ATOM MICROSCOPY

CHANGES IN THE NSW PHYSICS CURRICULUM

NONLINEAR OPTICS AT NANOSCALE
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ASTOUNDING ACHIEVEMENT

It is not surprising that this year’s Nobel Prize for Physics went to Rainer Weiss, Barry C. Barish and Kip S. Thorne “for decisive contributions to the LIGO detector and the observation of gravitational waves”. Despite the enormous detector sensitivity required the signal was unambiguous and its interpretation convincing. Five gravitational wave events have now been detected in a period of about two years. The most recent, the fifth event, detected on 17 August this year is remarkable for the fact that many astronomical observatories were ready to observe the evolving event across the electromagnetic spectrum from gamma rays to radio waves. Among these was an Australian group led by Associate Professor Tara Murphy (The University of Sydney and the ARC Centre of Excellence for All-sky Astrophysics) using CSIRO Astronomy and Space Science’s Australia Telescope Compact Array at Narrabri NSW. The amount of detail about the nature of the event resulting from the combined observations is astounding (See News & Comment and Samplings. This event provides an outstanding endorsement of international scientific collaboration.

We have three articles in this issue. The first, Atom Microscopy – Imaging with a deft touch by Tom Myles, Joel Martens, Adam Fahy, Matthew Barr and Paul C. Dastoor (University of Newcastle) describes a new surface imaging technique: a scanning helium microscope that allows non-destructive imaging of the surface of fragile samples.

The second article, Watching the pendulum swing: changes in the NSW physics curriculum and consequences for the discipline by Helen Georgiou (University of Wollongong) and Simon Crook (Crook-ED Science and The University of Sydney) describes and discusses the major changes to the NSW Higher School Certificate curriculum.

The final article Nonlinear Optics at Nanoscale: Where are we? by Mohsen Rahmani (ANU) describes nonlinear optical behavior in nanoscale tailored structures and the possible applications for these miniaturised components.

The scanning of past issues of Australian Physics continues slowly. Although my target set for this year has not been achieved, a plan to finish the scanning has been established.

As with previous November-December issues, this issue includes a list of all articles for 2017 on the inside back cover. Finally, best wishes to all members for the end of year activities and the new year.

Brian James
I often get into discussion with people about why they are physicists. Very loosely speaking the main two camps I have come across are those that love the science and just want to know how or why things work and those who love what they can do with that knowledge. Of course it is not a binary distribution and people will often profess a mix of the two to varying degrees. However, the two reasons given form the basis of two archetypes that pervade popular thinking about physics and, more broadly, science. Incidentally, this distinction in the types of science is often attributed to writings from some 400 years ago by Francis Bacon, and they are sometimes described as “Experiments of Use (or Fruit)” and “Experiments of Light and Discovery”.

Something that is frequently overlooked in the popular discourse is that the early writers, such as Bacon, would stress that you don’t get Experiments of Use unless you first have Experiments of Light and Discovery. Why is this point of pedantry useful to us now some four centuries later? Like all good arguments the discussion about the relative benefits of pure and applied science is a hardy perennial. Around the time of major grant funding announcements there is inevitably an article about “wasteful” funding of “purposeless” research. Possibly as a reaction to this type of criticism, there are now increased requirements to justify the impact of proposed research in certain grant applications. Conversely, there are groups that have decried the requirement to justify impact in research applications at all. What Bacon shows us is that maybe each of these two camps is a little bit wrong and a little bit right (instead of a binary separation perhaps they are in a state of quantum superposition?). For those who buy into the importance of science (hopefully everybody reading this magazine), it is part of the accepted fabric of things that Experiments of Light and Discovery have an intrinsic purpose – to build the foundation for Experiments of Use, which in turn create Use or value. However, the fact that airspace is given to reports about “purposeless” research shows that there are people who do not understand, or believe, in the benefit of contributions to knowledge. As an aside, there is another (binary?) distinction, which is that not all Experiments of Light and Discovery are good experiments in the sense that they are performed well or that they do not result in contributions to knowledge. However, we already have a longstanding mechanism for dealing with this case, which is to assess the quality of the research. Is there a properly formed hypothesis, has the background knowledge been considered appropriately, has the research been conducted according to the scientific method, are some of the questions that can be used to assess whether a particular piece of research is valid. What can we do about the (binary) disconnect between those who see the value of Experiments of Light and Discovery and those who don’t? The experience of science communication of climate change is that there will always be those for whom no amount of evidence-based reasoning will change their minds. Fortunately, in a democratic society it is neither necessary (nor desirable) to convince everybody – we only have to convince enough people to make a difference. It is a notoriously difficult task to show a direct causal link between specific examples of basic or fundamental research and economic impact. Using the tools of big data there are now studies that are starting to show connections between the body of knowledge, as represented by the published literature, and real-world applications, for instance those showing the connectivity between patents and the underpinning basic research cited in the applications. As the network of all things grows, it becomes more and more possible to establish the statistical evidence showing the value of investment in research.

However, no matter how good the underlying evidence and statistics, there is nothing more powerful than an iconic example to capture hearts and minds – even if linking ultimate impact to a single seminal experiment or theory is, on average, somewhat misleading. It is also important to keep refreshing those examples to remain current and we do not need to look far to find a brilliant recent example of an iconic Experiment of Light and Discovery. The Nobel Prize in physics this year for the observation of gravitational waves and the more recent announcement of the observation of a (you guessed it) binary system of neutron stars has received plenty of attention. What better way to point out the contribution of excellent research to the body of knowledge? At the same time it is fair to say that applications for gravitational waves that have an impact on jobs, health or the economy are not even a gleam in inventors’ eyes as yet – we are a long way from Experiments of Use. But if there is any doubt that there will be, we only need to look at the track record of the fellow that developed the underlying theory. The importance of Special and General Relativity to high-tech applications that beneficially affect millions today is undisputed. It is also provides a great argument for looking at track record and impact over considerably longer periods than five or ten years, but that is another story.

Another way to deal with the (binary?) translation of Experiments of Light and Discovery to those of Use, is to cite a well-known quote attributed to Faraday in 1850 (possibly apocryphally, but it works too well here to resist). When the Chancellor of the Exchequer asked him what was the practical value of electricity, he purportedly replied – “Why, sir, there is every probability that you will soon be able to tax it.” We should never be too caught up in splendour of Light and Discovery to acknowledge, and to show, that our science has an impact.

Finally, on the topic of binary distributions, there are 10 types of people in the world; those that understand binary and …

Andrew Peele
NEWS & COMMENT

Eureka Prizes 2017
Presented annually, the Australian Museum Eureka Prizes reward excellence in the fields of research & innovation, leadership, science engagement and school science. The winners of the Eureka Prizes for 2017 were announced in Sydney in August. They included the following.

2017 ANSTO Eureka Prize for Innovative Use of Technology
This Prize was awarded to a University of Melbourne team – FREO₂ – for developing a live-saving oxygen supply system for the world’s poorest areas. The multidisciplinary team of physicists and medical experts is led by Dr Bryn Sobott, with Associate Professor Jim Black, Associate Professor Roger Rassool, Dr David Peake and Mr Kevin Rassool.

The FREO₂ team. Credit: Peter Casamento

The FREO₂ Siphon concentrator produces, stores and delivers medical-grade oxygen to critically ill newborn babies without needing a secure source of electricity. This innovative technology has the potential to substantially reduce infant mortality rates arising from hypoxic illnesses in low-resource settings, such as Papua New Guinea, East Timor and sub-Saharan Africa.

2017 Defence Science and Technology Eureka Prize for Outstanding Science in Safeguarding Australia
This Prize was awarded to Associate Professor Rich Mildren, Macquarie University. Associate Professor Mildren and his team developed a technique to make diamond lasers that, in theory, have extraordinary power range.

Assoc Prof Rich Mildren

Five years ago, their lasers were just a few watts in power. Now they’ve reached 400 watts, close to the limit for comparable conventional lasers.

“The award is a terrific recognition, not just for the diamond laser team but also as a tribute to the strong tradition of the high power laser research at Macquarie and MQ Photonics over decades. It is also very timely – one of our goals is to reach out to government and industry partners for translating the research to end users. We hope the additional exposure will be a great help for promoting these activities,” said Associate Professor Mildren.

The diamond-based technology invented by Associate Professor Mildren is capable of radically increasing the power and spectral range of lasers. Australian and United States defence agencies are investing in this technology to increase their power capability, and a UK company has licensed commercial applications in quantum science and biomedicine.

Funding and infrastructure boost for Australian Synchrotron
ANSTO has secured $80.2 million in new funding to expand the research capabilities of the Australian Synchrotron. The funding boost was made by the New Zealand Synchrotron Group Limited (representing funding from the New Zealand Government and 10 New Zealand universities and research institutions), the Defence Science and Technology Group and 19 universities and medical research institutes across Australia.

The new funding will expand the number of beamlines at the Synchrotron from 10 to as many as 18, increasing
research output at the facility and helping keep up with significant researcher demand for the state-of-the-art facility. The first stage of the expansion will see the construction of the Micro-computed Tomography (MCT) beamline and the Medium Energy XAS (MEX) beamline:

The MCT beamline will complement the Imaging and Medical Beamline (IMBL), by allowing 3D structures to be studied in close detail, which will enable advanced research in the fields of biological and health sciences.

The MEX beamline will enable mapping of lighter elements such as sulphur, phosphorous, chlorine, calcium and potassium, with applications across sectors including aiding in the development of cancer treatment.

These beamlines will be closely followed by a Small Angle X-ray Scattering (BioSAXS) beamline. Supported by the New Zealand Synchrotron Group’s significant $25 million investment, the beamline will allow for detailed protein studies focussed on improving drug design and validation processes.

Minister for Industry, Innovation and Science, Senator the Hon Arthur Sinodinos, welcomed the funding for the beamline expansion, which will be supported by the Australian Government’s significant operational investment made via the National Innovation and Science Agenda (NISA). The NISA provides $520 million in operational funding to the Australian Synchrotron, which includes operational funding for the new beamlines. (Source: ANSTO, Australian Synchrotron)

**Australia International Collaboration on Next Gen Nuclear Energy Systems**

Australia has been officially welcomed to the Generation IV International Forum (GIF) Framework Agreement, a partnership through which ANSTO will contribute to international work on the development of future nuclear energy technologies.

As the 14th Member of the GIF, Australian researchers will work with countries including Canada, France, Japan, China, South Korea, South Africa, Russia, Switzerland and the United States. Members of GIF work collaboratively to develop Generation IV designs of nuclear energy systems, which will use fuel more efficiently, produce less waste, be more economically competitive and meet stringent standards in relation to safety and non-proliferation. GIF research is focused on six reactor designs that will deliver safe, secure, sustainable, competitive and versatile nuclear technology in the future.

In September the CEO of ANSTO, Dr Adi Paterson, attended a ceremony at the OECD Château in France to
officially welcome Australia to GIF. ANSTO, on behalf of Australia, signed the GIF Charter in June 2016, and this event marked Australia’s accession to the Framework Agreement.

Although Australia does not have a nuclear power program its membership of GIF will enable Australia to become actively engaged in research and development projects related to Generation IV systems, particularly in relation to advanced materials.

“This Agreement will enable Australia to contribute to an international group focused on peaceful use of nuclear technology, and the international energy systems of the future,” said Dr Paterson. “Our participation in GIF is an affirmation of Australia’s exemplary research capabilities and STEM industry, strengthened by ANSTO’s expertise and highly developed nuclear science infrastructure.”

National competition for quantum physics game designers
The Australian Research Council Centre of Excellence for Engineered Quantum Systems has launched a competition that asks competitors to design an electronic game inspired by quantum physics.

University of Queensland physicist Associate Professor Tom Stace said that quantum physics has inspired artists, writers, and filmmakers. Even some of the latest Marvel movies venture into the Quantum Realm.

“We are now turning to game developers with an interest in science, or scientists who enjoy game development,” Dr Stace said. “Quantum mechanics makes some pretty odd predictions about the world – which have turned out to be true. “We’re looking for playable, fun computer games that explore some of the themes from quantum mechanics – such as superposition, entanglement, or even black hole evaporation.”

“Possibilities abound for game developers. On human scales, quantum effects are tiny, but what if they were amplified to everyday scales? What happens if your racing car has a quantum mechanical breakdown? We’re really curious about what developers will come up with.”

To be in the running for first prize of $1500, individuals and team should submit their game in January 2018. The Quantum Games competition will accept games that run on common platforms (web, Android, Mac, PC, or iOS). Entrants need to create the game and film a short video showcasing gameplay. The judging panel will create a shortlist of entries based on the video submission. Entrants can find inspiration at http://equs.org/games. They can also get in touch with a quantum physicist at games@equs.org.

(source: University of Queensland)
2017 Nobel Prize for Physics

The Nobel Prize in Physics 2017 was divided, one half awarded to Rainer Weiss, the other half jointly to Barry C. Barish and Kip S. Thorne "for decisive contributions to the LIGO detector and the observation of gravitational waves".

At the time of the award, Weiss, born in Germany, was a member of the LIGO/VIRGO Collaboration, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA; Barish and Thorne, both born in the USA, were members of the LIGO/VIRGO Collaboration, California Institute of Technology (Caltech), Pasadena, CA, USA.

LIGO, the Laser Interferometer Gravitational-Wave Observatory, is a collaborative project with over one thousand researchers from more than twenty countries. Together, they have realised a vision that is almost fifty years old. The 2017 Nobel Laureates have, with their enthusiasm and determination, each been invaluable to the success of LIGO. Pioneers Rainer Weiss and Kip S. Thorne, together with Barry C. Barish, the scientist and leader who brought the project to completion, ensured that four decades of effort led to gravitational waves finally being observed.

On 14 September 2015, gravitational waves were observed for the very first time. The waves, which were predicted by Albert Einstein a hundred years ago, came from a collision between two black holes. It took 1.3 billion years for the waves to arrive at the LIGO detectors in the USA.

Prime Ministers Science Prizes 2017

The Prizes for 2017 included the following:

Professor Dayong Jin, University of Technology Sydney, was awarded the Malcolm McIntosh Prize for Physical Scientist of the Year for creating new technologies to image the processes of life.

Using quantum dots, lasers, nanocrystals and other technologies, he has created new kinds of microscopes that allow us to watch molecules at work inside living cells, such as the inner workings of our immune system, how bacteria become resistant to antibiotics, and to find one cancer cell amongst millions of healthy cells. He is working with Olympus to commercialise his inventions. He believes that his technologies will enable portable, easy to use devices to detect the first signs of disease and evidence of drugs, or of toxins in food and the environment. With the support of the Australian Research Council he's working to give Australian companies the opportunity to create these new devices.

Brett McKay, Kirrawee High School (NSW), was awarded the Prime Minister's Prize for Excellence in Science Teaching in Secondary Schools for his achievements in inspiring his students to love science and to use it in their daily lives.

Brett McKay is Head Teacher Science, at Kirrawee. As a physics and science teacher he has overseen a four-fold increase in students taking physics. Many have gone on to careers in science around the world. He has inspired young women to consider science careers.

Importantly he’s brought science to life for students not considering science as a career. He recognises that we all need a grounding in science to make informed decisions in the modern world.

And he’s shared his knowledge of science teaching with his peers through the Science Teachers Association of NSW and with primary schools in his area. He is seen as an encouraging, resourceful, and engaging teacher who brings science alive for students.
**Australia’s new space agency**

After years of speculation, Australia is finally set to launch its very own space agency. Formally announced at the International Astronautical Congress in Adelaide in September, the agency will anchor Australia’s participation in the burgeoning $420 billion global space industry and stimulate what local space entrepreneurs have called “the next industrial revolution”.

The decision is the result of an exhaustive review by former CSIRO chief Megan Clark which revealed an overwhelming need for a local space agency. Education Minister Simon Birmingham broke the news at the opening of the Congress, promising that the new space agency would feature in next year’s May budget and articulating the government’s vision for a “private sector-driven undertaking” that would “make sure Australia is at the forefront” of the booming space economy.

Acting Science Minister Michaelia Cash also lauded the “crucial” addition to Australian national infrastructure and the “several billion dollars of extra economic activity” it could bring. The initiative has bipartisan support, with Opposition science spokesman Kim Carr lauding the “enormous opportunities” in store.

**Bragg Medal for 2017**

The 2017 Bragg Gold Medal winner is Dr Daniel Leykam from the Australian National University for his thesis titled *Wave and spectral singularities in photonic lattices*.

Dr Daniel Leykam carried out his PhD work at ANU’s Nonlinear Physics Centre, specialising in the field of singular optics - the study of structured light – under the supervision of Dr Anton Desyatnikov, Prof Yuri Kivshar, and A/Prof Elena Ostrovskaya. Such ‘photonic lattices’ could have wide-reaching impacts in the not-too-distant future, from spectroscopy to solar power, astronomy to computing. Dr Leykam’s work brings new insights into the ‘singularities’ that make such manipulations possible.

The Bragg Medal, instituted in honour of William and Laurence Bragg in 1993, is awarded every year to a single PhD student recently graduated from an Australian university whose thesis is judged to be particularly outstanding. Each university may nominate only one candidate per year.

**Fifth gravitational wave event**

A fifth gravitational wave was detected by the international LIGO-Virgo team on 17 August this year. Telescopes around the world made follow-up observations of this latest event and, for the first time, detected electromagnetic radiation – gamma-rays, light, radio waves and more – along with the gravitational waves.

An Australian group led by Associate Professor Tara Murphy from the University of Sydney and the ARC Centre of Excellence for All-sky Astrophysics used the CSIRO’s Australia Telescope Compact Array near Narrabri in NSW to confirm radio-wave emission from the gravitational wave event.

This is significant because it allows astronomers to determine where the gravitational-wave event took place. Professor Murphy’s team has used more than 40 hours of observing time on the Compact Array over several weeks. Thanks to the telescope’s ‘Target of Opportunity’ system, once alerted to the gravitational-wave event the team was able to quickly gain permission to override scheduled observations and begin using the telescope as soon as the source had risen in the sky above Australia.

The observations suggest that the event that created the gravitational waves was the merger of two neutron stars on the outskirts of the galaxy NGC 4993, about 130 million light-years away. Douglas Bock, Director of CSIRO Astronomy and Space Science, said this extraordinary detection by an Australian team, using Australian facilities, made a significant contribution to the global discovery.
The radio source has remained and will continue to be monitored. How much it strengthens and when it reaches peak strength will allow astronomers to better understand the physics of the event.

CSIRO’s Manufacturing team was responsible for coating many of the optics used in the ‘Advanced LIGO’ instrumentation including ultra-high performance optical mirrors to give the required reflective properties and thermal shielding. We continue to be one of the only research groups in the world able to deliver to this level of precision.

Of these latest achievements, our Chief Executive Larry Marshall said “As Australia’s national science agency we are proud to have delivered the unique optics that helped enable the original discovery, and are excited to continue supporting the global community through the delivery of excellent science and world-class facilities like the Compact Array whose applications are as unlimited as space itself.”

Jacq Romero receives L’Oreal Fellowship

Dr Jacq Romero from the University of Queensland received one of this year’s L’Oreal Australia For Women in Science fellowships. The award was accompanied by the following citation.

Jacq’s research lies within the mysterious world of quantum physics and the intriguing theory of entanglement – that information is shared between particles regardless of how far apart they are (even existing at opposite sides of the universe).

The quantum world is relatively unknown, but holds a lot of potential for the future, in terms of increased capacity to transmit data, increased security, but more importantly unlocking a new science not yet fully understood. Jacq creates large quantum alphabets using a less well known property of light, known as the orbital angular momentum (or OAM). By creating an alphabet where the different OAMs, which are the different helical twist formations of a beam of light, serve as the different letters, Jacq is able to create a unique quantum encoding system of a much larger capacity (theoretically infinite!). By creating quantum alphabets, Jacq is able to unlock some of the mysteries of the very puzzling properties of higher dimension quantum information.

“Jacq will provide the first experimental evidence to an existing theory to verify the fundamental differences in the way information works for larger quantum alphabets, compared to the classical encoding system we use today. Jacq’s findings will provide critical knowledge as we start to access more of the benefits of the quantum world.

New ATSE Fellows

The Australian Academy of Technology and Engineering has elected 25 new Fellows for 2017 with physics and applied physics disciplines well represented, including:

Dr Steve Frisken, a world leader in optical communications. Dr Fisken is CEO of Cylite Pty Ltd, a technology development company that is creating the next generation of imaging and metrology systems for ophthalmic and related markets.

Prof Ewa Goldys, who pioneered a unique, non-invasive label-free fluorescence tool providing a colourful ‘fingerprint’ for deadly diseases. Prof Goldys, Department of Physics and Astronomy at Macquarie University, is Deputy Director of the Australian Research Council Centre of Excellence for Nanoscale Biophotonics.

Dr Sarah Ryan, one of the world’s most experienced reservoir geophysicists, as well as an inventor, innovator, and advocate for STEM. Dr Ryan has more than 25 years’ experience in the oil and gas industry in various technical, operational, senior management, and corporate officer positions. She is a Non-Executive Director of Woodside Petroleum.
Atom Microscopy – Imaging with a deft touch

Tom Myles, Joel Martens, Adam Fahy, Matthew Barr and Paul C. Dastoor
Centre for Organic Electronics, University of Newcastle, Callaghan, NSW, Australia 2308.
Email: Paul.Dastoor@newcastle.edu.au

The destruction of fragile samples is an inevitable side-effect of many current microscopy techniques. A new type of instrument, the scanning helium microscope or SHeM, utilises neutral helium as the probe particle to provide an alternative solution for such materials. The helium atoms are inert, neutral, and have an energy several orders of magnitude lower than that of photons or electrons at comparable wavelengths. As a result, the technique is totally surface sensitive and completely non-destructive, making it ideal in instances where exposure to high energy beams would either limit experimental time, or the reliability of the results.

Introduction

Over the years, scientists have assembled an array of imaging techniques that have allowed us to go beyond simple optical microscopy. For example, electron microscopy techniques, such as high resolution transmission electron microscopy (HRTEM), are now capable of imaging surfaces with sub-Ångstrom resolution [1]. Synchrotron-based X-ray microscopy techniques, such as scanning transmission X-ray microscopy (STXM) can map material compositions on the nanoscale [2]. Scanned probe techniques, such as scanning tunnelling microscopy (STM), enable us to image (and manipulate) materials on the atomic scale and have opened up a new world of sub-micron structural design, fabrication and characterisation [3]. Finally, scanning helium ion microscopes operating at 30 keV offer resolutions of <0.3nm and high surface sensitivity [4].

Despite this impressive library of imaging techniques, there remains a class of samples which prove difficult, or nigh impossible, to image. The advent of organic and molecular electronics means that the manipulation of soft materials (such as polymers and biological molecules) is a major new focus for nanotechnology [5]. These delicate materials are very sensitive to damage from the energetic photons or charged particles used in X-ray, ion beam or electron microscopies or the currents used in STM [6]. Indeed, there exists a wide array of fragile structures which suffer degradation under the energetic probes of traditional microscopies. The wavelength (and hence ultimate resolution) of the photons and particles used is intrinsically linked to the energy of the probe - in other words increasing resolution requires a corresponding increase in probe energy, and thus an increase to the risk of damage.

Damage can take many forms, both the obvious, and the insidious. As an example of the former, Figure 1 (a) shows the typical electron-beam damage incurred whilst obtaining high resolution images of an organic electronic film. Regions of the sample exposed to the electron beam are easily identified by the dark rectangles. Chemical bond damage is much harder to identify. Figure 1 (b) and (c) shows the TEM and STXM images taken of the same set of polymer nanoparticles at the University of Newcastle and at the Advanced Light Source (ALS) in Berkeley, USA. The samples were prepared in Newcastle and characterised using TEM before being subsequently flown to the ALS for STXM analysis. Despite the time and distance between collecting the images, it is possible to navigate to the same spot on a sample surface with a resolution of ~20 nm. However, subsequent X-ray absorption experiments revealed that while the two images demonstrate identical morphologies, the initial TEM analysis had destroyed the chemical structure of these delicate nanoparticles resulting in a completely graphitised carbon surface.

This experiment, and many others like it, have highlighted for many decades the need for a new imaging technology; one that cannot damage the surface at all. It is with this application in mind that researchers from
Newcastle have developed the Scanning Helium Microscope (SHeM), a new technique that uses neutral helium atoms rather than light or charged particles. Neutral helium is the ideal probe of delicate surfaces, owing to its low mass, lack of net charge or spin, and short de Broglie wavelength. Moreover, the low kinetic energy of room-temperature helium atoms (of the order meV) means that these probe particles are unambiguously surface sensitive, scattering only from the outermost electron corrugation of the sample. The advantages of helium atoms as a surface probe are well documented by the established technique of Helium Atom Scattering (HAS). HAS is used routinely in the study of nucleation and growth of thin films, adsorbate diffusion, surface structure, alloying and surface phonons [7]. Nevertheless, HAS is limited by its lack of spatial resolution, and therefore constrained to relatively simple, heterogeneous systems. In addition to the lack of damage and the extreme surface sensitivity, SHeM can take advantage of the unique helium-surface interactions in the form of multiple contrast mechanisms to provide new insights.

History of the Scanning Helium Microscope

The tantalising possibility of constructing optical systems that utilise atom beams instead of light has been considered ever since de Broglie first proposed his theory of matter waves in 1924 [8]. In the broadest sense, matter-wave microscopy dates back to 1932 when Max Knoll and Ernst Ruska published an image obtained with a beam of focused electrons [9]. Electron-based optical systems have seen steady and continual evolution, spawning a wide variety of techniques including scanning and transmission electron microscopy, electron diffraction and electron beam lithography.

The use of neutral atoms in a similar way presents a greater challenge for a very simple reason: they are notoriously difficult to manipulate. In particular, helium-4 in the ground state has zero spin, zero charge, the lowest known polarisability and the highest first ionisation energy of all neutral species, and is thus almost impossible to electromagnetically focus or steer. Focusing of the more exotic helium-3 [10] and metastable helium-4 [11] has been demonstrated; however, neither are currently viable as structural probes. Helium-3 is prohibitively expensive and hence requires large, sophisticated recovery systems. On the other hand, metastable helium-4 interacts strongly with the electronic de-excitation channels of a surface [12]. These interactions result in scattering that is less indicative of the topology of the surface, making it more appropriate for spectroscopy. We are thus left with limited means to manipulate our neutral atoms. The earliest attempts to achieve a focused helium spot for use in microscopy used diffractive focusing, namely nanofabricated Fresnel zone plates, or pure surface scattering via atom mirrors [13, 14]. Reflective focusing has, in principle, no limits to its solid angle of collection and accordingly offers the maximum theoretical signal. The intensity of the reflected helium beam is determined by the nanostructure of the mirror surface and thus an atomically smooth mirror is required to ensure high reflectivity. Despite many advances in the field (including reflective focusing below 50 um), the development of a complete imaging system based on atom
mirrors has remained elusive, primarily due to the very stringent cleanliness and fabrication required.

Early diffractive focusing attempts using Fresnel zone plates reduced the intensity of the incident helium beam below the useful threshold for microscopy [13]. Given the challenges associated with atom mirrors, the focus returned to Fresnel lenses and rapid improvements to the quality followed. As a result, the first transmission-mode atom images were achieved in 2008 [15] through the use of such a lens (see Figure 2). Further developments of the technology has resulted in sub-micron focusing, with the efforts now shifting to improving the intensity at the focus spot, which in principle should allow for reflection-mode imaging via a zone plate.

With transmission imaging achieved, research moved to producing images from reflected helium. Such reflection-mode imaging introduces further signal losses, greatly increasing the requirements for high helium flux. The low throughput of current focusing methods mean that a reflection-mode microscope based on these approaches has proved elusive. In order to overcome the lack of signal within the focused spot, multiple research groups turned to designs which simplified the optics. Through use of a pinhole as the means to produce a spot on the sample surface, work including reflection images was successfully produced published in 2011 and 2014 [16, 17]. The former instrument maximised intensity via extremely short working distances, limiting the range of amenable samples. The latter (SHeM) was able to produce not only highly contrasting topological images of the sample surface, but in 2016 also demonstrated chemical contrast for the first time [18].

**Instrumentation**

Although the possibility of a reflection-mode SHeM with nanoscale resolution has long been foreshadowed, the development of real instrument required overcoming a number of considerable technical challenges. Firstly, small spot size, intense helium beams need to be generated and scanned over the sample. Secondly, the resulting scattered helium beam needs to be received by a detector and an image generated. Based on the de Broglie wavelength of such atoms, the ultimate resolution of a scanning helium microscope is sub-Ångstrom, although technical limitations with regards to both neutral atom optics and detectors means that this limit is currently out of reach.

The basis for the Newcastle SHeM [19] is a traditional helium atom scattering system. In a typical HAS experiment, monochromatic, extremely low energy (10 – 300 meV) helium atoms are scattered from a sample surface, under Ultra High Vacuum (UHV) conditions, and detected in a tuned mass spectrometer. In comparison to HAS, the SHeM requires the use of a final collimating pinhole, and has a much shorter beamline. Figure 3 shows a schematic diagram of the SHeM. In the source chamber (1) a helium free-jet beam expansion (maxi-
mum pressure of 240 bar, temperature adjustable from 100 to 400 K) is created with the aid of a 10 micron nozzle before the centreline of the expansion is selected out by a 100 micron skimmer. The resulting beam of helium passes into the differential stage (2) moving into the back of the pinhole plate, with excess gas pumped away. In the tip of the pinhole plate a silicon nitride disc with a milled pinhole (typically 1-5 microns in diameter and fabricated via ion beam milling) apertures the beam, leaving a small spot to strike the sample surface in the sample chamber (3) as shown in the inset. The reflected helium moves on to the detector chamber (4) through a 1 mm diameter aperture where it stagnates to form a stable pressure, subsequently measured by a mass spectrometer. The image of the surface is constructed by rastering the sample back and forth in front of the beam. A sample SHeM micrograph is shown in Figure 4.

**Understanding Contrast Mechanisms in the SHeM**

A key issue in any microscope is understanding the changes in relative intensity (contrast) mechanisms that are likely to be in operation behind the scenes. The contrast apparent in SHeM micrographs ultimately derives from the nature of the probe-sample interaction. Low energy (as achieved by a room temperature beam) helium atoms are scattered by the corrugated surface electronic potential, mapping out a surface of constant electron density, typically 3 – 4 Å above the surface. The scattering process therefore inherently determines the contrast mechanisms that are likely to operate in any helium beam based imaging instrument.

There are three important trajectories by which a helium atom will backscatter from a surface, as shown in Figure 5. First, the dominant trajectory (trajectory 1) is elastic scattering, whereby the helium atom does not exchange any energy with the solid surface. This elastic trajectory will yield either “mirror-like” specular reflections, or, if the wavelength of the incident atoms is comparable with the crystallographic dimensions, a diffraction pattern characteristic of the surface’s crystal structure.

Second, there is a finite probability that an incident helium atom may exchange energy with the surface or an adsorbate, resulting in inelastic scattering (trajectory 2). The mean energy of a thermal helium atom is well matched to those of phonon-induced surface charge density oscillations, and any such energy exchange may increase or decrease the scattered helium atom’s kinetic energy [20]. Helium in particular is ideal to probe such surface charge oscillations as its small size and mass (compared with other atomic species) means that it minimizes the total lattice displacement and hence will excite or de-excite the largest number of vibrational modes [21].
The amount of helium that is scattered into this “diffuse” channel by single phonon scattering is typically 2-3 orders of magnitude lower than the elastic contribution [21, 22].

Third, for highly corrugated surfaces, transient scattering into resonant states (trajectory 3) may also occur if the momentum exchange involved in diffraction robs the atom of sufficient energy to escape from the surface potential. This trapped atom will eventually be ejected into either the first or the second trajectory. Nevertheless, the low polarisability of neutral helium means that the probability of this resonant state trapping occurring is vanishingly small.

Figure 5: Schematic illustrating the various possible trajectories for a helium atom interacting with a sample surface. 1 – elastic scattering yielding either specular reflections (zeroth order) or a diffraction pattern characteristic of the surface periodicity. 2 – inelastic scattering as a result of energy exchange with phonons, which produces an angular broadening of the distributions of the first trajectory. 3 – temporary trapping of atoms into one of the resonant states of the shallow van der Waals potential well. Note that the dotted lines represent equipotentials for the helium-surface interaction. Figure adapted from MacLaren [23].

In order to simplify the understanding of the contrast originating from the aforementioned atom-surface interactions, we have categorised image contrast into three classes; namely topological, chemical, and diffractive (interference).

**Topological Contrast**

Topological contrast is the dominant mechanism present in SHeM images of microscopically rough specimens, with changes in the surface morphology influencing the intensity recorded at each pixel of the image. This contrast originates from elastic scattering from surface isopotentials, with the relative angle between the surface mean plane and the detector dictating the observed signal. Further topological contrast in the form of shadowing and masking is possible if either the beam or detector (respectively) is occluded due to a surface asperity.

Figure 6 shows a comparison of optical and SHeM micrographs of a section of a wing from a species of honey bee *Apis mellifera*. It should be noted that unlike SEM (whereby a conductive coating is generally required to prevent sample charging), no special preparation of the wing was conducted before being entered into the instrument. The transparent nature of the wing membrane means that the complex folds of the material are difficult to discern in the optical image, additionally complicated by features from the underside of the wing being visible. The absolute surface sensitivity of the helium probe removes such an is-
In the SHeM image - the changing angle of the surface towards the detector (located on the left hand side of the SHeM micrographs) results in a shifting intensity, highlighting their location. Masking of the incident helium beam can be seen by the hairs on the surface (particularly in the zoomed region), as well as where the wing rests on the substrate. Taken in total, topological contrast produces intuitive images of samples with the inherent benefits of no risk of beam damage and no sample preparation.

Chemical Contrast
Whilst topological contrast is readily observed, one of the most exciting prospects for the SHeM has been the possibility of obtaining chemical contrast. The composition and local atomic character of a sample surface should give rise to variations in helium reflectivity - for example, the highly-corrugated isopotentials of a semiconductor would result in more diffuse scattering than would the delocalised electrons of a metal. Image contrast will also arise due to inelastic scattering of helium due to energy exchange with surface vibrations (phonons), known to be highly dependent upon sample composition [22]. Moreover, the influence of surface vibrations on the helium atoms will depend on both surface and bulk effects, meaning that the helium reflectivity will (perhaps counterintuitively) be modulated by the sub-surface structure - the so-called Quantum Sonar Effect [24].

Figure 7 is a composite showing the very first observations of chemical contrast effects with neutral helium [18]. The samples consisted of 40 nm thick patterned layers of gold, chromium, nickel, and platinum deposited on a silicon substrate with a 3 nm titanium wetting layer. The SHeM images clearly show that there is distinct contrast between each metal and the silicon substrate, as well as between the different metal species. The observed contrast does not correlate at all with the roughness (as measured by AFM) and thus changes in diffuse scattering arising from the nanometre scale surface irregularities are incapable of explaining the observed contrast differences.

Diffractive and Interference Contrast
Under normal scattering conditions, room temperature helium atoms have a de Broglie wavelength comparable to typical crystallographic dimensions. As a result, elastic scattering will result in diffraction from the surface, causing angular variations in the scattered helium intensity, and thus contrast. Additionally, interference effects can occur from coherent scattering from neighbouring atomic layers. To resolve these diffraction and interference patterns, typical HAS apparatus have an angular resolution of less than half a degree. The current SHeM instrument has a larger detector aperture to account for the deficiency in terms of helium signal, therefore precluding the observation of individual diffraction or interference peaks. Consequently, diffractive effects do not presently play a role in the generated contrast. Significant technical advancements in detector technology and/or atom optics will be required to harness this final contrast mechanism.

Conclusions and Future Prospects
The development of the SHeM represents a breakthrough in imaging technology and offers a new, completely non-destructive microscopy capable of imaging the true nature of surfaces. Thus far, the SHeM has demonstrated contrast arising not only due to surface topology, but also to the local chemical environment through inelastic interactions. Looking ahead, there is a range of exciting opportunities available to the technique. First and foremost, there is an additional contrast mechanism - diffraction and interference - that is, in principle, available to the instrument. It is well known from prior HAS studies that even small amounts of disordered adsorbates lead to a reduction in the intensity of the helium diffraction peaks, and so sample cleaning would be a necessary requirement. In order to adapt the SHeM to achieve HAS-like angular resolution, a 3-4 order of magnitude increase in detector sensitivity is required (based on the reduction in detector aperture size), which will be realised by utilising a solenoidal ion source as the detector.
Improvements to the total available signal can also be utilised to improve the resolution of the instrument, or reduce the scan time per image. Analogously to SEM, the topological contrast observed within a SHeM makes the technique amenable to capturing 3D information through either stereo-photogrammetry or photometric stereo techniques. Based on the technique’s surface sensitivity, non-destructive nature, potential for nanometre resolution, and range of novel contrast mechanisms, SHeM will open the door to the imaging and analysis of many surfaces previously inaccessible to other techniques. The future for SHeM is bright!

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Author biographies
Paul Dastoor
Professor Paul Dastoor is Professor of Physics at the University of Newcastle in Australia. He received his B.A. in Natural Sciences and his PhD in Surface Physics from the University of Cambridge. He has been Visiting Research Fellow at Fitzwilliam College, Cambridge, UK, at the Daresbury Laboratory, Cheshire, UK and at Nanyang Technological University. He is Director of the Centre for Organic Electronics, which he established in 2007. His research interests encompass the growth and properties of thin films, surface coatings and organic electronic devices based on semi-conducting polymers. He has been developing neutral atom microscopy for over 20 years.
Joel Martens
Joel Martens is a PhD candidate working on the SHeM project since 2014. His work is on the design and construction of a new permanent magnet based solenoidal ion source which will serve as a detector upgrade for the helium microscope, potentially raising the signal level up to five orders of magnitude above the current value achievable with commercial ionizers.

Matt Barr
Matthew Barr recently completed his PhD candidature at the University of Newcastle, for which he received the Royal Society’s Jak Kelly Prize for Excellence in Postgraduate Physics. He completed his Honours Degree in Physics at Newcastle in 2010 and received First Class Honours and University Medal. His research interests include the design and development of a new type of microscope utilising neutral helium atoms as the probe particle. In 2011 he received an Australian Nanotechnology Network travel fellowship to travel to the University of Cambridge UK, where he was involved in the successful construction of a first-generation helium microscope.

Thomas Myles
Tom Myles is a PhD student at the University of Newcastle who has been working on the Scanning Helium Microscope (SHeM) since early 2016. His doctoral work concerns investigating the nature and origin of the chemical contrast observed by the SHeM, in addition to developing a greater understanding of image formation in general.

Adam Fahy
Adam Fahy is a PhD (Physics) student at the University of Newcastle, Australia, within the Priority Research Centre for Organic Electronics (COE). He completed his Honours degree in Physics at Newcastle, achieving First Class Honours. His research interests include applications of carbon nanotubes, ionisation mechanisms for neutral species, and novel instrument design. In particular, his PhD project concerns the construction and operation of a new type of microscope utilising neutral helium as the probe particle.

Seeking speakers for Girls in Physics Breakfasts

The Vicphysics Teachers’ Network invites women who have made a contribution in physics or engineering to be the keynote speaker at one or more of the Girls in Physics Breakfasts the group is organising in Victoria for the first half of 2018.

There will be two breakfasts in different parts of Melbourne and three breakfasts in regional Victoria in Geelong, Ballarat and Bendigo.

At each breakfast students from Years 10 to 12 will share a table with and ask questions of two or three young women who are either in the early years of a career in physics or engineering, or are still at university as an undergraduate or a post-graduate. The cost to each student is a subsidised $15, the young women are guests of Vicphysics and do not pay.

A key feature of each event will be an address by a woman active in physics. The breakfasts will be held in March to June 2018. The exact dates will depend on the availability of the speakers.

Vicphysics is seeking women to speak at one or more breakfasts who:

• Have public speaking experience,
• Offer a topic that will engage the secondary students present as well as the young women,
• Available to speak at some time between March and June.

There will be an honorarium for each speaking engagement. Travel and accommodation costs will also be covered. For any queries, please email Vicphysics at vicphys@vicphysics.org.

Nominations can be made on line at http://www.vicphysics.org/speaker.html Nominations close: Friday, 1st December, 2017. Decisions will be made by mid December.

This initiative is supported by the Federal Department of Industry, Innovation and Science through the Inspiring Australia – Science Engagement Programme.

Vicphysics Teachers’ Network
www.vicphysics.org
Australian Science
The excitement around and appreciation of the necessity of Science or STEM (Science, Technology, Engineering and Mathematics) for the country’s future [3, 4] seems a sentiment not fully reflected in our schools and universities. In fact, evidence from several different sources is telling us that students are losing interest, performing worse and shunning STEM-related degrees and careers. For example, the Programme for International Student Assessment (PISA) shows Australian students are slipping behind their international peers in both science and mathematics [5, 6]. Results from TIMSS (Trends in International Mathematics and Science Study) show that compared to the top five performing countries, only half as many Australian year 8 students achieve the highest performance band in science (11%, compared to 23%) and this is worse at 9% (compared to 41% in top band) for maths. TIMSS also tells us that that student interest in science and maths declines throughout schooling with a healthy 55% of students ‘liking’ science in year 4 transforming into a disappointing 25% in year 8. This is not to mention the teaching profession, where one in five science teachers are not technically qualified to teach science and 40% of schools report they have difficulty filling maths and science teaching positions. Nationally, there has been a decline in participation in almost all science subjects (apart from Earth and Environmental Science) between the years 1994-2013, with physics participation decreasing by 5% (Figure 1). Physics is easily the most ‘extreme’ example in the sciences; with lower enrolments (both high school and University), a more skewed male to female ratio and the enduring reputation for being ‘hard’ [7].

For the first time in 17 years, the Higher School Certificate (HSC), New South Wales’ (NSW) flagship course that wraps up 13 years of schooling for around 76 000 students each year, is undergoing major changes. As part of the reforms, many courses will be rejuvenated, removed or newly created in an effort to reflect a changing world and workplace and to ‘increase standards’ [1]. In this article, we discuss the nature and consequences of these changes in terms of HSC physics specifically, whilst commenting more generally on how physicists can positively influence the science education space.

Figure 1: Enrolment trends for Australian high school science subjects [2]
Syllabus changes and consequences

Though there are some who debate the significance or magnitude of the ‘STEM crisis’, the value of having strong scientific literacy is clear and the impetus for change is profound [8]. The mechanism most available and possibly influential in affecting students’ scientific literacy is the school curriculum and thus, contestations around it have always existed. In an article outlining the history of physics education reform in the United States, for example, Otero and Meltzer [9] demonstrate that from as early as 1880, calls for more ‘authentic’ studies of science (rather than ‘lectures’ of ‘facts’) have featured every few decades in successive curricula reform; at first it was laboratory work, then inquiry, scientific practice, the nature of science, the scientific method, and so on. They also interestingly suggest that “current reformers have failed to acknowledge similar efforts and issues from previous times.” (p. 54), implying many of these suggested reforms are fundamentally identical, except in name.

What we see now in science education reform in Australia, NSW specifically, is an example of such a contestation: a syllabus that is broad in scope, contextualised and focused on the nature and history of science will give way to a modular and mathematical syllabus, focused on ‘classical’ physics (See Table 1). But it’s more complicated than that. Though aspects of the syllabus have become more ‘traditional’, there has been a stronger emphasis on the scientific practice within the subject (e.g., Depth Studies) and in general across the whole reform (e.g., Extension Stage 6 and the new subject, Investigating Science). The question then arises; what does this change mean and how should we respond to it?

The likely consequences of the new NSW physics syllabus

Contestations around the syllabus are frequent and often quite vociferous, and with good reason; changes in policy do make a difference. For example, research around the previous change showed that though students understanding of key concepts remained the same, the students from the current syllabus actually demonstrated superior understanding of the nature of physics knowl-

<table>
<thead>
<tr>
<th>DIMENSION</th>
<th>2001 (CURRENT) SYLLABUS</th>
<th>2018 (NEW) SYLLABUS</th>
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<tbody>
<tr>
<td>Rationale</td>
<td>Reduced content, embedded ‘nature and history of Science’ and contexts, intended to increase accessibility to wider group of students</td>
<td>Increased mathematical content, reduced ‘social’ dimension, removal of contexts, opportunities for authentic practice of science (depth study), reduced opportunities for ‘rote learning’</td>
</tr>
<tr>
<td>Organisation</td>
<td>Content organised under ‘Prescribed Focus Areas’ (e.g., Moving About, From Ideas to Implementation), separate ‘option’ topics (e.g., medical physics, geophysics and electronics).</td>
<td>Organised under topics (e.g., Thermodynamics, Advanced Mechanics etc.). New type of content, known as ‘depth studies’, intended to allow autonomous ‘deep learning’ of a particular content or skill area. No options</td>
</tr>
<tr>
<td>Mathematical Content</td>
<td>Decreased but still prominent (Newton’s Laws, Motor Effect, Photoelectric effect etc.)</td>
<td>Increased. Vector algebra in Year 11, derivations across the board, twice as many equations as the current syllabus.</td>
</tr>
<tr>
<td>Topics</td>
<td>Cover a broad range of content: e.g., equations of motion, specific scientific breakthroughs and scientists (e.g., J.J Thomson’s cathode ray tube experiment and Planck and Einstein’s view of science), and social issues (e.g., impact of transistors)</td>
<td>Mostly ‘classical’ physics topics (waves, mechanics, electricity, thermodynamics) with astrophysics and particle physics becoming part of the core, rather than options.</td>
</tr>
<tr>
<td>Assessment</td>
<td>Mixture of school-based assessment and state-wide HSC examination, which contains a mixture of multiple choice, short answer and longer response questions.</td>
<td>Though assessment has not been finalised at the time of writing, it has been conjectured that the essay-type (longer response) questions will be greatly reduced, less opportunities for rote learning are a feature (as an overall philosophy among all new syllabuses in NSW).</td>
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Table 1: Comparison of the ‘current’ (2001) and ‘new’ (2018) NSW HSC syllabus
edge when compared to students studying the pre-2001 syllabus [10]. Another piece of research examining the use of technology in teaching and learning in the HSC sciences showed that the use of technology in physics resulted in improved HSC scores, compared to both other science subjects and groups without technologies. Since the physics syllabus recommended or even mandated various technology use, including simulations, and the biology syllabus, for example, does not, it is hypothesised that the effect was based on the explicit presence of these requirements in the syllabus [11].

It has been widely speculated that there will be several knock on effects of the current change. Firstly, with the increase in mathematical rigour, it has been predicted that numbers studying HSC physics could markedly decrease [12]. Abrahams’ work on HSC physics persistence shows that one of the key factors is the perception of performance; that is, students that perceive a topic to be one in which they will not perform well are more likely to not continue in physics [13]. The new Physics syllabus, has, in Year 11, all three of topics, mechanics, waves and electricity, that are considered the least likely to result in perceptions of better performance (and hence persistence in the subject).

On the other hand, it has also been anecdotally suggested that the new rigorous syllabus will attract back more able students who currently opt for the humanities to play the ‘ATAR (Australian Tertiary Admission Rank) game’ (selecting subjects to maximise final marks, an issue that is promised to be rectified in the reforms). Students are most likely to be gained at private and selective schools (with a higher concentration of students with stronger academic ability) and lost from regional, remote and low socioeconomic schools. These schools are already suffering from staffing difficulties and small physics class sizes, meaning that even if a student is capable of studying the subject, they may not be able to. Beyond the issues this raises for participation in the future workforce, this does nothing for inclusivity in a subject which is already known to struggle to attract minorities [14].

The changes offer substantial challenges for teachers. The new content, e.g. thermodynamics, will be new to many physics teachers, even experienced teachers. However, unlike the introduction of the new K-10 Australian Curriculum, there is no additional funding for the roll out of the new HSC syllabuses. Physics teachers need to be taught the new content and associated experiments in an already time-restricted environment [15]. Recalling our earlier reporting of the state of teacher qualification and shortages, where over 20% of physics teachers are teaching out of specialism i.e. are not physics-trained, and considering nearly half of all physics teachers retiring over the next 10-15 years [16], this is a serious concern.

Going a little deeper
Though the syllabus will have some tangible and possibly concerning consequences, the teaching of physics is actually notoriously quite resistant to curricula changes. Carlone explains that the ‘prototypical’ view of physics as being ‘difficult, hierarchical, objective’ is maintained and reproduced despite policy changes, and that this characterisation undermines inclusivity [17]. Physics is considered the ‘prototypical’ science both from within, where it is referred to as the most ‘fundamental’ [18] but also from the outside, where it is considered ‘pure’ [19], ‘abstract’ [20] and ‘hierarchical’ [21]. So despite calls for broader, contextualised ways of teaching physics, a certain rigidity in what physics is and is not seems to persist. This rigid view quite possibly underlies the decades of unsuccessful reform of physics education and is perhaps why physics is suffering particularly badly in the current crisis.

It is interesting to uncover these tensions over the decades. A fascinating excerpt from an early 20th Century policy discussion piece, for example, demonstrates that even at that point in history, the ‘new’ approach to teaching physics was one that:

“emphasize(d) “the development of habits of scientific thought” and “the method by which science obtains its results” rather than “more or less scattered facts and theories taught in such a way that they could only be committed to memory.” (quoted on p. 53 in [9])

Exam questions from The University of Sydney (Figure 2), a university known for its excellent reputation in the sciences, show that ‘essays’ and the history of physics were considered to be extremely important as far back as 1888.

In 2001, the syllabus change heralded a new era of incorporating the nature and history of science after decades of work and substantial robust research in the local context [22, 23]. However, in the wake of the new syllabus, the old has been branded ‘soft’, lacking in substance, weighed down by unnecessary history and sociology and, very unfortunately, ‘feminine’ [24]. Instead,
the new syllabus signals a ‘return to basics’, increased rigour and back to form [1].

Why are the holistic, contextualised, humanistic and social qualities placed in opposition to rigour and mathematics? And why are these currently considered ‘bad’ and ‘good’, respectively?

This is the important question to consider. Rather than propagating an erroneous view of physics as ‘objective’, ‘rigorous’ and ‘masculine’, we must instead discuss the nature of a discipline, its values, and its ‘epistemology’ in curricula reform and in education more generally. Speak to any practicing physicist, for example, and they will tell you that ‘mathematics’ does not necessarily equate to ‘rigour’. A conceptual understanding, and one where equations are understood, rather than algorithmically solved, is instead superior; a view supported by decades of physics education research [25,26]. Furthermore, if the syllabus aims to reflect the scientific practice, essay writing, which is often reported to be the anti-thesis of Physics, is actually essential; without it, grants cannot be won and physics cannot be done.

Such critical examinations of a discipline/subject, rarely happen but can be extremely insightful when they do. Existing research, for example, shows how a focus on the way physics knowledge is structured can help students overcome misconceptions [27] and explicitly pointing out the characteristics of scientific practices reduces confusion about how science works [28].

What do we do about it?

If we do nothing about the issues raised then the inequality of access to high school physics will be greatly amplified as the regional, remote and low socioeconomic schools struggle further in attracting both students and physics-trained teachers, whereas metropolitan, high socioeconomic and selective schools will continue to recruit relatively healthy numbers of students and trained teachers. Exclusion of females and other groups, who just don’t ‘see’ themselves as physicists, will also likely continue, or even worsen. We can though, do something about this.

Firstly, and practically, universities and institutions can develop online resources and outreach programs for teachers and students, particularly regarding the new content. In addition, teacher professional development courses focused on developing disciplinary expertise can be developed and widely promoted.

On a more ‘theoretical plane’, though scientists, particularly physicists, tend to commonly avoid ‘political’ or sociological inquiry, there is no hiding from the fact that the existing contestations, particularly in physics, are already socially charged. The very group (university academics) that call for a syllabus to be mathematical and rigorous will also explain to you that conceptual understanding and appreciation of the context of an equation are just as important. Physics being perpetuated as ‘rigorous, mathematical and masculine’ is not only halting inclusivity and equity; it’s not a true reflection of a discipline which is ever-changing, humanistic, beautiful and, sometimes, subjective. Instead of reacting against the ‘socialisation’ of physics, perhaps a deeper study of what the discipline is and is not should occur. Maintaining and promoting this conversation, such that all stakeholders are aware of the impending issues, will go a long way to addressing the postulated demise of physics for all in NSW and Australia at large.
Nonlinear Optics at Nanoscale: Where are we?

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Many consider optics and photonics to be the technological revolution of the 21st Century. Nonlinear optics (NLO), whereby light is directly controlled by light, has a wide range of applications in our daily lives. However, current nonlinear optical interactions are generally based on large crystals, which are not compatible with the size requirements of cutting-edge miniaturized systems. Here, I review the latest advances in obtaining efficient nonlinear signals from tailored structures at nanoscale, whose thicknesses are typically a few hundred times less than a human hair.

What is Nonlinear Optics?
Nonlinear optics (NLO) describes the behavior of light in nonlinear media, where the response intensity of the medium does not depend linearly upon the intensity of the incident light. For example, twice the optical input intensity does not simply result in twice the output intensities. The non-linear optical response of a material is generally very weak, however at high powers, the material properties can change more rapidly. Therefore, a nonlinear effect can be achieved with high intensity lasers, since the nonlinearity also implies a super-linear dependence on the intensity of the light. Currently, nonlinear optical interactions are generally based on large anisotropic crystals that gradually accumulate a strong effect.
NLO phenomena have been observed in a wide range of wavelengths starting from the deep infrared to extreme ultraviolet, and have even been used to generate THz radiation. This is the heart of modern photonic functionalities, including diversifying lasers and light, material interactions and more importantly information technology. The impact of NLO on science is widely understood nowadays, as it has enabled at least nine Nobel prizes in physics and chemistry. As shown in Figure 1, NLO has caused many developments in our daily life, with broad applications in laser-materials interactions, information technology, sensing, communications, data processing, etc. [1]

Nonlinear Optics at Nanoscale

The nonlinear optical response of a material is weak. In order to obtain strong nonlinearity, the size of the optical field must be matched to the length scales of electronic wavefunctions, which correspond to more than a thousand-fold reduction beyond the diffraction limit of light. Therefore, large anisotropic crystals are required to accumulate a strong effect. This is why, current large nonlinear crystals are not compatible with the size requirements of photonic and optoelectronic systems. However, recent studies have revealed the potential of nanophotonics to address this issue via the artificially induced nonlinear responses in certain nanostructures. This is possible, since nanostructures are capable of squeezing light fields into volumes orders of magnitude smaller than the diffraction limit of light – this is the key to strong optical nonlinearity. Furthermore, the materials used to make such nanostructures have naturally strong optical nonlinear responses.

Together with advancements in nano-fabrication, numerical simulation and characterization technologies and techniques, the quest to realize NLO with enhanced optical nonlinear response at nanoscale has become very active in the last decade. Nano lithography is a common method used in nano patterning. Figure 2 shows a picture of the author in the cleanroom during a nano fabrication process, accompanied with a simplified demonstration of the most common nano lithography technique. For fabricating nanostructures, first, an ultraclean substrate/wafer is covered with a thin layer of electro- or photo-sensitive polymer, a so-called resist. Then the wafer is placed in a tool that exposes the sample via a writing electron beam or light source through a mask. Subsequently, the patterned resist is placed in a developer chemical which washes away the exposed (or unexposed) resist, based on the type of resist. This leaves a pattern of nanoholes in the resist on the wafer's surface. It is followed by a transfer step, where a thin film of metal/dielectric is deposited everywhere, including inside the holes. By removing the resist via certain chemistry, only the desired pattern of nanostructures remains on the wafer.

Characterization of nonlinear nano media is also challenging. A nonlinear response from individual optical antennas is generally measured by focusing an intense laser with a microscope objective (see Figure 2c). This
configuration provides a spot diameter on the order of a few μm covering the whole surface of the nanostructure, which acts as a nonlinear element that converts the input signal (red) into an output signal with a different frequency (blue). The intensity is so weak and should usually be measured with cooled ultrasensitive spectrometers. The scheme shown works in the reflection regime; however, the setup can be made to measure the transmitted signal. [2] Here, I review the state-of-the-art in the field of efficient nonlinear optics from tailored nanostructures, whose thicknesses are typically a few hundred times less than a human hair, including metallic and high-index dielectric, semiconductors and hybrid nanoantennas.

**a. Metallic nanoantennas**

Metallic nanodevices represent an interesting approach to bridge the gap between conventional optics and highly integrated nanophotonic components via stimulating the oscillation of free electrons on the surface, so-called surface plasmons, that subsequently cause electric dipoles and higher order modes. [3] By reversibly converting propagating electromagnetic waves into volumes orders of magnitude smaller than the diffraction limit of localized light, so-called hot spots, nanostructures can act as actual antennas: this is the key to strong optical non-linearity. [4] Furthermore, the metals used to make such nanoantennas, gold and silver, have naturally strong optical non-linear responses. In this context, special attention has been recently devoted to optical antennas, counterparts of radio and microwave antennas in the optical regime. The most studied metallic nanoantennas are dimers, where the antenna consists of a pair of bars, disks, bowties etc., with a nanoscale gap in between. [5] It has been demonstrated recently that the highest non-linear intensity is not linked to a specific shape, but to the smallest antenna volume. This has been shown through a third harmonic generation (THG) process, which is a nonlinear interaction when three photons are destroyed, creating a single photon at three times the frequency. As can be seen in Figure 3, Henke, et al. have shown that resonant nanoantennas are mostly radiation-damped systems, where a few-femtosecond plasmon damping time suffices to quantify the intensity of coherent non-linear light emission. Because of radiative damping, the lowest antenna volumes generate, by far, the strongest third-harmonic emission. [5]
As can be seen in the calculated extinction cross section of the three-arm nanoantenna in Figure 4b (blue curve), four resonance peaks are present within the bandwidth of interest, where they overlap with each other preventing the extinction cross section from decreasing to zero. The grey dots on the same plot show the experimental measurements. Figure 4c shows numerical simulations of the electric field intensity enhancement distribution, demonstrating hot spots in the middle. As can be seen in Figure 4c, a strong hot spot for various polarizations of the incident light at a wavelength of 1800 nm appears that consequently provides a nearly equal SHG signal for all incident polarizations.

b. Hybrid metal-dielectric nanoantennas
Although light-plasmon interactions in metallic nanoantennas have offered great opportunities for nonlinear interactions at nanoscale, the conversion efficiency rates remain low due to the weak penetration of the exciting fields into the metal. A few years ago, the author and co-workers introduced a hybrid system, which can significantly increase the intensity of the nonlinear light. It was demonstrated that THG from an individual semiconductor indium tin oxide (ITO) nanoparticle is significantly enhanced when coupled within a plasmonic gold dimer (see Figure 5). The plasmonic dimer acts as a receiving optical antenna, confining the incident far-field radiation into a near field, localized at its gap; the indium tin oxide nanoparticle located at the plasmonic dimer gap acts as a localized nonlinear transmitter upconverting three incident photons. As can be seen, this hybrid nanodevice provides THG enhancements of up to 10^6 fold compared with an isolated indium tin oxide nanoparticle.

Despite numerous advantages, metallic structures suffer from Ohmic losses at optical frequencies which limit their efficiency and functionalities. Alongside this, metals tend to have a relatively low heat resistance to high power lasers and this could be a key limiting factor to

Figure 4: (a) SEM image of a fabricated polarization-independent multi-frequency optical antenna. (b) Experimentally measured (grey dots) and simulated extinction cross section (blue solid line). (c) Numerical simulation of the electric field intensity distribution (|E(x,y)|^2/|E_0|^2) at the cross sectional plane of the nanoantenna for different polarization angles (0, 15, 30, and 45°) at incident wavelength λ = 1800 nm. The sample is fixed and the incident plane-wave, initially x-polarized, is rotated. Adapted with permission from [6]. Copyright (2012) American Chemical Society.
nonlinear optics at nanoscale. This is why employing the capabilities of other materials for nonlinear enhancement at nanoscale has been an active research direction more recently.

c. High refractive index nanoparticles

High-refractive index resonant nanoparticles, e.g. silicon [7] and germanium [8] are emerging as a promising alternative to metallic nanoparticles for a wide range of nanophotonic applications that utilize localized resonant modes. Such nanoparticles offer unique opportunities for the study of nonlinear effects due to very low losses in combination with multipolar characteristics of both electric and magnetic resonant optical modes. Importantly, the nonlinear optical effects of a magnetic origin can have fundamentally different properties when compared with those of an electric origin (at metallic nanoparticles). When nonlinearities of both electric and magnetic origins are present, the nonlinear response can be modified substantially, being accompanied by nonlinear mode mixing and magneto-electric coupling studied so far only at microwave frequencies. It is therefore, an important task to characterize the optical nonlinear effects originating from the magneto-electric response of high-index nanostructures. Furthermore, silicon is a material with high third-order nonlinearity; hence, strong enhancement can be expected in the nonlinear optical response of high-index nanoparticles. Recently, Shcherbakov et al., demonstrated that by engineering the resonant modes of silicon nanoparticles, one can control the locally enhanced electromagnetic fields, giving rise to two orders of magnitude enhancement of THG with respect to bulk silicon. [7] As can be seen in Figure 6b, the third harmonic radiation is bright enough to be observed by the naked eye under the table-lamp illumination conditions.

The caveat of dielectric benefits, however, is a considerably weak intrinsic non-linearity, in particular SHG. This is because the centrosymmetric nature of these materials has voided the study of SHG. [9]

d. Semiconductor nanoantennas

Exploiting materials with second-order susceptibilities, such as III-V semiconductors would intrinsically increase the conversion efficiency due to the lower-order nonlinearity. SHG efficiencies larger than $10^{-3}$ have been theoretically predicted for free standing AlGaAs nanoantennas [10] and efficiencies exceeding $10^{-5}$ have recently been measured in backward scattering for AlGaAs and GaAs sitting on an oxide layer. [11, 12] Recently, the author and colleagues obtained experimental measurements of the radiation patterns of SHG from high-quality AlGaAs nanostructures fabricated on a glass

Figure 5: (a) SEM image of a single nonlinear upconversion system. Scale bar is 200 nm. Bottom panel: FDTD computation of intensity enhancement along the middle cross-sectional plane for a wavelength of 1,500 nm and an incident plane-wave polarized parallel to the dimer axis. (b) Experimentally measured THG spectrum of an isolated 25 nm ITO nanoparticle for an incident wavelength at 1,500 nm. (c) THG spectrum of a single ITO nanoparticle localized at the centre of a 35-nm-gap nanorod dimer under parallel polarized excitation. [4]
substrate. [2] The standard fabrication techniques do not allow for this, as they require a non-transparent III-V substrate for direct growth of III-V semiconductors. The growth on transparent substrates (e.g., glass) is avoided [11, 12] because it results in a high density of dislocations. However, the author implemented a novel fabrication procedure of AlGaAs-in-insulator, containing epitaxial growth in conjunction with a bonding procedure to a glass substrate. [2] The configuration of our fabricated sample allows us not only to achieve strong linear resonances and control their spectral positions, but also to characterize through the substrate both forward and backward SHG signals. Figure 7 shows the results of a successful transfer of the grown Al_{0.2}Ga_{0.8}As nanodisks with 300 nm thickness from a GaAs wafer to a thin glass substrate. The measured SH efficiency is shown in Figure 7b and is derived as the sum of the measured forward and backward SH signals. The overall dependence of the efficiency on the antenna size is complex due to the large number of higher-order modes that exist in the SH frequency band. The most efficient SHG is observed for the disk with diameter of 490 nm, having a conversion efficiency as high as ~ 10^{-4}.

Figure 6: (a) Illustration of THG from individual Si nanodisks at the magnetic dipole resonance at optical frequencies. (b) Power dependence and conversion efficiency of the resonant THG process in Si nanodisks. Blue circles denote the THG power dependence upon increasing the power of the pump, while red circles denote the reverse procedure both obtained at \lambda = 1,260 nm fundamental wavelength. The left inset shows a photographic image of the sample irradiated with the invisible IR beam impinging from the back side of the sample as indicated by the red arrow. The blue point represents the scattered TH signal detected by the camera. Adapted with permission from [7]. Copyright (2016) American Chemical Society.

Figure 7: (a) Image of a glass substrate (top) supporting the fabricated AlGaAs nanostructures (bottom). (b) Experimentally measured SHG efficiency from a single nanodisk of different diameter at the pump wavelength of 1556 nm. Blue indicates forward radiation; red indicates backward radiation; green indicates the sum of forward and backward. Adapted with permission from [2]. Copyright (2016) American Chemical Society.
Conclusions
In order to expand NLO to the nanoscale, several approaches were proposed in the last decade to enhance the nonlinear properties of artificial materials. As discussed, plasmonic nanostructures are powerful tools due to their capabilities for light localization at the nanoscale. However, low damage threshold and Ohmic losses of metals have guided the attentions to high-index dielectric nanostructures, which support a high damage threshold. III-V semiconductors provide a strong second-order nonlinear response, expanding the use of high-index nanoparticles to second-order nonlinear effects.

References

Author biography
Mohsen Rahmani graduated with a PhD from the National University of Singapore (2013) and after 2 years working as a research associate at Imperial College London, joined the Australian National University (ANU) in 2015. He is currently a Research Fellow. He is the recipient of a number of national and international awards, including the Discovery Early Career Research Award (ARC 2017), and Early Career Medal from the International Union of Pure and Applied Physics (IUPAP), for outstanding contribution to the “Fundamental Aspects of Laser Physics and Photonics”. His activities span over several branches of optics, including plasmonics, metamaterials, and nonlinear nanophotonics.

Conferences
14 December 2017
Frontiers in Nanoplasmonics Workshop
RMIT University, Melbourne
au.eventscloud.com/nanoplasmonics

29 January – 2 February 2018
ICONN 2018 - International Conference on Nanoscience and Nanotechnology
University of Wollongong, NSW
ausnano.net/iconn2018/

30 January-2 February 2018
The 42nd Annual Condensed Matter and Materials Meeting. Charles Sturt University, Wagga Wagga, NSW
cmm-group.com.au/

6-7 March 2018
CUDOS Frontiers in Nanophotonics
Australian National University, Canberra
cudos.org.au

20-23 May 2018
5th Asian and Oceanic Congress on Radiation Protection – AOCRP5 Melbourne Exhibition & Convention Centre
www.aocrp-5.org

13-16 August 2018
9th Vacuum and Surface Science Conference of Asia and Australia SMC Function and Conference Centre, Sydney

25-29 May 2019
International Particle Accelerator Conference (IPAC 2019) Melbourne Convention and Exhibition Centre, VIC
www.ipac2019.org
BOOK REVIEWS

**Space Weather**

by Mike Hapgood

IOP Publishing, 2017
Free ebook, 23 pages
Online ISBN: 978-0-7503-1372-8

Reviewed by Dr Marc Duldig, School of Physical Sciences, University of Tasmania

The problem with this short ebook, 23 pages, is that it is unclear who it is intended for. In the “Abstract”, (implying it’s for scientists) it states it’s intended to “offer an insight into our current scientific understanding of space weather”, how that knowledge can be used to mitigate risks to technology and challenges for future research. It achieves these aims but the intended audience seems to vary throughout the book.

Mike Hapgood is a space weather expert and he knows his subject well. The style of the book is to explain complex physics in an easy to read manner. This is an excellent approach if the book is intended for the intelligent public reader or policy makers but unfortunately many concepts are explained with too high a level of assumed physics knowledge for such people to follow. For example, there is a description of magnetic recombination and plasma inflow and outflow involved; the text reads, “Reconnection can happen at the interface between two volumes of plasma with opposed magnetic fields …” but nowhere does the author state what happens to the field, even in the broadest conceptual way. Even the figure is not that instructive unless you happen to already know what reconnection is and then you can visualise the progression anyway. In passages like these saying how it happens in more detail rather than an incomplete description of what happens would have made the book appeal to a much wider audience rather than a primer for physicists in other fields who may be interested.

A couple of the figures don’t include information on the view orientation. After a moment you figure it out but a simple “View from …” would help readers unfamiliar with the subject.

The last half of the book centres on the role of research in increasing mitigation of the risks that space weather has on our technologies and the future needs of that research. In this context, the book is a sales pitch for future research aimed more at industry and policy, adding to the confusion about the intended audience. It is, however, still valuable for the interested physicist.

The book contains no reference list and only a few indirect references. This reduces its value to any physicist wishing to discover more about the topic in general or specific aspects. Furthermore, there is no bibliography or suggested further reading list so there is a similar lack of resource for a more general reader. When downloaded from the IOP website the IOP has added references to a mixed bag of articles that it has published on related matters but this is advertising for IOP rather than a useful addition to the ebook.

The book does cover the broad field of space weather and includes all the important aspects, the sun as the generator of (most) space weather, the linkage to the earth, the processes at earth and their impact, what we understand and the levels of that understanding. It failed to mention the economically important induced currents in metal pipelines, which degrade the segment welds over time and so require a reverse current to be applied to stop the degradation. There is also little description of many of the mitigation strategies in impacted industries but a few are mentioned, the author perhaps assuming this was sufficient for the purpose of the book. I would have liked to see more mitigation strategies and the problems with them. The author clearly describes the shortcomings in our knowledge and our ability to predict the impact of space weather events as they unfold. It describes the future directions that major aspects of research must take to improve forecasting and to better understand and assess the risks space weather presents. There is a single comment about historical “proxy” data to help improve risk assessment but, sadly, none of these proxy observations are discussed and an extra few paragraphs would have opened exciting avenues for the reader in very different fields.

Overall the book is a useful free read for a physicist interested in finding out more about space weather but, if you really are interested, be prepared to use key words you find to generate a web search for some more information.
Outside the Research Lab
Volume 1: Physics in the arts, architecture and design
By Sharon Ann Holgate
Paperback, 131 pages
ISBN: 9781681744681
IoP ebooks, 2017
ISBN: 9781681744698

Reviewed by Dr Joanna Turner, University of Southern Queensland.

The goal of this book, as acknowledged by the author, is to interest and encourage students and other non-scientists by profession, and in turn provide the benefit of understanding more about physics in a multitude of professions. The goal is commendable, however I am not necessarily convinced its execution produced the desired effect.

The book seeks to investigate a variety of industries in the artistic arena, where physics is used as a support to the profession, where an understanding of physics concepts and how they can be applied to techniques of an industry are explained and described. These include sculpture, music and instruments, sound recording, fashion and footwear, and finally architecture. Each section briefly covers examples of how physics concepts are used in each industry. Each chapter also explains in separate boxed sections, some of the theory behind the concepts. In a physical hard copy, I expect this format works well, where the reader can complete reading a section then go back to the highlighted box to read further on the theory. However in a ebook version (as reviewed), the effect is disjointed, as you must scroll through the pages in order to find the rest of the text in order to continue reading the passage. As a person familiar with many of these theoretical side notes, I was able to quickly skim these and move on, however this might be problematic for the non-scientific reader.

The main concern I have with the content is that, while it does a good job in explaining how physics is important, it often explains concepts to a level that I suspect may not be conducive to the introductory readers who are not familiar with some of the physics concepts. This may be due to the author’s tendency to quote large passages of the experts she interviewed. The expert speaks using specific technical terms, which are not always explained fully for a novice audience. The delivery of this content could have benefited from the author taking the expert’s information, and breaking it down further into explanations for the novice.

It may just be that I also did not enjoy the author’s style of writing, which is reminiscent of interview styles used for magazines (which I believe the author is proficient at doing) that are meant to generate a lot of information in a sentence or paragraph. Unfortunately this led to paragraphs of long sentences, which have multiple ideas, rather than keeping a sentence to one idea. I do not feel this works for this book, which could benefit from explaining more of the concepts with a bit more detail, and creating a narrative for the reader using a variety of sentence structures.

Despite my pessimistic views stated earlier, the book did provide enjoyment, and I learnt about areas that I was not familiar with in industries that I would not have considered previously. I am not convinced this book is written for a novice level, but I think we should have more books like this, that students in the future can consult when considering study choices for their industry. I look forward to seeing what the next volumes of this series will produce.

Rutherford Documentary
A documentary about Ernest Rutherford’s life, consisting of three one-hour episodes (1-The Apprentice; 2-The Alchemist; 3-The Statesman) is available for download from www.rutherford.org.nz under DVD/Books. This site also includes a 7 minute trailer.

For anyone travelling internationally on Air NZ in the next six months, the Rutherford Documentary is on the AirNZ inflight entertainment.
SAMPLINGS

Does self-interacting dark matter explain galactic diversity?
A new computer simulation by physicists in the US suggests that interactions between dark matter particles can explain why galaxies with similar masses can have different rotation curves.

The cold dark matter (CDM) model assumes that dark-matter particles interact with each other very weakly. When combined with a cosmological constant ($\Lambda$) that describes the expansion of the universe, the $\Lambda$CDM model is very good at explaining the large-scale structure of the universe. However, CDM is not very good at predicting the distribution of mass within individual galaxies once they have formed.

In 2000 David Spergel and Paul Steinhardt at Princeton University argued that this shortcoming could be eliminated if dark-matter particles interacted more strongly with each other. This has since been dubbed the self-interacting dark matter (SIDM) model. Now, Hai-Bo Yu at the University of California Riverside, Monoj Kaplinghat at the University of California Irvine have shown that SIDM can explain the observed diversity of mass distributions in some galaxies.

Yu, Kaplinghat and colleagues created a computer model that calculates the rotation curve of a galaxy of a certain mass containing both dark and visible matter. SIDM is used to describe dark-matter in the central region of the dark-matter halo, where collisions between dark-matter particles are more likely to occur. CDM is used to model dark-matter interactions in the outer region of the halo, and the effect of visible matter on the structure of the galaxy is also included. In addition, the history of the formation of the dark-matter halo is factored into the model.

The team used their model to calculate the rotation curves of galaxies with parameters similar to that of 30 galaxies that are well-known to astronomers. Writing in Physical Review Letters, the team says that they were able to reproduce the diversity of rotation curves describing the 30 galaxies. This allowed them to conclude that SIDM could be a contributing factor to the observed diversity of rotation curves.


Extracted with permission from an item by Hamish Johnston at physicsworld.com.

Ions and atoms react in magneto-optical trap
A magneto-optical trap has been used by physicists in the US to study how ions and atoms interact to create hypermetallic alkaline earth oxides – materials that have potential technological applications.

Hypermetallic alkaline earth oxides are linear molecules in which an oxygen atom is sandwiched between two alkaline earth atoms. The properties of these oxides can be finely tuned through the choice of the alkaline earth atoms, creating structures that could prove useful for a
wide range of applications including nonlinear optics, materials science or chemical synthesis. Currently these oxides are made and studied in plasmas and this means that it is difficult to both control the process and to gain insights into how they form.

The magneto-optical trap used to study hypermetallic alkaline earth oxides. (Courtesy: Steven J Schowalter)

Now, Prateek Puri and colleagues at the University of California Los Angeles, University of Connecticut and the University of Missouri have come up with a way of making hypermetallic alkaline earth oxides by reacting ions and atoms in a magneto-optical trap. The process involves cooling the reactants to temperatures as low as 5 mK and controlling the reactants’ initial quantum states. As a result they were able to make an extremely precise study of the formation of an alkaline earth-oxide ion comprising barium and calcium (BaOCa⁺).

The team began by loading barium ions into the magneto-optical trap to create a string of equally spaced ions – dubbed an ion crystal. Then molecular ions comprising barium, oxygen and a methyl group (BaOCH₃⁺) were introduced to the trap. These were cooled through interactions with the ion crystal. Then, a cloud of about three million calcium atoms are reacted with the BaOCH₃⁺ and the desired BaOCa⁺ appears as new ions in the crystal. Finally, the trap is switched off and all the ions are directed at a mass analyser that determines the make-up of the products of the reaction.

By varying the temperature of the reactants – and therefore the kinetic energy with which they collide – over a temperature range of 5 mK–30 K, Puri and colleagues were able to study the effect that collision energy has on how the reaction occurs. They also used a laser to put the calcium atoms into specific quantum states before the reaction occurred. This allowed them to work out that atoms in certain quantum states are more likely to react than atoms in other states.

[Prateek Puri et al., Science, 07 Sep 2017: eaan4701, DOI: 10.1126/science.aan4701]

Extracted with permission from an item by Hamish Johnston at physicsworld.com.

**Shape-shifting soft projectiles travel faster**

Liquid droplets or soft solid objects can be catapulted with more than twice the energy of rigid projectiles, according to physicists in France. They say that this “super propulsion” relies on additional momentum provided by the stretching and compression of deformation and could have practical applications in areas ranging from ballistics to bioengineering.

The effect involves superhydrophobic surfaces, which, like lotus leaves, are very hard to wet. Previously, scientists had shown that liquid droplets can bounce off these surfaces just like elastic balls, and now Franck Celestini of the University of Côte d’Azur in Nice and colleagues have demonstrated that these surfaces can be used to make very effective catapults.

The catapult in their case was a tiny upright spring with one end anchored to the ground and the other supporting a metal plate. Initially compressed and held at rest by an electromagnet, the spring undergoes harmonic motion when released – rising and falling over a distance of just a few millimetres but with an acceleration up to 10 times that of Earth’s gravity.

Had the researchers simply placed small rigid objects on the plate, the outcome would have been straightforward.
Each object would be pushed upwards until the plate reaches its maximum velocity and then starts decelerating, which occurs halfway through the spring’s expansion. At that point, the object – continuing to move upwards with the plate’s peak velocity – would be ejected by the catapult.

Instead the team covered the plate with a superhydrophobic polymer and then placed droplets of water on top of that. In this case the upward acceleration of the plate spreads the drop outwards, compressing it in the vertical direction. This slows down its centre of mass compared with the plate – so tending to delay the drop’s moment of ejection.

However, the horizontal spreading does not go on indefinitely. At a certain point, surface tension causes the drop to reassume its normal spherical shape, before overshooting and then expanding along the vertical axis. This vertical expansion gives the drop additional vertical velocity, which means that when it does fly off the plate its speed is greater than it would otherwise be.

Celestini and colleagues did their experiment using a range of spring stiffnesses and drop sizes, which varied the frequency of both the catapult’s up and down motion and the drops’ compression and expansion. As they report in Physical Review Letters, they found that drops got the biggest boost when oscillating about three times as fast as the spring did – the ejection speed and kinetic energy being, respectively, about 1.5 and 2.5 times greater than those of a rigid object.

[Christophe Raufaste et al., Phys. Rev. Lett. 119, 108001 (2017)]

Extracted with permission from an item by Edwin Cartlidge at physicsworld.com.

**Solar core spins four times faster than expected**

The Sun’s core rotates four times faster than its outer layers – and the elemental composition of its corona is linked to the 11 year cycle of solar magnetic activity. These two findings have been made by astronomers using a pair of orbiting solar telescopes – NASA’s Solar Dynamics Observatory (SDO) and the joint NASA–ESA Solar and Heliospheric Observatory (SOHO). The researchers believe their conclusions could revolutionize our understanding of the Sun’s structure.

Onboard SOHO is an instrument named GOLF (Global Oscillations at Low Frequencies) – designed to search for millimetre-sized gravity, or g-mode, oscillations on the Sun’s surface (the photosphere). Evidence for these g-modes has, however, proven elusive – convection of energy within the Sun disrupts the oscillations, and the Sun’s convective layer exists in its outer third. If solar g-modes exist then they do so deep within the Sun’s radiative core.

A team led by Eric Fossat of the Université Côte d’Azur in France has therefore taken a different tack. The researchers realized that acoustic pressure, or p-mode, oscillations that penetrate all the way through to the core
which Fossat dubs “solar music” – could be used as a probe for g-mode oscillations. Assessing over 16 years’ worth of observations by GOLF, Fossat’s team has found that p-modes passing through the solar core are modulated by the g-modes that reverberate there, slightly altering the spacing between the p-modes.

Fossat describes this discovery as “a fantastic result”, in terms of what g-modes can tell us about the solar interior. The properties of the g-mode oscillations depend strongly on the structure and conditions within the Sun’s core, including the ratio of hydrogen to helium, and the period of the g-modes indicate that the Sun’s core rotates approximately once per week. This is around four times faster than the Sun’s outer layers, which rotate once every 25 days at the equator and once every 35 days at the poles.

Not everyone is convinced by the results. Jeff Kuhn of the University of Hawaii describes the findings as “interesting”, but warns that independent verification is required.

“Over the last 30 years there have been several claims for detecting g-modes, but none have been confirmed,” Kuhn told physicsworld.com. “In their defence, [Fossat’s researchers] have tried several different tests of the GOLF data that give them confidence, but they are diving far into the noise to extract this signal.” He thinks that long-term ground-based measurements of some p-mode frequencies should also contain the signal and confirm Fossat’s findings further.

If the results can be verified, then Kuhn is excited about what a faster spinning core could mean for the Sun. “It could pose some trouble for our basic understanding of the solar interior,” he says. When stars are born, they are spinning fast but over time their stellar winds rob their outer layers of angular momentum, slowing them down. But Fossat suggests that conceivably their cores could somehow retain their original spin rate.

[E. Fossat et al., *Astron. & Astrophys.*, 604, A40 (2017); doi.org/10.1051/0004-6361/201730460]

Extracted with permission from an item by Keith Cooper at physicsworld.com.
Spectacular collision of two neutron stars observed for first time

Astronomers have made one of the biggest breakthroughs of the decade after detecting both gravitational waves and gamma rays from the merger of two neutron stars. Announced 16 October at a co-ordinated set of media briefings in Washington DC, London, and elsewhere, the detection was made on 17 August, with the gravitational waves spotted by the LIGO–Virgo collaboration and the gamma rays picked up by the Fermi Gamma-ray Space Telescope. The observations prompted astronomers to point dozens of different telescopes and detectors around the world, and in space, at the origin of the signals in a distant galaxy. Together, these facilities captured radiation from the aftermath of the merger across the electromagnetic spectrum from gamma rays to radio waves.

As well as being the first-ever example of “multimessenger astronomy” involving gravitational waves, the observations have yielded important clues about how heavy elements, such as gold, are produced in the universe. The ability to measure both gravitational waves and visible light from neutron-star mergers has also given a new and independent way of measuring the expansion rate of the universe. In addition, the observation settles a longstanding debate about the origin of short, high-energy gamma-ray bursts.

The gravitational-wave observation, dubbed GW170817, is the loudest ever seen in both US-based LIGO gravitational-wave detectors, which are in Hanford, Washington, and Livingston, Louisiana. A somewhat weaker signal was seen by the Virgo gravitational-wave detector near Pisa, Italy. Virgo had on 14 August detected its first gravitational wave from a black-hole merger, which not only told scientists that the detector was working properly but also suggested that the GW170817 signal came from a direction that Virgo is least sensitive to.

The merged neutron stars seen in the GW170817 event likely formed a black hole with a powerful jet, which produced the gamma rays that were also observed. Information from the three detectors enabled the LIGO–Virgo team to limit the location of the merged neutron stars to about 28 square degrees of sky. A battery of telescopes and other instruments was then able to pinpoint the source to galaxy NGC 4993, which lies about 130 million light-years from Earth.

High-energy gamma rays from GW170817 were detected in the form of a short burst, some 2 s after the gravitational waves. Astronomers had suspected that such bursts are caused by neutron-star mergers, but had little understanding of how it happens.

The prompt arrival of the gamma-ray signal also confirms that gravitational waves travel at the speed of light, while the ability to observe light and gravitational waves arriving from distant objects will allow physicists to perform more stringent tests of Einstein’s general theory of relativity.

Subsequent observations by as many as 70 other telescopes, however, suggest that the ultimate result of the merger was a black hole surrounded by an accretion disc of material. As this material was sucked into the black hole, a fast-moving jet of material blasted outward along the black hole’s axis of rotation. When this jet collided with gas in the galaxy, it started slowing down and the

A map of the approximately 70 light-based observatories that detected the gravitational-wave event called GW170817. Light-based telescopes around the globe observed the aftermath of the collision in the hours, days and weeks following. They helped pinpoint the location of the neutron stars and identified signs of heavy elements, such as gold, in the collision’s ejected material. (Credit: LIGO–Virgo)
lost kinetic energy was broadcast as gamma rays. Because Earth is roughly in the same direction as the GW170817 jet, astronomers were able to detect those rays. As it moved outward from the black hole, the jet slowed down and the energy of the emitted radiation dropped too. This explains why emissions of lower-energy X-rays, visible light, infrared and radio waves were also all detected in the weeks after 17 August. Indeed, astronomers are still observing signals from GW170817 two months on.

Extracted with permission from an item by Hamish Johnston at physicsworld.com.

Cosmic rays probe nuclear waste

Physicists in the US reckon that cosmic-ray muons could help solve a major problem with nuclear waste – how to monitor the long-term storage of spent reactor fuel cheaply and safely. Applying detector technology normally used by particle physicists, the researchers have shown experimentally how the subatomic particles can be used on site to determine whether or not any fuel has gone missing from dry storage casks.

Spent nuclear fuel contains fission products as well as isotopes of plutonium, and must therefore be carefully monitored when removed from a nuclear reactor. It is first placed in a cooling pond for several years while short-lived fission products decay. It is then transferred to large and heavily shielded containers known as dry storage casks, located either close to the reactor or at a special waste facility.

Inspectors place special seals on the casks to reveal tampering. But if a seal degrades for any reason – it might, for example, simply corrode when exposed to the elements – then the cask in question ought to be sent back to a cooling pond for re-examination. Ideally, says Matt Durham of the Los Alamos National Laboratory in New Mexico, the contents of casks would be verified on site. Numerous technologies have been put forward to do this, he notes, but all have their drawbacks – neutrons or X-rays, for example, cannot penetrate the casks’ thick shielding, while neutrinos would require enormous detectors. Muons, however, may provide the answer. Produced naturally by cosmic rays passing through the Earth’s atmosphere, muons penetrate material with a low atomic number – including a cask’s steel and concrete shielding – but are instead deflected by heavier elements, such as uranium fuel. Their degree of scattering as they pass through a cask should, therefore, reveal how much spent fuel is inside.

To put the idea to the test, Durham and colleagues at Los Alamos headed north to the Idaho National Laboratory. There they positioned a couple of muon trackers containing ionizable gas around a roughly 3 m-diameter, 5 m-high cask, with one tracker plotting the trajectories of muons as they entered the cask and the other mapping out the exit routes. The cask contained fuel removed from a Westinghouse power reactor in the 1980s. It was chosen because only 18 out of a possible 24 fuel assemblies were present, thereby allowing the researchers to try and identify the (known) empty slots.

Over the course of around three months, Durham and co-workers recorded about 450,000 muon tracks. With these data they plotted the muon scattering angle as a function of position along the cask’s diameter and also modelled how the scattering angle ought to vary if the 24 fuel-assembly slots are either all full or all empty. They then estimated the number of assemblies in six different groupings positioned along the cask diameter by gauging at each point whether the empirical plot was closer to the “all-full” or “all-empty” modelled curves.

Although they had to discard some of the data after strong winds shook the detectors for a few days, the researchers nevertheless correctly identified whether or not there were missing assemblies in four out of the six groupings. On this basis, they conclude that their technique is sensitive to the removal of a single fuel assembly from the centre of a cask. [J.M. Durham et al., arXiv:1710.03098 [nucl-ex]]

Extracted with permission from an item by Edwin Cartright at physicsworld.com.
PRODUCT NEWS

Warsash Scientific

EnSpectr R1064 express IR Raman Analyser
Enhanced Spectrometry, a manufacturer of portable Raman and luminescent spectrometry solutions for real-time testing and for quality control, announce the release of the EnSpectr R1064 IR Raman Analyser.

The EnSpectr R1064 is a unique instrument that enables the user to obtain Raman spectra in applications where the Raman signal is typically dominated by fluorescence. With the EnSpectr R1064, you can easily analyse, oils, dyes, paints, organic substances, etc. due to its record wide spectral range. It is the only portable 1064nm device which can see the water Raman line. This makes it a comprehensive tool for analysis of liquids through transparent and semi-transparent packaging.

The EnSpectr R1064 has the following key features:
- Wavelength: 1064 nm
- Laser power: 300 mW
- Spectral range: 200-3600 cm⁻¹
- Spectral resolution: 15-21 cm⁻¹
- Dimensions: 222x145x55 mm³

C-FLEX laser combiner from HÜBNER
Warsash Scientific is pleased to announce the C-FLEX from HÜBNER Photonics, a leading manufacturer of laser, terahertz and radar system solutions.

The C-FLEX is a highly-flexible and extremely compact laser combiner that lets you combine up to six wavelengths from a possible 30 commercially available wavelengths from different laser manufacturers. The lasers can be controlled either separately or via a common USB port. The C-FLEX is field upgradable for when additional lasers are purchased. Individual AOM modulators can be integrated to five of the wavelengths for fast modulation of DPSS lasers. Free space or fiber coupling of the output is available.

Applications include:
- Fluorescence microscopy
- Flow cytometry
- Optogenetics
- Single particle spectroscopy
- Photochemistry

U-523 and U-723 PILine stages from Physik Instrumente

Physik Instrumente, a global leader in the design and manufacture of high precision motion control systems has launched the U-523 linear and U-723 XY stages with the PILine ultrasonic piezomotors. The stages are highly suited to applications that require fast, precision positioning with low duty cycles. The U-523 and U-723 have the following key features:

- Travel range: 22 mm and 22x22 mm²
- Velocity: 200 mm/s
- Resolution: 10 nm
- Self-locking at rest (no heat generation)
- Highly compact form factor hPa
- Vacuum compatible: 10⁻⁶ hPa
Applications include:
• Micromanipulation
• Automation
• Sample positioning

For more information, contact Warsash Scientific on:
+61 2 9319 0122, or sales@warsash.com.au

Coherent Scientific

New from Quantel : Q-smart DPSS
Quantel has set the standard yet again, this time with their new DPSS laser system based on the highly successful Q-smart platform. Q-smart DPSS lasers are the most cost effective high performance diode pumped Nd:YAG lasers. Delivering up to 650mJ at 100Hz, they combine high energies with high repetition rate in the most compact package, with no need for an additional amplifier stage.

The Q-smart DPSS series benefit from high efficiency laser diodes and gain modules designed and manufactured in house. With its robust and stable monolithic design, it is ideal for applications demanding both high peak power and high average power.

Best of all, this new addition to the Quantel family provides all of the user friendly features of the Q-smart platform:
• Plug-and-play harmonic modules for easy access to 532nm, 355nm, 266nm and 213nm
• Automatic phase matching
• 2 year warranty on all components, 2 billion shot warranty on diodes
• Lightweight and compact design
• Quick-connect cables and cooling lines for fast installation

Combined with Andor’s high resolution and high sensitivity CCD, EMCCD, ICCD and sCMOS detectors, it offers the perfect platform for a wide range of routine and more advanced spectroscopy experiments.

New Intelligent Spectrograph from Andor
Kymera 328i is Andor’s next generation “intelligent” spectrograph for applications in Physical and Life Sciences. It is designed to provide maximum configurability and flexibility, high spectral performance and enhanced user-experience.

Combined with Andor’s high resolution and high sensitivity CCD, EMCCD, ICCD and sCMOS detectors, it offers the perfect platform for a wide range of routine and more advanced spectroscopy experiments.

TMC Sale
The annual TMC sale is now on.
Savings are available on TMC’s range of optical tables, active vibration isolation products, workstations and breadboards (standard products only).

If you are flexible with timing of the delivery, you can also take advantage of our consolidated shipment resulting in further savings.

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**Zurich Instruments**

**Multi-Channel Arbitrary-waveform Generator**

Zurich Instruments announces the HDAWG, an arbitrary waveform generator with the highest channel density and shortest trigger latency (<50 ns) on the market. The HDAWG comes in either a 4 or 8 channel configuration, both offering a 16-bit output and signal cache of 500 MSamples per channel. The maximum sample rate is 2.4 GSa/s at a signal bandwidth of 750 MHz, and each signal output has both a TTL marker-output and a TTL trigger input.

Furthermore, there is a 32-bit digital IO which can produce and read complex bit-patterns. For applications where a large number of channels are required, multiple instruments can be synchronized and centrally controlled. The HDAWG is controlled via the browser-based LabOne user interface and through MATLAB, LabView, Python, .NET or C. Sequences can be easily written, edited and compiled using the embedded scripting language and compiler. The resulting sequences are lean and can be swiftly transferred to the instrument over 1 GbE or USB 3.0. This saves time and increases workflow efficiency, and allows the user to maintain an overview of complex signal patterns.

The HDAWG has been developed to meet the highest R&D requirements, for example, in Quantum Computing Applications to produce pulsed signal sequences with minimal noise. Further applications include NMR, electronic component testing, spectroscopy and Radar/Lidar.

For further information contact Dr Jan Benhelm.

**For further information contact Dr Jan Benhelm.**

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**Lastek**

**Ocean Optics Ocean FX Fast Spectrometer for high-speed process applications**

Ocean FX is ideal for UV-Vis applications in food and agriculture, where acquisition speed helps with food sorting and processing; biomedical sciences, especially for absorbance measurements requiring enhanced UV sensitivity; rapid events measurements including flicker and fast colour cycling in LEDs; and security and authenticity, where added communication interfaces enable simpler point-of-use instruments.

**Highlights:**

- Fast acquisition – acquires up to 4,500 spectra per second
- Buffering and time stamping – onboard buffer holds up to 50,000 spectra so you don’t miss a single data point
- Onboard averaging – average up to 5,000 spectra
- Easy connection to other devices – operates via Giga bit Ethernet, Wi-Fi, SPI and USB simultaneously

**PixelSensor™ Multispectral Sensors**

PixelSensor™ multispectral sensors use exclusive on-chip filtering to pack up to 8 wavelength selective photodiodes into a compact 9x9mm array format for simpler and smaller optical devices. One PixelSensor™ replaces multiple components, helping OEMs shrink multi-wavelength instruments for applications including in vitro diagnostics, biochemical assays and colorimetry applications.
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Omni-λ Monochromators and Spectrographs from Zolix Instruments
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• These instruments can be integrated with single point detectors, InGaAs cameras and CCDs to offer a versatile, most sensitive modular solution for different applications
• Accessories including filter wheels, fiber adapters, shutters, motorized slits, sample chambers etc.
• Software can complete data acquisition for detectors including single point detectors and
• Labview driver for programming to operate Omni-λ Series spectrographs and monochromators.

For more information please contact Lastek at sales@lastek.com.au

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