In this work we have presented a new semi-analytic galaxy formation model, with updates to deal with the high temporal resolution of galaxy formation and supernova feedback in the early Universe. 

Using our fiducial model, including both UV background supernova feedback and supernova feedback, we are able to quantify the effect of each feedback mechanism on galaxy formation. 

The magnitude of these statistical uncertainties are representative of those of all of the models shown in each panel. The grey dashed lines represent the halo mass bins for which at least 98% of member haloes have had more than 100 particles in at some point in their history.

The ionisation state of a thin intergalactic medium is represented by the ionizing photon escape fraction, which decreases as a function of redshift and halo mass. The green data points represent the halo mass bins for which at least 98% of member haloes have had more than 100 particles in at some point in their history.

The solid blue line indicates the result of the fiducial model which matches both the 2014 RAS, MNRAS summary table of the different model runs explored in this work (see Table 2).

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4.1 The relative evolution of the galaxy stellar mass function (Figure 3) as function of lookback time. The blue solid line represents the observed high-z stellar mass function, we find that the reionisation history of the intergalactic medium is largely insensitive to reionisation feedback. This implies that the production of ionising photons is not self-regulated (Section 2015) constraints on the electron optical scattering depth (Section 3.2.1).

Using our framework we are able to quantify the efficiency of each model with respect to this fiducial case. Thick lines represent stellar mass bins within which greater than 98% of haloes have had more than 100 particles in at some point in their history. There is remarkably little variation in the mass functions predicted by comparing the fiducial reference of each model with respect to this fiducial case. Lower panels indicate the fractional escape fraction of ionising photons (grey solid) lines demonstrates the close agreement between the semi-analytic model, with updates to deal with the high temporal resolution of baryonic accretion and supernova feedback processes, and a custom N-body simulation with the volume and mass resolution parameters refer to the low mass slope of the corresponding mass function, we find that the reionisation history of the intergalactic medium is largely insensitive to reionisation feedback. This implies that the production of ionising photons is not self-regulated (Section 2015) constraints on the electron optical scattering depth (Section 3.2.1).

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EDITORIAL

Let the scanning begin

Welcome to the first issue of volume 53, 2016. By the end of this year I hope to be close to having all past issues scanned and available on line. The reason for not saying “all past issues” is the result of an early discovery of missing issues. For issues up to 1974 I am relying upon the “complete” collection at CSIRO Lindfield. With Cathy Foley’s assistance we started scanning only to find the first issue, vol 1(1) missing. How incomplete the collection might be is yet to be revealed. At this stage however it is clear we will need to have a search elsewhere for one or more missing issues. When the situation is clarified I hope members may be able to help us track down alternative copies. Issues will be mounted on the AIP website as they become available.

In this issue we have a bigger than normal News & Comment section. While most of the items report matters that have come to my notice, some are the result of submissions from members. Indeed, I would welcome suggestions for news items from members. The only criteria is that an item should be of interest to the broader Australian Physics community. It is my strong belief that Australian Physics should be the journal of record for physics in Australia.

In this issue we have articles from the last two Boas Medal winners. The first is Cosmic Hydrogen and the First Galaxies in the Universe by Stuart Wyithe (University of Melbourne) who received the Boas Medal for 2014. The second is Nanophotonics beyond the limit of Abbe’s law by Min Gu (Swinburne University of Technology) who received the Boas Medal for 2015.

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In this issue we publish a first announcement (p29) for the 22nd AIP Congress (Brisbane, 4-8 December 2016), which is being held in conjunction with the 13th Asia Pacific Physics Conference. The latter is the next of the triennial meetings of AAPPS, the Association of Asia Pacific Physical Societies. As a timely reminder of the role and activities of AAPPS, a short item is included in this issue (p15).

To further publicise the Science in Australia Gender Equity Initiative (SAGE) of the Australian Academy of Science, an information poster is reproduced on the inside back cover.

Brian James
Innovation and science at the national forefront

With this being the first issue of *Australian Physics* for 2016, I would like to wish everyone a Happy New Year, with the hope that it will be a positive and productive one for you all professionally, as well as for the physics discipline itself.

Reflecting back on the final months of 2015, particularly December, it was dominated by a number of important announcements relating to science and research funding. The most significant of these was the Federal Government’s multi-billion dollar National Innovation and Science Agenda “Welcome to the Ideas Boom” initiative that was announced on 7 December. This certainly delivered in spades on the need I highlighted in my last column for specific actions and policies in follow up to Prime Minister Turnbull’s statement that the industry, innovation and science portfolio was his new government’s most important agenda. Contained within this announcement were 24 new initiatives that address such important needs as the provision of secure long-term funding for research infrastructure, increasing collaboration between industry and universities, incentivising investment in research and innovation, and boosting the ability of CSIRO, universities, and other research organisations to commercialize their research.

At the detailed level, there is much for the physics and the broader science communities to be pleased about. Firstly, and perhaps most significantly, the funding of national research infrastructure has been secured for the long term, with the National Collaborative Research Infrastructure Strategy (NCRIS) being allocated $1.5B over the next 10 years. This will ensure much needed funding stability and certainty (and, in turn, a much greater chance of co-investment) for national research facilities, in contrast to the last few years where NCRIS has been funded on a year-by-year basis. More specific to physics, there was also the very good news that the ongoing operations of the Australian Synchrotron Facility have been funded well into the future with an allocation of $520M. In addition, there was an allocation of $294M for Australia’s commitment to the Square Kilometre Array, and $26M for the ARC Centre for Quantum Computation and Communications Technology, led by Prof Michelle Simmons at UNSW, to develop its silicon-based quantum computing technology.

Importantly, the announcement also contains a number of initiatives aimed to address systemic problems in the Australian research ‘ecosystem’. Our under-performance as a nation in industry-university research collaboration has been addressed in a number of ways, with the level of industry engagement being introduced as a new metric in assessing universities’ research performance, this metric being given equal weight to research quality when determining university research block grant allocations, and the ARC’s industry-focussed “Linkage Project” scheme now becoming open to continuous applications that will be assessed on a much shorter time-scale. The importance of STEM to an innovation-driven economy has also been recognised through the allocation of $48M for programmes that will inspire all Australians to engage with STEM, particularly through further study.

Finally, the move to create an Innovation and Science Committee of federal cabinet is also very heartening. This further underscores the importance placed on science and innovation by the government, in that it has been elevated to the very highest decision-making levels of government.

Another welcome announcement in December was the outcome of the ARC’s 2015 Future Fellow-ship round. This saw 50 fellowships being awarded and, notably, 11 of these were in the field of physics, including 8 in astrophysics. My warmest congratulations to all these new Future Fellows! Of course the 50 fellowships awarded in 2015 was only half the usual number that had been awarded in previous years. Given the well demonstrated importance of this scheme in supporting research excellence at the mid-career level, I very much hope it will be continued and restored to its full level in 2016 and beyond.

To conclude, a reminder that 2016 is AIP Congress year, and on this occasion it will be held as the joint 13th Asia-Pacific Physics Conference and 22nd AIP Congress at the Brisbane Exhibition and Convention Centre from 4-8 December. This will be the first time that both meetings have been held jointly, and is certain to enrich the scientific program, as well as facilitate new links to be made between the Australian physics community and those throughout the Asian-Pacific region – something that is a high priority for the AIP. Further details can be found at the meeting website (www.aip-appc2016.org.au), and I strongly urge you to visit it and register your initial expression of interest now, so you will receive regular updates prior to full registration and attendance later in the year.

Warrick Couch
NEWS & COMMENT

The Prime Minister’s Prize for Science
The Prime Minister’s Prize for Science was awarded to Prof Graham Farquhar AO from the ANU, whose work on photosynthesis from the perspective of a biophysicist has transformed our understanding of that key biological reaction. He has also addressed the lower evaporation rates and wind speeds that puzzle many climate scientists.

Professor Farquhar is Distinguished Professor at the ANU’s Research School of Biology and Chief Investigator of the Australian Research Council’s Centre of Excellence for Translational Photosynthesis. He has a Bachelor of Science from the ANU, Bachelor of Science (Honours in Biophysics) from the University of Queensland and a PhD in Environmental Biology from the ANU.

Academy Early Career awards
The early career awards of the Australian Academy of Science for 2016 include the following:

The 2016 John Booker Medal has been awarded to Dr Paolo Falcaro, CSIRO Materials Science and Engineering.

Dr Paolo Falcaro engineers nano-materials to bring materials with exceptional functional properties to our everyday life. He makes nano-particles and ultra-porous crystals for medicine and the environment, targeting applications where other materials fail. His research team engineer these materials down to the molecular level, which allows for fine-tuned control over the functional properties. By tailoring the characteristics of these materials, specific applications can be met. For example, Dr Falcaro has developed magnetic materials for the decon-
tamination of water from carcinogens and heavy metals. He has pioneered new carriers for the encapsulation, preservation and release of pharmaceuticals, addressing a major problem facing biotechnology, especially for treatment in developing countries. He is also developing miniaturized portable chips for the detection of deadly pathogens, useful for preventing viral outbreaks.

The **2016 Frederick White Prize** has been awarded to Dr Michael James Ireland, Research School of Astronomy and Astrophysics, Australian National University.

![Dr Michael Ireland](image)

Dr Ireland develops and applies the latest optical and infrared technologies to build innovative astronomical instruments to probe the lifecycles of stars and planets. A central aim of Dr Ireland’s research has been to develop instrumentation and techniques capable of finding out how planets form and evolve. One example of this research has been the discovery of the first planet orbiting another star to be caught in the process of formation. He has also shown, both from theory and from observations using innovative astronomical instruments, just how dying solar-type stars shed their outer layers in a wind of molecules and tiny transparent dust grains. Dr Ireland is currently building innovative astronomical instrumentation for detecting planets around other stars, both for Australian telescopes and the largest international telescopes.

(Source: Australian Academy of Science)

**2016 Pawsey Medal**

The Australian Academy of Science has awarded the Pawsey Medal for 2016 to Dr Ilya Shadrivov of the Nonlinear Physics Centre, Research School of Physics and Engineering, Australian National University.

![Dr Ilya Shadrivov](image)

Dr Shadrivov is developing new forms of metamaterials for future use in photonics and communication technologies. Metamaterials are composite structures with carefully designed properties that are not found in nature. They can manipulate light and other electromagnetic waves in many unusual ways. For example, they can be tuned to absorb some ‘colours’ of light, which is useful for the next generation of security cameras which use invisible long wavelength, or Terahertz, radiation. Alternatively, metamaterials can be used in novel antennas, which will beam electromagnetic waves in carefully chosen directions and rapidly scan the surrounding environment. This is useful for many applications in modern industry and for car radar-type sensors.

(Source: Australian Academy of Science)

**2016 Ian Wark Medal and Lecture**

The Ian Wark Medal and Lecture for 2016 has been awarded to Scientia Professor Martin Green AM FAA FRS FTSE of the Australian Centre for Advanced Photovoltaics, UNSW.

![Prof Martin Green](image)

Professor Green is an acknowledged world-leader in field of photovoltaics. He has published extensively and influentially, made many highly significant contributions to the knowledge base of the field, and successfully established a world-class research hub that is responsive to Australian needs in the photovoltaics industry. Several generations of his group’s technology have been successfully commercialised including, most recently, the Passivated Emitter and Rear Cell (PERC) that produced the first 25% efficient silicon cell in 2008 and accounted for the largest share of new manufacturing capacity added worldwide in 2014.

(Source: Australian Academy of Science)
Innovation Statement
In December 2015, Prime Minister Malcolm Turnbull released the Innovation Statement, saying he wanted to drive an “ideas boom”. The statement envisages almost $1.1 billion in expenditure by the Federal Government over the next four years to promote business-based research, development and innovation. A key element of the plan is to strengthen ties between the business community, universities and scientific institutions.

The plan’s major initiatives are:
- $106 million in tax incentives for “angel” investors, who provide seed funding in the early years of a venture’s creation
- $75m to the CSIRO’s data research arm Data 61
- $30m for a Cyber Security Growth Centre to create business opportunities in cyber security, which the Government spends $5b on each year
- $15m over four years towards a $200m CSIRO Innovation Fund
- $10m over four years towards a $250m Biomedical Translation Fund, in partnership with the private sector


2015 WH “Beattie” Steel Medal
The Australian Optical Society has awarded Professor Joss Bland-Hawthorn the 2015 WH “Beattie” Steel Medal in recognition of his leadership and significant contribution to the field of optics, particularly in the application of photonics to astronomical and space instrumentation. He is the first astronomer to receive this award.

Prof Joss Bland-Hawthorn

The Medal is the most prestigious award of the Australian Optical Society. It is presented to a nominee with a strong and sustained record of authority, enterprise and innovation in the field of optics in Australia or New Zealand. It is named in honour of W.H. (Beattie) Steel who worked at CSIRO National Measurement Laboratory 1953-85 and was first president of AOS.

Professor Bland-Hawthorn is Director of the Sydney Institute for Astronomy (SIFA), and Associate Director of the Institute of Photonics and Optical Science (IPOS). His revolutionary developments are made possible through the work of the Sydney Astrophotonic Instrumentation Labs (SAIL) at the University of Sydney, funded by his ARC Laureate Fellowship and directed by Dr. Sergio Leon-Saval.

VSA Vacuum Technology Short Course. Australian Synchrotron, Clayton, Vic
March 15-16 (Tues-Wed), $480* *Special Rates - AIP, VSA Members, Post Grad Students

Content:
- **Fundamentals** - Gas laws, kinetic theory, conductance etc
- **Pump Systems** - Rotary, Diffusion, Turbo, Cryo, Sorb, Ion pumps
- **Gauges** - Diaphragm, Thermal, Capacitance, Ionization, RGA
- **Leak Detection** - Virtual & Real leaks, Detectors, Techniques, MSLD
- **Accessories** - Outgassing, Chambers, valves, fittings
- **Simulations** - Interactive Pump Systems & Leak Detection

For Whom:
- **Researchers** - Concise theory & practice of Vacuum Technology
- **Technicians** - maintaining electron microscopes, coaters, accelerators etc
- **Engineers** - in large projects involving vacuum equipment
- **Industrial Staff** - eg freeze drying, semiconductors, packaging, moulding
- **Workshop Staff** - specializing in machining & construction of equipment
- **Sales Staff** - essentials of pumping systems, gauges, leak detectors etc

Further Information & Enrolment Options - www.vacuumsociety.org.au
New Chief Scientist
Dr Alan Finkel AO, Monash University Chancellor and President of the Academy of Technological Sciences and Engineering, took up his appointment as Chief Scientist in January 2016, following Prof Ian Chubb AC who completed his term at the end of 2015. Dr Finkel is a prominent engineer, respected neuroscientist, successful entrepreneur and philanthropist with a personal commitment to innovation and commercialisation.

In announcing the appointment Prime Minister Malcolm Turnbull said science and innovation are at the centre of the Government’s agenda and key to Australia remaining a prosperous, first world economy with a generous social welfare safety net. “The Australian Government recognises the importance of science, innovation and technology to our future prosperity and economic security in an increasingly competitive and diverse global economy,” the Prime Minister said.

Dr Finkel said he was thrilled with the opportunity to contribute to framing Australia’s participation in the agile 21st century. “My personal experience across research, business and STEM education will guide my ability to formulate relevant advice,” Dr Finkel said. “We exist in a competitive international environment and to compete effectively, business needs science, science needs business, Australia needs both.”

Canon Australia’s Extreme Imaging Competition
The 2015 winners of the Canon Australia’s Extreme Imaging competition were announced in November 2015 at The International Conference on Digital Image Computing: Techniques and Applications (DICTA) in Adelaide.

The four winners included Cleo Loi, a PhD student supervised by Dr Tara Murphy at the Sydney Institute for Astronomy at the University of Sydney. Cleo was the Open Winner for her project: Waves in the sky: Probing the ionosphere with the Murchison Widefield Array. The image below shows electron density irregularities aligned along the geomagnetic field, as imaged by the MWA. Red and blue colours represent high and low relative densities. Stereo imaging reveals an altitude of ~600 km.

The Murchison Widefield Array (MWA) is a low-frequency radio telescope operating between 80 and 300 MHz. It is located at the Murchison Radio-astronomy Observatory (MRO) in Western Australia, and is one of three telescopes designated as a precursor for the Square Kilometre Array.

Cleo used imaging technology to analyse the distortions of the radio signals due to the Earth’s ionosphere. “My key task on this project was to investigate how much the ionosphere was affecting astronomical observations with the MWA. This project has opened up many doors for me – and I’m now continuing my study at the University of Cambridge, in the UK,” said Cleo.

Boas Medal for 2015
The AIP’s Boas Medal for 2015 has been awarded to Professor Min Gu, a University Distinguished Professor and Director of the Centre of Micro-Photonics at Swinburne University of Technology.

Prof Min Gu (credit: Swinburne University of Technology)
Quantum computer coding in silicon now possible

A team of Australian engineers has proved – with the highest score ever obtained – that a quantum version of computer code can be written and manipulated using two quantum bits in a silicon microchip. The advance, published in *Nature Nanotechnology*, removes lingering doubts that such operations can be made reliably enough to allow powerful quantum computers to become a reality.

This effect is famous for puzzling some of the deepest thinkers in the field, including Albert Einstein, who called it ‘spooky action at a distance’, said Professor Andrea Morello, of the School of Electrical Engineering & Telecommunications at UNSW and Program Manager in the Centre for Quantum Computation & Communication Technology, who led the research. “Einstein was sceptical about entanglement, because it appears to contradict the principles of ‘locality’, which means that objects cannot be instantly influenced from a distance.”

(Source: UNSW)

Telstra, Commonwealth Bank back UNSW in quantum computer race

Telstra has invested $10 million in the University of NSW project to develop the world’s first practical quantum computer, matching a $10 million contribution from the Commonwealth Bank. The money comes on top of $26 million for the project, led by physicist Michelle Simmons at the University of NSW, from the federal government which was announced in the recent innovation statement.

Professor Simmons’ research team is in an international race to create the first full-scale programmable quantum computer which, if it succeeds, promises to transform digital technology by operating at speeds millions of times faster than today’s best machines.

She said the investment sent a “very powerful message about supporting internationally-leading Australian research in areas of breakthrough technology”. The UNSW research is world leading because the project team is developing its quantum computer components in silicon - the material now most commonly used to make computer chips - which promises to be more easily scaled into commercial manufacture than more exotic designs used by other research groups.

**Project leader Andrea Morello (left) and lead authors Stephanie Simmons and Juan Pablo Dehollain. Credit: Paul Henderson-Kelly.**

The quantum code written at UNSW is built upon a class of phenomena called quantum entanglement, which allows for seemingly counterintuitive phenomena such as the measurement of one particle instantly affecting another – even if they are at opposite ends of the universe.

The award recognises Professor Gu for his major contributions to three-dimensional optical imaging theory and its applications in optical data storage, biometrics and optical endoscopy. He is sole author of two standard reference books and has over 500 publications in nano/biophotonics.

“It is a great honour to be selected by the Australian Institute of Physics to receive this medal,” Professor Gu said. “The award is particularly meaningful to me as I have been focused on fulfilling the translational vision from physics to societal impact. I am glad that our contributions at Swinburne have been recognised.”

The Boas Medal was established in 1984 to promote excellence in research in Physics and to perpetuate the name of Walter Boas, who was chief of the CSIRO Division of Tribophysics; from 1949 to 1969. The award is for physics research carried out in the five years prior to the date of the award.

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The new money from the federal government, Telstra and the Commonwealth bank will cover more than half of the $70 million to $80 million which Professor Simmons said she estimated would be needed to reach the research team’s next goal of building a 10 qubit quantum computer in silicon by 2020. However it is estimated that at least 300 qubits are needed to realise the potential of quantum computers to speed up computing operations.
(Source: UNSW)

**Australian Synchrotron milestone**

Australian research into the molecular make-up of cells in the body, common elements, and minerals has reached a milestone with researchers at the Australian Synchrotron releasing detail of their 1000th protein structure to the world, paving the way for improved understanding of disease and more targeted therapies.

Detailed imagery of the Bax protein, determined by scientists from the Walter and Eliza Hall Institute of Medical Research in Melbourne using the Australian Synchrotron, was the 1000th structure submitted to the Protein Data Bank, a free and open-access central repository for crucial molecular information that supports global biological research.

Atomic structure of the Bax protein

Dr Peter Czabotar from the Walter and Eliza Hall Institute says Bax will now be analysed to understand key steps involved in programmed cell death in diseases.

‘Through our experiments at the Australian Synchrotron, we can now picture the molecular structure of Bax and, by analysing its surface, shape and interactions, we can now work toward treatments that support, or block, its activity, depending on its role in different diseases, including cancer.’

**2016 Richtmyer Memorial Lecture Award**

The American Association of Physics Teachers (AAPT) has selected Derek Muller to receive the 2016 Richtmyer Memorial Lecture Award. Muller, who completed a PhD in Physics Education Research at the University of Sydney in 2008 received the award for outstanding contributions to physics and for effectively communicating those contributions to physics educators. The award was presented at a Ceremonial Session of the AAPT Winter Meeting in New Orleans, Louisiana. The topic for his lecture was *Why some confusion is good - Evidence for how to make learners think.*

Dr Derek Muller

Derek was born in Australia, raised in Canada, where he graduated with a B.Sc in Engineering Physics from Queen’s University in Ontario. He then completed a PhD at the University of Sydney with a thesis entitled, *Designing Effective Multimedia for Physics Education*. He began putting his research into practice with his Veritasium YouTube channel in 2011. This quickly led to joining the team of the ABC’s Catalyst. He has also been featured on the BBC, Discovery Channel, History Channel, and he recently presented a two-part documentary on PBS entitled *Uranium: Twisting the Dragon’s Tail.*
Bust of William Bragg unveiled
A bust of William Bragg was unveiled on 2 December on North Terrace, Adelaide next to the existing bust of his son Lawrence Bragg. The unveiling was performed by the Governor of South Australia, Hieu van Le on the centenary of the awarding of the 1915 Nobel Prize for Physics to William and Lawrence Bragg.

(Left to Right) the Governor, Hieu van Le, Mr Andrew Bragg (grandson of WLB), Lady Lucy Adrian (grand-daughter of WHB), and John Patterson (Physics, University of Adelaide) with the two busts.

Erratum
On page 212 of the last issue - vol 52(6) - the cover image accompanying David Jamieson’s review of One Hundred Years of the Bohr Atom: Proceedings from a conference, F. Aaserud and K. Kragh (eds.), was erroneous. The correct image is reproduced here.

BRANCH NEWS

New South Wales
The NSW Branch and Royal Society of NSW held their annual Postgraduate Awards Day in November.

Each of the state’s universities was asked to nominate a student to make a 20 minute presentation on their postgraduate research. Presentations were judged on content and scientific quality, clarity, and presentation skills. The winners were:
- Postgraduate Presentation Award: Katie Chong (ANU), Shaping Light with Optics
- Royal Society of NSW Jak Kelly Award: James Colless (University of Sydney), Quantum Machines

The audience also heard from postgraduate students Yevgeny Stadnik (UNSW) on Dark Matter and Astrophysics, Frederick Wells (University of Wollongong) on Imaging of Superconducting Thin Films, and Michael Cowley (Macquarie University) on Supermassive Black Holes.

The Branch’s Community Outreach to Physics Award was presented to Amanda Bauer from the Australian Astronomical Observatory.

Invited speaker Michael Burton (UNSW) spoke on Interstellar Explorers – Mapping the Molecular Clouds of the Southern Milky Way. The Branch annual dinner followed the presentations.

Items for News & Comment

Items for this section are welcome.
Submit items (with a suitable image) to the editor:
aip_editor@aip.org.au
The Association of Asia Pacific Physical Societies (AAPPS) is an umbrella organization which encompasses the physical societies and institutes in the region. It is devoted to the joint promotion of research, teaching and regional collaboration in physics.

It has its origins in the first Asia Pacific Physics Conference (APPC) in Singapore in 1983. The physics community in the Asia Pacific region, led by Prof. C. N. Yang and Prof. A. Arima, started to organize academic activities of their own in the Asia Pacific region, which attracted strong bottom-up support from Asia Pacific physics communities. The success of the ensuing APPC series consolidated a newly found sense of a physics community in the Asia Pacific region, which eventually led to the formation of the Association of Asia Pacific Physical Societies (AAPPS) and the Asia Pacific Center for Theoretical Physics (APCTP).

The AAPPS was founded in 1990 in Seoul, Korea where the Fourth Asia Pacific Physics Conference was held. There had been a growing recognition of the need to form an Asia Pacific society similar to the European Physical Society (EPS) and the American Physical Society (APS).

AAPPS is governed by an 18-member council. For 2014-6 the president is Seunghwan Kim (Asia Pacific Center for Theoretical Physics/POSTECH, Korea). The immediate past AIP president, Rob Robinson, is a member of the Council.

The Asia Pacific Physics Conference (APPC), held every three years, has been the core conference organized by the AAPPS. The AAPPS Bulletin, launched in 1991 and published bimonthly, serves as the official publication of the association, and carries both news items and review articles from the Asia Pacific region. The bulletin is now an online publication: http://aappsbulletin.org/

The 13th APPC will be held in Brisbane in December 2016, in conjunction with the 22nd AIP Congress (Brisbane, 4-8 December, 2016; see first announcement on p29)

At present there is a drive to establish a divisional structure for AAPPS, with the first division, the Division of Plasma Physics, established in 2014

**AAPPS MEMBER SOCIETIES**

- ASEAN Institute of Physics
- Australian Institute of Physics
- The Chinese Physical Society
- The Physical Society of Hong Kong
- Indian Physics Association
- Indonesian Physical Society
- The Physical Society of Japan
- The Japan Society of Applied Physics
- The Korean Physical Society
- Malaysian Institute of Physics
- Mongolian Physical Society
- Nepal Physical Society
- New Zealand Institute of Physics
- Physics Society of the Philippines
- Institute of Physics, Singapore
- The Physical Society located in Taipei
- Thai Institute of Physics
- Vietnam National Institute of Physics
Cosmic Hydrogen and the First Galaxies in the Universe

Stuart Wyithe*

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*Awarded the AIP's Boas Medal for 2014.

Astrophysics seeks to both understand how the Universe works today, and to uncover how it formed and evolved throughout cosmic history. Fortunately the finite speed of light allows us to view the Universe at large distances as it existed in the past. This cosmic archeology can be observed in electromagnetic radiation back to times when the Universe was just 380 thousand years old. However there is a large gap in the historical record, encompassing times between 380 thousand and 1 billion years after the Big Bang where observations are sparse. This important epoch includes the formation of the first galaxies and the ionisation of hydrogen throughout the cosmos. This article reviews what we know of this period, the new observations that will fill in pieces of the puzzle, and describes some of the theoretical challenges for understanding the formation and evolution of the first galaxies.

Three major stages in the evolution of our Universe are written in the phases of cosmic hydrogen. Current theory has the Universe beginning with a “Big Bang”, followed by a period of exponential expansion known as inflation that drove the Universe to a flat Euclidean space-time and introduced macroscopic fluctuations of energy density. Light elements were subsequently created through nucleosynthesis as the expanding Universe cooled, producing ionised plasma dominated by hydrogen and helium. As expansion further cooled the Universe, hydrogen went through a phase transition in which the primordial plasma “recombined” to form atomic hydrogen approximately 380 thousand years after the Big Bang. Following this recombination event photons were able to travel freely for the first time, and are observed today as a diffuse glow on the sky known as the Cosmic Microwave Background (CMB).

The power-spectrum describing the spatial frequency of fluctuations in the CMB has been measured with great precision, and provides statistics of the density field that represent the initial conditions for the observable Universe. The small ripples (1 part in $10^4$) of density observed at this time grew under the influence of gravity, forming the sites of the first stars and eventually leading to modern-day galaxies. Subsequently, photons produced by the first stars forced hydrogen in the Universe back through a second phase transition. These phase changes in the ionisation state of cosmic hydrogen bookend the period of cosmic history during which the first galaxies formed.

Our modern picture of the Universe includes an expanding space-time that is flat, homogeneous and isotropic on very large scales. The Universe contains 25% of its mass energy in a collision-less dark matter, and 71% in dark energy that has a density that is constant during expansion, with the remaining 4% being baryonic matter. Within this expanding space-time, gravitationally driven formation of dark-matter halos provided deep potential wells where baryonic material could reach sufficient densities to form stars. The CMB reveals that the density fluctuations seeding these dark matter halos had the properties of a Gaussian random field at early times. One outcome is that small galaxies grew first and are clustered, leading to the formation of larger objects at later times through gravitationally driven mergers. This picture is referred to as the hierarchical growth of galaxies.

While some of the atomic hydrogen in the early Universe formed stars within galaxies through this hierarchical formation, most baryons remained in the space between galaxies. Theory suggests that the first stars should have appeared a few hundred million years after the Big Bang in very low mass, mini dark matter halos, producing the first heavy elements. Galaxies subsequently formed in more massive dark matter halos resulting in a large flux of UV photons with energies greater than 13.6 eV (corresponding to the bound-free transition of the hydrogen electron), that reionised hydrogen in the Universe. The ionisation of the intergalactic hydrogen released the 13.6 eV of binding energy per hydrogen atom and in doing so raised the temperature of the expanding intergalactic gas from a few 10s of Kelvin to more than
The time during which intergalactic hydrogen was ionised by UV flux from early galaxies is referred to as the Epoch of Reionisation (EoR), and represents the last cosmic event that is yet to be studied in detail. The EoR was an important milestone in the history of the Universe for two reasons. First, the EoR identifies the epoch when astrophysical sources produced at least one UV photon per baryon, and so became the dominant influence on the thermodynamic conditions of the intergalactic gas from which galaxies form. Turning this around, the EoR provides an opportunity to study the properties of the first galaxies and stars that cannot be observed directly. The place of reionization in the cosmic timeline is illustrated in Figure 1. Since the ionisation and temperature of the intergalactic gas play a significant regulatory role in all subsequent galaxy evolution, the EoR must be understood as part of a complete theory of galaxy formation at any cosmic epoch.

**OBSERVING THE EoR**

Measurements of the EoR remain limited despite some significant advances over the past two decades. The CMB can be used to estimate the redshift\(^1\) of the EoR by looking at the fraction of CMB photons that Thomson scatter from free electrons in the reionised intergalactic medium. This is because the Thomson scattering optical depth measures the integrated ionisation along lines-of-sight between the observer and the CMB, probing the whole history over which the Universe was reionised. The earlier in the Universe's history that the EoR took place, the more path-length over which CMB photons are exposed to free electrons, and hence the larger the Thomson scattering optical depth. This optical depth can therefore be used to estimate the redshift at which the EoR was substantially underway, although it provides only a single number to describe the integrated reionisation history, and so is degenerate among a wide range of EoR scenarios. The most recent measurements from the Planck satellite indicate that significant reionisation was underway by a redshift of \(z \sim 10\).

While Thomson scattering of the CMB photons can be used to probe the distribution of ionised hydrogen, atomic hydrogen also has an extremely large optical depth for resonant scattering of radiation at 1216 Å corresponding to the 1s-2p transition. Redshifting of photons through this resonance therefore results in broad gaps or troughs in the spectra of high redshift sources. Conversely, the absence of absorption troughs in the spectra of the most distant known quasars indicates that hydrogen in the intergalactic medium was highly ionised by a redshift of \(z \sim 6\), and has remained so for the subsequent 12 billion years.

Thus, some constraints on the reionisation history are available based on a combination of existing observations. These studies indicate that reionisation was a reasonably extended process that must have been completed by \(z > 6\), but which could not have been completed at a redshift substantially higher than \(z > 7-8\). An example reionisation history showing the evolution of the mean atomic hydrogen fraction (designated \(<x_{\text{HI}}>\)) in a model that is consistent with current constraints is shown in Figure 2. While informative, these analyses illustrate the limited utility of current observational probes for studying the EoR in detail. In particular, hydrogen absorption studies become ineffective during the EoR due to the high scattering optical depth of the resonant line, and can only be studied along a few sight lines due to the rarity of the bright quasars required. On the other hand,

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\(^1\) The redshift \((z)\) of a source is defined such that the wavelength \((\lambda)\) of the radiation has redshifted by a factor of \(z = (\lambda_{\text{observed}}/\lambda_{\text{emitted}}) = (\lambda_{\text{emitted}}/\lambda_{\text{observed}}) = (1+z)\) owing to the expansion of the Universe. For reference, the Universe has an age today of 13.7 Gyr, \(z = 6\) corresponds to an age of \(0.8\) Gyr, and \(z = 10\) to an age of \(0.5\) Gyr.
the CMB Thomson scattering optical depth currently offers our most robust constraints, but it is restricted to being an integral, sky averaged measure.

In addition to observations of the ionisation state of cosmic hydrogen during the EoR, key information is provided by observing galaxies that produce the ionising UV radiation. These galaxies are distant and faint, and their spectra are absorbed by intervening atomic hydrogen across the entire optical spectrum, requiring observations to be carried out in the infra-red. Nonetheless, there has been great progress in this area with successive generations of cameras on the Hubble Space Telescope. Extremely sensitive observations have pushed the boundary back as far as \( z \approx 10 \) (Figure 3), with thousands of galaxies now observed during the EoR. An obvious question to ask is whether enough galaxies exist to provide the necessary star-formation to drive reionisation? Here, an important limitation is that only the intrinsically brightest galaxies can be detected, and so the observed radiation may only be the tip of the iceberg. Indeed, while the fraction of ionising radiation that escapes galaxies is uncertain, the star formation rates implied by the observed high redshift galaxy population suggests a total production of ionising photons that struggles to have been sufficient to complete reionisation by \( z \approx 6 \).

There are several key observational areas in which substantial progress will be made in the study of galaxies during the EoR over coming decade. In particular, forthcoming programs, using new surveys and instruments, will push observations of galaxies beyond the current redshift frontier. Following the success of the Hubble Space Telescope, the James Webb Space Telescope (JWST) is scheduled for launch in 2018. JWST is a large infrared optimised telescope that will be used to search for the high redshift galaxies thought to be responsible for reionisation. The advent of 30-meter class optical/IR telescopes in the next decade, such as the Giant Magellan telescope, will also open a new window on the Universe, allowing spectra to be taken of the earliest forming galaxies.

Until now, constraints on the reionisation of hydrogen have focused on the evolution of the mean ionised fraction. However theoretical simulations indicate that reionisation was not a uniform process. Rather, the EoR is thought to have started with small ionised regions around the first galaxies to form, and that these later grew to surround groups of galaxies. Reionisation is said to have completed once ionised regions overlapped, occupying most of the inter-galactic volume and leaving only dense islands of neutral gas (as shown in Figure 4). Thus, the process of reionisation is thought to have been inhomogeneous, owing to fluctuations in the ionisation structure of the intergalactic hydrogen. Measurements of the ionisation state as a function of both time and space are therefore required to advance our knowledge of reionisation and the first galaxies.

Such an opportunity is provided by tomography of the redshifted 21 cm emission line [1] from the forbidden spin-flip transition of the ground state electron. These observations will provide the first direct probe of atomic hydrogen in the high redshift Universe, enabling detailed studies of structure formation and the formation of the first galaxies. The 21 cm line has a long history in galactic and extra galactic astronomy, with a focus on the inter-stellar medium either of our own or of other galaxies. However recent advances in low frequen-
cy radio telescope arrays are making it possible to study diffuse atomic hydrogen that resided between galaxies during the EoR, using 21 cm radiation redshifted to wavelengths of ~2m. Radio telescopes such as the Murchison Widefield Array\(^2\) (Figure 5) currently lead efforts in this exciting new field, and the study of reionisation is a key scientific driver for the Square Kilometer Array\(^3\).

The goal of these new observations will be to elicit the physical history and origin of the first galaxies and the EoR, which can only be achieved using a sophisticated physical framework. Within this context, the development of theoretical models that include detailed physics of galaxy formation and intergalactic hydrogen are playing a key role. Utilizing these in combination with observational data to better understand the evolution of the EoR is key to making progress in this field.

**MODELING THE EoR**

In anticipation of forthcoming EoR observations, a great deal of theoretical attention has focused on connecting the galactic sources of ionising radiation with the inhomogeneous bubble-like structure of intergalactic ionization. This theoretical work can be divided into analytic studies, full numerical simulations, and so called semi-numerical approaches.

Analytic descriptions of the reionisation process successfully describe the statistics of ionisation structure during hydrogen reionisation \(^2\). These models rely on the fact that the Fourier components of the density field evolve independently in the linear regime, and calculate the fraction of the density field that has evolved to a point where intergalactic hydrogen is ionised. Such methods can be used to calculate properties of the EoR like the evolution of the ionised fraction of cosmic hydrogen, and the size distribution and clustering of ionised hydrogen regions.

On spatial scales much larger than the bubble size (predicted to be ~10Mpc), analytic models have also been used to investigate the probability distribution for the intensity of the 21 cm signal. Galaxy bias, which quantifies the enhanced clustering of galaxies in denser than average regions of the Universe, is found to lead to a non-Gaussian distribution of 21 cm signal. The skewness in the statistics of 21 cm intensity fluctuations is not monotonic with redshift, even in a simple reionisation scenario, and so may provide an important probe of galaxy formation during the EoR \(^3\).

While analytic studies reveal many of the generic features of the reionisation process, the inhomogeneous, non-linear and non-Gaussian nature of reionisation implies that detailed modeling and understanding of the ionisation structure requires numerical simulation. A complete simulation requires high spatial resolution to study small-scale internal structure of galaxies, as well as the dense gas systems that regulate propagation of the ionising radiation. At the same time, a large simulation volume is necessary in order to contain a representative distribution of galaxies and the ionised regions generated. The fundamental problem for studying the first galaxies and associated reionisation processes therefore lies in the enormous range of spatial scales that must be included. Indeed, the characteristic sizes of ~10 Mpc...

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\(^2\) http://www.mwatelescope.org/

\(^3\) http://skatelescope.org/
reached by ionised regions contain a mass seven orders of magnitude larger than the host dark matter halos of small galaxies thought to drive reionisation. Furthermore, including a representative sample of ionized regions requires even larger volumes.

Compromises have necessarily been made in the modeling of galaxy formation in order to achieve the volumes required to make predictions for 21cm EoR experiments. Pioneering studies (e.g. [4]) were restricted to small box sizes of only ~10−20 Mpc, with a consequently small number of sources. However the results of these works illustrated that the abundance and luminosities of galaxies clearly affect the ionisation process. In large modern simulations, the most common approach has been to populate dark matter halos within an N-body simulation with ionizing sources, and then to use a simple prescription for assigning ionising luminosity. Radiative transfer methods are then employed to model the generation of ionised structure on large scales, based on the distribution of ionising sources. These numerical simulations describe the generic features of reionisation (e.g. [5]), confirming expectations from analytic models that large-scale, over-dense regions near galaxies are reionised first, and that massive galaxies tend to be surrounded by clusters of smaller galaxies that drive formation of large ionised regions. In addition, simulations show that ionised regions are generally aspherical, even where the sources are assumed to emit isotropically.

Given the extreme computational expense of running even approximate radiative transfer techniques on the tens of thousands of ionising sources needed to correctly simulate the EoR, “semi-numerical” models have been developed that estimate the ionisation field by applying a filtering technique on the source galaxy population that determines whether enough galaxies have formed to ionise a particular region [6]. These techniques are in good agreement with full radiative transfer because of the relatively short mean-free-path of ionising radiation, and can therefore be used to explore a larger range of EoR scenarios than possible with current numerical simulations. Importantly, these models retain information on the spatial distribution of sources and ionisation structure. However, further progress towards realistic simulations of the EoR will require more realistic modeling of galaxies.

**SIMULATED GALAXIES DURING THE EoR**

Within our modern understanding of hierarchical galaxy formation, infalling gas is assumed to gain kinetic energy, and then to be shock heated to the virial temperature of a dark matter halo following its formation or merger. This hot gas can subsequently cool via a number of mechanisms, including free-free and bound-free emission, which remove the thermal energy, resulting in a more compact bound system with reduced total energy. The cooling time is longer than the gravitational infall time in both large (M > 10^{13} M_\odot) and small (M < 10^8 M_\odot) mass dark matter halos due to the inefficiency of free-free radiation and the lack of collisional excitation of hydrogen respectively. Stars cannot form within these systems as hydrostatic forces keep the hot gas at low density. However for halos within this mass range there is a cooling radius for which the cooling time is equal to or less than the gravitational infall time. At radii smaller than the cooling radius the shock-heated gas has sufficient time to cool, and the loss of energy from the system removes the hydrostatic support, allowing gas to flow to the center where it settles into a rotationally supported disk. Star formation occurs in the cold (< 10^4 K) gas in this disk, where the density is sufficiently high.

Several processes reduce the efficiency of galaxy formation. Once the intergalactic gas is heated, gas infall into the gravitational potential requires dark matter halos to be more massive than the cosmological Jeans\(^4\) mass [7]. Thus, the temperature increase of the intergalactic hydrogen during the EoR leads to a reduced baryon fraction in individual host dark matter halos of galaxies, and hence a slowing of low mass galaxy formation (termed self-regulated reionization). In addition, even within systems where gas is able to cool onto a dense central disk, internal galaxy feedback from supernova limits subsequent star formation by heating cold gas and by injecting thermal energy into gas that is yet to cool, potentially unbinding it from the dark matter halo.

As part of the Dark-ages Reionisation And Galaxy

\(^4\) The Jeans mass is the minimum mass of dark matter halo required to provide the gravitational force necessary to overcome gaseous pressure support.
Figure 6: The galaxy stellar mass function at $z=6$. Data points show the observed values [9]. The blue line shows the fiducial Meraxes model, and the grey line indicates how supernovae are required to suppress run-away star formation in low mass galaxies. Galaxies with stellar masses smaller than $10^9$ $M_\odot$ are too faint to observe [8].

Observables Numerical Simulation (DRAGONS) program, a new semi-analytic galaxy formation model (Meraxes) has recently been developed for studying galaxy formation during the EoR [8]. Meraxes implements the galaxy formation scenario described above within a dark matter only N-body simulation of the hierarchical growth of structure [10]. The model is the first of its type to include a temporally and spatially coupled calculation of ionisation structure in order to self-consistently model the evolution of high redshift galaxies, and their effect on the surrounding intergalactic medium.

The Meraxes model with supernova feedback naturally reproduces the observed evolution of the galaxy stellar mass function (number of galaxies per unit stellar mass per unit volume) during and after the EoR (Figure 6). The galaxy stellar mass function describes both the total number of stars produced in the Universe as well as the dark matter halos in which they formed, and so provides the key test for galaxy formation models. As shown in Figure 6, the Meraxes model produces many more stars than observed if supernova feedback is removed, particularly at small galaxy masses. Supernova feedback was therefore very important for early galaxy formation.

By treating both supernova, and reionisation feedback self-consistently, the Meraxes model demonstrates that reionisation has only a small effect on the history of galaxy formation. This lack of “self-regulation” in the production of ionising photons arises due to the already efficient quenching of star formation in low mass galaxies by supernova feedback. The predictions of the Meraxes model can also be compared to the most recent measurements of the Thomson scattering optical depth for CMB photons. Because Meraxes has been calibrated to the number of stars produced in galaxies during the EoR, the model can in turn constrain the fraction of ionising photons escaping from high redshift galaxies. This escape fraction is found to be in the range of $0.1 < f_{esc} < 0.4$.

**FUTURE 21cm CONSTRAINTS**

An important outcome from the large cosmological volumes attained by modern numerical simulations has been the prediction of the redshifted 21 cm signals that will be observable using forthcoming low frequency arrays (e.g. [11]). Owing to the modest signal-to-noise expected for first generation telescopes, including the MWA, most attention has been focused on statistical observations of the power-spectrum of 21 cm fluctuations together with its evolution, which will trace the timing of the EoR as well as properties of the ionised regions. The generic features of the predicted 21 cm power-spectrum and its evolution are shown in Figure 7. The amplitude and slope of the power-spectrum both vary in a non-monotonic way relative to the expected shape in the absence of ionisation structure. In particular, the formation of large ionized regions late in the EoR (blue curves) results in excess power on large spatial scales that probes galaxy formation, providing a discriminant from the gravitational evolution of structure that probes cosmology.

Thus, measurement of evolution in the 21 cm power
spectrum will provide the first clues regarding clustering of ionising source galaxies during the EoR. Simulations show that the amplitude of the 21 cm power-spectrum reaches a maximum close to the epoch when ~ 50% of the volume of the IGM is ionised. Current EoR telescopes like the MWA are designed with sufficient sensitivity to measure redshift evolution in the amplitude of the power spectrum at spatial frequencies of $k \sim 0.1\,\text{Mpc}^{-1}$.

The power-spectrum is the natural quantity with which to describe fluctuations in redshifted 21 cm emission during the early phases of reionisation when the statistics are expected to be Gaussian. However the distribution of fluctuation amplitudes becomes non-Gaussian as ionised regions form during the EoR. As a result, the power-spectrum does not provide a complete statistical description of the reionisation process, and the full probability distribution of intensity fluctuations should be considered. Unlike the power-spectrum, the probability distribution for intensity fluctuations must be derived from direct imaging of the ionisation structure. Such observations require the much greater sensitivity of the Square Kilometer Array (SKA), which will allow observation of individual ionised regions and open up the possibility of directly probing galaxy formation physics during the EoR. Before finishing this article we therefore look forward to what can be expected from the future of instrumentation in this field.

Figure 8 illustrates a simulation of the expected response of the SKA to the predicted ionisation structure. The simulated stage of reionisation corresponds to 50% ionisation at a redshift of $z = 7.3$. Radio telescope interferometers sample the Fourier transform of the image at the spatial frequencies corresponding to the distribution of antenna separations. The image shows how the telescope array configuration impacts the features of the image that can be measured. On spatial scales where there are no antenna pairs, features in the image cannot be observed. This includes both small and large angular scales. Thus, in addition to dictating the behaviour of noise, the telescope array configuration determines which properties of the ionised regions can be imaged. The central panel of Figure 8 shows a simulation slice including only signal on scales measured, as well as the extent of the primary beam gain.

Experimental barriers to measuring the reionisation structure include foreground emission from Galactic synchrotron and extra-galactic point sources as well as the effects of removing the diffuse Galactic foregrounds, which can lower the contrast of observed images. The right panel of Figure 8 shows a simulated image following removal of the diffuse foreground radiation from our galaxy. The simulation suggests that large ionised regions produced by galaxies with supernova feedback can be imaged by the SKA.

The EoR remains the last unexplored era in the history of galaxy formation. Although sophisticated numerical simulations provide us with some physically motivated scenarios and predictions to test, fundamental questions remain unanswered. These questions include how and where the first galaxies formed and how massive they were, as well as how these first galaxies influenced their surroundings and the subsequent history of the Universe. Using a fleet of new infrared and radio telescopes over the coming decade, we will soon be able to study the connection between galaxy formation and the EoR in detail for the first time. This will herald an excit-
ing new era of discovery and complete some of the missing pieces in the puzzle of the history of our Universe.

Acknowledgements
The author would like to acknowledge support from the Australian Research Council through the Centre of Excellence for All-sky Astrophysics (CAASTRO), and the Australian Laureate Fellowship scheme.

References

AUTHOR BIOGRAPHY
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Nanophotonics beyond the limit of Abbe’s law

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Photonics has transformed massively our everyday life and global economy for a sustainable future. Nanophotonics, which studies optical science and technology at a nano-scale, has enabled the development of nano-scale optical and photonic devices that provide a green-technology platform. Abbe’s law, originating from the diffraction nature of light, has set up a barrier for any efforts from the researchers to access extremely small regions in the nanometre scale. In this paper, we will show that removing this barrier can provide a new horizon for the development of ultrahigh-capacity optical storage devices, nano-engineered biomimetic photonic crystals and superresolution fibre-optical endoscopy.

Introduction

In 1873, a German physicist Ernst Abbe discovered a fundamental law regarding the size of the focal spot when a light beam propagates through an optical lens, which originates from the diffraction nature of light. Specifically, Abbe’s law states (Figure 1) that the focal size \(d\) is proportional to the wavelength of the illumination beam, \(\lambda\), but inversely proportional to the product of the sine of the maximum angle of convergence, \(\alpha\), when a light beam propagates through the lens and the refractive index \(n\) of the medium where a lens is immersed [1]. This product is the concept of numerical aperture in the microscopy community.

On the basis of this law, the focal spot cannot become smaller than half of the wavelength or around 500 nm for visible light. Abbe’s law has boosted the technique revolution in modern optical microscopy which plays an irreplaceable role in multidiscipline research fields in physics, chemistry, material science, and biological science. However, the law also set up a barrier for any efforts from the researchers to access extremely small regions in the nanometre scale.

Optical microscopy established on Abbe’s law exhibits the diffraction-limited resolution barrier that an optical microscope can reach in an image plane. Two-photon or multiphoton optical microscopy, physically based on the phenomenon discovered by Maria Göppert-Mayer [2], a Nobel Laureate in 1963, has revolutionised modern optical microscopy [3]. Along with confocal optical microscopy, multiphoton optical microscopy provides a powerful tool to view the three-dimensional (3D) microscopic world which is inaccessible by conventional two-dimensional (2D) optical microscopic. These technological breakthroughs led to major fundamental investigations in optical imaging science, which includes the effect of optical diffraction on 3D optical imaging resolution [4, 5], the effect of multiple scattering in a turbid medium on 3D optical image formation [6] and

![Figure 1: Abbe’s law engraved on his monument erected in a central park of Jena, Germany.](image)
the innovations to overcome Abbe’s diffraction-limited resolution barrier so that scientists can access small structures on a nanometre scale. In the following, two breakthroughs in overcoming the diffraction-limited resolution barrier, superresolution photoinduction-inhibited nanolithography (SPIN) under two-photon excitation [7] and superresolution fibre-optical two-photon endoscopy [8], are introduced and their impacts in nano/biophotonics are explained.

Almost 100 years after the discovery of Abbe’s law, the concept of optical disks was developed by James Russell. Although optical disks, carrying loads of application software, entertaining films and games, and private documentary information, have great advantages over other recording media in terms of cost, longevity and reliability, the low capacity of the device is the main hurdle for further development. The operation of optical data storage is rather simple. The information is transformed to strings of bits and each bit is in the form of dots made by a light beam focused by a lens into a recording medium [9]. 

The storage capacity of optical disks is mainly determined by the physical dimensions of the dots limited Abbe’s law. Many current methods such as DVD and Blue-ray disks, which have tried to increase the numerical aperture of the recording lens or reduce the wavelength of the recording beam, continue to suffer from the low level of the storage density in the age of big data. One of the breakthroughs in this field is the adoption of two-photon optical microscopy in conjunction with the utilization of a recording medium doped with nanoparticles such as nanorods [9, 10]. This multi-dimensional optical data storage invention has allowed an increase in the data capacity up to Terabytes/disk [10]. However, the size of the recorded dots is still limited by Abbe’s law.

Our solution to break the Abbe’s limit is SPIN [7], transforming the conventional single-light-beam method to a two-light-beam method of different colors for recording. The principle of SPIN is illustrated in Figure 2(a). Both of the beams have to abide by Abbe’s law, which cannot produce smaller features individually. But we endow the two beams with different functions in SPIN. One beam with a football-like shape focus (vertical direction) is used to initiate polymerization in a photosensitive which we call the writing beam. The second beam with a doughnut-shape focus (horizontal direction) is used to inhibit the photopolymerization triggered by the writing beam in the donut ring, which plays an anti-recording function. The two beams are spatially overlapped. As the second beam terminates the polymerisation in the out ring, the recording process is tightly confined in the centre of the writing beam. By increasing the intensity of the second beam, one can generate recording dots with a size far below Abbe’s limit. For the case of photopolymerisation, the size of the recorded bits is given by

$$
\gamma / \sqrt{1 + \beta \times I_{\text{inhibition}}^4 / I_S}
$$

where \(I_{\text{inhibition}}\) is the intensity of the writing beam and \(I_S\) is the saturation intensity of the material; \(\gamma\) and \(\beta\) are constants related to the illumination wavelengths and the numerical aperture. Eq. (1) implies that ultimately the recorded feature size is determined by the inhibition intensity and is unlimited. Figure 2(b) shows that a recorded feature size of 27 nm, which is approximately \(\lambda/30\) for a wavelength of 800 nm. For 3D recording, this new technique produces an effective focal spot of 9 nm that is 1 ten thousandth of a human hair [7].

We have shown how we break the fundamental

![Figure 2: (a) Principle of superresolution photoinduction-inhibited nanolithography (SPIN); (b) Diffraction-unlimited optical data storage.](image)
limit associated with the diffraction limit of the light, and realise the optical beam lithography technique with a nanometre recording ability that could lead to ultra-high density data storage. The exceptional penetration feature of light beams associated with two-photon excitation by the writing beam allows 3D recording or fabrication, which can dramatically increase the integrated components in a single optical device. Comparing with the conventional DVD with the storage capacity of 4.7 Gigabit, the new technique enables a data capacity for digitalized information up to 1 Petabytes on a single disc, an increase of around 6 orders of magnitude. The new breakthrough allows for the development of optical data storage possessing a long life and the low energy consumption, which can become an ideal platform for a big data centre [11]. As information generated worldwide doubles every two years, the pursuit of more storage capacity for smart and highly compact devices will continue indefinitely. This breakthrough could lead to reduced cost and increased energy efficiency for the sustainable development of information technology.

**Biomimetic photonics**

In 1828, William Nicol, a Scottish scientist invented the polarizing beamsplitter, a device that was able to split light based on its linear polarisation state. It works by using crystals that refract light differently based on their linear polarisation. This optical property is known as birefringence. Since then polarising devices such as Nicol’s beamsplitter have been an essential tool in modern optical technology including photography, microscopy, telecommunications, multimedia and of course photonics. However, circularly polarised analogues of the Nicol beamsplitter are much harder to realise as naturally grown crystals lack circular birefringence. So to construct such a device one must create an artificial material, specifically, one with very strong sensitivity to circularly polarised light. The design of such a crystal is quite a challenge and has been a sought-after goal of scientists for many years. We have shown how we have achieved this goal by making artificial crystals inspired by the wings of a butterfly [12]. The design for these new “photonic crystals” was inspired by nano-structures called gyroid structures, found within the wings of the *Callophrys Rubi* butterfly, also known as the Green Hairstreak (Figure 3(a)). A gyroid structure has a 3D chiral geometry with a cubic symmetry and is the unique platform for developing chiral nanophotonic chips.

To build these nano-structured crystals we have used 3D direct laser writing (DLW) with nano-scale resolution. DLW is an important milestone resulting from the integration of ultrafast laser beams with an optical microscope as it allows for nonlinear excitation in the focal region. Nonlinear excitation such as two-photon excitation removes the necessity of using a confocal pin-hole for 3D imaging. In the context of optically induced fabrication, two-photon excitation is a flexible tool for 3D micro-fabrication.

To fabricate a biomimetic gyroid structure, we have invented an entirely new two-photon-induced galvo dithering DLW method [12]. The resultant breakthrough unequivocally shows that a biomimetic beamsplitter, (Figure 3(b)) that exhibits optical chirality, which cannot be achieved with a linearly polarising beamsplitter is feasible at telecommunication wavelengths (Figure 3(c)). With SPIN, it is possible to reduce the lattice constant of the gyroid structure, \( a \), from 3 \( \mu \)m (Figure 3(c)) to 300 nm (Figure 3(d)) which is smaller than the one existing in the natural *Callophrys Rubi* butterflies. As such, we have convincingly observed the world-first biomimetic chiral bandgap effect in the visible [13].

![Figure 3: (a) Callophrys Rubi butterfly with a 3D gyroid structure (inset); (b) A chiral beam splitter fabricated by two-photon-induced galvo dithering direct laser writing.](image-url)

Using this technology we can build our photonic crystal based on the butterflies nanostructures and create an artificial crystal with extremely high circular polarisation sensitivity. The technology offers new possibilities for steering light in nano-photonic devices and takes us a step closer towards developing optical chips that could overcome the bandwidth bottleneck for ultra-high speed optical networks. As to why the butterfly has such a
complex nano-structure with circular polarisation sensitivity within its wings is still a question under debate. Hopefully these advancements in nano-technology can unravel some of these mysteries.

4. Optical endoscopy

The invention of lasers in 1960 marked the birth of an entirely new era of optical science and technology. The combination of a laser beam and an optical microscope offers a way to confine a laser beam to a region smaller than the wavelength of the beam, determined by Abbe’s law. Scanning this focused spot across a sample under illumination leads to the invention of laser scanning microscopy such as confocal microscopy which gives an optical sectioning property for 3D imaging. Nonlinear excitation such as two-photon excitation under femtosecond laser beam illumination [14] removed the necessity of using a confocal pinhole for 3D imaging and inspired many exciting breakthroughs in superresolution microscopy by removing Abbe’s limit. The core of the stimulated emission depletion microscopy method, invented by the 2014 Nobel Laureate Stefan Hell, is the use of two laser beams rather than one [15]. In this case, the first laser beam induces fluorescence while the second one terminates it. With an appropriate spatial overlapping arrangement of the two beams, one can break the diffraction limited resolution barrier, leading to nanoscopy.

Optical endoscopy is miniaturised optical microscopy that is a vital tool for in vivo studies inside a human body. There is a high demand for the development of high resolution endoscopy for cellular investigation, treatment and surgery. This demand has inspired the development of multiphoton optical endoscopy [14]. The use of an optical fibre provides a unique advantage for the flexible delivery of a laser beam and the collection of a signal. However, single mode fibre cannot fulfill this role as it cannot propagate two optical beams at different wavelengths efficiently. We have pioneered a 3D multiphoton optical endoscope using cutting-edge double-clad photonic crystal fibres, providing a revolutionary tool for studying the origin of cancers under in vivo conditions [14]. However, its imaging resolution is limited by the low numerical aperture ( normally 0.3) of the imaging lens whose size is restricted by the compact design of an endoscope. Therefore, breaking Abbe’s diffraction limited resolution barrier is particularly needed for cellular studies at sub-micrometre resolution.

Figure 4 shows the superresolution two-photon optical endoscope with a probe of 4.1 cm in length and 0.5 cm in diameter (Figure 4(a)) [8]. A femtosecond laser beam (FS) with an ellipsoidal focal shape (Figure 4(b), (c), (d)) was used for two-photon excitation, while a continuous-wave (CW) beam with a doughnut focal shape (Figure 4(b), (e), (f)) for depletion of the fluorescence excited by the femtosecond beam. The key for this invention is the use of an azimuthally-polarised beam preserved through the double-clad fibre. The image resolution by this technology is increased by a factor of 3, reaching 300 nm.

Figure 4: Superresolution two-photon optical endoscopy.

Superresolution 3D multiphoton optical endoscopy will enhance our detection of these early lesions and enable appropriate screening for early cancer in a non-invasive way. As 1 in 3 Australians will feel the effects of cancers and there are over 10,000 cancer cases in gastroenterology every year, the new compact and portable endoscopy device will enable biomedical scientists to gain the fundamental knowledge needed to enable Australians to develop better medical strategies for healthy and productive lives.

Future

Optical microscopy based on diffraction-unlimited resolution feature holds a great future for nanophotonics. With the 3D SPIN ability, it is possible to develop exabyte optical data centres of century-long time span, topological photonic crystals, and the vertical integra-
tion of integrated circuits leading to ultra-fast optical information signal processors in the near future. Increasing image resolution to a sub-100 nm region in optical endoscopy will allow us to study the opto-magnetic sensitivity in brain functions.

Acknowledgement
The author thanks the Australian Research Council for its support through the Australian Laureate Fellowship, Discovery Project and Centre of Excellence (CUDOS) schemes.

References
1. Ernst Abbe, Über einen neuen Beleuchtungsapparat am Mikroskop (Bonn, Germany: Verlag von Max Cohen & Sohn), 9 (1873), 469.
8. Min Gu, Hong Kong, Xiangping Li, Breaking the diffraction-limited resolution barrier in two-photon fluorescence endoscopy by an azimuthally-polarized beam, Scientific Reports, 4 (2014), 3627.
9. Min Gu, Xiangping Li, A road to multi-dimensional optical data storage, OPN, July/August (2010), 28-33.
13. Zongsong Gan, Mark D. Turner, Min Gu, Superresolution optical beam lithography for biomimetic photonics (Presentation at the International Conference on Confocal Microscopy (FOM2015), Göttingen, Germany, March 29- April 1, 2015).

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Have you read a book recently that might be of interest to other members?
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INVITATION

One of the highlights on the Australian Institute of Physics’ (AIP’s) calendar is its biennial Congress, where physicists from all over Australia and overseas come together for a week-long program of plenary, keynote and contributed talks, social events, and the opportunity to network. We are delighted to announce that the next (22nd) such Congress will take place in the vibrant and progressive city of Brisbane from 4-8 December, 2016.

Brisbane is a significant physics ‘hub’, with major research facilities and groups at the University of Queensland, Griffith University, Queensland University of Technology, and the nearby University of Southern Queensland. Furthermore, and most importantly, the Congress will be held in conjunction with the 13th Asian-Pacific Physics Conference, the triennial meeting of the Association of Asian-Pacific Physics Societies that brings together physicists from across the entire Asian-Pacific region. This will be the first time that both meetings have been held jointly, and is certain to enrich the scientific program, as well as facilitate new links to be made between the Australian physics community and those throughout the Asian-Pacific region – something that is a high priority for the Australian Institute of Physics.

We very much look forward to your attendance at this joint 13th Asian Pacific Physics Conference and 22nd Australian Institute of Physics Congress and making it an outstanding success, both scientifically and collegially.

Warrick Couch
AIP President and Meeting Co-Chair

Halina Rubinsztein-Dunlop
Meeting Co-chair

To receive updates prior to registration opening, please register your expression of interest at the website:

http://aip-appc2016.org.au
If someone wanted to develop a schematic and build their own Large Hadron Collider, this would definitely be the book. Don Lincoln’s recent work *The Large Hadron Collider* is both very personable as well as being a thoroughly explained publication. Lincoln's skill is that he brings to bear an insider’s-eye view of the famous European particle accelerator and its workings.

Lincoln’s work combines the technical understanding of the LHC combined with the essential physics of what is happening at each stage of the process, and also what the researcher is attempting to measure. Lincoln enables readers with minimal to advanced physics training to enjoy the adventure. The descriptions of the teething problems of such an enormous device and yet the tight parameters for its construction cause any reader to pause. Especially when problems occur, the amount of energy being used and the subsequent damage caused by imperfections speaks of the scale of this project.

If tampering with the fabric of the universe was the goal of the ancient alchemists, then the physicists at the LHC are as close to performing magic as anyone in history. Lincoln’s account is factual, direct, and unembellished, but his voice never loses the tinge of excitement that a researcher feels at being handed this incredible machine. It is impossible to leave *The Large Hadron Collider* without being moved by the magnitude of the secrets being unlocked at CERN. Divided into eight easily readable chapters moving from what is known to what is still to be understood. The final chapter, ‘the future is bright’ is a fascinating glimpse into the realm of possibilities of direction for further research that the LHC and particle physics still has to offer.

The narrative does jump around a little bit between descriptions of subatomic particles and of the activities and construction of the LHC. The book’s easy, casual tone helps to make the normally daunting topic accessible, and playful anecdotes about the collider and the science that surrounds it will engage even those without initial interest. In fact, this book could hardly have been better published as a recruiting tool for universities specializing in physics. Lincoln makes the discovery of minuscule particles sound like so much fun that any high schooler with a passing interest in general science may be in danger of full conversion to professional theoretical physics.
analogies the physicists drew between sound and light, and the use of harmony as a metaphor, and infers that music had an important influence on modern science, or at least physics. Some of his longest such leaps concern Planck.

Like most of the heroes of this book, and indeed a reasonable proportion of physicists, Planck was an accomplished musician: he participated in musical evenings with his advisor Helmholtz, then later with Einstein and Joseph Joachim, a celebrated violinist. In his biography, Planck recounts how, soon after taking up his post in theoretical physics at Berlin in 1893, he ‘was temporarily assigned a … study of the untempered, ‘natural’ scale’. To test whether singers tended to sing using ‘natural’ or just intervals (i.e. those having simple whole number ratios) or whether they favoured equal temperament (where all semitones are equal with ratio $2^{1/12}$), Planck wrote a simple chorale in which consistent use of just intervals would lead the singers to a gradual descent in overall tuning. In an experiment, a chorus of ‘friendly musical ladies and gentlemen’ did indeed drift slowly down in pitch. Perhaps knowing that no-one experienced in choral music would accept this without considering other explanations, he then tried another experiment: a new chorale in which just intonation would lead to a slow rise in overall intonation. Result? The choir did not drift up! From this, Planck was converted from the natural tuning – whose ubiquity Helmholtz and he had hitherto staunchly defended – to accepting equal temperament, at least in most circumstances.

In this conversion about musical harmony, Pesic sees Planck readying himself to accept quantisation of energy. Pesic even draws an analogy between the equally spaced pitches of equal temperament and ‘the equally spaced quanta of his expression $E = h\nu$. Strange, because I don’t think Planck analysed the simple harmonic oscillator (where the energies are equally spaced), and in any case, the frequencies in the equal tempered scale are exponentially spaced. Pesic also makes much of the contrast between the arbitrary nature of musical pitch standards and the absolute nature of the (physical) Planck scale. This book doesn’t support its title and physicists will wince occasionally when reading it, but the history seems well researched and it’s full of good stories. It’s well illustrated with reproductions of historical drawings and, on an associated web site, a few dozen sound examples, some of them beautiful.

*Joe Wolfe researches the acoustics of the voice and of music at the University of New South Wales. He is also a composer, and one of his orchestral works uses the circle of fourths as a chord and a melodic nucleus.

**SAMPLINGS**

**New high-capacity battery goes with the flow**

Redox-flow batteries could be very useful for the safe storage of excess energy in electricity grids, but their deployment has been held back because they have far lower energy capacities than conventional lithium-ion batteries. Now, researchers in Singapore have built a new type of redox-flow battery that offers a higher energy capacity without losing the safety advantages that such batteries bring.

As more electricity is generated from renewable sources, electricity suppliers will have to find efficient ways of storing energy produced when the Sun is shining (or the wind is blowing) for use at times of peak demand. Storing energy in rechargeable batteries is one option, and various technologies that are used today include traditional lead–acid batteries and state-of-the-art lithium-ion batteries. However, these established technologies have their problems. Lead–acid batteries have limited storage capacity and lithium-ion batteries are prone to overheating, which makes the latter unsuitable for use in large-scale facilities.

**Charging up: the new redox-flow battery**

A redox-flow battery employs liquid electrolytes that are stored in two separate tanks. During charging or discharging, one liquid is circulated around the battery’s anode and the other around its cathode – which are themselves separated by a semipermeable membrane. Such batteries are less prone to overheating and combustion because the energy is stored in the tanks, which can be isolated from the point at which the electrochemical power generation takes place.

“It’s a bit like with the internal-combustion engine, where you have a tank for the gasoline and you just...
pump it into the engine to produce power,” says materials scientist Qing Wang, who led this latest research. The most developed designs use vanadium, which is stored and transported in aqueous solution. Unfortunately, this severely restricts energy capacity, because the vanadium salts are not very soluble in water.

Wang and colleagues have developed a new type of redox-flow battery in which the cathodic tank contains lithium-iron-phosphate granules and the anodic tank contains granules of titanium dioxide. When the battery is charged, “redox mediators” dissolved in the electrolyte are pumped through both tanks. Under the influence of an applied voltage, one of the redox mediators oxidizes the lithium in the tank, transporting the lithium ions into the reaction vessel. The reaction vessel is divided by a partially permeable membrane that allows lithium ions to pass but not the redox mediators. In the anodic half of the reaction vessel, other redox mediators combine with the lithium ions. These are then pumped through the titanium dioxide, where the lithium ions are reduced back to lithium metal, which intercalates into the titanium dioxide.

When the battery is discharged, the reaction runs in reverse, returning the lithium to the cathode. Because the lithium is stored in solid form in both of the charged and discharged states of the battery, the energy density of the new lithium-flow battery is about 500 Wh/l. This is around 10 times that of a vanadium redox battery.

[Chaunkun Jia et al, Science Advances, 1(10), e1500886; doi: 10.1126/sciadv.1500886 (2015)]

Extracted with permission from an item by Tim Wogan at Physicsworld.com.

Physicists put the arrow of time under a quantum microscope

Disorder, or entropy, in a microscopic quantum system has been measured by an international group of physicists. The team hopes that the feat will shed light on the “arrow of time”: the observation that time always marches towards the future. The experiment involved continually flipping the spin of carbon atoms with an oscillating magnetic field and links the emergence of the arrow of time to quantum fluctuations between one atomic spin state and another.

“That is why we remember yesterday and not tomorrow,” explains group member Roberto Serra, a physicist specializing in quantum information at the Federal University of ABC in Santo André, Brazil. At the fundamental level, he says, quantum fluctuations are involved in the asymmetry of time.

On target: the arrow of time could originate in quantum fluctuations

The arrow of time is often taken for granted in the everyday world. We see an egg breaking, for example, yet we never see the yolk, white and shell fragments come back together again to recreate the egg. It seems obvious that the laws of nature should not be reversible, yet there is nothing in the underlying physics to say so. The dynamical equations of an egg breaking run just as well forwards as they do backwards.

Entropy, however, provides a window onto the arrow of time. Most eggs look alike, but a broken egg can take on any number of forms: it could be neatly cracked open, scrambled, splattered all over a pavement, and so on. A broken egg is a disordered state – that is, a state of greater entropy – and because there are many more disordered than ordered states, it is more likely for a system to progress towards disorder than order.

This probabilistic reasoning is encapsulated in the second law of thermodynamics, which states that the entropy of a closed system always increases over time. According to the second law, time cannot suddenly go backwards because this would require entropy to decrease. It is a convincing argument for a complex system made up of a great many interacting particles, like an egg, but what about a system composed of just one particle?

Serra and colleagues have delved into this murky territory with measurements of entropy in an ensemble of carbon-13 atoms contained in a sample of liquid chloroform. Although the sample contained roughly a trillion chloroform molecules, the non-interacting quantum nature of the molecules meant that the experiment was equivalent to performing the same measurement on a single carbon atom, one trillion times.
Serra and colleagues applied an oscillating external magnetic field to the sample, which continually flipped the spin state of a carbon atom between up and down. They ramped up the intensity of the field oscillations to increase the frequency of the spin-flipping, and then brought the intensity back down again.

Had the system been reversible, the overall distribution of carbon spin states would have been the same at the end as at the start of the process. Using nuclear magnetic resonance and quantum-state tomography, however, Serra and colleagues measured an increase in disorder among the final spins. Because of the quantum nature of the system, this was equivalent to an increase in entropy in a single carbon atom.

According to the researchers, entropy rises for a single atom because of the speed with which it is forced to flip its spin. Unable to keep up with the field-oscillation intensity, the atom begins to fluctuate randomly, like an inexperienced dancer failing to keep pace with up-tempo music. “It’s easier to dance to a slow rhythm than a fast one,” says Serra.


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**Satellite sensor unexpectedly detects waves in upper atmosphere**

Atmospheric gravity waves drive winds, temperature and chemical composition in the middle and upper atmosphere, but not enough is known about those that occur at higher altitudes. Now though, an international team of researchers has unexpectedly discovered that the new “Day/Night Band” (DNB) sensor, on-board a US environmental satellite, can detect disturbances in the upper atmosphere’s nightglow caused by the waves.

“The DNB observations reveal a complex array of gravity waves in the upper atmosphere that have never before been observed globally at this spatial detail”, says Steve Miller of Colorado State University, US, adding that all of the data are available thanks to the sensor’s extreme sensitivity to visible and near-infrared light.

The DNB is part of the Visible Infrared Imaging Radiometer Suite (VIIRS) on the US NOAA/NASA Suomi National Polar-orbiting Partnership environmental satellite launched in October 2011. The sensor, which detects wavelengths of 505–890 nm, sits 834 km above the Earth and images the atmospheric state as it races by at about 7 km/s. When assessing their sensor’s performance, Miller and colleagues noticed clouds in images taken on nights without moonlight. They realized that the instrument could detect nightglow emissions, which in this case were reflecting off the clouds. Nightglow, also known as airglow, is due to emissions of light in the upper atmosphere from atomic oxygen, sodium and hydroxyl radicals. The emissions are strongest at about 85–95 km, around the mesopause.

**Thunderstorm creates concentric gravity waves above Bangladesh**

Although the DNB sensor is optimized to image the nocturnal surface and lower atmosphere at extremely low levels of light, the team discovered it can pick up nightglow emissions on dark nights. These emissions are sometimes disrupted by gravity waves – disturbances to the density of the atmosphere that gravity and buoyancy act to restore – that are the main form of energy exchange between the lower and upper atmosphere.

The gravity waves alter the local temperature and density, modulating the intensity of nightglow emissions and creating rippling patterns of visible light. They may appear as alternating bright and dark bands or as complex patterns, and the team found that the DNB can image the waves with a horizontal resolution of around 0.74 km.

The team imaged gravity waves resulting from a number of phenomena, including mountains, hurricanes, thunderstorms, tropical cyclones, the jet streams of intensifying cold fronts, mesospheric bores and, in the first known spaceborne measurement of its kind, a volcano. Chile’s Calbuco volcano erupted in April 2015, sending a plume of ash into the stratosphere and making a concentric-ring gravity-wave pattern in the nightglow.
above.

Miller says that the volcanic eruption suggests that other seismic-related airglow signals are yet to be observed, such as “a large earthquake, which may produce an observable ‘bright-sky’ airglow response and/or gravity-wave train coupled to a tsunami front”.


Extracted with permission from an item by Liz Kalaugher at physicsworld.com.

**Spectroscopy technique offers a new way to define temperature**

A special type of laser spectroscopy has been used by researchers in Australia to measure the velocities of atoms in caesium vapour. The technique could allow researchers to infer both the temperature of the vapour and the lifetimes and energy separation of the atomic states. It can also be used to measure Boltzmann’s constant, thereby helping to redefine the kelvin relative to universal physical processes.

![Heating up: physicists have a new way of measuring temperature](image)

Today, the temperature of an object in kelvin is defined relative to the triple point of water – the point at which ice, liquid and steam exist in equilibrium. In 2018 the kelvin is to be redefined in terms of the physics underlying temperature, which is “fundamentally a measure of the energy of the atoms and molecules in an object”, says metrology expert Michael de Podesta of the National Physical Laboratory in Teddington, UK. “We’re going to specify a value of Boltzmann’s constant, which is a certain number of joules per degree. That will tell you fundamentally that, if an object has this much energy of motion, then its temperature is this.”

Several groups are attempting to measure Boltzmann’s constant in different systems. The best measurement to date has an uncertainty of less than one part per million. It was made in 2013 by a team led by De Podesta, who used the speed of sound in argon gas to deduce the constant. In the new research, a team of physicists at several Australian universities used a different technique called Doppler-broadening thermometry, which relies on the spectral width of specific atomic transitions.

The researchers focused on two absorption lines in the caesium spectrum, corresponding to the same atomic transition but separated by the hyperfine splitting of the excited states. These lines are broadened by two underlying effects: the intrinsic uncertainty of the state’s energy as defined by Heisenberg’s uncertainty principle – which leads to a Lorentzian distribution – and the fact that, if an atom is moving towards or away from the laser, it sees a Doppler-shifted laser frequency. This latter effect provides a Gaussian variation in the frequencies to which the laser responds. The hotter the sample becomes, the faster the particles are moving, so this Doppler shift becomes more significant and the peaks become broader. By measuring the relationship between peak width and temperature, one can deduce the value of Boltzmann’s constant.

The researchers used a gas of ultra-low-density caesium atoms in a vacuum chamber and probed it with a cavity-stabilized microwave laser. They measured the transmission through the cell and recorded the two distinct dips at the positions of the absorption lines. Textbooks have previously modelled the line width as a simple combination of Gaussian and Lorentz distributions, but the precision of the researchers’ measurements revealed small yet significant deviations from this model. Most noticeable, at the level of hundreds of parts per million, were deviations caused by changes in the population statistics of the caesium gas by the laser.

Having corrected for these effects, the researchers extracted and separated the Gaussian component caused by temperature with unprecedented precision, producing an estimate of Boltzmann’s constant consistent with other measurements that has a precision of six parts per million and an uncertainty of 71 parts per million.

[G.-W. Truong et al, *Nature Communications*, 6, Article number: 8345; doi:10.1038/ncomms9345 (2015)]

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COHERENT SCIENTIFIC

Quantel Q-smart 100 – Compact, Rugged and Flexible

The Q-smart 100 is a 100 mJ @ 1064 nm laser with external, modular harmonic modules in compact platform reminiscent of the Quantel Ultra. The Q-smart 100 offer added flexibility in changing wavelengths, suitable for various applications. The hands-off alignment of the harmonic generators enables a new level of simplicity so that you can focus on your research and not on laser maintenance.

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For further information please contact: Jeshua Graham: jeshua.graham@coherent.com.au

SR124 Analog Lock-In amplifier for high-frequency noise reduction

For over a half century, the lock-in amplifier has been the instrument of choice for measuring small AC signals in the presence of noise. Modern digital signal processing (DSP) lock-in amplifiers typically are ideal for many applications. But for a core group of users, including low-temperature researchers in particular, DSP becomes a potential source of high-frequency interference.

Recognising that one size shouldn’t have to fit all, SRS offers the SR124 200 kHz Analog Lock-In Amplifier. Inspired by the best of an earlier generation’s lock-ins, but availing itself of today’s low-noise analog components and design methodologies, the SR124 is an uncompromising tour de force in low-noise, high-performance analog instrumentation.

The SR124 brings a <200 kHz lock-in capability to the lab without any digital interference and a low-noise, all analog design.

For further information please contact: Dr Dale Otten: dale.otten@coherent.com.au

New Research-grade Galvanostat/Potentiostat

Stanford Research Systems has recently released the EC301 30V/1A galvanostat/potentiostat. The EC301 gives electrochemists the opportunity to equip their labs with high compliance, research-grade instrumentation at a very attractive price. Stand-alone front-panel operation allows easy use in the field or in handling routine electrode preparation. The free Windows software (SRSLab) has routines for all major electrochemical experiments and can be downloaded from the SRS website (thinksrs.com). Further the EC301 has an open command set which allows scientists to write their own unique waveforms and even write custom software.

Available measurement types include: Cyclic Voltammetry (CV), Linear Sweep Voltammetry, Cyclic Staircase Voltammetry (also known as Tast), Square Wave Voltammetry and many more.

Galvanometric measurements of these techniques are accessed by simply changing the instrument mode, bringing this full suite of electrochemical experimentation to labs in a single, economic device.

For further information please contact: Dr Dale Otten: dale.otten@coherent.com.au

LASTEK

PHAROS single-unit integrated femtosecond laser system from Light Conversion

“PHAROS” is a single-unit integrated femtosecond laser system combining millijoule pulse energies and high average power. It features market leading compact size for easy OEM integration and laboratory space saving. Most of “PHAROS” output parameters can be easily set via control pad or PC tuning the laser for your particular application in seconds. Tunability of laser output parameters allow “PHAROS” system to cover applications normally requiring different classes of lasers. Tunable parameters include: pulse duration (190 fs – 10 ps), repetition rate (single-pulse – 200 kHz, extendable to 1 MHz), pulse energy (up to 2 mJ) and average power (up to 20 W). Its deliverable power is
abundant for a number of material processing applications, while the tunability in pulse durations and energies make it an attractive tool for the research applications.

Features:
- Pulse duration <190 fs - 10 ps,
- Pulse energy up to 2 mJ,
- Average power up to 20 W,
- Flexibility in repetition rate: single-pulse to 200 kHz (extendable to 1 MHz),
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Laser Quantum’s finesse pure CEP: The only 532 nm high power pump laser with direct power modulation for CEP stabilisation

Laser Quantum’s finesse pure CEP is the first and only 532 nm high power pump laser on the market that provides direct modulation input to its output power. Its patented technology has the ability to receive a phase related error signal from an f-to-2f interferometer into its controller, thereby modulating the output power and hence the carrier envelope phase of a few-cycle laser pulse. The enhanced bandwidth of the finesse pure CEP control loop permits a further reduction of integrated phase noise compared with the more conventional AOM method of phase control, particularly above 10 kHz making it simpler and more cost-effective.

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Applications:
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WARSASH SCIENTIFIC

Ophir – Spiricon NanoScan 2s
Warsash Scientific is pleased to announce the release of the latest version of NanoScan™2s scanning slit laser beam profiler for sub-micron measurement of beam position and size from Ophir-Spiricon, global leader in precision laser measurement equipment and a Newport Corporation company.

Now available in a more compact size, NanoScan 2s is a NIST-calibrated profiler that instantly measures beam position and size with sub-micron precision for CW and kilohertz pulsed lasers with measurement update rates to 20 Hz. The profiler offers silicon, germanium, or pyroelectric detectors; this allows profiling lasers of any wavelength from UV to far infrared, to 100 μm and beyond.

NanoScan 2s uses moving slits – one of the ISO standard scanning aperture techniques – to measure beam sizes from μm to cm at beam powers from μW to kW. The natural attenuation provided by the slit allows the measurement of many beams with little or no additional attenuation required. The digital controller
provides deep, 16-bit digitization of the signal for high dynamic range up to 35 dB power; this makes it possible to measure beam size and beam pointing with 3-sigma precision to several hundred nanometers. The silicon or germanium detector-based versions include an integrated 200 mW power meter that displays both total power and individual power in each of the beams being measured.

NanoScan 2s software can measure from one to 16 beams in the aperture with sub-micron precision. A beam can be found in less than 0.3 seconds and real-time updates can be displayed to 20 Hz. The software controllable scan speed and a “peak-connect” algorithm allows the measurement of pulsed and pulse width modulated lasers with frequencies of 10kHz and higher. The NanoScan 2s software comes in two versions, STD or PRO. The Professional version includes ActiveX automation for integrating the profiler into OEM systems or creating custom user interface screens using C++, LabVIEW, Excel, or other software packages.

SolsTiS® laser
Warsash Scientific is pleased to announce the latest release of the SolsTiS® laser from M Squared Lasers.

The SolsTiS is an ultra-compact, automated, widely-tunable, CW narrow linewidth alignment FREE Ti Sapphire laser system. This next-generation laser provides a narrow linewidth, high output power, broad tuning, all with the lowest noise in the industry.

SolsTiS wavelength control consists of nothing more than selecting a value – “dial a wavelength”. Single linewidth scans and scan stitching are also possible. The entire tuning range can be accessed without changing optics or re-alignment. The SolsTiS can also be locked externally to a transition, reference cavity or wavemeter. Fully integrated accessories such as beam pick-offs, fibre coupling and frequency conversion are available.

The system can also be integrated into an automated experiment via external commands through its controller, ICE-BLOC. The ICE-BLOC (‘instrument Control by Ethernet’) are super-fast ethernet connection based controllers which allow the laser to be controlled, monitored or diagnosed from across the room or half way around the world.

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

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ZURICH INSTRUMENTS AG

Low Noise Digitizer and Lock-in Amplifier
Zurich Instruments sets a new milestone with the Digitizer Option for the MFLI, a lock-in amplifier for the middle and low frequency range. Current and voltage signals are digitized with a sampling rate of 60 Msamples/s and a bandwidth of 7 MHz. Exceptional is the low input noise of 2.5 nV/√Hz and the 16 bit resolution (24 bit in HD-mode). The input range is adjustable from ±1 mV up ±3 V, or ±10 nA up ±10 mA, allowing a perfect adjustment to the signal amplitude.

Current and voltage signals can be acquired continuously as well as triggered with a demodulated signal, a signal threshold or a pattern on the digital inputs. This so called cross-domain triggering allows new measurement approaches.

The digitizer option is completely integrated into the LabOne user-interface. The instrument can be controlled from a web-browser without additional software installation, but LabOne also offers simple integration into MATLAB, LabVIEW, Python or C based programs. Additionally the input signal can be analyzed with the integrated oscilloscope, plotter, software trigger and spectrum analyzer. To complement the intuitive LabOne software, detailed documentation with tutorials and examples is available.

Application fields for the MFLI lock-in amplifier include optical chopper applications, MEMS characterization, pump-probe experiments, ultrasonic material research as well as quantum electronic research.

For more information contact Zurich Instruments AG at info@zhinst.com

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RAYMAX

HySpex Mjolnir-1024
The HySpex Mjolnir-1024 hyperspectral imaging system provides a unique combination of small form factor and low mass, combined with high performance specifications and scientific grade data quality. HySpex Mjolnir
covers the VNIR spectral range, 400 - 1000 nm, and is built with an optical architecture based on the high-end HySpex ODIN system.

With a weight of less than 5 kg and less than 50 W power consumption, HySpex Mjolnir-1024 is very well suited for a wide range of UAVs and applications. The UAV bundle offered by NEO integrates a hyperspectral camera with a PicoITX i7 SSD computer and an Applanix APX-15 UAV navigation system, all fitted into a self-contained module mounted on a passive damping platform.

NEO offers a high-performance unmanned aerial vehicle which is fully integrated with the HySpex Mjolnir-1024 UAV bundle. The system is fitted with a standard battery package allowing up to 30 minutes flight time.

**Specification**

**Mjolnir-1024**

<table>
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<tr>
<th>Spectral range [nm]</th>
<th>400 - 1000</th>
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<tbody>
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<td>Spectral sampling</td>
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<td>Spatial pixels</td>
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<td>Spectral channels</td>
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<td>Field of view (FOV)</td>
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<td>Pixel FOV across/along</td>
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<td>Bit resolution</td>
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<td>Noise floor</td>
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<td>Dynamic range</td>
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<td>Max speed</td>
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<td>Power consumption</td>
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<td>Dimensions (l-w-h)</td>
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<tr>
<td>Weight [kg]</td>
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</table>

**Introducing the MicroNIR from SPIE Technologies - Enabling Handheld, Portable and On-line Near-Infrared Applications**

JDSU is introducing an ultra-compact, lightweight, cost-effective near-infrared (NIR) spectrometer that relies on an LVF as the dispersing element. The LVF is a bandpass filter coating that has been intentionally wedged in one direction. Since the center wavelength of the bandpass is a function of the coating thickness, the wavelength transmitted through the filter will vary in a linear fashion in the direction of the wedge. The JDSU line of LVF spectral sensors uses an LVF coupled to a linear detector array to create a sensor capable of providing spectral information for a wide variety of commercial, industrial, and scientific applications.

The LVF detector, light source, collection optics, and electronics are fully integrated in a palm-size device weighing <60 grams. The wavelength range is 950-1650 nm; 1150-2150 nm. Robust architecture with no moving parts the MicroNIR is ultra-compact at 45 mm diameter x 42 mm high. Data collected with the system is easily exported to the embedded Calibration development software powered by CAMO software’s The Unscrambler® X.

The MicroNIR™ Pro spectrometer is offered with model building and real-time prediction software capability for at-line, on-line, and field-use applications.

**uFab3D from TeemPHOTONICS**

This low-cost nanosecond Q-switched Nd-YAG laser, developed by a team from Grenoble University and commercialised by TeemPhotonics of France, is suitable for applications in research and development, will greatly broaden access to direct-write protein microfabrication. Research into three-dimensional microstructures from different materials like polymers, proteins and noble metals are obtained by two-photon induced photochemistry which is a promising laser stereo-lithography technique. This cost effective laser will deliver suitable results comparable to its expensive cousin the Ti:sapphire femtosecond laser.

An open-ended system provides µManager based open source microscopy software. The system can be used with the following micro-fabrication materials: Monomers polymerisation, Microfluidic, Proteins crosslinking, Microstructure to control living cells, Bio-compatible materials and Metals precipitation, Photonic crystal.

For more information contact Raymax Applications Pty Ltd at

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Australia needs women in science

The SAGE Initiative was formed by the Australian Academy of Science to support the hiring, promotion, participation and retention of women in science, engineering, technology & mathematics (STEM), with the aim of reaching gender parity in science leadership. Women comprise more than half of science PhD graduates and early career researchers, but just 17% of senior academics in Australian universities and research institutes. The loss of women scientists is a significant waste of expertise, talent and investment, and negatively impacts our nation’s scientific productivity.

The SAGE pilot of the Athena SWAN Charter in Australia

The Athena SWAN Charter was established in the UK in 2005 to address the underrepresentation of women in science. Athena SWAN provides an evaluation and accreditation framework to help improve gender equity policies and practices, and it’s showing demonstrable results in the UK.

In August 2015, SAGE will launch a two-year pilot of the Athena SWAN Charter involving up to 20 Australian universities, medical research institutes and publicly-funded research agencies. This is your organisation’s chance to be a leader in Australia.

SAGE Pilot participants will:

• become members of the Athena SWAN Charter in Australia
• initially work towards accreditation under Athena SWAN for the Bronze institutional award
• be encouraged to promote their Athena SWAN membership to demonstrate their commitment to gender equity.

Benefits of joining the SAGE Pilot include:

• utilising a system that has a 10-year track record of success in improving gender equity policies and practices in the UK
• accessing a standardised methodological framework for collecting data and identifying gaps and opportunities in gender equity processes
• participating in workshops to support successful accreditation under Athena SWAN
• gaining constructive feedback, encouragement and support from an experienced team of gender equity experts.

Applications to participate in the SAGE Pilot are due on 20 July 2015. Learn more at www.science.org.au/SAGE

Enquiries to the SAGE Program Manager, Dr Zuleyka Zevallos: sage@science.org.au
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