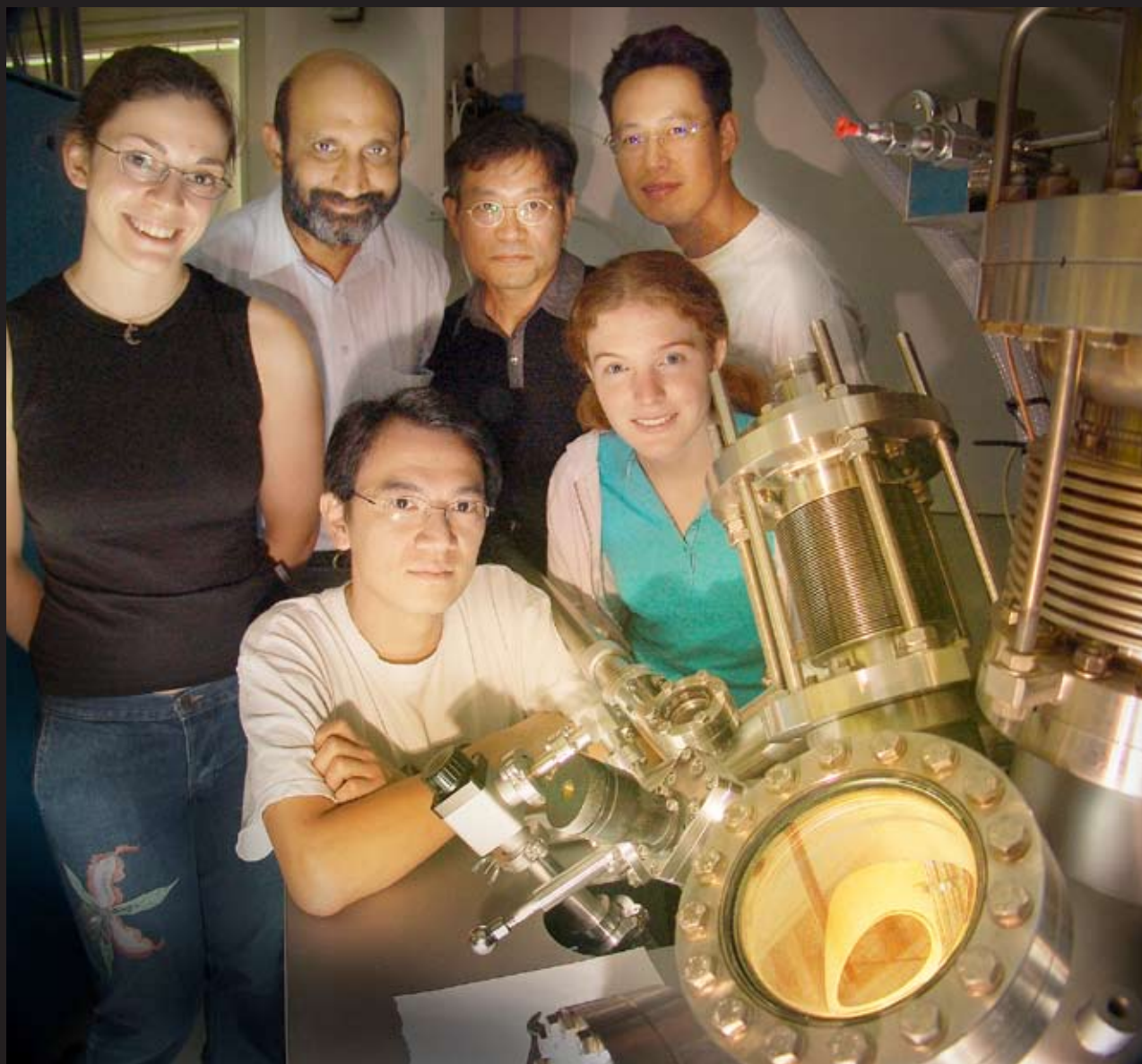


RESEARCH SCHOOL OF PHYSICAL SCIENCES & ENGINEERING



ANU

THE AUSTRALIAN NATIONAL UNIVERSITY



Some Research Highlights from the
2005 ANNUAL REPORT

ROUGH PIPES HELP DROUGHT SURVIVAL

Mika Kohonen, Vince Craig & Roger Heady

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.

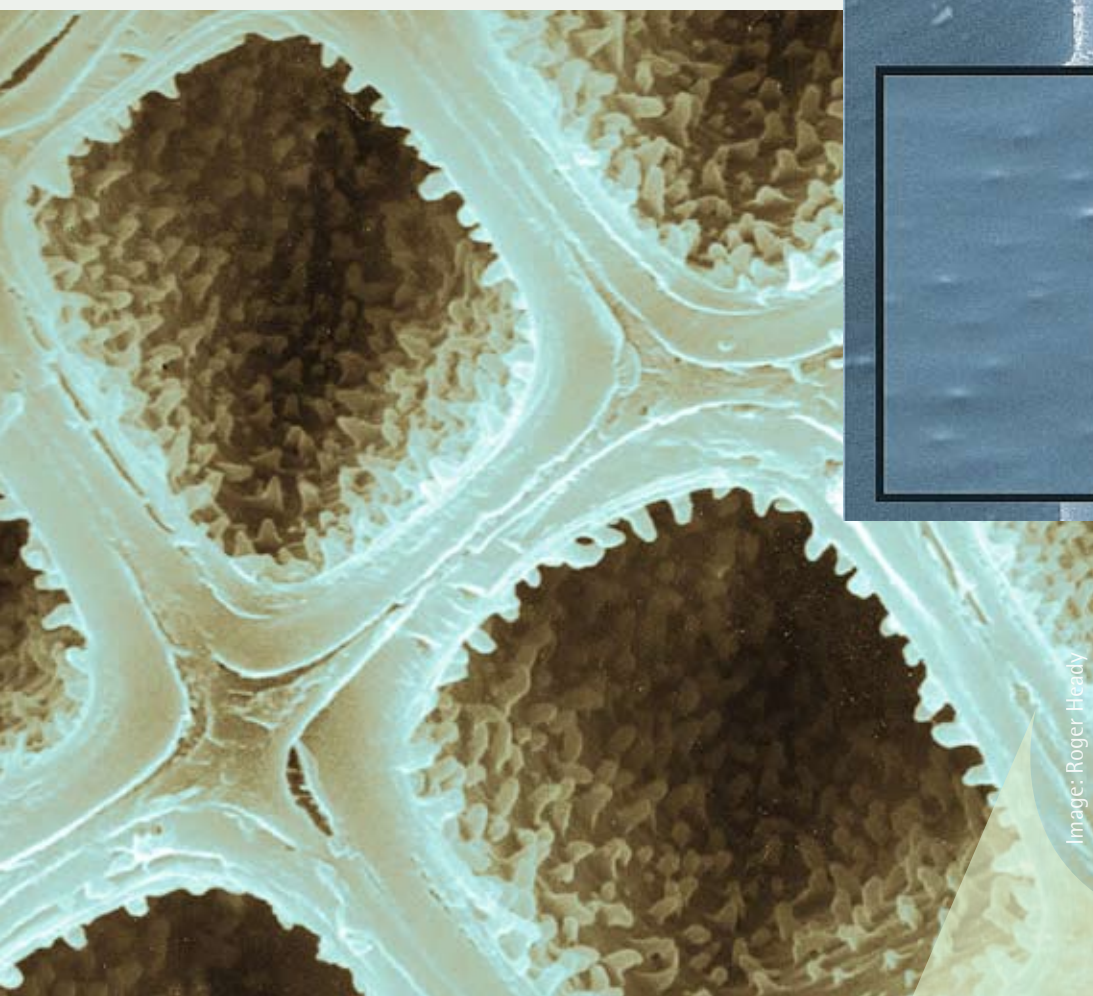
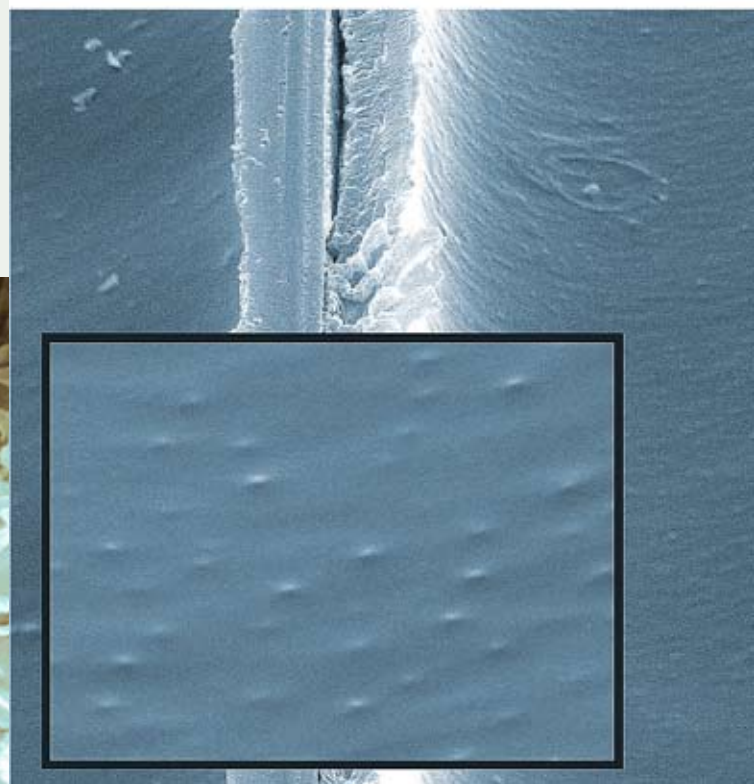
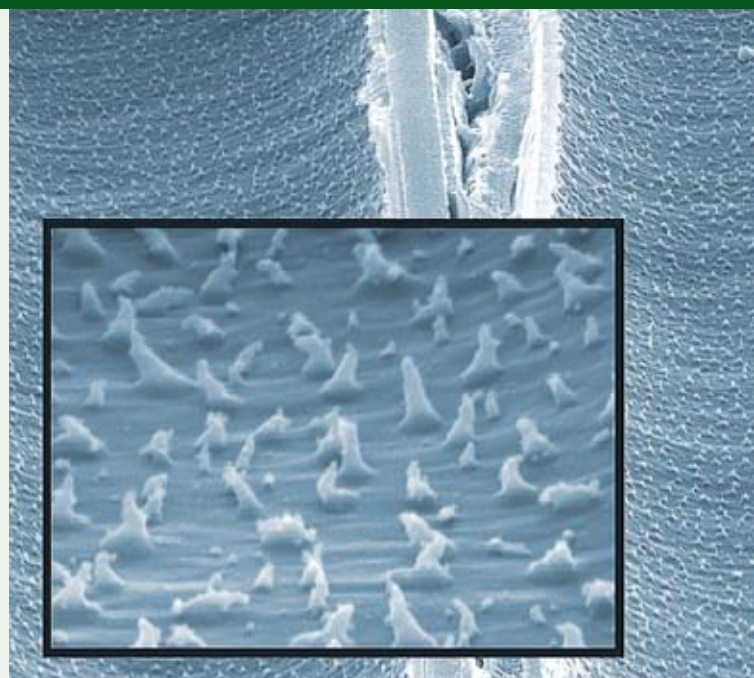


Image: Roger Heady

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.

crops better suited to dry conditions



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 knobby 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.

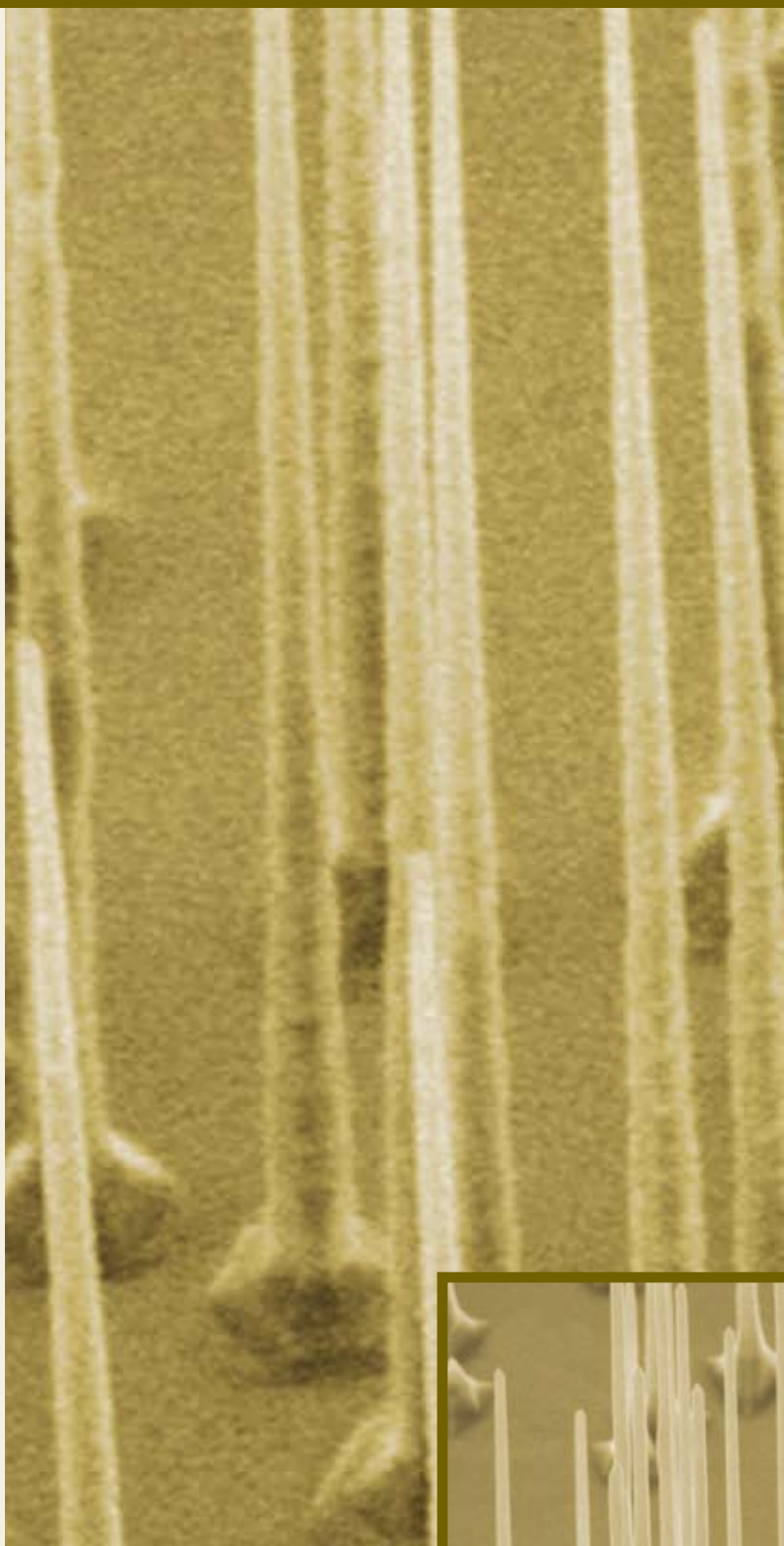
This research not only promises to aid in solving one of the longest standing mysteries in plant biology, but may also help in developing new and improved crops better suited to dry conditions. And with climate models predicting decreasing rainfall in many areas of Australia, this may have massive economic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

GOLDEN SEEDS TO GROW NANOWIRE LASERS

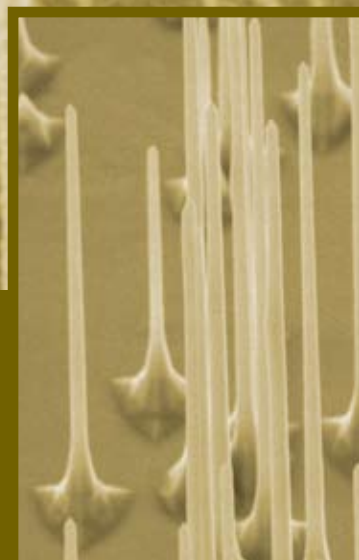
Chennupati Jagadish, Yong Kim, Qiang Gao, Hannah Joyce, Victoria Coleman, Lan Fu & H. Hoe Tan

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 metallic 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.

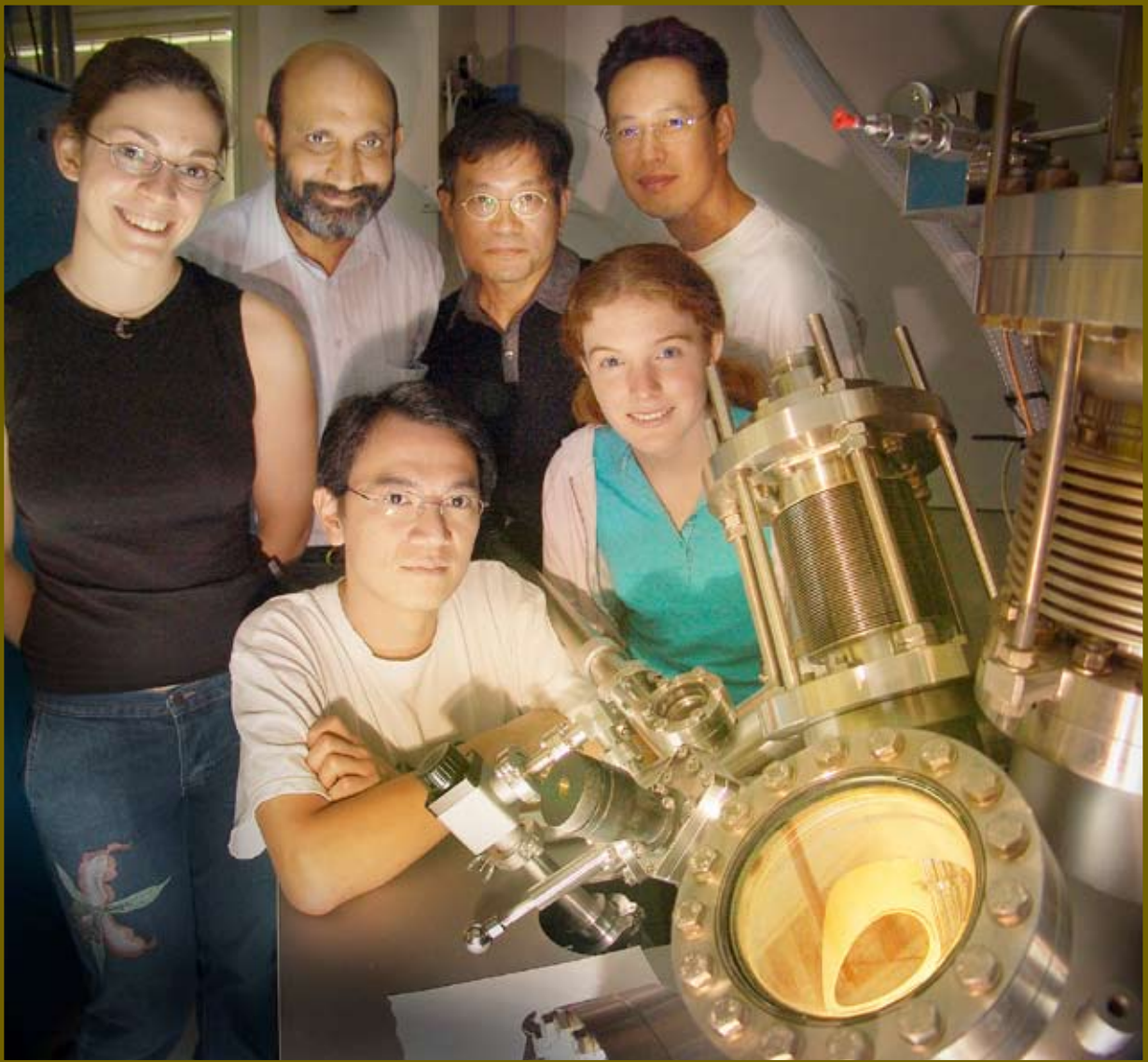
At the right temperature and pressure, gold and gallium arsenide form a eutectic - an alloy of the two materials with a lower melting point than either of its components. If a wafer of gallium arsenide is covered with microscopic gold spots and heated to just the right temperature, a tiny pool of liquid 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.



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



modulated at vastly higher speeds than conventional lasers



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.

FUSION SCIENTISTS AVOID MAKING WAVES

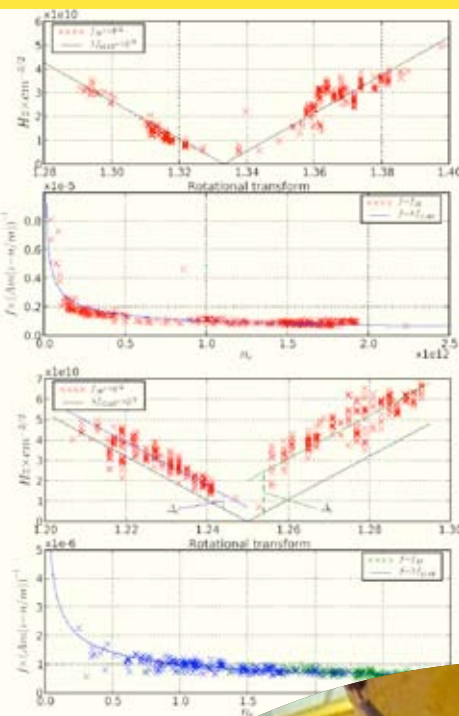
David Pretty, David Oliver, Santhosh Kumar, Boyd Blackwell, John Howard,

The fusion of deuterium and tritium to create helium in large-scale fusion reactors offers the promise of vast quantities of electricity with almost no greenhouse gas emissions. The most practical way to achieve this is to magnetically confine a ring or loop of plasma within a reactor and heat it to tens of millions of degrees. In order to make the process as efficient and elegant as possible, one would like the fusion reactions themselves to heat the plasma rather than having to use an external heating method such as high power microwaves. Theoretically, this is possible since one of the fusion products is helium in the form of highly energetic alpha particles. These alpha particles could in principle, transfer their energy to the remaining deuterium and tritium fuel. There is however a significant obstacle to implementing this idea in practice.

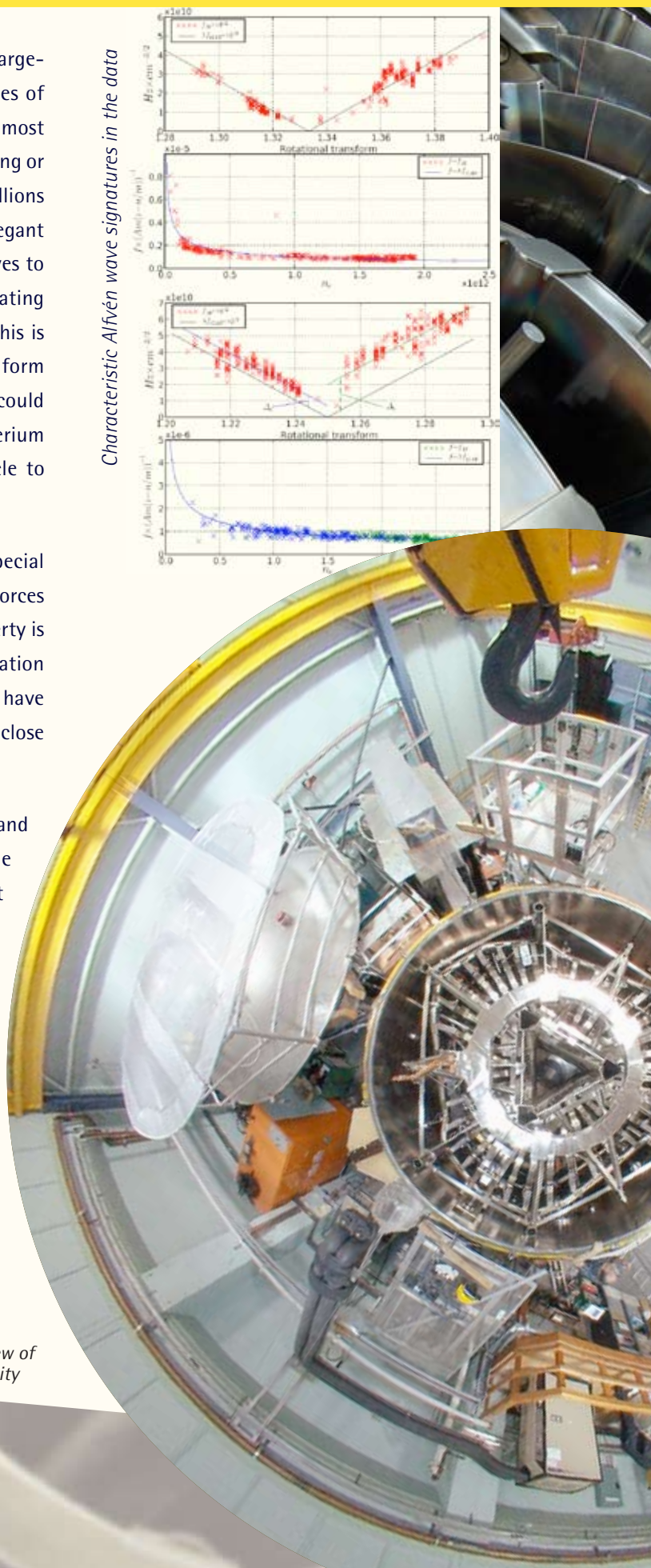
Electrically conductive fluids, such as plasmas, have special properties resulting from the electrical and magnetic forces generated by their many moving charges. One such property is the presence of so called Alfvén waves – a travelling oscillation of ions along magnetic field lines. As coincidence would have it, the speed of the alpha particles produced by fusion is close to that of the Alfvén wave modes.

Confined superheated plasma is a turbulent, unstable and delicate thing and the presence of any large amplitude Alfvén waves could easily disrupt the flow to the point where the plasma dissipates and the reaction ceases. Because of this, an understanding of the physics of Alfvén waves in confined plasmas is of critical importance to the international efforts to develop viable fusion power. Prototype fusion power reactors are multi billion dollar undertakings designed for efficiency and robustness, which generally makes them far from ideal to conduct experiments on the impact of different coil configurations on Alfvén waves. However, this is where Australia is able to make an important contribution to the international fusion effort.

Characteristic Alfvén wave signatures in the data



Bird's eye view of the H-1 facility



critical to the physics of suppressing Alfvén waves



The ANU hosts the only large-scale stellarator plasma confinement facility in the southern hemisphere, the H-1NF. Although the plasma contained within H-1NF does not undergo fusion reactions, the confinement system does have a highly flexible design coupled with sophisticated and innovative diagnostic systems. This allows different coil configurations and containment parameters to be tried with comparative ease. This flexibility coupled with highly advanced diagnostics allows more accurate measurements to be made on parameters such as plasma rotation and density profiles than any other plasma device in the world. And it is precisely these factors that are so critical to the physics of Alfvén waves.

But generating the data is only half the battle; because moving superheated plasma is such a complex system the signals produced by the multitude of sensors are extremely hard to interpret. A substantial part of the research effort is the development of advanced data mining algorithms to filter key features from the mass of individual measurements. Recent results are beginning to clearly show characteristic Alfvén wave signatures in the data (shown on the plot above), which is an exciting beginning to the development of an improved understanding of the physics of plasma confinement.

A BURNING DESIRE TO UNDERSTAND COMPLEXITY

Andrew Sullivan, Rowena Ball & Robert Dewar

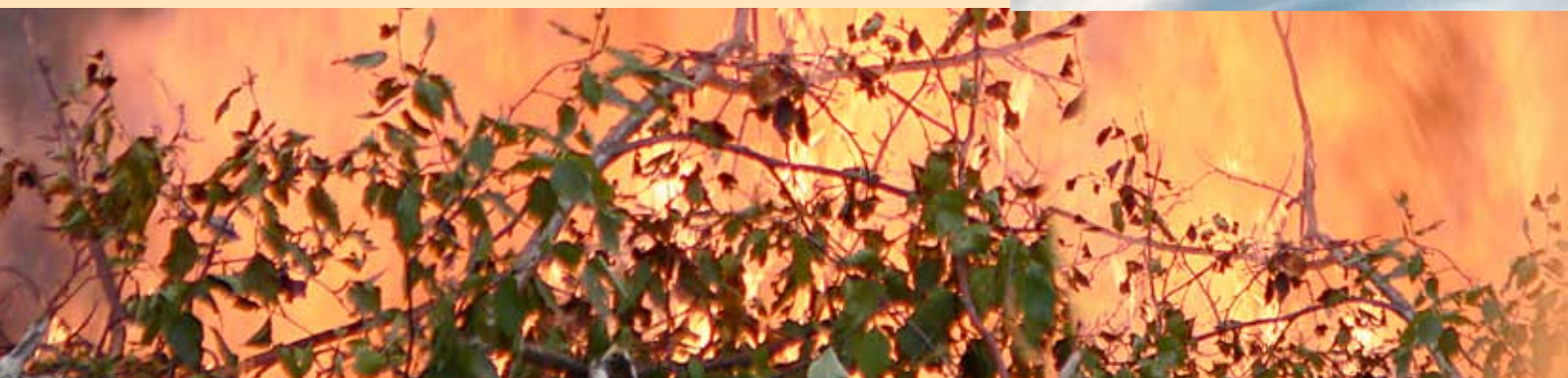
When physicists talk about chaos, they generally mean that the outcome of a sequence of events depends sensitively on the starting conditions. The common example is the flap of a butterfly's wings in Brazil creating a hurricane in Texas. Many real-life systems are to some extent chaotic. At first glance, 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 of a new kind of science, Complex Systems Science, which has spread far beyond physics.

Although the study of many-body 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.

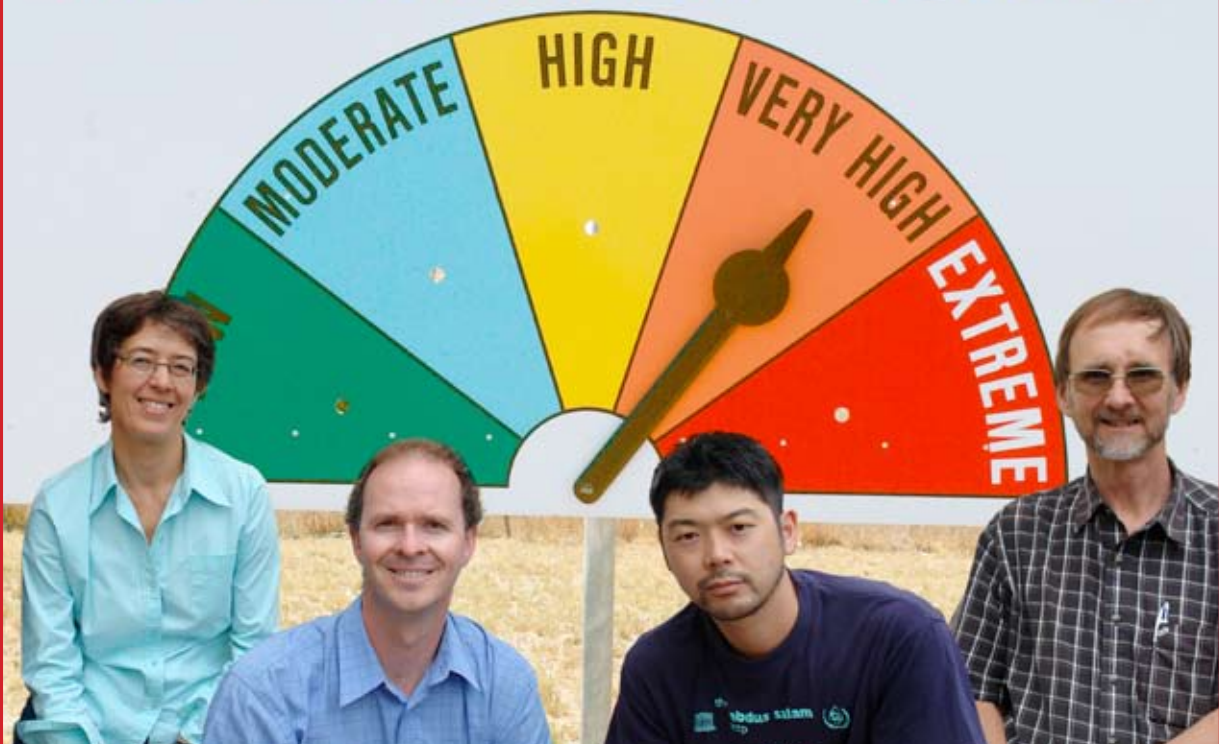
Physicists at ANU are adopting a two-pronged approach to modelling such fires. Firstly by developing a better understanding of the physics and chemistry of cellulose combustion they hope to describe the heat production mechanism more accurately. Secondly, they are designing new continuum models that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



The Plasma and Fluids Theory Group also apply their modelling techniques to many other complex systems ranging from the behaviour of plasma in fusion reactors to climate modelling.



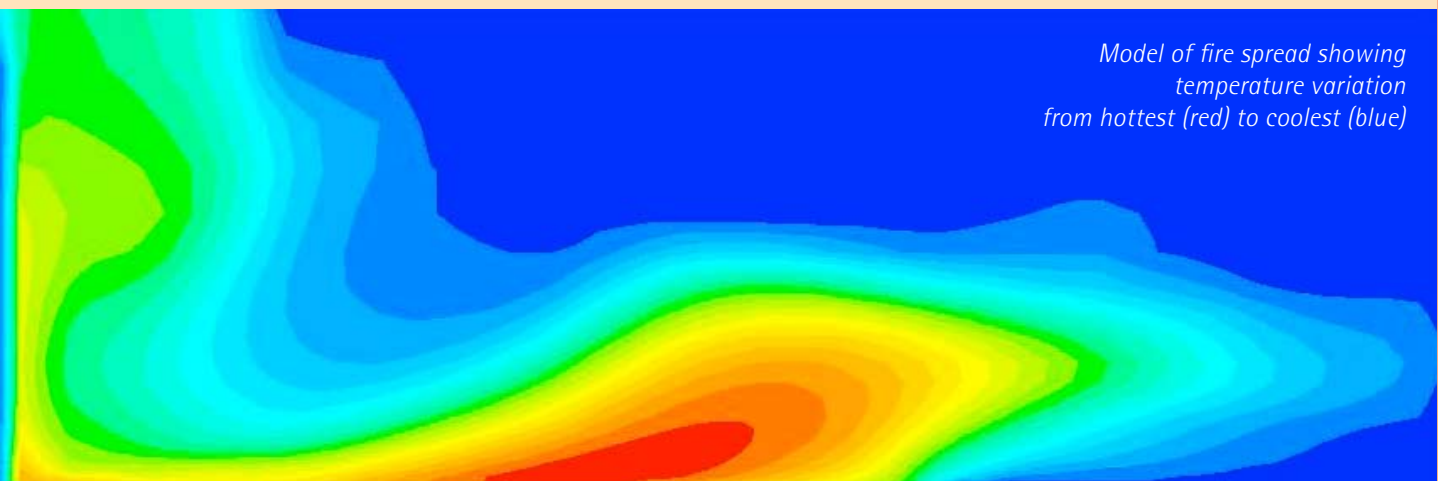
FIRE DANGER TODAY



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)



ensis

This work in collaboration with CSIRO's joint venture Ensis and the CSIRO Centre for Complex Systems Science

transitions to life-threatening situations might be avoided

Mission Statement

- to undertake research and research training in selected areas of physics and engineering at the highest international levels
- to provide research facilities unique in Australia and of international importance
- to interact and cooperate with other Australian universities in our areas of expertise through joint research programs, providing access to our major facilities, providing visiting fellowships, specialist lecture courses and science schools
- to encourage technology transfer to Australian industry

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