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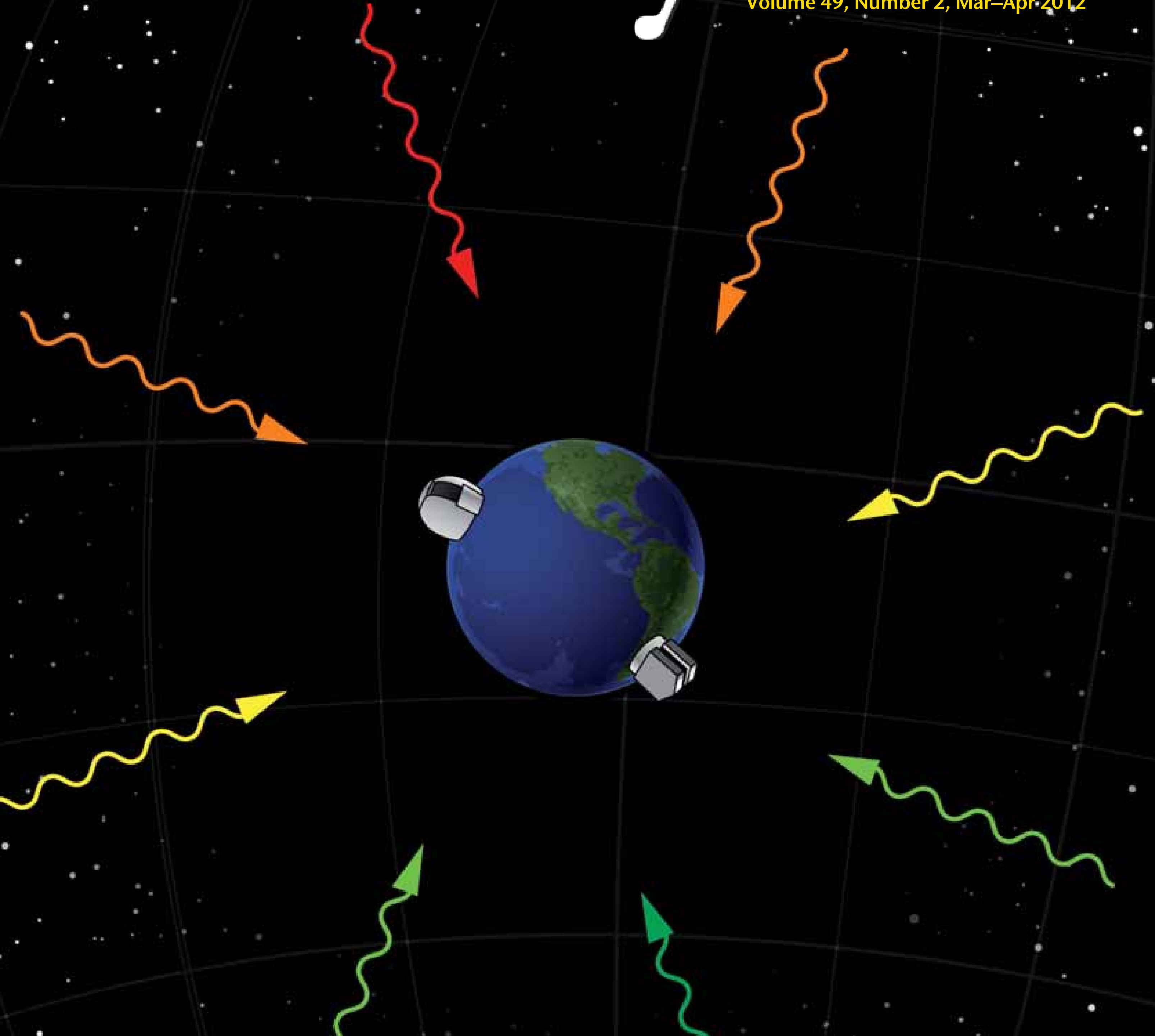

Is the fine-structure constant not actually constant?

Clarifying the concept of entanglement

Trapped atomic ions and precision sensing

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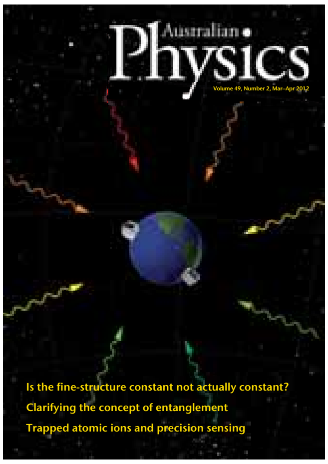

Cover

Observations of the northern sky from Hawaii and observations of the southern sky from Chile have now been combined to provide evidence that the fine-structure constant varies across the Universe – see the article by Michael Murphy on page 43 [credit: Julian Berengut, University of NSW].

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Articles for submission to *Australian Physics* should be sent by email to the Editor: prob@unimelb.edu.au. The text should be sent as a Word file and authors are advised to consult a recent issue as a guide to style. Images should not be embedded in the document, but should be sent as high resolution attachments in JPG or PNG format. Authors should also send a short bio and a recent photo. The Editor reserves the right to edit articles based on space requirements and editorial content. Contributions should be sent to the Editor.

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EDITORIAL

Warm welcome to Synchrotron funding

After a year or more of uncertainty, *Australian Physics* welcomes the long overdue announcement that the immediate future funding of the Australian Synchrotron has been secured. Under a memorandum of understanding signed in late March, the Federal and Victorian governments have agreed to jointly commit $95 million to running the synchrotron for the next four years.

The funding crisis had its origins when the Brumby Labor government in Victoria trumped a rival bid from Queensland and agreed to build the $250 million facility next door to Monash University in Melbourne. Although state funded, the new facility was obviously of national and international importance and deserved some level of federal funding. The crunch came when Victorian Labor was replaced by the Liberal Baillieu government in 2010, which was soon at odds with federal Labor as to how the facility would be funded. During 2011 threats were made to shut down the facility over the funding issue. Unfortunately, the synchrotron had become a political football, a disgraceful state of affairs for what is one of the world's most advanced synchrotrons and clearly one of Australia's premier scientific facilities.

We are pleased to present three feature articles in this issue. Our remarkable cover story by Michael Murphy describes his work with colleagues at Swinburne University and the University of NSW. They have provided compelling evidence that the fine structure constant – and thus the strength of the electromagnetic force – shows small but definite variations over cosmic scales. Could this be a clue to new fundamental physics?

Next, Gordon Troup, David Paganin and Andrew Smith at Monash University note that the concept of entanglement is sometimes introduced in the literature where it is unnecessary. They clarify the concept of entanglement in Special Relativity and Quantum Mechanics, with a view to helping undergraduate students understand the concept.

Finally, Michael Biercuk describes a new technique developed by his group at the University of Sydney of using trapped atomic ions to detect extremely small forces, with a sensitivity over 1000 times better than previous approaches. The technique achieves performances at the scale of 'yoctonewtons' (10^{-24}), the smallest existing SI prefix.

We would like to pay tribute to Professor Jak Kelly, formerly at the University of NSW, who passed away recently. Jak was a colourful, talented and respected editor of this magazine during the 1990s. His obituary will appear in a future issue.

Peter Robertson

PRESIDENT'S COLUMN

Where are the legislative checks and balances?

I start this column with congratulations. Firstly to Professor Ben Eggleton who received his Walter Boas Medal at a ceremony at Melbourne University at the end of March. I was expected to present the medal but was prevented from doing so by the vagaries of air travel! Our Victorian Branch Chair Andrew Stevenson deputised for me. Secondly to our AIP members who were elected to the Australian Academy of Science recently: Professors Joss Bland-Hawthorn, Paul Leslie Burn, John Church, Tanya Monro, Michael Tobar; and from our cognate society the Astronomical Society of Australia, John Norris. It is great to see so many in our ranks recognised.

I was very pleased to hear of the agreement for funding of the Australian Synchrotron though a collective funding arrangement. I reported in one of my columns last year that I had written to Premier Baillieu expressing the AIPs concerns for the future of the synchrotron and had received a positive reply. It is good to see those words come to fruition, but it is still disappointing to find that no additional beam lines will be funded in the four years of agreed funding. This facility has the capacity to do so much more.

Another matter of concern has been a recent bill before the federal parliament. The *Defence Trade Controls Bill 2011* has passed through the House of Representatives and is currently with the Senate Foreign Affairs, Defence and Trade Committee before a Senate vote planned for the Budget sitting. The bill aims to bring our laws into line with our US defence treaty partner. It restricts the transfer of information on a large range of materials and technologies to Australian residents, citizens or companies. This is done through inclusion of "the intangible transfer of research results, papers, seminars, conferences, and instructions written or recorded, working knowledge, design drawings, models, operation manuals, skills training, potentially including the content of some post-graduate courses and catalogues."

There had been little or no consultation with the tertiary education and scientific research sectors when the bill was drafted. The Vice-Chancellor at Sydney University took action (with Universities Australia) after seeking legal advice about the impact of the bill. It was clear that, under the bill in its present form, many standard laboratory techniques, processes, chemicals and micro-organisms, as well as equipment incorporating electronic and optical systems could not be used in teaching of foreign students or in research collaborations with foreign nationals across science, engineering and health. Sydney University was called before the Senate committee with less than 24 hours notice to give evidence of the consequences as a result of their earlier input. The Senate committee agreed that the consequences were unintended and severe and has delayed the bill until August to allow time for proper consideration of the issues.

I became aware of the problems, through the Australian Optical Society, shortly before Sydney University was called before the Senate committee. I raised the issues with Science and Technology Australia which immediately contacted relevant ministers. I also wrote to the same ministers. I noted an additional problem with the bill that would mean that research proposals or papers referring to any of the declared range of materials and technologies may not be allowed to be reviewed or refereed by foreign nationals. This could critically impact on our grant assessment processes and on the dissemination of our research results.

Fortunately this precarious situation has been caught in time and we should be very grateful to the prompt action of Sydney University and its Vice-Chancellor. We are now in campaign mode with appropriate ministers to ensure that the issue is fully resolved, but it begs the question how could such a damaging bill have got so far? What has happened to the public service checks and balances? I don't have an answer to that but it concerns me deeply, especially as a former public servant myself. We should not have to spend time ourselves or need to employ specialists to keep an eye out for the consequences of every piece of legislation before the various parliaments of Australia – but perhaps that is the future that science administrators will, sadly, have to deal with.

Marc Duldig

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Exposure Draft of the Physics Decadal Plan

We need your comments!

After a process spanning more than one year, dozens of one-on-one interviews, analysis of data and workshops conducted by the working group, the Exposure Draft of the Plan has been released for comment. The Exposure Draft contains an overview of Australia's opportunities for the future identified by sub-discipline committees that sought opinions from physicists working in the field. The plan also reviews the environment for physics in Australia and presents recommendations for the prosperity of physics in the future. These range from supporting our science and physics teachers to streamlining funding processes, through supporting a diverse human capital and ensuring Australia continues to be an attractive place for excellent physicists to come and work.

The next steps with the plan will turn the Exposure Draft into the final plan. We seek community feedback until mid-April on the contents of the Exposure Draft. Have we missed anything important? Are there innovative recommendations we have overlooked that could build on the excellence in physics today for an even brighter future? At the same time, as for any publication, we are having the plan reviewed by expert physicists with a distinguished track record in the field. Once these final steps are completed, the plan will be handed to the National Committee for Physics of the Australian Academy of Science to be launched. Have your say and help us build the future of physics in Australia.

To download the Exposure Draft (part 1) and the associated research data (part 2) go to the decadal plan web site: www.physicsdecadalplan.org.au. Send your comments to: info@physicsdecadalplan.org.au.

In our next issue…

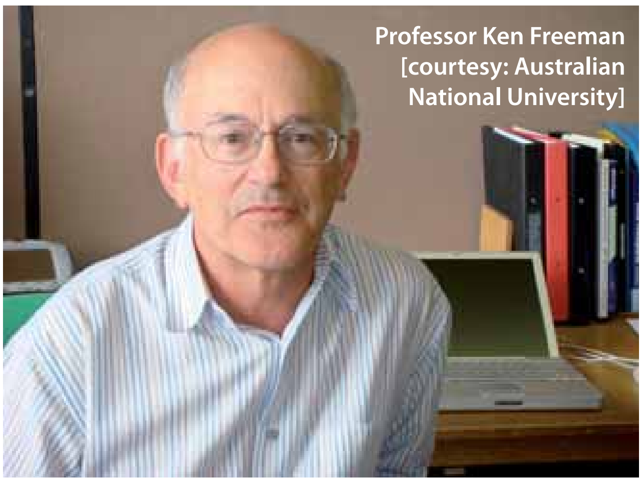
- John Jenkin examines the roles played by father William Bragg and son Lawrence Bragg in the discovery of Braggs' Law
- Dave Neudegg discusses space weather and Australia's Ionospheric Prediction Service
- Fulvio Melia argues for a rational reinterpretation of Cosmology that leads to a simpler and more elegant Universe

Matthew Flinders Medal awarded to Ken Freeman

Professor Ken Freeman has been awarded the Matthew Flinders Medal for 2013 by the Australian Academy of Science. The award is made every two years and the nominations are made by Fellows only. Among the numerous medals and awards made by the Academy, the Flinders medal is considered to be the most prestigious.

Freeman is currently Duffield Professor of Astronomy in the Research School of Astronomy & Astrophysics at the Mount Stromlo Observatory of the Australian National University. He was born in Perth in 1940, studied mathematics and physics at the University of Western Australia, and graduated with first class honours in applied mathematics in 1962. Ken then went to Cambridge University for postgraduate work in theoretical astrophysics with Leon Mestel and Donald Lynden-Bell, and completed his doctorate in 1965.

Following a postdoctoral appointment at the University of Texas with Gérard de Vaucouleurs, and a research fellowship at Trinity College, Cambridge, he returned to Australia in 1967 as a Queen Elizabeth Fellow at Mount Stromlo. Apart from a year in the Kapteyn Institute in Groningen in 1976 and some occasional absences overseas, Ken has been at Mount Stromlo ever since.



Professor Ken Freeman [courtesy: Australian National University]

Measuring cosmic distances with active galactic nuclei

University of Queensland astrophysicist Dr Tamara Davis, together with researchers from Denmark, has earned fourth spot on *Physics World* magazine's top ten physics breakthroughs in 2011, for developing a ground-breaking method to measure cosmic distances using light from active galactic nuclei (AGNs).

Determining accurate distances to objects is the key to establishing the age and energy density of the Universe. AGNs are active super luminescent galaxies fuelled by a black hole at their heart. They outshine almost all other sources of light, making them ideal for measuring distances.


Dr Tamara Davis [credit: Andre Linde]

"I was stunned to be chosen amongst the top ten breakthroughs of the year, partly because this is the discovery of a technique, rather than a fundamental discovery about the Universe", Davis said. "However, they're acknowledging this as a breakthrough because every time a new way to measure the Universe is discovered, it seems new knowledge soon follows – the discovery that supernovae could be used as distance indicators led to the discovery of the acceleration of the Universe, and the 2011 Nobel Prize in Physics." From UQ's School of Mathematics and Physics, Davis worked with Darach Watson, Kelly Denney and Marianne Vestergaard at the Niels Bohr Institute in Copenhagen.

The secret to calculating astronomical distances is to be able to know the intrinsic brightness of an object. In the 1990s it was discovered that supernovae could be used as 'standard candles'. The team's discovery shows that AGNs can be used in a similar way, and because they are more luminous than supernovae they can potentially be used to determine much larger distances. "AGNs don't disappear after a couple of months like supernovae do. That means that in addition to being observed out to greater distances, repeat observations can be conducted to make the measurements more accurate," Davis said. In deciding the top 10 breakthroughs of the year, the editorial team at *Physics World*, published by UK's Institute of Physics, looked at factors such as the fundamental importance of the research, its significant advance in knowledge, its strong connection between theory and experiment, as well as its general interest to all physicists.

"We are particularly impressed with how you and your colleagues have expanded astronomers' ability to look back in time using AGNs, objects that are ubiquitous in the universe", reads the citation from *Physics World*.

Tamara Davis is an ARC Future Fellow, and winner of a number of prestigious awards, including the L'Oréal Women in Science Award (2009), the Queensland Young Tall Poppy overall winner (2011), and the AIP Women in Physics Lecturer Award (2011) [see *AP* **48**, 7–8 (2011)].

According to the Academy's citation, Freeman is widely acknowledged as the world's most eminent galactic astronomer. He was the first to identify the necessity for dark matter in galaxies and has shaped our current understanding of the dynamics and structure of galaxies. Over the past decade Ken has co-established the field of galactic archaeology, where fossil records of stars are used to trace the formation of the Milky Way. His ideas have helped launch the $1 billion European Global Astrometric Interferometer for Astrophysics satellite. GAIA will work with a purpose-built instrument on the Anglo-Australian Telescope to fossick for stars that will chronicle the history of the galaxy since its birth over 13 billion years ago.

Freeman has acted as primary supervisor for over fifty PhD students and seven postdocs, and five of his students

have won Hubble Fellowships. He is active in international astronomy, as a division past-president of the International Astronomical Union, and serves on visiting committees for several major astronomical institutions around the world.

Ken was elected a Fellow of the Australian Academy of Science in 1981 and a Fellow of the Royal Society in 1998. In 2001 the US Institute for Scientific Information named him as the fifth highest cited Australian scientist of all time.

Eggleton wins Walter Boas Medal

Professor Ben Eggleton, Director of the ARC Centre of Excellence for Ultrahigh bandwidth Devices for Optical Systems (CUDOS) at the University of Sydney has won the 2011 Walter Boas Medal awarded by the Australian Institute of Physics. He received his medal at an awards ceremony at the University of Melbourne in March this year.

The medal was established in 1984 to promote excellence in physics research and is awarded annually to a physicist working in Australia whose original research – over the five years prior to the award – has made an important contribution to physics. The medal is named after Walter Boas who emigrated from Germany to Australia in 1938 and later served for over twenty years as chief of CSIRO's Division of Tribophysics.

"Winning the Walter Boas Medal is certainly a tribute to the excellent research being done in my group in the School of Physics and at CUDOS", said Eggleton. "The award recognises our recent research achievements in nonlinear optics, the physics of slow light and optical signal processing – work done in my group by outstanding postdocs and students in collaboration with other top groups in Australia and overseas."

Eggleton won the medal for his fundamental research in the physics of nonlinear optics and the application of this work to the development of practical devices and disruptive technologies in optical communication, data storage and information processing. The AIP judging panel was particularly impressed with Eggleton's development of chalcogenide devices for nonlinear optics applications and the ability to precisely control the flow of light via innovative photonic-crystal structures.

AIP President Marc Duldig said: "It is testament to the calibre of his original research and his scientific output that the selection committee was able to come to a unanimous decision, despite an extraordinarily strong field of nominations, to award the 2011 medal to Ben. His establishment and leadership of CUDOS and the Institute of Photonics and Optical Science at the University of Sydney augurs well for the future of this exciting work."

Professor Ben Eggleton, Director of CUDOS [courtesy: University of Sydney]

At the awards ceremony Eggleton delivered a seminar on his research, detailing his ground-breaking work on nonlinear optical signal processing in photonic chips, which has opened up new opportunities for energy efficient optical signal processing and quantum processors. The photonic chip technology is the basis of the current CUDOS program. Eggleton's team has published in leading journals such as *Nature Photonics* and their papers are highly cited.

AIP Medals and Awards for 2012

Call for Nominations

Harrie Massey Medal to recognise contributions to physics made either by an Australian physicist or by work carried out in Australia.

General Conditions: The prize is awarded biennially for contributions to physics or its applications made by an Australian physicist working anywhere in the world, or by a non-Australian resident in, and for work carried out in, Australia. The recipient must be a member of the Australian Institute of Physics or the Institute of Physics.

Alan Walsh Medal recognises significant contributions by a practising physicist to industry in Australia.

General Conditions: The prize is awarded biennially for physics research and/or development that has led to patents, processes or inventions which, in the opinion of the judging panel, have led to significant industrial and/or commercial outcomes, such as devices that are being manufactured or have influenced a major industrial process.

Walter Boas Medal to promote excellence in research in Physics in Australia and to perpetuate the name of Walter Boas.

General Conditions: The prize is awarded annually to a member of the AIP by the Victorian Branch for physics research carried out in the five years prior to the date of the award, as demonstrated by both published papers and unpublished papers prepared for publication.

Education Medal to emphasise the importance of all aspects of physics education in Australia.

General Conditions: The prize is awarded biennially to a member of the AIP who is judged to have made a significant contribution to university physics education in Australia. In determining the recipient of the award, the quality of the work, the significance to physics education, and the creativity displayed will be taken into account.

Bragg Gold Medal to recognise the work done by a PhD student in Australia that is considered to be of outstanding quality.

General Conditions:: The medal is awarded annually to the student who is judged to have completed the most outstanding PhD thesis in Physics under the auspices of an Australian university, whose degree has been approved but not necessarily conferred in the previous thirteen months. No candidate may be nominated more than once.

Outstanding Service to Physics to recognise an exceptional contribution on the part of an individual.

General Conditions: The AIP Award for Outstanding Service to Physics will recognise an exceptional contribution on the part of an individual who gives great amounts of time and effort to the furtherance of Physics as a discipline. Nominations may be made by a Branch Committee or by three members of the AIP. There will be no more than three awards nationwide in any one year.

Presentation of the Awards

All the above awards will be presented at the biennial Congress by the President of the AIP. The next presentation will be made at the 2012 Congress in Sydney. Each recipient is expected to present a talk at the Congress on her/his work.

Nominations

Nominations for all awards (except the Bragg Gold Medal) should be sent to Olivia Samardzic, Special Project Officer AIP, by 31 July 2012. Details for the Bragg Gold Medal nomination process can be found on the web site listed below.

Further information about these awards can be found at www.aip.org.au/content/medals or obtained by email from the AIP Special Projects Officer at olivia.samardzic@dsto.defence.gov.au or by phone on (08) 7389 5035. Applications and nominations (except for the Bragg Gold Medal) should be sent by email attachment to the above email address or to the Special Projects Officer at Olivia Samardzic, 205 Labs, EWRD, DSTO, PO Box 1500, Edinburgh, SA 5111.

Electromagnetism: Does Its Strength Vary Across the Universe?

Michael Murphy

The fundamental constants are central to our theories of physics, yet those theories offer no understanding of the constants, no way to calculate them. If the constants were found to vary, we might learn what they depend on and perhaps glimpse a more fundamental theory, perhaps 'the' theory. For a decade we've found that α, the fine-structure constant, which characterises electromagnetism's strength, is slightly smaller in distant galaxies, at least those appearing in the northern sky, than on Earth. But now, with measurements over both hemispheres, we find evidence for a dipole-like variation in α across the sky. The fine-structure constant α could be the first fundamental constant that isn't.

Fundamental? Constants?

To many physics undergraduates, the fundamental constants of Nature must seem little more than a rather long list of obscure numbers at the back of their textbooks. Annoyingly, they have to be committed to memory, not quickly re-derived in a side-calculation as physicists would prefer to do. And they're (irrational) real numbers, not nice, easy-to-remember, round ones – how many digits of Planck's constant can you rattle off without googling 'h'?

But these inconveniences go much deeper, right to the heart of our current understanding of physics, in fact. Richard Feynman said it best (as usual) about $\alpha = e^2/\hbar c$, the fine-structure constant of electromagnetism:

"It has been a mystery ever since it was discovered... and all good theoretical physicists put this number up on their wall and worry about it. Immediately you would like to know where this number for a coupling comes from: is it related to pi or perhaps to the base of natural logarithms? Nobody knows. It's one of the greatest damn mysteries of physics... We know what kind of a dance to do experimentally to measure this number very accurately, but we don't know what kind of dance to do on the computer to make this number come out, without putting it in secretly!" [1].

That is, within current physics theories, an expression for any observable quantity inevitably includes at least one fundamental constant, the value of which is known only from experiment. The constants cannot be derived within the theories; hence the title 'fundamental' and the annoying need to commit them to memory. Similarly, the theories say nothing about their constancy – only experiments can establish that or rule it out. So far, some of the most staggeringly precise laboratory measurements ever made have not revealed any variability (e.g. [2]).

And why so many fundamental constants to 'worry about'? Probably because our current theories don't describe the most fundamental physics, but merely a set of approximate physical laws. Much like the Newtonian concept of gravity is fundamentally incorrect and Einstein's general relativity is better, probably our current concept of all physical laws is fundamentally incorrect. The aim,

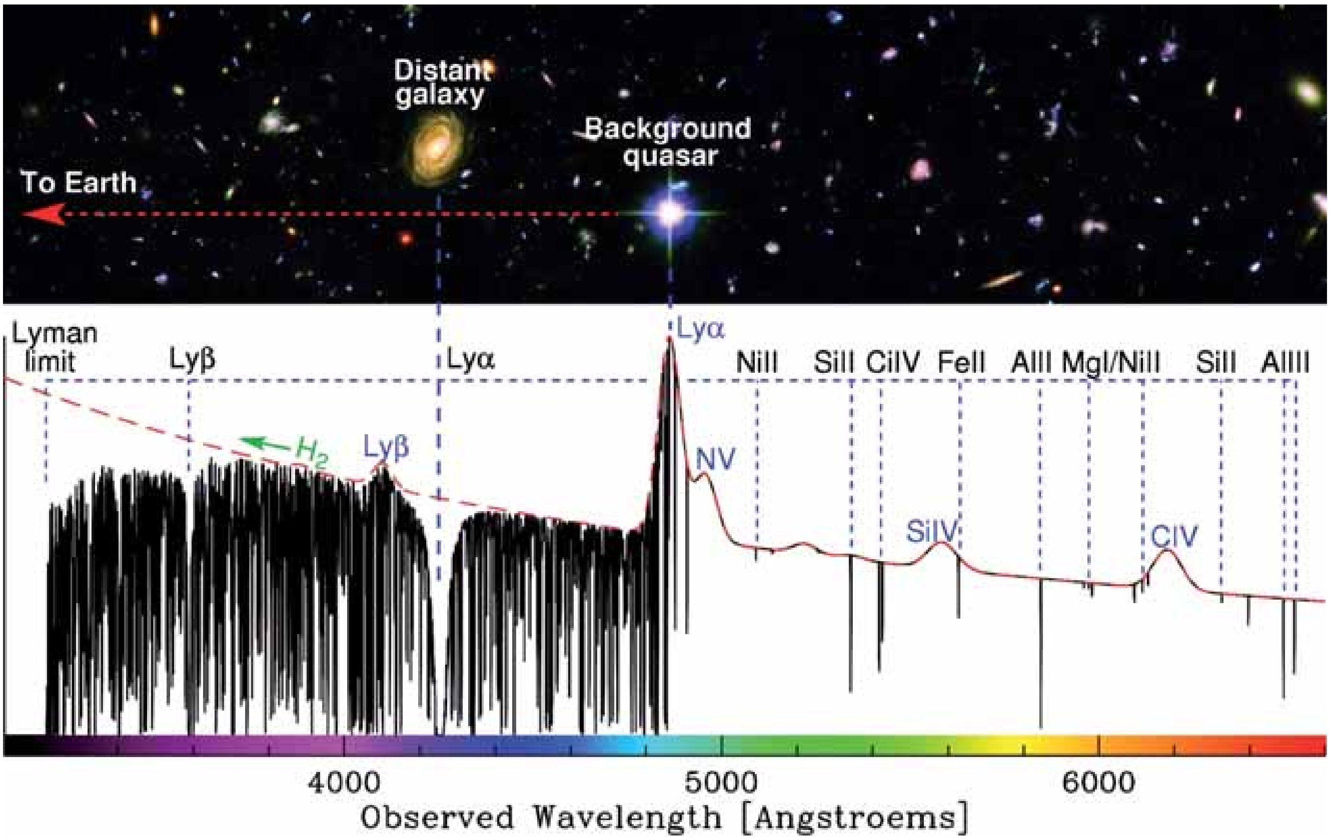


Fig. 1. The quasar absorption line experiment. The top panel shows quasar light intersecting a galaxy on its way to Earth. The bottom panel shows a synthetic (but realistic) quasar spectrum with important emission lines (blue labels) from the quasar and absorption lines (black & green labels) from the intervening galaxy. The relative separations between the metal lines are sensitive to the fine-structure constant α.

of course, is to find a better theory, maybe 'the correct one', maybe one without seemingly arbitrary fundamental constants.

The search for 'variable constants' is therefore a basic test of physics beyond the Standard Model. But beyond-Standard theories currently offer little to guide where and when in the Universe any variability is strongest, or easiest to spot. We therefore need to test the variability of fundamental constants in as wide a variety of places and times in the Universe as possible.

α, quasars and the Many Multiplet method

The time variability of α has, of course, been scrutinised in highly controlled, Earth-bound laboratory experiments. The degree to which frequencies of electromagnetic transitions depend on α varies from transition to transition, ion to ion. By comparing the ticking rates of single-ion optical atomic clocks based on Al and Hg over 10 months, the relative rate of change in α was recently limited to just a few parts in 10^{17} per year [2]. Impressive, certainly, but what if α changes, say, non-linearly with time and you want to know its value in a far-flung galaxy 10 billion light-years away? Without a theory of varying α, that 10-month laboratory experiment in our little corner of the Universe can't say much about the laws of physics across the entire Universe and throughout its 14 billion year history.

Quasars, and the odd 10-m diameter telescope, make looking back 10 billion years routine. Quasars are supermassive (~10^9 solar mass) black holes at the centre of galaxies. Friction and gravitational energy from an accretion disc of in-falling gas and dust means quasars outshine all the stars in their host galaxies, radiating ~10^{40} W of light which, even 10 billion light-years away, appears as a relatively bright, star-like continuum of radiation in our sky – see Fig. 1.

While quasars are obviously interesting in themselves, ripe with extreme physics and complex interactions with their host galaxies, their brightness, distance, compactness and spectral simplicity (no narrow features) also make their lines-of-sight to Earth perfect probes of the narrow absorption lines from intervening gas. Fig. 1 shows the (simulated) spectrum of a quasar and labels the absorption lines. Most arise from the Lyman α transition of neutral hydrogen in the pervasive intergalactic medium, causing a 'Lyman α forest' bluewards of (at lower redshifts than)

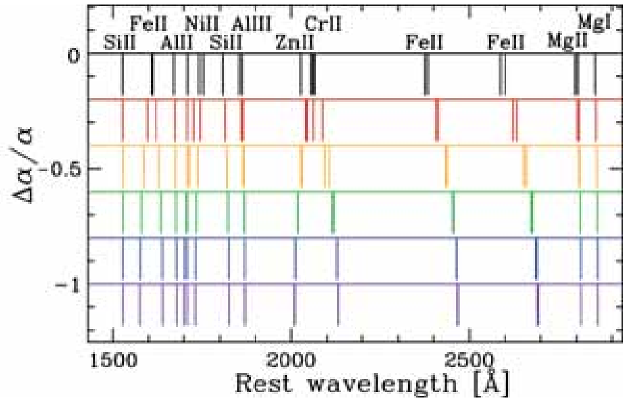


Fig. 2. Sensitivity to α variation of metallic transitions seen in quasar absorption systems. Here Δα/α is the relative deviation in α from the current laboratory value, while 'I' denotes a neutral species, and 'II', 'III' denote singly- and doubly-ionised species. Note that the redder Fe and Mg transitions have a very different pattern of shifts to the bluer transitions; low- and high-redshift absorption systems respond very differently to systematic effects.

the quasar's Lyman α emission line. But the line of sight to many quasars also passes near enough to a distant galaxy to produce a deep, damped Lyman α line, a Lyman ionisation edge, molecular hydrogen bands (sometimes) and, most importantly for us, narrow metallic absorption lines.

It's these metal lines from intervening gas clouds towards background quasars that provide the best (optical) probe of cosmological variations in α. Their sensitivity to α is shown in Fig. 2. This figure is the essence of the so-called 'Many Multiplet' method: like a barcode, the relative wavelength separations of transitions from different multiplets, and different ions, encode the value of α. Thus, by comparing the pattern of separations seen in a quasar spectrum with laboratory standards, any difference in α between a distant gas cloud and the laboratory can be measured.

It's worth noting that the set of transitions observed in any given quasar spectrum, from any given absorption system, varies considerably. Looking back at Fig. 2, this means that the pattern of wavelength shifts from the laboratory standards will be different from one absorber to another; each one has a different barcode depending on which transitions are observed. From the point of view of minimising systematic effects, this is very much a good thing: most instrumental systematics one can imagine tend to affect all quasar spectra in the same general ways, so different barcodes will be affected in different ways by such systematics. That is, the diversity of transitions observed in different absorption systems helps to average over and/or expose simple systematic errors.

A stubborn result: smaller α in quasar absorbers

The Many Multiplet method of analysing quasar spectra for the variability of α was proposed and first demonstrated [3, 4] in 1999 by John Webb, Victor Flambaum and Vladimir Dzuba at the University of New South Wales. At that time, the first largish samples of high-quality, high-resolution spectra were coming from the 10-metre diameter Keck Telescope in Hawaii. Even with a sample of 30 absorption systems, there was an indication that α was smaller in the absorption clouds, on average, than in the laboratory by about 10 parts per million, with a statistical significance of about 3σ [4]. Only the redder Fe and Mg lines could be used in those spectra – those on the right of Fig. 2 – and, consequently, the absorption redshifts were all below 1.8, placing the transitions in the visible observing window.

Many 3σ results go away, usually quite quickly. Not through lack of attention, this result didn't... and still hasn't. Its first test was at higher redshifts where, as you'll note in Fig. 2, an entirely different pattern of line shifts was expected. But we saw the same result [5, 6]: a smaller α in the absorption clouds by about 7 parts per million at redshifts 1.8–3.3, the same as the (re-analysed) lower

"The fine-structure constant α could be the first fundamental constant that isn't."

redshift results. Combined, they constituted 4σ evidence of α varying on cosmological scales.

A larger sample added in 2002, this time covering both low and high redshifts, gave the same result as the previous two datasets [7]. By 2004 we had published 143 measurements of α in distant galaxies with the consistent result that α was about 6 parts per million smaller than the current laboratory value [8]. The formal statistical significance of the evidence for varying α was now above 5σ.

So the signal had not disappeared with added data. Indeed, it had become clearer, as one expects from a real variation in α... or, of course, a well-defined systematic error. For an observational (rather than experimental)

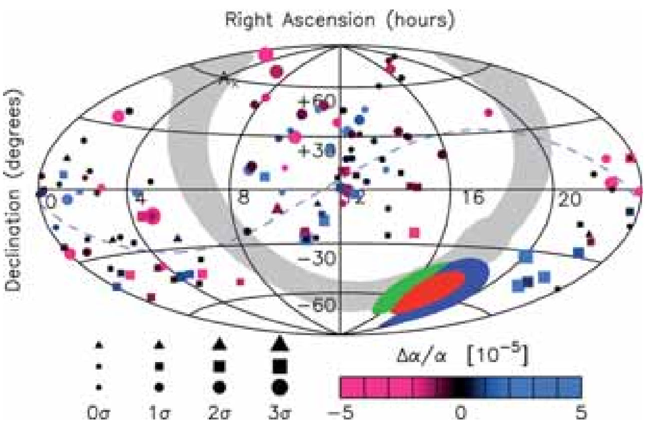


Fig. 3. Distribution of Δα/α values from Keck (circles), VLT (squares) and both telescopes (triangles) across the sky. The relative deviation from the laboratory value is colour-coded, while the point size scales with the significance of that deviation. The grey band indicates the Milky Way disk, behind which few bright quasars are known. The red blob near the Galactic centre (grey bulge) is the direction and 1σ contour of a dipole fitted to all Δα/α measurements, while the green and blue blobs are the dipole directions fitted to the Keck and VLT data independently. The cross marked 'A' and the blue dashed curve indicate the Keck + VLT dipole's anti-pole and equator, respectively. Weighted mean values were used for quasar lines of sight with two or more absorption systems.

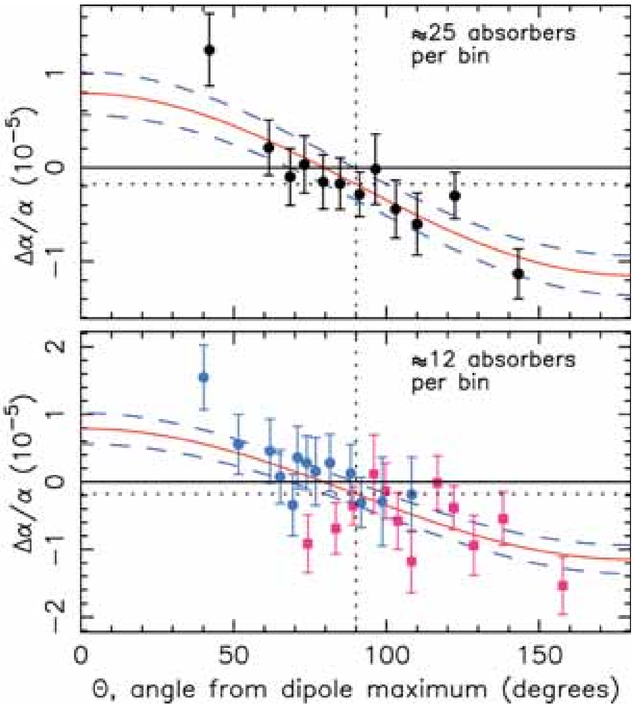


Fig. 4. Binned values of Δα/α versus the angle from the best-fitting dipole direction. The bottom panel separates the Keck (pink) from the VLT (blue) values, while the top panel combines them. The red line indicates the best-fitting dipole model, while the blue dashed line shows its 1σ error.

result like ours, this is, and remains, the most difficult question to answer: can systematic errors explain it? One by one, we analysed and ruled-out or limited the effect of many possible astrophysical and instrumental systematic errors [7, 9]. None could explain what we'd found.

However, all the indications for a varying α had so far come from just one telescope, the Keck Telescope in Hawaii. No matter how good the Keck is, no-one should trust a fundamental result like this from just a single instrument. Enter the VLT – the Very Large Telescope – in Chile.

New result: an α dipole?

In 2004 we began the long task of compiling a similarly large sample of high-quality, high-resolution quasar spectra from the VLT. The previous Keck data were generously donated to us (see the Acknowledgments) already 'reduced' from their raw form taken at the telescope into analysis-ready, science-grade quasar spectra. The VLT spectra had to be reduced from scratch. We also discovered problems with the way VLT spectra were wavelength calibrated – the crucial calibration step when looking for shifts between absorption lines – and these needed to be overcome [10]. But with the hard work of PhD student Julian King at UNSW, we began measuring α in 153 absorption systems in 2008, over the same redshift range, using the same Many Multiplet method as before.

In my mind, there were two likely possibilities: The VLT would show no variation in α, or it would give the same, smaller value of α in the absorbers as the Keck data. Neither was true. Nor was it something in between. In fact, the VLT spectra showed the *opposite* variation in α to the Keck spectra! That is, on average, the VLT values of α were *larger* in the absorbers than the current laboratory value [11, 12].

Your immediate reaction is probably similar to mine: the VLT results simply disagree with the Keck results, neither are correct, and both are the product of (probably different) systematic effects. Well, we had not found a simple systematic error that explained the Keck results and it is similarly difficult to explain the VLT results by a systematic error. Explaining both away probably requires two different systematic errors. But, I'm sure you say, this is still the most likely answer. Maybe.

There's another possibility. We projected the results onto the sky, as in Fig. 3. The Keck and VLT see different skies on average – Keck is at +20° latitude and the VLT is at −25°. Our Keck quasars were predominantly northern ones, our VLT quasars predominantly southern, but many

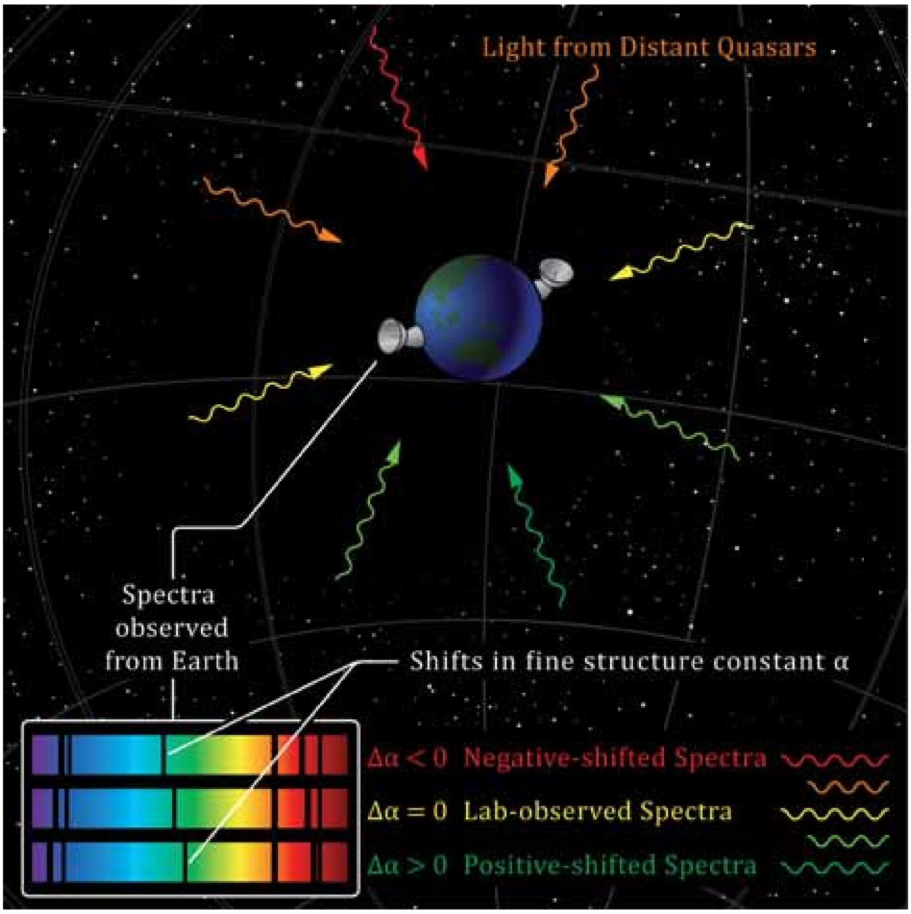


Fig. 5. Illustration of the α dipole and the spectral line shifts (see also Fig. 2) which are observed, on average, over many quasar lines of sight from two different telescopes, the Keck and the VLT. [credit: Julian Berengut, UNSW]

"The aim, of course, is to find a better theory, maybe 'the correct one', maybe one without seemingly arbitrary fundamental constants."

in both samples were equatorial. In Fig. 3 you notice a tendency for larger blue squares – greater positive deviations in α from the laboratory value – to appear near the bottom right of the plot, and larger pink circles to appear near the top left, indicating larger negative deviations. In the middle you notice a mix of smaller symbols, ie. less significant deviations from the laboratory value. The data seem to suggest variation in α across the sky!

Modelling α as a dipole on the sky (ignoring any redshift dependence for now), we can show in Fig. 4 the deviation in α as a function of angle from the best-fitting dipole direction. The dipole model does seem to describe the data very well. Indeed, compared to a monopole model (ie. constant offset in α in all directions), the dipolar variation in α is significant at 4σ, as assessed by both analytical means and by a bootstrap technique (ie. randomly reassigning α measurements to different quasar sight-lines) [11, 12].

The dipole direction is shown as a red 1σ error blob in Fig. 3. Because it's deep in the southern hemisphere, you may still suspect that the apparent dipolar variation in α is driven by systematic effects *between* the two different telescopes, Keck and VLT, even though they agree for equatorial regions. But the blue and green blobs in Fig. 3 give significant pause for thought: when dipoles are fitted to the Keck and VLT data independently, they point in the same direction on the sky. If the dipolar variation from the combined results was driven by systematic errors between Keck and VLT, you would not expect this. We estimate such close alignment would happen 6% of the time by chance alone, given the distribution of quasar sight-lines across the sky [11, 12].

We also find similarly-close alignment between dipoles fitted independently to low- and high-redshift subsamples of the combined Keck + VLT results, with a 2% chance of occurring by chance alone. The joint probability of both these chance alignments happening is difficult to estimate, but a bootstrap technique suggests that it's about 0.1% [11, 12]. All in all, the current data leave us with the strange picture of the Universe illustrated in Fig. 5.

Conclusions and future tests

After a decade of finding α to be ~6 parts per million times smaller than on Earth in distant galaxies, predominantly in the northern sky, we now find the opposite result on the other side of the sky. But, rather than contradicting each other, these two results show a remarkable consistency: there is 4σ evidence for a dipole-like variation in α across the sky; the dipoles from the two telescopes

"After a decade of finding α to be ~6 parts per million times smaller than on Earth in distant galaxies, predominantly in the northern sky, we now find the opposite result on the other side of the sky."

coincide; the low- and high-redshift dipoles also coincide. And we still have not found systematic errors that can explain the results from either telescope, let alone the combined results.

I have not mentioned other constraints on variations in α from work by other groups using the Many Multiplet method, or from radio and millimetre-wave absorption lines, or from meteoritic analysis, or from the Oklo natural fission reactor, etc. While none of these other methods has yielded evidence for a varying α, they are all consistent with the α dipole from our work [13].

Dedicated observing programs on both Keck and the VLT are now aimed directly at refuting or confirming our results. And we are starting to target the anti-pole of the dipole with quasars high in the northern sky and near our Galaxy's anti-centre (see Fig. 3): the signal is largest there and even a modest sample could rule it out (or confirm it!). Crucially, we are trying to do this with two telescopes to make absolutely sure that systematic errors are not responsible for whatever we find.

What if all these future astronomical measurements confirm that α varies on cosmological scales? It would still be important to test with a different technique altogether. And laboratory atomic clock experiments may be the key test. We see tentative evidence for the amplitude of the α dipole increasing radially outwards from Earth, supporting a 'simple' picture of an 'α gradient' in the Universe [11, 12]. If such a gradient exists in our Solar System, it may be detected as an annual modulation in the relative ticking rates of atomic clocks at the 10^{-20} level [13]. While this is three orders of magnitude below current sensitivity, the last decade has already seen a 1000-fold improvement. With such rapid progress, a laboratory test may see a varying α in the next decade or two.

Acknowledgments

This article reports work done in collaboration with the authors of references [3–13] below, especially Julian King, John Webb and Victor Flambaum (University of NSW). Keck spectra were kindly contributed by Chris Churchill (New Mexico State Univ.), Jason Prochaska (Univ. California, Santa Cruz), Arthur Wolfe (Uni. California, San Diego) and Wallace Sargent (California Inst. Tech.). VLT spectra are publicly available on the European Southern Observatory Archive. I thank the Australian Research Council for a QEII Fellowship (DP0877998) and a Discovery Project grant (DP110100866).

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BIO

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Cutting Entanglement

Clarifying the Concept in Special Relativity and Quantum Mechanics

Gordon Troup, David Paganin and Andrew Smith

The concept of entanglement is sometimes introduced in the published literature where it is unnecessary. The cases of Newtonian, special relativistic and quantum mechanical conservation of linear and angular momentum are treated here without entanglement, as is the two-slit interference experiment. A treatment of a topic where entanglement *is* necessary, q-bits, is then given. This is in the interest of helping students to learn Quantum Mechanics.

Introduction

This article is written in the spirit of not unnecessarily complicating things when teaching students, especially where Quantum Mechanics is concerned. The systems discussed are idealised, in the sense that they are isolated. Let us start with the laws of conservation of Energy, Momentum, and Angular Momentum. In a Newtonian system and an Einsteinian special relativistic system, these laws hold.

So consider, in a Newtonian system, a device we shall call a 'bomb', with mass M, which is isolated and initially at rest in an inertial reference frame. We can detonate it so that it splits into only two pieces with masses m' and m'', the sum of which is equal to M. Then we know that the momentum conservation law states that the momentum of m' is equal and opposite to that of m''. So m' and m'' are related together as a system, so long as they are not interfered with, from one end of the Universe to another, in distance and in time. And if the momentum of m' is measured, then the momentum of m'' must be equal and opposite. So if an observer 1 in the inertial frame is the first to make a measurement, he or she correctly predicts the result of observer 2, no matter how far away they are separated in time or distance. This is also true for Special Relativity, though the formalism is a little different.

Do we call this *entanglement*? No, we do not even question it, because it is a consequence of the conservation law. Do we talk about *pre-programming*, as in some discussions of entanglement? Only if we are talking about the bomb designers, that is, the arranged properties of the two parts of the bomb.

Fig. 1. Roy J. Glauber shared the 2005 Nobel Prize for Physics with Theodor Hansch and John Hall [credit: Mike Kurry/Wikipedia Commons].

If m' has an angular momentum imposed on it, we know that m'' has an equal and opposite angular momentum, because of the conservation law. The same comments and question, and the answer above, apply. Especially, Special Relativity applies.

Relativity and Quantum Mechanics

We are now going to consider relativistic problems, to which Quantum Mechanics applies. It should be pointed out that Quantum Mechanics and Special Relativity are compatible. Even stimulated emission is compatible with Special Relativity, though Einstein used what might be called a 'semiclassical' argument in his paper introducing it.

Pair annihilation: When an electron–positron pair annihilates, positronium is formed first, and the particle spins are opposed, so the initial angular momentum is zero. Therefore the sum of the spins of the resulting photons must be zero, leading to them having opposite spins, each of magnitude 1. So if we detect a spin of +1, the other photon must have spin -1.

How is this result different from the two spinning bomb parts? It is not: we have a similar expanding system brought about by the conservation law.

Pair production: The photon producing the pairs has a spin of ±1. Therefore the electron and the positron must have the same spin direction, to give a total spin of ±1. Again, this is, by extension, no different from our bomb parts result. Yet these results are called entanglement unnecessarily. Entanglement is much more than this!

We examine now the quantum mechanical treatment of a created 'electron' pair, travelling in opposite directions, subject to conservation of angular momentum, so that the spins are both 'up' or both 'down'. Our detector can detect either configuration, and distinguish between them. The beams have been filtered so that only spin up is detected. In what follows, operators will be denoted by roman letters, thus: a, A. Ordinary quantities and scalars are denoted by italics, thus: *A*, *a*.

Let one of the 'electron beams' be travelling along the x direction, with spins up in the z direction. The spin states are represented by the column vectors $|1\ 0\rangle$ (spin-up) and $|0\ 1\rangle$ (spin-down). In the situation described, our detectors will only detect $|1\ 0\rangle$. Now a detector is rotated by an angle α. This is equivalent to a unitary transformation of the S_z spin operator, so the eigenvalues are the same. But since the new state detected is a mixture of the S_z and S_y states, our detector can and will now detect spin-down as well as spin-up.

The same must be true of the detector in the other beam, if it is similarly rotated. The states $|1\ 0\rangle$ and $|0\ 1\rangle$ will have different probabilities of being detected, *but these probabilities will be the same for each beam*. This is considered by some to be the quantum mechanical contribution to 'entanglement', but it is only state mixing. Yes, it is strange, but initially so was potential barrier penetration, and the zero orbital angular momentum of all *s*-state atomic orbitals. The quantum mechanical result for the beams obeys the appropriate law of angular momentum conservation, and the rules of quantum mechanics.

Two-slit interference experiment: This experiment has been performed with photons, electrons and atoms. The comment by Professor Roy Glauber (see Fig. 1), discoverer of the coherent state representation, and developer of a new theorem in Quantum Mechanics, is very relevant: "The things that interfere in Quantum Mechanics... are probability amplitudes for certain events" [1]. The following discussion is on photons, but most of it is applicable to other particles, *mutatis mutandis*.

Let the slits have a separation d. Let the wavelength of the incident radiation be λ. The uncertainty principle is $\Delta p \Delta q \sim h$, where p is the momentum, q is the appropriate displacement, and h is Planck's constant. Now $\Delta q = d$, so $\Delta p \sim h/d$, in the direction perpendicular to the incident momentum $p = h/\lambda$. So the sine of the angle between the resultant momentum and the incident momentum is λ/d. This is the separation angle between two bright fringes... .

Is it necessary to invoke entanglement here? Obviously not. Better is to come. An experiment after the style of that by Basano and Ottonello [2] has been performed with two identical frequency stabilised lasers, each focussed on only one slit of the pair. One laser was run below threshold, so emitting amplified 'thermal' noise, which has a Bose–Einstein distribution over the number states of the representative harmonic oscillator. The other laser was operated well above threshold, giving the 'coherent state' distribution for the harmonic oscillator. Of course fringes occurred! A photon counting experiment on the central maximum of the fringe pattern should show the distribution for 'signal plus noise' which is well known.

In all this discussion, no mention of entanglement has been made, yet one can find discussions where it *is* mentioned. Why? It is clearly not mentioned in these situations.

Fig. 2. A playfully earnest David Paganin illustrates two of the states of a coupled twin spin-½ system [credit: Steve Morton, Monash University].

Entanglement, decoherence and quantum computation

Thus far we have largely focussed our attention on what entanglement *is not*. This context allows us to sharpen our degree of understanding of what entanglement *is*, in a purely quantum setting divorced from the conservation-induced correlations discussed earlier.

To this end, we return to a consideration of the electron–electron pair; suppose that a relevant conservation law implies the electron–electron pair to have opposite spin projections with respect to the axis of quantisation imposed by a given uniform external magnetic field. Quantum mechanically, and ignoring an irrelevant normalisation constant, assume the two-electron system to be specified by the pure-state two-body state vector $|1\ \text{-}1\rangle$ + $|\text{-}1\ 1\rangle$. Let us whimsically picture this as a coherent superposition of: (i) a physicist pointing their left thumb up and their right thumb down, with (ii) the same physicist pointing their left thumb down and their right thumb up (see Fig. 2).

Such a state is said to be entangled because we have lost the classical notion that meaning can be given to 'the state' of any component of the whole system. That is, replacing electron spins with directions of thumbs, we can no longer speak of 'the state' of the left thumb, or 'the state' of the right thumb – thus the system is entangled, in precisely the sense originally envisaged by Schrödinger.

The perturbing effects of the environment upon such a superposition can have the effect of imposing classicality, in the sense that coupling to the environment can be viewed as a form of measurement, which destroys entanglement by detecting the state of either thumb/electron.

Yet how much is lost in the process! An arbitrary entangled state of the electron–positron pair can be described by three real numbers (the complex coefficients of $|1\ \text{-}1\rangle$ and $|\text{-}1\ 1\rangle$ yield four real numbers, with the demand for normalisation reducing this to three real numbers). The corresponding classical state is described by either a 'zero' or a 'one', depending on whether one has the classical state $|1\ \text{-}1\rangle$ or the classical state $|\text{-}1\ 1\rangle$.

This huge discrepancy between the amount of information needed to describe the classical versus the quantum state, which becomes exponentially more vast as the number of quantum particles increases, can be loosely encapsulated in the phrase 'Hilbert space is big'. As has been emphasised by Bennet and Vincenzo [3], this fact lies at the heart of both the power of quantum computation (here we identify entangled two-body or *n*-body quantum systems with quantum bits, ie. 'qubits') and the challenge in building such devices.

The real world intervenes to make our job of building a quantum computer more challenging. The effects of entanglement do not last very long in all but the most isolated systems, with the environment serving to 'decohere' delicate quantum-mechanical entangled superpositions into merely classical states. The means of protecting quantum systems from such perturbing effects of the environment, which destroy quantum entanglement and cripple quantum computation, remain the subject of active research – and one of the most exciting contemporary consequences of the phenomenon of quantum-mechanical entanglement.

In this context, we re-iterate a central point of these discussions, that one's understanding of the essence of entanglement may be sharpened by drawing a clear distinction between conservation-induced correlations (which may occur in both classical and quantum systems) and purely quantum phenomena which have no classical counterpart.

Conclusion

In the cases that we have discussed, it is unnecessary to introduce the concept of entanglement: conservation laws, and the principles of Quantum Mechanics suffice. Students have difficulties in being introduced to Quantum Mechanics, and also in continuing to study it. Simplicity and reassurance help in dealing with these difficulties. Of course, things change when dealing with the 'Schrödinger cat' states, used in 'q-bit' studies, where entanglement *is* necessary.

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PRECISION SENSING:
A New Role for Trapped Ions

Michael J. Biercuk

Trapped atomic ions have for decades been a key technology in precision metrology research focused on the development of new time and frequency standards. Recent efforts have shown that they may now find new life at the heart of precision sensors for forces and fields. Experimental measurements of the achievable force-detection sensitivity of trapped-ion-based sensors achieved performance at the scale of yoctonewtons (normalised per square-root Hertz), more than 1000 times better than previous reports; the prefix 'yocto' represents 10^{-24}, the smallest existing SI prefix.

Force detection and sensitivity

The ability to detect *extremely small* forces is vital for industry and research disciplines such as precision spin-resonance imaging, microscopy, mining, and tests of fundamental physical phenomena. As technologies progress, the demands on sensor performance continue to grow. In particular, the fields of stand-off detection and nanoscience are pushing the limits of achievable sensor performance.

In nanoscience, for instance, atomic force microscopy (AFM) permits imaging of single molecules with sub-nanometre resolution – a fundamental technique used in laboratories worldwide. This approach relies on the detection of van der Waals forces and employs a canonical detection modality: looking for changes in the motion of a small mass-on-a-spring (here a microfabricated cantilever) due to external forces. Like any mass-on-spring system the AFM cantilever exhibits a resonant response at a particular frequency set by its size and structure. External forces applied to the system modify the resonant motional response (e.g. slightly changing the resonant frequency), producing a detectable signal. In the case of AFM this allows detection of forces on the scale of nanonewtons.

In evaluating the performance of a force sensor, it is frequently asked how small a force one can detect. Indeed, the magnitude of the minimum detectable force is important, but only one part of the picture. For real applications we need to discuss the concept of *sensitivity*, ie. how small a force can be detected per unit time, resulting in a metric with units of $N/\sqrt{Hz}$ (given certain technical assumptions). This metric accounts for the fact that detecting any signal requires discrimination from background noise, often accomplished by averaging repeated measurements over an extended time period. It effectively normalises detector performance by the efficiency of information extraction and captures a practical issue; a detector is only *useful* if it can perform a measurement within a reasonable time.

In the metrology community nearly all precision-force-detection studies focused on the use of integrated nanomechanical devices – mechanical and electronic circuits built using nanofabrication techniques. Prior to our work, force-detection sensitivity surpassed the (rather

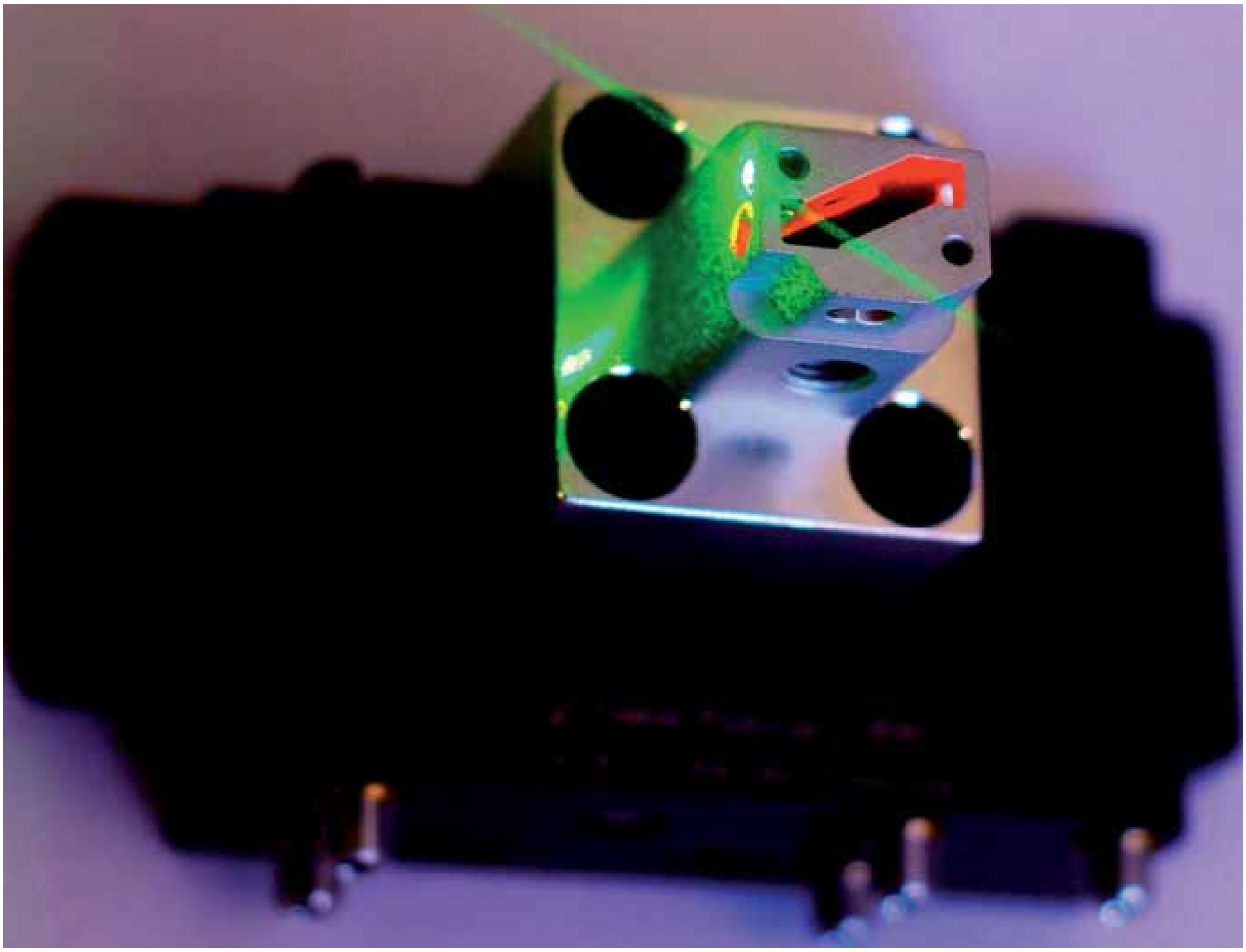

Fig. 1. Custom fabricated optical components used for optical frequency conversion allowing access to beryllium's atomic transitions in the ultraviolet [design courtesy NIST, photo credit David Reilly].

astounding) level of attonewtons/√Hz (atto = 10^{-18}), through coupling of integrated nanomechanical resonators to a variety of physical readout systems [1]. These experiments, in many ways, are nanoscale extensions of the AFM.

The extraordinary sensitivity of these systems comes from their small size – since the resonator mass is so small, a given applied force induces an easily detectable change in the motional response. This observation shows us a way forward in the quest to continue advancing sensor performance. Why not make them even smaller in order to increase their sensitivity? Why not make these detectors so small that they are composed of only a handful of atoms?

Ion trapping

The field of ion trapping has a long and rich history. Paul and Dehmelt won the 1989 Nobel Prize for Physics for 'the development of the ion trap technique' and were followed by modern giants including Bergquist, Blatt, Bollinger, Drullinger, Itano, Leibfried, Monroe, Roos, Udem and Wineland. Today, an entire generation of young ion trappers has emerged in the field, myself included, spreading research in this area around the globe.

The key technological basis of ion trapping is the ability to confine charged atoms (from one to one billion) using electromagnetic fields in an ultra-high vacuum environment. While employing an electromagnetic 'bottle' overcomes the issue of interactions between trapped ions and the walls of a real bottle, Earnshaw's theorem tells us that it is not possible to use a simple static electric field for confinement, as a local field sink would be required. Instead we need to be somewhat more clever.

Broadly, ion traps come in two distinct flavours. First, RF or Paul traps provide confinement using the ponderomotive potential associated with a rotating electric quadrupole or 'saddle-point' potential. A charged particle in such a trap wants to 'roll down' the concave-down part of the quadrupole potential, but so long as the time it takes to escape is long compared to the rotation rate of

the potential (set by the applied RF frequency, typically of order ~10–100 MHz), the particle will be trapped. By contrast, Penning traps use static electric and magnetic fields; a static electric quadrupole set up by a stack of ring electrodes provides confinement along the trap axis. This field, however, is radially divergent at the symmetry point of the trap axis, and charged particles will move outwards and escape the trap in the radial direction. To overcome this, a magnetic field is applied parallel to the trap axis which gives rise to a Lorentz ($\boldsymbol{v} \times \boldsymbol{B}$) force. This force causes the radially directed particles to be deflected in a direction perpendicular to their motion; if the magnetic field is sufficiently large, closed trajectories are formed and three-dimensional confinement achieved.

Ion trapping has found applications in a range of disciplines such as mass spectroscopy, precision frequency standards, and more recently quantum computation. It is in the latter disciplines that the greatest attention has been focused, given outstanding advancements in the last few decades.

Once confined, trapped ions behave as nearly perfect (perfection dictated by natural symmetries) quantum systems. Every ion is as close to identical as nature permits, and the electron and nuclear states give us a flexible manifold of quantum mechanical energy levels that may be coherently manipulated using radiofrequency, microwave, and laser radiation [2]. Generating lasers with the correct properties is no mean feat, and requires significant engineering – see Fig. 1.

More germane to our interests (described below), the trapped ions behave as tiny mechanical oscillators, with their motional degrees of freedom well described by quantum mechanics. Multiple ions in a shared trapping potential share these motional modes, giving us a technique by which we may coherently couple different ions.

Leveraging these capabilities, the fields of precision frequency metrology and quantum information have seen significant convergence over the last several years. For instance, the techniques of laser cooling, quantum control of electron and nuclear spin states, and the coherent coupling of spin and motional degrees of freedom were developed in the context of clock development, but have been transitioned to applications in quantum computing. In fact, the first multiqubit logic gate for quantum computation was realised using trapped ions [3], following techniques developed for entanglement-assisted precision metrology. Conversely, recent developments in multiqubit quantum logic have been transferred back to clock experiments enabling the most precise frequency/time standard in the world [4], with fractional uncertainty at the level of parts in 10^{18}. In both fields, precise control and engineering of ion motion has played a key role in enabling new capabilities.

In both frequency-standard and quantum information experiments a significant challenge in the field has arisen due to so-called spurious motional heating. Once an ion is laser-cooled to its quantum mechanical ground state

"The ability to detect extremely small forces is vital for industry and research disciplines such as precision spin-resonance imaging, microscopy, mining, and tests of fundamental physical phenomena."

of motion, over time it simply heats up and starts moving. This thermal activation is an error source in multi-ion quantum logic operations, which generally depend on precise control of the ion motional state.

A variety of experimental and theoretical studies addressed the issue of motional heating, and suggested the cause to be random electrical fluctuations in the trap electrodes. Unfortunately, the high charge-to-mass ratio of trapped ions means that even in the presence of small electrical fluctuations, ions could experience significant motional excitation. Simply put, for a given force (charge times field), the small mass indicates a large acceleration.

A new role for trapped ions

This observation was a double-edged sword; mitigating such fluctuations would require clever and extensive engineering, but if ions were so *sensitive* to small electric forces, perhaps they could be used as... *sensors*. Building on this knowledge, Maiwald *et al.* [5] in developing a new form of ion trap that resembled a scanning probe microscope tip, calculated that ions should be able to achieve force-detection sensitivities at the scale of yoctonewtons/$\sqrt{\text{Hz}}$, where yocto = 10^{-24}, the smallest prefix

Fig. 2. A Coulomb crystal of laser-cooled beryllium ions in a Penning trap [courtesy: NIST].

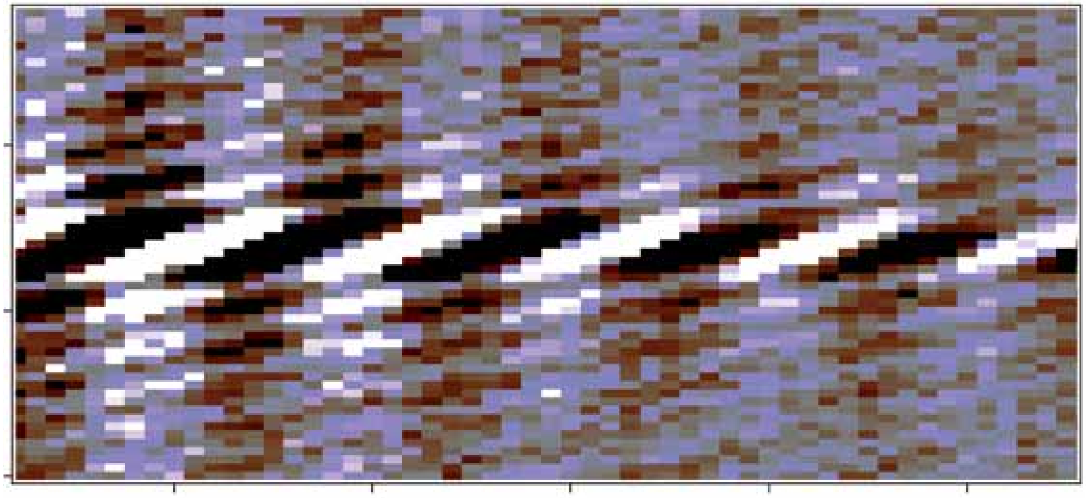

Fig. 3. Measurement signal indicating phase-coherent excitation of a motional response. The colour-scale indicates peaks in a histogram of photon detection events as a function of drive frequency and time. Diagonal features indicate the presence of a periodic oscillation in ion position, and the evolution of the oscillator's phase as the drive frequency is swept through resonance.

in the SI measurement system. This was an exceptional insight, and motivated a new avenue in trapped-ion research towards ion-based sensors. In many respects, trapped-ions represented the ultimate scaling limit of the nanomechanical resonators that dominated the force-sensing literature.

While the intrinsic responsiveness of trapped ions to external forces and fields was well supported, it remained an experimental challenge to determine the *achievable sensitivity* of an ion-based detector, as set by systematic limitations including the efficiency of a measurement procedure. Prospects were promising, but careful characterisation was required.

We were interested in taking up this challenge in order to perform direct comparisons between ion-based and nanomechanical sensors, with an aim of overcoming differences in experimental techniques and technical language. To do so, several technical challenges needed to be met:

- A new technique to efficiently detect the effect of an applied force on a trapped ion had to be developed
- A well-calibrated force had to be applied as a reference
- All systematics pertaining to timing had to be accounted for in order to effectively calculate the detection *sensitivity*.

Measuring yoctonewtons (per square-root Hertz)

Our research involved the development of a new detection scheme based on laser Doppler velocimetry that allowed sensitive discrimination of an ion's motional response to an applied force [6, 7]. This technique coupled the uniform motion of a small crystal of ions in a Penning trap (see Fig. 2) to a modulation of resonant-scattering of laser light tuned near an internal atomic transition in beryllium. This modulation would arise because the incident laser light, in the rest frame of the excited ions, moves closer and further from the atomic resonance due to Doppler shifts (Fig. 3). Under oscillatory ion motion the intensity of ion fluorescence itself oscillates in phase with the motion. This modulation in light scattering – with amplitude approximately proportional to a known applied force – was our signal of interest.

Resolving modulation of the scattered fluorescence required a new, phase-synchronous detection protocol. This was due to both noise in the measurement system and the fact that *driven* ion motion was superimposed on *random* motion from both thermal excitation of the ions and stray electric fields. Unfortunately, this randomised motion could be orders of magnitude larger than the signal to be detected. However, using phase-sensitive detection the broadband environmental noise was excluded, and only the integrated noise over the narrow bandwidth of the measurement was germane.

In our experiments we applied a drive force using a pulsed excitation/detection protocol to minimise the effects of laser damping. Modulation of ion fluorescence due to the applied drive was detected by recording the arrival time of scattered photons relative to the applied drive. Any driven motion would create a periodic pattern in a histogram of synchronised photon arrival times – remember that the intensity of the laser scattering (and hence the likelihood of photon detection) varied periodically as the moving ions were Doppler shifted closer

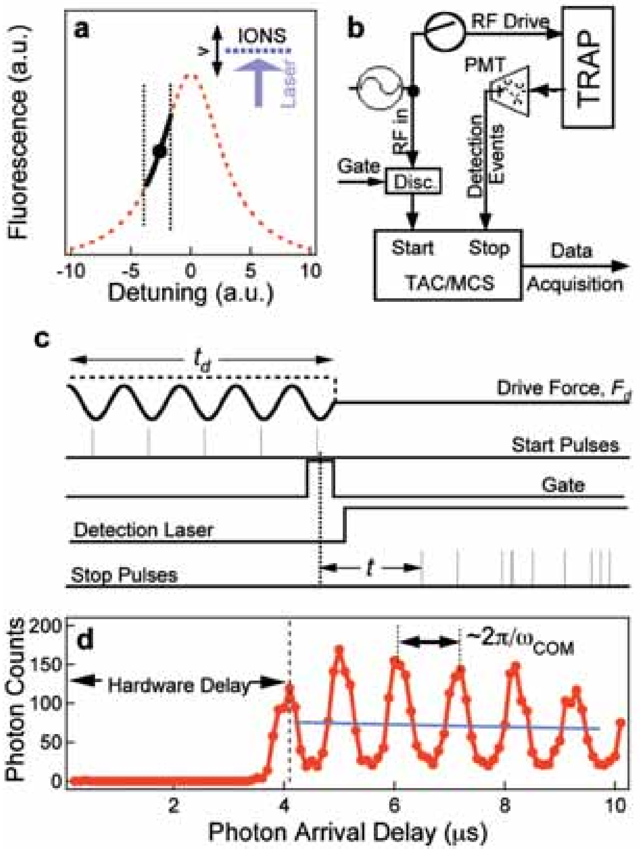

Fig. 4. Depiction of the method of phase-coherent Doppler velocimetry: (a) Atomic resonance employed for ultrasensitive detection of ion motion, exploited through the equipment configuration in (b). (c) Schematic of pulse sequencing/triggering for phase-coherent detection, in which excitation and detection are segregated into different parts of the measurement procedure, improving the measurement's signal-to-noise ratio. (d) A histogram of photon arrival times synchronised to the driving force shows oscillations with period corresponding to the ion oscillation frequency – this is the key signature of phase-sensitive detection, and permits discrimination of motion with amplitude smaller than the thermal wavelength of the ions. [Reproduced from *Nature Nanotechnology*]

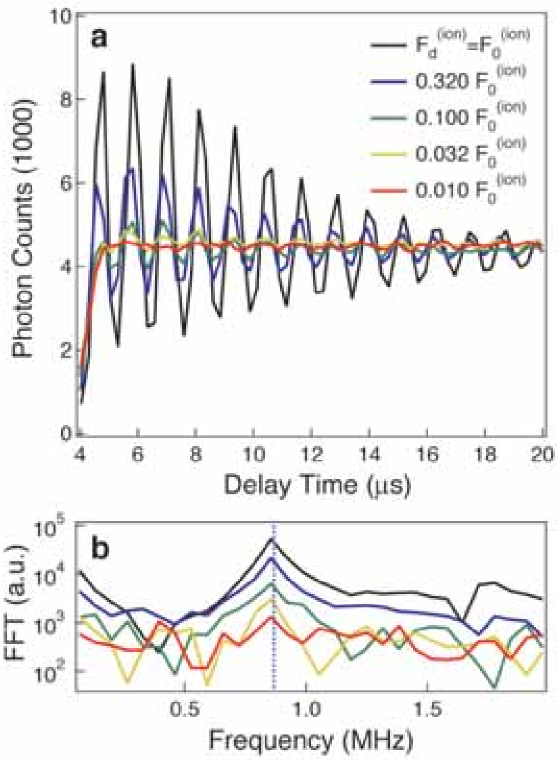

Fig. 5. Calibration of force-detection sensitivity by Fourier analysis: (a) Temporal response to applied forces on an ion crystal with n = 130 ions for decreasing drive strength. The oscillations decay in time due to radiation damping occurring once the detection laser is turned on. (b) Fourier transform of temporal response traces recorded above, showing the diminishing centre-of-mass response with decreasing applied force. [Reproduced from *Nature Nanotechnology*]

and further from resonance (see Figs 3 and 4).

Once a signal was detected, a well-calibrated drive force and a precise determination of measurement time were required to characterise our system's force-detection sensitivity. We employed an AC electric force that could be calibrated precisely by measuring the ion number and the spatial displacement of ions to a given DC voltage applied to the trap (and could be confirmed independently using Doppler shift measurements). With this knowledge, any AC voltage applied to the trap could be precisely converted to a known force exerted on the ion crystal. Similarly, we recorded the measurement time, accounting for all systematic delays arising from hardware through to data acquisition.

Measured sensitivities were established in two ways; we either mathematically extracted the minimum detectable force given the signal-to-noise ratio of a detected signal, or we systematically reduced the drive force until the measured signal gave a signal-to-noise ratio of unity. Both approaches gave approximately the same value (see Fig. 5).

Experiments using applied forces down to ~170 yN resulted in an extracted force-detection sensitivity of 390±150 yN/√Hz, more than 1000 times better than existing reports [6]. Smaller forces had been *detected* previously, but this level of detection *sensitivity* had never been reported. Calculations suggested that technical modifications to the experimental system could permit force detection with sensitivity better than 1 yN/√Hz, validating the brilliant insights of Maiwald *et al.* [5].

This method indeed allowed the efficient detection of very small forces – a fact that excited many in the media – but there's another way of looking at our results. Unfortunately it's not necessarily obvious that detecting forces in the yoctonewton regime will give discernible benefits in all instances. However, by focusing on *sensitivity*,

our results show that in addition to measuring smaller forces, it is also possible to measure forces at the same scale as previous experimental results, but *one million times faster*. That is the beauty of force-detection sensitivity: one may trade-off the size of a detected force for the speed with which the detection may be performed.

"... our results show that in addition to measuring smaller forces, it is also possible to measure forces at the same scale as previous experimental results, but one million times faster."

Beyond force-detection sensitivity, however, the detection technique we developed provided an ability to discriminate ion motional excitations deep below the resolution-limits imposed by real-space optical imaging systems. Our experiments allowed measurement of ion motion down to 18 nm (sensitivity 50 nm/√Hz), more than an order of magnitude smaller than the thermal extent of a single ion's wavefunction in the trapping potential. Recent experiments exploiting quantum entanglement can do even better (much better) – stay tuned.

This work represented the first demonstration of a technique to leverage the well-known intrinsic force-sensitivity of trapped ions by creating a measurement protocol able to efficiently extract information on the ions' motional response. We are very excited that our measurements have helped establish trapped ions as an ideal technology for new high-performance sensors, and I was personally very humbled that this work was deemed significant enough to warrant the 2011 NMI Prize for Excellence in Measurement Science.

Of course that's not the end of the story. These experiments form just one part of an ongoing research program in quantum-enabled sensing and metrology through the ARC Centre for Engineered Quantum Systems. Our Centre's efforts explore techniques by which quantum effects can be leveraged in a variety of technologies in order to enable a new generation of precision sensors for industrial and scientific applications. This includes research not only on trapped ions, but also single electrons in semiconductors, opto-mechanical resonators, and even nanoscale particles of diamond. The research continues, and we keep pushing the limits of sensor technology.

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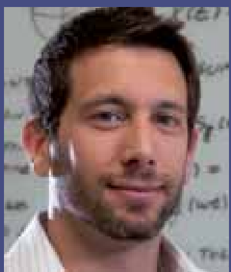
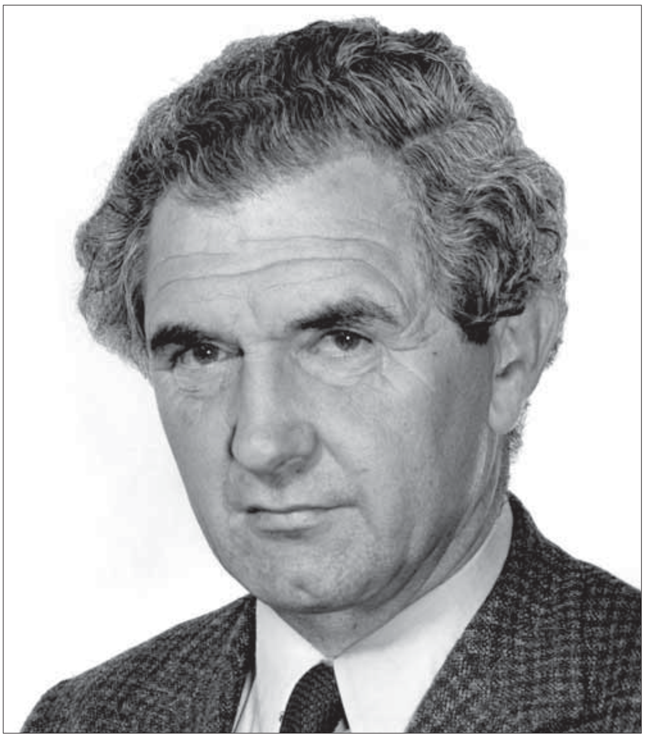


BIO

Dr Michael J. Biercuk is an experimental physicist in the ARC Centre for Engineered Quantum Systems, School of Physics, University of Sydney (see www.equs.org). His research group – the Quantum Control Laboratory – performs cutting-edge experiments using trapped atomic ions for the development of new quantum-enabled technologies. Michael's specialties include quantum physics, quantum control, quantum error suppression, ion trapping, nanoelectronics, and precision metrology. He was educated in the United States, earning his undergraduate degree from the University of Pennsylvania, and his Master's and Doctoral degrees from Harvard University. Following his PhD Michael served as a full-time scientific consultant to DARPA, the premier research funding agency in the United States. He then returned to the laboratory when he assumed a postdoctoral research appointment in the Ion Storage Group at NIST, Boulder. In September 2011 Michael was awarded the National Measurement Institute Prize for excellence in measurement research by a scientist under 35 for his efforts on precision force detection using trapped ions [see *AP* 48, 170 (2011)].

Angas Hurst, AM FAA (1923 – 2011)

Alan Carey (ANU), Peter Bouwknegt (ANU) and Max Lohe (U. Adelaide)



Professor Angas Hurst was a distinguished Australian scientist who was an international leader in research and a major contributor to the scientific community. He served his country in World War II, played an extensive part in the management of the University of Adelaide and contributed actively to his local community. With his co-professor in Adelaide, Professor H. S. 'Bert' Green, he was responsible for the establishment of mathematical physics within Australia as a research field of international distinction. He was a fine ambassador for his country and for Australian science.

Born in Adelaide, Angas grew up in Hawthorn, Victoria, where he attended Scotch College and was dux of both the Preparatory and Senior Schools. He completed degrees at the University of Melbourne and subsequently his PhD at Cambridge in 1952. In 1952–56 he was appointed to the Mathematics Department at the University of Melbourne, and in 1957 accepted the position of senior lecturer, Department of Mathematical Physics at the University of Adelaide. He held the position of Professor from 1964 until his retirement in 1988, when he became Emeritus Professor of Physics and Mathematical Physics. He was appointed Fellow of the Australian Academy of Science in 1972, and was awarded an honorary DSc by the University of Melbourne in 1991. In the Australia Day Honours list 2003 he was awarded Member in the General Division (AM) 'for service to science, particularly in the field of mathematical physics as an educator, researcher and administrator'.

Angas's PhD at Cambridge was a seminal work on quantum field theory, showing the divergence of perturbation expansions for any value of the coupling constant. It later emerged that W. Thirring, who at that time (1951–52) was assistant to Wolfgang Pauli at ETH in Zurich, was working on similar problems. According to Thirring's book *Cosmic Impressions* (2007), Pauli came in to his office one day to announce "... Angas Hurst, an Australian who's now working in England, has made the same calculations and has arrived at the same conclusion...". Hurst and Thirring later became good friends, and Angas wrote a typically humorous and anecdotal tribute for Thirring's 80th birthday in 2007.

Angas's best known result is probably the Griffith–Hurst–Sherman inequalities, which established the concavity of magnetisation for Ising ferromagnets. Other research topics included relativistic wave equations, C*-algebra approaches to quantum field theory, infinite-dimensional algebras, and topics in statistical mechanics.

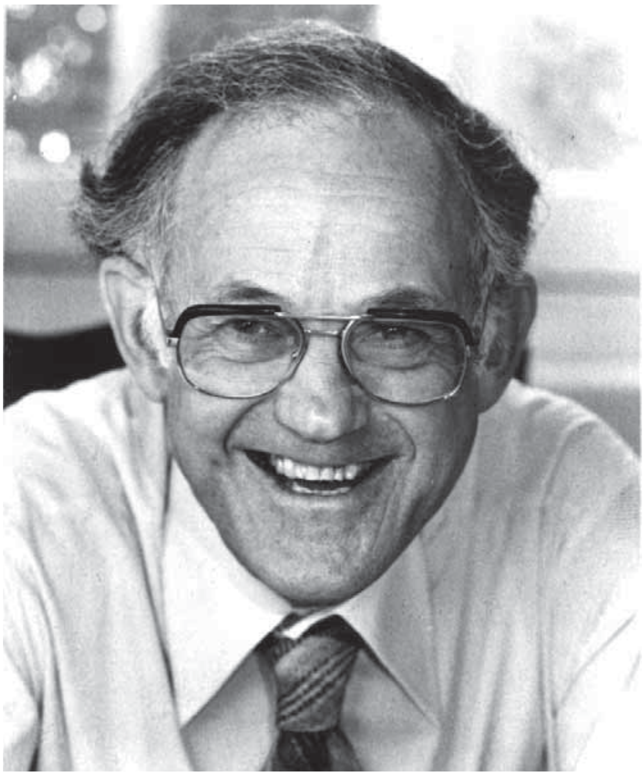
Angas's commitment extended beyond physics and mathematical physics. He served the Australian scientific community generally as a Member of the Council of the Academy of Science from 1983–86 and as Vice-President in 1984–85. He was always interested in fostering links across disciplines and did so particularly with mathematics as a founding member in 1956 of the Australian Mathematical Society. He chaired the senior Committee of the University, the Education Committee, and served as a member of the Council of the University from 1975–78. He was appointed acting Vice-Chancellor in 1985, then Pro-Vice Chancellor (Research) from 1986–88 and was responsible for a number of influential reports. He was a member of the University of Adelaide (student) Union House Committee, a member of the Union Council and chaired the Union Planning Committee from 1965–73. He was concerned with the welfare of postgraduate students and was one of the prime movers for establishing the Kathleen Lumley College of the University of Adelaide.

Angas passed away on 19 October 2011, and is survived by his wife Elinor, three children, and four grandchildren.

OBITUARY

John Prescott (1924 – 2011)

Laurence Campbell (Flinders) and Nigel Spooner (DSTO)



John Russell Prescott was born in Egypt on 31 May 1924, but spent only three months there before his family moved to Adelaide. He attended Scotch College where he excelled both academically and on the sports field, and in 1942 entered the University of Adelaide to study Physics. He graduated in 1945 with the degree of BSc (Honours) and in the same year became engaged to Josephine Wylde. He moved to Melbourne to undertake his PhD studies, and he and Jo were married in 1947. In April 1949 John was awarded his PhD for his dissertation on cosmic ray showers and bursts. He also worked as a foundation employee of the nascent Australian Atomic Energy Commission.

Now starting a family, John took up a scholarship awarded by Christchurch College, Oxford, to study for the D.Phil. (Oxon), received in 1953. His thesis was on the nuclear structure of heavy elements, and John regarded his work on the decay of Bi-207 to be his greatest scientific achievement. In 1953 the family returned to Australia where John rejoined the AAEC based at the University of Melbourne.

In 1956 John was appointed Lecturer at the University of British Columbia in Vancouver and, in 1960, he moved to the University of Calgary, Alberta, where he remained for eleven years. John was promoted to Professor in 1968. Here he revived his interest in cosmic ray physics through studies at Sulphur Mountain, and started pioneering work on radio emission from cosmic ray showers at the Dominion Radio Astrophysical Observatory near Penticton.

In 1971 John returned to Australia where he took up a position as Professor of Physics at the University of Adelaide, and in 1982 he was appointed Elder Professor of Physics. John was passionate about teaching, and made a special study of the teaching of elementary physics courses, particularly undergraduate laboratories in which he enjoyed performing entertaining experiments. His main research interest continued to be in cosmic rays, and together with colleagues, he relocated the Penticton cosmic ray detectors to Buckland Park. This was the beginning of the Adelaide Cosmic Ray Physics group which John led for 20 years.

He also played a major role in raising awareness of employment opportunities in physics, and published extensively on physics education. He surveyed all advertisements for physics employment in *The Australian* newspaper weekly for 25 years and regularly published the results and trends, for which he received the Australian Institute of Physics Outstanding Service award in 2003.

During the mid-1970s John and Jo participated as volunteers in archaeological digs. This led to asking how could physics assist archaeology? John was advised that dating would help, and hence developed an interest in the relatively new technique of thermoluminescence dating. Luminescence soon began to dominate his academic research, and John wrote over a hundred papers on the subject.

In 1990 he officially retired, which to John meant coming into the Physics Department at least four days a week and honing his expertise in luminescence dating and the physics of luminescence. His publication output did not decrease and he continued with pioneering research, particularly that involving use of his 3D spectrometer. His last message to colleagues was "I may not be in for the rest of this week. Please keep my laptop charged up".

John died on 1 September 2011. He is survived by his wife Jo, with whom he shared a true partnership for 70 years, and children James, Ann and Kate.

LASTEK – TOPTICA PHOTONICS

Quantum Composers 9520 Series Digital Delay Pulse Generator

The 9520 Series Pulse Generator provides the utmost flexibility and performance in a bench-top digital delay pulse generator. Designed in a modular architecture, customers can choose from a variety of output and input options. Dual inputs provide trigger and gating or two separate triggers. Illuminated front panel buttons and large display provide clear manual programming. External clock in/outputs allow synchronising to an external clock source up to 100 MHz. Features include:

- 2, 4 or 8 independent outputs providing pulse width and delay at 250 ps, amplitude, rate, and mode programming control
- 250 ps timing resolution with less than 50 ps jitter
- Benchtop and modular design
- High current and high voltage
- Internal rate generator – 10 ns period resolution spanning entire frequency range (10 MHz)
- Complete channel and system setup stored in memory – includes 12 memory storage slots
- Remote programmability – RS232 and USB standard
- GPIB, ethernet available
- Free LabVIEW driver
- Dual inputs with gate and/or trigger.

9520 Pulse Generator Advanced features include:

- Clock input/output allowing master clock input up to 100 MHz with whole system timing relative to that signal with low jitter (<50 ps) through completely programmable FPGA
- Settings and programming saved when powered down
- Programmable in the field – customisation of features, upgrades and modifications
- Full customer support and two year warranty.

New Aerotech MPS50SL Miniature Linear Positioning Stages

MPS50SL Stages meet the needs of space-constrained laboratories and production floors:

- Compact 50 mm width with travels of 25 or 50 mm
- High resolution (0.1 μm), repeatability (±0.75 μm) and accuracy (±1.5 μm)
- Precision ground ball-screw or lead-screw drive
- DC servo or stepper motor
- Crossed-roller bearings
- High-vacuum capable
- Compact multi-axis configurations

The MPS50SL stage is perfect for the confines of the laboratory while retaining the high reliability required in production environments. It is an ideal choice for measurement, testing, alignment and component assembly in any space-constrained applications whether on the factory floor or in laboratory environments.

High accuracy – The precision ground ball-screw or lead-screw has excellent accuracy and repeatability, with ultra-fine positioning resolution capability of 0.1 μm. The DC servomotor is equipped with a rotary encoder and the crossed-roller linear bearings provide exceptionally smooth travel and payload capabilities up to 5 kg with a stage mass of just 0.85 kg.

Optional vacuum preparation – The MPS50SL is available vacuum prepped to 10^{-6} torr for applications in markets such as semiconductor manufacturing and inspection, optics fabrication, and military/aerospace.

Highly configurable – A breadboard mounting plate provides direct mounting to both English and metric breadboards. Any model can be mounted in an XY configuration and, with the right-angle L-bracket, in XYZ configurations. The MPS50SL can also be directly mounted to the larger MPS75SL stage for a compact, high-performance XY system.

The MPS50SL is a member of the MPS (miniature positioning stage) family of linear, rotary, goniometer, and vertical lift and Z stages from Aerotech. Two or more MPS stages can be mounted together in numerous combinations for a compact, accurate multi-axis motion solution. Aerotech manufactures a wide range of positioning stages, drives and controls to provide a fully integrated and optimised motion solution.

Picoquant Releases Green Picosecond Pulsed Laser Diode Head

The LDH 500 and LDH 510 are now available. The new green laser head emits around 500 and 510 nm with pulsewidths less than 130 ps and can generate up to 2 mW average power at 40 MHz repetition rate (5 and 10 mW in the optional continuous-wave mode).

The LDH Series Heads produce light pulses as short as 50 ps at repetition rates from single shot to 80 MHz (depending on the wavelength). For selected wavelengths peak powers up to 1 W can be emitted. The short pulse width perfectly matches the time resolution of mainstream detectors, yet at a price ten times lower than that of commonly used Ti:Sapphire or Argon ion lasers. A combination of interchangeable Heads, together with the PDL 800-B, PDL 800-D, PDL 808 'Sepia' or PDL 828 'Sepia II' drivers, satisfies the demand for compact and affordable excitation sources that cover a wide range of wavelengths. Features include:

- Centre wavelength: 500 or 510 nm
- Pulse width below 130 ps (FWHM)
- Repetition rate from single shot to 40 MHz
- Up to 2 mW average output power with collimated output.

Applications include:

- Time-resolved fluorescence spectroscopy & microscopy
- Biochemical analytics
- Time response characterisation of opto-electronic devices
- Optical time domain reflectometry (OTDR)
- Diffuse optical tomography (DOT)
- Single photon source
- Quantum optics

Latest – The new green (532 nm) laser LDH-P-FA-530XL generates >200 mW average output power at 80 MHz repetition rate.

For more information please contact Lastek at
sales@lastek.com.au
Lastek Pty Ltd
10 Reid St, Thebarton, SA 5031
Toll free: Australia 1800 882 215; NZ 0800 441 005
Tel: +61 8 8443 8668; Fax: +61 8 8443 8427;
Web: www.lastek.com.au

WARSASH SCIENTIFIC

Sintering with Adjustable Pulse Width Capability

Warsash Scientific delivers even greater flexibility for sintering conductive Cu and Ag metallic inks, curing thin-film substrates and for solar and surface modifications with the Sinteron 2010 from Xenon Corporation. The new **Sinteron 2010** now allows for digitally programmable pulse widths, making it extremely flexible and valuable to process development.

A number of attractive features are designed into this 19 inch rack-based stand-alone system. The pulse width is adjustable in increments of 5 µs in the range 100 to 2000 µs. With total control of the pulse amplitude and pulse width, the optical energy delivered by the system can be precisely controlled. As the pulse profile is very linear at maximum amplitude, a relationship of 1000 J/ms can be assumed. The **Sinteron 2010** allows connection for either Spiral or Linear Lamp housings. These can provide optical footprints of 19×305 mm or 127 mm diameter areas.

Sinteron 2010 is welcome news for those involved in photonic sintering of conductive inks for printed electronics in areas such as displays, smart cards, RFID and solar applications. The non-contact, low thermal characteristics for this process make it suitable for web-based printing techniques such as inkjet, flexography, gravure, and screen print.

In addition to offering sintering systems for the printed electronics industry (making it possible to print, at room temperature, on substrates such as paper and PET), Warsash Scientific offers high performance pulsed UV systems for decontamination, UV curing and food enhancement.

Fast Piezo Focusing Systems for Microscopy

Warsash Scientific offers a more affordable series of fast piezo focusing devices with the new PIFOC system packages from PI. These packages are designed to improve results in fast focussing and lens positioning, as well as in deconvolution/3D imaging, and reduce costs at the same time.

System packages consist of closed-loop, piezo-mechanic objective positioners and custom-tuned, compact digital servo controller/driver units. This combination provides higher performance at reduced costs. The integrated, frictionless and high-stiffness piezo flexure drive ensures fast response and short settling times, as well as exceptional guiding accuracy. The settling time of less than 10 ms increases throughput and allows for rapid Z-stack acquisition.

The digital controller provides several advantages compared with the conventional analogue controllers of the fast focussing systems currently available. Higher linearity, improved settling performance, quick adaptation to changing motion requirements and access to advanced automation are all benefits.

The included software facilitates system setup and allows swift switching between different sets of parameters. For the user this means extracting the maximum performance from the piezo focusing mechanism all the time, no matter what size objective is used or whether aggressive long-travel stepping or smooth nanometre size dithering motion is needed. Since jumpers and trim pots no longer have to be accessed to make changes, system integration becomes much more straightforward.

Key features:

- Complete and affordable system with fast digital controller and software
- Choice of travel ranges: 100, 250 or 400 µm
- Ideal for fast autofocus applications
- Sub-nm resolution
- Choice of position feedback sensors: piezoresistive or capacitive
- Improved performance and easy system integration.

M-660: Low Profile Rotation Stage

One of the lowest profile rotary tables on the market, the M-660, available from Warsash Scientific, is now complemented by a higher performing model providing more than eight times the position resolution of the existing version.

The compact design with minimised mass and inertia provides high precision, bidirectional speed and position control, as well as high speed motion contouring. The M-660 is based on the new U-164 Piezo Motor and outperforms the stability, acceleration and settling speed of traditional servo motor direct drives and gear-driven mechanisms. The innovative motor drive can provide significantly higher speeds, shorter positioning times and a very high positioning accuracy when moving the measuring optics.

The stage can accelerate to velocities of 720 degrees/sec and resolves positions down to 4 µrad (8 arcsec). Its self-clamping ceramic drive provides very high stability, with no energy consumption at rest and no heat generation. A directly coupled precision optical encoder provides phase lag-free, backlash-free feedback to the servo controller.

The newly designed piezo motor controller is available to take advantage of the specific motion characteristics of ultrasonic ceramic motors. USB interfacing and a solid software and driver package for seamless integration are included.

For datasheets and more information on all three products, please contact Warsash Scientific at sales@warsash.com.au
Warsash Scientific Pty Ltd
Tel: +61 2 9319 0122; Fax: +61 2 9318 2192;
Web: www.warsash.com.au

COHERENT SCIENTIFIC

PI-MAX3 Intensified CCD Cameras

Princeton Instruments's PI-MAX series of intensified CCD cameras has set the standard for time-resolved imaging and spectroscopy for almost a decade. Now Princeton's PI-MAX3 takes ICCD performance to a new level with order of magnitude speed improvements and a host of new features to allow easier and more accurate time-resolved imaging.

PI-MAX3 is available in formats of 1024×1024 pixels for imaging and 1024×256 pixels for spectroscopy. Video frame rates can be achieved in the imaging format and spectral rates of thousands of spectra per second can be achieved. Most importantly, the camera allows sustained gating rates up to 1 MHz, a 20-fold improvement over previous designs. The camera includes the improved SuperSynchro timing generator, SyncMaster clock output, a compact 'one-box' design, convenient GigE interface and much, much more.

PyLon CCD Cameras

Princeton Instruments has released PyLoN™, a new line of controller-less, cryogenically cooled CCD cameras designed for quantitative spectroscopy applications that demand the highest possible sensitivity.

Features:

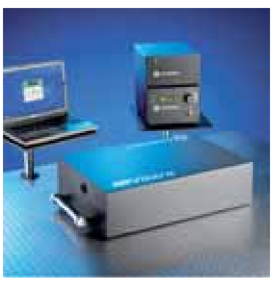
- Supported by LightField™
- No external controller
- More ADC speeds
- Indium metal seals
- Ideal for low-light, long acquisition applications
- GigE communication
- Digital correlated double sampling
- PI's exclusive eXcelon technology
- Reduced binning noise
- AR coatings from Acton Optics

In creating the new PyLoN platform, Princeton redesigned its industry-leading Spec-10 family of cameras to remove the external controller, increasing experimental flexibility while further improving the ultra-low-noise electronics. Liquid nitrogen cooling virtually eliminates dark current, and readout noise has been further reduced from the already low levels in the Spec-10 platform.

PyLoN is available with Princeton's unique eXcelon technology which delivers the highest sensitivity in the UV and NIR while suppressing etaloning that occurs in standard back-illuminated deep depletion or back-illuminated CCDs.

The camera includes a GigE interface allowing operation at four times higher speed that its predecessors, and is supported by Princeton's 64-bit LightField software with Intellical wavelength and intensity calibration option. No other spectroscopy CCD is this cool, this quiet and this fast!

Vitara Ultrafast Laser



Coherent's new Vitara is the first widely tunable, ultrafast laser to deliver pulsewidths shorter than 12 fs, while also offering true hands-free and fully automated operation. This includes automated wavelength tuning from 755 to 860 nm and push-button bandwidth adjustment from 30 to 125 nm.

Features:

- Fully automated for hands-free, reliable operation
- Computer controlled bandwidth (<30 to >125 nm)
- Computer tunable centre wavelength
- PowerTrack active optimisation
- <12 fs pulsewidth capability
- Low noise (<0.05% rms)
- Integrated Verdi-G pump laser
- Compact footprint

Vitara's 125 nm maximum bandwidth delivers a specified pulsewidth of <20 fs directly from the laser output. In addition, the optional compact compressor enables the Vitara pulsewdith to be further compressed to 12 fs or less. Other options for Vitara include a new generation CEP stabilisation module that delivers the industry's highest phase stabilisation specification, and a Synchrolock module for external pulse timing stabilisation.

Applications for Vitara include seeding short-pulse amplifiers and CEP-stabilised amplifiers, which benefit from Vitara's stability and bandwidth, as well as pump probe spectroscopy where the short pulsewidth is an important advantage.

Engineered to meet the ultimate stability requirements of CEP stabilisation, Vitara demonstrates unprecedented levels of stability in the most challenging environmental conditions and most demanding applications. No other laser offers this combination of exceptional performance, flexibility and power in a solid, hands-free package.

For further information please contact Paul Wardill or Dale Otten on sales@coherent.com.au
Coherent Scientific
116 Sir Donald Bradman Drive, Hilton, SA 5033
Tel: +61 8 8150 5200; Fax: +61 8 8352 2020;
Web: www.coherent.com.au

AGILENT TECHNOLOGIES

High Resolution Wide Bandwidth Arbitrary Waveform Generator

Agilent Technologies has added a high-resolution, wide-bandwidth, 8- or 12-GSa/s modular instrument to its portfolio of arbitrary waveform generators. The new M8190A arbitrary waveform generator is able to deliver simultaneous high resolution and wide bandwidth along with spurious-free dynamic range and very low harmonic distortion.

This functionality allows radar, satellite and electronic warfare device designers to make reliable, repeatable measurements and create highly realistic signal scenarios to test their products.

The M8190A helps engineers:

- build a strong foundation for highly reliable satellite communications
- generate multilevel signals with programmable ISI and jitter up to 3 Gb/s.

The M8190A offers:

- 14 bits of resolution and up to 5 GHz of analog bandwidth per channel simultaneously
- the ability to build realistic scenarios with 2 GSa of waveform memory
- reduced system size, weight and footprint with compact modular AXIe AWG capability.

The high performance of the M8190A arbitrary waveform generator is made possible by a proprietary digital-to-analog converter (DAC) designed by the Agilent Measurement Research Lab. Fabricated with an advanced silicon–germanium BiCMOS process, the DAC operates at 8 GSa/s with 14-bit resolution and at 12 GSa/s with 12-bit resolution. At 8 GSa/s, the Agilent DAC delivers up to 80c-dB SFDR.

More information is available at www.agilent.com.au/find/M8190.

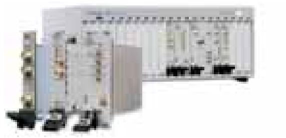
Agilent PCIe High-Speed Digitiser

Agilent U1084A is a dual-channel, 8-bit PCIe digitiser with up to 4 GS/s sampling rates, 1.5 GHz bandwidth and incorporates a 15 ps trigger time interpolator for accurate timing measurement.

The U1084A's digitiser technology combines fast analog-to-digital converters with on-board field programmable gate array technology allowing original equipment manufacturers to easily design-in high-speed signal acquisition and analysis.

More information is available at www.agilent.com.au/find/u1084a.

One Box EMI Receiver that Enhances Compliance Testing



Agilent Technologies has announced the introduction of the N9038A MXE EMI receiver, which is designed for laboratories that perform compliance testing of electrical and electronic products. The MXE enhances electromagnetic interference (EMI) measurement accuracy and repeatability with a displayed average noise level of -163 dBm at 1 GHz. This represents excellent input sensitivity, an essential receiver attribute that reduces the effects of electrical noise.

The MXE is fully compliant with CISPR 16-1-1 2010, the International Electrotechnical Commission recommendation that covers measurement receivers used to test conducted and radiated electromagnetic compatibility of electrical and electronic devices. With outstanding measurement accuracy of ±0.78 dB, the MXE exceeds CISPR 16-1-1 2010 requirements.

The built-in suite of diagnostic tools, including meters, signal and measurement lists, markers, span zoom, zone span and spectrogram displays, makes it easy to monitor and investigate problem signals. The MXE is also an X-Series signal analyser capable of running a variety of measurement applications such as phase noise. By enhancing the analysis of noncompliant emissions, these capabilities enable EMI test engineers and consultants to evaluate signal details and deliver new insights about the products they test.

More information is available at www.agilent.com.au/find/MXE.
For further details, contact tm_ap@agilent.com.
Agilent Technologies Australia Pty Ltd
Tel: 1800 629 485
Web: www.agilent.com.au/find/promotion

CONFERENCES IN AUSTRALIA 2012

4 – 11 July 2012
Thirty-sixth International Conference on High Energy Physics, ICHEP2012
Melbourne Convention and Exhibition Centre, VIC

30 July – 3 August 2012
ANU Nuclei in the Cosmos Winter School
ANU, Canberra, ACT

5 – 10 August 2012
Nuclei in the Cosmos 2012
Cairns Convention Centre, QLD

12 – 17 August 2012
Seventy-fifth Annual Meeting of the Meteoritical Society
Cairns Convention Centre, QLD

23 – 28 September 2012
Thirty-seventh International Conference on Infrared, Millimetre and Terahertz Waves
Wollongong, NSW

25 – 28 September 2012
Twentieth International Workshop on Electron Cyclotron Resonance Ion Sources (ECRIS 2012)
Darling Harbour, Sydney, NSW

16 – 19 October 2012
Twelfth Conference of the South Pacific Environmental Radioactivity Association (SPERA 2012)
ANSTO, Lucas Heights, NSW

18 – 23 November 2012
Fifteenth International Conference on Small-angle Scattering, SAS 2012
Sydney, NSW

2 – 6 December 2012
Engineering & Physical Sciences in Medicine Conference (EPSM 2012)
Gold Coast, QLD

9 – 13 December 2012
Twentieth Australian Institute of Physics Congress
University of NSW, Sydney, NSW

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Quantum Composers provides innovation and value to our customers with our diverse family of Precision Pulse Generators. Our wide range of pulse generator technology has been created to fit the needs of any budget and application. Our pulse generators provide a cost-effective method to create and synchronize multiple sequences, delayed triggering, or any precisely timed series of events.

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Our 9500+ series of pulse generators provides a cost-effective yet highly flexible and functional approach for your synchronization and timing needs.

9520 Digital Delay Pulse Generator

Our 9520 Series Pulse Generator provides the utmost flexibility and performance in a bench-top digital delay pulse generator.

9530 Digital Delay Pulse Generator

Our 9530 Pulse Generator provides the latest in laser timing and synchronization. Offering a unique 1U 19″ rackmount package with all rear panel connections, it is well suited for integration into your rack timing and control systems.

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Our 9600+ Pulse Generator is the most affordable Digital Delay Pulse Generator in our family of products. Despite its low cost, this robust model offers a full range of features, making it ideally suited for the budget sensitive user.

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