A NEW VIEW OF THE UNIVERSE

Big science for the big society

ROYAL ASTRONOMICAL SOCIETY
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1820
Advancing Astronomy and Geophysics

Science & Technology Facilities Council

A NEW VIEW OF THE UNIVERSE
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Cover:
NASA's Hubble Space Telescope captured this billowing cloud of cold interstellar gas and dust rising from a tempestuous stellar nursery in the Carina Nebula, 7500 light-years away. This pillar of dust and gas serves as an incubator for new stars and is teeming with new star-forming activity.

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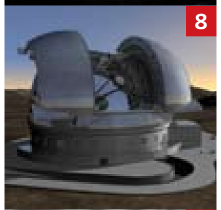
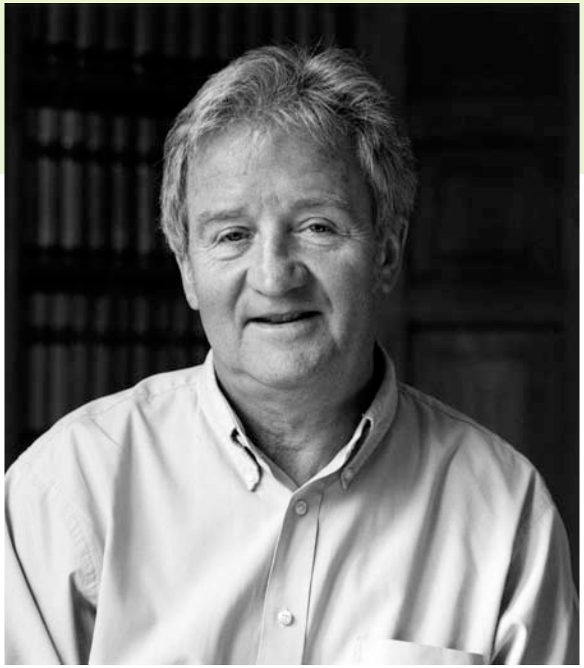


FROM THE PRESIDENT OF THE ROYAL ASTRONOMICAL SOCIETY



My interest in astronomy began when I was seven. Then, as a teenager, I learnt the constellations and watched satellites cross the night sky. Following a physics degree, I was inspired to pursue astronomy and have spent my subsequent career using many different orbiting and ground-based telescopes to study the universe.

We live in a golden age of astronomical discovery. In the past 40 years, we have proved the existence of black holes, found hundreds of planets around other stars, and discovered that 95% of the universe is made up of enigmatic "dark matter" and the even more mysterious "dark energy". In the next 40 years, we should detect gravitational waves – a key prediction of Albert Einstein in his General Theory of Relativity – and just possibly the first signs of life on other worlds. Astronomers and space scientists in the UK are incredibly good at all this – and, after the US, have more citations of our research papers than any other nation.

With such astonishing progress in our science, it isn't surprising that astronomy is so interesting to the wider public. The innate curiosity we all share about the universe is an important part of our culture, and at least as important as our contemporary concerns about health, the ageing process and security. For that reason alone, we could argue that our science should receive a decent level of investment, at least as much as that spent by other developed countries. This booklet, produced by the Royal Astronomical Society and backed by the Science and Technology Facilities Council (STFC), highlights many of the other reasons, from the way in which astronomy inspires people to study and work in science to the plethora of spin-off technologies that shape our society.

In the past, the impact of astronomy was obvious, as navigators and explorers depended on knowledge of the night sky to find their way around the world. Now we have more subtle but nonetheless highly significant outcomes, including the development of super-sensitive charge-coupled devices (CCDs) found in almost every mobile phone and digital camera, medical and airport scanners, and wireless computer networks. All of these were discovered or developed by astronomers, in many cases through serendipity, where work on one topic led to an unexpected beneficial result elsewhere.

"The articles that follow invite you to think about why our science matters and the sometimes surprising ways in which it affects our lives"

The articles that follow invite you to think about why our science matters and the sometimes surprising ways in which it affects our lives. As such, it is a timely reminder that research in "blue-skies" subjects like astronomy – an area in which the UK excels – not only enriches our culture but also brings real benefits to society as a whole.

Prof. Andrew Fabian
President of the RAS 2008–2010

WHAT'S THE USE OF ASTRONOMY?

Humans have always gazed up at the Heavens and wondered what was beyond their everyday world.

Astronomy is the oldest science. The earliest civilizations made astronomical observations that led to the units of time we use today – possibly the first scientific measurements made. Many human activities, particularly navigation, have depended on observations of the Sun, Moon and stars.

Over the past couple of centuries, more detailed astronomical studies have underpinned the formulation of our current understanding of physics: the fundamental forces, in particular gravity as described by Einstein's General Theory of Relativity; and the building-blocks of matter and the theory describing them, quantum theory. Today, the universe continues to provide a laboratory for testing basic theories that lead to a deeper understanding of nature and our own place in it.

Astronomy now covers a huge range of topics: understanding how the universe got started and how its large-scale structure evolved into what we see today; the formation and evolution of galaxies, stars and planetary systems; and, excitingly, the search for planets that might support life. A major mystery recently uncovered is the existence of "dark energy" which is accelerating cosmic expansion. The dynamics of the universe seem to be dominated by this phenomenon, as well as by large amounts of invisible "dark matter". The universe we see directly is only a small component of what is really out there.

Discoveries made via astronomical observations also play a pivotal role in shaping progress in other fields. A major goal of nuclear physics is to understand how the elements are made in stars. Studying the outer layers of the Sun and other stars tells us about the physics of plasmas relevant to clean nuclear-energy generation. Exploring the geology and atmospheres of planetary bodies in the solar system may throw light on climate change on our own planet, while the burgeoning science of astrobiology – exploring the conditions in which life could exist elsewhere in the universe – could explain how life first evolved on Earth.

Astronomy inspires

It is not surprising that children are fascinated by the universe's sheer scale and strangeness. Many young people are drawn into studying science and engineering at university through an early introduction to the wonders of the cosmos. A report funded by Kings College London and the Wellcome Trust, *Pupils' & Parents' Views of the School Science Curriculum*, stated: "The one topic (among the sciences) that generated universal enthusiasm was any study of astronomy." The UK has built on this response, establishing projects such as the National Schools' Observatory (NSO), through which pupils can make observations with the same robotic telescopes (page 6) that are used by professional astronomers. About 1200 schools across the UK are full NSO members, and more than 17000 observing requests have been delivered to pupils so far. The Royal Observatory Greenwich (ROG) hosts 14000 pupils annually, as part of an astronomy education programme catering for all ages from 5 to 19. Children's enthusiasm for planets and black holes is channelled into active learning related to the school science curriculum.

"The one topic that generated universal enthusiasm was any study of astronomy"

Providing a skilled workforce

At university, astrophysics research continues to attract some of the strongest physics graduates. It equips PhD

◀Schoolchildren watching the skies around the cone of the Peter Harrison Planetarium at the Royal Observatory, Greenwich.

students with the kind of training needed by industry, business and other economically important sectors. Modern astronomy, like global commerce, usually involves working in international teams on large-scale projects. Students therefore develop good management as well as strong analytical (mathematical and computational) or engineering skills.

Cutting-edge technology

Pushing back the boundaries of what we know about the universe requires ever more sophisticated instruments and computing methods. As telescopes grow in size and sensitivity, they require increasingly complex optical systems (pages 8 and 12) and innovative detectors (pages 7 and 13). Instruments may have to endure the harsh radiation of space or require an extremely cold, "quiet" environment. Inevitably, they often provide a testbed for novel advanced materials and fabrication methods (page 7 and 9), as well as analytical and engineering techniques, which later find use in industry or in the health sector. Some astrophysicists even go on to set up their own companies to develop their technology for applications outside astronomy (pages 10 and 11).

Popular culture

Astronomy, cosmology and space science address the big questions about the nature of existence, exciting the public imagination in the process. The concepts and imagery of astronomy saturate popular culture, from blockbuster movies to toys and computer games. Although astronomy research is intellectually challenging, it also lends itself to explanation at a level that can be appreciated and enjoyed by everyone. In 2009, more than 1.4 million people visited the Royal Observatory, Greenwich's galleries or attended one of its planetarium shows, public lectures or stargazing events. The National Space Centre in Leicester receives a quarter of a million visitors each year.

Citizen science

Astronomy also enhances public engagement in science in another way: it can be pursued at an amateur level. There are about 200 astronomical societies in the UK, and many universities run distance-learning courses or evening classes for anyone interested in the science. Astronomers have recently exploited the internet to engage this interest further and enable the public to be involved in front-line research. Web-based projects such as Galaxy Zoo and Solar Stormwatch, which respectively classify galaxies and monitor space weather (page 14), enlist the help of hundreds of thousands of people.

Anyone can help professional astronomers, via the Galaxy Zoo or Solar Stormwatch websites.

"There are about 200 astronomical societies in the UK, and many universities run distance-learning courses or evening classes"

ASTRONOMY IN THE UK

Modern astrophysical observations rely on a complementary range of powerful astronomical instruments that detect radiation over the whole electromagnetic spectrum. The microwaves that permeate the cosmos tell us about conditions just after the Big Bang, while infrared radiation provides information about the cold, dusty reaches of space – for example, where stars form. X-rays and gamma-rays are messengers of violent processes such as the formation of black holes, as are other types of radiation: cosmic rays (high-energy particles), neutrinos, and gravitational waves (page 7). Another vital aspect of astrophysics is computer simulation, for example to model the evolution of structure across the cosmos, which requires powerful supercomputers.

Depending on requirements, telescopes may be ground-based or may orbit in space, and because of their size and complexity they are usually constructed and operated by international teams. The UK plays a major role, particularly through its membership of the European Southern Observatory (ESO) and the European Space Agency (ESA). The UK has also pioneered astronomical studies with dedicated observatories working at millimetre and infrared wavelengths at the Joint Astronomy Centre in Hawaii. For example, pictured is the James Clerk Maxwell Telescope, the world's largest single-dish submillimetre telescope. It collects faint submillimetre signals with its 15-metre diameter dish. It is situated near the summit of Mauna Kea on the Big Island of Hawaii, at an altitude of approximately 4000 metres (14000 feet) above sea level.

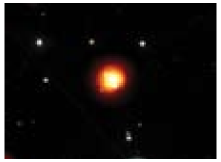
Amateur astronomers enjoying the night sky.

An exciting future

The future for astronomy is extremely exciting. New telescopes and instruments being planned are likely to lead to world-changing fundamental discoveries about the nature of the universe and the forces governing it. They also have the potential to provide life-enhancing technical developments. Even more extraordinarily, we may soon know whether there is life beyond the Earth, which will redefine our perceptions of human existence for ever. ■

REVEALING THE SECRETS OF GAMMA-RAY BURSTS

An artist's impression of a gamma-ray burst. They are thought to be associated with the explosion of stars that collapse into black holes. Two jets of material are ejected – if one is aimed at Earth, we see a brief but powerful GRB.



This gamma-ray burst is the furthest object ever observed. It is 12.8 billion light-years away.

Using a combination of space and ground-based telescopes, astronomers have been observing the most cataclysmic explosions in the cosmos.

Gamma-ray bursts (GRBs) are among the most remarkable phenomena known to science. Thought to mark the birth of a black hole when a massive star collapses at the end of its life, GRBs are by far the most violent and luminous explosions known. To put this into context, the debris from a GRB explosion moves with a velocity of around 99.999% of the speed of light, and the brightest GRB so far observed was about 10 million times brighter than the entire Milky Way galaxy.

The key to unlocking the nature of GRBs was uncovered in 1997, with the discovery that the short flash of gamma-rays is followed by a longer-lived emission in optical light, the so-called afterglow. This discovery, made with the UK's William Herschel Telescope on La Palma in the Canary Islands, enabled the distances to GRBs to be measured for the first time, and earned the team involved the Descartes Prize for Research in 2002.

Artist's impression of the Swift satellite swivelling to capture images of a GRB.

The UK has remained at the forefront of this rapidly moving field, supplying key instrumentation for NASA's Swift satellite, which has found more than 500 GRBs since its launch in 2004. In April 2009, Swift observed a remarkable GRB that was revealed by immediate follow-up ground-based measurements to be the furthest object ever located. Its light had travelled for 13.1 billion years before reaching Earth, indicating that the burst had happened only 600 million years after the Big Bang.

Extreme events

In the future, we hope to use GRBs as searchlights to reveal the nature of the first stars to form in the universe. There are also many mysteries surrounding the physics of GRBs, which probe physical conditions not met elsewhere. For example, the so-called "short duration" GRBs, which appear to be completely different kinds of events, are thought most likely to occur when two ultra-dense neutron stars merge in a cataclysmic collision. Such objects may provide fundamental tests of Einstein's Theory of Relativity, and are prime targets for searches for gravitational waves (see opposite), one of the holy grails of contemporary astrophysics. However, short-duration bursts are even harder to observe than the classical "long-duration" variety, so our understanding of them is rudimentary.

"GRBs are by far the most violent and luminous explosions known"

One of the interesting aspects of GRB science is that because each one occurs only once, and even its afterglow fades fast and has usually almost disappeared within a few days, observations must be made very quickly. This means UK astronomers must be ready to respond to alerts transmitted from Swift at any hour of the day or night, so they can instruct observers at telescopes around the world on what measurements are required. An important reason for the success of UK astronomers in this field has been their access to a range of 2-metre robotic telescopes (see box), and powerful 4 and 8-metre telescopes, which means that they can make important observations of any GRB. ■

THE UK'S ROBOTIC TELESCOPES

The UK has pioneered large, autonomously operating telescopes, of which the 2-metre Liverpool Telescope (LT) on La Palma is the prototype. It was built by a spin-out company from Liverpool John Moores University, Telescope Technologies Ltd (TTL), which has since constructed robotic telescopes worldwide. In 2007, the LT scientists won the THES Research Project of the Year for the rapid measurement of polarization in GRBs. TTL has now been bought by former Google vice-president, Wayne Rosing, who is continuing the original concept of establishing a global network of robotic telescopes to monitor events such as GRBs.

THE SEARCH FOR GRAVITATIONAL WAVES

The discovery and measurement of gravitational waves will usher in a new era for astrophysics.

Most of what we know about the universe has been gleaned from the electromagnetic radiation (gamma-rays, through visible light to radio waves) that reaches us from distant stars and galaxies. Einstein's General Theory of Relativity, however, predicts the existence of another kind of radiation – gravitational waves – which, if identified, would provide astronomers with a unique and powerful tool to study the cosmos.

Gravitational waves are ripples in the fabric of space. Although not yet discovered, they should be emitted in extremely violent events such as the merging of two black holes; the Big Bang itself is predicted to have generated gravitational radiation, which persists today as a pervasive cosmic background. Gravitational-wave measurements could thus not only test theories about black holes and other "extreme" objects such as neutron stars, but also probe the evolution of the early universe.

Detecting gravitational waves is extremely challenging, to say the least, because the resulting distortions in space are less than one part in a thousand billion billion. Nevertheless it can be done. Gravitational-wave projects employ an L-shaped instrument called an interferometer, consisting of two arms of equal length up to several kilometres long. Light from a powerful laser is split in two identical beams, which travel down the arms to mirrors on suspended test masses, where they are reflected back again before being recombined. A passing gravitational wave would stretch one arm and squeeze the other, resulting in a tiny difference in arm-length that then generates a signature interference pattern in the recombined laser light. The minute change is less than one-thousandth of the diameter of an atomic nucleus.

The UK role

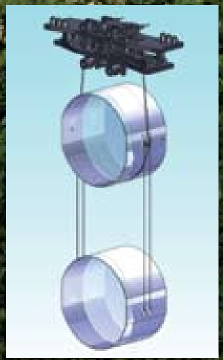
UK scientists are playing a key role in gravitational-wave research, and are participating in Advanced LIGO, a two-site observatory being built in the US. It is expected to be 10 times more sensitive than its predecessor, LIGO. A collaboration led by the University of Glasgow is providing both hardware and theoretical support. Based on work done for the smaller, joint German–UK gravitational wave detector GEO 600, the researchers have developed extremely strong fused-silica fibres designed to hold still the suspended, 40-kilogramme mirrors. A prototype is being installed in a test facility at the Massachusetts Institute of Technology.

> "Detecting gravitational waves is challenging, because the distortions are less than one part in a thousand billion billion"

Applications

The silica-fibre technology is also finding use in other fields. The Glasgow team is working with a company to develop fused-silica fibres for gravity gradiometers used in oil exploration. The bonding technology used in the construction of the fibre suspensions has a wide number of applications in the optics industry, in particular in constructing novel high-power lasers based on optical fibres. The same technology has been adapted to bonding silicon carbide to different materials, which could be applied to car disc brakes. Finally, the jointing technology is being deployed to make optical systems stable enough to withstand launch conditions in a variety of space missions.

The UK's German colleagues are also involved in Advanced LIGO, in providing the high-power lasers. A spin-off from this programme is novel technology that reduces the quantum fluctuations (shot noise) in the emitted light, which researchers can exploit in highly sensitive optical experiments relevant to quantum information and quantum-computing applications. ■



▲**Background image: The Livingston, US, site of LIGO, where Advanced LIGO will be housed. Each arm is 4 km long.**

◀**A CAD rendering of the core suspension system that the UK has developed and will contribute as part of the upgrade programme in building Advanced LIGO.**

A GIANT EYE ON THE COSMOS

Europe's new 42-metre telescope, to be completed in 2018, will not only revolutionize our knowledge of the universe but will also offer major commercial opportunities for UK business.

The current E-ELT design. The protective dome is 90 metres high, while the concrete base rises about 10 metres above the ground.

Modern astronomy demands precision-engineering on a grand scale. The world's largest telescopes have huge, perfectly shaped giant mirrors – some more than 10 metres across – that collect the faintest light signals from planets, stars and far-flung galaxies. Today, an even more ambitious instrument is being planned: the European Extremely Large Telescope (E-ELT). With a main mirror 42 metres across, it will collect nearly 20 times more light than any other current telescope, and see objects 17 times more clearly than the Hubble Space Telescope. Astronomers hope that it will help to answer the big questions about existence: how did the universe evolve into what we see today, and is there life beyond the Earth?

A technological step-change

The E-ELT will also drive forward technological development, because it must deliver the best possible optical performance in the face of changing atmospheric conditions, variable mechanical loads as the telescope moves around, wind forces and even the occasional earthquake.

The surface shape of the main mirror has to be extremely smooth, with a roughness of less than 10 nanometres peak-to-trough that is equivalent to having waves no higher than 2 millimetres across the Atlantic Ocean. The mirror is made up of nearly 1000 hexagonal segments, each 1.4 metres across. The segments are independently controlled to maintain the mirror's shape against gravity and wind.

Atmospheric turbulence causes image blurring but can now be compensated for using adaptive optics (AO, page 12). The light reflected from the main mirror is passed to two further mirrors that are deformed or tilted at high speed to make a real-time correction. The result is an image that is as sharp as is optically possible. AO for the E-ELT is a significant engineering challenge. It requires a deformable mirror only 2 millimetres thick but 2.5 metres across, more than twice the size of mirrors used today, and 8000 actuators will have to push on the different parts of the mirror up to 1000 times each second.

Answering the scientific questions of the 21st century

Once the E-ELT is operating, it will have a major impact on our understanding of the cosmos. Astronomers will be able to search for and take the first images of Earth-like planets around nearby stars, and even look for water and oxygen in their atmospheres. If such worlds are found, then the

prospects for finding life elsewhere in the universe will receive a huge boost.

The E-ELT will also be able to study the first galaxies that formed. These are so distant that their light has taken almost the whole history of the universe to reach us, so we see them as they were only a few hundred million years after the Big Bang. Astronomers will not only be able to detect these galactic infants, but also see their shapes, measure their chemical properties and understand how their stars formed.

Astronomers recently discovered that the expansion of the universe is accelerating, apparently driven by a mysterious and pervasive force, "dark energy". Scientists may be able to make the first direct measurement of the acceleration and so gain insight into this fundamental phenomenon.

E-ELT will also be used to see whether the physical properties of the universe, such as the strength of gravitational and electromagnetic forces, have changed over time. If any change is found, then it will have far-reaching consequences for our understanding of the basic laws of physics that shape the world we live in.

▲This is Cerro Armazones in the Chilean desert, near ESO's Paranal Observatory, where the E-ELT will be built. The image shows equipment used to survey the site.

"The E-ELT will have a major impact on our understanding of the cosmos"

Impacts on the wider world

Technology developed for astronomy has already fed into many applications, from medicine to security and communications. Those resulting from the E-ELT include:

- adaptive optics, used to sharpen diagnostic images of vascular disease in the eye;
- high-performance optical and infrared detectors, deployed in biomedical imaging and security scanners;
- large-scale precision optics, important in fabrication of microelectronic devices, in laser-driven nuclear fusion, Earth-observation satellites and solar energy;
- the techniques for making large, complex instruments for telescopes are applied in areas such as satellites and medicine;
- image and data-processing, in which researchers extract data from noisy and complex images, have a direct application to medical instruments such as body scanners;
- the structural engineering needed to build a giant but precisely aligned telescope could be applied to a future laser fusion system.

Opportunities for UK industry

The UK has a strong involvement in the E-ELT programme, and so our industry is in an excellent position to win contracts for the construction of the telescope, and its associated instruments and components. About 80% of the UK contribution (estimated to be €200m) is expected to be awarded to industry. Companies that may benefit include:

- ARUP, responsible for one of the telescope enclosure studies;
- Observatory Sciences and Scisys, which are working on the software and control systems;
- the North Wales-based OpTIC Technium consortium, which is prototyping the primary mirror segments.

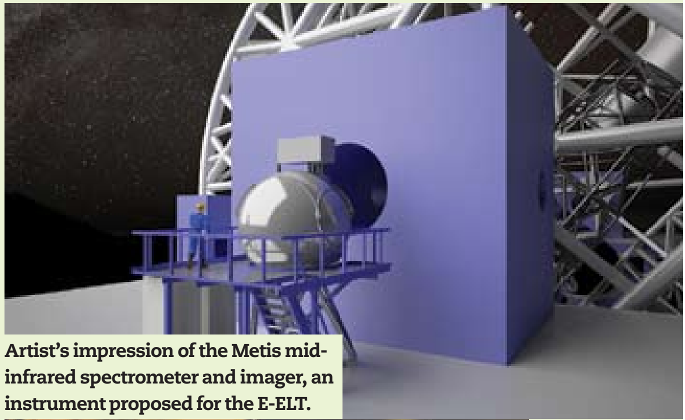
The programme is also pursuing commercialization and spin-out opportunities, for example, in medical imaging and turbulence monitoring. Several spin-out companies, including Zeeko and Blackford Analysis, have already emerged from astronomy technology, with other enterprises expected to come into being in response to E-ELT procurement requirements.

Predicting the value of new industries and companies is difficult. The market for AO in biomedical and communications applications could be as large as £500m per year within a decade, similarly for detector technology. The greatest possibility for wealth creation stems from laser nuclear fusion, which if successful as an energy-generation technology, could be worth hundreds of billions of pounds.

A highly skilled cadre of scientists

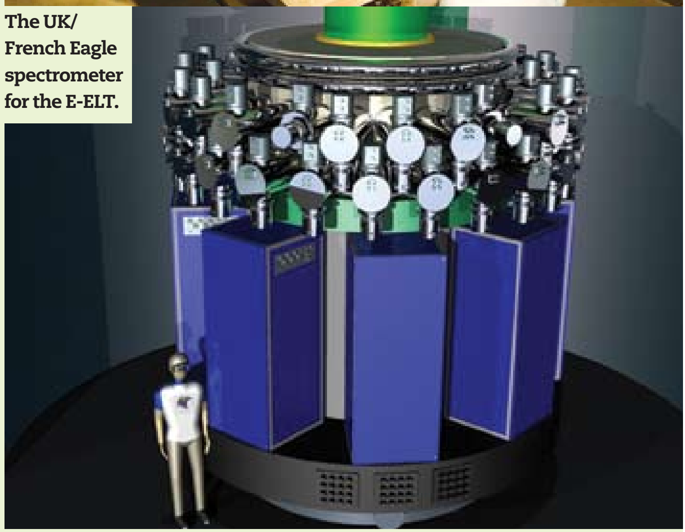
Constructing and operating the E-ELT depends on a partnership between institutes, university research groups and industry. This extraordinary scientific project will deliver a cohort of trained scientists and engineers, whose skills and know-how are honed by the challenges of developing such a huge and complex machine. At its peak, 100 scientists and engineers will be employed on the project in the UK, at least 40% of whom will be new graduate and postdoctoral researchers able to transfer their skills to industry. ■

DEVELOPING ADVANCED INSTRUMENTS



Artist's impression of the Metis mid-infrared spectrometer and imager, an instrument proposed for the E-ELT.

Testing mirror components.



The UK/French Eagle spectrometer for the E-ELT.

RADIOASTRONOMY OPENS THE WAY TO A WIRELESS WORLD

Wi-fi – an invention now used daily by almost a billion people – owes its origins to searching for the radio signals from exploding black holes.

One of the challenges in observational astronomy is to obtain the clearest signals from distant objects in the universe. For example, a major problem for ground-based telescopes is atmospheric turbulence which distorts optical images (see p12). In the late 1970s, a small team of radio-astronomers, based in the Netherlands, found a way of analysing the images using a mathematical technique called a Fourier transform, and so provided a means to sharpen them. This led to the development of a hardware solution – adaptive optics, whereby a telescope mirror is continuously reshaped to compensate for the turbulence. Today adaptive optics is used on large telescopes and has applications in fields such as microscopy and ophthalmics.

Later one of the researchers, Australian John O'Sullivan, applied the same approach to radio signals. He was searching for radio waves from exploding black holes. Stephen Hawking had predicted that black holes do emit radiation and could eventually collapse and explode. O'Sullivan and his colleagues needed to design radio equipment that could sharpen radio pulses that had been broadened by their journey through interstellar gas and dust. Originally they used an analogue system involving 35-mm film but then decided to record the data digitally – and used Fourier transforms to process the data and remove the effects of the interstellar medium.

"John O'Sullivan and his team realized they had the skills to move from wired computer networks to the use of wireless transmitters to communicate between devices"

Although exploding black holes have never been found, the work led to developments that were to transform telecommunications. Having returned to Australia, O'Sullivan was able to apply the same methodology to signal processing for a new radio-telescope array, the Australia Telescope Compact Array, whereby six identical antennas work together to generate a high-resolution radio image. This work resulted in a dedicated computer chip that could automatically process the transforms.

Five of the six antennas of CSIRO's Australia Telescope Compact Array. Work developing signal-processing techniques for ATCA led to the world's first wireless local area network.

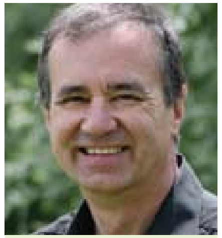
Commercializing radioastronomy

By 1990, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) was looking for ways to commercialize its capability in radio physics. O'Sullivan and his team realized that they had the skills and techniques to move from wired computer networks to the use of wireless transmitters to communicate between devices. But there was a problem: in the confines of buildings and rooms, radio waves bounce off many surfaces, so that a transmission arrives at a receiver followed by a series of echoes. The solution to this multiple reflection issue was a "fast Fourier transform" chip that could disentangle the web of wireless signals. This led to the first workable high-speed wireless local area network (WLAN).

CSIRO patented the invention and, following a legal battle, will now receive revenue approaching AUD$200 million, which will be ploughed back into basic research. After a decade spent in industry working on wireless networking and satellite TV, O'Sullivan is now back in radioastronomy, working on the design of the new giant international radio-telescope, the Square Kilometre Array.

LOCATION, LOCATION, LOCATION

Sat-navs and mobile phones both use GPS to track where you are, a technology developed following Cambridge astronomers' investigations of quasars.



Peter Duffett-Smith.

Part of the One-Mile Telescope developed by the Radio Astronomy Group at Cambridge.

Quasar 3C273, more than 3 billion light-years from Earth. This Chandra image helped reveal an X-ray flow from the core to the jet. It was trying to measure the size of quasars that led to the development of GPS.

UK radioastronomy has made major contributions to a mobile-phone location technology worth billions of dollars a year.

If you are on your way to meet a friend and can't find the agreed rendezvous, you can instantly download the location using a mobile phone with a GPS (Global Positioning System) receiver. The reliability of such "smart phones" with this inbuilt connectivity may well depend on an invention first developed by UK radio-astronomers.

In the late 1970s and early 1980s, a research group led by Peter Duffett-Smith at the University of Cambridge wanted to measure the sizes of quasars (quasi-stellar radio sources) – the highly active cores of distant galaxies. This required a pair of radio antennas working together but separated by up to 1000 kilometres. One component was a large radio telescope at Cambridge, while the other was a small portable antenna that could be transported around the country on a trailer. "We would go and ask a farmer if we could set up the unit in his field and make the observations," says Duffett-Smith.

To work effectively, the researchers needed to know the position of the moving component to within a few metres. They realized that the transmissions from national FM broadcasts offered the solution – knowing the distance to each transmitter allowed them to pinpoint the component's location.

A spin-out company from radioastronomy

"It then didn't take a whole lot of rocket science to realize that the system could be miniaturized and applied to locating anything," he says. Duffett-Smith first tested out the idea by driving around in his car and plotting his position with a laptop computer using medium-wave pop music broadcasts. "We got some venture capital; it was all very exciting," he says. Nothing much happened at first because there was no immediate mass-market application. But then in the middle of the 1990s, everyone started buying mobile phones – which contained all the necessary electronics. Peter took five years out from astronomy to set up a company called Cambridge Positioning Systems to market the technology.

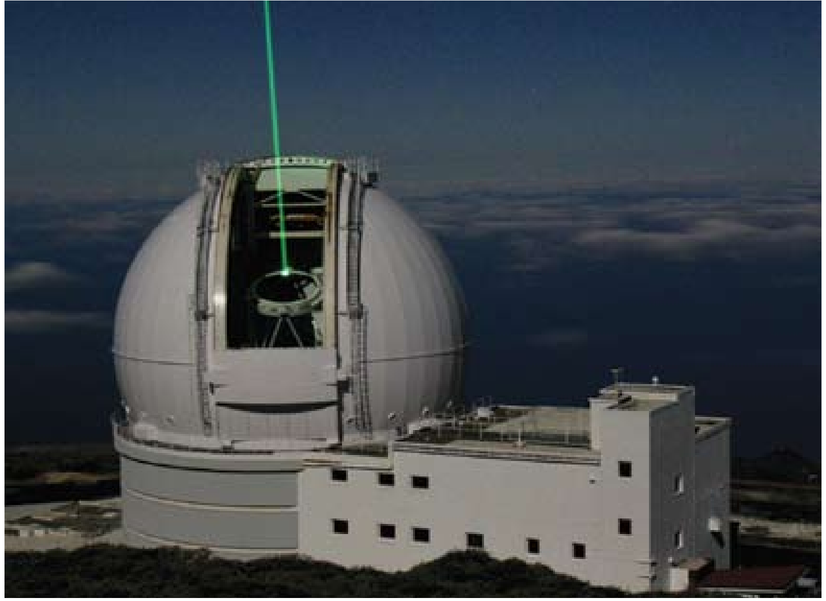
Today, the invention uses the signals from a mobile-phone network to find a phone's position to within 75 metres or so, and also to keep precise track of time. Many mobile phones have chips that detect signals from GPS satellite networks, but need help to work properly inside buildings. The satellite signals are so weak that the receiver has trouble finding them buried in the background radio noise. The Cambridge Positioning Systems device provides a precise time and approximate position to the satellite receiver, which can then dig into the noise at exactly the right spot to retrieve the satellite signals. The mobile-phone user remains unaware of what is happening behind the scenes, but enjoys a much faster and more accurate response.

"He first tested the idea by driving around and plotting his position with a laptop using pop music broadcasts"

At its peak, Cambridge Positioning Systems employed more than 100 people and it has more than 20 granted patents and applications. In 2006 the company was bought by Cambridge Silicon Radio, which is now incorporating the technology into its Bluetooth chips. Meanwhile, Duffett-Smith has returned to radio astronomy, in the knowledge that his academic work has directly contributed to wealth creation in the UK. ■

SEEING CLEARLY WITH ADAPTIVE OPTICS

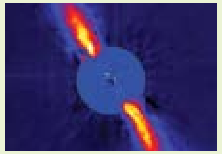
An optical technique largely developed by astronomers is now being applied in manufacturing, medicine, communications and clean energy generation.



A Rayleigh laser guide star is launched from the William Herschel Telescope on La Palma to probe the atmospheric conditions above the telescope for adaptive optics.

Most people are familiar with the extraordinary images of distant galaxies as revealed by the Hubble Space Telescope. The main reason they are so good is that they are not blurred by the turbulence of the Earth's atmosphere, which, until recently, has afflicted the "seeing power" of ground-based instruments (with much larger mirrors). Now, however, observatories on the ground are also able to achieve their full imaging potential using adaptive optics (AO). This ingenious technology compensates in real time for the rapidly changing wavefront distortions (aberrations) generated by temperature fluctuations in the atmosphere. Conventional AO systems consist of three parts: a wavefront sensor, a corrector (usually, a very thin mirror whose surface can be rapidly deformed by arrays of piezoelectric or electromechanical actuators to correct for the aberrations), and a linking control system.

AO was first proposed for telescopes by astronomer Horace Babcock in 1953. Following its development by the military in the 1980s, astronomers quickly saw the potential of AO. Since then, research groups in the UK, for example at the University of Durham, have made major technical improvements in the performance of the AO components. Today, almost all major ground-based observatories apply AO systems for routine science observations, and in certain cases can obtain images equivalent to those that would be obtained from a similar (but much more expensive) telescope in Earth orbit.



Beta Pictoris seen in infrared light with an adaptive optics system at the ESO VLT. The image shows an extended "debris disc" thought to be a proto-planetary system, and evidence for a newly formed planet at a projected distance of 0.4 arcseconds.

Originally, to make corrections, the AO system relied on observations of a bright "guide" star near the line-of-sight to the object being observed. This restricted where in the sky AO could be used. However, astronomers have now developed artificial guide stars in the form of bright laser beams which create beacons in the upper atmosphere that directly probe the turbulence. This, in turn, has led to technology advances in powerful lasers and novel wavefront-sensing techniques. New variations on the AO principle have also been developed, which lend themselves to a wide range of applications.

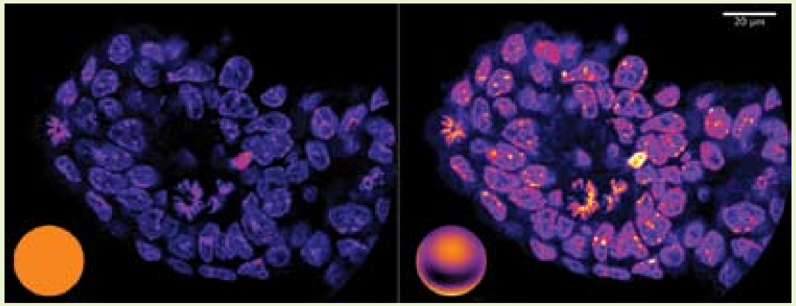
Applications outside astronomy

During the past decade, there has been a significant growth in technology spin-offs from AO, particularly in industrial and medical areas. These applications range from lasers and optoelectronics to biological microscopy and medical imaging.

"A few adaptive optics systems are now licensed for laser eye-surgery"

Adaptive optics provides a tool for manipulating and controlling laser beams, either by modifying the properties of the laser resonator itself, or by altering the characteristics of the output beam. Applications include laser materials-processing in which precise focusing control is essential for achieving fast and accurate results, and the generation of ultra-short laser pulses. Commercial systems are already available for providing focus-only control of CO_2 lasers, while manufacturers of high-power solid-state lasers are showing a real interest in exploiting AO to maintain the laser performance of a range of output powers, particularly for applications in laser-driven nuclear fusion – a future option for energy generation now being actively explored.

In the medical field, several companies supply AO-based systems for measuring optical aberrations in the eye, and a few systems are now licensed for guiding customized laser eye-surgery. AO also provides a valuable tool for enhancing images of the retina for improved diagnosis of diseases such as glaucoma and diabetes.



AO FROM LARGE- TO SMALL-SCALE

False-colour image of fluorescently labelled mouse embryo without (left) and with (right) adaptive optics. The image was taken using an adaptive two-photon fluorescence microscope at a focusing depth of 30 micrometres into the embryo. The inset shows the shape of the deformable mirror.

THE RISE OF THE CCD

Charge-coupled devices (CCDs) – now ubiquitous in digital and video cameras, and the imaging technology of choice in most scientific and technological fields – were first developed largely for astronomy.

The CCD image detector in millions of digital cameras is with us largely thanks to astronomers realizing their potential and pushing their development.

Almost every mobile phone now has a small, in-built digital camera with a solid-state detector called a CCD, which converts the light passing through the lens into a electrical signal, and then into an image. The success of CCDs as digital imaging devices owes much to development work done within the astronomical community, who early on realized their potential for observational astronomy. CCDs are sensitive enough to detect almost every incoming particle of light (or photon), making them ideal for capturing images of the faintest and most distant objects in the universe.

Invented in 1969, CCDs are silicon chips with surfaces divided up into pixels that store accumulated electric charge generated by incident photons. The charge from each pixel is transferred out of the chip in sequence, measured, recorded and processed to give a two-dimensional image. CCDs began to find tentative use in astronomy from the mid-1970s, when astronomers realized they were much more sensitive than the traditional photographic plates. In the following decades, CCDs took off, and today every major telescope in the world uses CCD imaging cameras.

The technology developed has rapidly been applied in other fields. In particle physics, similar pixellated silicon detectors are used in experiments like the Large Hadron Collider (LHC) at Europe's main high-energy laboratory, CERN. In medicine and biochemical research, CCDs are employed for diagnostic imaging and to record data from analytical instruments. CCDs sensitive to X-rays, and first developed for X-ray astronomy, have virtually replaced film at the dentist's. Similar sensors are used for mammography screening where high-resolution imaging is vital to spot tissue abnormalities. CCDs are also used in the aerospace industry, where they are employed in X-ray stereo imaging cameras for inspecting critical aircraft components.

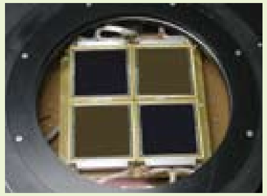
"In the mid-1970s, astronomers realized CCDs were much more sensitive than traditional photographic plates"

Economic impact

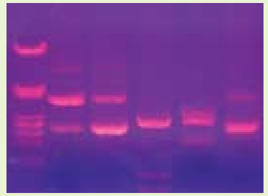
UK astronomers have not been slow to exploit CCD technology commercially. With its long-standing ties to the astronomical community, the Cambridge-based company AstroCam (now part of Perkin Elmer Life Sciences) patented the use of CCDs for automated DNA sequencing, gel electrophoresis (a technique used to separate specific molecules for study) and imaging with X-rays and electron or neutron beams. Another spin-out company from the University of Leicester, XCAM, markets its CCD cameras around the world.

UK astronomers have also worked closely, over the years, with e2v Technologies based in Chelmsford, Essex (with a turnover in excess of £230m), which has pioneered the design of advanced CCDs. Responding to the need for large-area CCDs in astronomy (the first CCDs were very small), the company successfully stitched together devices into arrays. It also developed a back-illuminated CCD, which greatly increased the light detection efficiency. The company now produces some of the world's most advanced imaging devices. UK astronomers continue to work with companies such as e2v to develop novel CCDs for specific applications that eventually find use in the wider world.

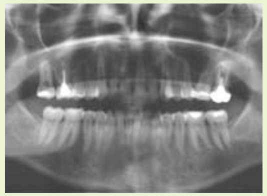
APPLICATIONS OF CCDs



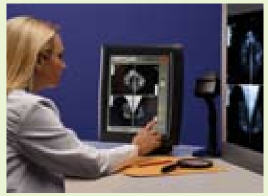
A mosaic of four 4k × 4k CCDs on the 90prime wide-field imager on the Steward Observatory 90-in telescope.



Gel electrophoresis – here being used to track DNA – can now be automated using CCDs.



Most dentists have replaced their X-ray film with CCD imaging cameras, so no wait for developing is necessary.



High resolution images are vital for spotting tissue abnormalities in mammography screening.

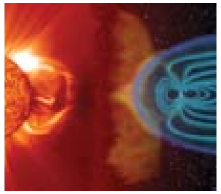
AND NOW, THE SPACE WEATHER FORECAST...

The Earth is continually exposed to a tenuous wind blowing out of the Sun. This wind enables the energy from solar storms to reach Earth and thereby generate 'space-weather' phenomena. Space- and ground-based missions are providing a better understanding of this vital Sun–Earth connection.

While we rely on the Sun for life-giving heat and light, our host star has another, more violent side – it blasts out a gale of electrically charged particles: the solar wind. Fortunately, the Earth is largely protected from this onslaught by its strong magnetic field. The solar wind flows around the Earth's magnetic field and stretches it to form a long tail downwind of the planet. Magnetic energy in this tail can generate electric currents in space that flow into the polar atmosphere to create glowing displays of "northern lights" or auroras.

The Sun's behaviour is far from constant. Magnetically active regions on the solar surface can suddenly explode as solar flares, generating gusts of high-energy electromagnetic radiation and charged particles. Occasionally, billions of tonnes of matter are hurled far out into the solar system at more than 500 kilometres per second. These coronal mass ejections (CMEs), if travelling towards the Earth, can have dramatic consequences for both humans and electrically-based systems.

Vital space systems are first in the firing line because the high-radiation environment generated by CMEs can disrupt – and sometimes completely destroy – satellite electronics. The harmful effects of extreme space weather are now a major consideration in operating space-based communications and navigation systems (which are increasingly important). This radiation is also very dangerous to astronauts leaving the protection of Earth's magnetic field, and thus critical to plans for human space exploration.



The Earth's magnetic field (blue) helps protect us from the solar wind.

Cameras built in the UK (at RAL) have been key instruments in the success of NASA's Solar Dynamics Observatory. This is the first SDO image, taken on 30 March 2010.

UK RESEARCH

UK scientists and engineers have been playing a leading role in space-weather research, from scientific studies of the solar surface and solar wind with space observatories such as the incredibly successful SOHO and the twin STEREO missions, to looking at changes in the terrestrial magnetosphere with the Cluster satellites (funded through the ESA). Ground-based radar systems such as EISCAT and SuperDARN have been used to study effects in the upper atmosphere. Teams also work on modelling space-weather phenomena, in an effort to improve our ability to predict adverse events and understand how a solar outburst will affect the Earth.

The radiation-proof cameras for the STEREO telescopes were developed at the STFC Rutherford Appleton Laboratory. Now sold through spin-out company Orbital Optics, they are used in Earth-observation missions.

"We usually have no more than an hour's warning of unusual space weather"

Solar outburst means lights out

Even at the Earth's surface, large-scale infrastructures can be severely affected, creating life-threatening situations. A powerful solar outburst can damage power grids, leading to severe outages, as happened in Quebec in 1989 and Sweden in 2003.

Clearly, it is increasingly important to be able both to understand and predict the effects of major space-weather events. Over recent decades, space scientists have been investigating how solar storms are generated, how CMEs spread into space, and how they interact with the Earth's magnetosphere. CMEs take about three days to reach us, and although scientists can predict the general pattern, the complex interplay between CMEs and the Earth's magnetosphere means that at the moment we usually have no more than an hour's warning of unusual space weather.

Researchers are also studying more long-term changes in the Sun–Earth connection, to see whether, and how, the solar activity affects the climate and agriculture – a little-understood consideration in the global-warming debate.

THROUGH A GRAVITATIONAL LENS DARKLY

CAREERS

Cosmologist Sarah Bridle maps dark matter and dark energy in the universe.

Recent observations have dramatically changed our view of the universe and its structure. Large amounts of invisible dark matter and mysterious dark energy appear to control what the universe looks like and how it is evolving. This is what fascinates Sarah Bridle, a member of the recently formed cosmology group led by Ofer Lahav at University College London (UCL). She explores how to map dark matter using a phenomenon called gravitational lensing, whereby the light from distant galaxies is warped by the gravity of intervening matter, giving them a distorted appearance to observers on Earth. She developed a computer code that analyses how their apparent shape is affected by foreground material, in particular dark matter.

Sarah sees gravitational lensing as a key tool in cosmology: "We aim to crack the problem of measuring gravitational-lensing distortions to the highest possible precision. This should let us unleash its full potential as a probe of the dark energy that seems to dominate the cosmos and yet about which we know almost nothing."

Sarah has always been interested in astronomy. While at school in Gloucestershire, her physics teacher supported her nascent interest in the wider universe, recommending evening classes run by an "inspiring" lecturer from the University of Bristol. She went on to do a degree in natural sciences at the University of Cambridge, where she excelled, winning five prizes and graduating with first-class honours. A PhD at the Cavendish Laboratory in Cambridge followed, on statistical methods to analyse and understand the structure and expansion rate of the universe.

Early success

Sarah then took up a postdoctoral position at the Laboratoire d'Astrophysique in Toulouse, France in 2000, with a European fellowship to work on gravitational lensing. A year later, Sarah returned to Cambridge, to the Institute of Astronomy, where she began a Royal Society Research Fellowship. Since 2004, Sarah has been a lecturer at UCL. Her early achievement has been recognized through several prizes, including the Fowler Award of the RAS in 2009.

At UCL, Sarah led an international team that put the galaxy-shape measurement problem to computer scientists. To further this, she now holds a European Research Council grant of €1.4m, and has assembled an interdisciplinary team to take it forward, collaborating with the UCL Centre for Computational Statistics and Machine Learning.

Sarah currently works on ground-based projects including the Dark Energy Survey, and space missions including the ESA Euclid observatory. This will launch in 2017, and will use images of the entire sky to map the large-scale distribution of dark matter and dark energy. Sarah obviously relishes the challenge of these demanding projects: "I thoroughly enjoy the collaborative nature of scientific research and love being a part of the endeavour to understand our universe."

"I thoroughly enjoy the collaborative nature of scientific research"

Sarah recently had her first child, and understands the challenges of maintaining a sensible work–life balance, juggling research with the demands of being a new parent. Earlier that year she led a workshop on "Work–life balance in astronomy", funded by a L'Oréal–UNESCO UK and Ireland Fellowship for Women in Science. ■

FROM COSMOLOGY TO OIL PRODUCTION

CAREERS

Colin McGill found that astrophysics research provides just the training industry needs.

Colin McGill (right, wearing a hat) outside the recording unit for the Bourarhet seismic survey in the southern Sahara, just west of the Libyan border. A new technique, whereby the seismic signals (created by trucks with large vibrating plates) can work independently, allows the collection of seismic data four times as efficiently as conventional techniques.

Research into "big problems" in astronomy attracts the very brightest people, as the profile on page 15 shows. However, it also provides an excellent training for solving difficult problems encountered in commerce. The energy industry is a typical example: the exploitation of fossil-fuel reserves, for instance, may require the same advanced mathematical techniques used to solve astrophysics problems. This is what Colin McGill discovered when applying his computational skills, developed during research in theoretical cosmology, to his future job in oil and natural gas production.

Following a degree in natural sciences at the University of Cambridge in the early 1980s, Colin pursued a doctorate in cosmology at the University of Oxford, investigating the large-scale structure of the universe. He developed a model for the so-called Lyman-α forest – the complex pattern of spectral absorption lines characterizing intergalactic hydrogen gas, which carries information about the light absorbed from distant, background galaxies. Colin then took a two-year post at the Canadian Institute for Theoretical Astrophysics in Toronto, before returning to Oxford. Newly married by that time, he decided to move out of academia, although he remains enthusiastic about his doctoral and postdoctoral work to this day.

Universal mathematical models

Colin joined BP's IT department in London. Within six months the department was outsourced, at which point he considered becoming a lecturer at QMC, but noticed that the company was looking for scientific programmers and so took up one of these posts at BP's Sunbury-on-Thames office in Middlesex. He explains: "To my surprise, the work I had been doing as a cosmologist turned out to be incredibly useful in my new role. The mathematical model that BP used for predicting how oil flows employs very similar techniques to those used to try to understand the universe. Put simply, the mathematics employed to characterize the distribution of galaxies are exactly the same as those required to describe the distribution of sand bodies. They are of vital importance for predicting how oil will flow and how much can be recovered."

In the 1990s, Colin became a reservoir engineer, working in BP operations as far afield as Alaska, Texas, Colombia and Norway. After spells in Australia and China, he is now based in the UK and has risen to become Director of Appraisal for North Africa, leading a team of 170 people shaping a multi-billion-dollar gas development in Algeria.

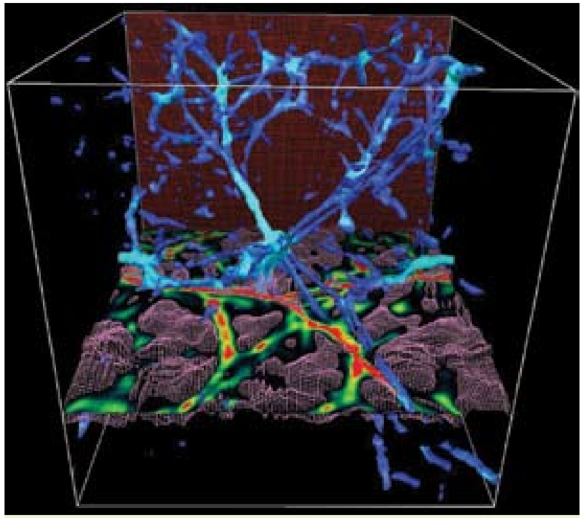
Industry wants postgrads

Colin adds that a postgraduate in astronomy can be exactly the kind of person that his industry wants: "People with an academic 'blue skies' background enjoy finding out new things and like getting to grips with new challenges. We recognize that their flexibility and intellectual calibre make them stand out from the general population. They are highly numerate, think logically and can see their way through complex arguments. When you have a PhD you also tend to have tremendous confidence."

Interestingly, he sees his training in cosmology reflected in his current role: "My real strength is in 'big-picture' strategic thinking and you can't get a much bigger picture than the whole universe!" But other PhD graduates are good at detail and complement the 'big thinkers'.

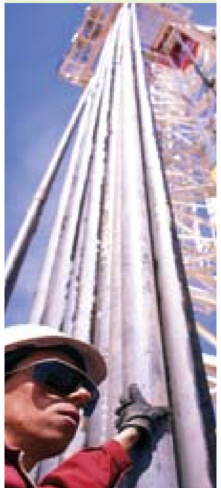
"For a good team, you need a mix of people. We need the best possible people and in many cases blue-skies scientific researchers are exactly that."

"The model BP used for predicting oil flows employs similar techniques to those used to try to understand the universe"



Large-scale structure in the Lyman-α forest (see text at left). According to current models of the formation of large-scale structure in the universe, the Lyman-α forest, which traces the tenuous material between galaxies, is the remnant of the gravitational processes that shaped the filaments and sheets of material that make up the present-day cosmos.

A BP rig, drilling for gas in Algeria.



ADAPTING TO CLIMATE CHANGE

CAREERS

***Pete Newman** found his training in astronomy invaluable when working on climate change policy.*

After leaving school with A-levels in 1972, Pete Newman spent 20 years in the computer software industry, working his way up from trainee programmer to project leader. However, by the late 1980s he was plotting how to advance his amateur passion for astronomy, and soon realized that the only way to do it properly was to leave work and go to university.

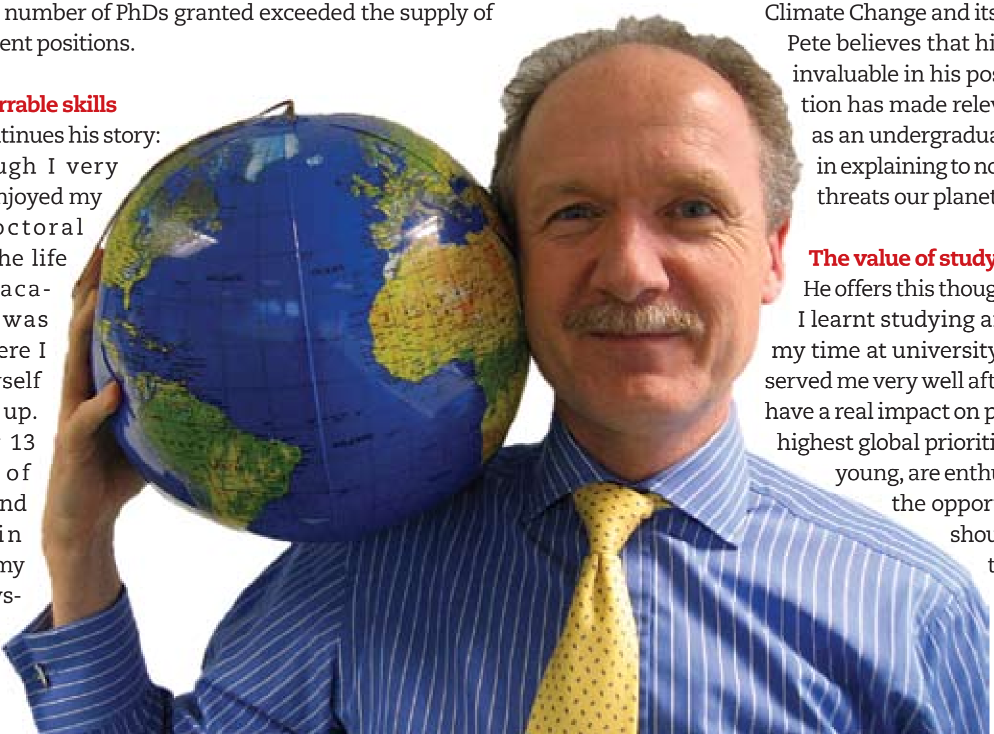
Pete took a BSc in astronomy at University College London in 1995. Delaying his plan to return to the computer business, he decided to pursue his passion a little longer and went on to do a PhD at the University of Central Lancashire, researching in observational cosmology, working on a survey of quasars (distant, very active galaxies).

He then worked on the Sloan Digital Sky Survey at the Apache Point Observatory in New Mexico and stayed there until 2005. Pete describes his time there as “wonderful”, but decided to leave astronomy, as he had long realized that the number of PhDs granted exceeded the supply of permanent positions.

“If students are enthusiastic about astronomy and have the opportunity to do a PhD, they should go for it”

Transferrable skills

Pete continues his story: “Although I very much enjoyed my postdoctoral work, the life of an academic was not where I saw myself ending up. But my 13 years of study and work in astronomy and physics had given me strong transferrable skills including formal analysis, mathematics, modelling and simulation, working with noisy and incomplete data and communicating technical information. I found it easy to transfer those skills into a new career in operational research and, in 2005, I joined the Government Operational Research Service to work in what is now the UK Border Agency.” At the UKBA Pete was quickly promoted and by 2007 he was the co-leader of a 12-strong team delivering modelling, forecasting and analysis.



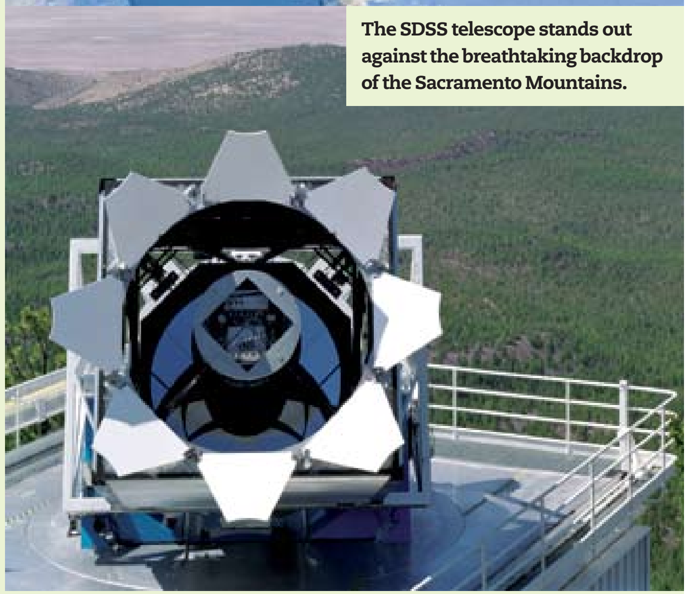
Just recently, he has moved to join the evidence team in the Adapting to Climate Change programme in Defra (Department for Environment, Food and Rural Affairs), where he leads the science strand and runs a multidisciplinary team. Pete’s formal scientific training enables him to work closely with climate scientists at the Met Office Hadley Centre and elsewhere. He also works with the independent scientific advisers in the Committee for Climate Change and its Adaptation Sub-Committee.

Pete believes that his training in astronomy has been invaluable in his post-academic career: “My new position has made relevant the planetary science I learnt as an undergraduate, and this has helped me greatly in explaining to non-scientists the nature and scale of threats our planet faces from climate change.”

The value of study

He offers this thought on his training: “The techniques I learnt studying and working in astronomy during my time at university, and then at Apache Point, have served me very well afterwards. They are now helping me have a real impact on policy in climate change, one of the highest global priorities. If students, whether mature or young, are enthusiastic about astronomy and have the opportunity to pursue a PhD, then they should go for it. Even if they move out of the field, their training is respected and valued by employers across the whole economy.” ■

Climate change is causing loss of sea ice in the Arctic.



The SDSS telescope stands out against the breathtaking backdrop of the Sacramento Mountains.

MAKING GOVERNMENT POLICY WORK

CAREERS

After studying distant galaxies, Pippa Goldschmidt now advises the Scottish Government on energy, as well as writing science-based fiction.

Good analytical skills are important in any field involving managerial responsibilities, especially in government. Pippa Goldschmidt has certainly found this to be true in her role as a government policy adviser – which often requires commissioning quantitative research and understanding the complex statistical data it produces.

Having studied physics with astronomy at the University of Leeds in the 1980s, and then done a PhD in astronomy at the University of Edinburgh followed by postdoctoral research in London, Pippa wanted to move on to a different career. The Civil Service appealed to her, as it offered a variety of roles for candidates with scientific backgrounds. Accepted into the Fast Stream graduate-training programme, Pippa started out in the British National Space Centre (BNSC), developing space policy for the then Department for Trade and Industry (now the Department for Business Innovation and Skills).

As she expected, and wanted, she quickly moved around, working on primary legislation for Westminster and advising Alan Johnson in his first ministerial role.

Problem-solving skills

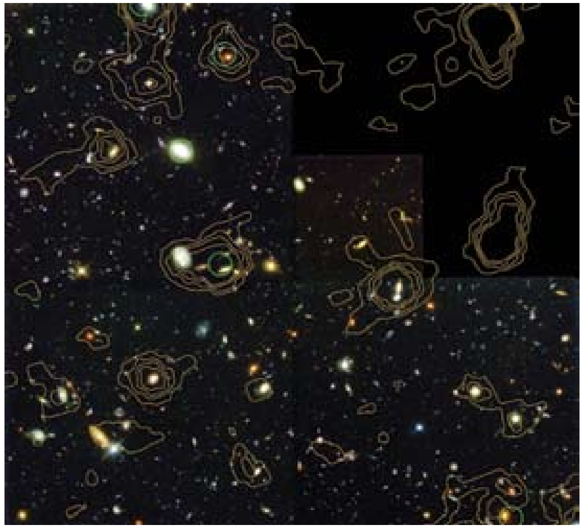
Pippa explains how her background proved invaluable in her job: "For legislation to work, it needs to be robust. And that demands sharp problem-solving skills and the ability to express ideas concisely. Those are things that featured throughout my time as a researcher. In fact it would have been pretty difficult to complete a PhD without them. In policy work, you first have to define the problem, then find the best way to solve it, all the while remaining open-minded about the solution and being able to challenge assumptions. This independent thought is something you develop during a research career, particularly in a blue-skies subject like astronomy."

During her doctorate, Pippa investigated quasars – distant galaxies with highly luminous centres containing giant black holes. She used big photographic plates to survey a large area of the sky, to find quasar "candidates". Using spectrographs on UK telescopes in the Canary Islands and Australia, she also analysed their spectra, allowing her to confirm their identities and measure their distances. She then took up a postdoctoral post at Queen Mary, University of London and later at Imperial College London, studying galaxies using the ESA Infrared Space Observatory.

Pippa also likes to use her scientific knowledge in her second interest: writing. Leaving the DTI in 2004, she went to work for the Scottish Government on social policy, concentrating on legislation to tackle homelessness, and later took an MLitt degree in creative writing at the University of Glasgow. She then took a career break to be writer-in-residence in the Genomics Forum at the University of Edinburgh. Although Pippa later returned to a research-intensive role in the Scottish Government to work on offshore energy policy, she continues her writer's residency, and runs workshops on using fiction to examine aspects of science. She is also working on a novel about a female astronomer. "I love being able to use my scientific background in both my 'day job' at the Scottish Government as well as in a more creative way through writing fiction," she says.

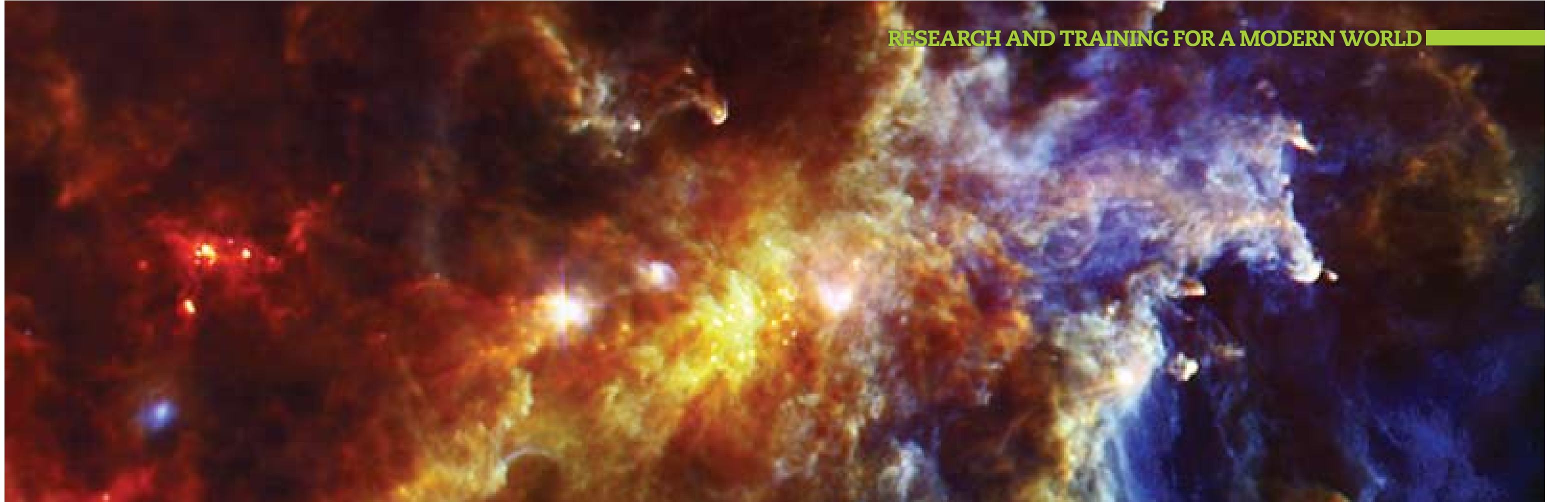
"I love using my scientific background in my day job as well as in a creative way through writing"

The Scottish Government building in Leith, near Edinburgh.



An image of distant galaxies, made using the ISOcam instrument on the Infrared Space Observatory.

Starbirth in the clouds. This infrared image from the Herschel Space Observatory shows dust associated with the Rosette nebula, about 5000 light-years from Earth. The bright smudges are dusty cocoons containing massive embryonic stars. The small spots near the centre are lower mass stellar embryos. The Rosette nebula itself, is located to the right.



RISK, UNCERTAINTY AND INTERSTELLAR SHOCK WAVES

CAREERS

Mark Malone found that studying the dynamics of star formation provided all the right skills for a career as an actuary.

The job of an actuary – assessing the financial impact of risk and uncertainty – may seem far removed from that of an astronomer trying to understand the processes leading to star formation, but both involve data analysis and modelling. This is why Mark Malone decided to use his astronomy training to pursue a career as an actuary. He says: "I greatly enjoyed my time as a postgraduate but by the end of my PhD I wanted to pursue a different challenge. When I looked around, I realized just how valuable my skills were. And even better, as an actuary, dealing with the financial impact of risk and uncertainty, I could apply my talent for theoretical modelling to the business world."

Born in Edinburgh, Mark completed a degree at the University of Edinburgh before going on to a PhD in astrophysics at the University of Manchester in 1990. There, Mark looked at the dynamics of the supersonic molecular hydrogen that makes up much of the clouds of gas and dust where stars are forming. Supersonic flows usually result from the passage of a shock wave through the clouds and would normally disrupt molecular gas. Mark's research investigated the gradual acceleration of molecular hydrogen in turbulent layers between supersonic emissions from newly forming stars and the dense pockets in the material between them, the so-called interstellar medium.

"As an actuary, I could apply my talent for theoretical modelling to the business world"

Life in insurance

In 1994, Mark joined Coopers & Lybrand, now PriceWaterhouseCoopers, to train as an actuary in the area of general (non-life) insurance. He worked with many clients in the London international insurance market including Lloyd's of London, Aviva and European and US insurance carriers. His ability was recognized by headhunters, who in 2004 persuaded him to move to run the London office of Aon's actuarial team. Aon is the largest insurance brokerage business in the world. There, Mark works with a diverse range of clients, not only in the insurance industry but also multinational corporations, governments and local authorities. All of these clients share a need for rigorous assessment and clear advice on the risks they manage.

Mark sees his PhD training as being incredibly helpful in his actuarial career. "Both scientific research and actuarial work require you to be comfortable with data-analysis and problem-solving. And an expert understanding of probability and statistics is essential too – bread and butter for theoretical astrophysicists. PhDs develop very specific qualities in people. When you tackle a problem you are often unsure about the method you need to use to solve it and in many cases have to develop this as you go along. That ability, to create bespoke models to solve non-standard problems, is exactly what our clients demand."

Interdisciplinary subject

Mark also believes there are specific benefits that follow study in astronomy: "It is very much an interdisciplinary subject, drawing on topics in physics, chemistry and mathematics. As an actuary, I quickly need to become familiar with a diverse range of areas too – from medical data to specialist points in law, to the trajectories of aircraft. I genuinely believe my background in a blue-sky discipline like astronomy has been a fantastic preparation for my subsequent career. Once you've done a PhD, you're set up to tackle challenges wherever you end up."

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About the RAS

The RAS, founded in 1820, encourages and promotes the study of astronomy, solar-system science, geophysics and closely related branches of science. The RAS organizes scientific meetings in Burlington House, its London HQ, and throughout the country; publishes international research and review journals; recognizes outstanding achievements by the award of medals and prizes; maintains an extensive library; supports education through grants and outreach activities; and represents UK astronomy nationally and internationally. Its nearly 3500 members (Fellows), a third based overseas, include scientific researchers in universities, observatories and laboratories as well as historians of astronomy and others. Its central London premises are available for use by its Fellows and others.

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