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EDITORIAL

What is the purpose of Australian Physics?

I was recently asked: ‘What is the purpose of Australian Physics?’ A good question but, with five years as editor coming up, one that I have pondered at length. My simple, and ready answer, was ‘to inform the Australian physics community about activities within that community’. This rationale has guided me as I have sought articles and news items. While not wishing to limit the scope of Australian Physics, I see three clear categories of articles:

- Reviews of areas of research being carried out in Australia, written for an audience of physicists, most of whom will not have detailed knowledge of the field in question
- Articles related to the teaching of physics at all levels
- Career profiles of persons, who trained as a physicist but have undertaken a career outside the more obvious academic and government institutions

Australian Physics also serves as a forum for news and discussion of matters of concern for physicists. Accordingly, I see it as the journal of record for physics in Australia. This has been reinforced as I glance at content while continuing to scan old issues – in the last month issues from the late 1960s and early 1970s. They can now be found on the AIP website!

The first two articles in this issue fit clearly in the first category; the third article in the second category.

In their article, A metrological Scanning Probe Microscope for accurate length measurements at the nanoscale, Bakir Babic, Christopher H. Freund, Victoria A. Coleman and Jan Herrmann describe work carried out at the National Measurement Institute (Lindfield, NSW).

Daniel Leykam, who was awarded the AIP’s 2017 Bragg Medal for Excellence in Physics describes his thesis project in Wave and spectral singularities in photonic lattices. Daniel, now at the Center for Theoretical Physics of Complex Systems, Institute for Basic Science, Daejeon, Korea, completed his PhD at the ANU.

Finally in the first part of a two-part article Jason Dicker, formerly teaching physics at Launceston College, draws on his involvement in writing the physics syllabus for Tasmania and as a Tasmanian representative during the reviews and writing of the National Curriculum Physics to discuss expectations at the senior high school level across Australia in his article Year 11 and 12 Physics and Maths Expectations across Australia – a Survey (Part 1).

Brian James
I wrote in the last edition of the *Australian Physics* that we should never be shy of explaining why basic research is important. It is also true that we should be vociferous when it comes to highlighting the benefits of applied physics and the applications of physics as these may not be obvious to all. If you want an argument as to why this is important take a look at the Science and Technology article in January's edition of *The Economist*, which in discussing particle physics and collider funding, delivered this depressing thought – “That fundamental physics has got as far as it has is, essentially, a legacy of its delivery to political leaders of the mid-20th century of the atom and hydrogen bombs. … That legacy has now been spent, though, and any privilege physics once had has evaporated.”

I am not sure that things are as bad as *The Economist* makes out and funding for gravitational wave research is a good counterexample. It is also true that significant funding continues to flow into research that has a significant fundamental component where the ultimate applications are well signposted. Fusion research, in particular the ITER project, and quantum computing being two cases in point. It is also great to see Australian efforts, and strength, in both of these fields. Another area where physics research has received strong ongoing support is in light source technology and its applications with the operation of the European X-ray Free Electron Laser being among the top ten science stories for various publications in 2017. Interestingly, such research has both a strong Australian representation and is a field that arose as an application from particle physics accelerator research.

But iconic examples like these belie the feeling that there is difficulty in justifying support for physics and science more broadly. For instance the end of 2017 was only the second time since the 1930’s that Australia has not had a minister for science in cabinet. It is tempting to simply continue exhorting other scientists to do more in pointing out the links between scientific research and value to society but an exhortation without some tips on what to do is not that helpful.

In my last column I pointed out the lessons from communicating climate change and the importance of some good examples. The climate change case is not a bad place to use for more help – it can be complicated to demonstrate climate change and causality with human activity, it can also be complicated to demonstrate causality between scientific research and various measures of societal wellbeing. It may well be the case that there are social or cognitive factors that help explain why there can be resistance to the arguments put forward by scientists and there may be similar questions of degree – how much human activity is significant; how strong is the link between research and wellbeing and therefore how much support for science should there be?

While space precludes from summarising all of the lessons learned and how to apply them to help the cause of physics I can suggest two interesting articles that may prompt some of you out there to develop approaches that (if successful!) can be shared: “Why Facts Don’t Change Our Minds” by Elizabeth Kolbert in the February 2018 issue of *The New Yorker* examines some of the psychology behind how we think and form opinions; and “How to Convince Someone When Facts Fail” by Michael Shermer in the January 2017 issue of *Scientific American* considers issues of worldview and cognitive dissonance and, importantly, offers some tips on how try to convince people of your point of view. From those tips I would highlight the importance of showing respect and acknowledging an understanding of why others hold their opinions.

An area where worldviews are (slowly) changing with the help of respect and understanding is that of diversity in physics. The Australian Institute of Physics Women in Physics group is instrumental in this work in its advocacy on behalf of women and its efforts to bring cultural change within the discipline.

The Women in Physics team is currently bidding for the rights to host the 2020 *International Conference on Women in Physics* in Australia. Success in this venture would provide an excellent opportunity for the Australian Institute of Physics as a whole to interact with a wide range of experts in the field and to contribute to the ongoing vitality of programs supported by the Institute. To strengthen this effort the organising committee is looking for volunteers to help with the bid and, if successful, with the conference organisation. The committee is looking for diversity and all are welcome to apply. If you are interested in being involved please send a short biography to aip_WIP_chair@aip.org.au.

Andrew Peele
Letter to Editor

Our electromagnetic view of the world
Ever since reading Einstein's 1905 paper and studying relativity more than half a century ago, I have had a nagging feeling that I am missing something that everyone else finds obvious. The core of Einstein's argument was that the laws of physics are the same in any uniformly moving reference frame, and therefore, as Maxwell's equations express the laws relating to the electromagnetic field, the velocity of light must be the same in any such reference frame. From this, using light signals to communicate between events in different reference frames and to establish simultaneity, it follows that the elapsed time between two events depends on the observer's frame of reference. A further consequence was the connection between mass and energy, and from there it was, more or less, a matter of mathematics to formulate the theory in terms of the geometry of space-time.

The thing that puzzled me was that this seemed to say that there could never be another field with a velocity of propagation greater than c, thus giving a very special importance to the electromagnetic field. But is this not a very human-centric view? Just like we tend to think of ants as small and whales as big, and of ourselves as the final result of the evolution of life, and even something with a divine connection, is it not true that our interaction with the world is (except for hearing, smell, and touch) through the electromagnetic field, and so we interpret the world through this lens? But does the fact that we cannot perceive something mean that it cannot exist? Is this not a very restricted definition of existence? With the discovery of dark matter and dark energy, which we can observe only indirectly through gravitation, we should perhaps take a step back and rethink our theories outside the electromagnetic box.

And this goes not only for relativity, but for quantum theory as well. Don't forget that Planck introduced the quantum in order to explain the experimentally determined spectrum of black-body radiation, and the early development of quantum mechanics in terms of the energy levels of atoms is all based on the electromagnetic field.

Dr Erik W Aslaksen, FRSN

NEWS & COMMENT

Additional funds for NCI
In December 2017 the Australian Government announced funding of $70 million to replace Australia's highest performance research supercomputer, Raijin, at National Computer Infrastructure (NCI). Raijin is rapidly nearing the end of its service life.

NCI Australia is the nation's most highly integrated high-performance research computing environment, providing world-class services to government, industry, and researchers. Based at The Australian National University, NCI is home to the Southern Hemisphere's fastest supercomputer, its highest performance research cloud, its fastest filesystems and Australia's largest research data repository.

NCI is supported by the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS), with operational funding provided through a formal collaboration incorporating CSIRO, the Bureau of Meteorology, The Australian National University, Geoscience Australia, the Australian Research Council, and a number of research intensive universities and medical research institutes.

Bright future for Australian energy storage
A report released in November by the Australian Council of Learned Academies (ACOLA) suggests that Australia has the potential to lead the world in developing large and home scale energy storage systems if public uncertainty can be overcome.
The report, *The role of energy storage in Australia’s future energy mix*, shows that Australia has a wealth of natural advantages that could aid the development of new industries and exports while also creating jobs in mining and manufacturing. It also warns that without proper planning and investment in energy storage, electricity costs in Australia will continue to rise and electricity supply will become less reliable. The report finds the public had some awareness of energy storage such as batteries and pumped hydro but had very limited knowledge of other emerging technologies such as renewable hydrogen.

"This report clearly shows the two sides of the coin – that energy storage is an enormous opportunity for Australia but there is work to be done to build consumer confidence," said the chair of the ACOLA expert working group, Dr Bruce Godfrey.

"Given our natural resources and our technical expertise, energy storage could represent a major new export industry for our nation," said Australia’s Chief Scientist, Dr Alan Finkel.

"This is the first in a series of ‘horizon scanning’ reports. By working closely with the Office of the Chief Scientist ACOLA aims to present evidence-based reports on key issues to the Prime Minister’s Commonwealth Science Council to inform policy making and identify opportunities," said ACOLA President, Professor John Fitzgerald.

The report explains that energy storage solutions can improve Australia’s energy system in two major ways. First, by providing greater security by stabilising frequencies that fluctuate within seconds especially with renewable energy sources such as wind and solar farms. Second, by improving reliability by providing additional back-up power when needed in times of high demand such as heatwaves.

The report was co-funded by ACOLA and the Office of the Chief Scientist. The full report can be found at [www.acola.org.au](http://www.acola.org.au)

**Manjula Sharma elected to IUPAP**

Professor Manjula Sharma has been elected as the Australian representative on IUPAP – the International Union of Pure and Applied Physics.

IUPAP is an international body with almost 100 years of heritage behind it. Its mission is to promote physics collaboration across borders through co-ordination of standards, free circulation of researchers, international meetings, and science advocacy.

Prof Manjula Sharma is a leading researcher and advocate for physics education in Australia. She is a member of the Sydney University Physics Education Research Group, a pioneering think tank in the field, and has previously been recognised by the AIP with the AIP Education Medal.

Prof Sharma has also been voted in as a Member of Commission C14 on Physics Education of the IUPAP for a three-year term.
Science & Technology Australia announces new executive

At their General Meeting in November Science and Technology Australia elected their new executive committee, with outgoing president Professor Jim Piper to be replaced by Professor Emma Johnston, one of Australia’s leading marine scientists and science broadcasters.

Macquarie University optical physicist Professor Judith Dawes takes over as Treasurer. Judith joins fellow physicists Alan Duffy and Cathy Foley who are already serving on the Executive.

Science and Technology Australia is the nation’s peak body in science and technology, promoting the sector’s work with government, industry and the general public. From its Canberra-based headquarters, STA serves as a respected and influential contributor to debate on public policy, providing a strong voice for Australia’s roughly 70,000 scientists and technologists from every discipline.

At the STA General Meeting where the elections were held, Professor Johnston congratulated Jim Piper before articulating her enthusiasm for the coming year: “We have an outstanding leadership team to take us to the next federal election, where we will be unabashed about promoting the value of science, technology, engineering, and mathematics.”

Pawsey Medal to Monash physicist

The Australian Academy of Science has awarded the Pawsey Medal for 2018 to Dr Paul Lasky from the Monash University School of Physics and Astronomy in recognition of his outstanding contributions to physics.

Paul’s research area is gravitational astrophysics, particularly the incipient field of gravitational waves. Paul’s contributions to the LIGO Scientific Collaboration and the Parkes Pulsar Timing Array have helped put Australia in the vanguard of this exciting new movement in astrophysics.

The Pawsey Medal recognises the contributions to science in Australia by the late Dr JL Pawsey, FAA. Its purpose is to recognise outstanding research in physics by scientists up to 10 years post-PhD in the calendar year of nomination, except in the case of significant interruptions to a research career. The award is made annually and is restricted to candidates who are normally resident in Australia and for research conducted mainly in Australia.

Selby Research Award to physicist

One of three Selby Research Awards for 2017 has been awarded to Dr Sergio Leon-Saval (School of Physics, University of Sydney) to aid his research on advanced photonic sensors for agriculture.

The production of fresh produce, a major growth area of the Australian food market, has undergone dramatic evolution in recent years. Suppliers must be able to demonstrate their adherence to food safety protocols as well as the quality of their crops. Moreover it is essential that contaminated produce and sterile soils be identified and traced back to the source to prevent breaks in the
supply chain. Advanced photonics sensors for Raman and Near-Infrared (NIR) spectroscopy could offer the opportunity to cheaply and rapidly detect deadly pathogenic bacteria as well as to access the quality and health of the soil, thereby protecting Australian vegetable growers from the risk of dangerous food safety outbreaks and/or devastating supply shortages.

The proposed project will explore a new compact photonic technology for NIR spectroscopy to test the detection of nitrate and phosphate content in soil. The technology was developed in the Sydney Astrophotonic Instrumentation Laboratories (SAIL) part of the School of Physics at The University of Sydney. The instrument will be integrated and tested in the lab before installation on a new farm robot under development at the Australian Centre of Field Robotics, also at the University of Sydney. This small project will deliver a comprehensive study of the spectral properties and needs of this new type of sensor for the farming industry.

The Selby Research Awards are granted annually by both the The University of Melbourne and The University of Sydney. The award is to assist an outstanding academic establish his or her research career.

Emeritus Professor Neville Fletcher died on 1 October 2017. Neville Fletcher was born in Armidale, NSW in 1930. He was educated at Armidale Demonstration School (1935-41) and at Armidale High School (1942-46). He attended New England University College, which was part of Sydney University, receiving a BSc in 1951. He then went to Harvard University where he gained a PhD in 1955 for his research on impurity levels in semiconductors.

Neville returned to Australia in 1956 to work in the Radiophysics Division of CSIRO. After 4 years at CSIRO, he moved to the University of New England where he was a senior lecturer in physics (1960-63) and then professor of physics (1963-83). Here his research interests included musical acoustics and studies on the physics of ice and water.

In 1983 Neville was appointed director of CSIRO’s Institute of Physical Sciences, a position he held until 1987. When he completed his term as director, he remained at CSIRO as a chief research scientist until 1995. Neville was the 10th president of the Australian Institute of Physics (1981-2).

Conferences

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

20-23 May 2018
5th Asian and Oceanic Congress on Radiation Protection – AOCR5 Melbourne Exhibition & Convention Centre
www.aocrp-5.org

13-16 August 2018
9th Vacuum and Surface Science Conference of Asia and Australia SMC Function and Conference Centre, Sydney
www.ansto.gov.au/

9-14 December 2018
AIP National Congress, UWA, Perth, WA
www.aip2018.org.au
A metrological Scanning Probe Microscope for accurate length measurements at the nanoscale

Bakir Babic, Christopher H. Freund, Victoria A. Coleman and Jan Herrmann
National Measurement Institute Australia, West Lindfield, NSW 2070, Australia

An overview is presented of the design and operational principles of a primary standard for dimensional measurement at the nanoscale, realised at the National Measurement Institute with a metrological Scanning Probe Microscope (mSPM). Traceability to the SI metre is achieved by heterodyne interferometry with a calibrated frequency stabilised laser to measure the displacement of the sample stage relative to a fixed tip. The mSPM operates in frequency modulation dynamic atomic force microscopy mode using a quartz tuning fork oscillator as a force sensor. The instrument performance has been characterised and measurement results for two-dimensional grating are presented. For typical measurements, e.g. of step heights below 100 nm, sub-nanometre accuracy is achieved.

1. Introduction
Measurement lies at the heart of science. A famous example is the measurement problem in quantum mechanics which led to Heisenberg’s uncertainty principle that determines the ultimate measurement accuracy permitted by the fundamental laws of nature. As science advances and technology develops, measurements must also evolve and improve. Scientific progress drives measurement science, and measurements at the limit of what is currently possible stimulate and enable scientific progress and the emergence of new and disruptive technologies. Nanometrology for example, the science of dimensional measurement at the nanoscale, will play a pivotal role in achieving the control and reproducibility necessary for realising the promises of nanotechnology. The National Measurement Institute (NMI) established a Nanometrology section to support research, development and the commercial application of nanotechnology in Australia, inform fact-based decision making for industry, government and consumers, and reduce technical barriers to the global trade of nano-enabled materials and products. To achieve these aims, NMI created two facilities: a metrological scanning probe microscopy (mSPM) laboratory, and a nanoparticle characterisation laboratory with capabilities for measurements of nanomaterials at the nanoscale.

The purpose of the mSPM is to provide Australia with a primary measurement standard for accurate dimensional measurements at the nanometre scale that are traceable to the unit of length in the International System of units (SI), the metre. Metrological traceability – the process of linking a measurement to an established reference – forms the basis for the comparability of measurements in space and time. In the case of dimensional measurements, this starts with the SI definition of the metre [1] and its practical realisation, followed by an unbroken chain of comparisons while keeping record of all associated measurement uncertainties. In NMI’s mSPM, laser interferometry is used to measure the relative linear displacements, along three orthogonal axes, of a sample stage with respect to a fixed tip. The tip serves as a sensor that, via closed-loop feedback, allows to trace a contour of constant interaction force which approximates the sample’s surface topography as it is scanned past the tip. From the interferometer data, we can determine the dimensions of features on the sample surface. The wavelength of the radiation generated by the mSPM laser source is calibrated against an optical frequency comb used to realise the SI metre at NMI. This approach enables the SI-traceable measurement of the dimensions of artefacts for subsequent use as calibration standards, as well as the dimensional characterisation of nano-objects such as nanoparticles. Using such transfer standards, other instruments that measure nanoscale dimensions can be calibrated, such as SPMs, including atomic force microscopes (AFMs), electron microscopes or optical super-resolution microscopes. Once calibrated, such in-

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Instruments can be used in turn for measurements of artefacts that become transfer standards with lower accuracy, due to the combination of measurement uncertainties. Calibration of routinely used measurement instruments in laboratories or industry can be achieved using such transfer standards. This enables an end user to obtain measurements of nanomaterials and nanostructures that are traceable to the SI definition of the metre, as shown in Figure 1.

In this paper, we present an overview of the design and operation principles of NMI’s mSPM. We highlight some of the challenges associated with making SI-traceable and accurate displacement measurements at the nanoscale with a macroscopic instrument. We summarise the NMI’s mSPM operational characteristics and demonstrate its performance by presenting and discussing measurements of a transfer artefact.

2. The mSPM design

While metrological traceability of displacement measurements at the nanoscale to the SI can be achieved reliably by interferometry [2-4], the design of measuring systems that provide the associated primary measurement standards is neither uniform nor harmonised. Such instruments are not available commercially, and their design and operational principles are typically developed by metrologists, aiming to achieve the highest operationally possible accuracy within the accessible volume of the instrument. The mSPM, as NMI’s primary measurement standard for nanoscale dimensional measurements, was designed at the institute, and many of its components were manufactured in Australia. The instrument also contains commercial components such as interferometers, and custom-made precision parts fabricated overseas such as the movable and reference mirrors.

The design of the mSPM was guided by metrological and performance considerations. These include a compact reference frame for displacement measurements (the “metrology loop”), kinematic design [5], use of laser interferometry for SI-traceable displacement measurement, and a high sensitivity detector with a sharp tip to quantify the interaction between the tip and the sample and enable tracking surface features. Careful consideration has been given to minimising the magnitude of the main contributions to the measurement uncertainty caused by alignment errors, environmental fluctuations, mechanical distortions and vibrations. To maintain the relative alignment of the contact point between the tip and the sample with respect to the orientation of the interferometers, a configuration was chosen where the tip is rigidly attached to the structural frame while the sample is scanned using a piezoelectric flexure stage. The structural frame is octagonal in shape; a compromise be-
tween preserving the highest symmetry around the tip axis and enabling opto-mechanical accessibility to the instrument’s components. This shape maintains an axially centred tip position even when the frame expands or contracts due to temperature fluctuations. A cross-sectional design drawing of the instrument is shown in Figure 2 (A). The structural frame is placed within an enclosure that allows operation under accurate control.
of environmental parameters such as temperature, pressure and humidity.

The geometrical centre of the instrument is defined by the contact point between the fixed force-sensing probe and the surface of the sample. A conventional AFM tip mounted on one of the tines of an oscillating quartz tuning fork (QTF) is used as the probe [6] in this mSPM. As macroscopic mechanical resonators with good frequency stability at room temperature, QTFs can serve as accurate sensors of tip-sample interaction in scanning probe microscopy [7]. The QTF based probe reduces both heat dissipation in the instrument and the complexity of the AFM probe head design since, unlike systems with mechanical excitation and conventional “beam bounce” detector configurations, it requires neither a piezo actuator for excitation nor a laser and position-sensitive detector to read-out cantilever deflection. An optical micrograph of a QTF used in the mSPM is shown in Figure 2 (B).

To scan the sample past the fixed tip, it is mounted on a piezoelectrically actuated flexure translation stage with scan ranges of 100 µm × 100 µm in the (“X-Y”) plane perpendicular to the tip axis and 25 µm along the tip (“Z”) axis, respectively [8]. The stage, which features an aperture around the Z-axis for optical access, can be operated in closed-loop position feedback, whereby the position of the moving platform is monitored by capacitive sensors incorporated into the stage or external position signals. A mirror structure (the “movable mirrors”) and a sample holder are both kinematically stacked on the nanopositioning stage. Kinematic design minimises strains and distortions due to thermal expansion and allows for accurate positioning of instrument components during assembly. Samples are fixed on the sample holder by shear friction or, if necessary, magnetic strips. The structural frame and the translation stage are precision engineered from SuperInvar®, a FeNiCo alloy with a thermal expansion coefficient of $\alpha = (-1.7 \pm 0.2) \times 10^{-7} \, \text{K}^{-1}$ at 20 °C [9].

The instrument’s metrology frame is defined by the orientation of the three linear displacement interferometers. Two of these interferometers (X and Y) are visible in the top view of the interferometer platform in Figure 2 (C); the Z-axis interferometer is situated below the platform. In the same figure, the two interferometers situated opposite the X-axis and Y-axis linear displacement interferometers measure the (parasitic) angular motion of the translation stage. The linear displacement interferometers are double pass, differential interferometers with plane mirrors. The reference mirrors are fixed to the structural frame while the movable mirrors are realised by five orthogonal planes of the pseudo-cubic movable mirror structure that rests kinematically on the translation stage. The mirrors are manufactured from

---

Figure 3. (A) An overview of the mSPM laboratory and the control room. The mSPM is located in the atmospheric control enclosure. (B) Simultaneous measurements of the differential interferometer signal from a plane mirror (dotted line; left axis) and of the temperatures in the mSPM body, at one of the interferometers and in the laboratory (solid lines; right axis). The inset shows temperature variations within the instrument body over 24 hours.
Zerodur®, a lithium-aluminosilicate glass-ceramic with a thermal expansion coefficient of $\alpha = (-0.5 \pm 1) \times 10^{-7} \text{K}^{-1}$ at 20°C [10], and polished to achieve a surface flatness below 5 nm. The five faces of the pseudo-cubic movable mirror structure are orthogonal to within 5 μrad. We describe the laser source for the interferometry system in Section 4 below.

Minimising external disturbances such as electronic and acoustic noise, and variations of environmental parameters during operation of the mSPM is of paramount importance to achieve the desired measurement accuracy. Temperature changes, for example, can result in differential thermal expansion of system components and thus introduce spurious changes in the differential optical path lengths registered by the interferometers. Such changes can also arise due to variations of the refractive index of the atmosphere through which the interferometer beams propagate, which in turn can arise from fluctuations in temperature, pressure, humidity and chemical composition of the atmosphere. The influence of these environmental fluctuations is reduced by a multi-faceted approach that includes: placing the instrument on an anti-vibration optical table which is seismically isolated and has high natural frequencies; surrounding the mSPM chamber with an acoustic control enclosure with controlled airflow; keeping the instrument compact; using only a few different materials with low thermal expansion coefficients for the manufacture of the mSPM components; minimising the separation between the moving and reference mirrors (the “dead path”); and by locating heat sources away from the instrument in an adjacent laboratory. A layout of the control room where the laser source, instrument controllers and data acquisition are situated and the mSPM laboratory where the instrument itself is stationed is shown in Figure 3 (A).

Multiple environmental sensors (e.g. for measurements of temperature, pressure, carbon dioxide concentration and relative humidity) are embedded within or adjacent to the instrument to monitor environmental parameters during experiments. Measurements of the temperature change at different locations in the mSPM system over a time span of several days are shown in Figure 3 (B). In the mSPM laboratory, peak-to-peak temperature variations below 0.1 K/day are measured, whereas the thermal mass of the instrument reduces these fluctuations within the mSPM body to under 0.01 K/day. Figure 3 (B) illustrates that temperature measurements at different locations within the instrument show a similar time evolution, with the observed temperature offsets most likely originating from intrinsic variation between

3. AFM operation

The mSPM tracks surface features as an AFM, i.e. by raster scanning a sample past the tip in the X-Y plane, whereas an electronic feedback loop maintains a constant tip-sample interaction by adjusting the stage position along Z. The force sensor is realised by a QTF mechanical oscillator configured with both tines free to vibrate. The QTF is electrically excited at the fundamental mode of its resonance frequency, and the tine displacement and thus the oscillation amplitude is obtained by monitoring the current through the QTF [11]. A feedback error signal, proportional to the shift of the QTF resonance frequency due to the interaction between the tip and the sample surface (usually an attractive van der Waals force) is measured by a phase locked loop (PLL). Operation in this attractive, frequency modulated (FM) mode minimises mechanical contact between the tip and the sample, hence reducing the problem of tip wear and sample surface degradation associated with other AFM modes [12]. A dedicated controller provides a pre-programmed signal for the XY stage scanning motion and the closed-loop feedback of the drive voltage for the Z-axis stage actuator. By recording these signals and plotting them, an approximate image of the sample’s surface topography can be constructed, as shown on the left of Figure 4 (A) for a two-dimensional (2D) pitch calibration artefact. An alternative representation of the sample’s surface topography is obtained by recording the output from the capacitive displacement sensors built into the positioning stage for each translational displacement direction as shown at the centre of Figure 4 (A). Both of these measurements are not SI-traceable, and rely on independent calibration of the controller and the capacitive sensors, respectively.

4. SI-traceable displacement measurement

An SI-traceable displacement measurement can be derived from the signals acquired by the three translational interferometers. A reconstructed image of the surface topography of the 2D artefact discussed in the previous section, traceably measured concurrently with the mSPM interferometers, is shown in the right panel of Figure 4 (A). The laser light for the interferometers is
provided by a HeNe laser where high wavelength stability (1 part in $10^9$) is maintained by offset locking to a single frequency of a Zeeman-stabilised reference laser. The laser output is then frequency shifted by two acousto-optic modulators to provide a synthetic heterodyne source that is used in all interferometers and launched into the mSPM laboratory using single mode optical fibres. The interferometer output signals are picked up with single mode fibres and delivered to optical detectors in the control laboratory where their analog outputs are digitised using high-speed analog-digital converters. To obtain a real-time readout of the differential phase relative to a reference signal, the phase shift (and therefore displacement) is measured and processed by a multi-channel, all-digital phasemeter developed on field-programmable gate arrays (FPGAs) [13]. The resulting 8-channel digital phasemeter has a 400 kHz signal bandwidth and a displacement noise of 0.02 pm/√Hz at 1 Hz [14].

5. Measurement errors and uncertainty budget

To establish the accuracy of an SI-traceable measurement requires quantification of error contributions and an estimation of the related measurement uncertainties. This is known as establishing an uncertainty budget. Evaluating the numerous and potentially inter-dependent contributions to the uncertainty of displacement measurements made using the mSPM is a formidable task. In displacement interferometry, some of the most prominent error sources include non-linearities (such as cyclic errors), Abbé errors, cosine errors, and variations in the refractive index of the atmosphere in which the instrument operates. However, for large displacements (>1 µm), the uncertainties associated with Abbé errors are the largest cumulative contributions to the uncertainty budget. Abbé errors can arise when the moving mirror, in addition to the desired linear motion, rotates around an axis that is not coaxial with the axis of the interferometric measurement and the measurement axis does not intersect (i.e. is offset relative to) the rotation axis. These errors can be estimated from the Abbé offsets and from interferometric measurements of parasitic stage rotations [15]. In the mSPM, the fixed tip defines the measurement position of the instrument while the interferometer beams define the metrological reference frame, and any separation between the two corresponds to the Abbé offset. Adding to the complexity of the problem is that each translational (differential two-pass) interferometer has four beams, where in order to minimise alignment errors and associated Abbé offsets, the “geometric mean” of the four beam axes for each of the three interferometers has to intersect at the same point, i.e. the tip position. The interferometric alignment procedure is performed using an auxiliary alignment target which is attached to the structural frame of the instrument and features four circular apertures for the inter-

![Figure 4. (A) Unprocessed FM-AFM images of a 2D pitch calibration artefact acquired using different displacement sensors in the mSPM: left – controller drive (scans in X- and Y-, feedback in Z-axis), centre – capacitive sensors integrated in the translation stage; right – laser interferometry. (B) Yaw (left), Pitch (centre) and Roll (right) in radians with respect to the Y-axis.](image-url)
ferometer beams, arranged such that an axis parallel to the apertures and located at their “geometric mean” is aligned with the tip location. In contrast to alignment to a mirror which involves only angular degrees of freedom (minimising cosine errors), using this procedure for each translational interferometer requires a two-dimensional alignment procedure consisting of two positional and two angular beam alignments. This imposes stringent conditions on the interferometric beam positioning and results in an uncertainty of the magnitude of the Abbé offset of ±80 µm.

The mSPM is capable of measuring the angular stage errors with two angular interferometers simultaneously during the translational interferometric measurement. Measurements of these parasitic stage rotations for yaw, pitch and roll in radians, with respect to the Y-axis, are shown in Figure 4 (B). The measured angles, multiplied with the estimated uncertainty of the Abbé offsets, gives the uncertainty contributions to the displacement measurements arising from Abbé errors. For the particular experiment shown in Figure 4, the maximum of the uncertainties originating from the Abbé errors for yaw, pitch and roll are 1.2 nm, 0.2 nm, and 0.1 nm, respectively. Since information about parasitic stage rotations is accessible via angular interferometric measurements for each point of the scan, local corrections of the associated errors can be applied to improve the accuracy of measurements obtained by the mSPM [16]. Similarly, a local correction to the displacement measurements to compensate errors originating from environmental changes in the instrument is possible thanks to the simultaneous, synchronised acquisition of environmental sensor signals associated with different mSPM components and the interferometric displacement signals. For example, dedicated thermistors are located between the reference and movable mirrors for the X-, Y-, and Z-axes, respectively, which enables real-time monitoring of temperature variations in the corresponding death path volume and thus allows to correct for changes in the refractive index in the dead path and the associated spurious optical phase shift.

Following the above mentioned strategies to actively minimise the measurement uncertainties, the NMI’s mSPM provides a unique measurement capability for SI-traceable dimensional measurements of nanostructures such as calibration artifacts and of nanomaterials such as nanoparticles with an uncertainty below 1 nm. Besides establishing the primary measurement standard for nanoscale dimensional measurements at NMI, this unique instrument is accessible to users outside of NMI who wish to obtain the most accurate dimensional measurements at the nanoscale in Australia. We envisage that this user community will include researchers, national fabrication and characterisation facilities, science and technology startups, businesses that develop, apply or manufacture nanomaterials, precision engineering and advanced manufacturing companies, as well as government agencies.

References
8. Model NPYXYZ100A-I, npoint Inc., Madison USA.
Author Biographies

**Dr Bakir Babic** joined the Nanometrology Section at NMI in 2010 where he is the principal developer of the metrological scanning probe microscope. He is interested in technical and operational aspects of SI-traceable and accurate measurement at the nanoscale.

**Christopher Freund** is an instrumentation engineer with the Nanometrology Section at NMI. Since joining the Section in 2007, he has worked on the design and development of the metrological scanning probe microscope. His main interests are in CAD, analysis software and optical interferometry. Prior to 2007, Chris had been with the Optics Group of CSIRO since 1974 working on the design of optical instrumentation systems. Chris is a scientific instrument maker by trade and received his Mechanical Engineering certificate in 1975.

**Dr Victoria Coleman** leads the Nanometrology Section at NMI, which holds Australia’s primary standard for nanoscale dimensional measurements. The team focuses on accurate and fit-for-purpose nanoscale measurements; including developing and evaluating methods with a focus on the characterization of nanomaterials.

**Dr Jan Herrmann** leads the Physical Metrology Branch at NMI which provides Australia with measurement standards and expertise for physical quantities. He has made significant contributions to the design and development of NMI’s metrological scanning probe microscope.

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**AIP Physics Education Group**

**Notice of upcoming conferences:**

The **Australian Conference on Science and Mathematics Education** (ACSME) will be held on Wednesday 26 September and Thursday 27 September 2018 at Flinders University in Adelaide, South Australia. The Physics Discipline day is on Friday 28 September 2018 at Flinders University.


The **GIREP 2018** (International Conference on Research and Innovation in Physics education) will be held 9-13 July 2018, San Sebastian, Spain

Coherent laser light with a well-defined phase plays a vital role in a wide range of technologies from the manipulation of biological samples using optical tweezers to LIGO’s gravitational wave detectors. Essential to these applications is the ability to precisely control light propagation using appropriately designed materials. One fruitful source of inspiration in the design of new photonic media has been analogies with condensed matter physics, an idea pioneered by Yablonovich and John in 1987. They proposed “photonic crystals” for light, which host band gaps of forbidden wavelengths similar to the electronic band gaps of solids. In addition to device applications, these analogies can also provide new perspectives to better understand exotic phenomena in condensed matter.

When I began my PhD in 2011 there was significant interest in studying photonic analogues of the two-dimensional material graphene, the subject of the previous year’s Nobel Prize. Many of graphene’s exotic properties are related to its sublattice “pseudospin” degree of freedom, and my supervisor Anton was interested in the coupling between this pseudospin and the orbital angular momentum of light. He suggested I investigate whether this coupling could be observed in the graphene-like honeycomb photonic lattice shown in Figure 1(a,b), which could be produced by our experimental collaborators at Münster University in Germany.

To my dismay, initial numerical simulations suggested that the anisotropy present in the experiments would spoil the effect we wanted to see. I had the idea of instead using a square lattice with a graphene-like conical dispersion, which I hoped would be less sensitive to the anisotropy. This lead me to studying the face-centred square lattice shown in Figure 1(c,d), called the Lieb lattice, which had recently attracted the attention of cold atom theorists.

I found that a similar pseudospin-orbit coupling occurred in the Lieb lattice, but its conical dispersion involved spin-1 operators rather than the spin-1/2 Pauli matrices occurring in graphene, resulting in some qualitatively different properties. For example, the Lieb lattice’s Bloch wave spectrum hosts a dispersionless “flat band” where the wave group velocity vanishes, and its higher pseudospin is associated with the generation of double charge phase singularities - optical vortices. At that time, however, there had been no demonstration of a Lieb lattice in any experiment.

My analytical and numerical work showed that these novel properties could be observable in a photonic lattice of laser-written optical waveguides. This idea was then successfully pursued by a few experimental groups, including our German collaborators.

This study of the Lieb lattice formed the inspiration for the remainder of my thesis work, which established more broadly connections between “spectral singularities” including conical and flat dispersion relations, and singularities in the phase of light. I demonstrated that wave propagation in photonic lattices hosting spectral singularities can serve as a new mechanism for the generation of phase and polarization singularities, and conversely the observation of wave singularities in these structures can be used to characterise their eigenvalue spectrum.

The rapid progress since the submission of my thesis has been exciting to watch. Lieb lattices have now been achieved in other settings: as optical lattices for cold atoms, for polariton condensates, and in March 2017 the first reports of artificial Lieb lattices for electrons fabricated by positioning atoms on a substrate with a scanning tunnelling microscope were published. Other classes of artificial lattices inspired by condensed matter systems continue to be an active research topic for both theorists and experimentalists in photonics and beyond.
Figure 1: (a) Simulated refractive index profile of a “photonic graphene” waveguide array and (b) its Bloch wave band structure, exhibiting conical singularities (circled) associated with half-integer pseudospin. (c) Phase contrast image of a Lieb lattice in fused silica glass and (d) its band structure with integer pseudospin conical intersections (circled). The inset details the individual sublattices and waveguide anisotropy.

Author Biography
Daniel completed his PhD at the Nonlinear Physics Centre at the Australian National University under the supervision of Professors Anton Desyatnikov, Yuri Kivshar, and Elena Ostrovskaya. Following a postdoctoral position at Nanyang Technological University, Singapore, he was awarded a Young Science Fellowship by the Institute for Basic Science in Korea, where he now leads a junior research team studying nonlinear effects in photonic topological insulators.
Students entering Year 11 to study Physics will have differing backgrounds in science depending on the school science taught and the levels of the teachers. In most schools, the transition from Year 10 to 11 would be reasonably smooth and some care would be made within the school for continuity of science development. In Tasmania and possibly ACT this cannot be taken for granted due to the Senior Secondary Colleges separation from general High schools.

Teachers of Physics at Years 11 and 12 must assume that their students have little applied mathematical skills as the National Curriculum for Years 9 and 10 do not specify any mathematical outcomes for the physics parts of the Science Curriculum [1]. They must therefore rely on the individual students mathematical grade 10 results to provide a reasonable indicator of future success. Typically a minimum of a B is needed for entry to Year 11 Physics on the 10, preferably the 10A National Curriculum mathematics.

Of interest is the increasing quantity of statistics in the Mathematics of the National Curriculum of Grade 10 [2]. Most physics teachers would therefore prefer students also study the Methods strand of mathematics rather than the General strand in Year 11 as the General strand has relatively low algebraic levels of study. With more statistics, less geometry or extended trigonometry is taught. Students may never meet the sin rule or cosine rule unless through Physics. Some state syllabi seem to have vector problems restricted to right angles presumably because of this.

Higher level year 11 12 mathematics now incorporates the use of Graphing Calculators rather than simple calculators. This implies students may be less confident manipulating formulae and be less capable of solving problems “on the fly”.

Calculator use is a necessity in Physics. Different states allow different calculators in sophistication. Since graphing calculators are required in Year 11 12 mathematics at all preteriary levels, some states have allowed them to be used in Physics external exams. This affects the ability of students to solve routine equations by more traditional means.

**State responsibilities**

Each state is responsible for the education of its students and so each has a body responsible for the maintenance of syllabi and forms of assessment. However each has different ways of writing and maintaining these syllabi and so differences appear in the way a subject syllabus interprets content and outcomes. Physics in Years 11 and 12 is in no way different across the country.

Competing pressures exist on Physics syllabi

- “Rigour” vs “Context”;
  - Context based learning is a style of teaching whereby students learn a topic entirely within a context such as Silicon in Society. Here students would learn about electricity, energy and such as side issues to the influence of physics in the current era. Content-based learning is based on fixed, defined fundamentals in which contexts arise out of the content. An example of the latter is when Newton’s Law of Gravity
leads to discussions of increasing gravity Field Strength near exotic bodies and the limitations of Newton’s Law. The former way of teaching has significant merit but can lead to a lack of basic knowledge of the subject and a lack of detailed learning of fundamental concepts. It is frequently used with younger students than the 16 to 18 year old cohort of Years 11 and 12.

The latter, content based learning, can lead to over-tightly focussed teaching whereby broader and interesting current ideas are not explored to the detriment of excitement of the subject.

- Extent of scope of the syllabus. As Physics is, itself, very wide and exciting, it can accidentally become a vehicle for carrying a lot of content at the expense of rigour or detail. Writers of syllabi will be influenced by enthusiasts who see say, Special Relativity, as essential for all modern students as opposed to conservatives who feel that “time would better be spent learning how to calculate vector fields and anyway they don’t really understand Galilean Relativity!”

- The target student body. Does the syllabus need to be pitched at only the elite students who are excellent at Maths or is it a general science at Year 11 and 12. This matters, unless the school has a large cohort in Years 11 and 12, a very rigorous syllabus may preclude the subject running at all as the school cannot afford to run a class. Student maths background and current learning expectations are a major player in physics syllabus writing.

- Future users of the outcomes; Universities, TAFE institutes, employers. What does a School of Physics as opposed to an Engineering School require? What of Medicine or Radiology?

- The origin of the syllabus writers plays a part. Some syllabi are written by current Year 11-12 physics teachers with little reference to other stakeholders. Other writers may be Science Association members or Curriculum Design specialists. The degree of actual subject knowledge can be quite low and reliance then comes from feedback only or top down direction.

- Current educational ideas on the wider aspects of education can also play a part in the writing and expectations.

- Year 10 Science plays a varying role. Generally Grade 10 science is a broad theme based subject in most states with some reference to the needs of students progressing to Physics and Chemistry. The Physics content in the National Curriculum is very vague with a reference to Energy Conservation and Motion [3].

- Proportion of time in practical work

- Mathematical development of students

- Lastly, the method and details of external assessment plays a part. Most states whole-heartedly accept external exams with some degree of teacher input but the form of the exams differ. Queensland and ACT currently do not have external exams. Few states use Multiple Choice questions but NSW is a keen user of this technique. These decisions by the Examining bodies do affect the teaching of, and rigour expected of the students.

The Australian Curriculum, Assessment and Reporting Authority (ACARA) [4] attempted to define a common core across Australia upon which new syllabi were to be based. The Physics is broken into 4 Units to be taught across Years 11 and 12 detail core content and common equations to be used. These units are quite detailed and reflect much of common practice across the various states.

The content of the Australian Physics Curriculum [5] has been closely analysed by physics teachers from all states before acceptance in the final document. The initial draft Year 12 Stages 3 and 4 documents met very heavy criticism. They completely ignored the fundamental forces of gravity, electrostatics and magnetism and an elementary quantum mechanics introduction and seemed mathematics free. The revised draft reverted to a far more acceptable form.

Criticism has included too much content to allow in depth study to be carried out. The revised draft was modified by the deletion of some topics such as “Escape speed from a mass” and “Torque of an electric motor”, the former as, while interesting, relies on calculus to derive it properly while the latter touches on rotating kinematics that is nowhere else part of the syllabus. The revised 2017 NSW syllabus has however, included these two topics.
The Australian Physics Curriculum Units have an explicit call for teachers to draw on Contextual Learning aspects that can derive from local or general contexts. For example, Victorian physics teachers often refer the Australian Synchrotron near Monash University while this means nothing to a Tasmanian teacher! In general contexts, Fukushima or tsunamis may provide more current and relevant exemplars. It is important to note that for a 16 to 18 year old, a “current” topic may not be older than about 4 years. Further, the Curriculum regards broad discussion of science generally as important as the concept of “Science as a Human Endeavour” is across all Year 11, 12 Science Curricula.

Interpretation of the Australian Physics Curriculum varies slightly from State to State depending on the history of the subject in the State.

All states offer a nominal 220 hours of physics across Years 11 and 12 with most having the time equally distributed across each year. The Australian Physics Curriculum reflects this as 4 equal stages, Units 1 and 2 in Year 11 and Units 3 and 4 in Year 12. Tasmania, however offers a nominal 75 hours of physics in Year 11 but 150 hours in Year 12. The Year 11 physics is taught in conjunction with an introduction to chemistry that also requires 75 hours as a subject called Physical Sciences. An external examination takes place at the completion of Year 11 and students may then go onto Year12 Physics and/or Chemistry.

In reality, it is rare for a whole 220 hours to be available for teaching the syllabus. Due to pressures on timetables in schools, it is far more likely that about 200 hours is available for the subject over the two years at a given school.

The Australian Physics Curriculum [5]

Unit 1. Thermal, nuclear and electrical physics (Designed for Year 11)

- Level of mathematics confined to substitution and cross-multiplying
- “Ionising radiation and nuclear reactions” – Elementary introduction to decay and mass energy.
- Level of mathematics includes half-life calculation at the whole number of half-lives level.
- “Electrical Circuits” – Basic DC circuits extending to Series and Parallel systems. Energy and Work in these systems.
- Mathematics now requires visualisation of circuits and selecting appropriate equations to solve for currents, PDs and energy losses.
- (It is interesting to note that “energy”, “kinetic energy”, “potential energy” and “work” are concepts that are referred to and also to be calculated, but no formal definition of these in terms of forces has yet to be given as forces are yet to be discussed. In this sense, the Curriculum does not follow a logical sequence but relies on a vague sense of “knowing about energy”!)

Unit 2. Linear Motion and Waves (Designed for Year 11)

- “Linear motion and force” – The basic straight line motion formulae, introduction to vectors vs scalars, Newton’s laws, momentum, energy, work and power.

The Mathematics needed to solve quadratics, scaled drawings, solve fairly complex motion problems. Confidence is needed in substitution, visualising problems and finding systems leading to solutions. Implied is the interpretation of slopes and areas of graphs though these are not explicitly mentioned.

Note 1: Projectile motion is not present in this statement

Note 2: Momentum is presented after Newton’s Laws so appears an adjunct instead of a basic principle. The ability to describe Newton’s Laws in terms of momentum is not made clear.

- “Waves” – a comprehensive covering of reflection, refraction, intensity, standing waves in pipes and strings not extending to two-dimensional interference or polarization. Transverse and longitudinal situations are explored.

- This topic requires a good visual understanding of physics, the mathematics is fairly straightforward algebra but it is easy to use incorrect modelling to produce incorrect answers. Refraction situations require the use of trigonometry and ratios, and geometry.
Unit 3. Gravity and Electromagnetism (Designed for Year 12)

• “Gravity and Motion” - more sophisticated Newtonian situations like inclined planes, Projectile Motion, Circular Motion, Newton’s Law of Gravity, simple circular orbits, Kepler’s Third Law in Newtonian terms, gravitational fields.

Mathematical expertise required is clearly now at a higher level. Students need not only to have basic algebraic manipulation abilities but also the ability to visualise and adopt techniques and ideas from other topics.

• “Electromagnetism” – Coulomb’s Law, Electrostatic Field Strength, Field Strength around single charges, Energy Changes related to Potential Difference and definition of PD. Magnetic Field around a straight wire, forces on a current carrying wire, Forces on charges in magnetic fields, Flux, induction, Faraday’s Induction Law, transformer theory.

This statement does not include the relationship between electric field and potential difference in a uniform field or the force between current carrying wires. It also does not explicitly mention of motion of a charge in a uniform electric or magnetic field. Selection of correct formulae to solve problems is now of a high order.

Unit 4. Revolutions in Modern Physics (Designed for Year 12)


• As examples of Human Endeavour; Evidence for Higgs Boson, Big Band Theory and Particle Accelerators.

The next part of this article, to be published in a subsequent issue of Australian Physics, attempts to document the present content of each state’s Year 11 and 12 programme.

References

Author biography

Jason Dicker has been teaching Year 11 and 12 physics in Tasmania since 1971 having obtained an Honours degree in Physics at UTAS. He has largely been teaching at Launceston College and has been involved in writing the physics syllabus for his state for many years. He also represented Tasmania during the reviews and writing of the National Curriculum Physics.

AIP Congress, Perth 2018
9-14 December, 2018
University of Western Australia, Perth WA.
www.aip2018.org.au
This book aims to convince the reader that a unifying ‘final theory’ describing phenomena beyond the Standard Model is worth pursuing. It suggests that experimentally verifiable theories will be available in the near future, and that the most promising candidates for such theories arise from considerations of string phenomenology. The text is heavily focused on the author’s own research area of M-theory compactifications. It attempts to motivate and justify the argument that string theory is testable in the traditional physical sense and that we may see evidence in support of string theory in the near future.

The book is split into roughly two parts. The first gives a general introduction to the Standard Model, highlighting the successes and open questions that still remain. This is accessible to a reasonably general audience, providing motivation for fundamental physics research, and emphasising the expected arrival of experimental particle physics beyond the Standard Model. The second part of the book provides a jargon-heavy description of phenomenological string theory, particularly M-theory. The book contains virtually no equations or formal technical details, but an intimidating amount of terminology for someone without a particle physics background. This latter section may be targeted at theoretical physicists, working outside of string theory, who are nevertheless interested in string/M-theory and any experimentally realisable predictions that it may provide. If this is the case, then the paucity of technical detail and assumption of non-expert readership strongly reduce the impact of the text. Ultimately, the target audience of the book is hard to ascertain.

The successes of the Standard Model, as well as the need for a more complete theory, are outlined in the book. The Standard Model provides an excellent description of the quantum theory of particles and fields with incredible predictive power. However, it is well known that the Standard Model is incompatible with the description of a quantised theory of gravity suggested by general relativity. In addition, there are more than 20 parameters in the Standard Model which must be put in by hand—while the Standard Model describes the universe incredibly well, it doesn’t explain why it is the way that it is. It is generally hoped that a more complete theory with no free parameters could unify all known physics. At this point, string theories/M-theory are perhaps the most promising candidates we have for a ‘final theory’.

A generic feature of string theories is the requirement of extra dimensions of spacetime - M-theory for example requires 11 dimensions. One of the more commonly explored attempts to connect this to the four dimensional spacetime we experience is to ‘compactify’ the remaining dimensions. The book outlines the role of compactification in creating models to describe the observed non-gravitational forces in our universe. The different ways of compactifying the extra dimensions give rise to different physics on the uncompactified portion of space. For example, an 11-dimensional gravity theory with 7 compactified dimensions gives a 4-dimensional theory of gravity coupled to additional Yang-Mills type gauge fields associated with the compactified dimensions. The details of this gauge group depend on the details of the compactification, and trying to find compactifications which reproduce the forces and particles observed experimentally is an active area of study. Furthermore, it is hoped that novel features of string theory, such as the existence of additional fields and particles, can help solve important open problems in theoretical physics such as the identity of dark matter and the source of cosmic inflation.

This book highlights and discusses a particular class of M-theory compactifications, G2-MSSM models, and explains some of the features of this class. Key results, such as a resolution of the hierarchy problem, prediction of the Higgs boson mass (125 GeV, before the LHC results were released), dark matter candidates, baryogenesis, and predictions of the masses of supersymmetric partners are included in the discussion. In particular, the author argues that the masses of some of the lighter supersymmetric particles predicted by the theory should be accessible by the LHC in the next few years.
In summary, this book provides an exciting albeit optimistic look into M-theory compactifications. It provides solid arguments for why G2-MSSM models are promising candidates for explaining beyond the Standard Model physics. Many parts of the text are transparent, but many others are likely to quickly lose the non-expert reader. Technically trained readers may treat this work as a glossary of terms, useful as a jumping-off point for more detailed personal study.

**Radio Astronomer: John Bolton and a New Window on the Universe**

by Peter Robertson

NewSouth Publishing, July 2017

Hardback, 421 pages

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Reviewed by Dr David Jauncey, Australia Telescope National Facility, CSIRO Astronomy and Space Science, and Research School of Astronomy and Astrophysics, Australian National University

This is a most impressive account of the life, work and influence of John Gatenby Bolton. He was a remarkable man who made a major scientific impact world-wide on the early development of the 20th century's first new window on the Universe, radio astronomy. The author, Peter Robertson, began his research on Bolton well over 30 years ago (prologue p.2) and over the years has added to those first questions with extensive reading of archival material, scientific papers, books from 1947 to the 2000s, and interviews with a wide range of people around the world. Peter is to be congratulated for his careful and scholarly documentation of all these sources as evidenced in his comprehensive endnotes and bibliography.

The book is a development of Robertson’s earlier publication, *Beyond Southern Skies; Radio Astronomy and the Parkes Telescope* (Cambridge University Press, 1992) where the third section was dedicated to John Bolton, the first director at Parkes. Peter’s biography of Bolton has thus come about through his own interest in the history and workings of science, through his years of personal interaction with John, as well as with many of those who knew and worked with John throughout his career. The result is a highly readable and sympathetic Bolton ‘story’, engaging the reader in the personal life and career of the man, and giving a full and accurate account of his contribution to science. The book does an excellent job of making the John Bolton story accessible to a very wide audience. I found Peter’s book well-researched, and enthralling, illuminating reading. It was a special pleasure for me to follow John’s early life, growing up in Yorkshire, his school years and personal development, his family, and always his independence and interest in science and maths. As Peter says, these prepared him well for his later career in radio astronomy.

Drive and technical understanding were essential ingredients for his successful career, and for inspiring those around him.

The book is a chronological journey of 15 chapters through John Bolton’s life. As Peter himself says (p.401), “Bolton’s professional career can be divided into three distinct stages”, as exemplified by Dover Heights, Caltech and Owens Valley, and Parkes. These are dealt with in, respectively Chapters 3-5, Chapters 7-8, and Chapters 9-11. Prior to these, Chapters 1 and 2 describe Bolton’s early life in Yorkshire from his birth in 1922 through to his time at Trinity College, Cambridge and then documents his time as a naval officer from 1942, his move to Australia in 1946, and his appointment at the Radiophysics Lab. Chapter 6 marks an ‘intermediate’ stage in Bolton’s career with a brief move to Cloud Physics, at the same time that he and his wife Letty settled in Wahroonga. The final chapters (12-15) describe Bolton’s travels and influence from 1966, his involvement in NASA’s Apollo space exploration programme and the subsequent implications for Parkes, and Bolton’s role in planning for new astronomical facilities. The last chapter of the book details the accolades from others and Bolton’s accomplishments as seen by others and by himself.

As well as the accessible nature of Peter’s writing for scientists and the interested layperson alike, the book provides over 110 black and white photographs of people, places and equipment, many from CSIRO archives, and several cartoons and figures. Peter’s well-chosen use of these photos enables the reader to effectively ‘connect’ the written names in the story with the individual people via the photos; this works well because so much of the research was a collaborative process. In the Prologue, Peter introduces John Bolton to a more general public.
via the iconic film “The Dish”, where he points out that the main character in the movie, Cliff Buxton, played by Sam Neill, is John Bolton in real life.

Peter highlights Bolton’s move to Australia, chapters 3, 4 and 5, which proved to be a game-changer; there John met his wife, Letty, and they decided to stay. This was the beginning of his radio astronomy career at the CSIRO Radiophysics lab. The early days in radio astronomy were at the Dover Heights field station where John’s drive, plus the technical and instrumental developments from John and his collaborators gave Australian radio astronomy a head start in this new and exciting field. As Peter tells us, at that time, the astronomy was secondary to developing the technology; they learned the astronomy on the job while observing. The climax was the optical identification of three of the strongest radio sources, Taurus A, with the remnants of the Crab nebula in our own Milky Way Galaxy, and Virgo A and Centaurus A with bright, extended objects. However, Bolton suggested the later two were bright nebulae in our own Milky Way Galaxy, but they proved to be extragalactic. This was the real beginning of extragalactic radio astronomy as we know it today.

The successes of the group lead to a competition for a new CSIRO radio telescope. As Peter tells it, Bolton lost out to the Mills pencil-beam ‘cross’ design, and unfortunately resigned from radio astronomy. This resulted in a brief move across to CSIRO’s Cloud Physics Division, as discussed by Peter in chapter 6. Bolton had barely begun the analysis of his cloud seeding data, before events were underway for him to leave Australia for a new professorship in radio astronomy at the prestigious California Institute of Technology in Pasadena.

The next two chapters deal with John’s years at Caltech, leading on to his move back to Australia and Parkes in 1961. John’s time at Caltech started his major surveying and investigation into the radio sky, and his interaction and collaboration with the Palomar optical astronomers form an important part of Peter’s story. John became well aware of the value of this radio and optical ‘connection’ which was natural at Caltech.

As Peter explains in chapter 7, with considerable US$ funding now available to start up the new Radio Astronomy group at Caltech, John was then faced with designing and building the first big dishes of the Owens Valley Radio Observatory. As a Professor he was expected to take on graduate students and postdocs, and this he did with pleasure, as they were to form a powerful team for the construction and for the science. John always insisted that his greatest contribution was through his students, postdocs and collaborators. John was an excellent supervisor with respect, friendship and inspiration as major parts of his many strengths. It is these people who keep John’s life and contribution alive today.

Nevertheless, Peter Robertson does document other aspects of his personality. Bolton’s “driven, single-minded style” (p.325) as described by Don Mathewson, and ‘win at all costs’ attitude could cause conflict. His feud with Ruby Payne-Scott was legendary (pp.79-80), his fierce row with Joe Pawsey ended in his walkout from astronomy at that time (p.133), and he railed at what he considered irritating directives from CSIRO bureaucracy. This was particularly evident when he threatened this same bureaucracy with his resignation when they turned down his request to provide a Caesium Atomic clock and frequency standard which he correctly noted was essential for their planned Very Long Baseline Interferometer, VLBI, observations (pp. 325-26). Bureaucracy gave in. With John’s foresight VLBI has since become an important tool of global radio astronomy, where Australia and the Parkes telescope now anchor the Southern Hemisphere and provide essential connections globally and into space.

The period of the Apollo Moon landings, 1969 through 1973, brought John’s technical expertise to the forefront. In chapter 13 Peter takes the reader through the sometimes complex negotiations between Parkes and NASA’s Jet Propulsion Laboratory in Pasadena, aimed at getting the support of the Parkes telescope for backup in tracking the Apollo landings. The NASA 26 m antenna at Honeysuckle Creek, near Canberra, was the principal Apollo tracking station in Australia. For Apollo 11, after considerable changes of plans and confusion, Neil Armstrong’s first steps on the Moon were to take place just before the Moon rose into the main beam of the Parkes telescope. Both Honeysuckle and Parkes were tracking, but history has shown that for various reasons, the first ten minutes of the TV broadcast, the actual signal came through Honeysuckle, not Parkes. But once Parkes was fully tracking, they took over the TV broadcast to the world. The Parkes support of Apollo 11 and then later of the Apollo 13 accident brought Parkes and Australia into world attention. An interesting sidelight to this collaboration was that Australian astronomers were given free astronomy access to the NASA facilities for up to 5% of the time. This was a nice win-win situation for both countries.
John was a complex character as is shown by his reaction against the notion of National Facilities as being open to all, as Peter has made clear. It must have been difficult for John and for Radiophysics senior management to have had their first two major discoveries with the newly commissioned Parkes 210 ft telescope, radio polarisation and 3C273 the first quasar, made by outsiders, especially outsiders with their Sydney University association, as Peter has made clear in chapter 10. But despite John’s feelings then, it was clear that he was perfectly happy to avail himself of the bi-national facilities of the new Anglo-Australian 150” telescope when it came available in the mid-1970s (chapter 14).

Very early in the book (p.9), Peter quotes Roy Hattersley, one-time deputy Labour leader, as describing Yorkshire people as having a strong “belief in the importance of self improvement and the propriety of self-confidence”, as well as “…a compulsive desire to compete and an obsessive need to win”, that was not necessarily just at table tennis (p.204) or golf (p.371). Peter adds that these traits ring true of John Bolton. He was a proud Yorkshireman who never took out Australian citizenship, but contributed enormously to Australian radio astronomy. Peter Robertson, in turn, has contributed enormously to our understanding and appreciation of the life of John Gatenby Bolton.

SAMPLINGS

Putting a damper on wobbly bridges

Wobbly footbridges can both delight and terrify pedestrians. Now, researchers in the USA and Russia have developed a model showing how an apparently stable bridge can suddenly show alarming, potentially dangerous wobbles when a certain number of people walk across it.

Designing a footbridge can be a challenge because it can be difficult to predict how a structure will respond to the pounding of many feet at once. The London Millennium Footbridge across the River Thames, for example, opened with great fanfare in 2000, only to close within days after large crowds found the bridge rocking unnervingly as they walked. The bridge remained closed for almost two years while dampers were installed.

Bridges, like any other structures, have natural frequencies of vibration. It is well known that bridges can collapse if large numbers of feet simultaneously excite vibrations at these natural frequencies. The Albert Bridge – built across the Thames in 1873 – bears a sign instructing marching soldiers to break step when crossing. However, ordinary pedestrians do not march in step. Moreover, the Millennium Bridge oscillated left to right, not up and down.

In 2004 Steven Strogatz of Cornell University in the US, and international collaborators, modelled pedestrians on a bridge as coupled oscillators to show how, if a bridge does begin to vibrate naturally, pedestrians can fall into step with the vibrations to maintain their balance. In doing so, they inadvertently amplify the oscillations. This is analogous to the famous model, first developed by the Dutch physicist Christiaan Huygens in 1665, of pendulums suspended from the same beam becoming synchronized in phase because of motion transmitted through the beam.

Strogatz’ model has been highly influential in the applied mathematics community, but it cannot provide precise, quantitative predictions of the conditions under which a given bridge will wobble that could be used for computer modelling in the design of bridges. “The existing industry programs used to develop bridges are based on linear calculations,” explains Igor Belykh of Georgia State University in the US. “These are very outdated and cannot capture highly non-linear phenomena like this switching to larger wobbling as a result of very complicated two-way interactions between the pedestrians and the bridge.”

Belykh and colleagues in Russia combined crowd synchronization and bridge dynamics with a biomechanical model of walking humans as inverted pendulums pressing alternately on the ground with left and right feet. They considered many such pendulums
on the bridge at once, with a range of frequencies and phases, and formulated two nonlinear differential equations for the amplitude and phase of the bridge's oscillations.

The researchers showed that, above a specific critical number of pendulums, a stable solution can appear in which the oscillators all fall into phase and the amplitude suddenly increases: “We were able to give specific estimates of the relationship of this critical size to the natural frequency of the bridge, to the mass of the bridge and to the natural frequency of human walking,” says Belykh. The model predicted oscillations of the Millennium Bridge would occur when more than around 165 people walked on it at once – matching the experimental findings of the engineering company Arup, who designed and fixed the bridge.

[Igor Belykh et al., Science Advances 3 (2017), e1701512, doi: 10.1126/sciadv.1701512]

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

Gyrated dice achieve perfect packing
A new and rapid way to pack identical cubes in a dense configuration has been discovered by physicists in Spain and Mexico. Their work offers new insights into granular compaction and could lead to the development of new methods for producing dense granular systems both on Earth and in space.

The team, led by Diego Maza of the Universidad de Navarra, poured 25,000 small plastic dice into a clear cylindrical barrel of radius 8.7 cm (see figure). They then began twisting the barrel back and forth, rotating it clockwise then anticlockwise repeatedly about one cycle per second. The twisting action itself did not agitate the dice, but the jolt from changing direction did, inducing shear.

When they twisted the barrel slowly, dice at the edges tended to align but the central region remained disordered. At this rate, they calculated that it would take 10 years of twisting to attain perfect packing: a state where the dice lie in horizontal layers and in nearly perfectly ordered concentric rings within each layer.

However, when they increased the twist acceleration above 0.52 g, the alignment process also accelerated. Indeed, after 10,000 twists the dice were packed together in a perfect pattern. “Dice inertia and boundary interaction combine to drive the system to a highly-ordered state, with the number of arranged particles in each layer near its maximum,” says Maza. “This limit represents a complex mathematical problem, which is not yet solved.”

On the face of it, a barrel of dice seems to be a simple system. Each die is regular and interacts via direct contact with its neighbouring dice. Yet a granular material like this behaves neither as a solid, liquid nor gas. Indeed, granular materials could be regarded as an additional state of matter.

Understanding and optimizing the dynamics of how granular materials pack together remains an open challenge. And with materials like grain, sand, ores, pharmaceuticals and many more needing to be packed tightly together to minimize the volume of their container in myriad industries, solving this problem is an economic priority.

The conventional packing technique used for everything from packing powders in the pharmaceutical industry to compacting soil for highways consists of repeatedly tapping the material. By first tapping at high intensities and then reducing the intensity, grains can be packed densely. Yet this process is slow and involves large accelerations.

“Although this technique is undoubtedly useful, it might not always be the most energetically efficient process,” adds Maza. In contrast, the new twist technique requires less intense acceleration and allows the dice to rapidly achieve maximum order.


Extracted with permission from an item by Benjamin Skuse at physicsworld.com.
Continuous atom laser one step closer

A “laser” that puts out a continuous beam of coherent atoms is one step closer, say physicists in the Netherlands, who have devised a new way of cooling atoms to create a Bose-Einstein condensate (BEC).

A BEC is a distinctive state of matter in which all atoms are in the same quantum state. Therefore, a beam of atoms drawn from a BEC will behave as a coherent matter wave — in much the same way as light from a laser is a coherent electromagnetic wave. Atom lasers could prove useful for making high-precision measurements of rotations, accelerations and magnetic fields.

Atom lasers have been around since the first BECs were created in the mid-1990s, but these systems have produced a pulse of atoms lasting less than a second, rather than continuous waves of atoms. This is because there is no practical way to replenish atoms in the BEC on the fly — a BEC involves trapping and cooling atoms to temperatures just a tiny fraction above absolute zero in a multi-stage process that takes tens of seconds.

Now, Florian Schreck and colleagues at the University of Amsterdam have addressed this cooling problem by performing the different cooling stages in different locations, essentially creating a cooling assembly line that can operate continuously. Key to their success is the use of strontium to make the BEC — strontium atoms have just the right electronic structure to be cooled step-by-step, while being moved from one location to the next.

The team can use the technique to create a “permanent” cloud of gas that is much colder and 100 times denser that that achieved by previous efforts at continuous cooling. They have also shown that their process is compatible with the creation of a continuously existing BEC. Schreck believes that the team should be able to make a continuous atom laser within one year.

[Shayne Bennetts et al., Phys. Rev. Lett. 119, 223202 (2017); DOI:https://doi.org/10.1103/PhysRevLett.119.223202]

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

James Webb Space Telescope completes final cryogenic testing

The James Webb Space Telescope (JWST) has completed its final round of cryogenic testing at NASA’s Johnson Space Center in Houston, Texas. On 10 July the spacecraft’s optical telescope and integrated science instrument module were sealed in Chamber A, which is a huge cylindrical vacuum chamber that is 27 m tall and 17 m in diameter. There, it was cooled to temperatures as low as 11 K, using cold helium gas and then put through a three-month testing programme to ensure that the JWST will function in a cold and airless environment similar to space.

The James Webb Space Telescope in Chamber A (Courtesy: NASA/ Chris Gunn)
One of the tests involved ensuring that the telescopes’ primary, gold-coated mirror segments continue to act as single mirror when cooled. Engineers also ensured that the telescope optics and instrument module can function together under extreme conditions.

Before the tests could begin, it took a week to remove most of the air from the chamber and a month to cool the instruments to the required temperature for testing. The programme of tests coincided with Hurricane Harvey, which dropped more than one metre of rain on parts of Houston. Despite the difficult conditions during the storm, the team managed to safeguard that the testing was not interrupted.

The instrument module and optics will now be shipped to Northrop Grumman Aerospace Systems in Los Angeles, where it will be integrated into the JWST spacecraft. Once this is complete, the spacecraft will be subject to a final round of “observatory-level testing” before being launched in the spring of 2019.

The JWST programme is led by NASA and involves the European Space Agency and the Canadian Space Agency.

Integrated circuits could make quantum computers scalable

Researchers at TU Delft and University of New South Wales have designed a scalable quantum computing architecture based on widely used complementary metal-oxide-semiconductor (CMOS) manufacturing techniques. The approach encodes information in the spins of individual electrons confined in quantum dots, and could allow the development of large-scale computers incorporating millions of qubits.

For now, the state of the art in quantum computing is represented by devices with a few dozen qubits: as of November 2017, the 50-qubit, superconductor-based IBM Q is the record holder. Systems of this size are about as complex as can be simulated using a classical computer, so the field has reached an important milestone. But although quantum computers at this scale do have their uses, individual devices will need to harness hundreds, thousands, or even millions of qubits before they really come into their own.

No technology epitomizes the concept of scalability like silicon-based integrated circuits. So reliably and profoundly has this field advanced over the last half-century, that Moore’s Law – essentially just an observation about the regularity of increases in available computing power – has become firmly established in consumer culture. No wonder then that researchers are hoping that the same manufacturing process that has underpinned this growth for so long might do the same for quantum computers.

Writing in Nature Communications, Menno Veldhorst and colleagues describe how cutting-edge CMOS processes are approaching the point at which silicon micro-electronic components can be made small enough to be integrated with quantum-dot spin qubits. The architecture designed by Veldhorst and his team is based on a silicon qubit layer enriched with silicon-28. Above this, and separated by a silica interconnect layer, the classical control and readout circuits would be patterned in isotopically normal silicon. Working at a temperature below 1 K, qubit operations would be controlled by electron spin resonance, coupling by exchange interactions between the confined electrons, and measurement by radiofrequency dispersive readout.

Using minimum feature sizes that are achievable now or anticipated in the near term, the researchers propose a circuit geometry that would result in individual 2D modules of 480 qubits each. Thousands of these modules could be combined, producing a computer containing millions of interacting qubits.

[Menno Veldhorst et al., Nature Communications 8, article no.: 1766 (2017); doi:10.1038/s41467-017-01905-6]

Extracted with permission from an item by Marric Stephens at physicsworld.com.
PRODUCT NEWS

Lastek

New Picowatt Photoreceiver from Femto
The new Femto picowatt photoreceiver series PWPR-2K is the perfect choice for cw-measurements, time resolved signal acquisitions and highly sensitive modulated measurements.

Features:
• Ultra-low noise, NEP ≤ 10 fW/√Hz
• Si and InGaAs models cover the wavelength range from 320 to 1700 nm
• Transimpedance gain switchable 109 V/A, 1010 V/A
• Easily convertible to fiber optic input (FC and FSMA) with optionally available screw-on adapters

In addition to precise and fast cw-measurements the relatively large bandwidth from DC to 2 kHz also allows time-resolved and modulated measurements. Particularly the combination with lock-in amplifiers results in ultra-sensitive measurement systems being almost immune to disturbances from external sources. In this way the PWPR-2K can easily detect optical powers from about 100 fW up to 10 nW.

The PWPR-2K photoreceivers are factory equipped with an optical free-space input. There is the choice between a 1.035”-40 threaded flange (FST) and a 25 mm unthreaded flange (FS).

Omni-λ Monochromators and Spectrographs from Zolix Instruments
Omni-λ Series of imaging spectrographs and monochromators from Zolix Instruments are profession standard for researchers who demand the highest quality data. Zolix spectrographs and monochromators feature a very flexible design that can be configured for a wide range of applications & spectral range from UV to NIR.

Features:
• 200 mm, 320 mm, 500 mm, 750 mm focal length
• Rugged Czerny-Turner spectrographs come as pre-aligned and pre-calibrated for ease of operation.
• Interchangeable triple grating turret offers different wavelength ranges and resolutions and provides a simple, accurate and convenient way to change gratings within the spectrograph unit
• These instruments can be integrated with single point detectors, InGaAs cameras and CCDs to offer a versatile, most sensitive modular solution for different applications
• Accessories including filter wheels, fiber adapters, shutters, motorized slits, sample chambers etc.
• Software can complete data acquisition for detectors including single point detectors and CCD.
• Labview driver for programming to operate Omni-λ Series spectrographs and monochromators.

Gentec-EO announce Blu, the Bluetooth connected All-in-One detector & meter
This new line of All-in-One detectors from Gentec-EO combine a detector and a meter with Bluetooth connectivity in one convenient product. The small but powerful meter of the BLU Series presents a Bluetooth connection so you can display the results on your mobile device with the Gentec-EO BLU app available for both iOS and Android systems. Need to use it with a PC? Simply plug in the included Bluetooth receptor
and be ready to make power or energy measurements within seconds!

- All-in-one detector + meter: this new line of All-in-One detectors combine a detector and a meter with Bluetooth connectivity in one convenient product

- Safer work environment: operators can be far from the detector while making measurements (up to 30m, depending on the environment and barriers). And with less cables in the workspace, accidents are less likely to happen!

- Incredible performance: BLU detectors offer the same performance as the usual detector + monitor combination, from mW to kW

- Long battery life: the USB-rechargeable Li-ion battery lasts up to 5 continuous days with the device running

- Compact size: perfect for the lab, OEM applications and field servicing. No need to carry a meter!

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Cobolt AB, a part of HÜBNER Photonics, introduces the Cobolt 08-NLD 405 nm frequency stabilized, Narrow linewidth Laser Diode with up to 30 mW and including an integrated optical isolator. With totally integrated electronics, the compact Cobolt 08-NLD 405 nm is ideally suited for high end Raman spectroscopy or other analytical measurements.
Also available in the 08-01 Series is the Cobolt 08-DPL 532 nm (diode pumped laser), either with or without an optical isolator, Cobolt 08-DPL 561 nm and the Cobolt 08-NLD 785 nm. The Cobolt 08-DPL 532 nm and 561 nm are truly SLM with excellent spectral purity and wavelength stability while the Cobolt 08-NLD 785 nm is a narrow linewidth laser with up to 500 mW.

**P-616 NanoCube multi-axis alignment system**

Physik Instrumente, a global leader in the design and manufacture of high precision motion control systems has launched the P-616.3C parallel-kinematic multi-axis alignment system.

The NanoCube’s parallel-kinematic design offers the highest stiffness in all spatial directions as well as high dynamic motion and resonant frequencies with friction free motion and is highly suited to applications that require fast, precision positioning. The P-616.3C has the following key features:
- Travel range: 100 μm x 100 μm x 100 μm
- Resolution: 0.4 nm
- Resonant frequency: 700 Hz (unloaded)
- Highly compact form factor
- Dimensions: 40 mm x 40 mm x 40 mm

Applications include:
- Fibre alignment
- Microscopy applications
- Two-photon polymerisation
- Nanotechnology and nanomanufacturing

**Extended range NIR spectrometer**

StellarNet’s high performance RED-Wave-NIRX-SR Spectrometers cover the NIR wavelength range from 900-2300 nm in one unit.

The spectrometers are exceptionally robust with no moving parts and are packaged in small rugged metal enclosure (100 m x 152 mm x 70 mm) for portable, processes, and lab applications. The InGaAs detector is a Sensors Unlimited linear photo diode array with 512 pixels (1024 optional) 25 μm by 250 μm tall to provide best signal performance. The detector has an integrated two-stage thermo electric cooler (TEC) maintained at ~20 °C, stabilized within +/-0.1 °C. The RED-Wave-NIRX-SR-InGaAs spectrometers use single strand SMA 905 fiber optic input.

Applications include chemical absorption, moisture analysis, transmission of filter and optical components and high power radiometric measurements such as laser characterisation.

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