

# Not green cheese, then?

**What is the Moon made of? A UK-led instrument – part of ESA's SMART-1 lunar mission – should soon be able to answer this question**



The D-CIXS instrument

Surprisingly, we still do not know the overall elemental composition of the Moon. The NASA Apollo missions landed in basins where the lunar surface had been considerably changed by impacts. This means that the rocks they brought back to Earth are not actually representative of the primordial highland material making up most of the Moon's surface. Now, thanks to new technology, scientists will be able to map the true global composition of the lunar surface remotely from the orbiting SMART-1 spacecraft, using a novel imaging spectrometer. It works by detecting the characteristic spectra of X-rays emitted from elements in the Moon's crust when solar X-rays shine on its surface.

## D-CIXS spectrometer

The instrument – D-CIXS – has been built by an international team led by Manuel Grande of the Rutherford Appleton Laboratory. Because the lunar X-rays are extremely weak, D-CIXS is designed to collect as many photons as possible in

order to build up the spectra. Even so, only about 1000 photons are detected per 50 square kilometres of lunar surface. The team has made use of microfabrication technology borrowed from the semiconductor industry to create a detector consisting of a very thin metal grid which can collect X-rays according to the direction from which they came. Such a device is light and compact enough to be put

aboard SMART-1, along with the other instruments making up its payload.

SMART-1, which will be launched in March, is the first of ESA's missions designed to test advanced technologies. Its main role is to demonstrate a new type of propulsion, solar electric propulsion, (*Frontiers* 13, p.30) on the way to the Moon. When it gets there, it will orbit the Moon for 6 months. If all goes well, this technology will be used in deep-space projects such as the BepiColombo mission to Mercury, and indeed, Professor Grande and his team have proposed to build a CIXS device to map X-rays from Mercury and its aurora.

In the meantime, D-CIXS will map the main constituents of moon rock – magnesium, silicon, aluminium and calcium – across the lunar surface. The data will provide valuable

information on how the Moon formed, in particular whether it has the same origin as the Earth.

**Manuel Grande and Nina Hall**

**E-mail: [m.grande@rl.ac.uk](mailto:m.grande@rl.ac.uk)**



SMART-1



## Observing the stars at high-speed



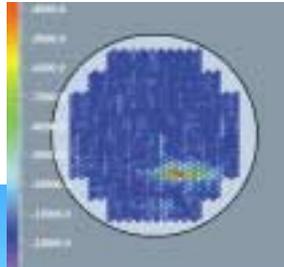
The ULTRACAM instrument

The William Herschel Telescope is not only seeing more clearly with the NAOMI adaptive optics system (see p.10) but can also register images more quickly with a new camera, ULTRACAM, capable of taking up to 1000 pictures a second at three different wavelengths simultaneously. ULTRACAM, which is based on advanced CCD technology, was built by teams from the Universities of Sheffield and Southampton in collaboration with the UK

Astronomy Technology Centre.

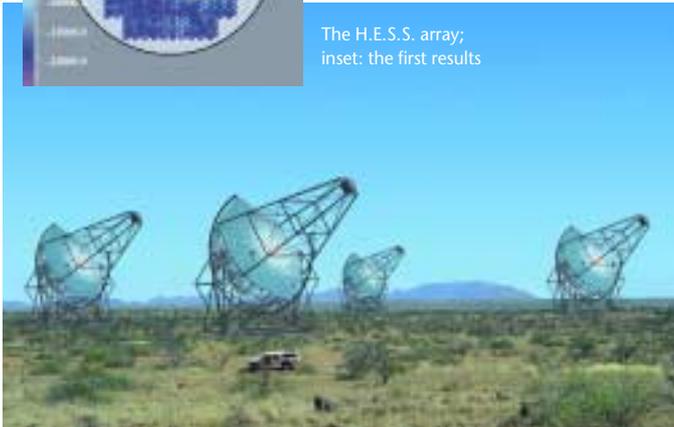
The high-speed imaging will allow astronomers to study some of the most extreme astronomical objects in the Universe – compact binaries, pairs of stars containing very dense bodies such as white dwarfs, neutron stars and black holes. These objects suck material away from their larger companions onto an accretion disc. By observing the ultra-rapid changes in light from these systems due to the

# A new era in detecting gamma-rays from the ground



**The first telescope in the High Energy Stereoscopic System (H.E.S.S.) array to detect very high-energy gamma-rays was officially inaugurated at the beginning of September**

The H.E.S.S. array; inset: the first results



Situated in the Khomas highland region of Namibia (an area originally shortlisted for the site of the European Southern Observatory), the project is the result of a large collaboration including contributions from both Europe and Africa. The principal European nations contributing are Germany, France and the UK. The UK institutions involved are the University of Durham and the Open University, both supported by a PPARC grant.

The telescope has already recorded its first engineering data and the information will soon start to flow in earnest. This facility represents the state of the art in very high-energy gamma-ray astronomy, achieving sensitivity and spectral resolution far in excess of its predecessors. This telescope is the first of four that will make up H.E.S.S. phase I, which should be complete in 2004. The telescopes detect the faint flashes of Cherenkov light

(*Frontiers 5*, p.5) caused by the interaction of high-energy gamma-rays in the upper atmosphere. Careful imaging of the light produced in a number of telescopes simultaneously allows the original arrival direction and energy of the gamma-ray to be determined.

## Extreme astrophysics

The H.E.S.S. array will allow astronomers to probe the most extreme astrophysical environments, including supernova remnants, pulsars and the jets of active galaxies. It will be able to detect sources down to a few thousandths of the output of the Crab nebula (a supernova remnant) from energies of 100 giga-electronvolts (GeV) upwards. Pulsars may be detectable down to around 30 GeV, using the characteristic pulsations to identify a signal when the small amount of light generated makes it difficult to use the

images to their full effect.

We still have much to learn about the physics of these extremely energetic processes, and detailed observations in this energy band will be crucial in advancing our understanding, especially if they are accompanied by simultaneous observations at other wavelengths. In addition to all this, we hope that H.E.S.S. observations may finally indicate where cosmic rays are being accelerated. Careful study of the spectra of active galaxies should yield measurements of the intergalactic background infrared radiation, which will be significant for models of galaxy formation.

If we are lucky, it may even be possible to identify the signature gamma-rays produced by the annihilation of the lightest stable supersymmetric particle in the Galactic centre or halo – simultaneously measuring the particle mass and identifying this significant component of dark matter in the Universe (*Frontiers 13*, p. 21). The results from this new instrument will thus be of interest to people studying a wide range of astrophysical systems.

**Lowry McComb, e-mail:**  
[T.J.L.McComb@durham.ac.uk](mailto:T.J.L.McComb@durham.ac.uk)

eclipsing effects of the matter swirling round the compact object, astronomers can measure their size and mass. They can also measure the temperature by making observations at different wavelengths.

## Improved CCD detector

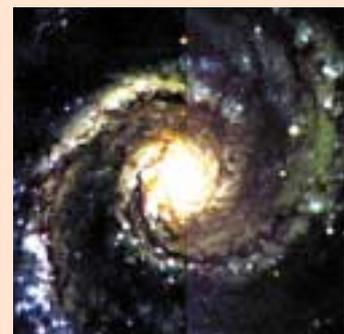
ULTRACAM employs the latest in CCD detector technology in order to take, store and analyse data at the required sensitivities and speeds. CCD detectors can be found in digital cameras and camcorders, but the devices used in ULTRACAM are larger,

faster and most important, much more sensitive to light than the detectors used in today's consumer-electronics products. Work started on the instrument during the summer of 1999, when the project was awarded £300,000 of funding by PPARC. The project was completed on budget and ahead of schedule in May 2002, when the instrument saw 'first light' on the 4.2-metre William Herschel Telescope on La Palma. As well as successfully commissioning the

instrument, the project team also acquired the first scientific data on white dwarf stars, showing that the instrument is working to specification.



The first images taken with ULTRACAM: the globular cluster M13 in the constellation Hercules (left); the spiral galaxy M51 in the constellation Canes Venatici (the Hunting Dogs)



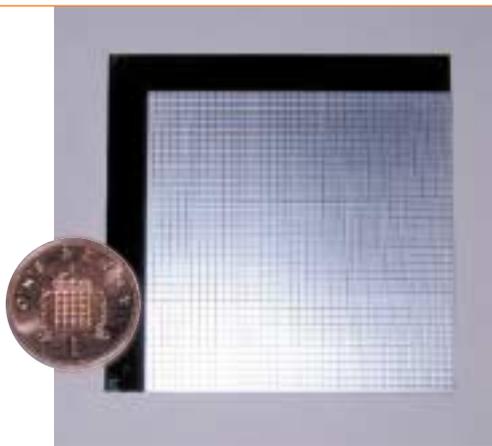
Over the past decade, the UK has established itself as a world leader in submillimetre astronomy with access to the best telescope facilities and the most advanced instrumentation. In particular, the SCUBA camera (*Frontiers* 12, p.16), operating on the James Clerk Maxwell Telescope (JCMT), has revolutionised this previously unexplored waveband.

The next generation instrument, SCUBA-2 is already under development, and seeks to capitalise on this success by providing a state-of-the-art wide-field camera of unprecedented sensitivity and imaging power. SCUBA-2 will map areas of sky up to 1000 times faster than SCUBA. Such an instrument will have an impact on almost all areas of astronomy, from studies of our Solar System and surveys of star formation in the Milky Way, to answering key questions about the formation and evolution of galaxies in the early Universe.

The submillimetre waveband (at wavelengths of about 0.2 to 1 millimetre) is used to study objects that are often completely invisible to more traditional optical telescopes. The submillimetre waveband is most sensitive to cold gas and dust, which is often associated with objects in formation – that is, the mysterious earliest evolutionary stages of galaxies, stars and planets. SCUBA-2 should make significant contributions in understanding these ‘origins’ questions.

### New technologies

SCUBA consists of two novel arrays of 128 detectors cooled close to absolute zero, which are sensitive to the small rises in temperature caused by the radiation from the cool objects mentioned above. With recent advances in superconducting technology, much bigger arrays of many thousands of pixels are now possible for the first time. SCUBA-2 will have 100 times as



The prototype array chip

**The new imaging instrument, SCUBA-2, for the James Clerk Maxwell Telescope (JCMT) is now being developed**

## CCD-style detector for submillimetre astronomy

many pixels as SCUBA and will be the submillimetre equivalent of a CCD (charge-coupled device) camera used at optical/infrared wavelengths. It will be able to cover a wide area of the sky all at once.

The technology exploits state-of-the-art chips called transition edge sensors arranged in two arrays with some 6400 pixels in each. The signals from each column of pixels are read out using multiplexed amplifiers (another first for the submillimetre waveband). Multiplexing is a technique that allows the simultaneous transmission of multiple signals across a single data link. The multiplexers have unique advantages in that they employ SQUIDs (superconducting quantum interference devices), which consume much less power than conventional amplifiers, and can operate at the same cryogenic temperatures as the detectors.

The National Institute of Standards and Technology in Boulder, and the Scottish Microelectronics Centre in Edinburgh are leading this array development, while the actual instrument is being designed at the UK Astronomy Technology Centre (Edinburgh), in consultation with the University of Wales (Cardiff) Astronomy Instrumentation Group. The

optics of the camera have to match the large telescope field (600 millimetres across) to an array size of only 100 millimetres. This presents quite a challenge! SCUBA-2 will be too big to fit into the cabin that rotates with the telescope, and so the optics have to relay the light from the telescope through a narrow bearing tube to a mezzanine floor. A much improved cooling system for the arrays is also being developed.

### Improved sensitivity

SCUBA-2 represents a major advance on current submillimetre instruments. The improved sensitivity and imaging power will allow the JCMT to really exploit periods of excellent weather on Mauna Kea (the mountain in Hawaii where it is based). Furthermore, just as maximising the potential of the new generation of 8-metre optical/infrared telescopes requires preliminary surveys (using, for example, the UK Infrared Telescope and the new 4-metre survey telescope VISTA being built) so the future giant submillimetre interferometers (such as ALMA) will require their own surveys. SCUBA-2 will provide this essential wide-field complement.

It should be delivered to the JCMT before the end of 2005.

Finally, SCUBA-2 represents a strategic investment for the UK in new technology (superconducting detector arrays) that has potential applications not only in other areas of astronomy but also in industry. Given that 5 years ago we had only the equivalent of a single pixel on the sky, submillimetre astronomy has come a long way. The realisation of the first ‘submillimetre CCD’ camera is getting ever nearer.

**Wayne Holland and William Duncan, e-mails:**

*wsh@roe.ac.uk, wdd@roe.ac.uk*  
More information on SCUBA-2 can be found at: [www.roe.ac.uk/atc/projects/scuba\\_two](http://www.roe.ac.uk/atc/projects/scuba_two)



A cutaway of the SCUBA-2 detector

# BaBar consolidates its success

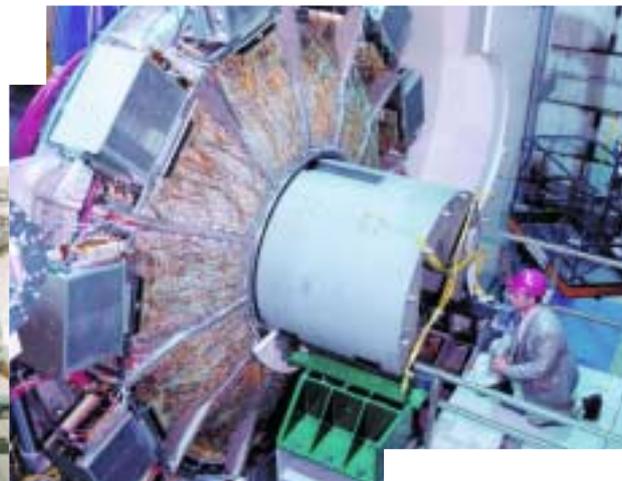
**Major advances in why there is an excess of matter over antimatter in the Universe, were made last summer with the announcement of the latest results from the BaBar experiment**

Mechanisms that differentiate between matter particles and their antimatter counterparts must exist to explain how the matter came to dominate the Universe we observe today – starting from equal amounts of matter and antimatter produced in the Big Bang. The Standard Model of Particle Physics contains such a mechanism, which allows for differences in some transitions between different types of quarks (fundamental particles in the Standard Model) and those of their anti-quark equivalents.

This mechanism, known as *CP*-violation, results in differences between the rates of decay of quark-containing particles called B-mesons and their antiparticles –  $\bar{B}$  mesons.

BaBar is an international collaboration, based at the Stanford Linear Accelerator Center (SLAC) in California, of 560 physicists (*Frontiers* 2, p.22) – including 70 from 10 UK institutes – whose aim is to investigate *CP*-violation. The experiment detects and records millions of pairs of B and  $\bar{B}$  mesons, produced by the PEP-II accelerator at SLAC. BaBar started accumulating data three years ago and successfully confirmed the existence of *CP*-violation in the B-meson system in 2001 (*Frontiers* 11, p.6). In the summer of 2002, the BaBar team presented results from the analysis of 87 million B and  $\bar{B}$ -meson pair events. Many of the analyses were carried out in the UK, using large multiprocessor computer farms at the participating institutes, which are linked in the 'BaBar Grid'.

The Standard Model predicts



Above: the BaBar detector; left: the Belle experiment which reported similar results to Babar

the values of a series of experimentally measurable quantities in the B-meson system, which are related to the model's fundamental parameters. These can be represented in the form of a triangle (called the Unitarity Triangle): the lengths of its sides are related to specific B (and  $\bar{B}$ ) parameters, while its three angles ( $\alpha$ ,  $\beta$ , and  $\gamma$ ) are related to *CP*-violation.

## Measuring parameters

Measuring all the sides and angles of the Unitarity Triangle independently will allow us to verify if they do form a unique, proper triangle. A positive result will be another success of the Standard Model; however it will leave something more to be discovered, as the *CP*-violation predicted by the Standard Model is several orders of magnitude too small to solve the cosmological problem of matter dominance. A negative result – if some measurements don't fit in the picture of a triangle – will signal the presence of new physics. In

either case, the implications for both particle physics and cosmology will be paramount!

The discovery of *CP*-violation in the B-meson system in 2001 was achieved by measuring a non-zero value of the angle  $\beta$ . By summer 2002 this became a precision measurement, with BaBar reporting  $\sin(2\beta) = 0.74 \pm 0.07$ , and BELLE (a similar experiment at the KEK laboratory in Japan) reporting  $\sin(2\beta) = 0.72 \pm 0.08$ . The Standard Model passed this test with flying colours, as its prediction is in excellent agreement with these direct experimental measurements.

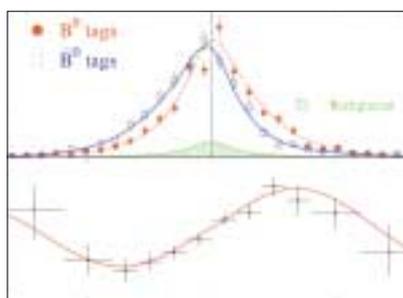
The focus now turns on the angle  $\alpha$ . The preliminary results of BaBar and BELLE on  $\sin(2\alpha)$  are quite different, but still have large uncertainties. The higher data samples that both collaborations plan to

accumulate in the next few years will provide the precision necessary to settle the issue and confront the Standard Model one more time.

A slightly different manifestation of the effect, called direct *CP*-violation, is the other frontier that will allow experiments to confront the Standard Model predictions very soon. The large amount of new BaBar results shown at the main particle physics meeting last summer (ICHEP02) included updates on searches for direct *CP*-violation in 17 different rare B decay modes, presented on behalf of the collaboration by Adrian Bevan of the University of Liverpool. While no conclusive experimental evidence for this phenomenon in the B-meson system exists yet, the researchers are poised to discover and measure many such effects in the next few years.

**Christos Touramanis**

**E-mail:** [christos@hep.ph.liv.ac.uk](mailto:christos@hep.ph.liv.ac.uk)



If *CP* symmetry was exact in Nature, the decay rate of B-meson particles (red) and antiparticles (blue), shown as measured in BaBar would be identical. The difference between the blue and red experimental points is a direct manifestation of *CP*-violation

# One hundredth extrasolar planet

Using the Anglo-Australian Telescope (AAT), UK, Australian and US astronomers recently detected the 100th new planet outside our Solar System. The Jupiter-sized planet circles its star Tau1 Gruis (100 light years away from our Solar System) about once every four years. The planet is three times as far from its star as the Earth is from the Sun.

"Now our searches have become precise enough to find many planets in orbits like those in our Solar System. We are seeing clues which may help us understand how planets are formed," said the UK team leader Hugh Jones of Liverpool John Moores University. "We are seeing a pattern for these planets to be of two types, those very close-in and another set with orbits further out. This Tau1 Gruis planet builds this second group. Why are there these two

groups? We hope the theorists will be able to explain this."

The long-term goal of this programme is to detect true analogues to the Solar System. The AAT is providing the most accurate planet-search observations in the Southern Hemisphere, according to Alan Penny, the other UK team member from the Rutherford Appleton Laboratory.

## True 'solar systems'

The researchers have found that as they probe for planets in larger orbits, the distribution of planets around single stars is quite different from that of binary stars orbiting one another where there is a smooth distribution of orbits. In contrast to the early discoveries of exoplanets, we now find that less than one in five exoplanets are to be found very close to their stars – a few orbiting with



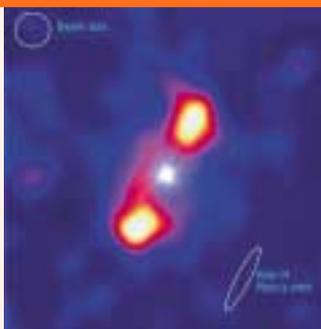
A possible scene from a moon of the extrasolar planet in orbit around Tau1 Gruis

a period of 5 to 50 days but most giant planets are orbiting at large distances from their host stars. This supports the idea that they are formed at Jupiter-like distances from their host star. Dependent on the details of the early solar system, most giant planets probably spiral inwards towards their star until they reach a point where a lack of frictional forces stops their further migration.

To find evidence of planets, the astronomers use a high-precision technique developed by Paul Butler of the Carnegie Institute of Washington and Geoff Marcy of the University of

California at Berkeley to measure how much a star 'wobbles' in space as it is affected by a planet's gravity. As an unseen planet orbits a distant star, the gravitational pull causes the star to move back and forth in space. The wobble can be detected by the 'Doppler shifting' of wavelength of the star's light as it moves (just as an ambulance siren changes pitch as it speeds past). The AAT team measure the Doppler shift of stars to an accuracy of 3 metres per second – bicycling speed. This high precision allows the team to find planets.

## More extrasolar planets found



The dust emission around Fomalhaut taken with SCUBA. The brightest emission is represented by the brightest colours

star than Jupiter is to our Sun.

Therefore, based on the evidence so far, it seems that our Solar System may not be the 'blueprint' for other planetary systems. New research using the SCUBA camera on the James Clerk Maxwell Telescope (JCMT) sets out to address the issue of just how typical our own Solar System is? Astronomers believe planetary systems are born in vast discs of gas and dust, but

this dust tends to obscure our picture of the Universe.

The JCMT views the sky at submillimetre wavelengths which can penetrate the vast majority of the 'hot' interstellar dust we see at optical and infrared. By observing at longer wavelengths, the JCMT sees a population of cold dust, which typically resides at large distances from the star. Our research team used this to understand the dynamics of unseen bodies such as planets

on wide orbits.

One of the first stars observed was Fomalhaut (pronounced 'Fo-mal-ought') – one of the brightest stars in the autumn sky. The SCUBA observation (left), revealed a huge distorted disc of cold dust with a hole in the centre. Since we view the disc close to edge-on, it looks like the cross-section of a doughnut in which the ends appear brighter. The disc is about the same size as the Sun's Kuiper Belt of comet, which orbits outside

**One of the biggest questions in modern-day astronomy is whether other stars have planetary systems similar to our own. Astronomers are learning ever more about how planets form as shown by two recent discoveries made with UK telescopes**

# Large amounts of antihydrogen made for the first time

Antimatter has fascinated scientists, and captured its fair share of public imagination, ever since its existence was predicted by the British physicist Paul Dirac in 1931. How fitting then that in 2002, the year we celebrated the centenary of Dirac's birth (*Frontiers* 13, p.17), antihydrogen – the bound state of an antielectron (positron) and an antiproton – has been created under controlled conditions for the first time. This antimatter landmark was achieved by the ATHENA antihydrogen collaboration working at CERN's Antiproton Decelerator (AD) facility.

The AD was opened only 3 years ago, allowing physicists to resume their studies of antiprotons at very low energies, with the aim of making antihydrogen being a top priority (*Frontiers* 9, p.10). The AD supplies antiprotons in short bursts and the ATHENA team has developed a special trap which holds about 10,000 of them in a particular arrangement of electric and

magnetic fields called a Penning trap. The antiprotons are cooled in this trap to a temperature of about 15 degrees above absolute zero (or  $-258^{\circ}\text{C}$ ).

## ATHENA UK involvement

I lead the University of Wales Swansea (UWS) team which developed the positron accumulator for ATHENA. This customised instrument can collect more than a 100 million positrons every few minutes. At the end of the accumulation cycle, our positrons are gently nudged across a few metres in vacuum and allowed to settle into their own Penning trap – located only a few millimetres away from the cloud of antiprotons.

The electrical potential confining the cold antiprotons is then gently lowered and they mix with the positrons. During this complex dynamic process, many antihydrogen atoms are formed. Once the antiparticle pair unites to form the



The ATHENA experiment

electrically neutral antiatom, the electromagnetic trap can no longer provide confinement. The antihydrogen quickly migrates to a nearby material object where it annihilates, releasing a characteristic shower of particles and gamma-rays. The ATHENA collaboration has developed a uniquely sensitive detector to register this special event (*Frontiers* 9, p.11).

So far, ATHENA has amassed signals from more than 50,000 antihydrogen events, with more data coming in all the time as the mixing technique is

systematically investigated and refined. We can now look forward to physics studies on antihydrogen – in particular precise comparisons of its spectrum with that of ordinary hydrogen, that will provide stringent tests of the so-called CPT theorem, which predicts subtle differences between the behaviour of matter and antimatter.

**Mike Charlton, e-mail:**

*m.charlton@swansea.ac.uk*

*The UK work is supported by the Engineering and Physical Sciences Research Council*

# A wake of a planet around a nearby star

Pluto, and so perhaps we are seeing a region near Fomalhaut that has many millions of comets. The central hole has most likely been cleared by the formation of one or more planets that 'sweep-up' the dust to form a rocky core. One of the most intriguing features of the disc is that it appears to bend around the star. Models of the Fomalhaut disk suggest that a planet, similar in mass to Saturn, is creating a 'wake' or trail in the dust. The artist's impression shows how the Fomalhaut planetary system may look. The

gravity of the planet creates points near its orbit called 'resonances' where comets get trapped. When two comets collide, they release a shower of dust that is seen as a bright spot in the disc. The new data provide the strongest evidence so far that solar systems similar in size, or even bigger than our own, may exist. It is likely that Fomalhaut looks quite similar to our own Solar System when it was only 200 million years old. At that age, a planetary system would already have formed but we would have trouble seeing it



David A. Hardy/PPAC

with optical telescopes because of the shroud of dust.

**Wayne Holland**

*E-mail: wsh@roe.ac.uk*

Artist's impression of the Fomalhaut planetary system

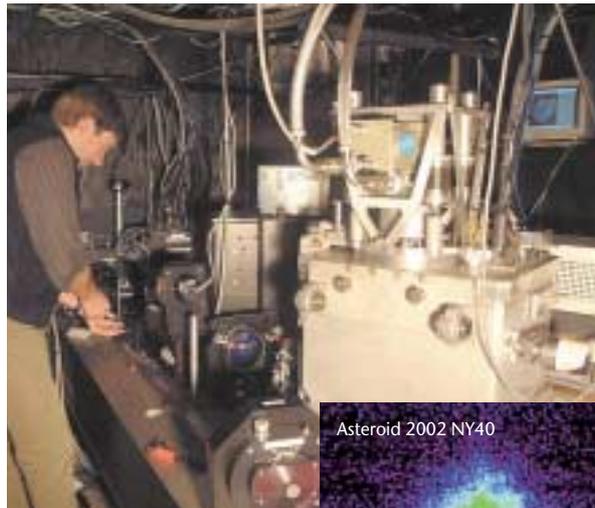
## NAOMI focuses on a near Earth asteroid

The adaptive optics system NAOMI on the William Herschel Telescope (WHT) in La Palma was recently used to take a remarkable image of a near Earth asteroid. Adaptive optics (AO), whereby an optical system compensates for the blurring effect of the atmosphere to give much clearer images, is revolutionising observational optical/infrared astronomy (*Frontiers* 10, p.5). NAOMI is the first AO system on a UK telescope, and was built by a team from the University of Durham and the UK Astronomy Technology Centre. In good conditions, it can deliver images as sharp as those from the Hubble Space Telescope.

The asteroid 2002 NY40 was

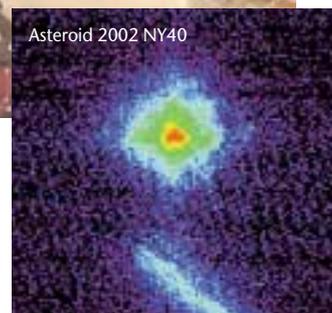
observed last August when it was 750,000 kilometres away, twice the distance to the Moon, and moving rapidly across the sky at 65,000 kilometres per hour. Despite the technical difficulties this caused, the astronomers using the WHT obtained very high quality images in the near-infrared with a resolution of 0.11 arcseconds. This resolution is close to the theoretical limit of the telescope, and sets an upper limit to the size of the asteroid, which is only 400 metres across.

Near Earth asteroids are those that periodically approach or cross the orbit of our planet, and there is a very small probability that one could collide with the Earth.



The NAOMI adaptive optics system on the William Herschel Telescope

Measuring the size of asteroids helps astronomers understand their nature and how they formed, as well as the potential threat they pose. Variations in the brightness of 2002 NY40 suggest that it is highly elongated and is tumbling. Further monitoring of these



variations will tell us whether the asteroid was viewed end-on or side-on, thus allowing us to determine the size and shape more precisely.

## Physics beyond the Standard Model

### Measuring the magnetic moment of the muon is exciting particle theorists

Usually we think that major discoveries in particle physics come from experiments using accelerators that collide particles at the highest energies. Sometimes, however, very high precision measurements at low energies – where new physics may reveal itself as a tiny deviation from the expected value – can be just as powerful. Such is the case for the recent measurement of a subtle parameter,  $g-2$ , of an elementary particle called the muon, which is a heavier version of the electron, having 200 times the mass. This experiment, carried out at the Brookhaven National Laboratory (BNL) in the US, has revealed hints of physics that go beyond the famous Standard Model of Particle Physics which is the current description of all

the elementary matter particles we know of, and three of the four fundamental forces between them – the electromagnetic, weak and strong forces.

The Dirac equation, introduced in the 1920s (*Frontiers* 13, p.17), enabled the electron to be described using quantum theory. A triumph of the equation is that it predicted that the magnetic moment of the electron is proportional to its

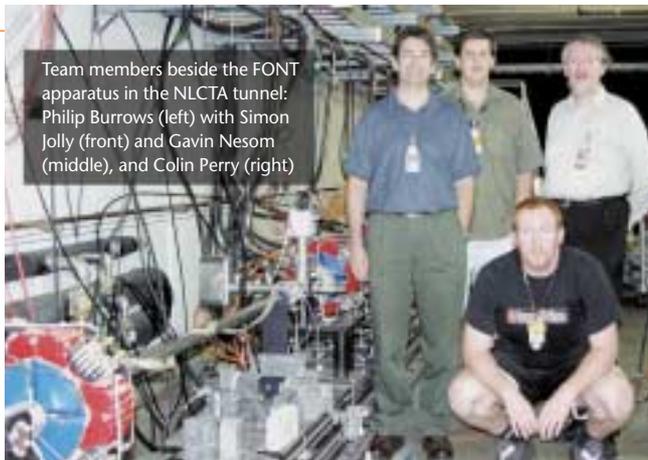
spin, with a proportionality constant  $g$ , equal to 2, in units of  $e/2m$  where  $e$  is the electric charge and  $m$  is the mass of the particle. The constant  $g$  is known as the gyromagnetic ratio.

Later, theorists, Julian Schwinger, Richard Feynman and others, improved the description of the electron, developing a theory in which 'virtual' photons carry the electromagnetic force (quantum electrodynamics). This more developed theory predicts that the gyromagnetic ratio is a little more than 2. To represent the

deviation from Dirac's value of 2, it is usual to quote the value of  $(g-2)/2$  and call it the 'anomalous magnetic moment'. In fact, the anomalous moment of the electron has now been measured to a few parts per billion and is found, after an heroic calculation, to be completely described by quantum electrodynamics. This is the most precisely tested agreement between experiment and theory that exists in science.

Similar arguments also apply to the muon, but because it is some 200 times heavier than the electron, its anomalous magnetic moment is sensitive to the additional interactions due to the strong and weak forces, felt over only very small distances. Since the quantum field theory description of the electromagnetic, weak and strong interactions is the bedrock of the Standard Model,





Team members beside the FONT apparatus in the NLCTA tunnel: Philip Burrows (left) with Simon Jolly (front) and Gavin Nesom (middle), and Colin Perry (right)

## Winning LC technology

In September, a team of UK physicists successfully ran the first phase of the FONT (Feedback on Nanosecond Timescales) experiment (*Frontiers* 14, p.6) at the Next Linear Collider Test Accelerator (NLCTA) at the Stanford Linear Accelerator Center (SLAC) in California. The experiment, carried out by researchers from Queen Mary University of London and Oxford University,

tested a novel system aimed at maximising particle collisions and therefore the ultimate efficiency of the collider.

The Linear Collider (LC) is the next generation electron-positron accelerator designed to investigate in detail phenomena such as Higgs or supersymmetric particles likely to be identified in the Large Hadron Collider being built at CERN. Such heavy new particles

should be produced when bunches of electrons and positrons are fired head-on and annihilate. In order to maximise the probability of the collisions, the electrons and positrons must be packed tightly in bunches a few nanometres across, and steered so as to hit each other to within this accuracy. However, ground

deflects the later bunches. The system must respond within a few tens of nanoseconds, or all the bunches in the train will have passed by before any correction can be applied. This requires analogue, rather than digital, electronic components.

After a year of simulation work to understand the problem and devise a solution, the team proposed an experimental test of a prototype system at the NLCTA. We built a high-power amplifier to drive the kicker, as well as the analogue feedback electronics and the BPM. SLAC provided a kicker, beamline upgrades and operational support.

The first test results were extremely pleasing. The 170 nanosecond-long bunch train was deliberately mis-steered using a dipole magnet. FONT made the corrections, responding within 66 nanoseconds. This represents a 'proof of principle' that the system can work on the timescale needed for the LC. Nevertheless, we think we can save a further 10 nanoseconds by optimising the electronics, and we are keen to have a second run this coming spring. This would provide a gold-plated demonstration that ground-motion effects at the LC can be overcome with a nanosecond beam feedback system.

vibrations will tend to shake up the accelerator components causing the bunches to jitter, perhaps on the scale of tens to hundreds of nanometres. If uncorrected, this would cause the electrons and positrons to miss each other completely which would be a disaster for the physics programme!

### Compensating for movement

The UK group has come up with a solution. Since the electrons and positrons will be sent in 'trains' of several hundred bunches separated by a few nanoseconds, it should be possible to detect whether the early bunches are misaligned, and then correct the positions of the later ones. This can be done by using a beam position monitor (BPM), which registers the position of the early bunches, just downstream of the collision point, and a fast 'kicker', just upstream, which

**Philip Burrows**  
E-mail: [p.burrows@qmul.ac.uk](mailto:p.burrows@qmul.ac.uk)

a precise measurement of  $g-2$  of the muon therefore offers a sensitive test of the Standard Model, and the possibility to explore what may lie beyond the Model.

### A new experiment

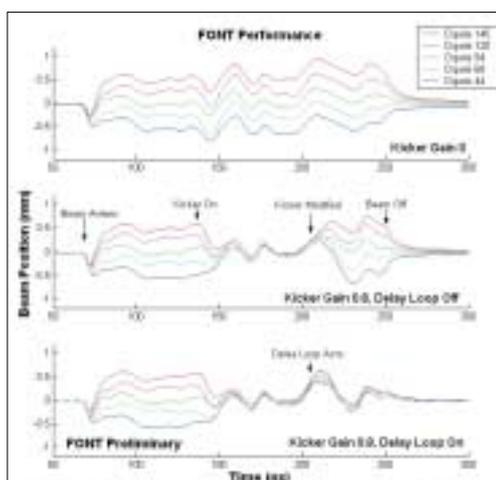
For this reason, a team at BNL – the Muon  $g-2$  collaboration – chose to measure the magnetic moment of the muon by detecting the effect of a magnetic field on its spin. Early last year, they presented a very accurate measurement that differed significantly from the prediction given by the Standard Model. This consequently unleashed much theoretical activity and speculation. However, a sign error was found in one aspect of the theoretical calculation, which when corrected meant that the discrepancy was no longer statistically significant.

Now, after analysing further data, the BNL collaboration

presented in July 2002 another measurement with essentially the same value for  $g-2$  but with twice the precision, which may be compared with an improved theory prediction made recently by our research group at the University of Durham. The discrepancy between the new result and the Standard Model prediction has re-emerged, and renewed the excitement.

The aim is high. If the discrepancy is confirmed by future improvements in the  $g-2$  measurements and in the Standard Model prediction, it will herald new physics. It may suggest the existence of a theory that goes beyond the Standard Model, called supersymmetry, which postulates that each of the fundamental particles has a partner with different spin. Indeed it already imposes constraints on their properties. Watch this space.

**Alan D. Martin, e-mail:**  
[a.d.martin@durham.ac.uk](mailto:a.d.martin@durham.ac.uk)



The position of the incoming electron bunch train, deliberately steered to different positions (top). With the kicker activated, the beam is steered back to the centre after 66 nanoseconds (middle), and with the full feedback turned on, all the trailing bunches in the train are corrected (bottom)