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# CosmicFlows for exploring gravitation on large scales

H. Courtois and collaborators

*The idea is : on large scales the motions of galaxies are exclusively due to expansion and gravitation.*

*The methodology :*

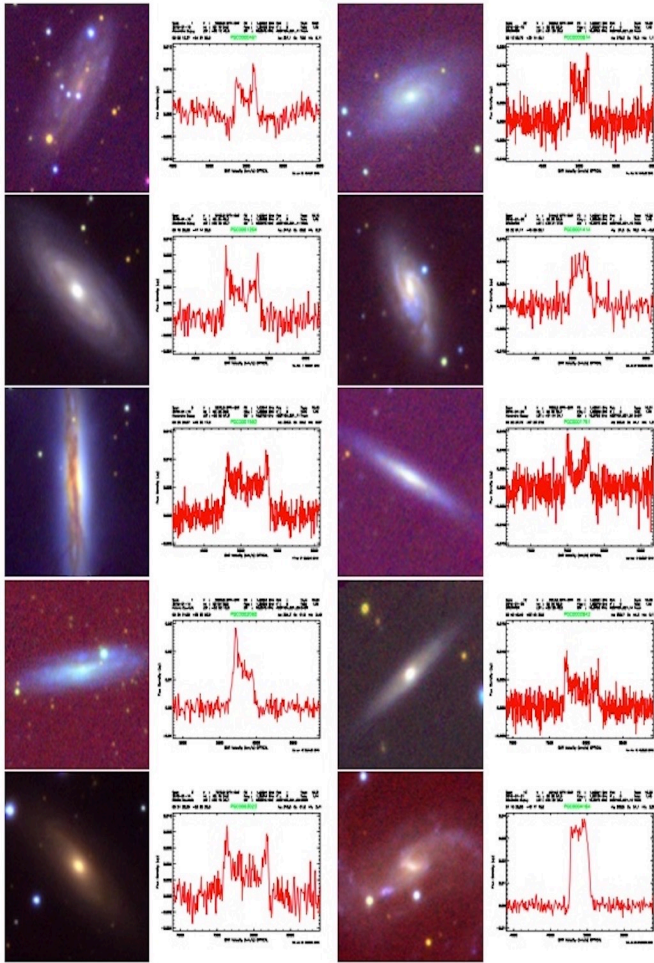
- *we can observe only the radial part of these motions,*
- *we can observe them in different environments : empty, medium, dense,*
- *we can observe them at different epochs.*

Obtaining datasets



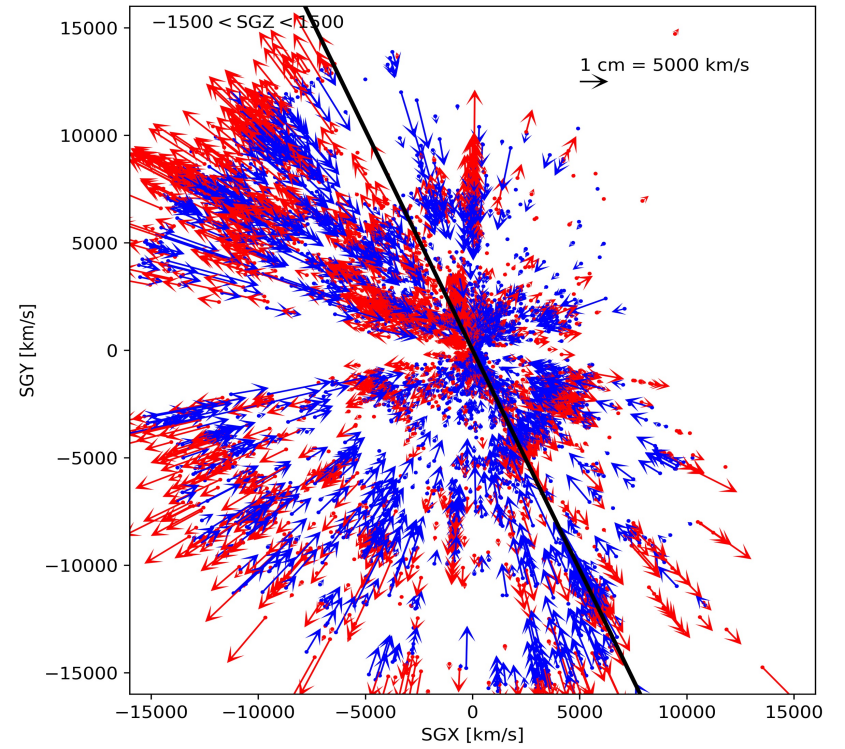


# Observed distance moduli to estimated radial peculiar velocities in distorted redshift space



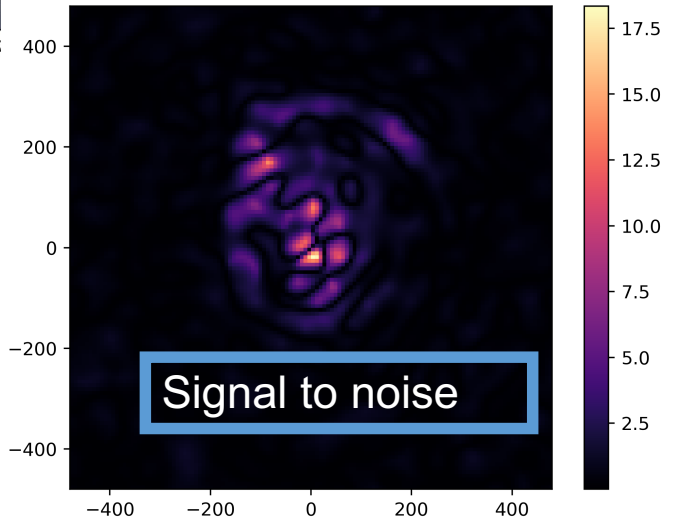
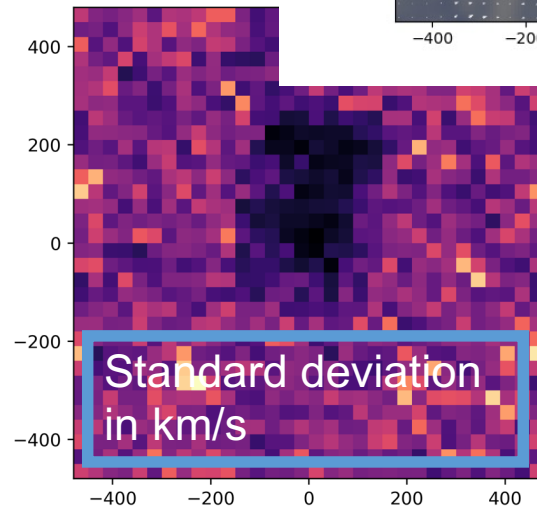
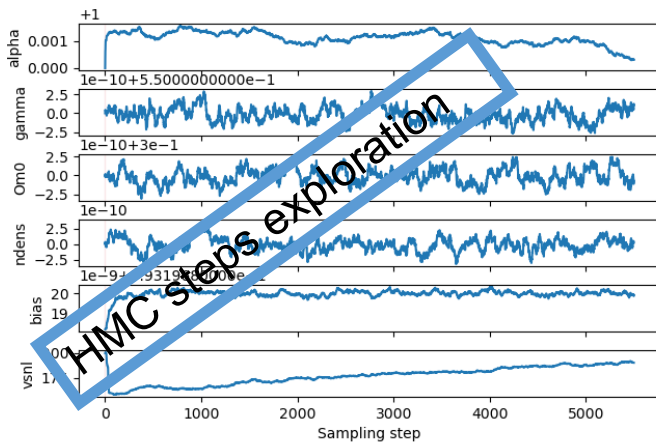
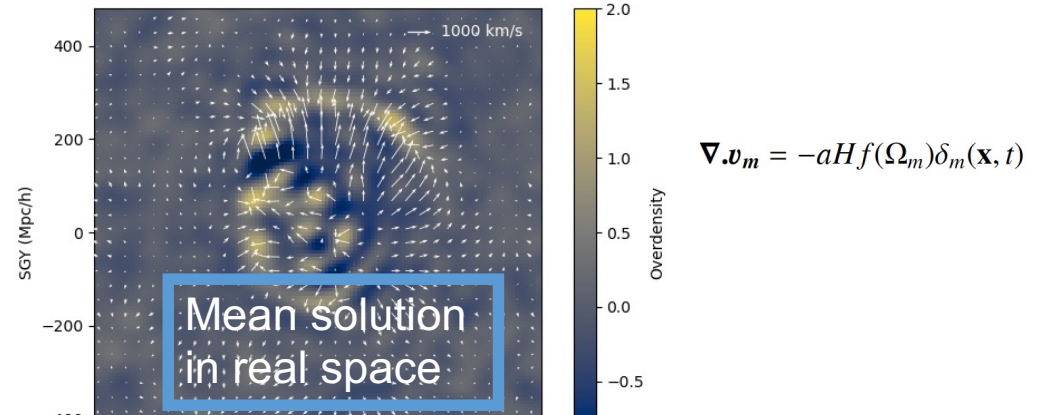
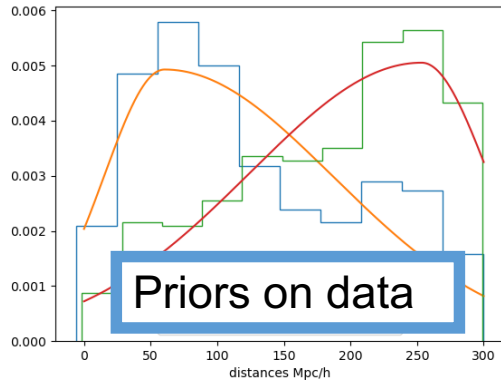
$$v^r \sim cz - H_0 d_I$$

→





# ΛCDM Hamiltonian Monte Carlo forward modeling of the observational dataset to compute a 3 dimensional reconstruction of the gravitational velocity field



# A study of the matter content of nearby voids

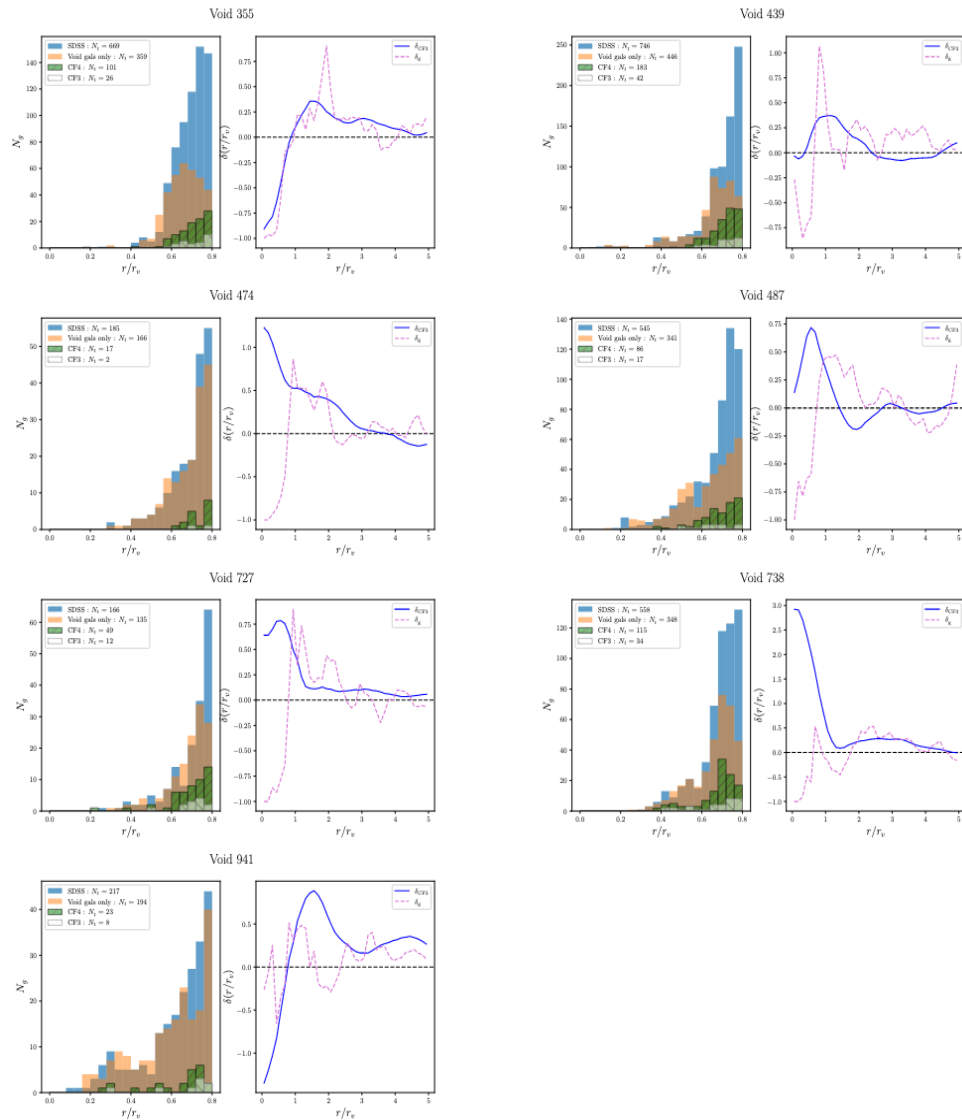
H. Courtois et al. submitted

*the question we try to answer is : how empty are voids identified with a classic void finder ?*

*To answer this we compare two different probes for their matter content :*

- galaxy redshift 2point correlations,*
- observed dynamical environment.*

# Comparison of Density profiles from galaxy counts and from CosmicFlows LCDM reconstruction

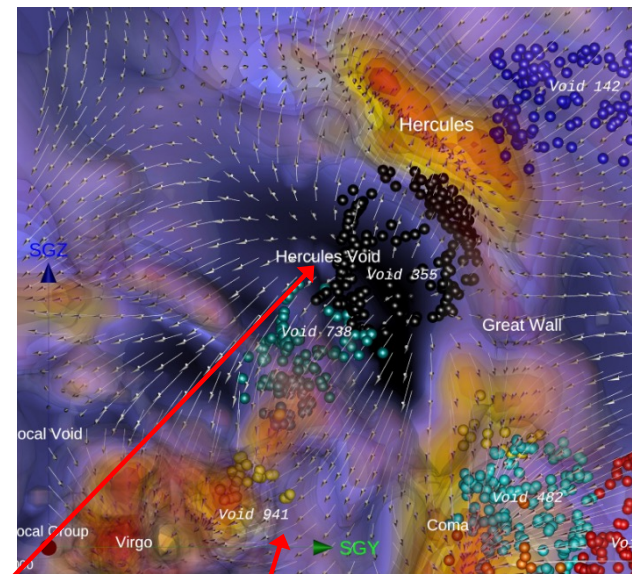


Computation – Equations – Discuss Linear / Non Linear

$$\delta_g(r) := \xi(r) = \frac{D_v D_g(r)}{D_v R_g(r)} - 1 \quad \nabla \cdot \mathbf{v}_m = -aHf(\Omega_m)\delta_m(\mathbf{x}, t)$$

Results :

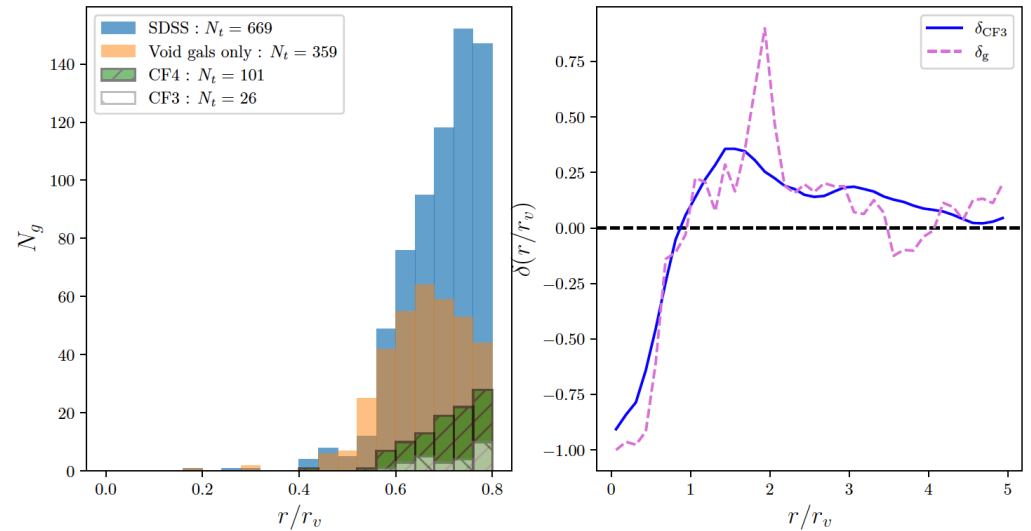
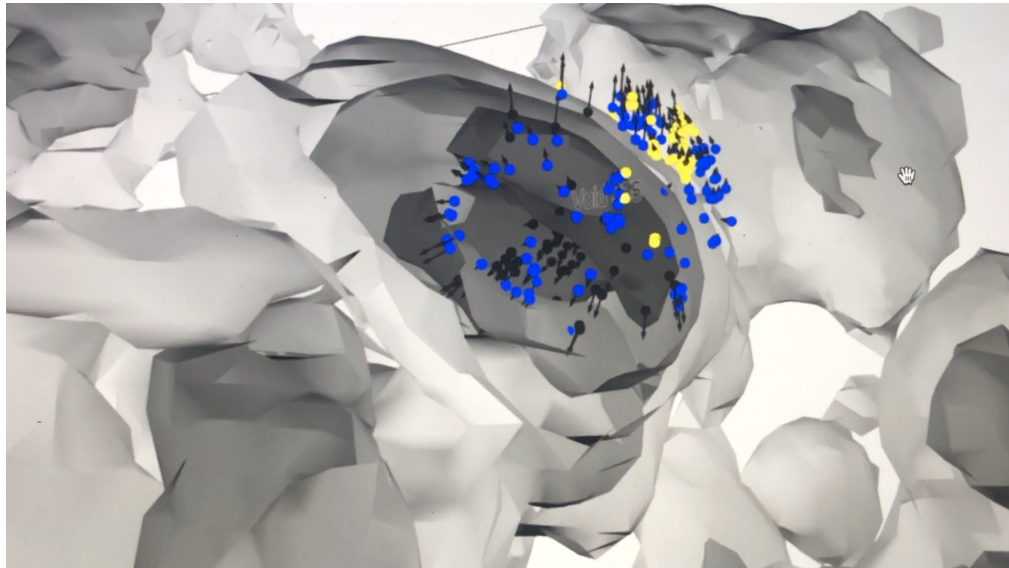
-Voids 474 – 487 – 727 and 738 are not empty (merging torrents)



-Void 355 is a true void : empty (pristine lake) Hercules void  
 -Voids 439 and 941 are not isolated (941 is a zone merging onto Virgo)



## Matter and galaxy profile of Void 355



V-web color code of galaxies

Isosurfaces of negative  $\delta_m$  field

Local particular flow with velocity of the void center subtracted

Conclusions:

discuss the bias galaxy/matter in true voids (expanding along two or three directions)

Implication for  $f\sigma_8$  computations

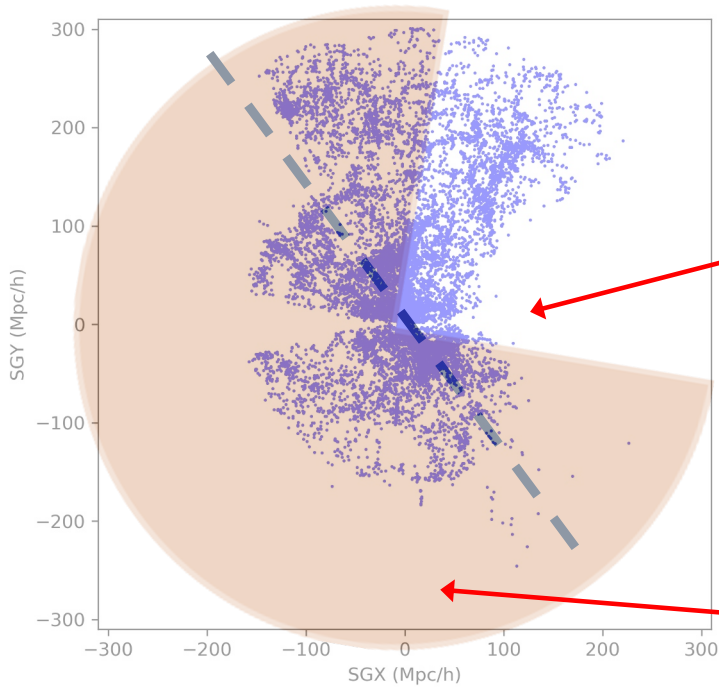
# Wallaby pilot and start of full survey in 2023

H. Courtois et al. 2022, arXiv:2210.12498

*the question we try to answer is :*

*Today : a new technology : sensitivity of interferometric multi-antennas radio-telescope (how far, how good) ?*

# Today : new radio technologies : SKA (square kilometer array)



**MeerKAT :**  
**Obscuration zone**

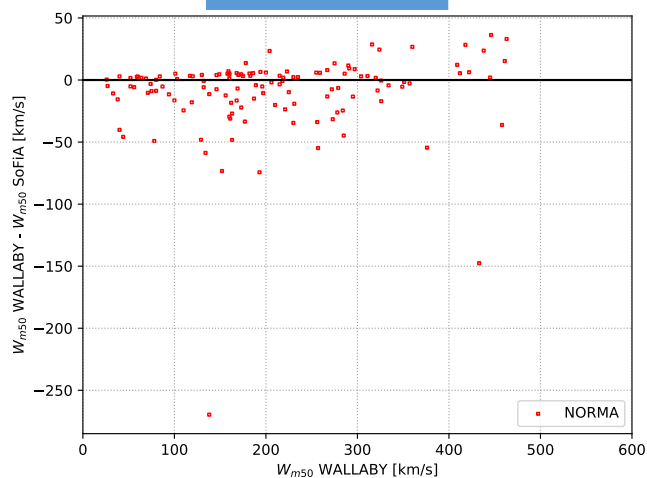
**WALLABY :**  
**+200,000 galaxies**



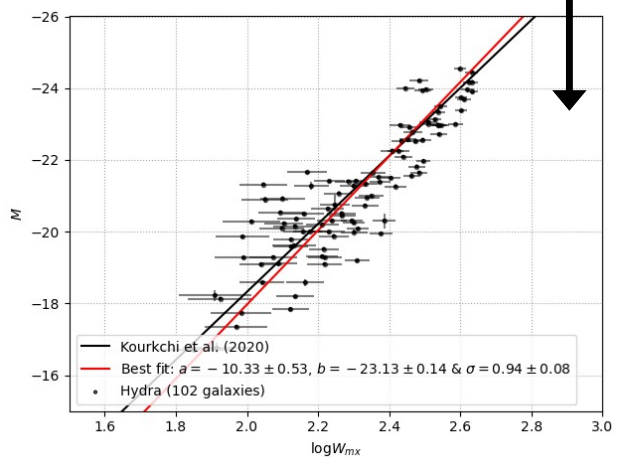
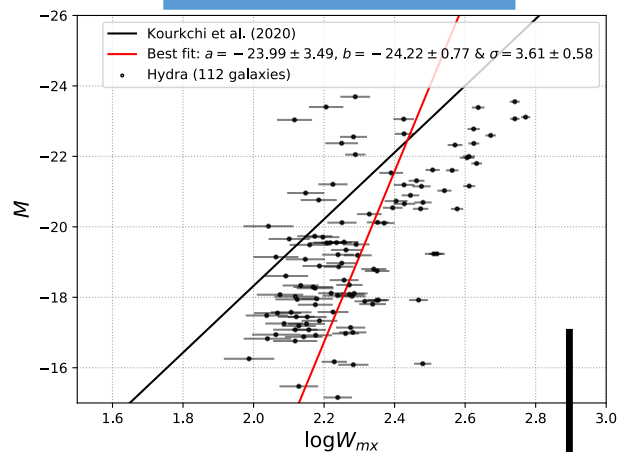


Phase 1 Wallaby Pilot Survey :  
 from radio HI linewidth algorithms pipeline and space near-infrared photometry  
 to distance moduli using in 4 test fields

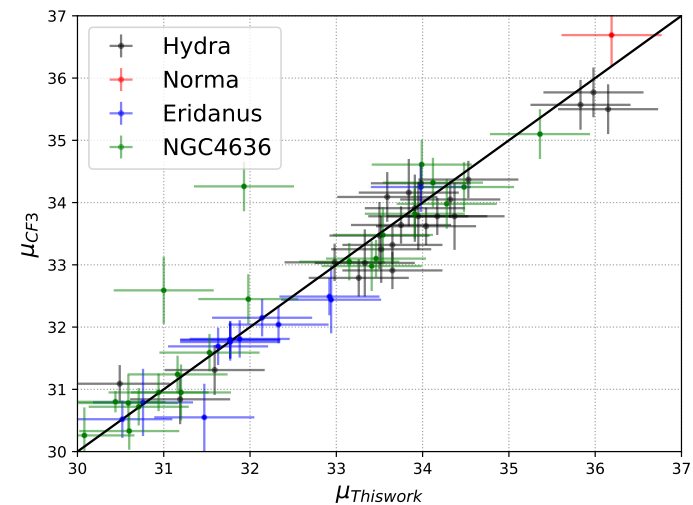
radio



photometry



Distance moduli



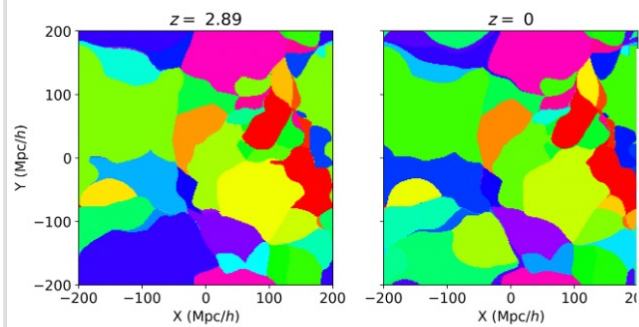
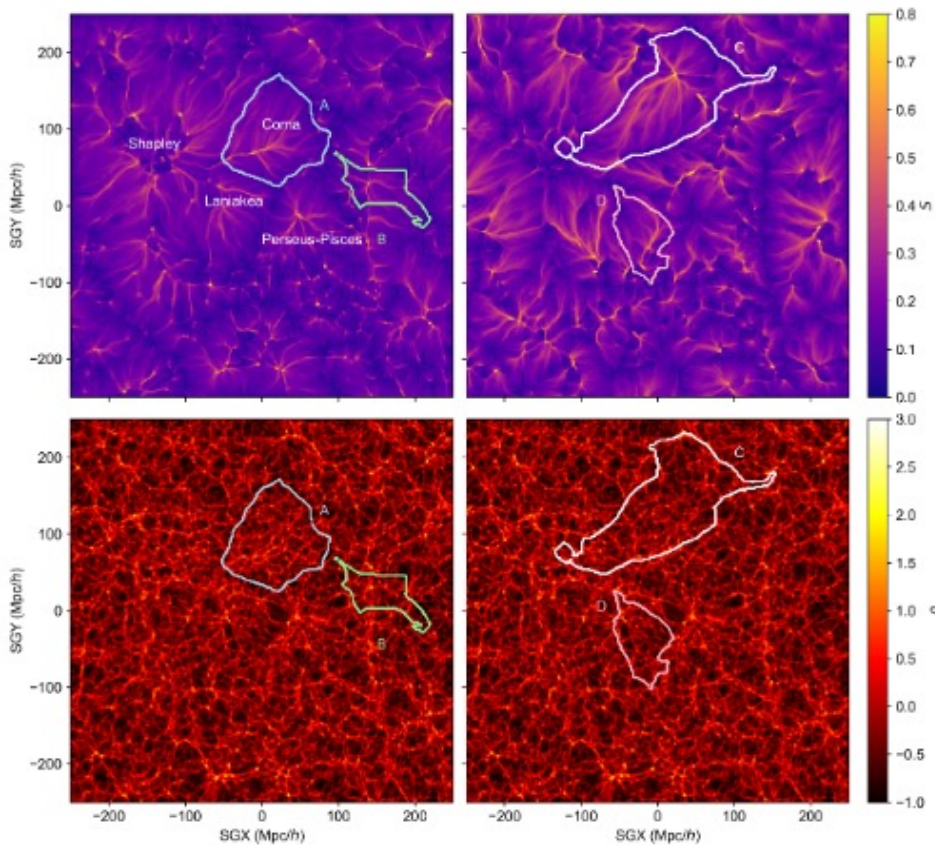
# Testing gravitation using homogeneity and growth rate of structures

H. Courtois et al. Submitted 2022

*the questions we try to answer are :*

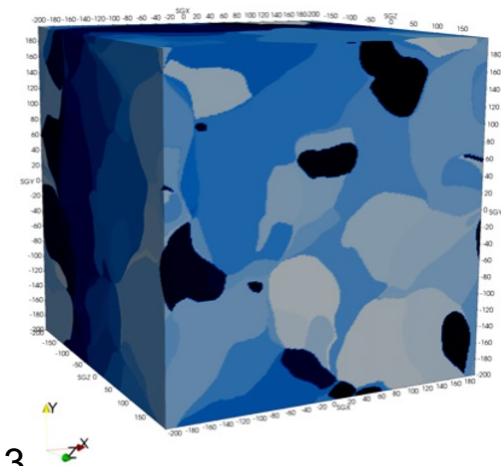
- Do we find a scale at which the universe is homogeneous : no more large tidal flow due to large gravitational instabilities ?*
- How fast does gravitation pull galaxy structures together ?*

# Watersheds, bulk flow, growth rate



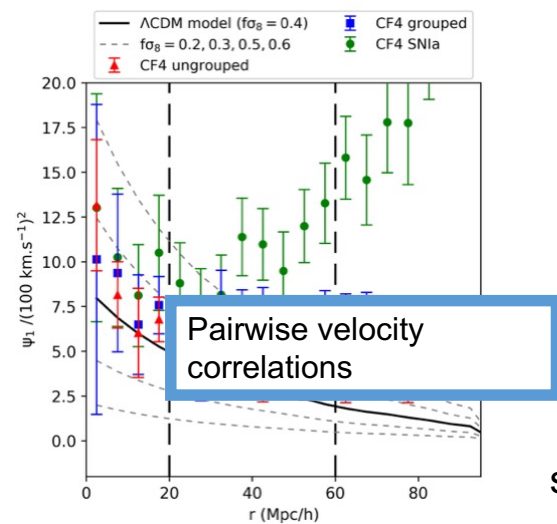
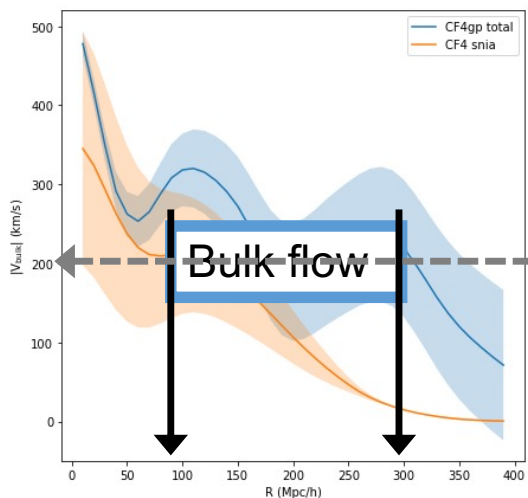
***Evolution in time of the gravitational watersheds in a simulated universe at 2 billions years and today 13,7 b.years***

Dupuy et al. 2020 MNRAS 493, 3513

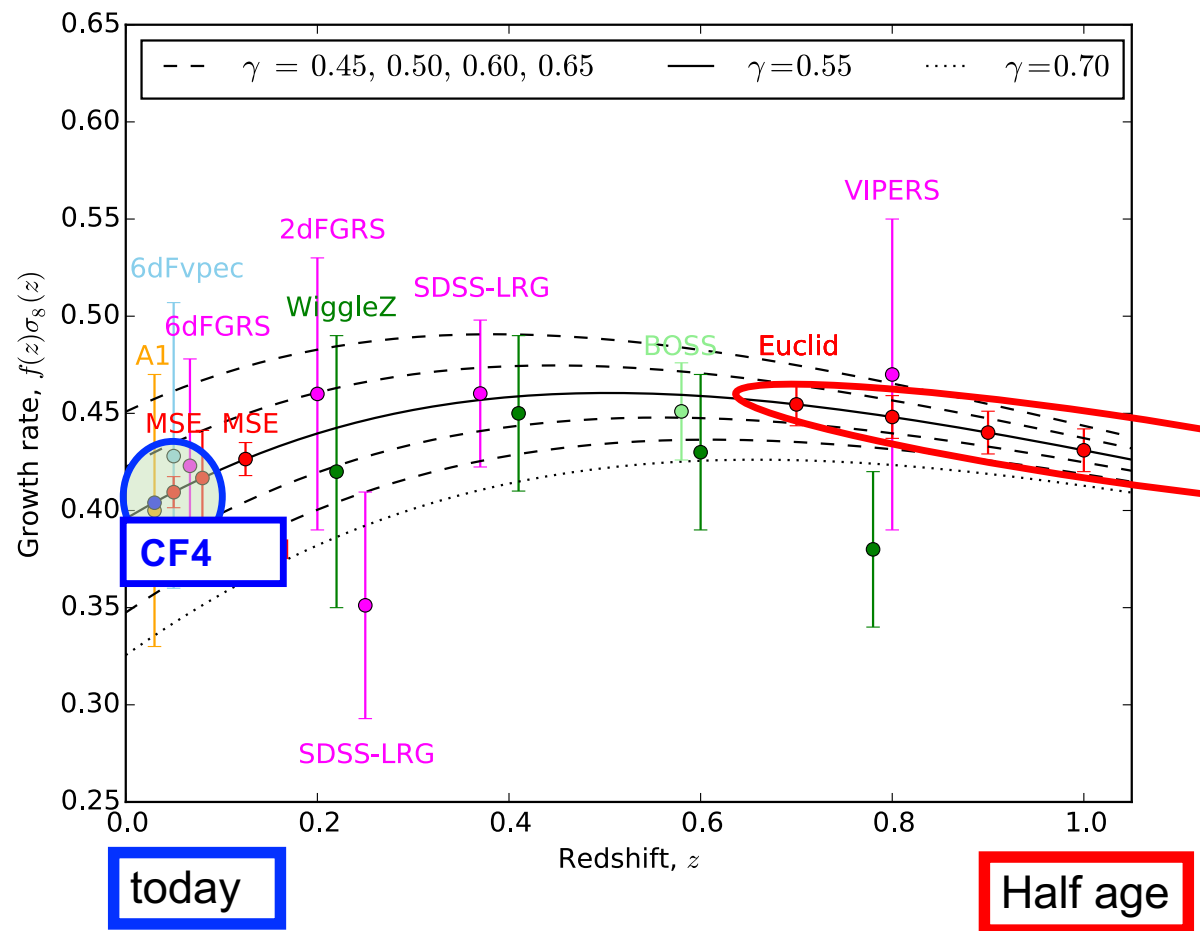




# Homogeneity and growth rate of large scale structures as tests for general relativity / gravitation



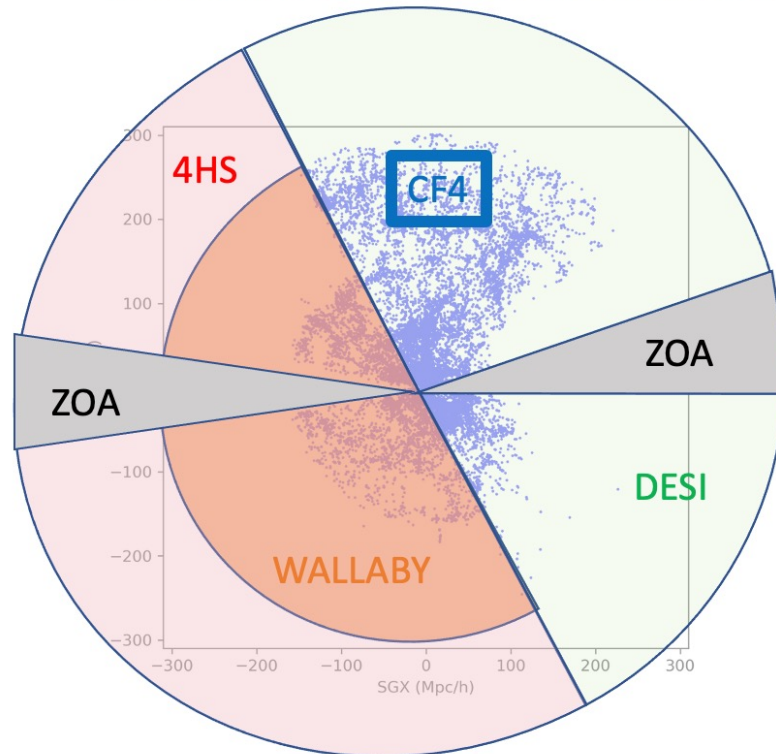
submitted



upcoming peculiar velocity datasets for further gravitation investigations

Leader WP  
ANR voids  
Executive board

**WALLABY [22-27] : 90 000 spirals up to  $z=0.1$**   
**DESI-BGS-PV [21-26] : 500 000 ellipticals up to  $z=0.15$**   
**4MOST-4HS-PV [24-29] : 500 000 ellipticals up to  $z=0.15$**



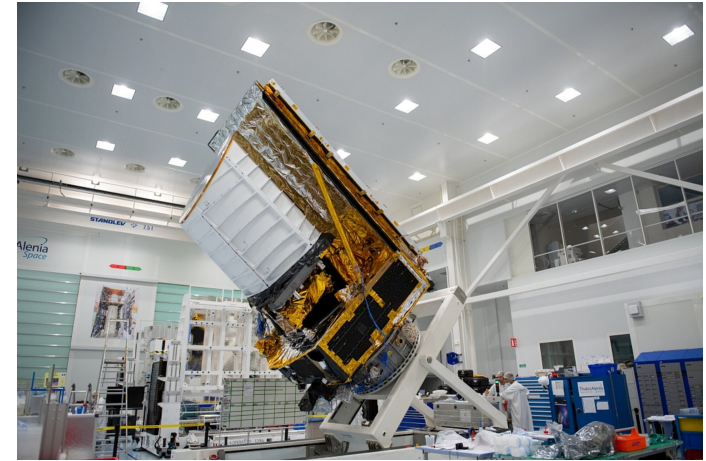
Euclid mission launch 2023 (July? Space X) : non-linear reconstructions of velocity fields in different environments and at different epochs



**15 European countries +**

**1,500+ researchers**

**10? millions galaxies for redshift space distortions**





# EDSU 2022

**Huge thanks to all the organizers**



Cosmic Flows in La Réunion  
Le Voile de la Mariée

