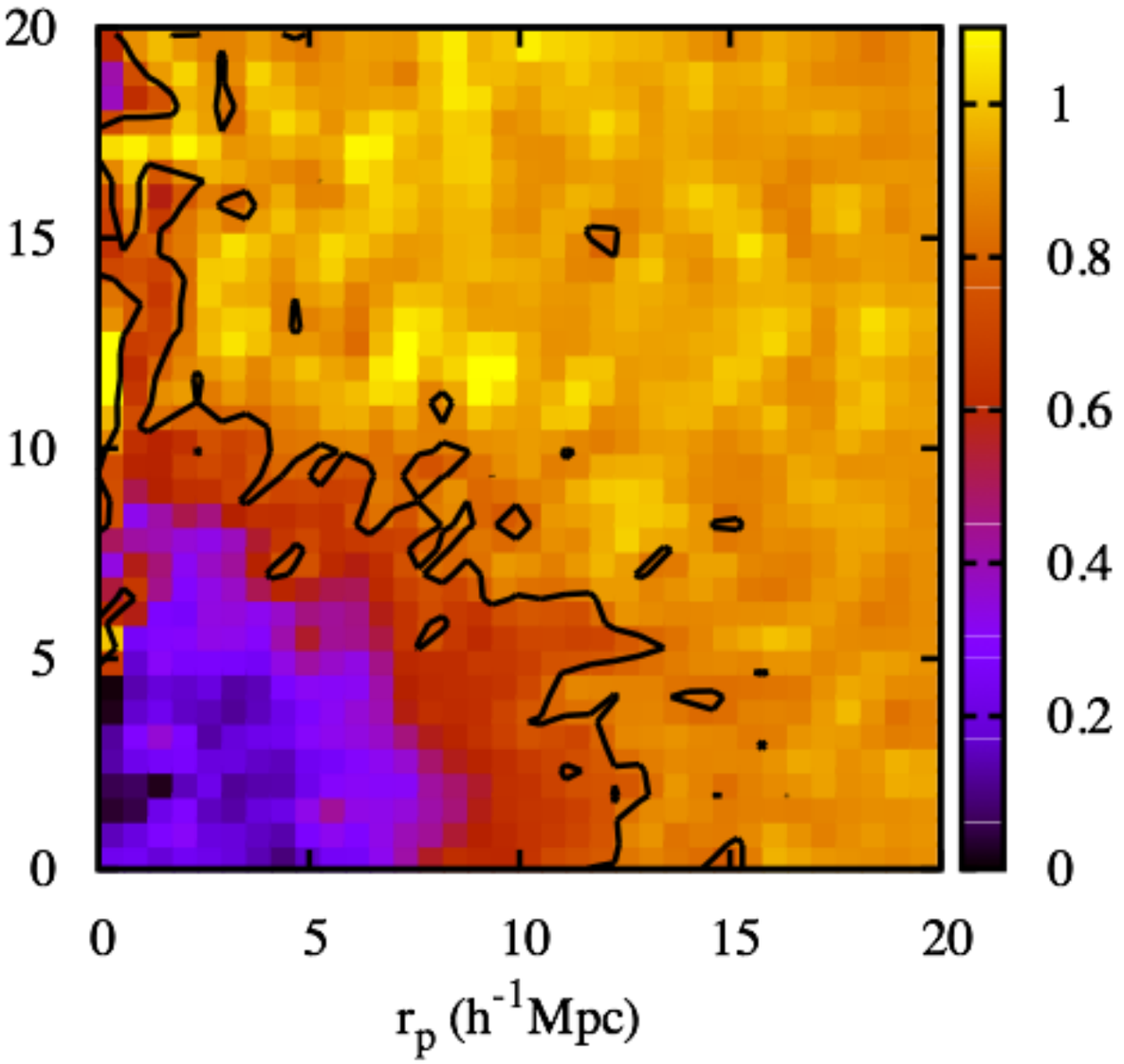


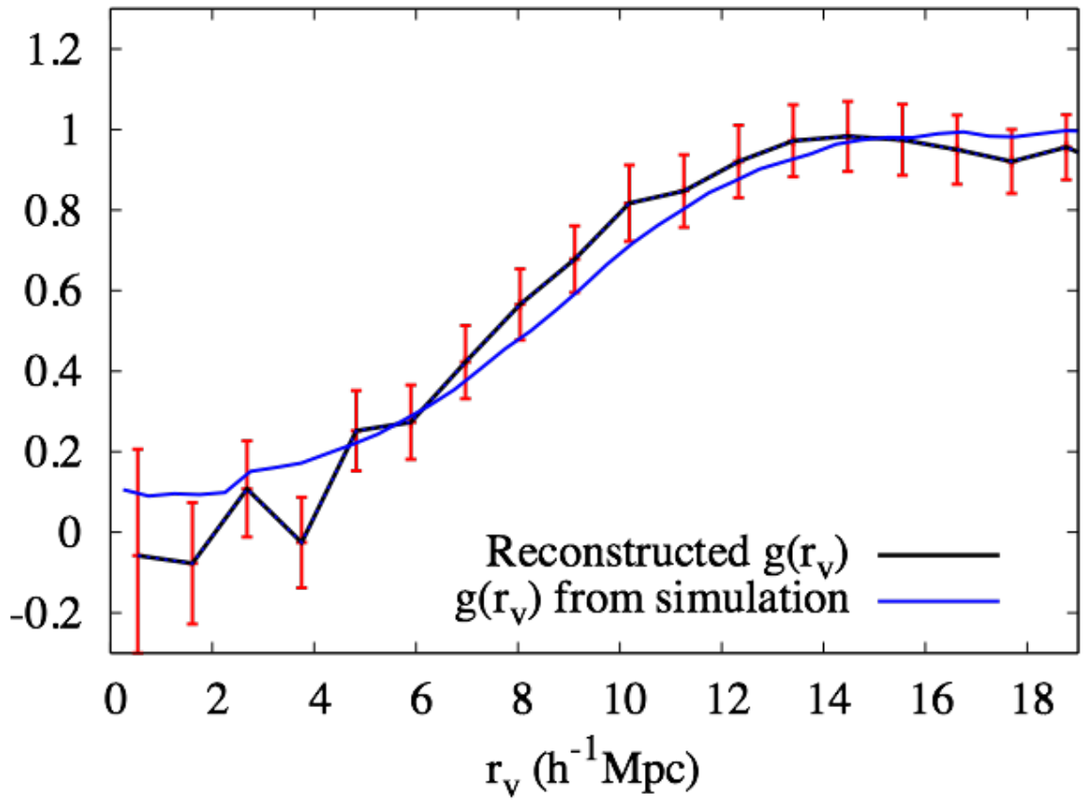


RESULT:
Very good
reconstruction!

Result II

The full simulated stacked void



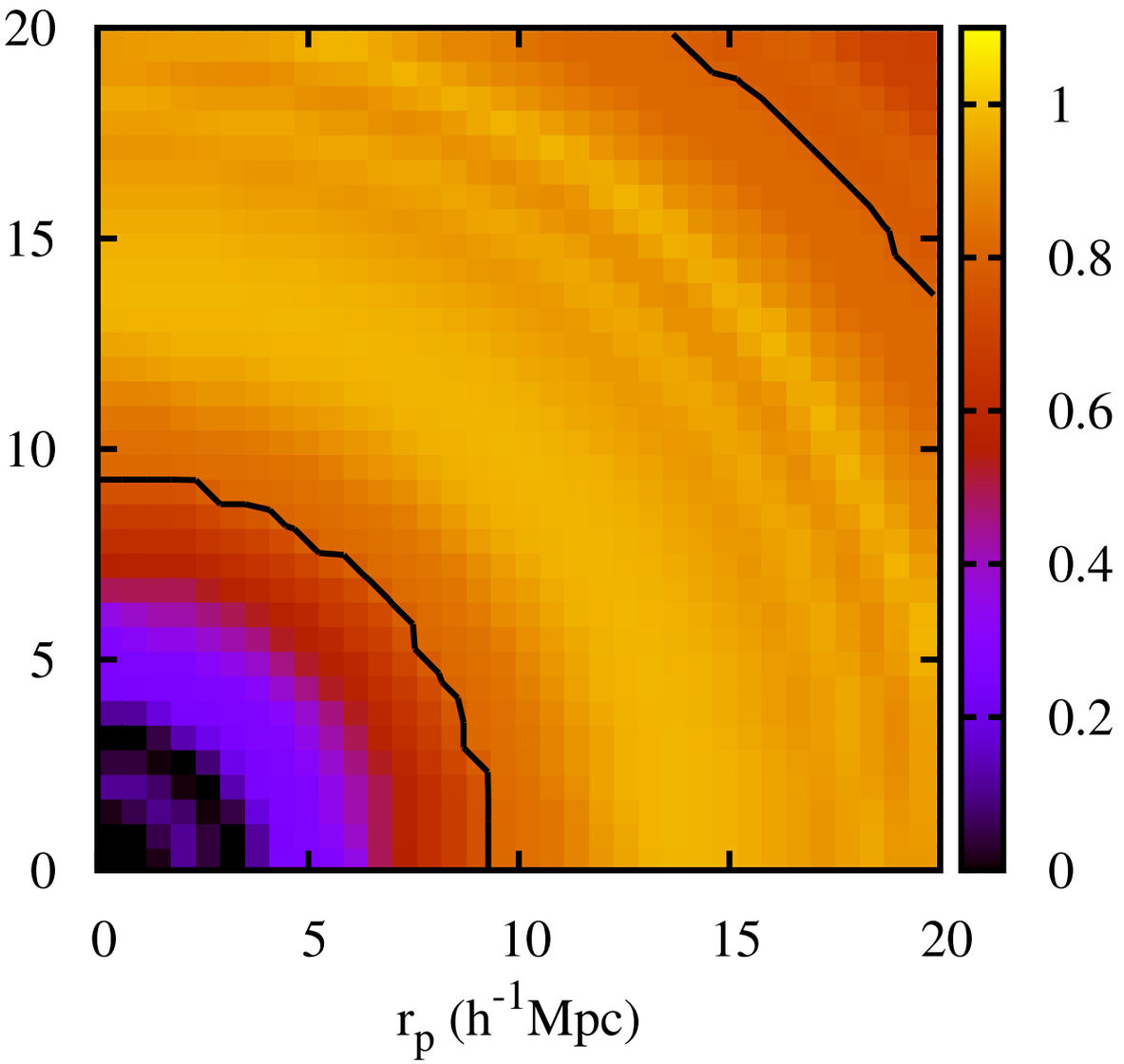


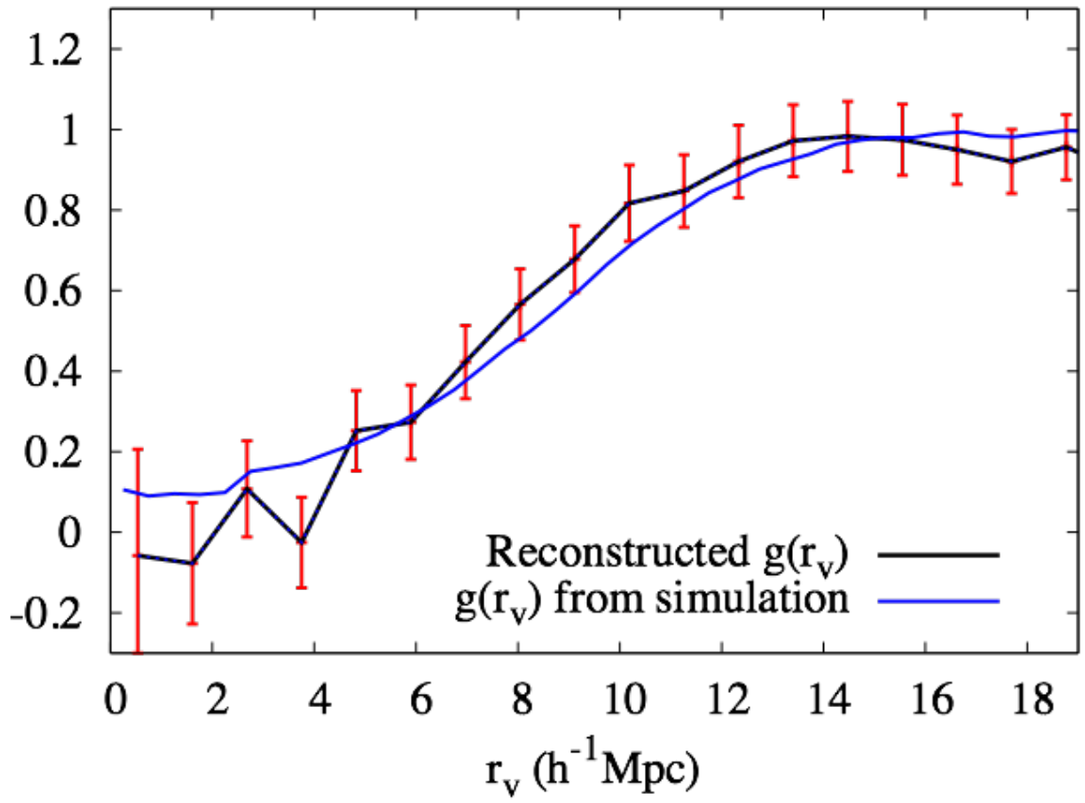
Stacking from 10 to 12 Mpc/h

Simulated void from G. Lavaux

Result II

The full simulated stacked void



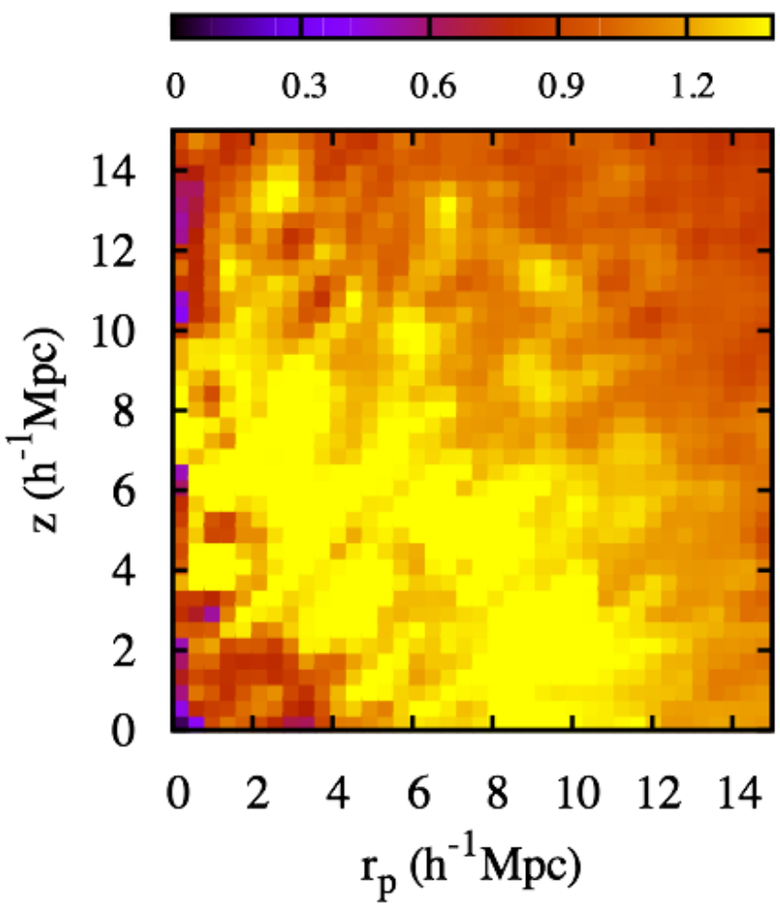


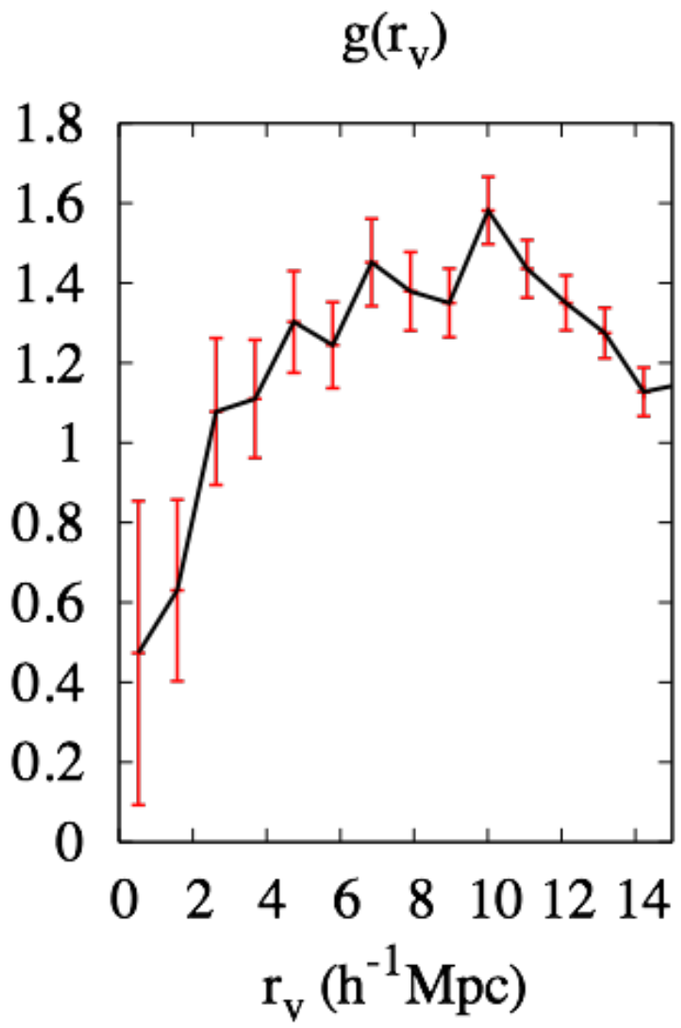
Stacking from 10 to 12 Mpc/h

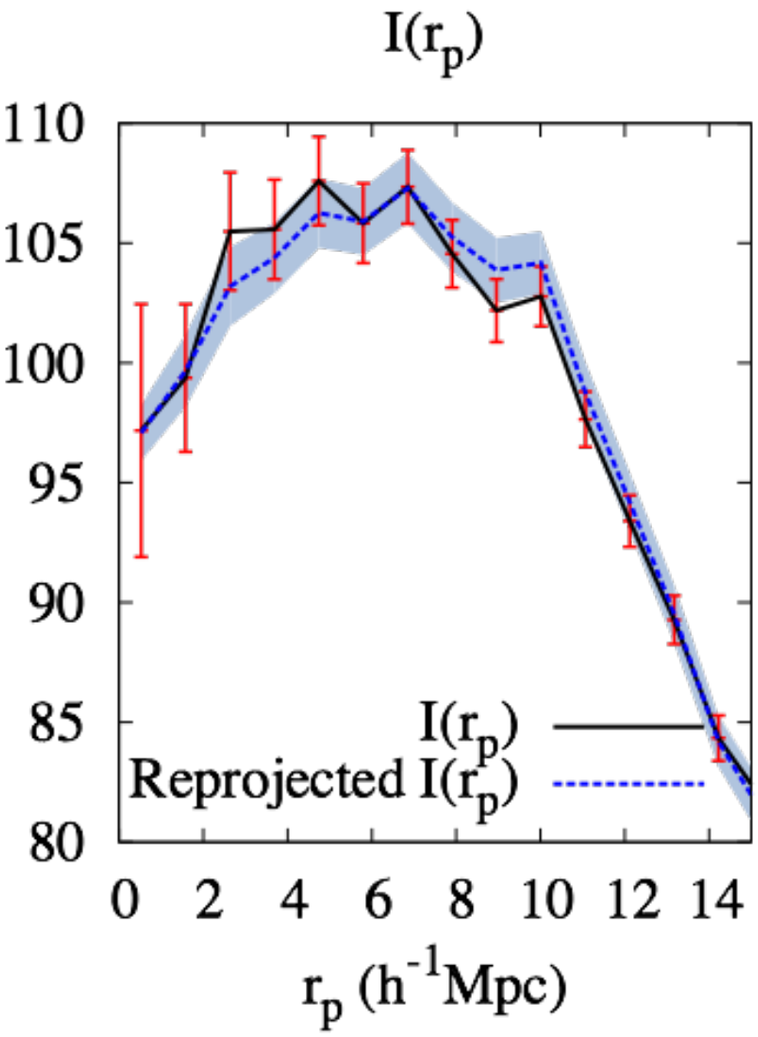
Simulated void from G. Lavaux

Result III

REAL DATA from SDSS!!!







Dim 2 (5-15 Mpc/h)

arXiv:1306.3052 (A. Pisani, G.Lavaux, P. M. Sutter, B. D.Wandelt 2013)

What can Cosmic Voids constrain?

Modified Gravity

Lambda-CDM

Fundamental Physics

If something is going to respond to neutrinos or Dark Energy it's void features!

Dark Energy

Neutrinos

Acceleration of the universe expansion

What can Cosmic Voids constrain?

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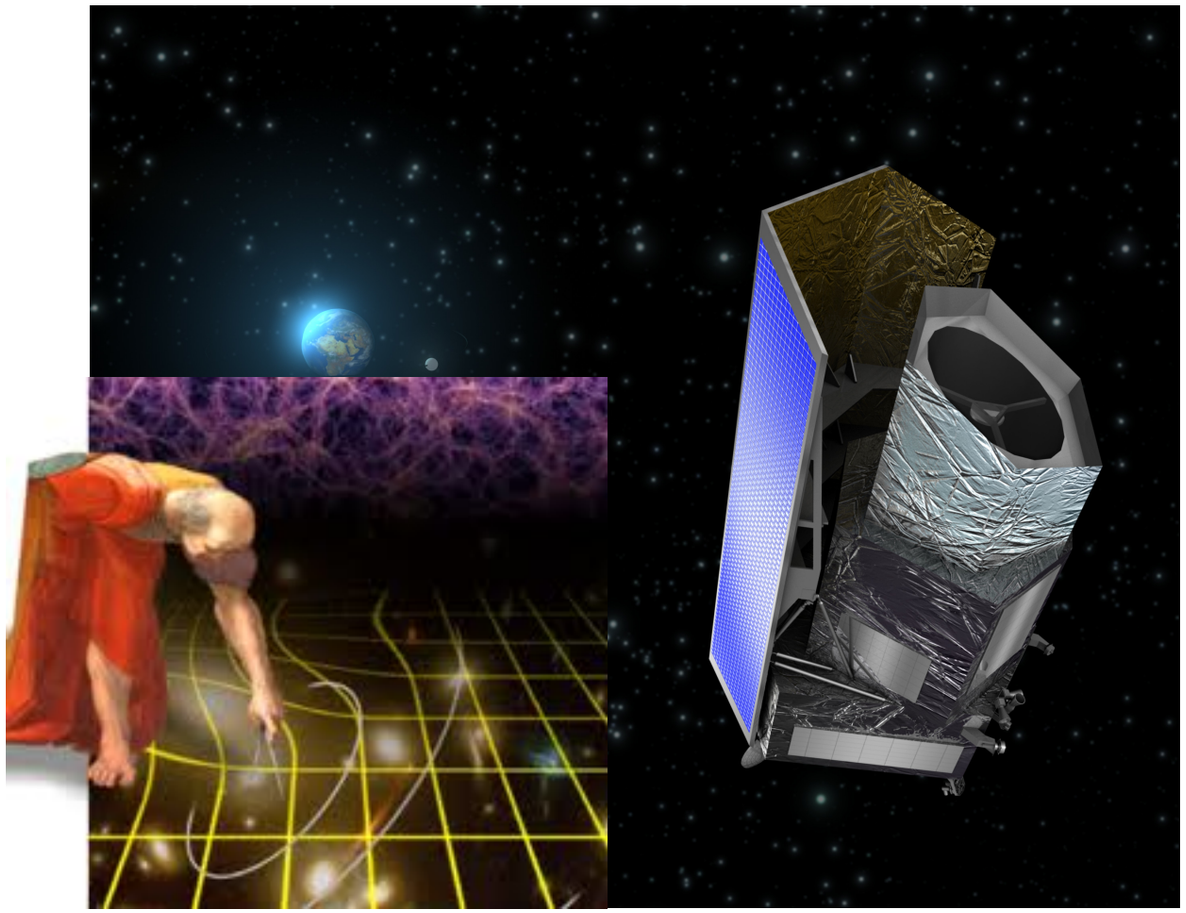
Paul M. Sutter's talk

Back to the future: upcoming surveys & telescopes

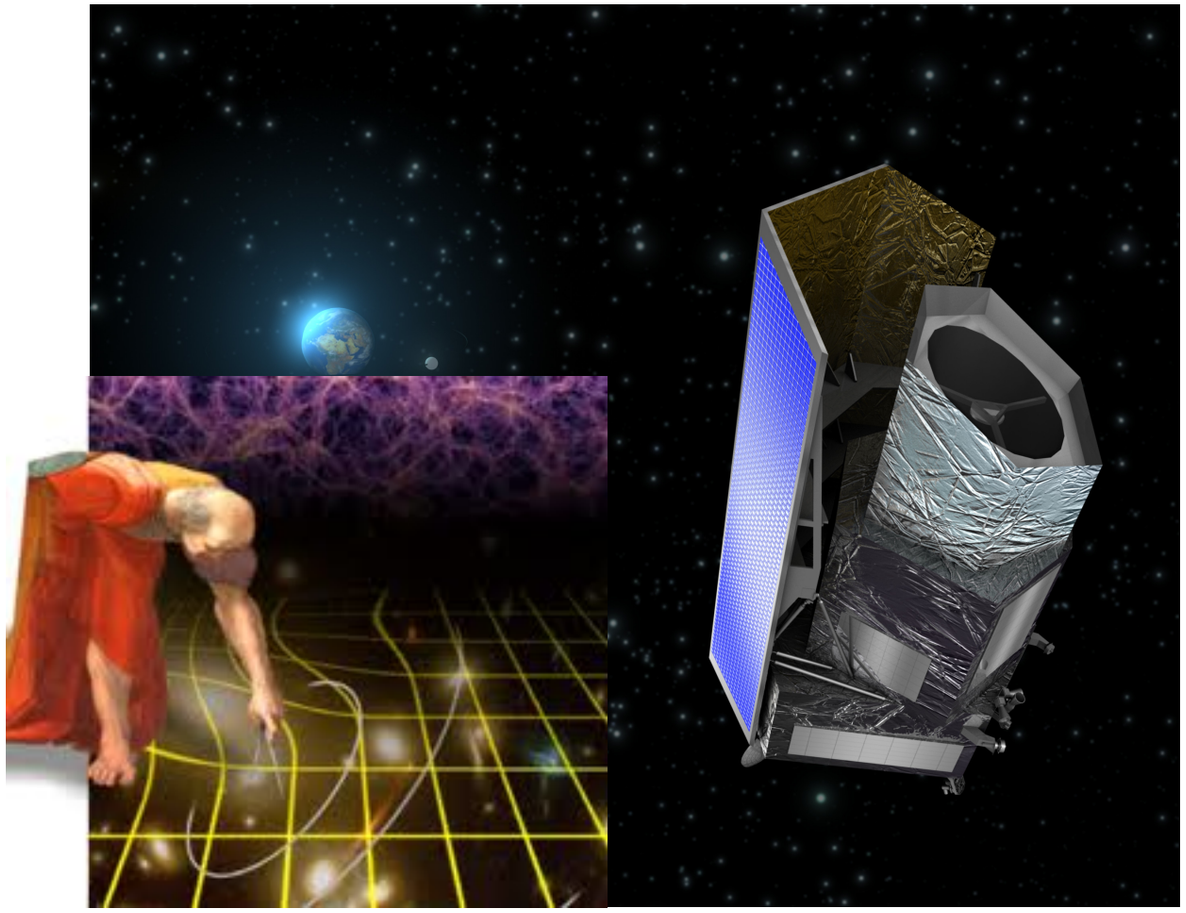
Back to the future: upcoming surveys & telescopes



EUCLID

$5.0 \cdot 10^7$ galaxies $z \simeq 1.5$

Back to the future: upcoming surveys & telescopes



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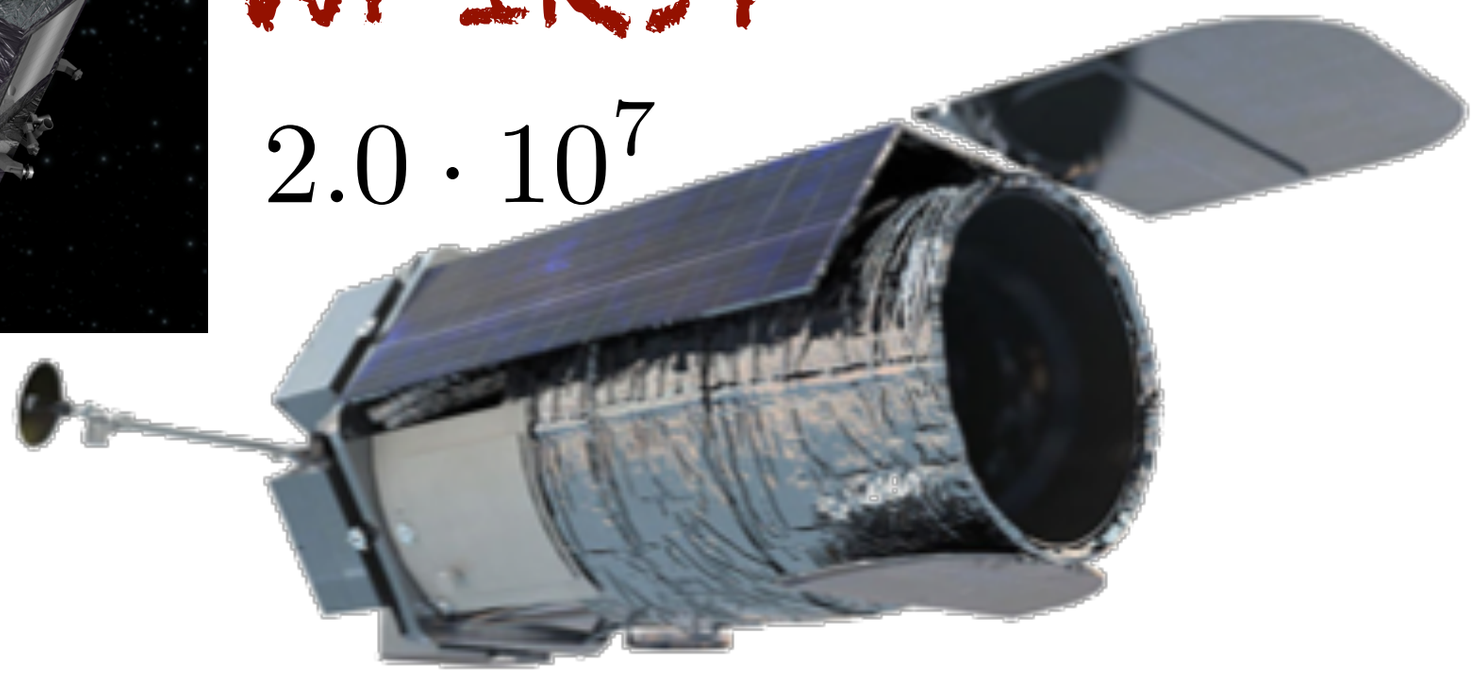
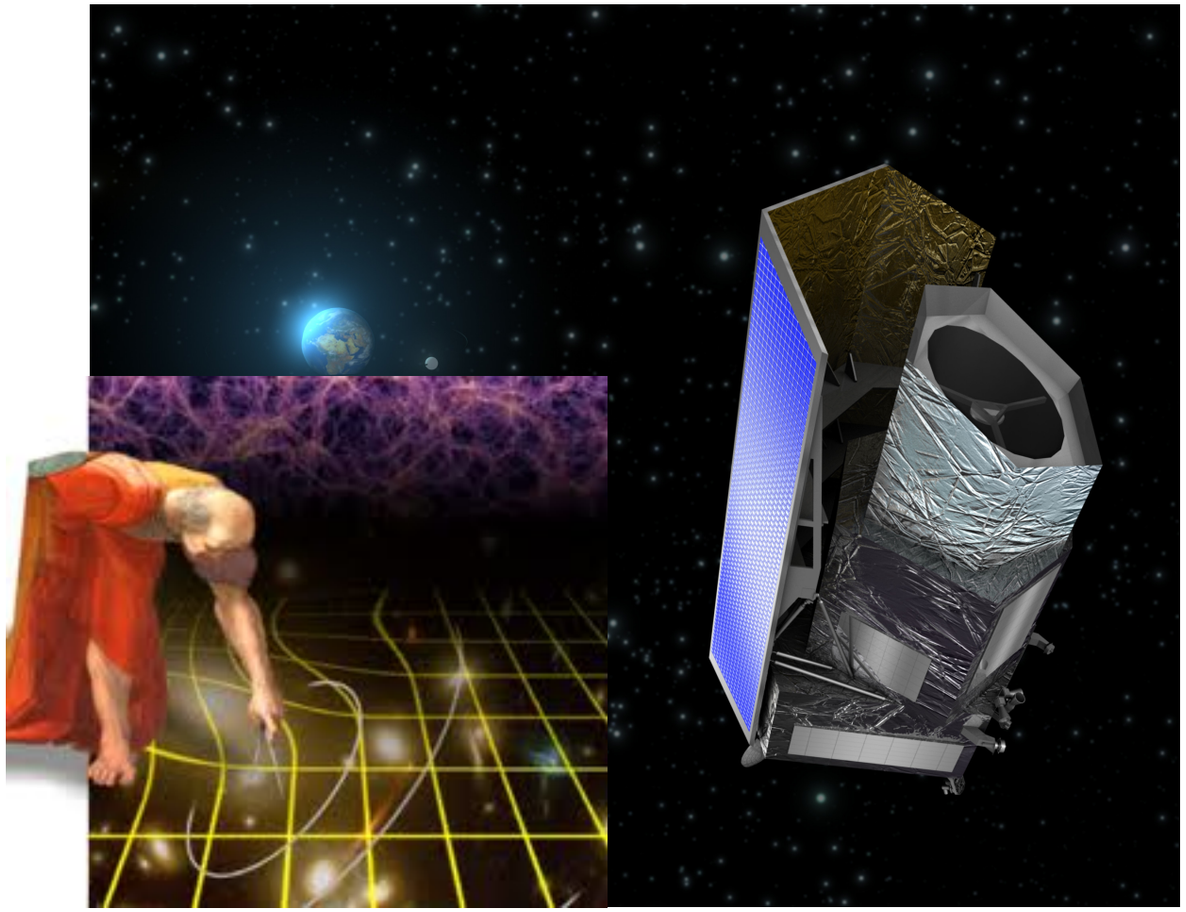
WFIRST

$2.0 \cdot 10^7$



Back to the future: upcoming surveys & telescopes

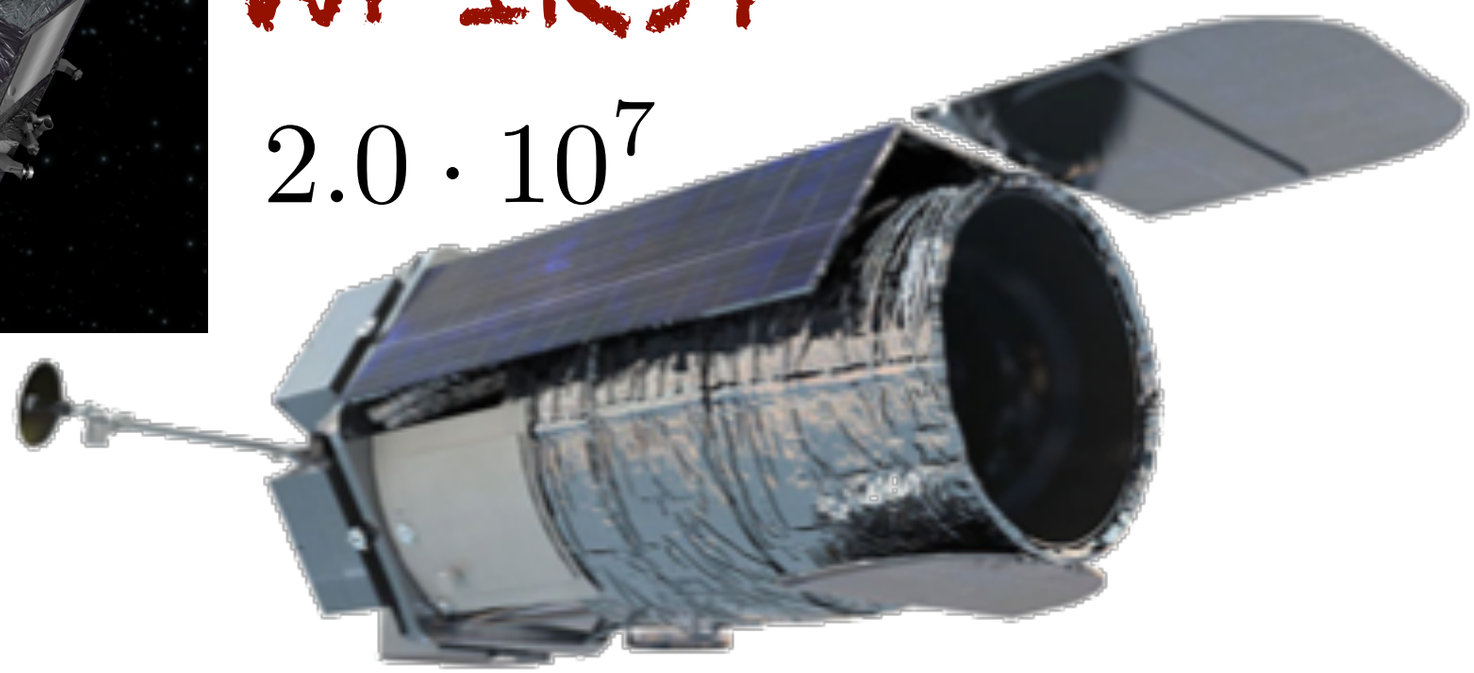


EUCLID

$5.0 \cdot 10^7$ galaxies $z \simeq 1.5$

WFIRST

$2.0 \cdot 10^7$



SDSS DR7 $1.5 \cdot 10^6$

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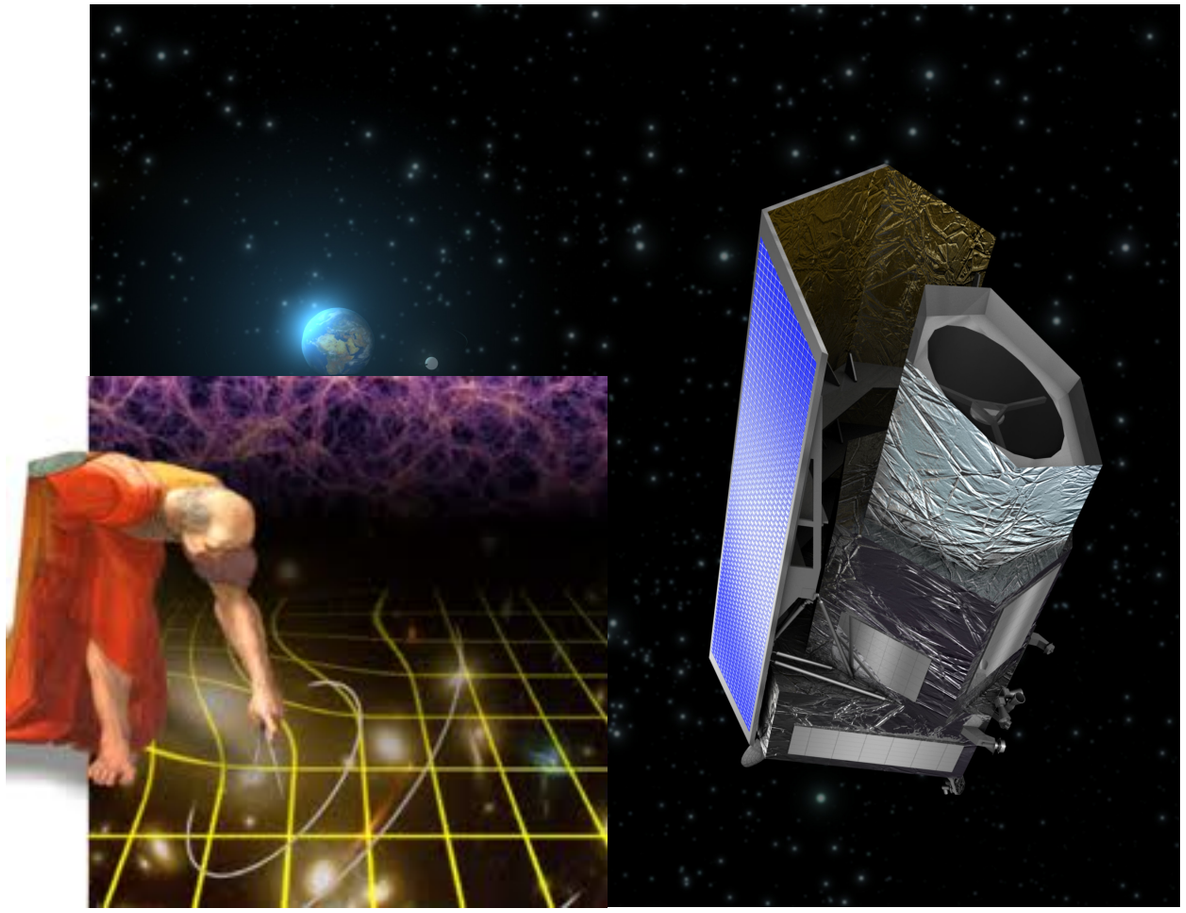

EUCLID

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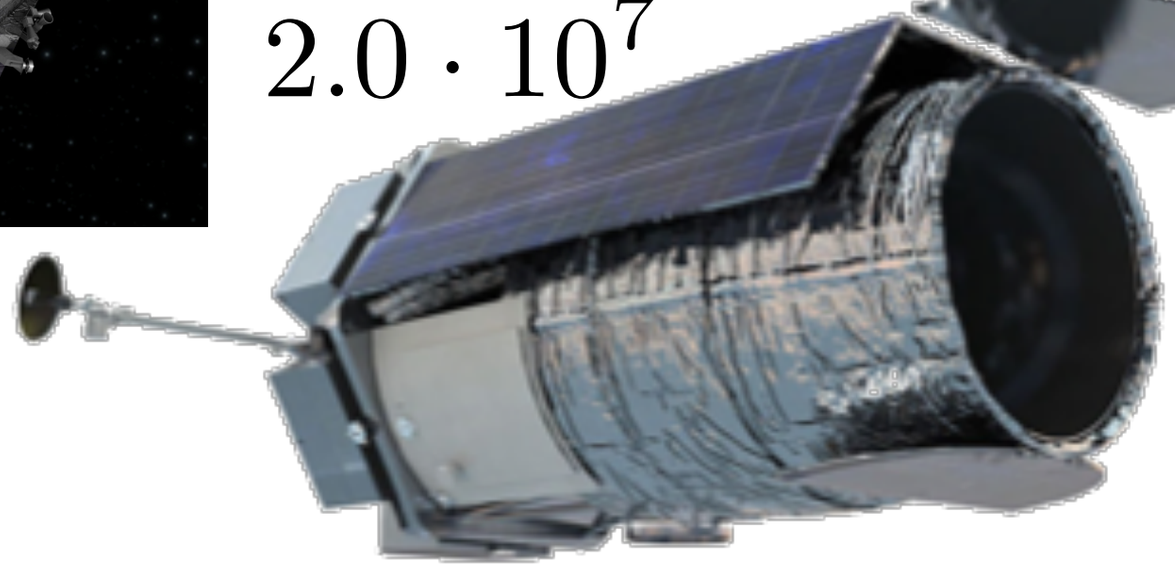
WFIRST

David Spergel's talk

$2.0 \cdot 10^7$



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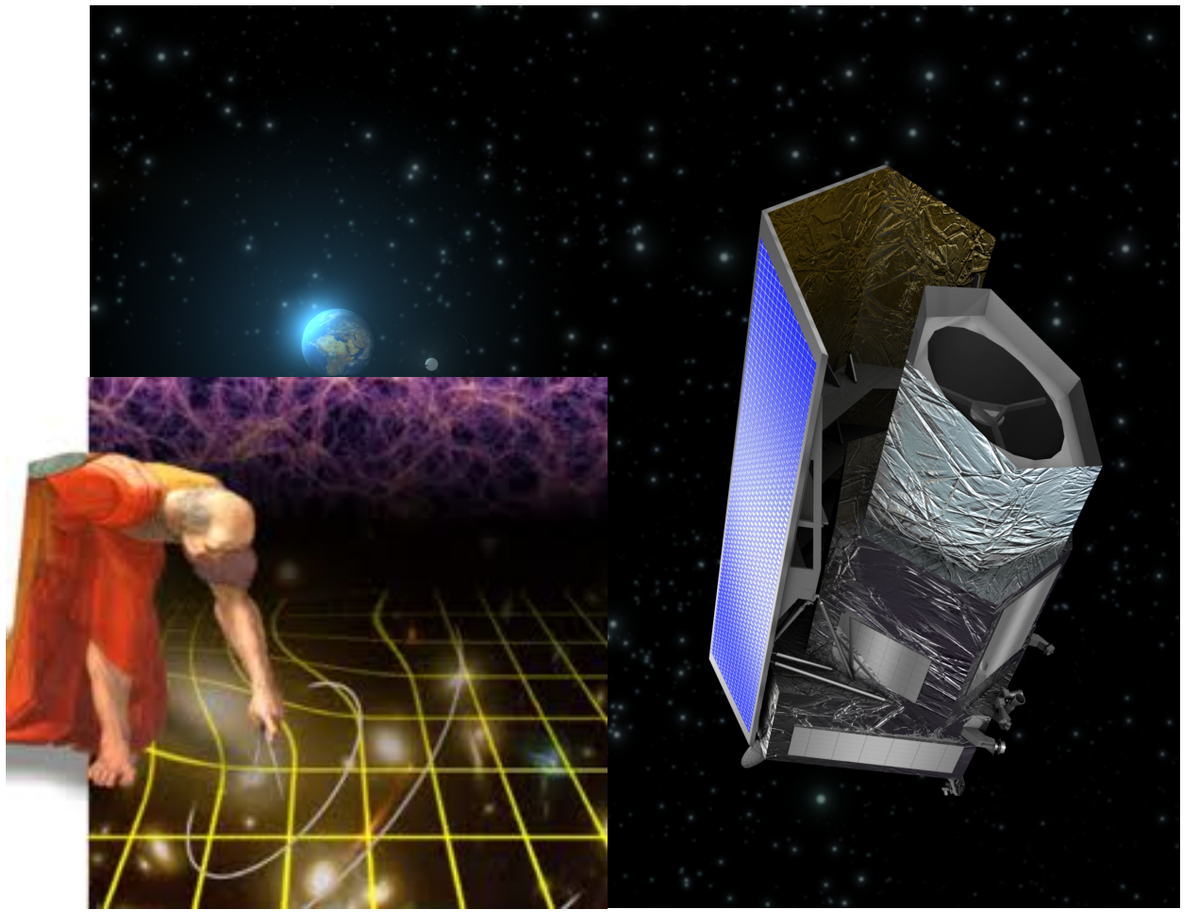
Back to the future: upcoming surveys & telescopes



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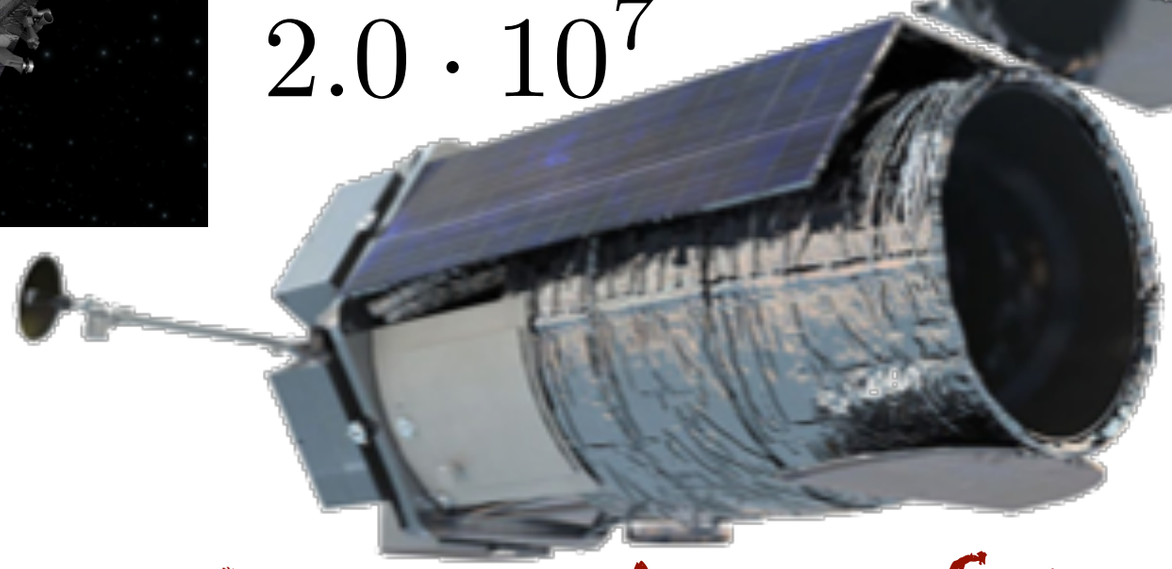


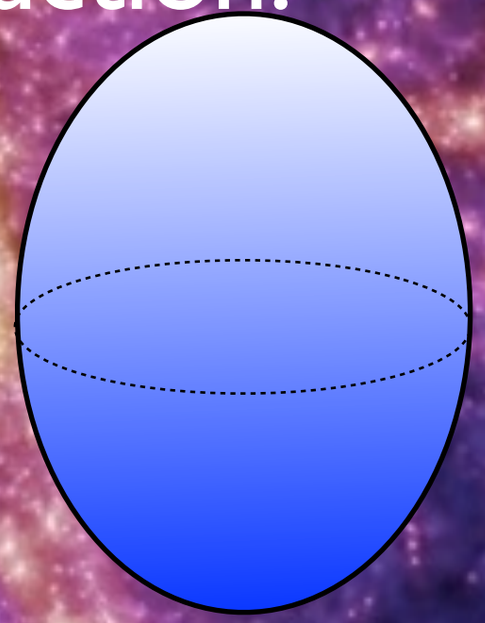
SDSS DR7 $1.5 \cdot 10^6$

Real-space density void profiles of increased precision!

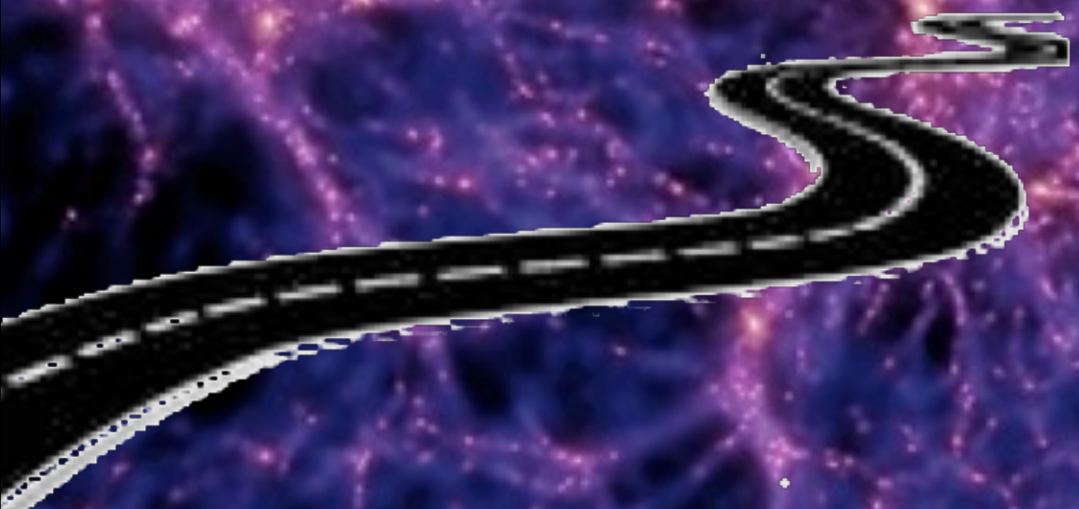
Conclusion

- Algorithm for density profile reconstruction.

➡ Tested on toy model, simulations.
➡ Successfully applied on real voids, first density profiles in real space!



- Knowledge about voids: the way to measure the Hubble constant and test cosmological models.



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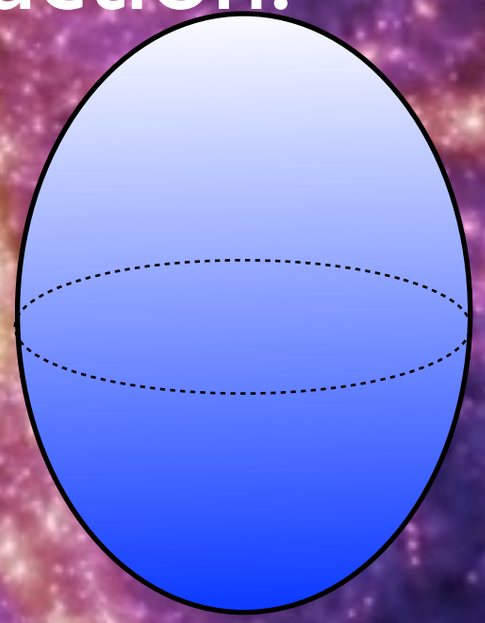

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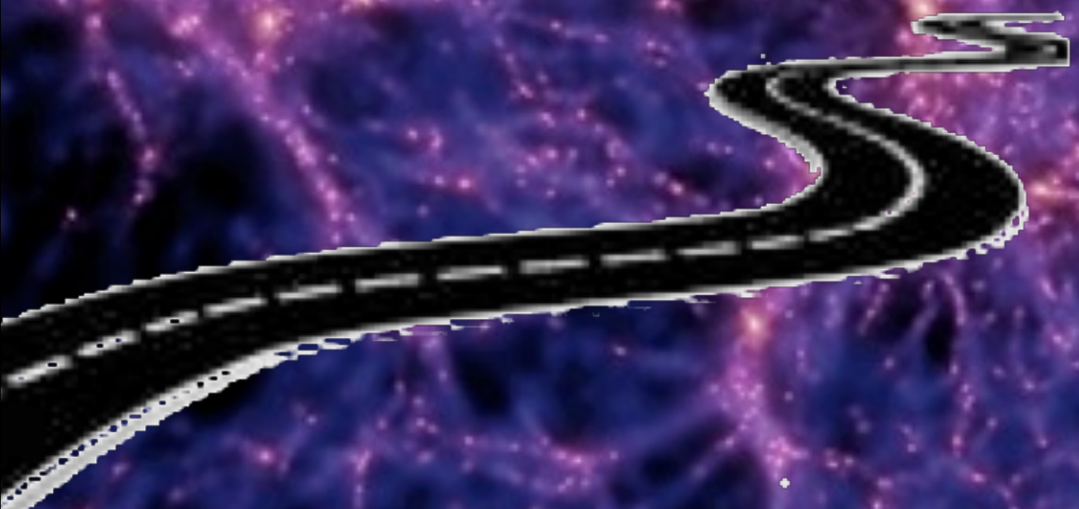
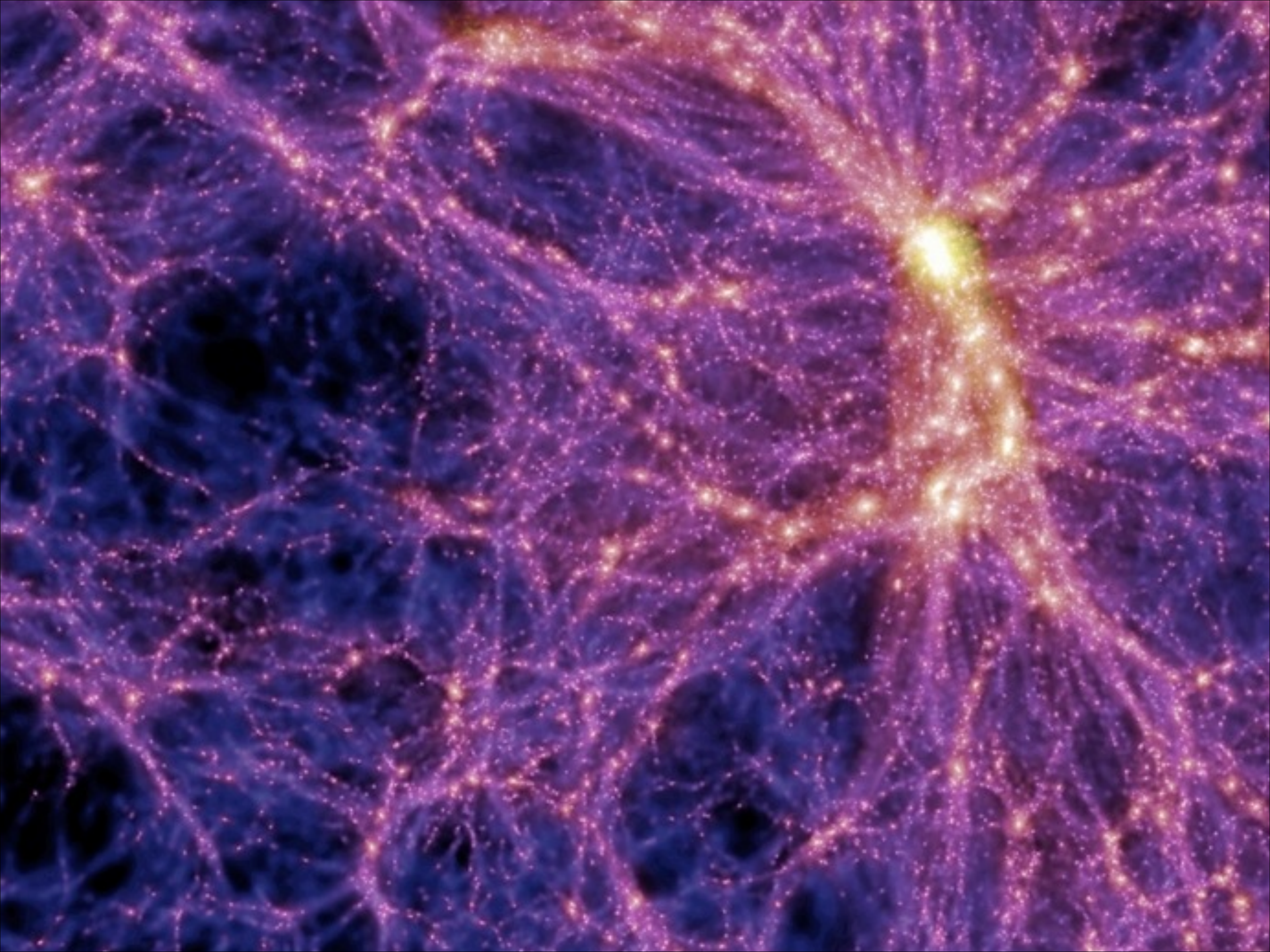
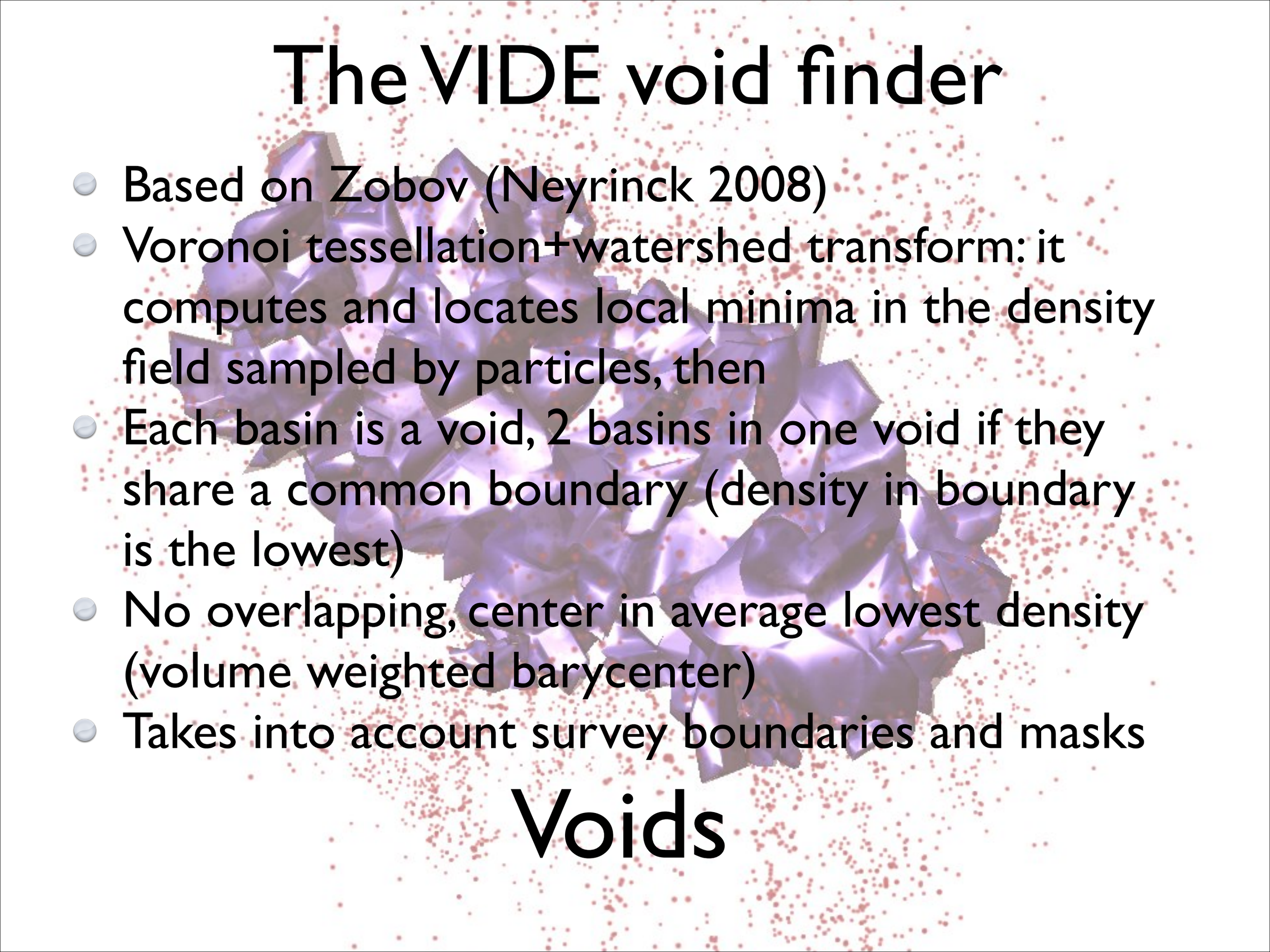




The VIDE void finder

- Based on Zobov (Neyrinck 2008)
- Voronoi tessellation+watershed transform: it computes and locates local minima in the density field sampled by particles, then
- Each basin is a void, 2 basins in one void if they share a common boundary (density in boundary is the lowest)
- No overlapping, center in average lowest density (volume weighted barycenter)
- Takes into account survey boundaries and masks



Voids

Alcock-Paczyńnski test

The deviations from fiducial cosmology cause geometrical distortions.

$\delta r_\perp = D_A(z)\delta\Theta$ comoving line of sight distance

$\delta r_\parallel = cH^{-1}(z)\delta z$ projected angular extent

where

$$D_A = c\int_0^z H^{-1}(z')dz' \qquad H(z) = H_0\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}$$