

Astrowatch

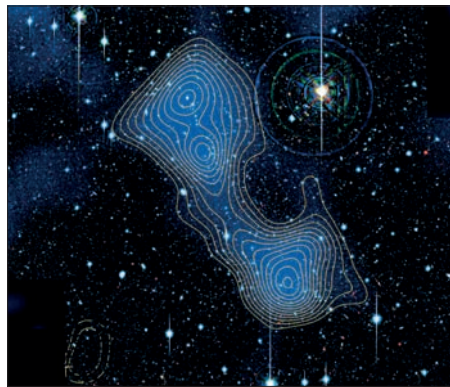
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Dark-matter filament binds galaxy clusters

Numerical simulations of structure formation in the universe reveal how clusters of galaxies form at the intersection of dark-matter filaments. The presence of such a filament connecting the galaxy clusters Abell 222 and Abell 223 has finally been detected through its weak gravitational lensing effect on background galaxies.

With the advent of supercomputers it became possible to simulate the action of gravity over cosmic time starting from a rather uniform distribution of matter in the early universe (*CERN Courier* September 2007 p11). Time-lapse films based on these simulations show the evolution of structure formation in a large volume of the universe. While the universe expands globally, gravity tends to collapse small initial regions of over-density. Matter is therefore contracting locally while being stretched on large scales. The opposite effects of gravitational collapse and cosmic expansion result in a sponge-like structure with a web of filaments delimiting big voids. The densest regions are at the intersection of filaments and are the formation sites of clusters of galaxies. As time proceeds, matter flows along the filaments to the nearest cluster, making the filaments thinner and thinner.

This sponge-like distribution of matter in the universe has been confirmed by mapping the position of thousands of galaxies in the nearby universe for decades. According to the simulations, it is primarily cold dark matter that collapses to shape the filamentary skeleton of the universe; normal, baryonic matter follows the same route to form galaxies along these filaments. The detection of warm-hot intergalactic gas



A bridge of dark matter is found to connect the two main clusters in the Abell 222 and Abell 223 galaxy clusters. The distribution of mass is shown with contours and a blue glow, on a background image obtained by the 8.2m Subaru telescope on Mauna Kea, Hawaii. (Image credit: JP Dietrich et al. 2012.)

along walls of galaxy over-densities was another piece of evidence for the validity of this scenario (*CERN Courier* July/August 2010 p14). What remained to be detected was the actual presence of dark matter in these filaments. This has now been achieved by Jörg P Dietrich of the University of Michigan and collaborators in Germany, the UK and the US, looking at the galaxy supercluster Abell 222 and Abell 223.

The technique used to map the distribution of dark matter in clusters of galaxies is always the same. It is called weak gravitational lensing and consists of measuring the small distortion of the shape of background galaxies induced by the presence of the invisible matter (*CERN*

Courier January/February 2007 p11). As mass distorts space-time locally, it changes the path of light from remote galaxies and thus alters their shape as observed from Earth. The problem is that the true shape of the individual galaxies is not known, so it is difficult to know how strong their distortion is. However, by analysing tens of thousands of galaxies, a global trend of distortion can emerge with statistical significance.

Dietrich and colleagues find a bridge of matter between Abell 222 and Abell 223 at the 96% confidence level. The derived surface density of this structure is unexpectedly high compared with dark-matter filaments in numerical simulations. This suggests that the filament is not seen from the side but almost along its major axis, thus increasing its projected mass. The red-shift difference between the two galaxy clusters does, indeed, suggest that they are at about 60 million light-years apart. The binding filament contributes as much as a complete galaxy cluster to the total mass of the supercluster. It is the site of an over-density of galaxies and includes hot intergalactic gas detected in X-rays. This gas contributes to about 9% of the total mass of the filament at most. The remaining mass would essentially be composed of dark matter. This discovery is new evidence that the basic assumptions of numerical simulations are valid; in particular, that cold dark matter is an essential ingredient governing the formation of large-scale structures in the universe.

● Further reading

JP Dietrich *et al.* 2012 *Nature* **487** 202.

Picture of the month

Who is smoking in space? This delicate curl of smoke is blown away by a newborn star hiding in a cloud of dust. In the process of star formation, the infall of matter may form an accretion disc around the infant star, where magnetic fields are thought to funnel some of the incoming matter away in twin jets of gas ejected in opposite directions. Such stellar jets are the analogues of the extremely powerful jets of supermassive black holes in quasars (*CERN Courier* July/August 2006 p10). Herbig-Haro (HH) objects – so called in honour of George Herbig and Guillermo Haro, who studied these nebulosities in the 1940s – travel with speeds of several hundred kilometres a second. This jet of HH 110 has been captured beautifully by the Hubble Space Telescope in front of a background of distant spiral galaxies. (Image credit: NASA, ESA and the Hubble Heritage team (STScI/AURA).)



Refrigerators for the cryogenic particle racetrack

On 4 July 2012, the eyes of the world were firmly fixed on CERN in Geneva. It was on this day that the physicists at CERN announced their sensational discovery of a new particle that could be the Higgs boson. Linde Kryotechnik AG is proud to have played a part in this momentous occasion, providing the cutting-edge cryogenic technology for the accelerator's ring and detectors.

Outstanding achievement

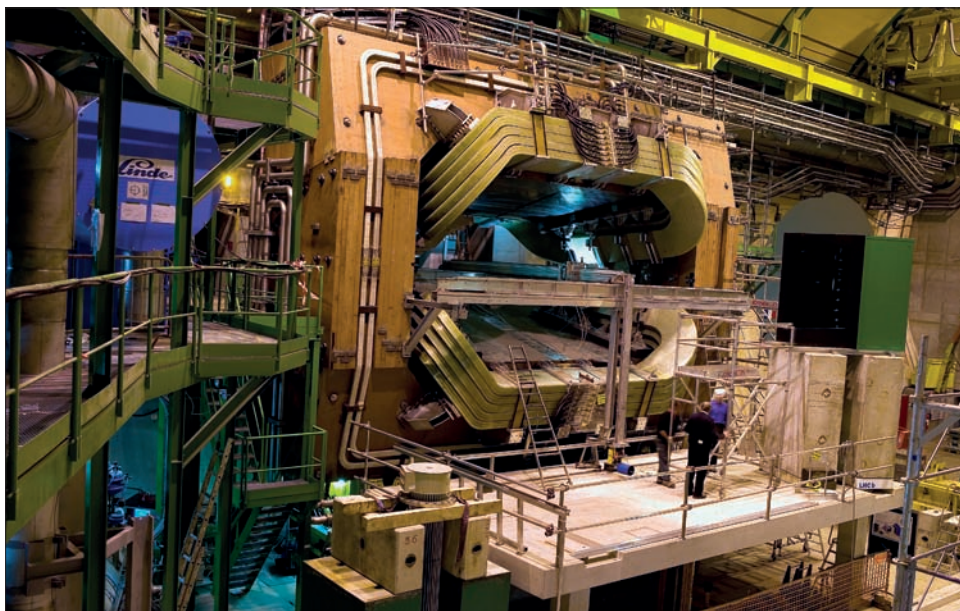
Two international teams conducting the ATLAS and CMS particle physics experiments at CERN have proven the existence of a particle that could be the Higgs boson – which would without doubt be one of the most important discoveries in particle physics, since the Higgs boson provides the key to explaining how elementary particles acquire mass.

Linde Kryotechnik would like to congratulate the physicists on their outstanding achievement. The findings once again highlight the ground-breaking work carried out at CERN. Linde Kryotechnik also expresses its thanks for the many years of successful collaboration with CERN. The cutting-edge cryogenic technology supplied by Linde Kryotechnik played a key role in keeping the CERN particle accelerator and detectors running smoothly in the long-standing search for the Higgs boson.

The Large Hadron Collider (LHC) has an operating temperature of just 1.8 K (-271.3°C), and is thus close to absolute zero. The superconducting magnets in the collider need this low temperature to generate intense magnetic fields for the ring. If the scientists at CERN used normal conducting magnets, the circumference of the particle accelerator would end up being 120 km long and energy consumption would rise thirty-fold.

The bending magnets have to be cooled using helium as this is the only element that remains liquid at this temperature. Together, the magnets have a combined weight of 37,000 tons, and 10,000 tons of liquid nitrogen is needed to cool this mass to 80 K. A further 130 tons of helium is used in the accelerator's closed cooling cycle, making the LHC the world's largest refrigerator.

Three consecutive phases are required to cool the LHC to these low temperatures. During an initial purification and cooling phase, liquid nitrogen brings the helium stream to a purity level of 99.9999 percent and a temperature of 80 K. This procedure has to be carried out after



Linde equipment (left) at LHCb, Point 8

complete warm-up of the accelerator, which takes place as scheduled every three to four years.

The preliminary cooling phase lasts two weeks. In the second cooling phase, helium expansion turbines cool the helium further, gradually reducing the temperature from 80 to 4.5 K – the boiling point of helium at an absolute pressure of 1.25 bar. The temperature of the helium is then reduced to 1.8 K during a third phase. This additional cooling is achieved by vaporizing the helium at an absolute pressure of 16 mbar. Multi-stage cold compressors with active magnetic bearings, variable speed and a sophisticated control system are used to recompress the vapour.

The temperature has to remain consistent at every point along the long proton racetrack. Cryogenic experts overcame this challenge by developing a complex distribution network comprising five different stations spread out along the entire accelerator ring. One or two cooling units are positioned at each station. Each unit delivers two helium streams, one gaseous flow at 50 K, and one supercritical flow at 4.5 K. The cryogenic helium streams are then pumped down to the ring elements at a depth of around one hundred metres. Here they flow through magnetizing coils, cooling jackets and cooling plates.

In recognition of the outstanding technology in Linde Kryotechnik's cooling solutions, CERN management honoured Linde Kryotechnik with the Golden Hadron Award in 2003.

CERN presented Linde Kryotechnik with a special honorarium in acknowledgement of the exceptional efficiency of its systems and publicly commended the design at the ICEC conferences in Beijing, China (2004) and Fukuoka, Japan (2012). CERN also lauded the extremely compact footprint and outstanding reliability of the solution.

Linde Kryotechnik also upgraded two existing refrigeration systems from the predecessor accelerator, LEP, equipping them with two new turbines. Linde's cryogenic technology is also being deployed in the ATLAS experiment to help cool the heat shield in the ATLAS detector to 40 K, and to cool the test bench for superconducting bending magnets to 4.5 K.

Linde Kryotechnik is proud to have been able to contribute to such a ground-breaking discovery and wishes CERN every success in its future research endeavours.

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