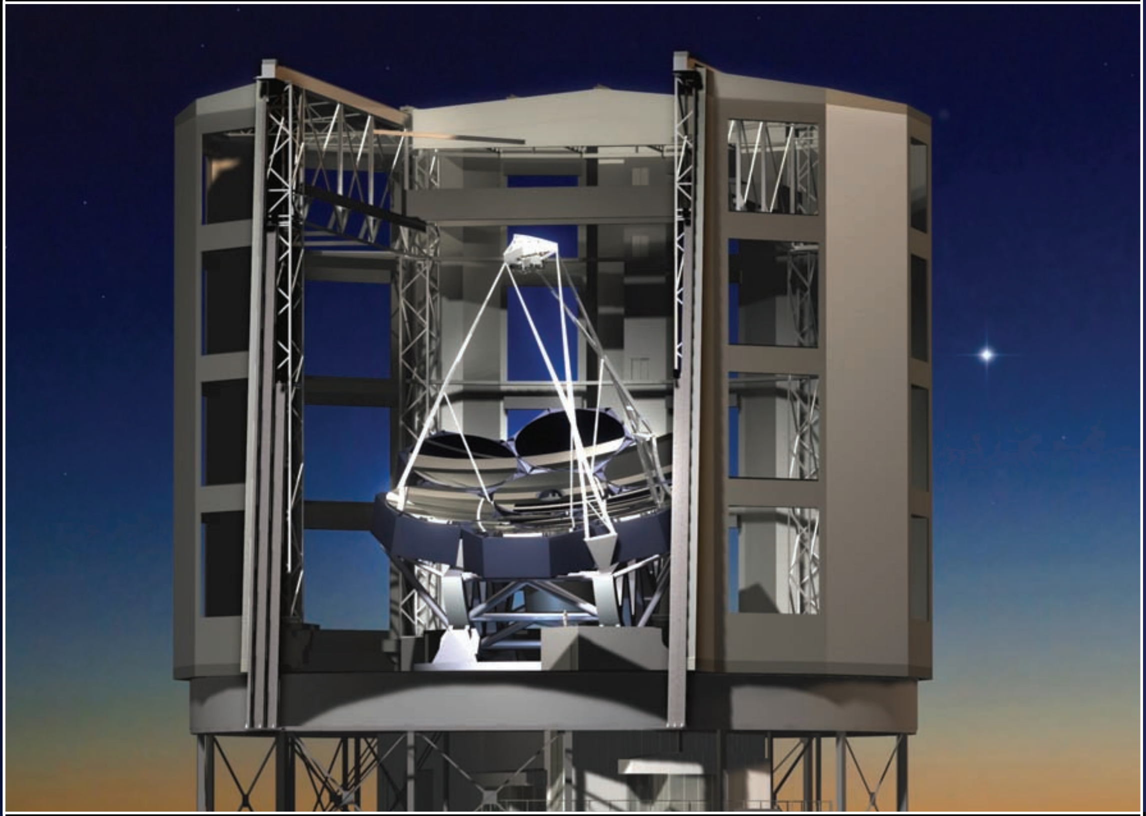
ANNUAL REPORT 2006

Back Cover: The Advanced Instrumentation and Technology Centre (AITC), opened in October 2006 (photo Chris Neil)

Front Cover: The Giant Magellan Telescope (GMT) is a collaborative effort between universities and research organisations to develop and build a state-of-the-art next-generation extremely large telescope. ANU became a partner instiution in 2006.

THE AUSTRALIAN NATIONAL UNIVERSITY

RESEARCH SCHOOL OF ASTRONOMY & ASTROPHYSICS



ANNUAL REPORT 2006

ANU COLLEGE OF SCIENCE

2006 Annual Report

Research School of Astronomy & Astrophysics

Research School of Astronomy and Astrophysics
ANU College of Science
The Australian National University
(CRICOS # 00120C)
Annual Report 2006
Published : 2007
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RSAA Mission Statement

Our Mission is to:

Advance the observational and theoretical frontiers of astronomy and its enabling technologies,

Provide national and international astronomical leadership;

and,

Train outstanding scientists.

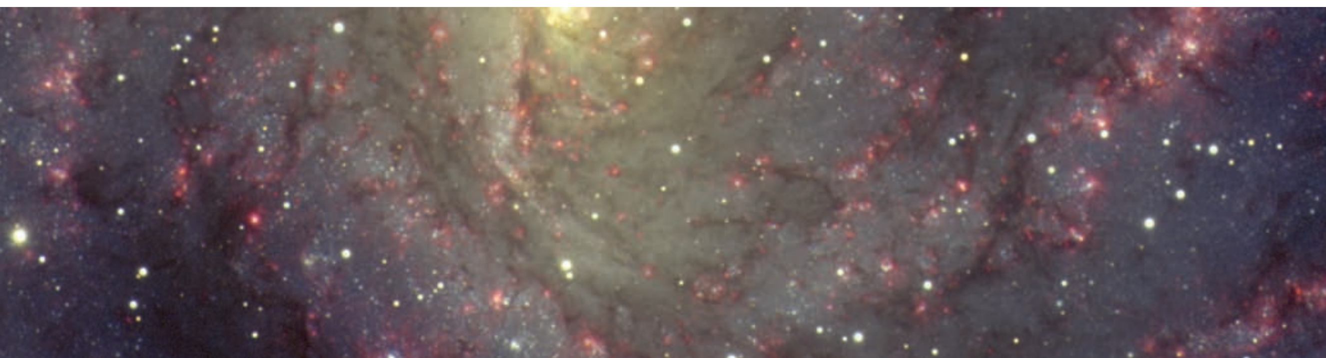

Image: NGC 6946 “Fireworks Galaxy” Gemini Observatory/AURA

2006 Annual Report

ANU Telescopes at Siding Spring Observatory (Tim Wetherell)

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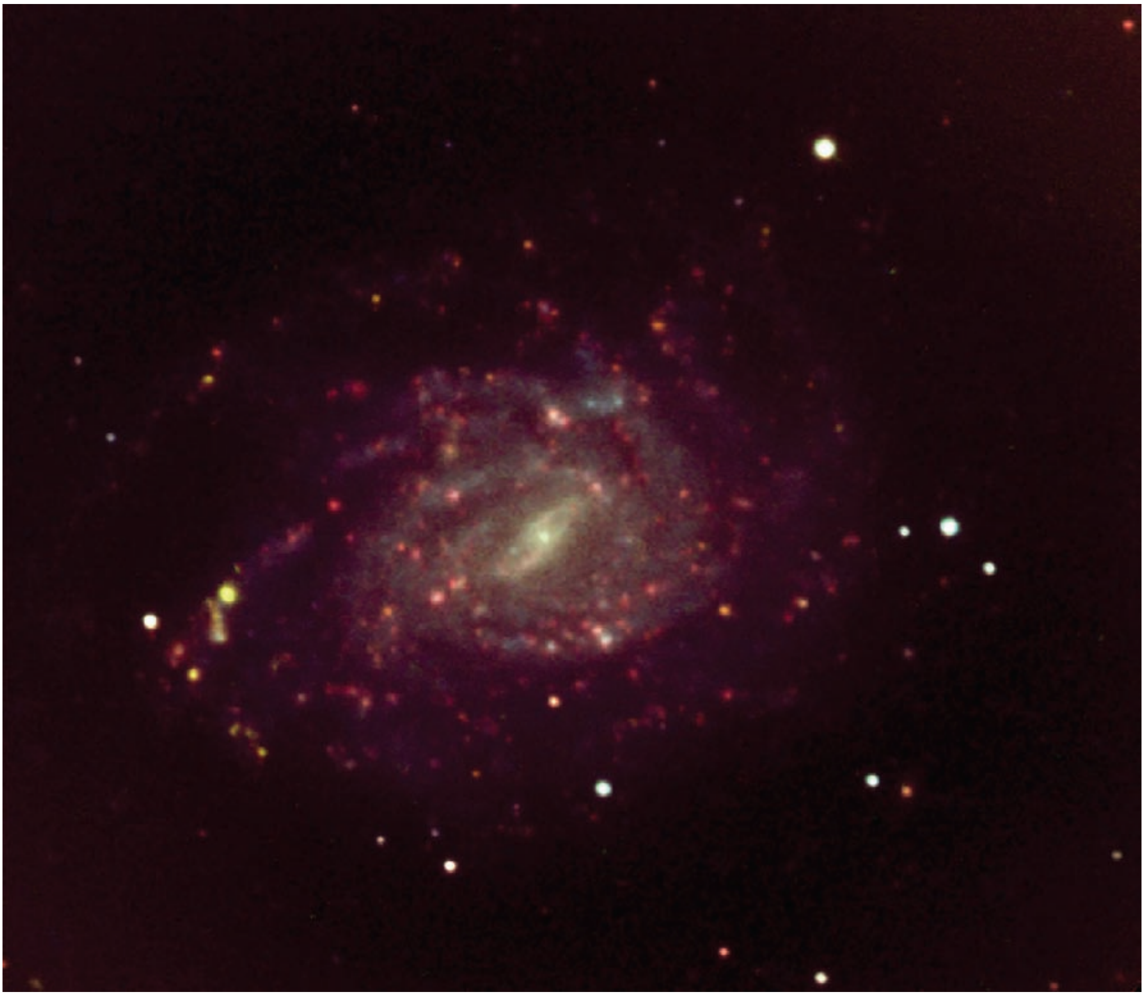


The galaxy NGC5334, imaged with the 2.3m telescope at SSO. The image consists of light from stars and from the glowing red hydrogen gas around regions where massive young stars are forming. (Image: Mike Dopita)

Director's Message

A Giant Year

The Research School of Astronomy and Astrophysics (RSAA) at ANU realised in 2006 the first of what will be several giant steps to securing a new leadership role in the international science of the next decade.

In April, The Australian National University joined the Giant Magellan Telescope (GMT) consortium, a group of elite international institutions with the goal to design, build and operate an optical-infrared telescope far larger and more powerful than any in existence today. ANU is working with its national colleagues to secure full Australia partnership in the project, and will serve as the country's national GMT project office.

With the ability to detect objects 100 times fainter than can the Hubble Space Telescope, and produce images 10 times crisper, the GMT will open vast new windows of exploration into the cosmos when it sees first light in ten years time. In the meantime, much work remains to be done, including GMT-related astro-engineering, some of which will take place in the new facility on Mt Stromlo designed specifically for the purpose: The Advanced Instrumentation and Technology Centre was opened by Science and Education Minister Bishop in October 2006. Already, first results from the Stromlo atmospheric turbulence program is paving the way toward Australian contributions to site testing in Chile for the giant new eye.

Participation in the GMT is the most future-oriented implementation of our general philosophy that talented astronomers using and designing state-of-the-art instruments yield excellent science and the best training opportunities. Just a few of the results in this year's report serve as illustrations:

- A cosmic stock take conducted by an RSAA team using international and Siding Spring telescopes and those at Siding Spring Observatory reveals that approximately half of all stars currently reside in the central dynamically mixed bulges of galaxies, while the other half are in more orderly extended galactic discs.

- Spitzer space telescope observations enabled RSAA astronomers and their collaborators to derive an empirical relationship for the amount of mass ejected by the super winds of highly evolved AGB stars as a function of their rotation period (a proxy for age). This material forms the reservoir from which subsequent generations of stars will be borne.

- First observations with the RSAA-designed NIFS instrument on Gemini North show unprecedented spatial and spectral detail in otherwise dust-obscured regions, allowing young stellar wind speeds and black hole masses to be measured.

- Calculations by an RSAA PhD student using some of the best available planetary models indicate that many of the middle-range (10-30 Earth-mass) planets just now being discovered may be huge icy "snowballs" formed as the proto-planetary disks of young M dwarf stars cool at an early age.

- The advanced electronics of the 268-million pixel RSAA-built SkyMapper camera has achieved the ultra-high data rates that will be required for the massive 150 Terabyte ANU Southern Sky Survey to begin late 2007. The survey will be the first, fully digital and publicly accessible survey of the southern skies.

Success is driven by the skill, foresight and determination of those who undertake it. It is a pleasure, therefore, to see external recognition of the quality of our staff. This year, these honours included awards for teaching, public education, and research.

- Dr Paul Francis received a national citation by the Carrick Institution for his outstanding contribution to student learning.

- Dr Charles Jenkins received the Kelvin Medal from the UK Institute of Physics for development of the "Lab in a Lorry" project as a mobile education and outreach facility.

- Professor Brian Schmidt was awarded the prestigious international Shaw prize for work resulting in a "positive and profound impact on mankind" in recognition of his discovery, with colleagues, of the existence "dark energy" – a previously unknown force connected to the fabric of space-time that opposes gravity, driving the accelerated expansion of the Universe.

Throughout this report you can read about these and other achievements that serve as the foundation upon which we will build to meet the giant challenges of deduction and discovery that await.

Penny D Sackett

Penny D. Sackett, Director RSAA 2006

2006 Highlights

Shaw Prize for Astronomy 2006

ANU astronomer and Federation Fellow Professor Brian Schmidt has been awarded the prestigious Shaw Prize for Astronomy 2006 jointly with US colleagues.

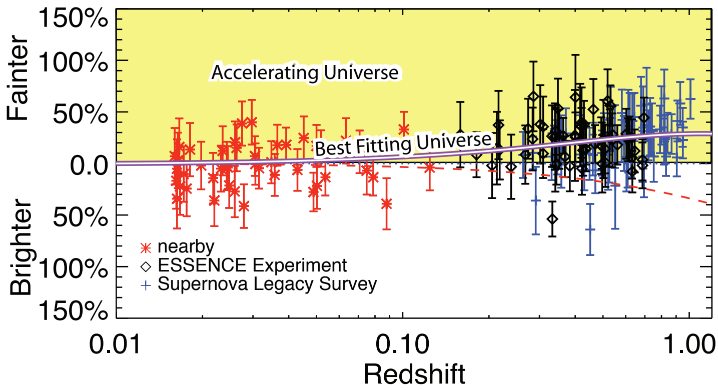
Professor Schmidt, with Saul Perlmutter from the University of California Berkley and Adam Riess from the Space Telescope Science Institute, were commended for discovering the rate of the expansion of the Universe is accelerating. Their result requires the existence of a previously unknown 'force' connected to the fabric of space-time - known as 'dark energy' - that opposes gravity, driving the acceleration.

Professor Schmidt led an international team, including Riess, called the High-Z Supernovae Search that found the expansion of the Universe was speeding up, not slowing down (the commonly held view), by studying a class of exploding stars called Type 1a supernovae. Professor Perlmutter led a second team, which reached similar conclusions.

Professor Schmidt, from the Research School of Astronomy and Astrophysics, also leads the SkyMapper project, which will provide the first deep digital map of the southern sky, allowing astronomers to study everything from nearby objects such as asteroids in our Solar System to the most distant objects in the Universe called quasars.

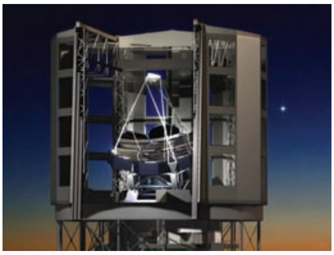
The US$1 million Shaw Prize is awarded in three categories - Astronomy, Life Science and Medicine, and Mathematical Sciences - to individuals whose work has resulted in a positive and profound impact on mankind.

Professor Penny Sackett, Director of the Research School of Astronomy and Astrophysics at ANU said that she was delighted at this prestigious public recognition of Professor Schmidt's paradigm-shifting work.



Right: Evidence for the Accelerating Universe: Luminosity distance modulus vs. redshift for the ESSENCE, SNLS, and nearby SNe Ia for SALT. For comparison the overplotted solid line and residuals are for a ΛCDM (w, Ω_M, Ω_Λ) = (−1, 0.27, 0.73) Universe. (From Riess et al 2006)

The Giant Magellan Telescope Project



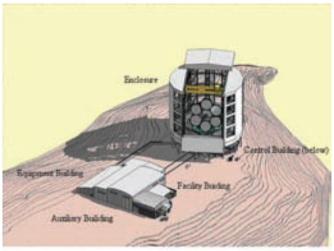
An artisit impression of the Giant Magellan Telescope, courtesy of www.gmto.org

ANU to help build the world's most powerful telescope

In April 2006, the RSAA celebrated as the Australian National University signed a Memorandum of Understanding making it a member of an international consortium of research organisations that will build the world's most powerful telescope.

The Giant Magellan Telescope, or GMT, has just finished its preliminary planning stage and is likely to be one of the first of a small number of next generation Extremely Large Telescopes (ELTs) due to come on-line in the next two decades. The GMT will detect and study planets around other suns, probe the dark matter and dark energy that controls the expansion and development of the cosmos, and unlock the secrets of star and planet formation.

As part of the GMT consortium, ANU joins an elite group of research and teaching institutions in the US to undertake the detailed design of the telescope (see **www.gmto.org**), including the Carnegie Institution of Washington, Harvard University, Massachusetts Institute of Technology, the University of Arizona, the University of Michigan, the Smithsonian Institution, the University of Texas at Austin and the Texas A&M University.



Proposed GMT Observatory layout

ANU Vice-Chancellor, Professor Ian Chubb, said involvement in the project was an important initiative for the University.

"The Giant Magellan is one of several international projects ANU will be conducting with overseas partners to solve some of the biggest questions facing humankind. We're pleased to be part of this visionary project, which captures the forward strategic plan for the Research School of Astronomy and Astrophysics and that of the ANU more generally," Professor Chubb said.

Director of the Research School of Astronomy and Astrophysics, based on Mt Stromlo in Canberra, Professor Penny Sackett, signed the Memorandum of Understanding in Texas.

"Stromlo has always been at the forefront of astronomy and its instrumentation. This partnership is a giant step toward the astronomy of the next decade, and will ensure that ANU - and Australia - remains at the cutting edge of scientific research into our Universe," Professor Sackett said.

Computer generated view of GMT.

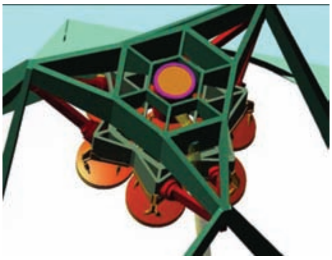
The telescope's conceptual design anticipates a moving mass of 1000 metric tonnes and a cylindrical enclosing dome towering 65 metres - about 18 storeys - high. The primary mirror of the Giant Magellan Telescope will be composed of six segments, each 8.4 metres in diameter surrounding a seventh central mirror of the same size. The total light gathering power thus will be nearly seven times that of the international Gemini telescopes, the largest telescopes to which Australian astronomers now have access.

Based at a superb observing site in northern Chile, the telescope is expected to "see first light" in 2015 and come into routine operation one year later. The first mirror of the huge assembly has already been cast in Tucson, Arizona, and is being prepared for polishing. Over the next three years, the GMT Partnership will engage in an intense detailed design phase in which contracts could flow to Australia before building begins in 2010.

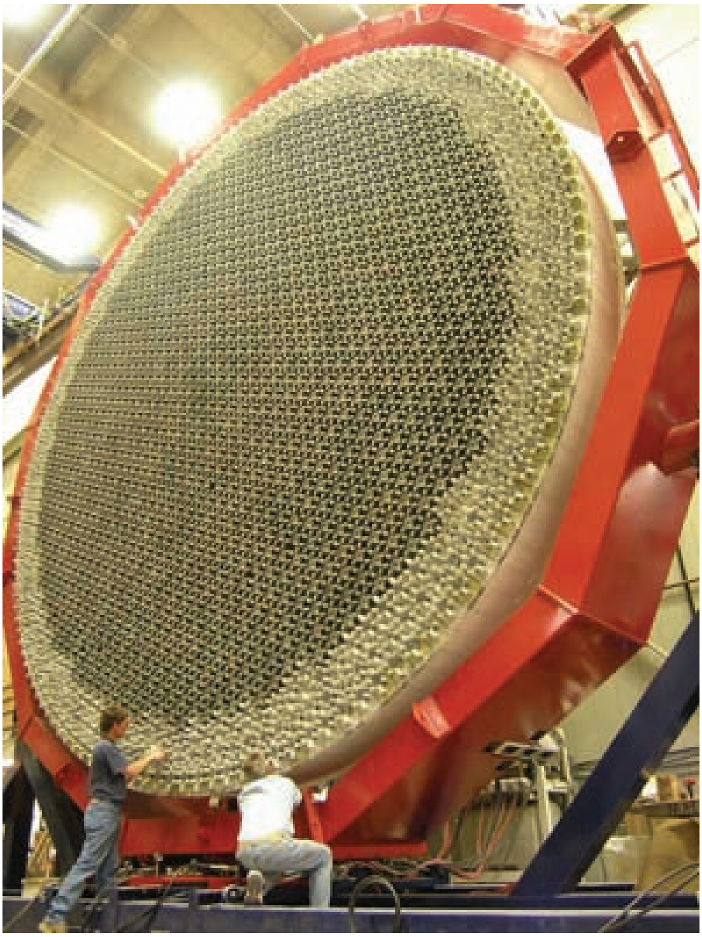
Dr Wendy Freedman, Director of the Observatories at the Carnegie Institution of Washington and Chair of the GMT Board warmly welcomed the entry of ANU into the project. "I'm delighted that ANU is entering the consortium. Australia is a world-leader in astronomical research and instrumentation, and will bring a great deal to the project. All of us in the GMT consortium are tremendously excited about this partnership with ANU."

Professor Sackett said this was a giant step for Australia as well as for ANU. "Nothing would please me more than if our initial membership would prompt other institutions in Australia, or Australia as a nation, to join the partnership. We'll be working with our colleagues to assist in reaching this goal. Participation in an ELT is a cornerstone of Australia's Decadal Plan for Astronomy, and Australia has a tremendous capacity to add to the GMT consortium and benefit from it."

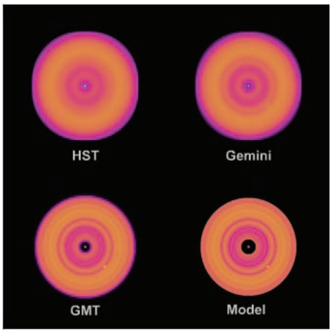
The GMT, note the tiny human figure to scale.



Schematic view of the GMT secondary mirror and its support system from above.



The first 8.4m mirror blank from the furnace in 2006.



Comparison potential views of a model proto-solar system from HST, Gemini and GMT.

Opening the AITC

Advanced Instrumentation and Technology Centre

Photo: Chris Neil

The ANU Research School of Astronomy and Astrophysics (RSAA) Advanced Instrumentation and Technology Centre (AITC) was officially opened on October 16, 2006, by Federal Education Minister, the Hon. Julie Bishop MP. The Federal Government, through the Department of Education, Science and Training, contributed $7.3 million towards the building. Design was by Daryl Jackson Alastair Swayn architects, and construction was project managed by IQON.

Director Professor Penny Sackett, starts the opening speeches.

ANU Vice-Chancellor Professor Ian Chubb AC, speaks.

Over 100 official visitors and RSAA staff attended the opening, jointly hosted by ANU Vice-Chancellor Professor Ian Chubb AC, and RSAA Director Professor Penny Sackett.

Federal Education Minister, the Hon. Julie Bishop MP.

The AITC opening heralds a new era for RSAA and ANU in terms of its ability to participate scientifically and technically in the development of large international astronomical instrumentation, replacing capabilities lost in the 2003 fires with new capabilities that will be required in coming decades.

RSAA Director Professor Penny Sackett said the AITC cemented Australia's participation in front-line international astronomical research.

The unveiling by the Minister and the Vice-Chancellor.

Photos: Stuart Hay

"It's essential that Australian researchers have access to the best facilities in the world to participate in the global effort to better understand the Universe around us. This facility keeps Stromlo, which has always been at the forefront of astronomy and its instrumentation, on the map, and allows us to play an important role in future developments." Professor Sackett said.

"The future of Australian astronomy relies on its continuing participation in front-line international astronomical facilities. ANU has invested

Advanced Instrumentation and Technology Centre

Photo: Emma Cross

heavily in the 25-m diameter Giant Magellan Telescope consortium with ANU becoming a founding partner in the GMT. The AITC building has been designed specifically so that parts of the GMT and its instruments can be designed, constructed, and assembled here. We are targeting the adaptive optics systems and the instruments that will be used with adaptive optics.", said Vice-Chancellor Chubb.

Ms Bishop said the rebirth of Mt Stromlo was testament not only to Australia's "success in the field of astronomy on a global scale, but also a testament to the resilience of the Australian spirit".

The AITC is a facility that will serve the School's needs well into the future by :

- Integrating academic, technical, and educational activities.
- Providing laboratory space for research and development of new technologies that will lead to new instruments in the future.
- Emphasizing the key engineering functions of opto-mechanical and electronics design. These are at the core of all instruments that collect and analyse light, which is the foundation on which all of astronomy is built.
- Providing a large Integration Hall for assembling instruments for telescopes of the future such as GMT. Big telescopes need big instruments, and the Integration Hall has been specifically sized to allow us to assemble large scale instruments.
- Providing easy access to the public while not disrupting technical activities. The walkway on the upper level connects the carpark at one end to the Duffield Building at the other and allows views of the Integration Hall and the Optics Lab.

Federal Education Minister, the Hon. Julie Bishop MP, speaks to the invited guests and RSAA staff and students.

Morning tea after the opening in the Integration Hall.

RSAA Associate Director for Instrumentation and Technology, Dr Peter McGregor (left); Head of Science at the Anglo Australian Observatory, Dr Chris Tinney (centre left); RSAA Executive Officer, Ms Suzanne Mendes (centre); Director of the Anglo Australian Observatory, Professor Matthew Colless (centre right); and RSAA Research Fellow, Dr Alister Graham (right).

Under development, a wide-field imager instrument for the SkyMapper telescope being built for RSAA's Siding Spring Observatory.

Photos: Stuart Hay

Cosmic Stocktake Reveals What's Left of Big Bang

An international team of astronomers involving researchers at The Australian National University have announced the completion of a large survey of the nearby Universe. Amongst their findings is that 20 per cent of the normal matter in the Universe has already been turned into stars.

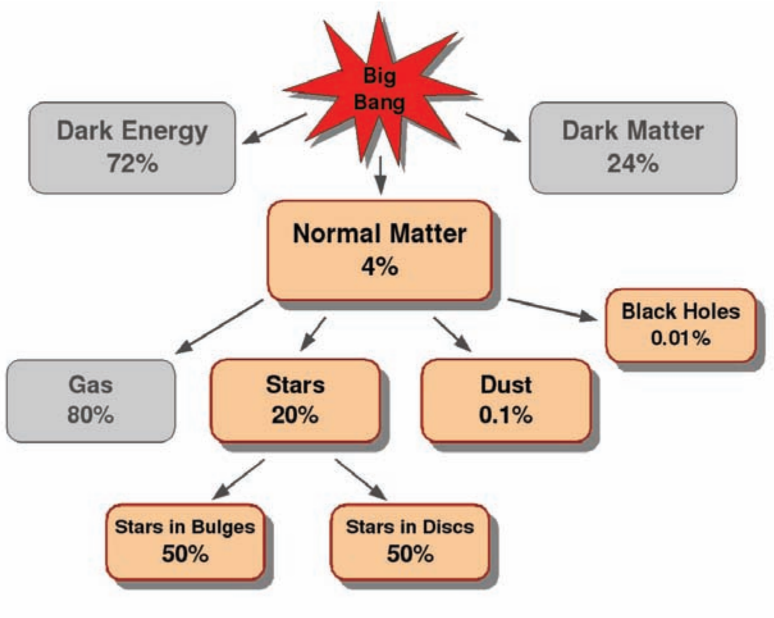
One of the most important goals for cosmologists is to find out where all the normal matter that was produced in the Big Bang is today, 14 billion years later. The new survey reveals that about 20 per cent is in stars, a further 0.1 per cent lies in dust expelled from massive stars (and from which solid structures like the Earth and ourselves are made), and about 0.01 per cent is in super-massive black holes.

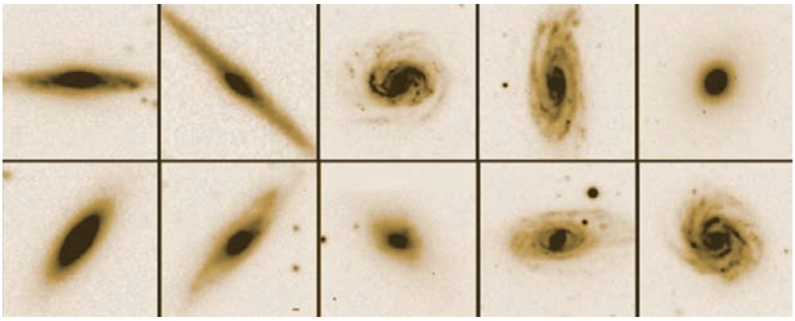
According to the survey leader, Dr Simon Driver at the University of St Andrews, the remaining material is almost completely in gaseous form lying both within and between the galaxies, and forming a reservoir from which future generations of stars may develop.

The Cosmic Inventory

"I guess the simplest prognosis is that the Universe will be able to form stars for a further 70 billion years or so after which it will start to go dark," said Dr Driver. "However, the Universe is definitely tightening its belt with a steady decline in the rate at which new stars are forming."

The survey data was released at the General Assembly of the International Astronomical Union in Prague on 18 August 2006. This 21st century





Left: A selection of galaxy images from the Millennium Galaxy Catalogue.

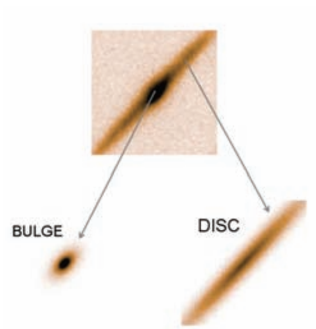
database, aptly named the Millennium Galaxy Catalogue, was constructed from over 100 nights of telescope time at the University's Siding Spring Observatory in NSW and observatories in the Canary Islands and Chile. The final Catalogue contains over ten thousand giant galaxies, each of these containing 10 million to 1000 billion stars.

"We were able to determine how much matter is in stars through what was, in effect, a cosmic stocktake," said Dr Alister Graham. "By careful separation of a galaxy's stars into its central bulge component and surrounding disc-like structure we have found that the Universe has been remarkably even-handed, placing half of the stars in galaxy discs and the other half in galaxy bulges."

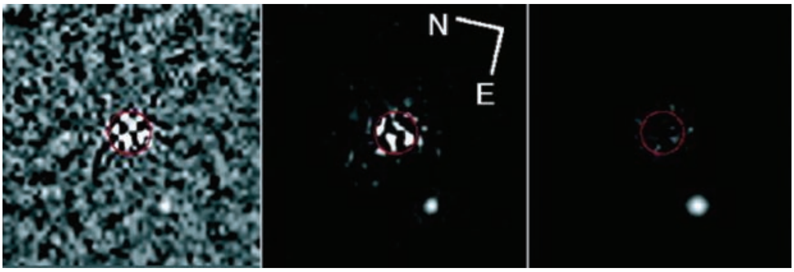
Other members of the research team include Paul Allen and Ewan Cameron of The Australian National University, Jochen Liske of the European Southern Observatory and Roberto De Propris of the Cerro Tololo Inter-American Observatory.

The Millennium Galaxy Catalogue consists of imaging data from the Isaac Newton Telescope at the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofisica de Canarias, and spectroscopic data from the Anglo Australian Telescope, The Australian National University's 2.3 m telescope at Siding Spring Observatory; the ESO New Technology Telescope, the Telescopio Nazionale Galileo, and the Gemini Telescope.

Financial support for this project was jointly provided through grants from the Australian Research Council and the United Kingdom's Particle Physics and Astrophysics Research Council.



Above: An example of a galaxy image decomposed into its bulge and disc components.



Above: First-epoch NICMOS camera 1 PSF-subtracted images of 2M 1207 (centered in the 0.2" radius circle) and its companion (0.77" to the southeast) at 0.9, 1.1, and 1.6µm (from left to right). By subtracting a second image of 2M 1207 at a different celestial orientation, background light from the primary at the location of 2M 1207b is effectively eliminated. In addition, in each difference image, a flux-scaled, astrometrically registered model PSF, fit to the "negative" image of 2M 1207b, was added to eliminate the negative imprint from the difference image.

Confirmed Image of an Extra-Solar Planet

RSAA Astronomer Mike Bessell, with Ben Zuckerman and Inseok Song, has been contributing to an international collaboration attempting to directly image extrasolar planets. The group is using the Young Nearby Star database, then identifying and selecting candidate nearby young stars for more detailed study on larger telescopes, using the 2.3m telescope at Siding Spring Observatory.

Among the objects followed up so far with Spitzer, Keck, VLT and HST telescopes, looking for planetary-size companions, was 2M 1207, a brown dwarf member of the TW Hydra moving group, first announced in 2005 (www.eso.org/outreach/press-rel/pr-2005/pr-12-05-phot.html). Space telescope NICMOS photometry confirms the existence of a common proper motion companion 2M 1207B, whose Infrared observations are consistent with an object of a few Jupiter masses.

The system is 59±7 pc from the Earth and the components are separated by 46±5 AU. These observations now unambiguously establish that we have obtained the first direct image of a planetary-mass companion orbiting a self-luminous body, other than our Sun. The results were published in the Astronomical Journal in 2006.

Super-earths Emerge from Cosmic Snowstorm

Hefty planets that weigh up to 15 times more than Earth - known as "super-Earths" - may actually be giant ice balls that formed during a cosmic snowstorm that lasted millions of years, according to research by a team of astronomers that includes Grant Kennedy from The Australian National University.

Mr Kennedy, a PhD scholar at the ANU Research School of Astronomy and Astrophysics at Mount Stromlo Observatory and his colleagues Scott Kenyon from the Smithsonian Astrophysical Observatory and Benjamin Bromley from the University of Utah, calculated that some super-Earths build up rapidly when local temperatures drop and ices condense out of the surrounding gas.

There is great variety among the 200 known planets that orbit other stars, ranging from the recently discovered icy "super-Earth" planets to low-mass gas giants. Scientists have been able to explain how planets form around Sun-like stars, but have been surprised by the discovery of planets around the relatively smaller and cooler red dwarf stars.

In a planetary system such as our Solar System, planets form within a disk of gas and dust surrounding a newborn star. Rocky planets like Venus, Earth and Mars form close to the star, where it is warm, while icy and gaseous planets like Jupiter, Saturn and Uranus form farther out. When it was young, the Sun was relatively stable, leading to a natural progression of small, rocky worlds in the hot inner Solar System and large, gaseous worlds in the cold outer solar system.

The planetary systems around newborn red dwarf stars undergo more dramatic changes. As the young star evolves, it dims and the warm inner disk begins to freeze, creating conditions where water and other volatile gases condense into snowflakes and ice pellets.

"It's like a massive cold front that sweeps inward toward the star," Kennedy said. "The ices add mass to a growing planet, and also make it easier for particles to stick together. The two effects combine to produce a planet several times the size of Earth.

"The disks that surround red dwarf stars tend to contain less material than the one that formed our Solar System. Without the "snowstorms" in these smaller disks, there isn't enough material to make super-Earths."

The astronomers presented their calculations in a paper published in The Astrophysical Journal Letters.

Above: An artists impression of an icy super-Earth, more massive than Earth, but without the massive atmosphere of a gas gaint like Jupiter.

Bruce Peterson Colloquia

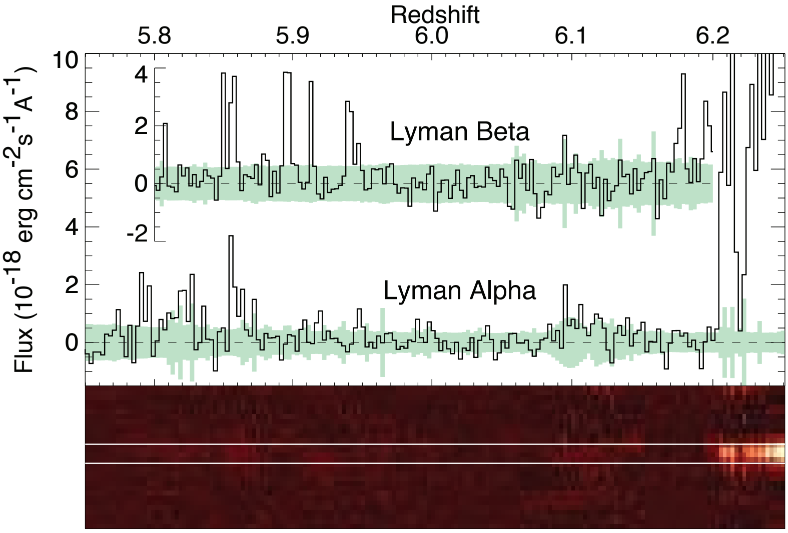
CalTech circa 1966, Bruce on the right, talking with Maarten Schmidt on the left.

Colloquia in Honour of Bruce Peterson

Bruce Peterson formally retired from ANU during 2006. Bruce is one of the leading ISI-Thomson citation laureates in Australia and was a co-discoverer of the very important Gunn-Peterson effect which shows that the intergalactic gas in the universe is ionised. This in turn led to the realization that the universe was reionised at some epoch in the distant past. Understanding when and how reionization occurred is now one of the big themes of contemporary cosmology.

To celebrate his career and achievements, RSAA held an afternoon of science, focussed on Bruce's various research interests. Frank Briggs spoke on reionization and the Gunn-Peterson effect, and then Dave Jauncey described the turbulence in the ionised intergalactic medium. Brian Schmidt reviewed the subject of gamma-ray bursters, and Dick Manchester talked about pulsars, including some of the work that he and Bruce had done on optical pulsars. Matthew Colless described the 2dF Galaxy Redshift Survey, and Bruce Peterson gave a talk on Galaxy Counts and the Structure of the Universe, including some of the galaxy counts done about a decade ago which indicated that the cosmological constant is non-zero.

We expect that Bruce will remain active in research, but wish him well for his formal retirement.



Above: The 2001 detection of the Gunn-Peterson Effect in a Quasar at a redshift of 6.28 (From Becker et al. 2001), more than 35 years after the prediction of the effect. The empty, dark, parts of the spectrum are due to the presence of neutral gas in inter-galatic space, prior to reionization.

The Fifth Stromlo Symposium: Disks, Winds and Jets – from Planets to Quasars

The Fifth Stromlo Symposium was held from 3 December to 8 December 2006 with the subject matter being disks, winds and jets in widely different astrophysical environments, including black holes, protostars and planetary systems. The idea of the meeting was to explore the common physics related to phenomena in these environments. The subject matter ranged widely over the electromagnetic spectrum – from radio waves to the highest energy gamma-rays ever observed. Topics included the physics of accretion disks and their connection with jet outflows, galactic winds, extragalactic jets on scales from parsecs to kiloparsecs, high energy emission from jets, pulsar winds and their nebulae, disk and jets associated with star formation and planetary disks.

The meeting was a truly international occasion attracting 76 participants from 15 different countries with scientists travelling from as far as Ireland, Finland and Russia. In all there were 33 invited talks, 39 contributed talks and 5 posters. Many of these presentations will be published in a special edition of the journal Astrophysics and Space Science. The quality of work presented by Australian researchers on broad range of topics was outstanding and there were numerous opportunities to discuss research with international colleagues.

The eminent astronomer Professor Ed van den Heuvel from the University of Amsterdam also gave a very interesting public lecture on gamma-ray bursts and their host galaxies in the Finkel Lecture Theatre at ANU. This included an account of the contribution of Dutch navigators to the early history of Australia as part of Ed's contribution to the celebration of 400 years of Netherlands–Australia interaction.

One of the main themes of this conference was astrophysical turbulence, especially in magnetised accretion disks. Turbulence is one of the key themes of the Australian Research Council Complex Systems Network (COSNet). Hence, financial support from COSNet was both appropriate and invaluable.

Left: Attendees of the Symposium gathered in the courtyard of the AITC.

Research

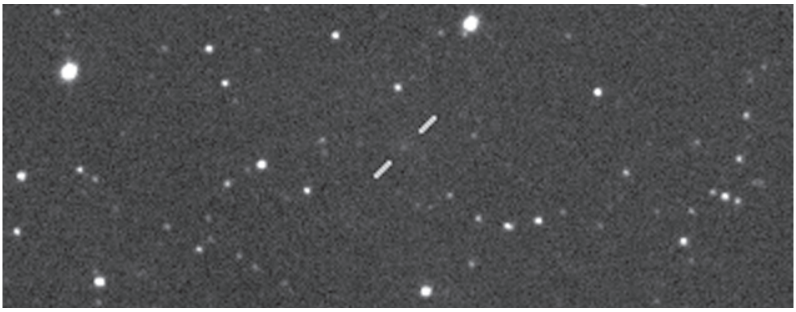
The Siding Spring Survey

The Siding Spring Survey operates the 0.5-m Uppsala Southern Schmidt at Siding Spring Observatory in a dedicated program as part of the international Spaceguard program. This aims to discover 90 per cent of Near-Earth Asteroids (NEAs) larger than 1km by the end of 2008. The Siding Spring Survey is operated by the University of Arizona in collaboration with the ANU.

Our third year of operation saw a stable system working very efficiently. This was due to the excellent programming efforts of the staff at the University of Arizona who run a two telescopes operation near Tucson using the same software. Of the 640 NEAs discovered worldwide in 2006, our three telescope operation found 397, or 62 per cent, the contribution of the Siding Spring Survey being 63. Of greater relevance are the larger than 1km asteroids, of which we discovered six from a worldwide total of 50. For the previous three years, the annual total for these large asteroids has averaged around 80, so it does appear that we are approaching completion.

The main discovery of the year turned out to be comet C/2006 P1 (McNaught), discovered on 7 August, which reached perihelion inside the orbit of Mercury in mid-January 2007. It became the brightest comet in 41 years reaching around magnitude -6 and visible to the naked-eye in full daylight only five degrees from the Sun. After perihelion, the comet's tail became a wonderous spectacle with multiple dust bands draped across the western twilight sky for southern observers.

Other comets of interest were P/2006 R1 (Siding Spring) which is the shortest period retrograde comet having a period of only 13 years, and P/2006 HR30 (Siding Spring) a Near-Earth Comet with a period of 22 years and perihelion distance of 1.23AU. This comet is of very low activity, appearing almost asteroidal, and is notable for its very large size at around 10 km. These two comets received survey names as, at the time of discovery, they were not recognised as comets.



Right: The Discovery image of C/2006 P1 (McNaught) taken with the 0.5-m Uppsala Southern Schmidt at Siding Spring Observatory

C/2006 P1 (McNaught) on 2007 January 20 taken from Siding Spring. The tail covers some 40 degrees. Copyright Robert H. McNaught

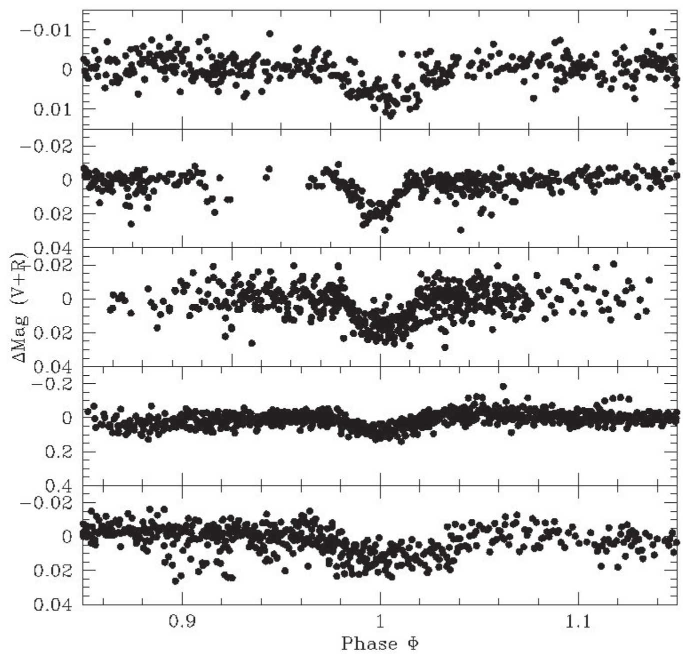
The Search for Hot, Tight-Orbit Jupiters

Measuring the brightness of tens or hundreds of thousands of stars simultaneously for nights on end is becoming the speciality of Sackett and her young collaborators. Their primary goal is to search for the slight and periodic dimming that could be the signature of a large planet partially eclipsing, or transiting, its host star.

At the 2006 Transiting Extrasolar Planet workshop in Heidelberg, Germany, work being carried out at RSAA was presented. Transiting extrasolar planets are of great interest to planetary scientists as they provide a unique opportunity to determine the radius and density of extrasolar planets, which aids in the understanding of planet formation and migration.

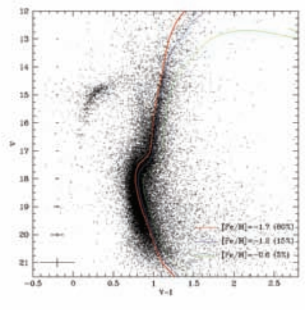
Sackett, Weldrake (now at Max Planck, Heidleberg), Bayliss and Tingley (now at Bruxelles) presented work on the large photometric survey for transiting extrasolar planets that was carried out using the ANU 40 inch telescope at SSO. The survey covered a 0.75 square degree area of sky in the galactic plane and was conducted over 53 nights in 2005 and 2006. Altogether 26,000 stars were monitored for the characteristic 1 per cent dip in apparent flux that would indicate a transiting extrasolar planet. A number of candidates identified from this survey were presented (see figure below), and these candidates are currently being followed-up using spectroscopy to determine if they display a radial velocity signal consistent with a transiting planet.

Right: Phase-wrapped lightcurves of five of the planetary candidates identified from our transit survey using the ANU 40 inch telescope at SSO.



SkyMapper Transit Survey

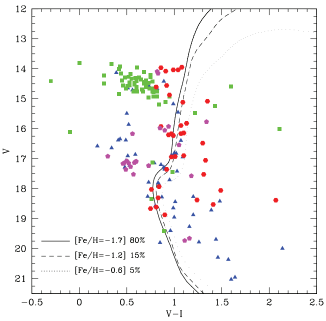
Preparatory work for the SkyMapper Transit Survey was presented at the conference by Bayliss and Sackett. The SkyMapper Transit Survey is a survey for extrasolar planets that will use SkyMapper's wide field of view to monitor 5.7 square degrees of sky. The survey is planned for 2008, with field selection and data reduction pipelines currently being finalised. Preliminary work suggests that the survey will monitor enough stars to allow us to address the question whether extrasolar planet formation is dependent on the mass of their host stars.



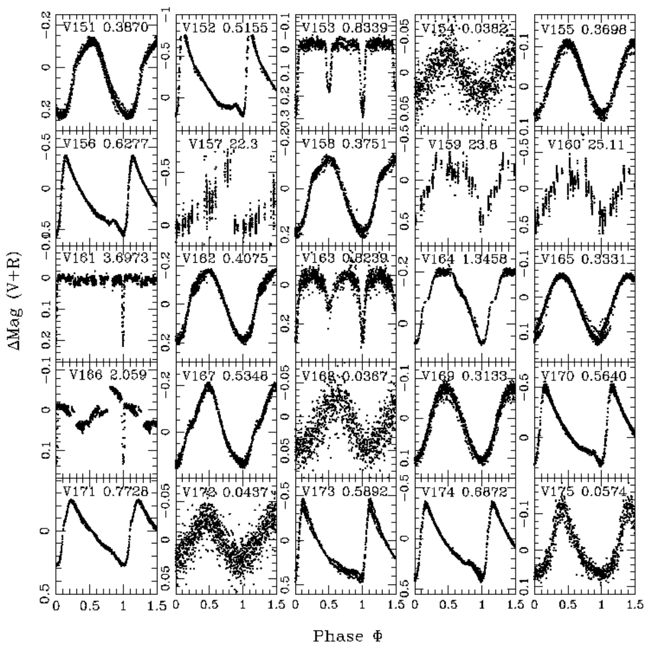
Above: The colour-magnitude diagram of the globular cluster Omega Centauri, as determined using the ANU 40" telescope at Siding Spring.

Cataloguing Change

A side product of these searches for Hot Jupiters is the production of large catalogues of variable stars (stars that change in brightness due to pulsations, accreting material, flares or large eclipsing companions) in the same sky fields monitored for signs of transiting planets. By examining the famous globular cluster Omega Centauri, RSAA alumnus Weldrake, Sackett and their collaborator Bridges identified 187 variable stars, 81 of which are new discoveries. Analysis of the eclipsing binary radial distribution revealed an apparent lack of binaries in the 8'-15' range, that may indicate two separate binary populations. The full database contained photometry in the V and I filters for 203,892 stars, and associated astrometry with accuracies of 0.25" or better. Their work was published in volume 133 of the Astronomical Journal.

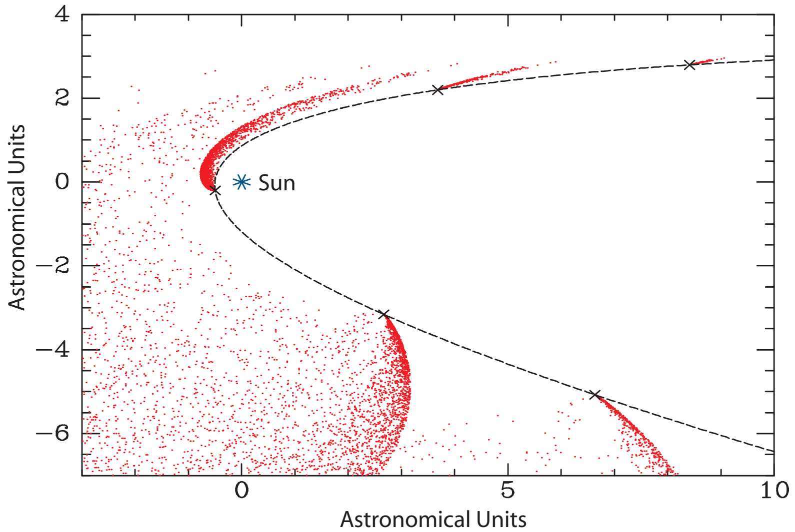


Above: Positions of the variable stars , discovered by Bridges, Weldrake and Sackett on the Omega Centauri colour-magnitude diagram. Colour coding denotes the type of variable star.



Left: Just a small sample of the light curves from the variable star catalogue of Omega Cen. Notice the variety of forms.

Right: A simulation of a long period comet undergoing a close encounter with the Sun, similar to the orbit of Comet McNaught. The red dots represent dusty material that boils off the comet to form the comet tail. The comet appears at the top right and exits bottom right.



What lies beyond Pluto?

We can observe the Kuiper belt of comets that lies just beyond Neptune's orbit. We can also infer something about the Oort cloud of comets, that lies about one light-year from the Sun. But what lies between these two clouds? Theories suggest that a so-called 'Inner Oort Cloud' should lie here, containing up to 10^{13} comets, and possibly a number of quite large planets.

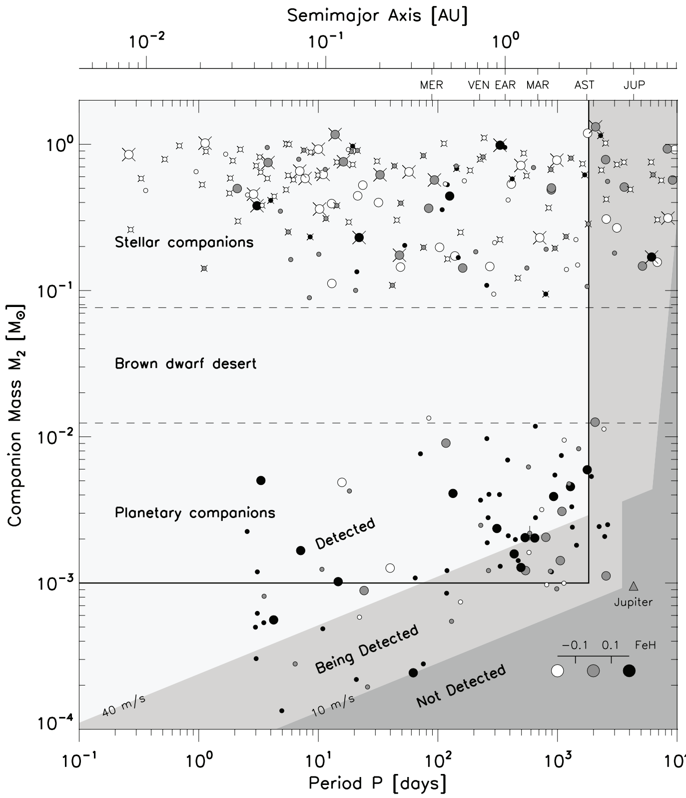
Unfortunately this vast hypothetical cloud is too far away to see directly. Comets from it cannot reach the inner solar system - they are blocked by Jupiter's gravity.

Francis and Kennedy simulated the orbital evolution of these comets, and showed that there should be vast numbers orbiting just beyond Saturn. These should be bright enough to have been seen already. They predict that existing telescopes should have seen more than 100 such comets. In fact, none have been seen. This casts doubt on the existence of this hypothetical inner Oort cloud.

The resolution of this conundrum may lie in the models: most models assume a uniform Galactic Tide, but for comets like these, the Galactic Tide should be very erratic.

Brown Dwarf Desert Quantified

Lineweaver and PhD student Grether have shown that the observed absence of low-mass stellar companions, Brown Dwarfs, is not simply an observational selection effect, but a genuine gap between planetary and stellar mass companions.

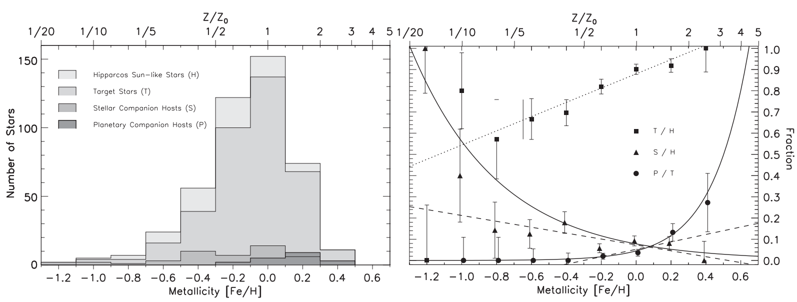


Left: Masses and periods of close companions to stellar hosts of FGK spectral type. The lack of companions in the Brown Dwarf mass regime is shown prominently and is known as the Brown Dwarf Desert.

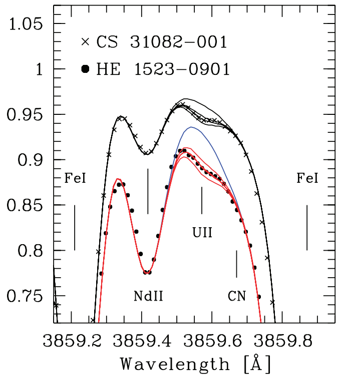
Extrasolar Planetary and Stellar Companions

Lineweaver and Grether also confirmed the positive correlation between metallicity of stellar hosts and the presence of a planetary companion. They discovered an unexpected anti-correlation between metallicity and binarity in stars slightly less massive than our Sun. K dwarfs with low metallicity were found to have stellar companions more often than K dwarfs with high metallicity.

A kinematic analysis suggests that this unexpected anti-correlation is associated with different modes of star formation in the thick and thin disk of our galaxy.



Left: Metallicities of 453 nearby stars were used to identify the unexpected anti-correlation between metallicity and stellar binarity in K dwarfs.



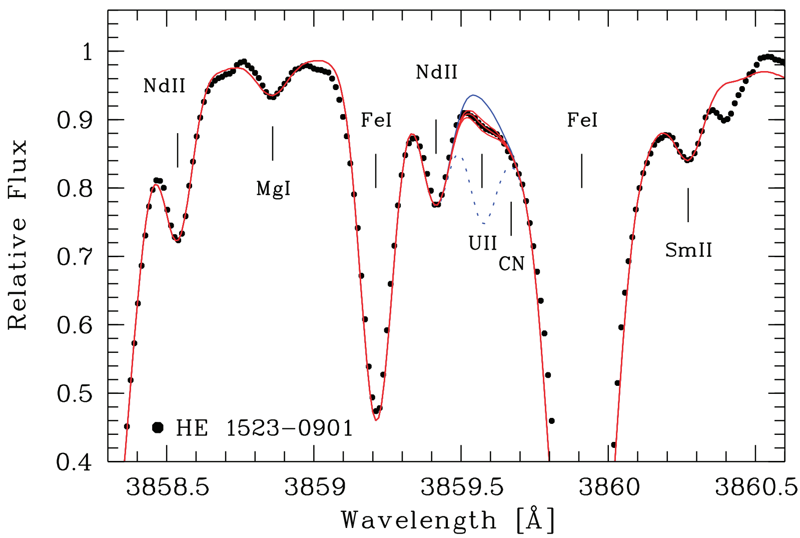
The Most Metal Poor Stars

Asplund, Bessell, Frebel and Norris, working with Beers and Christlieb, continued their search for the most metal-poor stars. As part of that endeavour, graduate student Anna Frebel completed her thesis on the discovery and analysis of bright metal-poor stars from the Hamburg/ESO Survey (HES). From a sample of some 1800 bright (10 < B < 14) metal-poor candidates drawn from the HES, she found 145 objects with heavy element abundance less than one hundredth that of the Sun ([Fe/H] = -2.0). Of these, 79 have [Fe/H] < -2.5, while 17 have [Fe/H] < -3.0.

As noted in the previous Annual Report, the sample contains HE1327-2326, which, with an iron abundance only 1/250000 that of the Sun ([Fe/H] = -5.4), is the most metal-poor star currently known. Following her analysis of that object, and as part of her thesis investigation, Frebel obtained high-resolution, high signal-to-noise spectra (from the ESO Very Large Telescope) of HE1523-0901, another outstanding object in her sample. HE1523-0901 has only 1/1000 the iron abundance found in the Sun ([Fe/H] = -3.0), but is tremendously enhanced in the heavy neutron capture elements relative to iron ([neutron-capture/Fe] = 1.8). The enhancement is so large that she was able to not only detect, but also accurately determine the abundances of the radioactive elements thorium and uranium (for only the second time in the same star). Utilizing the radioactive decay of these elements as cosmic chronometers, Frebel was able to determine tha age of HE1523-0901 – 13.1 Gyr – with an accuracy of 2 Gyr.

Norris and Bessell, working with Christlieb and others on the metal poor candidates in the HES, discovered a further object with an iron abundance significantly less than 1/10,000 that of the Sun ([Fe/H] = -4.0). With [Fe/

Figures: Right and Above: Determination of the abundance of uranium in HE1523-0901, and comparison star CS31082-001. The dots and crosses refer to observational data, while the lines represent model atmosphere synthetic spectra. The continuous blue line is what the spectrum would look like if the star contained no uranium, while the dashed blue one is computed for the U/Fe ratio found in the Sun. The intermediate red line fits the observations, leading to an intermediate uranium abundance, resulting from the radioactive decay of uranium during the 13 Gyr since the star was born.



H] = -4.7, this is only the third such object currently known. They have obtained high-resolution, high signal-to-noise spectra from the ESO Very Large Telescope, which are currently being analyzed to obtain detailed chemical abundances.

Young Stars in the Solar Neighbourhood

The next generation AO instrument for Gemini, Gemini Planet Imager is being currently developed by Bruce Macintosh's group at Lawrence Livermore National Laboratory. Gemini will award campaign science time for GPI and the anticipated telescope time to be awarded to the winning team is ~1000 hours. Thanks to the much better AO correction (~95 per cent Strehl) and smaller inner working angle (good sensitivity at 0.5"-1.0"), we can try to image planetary companions around nearby intermediate age stars of up to ~1 Gyr. This means that we need several hundred targets.

In our Young Nearby Star database, identified mainly using the 2.3m telescope, the aim is to find ~200 targets. We believe that we can select late FG to early K candidate young stars from their X-ray luminosity followed by spectroscopic age confirmation using facilities like the RSAA's Double Beam Spectrograph on the 2.3m.

In 2006 Bessell, Ben Zuckerman and Inseok Song continued their very productive program of identifying nearby, young low-mass stars using the 2,3m DBS and echelle – identifying a new group of ~20 comoving, mostly southern hemisphere, ~200 Myr old stars near Earth. Of the stars likely to be members of this Carina-Near moving group, in either its nucleus (~30 pc from Earth) or its surrounding stream, all but three surprisingly are plausible members of a multiple star system.

Monitoring Variable Stars

Dr Robert Shobbrook worked at the 40-inch with the Wide Field Imager to obtain precision multicolour photometry (0.2 to 0.4 per cent) of a total of 15 beta Canis Majoris pulsating multiperiodic B stars in two young galactic clusters. These stars were also being observed at other observatories around the world in order to follow the variations of light and colour of the stars throughout the 24-hour day.

The low amplitude (typically 0.5 to 3 per cent) and very complex light and colour variations are used to deduce the way in which the atmospheres of the stars behave. This also depends on their internal structure and the relatively recent science of astero-seismology is now being used to probe somewhat deeper into stellar structure than was possible earlier.

The large number of images from all sites are still being reduced at the University of Vienna, where the principle investigators of the program, notably Dr Gerald Handler, are located.

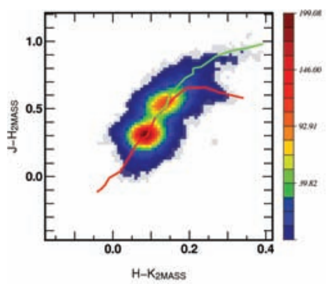
Confirmimg an Important Source of Nitrogen

Nitrogen is a vital element for life as we know it, but its method of production in the universe is still uncertain. One postulated source is "hot-bottom burning" during the final, red giant stages of stars of initial mass 3–8 Solar Masses.

During the hot-bottom burning process, carbon and oxygen in the envelopes of intermediate-mass stars are cycled through the hydrogen-burning shell by convection, producing nitrogen. The carbon in the envelope may itself have been ``dredged-up'' from the nuclear-burning interior.

Until now, the hot-bottom burning mechanism has been a theoretical prediction only and no measurements of large nitrogen enhancements have been made. Finally, McSaveney and Wood and their collaborators Scholz (Heidelberg), Lattanzio (Monash) and Hinkle (NOAO) have succeeded in showing that highly evolved intermediate-mass stars do indeed have very enhanced nitrogen abundances. This proves the reality of the hot-bottom burning mechanism. Thus a large fraction of the nitrogen we breathe was almost certainly produced by adding two protons to carbon nuclei deep inside a star of 3–8 Solar Masses.

The results were derived from observations made with the Gemini South telescope and the Phoenix spectrograph. Since the stars exhibiting the enhanced nitrogen are pulsating in and out with large amplitudes of up to 30–40 km/s, it was necessary to make a pulsation and atmospheric model for each observed star at the time of its observation in order to determine the nitrogen abundance. This difficult task had never been attempted before.



Above: The 2-MASS infrared colour-colour diagram for RAVE targets in the first data release. For clarity, the predicted loci for dwarfs and giants (resp. red and green curves) from Wainscoat et al. (1992) have been added. The Colour-code indicates the number of objects per bin.

The Radial Velocity Experiment (RAVE)

RAVE is a large international project involving astronomers from 10 countries. Freeman (RSAA) is the science coordinator. RAVE is acquiring spectra of about a million bright southern stars (I magnitudes in the range 9 to 12 using the wide-field fibre spectrometer on the UK Schmidt telescope at Siding Spring Observatory. The spectra provide stellar parameters and radial velocities with an accuracy of about 2 km/s. In 2006, the RAVE collaboration made its first public data release of velocities for about 25,000 stars.

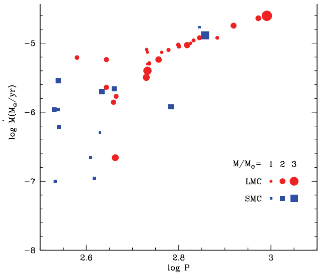
Further data releases are expected each year. The RAVE data are being used for a wide variety of galactic programs, including an estimate of the total mass of the Galaxy from stars of extreme velocity passing through the solar neighbourhood.

RAVE
RADIAL VELOCITY EXPERIMENT

The Rate of Mass Loss from AGB Stars

In its final stages, a star like the Sun will become an asymptotic giant branch, or AGB, star. This AGB stage of evolution is characterised by a very large luminosity (about 5000 times the Sun's present energy output rate), cool temperatures (half the Sun's present surface temperature), large amplitude pulsation (the surface of the Sun will oscillate between Earth and Mars) and a strong outflow of matter in a ``superwind''. The strength of this wind, which is very hard to predict theoretically, determines how much mass will be lost from the star and how much nuclear-processed material will be ejected into space to form the next generation of stars and planets.

In order to get an accurate empirical measure of the strength of the winds emanating from AGB stars, Wood , Groenewegen (Leuven), Sloan (Cornell) and a team of 12 collaborators have used the Spitzer Space Telescope to measure mass loss rates in 60 AGB stars in the Magellanic Clouds. As shown in the figure, when an AGB star is pulsating with periods of less than 500 days, the mass loss rate varies by a factor of up to 100, presumably as a "superwind" is established. Then, as the period increases beyond 500 days due to evolution of the star, the mass loss rate seems to follow a tightly constrained increase with pulsation period. This mass loss "law" will be very useful for calculating the late evolution of AGB stars and the amount of enriched material they eject into the interstellar medium.

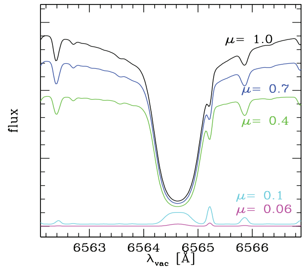


Above: The mass loss rate plotted against the period for AGB stars in the Small and Large Magellanic Clouds. The size of the points is proportional to the mass of the star, which is estimated from pulsation theory.

Using Nature's Telescope to Resolve Stellar Surfaces

For her PhD thesis, Christine Thurl is studying how to best take advantage of microlensing, nature's own telescope to resolve the surface of distant stars, which would otherwise look point-like. As the gravitational microlensing pattern sweeps over a background star, spectroscopic measurements over time measure the strength of spectral features at different positions on the face of the star. Using the H-alpha line of hydrogen, Thurl, together her supervisor Sackett and advisor Peter Hauschildt, has shown that if the H-alpha line is strong, models that include the NLTE (non Local Thermodynamical Equilibrium) effects must be used to compare with data. Thurl defined a new line shape parameter that, when used in conjunction with the usual equivalent-width provides more discriminating power than the latter alone.

Although the NLTE Phoenix models provided a better fit than LTE models to the equivalent widths measured for the H-alpha line throughout the microlensing event OGLE-BULGE-2002-069, neither LTE or NLTE models provided a good fit to the H-alpha line shape. The team suggests that non-modelled chromospheric H-alpha emission is the likely reason. Their work was published in the 2006 Astronomy and Astrophysics.



Above: The H-alpha line from Phoenix the model atmosphere for a low temperature giant like the source star of microlensing event OGLE-BULGE-2002-069. The line is shown in different colours for different positions across the face of the stellar disk. The parameter μ measures the cosine of the angle between the surface of the star and the line of sight: μ = 1 is the centre of the star where the line is in absorption; μ near zero is the limb of the star where the line goes into emission.

Above: Omega Centauri Globular Cluster, containing over a million stars, images with the Wide Field Imager.

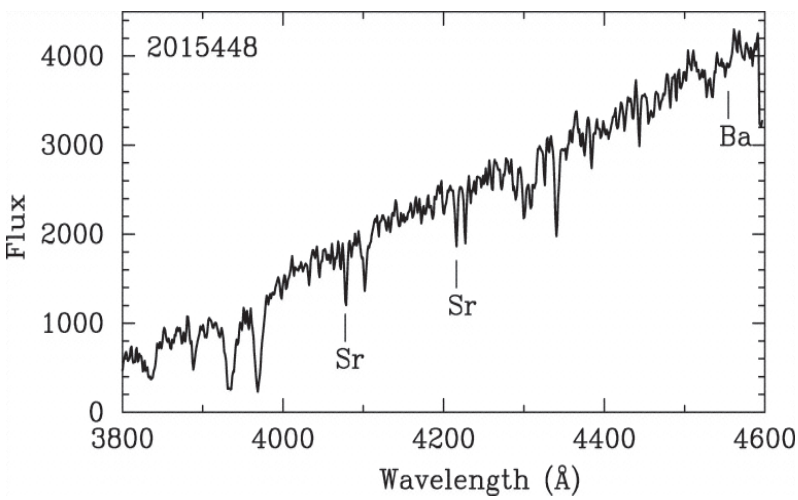
The Unusual Globular Cluster Omega Centauri

During 2006 graduate student Stanford, Da Costa, Norris and Cannon (AAO) presented a metallicity distribution for the unusual globular cluster Omega Centauri based on photometry, obtained with the ANU 40inch telescope, and spectra, obtained at the Anglo-Australian Telescope, for 442 cluster members that lie at the main-sequence turnoff region of the colour-magnitude diagram. The metallicity distribution is similar to that found for the red giant branch: it shows a sharp rise to a mean of [Fe/H]=-1.7 with a long tail to higher metallicities. Ages were then determined for the stars by using theoretical isochrones, enabling the construction of an age-metallicity diagram.

Interpretation of this diagram is complicated by the correlation of the errors in the metallicities and the ages. Nevertheless, after extensive Monte Carlo simulations, the data were interpreted as showing that the formation of the cluster took place over an extended period of time: the most metal-rich stars in the sample ([Fe/H]~-0.6) are younger by 2-4 Gyr than the most metal-poor population.

Graduate student Stanford, Da Costa, Norris and Cannon (AAO) then used spectrum synthesis methods to calculate carbon, nitrogen and strontium abundance ratios, relative to iron, for the sample of main sequence and turnoff stars. The resulting abundance ratios show several different patterns as a function of iron abundance. The source of the observed enhancements in carbon, and of the enhancements observed in both nitrogen and strontium, most likely lies with enrichment from both low (1-3 solar mass) and intermediate (3-8 solar mass) mass asymptotic giant branch stars during the early phases of the cluster's evolution. Rotating

Right: Spectrum of the unusual main sequence star 2015448 in the globular cluster omega Centauri. The lambda4077 and lambda4215 lines of Sr II are unusually strong, yet there is no corresponding enhancement of the Ba II line at lambda4554. Figure from Stanford et al., 2006 ApJ, 653, L117].

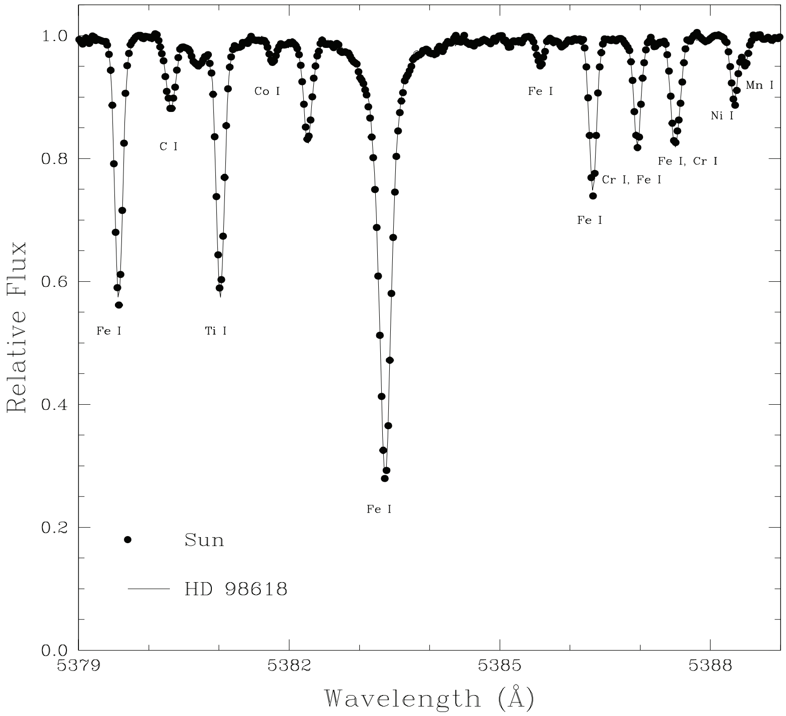


massive stars may have also played a role in generating the observed nitrogen enhancements.

As part of this work, graduate student Stanford, Da Costa, Norris and Cannon (AAO) discovered a relatively metal-rich ([Fe/H] = -0.74) main sequence star in omega Centauri that has highly unusual abundance ratios. The star shows a modest carbon depletion and no sign of any significant nitrogen enhancement, yet the abundance ratio of the light s-process element strontium exceeds the solar value by a factor of approximately 40! Further, while the usual expectation is that the abundance ratio of the heavy s-process element barium should be similar to that of strontium, the spectra reveal no obvious enhancement in the barium abundance; the observations

Discovery of a Solar Twin

Melendez has been working in the determination of isotopic ratios in metal-poor stars employing spectra of exquisite quality (typically with signal/noise between 500-1000) taken with the 10m Keck I telescope in Hawaii. With Asplund and Cohen (Caltech), he has been analyzing Li and Mg isotopes, respectively. Melendez has been also studying solar twins with high quality Keck spectra, which were analyzed by summer research scholar Dodds-Eden, finding that HD 98618 is the second star known to be very similar to the Sun (the closest solar twin, 18 Sco, was discovered a decade ago by Brazilian astronomers). This work was done in collaboration with graduate student Robles.



Left: A small portion of the spectrum of HD98618 (Line) compared with the solar spectrum (Dots). The detailed correspondence between the two spectra is remarkable.

The Missing Milky Way Satellites Survey

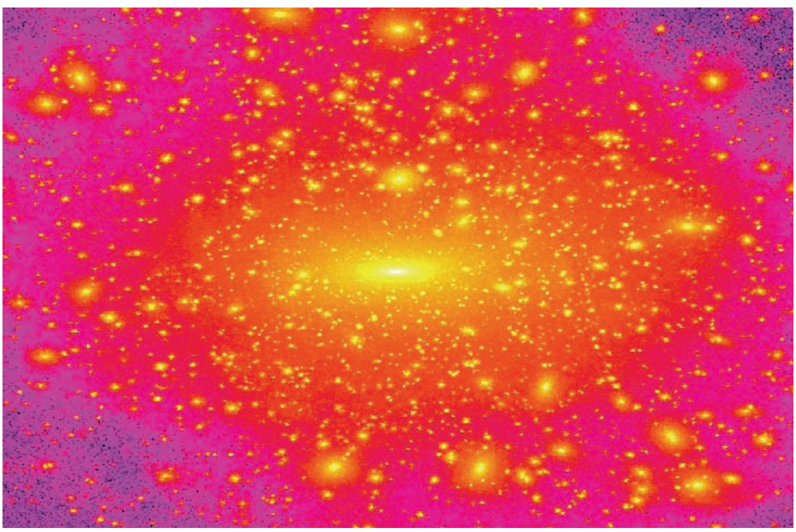
Cold Dark Matter (CDM) theory was considered a triumph of theoretical astrophysics. Today it must be regarded as incomplete, a mere stepping stone to something better. The Missing Milky Way Satellites Survey, initiated and led by Helmut Jerjen from RSAA, will use a catalogue of one billion stars produced by the new ANU SkyMapper telescope to resolve a long-standing discrepancy between the CDM paradigm and observations.

The Missing Milky Way Satellites Survey is the most sensitive search for 500 theoretically predicted but still undetected dark matter dominated satellite galaxies around the Milky Way (see Figure 1). The results will provide stringent observational constraints to uncover flaws in CDM theory.

In the initial phase of the program and in preparation for the first SkyMapper data, Jerjen and his PhD student Shane Walsh developed detection algorithms as specialised tools to find and physically characterise the faintest, most elusive galaxies believed to exist in the Universe. The search strategy has been extensively tested throughout 2006 taking advantage of Sloan Digital Sky Survey (SDSS) data. In single-blind experiments employing dedicated high-performance computers, Walsh and Jerjen recovered every one of the few known Northern Hemisphere Milky Way satellites including the faintest systems reported by the SDSS team in 2005/6.

Even more exciting was the discovery of 14 satellite candidates that have been overlooked so far (see Figure 2). The new detections further support the finding that Milky Way satellites are preferentially distributed in a plane (Kroupa, Theis & Boily 2005).

Figure 1: Lambda Cold Dark Matter theory predicts 500 dense, gravitationally bound small clumps of dark matter in a spherical symmetric distribution around the Milky Way. (Image from Prof. Ben Moore, University of Zürich, Switzerland).



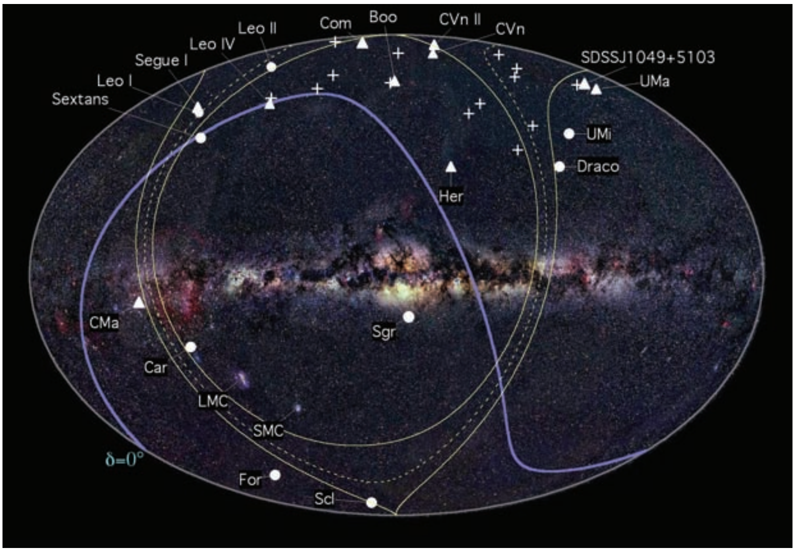


Figure 2: The observed distribution of the 21 known satellites and 14 new candidates in the vicinity of the Milky Way out to 250 kpc. The apparent arrangement of the dwarf galaxies in a plane (Kroupa, Theis & Boily 2005) is highlighted with a dashed line enveloped by the ±15 degrees lines in solid. Half of the entire sky (area below the blue line) will be surveyed by the Missing Milky Way Satellites program.

Early-Type Dwarf Galaxies in Nearby Groups

During the report year graduate student Bouchard, Jerjen, Da Costa and Ott (ATNF) presented the results of a 21 cm neutral hydrogen (H I) line detection experiment carried out in the direction of 18 low-luminosity dwarf galaxies in the relatively nearby Centaurus A group, using the Australia Telescope National Facility 64 m Parkes Radio Telescope and the Australia Telescope Compact Array.

Five dwarfs were detected with neutral hydrogen gas masses between $M(HI)=4\times10^5$ and 2.1×10^7 solar masses and corresponding M(HI)/L(B) ratios between 0.04 and 1.81 in solar units. The other 13 systems were not detected. The upper limits on the gas contents lie between 5×10^5 and 4×10^6 solar masses with in all cases $M(HI)/L(B) < 0.24$ in solar units. Among the non-detected systems were two mixed-morphology dwarfs, a situation that contrasts with that in the Local Group and in the Sculptor group where all the mixed-morphology dwarfs contain significant amounts of neutral gas.

The distribution of neutral gas properties of the Centaurus A group low-luminosity dwarfs is also unusual in that it shows a discontinuity: all the dwarfs fainter than $M(B)=-13$ have either $M(HI) > 10^7$ solar masses or $M(HI) < 10^6$ solar masses. No such discontinuity is seen in the corresponding distribution for the low-luminosity dwarfs in the Sculptor group. The origin of the discontinuity may lie with a ram pressure stripping mechanism at work in this relatively dense environment, in which all galaxies with $M(HI) < 10^7$ solar masses have been stripped of their gas. The density of the intergalactic medium required to achieve this is approximately 10^{-3} cm^{-3}.

The Dynamical Age of the Fornax Cluster

A sophisticated surface brightness fluctuation (SBF) analysis package has been developed by RSAA PhD student Laura Dunn and her supervisor Dr Helmut Jerjen, designed to measure accurate distances of galaxies by means of the statistical fluctuation signal of unresolved stars.

This suite of programs, called SAPAC, was made readily available to the astronomical community worldwide with the goal of providing the analysis and calibration tool for systematic distance surveys of early-type galaxies using state-of-the-art optical/near-IR telescopes equipped with wide-field CCD cameras such as the ANU SkyMapper telescope or the 8m Large Synoptic Survey Telescope.

SAPACs capabilities have been demonstrated in a pilot project, analyzing deep images of dwarf galaxies in the Fornax galaxy cluster at 66 million light years. Data were obtained from the 8m Very Large Telescope of the European Southern Observatory.

Combining accurate galaxy SBF distances with galaxy redshifts revealed for the first time a pronounced S-shaped infall pattern (see Figure 3), indicative for a galaxy aggregate still in process of formation through a general collapse and accretion of smaller groups of galaxies. Dynamical models were employed to estimate the cluster mass, including dark matter, at 2.3×10^{14} solar masses and the associated collapse time is 2.9 billion years (Dunn & Jerjen 2006).

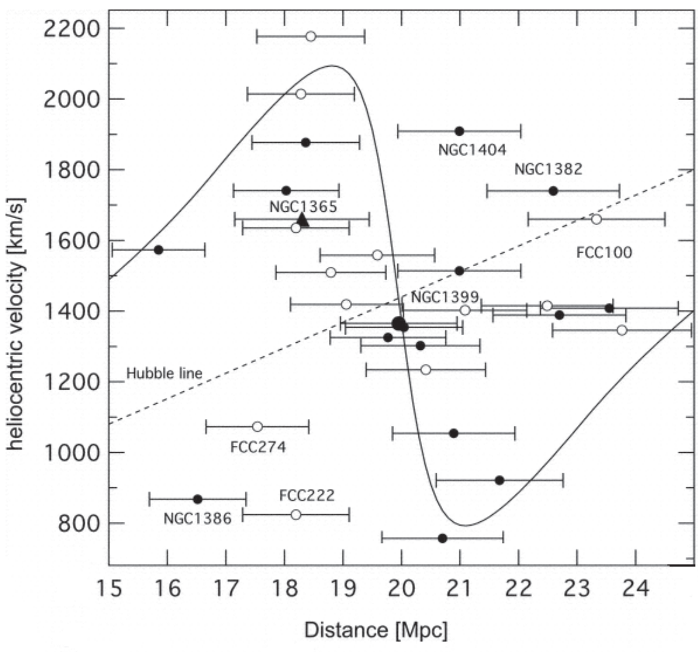
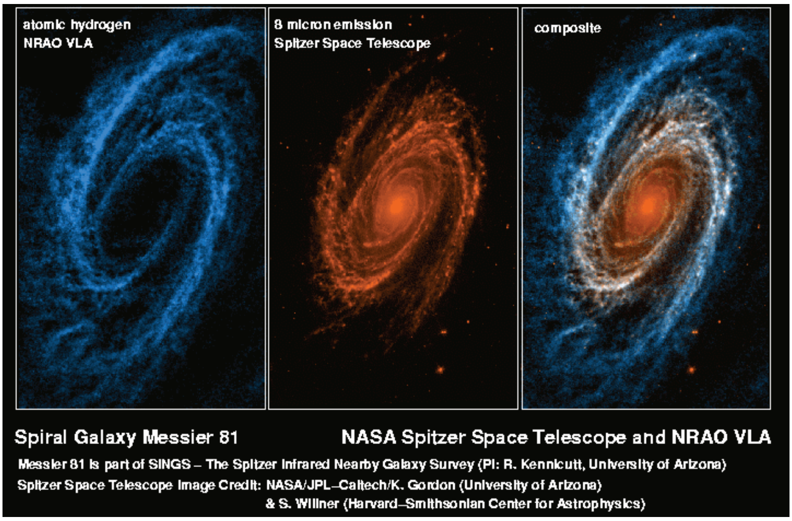


Figure 3: Hubble diagram of galaxies in the Fornax cluster. Open circles refer to dwarf elliptical galaxies and filled circles to giant ellipticals. The solid S-curve represents the best-fitting mass-age cluster infall model. Without the gravitational field of the cluster, all galaxies would follow the Hubble line. The spiral galaxy NGC 1365, which is located in the central cluster region is shown as a filled triangle. Other named galaxies are members of various subgroups falling into the cluster for the first time.



Left: Combining HI radio images (Right panel) and Infrared images from the Spitzer space telescope is allowing astronomers to build up a more complete view of the composition of a galaxy. Here Radio and IR images of M81 are shown.

HI Gas content in Nearby Galaxies

De Blok continued his research into the dynamics and interstellar medium of nearby disk galaxies. Projects on the star formation threshold in NGC 6822 reached their conclusion, showing that an appropriate choice for the velocity dispersion of the neutral hydrogen can unify several alternative descriptions for this phenomena.

Analysis and reduction of the THINGS (The HI Nearby Galaxy Survey) continued. PhD student Se-Heon Oh worked on the dynamics and rotation curves of several of the THINGS dwarf galaxies showing that the CDM description of dark matter haloes still does not suffice. PhD student Joshua Rich concluded work on the Multi-Scale Clean techniques and started investigations of the structures, holes and shells in the ISM of a number of THINGS galaxies.

Work was also started on analysing data from the LVHIS (Local Volume HI Survey) project. PhD student Nicolas Bonne will analyse several HI data cubes from this survey and combine these with deep H-band imaging to test predictions made by MOND, an alternative theory describing the dynamics of galaxies.

Above: Three of the thirty antennas of the Giant Metrewave Radio Telescope (GMRT) located in India.

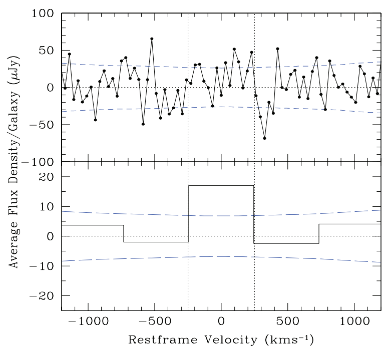
The gas content of star-forming galaxies ~3 billion years ago

The amount of star formation in galaxies is known to have been much higher in the past, reaching a factor of ten higher 8 billion years ago (60 per cent of the age of the universe ago). However the amount of neutral hydrogen gas (the fuel for star formation) in galaxies is only poorly constrained over this time period. A group consisting of Philip Lah, Frank Briggs, Jayaram Chengalur (NCRA), Matthew Colless (AAO), Roberto De Propris (CTIO), Michael Pracy and Erwin de Blok, have been working on improving the constraints.

Neutral hydrogen gas gives off a radio signal that can be used to quantify the amount of gas present. This radio signal from galaxies in the past is only now reaching us but it is quite weak due to the large distances involved and so is difficult to detect even with the largest radio telescopes available today. However, using optical observations of the position and redshift of a galaxy, we can identify where we expect the weak neutral gas signal to be in the radio data for that galaxy. The combination of these signals from multiple galaxies is strong enough to measure, allowing us to quantify the average amount of neutral hydrogen gas in the galaxies.

The study sample of several hundred galaxies from ~3 billion years ago show active star formation. These galaxies were first identified by a Japanese collaboration using the Subaru Telescope, a large optical telescope. Radio observations of these galaxies were done using Giant Metrewave Radio Telescope (GMRT) in India. Followup optical observations with the Anglo-Australian telescope were done to obtain the necessary precise redshift for the galaxies. Using the coadding technique, we were able to measure the radio signal from the neutral hydrogen gas from the galaxies. We find that the amount of neutral hydrogen gas in galaxies ~3 billion years ago is of order twice that found in galaxies at the present day. At this time in the past, galaxies show an amount of star formation three times greater than found today. The observed increase in the gas content of the galaxies is enough to fuel their observed star formation without requiring changes in what is known about how star formation works.

Right: The average neutral hydrogen gas radio signal from coadding the signal of all 121 galaxies with known optical redshifts. The top spectrum has no smoothing or binning. The bottom spectrum has been binned to the expected width of the galaxy signals.



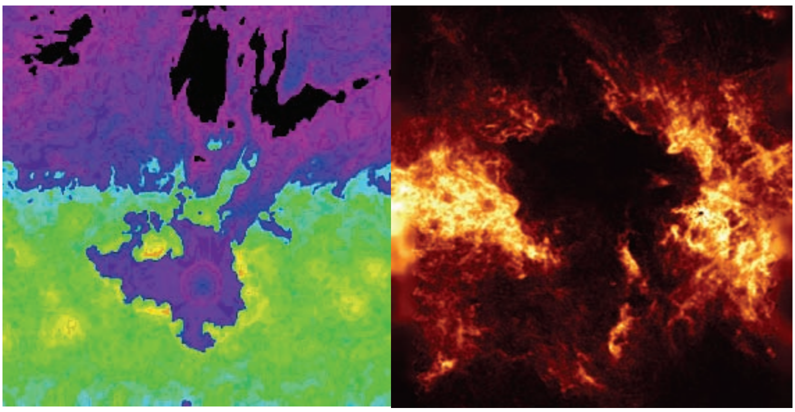
HI Superbubble Modelling

Working with Alyson Ford (Swinburne) and Dr Naomi McClure Griffith (ATNF) we are simulating the breakout of supergiant HI bubbles from the HI disk of the Milky Way.

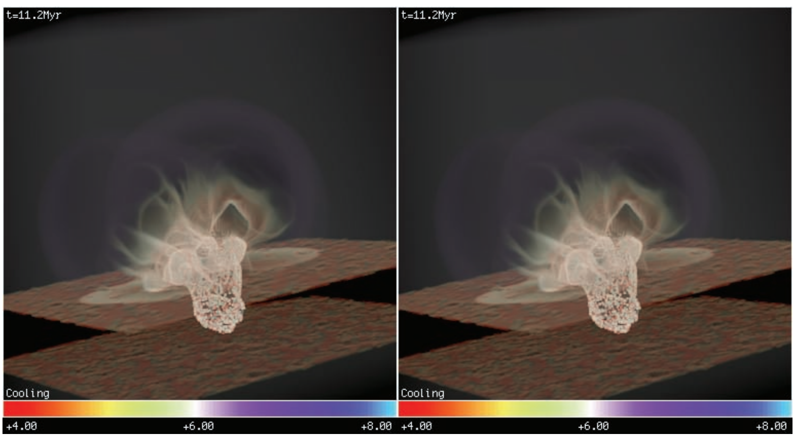
The models show that small, fast moving HI cloudlets observed up to 1kpc above the main plane of the disk can be the debries from a bubble 'blowout', as a high pressure bubble driven by a cluster of stars, breaks out into the low pressure halo of the galaxy.

The work has been the first major use of the new hydrodynamics code Fyris Alpha, which allows for a detailed equation of state, and in some models time-dependent ionisation to be incorporated in a massively parallel hydrodynamical calculation.

So far the simulations have been run on the multi-processor development machine *myriad* at Mt Stromlo and on the Swinburne linux cluster.



Left, simulated superbubble breakout, showing the logarithm of the gas density in false colour, red-yellow is high density, purple-black is very low density. Right, The observed Superbubble, GSH277, seen as a velocity slice in the HI gas of the galaxy (McClure Griffith ATNF).



Bottom panels: a 3D stereo pair view of another simulated bubble breakout in the light of X-ray emission. The X-rays come from high pressure multi–million degree gas from a cluster of young stars at the centre. This view looks down on the cool HI disk which is invisible in X-rays, and the complex bubble of hot gas is seen expanding into the hot halo of the galaxy. The colour of the gas is given by the temperature shown in the logarithmic colour bars below.

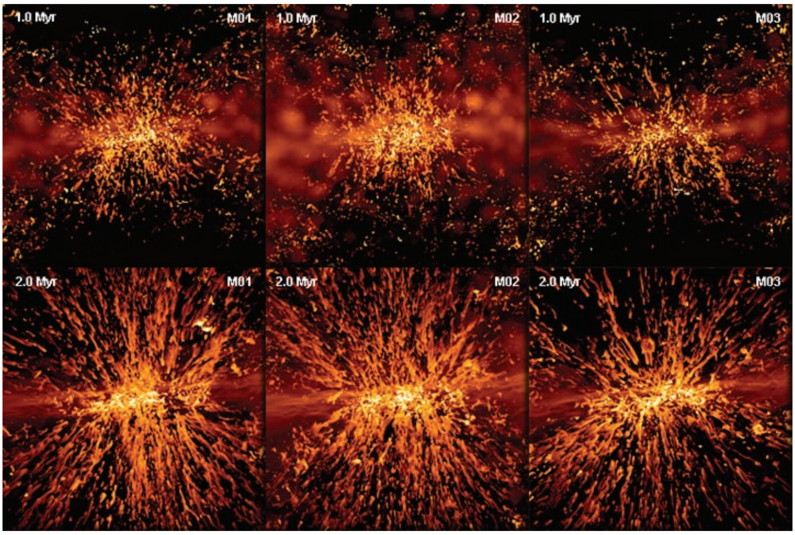
The Formation of Filaments in Outflows from Starburst Galaxies

Following work by Joss Band-Hawthorn in 1988 which demonstrated that M82 has a colossal bipolar outflow, it is widely accepted that the filaments in M82 and many other similar ***starburst*** galaxies are the optical manifestation of galactic-scale outflows of gas, which are powered by the energy produced by massive stars and supernovae. While galactic winds are ubiquitous in starburst galaxies, the mechanism behind the formation of the filaments seen at optical wavelengths, such as Hα, had been uncertain until recent research carried out by graduate student Jackie Cooper in collaboration with supervisors Geoff Bicknell, Ralph Sutherland and Joss Bland-Hawthorn.

To better understand the formation of these filaments, Jackie Cooper has performed a series of three-dimensional hydrodynamical simulations of starbursts occurring in an inhomogeneous interstellar medium. The simulations, which utilise the processing power of the APAC supercomputer installed at ANU, cover a spatial range of 1 kpc over a 2 million year period in time. The figure below shows the simulated Hα emission in each of her models at 1 Myr and 2 Myr epochs. The three models differ only in the initial distribution of clouds in their disks. The filaments appear as strings of disk clouds that emanate from the starburst region and rotate in the same direction as the disk.

The filaments are formed via the break-up of clouds in the starburst region. As the energy in the starburst region of the galactic disk increases, the binding energy of the clouds in this region is overcome and they fragment. The fragments are then accelerated into the outflow by the ram pressure of the wind powered by the starburst. Filaments are also formed from gas stripped from the sides of the starburst region.

Right: Simulated Hα emission from a starburst wind at 1 (top) and 2 (bottom) million year epochs in three models. Each model differs only by the initial distribution of clouds in the disk of the galaxy.



Radio Galaxy Jet-ISM Feedback

A major series of simulations by Sutherland and Bicknell culminated in 2006, showing the detailed interaction of a powerful radio jet in the centre of a disk of gas, representing the interstellar medium of a host galaxy.

The models identified a series of evolutionary stages, including an energy driven bubble stage and a rapid jet breakout phase. These phases display many properties that can be related to the observations of young radio sources, in particular the GPS and CSS classes of young radio galaxies.

The models showed that despite the enormous power present in the jet, and the high pressure bubble driven by the jet, the inhomogeneous ISM is remarkably robust and difficult to sweep away.

The fractal nature as well as the non-linear cooling in the disk gas enable it to lose some of its mass easily, while a significant fraction of the disk mass is unable to be swept away as it cools and forms extremely dense 'clumps' that resist the flow.

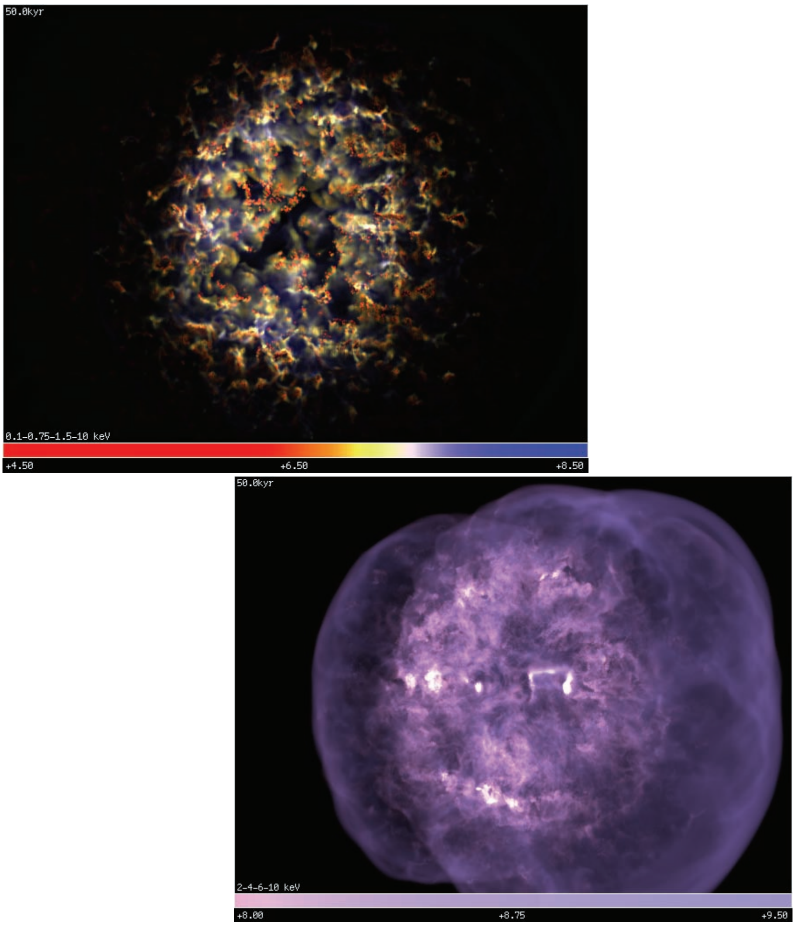


Figure: 3D model X-ray emission from a Jet-Disk interaction.
Top: Soft X-rays showing the compression of the disk gas into small clumps, seen as red dots.
Bottom: Hard X-rays from 2- 10keV show the distribution of the very hot gas, and the outer blastwave.
In each case the colour bar is labelled with the logarithm of the gas temperature that emits the corresponding colour.

First NIFS Observations

First Year of NIFS

Highlighted in the 2005 Annual Report, NIFS was commissioned on the Gemini North Telescope. In 2005/2006 the first science observations were taken by McGregor and Tracy Beck (Gemini Observatory), some being analysed and modelled at RSAA by McGregor, Dopita and Sutherland, along with Honours student Catherine Farage. Here a preliminary gallery of the data are presented, and analysis continues in 2007.

Perseus A

The powerful radio galaxy Perseus A (NGC 1275), located at a redshift of 0.017559 (5264 km/s), is the central component of the Perseus cluster, Abell 426. NIFS has revealed a remarkably detailed disk structure in the innermost region of Perseus A, shown in Figure 1. The inner portions of the molecular hydrogen and [Fe II] line images are best interpreted as a turbulent disk around the central active nucleus seen at a relatively small angle of inclination, and warped in its outer portions.

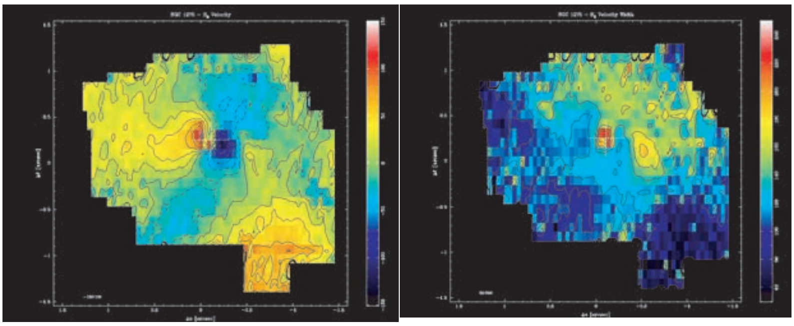


Figure1. Left: The radial velocity field of the H2 line in Perseus A (NGC 1275). This is consistent with Keplerian rotation of a warped accretion disk seen almost face- on around a massive central black hole. **Right**: The velocity dispersion of the H2 line in Perseus A (NGC 1275). Note how it increases sharply towards the nucleus. This is consistent with a model in which the disk is predominately heated by turbulence and shocks as the molecular material works its way towards the nucleus. In this model the surface brightness of the disk is predicted to increase sharply towards the nucleus, in accord with the observational results.

Cygnus A

Cygnus A is the most powerful radio-emitting AGN in the local universe. Indeed, its power is great enough for it to be regarded as a radio quasar. In this sense, its proximity makes it a uniquely interesting object for study.

The circum-nuclear region shows a complex dusty bipolar structure, whose axis is very well aligned with the large-scale radio jets. Adaptive optics near-infrared images clearly show an unresolved nucleus between two spectacular ionization/scattering cones. There is clear evidence of copious quantities of dust and heavy nuclear obscuration.

The spatial structure of the emission line regions observed with NIFS in the different ions is extremely instructive. This is shown for some of the brighter lines in Figure 2. The ionization structure observed is consistent with photoionization in the radiative pressure dominated regime modelled by Groves, Dopita & Sutherland (2004a,b). It reaches very high ionization parameters in the easterly cone; U ~1.0. Finally, we can tentatively conclude from the rapid rotation seen over the central 0.2 arc sec. (200 pc) that the mass of the central Black Hole is of order 3 billion solar masses.

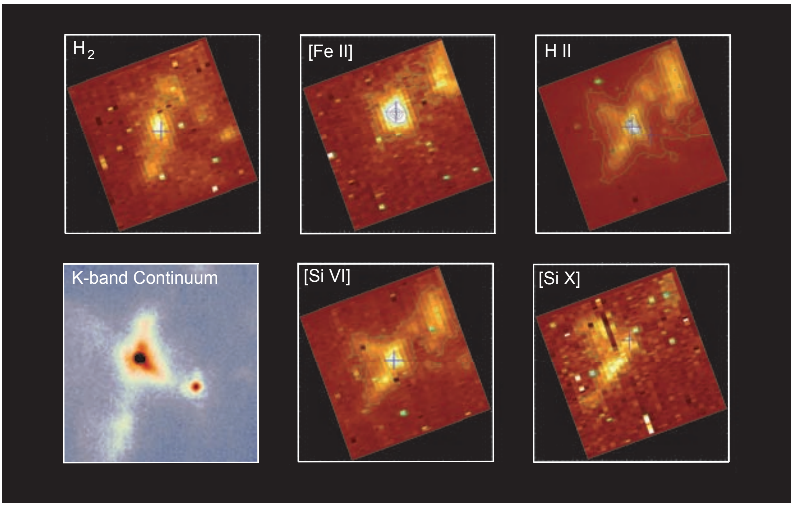


Figure 2 – The nuclear regions of Cygnus A as seen by NIFS compared to a Keck K-Band image (lower left). Note how the molecular hydrogen image reveals the bright inner accretion disk and a system of clouds which help define an ionization cone. The [Fe II] line is confined to the circum-nuclear region and the innermost portions of the ionization cone, with a bright feature to the NW which likely represents a cloud illuminated by the central engine. The size of the white square is 4×4".

Young Stellar Outflows and Jets

The object HV Tau C is one component of a triplet of pre-main sequence stars. It represents a fine example of an accretion disk around a young star. The NIFS data reveal an [Fe II] jet embedded in a slower H2 conical bipolar outflow with a cone with total opening angle of about 120°. This is shown in figure 3. The [Fe II] jet is clearly visible in the -125 km/s velocity channel to the E, and at +25 km/s to the W (velocities given are Heliocentric radial velocities). For an inclination angle of 10°, would give a true outflow velocity of 400 km/s.

DG Tau B is another bright T-Tauri star with jet like outflows. It shows a sharply defined conical reflection region extending out to 400 AU and with a full opening angle of 80° on the near side, and a less clearly delineated outflow on the far side. An absorbing equatorial disk is present. The NIFS image in the integrated light of the [Fe II] line is shown in Figure 4.

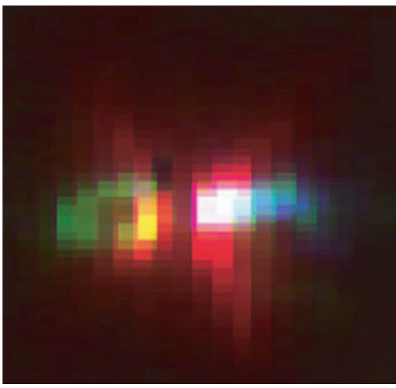


Figure 3 Left– The jet and molecular outflow in HV Tau C. This image is 2" on a side. The H2 2.122µm emission is shown in red. This has an outflow velocity of less than 50 km/s. The [Fe II] line at 1.644µm is shown in the green and the blue channels. The green represents the velocity range -100 to -50 km/s, while the blue represents the velocity range -50 to 0 km/s.

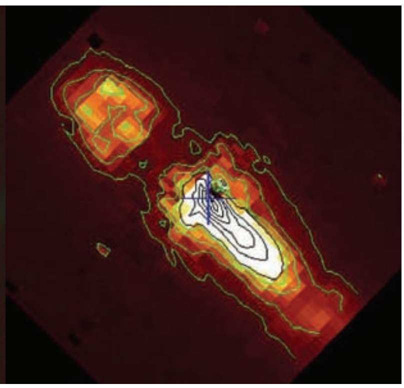


Figure 4: Right – The DG Tau jet as seen by NIFS in the integrated light of the [Fe II] line at 1.644µm. North is at the top east at the left, and the image is 3×3" in size, which corresponds to 460 AU. Note that the equatorial disk is clearly visible, and is therefore still optically thick at 1.644µm within a projected distance of about 100 AU .

Right: The Gamma Ray Burst GRB050904 was found by the SWIFT satellite at 1:51 UT on Sept 04. Follow-up observations with ground-based telescopes rapidly identified the optical afterglow. The Magnum telescope began to observe the source after 12 hours. It obtained simultaneous optical and infrared images. Here the GRB, identified by the red circle, is seen in a combined I (blue), J (green) and K(red) image.

Gamma Ray Bursts

Brian Schmidt, Bruce Peterson and collaborators continued their work in chasing the largest bangs in the Universe since the Big One – Gamma Ray Bursts. This work included publishing observations of the most distant stellar explosion yet discovered – GRB050904 – a star which exploded some 12 Billion years ago, and one of the most distant objects discovered of any kind. The observations showed the galaxy that hosted the stellar explosion had already formed many stars, and was relatively old for a Universe so young.

In addition, Schmidt and Peterson observed several nearby bursts in the hope to better understand these largest of cosmic explosions. These studies revealed in the case of one very weak explosion, the presence of a relatively normal supernova explosion of a massive star, providing further evidence that Gamma Ray Bursts are formed by certain massive stars as they run out of nuclear fuel and collapse into a Blackhole, or in this case, maybe a neutron star. The other study complicated matters, revealing a burst, which for the first time, definitely did not have an associated supernovae. The researchers are hoping 2007 will provide observations that present a clearer picture of how Gamma Ray Bursts are formed.

Supernovae and the Essence Project

Brian Schmidt and his students Marilena Salvo and Josh Blackman continued their work on the Essence Project, a 5 year project to measure the properties of Dark Energy using exploding stars called supernovae. This same class of objects was used to discover the Dark Energy in 1998 by a team lead by Schmidt, by seeing that the expansion of the Cosmos is accelerating in time. The Essence Project is dedicated to making a very fine measurement of this acceleration over the Universe's last 6 Billion years. In December the Essence team announced that they could see no deviation of the Universe's trajectory from the simplest model of the acceleration – Einstein's Cosmological Constant. This form of Dark Energy was proposed by Einstein to counter the expansion of the Universe before Hubble's measurement of Cosmic Expansion – an invention he later called his greatest blunder. The Cosmological Constant is a form of Dark Energy that is directly connected to space, and does not vary over time or in location. Further work is planned to continue to look for possible deviations from this very simple model – motivated by a wide range of possible theories that predict such deviations.

The EROS Experiment

The microlensing EROS experiment was to search for dark matter in the halo of the Milky Way in the form of hypothetical dark stellar-like objects, commonly called 'machos' (for Massive Compact Halo Objects). Machos can be detected if they are sufficiently close to the line of sight of a visible background star in which case the macho acts as a gravitational lens.

As background source stars, EROS uses 33 million stars in the Large and Small Magellanic Clouds (LMC and SMC), two dwarf galaxies orbiting the Milky Way. If our halo is entirely comprised of machos, about one Magellanic star per million is effectively lensed at any given time. The signature of the lensing effect searched is an apparent brightening then dimming of the star as the macho moves toward then away from the line of sight. To that end, EROS-2 monitored 93 deg^2 of the Magellanic Clouds from 1996 through 2003. These observations followed the EROS-1 observations of 1990-1995. The EROS observations were in part simultaneous with those of the MACHO collaboration who monitored the inner 13.5 deg^2 of the LMC from 1992 to 2000.

The first candidate microlensing events were announced in 1994. Since then, the MACHO collaboration observed 17 microlensing candidates that can be interpreted as implying that between 10 and 50 per cent of the Galactic Halo consists of machos of mass near 0.4 solar masses.

The EROS collaboration took a more conservative approach, publishing only upper limits to the halo macho content. The totality of the results are summarised in Figure 1 (Tisserand et al., 2006). Based on no observed microlensing event of bright Magellanic stars, EROS-2 placed a limit for the mass range favoured by the MACHO collaboration of 7 per cent of the halo. Therefore, the EROS result is in conflict with the MACHO one, the presence of dark matter under the form of compact dark objects is not confirmed. Both results are compatible only if one assumes that the MACHO events detected are due to normal stars in the dense central region of the LMC where most of the MACHO data was taken.

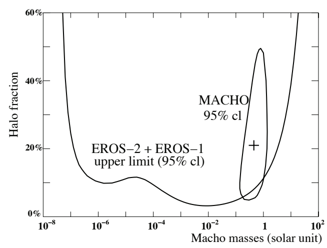


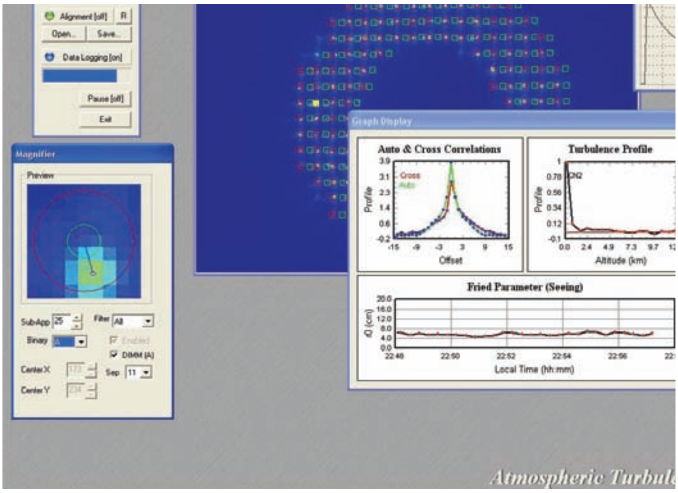
Figure 1: The mass fraction of the dark galactic halo versus the different possible masses for Machos, from the mass of the Moon to a Black Hole. The contour shows the signal of the MACHO collaboration. The solid line shows the EROS 95 per cent CL upper limit.

Technology

SLODAR Turbulence Measurement

Conroy, Goodwin and Jenkins, in collaboration with Lambert (UNSW), continued characterization of the turbulent atmosphere above Siding Spring. An improved SLODAR turbulence-ranging instrument was deployed on several occasions on the 1-m telescope; the enhanced instrument features real-time data assessment (Figure) and optical adjustments which allow much finer vertical resolution. It seems that on many nights the bulk of the seeing at Siding Spring arises within a few hundred meters of the ground, a favourable condition for Ground Layer Adaptive Optics.

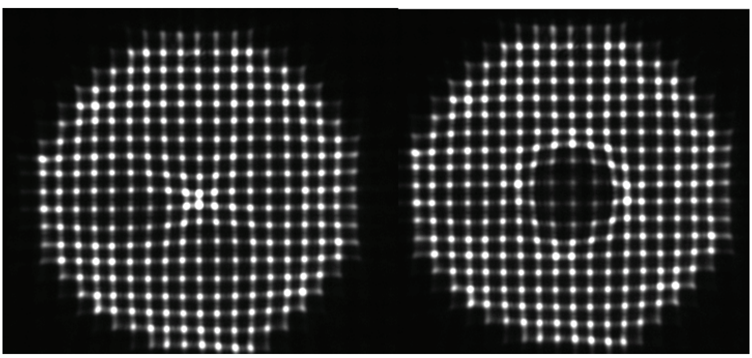
Right: The control screen of the RSAA SLODAR shows Shack-Hartman image data, current estimate of turbulence profile, and various diagnostics of the real-time data reduction. The system handles 200 camera frames per second.



Adaptive Optics Development

Beasley and Jenkins have been ramping up adaptive optics R&D in the new AITC laboratories, concentrating on techniques for open-loop control of MEMs deformable mirrors. As a training exercise, a conventional Xinetics deformable mirror (on loan from the Gemini project) has been characterised using a Shack-Hartmann wavefront sensor and in-house software.

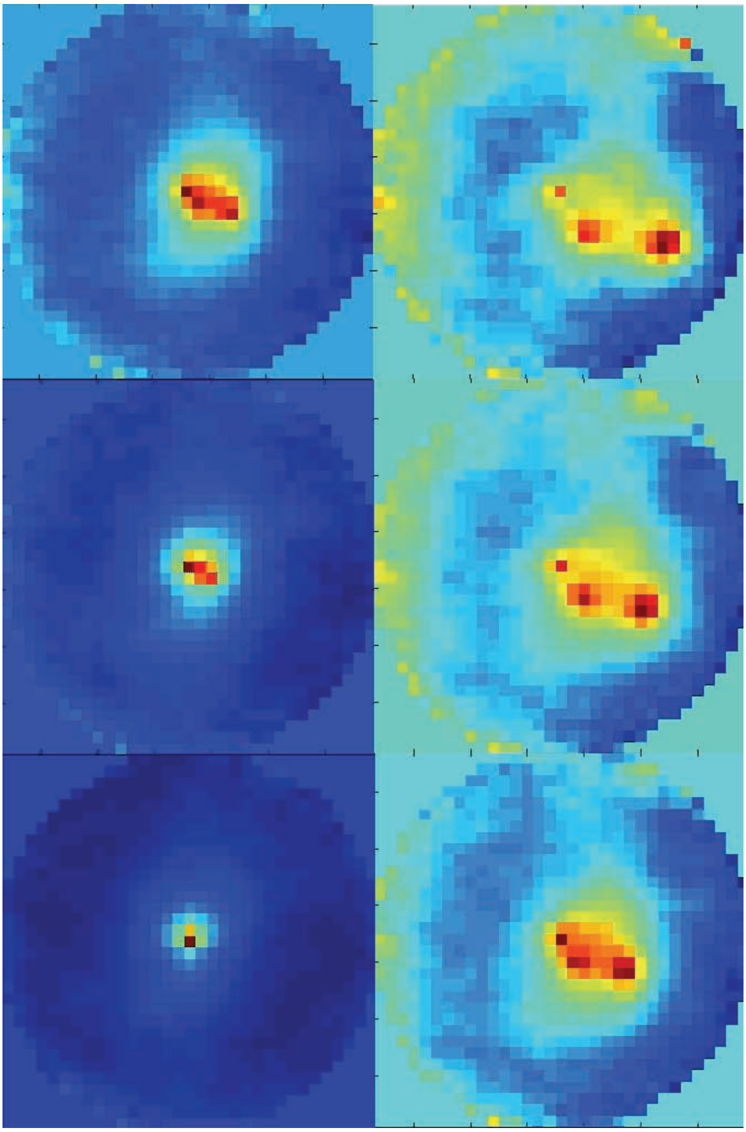
Right: Images from a Shack-Hartmann sensor of the Gemini Xinetics mirror, showing the displacements of the sub-images as the central actuator of the deformable mirror is powered up and down.



Turbulence Correlation

A correlation technique has also been developed to visualise the distribution of wind speed above the site. Regions of intense turbulence can be tracked across the telescope pupil (Figure), frequently showing different wind direction at various altitudes. The ground-level wind speeds agree with those measured by the AAT weather station but the high-altitude winds can be much faster.

The combination of wind speed and turbulence height and strength data will allow realistic assessment of the prospects for seeing improvements on Siding Spring by the use of adaptive optics techniques.



Above: These six correlation images, each spaced by 10 msec from top left to bottom right, show fast-moving higher-altitude patches of turbulence (about 3 km altitude, propagating SSW at about 10 m/sec), plus the slower-moving ground layer propagating about SW at 5 m/sec.

Software Engineering

The Computer Section was involved in a number of projects during 2006. From a software engineering point of view we contributed to the acceptance, delivery and phase 1 commissioning of Gemini's GSAOI instrument, the SII projects TAROS and the 2.3m TCS upgrade, the SkyMapper camera and the 2.3m WiFeS instrument. The Section also supports the School's computing infrastructure and assists all users with their computing needs.

GSAOI

Software for GSAOI was developed by Mark Jarnyk, Greg Wilson, Jon Nielsen and Peter Young. During the year the instrument successfully passed the Gemini Acceptance Test procedure where a team from Gemini visited Stromlo and put the instrument through its paces. The instrument was then shipped to Gemini South at Cerro Pachon in Chile and phase 1 software commissioning tasks were completed successfully. These tasks largely involved the integration of the instrument with Gemini South systems and system verification in the lab. It is anticipated that on-sky commissioning and integration with the Gemini MCAO system will proceed in the latter part of 2007.

Right: The commissioning team (left to right) of Peter Young , Matt Doolan, and Mark Waterson at Gemini South.

TAROS

The TAROS SII project is nearing completion with commissioning being done in stages during 2007 (in support of WiFeS and SkyMapper) with full commissioning expected by the end of the year. Most TAROS functionality has been implemented and current effort is mostly toward integration and testing. Significant milestones were completed in May when TAROS was demonstrated controlling the 2.3m Imager mechanisms and taking an exposure using the TAROS Java GUI running on a Mac laptop. Areas of development still to be completed are the observations database, A&G system, telescope, operational environment and the health system Java GUI interfaces, and the data distribution system (which is being undertaken by a team of senior ANU Computer Science students).

2.3m TCS Upgrade

This upgrade project aims to replace the aging VAX/VMS based TCS currently in operation on the 2.3m with a new system comprising industry standard x86 hardware together with a modern software component based around Pat Wallace's TCSpk telescope control software library. Progress throughout 2006 has been good. Specification work is nearing completion. Modifications to the 2.3m electronics are largely complete. The first major milestone of the software component has been reached, with the DEMON engineering GUI being used to successfully control the telescope hardware. 2007 will see the conclusion of specification work, an overhaul of the 2.3m met system, and a continuation of software effort including a staged implementation of hardware control loops together with associated commands. Commissioning is currently planned for late 2007.

SkyMapper

Development of the automated data acquisition and control software is well under way with many of the hardware subsystems integrated into the observatory control system and are currently undergoing unit and integration testing. A critical component of the autonomous operations for SkyMapper is the TAROS Monitor successfully implemented as a student project with the ANU Department of Computer Science. The TAROS Monitor is an application which interfaces with TAROS to monitor the status of each component of the hardware and autonomously issue alerts via SMS or email to a designated individual in the case of a hardware failure.

Development of the automatic observation scheduling and data reduction pipeline software is continuing and both software suites will enter the testing and integration phase mid-year. The scheduling software enables the telescope to operate without human intervention, selecting the best field to observe based on current conditions, while the data reduction pipeline will enable scientists to process the 0.7-1 terabytes of image data per night with minimal effort.

WiFeS

The WiFeS instrument control system will provide users of the 2.3m telescope with an instrument that is significantly more integrated and simpler to operate than previous 2.3m instruments. Many of WiFeS key functions are implemented and the WiFeS TAROS user interface is currently under development. The Java GUI will provide a single operational console for the instrument, greatly enhancing the observer experience at the 2.3m. Around mid 2007, the key integration activities of the WiFeS instrument control system with the telescope control system and TAROS A&G system will occur. This will permit end to end verification of system functions before commissioning.

The Wide Field Spectrograph (WiFeS) Takes Shape

The Wide Field Spectrograph (WiFeS) will be soon mounted on the 2.3m telescope at Siding Spring. When operational it will deliver 950 independent spectra with 4096 independent spectral elements with a single exposure, and will be many times more efficient at gathering in science data than the existing generation of spectrographs. Integration of the WiFeS spectrograph is now taking place in the new Advanced Instrumentation and Technology Centre (AITC), with first light on the telescope expected by fourth quarter 2007.

Important milestones have been:

* Completion of the image slicer and coating of the mirrors. The fanned slicer is shown in the clean room in its mounting support in Figure 1. It consists of 25 slices, each fanned to a precise angle, between two thick end plates for structural integrity. Each of these slices will project to a slit on the sky 38 arc sec. long by 1 arc sec. wide, giving a complete science field of 25x38 arc sec. The coatings are from Lawrence Livermore Laboratories, and deliver a peak reflectivity of over 99.4 per cent.

* Completion of optics acquisition for the spectrograph.

* Completion of the mechanical design work, and the manufacture

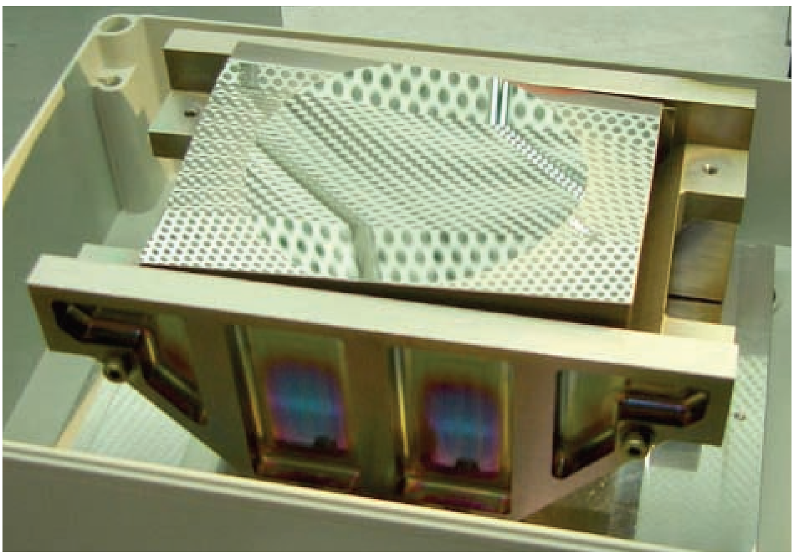


Figure 1, The fanned image slicer is shown in the clean room in its mounting support. The curious optical effect is real, and is a result of the changing slopes of the individual image slicer mirrors reflecting the clean room air filter above the slicer.

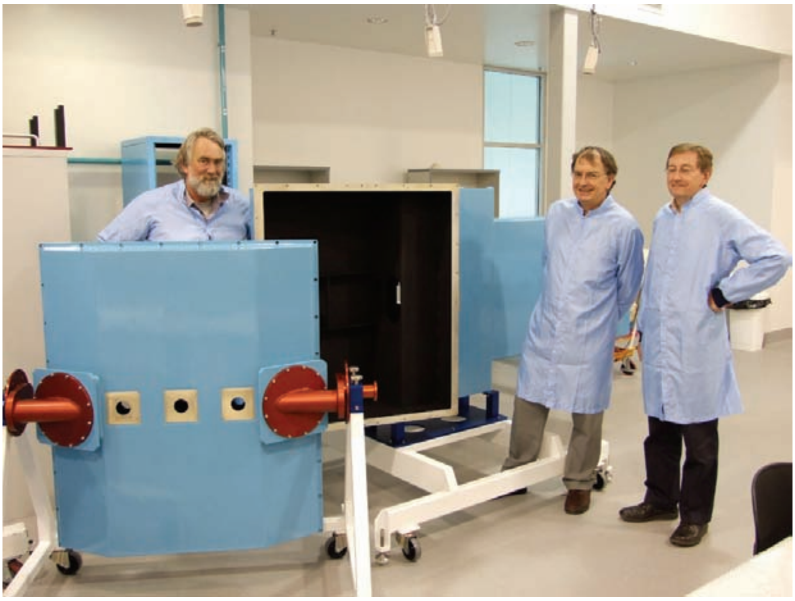


Figure 2. The major structural components of WiFes on their handling dollies in the integration area of the AITC. Left to right: Gabe Bloxham (optics design engineer), Mike Dopita (project scientist) and John Hart (mechanical design engineer).

of the major components. The size of the WiFeS instrument can be judged from Figure 2.

*Funding of the blue camera through an ARC LIEF grant (Chief investigators Mike Bessell & Mike Dopita), with additional support from the ANU Major Equipment Fund, and from the AAO, the University of Sydney, the University of New South Wales, and the University of Queensland. The full blue camera module is illustrated in Figure 3.

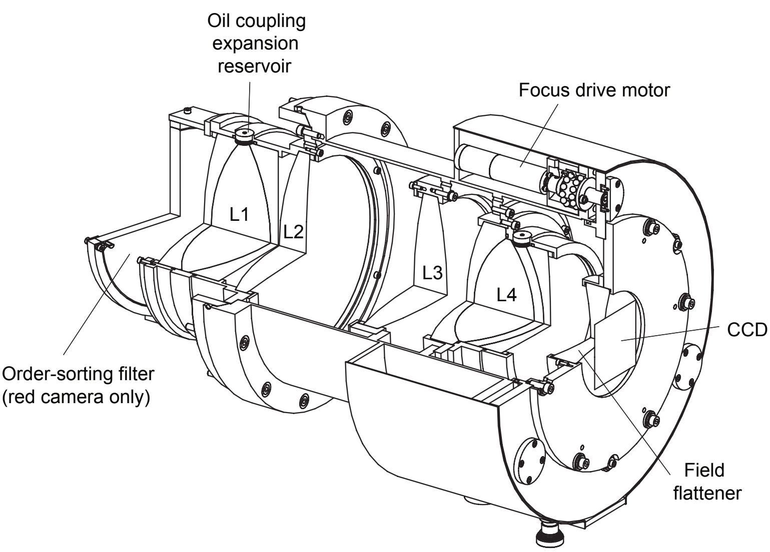


Figure 3. The WiFeS blue camera module design.

SkyMapper Project Report

SkyMapper

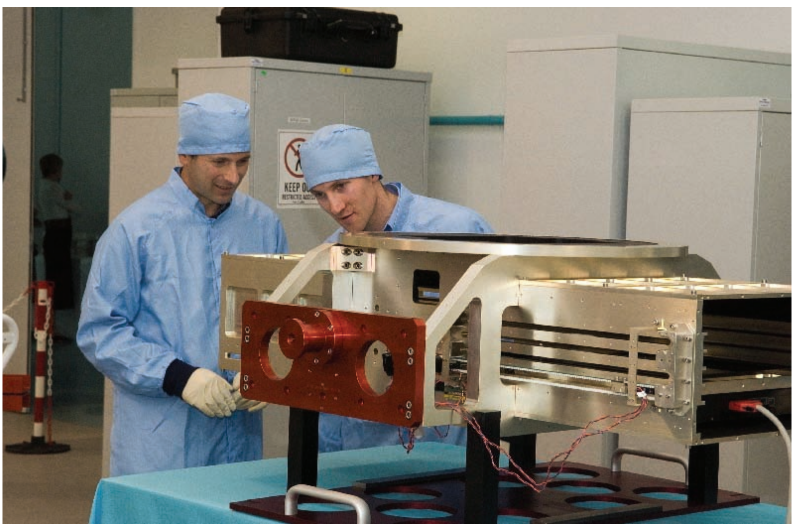
This year saw a continuation of the construction of RSAA's new SkyMapper telescope. SkyMapper is a 1.35 metre diameter telescope to reside at Siding Spring Observatory. The telescope and enclosure are under construction by local industry partners Electro Optic Systems of Queanbeyan, NSW. Matched to the telescope is a new 268 million pixel digital camera designed and under construction by RSAA's technical section.

The design of the telescope enables a patch of sky 5.7 square degrees in size - twenty times larger that the full moon - to be imaged in a single frame. SkyMapper will conduct the Southern Sky Survey, a digital map of the southern sky in six colours. The survey will look for changes in the sky by returning to each position six times during the five year programme.

Major progress in the fabrication of the SkyMapper telescope was made this year. The filter slide assembly has been completed (see Below) along with the telescope mount and truss framework (see Opposite). The primary and secondary mirrors were also completed.

SkyMapper makes use of innovative electronics to control the camera. This new technology is made available through our close links to the instrument development team at the University of Hawaii. These electronics were successfully tested with our camera and will enable us to read out the camera at over 200 megabits per second.

Right: Annino Vaccarella and Andrew Granlund inspect the SkyMapper Cassegrain Imager filter housing in the new AITC assembly space.



Left: The SkyMapper telescope under construction at EOS telescope plant, Tucson, USA.

The dataset from the Southern Sky Survey, 150 Terabytes in size, will be one of Australia's largest publicly accessible datasets. The images of all the stars, galaxies and nebulae in the southern celestial hemisphere as well as a database containing the accurate brightness, colour, position, shape, and variability of each object will be made available to the broader community after data validation.

SkyMapper – To Uncover the Most Distant Quasars

The Southern Sky Survey will find more than a 150 of the most distant objects in the Universe, Quasars, vastly luminous objects powered by central black holes. The study of these most distant objects will tell us when the first stars switched on in the Universe. As the first stars began to shine they heated material surrounding them causing the gas to become ionised. The transition to the predominantly ionised Universe of today depends critically on how the first stars lived their lives. We expect SkyMapper to increase the sample of known distant quasars by a factor of ten.

These objects will be targets for the Low Frequency Demonstrator (Mileura; a facility in which RSAA staff are actively involved).

The Gemini South Adaptive Optics Imager (GSAOI).

Gemini South Adaptive Optics Imager (GSAOI)

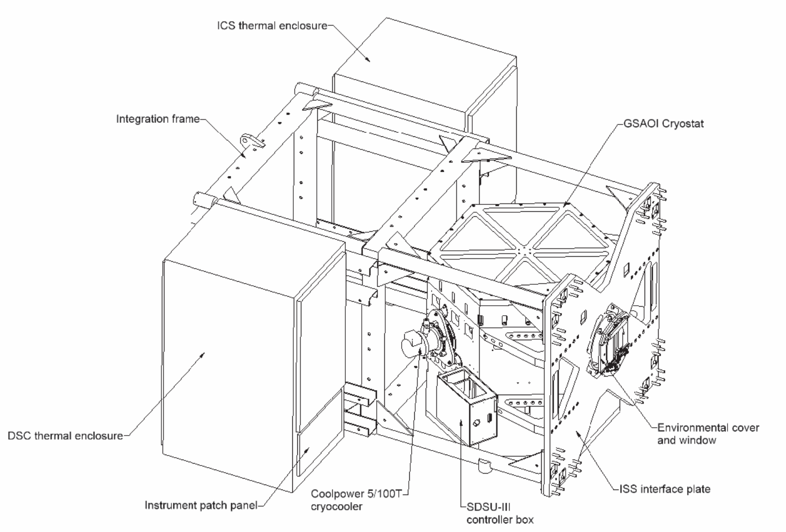
The Gemini South Adaptive Optics Imager (GSAOI) was designed and built at the RSAA by a team of engineers lead by Dr Peter McGregor: Peter McGregor, John Hart, Dejan Stevanovic, Gabe Bloxham, Damien Jones, Jan vanHarmelen, Jason Griesbach, Murray Dawson, Peter Young, and Mark Jarnyk. The multi-million dollar camera was shipped to the eight metre diameter Gemini South telescope in Chile in October 2006.

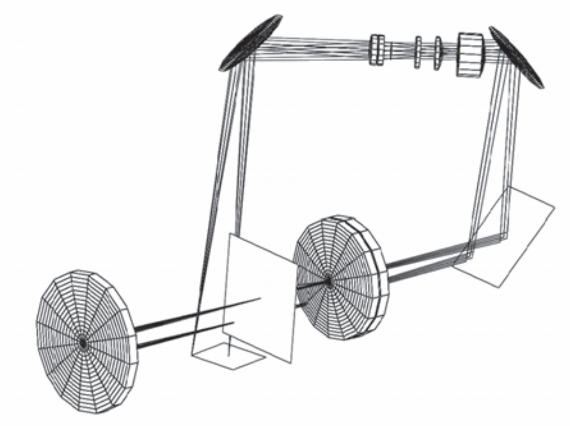
The Gemini 8-m telescopes are designed to achieve unprecedented ground-based image quality using adaptive optics (AO) techniques. This has been demonstrated with Hokupa'a on Gemini North, and with ALTAIR. These are classical AO systems that are restricted in their corrected fields and sky coverage. The Gemini South Multi-Conjugate Adaptive Optics (MCAO) system is being designed to overcome these limitations. MCAO will provide uniform, diffraction limited image quality at near-infrared wavelengths across an extended field-of-view. Useful levels of atmospheric seeing correction will be achieved over a two arcminute diameter field-of-view, the maximum possible with the Gemini telescope design.

MCAO will use three deformable mirrors conjugated to distinct altitude ranges in the atmosphere. These will be driven with commands computed from wave front sensor measurements of five laser guide stars and three natural guide stars.

When fully commissioned, the Gemini South Adaptive Optics Imager (GSAOI) will be the workhorse instrument used with MCAO. GSAOI is a near-infrared, diffraction-limited, imaging system. GSAOI has a single fixed-format camera with 0.02" pixels, designed to match the diffraction limited infrared images produced by MCAO of between 0.03 and 0.06" FWHM.

Right: The GSAOI cryostat, ISS interface plate, integration frame, and thermal enclosures.





Left: The imager consists of the cryostat window, a field lens, and an optical relay system. The Folded layout of the imager is shown here.

GSAOI uses a mosaic of Rockwell detectors with 4080×4080 18 μm pixels arranged in four 2040×2040 quadrants. Thus GSAOI records a square field-of-view 84.7″ on a side. This neatly fits within the 120″ circular field delivered by the MCAO system. The GSAOI optics are stable and have low distortion that will permit high precision astrometric observations, which will be limited in performance only by the stability of MCAO.

GSAOI will address the following diverse science, from studies of nearby low mass stars, to studies of distant forming galaxies including:

- Low mass stellar and substellar mass functions in young star-forming regions such as the Orion Nebula Cluster.
- Stellar population variations in star-forming regions such as Ophiuchus, Corona Australis, and Chamaeleon.
- Open cluster mass functions to the bottom of the H-burning sequence and the end of the white dwarf cooling sequence.
- Mass functions in nearby globular clusters over a range of metallicities.
- Stellar populations of super-star cluster analogs in the Galaxy and Magellanic Clouds such as NGC 3603 and 30 Doradus.
- Missing mass in Magellanic Cloud planetary nebulae.
- Proper motions of Local Group galaxies.
- Stellar populations in dwarf galaxies.
- Stellar populations in starburst regions of nearby galaxies.
- Evolution of dwarf irregular versus elliptical galaxies
- Early chemical histories of nearby galaxy spheroids.
- Colour distributions among extragalactic globular clusters.
- Measuring the bulk motion of galaxies to $cz < 6000$ km/s .
- Spatially resolved spectral energy distributions of high redshift field galaxies.
- Evolution of galaxies in clusters.
- The formation of the disks of disk galaxies.
- Exploring dark energy via high redshift supernovae.

The common characteristic of these programs is that they require extremely deep near-infrared photometric imaging of extended regions. This necessitates high system throughput, excellent image quality, and a uniform PSF over the available field. Many science programs encompass large samples of objects that can be selected to have suitable MCAO.

The Gemini South Telescope in Chile.

The MWA – A New, Low Frequency Radio Telescope

The international consortium building the MIRA Wide Field Array marked 2006 with its official "kickoff meeting" in San Diego in June. The group now includes the RSAA, Massachusetts Institute of Technology, Harvard-Smithsonian Center for Astrophysics, Raman Research Institute, University of Melbourne, Curtin University, University of Tasmania, University of Western Australia, Sydney University and the Australian National Telescope Facility. The award of funding through competitive, peer-reviewed programs through the Australian Research Council and the US National Science Foundation now permits the project to proceed to the final design and build phases.

The MIRA Widefield Array is a novel, low frequency radio array, covering the frequency range from 80 to 300 MHz. Since this band includes a broad selection of communication channels that are heavily used in populated areas of the globe, the MWA is being built in a remote, radio-quiet site in Western Australia.

When complete, the 512 antenna array will focus on three principal scientific areas:

1) The detection and characterization of redshifted 21cm line signals from neutral hydrogen that were emitted during the Epoch of Reionisation that occurred at redshifts beyond 6.5.

2) Performing a wide field search for transient sources of radio emission which is 6 orders of magnitude more sensitive than any previous work in this frequency range.

3) Probing the magneto-ionic medium of the heliosphere with unprecedented precision using interplanetary scintillation (IPS) and Faraday rotation techniques.

Several other scientific topics, such as pulsar studies, solar bursts, the local structure of the interstellar medium, and radio recombination lines, can also be effectively addressed with the array.

The year 2005 saw an MWA on Mileura Station about 200 km west of Meekathara, WA as part of the design and development effort, which included Briggs and Kocz from RSAA. In 2006, there was a hiatus in activity on site, while funding support was put in place. With funding now in place, work packages have been distributed among the partner institutes, and design and prototyping have begun in earnest.

RSAA Scientific Interests in the MWA

At this early stage of the project, RSAA is represented in the science teams by Briggs and Schmidt whose interests emphasise the Epoch of Reionisation science and the opening of a new, long wavelength regime for the detection of celestial "transient events."

The MWA studies of reionisation have a high degree of synergism with the compilation of QSO catalogs that will occur during the Stromlo Southern Sky Survey being performed with the SkyMapper telescope. The luminous high-redshift QSOs that SkyMapper will identify at redshifts greater than 6 are expected to form ionised bubbles in the neutral intergalalactic medium. The signature of these bubbles in MWA observations may be the first precise indicator of just when the reionisation occurred.

RSAA Participation

RSAA contribution to the construction have centred on the design and prototyping of the "field systems," which include the signal processing elements that are distributed throughout the 1.5 kilometre diameter of the array itself. The 512 antenna "tiles" (see photo below) are grouped in clusters of 8 tiles, with each cluster being controlled by a "receiver node" containing power supplies, digitizers, digital filter banks, and transmitters for formatting the digital signal for transmission to the correlator, which is located several kilometres from the antenna array.

At RSAA, Briggs, Waterson, Dawson, Vaccarella, Torr, and Kocz have provided technical support to the design, prototyping and testing of the receiver node components.

The MWA will take shape over the next two years, with science campaigns to perform the key science programs by the end of 2009.

Left: An MWA antenna 'tile' being field tested in the outback of Western Australia.

Student Programme

Graduate Programme

The RSAA Graduate Programme is growing strongly, with 8 new PhD students starting in 2006. Currently (at the end of 2006) 31 students are enrolled. Our very successful astrophysics honours programme continues to attract top students from ANU and from other Australian universities, and many of the honours students choose to stay at RSAA for their graduate work.

As usual, the first year graduate students started their programme with a short research project and lectures on several areas of astrophysics, and then progressed to choose their thesis topics.

Several of our students are involved in collaborations with astronomers outside Australia, and a number of them spent time in 2006 working at institutes in Europe and the US. RSAA encourages these international activities, because they broaden the students' experience and help them to build their own network of international contacts.

Some of these visits are supported by the Alex Rodgers Travelling Scholarships, which are available to students for international trips related to their PhD thesis (e.g. conference attendance or working with overseas collaborators). Mary Williams was the recipient in 2006.

Each year, the incoming student with the best grades is offered the Duffield Scholarship. This is a stipend top-up scholarship, funded from a generous benefaction by Miss Joan Duffield, daughter of the first director of Mt Stromlo Observatory. The 2006 Duffield scholars are Karen Lewis and Emma Kirby. Karen is working with Prof. Penny Sackett on extra-solar planets, while Emma Kirby works with Dr. Helmut Jerjen on aspects of the evolution of galaxies.

Each year a Bok Honours Scholarship is offered to a student studying astrophysics at honours level at ANU. The 2006 recipient of this scholarship was Simon Murphy, who will commence a PhD at RSAA in 2007.

RSAA Graduates & Theses completed in 2006

2006 was a record year for graduations, with the most PhD completed since 1993. Congratulations to the graduates and their supervisors.

Graduate	Thesis	Current Position
Antoine Bouchard	The Evolution of Dwarf Galaxies in Nearby Groups	Observatoire de Lyon, France
Gayandhi de Silva	Chemical Homogeneity in Open Clusters	ESO Fellowship, European Southern Observatory, Chile
Anna Frebel	Abundance Analysis of Extremely Metal-Poor Stars from the Hamburg/ESO Survey	W.J. McDonald Fellow, McDonald Observatory, University of Texas
Marilena Salvo	SN Ia and Cosmology: How good are NS Ia as Distance Indicators?	Disaster Recovery and Business Continuity Planning, Continuity Forum, Sydney
Holly Sims	MHD Simulations of Twisted Magnetic Flux Tubes	
Brandon Tingley	Going from Light Curves to Confirmed Exoplanets	Free University of Brussels

Summer Scholars

RSAA Summer Scholarship Programme

The RSAA Summer Scholarship Programme continued, and we hosted six summer scholars.

Scholar	Home Institution	Supervisor (s)	Project
Aditya Chopra	University of Western Australia	Charley Lineweaver	"The Abundance of the Elements of Life"
Ryan Cooke	Queensland University of Technology	Mike Bessell and Stefan Keller	"Investigating the metallicity of stars"
Shaun Ferris	University of Queensland	Michael Pracy	"A redshift list and analysis of A370"
Brendan Griffen	University of Queensland	Frank Briggs, Helmut Jerjen and Michael Pracy.	"Solving the mystery of Malin I"
Kim Heenan	ANU	Brian Schmidt and Stefan Keller	"Measuring the Light Curves of RR-Lyrae Stars in our Galaxy's Halo"

Sebastian Horvath (Canterbury University) joined our summer scholars during our observatory tour which included The Dish at Parkes, Siding Spring Observatory near Coonabarabran and the Australian Telescope National Facility in Narrabri. We acknowledge our helpful hosts at these observatories John Sarkissian (Parkes), Fred Watson and Peter Starr (Siding Spring) and Philip Edwards (Narrabri).

Right: RSAA Summer Scholar Shaun Ferris inspects "The Dish" at Parkes. Photo: C. Lineweaver

Public Outreach and Events

SSO Open Day

The annual Siding Spring Open Day in October was a great success, with hundreds of people - young and old - visiting the Mountain. The weather was perfect and visitors were treated to tours of the 2.3m telescope, and the 40 inch telescope, as well as getting a good look at the Warrambungle National Park from the site of the new SkyMapper Telescope.

In amongst the tours and their visits to the other facilities on the Mountain, guests were able to eat a sausage cooked up by the lodge staff and listen to the tunes of the Orbital Swing Band, made up of many of Coonabarabran's young musicians.

Left: Open Day 2006. photos Margaret Noy.

Astro Camp 2006

Siding Spring Observatory played host to Astro Camp 2006 in June. This year 60 students from schools including Sydney, Armidale and Mudgee (and others) all learned about astronomy through guided telescope tours, lectures and sun viewing demonstrations.

Left: Astro Camp 2006 students, photo John Goodyear.

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1. Stromlo students past and present who worked with Vince.
2. Explainers and outreach staff who worked with Vince.
3. Astronomers who have been observing with Vince.
4. Vince at work talking to a visiting group.
5. Talking to a dedicated group of visitors on a cold night at the 2.3m.
6. Don Mathewson (Centre) with Vince (above Don) and Don's research group studying galaxy motions, circa 1989. (Also appearing, students: Angela Samuel, Emannuel Vassiliadis, Marcus Buchhorn, Carl Grillmair, and Stuart Ryder, clockwise from left)

Retirement of a Long Serving Observatory Stalwart

Vince Ford (front) and Don Faulkner (back), at the 2.3m telescope control desk, c. 1987.

After more than 40 years of service to the observatories and to astronomy at large, Vince Ford officially retired in November 2006. He will be missed. (Especially as he refuses to sit still!)

Vince served many roles in the life of Mt Stromlo and Siding Spring, scientifically, socially and the very important job of spreading the word about astronomy to the public. He is reknown for his abilty to enthuse young and old about astronomy, with his engaging public talks and demonstrations, and represented us on numerous radio and TV appearances across the country, over many years.

Vince came to Mt Stromlo in 1965, and after helping to start the PASA journal with the article on the globular cluster NGC6266: Gascoigne & Ford, 1967, PASA, Vol 1, page 16, he began a long productive association with Prof. Don Mathewson (retired). With Don and others, Vince co-authored 23 main journal articles from 1970 to 1996, including polarization studies of the Magellanic clouds and the Milky Way, significant work on supernova remnants, and mapping the distances and motions of galaxies in the nearby universe (Including the memorable title: Mathewson, Ford, & Buchhorn, 1992, "*No back-side infall into the Great Attractor*", 389L, 5).

Vince readily became 'the person on the mountain who knew where things were' and kept track of keys to domes and so on. Many will recall the inflatable yellow baseball bat that was kept behind the door, and used for 'enforcement' when the borrowers needed to be kept in line.

The advent of the Visitors' Centre gave full scope to Vince's public persona, playing a key role in the running of the Centre and the full programme of school and public visits. In 1999 he deservedly received the national award: "*The Michael Daley Eureka Prize for Promotion of Science.*"

As if professional astronomy weren't enough, Vince has been a pillar of the Canberra Astonomical Society for many years and shows no sign of letting up, becoming a Life Member of CAS in 2005.

Goon but not forgotten. Thanks Vince.

Staff & Resources 2006

Academic Staff

Director

PD Sackett , BSc Nebr, MS PhD Pitts

Associate Directors

GS Da Costa (Associate Director for Academic Affairs)
PJ McGregor (Associate Director for Instrumentation and Technology)

Duffield Professor

KC Freeman, HonDSc WA, PhD Camb, FAA, FRS

Federation Fellows

MA Dopita, MA Oxford, MSc PhD Manc, FAA
BP Schmidt, BS Ariz, AM PhD Harv

Professors

M Asplund, BSc PhD Uppsala
MS Bessell, BSc Tas, PhD ANU
FH Briggs, BS Swarthmore, MS PhD Cornell
GS Da Costa, BSc Mon, PhD ANU
JE Norris, BSc PhD ANU
PD Sackett, BSc Nebr, MS PhD Pitts

Senior Fellows

GV Bicknell, MSc PhD Syd
WJG de Blok, BSc PhD Groningen
C Jenkins, BSc Witwatersrand, PhD Camb
C Lineweaver, BSc Mun, MA PhD Berk (joint RSES)
PJ McGregor, BSc Adel, PhD ANU
BA Peterson, SB MIT, MS PhD Caltech
PR Wood, BSc Qld, PhD ANU

Fellows

SP Driver, BSc Leics, PhD Cardiff
PJ Francis, BA PhD Camb
H Jerjen, Dipl (BSc MSc) PhD Basel
RS Sutherland, BSc PhD ANU

Research Fellows

A Graham, BSc Monash, PhD ANU
S Keller, BSc Syd, PhD ANU
J Meléndez, PhD, Sao Paulo
D Yong, BA Monash, BSc Monash, PhD Texas

Postdoctoral Fellows

P Allen, MSci Durham, PhD Oxf
J Fischera, Diploma CAO Kiel, PhD Heidelberg
J McSaveney, PhD Canterbury
M Pracy, PhD UNSW
R Salmeron, PhD Syd
A Karakas, PhD Monash
R Trampedach, MSc Arhus, PhD Mich.
P Tisserand, PhD CEA, Saclay

Mark Andrew Jarnyk, 1963 – 2006

We were deeply saddened by the loss of our dear friend and colleague, Mark Jarnyk in January 2006, after a battle with cancer. His contributions to the School and to its staff were large and he'll be greatly missed. He remains a part of us and our work, as signified by a Kurrajong tree planted in his memory in the MSO Visitor Centre garden.

Mark is also remembered by the naming of Asteroid 90564 MarkJarnyk (2004 GJ2), the first numbered discovery from the Siding Spring Survey, in honour of his significant contributions to instrumentation for the Gemini Observatory and the Antarctic JACARA project.

Mark at the South Pole during the JACARA project

Postgraduate Students (* thesis in 2006)

D Bayliss, BSc (Hons)
A Beasley, BSc (UQ), BSc (Hons) ANU
J Blackman, B.Sc (Hons)/B.A. (Adelaide)
N Bonne, BSc Monash, BSc (Hons) ANU
**A Bouchard, BSc MSc Montreal*
E Cameron, BSc ANU
L Campbell, BSc ANU
J Cooper, BSc Latrobe; BSc (Hons) ANU
**G De Silva, BSc Monash*
L Dunn, BSc, La Trobe, BSc (Hons) ANU
D Fabbian, Laurea degree, Padova (Italy)
**A Frebel, BSc Freiburg*
L Godfrey, BSc (Hons), UTas
M Goodwin, BEng (Hons) UWA
S Gurovich, BSc UWS
C Harrison BSc QUT, BSc Hons ANU
W Hayek, Physics, Hamburg
G Kennedy, BTech (Hons), BSc (Hons)
E Kirby, BSc (Hons) ANU
J Kocz, BIT/BE (Hons), ANU
P Lah, BSc ANU
K Lewis, B.Sc (Hons) Murdoch
J O'Brien, BSc Melb
S-H Oh, BSc Yonsei
T Pereira, Physics Eng. (IST/UTL, Lisbon)
S Prior, BA (UQ), BSc (UQ) BSc Hons ANU
J Rich, BSc/BI CQU, BSc Hons ANU
J-A Robles-Martinez, BPhys (Hons) UDLA
**M E Salvo, BSc Padova*
S Sankarankutty, BSc MSc UFRN
V Safouris, BSc Syd
**H Sims, BSc ANU*
L Stanford, BSc ANU
C Thurl, BSc Regensburg; MA Wesleyan
**B Tingley, BA Virginia, MS Mass*
S Walsh, BSc (Hons), Curtin
E Westra, M.Sc. Rijksuniversiteit Groningen
M Williams, BSc/MSc Auckland

Computing Laboratory

Head
P Young, BSc ANU
Engineer
G Hovey, BSc(Hons) , PhD ANU
Programmers
A Czezowski, BSc Warsaw, MSc, PhD
A Green, BEng Hons
J Nielsen, BSc WA, BA Murdoch
W H Roberts, BSc, Grad Dip IT
K M Sebo, BSc WA, PhD ANU
D Smith, BSc (Hons) ANU
A Vaccarella,BSc (Hons) UNSW, MSc UNSW, Grad Dip IT
G Wilson, BSc, PhD ANU

Skymapper Project
T Preston, BIT Canberra, MSE
T Martin-Jones, BA Maquarie, Grad Dip Elect.

Staff 2006

Project Management

J van Harmelen, Drs Delft
L Waldron , BSc (Hons), PhD, MIEAust CPEng, SMIEEE, MAIP
M Petkovic

Mechanical Engineering

Head
J Hart, BE (Mech) UNSW
Engineers
P Conroy, CME CTC
M Doolan, BSc, BE (Hons), PhD
D Stevanovic, BE (Hons), PhD
A Granlund, BEng (Hons)/ BIT

Mechanical Workshop

Workshop Supervisor
C Vest
Instrument Makers
A Cappuccio
J DeSmet
R Tranter

Optical Workshop

Senior Optician
G Bloxham, DAP GIT
Optician
R Zhelem BSc Hons, PhD

Electronics

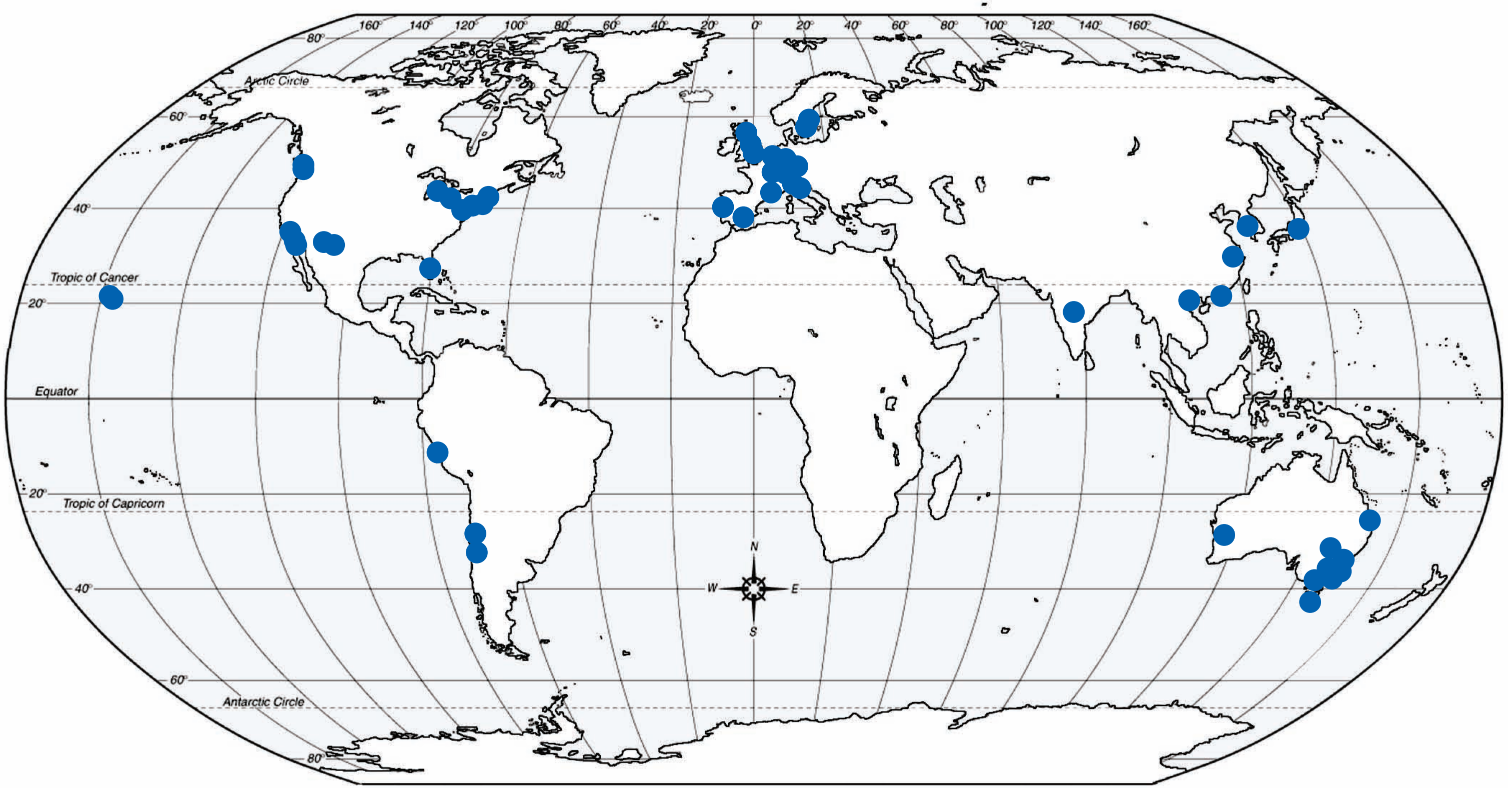
Head
M Dawson, BEng MEng
Engineers
P Oates BA.(Hons), BSc (Hons), MSc, PhD
M Waterson BSEE Colorado, MSc Hawaii
E Kowald, BEEE, MIEEE
Technical Officers
B Keys
A de Gans

Administration Staff

Executive Officer
S Mendes, BAppSc, Technol. Syd, MBA C.Sturt
M McDonald(Acting), BAppSc,USyd, Dip Acc
B Payne
Business Officer
M McDonald, BAppSc,USyd, Dip Acc
Site Manager
M Maloney, BSc
Academic Services Officer
T Gallagher
R Noble
Exec. Assistant to the Director
M Ni Mhordha, BBS DCU
P Thomson
HR Officer
Jo Balban
Development Officer
C Neil
Research Officer
V Ford, BSc CCAE
Purchasing Officers
M Miller
S Maloney, Dip Bus (Adv)
Grants and Finance Officers
A Eichholzer
L Micallef
Site Officer
G Blackman
Asst Site Officer
P Walshe
Gardening (ANU Facilities and Services)
H Coyle
M Sullivan

Siding Spring Observatory Staff

Manager
P Starr, BSc
Research Officers
G Garradd
R McNaught, BSc (Hons), St Andrews
D Burton
Engineer
M Harris, BEng UNSW
Technical Officers
M Callaway
W Campbell, B App Sc, U Canb
J Goodyear, HND BEEng, Edin.
P Weekes
Commercial Officer
M Noy
Maintenance
Phong Nguyen
SSO Exploratory
M Verrender



Staff Travel in 2006

The map shows the destinations for RSAA staff in 2006, for observing, conferences and international collaborations. Some dots represent mulitple visits. This shows clearly how Astronomy is a truly global science, and how widely Mt Stromlo staff and students are known!

Australian Gemini Office

RSAA is host to the Australian Gemini Office. This office is responsible for Australian access to the twin Gemini telescopes: the largest and most powerful optical/IR facilities in which Australia is a partner. It also provides access to time on the Keck and Subaru telescopes, via a time exchange with Gemini. In 2006, Australia started buying time on the twin Magellan 6.5m telescopes in Chile: the Australian Gemini Office supported this too. Dr Paul Francis is the Australian Gemini Scientist and oversees the office.

The Australian Gemini Office has the following roles:

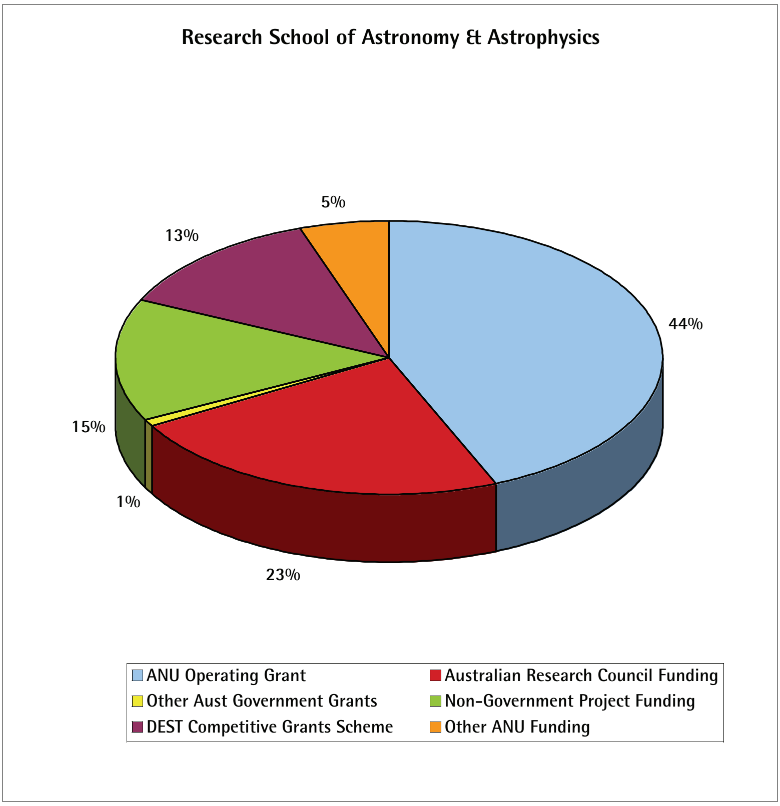
- It supports Australian users of the Gemini, Keck, Subaru and Magellan telescopes. It maintains a web page, handles the proposal submission process, answers user questions, assists users to develop their observing strategies, and advertises the capabilities of these telescopes to the Australian Community.
- It represents the views of the Australian community on a wide range of international Gemini project committees.

During 2006, the office handled 58 proposals to use the Gemini telescopes, 12 proposals to use the Magellan telescopes, 3 proposals to use Subaru and 2 to use Keck. Workshops on how to apply for time on large telescopes were run in Canberra, Sydney, Melbourne and Brisbane. The office represented the Australian community's views at three international committee meetings.

Gemini North, Mauna Kea, Hawai'i (left) / Gemini South, Cerro Pachón, Chile (right) / P. Michaud

School Funding 2006

ANU Recurrent Funding is the single biggest source of RSAA income in 2006, though income received through the ARC Competitive Grants scheme is an increasingly important source of school funds. Compared with previous years, funding from other sources, both government and non-government, has decreased as special instrumentation projects near completion.



Grants

External Grant Funding

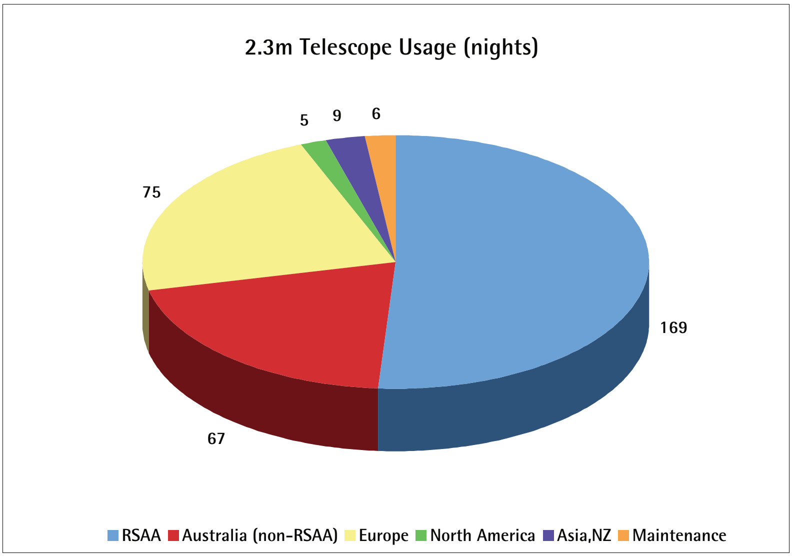
External grant funding in 2006 for the Research School of Astronomy and Astrophysics, principally ARC funding, is summarised in the table below.

Name of Grant	Amount awarded in 2006	Amount awarded for life of grant	2006 Status	ANU Lead Researcher	Funding Body
The Epoch of Galaxy Formation	$283,500	$1,417,500	Ending	Dopita	ARC
The Southern Sky Survey	$90,000	$510,000	Ongoing	Schmidt	ARC
Galactic Archaeology: A Radial Velocity Experiment to Unveil the History of the Milky Way	$180,000	$730,000	Ending	Freeman	ARC
Illuminating the Universe with Exploding Stars	$14,000	$49,000	Ending	Schmidt	ARC
The First Deep Infrared Study of the Nearby Galaxy Population	$100,000	$300,000	Ending	Jerjen	ARC
Star Formation and Gas Consumption in High Redshift Galaxies	$80,000	$260,000	Ongoing	Briggs	ARC
Probing the Universe with Exploding Stars	$100,000	$310,000	Ongoing	Schmidt	ARC
Stellar Abundances as Records of Stellar Nucleosynthesis and Galactic Evolution	$110,000	$567,000	Ongoing	Asplund	ARC
Understanding the Evolution of the Universe	$310,325	$1,551,625	Started	Schmidt	ARC
Feedback Processes in Galaxy Formation	$180,000	$440,000	Started	Sutherland	ARC
Nucleosynthetic Signatures off the First Stars	$190,000	$591,000	Started	Bessell	ARC
The Australian Virtual Observatory	$330,000	$330,000	Started	Schmidt	ARC
Nucleosynthesis Today and Tomorrow	$7,000	$31,000	Started	Wood	Externally led ARC
Nucleosynthesis of Low and Intermediate Mass Stars: A Study into the Origin of the Elements	$84,000	$232,680	Started	Karakas	ARC
Total:	*$2,058,825*	*$7,319,805*			

Telescope Usage

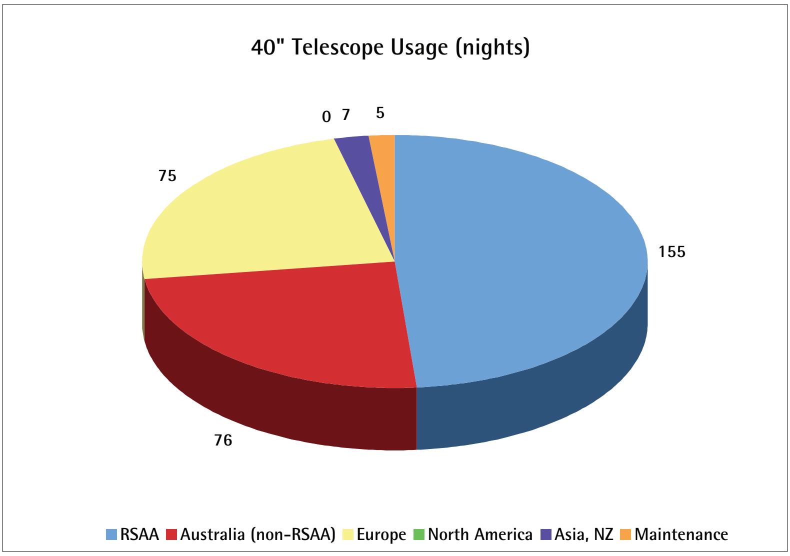
The Research School of Astronomy and Astrophysics allocates time on its telescopes through a peer review process to the national and international astronomical community. The breakdown of the observing nights allocated in 2006, by astronomer's host institution location, is shown in the pie charts below.

2.3m Telescope Nights in 2006



The 2.3m Telescope(Tim Wetherell)

40 inch Telescope Nights in 2006



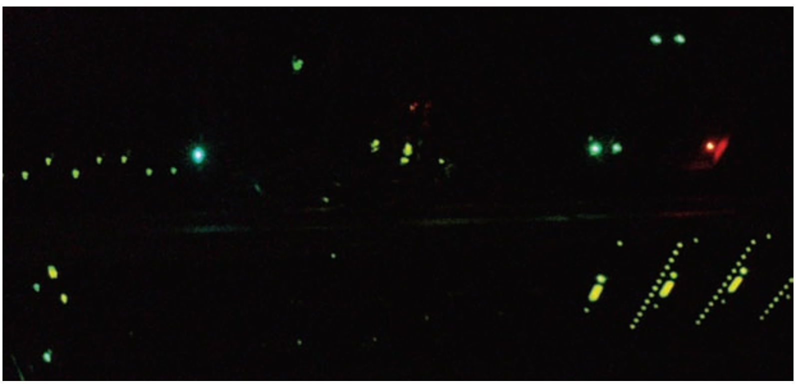
The 40" Telescope (Tim Wetherell)

Computer System Developments

The Computer Section resolved over 1600 problems and questions submitted to the 'sysman' queue during the year. In addition, four new servers and 20TB of additional storage were deployed on Mt Stromlo and several projects to retire old hardware and software were well advanced. Using hardware supplied by ANU DoI, the network was upgraded to 1Gbps and a firewall was implemented.

The communication link between Siding Spring and Stromlo was upgraded to 1Gbps and the computer facilities at the 2.3m and 40" received some much-needed hardware and operating system upgrades.

Above and Below: The main RSAA computing array racks



2006 Publications

Peer Reviewed Journal Publications

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