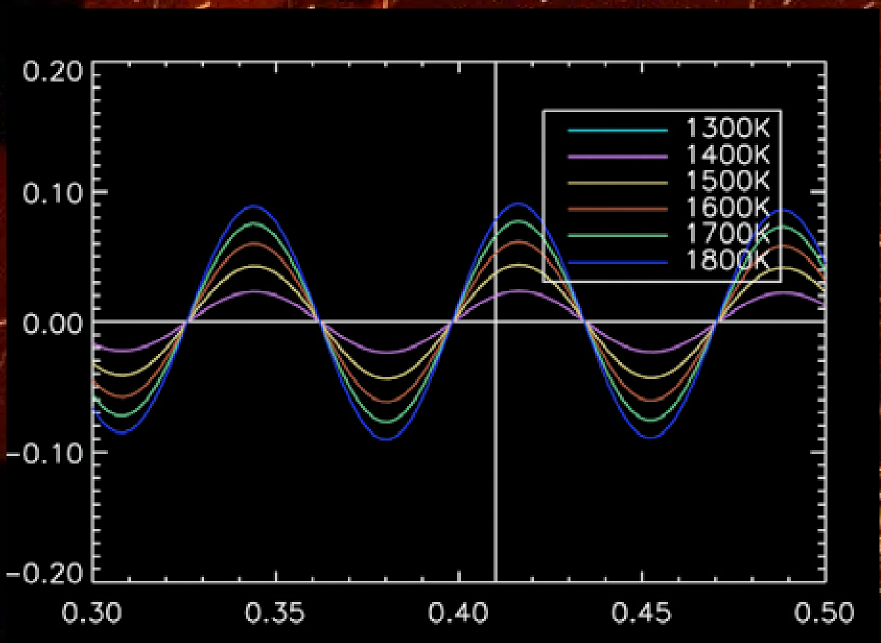
Plasma Diagnostic Solves Steel Industry Problem

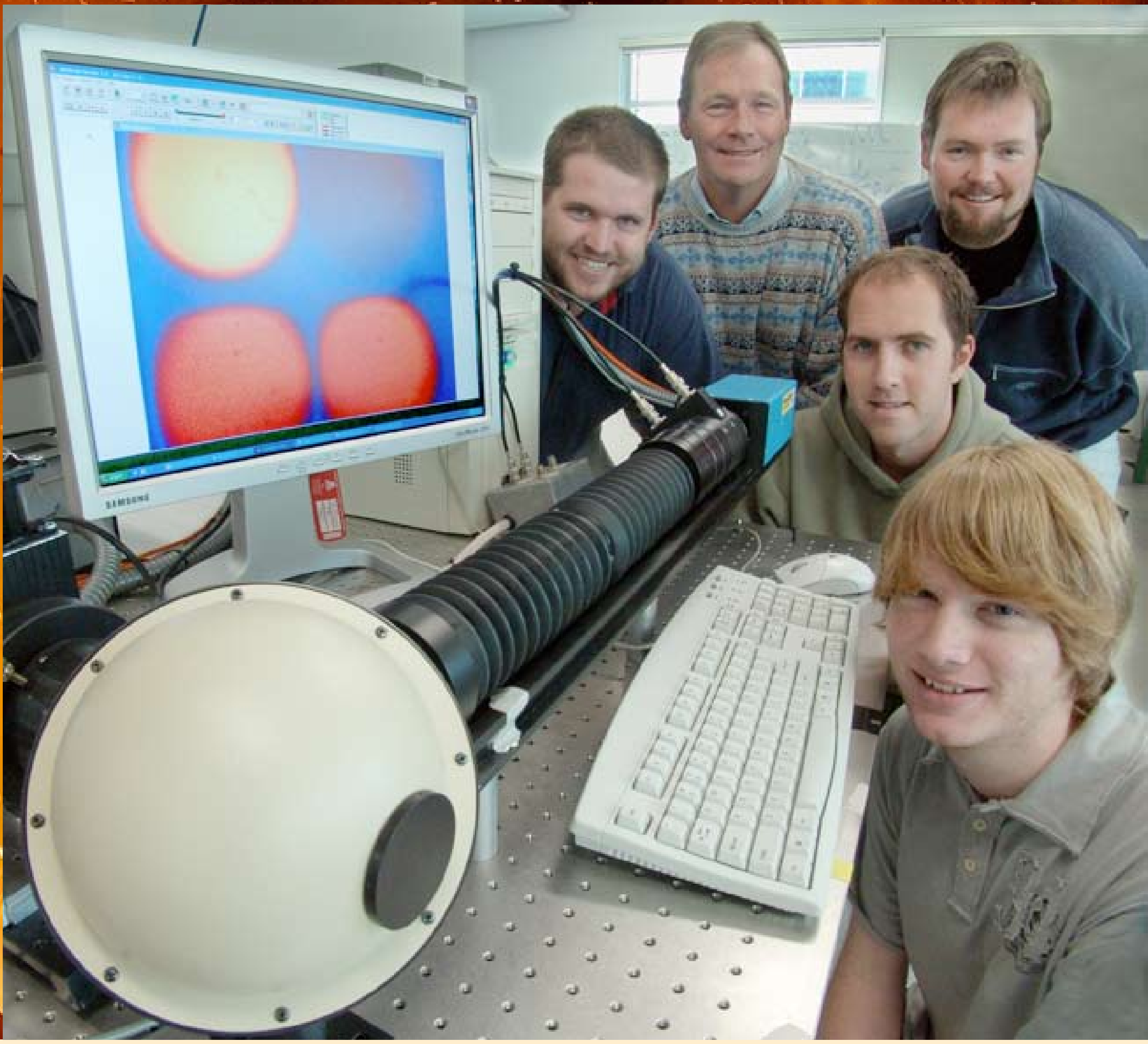
John Howard and the Advance Imaging and Inverse Methods team (L-R Scott Collis, John Howard, David Oliver, Ben Powell and Michael Hush (foreground)

Prototype MOSS camera undergoing testing at Bluescope Steel



Interferometer waveform for sources of different temperature

Background photo courtesy of US Navy



The conventional way to measure the temperature of molten metal is optical pyrometry. This takes advantage of Planck's blackbody law - as surface temperature increases, the peak emission wavelength of a hot object shifts to the blue and the amount of radiated power increases. Pyrometry is effective for some practical situations but it often falls down because most real objects have emission efficiencies that are less than unity, and which depend on the emission wavelength (so called emissivity slope).

This uncertainty, known as the emissivity problem, presents a particular difficulty in the steel industry because the emissivity of slag and steel are quite different. To the conventional pyrometer hot liquid iron with slag looks exactly the same as even hotter iron with no slag. This confusion not only prevents identification of slag, it also makes reliable measurement of the iron temperature itself, extremely difficult.

However recent work at the ANU may offer an ingenious solution from an unexpected quarter, the Quadrant Coherence Imaging (QCI) Spectrometer - a diagnostic instrument developed for Doppler-based high speed imaging of temperature and flows in superheated plasma.

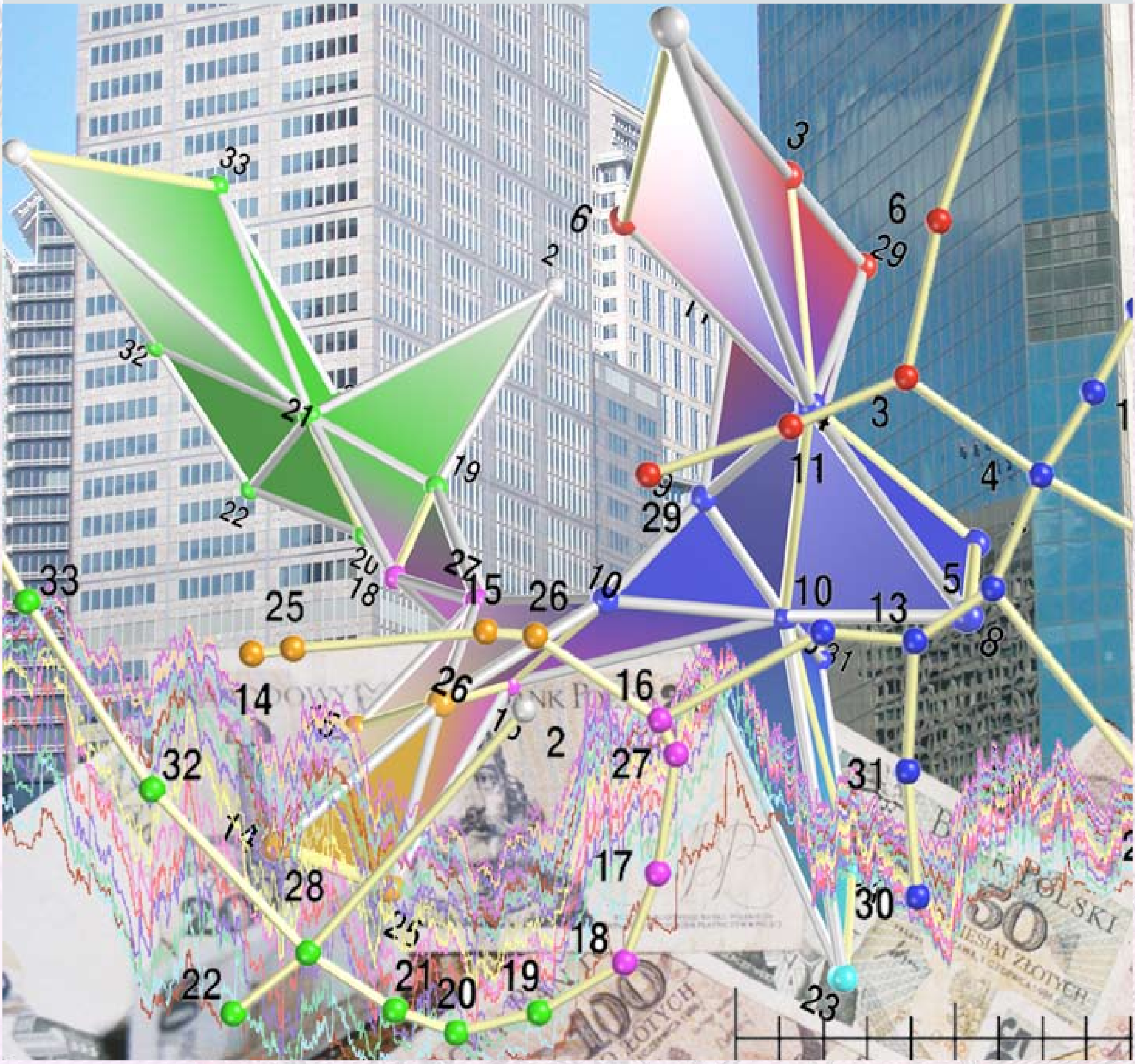
At the heart of the QCI system is a new type of imaging polarization interferometer. By looking at changes in the interference pattern and applying Fourier theory, it is possible to determine the gradient and brightness of the emission spectrum in a particular wavelength band. By doing this in two adjacent bands it becomes possible to extract information about the emissivity of the material. Furthermore, the ingenious solid state and spatial multiplex design of the interferometer allows the formation of simultaneous 2D images of the temperature, emissivity and emissivity slope.

The differences between the emissivities of steel and slag that confuse conventional pyrometers can now be turned into a positive advantage. Using the QCI technology and computer processing it is possible to produce real time video images of the furnace interior which clearly distinguish slag from steel and which are able to accurately measure the temperature of both.

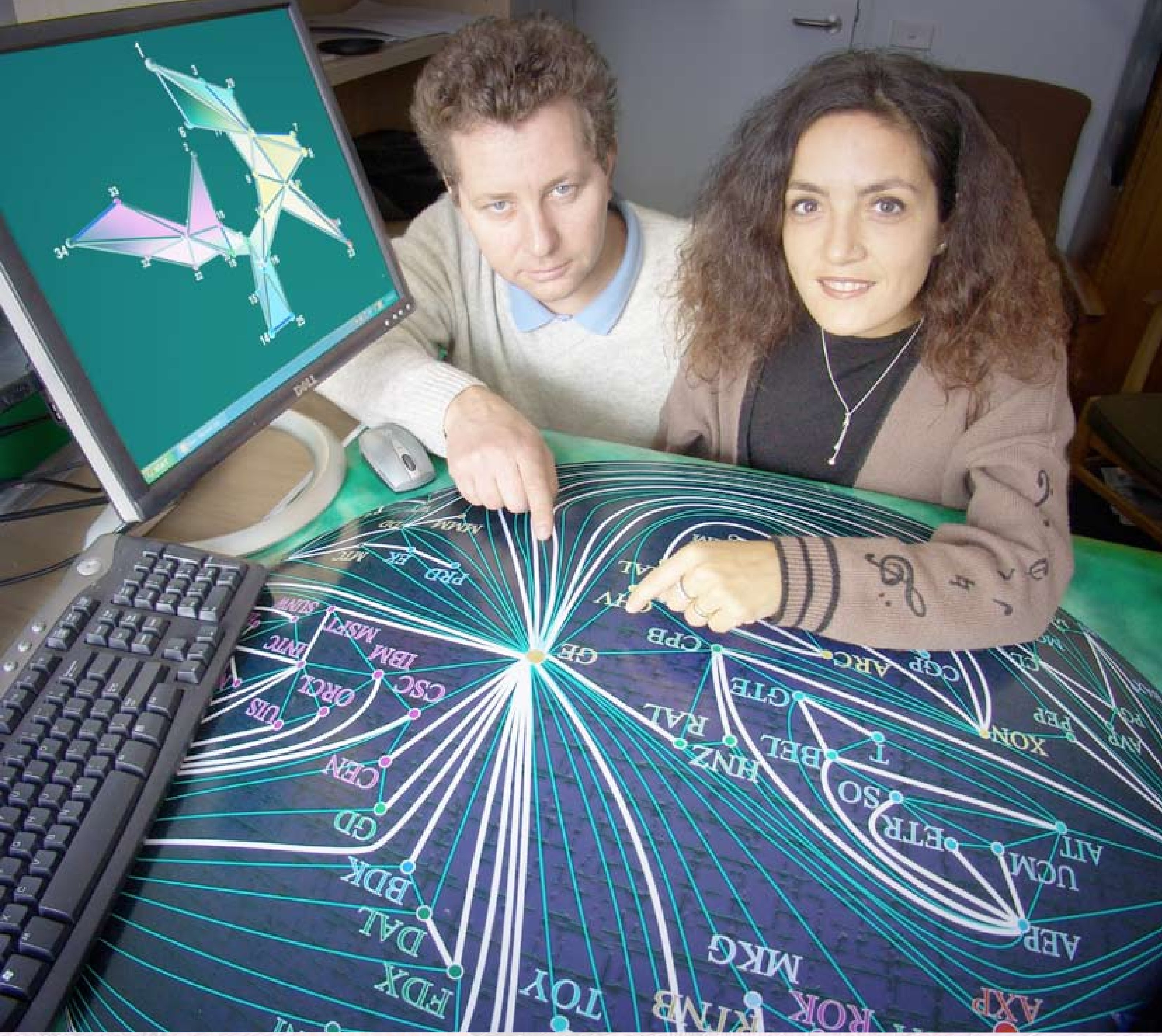
Econophysics: inside the complexity of markets

Tiziana Di Matteo and Tomaso Aste

Financial markets are intrinsically complex systems in which a large number of agents interact in an interdependent way, generating actions that span several orders of magnitude in size and time. A surprising and fascinating aspect is that from such intricate systems there emerge behaviors and patterns that appear to be universal and common to several other complex physical systems. The disentanglement of such complexity and the understanding of the mechanisms underlying the emerging pattern behavious are challenging, and potentially rewarding, research area.



Econophysics aims to apply techniques developed to model complex natural phenomena to financial market analysis and economic modelling.



A better understanding of the properties of financial markets is of great importance: the lives of most of us depend on the dynamics of financial markets that affects investments, savings, business, employment, growth, wealth and — ultimately — the daily functioning of our society.

Scientists at ANU are applying conceptual and computational methods from statistical physics to explore the structure and dynamics of financial markets.

Breakthrough results have been obtained by a new technique which allows them to map complex systems into graphs with controllable inter-connectedness. This enables them to uncover hidden mechanisms that lead to the emergence of patterns in the markets.

It has been shown that the so-called multifractal properties of price fluctuations are deeply related to the stage of development of the markets. This fact can be used to differentiate between the maturity of markets and help investors to hedge their risk.

The general aim of these researches is to contribute to the understanding of the fundamental aspects of the science of complex systems. Specific goals concern the development of tools to analyse the collective behaviour of complex systems to understand their structure, to manage and control risk.

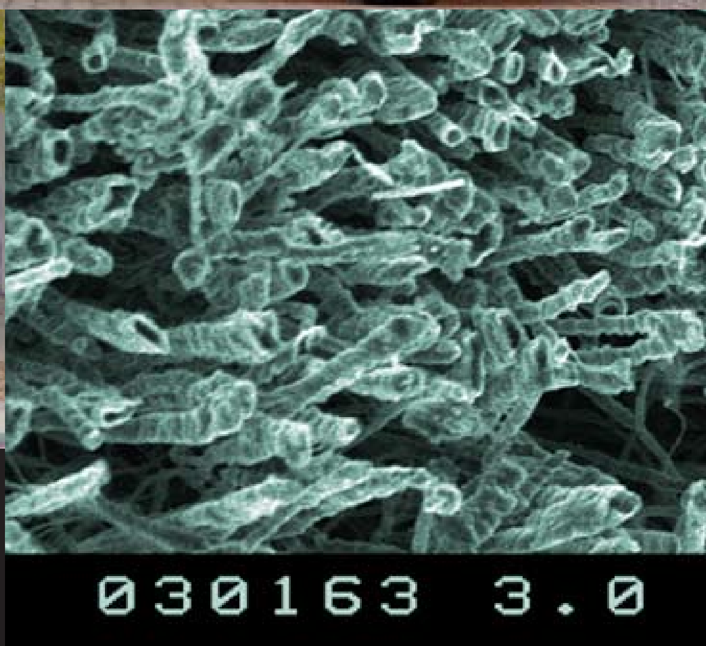
Cleanroom Science on the Road to Cleaner Air

Jun Yu, Hua Chen, Lewis Chadderton, Jim Williams, Yong Jun Chen, Hongzhou Zhang, Bill Li, Tom Halstead, Alexey Glushenkov and Ying Chen

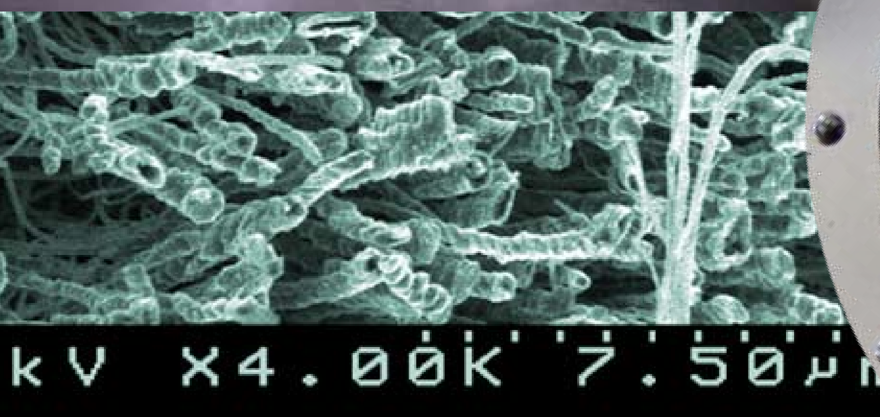
Rising world oil prices and concerns about greenhouse gas emissions are increasing pressure to find a viable alternative to petrol and diesel as transport fuels. One very promising candidate is hydrogen which can be combined with atmospheric oxygen in fuel cells to produce the large quantities of electrical power required to drive a car. Hydrogen is a very attractive transport fuel because it is abundant, renewable and its consumption in fuel cells produces no greenhouse emissions at all.

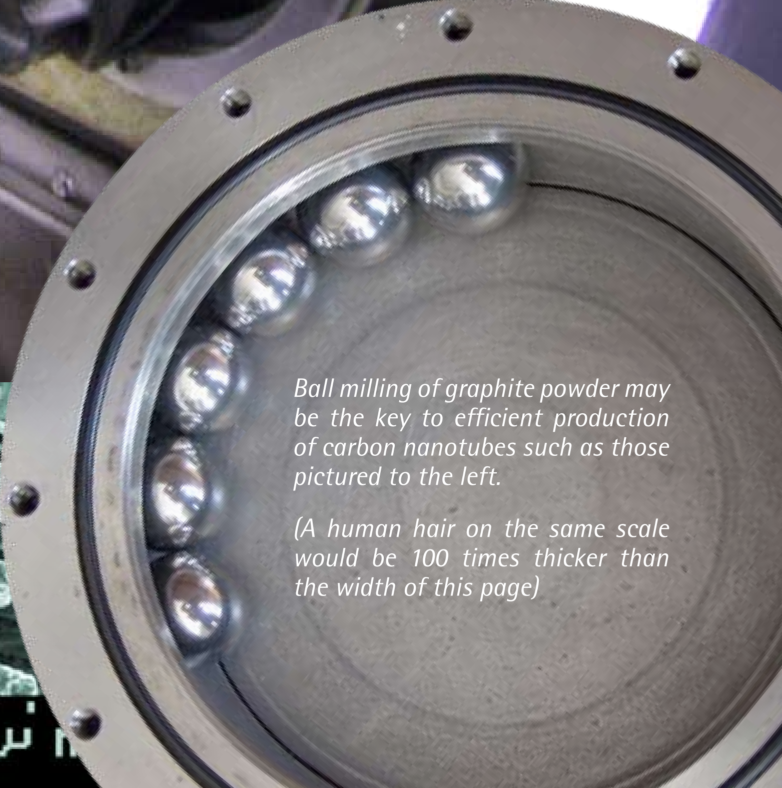
The difficulty to date has been devising a safe way to store the volatile gas in a motor vehicle. Both gas cylinders and hydrogen liquid in cryogenic containers present an explosion hazard in the event of an accident. One revolutionary option for hydrogen storage is carbon nanotubes - microscopic cage like tubes of carbon atoms. Because of their structure and size the tubes have the ability to adsorb hydrogen gas in large quantities which can be re-released by mild heating. One stumbling block is that to date, manufacture of very large quantities of nanotubes has simply not been an economically viable proposition.

However work by scientists at the ANU may be set to change all this. A novel process involving high-energy ball milling followed by a series of carefully controlled annealing stages has enabled scientists to manufacture large quantities of nanotubes in carbon, boron nitride and other materials cheaply and easily. This ANU process is readily adaptable to manufacture nanotubes on an industrial scale and has led to the first commercial availability of boron nitride tubes. It is now hoped that the ANU nanotube technology will be a crucial step on the road to hydrogen cars and a safer cleaner environment.



Carbon nanotubes may present the perfect solution to hydrogen storage and pave the way for clean fuel cell cars of the future





Ball milling of graphite powder may be the key to efficient production of carbon nanotubes such as those pictured to the left.

(A human hair on the same scale would be 100 times thicker than the width of this page)

Reversing the Roles of Light and Matter

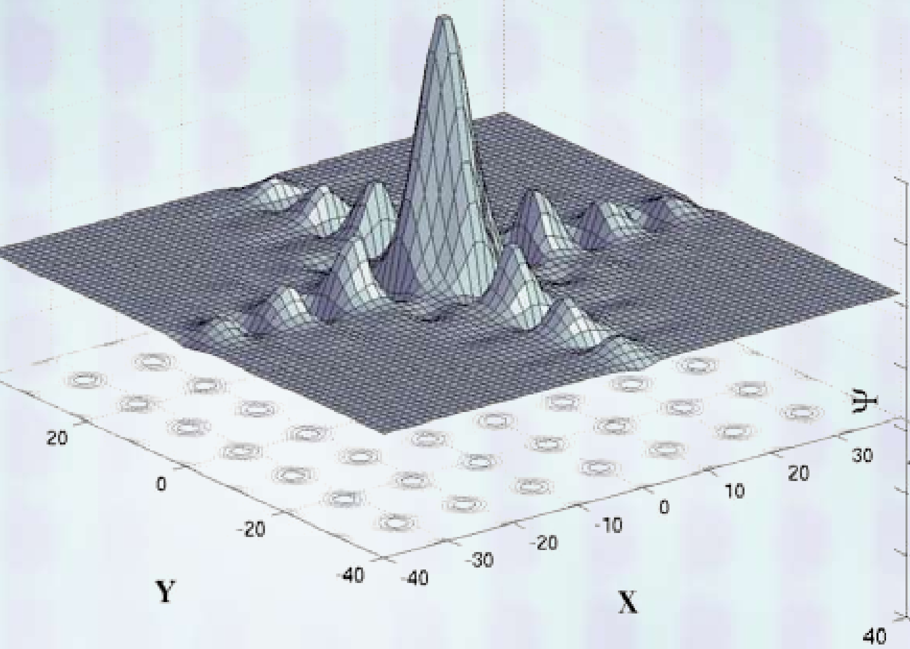
Elena A. Ostrovskaya, Tristram J. Alexander, Pearl J. Louis, Beata Dabrowska, and Yuri S. Kivshar

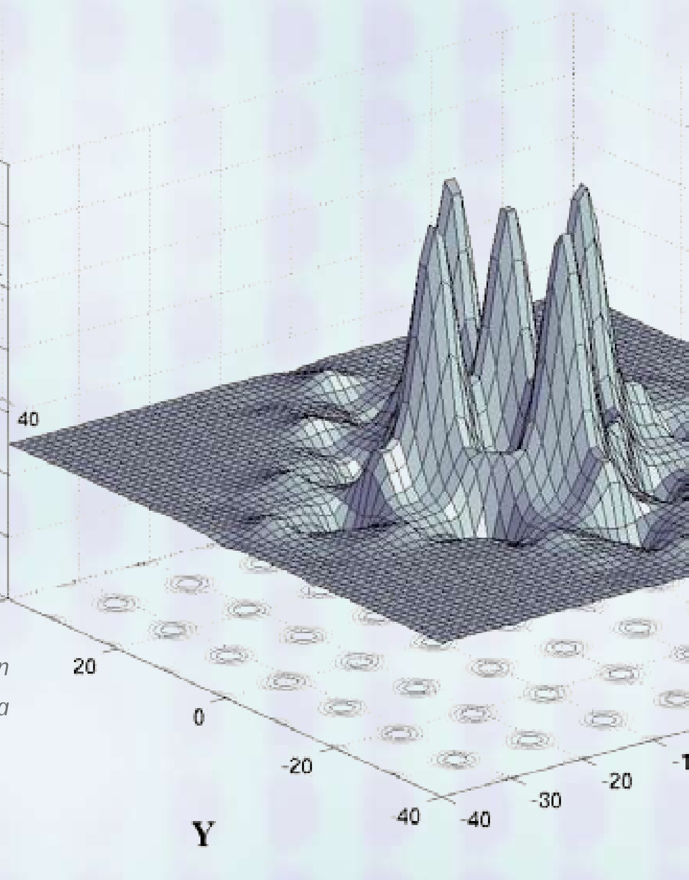
For years physicists have studied the interaction of laser light with the regular atomic lattices of crystals. But what happens when the roles are reversed and the laser beam is made of atoms and the crystal is made of light? This is exactly the question that scientists at the ANU are currently exploring.

The laser beam of atoms is created by cooling a gas to almost absolute zero. This causes its atoms to undergo a transition into a single quantum state known as a Bose-Einstein condensate (BEC). Such BECs can behave like giant coherent matter waves or laser beams composed of atoms. A fascinating feature of the atom laser beam is its inherent nonlinearity; due to atom-atom interactions it can display focusing or defocusing behaviour even in vacuum. To make the light crystal, scientists combine multiple coherent light beams so that the interference pattern forms an optical lattice - perfectly periodic and stationary arrays of microscopic high and low intensity regions that attract or repel the ultracold atoms.

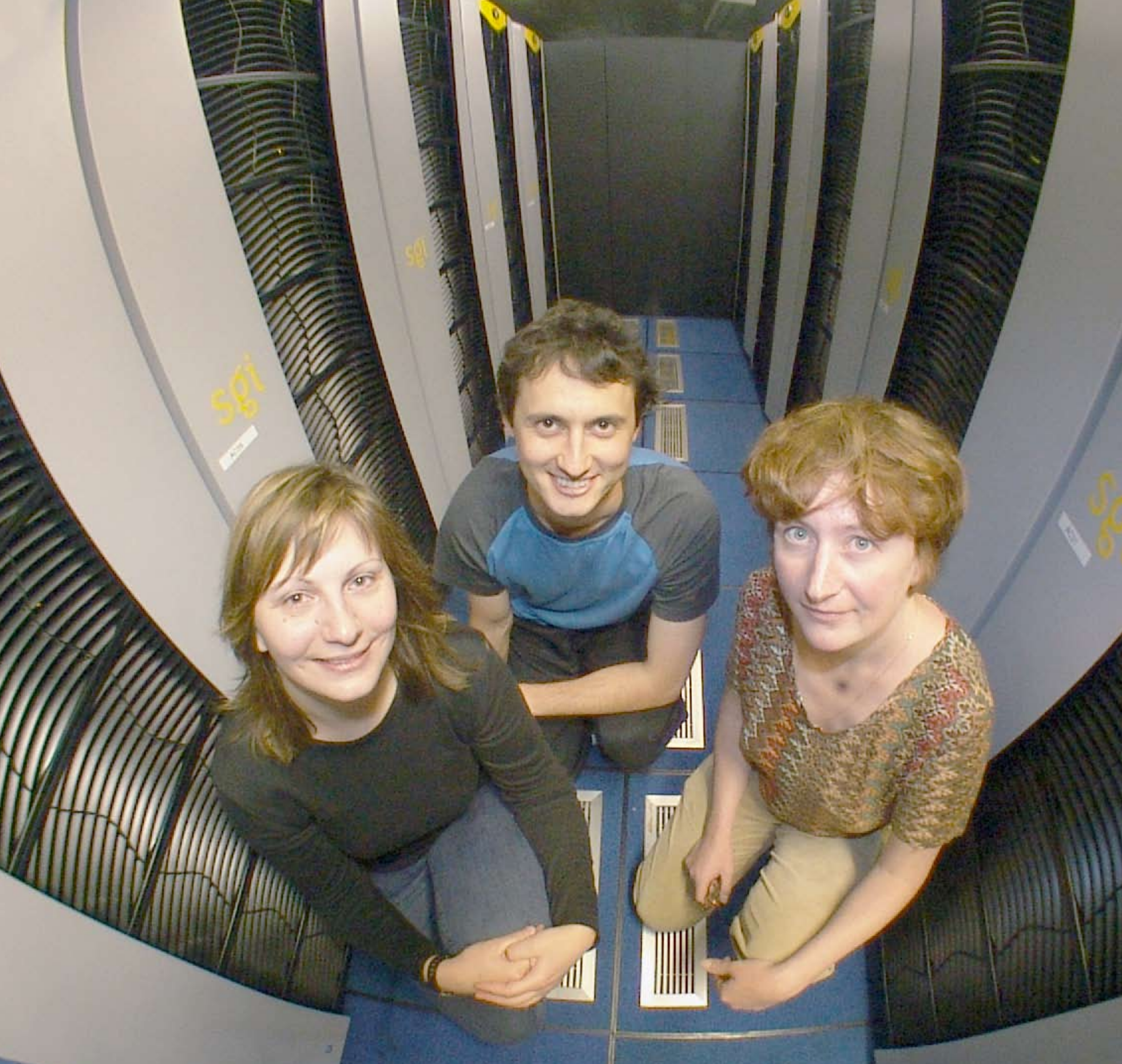
One of the most intriguing predictions of the new ANU theoretical model is the existence of so called atomic gap solitons - stable localisations of the defocusing atomic beam within the light lattice that are induced by the combination of nonlinearity and nontrivial scattering of the matter wave. The theory has recently been given a boost by the first experimental observation of these atomic gap solitons in Konstanz, Germany. Other fascinating and counter intuitive prediction of the theory is that even a "square" optical lattice can trap and sustain circular currents in condensates, BEC vortices. The lattice fragments the BEC into a regular array of condensate droplets but maintains the common circular particle flow.

The physics of BECs in optical lattices opens up novel possibilities of control and micro manipulation of matter waves by optical laser beams. It contributes into the foundation of amazing emerging technologies based on the principles of new cutting-edge science - quantum-atom optics.

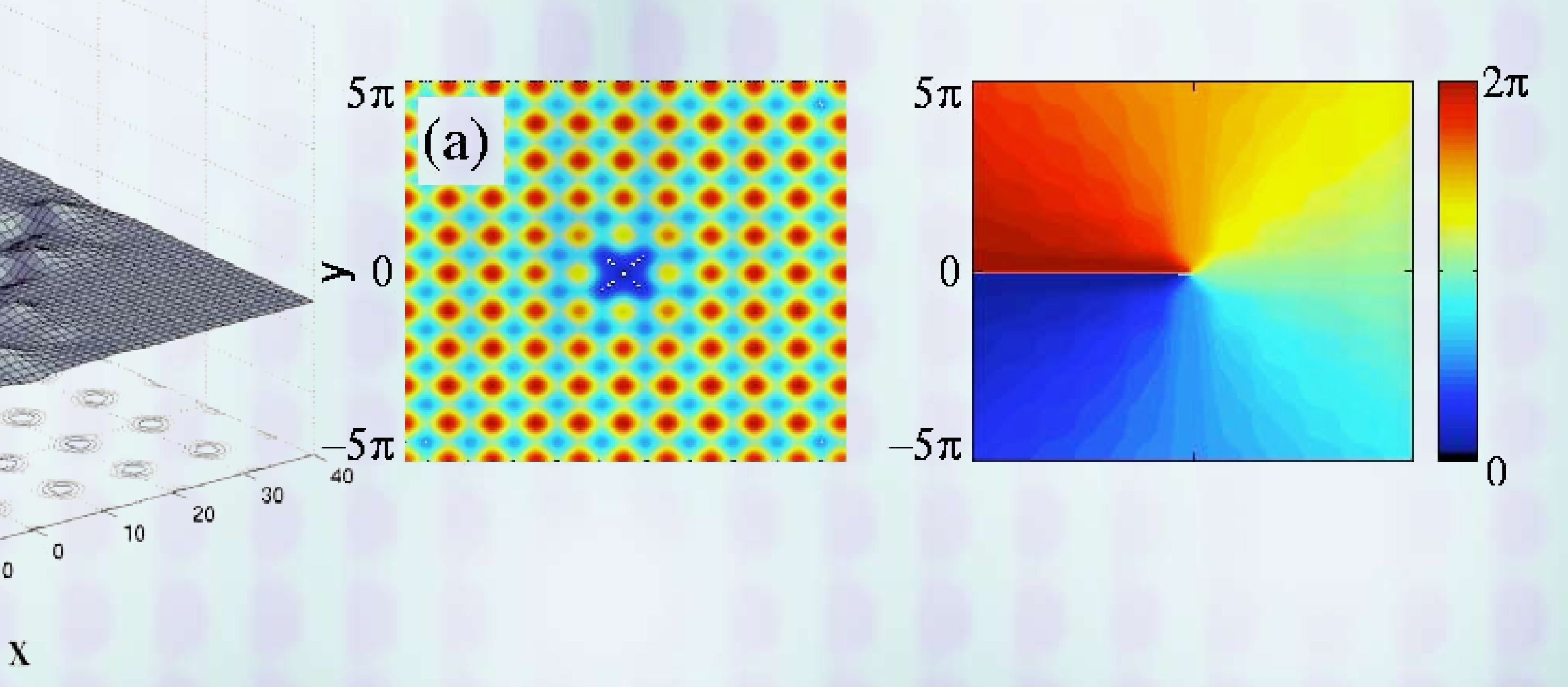




Macroscopic wavefunction of the atomic gap solitons localized in an optical lattice (left panels) and atomic density and phase distribution in a matter-wave Bloch vortex (right panels).

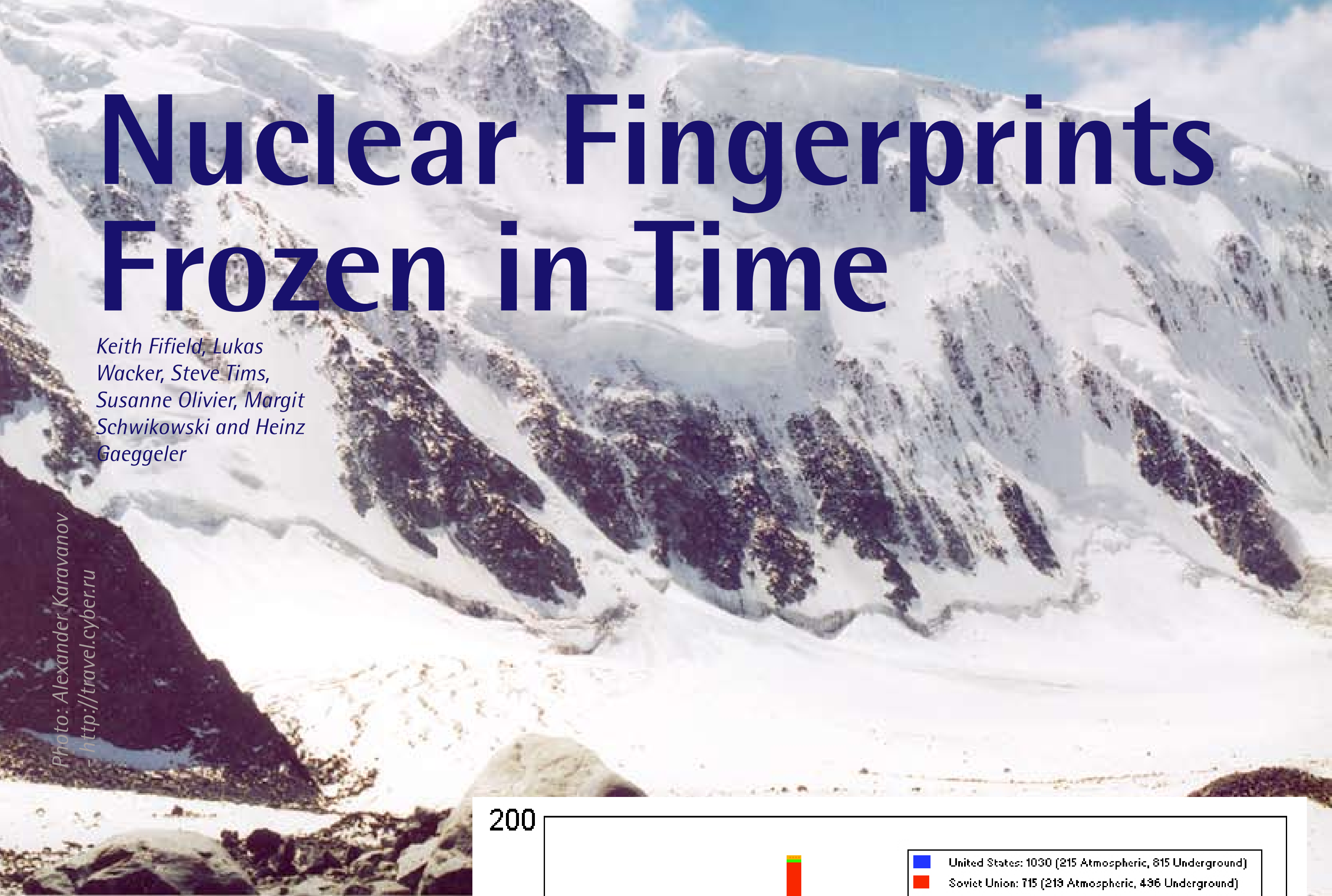


Members of the research team with the ANU Supercomputer on which modeling calculations are performed

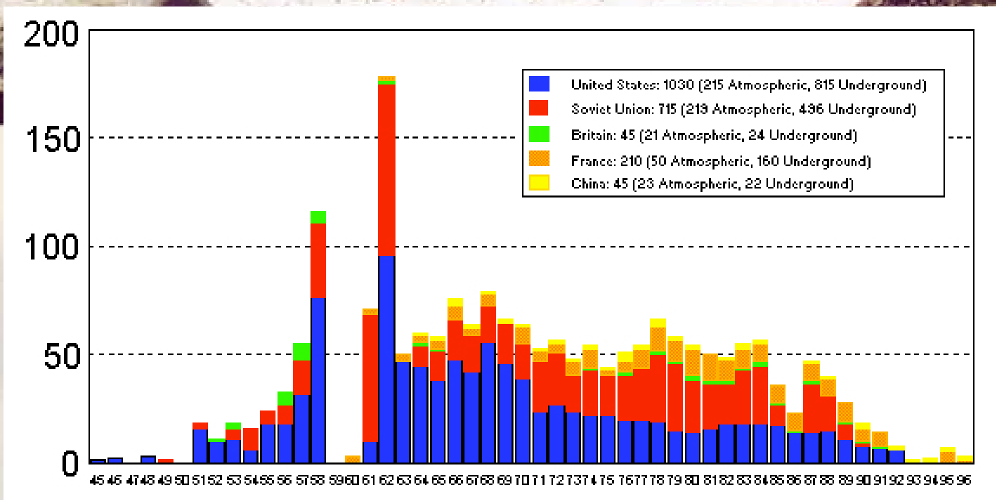


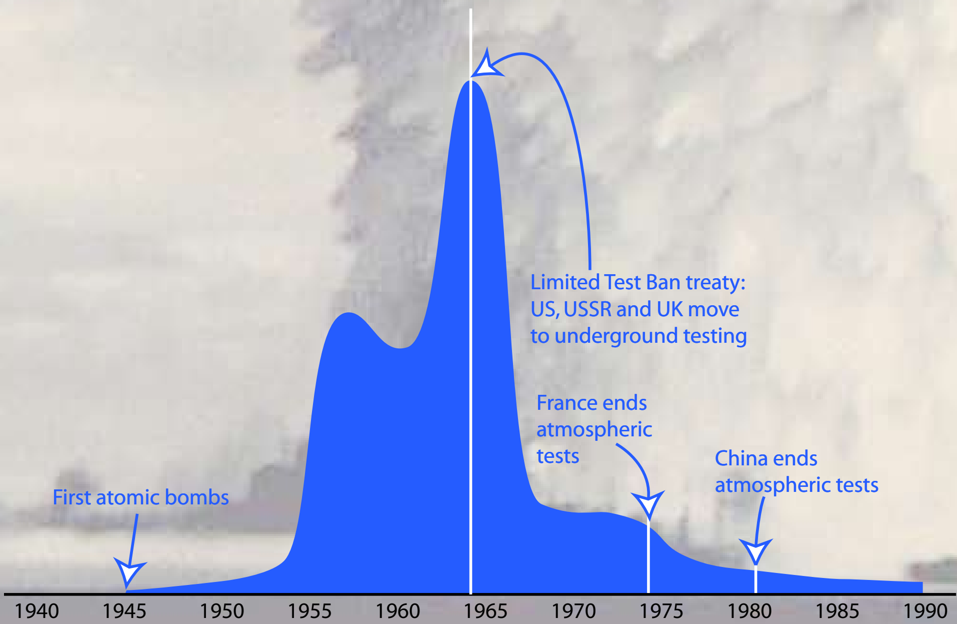
Nuclear Fingerprints Frozen in Time

Keith Fifield, Lukas Wacker, Steve Tims, Susanne Olivier, Margit Schwikowski and Heinz Gaeggeler



Each year as the snow falls on the Belukha Glacier in Siberia it carries down with it tiny traces of atmospheric pollutants. Of special interest to scientists are the miniscule quantities of plutonium that attach themselves to the atmospheric dust particles around which the snow flakes form. Each years precipitation gets compacted and frozen and in this way the glacier forms a record of nuclear material present in the atmosphere at any given time. By drilling a core down through the glacier it is possible to read the layers like the rings of a tree, each layer yielding information about the atmosphere during the year in which it formed. The catch is of course, that the quantity of nuclear material in the ice is unimaginably small. Too small in fact, for meaningful analysis by conventional means.





To overcome this difficulty, scientists at the Australian National University have perfected the technique of accelerator mass spectrometry (AMS) using the powerful 14UD Accelerator to measure traces of plutonium with unprecidented sensitivity. This technique is so sensitive that if you were to dissolve a particle of plutonium the size of a single grain of salt in Sydney Harbour it could be readily detected by sampling a few liters of the water.

This work is performed in collaboration with scientists at the University of Berne in Switzerland, who drilled the ice core and carried out the delicate chemistry to extract the few plutonium atoms from the ice. The concentrated samples were then shipped to Australia for AMS analysis. By measuring plutonium concentration at different depths in the glacial core, it has been possible to construct a year by year record of the quantity introduced into the atmosphere as a result of global nuclear testing and accidents such as Chernobyl. The resulting curves of plutonium concentration match well the history of atmospheric testing carried out across the world.

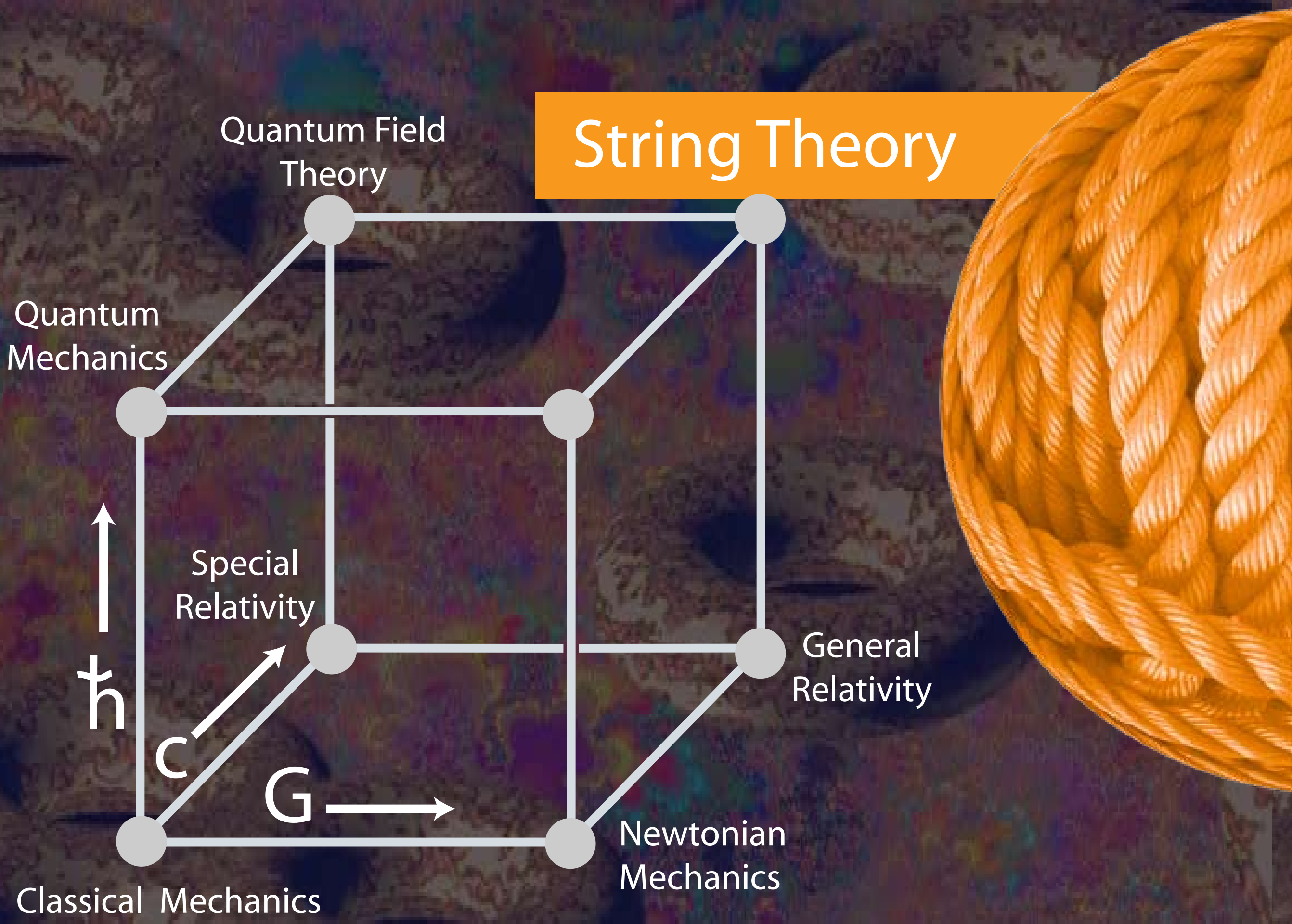
It's not just the ability of AMS to detect fantastically small traces of nuclear material that makes it so appealing in a range of security and environmental applications. The technique also reveals which particular isotopes are present and in what ratios. Armed with this information, scientists are able to infer the source of any contamination, be it weapons testing, power plants or illegal weapons manufacture or smuggling.

Stringing Together Fundamental Forces

Peter Bouwknegt, Alex Flournoy, David Botman, Josh Garretson, Peggy Kao and Madeleine Smith

String Theory is a consistent description of the physics of the very small (as described by Quantum Mechanics) and that of the very large (General Relativity), and thus is a candidate for the elusive "Theory of Everything". That is, a model of the universe that unifies the four known fundamental interactions into one coherent and consistent picture.

String Theory is based on the premise that the fundamental building blocks of matter are not point-like particles but are actually tiny pieces of vibrating string, which can be either open or closed. Surprisingly, the spectrum of such quantised strings contains both a massless spin-2 excitation, which can be identified with the graviton, (i.e. the force field of gravity) and



The Magic Cube of String Theory: String Theory, also known as M-Theory, generalises the main theoretical pillars of 20th century Theoretical Physics in that it is a consistent description in the case where all three fundamental constants of nature (G, h and c) are turned on.

massless spin-1 excitations, which ultimately need to be identified with the gauge bosons of the standard model. Hence one could say that String Theory predicts both gravity and gauge theory! Other predictions of String Theory are that we live in a 10-dimensional spacetime, supersymmetry, the existence of a holographic principle, and the Bekenstein-Hawking black hole entropy formula.

Over the past 10-15 years a coherent picture has emerged in which the five previously thought to be distinct (super) String Theories are now understood to be just different manifestations of one underlying theory, known as M-theory, related by a web of so-called dualities.

Scientists at the ANU, in close collaboration with both physics and mathematics colleagues at other Australian universities as well as overseas, predominantly work on the foundational aspects of String Theory/M-theory. This involves understanding and developing the mathematics behind these dualities (and leads to modern fields such as noncommutative geometry) with the ultimate aim of unraveling the physical principles behind M-theory.

Putting the Big Chill on Excited Atoms

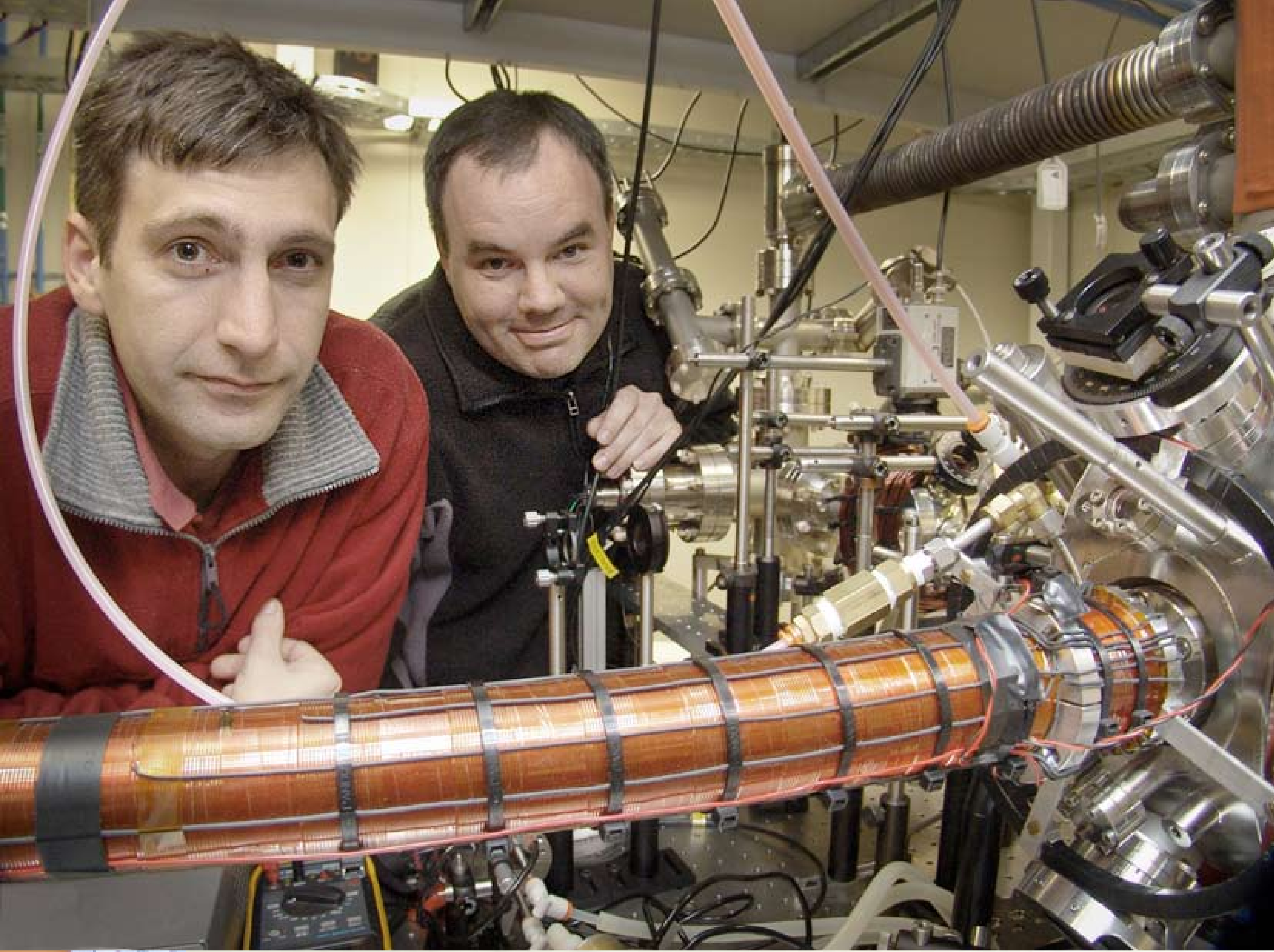
Robert Dall, Steve Battisson, Ken Baldwin and Andrew Truscott

In 1925, based on work by Satyendra Nath Bose, Albert Einstein proposed that if one could make a collection of atoms cold enough, they would condense into a single quantum state making each atom identical to its neighbours in a similar way to photons in a laser beam. It wasn't until seventy years later that scientists were able to actually create the world's first Bose Einstein-Condensate (BEC) in the laboratory.

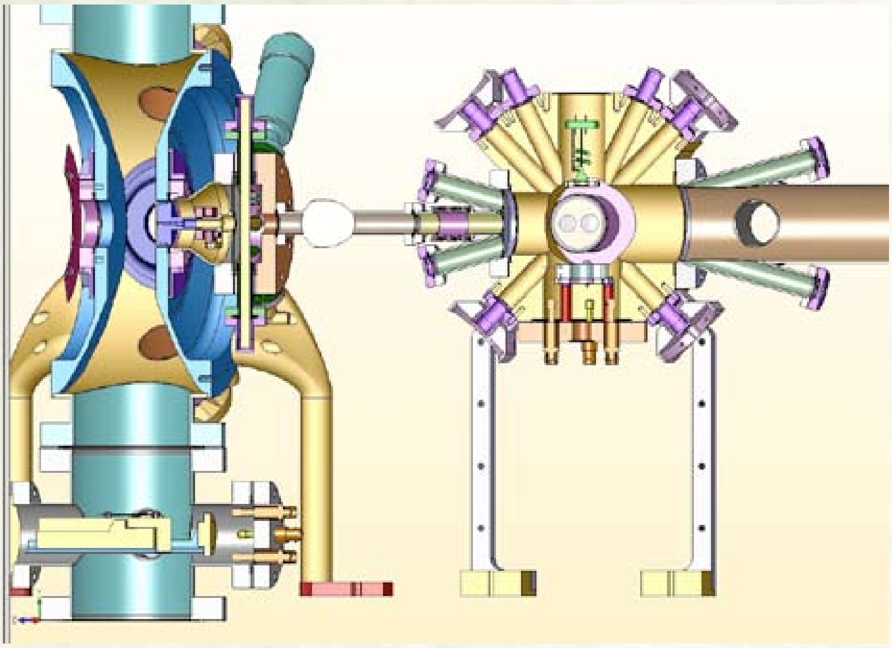
BECs are interesting because they represent an entirely new state of matter not found naturally anywhere in the universe. Even the coldest depths of space are a billion times too hot for a BEC to exist because of residual radiation from the big bang. BECs have strange quantum properties that may yield useful future technologies. However, in order to unlock this potential, scientists need to better understand BECs and especially their process of formation. Studying the formation process in conventional ground state alkali atom BECs is complicated by the inability to detect individual constituent atoms. Measurements on such systems are limited to averaging over the quantum ensemble.

To get around this, scientists at the ANU have recently become one of only four groups in the world to develop a novel laser cooling apparatus capable of creating BECs using excited helium atoms rather than atoms in the ground state. The advantage in using excited atoms in the BEC is that they can be detected individually. This is because they decay to their ground state on contact with a detector, the energy thereby released liberating an electron and producing a detectable signal in the process. Since the atoms in the BEC cloud are all quantum identical, probing one yields a perfect snapshot of the others and individual quantum effects become visible in much greater detail. The ANU team is hopeful that this newly commissioned system will yield vital clues to the mechanism of BEC formation.

The history of physics is full of examples of strange and exotic phenomena that having been developed out of pure curiosity, have gone on to spawn unimaginable technological advances. Lasers, X-rays, and transistors all belong to this family and BECs may well be its newest member.



Much of the new BEC Beamline was designed and built within the School's workshops. The facility for inhouse design and production of unique experimental facilities underpins much of the School's research activity.



ARC COE FOR QUANTUM-ATOM OPTICS

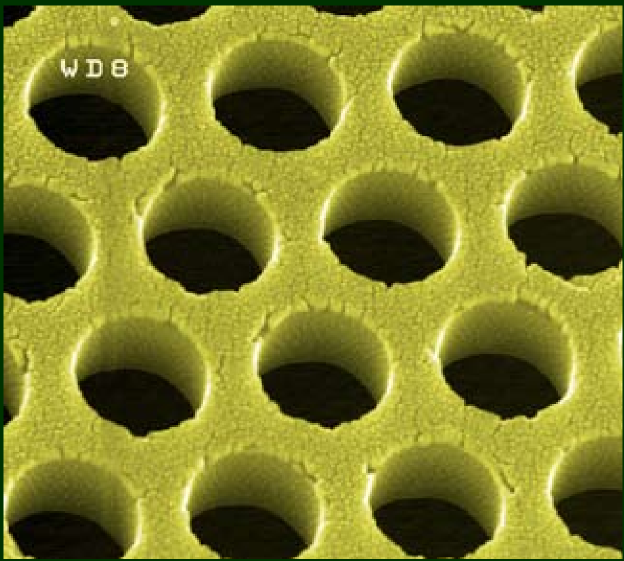
The helium BEC project is part of the ARC Centre of Excellence for Quantum-Atom Optics (ACQAO - see www.acqao.org) headquartered at ANU.

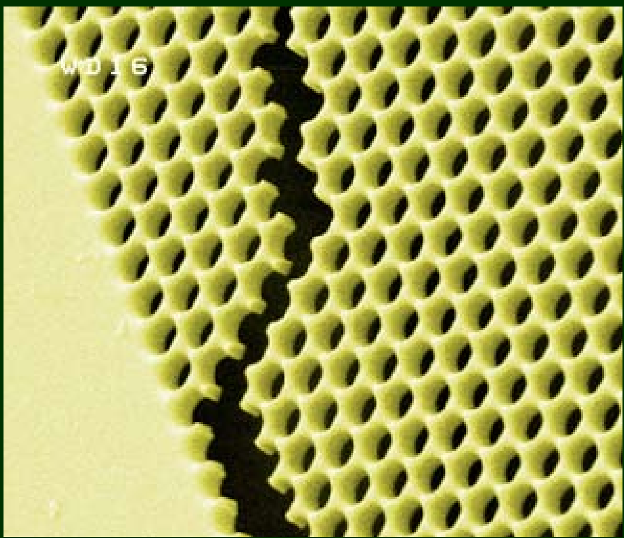
Australian Government

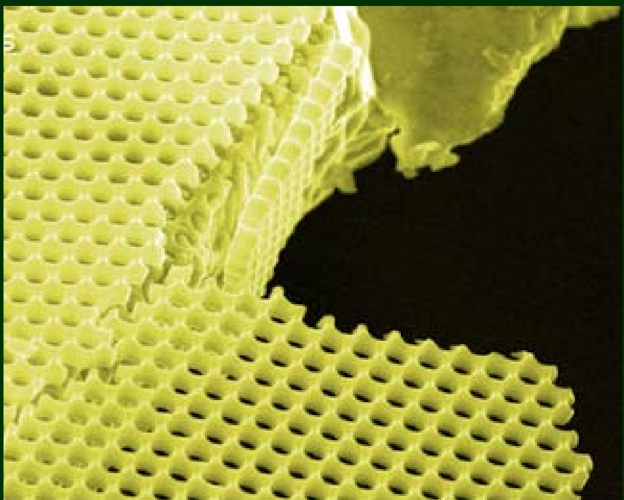
Australian Research Council

Chalcogenide Glasses Reveal the Hole Picture

Darren Freeman, Barry Luther-Davies and Steve Madden





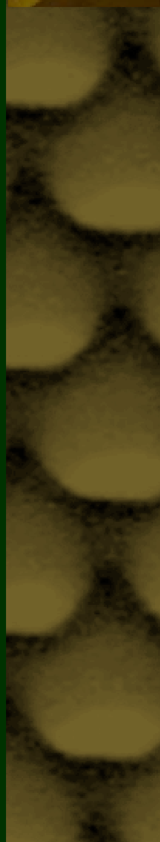


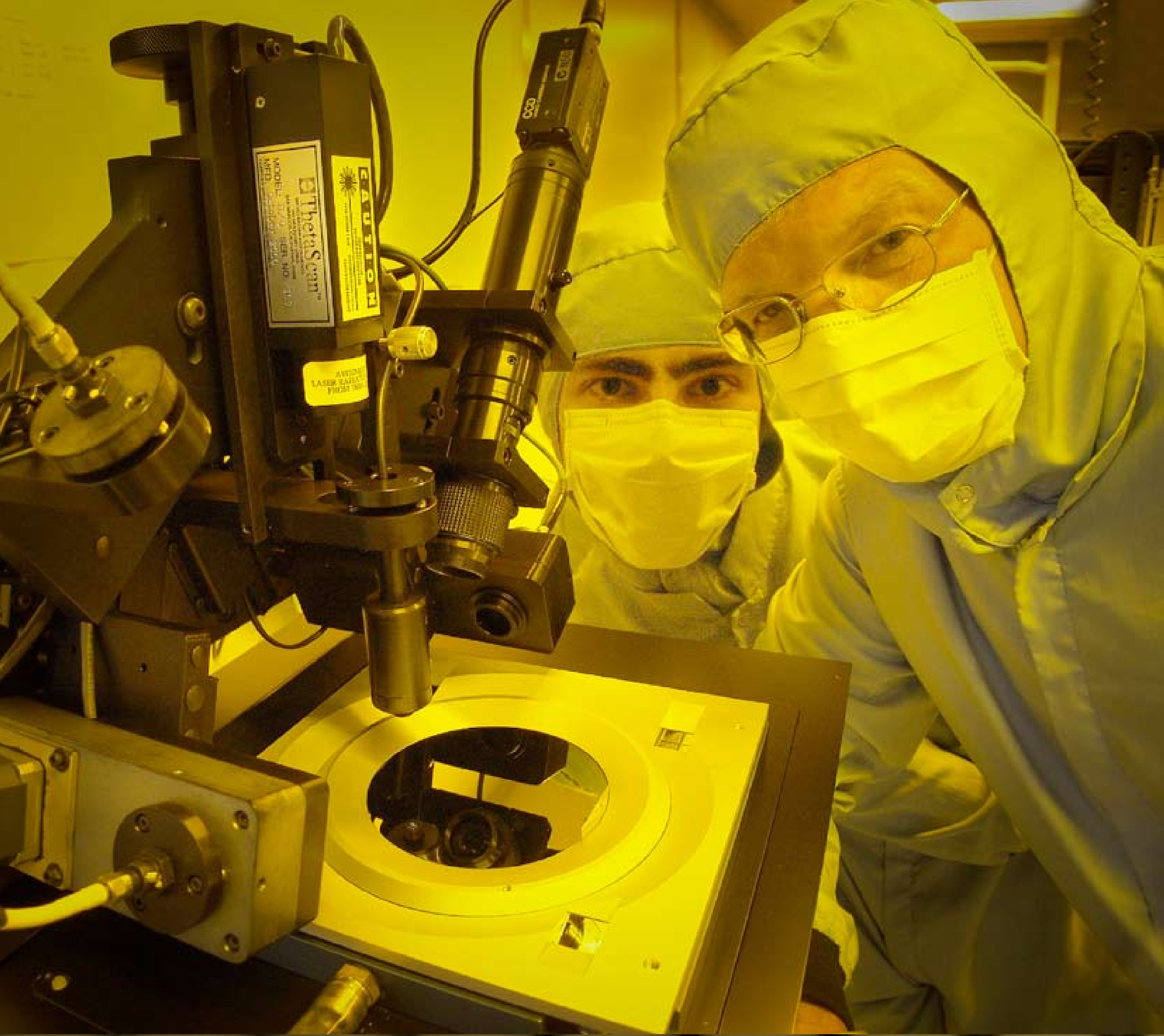
The periodic lattice of atoms in a semiconductor crystal can under some circumstances, interact with electron de Broglie waves to produce forbidden energy gaps and other interesting phenomena. The transistor and thus the entire modern electronics industry is based on this interaction between wave and lattice.

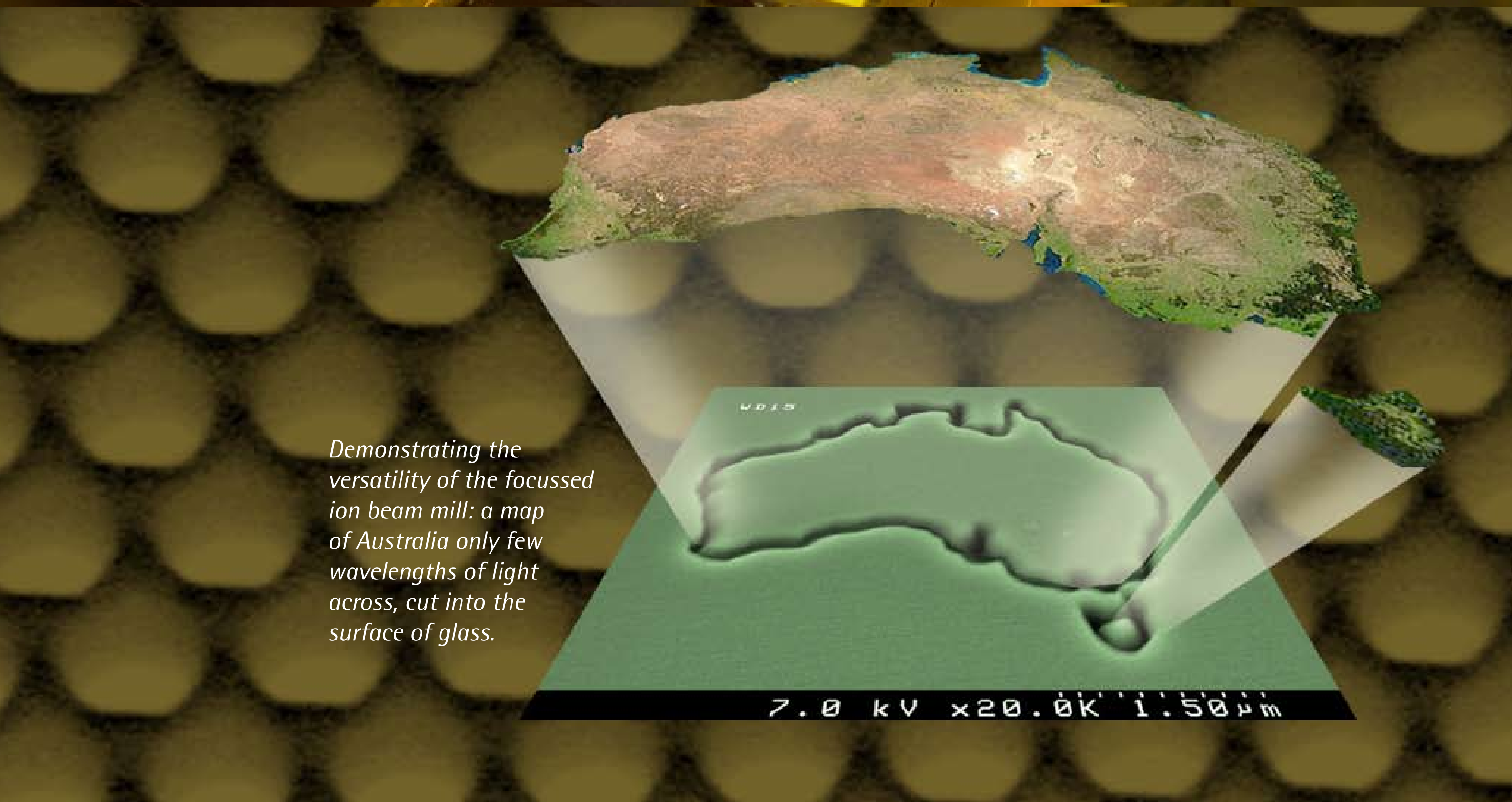
However the underlying physics of wave/lattice interaction isn't just confined to electrons in semiconductors. In more recent years, scientists have begun to study light waves propagating in Photonic Crystals (PhCs) - transparent structures containing a regular lattice of high and low refractive index regions. In principle, these photonic crystals promise an entire suite of optical devices, analogous to those of semiconductor electronics.

The fabrication of such structures has until now, required special techniques such as electron beam lithography and dry etching to achieve the required patterns (periods in the range of 500nm containing holes in the 200-300nm range). To perform well as an optical device the interfaces in these structures must also be very smooth and the pattern regular over many tens of periods both of which are quite difficult to achieve using these conventional techniques.

However, scientists at the ANU, supported by funding from the ARC Centre of Excellence Program, have recently developed an alternative method of fabricating Photonic Crystals using a single step approach. They use a focussed ion beam to mill out holes in high index chalcogenide glass. The air filled holes have a much lower index of refraction than the surrounding glass thus forming a high contrast refractive index lattice. This method produces top quality periodic patterns with very smooth side-walls without the complication of the standard multi-step process. In addition, unlike chemical etch processes, the focussed ion beam mill can generate gratings in almost any material and can even generate three-dimensional "grey-scale" structures.







Demonstrating the versatility of the focussed ion beam mill: a map of Australia only few wavelengths of light across, cut into the surface of glass.

Aussies Take World Record for Stopping Light

Jevon Longdell , Elliot Fraval, Matthew Sellars and Neil Manson

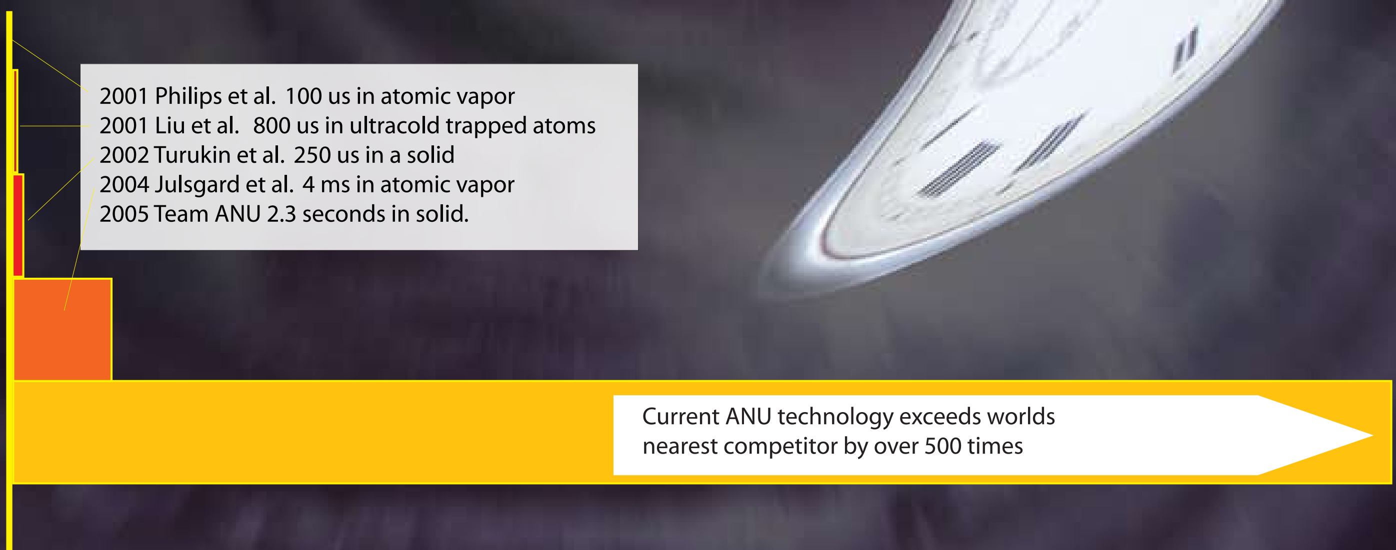
As part of their research into the emerging technologies of quantum computation and encryption, researchers at the ANU have managed to stop light with storage times longer than one second. While they were able to stop light previously, researchers hadn't been able to stop it for very long - about a thousandth of a second. These early experiments were carried out in an atomic gas and were limited by movement of the atoms. The researchers at ANU have been able to increase storage times one thousand-fold, using solid state materials in carefully controlled magnetic fields.

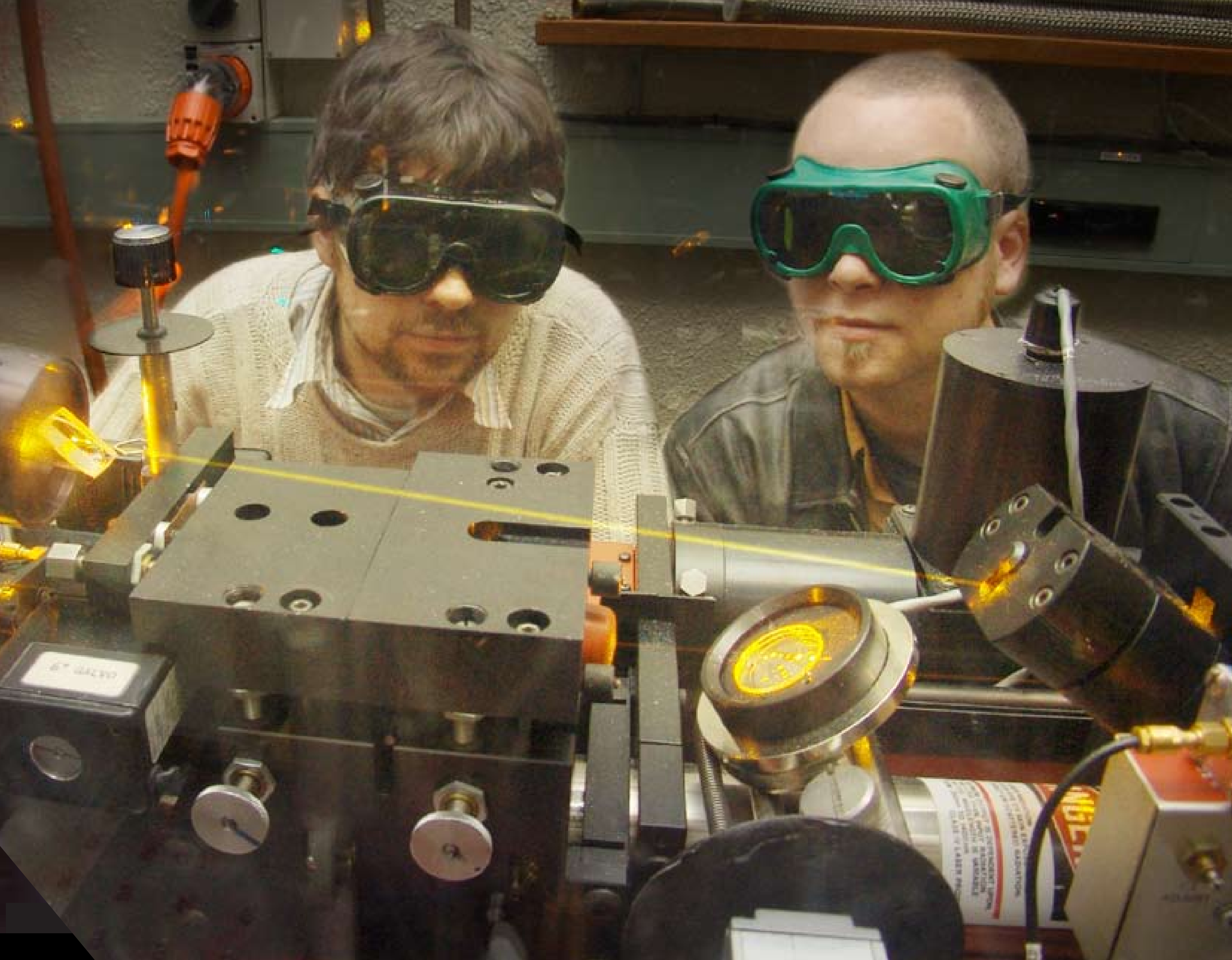
One of the tenants of Einstein's theory of relativity is that no effect can propagate faster than light in a vacuum. What he didn't say was how slow light could be. Light slows down by about a third in normal glass and goes a bit slower than that in some special materials, but until a few years ago it was hard to make light do anything other than travel really fast.

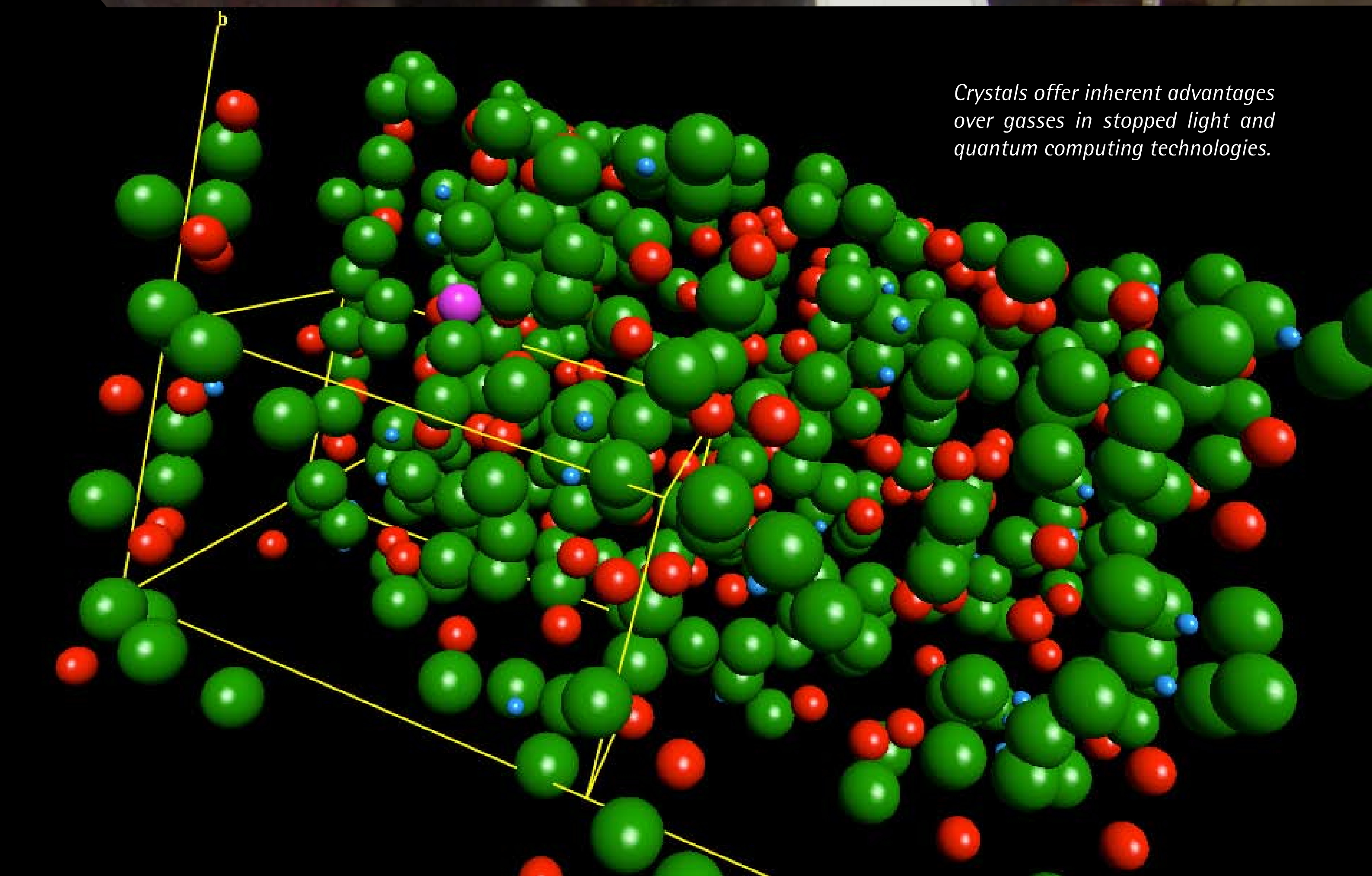
A phenomenon called electromagnetically induced transparency allows a material that would usually be opaque to become transparent by applying an auxiliary laser beam. This auxiliary laser beam, called the coupling beam, also changes the speed of the light. Not only does this enable very slow propagation velocities, but if the coupling beam is slowly turned off light can be stopped completely and then recalled when the coupling beam is turned back on.

The Heisenberg uncertainty principle places a limit on how accurately one can measure and then regenerate a light beam. Because of this conventional memories are not suitable for quantum computation and communication networks and more exotic memories such as one based on "stopped light" will be required. The dramatic increase in storage time achieved by the ANU team brings the promise of these quantum information processing technologies closer to reality.

The team's previous accomplishments include a two bit quantum logic gate and they are currently working towards the goal of a 6-bit quantum processor.







Crystals offer inherent advantages over gasses in stopped light and quantum computing technologies.

Ion Beam Creates Amorphous

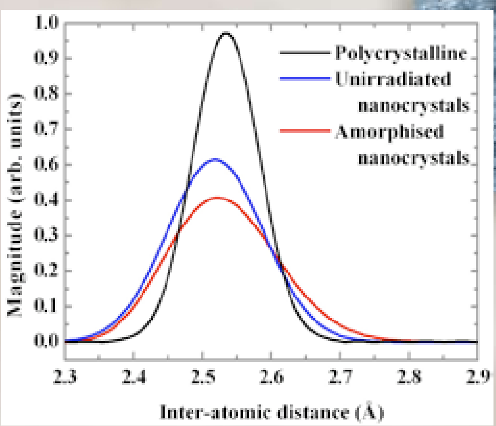
Bernt Johannessen, Patrick Kluth, David Llewellyn and Mark Ridgway

The physical properties of metals depend critically on their crystalline structure. Surprisingly amorphous metals with a highly disordered structure can sometimes greatly outperform more perfect polycrystalline versions of the same material. For example, golf club heads fabricated from amorphous "Vitreloy" are twice as hard and four times as elastic as those made from polycrystalline Ti and consequently 99% of the impact energy is transferred to the ball compared to only 70% for Ti.

To form an amorphous metal, one tries to "quench in" the disordered structure by rapid cooling from the molten state. Alloys such as Vitreloy have a very high viscosity and can freeze into amorphous states even at quite modest cooling rates. But for pure metals it's impossible to cool castings fast enough to yield the desired amorphous structure. To get around this, scientists have long experimented with ion implantation - accelerating ions to high velocity and smashing them into the material with the aim of displacing atoms and transforming the metal structure from a polycrystalline to amorphous state. However, to date, this has only yielded amorphous metals when using foreign ions whose inherent chemical properties inhibit the undesired recrystallisation. The trouble is that this also introduces undesirable impurities which themselves alter the properties of the metal.

Scientists at the ANU may soon have a way round this problem. They employ nanotechnology to generate metal nanocrystals with modified microscopic structure, then implant these materials with high-energy ions that pass straight through the nanocrystals to minimise impurity effects. The ANU group has recently demonstrated that for pure copper, their nano-preparation technique creates an amorphous structure that is unachievable when implanting

Cross-sectional transmission electron micrographs showing the disappearance of Cu nanocrystals, apparent as dark circles, due to Sn ion irradiation for a dose range of 0, 1x1014, 3x1014 and 1x1015 /cm2 (from top left to bottom right).



Inter-atomic distance distribution surrounding a Cu atom comparing polycrystalline material with nanocrystals in an unirradiated and amorphised state, the latter achieved by Sn ion irradiation (5 MeV, 1x1014 /cm2).

Mono-Elemental Supermetals

bulk polycrystalline material yet is consistent with theoretical predicitons for a pure amorphous metal. The ANU scientists were able to fine tune their process such that the implantation disrupted all trace of the normal face centred cubic crystalline structure whilst leaving the particle size intact. The group is hopeful that this technology could soon find applications throughout the electronic, photonic and metallurgical industries.

The key to success has been developing a thorough understanding of the implantation process on the nanoscale. This has been made possible by collaborative interactions with some of the world's most advanced and brightest x-ray facilities such as the Photon Factory in Japan and the Advanced Photon Source in the USA. However, by 2007 these measurements will be possible for the first time in this country when the Australian Synchrotron opens in Melbourne. These same ANU scientists are also actively contributing to the design and construction of this new, state-of-the-art national facility.