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PREFACE

This biennial report to the ICSU Committee on Space Research (COSPAR) contains contributions from the wide range of institutions undertaking space related research in Australia. It covers the period from July 2004 to June 2006. The 36th COSPAR meeting will be held 17-22 July 2006 in Beijing, China. The report is available electronically at http://www.science.org.au/natcoms/cospar2006.pdf , with a related report at http://www.science.org.au/natcoms/hayabusa2006.pdf .

Australian institutions active in space research include numerous University groups across Australia, several divisions of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and various government bodies such as the Australian Antarctic Division, Defence Science and Technology Organisation (DSTO), Geoscience Australia, and IPS Radio and Space Systems. The research areas cover the gamut of space science, ranging from studies of the Sun, solar terrestrial interactions, and space weather, to magnetospheric, ionospheric, and atmospheric physics, to Earth observation and associated remote sensing studies, to climate and weather modeling, to planetary sciences and the evolution of the solar system, to space communications and technology, to the outer boundaries of the solar system and space astronomy. Industry is also involved, including companies such as Auspace, Ball Solutions, British Aerospace, Electro Optic Systems, and Genesis Software. This report presents aspects of Australian space activity which the contributors regard as relevant and appropriate to COSPAR. Submissions were sought widely, in an attempt to allow all organizations involved in space research the opportunity to contribute and to more accurately document the breadth of Australian space science.

Significant events in Australian space science during the last two years are numerous. They include: (1) The successful operation of FedSat, Australia's first scientific satellite since the 1960's, by the Cooperative Research Center for Satellite Systems (CRCSS) for 2002-2005 and since January 2006 by the Defence Department, with continuing provision of data to the University and CSIRO partners. (2) Australian members of the Japanese Hayabusa (MUSES-C) spacecraft team helped the spacecraft reach, identify a safe landing site, and land on asteroid Itokawa for its sample-return mission. (3) Completion of the Unwin radar at Invercargill, New Zealand, and its successful operation with the similar Bruny Island radar to form the Tasman International Geospace Environment Radar (TIGER) system, within the international SuperDARN network. (4) An international team, including Australian scientists, has NASA's Solar Terrestrial Relations Observatory (STEREO) ready to launch from Cape Canveral in mid 2006, in order to study the Sun, solar wind, and space weather effects on the Earth's environment and human technology. Many additional scientific accomplishments are described in the report below.

Australia's space science community is developing its first Decadal Plan for Space Science. Its objectives are to build a more cohesive community with widely agreed scientific and technological objectives and a set of projects and facilities to accomplish them, that leverage existing Australian capabilities and expertise to produce major international advances that benefit Australia and the global community.

I thank all contributors, both individuals and organizations, for their efforts and Jeanette Mill and the Academy's National Relations Office for combining these contributions into this report.

Professor Iver Cairns,
Chair,
National Committee for Space Sciences,
Australian Academy of Science.

AUSTRALIAN ANTARCTIC DIVISION

Space and Atmospheric Sciences (SAS)

The Australian Antarctic (Mawson, Davis and Casey) and sub-Antarctic (Macquarie Island) stations continue to provide a platform for the projects listed in Table 1. This work supports research programs of the Australian Antarctic Division (part of the Federal Department of the Environment and Heritage), Australian Government agencies and Universities and the international community. The SAS program conducts research and monitoring studies in 'middle atmosphere' and 'space weather' in line with Australia's Antarctic Science Program Science Strategy 2004/5-2008/9 (http://www.aad.gov.au/default.asp?casid=13950). The goals within that strategic plan of most relevance to the group are, *To Understand the Role of Antarctica in the Global Climate System* and *To Undertake Work of Practical, Economic and National Significance*.

Understanding the Role of the Antarctica in the Global Climate System

The role of the mesosphere in atmospheric energy transport is not well understood and the Antarctic polar vortex is of particular interest. Its break up in the southern spring and the role that this plays in global climate is of particular importance to the Australian Antarctic program. A suite of instruments have been developed and deployed at the Australian Antarctic base, Davis, to study mesospheric phenomena including temperature and wind profiles, polar stratospheric and noctilucent clouds, polar mesospheric summer echoes and atmospheric ozone depletion and aerosols. The instruments include a Rayleigh and Doppler Lidar, an MF radar, Czerny-Turner and Fourier transform I/R spectrometers for hydroxyl airglow measurements, a Fabry-Perot spectrometer and a VHF radar installed in the Austral summer of 2002-3. Results reported here relate only to projects where the Australian Antarctic Division staff are lead authors.

Specific Results

The MF radar at Davis continues to gather high quality wind data from the height range 70-100 km. In combination with similar systems spaced around the Antarctic continent, but at similar latitudes, Davis data is being used to develop our understanding of waves in the stratosphere and MLT, their interactions and their coupling from above and below. Analysis of concurrent radar (MLT) and superpressure balloon (lower stratosphere) gravity wave observations made possible by a Franco-Australian collaboration (RAV) will give unprecedented insight into vertical coupling. The extraction of information on the 'non-migrating' tide in the Antarctic MLT has been extended to finer time scales than previous studies. Investigations that show a long-period modulation of these tides are providing insight into wave-tide interactions and the sources of this form of tidal variation. This technique is being applied to the 8- and 24-hour tides (as well as the 12-hour, which has been the subject of previous studies and publications).

The 55 MHz atmospheric radar 'spaced antenna' mode observation with its full power output of 120 kW of transmitted power following its upgrade over the 2004-05 summer. Observations of meteor trails and lower atmosphere winds continued. Two complete seasons of Polar Mesosphere Summer Echoes (PMSE) observations above continental Antarctica were recorded using the VHF radar at Davis during the 2004-05 and 2005-06 summers. Other first time observations were: interhemispheric comparison of PMSE intensity observed between Davis (68.3S) and Andenes (69.0N); southern hemisphere observation of polar mesosphere winter echoes (PMWE); and southern hemisphere coincident observation of PMSE and lidar polar mesosphere clouds (PMC). Several papers on the observations of PMSE are in preparation. Mesopause region temperatures measured at Davis (hydroxyl rotational temperatures) have shown that the Antarctic mesopause region was generally significantly warmer than usual, well before the occurrence of a stratospheric warming (~September 23rd 2002) and this severely disrupted the spring ozone depletion. Russian colleagues re-established an Electric Field Mill (EFM) at Vostok and data were collected during 2004. An upgraded EFM was manufactured and deployed at Vostok in February 2005 and a new combined EFM and Air-Earth Current Meter system was deployed there in early 2006 after field testing inland of Casey the previous austral summer. The research has demonstrated that seasonal variations in the global electric circuit are consistent from year-to-year and that these

variations are broadly consistent with expected seasonal variations in global thunderstorm activity. An analysis of the extensive modern Vostok electric field data set has shown that a previously reported variation associated with heliocentric current sheet crossings that had been postulated as the signal of a sun-weather association is incorrect.

The Rayleigh lidar at Davis observed the dust cloud from the disintegration of a small asteroid in the middle stratosphere during September 2004. This event was reported in Nature and provided the first direct lidar measurement of meteoritic dust. It allowed studies of aerosol transport, the effect of aerosols on stratospheric ozone and climate and the dynamics of the polar atmosphere and proved a useful test of atmospheric circulation models. Lidar observations of Polar Stratospheric Clouds, in concert with high resolution radiosonde and ozonesonde data are being used to investigate the action of gravity waves on cloud formation and ozone chemistry. As noted above the lidar measurements during the 2005/06 summer contributed to the first simultaneous detection of PMC and PMSE from a southern hemisphere site. These phenomena are a sensitive indicator of conditions in the mesopause region, and their measurement is providing new information of inter-hemispheric asymmetry in the climate of the upper atmosphere.

Research of Practical, Economic and National Significance

The Australian Antarctic Program has a long and proud history of research in upper atmosphere and cosmic radiation physics. This research has continued with the thrust aimed at understanding space weather phenomena better and to contribute toward usable forecasting models. Much of the observational component of this program has been automated and the responsibility for the data and its archiving has been passed to the Ionospheric Prediction Service (IPS), both for predictive use and as a world data centre, and to Geoscience Australia. Similarly, much of the research is conducted by Australian universities and the Antarctic Division operates the equipment on their behalf. Results reported here relate only to projects where the Australian Antarctic Division staff are lead authors.

Specific Results

The program of automation of data collection at all bases continued. Standard Riometer, Fluxgate Magnetometer and Magnetic Pulsations experiment logging produces daily data files that are transferred back to IPS Radio and Space Services in Sydney who receive the data in their capacity as a World Data Centre. These systems also send back smaller amounts of data every five minutes, which are used by IPS for ionospheric forecasting. A data collection system records digital all sky camera images from all stations. These automated systems can be controlled and interrogated from the Australian Antarctic Division Head Office in Kingston with minimal interaction from station personnel. Instruments operated were: Fluxgate Magnetometers at Casey and Davis; Induction Magnetometers at all stations; Wide Angle Photometer at Davis; 30 MHz Riometers at all stations; All Sky Imaging Systems at all stations (the Mawson camera failed in 2005 and has not been replaced). Casey magnetometer data is now collected remotely and processed by the Geomagnetism Section of Geoscience Australia. The previously reported communications and other interference caused by the digital ionosonde (DPS-4) following its move to Davis were resolved by the incorporation of a limited number of notch filters. The DPS-4 now operates satisfactorily but can be switched off if necessary for emergency radio communications or when aircraft are operating in the area. The Davis DPS-4 data set has now reached sufficient maturity to warrant the development of an experimental ionosphere convection model using five years of E- and F-region vertical and horizontal drift velocity records. Hence the main emphasis for the last year has been the processing of raw data records to produce bins of velocity data, in readiness for the development of the first southern hemisphere polar cusp region ionospheric convection model. A comparison between the proposed Davis ionosphere convection model (using ionosonde drift velocity measurements) and the latest international ionosphere electric-potential convection models (using ground-magnetometer and space-particle measurements) will then be possible. The Davis DPS-4 was modernised during the 2005-06 summer with the introduction of new embedded computers and the introduction of the latest version of analyses software. The cosmic ray laboratory at Mawson houses an 18 counter super neutron monitor 3 surface high inclination muon telescopes and 4 underground muon telescopes. It is the only surface and underground muon observatory at polar latitudes in either hemisphere. Research has continued with further

development of Ground Level Enhancement (GLE) analysis, in particular the development of alternative particle acceleration modelling. It has been demonstrated that at least two different acceleration mechanisms were responsible for the relativistic particles that reached earth during the Bastille Day 2000 event. The largest GLE in almost 50 years was observed on 20 January 2005. It had an extremely soft spectrum and so was only observed at moderate to high magnetic latitudes. The background radiation level was observed to increase by up to a factor of 55 (at the high altitude South Pole station). Although this is larger than any single increase observed in the February 1956 GLE, in this earlier GLE the spectrum was extremely hard and was observed worldwide and with higher sea level responses. Further advances in determining the geometry of the CME driver plasma from muon observations were achieved and may help in future Space Weather forecasting. A new study of the radiation doses at aircraft altitudes was initiated. It was shown that the model techniques currently used to estimate doses did not account for transient cosmic ray modulation. In particular the models overestimate the dose during Forbush decreases (which is acceptable) but more critically do not account for the increase during a GLE which, in a worst case event, could attain the annual dose limit for the general public in a single long duration, high altitude, polar flight. Further study to improve the dose estimates is continuing.

Table 1: **Experiments in the Australian Antarctic Program showing location and collaborating agencies.**

Experiment	*Casey*	*Davis*	*Mawson*	*Macquarie Island*	*Other*	*Research Agency*
Cosmic Ray Neutron Monitor			***X***		*Kingston Tasmania*	*AAD*
Cosmic Ray Surface Muon Telescope			***X***		*Kingston Tasmania*	*AAD, Shinshu U, Nagoya U*
Cosmic Ray Underground Muon Telescope			***X***		*Liapootah Tasmania (closed Mar 06)*	*AAD, Shinshu U, Nagoya U*
30 MHz Riometer	**X**	**X**	**X**	**X**		*IPS*
Fluxgate Magnetometer	**X**	**X**				*IPS, GA,*
Magnetic Absolutes	**X**		**X**	**X**		*GA (via Comms)*
Induction Magnetometer	**X**	**X**	**X**	**X**	*Zhongshan Station*	*Newcastle U, AAD*
Digital All-sky Imagers	**X**	**X**	**closed 2005**	**X**		*AAD, IPS*
Ionosonde	**X**		**X**	X		*IPS*
Digital Portable Sounder		***X***				*AAD, La Trobe U, IPS*
Satellite Scintillations		–		–		*La Trobe U, AAD (<2005)*
Total Electron Content	**X**	**X**	**X**	**X**		*GA, La Trobe U (auto)*
VLF/ELF Radio Receiver	***X***					*BAS*
SHIRE Imaging Riometer		**X**				*Newcastle U, U Maryland, AAD*

MFSA 2MHz Radar		**X**				*Adelaide U, AAD*
MST Radar		**X**				*AAD, Adelaide U*
55 MHz Meteor Radar		**X**				*Adelaide U, AAD*
33 MHz Meteor Radar		**X**				*Adelaide U, AAD*
Fabry-Perot Spectrometer		**X**				*La Trobe U*
Czerny-Turner Spectrometer		**X**				*AAD*
Scanning Radiometer		**X**				*U West. Ontario, AAD*
Fourier Transform I/R Spectrometer		**X**				*AAD, U West. Ontario*
3 Channel Photometer		**X**				*La Trobe U, AAD*
2 Channel Photometer		**X**				*AAD*
Electric Field Mill/Air Earth Curent Meter					*Vostok*	*AAD*
UV-B		**X**				*Arpansa*
TIGER SuperDARN Radar					*Bruny Is Tasmania*	*La Trobe U, AAD, IPS, BAS, Newcastle U, Monash U, DSTO, RLM*
Lidar		**X**				*AAD, Adelaide U*
Ozone Sondes		**X**				*AAD, BoM*

Publications
This publication list comprises all papers from 2004 to early 2006 having an Australian Antarctic Division author or using Australian Antarctic Division data from the Space and Atmospheric Sciences program.

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AUSTRALIAN NATIONAL UNIVERSITY
Planetary Science Institute

ANU has a distinguished history in the Planetary Sciences. Within the Research School of Earth Sciences, geochemical and geophysical research has focussed on the Earth as a planet including its role in our own solar system, as well as the mechanistic aspects of what makes this planet work in terms of its structure, driving forces for plate tectonics, and the unique aspects that make Earth suitable for life. We are continually faced with the question of whether Earth is unique in terms of the myriad aspects that make it the way it is. A recent development at the ANU's Research School of Astronomy and Astrophysics is a programme in exoplanet research. These studies allow the Earth to be placed in a planetary context throughout the galaxy. At this stage, the planets being found are large and eccentric and it will be some time before we can gain insights into smaller terrestrial-style planets. The joint interests at RSES and RSAA have led to the formation of the Planetary Science Institute (PSI), a jointly funded initiative between the two schools. The concept is to develop cross-disciplinary research programs between astronomers and geoscientists, and new expertise in planetary systems.

Topics of current interest include:

• the nature of exo-planetray systems and what are the requirements of making any of these systems habitable.

• mechanisms by which protoplanetary nebulae accrete into planetary systems.

• source materials and the processes that have affected elemental abundances in planetary objects and the chemical state of the elements (e.g. from oxygen fugacity).

• isotopic systems in the earliest solids from the solar nebula (refractory inclusions found in the most primitive meteorites) in terms of early solar system chronology and thermal structure of the nebula.

• isotopic systematics of presolar grains that incorporate a great isotopic diversity of components of stellar nucleosynthesis.

• chemistry and isotopes systematics of lunar samples and meteorites to better understand the formation and evolution of the Moon, Mars, and asteroids.

• numerical modelling to produce synthetic planets on computers. The incorporation of physical data from Earth allows the development of self-consistent models for the evolution of planetary interiors and the testing of such models through current geophysical and geochemical observations.

• the earliest vestiges of the Earth in Western Australia (oldest detrital zircons) and Greenland (oldest rock sequences) to elucidate conditions on Earth's surface at these ancient times.

• development of analytical methods for samples returned to Earth from space missions, including Genesis (solar wind), Stardust (comet), Hayabusa (Asteroid Itokawa), as well as ongoing research on the Apollo lunar samples.

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Space Plasma, Power and Propulsion Group

The Space Plasma, Power and Propulsion (SP3) Group (http://prl.anu.edu.au/SP3) is situated in the Australian National University's (ANU) Research School of Physical Sciences and Engineering (RSPhysSE) and is involved in fundamental space plasma physics as well as the research and development of electric propulsion (EP) for spacecraft applications.
The group, led by Professor Rod Boswell, has had an ongoing collaboration with the European Space Agency (ESA) since 2004 and has signed a Space Act Agreement with the National Aeronautics and Space Administration (NASA).

The portion of the group dedicated to space science comprises 5 academics and 4 students.
In 2005 SP3 achieved two significant milestones in its EP thruster development program with the successful firing of both the Helicon Double Layer Thruster (HDLT) in May (http://prl.anu.edu.au/SP3/research/HDLT/recent) and the Dual Stage Four Grid (DS4G) Ion Thruster in November (http://prl.anu.edu.au/SP3/research/SAFEandDS4G), both at ESA's test facility in the Netherlands. The success of these tests has lead to a continuation of contract being signed in 2006 for further testing in May 2006.

These developments follow on from the group's 2001 - 2004 collaboration with NASA's Advanced Space Propulsion Laboratory (ASPL) on the VASIMR VX-10 plasma rocket concept.
In the period from 2004 – 2006, the group continued its work on electric double layers (DL) and plasma instabilities with further experimental studies and a theoretical program encompassing both analytical and computation models. This work has attracted the involvement of French, Dutch, Austrian and local Masters and PhD students as well as research collaborations with UC Berkeley and the University of West Virginia in the US, Ecole Polytechnique de Paris and the Université Paul Sabatier in France, Eindhoven University of Technology in the Netherlands, Dublin City University in Ireland and Tromso University in Norway.

Dual Stage Four Grid (DS4G) Ion Thruster

The Dual Stage 4 Grid (DS4G) ion thruster is a new concept in spacecraft propulsion for interplanetary missions (http://prl.anu.edu.au/SP3/research/SAFEandDS4G). A prototype was successfully tested in November of 2005 at ESA by a team of scientists led by the ANU. Under contract to ESA, the experimental ion engine was developed and manufactured at the ANU in 4 months by a small team lead by Dr Orson Sutherland. The work is based on a 5-year development program in the related but disparate field of focused ion beam nano-milling.
The new computer-designed ion optic developed specifically for the DS4G allows much higher voltages to be used in the extraction of ions from a plasma source than with conventional gridded ion thrusters (GITs). The DS4G was tested in a large space simulation chamber at the ESA technology centre (ESTEC) in the Netherlands with a beam energy of up to 30kV resulting in an ion exhaust velocity of 210km/s, over four times higher than what current state-of-the-art devices can achieve. It is anticipated that the system can be run up to a 70 kV beam energy.
This increased plume velocity results in order of magnitude improvements in propellant usage efficiency, beam power and thrust density making possible heavy payload missions to Mars (including crewed missions) and the outer planets. The system would also be suitable for satellite missions to the Kuiper Belt and beyond into the Precursor Interstellar Medium.

Helicon Double Layer Thruster (HDLT)

The SP3 group has developed the first prototype of the Helicon Double Layer Thruster (HDLT), a radically different space plasma engine for interplanetary travel (Mars) and attitude control of earth orbit satellites, in collaboration with the CRC for Satellite Systems and AUSPACE and funded by a DEST Innovation access grant. In April 2005, a test campaign of the HDLT prototype was carried out in a space simulation chamber at the European Space Agency science and technology centre (ESTEC, Netherlands). The HDLT is simple, has no moving or degradable parts, no electrodes

and no need for a neutraliser. Its advantages are high fuel and power efficiency, increased lifetime, simplicity, scalability and safety, making it a very attractive candidate for deep space travel.

It is a new type of magneto-plasma thruster and its advanced concept is based on a recent discovery by Dr Christine Charles of a current-free electric DL in an expanding plasma: these behave like a pair of virtual electrodes and rapidly accelerate ions to supersonic speeds thereby generating thrust. The energy and profile of the supersonic plume have been studied in depth. An extensive experimental study of current-free double layers in expanding plasmas is being carried out in parallel with the development and testing of the HDLT prototype. Recently, a small space simulation chamber was built and set up by the SP3 group to resume testing of the HDLT in Australia.

Electric Double Layers – Fundamental Research

Electric double layers exist in the plasma environment of the earth and the stars and can cause phenomena as diverse as aurorae, luminous draperies in the polar sky, and electromagnetic radiation from rotating neutron stars called pulsars. In March 1999, Dr Christine Charles discovered such a double layer in the laboratory plasma systems at the ANU and measured the energy of the highly supersonic ions it had accelerated. In addition to optimising this effect to create a very efficient thruster for interplanetary spacecraft, the Australian SP3 team and its various collaborators in the USA, and in Europe have been developing a theory, based on analytical and numerical models, to explain the underlying physics of the current-free DL phenomenon. It has also demonstrated the possible role of current-free electric DL's in heating ions in the magnetic funnels of the solar corona.

The large area ion beam downstream of the double layer can also be used for surface functionalisation, in particular for the development of proton exchange fuel cell components (used as onboard spacecraft for power generation).

Plasma Instabilities – Fundamental Research

The SP3 group has been investigating both low and high frequency (1 kHz – 50 MHz) instabilities in magnetised plasmas for a number of years. The primary aim of this research has been to discover the flow of energy in basic wave and wave/particle phenomena and is of equal importance for both the space physics and the fusion physics communities. Important areas of research involve multi-wave decay processes, wave-particle heating and beam/plasma interactions. Wave types that have been of particular interest include pressure-gradient driven Ion Acoustic and Whistler pumped Ion Cyclotron waves. These wave phenomena have been identified as possible pathways for energy transfer to ionospheric ions. More recently instability phenomena have been measured in association with the current-free DL and this continues to be an active field of research.

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Spatial measurements of an ion beam emitted from a double-layer
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IEEE Transactions on Plasma Science **33**, 334-335 (2005)

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COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANISATION (CSIRO)

INTRODUCTION

CSIRO, Australia's largest scientific and engineering research organisation, carries out R&D work under the terms of the Science and Industry Research Act 1949. The Act notes that CSIRO has a responsibility to carry out research that:

- assists Australian industry;
- furthers the interests of Australian community;
- contributes to the national objectives or international responsibilities of the Commonwealth; and
- responds to any other purpose determined by the responsible Minister.

Although not a space agency per se, CSIRO has a long recognised the relevance of space science and technology to its "core business", summarised above. Accordingly, CSIRO maintains an active space research program, particularly in the fields of earth observation; space-related engineering; and radioastronomy.

The **CSIRO Office of Space Science and Applications – COSSA** was established in December of 1984, to coordinate and further develop R&D in space related science applications and engineering. The unit is currently headed by Dr. Alex Held and located at the Earth Observation Centre based in Canberra, and its primary roles are:

- National and international representation of CSIRO and Australian interests in Earth Observation, and associated space science
- Strategic planning and coordination of new research partnerships
- Brokering of technology transfer and interdisciplinary project development on behalf of Earth Observation teams across CSIRO

COSSA is a member of the Australian Government Space Forum. Internationally, the Head of COSSA, Dr. Alex Held, is the national focal point for the Committee for Earth Observation Satellites – CEOS, and for the United Nations Regional Space Applications Programme for Sustainable Development in Asia and the Pacific – RESAP.

COSSA is a member of the Australian Delegation to the Intergovernmental Group on Earth Observation – GEO. The COSSA unit currently administered through the CSIRO Division of Marine and Atmospheric Research, which has a Research Stream in Canberra and Headquarters in Hobart, Tasmania.

EARTH OBSERVATION

Within CSIRO, almost 70 staff are involved in earth observation research, across 7 Divisions (Marine and Atmospheric Research, Land and Water, Mathematics and Information Sciences, Sustainable Ecosystems, Exploration and Mining, Forestry and Forest Products, Livestock Industries). Where possible, COSSA assists these teams with better access to new satellite data streams and represents their interest at various national inter-agency and international committees.

Calibration and Validation Activities

CSIRO has been engaged in an international activity to provide calibration and validation data from carefully selected field sites for compariosn with satellite measurements. The primary goal of the work is to establish a set of ground-truth radiation measurements that can be used to verify

satellite measurements, and be used for intercomparions with climate model simulations. One of the primary sites used by CSIRO is a site called Tinga Tingana in Australia's center Strzelecki Desert Loc: (S29.0, E139.75). The site is well characterised as being one of the brightest desert targets in Australia (r~0.35) and with most uniform target over time on a 1+ km scale (cv<2% over large areas). For close to 10 years CSIRO has undertaken continuous aerosol characterisation at this site.

In 2002, several CSIRO Divisions took part in NASA's EO-1 Science Validation activities, in particular for the 'Hyperion' hyperspectral sensor on-board this technology-demonstration satellite. A number of field calibration campaigns with a range of field spectroradiometers were undertaken, in particular to Lake Frome, and an agricultural site called Colleambally. The project was coordinated by Dr. David Jupp at the EOC, and he has prepared a full report on this activity available on the COSSA website [www.COSSA.csiro.au]. In part due to this experience and a long interest in imaging spectroscopy applications, CSIRO undertook a consultancy for a Japanese consortium headed by Itochu Corporation, to design and establish the commercial market for a hyperspectral satellite called " Hyper-X. At the time of this writing, Japan and international partners are in discussion about the timing and funding of this mission.

NASA Deep Space Network

CSIRO is responsible to NASA under a cooperating agencies agreement for the operation of the Canberra Deep Space Communications Complex located at Tidbinbilla. This complex, as one of the three in the global network, featured in supporting the successful Mars missions in late 2003 and early 2004. The Parkes radio telescope was added to the network for this period to support the tracking of the large number of spacecraft.

Common AVHRR Processing Systems (CAPS)

The Common AVHRR Processing System (CAPS) is a suite of platform-independent software that has been developed to provide uniform base processing (calibration and navigation) of AVHRR data at all Australian reception and distribution sites.

The CSIRO science working group CAPS continues to establish "best practice" approaches to process AVHRR data. The approach is to reduce redundant algorithm development; to increase scientific return on investment; to ensure that those who develop useful algorithms are appropriately acknowledged; to assure greater scientific integrity; and to make provision for easier re-processing in the event of improvements to algorithms.

The CAPS project has been funded by COSSA, and the CSIRO Division of Marine and Atmospheric Research, in close cooperation with Australian Bureau of Meteorology. The use of this processing system at all Australian AVHRR stations will ensure that common formats, products, and archives will be applied to all data sets. Research programs and applications across CSIRO requiring data have already begun using CAPS time-series data from Australian AVHRR stations.

CSIRO has participated in the geophysical validation of sea surface temperature as derived from infrared satellite sensors such as AVHRR, MODIS and AATSR instruments launched on NASA, European, and Japanese satellites respectively. Radiometric instruments have been developed and deployed on vessels in three coordinated programs. One is a joint project with the Australian Institute of Marine Science that uses a tourist ferry which makes daily trips to the Outer Barrier Reef, the second uses a passenger ferry between Fremantle and Rottnest Island, and the third, based in Hobart, is a joint program with the Bureau of Meteorology, and uses the 3 Hobart-based research vessels (Franklin, Southern Surveyor, and Aurora Australis). Both radiometric and bulk SST data have been collected on a regular basis for comparison with the satellite-derived products. The extensive data sets collected are also aiding in air-sea interaction and climate-related studies.

SeaWiFS and MODIS Data Reception

The CSIRO Division of Marine and Atmospheric Research has maintained a reception capability of ocean colour data from well as MODIS data from the Terra and Aqua satellites, via the Hobart, Tasmania X-Band receiving station (TERSS) SeeWiFS data ais acquired primarily for the Indian Ocean through through a Perth-based receiving station (WASTAC). The full data set within the range of the Hobart and Perth stations are being archived for use in climate, fisheries, and terrestrial applications programs.

The Tasmanian Earth Resources Satellite Station (TERSS) in Hobart continues to receive satellite-data. The receiving station was wholly Australian designed and built. Dr David Griersmith from the Australian Bureau of Meteorology now heads the operating board responsible for the management of the facility. Dr. Alex Held, Head of COSSA is a member of the TERSS board, as well as the Western Australian Satellite Technology and Applications Consortium (WASTAC) board.

Near Real-Time Satellite Data Delivery

In 2002, members of the CSIRO Division of Land and Water, implemented a system called 'Sentinel Hotspots' intend to showcase the utility of satellite image products deliver in a time-critical manner to emergency managers. The system was officially launched to the Australian public by Australia's science minister just days before the devastating January 2003 fires in South Eastern Australia. The system proved extremely popular, and is currently being expanded to provide additional information of other emergencies such as flooding, toxic algae and oil spills. In early 2005, the system was further operationalised and transferred to computers operated by Geoscience Australia as a regular wildfire spotting and tracking service [See: www.sentinel.ga.gov.au]. A larger, multi-hazard system with similar functionality and webGIS delivery called 'Sentinel Asia' is currently being implemented in the region under the Auspices of the 'Asia Pacific Space Agency Forum [www.aprsaf.org] .

ATSR-2 and AATSR

CSIRO continues to be a major user of ATSR data for both marine and land surface applications. Algorithms are continually improved and developed for the derivation of land and sea surface temperatures and for climate research applications. The AATSR Science Plan is well advanced and involved significant input from CSIRO.

INTERNATIONAL REPRESENTATION

CEOS Working Groups and Plenary

Dr Alex Held, Head of COSSA is expected to be the Australian CEOS (Committee on Earth Observation Satellites) Plenary representative in November 2004. Australia hosted the November 1996 Plenary. CSIRO strongly supports its continuing role as CEOS Member, and will continue to enthusiastically support scientists attending and actively developing CEOS Working Groups and Tasks.

GEO and Earth Observation Summits

Drs Held and Raupach have attended the Earth Observation Summit I (July 2003) and GEO-3 (February 2004) in Washington and Cape Town, respectively. Together with the Australian Bureau of Meteorology, COSSA–EOC will continue to represent Australian government's interests in this international coordination activity.

Asia-Pacific Space Agency Forum

Dr. Alex Held is the Australian representative at this annual forum which was established in 1993 in response to the declaration adopted by the Asia-pacific International Space Year Conference (APIC) in 1992, to enhance the development of each country's space program and to exchange views toward the future cooperation in space activities in the Asia-Pacific region. APRSAF has been holding annual meetings initiated jointly by MEXT/JAXA, and co-host organizations to discuss current space-related issues and possible cooperation among countries mainly from the Asia-Pacific region. APRSAF intends to ensure wider participation of space agencies, government officials, regional and international organizations and institutions responsible for applying space technology, as well as space agencies from outside the region and private sectors as observers.

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Australia Telescope National Facility

Huygens Probe January 2005

On 14 January 2005 ESA's Huygens probe descended on to the surface on Saturn's moon, Titan. During the descent a global VLBI array of radio telescopes, including Australian radio telescopes at Parkes, Hobart, Ceduna and Mopra, tracked the trajectory of the probe. During the descent to Titan, the data gathered by the Huygens probe's on-board science package was transmitted to the Cassini spacecraft which stored then re-transmitted the data back to Earth. The VLBI experiment, which was coordinated by the Joint Institute for VLBI in Europe (JIVE), directly observed the carrier signal of the transmission from Huygens to Cassini. The VLBI experiment pinpointed the exact location of the probe during its descent. When combined with measurements of the Doppler shift of the carrier signal also measured at Green Bank and Parkes, the "Doppler Winds Experiment" which was coordinated by JPL, this allowed the full three-dimensional trajectory of the descent to be re-constructed. Titan has an appreciable atmosphere and the probe's parachute was caught by the winds which proved to be much stronger than expected. The VLBI observations allowed a direct measurement of the wind speeds through a cross-section of the atmosphere. As the signal from Cassini was very weak, the experiment depended critically on having at least one large telescope in the array. At the start of the experiment this role was filled by the 100-m GBT; a few minutes after Titan set at the GBT, it rose at Parkes which tracked it for the rest of the experiment.

Deep Impact

On July 4 2005 NASA's Deep Impact spacecraft collided with comet Tempel 1. Observations of the gas and dust ejected after the impact provided a unique probe of the comet's constituents. The Parkes radio telescope of the ATNF was used to search for the characteristic signal at 18 cm wavelength from the OH molecule, while the ATNF's Compact Array and Mopra radio telescopes were used to search for the HCN molecule which is a tracer for a range of Carbon-based compounds. The OH molecule was detected at a weak level at Parkes in data averaged over the

three days after the spacecraft impact. Upper limits were obtained from the non-detections in the Compact Array and Mopra data. A paper describing the results has been submitted to Monthly Notices.

Australian shares in the International Academy of Astronautics "Laurels for Team Achievement Award" for 2005 which was awarded to the VLBI Space Observatory Programme Team

The International Academy of Astronautics (IAA) has given its "Laurels for Team Achievement Award" for 2005 to the VLBI Space Observatory Programme (VSOP) Team. The Award was made to an international group of 15 scientists and engineers, and presented on 16 October at the 56th International Astronautical Congress in Fukuoka, Japan. The radio astronomy satellite HALCA carrying an 8-m radio telescope was launched by ISAS from Kagoshima on 12 February 1997 to participate in VLBI observations with arrays of ground radio telescopes across the world. Radio telescopes from 14 countries contributed observing time to the VSOP mission. The IAA citation notes that the technique of Very Long Baseline Interferometry has enabled the longest astronomical wavelengths to be used to produce the highest angular resolution images. VSOP realized the long-held dream of radio-astronomers to extend those baselines into space. The award highlighted the astronomers and engineers who made key contributions to realizing, and operating, a radio telescope bigger than the Earth. The Team included astronomers and engineers from Japan, Australia, Canada, the USA and Europe.

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COOPERATIVE RESEARCH CENTRE FOR SATELLITE SYSTEMS (CRCSS)

The following report is the Executive Summary from the Final Report 2005/2006 of the Cooperative Research Centre for Satellite Systems.

In spite of its closure on 31 December 2005, the CRC for Satellite Systems has an impressive list of achievements over its eight years of operation.

FedSat has continued to perform very well since its launch from Tanegashima on 14 December 2002, and reached its design lifetime three years later. At the *FedSat* Research Outcomes Symposium conducted on 14 December 2005 in conjunction with our last Research Panel meeting, significant research outcomes from the *FedSat* mission in space physics, satellite communications and satellite systems research were presented. These research outcomes are summarized in the CRCSS Final Report. Prominent among the achievements were:

- Construction, launch and three years operations of *FedSat*, the first satellite built in Australia in more than thirty years
- World's first microsatellite capable of operating in Ka band
- World's first demonstration of self-healing space computers
- Two data and messaging systems supplied for foreign satellites, with one already in orbit
- Over seven hundred research papers, theses, conference presentations and technical reports, with sixty percent being refereed and twenty one percent with a co-author outside the Centre
- Forty seven research degree completions, of which thirty seven were PhDs: twenty two more completions are anticipated by the end of 2007
- Over $7M in competitive research grants achieved, and over $4M in in-kind contributions received from external research collaborators
- Total in-kind contributions from CRCSS participants and collaborators exceeded contracted total by nine percent.

Well before the third anniversary of the *FedSat* launch it became apparent that *FedSat* was showing little degradation in performance. Extensive discussions with colleagues in the Department of Defence led to a proposal for the Commonwealth to assume responsibility for *FedSat* in January 2006 and to fund the continuing operation of *FedSat*. The then Minister for Defence, Senator the Hon. Robert Hill, announced the new arrangements in December 2005. The Cooperative Research Centre for Satellite Systems is grateful to the Department of Defence for continuing to make this valuable piece of research infrastructure available to Australian and international researchers. *FedSat*'s peaceful scientific objectives have been preserved in these arrangements.

We are also grateful to the Japan Aerospace Exploration Agency (JAXA), who generously provided the launch of *FedSat* and assisted greatly through the launch campaign.

In order to maximise the use of *FedSat* scientific data, agreement was also reached with the Australian Government IPS Radio and Space Services to archive the data on its World Data Centre, These data are now available to researchers, on application through the University of Newcastle.

Our international profile was maintained by our involvement in several prominent space related activities, including significant participation in the Twelfth Asia Pacific Regional Space Agencies Forum held in Japan in October 2005. The CRCSS co-hosted, with JAXA, the Eleventh session of the Forum, held for the first time in Australia, at Canberra in November 2004. The CRCSS was also strongly represented in the Australian delegation to the return to flight launch of NASA's space shuttle Discovery in July 2005. Nationally, we have participated in scientific, technological and policy debates relating to space, including two members – the Chief Executive, Professor Andrew Parfitt, and Centre Manager Jeff Kingwell – in the Space Science Policy Advisory Group

established by Senator Grant Chapman, Chair of the Government Members' Committee for Industry and resources.

In late 2004, we commenced a number of pilot projects intended to support and initiate activities that might continue beyond the life of the Centre. These have been spectacularly successful. In particular:

- Trials of a new satellite network technology for broadband communications with potentially significant cost savings to rural and remote communities demonstrated the improvements available over existing approaches, and may lead to new business opportunities with internet service providers offering applications to the bush.
- Work on ground infrastructure for global navigation satellite systems (GNSS) applications, particularly in preparation for the new Galileo system, continued to gain support from state governments. A national representative body, the Australian Galileo Joint Undertaking (AGJU) was formed to take over from the CRCSS as the point of contact with the EU in coordinating access to Galileo technology for research and development.
- Research in UAVs, undertaken as part of the Centre's pseudo-satellites program, has led to the funding of the Australian Research Centre for Aerospace Automation, funded by industry and government.

The Centre has met all of its performance targets and has left Australia with a significant knowledge base in space research as well as a legacy of highly trained PhD and Masters graduates. While Australia's future in space is uncertain, the Centre has demonstrated that an internationally significant effort can be mounted with Australian capability to address its space needs. It is regrettable that those needs, and our reliance on space for maintaining our prosperity and security, have not yet been identified as a national priority.

We would like to express our thanks to all participants, stakeholders and supporters of the Centre for their contributions over the Centre's life.

Professor Andrew Parfitt
Chief Executive Officer

The Hon. Tony Staley
Chair of the Governing Board

GEOSCIENCE AUSTRALIA
Geospatial and Earth Monitoring Division

Remote Sensing Science and Strategy Project Activity Report – July 2006

Oil Seeps & Signatures in Australian Coastal Waters

The appearance of slicks is a regular occurrence in synthetic aperture satellite imagery of Australian Coastal waters. There are several causes of slicks, with the slicks created by the presence of natural oil seeps of particular interest to Geoscience Australia. The presence of naturally occurring oil seeps is one source of information used in identifying areas with some pot retail for recoverable oil and gas reserves. The slick identification work at Geoscience Australia is currently focussed on the separation of slicks caused by natural oil seeps from other known sources of slicks.

Terrain Surface roughness mapping

The development of wind risk models is a current research activity at Geoscience Australia. Knowledge of terrain surface roughness is an important input into the development of the models. The use of optical and SAR imagery, primarily Landsat, is being used to generate the terrain surface classes required by the models. These classes include cleared land, forested areas, and urban regions. Guidelines are being prepared for the production of continental coverage terrain surface maps.

Development of atmospherically corrected near real time MODIS imagery

ACRES has recently made a significant enhancement provided MODIS image data products. The MODIS product range now includes atmospherically corrected imagery generated with the MOD09 software code supplied by the NASA Earth Observing Systems Direct Readout Laboratory. The generation of atmospherically corrected products greatly improves the results from multi temporal and cross sensor analysis of MODIS imagery.

Sentinel Hotspot detection System

The Sentinel bushfire monitoring system is now hosted by Geoscience Australia after nearly three years as an R&D demonstrator project, providing a very valuable service to the fire management community.
The system was jointly developed by the CSIRO Land and Water, Geoscience Australia and Defence Imagery and Geospatial Organisation (DIGO) following the severe bushfire season of 2001-02. The main feature of the Sentinel System is the near real time hotspot data generated from the MODIS sensors on the TERRA and AQUA spacecraft. This data is generated at Geoscience Australia's remote sensing data acquisition facilities in Alice Springs. A project to validate the hotspots mapped in the Sentinel system has commenced. The sources of validation include field based observations from Fire Management Authorities and comparison with image data from other satellite sensors such as ASTER and NOAA AVHRR.

Water Quality Monitoring

RSSS staff are using Landsat and MODIS imagery to map the distribution of elevated sediment level resulting from dredging activities at the Hay Point terminal in Queensland. The satellite imagery is a timely low cost source of data suitable to map the extent of elevated sediment levels associated with the dredging activity. The results from the satellite based sediment mapping will be compared with field data being acquired during the dredging activities.

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IPS RADIO AND SPACE SERVICES
Department of Industry, Tourism And Resources

Ionospheric monitoring, modelling and mapping

IPS operates and analyses data from a ground-based network of ionospheric monitoring sites to provide data in near-real-time (hourly intervals) and archival data at five-minute intervals. Real-time data are obtained from Vanimo, Pt. Moresby, Darwin, Townsville, Learmonth, Brisbane, Norfolk Is., Mundaring, Canberra, Camden, Hobart, Macquarie Is., Scott Base, Casey, Davis and Mawson. A new ionosonde station was opened at Niue (19.1ºS 169.9ºW, Dip -37.8º) on 31 October 2004.

All ionograms recorded are analysed automatically and the data are used to generate real time ionospheric regional and global maps that are available on the IPS Web site (http://www.ips.gov.au). The data are used as the basis of a variety of on-line real time space weather services. The ionograms are available by ftp from the IPS World Data Centre Internet page.

IRI-2001 is now used for tasks such as on-line total electron content (TEC) maps (http://www.ips.gov.au/Satellite/2/2; http://www.ips.gov.au/Satellite/2/1), and as the ionospheric profile for numerical ray tracing for simulation tasks (e.g. HF radar propagation).

A near real-time ionospheric TEC model for the Australian region is currently being developed using hourly GPS data from the Geoscience Australia network of GPS receivers. The near real-time ionospheric TEC model will be used to monitor the ionosphere for both ionospheric research applications and calibration information for GPS users and for other space geodesy techniques. The model uses a grid-based algorithm and Kalman filter to estimate vertical TEC values. In parallel with the TEC model development, a detailed study into ionospheric variability in the northern Australian / equatorial anomaly region is being undertaken jointly with Department of Defence. This study aims to understand the source of ionospheric variability and improve modelling of TEC gradients in this region.

The range of ionospheric conditions was specified for the proposed Australian Square Kilometre Array (SKA) radio telescope site at Mileura, Western Australia. This included ionospheric TEC conditions, ionospheric scintillation conditions, the prevalence of large scale ionospheric phenomena, and the effects of anomalous ionospheric regions such as the Equatorial Anomaly (Equatorial Electrojet), and the South Atlantic Anomaly. The report contributed to a larger proposal by the CSIRO promoting the Mileura site for the SKA.

In cooperation with the Australian Antarctic Division, wide beam riometer observations continue to be collected at Macquarie Island, Casey, Davis and Mawson, along with cosmic ray data from Mawson, to support space weather services. These data were also used with data from SHIRE (Southern Hemisphere Imaging Riometer Experiment) to investigate the relationship between Polar Mesospheric Summer Echoes (PMSE) and Cosmic Noise Absorption.

Geomagnetic pulsations

The IPS magnetometer network (Darwin, Townsville, Culgoora, Canberra, Hobart) samples at 1 second intervals and is used to produce estimated K-indices and "pc3-indices" for the Australian region. Pc3-indices are the root-mean square values of the component data filtered over the Pc3 pulsation period range (10-45 seconds) and scaled by a factor of 10. Both types of indices are used to generate on-line real-time contour maps, which indicate the levels of geomagnetic activity for the associated period ranges. Magnetograms and time series index plots are produced from the data, with the indices being used as alerts for adverse space weather conditions. Alerts include early warnings of very large geomagnetic field rates of change.

Magnetic Data

In collaboration with the Kyushu University Space Environment Research Centre (SERC), IPS has hosted magnetometers at Hobart, Camden (Sydney), Culgoora (Narrabri, NSW), and Townsville. These are part of a larger array spanning the 210 magnetic meridian. The data are collected by SERC and IPS as part of their respective space weather monitoring systems. The data are used for real-time monitoring and modeling of the global 3-dimensional current system and the ambient plasma density so as to forecast the electromagnetic and plasma environment changes in geospace.

IGRF-10, the latest version of the International Geomagnetic Reference Field is used as the reference field for calculating polarisation coupling loss for HF radio propagation through the ionosphere in the software ASAPS v5.1 and v5.2 (Advanced Stand Alone Prediction Service). It is also used stand alone for calculating gyro-frequencies and ionosonde magneto-ionic component separation.

Solar observations at Culgoora, NSW

The radio spectrograph at the IPS Culgoora Solar Observatory, near Narrabri, records solar emission from 18 MHz to 1.8 GHz. The data are available from the IPS Web site (www.ips.gov.au).

The Learmonth Solar Observatory, WA

The Learmonth Solar Observatory (22S, 114E) on North West Cape, Western Australia, is jointly managed by IPS and the US Air Force Weather Agency. Continuous automated H-alpha patrol is accomplished with on-site human analysis and digital archive. The H-alpha data are supplemented by photospheric magnetograms (longitudinal component), and daily manual white light sunspot analysis. All data products and a selection of H-alpha images are available from the IPS website (solar section, www.ips.gov.au).

Continuous solar radio observations are made on eight discrete frequencies (245, 410, 610, 1415, 2695, 4994, 8800, and 15400 MHz) and from 25 to 180 MHz with a swept frequency solar radio spectrograph. These data are archived digitally at a cadence of one second for the fixed frequencies and every three seconds for the spectrograph scan. The spectrograph data are available on the website at the real-time cadence, and the fixed frequency data at reduced (1-minute) cadence. Radio burst analysis messages are also available in near-real time on the website.

Geomagnetic data are collected from total field (proton precession) and component (fluxgate) magnetometers run in cooperation with Geoscience Australia. These data are available within 5 minutes of collection. Ionospheric data are collected at half hourly intervals from a University of Massachusetts Lowell DGS-256 ionosonde.

Several international research experiments are hosted on-site. These include a station of the GONG helioseismic network (hosted for the US National Solar Observatory), that also provides real-time magnetograms and white-light images. Other monitors include a high time-resolution magnetometer (STEL Magnetic Meridian 210 Network) from the Solar Terrestrial Environment Laboratory of Nagoya University. Since 2003 a small aperture telescope with megapixel CCD camera has monitored Near Earth Objects in collaboration with the Space Watch Program of the University of Arizona.

World Data Centre for Solar-Terrestrial Science

The IPS World Data Centre (WDC) continues to provide long sets of ionogram and solar radio spectrograph and magnetic variometer data. Data are available for on-screen viewing (www.ips.gov.au). The WDC is also the local SuperDARN data archive.

New datasets include NewMag magnetometer data from the Australian FedSat micro-satellite (http://www.ips.gov.au/World_Data_Centre/1/5) and Newcastle University, and the Southern Hemisphere Imaging Riometer Experiment (SHIRE) data from Davis, Antarctica (http://www.ips.gov.au/World_Data_Centre/1/6). Both these have on-line summary plot facilities.

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LA TROBE UNIVERSITY - DEPARTMENT OF PHYSICS

1. Introduction

The Space Physics Group at La Trobe [http://www.latrobe.edu.au/www/physics/space/space.htm] conducts research in Solar-Terrestrial Physics. The group consists of staff and students from the Departments of Physics and Electronic Engineering and the research program is a major area of focus for both departments. The research team is led by Prof Peter Dyson in Physics and A/Prof John Devlin in Electronic Engineering. Over the period of this report, staff included Dr Mark Conde, Dr Roman Makarevich, Dr Murray Parkinson, Dr Robert Norman and Mr Theo Davies in Physics and Mr Jim Whittington and Dr Harvey Ye in Electronic Engineering. The program has also involved over 15 graduate PhD and masters students and Honours undergraduate students who have completed research projects.

The Group conducts research in Solar-Terrestrial Physics in the areas of the behaviour and interactions of the ionosphere, magnetosphere, thermosphere and mesosphere. It also conducts research into properties of radio wave propagation in and through the ionosphere and plasmasphere and applies the results to practical communications and surveillance systems. New ionospheric radars and optical instruments are designed, developed and deployed at sites in Australia, Antarctica and New Zealand. Experimental programs involve observations of the ionosphere, plasmasphere, thermosphere and mesosphere at mid and high latitudes using ionospheric radars, satellite transmissions and optical spectrometers. Theoretical and modeling programs involve the development of ray tracing and inversion techniques applicable to research sounders and radars and, to applications in surveillance techniques and communications.

2. Research Facilities

2.1. TIGER (Tasman International Geospace Environment Radar)
[http://www.tiger.latrobe.edu.au]

Unwin TIGER radar at Awarua Station near Invercargill, NZ (courtesy M. Gentile)

TIGER radar at Bruny Island, Tasmania, Australia. (composite picture with skyscape of aurora over Tasmania. Courtesy D. Ratcliffe

The Group leads a consortium comprising Australian universities (La Trobe, Monash, Newcastle) and government departments (Australian Antarctic Division, DSTO ISR Division and IPS Radio and Space Services that has built and operates the two TIGER radars and operates them.

TIGER consists of two HF radars, one located at Bruny Island, Tasmania and the other, named Unwin, at Invercargill, NZ. Both radars are operated remotely from La Trobe. The Bruny Island radar began operations in November 1999 and Unwin in November 2004.

The radars look towards Antarctica and are designed to have overlapping footprints in order to map ionospheric motions by observing ionospheric scatter.

The radars also detect meteor echoes and backscatter echoes from the sea and so are also used to study mesospheric winds and the sea state.

As well as conducting stand-alone campaigns and experiments, TIGER also operates as a component of the Super Dual Auroral Radar Network (SuperDARN) [http://superdarn.jhuapl.edu/]. As TIGER is located more equatorward than the first series of SuperDARN radars it is able to routinely observe sub-auroral processes not observed by most of the other SuperDARN radars.

2.2. Fabry-Perot Spectrometers

FPS at Davis (courtesy P. Nink)

Large Fabry-Perot Spectrometers are used to observe airglow and auroral emissions in order to determine neutral winds and temperatures in the mesosphere-thermosphere region. Instruments have been located at high latitudes (Mawson and Davis, Antarctica) and mid-latitudes (Beveridge, Australia) for a considerable number of years. Over the austral summer of 2003/04 a new FPS designed by Mr Theo Davies was installed at Davis, replacing an older instrument. The new instrument operates autonomously and has greater sensitivity than the instrument it replaced. Its performance is monitored from La Trobe and operations can be programmed remotely. The basic observing mode of this instrument is similar to our previous instruments in that observations are made by pointing a periscope sequentially through a set of directions, usually N, S, E, W and zenith.

A new sky-imaging FPS, designed by Dr Mark Conde, is under construction for deployment at Mawson over the 2006/07 austral summer. Each observation by this instrument will produce images of the wind and temperature fields across the sky above the station. By comparison with the old instrument that it will replace at Mawson this new FPS will provide a very significant advance in our ability to map the details of wind and temperature fields both in space and time.

2.3. FedSat GPS

La Trobe's research with FedSat has been conducted as part of program of the Cooperative Research Centre for Satellite Systems. The GPS receiver on FedSat provided information on the Total Electron Content (TEC) along ray paths from the FedSat orbit (about 800 km altitude) to GPS satellites (at about 20,200 km altitude). Since the FedSat GPS receiver detects signals simultaneously from several GPS satellites, tomographic images of the electron density in the upper ionosphere and plasmasphere can be constructed by combining all the TEC measurements obtained along a segment of the FedSat orbit. Since FedSat is well above the peak density of the ionosphere, FedSat tomographic images reveal the structure of the plasmasphere in much more detailed than tomographic images obtained using several ground stations because the density at the peak of the F2 layer dominate the ground based images whereas this is not so for FedSat images because FedSat is always well above the F2 layer peak height.

2.4. Digital Ionosondes

A Lowell DPS-4 digital ionosonde is located at the Bundoora Campus near Melbourne and is currently operated only for specific projects.

The Australian Antarctic Division Lowell DPS-4 digital ionosonde at Casey Antarctica is used for projects in collaboration with Dr Ray Morris, AAD.

3. Research Progress[1]

3.1. Progress in Radio Ray-tracing in the Ionosphere.[4.2]

In an invited paper the theoretical basis of ray-tracing, as part of the construction of an approximate solution of Maxwell's equations was discussed. In this approach rays can be seen as arising as characteristic curves of a partial differential equation for the phase of the wave. If carried through in detail, this approach leads to an additional phase shift that has been discussed in previous papers. Methods of efficiently calculating field strength, doppler shift and absorption of the waves were discussed, based on a variational formulation. Some history of the evolution of ionospheric radio ray tracing was also given. Numerical and analytic or closed form ray-tracing were contrasted, and guidance given on the choice of appropriate technique in a particular application. Finally, some possible useful extensions of the ray-tracing approach were discussed.

3.2. Medium Scale Travelling Ionospheric Disturbance.[4.3]

Seasonal and diurnal variations in the direction of propagation of medium-scale travelling ionospheric disturbances (MSTIDs) have been investigated by analyzing sea echo returns detected by the TIGER SuperDARN radar at Bruny Island. A strong dependency on local time was found, as well as significant seasonal variations. Generally, the propagation direction has a northward (i.e. equatorward) component. In the early morning hours the direction of propagation is quite variable throughout the year. It then becomes predominantly northwest and changes to northeast around 09:00 LT. In late fall and winter it changes back to north/northwest around 15:00 LT. During the other seasons, northward propagation is very obvious near dawn and dusk, but no significant northward propagation is observed at noon. It is suggested that the variable propagation direction in the morning is related to irregular magnetic disturbances that occur at this local time. The changes in the MSTID propagation directions near dawn and dusk are generally consistent with changes in ionospheric electric fields occurring at these times and is consistent with dayside MSTIDs being generated by the Lorentz force.

3.3. Ionospheric Response to the Severe Magnetic Storm on 22 September 1999.[4.5]

The evolution of the ionospheric effects of the 22 September 1999 magnetic storm were monitored over the eastern Australian region by measuring the ionospheric Total Electron Content (TEC) using seven Global Positioning Systems (GPS) stations. The main ionospheric effect of the storm were: a long lasting negative storm effect at mid-latitudes; strong, positive disturbances at auroral latitude regions during the storm's main phase; a storm-induced equatorward that caused a positive disturbance that moved from high to mid-latitudes; a daytime poleward movement of a region of depleted plasma that caused temporary suppression of the equatorial anomaly during the start of the storm recovery phase; and prompt penetration of eastward electric fields to ionospheric altitudes and the occurrence of nearly simultaneous TEC enhancement at all latitudes.

3.4. Magnetic local time, substorm, and particle precipitation-related variations in the behaviour of SuperDARN Doppler spectral widths.[4.7]

Super Dual Auroral Radar Network (DARN) radars often detect a distinct transition in line-of-sight Doppler velocity spread, or spectral width, from <50ms-1 at lower latitude to >200ms-1 at higher latitude. They also detect a similar boundary, namely the range at which ionospheric scatter with large spectral width suddenly commences (i.e. without preceding scatter with low spectral width). The location and behaviour of the spectral width boundary (SWB) (and scatter boundary) and the open-closed magnetic field line boundary (OCB) are thought to be closely related. The location of the nightside OCB can be inferred from the poleward edge of the auroral oval determined using energy spectra of precipitating particles measured on board Defence Meteorology Satellite Program (DMSP) satellites. Observations made with the Halley SuperDARN radar (75.5° S, 26.6°

[1] Primarily edited paper Abstracts

W, geographic; -62.0°Λ) and the Tasman International Geospace Environment Radar (TIGER) (43.4° S, 147.2° E; -54.5°Λ) were used to compare the location of the SWB with the DMSP-inferred OCB during 08:00 to 22:00 UT on 1 April 2000. This study interval was chosen because it included several moderate substorms, whilst the Halley radar provided almost continuous high-time resolution measurements of the dayside SWB location and shape, and TIGER provided the same in the nightside ionosphere. The behaviour of the day- and nightside SWB can be understood in terms of the expanding/contracting polar cap model of high-latitude convection change, and the behaviour of the nightside SWB can also be organised according to substorm phase. Previous comparisons by others with DMSP OCBs have proven that the radar SWB is often a reasonable proxy for the OCB from dusk to just past midnight. However, the present case study actually suggests that the nightside SWB is often a better proxy for the poleward edge of Pedersen conductance enhanced by hot particle precipitation in the auroral zone. Simple modeling implies that the large spectral widths must be caused by ~10-km scale velocity fluctuations.

3.5. Digital HF Radar Development.[4.10,15,16,17, 26]

This program aims to develop a fully digital radar for space weather investigations, based on Field Programmable Gate Array (FPGA) technology. The new radar will replace analogue electronics in the existing Tasman International Geospace Environment Radar (TIGER) in Tasmania. The new radar will be sixteen times more sensitive and provide precise measurements of the arrival direction of echoes. Because it is a digital system it will be very flexible in operation allowing new definitive experiments to be undertaken, such as the potential to detect ocean wave heights and surface winds.

The basic digital techniques to be used have been applied to similar radio systems in astronomy and general communications, however there are problems specific to HF radar development. For example, accurate synchronisation between transmit and receive signals is essential, adding a significant level of complexity compared with similar radio systems (e.g. in radio astronomy). Also, a wide range of input frequencies are required for frequency agile radars and this means that filtering of image frequencies is extremely challenging. Thus, novel approaches must be used to overcome introduced images whilst keeping the pulse response matched between twenty receivers. A conceptual design for the new radar has already been developed and tested in the laboratory, various modules are under development.

This new digital radar system will ensure the Australian TIGER group remains a leader in upper atmospheric science and environmental remote monitoring systems. Such enhanced space weather capabilities will support two specific Australian national programs: the JORN the over-the-horizon radar system and IPS Radio and Space Services space weather monitoring activities. Due to its inherent reconfigurability through implementation in reprogrammable microchip technology, this digital, integrated radar will find application in many different HF communication tasks.

3.6. Ionosphere dynamics during the 31 March 2001 severe magnetic storm.[4.18]

The effects of the 31 March 2001 severe magnetic storm on the Southern Hemisphere ionosphere were studied using ground-based and satellite measurements. The prime goal was to track ionospheric responses from high-to-low latitudes to obtain a clearer understanding of storm-time ionospheric changes. The study used a combination of GPS Total Electron Content (TEC) observations, ionosonde data, and data from satellite instruments on DMSP, TOPEX and ACE. A chain of Global Positioning System (GPS) stations near the 150° E meridian was used to give comprehensive latitude coverage extending from the cusp to the equatorial region. A tomographic inversion algorithm was been applied to the GPS TEC measurements to obtain maps of the latitudinal ionospheric structure during this severe magnetic storm period, enabling both the spatial and temporal response of the ionosphere to be studied. It was found that a strong density enhancement occurred at mid-latitudes at 11:00 UT on 31 March 2001 that was followed by an equatorward propagating large-scale Travelling Ionospheric Disturbance. The tomographic reconstruction revealed quasi-wave formations extending finger-like to higher altitudes. The most pronounced ionospheric effects of the storm occurred at high- and mid-latitudes, where strong positive disturbances occurred during the storm main phase, followed by a long lasting negative

storm effect during the recovery phase. Relatively minor storm effects occurred in the equatorial region.

3.7. Interhemispheric asymmetries in the occurrence of magnetically conjugate sub-auroral polarisation streams.[4.18]

Earthward injections of energetic ions and electrons mark the onset of magnetospheric substorms. In the inner magnetosphere (L ~4), the energetic ions drift westward and the electrons eastward, thereby enhancing the equatorial ring current. Wave-particle interactions can accelerate these particles to radiation belt energies. The ions are injected slightly closer to Earth in the pre-midnight sector, leading to the formation of a radial polarisation field in the inner magnetosphere. This maps to a poleward electric field just equatorward of the auroral oval in the ionosphere. The poleward electric field is subsequently amplified by ionospheric feedback, thereby producing auroral westward flow channels (s). In terms of electric field strength, AWFCs are the strongest manifestation of substorms in the ionosphere. Because geomagnetic flux tubes are essentially equi-potentials, similar AWFC signatures should be observed simultaneously in the Northern and Southern Hemispheres. This study examined magnetically conjugate SuperDARN radar observations of AWFC activity observed in the pre-midnight sector during two substorm intervals including multiple onsets during the evening of 30 November 2002. The Northern Hemisphere observations were made with the Japanese radar located at King Salmon, Alaska (570 invariant latitude) and the Southern Hemisphere observations with the Tasman International Geospace Environment Radar (TIGER) located at Bruny Island, Tasmania (550 invariant latitude). LANL geosynchronous satellite observations of energetic ion and electron fluxes monitored the effects of substorms in the inner magnetosphere (L ~6). The radar-observed AWFC activity was coincident with activity observed at geosynchronous orbit, as well as westward current surges in the ionosphere observed using ground-based magnetometers. The location of AWFCs with respect to the auroral oval was inferred from FUV auroral images recorded on board the IMAGE spacecraft. DMSP SSIES ion drift measurements confirmed the presence of AWFCs equatorward of the auroral oval. Systematic asymmetries in the interhemispheric signatures of the AWFCs probably arose because the magnetic flux tubes were distorted at L shells passing close to the substorm dipolarisation region. Transient asymmetries were attributed to the development of nearby field-aligned potential drops and currents.

3.8. Southern Hemisphere ionosphere and plasmasphere response to the interplanetary shock event of 29–31 October 2003.[4.20]

This study examined effects on the Southern Hemisphere ionosphere and plasmasphere of the 29–31 October 2003 geomagnetic storms (the so-called series of Halloween storms). Solar wind data from ACE and ionospheric data from the GPS (Global Position System) ground and LEO (Low Earth Orbit) receivers, the TOPEX/Poseidon altimeter, the IMAGE FUV camera, and the DMSP drift meter were used to investigate ionospheric dynamics as a function of the storm phase. The detailed structure of the ionosphere was obtained using tomographic reconstruction applied to both ground- and space-based GPS TEC observations. The tomographic approach using LEO observations of GPS signals allows investigation of the topside ionospheric and plasmaspheric density distribution in more detail than can be obtained using ground-based GPS receivers. This is because with groundbased receivers, the higher topside ionosphere and plasmasphere contribute only a small fraction to the total electron content (TEC) and so the measurements are dominated by the ionospheric structure at the F2 peak. In contrast, the Australian LEO satellite, FedSat, which was used for this study, orbits at 800 km altitude, well above the F2 peak and hence the TEC measured is primarily due to the upper topside ionosphere and plasmasphere. Temporal and regional maps of TEC and the IMAGE FUV data showed that the storm that commenced on 29 October dramatically decreased the plasma density in the Southern Hemisphere middle and high latitudes. The region remained depleted of plasma for more than 24 hours until 31 October, when the second severe storm began. TOPEX/Poseidon data showed that a daytime localized density enhancement occurred above the middle of the Pacific Ocean. Large interhemispheric and longitudinally narrow density structures were also observed in the ionosphere and topside ionosphere/plasmasphere during the storm.

3.9. Signatures of the nightside open–closed magnetic field-line boundary during moderately disturbed conditions and ionospheric substorms.[4.21]

TIGER's comparatively low latitude facilitates the observation of extensive backscatter from decametre-scale irregularities drifting in the auroral and polar cap ionosphere in the midnight sector. The radar often detects a persistent, sharp increase over ~90 km of range in line-of-sight Doppler velocity spread, or spectral width, from <50 m s^{-1} at lower latitude to >200 m s^{-1} at higher latitude. It was previously shown that for moderately disturbed conditions in the pre-midnight sector, the location of the spectral width boundary (SWB) corresponds to the poleward edge of the auroral oval, as determined from energy spectra of precipitating particles measured on board Defense Meteorology Satellite Program satellites. This implies the radar SWB is a proxy for the open–closed magnetic field-line boundary (OCB) under these particular conditions. An investigation of whether the radar SWB is aligned with the satellite OCB under a broader range of geomagnetic conditions, including small to moderate substorms occurring in the pre- and post-magnetic midnight sector, revealed that the behaviour of the SWB can be understood in terms of the spatial and temporal variations of energetic particle precipitation throughout the substorm cycle.

3.10. Investigation of the sea-state.[4.27]

Powerful HF over-the-horizon radars (OTHRs) such as the Australian Jindalee Operational Radar Network (JORN) can measure ocean wave heights, surface currents, and surface wind directions over vast, remote regions. This is achieved by analysing the Bragg backscatter from wind-driven surface ocean waves. This study demonstrated the potential for relatively compact Super Dual Auroral Radar Network (SuperDARN) radars to acquire valuable wind-wave direction information. This study used the TIGER Bruny Island radar operating in a non-standard mode that permitting the acquisition of coherent, long time series data out to great ranges without range aliasing. The study showed that SuperDARN radars can monitor sea-state so that depending on geographic location, HF propagation conditions, and radar performance, such radars could provide real-time mapping of wind and wave directions at a spatial resolution of ~1500 km^2 and a total footprint up to ~10^6 km^2 per radar.

3.11. High-Resolution Observations of the Magellanic Stream.[4.29]

The Magellanic Stream consists of a stream of gas stretching from the Magellanic Clouds, which extends well into the northern hemisphere. Except for small regions, existing observations of neutral hydrogen (HI) in the Magellanic Stream have only been made at relatively low angular resolution (~14 arcmin or larger). A higher resolution study of the Magellanic Stream has been completed by combining data obtained using the Australia Telescope Compact Array (ATCA) with data obtained by the Parkes telescope. This has allowed the first detailed HI study of the important region at the head of the Stream, where it peels away from the Magellanic Bridge and Small Magellanic Cloud. Over a region of area 140 deg2, sll structures with spatial scales in the range 0.1 to 2 kpc have been fully imaged. An initial analysis of the morphology of the gas distribution has been completed.

3.12. Dynamical critical scaling of electric field fluctuations in the greater cusp and magnetotail implied by HF radar observations of F-region Doppler velocity.[4.30]

Akasofu's solar wind ε parameter describes the coupling of solar wind energy to the magnetosphere and ionosphere. Analysis of fluctuations in ε using model independent scaling techniques including the peaks of probability density functions (PDFs) and generalised structure function (GSF) analysis show the fluctuations were self-affine (mono-fractal, single exponent scaling) over 9 octaves of time scale from ~46 s to ~9.1 h. However, the peak scaling exponent α0 was a function of the fluctuation bin size, so caution is required when comparing the exponents for different data sets sampled in different ways. The same generic scaling techniques revealed the organisation and functional form of concurrent fluctuations in azimuthal magnetospheric electric

fields implied by SuperDARN HF radar measurements of line-of-sight Doppler velocity, vLOS, made in the high-latitude austral ionosphere. The PDFs of vLOS fluctuation were calculated for time scales between 1 min and 256 min, and were sorted into noon sector results obtained with the Halley radar, and midnight sector results obtained with the TIGER radar. The PDFs were further sorted according to the orientation of the interplanetary magnetic field, as well as ionospheric regions of high and low Doppler spectral width. High spectral widths tend to occur at higher latitude, mostly on open field lines but also on closed field lines just equatorward of the open-closed boundary, whereas low spectral widths are concentrated on closed field lines deeper inside the magnetosphere. The vLOS fluctuations were most self-affine (i.e. like the solar wind ε parameter) on the high spectral width field lines in the noon sector ionosphere (i.e. the greater cusp), but suggested multi-fractal behaviour on closed field lines in the midnight sector (i.e. the central plasma sheet). Long tails in the PDFs imply that "microbursts" in ionospheric convection occur far more frequently, especially on open field lines, than can be captured using the effective Nyquist frequency and volume resolution of SuperDARN radars.

3.13. HF Radar Backscatter Inversion.[4.32]

Methods of inverting High Frequency HF radar land and sea backscatter to obtain ionospheric vertical profiles offer an important means of remote sensing the ionosphere up to thousands of kilometers from the transmitter/receiver location. A new inversion technique has been developed using the received elevation angle as well as the time delay or group path of a backscattered signal. The technique can be used with both fixed frequency and swept frequency radars. The advantage of using swept frequency radar is that the down range gradients in electron density can more readily be determined.

3.14. Mesospheric Neutral Winds.[4.34]

SuperDARN radars detect meteor echoes at relatively close range (<600 km). The radars scan 16 beam directions over an azimuthal field of view of ~52° and in the common mode of operation, data is collected using 45-km range gates and 7-s integrations on each beam. Application of a beam-swinging algorithm permits mesospheric neutral winds to be estimated from the line-of-sight (LOS) Doppler velocity of meteor echoes detected at near ranges (<600 km). Larger meteor echo detection rates better constrain the solutions and thereby increase the accuracy of wind estimates. Greater rates also lead to wind estimates with better time and height resolution. Observations have been made with TIGER in which meteor echo detection rates were increased by running specially devised dedicated radar control programs. This involved the use of shorter 15-km range gates and 2-s integration times. The Doppler characteristics of different echo types at meteor echo ranges were identified. The echoes were then filtered according to these characteristics, and their suitability for estimating neutral winds investigated. One echo type was clearly of ionospheric origin, forming thin, continuous traces decreasing in group range from ~1200 to ~300 km before midnight. These “descending plasma streams” (DPS) at times merged into and contaminated the meteor scatter. Nevertheless the study showed that significantly improved mesospheric wind estimates can be obtained by using a dedicated operational mode designed to enhance the detection of meteor echoes.

3.15. Auroral Westward Flow Channels (AWFCs).[4.35]

These are intense, narrow channels of westward drift overlapping the equatorward edge of the auroral oval in the pre-magnetic midnight sector and are closely related to the sub-auroral polarisation stream which encompasses polarisation jets, a phenomenon also known as sub-auroral ion drift events. Observations by the TIGER Bruny Island radar (147.2°E, 43.4°S Geodetic; 55.0° Geomagnetic) have revealed close associations between the energence of AWFCs and substorm onset, and their subsequent decay toward the end of recovery phase. In fact, in terms of electric field strength, they are the strongest signatures of substorms in the ionospheric convection (>50 mV m^{-1}). In terms of electric potential difference (>10 kV), they also represent a substantial fraction of the total potential difference generated during substorms. AWFCs exhibit a diverse range of behaviour, there being no typical event. TIGER observations show that radial polarisation fields sometimes oscillate towards and away from the Earth, and bifurcate, within regions of closed flux in the magnetotail throughout substorm evolution. By examining the AWFC’s observed by

TIGER in 2000, simple statistical arguments imply that one, if not more, AWFC probably occurs during every substorm.

3.16. Tomographic images of the plasma density distribution in the topside ionosphere and plasmasphere obtained using the FedSat GPS receiver.

Initial results show detailed structures at all latitudes that are not described by existing models of the region. In particular magnetic field-aligned structures extending thousands of kilometres up into the plasmasphere are observed and mapped in some detail. Several papers have been submitted for publication.

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MACQUARIE UNIVERSITY
Australian Centre for Astrobiology

Research on astrobiology in Australia is focused on the Australian Centre for Astrobiology (ACA) at Macquarie University in Sydney. The ACA is a networked organisation with members at other universities and research organisations throughout Australia (and some overseas). Details can be found at http://aca.mq.edu.au.

The key objectives of the ACA are to make a unique and highly significant contribution to understanding the origin of life on Earth and to the search for life on Mars and beyond. This is the unifying focus of the Centre's five key research areas: 1. Ancient microbial systems; 2. Modern microbial systems in "extreme" environments; 3. Remote sensing of Mars, Venus and other bodies in the Solar System; 4. Extrasolar planets; 5. Science communication. The Centre was inaugurated in July 2001 with international affiliate membership of the NASA Astrobiology Institute (NAI). It later gained the more formal status of Associate Member of the NAI, one of only two such international members (the other being in Spain).

Research projects

1. Ancient hydrothermal systems

- **a.** The palaeobiology of hydrothermal mineral deposits of the McArthur River HYC lead-zinc-silver deposit in the Northern Territory. The work includes sedimentology, organic geochemistry, isotope geochemistry and palaeobiology.
- **b.** The analysis of infrared remote sensing data acquired from the North Pole Dome Region in the Pilbara region of Western Australia. The data cover an area of 600 sq. km containing putative early Earth habitats, including large regions of the 3.5 billion year old Warrawoona Group basalts.
- **c.** An innovative analysis method for mapping hydrothermal minerals was used to produce unique maps of the region. These led to new interpretations of the genesis of the North Pole Dome and later hydrothermal alteration. These maps will be used by future researchers in the area to help learn more about Earth's earliest biosphere.
- **d.** Other work has been on the stromatolitic 3.43 billion-year-old Strelley Pool Chert of the Pilbara. This has revealed a stromatolite reef ecosystem, providing very strong evidence for microbial life at this time. The stromatolites for the most part formed in a normal marine environment during a pause in hydrothermal activity, as demonstrated by sedimentary facies analysis combined with trace and rare earth element analyses.

2. Extrasolar systems detection

This research has included the following extrasolar planet discovery observations:

- **a.** The Anglo-Australian Planet Search project, using high resolution spectroscopy on the Anglo-Australian Telescope to detect extrasolar planets by the Doppler method.
- **b.** A collaboration with Marcy (University of California Berkeley), Butler (Department of Terrestrial Magnetism, Carnegie Institute of Washington, Washington DC), Tinney (Anglo Australian Observatory), Jones (University of Hertfordshire), and Carter (University of Southern Queensland).
- **c.** The PlanetPol project using a new high sensitivity astronomical polarimeter to attempt to directly detect extrasolar planets by observing the scattered light from their atmospheres.
- **d.** A collaboration with Hough and Lucas (University of Hertfordshire) and Tamura (National Astronomical Observatory, Japan). During the year a preliminary version of a new high-spectral-resolution planetary atmosphere radiative transfer model was developed. The model combines a line-by-line treatment of molecular absorption with a full multiple scattering solution of the radiative transfer equation. It is designed to be sufficiently general to apply to the Earth, other solar system planets, and extrasolar planets.

3. Remote sensing of Mars and Venus and Comet Observations

The following programs together with the extra solar planet observations have been allocated a total of 103 nights of competitive large (>3m) telescope time during 2005 on the Anglo-Australian Telescope, the William Herschel Telescope, the NASA Infrared Telescope Facility, and the Gemini South Telescope. There have also been a number of runs on smaller telescopes at the Siding Spring Observatory.

a. Near infrared spectroscopic imaging of Mars and Venus to study their atmospheric structure and composition.
b. A collaboration with Meadows (Caltech) and Crisp (Jet Propulsion Laboratory).
c. Observations of the spectrum of the lunar Earthshine to search for possible biosignatures that might be observed in the spectra of extrasolar terrestrial planets, as part of the NASA Astrobiology Institute's Virtual Planetary Laboratory project.
d. A collaboration with Turnbull (DTM), Meadows (Caltech), Crisp (JPL) and Kiang (NASA Goddard Insitute for Space Studies).
e. Observations of Comet Tempel/1 during the encounter of the NASA Deep Impact spacecraft. These were part of a world wide Earth observation program coordinated by Meech (Univ. of Hawaii).
f. Observations of Mars obtained with the United Kingdom Infrared Telescope in 2003 have been analysed to show that we can use measurements of the 2 micron CO_2 band as a way of detecting the topographic variations in surface atmospheric pressure to an accuracy of about 5 Pascals. The results suggest a possible approach to weather monitoring and forecasting on Mars. New higher-spectral-resolution observations obtained in 2005 will be used to refine this technique by developing ways of separately retrieving pressure, temperature and dust content.
g. We are researching near infrared images and spectra of Mars obtained during the Aug/Sep 2003 opposition. From these data a method is being developed by which the pressure systems in the Martian atmosphere might be monitored.
h. Spectra are being simulated to investigate how variations in optical density and surface temperature affect the apparent surface pressures and how these compare with the observed data.
i. A spectral component analysis program is also being adapted to attempt to separate the main surface and atmospheric spectral constituents. This has the possibility to be able to identify the surface mineralogies of Mars.
j. This program will also be applied to spectra obtained of Venus in order to identify the atmospheric gas compositions and distributions.
k. During October-December 2005 (around the time of Mars opposition) high-resolution near-infrared spectra of Mars were obtained using two separate instruments, CSHELL - the Cryogenic Near Infra Red Facility Spectrograph on the NASA Infra Red Telescope Facility, and GNIRS (Gemini Near Infra Red spectrograph) on Gemini South. In 2006 we will be making use of these spectra as inputs for our forward-modelling algorithm.

4. Modern hydrothermal and hypersaline systems

The study of modern-day early Earth analogues is critical for understanding how terrestrial life originated, and whether it once did, or still does, exist on Mars. Through the use of techniques such as 16S ribosomal RNA analysis, FISH and culturing we study prokaryotic thermophilic microbes inhabiting modern hydrothermal systems. Our aim is to obtain a complete picture of the microbial ecology of such sites, and determine the role(s) of the microorganisms in the following ecosystems:

a. Paralana hot spring, South Australia. As part of an ARC funded Discovery project, molecular-based studies indicated the existence of a number of uncultured species, in agreement with data from our previous work. In addition, extensive culturing was conducted, using both traditional and novel techniques. The ultimate aim is to isolate previously uncultured Paralana microorganisms. A novel culturing technique, called ABESS (Agar-Based Environmental Substrate System) was developed that allows more intimate contact between microbial cells and growth substrates, and permits the isolation of slow-growing microbes. Furthermore, micromanipulation was used to isolate single cells cultured using ABESS.

b. White Island is New Zealand's most active volcano. It is considered a modern analogue for ancient hydrothermal systems in which early life is postulated to have originated and/or evolved. Sulfur appears to be a key element for many microorganisms within modern hydrothermal systems and it is thought to have played a pivotal role in life's origin. Despite these facts sulfur cycling by microorganisms within hydrothermal systems is poorly understood. We have produced the first comprehensive microbial survey carried out on White Island, involving the analysis of multiple areas, including terrestrial and shallow submerged vents, with a range of physical and chemical conditions. The first stage of his research involved building a picture of what microorganisms are present within this system. The current stage of investigation involves uncovering what the organisms are doing and how they are interacting with each other and their environment. The eventual aim is to build a holistic picture of this extreme system particularly pertaining to the sulfur cycle. This research will not only increase our knowledge of modern sulfur rich hydrothermal systems but may aid us in the interpretation of ancient systems both on Earth and on Mars.

c. Another project aims to determine the microbial ecology and biogeochemistry of hydrothermally heated, acidic volcanic soils such as those found on Mt Hood, USA. Microorganisms are believed to be intimately involved in geological phenomena and the cycling of geologically important elements such as sulfur and iron. For example, microbes in volcanic areas are often responsible for sulfur cycling. Furthermore, it is widely recognised that the study of microorganisms in extreme environments, especially in hydrothermal systems, provides important insights for the search for the origin of life on Earth, and life on other planets. Hydrothermally altered andesite was collected from Devil's Kitchen, a fumarolic field in the summit area of the Mt. Hood volcano (Oregon, USA; Aug 2004 and Jul 2005) and from the Washburn/Inkpot Hot Springs fumarolic fields, Yellowstone National Park (Wyoming, USA; Jul 2005). During 2005 these volcanically heated (temperatures up to 89 ºC) and acidic (pH 1.3 – 3) soil samples were subjected to a diverse array of molecular biological, microbiological and chemical analyses. Residing microorganisms were visualised by confocal laser scanning microscopy and fluorescent *in situ* hybridisation. Microbial genomic DNA was isolated from the samples and microorganisms were identified by DNA sequencing of 16S rDNA. Enrichment cultures were obtained and analysed by microscopy and DNA sequencing. The microorganisms identified thus far (*Ferroplasma* sp. and *Sulfobacillus* sp.) are commonly found in bioleaching environments and are known to be involved in biogeochemical cycling of sulfur and sulfide metals.

d. We have worked on both the development of the Quantum Dots technique and the study of the microbial biodiversity of White island. The study of microbial diversity in extreme environments represents a major opportunity for understanding the biotransformations and the physiological roles that microorganisms perform in the biosphere, as well as their value for basic and applied research in biology and their potential for biotechnology purposes. A diverse range of cultivation and isolation methods have been used to enrich representative bacterial populations from White Island. The "unculturable" microorganisms are being identified using molecular methods (16S rDNA) and the culturable ones by fluorescence *in situ* hybridization (FISH). From this information, a novel technique is being developed which will allow multiplexed high-throughput analysis for rapid detection and quantification of microorganisms from the environment. Quantum dots (QDs) are inorganic semiconductor nanoparticles made up of crystals about 10-20 nm in diameter. QDs conjugated with specific oligonucleotide probes will label the DNA of extremophiles thriving in the environment, thus facilitating their detection. Development of the technique will provide a rapid and efficient tool not only for the identification of the microbial populations but also it will assist in the isolation of the desirable microorganims by flow cytometry.

e. We are also working with another extremophile community in Shark Bay, Western Australia, investigating a novel isolate *Halococcus hamelinensis* sp. nov, as well as reactions on different osmotic conditions and for the yet uncharacterised gene which encodes for the enzyme Ribonucleotide reductase, a key player in providing nucleotides

for DNA repair. We also worked on the low salt adaptation of *H. salinarum* NRC-1, finding a gene that encodes for Ribonucleotide reductase. Another important fact of this enzyme is that it might have played a pivotal role during the evolution from the RNA to the DNA world.

5. Science Communication

We have gathered science literacy data from several points during the course of the development of the NASA Macquarie University Pilbara Project – 270 entry and exit surveys from 16-year-old top science class students from seven high schools in Sydney and three schools near Cardiff in Wales, UK. More than another 400 entry and exit surveys were gathered from Year 10 lower level science classes in the seven Sydney high schools. Plans were made to acquire another data collection point among university first year students to test the hypothesis that even the best science students may be leaving high school scientifically illiterate, when measured against expectations from adult science literacy surveys as opposed to content-driven science curricula testing. Data analysis is underway. The aim is to understand why science illiteracy appears to remain widespread, in spite of efforts both in the formal education arena and in communicating science to adult populations via media and other channels. It may also provide additional information in understanding how to curb falling numbers of students interested in studying science at university.

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MARS SOCIETY AUSTRALIA

INTRODUCTION

MSA is an incorporated non-profit organisation whose goals are:

- Broad public outreach to instil the vision of pioneering Mars;
- Support of more aggressive government-funded Mars exploration programs around the world;
- Conducting Mars exploration on a private basis;
- Encourage Australian participation in education, industry and government and individuals to actively participate in space research and development.
- Undertaking scientific research to extend that knowledge relevant to the understanding and eventual human exploration of Mars, with a view to positioning Australia for a role in future missions as well as for analogue research with international backing.

To realise these goals MSA is undertaking comparative research and testing surface exploration strategies and technologies in renowned Mars analogue locations. The vision is to position Australia for participation in the eventual establishment of a human presence on Mars. MSA has applied for approved research institute status under section 73A of the Australian income tax assessment act 1936. All MSA projects are carried out on a voluntary basis.

MAJOR PROJECTS

MSA has four ongoing major projects; MarsSkin, Marsupial, Mars-Oz, and its annual conference.

MarsSkin

Project MarsSkin aims to design, produce and test analogue mechanical counter pressure (MCP) space suits that will behave nearly identically to the real MCP suits which may one day be worn on Mars yet are usable in Mars analogue research projects on Earth. Three versions have been produced to date and field tested in the United States and Australia. An updated version of the suit is being prepared for use by students at the Victorian Space Science Education Centre at Strathmore Secondary College, Victoria, in a simulated Martian environment in which students will carry out a range of scientific and engineering tasks. MarsSkin 4.0, which MSA hopes will be field trialled in 2006, is currently under development.

Starchaser Marsupial

The Starchaser Marsupial Rover is being built in Perth with the vision of contributing to the design database for future crew-carrying pressurised exploration vehicles. The vehicle is based on the chassis of a Forward Control Landrover. As well as a platform for new design ideas, the prototype vehicle will provide for a wide range of Mars analogue research activities and be a focus of attention for education and outreach.

Mars-Oz

Mars-Oz is a MSA-designed simulated Mars base to be erected at Arkaroola, South Australia. It will complement other research stations in the US Canada, and Iceland. The design will be used to test alternative station configurations for human Mars missions. The proposal has been put out to tenders for construction. As with the Starchaser Marsupial rover, Mars-Oz will provide a platform for design, education and Mars analogue research.

Annual Conference

MSA has run an annual conference since 2000. The 2005 conference was held over three days at the Australian National University in August. The keynote speaker was Professor Steve Squyres of Columbia University, Principal Investigator for the Mars Exploration Rover Project. The 2006 Conference will be held in Melbourne. All conference proceedings are lodged in the National Library of Australia.

OTHER ACTIVITIES

Consultative bodies

MSA made a submission to the Australian Academy of Science's Decadal Plan for space science and has representatives on two committees workshop committees. The Society also has representation on the Australian Space Industry Chamber of Commerce.

Australian Space Science Conference

MSA chaired a Mars research stream at the 2005 ASSC convened by the National Space Society Australia at RMIT in Melbourne in September. The Society will be similarly assisting at the 2006 conference in Canberra.

PARTNERSHIPS

Starchaser Industries (UK) is a corporate member of MSA, as is the Arkaroola tourist resort in South Australia. MSA also works closely with other national Mars Societies in the United States, Canada and Europe.

PUBLICATIONS July 2005-June 2006

The following papers are publications that have emerged out of specific research by or on behalf of MSA society. In addition to these papers, society members have published numerous papers on relevant themes of behalf of other organisations. MSA members at the time of writing are highlighted in **bold.**

Refereed

Clarke, J. D. A. (ed.) 2006. Mars Analog Research. American Astronautical Society Science and Technology Series Volume 111, Univelt, California (in press).

Clarke, J. D. A., Persaud, R., Rupert, S. and the **Expedition Two Crew**. "A Multi-Goal Mars Analogue Expedition (Expedition Two) to the Arkaroola Region, Australia". In Clarke, J. D. A. (ed). (in press).

Battler, M. M., **Clarke, J. D. A.**, and Coniglio, M. 2006. Possible analog sedimentary and diagenetic features for Meridiani Planum sediments near Hanksville, Utah: implications for Martian field studies. In Clarke, J. D. A. (ed.) In press.

Bishop, S., **Dawson, S**., Rawat, N., Reynolds, K., Eggins, R., and Bunzelek, K. 2006. Assessing teams in Mars simulation habitats: lessons learned from 2002-2004. In Clarke, J. D. A. (ed.) In press.

Clarke, J. D. A. **and Willson, D.** 2006. Exploration radii at the Arkaroola Mars-Oz site:implications for Mars. In Clarke, J. D. A. (ed.) In press.

Clarke, J. D. A., Martinez, E., and Rupert, S. 2005. Geophysical and Chemical Characterisation of Water Sources at Arkaroola, South Australia. Proceedings of the 5th NSSA Space Science Conference. Melbourne, September 2005

Heldmann, J., **Brown, A., Clarke, J**., Martinez, E., Rupert, S., and **Thomas, M.** 2006. Follow the water: applying a Mars exploration strategy to the Arkaroola analog region, South Australia.

Mann, G. A. 2006. Design, Construction and Test Operations of an Analog Pressurised Planetary Exploration Vehicle. In Clarke, J. D. A. (ed.) In press.

Mann, G. 2005. A Practical Astronautical Research Laboratory at an Australian Secondary School. Proceedings of the 5th NSSA Space Science Conference. Melbourne, September 2005.

Thomas, M., Clarke, J. D. A., and **Pain, C. F**. 2005. Weathering, erosion and landscape processes on Mars identified from recent rover imagery, and possible earth analogues. Australian Journal of Earth Sciences 52(3): 365-378.

Waclawik, V., and Gostin, V. 2006. Significance of remnant gravel lags as landscape evolution indicators, Arkaroola Mars analog region geology. In Clarke, J. D. A. (ed.) In press.

Waldie, J. and Cutler, N. 2006. The flexibility of mechanical counter pressure space suit gloves. In Clarke, J. D. A. (ed.) In press.

Waldie, J. 2005. Mechanical Counter Pressure Space Suits: Advantages, Limitations and Concepts. Proceedings of the 5th NSSA Space Science Conference. Melbourne, September 2005.

Willson, D. and **Clarke, J. D. A.** 2005. MARS-OZ: A Proposed Mars Base Design Adopting a Horizontally Landed Bent Biconic Vehicle. Journal of the British Interplanetary Society 58 (5/6): 181-196.

Willson, D. Clarke, J. D. A., and **Murphy, G. M.** 2005. MARS-OZ: a design for a Simulated Mars Base in the Australian Outback Journal of the British Interplanetary Society 58 (9/10): 282-293.

Willson, D., Clarke, J. D. A., and **Murphy, G. M.** 2005. Mars-Oz: A Design for a Simulated Mars Base in the Australian Outback. Proceedings of the 5th NSSA Space Science Conference. Melbourne, September 2005.

Non-refereed

Clarke, J. D. A., Pain, C. F. and **Thomas, M.** 2005. Regolith Landform Mapping of Meridiani Planum and Surrounds, 2nd Mars Expedition Planning Workshop, Vancouver BC, Abstract #PS102

Clarke, J. D. A. and **Willson, D.** 2005. Exploration radii for a crewed mission to a human landing at Terra Meridiani. The 2nd Mars Expedition Planning Workshop, Vancouver, 2005, Abstract #PS202

Laing, J. H. 2005. Tourism to the Red Planet: Considerations for Early Martian Expedition Planning, 2nd Mars Expedition Planning Workshop, Vancouver BC, Abstract #PS501

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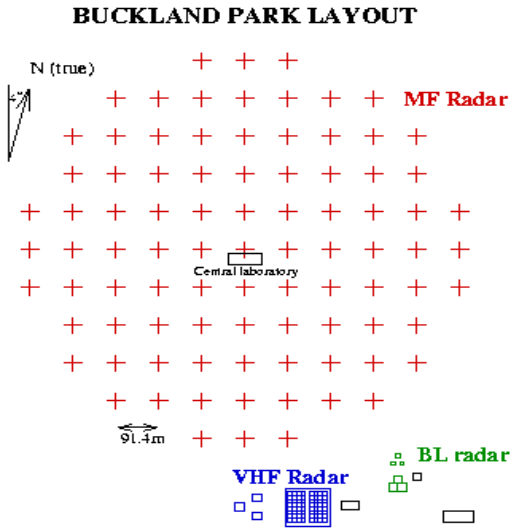
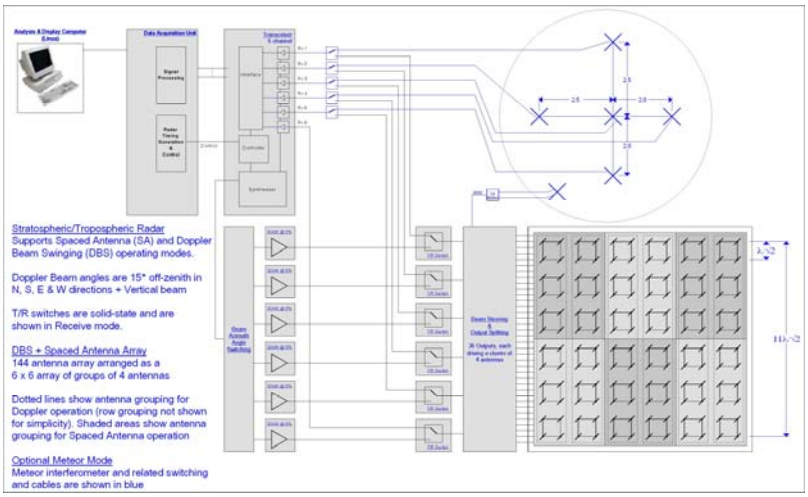
THE UNIVERSITY OF ADELAIDE
Atmospheric Physics Group

Introduction

The Atmospheric Physics Group at the University of Adelaide (http://www.physics.adelaide.edu.au/atmospheric/home.html) is located in the Discipline of Physics in the School of Chemistry and Physics of the Faculty of the Sciences.



The Buckland Park Research Station near Adelaide (35°S, 138°E) was established in 1964, and the large MF aerial array constructed over the next 3 three years [1]. A schematic of the aerial layout showing the large MF antenna array is shown in figure 1 (left). The square grid on which the MF antennas are arranged indicates the scale. It has a basic spacing of 91.4 m. The original large MF array was refurbished in the early 1990's [2], [3], and is still being actively used for research into the upper atmosphere. This includes observations Mesosphere Lower Thermosphere (MLT) mean winds [4], planetary waves [5], tides [6], gravity waves and turbulence [7], and of electron densities [8], meteors [9], and momentum fluxes [10].



Adelaide is a lower mid-latitude site, so it is potentially simpler from a geophysical point of view for instrument development or initial studies of new techniques. In the MLT region we are pursuing integrated observations of aeronomy using radar, lidar and passive optical techniques. For this height region, no one technique covers the entire height range, and so we need to use co-located instrumentation. A number of other instruments are located at the site, and are also shown in figure 1. Most notably, a 54.1 MHz Stratospheric Tropospheric (ST) radar was installed in the early 1980's [11], and a Boundary Layer Tropospheric (BLT) radar was installed in the late 1990's [12].

A new 55 MHz VHF radar and antenna array was installed at the site in 2005. This array is being used with various transmitters in a dedicated Doppler mode for ST observations. It also has a five-channel interferometer for use in meteor observations of the MLT region. This arrangement is similar to that used with the 55 MHz VHF radar at Davis Station in Antarctica [13], and is shown schematically in figure 2 (above) and in figure 3 (right)

A number of optical instruments are also operated at the site. These include a three-field photometer (3FP) [14], a spectrometer [15], and an all-sky imager [16]. A combined Rayleigh and Na lidar is presently under development. The telescope for this system is shown in figure 4 (left). Optical and radar instrumentation at the BP site is summarized in table 1.

One observing site cannot provide observations sufficiently separated horizontally to investigate the spatial variability of the wind field, so there is a need for observing networks. The locations of the various observing sites that constitute our local radar network are shown in figure 5 (below). We operate the radars at Adelaide, Katherine, Pontianak and Christmas Island (see table 2 for details). Two additional radars are being operated on a campaign basis at Darwin [17]. We also cooperate with the Australian Antarctic Division at the Davis Station field site. The radars at this site are part of the Antarctic radar network shown in Figure 6 (below).

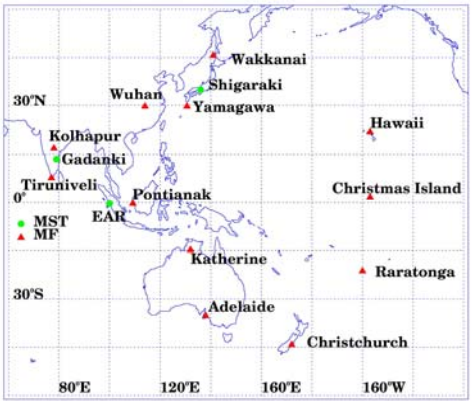


Table 1: Instrumentation at the Buckland Park Field Site

Instrument	Parameters Measured	Height Coverage
VHF Meteor / Atmospheric ST radar (54.1 MHz)	Winds:	1 – 15 km (ST mode)
	Winds & Temperatures:	80-100 km (meteor mode)
MF Doppler / SA Radar	Winds	60 – 100 km (day) 80 – 100 km (night)
	Electron densities	60 – 80 km
VHF Meteor Radar (31.0 MHz)	Winds & Temperatures	80-100 km (meteor mode)
VHF Boundary Layer Radar	Winds	0.3 – 6 km
OH, O2 Spectrometer (with Embry Riddle)	OH temperatures	85 km
	O2 temperatures	94 km
3FP (558 nm and 730 nm)	OH intensities three fields	85 km
	OI intensities in three fields	97 km
All-sky airglow Imager (OH and O2) (with Aerospace Corp)	OH temperatures	85 km
	O2 temperatures	94 km
	OH and O2 all sky images	85 and 94 km
Rayleigh Lidar / Na Lidar (under development)	Neutral densities	20 to 60 km
	Na temperatures	80 – 100 km
Weather station	Temperature, wind speed and direction, precipitation	ground

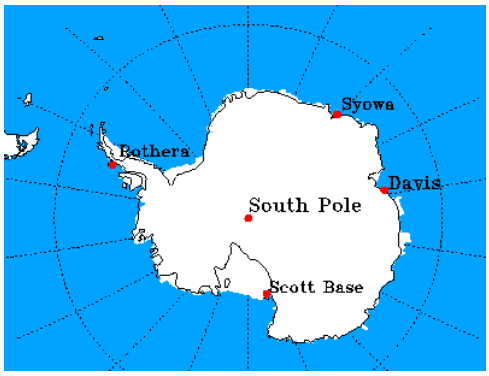


Figure 6 (left). The Antarctic radar network.

Comparison with results from similar instruments in the local regional network can provide additional insight into the aeronomy of the region. Table 2 summarizes the instrumentation at the various field sites we operate.

Table 2: Field sites in the local network, and the instruments operated there.

Adelaide	**Pontianak (with University of Kyoto and LAPAN)**	**Davis Station (With Australian Antarctic Division)**	**Katherine**	**Darwin**	**Christmas Island**
VHF Meteor / Atmospheric radar (54.1 MHz)		VHF Meteor / Atmospheric Radar (55.0 MHz)		VHF Meteor / Atmospheric Boundary Layer radar (55 MHz)	
OH O2 Spectrometer (with Embry Riddle)		Czerny-Turner Spectrometer (OH band)			
3FP (558 nm and 730 nm)		3FP (558 and 630 nm)	MF SA Radar		
MF Doppler / SA Radar	MF Doppler / SA Radar	MF SA Radar			MF SA Radar
VHF Meteor Radar (31.0 MHz) currently in Darwin				VHF Meteor Radar (31.0 MHz) until early 2004	
All-sky airglow Imager (OH and O2) (with Aerospace Corp)					
Rayleigh Lidar / Na Lidar (under development)		Rayleigh Lidar			
VHF Boundary Layer Radar (currently at Adelaide Airport)				VHF Boundary Layer Radar	

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UNIVERSITY OF NEWCASTLE - Centre for Space Physics
School of Mathematical and Physical Sciences

Research within the Centre for Space Physics (formerly the Space Physics Group) is primarily concerned with plasma waves, current systems and boundary regions in the Earth's magnetosphere and ionosphere. These include the study of ultra-low frequency (ULF) hydromagnetic and ion-cyclotron waves in the magnetosphere, using observations from spacecraft and from ground magnetometer arrays at low and high latitudes; the transmission of these waves through the ionosphere; high latitude studies of magnetosphere-ionosphere coupling, including with HF radars and riometers; and the use of ULF waves as diagnostic probes of the magnetospheric plasma and its variation, and the energy flux coupled to the atmosphere. The spatial and temporal variability of the high latitude current systems and convection are studied using satellite and ground observations to provide a measure of energy input and the location of the open-closed field line boundary.

The Centre was a core partner in the Cooperative Research Centre for Satellite Systems (CRCSS; 1998 - 2005), which built the first Australian satellite to be launched in 30 years, FedSat. This low-Earth orbit microsatellite was launched in December 2002, carrying the NewMag magnetometer experiment to measure the Earth's main field, current systems and ULF waves.

High Latitude Studies of Magnetospheric ULF Waves, Boundary Regions and Absorption

Plasma waves are important in distributing energy of solar wind origin throughout the magnetosphere and down to ionospheric altitudes. General studies using the Centre's Antarctic magnetometer array (Casey, Davis, Mawson, Macquarie Island, Scott Base (NZ) and Zhong Shan (PRC)) and from the IMAGE array in the Arctic have shown that Pc1-2 (0.1-5 Hz), Pc3-4 (7-100 mHz) and Pc5 (< 7 mHz) pulsations are generated in specific regions of the outer magnetosphere, boundary layer and dayside cusp. Pc5 waves generated by boundary layer instability processes such as the solar-wind driven Kelvin-Helmholtz instability have been found to couple to field line resonances (FLRs) in the outer magnetosphere. The FLR signatures are detected by high latitude magnetometers and HF radars, and often exhibit a set of discrete frequencies.

More detailed studies of wave propagation have been undertaken using a close-spaced square array of solar-powered magnetometers near and inland from Davis and Zhong Shan (PRC), Antarctica. These have allowed spatial phase studies of daytime Pc3-5 waves, and field line tracing using Pc5 waves. Detailed studies using the Antarctic magnetometers and the Arctic IMAGE array have shown that monochromatic Pc3-4 pulsations exhibit high coherence over at least 1000 km and propagate poleward across the ground. The wave energy spreads across the ionosphere at apparent speeds of a few tens of km/s. This speed can be interpreted as a time delay between two different paths by which compressional and Alfven wave energy may reach the ground from a sub-solar magnetopause source. Sometimes the pulsations have the signature of FLR harmonics. These pulsations are therefore probably due to fast mode waves propagating through the magnetosphere, excited by compressional mode hm waves generated in the upstream solar wind by ion-cyclotron resonance with backstreaming ions. Under appropriate conditions these waves may couple energy to field line eigenoscillations in the outer magnetosphere.

It has been shown that high latitude Pc5 FLRs can be used to provide information on the open-closed field line boundary. This is important for space weather diagnostic studies and the focus of current research using the remote magnetometer array and Davis-Mawson data. The precise time of the near-noon Pc5 polarisation reversal has been shown to be a proxy for the polarity of IMF By, while the latitude of the open-closed boundary varies with IMF Bz.

A new diagnostic of dayside reconnection at the magnetopause uses the azimuthal propagation properties of ULF waves near the open-closed field line boundary. During times when IMF Bz is slightly negative intervals of broadband wave activity in the 1 – 10 mHz band are seen moving

toward noon, opposite to the usual dawn or dusk propagating Pc5 waves. This is interpreted as a signature of dayside reconnection.

The spatial structure of the density discontinuity across the plasmapause is often based on H+ ion or electron density profiles with the contribution of heavy ions (He+, O+) neglected. Using Dynamics Explorer-1 plasma and magnetic field data we have shown that the location of the plasmapause and the associated density gradient may be drastically modified or the plasmapause completely removed when heavy ions are included. This is particularly the case following storms during plasmasphere refilling and when the oxygen torus is present.

Another study addresses the contentious issue of the identification and modelling of the open-closed field line boundary and its relationship to the poleward auroral emission boundary using different types of data. Nightside polar cap boundary dynamics and morphology under transient reconnections are being studied. Auroral boundaries from the POLAR UVI imager experiment and DMSP electron fluxes are used to establish a reconnection driven model to eventually provide space weather information for boundary determination.

The Centre also operates an imaging riometer at Davis in Antarctica, as a cooperative program with the University of Maryland and the Australian Antarctic Division. This is providing data on precipitation signatures and motions of impulsive events that are also recorded with nearby magnetometers. In particular, we are focusing on the evolution of transient magnetic impulse events (MIE), associated with flux transfer events or solar wind pressure pulses, and mapped these with respect to associated ionospheric current systems.

The location of a similar imaging riometer at Zhong Shan, 120km west of Davis, has provided an opportunity to apply parallax methods to measure for the first time the true height of absorption. Absorption mainly occurs between 85-95km, with a peak at ~92km. F2 region absorption is seen at 200km altitude.

Magnetospheric Diagnostics Using ULF Waves

The inner magnetosphere supports two types of particle distributions. One of these is a relatively dense population of low energy (few eV), co-rotating particles of atmospheric origin that defines the plasmasphere. Recent observations from the EUV imager experiment on the IMAGE spacecraft have shown that this particle population exhibits high spatial and temporal variability, even at magnetically quiet times. This challenges present understanding of basic geophysical and space weather processes.

The other important population is of energetic radiation belt particles. The radiation belts extend from low altitude roughly through to geostationary altitude and comprise particles with sufficient energy to damage spacecraft. The mechanisms for accelerating these particles to their high energies, or for their loss via precipitation into the atmosphere, are not yet clear, although ULF waves are likely to be involved in both situations.

One important technique for probing these regions is that developed at Newcastle with ground-based magnetometers. This uses the cross-phase and power difference and ratio between adjacent stations and to measure the field line eigenfrequency, from which the equatorial mass density is calculated. This in turn can be compared with model calculations and in situ observations. Importantly, the effects of heavy ions in the thermosphere and ionosphere on low latitude FLRs can also be evaluated.

In support of such studies we have been undertaking a collaborative project with the British Antarctic Survey, who established VLF Doppler receivers and a 3-station array of solar-powered magnetometers near Rothera, Antarctica. These instruments allow the VLF- and ULF-derived electron and mass densities to be compared for the same L=2.5 flux tube. These densities are may then be compared with results from model results, and with observations from the IMAGE EUV (imager) and RPI (electron density) experiments. The EUV images provide two-dimensional line-of-sight data on He^+ concentration that require information on the ion composition of the inner-

magnetosphere for detailed interpretation. The RPI experiment furnishes snapshot observations of electron density along the spacecraft's orbit.

We have used all these independent techniques to observe the same geomagnetic field-line under a variety of geomagnetic conditions. This has provided important new information on plasma dynamics, such as refilling from the underlying ionosphere and convection processes and changes in the H^+, He^+ and O^+ concentrations in the inner magnetosphere

A separate study with the BAS magnetometers and VLF receivers has examined Doppler shifts of VLF whistler signals that correlate with ULF pulsations at co-located magnetometers. The VLF Doppler oscillations are due to radial motions of plasmaspheric flux tubes of order 1 km in the equatorial plane. These are due to plasma motions driven by the electric field of incoming compressional mode ULF waves. The waves are generated in the upstream solar wind by the ion-cyclotron resonance mechanism and may also couple energy to field line eigenoscillations when the frequencies match. The ULF pulsations exhibit cross-phase FLR signatures in both the H and D components on ground magnetometer arrays. In future work we will examine the phase difference between simultaneous oscillations of multiple VLF flux tubes, to estimate the propagation speed of the compressional ULF waves.

In related work we are using data from SAMNET/BGS and IMAGE ground magnetometer arrays that span the UK, Europe and Scandinavia to explore the spatial and temporal evolution of plasma mass density from magnetically quiet to disturbed times. We have already shown that the plasmapause shape and location can evolve quite rapidly on the dayside in response to sudden changes in solar-wind driven convection. These studies also make use of images of the He^+ distribution in the plasmasphere from the IMAGE EUV experiment.

Hydromagnetic Wave Propagation in the Ionosphere

One program at Newcastle is investigating both experimentally and theoretically the appearance of ULF oscillations monitored in the ionosphere using HF radio techniques. These are the ionospheric signature of down going hydromagnetic waves, and exhibit high correlations with ULF waves detected by ground based magnetometers.

We have developed the theoretical modeling aspects of this work, formulating and solving the equations that describe the interaction between the ionosphere and ULF waves for oblique geomagnetic field dip angles and an ionosphere approximated by height integrated conductivities. The complex wave reflection and mode conversion matrix, including the inductive response of the ionosphere currents has been obtained, providing insight into the reflection, transmission and mode conversion of the two Alfven ULF waves modes. A 1-D numerical model that includes altitude information through the ionosphere has also been developed. Results from the 1-D model indicate that the ionosphere affects the properties of ULF waves in a complicated way which depends on the spatial scale size of the ULF disturbance, the dip angle of the magnetic field (latitude), the ionosphere conductivities (Hall and Pedersen) and ULF wave frequency. The insight gained from both the analytic and numerical 1-D codes is presently being applied to the development of a 2-D computer model of these processes.

Using predictions from the 1-D ionosphere/ULF wave computer model, the effect of ULF wave interaction with the ionosphere on HF propagation is being investigated. Initial comparisons between the model predictions and the Doppler shift data from the University of Leicester DOPE experiment show agreement with the experimental Doppler frequency shifts. The results are shown to depend on the spatial scale size of the ULF disturbance above the ionosphere and the way that the evanescent wave mode fields attenuate through the neutral atmosphere. We are pursuing the merging of the ionosphere ULF wave computer simulation code with computer simulations of ULF wave propagation throughout the magnetosphere.

Spacecraft Studies

It is now known that electromagnetic ion cyclotron waves in the 0.1-5 Hz frequency range are generated by wave-particle interactions involving ring current keV protons in the middle magnetosphere.

The Combined Release and Radiation Effects satellite (CRRES) in an elliptical 6.3 Re x 350 km orbit of period -10 hr carried a full complement of wave and particle experiments including fluxgate and search coil magnetometers, plasma wave and electric field experiments, and low, medium and high energy particle detectors. Studies on ion cyclotron waves are continuing using new analysis techniques which display wave Poynting flux in a dynamic spectral display. This allows the energy flow in multiple harmonics and individual wave packets to be studied. Results show that ion cyclotron waves are generated preferentially within +/-11^{o} geomagnetic latitude in the middle magnetosphere, with propagation always away from the equator. Bi-directional propagation is very rarely observed. The plasmapause is not the favoured region for wave sources as previously thought with waves equally likely to be generated in the outer plasmasphere or the plasmatrough. These results question the paradigm of bouncing wave packets that leads to important implications for the equatorial wave generation process.

An EMIC wave event observed by CRRES during an active storm period has been studied in order to estimate the minimum interaction kinetic energy. This used quasi-linear theory to calculate the resonant scattering rate over a finite bandwidth. The results support the suggestion that relativistic electron scattering by EMIC waves is a viable mechanism for decreasing relativistic electron fluxes from the outer Van Allen zone during magnetic storms.

It has been suggested for many years that EMIC waves make an important contribution to ring current ion loss during the storm recovery phase. In this scenario the proton cyclotron instability produces pitch angle diffusion which leads to the partial refilling of the loss cone resulting in the precipitation of keV particles Recent NOAA GOES satellite high resolution magnetometer observations at geostationary orbit have shown EMIC waves which occur in association with precipitation and EMIC waves seen on the ground. More importantly the GOES EMIC waves were observed in enhanced plasma density regions associated with radial plasma plumes observed by the IMAGE satellite EUV experiment.

At lower frequencies, Pc5 field line resonance and Pc3-4harmonic structure are being studied using up to five NOAA GOES geosynchronous spacecraft. Pc5 waves are seen to propagate simultaneously from the noon sector towards the dawn and dusk flanks, while Pc3-4 waves propagate westward all day.

Cooperative Research Centre for Satellite systems

The Centre was a core partner in the Cooperative Research Centre for Satellite Systems (CRCSS) that functioned from 1998 until closure in December 2005. This Australian Government supported Centre brought together leading university groups, space industries, and the CSIRO (national government research agency) to work on projects that will stimulate space-related activities in Australia. The Centre is responsible for the operation and the science undertaken by the NewMag fluxgate magnetometer experiment onboard FedSat. FedSat was launched into low-Earth orbit (LEO) at an 800km altitude, with 98.7 degrees inclination and Sun-synchronous in the 10:30 - 22:30 LT plane, in December 2002. The NewMag fluxgate magnetometer payload samples three mutually perpendicular components of the geomagnetic field. In order to reduce background noise the triaxial sensor head is mounted on a 2.5 m long boom. NewMag samples at rates of 100 or 10 vectors/second for high resolution or synoptic study modes respectively.

One of the primary goals of NewMag is to measure currents and waves at LEO while FedSat is flying over the auroral regions and ground magnetometer arrays. NewMag has been operational for 3.5 years with a 70% or greater duty cycle on average. Research has concentrated on studying the high latitude auroral zone field-aligned current (FAC) systems. Of particular interest is the fine structure in FAC sheets and collaboration with the Danish satellite Oersted has show that filamentary current sheets may be tilted with respect to the longitudinal east-west orientation.

Recent Oersted satellite research has shown that the equatorward boundary of the particle cusp identified by DMSP coincided with the centre of intense small scale fluctuations in the magnetic field. FedSat-NewMag results derived using many more cusp identifications over a longer time scale and a wider range of IMF conditions, appear to show this not true. Due to the nature of the DMSP orbits, there are many ‘glancing’ passes of the cusp, so the full latitudinal width of the cusp

is not well observed. However, FedSat passes closer to the pole and cuts the cusp more perpendicularly, thereby allowing a more accurate location of the cusp and its latitudinal width to be determined. Statistical results show Fedsat-NewMag perpendicular RMS magnetic field peaks at a higher latitude than the DMSP-measured particle cusp, although at this stage no account has been taken of the IMF Bz variation in this study.

Another NewMag study investigated the effect of FAC on the ability of the FedSat attitude control system (ACS) to maintain stable attitude. Small-scale currents produced perturbations within the stability of pointing accuracy and were not a problem. However, it appears that the large-scale FAC does have a significant effect on the ability of the ACS to keep the satellite attitude at its ideal. The time required for Fedsat to cross the Birkeland current regions is of the order of 3 minutes, and the magnitude of the magnetic perturbation associated with these currents of order of hundreds of nT. This is sufficient to produce a deviation in the satellite pointing from the ideal. The distribution of total ACS pointing 'error' above 0.3 degrees traces out the R1/R2 current regions in the polar regions, as well as those currents in the vicinity of the cusp.

Global Field Aligned Currents and Electromagnetic Energy Input

The ionosphere represents the inner boundary of the magnetosphere, the near-Earth space environment. Large electric currents (Birkeland currents) link stresses in the outer magnetosphere with the ionosphere. These field aligned currents (FAC) cannot be remote sensed using ground based magnetometer networks due to their solenoidal structure. Localised or long time averaged (~months) measurements of these currents and associated energy (Poynting flux) have provided limited understanding of the dynamics of magnetosphere-ionosphere interactions, the difficulty being the limited number of spacecraft for in-situ measurements.

Global estimates of the spatial variation of the Birkeland currents are available from the Iridium satellite constellation through collaboration with the Johns Hopkins University Applied Physics Laboratory (JHU/APL). The Iridium LEO constellation comprises over 90 satellites located in 6 equally spaced longitude, polar orbit planes, all at an altitude between 780 and 800 km. The Iridium magnetometers can detect the auroral (Birkeland) FACs. Obtaining the perturbation magnetic field is a complicated process involving subtraction of the main field, correcting for orientation, cross-talk and so on. The perturbation signatures are then processed using a spherical harmonic fit to provide the vector magnetic field and field aligned current pattern over the north and south auroral zones. The over the horizon radars comprising SuperDARN provide data on the electric field in the F region of the ionosphere. Using similar spherical harmonic expansions, the electric field over the auroral zone is obtained. Combining these data sets gives direct global estimates of the Poynting flux into the ionosphere on time scales of ~1 hour.

In addition to SuperDARN and Iridium data, ground magnetometer network data provides the extra information that allows estimates of ionosphere conductivity. Measurements above the ionosphere (Iridium), at the topside ionosphere (SuperDARN at ~300 km), and beneath the ionosphere (ground magnetometers) are combined to produce global estimates of the ionosphere Hall and Pedersen conductivities. Results to date show a variability of up to 8 times in the Hall to Pedersen conductance ratios. The method is limited by the spatial distribution of ground magnetometers. However, conductivity estimates have been obtained in regions where the Birkeland currents enter and leave the ionosphere.

Instrumentation

The Centre has established and operated arrays of induction and fluxgate magnetometers at up to 16 sites in Australia and New Zealand on a campaign basis. In addition, induction magnetometers are operated for the Centre at 6 sites in Antarctica (in cooperation with the Australian Antarctic Division). The induction magnetometers, using magnetic feedback to optimise amplitude, spectral and phase characteristics, and the associated digital data loggers have been designed and constructed within the Centre. They are relatively inexpensive and have also been provided to research groups in India, South Africa and China.

The Centre has obtained 10 low power fluxgate magnetometers developed by Narod Geophysics, Canada. These contain palmtop data loggers and are powered by solar panels and battery. They

are currently used for specific campaigns in central Australia and Antarctica and to provide routine magnetic field observations at Newcastle and Launceston.

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Ionospheric Physics and Geomagnetism

Research has been proceeding in the following areas:

l. Analysis of AWAGS data by spherical cap harmonic analysis to determine changes in the ionospheric current system over Australia
m. Analysis of magnetic data from the Oersted and CHAMP satellites
n. Detailed examination of changes in the Sq current system using AWAGS and other data

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FedSat Research

ITR provides S-band tracking facilities for Australia's FedSat satellite, now owned by the Australian Department of Defence. Instrument and payload data is downloaded daily via the ground station and made accessible to payload research groups.

ITR also operates the Advanced Data Acquisition and Messaging (ADAM) payload on FedSat. The ADAM payload comprises UHF uplink and downlink capability together with on-board storage and processing. Collaborative work over the period with Korean Advanced Institute of Science and Technology has led to a copy of the ADAM payload flying on the Korean ST-SAT 1. Further work developing mobile terminals for the ADAM payload has been conducted with Nanyang Technological University (NTU) in Singapore. The ADAM payload operates in store-and-forward mode to acquire data from ground terminals which may have sensors or other data sources, and then downlink that data via the FedSat data sets at the S-band ground station.

Ground Station Facilities

In addition to operating a 3m diameter S-band ground station facility, ITR also operates a 6.8m X-band ground station for acquisition of earth observation data. In partnership with Raytheon Australia, ITR acquires image data from SPOT satellites. Other opportunities employing different time windows are also pursued from time to time. The X-band ground station uses ITR developed Earth Resource Demodulator technology.

Satellite Demodulators and Ground Station Equipment

ITR continues to work through strategic partnerships with industry to develop and deploy world-leading satellite demodulators. Our Earth Research Demodulator technology is marketed through Satellite Services BV (the Netherlands) and we are funding through the Australian Research Council Linkage Scheme to develop Gbit demodulator technology for next-generation satellite demodulators.

ITR licenses its turbo-coding technology through a spin-off company Iterative Connections. Recent partnerships have seen uptake of this technology and have led to the development of new communication satellite modems using its S-TEC product.

On-board Satellite Technology

ITR has been working closely with Cisco Systems to explore new satellite systems employing inter-satellite links. Methods for managing transient links have been developed to maximize the availability of cross-satellite transport and networking, with an aim to reduce critical packet delay in low-earth orbiting satellite constellations.

In collaboration with other overseas partners, ITR has been exploring new on-board processors for digital video broadcasting applications.

International

ITR has maintained a strong connection with the International Space University since its successful SSP in Adelaide in 2004. ITR continues to contribute teaching staff for the SSPs in the satellite communications program.

ITR has continued its connection with the Asia Pacific Regional Space Agency Forum through contributions to the 2004 and 2005 annual meetings of the Communication Satellite Applications Working Group. The ITR Director co-chaired the 2004 APRSAF forum in Canberra.

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UNIVERSITY OF SYDNEY
Space Physics at the School of Physics

1. Introduction

Space Physics is a major research focus at the School of Physics, University of Sydney. The primary research team has four senior academics, Professor Iver Cairns (an ARC Australian Professorial Fellow), Professor Peter Robinson (an ARC Federation Fellow), Professor Serguei Vladimirov (an ARC Australian Professorial Fellow) , and Dr Zdenka Kuncic. As of June 2006 this team includes four postdoctoral scientists (Drs Bo Li, Eun-Hwa Kim, Yuriy Tyshetskiy, and Xingqiu Yuan), three PhD students (Amaal Mohamed, Jeremy Mitchell, and Alix Nulsen), and a visiting postgraduate student (Magali Florens). Dr Ben McMillan recently took up a postdoctoral position in Switzerland. Another postdoctoral fellow is expected to join in late 2006 to work on space weather, as are two new PhD students. Professor Robinson is Director of the University of Sydney's Center for Wave Science, of which Prof. Cairns is also a member. The team works on multiple facets of space physics, focusing on the detailed plasma physics of the growth of plasma waves and radiation, on particle acceleration at shocks and in reconnection regions, on solar system radio emissions associated with shocks, and the effects of dust and generation of complexity in plasmas. Applications include solar and interplanetary radio bursts, solar and magnetospheric magnetic reconnection regions and space weather. Several members of this team also work in theoretical plasma astrophysics, specifically pulsar physics and the statistics of astrophysical emissions.

The second team includes Dr Michael Wheatland (an ARC Queen Elizabeth II Fellow), Professor Donald Melrose (an ARC Professorial Fellow) and postdoctoral fellow Dr Paul Watson. Their interests are primarily in solar physics, specifically the statistics of solar X-ray bursts, development of magnetic structures, and magnetic reconnection. Professor Melrose also has widespread interests in plasma astrophysics. Profs Cairns and Melrose share supervision of PhD student Nulsen.

This report summarizes the progress made during the period 2004 - 2006, including the scientific papers published or submitted for publication, and professional service and awards.

2. Research Progress

Major progress was made in developing and understanding theories for bursty wave growth, the applicability of stochastic growth theory (SGT) to plasma waves in many regions of space, type II and III solar radio bursts, plasma waves and radio emissions in planetary foreshocks, radiation from the outer heliosphere, the nature and conditions for nonlinear processes involving Langmuir and low frequency MHD-like waves, linear mode conversion, critical phenomena involving the growth and damping of plasma waves, and new theories for particle acceleration and heating. This research involves analytic and numerical plasma theory, numerical simulations, analysis and interpretation of spacecraft data, and comparisons between theory and observation. In addition, significant time was devoted to identifying important research questions that could be answered using data from NASA’s upcoming STEREO spacecraft (for which Drs Cairns and Robinson are Co-Investigators on the radio and plasma wave instrument SWAVES) and the recently funded LOFAR (Low Frequency Array Radio, in Holland) and Mileura Widefield Array (MWA) Demonstrator (sometimes called the Low Frequency Demonstrator or LFD; located at Mileura in Western Australia) radio telescopes.

2.1 Theories for Wave Statistics

2.1.1 Basic Theory

f. Robinson et al. [2004] published a new theoretical analysis which extends and combines previously separate theories for wave growth, Stochastic Wave Growth (SGT) and Elementary Burst Theory (EBT). The new theory predicts new constraints for when the growth should be bursty and stochastic, as well as new predictions for the lognormal properties of the wave statistics. An extended paper is currently being written up.

g. Hole et al. [2004, 2006] published the first analytic and numerical predictions for the probability distributions of the standard Stokes parameters, and the degrees of linear and circular polarization, for one or multiple populations of stochastically growing waves. Future applications include solar radio bursts and pulsar radio emissions.

- Li et al. [2006a,b] have developed a new quasilinear simulation code for the self-consistent interaction of electrons and Langmuir waves in an inhomogeneous background plasma. The inhomogeneities include a regular/monotonic gradient in density and turbulent inhomogenities evolved using standard wave equations. The new results show that bursty Langmuir waves are produced, with the lognormal statistics produced by SGT and the new generalized theory [Li et al., 2006a]. The new code has also produced the first multi-scale simulations of type III solar and interplanetary radio bursts, as described more in Section 2.2.2.
- Analytic and numerical theoretical analyses of the field statistics and correlation functions of bursty waves are ongoing, using stochastic differential equations to produce field time series and then various sampling schemes to investigate the effects of spatiotemporal inhomogeneities such as wave clumps. Deviations from lognormal statistics due to clumping and sampling issues are found under various conditions, and may mimic the effects of nonlinear processes at high fields and convolution with multiple wave populations at low fields, thereby perhaps changing some previous interpretations. The results are being written up for publication by student D. Konkolewicz, and Profs Cairns and Robinson.

2.1.2 Widespread applicability of SGT

- Cairns et al. [2004a] analyzed the variability of pulsars B1641-45 and B0950+08, both from pulse to pulse at a given phase and also from phase to phase in a given pulse, and found consistency with SGT (lognormal statistics) at most phases. However, power-law statistics reminiscent of giant pulses were found in a few narrow phase ranges, and weak evidence for nonlinear processes were found. While the role of Lorentz boosting still requires detailed analysis, these analyses extend SGT's applicability to the normal pulsed emission from pulsars, the archetypal astrophysical example of coherent emissions, and also to freely propagating electromagnetic radiation.
- Analyses of giant pulses and giant micropulses from pulsars were found to have power-law statistics [Cairns, 2004a], so that not all emissions are directly consistent with SGT. The most probable interpretation is that wave collapse produces the giant pulse phenomenon, although the role of Lorentz boosting requires further examination.
- Boshuizen et al. [2004] analyzed the statistics of Langmuir waves driven by electron beams in the foreshocks of Earth, Saturn, Uranus and Neptune. Averaged over foreshock location, the statistics are power-laws with low index close to -1.0 that are inconsistent with wave collapse. Crucially, scaled by the thermal plasma energy density, it is found that the results from all the planets overlie each other and, moreover, that the data are consistent with convolution over foreshock depth of the lognormal statistics predicted by SGT based on Earth data. These results support SGT and argue that the same physics is relevant in all planetary foreshocks.
- Drs T. Lotoaniu (also known as Dr P. Manusiu) and Prof. B.J. Fraser (U. Newcastle) are working with Dr Cairns on the statistics of Pc1 events in Earth's magnetosphere. While broadly lognormal the statistics have deviations therefrom at small fields, perhaps due to convolution and sampling/clumping effects (see last item in Sect. 2.1.1).
- Dr Cairns worked with Drs M. Samara and J. Labelle (Dartmouth College, USA) and Dr R. Treumann (Max Planck – Lindau. Germany) on bursty Langmuir waves driven by electron beams in Earth's auroral regions. Broadly lognormal statistics were found and a paper submitted for publication.

- This research shows that SGT is widely applicable in space plasmas and some astrophysical plasmas, applying in all but one context considered to date.

2.2. Theories for Radio Emissions

Radio emissions associated with shock waves are common in our solar system. A foreshock is the region upstream of and magnetically connected to a shock waves, thereby containing energized particles reflected and accelerated at the shock, as well as the plasma waves and radio emissions generated by these particle. Foreshocks are a common theme in our current research program since type II solar radio bursts and the 2-3 kHz radio emissions observed by the Voyager spacecraft in the outer heliosphere are most likely generated in foreshock regions upstream of traveling shock waves, and so are qualitatively similar to the radio emissions generated in Earth's upstream of Earth's bow shock, for which abundant spacecraft data exist.
We also worked on radio emissions associated with electron beams released during solar flares, the so-called type III solar radio bursts, and on other solar radio bursts.

2.2.1 General Theory

Melrose and McPhedran [2005] published a book on electromagnetic processes in dispersive media.

2.2.2 Type II Radio bursts in the Corona and Solar Wind

- Knock and Cairns [2005] predicted dynamic spectra for a type II shock interacting with coronal structures like loops and interplanetary structures like CIRs and CMEs. The theory appears able to account for some fine structures observed on type II bursts, including multiple lane events, both broad- and narrowband events, and different behaviours for shock fronts moving along or transverse to the local magnetic field.
- Mitchell et al. [2005a] generalized the type II code to include additional nonlinear Langmuir wave processes involving scattering off thermal ions (rather than just those involving the electrostatic decay) and considered the implications for type II bursts and the outer heliosphere (see section 2.2.4) . They showed that the electrostatic decay process dominates under most conditions and that including both processes leads to radiation fluxes larger by less than a factor of 2 for electrostatic decay only.
- Cairns and Knock [2006] predicted how the source region and dynamic spectra of a type II burst would appear for multiple, widely separated observers, thereby positioning us for NASA's STEREO mission. Reviews of associated theoretical issues include those of Aschwanden et al. [2006] and Cairns [2004b].
- French Masters student M. Florens and Dr Cairns have developed realistic ecliptic plane models for the solar wind based on spacecraft data and have incorporated them into the Knock type II code. The solar wind models appear useful for understanding the 2D structure of the solar wind, e.g., for space weather studies, while the resulting dynamic spectra appear rather similar to the observations. Further research is proceeding and the results will be written up for publications.
- PhD student A. Mohamed is working with Drs Cairns and Robinson on absolute flux spectra for type II bursts and their comparison with the type II theory's predictions. A paper is expected to be submitted in 2006.

2.2.3 Type III Radio bursts in the Corona and Solar Wind

Type III solar radio bursts are well modeled by our new quasilinear simulation code for the self-consistent interaction of electrons and Langmuir waves in an inhomogeneous background plasma (including a regular/monotonic gradient in density and turbulent inhomogenities evolved using standard wave equations). In the first multiscale simulations Li et al. [2006a,b] show that the bursty Langmuir waves produced have lognormal statistics, thereby being consistent with SGT, and are closely analogous to those observed.
Li et al. [2005a] included the nonlinear Langmuir processes responsible for radio emission at twice the electron plasma frequency into the quasilinear code and showed that significant emission is predicted. Li et al. [2005b] generalized this new code to include emission near the electron plasma frequency, again showing that significant emission is predicted.

Li et al. [2006a,b] simulated the electromagnetic emission of type III bursts, focusing on the generation and propagation of the radiation for the generalized quasilinear code (including both nonlinear processes and inhomogeneities. Ongoing research is producing the first predicted dynamic spectra and initial attempts to predict quantitative fluxes.
Foroutan et al. [2005] developed a refined gasdynamic model for electron propagation and Langmuir wave growth in type III bursts, resolving several controversies and showing that the electron results are very similar to those from the Li et al. quasilinear code. A second paper [Foroutan et al., 2006], that includes the effects of turbulent inhomogeneities, has been submitted for publication.
Nulsen et al. [2006] analyzed the field statistics and detailed shapes of Langmuir wave packets in type III sources near 4 AU. They show that the wave packets come in two classes, neither of which are consistent with strong turbulence wave collapse while one (the less localized waves) are consistent with SGT. The remaning class, of intense localized structures, is inconsistent with pure SGT and most likely corresponds to waves trapped in density irregularities with intensities that are below the collapse threshold.

2.2.4 Solar radio bursts: Types I, IV, V and metric spike bursts

- A number of important theoretical issues remain for the acceleration of the type III electrons and the generation of Type I, IV, V, and metric spike bursts. Reviews of these issues and the theory were published [Cairns, 2004b; Aschwanden et al., 2006], including discussion of how the proposed LOFAR and MWA radio telescopes and STEREO spacecraft might allow these issues to be resolved.
- Melrose [2005a] reviewed the theory of electron cyclotron maser emission in astrophysical plasmas, including the corona and planetary magnetospheres.

2.2.5 Radiation from planetary foreshocks and magnetic anomalies on moons

- Kuncic et al. [2004] generalized the type II theory to Earth's foreshock radiation, showing that the theory appears consistent with available data, typically predicting fluxes within a factor of about 5-10 of those observed. The theory also predicts the average level of Langmuir waves in the foreshock. Detailed comparisons with Geotail and other spacecraft data, with Dr Y. Kasaba (ISAS, Japan), were performed and need to be written up for publication.
- Kuncic and Cairns [2004] extended the foreshock model to magnetic anomalies on the Moon and predicted that detectable levels of emission should be produced. Such radio emissions (especially for moons around other planets) could be a remote diagnostic for the presence of magnetic anomalies, and associated magnetic shielding from cosmic rays (cf. life on Europa, for example).
- Kuncic and Cairns [2005] predicted the levels of foreshock radiation at all the planets in our solar system and compared them with noise limits for missions like Cassini, Bepi-Colombo, and Galileo. Observable levels of emission are predicted.

2.2.6 2-3 kHz radiation from the outer heliosphere

1. Mitchell et al. [2004] and Cairns et al. [2004b] combined the Cairns and Zank priming theory with Knock et al.'s theory for type II bursts in order to predict the level and dynamic spectrum of radiation produced by a GMIR shock moving from the 10 AU to beyond the heliopause. The radiation is found to be primarily fundamental radiation with levels of order those observed and a dynamic spectrum that closely resembles one of the observed classes of radiation event.
2. Recent Voyager data from Kurth & Gurnett show that the radio source region appears along an approximately linear band on the sky, roughly parallel to the galactic plane. Cairns [2004c] argued that magnetic draping is expected to lead to the magnetic field being enhanced in an approximately linear band aligned with the local magnetic field direction, based on intuition and simple convected-field arguments. He then argued that the Priming/GMIR theory appears consistent with the Voyager data and that the magnetic field in the local interstellar medium is parallel to the galactic plane.
3. Cairns [2004d] reviewed the observations and theories for the 2-3 kHz radiation, summarizing a number of unresolved issues and directions for further research.

4. Mitchell et al. [2005b] predicted that the brightness of the 2-3 kHz emissions should vary with the solar cycle, due to variations in the properties of both pickup ions and GMIRs,. They found that the emissions should be most observable a few years after solar maximum, consistent with existing observations.
5. Mitchell et al. [2006] also worked quantitatively on draping of the interstellar medium's magnetic field over the heliopause, predicting how the draping region's shape and characteristic magnetic amplification factor should vary with orientation of the interstellar magnetic field. Cairns et al. [2006] used these calculations and constraints on the priming theory to place limits on the interstellar magnetic field: it should exceed 0.03 nT.
6. Work is proceeding on quantitatively evaluating the priming mechanism, including prediction of the distribution function of pickup ions by Liouville methods and quasilinear simulation of the lower-hybrid drive process in which pickup ions generate lower hybrid waves which then resonantly accelerate a superthermal tail on the electron distribution. See Section 2.3.1 for related work.

2.3 Particle Acceleration and Plasma Waves

2.3.1 Particle Acceleration in Reconnection Regions

How electrons are accelerated and both ions and electrons are heated in magnetic reconnection regions remains one of the fundamental unsolved issues in space physics, plasma physics, and astrophysics. Cairns and McMillan [2005] proposed a new and natural model based on lower hybrid (LH) waves generated by spatial inhomogeneities in reconnection regions: electrons are resonantly accelerated parallel to the magnetic field by the electric fields of LH waves (the so-called LH drive process) generated by the lower hybrid drift instability (LHDI). Analytic theory and quasilinear simulations show that the LHD/LHDI model should accelerate electrons from the thermal energy to greatly superthermal (even relativistic) parallel energies, while ions are heated perpendicular to the magnetic field. The model appears qualitatively consistent with Wind spacecraft data for magnetotail reconnection.

McMillan and Cairns [2006a] proposed and simulated a second mechanism for electron and ion acceleration/heating in reconnection regions, again involving LH drive but with LH waves driven by the parallel electron drift expected in reconnection regions. The simulations show that the mechanism proceeds effectively and appears to be a better explanation of LH waves and electron acceleration found in other works. PIC simulations presented in a second paper [McMillan and Cairns, 2006b] strengthen and extend the quasilinear results.

PhD student Nulsen is working with Cairns and McMillan to further examine LH drive via quasilinear simulations and to apply the results in solar and magnetospheric environments.

2.3.2 Particle Acceleration at Shocks

Melrose [2005b] considered the generation of nonresonant Alfven waves by cosmic rays and the associated constraint on acceleration of cosmic rays.

Postdoctoral fellow Yuan is working with Cairns and Robinson on electron acceleration at shocks. A paper demonstrating the important role of magnetic overshoots on electron reflection and leakage, using test-particle simulations for prescribed shock profiles, as well as the likely importance of shock reformation and associated time variations in the upstream electron distribution, has been submitted for publication [Yuan et al., 2006]. Another, larger paper is being written.

Yuan has written a new 2-D hybrid simulation code for simulating reformation processes, as well as a Liouville code for calculating upstream and downstream electron distributions more rapidly than using test-particle simulations. These two codes are being combined to predict the time-varying electron distributions in the foreshock.

Cairns is working with Yuan and Dr N. Omidi (Solana Scientific, USA) on the new phenomenon of solitary shocks, focusing on the electron physics.

2.3.3 Linear mode conversion

1. Linear mode conversion involves Langmuir energy being converted into o-mode energy at a density gradient. We investigated theoretically the efficiency of linear mode conversion in non-monotonic density gradients when averaged over the range of incident angles and wavelengths and density scale lengths in the plasma. Cairns and Willes [2005] showed that averaging reduces the conversion efficiency by a factor of order c/V, where V is the electron thermal speed, in 2-D and by this factor squared in 3-D. For the solar wind at 1 AU the efficiency is then of order 5 orders of magnitude smaller than the peak unaveraged efficiency of order 50%.
2. Postdoctoral fellow Kim is working with Cairns and Robinson on fluid simulations of linear mode conversion. Foci are the effects of magnetization, damping, and wave packet shape on the conversion efficiency.

2.3.4 Nonlinear processes in plasmas, including dusty plasmas

1. In a warm plasma, the parallel modes can interact with transverse and acoustic modes. A tenth-degree polynomial dispersion equation was obtained, describing the interaction of the pump with two acoustic modes and sideband-beatwaves [Hertzberg et al., 2004a]. In the low temperature regime the effect of a second ion (dust) species is to reduce the usual modulational instability, and a new decay instability arises. In the high temperature regime two new decay instabilities, narrow in wavenumber, were found.
2. When considering parametric instabilities, it was found that pairs of slow and fast parallel propagating modes are parametrically excited [Hertzberg et al., 2004b].. The growth rates of the various interactions were calculated and it was shown that the growth rates of slow–fast and fast–fast mode interactions can be maximized by varying the proportion of negative charge on the dust. Furthermore, both the ion-like species (including dust) were allowed to be fully mobile. The collection of charge by the dust from the background neutral plasma modifies the dispersion properties of the pump and excited waves. The introduction of an extra mobile species adds extra modes to both these types of waves. We investigated the pump wave in detail, in the case where the background magnetic field is perpendicular to the direction of propagation of the pump wave. Then we derived the dispersion equation relating the pump to the excited wave for modes propagating parallel to the background magnetic field. It was found that there are a total of twelve resonant interactions allowed, whose various growth rates are calculated and discussed.

2.3.5 Complex systems research involving waves and plasmas

Ivanov et al. [2004] showed that Landau damping is a critical phenomenon, similar to a phase transition, with exponential damping below an initial threshold amplitude but multiple damping/growth phases that lead to a finite wave amplitude above this threshold. oscillation Ivanov and Cairns [2006] demonstrated that wave trapping is not responsible for the critical phenomenon.
Ivanov et al. [2005] considered the behavior near marginal stability for a beam-plasma system, again showing the behaviour to be a critical phenomenon representative of a new universality class.

2.4 Solar magnetic fields, CMEs, and flares

2.4.1 Solar magnetic fields

1. The energy release in solar flares has been investigated, emphasizing the role of currents inferred from vector magnetograms, and the constraints of current and helicity conservation [Melrose, 2004a,b].
2. The global energy balance in the solar corona is addressed in a paper [Litvinenko and Wheatland, 2004] produced in collaboration with Dr Yuri Litvinenko (University of New Hampshire). Wheatland and Metcalf [2006] addressed the energy of solar active regions.
3. A paper demonstrating the relative accuracy of simple circuit estimates of coronal magnetic fields (Wheatland & Farvis 2004) has been accepted for publication in Solar Physics. It presents the surprising result that circuit estimates are inaccurate for large values of current,

because of the influence of the magnetic field due to the current on the path taken by the current. However, circuit estimates are accurate for smaller values of current. These findings will be useful for future determination of the energies of solar active regions.

4. A new parallel method of computation of nonlinear force-free fields has been developed, implemented in code, and tested on a variety or parallel computers including the ac3 cluster at the Australian Technology Park [Wheatland, 2004a]. It uses a mathematically well-founded current-field iteration technique. The method will soon be applied to vector magnetic field data for active regions on the Sun, which should lead to accurate estimates of magnetic free energy.
5. Litvinenko and Wheatland [2005] developed a dynamical model for formation of filaments in the solar corona.
6. The modeling of force-free magnetic fields was investigated by quantifying various approaches using known solutions [Barnes et al., 2006] and comparing various nonlinear models [Schrijver et al., 2006], both in collaboration with overseas colleagues.

2.4.2 Statistics of CMEs and solar flares

7. A new method for solar flare prediction was developed [Wheatland, 2004b], based on the application of Bayesian inference to observed solar flare statistics in active regions. The method "refines" an initial prediction for the probability of occurrence of a large flare during a period of time by consideration of the number and size of flares already observed in an active region. The initial prediction may come from any of a number of conventional flare prediction schemes. Discussions are proceeding with the Ionospheric Prediction Service in Sydney concerning their needs for flare prediction.
8. Initial tests of the Bayesian method for solar flare prediction [Wheatland, 2005a] were extended into a method for forecasting solar flares [Wheatland, 2005b] and then used to test whether ``sympathetic'' solar flares exist [Wheatland, 2006].
9. Work with Professor Peter Sturrock (Stanford University) on solar neutrino time series has lead to the recent submission of two papers, one on methods of combining power spectra [Sturrock et al., 2005] and the other on the analysis of Super-Kamiokande solar neutrino data [Sturrock et al., 2006].

2.5 Other Space Physics Topics

2.5.1 Shock models and location in Earth's foreshock

Models for the 3-D shape and location of Earth's bow shock are important for determining a spacecraft's location in the foreshock and so the properties of electron beams, Langmuir waves, and radio emissions as a function of foreshock location and solar wind conditions. Accordingly we analyzed and interpreted 3-D global MHD simulations of the magnetopause's interaction with the solar wind. The IMF direction was shown to have dramatic effects on the bow shock's shape and symmetry axis for low M_A [Chapman et al., 2004]. Specifically, due to the fast mode speed (and so the Mach cone) varying with these parameters in an asymmetric fashion, the shock was shown to become asymmetric for low M_A < 5. These effects are predicted to be observable.
Chapman and Cairns [2005] compared the new shock models with spacecraft observations, using both case studies and statistical analyses: the new models agree very well statistically in their expected domains of applicability, although finite propagation times and the relative paucity of stationary observations of the shock (typically it moves across the spacecraft) make the quantitative agreement relatively poor in case studies.

2.5.2 Waves in Earth's foreshock

Generation of waves below the electron plasma frequency has been a longstanding issue. Lobzin et al. [2005] presented a new model for this, involving wave generation by a loss cone instability rather then the beam instability considered before. The required loss cones are expected theoretically and observed, and the mechanism looks very attractive.
Cairns is working with Drs Krasnoselskikh and Lobzin (Orleans, France) and Lucek (Imperial College, UK) on new Cluster II spacecraft data which suggest that multiple electron

populations and acceleration processes exist and produce the multiple classes of waves observed in the foreshock. Results to date show that SLAMS are not important in producing Langmuir waves and associated electrons in Earth's foreshock.

2.5.3 Density turbulence in the outer heliosphere

Student Bellamy worked with Cairns and Dr C.W. Smith (U. New Hampshire, USA) to calculate the spectra and levels of density turbulence in the outer heliosphere, from 1 to 60 AU, using data from the Voyager spacecraft. The results show significant evolution with heliocentric distance, including a relative rise in the level beyond the orbit of Uranus that is very plausibly associated with pickup ions [Bellamy et al., 2005]. This turbulence should lead to significant scattering of the outer heliospheric radiation, research on which is ongoing.

2.5.4 Space Missions

The Sydney Group is interested in space missions, being the primary theoreticians for the SWAVES instrument on STEREO, and in the MWA radio telescope. They are playing a major role in the development of Australia's first Decadal Plan for Space Science. This includes investigating possible opportunities for the Australian community and the Sydney Group to participate in space missions [Yau et al., 2006].

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UNIVERSITY OF WESTERN AUSTRALIA

The first Southern Hemisphere User Group for the European Space Agencies (ESA) Atomic Clock Ensemble in Space (ACES) Mission

Funded by ESA, ACES is one of the most exciting microgravity physics experiments ever conceived and will involve many institutes worldwide. ACES will take the new generation of atomic clocks to space on board the International Space Station in 2010, where the perturbation of the Earth's gravitational force is almost totally removed. A Caesium cold atom clock (PHARAO) and a Space Hydrogen Maser will be characterised and intercompared and will be linked to national frequency standards across the world using a specially developed Microwave Link. This will represent the most precise synchronization of time worldwide, which has many technological and fundamental physics applications. The ultimate performance of PHARAO in a microgravity environment will be explored and a number of exciting experiments and tests across various domains of applications will be performed. Some fundamental physics experiments include: 1. Gravitational Frequency Shift (Einstein effect). 2. Time Variation of the Fine Structure Constant. 3. Test of Special Relativity.

There are two basic requirements for a User Group to participate successfully in the mission: First, a local ensemble of precision oscillators and clocks, which are sufficiently stable for a meaningful comparison with the worldwide network; and second, experience and expertise in ultra-high accuracy long-distance time transfer techniques. In Australia two groups satisfy the first requirement: the FSM research group at UWA, and the National Measurement Institute (NMI) at Lindfield in Sydney. Both groups offer access to some of the most precise clocks in the world, and their expertise and infrastructure complement one another very well. NMI has substantial practical experience in time transfer technology and data analysis, satisfying the second requirement.

From 2005-9 the FSM and NMI groups have been funded via the Australian Research Council's Infrastructure and Discovery schemes as the only Southern Hemisphere User Group, which is a vital addition to the ACES collaboration. It will guarantee orbitography and enable monitoring of the ACES clocks at times, which are impossible from the Northern Hemisphere, which is crucial for several of the research goals. Truly global coverage will help to offset any bias introduced by the many Northern Hemisphere centres. Consequently, an Australian User Group has the potential to make a significant and high profile impact of international importance, maintaining and enhancing Australia's reputation for excellence in space research.

Funding has been obtained to development apparatus to compare clocks across the continental baseline of Australia; using both GPS carrier phase as well as two way satellite time and frequency transfer (TWSTFT) techniques. Both groups possess hydrogen masers and caesium beam clocks and are developing cold atom/ion clocks. The UWA group is developing a new liquid-helium cooled ultra-stable Whispering Gallery (WG) mode sapphire cryogenic oscillator (CSO) based on a 51mm diameter HEMEX sapphire cylinder, with state-of-the-art control electronics. A microwave synthesis chain has been developed that combines the output of the H-Maser and the CSO to generate signals across the RF and microwave domain that exhibit the best properties of each of the reference oscillators. The NMI group has an earlier generation liquid-helium cooled CSO, that operates on a 30mm diameter sapphire, which is used as a stable local oscillator for their ytterbium cold ion clock.

At the time of writing, equipment for both GPS and TWSTFT links is being commissioned and tested, and we anticipate that preliminary transfer results will be available later in 2006. The experience gained from this collaboration is essential for the UWA-NMI team to be ready for the Atomic Clock Ensemble in Space (ACES) mission, and will enable preliminary comparisons of remote clocks. Also, a demonstration for an extended period by comparison with a parallel TWSTFT link with a GPS carrier phase link will be essential in order to be confident that ionosphere, atmospheric and other effects associated with the geographic separation of the two laboratories are optimally accounted for in the data processing.

Related publications 2004-2006

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