Our deepest view of the X-ray sky

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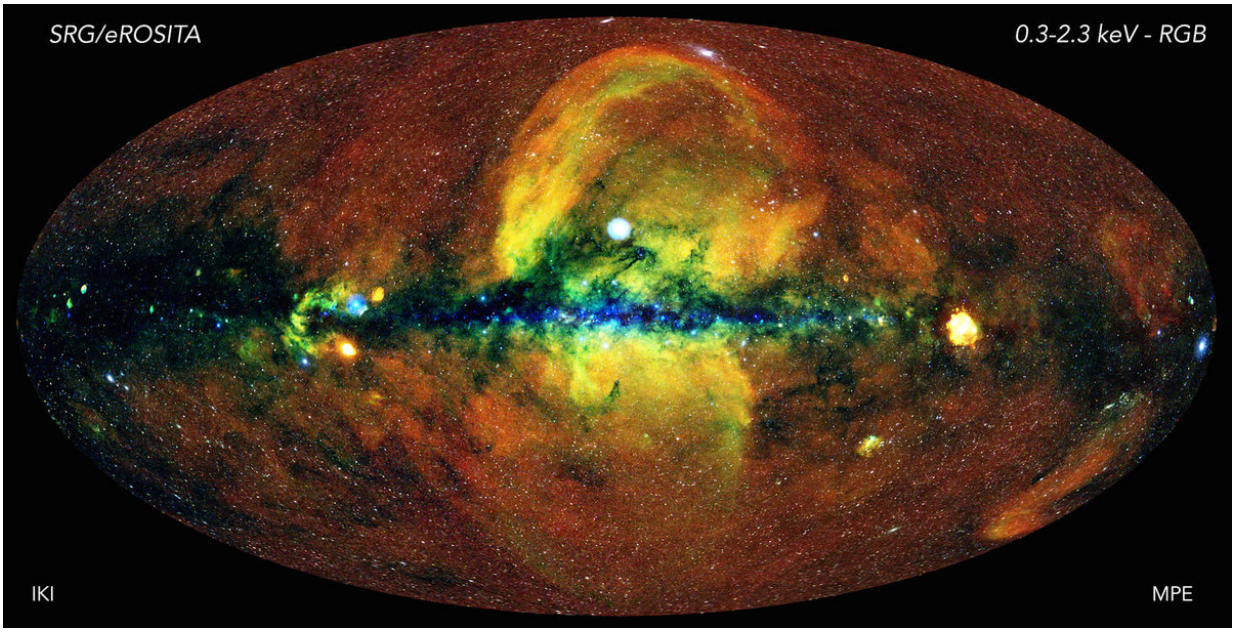


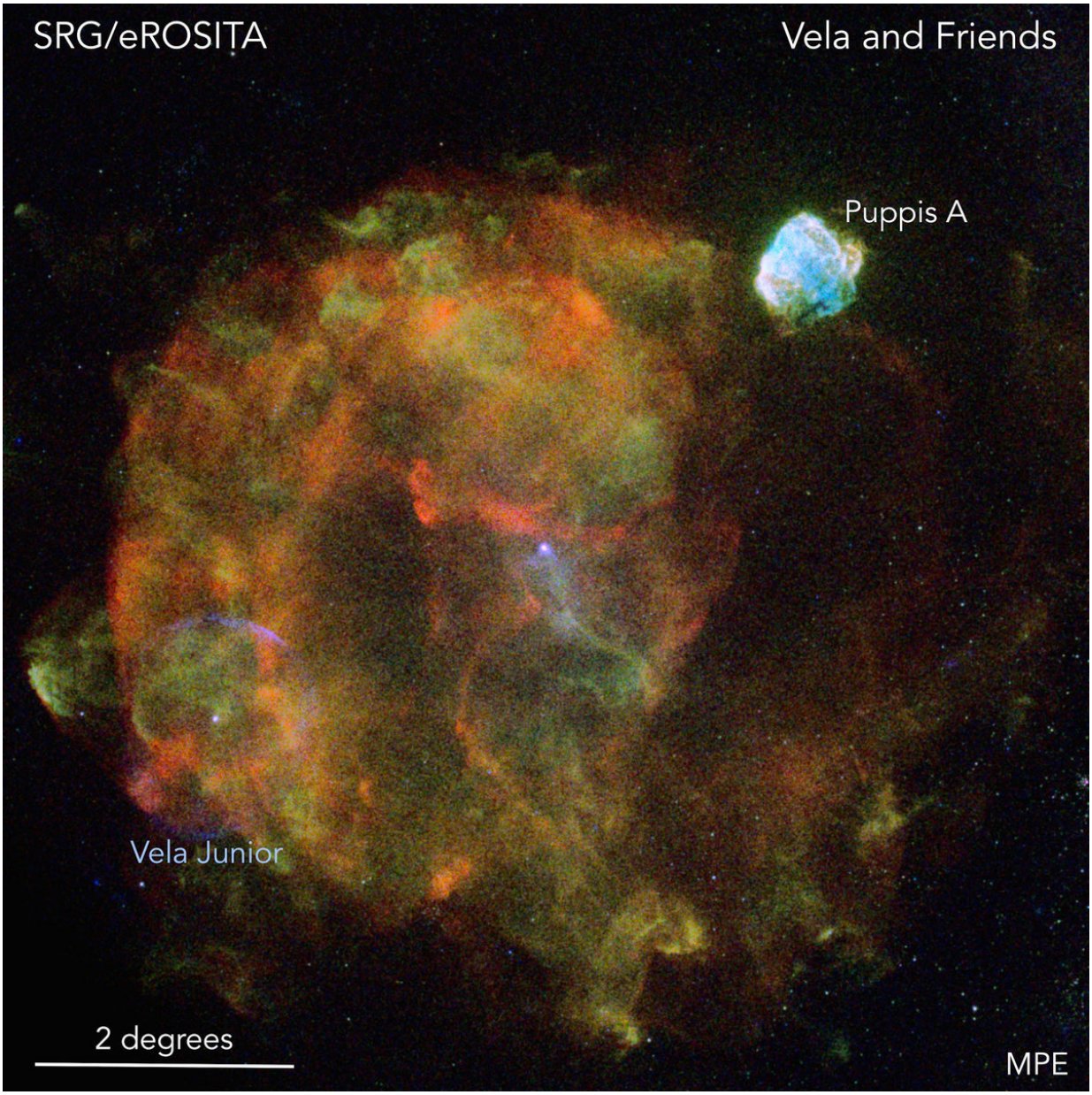
The energetic universe: The first eROSITA all-sky survey was conducted over a period of six months by letting the telescope rotate continuously, thus providing a uniform exposure of about 150-200 seconds over most of the sky, with the ecliptic poles being visited more deeply. As eROSITA scans the sky, the energy of the collected photons is measured with an accuracy ranging from 2% - 6%. To generate this image, in which the whole sky is projected onto an ellipse (so-called Aitoff projection) with the centre of the Milky Way in the middle and the body of the Galaxy running horizontally, photons have been colour-coded according to their energy (red for energies 0.3-0.6 keV, green for 0.6-1 keV, blue for 1-2.3 keV). Credit: Jeremy Sanders, Hermann Brunner und das eSASS-Team (MPE); Eugene Churazov, Marat Gilfanov (im Namen von IKI)

Over the course of 182 days, the eROSITA X-ray telescope has completed its first full sweep of the sky which it embarked upon about a year ago. This new map of the hot, energetic universe contains more than one million objects, roughly doubling the number of known X-ray sources discovered over the 60-year history of X-ray astronomy. Most of the new sources are active galactic nuclei at cosmological distances, marking the growth of gigantic black holes over cosmic time.

A million X-ray sources revealing the nature of the hot universe—this is the impressive harvest of the first scan of the entire sky with the eROSITA telescope onboard SRG. "This all-sky image completely changes the way we look at the energetic universe," says Peter Predehl, the Principal Investigator of eROSITA at the Max Planck Institute for Extraterrestrial Physics (MPE). "We see such a wealth of detail—the beauty of the images is really stunning."

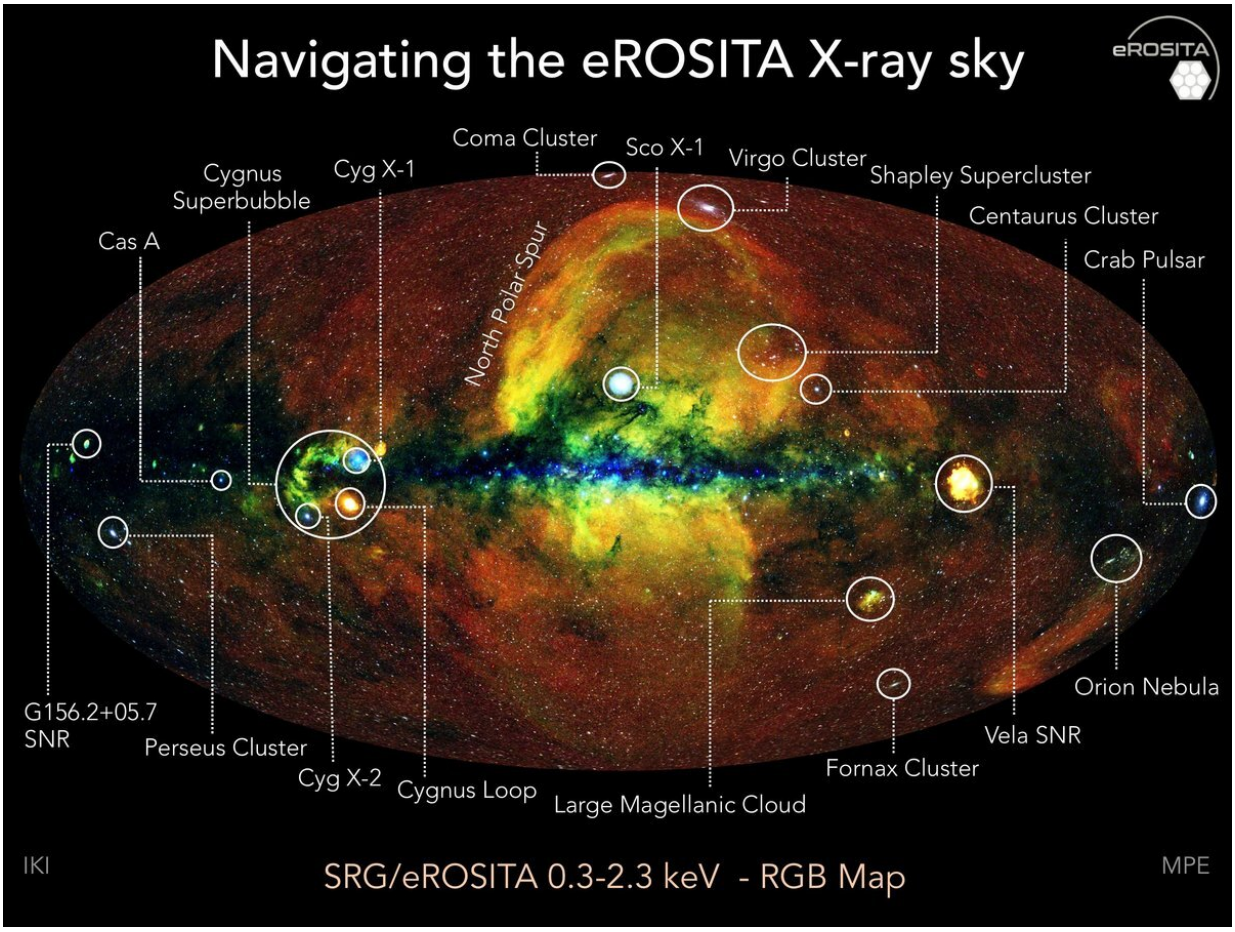
This first complete sky image from eROSITA is about four times deeper than the previous all-sky survey by the ROSAT telescope 30 years ago, and has yielded around 10 times more sources: about as many as have been discovered by all past X-ray telescopes combined. And while most classes of astronomical objects emit in X-rays, the hot and energetic Universe looks quite different to the one seen by optical or radio telescopes. Looking outside the body of our Galaxy, most of the eROSITA sources are active galactic nuclei, accreting supermassive black holes at cosmological distances, interspersed with clusters of galaxies, which appear as extended X-ray haloes shining thanks to the hot gas confined by their huge concentrations of dark matter. The all-sky image reveals in exquisite detail the structure of the hot gas in the Milky Way itself, and the circum-galactic medium, which surrounds it, whose properties are key to understanding the formation history of our Galaxy. The eROSITA X-ray map also reveals stars with strong, magnetically active hot coronae, X-ray binary stars containing neutron stars, black holes or white dwarves, and spectacular supernova remnants in our own

and other nearby galaxies such as the Magellanic clouds.



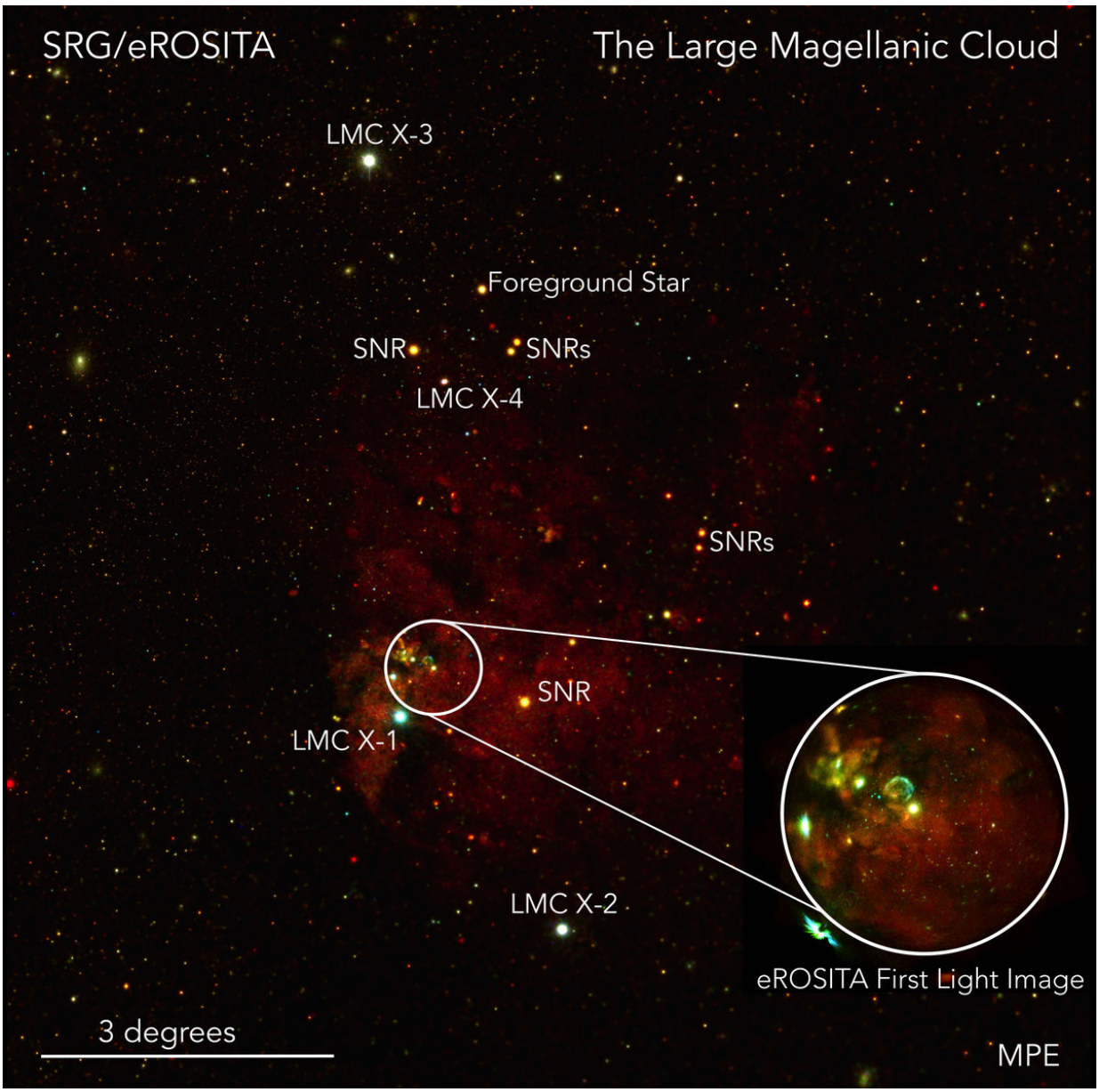
Due to its size and close distance to Earth, the "Vela supernova remnant" which is shown in this picture is one of the most prominent objects in the X-ray sky. The Vela supernova exploded about 12000 years ago at a distance of 800 light-years and overlaps with at least two other supernova remnants, Vela Junior (in the picture seen as bluish ring at the bottom left) and Puppis-A (top right). Vela

Junior was discovered just 20 years ago, although this object is so close to Earth that remains of this explosion were found in polar ice cores. All three supernova explosions produced both the X-ray-bright supernova remnants and neutron stars, which shine as intense X-ray point sources near the centres of the remnants. The quality of the new eROSITA data of this "stellar cemetery" will give astronomers many exciting new insights into the physical processes operating in the hot supernova plasma as well as for exploring the exotic neutron stars. Credit: Peter Predehl, Werner Becker (MPE), Davide Mella



Annotated version of the eROSITA First All-Sky image. Several prominent X-ray features are marked, ranging from distant galaxy clusters (Coma, Virgo, Fornax, Perseus) to extended sources such as Supernova Remnants (SNRs) and Nebulae to bright point sources, e.g. Sco X-1, the first extrasolar X-ray source to

be detected. The Vela SNR is to the right of this image, the Large Magellanic Cloud in the bottom right quadrant, the Shapley supercluster in the upper right (though not easily visible in this projection). Credit: Jeremy Sanders, Hermann Brunner, Andrea Merloni and the eSASS team (MPE); Eugene Churazov, Marat Gilfanov (on behalf of IKI)

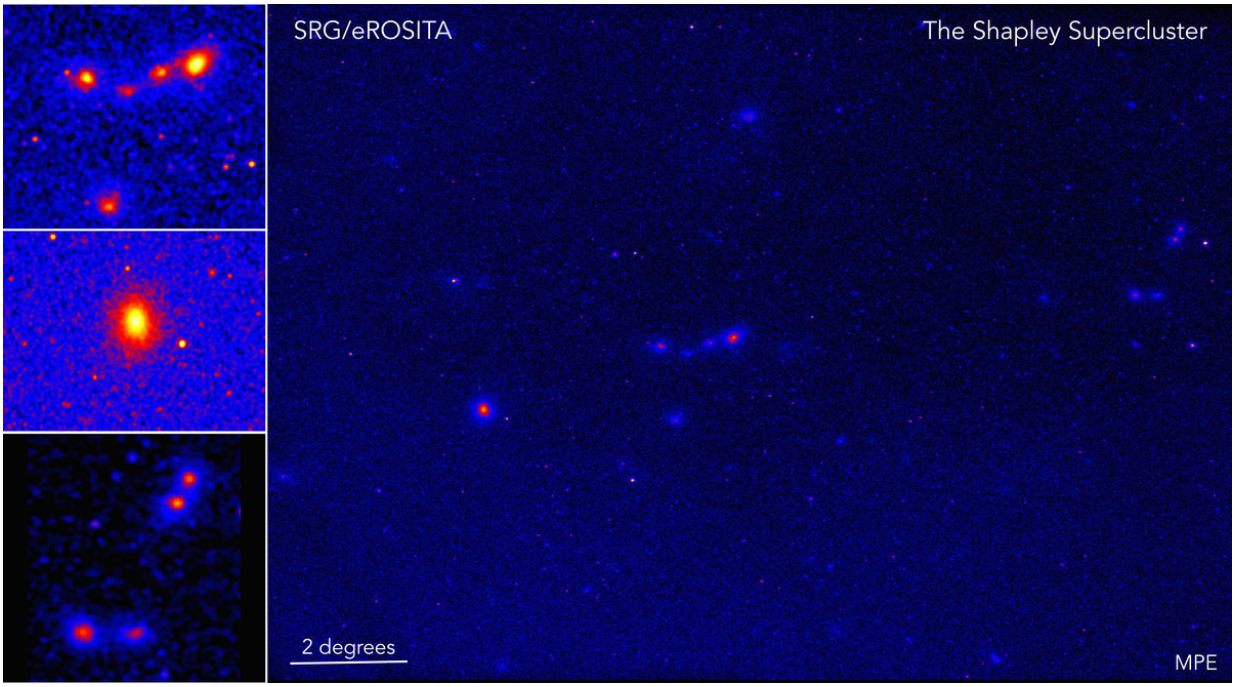


the four brightest X-ray sources in the LMC region are marked (LMC X-1 to 4). Also visible are numerous Supernova Remnants (SNR) and many foreground stars, the brightest of which is marked, too. On the bottom right, a zoom is shown into the central region of the LMC, which was the first image captured by eROSITA with its seven telescopes back in October 2019. Credit: Frank Haberl, Chandreyee Maitra (MPE)

"We were all eagerly awaiting the first all-sky map from eROSITA," says Mara Salvato, the scientist at MPE who leads the effort to combine eROSITA observations with other telescopes across the electromagnetic spectrum. "Large sky areas have already been covered at many other wavelengths, and now we have the X-ray data to match. We need these other surveys to identify the X-ray sources and understand their nature." The survey is also a treasure trove of rare and exotic phenomena, including numerous types of transients and variables, such as flares from compact objects, merging neutron stars, and stars being swallowed by black holes. "eROSITA often sees unexpected bursts of X-rays from the sky," continues Salvato. "We need to alert ground-based telescopes immediately to understand what's producing them."

Assembling the image has been a mammoth task. So far, the operations team has received and processed about 165 GB of data collected by eROSITA's seven cameras. While relatively small by "big-data" standards on the ground, operating this complex instrument in space provided its own special challenges. "We check and monitor the health of the instrument on a daily basis, in cooperation with our colleagues in Moscow who operate the SRG spacecraft", explains Miriam Ramos-Ceja, a member of the eROSITA operations team at MPE. "This means we can respond quickly to any anomalies. We've been able to react to these immediately to keep the instrument safe, while collecting data at ~97% efficiency. It's amazing to be able to communicate in real time

with an instrument located 1.5 million kilometres away!" The data downlink occurs daily. "We perform immediate quality checks on the data", she continues, "before it is being processed and analysed by the teams in Germany and Russia."



The Shapley supercluster of galaxies is one of the most massive concentrations of galaxies in the local universe at a distance of about 650 million light-years (z~0.05). Each of the dozen extended structures is itself a cluster of galaxies, consisting of 100s to 1000s of individual galaxies, each denoting an intersection of filaments making up the large-scale structure in the Universe. This image spans 16 degrees across the sky (about 30 times the size of the full moon), which translates into about 180 million light-years across at the distance of the Shapley supercluster. The images on the left show a zoom of the the most massive clusters in the Shapley supercluster. Credit: Esra Bulbul, Jeremy Sanders (MPE)

While the team is now busy analysing this first all-sky map and using the

images and catalogues to deepen our understanding of cosmology and high-energy astrophysical processes, the telescope continues its sweep of the X-ray sky. "The SRG Observatory is now starting its second all-sky survey, which will be completed by the end of this year", says Rashid Sunyaev, Lead Scientist of the Russian SRG team. "Overall, during the next 3.5 years, we plan to get seven maps similar to the one seen in this beautiful image. Their combined sensitivity will be a factor of five better and will be used by astrophysicists and cosmologists for decades."

Kirpal Nandra, head of the high-energy astrophysics group at MPE, adds "With a million sources in just six months, eROSITA has already revolutionized X-ray astronomy, but this is just a taste of what's to come. This combination of sky area and depth is transformational. We are already sampling a cosmological volume of the hot Universe much larger than has been possible before. Over the next few years, we'll be able to probe even further, out to where the first giant cosmic structures and supermassive black holes were forming."

Provided by Max Planck Society

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