SCIENCE WISE

ANU COLLEGE of SCIENCE Magazine

THE AUSTRALIAN NATIONAL UNIVERSITY

- **Why Tibetan poppies have the blues**
  Studying the impact of humans on Meconopsis
- **Cloak of invisibility?**
  Exploring the properties of materials with negative refractive index
- **How wombats are getting their teeth into the climate change debate**
- **Mechanisms of myopia**
  How the retina can regulate the growth of the eye

Volume 5 No. 2 March / April 2008

http://cos.anu.edu.au

SCIENCE WISE

Volume 5 No. 2 (March / April 2008)

ScienceWise is published by
the ANU College of Science.

THE AUSTRALIAN NATIONAL UNIVERSITY

Managing Editor:

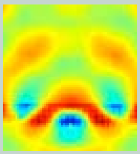
Dr Tim Wetherell

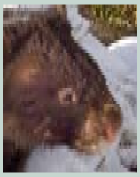
T: +61 2 6125 0361

E: tim.wetherell@anu.edu.au

Cover image:
ANU graduate student Hongyan Xie during field work in Tibet

In This Issue





NEWS

For the very latest news from ANU see
http://info.anu.edu.au/mac/Media/Media_Releases/

The Editor's Corner -

Bend it like Bozons

Dr Tim Wetherell

We're covering a couple of stories on optics in this issue, one about human engineered optical materials (page6) and one about an amazing natural instrument - the eye (page 10). Both human engineers and nature tend to employ much the same principles. Sometimes because we copy nature but often because when faced with a given set of physical laws and a given problem, there is only one good solution. This situation can been seen time and again in the history of invention. It's easy to make the mistake of thinking that one has a good idea and that it's new and amazing. Then to discover many others have reached the same conclusion. Throughout history widely separated groups of humans have often developed similar technologies and social traditions in response to being faced with similar biology and similar problems. I suppose its what makes all cultures more similar than they are different.

During prehistory many humans must have noticed that drops of water bend light in strange ways and that if correctly placed, have the ability to make things appear larger. Those fortunate enough to live in regions where natural crystals like quartz were polished round by rivers would doubtless have made use of these natural magnifiers. Some archeologists argue that an ancient biconvex quartz crystal found in Nineveh (now a part of Iraq) is evidence for use of lenses at least 2500 years ago. Others suggest that this is putting a modern functional interpretation on an ancient object. Whichever is true, the lens' original owner would have been just as intelligent as you and I and surely can't have failed to notice that it magnified objects.

What I personally find strange is that it took humans so long to develop better optical instruments. Perhaps that's the perspective of a scientist interpreting history using modern concepts? Perhaps that's why they don't let scientists teach history? But whatever the reason, the development of lenses and the instruments they are used in took a very, very long time.

Any simple biconvex lens will magnify but there's a practical limit on how much. The apparent magnification depends on the ratio of the lens to eye, and lens to object distance. When this becomes about ten, you are either too close to the object to allow any light in or so far back that the field of view is tiny. The way round this took more than a thousand years to discover. Two lenses in combination, separated by a distance make a far better magnifier than one. It took another 300 years to perfect the art of designing and grinding two lenses to the required tolerance to make a microscope. Even with two lenses, you are limited to about 1500 times magnification in visible light because of diffraction. The way around this is to use electrons rather than visible light. The effective wavelength is much shorter so the diffraction limit is greatly extended. But it's still there. Physics is a bit annoying like that, beyond every breakthrough lies another obstacle.

So what does this have to do with bozons? Well Bozons are a family of particles with integer spin that include photons of light. Their trajectory bends when entering or leaving refractive media and well, sometimes I'm stumped for a snappy title!

These two magnifiers employ the same basic principle, but getting from left to right took humanity about 3000 years. Fortunately in the century since this beautiful brass microscope was made, we've picked the pace up a little.

Why Tibetan poppies have the blues

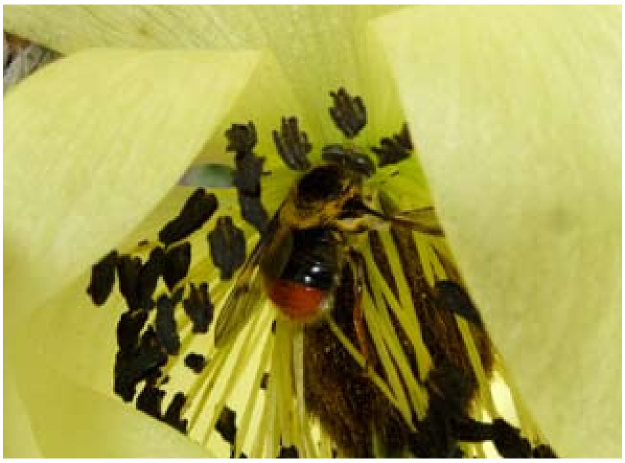
PhD student Hongyan Xie is passionate about the flora, fauna and unique culture of her native Tibet. Her current research focuses on an exceptionally beautiful genus of poppy known as Meconopsis. Among these is the famous blue poppy, but different species grow a range of striking colours including yellow, red and purple. These poppies grow in the thin air of the alpine regions of Tibet and are amongst the highest growing flowering plants on earth. However the fragile ecosystem that supports Meconopsis is under threat from three different directions.

Hongyan Xie and Felicia Pereoglou (a PhD student in The Fenner School of Environment and Society) after a long day field survey in Northern Sichuan, China

Climate change is beginning to increase temperatures in many alpine regions of the world. The stark reality of this was underlined by a recent decision by European banks not to offer development loans to lower altitude ski resorts in the Alps, for fear that there would be no more snow. In the case of Meconopsis, the problem is that with increasing temperatures, competitor species are able to colonise its habitat. The poppies can't easily move to higher altitudes because the soil, rainfall and other environmental factors are different. An area that has been too high to support plant life for hundreds of thousands of years has very much less organic matter in the soil than a vegetated area. In the course of evolution, plants can accommodate such factors but not on the short time scale of the current changes.

Meconopsis racemosa

The second threat to the poppies is their value in traditional Tibetan medicine. Meconopsis in combination with other local herbs is used to treat inflammation and to assist in the healing of fractures. In addition to local needs, traditional Tibetan medicine is becoming increasingly popular in China. This has raised the market price of the plants, which encourages locals to supplement their incomes by gathering poppies whilst out on the mountains tending their yaks. Unfortunately, Meconopsis is extremely difficult to cultivate and


Arctophila khamensis sheltering in Meconopsis

to date, efforts to grow them in commercial quantities have proved unsuccessful. As a result, all medicinal plants must come from specimens collected in the wild.

The third threat to Meconopsis comes from increasing human population, which in turn leads to more yaks and heavier grazing. Although yaks don't eat the poppies directly, they do displace smaller grazing animals into areas where the poppies grow. More humans also means more picking and more demand for medicine.

Establishing whether or not these three pressures on the poppies are causing their numbers to decline is a matter of careful survey work. But establishing the root cause of such declines is a lot more complicated. Hongyan came to Australia to learn more about plant biology and conservation; she found the expertise she needed in ANU School of Botany and Zoology, and CSIRO Entomology.

Through the course of her studies, Hongyan hopes to fill in many of the sketchy details of the life cycle of various species of Meconopsis. Of special interest is the mechanism of pollination. The study region is a centre of diversity for bumble bees, which are well suited to higher altitude environments. In the short warm part of a summer day in the mountains bumble bees can be seen busily moving from flower to flower, their furry bodies coated with pollen. In the cool of the afternoon hoverflies settle down inside the poppy flowers where they shelter for the night. As they fly off in the warm of the following day they too can be pollinators. It seems that a large part of the reward for pollination in this case is the provision of shelter from the cold of the alpine night.

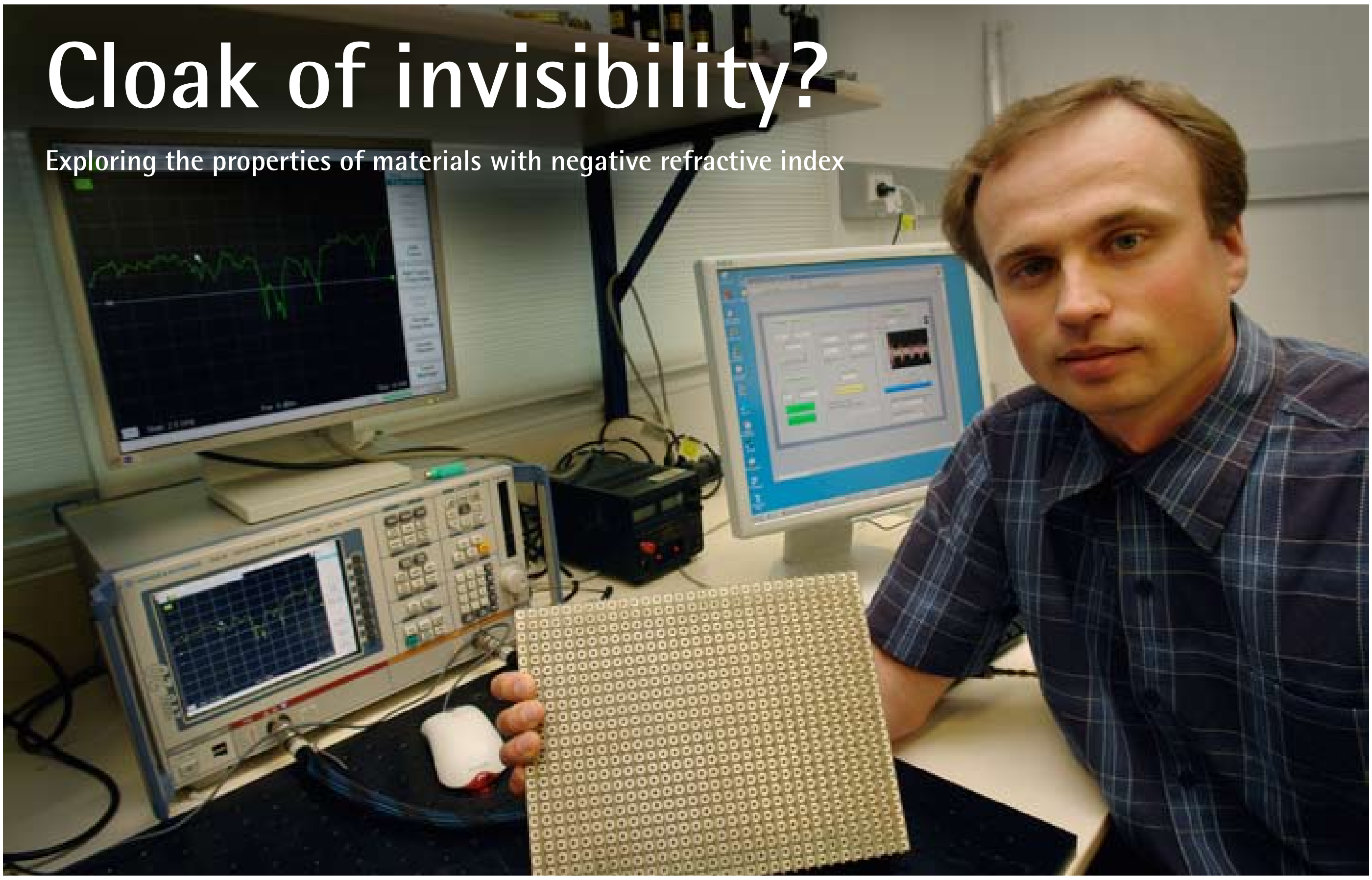
Ironically, one of the first major contributions to come from this study has been a discovery in entomology. During the course of collecting samples of pollinating insects, Hongyan found a previously unreported species of hoverfly. After consulting with experts at CSIRO and the Smithsonian Institute in the USA, the fly was declared a new species and as its finder, Hongyan was given the honour of naming it. Arctophila khamensis after the region of Tibet it inhabits.

Whilst the Meconopsis poppies are beautiful and economically important in themselves, their plight is linked to that of many other plants and animals in the area including the newly discovered Arctophila khamensis. Hongyan explains, "You can think of Meconopsis as an indicator species. It's charismatic and people care about it, but what happens to Meconopsis will also affect what happens to other species that may be less visible and less attractive, but are just as vital to the complex webs that form an ecosystem.


Often called "the roof of the world" Tibet is famous for its spectacular natural beauty. Image courtesy of www.free-slideshow.com

Cloak of invisibility?

Exploring the properties of materials with negative refractive index



Dr Ilya Shadrivov with a nonlinear metamaterial, other members of the group are Dr. David Powell, Mr. Steven Morrison, Professor Yuri Kivshar

Have you ever wondered why completely transparent objects like wine glasses are so easy to see when windows made of the exact same material are almost invisible? The answer lies in a property of materials known as refractive index – their ability to bend light. Materials like glass have a high refractive index and therefore bend light as it enters or leaves them. Light hitting a flat window is all deviated in the same way, so the image remains undisturbed and consequently, the window is almost invisible. However the curves of a wine glass mean that light strikes the glass at different angles in some places than others and is therefore bent differently. In this case what we see is a warping of the surrounding image, which our brains conceptualize as a physical object – the glass.

But why do materials refract light in the first place? The refractive index of a material is created by a combination of the electric permittivity and magnetic permeability, which are themselves, dictated by the atomic structure and composition. In plain English, this means that a photon of light, which is made up of oscillating electric and magnetic fields, is perturbed by the rows of tiny electric and magnetic dipoles formed by the individual atoms making up the glass.

The mathematical analysis of refraction at the atomic scale is highly complex but the important end result is that light changes direction when entering and leaving refractive media. All materials found in nature have positive permittivity and positive permeability leading to positive refractive indices. There are however a class of artificially created substances called left handed metamaterials, that can be engineered to exhibit negative refraction.

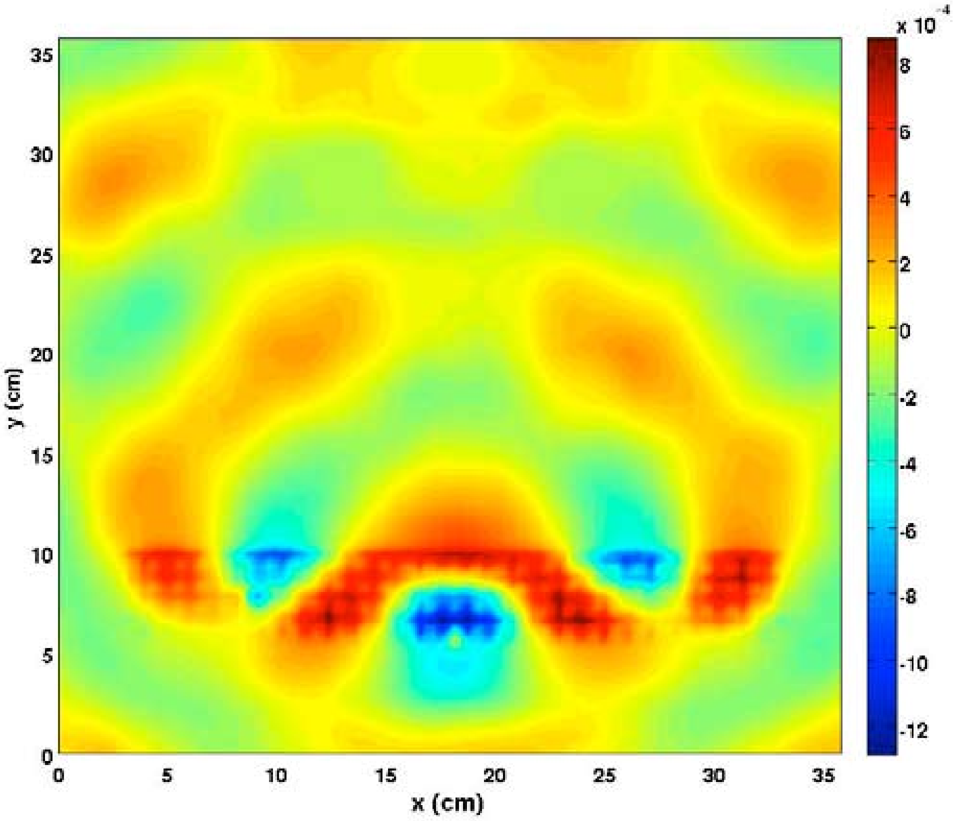
Dr Ilya Shadrivov has spent many years with the Nonlinear Physics Centre

Refraction is a key factor in rendering transparent objects visible investigating these exotic negatively refracting matamaterials, initially developing sophisticated theoretical models then later testing their predictions in the laboratory using real materials. The process of producing crystals with such negative refracting properties in visible light would be a highly complex and expensive exercise in nanotechnology and would not offer the control and flexibility required to work on developmental systems. So instead, the researchers use large-scale arrays of dielectrics such as fibreglass containing lattices of electronic components. Instead of visible light, the scientists irradiate these test arrays with microwaves that have far longer wavelength - in keeping with the scale of the lattice. "In optically transparent materials such as glass, the individual atoms are in effect tiny row of electric dipoles interacting with passing waves. In the large-scale lattices used in our research, the diodes serve the same purpose. What's more, if we use variable capacitance diodes on wire loops whose electrical properties change with field strength, we can induce non-linear behaviour." Dr Shadrivov explains.

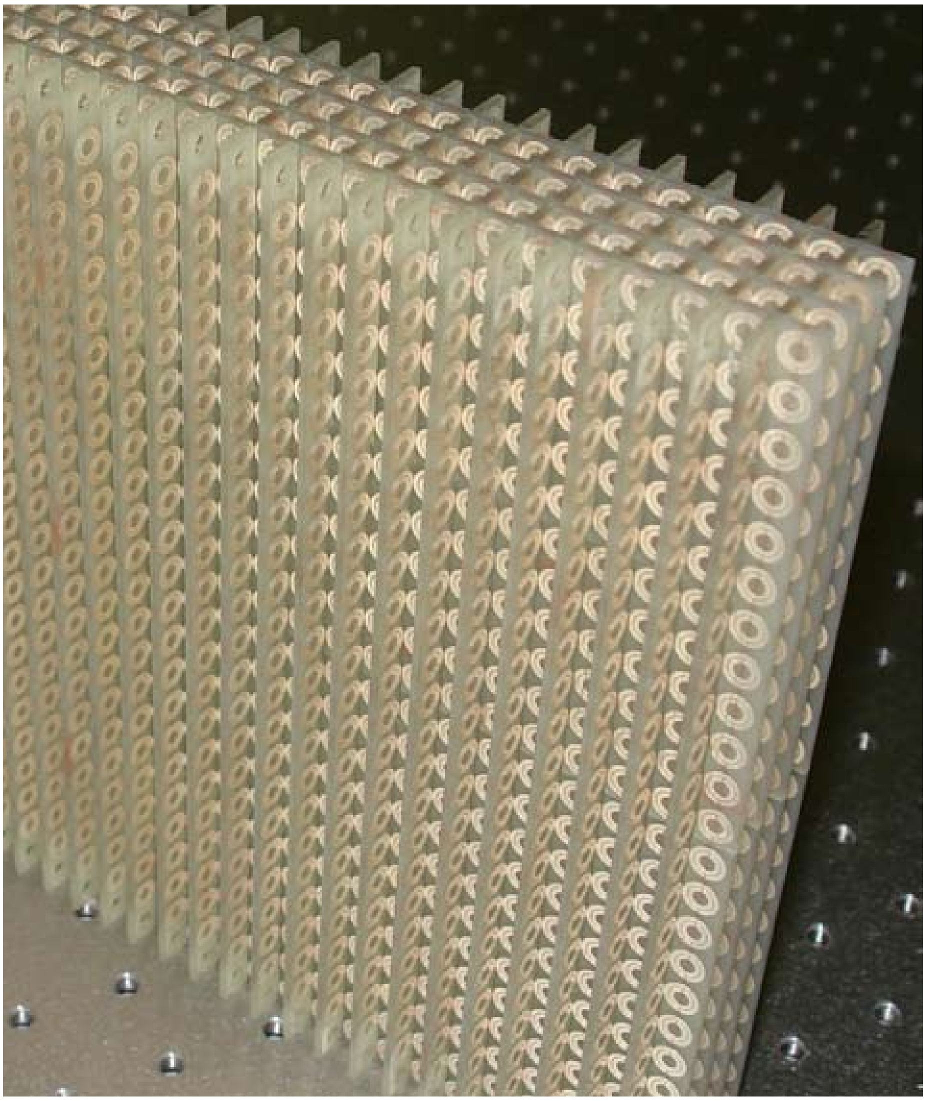
"The use of these large-scale diode arrays gives us the flexibility we need to test and further develop our models, yet is on a scale easily constructed by humans. The electromagnetic microwaves are longer and the lattice is bigger, but the physics and mathematics is exactly the same as for visible light."

The ANU group has for years been a world leader in the theoretical treatment of nonlinear matamaterials and has recently become one of the first groups in the world to practically demonstrate such behaviour in the laboratory.

At the moment these exotic nonlinear matamaterials represent the forefront of materials physics. However it's quite possible that within a few years they will lead to the realization of technology straight from the pages of science fiction. For example, an appropriately used shell of the right negatively refractive metamaterial may be able to bend light or radar around an object and redirect it to its original path on the other side. Such a device would render the object inside, completely invisible.



Laboratory measurement of an electromagnetic wave scattering on a nonlinear metamaterial. The large scale of the microwave based materials enables researchers to more easily measure the spatial behaviour of electromagnetic radiation as it interacts with them.



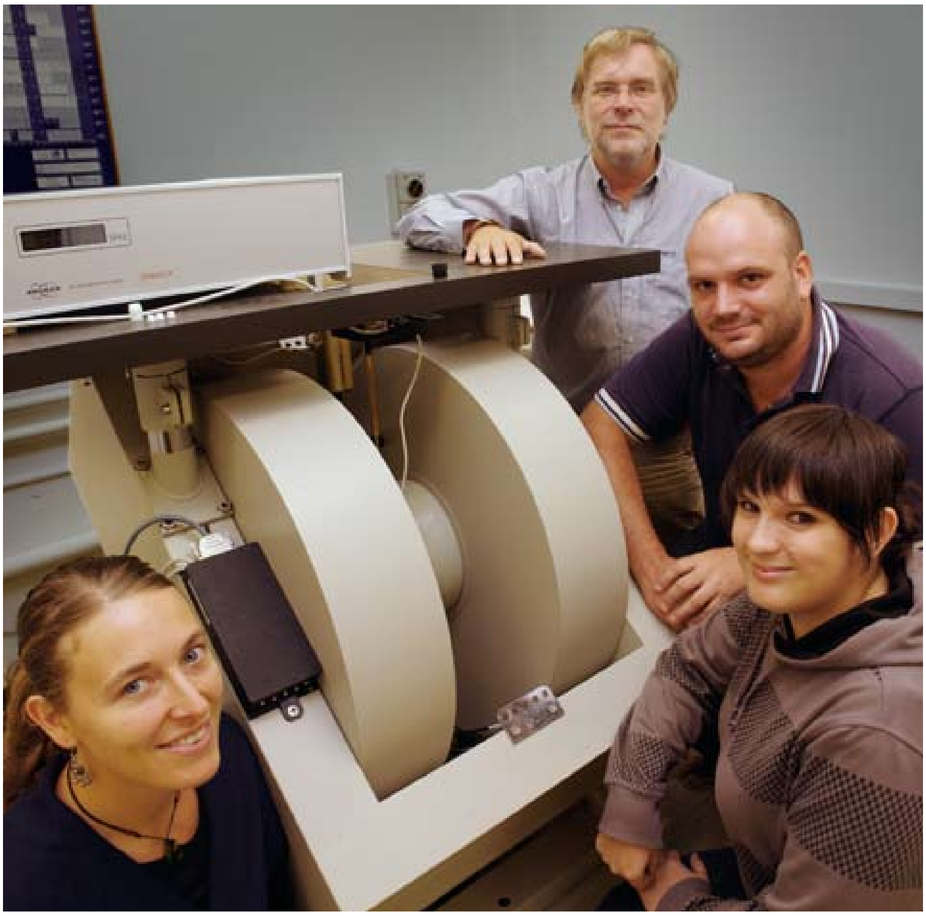
Close up of a metamaterial designed to operate at microwave wavelengths

How wombats are getting their teeth into the climate change debate

The Willandra Lakes Region of South Australia comprises quarter of a million hectares of semi-arid landscape incorporating dried saline lakebed plains, sand dunes and grassy woodlands. The region has been World Heritage Listed for both its diverse ecology and its cultural significance to indigenous people. This unique and beautiful landscape has undergone continuous human habitation for almost 50,000 years. For scientists like Professor Rainer Grün, this makes the Willandra Lakes a unique and fascinating place.

Professor Grün's research team, together with the Department of Environment and Heritage and the Traditional Tribal Groups, have recently received an ARC linkage grant to study the history of the region's climate, using a wide variety of techniques. Professor Grün explains, "The exciting thing about Willandra Lakes is that it has the potential to provide detailed information about climate variation spanning an earlier warm period through the last glaciation and right into the present warming." By better understanding climatic variations in the past, the team hopes to glean important information about predicting future climate scenarios.

Many disciplines will be brought together within this project. It is hoped that archaeological studies of human habitation carried out in collaboration with the Three Traditional Tribal Group Elders, will yield information about the diet of the indigenous people of the region. The quantities and types of fish and molluscs being consumed at each period in history closely reflects the water levels in the lakes which are in turn linked to climate. Optically stimulated luminescence dating of sediment samples will be used to calculate how long each layer has been buried which, in turn, gives clues about water levels and flows. And of course isotope-dating studies, including radiocarbon dating, will be conducted on organic material.



Professor Rainer Grün, Dr Kathryn Fitzsimmons, Ian Moffat and Tegan Kelly with an electron spin resonance machine uses for dating samples.

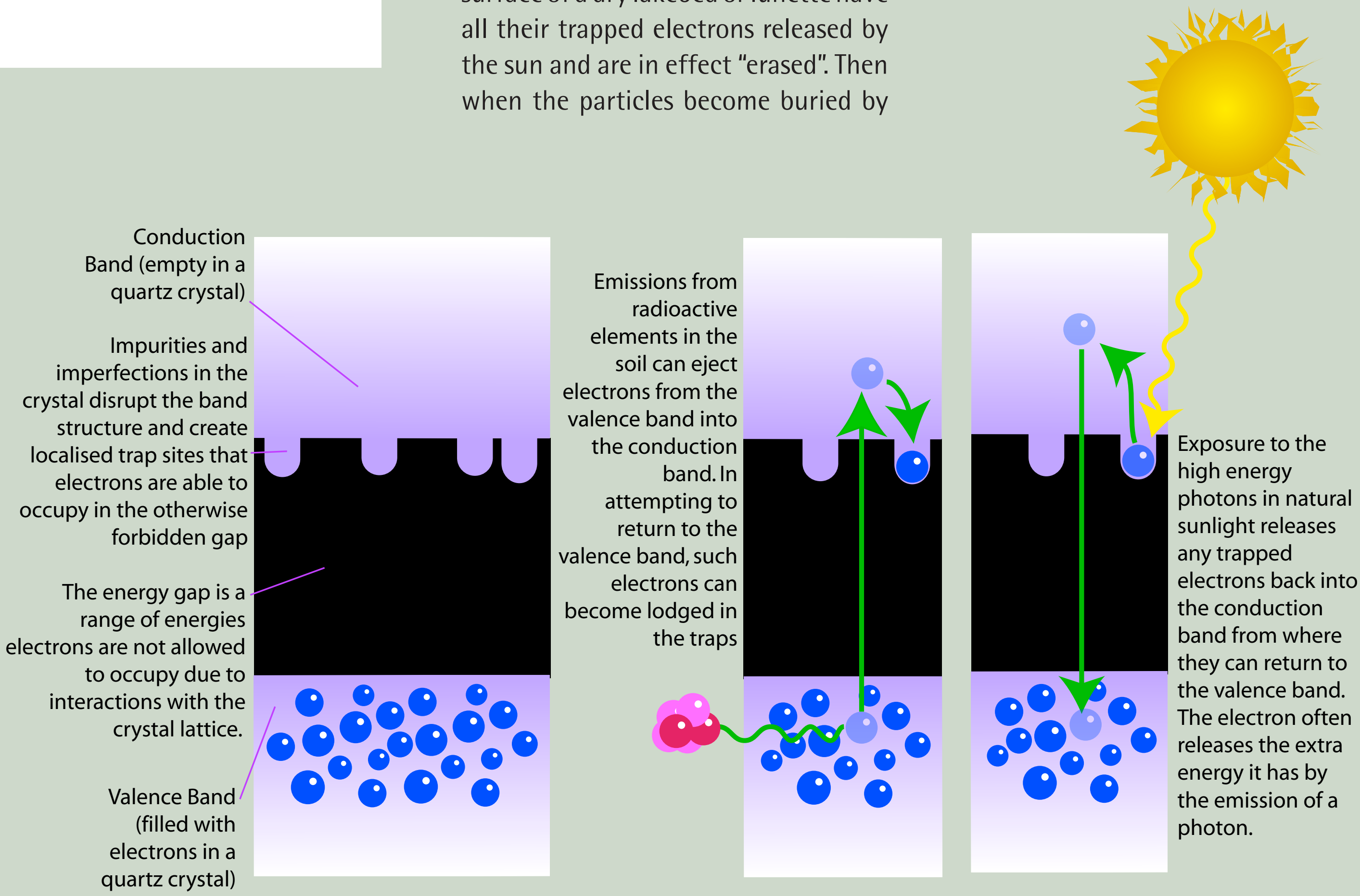
One particularly interesting facet of these studies will focus on wombat teeth. Wombats are herbivores so various different types of grass form a large part of their diet. Unlike most other herbivores, a wombat's teeth grow continuously from the roots and are worn down at the grinding surfaces. Consequently, a typical wombat tooth has enamel ranging from zero to just over one year old. As the tooth grows from the root, the isotopic ratio of elements such as carbon and oxygen that are incorporated into the enamel are controlled by the isotopic ratio of the grass in the wombat's diet.

There are two common photosynthetic pathways found in grasses and other green plants known as C3 and the more evolutionary advanced C4. Species employing the C3 pathway tend to thrive in areas with plentiful groundwater. C4 plants, on the other hand, enjoy a significant advantage in times of drought. In this way, the relative prevalence of C3 vs. C4 vegetation provides an indicator of local rainfall. Because of the slightly different photochemistry between C3 and C4, the isotope ratio of the plant tissue created by each is subtly different. The practical upshot of this is that in times of drought wombats eat more C4 plants because they are more abundant and in wetter times the reverse is true. Because of the differing isotope ratio in the wombat's food, the isotopic composition of its tooth enamel provides an indirect measure of local rainfall. Different points along the tooth provide data on how the rainfall varies from month to month which can be put into a broader historical timescale by radiocarbon dating. In this way researchers can deduce which points in history had wet springs, dry summers etc. Wombats are a particularly good animal for this type of study because they generally die within their burrows, so their remains are protected from scavengers and the weather.

By pooling the data from wombat teeth and the various other climate indicators of this study, researchers hope to build up a picture of the climate of the Willandra Lakes region spanning back over 100,000 years. Armed with this data, scientists should be able to refine climate models and better understand how to place in context the changes Australia is currently experiencing.

What is optically stimulated luminescence ?

Sands forming the lunettes the lee-side of Australian lakes consist mainly of anorganic minerals, so radiocarbon dating is of little use in ascertaining their age. However, such sands can be dated by optically stimulated luminescence. When grains of quartz are exposed to natural radioactivity from elements such as uranium in the surrounding soil, electrons within the crystal are excited to high energies. These energetic electrons often become trapped in potential wells formed by the complex interaction of impurities within the crystal and its band structure. Such traps are too deep for ambient temperatures to release the electrons but they can be released by the energy of photons in direct sunlight. In effect, this means that any quartz particles lying on the surface of a dry lakebed or lunette have all their trapped electrons released by the sun and are in effect “erased”. Then when the particles become buried by subsequent sediment deposits, the naturally occurring radioactivity in the surrounding soil slowly begins to fill the electron traps again. If a quartz sample is exposed to a monochromatic light source in the lab, the trapped electrons are released again and they emit light with specific spectral qualities as they escape the traps. By measuring the total emitted light during the optical stimulation cycle, it is possible to calculate the proportion of traps that originally contained electrons. An exposure age can then be deduced from the highly complex relationship between the light emission of the stimulated quartz, the environmental radioactivity and the time it has spent buried since its last exposure to sunlight.

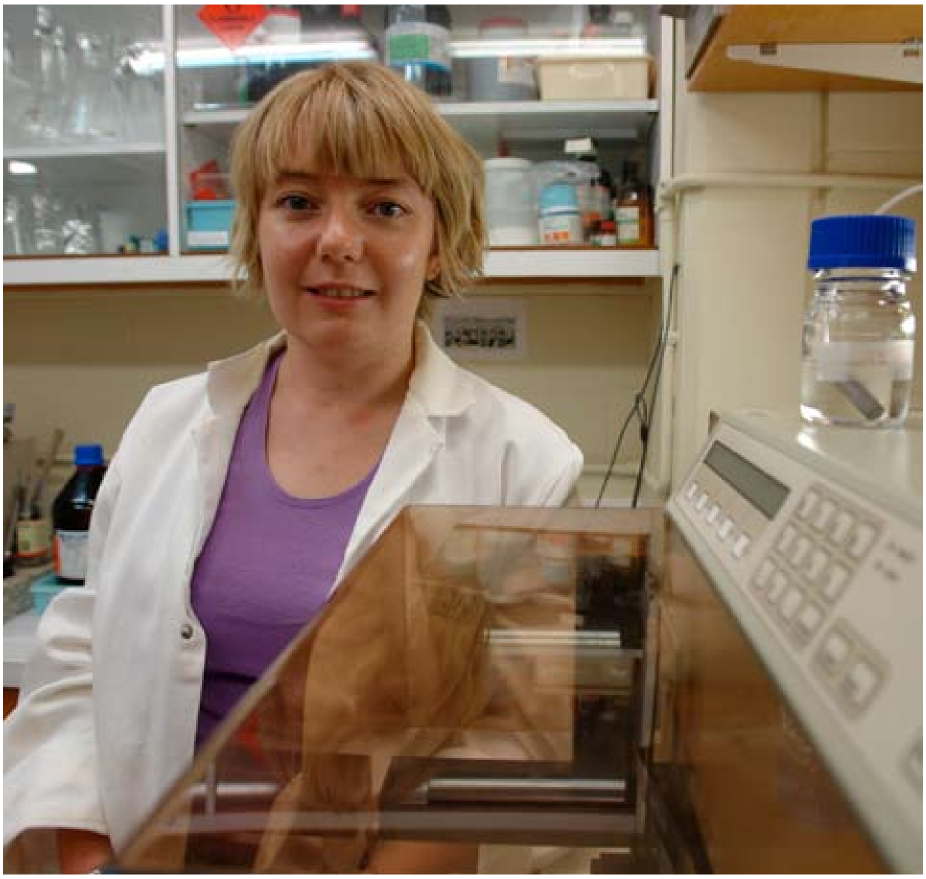


Mechanisms of myopia

How the retina can regulate the growth of the eye

It has taken humans thousands of years to master the technology of making optics such as telescopes and cameras that produce good images. Yet on the surface of it, nature seems to have little difficulty producing remarkably precise optical surfaces and alignments within the eyes of most animals. How does nature manage to get the length of the eyeball right to within optical tolerances? This is a question that lies at the core of the research of Siobhan McCarthy from the Research School of Biological Sciences. Siobhan has just submitted her Doctoral thesis on the role of the retina in controlling myopia (short sightedness) and is about to begin a postdoctoral fellowship in the same area.

Siobhan explains that in most animals at birth, the eye is hyperopic or long-sighted. Structurally this means that the eye is shorter than ideal. In terms of practical vision, this isn't a major problem because the animal can clearly see images at long distances and accommodate to see close objects clearly. As the animal matures the eye will grow and gradually the point of focus will become exactly correct. However in some people the eye becomes too long and thus myopic. This growth of the eye is thought to be at least in part, controlled by the neurotransmitter dopamine. Dopamine is released from specialized cells within the retina called dopaminergic amacrine cells. Dopamine release increases in response light and particularly flickering light which increases the temporal contrast in the image on the retina. In other words, the focused patterns of light and dark on the retina that occur during the process of normal seeing, actually stimulate the retina to produce chemicals which regulate the growth of the eye. By the use of this ingenious feedback mechanism, nature is able to manufacture a precision optical instrument using soft "goey" materials that would be a nightmare to a human engineer.



Siobhan McCarthy

A large part of the motivation behind this work is to try to understand how the mechanism works so that we can develop better treatments for the cases when doesn't. Myopia is becoming a large problem in many areas of the world, with some east Asian countries recording myopia rates as high as 90%. Whilst mild myopia can be treated with corrective lenses or even advanced laser procedures such as LASIK, extreme cases can lead to other serious complications. If the eye becomes extremely extended and highly myopic, this can lead to structural problems such as tears and detachments of the retina that are far more difficult to treat.

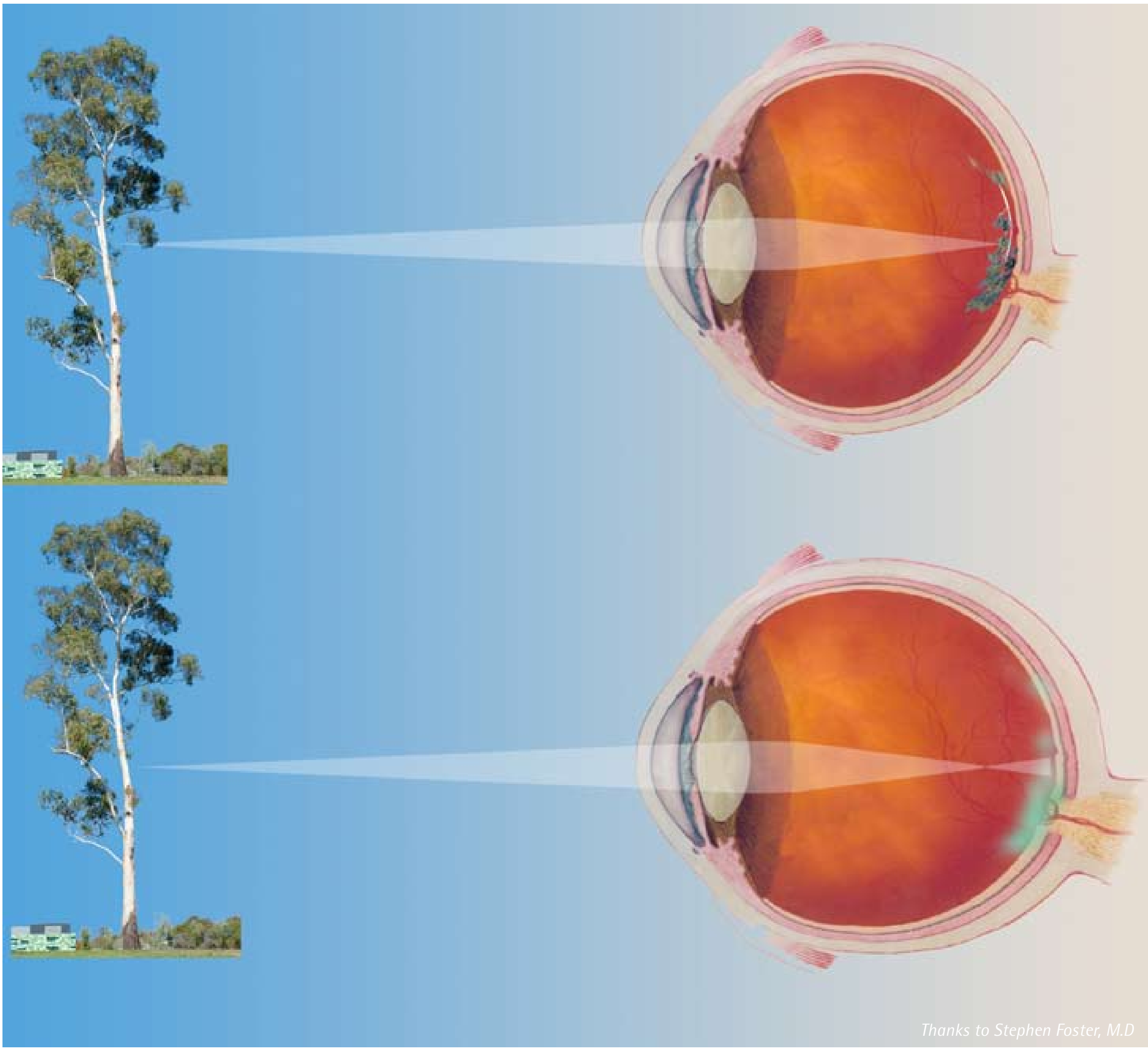
There have been quite a few animal studies in which the influence of externally introduced dopamine agonists (mimickers) and antagonists (inhibitors) have been used to investigate eye's development. Whilst such studies are valuable, Siobhan wanted to develop a different technique that was less invasive and that perturbed the natural mechanisms of eye development as little as possible. Her study was based on chickens that were fitted with little goggles. Over one eye a plastic diffuser allowed light through but frosted out any clear image, the other eye was left uncovered as a control. The chickens were then free to wander around their enclosure doing the normal things that chickens do. Over the course of their development, Siobhan measured the levels of dopamine and correlated this with the growth of both the covered and the control eyes.

Of course you can't get a chicken to read an eye chart, so alternative measures of visual acuity must be employed. Because a myopic eye is a longer than a normal eye, Siobhan measured the length of the eye using an ultrasound scan of the eye which gives the spatial dimensions.

The research to date has supported the role of retinal dopamine in the control of eye growth but it has also highlighted some other surprising findings. In order to correctly regulate eye growth the retina does not absolutely need to have a contrasty image all of the time. Removing the diffuser for as little as three hours a day is enough to fully restore the regulatory growth mechanism. Siobhan also explored the rather surprising phenomena of intensity related dopamine stimulation. It appears that exposure to bright light can stimulate dopamine production even in the absence of any spatial contrast. She believes this may relate to the long standing observation that children in cities that spend a great deal of time indoors, tend to have higher rates of Myopia than those living in more rural areas that spend more time outside in brighter light.

The ultimate picture that emerges from this work is of a highly complex series of mechanisms by which the retina controls the development of the eye using dopamine and other chemical messengers. There is still a great deal to learn but the researchers hope that one day we may be able to create simple non-invasive treatments for children diagnosed with the potential for myopia. Such treatments may be able to restore the eyes defective regulatory mechanism and enable it to halt growth at the correct point. Siobhan acknowledges that it's unlikely that any treatment can eliminate all visual defects in developing eyes, but even if it were possible to limit the severity of myopia in most patients, that would be a very worthwhile result.

More Info:
c.siobhan.mccarthy@gmail.com



In a normal mammalian eye the refractive surfaces of the cornea and lens create a sharply focused image of a distant scene on the light sensitive retina. The cornea has a fixed curvature but the lens is able to adjust its shape by tension and relaxation of the ciliary muscle. This allows the eye to accommodate (adjust its focus) for near and far objects. However the range of this compensation is limited. If the eye grows too long, the focused image is created within the vitreous humour of the eye and by the time the rays reach the retina, they have diverged again. Under these conditions the eye cannot achieve a sharp focus on the retina, and is termed myopic or short sighted.

THE AUSTRALIAN NATIONAL UNIVERSITY

ScienceWise is published by the

ANU College of Science

Editor: Dr Tim Wetherell

Subscription

Subscription to ScienceWise is free to schools, if you would like to be added to our lists please visit

http://sciencewise.anu.edu.au

ANU COLLEGE OF SCIENCE

CoS@anu.edu.au

http://cos.anu.edu.au

CRICOS Provider No.00120C

ScienceWise offsets its paper consumption with contributions to native tree planting programs.