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Sensitivity in Space Research

Astronomers are charting out a radio map of the sky, showing hundreds of thousands of previously unknown galaxies.

It might seem that the concept of tender sensitivity is terribly out of place in distant, outer space. That the cosmos is empty and uncaring – nothing but a "careless, cold infinity," as Floor Jansen sings in a song by the European metal band Nightwish. And yet, a certain non-emotional kind of sensitivity is indeed highly cherished by anyone involved in space research. In the case of a radio telescope, such as the LOFAR interferometer depicted in the illustration, sensitivity is one of the key parameters. It is defined as the weakest radio emission such an instrument is able to detect (it would be nice, of course, to study only strong radio sources, but unfortunately clues to most of the questions we find challenging can only be found by observing very weak ones).

Thanks to its extraordinary sensitivity – in the non-emotional sense, of course – LOFAR has been able to embark upon a new survey of the whole sky, known as LoTSS (LOFAR Two-Meter Sky Survey). LoTSS is the most sensitive radio-frequency survey of the sky that has ever been undertaken: although just a fraction of the map of the northern celestial hemisphere has so far been published, it has already brought the discovery of thousands of previously unknown galaxies. And that's just for starters – the first studies harnessing data from the new survey have also reported, for instance, the discovery of an intergalactic medium radiating in the radio continuum in undisturbed galaxy clusters (a completely new discovery), a dozen-odd compact radio-emitting galaxy groups (before this only a few such objects had been discovered over the past 50 years), and confirmation that supermassive black holes at the centers of massive galaxies are never satiated – they continue to devour matter from their surroundings until absolutely nothing is left. What will the analysis of further portions of LOFAR data bring? No one knows, and that's what's most exciting of all.

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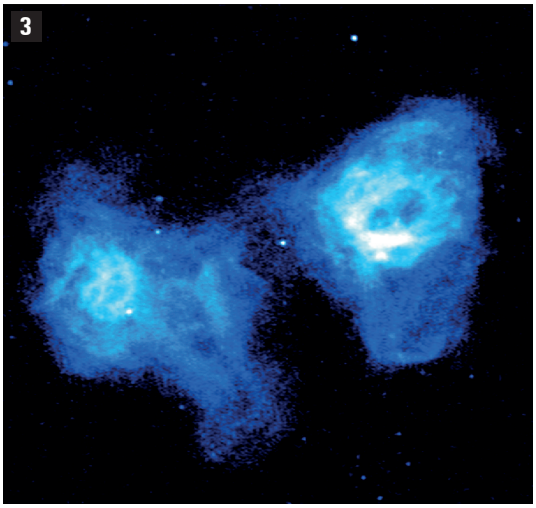
Fig. 1
The Superterp, the heart of the LOFAR core: six separate interferometer stations situated on an artificial island 320 m across. A further 18 stations are situated within a radius of 2 km, and another 14 within the whole of the Netherlands. There are a further 14 international stations (including three in Poland) and that number is continually increasing

MARIAN SOIDA, OA UJ

Fig. 2
One of the LOFAR interferometer stations, situated in Łazy near Bochnia, not far from the city of Kraków. Dozens of such sites strewn across Europe, linked together by a fiber-optic network, work together as a single instrument. The Polish involvement in the project is supervised by the POLFAR consortium



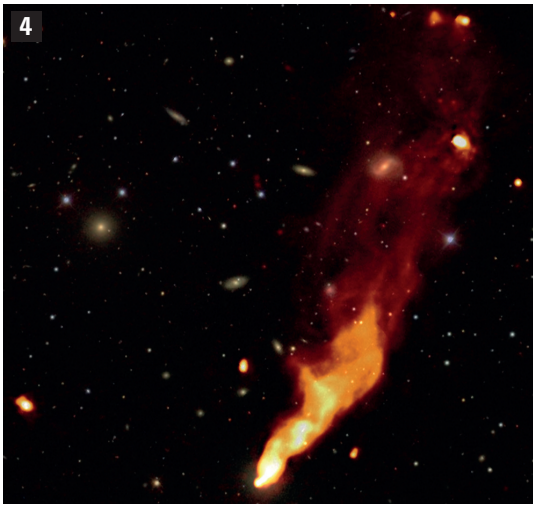
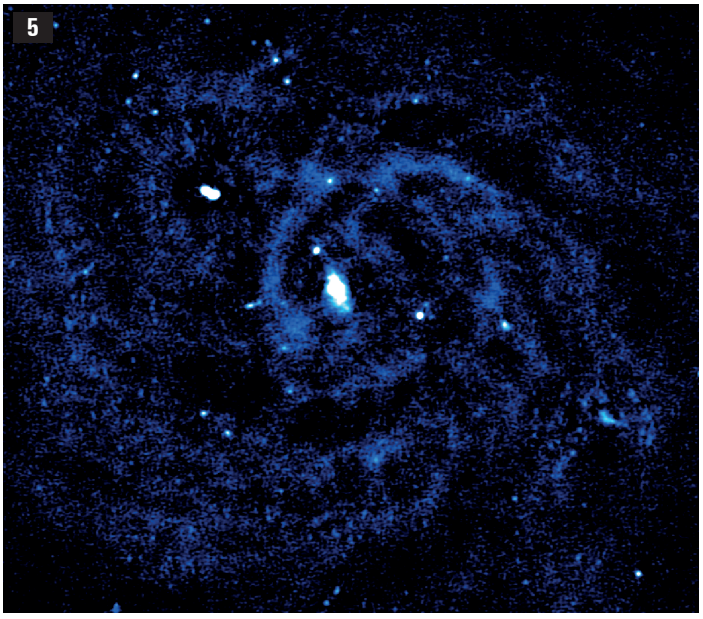


Fig. 3
Radio source B3 0157+405A (as identified in the Third Bologna Radio Survey, based on its position in the sky). This radio galaxy has extensive radio lobes, arising when a stream of ultra-relativistic particles meets the intergalactic medium. The complex structure of the radio lobes suggests the presence of large-scale turbulent structure in their magnetic fields

Fig. 4
Going down in flames? This "head-tail" radio galaxy is moving through the intergalactic medium in a cluster of galaxies. Its interaction with the hot medium draws out jets and lobes in keeping with its direction of movement, opposite to its turning, giving rise to a descending, "comet-like" appearance



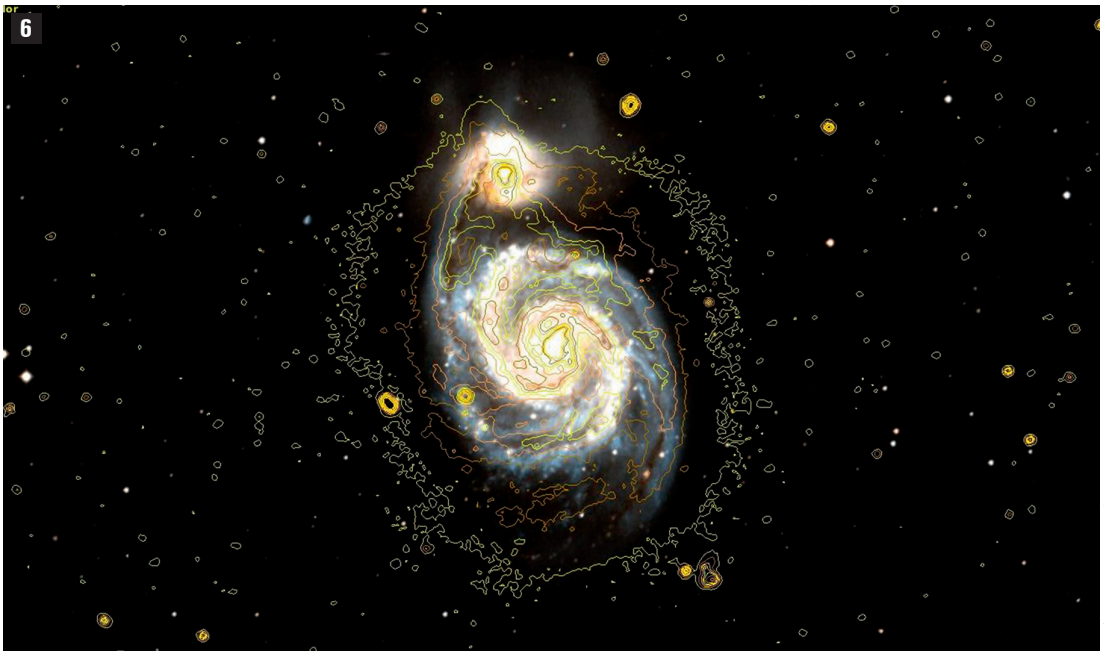


Fig. 5
Observing the nearby galaxy IC342, greatly occluded by objects in our own Milky Way, is no trouble for LOFAR, thanks to the synchrotron radio emissions caused by supernova explosions in its spiral arms. IC342 shows itself in its full glory in the LoTSS survey, with quite a few background objects also visible

Fig. 6
One of the best-known spiral galaxies, M51 or the Whirlpool Galaxy, is situated 15–35 million light years from earth and has a diameter of around 60,000 light years. At its center is a supermassive black hole. With LOFAR data (the yellow outlines) we can confirm that the spiral galaxy and its nearby companion are interacting: they are linked by a bridge of radio-emitting matter and a common environment

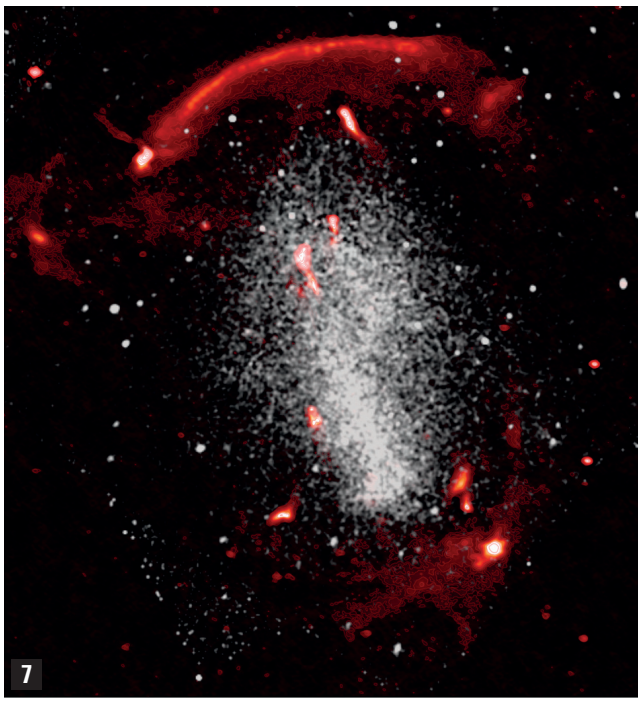


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Fig. 7
This is one of the galaxy clusters in the Zone of Avoidance, an area of the sky where the Milky Way hampers or prevents observations. CIZA J2242.8+5301 is a huge radio relic (left behind by processes of galactic interaction) with a distinctive shape, and so has been nicknamed "the sausage." LOFAR emissions sources are shown in shades of red, x-ray sources (from the Chandra telescope) in white. The source of the latter is the hot gas in central portions of the cluster, at temperatures reaching millions of degrees kelvin

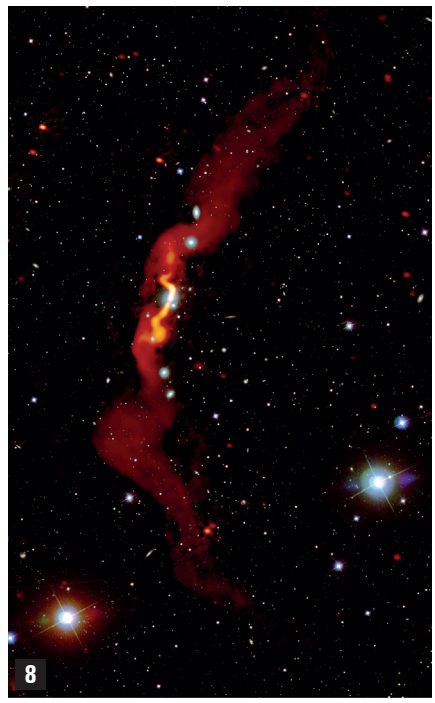

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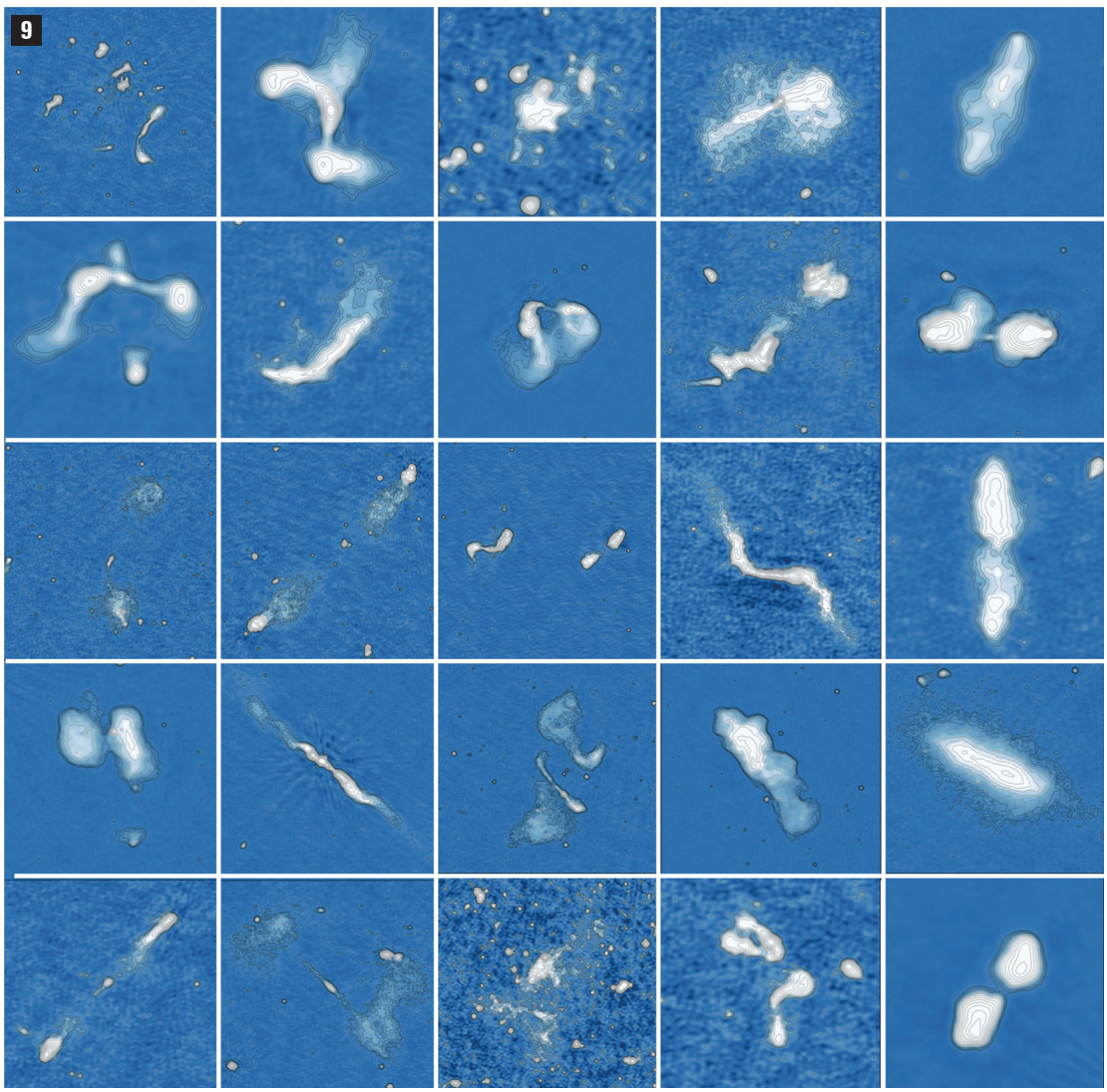
Fig. 8
Radio galaxy 3C31 (the thirty-first object in the Third Cambridge Catalog of Radio Sources) is another object whose optical image does not show much, but whose radio image reveals a structure of jets and lobes stretching out over more than 3 million light years!

Fig. 9
A collage showing the radio maps of several dozen radio sources as seen by LOFAR. They include "normal" galaxies, radio galaxies, and galaxy clusters. All of these objects shine brightly in the radio sky



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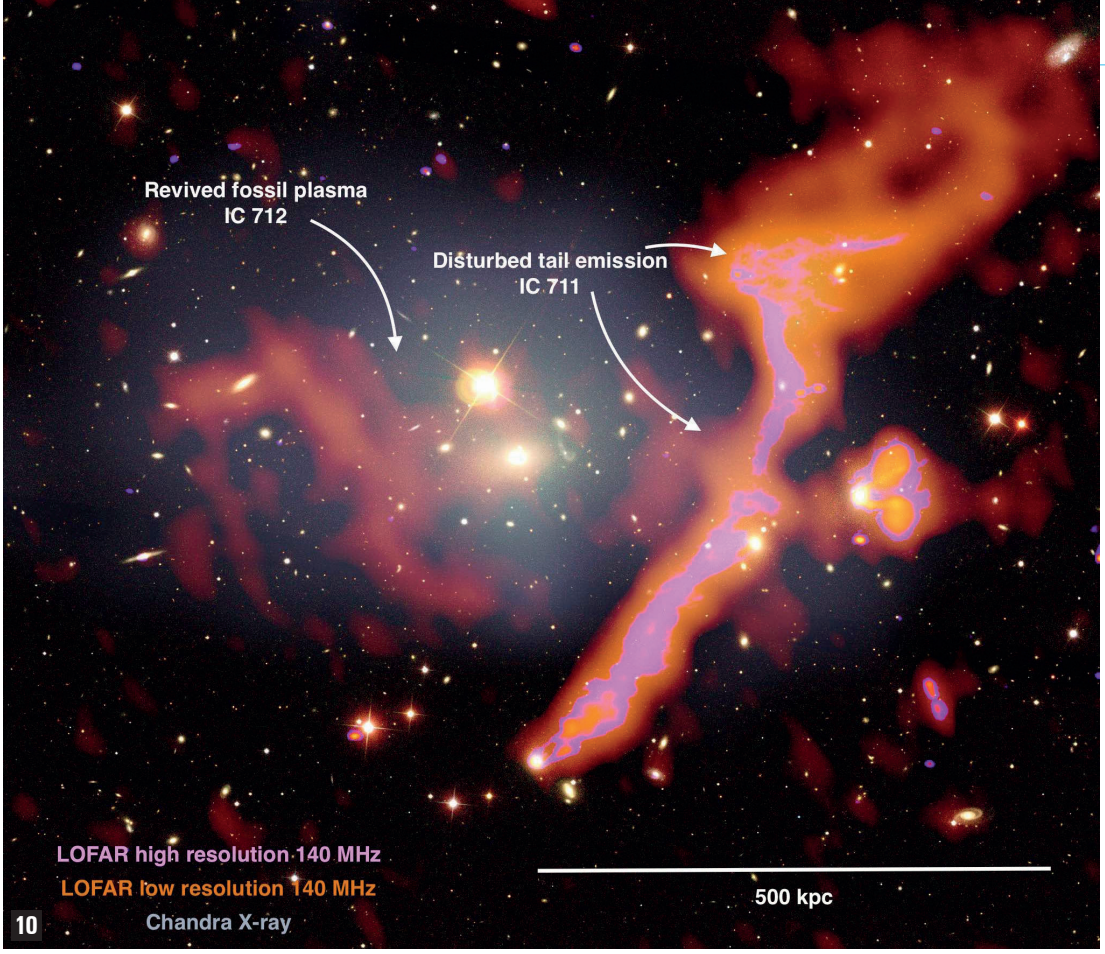

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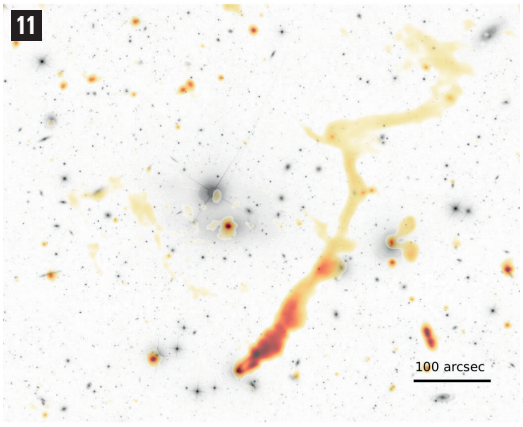

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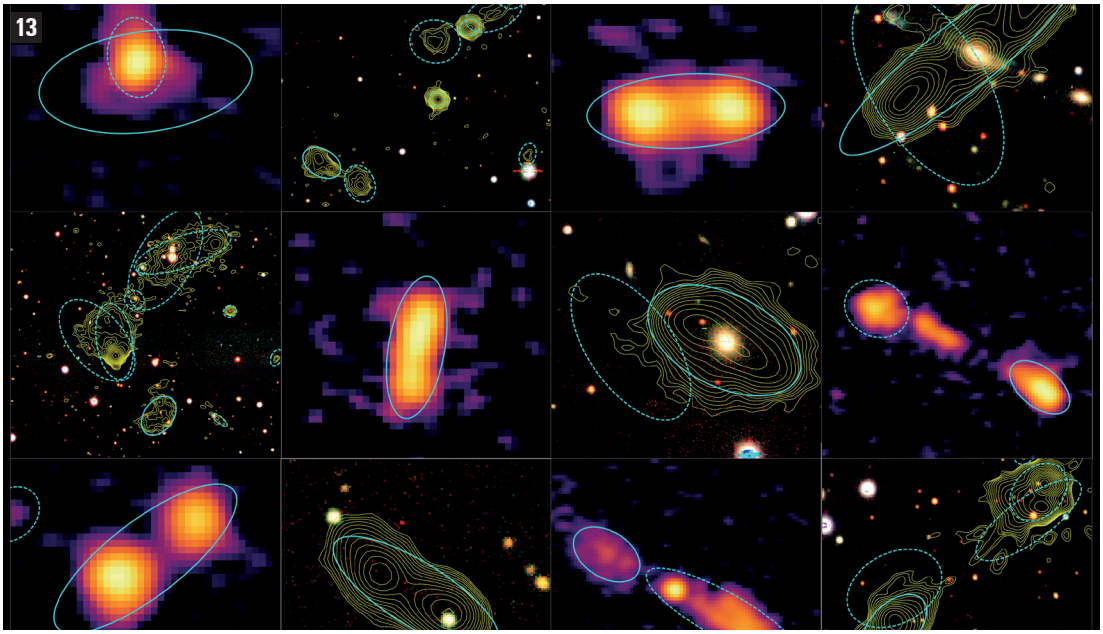

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Fig. 10, 11
How is LoTSS opening up a new window on the cosmos? The gray color in Fig. 11 shows a (quite uninteresting) optical image of the galaxy cluster Abell 1314, from survey SDSS DR13. LOFAR additionally perceives an "invisible" huge tail (yellow and red colors) leading away from one of the galaxies. It arises due to the synchrotron effect; most of the objects seen by the radio telescope are visible due to this process. In Fig. 10, in turn, the same galaxy cluster Abell 1314 is shown with an admixture of x-ray information. The pink and orange radio data (high- and low-resolution, respectively) are combined with red x-ray data. The previously detected radio emissions coincide with the area occupied by the hot gas being wrested away from the galaxy IC711. Here, the weak radio "arch" visible in Fig. 11 around the bright star at the center of the image also turns out to be an x-ray source

Fig. 12
One spiral galaxy within another? In essence, precisely so. Here, when the radio emissions from LOFAR are superimposed on an optical image of the galaxy M106, we see a second spiral structure. The latter is related not to the arms of the galaxy, but to the emissions associated with the central black hole

Fig. 13
Want to try for yourself what it's like to be a radio astronomer? As preparations are being made to release another portion of LOFAR data, a "radio galaxy zoo" has been set up at http://lofargalaxyzoo.nl/. Everyone can register and help try to identify the optical counterparts to more than 4 million radio sources found in the new survey