ASTRONOMY MEANS BUSINESS

How UK research benefits industry, education and society

Advancing Astronomy and Geophysics

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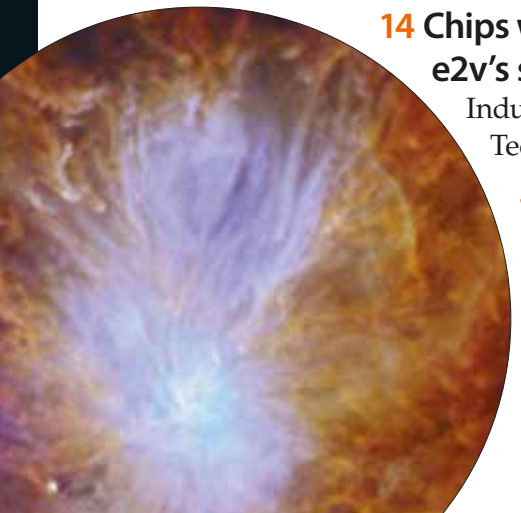

ASTRONOMY MEANS BUSINESS

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www.ras.org.uk

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Cover: The star cluster NGC 6604 is shown (top right) in this image taken by the Wide Field Imager attached to the 2.2 m MPG/ESO telescope at the La Silla Observatory in Chile.

Introduction: from the President of the Royal Astronomical Society

It is a pleasure to introduce this overview of developments in business, industry and society that have arisen from research in astronomy and astrophysics. So much of the technology we rely on in our day-to-day lives sprang from or was developed as part of fundamental, blue-skies research: sensors for security scanning and medicine, wi-fi connections, complex software for big data, imaging systems and the ubiquitous smartphones using satellite navigation, compact cameras and more.

Astronomers study the distant universe using the light that stars and galaxies emit; that light might be ultraviolet or infrared radiation, or it might be radio waves, but astronomers squeeze every last bit of information from it. That expertise in making the most of information translates to down-to-Earth applications where getting the biggest bang for the buck helps industry keep costs down and effectiveness up, driving economic growth for the UK.

We are seeing the benefits from government investment in universities, research centres such as the Harwell Campus and world-class facilities such as the Square Kilometre Array and the European Extremely Large Telescope, two innovative next-generation observatories that will lead the world. That investment, in turn, will bring business for UK companies, give UK industry a headstart in the applications that will arise from these new research areas, and inspire a new generation of young people to take up careers in science and engineering.

This booklet is based on returns to the 2014 Research Excellence Framework. It represents a snapshot of research activity in universities with a wider impact. This is not the only significant work undertaken by the UK astronomy community, and these fields will have already developed by the time you read this. But the summary it provides paints a picture of a healthy research culture with a keen eye for how to put ideas to work.

Prof. Martin Barstow
President of the RAS
2014–16

THE ROYAL ASTRONOMICAL SOCIETY REPRESENTS ASTRONOMERS, PLANETARY SCIENTISTS, SOLAR–TERRESTRIAL PHYSICISTS AND SOLID-EARTH GEOPHYSICISTS. OUR FELLOWS WORK ON ALL ASPECTS OF RESEARCH, EDUCATION, OUTREACH AND SCHOLARSHIP.

The race for the space industry

Space is a growth industry worldwide. UK research means that UK industry is in a prime position to win shares in that market.

SPACE FOR GROWTH

We rely on space technology: satellites provide environmental monitoring and a host of navigation and timing services that we have come to take for granted. Space is the place to go for growth: spacecraft and satellite technology is increasingly a part of our lives and UK industry can take a leading role, thanks to UK research. Universities such as Leicester and University College London provide expertise and academic leadership.

The UK space industry is already worth £11.8 billion and is growing at 8.6% year-on-year on average. The UK Space Agency estimates that there are 37 000 people employed directly in the space industry, with 115 000 jobs associated with this sector in all. The sustained growth, export success and new businesses in the UK space sector demonstrate that we are well on our way to the target of 10% of the global space market by 2030.

▶ **Blast off**. The European Space Agency has delivered cutting-edge science and technology for 50 years, including this Ariane 5 rocket launching the Herschel–Planck satellite in 2009.

REACHING FURTHER WITH ESA

Space missions demand low-mass, high-reliability, high-performance instruments that function in extreme environments. Development of innovative technologies for European Space Agency contracts boosts UK industrial capabilities. Researchers at the Open University (OU) have developed analytical instruments for solar system exploration for several ESA missions, most recently the successful Rosetta comet-chasing mission. The OU-led spectrometer PTOLEMY on the Philae lander discovered organic molecules on comet 67P/Churyumov-Gerasimenko (pictured above).

OU and Leicester researchers built sophisticated but small mass spectrometers for the Beagle 2 Mars lander; they are now applying that knowledge to new instruments to explore Mars and the Moon, in collaboration with RAL Space and companies including AirbusDS, Fluid Gravity Engineering and Magna Parva (see right).

INDUSTRY FOCUS

POWER FOR SPACE

Spacecraft exploring the solar system usually use nuclear energy. Researchers at the University of Leicester, in collaboration with other UK and international partners, have identified an isotope of americium as a viable alternative to plutonium. They developed a technique to extract it from radioactive waste, providing Europe with an independent slice of the wider international market, where supply is dominated by Russia.

Americium (pictured above) is also used for smoke alarms, in well-logging instruments for the hydrocarbons industry and in radiation sources; the new techniques for safer processing and handling of this material will benefit these industries. Leicester's involvement in space nuclear power has earned investment of more than £4 million, providing high-value jobs in UK industry and academia.

TESTING TEAMWORK

Space research and any space industry requires teams of specialists working together on complex problems in demanding projects where failure is not tolerated. UK researchers have considerable experience in project management as principal investigators; researchers at the Mullard Space Science Laboratory of University College London have examined how complex technology projects succeed in the real world. They offer continuing professional development in project management, systems engineering and technology management. Clients include the European Space Agency, General Electric, National Air Traffic Services, Mahindra and Transport for London. Between 2008 and 2013, clients paid £2.4 million for these services.

Ultra Electronics, a technology company that employs 5000 people worldwide, sought systems engineering training. "Through the adoption of best practice, senior management has the confidence to compete for large engineering programmes without the necessity of including excessive contingencies in competitive bids," says Ultra's chairman Douglas Caster. "As a result, the company has been successful in securing more business through competition."

MAGNA PARVA: MARS, MERCURY AND MEDICINE

MAGNAPARVA™

Magna Parva is a space engineering consultancy that has worked with researchers from the University of Leicester and the Open University to develop instruments for exploring Mars and Mercury. The management and technical support Magna Parva supplied to Leicester researchers in the development of instruments for ESA's ExoMars mission led to the company gaining a contract with ESA for the BepiColombo mission to Mercury. The new income stream for the company produced seven extra jobs – effectively doubling the size of the company.

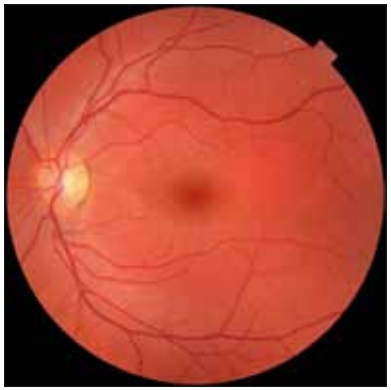
OU researchers developed an elegant solution to the problem of dust settling on solar panels of Mars landers and limiting mission power; with Magna Parva and Fluid Gravity Engineering they won a contract from ESA to develop the system. This new technology has applications in future space missions and in the wider industrial world.

▶ **Mercury rising**. The BepiColombo spacecraft being prepared for a 2017 launch to the extreme environment of the smallest planet.

Seeing the unseeable

It's not just sensitive detectors that matter in astronomy – images that show the invisible are now used in medicine, nuclear power, aeronautics and security.

STARS IN YOUR EYE TESTS



Astronomical technology is proving useful for our own optical instruments – our eyes (pictured above). University of Leicester researchers have used their expertise in space instrumentation to build a device that measures how the eye reflects light, providing a diagnostic tool for the eye condition scleritis; detection of corneal ulcers also appears promising.

The computing technique adaptive optics, used by astronomers to compensate for blurring of images by atmospheric conditions, is being applied to ophthalmology by researchers at the University of Bradford. Constant involuntary movements in the lens of the eye limit the detail that can be seen of the retina, in turn limiting the precision of treatment of retinal damage. Adaptive optics offers a way to better maintain the eyesight of patients with diabetes, for example.

SCANNING FOR SECURITY

Space use demands low-mass, low-voltage, robust devices, which are also useful for imaging in difficult and dangerous environments on Earth. University of Southampton researchers developed spectrometers for the European Space Agency's INTEGRAL mission to detect flashes of gamma rays from outside our galaxy. The technology developed for these instruments is now improving radiation detectors on Earth, useful in situations such as border control and nuclear safety.

SUPPORTING NUCLEAR POWER

The transition from experimental fusion reactors to working fusion power stations is a major engineering project. Europe's JET and ITER projects are leading the way; QMC Instruments supplied detector technology that has played a key role in the study and understanding of the processes within the plasmas, where fusion takes place to generate this clean new form of nuclear energy.

ARCHAEOLOGY TO AEROSPACE

Investigating ancient astronomical technology has led to sharper, more powerful scanning for flaws in aerospace materials such as turbine blades. A fragile archaeological find from 2100 years ago – the Antikythera mechanism shown below – is the earliest astronomical calculator. Techniques developed to analyse this artefact – the Bladerunner scanning system among them – have generated some £15 million turnover for X-Tek, an X-ray imaging company. Collaboration between Cardiff University researchers, Hewlett-Packard and X-Tek developed new high-power computer tomography (CT) imaging to scan the artefact in 3D.

"The Antikythera work was the spur to develop a new range of high-powered microfocus X-ray sources," says Roger Hadland, director of X-Tek. "The details and precision of the 2D and 3D CT information was stunning, far better than any competition. X-Tek is now part of Nikon, with the Bladerunner scanner accounting for a large proportion of X-ray production." More than 25 Bladerunners have been sold, at a total cost of more than £20 million.

▶ **Inside the Antikythera mechanism**. This corroded relic proved to be an astronomical calculator, packed with interlocking cogs. The X-ray tomography needed to probe its interior also detected flaws in aerospace turbine blades.

INDUSTRY FOCUS

SYMETRICA

Symetrica, a company set up in 2002 based on research at the University of Southampton, is using spectroscopic detector technology to produce better radiation detectors for security applications, for example handheld devices for use at airports and in the nuclear industry. Symetrica worked with leading US company Smiths Detection to provide technology used to screen debris from the Fukushima tsunami when it reached Hawaii. Symetrica had a turnover of £10 million in 2013–14 and employs 26 people. It is now expanding into related security fields, meeting stringent US Homeland Security and European standards.

www.symetrica.com

QMC INSTRUMENTS LTD

This spin-off company, based on research at Cardiff University, builds instruments developed to detect dust and gas in space for the ESA Herschel and Planck satellites and the world-leading Atacama Large Millimetre Array. QMCI developed the technology to meet industry needs, for example producing detectors that do not need costly liquid helium cooling. They have also developed software based on astronomical imaging to improve cameras used by fire services and rescue teams. QMCI serves worldwide markets, with more than 90% of its activity in exports, spread evenly between Europe, the US and the Far East. Between 2008 and 2014, it cites an aggregate business volume of more than £4 million, with managing director Richard Wylde estimating that 80% of that business depended directly on the work of the Astronomy Instrumentation Group at Cardiff.

www.terahertz.co.uk

► **Seeing more with Herschel**. A dense cloud of gas and dust in the constellation Monoceros, where blue bubbles of hot gas are forming new stars. The ESA space observatory Herschel uses infrared light to unveil this sort of exotic space environment, which is hidden by dust when seen in visible light.

Europe's billion-star mapper

Space telescope Gaia is mapping 1% of the stars in our galaxy. That's big data, and it demands the development of innovative IT methods for data transfer and management.

BRINGING BUSINESS TO THE UK

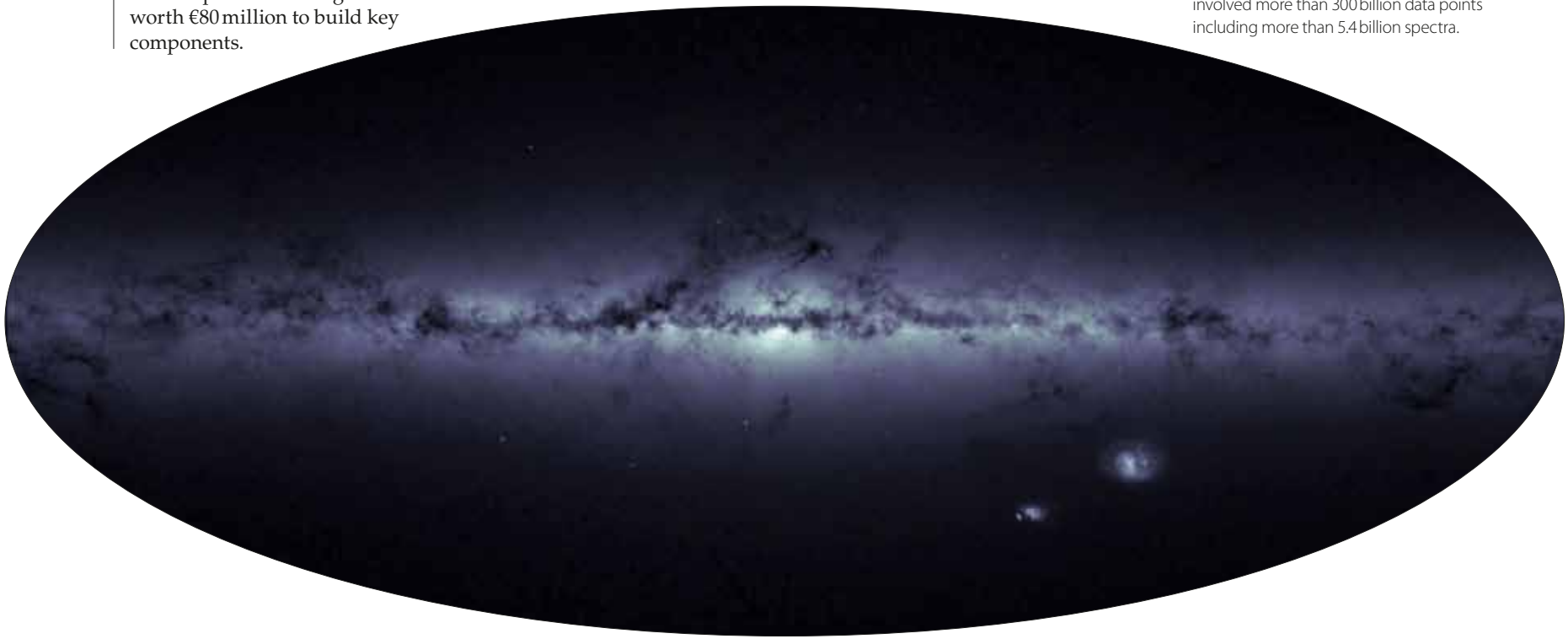
Gaia is a European Space Agency mission mapping the composition, position and movement of a thousand million stars using the biggest camera ever launched into space – built with sensors developed in the UK. Gaia was launched in 2013 and is repeatedly surveying the skies to reveal variable objects such as supernovae, asteroids moving through our solar system and stars with planetary systems. It will also map the elusive dark matter. The UK has leading roles in this European project, with UK companies winning contracts worth €80 million to build key components.

Airbus Defence and Space was responsible for service and propulsion systems, as well as key structural components, building on the company's expertise in space technology. Selex Systems provided support with documentation and scheduling, ABSL provided batteries, and e2v supplied the CCDs. The Mullard Space Science Laboratory (University College London) worked on the focal plane assembly electronics and the Radial Velocity Spectrometer, winning contracts from ESA and AirbusDS.

THE BIGGEST CAMERA IN SPACE

Gaia takes pictures digitally, measuring the brightness of different wavelengths of light, in the same way as your phone camera records colours on Earth. But while you might have an 8 megapixel camera you can hold in your hand, Gaia has nearly 1000 megapixels from an array of 106 sensors covering half a square metre. These are CCDs, charge-coupled devices, and some of the largest and most complex ever made. UK contractor e2v won the €20 million contract from ESA to build them for Gaia.

Gaia's CCDs have to perform well for five years in the harsh environment of deep space; radiation from the Sun and from cosmic rays can damage them, distorting the data. UK researchers from the universities of Cambridge, Edinburgh, Leicester, MSSL and the Open University were involved in testing the chips and modelling their behaviour.



▼ **Data across the Milky Way**. Gaia's map of our sky from its first year of operation, which involved more than 300 billion data points including more than 5.4 billion spectra.

GETTING GIGABYTES DOWN TO THE GROUND

Downloading big files from the internet can be tedious, as any film fan knows. The Gaia team has a rather bigger challenge: getting data to Earth from the spacecraft 1.5 million kilometres away. Compressing big files can help them download quicker, but you can lose information. So the Gaia team records the minimum amount of data in the first place, in a method developed by researchers from the University of Edinburgh, as part of an international team. The software automatically discards parts of each image that show just dark sky, while keeping details of interesting objects. Then the data are compressed for transmission, in ways that can be "undone" on Earth, restoring all the important data without introducing errors. Researchers from the universities of Bristol, Cambridge, Edinburgh, Leicester, the Mullard Space Science Laboratory, the Rutherford Appleton Laboratory and the Open University are involved with developing software for Gaia, as part of the Europe-wide teams running this project.

PROCESSING WITH PETABYTES

Gaia is producing immense amounts of data, measured in petabytes: one petabyte is a million gigabytes. The University of Cambridge hosts one of Gaia's Data Processing Centres (pictured above), developing innovative ways of handling the immense amounts of data from the mission. Preliminary development of the IT systems led researchers to realize that traditional software architectures could not cope with the large amounts of data that need processing from Gaia. Instead they developed a new file system based on open source software – an innovative approach using young technology. The new software architecture was designed and optimized for resilient, massively distributed bulk data processing, together with processing applications, and extensive prototyping and testing showed that it was up to the job – an example of astronomical applications driving the development of technologies to handle extreme situations.

ARTISTIC LICENCE: HOW BIG IS A BILLION?

The scale of the task undertaken by the Gaia team is difficult to grasp. Tania Kovats aimed to make the scope of the mission real through art. She developed a 3D artwork, *One Billion Objects in Space*, as part of her year as artist in residence at the University of Cambridge's Institute of Astronomy. She considered not only the astounding scope of ESA's Gaia mission, but also the cultural implications of this new map of our local universe. Metal objects hung over and around a metal grid, with mirrors to multiply them, reflecting the universe Gaia is mapping.
www.bit.ly/1XHP2vy

INDUSTRY FOCUS

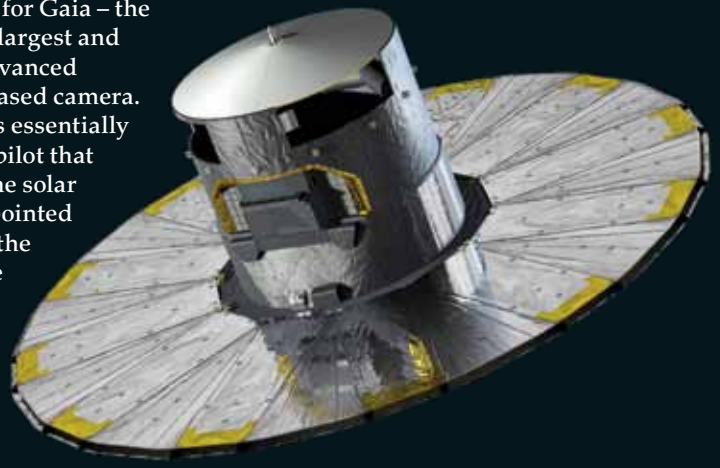
VICKI LONNON, AIRBUS DS, STEVENAGE

AIRBUS DEFENCE & SPACE

My name is Vicki Lonnon, and I am proud to be part of the team from Airbus Defence and Space right here in the UK who contributed to the Gaia mission (artist's impression below).

I joined Airbus Defence and Space (formally Astrium) in July 2006 after a degree in Physics with Satellite Technology from the University of Surrey. My career began as part of a 10-strong team tasked with designing and testing the AOCS (attitude and orbit control system) for Gaia – the world's largest and most advanced space-based camera. AOCS is essentially an autopilot that keeps the solar arrays pointed toward the Sun, the communication antenna pointed toward the Earth, and the telescope itself pointed toward deep space. The spacecraft orientation and position must be maintained to within a few milli-arcseconds, that's 1/3 600 000th of a degree!

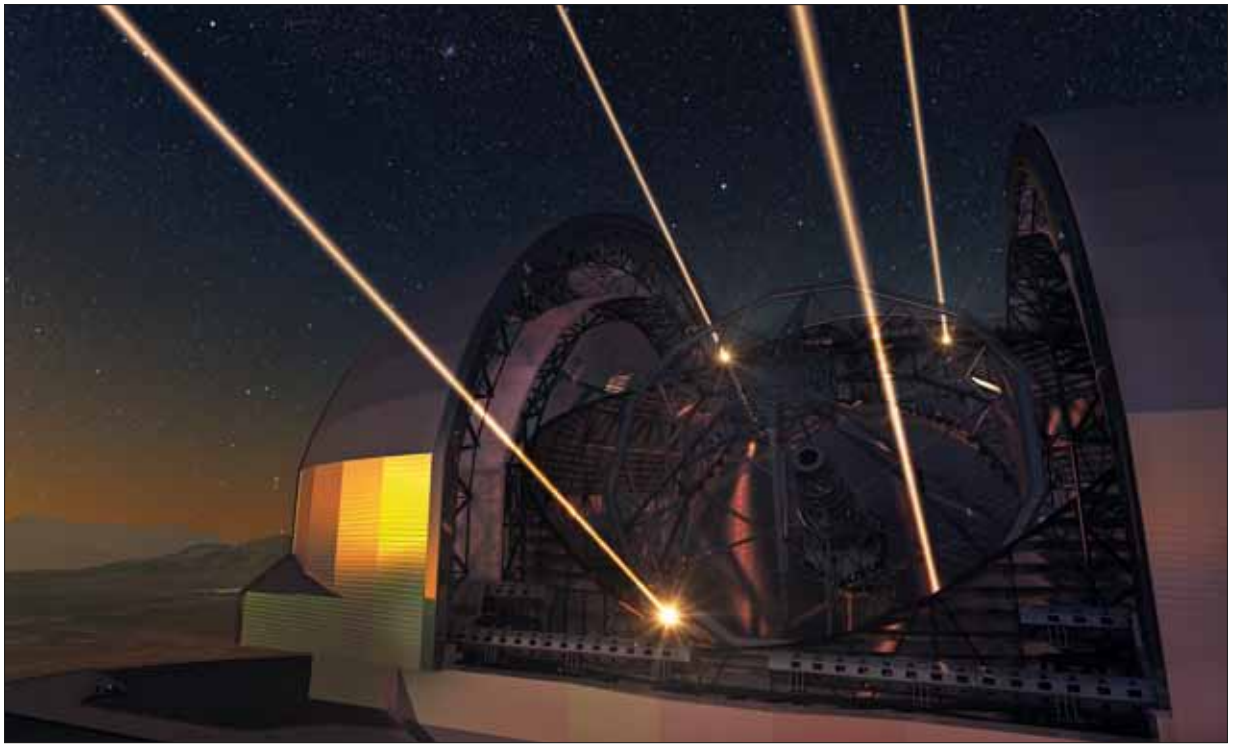
I have now changed roles and am currently the quality assurance engineer responsible for all assembly, integration and test quality matters for the LISA Pathfinder spacecraft. My job is incredibly varied and interesting. One moment I can be inspecting the spacecraft and the next I am helping to troubleshoot issues that have come up during testing. I was at the launch in Kourou, French Guiana on 3 December – my career is quite literally out of this world!



Together we are strong

World-class research needs world-class instruments – and that now demands international collaboration. Participation in European projects broadens the horizons of UK researchers and allows them to lead the world.

BUILDING THE BIGGEST TELESCOPE

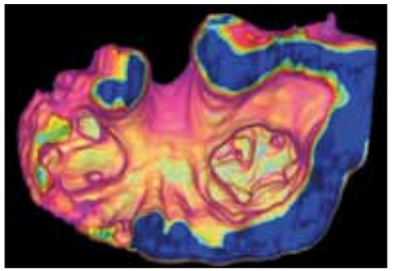


Star track. The European Extremely Large Telescope will use four enormous lasers to monitor how the atmosphere distorts astronomical images collected by its huge mirror, 39 m across. The resulting images will be better than those from space telescopes.

The UK is part of the European Extremely Large Telescope, a project to build the world's biggest optical–infrared telescope. This new observatory with a mirror 39 m across will reach further out into the universe than any existing telescope on Earth – imaging planets like Earth, stars and galaxies and unravelling the workings of the universe. The UK has invested £88 million in the E-ELT, over and above our continued membership of the European Southern Observatory, which is leading the E-ELT project. UK scientists are involved in defining the science programme, and researchers at the Astronomy Technology Centre in Edinburgh, the STFC's Rutherford Appleton Laboratory in Oxfordshire and the universities of Durham and Oxford are involved in building instruments, support systems and software for the new observatory, including leading the development of HARMONI. This spectrograph provides data on the composition and movement of astronomical objects, and will be one of the instruments UK astronomers will use when the E-ELT starts work.

The investment in the E-ELT is already benefiting UK industry, which has already won more than £10 million in contracts ahead of the construction of HARMONI. The return to companies across the UK is planned to match or exceed UK government investment in the project.

ADAPTING TO MEDICAL IMAGING



Stars twinkle because their light is blurred by the atmosphere. This might add to the pleasure of watching a starry sky, but it limits what astronomers can see. Earth-bound observers track and remove the twinkling, millisecond by millisecond, resulting in performance to match or even better that of space telescopes. UK researchers developing this technique – called adaptive optics – for the E-ELT have found that it can also bring better medical imaging.

Organs in living bodies are constantly moving, making it difficult for doctors to produce sharp images. Researchers at the University of Durham are applying adaptive optics to images of beating hearts, an especially tricky organ to image because it lies deep in the body. The Durham team has been looking at zebrafish – which are transparent – and analysing the motion of heart muscles (pictured above). Their sharper images are helping medical researchers to understand how zebrafish – and human – hearts work.

FAIR'S FAIR: INDUSTRY FOR EUROPE

UK industry benefits from involvement in European space and astronomy research, in proportion to the contribution that the UK makes to Europe-wide organizations such as the European Space Agency.

Membership of the European Southern Observatory also offers opportunities for specialist, high technology companies, such as Glyndwr Innovations, a spin-off from Glyndwr University in St Asaph, Wales. It won a contract to produce prototype segments for ESO's E-ELT. Now the company is developing new applications for its precision technology, in turn supporting the development of a wider base of technical skills and a pool of highly trained staff.

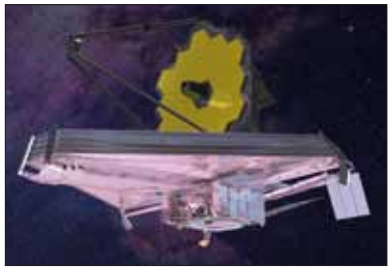
The European Regional Development Fund helped Liverpool John Moores University develop the world's first multi-instrument robotic telescope, the Liverpool Telescope. Spin-out company Telescope Technologies Ltd employed 50 skilled staff at its peak, while local engineering company SENAR built an international reputation for high-technology projects.

EUCLID: STARING INTO THE DARK

EUCLID is an ESA mission to answer fundamental questions about space and time by looking back to when the universe was young. After launch in 2020, the spacecraft will target faint, distant and very ancient galaxies, looking back 10 billion years.

EUCLID is to be launched in 2020; its development is setting new challenges in measurement and data handling for the international consortium that includes UK, European and US teams. The UK's involvement in EUCLID builds on fundamental research by scientists at the University of Portsmouth, and on UK expertise developed though work on ESA's Planck satellite and the Dark Energy Survey. Researchers from UCL are leading the development of the huge digital camera at the heart of the mission. This will take images 100 times bigger and more detailed than those from the Hubble Space Telescope. Each frame will be the equivalent of 300 HDTV screens, and the camera will produce one every 15 minutes.

BUILDING THE BEST



UK expertise in building instruments for astronomical space missions has been recognized by contracts from ESA and NASA. UK researchers jointly led the team of 10 countries that built the first instrument for the James Webb Space Telescope (pictured in an artist's impression above), the Hubble Space Telescope's successor.

MIRI is the Mid-Infrared Instrument, a powerful tool to pick out gas and dust, and analyse the chemistry of gas clouds, stars and even planetary atmospheres. MIRI detects infrared light that is hard or impossible to pick up on the surface of the Earth, but holds information about how planets, stars and galaxies form. The JWST will have a much bigger mirror than other infrared telescopes in space, giving it a higher resolution, sharper view; MIRI will also be cooled to a very low temperature in space, making it a more sensitive detector. And imaging technology for MIRI has been developed at the STFC UK Astronomy Technology Centre (UKATC) in Edinburgh. This innovative instrument will allow the JWST to find a whole host of new planets – and some of them may well prove habitable.

The UKATC provided the overall science lead, with the STFC's Rutherford Appleton Laboratory responsible for testing and verification, as well as some design and calibration. Researchers from the University of Leicester oversaw mechanical design and analysis. The involvement of UK researchers in the development of MIRI means that UK researchers will be able to use MIRI data – an investment in UK astronomy for the future.

► **Team-building for MIRI**. Some of the team who integrated MIRI into the JWST assembly at NASA Goddard Space Flight Center ahead of launch in 2018. UK scientists and engineers play key roles in the international teams behind tomorrow's space instruments.

Big data: astrophysics gets ahead of the game

Our future society will rely on ever bigger and more complex data, from shopping to security. Astrophysics is leading the way, with new observatories demanding innovative IT for data collection, analysis and synthesis.

SKA – ORGANIZING A NEW RADIO WORLD

The Square Kilometre Array is the next big step in radio astronomy: an observatory that will use new technology to map the radio sky, giving astronomers the equivalent of a movie rather than a photo album.

The SKA will bring discoveries across astrophysics, including the formation and evolution of the first stars and galaxies, investigating the evolution of the universe itself, mapping cosmic magnetic fields, detecting the molecules in interstellar space that are the building blocks of life – and maybe even picking up the faintest of extraterrestrial signals. And it will be run from Jodrell Bank, near Manchester.

The science of this game-changing new observatory builds on a UK heritage of strength in radio astronomy. Researchers at the universities of Manchester, Cambridge and Oxford are taking the lead in developing SKA science and technology. The project requires collaboration between astronomy and high-performance computing, data science and cloud computing. The project is expected to involve contracts worth more than €1 billion by 2017.

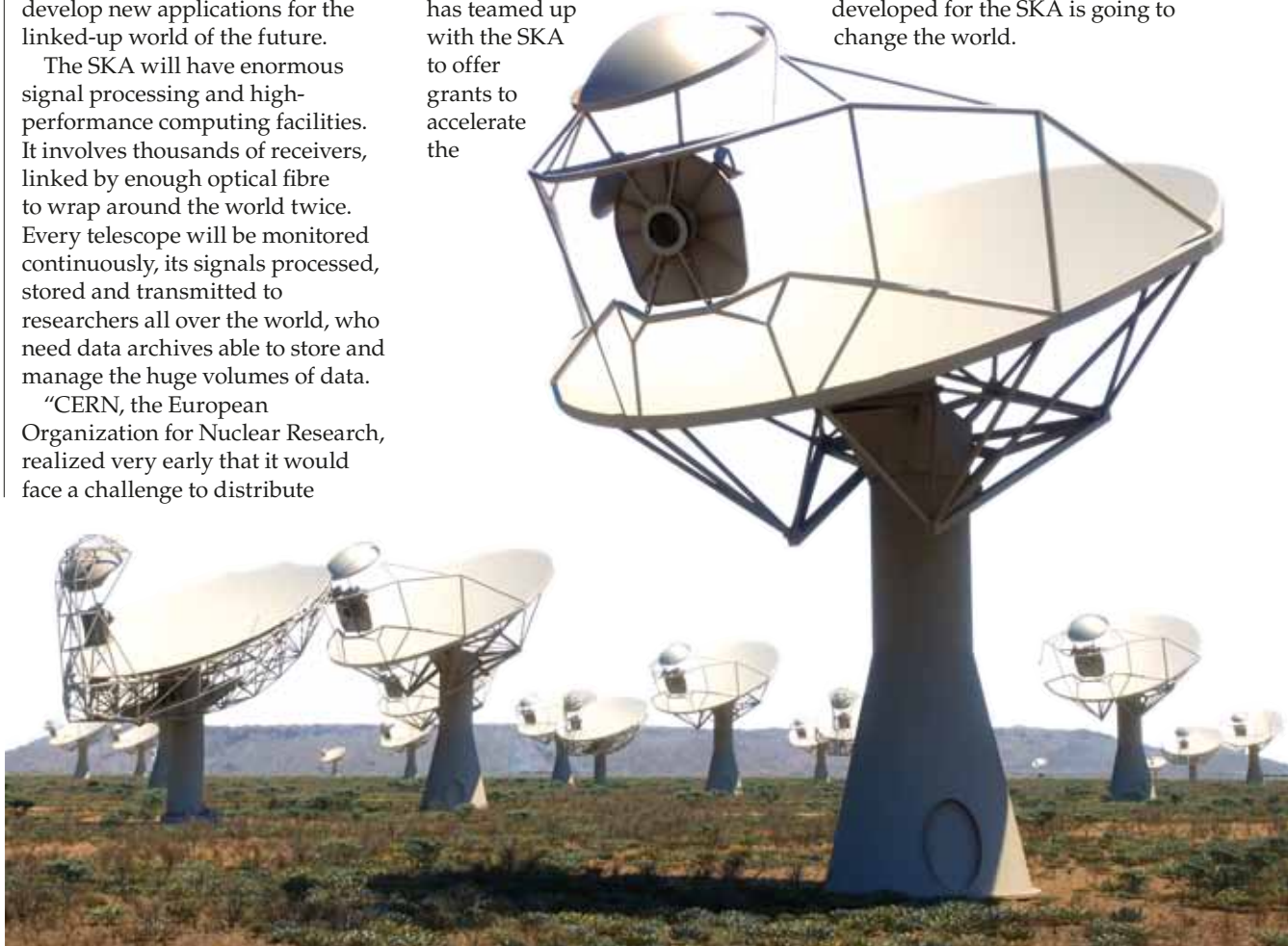
SQUARED AWAY: BIG DATA AND THE SKA

For the Square Kilometre Array, big data is really big. It will produce data equivalent to today's worldwide internet traffic – like downloading the contents of a large desktop computer (3 Tb) every second. The project will stretch technology to its limits – and SKA is working with the IT industry to develop new applications for the linked-up world of the future.

The SKA will have enormous signal processing and high-performance computing facilities. It involves thousands of receivers, linked by enough optical fibre to wrap around the world twice. Every telescope will be monitored continuously, its signals processed, stored and transmitted to researchers all over the world, who need data archives able to store and manage the huge volumes of data.

"CERN, the European Organization for Nuclear Research, realized very early that it would face a challenge to distribute the amount of data from its experiments to physicists around the world", says Tim Cornwell, the SKA organization architect. "To solve it, CERN created the World Wide Web. SKA is the next step."

Research and industry are working together on this. For example, Amazon Web Services has teamed up with the SKA to offer grants to accelerate the development of cloud computing for these huge datasets. "We're looking into innovative cloud solutions to help us cope with never-before-seen volumes of data," says Cornwell, "using techniques that are yet to be invented." The new network infrastructure – hardware and software – being developed for the SKA is going to change the world.



▶ **Things are looking up**. Artist's impression of SKA1 MID in South Africa.

ZOONIVERSE TO THE RESCUE

Since 2007, the Zooniverse platform has been supporting astronomers to work with the public to sort through mountains of data about planets, galaxies and star clusters. The platform also supports other data-rich sciences, from papyrology to particle physics.

The open-source software that supports Zooniverse also makes it easy to set up new projects in a hurry; the expertise the team has developed in translating input from the crowd into reliable results also has unexpected uses. After the devastating earthquake in Nepal in April 2015 (pictured above), relief teams needed updated maps of the area urgently.

The Zooniverse team worked with charity Rescue Global and satellite imaging company Planet Labs, focusing on rural areas outside Kathmandu. In all, 13 000 km^2 of land was surveyed, highlighting two affected towns that were not shown on other maps. Crowdsourcing directly contributed to disaster relief; knowledge acquired to speed up astronomical research has a timely real-world impact.

www.zooniverse.org

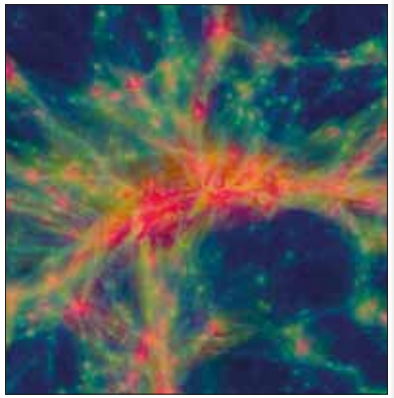
UNDERSTANDING HEALTH RISK – WITH ASTROPHYSICS

Linda Walsh of the Medical Physics group, University of Zurich, Switzerland and Federal Office for Radiation Protection, Germany, works on the health risks of ionizing radiation. But she started her research career in astrophysics at the University of Manchester, modelling how galaxies evolve.

She used *N*-body simulations, tracking 3D interactions between many different particles, modelling that required state-of-the-art computing. "In tackling the *N*-body simulations, I needed to acquire general programming skills that were also specially adapted to one of the most powerful computers available at that time – the CRAY I," says Linda. "We also projected the 3D model outputs onto 2D, for comparisons with the observational data – so I developed skills in data analysis and statistics for this task. And then I found that my programming, statistics and data-analysis skills were in high demand in other scientific areas."

"I found that the programming skills I developed for astrophysical work were especially useful for these risk calculations after the 2011 Fukushima nuclear power plant disaster. My contribution as one of the World Health Organization's expert panel involved selecting the risk assessment methods, co-ordinating and contributing to the risk calculations."

DIRAC – BIG DATA DEMANDS NEW IDEAS



The STFC's DiRAC facility (Distributed Research using Advanced Computing; above left) is the UK's powerhouse for supercomputing resources in theoretical astronomy, cosmology, particle and nuclear physics. DiRAC are part of the National e-Infrastructure, and received £15 million from the Department of Business, Innovation and Skills in 2011, as well as £1.4 million per year running costs from STFC. DiRAC systems are hosted at four universities: Cambridge, Durham, Edinburgh and Leicester.

DiRAC research has generated 495 published papers in astro-physics and cosmology (and 14 000 citations) since 2012. DiRAC played a part in the recent discovery of gravitational waves. Simulations, such as of the structure of the universe (e.g. the EAGLE project, above right) and the birth of stars and planets, test the limits of today's high-performance computing (HPC) systems.

DiRAC researchers collaborated with the IT industry to design the current DiRAC computers, selecting a range of computational architectures to reflect the diversity of the complex, data-intensive science questions being tackled by DiRAC researchers. These collaborations continue – for example, INTEL funds three DiRAC parallel computing centres (IPCC) that optimize DiRAC codes to make the most of their hardware. In 2015, a DiRAC team at Cambridge won a HPCwire prize for the best use of high-performance data analytics.

"What we do influences INTEL's decisions for future developments," says DiRAC's Mark Wilkinson. "We're pushing the envelope with what we can do in astrophysical simulations, and co-designing architectures intended for big-data analytical problems."

SUPERCOMPUTING TRAINING TECHNOLOGISTS

Taking the next leap forward in supercomputing relies on using today's and tomorrow's hardware as efficiently as possible. Designing and building faster, more powerful chips is only half the story. The right software, making the most efficient use of those chips, is the key to getting the most out of the fastest, most powerful machines. With the right coding, the chip in your laptop can perform calculations up to four times faster. Knowing how to gain that efficiency is key and it is something academic users of DiRAC increasingly need to learn.

DiRAC are developing training to help their research students to hone their HPC skills for use both in academia and industry. The training programmes being developed by DiRAC – in partnership with the Software Sustainability Council and Software Carpentry – will provide accreditation of those skills. Early-career researchers are gaining cutting-edge coding skills that can be transferred to many areas, supporting big-data applications across industry.

www.dirac.ac.uk
www.hpcwire.com
www.dirac.ac.uk/training_v2.html
www.software.ac.uk
www.software-carpentry.org

INDUSTRY FOCUS

Chips with everything: e2v's success stories

e2v Technologies plc is a UK-based company with global reach. Its high-tech products lead the world and lead in space – with €30 million contracts from the European Space Agency.

OUT OF THIS WORLD: E2V IN SPACE

e2v Bringing life to technology

Space means business for e2v: it has imaging devices in more than 150 space-based instruments.

The company makes CCDs – the chips that produce images in everything from night vision cameras to medical biomarker detectors. It was e2v chips that brought us captivating images of Pluto from NASA's New Horizons mission, and the continuing stream of data from ESA's comet-chasing Rosetta mission. Its chips are in the Hubble Space Telescope and NASA's Curiosity rover on Mars. Between 2006 and 2013, the company's operating profits tripled from £10 to £34 million, and turnover doubled to £200 million. The growth continues: operating profit was up 16% from 2014 to 2015. e2v is based in Chelmsford and employs 1650 people worldwide.

e2v.com

IMAGING FOR BUSINESS

e2v develops semiconductor technology for industries from civil aerospace and defence to medicine, security and rescue. In astronomical imaging, e2v has developed strong and mutually beneficial links with UK research, notably the Centre for Electronic Imaging at the Open University. This collaboration was instrumental in e2v winning a £3.8 million Regional Growth Fund award in 2012, leading to around 100 new jobs.

The CEI designs new sensors, and streamlines manufacturing to bring better performance, such as providing better protection against radiation in space. Changes made by the CEI to the electronics that drive the image sensors for ESA's Euclid mission have made them twice as resistant to space radiation, for example.

The University of Nottingham has a combined manufacturing, research and development facility in the School of Physics and Astronomy with e2v, to test new fabrication techniques with the company.

Researchers at the Mullard Space Science Laboratory have been evaluating and characterizing e2v's CCDs since 1995, in order to understand and enhance their performance at the extremes demanded by innovative space missions.

"By rethinking how it can get more out of its technology across the business, and working with the University of Nottingham and the Open University, e2v has expanded the size of its potential markets from £2 billion to £3.5 billion a year"

Keith Attwood, former CEO

BIG CHIPS FOR A BIG CAMERA

Space has boosted e2v's international reputation – and its bottom line. The ESA contract for the Gaia chips (pictured above) was worth €20 million. "The supply of custom CCDs to the Gaia mission is the largest space contract that we have won," says e2v's chief engineer David Morris, "and the support of MSSL is significant. The capability that this has built at e2v now makes it possible for us to be a credible supplier to ESA science missions. For example, we have won a contract for €10 million to supply CCDs for the Euclid VIS instrument."

▶ **A new horizon**. The amazing new images from NASA's New Horizons mission to Pluto were captured with CCDs made by e2v in the UK.

Stretching the tourist season – with astronomy

In Northumberland, astrotourists come to the International Dark Sky Park in winter as well as summer, boosting local businesses across the region.

KIELDER OBSERVATORY: THE PLACE FOR SPACE

◀ **Skies at night**. A Perseid meteor streaks through the spectacular skies above Kielder Observatory, where anyone can come and find out more about the universe.

Kielder Observatory, opened in 2008, provides a focus for astronomy in the Northumberland International Dark Sky Park. Canny observers had long sought out Kielder for its lack of development and resultant dark skies. Observatory director Gary Fildes started hosting "nightwatch" events at Kielder Castle in 2000, with the support of the Forestry Commission, which wanted to develop astrotourism. The popularity of these events led to the Kielder Star Camps and, eventually, to the observatory.

The sleek, modern observatory buildings offer visitors the opportunity to see the skies for themselves, through telescopes and with expert advice on hand. Visitor numbers have surprised the observatory team; they planned to run a few dozen observing events a year, but now host on average 40 a month – more than 70 000 people in five years. The opening of the Dark Sky Park in 2013 brought even more visitors and more and more people now seek out Northumberland for its dark skies – and not just at Kielder. There are Dark Sky Discovery Sites across the region, places with little light pollution where you can simply stop and look, or set up your telescope.

www.kielderobservatory.org

ASTROTOURISM ON THE UP

"We have to use the location and make it easy for visitors to enjoy the dark skies," says Duncan Wise, of Northumberland National Park. "It might be as simple as giving visitors a 24-hour key and providing hats and scarves, but some businesses are going further."

Sue Hugenholtz (pictured above, right) has a holiday let, Blacksmiths Cottage, on the eastern edge of the park. "There's no question that astronomy is bringing me more business and extending the season," she says. "I've been mostly full in October and November with weekend and midweek breaks – and they all want to stargaze." Sue enjoys giving visitors a "beginners guide" to the skies and works with the park to promote Star Host training for other businesses. "In the first three months of 2015, my visitors totalled 111 days, spending money in Northumberland," she says. "They would not have come without astronomy."

www.blacksmiths-cottage.co.uk

THE SKY'S THE LIMIT FOR BATTLESTEADS

"I'm not an astronomer, I'm a businessman," says Richard Slade. "When I first saw Battlesteads in 2004, it was rundown, cold and damp. The thing that sold it to us was the night sky – I had never seen anything like it."

Battlesteads Hotel and Restaurant is now an award-winning sustainable business within the Dark Sky Park, and the first hotel in the UK to have a purpose-built observatory. Richard recognized the award of Dark Sky Park status in 2013 as a business opportunity. By then Battlesteads was busy in summer, but much quieter in winter. Long nights are a bonus for stargazing – Richard saw that astronomy could draw in visitors year-round, Nature tourists as well as amateur astronomers.

Battlesteads Observatory opened in spring 2015 and has proved popular – especially the hot chocolate! Winter bookings this year look to exceed expectations of 70% occupancy. As a result, Richard has been able to keep on five more staff year-round. "We've found a market that didn't exist before," he says. "Astronomy can be a hobby for kids and adults, or it can be another interest for those who enjoy the natural world. For us it is an opportunity to offer visitors more."

www.battlesteads.com

INDUSTRY FOCUS

Data science goes to the markets

Winton Capital Management Ltd succeeds by applying scientific methods to financial markets, employing skilled researchers from quantitative data-rich disciplines – including astrophysics.

WORKING TOWARDS SUCCESS

The company, founded in 1997 by David Harding, employs more than 400 people worldwide, some 145 of them in research and development. Astrophysicists are among the 60+ staff with PhDs who together contribute more than 150 years of postgraduate experience.

Winton's approach depends on research by highly trained, research-experienced scientists from a range of quantitative disciplines, in order to better understand investment, now and in the future, and drive profits. The strategy has paid off: Winton has more than $30 billion currently in assets under advice.

INVESTING IN STAFF

Winton's approach to investment is to understand the mathematics of the financial markets. Market data are very noisy; investment decisions can be driven by ideology, social behaviour or even wishful thinking. Winton's approach is to apply mathematical methods to find the little bit of order within the large random variations – the small signal hidden within the noise.

"You wouldn't think that we could make money out of this," says David Harding, chairman and CEO of Winton, "but then, you wouldn't think that the tiny signal found in the data at CERN could change the way we see the universe." Winton seeks out astrophysicists because of the expertise that the field can give in teasing out information from necessarily noisy data.

"Astrophysics is not only a fascinating field of study," says Harding, "but also one that is in the lead in developing the skills necessary for success in the big data economy"

EYES ON THE PRIZE – WITH KAGGLE

How do you get more people tackling tricky science problems? Set up a competition and offer a big prize. That's what astrophysicists at University College London did to engage more people in the problems of mapping dark matter – unseen matter known only from its gravitational effects. Using the competition platform established by data science company Kaggle, they set up an online competition based on gravitational lens research for the European Space Agency mission Euclid. 353 teams took part, producing 3553 entries overall, and the competition was notable for the extensive and in-depth online discussion among the teams. And the big prize? Winton Capital donated $20 000.

Winton saw the competition as a way to engage with prospective employees. "Kaggle was a hugely successful venture for Winton. We expend huge amounts of money and time on identifying and trying to hire exceptional research scientists for our business," says Winton's recruitment manager. "We only manage to hire 10 to 15 a year, though we interview several a week. The competition was great branding and, even better, it allowed us to help generate new physics research!"

▶ **Map the dark.** Gravitational lensing, the distortion of light from distant galaxies by more massive, closer objects, provided a puzzle that challenged data scientists.

Skills for future growth

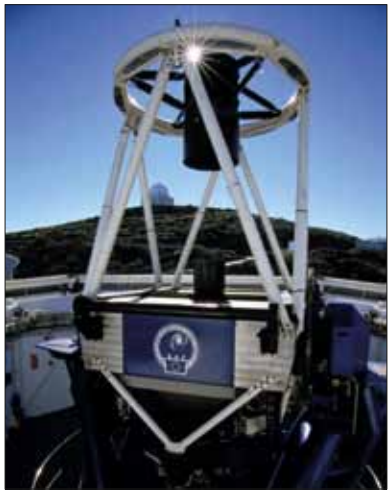
Astronomy can be the spark that lights up a lifelong interest in science – and takes young people into careers in science and engineering.

ENCOURAGING SCIENCE CHOICES

Astrophysics offers inspirational research to broaden horizons and influence subject choices at school. Keele University's Exoplanetarium introduces extrasolar planet research through a mobile planetarium. UCL researchers bring schools cosmology and dark energy research from the Planck and Euclid missions. Summer schools such as Queen Mary University of London's Media Space project and masterclasses from astrophysics researchers at Portsmouth and Birmingham aim to engage young people ahead of university choices. Oxford and Portsmouth astronomers have developed ZooTeach, a tool for teachers and students based on the Galaxy Zoo citizen science platform. Taking a different tack, Glasgow University researchers have produced a computer game, Black Hole Hunter, teaching science by stealth.

▼ **Hello down there!** ESA astronaut Tim Peake during his first spacewalk outside the International Space Station. UK schoolchildren are following his Principia mission through experiments on plants, exercise, environmental observation and even through radio links with Tim.

HANDS-ON ASTRONOMY FOR ALL



The National Schools' Observatory – based at Liverpool John Moores University – makes schoolchildren users of the Liverpool Telescope, a robotic instrument in La Palma, Canary Islands (pictured above). Through the NSO, pupils can take images of astronomical objects, tackle problem-solving tasks across the sciences – such as measuring how high the mountains are on the Moon – and even collect data for hot topics in research, including exploding stars and transiting exoplanets. The NSO provides more than 4000 partner schools with astronomy activities and resources as well as training for teachers; links with research at LJMU are a key element of engagement for pupils and teachers alike.

TARGETING TEACHERS

Continuing professional education for teachers is a focus for astronomy researchers, including those from the universities of Birmingham, Cardiff and Sussex – and Hertfordshire, where teachers can use the university telescopes. Current research – including Herschel space observatory data at Cardiff and Sussex – provides teaching resources as well as training; even ESA astronauts develop resources for teaching. Other approaches include Portsmouth cosmologists working with teachers at public events such as the BBC's *Stargazing Live*; and Birmingham University astronomers have established a residential teachers' conference. The National Space Centre in Leicester has set up the National Space Academy for teacher engagement and student events, reaching nearly 7000 students and more than 1000 teachers annually.

CHOOSING PHYSICS DEGREES

SEPnet, a consortium of universities in the southeast (Kent, Oxford, Portsmouth, Royal Holloway University of London, Queen Mary University of London, Southampton, Surrey and Sussex), encourages students to choose physics at university. They supply topical information for teachers and examples of careers in science, as well as visits including mobile planetariums, for GCSE and A-level students.

It works: "SEPnet has had an extraordinary impact on recruitment to the Physics Department at Sussex University at a time when it's of national importance to UK plc to increase STEM and particularly physics recruitment," says Prof. Sir Peter Knight FRS of Imperial College London.

▼ **Hello up there!** UK kids cheer on Tim Peake.

INDUSTRY FOCUS

Cornwall reaches out to space

Goonhilly has gone from part of our industrial heritage to a space communications gateway, thanks to a clever mix of industry, training and research.

GETTING TOGETHER AT GOONHILLY

The big antennas at Goonhilly Downs were built for the first intercontinental satellite communications and television broadcasts. But this unique infrastructure is now leading the way for the UK's space communications gateway.

Goonhilly Earth Station Ltd (GES) is in the process of redeveloping the site to provide companies with satellite communications and control services, alongside communications engineering research and development, plus manufacturing, training and education. The site, in the south of Cornwall, gives excellent visibility for satellites and is well connected to London and the rest of the UK.

There are also plans to link one of the big Goonhilly antennas to the eMERLIN radio astronomy network, boosting research capabilities and opening up opportunities for education and business. This would also link Goonhilly to the main UK academic network and open up new research and big data services.

BUILDING A BASE FOR SPACE BUSINESS

The world's largest satellite operators such as IntelSat, Eutelsat and Inmarsat, governments and businesses take advantage of the well-connected site for satellite services. The expertise of the GES team means that it offers specialist services such as telemetry tracking and control, in-orbit testing and launch monitoring. It also aids broadcasters across Europe. GES supports the UK space industry by developing systems for downloading data; Planets Labs and the Satellite Applications Catapult have chosen GES to host new tracking antennas for environmental data. And the development of Deep Space Communications at Goonhilly has attracted the interest of ESA and NASA for future Moon missions.

SITE MATTERS: TECHNICAL SKILLS FOR CORNWALL

Location is important for Goonhilly – but Goonhilly also matters to its location. The site is in rural Cornwall, a low-employment region where educational outreach and training in technical services is especially valuable. Alongside the intensive commercial development of the Goonhilly site comes investment in training and education. GES provides training in mission operations and satellite communications, and works with university partners to support professional development for teachers. It also offers business and communication engineering training in Africa.

The key to the success of this project has been the development of a joint vision between scientific-curiosity-driven universities and commercial partners interested, in the words of Truro and Falmouth MP Sarah Newton, in "rebalancing our economy away from London-centric financial services towards sustainable jobs in science, technology and engineering".

◀ **Washing the dishes.** Commercial success hosting satellite services drives further investment for business, training and research.

▼ **Looking up in Cornwall.** The new Goonhilly development offers employment in a region with limited opportunities.

Towards a scientifically literate society

Astronomy inspires awe and wonder, engages adults in learning and research, and drives tourism and regeneration.

BUILDING THE ZOONIVERSE

Galaxy Zoo, led by researchers from Oxford University, harnesses the power of the human brain to classify galaxies, better and faster than computers can. This is people-powered science, dealing with the flood of data from modern observatories – well over a million galaxies have been classified – and involving ordinary people in research. Researchers at the universities of Oxford, Sussex and Portsmouth work with Galaxy Zoo, and the software developed to engage and train volunteers is now used in other scientific disciplines, collectively called the Zooniverse.

ANSWERING FUNDAMENTAL QUESTIONS

Astronomers across UK universities provide talks and courses, including those from the universities of Birmingham, Cardiff, Central Lancashire, Edinburgh, Hertfordshire, Keele, Glasgow, Portsmouth and University College London. *Stargazing Live* events with the BBC brought new audiences to iconic locations such as Manchester University's Jodrell Bank Observatory and Portsmouth harbour. Online resources include the *Sixty Symbols* YouTube videos produced by the University of Nottingham.

INSPIRING SOCIETY AND CULTURE

Science is part of wider human culture; the National Schools Observatory's astronomical garden (pictured above) brought dark matter to thousands at the 2015 Chelsea Flower Show. Drama on astronomical themes has been inspired by the work of Cardiff astronomers on the Herschel space observatory, for example, and by solar physics at the University of Birmingham; literature addressing scientific themes is now part of the National Eisteddfod. The University of Edinburgh also researches the role of science in policy decisions for organizations such as the United Nations.

DRIVING URBAN REGENERATION

The National Space Centre, on a brownfield site in Leicester, has brought £100 million to the local economy, with more than 3 million visitors attracted to the mix of galleries and active research links to Leicester University. The centre is leading regeneration, creating more than 100 jobs and acting as the focus for a science park.

The Spaceport in Merseyside involves researchers from Liverpool John Moores University as well as specialist exhibitions and talks. The Spaceport, with 70 000 visitors a year, brings a net gain of £2 million each year into the local economy in and around Birkenhead, including 50 new jobs.

PROVIDING OPPORTUNITIES

Those inspired by the skies can develop practical skills through organizations such as the Workers' Education Association. The WEA has been funded by the RAS to develop courses for adults inspired by astronomy, to boost maths and science skills and employability. In a similar initiative, The Prince's Trust is using astronomy to engage young people and encourage them to gain technical skills and engage with science.

▶ **Outreach for the stars**. The RAS has supported an initiative at Glastonbury to encourage festivalgoers to experience looking through a telescope.

ASTRONOMY MEANS BUSINESS

How UK research benefits industry, education and society

The booklet gives examples of fundamental research in astronomy and astrophysics that are good for our society and prosperity

Astronomy inspires Stargazing draws young people into careers in science and technology

Astronomy discovers World-leading research addresses fundamental questions about life and the universe

Astronomy builds UK industry develops new technologies for observatories and for business

Astronomy benefits Skills developed for astronomy support a prosperous economy and society

www.ras.org.uk

Advancing Astronomy and Geophysics