Novel maps of matter flows in our cosmic neighbourhood

A new cartography of dark matter dynamics in the Universe has been produced by a collaboration of cosmologists in the United Kingdom, France and Germany. Dark matter is a substance of yet unknown nature that makes up more than 80% of the total mass of the Universe. As it does not emit or react to light, its distribution and evolution are not directly observable and have to be inferred. Using advanced computer modelling techniques, the research team has succeeded in translating the distribution of galaxies, observed by the *Sloan Digital Sky Survey* (SDSS, http://www.sdss.org), into detailed maps of matter streams and their velocities. The results of this project, carried out at the Institute of Cosmology and Gravitation (ICG, Porsmouth), the Institut d'Astrophysique de Paris (IAP, Paris) and the Excellence Cluster Universe (Garching), are published in the *Journal of Cosmology and Astroparticle Physics* dated June 26th, 2017 (Leclercq *et al.*, 2017).

THE INVISIBLE PHASE-SPACE STRUCTURE OF THE COSMIC WEB

At the largest scales in our Universe, matter is organised in a complex network where sheets and filaments connect the densest clusters and are surrounded by larger voids. Galaxies, which are the luminous component of the overall matter distribution, form in regions where dark matter concentrates. Their clustering therefore traces the underlying structure, in the form of a static snapshot.

Beyond this picture, it is known from simulations that the dark matter distribution of our Universe should be evolving, organising itself in different streams, each with its peculiar velocity. However, accessing this information (the *phase-space structure*), which lives in six dimensions, not only requires the positions of galaxies, but also the initial conditions from which the cosmic web originates. In 2015, three researchers of the IAP developed and used an advanced software (BORG: *Bayesian Origin Reconstruction from Galaxies*) to reconstruct the initial conditions of the nearby Universe as probed by the SDSS *main galaxy sample* (Jasche, Leclercq & Wandelt, 2015). Building upon these results and using a set of phase-space analysis tools, the enlarged research team has been able to describe, for the first time, the dynamics of dark matter in the same volume. The new maps cover the Northern Sky up to a distance of 600 megaparsecs, which corresponds to a look-back time of about two billion years. They have been made publicly available to the scientific community (www.florent-leclercq.eu/data.php).

NEW MAPS OF VELOCITY FIELDS AND DYNAMIC COSMIC WEB ELEMENTS

Adopting the phase-space approach discloses a wealth of information, which was previously only analysed in simulations and thought to be inaccessible using observations. In particular, the researchers have produced up-to-date maps of velocity fields, accurate even in regions of low galaxy density. Figure 1 shows, as an example, how matter flows towards or away from us. The *Sloan Great Wall*, one the largest structure of the known Universe, is clearly visible at the centre of the slice, with dark matter falling onto it from both sides.

Phase-space information can also be used to redefine the usual four cosmic web components (voids, sheets, filaments, and clusters) on the basis of their dynamical characteristics (see figure 2). Because these classifications use matter dynamics instead of the sheer local density, identified structures explicitly carry physical information about their formation history.

Accessing the phase-space structure of dark matter in galaxy surveys opens up new ways of assessing the validity of theoretical models in light of observations. Applying these techniques to the next-generation deep surveys of galaxies, such as the one performed by the Euclid satellite (http://www.euclid-ec.org), the Dark Energy Spectroscopic Instrument (http://desi.lbl.gov) or the Large Synoptic Survey Telescope (https://www.lsst.org), will allow unprecedented tests of the standard paradigm of cosmic web formation and evolution.

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FIGURES

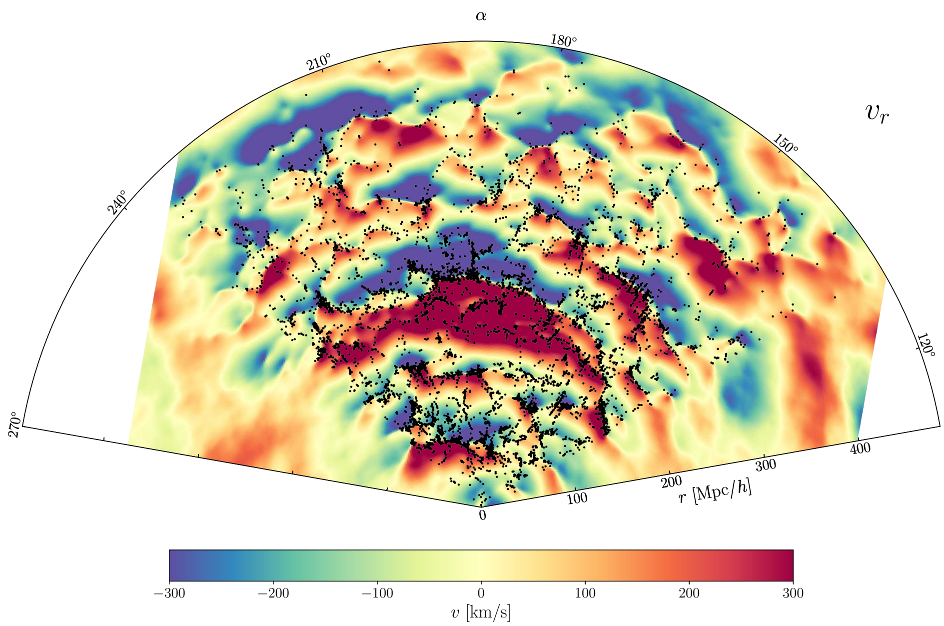

FIG. 1. Slice through the celestial equator showing the radial component of the velocity field (in kilometers per second). Blue regions are falling towards us and red regions are flying away from us. Galaxies of the *Sloan Digital Sky Survey* main galaxy sample are overplotted. In the centre of the slice, the infalling dynamics of the *Sloan Great Wall*, one of the largest structure of the known Universe, can be observed.

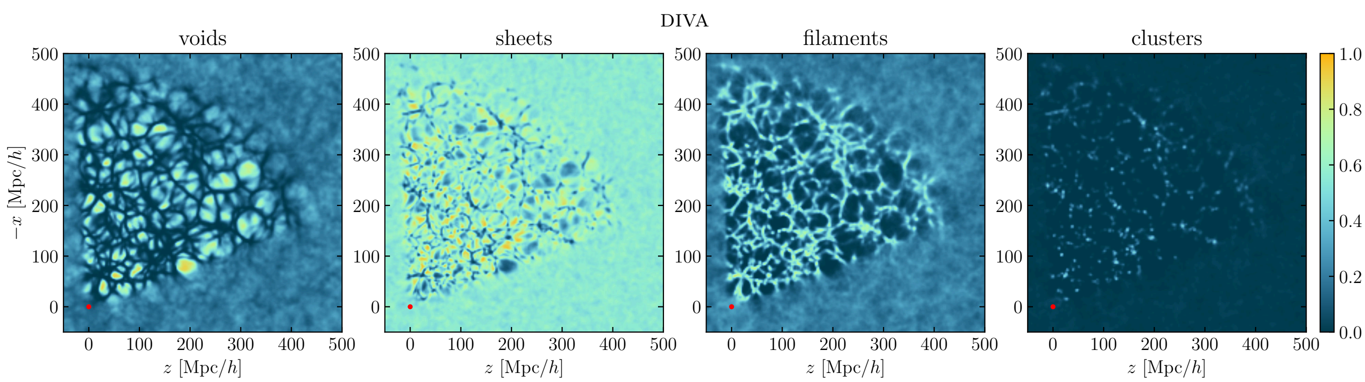

FIG. 2. Detection probabilities for different structure types (from left to right: void, sheet, filament, and cluster), in the cosmic web as observed by the *Sloan Digital Sky Survey*. Structure types are classified using DIVA, an algorithm reflecting the dynamical trend, instead of the current density configuration. The red dot on the map shows our location.

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