Astronomers publish sky map of thousands of newly discovered galaxies

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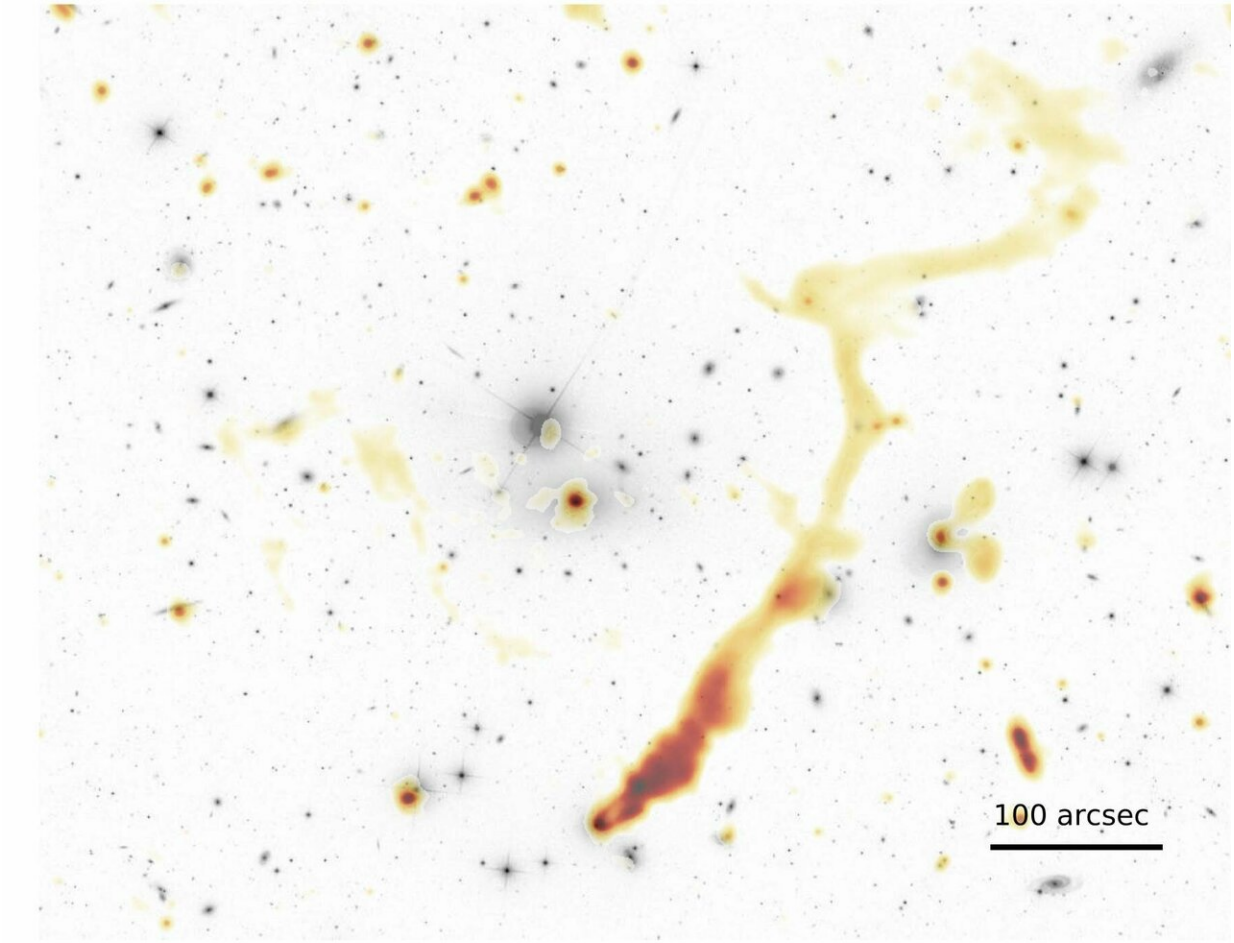


This image shows how the LOFAR radio telescope opens a new view of the universe. The image shows galaxy cluster Abell 1314. In shades of grey, a piece of the sky can be seen as we know it in visible light. The orange hues show the radio emitting radiation in the same part of the sky. The radio image looks completely different and changes our assumptions about how galaxies arise and

develop. These objects are located at a distance of approximately 460 million light years from earth.In the middle of every galaxy there is a black hole. When matter falls into it, an unbelievable amount of energy is released and electrons are ejected like a fountain. These accelerated electrons produce radio emission that can extend over gigantic distances and is not visible at optical wavelengths. Credit: Rafaël Mostert/LOFAR Surveys Team/Sloan Digital Sky Survey DR13

An international team of more than 200 astronomers from 18 countries has published the first phase of a major new radio sky survey at unprecedented sensitivity using the Low Frequency Array (LOFAR) telescope. The survey reveals hundreds of thousands of previously undetected galaxies, shedding new light on many research areas including the physics of black holes and how clusters of galaxies evolve. A special issue of *Astronomy & Astrophysics* is dedicated to the first twenty-six research papers describing the survey and its first results.

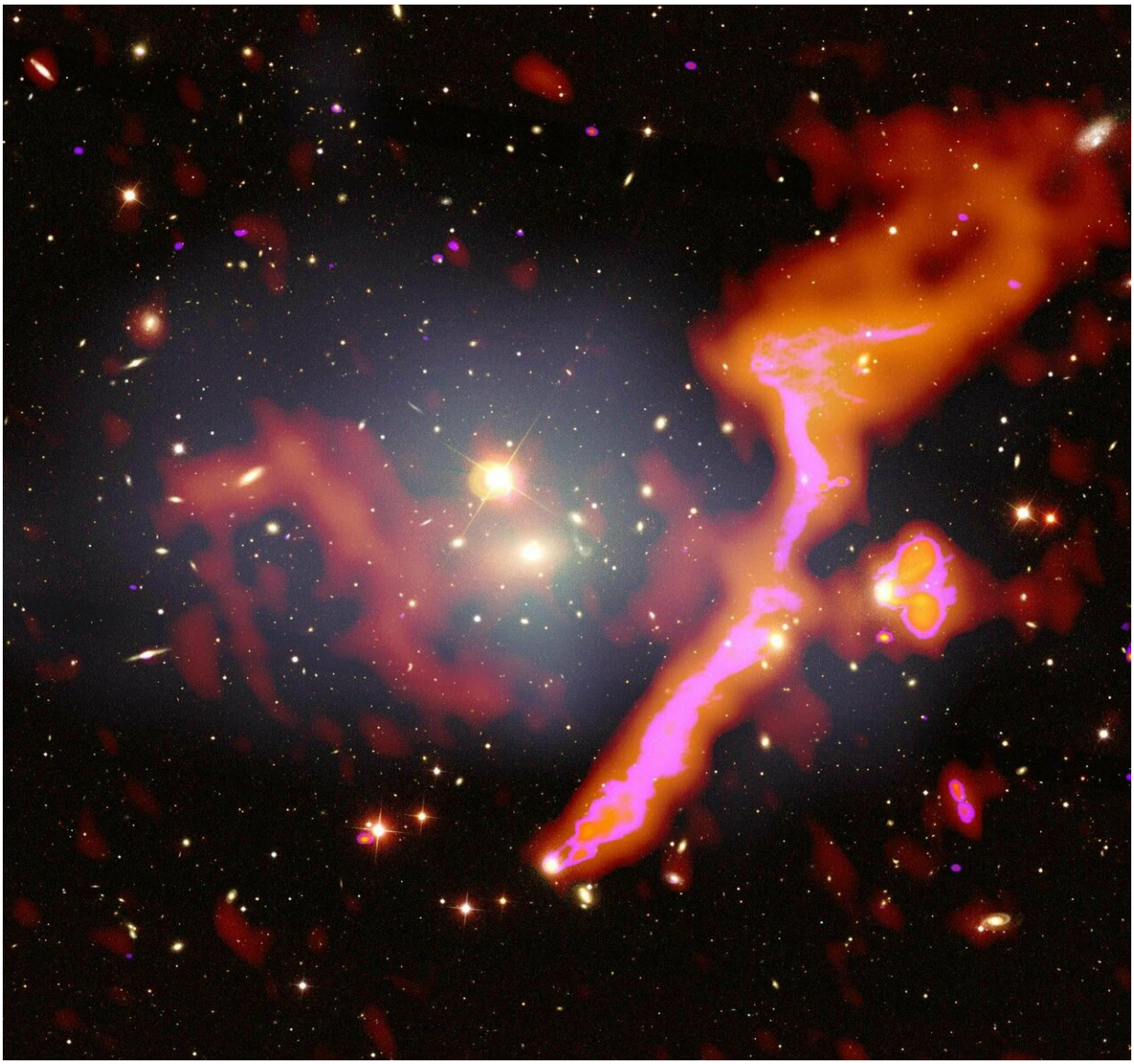
Radio astronomy reveals processes in the universe that cannot be seen with optical instruments. In this first part of the sky survey, LOFAR observed a quarter of the northern hemisphere at low radio frequencies. At this point, approximately 10 percent of that data has been released to the public. It maps 300,000 sources, almost all of which are galaxies in the distant universe; their radio signals have traveled billions of light years to reach Earth.

Black holes

Huub Röttgering, Leiden University (The Netherlands) says, "If we take a radio telescope and we look up at the sky, we see mainly emission from the immediate environment of massive black holes. With LOFAR, we hope to answer the fascinating question: Where do those black holes come from?" Researchers do know that black holes are messy eaters.

When gas falls onto them, they emit jets of material that can be seen at radio wavelengths.

Philip Best, University of Edinburgh (U.K.), says, "LOFAR has a remarkable sensitivity and that allows us to see that these jets are present in all of the most massive galaxies, which means that their black holes never stop eating."



The galaxy cluster Abell 1314 is located in Ursa Major at at distance of approximately 460 million light years from earth. It hosts large-scale radio emission that was caused by its merger with another cluster. Non-thermal radio emission detected with the LOFAR telescope is shown in red and pink, and thermal X-ray emission detected with the Chandra telescope is shown in gray, overlaid on an optical image. Credit: Amanda Wilber/LOFAR Surveys Team/NASA/CXC

Clusters of galaxies

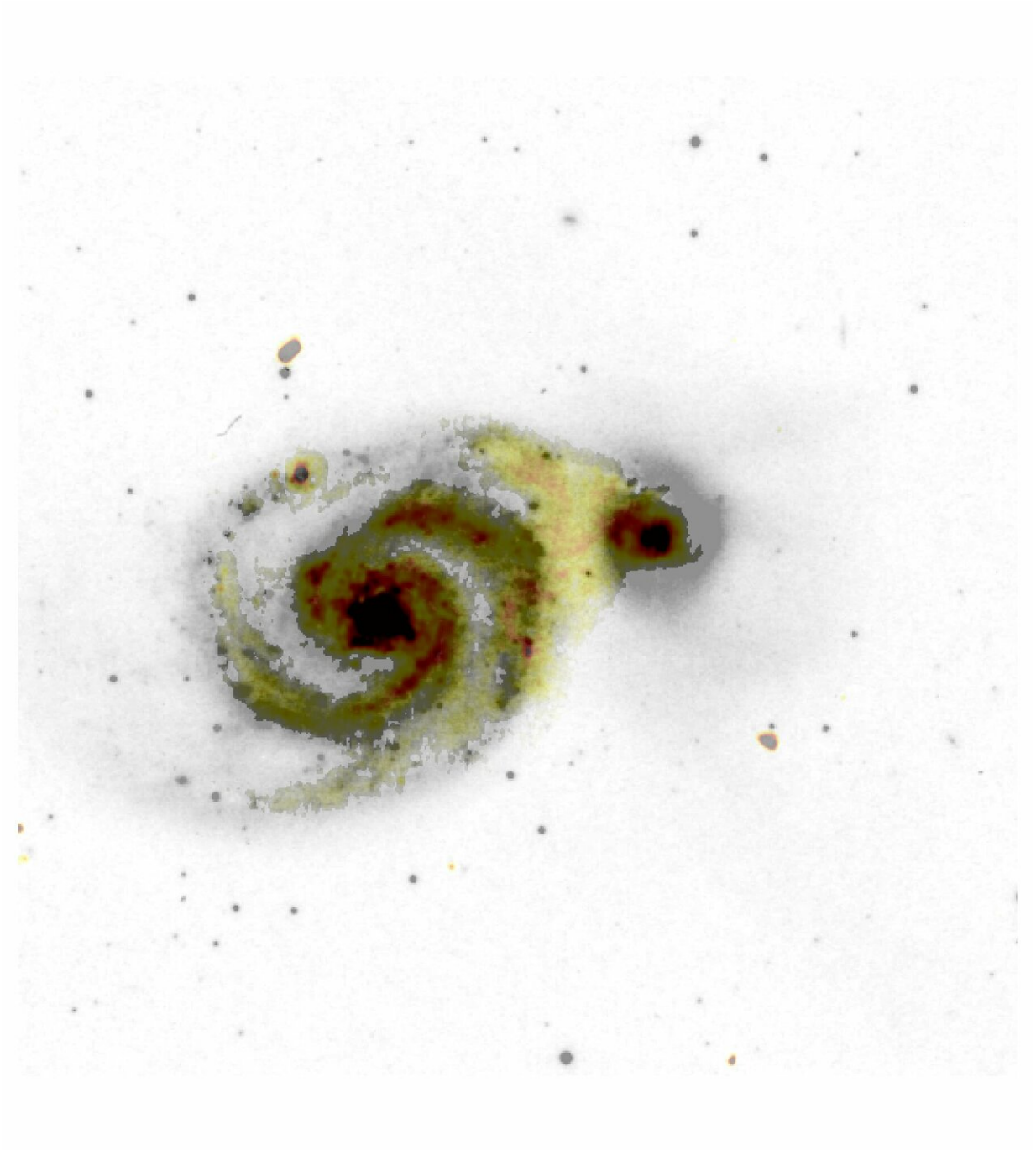
Galaxy clusters are ensembles of hundreds to thousands of galaxies. It has been known for decades that when two clusters of galaxies merge, they can produce radio emissions spanning millions of light years. This emission is thought to come from particles that are accelerated during the merger process. Amanda Wilber, University of Hamburg (Germany), says, "With radio observations we can detect radiation from the tenuous medium that exists between galaxies. This radiation is generated by energetic shocks and turbulence. LOFAR allows us to detect many more of these sources and understand what is powering them."

Annalisa Bonafede, University of Bolognaand INAF(Italy), says, "What we are beginning to see with LOFAR is that in some cases, clusters of galaxies that are not merging can also show this emission, albeit at a very low level that was previously undetectable. This discovery tells us that besides merger events, there are other phenomena that can trigger particle acceleration over huge scales."

Magnetic fields

"Magnetic fields pervade the cosmos, and we want to understand how this happened. Measuring magnetic fields in intergalactic space can be

difficult, because they are very weak. However, the unprecedented accuracy of the LOFAR measurements has allowed us to measure the effect of cosmic magnetic fields on radio waves from a giant radio galaxy that is 11 million light years in size. This work shows how we can use LOFAR to help us understand the origin of cosmic magnetic fields," explains Shane O"Sullivan, University of Hamburg.



This image shows M51, also known as the Whirlpool Galaxy. It is 15-35 million light years from Earth and around 60,000 light years in diameter. At the centre of the spiral galaxy there sits a supermassive black hole. With the LOFAR data (yellow and red hues), we can see that the spiral galaxy and its companion are interacting because there is a bridge of emission joining them. Credit: Sean Mooney/LOFAR Surveys Team/Digitized Sky Survey

High-quality images

Creating low-frequency radio sky maps takes both significant telescope and computational time and requires large teams to analyse the data. "LOFAR produces enormous amounts of data—we have to process the equivalent of 10 million DVDs of data. The LOFAR surveys were recently made possible by a mathematical breakthrough in the way we understand interferometry," says Cyril Tasse, Observatoire de Paris—Station de radio astronomie à Nançay (France).

"We have been working together with SURF in the Netherlands to efficiently transform the massive amounts of data into high-quality images. These images are now public and will allow astronomers to study the evolution of galaxies in unprecedented detail," says Timothy Shimwell, Netherlands Institute for Radio Astronomy (ASTRON) and Leiden University.

SURF's compute and data centre located at SURFsara in Amsterdam runs on 100 percent renewable energy and hosts over 20 petabytes of LOFAR data. "This is more than half of all data collected by the LOFAR telescope to date. It is the largest astronomical data collection in the world. Processing the enormous data sets is a huge challenge for scientists. What normally would have taken centuries on a regular computer was processed in less than one year using the high throughput compute cluster (Grid) and expertise," says Raymond Oonk (SURFsara).

LOFAR

The LOFAR telescope, the Low Frequency Array, is unique in its capabilities to map the sky in fine detail at metre wavelengths. LOFAR is operated by ASTRON in The Netherlands and is considered to be the

world's leading telescope of its type. "This sky map will be a wonderful scientific legacy for the future. It is a testimony to the designers of LOFAR that this telescope performs so well," says Carole Jackson, Director General of ASTRON.

The next step

The 26 research papers in the special issue of *Astronomy & Astrophysics* were done with only the first two percent of the sky survey. The team aims to make sensitive high-resolution images of the whole northern sky, which will reveal 15 million radio sources in total. "Just imagine some of the discoveries we may make along the way. I certainly look forward to it," says Jackson. "And among these there will be the first massive black holes that formed when the universe was only a 'baby," with an age a few percent of its present age," adds Röttgering.

More information: T. W. Shimwell et al. The LOFAR Two-metre Sky Survey, *Astronomy & Astrophysics* (2018). DOI: 10.1051/0004-6361/201833559

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