The filamentary structure of the Universe

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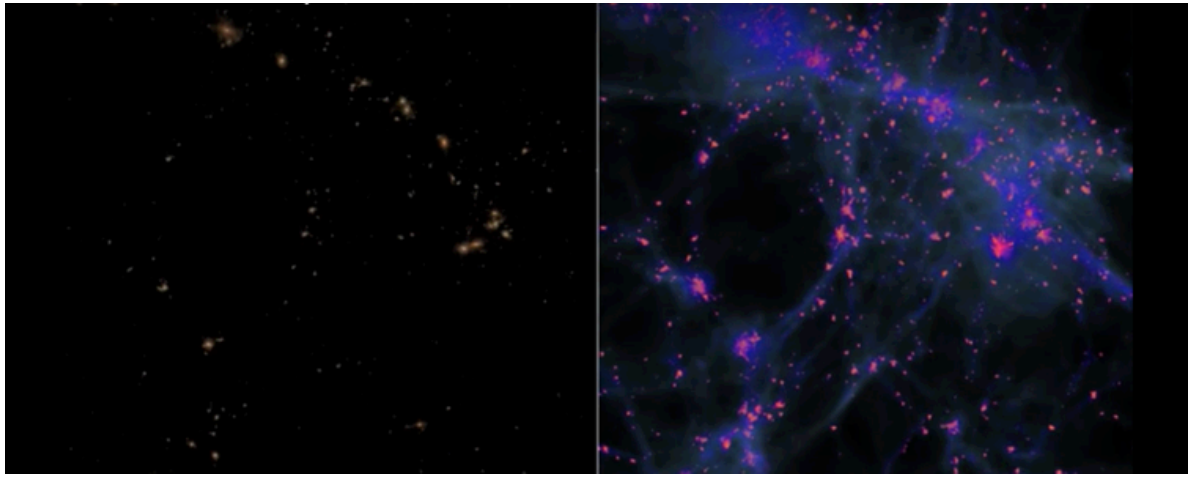
What does a map of the cosmos look like? By plotting the positions and distances of many thousands of galaxies, astronomers discovered decades ago that the Universe was structured according to a fascinating pattern. In it, galaxies are minuscule dots of light that trace a much larger underlying network of cosmic filaments and knots. The space between the galaxies in this so-called cosmic web is filled with very hot and rarefied plasma that "connects the dots" and glows dimly in X-ray light. *Athena* will enable scientists to study the faint emission from the gas that permeates the cosmic web over scales of many millions of light years much more accurately than ever before.



The distribution of galaxies (left) and X-ray gas (right) predicted by the state-of-the-art computer simulation Illustris. Athena will reveal the properties of the invisible gas that fills the space between galaxies in the cosmic web. Credit: Illustris Collaboration / Illustris Simulation.

Under the pull of gravity, regions of the Universe that were just slightly denser than their surroundings right after the Big Bang drew in the matter around them, forming more and more massive structures. During this process, most of the gas permeating the cosmic web was compressed and shock heated to tens of millions of degrees so that it now shines in X-ray light. Seeing the cosmic web in X-rays, therefore, tells the tale of the growth of our Universe – but so far, the story is full of holes. ESA's XMM-Newton and NASA's Chandra flagship missions can only study in detail the X-ray brightest regions of the cosmic web: the densest "knots" of the large-scale structure, which host the central regions of clusters of galaxies... Only a handful of cosmic web filaments have been reliably detected to date, and their physical properties such as temperature and density remain uncertain.

Several of *Athena*'s capabilities give it a tremendous advantage over previous X-ray observatories in revealing the filamentary structure of the Universe. Firstly, *Athena*'s large collecting area allows it to study very faint emission from cosmic web filaments. Secondly, *Athena*'s X-IFU (X-ray Integral Field Unit) detector provides a dramatic improvement in spectral resolution compared to current observatories, so that emission lines from our Galaxy can be clearly separated from the hot gas in cosmic web structures at other redshifts. *Athena*'s Wide Field Imager (WFI) observes large areas of the sky around known clusters of galaxies to search for the filaments that connect to these cosmic web knots, separating their signal from that of the Galaxy by local comparisons of the X-ray surface brightness. Thirdly, *Athena*'s instruments are shielded from energetic particles from the Sun and from the Galaxy by their own active and passive shieldings and by a magnetic diverter system, providing a stable background that is more suitable for studies of faint X-ray signals than previous observatories. With these technical advances, *Athena* promises to "connect the dots" and reveal the properties of the invisible gas that fills the space between galaxies in more detail than ever before.

See also the related Athena Nugget 26.