Cartographers of the Universe

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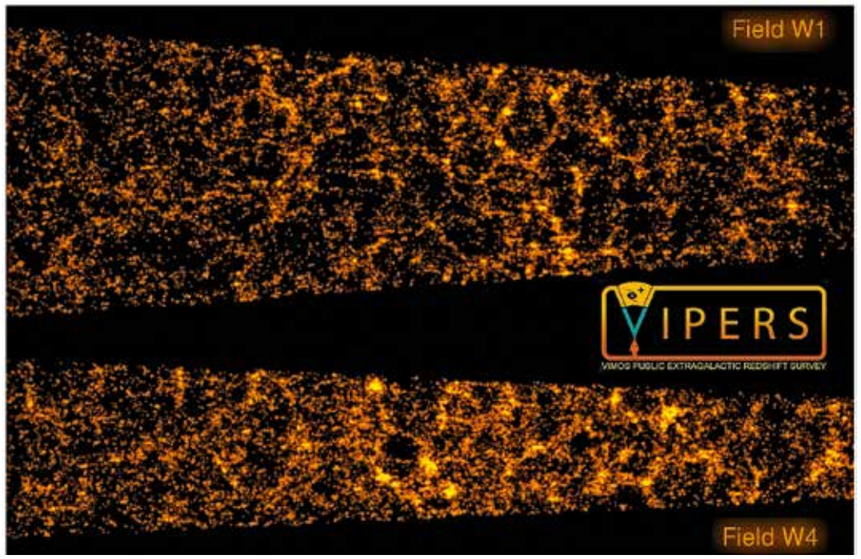
Cartography is the study and practice of making maps. Although originally defined for Earth, the term is also a perfect description of the aims of the VIPERS team, whose members include Polish astronomers.



VIPERS

Two "slices" of the Universe from between five and eight billion years ago, observed by the VIPERS project. The bright pinpoints – galaxies – were already arranged in a complex structure of filaments, walls and voids.

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Having conducted extensive maps of the whole sky, we are now intimately familiar with our own corner of the Universe – the region within a few billion light years of Earth. We know that it's filled with galaxies with myriad properties: from lumbering giants at the centers of galaxy clusters to dwarfs comprising just a few thousand stars; from red, burnt-out elliptical galaxies filled with ancient stars to young bluish spiral and irregular galaxies still producing young stars. They all come together to form a complex cosmic structure, kind of like a vast sponge in which galaxies are individual pinpoints.

One of the burning questions of contemporary astronomy concerns when this structure was first formed. Also, when did red, dead galaxies stop cre-

Panorama of the night sky over the ESO observatory on Mount Paranal, showing the arc of the Milky Way, rising Moon and zodiacal light. Domes of the four units of the Very Large Telescope shown on the left. Installed in one of these units is the VIMOS spectrograph, used to conduct observations for the VIPERS project.

ESO/H.H. HEYER

Małgorzata Siudek, PhD recently completed her doctorate on the evolution of red passive galaxies using data originating from the spectroscopic review provided by VIPERS.
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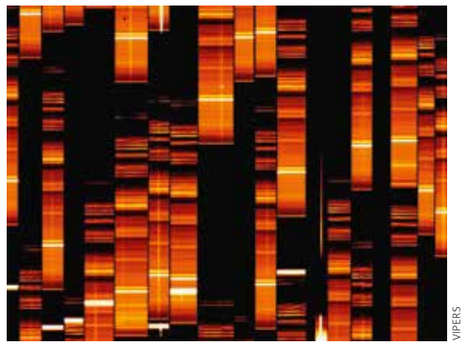
ating new stars? How did the different kinds of galaxies first arise? How significant was their position in the cosmic network in their development? To seek answers, we need to conduct surveys of galaxies stretching far, far into the distant past. However, even given the vast technological progress made in recent decades, this is no easy task.

3D universe

The VIMOS Public Extragalactic Red-Shift Survey (VIPERS) team has created a three-dimensional map of the Universe, bringing us closer to finding answers to questions like those above. The project has conducted observations of almost 100,000 galaxies at distances of up to eight billion light years, using the Visible Multi Object Spectrograph (VIMOS). The observations and measurements have been conducted over the last eight years as part of the largest project of the European Southern Observatory (ESO). VIMOS is attached to Melipal, one of the four 8.2 meter units of one of the largest terrestrial telescopes: the Very Large Telescope in Chile. It has been used to determine the redshift of galaxies (which can be loosely described as a measure of distance) and register their spectral lines. Using this data VIPERS has created the largest 3D map of the Universe at around half its current age, allowing astronomers to study the physical properties of distant galaxies. The full map and data have recently been made public on the project's website.

The VIPERS map shows the distribution of galaxies when the Universe was around half its current age, revealing surprising similarities to the present day. The map clearly shows enormous structures: vast metropolises of ancient, red galaxies with no signs of starburst activity, and less dense regions dominated by younger blue starburst galaxies. The regions are connected by "highways" known as filaments, and bordered by cosmic walls – the largest known structures in the Universe. The map also shows immense voids containing very few or no galaxies.



VIPERS

An enlarged section of the image captured by VIMOS. The vertical stripes are galactic spectra. The pale horizontal stripes represent emission lines, while the dark stripes are absorption lines. Astronomers use the properties of these lines to study galactic properties; the amount by which they are shifted tells us about how distant they are from Earth.

More accurate measurements of the structures enable us to visualize the distribution of galaxies in the Universe and to learn more about the properties of dark matter, responsible for the clustering of "normal" baryon matter and dark energy – the mysterious force behind the accelerating expansion of the Universe.

Processing vast quantities of data requires painstaking work and an in-depth understanding of many branches of astronomy. It would be impossible for scientists to conduct such research on an individual basis, so data accumulated by VIPERS has been processed by large team of people from many countries. Polish researchers, comprising the third-largest group after Italy and France, specialize in statistical analysis of the properties of the large-scale structure of the Universe and evolution of galaxies, and in developing machine-learning methods for processing such vast volumes of data.

Historical guide?

By analyzing the spectra of each galaxy in detail, the VIPERS team has been studying starburst activity and defining types of galaxies. They discovered that massive elliptical galaxies filled with old stars were formed around seven billion years after the creation of the Universe. This means that our classification system of active blue starburst galaxies and "dead" red galaxies was already applicable when the Universe was less than half its current age. This has helped astronomers analyze how different types of galaxies have evolved, accumulated their stellar mass and become brighter. Using machine-learning algorithms, the VIPERS team has defined 12 classes of galaxies evolving over the course of around four billion years (the farthest galaxies included in the project are around nine billion light years away, with the closest at around five billion light years). The analysis reveals that the simple, commonly used classification of galaxies as red, blue and transition ("green") is not enough to mirror the real panoply of galaxies.

Cosmic cartographers study how the properties of galaxies vary depending on their shape, surroundings, color and intensity of spectral lines. The data amassed during the VIPERS project provides a veritable goldmine of information on galactic evolution. Having an understanding of how properties of galaxies have changed over the course of eight billion years will help astronomers test cosmological models and create state-of-the-art simulations.

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Further reading:

Krywult J., Tasca L.A.M., Pollo A., et al. 2017, The VIMOS Public Extragalactic Redshift Survey (VIPERS). The coevolution of galaxy morphology and colour to z 1; *Astronomy & Astrophysics* 598, A120

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