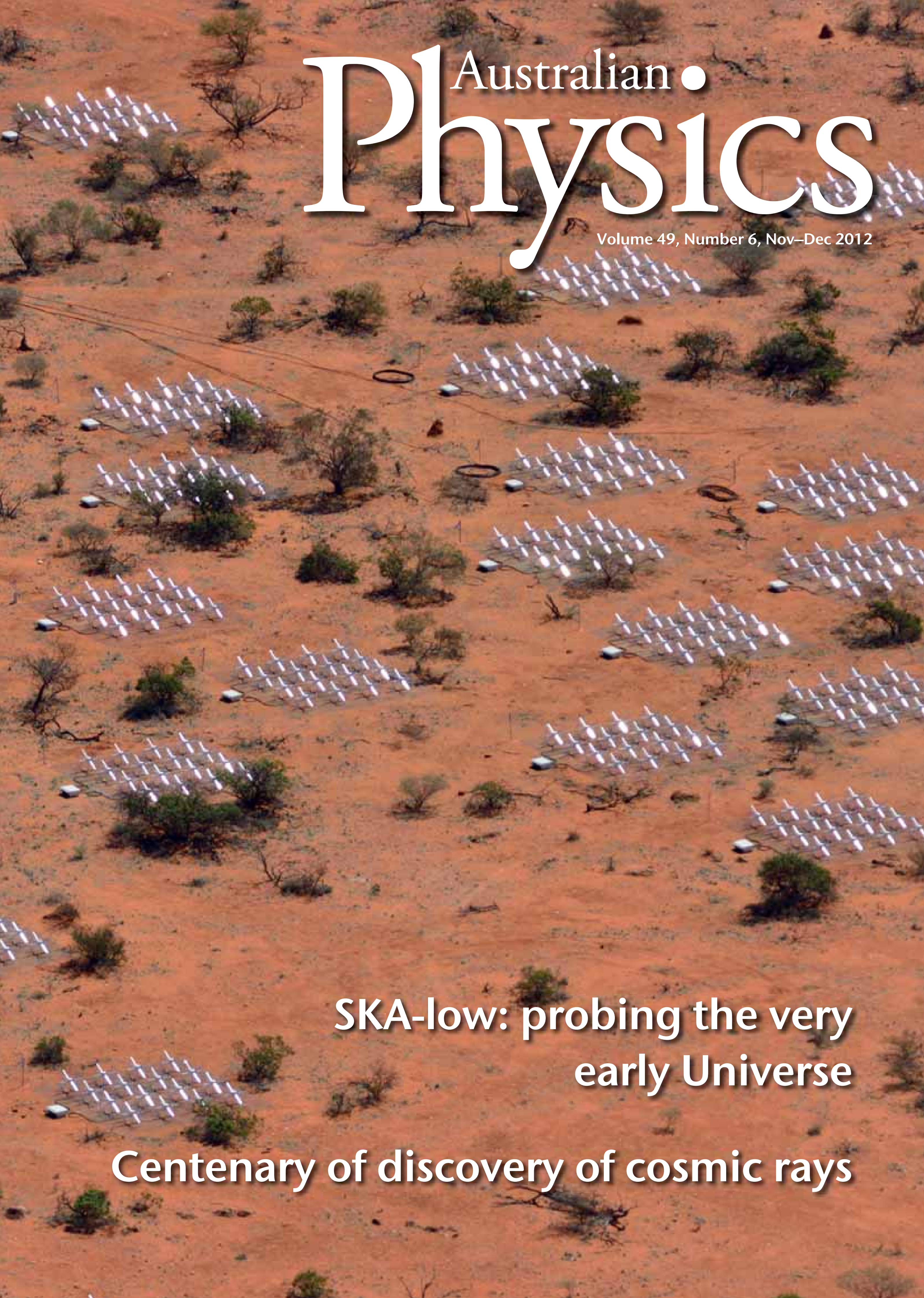
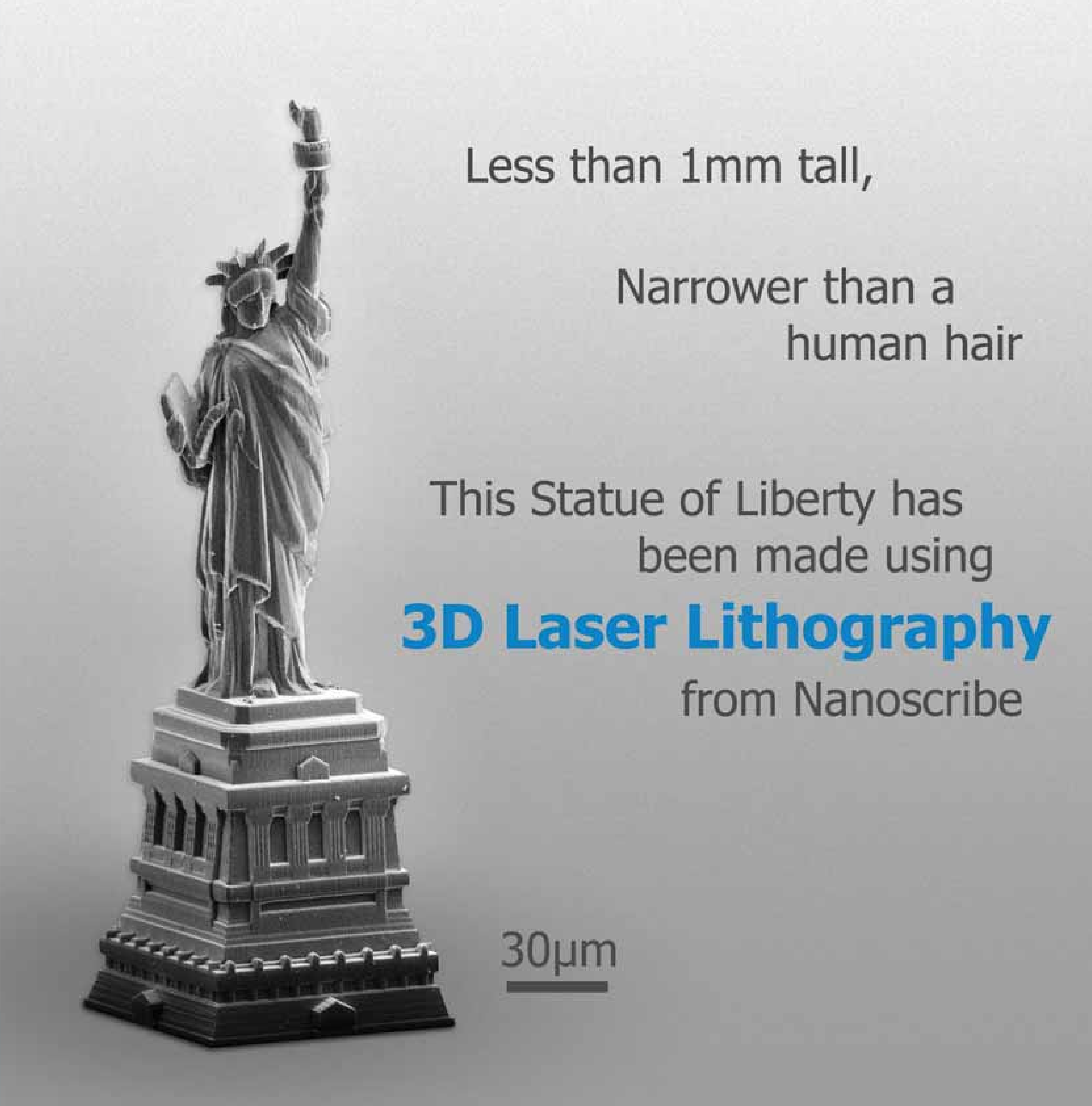


Australian Physics

Volume 49, Number 6, Nov–Dec 2012

SKA-low: probing the very early Universe

Centenary of discovery of cosmic rays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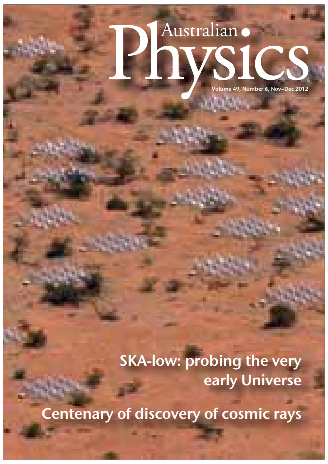

Cover

Part of the Murchison Widefield Array.
See page 174

Australian Institute of Physics

Promoting the role of physics in research, education, industry and the community

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EDITORIAL

Past, Present, Future

The two articles in this issue are, for different reasons, of historical interest. The article by Drs Duldig and Humble is the first of two marking the centenary of the discovery of cosmic rays. This article concentrates on the early history up to the Second World War with particular emphasis on Australian contributions. A second article covering the post-war period will follow next year. The decision that Australia and New Zealand will jointly host the Square Kilometre Array (SKA) with South Africa marks another major step for radio astronomy in Australia. The article by Professors Tingay and Hall describes one part of the project, SKA-low, which will be sited entirely in Western Australia at the Murchison Radioastronomy Observatory and is optimised for investigating the very early universe.

I welcome two new associate editors, Bruce Hartley from Western Australia and Christian Langton from Queensland. The main function of associate editors is to supply news from branches that may be of wider national interest. Associate editors can also be a source of any news from their states that should be more widely disseminated and ideas for articles.

By the time this issue of *Australian Physics* arrives many members will be preparing to attend the 20th AIP Congress at UNSW (9-13 December). This Congress coincides with the 50th anniversary of the founding of the AIP, which emerged from the Australian branch of the Institute of Physics. Depending upon how you define the beginning, it was either late 1962 or early 1963 (see discussion in the second of Anna Binnie's articles on the history of the AIP: *A Short History of the Australian Institute of Physics, Part 2: Aust. Phys.*, **44** (2007) 128-37). The first issue of this journal (then called *Australian Physicist*) appeared shortly after in 1964. The editor John Symonds (AAEC/ANSTO) is the last surviving member of the first executive.

While our 50th anniversary is a time to recognise and celebrate achievements, it is also a time to look to the future. Many journals of a similar nature to this one are beginning to offer online alternatives to printed versions. I would be very interested to hear from any member with appropriate expertise who might be interested in exploring such opportunities for *Australian Physics*.

As acting editor for the present I gratefully acknowledge assistance I have received from Dr Tony Farmer and am pleased to announce that Tony will take over as editor from the first issue of 2013.

Finally, best wishes to all members for 2013.

Brian James

2012 Physics in reflection

As we approach the end of the year it is a good time to reflect on the last 12 months. But first an apology to our cognate society ACPSEM which I incorrectly titled in the last issue. The title should have been the Australasian College of Physical Scientists and Engineers in Medicine.

As I write this column it is 12 months since Brian Schmidt was awarded his Nobel Prize. Brian has been an outstanding ambassador for Australian science overseas and perhaps more importantly he been an influential champion of science within Australia.

About the same time FASTS underwent a transformation changing its trading name to Science and Technology Australia but also losing government funding. It was a challenging time. Internal restructuring and cost cutting commenced plus a refocus on profitable activities that support and promote science. Some funds were secured from government and the changes are building a stronger organisation that is less reliant on government funding and more financially robust.

Throughout the year the Physics Decadal Plan has been tweaked and massaged and the final version should be out by year's end with David Jamieson presenting it to the AIP Congress in December. The plan sets out a vision for the future of Physics in Australia and the job of implementation will be at hand.

There were two significant infrastructure announcements during the year. Funding for the Australian Synchrotron provided operating funds but not additional beam lines. There will also be changes to the management structures and we can only hope that funding for beam lines can be found over the next few years. The second announcement was the decision to site the low frequency part of the Square Kilometre Array, or SKA, in Western Australia. This was a fantastic result for Australian astronomy and will have an impact for several decades. The official opening of ASKAP, the Australian SKA Pathfinder took place on 5 October.

The Defence Trade Controls Bill was an issue of concern during the year but was halted in the Senate awaiting further consultation. This was undertaken through the Office of the Chief Scientist with negotiations reaching a good compromise. Although some media reports later in the year suggested passage of the Bill would have dire consequences for research this was not accurate. A sensible agreement was achieved aimed at minimising impact on researchers or research groups, with compliance only required at high levels, and allowing the vast majority of research programs to continue relatively unaffected. By the time you read this we'll know if the revised legislation passed.

Shortly we will have what is looking like the largest AIP Congress ever. There is a wide program of sessions to choose from and plenty of quality plenary and invited speakers. At the congress we will launch our 50th anniversary year. The AIP executive has decided to establish an annual Early Career Award in the form of a medal as part of the celebrations and details will be announced at the congress. There will also be other events throughout next year in celebration.

Finally, the executive for 2013-15 will be elected unopposed at the AIP AGM at the end of January. It will comprise Dr Rob Robinson from ANSTO as President, Prof Warrick Couch from Swinburne as Vice President, Dr Judith Pollard from the University of Adelaide as Treasurer, Prof Ian McArthur from University of Western Australia as Registrar and Ass Prof Joe Hope from ANU as Secretary. In addition there will be two seconded positions: Dr Olivia Samardzic from DSTO as the Prizes and Awards Special Projects Officer and Ass Prof Andrew Greentree from RMIT as 50th Anniversary Events Special Projects Officer. Based at the University of Tasmania, I continue as ex-officio Immediate Past President. As you can see there is a very wide range of institutions and geographic locations providing a good representation of physics across Australia.

It has been a good year for physics, the future looks bright and we are ending the year on a positive note with the congress. May I take this opportunity to wish all members a safe, happy and joyous holiday period and a productive and fulfilling 2013.

Marc Duldig

NEWS & COMMENT

The Nobel Prize in Physics for 2012 has been awarded jointly to:

Serge Haroche (Collège de France and Ecole Normale Supérieure, Paris, France) and David J. Wineland (National Institute of Standards and Technology (NIST) and University of Colorado Boulder, CO, USA) *"for groundbreaking experimental methods that enable measuring and manipulation of individual quantum systems"*

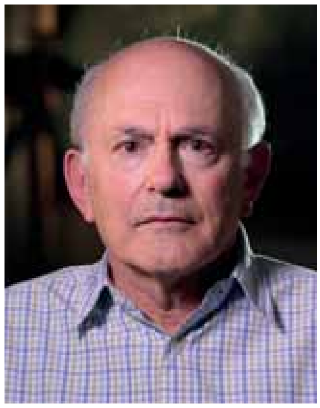
Serge Haroche and David J. Wineland have independently invented and developed methods for measuring and manipulating individual particles while preserving their quantum-mechanical nature, in ways that were previously thought unattainable.

The Nobel Laureates have opened the door to a new era of experimentation with quantum physics by demonstrating the direct observation of individual quantum systems without destroying them. Through their ingenious laboratory methods they have managed to measure and control very fragile quantum states, enabling their field of research to take the very first steps towards building a new type of super fast computer, based on quantum physics. These methods have also led to the construction of extremely precise clocks that could become the future basis for a new standard of time, with more than hundred-fold greater precision than present-day caesium clocks.

For single particles of light or matter, the laws of classical physics cease to apply and quantum physics takes over. But single particles are not easily isolated from their surrounding environment and they lose their quantum properties as soon as they interact with the outside world. Thus many seemingly bizarre phenomena predicted by quantum mechanics could not be directly observed, and researchers could only carry out 'thought experiments' that might in principle manifest these bizarre phenomena.

Both Laureates work in the field of quantum optics studying the fundamental interaction between light and matter, a field which has seen considerable progress since the mid-1980s. Their methods have many things in common. David Wineland traps electrically charged atoms, or ions, controlling and measuring them with light, or photons. Serge Haroche takes the opposite approach: he controls and measures trapped photons, or particles of light, by sending atoms through a trap.

Physicists receive Prime Minister's Prizes for Science



Two physicists received Prime Minister's Prizes for Science at a dinner at Parliament House on 31 October. Prof Ken Freeman from the Australian National University received the $300,000 Prime Minister's Prize for Science. Ken has been at the forefront of Australian astronomical research for many years and is a world leader on investigations into dark matter in galaxies. His work has set the benchmark in this field and his international reputation is outstanding.

Prof Eric May of the University of Western Australia, has received the $50,000 Malcolm McIntosh Prize for Physical Scientist of the Year for his work in improving the efficiency and sustainability of liquid natural gas production. Eric's techniques for making accurate measurements of the thermodynamic properties of fluids are central to the engineering of extraction and production facilities and to capturing carbon dioxide in the process.

Image credits: Prime Minister's Science Prizes/Bearcage

AIP medal winners announced

The AIP Education Medal for 2012 has been awarded to Associate Professor Manju Sharma of the University of Sydney in recognition of her significant contributions to Physics education in Australia and her leadership of national physics teaching initiatives. A/Prof Sharma is

director of the Institute for Innovation in Science and Mathematics Education at the University of Sydney and leader of SaMnet, the Science and Mathematics network of Australian University Educators, which aims to to develop 100 leaders of change in physics and mathematics education in Australia.

The 2012 Bragg Gold Medal for the best PhD thesis by a student from an Australian university has been awarded to Dr Eva Kuhnle from the Swinburne University of Technology for her thesis titled: Studies of Universality in Strongly Interacting ^{6}Li Fermi Gases with Bragg Spectroscopy. Dr Kuhnle used Bragg spectroscopy to study pairing mechanisms of fermions in a dilute strongly interacting Fermi gas formed from ultracold ^{6}Li atoms.

Both medals will be presented at the 20th AIP Congress at UNSW, 9-16 December 2012.

Young Tall Poppy award

Dr Tara Murphy, a Senior Lecturer in Astroinformatics at the School of Physics, University of Sydney has been awarded one of the Young Tall Poppy awards for New South Wales for 2012.

These awards recognise young scientists who are doing outstanding work in their field and actively engage and educate the community about their work. Dr Murphy's research is interdisciplinary, investigating the application of novel computer science and software engineering techniques to data-intensive astronomy research. Her unique contribution has been to apply sophisticated data mining and machine learning algorithms to key problems in radio astronomy. As a recipient of the Young Tall Poppy Science Award, Dr Murphy becomes a science ambassador and will undertake outreach activities as part of the Tall Poppy Campaign programs targeting school students, teachers, the general public, media, members of parliament, policy makers, as well as a range of science promotional activities throughout NSW during 2013.

New national initiative in teaching and research in Medical Physics

A new national inter-university medical physics group was recently set up to link the 6 Australian universities that provide comprehensive post-graduate programs in the subject (Adelaide, QUT, RMIT, Sydney, UWA, Wollongong). These include provision of professionally accredited Masters courses, being the necessary educational qualification for physics graduates to enter the linked hospital-based clinical medical physics training program. The group hosted by the Institute of Medical Physics (IMP), in the School of Physics at the University of Sydney and chaired by the IMP's Director, Professor David Thwaites, recently successfully bid to a DoHA research funding scheme to support innovation in Radiation Oncology, receiving \$1.75M over 2 years to develop a national network encompassing both education and research. Workstreams include developing a national Virtual Teaching Laboratory in Radiation Oncology Medical Physics and developing an integrated research collaboration between universities and partner hospital medical physics departments to support translational research in advanced radiation oncology imaging and treatment methods. These grants have also led to additional linkage-type funding from universities and hospital research funds, providing an overall resource into this national initiative approaching \$4 million over 2 years. This is expected to give a significant boost to the national medical physics research effort and to have a significant impact on the development and implementation of high-physics-content treatments in radiation oncology departments around Australia.

Australian SKA Pathfinder telescope opened

Australia's newest radio telescope was opened on Friday 5 October by Senator Chris Evans, Minister for Science, in front of a 300-strong crowd at the telescope location, 315 km northeast of Geraldton in Western Australia.

The thirty-six 12-m dishes of CSIRO's Australian SKA Pathfinder telescope, ASKAP, have been quietly taking shape over the past few years. All are now in place and outfitting and commissioning have begun, with a view to science operations starting in 2013.

ASKAP will be the world's fastest radio telescope for surveying the sky, 30 times faster than the current record holder (the Very Large Array in the USA). This is thanks to a new CSIRO-designed phased-array feed for ASKAP, which gives ASKAP a field of view of 30 square degrees.

In the telescope's first five years of operation, 75% of its research time will be used for ten survey science projects,

Senator Chris Evans (Minister for Tertiary Education, Skills, Science and Research) presses the button to set ASKAP going, while CSIRO Chief Executive Megan Clark looks on. Credit: Dragonfly Media

which will be focused mainly on furthering our knowledge of the formation and evolution of galaxies, magnetic fields in galaxies, the interstellar medium, and transient radio phenomena. These projects involve more than 360 researchers from around the world.

The site at which ASKAP is located, the Murchison Radio-astronomy Observatory (MRO), has outstandingly low levels of radio-frequency interference.

As well as ASKAP, it hosts a low-frequency radio telescope, the Murchison Widefield Array. And from 2016 it will also become home to part of the giant international Square Kilometre Array radio telescope, which is to be jointly hosted by Australia and southern Africa.

Sixty SKA dishes using the new CSIRO phased-array feed will be added to ASKAP's existing 36. Thousands of dipole antennas will also be deployed on the site, forming the low-frequency component (70 – 200 MHz) of the SKA. The cost of building the €1.5 billion SKA will be shared by SKA partner countries, which are drawn from Europe, Asia, Australasia, Africa and the Americas.

More information
ASKAP and SKA fact sheets

http://www.ska.gov.au/media/pubs/Pages/default.aspx

QuintessenceLabs

QuintessenceLabs, a Canberra based advanced technology company, has recently been contracted by NASA to supply its secure messaging platform. Born out of research originating from the Australian National University the company develops information security products that incorporate the laws of quantum physics in the protection of personal data, trade secrets and national security secrets. The company has assembled a unique team of world class quantum physicists, mathematicians and security engineers and it is through this relationship breakthrough techniques in strengthening information security are being achieved.

Though the company began commercial operations in only 2008 it has managed to develop a foothold and continues to grow in the markets of National Security, Banking & Insurance, Health and Critical Infrastructure. Ultimately the work with NASA will result in ultra-secure communications between earth and the International Space Station.

For more information about QuintessenceLabs you can visit www.quintessencelabs.com

Branch News
New South Wales

The 2012 Dirac Lecutre "The Expanding Universe", held on 19 July at the University of New South Wales, was a great success. Over three hundred people attended the lecture delivered bv Professor Brian Schmidt, 2011 Nobel Prize Winner, Laureate Fellow at the Australian National University Mount Stromlo Observatory.

L to R Fred Osman, Scott Martin, Brian Schmidt and Graeme Melville

This year the Einstein Lecture was held at the Powerhouse Museum on Tuesday 21 August 2012 and featured Dr Michael Biercuk, an experimental physicist in the Centre for Engineered Quantum Systems at the University of Sydney, on the topic of "It's a small, small world"!

Western Australia

The annual postgraduate conference for 2012 was held on 27 September Wednesday at the Holiday Haven, a rural conference venue, just an hour out of Perth in the foothills of the Darling Range. The conference was attended by nearly 30 students and only two supervisors. The conference was held over two days and a total of twenty papers presented. The topics ranged from medical imaging through geophysics and the imaging and modelling of stress fractures in rocks to detection of gravity waves and topics of fundamental physics. In a close count the best presented paper was awarded to Rahi Varsani who presented her work on the clumping of magnetic nanoparticles in the body.

Conferences in Australia 2012-13

2 – 5 Dec 2012
Australian & New Zealand Association of Mathematical Physics (ANZAMP) Inaugural Meeting
Lorne, Vic

2 - 6 Dec 2012
Engineering & Physical Sciences in Medicine conference (EPSM 2012)
Gold Coast, QLD

6 Dec 2012
Bragg Symposium – Celebrating 100 years of Crystallography
University of Adelaide, SA

6 – 9 Dec 2012
Micro- Mini- and Nano- Dosimetry & International Prostate Cancer Treatment Workshop
University of Wollongong, NSW

9 - 13 Dec 2012
20th Australian Institute of Physics Congress
University of NSW, Sydney, NSW

15 February 2013
2013 Physics Teachers' Conference, VCE Science Conference Series (Science Teachers' Association of Victoria)
Monash University, Vic

6 - 9 May 2013
17th International Conference on the Use of Computers in Radiation Therapy
Melbourne Convention & Exhibition Centre, Vic

100 Years of Cosmic Rays – An Australian Perspective: Part 1

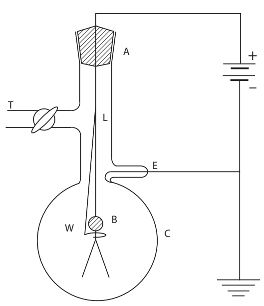
Marc Duldig and John Humble

The year 2012 is the centenary of Viktor Hess's discovery of cosmic radiation. In this first part we present a review of the history of the observations that led to the discovery of cosmic rays, together with the subsequent development of the research field through to the mid 1940s.

Introduction

Every account of the history of science written by practicing scientists is biased toward the authors' experience. This is clearly evident in several articles that have appeared recently recognising the centenary of the discovery of cosmic rays (Carlson 2012 [1], Israel 2012 [2], Watson 2012 [3]). We therefore make no apology for this article placing some emphasis on the Australian contribution to the field over the last 100 years.

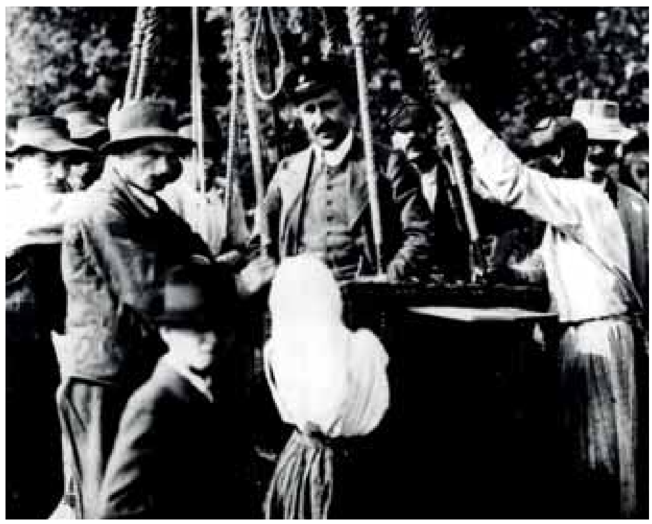
The first record that could be associated with cosmic rays was reported in Paris in 1785 by Charles-Augustin de Coulomb when he noted that electrically charged objects lost their charge even when well isolated from a discharge path. He concluded that the discharge must be through the air though the mechanism remained a mystery for more than a century. In the late 1800s when various forms of penetrating radiation were discovered it became clear that air could be ionised and allow an electroscope to discharge. However, even heavily shielded electroscopes discharged when all known forms of radiation would not have penetrated the shielding. It was becoming clear that an extremely penetrating ionising radiation from above the earth's surface might be responsible.



A schematic figure of the gold leaf electroscope used by Wilson in 1900 (from Fenton, A.G., *Geiger Muller Counters before and After 1946*, ANARE Research Notes, 102, 61-80 in [4])

Cosmic Rays – The First Observations

With improved instrumentation, Viktor Hess made a series of measurements from hydrogen-filled balloon flights between 1911 and 1913. On 7th August 1912 his balloon reached an altitude of 5350 metres and, after an initial fall in the ionisation over the first ~1000 metres, there was a progressive rise in the ionisation recorded by two of the ionisation chambers in the gondola (the third chamber being set up to only record beta radiation). Hess reported his results at a meeting in Münster and shortly afterwards published his results [5]. He had clearly demonstrated that the source of the radiation had to be celestial and in later flights proved that the radiation was independent of day or night and weather conditions. In 1936 Hess shared the Nobel Prize in Physics for his discovery.



Viktor Hess in his hydrogen balloon gondola around the time of his 7 August 1912 flight (image credit: American Physical Society)

Instrument improvements continued, allowing Werner Kolhörster to confirm Hess's results and extend them with flights in 1913 and 1914 to altitudes of 9300 metres. He showed that the ionisation continued to rise to at least that height and that the radiation was indeed extremely penetrating, with an absorption length an order of magnitude higher than that for the most penetrating known form of radiation, γ-rays. This work and all further study of cosmic rays ceased with the outbreak of the Great War.

"The first record that could be associated with cosmic rays was reported in Paris in 1785 by Charles-Augustin de Coulomb"

After the war, research into the mysterious radiation continued. Millikan and his associates strongly believed that the radiation was γ-rays but of much higher energy than found in radioactive materials. After initially believing the source to be terrestrial and within the atmosphere, Millikan ran a series of balloon experiments and measurements at different depths in lakes at differing altitudes and showed that the source could not be from the atmosphere over the range of altitudes he had covered. Furthermore he demonstrated that there had to be more than one component to the radiation as different experiments gave different absorption lengths. He was also the first to name the radiation 'cosmic radiation of extraordinary penetrating power' in his paper that was submitted for publication on Christmas Eve 1925 (Millikan and Bowen [6]). By this time Millikan and most other researchers had been convinced that the radiation was not of terrestrial origin.

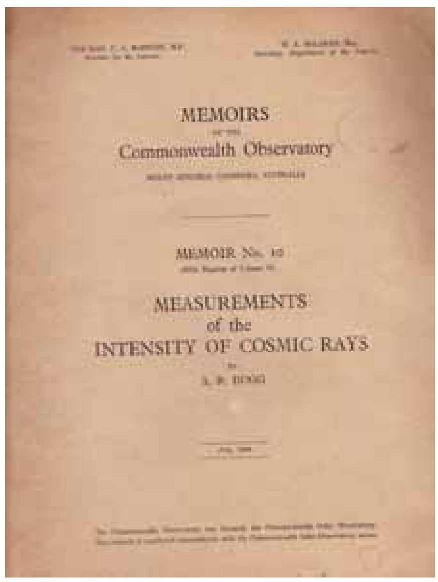
While Millikan was making these measurements an early, almost certainly the first, Australian cosmic ray experiment was in progress. Prof A.L. McAulay, who was Professor of Physics at the University of Tasmania, together with Miss N.L. Hutchinson measured the radiation using a cast iron spherical ionisation chamber (McAulay and Hutchinson [7]). Their results were comparable to those of other locations and they noted a small diurnal variation with other larger erratic changes superimposed. Such a variation had been reported earlier (Downey [8]). The time of maximum had not yet been confirmed, and McAulay and Hutchinson speculated that it might be related to the diurnal variation in the atmospheric potential gradient. Sadly, the Tasmanian experiment was discontinued as recording the readings was very labour intensive.

"Millikan … was also the first to name the radiation 'cosmic radiation of extraordinary penetrating power'"

In the late 1920s and early 1930s the nature of the radiation was generally believed to be γ-rays but measurements at different locations showed that the variation varied depending on position relative to the earth's magnetic field. This latitude effect was first discovered by Jacob Clay in 1927 [9] when he took measurements in Holland and Java. He subsequently took an ionisation chamber on three sea voyages from Europe to Java via the Suez Canal between 1928 and 1932, finding consistently lower intensities near the equator [10]. As already noted, several significant figures including Millikan disputed the results but Arthur Compton, Millikan's former student, accepted the findings and arranged for global measurements to be made with standard ionisation chambers and standardised Radium calibration sources and conclusively demonstrated the effect [11]. Several further latitude surveys were conducted by aircraft and sea further confirming the result. The latitude effect was thus accepted and as γ-rays would not vary in such a way it was clear that the radiation was predominantly made up of charged particles.

In Australia, A.R. Hogg of the Mount Stromlo Observatory commenced observations of cosmic rays in September 1935 using a cylindrical ionisation chamber. The observations ceased in August 1940 when wartime conditions precluded continuation. The results were not published until after the war [12]. The observations proved a valuable comparison to the observations Scott Forbush carried out in North America as well as providing early analyses of the diurnal variations in solar and sidereal time and the 27 day periodicity related to solar rotation.

Geiger and Müller [13] developed the Geiger-Müller counter, more commonly known today as the Geiger counter. This counter revolutionised charged radiation detection as it allowed large collection areas to be employed through the use of arrays of the detectors. Bothe and Kolhörster [14] invented the coincidence circuit, often misattributed to Rossi, but which Rossi [15] refined. In combination with the development of the electronic counting circuit it was then possible to construct trays of detectors and determine the arrival direction of the particles for the first time. Thus the cosmic ray telescope had been born.


MEMOIRS

Commonwealth Observatory

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MEASUREMENTS
of the
INTENSITY OF COSMIC RAYS

The cover of the 1949 publication of the data collected by Hogg over a decade earlier but halted due to the war.

The Particle Physics Era

Wilson had invented the cloud chamber in 1911 and over the next 20 years it was greatly improved. It was possible to synchronise a photograph to the gas expansion and so record the ionising tracks. Carl Anderson added a strong magnetic field to the system allowing the particle charge and momentum to be measured. In 1932 he discovered the positron but continued to improve his equipment to make the results more convincing before publishing his findings [16]. He shared the 1936 Nobel Prize for Physics for his discovery of antimatter with Hess for the discovery of cosmic rays. Blackett and Occhialini [17] further improved the experimental setup by adding Geiger-Müller counters around the system to act as a trigger for selected events instead of the random expansions used by Anderson. They quickly confirmed Anderson's results.

Within a few years Anderson and Neddermeyer [18] had discovered the muon, initially believing it to be the strong force mediating particle that Yukawa had postulated. However the lifetime of ~2 μsec was much too long for it to be this particle and the pion was not observed until 1947 when Powell and his co-workers (Lattes et al. [19]) employed emulsion stacks at high altitude to observe the shower particles induced by cosmic ray interactions. Powell received the 1950 Nobel Prize for Physics for his development of the nuclear emulsion techniques and the discovery of the pion. Many more particles were discovered in cosmic ray measurements in subsequent years.

The East-West Effect

With the advent of Geiger-Müller counter telescopes many researchers studied the arrival directions of cosmic rays at ground level and an east-west asymmetry was observed (excess from the west) that was of the order of 15% for the total flux at 45° zenith angle and closer to 30% when the soft component was shielded from the experiment. This difference could only be explained if the particles were predominantly positively charged. This had been predicted by Georges Lemaître and Manuel Vallarta [20] and independently by Bruno Rossi, though the latter was not credited in the initial observation paper by Alvarez and Compton [21] using observations they made from Mexico City only a few months earlier than Rossi's own measurements made from mountain altitudes in Africa. It was not until 1941 that Marcel Schein undertook an unmanned balloon experiment which demonstrated that protons were the major component of cosmic rays [22].

At high magnetic latitudes, where the latitude effect ceases, no east-west effect was expected. However Thomas Johnson from the Bartol research Foundation of the Franklin Institute had explained its existence as being due to the deflection of muons in the geomagnetic field as they traversed the atmosphere [23]. The difference in the path length for positive and negative muons and the excess of positive muons resulted in different energy losses for muons arriving at different zenith angles. Seidl [24] measured this at New York (54° N geomagnetic latitude) to be less than 1%.

"It was not until 1941 that Marcel Schein … demonstrated that protons were the major component of cosmic rays."

In 1945, after the war efforts of the Physics Department, A. G. (Geoff) Fenton was initiating cosmic ray studies at the University of Tasmania. He felt that a similar experiment to that of Seidl would be an achievable start for his research group. He and D. W. P. (Peter) Burbury (who received the second PhD awarded by the university) carried out this experiment, obtaining a significant result which appeared in Physical Review [25]. This was the first publication of the research group that was to continue for in excess of another half century.

Extensive Air Showers

Very high energy cosmic rays initiate an atmospheric cascade of gamma rays and electron-positron pairs that spread out as the shower progresses through the atmosphere. Rossi [26] was the first to observe this phenomenon but it was Pierre Auger and his co-workers that systematically studied the showers using Geiger-Müller tubes in coincidence separated by up to 300 metres [27]. Auger showed that the energy of the initiating cosmic ray must be at least 10^{15} eV based on the number of particles he observed in a large shower and the average energy of these particles. In fact this lower limit was a considerable underestimate as Auger had no way of determining the energy losses of the cascade as it progressed through the atmosphere. This was an extraordinarily large energy which was of great interest as there was no known way for particles to attain such energies.

In part 2 we will discuss the post-war development of cosmic ray research in Australia and globally.

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Marc Duldig joined the Australian Antarctic Division's (AAD) Cosmic Ray research group in 1980 becoming Head of the group in 1984. He led the group until his retirement in June 2011. He was Senior Principal Research Scientist and Program Leader of Space and Atmospheric Sciences at the AAD prior to his retirement. He is now an Honorary Research Associate in the School of Mathematics and Physics at the University of Tasmania. He has held numerous national and international committee and editorial positions and is, of course, the current President of the AIP.

John Humble has been a member of the cosmic ray group at the University of Tasmania since 1959. He wintered at Mawson in 1960 as the cosmic ray physicist, returning to Hobart to undertake a PhD. He subsequently became a lecturer in the Physics Department, rising to become Head of Department in 1991 and remaining in that role until retirement in 2000. He is currently an Honorary Research Associate in the School of Mathematics and Physics at the University of Tasmania, has been a member of the AIP's National Executive for the past five years and at present is the AIP's Honorary Registrar.

The path to the low frequency Square Kilometre Array in Australia

Steven Tingay and Peter Hall

International Centre for Radio Astronomy Research, Curtin University

The Square Kilometre Array (SKA) is a planned next-generation radio telescope to be constructed at two locations, in Western Australia and Southern Africa, utilising a range of antenna technologies to cover the radio frequency range required to satisfy its science goals. The SKA pushes the boundaries of physics and engineering on a number of fronts simultaneously and is thus a very ambitious project with innovation at its heart. In this article we consider the component of the SKA to be built in Western Australia in full scope, a survey telescope designed for very early Universe cosmology, operating at low radio frequencies. The path to the low frequency SKA in Australia involves precursor instrumentation, SKA pre-construction activities, and the deployment of the final instrument in two phases over approximately the next decade.

Science goals for the low frequency SKA

A significant component of the SKA (Hall et al. [1]) will operate at frequencies in the range 70 – 450 MHz, this portion of the telescope being referred to as SKA-low. The frequency range is driven by science goals that seek to use redshifted radiation from neutral hydrogen as a probe of conditions in the early and evolving Universe (Morales & Wyithe [2], Furlanetto, Oh & Briggs [3], Carilli et al. [4]).

The SKA-low focus on early Universe cosmology (summarised in Figure 1) will largely be via the study of the so-called dark ages of the Universe, the period after the Big Bang when the first stars and galaxies formed. The highly successful Wilkinson Microwave Anisotropy Probe (WMAP: http://map.gsfc.nasa.gov/) has extensively investigated the cosmic microwave background (CMB), the radiation leftover from the Big Bang. The CMB radiation originated from the time in the early Universe (approximately 300,000 years after the Big Bang) when baryonic matter and radiation decoupled, known as the Epoch of Recombination. Prior to the Epoch of Recombination, the Universe was fully ionised.

Once baryonic matter and radiation decoupled at the Epoch of Recombination, photons were free to propagate through the Universe and the baryonic matter (overwhelmingly hydrogen) was able to coalesce under the influence of gravity to form the first luminous structures, stars and galaxies. Over time, as these stars and galaxies produced ionising radiation, the remaining baryonic material that was not formed into stars and galaxies was progressively ionised. The transition from a Universe in which the baryonic material was neutral, to a Universe in which the baryonic material was largely ionised, is known as the Epoch of Reionisation (EoR) and is thought to have occurred within the first billion years after the Big Bang (the Universe is almost 14 billion years old). The most promising observational probe of the EoR is the radio wavelength signature from neutral hydrogen gas that was the fuel for the formation of the first stars and galaxies, the emission being heavily redshifted to low radio frequencies for an observer on the Earth.

"The transition from a Universe in which the baryonic material was neutral, to a Universe in which the baryonic material was largely ionised, is known as the Epoch of Reionisation"

It is rather straightforward to make the statement that the EoR was a major phase in the evolution of the Universe, given evidence for the Big Bang and given the fully ionised state of the Intergalactic Medium in the Universe today. However, the details of the physics of the transition are likely to be complex and models for the EoR are currently a point of major debate. An enormous amount of interest in the EoR, both theoretical and experimental, exists within the physics and astrophysics community. As well as being a substantial part of the SKA science case, the search for the EoR signal features heavily in the motivations behind a new generation of low frequency radio telescopes: The Low Frequency Array, LOFAR (van Harlem et al. 2012, in preparation); the Murchison Widefield Array, MWA (Tingay et al. [5]); the Long Wavelength Array,

LWA (Greenhill & Bernardi [6]) and the Precision Array to Probe the EoR, PAPER (Parsons et al. [7]). In the period 1997 – 2012, 240 papers with the phrase "Epoch of Reionisation" in the title have been published, garnering 4681 citations. Many of these papers are theoretical predictions of what the EoR signal will look like, with the first significant observational constraints at radio wavelengths being generated only very recently (e.g. Paciga et al. [8]).

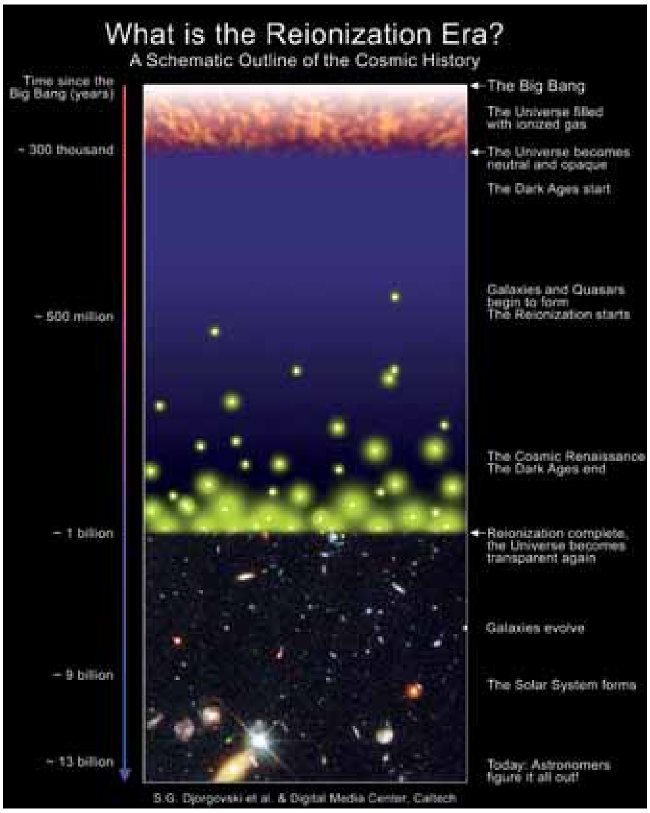

Figure 1: a schematic summary of the evolution of the early Universe (Credit: S.G. Djorgovski et al., Caltech).

This high level of interest is prompted by the fundamental physics that influences the evolution of the Universe at early times, including the role of enigmatic dark matter. Dark matter has been known to exist from the 1930s via astronomical observations but it is only recently that some understanding of its properties has started to emerge. As a significant component of matter in the early Universe, dark matter is likely to have had an influence on how the first stars and galaxies formed from neutral hydrogen during the EoR, as modeled recently by, for example, Visbal et al. [9].

The low frequency SKA concept

With its probing of fundamental physics, the low frequency component of the SKA is complementary to other large-scale physics experiments such as the Compact Muon Solenoid detector at the Large Hadron Collider and is of great interest to physicists and cosmologists. But how will SKA-low be implemented?

"Advances in technology mean that direct interface of SKA-low radio receivers to programmable digital signal processing engines, and general-purpose computers, is now feasible"

The low radio frequencies demanded by EoR investigations allow a departure from the dominant form of radio astronomy antenna technology used over the last 40 years, these earlier instruments being based on large steerable dishes and arrays of small dishes. Advances in technology mean that direct interface of SKA-low radio receivers to programmable digital signal processing engines, and general-purpose computers, is now feasible. This marriage of technologies gives a software-defined telescope of unprecedented capability and flexibility. In particular, the all-important forming of beams on the sky takes place in digital electronics rather than in parabolic dishes, allowing the use of simple, stationary antennas having a large natural field-of-view. One potential antenna type is shown in Figure 2 but a number of other types, some resembling the TV antennas which also operate in this frequency band, are being evaluated. With all the beamforming done electronically, there is no reason why many such operations cannot be done in parallel, allowing astronomers to "re-use" the telescope collecting area. Many beams, pointed at different areas of the sky, can be used to support simultaneous, independent science programs.

The simple nature of the SKA-low antennas means they are well suited to mass manufacture techniques and can be produced at low unit cost. Large arrays of these antennas can therefore be produced at modest cost, with the main functionality of the resulting telescope being defined by increasingly cost-effective ICT systems, allowing an evolution of SKA-low capability. Of course, supporting infrastructure, deployment and operations costs remain major engineering challenges.

The full SKA project is envisaged to proceed in a staged fashion, with two phases of construction. Phase 1

is intended to build 10% of the full SKA, with construction commencing in 2016. After Phase 1 is complete, Phase 2 will construct the remaining 90% of the SKA. SKA-low construction will be part of these phases, with Phase 1 SKA-low consisting of several hundred thousand low frequency antennas and Phase 2 consisting of several million.

About half the SKA-low antennas will be located in the central 10 km region, with the remainder being distributed in clumps, or stations, located out to perhaps 1000 km. Custom fibre networks for the core region and remote, radio-quiet power solutions are particularly challenging aspects for a project likely to be cost-capped at less than 300 million euro. Curtin University has been a driver of the sparse aperture array developments central to SKA-low and is leading the Murchison Widefield Array (MWA) project, described below. In a significant direct contribution by MWA, International Centre for Radio Astronomy Research (ICRAR)/Curtin and international colleagues are using MWA infrastructure in their deployment of the first SKA-low test antennas in WA in late 2012. The next few years will see a succession of increasingly capable verification systems in the Murchison, culminating in a 10,000 element array prior to the start of actual SKA-low Phase 1 construction.

Selecting the site for the low frequency SKA and the pre-construction phase

SKA-low is an ambitious undertaking in terms of the complexity and scale of the system. Furthermore, the telescope requires an extraordinary host site. At low radio frequencies, the electromagnetic spectrum is heavily polluted by human activities. In particular, FM radio between 87.5 and 108.0 MHz lies right in the region of interest for EoR signal detection. Some recent theoretical work places the region 50 – 100 MHz as a very important frequency range for the EoR (Visbal et al. [9]). Thus, a location that is remote from FM radio stations and other forms of low frequency transmitters is a strong requirement for the SKA-low site.

Four locations were originally in the running as potential sites for the SKA and, in 2006, a down-selection produced two candidates: Australia–New Zealand (centred on the Murchison region of Western Australia) and Southern Africa (centred on the Karoo region of the Northern Cape of South Africa). After six years of in-depth investigation and preparatory work by the international SKA community, on the 25th of May, 2012, the outcomes of the final site selection process were announced. The Board of the SKA Organisation, made up of the nations with a financial stake in the SKA Organisation, decided that the SKA would be split between the two candidate sites.

The full text of the SKA site decision announcement can be found at http://www.skatelescope.org/the-location/ and the full set of documentation used in the site selection process has been made public at http://www.skatelescope.org/the-location/site-documentation/

Briefly, in Phase 1, 190 dish antennas will be built in South Africa (extending the 64 dish South African MeerKat SKA precursor), 60 dish antennas will be built in Western Australia (extending CSIRO's 36 dish Australian SKA Pathfinder) and 50 SKA-low stations (a station consists of a clump of the simple antennas described above)

Figure 2: possible SKA-low antennas, featured as part of the SKA reference design (Credit: SPDO/Swinburne Astronomy Productions)

would be built in Western Australia.

In Phase 2, a further 3000 dishes will be built in South Africa, along with 250 stations of mid-frequency aperture arrays. In Western Australia, a further 250 stations of SKA-low antennas will be built.

Thus, the Western Australian site has been endorsed to host the entire SKA-low, in recognition of the superb conditions for low frequency radio astronomy that are a consequence of its remote location.

The long-awaited site decision is behind us and the SKA project now enters the pre-construction phase. With SKA technologies mapped to sites, this final stage of the design process will focus on producing tender-ready specifications for construction. Pre-construction will take place between 2012 and 2016, with significant involvement of Australian research institutions and companies in many of the design and prototyping activities.

The Murchison Widefield Array (MWA), the SKA low frequency precursor

A major portion of the international SKA program in the lead-up to the site decision and the pre-construction phase has focussed on several SKA precursor projects. An SKA precursor is defined as a science and technology pathfinder telescope located on one of the two SKA sites. The precursors are used to test various technologies and techniques, and to provide early insights in SKA key science programs.

Three precursor telescopes are under development. Two dish-based instruments are being built, CSIRO's Australian SKA Pathfinder (ASKAP: Johnston et al. [10]) and the South African MeerKAT array (http://public.ska.ac.za/meerkat). Both of these precursors will operate at frequencies higher than 450 MHz.

A single low frequency SKA precursor is under development, the Murchison Widefield Array (MWA: Tingay et al. [5]). The MWA is funded by 13 institutions in four countries (Australia, the USA, India, and New Zealand) and is in the final stages of construction and commissioning at CSIRO's Murchison Radio-astronomy Observatory (MRO), alongside ASKAP. Curtin University leads the MWA consortium.

As outlined earlier, low frequency radio telescopes can make use of inexpensive antennas and this is the case for the MWA, with 2048 individual dual-polarisation dipole antennas operating between 80 and 300 MHz, and grouped into 128 "tiles" (each equivalent to a mini SKA station). These 128 tiles (see front cover image) are distributed over an area 3 km in diameter, giving an angular resolution of a few arcminutes over an extremely large field of view, thousands of square degrees in extent. The full technical description of the MWA is given in Tingay et al. [5].

"The MWA is fulfilling its obligation as an SKA precursor, exploring novel solutions for antennas, signal processing, imaging and calibration that will be highly relevant during the SKA pre-construction phase."

While the MWA antennas are simple, complexity in the system is pushed into the electronics and, in particular, the back-end signal processing. The antennas send the received analogue signals to receiver packages built by Small to Medium Enterprise industry partner, Poseidon Scientific Instruments in Fremantle, WA. From the receivers, digital data streams enter a correlator and real-time imaging and calibration system based on Field Programmable Gate Arrays and an IBM iDataPlex Graphical Processor Unit compute cluster. All of the complex signal processing and imaging calculations are implemented on this essentially commodity platform running custom algorithms. Finally, processed data are transmitted over a 800 km high speed network that terminates at the new $80m iVEC Pawsey Supercomputing Centre in Perth, where a 15 PB archive will be the portal through which scientists access MWA data.

The MWA is fulfilling its obligation as an SKA precursor, exploring novel solutions for antennas, signal processing, imaging and calibration that will be highly relevant during the SKA pre-construction phase. In addition, the MWA will be the first of the SKA precursors to be completed (in late 2012) and will be the first to deal with the massive data challenge. A team at ICRAR (a joint venture between Curtin University and The University of Western Australia), is implementing the 15 PB archive and MWA data interface for users, one of the first steps toward dealing with the much bigger challenge posed by the SKA itself.

And a significant factor is the fact that the MWA has been implemented at the site chosen for SKA-low, ensuring that we are learning the right lessons in exactly the environment in which SKA-low will be built. The background knowledge gained will be very valuable for the international team being constituted for SKA-low pre-construction. The experience will extend even to the use

of the data path to the Pawsey Centre and the use of the computing environment at Pawsey that will eventually be used to support the SKA.

The MWA will not simply be a technology demonstrator for SKA-low, but intends to make significant advances in areas of science that will inform the SKA-low science case and design parameters. The search for the first hint of the EoR signal is a significant part of the MWA science case, as are surveys of our own Galaxy and other galaxies, searches for transient and variable phenomena at radio wavelengths, and detailed investigations of the Sun, and the Sun – Earth connection. Many of these areas of scientific investigation with the MWA mirror areas of SKA science. A full description of the MWA science case will appear in Bowman et al. (2012, PASA submitted).

An example of some early MWA science is shown in Figure 3, an image of the plane of our own Galaxy produced by Hurley-Walker et al. (2012, in preparation). Made with a 32 tile MWA prototype that has since been de-commissioned to accommodate construction of the final 128 tile array, Figure 3 shows a great range of detail associated with supernova remnants in the disk of the Galaxy and complicated structures that extend well away from the plane, emitting non-thermal synchrotron emission. While beautiful, and rich in the physics that drives our own Galaxy, this emission masks the EoR signals that the MWA also seeks, the EoR emission being factors of ~10^4–10^5 weaker than the levels shown in Figure 3.

Detection of the EoR is an extraordinarily demanding experiment that will reach its full power with SKA-low. However, the MWA precursor (and other instruments such as LOFAR and PAPER) will make the first important steps on this path, blazing a trail to early Universe cosmology and giving an insight into fundamental physics. These steps will start to be taken in the first half of 2013, when the MWA becomes fully operational for science.

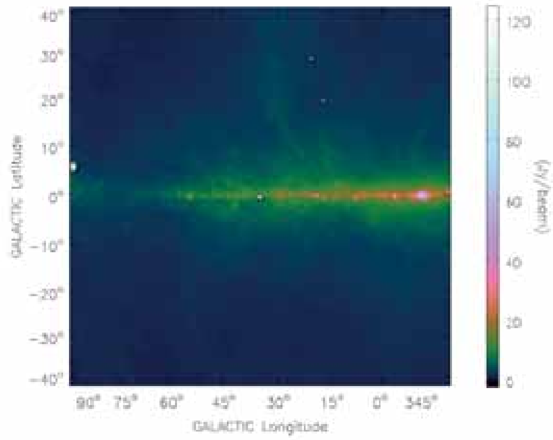

Figure 3: an early MWA image of our Galaxy, showing a range of structures (image credit: Dr Natasha Hurley-Walker).

Acknowledgements

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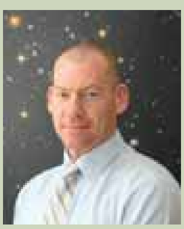


Steven Tingay is Professor of Radio Astronomy at Curtin University and a Western Australian Premier's Research Fellow. He is Director of the Murchison Widefield Array (MWA), co-Director of the Curtin Institute of Radio Astronomy (CIRA) and Deputy Director (Murchison Radio-astronomy Observatory) at the International Centre for Radio Astronomy Research. Tingay's research interests include a range of galactic and extragalactic astrophysics and instrumentation ranging from low frequency telescopes to VLBI. Before starting the Curtin radio astronomy group in 2007, he held positions at Swinburne University of Technology, CSIRO and NASA. Tingay is a Fellow the Australian Institute of Physics and the Astronomical Society of Australia.

Peter Hall is Professor of Radio Astronomy Engineering at Curtin University. He is a Fellow of the Institution of Engineers (Aust) and, until his appointment at Curtin in 2008, was foundation International Project Engineer for the SKA. He led CSIRO's SKA program from 1999-2003, and is now Co-Director of the Curtin Institute of Radio Astronomy (CIRA) and Deputy Director (Engineering) of the International Centre for Radio Astronomy Research (ICRAR). Peter has been responsible for many policy and technical decisions in the SKA project, both nationally and internationally. His current professional interests include the design of SKA-low and instrumentation for time domain astronomy.

Quasicrystals and topological insulators

Quasicrystals, solids that are ordered, have rotational symmetry but do not contain structures that repeat periodically, were discovered by Dan Shechtman in 1984, for which he was awarded the 2011 Nobel Prize in Chemistry. Synthetic quasicrystals have been produced but such structures have been thought not to occur in nature. Recently however, writing in Reports on Progress in Physics [75, 092601 (2012)], Paul Steinhardt and Luca Bindi have confirmed the existence of an icosohedral quasicrystalline material in a carbonaceous-chondrite meteorite found in the Koryak mountains in far-eastern Siberia. Not only did this rock contain a naturally occurring quasicrystal, it also came from outer space.

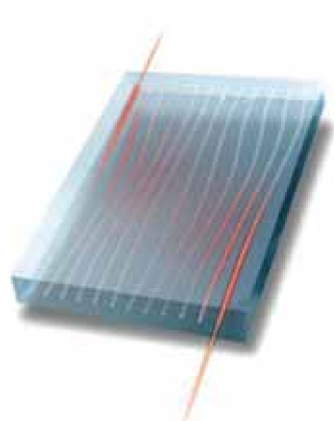
Topological insulators, on the other hand, are currently one of the hottest topics in condensed-matter physics. Insulators on the inside, they manage to conduct electricity on their surface thanks to special surface electronic states that are "topologically protected", which means that, unlike ordinary surface states, they cannot be destroyed by impurities or imperfections. These insulators have an unusual history because, unlike almost every other exotic phase of matter, they were predicted theoretically in 2D and 3D materials in 2005 and 2007, before being experimentally discovered in 2007. Recently, three condensed-matter physicists who have advanced our understanding of this strange type of material, have won this year's Dirac medal from the International Centre for Theoretical Physics in Trieste, Italy. They are Duncan Haldane of Princeton University, Charles Kane of the University of Pennsylvania and Shoucheng Zhang of Stanford University, all in the US.

Now, a surprising connection between quasicrystals and topological insulators has been discovered mathematically and demonstrated in the lab by Yaacov Kraus, Oded Zilberberg and colleagues at Israel's Weizmann Institute of Science. The team has studied how light propagates through a 1D quasicrystal and found that it is similar to the way electrons conduct in a 2D topological insulator. The surprising result suggests that quasicrystals could be used to create systems with dimensionality higher than 3D – something that could be useful both in studying fundamental physics and creating materials with new and useful properties.

The team performed experiments using 2D arrays of parallel optical waveguides. The separation between the waveguides is set so that some of the light propagating down one waveguide can leak into an adjacent waveguide, then into the next and so forth. If the movement of the light in the direction perpendicular to the waveguides is considered, it is similar to an electron moving through a 1D lattice with lattice spacing equal to the distance between the waveguides. The fact that the light "hops" from one waveguide to the next makes the system analogous to a model of electron conduction.

If the waveguide spacing is non-periodic, conduction in a 1D quasicrystal is simulated. When a pulse of light is fired into a waveguide in the centre of the quasicrystal it spreads out to adjacent waveguides as it propagates through. However, when a pulse is fired at the waveguide at the left edge of the quasicrystal all the light remains in that channel, which the team say is a "clear signature of the existence of a localized boundary state". A second "quasicrystal" structure produced a different effect: when a light pulse is introduced to a waveguide at the edge of the device the light migrates across the device with all of it ending up in the waveguide at the opposite edge (see figure). So once again, a 1D quasicrystal seems to behave in the same way as a system with 2D topology.

The research is published in *Physical Review Letters* [109, 106402 (2012)] and is discussed in a *Physics* Viewpoint article [*Physics* 5, 99 (2012)].



Waveguides that are used to create a 1D quasicrystal. Light enters at the right side of the structure and adiabatic pumping shifts it across to the left side.

ENCODE – taking knowledge of the human genome to the next level

2001 will always be remembered as the year of the human genome. The availability of its sequence transformed biology. It was an incredible achievement but it was always clear that knowing the 'code' was only the beginning. To understand how cells interpret the information locked within the genome much more needed to be learnt. This became the task of the major international collaborative project ENCODE, the Encyclopedia Of DNA Elements, the aim of which was to describe all functional elements

encoded in the human genome. Nine years after launch, its main efforts culminate in the publication of 30 coordinated papers, 6 of which are in the September 6 issue of Nature [vol 489, issue 7414 (2012)].

The ENCODE project provides information on the human genome far beyond that contained within the DNA sequence — it describes the functional genomic elements that orchestrate the development and function of a human. One of the more remarkable findings is that 80% of the genome contains elements linked to biochemical functions, dispatching the widely held view that the human genome is mostly 'junk DNA'. The authors report that the space between genes is filled with enhancers (regulatory DNA elements), promoters (the sites at which DNA's transcription into RNA is initiated) and numerous previously overlooked regions that encode RNA transcripts that are not translated into proteins but might have regulatory roles. Of note, these results show that many DNA variants previously correlated with certain diseases lie within or very near non-coding functional DNA elements, providing new leads for linking genetic variation and disease.

Major future challenges for ENCODE (and similarly ambitious projects) will be to capture the dynamic aspects of gene regulation; to identify how the genomic ingredients are combined to assemble the gene networks and biochemical pathways that carry out complex functions, such as cell-to-cell communication, which enable organs and tissues to develop; and ultimately to use the rapidly growing body of data from genome-sequencing projects to understand the range of human phenotypes (traits), from normal developmental processes, such as ageing, to disorders such as Alzheimer's disease.

While the ENCODE project has provided enormous amounts of new information and insights into the extremely complex functions of the human genome, there appears to be a general consensus that we are still far from the ultimate goal of understanding the function of the genome in every cell of every person, and across time within the same person.

Star seen whizzing around supermassive black hole

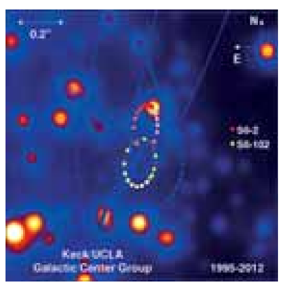
Astronomers using the Keck telescope have found a new star orbiting very near to the supermassive black hole believed to be at the centre of the Milky Way. This is only the second star that researchers have observed completing an entire orbit: its discovery will enable future observations of both orbiting stars to provide a unique test of general relativity.

The Keck telescope atop Mauna Kea in Hawaii has been used since the mid-1990s to systematically probe the area surrounding the centre of the Milky Way. In doing so, astronomers revealed several stars that appear to be orbiting a central object dubbed Sgr A* ("Sagittarius A Star"). From measurements of the stars' orbital characteristics, it was calculated that Sgr A* must weigh in at around four million times the mass of the Sun. The only known astrophysical object that fits all the observations is a black hole.

However, only the orbit of one star, S0-2, had data covering its entire 16.5 year journey around the centre. Data on the rest of the stars cover less than 40% of their orbits – the remainder has been projected using modelling. In order to characterize an orbit, astronomers believe that 50% of a star's orbit needs to be observed. With only S0-2 breaking this threshold, some sceptics have questioned whether a central black hole exists at all.

Now, improvements in adaptive optics have enabled the discovery of a new star named S0-102, with an orbital period of just 11.5 years – the shortest of any star known to orbit the black hole. Future more precise measurements of the orbits of both stars, in particular at their points of periapsis where they are closest to the black hole, and of the precession of these points, will allow unique tests of general relativity in such a strong gravitational environment. The orbits of two stars must be observed because of the likely presence of other dark mass orbiting the black hole – stellar remnants such as stellar-mass black holes and neutron stars. This means that the orbiting stars do not see a symmetrical distribution of mass as they pass through this crowded region of space, requiring the detection of the periapse shift in two stars to resolve the general relativistic component. Detailed orbit measurements will also enable refinement of the black hole mass.

The work, led by scientists from UCLA, is published in Science [338 (6103), 84 (2012)].



This image shows the central arcsecond of our galaxy, which is believed to contain a supermassive black hole. The red and yellow ellipses show the orbits of S0-2 and S0-102, respectively. The ellipses that fade into the background correspond to other stars that are believed to orbit near to the black hole.

Giant carbon-capturing funnels discovered in Southern Ocean

A team of scientists from the British Antarctic Survey and CSIRO Australia has shed new light on the mysterious mechanism by which the Southern Ocean sequesters carbon from the atmosphere. Winds, vast whirlpools and ocean currents interact to produce localized funnels up to 1000 km across, which plunge dissolved carbon into the deep ocean and lock it away for centuries. Critically, these processes themselves – and the Southern Ocean's ability to affect global warming caused by human activities – could be sensitive to climate variability in as-yet-unknown ways.

Oceans represent an important global carbon sink, absorbing 25% of annual man-made CO_2 emissions and helping to slow the rate of climate change. The Southern Ocean in particular is known to be a significant oceanic sink, and accounts for 40% of all carbon entering the deep oceans. And yet, until now, no-one could quite work out how the carbon gets there from the surface waters.

Scrutinizing 10 years of temperature, salinity and pressure data from a fleet of 80 small robotic probes dotted around the remote Southern Ocean, the researchers discovered that surface waters are drawn down – or subducted – at a number of specific locations. This occurs due to the interplay between winds, dominant currents and circular currents known as "eddies". The team pinpointed five such zones in the Southern Ocean, including one off the southern tip of Chile and another to the south-west of New Zealand. Elsewhere, currents return carbon to the surface in a process known as "reventilation", but overall, the Southern Ocean is a net carbon sink.

The mechanisms governing atmosphere-to-ocean carbon transfer – the mechanical mixing action of wind and waves, and biological uptake by micro-organisms in the sunlit top layer of water – are already well understood. The step that determines the rate of the oceanic uptake of carbon is the physical transport of this dissolved carbon from the surface waters into the ocean interior. This study is said to identify these pathways for the first time. Understanding these subduction pathways fully is key to predicting how climate change might alter the Southern Ocean's carbon sequestering capabilities, and this is not yet known.

The research is published in *Nature Geoscience* [5, 579 (2012)].

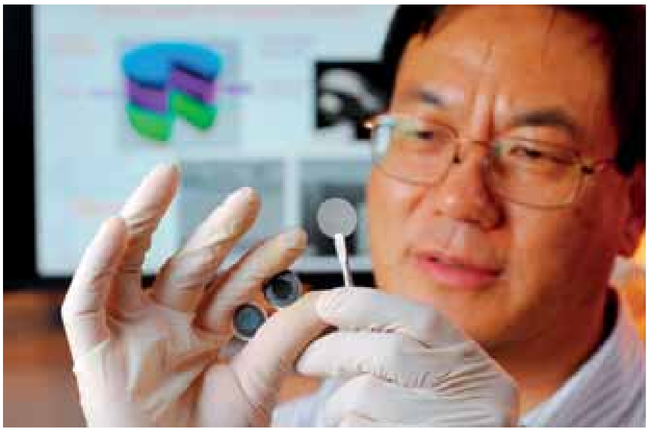
The King George Island (left), located off the coast of Antarctica in the Southern Ocean, and the Drake Passage (right), a body of water between the southern tip of South America at Cape Horn, Chile and King George Island. There are certain sites in the Southern Ocean where large amounts of carbon are subducted.

Power cell generates and stores energy in one step

Researchers in the US have created a power cell that directly converts mechanical energy to chemical energy, which can then be stored and converted to electrical energy upon demand. This new system is unlike other similar technologies that first convert mechanical energy to electrical energy, which is then stored chemically. By skipping the intermediate conversions, the team says that the system is more efficient. If the technology could be further improved, it could be used, for example, in the sole of a shoe, where it could charge a mobile-phone battery while the wearer is walking.

Several different approaches to energy harvesting are already in development, and now Zhong Lin Wang and colleagues at the Georgia Institute of Technology and the Beijing Institute of Nanoenergy and Nanosystems have created a new technology in which generation and storage occurs within a single unit. Their cell comprises a cathode made of lithium cobalt oxide and an anode of titanium-dioxide nanotubes that are grown perpendicular to a titanium surface. The electrodes are separated by poly(vinylidene fluoride) (PVDF) film, which is a piezoelectric material. When the cell is compressed, the PVDF creates a piezoelectric charge, which drives lithium ions from the cathode to the anode. This converts electrical energy to chemical energy, which is stored in lithium titanium oxide. When the compressing force is removed, the cell relaxes but the chemical energy remains stored. More energy can then be stored in successive compression cycles. This energy can then be retrieved as electrical energy by connecting an electrical load between the anode and cathode, allowing the lithium ions to flow back to the cathode, and the device is ready to be charged again.

While the technology is still in a very early stage, Wang



Zhong Lin Wang is holding the components of a new self-charging power cell that uses piezoelectric materials to directly convert mechanical energy to chemical energy.

believes that there are several ways that its performance can be boosted. For example, the researchers believe that most of the mechanical energy of compression is being dissipated in the cell's coin-like steel shell, rather than in the PVDF film. Improvements in packaging materials should therefore improve overall efficiency.

The research is published in *Nano Letters* [12 (9), 5049 (2012)].

Phonon theory sheds light on liquid thermodynamics

Physicists in the UK and Russia have revived concepts first put forth in the 1940s to develop a new theory of the heat capacity of liquids. Created by Dima Bolmatov and Kostya Trachenko of Queen Mary College, University of London and Vadim Brazhkin of the Institute for High Pressure Physics in Moscow, the new "phonon theory of liquid thermodynamics" has successfully predicted the heat capacity of 21 different liquids ranging from metals to noble and molecular liquids. The researchers say that the theory covers both the classical and quantum regimes and agrees with experiment over a wide range of temperatures and pressures.

While physicists have a good theoretical understanding of the heat capacity of both solids and gases, a general theory of the heat capacity of liquids has always remained elusive. One of the barriers to development of a general theory was that the relevant interactions in a liquid are both strong and specific to that liquid.

Using phonons to develop a theory of specific heat is nothing new in the world of solids. Indeed, Albert Einstein and Peter Debye famously developed separate theories early in the 20th century to explain the high-temperature and low-temperature heat capacity of solids, respectively. But, given that the atoms in a liquid are free to move and so can absorb or transfer heat without any need for phonons, it is not at first glance obvious why phonons should be a good way of describing how heat is transferred and absorbed in a liquid. While sound propagates very well in liquids in the form of longitudinal phonons, it is not obvious whether transverse or "shear" phonons, which exist in solids, also occur in liquids.

This problem was first tackled in the 1940s by the Russian physicist Yakov Frenkel. He pointed out that for vibrations above a certain frequency (the Frenkel frequency), molecules in a liquid behave like those in a solid – and can therefore support shear phonons. With this in mind, Bolmatov and colleagues derived an expression for the energy of a liquid in terms of its temperature and three parameters – the liquid's coefficient of expansion, and its Debye and Frenkel frequencies. The Debye frequency is the theoretical maximum frequency that atoms or molecules in the liquid can oscillate at and can be derived from the speed of sound in the liquid. The Frenkel frequency puts a lower bound on the oscillation frequency of the atoms or molecules and can be derived from the viscosity and shear modulus of the liquid.

The result is an expression for specific heat as a function of temperature that was able to describe simple liquids – such as the noble liquids, which comprise atoms – through to complicated molecular liquids such as hydrogen sulphide, methane and water. The physicists say that this broad agreement suggests that Frenkel's original proposal that the phonon states of the liquid depend upon a characteristic time applies to a wide range of materials.

The work is described in *Scientific Reports* [2, 421 (2012)].

The new phonon theory predicts the specific heat of a range of different liquids.

First flat lens focuses light without distortion

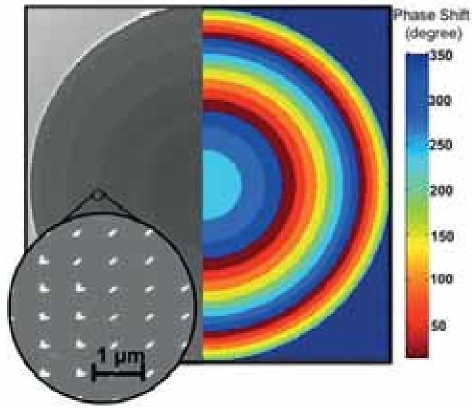
Physicists in the US, led by Federico Capasso of the Harvard School of Engineering and Applications, have made the first ultrathin flat lens. Thanks to its flatness, the device eliminates optical aberrations that occur in conventional lenses with spherical surfaces. As a result, the focusing power of the lens also approaches the ultimate physical limit set by the laws of diffraction.

In an ordinary lens, light rays travel more slowly in the thicker, central regions than in the thinner, peripheral ones. This distribution of phase delays in the lens leads to light refraction and focusing. The new flat ultrathin lens is different in that it is a nanostructured "metasurface" made of optically thin beam-shaping elements called optical antennas, which are separated by distances shorter than the wavelength of the light they are designed to focus. These antennas are wavelength-scale metallic elements that introduce a slight phase delay in a light ray that scatters off them - each antenna is simply a resonator that stores light and then releases it after a short time delay. The lens surface is patterned with antennas of different shapes and sizes that are oriented in different directions. This causes the phase delays to be radially distributed around the lens so that light rays are increasingly refracted further away from the centre, something that has the effect of focusing the incident light to a precise point. The metasurface can be tuned for specific wavelengths of light by simply changing the size, angle and spacing between the nanoantennas.

The new lens does not suffer from the image-distorting features, known as monochromatic aberrations, which are typical of lenses with spherical surfaces. Spherical aberration, coma and stigmatism are all eliminated and one gets a well-defined diffraction-limited, accurate focal spot. This is true even when light rays hit the lens away from the centre or at a large angle, so no complex corrective techniques are required.

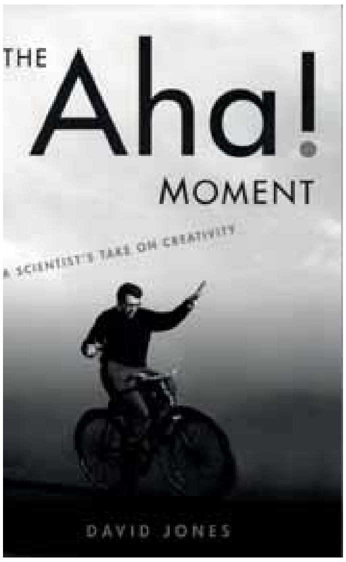
At the present proof-of-concept stage the focusing efficiency of the lens is still quite small but, according to the team, could easily be increased by increasing the packing density of the optical antenna and by using different flat-lens designs. Also, at this stage, the lens only focuses specific wavelengths of light but by arranging different antenna patterns onto the metasurface it could be made broadband.

The results are reported in *Nano Letters* [12 (9), 4932 (2012)].



A micrograph of the flat lens (diameter approximately 1 mm) made of silicon (left). The surface is coated with concentric rings of gold optical nanoantennas (inset), which impart different delays to the light traversing the lens. The coloured rings (right) show the magnitude of the phase delay corresponding to each ring.

BOOK REVIEWS



The Aha! Moment - a scientist's take on creativity

David Jones, Johns Hopkins Press.
ISBN-13: 978-1-4214-0331-1.

Reviewed by Jason Dicker,
Launceston College.

David Jones is well known to older readers of New Scientist as Daedalus, the mythical scientist who has brilliant but impractical ideas. These were a very witty series of articles. David is also remembered for TV series with demonstrations of chemistry and for promoting science through other articles. Some of Daedalus's ideas did eventuate and one experimenter even received a Nobel Prize.

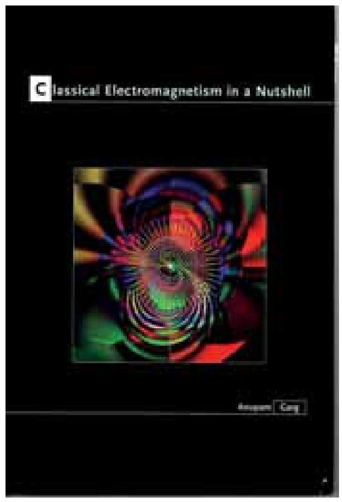
In this book David Jones attempts to explain his theories on creativity and how creative ideas seemed to occur to him. The book is almost written in the style of the Daedalus articles and it is very difficult to follow at times; it is difficult to pick when David is being "David" or if he is being more satirical as "Daedalus".

David uses his own concepts of the "Random Ideas Generator" thereafter known as RIG, "Censor" and "Observer-Reasoner" throughout the book to try to explain how he achieved his output. I am not at all certain how much of this is based on current psychological theories or whether these are his own ideas.

I began to truly enjoy David's book when he finally settled in to describe some of his demonstrations and experiments for TV. At this point his innovative brilliance at developing ideas out of little became apparent; however I was still somewhat annoyed at sporadic reversions to "DREDCO", the mythical lab of earlier writings, and Daedalus, and not being certain of his context. I also found that he sometimes started a story and failed to finish it within the section, then returning to it in a later section of the book without cross referencing between the two.

I was particularly perturbed when he proposes a test of the flatness of the Universe using geosynchronous satellites and lasers in a triangular arrangement implying that this would be a great break-through if the angles did not meet adding to 180^0. David seems oblivious to Eddington in 1919 and everything that has happened in measuring the local curvature of space since, let alone the spectacular pictures of gravitational lensing and uses made of these measurements.

In all, a book both interesting and annoying. Tighter editing and, perhaps, a different order of presentation may have produced a book that was more uniformly pleasing and easily read by myself. For very interesting discussions on many of David's non-academic experiments and demaonstrations, this is worth purchasing.



Classical Electromagnetism in a Nutshell

By Anupam Garg
Princeton University Press, 2012, pp 675 (hardback)
ISBN 978-0-691-13018-7

Reviewed by Lee Weissel
Trinity Anglican College, Albury

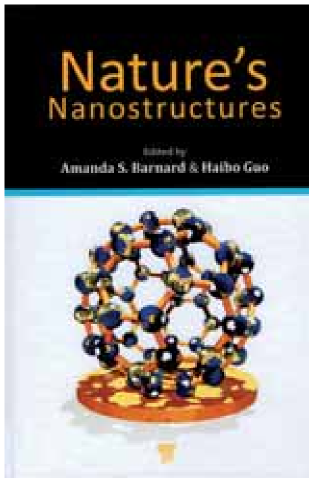
'Classical Electromagnetism in a Nutshell' is the latest offering from Princeton University Press's expanding presence in science. As part of the Science in a Nutshell series, the aim of this work is to provide a definitive treatment of the basic principles and phenomena known as classical electromagnetism. The author, Anupam Garg helpfully opens the work with references to other works he learnt the subject from. This introduction enables the reader to appreciate the scope and the magnitude of the work to come, and indeed lays the foundations of the problem

solving methods used.

The text scaffolds well the introduction of concepts with a developing set of problems to enable the reader to build their confidence in their understanding of the topics and the relevance to practical applications that are presented. Normally, much of the mathematics can be prohibitive for Physics students, thus causing them to spend inordinate amounts of time just attempting to understand Maxwell's equations. This work however, begins by reviewing previous work such as vector analysis, differential equations for particular applications, and relevant formulae to build up a helpful set of tools to ably engage with what is to follow. The inclusion of well over 300 problems ensures that there is plenty of practice to be had.

Tackling electromagnetic phenomena in all its classical applications, Garg at times calls on our historical understanding of a particular phenomenon or equation. This approach assists in contextualising the issue being examined and provides a helpful pointer for the direction our understanding would go in. From electrical and magnetic applications, to light, radiation and relativity, this text would work well at a university level. The six appendices provide innumerable extension possibilities, while examining topics which lie outside but are still related to the domain of electromagnetism.

The material contained within the text would go beyond a course for one year, as the topics discussed and demonstrated are varied and comprehensive enough to enable a lecturer to develop any electromagnetism course in different ways. The strengths of this work include a good balance between equation manipulation and practical explanation. For the reader it enables them to step into the text at any particular point of interest and be given well defined reference points. Another strength is the author's diligence in referring each of the different phenomena exhibited by electro magnetism back to the Maxwell equations, enabling the reader to see how the equations are applied in a variety of different ways. I personally found this aspect very helpful especially when examining areas I was unfamiliar with such as Quasistatic phenomena. The book, while not an easy going read, is very engaging on its own terms, leading to a deeper appreciation of both the background and many diverse practical implementations of classical electromagnetism.



Nature's Nanostructures

Amanda S. Barnard and Haibo Guo (Eds)
Pan Stanford Publishing Pte. Ltd., Singapore, 2012
553 pgs + 32 pages colour insets.
ISBN (Hardcover): 978-9814316-82-8

Reviewed by Victoria Coleman,
National Measurement Institute, Lindfield.

In an environment of global debate about the benefits and risks of engineered nanomaterials, it is appropriate to be reminded that nanomaterials are not as novel as we may think. Naturally occurring nano- and nanostructured materials are, and always have been, all around us. Furthermore, Nature has long been using its own form of nanotechnology to enhance the capabilities of biological systems, from basic bacteria to structures within our own bodies. However, it is only relatively recently with the development of instrumentation and methodology for the characterisation and detection of engineered nanomaterials that we have been able to detect and characterise natural nanostructures, and thus become aware of their existence.

In Nature's Nanostructures, editors Barnard and Guo have compiled a comprehensive and well structured overview of nature's nanostructures. Starting from an interesting "assessment and global budget" for naturally occurring inorganic nanoparticles, they consider nanominerals and where they are formed and distributed in the earth's crust, nanostructures and nanomaterials produced by biological processes, and the broader prevalence of nanoparticles in space and the atmosphere.

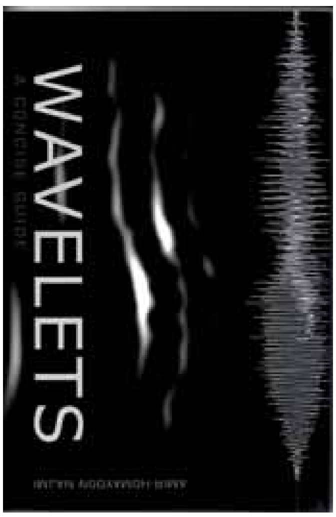
Although naturally occurring nanomaterials are thus a ubiquitous part of the natural environment, the use of engineered nanomaterials which have been designed to have unique properties in products may present new environmental hazards, especially as these products are used or

degrade. While the main focus of the book is on naturally occurring nanostructures, it concludes by considering how the environment may be impacted by inadvertently and intentionally produced engineered nanomaterials..

This interdisciplinary book covers a broad range of examples from peer reviewed literature, including naturally occurring gold nanoparticles, biomineralisation processes in plants and animals, nanomaterials in comets and meteors and the distribution of ultrafine particles near roadways. It is an excellent, approachable and timely overview of naturally occurring nanomaterials and nanostructures.

Read Nature's Nanostructures if you want to:

- get a good overview on the what, why where and how of naturally occurring nano structures and nanomaterials
- gain a greater appreciation for the environmental fate and potential hazards of nanomaterials
- develop a novel new nanotech product taking inspiration from nature
- broaden your understanding of nanoscience and simultaneously impress friends at your next dinner party with your knowledge of how birds navigate using magnetic nanoparticles.



Wavelets: a concise guide

by Amir-HomayoonNajmi
The Johns Hopkins University Press, Baltimore MA (2012). 270pp.
ISBN 10: 1-4214-0496-6

Reviewed by Ra Inta, ANU.

There was a period in the eighties/nineties where wavelets were supposed to be an algorithmic jackhammer, able to solve every ailment from cancer to brittle fracture. While perhaps not entirely living up to the hype, the internet would be a relatively barren and expensive domain if it weren't for the wavelet-based JPEG-2000 compression standard. Hence, riding on the mother wavelet gravy train, a lot of books on wavelets---of variable quality---have come out over the years. If you have any of these, I suggest throwing them out and instead reading Amir-HomayoonNajmi's "Wavelets: a concise guide". It contains a thorough, yet readable, summary with a refresher/primer on vector spaces and sampling and filter theorems before launching into the theory and some applications of both continuous and discrete wavelet transforms. Chapter 1 is an especially thorough and modern treatment of the mathematical foundations of signal processing, which, frankly, is necessary to understand the more recent advances in signal processing. The author clearly knows and loves his material, and this book covers all of the 'commonly' used wavelet and multi-resolution representations, from Haar through Morletto Daubechies wavelets.

While not a textbook per se, there are some nice exercises at the end of most sections. The chapterisation is well considered and the writing style is clear (and proudly typeset in LaTeX). Najmi goes to great lengths to be as comprehensible as possible: there are some very nice inline illustrations, from which I gained some insights into concepts I personally had trouble with previously.

However, for better or worse, it does read like a mathematics, rather than a physics, text. While the attention to rigour is laudable, retaining the 'Theorem-Lemma' structure throughout, I would personally have preferred more case studies or applications. The applications extend to the analysis of the sounds of a Bowhead Whale, and there is a decent treatment of two-dimensional wavelet transforms, and how they are applied in the JPEG2000 standard at the end. I did not find this an easy read. However, I do appreciate the depth and breadth of coverage.

This book would be most appropriate for a physics student at the graduate level looking to perform data or image analysis, or an under-/post-graduate electronic engineer or mathematician.

PRODUCT NEWS

AGILENT TECHNOLOGIES

High-Speed AXIe Digitizer for Large-Scale Applied Physics

Agilent Technologies has introduced the high-speed M9703A digitizer, the industry's first eight-channel, 12-bit digitizer that complies with the AXIe open standard. The AXIe digitizer is designed for use in large-scale applied physics applications.

The M9703A digitizer is capable of use in large-scale system configurations that pack 40 channels within a single 4U Agilent M9505A AXIe chassis or 80 channels into just 8U of rack-mount space giving it twice the channel density of comparable solutions. This makes the new digitizer well-suited for challenging experiments in particle physics, nuclear fusion, hydrodynamics and microwave radio astronomy.

The M9703A is a single-slot AXIe module with four- or eight-channel acquisition capability running at 1 GSa/s to 3.2 GSa/s. It can provide more than 1 GHz of instantaneous analog bandwidth. The digitizer also enables long acquisitions with its very large on-board memory of up to 4 GB.

To ensure high throughput, the digitizer module provides a four-lane (x4) PCI Express Gen 2 backplane, enabling sustained data transfer rates of up to 1 GB/s. With four on-board Xilinx Virtex-6 FPGAs, the M9703A also optimizes measurement throughput and supports future implementations of high-performance data processing.

The M9703A digitizer is compliant with the AXIe and AdvancedTCA(r) standards. Designed to benefit from fast data interfaces, the module can be plugged into AXIe or AdvancedTCA chassis slots.

In advanced applications such as high-energy physics experiments, the M9703A provides excellent measurement fidelity from DC to 1 GHz with up to 9.4 effective bits, 66 dBc spurious-free dynamic range and 59 dB signal-to-noise ratio.

The M9703A AXIe digitizer extends Agilent's portfolio of AXIe based products, and high-speed digitizers modules, which also includes solutions in the CompactPCI(r) format. To ease module integration into systems containing Agilent CompactPCI digitizer modules, the M9703A includes a comprehensive set of module drivers and a soft-front-panel graphical interface that also support other Agilent high-speed digitizer products.

More information about product configuration and pricing is available at www.agilent.com/find/M9703A.

Latest PXI Vector Signal Generator

Agilent Technologies has introduced the world's fastest vector signal generator in a PXI form factor. The Agilent M9381A is a 1-MHz to 3- or 6-GHz VSG that combines fast switching and excellent RF parametric performance: high output power, linearity and superior level accuracy, outstanding adjacent channel power ratio performance (for output levels up to +10 dBm or more) and wide modulation bandwidth (up to 160 MHz) for testing RF devices.

Agilent designed the M9381A for applications such as testing and validating the design of wireless power amplifiers and transceivers, public safety and military radios, and cellular base stations (primarily picocell and femtocell). The new PXIe VSG does more tests in less time, which reduces the cost of testing. Agilent's exclusive baseband-tuning technology innovation enables frequency and amplitude switching speed as fast as 10 μs in list mode and 250 μs from its programming interface. The switching speed is further enhanced by excellent linearity and repeatability associated with Agilent's signal generators.

The versatile list mode helps increase speed and provides flexibility by allowing engineers to change 80 parameters, including frequency, power and modulation in as many as 3,201 list mode points. This enables engineers to meet a wide variety of test requirements while improving test throughput.

Engineers can use the Agilent M9381A VSG to test wideband power amplifiers, front-end modules, transceivers and more, at standard 40 MHz RF bandwidth or options of 100 MHz or 160 MHz bandwidth with real-time corrections and ±0.1, ±0.2, and ±0.3 dB flatness, respectively.

The M9381A, with its excellent modulation quality

at high output power, can be used at power levels up to +10 dBm or more depending on the standard with little degradation to adjacent channel power ratio performance. This enables engineers to directly operate at the required power levels without additional amplification to compensate for test system losses. The M9381A delivers ACPR of up to -70 dBc (W-CDMA test model 1, 64 DPCH). The output power up to +19 dBm can be controlled precisely with accuracy of ±0.4 dB.

The Agilent M9381A PXIe vector signal generator simulates complex real-world communications signals through Agilent's Signal Studio software. Signal Studio is a flexible suite of signal-creation tools that offers performance-optimized reference signals validated by Agilent to support standards such as LTE and 802.11ac.

Agilent's unique and industry-leading calibration core exchange strategy maximizes system uptime by providing fast repairs.

The M9381A PXIe vector signal generator is the latest addition to Agilent's growing lineup of more than 60 PXI and AXIe modular products.

Available now, the Agilent M9381A PXIe vector signal generator consists of the following: M9311A digital vector modulator, M9310A source output, M9301A synthesizer and M9300A frequency reference. Starts with the base configuration, with license key upgrades available for increased modulation bandwidth, frequency range, memory, output power and faster switching. Four VSGs can be housed in a single 18-slot PXI chassis.

The M9380A PXIe CW source (a configuration without the M9311A digital vector modulator) is also available. The Agilent M9018A all-hybrid PXI chassis and M9036A embedded controller are ideal to complete both configurations.

Additional information about Agilent's modular test solutions is available at www.agilent.com/find/M9381A.

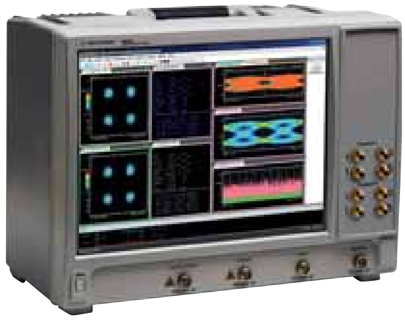
An in-depth Agilent modular products backgrounder is available at www.agilent.com/find/modular_backgrounder.

Fully Integrated Optical Modulation Analyzer for Testing 40/100G

Agilent Technologies has introduced a portable, fully integrated optical modulation analyzer with a laptop-size screen. The compact design and affordable price make the new Agilent N4392A optical modulation analyzer more accessible to all engineers who need to analyze complex modulated optical signals during development and manufacturing of 40/100G coherent transmitters and receivers.

The N4392A enables engineers to characterize components like in-phase quadrature modulators and integrated coherent receivers designed according to industry standards for 100G coherent transmission. The integrated design significantly accelerates setup and eliminates configuration effort so users can focus on design challenges.

Built-in performance verification and recalibration routines deliver high-confidence test results and extend the recommended recalibration period, improving uptime and lowering the cost of ownership.



Agilent used today's most advanced integrated circuit technology to create the first optical modulation analyzer in the form factor of a mid-size oscilloscope. The smaller size allows for true portability. A 15-inch analysis screen shows more information at the same time, making it easier for engineers to characterize complex modulated optical signals.

In addition to the features currently available in other optical modulation analyzers, the N4392A offers four differential RF input channels to help engineers characterize integrated coherent optical receivers. This makes the new instrument an ideal tool for R&D engineers involved in 40/100G characterization and debugging. The ability to analyze signals correctly whenever needed steeply increases the engineers' insight into the nature of complex modulated optical signals and helps them avoid possible pitfalls in their designs.

The N4392A, optimized for 40/100 Gbit/s test requirements, extends Agilent's portfolio of optical modulation analyzers. For 400 Gb/s to 1 Tb/s next-generation transmission rates, Agilent offers the industry-leading

N4391A optical modulation analyzer enabled by Agilent's 90000 X-Series oscilloscopes.

The new optical modulation analyzer family offers novel signal-processing algorithms for modulation-format-transparent polarization alignment and phase tracking. The family also offers chromatic dispersion and first-order polarization mode-dispersion measurement and compensation. All modulation analyzers provide a defined interface to customer-developed MATLAB algorithms. This feature enables consistent results from early research to final manufacturing qualification, including the exchange of configuration files.

Features of the Agilent N4392A optical modulation analyzer include:

- Full support of 32-Gbaud modulation formats.
- 63-Gs/s real-time sampling.
- Optical and differential RF inputs in one instrument.

Additional information about Agilent's N4392A optical modulation analyzer is available at www.agilent.com/find/N4392A.

For further details, contact tm_ap@agilent.com
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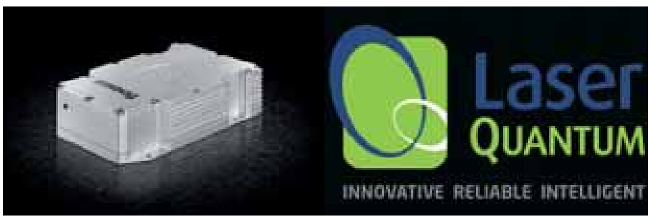

Lastek is proud to offer Laser Quantum products exclusively for the Australia/NZ research market.
Laser Quantum is a world-class manufacturer of high quality solid-state laser sources. Their products are known throughout the world for reliability, compactness, performance-excellence and long operational lifetime. You will find Laser Quantum products in scientific laboratories and integrated in systems and machines world-wide.

Laser Quantum's expertise meets the needs of industry, aerospace, medicine, biomedicine and research. By working closely with customers, their lasers, with patented technology, are found world-wide in applications such as cell-sorting, PIV, femtosecond Ti:Sapphire pumping, optical tweezers, laser doppler anemometry, microscopy, fluorescence imaging, Raman spectroscopy, Brillouin scattering and many more.

One such popular laser is the finesse pure laser. The finesse pure is built on the highly popular 532nm finesse platform and covers the same range of power levels, but with RMS noise reduced to below 0.03%. More significantly, the noise profile has been tailored to give optimal performance in all CEP systems, and in other noise-critical applications. As with the standard 532nm finesse laser, Laser Quantum offers a 5 year/15,000 hour warranty to scientific customers on the finesse Pure, which covers all specifications including, crucially, the <0.03% noise. When you buy a finesse Pure, you can be confident that it will remain Pure!

Features:

- RemoteCal
- Remote Vu
- Compact Design
- Permanently Aligned Cavity (PAC)
- Low Noise
- Low M-Squared
- Diode > 40,000 hours MTTF
- Zero-Stress Cavity

HORIBA Scientific Dual-FL – The world's FASTEST Fluorometer!

HORIBA Scientific combined the world's only CCD based bench-top spectrofluorometer with a UV-VIS spectrophotometer and created the Dual-FL. The result is an instrument that lets you collect incredibly rapid kinetics data, or complete excitation emission matrix (EEM's) in just seconds.

Now our customers can obtain spectral rates as fast as 80,000 nm/s, and acquire EEMs up to a 100 times faster than any other instrument. Dual-FL offers a sensitive cooled, back-illuminated CCD detector for rapid collection of emission spectra, and an excitation double monochromator for superior stray light rejection. Dual-FL can also be used as a stand-alone UV-VIS.

Dual-FL is a TE-cooled CCD fluorescence emission detector, and is the only true simultaneous absorbance - fluorescence system available.

See overleaf for features.

Features:

Hardware

- The only true simultaneous absorbance-fluorescence system available
- TE-cooled CCD fluorescence emission detector for rapid data acquisition up to 100 times faster than any other benchtop fluorometer
- Corrected UV-VIS absorbance detection path for stability and accuracy
- Double grating excitation monochromator for superior stray light rejection
- Matching bandpass for absorbance and fluorescence spectra
- Automatic sample changer option (2 or 4 position)
- Compatible with flow cells and titrator

Software

- Optimized experiment set-up menus minimize user confi guration time
- Complete NIST-traceable corrected fluorescence spectra automatcally generated
- Spectral and kinetic analysis tools for both absorbance and fluorescence data
- Methods and batch protocols for automating multiple sample measurement

New 880nm Pearl™ from nLight

Pearl™ P16 Series: 875 - 890nm

The Pearl™ P16 series is designed primarily for Solid State Pumping to maximize fundamental mode extraction from end-pumped lasers. Disk and slab laser geometries benefit when long-term mode stability and beam quality are critical.

These pump lasers use a revolutionary fiber technology, PowerCore™, which delivers high-brightness, Gaussian or top-hat pump profiles to maximize overlap with the TEM00 cavity mode for efficient brightness conversion to 1 μm. With the option to add VBG locking, the Pearl™ provides flexibility to pump architecture. The industry-leading efficiency of these wavelength-stabilized pump sources is enabling compactness, reliability and simplified cooling for the next generation of solid-state laser systems. Pearl's embedded nXLT™ single-emitter technology is resetting the benchmark for high-brightness semiconductor laser reliability.

Features:

- Patented nXLT™ diode protection for extended life
- Low-current, fault-tolerant architecture
- Industry-leading wall-plug efficiency >50%
- Field-replaceable, PowerCore™ mode-stable fiber
- VBG locking
- Plug and play compatibility with nLIGHT's DL system
- Electrically isolated housing

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

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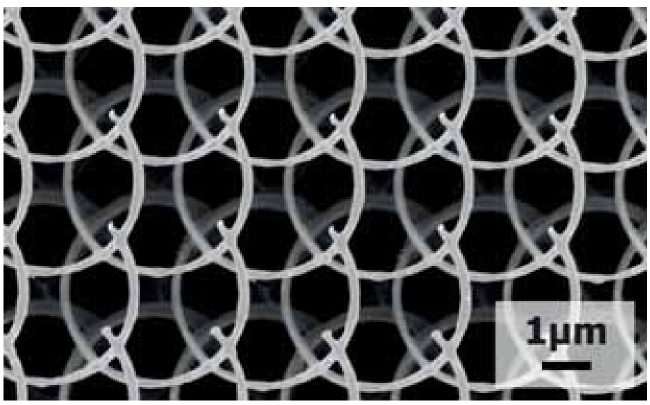
WARSASH SCIENTIFIC
3D Laser Lithography from Nanoscribe

Warsash Scientific are very excited to announce that they have been chosen as exclusive representatives for Nanoscribe in Australia and New Zealand.



As market and technology leader, Nanoscribe supports science and industry all over the world with high-tech solutions in 3D laser lithography. The product portfolio covers both laser lithography systems for 3D micro- and nanostructures based on two photon polymerisation as well as specifically designed IP-photoresists. In order to provide a complete solution, Nanoscribe additionally offers know-how in casting of 3D structures, e.g., into metals or semi-conductors. The applications are widely spread, including photonics, photonic waveguides and wire bonds, micro-optics, micro-fluidics, biomimetics or scaffolds for cell biology.

The Nanoscribe Photonic Professional is an easy-to-operate, table-top laser lithography system, allowing for true three-dimensional nanostructures in commercially available photoresists. Designed for the high demands of three-dimensional photonic crystal structures, the instrument is suitable for generating three-dimensional scaffolds for biology, micro- and nanofluidic circuitry and more.

Key Features

- True 3D writing capability with highest precision based on piezo nanopositioning.
- Autofocus: Due to patented technology, the interface between substrate and photoresist is determined exactly and autonomously. This establishes the basis for reliable anchoring structures to the substrate, whether 2D or 3D.
- Software: Provides easy access to all adjustable features of the lithography system. Complex 3D structures written in CAD software, e.g. STL files, can be easily and straightforward converted for the directly import to the controlling interface.
- Perfect Shape: High accuracy can be achieved by automatically adapting sample movement speed and laser power during the writing process.
- Easy Sample Exchange: The system is provided with a quick-change, slide-in substrate holder. A second set of substrates may be prepared and mounted to a spare holder while the system is in operation. The substrate holders can be exchanged without any tools within less than one minute.
- Capability for aberration constant writing with highest resolution for structures up to the mm-range by means of the Dip-In Laser Lithography (DiLL) technique.

The family of IP-photoresists is specifically designed for the demands of 3D Direct Laser Writing by two-photon absorption: Extraordinary resolution in three dimensions with highest mechanical stability. As a response to the vast variety of applications, Nanoscribe provides liquid and sol-gel negative-tone photoresists with outstanding features: IP-L (780), IP-G (780) and IP-Dip.

Key Features

- Feature sizes down to 150nm
- Low proximity effect
- Low stress
- Little shrinkage
- Good adhesion even on glass substrates
- Easy handling

The combination of these properties not only enables you to push resolution to its limits but also to work reproducibly with little effort in optimising process parameters. Depending on the choice of microscope objective and substrate used, the writing process can be observed in-situ and real-time. The visual feedback enables fast cycles of parameter optimisation for new 3D fabrication designs.

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

491nm Laser with Single Frequency and Perfect Beam

The new Cobalt Calypso™ 491nm is a continuous wave (CW) diode-pumped solid-state (DPSS) laser. It is a single-frequency laser with high level of stability, ultra-low noise, very narrow spectral bandwidth and a perfect quality beam over a wide range of operation temperatures. It is based on proprietary PPKTP technology which provides improved power efficiency, large wavelength flexibility and multiline emission possibility.

The Calypso operates at 491nm and emits up to 200mW CW output power in a perfect TEM00 beam, with <1 MHz linewidth and immunity to optical feedback. This high performance laser is ideally suited for demanding analytical applications such as super-resolution fluorescence microscopy, Raman spectroscopy, cell sorting and particle analysis. The laser is manufactured using proprietary HTCure™ Technology in a compact and hermetically sealed package which provides a very high level of tolerance to varying environmental conditions and exceptional reliability.

Key Features

- Compact blue DPSS laser
- CW output power 200 mW
- Single-frequency, <1MHz spectral bandwidth
- Ultra-low noise, typically <0.5% rms
- High quality TEM00 beam, M2<1.1
- Hermetically sealed, ultra-robust package
- Excellent spectral purity
- 12 months warranty

Continued overleaf

Available Wavelengths On The Same Platform

- 355nm
- 532nm
- 561nm
- 660nm
- 1064nm

For a data sheet, owners' manual or further information, contact Warsash Scientific on +61 2 9319 0122 or sales@warsash.com.au.

COHERENT SCIENTIFIC
Imaging Spectrograph with Aberration-free Performance

Princeton Instruments has released IsoPlane, a next-generation imaging spectrograph which produces sharply focused images or spectra across the entire 27mm x 8mm focal plane. Isoplane improves on traditional Czerny-Turner spectrographs by eliminating astigmatism and greatly reducing coma. The result is sharper images and sharper spectral lines with constant width across the focal plane. For spectroscopy, this means that more photons end up at the peak, thus improving signal to noise ratio.

The results have to be seen to be appreciated so please visit Princeton Instruments website (www.princetoninstruments.com/products/spec/isoplane/) to see sample images and videos illustrating the performance of this unique new instrument.

High Performance Camera for Near-infrared Imaging

Princeton Instruments has released NIRvana, a deep-cooled, scientific-grade InGaAs camera. The camera is specifically designed to give the highest sensitivity for low light, near infrared (NIR) imaging and spectroscopy applications in the range 900nm – 1700nm. NIRvana uses the latest generation InGaAs sensor with 640 x 512 resolution. Peak quantum efficiency of 80% provides exceptional sensitivity in the NIR range where standard Silicon CCD and CMOS detectors have low or no sensitivity. The camera is thermoelectrically cooled to -90°C to provide low dark charge without the inconvenience of liquid nitrogen. Gigabit Ethernet interface allows remote operation and the camera is fully supported by Princeton's new LightField data acquisition software.

Applications include nanotube fluorescence, solar cell inspection, singlet oxygen detection and any application involving highly sensitive imaging in the NIR.

Semrock Releases Femtosecond Laser Mirrors

Two 45° turning mirrors have been released in the soon-to-be-expanded line of PulseLineTM femtosecond laser optics. These mirrors are IBS-coated for maximum durability and feature high reflectivity R>99%, low dispersion and a high laser damage threshold over a broad wavelength range. They are ideal for applications where femtosecond laser beams need to be guided from the output of the laser head to the sample, and are especially useful in femtosecond laser spectroscopy.

MaxMirror ultrabroadband (350-1100nm) mirror from Semrock

The MaxMirror is a high-performance laser mirror that covers an exceptionally broad range of wavelengths, designed to replace three or more conventional laser mirrors. MaxMirrors are highly reflecting over the 350nm to 1100nm wavelength range and simultaneously reflect all states of polarization and all angles of incidence from 0 – 50° inclusive. These mirrors also offered in a 10-pack, providing additional savings.

For further information please contact Coherent Scientific at sales@coherent.com.au

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Princeton Instruments

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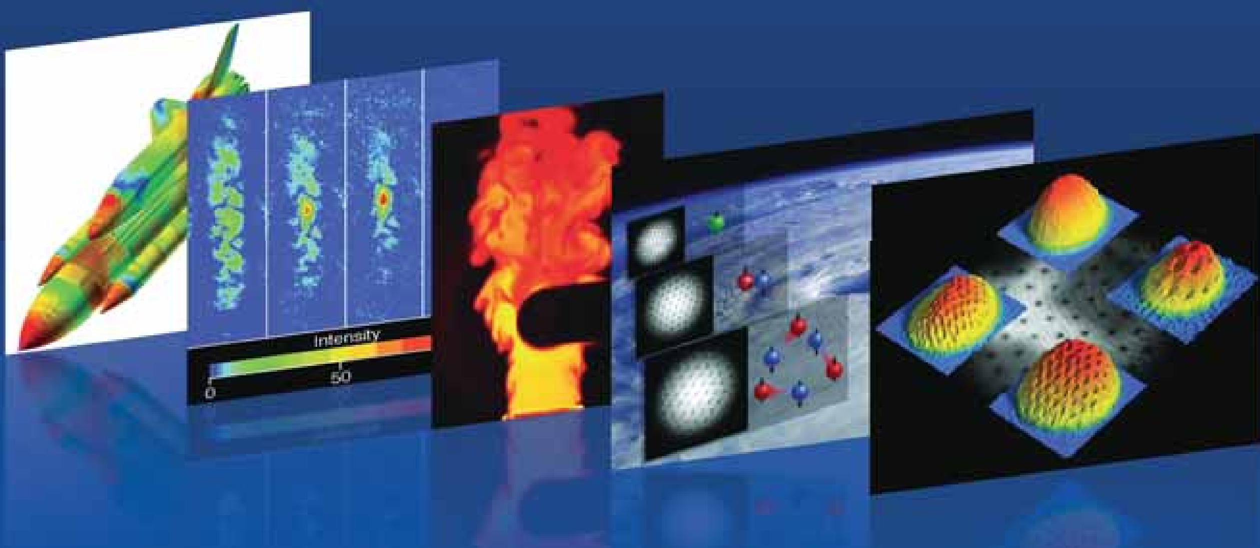
Optimised for today's most challenging applications



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