The Cosmic Flows project : voyage to the Great Attractor … and beyond … second episode
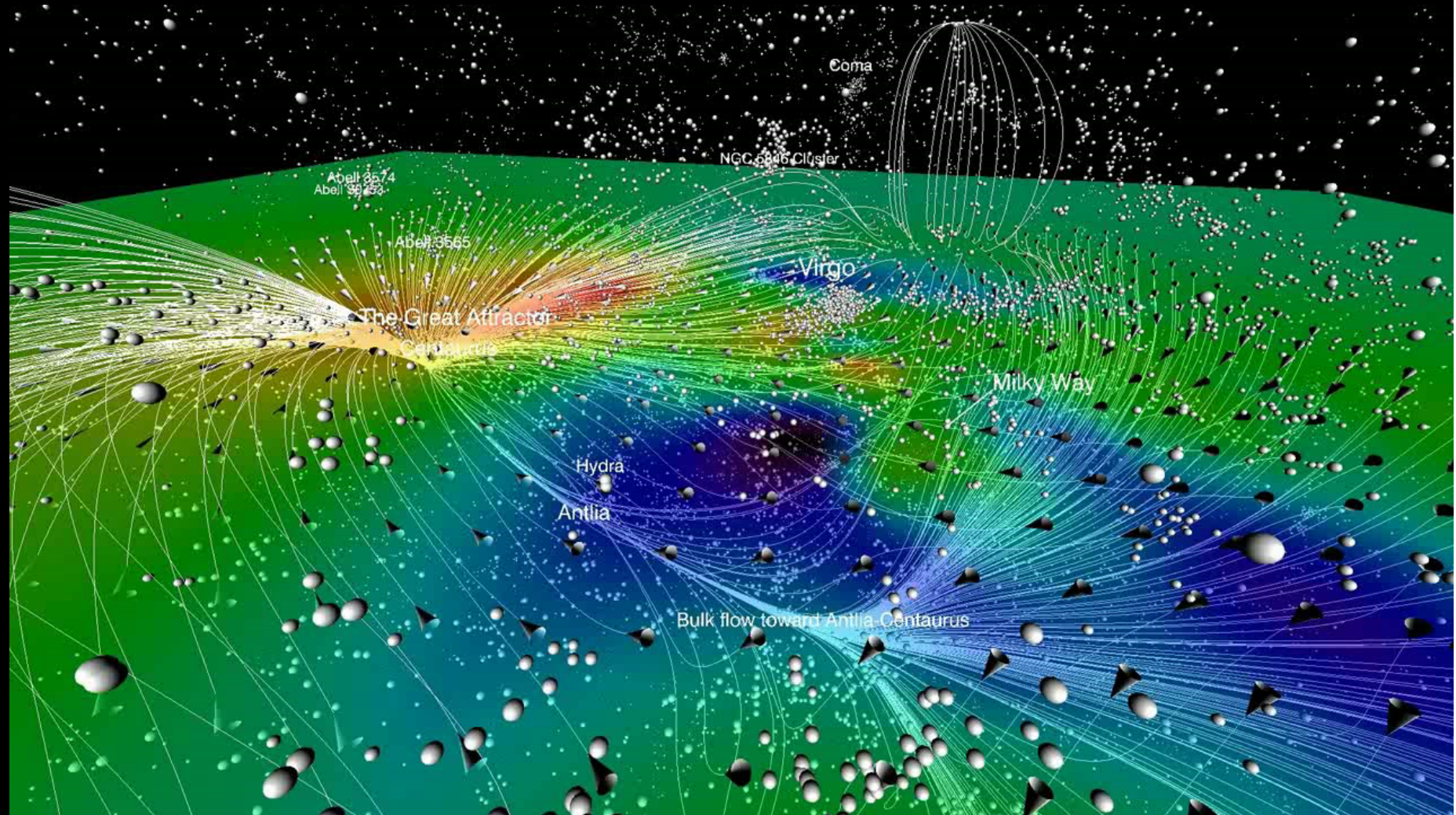
Hélène Courtois
Ass. Prof University of Lyon, France
Affiliate Researcher, Institute for Astronomy, Hawaii, USA

Dwingeloo, March 2014

On behalf of the five musketeers

Yehuda Hoffman, Hebrew University Jerusalem, Israel
Daniel Pomarede, CEA Paris, France
Brent Tully Institute for Astronomy, Hawaii, USA
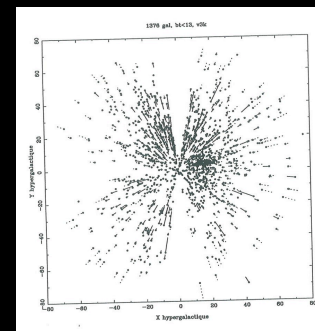Helene Courtois, Univ Lyon, France and IFA
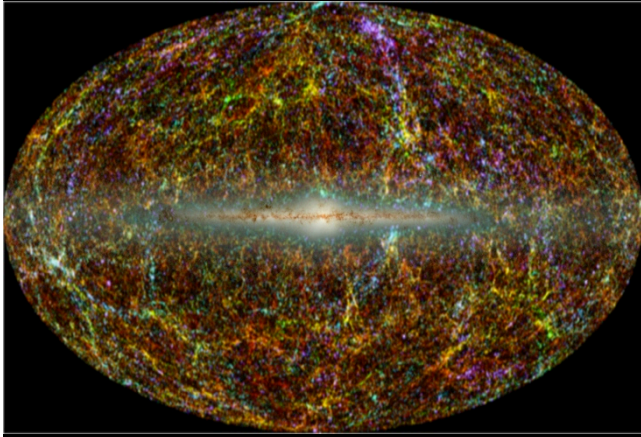Stefan Gottloeber, Potsdam, Germany

Open collaboration, current core team:
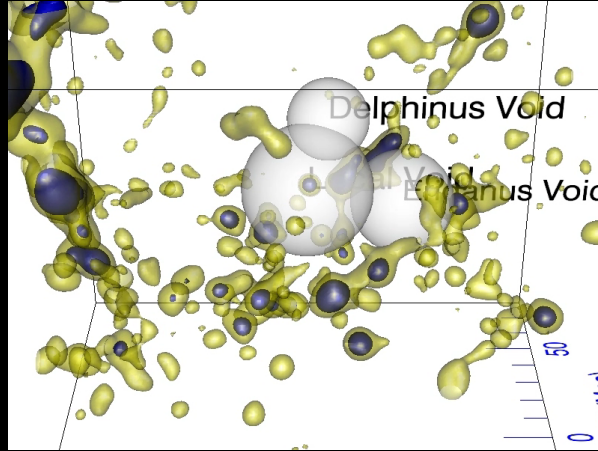Radioastronomy : R. Fisher, D. Makarov, S. Mitronova, I. Karachentsev, ...
Photometry ground + HST + Spitzer + WISE : D. Neil, M. Seibert, E. Shaya,, T. Jarrett, B. Madore ...
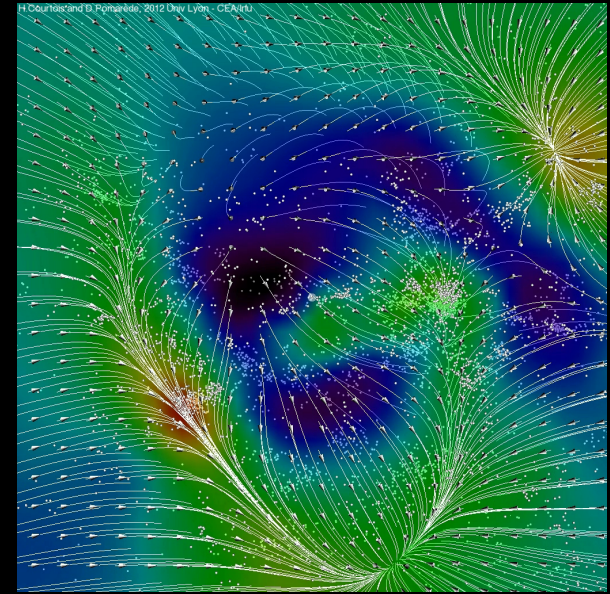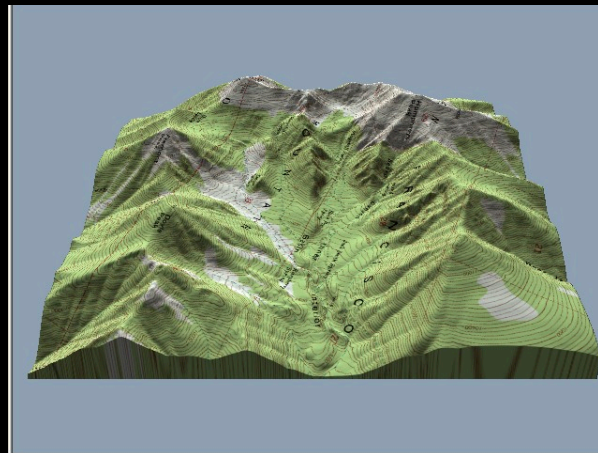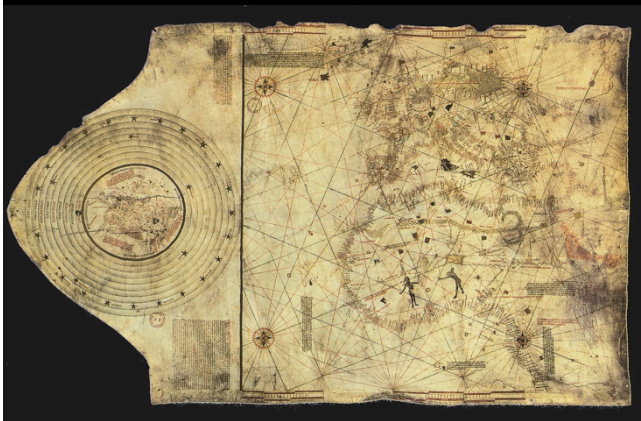PhD Students B. Jacobs, B. Depardon, N. Bonhomme, T. Doumler, J. Sorce

2D ⟶ 3D ⟶ 4D

Cosmography : mapping with dynamics.
Cosmology questions : cause of the CMB motion at 630 km/s, expulsion from voids?

The large scale cosmic flows constraints on cosmology

$V_{redshift} = H_0 * distance + V_{peculiar}$

Peculiar velocities are only due to gravitational interactions.
Our Galaxy has high deviant motion of 630 km/s   w.r.t. the CMB dipole *(Fixsen et al. 1996)*

Decomposition into components:
- Infall towards Virgo cluster at 16 Mpc: ~ 140 km/s *(Karachentsev et al. 2010)*
- Motion away from a large Local Void *(Tully, Courtois et al. 2008)*
- Great Attractor at ~ 50 Mpc *(Lilje et al. 1986; Lynden-Bell et al. 1988)*
- Perseus/Pisces cluster on the opposite side *(Hanski et al. 2001)*
- Shapley concentration at ~ 150 Mpc ?*(Pike & Hudson 2005; Erdoğdu et al. 2006; Bilicki et al. 2011)*
- Observed components cannot totally explain the flow? *(Lavaux et al. 2010; Nusser & Davis 2011; Courtois et al. 2012,2013)*

Cosmic flows project :
       Measure distances d
       Peculiar velocities: $V_{pec} = V_{obs} - H_0 d$
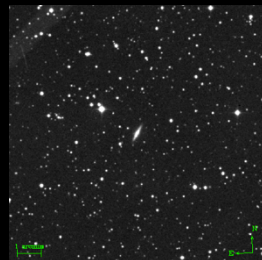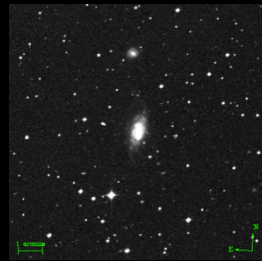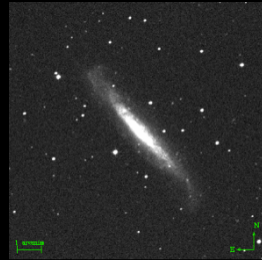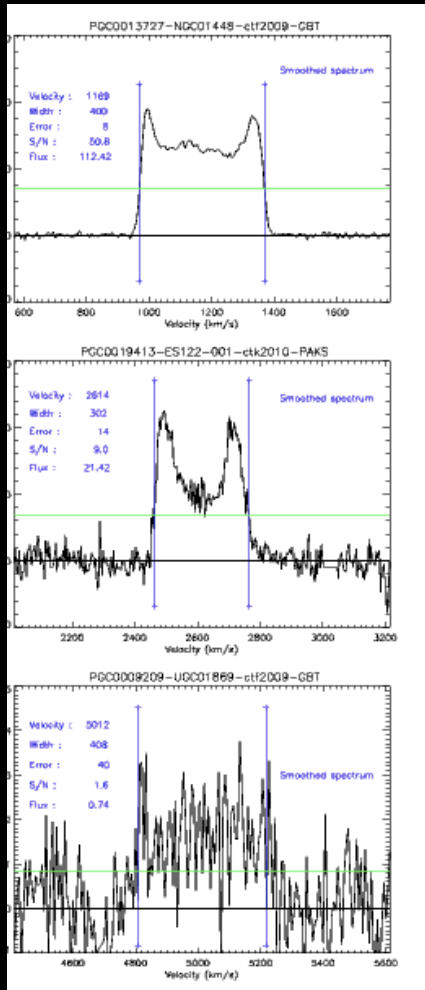   Infer 3D velocities and density field
       Project to initial conditions (back in time machine)
       Simulate evolution to present conditions

Status of Current observational surveys:
13,000 good HI – 10,000 good photometry

2008 : Cosmicflows-1

2013 : Cosmicflows-2

All reduced data is public edd.ifa.hawaii.edu
Courtois et al. AJ, 2009, 138, 1938
Courtois et al. 2011 MNRAS 415,1935

Data expands :

Deep I band + HST + Spitzer + WISE + Panstarrs

Deep HI exposures, NRAO large program
(+1,000 hrs GBT, Parkes, 200 nights/yr) + archives

The cosmography saga – episode 1
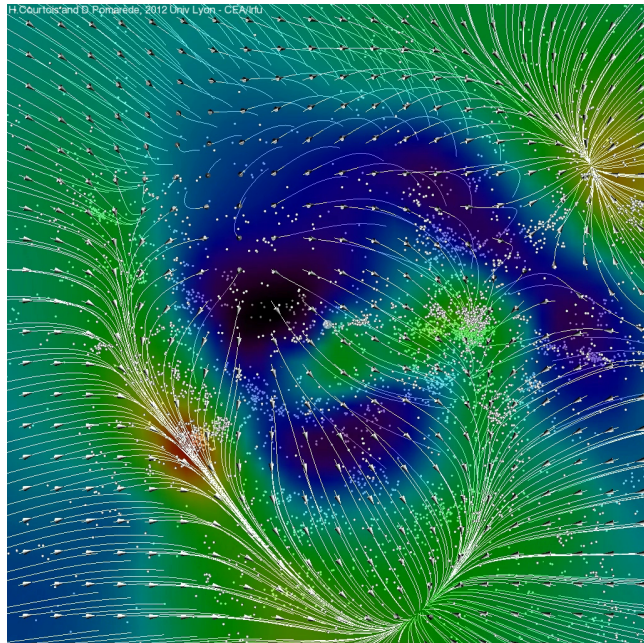
Cosmography with *Cosmicflows-1*

"Cosmography of the Local Universe",
Courtois et al, AJ 146 (2013) 169

22 maps connected by a 17 min video
+300,000 views, + 10,000 downloads
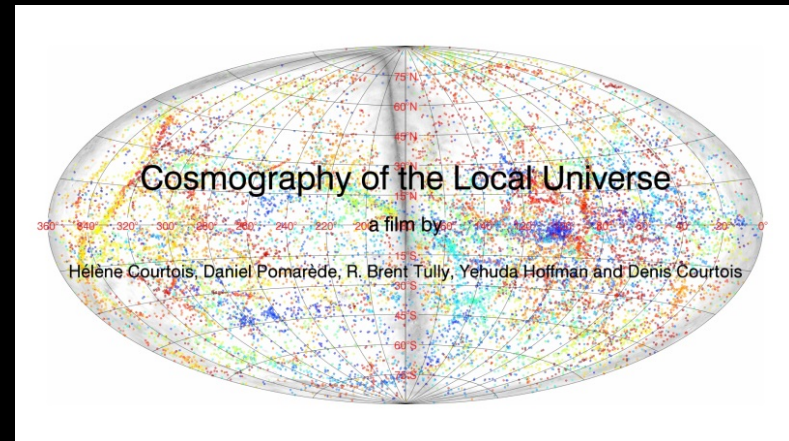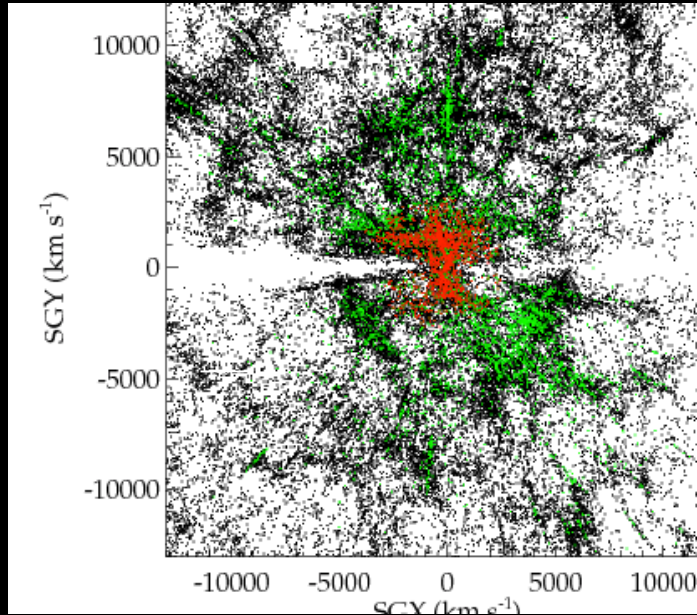
Cosmicflows-1: 1797 distances within 3300 km/s
(catalog in EDD)   Tully et al. 2008, ApJ, 676, 184

Contributions to Cosmicflows-2

297 TRGB: Tip of the Red Giant Branch
133 TRGB Literature
 31 RR Lyr, HB, EB, Maser
 60 Cepheid Period-Luminosity
382 SBF: Surface Brightness Fluctuation
306 SNIa: Type Ia Supernova
1508 FP: Fundamental Plane
5998 TF: Luminosity-Linewidth

1209

8315 distance measures
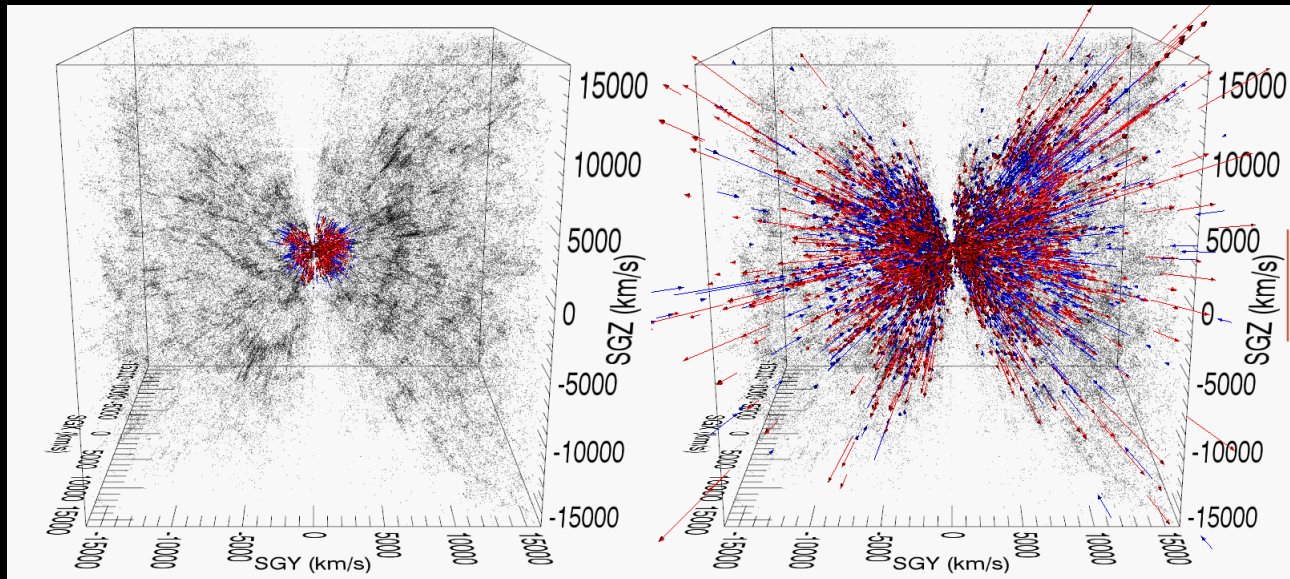
- I band Tully-Fisher calibration
- HI linewidth pipeline
- Photometry pipeline
- Malmquist Bias control
- Hubble constant derivation with SNIa

Tully, Courtois, Dolphin, Fisher, Heraudeau, Jacobs, Karachentsev, Koribalski, Makarov, Makarova, Mitronova, Rizzi, Shaya, Sorce, Wu
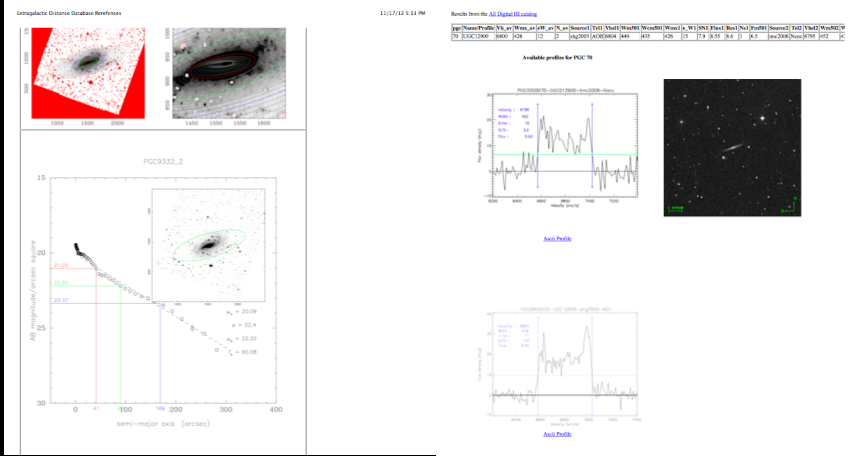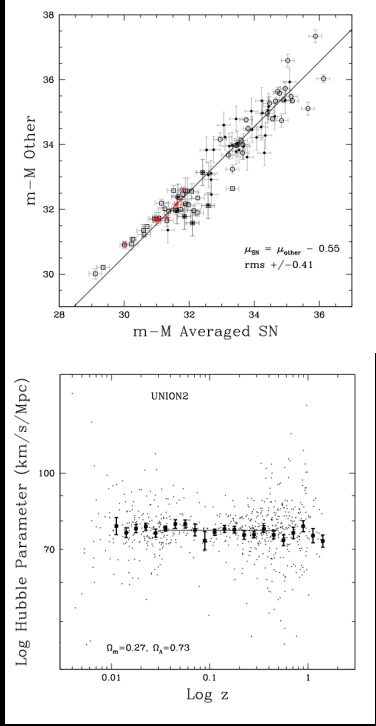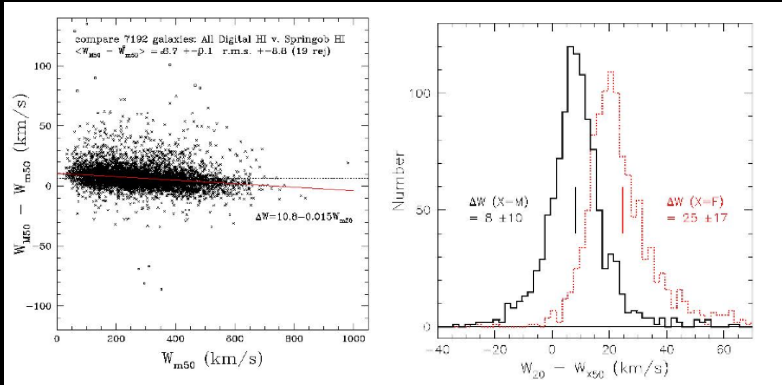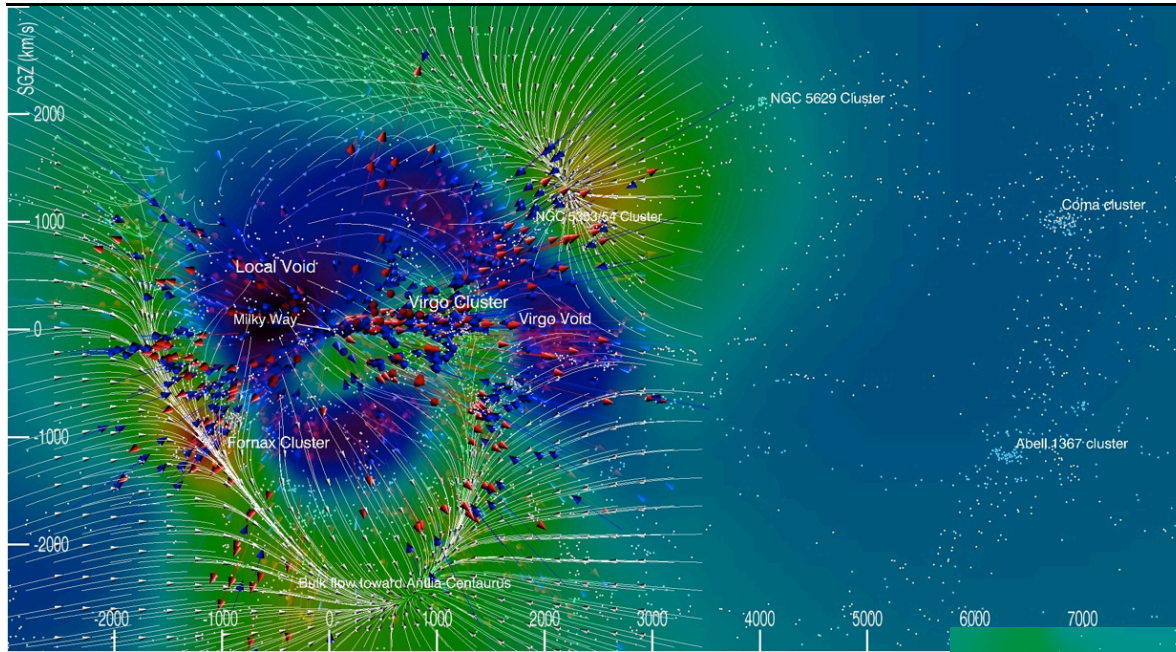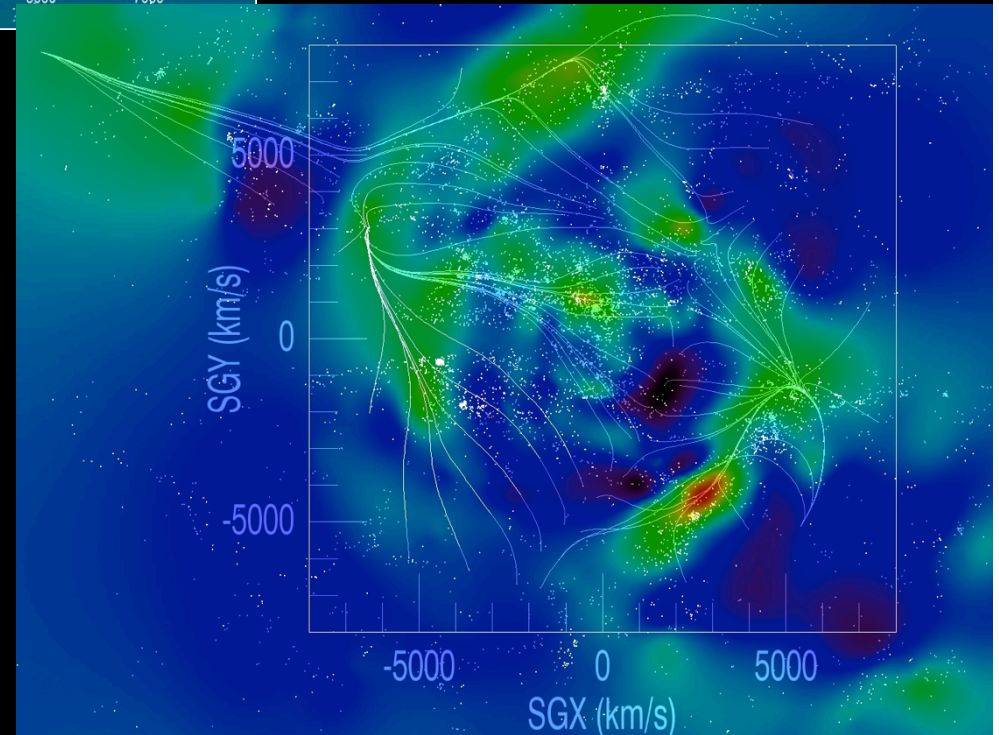
- I band Tully-Fisher calibration
- HI linewidth pipeline
- Photometry pipeline
- Malmquist Bias control
- Hubble constant derivation with SNIa
- Reconstruction control
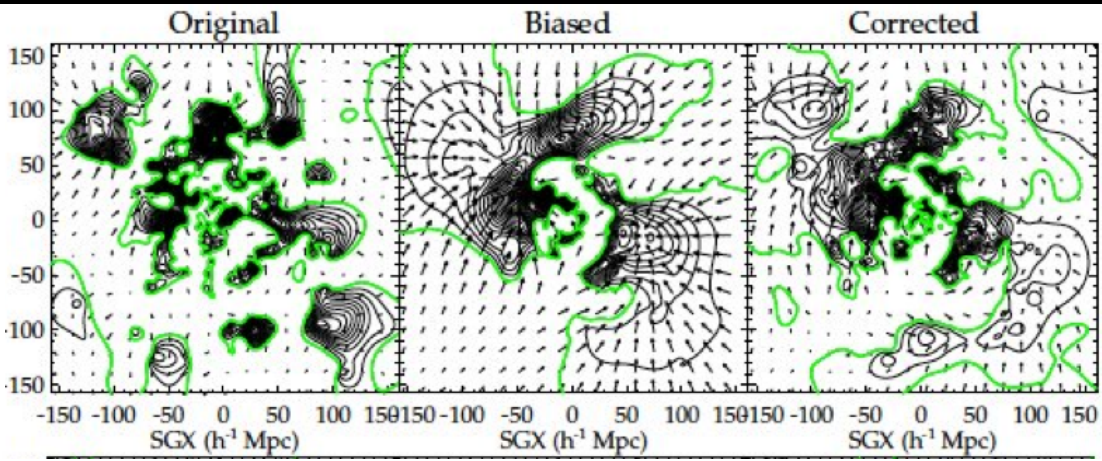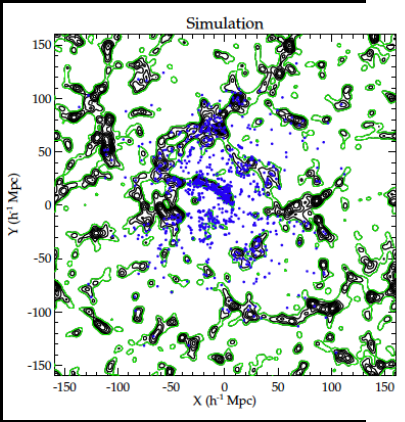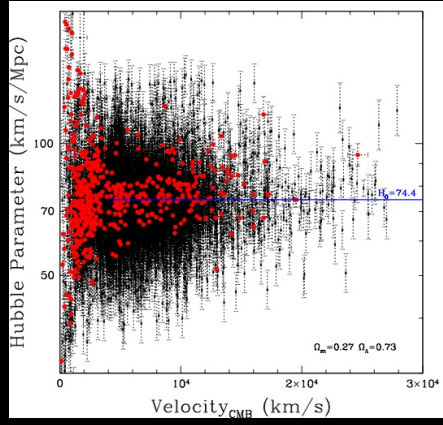
What was causing the tidal flow after 80 Mpc in CF1 ?

Current analysis of CF2

The cosmography saga – episode 2

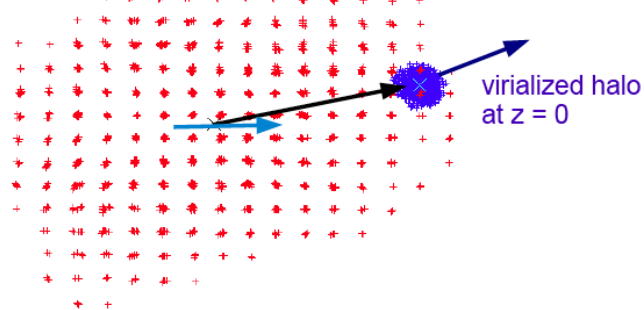*(avant-premiere grab your popcorns)*

Peculiar velocities are used in Initial Conditions to constraint cosmological simulations

The back in time machine

Wiener Filter + Reverse Zeldovich approximation
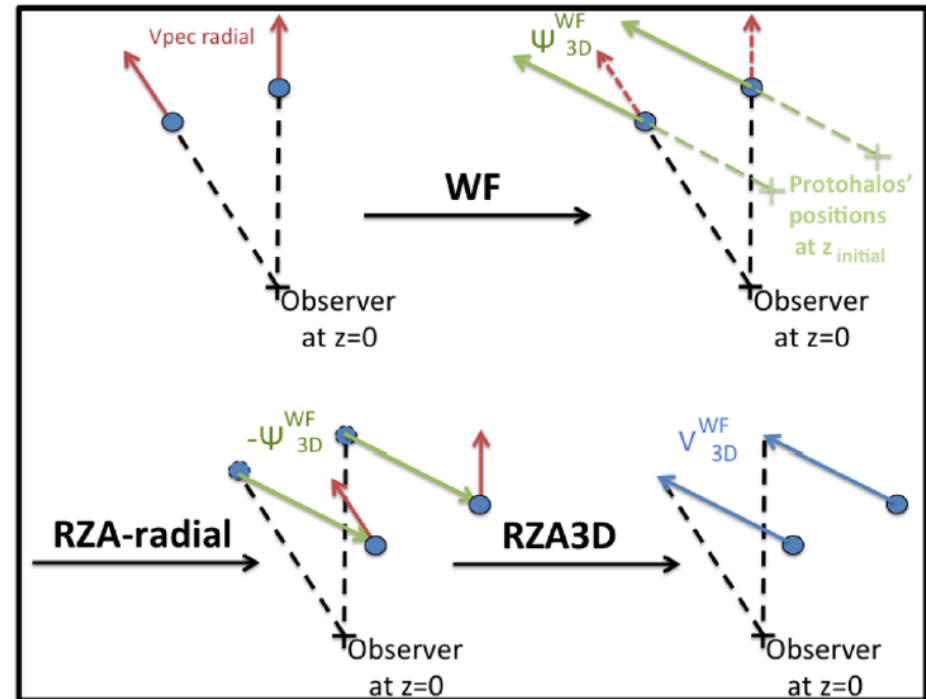
Halo and proto-halo

Lagrangian region R ~ M$^{1/3}$
at z = 50

virialized halo
at z = 0

$$x(t) = q + D(t)\psi(q)$$
$$v(t) = \dot{D}(t)\psi(q)$$

Zel'dovich approximation

Method described in papers :

Doumler et al 2013, MNRAS 430 (888,902,912)
Sorce et al 2014, MNRAS 437, 3586

COMA

LSC

GA

PP

30

60

Original simulation full box

Original simulation 30 Mpc

Re-simulation no RZA

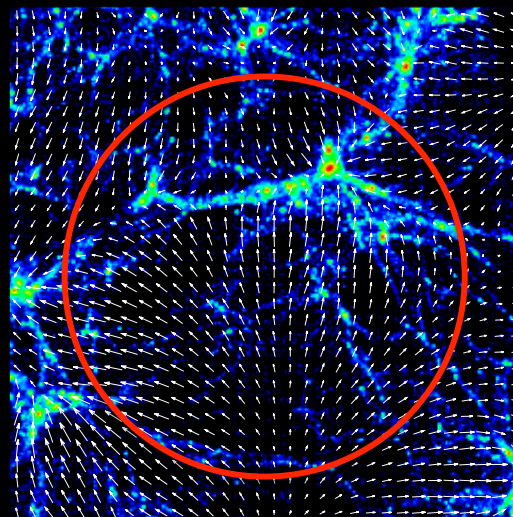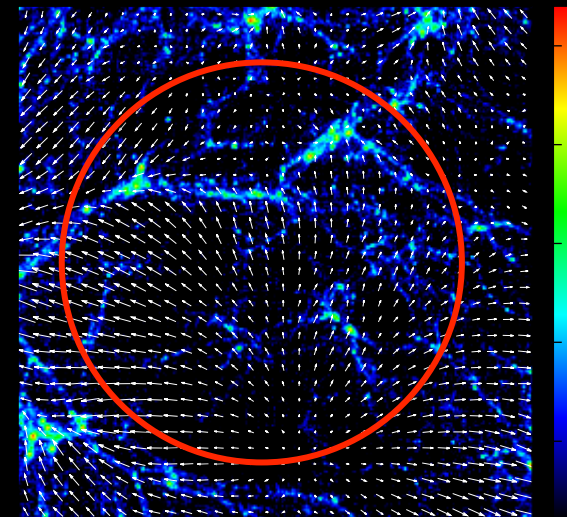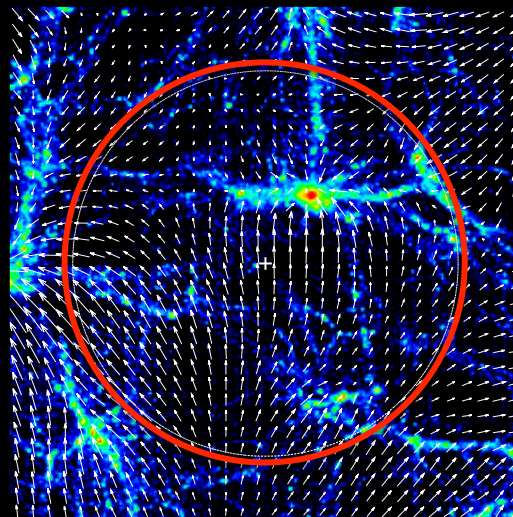Re-simulation with a CF1 mock

Re-simulation with a CF2 mock
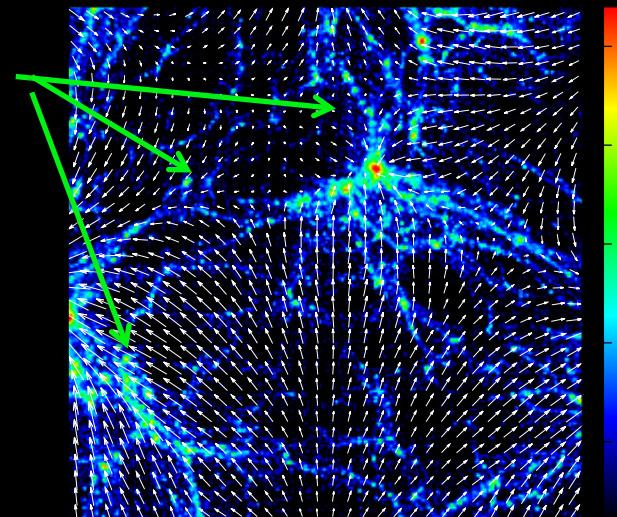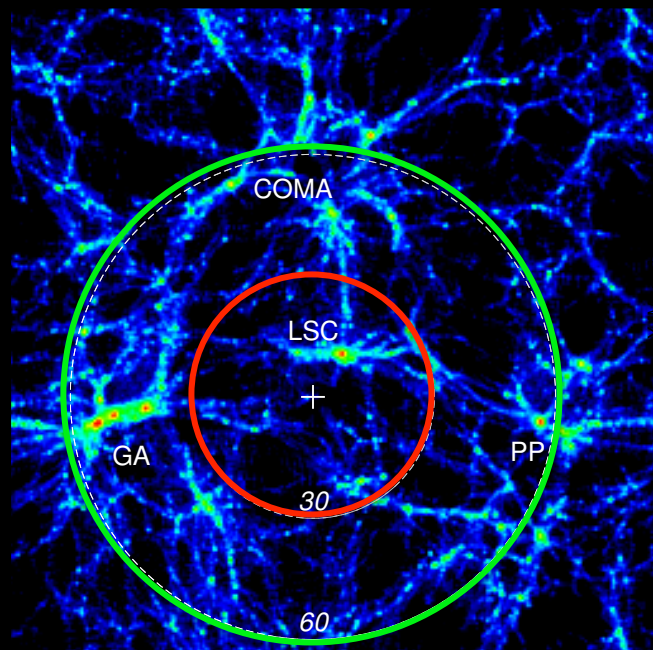
CLUES : Constrained Local Universe Simulations

Using cosmicflows-2 peculiar velocities as initial conditions + WMAP7 power spectrum

1π , 4 π, ZOA
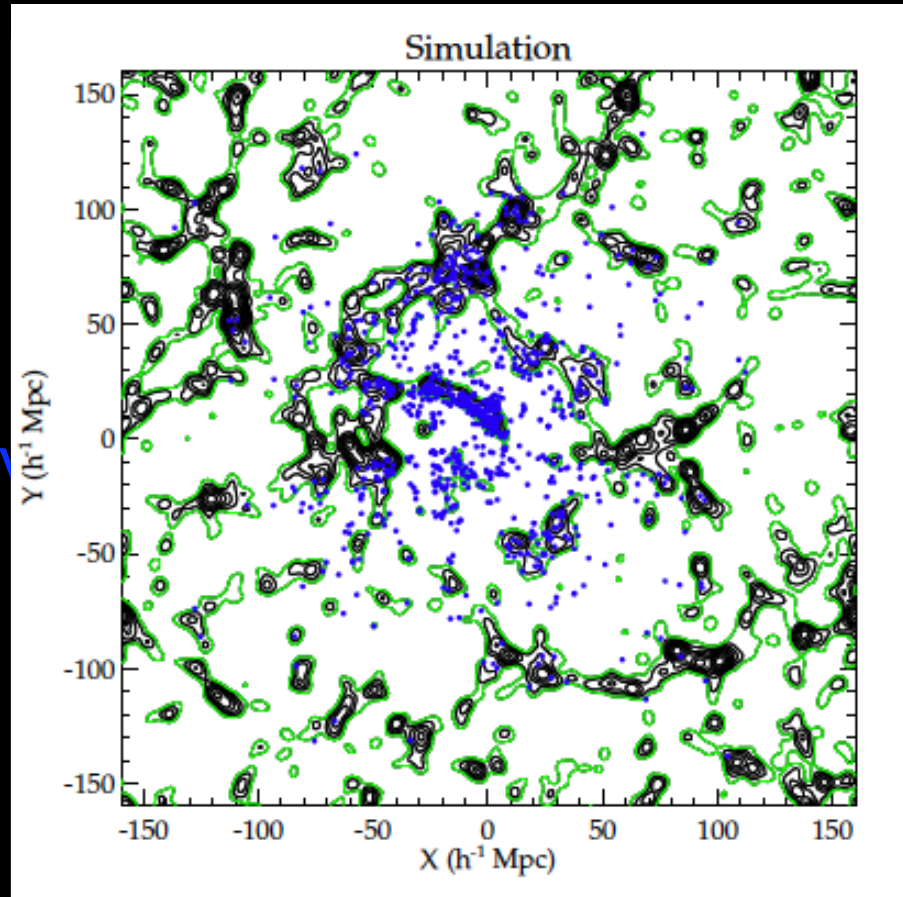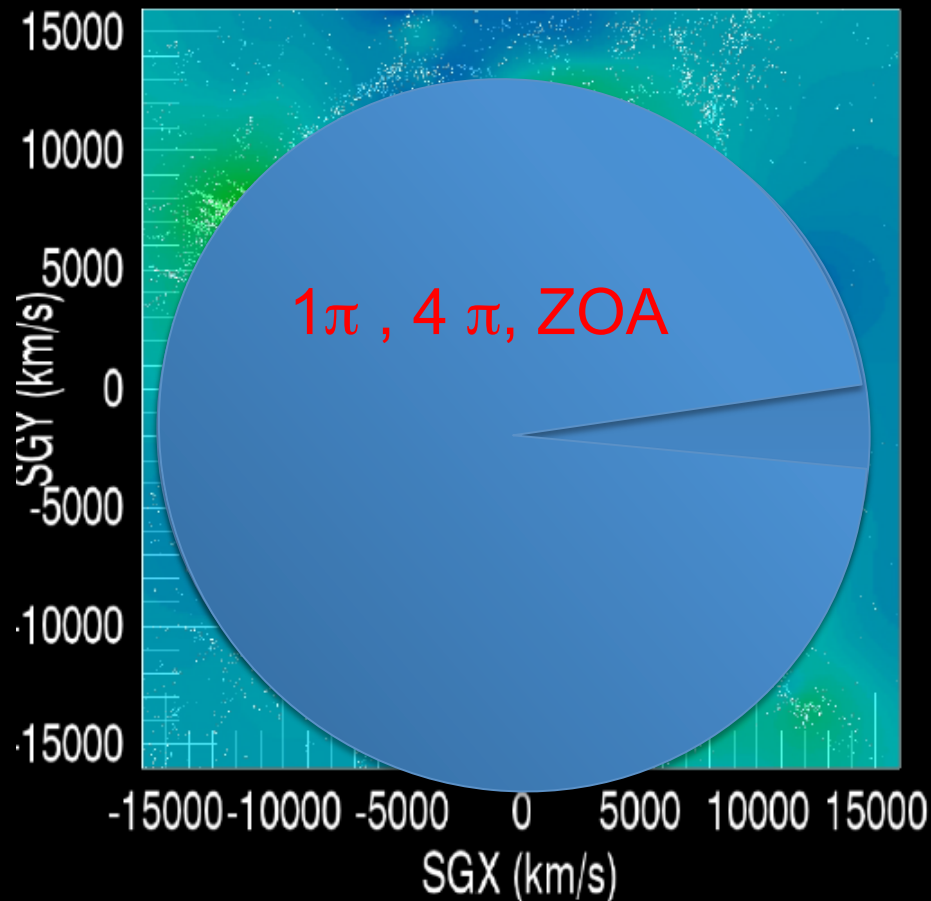
CF2 Wiener Filter reconstruction + XScz

Constrained dark matter simulation
10 different realizations = 10 random seeds

Current Cosmic-Flows-2 Wiener Filter reconstruction

Westerbrok back of PP

Shapley

Vela
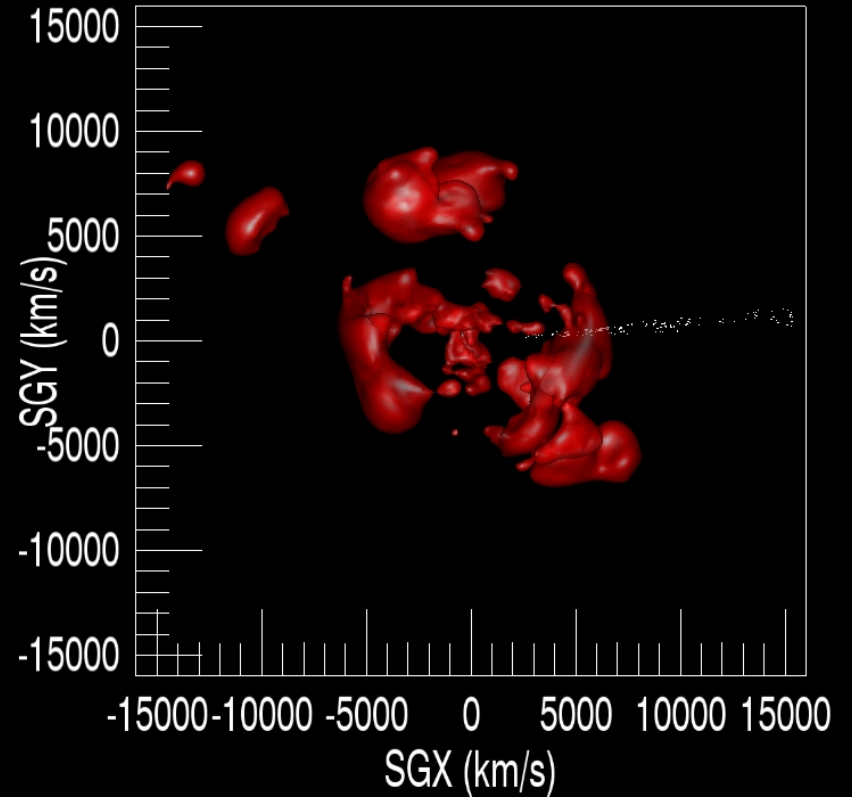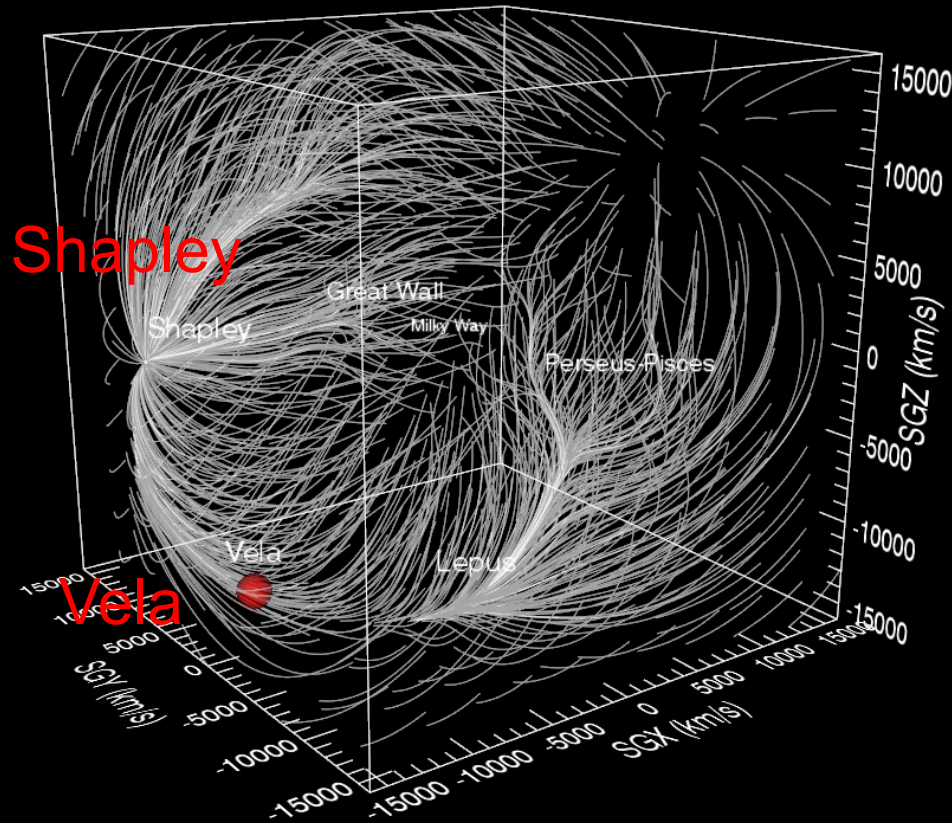
Science case : 1%-2% matter in universe cartographied with large uncertainties

Precision cosmology : we are not barely there yet and for local densities
we desperately need 4 pi (also in photometry)
3rd generation : 800k gal combining Wallaby – Westerbrok 2 to 77 k km/s
TF without inclinations ?

1π , 4 π, ZOA

Future surveys and simulations : unveiling the history of dark sectors

2016/2017 : cosmicflows-3   (data reduction started)
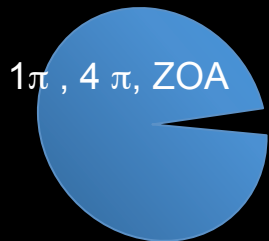
CF1 : 7 distances per 10 Mpc side grid cell

CF2 : 4 distances per 10 Mpc side grid cell

CF3: 128k distances in $V=3.10^7$ Mpc^3

1,800 > 8,000 > 100,000 distances

- Single dish HI surveys (Alfalfa, EBHIS)
- Photometry : adding near-infrared (SPITZER + WISE)
            . closer to ZOA (calibration TF + field galaxies)
            . avoid North/South filter band bias
-   Add methods like Baryonic TF (see Zaritsky, Courtois et al. 2014)

2020-25 : cosmicflows-4

Multi-dish WALLABY, WNSHS Apertif , MeerKAT

Multi-band Pan-STARRS + SKYMAPPER

700 Mpc= 10 millions to have 7 per 10 Mpc cell

Peculiar Velocity Data will include Shapley, Vela, other super-continents of galaxies, and a grand canyon 240 Mpc wide across ZOA

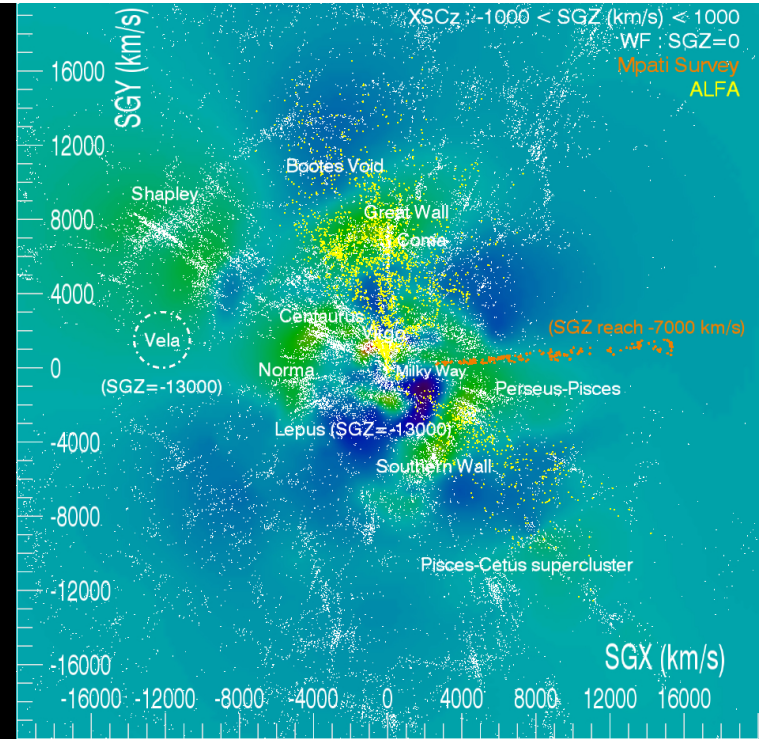*Do we reach the end of the cosmic flow dipole motion towards the CMB?*

Local densities for dark sectors, standard cosmology, scale of homogeneity, size of voids, structure growth factor, …
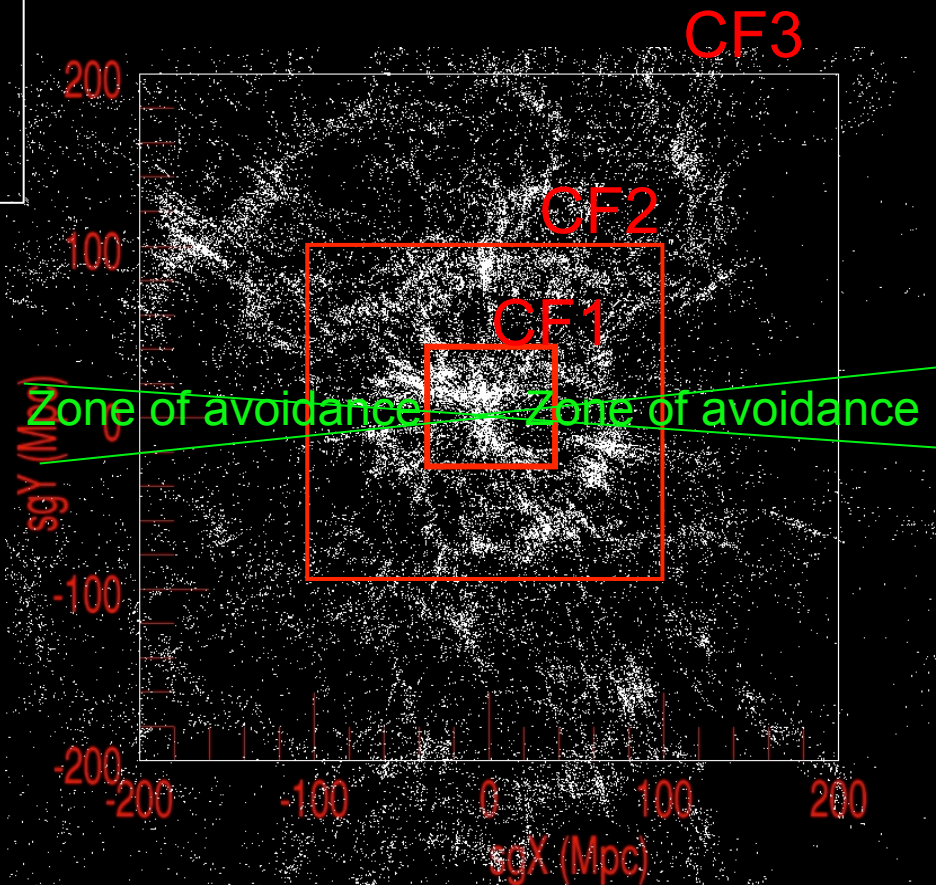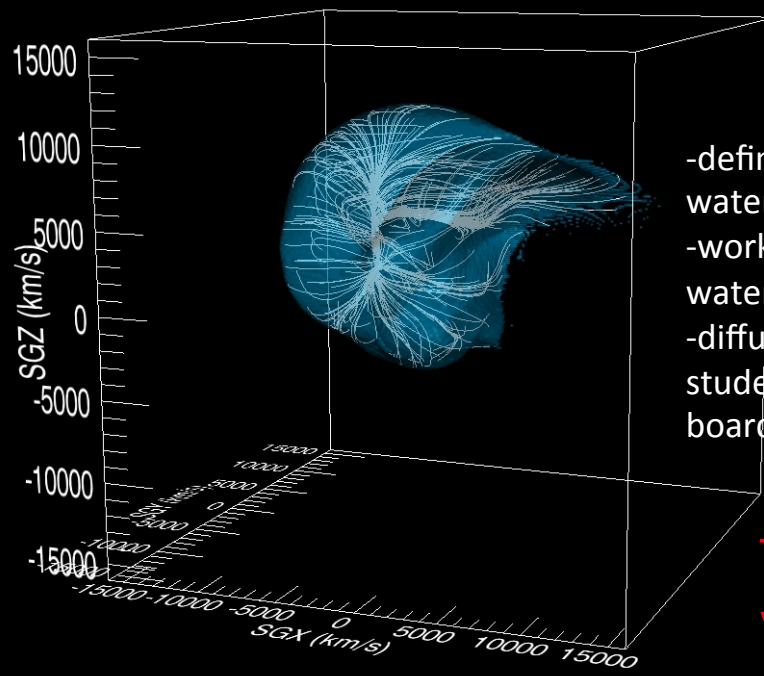
-definition of Laniakea watershed
-working Perseus-Pisces watershed
-diffusion of cosmography to students, public and decision boards

Thank you for your attention

A journey through our Universe ...

... discover the origin of life starting from the Big Bang, the formation and evolution of elements in stars and galaxies

Astronomy Museum and Planetarium,
4000 m² Vaulx-en-Velin, Lyon
200 m² exhibition dedicated to Cosmology
80,000 visitors/year