New 3-D Map of Dark Matter Reveals Cosmic Scaffolding

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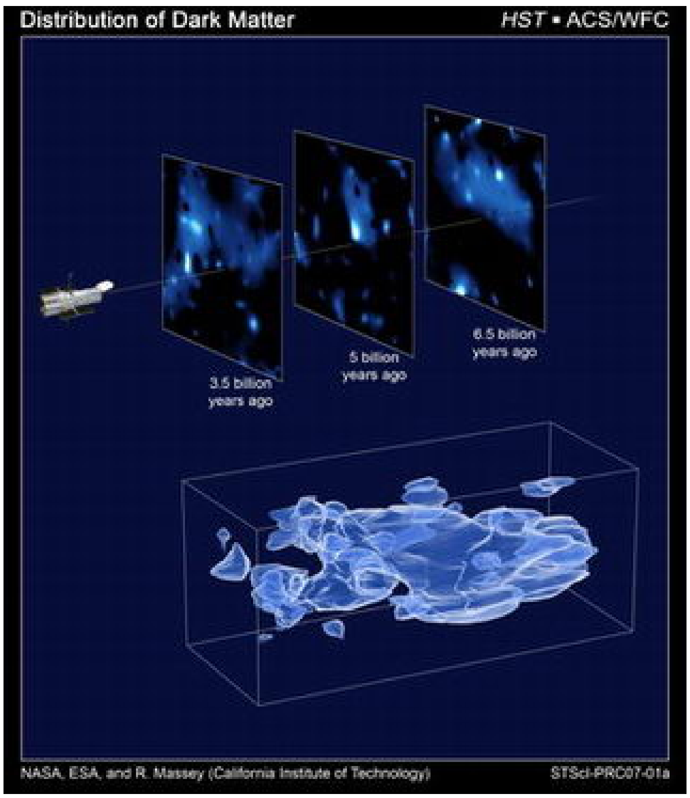
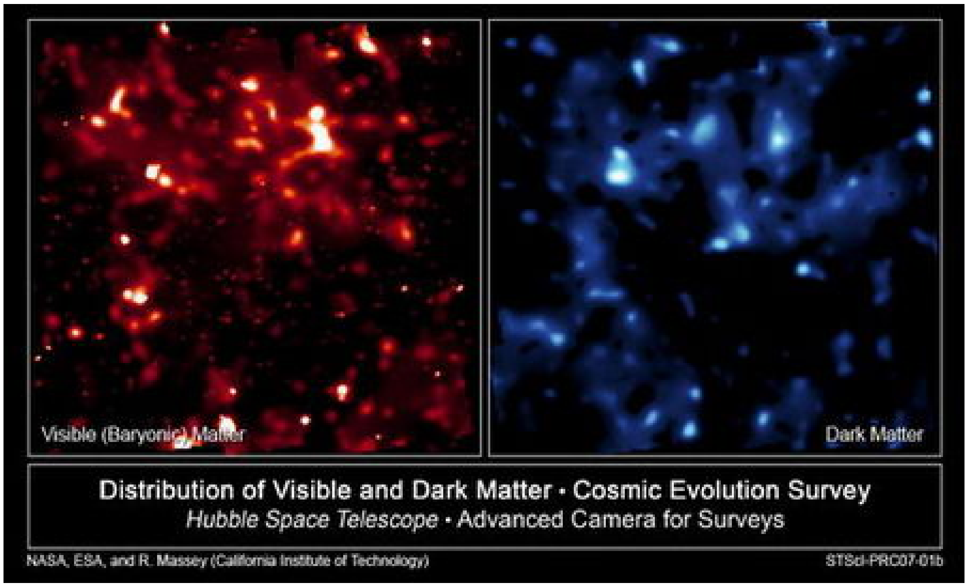


This three-dimensional map offers a first look at the web-like large-scale distribution of dark matter, an invisible form of matter that accounts for most of the universe&acutes mass. The map stretches halfway back in time to the beginning of the universe. The dark matter distribution was mapped with Hubble Space Telescope&acutes largest ever survey of the universe, the Cosmic Evolution Survey ("COSMOS"). [Top] - Three slices through the evolving distribution of dark matter in the universe. [Bottom] - When the slices across the universe and back into time are combined, they make a three-dimensional map of dark matter in the universe. The three axes of the box correspond to sky position (in right ascension and declination), and distance from the Earth increasing from left to right (as measured by cosmological redshift). Note how the clumping of the dark matter becomes more pronounced, moving right to left across the volume map, from the early universe to the more recent universe. Credit: NASA, ESA, and R. Massey (California Institute of Technology)

An international team of astronomers has created a comprehensive three-dimensional map that offers a first look at the weblike large-scale distribution of dark matter in the universe. Dark matter is an invisible form of matter that accounts for most of the universe's mass, but that so far has eluded direct detection, or even a definitive explanation for its makeup.

The map is being unveiled today at the 209th meeting of the American Astronomical Society, and the results are being published simultaneously online by the journal *Nature*.

According to Richard Massey, an astronomer at the California Institute of Technology who led in the map's creation, the map provides the best evidence yet that normal matter, largely in the form of galaxies, forms along the densest concentrations of dark matter. The map reveals a loose network of filaments that grew over time and which intersect in massive structures at the locations of clusters of galaxies.



These two false-color images compare the distribution of normal matter (red, left) with dark matter (blue, right) in the universe. The brightness of clumps corresponds to the density of mass. The map covers an area of sky nine times the angular diameter of the full Moon, and is the largest sample of the distribution of dark matter ever obtained. It demonstrates how normal matter -- including stars, galaxies and gas -- is built inside an underlying scaffolding of dark matter. The comparison of dark matter and normal matter will provide critical observational underpinnings to future theories for how structure formed in the evolving universe under the relentless pull of gravity. The map was derived from Hubble Space Telescope&acutes largest ever survey of the universe, the Cosmic Evolution Survey ("COSMOS"). Credit: NASA, ESA, and R. Massey (California Institute of Technology)

Massey calls dark matter "the scaffolding inside of which stars and galaxies have been assembled over billions of years."

Because the formation of the galaxies depicted stretches halfway to the beginning of the universe, the research also shows how dark matter has grown increasingly clumpy as it continues collapsing under gravity. The new maps of dark matter and galaxies will provide critical observational underpinnings to future theories for how structure formed in the evolving universe under the relentless pull of gravity.

Mapping dark matter's distribution in space and time is fundamental to understanding how galaxies grew and clustered over billions of years, as predicted by cosmological models. Tracing the growth of clustering in the dark matter may eventually also shed light on dark energy, a repelling form of gravity that influences how dark matter clumps.

The map was derived from the Hubble Space Telescope's widest survey of the universe, called COSMOS (for Cosmic Evolution Survey), led by Nick Scoville, the Moseley Professor of Astronomy at Caltech. In making the COSMOS survey, the Hubble imaged 575 slightly overlapping views of the universe using the onboard Advanced Camera for Surveys (ACS). It took nearly 1,000 hours of observations and is the largest project ever conducted with the Hubble.

The three-dimensional map was developed by measuring the shapes of as many as half a million faraway galaxies. These shapes are distorted by the bending of light paths by concentrations of dark-matter mass in the foreground along the line of sight. Then, the observed subtle distortion of the galaxies' shape was used to reconstruct the distribution of intervening mass projected along the Hubble's line of sight.

Richard Ellis, Steele Professor of Astronomy at Caltech explains that the analysis utilized the remarkable phenomenon of gravitational lensing, first predicted by Einstein and now a major tool of cosmological research.

"The depth of the COSMOS image and the superior resolution of Hubble Space Telescope are the key ingredients enabling this detailed map," adds Ellis. "The COSMOS field also covers a wide enough area for the large-scale filamentary structure to be clearly evident."

"The unique advance in our work is that we have made a three-dimensional map," adds Jason Rhodes of JPL, a coauthor of the study. "Because the distances to the faint background galaxies are known in the COSMOS field, we can examine the distortion as a function of the background distance."

The results also show that several of the early universe's cosmic structures inside the dark matter "scaffolding" are clusters of galaxies in the process of assembly, says Scoville. These structures can be traced over more than 80 million light-years in the COSMOS survey-approximately five times the extent of the nearby Virgo galaxy cluster.

The researchers further found that galaxies in the densest early universe structures have older stellar populations, implying that these galaxies formed first and accumulated the greatest masses in a bottom-up assembly of galaxies. The COSMOS survey shows that galaxies with on-going star formation, even to the present epochs, dwell in less populated cosmic filaments and voids.

"Both the maturity of the stellar populations and the 'downsizing' of star formation in galaxies vary strongly with the epoch when the galaxies were born as well as their dark-matter environment." says Scoville. His team's paper is to appear in the Astrophysical Journal at a later date.

Extremely deep color images of the two-degree COSMOS field were obtained in 30 nights of observing with the 8.2-meter Subaru telescope in Hawaii. Thousands of galaxies' spectra were obtained by using the European Southern Observatory's Very Large Telescope and the Magellan telescope in Chile. The distances to the galaxies were accurately determined from their redshifts, which were derived from galaxy colors and spectra. The distribution of the normal matter was partly determined with the European Space Agency's XMM-Newton telescope, looking at the hot gases emitting X-rays in the densest clusters.

Source: Caltech