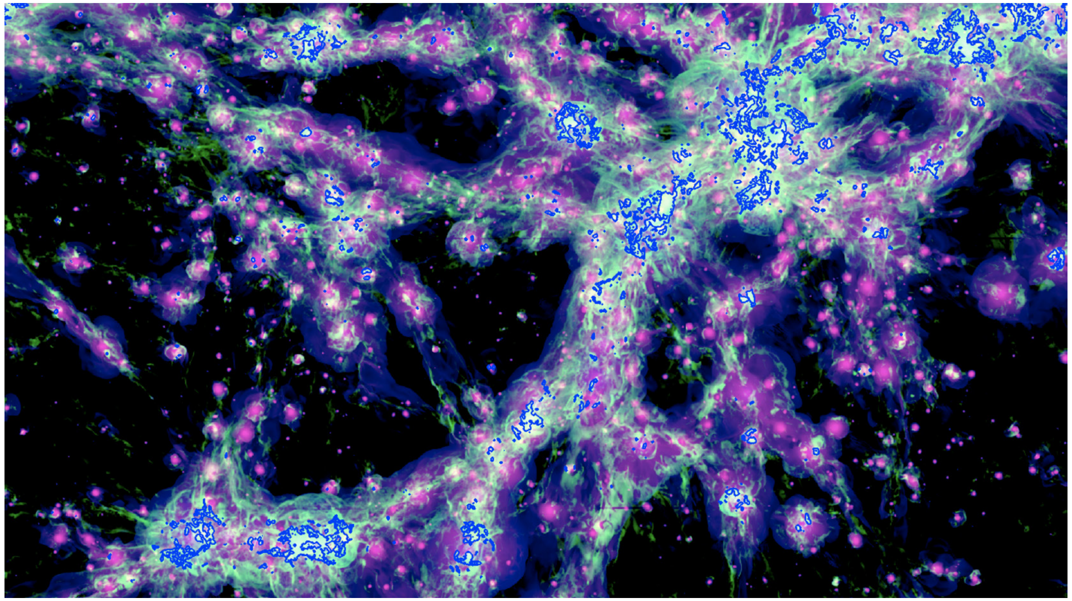
Athena and the Square Kilometer Array
joining forces to detect the most rarefied gas in the Universe

Franco Vazza (Università di Bologna, Italy/Universität Hamburg, Germany), Stefano Ettori (Osservatorio di Astrofisica e Scienza dello Spazio, INAF, Bologna, Italy) and Chiara Ferrari (Observatoire de la Côte D'Azur, Nice, France)

On scales larger than tens of millions light years, the Universe is self-organised by gravity into a spiderweb pattern filled by normal and dark matter: "The Cosmic Web." While the distribution of galaxies tracing the shape of the Web has been observed for decades in optical and infrared wavelengths, no direct detection of its dominant mass component – the gas – has been possible so far. This leaves a long-standing puzzle in astrophysics still open: where has a large fraction of the normal matter in the Universe gone?

While from cosmology we know the total number of baryons that were produced during cosmic nucleosynthesis, at least one third of them are still missing direct detection. For many years, astrophysicists have surmised that these "missing baryons" must reside in the most diffuse gas phase in the Universe, surrounding the extreme peripheries of clusters and distributed within the filaments of the Cosmic Web, in a gas phase which is up to $\sim 10^{29}$ times less dense than normal water. Such a low density makes this gas extremely faint at all wavelengths, preventing most chances of direct detection with current instruments.

We expect that the advent of the Square Kilometer Array (SKA), to be constructed in South Africa and in Australia, is going to drastically change this situation: the SKA will be the largest radio telescope ever built, and thanks to its unprecedented sensitivity it might detect faint and diffuse emissions from the cosmic web.



Simulated emission of X-rays (pink colors) and radio waves (green) for a portion of a large cosmological simulations. The additional blue contours mark the regions in which a future detection with both Athena and SKA-LOW should be possible. The simulation took nearly 2 millions CPU hours on the Swiss National Supercomputing Centre.

A movie of this simulation is visible here. Credit: Vazza et al. 2017

In big cosmological simulations (run for millions of CPU hours on thousands of computing nodes), dark and normal matter and intergalactic magnetic fields are evolved on an expanding space-time, and their final configuration can be used to predict what a real telescope may observe at different wavelengths. Based on simulations produced within the activities of the H2020 ERC Group MAGCOW, we can surmise that the SKA will detect the tip of the iceberg of the radio emission produced by shock waves as wide as tens of millions of light years that surround cosmic structures. Such radio detections will only trace the extreme population of the radio-emitting electrons in the Cosmic Web (electrons which get accelerated up to nearly the speed of light, and emit radio waves while spiralling into intergalactic magnetic fields), while the bulk of normal matter will still remain elusive.

However, by joining forces with the SKA, Athena should be able to map the missing baryons in several regions: by observing with long exposures regions previously selected in the radio band, Athena will be able to collect enough X-ray photons to build the first spectra in emission from the missing baryons around galaxy clusters and in filaments.

From the same numerical simulations (see Figure) we can predict that the interaction region of close pairs of galaxy clusters should emit enough radio waves to be detectable by the SKA, as well as enough X-ray photons to allow detections using the Athena/X-IFU, which will allow us to capture these elusive baryons for the first time, and study their thermodynamical properties in detail.