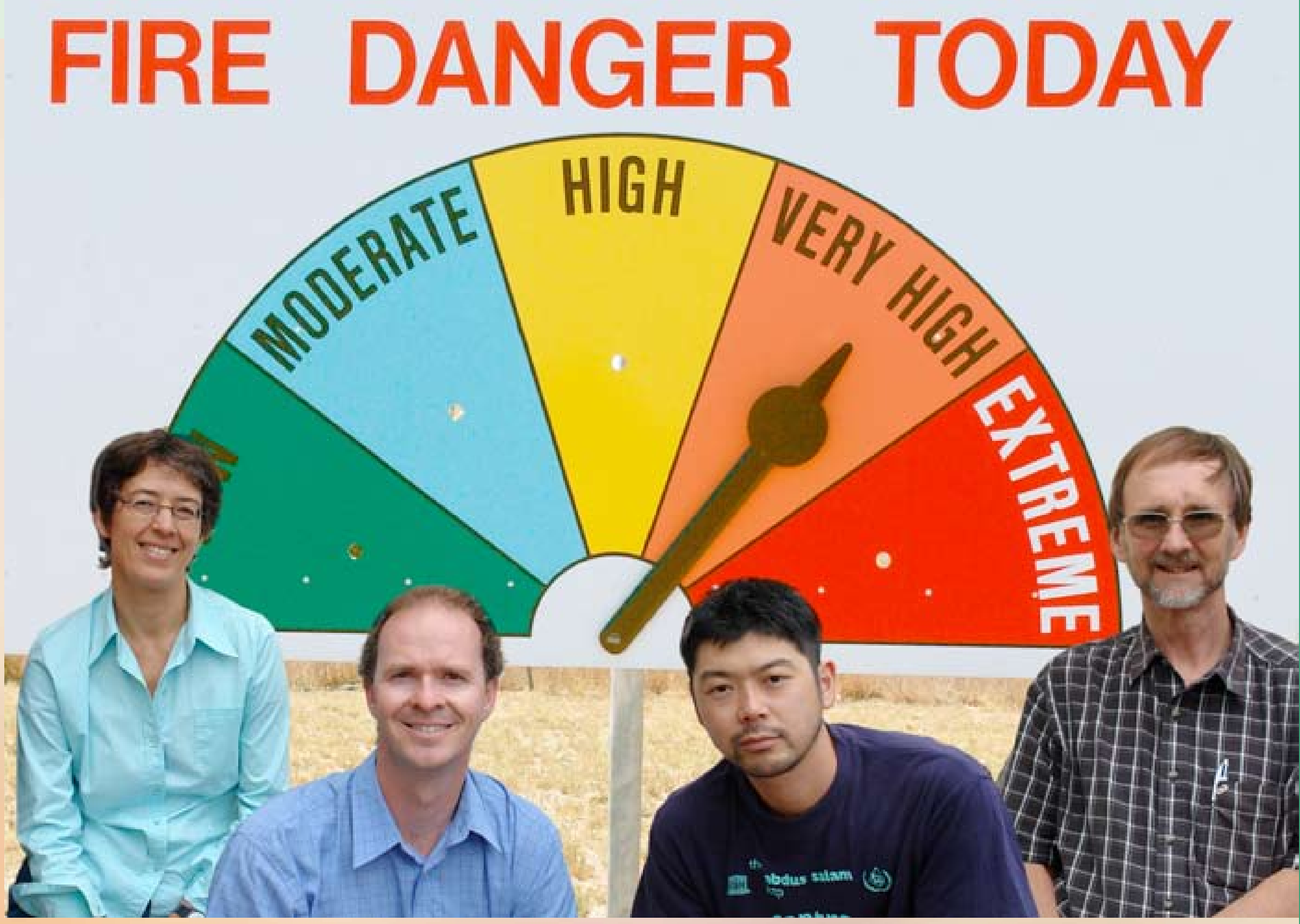
A BURNING DESIRE TO UNDERSTAND COMPLEXITY

Andrew Sullivan, Rowena Ball & Robert Dewar



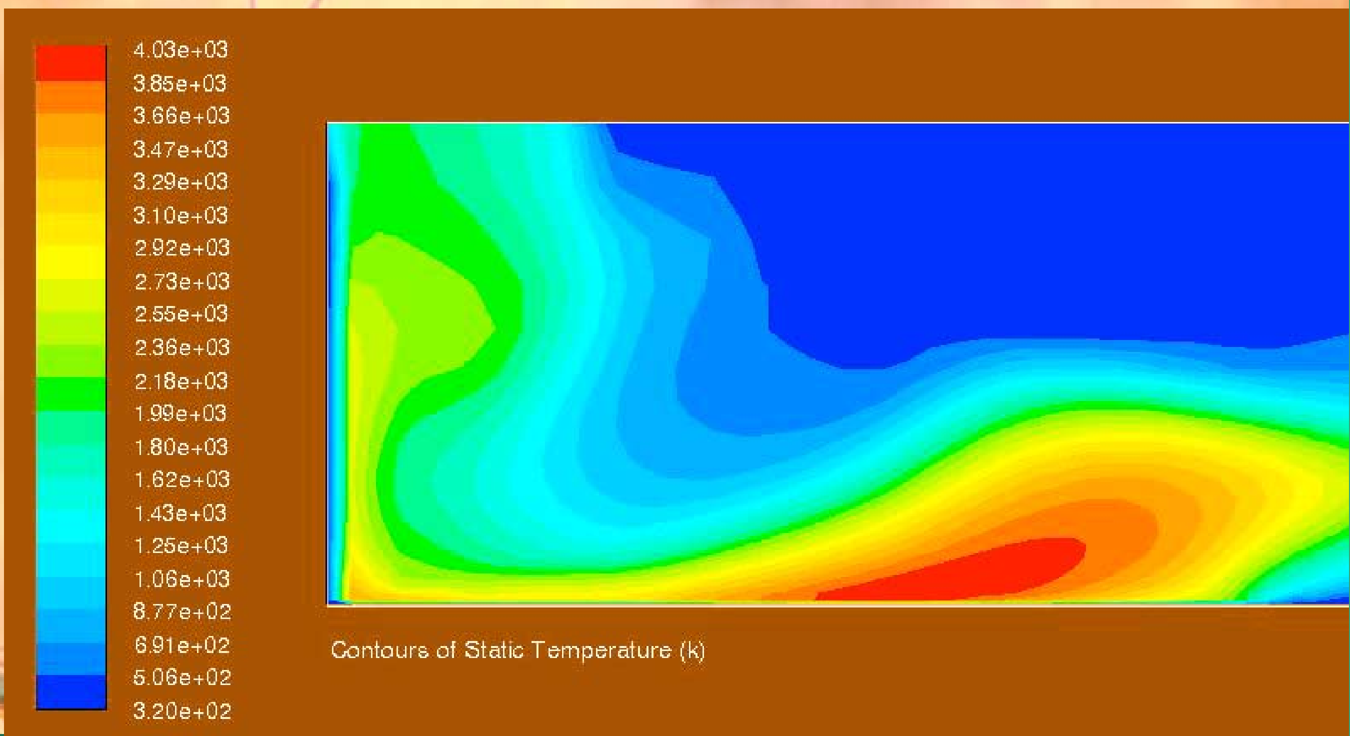
When physicists talk about chaos, they generally mean that the outcome of a sequence of events depends sensitively on the starting conditions. The common example is the flap of a butterfly's wings in Brazil creating a hurricane in Texas. Many real-life systems are to some extent chaotic. At first glance, modelling and predicting such systems might seem hopeless because no one could ever measure every tiny detail of the starting conditions. However physicists dealing with many-body systems have long realised that a great deal of progress can be made by throwing away most of the detailed microscopic information and describing the system in a coarse-grained, statistical sense – For example, in modelling the behaviour of the atmosphere, rather than focussing on individual molecules it is more productive to divide the system into a finite number of cells or grains each containing many individual molecules. If the size of these grains is chosen correctly the chaos diminishes, or disappears altogether and predictable patterns emerge that are insensitive to the minute details of the starting conditions. This approach has led to the development a new kind of science, Complex Systems Science, which has spread far beyond physics.

Although the study of complex systems in thermal equilibrium has reached a relatively mature state, modelling of open, driven, non-equilibrium complex systems is still a frontier field of physics. One example of such a system of particular relevance to Australia is large bushfires. A bushfire is an open system because it is a localised event in the wider atmosphere. It also has a fixed beginning, limited duration and the fire generates heat which in turn, drives the system out of thermal equilibrium.

Physicists at ANU are adopting a two-pronged approach to modelling such fires. Firstly by developing a better understanding of the physics and chemistry of cellulose combustion they hope to describe the heat production mechanism more accurately. Secondly, they are designing new continuum models that are more appropriate for describing fluid systems such as bushfires than traditional many-body statistical models.

The ANU team are optimistic that progress can be made in understanding fires because their behaviour is typical of a complex system: in a well-established fire patterns emerge which can be relatively insensitive to changes in external factors such as fuel load. This can lead to dangerous and counter-intuitive behaviour such as an ability to cross firebreaks by the coalescence of small spot fires on the other side. It's hoped that with a better understanding of the emergent properties of bushfires, transitions to life-threatening situations might be better identified and avoided.

Model of fire spread showing temperature variation from hottest (red) to coolest (blue



THE AUSTRALIAN NATIONAL UNIVERSITY

GOGO FISH REWRITES EVOLUTIONARY HISTORY

Gavin Young, Tim Senden, Dick Barwick, Ken Campbell & John Long

On a recent expedition to the Gogo formation in the Kimberley region of Western Australia a group of ANU scientists uncovered one of the most remarkable fossils of recent history. Partially emerging from one of the numerous limestone nodules that characterise the region, was the skull of a rare fish called Gogonasus. Only three Gogonasus skull fragments had ever been found before, so the largely intact fossil was a spectacular discovery.

Gogonasus is one of the most interesting fossils in the Gogo formation because it is the only one belonging to a major group called the tetrapodomorphs, an evolutionary branch that included early fish ancestors of the first four legged land animals, or 'tetrapods'. Tetrapodomorphs represent the very first steps that back-boned animals took to emerge from an aquatic existence onto dry land, ultimately evolving into all the amphibians, reptiles, birds and mammals that occupy the land today. By studying the brain and sense organs of these exquisitely preserved fossils, scientists can glean vital information about this pivotal process in the evolution of life on the planet.

One organ of special interest is the ear. Fish living in water have the semicircular canals of the inner ear for balance, but have no need for the middle ear with its tiny hammer, stirrup and anvil bones that transmit sound to the braincase from the outside. The first amphibians needed to adapt from hearing in water to the very different challenge of picking up sounds in the far less dense medium of air. This was achieved by modifying some of the bones supporting the gill cover into the middle ear. By studying the skull structure of tetrapodomorphs, scientists can unravel the intricate series of events that culminated not only in the development of modern mammalian ears, but also the complex brains that accompany them.

One difficulty in studying the ear is that its structures lie deep inside the bone of the skull. Two-dimensional x-ray radiographs are of limited value here and conventional CT scanners such as those used in hospitals, don't have anywhere near the spatial resolution to probe such very tiny objects.

This is where the revolutionary micro µCT scanner developed at ANU really came into its own. This instrument is able to perform three dimensional x-ray scans of objects with voxel (3D pixel) resolution of two micrometres. To put that into perspective, this is almost as fine as detail that can be seen in the optical microscopes. Using the µCT scanner, the team were able to build up a perfect 3D model of the tetrapodomorph skull.

The spectacular find and its subsequent analysis has turned some aspects of accepted theory on evolutionary history on their heads suggesting that tetrapods were beginning to evolve some 30 million years earlier than had previously been thought

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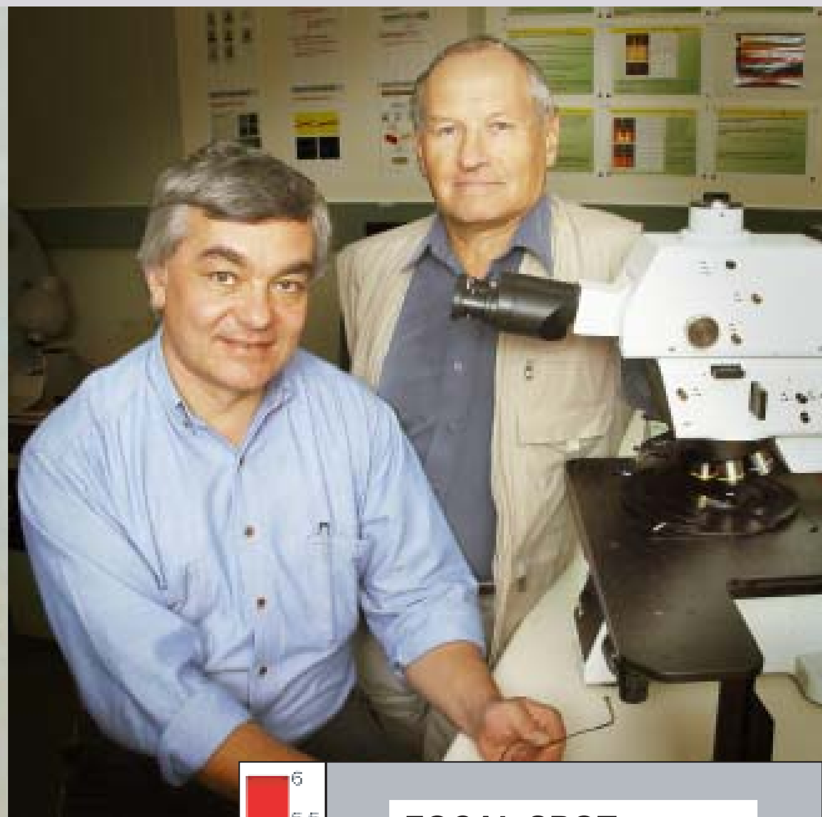
Ultrafast Lasers Drill Teeth and Improve Memory

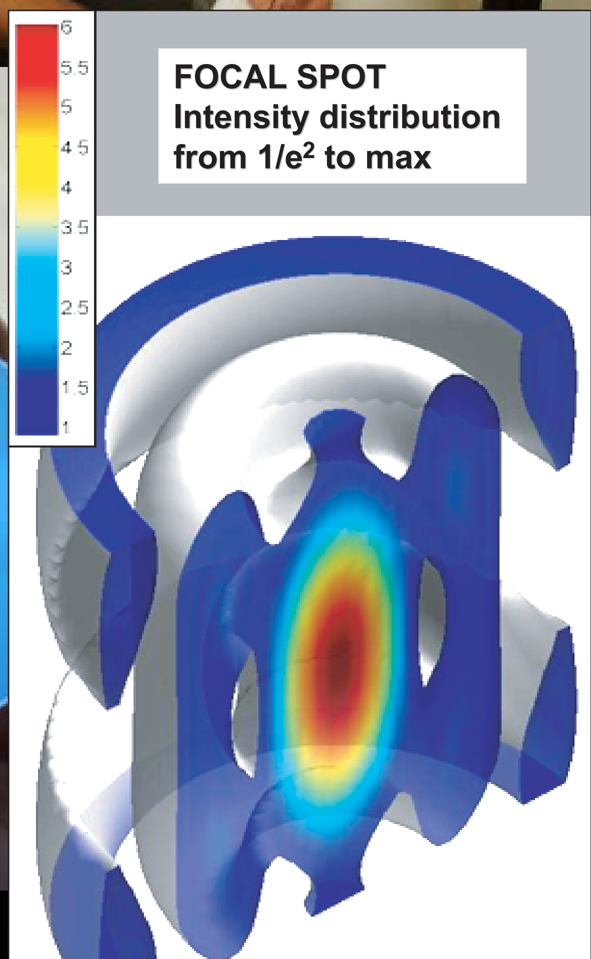
Eugene Gamaly, Saulius Juodkazis, Andrei Rode, Barry Luther-Davies, Hiroaki Misawa, Bronwen Taylor

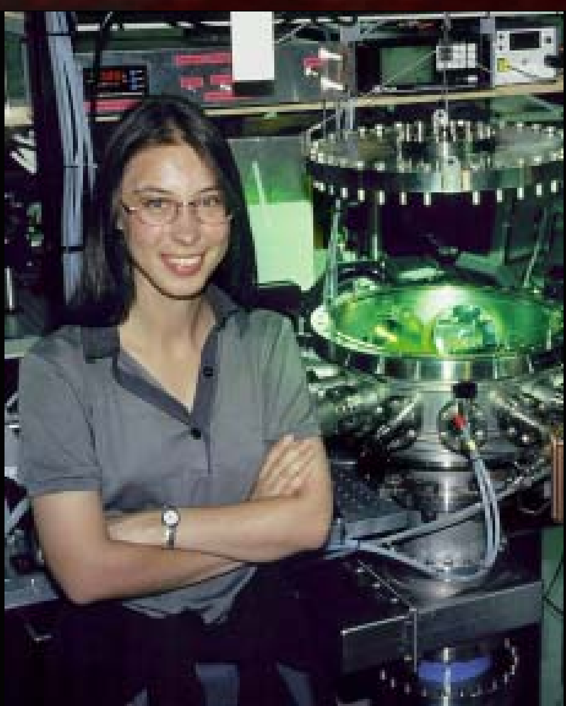
Applying the physics of underground nuclear explosions to 3D optical super-memories and laser dentistry.

ANU scientists, in collaboration with researchers in Japan, have been working on a 3-D optical memory based on creating very small three-dimensional "data bits" within a transparent solid. A single short laser pulse tightly focused inside the solid modifies the material in a region only a few hundred nanometers across. The pulse creates a local plasma and after cooling a void remains surrounded by a region of compressed glass. The physics involved in "writing" a data bit closely mirrors what occurs during an underground nuclear explosion but on a scale some 9-10 orders of magnitude smaller!

Making cavities in this way is straightforward but making them small enough and controllable enough to be useful in 3D memory has eluded scientists until now. The breakthrough came from an in depth understanding of the interaction of ultrashort laser pulses with materials. In particular recognizing that ionising the material in the focal spot to create plasma would restrict the volume in which the laser energy was deposited, and thereby the volume occupied by the data bit.







Anyone who has sat in a dentist's chair will be well aware of the problems with conventional drills. Lasers offer the potential of much cleaner and more precise tissue removal but until recently the heat dissipated in the process makes it totally impossible to use in dental applications. However, with the right control of conditions, the laser can be made to turn the decay directly into plasma, vastly reducing the heat transferred into the surrounding healthy tissue.

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Research Highlights

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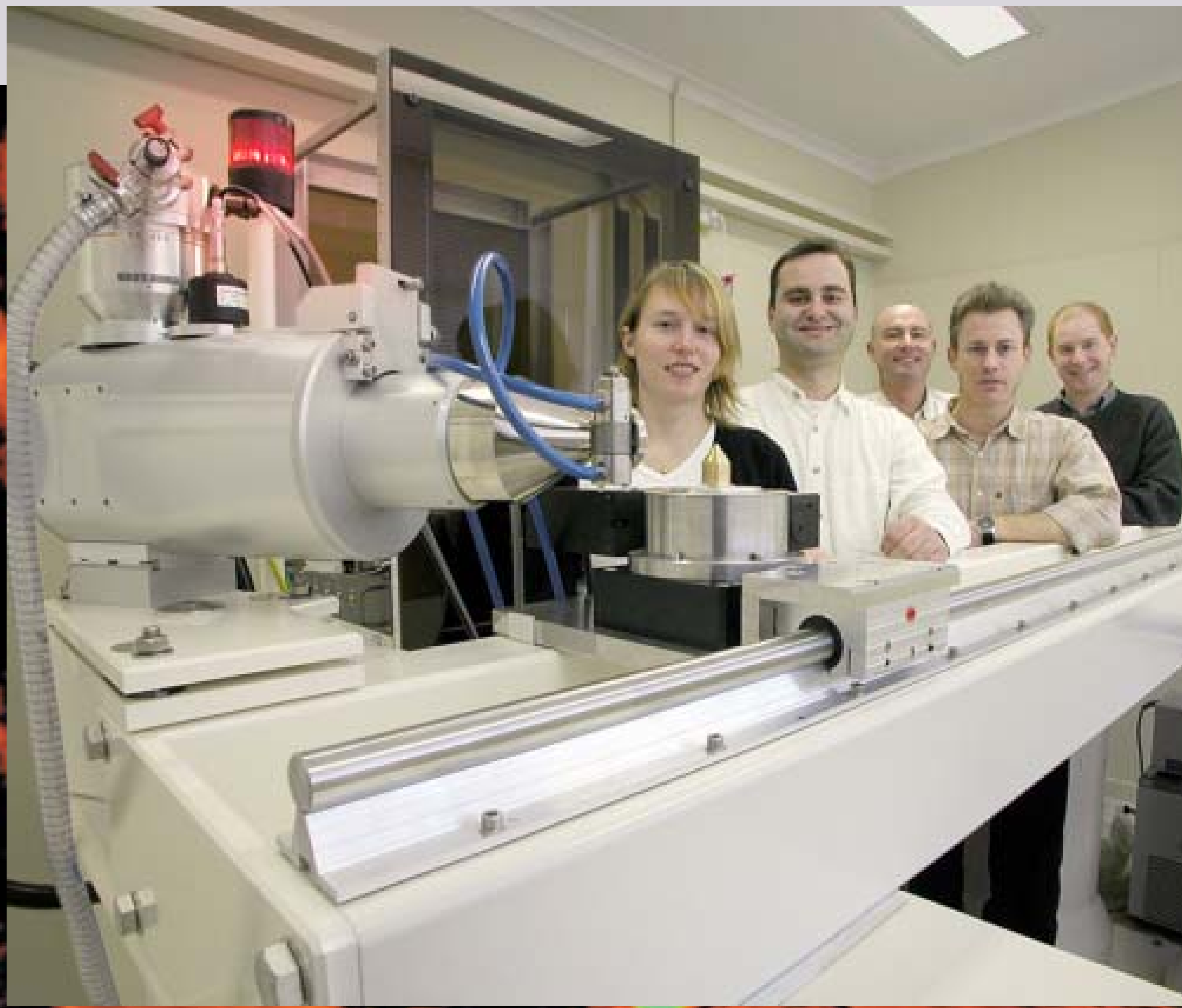
ANU X-Ray Specs Render Your Bones Transparent

Mark Knackstedt, Tim Senden, Anna Carnerup, Arthur Davies, Tim Sawkins



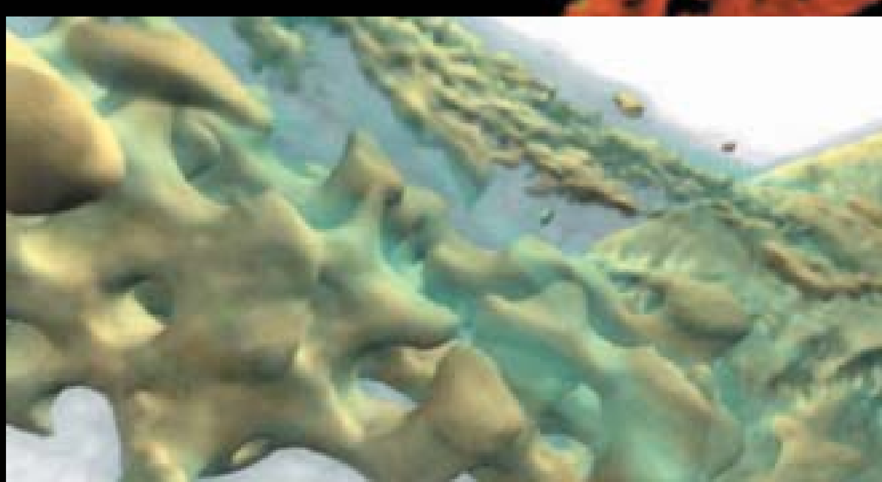
Micro computed tomography (µCT) is a technique that allows non-invasive imaging of systems in 3D.

An example of the technique is radiological imaging in hospitals such as CAT scans.

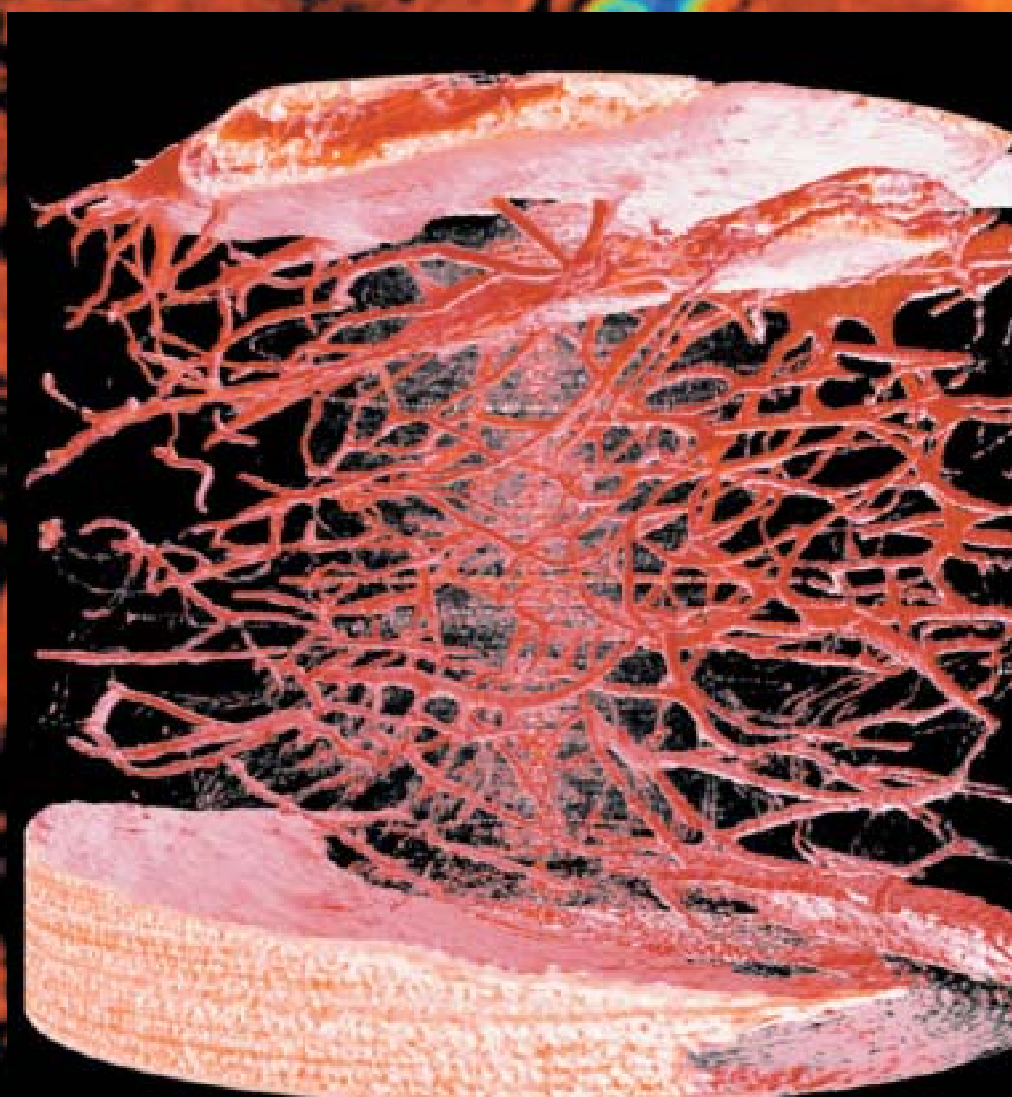
ANU scientists have built a state-of-the art facility to image materials at resolutions 1000 times greater than conventional hospital scanners. This facility allows us to image materials at scales down to the cellular level. This technology is being applied to biomedical research.

The image on the bottom right shows a small piece (5mm in diameter) of a human thigh (femoral) bone and the 3D reconstruction of the blood vessels within the bone. The channels of approximately 20 micron diameter, are visible within the bone structure.

The image below shows a visualization of the growth of tissue engineered bone within a plastic scaffold material. There is an urgent need to treat patients suffering from tissue loss and one goal of tissue engineers is to help the body grow and heal tissue without transplantation or grafts. Plastic scaffolds are used to mechanically support bone and to allow bone and blood vessel ingrowth. µCT allows scientists to visualize the bone growth into the scaffold non-destructively. This enables them to compare different techniques for promoting tissue growth and will help doctors develop optimal conditions to promote rapid healing within the body.



tissue engineered bone



blood vessels within a human thigh bone

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Stringing Together Fundamental Forces

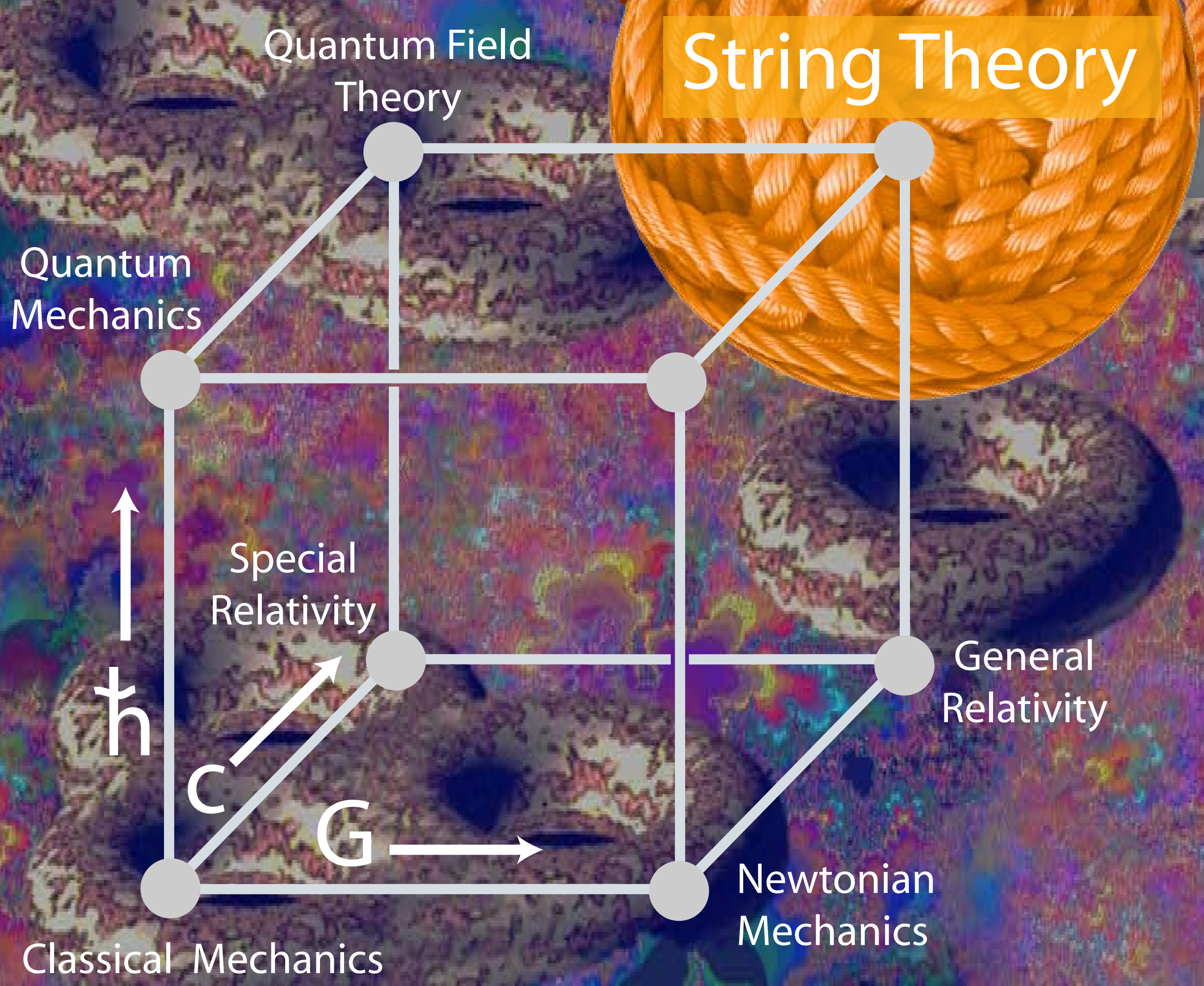
Peter Bouwknegt, Alex Flournoy, David Botman, Josh Garretson, Peggy Kao and Madeleine Smith

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 quantized strings contains both a massless spin-2 excitation, which can be identified with the graviton, (i.e. the force field of gravity) and 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.



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.

Research School of Physical Sciences and Engineering

Putting the Big Chill on Excited Atoms

R.Dall, S. Battisson, K. Baldwin and A. Truscott

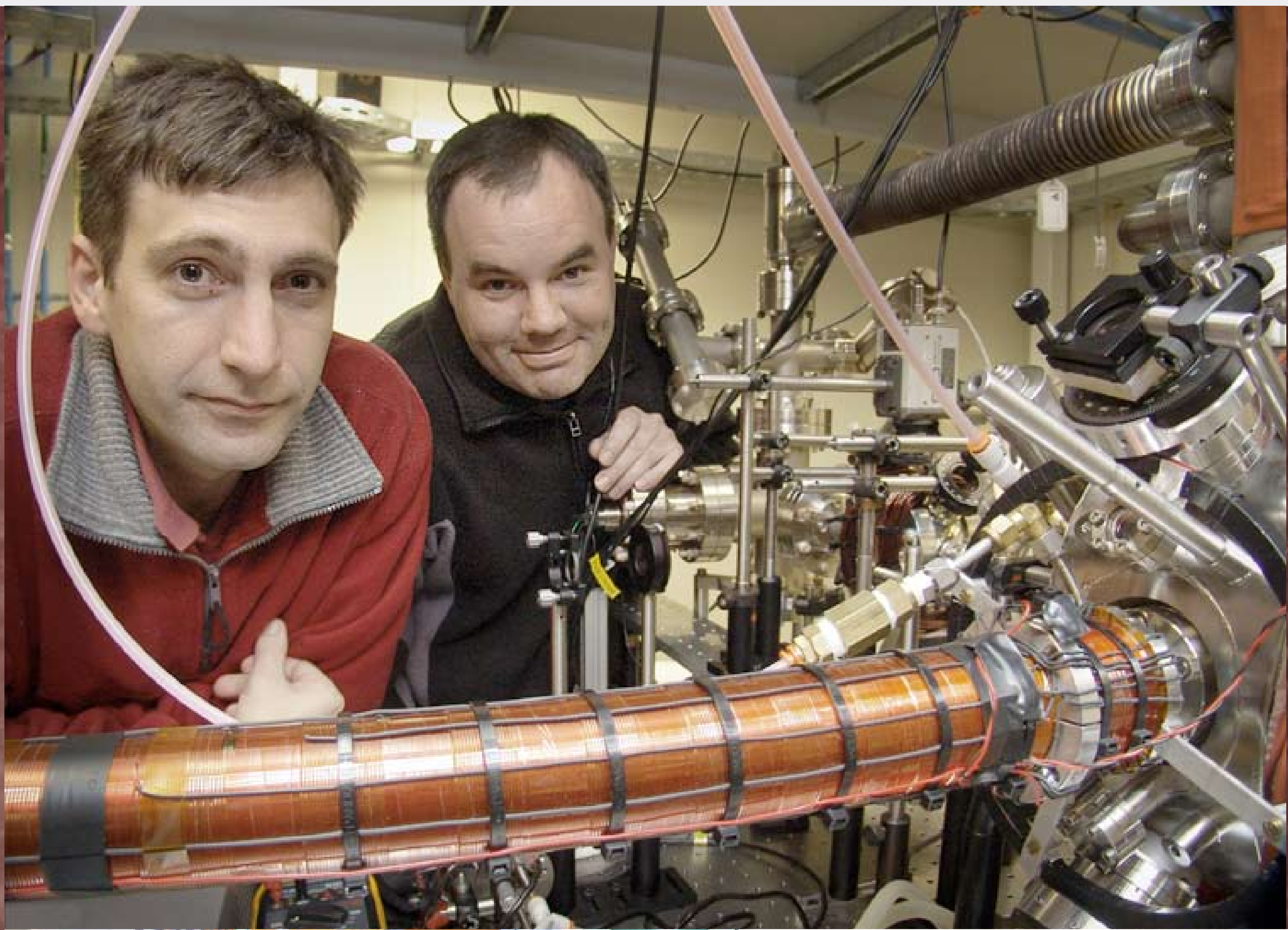
ARC COE FOR QUANTUM-ATOM OPTICS

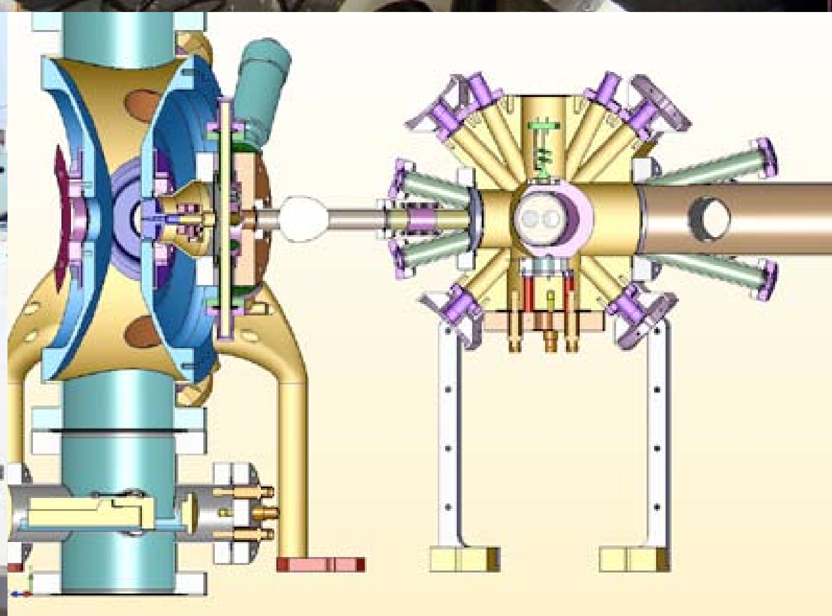
Research School of Physical Sciences and Engineering

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 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.





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.

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.

Australian Government
Australian Research Council

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

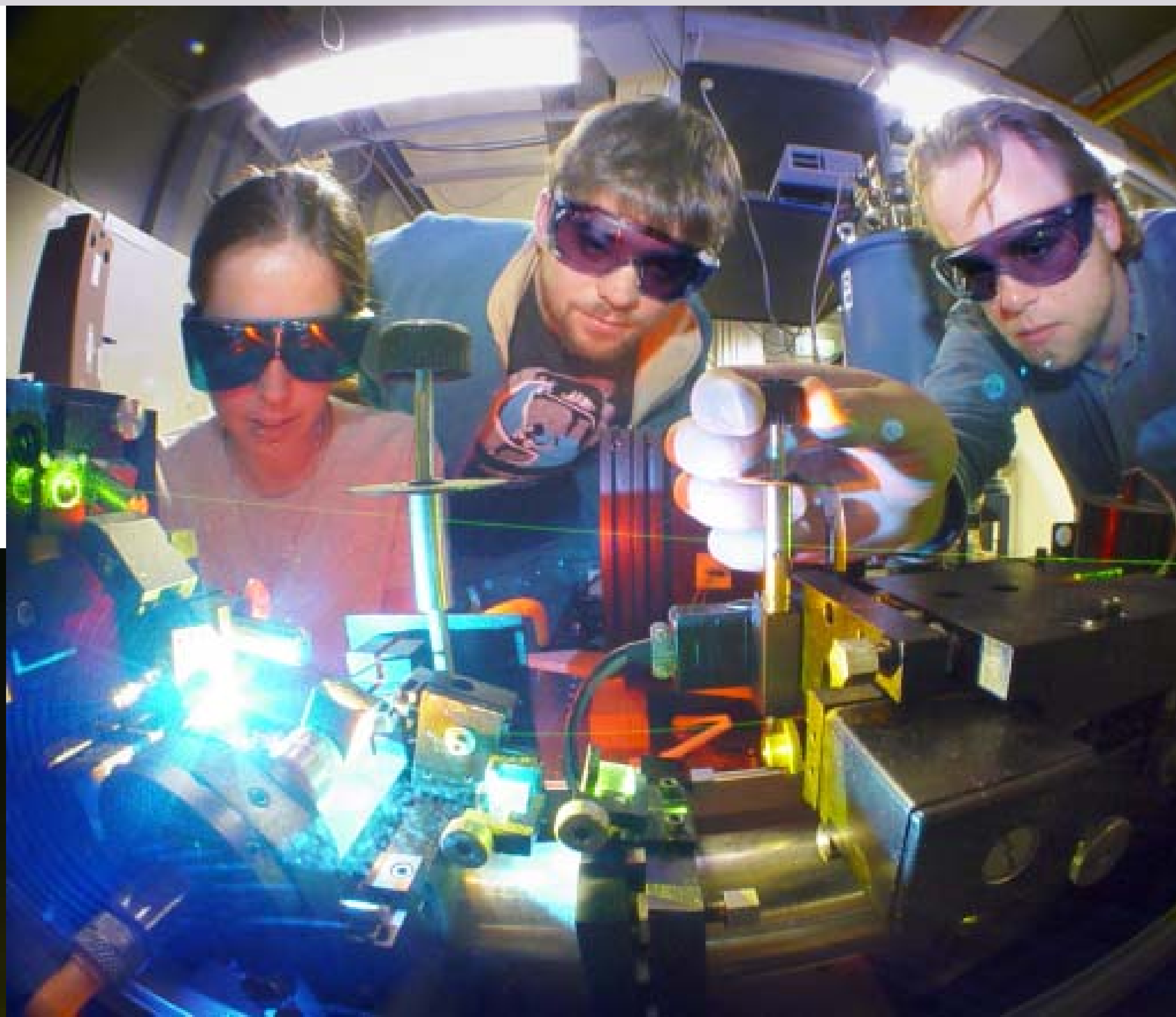
Research Highlights

THE AUSTRALIAN NATIONAL UNIVERSITY

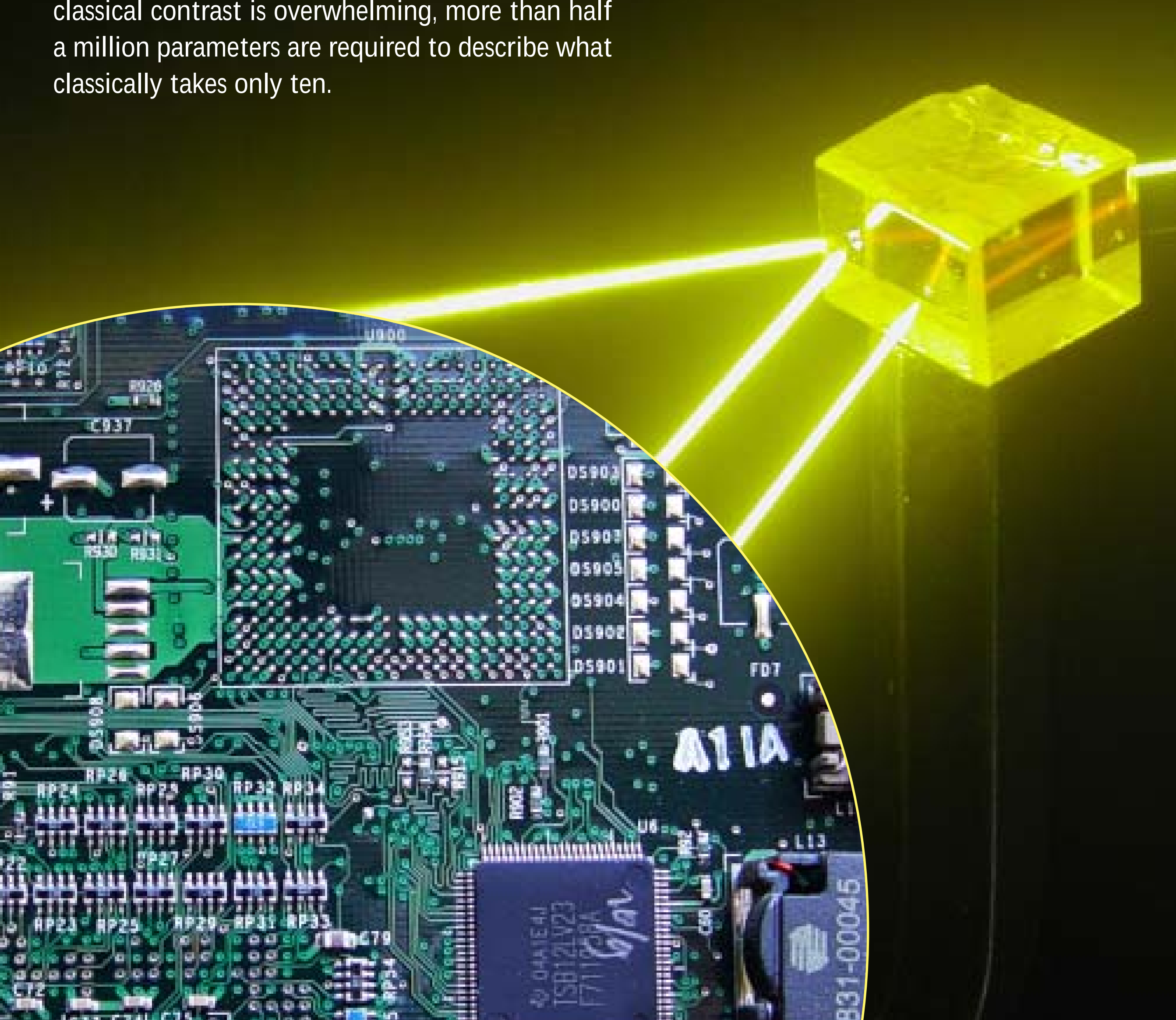
Quantum Supercomputer is a Step Closer

Matt Sellars, Jevon Longdell, Elliot Fraval, Annabel Alexander, Joanne Harison, David Pulford, Neil Manson

As the computer industry continues increasing the density of transistors on silicon chips a scale will be reached where quantum mechanical effects will introduce fundamental randomness into the chip's logic operations. This scale represents the ultimate limit for classical computing technology. These quantum effects whilst presenting a barrier, also provide a way forward. Quantum computing attempts to control and exploit quantum effects not as a means to cram more bits into silicon, but to support a new kind of computation with qualitatively different algorithms based on quantum principles.



The potentially awesome power of quantum computing is due to the numerous parameters needed to define the state of a quantum system. In a classical computer, a single 1 or 0 describes the state of a bit. In a quantum computer, each qubit has both an amplitude and phase term but in addition to this, information also resides in coherent superpositions of these states. In this way, the number of parameters rapidly increases with the number of qubits in the system. A two-qubit system has eight parameters, where equivalent classical systems have two. By ten qubits the quantum/classical contrast is overwhelming, more than half a million parameters are required to describe what classically takes only ten.



Despite the tantalizing advantages of quantum computers, there are many difficulties in realizing one. The coherence time of the quantum states has to exist for a useful computation period and data corruption through uncontrolled interactions with the outside world has to be avoided. ANU scientists are overcoming these difficulties by developing quantum technologies based on the nuclear spins associated with optically active centers in solids. The centres chosen have inherently long coherence times and the low temperatures and all optical addressing minimise interference.

This novel ANU quantum architecture was recently used to demonstrate the world's first two-qubit quantum logic operations based on solid-state impurity sites.

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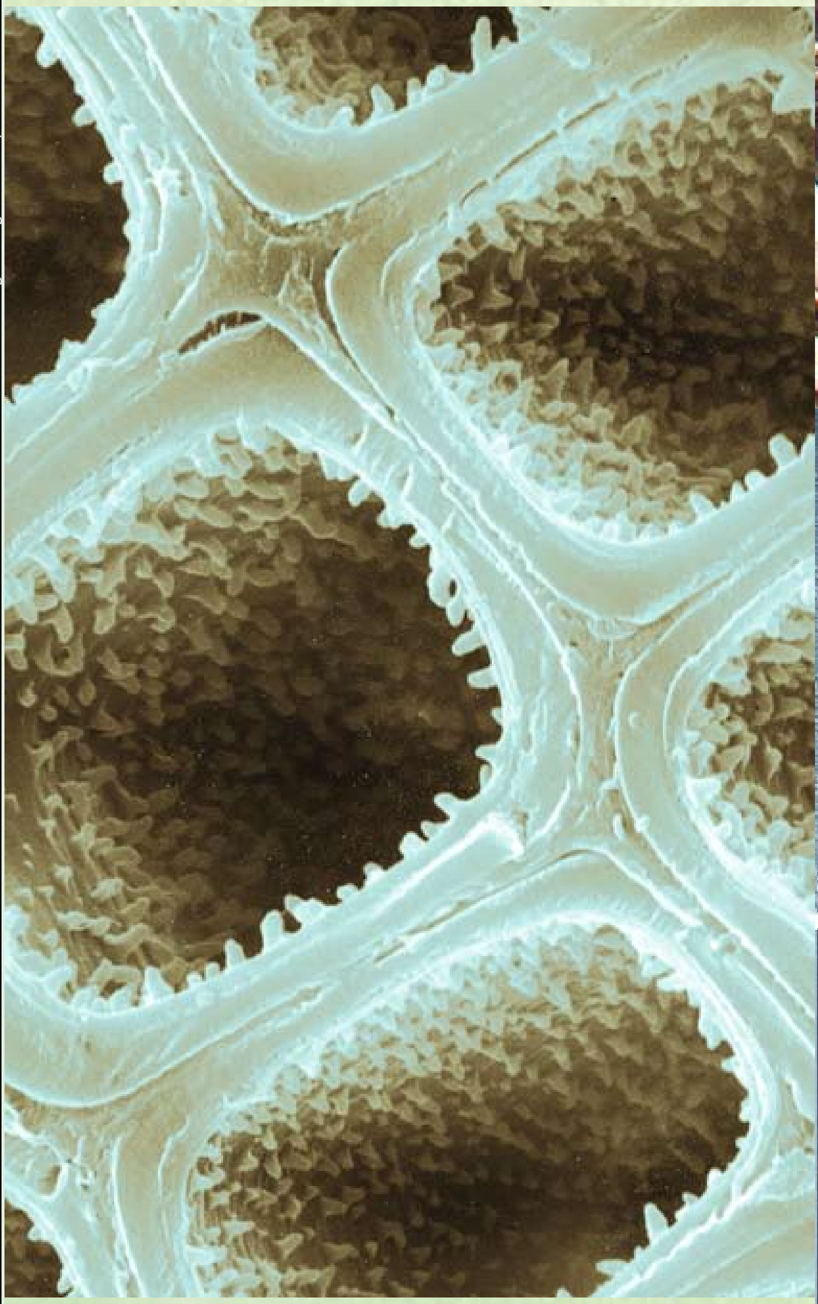
ROUGH PIPES HELP DROUGHT SURVIVAL

Mika Kohonen &
Vince Craig

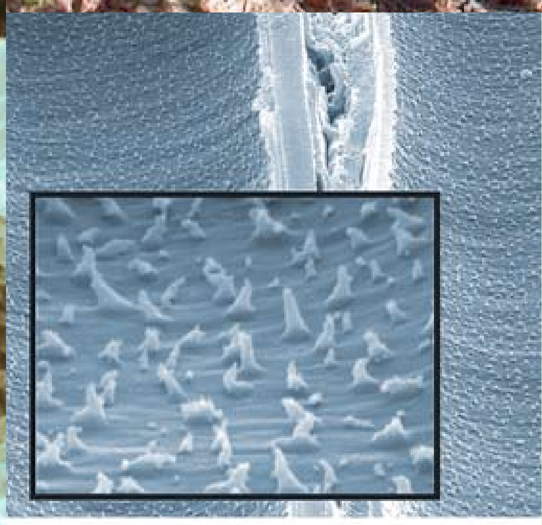
Research School of Physical Sciences and Engineering

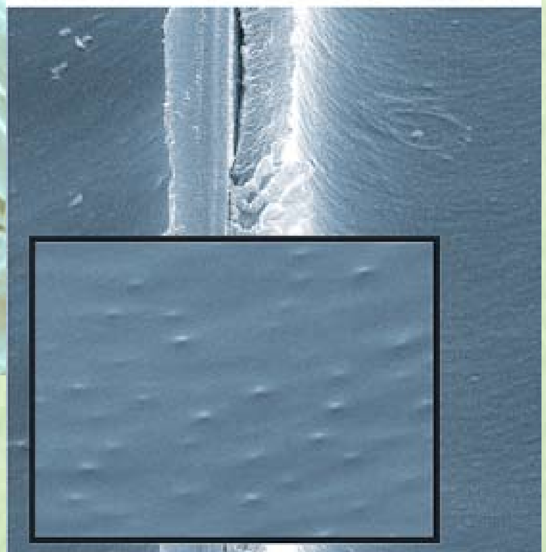
All around us everyday, plants are dealing with the problem of how to get the water from their roots in the ground to leaves which can be many tens of metres up in the air. A human engineer would solve this problem by installing a pump at the roots, because if you try to suck a tall column of water from the top, it simply cavitates, or forms bubbles. However, it turns out that plants pay no heed to this conventional wisdom; they use evaporation from the narrow pores in the leaves to draw long columns of water up through millions of hollow tubes, or xylem conduits, which are formed from dead cells known as tracheids and vessels. The mechanism is brilliant in that it costs the plant no energy to pump large quantities of water, but it suffers from the vulnerability that once a water column is broken by a bubble, the flow stops. Scientists used to believe that once the flow in a xylem conduit was stopped by a cavitation bubble, that particular conduit was lost to the plant forever. However, more recent work suggests that some plants are able to recover from cavitation.

Image: Roger Heady



Many drought resistant plants have curious structures, such as knobs and ridges, on the inner walls of their xylem conduits, whilst those from wetter areas commonly have smooth walls.





New research at The Australian National University may be about to shed light on how some plants are able to pull off this vitally important feat. When looked at under very high magnification, the xylem conduits of plants with good drought tolerance tend to have rough knobbly walls, whilst those with poor drought tolerance have smooth walls. The ANU scientists believe that the rough surface structures, in combination with deposited sap residue, enable the slightly hydrophobic walls to re-wet themselves, and that this in turn enables the cavitated xylem conduit to be refilled.

This research not only promises to aid in solving one of the longest standing mysteries in plant biology, but may also help in developing new and improved crops better suited to dry conditions. And with climate models predicting decreasing rainfall in many areas of Australia, this may have massive economic benefits.

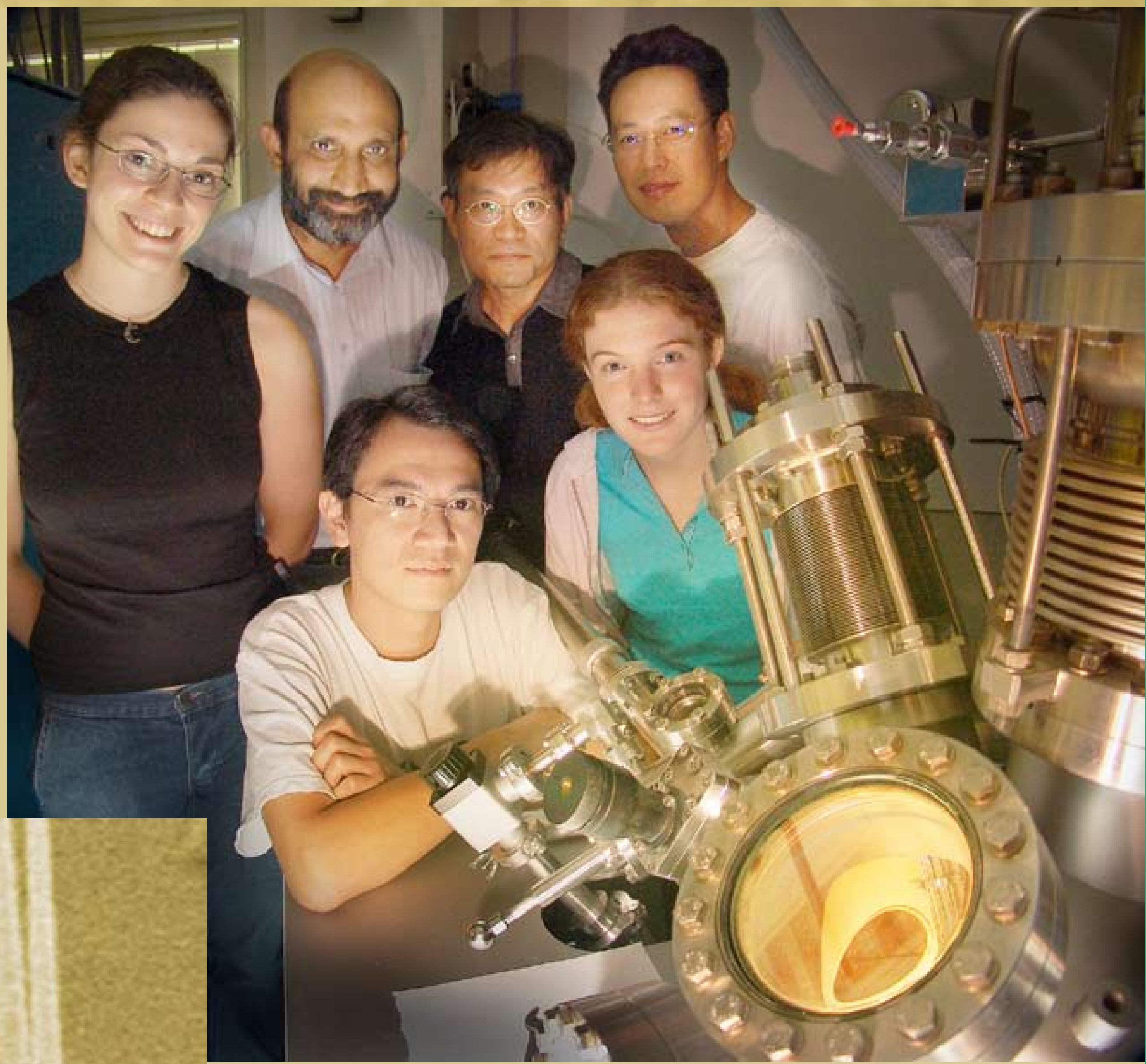
THE AUSTRALIAN NATIONAL UNIVERSITY

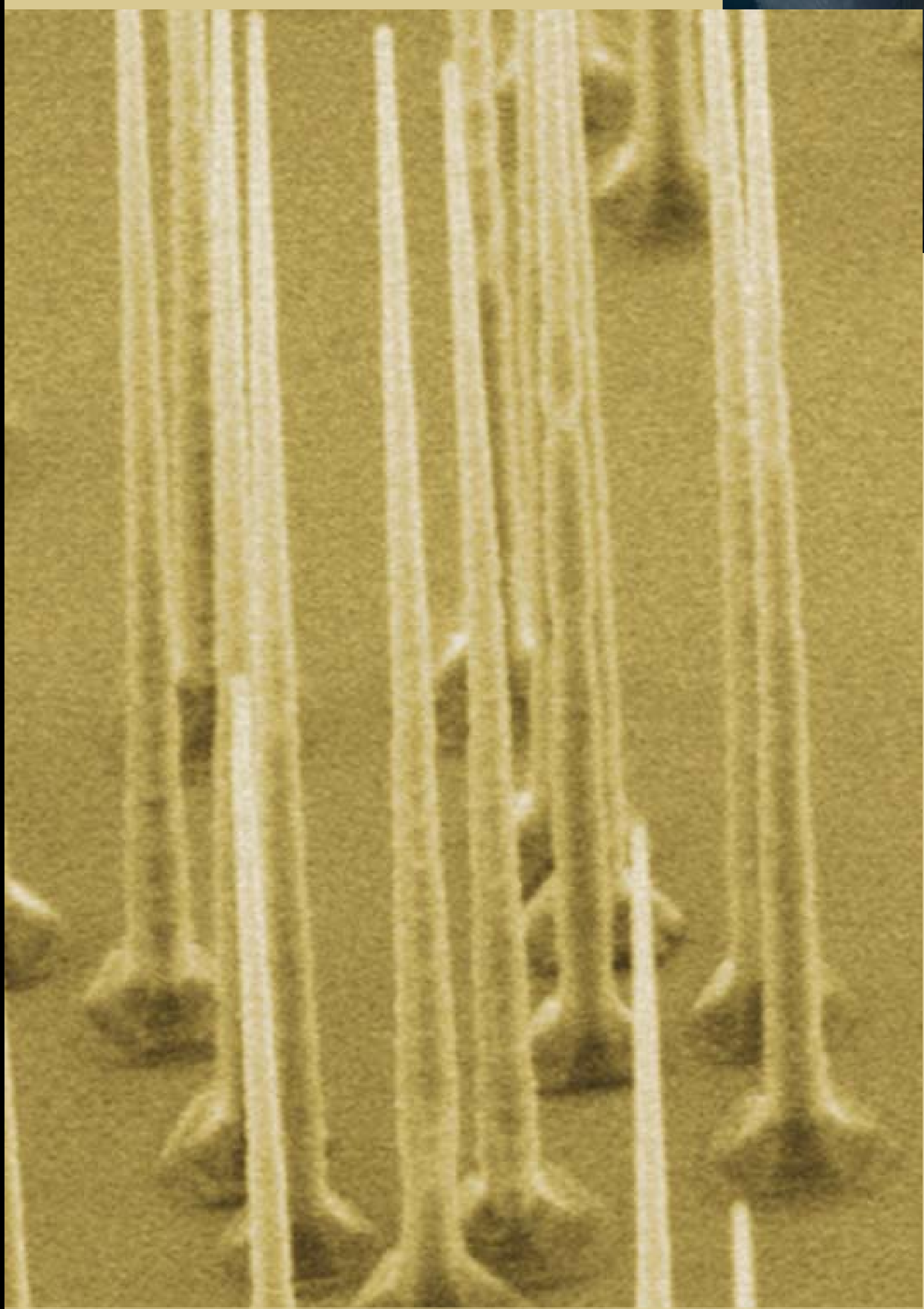
GOLDEN SEEDS TO GROW NANOWIRE LASERS

Chennupati Jagadish, Yong Kim, Qiang Gao, Hannah Joyce, Victoria Coleman Lan Fu & H. Hoe Tan

Research School of Physical Sciences and Engineering

Gallium arsenide is a semiconductor with many applications in solid-state lasers and detectors. One way to make such devices is a technique known as Metal Organic Vapour Phase Epitaxy or MOCVD. A complex molecule is formed between an organic group and the metalic component atoms of the required semiconductor. When passed over a heated substrate wafer, the molecules dissociate, depositing their metallic cargo atoms on the surface where they combine with arsenic from arsine dissociation to form new layers of semiconductor crystal. By changing the composition of the gases, it is possible to grow layers with different properties creating the sandwich structures needed for devices. The wafers can then be cleaved into individual device chips. The problem is that some devices such as nanowire lasers, can't be grown in a large sheet then cut into individual chips. They have to grow straight up like tiny hairs rising from the wafer surface. To create such devices, scientists at ANU make use of an interesting property of gold/ gallium arsenide mixtures.





Nanowire lasers rise like skyscrapers from the substrate wafer. The base of these structures is only a couple of hundred atoms across.

At the right temperature and pressure, gold and gallium arsenide form a eutectic - an alloy of the two materials with a lower melting point than either of its components. If a wafer of gallium arsenide is covered with microscopic gold spots and heated to just the right temperature, a tiny pool of liquid eutectic forms below each spot. When the MOCVD reactor is tuned to this eutectic point the temperature is too low for efficient deposition onto solid Gallium Arsenide so the metal organic and arsine molecules deposit their semiconductor cargo on the wet eutectic below each gold seed rather than the wafer surface. This causes the material below the seed to grow and crystallise into miniature towers of perfect semiconductor pushing the gold seed and its eutectic base upwards as they do so.

Conventional fabrication techniques such as the masking and lithography used in computer chip manufacture, simply can't make gold spots small enough to seed good nanowires. So the ANU group use nanometer sized gold balls suspended in solution. Due to their inherent electrical charge, the tiny gold particles stick electrostatically to the surface of the specially prepared wafer in a similar way to toner on photocopy paper.

With the conditions set just right, these tiny seeds can grow perfect straight nanowires 50 times as long as their 200 atom thickness. The wires are then coated with another semiconductor, aluminium gallium arsenide, which has a lower refractive index. This creates a tiny optical fibre only a few tens of atoms across. At one end of these fibres is the original gold seed, which not only makes a good laser cavity mirror but also a perfect electrical contact.

Due to their tiny size, such nanoscale fibre lasers can be modulated at vastly higher speeds than conventional telecommunications lasers offering the potential to speed up the networks. They also have very low threshold lasing currents reducing power consumption and unwanted heating effects.

Research Highlights

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Electric Double Layer is Secret Behind Revolutionary Space Thruster

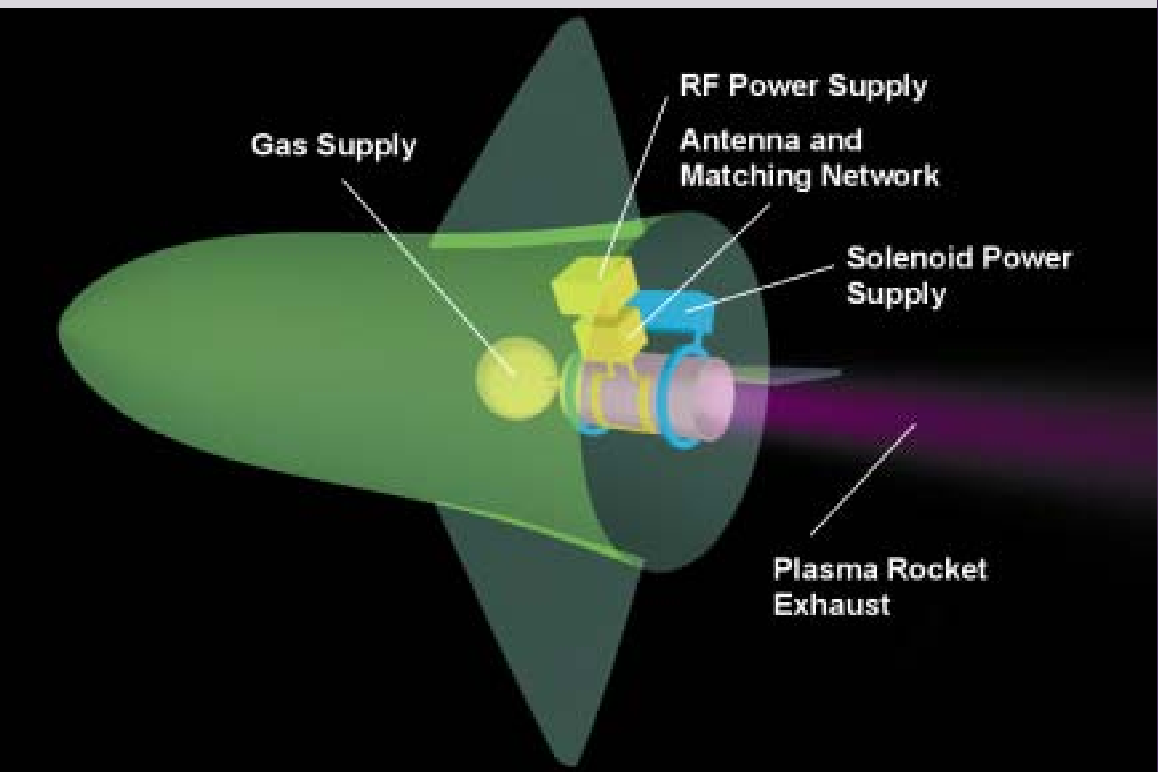
Dr C. Charles, Professor R.W. Boswell

One of the most beautiful mysteries in the heavens is the aurora which is seen during winter months at latitudes about 20 degrees away from the poles. These "lights in the sky" are caused by the impact of electrons on the upper atmosphere which excite various lines of oxygen and nitrogen resulting in the splendid colours and draperies. Many believe that the basic mechanism underlying most of the observable phenomena is the existence of a large electric double layer situated about one earth radius (about 6000 km) above the visible auroral regions.

An electric double layer is a local region in a plasma which can sustain a potential difference, much like a cliff of potential (like a riverwaterfall) that can energise charged particles falling through it. These double layers are rather exotic objects that can only be described by resorting to non-linear physics.

Apart from being an interesting phenomenon for space plasma physics, the ions accelerated by a double layer can be used for thrust in a space craft.

Scientists at the ANU are currently building a prototype of the Helicon Double Layer Thruster (HDLT) which will be tested at the ESA (European Space Agency) in Europe.



The ANU space thruster is simple, has no moving parts, no electrodes and no need for a neutraliser. Both the research (CHI KUNG reactor) and development (HDLT prototype) efforts are being carried out in parallel by a team of scientists and PhD students in collaboration with astrophysicists, rocket physicists, and plasma physicists around the world.

Research School of Physical Sciences and Engineering

ANU Materials Science Questions Pedigree of Martian Bugs?

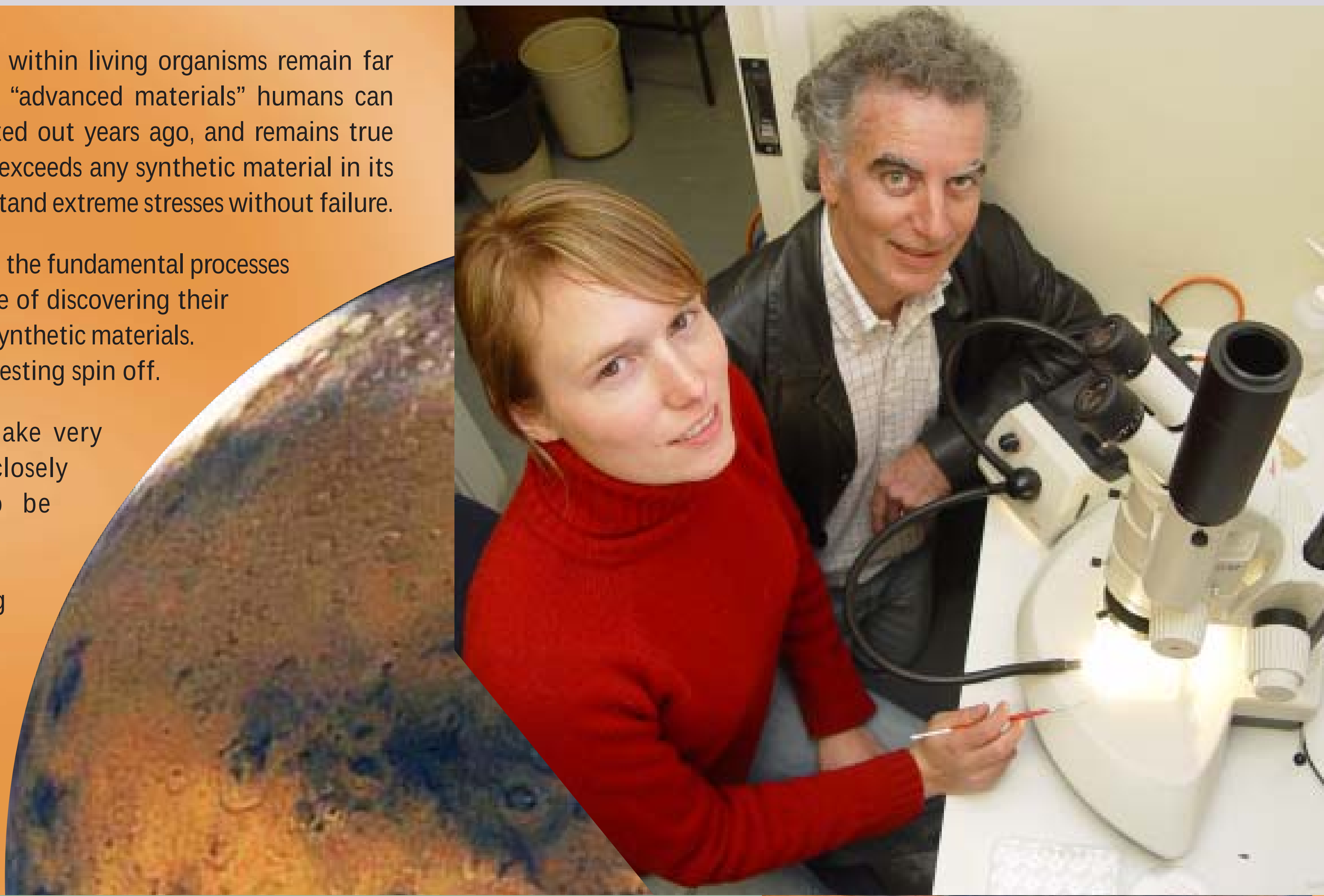
Stephen Hyde, Anna Carnerup, Andy Christy and Ankie Larsson

There is no doubt that materials made within living organisms remain far more advanced than the most lauded “advanced materials” humans can synthesize in the lab. It has been pointed out years ago, and remains true today, that a humble blade of grass far exceeds any synthetic material in its resistance to fracture and ability to withstand extreme stresses without failure.

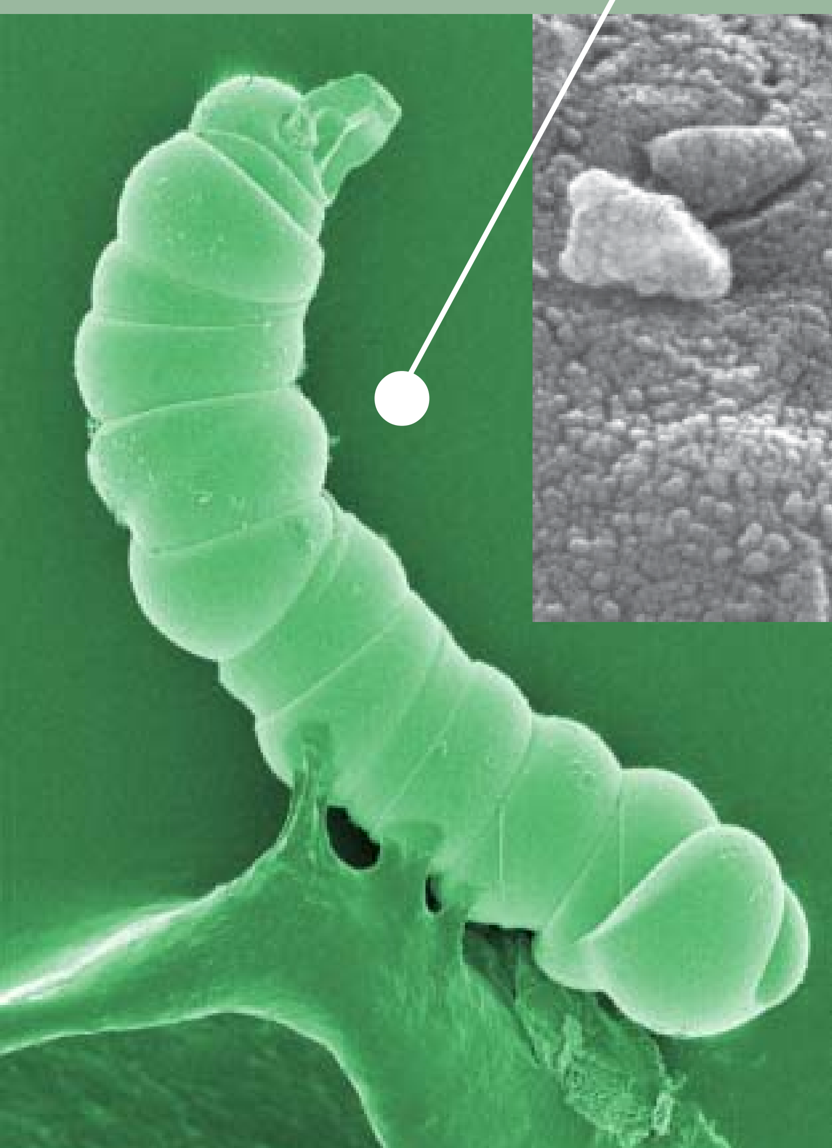
Scientists at the ANU have been studying the fundamental processes behind biological structures in the hope of discovering their secrets and applying them to advanced synthetic materials. However this work has also had an interesting spin off.

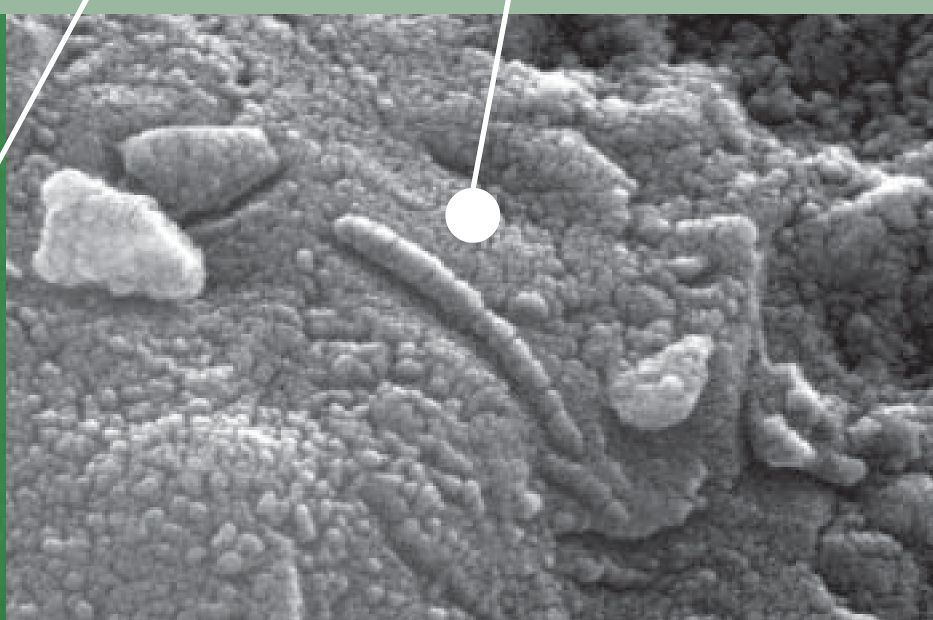
ANU scientists have been able to make very complex structures in the lab that closely resemble what were assumed to be microfossils in natural rock.

The syntheses are very simple, requiring only a source of carbonate ions (e.g. atmospheric CO_2), strong alkaline aqueous solutions, silica and rare earth cations (Ba and Sr, Ca at high T) - all common ingredients in early planetary formation.



Dead or Alive? Synthetic silicate & fossil from Mars





This discovery has profound implications for our understanding of early life on earth. It also casts a different light on worm like structures in the Martian meteorite found in Antarctica. The ANU synthetic silicates bear an uncanny similarity to the Mars microbe!

Research Highlights

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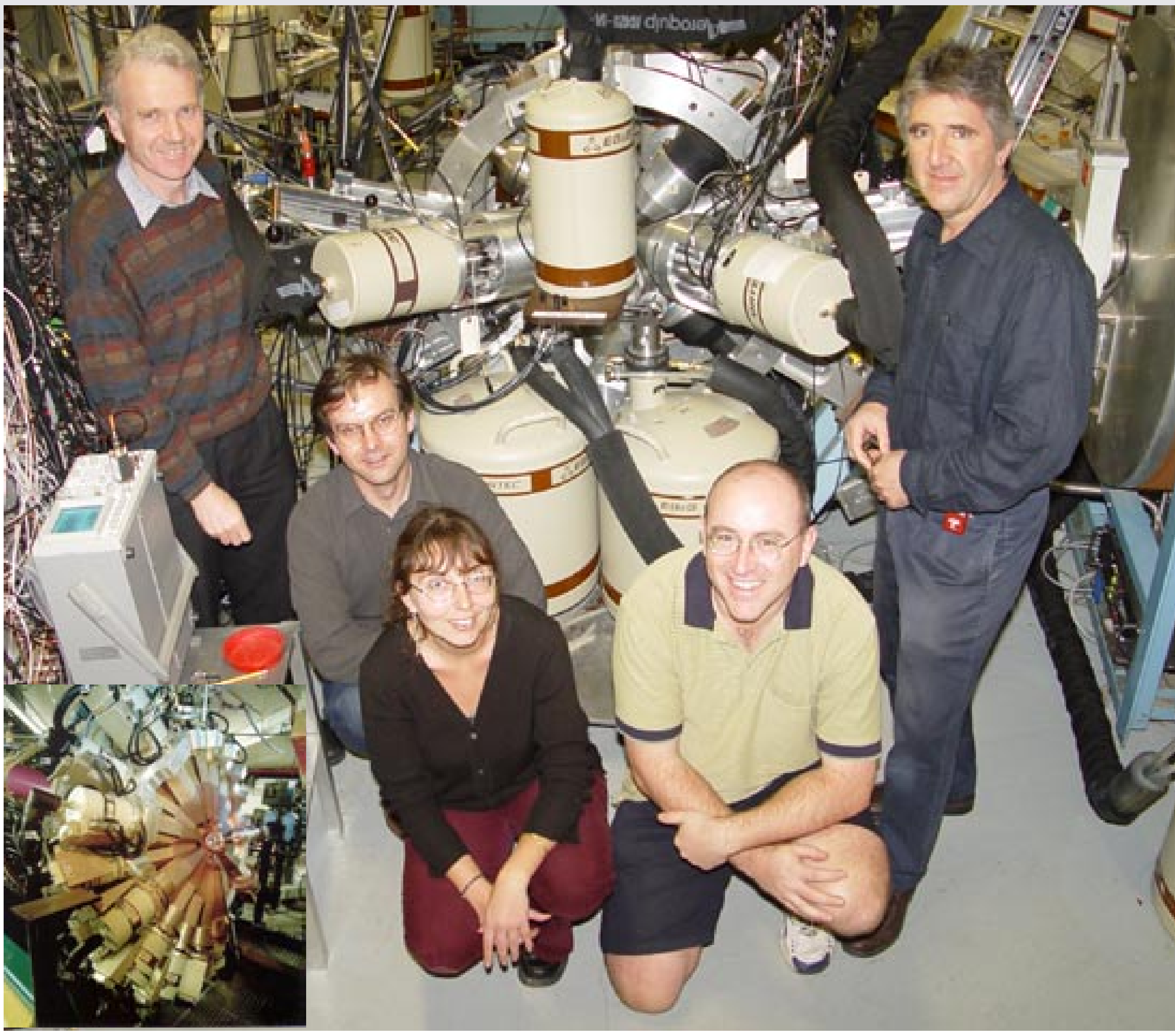
Nuclear Spin Doctors Uncover Missing Link

Anna Wilson, George Dracoulis, Aidan Byrne, Paul Davidson and Greg Lane

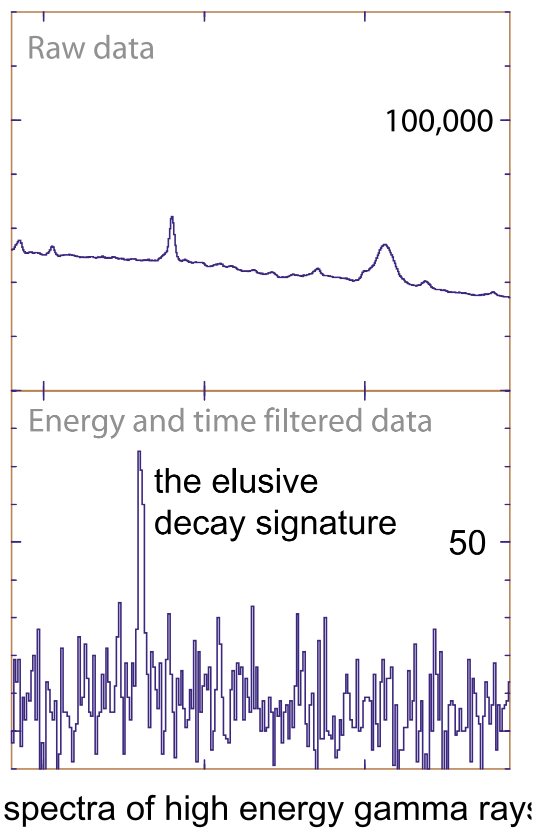
In the mid 1980's scientists made the surprising discovery that some atomic nuclei can spin themselves into highly deformed states without breaking apart. Even more surprising was the discovery that these superdeformed states have lower energies than many of the less deformed intermediate states. This creates a puzzle for scientists. How does the nucleus get from being superdeformed back to spherical without having to overcome the high energy barrier that the intermediate states pose?

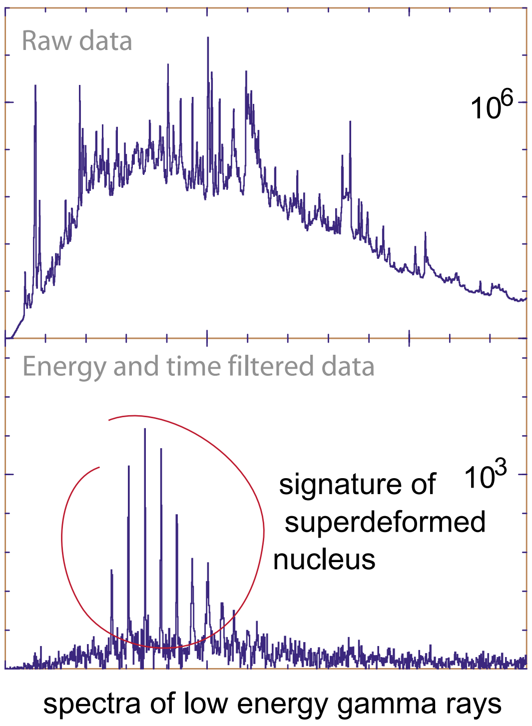
The key to understanding this phenomenon lies in studying the gamma rays emitted by the nucleus as it changes shape. It's possible make the nucleus adopt the superdeformed shape using a fusion reaction - but unfortunately, that also creates hundreds of different excited nuclear states only a tiny proportion of which are the superdeformed states of interest. Consequently, the gamma ray signature of the superdeformed nucleus is buried under thousands of other signals. To make matters worse, there can be thousands of possible decay paths from the superdeformed to normal nuclear shapes. This means that even if the superdeformed signature can be isolated, it's still very hard to uncover the signature of the shape change itself. However, scientists at the ANU have recently developed an ingenious solution to this problem. By adapting existing time sensitive data acquisition techniques, they have been able to filter the gamma ray emissions in order to focus their attention on decay pathways leading to particularly long-lived states. In this way the thousands of short lived decay processes that normally swamp the signal can be ignored. It's like trying to hear a pin drop at the same time as a gun shot. If you can delay the pin slightly, and only turn the microphone on after the shot your chances improve dramatically.

Using these special techniques and the Gamma Sphere facility at Lawrence Berkley National Laboratory in the USA, ANU scientists have been able to identify the illusive superdeformation spectrum for the lead isotope ^{192}Pb. These results look set to inspire a new theoretical investigation of superdeformation decay.

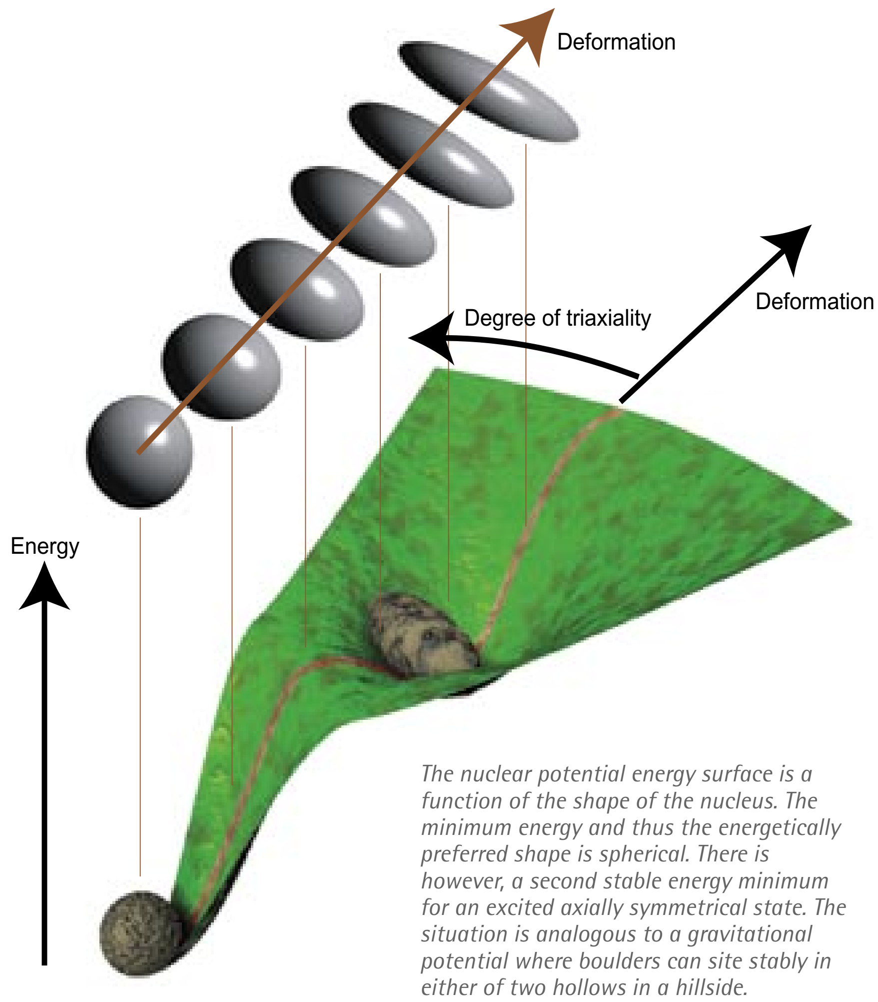


Researchers with the ANU gamma detector and insert: the gammasphere in the USA used to collect this data





Gamma ray spectra before and after application of the new energy and time filters. Prior to filtering, the superdeformation decay was swamped by other emissions 2000 times more intense.



The nuclear potential energy surface is a function of the shape of the nucleus. The minimum energy and thus the energetically preferred shape is spherical. There is however, a second stable energy minimum for an excited axially symmetrical state. The situation is analogous to a gravitational potential where boulders can site stably in either of two hollows in a hillside.

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Research Highlights

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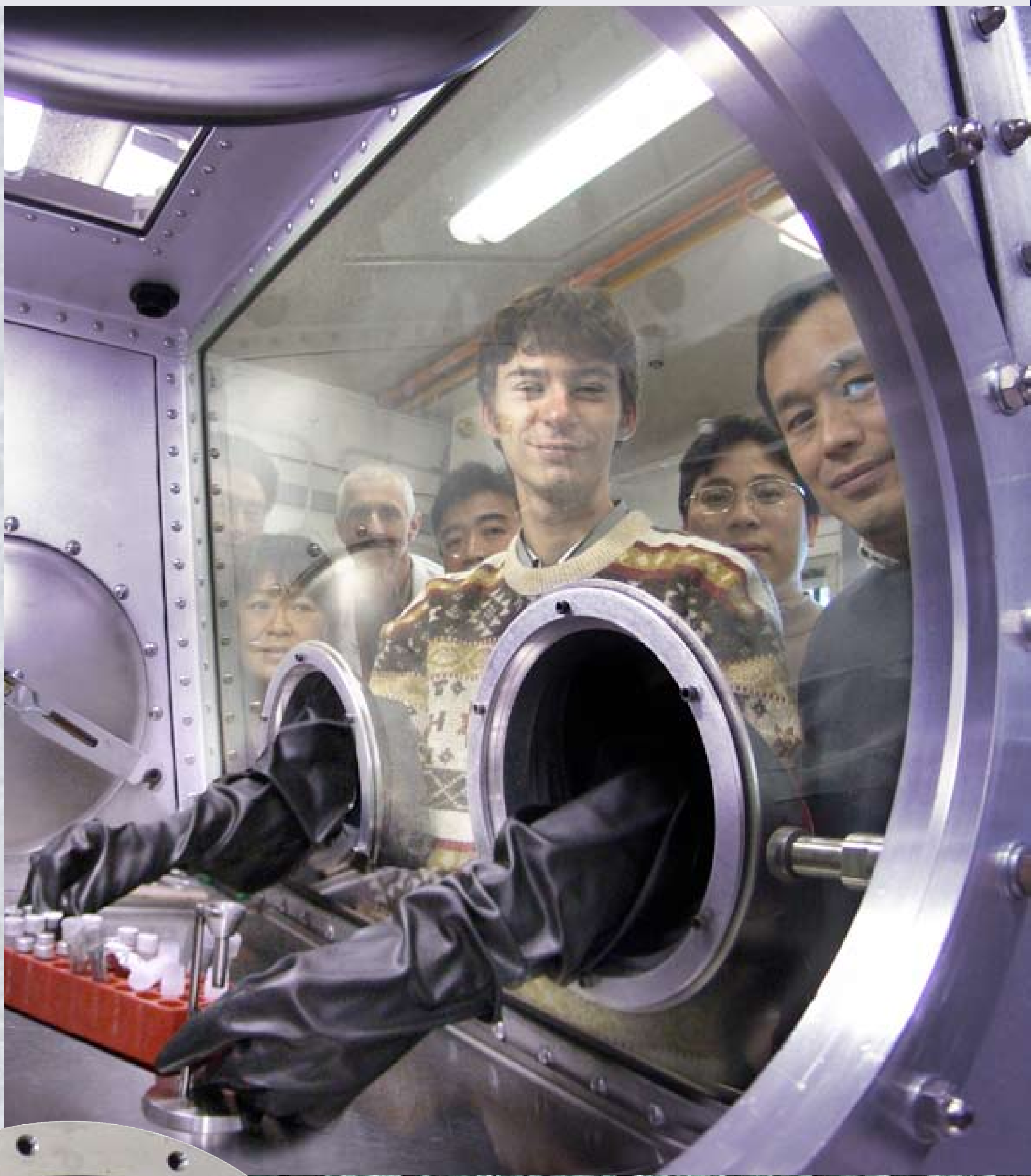
Cleanroom Science on the Road to Cleaner Air

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

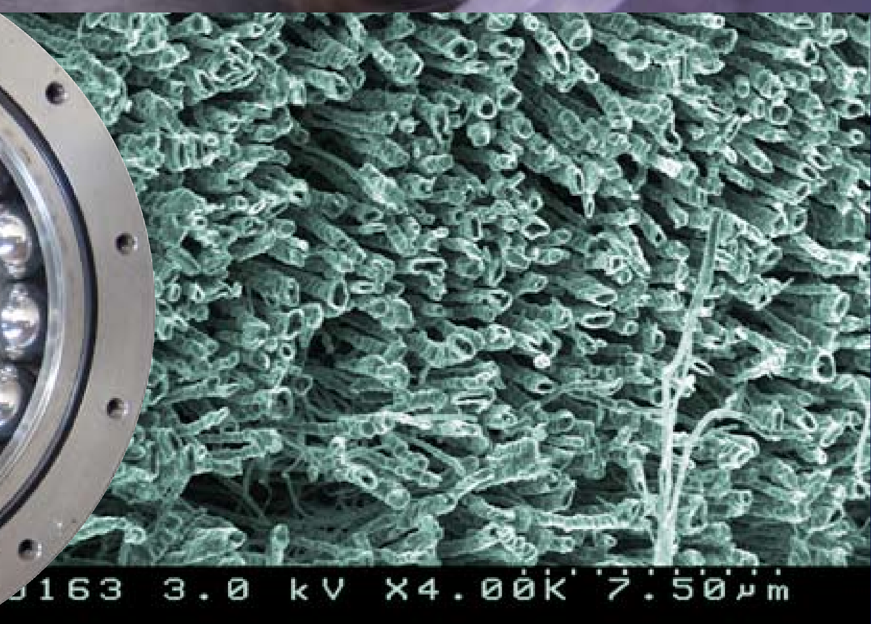
Rising world oil prices and concerns about greenhouse gas emissions are increasing pressure to find a viable alternative to petrol and diesel as transport fuels. One very promising candidate is hydrogen which can be combined with atmospheric oxygen in fuel cells to produce the large quantities of electrical 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 of 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.



Ball milling of graphite powder may the key to efficient production of carbon nanotubes such as those pictured to the right,. (A human hair on the same scale would be 100 times thicker than the width of this page



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

Nuclear Fingerprints Frozen in Time

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

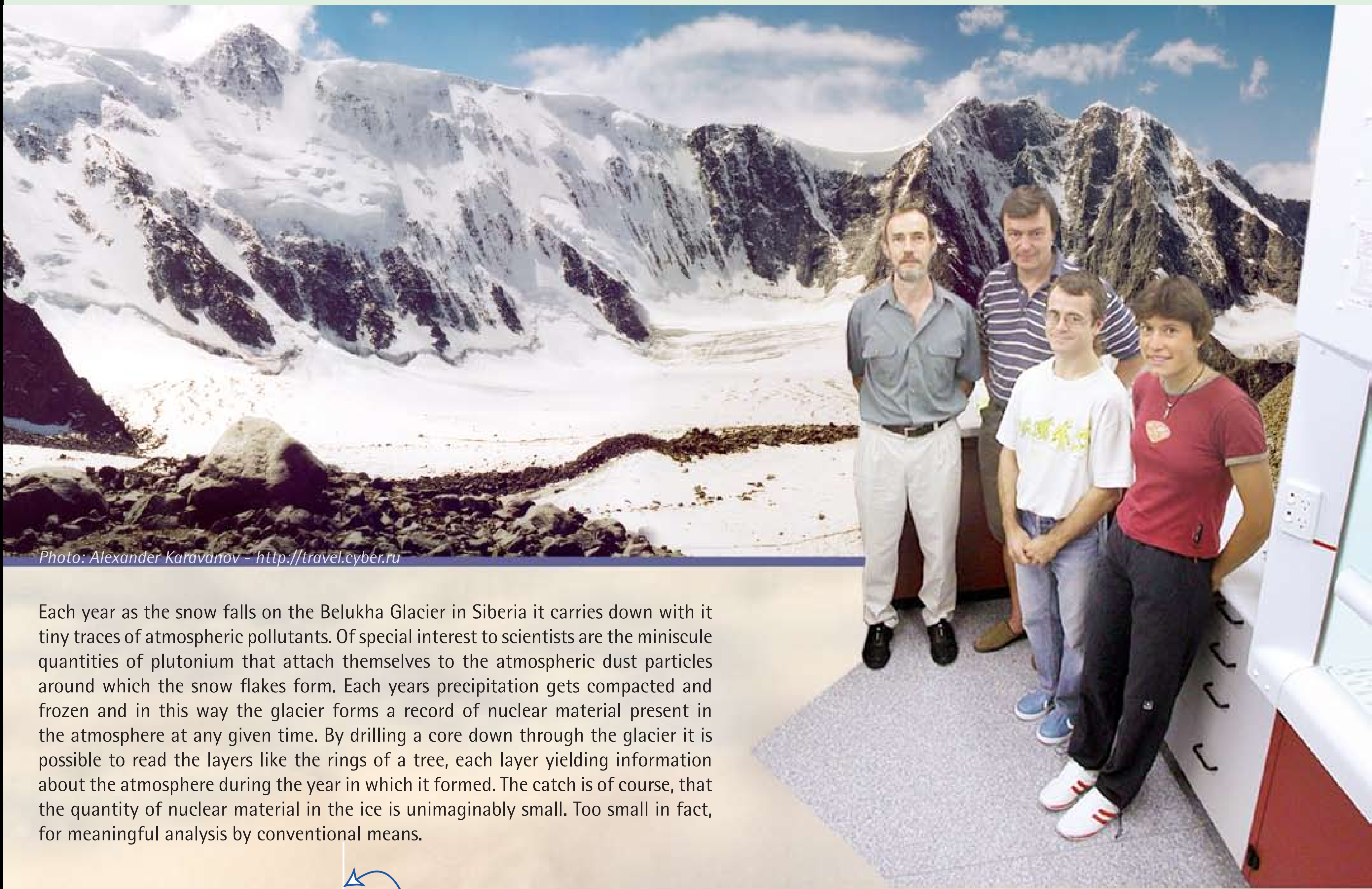
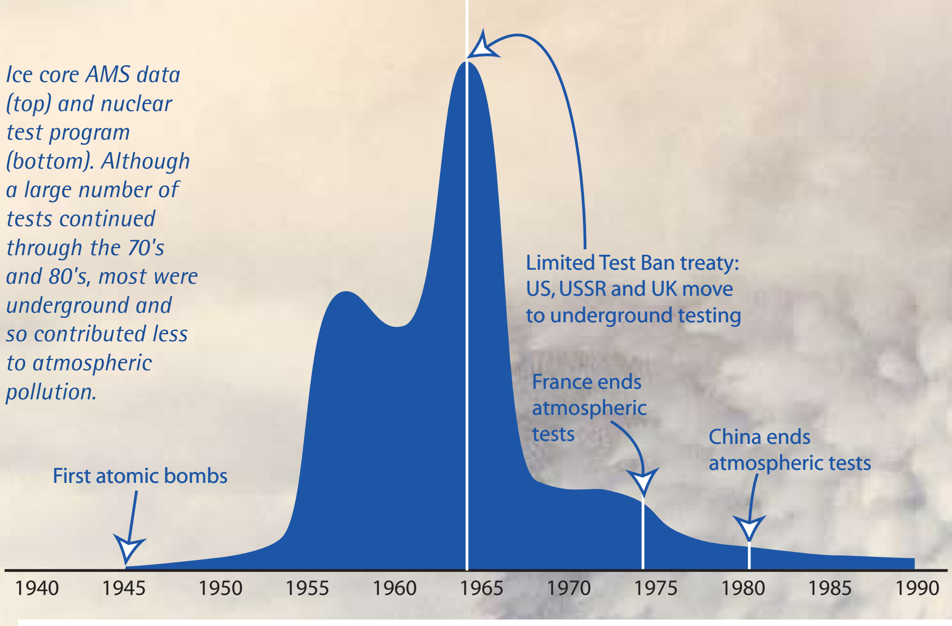
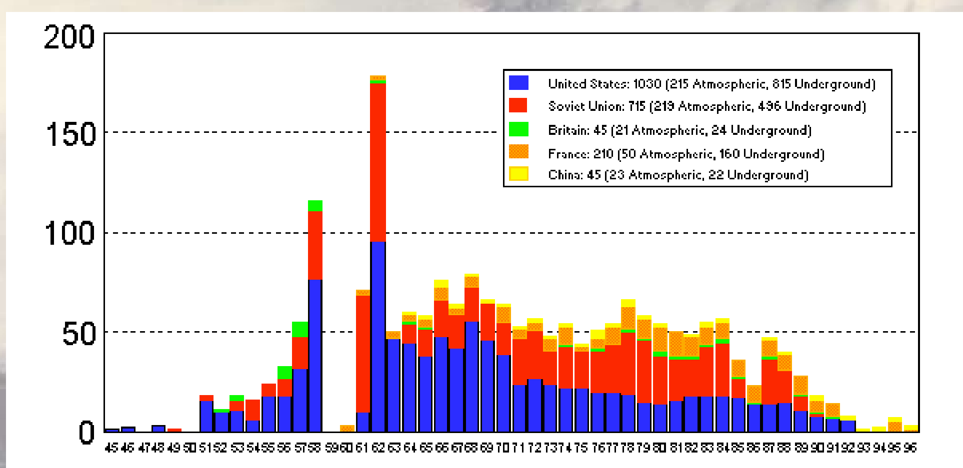


Photo: Alexander Karavanov - http://travel.cyber.ru

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.

Ice core AMS data (top) and nuclear test program (bottom). Although a large number of tests continued through the 70's and 80's, most were underground and so contributed less to atmospheric pollution.





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.

Research Highlights

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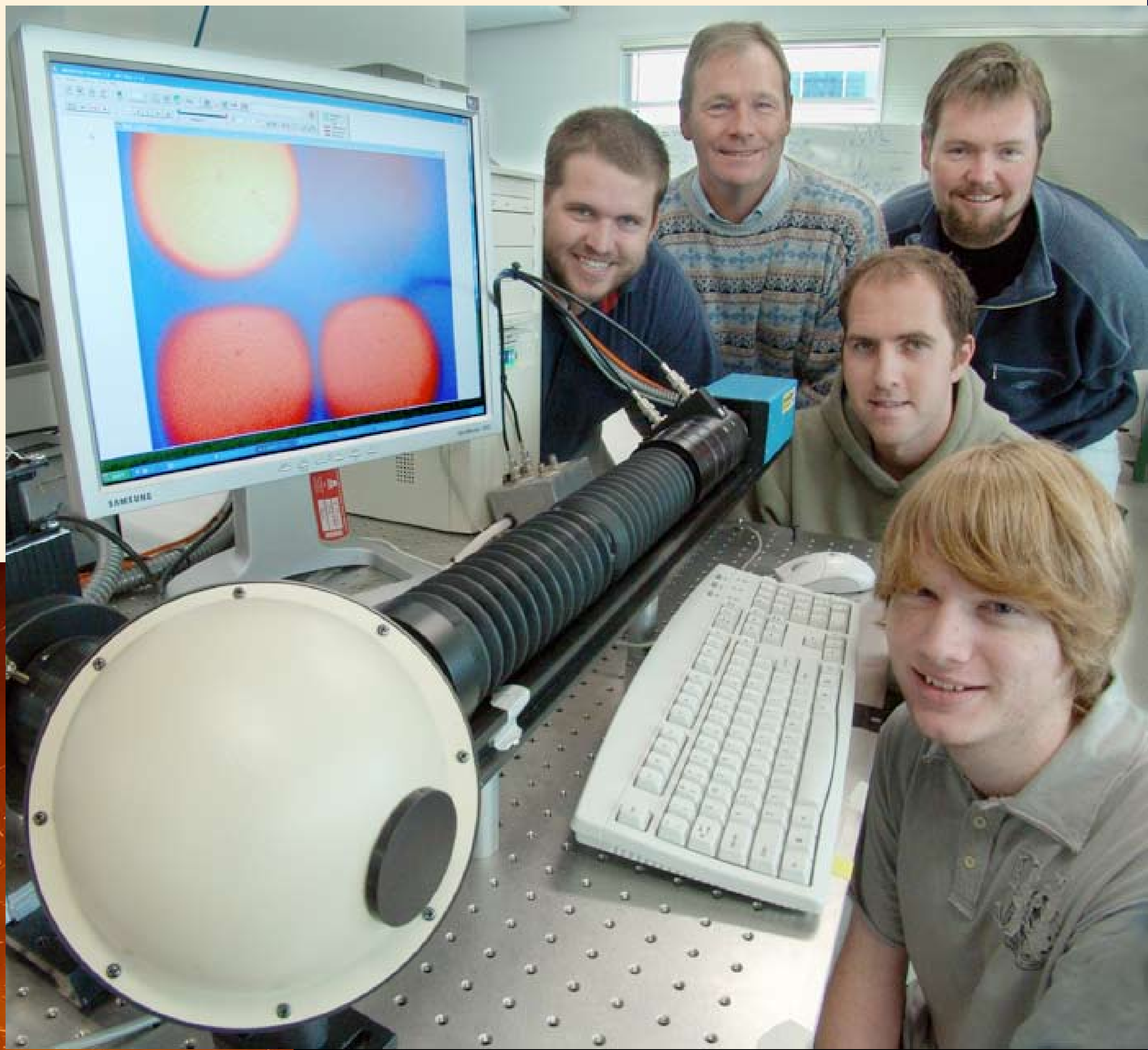
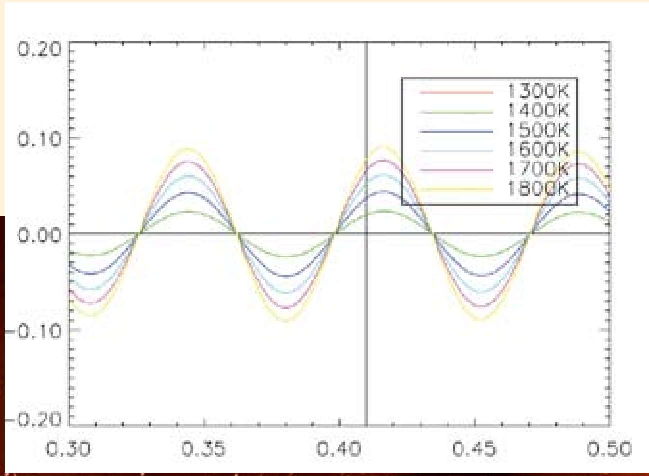
Plasma Diagnostic Solves Steel Industry Problem

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



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).



Interferometer waveform for sources of different temperature


Photo courtesy US Navy


Prototype MOSS camera undergoing testing at Bluescope Steel

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.

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Research Highlights

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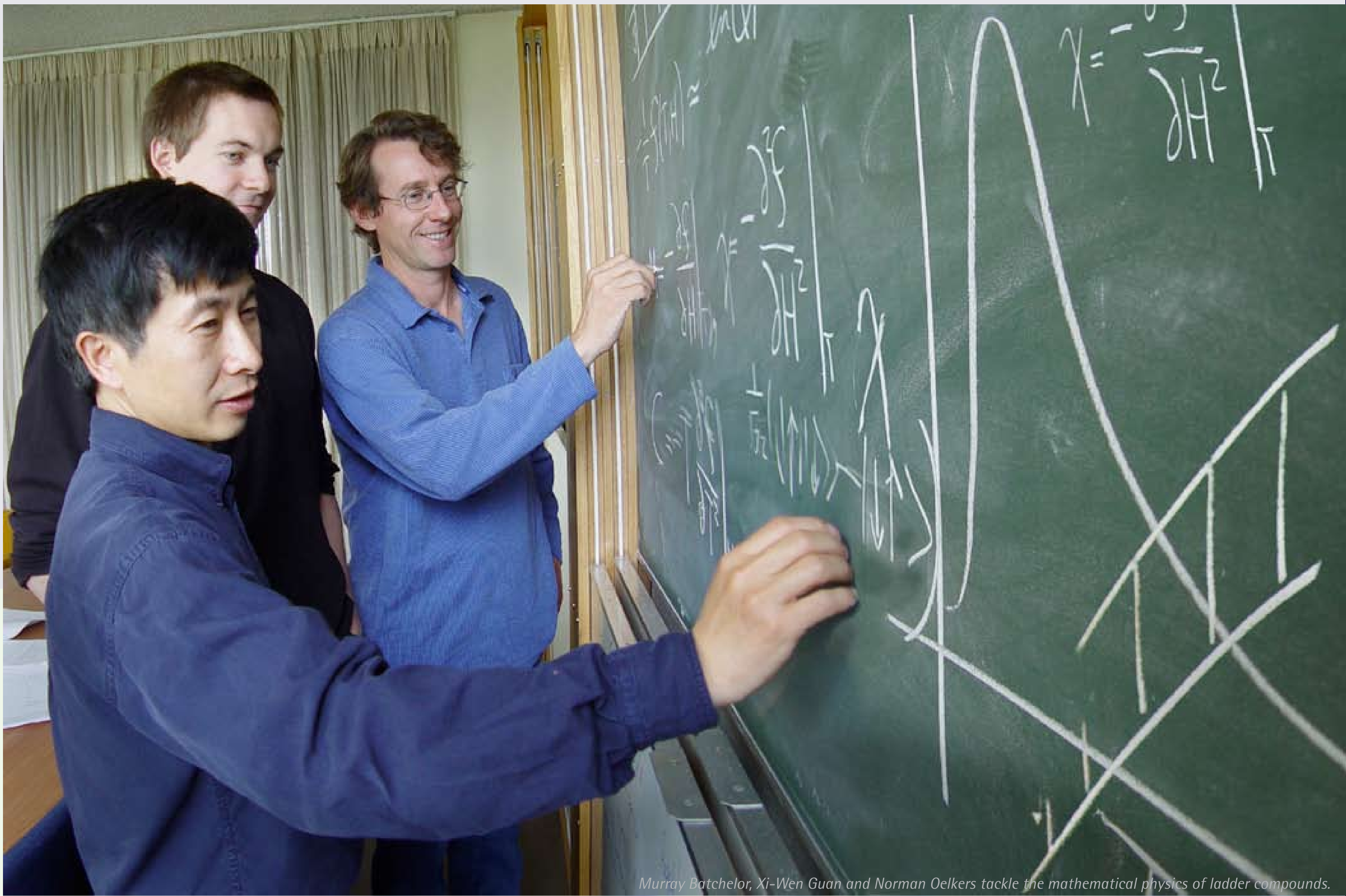
Climbing Quantum Ladders

Murray Batchelor, Xi-Wen Guan and Norman Oelkers

Research School of Physical Sciences and Engineering



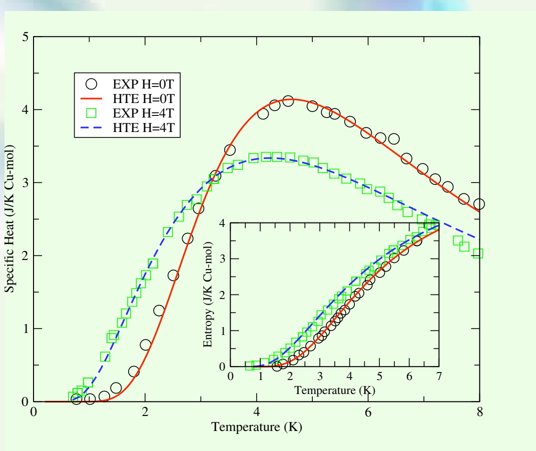
Murray Batchelor, Xi-Wen Guan and Norman Oelkers tackle the mathematical physics of ladder compounds.

The experimental realisation of novel materials with a ladder-like structure is contributing to the intense interest in low-dimensional quantum systems, which are made up of fundamental arrays of interacting quantum spins. The calculation and understanding of their physical properties provides a key challenge to theorists.

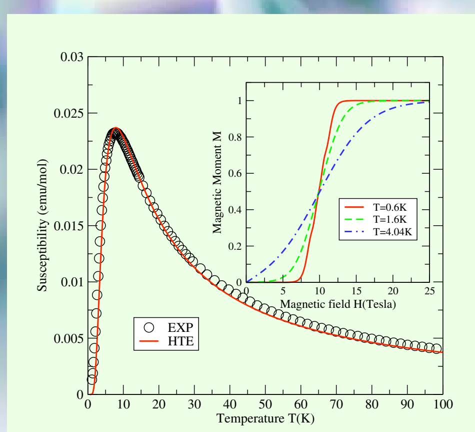
Physicists at the ANU are leading the application of integrable models to the physical description of the ladder compounds. Their work brings over 40 years of mathematical development of the theory of integrable models into direct contact with experiment. Integrable models are unique in that their physical properties can be calculated exactly, thus being far superior to numerical and perturbative approaches.

Excellent agreement between the theoretical curves calculated from the integrable ladder model and the experimental data has been found for a number of ladder compounds. Shown here are results for the spin-1/2 compound $Cu_2(C_5H_{12}N_2)_2Cl_4$, also known as CuHpCl. The calculations include the magnetic susceptibility and the specific heat as functions of magnetic field and temperature. The critical magnetic fields, defining quantum phase transitions, also follow from this approach.

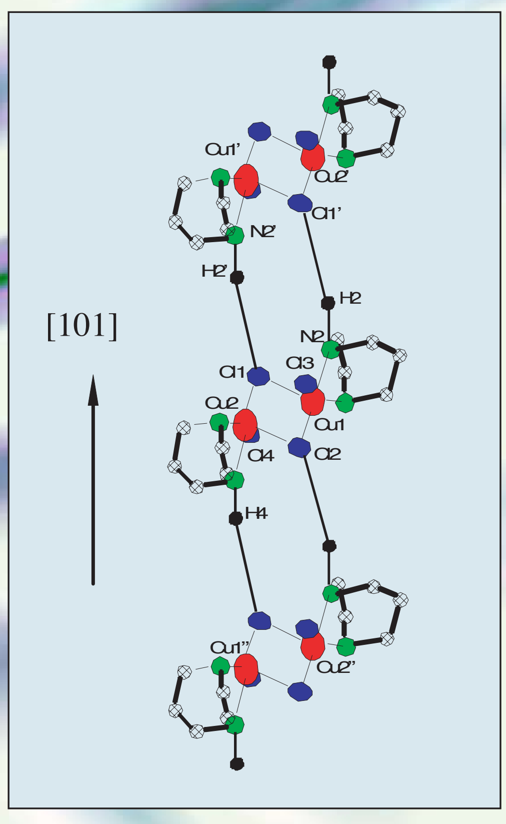
There is a strong expectation that the mathematical physics of integrable models will play a crucial role in understanding low-dimensional quantum effects, where they are most pronounced.



Comparison between theory and experiment for the specific heat and entropy of CuHpCl.



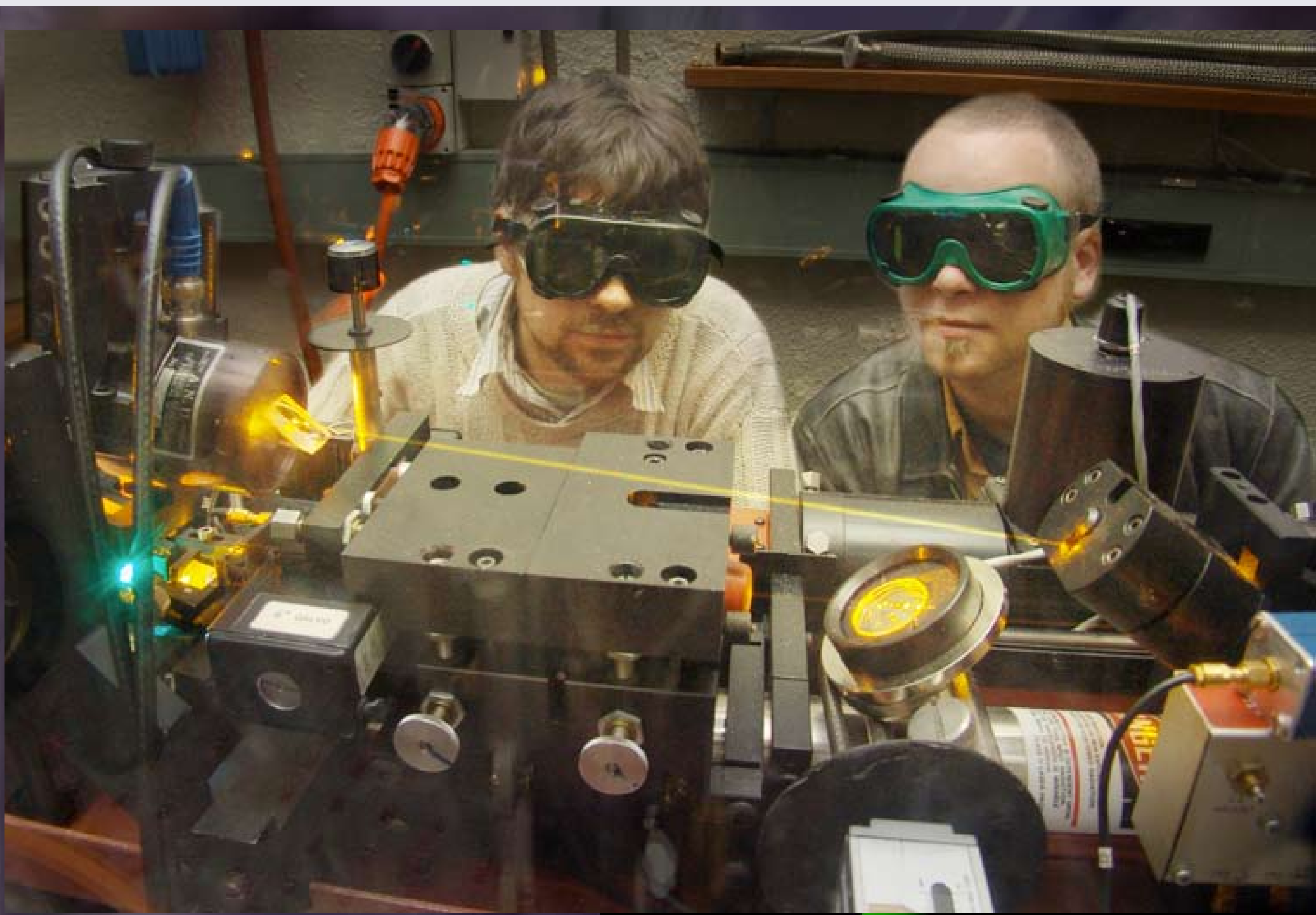
Comparison between theory and experiment for the susceptibility and magnetisation of CuHpCl.



The physics of novel materials like the spin-1/2 ladder compound CuHpCl [Chaboussant et al.] can be described by the integrable model based approach developed in the RSPhysSE group.

Aussies Take World Record for Stopping Light

Jevon Longdell , Elliot Fraval, Matthew Sellars and Neil Manson



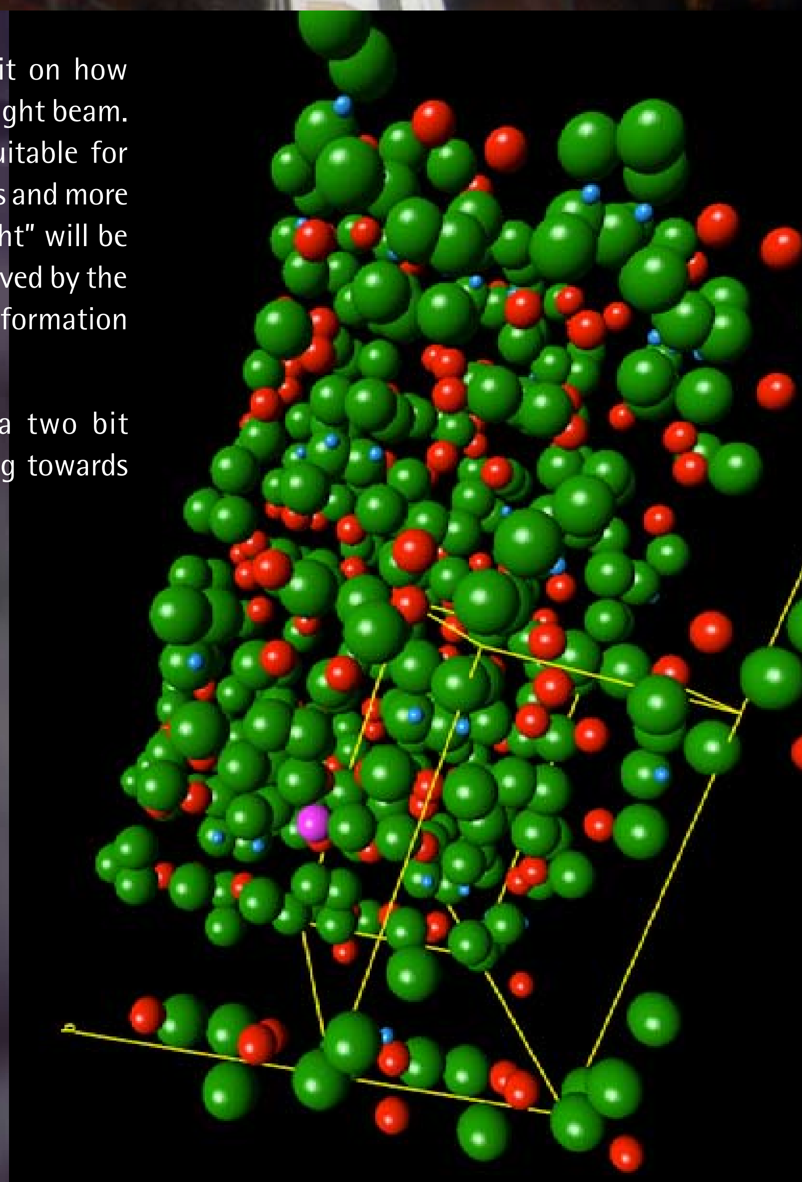
As part of their research into the emerging technologies of quantum computation and encryption, researchers at the ANU have managed to stop light with storage times longer than one second. While they were able to stop light previously, researchers hadn't been able to stop it for very long - about a thousandth 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.

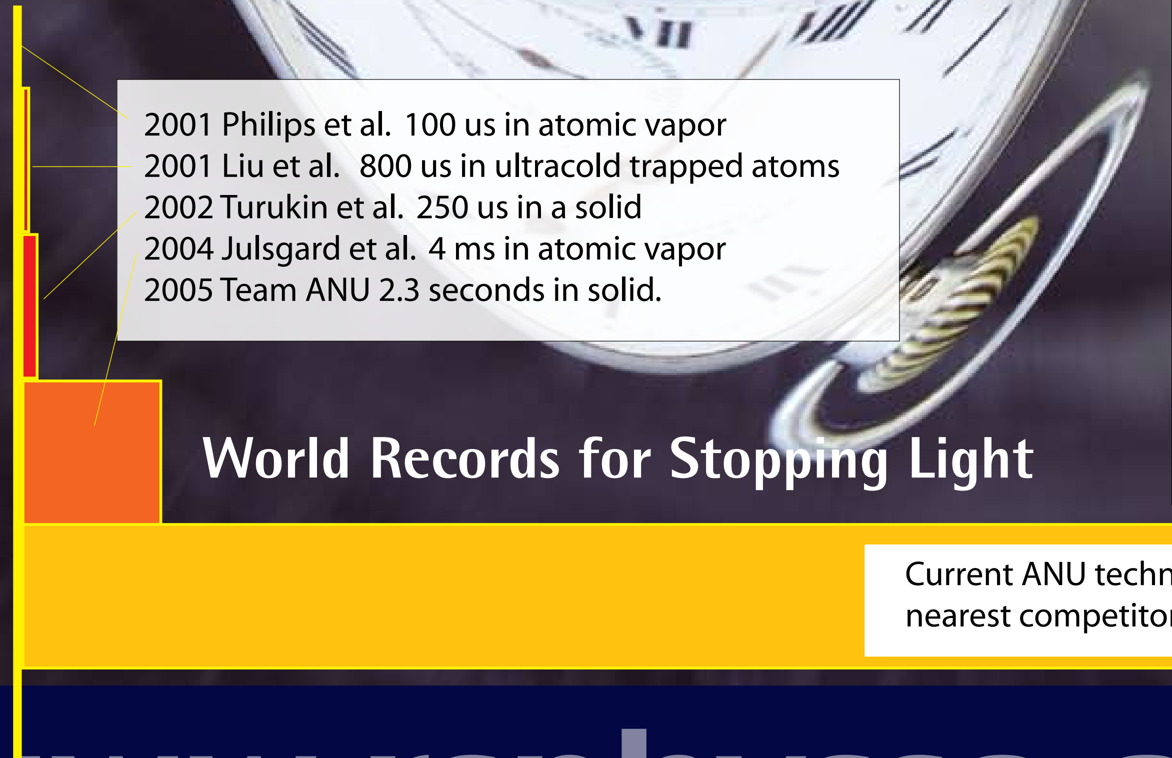
A phenomenon called electromagnetically induced transparency allows a material that would usually be opaque to become transparent by applying an auxiliary laser beam. This auxiliary laser beam, called the coupling beam, also changes the speed of the light. Not only does this enable very slow propagation 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



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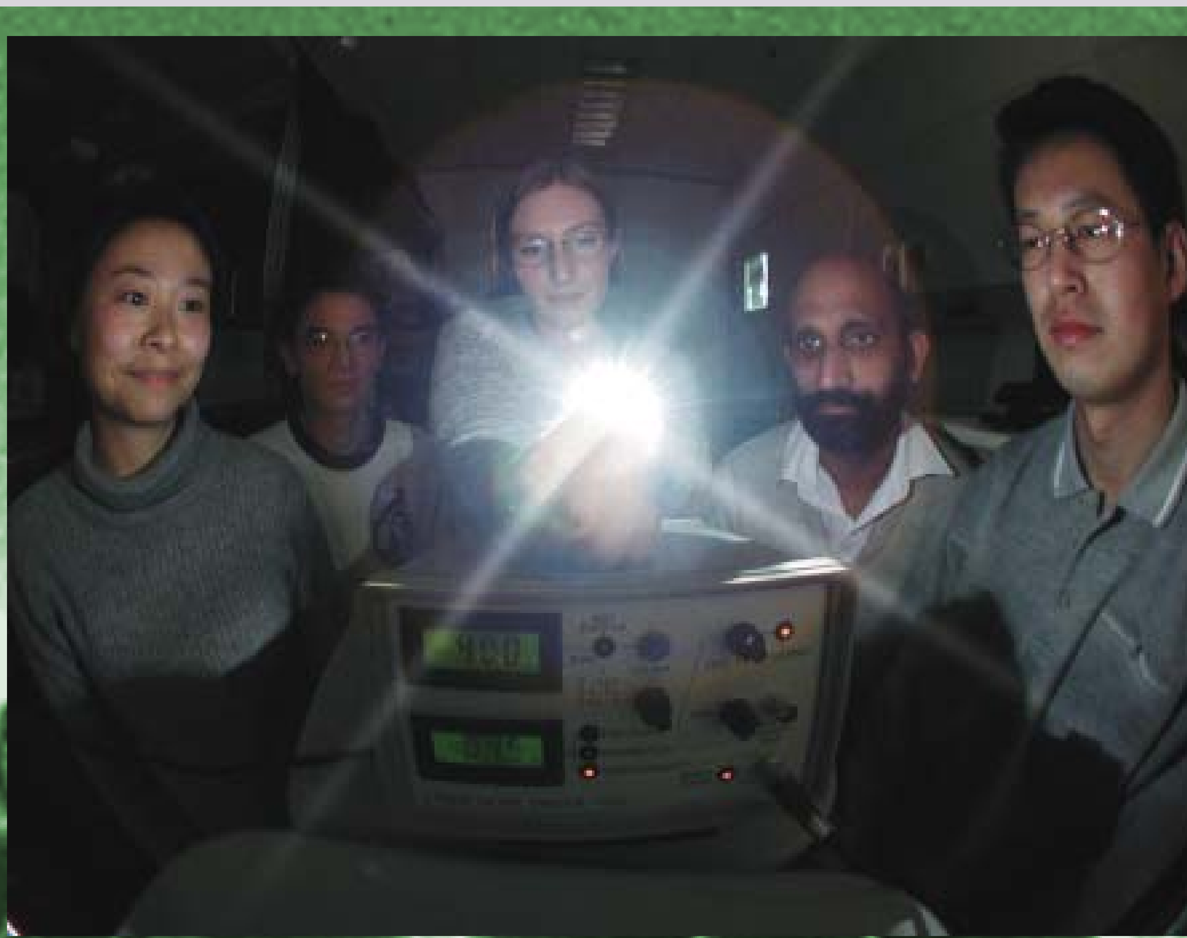
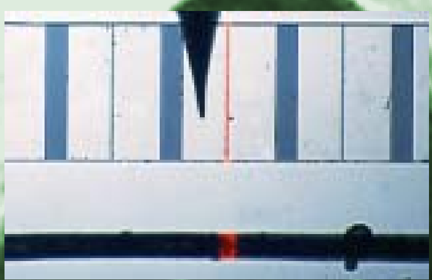
Taking the Strain out of Quantum Lasers

Hoe Tan, Penny Lever, Kallista Stewart, Fu Lan, Qiang Gao, Sudha Mokkapati, Satya Barik, Michael Fraser, Greg Jolley, Manuela Buda, Jenny Wong-Leung, Chennupati Jagadish

When different layers of different semiconductors are grown on top of each other, the foreign atoms don't naturally want to have the same spacing as the host layer. This can lead to strain deformation and even cracking in extreme cases. However lattice mismatch phenomena can also produce interesting growth phenomena such as - quantum dots.

A quantum dot is a tiny island of one type of semiconductor within a different material. Because of its extreme small size, electrons within the dot don't behave as they would in bulk material. By engineering these dots carefully, it is possible to build advanced lasers and detectors with properties that would be impossible to achieve in normal fabrication techniques.





Microscopic quantum laser illuminates a human hair

Where the problems come is that the strain conditions needed for good dots don't marry with those need for good laser performance. The solution to this until now, has been a growth technique known as Molecular Beam Epitaxy (MBE). The trouble with MBE is that it's too slow and laborious for economical industrial applications.

Recent research at the ANU, has demonstrated that under the right conditions, a much faster growth method Metal Organic Chemical Vapour Deposition (MOCVD), can be used to create excellent quantum dots. The secret behind the ANU success, is to alleviate undesirable strains by growing extra compensation layers with the opposite strain to the laser layer. It's a bit like prestressed concrete, where the material is cast with one strain to help it cope with the opposite strain.

Scientists at the ANU are amongst only a handful in the world to be able to grow quantum dot lasers by MOCVD. The new growth techniques are now being applied to lasers of specific interest for optical communication applications.

Research Highlights

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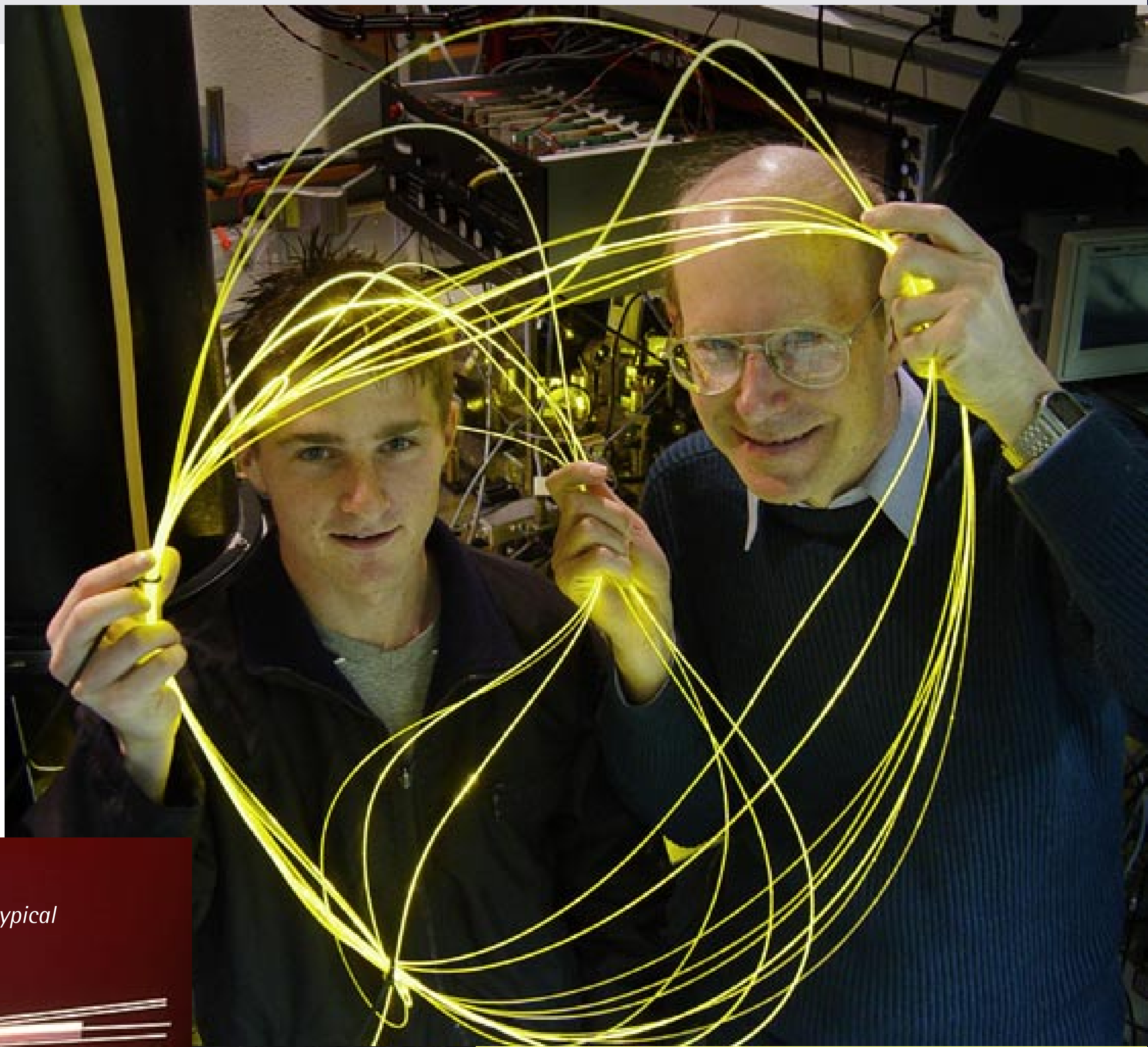
Cutting Corners in Fibre Optics

Adrian Ankiewicz and John Love

During the last two decades of the twentieth century, single-mode optical fibres rapidly became the back-bone of the world's vast telecommunications network both on land and under the oceans because of their ability to propagate large volumes of digitised data over vast distances with minimal light loss and signal distortion. These fibres are normally encased in optical cables to protect them from environmental hazards, but these cables, such as the one shown in the picture, are flexible enough to be bent into small radii of some tens of centimetres that are encountered when they are laid in ducting under city streets and elsewhere. The light propagating in these fibres readily follows these bends with essentially no propagation loss.



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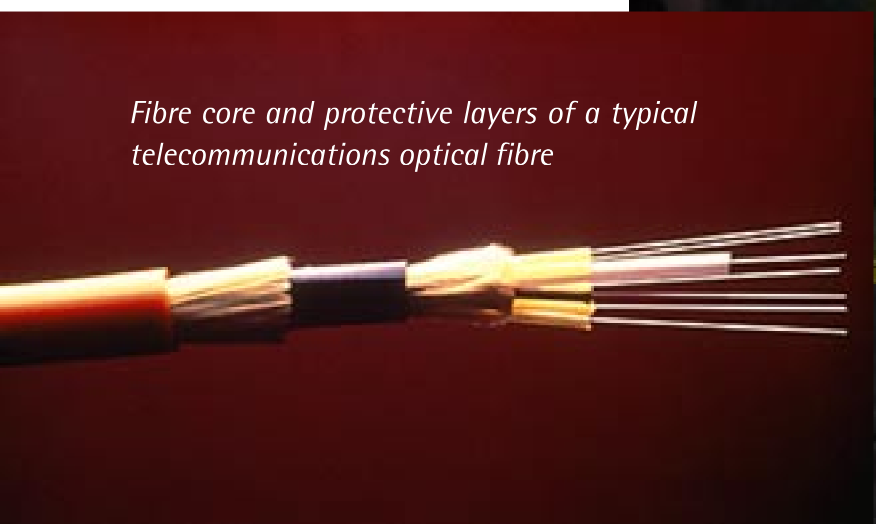

Fibre core and protective layers of a typical telecommunications optical fibre

Light traveling down an optical fibre is confined by total internal reflection. Each time the beam hits the wall the difference in refractive index at the boundary acts like a mirror bouncing the light back. However, because the reflectivity depends on the angle of incidence, sharp bends in the fibre tend to create poor mirrors leading to high light loss.

However, as optical fibre and especially optical waveguide, technology finds its way into ever more diverse areas such as medicine, remote sensing and aerospace, small radius bends become an inevitibility. These tight bends are especially desirable in integrated optics planar waveguides, because they reduce the overall device size. The problem is that such bends make it difficult to confine the the light within the waveguide. Conventional theoretical understanding of this phenomena has been unable to offer any practical solutions.

However, ANU researchers have recently developed a radically new model of bend loss which more strongly relates to the actual physics of the waveguide. This new approach examines the physical evolution of the waveguide mode into, along and out of the bend, and takes into account the finite structure of the cross-section of a practical single-mode waveguide.

Using this model, scientists believe it may be possible to engineer waveguide refractive index profiles to greatly improve light transmission in tight bends.

Research Highlights

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Unraveling the Enigma of Auroral Excitation

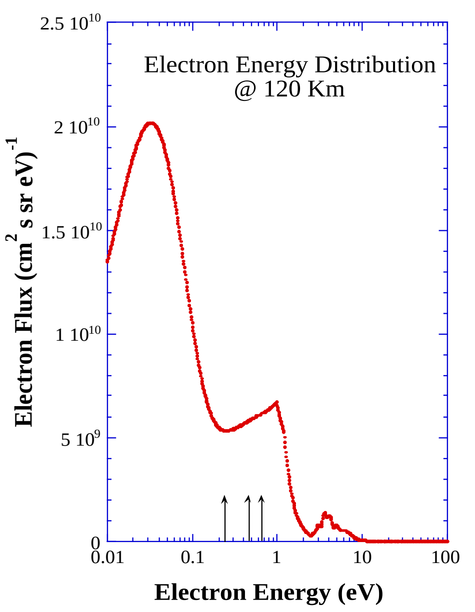
Steve Buckman and Milica Jelasavicic

The spectacular shows of the Earth's aurora are driven by processes that occur in the rarefied atmosphere, 120 km above the earth. Here, in the ionosphere, interactions between electrons, ions, atoms and molecules lead to excitations of molecules, which then produce the colourful displays of auroral light as they de-excite.

Steve Buckman and Milica Jelasavicic in the laboratory

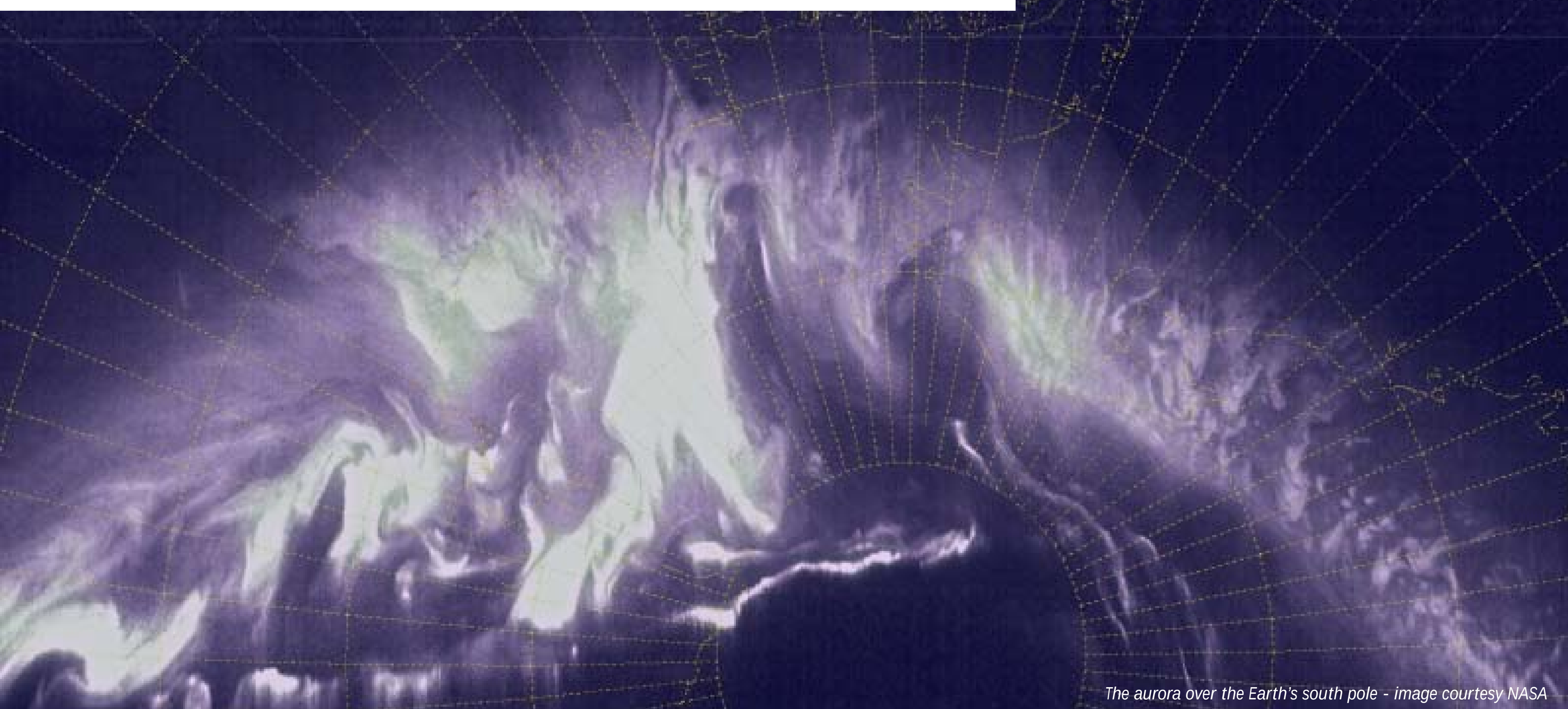
The nitric oxide (NO) molecule is only a minor constituent of the Earth's upper atmosphere. Nevertheless, it plays a major role in infrared auroral emissions due to radiation from vibrationally excited (NO*) states. Until recently it was thought that these NO* states were created by excited nitrogen atoms combining with oxygen. However, new work at the ANU (in collaboration with Flinders University) indicates that energetic electrons impacting unexcited NO molecules are also responsible for creating the excited NO states.

The electron energy distribution in the upper atmosphere has a peak, which by a strange coincidence, overlaps with the excitation of the vibrational modes of the NO molecule. The practical upshot is that there is a large population of electrons able to strongly interact with NO. These interactions, which only last for less than a million, millionth of a second, leave the NO molecule excited and with surplus energy which it is able to release as part of the spectacular auroral light display. ANU Scientists were able to deduce this by careful studies of the interactions of electrons and molecules in laboratory experiments, coupled with complex theoretical modelling of the atmospheric behaviour of NO carried out at Flinders.



The electron energy distribution with arrows showing the threshold energies for the first three vibrational modes of the ground state of the NO molecule.

Studies of such interactions between electrons and molecules have wider application than atmospheric physics. They are important in understanding many environmental, biological and technological processes. Better understanding of such events on the microscopic quantum scale can often lead to improvements in large scale industrial processes which are of great economic and environmental value.



The aurora over the Earth's south pole - image courtesy NASA

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www.rsphysse.anu.edu.au

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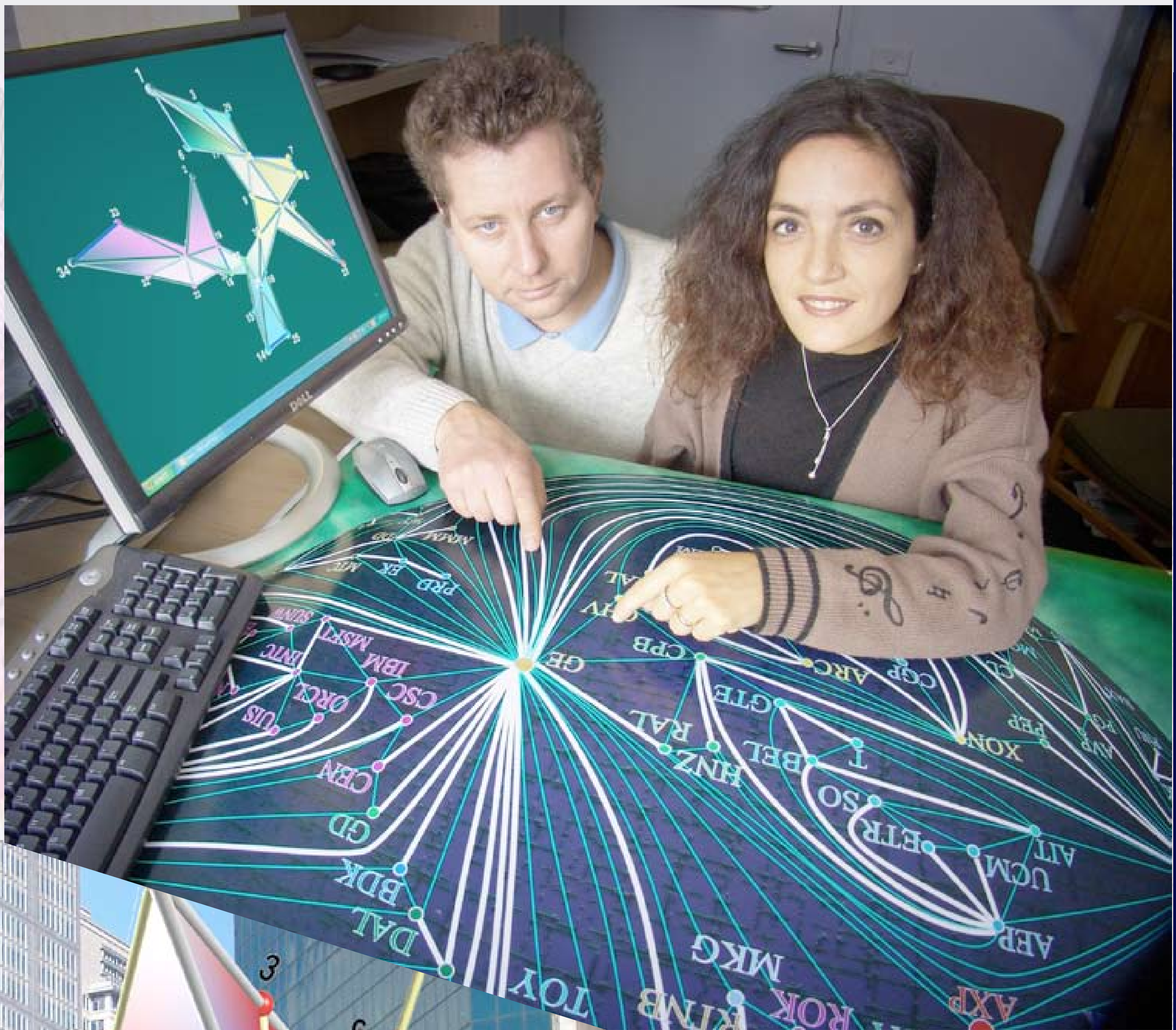
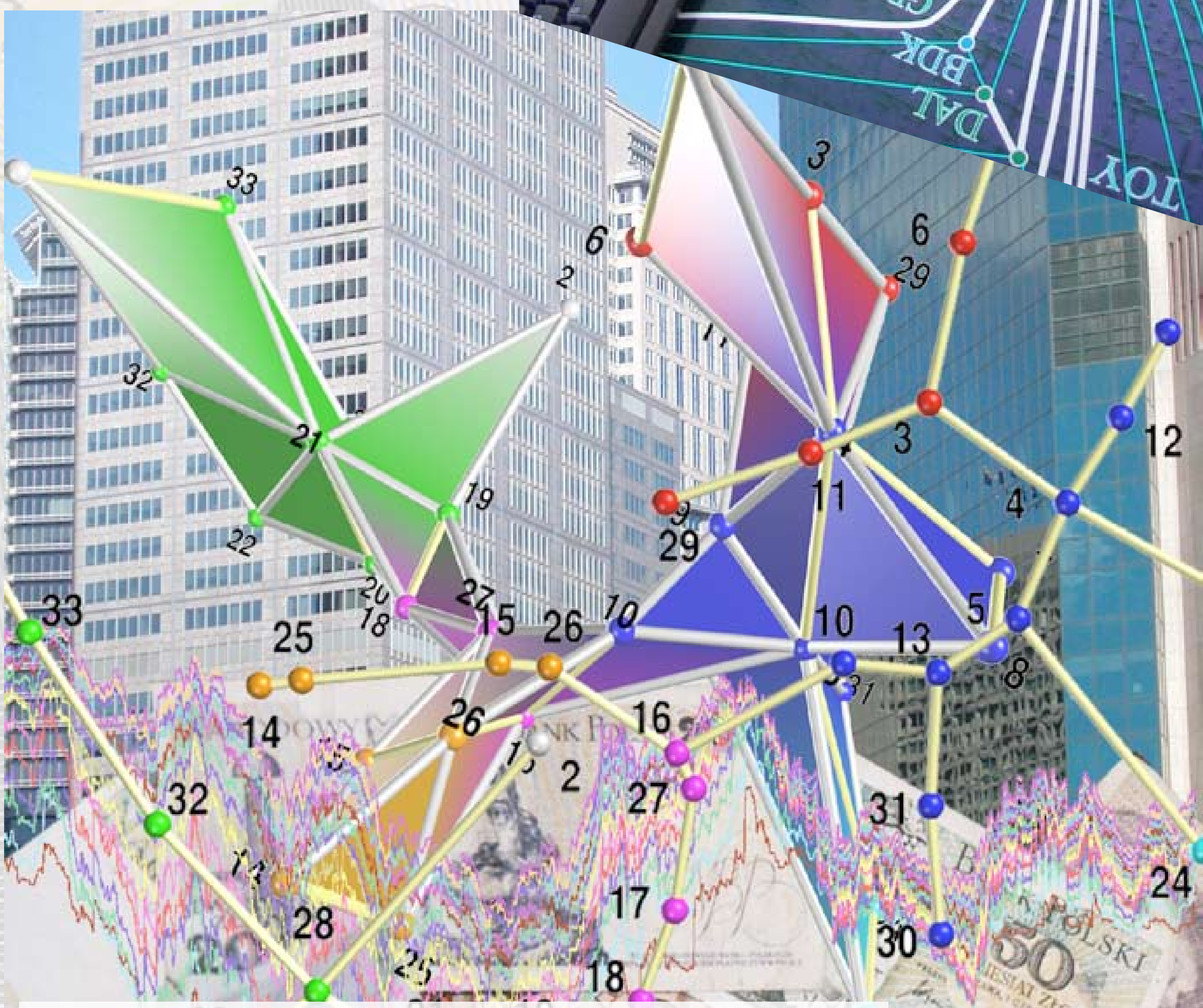
Econophysics: inside the complexity of markets

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 behaviors are challenging, and potentially rewarding, research area.

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.





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

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 allows 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 behavior of complex systems to understand their structure, to manage and control risk.

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Chalcogenide Glasses Reveal the Hole Picture

Darren Freeman, Barry Luther-Davies, Steve Madden

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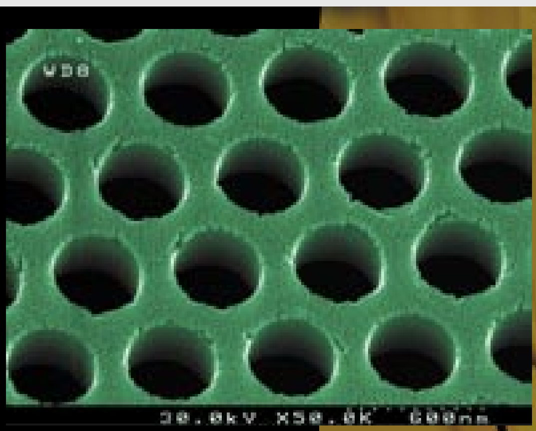
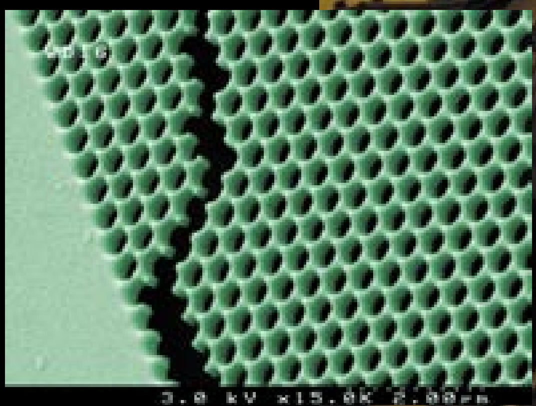
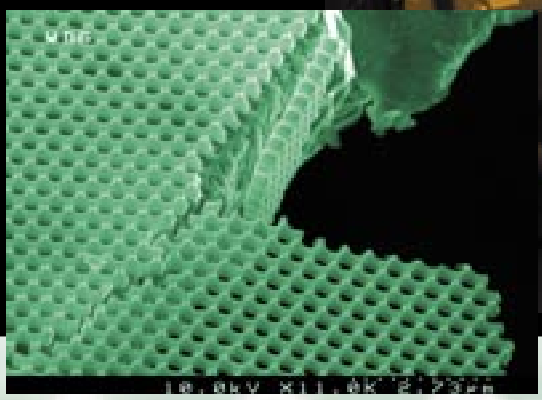
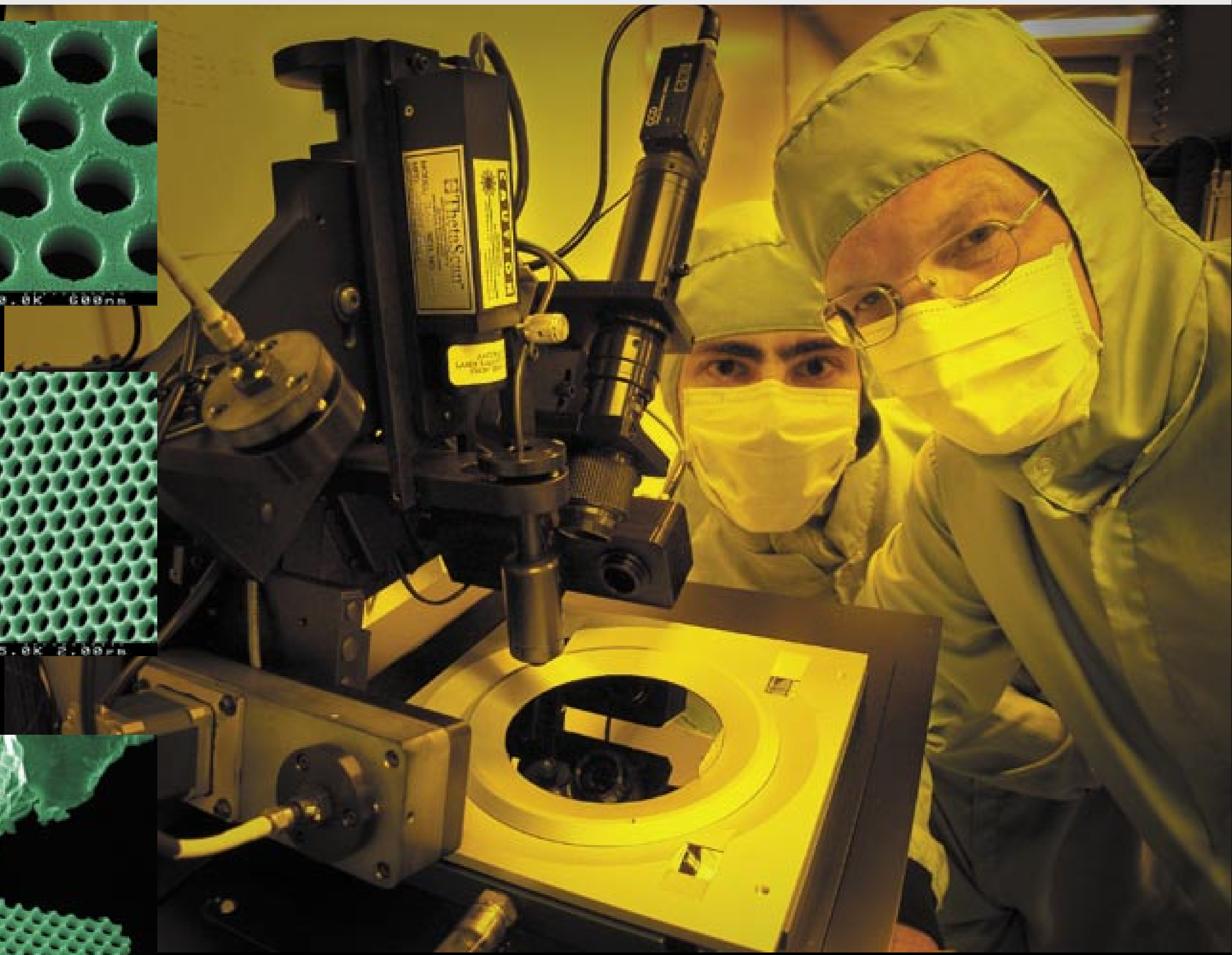






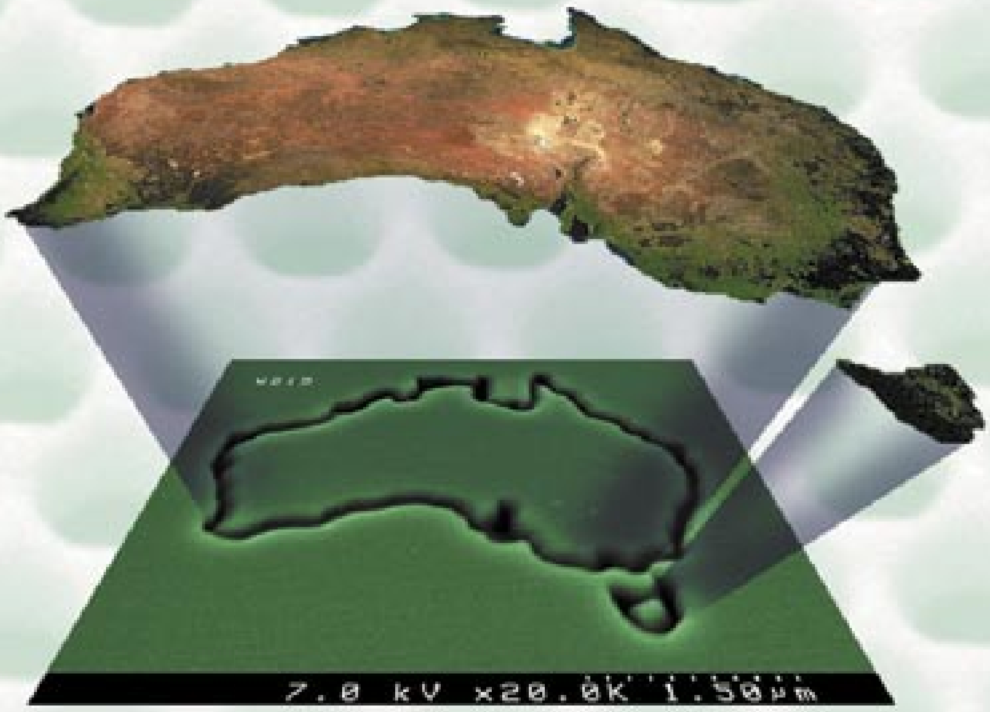


The periodic lattice of atoms in a semiconductor crystal can under some circumstances, interact with electron de Broglie waves to produce forbidden energy gaps and other interesting phenomena. The transistor and thus the entire modern electronics industry is based on this interaction between wave and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

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Research School of Physical Sciences and Engineering

The last Ice Age in Australia

Dr Timothy Barrows , Dr Keith Fifield, Accelerator Mass Spectrometry group

The technique of 'exposure dating' is a new tool which has revolutionised the way we study the history of glaciers and ice sheets. ANU scientists are using this technique to take a fresh look at the history of glaciation and climate change in Australia. By directly dating glacial debris and eroded bedrock, the timing of the advance and retreat of the ice (a sensitive indicator of climate) can be determined with unprecedented reliability.

Blue Lake in the Snowy Mountains, formed by glaciers

A boulder deposited by the Blue Lake glacier 20,600 years ago

Exposure dating is based on the principle that long-lived cosmogenic isotopes accumulate naturally at the Earth's surface as a result of interactions between cosmic rays from space and atomic nuclei in surface rocks. After a geological process freshly exposes a rock surface, these cosmogenic isotopes build up at a constant rate. Measurements of their present-day abundances, in conjunction with knowledge of the rate at which they are produced, allow an 'exposure age' of the surface to be determined.

Concentrations of cosmogenic isotopes in typical earth materials are incredibly low, being less than one in a million million (10^{-12}) relative to their stable counterparts. Hence, the ultra-sensitive technique of accelerator mass spectrometry (AMS) is required. The powerful and versatile 14UD tandem accelerator at the ANU has proved to be one of the best tools in the world for such measurements.

Studies of relics of the last Ice Age, particularly in the Snowy Mountains and Tasmania have led to a complete revision of the glacial history of these regions, which were the only areas in Australia where glaciers existed. Hypothetical ideas about glacier extent and its timing that stood for nearly a century have been replaced with a robust chronology placing Australia into a global context.

It transpires that there was not just one but at least four major advances of glacier ice during the last 70,000 years. The coldest part of the last ice age was 20,000-22,000 years ago and only lasted a few thousand years. The ensuing global warming is the greatest in recent geological history. Using the altitude of the ice age landforms we have calculated that mean temperatures around Canberra are about 9°C warmer today. This research provides an important baseline from which to assess climate variability and raises intriguing questions about the adaptation of Aboriginal people to the conditions at the time.

THE AUSTRALIAN NATIONAL UNIVERSITY

Reversing the Roles of Light and Matter

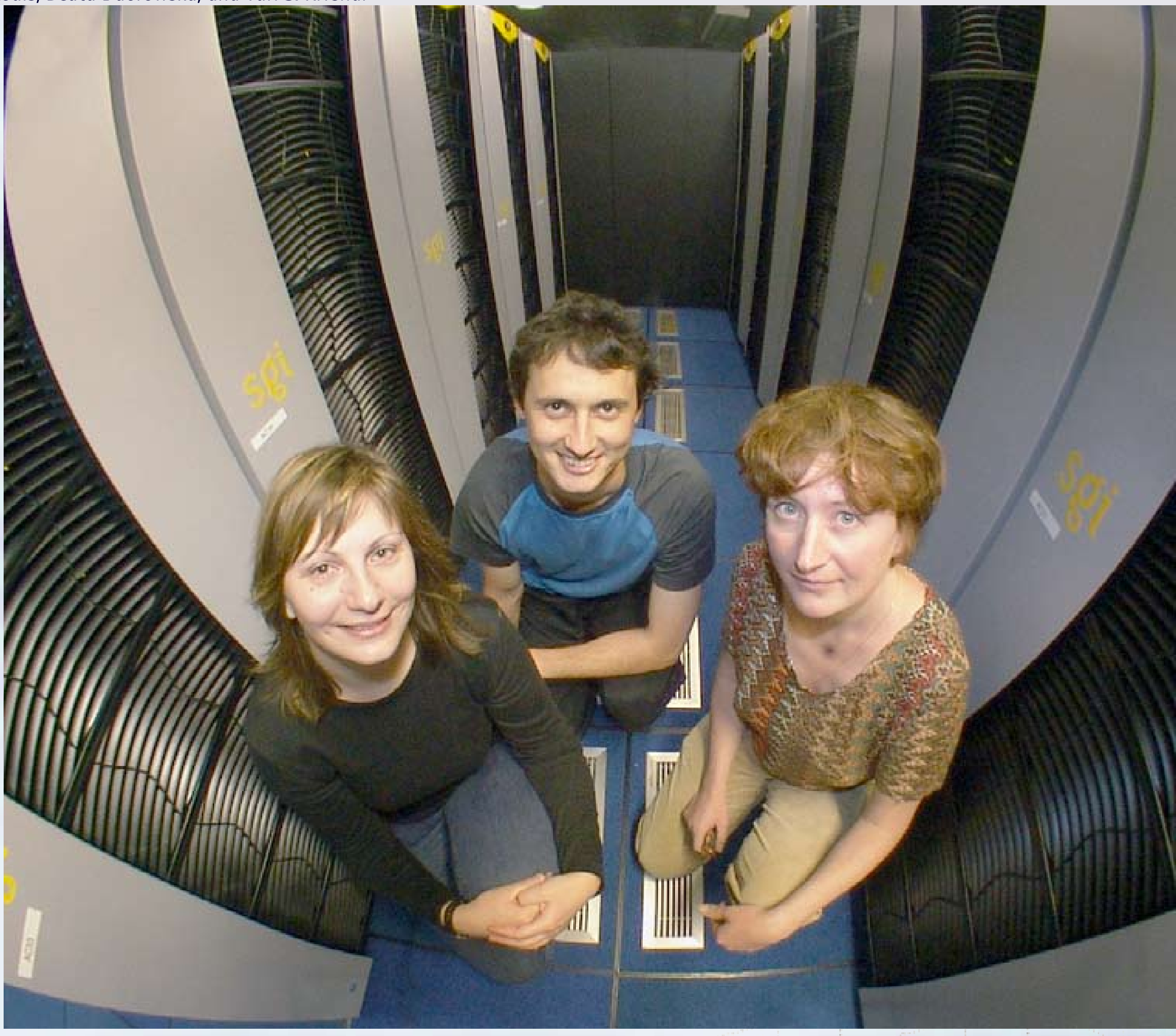
Elena A. Ostrovskaya, Tristram J. Alexander, Pearl J. Louis, Beata Dabrowska, and Yuri S. Kivshar

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.

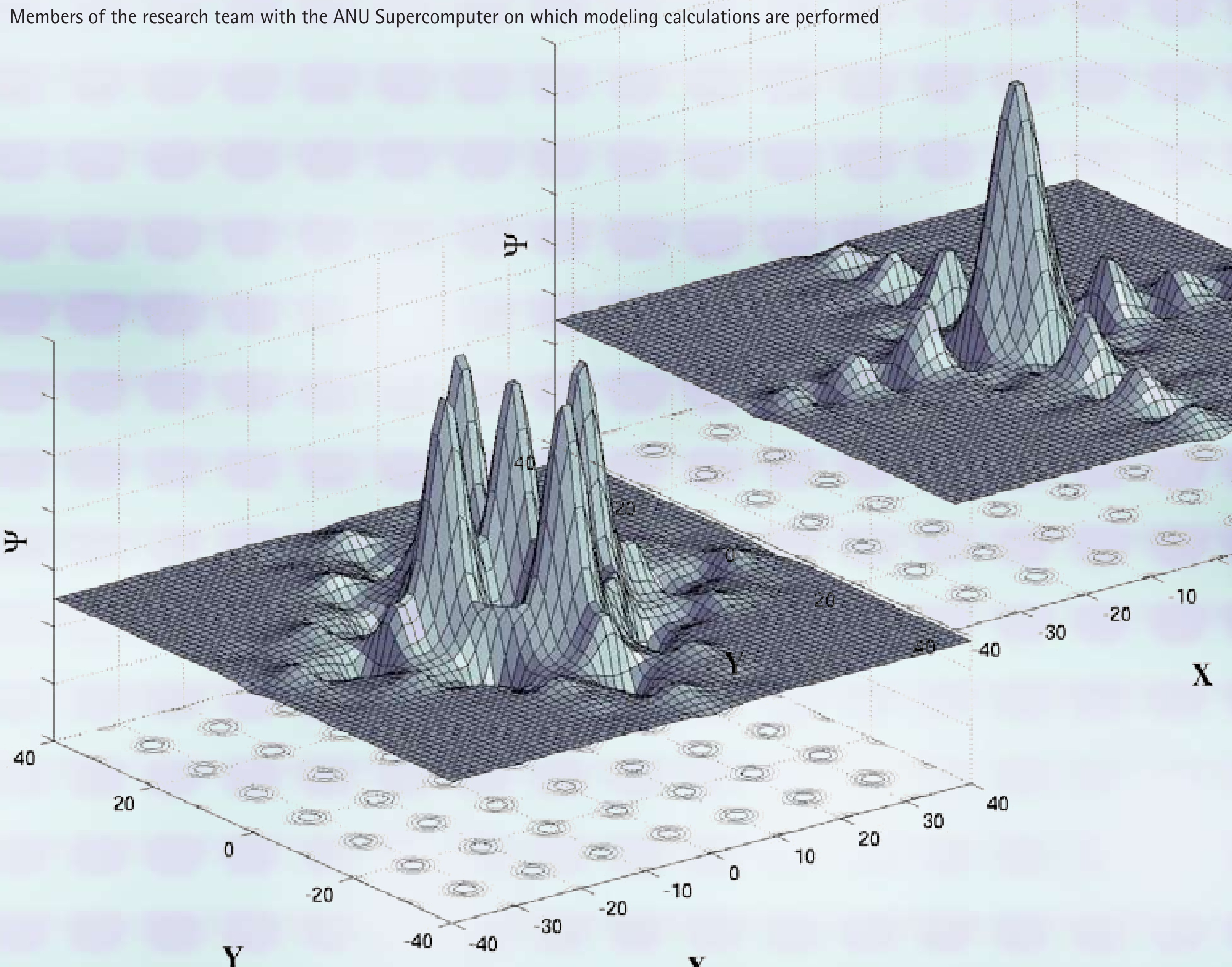
The laser beam of atoms is created by cooling a gas to almost absolute zero. This causes its atoms to undergo a transition into a single quantum state known as a Bose-Einstein condensate (BEC). Such BECs can behave like giant coherent matter waves or laser beams composed of atoms. A fascinating feature 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.



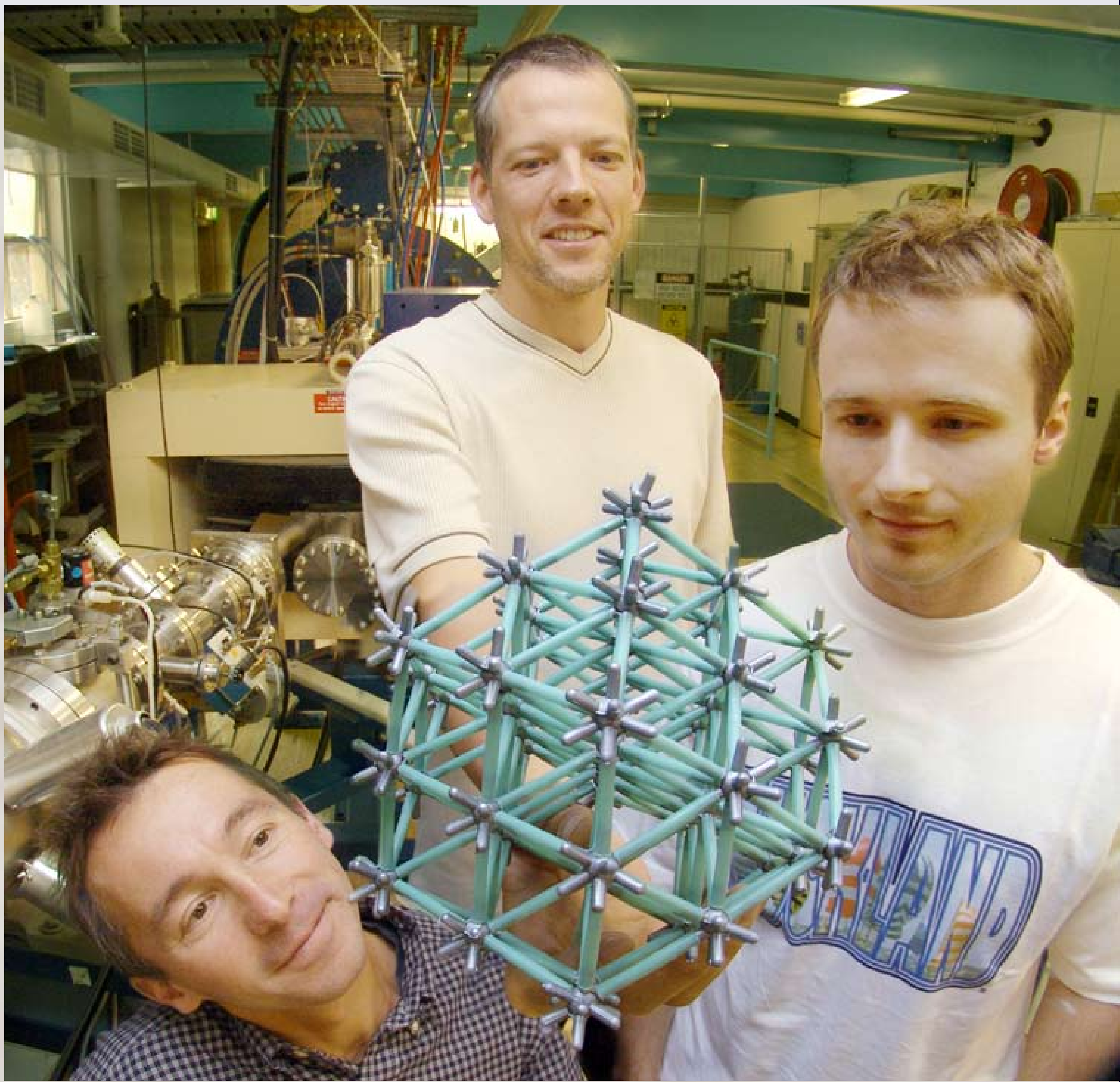
Members of the research team with the ANU Supercomputer on which modeling calculations are performed



Research School of Physical Sciences and Engineering

Ion Irradiation to form Amorphous Mono-Elementa

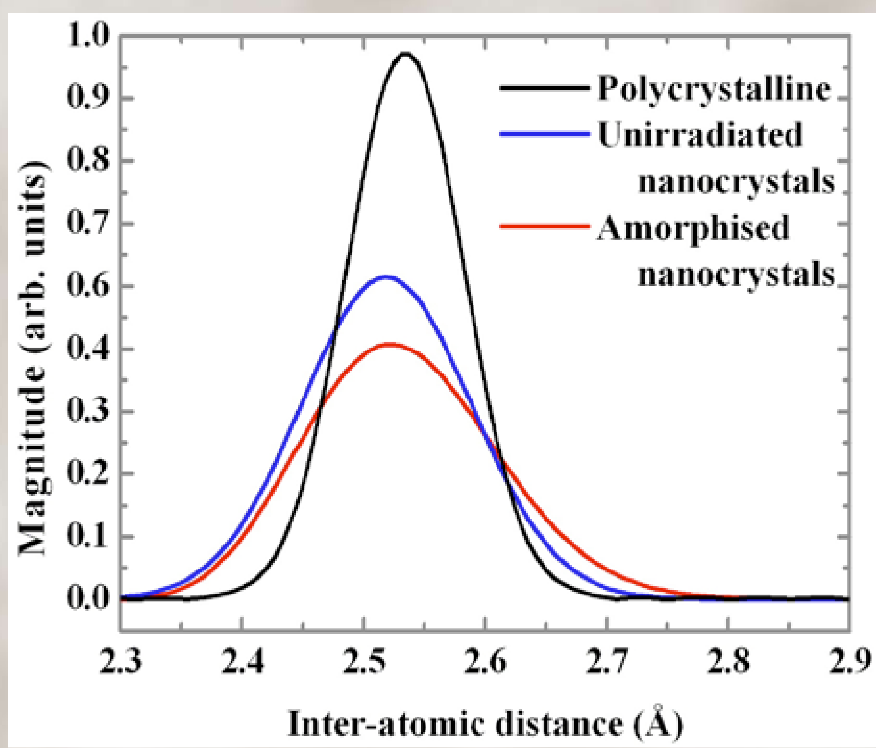
B. Johannessen, P. Kluth, D.J. Llewellyn and M.C. Ridgway



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 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.