The Universe in my pocket

The cosmic web

TUIMP
No. 13
THE UNIVERSE IN MY POCKET

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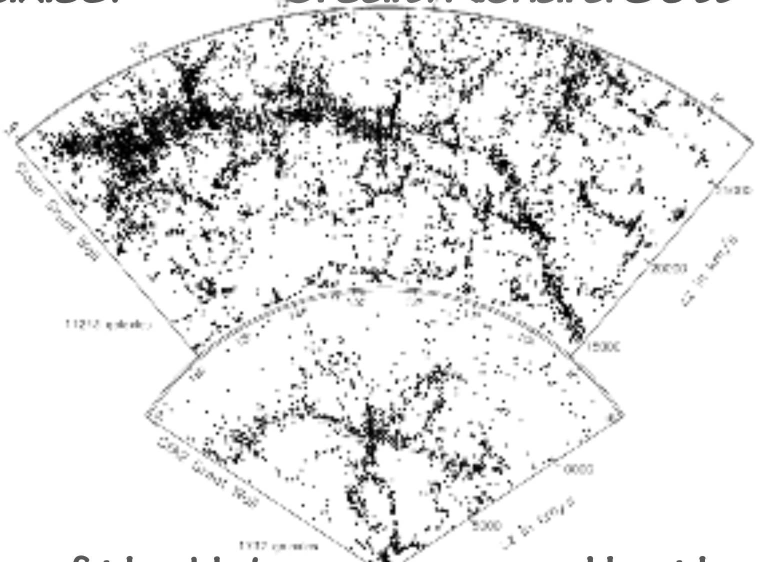
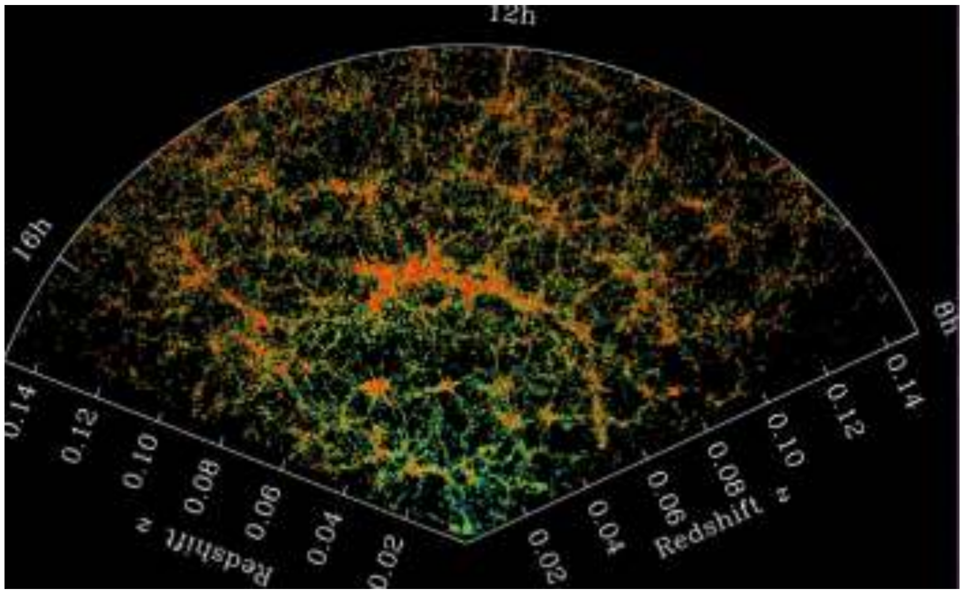
Slice of the Universe, mapped by CfA2. Each point is a galaxy. One can see a large "wall" of galaxies. Credit: Richard Gott



Slice of the Universe, mapped by the SDSS in 2000. One can see "walls" that are even larger than in the CfA2.

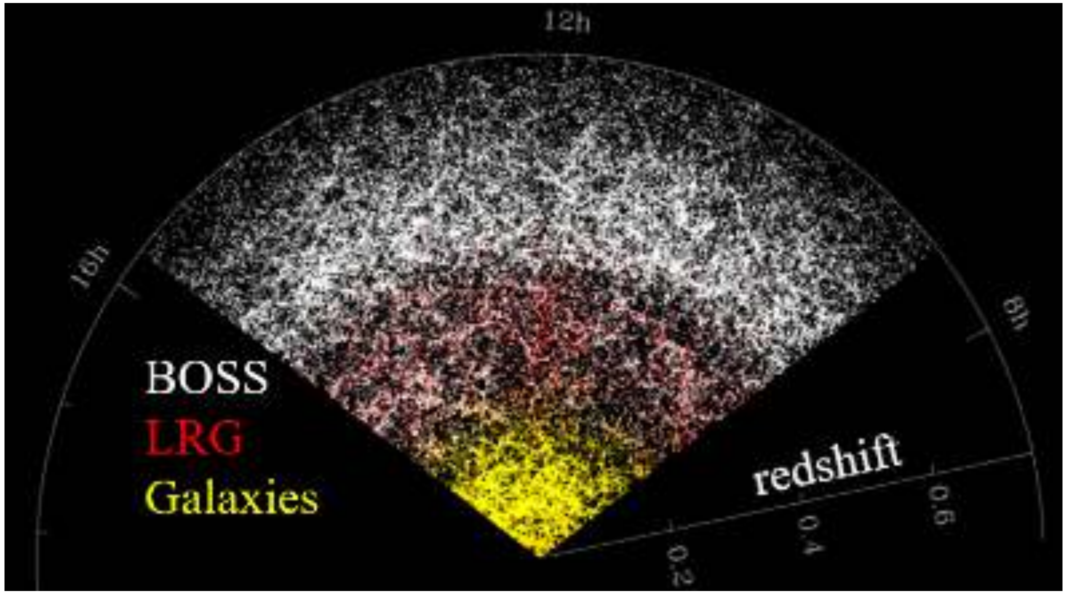


The nearby Universe is structured

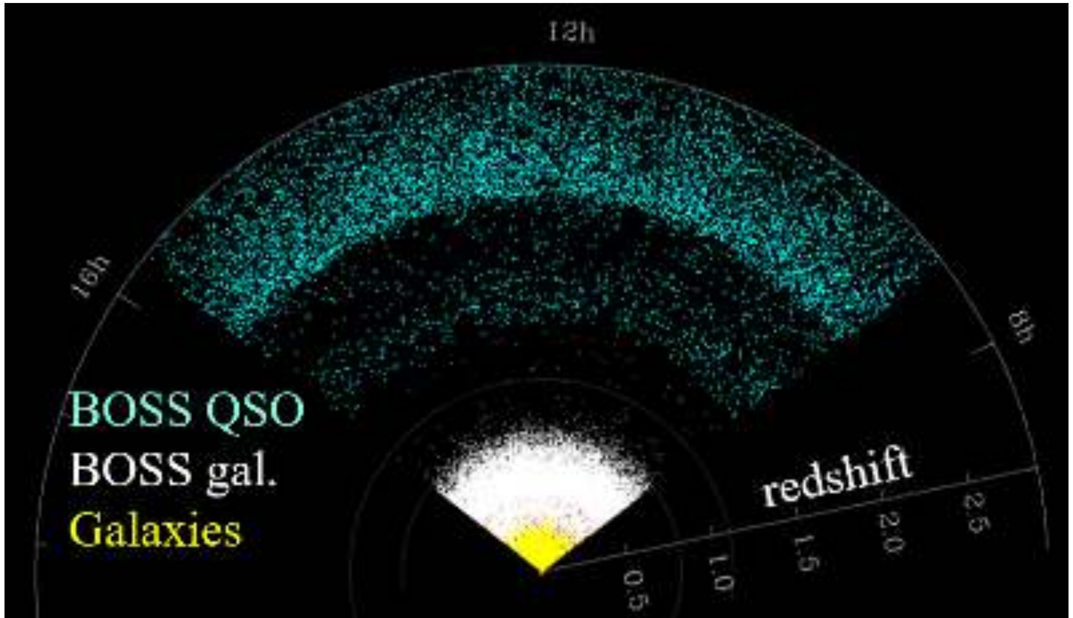
In 1925 there was a great debate, which concluded that there are galaxies outside of our own Milky Way. Large surveys of such galaxies were soon made. It was discovered that the "nearby" Universe is not homogeneous but consists of more-or-less flattened clusters of galaxies with a Swiss cheese-like structure, containing large voids. This is called the cosmic web.

The first "volume" survey, giving the positions of the galaxies along with their distances (measured by the redshifts*) was the CfA2 survey, at the end of the 20th century. It took ten years to observe 18,000 galaxies. 21st century spectrographs make it possible to observe hundreds of galaxies simultaneously and to survey millions of galaxies. Such surveys include the 2dF made in Australia and the SDSS from the USA.

* or shift of the spectral lines towards the red; see TUIMPs 2 and 12.



The main sample of SDSS galaxies is shown in yellow. The luminous red galaxy (LRG) sample is in red, while the galaxies of the BOSS project are in white. The BOSS project quasars (QSO) are in green.

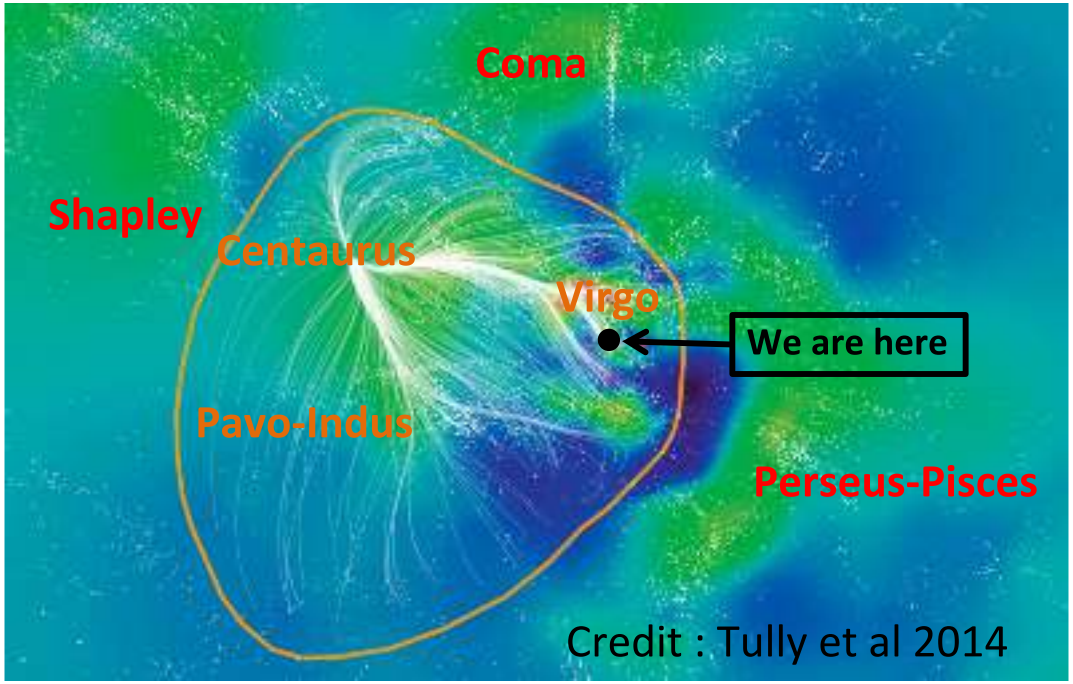


Deeper surveys

The main sample of SDSS galaxies has an average redshift of z = 0.1, corresponding to a distance of 1.5 billion light years. The sample of red luminous galaxies goes up to z = 0.7. The BOSS project goes to z = 1 (22 billion light years). With quasars, which are brighter than galaxies, one can reach z = 5 (155 billion light years).

As one might expect, the Universe is less structured at greater redshift, that is, when it was younger*. Clusters of galaxies form at z = 2 (3.3 billion years after the Big Bang). The filament and Swiss cheese structure was already present at this time, but less pronounced than it is today.

* See TUIMP 12



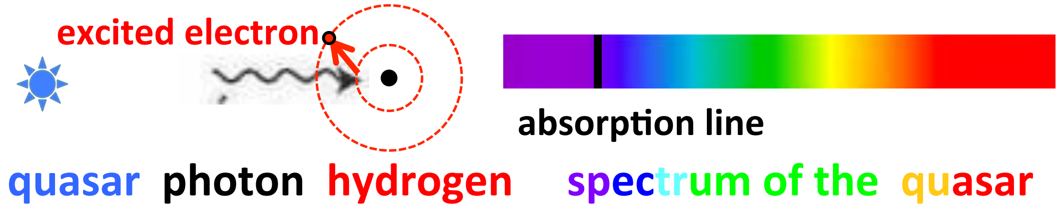
A representation of the local super-cluster Laniakea which means "immense sky" in Hawaiian. It was named in honor of Polynesian navigators who used their knowledge of the sky to navigate the Pacific Ocean.

Our Galaxy is near the big central black point. Galaxies are shown as white dots. The white lines indicate the direction of movement of the galaxies. The blue areas are cosmic voids. The orange line marks the Laniakea super-cluster. The Coma and Perseus-Pisces clusters are therefore not part of Laniakea.

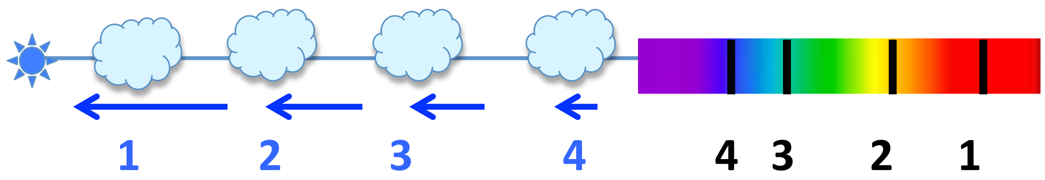
Laniakea : our super-cluster

Our Galaxy is on the edge of a super-cluster of galaxies, discovered in 2014 and called Laniakea. It is a structure that is slowly drifting apart. It measures 500 million light years across and contains more than one hundred thousand galaxies. To detect Laniakea, it was necessary to measure the galaxies' distances by methods that do not use radial velocities or the Hubble-Lemaître* law. Indeed, the radial velocities of galaxies, in addition to the component of cosmological expansion, are affected by disturbances due to the gravitational attraction which they mutually exert. This makes it possible to know if a galaxy has a dynamic link with others and thus belongs to the same group.

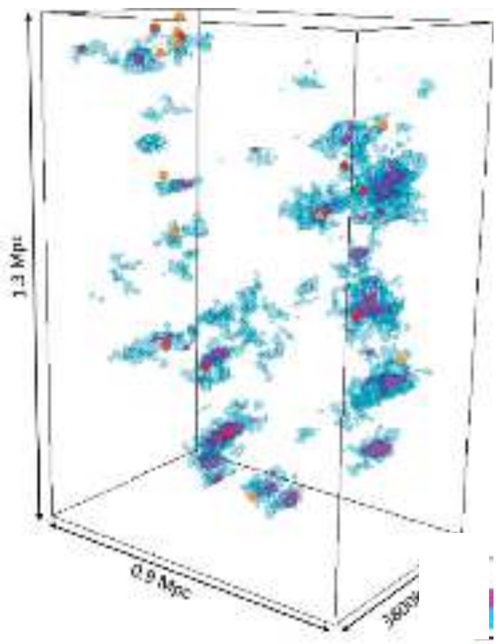
* See TUIMP 12



Energetic photons coming from a quasar can have sufficient energy to excite a hydrogen atom. These photons are absorbed to create an absorption line in the quasar's spectrum.



Each gas cloud between the quasar and us absorbs those photons whose wavelength corresponds to the cloud's redshift.



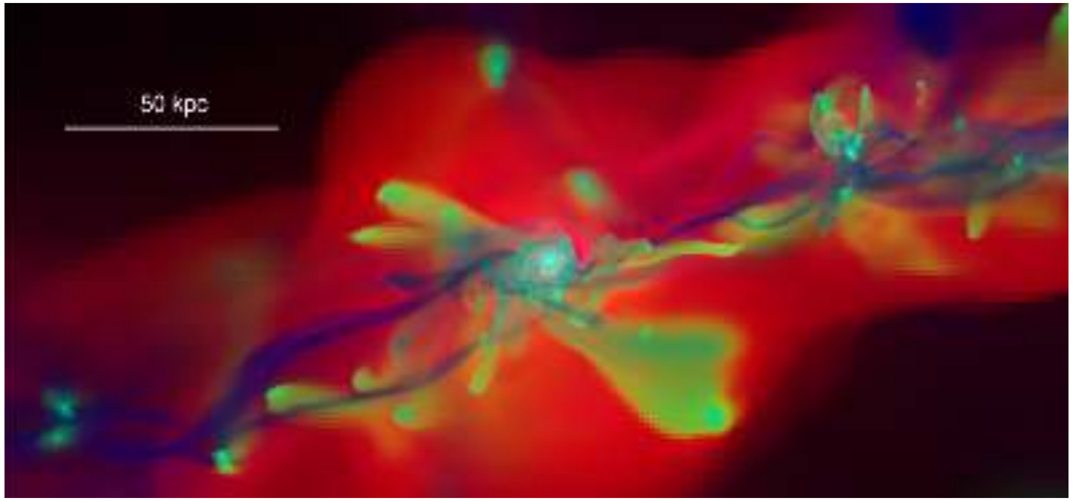
Left: spatial distribution of the filaments in the SSA2 cluster. In blue and magenta: gas. In red and orange: the galaxies. The filaments are several million light years in size.

After Umehata et al. (2019).

The gas in the filaments

Until very recently, cosmic filaments were only detected by the galaxies they contain. However, they are also made up of invisible dark matter and dilute gas. The hydrogen atoms in this gas absorb light from distant quasars. One can thus map the volume distribution of the filaments (see p. 8).

Gas in the filaments can also be detected by its emission, when excited by hot stars or quasars. Gas halos have been detected around 270 galaxies at redshifts between 3 and 6. This discovery was made by a group of European astronomers, thanks to the extreme sensitivity of the MUSE instrument on the Very Large Telescope (VLT) of ESO.



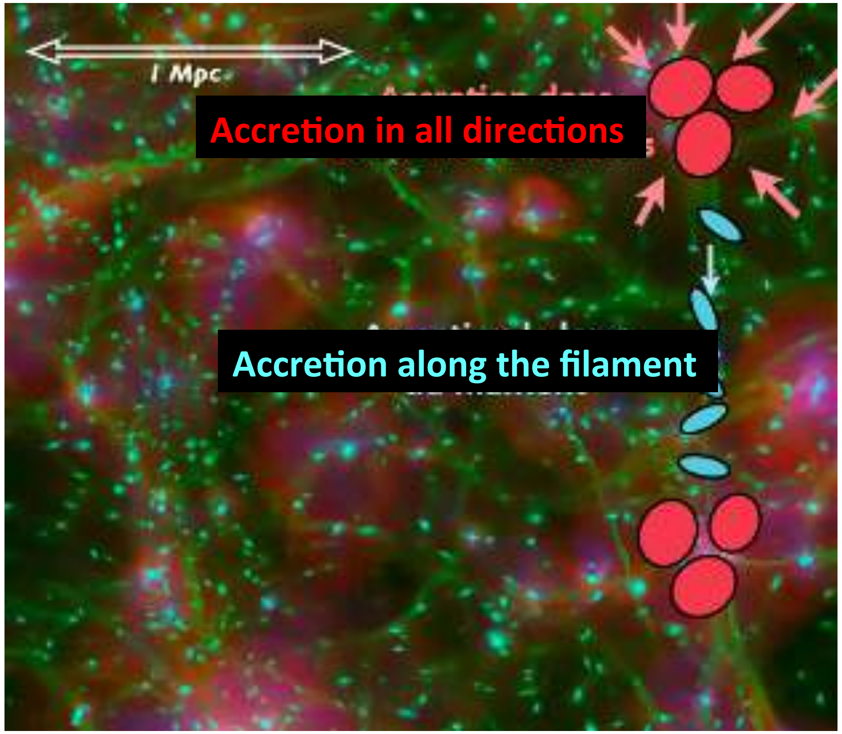
Result of a numerical simulation* by Agertz et al. (2009) showing the accretion of cold gas onto galaxies along cosmic filaments and the ejection of gas enriched in heavy elements produced in stars. In blue, cold gas. In red, a halo of gas heated to a very high temperature. In green, the enriched gas ejected by the galaxies.

* A numerical simulation is a computation performed on a computer that seeks to represent a real system taking into account the laws of physics. For example, one can simulate the flow of a river, the formation of a galaxy, etc. Simulations can take months of calculations even on the fastest computers.

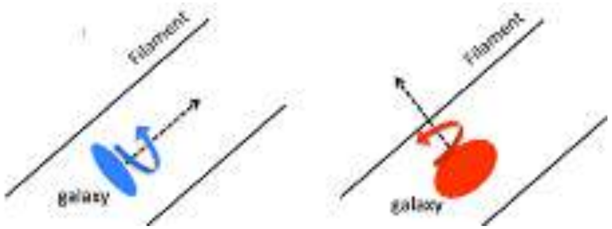
Baryons in the filaments

Contrary to what one might think, most ordinary matter (baryons) is not in galaxies. The Universe is composed of 5% baryons, 25% dark matter and 70% dark energy. The fraction of baryons in the matter component is therefore 5 / (25 + 5) = 17%. In galaxies, it has been measured that the fraction of baryons does not exceed 3%. More than 80% of baryons are therefore outside the galaxies. These baryons are thought to have been ejected by supernovae in low-mass galaxies, and by active nuclei* in more massive galaxies. This ejection of matter enriches the intergalactic medium with heavy elements produced by stars, such as carbon, oxygen, iron.

* See TUIMP 6



Massive elliptical galaxies, shown in red, are concentrated at the intersection of filaments. Spiral galaxies, shown in blue, are located within the filaments.



Spiral galaxies have their rotation axes aligned with the filaments. Elliptical galaxies, which result from the merger of spiral galaxies, have their axes perpendicular to the filaments.

Credit: Sandrine Codis

The orientation of galaxies

Different types of galaxies tend to be found in different places. In the clusters, we usually find massive elliptical galaxies at the intersection of filaments. These galaxies contain only old stars (hence their color is red). Within the filaments themselves, we typically find spiral galaxies. These galaxies accrete cold gas which then forms stars; this gives them their characteristic blue color.

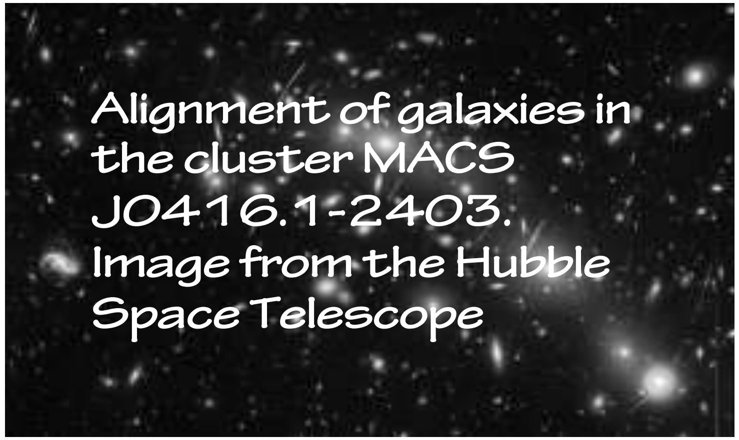
The gas accreting onto the blue galaxies comes from the outer parts of the filaments, and the rotation axes of these galaxies tend to be oriented parallel to the filament. The opposite is true for the red, elliptical galaxies, which are often the result of the merger of two disc galaxies. Page 12 shows these trends in numerical simulations.

Quiz

Which of these images shows:

- Aligned galaxies?
- Cosmic filaments?
- A spider web ?

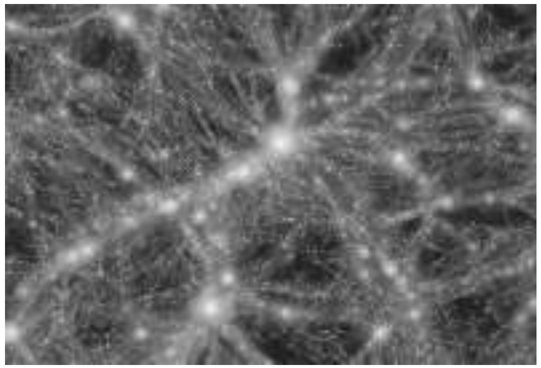
Answers on overleaf



Answers

A spider web

Simulation of the cosmic web



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This booklet was written in 2020 by Françoise Combes from Paris Observatory (France).

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<u>Cover image:</u> Numerical simulation of the distribution of dark matter in the cosmic web. The lighter the color, the higher the density. Galaxies form along the filaments, and clusters of galaxies at the crossroads of the filaments. This simulation is part of the Millenium project, Credit: Springel et al. (2005).

To learn more about this series and about the topics presented in this booklet, please visit http://www.tuimp.org

Translation: Stan Kurtz
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