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FRONTIERS

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Excavating the underground cavern that will house the ATLAS experiment at the LHC

PPARC

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from Martin Ward

ESA does more with less

There are times in the life of a major international organisation when re-assessments of priorities and the best strategy for achieving them are necessary. During the past 6 months or so, the European Space Agency (ESA) has been undergoing this process, following an ESA Ministerial meeting in Edinburgh towards the end of last year.

Although, the outcome has been positive in some respects – for example, a new initiative for planetary exploration called the Aurora programme has been approved – the future financial allocation was less favourable than assumed by ESA when planning its ambitious 'Horizons 2000' programme for space science (*Frontiers* 9, p.26). It therefore became imperative to re-assess the whole Space Science programme. This was carried out under the widely perceived, and possibly genuine, threat of cancellation of one or more of the major projects already selected within Horizons 2000.

The outcome, under the title 'Cosmic Visions 2020', came as a surprise to many ESA watchers. Far from cancelling a major mission, two new missions, not included in Horizons 2000, were proposed to ESA's Science Programme Committee this May. One in the astronomy area is Eddington, already selected as a 'reserve mission'. Eddington (*Frontiers*, 10, p.22) will probe the inner workings of stars using stellar seismology, and also search for extrasolar planets.

In addition, a new planetary mission called Venus Express was proposed. This ran into difficulties over payload funding, and looked as if it might have to be withdrawn. However, following further negotiations with member states providing a potential payload (in other words, instruments), it has now been tenuously re-instated pending clarification of payload funding during the next few months. In order to avoid such unfortunate situations developing on future missions, ESA now plans to integrate the process of selecting missions with the agreements to provide payloads by the member states, whereas in the past these processes have been separate.

Integrating mission technologies

How has it been possible to expand the ESA science programme on reduced resources? The answer is to implement a determined policy that aggressively exploits technical and programmatic synergies between missions, consequently accepting a higher level of risk during their development phases. In addition, some missions may have to be descoped (reduced), for example, the Mercury mission's BepiColombo lander (which if it is to be included may have to be funded by agencies outside of ESA), and the galaxy mapping mission, GAIA, which may not be launched as soon as we would have liked.

Looking further ahead to the next ESA Ministerial meeting, there is a message: if ESA's space science is to remain competitive over the long term, and be commensurate with Europe's financial and cultural position on the global stage, then an appropriate level of resources must be provided – the will to deliver scientific excellence with the associated spin-offs is strongly evident. However, to realise this vision, it must be shared by the politicians.

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ESA's revised plan

Missions are divided into production groups, allowing them to be built synergistically within each group using common technologies and engineering teams. This will reduce costs, but increase managerial complexity and thus risk.

Astrophysics

- **XMM-Newton** (launched in 1999); **INTEGRAL** (2002) – X-ray and gamma-ray observatories to study the extreme Universe.
- **Herschel**, exploring the infrared and microwave Universe; **Planck** – studying the cosmic microwave background; and **Eddington** – re-using the same bus platform as Herschel. The three missions will be launched in the 2007-2008 time-frame.
- **GAIA** – to be launched no later than 2012. It has recently been redesigned to reduce costs as explained on p.28.

Solar System science

- **Rosetta** – a trip to a comet (2003); **Mars Express** – a Mars orbiter carrying the **Beagle 2** lander (2003); and **Venus Express**, a Venus orbiter (2005) – go-ahead still to be finalised.
- **SMART-1** – demonstrating solar propulsion technology while on its way to the Moon (2003); **BepiColombo** – a mission to Mercury; and **Solar Orbiter** – a mission to take a closer look at the Sun (missions to be launched in 2011-2012).

Fundamental physics

- **SMART-2** – a technology demonstration mission (2006) for **LISA** – a joint mission with NASA searching for gravitational waves (2011).
- ESA will collaborate with NASA on the **Next Generation Space Telescope** (2010).

CERN Council and management agree future plans

Last September, a major funding shortfall for CERN's Large Hadron Collider (LHC) project came to light following a comprehensive cost-to-completion review carried out by the Laboratory's management. In response, the management established five internal task forces to examine ways of redeploying CERN resources to the LHC. In parallel, the governing Council established an External Review Committee (ERC) chaired by Robert Aymar, director of the International Thermonuclear Experimental Reactor.

CERN management presented the task forces' conclusions to Council in March. Measures recommended by the task forces are being implemented and form the basis of a medium-term plan that was then submitted to Council for approval. Elements of the plan include a cutback in the ongoing research programme, with the Proton Synchrotron (PS) and Super Proton Synchrotron (SPS) accelerators shutting down for all of 2005, redeployment of personnel to the LHC, new accounting and reporting measures, and a reduction in accelerator R&D. On the basis of this plan, Council approved an expenditure figure of 1217 million Swiss Francs for 2003 and released 33 million Swiss Francs from the 2002 CERN budget that had been frozen pending clarification of LHC funding issues.

Solving CERN's problems

The ERC presented its final report to Council in June. There was recognisable common ground between its conclusions and the management's medium-term plan, leading Council to issue a statement saying that it "believes that the ERC report and the management proposals are an important step towards solving the problems identified and re-establishing an atmosphere of trust."

The ERC found CERN to be a laboratory "justifiably proud of its past success and of its worldwide reputation". The committee also affirmed that the LHC is "the worldwide priority in high-energy physics: the support to CERN for this objective will not fade out". However, the ERC did find that the crisis that became apparent last year arose from "serious weaknesses ... in cost awareness and control, as well as in contract management and financial reporting."

The report makes various recommendations to improve financial procedures at CERN, including a transition to "earned value" reporting and to fully integrated personnel and materials accounting, currently treated separately. The ERC also looked at non-LHC related scientific activities, recommending a significant transfer of staff from the PS to the LHC, and the establishment of an independent audit committee.

CERN's management is now preparing an action plan and timetable to implement the ERC's recommendations for presentation to Council in September. The management will also prepare, for Council in December, a proposal for the revision of the 1996 financial framework for the LHC, with the completion of the LHC as the all-out priority in the years to come. This revision will include the cost-to-completion for the LHC project, the resources for the non-LHC programme, and a new long-term financial framework and staff plan for the Organisation.

With a clear convergence between the ERC, the internal task forces, and the CERN management, the June meetings of the Council ended in an atmosphere of renewed confidence in the Laboratory's ability to deliver the LHC, and in its long-term future.

James Gillies, e-mail: *james.gillies@cern.ch*

Ian Halliday, Chief Executive of PPARC, writes on the Government Spending Review 2002 announced in July

We now know the Government's view of the value of science. The Science budget will increase at 12.5 per cent per annum in cash terms – that is, 10 per cent per annum in real terms. Moreover, areas such as e-science, technology and genomics, highlighted in the last Spending Review, are kept funded at the baseline. Much of the money is assigned to very welcome developments such as further major increases in PhD student stipends, salaries for postdoctoral fellows, and money for university overheads. There will be more than £300 million to be used for uplift or further new science. The universities will now have very substantial resources (£500 million in 2005-06) for infrastructure.

PPARC's task will be to secure a substantial part of the £300 million for its programme (the individual Research Council outcomes will be expected in November). Our research community, working with PPARC, must also aim to persuade universities to spend some of their infrastructure money in our area; this may mean PPARC becoming more pro-active within the university system. There is a serious discussion going on as to how university finances can be put on a sustainable basis. Watch this space.

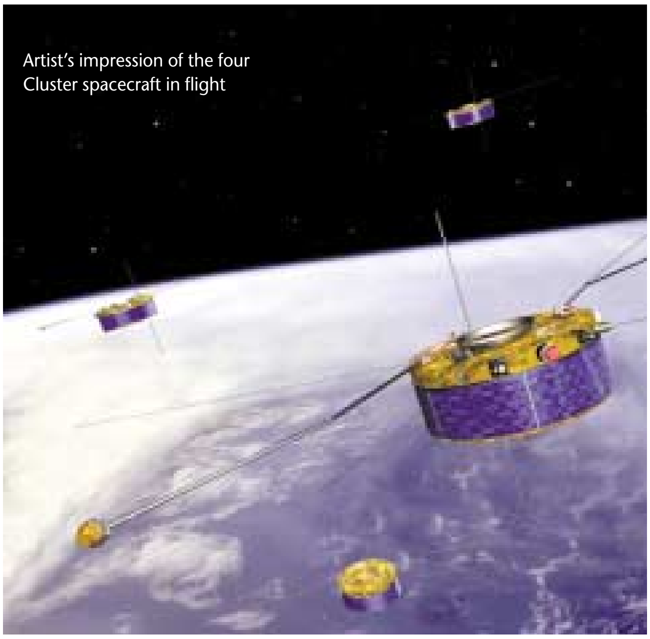
Cluster's cornucopia of results

Earlier this year Cluster, ESA's mission to study the interaction of the Earth's magnetic field with the solar wind of charged particles that streams out from the Sun, completed its first full tour of the outermost regions of the magnetosphere. This complex project is already bearing rich fruit

Launched during July and August 2000, Cluster began full operations in February last year, following an extensive commissioning phase to put the mission's four spacecraft with identical instruments into a near-polar orbit (*Frontiers* 7, p. 16).

Probing the boundary

Cluster's objective is to reveal the processes that control the interaction between the Sun's atmosphere and the Earth's environment – in both space and time. These processes are transient and spatially complex, therefore requiring a minimum of four simultaneous measurements (for the four dimensions of space and time). Key regions are the various boundary layers of the magnetosphere: the magnetopause which is the boundary between the magnetosphere and the solar wind; the bow shock where the solar wind is abruptly slowed down by the magnetosphere; the cusps where solar wind particles penetrate the magnetopause near the poles; and the geomagnetic tail – part of the magnetosphere that streams away from the Sun – where violent substorms release energy which powers the aurorae. Cluster aims to probe how mass, momentum, and energy can be exchanged between the solar wind and the magnetosphere across these layers.


Artist's impression of the four Cluster spacecraft in flight

Cluster scientists are now in a position to assess the mission's progress.

- *Crossing the magnetopause* Initial results of studies at the Earth's magnetopause have focused on the dynamic and imperfect nature of this layer. One of the key problems has been to understand how, when and if this membrane, which protects the lower atmosphere from energetic solar particles, is broken. Detailed Cluster studies have revealed that there are temporary breaks called Flux Transfer Events, or FTEs which have a rich and complex internal structure. We have now begun to attack the important question of how FTEs move across the magnetopause. The four-measurement strategy has allowed us to determine the electric current directly from 3D measurements of the magnetic field. This was then compared with data on the particles that carry the current. The current is found to be concentrated in a thin layer surrounding a tube-like FTE structure. The interior contains mixtures of electrons and energetic ions. Their flows within the tube have different lifetimes and properties, and give us clues as to how the Earth's magnetic field lines merge with those of the solar wind.
- *The bow shock* The Earth's bow shock is the front-line defence against major interplanetary disturbances such as huge solar eruptions called coronal mass ejections, or CMEs (*Frontiers* 9, p.12). Data relating to a recent CME provided an ideal test-bed for Cluster techniques to determine changes in the bow shock's dynamics and internal processes. Electric field measurements gave new insights into how the energy from a CME, is distributed by shocks, like the bow shock, amongst various types of charged particle. Finally, the part of the bow shock where the interplanetary magnetic field from the solar wind is nearly parallel to that of the Earth is known to be the site where charged particles are accelerated to high energies. Cluster has shown that the 3D structures and turbulence that are the agents of this acceleration are localised on spatial scales which are much smaller and evolve much more rapidly than previously envisaged. These studies, and similar surprises elsewhere in the magnetosphere, drove the mission scientists to re-adjust the separations of the four spacecraft down to scales under 100 kilometres so as to be able to analyse the physics of the boundary layers adequately.

Larger scale processes

Future operations during the extended mission (to December 2005) will explore much larger length scales (20,000 kilometres) to study more fluid-like processes – which have direct counterparts in more distant regions of the Universe, and also in laboratory-based plasmas. This will complete Cluster's objectives of probing both the behaviour of the charged particles, which govern the physics of what happens on the microscale within the boundary layers, and the effects of those processes on the behaviour of the magnetosphere on a large scale.

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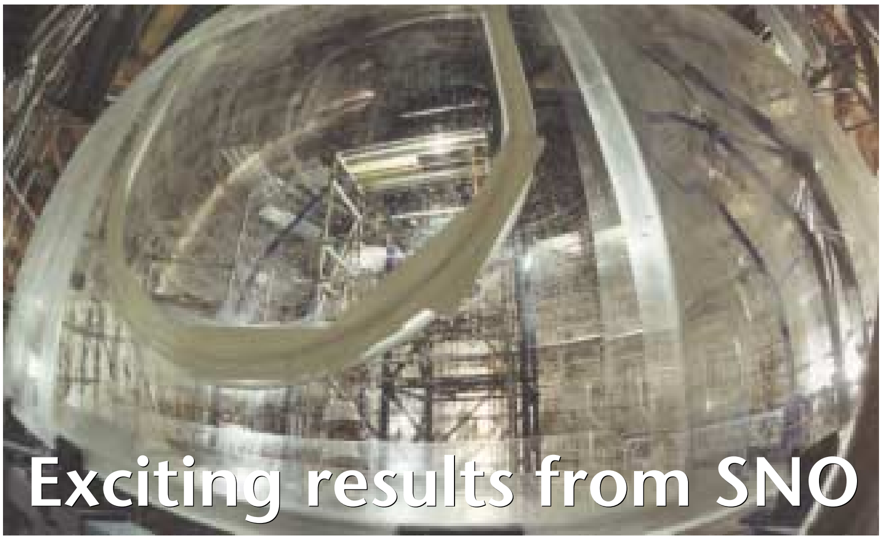

Exciting results from SNO

The Sudbury Neutrino Observatory designed to detect solar neutrinos with unparalleled accuracy has produced some exciting results that lay down major challenges for particle physics theory

Neutrinos are among the most fundamental particles in Nature and are produced by the basic nuclear reactions that fuel the Sun.

More than 35 years ago, Ray Davis set out to make the first measurement of the number of solar neutrinos arriving at Earth using 1000 tonnes of dry cleaning fluid in the Homestake mine in South Dakota. Occasional neutrino interactions with the chlorine in the fluid would transmute it into an isotope of argon, which could be detected chemically. However, Davis found only about one-third of the predicted number. Since then, four other experiments using two different techniques found a similar deficit of neutrinos, thus constituting the longstanding 'solar neutrino problem'.

Growing evidence suggested that perhaps neutrinos themselves were changing in character as they travelled to Earth. Such a scenario is theoretically possible if neutrinos (of which there are three types, or 'flavours' – the electron, muon and tau) have a small amount of mass and 'mix' with each other, though neither property is predicted by our current description of particle physics, the Standard Model. Only 'electron-type' neutrinos can be produced in the Sun and previous experiments have been able to look for only these, so the 'oscillation' of neutrinos into other flavours could therefore explain the perceived deficit. But, until recently, this has only been a conjecture.

Definitive experiment

More than 15 years ago, Oxford physicists, along with scientists from about a dozen other institutions in the US and Canada, proposed the Sudbury Neutrino Observatory (SNO) to solve the mystery. At its heart is 1000 tonnes of heavy water (D_2O). It is housed in the largest acrylic sphere ever constructed, suspended in 7000 tonnes of ultra-pure normal water, viewed by 10,000 highly sensitive light detectors and buried in one of the deepest mines in North America. Heavy water has the property of allowing different neutrino reactions to be studied. One of these (the 'neutral current' interaction) is sensitive to all neutrino flavours, and thus directly measures the total number of solar neutrinos.

In 2001, SNO released first results from 'charged current' interactions and compared them to measurements from a previous experiment to indirectly infer that neutrinos were changing from one type to another. In April 2002, further SNO results were released based on the first ever measurement of neutral current solar-neutrino interactions which directly confirmed, with much higher accuracy, that our theoretical models of the Sun are correct, and that neutrino flavour conversion is occurring. The accuracy of these measurements (which will continue to be refined) are now severely constraining possibilities regarding the precise mechanism responsible. For example, it now appears that the observed flavour conversion actually occurs during the passage of the neutrinos through the matter of the Sun, which greatly enhances the process.

Given the very fundamental nature of neutrinos, a detailed understanding of these bizarre properties is seen as one of the important keys to our greater understanding of what makes the Universe tick. There are still two more major phases of the SNO experiment to come and, with each new publication, theorists are being forced to modify their models – a well-deserved reward for the experimentalists who have had to overcome remarkable technical challenges to achieve their goal!

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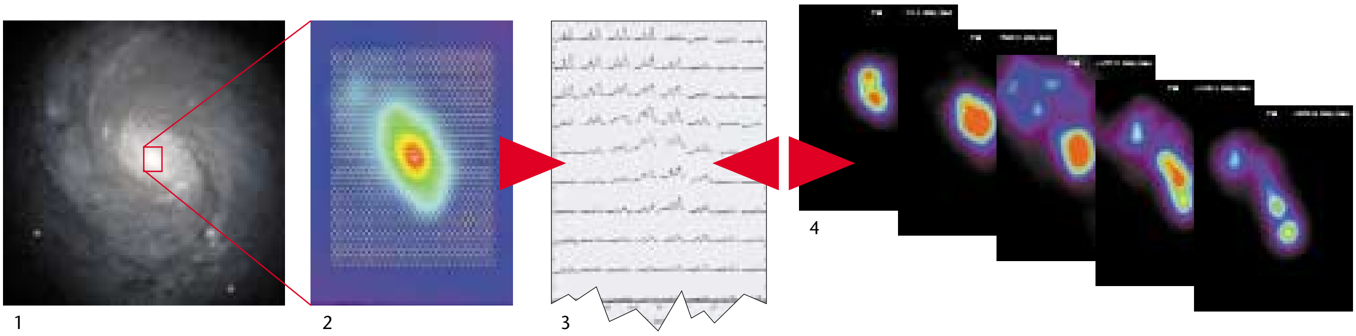
Driving the Linear Collider

A group of particle physicists from Oxford University recently took the driving seat at the Next Linear Collider Test Accelerator (NLCTA) at the Stanford Linear Accelerator Center (SLAC) in California. PPARC Advanced Fellow Philip Burrows and PPARC students Simon Jolly and Gavin Nesom formed the operations crew and ran the facility to deliver beams of electrons to their apparatus, about 30 metres downstream of the electron gun.

The group, which also includes Glen White, Colin Perry and Gerald Myatt, in collaboration with physicists from SLAC, has built a prototype of an ultra-fast feedback system, which they call FONT – Feedback On Nanosecond Timescales. FONT will be used at the next-generation high-energy linear collider to steer the electron and positron beams into collision.

When high-energy electrons and positrons meet they can annihilate one another to release their energies for the production of new particles, such as the Higgs boson, or 'supersymmetric' particles. Particle physicists would like to make and study samples of as many such new particles as possible. To do this they need to maximise the probability that annihilation occurs, by packing the electrons and positrons into



The active galaxy NGC1068 (1) observed with the GMOS' new integral field unit (2) to give either a spectrum for each location in the image (3), or an image at each wavelength (4), which in the light of a single spectral feature (here, an emission line of oxygen) can be interpreted as the recession velocity measured along the line of sight

New tool for probing galaxies

UK astronomers now have access to a novel facility on the Gemini North telescope that can dissect the heart of an active galaxy

The Gemini Multiobject Spectrograph (GMOS), recently installed on the Gemini-North telescope (*Frontiers* 12, p. 4) is designed to produce spectra of hundreds of objects such as galaxies at the same time. But it can be converted at the push of a virtual button to generate 1000 individual spectra of different parts of the same galaxy.

This means that the motions of the constituent stars and gas can be recorded by examining how spectral features shift in wavelength from one part of the object to another, while at the same time revealing physical conditions in the galaxy from a study of the precise shapes and ratios of different features in the spectrum. Not only can distant galaxies be studied in this way, but also star-forming regions in our own and nearby galaxies, where the velocity, density and temperature of star-forming gas can be traced.

The result is a three-dimensional 'datacube' with axes marking the two spatial dimensions plus wavelength. You can create an image at any desired wavelength by extracting the appropriate slice from the cube, or examine the spectrum at any point in the image. This approach overcomes two disadvantages of traditional spectroscopy where a slit is used to isolate light from the target: the difficulty in accurately positioning the object on the slit; and knowing from which part of a complex object the spectrum originated. With this approach (known as integral field spectroscopy), accurate targeting becomes a point-and-shoot operation, while the datacube gives an unambiguous link between the spectrum and the location in the target where it was obtained.

Amazing technology

The technology is impressive. The integral field unit (IFU) uses 1500 optical fibres, each finer than a human hair, to reformat the image produced by the telescope into the one-dimensional slit of a high-performance spectrograph (in this case, GMOS). For maximum performance, each fibre is tipped at either end with a microlens, less than half a millimetre across. The microlenses are deployed in close-packed arrays so that no light from the target is wasted.

Our group at Durham University designed and constructed the IFU. Although much of the fabrication was automated, the final job of threading each fibre into place was done by the steady hand of the project manager, Graham Murray. We then tested the IFU during GMOS' first commissioning run – with spectacular results.

One of the first targets was the active galaxy NGC1068 (above). This has a highly luminous nucleus which shoots jets of charged particles in opposite directions over great distances where they emit strongly at radio frequencies when they interact with inter-galactic gas. The energy source of this process is believed to be a supermassive black hole. Although the galaxy has been much studied over the years, the GMOS IFU has produced perhaps the best set of data.

This facility is now offered to all Gemini astronomers. As well as building similar devices for other large telescopes, including two more for Gemini, we are working with other UK and European research groups to adapt this technology for the Next Generation Space Telescope – a large infrared telescope to take over from the Hubble Space Telescope in 2010 (*Frontiers* 10, p. 18).

Jeremy Allington-Smith
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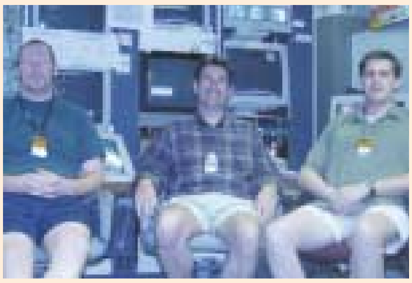
tiny beams and firing them at each other head-on. In practice, this means that the beams must be a few nanometres (billionths of a metre) across, and making such minuscule beams hit one another will not be easy. Even the vibrations of the ground – always present, but not normally experienced except during earthquakes – will be sufficient to shake up the accelerator components so that the beams miss one another.



From left: Simon Jolly, Philip Burrows, Gavin Nesom

FONT aims to correct this by measuring the misalignment between the beams and providing a feedback signal to correct it. However, in order to be useful this must be done within a few tens of a nanosecond, before all the beam particles have passed each other by. The Oxford group hopes to demonstrate that the FONT prototype, which is currently under commissioning at the NLCTA, can do this. First results with the complete system are expected by late summer of 2002.

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One of the cameras in front of one of the fluorescence detector mirrors

The Pierre Auger Observatory records its first events

An unusual observatory is taking shape in Mendoza Province, Argentina. It is designed to detect cosmic rays with energies of 10^{20} electronvolts (eV) and beyond (the kinetic energy of a tennis ball at 100 kilometres per hour). These are the highest energy particles in Nature. One such particle, perhaps a proton, hits a square kilometre on the Earth only every century. So far, about 20 have been observed.

Finding such particles was a huge surprise because most objects that might produce them are more than 100 million light years away and the energies of the protons would be severely degraded by the cosmic background radiation while travelling such distances. Our knowledge about these remarkable particles relies on being able to detect the giant showers of secondary particles that they create in the atmosphere. These spread over many square kilometres at ground level.

The Pierre Auger Observatory, named after the discoverer of the 'shower' phenomenon, is the focus of efforts by more than 250 scientists from 15 countries, including the UK. The Observatory comprises an array of 1600 water tanks overlooked by four massive photomultiplier cameras (*Frontiers* 7, p.22). It will cover 3000 square kilometres, roughly the area inside the M25. The shower particles are detected in the tanks using Cherenkov light (*Frontiers* 5, p.5). On clear, moonless nights, light produced by the particles hitting nitrogen molecules in the atmosphere and causing them to fluoresce is also seen by the cameras, and is used to trace the growth and decay of the cascades.

The detectors

Each tank is viewed by three photomultipliers, while each fluorescence detector has more than 2600 hexagonal photomultipliers that view the night sky through filters transmitting at wavelengths between 300 and 400 nanometres. Simultaneous measurements of the fluorescence and particle signals allow independent estimates of the primary energy. The direction of each event is found to within 1 degree using the relative arrival times of signals at the detectors measured with the GPS (Global Positioning System) network. The Observatory will record about 50 events above 10^{20} eV every year.

The fluorescence detectors are in conventional laboratory buildings, while the tanks detecting the particles stand on the Pampa in a more hostile environment. Gathering data from sensors spread over so vast an area is an unusual challenge. Data, recorded autonomously by each tank, are collected using a custom-built radio network coupled to a conventional microwave link. This system was designed and built by electronics engineers at the University of Leeds. Each tank sends trigger information to a central computer at 20 hertz. When nearby tanks are hit at roughly the same time, all details recorded locally are sent over the radio link. The 12 watts of power needed comes from solar panels.

Unlike an optical observatory, the Pierre Auger Observatory can take important scientific data before the whole instrument is completed. In November 2001 the first 'hybrid' events were recorded in which fluorescence light and water-tank signals coming from the same shower were measured. Already some events, with over 15 tanks struck, have been recorded: these are of high energy. Completion is scheduled for 2005, by which time several tens of events above 10^{20} eV will have been registered. We will have made preliminary searches for signals from sources of the highest energy cosmic rays, such as the Galactic centre and the strongly radio-emitting galaxy Centaurus A. The major period of operation will then begin.

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It looks as though the working life of the Yohkoh spacecraft, which has been observing the Sun in X-rays for more than a decade, has now come to an end

Yohkoh was launched on 30 August 1991 and has been studying the Sun's corona ever since, producing fantastic images of this turbulent outer region. Data were obtained by a suite of four instruments developed and built by a collaboration involving Japan, the UK and the US.

Following complications

Mapping the Cosmic Web

UK and German astronomers have produced a map of dark matter in the Universe on one of the largest scales ever

The team probed the structure of the dark matter in the massive Abell 901/902 supercluster of galaxies by analysing how its powerful gravity causes subtle optical distortions in images of thousands of more distant galaxies lying behind it. The work was carried out with the Wide-Field Imager (WFI) on the 2.2-metre ESO/MPG telescope in La Silla, Chile, and is part of a comprehensive multi-wavelength imaging campaign, the COMBO-17 survey.

Dark matter is known to pervade the Universe and plays a central role in its evolution and appearance today (*Frontiers* 13, p.10). Exploring its distribution on large scales is therefore of vital importance in cosmology. Although dark matter is, by definition, invisible, it can reveal its presence through its gravitational effects. This is because, according to Einstein's General Relativity theory, light is deflected when it passes through a gravitational field. Light reaching us from a galaxy, therefore, can be bent by the gravity of an intervening mass (such as a clump of dark matter) to give a distorted image, or even multiple images, of the galaxy. This 'gravitational lensing' phenomenon thus offers us a powerful tool to detect dark matter – it is one of the only ways to probe its distribution directly on large scales.

A two-dimensional map

Using this approach, the UK/German team, led by Meghan Gray and Andy Taylor of Edinburgh University, measured the distortion effects of the Abell supercluster on the shape of more than 40,000 faint and distant galaxies, and used them to create a two-dimensional map of the dark matter in the structure.

The map shows that the clusters of galaxies we observe within the supercluster not only lie within larger dark matter clumps, but also that these clumps are connected by filamentary structures of dark matter. The detection of such dark matter bridges verifies predictions from theories of cosmic structure that the Universe is a vast network of dark matter clumps and filaments: the 'Cosmic Web'.

Furthermore, the supercluster study reveals that the most massive dark matter clumps do not necessarily contain the largest numbers of galaxies. This indicates that luminous galaxies (the traditional tracers of large-scale structure in the Universe) do not always give a true guide to the overall distribution of matter.

Reconciling the descriptions of the dark and luminous matter in the supercluster will tell us much about the interplay between galaxies and their dark matter environments, and will help us understand how galaxies formed and evolved within such structures.

Meghan Gray
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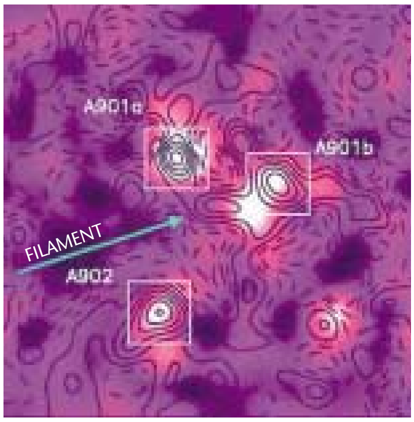
The image below shows a map of the dark matter within the Abell supercluster (top) revealing not only three clumps of matter corresponding to the three galaxy clusters but also bridging dark matter 'filaments'



Yohkoh bows out after heralding a new era of discovery in solar physics

during an annular lunar eclipse over the central Pacific, which drained the satellite's batteries, it lost its attitude control on 15 December 2001. The Yohkoh operations team suspended observations, and for six months made continuing attempts to recharge the spacecraft batteries. Despite these efforts, it is now thought unlikely that solar observations will be resumed, although monitoring of Yohkoh will continue until its re-entry.

During the 10 years of Yohkoh operations, a wealth of scientific discoveries have emerged. These include understanding better than ever before how the Sun's magnetic fields are broken and reconnected during solar flares, clarifying how the different areas of the Sun's corona are heated, and probing the origin of the mass ejections that have a crucial influence on the near-Earth environment – a discipline that has come to be known as 'space weather'. Analysis of the Yohkoh data will continue to provide scientists with many more decades of discovery from this intrepid spacecraft. A review of Yohkoh's remarkable successes will appear in a future issue of *Frontiers.*

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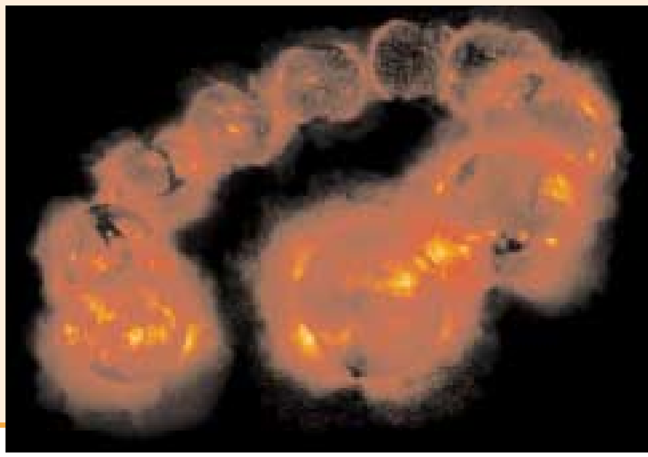
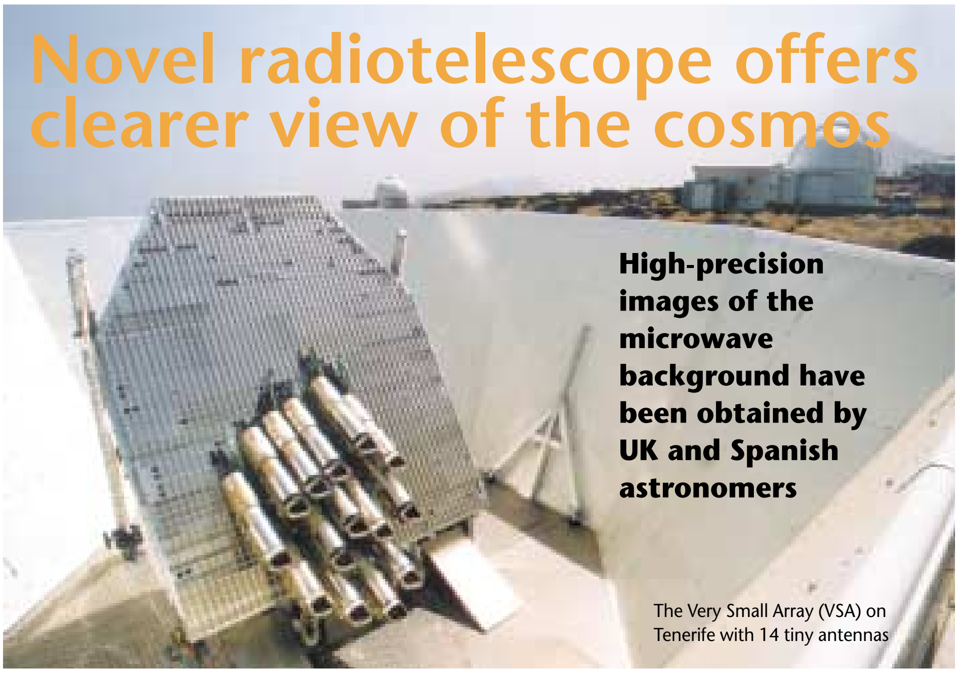
Ten Yohkoh images (1992-2002) show the dramatic change in X-ray output around a solar cycle of activity (which varies over 11 years)



Novel radiotelescope offers clearer view of the cosmos

High-precision images of the microwave background have been obtained by UK and Spanish astronomers



The Very Small Array (VSA) on Tenerife with 14 tiny antennas

Imaging the variations in the cosmic microwave background (CMB) – the pervasive relic radiation from the early, hot phase of the Universe – has long been a holy grail of cosmologists. The CMB is very cool, only 2.7 kelvin, but the tiny temperature variations imprinted on it offer us a 'direct' look at the beginnings of structure formation, a process that eventually results in the galaxies and clusters of galaxies we know today.

The amplitudes and angular scales of the imprints are strongly influenced by the geometry of the Universe (whether space is flat or curved) and how much dark matter and energy of vacuum, or 'dark energy', it contains (*Frontiers* 11, p.10). Measuring the variations therefore offers a way of testing different cosmological theories that make predictions about these parameters.

The problem, however, is that the variations are so faint – approximately one ten-thousandth of the 2.7 K – that observing them requires great ingenuity and effort. Nevertheless, the first results are coming out from a new generation of instruments – for example, a radiotelescope called the Very Small Array (VSA) on Mount Tiede in Tenerife, the Canary Islands.

The Very Small Array (VSA) is a novel interferometer array observing at a radio wavelength of 1 centimetre, and packed with design features to enable it to detect weak CMB imprints in the presence of strong contaminating effects. The project, largely funded by PPARC, is a collaboration between physicists at Cambridge University's Cavendish Laboratory, Manchester's Jodrell Bank Observatory and the Instituto de Astrofísica de Canarias on Tenerife.

First results

The VSA team has just announced the results from its first year of observation, and they are very exciting. In each of three images of 9 degrees by 9 degrees of sky, individual imprints are clearly detected. They result from enormous volumes of matter in the early Universe that started to contract under gravity, heat up, and then expand and cool, producing cycles of 'acoustic oscillation'. The power spectrum of the VSA maps (that is, the amount of temperature structure at increasing levels of angular size) clearly shows two peaks of acoustic oscillation. These tell us directly that our basic ideas about structure formation in the early Universe (including the exotic period when the very early Universe expanded extremely rapidly) are correct.

What is also pleasing is that these results fit remarkably well with those from other experiments making observations but in different ways (and with different possible sources of error). Combined, they enable us to fine-tune our understanding of what makes up the Universe. It's currently believed that almost all of the matter in the Universe is invisible 'cold dark matter' (likely to be exotic massive particles), and that the expansion of the Universe is accelerating because of the existence of 'dark energy' which causes empty space to expand (*Frontiers* 13, p.10). Fitting these ideas to the new results shows that cosmic space is extremely close to being flat (like the geometry of everyday experience), and also measures the amounts of dark matter and dark energy to accuracies of 10 per cent. Compared with what was known just two or three years ago, this level of accuracy is remarkable.

The VSA is currently observing in 'extended array' mode with higher angular resolution that may find further acoustic peaks. It may constrain the cosmological parameters even better – or it may even suggest that our basic cold dark matter model of the Universe is not the last word after all.

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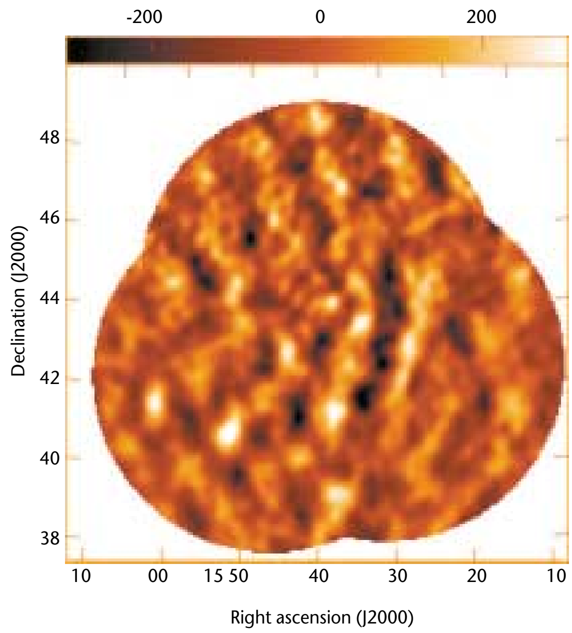

One of the three patches of sky imaged by the VSA, showing tiny variations of temperature imprinted in the early Universe. The patch was observed as three fields of view knitted together, and the fact that the imprints are seen coherently across the field joins is one of many checks that give confidence in the results