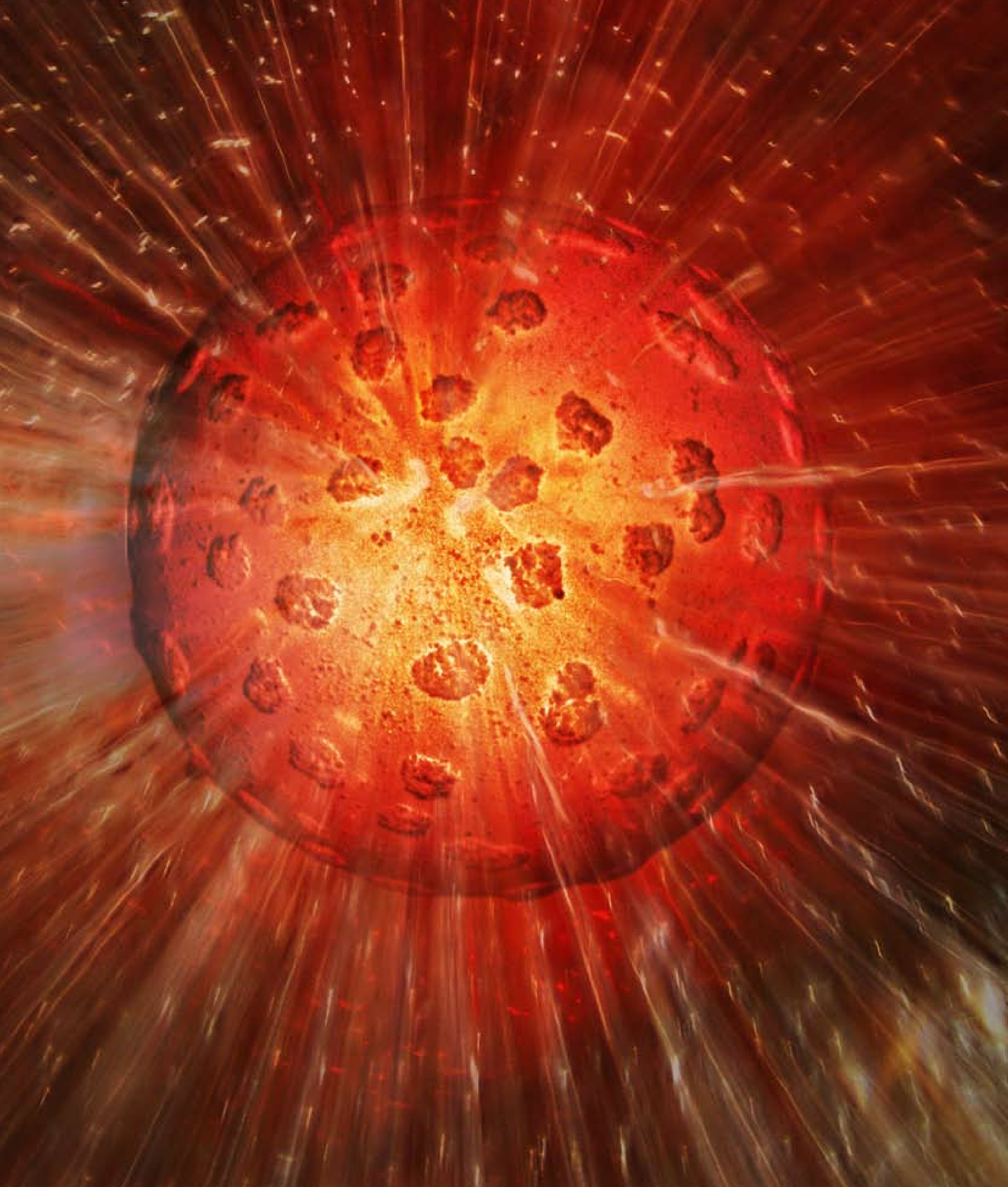
THE AUSTRALIAN NATIONAL UNIVERSITY

SCIENCEWISE

Winter 2013



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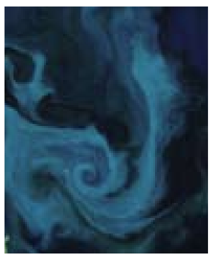
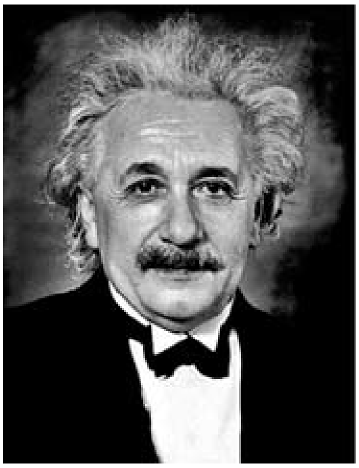


Dr Tim Wetherell

T S

Are you really part of the problem?



You must have seen the dozens of posts on social media captioned something like "If you know who the person on the right is and not the person on the left - you're part of the problem." Are you really? I don't think so myself.

I don't deny there is a problem. But blaming kids because they find Kim Kardashian more interesting than science is like blaming your customers for choosing to eat at someone else's restaurant. Clearly they go there because the food's better. If you want to change that, it's far more effective to improve your own cooking than it is to shout abuse at them from across the street. The customers are not the problem, we are.

Take a look at Kim. She's an attractive young woman with a moderately famous father like thousands of others. But she's taken those assets and built them into a multi-million dollar, world famous brand and I say well done lady!

Now lets look at science. We have billions of dollars, some of the best brains on the planet and have achieved incredible things - bionic limbs, robots on mars, insights into the nature of the universe. So why is science less interesting to kids than Kim?

Personally, I think one problem a perceived elitism. Many people who are fans of science though not necessarily scientists, use social media to continuously put down anything and anyone they see as unscientific. They do it in order to try to promote science - which is a laudable goal - but I don't think it really works.

Calling someone stupid because they find a celebrity interesting isn't going to make them want to join our science club. Nor is pouring ridicule on every belief you see as non scientific. It often comes across as arrogant and elitist even if it's not intended that way.

Science doesn't win arguments by scorning the opposition with childish taunts. It wins them by the application of reason. And scientists - at least good ones - don't project the notion that we're part of an exclusive club to which other less educated people are not welcome to join. It's something I feel quite strongly about. Science is for everyone!

Scorn a child for finding fashion and contemporary culture interesting and you probably alienate them for life. Why not instead simply show them something really cool that science is doing and encourage them to believe that they can become part of that?

Maybe the best balanced kids (and best future citizens) should know who both the people in that photo are!

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Cover Image: *Artist's impression of a radiotherapy microsphere See page 6*

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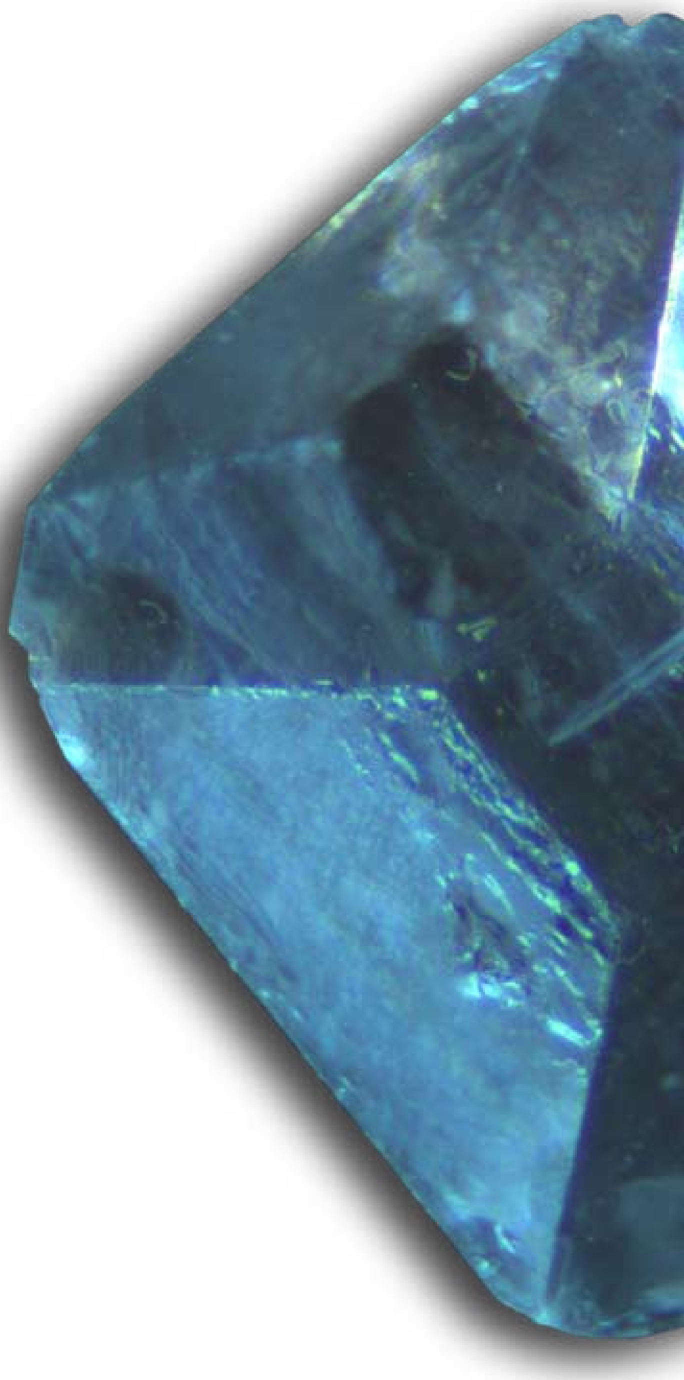
Crystal



Unlike electronic computers which all use transistor based microprocessors, there are many different ways to make a quantum computer, though few if any have yet proved totally practical. One of the most promising candidates is a crystal containing rare earth ions. Data is written in with a laser of incredibly well controlled wavelength and stored in the form of excited ions within the crystal. The quantum calculations are then performed by the interaction between these billions of excited ions.

In an everyday environment those subtle quantum interactions between different ions in the crystal are absolutely swamped by external influences such as the buffeting they receive from thermal vibrations and light shining in. So to make a working computer, scientists need to cool the crystal down close to absolute zero. But even then, problems remain.

Rose Ahlefeldt has just completed her PhD at the Australian national University, during which she's been working on the growth of crystals for use in quantum computers.

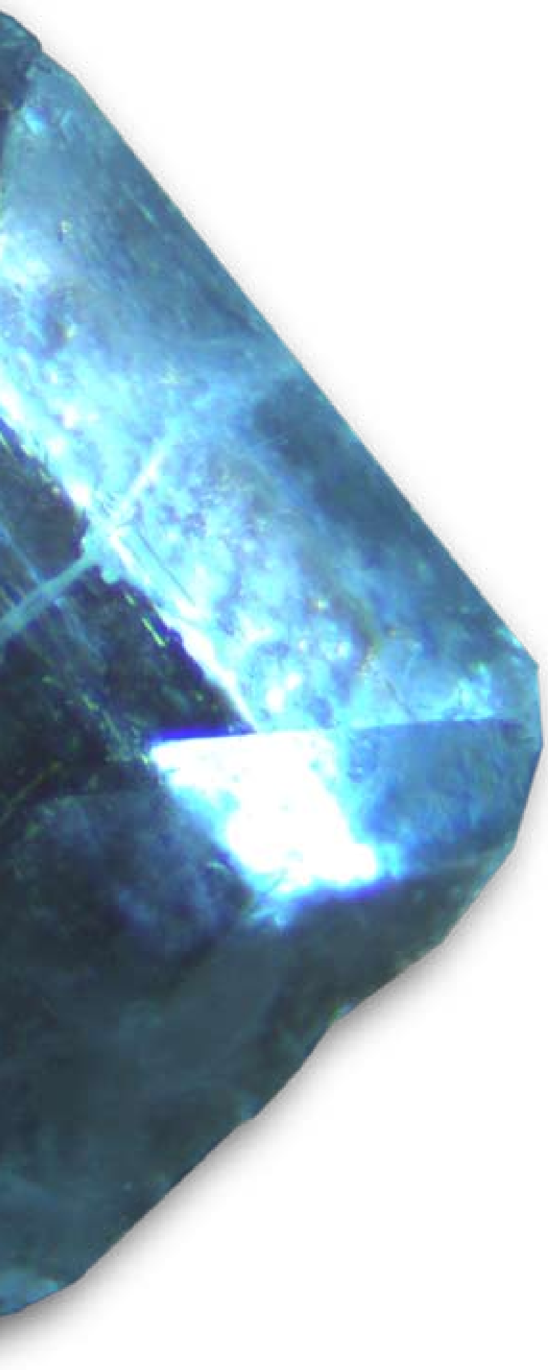
"If the crystal isn't perfect, in other words if the atoms aren't all lined up exactly as they should be, any ions that sit near the defects experience different conditions to their neighbours" Rose says, "So the way they store and manipulate the laser light changes and the computer won't work. So a lot of my work has focused on developing better ways to crystalise the materials we need."

All crystals grow by adding successive atoms, just like a bricklayer building a wall. And just like the bricklayer, the faster the job is done the worse the quality of the work tends to be. In the case of crystal growth it's the temperature of the solution that dictates how fast the atoms are laid down. If the solution is cooled too quickly, the atoms go on haphazardly leaving gaps and wrongly seated atoms, creating crooked rows in the lattice.

"The process starts with the creation of a good seed crystal. That's really important because it will dictate how the main crystal develops. We also have to carefully control the temperature and solution strength so that we get the best possible result," Rose says, "But even if every atom were in the right place, there can still be problems because of different isotopes."

power

Unleashing the potential of quantum computing

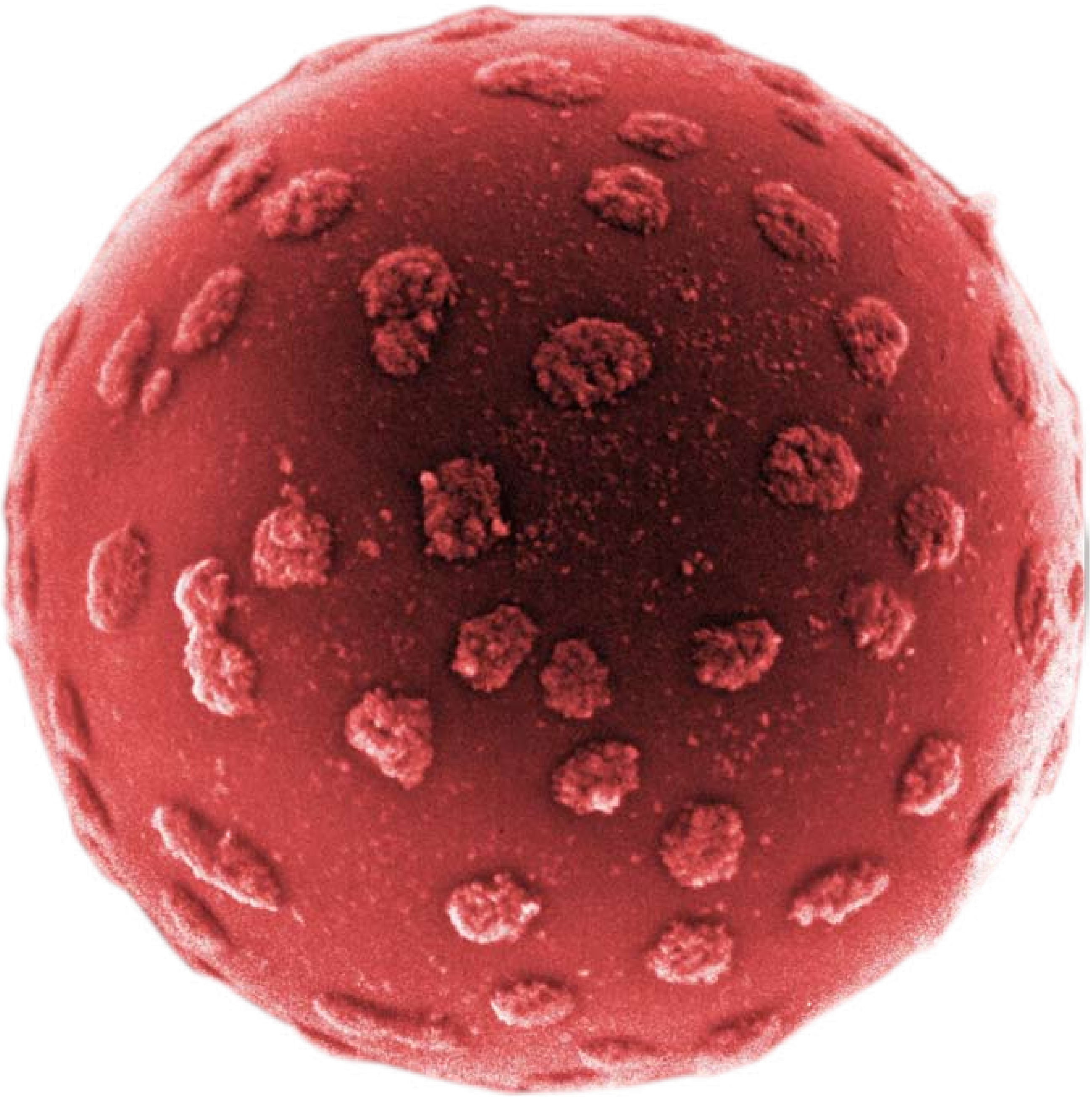


An isotope is an atom with fewer or additional neutrons in its nucleus. Because they have the same number of electrons, the chemical properties are usually exactly the same. “With many elements like carbon, there’s one common isotope and a couple of other very rare ones that are present in tiny proportions. However with europium and chlorine, the main ingredients in our crystal, isotopes are far more prevalent.” Rose explains. “They don’t make any difference chemically but the requirements for a working quantum computer are so stringent that the tiny difference that extra neutron makes can become a problem.”

The next step will be to grow crystals from a solution of isotopically pure chlorine. “isotopically pure salts are very difficult to produce and as a result they’re quite expensive. We’ve recently bought about half the world’s current supply which is still only a few grams. Naturally we want to get our growth techniques spot on before we start using that.”

The current world of quantum computing is a strange mixture of ultra high technology and some strangely incongruous every day materials. “Having tried many sophisticated methods to hold the delicate crystals in the near absolute zero temperatures of the cryostat, one of the most successful is common dental floss!” Rose explains. “Science is a bit like that, the functional properties of materials don’t often relate to our human perception of how good or exotic they are. So if dental floss works best, that’s what we use!”

The mini



Death Star

Nanotechnology in the fight against cancer

DNA is highly complex and relatively delicate molecule that can easily sustain damage from chemicals such as free radicals, ultraviolet light and other natural radiation sources in the environment. If left unchecked, such damage to DNA would rapidly limit a cell's life-span and its ability to replicate. To get around this, cells have evolved a number of mechanisms that are able to repair damaged DNA.

However, all cells are not equal in their ability to do this. In cancer cells, many of the repair mechanisms are absent or of compromised effectiveness. This coupled with their rapid division – a process during which all cells are especially vulnerable to radiation damage – means that radiation is far more lethal to cancer cells than healthy tissue.

More than 100 years ago doctors began to notice that radiation from x-rays and radioactive materials like radium had the capability to diminish tumours. Since then radiotherapy has become a highly advanced and highly effective branch of clinical medicine.

One of the limitations of radiotherapy is that although cancer cells are more sensitive to radiation, healthy cells also suffer damage in the process. So the goal of radiotherapy is to try to localize the radiation at the tumour site. And one approach to this is to place the radioactive material inside the body itself; for example thyroid cancer treatment with internal radioactive iodine is one of the most effective of all cancer treatments, with an excellent safety profile.

In a collaboration between Sirtex Medical and the Australian National University, a new nanotechnology based radiotherapy delivery system is being developed. Professor Ross Stephens is one of the scientists working on the project. "We're trying to fashion an internal therapy that's highly localised and that also gives doctors flexibility in designing individual treatment plans." He says. "Our initial focus is on liver cancer, because certain peculiarities of the blood supply to the liver, make it ideal for this kind of treatment."

Unlike other organs in the body, the cells in a healthy liver derive the majority of their nutritional support from venous blood passing through the organ but liver tumours create their own arterial blood network. "Tumours in effect hijack the liver's arterial supply to service their own needs," Professor Stephens says, "But in the liver this may be their downfall."

Blood from the heart passes through major arteries then smaller ones and finally down into in fine capillaries. At their narrowest points the individual red blood cells have to squeeze through gaps only a couple of micrometers across so that they can reach the venous blood system and circulate back to the heart. "Red blood cells have no difficulty doing this because they are quite 'squishy' and deformable." Professor Stephens says, "But those narrow constrictions provide us with the perfect trap for slightly larger rigid particles."

The current Sirtex liver cancer treatment, already in use internationally, consists of tiny resin spheres small enough to get into capillaries but too big to get out again. "The spheres can be delivered to the liver via a catheter inserted via the hepatic artery," Professor Stephens says, “And if they’re coated with a suitable radioactive material they jam in the tumour capillaries and provide intense radiation right where it’s needed. But to make really user-friendly microspheres requires a bit of nanotechnology too.”

Modern therapeutic isotopes that have replaced radium need to be produced in nuclear reactors then transported to the hospitals where they’re needed. To be effective in radiotherapy they must also be highly active which means they have a short half-life. So there isn’t much time to mess about incorporating them into the microspheres before sending them on their way.

The novel method the researchers have developed involves trapping tiny particles of isotope in a molecular cage made of carbon atoms then using a patented process to adhere those cages to the surface of the microspheres. The process is fast, efficient and most importantly the bond is very strong so the radioactive material can’t wash off in the bloodstream and end up in the wrong part of the body.

The isotope Yttrium 90 is commonly used for internal radiation treatment because it produces energetic electrons known as beta radiation. Due to the way electrons scatter in tissue, the range of this radiation is quite short, focusing the majority of the damage very near the source. Using X-rays the catheter can be directed into the liver and the microspheres delivered into the arterial blood supply of the tumour.

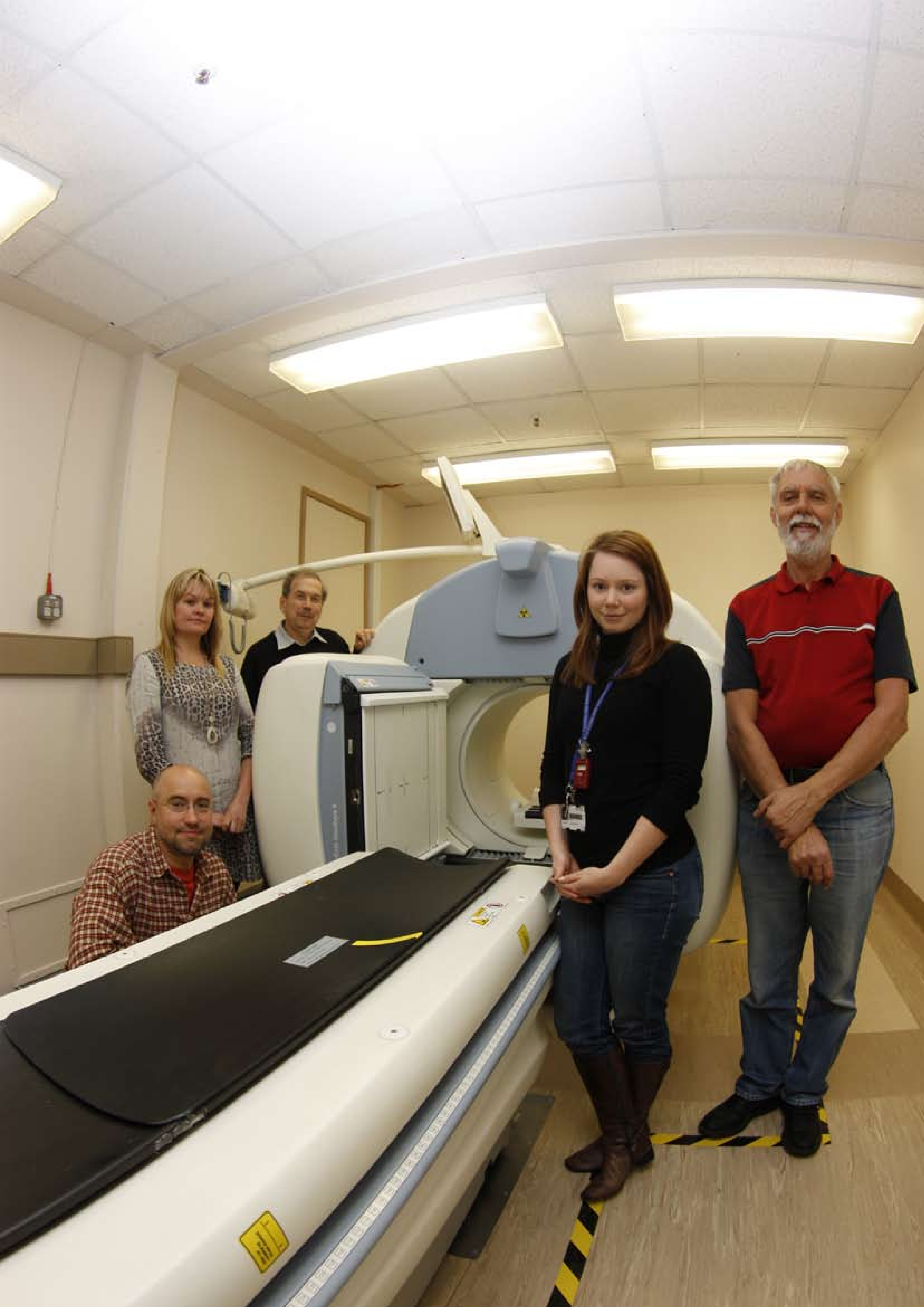
“If all liver cancers were the same that would be the end of the story,” Professor Stephens explains, “But the trouble is they’re not. Often they are multifocal or diffuse rather than just one distinct tumour and each has it’s own particular relationship to the blood supply.”

This makes it very difficult to judge how much of the dose injected is actually reaching the tumour tissue. To make matters worse, if too much of the dose escapes from the liver and lodges in other organs it can cause complications. So ideally, the doctor would like to be able to actually see how much of the radioactive material is going where, as it’s happening.

To achieve this, the scientists have found a way to add a second isotope to the microspheres, such as gallium 67. Gallium 67 emits gamma rays which pass right through the body and can be detected externally. By coupling gamma detectors with the X-ray it’s possible to create a superimposed three-dimensional image of both the liver and the radiation.

“So you have two kinds of radio isotope on the microspheres. Yttrium 90 which creates intense short range beta radiation to kill the cancer and gallium 67 which emits gamma rays that a clinical scanner can detect.” Professor Stephens says, “And because you can see the location of the radiation in the gamma scan along with its intensity, you can get an excellent measure of the actual dose being applied to the tumour.”

“This is proving an excellent collaboration between university and industry,” Professor Stephens says, “And we all get the satisfaction of knowing that the science we’re doing has the potential to really help many people.”



Hot flush

How thermal plumes affect the Southern Ocean

The Antarctic Circumpolar Current is the strongest ocean current in the world moving 140 million tons of water every second. It flows clockwise around the Antarctic continent distributing dissolved minerals, biological specimens and perhaps most importantly heat. However, as things stand, we don't know nearly as much as we should about this current especially considering the importance of the Antarctic region to climate science.

One scientist who is working to put that right is Dr Stephanie Downes of the ANU Research School of Earth Sciences. "Given how important the Southern Ocean is to climate models, we're especially interested to learn as much as we can about ocean currents in the region," Dr Downes says, "And we're starting to uncover some very significant things such as hydrothermal plumes that many current climate models don't take into account."

Hydrothermal plumes are jets of hot water created by volcanic processes along tectonic plate boundaries, and are found all over the global ocean. Such plumes spew out vast quantities of superheated water laced with many minerals dissolved from rocks deep in the mantle. It's not unusual for the highly pressurized water from such plumes to be at over 200°C. Once this hits the freezing cold water at the bottom of the ocean it mixes and cools but the quantity of plume water is so large and the temperature so high that it has a very significant heating effect.

"Collectively the deep thermal plumes around Antarctica are contributing heat in the same general ball park as solar radiation mixed down to the ocean floor, so it's not something we can simply ignore when modelling ocean circulation."

To study the effects of these plumes scientists like Dr Downes need to know where the water from them goes and what it does. But identifying which water comes from where in an entire ocean is a tricky business. "For these particular plumes originating in the south Pacific, we can look at what's called stratification to follow the movement of water, that's the profile of how density changes with depth," Dr Downes explains, "The plumes create a very specific stratification and the immensely strong current carries that warmer water thousands of miles east to the southern tip of South America, and south to the coast of Antarctica."

Whilst stratification measures give scientists a good clue to the origins of a particular mass of water, it's not absolute proof like a DNA sample. To be sure that the stratification measures are really signatures of a plume and not just a freak mixing of other water, scientists turn to those dissolved materials.

"The water from the vents contains lots of minerals like iron, magnesium and even gold," Dr Downes says, "But that doesn't give us certainty because after hundreds of years of venting, those elements are quite abundant in the sea at large. But what is rather unique are elevated levels of helium."

Helium is a common element in the universe but rare on Earth because our planet's gravity isn't strong enough to prevent this lightweight molecule from simply drifting off into space. However radioactive decay of heavy elements deep within the Earth create large quantities of helium in the form of alpha particles, which become trapped below ground. Water surging through thermal vents can pick up this helium and bring it to the surface.

"We correlate our stratification estimates with helium data so we can be far more confident that the flows we're mapping are really warmer water leaving those vents." Dr Downes says, "And it's fascinating to see how far this warm water travels because of the strong Antarctic Circumpolar Current."

"We know from recent studies that climate change is beginning to have an impact on deep ocean temperatures, so the behaviour of ocean currents around Antarctica is a really important thing to study. It's not just a case of what direct effects a warmer ocean floor has, those temperature changes also influence most of the great circulatory currents on the planet which in turn have a huge effect on local climate, and the global ocean storage of heat and carbon."

Left: The Antarctic Circumpolar Current is so powerful its effects can be seen as far away as New Zealand. In this NASA photo algae highlight the swirls and eddies as cold water driven north by the Antarctic Circumpolar Current mixes with warmer waters flowing south past North Island.

Increased capacity

One of the problems with all energy generation, be it green or not, is that the demand from households and industry varies enormously throughout the day. At five o'clock in the afternoon when the population start to arrive home and begin cooking dinner there may be a demand for three or even four times as much power as at five o'clock in the morning.

Even worse are unexpected heat-waves or cold-snaps, during which everyone turns on climate control. Clearly the simple answer is to just store the power as it's generated then release it again when it's needed. The trouble is that this simple answer isn't so simple to engineer. Conventional batteries such as the lead acid accumulator in your car, are simply not economic on the scales that would be required. They also have a limited life span. Imagine changing the entire national power infrastructure as often as you change your car battery!

A better way to store electricity is with a capacitor – a device that collects electrical charge on two closely separated plates.

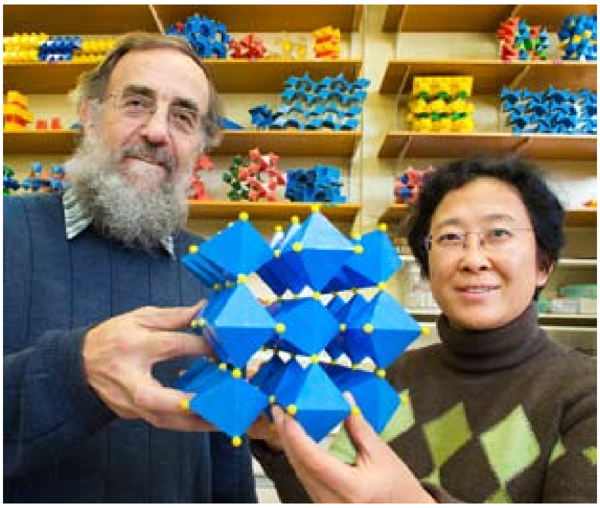
More or less any two conducting plates will do. For example two five cent coins with a piece of paper between will act as a capacitor. And like many other types of capacitor, the two coin device would never need replacing because unlike a battery, it has no wet chemical systems to deteriorate over time. However the reason Australia's power stations aren't coupled to a mountain of five cent coins is that such capacitors are only capable of storing a miniscule amount of electricity.

There are two ways to increase the storage capability of a capacitor. One is to make the plates larger and/or have more of them. The other way is to change the material that separates those plates. The effectiveness of that separating material is determined by a property known as the dielectric constant. The bigger the dielectric constant, the more energy that can be stored in a capacitor of a given size.

Professors Yun Liu and Ray Withers of the ANU Research School of Chemistry and their research groups have recently published a paper in the prestigious journal Nature Materials, in which they describe a totally new class of dielectric materials.

A capacitor can be as simple as this - though a good one will require some far more sophisticated materials science

New materials that may revolutionise green energy



Ray Withers and Yun Liu. Other members of the research team include Wanbiao Hu, Mandy Snashall, Lasse Noren, Terry Franckombe, Hua Chen, Frank Brink and Jennifer Wong-Leung

"Metals have an enormous dielectric constant but they're useless as separators in capacitors because they would simply conduct the stored charge, losing all the energy in the process," Professor Liu explains, "Insulators don't leak the charge away but neither do they tend to have such high dielectric constants. So what we've been trying to create is a dielectric that combines the best properties of both."

They've achieved that using clever adaption of a very common material, the mineral rutile (titanium dioxide). By adding small amounts of niobium and indium to the rutile the scientists were able to create tiny defects in the lattice. Rather like adding a few tennis balls to a hopper full of golf balls, the smaller balls have to sit awkwardly around the larger ones.

"The additional elements coupled with the defects they induce create what are in effect nanoscale regions that have the properties of a metal. But because these are dispersed in an insulating lattice you don't get the massive losses that would occur using solid metal" Professor Withers says.

The result is a super dielectric material with up to a million times the storage capacity of paper as well as low loss. But the material's excellent properties don't end there. Because rutile is a stable solid mineral its dielectric properties are very tolerant of high and low temperatures which makes it ideal for harsh industrial environments. It's also cheap and abundant which means that in principle, such storage devices could be mass produced very economically.

A huge amount of the cost of electricity is what's known as "gold plating" the supply. That is having vast spare generating capability on standby to cope with peaks in demand. Perhaps one day capacitive storage may offer a far more economical alternative and dramatically reduce our greenhouse emissions in the process.

Continent

Unravelling the mysteries of continent formation

The idea of large tectonic plates slowly drifting across the planet, forming and destroying continents, is now well established in science, but exactly how pieces of old mantle and crust interplay with newer freshly melted material is a hot topic in modern geoscience.

Alex McCoy-West is currently completing his PhD at the ANU Research School of Earth Sciences, looking at the processes that formed New Zealand. "There's been a lot of focus on the processes that formed very old continents like Africa or Australia but what I've been doing is looking at the other end of the spectrum, at a very young continental fragment, New Zealand." Alex says, "And as with all geology one of the first and perhaps trickiest steps is obtaining the right samples."

Obtaining samples from the Earth's crust is relatively straight forward. They can be collected from the side of a mountain, if you know what you're looking for, or from drill cores to approximately 8 km deep. However, to see the whole picture, scientists need to know what's going on in the deeper portions of the Earth.

The lithosphere consists of the crust and upper most solid part of the underlying mantle. These regions are quite rigid, rocky and brittle, whereas the lower mantle is hotter, more plastic and convects over geologic time. "You can think of sections of the rigid crust and upper mantle moving together, rather like an iceberg with a little piece visible and a vast keel beneath." Alex says, "and obviously obtaining samples from 'the keel of the iceberg' deep within the lithosphere is quite challenging because it's far deeper than drill cores can reach."

However, as is often the case, nature offers a solution. Basaltic volcanoes can rapidly bring up hot liquid rock from deep within the Earth, pouring it down their sides in the form of magma. As this magma makes its way up through cracks in the lithosphere, it sheers off fragments of the walls and drags them to the surface, rather like raisins in a cake mix; to the trained eye of a geologist, these mantle xenoliths 'foreign rocks' are easy to spot.

"I've spent quite a lot of time scouring the slopes of volcanoes around New Zealand looking for suitable samples." Alex says, "But even once we've found these xenoliths from deep in the lithosphere, it's quite difficult and complicated to derive information from them."

al life rafts

Magma forced up from deep in the mantle sometimes contains xenoliths 'foreign rocks' torn for the walls of the fissure, allowing scientists a rare chance to analyses material from deep in the Earth.

Much of the information that can be extracted from these xenolith samples relies on the measurement of isotope ratios of different elements.

When rocks melt the various trapped elements have the opportunity to either enter the melt phase and migrate away, or remain in the solid residue of the rock. This partitioning is controlled by the compatibility of the elements in the minerals present. For example, the extremely rare element rhenium strongly enters the melt phase when temperatures get hot enough because it is highly incompatible, whereas osmium is compatible in sulphide phases that are common in the mantle and therefore remains behind in the residue from melting.

One isotope of rhenium is unstable and undergoes radioactive decay into osmium (187Re beta decays to 187Os with a half-life of 41.2 billion years). Over long periods time this creates small variations in the isotopic ratios. By measuring very precisely the ratio of osmium, rhenium and their various isotopes, scientists can calculate how much time has passed since the sample was last melted.

"The concentration of osmium and rhenium in samples from New Zealand is ridiculously low, osmium concentrations are less than 5 parts per billion with rhenium generally 1000 times lower". Alex explains, "So we have to be careful during the analytical processes not to lose our sample. After I've crushed up the available samples and chemically purified the rhenium and osmium there's so little there that if it wasn't for the acid it's suspended in, you'd never be able to see it in the beaker!"

In spite of this, the team were able to deduce geological age information for the samples using some of the most sophisticated diagnostic equipment in the world at ANU and the University of Maryland in the USA, with the results recently published in the journal *Geology* (Feb 2013).

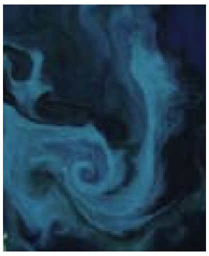
The picture that emerges is that a very ancient fragment of mantle lithosphere underlies eastern New Zealand and probably served as a nucleation point for the much younger material to form around. "The age difference between the crust and the underlying mantle is 1.5 billion years," Alex explains, "That's in stark contrast to older continents like Africa where there's typically no difference at all. It's quite exciting because it looks like New Zealand is a classic example of what's known as a continental life raft." Additionally, this discovery of ancient lithosphere within New Zealand provides new information on its origins and assembly history, with major tectonic implications for the present-day development of the Australia-Pacific plate boundary cutting through New Zealand.

ANSWERS

SCIENCEWISE

What do crystals have to do with quantum computers?

How is nanotechnology helping the fight against cancer?



What are hot volcanic vents doing to the southern ocean?

What simple device could save trillions in energy bills?

What does this rock have to say about New Zealand?