# Cosmography with SDvision

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***Abstract*— Cosmography is the creation of maps of the Universe. Using the SDvision 3D visualization software developed within the framework of IDL Object Graphics, we have established a cosmography of the Local Universe, based on multiple data products from the Cosmic Flows Project. These data include catalogs of redshifts, catalogs of peculiar velocities, and reconstructed density and velocity fields. On the basis of the various visualization techniques offered by the SDvision software, that rely on multicore computing and OpenGL hardware acceleration, we have created maps displaying the structure of the Local Universe where the most prominent features such as voids, clusters of galaxies, filaments and walls, are identified and named. Maps also display the dynamical information of the cosmic flows, which are the bulk motions of galaxies, of gravitational origin. These maps highlight peculiar conformations in the cosmic flows such as the streaming along filaments, or the existence of local attractors and repellers. This visualization software was used in the discovery of the frontiers of Laniakea, our Home Supercluster of galaxies.**

***Keywords—visualization; cosmography; maps; cosmology***

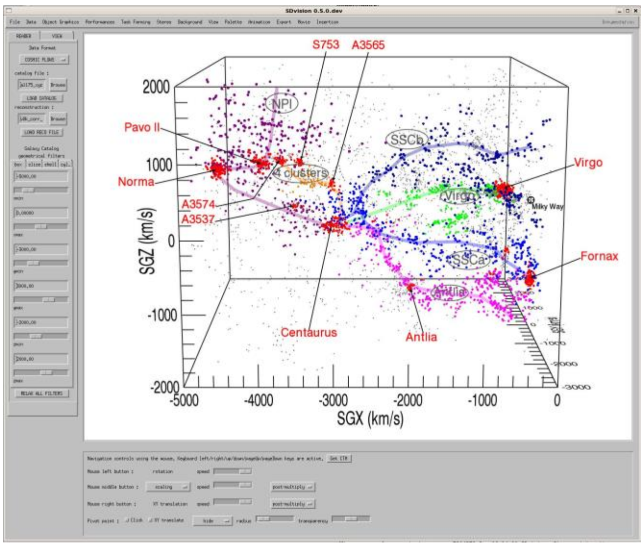
## I. Introduction

Cosmography is the science of mapping the Universe. Using the SDvision 3D visualization software developed within the framework of IDL Object Graphics, a cosmography of the Local Universe is being established, based on multiple data products from the Cosmic Flows Project [1]. These data include catalogs of redshifts, catalogs of peculiar velocities, and reconstructed density and velocity fields. On the basis of the various visualization techniques offered by the SDvision software, we have created maps displaying the structure within 700 million light years. In this structure, we identify and name the most prominent features such as superclusters, voids, filaments, walls, clusters and groups of galaxies.

## II. The SDvision Software

The SDvision visualization software [2] has been developed as part of the COAST "Computational Astrophysics" program [3] of the Institute of Research into the Fundamental Laws of the Universe. The primary target of this program is to improve our knowledge on the formation of structure in the Universe. The software environment is the IDL "Interactive Data Language" data analysis and visualization platform. The 90,000-lines of code of SDvision makes heavy use of Object Graphics, a collection of pre-defined object classes, each of which is designed to encapsulate a particular visual representation and supports OpenGL-based hardware accelerated graphics. This tool offers several ways to visualize scalar fields, vector fields, and clouds of points, in three dimensions. An example of the SDvision widget interface engaged in the visualization of a catalog of redshift positions of galaxies is presented in Figure 1. In terms of computing efficiency, this software is very flexible: it exploits hardware rendering acceleration if a graphics card is present, but it reverts to a pure software rendition if not. Several of its algorithms make use of multiple core parallel computing on shared-memory systems.

Fig. 1. The SDvision visualization widget



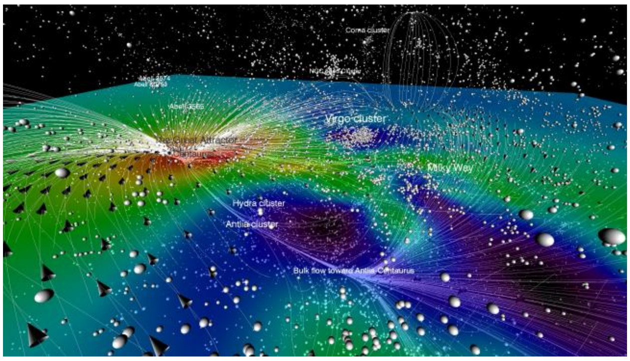
## III. THE COSMIC FLOWS PROJECT

The Cosmic Flows Project [4] is an open collaboration aiming at mapping the visible and Dark Matter content of the Local Universe using measurements of the galaxies deviant motion with respect to the Hubble expansion. These peculiar motions are input to a Wiener Filter algorithm which provides a three-dimensional reconstruction of the velocity and density fields at the origin of these peculiar movements [5]. Two catalogs were released so far: *Cosmicflows*-1 with 1822 galaxies with redshift within 3000 km/s [6] and *Cosmicflows*-2 with over 8000 galaxies, reaching out to 30,000 km/s [7].

## IV. COSMOGRAPHY OF THE LOCAL UNIVERSE

The SDvision software was used to produce a cosmography of the Local Universe consisting in 23 maps and a 17-minutes exploratory video, on the basis of the *Cosmicflows*-1 Catalog [8]. An example is shown in Figure 2, where the velocity field, reconstructed using the Wiener Filter technique, is visualized as streamlines. These streamlines are seen converging onto the so-called Great Attractor region near the Centaurus cluster of galaxies.
The video can be viewed at the following address:
http://irfu.cea.fr/cosmography

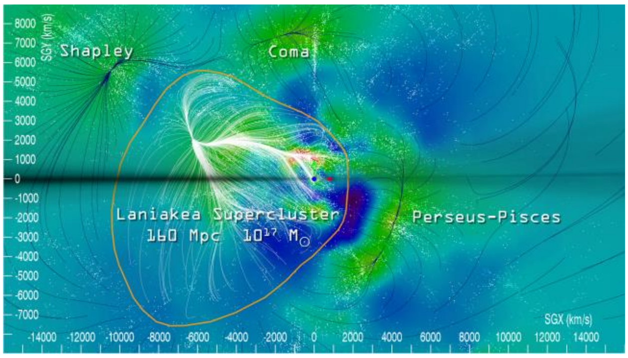
Fig. 2. Cartography of cosmic flows in the Local Universe




## V. THE LANIAKEA SUPERCLUSTER OF GALAXIES

The SDvision software was used in the discovery the frontiers of our home supercluster of galaxies, Laniakea, using the *Cosmicflows*-2 Catalog [9]. The frontiers of the supercluster are reconstructed and visualized using the concept of gravitational basin of attraction within which cosmic flows are converging onto a unique attractor. Proceeding by analogy with terrestrial watersheds, this concept provides a powerful tool to identify the boundaries of superclusters, as illustrated in Figure 3. The name of this structure means "Immense

Fig. 3. Cartography of the Laniakea Supercluster




Celestial Horizon" in Hawaiian. Videos elaborating on this discovery can be viewed at the following address:
http://irfu.cea.fr/laniakea

## V. CONCLUSIONS

Though being one of the most ancient sciences, cosmography is progressing fast forward in these day and age, owing to the conjunction of progresses in several fields: observations, theory, software and computing. These advances have allowed a conceptual breakthrough in the definition of the large-scale architecture of the Universe. This was accomplished with a Catalog of 8000 galaxies and Bayesian methods, while since 20 years the field was mostly dominated by Lagrangian methods operated on redshift catalogs of many hundred thousands galaxies.

The comparative visualization of three-dimensional structures and flows enrich the study of the cosmography of the Local Universe. New observations aggregated in the next *Cosmicflows*-3 Catalog will provide more data at greater distances. Reconstructions and visualizations of these data will extend our vision of cosmography to even larger scales.

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