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Department of Physics Newsletter

UNIVERSITY OF OXFORD

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IOP Institute of Physics Juno Champion

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EXPLORING THE HIGH ENERGY TRANSIENT UNIVERSE

Astrophysical transients – very short-lived astronomical events observed from earth – are both the sites and signatures of the most extreme phenomena in our Universe: for example, exploding stars, compact object mergers, black holes, neutron stars and ultra-relativistic flows. They are invaluable probes for subjects as diverse as relativistic astrophysics, stellar evolution and cosmology. They also have the potential to act as probes of the intervening interstellar and intergalactic medium on all scales, up to and including cosmological distances.

Our research group within Oxford Astrophysics focuses on observations of such phenomena in the radio and X-ray bands, using the world's largest radio telescopes and cutting-edge orbiting observatories. In the near future we will be embracing Oxford's commitment to the Large Synoptic Survey Telescope (LSST) project and expanding into the area of optical transients to cover the full range of electromagnetic phenomena from these events.

RADIO EMISSION FROM TRANSIENTS

Essentially, all explosive or relativistic phenomena in astrophysics have associated synchrotron emission, which is primarily detectable at radio bands. Extremely high velocity ejecta ('jets') from the explosion shock-accelerate electrons to relativistic energies and, at the same time, amplify and compress magnetic fields. The resulting spiralling motion of the electrons around the magnetic field lines produces the synchrotron emission we can observe with radio telescopes.

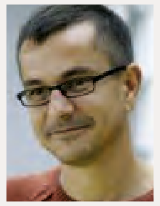
Radio emission provides some notable advantages to observations of transient phenomena at other wavelengths. Firstly, it is the only reliable tracer of the amount of kinetic energy released in an explosive event, as it is this kinetic energy which powers the shock-accelerated electrons that we observe. Without a good estimate of the kinetic feedback from an event, we cannot properly balance the energy budget associated with the phenomenon. Secondly, because radio observations can be performed by interferometers many 1,000s of km apart (effectively only limited by the diameter of the Earth), extremely high angular resolutions can be achieved, allowing an image detail impossible at other wavelengths where such techniques cannot be used.

Our group uses all of the world's major radio telescope arrays, and most notably is leading a project on astrophysical transients with the new MeerKAT radio telescope in South Africa (Fig. 1). On 13 July 2018 this major new radio telescope was inaugurated and began full operations. It is the most powerful radio telescope in the southern hemisphere, and part of the last stage of precursor telescopes before construction begins on the Square Kilometre Array in ~2025. Prof Rob Fender is co-lead, together with Prof Patrick Woudt (University of Cape Town), of a project called ThunderKAT to track the radio emission from relativistic transients with this telescope over a five-year survey. Oxford Astrophysics also leads other major programmes on MeerKAT, including deep extragalactic surveys and timing of pulsars. ThunderKAT's targets include accretion events onto white dwarfs, neutron stars and black holes; the explosions of massive stars; and gravitational wave bursts, which are accompanied by a short gamma-ray burst. We already have some breakthrough results, such as the discovery of a large-scale relativistic jet from a nearby black hole by third-year DPhil student Joe Bright.

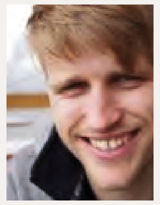
Fig. 1: The MeerKAT radio telescope, South Africa, the most powerful radio telescope in the southern hemisphere, began full operations in July 2018. Oxford leads several large survey programmes on this facility, including the ThunderKAT transients survey.

MULTI-MESSENGER OBSERVATIONS OF LIGO BURSTS

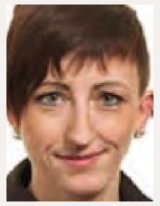
The electromagnetic counterparts of gravitational wave events is one of the hottest topics in astrophysics right now, following the joint discovery of gravitational and electromagnetic waves from the same event, for the first time in history, in August 2017. This event, the merger of two neutron stars codenamed GW170817 (the date of the discovery), produced at early times both a gravitational wave and gamma-ray signal. This was followed by strong optical emission from radioactive decay of rare r-process elements on a timescale of days, and then later by a synchrotron-emitting radio and X-ray afterglow, which was visible for nearly a year as relativistic ejecta from the event ploughed into the surrounding medium (see Fig. 2). First year DPhil student Lauren Rhodes, who is jointly funded by Oxford and The Max Planck Institute for radio astronomy in Bonn, as part of a radio transients collaboration, will lead future MeerKAT observations of such afterglows. This is a very exciting time, as LIGO resumed operation on 1 April 2019, and the estimated rate of neutron star mergers may be as high as several per year.



Prof Rob Fender (Astrophysics)

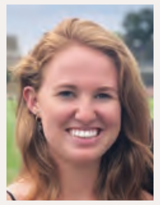


Dr Adam Ingram (Royal Society URF)

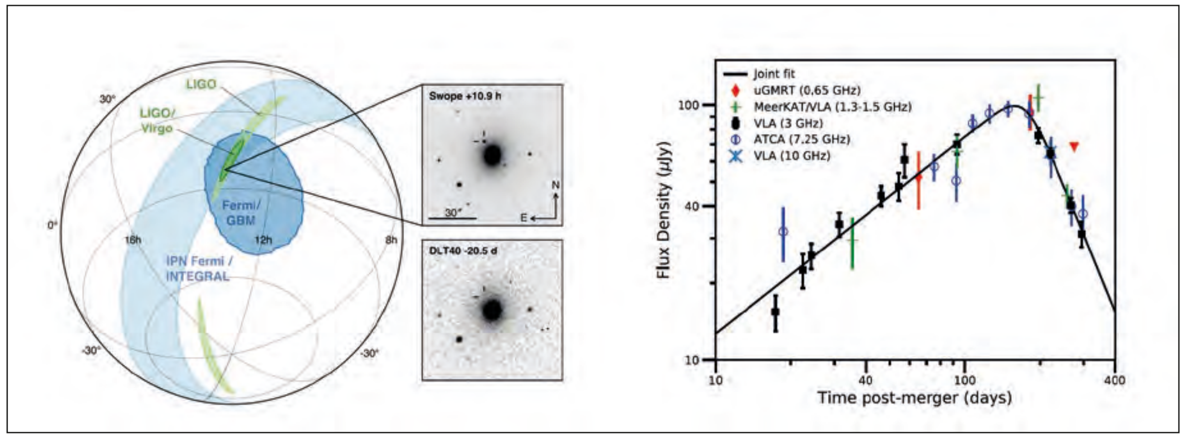


Dr Sara Motta (Glasstone Fellow)

Joe Bright (DPhil student working on jets with ThunderKAT)



Lauren Rhodes (DPhil student who will follow up new LIGO GW events with MeerKAT)



Right: Fig. 2. The hunt for the electromagnetic afterglow of the LIGO-Virgo neutron star-neutron star merger event GW170817. Left panel: combining localisations from LIGO and Virgo with those from the Fermi and INTEGRAL spacecraft allowed an optical transient to be identified in a galaxy 40 Mpc away. The optical emission probed the radioactive decay of rare elements formed in the merger event. Right panel: Within two weeks an X-ray and radio counterpart emerged, as a powerful relativistic outflow decelerated in the interstellar medium and produced synchrotron emission. Our group was involved in radio observations of this 'afterglow' with MeerKAT and is ready to follow-up new events when LIGO resumes operation on 1 April 2019.

X-RAY EMISSION

At almost the other extreme of the electromagnetic spectrum from radio emission is the X-ray band. X-rays tend to originate in the hot plasma (>10^8 K) very close to the central relativistic object or explosive event. Rapid X-ray variability can be used as a probe of the regions of largest gravitational curvature in the universe since the Big Bang. Plasma close to a black hole of mass ten times that of our sun (quite typical, we expect there to be millions of such black holes in our Galaxy) will orbit it 200 times per second, and we can probe these physical scales by performing Fourier analysis of photons collected with precise arrival times by orbiting spacecrafts. Accretion of matter onto these 'stellar mass' black holes is the origin of the brightest X-ray transients in the sky. Combining observations in the radio and X-ray bands can tell us how changes in the flow of matter in the most relativistic regions of the event couple to variations in the degree and form of kinetic feedback from the event.

RELATIVISTIC OSCILLATIONS

Analysis of X-ray emission from transients and high energy sources is led in our group by two fellows: Dr Sara Motta (Glasstone and Hintze Fellow) and Dr Adam Ingram (Royal Society University Research Fellow), with DPhil students Lise du Buisson and Ed Nathan. Together, Adam and Sara have shown that the most likely interpretation of oscillations in the X-ray flux from black holes, such as those illustrated in Fig. 3, is the precession of a torus of matter very close to the black hole. Adam has recently made predictions for the polarisation signature of such a precessing torus, which will be tested with the launch of NASA's Imaging X-ray Polarimetry Explorer in 2021.

Sara is also working closely with the ThunderKAT team to provide X-ray coverage of all radio transients observed with MeerKAT, and vice versa. By combining these data we are building a uniquely rich data set for understanding the connection between accretion and jets.

THE FUTURE

Combining radio and X-ray observations of high energy transients tells us about the matter very close to the relativistic event, and the explosive transport of kinetic energy to large distance away from the transient. Between these two frequency regimes lie the optical and infrared bands, in which the majority of transients are first discovered, and which provide us with information about the radioactive decays and mildly relativistic 'thermal' ejecta often associated with such events. Only by piecing together all wavelengths (and in some cases also the gravitational wave signal) can we build a coherent physical picture of what is taking place.

In the near future, the LSST will begin operations to monitor the southern sky with unprecedented depth and cadence to look for optical transients. Oxford has been a leading partner in LSST since its inception, and is looking to exploit this involvement in a range of science areas, not least of which is the study of optical transients. The goal for our group is that by combining our existing radio expertise, strengthening our X-ray expertise, and now moving into optical transients, we can provide the most coherent possible approach to the study of astrophysical transients.

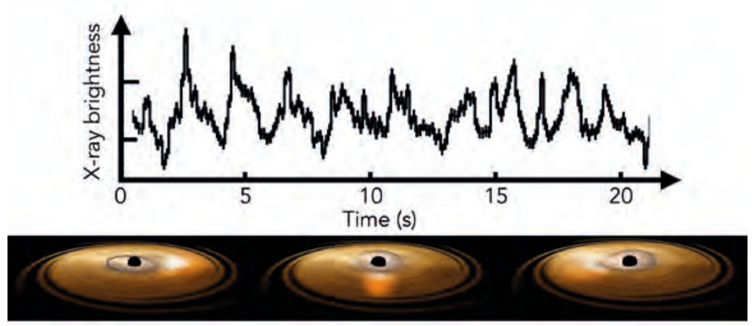
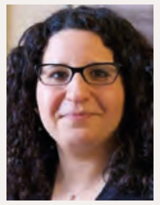


Fig. 3: A quasi-periodic oscillation in the X-ray flux of an accreting stellar-mass black hole. The inner accretion disk, close to the black hole, is undergoing a nodal precession – a 'wobble' of the inner disk, like a spinning top. This is due to the relativistic frame dragging effect, whereby a spinning massive object drags the surrounding space around with it, like a 'gravitational vortex'. This precession has been measured in the orbit of satellites around Earth, but the effect is tiny – one precession cycle would take around 33 million years! Around a black hole, a precession cycle takes only one second.

A CENTURY AND A HALF OF OCEAN WARMING AND SEA LEVEL RISE

Reconstructing the history of ocean temperatures using a 200-year-old mathematical model

Over the past century, increased greenhouse gas emissions have given rise to an excess of energy in the Earth system, most of which has been absorbed by the ocean, leading to increased ocean temperatures and sea level rise. Due to a scarcity of data, global estimates of ocean warming start only in the 1940s. In a recent study, published in the *Proceedings of the National Academy of Sciences of the United States of America*, we have estimated that, since 1871, the world's oceans have warmed the equivalent of roughly 1,000 times the annual global human primary energy consumption, with an associated sea level rise of over 5 cm. These results were obtained by combining observations with mathematical and numerical models.



Prof Laure Zanna
@laurezanna

Prof Jonathan Gregory (University of Reading; & Merton 1983)

OUR OCEANS

Oceans cover 71% of the Earth's surface, hosting millions of species and providing more than half of the oxygen needed for us to breathe. Oceans act as regulators and mediators of the climate system. For example, they modulate the surface temperature and feed moisture to the atmosphere, impacting rainfall over large areas of the planet. Oceans also serve as a vast reservoir of heat and carbon. The top 3 metres of the ocean contain as much heat as the whole atmosphere, and the top 50 metres contain as much carbon as the entire atmosphere.

A BUFFER OF CLIMATE CHANGE

Increased human-made greenhouse gas emissions give rise to an imbalance in the Earth's energy budget, which warms the planet. As the climate adjusts to more than a century of growing emissions, energy and heat from the atmosphere accumulate in the ocean. In the past 50 years, the oceans have absorbed roughly 93% of the extra heat now present in the Earth System. The remaining 7% is warming the atmosphere and land, and melting sea ice, glaciers and the Greenland and Antarctic ice sheets. Futhermore, since the industrial revolution, the ocean has also absorbed more than 30% of anthropogenic carbon dioxide emissions. Therefore, by absorbing human-made excess heat and carbon, the oceans delay the rate of climate change in the atmosphere.

OBSERVING THE OCEANS

Observational constraints on future anthropogenic warming critically depend on accurate estimates of past ocean warming. Near-global data coverage of ocean temperatures has only been achieved since 2006 with the full deployment of Argo profiling floats in the upper 2000 m. Earlier observations, which are geographically more sparse and often restricted to shallower depths, are insufficient to permit an accurate global estimate of ocean heat content before the 1940s.

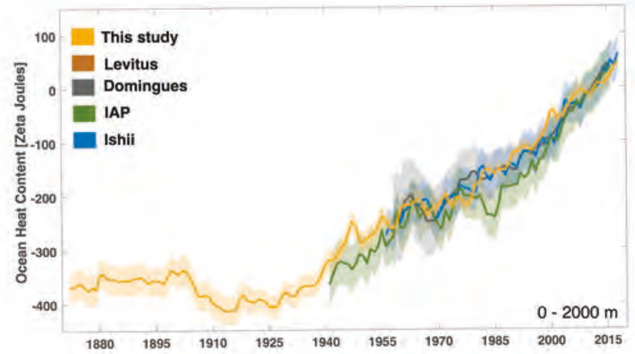


Fig. 1

AN OLD IDEA TO TACKLE A MODERN PROBLEM

The ocean interacts with the atmosphere at the sea surface, specifically air-sea fluxes imprint the current state of the atmosphere on ocean fluid parcels. These water parcels, which retain information acquired at the surface, are then transported away from the surface into the ocean interior. The timescales of transport of these water parcels from the surface into the interior constitute the memory of the ocean to surface atmospheric forcing. The large-scale ocean currents, and small-scale mixing and diffusive processes determine the transport and timescales of fluid parcels in the ocean interior. To reconstruct ocean temperature changes, we, therefore, need to know the transport pathways (and their timescales), and the temperature changes at the ocean's surface. Such problems can generally be solved by finding a so-called surface boundary condition propagator (also known as a type of Green's function) – an idea that originated in the 1830s from the British mathematician George Green. Green's functions are nowadays widely used to study partial differential equations.

Above: Warming stripes: visualisation of full-depth ocean warming from 1870 to 2018.

Fig. 1: Ocean warming reconstruction with standard error (orange) for the upper 2000 m of the ocean, compared with other available estimates.

Fig. 2: Observed ocean warming trends in the past 60 years over the top 2000 m (data from NCEI https://www.ncei.noaa.gov/), highlighting the non-uniform warming over the planet, argued to be due in part to a changing ocean circulation.

SINCE 1871, THE WORLD'S OCEANS HAVE WARMED THE EQUIVALENT OF ROUGHLY 1,000 TIMES THE PRESENT-DAY ANNUAL GLOBAL HUMAN PRIMARY ENERGY CONSUMPTION

430 x 10^{21} JOULES OF WARMING SINCE 1871

For our specific problem, we extracted ocean transport Green's functions, based on an approach initially developed by Prof Samar Khatiwala (Earth Sciences). The Green's functions were taken from a state-of-the-art estimate of the global ocean circulation that optimally combines satellite and *in-situ* measurements with a global ocean circulation model, provided by Prof P Heimbach (University of Texas). Our method is analogous to inserting dye at the surface of the ocean and monitoring how it spreads into the interior over time. Our dye is surface temperature, which is better observed than interior ocean temperature. We use a range of observational products of surface temperatures to sample the uncertainty. The surface temperature changes are the partial imprint of the atmosphere on the water parcels, which are then transported into the ocean interior with our Green's functions. Using this method we find global warming of the oceans of 436 ± 91 x 10^{21} Joules since 1871 (Fig. 1). With the help of former MPhys student Jonny Ison (Christ Church 2018), we find that our reconstruction agrees with estimates made from interior temperature measurements over the past 50 years. Our new method allows us to estimate the ocean heat uptake which occurred since the beginning of the industrial era, before interior temperature records began. As the oceans warm, the water expands, leading to global mean sea level rise. This increase in sea level is in addition to global mean sea level rise due to melting ice. Based on our reconstruction, we estimate that about 50 mm of global mean sea level rise in the past 150 years was due to ocean warming, roughly a quarter of the total.

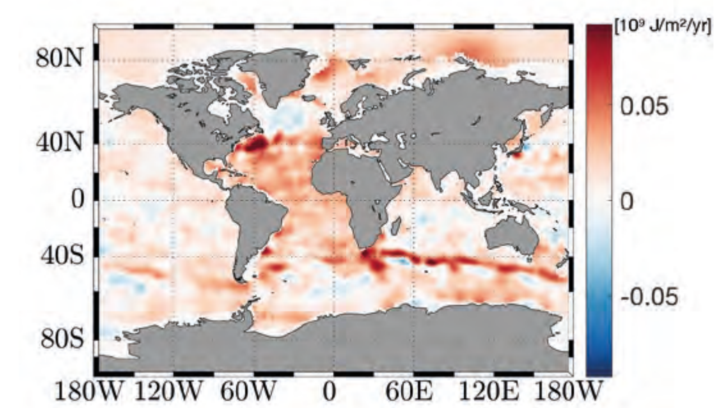


Fig. 2

A CHANGING OCEAN CIRCULATION?

The new estimate also suggests that in the last 60 years up to half of the observed warming and associated sea level rise in parts of the Atlantic Ocean are due to changes in ocean transport. During this period, more heat has accumulated at lower latitudes than would have if circulation were not changing (Fig. 2). While we identified a change in ocean circulation, we cannot attribute it solely to human-induced changes. Much work remains to be done to validate our method and understand how heat is transported around the world's oceans. As such, we are part of a large multi-institution NERC-funded grant, TICTOC (http://projects.noc.ac.uk/tictoc/) aimed at using collected physical and chemical ocean tracers, together with simulations, to refine our methods. The project will address many outstanding questions on the role of ocean circulation in shaping the regional distribution of global warming and sea level rise, with the goal of boosting confidence in our predictions of future climate change.

L Zanna, S Khatiwala, J Gregory, J Ison, P Heimbach (2019). *Global reconstruction of historical ocean heat storage and transport. Proc. Natl. Acad. Sci.*, 116 (4) 1126-1131, 10.1073/pnas.1808838115.

The new datasets are available online at https://goo.gl/SW731y

USING POLYMER PHYSICS TO IMPROVE CANCER TREATMENT

Polymers are large molecules that consist of long chains made of repeating subunits (monomers). Individual polymer chains can reach large macroscopic sizes, the DNA encapsulated in our cells is a two-metre-long polymer but their diameters are in the nano-scale, the diameter of DNA is two nanometres.

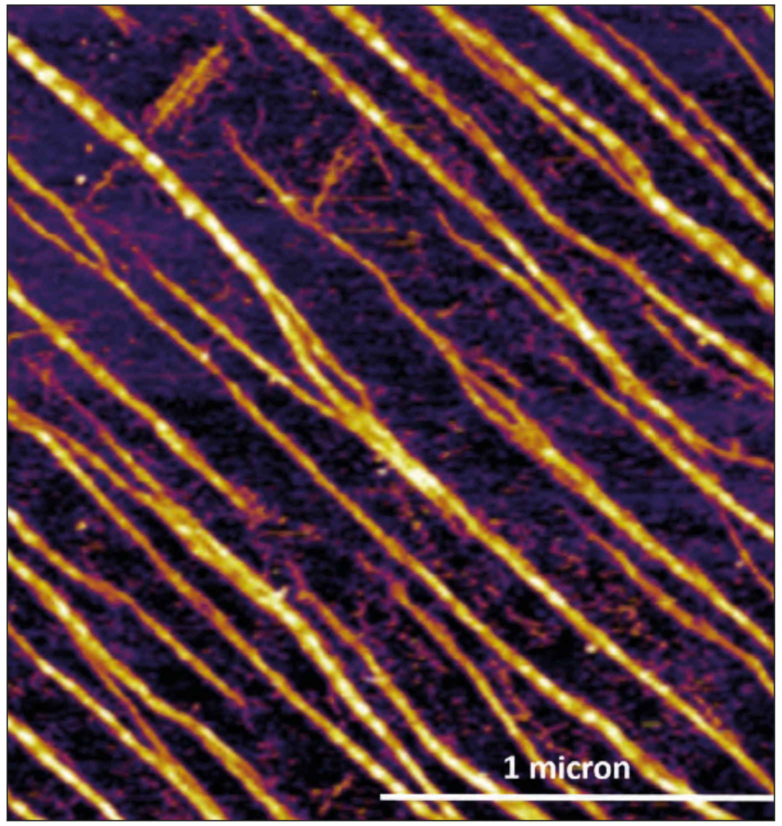
POLYMERS IN BIOLOGY

The particular ability to link what happens at the nanometre scale with larger size scales is one of the characteristics that makes polymers central to biology: polymers wriggling, assembling and catalysing chemical reactions in salty water gave rise, most likely, to the emergence of life on Earth (DNA, RNA and proteins are polymers). Polymers are also crucial to biological growth and form: collagen (the most abundant protein in humans) is a fibrous protein that underpins the formation of complex networks that shape our bodies to a large extent; cellulose fibres in cell walls create the structural frame of plants' shape and growth; and chitosan (the second most abundant polymer on Earth after cellulose) forms the shells of crabs, shrimps and other crustaceans.

FIBROUS PROTEINS AND TUMOURS

Polymers are also crucial in the development of tumours and the effectiveness of therapeutic treatments. In order to grow into surviving tumours, cancer cells need to create an environment that provides nutrients but, crucially, they also need to prevent the immune system from destroying them. The development of a tumour is often accompanied by the deposition of large amounts of fibrous proteins, such as collagen, that create a robust structural framework which facilitates its survival and growth. A particular example of this behaviour is pancreatic cancer.

Pancreatic cancer is one of the most deadly types of the disease. Chemotherapy is largely inefficient: surgery is the only curative treatment option in most cases. But, due to advanced stage at diagnosis, less than 20% of patients receive surgery. Chemotherapy can improve this figure by shrinking tumours, however, most pancreatic cancers do not respond to chemotherapy. The ineffectiveness of chemotherapy is thought to be related to the mechanical properties (eg stiffness) of the tissue emerging from the anomalous deposition of fibrous proteins (such as collagen), which result in a restriction of fluid flow within the tissue, impairing drug delivery. Chemotherapy is, therefore, inefficient because the drugs do not even reach the cells. Existing tumour-targeting chemotherapies are not designed to enhance or control the transport of fluids/drugs, or indeed the physics underlying it.

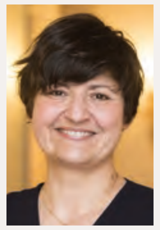


Left: Collagen fibres imaged in physiological fluid environment by AFM. Imaged by Casey Adam in Contera Lab at Oxford Physics.

PHYSICS COLLABORATES WITH MEDICINE

In the past few months my group at the Clarendon laboratory has started a collaboration with Dr Alex Gordon-Weeks from the Nuffield Department of Surgical Science. Dr Gordon-Weeks is a surgeon and an expert on biology of pancreatic cancer. We are interested in using physics to improve our understanding of pancreatic tumours and eventually make treatments more effective.

This project fits with the current focus of our lab: the study of the physics of biological systems (polymers, cells and tissues) using the combined powers of atomic force microscopy (AFM) and soft matter physics. AFM is the only tool that can produce images of biological systems in fluid at nanometre and sub-nanometre resolution. AFM is not an optical microscope, but relies on the precise measurement of the forces between a nanometre-sized tip and the specimen, to produce images of the sample as it is 'felt' by the touch of the tip. Doing this very accurately, in a quantitative way, allows us not only to 'see' the sub-molecular details of life, but also to extract other quantities such as the mechanical properties of biological structures (eg the softness of the materials or the time it takes to react to a nano-sized deformation). The combination of images with local quantitative information about the mechanics of biological systems make the AFM a unique tool to investigate the physics of tissues and the way they work. Ultimately, every chemical reaction in biology is catalysed by a mechanical force, and every biological movement is supported by a mechanical structure.



Sonia Contera is an Associate Professor of Biological Physics and author of the forthcoming book: *Nano Comes to Life: How Nanotechnology Is Transforming Medicine and the Future of Biology* (November 2019)

@SoniaContera

Atomic Force Microscopy provides unprecedented insight into the biology of tumour growth

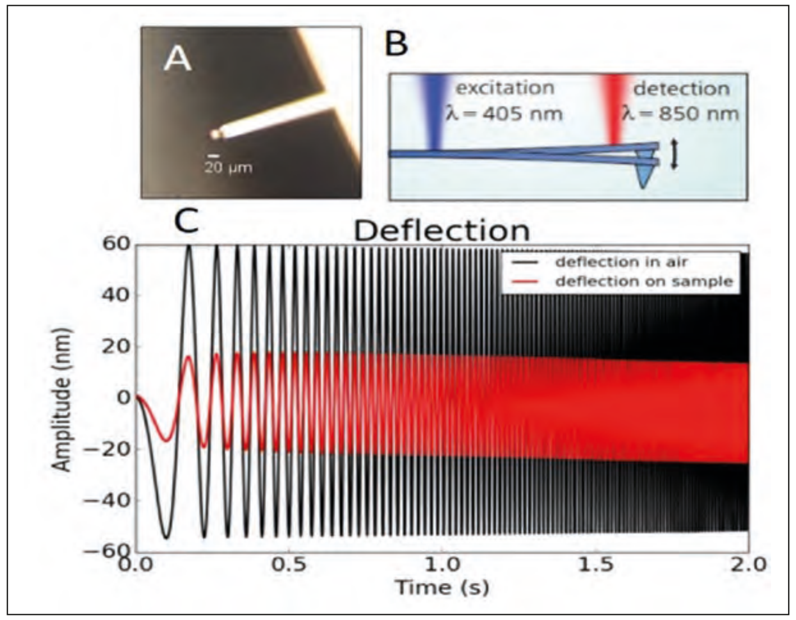
In the particular case of pancreatic cancers, we are using AFM to investigate the mechanical properties of collagen and of the networks it forms with other polymers. Our objective is to understand how collagen networks control the diffusion of molecules (including drugs) within the tumour. To achieve this goal, we make use of AFM experiments, combined with traditional biological and biochemical techniques and also modern biological advances such as proteomics. But, crucially, we make use of the predictions from 'polymer physics' theory.

POLYMERS WRIGGLING, ASSEMBLING AND CATALYSING CHEMICAL REACTIONS IN SALTY WATER GAVE RISE, MOST LIKELY, TO THE EMERGENCE OF LIFE ON EARTH

POLYMER PHYSICS AND ATOMIC FORCE MICROSCOPY

The field of polymer physics was born from the pioneering work of Paul Flory (Nobel Prize in Chemistry in 1974), which was followed by the advances of notable physicists such as Pierre-Gilles de Gennes (Nobel Prize in Physics in 1991), Sam Edwards and Masao Doi. Polymer physics theory is currently used in materials research, and has been particularly useful in developing applications such as the rubber of car tyres.

Imbued with the methods and concepts of polymer physics, we are currently developing experiments and experimental techniques based on the use of AFM which allow us to tackle complex biological and medical problems such as pancreatic cancer or heart disease. We also apply our techniques to the development of artificial materials that can be used in applications of regenerative medicine. Apart from medicine, we are interested in understanding how life is ultimately underpinned by the general laws of physics, in particular how biology exploits non-equilibrium thermodynamics to grow the shapes that allow survival and replication.



Right: Fig. 2. Nano-rheology technique developed by Alba Piacenti in the Contera lab. Fig. 2A shows a microcantilever that is used to deform the material. Fig. 2B shows a blue laser used to excite the cantilever and a red laser that is used to detect its movement. Fig. 2C shows the movement of the cantilever in air (black) and in contact with a polymeric material (red).

Alba Rosa Piacenti in our lab is currently working on a new technique which will improve our knowledge of the growth of tumours and plants, and enable us to design materials for regenerative medicine and drug delivery. To learn how a material performs, we need to know its structure (which we achieve through microscopy), and we also need to know how it responds to deformation. We do this all the time in 'real' life: imagine you are buying a pair of running shoes... first you look at them (nice? would they fit?), then you hold them (too heavy?), you stroke them (smooth?) and deform them (flexible enough? How long will they last if I use them every day?). In our experiments we are trying to answer these types of questions, but we are also seeking to unveil new information such as: will they grow, why and how? Will they allow the drugs to reach the cancer cells that need to be eliminated? To achieve this, Alba is developing a 'nano-rheology device' that focuses a laser on an AFM microcantilever (a small device shaped as a microscale diving board) with a nanosize tip at the front. When the laser hits the microcantilever, it bends. The bending of the microlever can be used to indent the polymeric material under study at the nanometre scale, and from both the deformation and the time the material takes to recover from it, many useful properties of the material can be determined. In order to extract the maximum information, we need to do this at many indentation speeds, and so Alba has designed a laser signal that interrogates the sample at many speeds from the Hz (one impact/second) to the MHz range (million impacts/second) (see Fig. 2). The information that she obtains from this technique can then be analysed using theory and mathematical models to, for example, understand water flow inside the polymer mesh, or its growth. Her research has attracted the interest of industry, and we now collaborate with Oxford Instruments Asylum Research to make the technique available for a large range of applications.

We have established a large network of collaborators in other departments, including Plant Sciences; the Mathematical Institute; Engineering Science; the Radcliffe Department of Medicine; and the Addenbrookes Hospital in Cambridge. Our lab is part of an increasingly large community of physicists working at the interface of physics and biological/medical sciences. This activity has emerged in part from the limitations of the current paradigms of biology to identify and cure diseases, but also from the development of tools such as AFM and polymer physics that are progressively pushing a significant part of biological research into the realm of physics.

WORKING WITH THE SPACE INDUSTRY

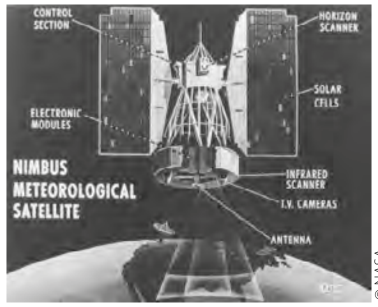
www.physics.ox.ac.uk/enterprise

Academics at the University of Oxford have been studying space for more than 400 years and have hosted the Savilian Professor of Astronomy since 1619, as well as including in our ranks famous scientists such as Sir Christopher Wren, Edmond Halley and Stephen Hawking. Today, we are playing a significant role in the UK's space industry sector, which is part of a rapidly growing global market valued at £190 billion and predicted to double in the next 10 years.

Dr Phillip Tait

THROUGH TIME AND SPACE

Oxford Physics entered the space age on 8 April 1970, with the launch of its first instrument, the Selective Chopper Radiometer (SCR) on Nimbus 4, a meteorological research and development satellite.

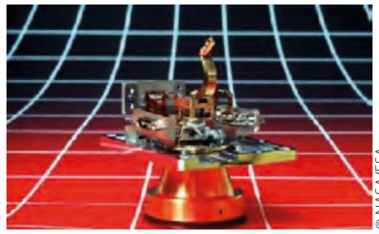


© NASA

Nimbus 4, 1970

A series of increasingly more sophisticated instruments followed, including the Improved Stratospheric and Mesospheric Sounder (ISAMS) experiment on the Upper Atmosphere Research Satellite (UARS), which was deployed from space shuttle 'Discovery' in 1991 and also the High Resolution Dynamics Limb Sounder (HIRDLS) instrument on the Aura satellite, launched in 2004.

Oxford Physicists have also applied the same techniques to remote sensing of other planets, and began building instruments for planetary missions, starting with the Orbiter Infrared Radiometer (OIR) experiment on Pioneer Venus in 1978, which was developed as a collaboration between NASA's Jet Propulsion Laboratory and Oxford. This was followed by many more infrared remote sounding instruments orbiting Mars, the Moon, Jupiter and Saturn. Notably, Oxford collaborated with NASA's Goddard Space Flight Centre on the development of the Cassini Composite InfraRed Spectrometer, which orbited Saturn from 2004 until September 2017 when its mission ended with a spectacular dive into the planet's atmosphere.



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Cassini Composite InfraRed Spectrometer

Oxford Physics has also developed meteorological and seismic instrumentation for other planets. Our most recent contribution to planetary exploration is the Short Period Seismometer (SEIS-SP) instrument, which was safely deployed on the surface of Mars just a few months ago by NASA's InSight lander. The project was led by Imperial College London in collaboration with STFC RAL Space, the UK Space Agency (UKSA) and a team from Oxford Physics led by Dr Simon Calcutt and Dr Neil Bowles. Oxford's role in this instrument development was to lead the assembly, integration and testing. The instrument can measure the tiniest seismic waves or 'Marsquakes', which will help scientists understand Mars' internal structure and subsequently its formation.

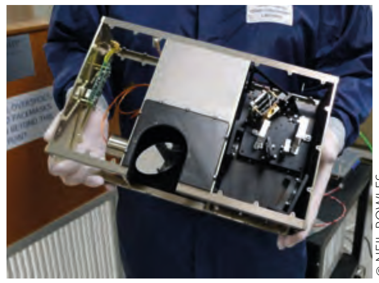
© NASA/JPL-CALTECH

InSight with SEIS deployed

EYE IN THE SKY

Oxford Physics continues to develop instruments for Earth Observation, providing the Compact Modular Sounder (CMS) on the UK's TechDemoSat-1 (TDS-1) Satellite. CMS is a modular infrared remote sensing radiometer, sensitive to the temperature of the Earth's atmosphere at different heights, as well as trace chemicals. TDS-1 was a technology demonstration satellite developed by Surrey Satellite Technology Ltd launched in 2014 and used to test novel instrument designs for future missions to Earth's orbit, Moon, Venus or an asteroid.

The CMS instrument has been further optimised and miniaturised so that its latest incarnation, the Compact Imager and Radiometer (CIIR) project, can fit on a CubeSat, a new class of miniaturised satellite weighing only 6 kg, designed to reduce the cost of deployment, allowing many more instruments to be launched and opening up more opportunities for novel commercial services. Developed in collaboration with Clyde Space Ltd, RAL Space and the Satellite Applications Catapult, CIIR is a multi-spectral imaging radiometer that operates in the thermal infrared. In addition to applications in solar and Earth system science, the design can be tuned to be sensitive to, for example, atmospheric trace gases, volcanic aerosol, which is an aviation hazard, or mineral composition mapping, as well as providing new sources of data for commercial sectors including agriculture, disaster monitoring and pollution control.



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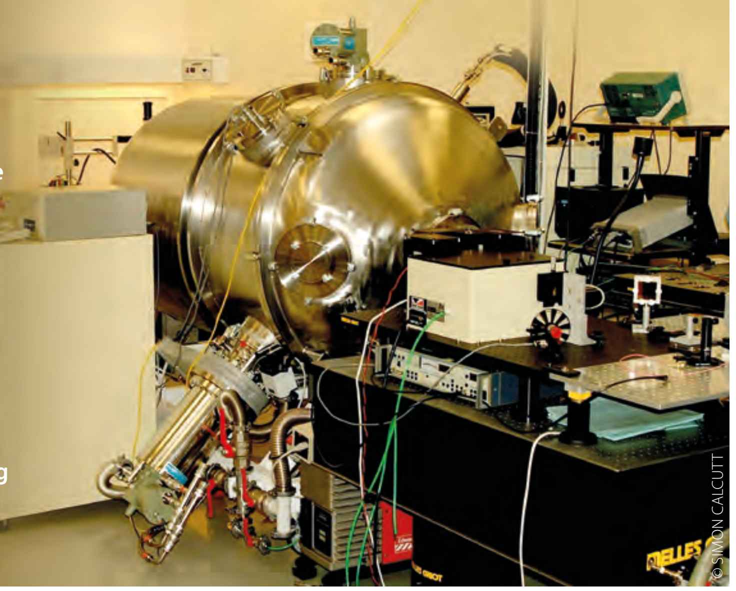
The Compact Infrared Imager and Radiometer

OUR SPACE INSTRUMENT TEST FACILITIES

To support the design, fabrication, testing and calibration of instruments for use in space and on the surface of other planets, specialist facilities have been developed at Oxford Physics. The pre-flight calibration of multiple remote sensing instruments has been carried out in chambers in our clean areas and we have facilities for thermal vacuum, vibration and shock testing as well as characterisation of infrared sensors and seismometers. These facilities and associated expertise are also now being used by space companies, particularly those based near Oxford, thus providing exciting opportunities to develop new collaborations with industry.



Thermal vacuum chambers in clean room

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THE GLOBAL SPACE MARKET IS ESTIMATED TO REACH **£400 bn** BY 2030 WITH THE UK SPACE INDUSTRY ANTICIPATED TO CAPTURE **10%**

13,000 small satellites will be launched by 2030

UNIVERSITY OF OXFORD

Oxford Physics is close to the emerging Space Hub at Harwell: **89** space organisations employing **950** people

ICONS MADE BY EUCALYP FROM WWW.FLATICON.COM

The Space Industry

- Oxford Physics is just 13 miles from the emerging Space Hub at Harwell, which includes the European Space Agency (ESA) Business Incubation Centre and its European Centre for Space Applications and Telecommunications; RAL Space and the Satellite Applications Catapult; as well as a range of space companies – in total 89 Space organisations employing 950 people.
- The space industry is segmented into 'upstream' and 'downstream' sectors. The latter relates to space-enabled services such as satellite communications, global positioning services or use of Earth observation data, whilst the 'upstream' sector includes space infrastructure, spacecraft, launchers and satellites.
- By 2030, it is forecasted that 13,000 small satellites will be launched.
- Downstream services and applications are estimated to reach revenues of £37 bn by 2030. The most significant areas of opportunity are in applications for the defence, health, environment, maritime and telecommunications sectors.
- The global space market is estimated to reach £400 bn by 2030 with the UK space industry anticipated to capture 10%.

OUR SPACE INSTRUMENT DEVELOPMENT AND TESTING EXPERTISE:

- Mechanical and thermal design
- Thermal vacuum testing
- Vibration and testing
- Focal plane design and manufacture
- Calibration target design and manufacture
- Facilities for CAD (mechanical and optical)
- Product assurance
- Planetary protection requirements for planetary missions
- Flight electronics manufacture

ENGAGE...

© BEN FERNANDO

DPhil student Rory Evans and postdoc Dr Tris Warren providing a tour of our Space Instrument Testing Facility

The Oxford Space Industry Day, held in September 2018 at the Department of Physics, was attended by more than 170 delegates from industry and academia and included keynotes from ESA's UK Director Magali Vaissiere and UKSA CEO, Dr Graham Turnock.

This engagement role is being supported by the Oxford Space Research Network, co-ordinated by Oxford Physicist Dr Colin Wilson, and brings together more than 100 researchers working across the University on research related to spacecraft technologies or data from satellites, from departments as diverse as Physics, Zoology, Computer Science, Materials and Law.

Other recent space events hosted by our department have included a public lecture on 'The search for life beyond Earth, in space and time' by NASA's Chief Scientist Dr James Green (jointly organised with the Worshipful Company of Instrument Makers and our DPhil student Ben Fernando) and also a panel discussion on the contribution to society of the space industry with a keynote from Prof Johann-Dietrich Wörner, Director-General of ESA, (jointly organised with the Oxford University Aeronautical Society and Science Innovation Union).

As nations develop their plans for space exploration, the role of physicists and industry is becoming more important than ever. SpaceX, led by Elon Musk, who studied business and physics as an undergraduate (and briefly started a PhD in Physics) is developing launch vehicles for NASA, whilst Oxford Physics alumnus Will Marshall, whose DPhil was in quantum physics before he joined NASA, is co-founder and CEO of Planet, a US-based company that has the largest fleet of Earth-imaging satellites in orbit. I hope this article has provided a flavour of the exciting projects under development at Oxford Physics, as well as our role in the UK's ambitions for space.

NOTES FROM THE HEAD OF PHYSICS


Prof Ian Shipsey, Head of Department

There has never been a better time to be the Head of Oxford Physics! When I began last September, there was a great foundation on which to build: we were number one in the Research Excellence Framework; research income was at an all time high; the Beecroft building was funded and about to be opened; and national recognition had been received for the advances made as a department in equality and diversity.

EXCELLENCE IN RESEARCH

A glance at the global rankings reveals that Oxford Physics is one of the top 10 departments in the world. The goal for the next 10 years is to become the best physics department in the world. This is ambitious and it will take a great team effort and very significant resources to achieve, but as Michelangelo said: 'The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark'.

As we embark on this journey, we are guided by our mission statement: *We apply the transformative power of physics to the foremost scientific problems; educate the next generation of leading physicists; and promote the public understanding of physics.*

Over the last two terms, all faculty have engaged in developing a decadal science strategic plan for Oxford Physics. The first part is largely in place: we have five faculty searches underway, and we plan to recruit six more members of faculty next year. This will be the largest infusion of faculty in many years. The University backs our plan. Our latest recruit is world-leading physicist, Prof Seamus Davis, who joins from Cornell, where he was the A J G White Distinguished Professor of Physics. Seamus specialises in the development of innovative instrumentation to allow direct visualisation (or perception) of characteristic quantum many-body phenomena at atomic scale.

We are powered by our people. They are our greatest asset and it has been a privilege to meet and be inspired by so many of the Oxford Physics team – students, staff, academics and alumni – in the last six months. In September, at the Beecroft opening, I met many of the alumni and benefactors who made the building possible. Their support and deep commitment to Oxford Physics is to be cherished and will be a key to reaching our goal as we seek funding for new professorships, five-year young researcher grants and graduate studentships.

In October I gave induction talks about our research programmes across all of physics to 160 new undergraduates and 90 new DPhil students. The anticipation and excitement of this highly-talented young cohort as they began their Oxford careers was palpable. Our DPhil students power much of our research, but they are too few compared to top US institutions. In November, colleagues and I were at Shanghai Tech, to discuss a long-term partnership that will support the creation of new international studentships. The Memorandum of Agreement is about to be signed as this article is being written (May, 2019). A similar partnership with the Max Planck Institutes is also about to be signed; these join a partnership I had the good fortune to establish in 2014 with the University of Tokyo that currently fully funds eight Oxford DPhil students.

OXFORD PHYSICS ON THE WORLD STAGE

In December I had the privilege to give the State of the Nation address to Oxford Physics in a packed Martin Wood Lecture Theatre. I shared the stage with talented colleagues: topics ranged from cutting-edge research in quantum computing, exo-planets, super-resolution microscopy and perovskite solar cells, to technical infrastructure and Physics Aptitude testing. It was moving to recognise Dame Jocelyn Bell-Burnell as we celebrated the award of the 2018 Special Breakthrough Prize 'for fundamental contributions to the discovery of pulsars, and a lifetime of inspiring leadership of the scientific community' and her decision to donate the £2.3M prize to create the Bell-Burnell Graduate Scholarship Fund. Just prior to Christmas, I was proud to share the image of the Mars Insight Lander, with an Oxford crest clearly visible on the surface of Mars, as a holiday card. As 2019 began, I visited alumni in New York. In February I represented the University along with Pro-Vice-Chancellor Patrick Grant at a Harwell-Oxford strategy meeting. We discussed the Oxford Cambridge Corridor; Harwell as an engine for national growth; the vision to grow Harwell into the most important campus of its kind worldwide, and how Oxford can play a pivotal role in enabling that. In March I welcomed delegations from IBM, Google-X, and the US Government to Oxford Physics. All three are exploring creating partnerships with us.

We are increasing investment in our superb technical infrastructure to support our faculty in research. We are engaging actively with industry and business (see p8–9 Philip Tait's article). And our rate of producing new spinout companies has also increased. We are developing exciting new programmes to improve access of under-represented groups to Oxford. I'd love to tell you all about them, but our talented Editor, Prof Dimitra Rigopoulou, has reminded me I've exceeded the word count. Much more in future newsletters.


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The University of Oxford logo on the Martian surface aboard the InSight lander


© S.SEBB/DEPT OF PHYSICS

Dame Jocelyn Bell-Burnell

Below: Prof Ian Shipsey delivering the State of the Nation address

Oxford Thinking
The Campaign for the University of Oxford

UNIVERSITY OF OXFORD

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- If you request University of Oxford Development Trust (OUDT) to collect a payment, confirmation of the amount and date will be given to you at the time of the request.
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- If an error is made in the payment of your Direct Debit, by OUDT or your bank or building society, you are entitled to a full and immediate refund of the amount paid from your bank or building society.
- If you receive a refund you are not entitled to, you must pay it back when OUDT asks you to.
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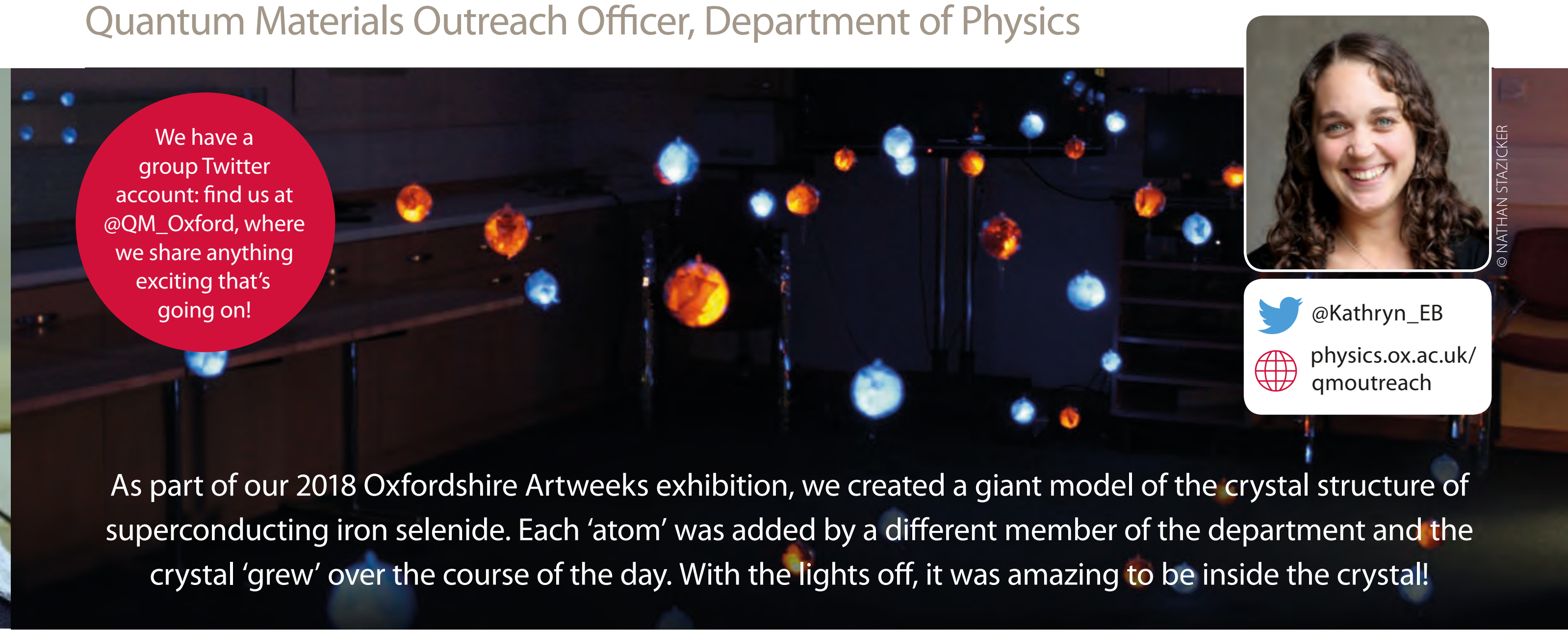
FIVE MINUTES WITH... DR KATHRYN BOAST

Quantum Materials Outreach Officer, Department of Physics



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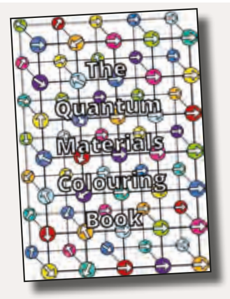
@Kathryn_EB

physics.ox.ac.uk/qmoutreach

We have a group Twitter account: find us at @QM_Oxford, where we share anything exciting that's going on!

As part of our 2018 Oxfordshire Artweeks exhibition, we created a giant model of the crystal structure of superconducting iron selenide. Each 'atom' was added by a different member of the department and the crystal 'grew' over the course of the day. With the lights off, it was amazing to be inside the crystal!



Above: The world's first Quantum Materials colouring book. Alongside images of labs, objects and structures, it features explanations of some of the phenomena we study. It's suitable for children and adults alike; you can download it for free from bit.ly/qmcolour.

Right: Making liquid oxygen using liquid nitrogen in the 'Magnets Fantastic' science show.

Bottom: Some of our highly esteemed professors feature on our group's YouTube channel! In this video, Prof Mike Glazer explains crystal growth with an exciting demonstration.

Tell us a little bit about your background

I started my Oxford Physics career as an undergraduate studying physics and philosophy. I loved the parts of the course that explored the philosophy of physics, and still have a soft spot for thinking about the nature of space and time. I then changed tack and did a DPhil in experimental particle physics, working on the LUX-ZEPLIN dark matter search. While an undergraduate and during my DPhil, I tried my hand at science communication and outreach. When I discovered that you could do it as a job, I was sold!

Can you explain the work you do?

I now work as the Outreach Officer for the Quantum Materials group. My challenge is to take their research and work with them to create exciting and engaging ways of explaining it to a wide range of audiences. We've done this through numerous activities, from interactive art installations to colouring books via science shows, workshops, public lectures, videos and festivals!

What scientific breakthrough would you like to see in your lifetime?

Room temperature superconductivity! It has the potential to create a step-change in the technology we rely on. Floating cars and hoverboards for everyone, but perhaps, more importantly, it could revolutionise electricity transmission and storage.

Who inspires you?

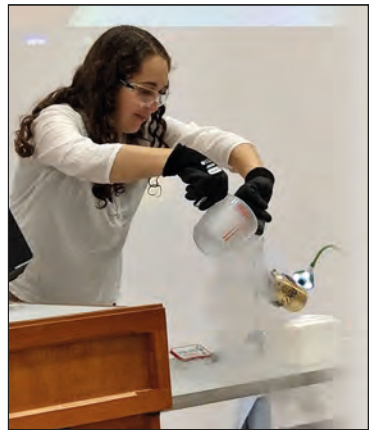
There are some really dedicated, strong and successful women in physics at Oxford, who I have often found myself looking up to. There's also a brilliant network of women in science around the world on social media, all of whom support and inspire each other.

What other interests do you have besides physics?

I spend quite a lot of my spare time promoting diversity in science. I created and have helped run the department's 'Marie Curious' girls-in-STEM event, and I'm currently planning a 'Diversity and Awareness in STEM' week, to take place in May. When I need a break from science, I enjoy cooking, reading and finding some sunshine!

What advice would you give people who want to study Physics?

If you want to study physics, you've probably already found something in it that excites you. Follow that up! Read more about it – I love the 'Very Short Introductions' series. You can watch videos or documentaries – YouTube is packed to the rafters with people explaining amazing physics, and some of it is stellar quality. Or, check out science magazines – a lot of them have great content on their websites, even if you don't want to subscribe. Student science magazines are good too – they're almost always freely available online



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and often cover slightly more obscure topics. And finally, do some physics of your own. That might be through some citizen science at www.zooniverse.org or a project you want to try at home, or maybe you just want to practice some physics problem-solving with www.isaacphysics.org – there are loads of ways to get involved. Whatever you decide to do, find the things that make your jaw drop – that's *your* physics.

Visit our YouTube channel: bit.ly/QMOYouTube

Events... IN PICTURES

PARTICLE PHYSICS CHRISTMAS LECTURE

This year's Particle Physics Christmas Lecture, took place on December 1st, hosted by Prof Daniela Bortoletto, Head of Particle Physics. Prof Mark Thompson, Chief Executive of the Science and Technology Facilities Council (STFC) and Professor of Experimental Particle Physics in the Cavendish Laboratory, Cambridge, gave a talk entitled: 'Particle physics: what next?'. The talk and panel discussions were followed by a sit-down lunch, mince pies and hot drinks in the Clarendon Common Room. The event was, as always, a great success.

A MORNING OF THEORETICAL PHYSICS

On 9 February we hosted another Morning of Theoretical Physics. The topic was 'The physics of life'. Prof Andrew Tuberfield talked about 'Programming dynamic DNA nanosystems', Prof Julia Yeomans, FRS, talked about 'Topology in biology' and Prof Ard Louis explained 'Why the world is simple'. Other senior members of the Rudolf Peierls Centre for Theoretical Physics, as well as the Head of Physics, took part. Some of the presentations are available to view at http://saturdaytheory.physics.ox.ac.uk/events/physics-life.

BREBIS BLEANEY MEMORIAL LECTURE

The inaugural Brebis Bleaney Memorial Lecture 'Electron paramagnetic resonance: past, present and future' was delivered by Prof Mark Newton on 22 February. The lectures, commemorating the life and achievements of Prof Bleaney (1915–2006), will be held annually, thanks to the generous support of Prof Michael Baker (1930–2017), one of Bleaney's students. If you would like to watch the video from the day, please visit: https://podcasts.ox.ac.uk/electron-paramagnetic-resonance-past-present-and-future.

ALUMNI EVENT AT THE OXFORD & CAMBRIDGE CLUB

With a slightly different format than in previous years, Prof Ian Shipsey (Head of Department) hosted this annual event at the Oxford & Cambridge Club on 24 April, with two special guests talks: Prof Achillefs Kapanidis gave a talk entitled 'DNA repair meets super resolution imaging' and Prof David Lucas talked about quantum computing. DPhil student Amy Hughes explained her work on quantum entanglement and showed some interesting results. The talks and Q&A were followed by a canapés and drinks reception. The audience included alumni whose matriculation ranged from 1949 to 2019! More photos in the next newsletter.

We are aware that alumni who live far from Oxford would like access to recordings of events. Because of data protection however, not all events can be filmed. Those that can, will be found here: http://podcasts.ox.ac.uk/units/department-physics

FORTHCOMING ALUMNI EVENTS

We hold a variety of events throughout the year for our alumni and their guests. All events take place in Oxford, unless otherwise stated. Please visit our website (**www.physics.ox.ac.uk/events**) regularly for latest updates and full details. Alumni and their guests are always welcome and all our events are free, but registration in advance is mandatory. If you have any questions about the events, please contact Val Crowder: alumni@physics.ox.ac.uk. Below is a list of some of the alumni events we have planned for the coming months. We look forward to seeing you soon.

'THINKING 3D' SPACE & TIME EVENT

22 June Various speakers, including Prof Steven Balbus and Prof Chris Lintott. This event, in collaboration with Magdalen College, is part of the 'Thinking 3D' programme organised by the Bodleian libraries. Alumni and general public are welcome. **www.thinking3d.ac.uk**

ALUMNI GARDEN PARTY

29 June (venue tbc) We are delighted to have Prof Steven Balbus, Head of Astrophysics and an expert on the subject of black holes and accretion, as guest speaker at our Garden Party this year. This is your chance to ask all you wanted to know about black holes. See website for details.

ALUMNI EVENT IN EDINBURGH

2 July *New Club, Princes Street, Edinburgh* We hope many of our Scottish and northern England alumni will join us at this new event to be hosted by Prof Ian Shipsey and alumna Dr Susan Hezlet. We are grateful to Dr William Duncan for his time and support, too.

SUMMER EXHIBITION AT THE ROYAL SOCIETY

1–7 July Stay tuned for more details of this event.

MEETING MINDS OXFORD

20 & 21 September The department will open its doors for the Alumni Weekend in September.

AOPP ALUMNI EVENT

15 November This annual event takes place at the Royal Society.

THE HENRY MOSELEY SOCIETY SPECIAL EVENT

Date TBC Members of the Society will receive details as soon as they are available. If you'd like to become a member or find out more about it, please visit https://www.campaign.ox.ac.uk/document or contact the alumni office.

MAKING PHYSICS ACCESSIBLE FOR ALL

For more information: www.physics.ox.ac.uk/outreachnews

Oxford Physics engages in a series of highly active outreach programmes, reaching more than 200,000 people in the last five years. Our outreach work is focused in four main areas:

INCREASING ACCESS TO OXORD

Supporting disadvantaged students who have the potential to benefit from study in the department

ENGAGING LOCAL COMMUNITIES

Building partnerships with local communities to enrich the life of the city

INCREASING DIVERSITY IN STEM

Working with children from under-represented backgrounds to raise aspirations

PUBLIC ENGAGEMENT

Supporting our researchers in engaging the public with their research

MARIE CURIOUS 2019

To mark International Day of Women and Girls in Science, Oxford Physics held its second annual girls-in-STEM event (science, technology, engineering and maths). 'Marie Curious' brought together 100 local girls aged 11–14 and 30 scientists for a day of interactive science, including hands-on workshops, a panel discussion and a science show about light. The day was thoroughly enjoyed by the girls and staff alike. During the panel discussion, the girls were invited to ask questions to five women in science. The questions were insightful and the answers from our panel were empowering.

I LIKED DOING ALL THE EXPERIMENTS AND SEEING HOW THINGS WORK

I GOT TO SEE HOW DIVERSE AND POSITIVE ALL OF THE SCIENTISTS ARE

WORKSHOPS INCLUDED:

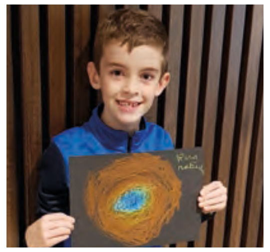
- EXPLORING THE GOOEYNESS OF SLIME
- SPOTTING CONNECTIONS BETWEEN DINOSAURS AND BIRDS (WITH SPECIMENS OF BOTH)
- GETTING TO GRIPS WITH GUTS
- FINDING π WITH A NEEDLE
- REVEALING RADIOACTIVITY WITH DIY CLOUD CHAMBERS

'One of the best things about the event was that it made female scientists a lot more accessible – rather than just reading about an inspirational female scientist, we actually got to meet and talk to them.'

SPACE AND YOU 2019

In September we ran another fun and relaxed day, SPACE and YOU, in the department to engage children with Additional Support Needs (ASN). We identified that young people with ASN and their families are interested in learning about physics but have been unable to access our events, such as Stargazing Oxford, as they are too busy and crowded. SPACE and YOU enabled both the children and their families to engage with space science in a more comfortable environment.

Thirteen families attended the event. This is the second SPACE and YOU event we have run, and it was followed by a dedicated hour for children with ASN at Stargazing Oxford 2019 in January. We hope to continue to develop our engagement with this group.



'THANK YOU FOR ORGANISING SUCH A SMASHING MORNING. JOSEPH LOVED IT AND PROUDLY SHOWED HIS CERTIFICATE AT SCHOOL.'

MARS INSIGHT LANDING

Map of mars showing landing sites and known impact crater locations

On 26 November, members of the public joined researchers from Oxford Physics, Imperial College, Bristol University, RAL Space and the UK Space Agency, who worked on the Mars Insight mission, to celebrate its scheduled landing on Mars. The event, held in the department, was fully booked and more than 200 people attended. The InSight lander will study the interior of Mars and listen for Marsquakes.

- The evening kicked off with introductions from Sue Horne (UK Space Agency), Dr Neil Bowles (Oxford Physics) and Dr Anna Horleston (Bristol University)
- The audience watched a live stream from the NASA control room and waited for news of the landing with bated breath
- News about the success of the landing was received with cheers and clapping in the theatre at around 8pm
- The audience went on to celebrate the launch with a drink in the foyer of the new Beecroft Building

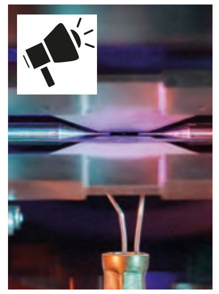
© NASA/JPL-CALTECH

The Oxford logo can be seen on the InSight lander. Image taken on Mars.

'IT WAS A TENSE AND ULTIMATELY AMAZING EVENING AND REALLY FANTASTIC TO SHARE THE EXPERIENCE WITH SO MANY PEOPLE.'
— DR NEIL BOWLES

TAKING PHYSICS FROM THE LAB INTO YOUR LIFE

On 16 October we opened our doors as part of IF OXFORD, Oxford's science and ideas festival, to showcase some of the ways research can become technology, and physics can move from the lab into your life.



170	40	6
GUESTS	VOLUNTEERS	LAB TOURS

170 adults and teenagers had the opportunity to explore the department and our research, with an evening of laboratory tours, talks and hands-on demonstrations. Forty volunteers – students and researchers from across the department – helped lead the tours, run the science stalls and present the talks. Various areas of physics were demonstrated, from levitating superconductors to water off a duck's back, digital archaeology, citizen science, malarial microscopy, virtual reality and a host of quantum fun and games.

The tours of laboratories were one of the highlights of the evening, with small groups of visitors being led behind the scenes by researchers. We were pleased to be able to open up six labs, covering quantum computing, superconductors, solar cells, nano-imaging and more.

On their way out, we asked everyone to write down one fact they had learned over the course of the evening, and we were thrilled by the range of ideas and knowledge that had been picked up, from the workings of a lab glove box to the details of cooling with lasers.

Such a great idea for a festival. We all loved looking behind the closed doors of the labs.

Everyone could pitch at all levels. We all had a very enjoyable, insightful evening, thank you

PRIMARY SCHOOL PUPILS EXPERIENCE LIFE AS A PHYSICS STUDENT

AMAZING

BEST SCHOOL TRIP EVER

On 12 March, during British Science Week, we welcomed 36 students from St Christopher's Primary School, Cowley, and John Henry Newman Academy, Littlemore, to the department to gain some first-hand experience of what it is like to study physics at university.

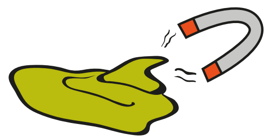
The students began the day in the lecture theatre with a talk about light. This was followed by three workshops exploring some key ideas in physics that our undergraduates use every day. The day also included lunch and a tour at Hertford College. For the final session, the students presented in groups what they had explored in the experiments. All of the students received a certificate of attendance.

The day aimed to encourage children to become curious, confident and creative in science and is part of a project that targets children from local primary schools, from backgrounds that are under-represented in STEM.

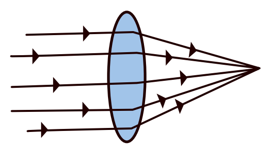
THREE EXPERIMENTS:

- POPPING ROCKETS – MIXING ALKA SELTZER AND WATER IN FILM CANISTERS TO GENERATE A FORCE STRONG ENOUGH TO MAKE THE CANISTER BLAST OFF INTO THE AIR.

- MAGNETIC SLIME – MAKING SLIME FROM LAUNDRY STARCH WITH ADDED IRON FILINGS TO EXPLORE HOW IT BEHAVES NEAR A MAGNET.



- LIGHT AND LENSES – INVESTIGATING THE IMAGE PRODUCED WITH A LENS IN FRONT OF A LIGHT SOURCE. THIS EXPERIMENT WAS CARRIED OUT IN OUR UNDERGRADUATE OPTICS LAB.

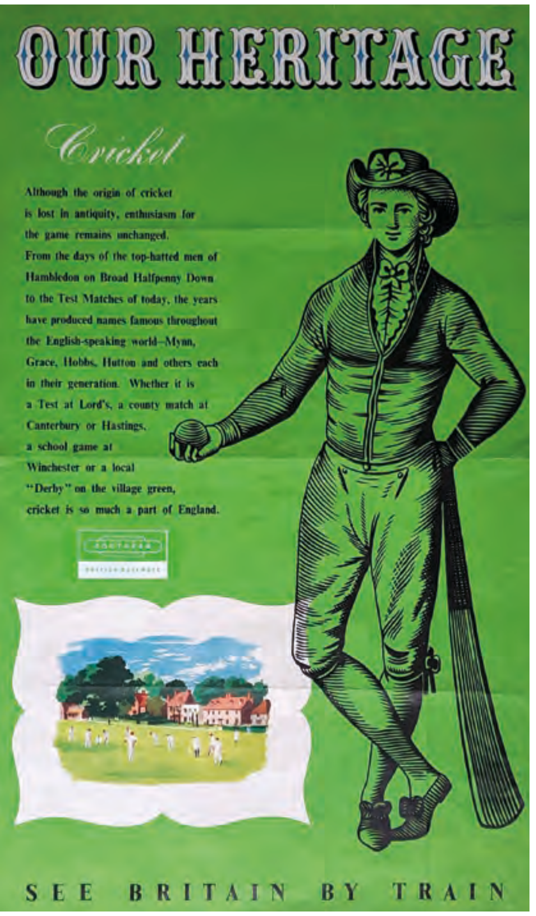


ALUMNI STORIES

We welcome stories from all alumni. Please email: ***alumni@physics.ox.ac.uk***

DR ALUN JONES, CHRIST CHURCH 1958

I am number 182 in the 1962 Clarendon photo shared in the Spring 2018 issue of the Physics newsletter. It was the end of my first year as a DPhil student in the nuclear physics department. The department was relatively newly formed under the leadership of Denys (note the spelling) Wilkinson who had come over from Cambridge. We had been banished from the Clarendon and resided in a one-time girls' school at 21 Banbury Road. I am surrounded in the photo by colleagues in the same department who also were the core of the Clarendon cricket team of the day: Dr Ian Hall (181), Yorkshireman, opening bat and Dr Warwick Darcey (121), Australian, wicketkeeper. They went on to academic lives in Liverpool and New Zealand respectively and I am still in touch with both.



Speaking of cricket, A J Croft (120), the lab administrator who lived with his wife in the cottage that was at the front of the Clarendon building, was the club's sponsor and would turn up at games in his vintage Rolls Royce. This same splendid carriage provided transport for a few of us annually to Worcester for the tourists' first match of the season. A J was also generous with his time, umpiring, but I did wonder about his eyesight when he gave me out ('caught behind') when I was going well and my bat was the proverbial mile from the ball! At the annual end of season cricket dinner, A J would delight in passing round the snuff – mostly politely declined.

Bill Stonnard (52), who was in charge of the Clarendon workshop, never missed a game even though he was within a year or two of retirement. Cyril Band (188), who was in charge of the media department, was also a keen member. We played two games a week. One an evening match at one of Oxford Council's grounds during term, and then at a college ground during the vacation. On Saturdays we played against village teams. They were great occasions. After the cricket, the competition continued at skittles, if the village pub had an alley, bar billiards and darts. There was also, of course, the annual match against the Cavendish, where honour was at stake and the atmosphere was test-match like. Those games invariably ended in a draw!

To show that we had interests outside cricket, a cohort of us at lunch time frequently visited The Eagle and Child Pub in St Giles (known, of course, as 'The Bird and Baby'). It was also a favourite watering hole of two distinguished Oxford figures – J R R Tolkein and C S Lewis – who, at times, sitting nearby were often disturbed by our presence but, of course, entranced by our discussions!

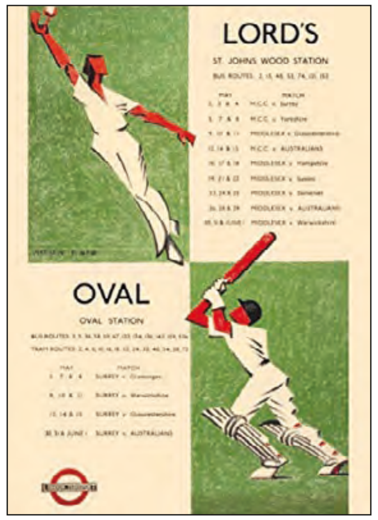
After 20 years in the wilderness of industry, consultancy, journalism and funding of science, I returned to physics in 1990 as CEO of the Institute of Physics. I then renewed acquaintances with many of those in the photograph. Sir Denys Wilkinson (as he then was), who had seemed remote in the early 1960s, had a fine sense of humour. I met him at a dinner in London towards the millennium and he approached me and said 'Alun, I am the Father of Jesus'. My response was 'Denys, we always knew that'. It transpired that he had become the Senior Fellow of Jesus College Cambridge.

Above: Dr Alun Jones. Left: English heritage poster. Below: Denys Wilkinson

Nicolas Kurti (37), who was a keen advocate of applying scientific principles to cooking, became a Tellydon in the 1990s. I remember him demonstrating how to make a reverse baked Alaska dessert in a microwave oven (think about it). He also wrote a book published by the Institute of Physics, entitled *The Crackling is Superb* that sold well. We decided to publish it in the United States but wanted to change the title as it was felt that, as it stood, it would not appeal to some religious sects. Nicolas objected and, in due course, arrived at my office to plead his case. He won.

Roger Blin Stoyle (33), who went to Sussex in the mid 1960s, was President of the Institute of Physics in 1990 and we became good friends. Roger was one of the best Presidents I worked with. He had the great ability in meetings with government and industry to hit the right level when pressing the case for physics. He also was much concerned about Physics Education and became President of the Association for Science Education. After retirement he taught science, on a part time basis, in primary schools in Sussex.

Gus Green (53) was the administrator of the Nuclear Physics Lab, who had left teaching physics in schools to take the job. He endured much teasing in the aftermath of the Great Train Robbery in 1963, when the papers were full of the police 'looking for the mysterious Mr Green'. An indoor cricket practice led to a broken window in 21 Banbury Road. Gus tried to identify the culprit, but we stuck together. I met Gus again at the opening of the Sir Denys Wilkinson building in 2001. 'Ah', he said when he saw me, 'Who broke the



window?' I gave him the same answer as I had all those years previously: 'I don't know, I wasn't looking'.

Dennis Shaw (46) invited me to be an A-level Physics examiner when I was a post-doctoral student. As well as intensive marking after the examinations, it involved visiting schools (all independent!) to supervise the practical exam. My memories of those visits are of lavish hospitality and a range of equipment that put the Clarendon undergraduate labs to shame.

It was a pleasure to renew acquaintance with Dennis many years later when he was Keeper of Scientific Books at the Bodleian. He died in 2017 at the age of 93.

Michael Grace (48) was my undergraduate tutor. When I returned to Oxford after years in the United States he was most helpful and welcoming. Sadly, he died before my period at the Institute started but I am in his debt, not only for his teaching but also, years later, he proposed me for Fellowship of the Institute of Physics.

Finally, apropos of nothing but nostalgia, one Friday during my early days as a graduate student, Ann Rees (21) who was Gus Green's secretary, mentioned to me that she was going to Reading Town Hall the following day to listen to a new group that had a strange name. They were called The Beatles. For you youngsters, there really was a life before the Fab Four!

Dr Alun Jones, with recollections and additions from Dr Ian Hall and Dr Warwick Darcey, January 2019

And this is the current physics cricket team! Back (left to right): Dylan Saunders, Matt Jarvis, Cam Allen, (missing name), Aidan Glennie, Tom Barrett. Front: Sameer Vajjala Kesava, Sean Ravenhall, Abe, Kieran Mccall (Captain) and Patrick Ledingham at Balliol College pitch. This wonderful photo is from the day they won the plate in 2017, and as this newsletter goes out, they are getting ready for the new season.

If you'd like to be part of the team (current staff/students and alumni, female or male) please get in touch with the captain: kieran.mccall@physics.ox.ac.uk.

Our team is looking for sponsors to help pay for a new kit, training, cages and entry to the interdepartmental cup. If you'd like to support them, please get in touch with the alumni office (alumni@physics.ox.ac.uk), no donation is too small. Thank You!

In memoriam: Jean Fooks

Jean read Physics at Somerville 1958–61 and went on to work at the then Radio and Space Research Station in Slough and at the European Space Data Centre in Darmstadt, Germany.

Jean remained close to the college, which still hosts an annual lecture in memory of her daughter Monica, who passed away in 1994.

She moved back to Oxfordshire in 1982 to work in health service research, doing data analysis on mental and physical health records, leukaemia and in her last job on problems faced by premature babies.

Jean was well known throughout Oxford as a formidable political force, kind and courteous but fiercely committed to the city. Jean was first elected to the City Council in May 1992 and represented North Ward until 2002. She was re-elected in 2006 to represent Summertown Ward until May 2018. She was Sheriff 2011–12, became group leader of the Liberal Democrats and Leader of the Opposition on the City Council 2012–16, and was Lord Mayor of Oxford 2017–18. She chaired the Highways and Traffic Committee 2000–01, Environment Overview and Scrutiny Committee 2001–04.

Jean was the Councillor in charge of the City Works Department in 2006 when wheelie bins were rolled out, and recalled that recycling rates doubled within six months.

She also served on Oxfordshire County Council, representing Oxford Cherwell Division in June 2001. She was re-elected in May 2005 and June 2009 for Summertown & Wolvercote Division. In May 2013, she was returned as the Councillor for Summertown & Wolvercote Division, finally standing down in May 2017.

Jean served as a school governor from 1992, and was involved with the Cutteslowe Community Association; Wolvercote Young People's Club; North Oxford Associations; Neighbourhood Forums; and many other groups. She was a strong advocate of ethical and environmental issues. Until recently, Jean was part of the city's twinning link with Bonn in Germany.

Her most recent efforts saw the installation of new play facilities; helped keep the community association funded; set up a community bus service after some routes were cut; and saved the local children's centre from closure. She also strongly championed children in care, forsaking her own Christmas to spend time with children and carers.

Jean was invested as an Honourary Alderwoman of the city of Oxford the day before her death in November 2018. She is survived by one daughter, Carolyn, and two grandchildren.

Nicola Small

COMINGS, GOINGS & AWARDS...

COMINGS...

Name	Position	Department
Prof Fabrizio Caola	Associate Professor of Theoretical Particle Physics	Theory
Prof Seamus Davis	Professor of Physics	CMP
Dr Thorsten Hauler	Head of Research Facilitation	Central
Dr Maxence Lefevre	PDRA	AOPP
Mr Roy Preece	Head of Technical Services	Central
Prof Gavin Salam	Royal Society Professorial Research Fellow	Theory
Dr Celia Yeung	NQIT Technology Associate	ALP

GOINGS...

Name	Position	Department
Dr Victor Burlakov	Senior Researcher	CMP
Dr Jorge Casalderrey	Solana Royal Society Fellow	Theory
Dr Michele Warren	Head of Grants Administration	Central
Dr David Jennings	Royal Society Fellow	ALP
Dr Dylan Saunders	Senior Researcher	ALP
Dr David Sloan	Project co-lead	Astro
Prof Giulia Zanderighi	University Lecturer	Theory

Would you like to host an event for physics alumni?

It could be a drinks reception or dinner, a visit to your company for a small or large group… the possibilities are endless. Please get in touch for an informal conversation, we'd love to hear from you!

Do you have a photo from your time in Oxford? A story or anecdote that you would like to share?

The alumni office is making the archives more accessible and interactive. Send your contributions, no matter how big or small, to Val Crowder, Alumni Officer: **alumni@physics.ox.ac.uk**

REGISTER FOR ALUMNI NEWS & EVENT UPDATES AT www.physics.ox.ac.uk/alumni/connect

AWARDS...

Prof Pat Irwin (centre holding the award), Dr Simon Calcutt, Prof Peter Read, Dr Fred Taylor, Prof Neil Bowles and the UK Cassini team were awarded the Sir Arthur Clarke Space Achievement Award for Academic Research by the British Interplanetary Society.

Prof Michael Johnston was awarded the Harrie Massey Medal and Prize last December, for his significant contributions to semiconductor physics which, together with materials design, growth and spectroscopic analysis, have led to notable advances in the fields of optoelectronics, photonics and high frequency electronics. This is a medal from the Institute of Physics which is awarded in conjunction with the Australian Institute of Physics.

Prof Laura Herz was awarded the IoP's Nevill Mott Medal and Prize for her ground-breaking research into the fundamental mechanisms underpinning light harvesting, energy conversion and charge conduction in semiconducting materials.

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We hope you enjoyed reading this issue of the Physics Department's Newsletter. To contact the Newsletter editor, Prof Dimitra Rigopoulou, please email **newsletter@physics.ox.ac.uk**. For latest news on developments at the Oxford Physics Department, see **www.physics.ox.ac.uk**. To contact the alumni office, email **alumni@physics.ox.ac.uk**. For events and lectures, **www.physics.ox.ac.uk/events**.