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NEW PHYSICS, NEW TECHNOLOGY

The Standard Model of particle physics describes three of the four fundamental forces (the electromagnetic, weak, and strong interactions), and at the same time classifies all known elementary particles. However, two observations indicate that the Standard Model is incomplete: the non-zero mass of the neutrinos and dark matter. There is a need for new physics. This is the topic of the article *The Quest for New Physics* by Ray Volkas (University of Melbourne), winner of the AIP’s Harrie Massey Medal for 2016. This article provides the motivation for the cover image showing the Stawell Underground Physics Laboratory (SUPL) under construction 1 km below ground in the Stawell Goldmine in Victoria, the ambitious goal of which is the first direct detection of dark matter.

At another extreme is the quest for a practical quantum computer, which would offer computational possibilities beyond the limits of ‘classical’ computers. A number of different technological approaches are competing in this quest, one of which is based on diamond. In his article *The State of Diamond Quantum Computing*, Marcus Doherty (ANU), and winner of the AIP’s 2016 Ruby Payne-Scott Medal for excellence in early career research, describes the current state of, and potential for this technology. At the same time Marcus gives an account of the significant Australian contribution to developments in this area.

The other two articles showcase activities in specialist areas of physics. In *Australasian Soft Matter Scattering Workshop* Chris Garvey (ANSTO) gives a report on the fifth in a series of workshops on soft matter scattering, which covers the use of photons, x-rays and neutrons to study soft matter.

The AIP has nine cognate societies – for a list see the column on the left of the main page of the AIP website. One of these is the Vacuum Society of Australia (VSA). In the article *On the Move with the Vacuum Society of Australia*, Anton Tadich (Australian Synchrotron), Karyn Jarvis (Swinburne University), Brett Johnson (University of Melbourne), Norman Booth (ANSTO) and Anton P. J. Stampfl (ANSTO) describe the aims and activities of the VSA. Other cognate societies might like to consider similar articles to inform AIP members.
POLITICS AND PHYSICS

Traditionally this is a busy time of year for activity that has a major impact on how we do physics in the months and years ahead. The current period has been no exception: the Federal budget was announced in May with state budgets released either side; the National Infrastructure Roadmap was released in May; the Chief Scientist’s Independent review into the future security of the National Electricity Market was released in June; and another review from the Chief Scientist’s office – Strengthening School-Industry STEM Skills was also released in June.

It can be hard to keep up with inputs and responses to the plethora of reports and initiatives that shape our environment as physicists. Fortunately, as members of the Australian Institute of Physics we have access to some trusted sources that can provide physics-related, or more broadly, science-related insight into things that matters to us.

Federal budget 2017 provided some much-welcomed funding for astronomy with provision for a long-term partnership with the European Southern Observatory. With this comes a transition of key functions of the Australian Astronomical Observatory, including operations of the 3.9-metre Anglo-Australian Telescope and the world-class Australian Astronomical Observatory instrumentation research and development functions from the government sector to the research sector. Other support in the budget included $100 million to establish the Advanced Manufacturing Fund, funding to operate and access the Macquarie Island Antarctic research facility and $13.4 million for CSIRO for energy use modelling and forecasting. Offsets included cuts to higher education, effective reductions in usable funding for CSIRO through imposition of an efficiency dividend, for Australian Research Council funding falling behind inflation in forward years and a slight reduction in National Health and Medical Research Council funding.

Overall the recent Federal and state budgets have provided science and innovation funding towards activities that enhance the translation of science outcomes into the economy and society. This focus was also supported in the Strengthening School-Industry STEM Skills report released by the Chief Scientist’s office.

The need for training was also identified in the National research Infrastructure Roadmap, along with recommendations regarding areas of focus and the need for an investment plan to be developed. The roadmap also identified the need for future infrastructure investment to include the requirement to foster strong links with industry and business.

There are clearly some common themes and they are there for a very good reason. We only need to look at some of the reports from the Chief Scientist’s office in recent years to recall that, while research strength in Australia is strong, links between academic research and industry are some of the less mature in the developed world.

Communicating the need for such links and supporting ways to develop them is one of the functions the Australian Institute of Physics can perform. However, in so doing we do not want to throw the baby out with the bathwater. Another important role of the Institute is to advocate for excellence in the fundamentals of physics. It is important to find ways to strengthen links to industry without weakening the strength of the discipline.

We do this in a number of ways. The Australian Institute of Physics is a member organisation of Science Technology Australia, which lobbies Canberra in the interest of science and technology for its member organisations. Another voice is the National Committee for Physics, which is a committee of the Australian Academy of Science. The National Committee for Physics is chaired by Ian McArthur who is the registrar of the Australian Institute of Physics and a number of observers on the committee are Institute members including myself as current president and some past presidents.

A recent opportunity to advocate for balance in the strategies being pursued in the national science and innovation system was to make submissions towards the 2030 Strategic Plan for the Australian Innovation, Science and Research System that is being coordinated by Innovation and Science Australia (https://industry.gov.au/Innovation-and-Science-Australia/Pages/2030-Strategic-Plan.aspx). This plan points out the need for a range of initiatives to maintain and strengthen physics over the decade. These include the need to strengthen industry links and to improve STEM training as well as the need to invest in basic research.

In short, to make effective and productive links to industry we need to make sure there is something that is useful to connect to.

So while the last few months have been busy with reports and budgets that impact physics, it is clear the Australian Institute of Physics, and many of its members, will be busy for some time to come in helping provide inputs to shape future policy.

Andrew Peele
LETTER TO THE EDITOR

It is unfortunate that the reviewer of the text book, “Physics of Radiation and Climate”, David Karoly, chose to use the review to vilify politicians and a physicist, Dr William Happer of Princeton University, whose opinions on the effects of climate change differ from his. The first three paragraphs, roughly one third of the review, were used by Karoly to establish his position as a protagonist in a global warming debate between himself and Happer. Karoly suggests that the exposition in the textbook counters the opinions of his opponent and claims that the book’s summary of climate science: “Our current climate is strongly influenced by atmospheric composition, and changes in this composition are leading to climate change”, supports his position on global warming. In fact, the summary reflects the inevitable conclusion of any study of the physics of climate, i.e. Earth’s climate is raised by about 33°C, to a temperature supportive of life, due to the H₂O and CO₂ content of the atmosphere. Karoly then states that it is not clear why Happer’s conclusions differ from the views expressed in the book and provides a reference to a “major statement” on-line by Happer. A cursory scan of this statement makes it clear why Happer’s conclusions differ from Karoly’s. However, it is also obvious that Happer’s position is not inconsistent with the books above mentioned summary of climate science. Eventually Karoly addresses the content of the book. His largely negative assessment suggests the book, intended to be used as a first course in climate physics, is an advanced treatment rendering it inaccessible to a broad range of students. In his conclusion Karoly suggests the book is appropriate for senior-level specialist courses or for researchers. He cannot resist finishing without a further comment on the character of his opponent, Happer.

Readers of reviews of physics textbooks do not expect to be embroiled in the politicisation of science, expect an objective review of the scientific and educational merits of a book, and do not expect character assassinations as in this confusing and abysmal review.

I. Edmonds, MAIP

NEWS & COMMENT

ANU stellarator ceases operation, moves to China

The H-1 flexible heliac, a stellarator at the ANU’s Australian Plasma Fusion Research Facility (APFRF) has ceased operation. After 25 years of successful operation, the last shot was fired on 8 May 2017 by Emeritus Professor Syd Hamberger. H-1 was designed, constructed and operated for many years under Prof Hamberger’s leadership.

H-1, which enables experimental research on magnetically confined plasma that is vital for developing fusion energy, will now be transferred to the University of South China (USC), becoming the first stellarator in China. The ANU will work with USC on fusion energy research, including exchanging technical and academic personnel between the two institutions.

Dr Cormac Corr, Director of the Australian Plasma Fusion Research Facility, said the Australian Plasma Fusion Research Facility was building a high-power linear magnetised plasma machine called MAGPIE II, which will support research on advanced fusion materials, basic plasma physics and instrumentation development.

“MAGPIE II will underpin our efforts to engage practically with industry and provide a great platform for training students,” Dr Corr said. “We are focusing on fusion materials research and plasma diagnostic development, to better understand how containment materials behave in the extreme environment of a fusion reactor.”

Science Fellow at ITER

Associate Professor Matthew Hole from the ANU Research School of Physics and Engineering has been made a Science Fellow at ITER, the world’s largest fusion ex-
periment, which is under construction in the South of France.

Associate Professor Matthew Hole and PhD student Zhisong Qu.

Associate Professor Hole is one of only 17 ITER Science Fellows from across the globe, who will work on key research issues, collaborating not only with international scientists, but drawing in the Australian science community to tackle these challenge. His appointment is the only one to a scientist outside the ITER member nations (the European Union, Japan, United States, Russia, South Korea, China and India).

Director of the Research School of Physics and Engineering, Professor Tim Senden, said the accolade consolidated the reputation of ANU as Australia’s leader in fusion science. ITER Director-General Bernard Bigot said he looked forward to a productive collaboration with ANU.

2017 IUPAP Young Scientist Prize

The 2017 IUPAP Young Scientist Prize in Laser Physics and Photonics (Fundamental Aspects) has been won by Dr Mohsen Rahmani “for his outstanding contributions to light-matter interactions at nanoscale, particularly nonlinear nanophotonics via metallic, dielectric and semiconductor nanostructures and metasurfaces, which have paved the road for extending nonlinear optics to nanoscale”.

Dr Rahmani is currently an Australian Research Council Discovery Early Career Research Award holder at the Australian National University, Canberra Australia. Until recently he was a research associate at the Blackett Laboratory, Imperial College London, United Kingdom; following a PhD from the National University of Singapore, Singapore (2013).

Prokhorov’s grandson visits FNQ

Alex Prokhorov, grandson of the Australian-born Nobel Prize winner Aleksandr Prokhorov visited his grandfather’s primary school - Butcher’s Creek Primary School - during a recent visit to Australia.

Alex Prokhorov at Butcher’s Creek Primary School (credit: David Anthony, Tablelander, Atherton)

Aleksandr was born in 1916 near Atherton, Far North Queensland, where his parents had settled seeking refuge from difficulties in Russia. He attended Butcher’s Creek Primary School for several years prior to the family’s return to Russia in 1923 when the political climate had become much more to the family's liking.

The Nobel Prize in Physics 1964 was divided between scientists from the USA and the then USSR (half awarded to Charles Hard Townes, the other half jointly to Nicolay Gennadiyevich Basov and Aleksandr Mikhailovich Prokhorov).

For more details of Aleksandr Prokhorov’s time in Australia see the article by Stephen Collins, Aust. Phys., 52(1), 23.

New Academy fellows announced

In May the Australian Academy of Science announced the election of 21 new fellows, including the following.

Professor Igor Bray (Curtin University) ranks in the top few in the world in the field of atomic and molecular collision physics. He is responsible for several major paradigm shifting research breakthroughs during his career. His convergent close-coupling (CCC)
formalism yielded unprecedented agreement with experiment, and has been extended to calculate ionization processes. This unified the approach to all collision processes. Igor and his group were also able to provide the first mathematically rigorous treatment of collisions involving the ubiquitous Coulomb potential. Most recently, the CCC method has been extended to heavy projectiles and molecular targets.

Professor Karl Glazebrook (Swinburne University of Technology) is an astronomer whose research has led to major advances in our understanding of how galaxies and the Universe evolve over time. His groundbreaking work includes, establishing the existence of massive galaxies only three billion years after the Big Bang, and discovering the local analogues of primordial galaxies. Karl has also pioneered near-infrared surveys and developed new award-winning instrumental techniques for carrying out ultra-deep spectroscopic surveys on the world’s largest telescopes. He has also been at the vanguard in the application of new observational techniques for quantifying the effects of dark energy on the accelerating expansion of the Universe.

Professor Timothy Ralph (University of Queensland) is internationally acclaimed for his pioneering theories in quantum information science. These include the theoretical development of secure communication systems based on quantum key distribution, and the demonstration of multi-qubit optical quantum computing algorithms. Tim has instigated a whole new field of continuous variable quantum key distribution, with influential new techniques in relativistic quantum information. His theoretical proposals have led to the world’s first demonstration of a two-qubit optical gate and subsequent demonstrations of multi-qubit behaviour. As a highly sought after theorist internationally, Tim is well-known for his foundational theories and his ability to work closely with experimentalists to realise their outcomes.

(Source: Australian Academy of Science)

**ASKAP telescope speeds up the hunt for new Fast Radio Bursts**

Mysterious bursts of radio waves from space that are over in a fraction of a second, Fast Radio Bursts (FRBs) are thought to occur many thousands of times a day, but since their first detection by the Parkes radio telescope a decade ago only 30 have been observed.

Once the Australian Square Kilometre Array Pathfinder (ASKAP) joined the hunt it found its first new FRB after just three and half days of observing. This was soon followed by a further two FRBs - and the telescope is not even fully operational yet.

The first FRB that ASKAP found was less than 1 millisecond long and was detected over a range of frequencies from 1,100 MHz to 1,400 MHz. FRBs are remarkable because they are outrageously bright in the radio spectrum yet appear extremely distant. As far as astronomers can tell, they come from halfway across the observable universe or more.

Astronomers are really excited about the fossil record imprinted on each burst by the matter it encounters during its multibillion-year crossing of the universe. Matter in space exerts a tiny amount drag on the radio waves as they hurtle across the universe, as the air drags on a fast-moving plane. However, the longer the radio waves, the more the drag.
By the time the radio waves arrive at a telescope, the shorter waves arrive just before the longer ones. By measuring the time delay between the short waves and the longer ones, astronomers can work out how much matter a given burst has travelled through on its journey from whatever made it, to the telescope.

If we enough bursts can be found, it will be possible to work out how much ordinary matter exists in the universe, and tally up its mass. The best guess so far is that we are missing roughly half of all the normal matter, with the rest lying in the vast voids between the galaxies — the very regions so readily probed by FRBs. For more detail see the article by Keith Bannister, Astronomer, CSIRO and Jean-Pierre Macquart, Senior Lecturer in Astrophysics, Curtin University in The Conversation.

Institute of Physics: careers 2017

The UK Institute of Physics has released its latest career guide for physicists: careers 2017. From manufacturing to finance, from medicine to defence, physicists are valued by employers across such a wide range of sectors: physicists are highly numerate, can analyse problems and break them down to first principles, and make rational estimates; they can create hypotheses and run experiments, or create computer simulations; they can adapt all the knowledge they have gained to areas that, on the face of it, may not seem at all related. Those are skills that are greatly in demand. This IOP publication can be accessed at http://aip.org.au/#career.

Most comprehensive and high quality records of greenhouse gases

Led by researchers from CSIRO's Climate Science Centre and the University of Melbourne, the records track the past and current changes in all 43 greenhouse gases that contribute to human-induced climate change. CSIRO Principal Research Scientist and report co-author Dr David Etheridge said the paper published in the journal Geoscientific Model Development (Malte et al., Geosci. Model Dev., 10, 2057-2116; doi.org/10.5194/gmd-10-2057-2017 (2017)) was one of the largest Australian contributions to global climate change assessments ever.

"This continuous record over the last 2000 years has been meticulously constructed by combining greenhouse gas measurements from dozens of laboratories around the world," Dr Etheridge said. "We took data from contemporary and archived air samples, and from air trapped in ice bubbles in polar ice cores and compacted snow, also called firn." Australia (through CSIRO and the Bureau of Meteorology) is the major contributor to this global greenhouse gas record, using observations from the Bureau of Meteorology’s Cape Grim station in northwest Tasmania and from the Cape Grim Air Archive.
drive global climate model simulations currently being conducted by international modelling groups ahead of the next Intergovernmental Panel on Climate Change (IPCC) assessment report, due in 2021-2022.

Dr Etheridge said that a comprehensive database of measurements was combined with information on aerosol, solar, volcanic and land-use impacts on climate to accurately simulate observed climate over past centuries in climate models. "Providing long-term spatially and seasonally precise measurements of greenhouse gases for input into climate models will allow more robust future climate estimates," Dr Etheridge said.

(Source: CSIRO)

Queen's Birthday 2017 Honours List

The Queen's Birthday 2017 Honours List included the following:

Companion (AC) In The General Division

Professor Kenneth Charles Freeman (ANU) “for eminent service to astronomy through pioneering contributions in the field of galactic archaeology, as a leading astrophysicist and researcher, to tertiary science education, to professional academies, and as a mentor of young scientists”. (photo supplied)

Dr Phillip Lyle McFadden, Chief Scientist at Geoscience Australia (1999-2007), “for distinguished service to earth sciences as a geophysicist, through leadership of Australia’s peak geoscience body, through collaboration and innovation in research, and to professional societies”. (credit: PESA)

Member (AM) in the General Division

Emeritus Professor Robert Alan Vincent (University of Adelaide) “for significant service to science, and to education, particularly in the field of solar-terrestrial physics, as an academic and researcher”. (credit: ATRAD)

Teaching and learning award to Dr Maria Parappilly

The Convenor of the AIP’s Physics Education Group, Dr Maria Parappilly has won the only 2017 D2L Innovation Award in Teaching and Learning prize to be awarded in Physics this year.

Maria, who is a Senior Lecturer and Course Coordinator for the Bachelor of Science (Physics) in the School of Chemical and Physical Sciences at Flinders University, has transformed physics teaching at Flinders by using research-led innovative approaches – many of which have since been adopted far beyond her classrooms.

Her strategies, including Team Based Learning (TBL), Inquiry-Based Lab (IB Lab) – and even “LEGO Physics” – have positively impacted her students over a number of years.

Through her work as founder of Flinders’ STEM: Women Branching Out group, she has specifically targeted young women in STEM through role model workshops and networking opportunities.

Dr Maria Parappilly

AIP 2017
Summer Meeting
3-8 December, UNSW, Sydney
www.aip2017.org.au

For more details see p150
The Quest for New Physics

Raymond R. Volkas
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One of the Holy Grails of particle physics is the search for “new physics”, meaning new particles, interactions and symmetries that extend the standard model. Excitingly, we know that new physics exists. Two ironclad empirical proofs are the need for nonzero neutrino masses and dark matter. The cosmological matter-antimatter asymmetry of the universe, and fine-tuning problems with hot big bang cosmology constitute near-proofs of two other varieties of new physics. Depending on taste, one may point to several theoretical shortcomings that also motivate the existence of physics beyond the standard model without absolutely requiring it. I will survey the evidence for new physics, ideas about what it could be, and how experiments may discover an extended standard model.

To explain what is meant by “new physics” in the context of this article, let me begin rather grandly, abstractly and generally with the following beautiful but mysterious equation:

$$S[g_{\mu\nu}, \phi] = \int d^4 x \sqrt{-g} \left[ \frac{1}{16\pi G} (R - 2\Lambda) + \mathcal{L}(\phi, D_\mu \phi, g_{\mu\nu}) \right].$$

This is an “action integral”, the central object in Hamilton’s Principle of Stationary Action. Although usually called a “principle”, it is actually a meta-principle, a principle about principles. Every fundamental physics theory that we know can be described by such an action integral, and, importantly for this article, it also guides the construction of new theories. Recall that at the classical level, physical field configurations are those that make the action stationary under small variations, while at the quantum level the action appears as the central object in the Feynman path integral. Our present best understanding of the fundamental laws of the universe require us to insert a certain function $\mathcal{L} = \mathcal{L}_{SM}$, called the “standard model (SM) Lagrangian”, into the above integral (see Figure 1 for an artistic rendering). This Lagrangian is a function of (quantum) fields $\phi$, and their first derivatives, and the (classical) metric tensor $g_{\mu\nu}$ of general relativity. There is an independent quantum field for every lepton and quark, for the photon, gluons, W-bosons, Z-boson and the Higgs boson. The SM Lagrangian describes in precise mathematical detail how these fields, which manifest as particles at the quantum level, interact with each other. It is an amazingly intricate and phenomenologically successful theory, but, as we shall see, we now know that it is inadequate and must be extended in ways that are as yet unclear. The general relativistic gravitational interaction, and hence cosmology, is included in the action via the Einstein-Hilbert term plus a cosmological constant. The quantity $R$ is the curvature or Ricci scalar that depends on the metric tensor and some of its derivatives, $g$ is the determinant of the metric, $G$ is Newton’s constant, and $\Lambda$ is the cosmological constant that, so far at least, does a good job of describing the accelerating expansion of the universe. Substituting the special relativistic flat-space metric $\eta_{\mu\nu}$ by $g_{\mu\nu}$ in the Lagrangian defines the standard form of how matter couples to gravity.

![Figure 1: Artwork entitled “Light rain – and everything we know about the universe (except gravity)” by artist Peter Kennedy, as displayed at the “Melbourne Now” exhibition at the National Gallery of Victoria. It depicts the standard model Lagrangian (credit: National Gallery of Victoria).](image)

The action integral deserves to be on a T-shirt, and indeed may even have appeared on one or two. Our goal in life is simply to find the action integral that describes in complete and successful detail all the microscopic fundamental laws of nature, the ultimate reductionist’s catharsis. Changing the gravitational part is called doing “modified gravity”, while changing the Lagrangian is an exploration of physics “beyond the standard model (BSM)”. Both are interesting ways to approach “new physics” theoretically, but in this article I shall mostly focus on BSM physics.

The 2015 Nobel Prize for Physics was awarded to Takaaki Kajita and Arthur B. McDonald for the discovery of “neutrino oscillations”, which is tantamount to the discovery of neutrino mass [1]. There are three known neutrinos – $\nu_e$, $\nu_\mu$, and $\nu_\tau$ – named through which charged lepton (e, $\mu$, and $\tau$) they interact with via the W-boson mediated weak interaction, the same force as responsible for beta decay. It turns out that these three familiar neutrinos, which are called “flavour eigenstates”, are not particles with definite masses, but are instead orthogonal coherent superpositions of states of definite masses. When these masses are non-degenerate, a neutrino created in one flavour state will oscillate into the other two, which is simply an example of quantum superposition and the familiar beating phenomenon in wave motion. It can be shown quite easily that the oscillation wavelengths depend on squared-mass differences divided by energy, while the amplitudes are determined by the magnitudes of the coefficients in the superpositions relating the flavour to the mass eigenstates.

The point is that in the SM neutrinos are massless! The SM Lagrangian as originally written down is therefore incomplete. Now, it is well known that all SM particles, except for the Higgs boson, are massless to begin with, and then attain mass through their interactions with the nonzero background Higgs field value that exists throughout the universe, the subject of the 2013 Nobel Prize in Physics to François Englert and Peter Higgs. Could not neutrinos gain mass through this same mechanism, in exact parallel with their close cousins, the charged leptons e, $\mu$, and $\tau$? The answer is yes, but then additional fields called “right-handed neutrinos” must be added to the Lagrangian, which means we have had to change the laws of physics to accommodate neutrino masses. This is an example of new or BSM physics. But the truth is probably not so straightforward. First, one must appreciate that while experiments have discovered non-degenerate neutrino masses, they have shed no light at all on how these masses arise. The minimal mechanism just described could be true, but it need not be. Second, neutrino masses are tiny, at most about 0.2 eV, which is six or seven orders of magnitude smaller than the mass of the next lightest fundamental fermion, the electron. This suggests that neutrinos gain mass in a different manner from the charged leptons and quarks. In fact, theorists have proposed a plethora of ways neutrinos could gain mass, but so far experiment has not been able to discriminate amongst these possibilities. They all involve extensions of the SM Lagrangian, of course. Will we ever know the origin of neutrino masses? That is an excellent question that would require an article of its own to properly discuss. But I’ll tell you what the answer is: “maybe”. For the moment, we know the SM Lagrangian is incomplete, but we do not know which better Lagrangian to replace it with in the textbooks.

The second empirical proof of the need for new physics is arguably more dramatic: the SM describes only about one-sixth of the matter mass density in today’s universe! The rest consists of an as-yet mysterious component we call “dark matter (DM)” [2]. The evidence for DM is overwhelming. It is needed to understand the gravitational dynamics of both galaxy clusters and galaxies themselves, it manifests through gravitational lensing measurements, and it is a vital component in our understanding of how large scale structures evolved out of the almost perfectly homogeneous very early universe. The acoustic peaks in the cosmic microwave background temperature anisotropy maps cannot be properly understood without the presence of DM. Importantly, all these various manifestations of DM are consistent with each other, and call for a DM mass density that is about five times larger than the density of ordinary matter. Since this evidence relies on gravitational effects, it can a priori be that gravity needs to be modified rather than DM being literally a new material component that does not emit electromagnetic signals. From the point of view of discovering new physics, it does not matter if the modifications are to be made in the gravity sector or the SM sector. However, the probability of a modified gravity explanation being correct must now be considered remote, especially after the famous Bullet cluster observations demonstrated that the strength of gravitational lensing does not trace the density of ordinary matter in that colliding galaxy-cluster system [3] (See Figure 2).

![Figure 2: The Bullet cluster with false colour highlighting. This famous image shows two colliding galaxy clusters. The pink areas are concentrations of gas and contain the majority of the ordinary matter by mass. The blue regions display the strongest gravitational lensing and thus contain most of the total mass. That mass is evidently dominated by an unseen and as-yet unidentified component. We call that component “dark matter” (composite credit: X-ray: NASA/CXC/CfA; Lensing Map: NASA/STScI; ESO WFI; Magellan/U. Arizona; Optical: NASA/STScI; Magellan/U.Arizona).](image)
So, DM is some unidentified stable, massive component that is cosmologically abundant. One possibility is primordial black holes, produced through some cataclysmic events in the extremely early universe, which would constitute a certain (quite exotic) kind of new physics. I shall, however, focus on the more straightforward idea that DM is a massive particle that is either absolutely stable or has a lifetime longer than the age of the universe, or a set of such particles. The only candidates amongst known particles are our friends the massive neutrinos: they are electrically neutral and weakly interacting, and they are either stable or very long-lived, so they have some of the required properties. However, neutrino DM is now known to be completely incompatible with an understanding of large-scale structure formation, as quantified through large-scale galaxy surveys and other data sets quantifying the power spectrum of density inhomogeneities in the universe. (The upper bound of about 0.2 eV quoted above for the neutrino mass scale is due to this cosmological consideration.) The problem with having DM dominated by massive neutrinos is that these very light particles were moving relativistically at the time that gravitationally-driven mass inhomogeneities began to form in the early universe. The effect of significant neutrino masses would have been to wash out structure on small scales, due to the neutrinos’ ability to freely stream out of overdense regions, carrying mass density with them. Such wash out is incompatible with astrophysical and cosmological observations [4]. Thus, DM must consist of a particle or particles that are beyond those in the SM, and that were not ultrarelativistic when inhomogeneities began to condense. Astrophysicists and cosmologists have proven that DM exists, and have constrained some of its properties. It is now up to particle physicists to identify its precise nature, and how it fits into some SM extension. Achieving this goal would be epochal. It would be one of the greatest scientific achievements of all time.

What could the DM be? This is a question of some notoriety, because the proposed candidates are manifold, from spin-0 bosons called “axions” at the micro- to milli-eV mass range, to primordial black holes that are orders of magnitude more massive than the sun, with many speculative candidates in between these extremes. The best-studied class are the “weakly interacting massive particles (WIMPs)” that fit into certain theoretical prejudices that favour the existence of something called “supersymmetry”. In their simplest form, they have the benefit of being experimentally testable in three different ways. One way is through direct detection via WIMP scattering off nuclei or electrons in experiments such as SABRE, the proposed DM detector to be located in the developing Stawell Underground Physics Laboratory in Victoria [5] (Figure 3 shows a possible design for the detector). A second way is direct production at the Large Hadron Collider, and the third is “indirect” detection via the products of their self-annihilation in dense astrophysical systems such as the Galactic centre. So far, there is no clear evidence in favour of WIMPs, with one important anomaly that remains unresolved: the annual modulation signal observed by the DAMA and DAMA/LIBRA direct-detection experiments [6]. This anomaly will be studied by SABRE. My favourite DM candidate is quite different: “asymmetric dark matter” [7]. To explain what this is, we must first review the cosmological matter-antimatter or baryon asymmetry problem.

Figure 3: Conceptual design for the SABRE dark matter detector to be located in the Stawell Underground Physics Laboratory. The target NaI(TI) high radio purity crystals are to be located inside an active liquid scintillator veto. An identical detector will operate in the Gran Sasso National Laboratory in Italy. They will test the DAMA and DAMA/LIBRA claims of the detection of dark matter-atom collisions whose rate annually modulates due to the passage of the Earth through the dark matter halo of the Milky Way. Detectors in both hemispheres are needed to test for the possibility of a seasonally varying unidentified background that mimics the dark matter signal. (credit: SABRE Collaboration and the University of Melbourne)

A wealth of evidence points to the existence of negligible antimatter within our Hubble volume, the observable universe. But at very early times, when the temperature of the universe was high enough to facilitate the pair cre-
ation of particle-antiparticle species, one must have had a cosmological plasma that had nearly equal number densities of matter and antimatter. From the baryon-to-photon ratio measured in today's universe, we know that the matter-antimatter number density asymmetry is about 1 part in $10^{10}$. We do not know the origin of this asymmetry. If we were to make the rather natural assumption that matter and antimatter was produced symmetrically at the big bang, then we would require some dynamical way to generate this small, but very necessary asymmetry during cosmological evolution. Before discussing the nature of this dynamics, we should question the above assumption. Could not the asymmetry simply be an initial condition for the big bang? The answer is almost certainly "no", though one cannot be as sure of this as one can that neutrinos have masses and DM exists. What, exactly, is the big bang? Is it the initial singularity demanded by classical general relativity? Suppose it is. But then we have to face the fine-tuning problems of standard radiation-dominated cosmology to be discussed below. These problems strongly suggest, but do not prove, the existence of a short period of vacuum-energy dominated exponential expansion known as "inflation" [8]. When inflation ends, the energy driving the exponential expansion gets turned into explosive particle creation ("reheating"), and the plasma thus born completely dominates whatever primordial soup was around prior to the inflationary epoch, diluting away any asymmetry that was in it. Indeed, the post-inflationary reheating of the universe is the big bang, for all practical purposes. It may then be that reheating happens asymmetrically. But, unlike a true initial condition, that is something we can analyse within a given inflationary theory, and for sure it requires new physics, as indeed does inflation itself.

If the initial (or post inflation) state of the universe was symmetric, then Sakharov’s general conditions for dynamically generating a baryon asymmetry guide us in the construction of the right kind of theoretical model [9]. The conditions are: (i) Baryon number (B-) violation, whose need is obvious. (ii) Different microphysics for matter and antimatter, to prevent the antimatter analogue of a B-violating matter process from washing out the effects of the latter. (iii) Out-of-equilibrium dynamics, to prevent the time-reverse of a B-violating process from cancelling the asymmetry. Interestingly, the SM adheres to the first two conditions (the second one rather weakly), but it fails to meet the third. Thus, new physics is needed. Similarly to the neutrino mass and DM problems, theorists have proposed many viable specific theories to accomplish “baryogenesis” [10]. We are not short of ideas! But we are short of observational and/or experimental evidence to permit a cull of the theory space.

It is possible for neutrino masses, DM and baryogenesis, or two out of the three, to be connected problems. Lack of space prohibits a proper discussion of this vast topic, so one example will have to suffice. In asymmetric DM models [7], one postulates that the DM in the present-day universe has the same origin as the ordinary matter: an asymmetry between dark matter and dark antimatter. Furthermore, one arranges for the number-density asymmetries in the two sectors to be related, meaning that the number of dark matter particles in the universe is engineered to be similar to the number of nucleons. I like this DM scenario because it has the potential to explain why the mass densities of ordinary and dark matter are so similar, only differing by a factor of five or so. For this to happen, it is interesting to observe that the DM particle mass must be related to the proton mass, which then provides direction for model builders (or “Lagrangian constructors”) such as me.

Let us return to the need for inflation, or something like it [8]. The hot big bang model in the absence of inflation suffers from two severe fine-tuning problems. The first one arises because an unreasonable amount of homogeneity is required to accommodate the observed fact that the temperature of the cosmic microwave background (CMB) radiation is almost the same in all directions of the sky. This primordial gas of photons decoupled from atoms about 400,000 years after the big bang. It can be shown that causal signals could not have travelled far enough since the big bang to produce the dynamical homogenisation needed to ensure such a uniform CMB spectrum. Thus, one is left with postulating an unreasonably homogeneous universe as an initial condition. The second problem concerns the “flatness” of space. Space (as distinct from spacetime) in today's universe is very close to being Euclidean. This requires the mass density of the universe to be at a certain critical value. The problem is that this critical value is an unstable quantity under cosmological evolution. To ensure that the universe is sufficiently close to critical density today requires an extreme fine-tuning of the initial mass density so that it be equal to the critical value to many, many decimal places. Inflation solves the homogeneity problem by exponentially inflating a causal patch, and
spatial flatness arises naturally from the extreme stretching of space during this expansion. As an important extra benefit, inflation also explains where the small inhomogeneities that eventually condense into galaxies and clusters of galaxies come from. The answer, by the way, is astonishing: from quantum fluctuations in the field that drove the inflationary epoch.

And what field was that? We do not know, but it has a name: “inflaton”. In most models, it is a scalar field beyond the content of the SM. Interestingly, there is also a proposal [11] that it might be the Higgs field discovered by the ATLAS and CMS experiments at the LHC in 2012 [12] with substantial contributions from Australian groups in the ARC Centre of Excellence for Particle Physics at the Terascale. But, if it is the Higgs, then one can show that a modification of the way the Higgs boson couples to gravity is required. Be the inflaton exotic or “just” the Higgs boson, new physics is needed. The circumstantial evidence for inflation is substantial, but the level of rigor is less than for neutrino masses and DM. But, certainly, the hot big bang model as originally conceived suffers from severe fine-tuning problems, and if inflation is not the answer then some other modified cosmological dynamics is needed, or perhaps some kind of “theory of initial conditions”.

There are also theoretical quibbles with the SM. These are observed facts about fundamental particles that the SM can accommodate but not explain. One is the proliferation of a priori arbitrary parameters, especially fermion masses and mixing angles, a problem that is now more acute after the discovery of neutrino oscillations. According to the SM, the mass of the electron at about 0.5 MeV has a similar origin to the mass of the top quark at about 172 GeV, which seems like a fact crying out for a profound explanation. There are other issues I do not have room to describe such as the strong CP problem and the hierarchy problem.

Do we have a shot at discovering all this necessary new physics? Probably the most likely success will be in identifying dark matter. We are able to experimentally search for some, but not all, mechanisms for neutrino mass generation, through dedicated neutrino experiments and at the LHC. Baryogenesis will be difficult, but there are avenues of investigation, such as the ongoing search for proton decay. The next development in inflationary cosmology is expected to come from the search for primordial gravitational waves as imprinted on the cosmic microwave background. The need for new physics is acute. Without these solutions, we will never understand even basic facts about our universe. The experimental and observational challenges are formidable, but with a wide-ranging experimental program on Earth and an equally diverse observational program for the sky, we have good cause for hope. And, manna might come from heaven in the form of something unexpected, perhaps unconnected with anything discussed above. Indeed, currently there are really interesting anomalies in the way that bottom quarks decay and in the magnetic properties of the muon [13]. The former will be addressed by the new Belle 2 experiment in Japan [14] with strong Australian participation from the Universities of Adelaide, Melbourne and Sydney, and by the LHCb collaboration at CERN [15]. Let’s wait and see.

Acknowledgments

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References

Ray Volkas obtained his PhD in 1987 from the University of Melbourne and is currently a Professor of Physics there. He is a Fellow of the Australian Academy of Science, a recipient of the Pawsey Medal, served as head of the School of Physics at Melbourne from 2014-2016, and is presently a Node Director of the ARC Centre of Excellence for Particle Physics at the Terascale. He has worked on many aspects of “new physics”, with recent concentrations on models of neutrino mass, asymmetric dark matter, baryogenesis mechanisms and the currently tantalising B-meson decay anomalies.

**Branch News**

**New South Wales**

The NSW Community Outreach to Physics Award is awarded annually by the NSW Branch to acknowledge an individual with a passion for the study of physics in New South Wales who has a notable record in relation to outreach and physics education. Nominations for this Award should demonstrate that the nominee has:

- Worked to engage the academic physics community
- Effectively developed community events for the public, or activities that engage the physics community
- Increased awareness, knowledge and experiential learning opportunities for students in relation to physics

The Award, open to everyone in NSW, consists of a $500 monetary award and a certificate citing the achievements of the individual.

Nominations for 2017 will close on Friday 6th October 2017. A statement of up to 500 words outlining the activities for which the nominee seeks recognition should be lodged by mail or email to: Dr Frederick Osman, NSW Branch Secretary, Australian Institute of Physics, PO Box 649, Moorebank, NSW 1875; fosman@trinity.nsw.edu.au.

The Award will be presented at the Australian Institute of Physics NSW Postgraduate Awards and Annual Dinner on Tuesday 14 November 2017 at the University of New South Wales.

**Conferences**

**26 July - 1 August 2017**
30th International Conference on Photonic, Electronic and Atomic Collisions (ICPEAC XXX)
Convention Centre, Cairns, Qld
icpeac30.edu.au

**4-7 December 2017**
Australian and New Zealand Conference on Optics and Photonics 2017 (ANZCOP 2017) (incorporating ACOFT and ACOLS)
Queenstown, New Zealand
anzcop2017.nz

**3-8 December 2017**
AIP Annual Scientific Meeting
UNSW, Sydney, NSW
www.aip2017.org.au

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

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

**AIP 2017 Summer Meeting**
3-8 December, UNSW, Sydney
www.aip2017.org.au

For more details see p150
The world appears to be on the cusp of the quantum computing revolution. The world’s governments and giant technology companies are starting to invest heavily to secure their place. For example, Google and IBM are applying their vast resources and capabilities to scale superconducting quantum computing. Hewett-Packard are focussing on photonic quantum computing and groups of scientists are biding to build a monolithic trapped-ion quantum computer. Even in Australia, we have seen bespoke innovation investment by the Federal Government, Commonwealth Bank of Australia and Telstra into the silicon quantum computing technology pioneered by CQC2T. But where is diamond quantum computing in this revolution? A technology that appears to lead in several dimensions and whose foundations (or at least a good portion of them) can be credited to Australia. In the following, I briefly outline the current state of diamond quantum computing, its technological niche, the grand challenges it faces ahead and their potential solutions. By doing so, I seek to define the important and auspicious future of diamond quantum computing in Australian physics.

Introduction

Quantum computers promise a new computing paradigm that transcends many of the physical and computational limits of the ‘classical’ computers of today [1]. In particular, quantum computers have the potential to solve particular classes of problems inaccessible to classical computers, including those related to factoring the large numbers at the foundations of modern encryption, searching large databases, optimising intricate designs, and the simulation of complex quantum systems (e.g. biomolecules and novel materials) [1]. Quantum computers thereby have diverse and highly disruptive applications in industries such as defence, finance, data services, biomedicine and engineering. Indeed, there is now widespread recognition of the highly transformative potential of quantum computers, as evidenced by the several substantial investments made by governments (e.g. United States of America, United Kingdom, Australia and European Union) and the giant technology companies (e.g. Google, Intel, IBM, HP and Microsoft) since 2014 [2].

Quantum computers differ from classical computers because they exploit the laws of quantum physics to fundamentally represent and compute information differently. Information is represented by the quantum states of individual quantum systems, known as qubits. Unlike bits of a classical computer, which are restricted to states of 0 or 1, qubits may form an arbitrary superposition of 0 and 1. Additionally, the states of different qubits may be entangled, which establishes correlations between the qubits that effectively allow many computations to be performed simultaneously. Owing to the additional capabilities of qubits, a quantum computer can perform algorithms unavailable on classical computers and solve certain problems exponentially faster than classical computers [1].

The number of qubits is the principal factor that determines the computing power of a quantum computer. For a quantum computer to outperform the most powerful supercomputers of today in the task of factoring large numbers, it must contain a large number of qubits – at least 10,000 and perhaps as many as 1 million [3]. Such large-scale quantum computers are far beyond current technologies, which contain no more than 20 qubits [3,4]. A closer goal for quantum computers is to outperform today’s supercomputers in quantum simulations of molecules, which may require as few as 50 qubits [3,4].

The various quantum computing technologies are thus racing to scale up to large numbers of qubits. The technologies currently leading this scaling race are based

1. Awarded the 2016 Ruby Payne-Scott Medal for excellence in early career research
upon superconducting circuits and trapped ions. For these systems, the path to scaling is relatively clear and is now considered to be an exercise in engineering [4] (although one must always be cautious of such statements!). For this reason, and for their existing expertise in microelectronics engineering, companies like Google and IBM have invested heavily in the scale-up of superconducting quantum computers. Indeed, Google has announced their aim of producing a prototype with ~50 qubits within 1-2 years [4], while IBM already provides cloud-access to a 5 qubit computer [5].

In Australia, the Federal Government, Telstra and the Commonwealth Bank of Australia have invested in the silicon quantum computing technologies pioneered by CQC2T [6]. The flagship technology being based upon qubits realised by the spins of phosphorus dopants. Although this technology is yet to be scaled beyond one qubit, it has many very promising features, including the support of incredible atom-scale fabrication techniques [7], the infrastructure of the established silicon-based electronics industry, and a discernible path to scaling [8].

Diamond quantum computing is another leading technology and one where Australian physicists were early pioneers and have continued to be major contributors. In diamond quantum computing, qubits are realised by the spins of atomic defects and it is currently believed that these defects possess properties that are unique across all solids. These unique properties permit remarkably simple and robust implementations of quantum computing. However, diamond quantum computing is yet to receive the massive investments enjoyed by the other leading technologies because there is currently no obvious way to scale it up beyond a handful of qubits. Why then continue research in diamond quantum computing? Particularly in Australia, where we already seem to have backed a potential winner through our investments in silicon technology. In the following, I will first define the unique technological niche of diamond quantum computing that motivates its continued research and its potential to be the long-term winner of the quantum computing revolution. I will then elaborate upon the grand challenges in scaling diamond quantum computing and outline their potential solutions. Finally, I will provide an outlook of the important future of diamond quantum computing in Australian physics.

**Diamond's technological niche**

The superconducting, silicon and trapped ion technologies each require complex and expensive infrastructure: superconducting and silicon technologies must operate at ~mK temperatures in dilution cryostats, and trapped-ion technologies require precisely controlled networks of lasers. As a result, the vision these technologies project for quantum computing is one where there are a few computers world-wide, each occupying large purpose-built installations and providing cloud-based computing services [9]. A vision not too dissimilar to that currently realised by classical supercomputers.

The scaling of superconducting and silicon technologies will eventually reach the point where they can no longer occupy a single dilution cryostat and processors in different cryostats must be linked together via quantum ports. This eventuality is echoed in today's supercomputers where racks of computing nodes are linked together to form a whole. In fact, the speed of these links is the primary limitation to classical supercomputing [10]. Diamond technologies may offer a niche solution to this problem. In cryogenic conditions below ~10 K, the spins of diamond defects can be optically manipulated and entangled with photons (see Figure 1) [11, 12]. Much like a trapped ion, albeit permanently engineered in a solid, rather than floating in an optical lattice. In fact, the NV centre in diamond is the only system that has created a network of entangled qubits of sufficient scale and fidelity to perform loophole-free tests of Bell inequalities [11]. Owing to their superior optical properties, the SiV and GeV centres promise to exceed the NV centre in this task of optically networking distant qubits [12]. Diamond defects can thereby complement other quantum technologies by acting as ports to an optical quantum network [13]. For example, consider the spin of a diamond defect interfacing with a superconducting or silicon dopant qubit via a microwave resonator (see Figure 1) [13].

Beyond complementing the other leading technologies, diamond has the unique potential to offer a completely different vision of quantum computing. One where quantum computers are smaller and more robust and do not require cryogenics, precisely controlled laser networks or purpose-built installations. Thus, leading to cheaper, more widely distributed and accessible quantum computers that could even be diversely inte-
Figure 1 Diamond defects as optical quantum ports for networking quantum computers. (a) Schematic of the critical quantum network function of mediating entanglement of distant superconducting flux qubits. Entanglement is first established between spins of the diamond defects and photon modes. If the photons emitted by the defects are indistinguishable, then the detection of a photon after their interference by a beam splitter heralds the entanglement of the distant defect spins. This entanglement is finally swapped onto the flux qubits via microwave pulses and magnetic flux qubit-defect spin coupling. Inset: schematic of a flux qubit with embedded dual-purpose diamond photonic/phononic structure used to enhance the spin coherence of and photon collection from a SiV or GeV centre. The atomic structure of the SiV/GeV centre depicts carbon atoms (black), carbon vacancies (transparent), silicon/germanium interstitial (brown) and the centre's electronic spin (red arrow) [12]. (b) The equivalent electronic structures of the SiV and GeV centres, including levels ($^{2}E_{g}$, $^{2}E_{u}$) and truncated spin states ($|\uparrow\rangle$, $|\downarrow\rangle$) [12], and the additional structure resulting from magnetic coupling with the persistent current states of the flux qubit ($|\uparrow\rangle$, $|\downarrow\rangle$) [13]. (c) With reference to the optical and microwave pulses depicted in b, the sequence to entangle distant flux qubits (A and B), where $|0\rangle$ and $|1\rangle$ are photon number states (adapted from [11]).

This vision is based upon current few-qubit diamond quantum computers that operate on laboratory benchtops in ambient conditions and with comparatively simple equipment [14]. The computers are based upon a NV centre that is used to implement small-scale quantum computing by initialising, controlling and reading out the nuclear spins of a surrounding cluster of $^{13}$C impurities (see Figure 2). The NV centre can achieve this feat due to its remarkable combination of a high-fidelity optical spin initialisation and readout mechanism, and long-lived electron spin coherence (the longest of any solid state spin at room temperature) [15]. In this manner, up to 4 qubit diamond quantum computers have been constructed and used to implement simple error correcting and quantum simulation algorithms [14]. It is without exaggeration to say that, if you really wanted one, you could have a few-qubit diamond quantum computer on your desk at home.
The problem is that there is currently no obvious way to scale up diamond quantum computing beyond a handful of qubits [16]. A single NV centre can control a cluster of at most 5-10 qubits, which leaves the problem of finding an on-chip quantum bus to connect many NV centres and their clusters together to form large quantum processors [14]. Additionally, the fabrication of NV centres surrounded with suitable $^{13}$C clusters currently relies on the unfavourable statistics of these randomly distributed isotopic impurities in the diamond crystal [14]. This makes for very low fabrication yields of NV-$^{13}$C clusters. These and other grand challenges must be met before diamond quantum computing can scale up and realise its full potential.

The grand challenges and their potential solutions

Let us now further explore the grand challenges facing diamond quantum computing and their potential solutions.

Realising an on-chip quantum bus.

To scale beyond a single NV-$^{13}$C cluster, a quantum bus is required to mediate entanglement between multiple NV-$^{13}$C clusters embedded in a single diamond chip (see Figure 2). The bus must be able to reliably generate entanglement with sufficient fidelity and speed for computation to be completed before the quantum coherence of the computer is lost (as characterised by the qubit coherence time). This is a very challenging task.
To date there has been three architectures of quantum buses proposed that operate in ambient conditions: (1) direct coupling of NV centres via their electron spin interactions by placing them less than ~25 nm apart and selectively addressing them optically using super-resolution techniques [17], (2) extending a chain of paramagnetic defects (separated by less than ~25 nm), such as the substitutional nitrogen (N) defect, between the NV centres and transmitting spin states via magnetic field gradients and microwave pulses [18], and (3) directly transporting electrons between NV centres whilst preserving their spin state by using an on-chip network of diamond nanowires and the electron photoionization and capture mechanisms of the centres [16]. At cryogenic temperatures, bosons enable additional architectures where NV centres are coupled via: (4) photons of an on-chip photonic network (either optical or microwave) [11], (5) phonons of a network of nanomechanical structures [19], or (6) magnons of an on-chip ferromagnetic circuit [20].

Out of all of these architectures, only (1) and (4) have been experimentally demonstrated to some degree, albeit with low entanglement fidelity and generation rate, respectively. There is much work to be done to improve these efforts and to test the other architectures. A great deal of this work demands advancements in diamond fabrication techniques.

Reaching high-yield atom-scale fabrication.
To scale beyond a single NV-13C cluster, it must be made possible for such clusters to be repeatedly created and positioned within tolerances. Due to the rapid decay of 13C hyperfine interactions with distance from a NV centre, the tolerance in the placement of the 13C impurities is constrained to a few shells of atomic lattice sites around a NV centre (i.e. on the scale of ~0.5 nm). Furthermore, in view of realising an on-chip quantum bus by direct coupling of NV centres or the extension of spin chains of N defects between them, the NV-13C clusters and N centres must be positioned within a tolerance of ~10 nm. Whilst a tolerance of 10 nm can be in-principle achieved using top-down nanoimplantation techniques [21], the atom-scale tolerance required within the NV-13C clusters is beyond nanoimplantation. A bottom-up self-assembly technique for the NV-13C clusters is needed – much like the technique used to position phosphorus dopants in Si with atom-scale precision [7]. The development of such a technique is a complicated and time-consuming task that will require new understanding of the surface and growth chemistry of diamond.

Extending coherence.
Even if you can scale up to 100 qubits or more, you will then be limited by the number of logic operations you can perform in one computation. This is defined by the coherence time of the computer and the time required to implement each operation. For current, room-temperature diamond quantum computers, this number is approximately 1 ms/10 µs = 100 [14]. Since operation times are speed limited by the hyperfine interactions within the NV-13C clusters [14], the number of logic operations can only be increased by extending the coherence time. The coherence time is currently limited by the spin-flip ($T_1$) time of the NV centre’s electron spin because, due to the hyperfine interactions, a single flip of the electron spin will immediately dephase the surrounding 13C nuclear spins [22].

There are two ways to extend the NV centre’s electron spin $T_1$ time and thereby extend the 13C qubit coherence time: (1) cool to reduce the spin-phonon scattering responsible for the electron spin flips, or (2) remove the electron spins by electronically switching the charge state of the NV centres (see Figure 2). In (1), cooling to ~4 K is known to result in an increase of $T_1$ by >4 orders of magnitude [23], thereby promising an increase of the maximum number of logic operations to a highly desirable value of >1 million (as long as the 13C spin coherence time is not limited by another mechanism). (2) should yield a similar increase and is more attractive owing to its operation at room temperature. However, initial attempts of electronic control of the NV centre’s charge state have yielded modest enhancement due to instabilities in the electronic structures [22]. Much work is required to fabricate more refined electronic structures and to better understand diamond electronics and the NV centre’s charge switching mechanisms.

Upgrading to new off-chip optical quantum ports.
The NV centre is limited in its application as an off-chip quantum port capable of networking distant qubits via spin-photon entanglement. Its primary limitation is its optical properties: its optical zero-phonon line has large inhomogeneous broadening and is weak compared to its phonon sidebands. This results in difficulties when tuning distant NV centres into optical resonance as well
as in low entanglement generation rates, since only the small portion of photons emitted in the zero-phonon line can be both entangled with its spin and interfered with photons emitted by other NV centres [11]. There is thus the need to identify and upgrade to defects that can act as superior quantum ports.

The SiV and GeV centres present as good candidates since they have far superior optical properties than the NV centre: virtually no inhomogeneous broadening and phonon sidebands; but much shorter spin coherence times ($T_2^\ast \approx 40$ ns), which limit the time that the spin can store a qubit state whilst waiting to be successfully networked with a distant spin [12]. The much shorter-lived spin coherences of the SiV and GeV centres are due to their larger spin-orbit interactions, which result in faster spin-phonon relaxations via scattering of resonant phonons [24]. A potential solution to this problem is to design diamond phononic cavities surrounding the SiV and GeV centres that do not have any phonon modes resonant with the spin-orbit energies of the centres. Given the similar length-scales of the relevant phonons and the visible photons emitted by these centres, the phononic cavities may double as parts of photonic microcavities that are aimed at enhancing the collection of the photons emitted by the centres into optical fibres for transmission (see Figure 1). This certainly poses as an interesting exercise in combined phononic and photonic engineering.

**An Australian outlook**

Australia has the capacity to play a leading role in the development of diamond quantum computing. It has a long history, starting with the foundational work of Prof Neil Manson at the Australian National University, who established the key physics of the NV centre [25], and continuing with the early work in quantum communications [26], quantum computing [27] and quantum sensing [28] at the University of Melbourne and Macquarie University. There are now several groups across Australia performing world standard research in the various forms of diamond quantum technology.

Beyond these diamond-focussed groups, Australia has the extensive expertise and research infrastructure developed through continuous funding of the quantum related Centres of Excellence: CQC$^2$T, EQuS and CUDOS. These centres could apply their capabilities in atomic-scale fabrication, electronics and photonic/phononic engineering (as well as fresh perspectives) to help solve the grand challenges facing diamond quantum computing. The motivation being the many lines of inquiry that remain open in pursuit of these challenges as well as the tantalising vision of quantum computing offered by diamond.

An Australian outlook for diamond quantum computing is highly promising and complementary to the ongoing development of other quantum technologies, as long as cooperation can be established and maintained. This cooperation may need to be simulated by a proof-of-concept demonstration of the potential of diamond quantum computing, such as the development of a few-qubit desktop-size quantum computer that you can use at home.

**References**


Author Biography

Marcus is currently a ARC DECRA Fellow at the Research School of Physics and Engineering, Australian National University (ANU). In 2016, He completed his postdoctoral fellowship at the ANU under the supervision of Prof Neil Manson and, in 2012, his PhD at the University of Melbourne under the supervision of Prof Lloyd Hollenberg. Marcus’ research focuses on the physics and quantum applications of defects in diamond and related materials. He has been awarded multiple early career researcher awards for his leading role in the emergence of diamond quantum technologies, including the 2016 Ruby Payne-Scott award of the Australian Institute of Physics.
Australasian Soft Matter Scattering Workshop

Chris Garvey
ANSTO, Locked Bag 2001, Kirrawee DC NSW 2232, Australia

The Australasian Soft Matter Scattering Workshop (ASMWS) was fifth in a series of workshops this year organised at ANSTO’s Lucas Heights Campus over the 6-9th February. Scattering techniques have a unique and extremely versatile perspective on the structure of soft matter. Simply put the technique probes the internal structure by matter by measuring the probability of light, x-rays or neutrons interacting with the sample and being scattered elastically through a particular angle. A series of well-defined geometries specify the neutron scattering technique. Further, by resolving the inelastic scattering probability the technique also probes the temporal fluctuations of matter. The perspective, which is a statistical view on structure and dynamics over many orders in magnitude in length and time- scales, has provided invaluable insight to those in theoretical, applied and fundamental aspects of soft matter.

The workshop is aimed at early career researchers (ECR) who may feel that scattering techniques in their research have an important role to play, already use scattering but wish to broaden their horizons, or those who are just simply curious. Attendees at the workshop came with diverse range of scientific problems from complex fluids, chemical engineering, structural biology, membrane biophysics and food science. The perspective of the organisers is to encourage a pool of enthusiastic researchers ready to utilise, and in particular at those large scale facilities at the Australian Centre for Neutron Scattering (ACNS) and the Australian Synchrotron, to solve scientific problems which have the potential for important societal and scientific impact.

The format of the workshop was a series of lectures giving a theoretical background into the analysis and practice of scattering measurements with a strong element of experimental practice developed by sessions on relevant neutron scattering instrumentation and common laboratory equipment. Important support from those large-scale facilities hosted by ANSTO was given as lectures from many of instrument/beamline scientists and access to the neutron scattering facilities for the practical sessions. Important support also came from the wider community of academic practitioners of scattering techniques within Australia and New Zealand with many senior academic researchers giving their time to provide instruction. Manufacturers and distributors of commercial scattering instrumentation including Xenocs (France and Denmark), Malvern (ATA Scientific) and Anton Paar (MEP Instruments) were also well represented providing technical expertise.

The first two days of the workshop were held at the Australian Institute of Nuclear Science and Engineering (AINSE) lecture theatres. AINSE is an integral organisation for enhancing Australia’s capability in nuclear science and engineering by facilitating world-class research and education. AINSE offers a range of programs and services to its members including generous conference support, inspiring symposiums, Honours / Postgraduate scholarships, internships and intensive education schools. These benefits aim to foster scientific advancement and promote an effective collaboration between AINSE members and ANSTO.

In all, 25 presentations reflected the gender and age diversity of the attending scientists with attendees from 6 different countries. The program contained introductions into those core techniques of small angle scattering, specular reflectivity, neutron diffraction and quasielastic neutron scattering but also that important complementary technique, light scattering. Molecular deuteration and its role in the design of neutron scattering measurements were introduced in the context of ANSTO’s National Deuteration Facility. Other complements to neutron scattering, most particularly molecular dynamics...
simulations were presented. The remaining presentations were a range of successful applications of scattering techniques, but also some scientific problems which may be amenable to the experimental approach.

The final 2 days of the workshop consisted of hands on instrument sessions with the aims of giving ECR’s practical sessions. The instrument sessions covered those important instruments, the complement of 3 small angle neutron scattering instruments, a neutron reflectometer and a cold diffractometer suitable for biophysical problems.

The small angle neutron scattering (SANS) Quokka instrument was the first of the SANS instruments entering user service at the ACNS. As a traditional pin-hole SANS, it has formed the backbone of the user service but more recently this capability has been expanded with the ultra-small angle neutron scattering (USANS) instrument Kookaburra. Kookaburra which has extended the ability of ACNS instruments to examine structure up to micron scale length-scales with the ability to measure at extremely small angles and thus extremely small value of the scattering vector. Most recently the SANS capability of the ACNS has been expanded with the time of flight (TOF) SANS technique by the newest SANS instrument Bilby. Bilby promises many innovative experiments facilitated by the TOF technique including the ability to explore a wider dynamic range of scattering vectors/length-scales and the ability to improve q-resolution and new kinds of neutron diffraction experiments. All instrument workshop attendees had the opportunity to make measurements on these three instruments.

Platypus is a time of flight neutron reflectometer which has the simple but powerful capability of studying the density and composition of thin films through the measurement and modelling of specular neutron reflectivity. The sessions on this instrument gave the experience of basics of this measurement with this technique as applied to the study of simple bilayer membranes models, and the demanding rigours of sample preparation for neutron reflectivity were discussed.

![Bilby sample enclosure with instrument scientists Liliana de Campo and Christine Rehm (Bilby and Kookaburra) and Andrew Whitten (Bilby).](image)

**The sample position of Platypus and the instrument scientists: from left Stephen Holt, Andrew Nelson and Anton Le Brun.**

Lamellar diffraction or as it is sometimes known in the biophysical context, neutron “membrane diffraction” may provide unique information of the internal structure of bilayers. The technique has been implemented on the cold neutron triple axis spectrometer S1KA. The practical session on this instrument explored the reconstruction of the scattering length density/compositional profile of simple model membrane - 1,2-dioleoyl-sn-glycero-3-phosphocholine (DOPC).

Also presented where the EMU and PELICAN spectrometers enabling quasielastic neutron scattering (QENS). While no hands on session was scheduled, QENS provides direct access to the relaxations occurring over short length scales, up to a few nanometre, and so the underpinning mechanisms of translational and rotational diffusion. Applications include exploration of the protein dynamical transitions, polymer dynamics, as well as internal fluctuations in e.g. surfactant membranes.

As the final presentation was on that special aspect of neutron scattering, which is its ability to probe structure in environments which are far more interesting than standard static characterisations. A particular strength of scattering techniques is their ability to directly probe
the structure in situ, in situations which are both interesting and instructive. Examples of such measurements are where the sample environment is a shear field (rheoSANS); electrochemical cells; and extensional strain in the neutron beam.

Author biography

Christopher Garvey divides his time between: duties as an instrument scientist at ANSTO’s Australian Centre for Neutron Scattering, where he acts to support and encourage those who would want to use small angle neutron scattering for their research; and a research career, where he uses scattering techniques in particular, to probe the organisation and dynamics of soft matter. The overarching theme to his research is to develop sustainable technologies. He is an Adjunct Associate Professor in Applied Physics at RMIT University.

On the move with the Vacuum Society of Australia

Anton Tadich, Karyn L. Jarvis, Brett C. Johnson, Norman Booth and Anton P.J. Stampfl
Vacuum Society of Australia

The Vacuum Society of Australia (VSA) promotes and supports vacuum science, techniques, applications, and technology in Australia with the current goal to extend these activities to the Pacific and Indian Ocean Rim regions. These aims are achieved through activities in four overlapping areas: Education, Research, Development and Industry which are currently being covered by short courses, schools, workshops, conferences, and web activities, some of which are briefly discussed below.

The VSA formed in 1989, as a not for profit society for the encouragement of vacuum science and technology under the State of Victoria incorporations act. In particular the society allows all those interested in vacuum science and technology to become its members. Before this period, during the 1970's and 80's, vacuum science and technology was represented through the activities of a number of groups, notably the Vacuum Physics Group of the AIP and a group from the Footscray Institute of Technology. The VSA is currently preparing a number of articles that describe the development of vacuum science and technology in Australia which are expected to be published in the next year.

The Vacuum Society of Australia is presently going through a renewal and revitalization phase with a number of new members being accepted into executive positions as either officers of the society or as ordinary members whose responsibilities are vital to its growth and operations. These new members will be introduced below.

The society is currently expanding its educational activities to include several capital cities in Australia. This year the well known intensive two day vacuum technology short course will be delivered in Melbourne, Adelaide,
Perth, Sydney and Brisbane, with the intention of offering these courses on at least an annual basis in each State in the future. The VSA views that a solid grounding in vacuum science and technology and its good practice as vital in keeping all those that use it in this country up to date with best practices and the latest trends as well as introducing those persons who are starting to use vacuum technology and techniques in their daily work, to the science of vacuum. The science of vacuum encompasses the physics and chemistry of surfaces and of gas kinetics. A variety of courses have been delivered since the inception of the VSA and even to this day there are no regular courses given by other societies or institutions in Australia. Currently, the VSA is building up a number of state-centric educational groups to run courses in each State, all of whom are based at Universities or Institutions of higher learning and research.

Another very important component of VSA activity is to host both local and international conferences in vacuum science and technology on a semi-regular basis. To this end, the VSA is hosting the first ever such international conference in Australia next year. The 9th Vacuum and Surface Science Conference of Australia and Asia (VASSCAA-9) will be held in Sydney (12-16 August, 2018). This conference is one of a series of conferences that are supported and organised by the International Union of Vacuum Science, Technique and Applications (IUVSTA). VASSCAA-9 will be held during National Science Week and the Sydney Science Festival. Part of the conference will be open to the public where a number of well known scientists will give public talks as well as provide a number of public exhibits in line with the spirit of the Sydney Science Festival. The week before the conference the first vacuum science, technique and applications school is planned, which will focus on vacuum fundamentals as well as sample environments. This school is targeted towards students and early career researchers and in particular those from the Pacific and Indian Ocean rim countries will be encouraged to attend.

The VSA is a full member of IUVSTA and has been since its inception. Engagement with IUVSTA has recently increased with a number of VSA members actively participating in all eight committees and nine scientific divisions of the union. This allows the VSA to keep up with the most current international trends in vacuum science and technology as well as participating as an integral part of the international vacuum community. The VSA is currently looking for further engagements with other international vacuum societies in order to share its resources and knowhow.

Lastly, and equally as importantly, the VSA is upgrading and transferring its internal accounting and membership systems to a cloud-based system along with giving its web presence a total overhaul and makeover. These activities will allow the VSA to expand its activities and membership and therefore provide tangible benefits to the community.

New executive members of the VSA are: Dr Anton Stampfl (President - ANSTO), Dr Anton Tadich (Vice-President - Australian Synchrotron), Dr Karyn Jarvis (Secretary - Swinburne University of Technology), Dr Norman Booth (Assistant to the Treasurer - ANSTO), Dr Brett Johnson (Web-administrator and design - University of Melbourne). Other current members of the executive committee are Mr Kevin Lawlor, Dr Tony Simpson (Treasurer), Professor Rod Boswell (ANU), Dr Barry Wood (University of Queensland), Mr Kevin Armstrong (AVT Services P/L), Mr Will Stanton (Stanton Scientific), and Professor Bruce King (University of Newcastle).

Anton Tadich is a senior beamline scientist at the Soft X-ray Beamline at the Australian Synchrotron. Anton has over 17 years experience in ultra high vacuum techniques and instrumentation through his expertise as a surface scientist specialising in photoelectron spectroscopy. Anton is currently the Vice-President of the VSA, and is also the Chair of the Victorian Branch of the Australian Institute of Physics.

Karyn Jarvis is a research engineer at the Swinburne University of Technology, managing the Australian National Fabrication Facility (ANFF) Bioninterface Engineering hub. Karyn has over 10 years experience in various vacuum thin film deposition and characterization techniques.
Antiproton excess linked to dark matter

An unexplained excess in the number of antiprotons detected by the Alpha Magnetic Spectrometer (AMS) is related to the annihilation of dark-matter particles, according to two independent studies. Dark matter is a mysterious substance that appears to account for most of the matter in the universe.

While its existence can be inferred indirectly from a number of different astronomical phenomena, dark-matter particles have never been detected directly. Writing in Physical Review Letters, Alessandro Cuoco and colleagues at RWTH Aachen University in Germany describe how they analysed antiproton, proton and helium cosmic-ray detection rates by AMS – which is located on the International Space Station – and other experiments. They found that the creation of antiprotons by the annihilation of dark-matter particles with masses of about 80 GeV/c² provided the best explanation for why AMS has detected more antiprotons than expected to be created by conventional astrophysical process. In the same issue of the journal, Ming-Yang Cui of the Chinese Academy of Sciences and colleagues describe an independent analysis of the antiproton excess, which suggests that it is the result of annihilating dark-matter particles with masses in the 40–60 GeV/c².

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Optical chip gives microscopes nanoscale resolution

A photonic chip that allows a conventional microscope to work at nanoscale resolution has been developed by a team of physicists in Germany and Norway. The researchers claim that as well as opening up nanoscopy to many more people, the mass-producible optical chip also offers a much larger field of view than current nanoscopy techniques, which rely on complex microscopes.

Nanoscopy, which is also known as super-resolution microscopy, allows scientists to see features smaller than the diffraction limit — about half the wavelength of visible light. It can be used to produce images with resolutions as high as 20–30 nm — approximately 10 times better than a normal microscope. Such techniques have important implications for biological and medical research, with the potential to provide new insights into disease and improve medical diagnostics.

"The resolution of the standard optical microscope is basically limited by the diffraction barrier of light, which restricts the resolution to 200–300 nm for visible light," explains Mark Schüttpelz, a physicist at Bielefeld University in Germany. "But many structures, especially biological structures like compartments of cells, are well below the diffraction limit. Here, super-resolution will open up new insights into cells, visualizing proteins ‘at work’ in the cell in order to understand structures and dynamics of cells."

There are a number of different nanoscopy techniques that rely on fluorescent dyes to label molecules within the specimen being imaged. A special microscope illuminates and determines the position of individual fluorescent molecules with nanometre precision to build up an image. The problem with these techniques, however, is that they use expensive and complex equipment. "It is not very straightforward to acquire super-resolved images," says Schüttpelz. "Although there are some rather expensive nanoscopes on the market, trained and experienced operators are required to obtain high-quality images with nanometer resolution."

To tackle this, Schüttpelz and his colleagues turned current techniques on their head. Instead of using a complex microscope with a simple glass slide to hold the sample, their method uses a simple microscope for imaging combined with a complex, but mass-producible, optical chip to hold and illuminate the sample.

"Our photonic chip technology can be retrofitted to any standard microscope to convert it into an optical nanoscope," explains Balpreet Ahluwalia, a physicist at The Arctic University of Norway, who was also involved in the research.

The chip is essentially a waveguide that completely removes the need for the microscope to contain a light source that excites the fluorescent molecules. It consists of five 25–500 μm-wide channels etched into a combination of materials that causes total internal reflection of light.

The chip is illuminated by two solid-state lasers that are coupled to the chip by a lens or lensed fibres. Light with two different wavelengths is tightly confined within the channels and illuminates the sample, which sits on top of the chip. A lens and camera on the microscope record the resulting fluorescent signal, and the data obtained are used to construct a high-resolution image of the sample.

To test the effectiveness of the chip, the researchers imaged liver cells. They demonstrated that a field of view of 0.5 × 0.5 mm² can be achieved at a resolution of around 340 nm in less than half a minute. In principle, this is fast enough to capture live events in cells. For imaging times of up to 30 min, a similar field of view at a resolution better than 140 nm is possible. Resolutions of less than 50 nm are also achievable with the chip, but require higher magnification lenses, which limit the field of view to around 150 μm. [Robin Diekmann et al., Nature Photonics 11 2017; doi: 10.1038/NPHOTON.2017.55]

Extracted with permission from an item by Michael Allen at physicsworld.com

Standard-resolution image of a biological sample (left) compared to high-resolution (centre) and super-resolution (right) images obtained with the chip-based technique. (Credit: Bielefeld University / Robin Diekmann)
Cosmic-ray balloon launches in New Zealand

A 532,000 m³ super-pressure balloon to study ultra-high cosmic rays has been launched in New Zealand by NASA. The balloon’s international Extreme Universe Space Observatory (EUSO) instrument will observe a broad swathe of the Earth’s atmosphere to detect the ultraviolet fluorescence as cosmic rays hit the Earth’s atmosphere. The instrument will aim to detect cosmic rays that have an energy greater than 10¹⁸ eV. The balloon will operate for around 100 days and is expected to circle the planet two or three times. If the mission is a success then it could pave the way for a EUSO instrument to be installed on the International Space Station that could then observe a greater area of the Earth’s atmosphere.

Remote tracking of moving objects has many applications, including in military and civilian surveillance. Radar and lidar, for example, involve transmitting electromagnetic waves – radio or microwaves in the case of radar and ultraviolet, visible or near-infrared light for lidar – and then analysing the waves that bounce back from objects.

Despite being powerful tools, they require a direct line of sight between the object and the antenna, becoming much less effective when an object is obscured by conditions that scatter the waves, such as clouds, rain and fog. Although it is possible to track obscured objects by repeatedly imaging them, this requires complex equipment and data processing. As the scattering effect of any disturbances increases, the techniques can become so ineffective that they can even fail.

Part of the problem is that conventional methods for tracking hidden objects rely on regular wave pulses at a certain frequency, or combination of frequencies – deterministic signals. “If you have a signal that is regular, something that is deterministic, and you pass it through some disturbance it becomes corrupted – more or less depending on the strength of that disturbance,” explains team member Aristide Dogariu from the University of Central Florida.

To tackle this difficulty, Dogariu and Milad Akhlaghi, also at the University of Central Florida, tried a different approach. In their latest research they describe a technique that uses a random, or “noisy”, light signal to track a moving object surrounded by concealing scattering media. This works because although the noisy signal is corrupted when it is sent through the disturbance, its average properties are much more robust than those of a regular signal. “What is already destroyed cannot be destroyed further easily,” says Dogariu.

Dogariu and Akhlaghi developed statistical methods that allowed them to separate fluctuations in the frequency of the light emitted by the obscuring medium from those that are returned by the moving object. This only works, however, if the object and the obscuring medium are moving at different speeds, which means they each return a different spectral composition.

“You take the intensity variations of the light that comes out and then you construct a power spectrum of those fluctuations and you look in different frequency bands in that spectrum,” Dogariu explains. “This is done in
real time as it does not require sophisticated calculations – it is just a power spectrum analysis.”


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**Australia gains access to ESO telescopes in Chile**

Astronomers in Australia will gain access to European Southern Observatory (ESO) telescopes in Chile in 2018 under a new agreement involving an A$26m payment to the ESO. Australia has also committed to the ongoing funding of the telescopes until 2028 at an average annual rate of A$12m and Australian astronomers and companies will be involved in developing new technologies for the telescopes.

Australia has been seeking access to ESO telescopes for the past two decades, and this new agreement is a significant step forward for Australian astronomy. The ESO’s Very Large Telescope in Cerro Paranal, Chile. (Credit: ESO)

Chris Tinney at the University of New South Wales Sydney says: “Australian astronomers have been seeking access to ESO for the past two decades.” Lisa Kewley, who chairs the Australian Academy of Science National Committee for Astronomy, adds: “This is great news for the future of Australian astronomy.” Nobel laureate and Australian National University vice-chancellor Brian Schmidt says access to ESO’s facilities and other infrastructure such as the next-generation Giant Magellan Telescope (GMT) and Square Kilometre Array (SKA) radio telescope is critical to the future of Australian astronomy. Tim de Zeeuw, the ESO’s director general, says: “The ESO community is well aware of Australia’s outstanding instrumentation capability, including advanced adaptive optics and fibre-optic technology.” He adds: “Australia’s expertise is ideally matched to ESO’s instrumentation programme, and ESO Member State institutions would be excited to collaborate with Australian institutions and their industrial partners in consortia developing the next generation of instruments.”

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**Space radiation brought down to Earth**

Space radiation has been reproduced in a lab on Earth. Scientists have used a laser-plasma accelerator to replicate the high-energy particle radiation that surrounds our planet. The research could help study the effects of space exploration on humans and lead to more resilient satellite and rocket equipment.

The radiation in space is a major obstacle for our ambitions to explore the solar system. Highly energetic ionizing particles from the Sun and deep space are extremely dangerous for human health because they can pass right through the skin and deposit energy, irreversibly damaging cells and DNA. On top of that, the radiation can also wreak havoc on satellites and equipment.

A high-energy laser creates a space-like plasma of electrons and protons. (Credit: University of Strathclyde)

While the most obvious way to study these effects is to take experiments into space, this is very expensive and impractical. Yet doing the reverse – producing space-like radiation on Earth – is surprisingly difficult. Scientists have tried using conventional cyclotrons and linear particle accelerators. However, these can only produce monoenergetic particles that do not accurately represent the broad range of particle energies found in space radiation.

Now, researchers led by Bernhard Hidding from the University of Strathclyde in the UK have found a so-
The team studied its plasma particles using electron-sensitive image plates, radiochromic films for protons and scintillating phosphor screens. Then, to prove the lab-made radiation was comparable to space radiation, the team used simulations from NASA. "The NASA codes are based on models as well as a few measurements, so they represent the best knowledge we have," says Hidding.

The next task was to prove that the system could be used to test the effects of space radiation by subjecting optocouplers to the particle radiation. Optocouplers are common devices that transfer electric signals between isolated circuits. As they are characterized by their current transfer ratio, Hidding and team were able to monitor the radiation-induced degradation by measuring this performance.

[B. Hidding et al., Scientific Reports 7, Article number: 42354 (2017); doi:10.1038/srep42354]

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**Tokamak Energy achieves first plasma**

The UK-based company Tokamak Energy has created the first plasma in its ST40 tokamak reactor. The firm will now complete the commissioning and installation of a full set of magnetic coils for the device, which will provide greater control over the plasma. The company plans to achieve a plasma temperature of 15 million degrees by autumn 2017 and have the plasma at 100 million degrees in 2018. At this temperature it should be possible for hydrogen nuclei in the plasma to fuse together, releasing large amounts of energy. Tokamak Energy has ambitious plans to create a fusion reactor capable of generating electricity by 2025 and have a commercially viable source of fusion power by 2030.

Unlike the much larger ITER tokamak fusion reactor that is being built in France, the ST40 is a compact device that can run at a much higher plasma pressure. This, according to Tokamak Energy, should make more efficient at achieving fusion. Creating a dense plasma will require very strong magnetic fields, which the firm plans to generate using superconducting magnets. Some critics, however, are sceptical that such magnetic fields can be achieved inside a tokamak. The firm’s chief executive David Kingham describes the ST40 as "the first world-class controlled fusion device to have been designed, built and operated by a private venture". However, he concedes that "we will still need significant investment, many academic and industrial collaborations, dedicated and creative engineers and scientists, and an excellent supply chain", for the company to achieve its goals.

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PRODUCT NEWS

Coherent Scientific

New High-power Femtosecond Lasers

Coherent’s original Monaco is a “one box” diode-pumped ultrafast laser delivering 40 µJ pulses at 1035 nm, with repetition rate variable from single shot to 1 MHz. Standard pulsewidth is <400 fs and an option is available for variable pulsewidth from <400 fs to 10 ps.

Coherent has recently released new versions of the Monaco. The Monaco 1035-60 delivers 60 µJ pulses at 1035 nm with average power of 40 W while the Monaco 517-30 delivers 30 µJ pulses at 517 nm with average power of 20 W.

Monaco has outstanding beam quality (M² < 1.2) making it ideal for demanding micromachining applications in research and industrial environments. Homogenous materials such as glass and metals as well as complex layered structures are readily addressed with Monaco’s sub-400 fs pulsewidth.

Paul Wardill (paul.wardill@coherent.com.au)

New Dual Phase Analog Lock-In Amplifier

For over half a century the lock-in amplifier has been the instrument of choice for measuring small AC signals in the presence of noise. The capabilities of the modern DSP lock-in amplifier in stability, dynamic reserve, and flexibility were revolutionary, making it a mainstay for researchers and engineers across multiple fields. But in moving forward, something was left behind. For a core group of users, low-temperature researchers in particular, the new instruments became a potential source of high-frequency interference.

Recognising that one size shouldn’t have to fit all, SRS is proud to introduce the SR124 Single-Phase and SR2124 Dual-Phase Analog Lock-In Amplifiers. Inspired by the best of an earlier generation’s lock-ins, but availing itself of today’s low-noise analogue components and design methodologies, the SR124 and SR2124 are a tour de force in low-noise, high-performance analog instrumentation.

Jeshua Graham (jeshua.graham@coherent.com.au)

Get 130 nm Resolution and 5x Better Dimension Repeatability on NanoScale Structures with Bruker’s Acuity XR

TBruker’s high resolution and high accuracy optical 3D microscopes, the Contour Elite product range, can resolve features down to 130 nm laterally through the patented Acuity-SR imaging algorithm. This sub-diffraction resolution capability combined with Bruker’s objective independent Angstrom vertical sensitivity and sub-Angstrom measurement repeatability provide the best possible capability for quick and easy metrology on sub-micro surface objects. Acuity-XR not only allows sub-diffraction limited measurement, but also improves dimensional repeatability on nanoscale structures by a factor of 5x compared with conventional techniques.

In addition, Bruker’s Vision64 software includes as standard automated data analysis to provide instant results as well as a wealth of options for automated measurement across one or multiple samples providing an unprecedented level of measurement efficiency and accuracy.

Christian Gow (christian.gow@coherent.com.au)

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Lastek

**Gentec-EO release new Pronto-250-PLUS Laser Power Detector**

The new Pronto-250-PLUS pocket-size power meter has 3 measurement modes: single shot power measurements up to 250 W (SSP), continuous power measurements up to 8 W (CWP) and single shot energy measurements up to 25 J (SSE).

Key Features:
- Pocket-Size: This mid to high power handheld probe is so compact it fits in your pocket
- Easy-to-Use: The touch screen colour LCD allows for a friendly user interface. You can make a measurement with just the touch of a button
- User Settable: You can set the wavelength, brightness and screen orientation to adapt to your application
- Data Logging: Save your data to the internal memory and then transfer it to your PC over the USB connection.
- From Low to High Powers: Thanks to a low noise level and high damage threshold, the Pronto can measure powers from 1 W to 250 W
- Fully Calibrated: The Pronto-250 comes fully calibrated: every wavelength between 248 nm and 2.5 micron (YAG), and a real calibration at 10.6 micron (CO2). The Pronto-250-PLUS has all these calibrations and is also calibrated for Energy measurements.
- Hands-Free Operation: Place it on a flat surface or use one of the 2 threaded holes that we have integrated in the casing for safe use with optical stands.

**TOPTICA’s CTL available at 1050, 1320 and 1470 nm – with up to 110 nm mode-hop-free tuning!**

Continuous, mode-hop-free wavelength tuning up to 110 nm is now possible around the new central wavelengths 1050, 1320 and 1470 nm. These new wavelengths complement the portfolio of TOPTICA’s laser platform CTL (Continuously Tunable Lasers).

The new wavelengths of the CTL support a variety of applications like spectroscopy, waveguide characterization, studying microresonators, seeding ytterbium amplifiers, as well as testing of ytterbium fibre components. In addition, the CTL at 1470 nm central wavelength lends itself for specific applications in the telecommunication range (s-band and part of e-band), especially where high resolution and low noise are required.

Key Features:
- Mode-hop-free tuning: 915 nm - 985 nm or 1530 - 1620 nm
- Up to 80mW
- Flexible motor, piezo and current tuning with high accuracy and small step sizes
- Low-noise and powerful digital control with DLC pro
- High frequency AC and DC current modulation inputs
- Hands-off operation with SMILE and FLOW

**Raptor Photonics Falcon III with third generation EMCCD technology**

Raptor Photonics, a global leader in the design and manufacture of high performance digital cameras, has launched its latest camera the Falcon III, Falcon II and Kestrel using ground-breaking EMCCD – GEN III technology.
The Falcon III incorporates a new EMCCD sensor developed by e2v which offers 1MP resolution with 10 µm square pixels. A back-illuminated sensor offers a peak QE of >95% offering unsurpassed sensitivity with a total noise floor as low as 0.01 electrons readout noise.

EMCCD – GEN III offers the combination of ultimate sensitivity and speed through a single output amplifier thereby maximizing uniformity. It is three times faster than previous generation EMCCDs with superior linearity and low gain performance. Up to 5000 x EM gain can be applied to the sensor using lower voltages resulting in reduced sensor ageing effects. The camera can be cooled to -100°C for lowest possible background events using Raptor’s long life ruggedized PentaVacTM vacuum technology.

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

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Warsash Scientific

Radially and azimuthally polarized beams generated by liquid crystal elements

ARCoptix’s Radial Polarizer converts a linearly polarized beam into a beam that has a continuous radial or azimuthal polarization distribution. This unique technology is based on a special alignment of the nematic liquid crystal molecules that are capable of locally rotating the orientation of the linearly polarized laser beam. Either azimuthally or radially distributed polarization is obtained depending on the orientation of the device with respect to the laser polarization.

This device has a working wavelength range from 350 to 1,700 nm, contained in a compact 6 x 4 x 1.5 cm³ housing with a 10 mm diameter active area.

The input/output extinction ratio is -100 at 633 nm. It can be driven with a standard function generator or the ARCoptix USB liquid crystal driver.

Potential applications for the Radial Polarizer include creating Laguerre-Gaussian beams for superresolution microscopy, optical trapping and laser cutting, as well as being a key component for a polarization axis finder system.

BenchMate vibration control platform

Kinetic Systems are now offering the BenchMate benchtop based vibration control platform in four different configurations that will suit a range of applications. The BenchMate platforms are designed for high resolution instruments and applications such as; AFM, SPM, interferometers, profilometers and microhardness testers.

The range of platforms includes;
• 8001 Series – Active vibration control platform that is compact and lightweight for floor or tabletop mounting that includes active feedback for all six translational and rotational modes of vibration.
• 2214 Series – Active-air vibration control platform that combines Kinetic Systems precision active-air vertical isolation and a multi-stage horizontal vibration control for environments and applications where horizontal vibrations are an issue.
• 2212 Series – Active-air vibration control cost effective platform designed to enhance the performance of precision tabletop equipment.
• 2210 Series – Passive-air vibration control low cost platform.

TC10 LAB Series temperature control

Wavelength Electronics has recently released the TC10 and TC5 LAB Series temperature control instruments. The TC LAB Series of temperature controller integrates
high-end digital control with a precision output current drive stage to offer the best stability temperature control instrument commercially available.

The TC10 (10 A, 15 V) and TC5 (5 A, 15 V) are ultra-stable digital controllers for thermoelectric and resistive heaters where tight temperature stability is required. Designed using the latest technology, stabilities better than 0.0009 °C can be achieved with thermistors. Wavelength Electronics proprietary IntelliTune™ intelligent tuning algorithm, adapts the PID control coefficients as you change setpoint or tuning mode, always keeping the load optimally controlled.

With Wavelength Electronics plug and play instrument you have the ability to quickly set the controls using either the instrument touch screen or a remote computer, and the results are easy to monitor.

Key features include;
- Output current 10 A.
- Temperature stability better than 0.0009 °C.
- Compatible with most sensor types.
- Intuitive user interface touchscreen.
- IntelliTune™ PID control.
- Adjustable over current limits.
- Over- and under-temperature protection.
- USB and Ethernet interfaces.

For more information contact Warsash Scientific at sales@warsash.com.au

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Nanosecond Nd:YAG lasers
Dye lasers & solid state OPOs
Fibre laser for cooling and trapping

Q-smart 850 Nd:YAG laser

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