BEYOND THE STARS: WHY ASTRONOMY MATTERS

Royal Astronomical Society · Quicquid nitet notandum · 1820

Advancing Astronomy and Geophysics

DISCOVERY • EDUCATION • APPLICATION • IMPACT

Science & Technology Facilities Council

BEYOND THE STARS
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Cover:
ALMA dishes under the spectacular skies of the Atacama Desert, Chile. World-class research demands technological advances that, in turn, bring economic and social benefits.

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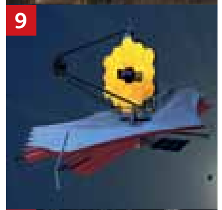
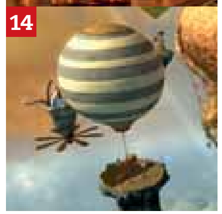




FROM THE PRESIDENT OF THE ROYAL ASTRONOMICAL SOCIETY

My working life has been in the space business. I strongly believe that astronomy and space science drive innovation and work as a mechanism for rebalancing and growing our economy. I started my career in space physics and for more than a decade was the Head of Science for the European Space Agency. Throughout my career I have been involved with discoveries about the universe, but I've also had the opportunity to see how ideas and technologies that arose from astronomy have moved into everyday applications that make our lives safer, easier and a lot more fun.

One of my predecessors as President of the Royal Astronomical Society, Sir William Herschel, discovered infrared radiation while looking at the spectrum of light from the Sun. His work was the bluest of "blue skies" research and yet from that came so many uses of infrared technology in everyday life: remote controls, weather satellites and in cameras that image body heat, to name but a few.

I came into this field because I was curious about space. That curiosity and wonder are fundamental to science. There's such a lot to find out about: What makes our planet different from the others in the solar system? Are there planets like Earth around other stars? How does the Sun affect our lives? What drives the tremendous energy flows in giant galaxies? What are the mysterious dark matter and dark energy that form most of the universe? We have some answers to these questions, but by no means all, and it is this sense of intellectual adventure that drives many of our successful researchers.

The potential for discovery also draws people into the subject, and in the process they are inspired to learn about the science, technology, engineering and maths (the so-called STEM subjects) that set them up for careers in the technical subjects that the country needs for its future prosperity. Some of those young people will go on to lead the world in research, as part of a community whose research success is measured as second only to the United States. They will do this through innovative theoretical ideas, by building instruments for the great telescopes and space missions of the future, and through international collaboration with their peers worldwide.

But many of them will discover skills and talents that they can bring to industry and business. I am very pleased to be President of the RAS and to represent the many strands of astronomical expertise in our community, but I am also inspired by the uses of our research in so many fields, from medicine to environmental monitoring, financial markets and preserving our cultural heritage. I hope that, by reading this booklet, you will find the current progress in astronomy and its impact on wider society as exciting and inspirational as I do.

"I hope that, by reading this booklet, you will find the progress in astronomy and its impact on wider society as exciting and inspirational as I do"

David Southwood

Prof. David Southwood
President of the RAS, 2012–2014

WHAT HAS ASTRONOMY EVER DONE FOR US?

Humans have always gazed upwards and wondered at the beauty and complexity of the night sky. But now the study of astronomy benefits culture, education, health, business and technology in the UK.

Go outside on a clear evening, away from the lights of the city and the streets, and you can see for yourself the glories of the night sky. Watch regularly, and the calendar shows itself as the Moon waxes and wanes and the constellations change through the seasons. This is what inspired our distant ancestors – astronomy has a good claim to be the oldest science – and still inspires creative and scientific minds today. Harnessing astronomical understanding for navigation led to commercial success in the 18th and 19th centuries; the subject continues to draw in intelligent and curious young people, who go on to world-leading roles in research and into industry, bringing advanced technological skills into the commercial marketplace.

Astronomy now covers a huge range of topics, from how the universe began and evolved into what we see today (pages 5 and 10), right up to the search for planets that might support life (pages 8 and 9). It involves the exploration of the unknown: the origin of the dark energy that is accelerating cosmic expansion is unknown, as is the composition of invisible dark matter, which together dominate the dynamics of the universe. The universe we see directly is only a small component of what is really out there.

It is not surprising that children are fascinated by the sheer scale and strangeness of the universe. 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*, 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 that are used by professional astronomers. Teachers in physics, chemistry and maths can then channel children's enthusiasm for planets and black holes into active learning related to the school science curriculum.

▲ **Seeing the light: stars amaze, intrigue, inspire and educate.**

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

Providing a skilled workforce

At university, astrophysics research attracts some of the strongest physics graduates. It equips PhD students with the kind of training demanded by industry, business and other economically important sectors (pages 15–19). Modern astronomy, like global commerce, involves working in international teams on large-scale projects, often involving tremendous volumes of data. Students develop good management as well as strong analytical (mathematical and computational) and engineering skills. And the enthusiasm for astronomy that drives so many researchers fosters excellent communication 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 and innovative detectors (pages 5, 10 and 14). They also bring in almost unthinkable amounts of data, demanding advanced hardware such as supercomputers and sophisticated software to make the information accessible to researchers (page 6). These methods have applications in a range of business and technical areas such as environmental management and national security. Specialized instruments provide a testbed for novel materials and techniques which find use in industry or in the health sector (pages 12 and 14).

Popular culture

Astronomy, cosmology and space science address the big questions about the nature of existence, exciting the public imagination in the process. Its concepts and imagery saturate popular culture, from toys and computer games to fashion. Although astronomy 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; the National Space Centre in Leicester welcomes 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. Astronomers have exploited the internet to engage people further and involve the public in front-line research through projects such as Galaxy Zoo.

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. ■

SOMETHING NEW UNDER THE SUN

UK scientists are at the forefront of solar system exploration, using magnetic fields, biotechnology and games to explore our neighbouring planets and moons.

Space exploration is an expensive business that demands international collaboration. In Britain, the UK Space Agency coordinates collaborations through the European Space Agency (ESA) with NASA and countries such as India and China. Planetary exploration has focused on Mars, Venus and Saturn, together with Saturn's intriguing moon Titan. UK scientists and engineers take leading roles, for instance by designing specific instruments such as magnetometers, and hosting data centres. This national expertise has been recognized in UK roles on the forthcoming European JUICE mission to Jupiter and its moon Ganymede, led from Imperial College London.

UK researchers have been exploring Mars and Venus, contributing to two ESA spacecraft that have a common design and several identical instruments – an economical approach that paid off in terms of data about the surfaces, atmospheres and climate of our neighbours. The UK-led Huygens lander, carried for eight years to Saturn in the ESA–NASA Cassini mission, touched down on Titan in January 2005, discovering an icy landscape of rivers and lakes under the thick nitrogen atmosphere. Cassini's magnetometer, developed and built by a team led from Imperial College London, revealed surprises about Saturn's magnetic field – and that something odd was happening at the small moon Enceladus. Here Cassini discovered plumes of water droplets coming from rifts in its icy surface and falling back like snow. Enceladus and other icy moons appear to have subsurface oceans of water, making them prime targets in the search for extraterrestrial life.

Smaller, lighter, tougher

A strength of British space science has been the transformation of instruments such as mass spectrometers into forms suitable for missions to Mars. Spectrometers that identify characteristic "fingerprints" of atoms and isotopes in labs on Earth are large, massive and delicate; development by groups at the University of Leicester and the Open University has produced instruments the size of a shoebox, that weigh less than half a kilogramme and are robust enough to meet the stringent demands of spaceflight. They don't use much power, either: UK researchers are working on a spectrometer for the forthcoming European and Russian ExoMars mission, for example, that uses a thousandth of the power of an incandescent lightbulb (0.1W) and has a mass of 300g, just a bit more than a packet of butter. UK researchers have also investigated the application of techniques developed in biotechnology. The Life Marker Chip will work a bit like a pregnancy test, using antibodies to detect specific molecules that indicate life.

Game for an autonomous Mars rover?

Autonomous vehicles that can navigate for themselves over unknown ground become increasingly important the further from Earth we explore, because of the time gap in telecommunications. They demand fast 3D mapping of the unknown terrain – a technique with many applications on Earth. For Mars, researchers at Astrium are developing software to allow a rover to assess the terrain in front of it and plot a route to its goal, testing it out on their own analogue martian landscape – Mars Yard – in Stevenage.

UK researchers are also involved in getting the most out of the data already gathered from Mars, for example by finding new ways to use it. One approach developed at University College London is to use surface data to generate immersive 3D maps of the surface for future autonomous rovers. Computer games offer sophisticated software designed to make players feel as if they inhabit the landscape; applying these techniques to existing imagery of the martian surface lets scientists approach it as they would examine the surface of the Earth. ■

"Exploring the solar system requires patience, because of the distances involved"

Plumes of water vapour from Saturn's moon Enceladus suggest an ocean of water beneath the icy crust of this moon, which may harbour extraterrestrial life.

A rover in Mars Yard, Stevenage, where Astrium is working with researchers to develop autonomous guidance systems that could work in hostile environments such as mines.

At Boulby Mine in the UK there is a unique collaboration between the mine operator Cleveland Potash Ltd and space scientists. Technology developed for space exploration, such as autonomous robots, could make mining safer by exploring dangerous underground environments.

INTO THE UNKOWN

The most exciting parts of science are the things we don't know. Astronomers seek the unknown through innovative instruments that push the envelope of engineering – such as the Square Kilometre Array – and, in turn, drive new systems and communications technology for the big data industries of the future.

▲ **Artist's impression of the SKA array of dishes, to be built on remote desert sites in South Africa and Australia.**

The Square Kilometre Array is just that: an array of radio receivers that combine to form the equivalent of a radio dish a square kilometre in area. It will be the world's largest and most sensitive radio telescope. Its size – 100 times bigger than any radio telescope today – and the range of frequencies that it can detect will make the SKA a game-changer for radio astronomy. And the SKA headquarters are here in the UK, bringing commercial opportunities to our doorstep. UK science and industry are combining to develop new methods of data transport and handling and efficient power use through the development of this new-generation radio telescope.

SKA will start work in 2024, addressing fundamental problems in the evolution of the universe, such as how gravity and magnetism work on a cosmic scale, the origin of the accelerating expansion of the universe driven by the mysterious dark energy, the processes that formed the first stars, and even the formation of the complex molecules that – somehow – combine to create life.

UK radio astronomy has been built on pioneering instruments such as the Lovell Telescope at The University of Manchester's Jodrell Bank Observatory. But SKA will not look at all like that iconic telescope dish. It will be an array instrument that combines data from various technologies, including 3000 radio dishes, each 15 metres across, and hundreds of thousands of innovative smaller detectors that boost the field of view of the array and give the project as a whole the sensitivity and resolution to look at the universe in new ways. The sensitivity – 50 times better than today's instruments – and the fact that it will be able to survey the sky 10,000 times faster – mean that the array will be able to examine diverse astrophysical environments, from black holes and pulsars to organic molecules in interstellar space.

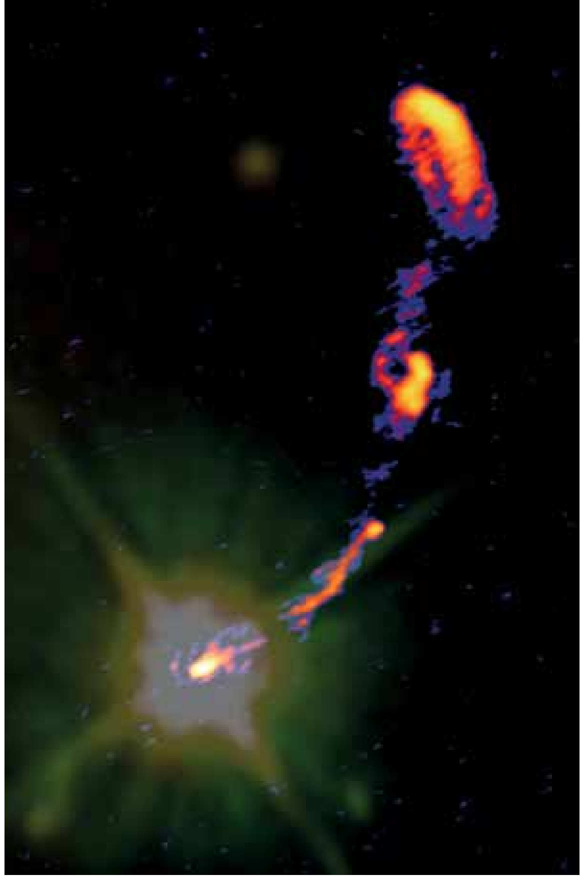
The SKA is a truly global project. The instrument arrays will occupy two sites, in Australia and Southern Africa, while the international headquarters are now at Jodrell Bank Observatory, recognizing UK expertise and leadership in radio astronomy. At present the project is in a detailed design phase before construction starts in 2017. SKA Precursor and Pathfinder projects are already underway, testing and evaluating different approaches to the challenge of such a vast and powerful instrument.

Big data

SKA will challenge current methods of data storage, transmission and processing. The data network that will be built for the SKA will carry around 100 times the current global internet traffic. The development of techniques to transport and process these vast amounts of data will find applications in many other areas that work with data-rich sources, from managing financial markets to meteorology. A major step-up in national and international network infrastructure is required and UK organizations will be involved, together with European partners.

The STFC is working to support the development of the project through formal consortia between industry and academia, with special emphasis on driving innovation in information and communications technology and in signals processing. The SKA's huge arrays will operate in remote desert areas and this iconic project will pioneer high-tech equipment running at low power, with practical economic and social benefits to the UK.

The transformation of radio astronomy expected from the Square Kilometre Array will not take place without several Pathfinder projects worldwide, designed not only to test technologies and approaches but also to carry out important science tasks in themselves. UK involvement builds on a strong research base in radio astronomy. The Lovell Telescope, for example, is part of a major UK network and SKA Pathfinder called e-MERLIN. This combines signals from seven telescopes spread over 217 km producing extremely sharp images of the radio sky. A dedicated optical-fibre network brings 210 Gb of data each second from



The Double Quasar was the first gravitational lens to be identified. This composite e-MERLIN/Hubble Space Telescope image shows radio emission from a jet arcing away from the black hole at the heart of the quasar (bottom). The jet is more than ten times the size of its host galaxy.

the telescopes to a powerful supercomputer at Jodrell Bank. This synchronizes the data at the level of a million-millionth of a second, carrying out one peta operation per second. The telescope array is now working on a programme of 12 legacy projects involving 300 astronomers from the UK and across the world. e-MERLIN also works as part of a larger European network of telescopes, making the most of the UK's considerable investment in high-speed data links and software. Building on e-MERLIN, The University of Manchester is leading a consortium involving industry working on signal transport and data synchronization for the SKA.

At lower frequencies, the UK has a stake in a Europe-wide project that includes a station in the UK, at Chilbolton: LOFAR, the Low Frequency Array. This is a radio telescope using thousands of simple radio receivers at low frequencies with the signals combined through software to act as a huge and sensitive radio telescope. Rather than using the steel infrastructure of conventional radio dishes, LOFAR is an IT telescope, built from electronic receivers, as much of the SKA array will be. And, in line with Moore's Law, these electronic components should become cheaper with time. Both LOFAR and e-MERLIN are collaborations between researchers in universities across the UK, as well as the STFC's Astronomy Technology Centre and Rutherford Appleton Laboratory.

"Radio observations are affected by ionospheric jitter, like the atmospheric variations that make stars twinkle"

At the low frequencies of LOFAR the data are affected by the changing ionosphere – the region rich in charged particles in the upper atmosphere. The effect, called ionospheric jitter, is a bit like heat haze on a hot day or the twinkling of stars; different parts of big arrays see different amounts. LOFAR's software and computing power are such that images of very wide fields can now be created and processed on short enough timescales to monitor and correct for the ionospheric jitter.

Down to Earth technology

SKA is an example of the way that the drive to grasp the unknown will bring tangible economic and social benefits – some foreseeable, others so far unthought-of. A new generation of high-speed networks, data analysis software and efficient power sources will enable UK business to be at the forefront of big data industries in the future. Industry and research are collaborating from the beginning of the project, so the wider economic and social benefits of the SKA for the UK will be on the agenda from the very start. ■

GOONHILLY GETS UP-CYCLED

The iconic satellite communication site at Goonhilly Downs in Cornwall is getting a new lease of life as part of the UK's scientific infrastructure, a hub for satellite communications for the space industry and a centre for technical training, tourism and public outreach, where academia and industry come together.

This change arises from answering the question: what do you do with an old satellite communications dish? As optical-fibre technology takes over, dishes worldwide run the risk of rusting quietly away. But with relatively modest changes they can be used as radio telescopes, for satellite communications or for tracking deep-space missions.

This is what is happening in Cornwall. Goonhilly Earth Station (GES) is on its way to becoming a space science park with employment and training opportunities in the UK's increasingly valuable satellite and space industries. The space industry is booming in the UK, worth an estimated £7.5bn and with a growth of nearly 10% over the past decade. Future growth forecasts of between 5% and 7% per annum to 2020 make this a key area for the UK economy.

Goonhilly was home to the world's first satellite communications station, but the large antennas there have not been used since 2008. Now Goonhilly Earth Station Ltd is refurbishing and modifying the dishes to make them suitable for satellite operations, radio astronomy and tracking deep-space missions – giving the UK a new capability in this area – and establishing a centre for innovation, knowledge transfer and technical and professional training. A visitor centre to engage the public in satellite and space technology as well as astronomy is also under development. In 2012 the government approved a Regional Growth Fund award for GES, that will fund these objectives and transform the site.

Goonhilly antenna GHY3 before the refurbishment that will bring it back to life as a useful part of Goonhilly Earth Station.

GES is already operating a satellite teleport at Goonhilly, working closely with companies such as British Telecom, providing satellite control and monitoring for SES ASTRA, and developing deep-space communications with QinetiQ.

CUGA, the Consortium of Universities for Goonhilly Astronomy, is working with GES to realize the scientific potential of the Goonhilly dishes – for both university teaching and research – through links to the UK's e-MERLIN radio interferometry network.

Goonhilly Earth Station offers an environment in which academia and industry can interact to mutual benefit, and where training of the skilled workforce that the UK needs can take place. There will be opportunities for technical posts and apprenticeships in the space science park envisaged by GES, where the combination of a high-level technical workforce with a visitor centre offers a real boost to employment prospects for the people of Cornwall.

FINDING STRANGE NEW WORLDS

Twenty years ago we knew of no other stars with planetary systems. Now astronomers have found planets orbiting hundreds of stars in the Milky Way, and confidently expect to find many more, thanks to innovative telescopes and clever data analysis.

In the past 20 years, planets around other stars (exoplanets) have moved from science fiction to science fact, with more than 800 found and more identified every week. The US Kepler mission, a space-based telescope, has found thousands of candidate planets orbiting other stars, and as their observations proceed, many of these will be conformed as discoveries. Exoplanets exist in multiple systems like – and unlike – our own Sun and planets. Some estimates suggest that there are more planets than stars in our galaxy, that many of these worlds are habitable and some of these may even harbour life.

Finding exoplanets pushes telescopes to their very limit and astronomers have devised three techniques to detect their existence:

- When a planet like Venus passes between the Earth and the Sun, we see it as a black dot crossing the face of the Sun; this transit dims the light from the Sun very, very slightly. Repeated measurements of the dimming of other stars as their planets transit – a drop of a thousandth of the star's brightness or less – is one way to find exoplanets.
- Telescopes can also pick up the slight back-and-forth wobble of a star caused by the gravitational pull of a planet in orbit around it. The maximum speed in this movement amounts to no more than a few metres per second, but leads to a subtle corresponding shift (known as the Doppler effect) in the lines that appear in the spectrum of a star.
- Massive planets can also be detected because of the way their gravity distorts spacetime and so bends light from more distant stars. The effects of planets are small compared to that of stars and galaxies, so the technique is called gravitational microlensing.

UK astronomers lead in all three methods, with an especially strong record on giant exoplanets orbiting close to their stars. In 2011 they were part of the team using the HARPS spectroscope on the Very Large Telescope at the European Southern Observatory that found a planet with roughly the mass of the Earth orbiting a star in the Alpha Centauri system. Since this is one of the nearest stars to the Sun, its exoplanet is the closest yet detected.

▲ **Background image: artist's impression of the nearest known exoplanet (left) orbiting the star Alpha Centauri B.**

UK – a hive of activity

Another consortium of UK researchers, SuperWASP, was a trailblazer in detecting planets from their transits, developing a dedicated instrument on a shoestring budget. Most telescopes are built to measure the brightness of a star to a precision of 1%; finding exoplanets requires a precision a hundred times better. As part of the development of SuperWASP, the team pioneered the production of ensemble telescopes, where several identical cameras are assembled to produce a powerful dedicated instrument – a new and cost-efficient way to collect these high-precision data. And SuperWASP had at its heart the biggest non-proprietary database in the world at the time, with the University of Leicester developing pioneering software to make the most of it for research. As a result, the UK now has several world-leading research groups tackling aspects of exoplanetary systems such as the composition of their atmospheres.

UK researchers are building on this success to work with the European Southern Observatory on the Next Generation Transit Survey. This will be an ensemble telescope too, dedicated to finding transiting planets the size of Neptune and smaller – the super-Earths. It is a robotic system and the UK astronomers leading the team will use much of the transformational technology developed by SuperWASP. The system offers the possibility of determining what such planets are like: whether they are rocky planets, whether they have water and what gases are in their atmospheres. This team, led by UK astronomers, has a good chance of finding signs of alien life on a planet around a distant star. ■

THE NEXT BIG THINGS

Astronomers are driving technological innovation in their quest for the furthest and faintest objects in the universe – and using it to protect people and society.

Astronomy is science at the edge – the edge of the universe, the edge of understanding and the cutting edge of technology. The investment required for the modern observatories that astronomers need – whether on the ground or in space – is so colossal that international collaboration is essential. International projects such as the European Extremely Large Telescope (E-ELT) draw together the best researchers in the world, including UK researchers not only as active members but also as leaders. With a main mirror almost 40 metres across, this new observatory under construction in Chile will be almost five times the size of today's world-class telescopes and demands considerable innovation in the instruments it will use – and the engineering challenges it poses. UK researchers are in leading roles in the design of instruments for the E-ELT and UK companies are bidding for the construction contracts. Zeeko, a precision grinding company based in North Wales, has produced prototype segments for the main mirror.

▲ **Artist's impression of the James Webb Space Telescope, due for launch in 2018 to replace the Hubble Space Telescope.**

◀ **JWST and MIRI will image the infrared sky using computer-based virtual assembly techniques, here applied to examine in detail the 1554 tomb of Thomas Howard, third Duke of Norfolk, as part of "Representing Re-Formation", an AHRC/EPSRC Science and Heritage Project.**

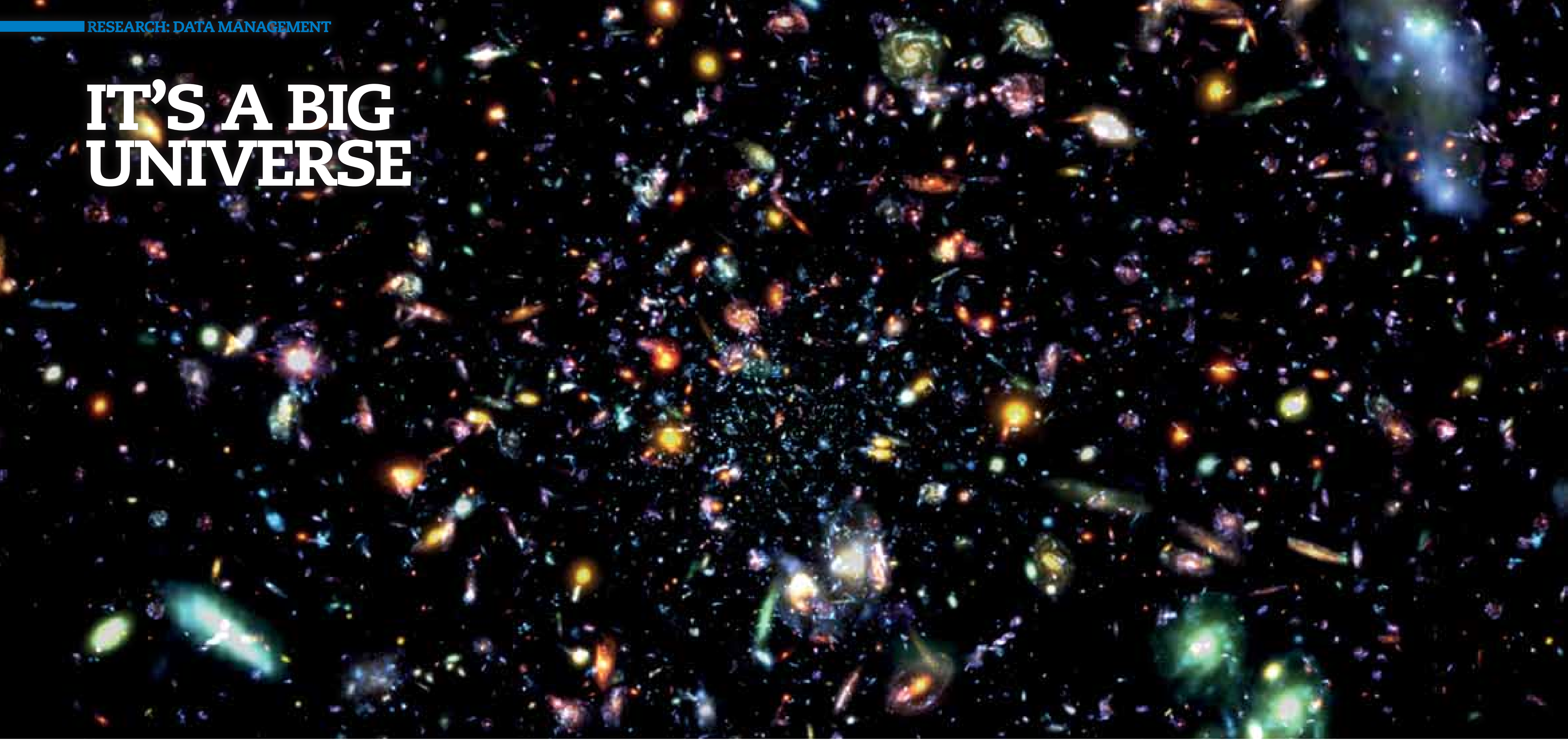
Telescopes need to get bigger because, broadly speaking, the larger the telescope, the finer the detail that can be seen with it. One way to do this is to combine signals from more than one receiver (a telescope or a radio dish, for example) in a technique known as interferometry. The blended signals work together as if they come from one huge telescope. 2013 saw the inauguration of the Atacama Large Millimetre Array (ALMA) in the high Atacama desert of Chile. This radio-frequency instrument combines signals from 66 dish antennas 12 and 7 m across, to act as the equivalent of a truly giant radio dish roughly 16 km across. The STFC's Rutherford Appleton Laboratory (RAL) at Harwell and the Astronomy Technology Centre (UK ATC) in Edinburgh have made major contributions to the success of this world-leading instrument. RAL Space, for example, built the cooling systems needed to keep the working parts of the telescopes at just 4° above absolute zero (–269°C). The UK ATC has provided software that observers use to propose uses for the telescope and to handle the data.

Instruments in space

Space-based instruments are also a key area for UK science. Researchers from the University of Cardiff led the consortium that developed the SPIRE instrument on ESA's Herschel Space Observatory, an infrared telescope that operated with great success for four years, 1.5 million kilometres from Earth. Infrared light – with just a bit longer wavelength than visible light – is essential for detecting gas, dust and molecules in space, and is an excellent tool for picking out what goes on when stars and planets form.

The world-class expertise at RAL, in the UK ATC and in UK universities has brought a steady stream of projects to the UK. One of the latest is MIRI, the Mid-Infrared Instrument, whose design and construction was jointly led from the UK, and will be one of four instrument on the joint US–European–Canadian James Webb Space Telescope (JWST). The JWST will take the place of the Hubble Space Telescope but it will be much bigger and more powerful, able to look back to the origins of the universe. MIRI will enable JWST to take images of relatively large areas of sky, continuing the tradition of stunning astrophotography established by the Hubble and other great observatories, bringing the awe and wonder of the universe into focus here on Earth. ■

IT'S A BIG UNIVERSE



▲ An image from the award-winning 3D film *Cosmic Origins*.

The universe is a big place. And the huge telescopes now trained on the skies are collecting ever more data, in ever more detail. Astrophysicists wanting to understand what they see have risen to the challenge by finding innovative – and useful – ways to manage the flood of information.

Modern telescopes and their associated instruments are huge – and produce huge amounts of data. For example, the VISTA camera developed by a consortium of UK universities and the Astronomy Technology Centre in Edinburgh, has a main mirror 4.1m across and is the equivalent of a 67-megapixel digital camera with a focal length of 13m! It produces up to 300Gb of data – 600 compact discs worth of music or 12,000 filing cabinets full of text on paper – per night. In its first five years of operation it is expected to collect enough data to map 5% of the observable universe in three dimensions.

Organization and management of these enormous datasets is vital for the success of such astronomical surveys, both in the research for which the data are collected and in open-access databases developed as the legacy of such projects. This wide dissemination of legacy surveys makes possible "citizen science" projects such as GalaxyZoo, and it also provides an invaluable resource for researchers tackling problems not imagined at the time of the original survey. Data mining wrings every drop of information out of astronomical observations.

The technical skills needed to manage data on this scale are portable. Spiral Software, winner of the Queen's Award for Industry in 2012 for its export success, is an example of a company whose product started out in astrophysics research. Mukund Unavane was a postgraduate student at

Data mining: ▶ techniques for extracting information from astronomical data can be applied to the oil business.

the University of Cambridge, working on the evolution of the Milky Way. Unavane was using data from ISOCam, the infrared camera on the European Space Agency's Infrared Space Observatory that flew in the late 1990s. He developed ways of linking the different sorts of data among the varied types of information present in the data – essentially statistical astrophysics. In 1998 he and fellow researchers in complementary disciplines set up Spiral Software to apply their understanding to the oil business. They developed software that informs decisions about oil production, refining and trading. The company now employs 60 people and deals with 85 companies worldwide, including major oil companies, offering a range of support services built on the core software business.

Visualization

One way to handle large datasets is to show the data as pictures. Astronomers have long appreciated the value of a good picture: visualization is a powerful way to understand and see patterns in complex information. Now that computers powerful enough to simulate processes such as star formation or galaxy evolution are available to researchers, this sort of modelling has become an integral part of understanding how the universe works. Modelling astronomical processes can demand powerful computers, and some of the biggest simulation projects – such as the VIRGO consortium, whose UK base is at the University of Durham – push at the boundary of what is possible with even the most powerful supercomputers. The Cosmology Machine, part of the DiRAC Facility jointly funded by STFC, the Large Facilities Capital Fund of BIS and Durham University, is one of the most powerful supercomputers in Europe.

VIRGO pioneered the use of supercomputer simulations to trace the origin of a cosmic web of galaxies. Their "cosmos in a computer" simulations emphasize the importance of the mysterious and invisible dark matter, thought to make up 23% of the universe, in forming the cosmos we see today.

The team at Durham has built on this success by making movies showing the evolution of the universe in their simulations. One of these, a three-dimensional tour of the formation of the universe called *Cosmic Origins*, won the Best Computer Graphics Film Award at an American industry conference in 2010, against competition from some of the biggest film studios in the world. ■

"Some simulations push at the boundary of what is possible with even the most powerful supercomputers"

SEEING THE WOOD FOR THE TREES

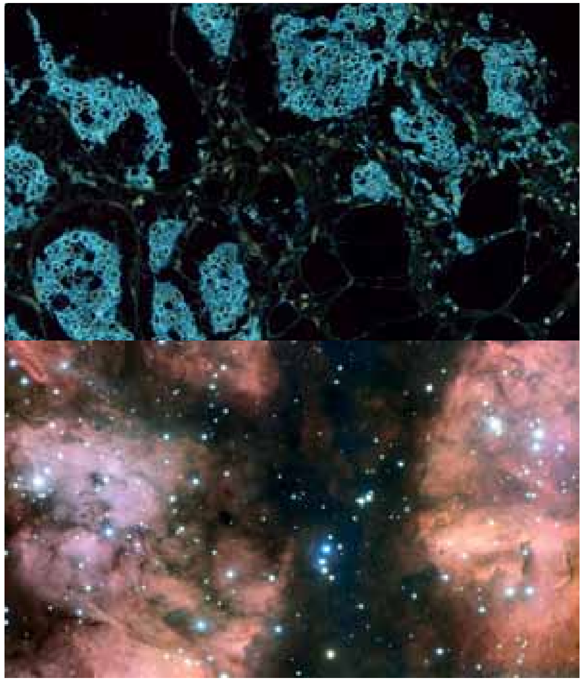
A major UK and European project to visualize astronomical information on a huge scale has the potential to unlock environmental information about the world's forests.

AstroGRID was the UK's Virtual Observatory development project, from 2001–2010, which aimed to combine astronomical imagery at multiple wavelengths with specific data about individual stars and galaxies. The result was effectively an observatory on your desktop, providing instant and searchable access to astronomical information. Now, for the World Forest Observatory, the same techniques are being used to draw together data monitoring the world's forests – and it is a task on about the same scale: there are some 400 billion trees on Earth, about the same number as there are stars in our galaxy.

AstroGRID faced key challenges that were both technical – building databases and user software – and organizational – establishing international standards and protocols for recording and sorting the information. The results included an image of the sky in which you can zoom in on one star, and pull up detailed information about its composition, velocity and brightness. The software makes possible efficient data mining for astronomy, and can do the same for the differing strands of data needed to monitor the world's forests. But it was the fundamental organizational lessons about data handling that made AstroGRID work so well, and these are what researchers hope to transfer to environmental monitoring. The World Forest Observatory is funded through the STFC's Challenge Led Applied Systems Programme, intended to drive applications of STFC-funded research in new areas.

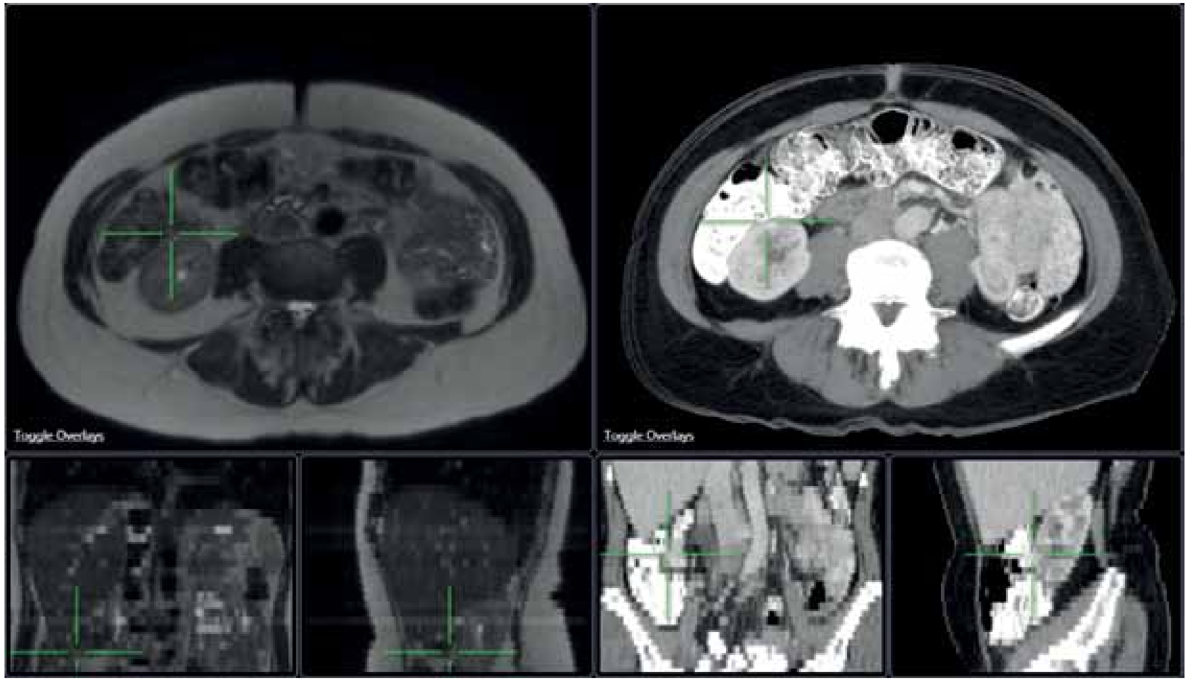
SAVING LIVES AND SPOTTING FAKES

Astronomy is all about seeing objects at the limits of visibility – distant galaxies, stars dimmed by interstellar dust – and wringing every last bit of information from the images. These techniques are surprisingly practical and can even save lives.



◀ Cancerous cells in a biopsy sample (above) can be recognized with software developed for identifying astronomical structures (below).

Images of the abdomen using different scanning methods. The green crosshairs show the matched anatomical location between the two scans. Previously the radiologist would have to scroll through both 3D volumes and manually locate the anatomy in both scans. Now, with Blackford's technology, they just click and are taken to the correct spot instantly. ▶



Imaging has been transformed by the development of CCD cameras: solid-state devices that were developed by astronomers and are now in every digital camera. These and other similar specialized detectors are invaluable for astronomy because they can detect individual packets of light or photons, making it possible to see immensely distant and faint objects. They also work at a range of wavelengths – not just visible light, but infrared and ultraviolet too – and so open up new views of the universe. Their development has led to applications in very different fields.

Astronomers at the University of Cambridge have developed a system to automate the analysis of pathology slides, both for biopsies and cancer research. PathGrid is based on algorithms used to pick out various sorts of fuzzy objects – star clusters, nebulae or distant galaxies – in astronomical images. For cancer diagnosis, tissue samples are stained to pick out biomarkers that indicate how aggressive a cancer is, for example. Both astronomical and medical tasks involve recognizing a varied range of characteristic shapes – distant stars, or fluorescent cells and tissue – amid other irrelevant information. PathGrid recognizes patterns and thus automates and accelerates the process of identifying the biomarkers. Patients get faster biopsies, and cancer researchers have a quicker method of testing new biomarkers, where many hundreds of samples must be assessed.

Faint astronomical objects can be picked up with supersensitive CCD cameras, such as superconducting tunnel junctions, that detect and measure faint emission, one photon at a time. This sensitivity means that scanners patented by BioAstral, a spin-off company from the University of Leicester's Space Research Centre, can recognize the characteristic fluorescence of biomarkers much more quickly than existing methods, which have to wait to collect enough light for a strong signal. BioAstral's scanner can handle 10 different biomarkers in one sample, giving a significantly better throughput of samples for research.

Pattern recognition

Pattern recognition is a key part of such automated systems in astrophysics, which is what makes them so widely applicable in other fields. Blackford Analysis is a company that originated in astrophysics research at the University of

COSMIC RAYS BRING SAFER TRAINS

The UK has taken a leading role in an international consortium that has built another vast array telescope, the Pierre Auger Observatory in Argentina, which uses 1600 detectors spread over 3000 km^2 – roughly the area within the M25 – to detect the very highest energy cosmic rays and discover where they come from. Cosmic rays are subatomic particles moving at close to the speed of light. They are observed from the light they generate in the atmosphere and in the array of detectors on the ground. The challenge lies in the precision timing needed to identify flashes of light in different detectors, to be sure that they come from the same particle. Timing systems developed for the project by researchers from the University of Leeds are now used to control train movements on single track railways. Fundamental research into subatomic particles from the far reaches of the universe has brought practical improvements to the safety of the railways.

COUNTERING COUNTERFEITS

Spectroscopic fingerprinting is widely used in astrophysics, from mapping the gas in distant galaxies to identifying martian rocks. One type of spectroscopy, Raman spectroscopy using infrared radiation, can also be used to find counterfeit goods on Earth. It has the advantage that it can assess the composition of a substance – by characterizing the types of bonds within its molecules – without being in direct contact with it. It is proving useful in determining whether the contents of a package or bottle are what they are supposed to be. Infrared radiation passes easily through the packaging of pharmaceuticals and Raman spectroscopy can tell if the drugs themselves contain the active ingredients, without needing to open the packets. The method, being developed at the Space Research Centre at Leicester University, can also be applied to high-value products at risk of contamination or dilution, such as whisky, without breaking the seal on the bottle. For a premium product where the export market was worth more than £4bn in 2011, authenticity is key; losses arising from contamination and counterfeiting amount to around £300m per year. The Scotch Whisky Research Institute is using optical spectroscopy to ensure the authenticity of its members' products.

Edinburgh. It works in defence and in the oil and gas industry, but its big success is in applying software developed for astrophysical research to support radiographers. Blackford's image-recognition and data-handling software speeds up comparisons between scans, allowing radiographers to compare scans taken on different dates, from different imaging instruments such as MRI, PET or CAT scanners, even when patients are lying in different positions. The pattern recognition systems developed by Blackford take into account what radiographers need to do, such as mapping blood vessels from one scan to the next, or changing the angle of view within data from a scan, for example to look from the side rather than from above.

The Blackford software was developed to speed up the analysis of spectra of light from distant galaxies. The spectrum of light from an astronomical object is essentially its physical and chemical fingerprint, carrying information about its composition and movement. Large astronomical surveys produce millions of data points with several different types of data associated with them, each needing time-consuming identification. For example, it can take a person 10 hours at a high-end workstation to identify the spectra of the elements present in one star. The software developed to automate this process reduced the time taken for this job to minutes. Blackford Analysis estimates that its products allow a radiographer to carry out an extra 10 studies a day, bringing a better service for patients.

Cancer surgeons need to know the size and extent of tumours in order to operate with precision, removing malignant tumours but preserving healthy tissue. Cancerous cells can be tagged with radioactive molecules so that they can be imaged in whole-body gamma-ray scanners – an established technique using astronomical experience. But researchers at the University of Leicester have refined the technique to produce hand-held scanners that can see a lot more detail, using research on the biggest explosions in the universe. Gamma-ray bursts are the brightest flashes in the universe, over all wavelengths of light, for the first few minutes of their tremendous explosions. Researchers have to record the energy emitted, in detail, and fast, as the radiation dies away very quickly.

"The gamma-ray burst detector has been developed into a hand-held mini gamma-ray camera for medicine"

Hand-held medical camera

The detector the Leicester team produced to do this has been developed into a hand-held mini gamma-ray camera for medicine, with 10 times better resolution than the whole-body scanners; the mini camera can resolve details as small as 1 mm rather than the 1 cm limit of the large scanners. As a result, surgeons have much more detailed images to work from, and they can easily rescan in the operating theatre. The technique has applications in, for example, the detection of sentinel lymph nodes, which are small enough to be missed in other scans. ■

◂ **The first patient trials of the mini gamma-ray camera are being conducted at Queens Medical Centre, University of Nottingham.**

◂Making the worlds of computer games look and feel plausible is a software skill, one that has been fostered by the Science and Technology Facilities Council.

THE WORLD IN 3D

Three-dimensional vision is the next big thing in entertainment. Step forward astronomers who, through adaptive optics, have made it their business not only to visualize complex structures in space, but also to understand image formation more generally.

Stars in the sky twinkle when we see them from the surface of the Earth. That's because their light passes through our planet's atmosphere, in which variations in temperature and composition distort the path of the light. Major telescopes such as those at the European Southern Observatory track these distortions in real time using lasers, while astronomers are using the telescopes. The distortions are then removed from the images, giving the observers almost as good a view as that from space-based observatories. What the astronomers also get from such adaptive optics systems is a deep understanding of how images are formed, which allows them to develop innovative lenses and instruments for completely different purposes.

The development of advanced optics has led to improvements in the physical make-up of instruments thanks to, for example, the precision grinding instruments developed by companies such as Zeeko for shaping telescope mirrors in minute detail. Zeeko now applies its precision machining methods to orthopaedics, including the manufacture of prosthetic knee and hip joints.

Entertainment

But understanding the optics of three-dimensional imagery is also valuable in the entertainment field. Films, television and computer games are all moving into 3D, and astronomers are applying what they have learned through adaptive optics to this growing – and increasingly valuable – field.

Watching films and TV in 3D requires special glasses, which mimic natural stereoscopic vision by giving each eye slightly different information, using differently coloured or polarized light. This allows the brain to merge the two images, giving the appearance of depth. However, this does not fool the eye completely, because we rely on changes in both focus and the direction in which our eyes look to judge depth. For example, moving a finger towards your face requires that each eye looks increasingly inwards – a process called veering – as well as changing focus. 3D images that carry stereo information actually exist on a screen at a fixed distance, so the eyes do not veer and the resulting "vergence accommodation conflict", a physiological effect in the brain, makes the 3D effect unconvincing.

Trick of the light: realistic 3D movies have to fool the brain, in this example by showing images alternately focused on the background then on the foreground scene.

Seeing and believing

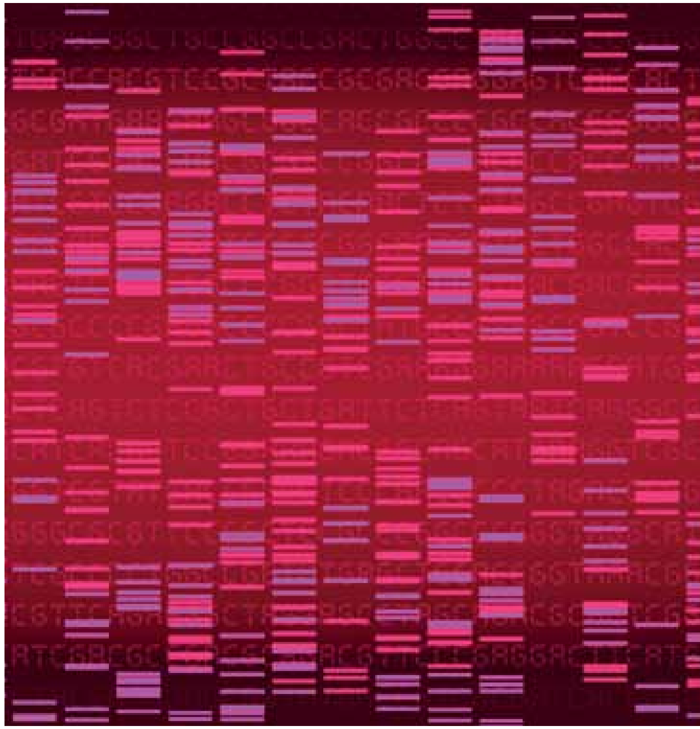
Researchers at Durham University have a solution, however, based on their adaptive optics research. They are developing a system that uses lenses with changing focal lengths, synchronized with the display. In one frame of a 3D film, the lens focuses on foreground elements of images. In the next, the focal length changes to match the background. Interleaving the images in this way allows the eye to see foreground and background elements of the object in their correct relative positions, without needing to know where the image is physically located; the vergence accommodation conflict does not arise.

Convincing 3D imaging really comes into its own in the design of computer games, where a realistic feel is important for players to identify with characters and enjoy the immersive feel of playing a role. This industry employs astrophysics graduates for their programming skills, to make sure that the images and environments they produce look and feel realistic for players.

Computer games are a significant industry in the UK, where the studios behind *Grand Theft Auto IV*, *Runescape* and other games offer high-value, high-technology jobs in a booming field. Gaming is big business; industry analysts PwC estimated that the global market for video games will grow from $52.5bn in 2009 to $86.8bn in 2014. The Science and Technology Facilities Council champions skills development for this field and estimates that the UK computer animation industry is currently worth £20bn including £2bn generated by UK video and computer games. ■

MARSHALLING SCIENTIFIC DATA

Looking into space can generate astronomical amounts of data – and the skills to deal with this information are valuable to business and industry.



The biomedical sciences now work with vast datasets– for example in DNA profiles – that need to be collected, stored and analysed.

CAREERS

David Harper, senior database administrator at the Wellcome Trust Sanger Institute, organizes information for current and future research in genomics.

"I know how to handle large quantities of data – it's what I learned in astronomy"

In terms of scale, astrophysics and genomics could hardly be more different: stars and galaxies spread over trillions of kilometres, whereas the details of DNA are measured in nanometres. Yet what these two sciences have in common is data, and lots of it! That is one of the main reasons why David Harper, after 15 years as an astronomer, moved to the Sanger Institute. "I know how to handle large quantities of data," he says. "It's what I learned in astronomy and that knowledge crosses over into many areas of science."

David developed an interest in astronomy as a child, and followed it in parallel with his aptitude for maths. His PhD was in the mathematically elegant area of celestial mechanics – understanding the paths on which solar system bodies move – and he went on to work on astronomical computing and software development. Moving into genomics was a challenge, but one that has been very rewarding. "At first I had no shared history or vocabulary with anyone, but it eventually began to make sense. Now I like the fact that I am working at the cutting edge of science and I like to keep up with progress in astronomy as well as in genomics."

Astronomical imaging for DNA

He was surprised to discover that one of the great developments of observational astronomy – the CCD chips used in modern telescopes and cameras – are a key part of modern automated DNA sequencing machines, used to take the images of arrays of fluorescent dots that represent the four chemicals that make up the DNA "code". What was not a surprise was the need to organize the vast amounts of data produced in DNA sequencing – equivalent to 50 complete human genomes every week. "I got my job at the Sanger Institute because of my astronomical work analysing large amounts of information," says David. "The work I did in software development also helped."

When the Sanger Institute was founded in 1993, DNA sequencing was a labour-intensive manual procedure, requiring a lot of people and lab time. Now the process is largely automated, very fast and produces hundreds of gigabytes of data every week. That information needs to be available to researchers, who increasingly work in applied fields of genomics, examining the DNA of malaria, for example. David is one of a small team managing the databases so that they are useful not only currently but also to support new areas of research – "the care and maintenance of scientific data" as Harper puts it.

He is not the only astronomer employed to handle data at the Sanger Institute, and he puts this down to some more general skills acquired through astronomy. "My astronomical research let me gain a lot of relevant technical expertise, but it also taught me a systematic and logical way of thinking that I can now apply in this very different field. I learned to solve problems, which is what I do day-to-day." ■

EXCITING THE SCIENTISTS OF THE FUTURE

CAREERS

Stephanie Kellett is a teacher who engages and inspires her science classes – and shows them that scientists are just like you and me.

Most successful people can recall an inspirational teacher whose support and enthusiasm for a subject sparked their curiosity. Astronomy, space and the planets attract enthusiasts who can transmit their passion for their subject to the next generation. Steph Kellett is just such a teacher at Beaumont Leys School in Leicester, after a PhD in space science, and is full of infectious enthusiasm for the subject. "Space is so exciting and because I am passionate about the subject, I can make it exciting for my students."

Steph was an undergraduate in Physics with Space Science and Technology at the University of Leicester, where she got involved in outreach, for example as a mentor to children at the University's Space School. She went on to do a PhD in planetary science, focusing on Saturn's magnetic field. After that, she went into teaching because, as she put it, "The idea of teaching gripped something inside me. I enjoyed my research, but I loved the idea of sharing it with young people. I can enthuse them and motivate them – I'm a bit of a one-person army to get people into science!"

Steph at work with her physics pupils.

Beaumont Leys is an inner-city school, where many students and their parents and carers do not have much to do with universities, let alone with scientists. Steph has been adept at using her contacts to show what working in science involves. "I can bring in friends who have exciting real jobs as engineers on space projects, to tell my GCSE physics class what it's like to do that job, and it has a massive impact. The students start to think about what they could do."

Saturn's rings as seen by the Cassini spacecraft. Steph's in-depth understanding of the planet's complex magnetic field gives her the edge in engaging students with science and technology.

"You learn to take things in your stride, such as a tap exploding in the classroom"

Engaging and enthusing

Steph's PhD in planetary science gave her a good breadth and depth of knowledge, as well as excellent contacts, but also developed skills that are now especially valuable: assimilating facts quickly, understanding complex concepts and explaining them in ways that the audience can understand, as well as confidence. "I learnt to engage an audience and I know I have the enthusiasm to handle a classful of 14-year-olds."

She mainly teaches physics, but the breadth of knowledge needed to work in planetary sciences means she also takes classes in chemistry and biology. Her broad knowledge and research skills mean she can respond to whatever questions come up in class, whether it's about the Higgs boson or a world without electricity. The flexibility and adaptability that come from the PhD help in all sorts of ways: "You learn to take things in your stride, whether it's a numerical model that won't come right or a tap exploding in a classroom."

She is also a role model in herself, with her research experience of success after a process of trial and error. "A lot of the students have very little confidence and low self-esteem. They are unfamiliar with the idea of university and overawed by it. I can tell them from my own experience that grit and determination matter, that doing hard things and sticking at it got me there in the end." ■

FROM ANCIENT GALAXIES TO OLD MASTERS

CAREERS

Radio astronomer Haida Liang has found that astrophysical research has a place in the analysis of paintings: making possible pigment analysis, prediction of fading and digital cleaning.

Haida Liang had two passions when young: history and physics. After a PhD and postdoctoral research positions in astrophysics, she now applies spectroscopic and interferometric techniques to artworks in national collections. She heads the Imaging Science for Archaeology and Art Conservation research group at Nottingham Trent University.

Haida followed up her early interest in physics with a PhD in which she worked on the rate of expansion of the universe. This fundamental research required measurements of subtle variations in the temperature of the cosmic microwave background radiation – the echo of the Big Bang – combined with measurements of X-rays emitted by hot gas in galaxy clusters. "Through astrophysics I learnt how to deal with very faint signals and imaging of especially demanding subjects," says Haida. "Astrophysics really pushes imaging science to the limits. And that gave me a really useful bag of tricks."

"Astrophysics really pushes imaging science to the limits – that gave me a really useful bag of tricks"

National Gallery

The link to art came when the National Gallery wanted an imaging scientist to work on a European collaboration to produce a multispectral scanner for paintings. The techniques of multispectral analysis are like those used in astrophysics: light is reflected off the painting, rather than being emitted by stars or hot gas, but it is split into different wavelength bands and analysed in much the same way. "I measured the percentage of light reflected off a specimen in the different channels to get a signature for a pigment, for example," says Haida. "And because the technique extends to near-infrared as well, we can see through the paint layers to the drawing beneath, which reveals the artist's technique and can be useful for attribution."

***The Virgin and Child* by Domenico Ghirlandaio, from the collection of the National Gallery, is an example of the application of astrophysical research to the understanding and preservation of art treasures.**

The parallels between art and science kept coming. A project examining whether it would be possible to "digitally clean" pictures so that you could see what the paintings originally looked like – without touching the original – led Haida to search for a way of measuring the thickness of the varnish layer – and that led her back to astrophysics. Papers on biomedical imaging referred to the Michelson interferometer, an instrument used in early 20th-century astrophysics that showed that the universe is not filled with ether. Haida investigated optical coherence tomography to measure the thickness of varnish, and soon found herself reading papers by Chandrasekhar and other noted astrophysicists who had studied a related light-scattering effect in the interstellar medium: degraded yellowed varnish turns hazy and masks the true appearance of a painting, much like the reddening effect on background galaxies due to dust in the interstellar medium. "It helped a lot that I understood interferometry – I had used a radio interferometer for my astrophysics research – and so I was working with familiar physics."

Tate Gallery

Haida also participated in a project for the Tate Gallery to investigate how vulnerable works of art are to fading. The device she worked on focused an intense beam of light onto a tiny spot on a painting or drawing. The fading could then be measured with a spectrometer, to undertsand how lower levels of light would affect the artwork as a whole over a much longer timescale. It is an accelerated ageing technique, one that Haida thought was about as far as you could get from astrophysics, but she was wrong. As she became involved in the project, she found that the amount of light falling on the painting and the fading experienced depends on the intensity of the light. Exactly the same problem had been addressed early in the 20th century by astronomers using photographic plates to assess the relative brightness of stars. Once again the art collections looked to the astrophysical literature, in this case Karl Schwarzschild in the first decades of the 20th century.

"I'm continually surprised by the parallels between research in astrophysics and in this field, but it is really imaging, and imaging is something astronomers know about," says Haida. "Astrophysics is both a fundamental science and applied physics. Nothing could be more fundamental than understanding the expansion of the universe, yet astrophysics uses pretty much every branch of physics." ■

BLUE-SKY THINKING

CAREERS

Stuart Eves dreams up new ideas for small satellites and their applications.

Stuart Eves loves his job. He's a Lead Mission Concept Engineer, looking to devise new applications and missions for small satellites for Surrey Satellite Technology Limited (SSTL), which is now owned by EADS Astrium. "I'm the ideas guy," he says. "It's my job to find new things to do with current and future small satellite technology." And he's doing this as part of the UK's thriving space industry, potentially worth £40 billion to the UK by 2030, working for SSTL, a company with a turnover of roughly £100 million per year. As well as design and manufacture, this successful industry also encompasses the running and servicing of existing satellites, providing long-term and growing income.

Eves works with constellations of small satellites which can now do many of the things that once needed big – and expensive – satellite platforms. For example, he is involved in proposals to use these types of satellites for science, with proposals for an ultraviolet observatory taking shape with researchers at the University of Leicester, taking Eves back to his roots in astrophysics.

Understanding astrophysics

Eves was attracted into science in the first place by a love of the unknown, and drawn to astrophysics because it was a field making discoveries. His degree in physics with astrophysics from Royal Holloway University of London was not enough for him, and he continued to study astrophysics part-time at Queen Mary University of London while working for the Ministry of Defence. While he gained some directly useful knowledge – about orbital mechanics, for example – Eves found less tangible but more useful benefits from his research. "To understand astrophysics, you have to know about more than just what to look at, you have to understand how your detectors work and what the atmosphere is doing – and if you don't know, you find out. That approach has been very useful to me."

"It's my job to find new things to do with current and future small satellite technology"

THE MOST EFFECTUAL TOPSAT

Stuart Eves developed the idea for the microsatellite TopSat (Tactical OPerational SATellite), which was launched in 2005 and orbits the Earth at a height of 700km, providing high-resolution images of the Earth quickly and at low cost. Imaging satellites prior to TopSat pointed their cameras at the ground at a fixed angle, with the result that their sensors swept across the ground at the orbital rate (close to 7km/s), allowing very little time for light to enter the optics. Uniquely, TopSat pitched backwards while passing over its targets. This pitching motion slowed the effective ground rate of the sensor, allowing more time for more light to enter the camera, and so generating a much higher quality image. Larger satellites find such motions hard to perform since motion on the satellite tends to set up vibrations in the solar panels and the structure, which then degrade the quality of the image. By contrast, TopSat's compact design with rigid, body-mounted solar panels, meant that it vibrated less. The agility that TopSat demonstrated has been a feature of most SSTL satellites since, and these more sophisticated satellite platforms are now being considered for astronomical small satellites, such as ESA's CHEOPS exoplanet mission.

As an example of how TopSat images are used, the satellite was included in the International "Space and Major Disasters" Charter, a joint initiative by international space agencies to provide relief agencies with rapid access to satellite data. The charter was first used in 2008, when TopSat images were used by the United Nations following a series of earthquakes on the Rwandan/Congolese border, which destroyed buildings, closed schools and left thousands of people homeless.

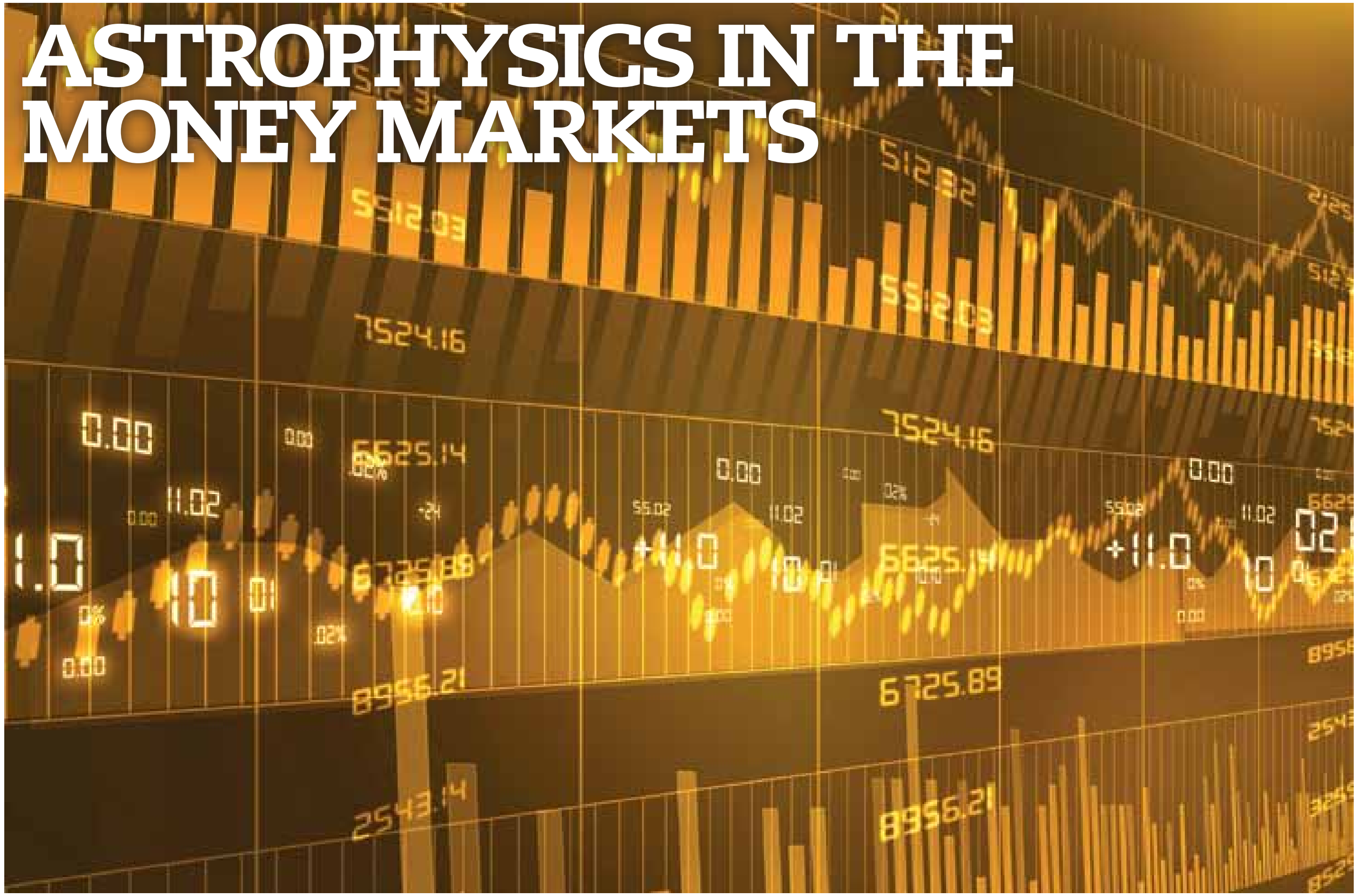
At the MoD, Eves conceived the surveillance satellite TopSat, making the most of its pointing and agility to boost its resolution, so much so that TopSat held the world record for resolution for a satellite of its mass – and he is very proud that the engineering model of that satellite was placed on display at the Science Museum in London.

Small is beautiful

Eves sees the future for small satellites as very bright indeed. Small satellites have changed the economics of space, because their cost has come down significantly, at the same time as their performance has improved. Thus they are now finding applications in hazard assessment, meteorology, navigation and even research worldwide – SSTL is providing the satellite payload hardware for Galileo, the European navigation system, for example.

Eves sees a step-change in the near future, as satellites become networked in the same way as terrestrial instruments now are. "At the moment, if you want a satellite to examine a specific target, perhaps an accident at sea, you have to wait until the satellite passes over its ground station to give it a command, wait again until it reaches the target, and wait for a third time until it is back within range of its ground station and can transmit the images it has collected," he says, pointing out that this is why it typically takes several days for satellite images to become available of, for example, the *Costa Concordia* grounding. "Imagine the difference if we have many small satellites, in constant contact with each other and with the ground via inter-satellite links. That's a whole new level of information and it's going to change how we do things." The ideas man is ahead of the game again.■

ASTROPHYSICS IN THE MONEY MARKETS



CAREERS

In a world awash with information, finding out exactly what you need to know, when you need to know it, saves time and makes money. Kaj Siebert, Director and CTO of Columba Systems, used his research in astrophysics to build a successful business providing timely relevant information to financial institutions and investors.

Seeing the night sky through a telescope captivated Kaj as a child, and brought him to University College London as an undergraduate and then a postgraduate research student. He started his PhD in 1995, at a time when email was widespread, but the internet was not yet ubiquitous. As a research student he built webpages for conferences and became interested in their potential for making the most of the large datasets that were becoming available in astronomy at the time. He set up a large hyperlink database linking observations from an astronomical satellite, the International Ultraviolet Explorer, with other astronomical datasets. “I realized that the skills I used could apply to any large dataset, because I set it up using XML,” he says.

“Reuters’ internal research group was very keen to find out how to apply this technology to their markets. They offered me a job and I started work applying XML to their news sheets.”

Money markets

Working at Reuters broadened Kaj’s experience and reinforced his conviction that managing data matters. He joined two former colleagues at Columba to apply their ideas to the financial sector. “We supply information that will be significant to the money markets to our clients, in whatever ways make it easy for them to use it – newsletters, emails, and software for larger concerns to embed in their in-house data systems. News is everything that has just happened – we provide everything that is going to happen.”

Timing is key for much of this information – the dates of company meetings, releases of trading figures and so on, and Kaj found an unexpected bonus from his understanding of astronomy – a sound awareness of the calendar and worldwide time. “If a company in Japan is releasing figures on a Monday morning ahead of the Tokyo stock market opening, clients in New York need to be aware that the information will be available on a Sunday for them.”

Learning resilience

As well as technical skills, Kaj identifies less tangible but equally significant aspects of his postgraduate research – how to tackle new situations and cope with failure. “We were using large computer models that took a long time to run, maybe a month, so we had to figure out how to avoid them crashing ten minutes after we left for the weekend,” he says. When they did crash, he learnt how to recover from failure. “The lessons I learnt gave me resilience and taught me about planning ahead and being aware of possible pitfalls – very useful in business.” Astrophysical modelling also taught him the value of a pragmatic approach, choosing a good-enough solution rather than chasing perfection: “I know that there is no ideal situation, in any problem and for any company.” ■

> *“The lessons I learnt as a postgraduate taught me about planning ahead and being aware of possible pitfalls – very useful in business”*

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About the RAS

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