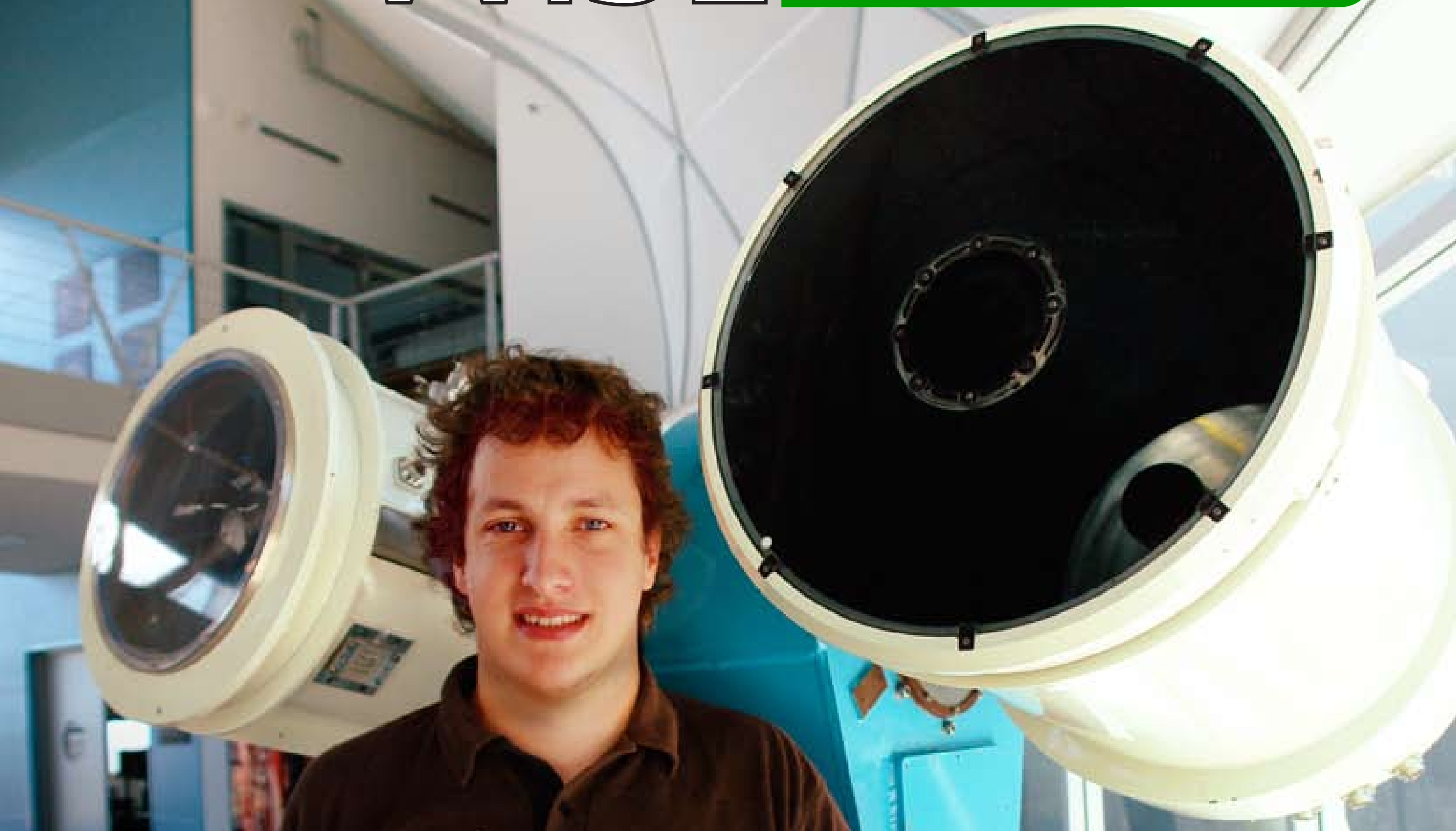
SCIENCE WISE

THE AUSTRALIAN NATIONAL UNIVERSITY

ANU COLLEGE of SCIENCE Magazine



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SCIENCE WISE

THE AUSTRALIAN NATIONAL UNIVERSITY

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Cover image:

Wolfgang Kerzendorf in the new Advanced Instrumentation Centre at Mt. Stromlo Observatory

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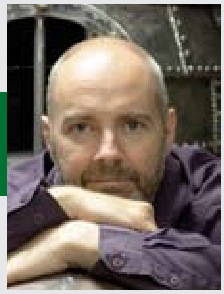


Dr Tim Wetherell

From the way science is often portrayed in popular culture, one could easily get the impression that it's the most complex and difficult thing in the world. This is ironic really, because whilst some science is highly complex, the underlying concepts are often beautiful in their simplicity. As Einstein said, "everything should be made as simple as possible - but not simpler!"

This is the goal of science. Not to generate complexity but instead to create the simplest possible, self consistent and mathematically elegant understanding of the Universe free of any unnecessary clutter. The job of the scientist is to identify the essential logic in a situation, develop a theory based on that logic then test his/her theory against observation - a useful life-skill in itself (see page 10).

Our lead story in this issue is about the changing rate of expansion of the universe. The results that underpin this work were gathered using some of the world's most sophisticated telescopes, but to illustrate that the universe really is expanding you only need your eyes and a line of reasoning developed by the nineteenth century German astronomer Heinrich Wilhelm Olbers.

Olbers argued that if the universe was infinite and filled with an infinite number of stars and if it had been around for ever then which ever way one looked into the sky one would be looking at a star. In this case the whole night sky should be blazing bright not black. The answer to this paradox is that the universe is not static, it's expanding.

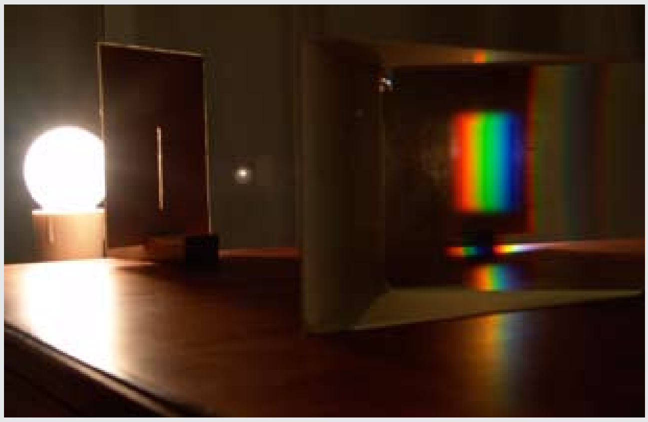
In the nineteenth century, the notion of an expanding universe wasn't acceptable to conventional wisdom and Olbers concluded that the dark sky was caused by interstellar dust obscuring distant skylight. Although interstellar dust does exist, if there were enough of it to absorb that much light, and the universe were static, the dust would become so hot it would radiate light itself. With no disrespect to Olbers, this illustrates the classic trap of becoming too wedded to one's expectations to see where the evidence is truly leading you.

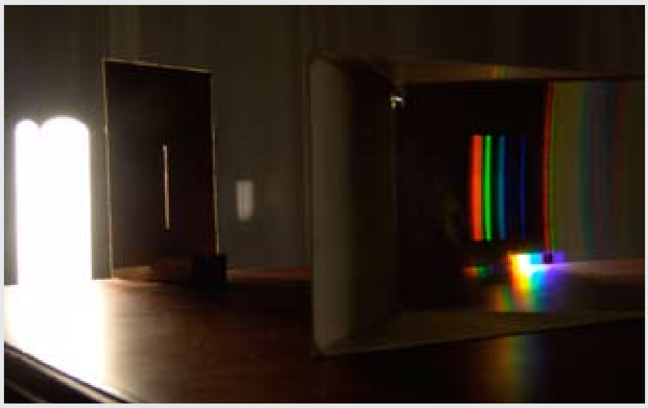
My favourite simple demonstration of a profound scientific concept is illustrating the quantum nature of the universe with a prism and a couple of light bulbs. The prism and a cardboard slit are used to make a rudimentary spectrometer. If you use this to examine a normal incandescent light bulb, you should see a continuous rainbow of emission (following the Stefan–Boltzmann black body radiation law.)

But a fluorescent light (such as one of the new low energy lamps) emits only in narrow lines of certain colours.

The explanation is that atoms in the excited gas within the fluorescent light only emit energy at set wavelengths. This in turn is because the orbitals of their electrons are only allowed to occupy certain quantum states. If there was no quantum physics the electrons would slowly wind down towards the nucleus radiating multiwavelength electromagnetic waves as any moving charge on the macroscopic scale does.

This is the cool thing about science, you don't have to just accept what you're told. You can test many of its theories for your self using the simplest of equipment, and logical reasoning. All you have to do is keep asking why? And be sure to follow your observations rather than your expectations.





The simplest of instruments can often illustrate the most profound of scientific concepts. This spectroscope consists of nothing more than a glass prism and cardboard with a slit cut in it. A normal incandescent light globe produces a rainbow of colours whilst a low energy fluorescent discharge lamp produces discrete narrow lines. The rainbow of colours illustrate how a hot object radiates continuously over a range of wavelengths. The narrow lines from the fluorescent lamp are a graphic demonstration that electrons can only occupy discrete energy levels.

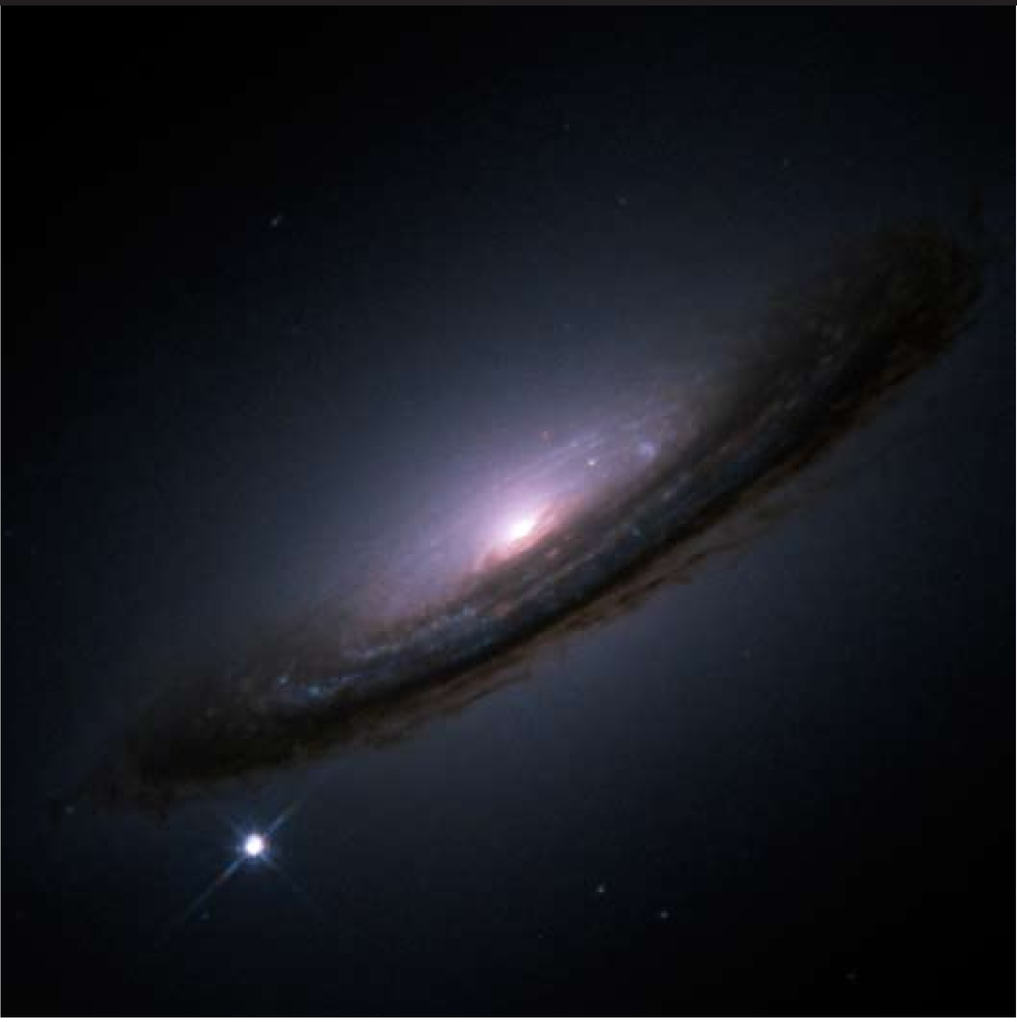
To explain these two observations and the difference between them requires classical electromagnetism, phonons, atomic physics and quantum mechanics.

Those pretty bars of colour from the fluorescent lamp are a simple lounge room proof that we live in a quantum universe - of course fully understanding that quantum universe requires a big brain and some rather more sophisticated lab equipment!

By the light of exploding stars:

How supernova data suggest the expansion of the universe is accelerating

Tim Wetherell



Hubble Space Telescope-Image of a type Ia Supernova SN1994D (bright star at lower left) in galaxy NGC 4526. For a brief period, this single star outshone the rest of its galaxy.

On casually glancing into the night sky, one might imagine that the brightest stars are the closest and dimmer ones are more remote. However the inherent brightness of stars varies by a factor of many millions, depending on their age, mass and other characteristics. The closest star to the earth (other than the sun) is Proxima Centauri – a dim dwarf completely invisible to the naked eye, yet the second brightest star in the entire sky, Canopus, is almost a hundred times more distant than Proxima. For these reasons, establishing the scale of the universe is a far from simple task and the first accurate measurements of stellar distances were not made until the nineteenth century. These used a method called parallax, based on the 300 million kilometre difference in the earth's position as it orbits the sun. This changing viewpoint causes stars that are fairly close to the earth to appear to shift slightly against the background of far more distant stars. The shift is tiny, but measurable. The nice thing about parallax is that it is a simple and therefore reliable geometric measurement but it only works for relatively close objects. For greater distances, astronomers must rely on what are known as "standard candles" – that is objects whose inherent brightness is known, or at least believed to be known. If you know how bright something really is and you can measure how bright it appears, you can work out the distance by the inverse square law.

One useful set of standard candles are Cepheid variable stars. In the late nineteenth century, Henrietta Swan Leavitt studied Cepheids that form part of the Large Magellanic Cloud – a small satellite galaxy of the Milky Way. Because they were all in one galaxy and therefore all at essentially the same distance, she was able to accurately estimate their absolute brightness relative to each other. She noticed that there is a direct relationship between how intrinsically bright a Cepheid is and its period. This means that by measuring the apparent brightness and periods of Cepheids, astronomers can determine their distance far beyond the range of parallax. However, even the most distant Cephieds observable are not that far away in cosmic terms. For huge distances, astronomers have to use brighter and more distant standard candles such as entire galaxies, though the absolute brightness of such objects is not known with nearly the same certainty as that of Cepheids.

In the early twentieth century, with the advent of spectroscopy, astronomers were able to measure both the distance and the relative velocity of objects by observing how far their light was red shifted by the Doppler effect. By combining the distance and velocity information astronomers concluded that almost everything in the universe is receding from us. Edwin Hubble, after whom the famous space telescope is named, noticed that the greater the distance of an object, the faster the object seems to be moving away.

Knowing the velocities and distances of stars and galaxies, one can extrapolate back to the big bang and in this way, estimate an age for the universe. Having done this, a natural question to ask would be what will happen in the future? Will the combined gravity of all the matter in the universe eventually slow the expansion enough to collapse everything back to a big crunch, or will the universe expand forever?

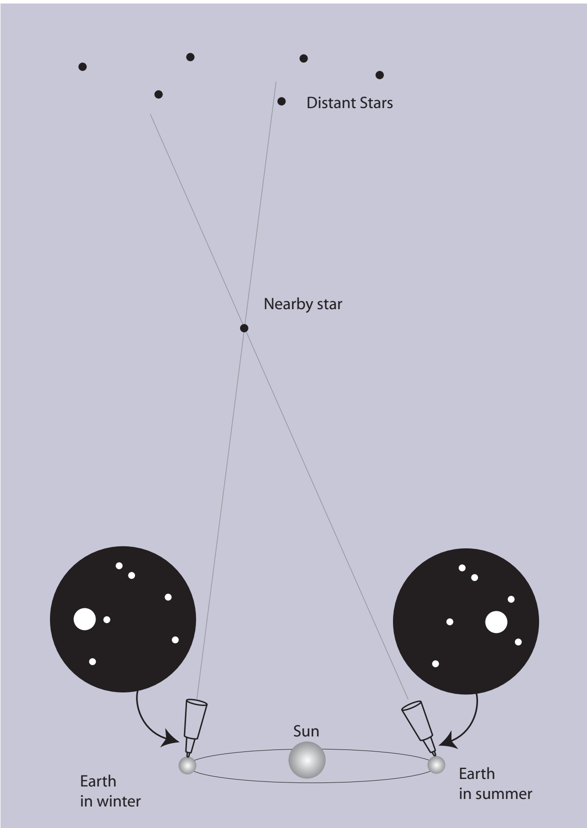
This is a question that fascinates Professor Brian Schmidt of the ANU Research School of Astronomy and Astrophysics. To answer it, professor Schmidt's research group have been measuring the velocities and distances of objects at far greater distances than that at which Cepheid variables could be observed. Entire galaxies can be used as standard candles and can be seen at great distances but it's hard to be sure about their inherent brightness, which in turn makes estimating their distance unreliable. To get around this, the group focused their attention on what are known as type Ia supernovae.

A type Ia supernova can occur in stars similar to the sun. These are not massive enough to enable gravity to compress and heat the core past the point of burning its nuclear fuel to carbon and oxygen. Since iron is the lowest point in nuclear potential, such stars still contain massive amounts of nuclear fuel when the reactions stop. However, if the star is part of a binary pair, it can continue to siphon material off its companion once its own reactions cease, growing in mass until a critical point is reached where gravitational contraction enables carbon and oxygen to begin to fuse into heavier elements. Once this process begins to happen, it happens all at once, like in a nuclear bomb - liberating a huge ammount of energy in a short time.

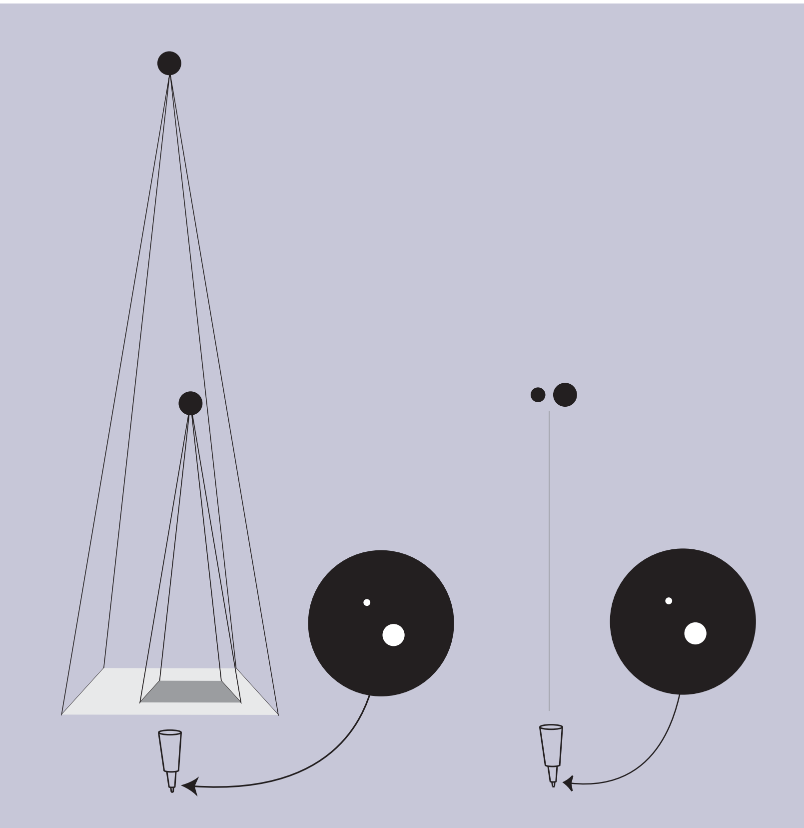
Professor Brian Schmidt with some members and friends of the Gruber Prize winning group

The special thing about type Ia supernovae is that they only occur in stars within quite narrow mass ranges which in turn means that they are all of similar brightness when they explode. This, coupled with their huge brightness, make them ideal as standard candles for extreme distances.

The group have been studying these supernovae for several years and having analysed their data, have come to the surprising conclusion that far from slowing down, the rate of expansion of the universe is actually speeding up. This counter intuitive scenario would have seemed almost inconceivable a few years



Parallax distance measurements are based on the tiny shift seen in the position of nearby stars as the earth orbits the sun. Because this is a simple geometric measurement, it is highly reliable - The difficulty is it only works for nearby stars.



Light spreads out according to the inverse square law so the light of a star becomes dimmer as it's distance increases. If a star's absolute brightness is known its distance can be calculated from its apparent brightness. This only works for a small number of star types whose absolute brightness can be calculated from their other physical properties. The method doesn't work with just any star because a dim and bright star at the same distance will look exactly the same through a telescope as two identical stars at different distances.

ago. Professor Schmidt explains that our observations may really mean one of three things:

- The Exciting: the Universe is accelerating. The Universe is accelerated by some unknown type of matter that is spread throughout the Cosmos.
- The Heretical: General Relativity is as sacred as anything in Physics, but it may be wrong. Since our work is comparing the predictions of General Relativity with observations, if General Relativity is wrong, so are our conclusions.
- The Mundane (at least from our point of view): We are simply wrong and have been fooled by Supernovae into believing the Universe is accelerating. Maybe supernovae are fainter in the past, and therefore look further away.

"We hope and believe it's the first alternative, but we have to work hard and test to see if it isn't the second or third. Checking these two other alternatives is a major focus of our current work".

More info - brian@mso.anu.edu.au   http://msowww.anu.edu.au/skymapper/

Smoking gun

Searching for the donor stars left over from type Ia supernovae

Tim Wetherell

We've covered a few stories in this edition of ScienceWise about the versatility that pure science degrees offer graduates and one such graduate is Wolfgang Kerzendorf who having completed his degree in physics is now performing research towards a PhD in Astronomy in the group led by Professor Brian Schmidt. The group are researching the apparent acceleration in the expansion of the universe (see previous story) and Wolfgang's part of this work is to investigate the nature of the type the Ia supernovae that provide the distance measurement data. He explains, "I'm interested to know what supernovae actually are because as much as we use them as tools in astronomy, there are still many things we don't know about them."

The widely accepted theory about type Ia supernovae is that they occur when a white dwarf star and a larger donor star are in orbit around each other. The white dwarf's nuclear reactions stop at carbon and oxygen because its mass isn't great enough to compress it sufficiently for fusion to progress all the way to iron as with larger stars. Astronomers believe matter is gradually transferred from the donor to the exhausted white dwarf until a critical mass is reached at which point it collapses and fuses heavy elements producing a sudden and enormous release of energy. A type Ia supernova can for a brief period, outshine an entire galaxy.

"If our current theories are correct about the mechanism of type Ia supernovae, then for the nearer ones, we should be able to see the left over donor star" Wolfgang explains. "Because the white dwarf and its donor are in orbit around each other their rotation should be tidally locked just like the earth and the moon. This means that in theory, we should be able to identify a left over donor star by either its velocity through space (increased by the kick of a nearby supernova), or its unusually high spin (because it was once tidally locked to a partner star)."

Part of Wolfgang's PhD project is to use some of the world's largest telescopes such as the Very Large Telescope (VLT) in Chile to investigate potential left over donor stars. Many of these are linked to historical observations such as Tycho's supernova of 1572 and the famous 1006 supernova that was recorded by Chinese astronomers in AD1006 who said that it cast as much light at night as the moon. However unlike the events themselves, the stars and gas envelopes left over are

Remnant of a brilliant type Ia supernova that occurred in AD1006. Image produced by the NASA Chandra x-ray observatory often incredibly dim. So much so that it wasn't until 1965 that the gas envelope associated with the 1006 supernova was identified using the Parkes radio telescope in rural Australia. Part of Wolfgang's' work will be to measure the radial and linear velocities of the very faint stars within the gas shells left over from known type Ia supernovae in order to identify potential donor stars.

Another aspect of his work is to look at the light curve of modern type Ia supernovae in other words how they vary in brightness with time. One valuable source of data for this is the increasingly excellent images created by amateur astronomers. Correlating brightness data with various theoretical models of the mechanism of supernovae can yield vital clues as to what is actually going on. "At the end of the day," Wolfgang says, "the thrust of this work is better understanding of the mechanisms of supernova phenomena so that we can make better predictions about their absolute brightness. When I look at supernovae exploding, there's a lot of particle physics involved, so by undergraduate physics background comes in quite useful."

For those with an aptitude for sciences, the journey from high school graduation to involvement in the forefront of major scientific discovery can by accomplished in surprisingly short times.

Astronomers bring the stars to ANU

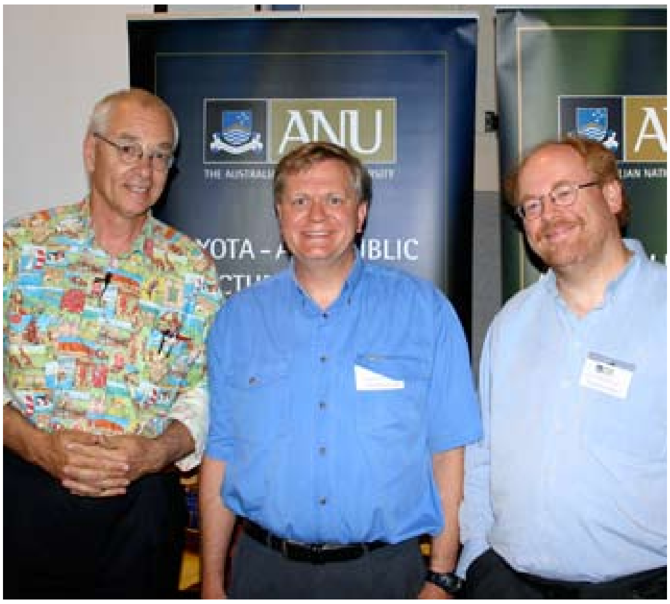
Scott Yates

Dr Karl's public lecture well received by all

On Thursday 15 November the Research School of Astronomy & Astrophysics (RSAA) presented one of Australia's star scientists Dr Karl Kruszelnicki as part of the ANU-Toyota public lecture series. Who better to introduce Dr Karl than our own star Professor Brian Schmidt (winner of the 2006 Shaw Prize and 2007 Gruber Cosmology Prize). Professor Schmidt reminded the audience of Dr Karl's immense range of experiences and accomplishments, and took the opportunity to grab Dr. Karl's autograph for his son. Dr Karl enjoyed the warm welcome and entered into some friendly banter with Professor Schmidt, pointing out his admiration for Professor Schmidt and the work he had done proving the universe was expanding at an accelerating rate. Dr Karl's entertaining presentation had most people on the edge of their seats and in fits of laughter for most of the session. We heard of his surfing saga, the resulting injury and how he almost drowned in a foot of water while his family watched on. We found out about the Mars Rover Explorers and the amazing feats required to land a space probe safely on another planet. Dr Karl shared with us the way he is generating solar power at home. The audience was told all about the mathematical secrets of falling in love, and how and when to find "The One". We received many useful pieces of information such as the scientific evidence that kind people tend to yawn more frequently. Dr Karl ended his talk and the applause from the crowd showed that he was very well received.

There certainly were a lot of challenging questions, which Dr Karl spent the next half hour answering. Afterwards, Dr Karl signed copies of his latest book Please Explain, which was on sale. The display of the Research School in the foyer drew a lot of attention with Dr Jerjen talking to the public about Astronomy and the various research activities at Mt. Stromlo Observatory. Our star student outreach group (recent winners of the Vice-Chancellor's Special Award in the ANU 2007 Staff Excellence Awards) had brought their telescopes along for public viewing outside of Manning Clark Centre. The public was treated to the craters on Moon and the planet Jupiter with its four Galilean satellites. There were also bags of lollies generously donated by The College of Science.

More info - http://www.drkarl.com/



Dr Karl, Professor Brian Schmidt & Dr Helmut Jerjen

The Research School of Astronomy and Astrophysics invites ACT schools to participate in our new outreach program.

http://www.mso.anu.edu.au/public/school_visits.php

Email: outreach-enquiries@mso.anu.edu.au

Science for science teachers

Professional development workshops for science teachers at the Centre for the Public Awareness of Science

Tim Wetherell

For more than a decade, the Centre for the Public Awareness of Science, CPAS have been running a variety of public lectures, science shows and workshops aimed at bringing science to a wider audience, and helping others to do the same. Professor Sue Stocklmayer explains "Our mission is to foster an awareness of and an enthusiasm for Science throughout the community." Science teachers are one group of people already actively involved in doing just that, because teaching science is about more than just facts, its about instilling a passion for science in the minds of students. And of course it's those very students that will become the much needed scientists of the future."

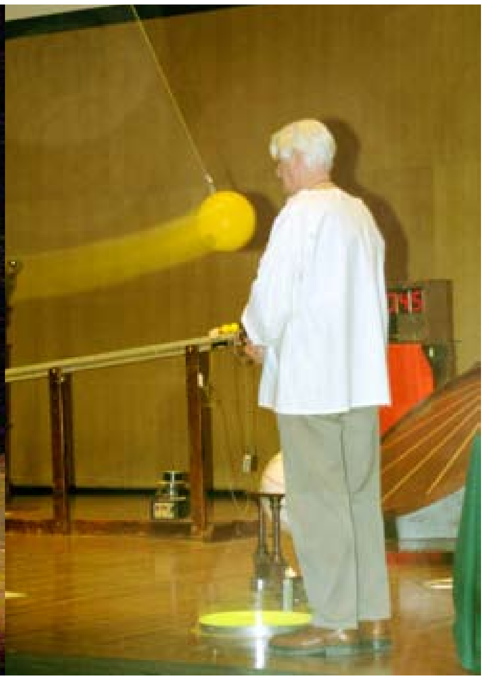
As a result of workshops specially developed for teachers in Queensland, the CPAS team has recently gone on to explore the idea of a series of workshops on specific physics topics. Based on feedback from teachers, the two areas of most interest were forces and fields, and these have formed the focus of the current workshops.

The underlying philosophy of the workshops is to help teachers to create fun and interesting classroom experiments and teaching methods that foster in their students a deep understanding of phenomena, rather than a just knowledge of the formulae. The workshops aim to be curriculum focused, covering material central to the understanding of the underlying ideas of forces and fields. The associated experiments require only commonly available materials and are designed to be thought provoking to students, yet easily achievable in a classroom situation. For example, when short strands of hair are suspended in baby oil and the bottle is brought near an electrostatically charged party balloon the hairs all line up – but why? What is it about the electrical and mechanical properties of the various objects that cause this effect?

The workshops have a special emphasis on common misconceptions, such as the frequent confusion that often surrounds the application of Newton's third law - For every action, there is an equal and opposite reaction. If a fly hits the windscreen of a truck, which one experiences the greatest force? From the fly's perspective it certainly may not look like it, but in fact the force on each is exactly the same. And what is the exact difference between action-reaction force pairs and sums of forces on bodies?

Imagine that two people are pulling a rope that supports a stationary weight in the middle. Would Fred have to pull harder if the rope is attached to a wall than if Jane is pulling on the other end? The surprising answer "no" comes from action-reaction pair analysis. The rope tension that supports the anvil is created by an equal and opposite action-reaction pair and is the same regardless of whether the far end of the rope is held by Jane or the wall.

But why do students often make the wrong intuitive choice in situations like this? Most probably because they imagine a situation where the anvil is being lifted upwards. In this case the answer



Professor Mike Gore demonstrates his faith in the physics of motion at one of CPAS' many science outreach events. When the 5kg bowling ball pendulum is released from the tip of mike's nose and completes its swing, its velocity will reduce to zero as it re-approaches his nose on the return swing. - Or so Isac Newton and Mike Gore believe!

Professors Sue Stocklmayer, Mike Gore and John Rayner of the Centre for the Public Awareness of Science demonstrate some interesting electrostatic phenomena using commonly available items like hair, baby oil and balloons.

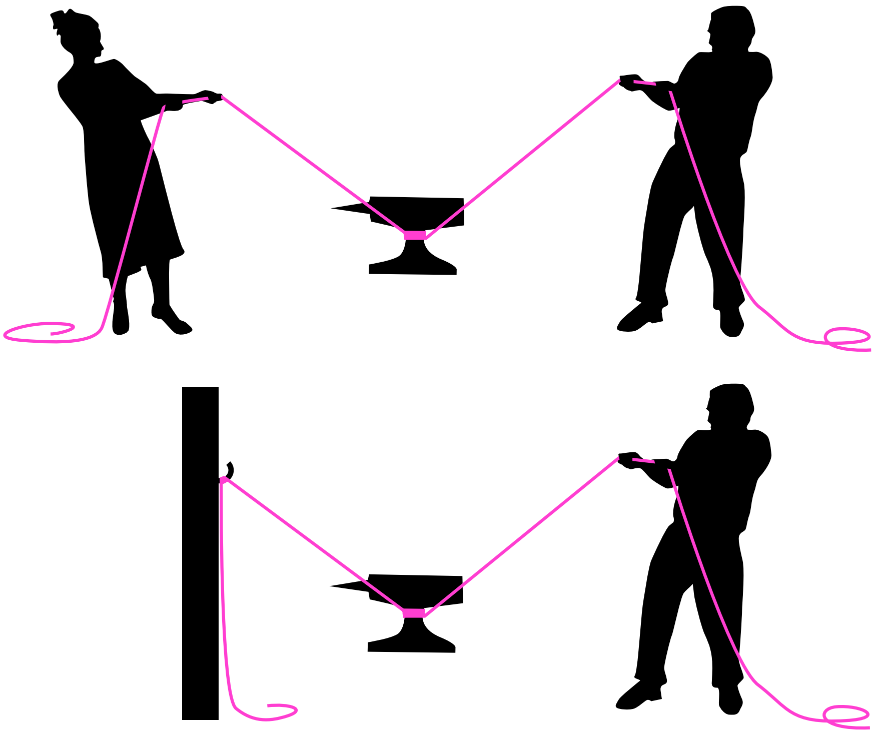
is different, because the anvil is moving. Whilst the wall can apply force, it doesn't move and therefore can't do any work. The energy to raise the anvil against gravity must come from the people pulling and if there is only one person, they have to work twice as hard.

In a similar way, the Fields Workshop explores the nature of fields and their commonalities whether they are sporting fields or the gravity, electrical and magnetic fields found in physics. Thinking in terms of fields is shown to be a powerful way of getting a deep understanding of the way in which electric circuits, motors and generators work.

The workshops focus on the best way to teach strategies for breaking down problems to their basic conceptual components. Obviously at the end of the day formulae and mathematics do need to be applied, but if the students have a really good intuitive understanding of phenomena, they are far better able to set up an appropriate mathematical framework – which in turn will serve them well as they tackle the problems they may one day encounter as professional scientists.

The CPAS workshops are conducted in collaboration with the ANU Physics department and enquiries are welcomed from interested teachers throughout Australia. For further details please contact Professor Sue Stocklmayer

sue.stocklmayer@anu.edu.au



Does Fred have to pull harder if the rope is attached to a wall than if Jane is pulling on the other end? The counter intuitive answer to questions like this comes from action reaction pair analysis at topic discussed in the forces workshop.

The Tarcus Prize

Tim Wetherell

Underlining the value of science graduates to the business world

Tarquin Ralph runs a highly successful management consultancy in the ACT and during his fifteen years in the business has seen more than his fair share of young graduates come and go. Some manage to take the step from academia to highly successful careers quite effortlessly whilst others seem to struggle. Tarquin explains that more often than not, the success stories are science graduates, even if their subsequent careers aren't directly linked to science. He believes that this is because graduates of the pure sciences have the ability to tackle conceptually difficult problems. "You can give them a mess and they have the ability to develop a logical framework and sort it all out - which is exactly what's so often needed in industry. I can teach them anything they need to know about management if they have the necessary mental horsepower" he says. "If you can understand quantum physics, you will have no difficulty handling the daily tasks thrown at you in the business world." Tarquin sees the three critical ingredients to success as, (1) great mind, (2) the ability to express ideas clearly and (3) excellent interpersonal skills.

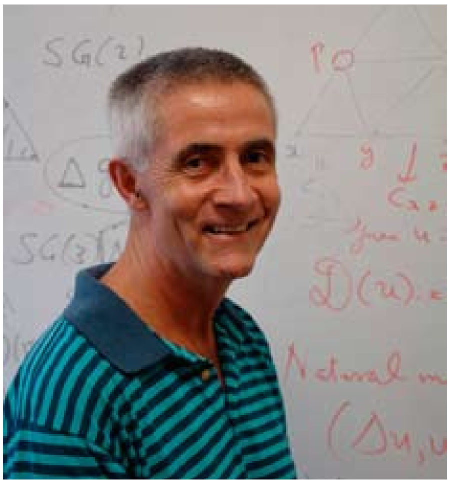
A believer in the value of pure sciences - Tarquin Ralph of Tarcus Consulting

However, Tarquin's belief in the value of science graduates extends beyond encouraging words. During National Science Week, he sponsored the $2000 Tarcus Prize, hosted at the Australian National University Melville Hall. A number of PhD students were invited to give a short public presentation about their work. The judges awarded points for the importance of the work, the passion the presenter had for his/her topic and their capacity to explain it clearly.

The judges were extremely impressed by the quality of the presentations, especially the rigor and depth of understanding the speakers conveyed. The winner was Steven Lade from the Nonlinear Physics Centre at the Research School of Physical Sciences and Engineering for a talk entitles Ratchets. He explained how it is possible to make a particle move, without subjecting it to a net external force if the symmetry of the system is broken and how such ratchet systems are interesting for their relevance to both fundamental physics and biophysics.

Tarquin would strongly encourage any students who have ability in the sciences to pursue a science degree. "You may well go on to have a stimulating career in the sciences, but even if this isn't the path you ultimately choose, the skills you learn in science can be invaluable in the business world too."

Steven Lade, winner of the 2007 Tarcus Prize



The beauty of mathematics

Creating an insight into 21st century maths

John Hutchinson

Imagine studying high school and first year university chemistry without learning about protons, electrons, neutrons or the periodic table; physics without ever discussing radiation, relativity or quantum mechanics; English literature without discussing Oscar Wilde, D H Lawrence or Virginia Woolf; information technology without mentioning the telephone, let alone the internet; biology without learning about evolution, DNA or the human genome project; music without learning about Schoenberg, Stravinsky or Rachmaninoff.

In other words, imagine learning a subject and leaving out any developments since 1850 or even earlier. Yet this is what happens when students study mathematics. And there is good reason. Mathematics is like a giant scaffold. One needs to build the superstructure before ascending for the view. Although the calculus and algebra learnt in high school and early university is an essential part of this scaffolding and is fundamental for studying further mathematics, most of it was discovered in the 18th century or earlier.

Professor John Hutchinson of the Mathematical Sciences Institute is working towards addressing this issue with two unique approaches. Firstly, the creation of a series of professional development workshops for college and high school mathematics teachers and secondly by the introduction of the new ANU secondary college course for Years 11-12 students.

The goal of the professional development courses for college and high school mathematics teachers is to introduce some elements contemporary mainstream 20th and 21st century mathematics. Although the topics covered are not within the current maths curriculum, the aim is to give teachers an insight into current directions in mathematical research so that they are better able to give students a context for their current studies. The courses are open to mathematics teachers from across Australia.

The ANU secondary college brings top year 11 and 12 maths students from across the ACT to the University for two hours a week for ¾ of the teaching year. The classes are taught by a small number of leading college and high school mathematics teachers, who have themselves been trained in the relevant disciplines.

In the college course and in the workshops we investigate some very exciting and useful concepts and get a feeling for "what mathematics is all about". Topics includes RSA cryptography - based on number theory and fundamental to secure internet and banking transactions; infinity - a topic of philosophical ruminations for millennia and understandable only through mathematics; chaos, fractals and dynamical systems - very pretty mathematics extensively applied in fields as diverse as biology, statistical mechanics, diffusion in disordered media and image compression; and geometry and topology - visualising the fourth dimension, classifying surfaces up to topological equivalence (including those which most naturally sit in four dimensional space), and even briefly discussing what the journal Science described as the most significant scientific achievement of 2006, the solution of the Poincaré conjecture.

This mathematics is usually not seen until higher level courses in second or third year at University. Of course, we do not cover the mathematics in the same depth or generality. Instead, we proceed by studying carefully chosen parts and representative examples from major areas of mathematics, which illustrate important and general key concepts. The hope is that students and teachers will gain a real understanding and feeling for the beauty, utility and breadth of mathematics.

More Info: John.Hutchinson@anu.edu.au

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