Australian Physics

Volume 48, Number 3, May–June 2011

The birth of nuclear physics

Measuring Rutherford's impact on science

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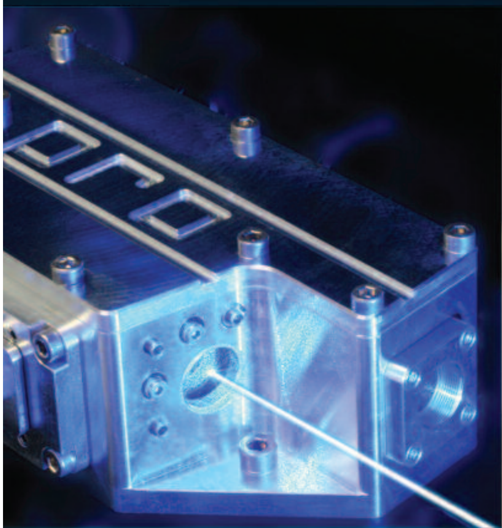
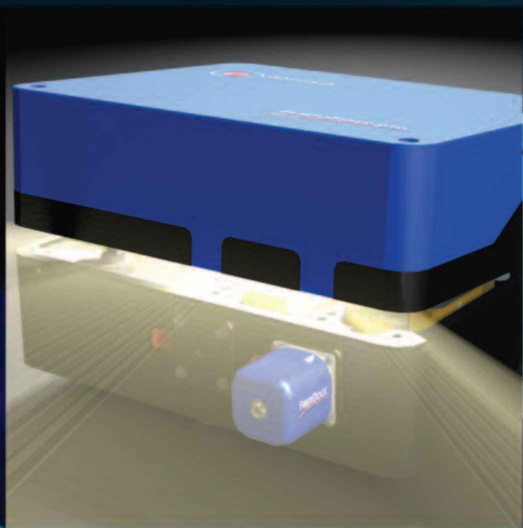
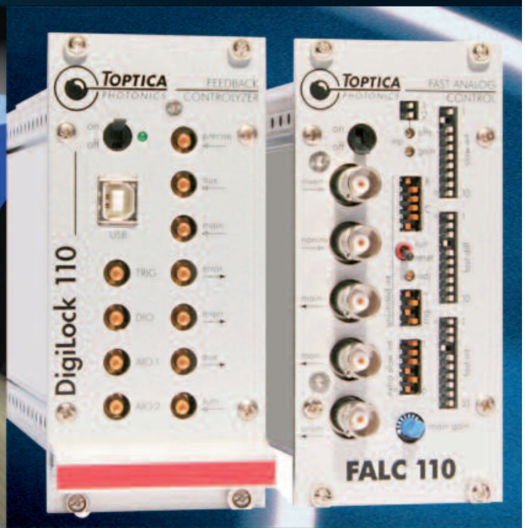

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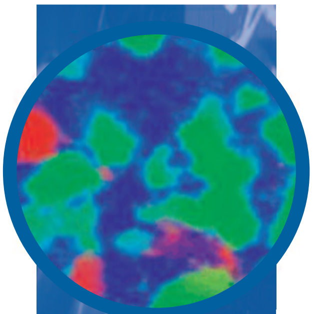

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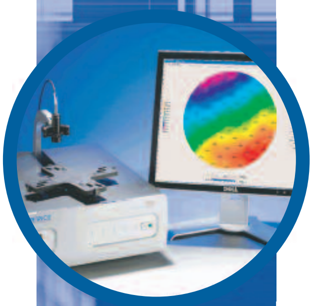

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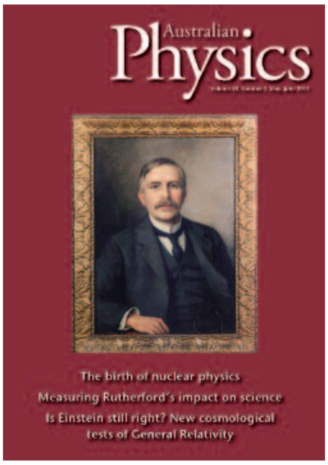

Cover

A portrait of Ernest Rutherford by the Belgium artist Jozef Janssens. A wartime refugee, Janssens settled in Cambridge where he befriended the Rutherfords. Although unsigned and undated, the portrait is thought to have been painted in 1916. Janssens also painted Rutherford's daughter Eileen in the same year. [Courtesy: John Campbell and the Rutherford family.]

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EDITORIAL

Our honorary Aussie Ernie

Welcome to this particularly international issue of *Australian Physics*. The authors of our three feature articles are all from overseas – three from Germany, one from Canada and one from New Zealand (admittedly one is an Australian postdoc).

If we were to conduct a poll to vote for the top ten physicists of the twentieth century, there is little doubt as to who would finish in top spot. But where would Ernest Rutherford rank in your top ten, if at all? I would certainly put him in my top five and probably in my top three. It's hard to think of a better or more influential experimental physicist over the past hundred years.

Rutherford was awarded the 1908 Nobel Prize for Chemistry (shared with Marie Curie and Henri Becquerel) but, as noted in a previous editorial, did not win a Nobel Prize for Physics. And yet, as noted in the two articles by John Campbell and by Werner Marx, Manuel Cardona and David Lockwood, if circumstances had been a little different Rutherford might have been the first scientist to have won three.

Arguably Rutherford's greatest achievement was the discovery of the atomic nucleus in 1911 while at the University of Manchester, one that founded a whole new branch of physics. But there was no Nobel gong. (Manchester had its Nobel breakthrough with Patrick Blackett in 1948 and again in 2010.)

Similarly in 1919, then at Cambridge, Rutherford bombarded nitrogen nuclei with alpha particles and observed the emission of protons, indicating that oxygen nuclei had been formed. This was the first controlled transmutation of atomic nuclei, fulfilling the old alchemists' dream of changing one element into another. For good measure, the following year he predicted the existence and properties of neutrons, confirmed in 1932 by his long-term collaborator James Chadwick. Would that get a gong today?

From the sub-atomic world, our third feature article goes to cosmological scales. Just as physicists are looking for new physics beyond the Standard Model of the structure of matter, Paul Lasky explains that there are clues emerging that the structure and evolution of the universe may be governed by new physics beyond General Relativity.

Finally, it's a pleasure to introduce our Samplings Editor, Don Price from CSIRO Lindfield.

Peter Robertson

Unethical advertising

This month our Editor allocated me a shorter column (for reasons of space), so I am going to have a little gripe. Not about physics or physicists but about advertising. Many of you will have seen the advertisements run by Neuroscience Australia that are asking for donations for brain research. I am sure that everyone agrees that this research is both necessary and worthy of public support and that it is most reasonable for Neuroscience Australia to have sought an advertising agency to help them make the public call for funds and to use the television stations' 'community service' slots to get the message out at minimal cost.

But now we come to the problem. The advertising agency chose to open with fantastic imagery from our colleagues the optical astronomers. Excellent eye candy to attract even the most hardened cynic to view the ad. But then to call that research into question, by implying it is a waste of time, whilst smoothly changing the imagery to a scan slice of the human brain and telling us all that research on the human brain is much more relevant and should be supported, is going too far.

I am appalled that Neuroscience Australia felt that this was a reasonable approach. Worse the Astronomical Society of Australia wrote to them stating that it was not in the best interest of any science to make such statements and received a reply saying that no one appeared to be complaining and they would continue to run the advertisements. I know that a number of other individuals and organisations raised objections to the advertisement.

Several people noted that those very brain scans that were being used to encourage donations would not have been possible had it not been for the image reconstruction work of radio astronomers who developed the techniques of building an image from an incomplete u-v plane coverage. It would have been so much better to have opened with the same imagery and stated that thanks to the pioneering work of astronomers who developed the imaging techniques used in scanners today (then fading to the brain scan) that we can now view the brain while it works; but we need funds to further understand the brain and to repair it when it goes wrong.

Not that I expect anything to change, but hopefully reading this will dissuade people from a similar action in future.

Marc Duldig

In our next issue…

Volume 48, Number 4

- ERA: Measuring the performance of Australian physics
- Searching for the highest energy particles in nature
- Teaching secondary school physics in Kenya

INTRODUCING OUR SAMPLINGS EDITOR

Don Price obtained a first class Honours degree (1966) and PhD (1970) in Physics from Monash University, the latter for magnetic and Mössbauer spectroscopic studies of dilute magnetic alloys. Following post-doctoral work in Canada, the UK and in Canberra (ANU), he worked as a Research Engineer on the development of a medical ultrasound imaging instrument at QIT in Brisbane from 1980–82. This led to an appointment as Research Scientist at CSIRO Applied Physics in 1982 to work on ultrasonic techniques for materials characterisation and defect detection in engineering materials. He contributed to and led a number of strategic and industrial projects, working extensively with international organisations such as NASA, Boeing and AEA Technology as well as a number of Australian companies. This work led to a more general focus on structural health monitoring and intelligent distributed sensing systems, utilising principles of self-organisation and information theory. At different times he held a number of Divisional leadership positions, including Discipline Leader for Acoustics and Ultrasonics, and ultimately Chief Scientist for the then Division of Industrial Physics. He retired in 2009 and now has an honorary appointment as Fellow in CSIRO Materials Science & Engineering, and divides his time between living in Sydney and Hobart. As Samplings Editor for *Australian Physics* he would welcome any contributions or suggested items.

NEWS & COMMENT

Not so FASTS: Science & Technology Australia

After 26 years of supporting and promoting the important work of Australia's scientists, the peak association of scientists has evolved to become Science & Technology Australia. The new name for FASTS – the Federation of Scientific and Technological Societies – was chosen following extensive feedback from both scientists and stakeholders and reflects a challenge for the sector to better communicate the nation building work of scientists.

Dr Cathy Foley, President of Science & Technology Australia, said the nation was on the threshold of a new era in science and technology where science will be valued and respected. "The role and value of science in all our lives cannot be underestimated, so it is critical that as scientists we better communicate the credibility of our work."

"It is this rigorous peer review science process that provides decision makers with the confidence they need to make important decisions about our nation's future. Across the board, scientific and technological research provides the foundation on which much of the current and future wealth and health of Australia is built," Dr Foley said.

Science & Technology Australia represents 68,000 scientists and technologists, and promotes their views on a wide range of policy issues to government, industry and the community. The organisation was formed in late 1985, following substantial cuts to science in the 1984 Federal Budget. The then Minister for Science, Barry Jones, had at the time accused the science and technology community of being 'wimpish' in its lobbying and blamed the budget cuts accordingly.

Science & Technology Australia contributes to discussions at the highest levels of policy making and communicates with the highest level of government. It has three formal objectives:

- to encourage scientific dialogue between industry, government, and the science and technology community;
- to promote public understanding of science; and
- to foster close relations between member societies.

See the new name and website for scientists at: www.sta.org.au.

Big step towards the SKA

The discovery potential of the future international Square Kilometre Array (SKA) radio telescope has been glimpsed following the commissioning of a working optical fibre link between CSIRO's Australian

Four antennas of CSIRO's ASKAP telescope in Western Australia [credit: Terrace Photographers]

Decadal Plan for Australian astronomy

Astronomers recently launched a plan to put Australia at the forefront of international astronomy over the next five years. Compiled by the Australian Academy of Science's National Committee for Astronomy, the 'Mid-Term Review of the Australian Astronomy Decadal Plan 2006–2015' calls for a radio-quiet zone to be maintained in Western Australia and the creation of a central international astronomical data bank linking high-performance resources from astronomy facilities around the world.

Committee chair and Fellow of the Australian Academy of Science, Professor Elaine Sadler, said the plan sets out measures to keep Australia at the forefront of international astronomy. "If Australia is to have a chance at attracting the Square Kilometre Array – the most powerful radio telescope in the world – it is essential that we preserve a radio-quiet environment in regions of Western Australia", she said.

The plan recommends Australia secures continued access to an 8-metre optical telescope – crucial infrastructure for which the best sites are overseas. "Eight-metre telescopes are the foundation of a large part of current

SKA Pathfinder (ASKAP) telescope in Western Australia, and other radio telescopes across Australia and New Zealand.

The achievement was announced at the 2011 International SKA Forum, which took place early in July in Banff, Canada. Six telescopes – ASKAP, three CSIRO telescopes in NSW, a University of Tasmania telescope and another operated by the Auckland University of Technology – were used together to observe a radio source that may be two black holes orbiting each other.

Data from all sites were streamed in real time to Curtin University in Perth (a node of the International Centre for Radio Astronomy Research) and were processed to make an image. This ability to successfully link antennas (dishes) over large distances will be vital for the future $2.5 billion SKA telescope, which will have several thousand antennas, up to 5500 km apart, working together as a single telescope. Linking antennas in such a manner allows astronomers to see distant galaxies in more detail.

"We now have an SKA-scale network in Australia and New Zealand: a combination of CSIRO and NBN-supported fibre and the existing AARNET and KAREN research and education networks", said SKA Director for Australasia Dr Brian Boyle.

The radio source the astronomers targeted was PKS 0637–752, a quasar that is more than 7.5 billion light-years away. This quasar emits a spectacular radio jet with regularly spaced bright spots in it, like a string of pearls. Some astronomers have suggested that this striking pattern is created by two black holes in orbit

Six telescopes linked to observe the quasar PKS0637–752 [credit: Carl Davies, CSIRO]

around each other, one black hole periodically triggering the other to 'feed' and emit a burst of radiation.

"It's a fascinating object, and we were able to zoom right into its core, seeing details just a few millionths of a degree in scale, equivalent to looking at a 10-cent piece from a distance of 1000 km", said CSIRO astronomer Dr Tasso Tzioumis. During the experiment Tzioumis and fellow CSIRO astronomer Dr Chris Phillips controlled all the telescopes over the internet from Sydney.

Curtin University's Professor Steven Tingay and his research team built the system used to process the telescope data. "Handling the terabytes of data that will stream from ASKAP is within reach, and we are on the path to the SKA", he said. "For an SKA built in Australia and New Zealand, this technology will help connect the SKA to major radio telescopes in China, Japan, India and Korea."

astronomical discovery", Professor Sadler said. "Failure to retain this crucial part of our astronomical portfolio significantly undermines our other astronomical investments."

Another proposal, to create an international astronomical data fabric, would open up opportunities for discovery by Australian researchers based on data flowing from major international telescopes, according to Professor Sadler.

Achievements in Australian astronomy over the last five years outlined by the Review include:

- Creation of major new astronomy infrastructure in WA
- Dramatic upgrade and improved sensitivity to the CSIRO Australia Telescope
- Australia's partnership in an Extremely Large Telescope to be built in Chile [see *AP* **48**(1), 23–28 (2011)]
- Australia's leading astronomers have won prestigious national and international prizes including the Malcolm McIntosh Prize, the Shaw Prize, the Gruber Prize, the Prime Minister's Prize for Science, and the Pawsey Medal.

The 'Mid-Term Review' was launched early in July at the Annual Conference of the Astronomical Society of Australia held in Adelaide.

ERNEST RUTHERFORD *and His Path to the* NUCLEAR ATOM

John Campbell

All great discoveries usually end up with one line in history. Ernest Rutherford's discovery of the nuclear atom is a prime example. Yet, behind this one line is an interesting and much more complicated pathway.

After three degrees and two years research at the forefront of the electrical technology of the day, Ernest Rutherford left New Zealand on an Exhibition of 1851 Science Scholarship, which he could have taken anywhere in the world. He chose the Cavendish Laboratory, Cambridge University, because its director, J. J. Thomson, had written one of the books on advanced electricity which Rutherford had used to guide his research [1].

This put the right man in the right place at the right time. Initially Rutherford continued his work on the high-frequency magnetisation of iron, developing his detector of fast current pulses to measure the dielectric properties of materials at very high frequencies and to briefly hold the world record over which electric 'wireless' waves were detected. Thomson, or JJ as he was known, appreciated Rutherford's experimental and analytical skills and so invited him to join in his own research into the nature of electrical conduction in gases at low pressures.

"Alpha particles were Rutherford's baby, having conceived them, and they featured in most of his researches."

Within five months of Rutherford's arrival at the Cavendish, the age of new physics commenced. Röntgen's discovery of X-rays and then Becquerel's discovery of radioactivity were announced. Rutherford used both to ionise his gases in an attempt to learn what it was that was conducting the electricity in an ionised gas. Very soon he changed to trying to understand radioactivity, with his research determining that two types of rays were emitted, which he named alpha and beta rays.

Thomson continued mainly with the ionisation of gases. Two years after Rutherford's arrival, Thomson carried out a definitive experiment which showed that cathode rays were objects a thousand times less massive than the lightest atom. The electronic age and the age of sub-atomic particles had commenced, though mostly unheralded. (Thomson's apparatus was the basis of glass–vacuum oscilloscopes and TV tubes for over 80 years, until recently when it was replaced by LCD and plasma screens.) Rutherford was a close observer of Thomson's discovery and became an immediate convert to, and champion of, sub-atomic objects. Beta rays were quickly shown to be high-energy cathode rays, ie. high-speed electrons.

Rutherford had no future at Cambridge. After three years there as a non-Cambridge graduate, he was not eligible for a fellowship for another year so he took the Macdonald Chair of Physics at McGill University in

Fig. 1. The Manchester University Physical and Electro-Technical Laboratories staff and research students in 1912. Ernest Rutherford is in the centre of the second row and to his right is Arthur Schuster who stood down from his chair in natural philosophy in order to persuade Rutherford to return to Britain from McGill University in 1907. Hans Geiger is at far left in the same row.
Ernest Marsden is at far right in the front row. Second from the left is Harry Moseley who discovered the essential feature distinguishing the natural elements – the atomic number. Moseley was killed three years later in WWI.

Directly behind Rutherford in the third row are May Leslie (left) who studied the diffusion of thorium and radium emanations and Margaret White who studied the electrical properties of the atmosphere, emphasising Rutherford's support of women. At far left in this row is the theoretical physicist Charles G. Darwin, named after his illustrious grandfather. Darwin was a close collaborator of Rutherford and later followed him to Cambridge where he played a significant role in the foundation of quantum mechanics.

William Kay, Rutherford's assistant, is second from left in the back row. Finally, at far right in the back row is James Chadwick who discovered the neutron exactly 20 years later. At last, there was a clear understanding of the Rutherford nucleus.

Hans Geiger returned to Germany in 1912, to the Physical–Technical Reichsanstalt in Berlin. During World War I he was an artillery officer. He and Marsden served opposite each other at the Front, during which Geiger (via Niels Bohr in neutral Denmark) congratulated Marsden on his Chair. In 1927 Geiger named a son Roland Ernst Arthur, in honour of his time at Manchester. In 1925 he became professor in Kiel, in 1929 in Tübingen, and from 1936 in Berlin. He helped develop coincidence counting and studied cosmic rays. In 1928 he and Muller modified the Rutherford–Geiger detector so today it is called the Geiger–Muller tube. Geiger died in 1945, not long after World War II ended.

Ernest Marsden graduated B.Sc. with First Class Honours in 1909, and was a lecturer at the University of London before returning to Manchester to succeed Geiger in 1912. In 1914 he was appointed professor at Victoria University College in Wellington, New Zealand, and served in World War I, in sound ranging of enemy guns, where he was awarded the Military Cross. From 1922 his career was in administration in New Zealand: Assistant Director of Education (1922–1926); Secretary of the new DSIR (1926–1944); scientific advisor to the NZ Government during World War II (1941–1946); Scientific Liaison Officer in London (1947 until retirement in 1954). He died in New Zealand in 1970. It is ironic, or a sign of modern times, that New Zealand's blue sky research fund, The Marsden Fund, is named for a science administrator and not for Rutherford, the supreme practitioner of blue sky research.

Montreal, Canada. (Cambridge changed its rules the following year.) From then on, the world centre of radioactivity and particle research was wherever he was based.

Fuzzy beams

At McGill, Rutherford showed that radioactivity was the spontaneous transmutation of radioactive atoms. For this he received the 1908 Nobel Prize in Chemistry. He also demonstrated that alpha particles were most likely helium atoms minus two electrons, and he dated the age of the earth using radioactive techniques. In studying the nature of alpha particles, by being the first to deflect them in magnetic and electric fields in beautifully conceived experiments, he observed that a narrow beam of alphas in a vacuum became fuzzy when either air was introduced into the beam or it was passed through a thin window of mica. Alpha particles were Rutherford's baby, having conceived them, and they featured in most of his researches.

Rutherford returned to England in 1907 where he was appointed to the Langworthy Chair of Physics at the University of Manchester. He first needed a method of tirelessly counting alpha particles, because the method of observing tiny flashes on a fluorescing screen quickly caused eye strain. He was an expert on ionised gases, and had been told by Townsend, his old friend from Cambridge days, that one alpha particle ionised tens of thousands of atoms in a gas. So with the assistant he had inherited, Hans Geiger, the Rutherford–Geiger tube was developed (with later minor improvements by Geiger this is today known as the Geiger tube).

"It is said that Rutherford often cursed and left the counting to the younger Geiger."

By this stage a number of laboratories were studying the scattering of beta particles from atoms. The Cavendish Laboratory claimed that the large scattering angles were due to many consecutive small angle scatterings inside Thomson's 'plum pudding' model of the atom, the electrons being the fruit scattered throughout the solid sphere of positive electrification. Rutherford did not believe this scattering was multiple, and so once again he had to quantify the science to undo mistaken interpretations of others.

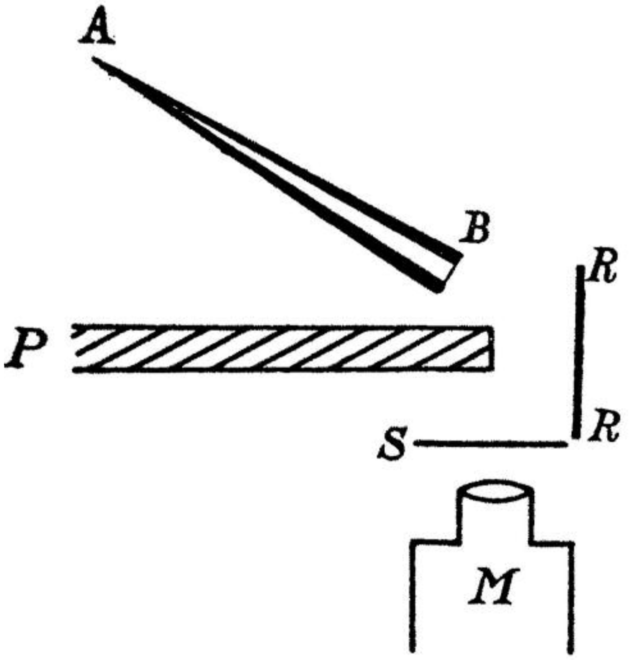

Fig. 2. Marsden's first large-angle scattering arrangement. AB contained radium emitting alpha particles through a thin window. The alphas were scattered by a metal plate RR onto a scintillation screen S and the scintillation flashes were observed through a low-powered microscope M. The lead shield P blocked unscattered alphas.

Geiger was given the task of measuring the relative numbers of alpha particles scattered as a function of angle over the few degrees that Rutherford had measured photographically at McGill. Photography could not however register single particles. Nor was the Rutherford–Geiger detector suitable for 'quickly' measuring scattered particles, but one of the reasons for its development was to determine whether or not the discovery by Crookes in 1903 of the 'spinthariscope' did register one flash of light for every alpha particle which struck a fluorescing screen. Once Rutherford and Geiger had established that this was the case, they were able to accurately measure Avogadro's Number and standardise radium samples.

Rutherford backscattering

Geiger used monochromatic alpha particles in a vacuum tube to impinge on a metal foil and then on a fluorescing plate forming the end of the tube. A low power microscope, looking at about 1 mm^2 of the plate allowed the alphas to be counted. It was tiring work, waiting half an hour for the eye to dark adapt then staring at the screen unblinking for a minute before resting the eye.

On a Diffuse Reflection of the α-Particles.

By H. Geiger, Ph.D., John Harling Fellow, and E. Marsden, Hatfield Scholar, University of Manchester.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 19,—Read June 17, 1909.)

When β-particles fall on a plate, a strong radiation emerges from the same side of the plate as that on which the β-particles fall. This radiation is regarded by many observers as a secondary radiation, but more recent experi-

Fig. 3. The Geiger–Marsden paper in *Proc. Roy. Soc. London* in 1909.

It is said that Rutherford often cursed and left the counting to the younger Geiger.

Another of Geiger's duties was to train students in radioactivity techniques. It was Rutherford's policy to involve undergraduates in simple researches. So when Geiger reported to Rutherford that a young Manchurian undergraduate was ready for an investigation, Rutherford set Ernest Marsden the task to see if he could observe alpha particles reflected from metal surfaces. This seemed unlikely, but beta particles did reflect.

Marsden used the same detecting system as Geiger, but had the alpha source on the same side of the metal as the fluorescing screen, with a lead shield preventing alphas going directly to the screen – see Fig. 2. William Bragg in Adelaide, whom Rutherford had met in 1895, had reported that there were alpha rays of several different energies emitted from radium salts, one for each member of the decay series. Rutherford could choose a monochromatic alpha source by allowing radium emanation (radon) to decay in the presence of a charged plate, which became plated with the metal decay product, and finally producing mono-energetic alphas solely from Radium C. Marsden replaced his tube of radon gas with such a mono-energetic source.

When Marsden reported that he did see about one in 10,000 alphas scattered at large angles Rutherford later recalled his astonishment. It was as if a 15-inch naval shell had been fired at a piece of tissue paper and it bounced back. Geiger and Marsden published their measurements in June 1909 – see Fig. 3. Characteristically, Rutherford's name was not listed as an author. As William Kaye, his laboratory steward, stated in a memoir many years later, Rutherford gave full credit to his helpers.

During Rutherford's time at Manchester an extraordinary number of 230 papers were published on radioactivity. Yet, his name appears on only 37 of the 200 or so for which he was not the sole author, though he had initiated almost all those studies. As evidence of his helpfulness to young scientists in distant parts (perhaps recalling how his own first planned research in New Zealand had been overwritten before he could complete it) Rutherford, in March of 1911, wrote to John Madsen at the University of Melbourne: "I had intended to test my theory by experiments with rays along very similar lines to that which I understand you are doing. I shall be glad, however, to leave the matter to you if you will be able to get through the work in reasonable time."

The nucleus unveiled

Ernest Marsden's discovery remained fallow for over a year, as he had exams to sit. Geiger continued obtaining more accurate statistics for alpha scattering from different materials and thickness of foils. It is recorded that one day Rutherford went into Geiger's room to announce that he knew what the atom looked like. By January 1911 Rutherford could write to Arthur Eve in Canada: "Among other things I have been interesting myself in devising a new atom to explain some of the scattering results. It looks promising and we are now comparing the theory with experiments."

On 7 March 1911 Rutherford presented his ideas to the Manchester Literary and Philosophical Society. He reported that Geiger's experimental test of the theory confirmed that the alpha rays scattered through large angles varied as $\mathrm{cosec}^4\phi/2$, where ϕ is the angle of deviation. One conclusion was that for gold the central charge was about 100 units and that for different

"… Rutherford later recalled his astonishment. It was as if a 15-inch naval shell had been fired at a piece of tissue paper and it bounced back."

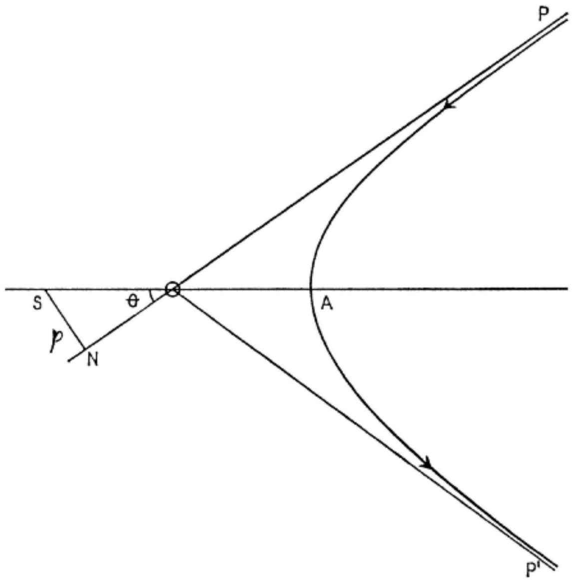

Fig. 4. Rutherford's theory of large angle scattering from his *Phil. Mag.* article of 1911.

materials the number was proportional to NA^2, where N is the number of atoms per unit volume and A the atomic weight. Another conclusion was that large scattering (hyperbolic) paths were independent of whether the central charge is positive or negative.

A reporter for the *Manchester Guardian* wrote that Rutherford's work "… involved a penetration of the atomic structure, and might be expected to throw some light thereon", before concluding that "… we were on the threshold of an enquiry which might lead to a more definite knowledge of atomic structure" [3].

Rutherford's talk was published in the Manchester Literary and Philosophical Society's Proceedings, and more fully in the *Philosophical Magazine* for May. In the latter, Rutherford acknowledged Nagaoka's mathematical consideration of a 'Saturnian' disc model of the atom, stating that essentially it made no difference to the scattering if the atom was a disc rather than a sphere [4].

Surprisingly, the nuclear atom created no significant scientific or public interest. Three nights later, Rutherford addressed the Society of Industrial Chemists on 'Radium' without mentioning the nuclear atom. Three weeks later, when addressing the Institution of Electrical Engineers on 'The properties of alpha rays of radio-active matter', he did mention that "he hoped very soon to form some reasonable view of the constitution of the atom itself."

Sir William Ramsay, in his Presidential address to that year's Annual General Meeting of the British Association for the Advancement of Science, never mentioned the nuclear atom. This seems most unusual today when reporters and science writers would now be keen to mention all sorts of trivialities such as that, if the electrons in our atoms were compressed into the nuclei, a human body would be the size of a grain of sand. Ramsay concentrated on his own discoveries, causing Arthur Schuster, who had stood down from the physics chair at Manchester on condition that it was offered to Rutherford, to write a letter to the editor of the *Manchester Guardian* pointing out which of those discoveries had been made by Rutherford.

An accompanying paper on p. 78 of this issue of *Australian Physics* [5] examines the citation index for Rutherford's papers and concludes that he has undergone 'scientific obliteration' – the greatest of accolades – whereby a scientist's work is so taken for granted that no one any longer sees a need to cite it.

Fig. 5. Niels Bohr and Rutherford at the Cambridge University rowing regatta in June 1923. Shortly after, Bohr was offered a prestigious Royal Society professorship to work with Rutherford at the Cavendish Laboratory, but he chose to continue developing physics at the University of Copenhagen in Denmark.

Fig. 6. Alpha scattering and the nuclear atom as depicted on the 1971 New Zealand 1¢ stamp to mark the centennial of Rutherford's birth and a Greek 100 Drachma banknote from 1967.

Rutherford's Nobel Prize in Chemistry of 1908 was too recent for physicists to nominate him again. It was to be 1922 before he was next nominated, unsuccessfully. To date there have been 27 Nobel Prizes awarded for the discovery of, or theories linking, subatomic particles, but there was never one for the nuclear atom. However, there was a related one. At the end of 1911 Rutherford was the guest of honour at the annual Cavendish Research Dinner, at which he was, not surprisingly, in fine form. The chairman, in introducing him, stated that Rutherford had another distinction. Of all the young physicists who had worked at the Cavendish, none could match him in swearing at apparatus. Rutherford's jovial laugh boomed around the room.

A young Dane, visiting the Cavendish for a year to continue his work on electrons in metals, took an immense liking to the hearty New Zealander. He resolved to shift to Manchester and spend the rest of his year working with Rutherford. And so it was that Niels Bohr received the 1922 Nobel Prize for Physics for "his services in the investigation of the structure of atoms and of the radiation emanating from them". Bohr had placed the electrons in stable orbits around Rutherford's nuclear atom.

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ABOUT THE AUTHOR

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Rutherford's Scientific Impact *from a Bibliometric Perspective*

Werner Marx, Manuel Cardona and David J. Lockwood

In 2011 we celebrate the centenary of the publication of the ground-breaking paper by Ernest Rutherford on the discovery of the nucleus and, hence, the beginning of nuclear physics. Rutherford (1871–1937) was a towering figure in scientific research in the early twentieth century. His three major experimental discoveries in atomic physics during that period could each have earned him a Nobel Prize. However, his scientific achievements and interests went well beyond just these notably huge advances in our knowledge of atomic physics at the time. Here we report on the impact of Rutherford's work on scientific developments over the past one hundred years through an analysis of citations to his publications.

Rutherford was awarded the Nobel Prize in Chemistry in 1908 for explaining radioactivity as the spontaneous disintegration of atoms, and in the process identified alpha, beta, and gamma rays. In other equally brilliant experiments performed with colleagues in 1911 he determined the structure of the atom and thereby produced his model of the atom – a minute nucleus (his term) surrounded by a cloud of electrons [1]. Thirdly, in 1919 he split the atom by converting nitrogen into oxygen using alpha-particle bombardment to become the first true alchemist.

Many of his secondary discoveries would have resulted in fame for any other scientist. When Rutherford first blew tobacco smoke into his ionisation chamber at McGill University in Montreal in 1899 and observed the resulting change in ionisation he lead the way to the development of the ubiquitous smoke detector alarm systems found in our buildings today. He pioneered the use of radioactive decay as a time marker for determining the age of the earth and also its subsequent use for dating the earth's artefacts, overcoming much resistance at the time from the scientific establishment in the process. For more on the life and work of Rutherford, see the comprehensive biography by John Campbell [2].

Applying bibliometrics to the history of science

Bibliometrics or the broader term scientometrics – both dealing with the quantitative analysis of science – has shifted from a very special subject to an issue most relevant to the majority of present day scientists. If they are seeking a job, a promotion or tenure, their publication output and citation impact will possibly be considered. Such metrics have not been established to replace committees of experts but to provide comprehensible and reliable numerical data for fair assessment. Only active researchers within the same research field are in a position to assess the scientific quality of their colleague's research. However, citation based metrics provide an objective counterweight to the peer-review

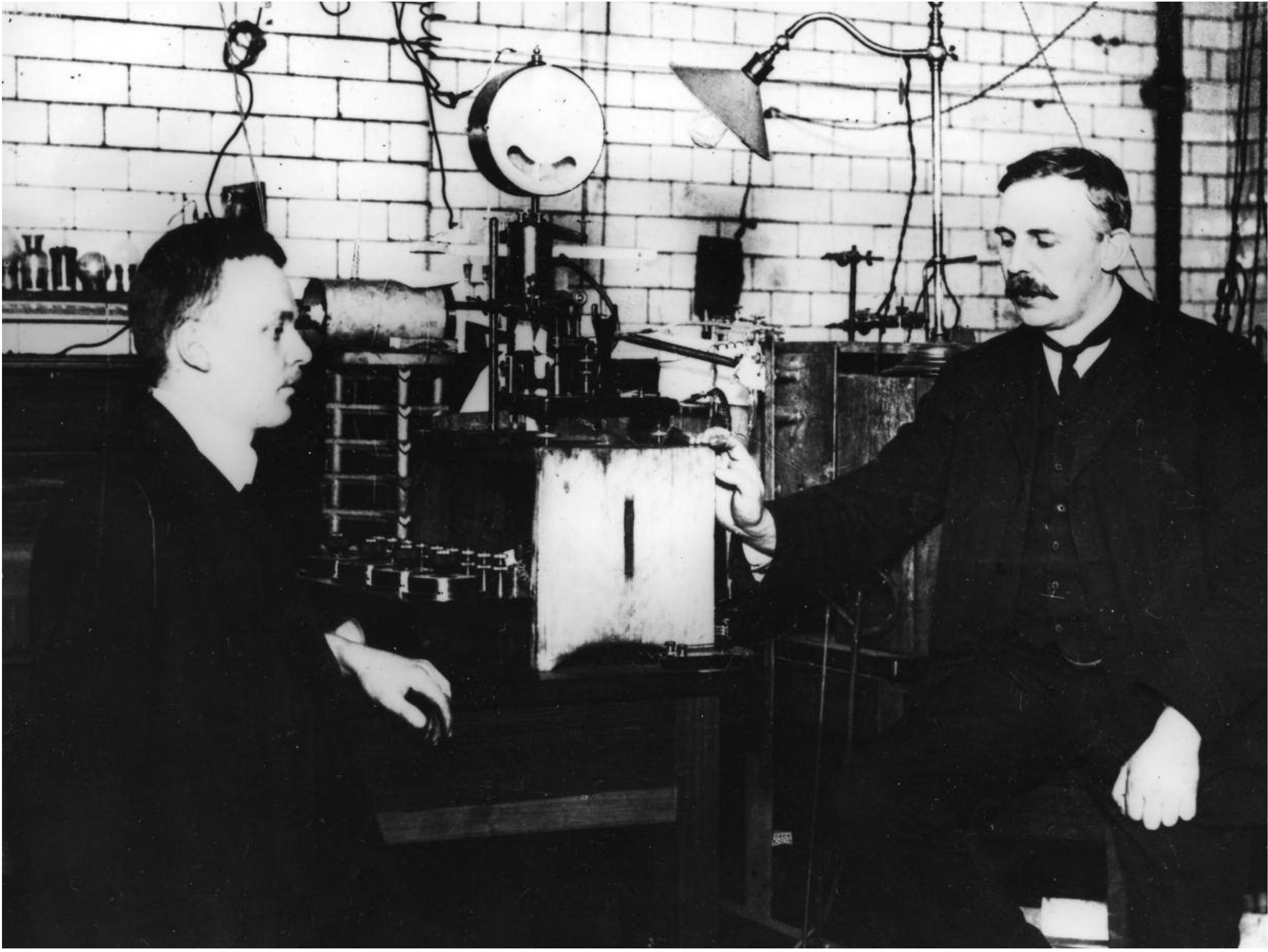

Fig. 1. Hans Geiger (left) with Ernest Rutherford in the laboratory at the University of Manchester, thought to be in 1908 [credit: AIP Emilio Segre Visual Archives].

process, which is prone to bias of many kinds (e.g. nepotism). The weakness of bibliometrics is not so much the method itself, but the lack of background information and understanding concerning what the data really mean – and what they do not mean!

The launching of the Web of Science (referred to hereafter as *WOS*) back-files by Thomson Reuters has extended the retrospective coverage of *WOS* (the most important source of citation based data besides Scopus from Elsevier) back to 1900 [3]. There is no real need for the evaluation of the lifeworks of the pioneers of science, who have long ago found their recognition by the incorporation of their discoveries into textbooks (or even as Nobel Laureates). However, we may be interested to detect their traces in the databases, the digital archives of science. Also, quantitative data on the reception of seminal works might be of interest. Furthermore, we can illustrate some basic laws of bibliometrics in the context of works well-known to most scientists. Finally, we may ask whether the citation based indicators applied to current scientists yield meaningful results also in the case of pioneers.

However, there are some caveats to searching historical papers and counting their citations as a measure of their impact: the limited coverage of journals, the limitations of specific search fields, database errors, problems arising from incorrect citations, and other sources of errors resulting from the citation practice in the past [4]. Moreover, in the case of historical papers there are some basic phenomena limiting the meaning of citation counts as a measure of scientific impact. We enter an area with a completely different publication and citation culture compared to the present one.

Nevertheless, Rutherford delivers an excellent example for applying bibliometrics to the history of science: (1) most of his papers have been published in the *Philosophical Magazine* after 1900 and hence are covered sufficiently by *WOS*; (2) most of his papers are of basic importance and are therefore cited throughout the twentieth century; and (3) there is not only one but other major discoveries in nuclear physics, which could each have earned him a second Nobel Prize.

Table 1: The ten most frequently cited papers by Ernest Rutherford [source: Thomson Reuters *WOS* at 27 May 2011]

Author(s)	Journal	Title	Citations
E. Rutherford	*Phil. Mag.* **21**, 669–88 (1911)*	The scattering of α and β particles by matter and the structure of the atom	370
E. Rutherford & H. Geiger	*Proc. Roy. Soc. London* **A81**, 141–61 (1908)	An electrical method of counting the number of alpha-particles from radio-active substances	90
E. Rutherford	*Proc. Roy. Soc. London* **A97**, 374–400 (1920)	Bakerian Lecture: Nuclear constitution of atoms	68
E. Rutherford	*Nature* **123**, 313–4 (1929)	Origin of actinium and age of the earth	67
E. Rutherford & C. Andrade	*Phil. Mag.* **28**, 263–73 (1914)	The spectrum of the penetrating gamma rays from radium B and radium C	65
E. Rutherford	*Phil. Mag.* **47**, 277–303 (1924)	The capture and loss of electrons by alpha particles	63
M. Curie, E. Rutherford *et al.*	*Rev. Mod. Phys.* **3**, 427–45 (1931)	The radioactive constants as of 1930 – Report of the international radium-standards commission	62
E. Rutherford	*Phil. Mag.* **47**,109–63 (1899)**	Uranium radiation and the electrical conduction produced by it	57
E. Rutherford	*Phil. Mag.* **37**, 581–7 (1919)	Collisions of alpha particles with light atoms IV. An anomalous effect in nitrogen	55
E. Rutherford & H. Geiger	*Phil. Mag.* **20**, 698–707 (1910)	The probability variations in the distribution of alpha particles	51
E. Rutherford & F. Soddy	*Phil. Mag.* **4**, 370–96 (1902)	Soddy on the cause and nature of radioactivity – Part I	51

* This paper has not been included as a source record because vol. 21 of *Phil. Mag.* was not covered by *WOS* until the present [4].

** Until now papers published pre-1900 are generally not covered by *WOS*, however, their citations since 1900 are searchable.

Papers, citations, and the h-index

The multidisciplinary *WOS* covers 164 papers published by 'our' E. Rutherford within the time period 1900–31 (the pre-1900 publications are not covered by *WOS*). Additionally, some 50 papers have been published since 1940 by namesakes. There are 63 out of 164 papers by Rutherford that appeared in the *Philosophical Magazine*. Obviously, this journal was his preferred choice for publishing his work, starting in 1896 and ending 1919. Rutherford ranks sixth in the list of authors having published most often in the *Phil. Mag.* since 1900. The 164 papers by Rutherford have garnered about 1500 citations until the present

> **"… Rutherford ranks in terms of citations with Max Planck and Albert Einstein as one of the main contributors to the development of modern physics during the early twentieth century."**

If we also include the citations of his books, of the pre-1900 papers (data available since 1900) and also the incorrect citations, we obtain altogether about 2100 citations. Compared to renowned present-day scientists, this seems not to be overwhelming, but these numbers are highly misleading! In the first half of the twentieth century the number of scientists was relatively small. Correspondingly, the number of publications was low (the publications covered per year by *WOS* increased by a factor of approximately hundred during the century).

We shall speak of the period before 1960 as 'little science', whereas the period after 1960 will be referred to as 'big science', a transition first observed by Derek De Solla Price [5]. It is easy to conjecture that the transition from the period of little to big science is due to the so-called 'Sputnik shock' that took place upon the orbit of the first satellite by the Soviet Union in 1957 [6]. As a reaction the Western industrial nations, especially the USA, allocated within a short time massive funding to support related scientific research and development. These measures resulted in a rapid increase in the number of scientists and research activities followed by a dramatic increase in the number of publications.

On average, early papers are cited less frequently than more recent papers. Hence, the citation numbers of early scientists are not directly comparable to those of present day researchers. The question arises: on average by what factors are contemporary papers more often cited than earlier papers. If we have to compare papers and researchers from different research fields of present day science, we need to take into account the field specific average citation rates by applying normalisation procedures. This can be illustrated by the

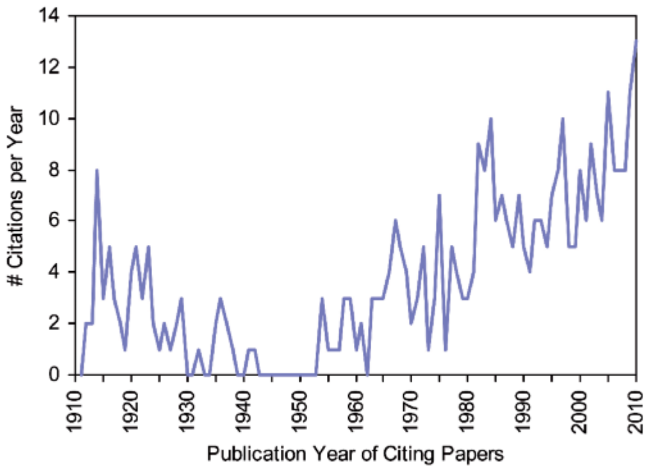

Fig. 2. Time evolution of the citation history of the seminal 1911 Rutherford paper on the discovery of the atomic nucleus [1]. This is a good example of a seminal paper with a long term impact, which receives an increasing number of citations per year along with the boom after the Sputnik shock half a century after its publication. [Source: Thomson Reuters *WOS*].

different average number of goals scored in different codes of football such as soccer and rugby. A similar problem arises if we compare citation counts of early papers published in the area of little science with citation numbers of more recent publications.

Applying our newly developed scaling method for papers published in the period of little science means that the overall number of citations (500) which Rutherford received until 1931 (the year of the last paper covered by *WOS*) has to be multiplied by an appropriate reference multiplier: a reference multiplier of 30 based on the *Phil. Mag.* or a reference multiplier of 40 based on the *Phys. Rev.* [7]. This procedure results for Rutherford in a present day scaled citation number of altogether between 15,000 and 20,000 citations, which is a truly respectable citation impact.

In 2005 the so-called Hirsch or h-index was introduced by Jorge Hirsch as a combined measure of both output (in terms of papers) and impact (in terms of citations) in a single number [8]. This new bibliometric indicator has had a major impact on the field of research evaluation, in part because of its simplicity and transparency. The h-index is defined as the number of papers *h* by an author in *WOS* source journals that have had *h* citations or more to each individual paper. We have obtained for Rutherford an unscaled h-index of 20. To calculate a time-adjusted h-index demands that all citation numbers of Rutherford papers be multiplied by the appropriate reference multiplier. This procedure results in a present day scaled Rutherford h-index of between 91 and 93 (depending on a reference multiplier of 30 or 40). For comparison, Max Planck has an unscaled h-index of 13 and a time-adjusted one of 95 [7].

Each paper develops its own lifespan as it is being cited. Over time, the citations per year normally evolve following a similar pattern: They generally do not increase substantially until one year after publication. They reach a maximum after about three years, the peak position depending somewhat on the research discipline. Subsequently, as the papers are displaced by newer ones and interest in the field wanes, their impact decreases. Finally, most papers are barely cited or forgotten. In contrast, the famous 1911 Rutherford paper on the discovery of the nucleus [1] belongs to the rather few papers published at the beginning of the little science era that have been remembered throughout half a century and were then increasingly cited within the big science period.

The citation ranking reveals the ten most frequently cited Rutherford articles, as presented in Table 1 (note of course that the citation counts are not time-adjusted in the way discussed above). Fig. 2 shows the citation history of the most-cited Rutherford paper [1] which differs markedly from the standard pattern mentioned above.

Rutherford also published at least seven books, but these are generally not covered by *WOS* as database records. However, the references assigned to books within *WOS* journal papers are completely captured. As a result of our analysis, Rutherford's books received altogether 350 citations (17% of his overall citation impact). Again, the present day scaled citation number is much higher.

Informal citations and 'scientific obliteration'

Citing is afflicted to a greater or lesser extent by many distortions which have been widely discussed in the bibliometric literature. In the case of historical papers there are two basic phenomena limiting the meaning of citation counts as a measure of scientific impact. Firstly, seminal work is often cited by mentioning the author's name or name-based items ('informal citations') instead of citing the full references as a footnote ('formal citations') [9]. The number of 'informal citations' is often many times higher than the number of reference based citations, in particular when the name of an author or their contribution has become a household

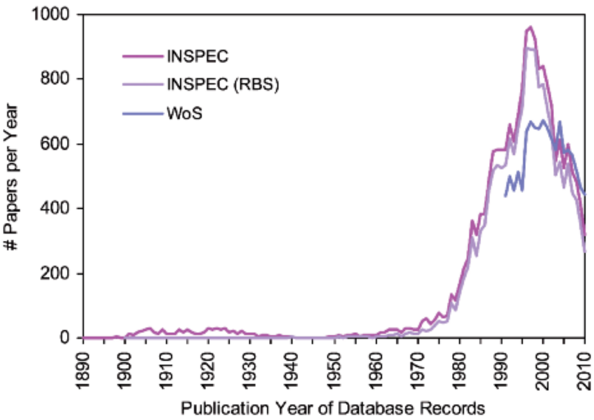

Fig. 3. Time evolution of Rutherford 'informal citations' based on the field-specific literature database for Physics, Electronics, & Computing (INSPEC) and on *WOS*. Besides all informal citations mentioning 'Rutherford', separately, those mentioning 'Rutherford backscattering' or 'Rutherford scattering' (RBS, RS) are also shown. [Source: INSPEC database for Physics, Electronics, & Computing under STN International [11] and Thomson Reuters *WOS*].

Fig. 4. Time evolution of the term 'Ernest Rutherford' appearing in books searched under Books Ngram Viewer of Google labs [13]. The y-axis shows the yearly percentage of the term 'Ernest Rutherford' of all equivalent terms contained in the sample of books written in English and published within the period 1871–2000 (after 2000 the corpus composition undergoes subtle changes around the time of the inception of the Google Books project) [14].

word. Hence, the formal citations measure only a fraction of the overall impact of seminal papers or of the entire publications of pioneers.

As a major consequence, the overall impact of pioneering papers cannot be entirely determined by merely counting their citations. In the case of Rutherford the most 'informal citations' correspond to Rutherford Backscattering (85%). Here we pose an interesting 'Gedanken-experiment': If for example the modern atomic model or a phenomenon related to radioactivity (his most important achievements) were to bear his name, the number of 'informal citations' would be much higher and thus would better give a quantitative measure of the importance of his many fundamental contributions to physics.

The second phenomenon limiting the meaning of citation counts for Rutherford is typified by his famous 1911 atomic nucleus paper [1], a prime example of 'obliteration by incorporation', an effect first described by the sociologist Robert Merton [10]. The process of 'obliteration' or 'palimpsest' (the latter referring to a piece of parchment that is erased more than once to make room for newer work) affects seminal works offering novel ideas that are rapidly absorbed into the body of scientific knowledge. Such work is soon integrated into textbooks and becomes increasingly familiar within the scientific community.

As a result of this absorption and canonisation, the original sources fail to be cited, either as full references or even as names or subject-specific terms. Therefore, we should not expect that the citations of the works of Rutherford could be taken as a real measure of the influence of his ideas in modern science. There are no metrics for quantifying fundamentality, significance or even elegance, which are terms falling under a completely different category.

We show in Fig. 3 the time curve of the Rutherford 'informal citations' based on the INSPEC database for Physics, Electronics, & Computing ('Rutherford' appearing in the titles, the abstracts or within the keyword terms). The corresponding time curve based on *WOS* is limited to the post-1990 literature, because the abstracts of the earlier records are not available in *WOS*. Besides all informal citations mentioning 'Rutherford', we have given, separately, those mentioning 'Rutherford Backscattering' or 'Rutherford Scattering' (RBS, RS).

Recently, a team at Harvard University has reported the creation of a corpus of over 5 million digitised books containing ~4% of all books ever published [12]. This corpus has emerged from Google's effort to digitise books. Computational analysis of the data has enabled an investigation of cultural trends, quantitatively surveying the vast terrain of a new field known as 'culturomics'. The authors focused on linguistic and cultural phenomena that were reflected in the English language between 1800 and 2000. The data allow carrying over the concept of 'informal citations' based on searching the titles, abstracts and keywords of journal articles to searching the full text of books. The search for 'Ernest Rutherford' results in the time pattern given in Fig. 4.

The distinct peak around 1905 undoubtedly corresponds to the appearance of Rutherford's first book entitled 'Radioactivity' published in 1904, but the

large broad peak centred around 1925 clearly demonstrates the rapid integration of his work into textbooks and the beginning of the process of its 'obliteration', as discussed above. The plot shows a remarkably steady reference to 'Ernest Rutherford' long after his death in 1937, confirming the lasting influence of Rutherford's work in the scientific literature.

In conclusion

Rutherford's influence on the course of science and nuclear physics in particular has been immense, as evidenced through our citation analysis of his published works. It should be noted in this regard that he seldom co-authored papers published by his students [2], otherwise he would have had many more citations. As it is, Rutherford ranks in terms of citations with Max Planck and Albert Einstein [7] as one of the main contributors to the development of modern physics during the early twentieth century. His name lives on primarily in the Rutherford back-scattering technique that was developed subsequent to his most important discovery of the atomic nucleus, but was soon widely applied in many other areas of science.

This is probably unfair. Rutherford's name should be at least as widely quoted in the modern literature as, for example, C. V. Raman, who was active in research in the same time frame as Rutherford and had the Raman effect named after him [9]. The process of 'scientific obliteration' lies at fault here – Rutherford's new ideas and discoveries, although they underpin so much of today's physics and chemistry, were rapidly incorporated into our scientific knowledge and then simply taken for granted.

"The process of 'scientific obliteration' lies at fault here – Rutherford's new ideas and discoveries, although they underpin so much of today's physics and chemistry, were rapidly incorporated into our scientific knowledge and then simply taken for granted."

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Werner Marx and Manuel Cardona are at the Max Planck Institute for Solid State Research, Stuttgart, and David J. Lockwood is at the National Research Council, Ottawa. A more detailed version of this article by the same authors appeared recently in *Physics in Canada* [15].

How Right Was Einstein?

Towards New Tests of General Relativity

Paul Lasky

Since its publication almost a century ago, Einstein's theory of General Relativity has revolutionised the way we think about space, time and the Universe as a whole. Originally based on limited empirical evidence, the intervening years have laid witness to countless gravitational experiments that have continued to push the boundaries of our understanding. With each experiment has come better agreement. Despite these vast empirical successes, Einstein's theory of General Relativity is continually being called into question – more so now than perhaps ever before.

There are three primary reasons why one would contemplate modifying such a successful theory. The first is the fundamental disagreement in theoretical foundations between Quantum Field Theory and General Relativity. The recent questioning of General Relativity is, however, borne about by more empirically tangible concepts acting on classical, ie. non-quantum, scales. A second rationale is as follows: despite years of increasingly accurate laboratory and solar system based measurements, *current experimental tests of gravity are far from exhaustive*. It is not a question of the accuracy of measurements, but rather of the scales on which the theory has been tested. I will quantify this statement below.

"When General Relativity is used to explain the dynamics of the Universe as a whole or the spacetime structure of neutron stars and black holes, the validity of the theory is being extrapolated many orders of magnitude away from experimental verifications."

The third and final reason is comparatively new and is based on possible empirical conflicts that manifest themselves as the theoretical constructs of dark energy and dark matter. Loosely stated: *there are many unanswered questions in cosmology*. These final two concepts, and their possible theoretical and empirical resolutions, are examined in this article.

Why should we modify gravity?

Current tests of gravity are far from exhaustive: Given the metric nature of General Relativity, one can calculate the degree to which spacetime is curved around an object, denoted by ξ [see ref. 1]. This quantity covers over fifty orders of magnitude, from the surface of the smallest black holes, $\xi \sim 10^{-10}$ cm^{-2}, to the curvature of the Universe as a whole, $\xi \sim 10^{-60}$ cm^{-2}. A second quantity ε measures the potential of the gravitational field. The event horizon of a black hole has $\varepsilon = 1$, whilst moving further from such objects reduces this value by up to twenty orders of magnitude.

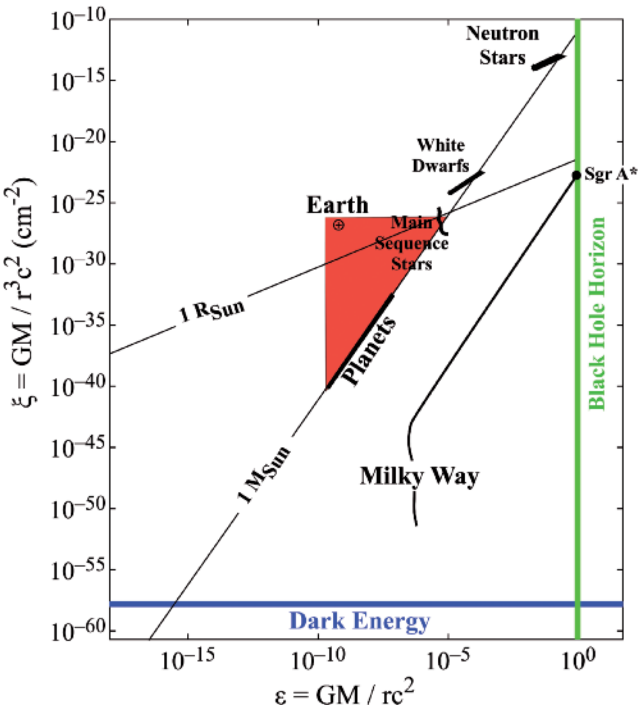

Fig. 1. A parameter space quantifying the strength of gravity (adapted from [1]). The horizontal and vertical axes are the potential of the gravitational field and curvature of spacetime respectively.

Fig. 1 shows the (ε, ξ) parameter space for the entire Universe. The area highlighted in red encompasses the region that has currently been experimentally tested. This is essentially the area of parameter space that our Solar System occupies, from the strongest fields at the surface of the sun, out to the furthest reaches of planetary orbits. It is therefore an understatement to say that truly 'strong' and 'weak' fields of gravity have not been experimentally tested. In fact, we are some 15 to 20 orders of magnitude in curvature from realising the most extreme parts of the Universe. When General Relativity is used to explain the dynamics of the Universe as a whole or the spacetime structure of neutron stars and black holes, the validity of the theory is being extrapolated many orders of magnitude away from experimental verifications. Despite this, one of the supposed pillars of modern astrophysics, the standard model of cosmology, is built upon the assumption that General Relativity is the correct theory of gravity on the largest scales.

Standard Model of Cosmology: The standard model was finalised in 1998 when two research groups discovered an acceleration of the Universe via Type Ia Supernovae (SNIa) observations [2]. SNIa are *standard candles* due to almost uniform light curves that can be used to simultaneously gain information about their distance and redshift. The standard model has three key assumptions: (1) General Relativity correctly describes gravitational interactions on cosmological scales and below, (2) the Universe is homogeneous, and (3) the Universe is isotropic. These assumptions, together with observations of SNIa, the cosmic microwave background (CMB), baryon acoustic oscillations, large-scale structure and weak lensing surveys, lead to a strange picture of the Universe. Namely, that from the total energy budget of the Universe, baryons compose just four percent. The remaining 96% of the Universe is 'dark energy' (~74%) and 'dark matter' (~22%).

The existence of dark matter was postulated well before the standard model of cosmology, originally based on missing mass inferred from the rotation curves of galaxies. The strongest candidates for dark matter are weakly interacting massive particles that, although not yet directly observed, fit relatively nicely into simple extensions of the standard model of particle physics.

The existence and nature of dark energy is more contentious. The simplest possibility is that dark energy is a cosmological constant. This fits all data extremely well. It is worth noting however that a cosmological constant is equivalent to the imposition of vacuum energy. The inferred value of the cosmological constant and the theoretically derived value of vacuum energy differ by some 120 orders of magnitude! Physical alternatives for dark energy include models of dark fluids, and even more exotic phenomena for which the only observational evidence is the concordance of observations listed above [3].

My presentation of cosmology is biased to promote contention. For equalities sake it should be noted that cosmological observations *do* form a concordance model. That is, accepting the three assumptions of General Relativity, homogeneity and isotropy, all observations lead to a single set of parameters describing the Universe. If this model were wildly wrong, one would expect tension between the datasets. But the lack of a physically viable interpretation of dark energy still motivates angst. For this reason, numerous researchers postulate that the inference of dark energy is due to one (or more) of the three theoretical assumptions being incorrect.

Research papers appear daily propounding an inhomogeneous Universe interpretation of dark energy, all with varying degrees of success. This would be the simplest of all solutions to the dark energy problem as it requires no new physics. Anisotropic interpretations

of the Universe are harder to muster given the isotropic (to one part in 10^5) observations of the CMB. But for the remainder of this article I will focus on the third possibility – that General Relativity only provides an accurate description of gravity on solar system scales, and that extrapolation to cosmological scales incorrectly describes the dynamics of the Universe.

What is General Relativity?

The main difficulty for creating a new theory of gravity lies in the requirement to retain the vast phenomenological and empirical successes of General Relativity. It is therefore worth understanding what made General Relativity successful.

General Relativity has two key ingredients: Special Relativity and Einstein's Equivalence Principle. Both of these postulates are extremely well tested and we shall not question their validity here. Einstein's Equivalence Principle unequivocally leads to the interpretation that any freely falling test body travels along geodesics in curved, four-dimensional spacetime – ie. that gravity is a metric theory.

> **"… the successful detection of gravitational waves will likely come from extreme events such as the inspiral, coalescence and subsequent ringdown of a binary black hole system."**

How does one then construct a metric theory of gravity? The answer is remarkably simple: using a variational principle approach, write down a gravity action as some four-dimensional geometrical quantity. Riemannian geometry is a natural choice, and so the Einstein–Hilbert action describing General Relativity contains the simplest geometrical quantity of Riemannian geometry – the Ricci scalar. As we are dealing with the geometry of four dimensions, the action is an integral over the three dimensions of space plus one of time. Couple this to a matter action with an empirically derived coupling constant, and one has constructed General Relativity. By varying this Einstein–Hilbert action with respect to the metric results in Einstein's field equations.

How can we modify gravity?

With a variational approach to General Relativity, one can immediately see that to create a modified theory of gravity relies only on changing the geometrical quantity used in the action. One of the great examples of this comes from Einstein himself, with the famous story about his 'greatest blunder'. To create a stationary Universe, Einstein realised he needed a repulsive force to counter gravity. He subsequently altered the Einstein–Hilbert action by adding a constant – the *cosmological constant*. This, believe it or not, is the first example of 'modified gravity'. Including a constant in the action alters the way in which the geometry of spacetime reacts to the presence of matter. Providing this constant is small enough, it will alter the field equations in such a way that observations of all phenomena on solar system scales will not be effected.

Including a cosmological constant in the Einstein field equations is seldom referred to as modified gravity. However, the process outlined highlights the availability of further generalisations of General Relativity. For example, one can introduce any functional dependence on the Ricci scalar in the action and create a viable theory of gravity. Such theories, known as $f(R)$ theories, can be designed to reproduce solar system experiments. Different functional forms will however yield different results on both cosmological scales and also in the strong-field gravity regime.

There is no reason to stop at the Ricci scalar. This is but one geometrical construct inherent to Riemannian geometry. There is a multitude of geometric objects that can be combined in various combinations to create viable theories of gravity. Many of these theories will have intrinsic problems such as vacuum instabilities that automatically render the theory unviable. However, large classes of theories exhibit no such flaws, and various coupling parameters and functional forms can be selected in such a way that *all* gravitational experiments are satisfied up to experimental uncertainty.

One can also add various other types of fields to the action such as scalar, vector and other tensor fields. This was first done in 1961 by Brans and Dicke [5], who introduced a scalar field to the intrinsic tensor field of General Relativity and allowed a coupling constant to parameterise their relative strengths. When this coupling constant, ω, limits to infinity, the Brans–Dicke theory reproduces General Relativity. This was the first time that deviations from General Relativity were parameterised, and gave experimentalists an

original way of testing the accuracy of Einstein's theory. The current best constraints on the Brans–Dicke parameter come from the Cassini–Huygens experiment, which set a value of $\omega > 4\times10^4$ [4, 6].

The above are a small portion of the total number of gravitational theories appearing in the literature. Extremely creative physicists have developed a regular cornucopia: Einstein–Cartan theory, massive gravitons, Horava–Lifshitz theory, Finsler geometries, non-Abelian tensor fields and the list goes on. Moreover, we have failed to mention any theory that deviates from the premise that we live in a four-dimensional Universe. Propounded by the string theory revolution, higher-dimensional theories of gravity have been around since the early part of the twentieth century. The modern day inception of their idea provides the impetus for hundreds to thousands of research papers per year.

The future of experimental gravity

The large number of viable gravitational theories is partially a consequence of the inadequate state of the empirically verified parameter space presented in Fig. 1. Couple this to the unresolved questions in cosmology, such as the nature of dark energy and dark matter, and it becomes obvious that new tests of gravity are required in regions of the Universe that have the potential to fundamentally discern the correct theory of gravity. Fortunately, it looks certain that the next one to two decades will provide these tests.

From Fig. 1 there are two apparent possibilities for testing the theory of gravity – in the cosmological regime of weak-gravitational fields and in the strong-field regime involving the spacetime near extremely dense objects such as neutron stars and black holes. Numerous tests of gravity are being conducted in the cosmological spectrum. However, there are intrinsic difficulties associated with such tests. In particular, it is extremely difficult to separate pure gravitational effects from other physics. This is embodied in the statement that "… cosmological observations are not 'clean' tests of gravitation since much 'dirty' astrophysics often goes into their interpretation" [4]. Of course, any candidate theory of gravity must correctly explain cosmological phenomena, however the shear number of candidate theories will exclude drawing definitive conclusions about the worth of an individual theory of gravity over another.

It is the other extreme of gravitational experiments that I believe will yield fruitful results about the theory

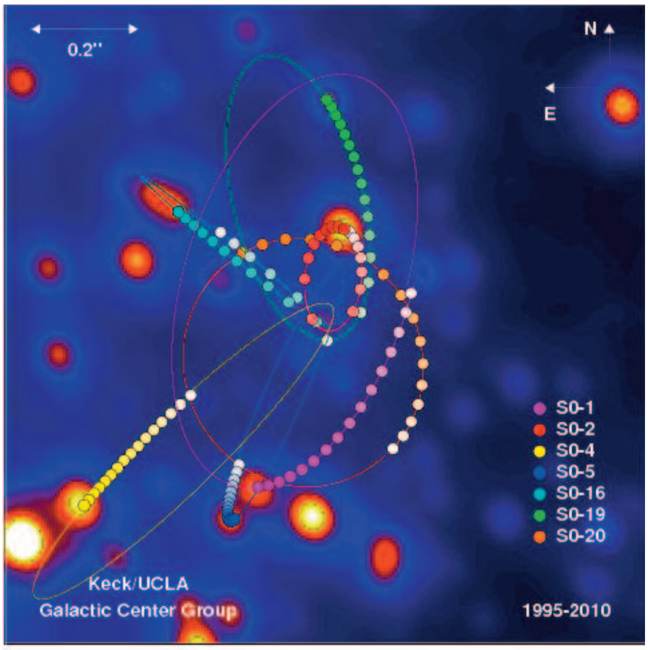

Fig. 2. Observationally determined orbits of the closest stars to the supermassive black hole in the centre of the Milky Way.

of gravity. In particular, by mapping the spacetime around neutron stars and black holes we will be able to definitively learn about pure gravitational effects.

Electromagnetic observations: Black holes in General Relativity are incredibly simple beasts. This is typified by the 'no-hair' theorem, which states that any black hole is characterised by just three quantities – mass, angular momentum and charge. Astrophysical black holes will not possess significant charge implying that any black hole has but two pieces of information. This theorem however, does not hold in most alternative theories of gravity, where black holes can have extra characterisations including scalar charge (due to background scalar fields) and higher-order mass moments.

One of the most promising ways to map the exterior region of a black hole is through observations of the most central stars orbiting the supermassive black hole in the centre of the Milky Way. Fig. 2 shows the orbits of seven such stars that have been observed over fifteen years. These orbits are determined by the geometric structure of the spacetime around the black hole, implying the geometry can be mapped from accurate determinations of their orbits. Knowing the orbits of two stars allows us to determine both the quadrupole moment and angular momentum of the black hole. Given that we independently know the mass, if General Relativity is correct and the no-hair theorem applies, the system is over-determined. Such observations are therefore able to accurately determine the validity of

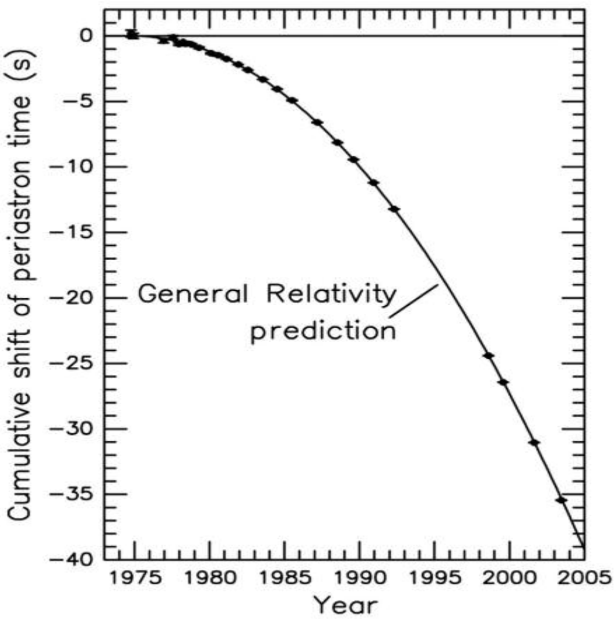

Fig. 3. Orbital decay of the Hulse–Taylor pulsar system over more than thirty years. Observations show remarkable agreement with General Relativity.

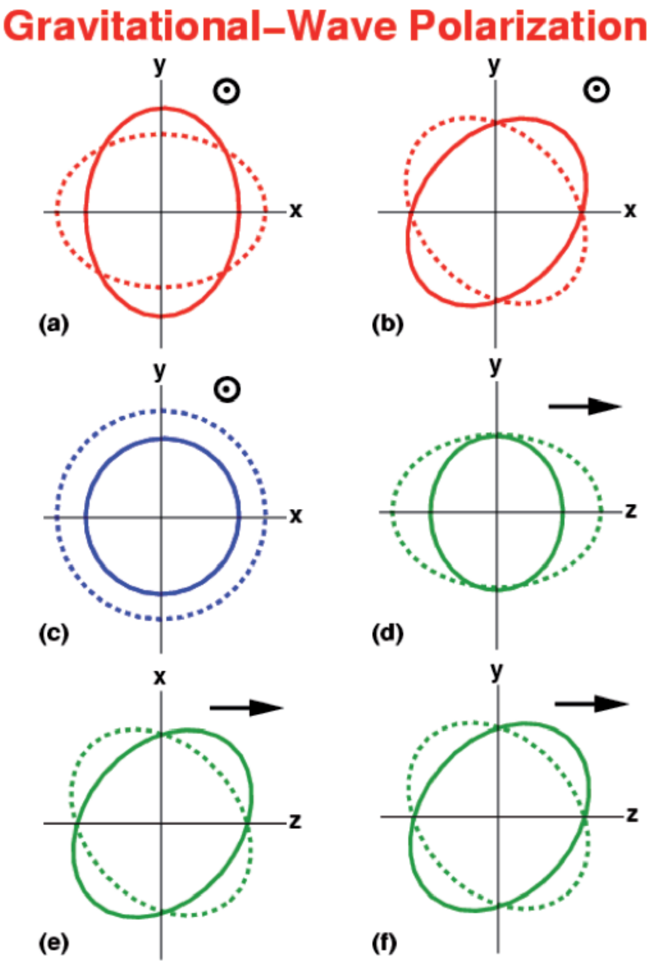

Fig. 4. Six possible gravitational wave polarisations (from [4]). General Relativity only predicts the existence of the (a) 'plus' and (b) 'cross' polarisations, whilst almost all other theories of gravity predict more modes.

the no-hair theorem and hence General Relativity.

There exist many more methods for determining the structure of the spacetime around astrophysical black holes using photon astronomy in the near future. These include direct imaging techniques and measurements of accretion disk dynamics. X-ray observations in the coming decade will provide sufficient resolution to probe many of these facets important for discerning accretion disk structure relevant for testing gravity.

Neutron stars also provide excellent candidates for testing gravity. By measuring various features of atomic spectra from the surface of neutron stars, one is able to determine compactness, radius, oblateness and frame-dragging effects. Observations on this front are still in their infancy. It should be noted however that, as with cosmology, these systems are extremely 'dirty'. While simultaneously measuring pure gravitational effects, an incomplete knowledge of microphysics at supranuclear densities implies the equation of state of neutron stars is an extra fitting parameter.

These are but a handful of possible observations that will yield exciting results in the coming decades. There is another exciting prospect for further developing our understanding of gravity that is the topic of much interest – gravitational waves.

Gravitational waves: These waves are a prediction of any metric theory of gravity. A worldwide effort is currently underway to directly detect these elusive waves. These include interferometers in the US, Italy, Germany and Japan. There is also a significant push to develop a full-scale observatory in Gingin, near Perth, atop the existing test facility [see *Aust. Phys.* **47**(6), 150–4 (2010)]. This would have significant benefits to the worldwide community, including significantly enhanced detection rates and directional sensitivity. In addition to interferometers, there are a number of resonant bar detectors located worldwide, and a planned space-based gravitational wave detector.

Possibly the best probes of gravity to date are indirect detections of gravitational waves from binary pulsar systems. In 1974 Russell Hulse and Joseph Taylor discovered such a system that allowed them to measure the orbital decay with remarkable accuracy. General Relativity predicts such a system should lose energy through gravitational wave emission, implying the two orbits should slowly coalesce. The theoretical prediction matches the observations with astonishing accuracy (Fig. 3), thus providing the first indirect detection of gravitational waves. Hulse and Taylor received the

Nobel Prize in 1993 for this momentous work. It is worth noting that such binary systems are still not true tests of *strong* gravity; neutron stars have typical masses of about one solar mass and separations on the order of one astronomical unit, therefore placing them firmly within the red region of Fig. 1.

Contrary to popular belief, the successful detection of gravitational waves does not verify General Relativity any more than any metric theory of gravity. However, observations of gravitational waves do have the potential to discern such theories in fundamental ways. A prime example is through their polarisation. General Relativity may be unique in that it predicts only two polarisations of gravitational waves – 'cross' and 'plus' modes. However, alternative theories predict up to six polarisations (Fig. 4). A single gravitational wave detector is not sensitive to most of these modes, however a combination of detectors can discern all polarisations. The detection of a single gravitational wave that is *not* of cross or plus polarisation would immediately falsify General Relativity.

Another discerning factor between theories of gravity is the speed of propagation of gravitational waves – whose velocities are determined by the field equations of the individual theories. General Relativity predicts gravitational waves to travel at the speed of light, however many metric theories predict different velocities. A simultaneous observation of electromagnetic and gravitational waves would yield invaluable information about the speed of propagation and hence the theory of gravity.

Finally, the successful detection of gravitational waves will likely come from extreme events such as the inspiral, coalescence and subsequent ringdown of a binary black hole system. Specific details of the waveform through these phases differ between theories of gravity. Detections of such events, which are expected in the coming decade, will yield more definitive tests of gravity in the strongest possible regime.

Conclusion

With the multitude of alternative theories of gravity, at some point Occam's razor must be invoked to select the simplest of theories that confirms all observations. Many argue that this is currently General Relativity and the standard model of cosmology, but a major hurdle is still the lack of an adequate interpretation of dark energy. With gravitational experiments probing such a small parameter space, extrapolating far beyond what is tested is no more aesthetically pleasing than remodelling other physical theories to incorporate dark energy. Perhaps the answer will not lie in observations on cosmological scales, but by probing the spacetime around some of the most exotic objects in the Universe such as neutron stars and black holes.

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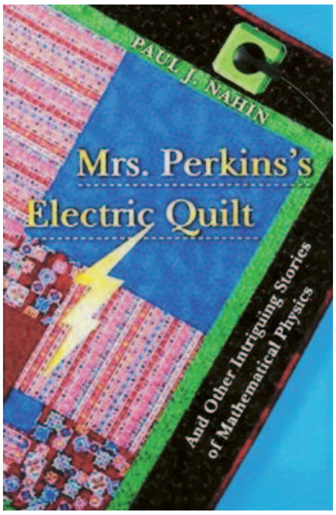
ABOUT THE AUTHOR

Paul D. Lasky is an Alexander von Humboldt Research Fellow at the Eberhard–Karls University in Tübingen, Germany. Born and raised in Melbourne, he received his PhD for research on the gravitational collapse of massive stars to form black holes from Monash University's Centre for Stellar and Planetary Astrophysics. Paul has since published research articles on an extensive range of topics under the broad heading of gravitational physics. These include work on neutron star and black hole physics, cosmology, gravitational lensing, extragalactic astronomy and alternative theories of gravity.

BOOK REVIEWS



Mrs Perkins's Electric Quilt and Other Intriguing Stories of Mathematical Physics

By Paul J. Nahin
Princeton University Press, 2009, 424 pp.
ISBN 978-0-691-13540-3
Price US$29.95
Reviewed by Anna Binnie, Sydney

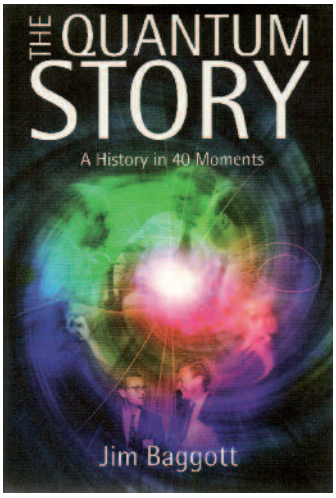
This is a fun book, one that you can take up and put down, delve into a chapter and then go back to an earlier chapter. As the title suggests it is a patchwork of physics ideas and concepts, but not in the standard textbook sense. It is well written with an amusing style that on occasion made me laugh out loud. Nahin shows how mathematics and physics interact to allow us to make sense of the world. He uses primarily mechanics problems with a few exceptions delving into electric circuits and statistics. Each chapter starts with a historical story or establishing a problem, then solves the problem. He includes additional problems which have detailed solutions at the end of the book.

The book's intended audience is upper high school and undergraduate physics students and physicists in general, and consequently most of the problems can be solved using basic calculus or algebra, but there are exceptions. Unfortunately I feel that the book misses his student audience unless a physics educator uses some of these problems as an enrichment exercise for their class and guides them through it.

The book will also be of use to those involved in physics outreach who want to demonstrate how maths and physics work together. One of the sections attempts to calculate how long it would take to fall into the Sun, while another takes you on a random walk. I particularly enjoyed the chapter on Mrs Perkins's Electric Quilt and was delighted to see a patchwork version made up by the author's wife.

On the down side, the answers are not given in SI units, but use miles per second or feet per second squared. Further, there is a chapter on Fourier transforms and Zeta functions with no explanation of what and how they are used. His chapters on statistical physics utilise his programs using Matlab, a program not available to high school or undergraduate students. Finally, there are a number of minor typographical errors that should have been corrected.

I really did enjoy this book despite its shortcomings. I would recommend it to anyone who enjoys physics and as something to read on a long flight; easy and amusing reading that allows your brain to tick over in a relaxing way.



The Quantum Story: A History in 40 Moments

By Jim Baggott
Oxford University Press, 2011, 469 pp.
ISBN 978-0-19-956684-6
Price US$29.95
Reviewed by Mukunda Das, Australian National University, Canberra

One of the strangest of quantum ideas is the indistinguishability of particles. In the quantum world there are two distinct types of particles, bosons and fermions. Bosons have a unique property: at low temperature, assemblies of identical bosons form a single macroscopic wavefunction, behaving as one quantum object and manifesting as a superfluid or superconductor. Fermions, on the other hand, obey Fermi statistics and the 'Pauli exclusion principle', another special quantum property that forbids more than one particle from sharing the same quantum state.

These two very different kinds of quantum statistics were discovered in the mid-1920s. Today we know that Nature's fundamental forces manifest a set of intricate interactions between the two complementary types of quantum particles.

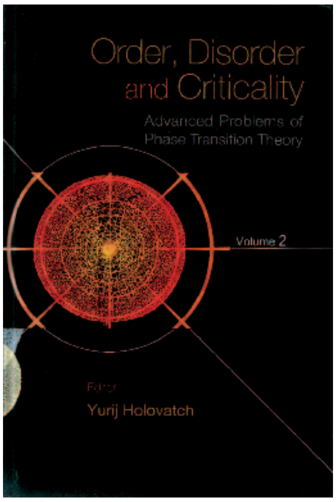
Quantum physics was born out of sheer necessity in 1900, when a confronting puzzle was revealed in the way that objects radiate blackbody energy. With an inspired guess, Max Planck gave a formula for blackbody radiation that implied the existence of discrete energy 'packets' or quanta. Planck's packets became the cornerstone of all quantum hypotheses. In 1924 Satyendra Nath Bose developed his statistical theory of photons, a new class of particles known as bosons. Bose gave the first complete justification of Planck's hypothesis, free of any and all gaps.

The discussion above highlights the complex historical links in quantum theory's origins. Those pioneering leaps of faith, contradictions, and the final resolutions, are well documented in the works by historians of quantum physics such as Helge Kragh, Jagdish Mehra and Helmut Rechenberg. It is difficult to present the century-old history of such an elusive subject, yet still provide a good understanding of its scope, from the infinitesimal subatomic realm to the grandest cosmology.

Jim Baggott, a successful science writer, makes a commendable attempt in this book which is structured around forty pivotal moments, set in seven parts. The first three parts cover philosophical aspects of quantum theory with many interpersonal human stories. Schrödinger's cat paradox is an example, where the state of a cat (living or dead) is deciphered as a quantum measurement. Parts 4 and 5 describe the rise of field theory, up to the Standard Model of electro-weak interactions. Here one anticipates the appearance of the 'God particle' (Higgs boson), super-symmetry and other phenomena: the apotheosis of CERN.

The next six moments, in Part 6, cover Quantum Realism – an abstract theme tracing how reality is understood through our mental maps of particles, waves and quantum measurements. The final five moments in Part 7 trace the coming of Quantum Cosmology, and the unification of quantum theory with general relativity and gravity. Finally, there is mention of current efforts by high-energy and mathematical physicists toiling in the field of string theory, a subject that seems to abound in abstractions, with more loose ends and less clear promise of final comprehension.

For a non-specialist these are hard topics in coming to grips with quantum physics. There is an implication that the quantum story is synonymous with that of particle physics. Such a view discounts a crucial area within the quantum realm, which is still probing the consequences of indistinguishability: namely, collective effects such as superconductivity and superfluidity. These underscore the truly universal applicability of quantum theory. Despite these pitfalls, Baggott's 'Quantum Story' is an enjoyable popular science book.



Order, Disorder and Criticality: Advanced Problems of Phase Transition Theory

By Yurij Holovatch (ed.)
World Scientific Press, Singapore
ISBN 978-9-8127-0767-3
Reviewed by Lee Weissel, Wagga Wagga Christian College

This work is the second volume of review papers on advanced problems of phase transitions and critical phenomena, following the success of the first volume in 2004. Broadly, the volume aims to demonstrate that the phase transition theory, which many believe experienced its 'golden age' during the 1970s and 1980s, is far from over and there is still a good deal of work to be done, both at the fundamental level and in respect of applications.

The work is not for the faint-hearted with the passion of each of the contributors spilling out in the book. As a non-expert in this area, it did mean it was slower going for me, but the rewards for perseverance are there. The topics presented are broad in range and help capture the scope of this important field. Included in this work are topics such as critical behaviour, critical dynamics, a space–time approach to phase transitions, self-organised criticality, and exactly solvable models of phase transitions in strongly correlated systems.

Consistent with the first volume, this book is based on the review of lectures that were given at Lviv (Ukraine) at the Ising Lectures – a traditional annual workshop on phase transitions and critical phenomena which brings together scientists and other interested parties.

Although the work is designed for the experts and postgraduate students, it is accessible to non-specialists. Chapter 3 is perhaps the best starting place as it helps to explain some of the general premises of the field and using Feynman's sum over paths approach. This can feel like walking on familiar ground as the reader is brought into contact with new ideas, or indeed old ones presented in new ways.

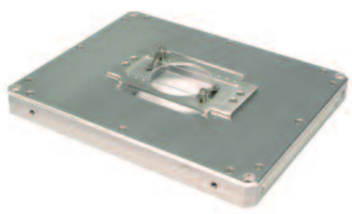
The one drawback in any book based on lectures is that a reader is tempted to ask questions either of clarification or extension, especially in the use of some of the graphical representations, but alas cannot. Overall, even though primarily a technical work, the book is extremely engaging.

PRODUCT NEWS

LASTEK

Lowest Profile 3-axis Nanopositioners from Mad City Lab

The Nano-LPQ is the lowest profile high speed XYZ nanopositioner available and offers 75×75×50 μm travel with picometer position noise under closed loop control. The Nano-LPQ features equal millisecond response times in XYZ, an integrated sample holder, analog and digital control with added scan synchronisation features, and compatibility with major image and au-



tomation software.

Designed to minimise the moving mass, lightweight sample holders are integrated into the stage and represent the only moving component. This unusual design allows the three axes of motion to have matched resonant frequencies and step response times. Equal 3-axis speed is particularly useful for applications like 3D particle tracking. The Nano-LPQ uses internal position sensors utilising proprietary PicoQ™ technology to provide absolute, repeatable position measurement with sub-nanometer resolution under closed loop control.

The Nano-LPQ is LabView™ and C++ compatible and is supplied with Mad City Labs' Nano-Route®3D software, for ease of use.

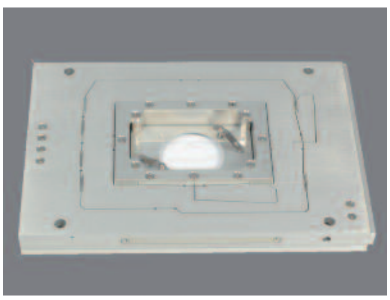
Features:

- Low profile, high speed, XYZ motion
- Built-in sample holders
- Equal speeds on all three axes
- Closed loop control

Typical applications:

- Optical microscopy, easy to retro-fit
- Optical trapping experiments
- Fluorescence imaging
- Particle tracking
- Single molecule spectroscopy

The Nano-LPS Series is the lowest profile 3-axis piezo nanopositioning system suitable for applications such as super resolution (SR) microscopy and force microscopy. The Nano-LPS series continues the innovative design approach originally introduced by Mad City Labs. At only 20 mm tall with 83 mm wide centre aperture, the Nano-LPS series is designed for practical microscopy users interested in nanoscale phenomena. The Nano-LPS series features up to 300 microns of motion per axis and picometer precision under closed loop control. The low height of the Nano-LPS Series allows it to be easily integrated into existing inverted optical microscopes. Like the related Nano-LP Series, the Nano-LPS Series is ideal for demanding microscopy applications which require long range travel, fast scan rates, and three axes of motion.



Mad City Labs proprietary PicoQ™ sensors enable picometer position noise with ultra high stability, which is important for demanding applications such as SR microscopy techniques.

Features:

- Lowest profile 3-axis nanopositioner available
- Large aperture for standard 3″ slides
- 100 μm, 200 μm and 300 μm ranges of motion (XYZ) under closed loop control

Typical applications:

- Optical microscopy, easy to retro-fit
- Optical trapping experiments
- Fluorescence imaging
- Alignment
- Single molecule spectroscopy

Ocean Optics acquires Sandhouse Design

Ocean Optics extended its product family after acquiring Sandhouse Design, LLC.

Sandhouse developed a unique line of high-powered LED light sources for research and spectroscopic applications.

These products have been widely used in biotechnology, process control and industrial applications.

LED Light Sources

These ergonomic and smartly designed fibre-coupled LED light sources are ideal for fluorescence, spectroscopy and general fibre illumination applications. The Ultra LED high-power light sources can be operated in continuous or external trigger modes. Available in UV, VIS and Infrared.

SIR Scanning Spectrometers

The SIR Scanning Spectrometer Series from Ocean Optics provides you a range of fibre-based spectral data collection in a detection instrument that is built to last and always reliable.

These SIR Scanning Spectrometers feature USB 2.0-compliant interfaces that provide fast data transfers. Plus, the included software can be used to control all of your SIR spectrometer's functions as well as analyse data.

The SIR spectrometer family includes:

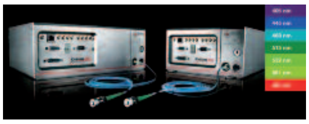
- SIR-1700: 400–1700 nm
- SIR-2600: 0.9–2.6 μm
- SIR-3400: 1.0–3.4 μm
- SIR-5000: 2.0–5.0 μm
- SIR-6500: 3.0–6.5 μm

Deep UV LEDs

Sandhouse Deep UV LEDs are available in a wide range of wavelengths and package sizes. These devices are manufactured using AlGaN/GaN technology, which enables a new generation of high band-gap energy opto-electronics devices, able to perform down to 240 nm.

LATEST NEWS FROM TOPTICA PHOTONICS

Multi-Colour Systems – Multi-Laser Engines and Tunable VISible Lasers



Three exciting new systems are now available from Toptica:

iChrome MLE-L

Multi Laser Engine with up to three diode lasers and one DPSS laser fully integrated in one compact box.

- Multi-line laser with up to four laser lines
- Wavelengths diode lasers: 405, 445, 488 and 640 nm (375, 473, 660, 785 nm and others on request)
- Wavelengths DPSS laser: 532 and 561 nm (505, 515, 594 nm and others on request)

iChrome MLE-S

All-diode Multi Laser Engine with up to four diode lasers fully integrated in one compact box.

- Multi-line laser with up to four diode laser lines
- Available wavelengths: 405, 445, 488 and 640 nm (375, 473, 660, 785 nm and others on request)
- High free-space and fibre coupled output power levels

Common to both MLE models

The individual lasers are efficiently combined and delivered free beam or via an all-in-one PM/SM fibre output. The microprocessor controlled system enables flexible OEM integration. High-speed analogue and digital modulations allow fast switching of laser wavelength and intensity.

TOPTICA's ingenious COOL^{AC} technology automatically aligns the system with a single push of a button. This feature ensures a constant optical output level even under strongly varying ambient conditions and completely eliminates the need for manual realignment – making the iChrome MLE the most advanced multi-line laser system on the market.

- Single mode, polarisation maintaining fibre output or free beam COOL^{AC} technology for highest coupling efficiency, ultimate stability and drop-shipment capability
- Direct modulation and fast switching between wavelengths
- True one-box solution with integrated electronics
- Unique features: COOL^{AC}, FINE and SKILL technology
- Most compact and cost effective solution for multicolour biophotonic applications

iChrome TVIS

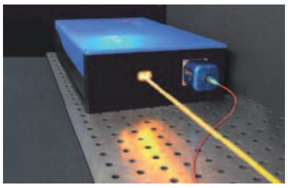
Our ultrachrome picosecond laser is:

- Continuously tunable in the visible range of 488–640 nm
- Fibre coupled output (single-mode)
- Fully automated operation
- Pure colour, narrow emission bandwidth (<3 nm)
- Perfectly suited for fluorescence lifetime imaging microscopy (FLIM) or optical testing of components

The iChrome TVIS laser system is a fibre laser with the flexibility to set automatically the laser output to any wavelength in the visible (488–640 nm). The coherent laser output ensures that the visible light exhibits the best intensity noise performance and the use of polarisation maintaining optical components a

stable linear polarisation of the fibre coupled output beam is achieved. The entire laser system is extremely user friendly: No alignment procedures of any optical components distract the user from the main task – to produce results.

DL-RFA-SHG pro 2 Watt @ 589 nm, single line for sodium cooling



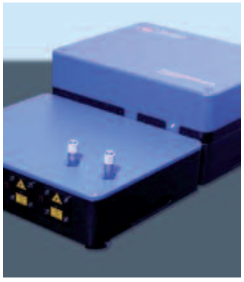
The new DL RFA SHG pro is a narrow-band tunable continuous wave laser for sodium cooling. The system is based on a near-IR diode laser in the successful 'pro-design' (DL 100/pro design, 1178 nm), with a subsequent Raman fibre amplifier (RFA) and a resonant frequency doubling stage (SHG pro).

The DL RFA SHG pro features a spectral linewidth below 1 MHz and 20 GHz mode-hop free tuning. For system operation, no water cooling and no external pump is required. The power scalable approach of the DL RFA SHG pro also offers solutions for other high power applications such as sodium LIDAR, medical therapy or super resolution microscopy. Customised systems with higher output powers up to 10 W are available on request. Wavelengths between 560 and 620 nm will soon be available as customised solutions.

FemtoFiber pro – the product family is expanded

After the successful introduction of the FemtoFiber pro IR, NIR and SCIR models, TOPTICA is now taking the final step to also include the remaining system variants such as tunable visible (TVIS), tunable near-infrared (TNIR) and tunable ultra compressed pulse (UCP). Options such as variable repetition rate (VAR) and a phase-locked loop Laser Repetition rate Control (LRC) by TOPTICA's well-established PLL-electronics are rounding up the FemtoFiber pro product family.

The first and fastest of the new models, UCP, shows short pulses in the range down to 13 fs, the fastest available on the market from a turnkey SAM modelocked fibre laser system.



The TVIS expands the super-continuum generation (SCIR) by a tunable second harmonic generation and allows transferring femtosecond pulse generation into the visible wavelength range from 490 to 700 nm.

The TNIR variant finally adds a new feature to the FemtoFiber pro family. As opposed to the TVIS, it uses the high-band continuum (>1560 nm) for second harmonic generation. This continuum part is a solitonic pulse and therefore needs no pulse compression. The output wavelength can be tuned from 800 to 1100 nm. This variant was not previously available in the FFS product family.

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

Lightweight Benchtop Vibration Isolation

Warsash Scientific is pleased to announce a new lightweight benchtop vibration isolation system from Kinetic Systems, Inc. Specifically designed for portability, the ELpF can be easily repositioned on the benchtop, even with a load and in float. Its unique, self-contained design provides this without causing damage to the vibration isolators.

An economical alternative to heavy- weight models, the Ergonomic Low-Profile-Format platform provides vibration isolation for sensitive devices. It features a load capacity of 100 or 300 lbs. in a light- weight, ergonomic system.

The platform has a low profile (only 3″ high), uses a small tabletop (16″×19″ standard) and weighs 40 lbs., making it very portable. Ergonomic features include gauges tilted upward for easier viewing and recessed handles for easy carrying.

Designed for use in laboratories and Class 100 cleanrooms, the ELpF platform is ideal for supporting atomic force micro- scopes, micro-hardness testers, analytical balances, profilometers, and audio equipment.

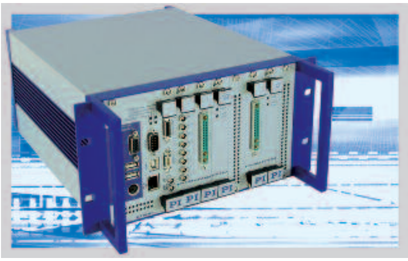
Self-levelling and active-air isolation give the platform low natural frequencies (1.75 Hz vertical, 2.0 Hz horizontal) and typical isolation efficiencies of 95% (vertical) and

92% (horizontal) at 10 Hz.

Other tabletop sizes can be customised per specifications. The top, which can be ordered with or without mounting holes, can be aluminium plate, ferromagnetic stainless steel, plastic laminate, or anti-static laminate.

For more details on this or other vibration isolation equipment, contact sales@warsash.com.au.

Real-Time Operating System for Systems Integration



PI (Physik Instrumente), the leading manufacturer of piezoceramic drives and positioning systems, offers a real-time module as an upgrade option for the host PC and also the connection of the GCS (PI General Command Set) software drivers. The module is based on Knoppix Linux in conjunction with a pre-configured Linux real-time extension (RTAI).

The use of real-time operating systems on the host PC allows it to communicate with other system components, e.g. a vision system, without time delays with discrete temporal behaviour and high system clock rate.

A library which is 100% compatible with all other PI GCS libraries is used for the communication with the real-time system. All PI GCS host software available for Linux can be run on this system.

The real-time system running in the real-time kernel can be used to integrate PI interfaces and additional data acquisition boards for control. Open functions to enable you to implement your own control algorithms are provided. Data, such as positions and voltages, is recorded in real time, and pre-defined tables, with positions, for example, are output in real time to the PI interface and to additional data acquisition boards.

You can program your own real-time functions in C/C++, MATLAB/ SIMULINK and SCILAB.

The system includes a PI GCS server, which allows the system to be operated as a blackbox using TCP/IP, via a Windows computer, for example.

The system can be installed on a PC or booted directly as a live version from the data carrier. A free demo version with restricted functionality is available.

For more information on the real time operating software or other PI positioning equipment, contact sales@warsash.com.au.

E-618: 3.2 kW Peak Power for New Piezo Amplifier

Available from Warsash Scientific is the new PI (Physik Instrumente) E-618 high power amplifier for ultra-high dynamics operation of PICMA® piezo actuators.

The amplifier can output and sink a peak current of 20 A in the voltage range between -30 and +130 V. The high bandwidth of over 15 kHz makes it possible to exploit the dynamics of the PICMA® actuators. This type of performance is required in active vibration cancellation and fast valve actuation applications.

The E-618 also comes with a temperature sensor input to shut down the amplifier if the maximum allowed temperature of the piezo ceramics has been exceeded. This is a valuable safety feature given the extremely high power output.

The E-618 is available in several open-loop and closed-loop versions with analogue and digital interfaces.

For more information on these and the range of other PI products, contact sales@warsash.com.au.
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New Sensors Improve Precision of S-340 Tip/Tilt Mirror

Warsash Scientific is pleased to announce the release of the new S-340 piezo tip/tilt mirror platform from PI (Physik Instrumente), equipped with new high-resolution strain gauge sensors.

The S-340 now achieves a resolution of 20 nrad at angles of 2 mrad about both orthogonal axes.

This large mirror platform is used for optics with diameters of up to 100 mm (4 inches) and achieves a resonant frequency of 900 Hz for a mirror of 50 mm diameter.

The S-340 can be operated by the new, low-cost E-616 controller. Together, they form a compact, high-performance solution for beam control and image stabilisation as

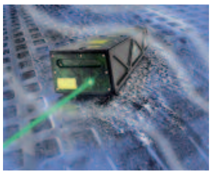
employed in astronomy, laser machining or optical metrology, for example.

For more information on the S-340 Tip/Tilt Mirror platform or other Positioning equipment from PI, contact sales@warsash.com.au.

COHERENT

Quantel release new dual-pulse later for PIV studies

Quantel has released EverGreen, a new dual-pulse Nd:YAG laser for PIV (particle imaging velocimetry) studies.



EverGreen incorporates dual laser cavities and common harmonic generation to produce two precisely overlapping beams. The lasers are integrated onto a common monoblock platform to guarantee perfect alignment and uniform light sheets. The power supplies and timing electronics are also integrated into a single housing. The EverGreen system requires no specialised installation and no adjustments of any kind. Pulse energies of 70 mJ, 145 mJ and 200 mJ are available. EverGreen is an ideal choice for a wide range of PIV applications and the simplified operation allows the researcher to concentrate on flowfield results rather than the laser.

For further information please contact Paul Wardill on sales@coherent.com.au.
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Brilliant Q-Switched Nd:YAG Lasers

The Brilliant laser from Quantel features a compact and reliable Nd:YAG oscillator of medium energy (up to 850 mJ at 1064 nm) with a full range of "plug and play" harmonic options (up to a 5^{th} harmonic generator) as well as OPO's for tunable output. With over 1000 units installed worldwide, the Brilliant laser is a proven scientific workhorse offering exceptional stability, reliability and ease of use.

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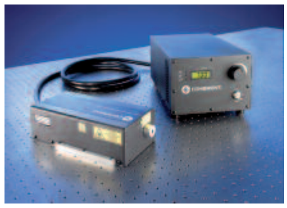
Verdi G Series expanded to 10 Watts of 532 nm output power



New! Photonics West announces release of the Coherent Verdi G10 DPSS-OPSL laser, the latest addition in the field-proven Verdi G product line with an output power of 10 W (532 nm CW). Featuring Coherent's next-generation of economical optically pumped semiconductor laser (OPSL) technology it offers a significantly smaller footprint, low-noise output and power-independent beam quality for higher power applications.

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CONFERENCES IN AUSTRALIA 2011–2012

12 – 13 August 2011
Summer School on Functional Imaging in Radiotherapy: Australasian College of Physical Scientists & Engineers in Medicine
Darwin, NT

14 – 18 August 2011
Engineering and Physical Sciences in Medicine and the Australian Biomedical Engineering Conference
Darwin Convention and Exhibition Centre, NT

28 August – 1 September 2011
IQEC/CLEO Pacific Rim 2011
Sydney, NSW

16 – 19 October 2011
Australian Radiation Protection Society Conference
Melbourne, VIC

30 November – 2 December 2011
Solomonoff 85th Memorial Conference
Melbourne, VIC

31 January – 3 February 2012
Thirty-sixth Annual Condensed Matter & Materials Meeting
Charles Sturt University, Wagga Wagga, NSW

25 February 2012
Queensland Astronomy Education Conference (QAEC)
Brisbane, QLD

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

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

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

Coherent Scientific

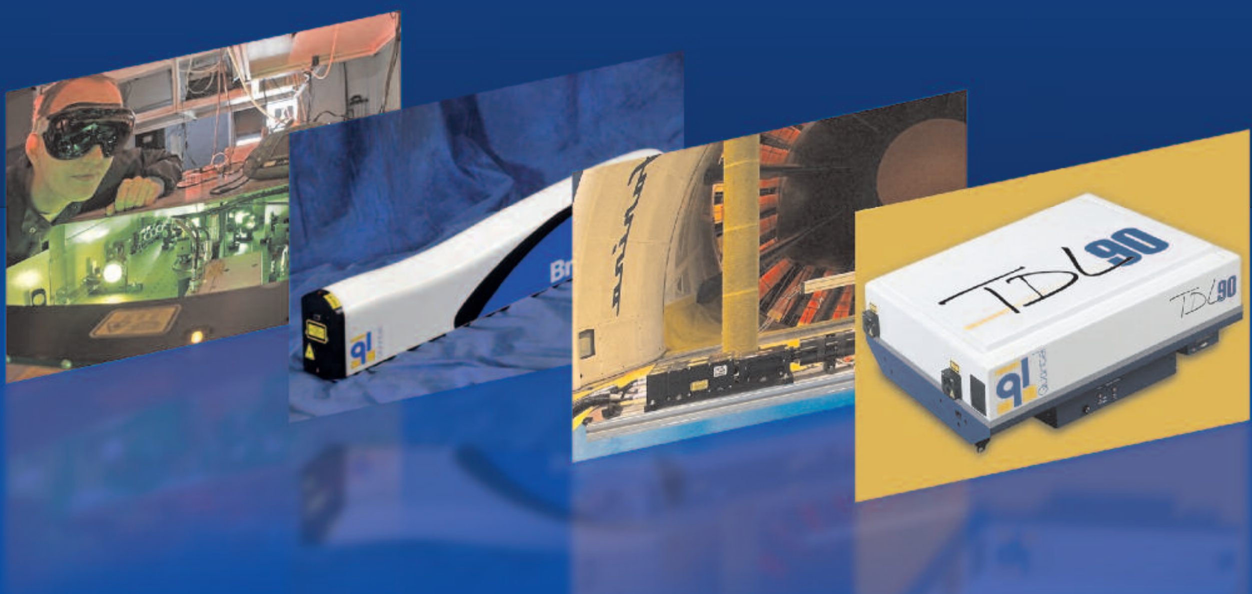
Quantel

High Performance Nd:YAG & Tuneable Lasers

Nanosecond Nd:YAG lasers

Dye lasers & solid state OPO's

Multipulse lasers



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SCIENTIFIC