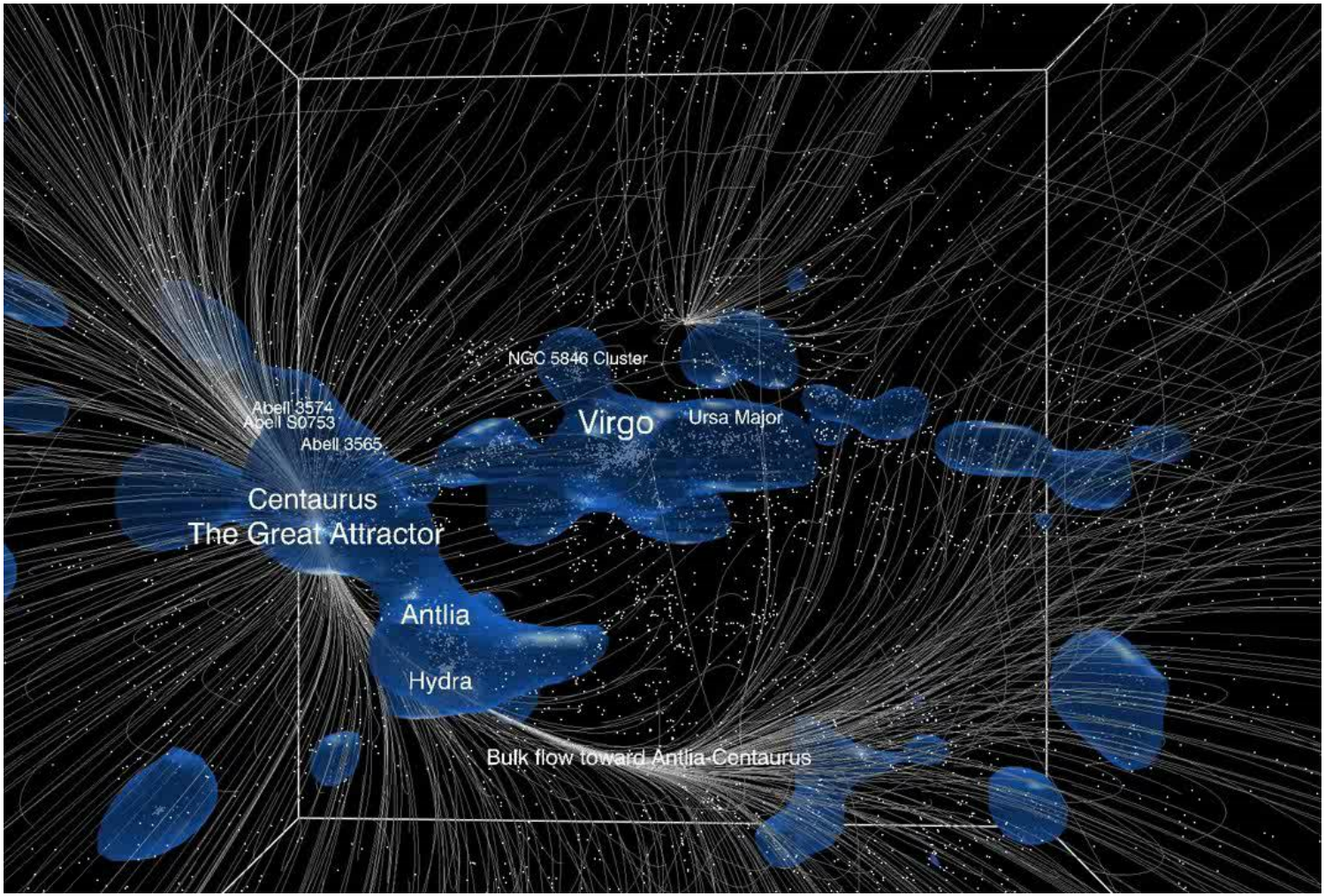
Cosmic flows and large scale structures vizualisation



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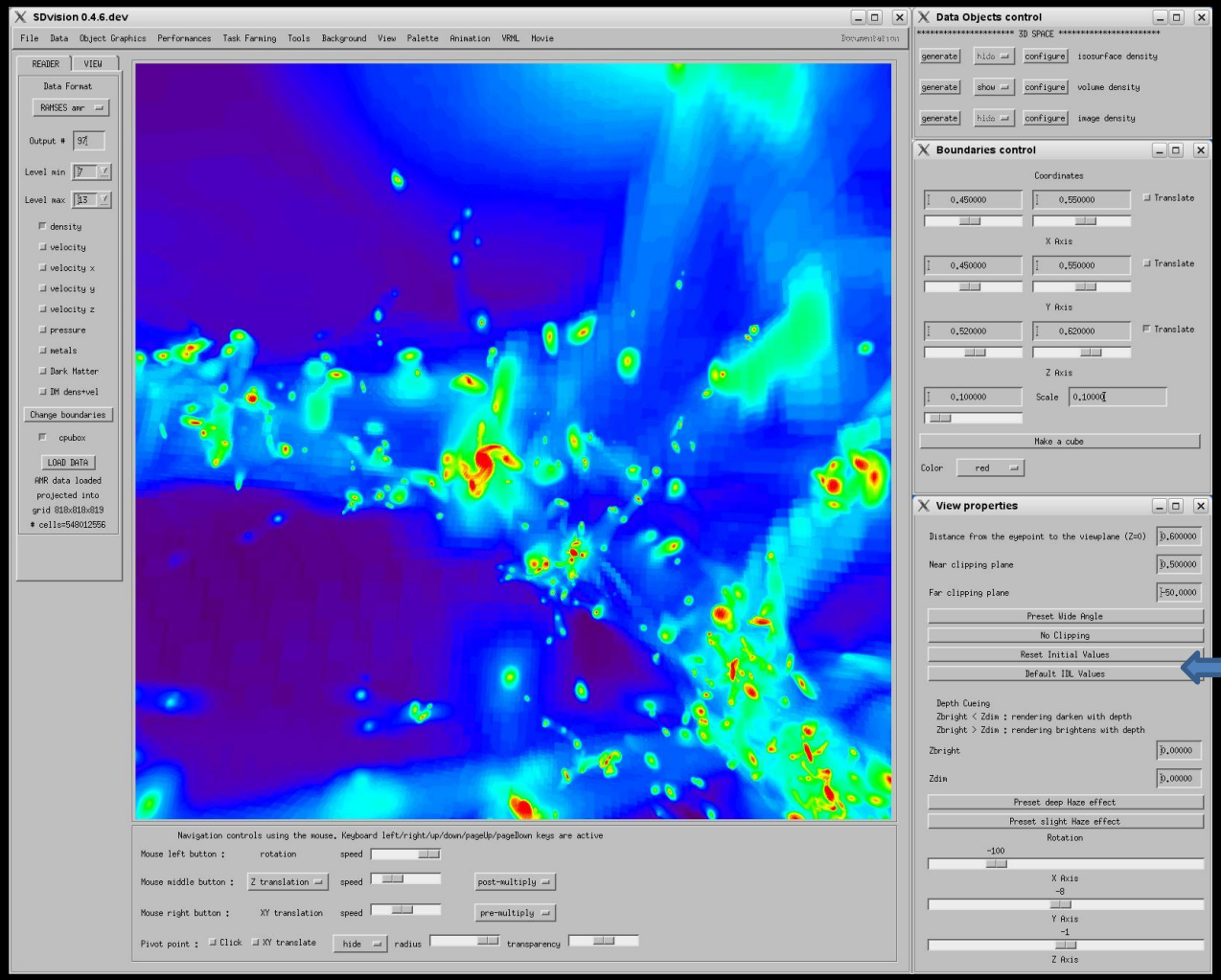
Hélène Courtois (U. Lyon 1 & IFA Hawaii)
R. Brent Tully (IFA Hawaii)

Motivations

- The three-dimensional, immersive visualization of :
  - redshift and distance catalogs from the Extragalactic Distance Database (IFA U. of Hawaii, U. of Maryland & IPNL/U. Lyon) :
    - V8k, a catalog of redshifts bounded at 8000 km/s (30124 galaxies)
    - Cosmicflows-1 distances within 3300 km/s (1797 galaxies)
  - reconstruction of the density field
    - corrected to account for growing incompleteness with distance
  - reconstruction of cosmic flows
    - based on the Wiener Filter analytic method
- with the objectives to obtain :
  - a cosmography of the Nearby Universe :
    - creation of maps
    - identification of the most prominent structures : voids, clusters, filaments and walls
  - a visual analysis of cosmic flows versus the cosmography
    - identify attractors and other sources of bulk motions
    - nature of the Great Attractor

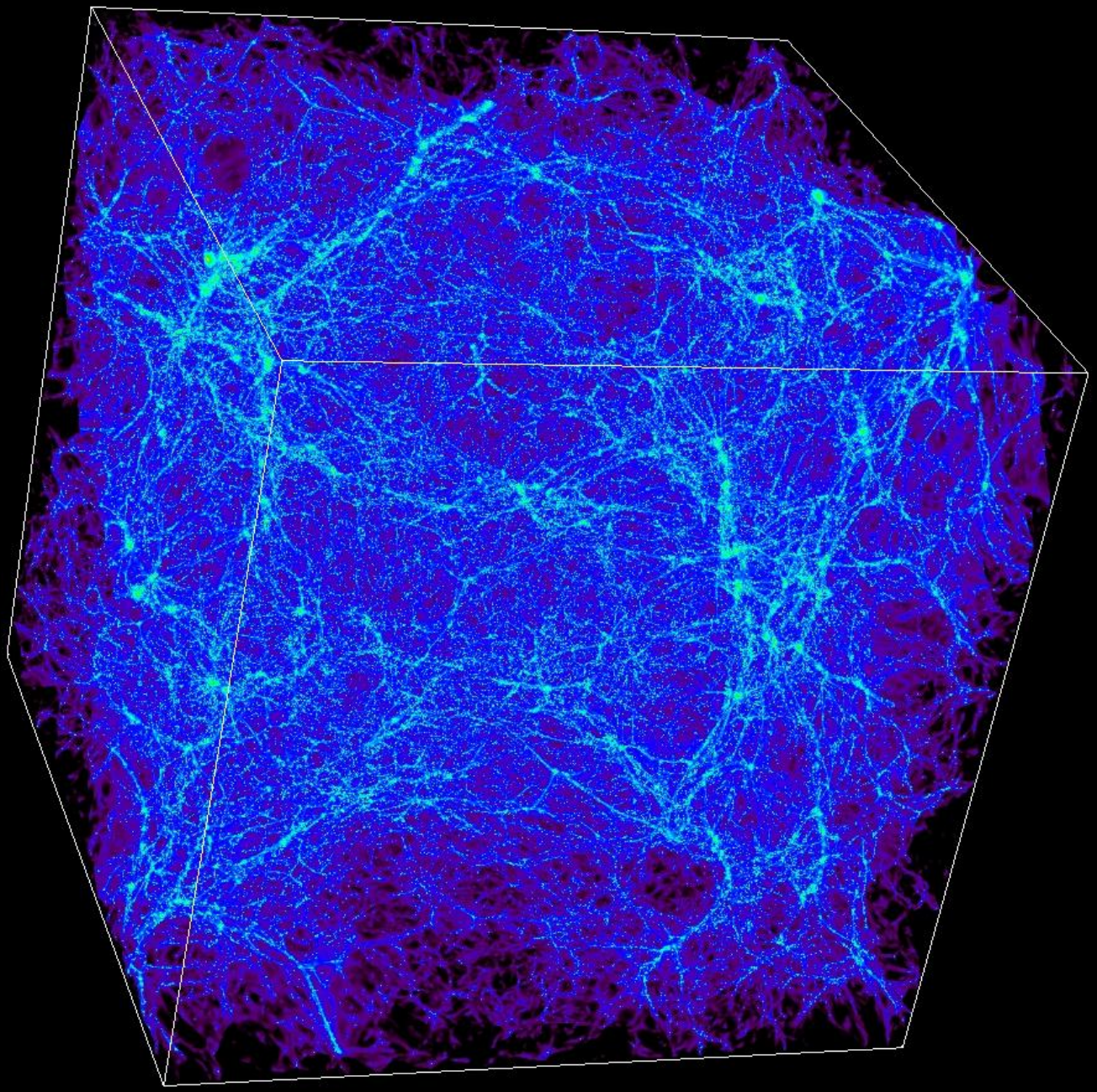
Visualization software : SDvision

- based on IDL Object Graphics, 65000 lines of code, started in 2005
- the primary intend was to visualize massively parallel simulations produced as part of the COAST « Computational Astrophysics » Project in Saclay

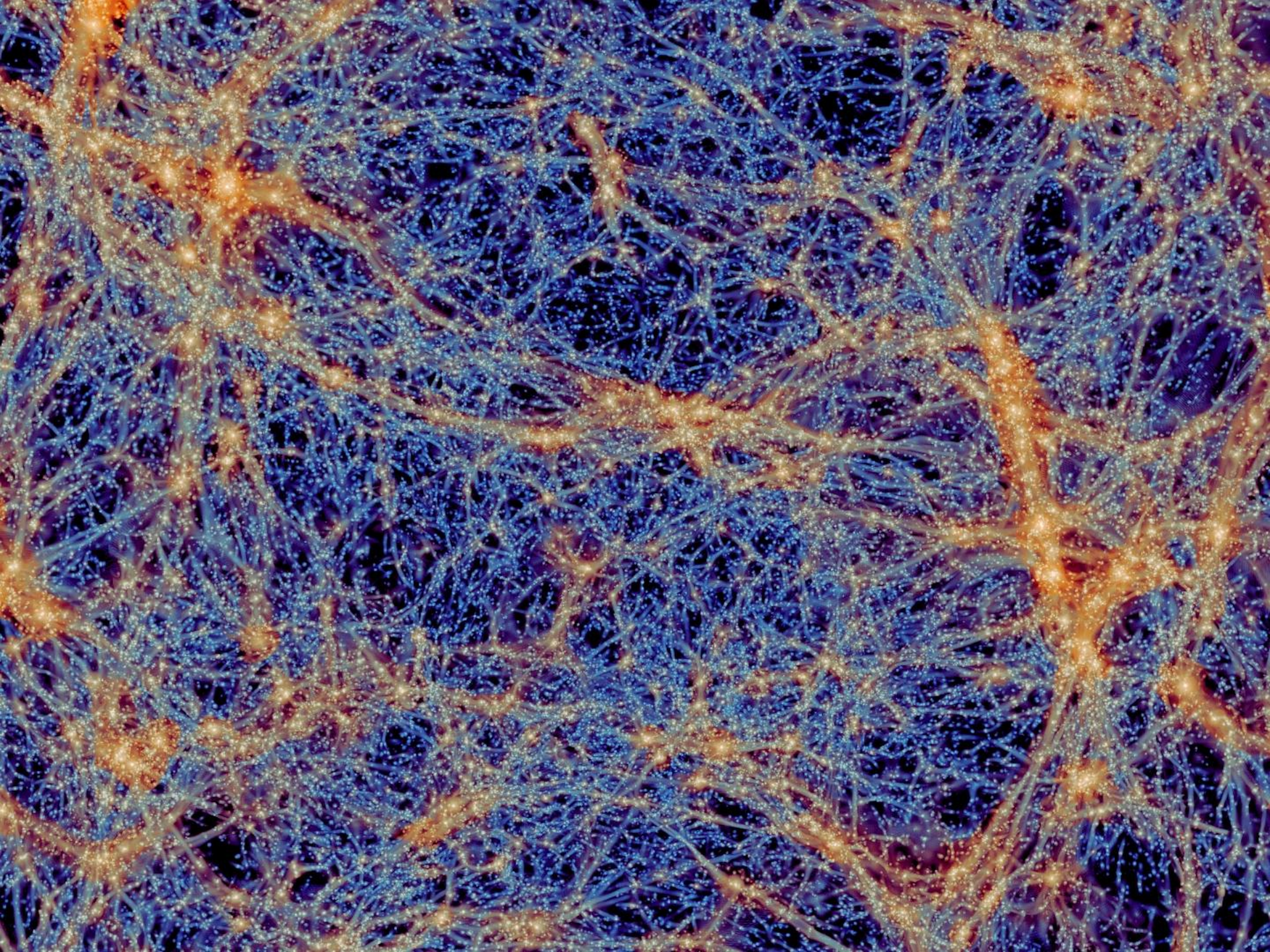


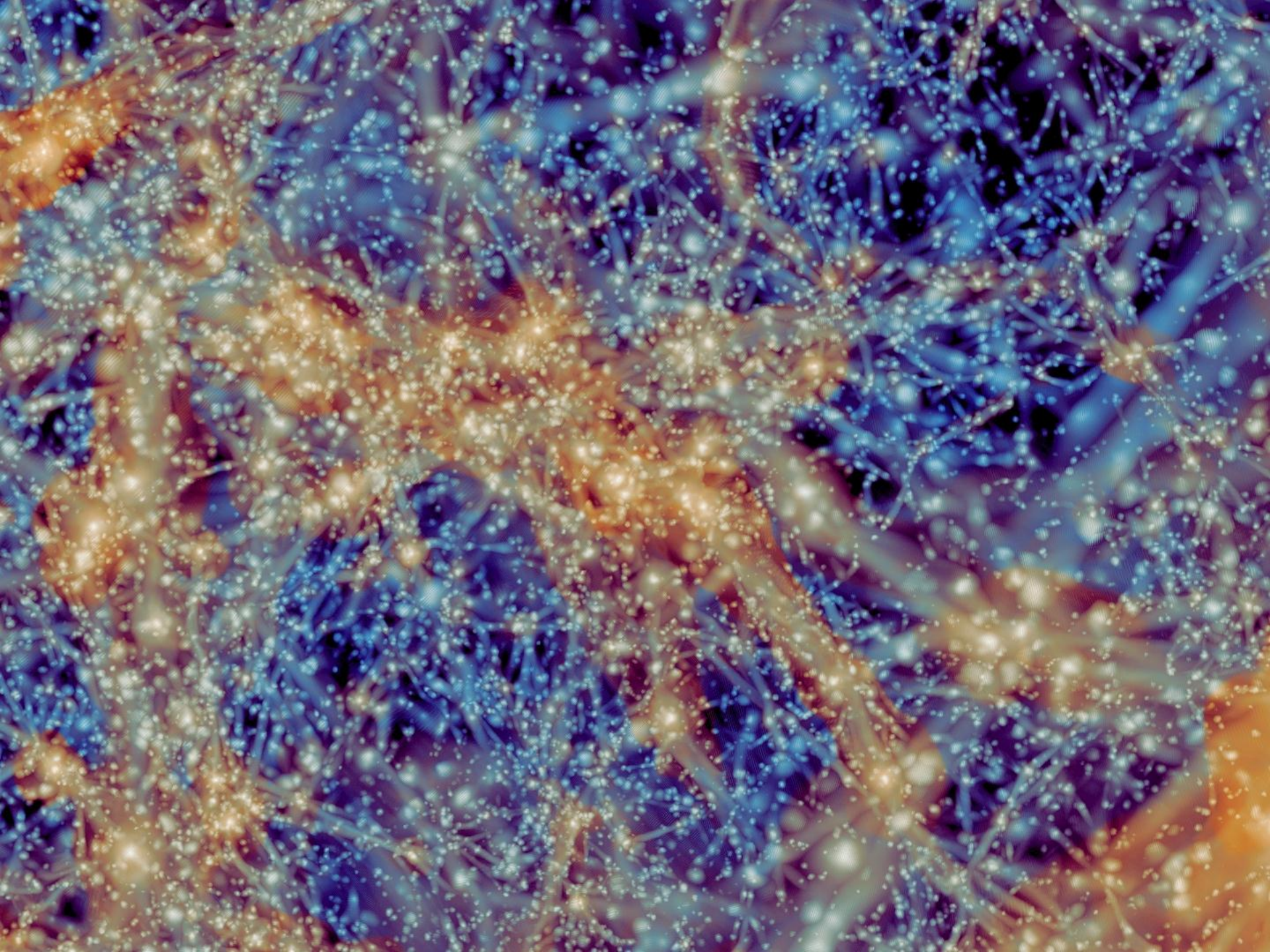
- example of the HORIZON « Galaxy formation » simulation including both the dark matter and the baryon gas
- performed with the RAMSES Adaptive Mesh Refinement code producing 20 TB of data
- using 2048 processors of the MareNostrum mainframe at the Barcelona Supercomputing Center during three weeks in 2007
- Interactive 3D visualization of the baryon density field using the ray-casting technique

RAMSES galaxy formation simumation (HORIZON Collaboration)

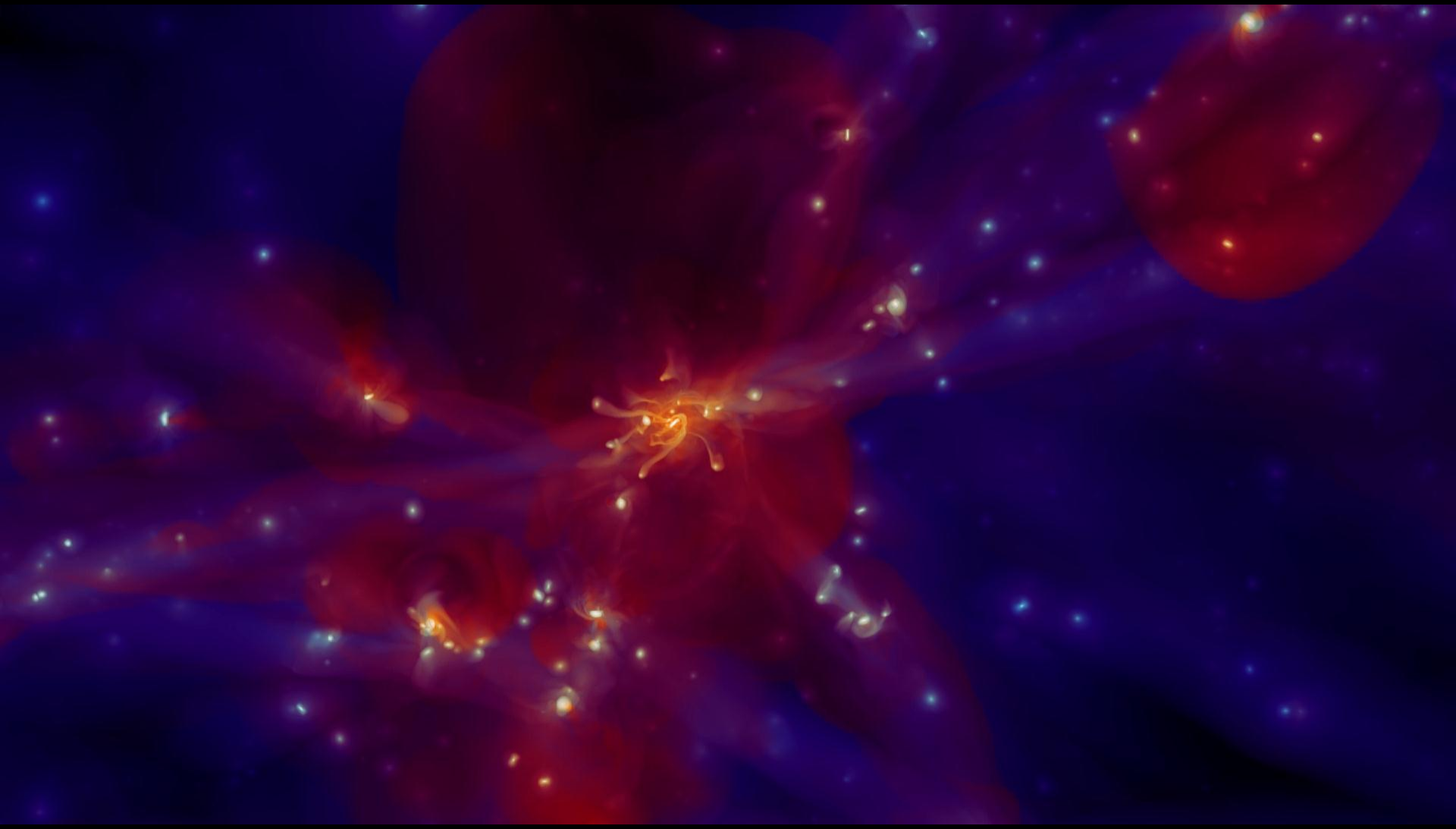


2048 processors
3 weeks of computation
Dimensions : 50 Mpc/h

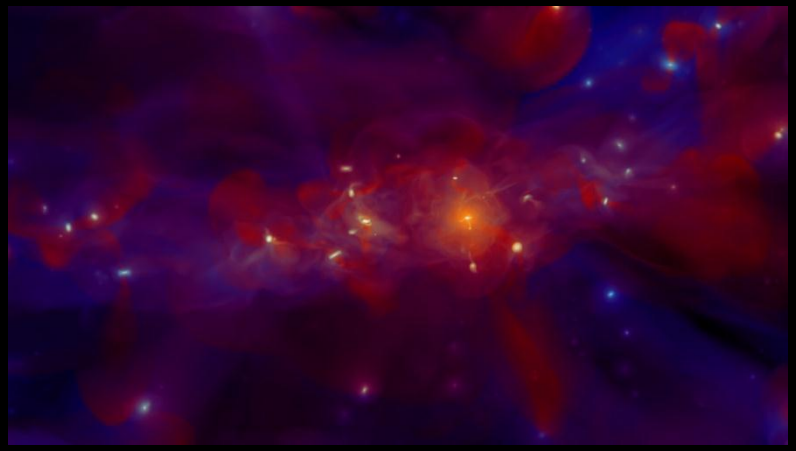




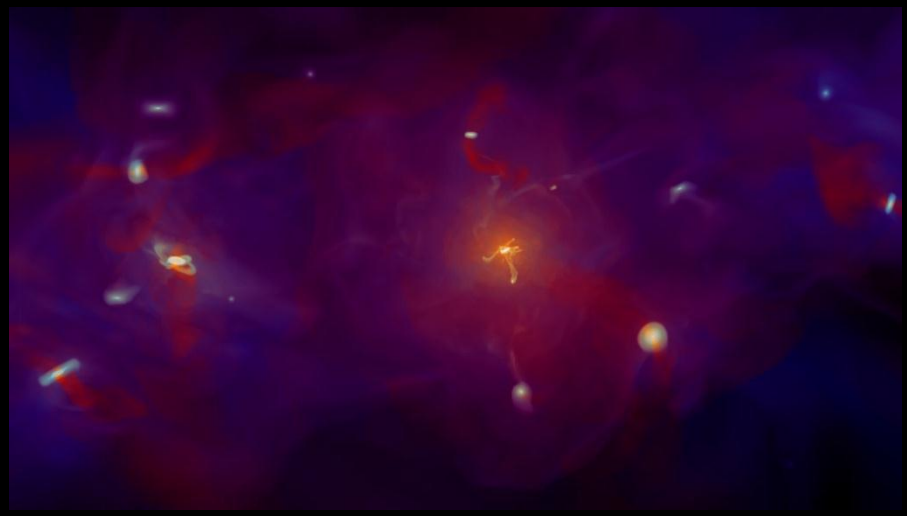
RAMSES zoom simulation: formation of a Milky Way-like spiral galaxy in a cosmological context (R. Teyssier)

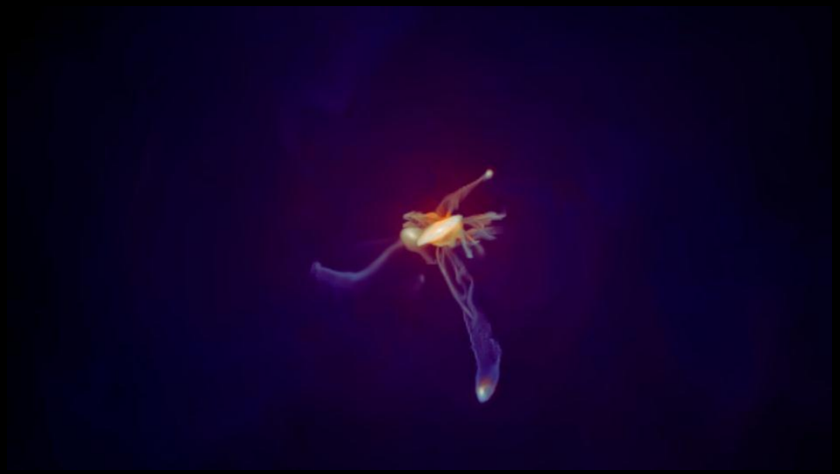


The galaxy is nourished by cold gas coming from the filaments. Hot gas is injected in the environment (“supernovae feedback”).



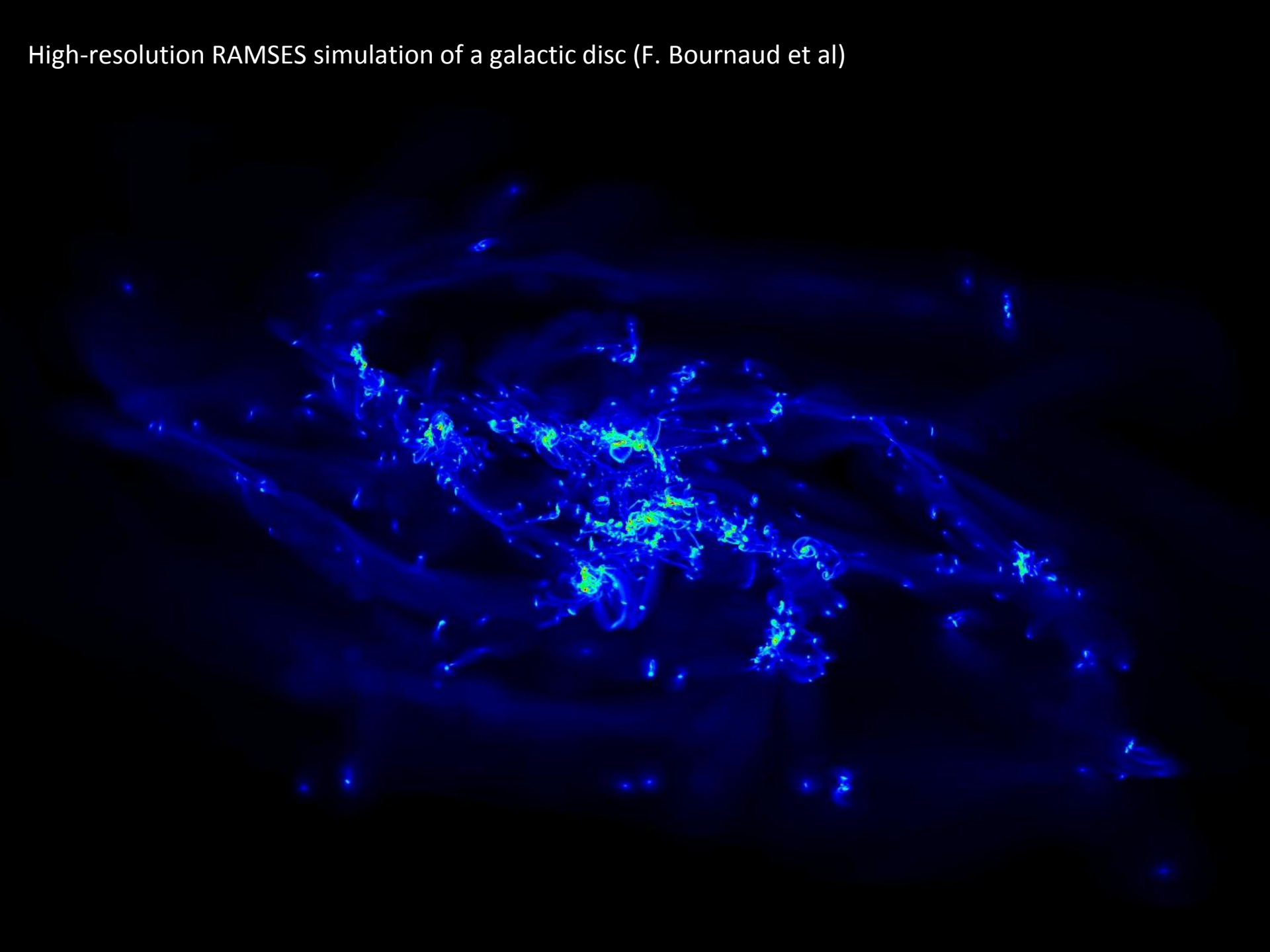
Zoom on the final state



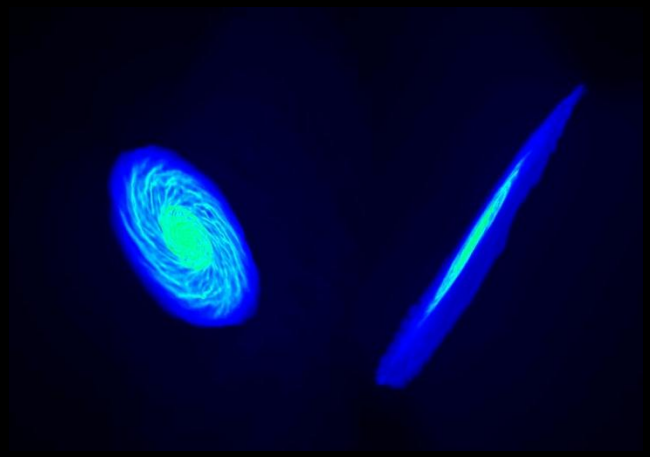


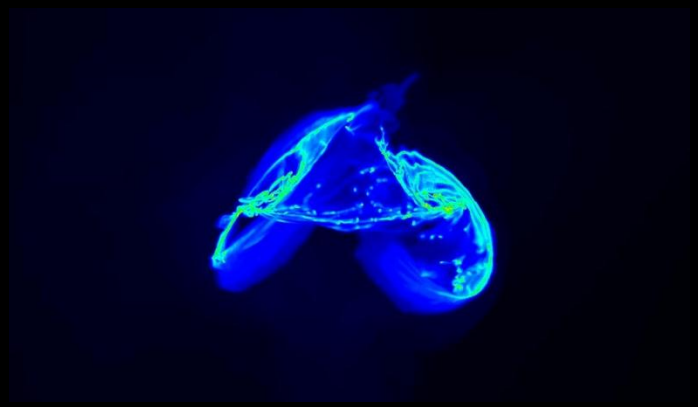
A spiral galaxy (the Milky Way) and its satellites (the Magellanic Clouds)

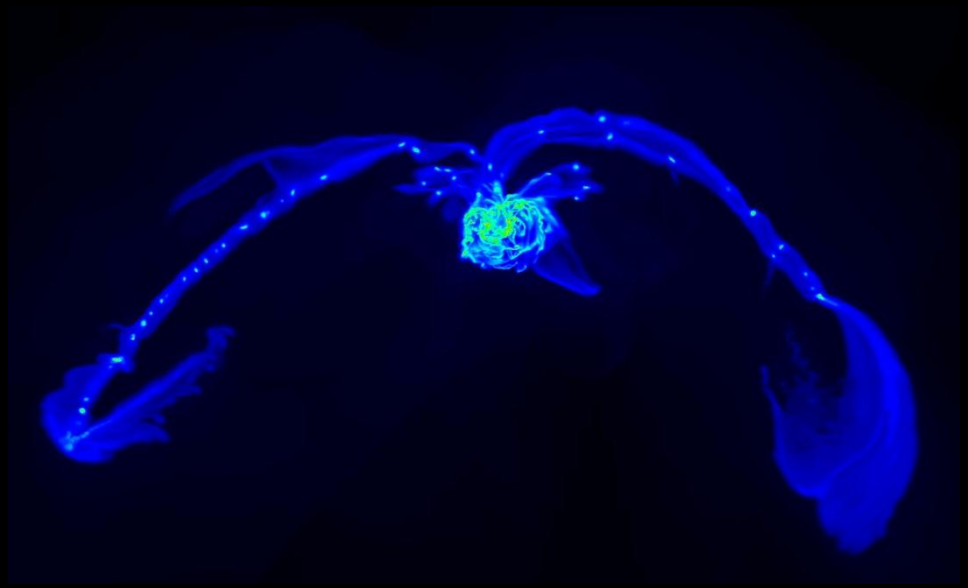
High-resolution RAMSES simulation of a galactic disc (F. Bournaud et al)



RAMSES of the Antennae galaxy interaction (D. Chapon et al)







Visualization of the V8k Catalog

visualisation as a cloud of particles (dots, spheres, sprites)

spatial navigation includes zoom, translations, rotations

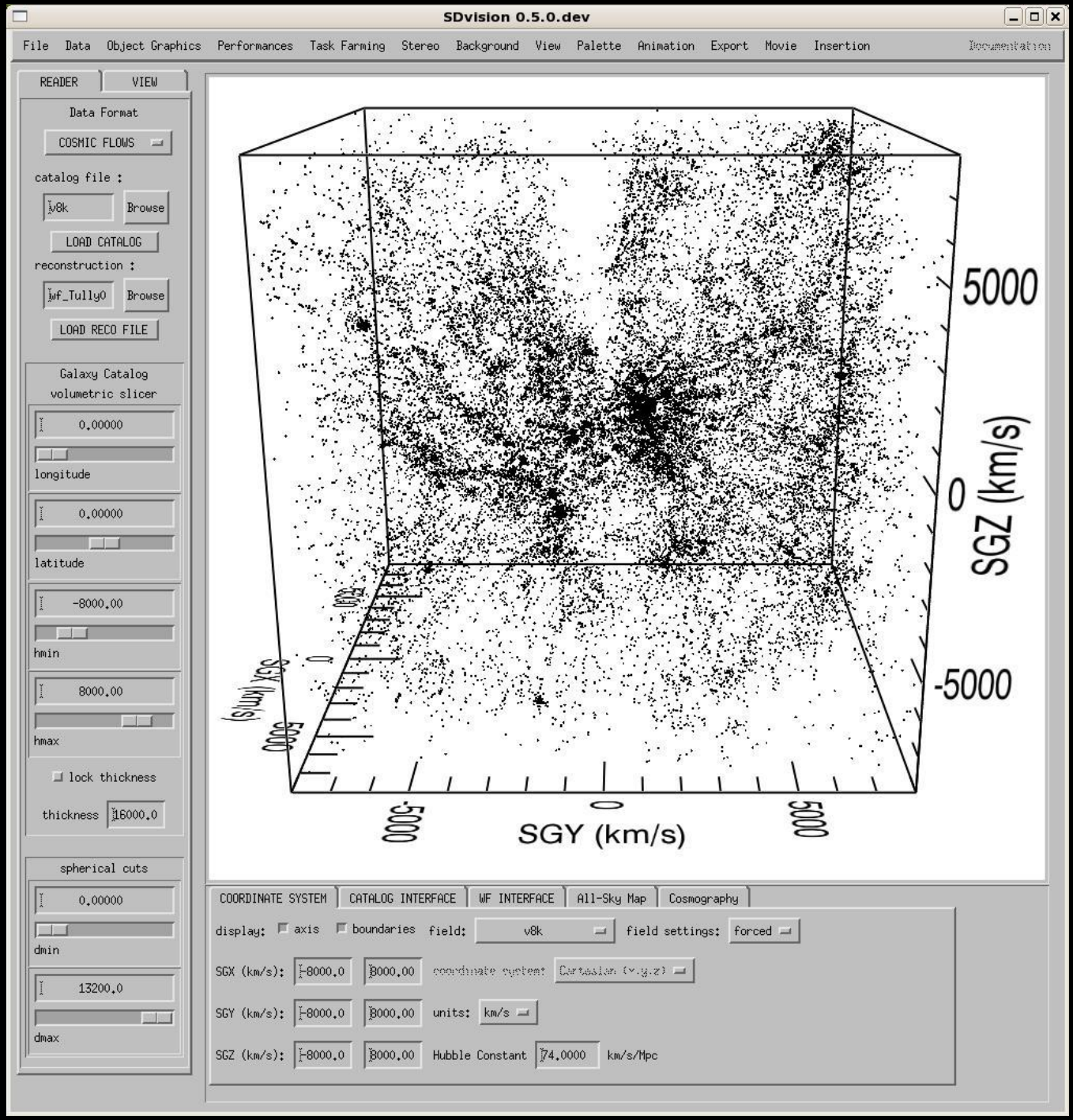
viewing facilities include isometric, perspective, wide-angle view, projection along the supergalactic axes

volumetric slicer to obtain slices along any directions

spherical cuts to obtain shells in the galaxy distribution

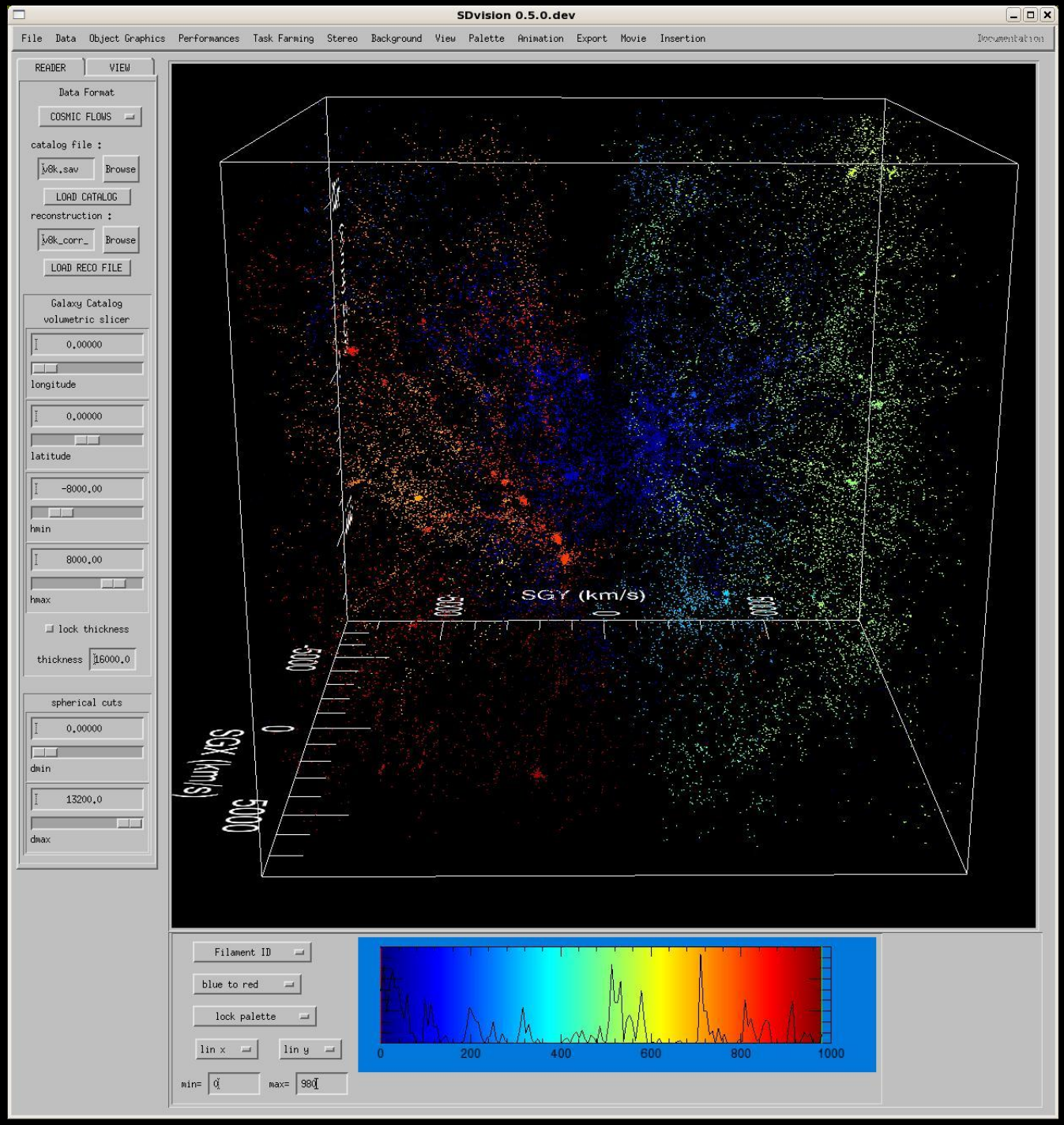
Major structures are readily identified :

- the Local Supercluster dominates the whole picture
- the Great Wall
- the Perseus-Pisces Chain
- the Pavo-Indus Chain

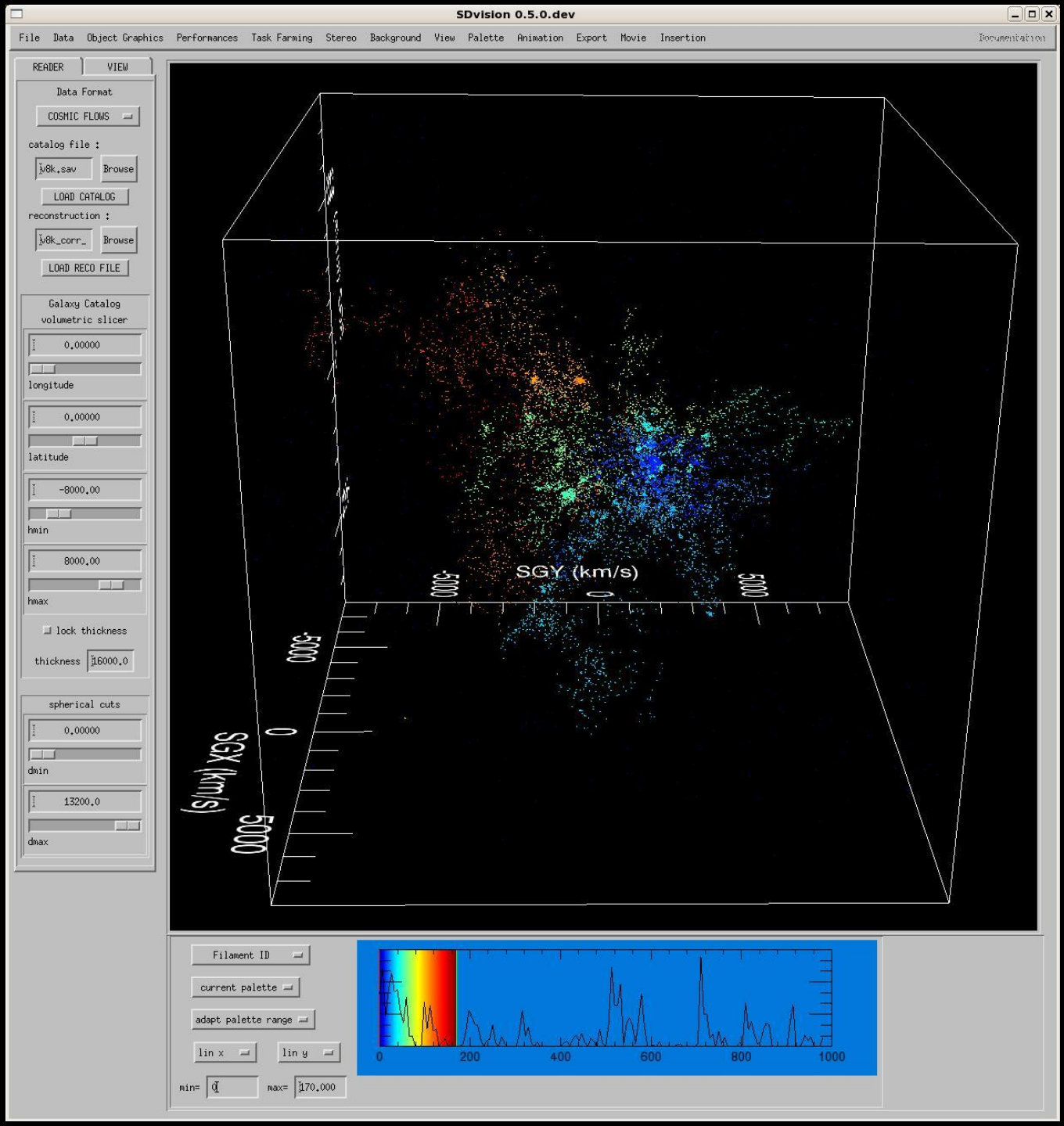


Galaxy color is set against the FilamentID

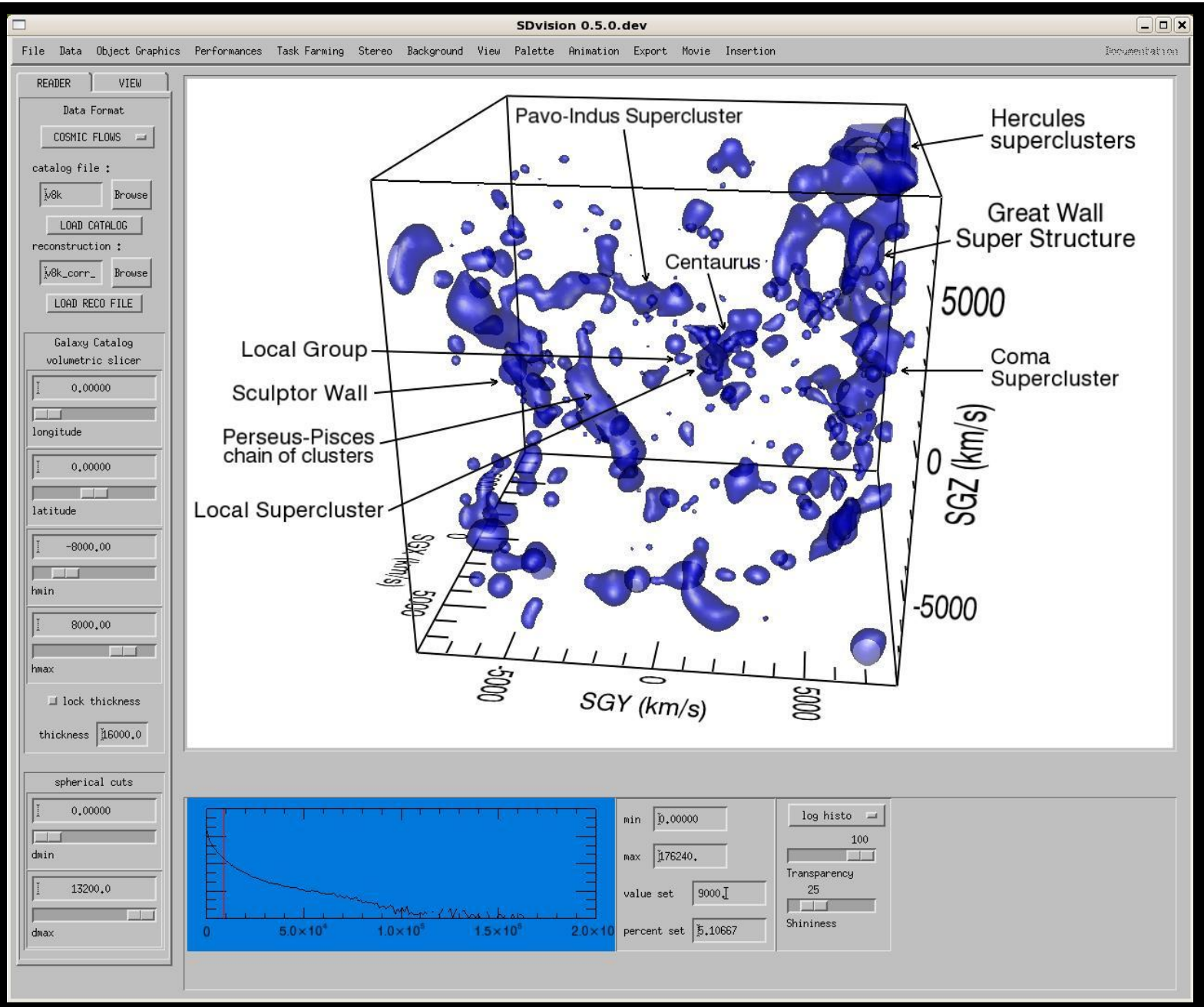
- the histogram shows the distribution of this variable
- the color palette shown in the background of the histogram is used to provide the colors to the galaxies
- this palette can be tuned using a dedicated interface
- a subsample of galaxies can be selected against this FilamentID distribution by setting a min and a max
- this can be done by clicking directly on the histogram or filling the min and max fields
- the color palette can either be stretched between the min and the max or kept locked
- variables other tha FilamentID can be used, for example the *Mabs*



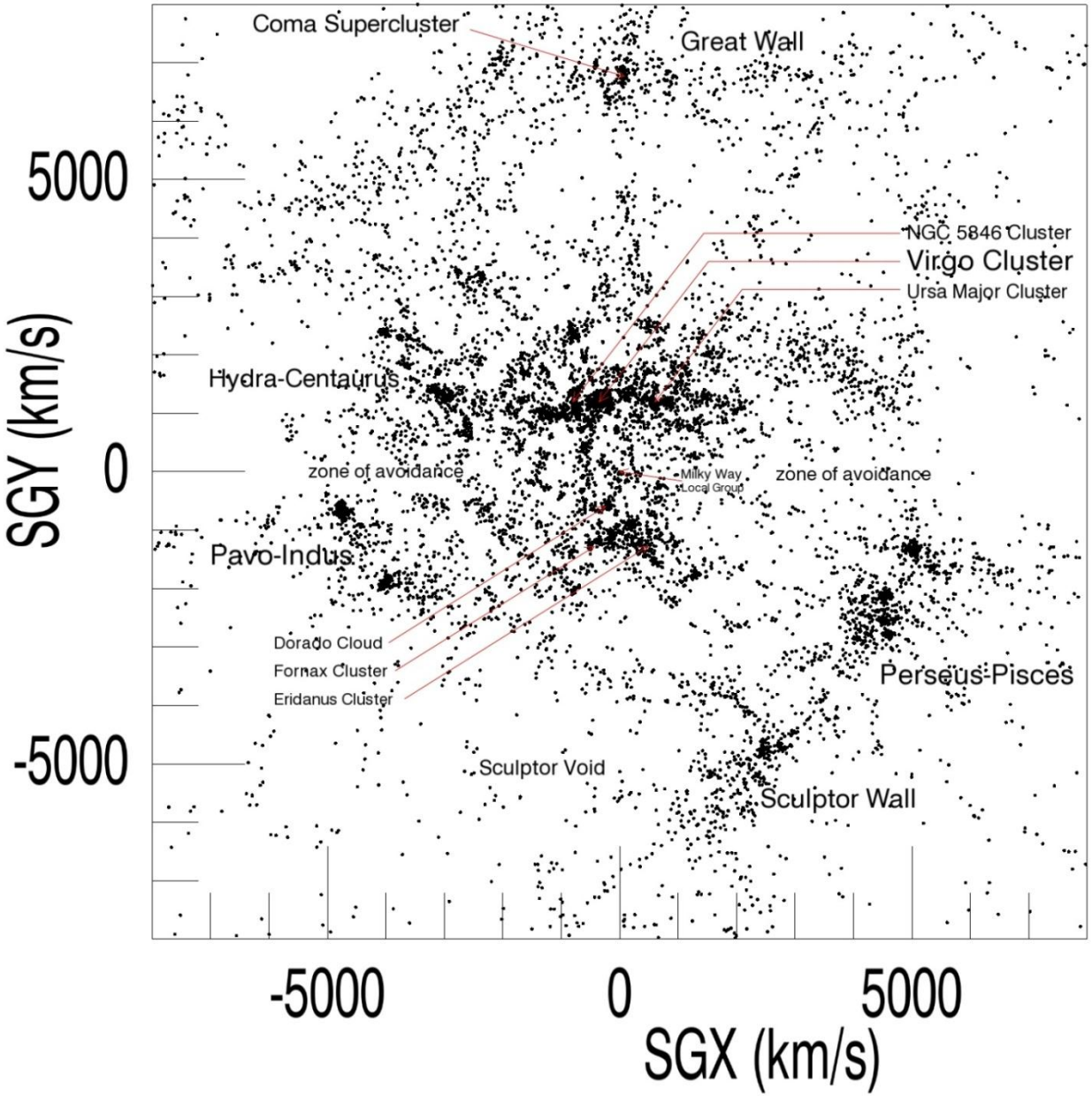
- here the selection is $0 \leq \text{FilamentID} \leq 170$
- we see the Virgo, Centaurus and Pavo-Indus filaments
- here the palette has been stretched to span over the selected sample to gain visual discrimination between the various compo-nents



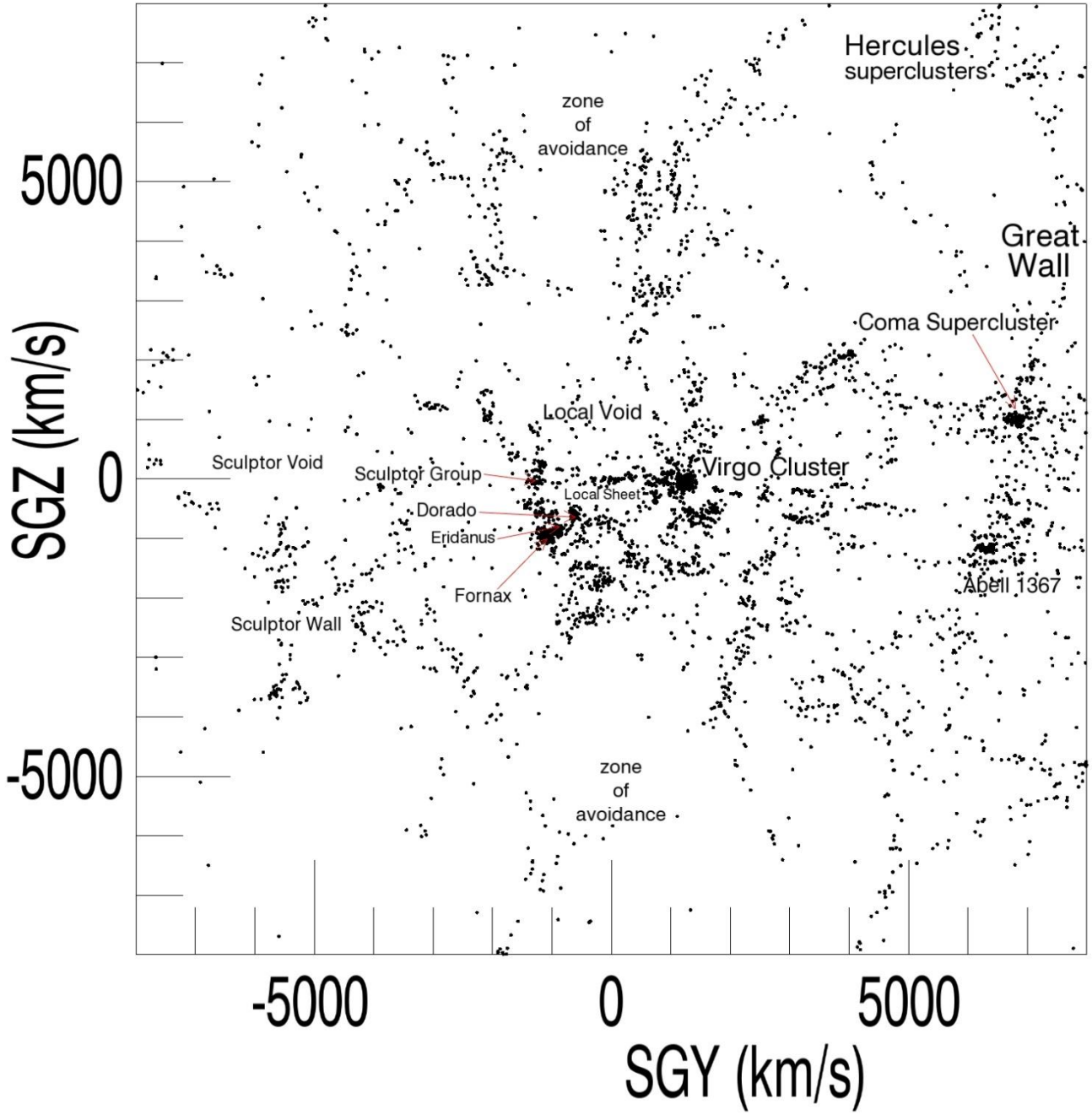
V8k density field corrected for the incompleteness by fitting the catalog with a Schechter function
Visualization of a high-density isosurface



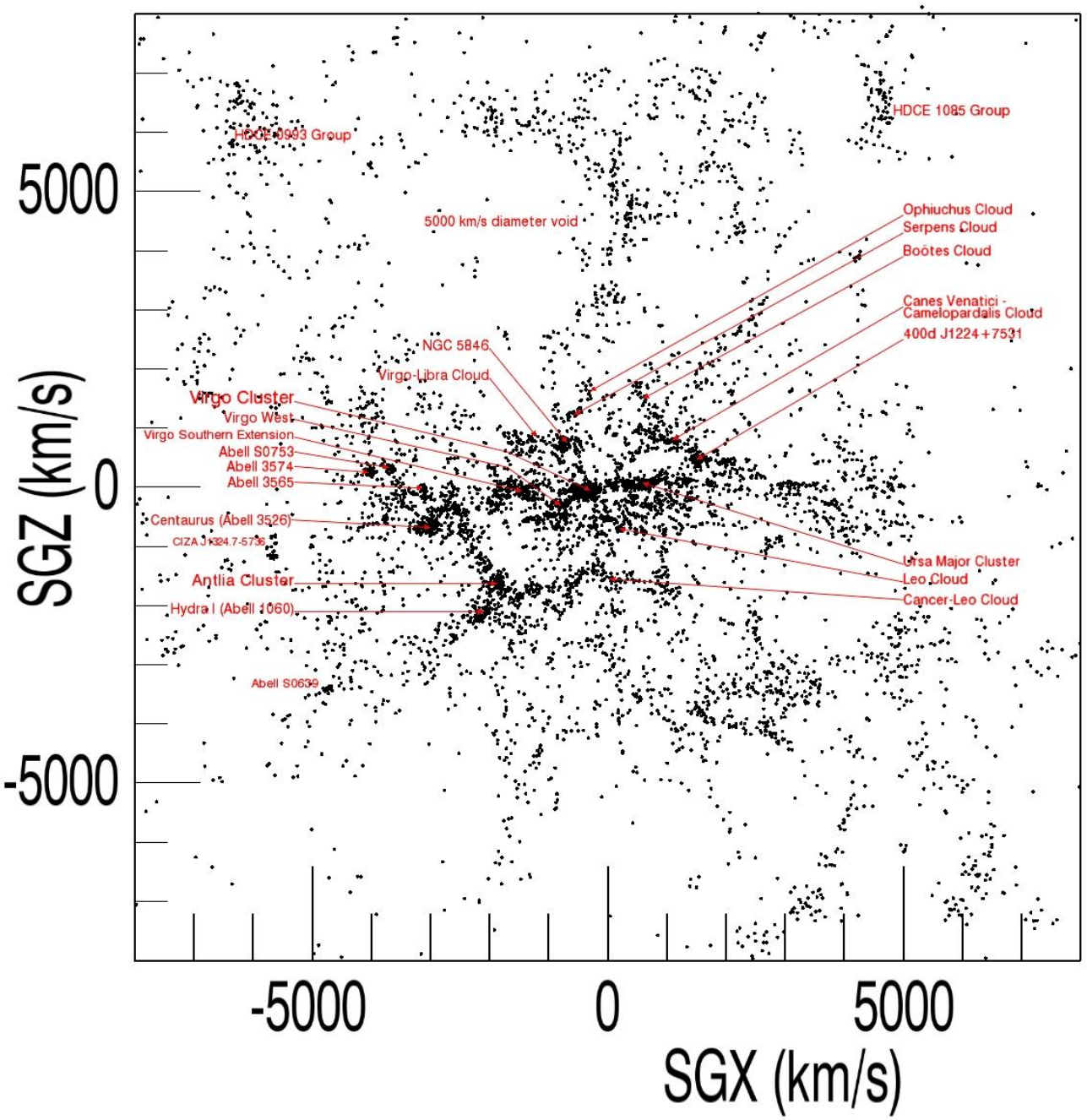
Map of the Supergalactic plane : -1000 km/s ≤ SGZ ≤ 1000 km/s



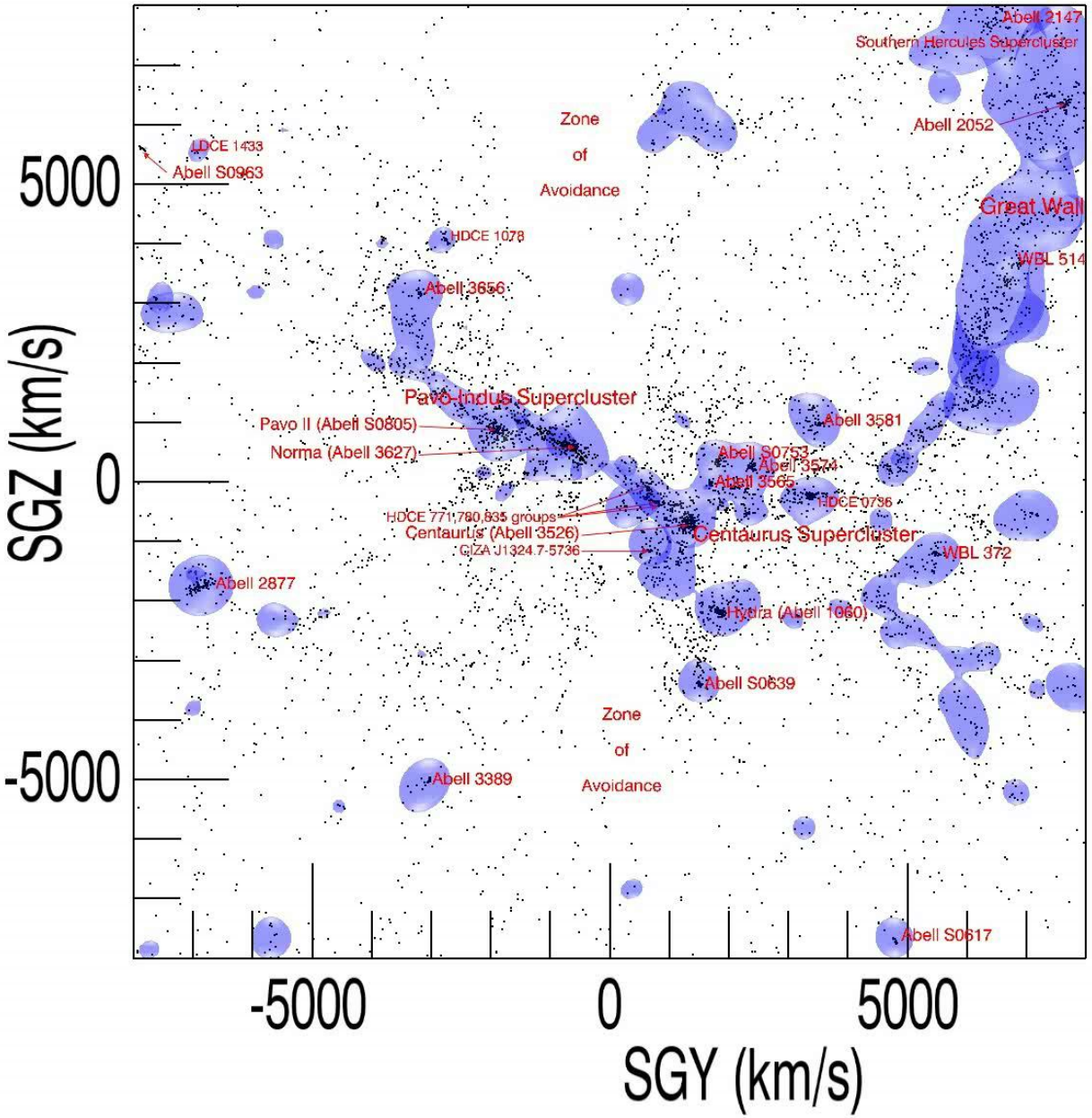
Map of the SGY-SGZ slice containing the Local Void : -500 km/s ≤ SGX ≤ 500 km/s



Map of the SGX-SGZ slice containing Centaurus and Virgo : 500 km/s ≤ SGY ≤ 2500 km/s

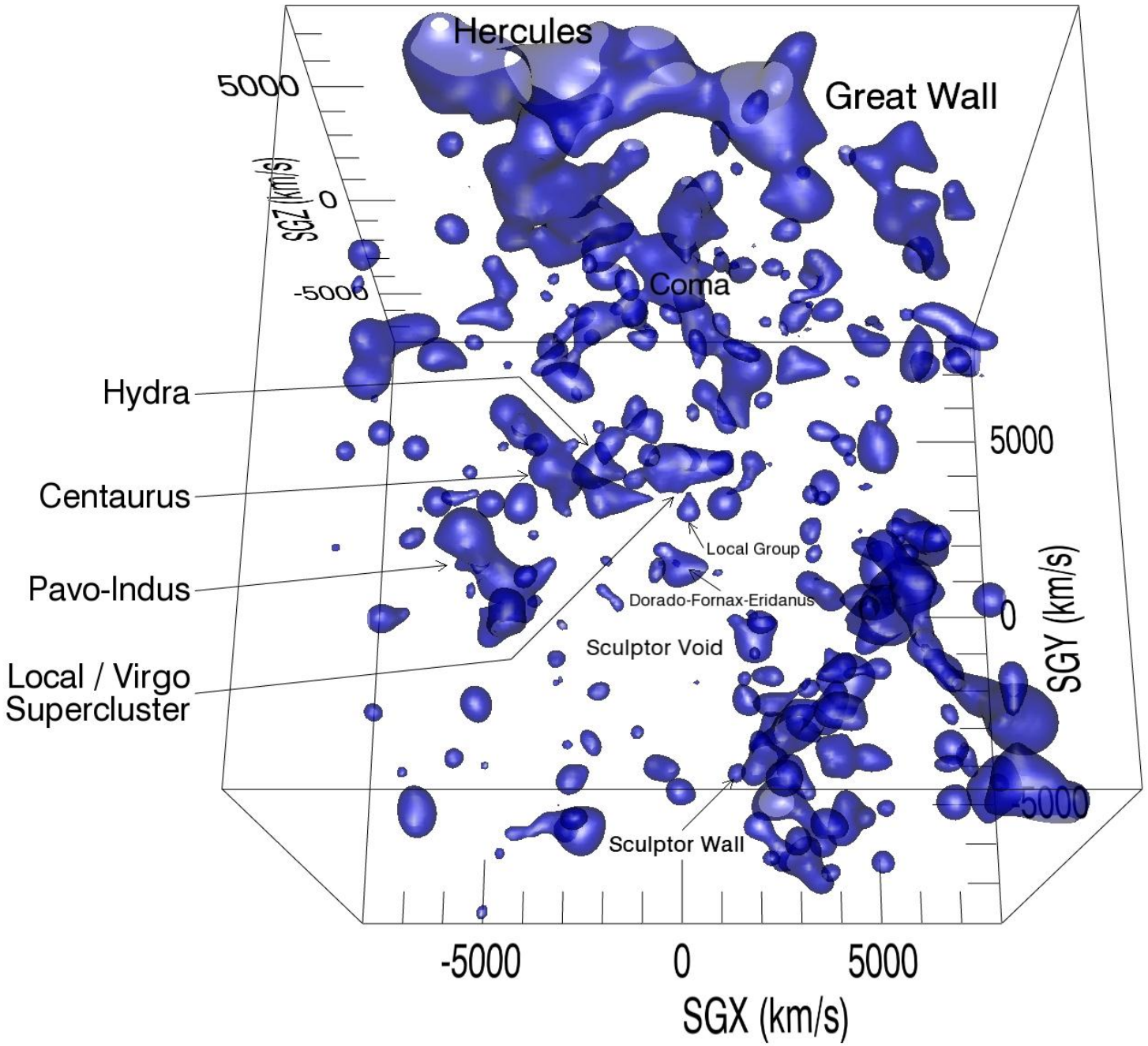


Map of the SGY-SGZ slice containing Norma, Hydra and Centaurus : -6000 km/s ≤ SGX ≤ -2000 km/s



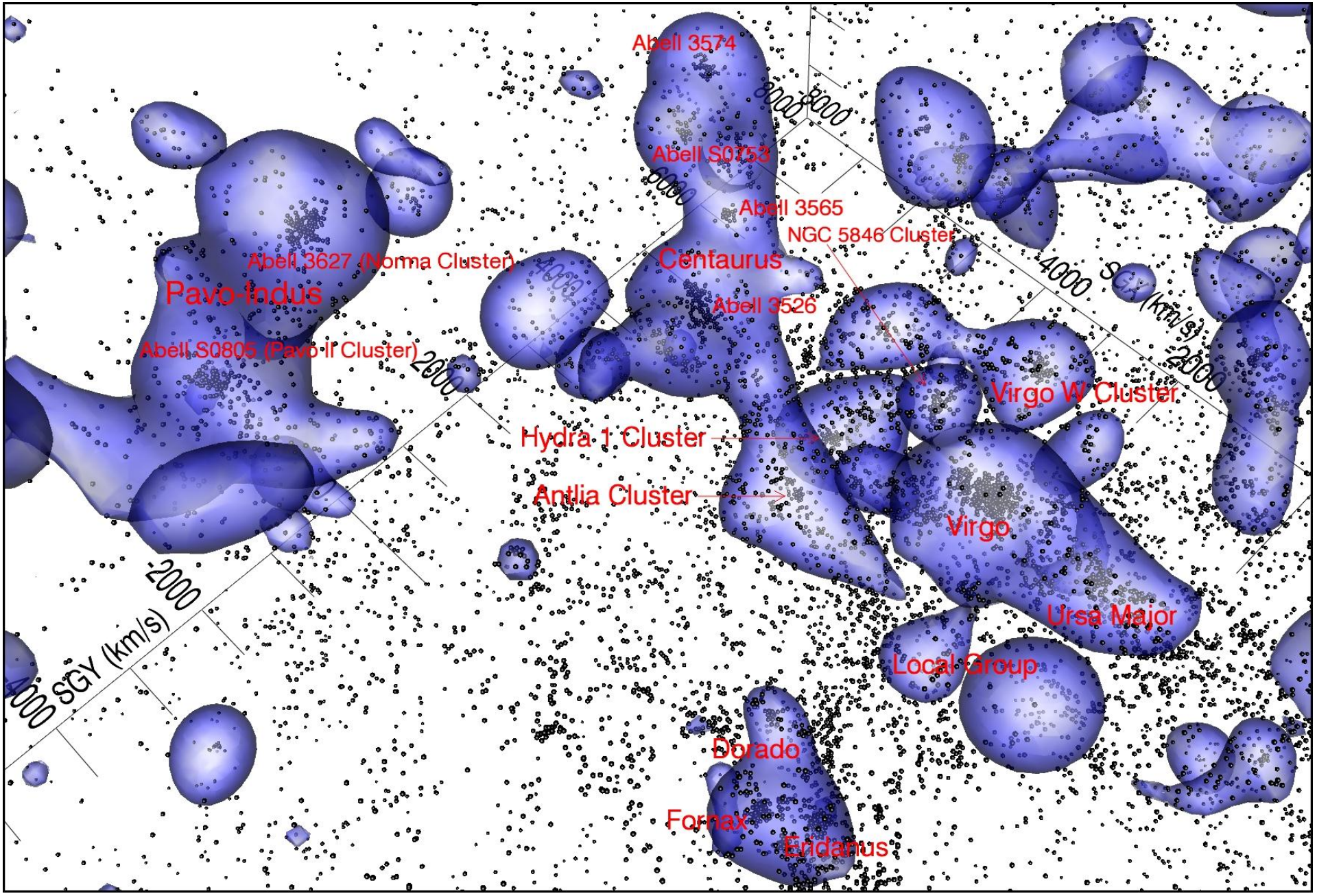
Cosmography : 3D maps

V8k corrected – Top view



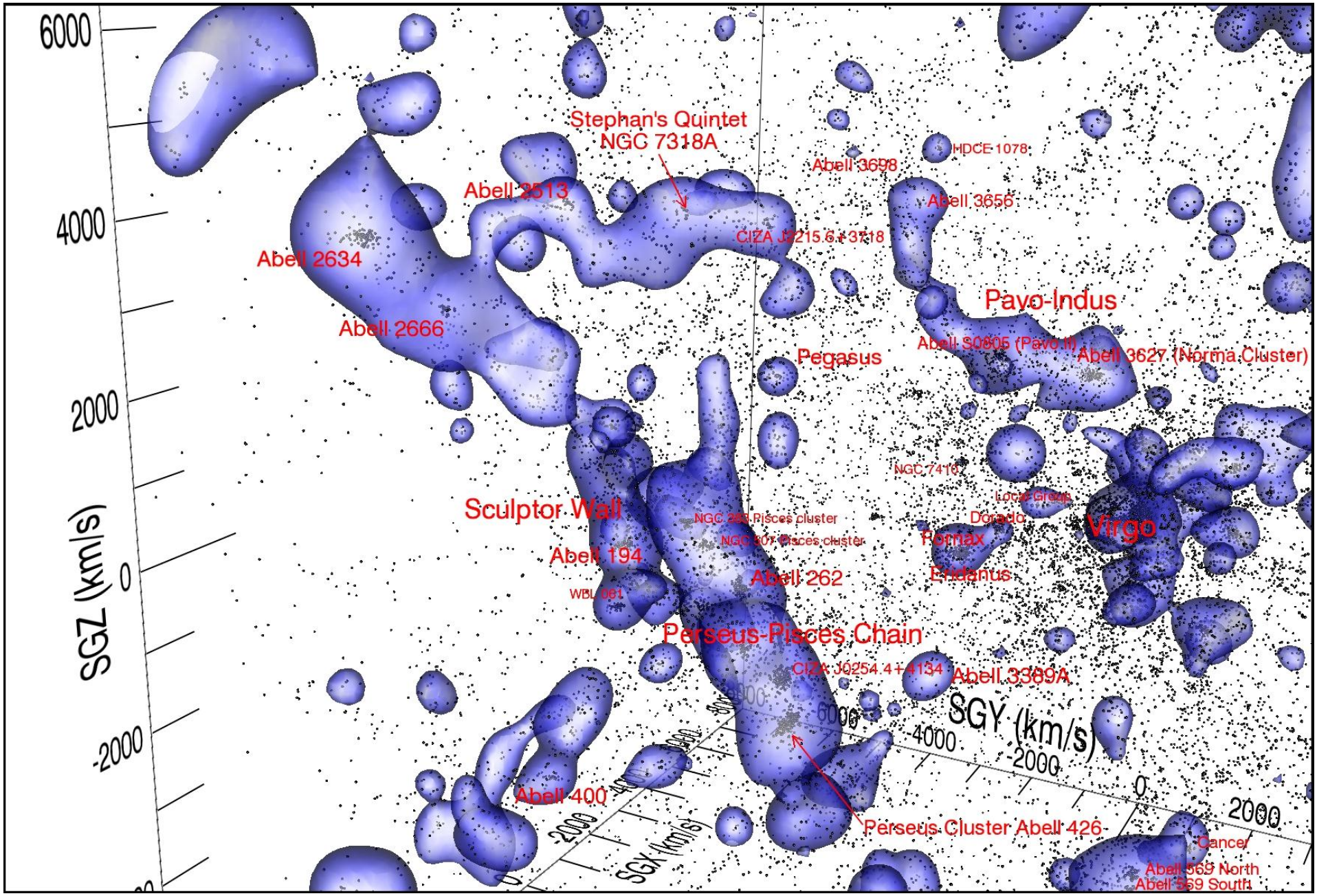
Cosmography : 3D maps

V8k corrected + V8k galaxies
closeup view toward the Hydra-Centaurus complex

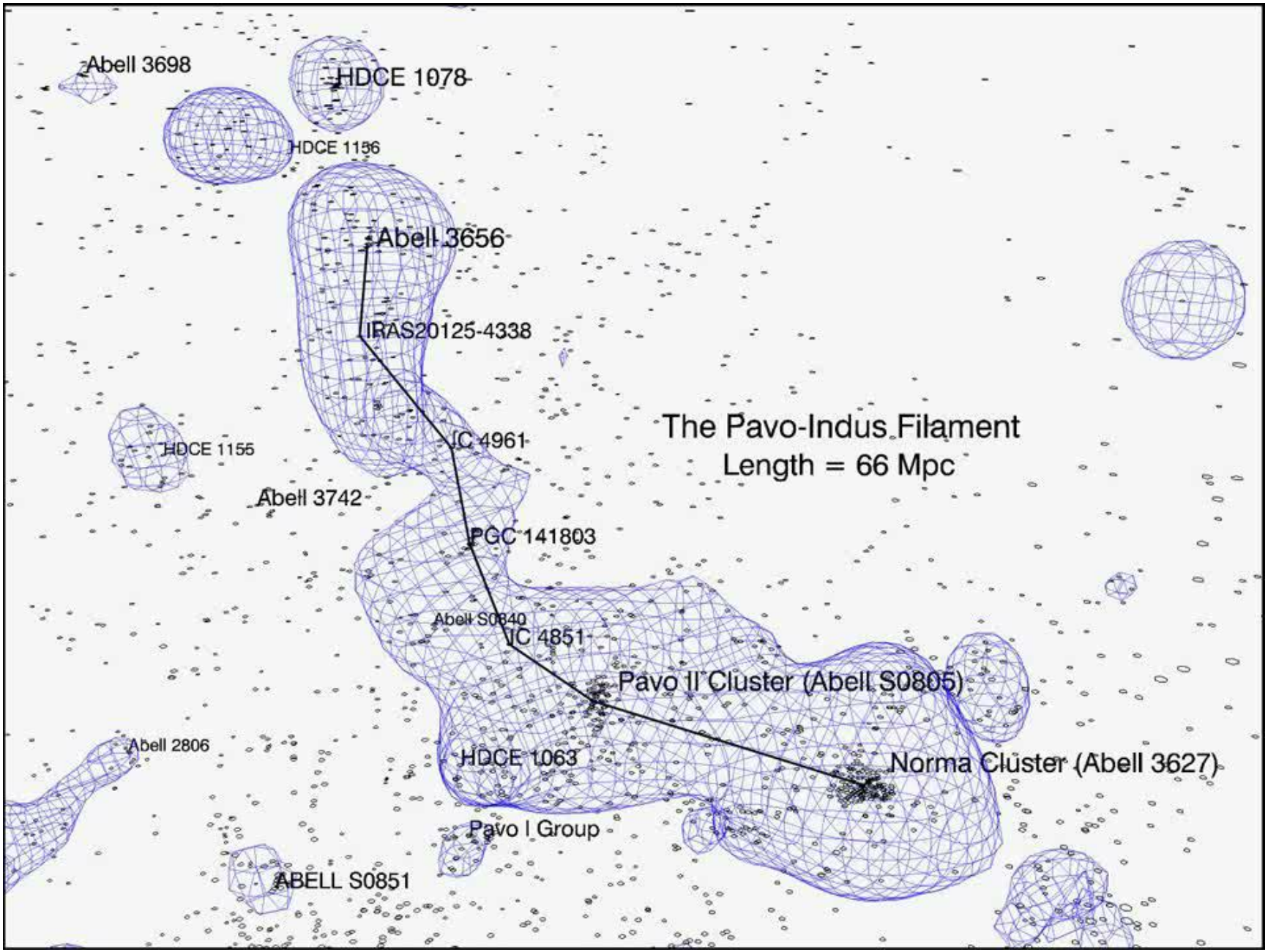


Cosmography : 3D maps

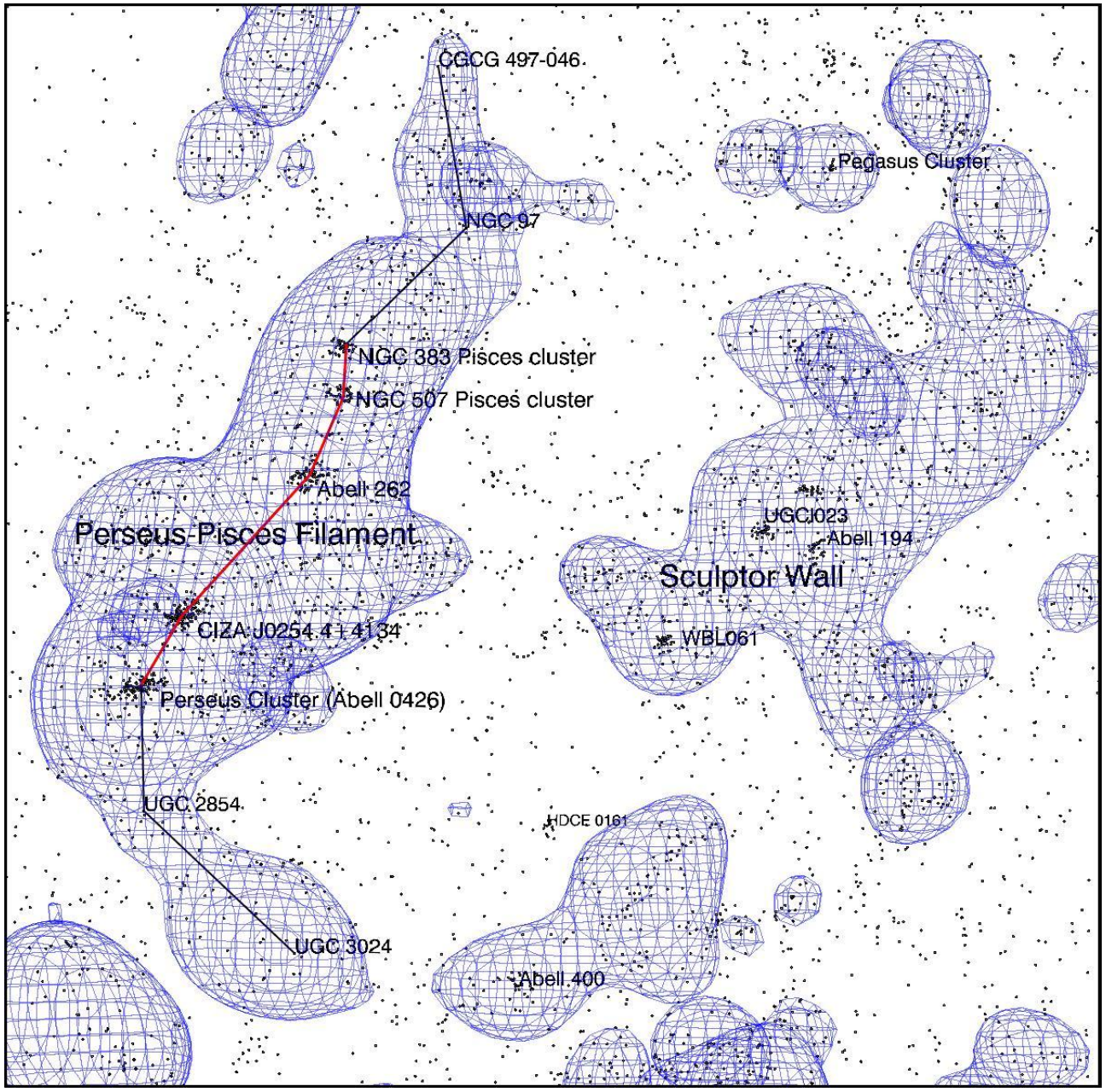
V8k corrected + V8k galaxies
closeup view toward the Pegasus sector



Cosmography : characterization of structures



Cosmography : characterization of structures



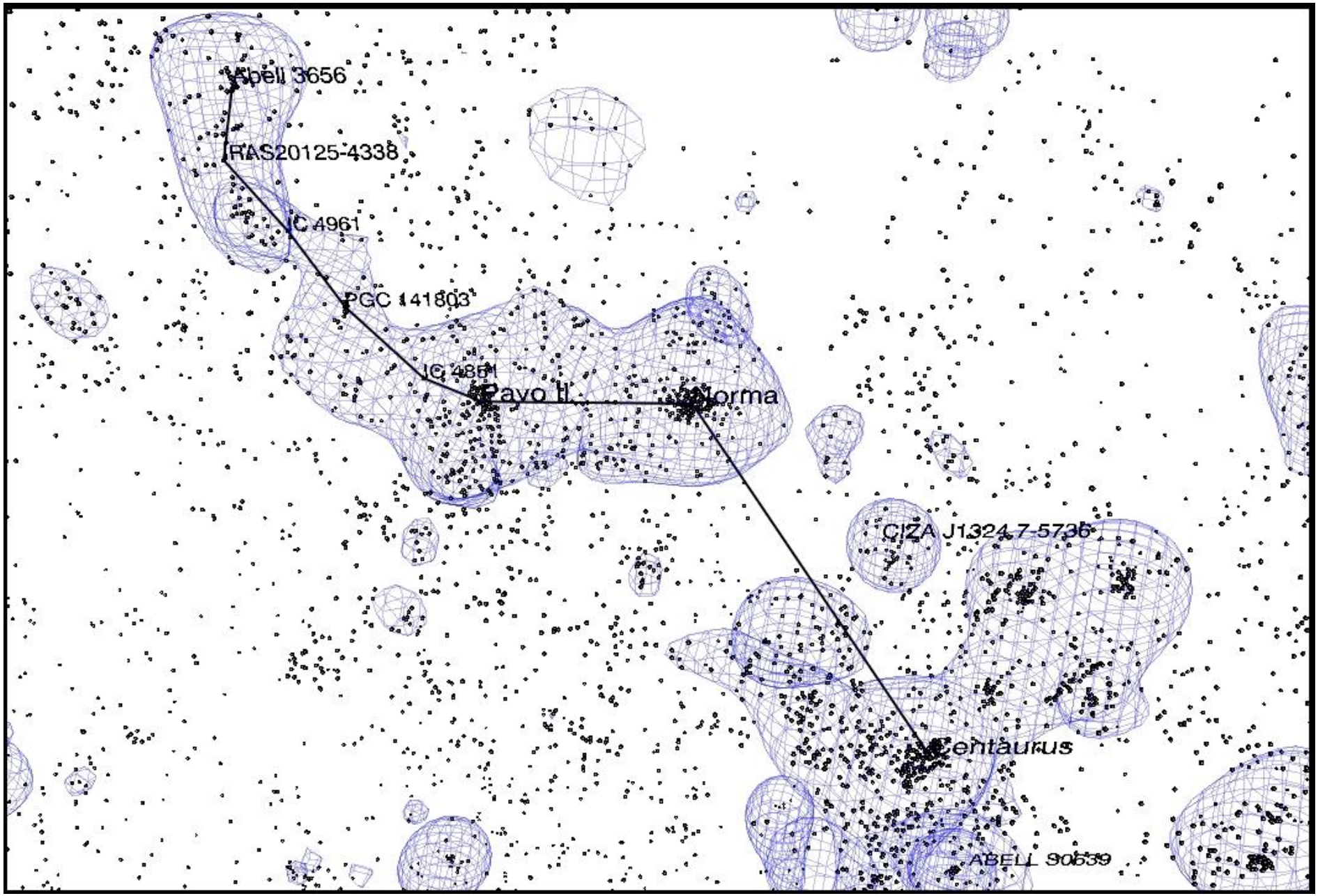
The Perseus-Pisces filament

perspective view

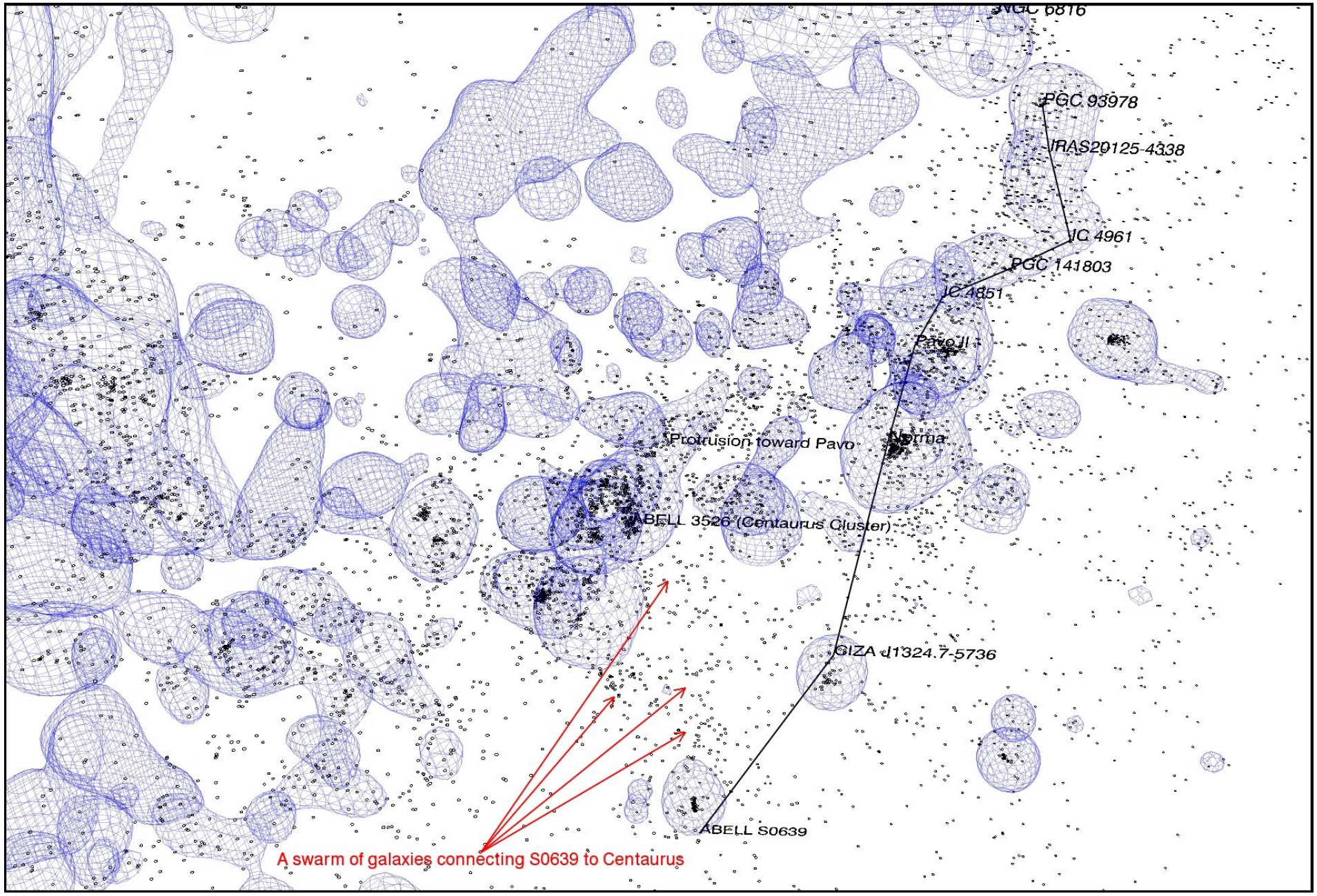
Estimates of its full length :

- **cluster-to-cluster 2700 km/s = 35 Mpc**
- **tip-to-tip 6600 km/s = 87 Mpc**

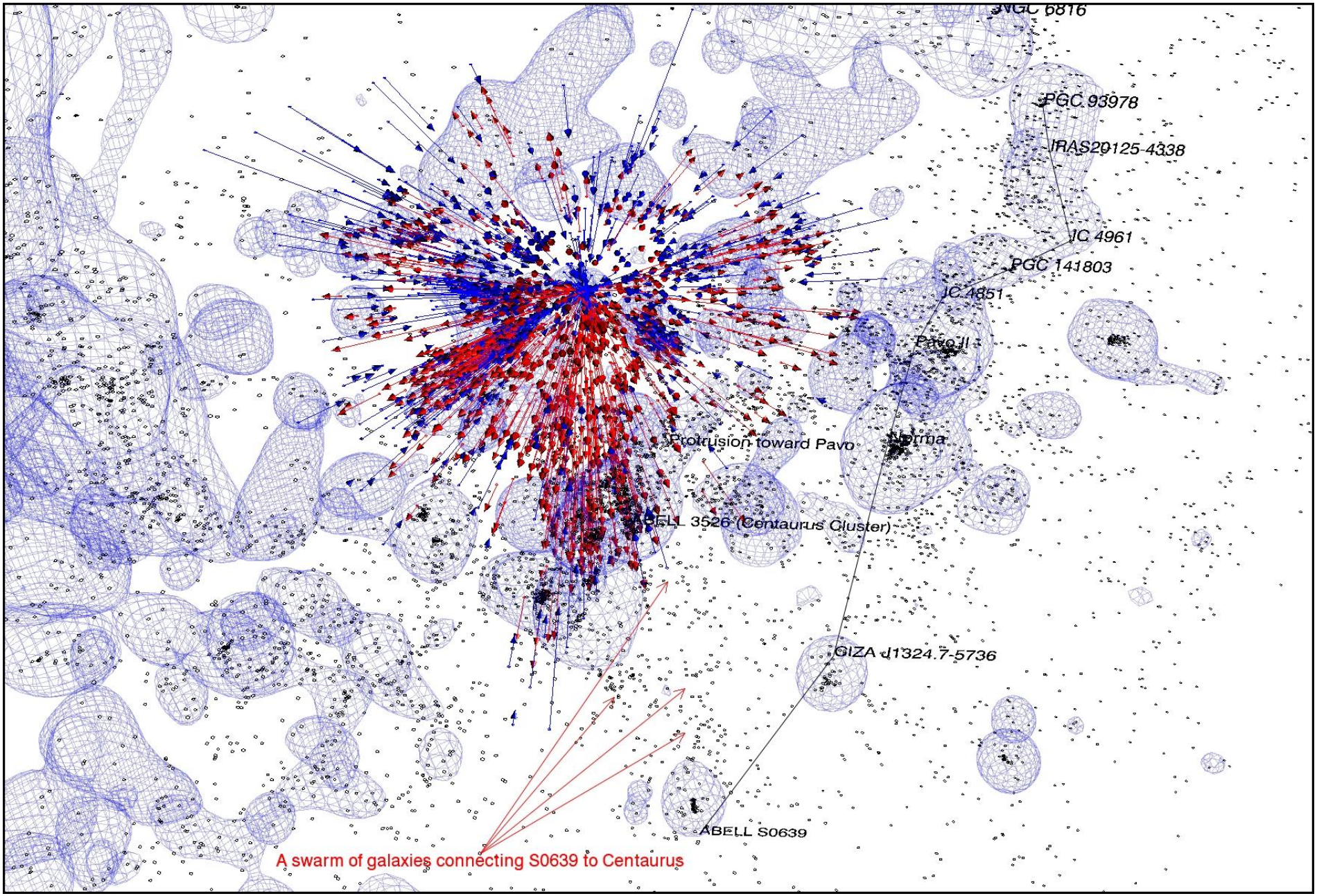
Visual testing of the hypothesis of a connection between Norma and Centaurus
total filament length = 7900 km/s = 104 Mpc



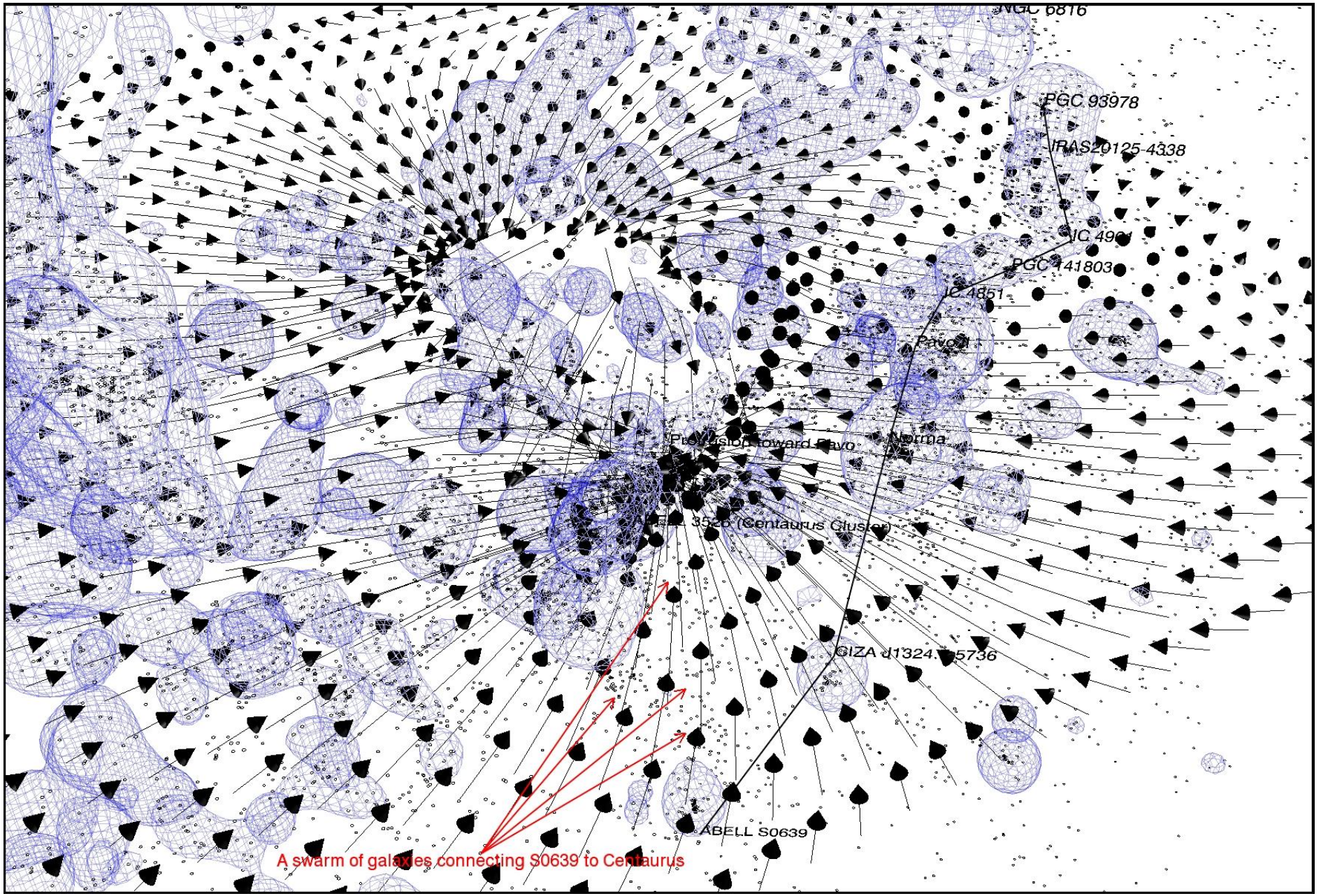
investigation of possible connections with Norma across the ZOA : the Norma Wall ?



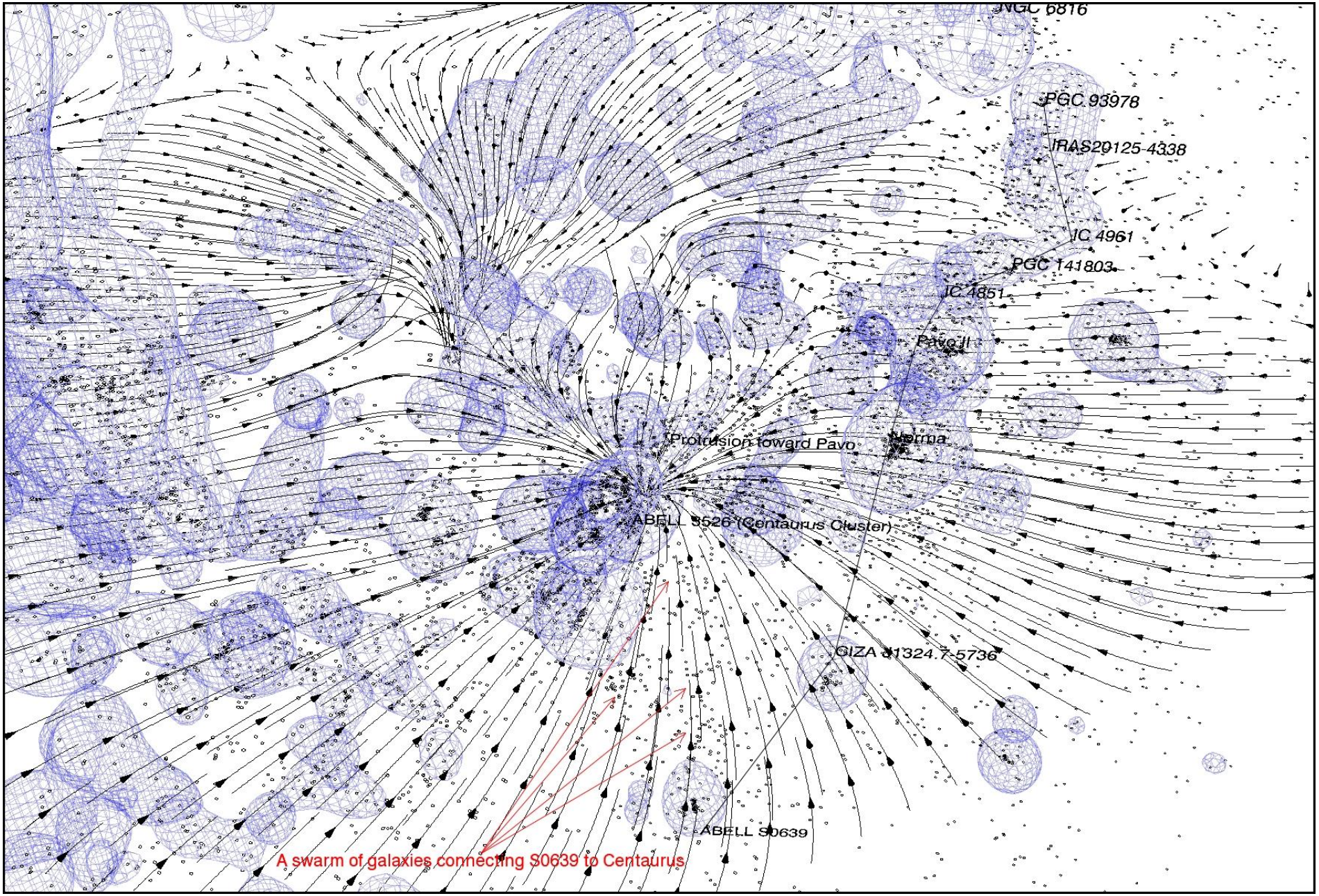
3D visualization of the Cosmicflows-1 galaxies radial velocities



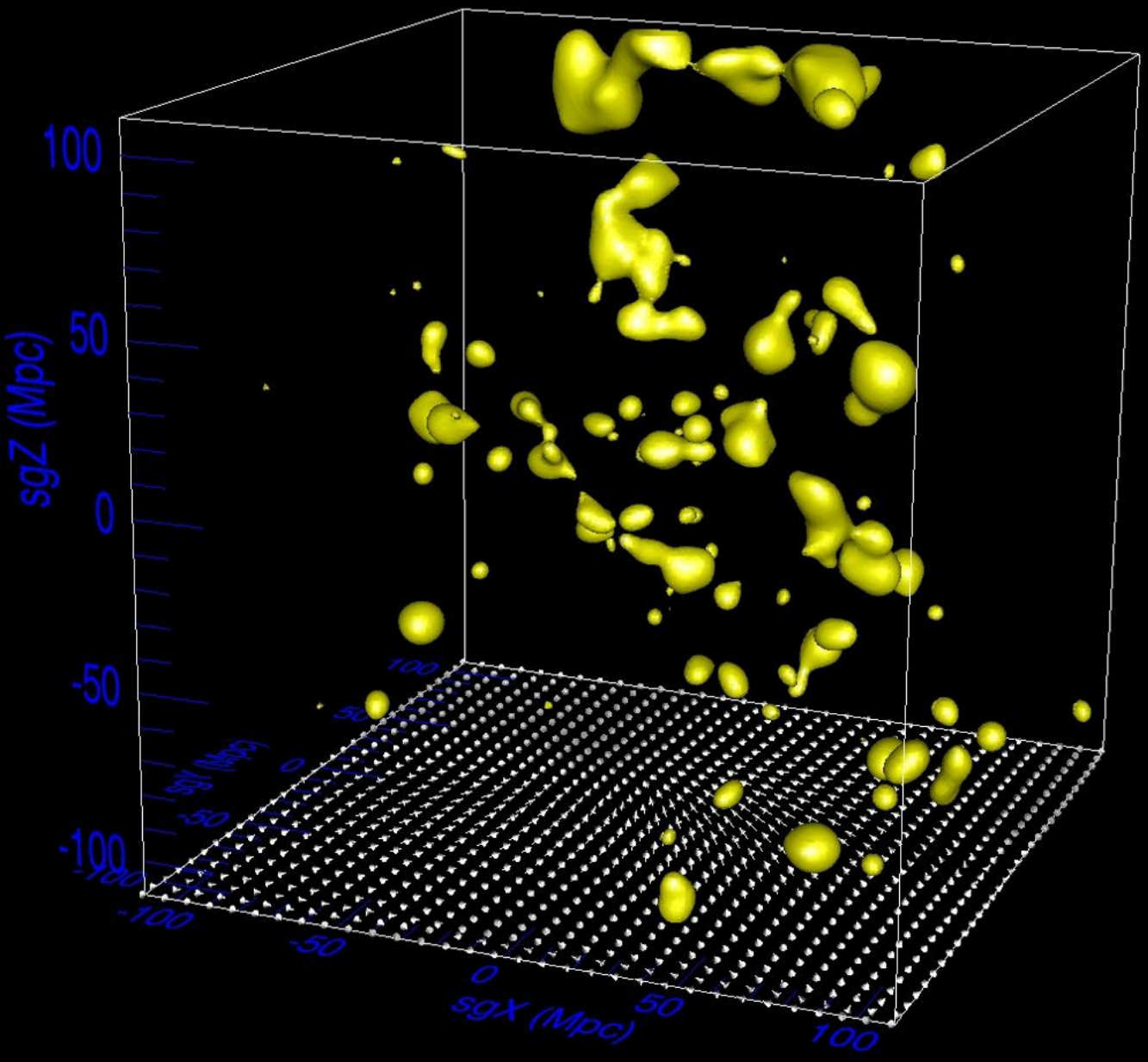
3D visualization of cosmic flows reconstructed using the Wiener Filter



3D visualization of cosmic flows reconstructed using the Wiener Filter



Tomography of the cosmic flows



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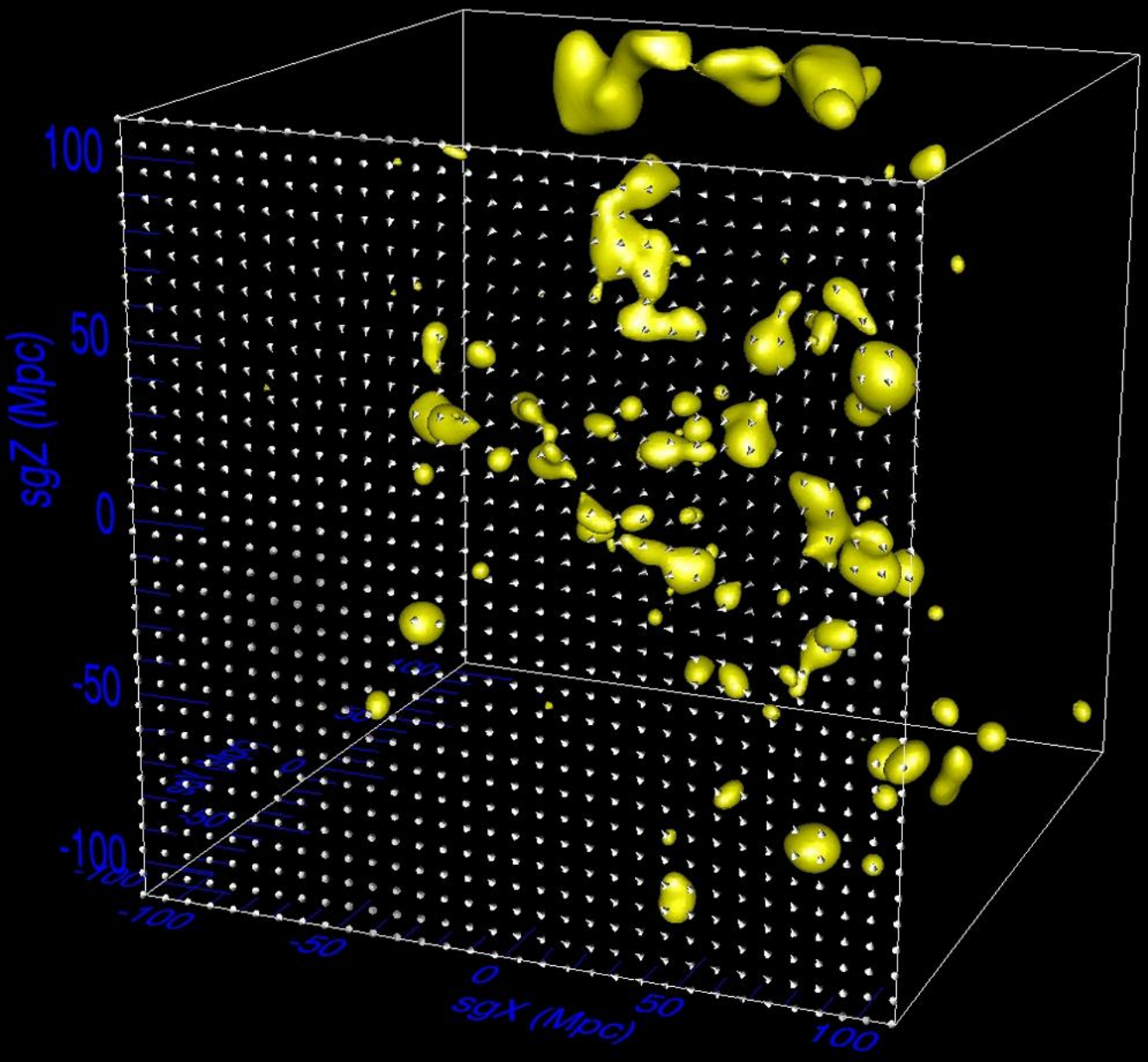
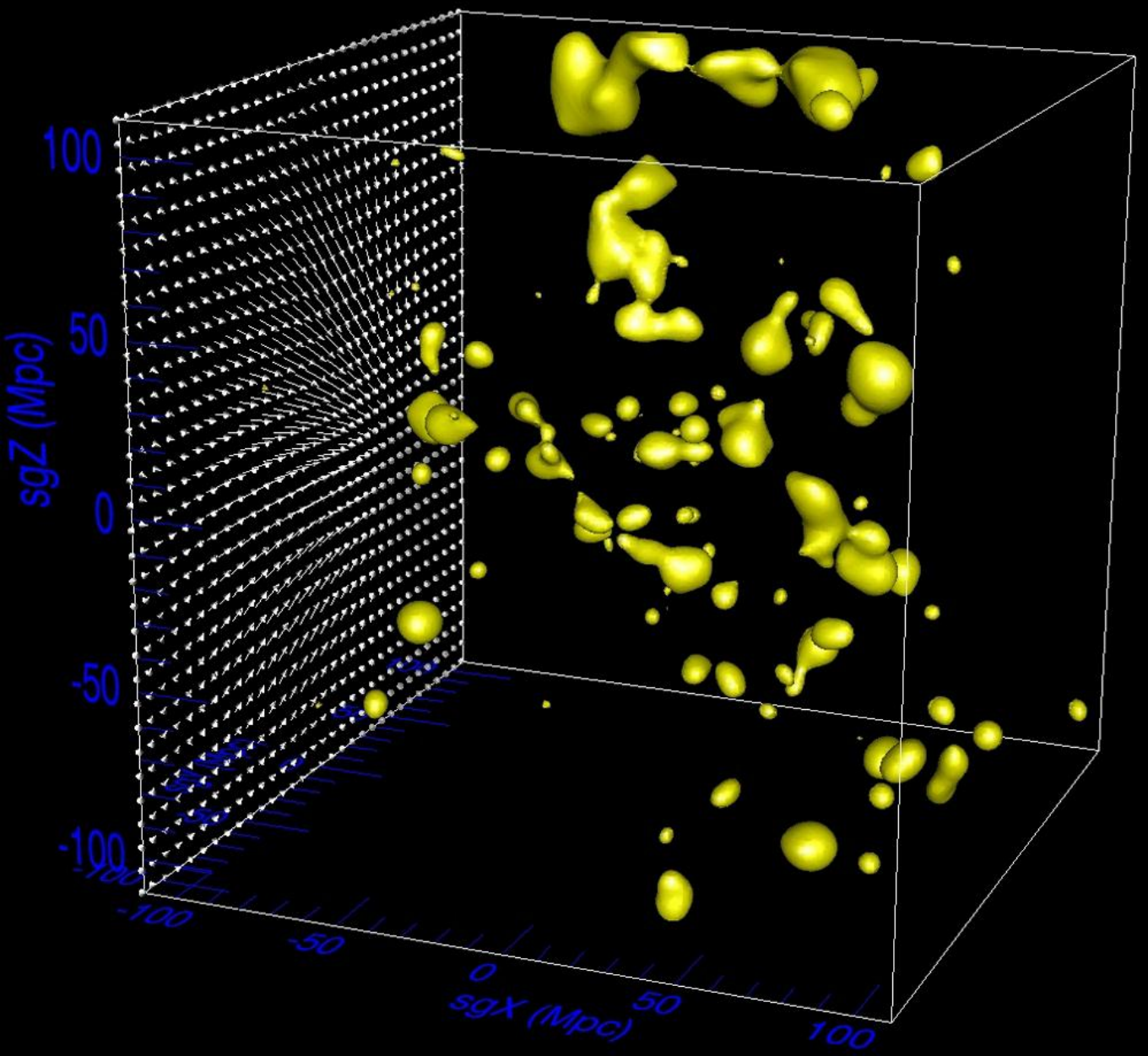
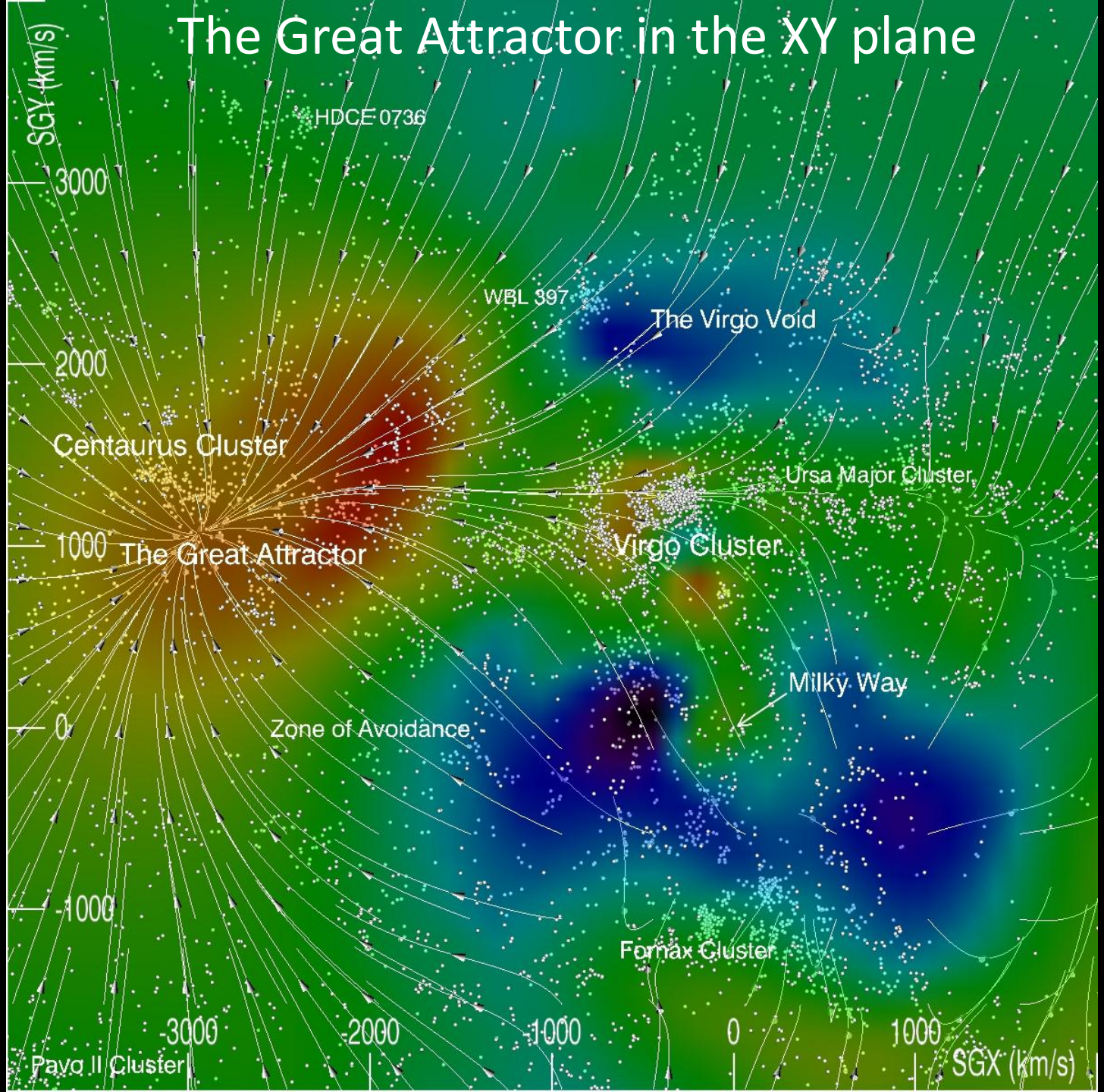
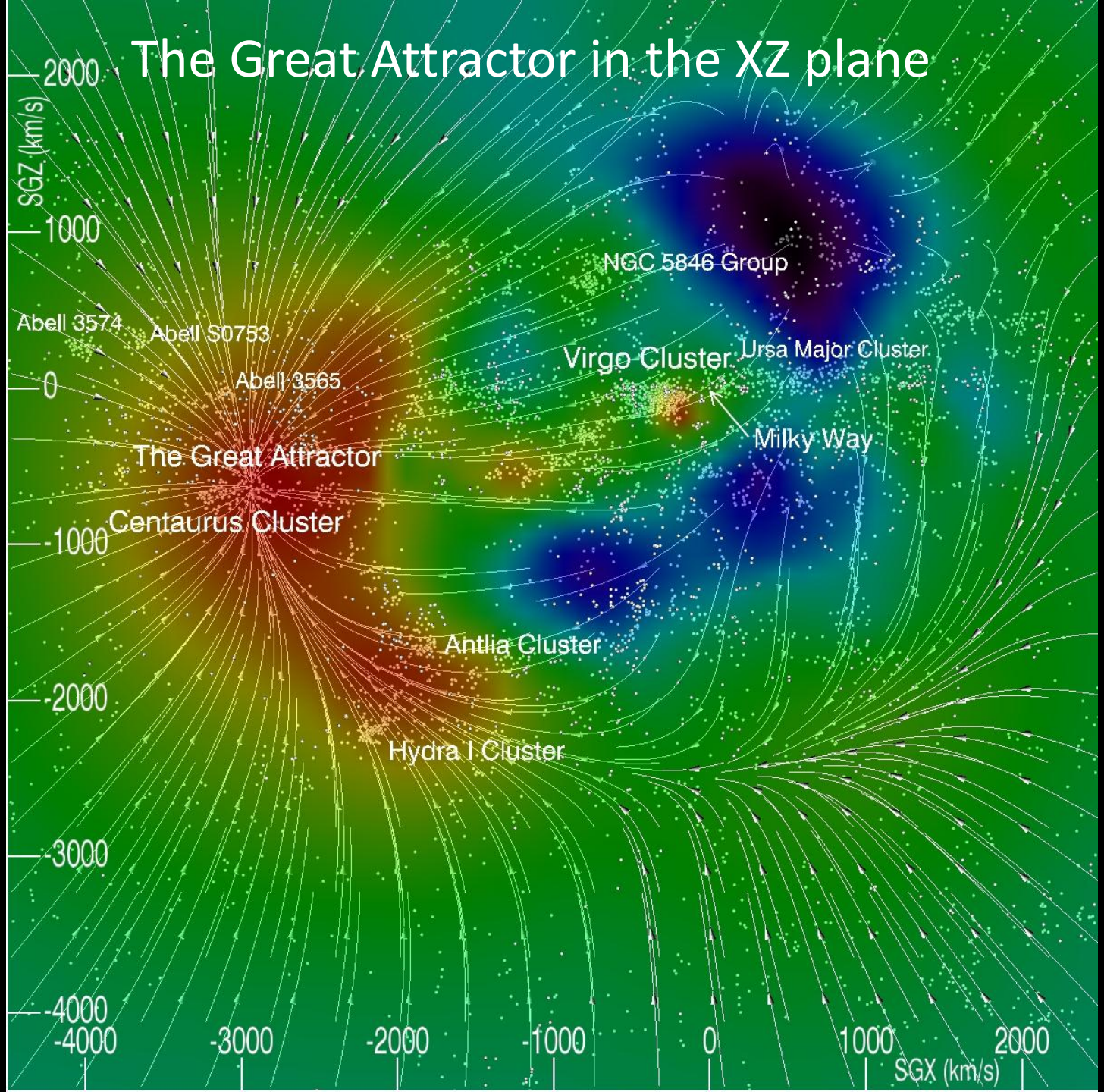


Tomography of the cosmic flows

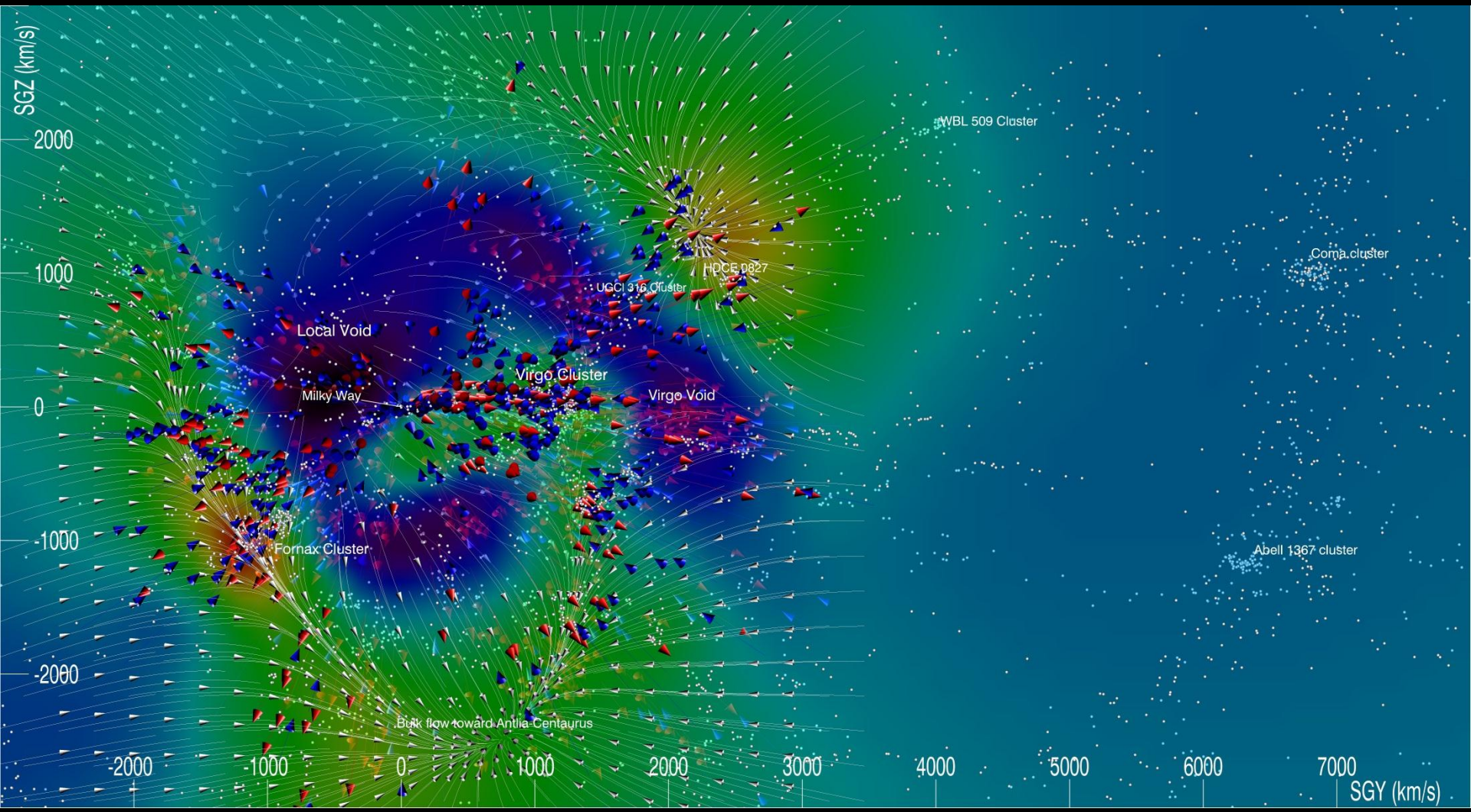


The Great Attractor in the XY plane

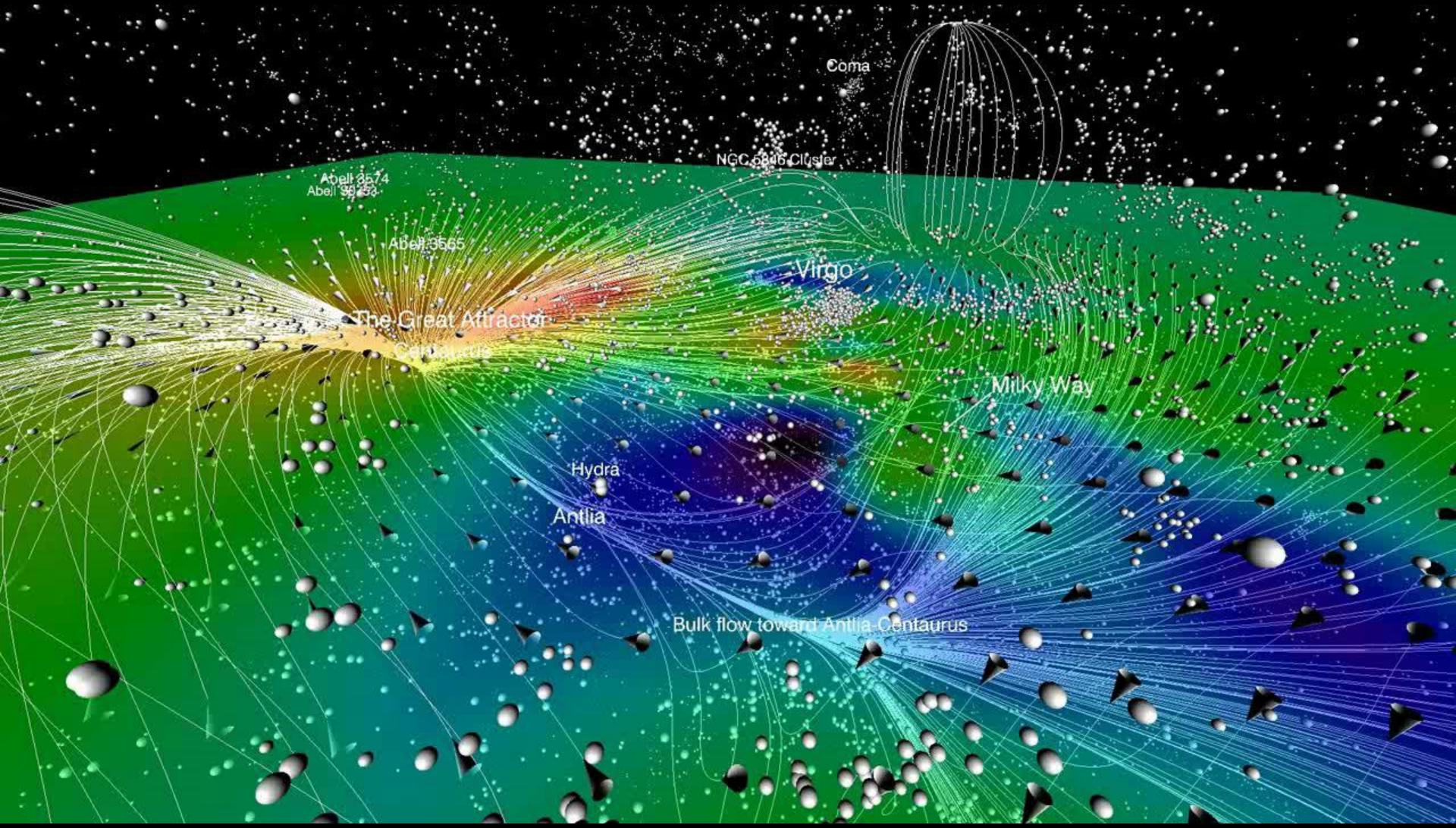



The Great Attractor in the XZ plane
SGZ (km/s)
2000
1000
0
-1000
-2000
-3000
-4000
-4000
-3000
-2000
-1000
0
1000
2000
SGX (km/s)
NGC 5846 Group
Abell 3574
Abell S0753
Abell 3565
Virgo Cluster
Ursa Major Cluster
Milky Way
The Great Attractor
Centaurus Cluster
Antlia Cluster
Hydra I Cluster

The Local Void in the YZ plane



3D view of the Cosmicflows-1 Wiener Filter reconstruction



Conclusions & perspectives

- We have developed a software tool aiming at
  - the study of the cosmography of the Nearby Universe
  - the comparative visualization of structures and flows
- Next step is Cosmicflows-2 and a new, extended catalog of galaxies