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Solar physics research in Australia

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Abstract. Australia has a small but world-class solar physics research community, with strong international ties, working in areas of particular strength defined by the research interests of individuals and small groups. Most research occurs at the major universities, and a small number of Ph.D. students are trained in the field each year. This paper surveys Australia's current contribution to solar physics research, and the prospects for future development of the field.

Keywords : Sun: general – history and philosophy of astronomy

1. Introduction

Historically Australia has made major contributions to research in solar physics. Early observational work was at the Commonwealth Solar Observatory, which became the Mount Stromlo Observatory near Canberra, and the solar observational work was incorporated into what became the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The CSIRO group was led by Ron Giovanelli, who built a solar optical observatory at Culgoora in New South Wales. A second group in the CSIRO led by Paul Wild built a solar radioheliograph at Culgoora. Australia was a world leader in the early decades of radio astronomy, in particular in solar radio astronomy. There was a golden era for Australian solar astronomy in the 1970s, when the IAU General Assembly was held in Sydney in 1973, and two associated IAU Colloquia were organized by the two CSIRO groups. During this early period, with few exceptions, observational solar astronomy was carried out in the CSIRO (an exception being Bill Ellis' group at the University of Tasmania), and supporting theoretical work

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was based in the universities (an exception being Jack Piddington in the CSIRO). The early research in solar physics is well documented in books (Bray & Loughhead 1964; Bray et al. 1991; McLean & Labrum 1985) and review articles (Wild, Smerd & Weiss 1963; Wild & Smerd 1971; Wild 1987).

Today Australia does not have a major solar observing facility. Routine solar observations are still made at Culgoora in New South Wales and Learmonth in Western Australia for space weather and ionospheric prediction purposes. Learmonth also hosts one of the six *Global Oscillations Network Group* (GONG) instruments providing high resolution helioseismic Doppler data as well as magnetograms and Hα images. Solar radio observations in Australia are currently restricted to routine monitoring (*e.g.*, the radiospectrograph at the Culgoora Observatory monitors solar radio bursts), but there is the prospect of a new era with the introduction of the Murchison Widefield Array (see Section 3). The observational situation may be contrasted with the wider field of astronomy, in which Australia has major ground-based observatories, in particular for observational radio astronomy. Australia's privileged position in the southern hemisphere and vast radio-quiet outback has naturally favoured funding and development in areas of astronomy other than solar.

The major groups in the CSIRO were closed down in the 1980s, and the emphasis in solar physics research shifted to the universities with a focus on theory and computation. There was a thriving *Solar Physics Association of Australia* (SPAA) in the 1980s. The early theoretical groups at Monash University led by René van der Borght, and at Sydney University led by Peter Wilson, plus a second group led by Don Melrose, have evolved into the present-day centres for solar-physics research in the universities. The current state of the field in the country is that a small number of researchers work in specific areas defined by the research interests of the individuals and their international collaborations. The work is funded by the universities and by the Australian Research Council.

This short paper summaries the current situation, listing the institutes and individuals involved in solar physics research in Australia. Here we broadly define solar physics research to be work on physical processes occurring at, or directly related to those occurring at, the Sun, consistent with the focus of the Asia-Pacific Solar Physics Meeting. The main solar physics research groups in Australia and their areas of interest are identified, and then prospects for the future of the field are discussed, with emphasis on the Murchison Widefield Array (MWA) being built in Western Australia.

2. Research groups in solar physics in Australia

Australian solar researchers are currently located at the University of Sydney, Monash University in Melbourne, and at James Cook University in north Queensland. Beyond solar physics *per se*, there is also strong interest in the heliosphere and solar-terrestrial physics, as well as work in related fields, including upper atmospheric physics, magnetospheric physics, and cosmic ray physics.

2.1 Sydney

Solar physics research at the University of Sydney is carried out in two groups based in the School of Physics.

One group including Don Melrose, Dave Galloway, and Mike Wheatland has particular interests in the theory and modelling of solar magnetic fields and solar activity, as well as broader interests in theoretical astrophysics and fundamental plasma physics. Don Melrose's main research interests are now non-solar, although he maintains an active interest in the theory of solar flares (Melrose 2009). Mike Wheatland works on modelling coronal magnetic fields (Wheatland 2011) and on understanding solar flare statistics (Wheatland 2000), as well as having broader research interests e.g. in Bayesian probability (Wheatland 2010). He currently has two PhD students working on projects in solar physics. Dave Galloway has a particular interest in the solar dynamo, as part of a wider interest in MHD modelling (Galloway & Weiss 1981). The international solar physics collaborations of the group include collaborations with Lockheed Martin Space and Astrophysics Laboratory in Palo Alto, NorthWest Research Associates in Boulder, and with Ian Craig and Yuri Litvinenko at the University of Waikato in New Zealand.

The second group at the University of Sydney, led by Iver Cairns and Peter Robinson, has particular interests in solar physics as part of a wider interest in space plasma physics and solar system phenomena. This research focuses on the growth and propagation of plasma waves and radio emissions associated with electron beams and shock waves in sources that range from the Sun's corona and solar wind to Earth's ionosphere and the boundaries of the solar system. The group includes postdoctoral fellows Bo Li, Vasili Lobzin, Joachim Schmidt, and Kunwar Singh plus 7 current postgraduate students, with another 2 PhD students graduated in the first half of 2011.

Recent solar physics research includes the following, in addition to work on MWA discussed in Section 3 (Oberoi et al. 2011). First, robustly detecting type II and III solar radio bursts in near real-time Culgoora and Learmonth data using ARBIS, the new Automatic Radio Burst Identification System (Lobzin et al. 2010) for prediction of future space weather events at Earth with partner IPS Radio and Space Services. Second, using novel techniques to infer the density profiles deep in the corona from the frequency-time profiles of type II and III bursts, so as to address the origin, heating, and acceleration of the coronal plasma and solar wind (Cairns et al. 2009; Lobzin et al. 2010). Third, developing quantitative theoretical models for type II solar radio bursts (Cairns 2011), that combine detailed models of plasma physical processes (such as electron acceleration at shocks) with detailed models for the spatially varying coronal and solar wind plasma and the propagation of shocks. Fourth, developing detailed simulation-based theoretical models for type III bursts that allow the effects of localized spatial structures in temperature (and soon the density) on the plasma microphysics and remotely-observed radio spectrum to be predicted and compared with observations (Li, Cairns & Robinson 2010). These show promise for explaining fine structures in type III bursts. Fifth, examining the effects of spatial variations in density turbulence and the background density profile on the angular scattering, propagation, and escape of radiation from the source plasma, with applications to both type II and III bursts (Subramanian & Cairns 2011). Finally, developing new understandings of plasma microphysics, such as radio emission from eigenstates of Langmuir waves trapped in density wells (Malaspina, Cairns & Ergun 2010) or from Langmuir waves undergoing linear mode conversion in density gradients (Kim, Cairns & Robinson 2007). The above research includes collaborations with colleagues in Australia (Curtin U. and IPS Radio and Space Services), China (National Astronomical Observatories China), Germany (Potsdam Astrophysikalishe Institut), India (IISER Pune), and the USA (Harvard Smithsonian CfA, MIT, Princeton, U Colorado Boulder).

2.2 Monash

The Monash Centre for Astrophysics (MoCA) is a top-rated astrophysics research centre, scoring a maximum 5 in the 2010 *Excellence in Research for Australia* (ERA) government research assessment exercise. It has wide interests in stellar, galactic, and solar astrophysics. MoCA's solar group, *Clique du Soleil*, consists of permanent staff Paul Cally and Alina Donea and a changing cast of postdocs and students. Jesse Andries (Leuven, Belgium), who works in coronal seismology and wave theory, recently spent two years at Monash on an EU Marie Curie Fellowship. The group has a major focus on practical and theoretical local helioseismology, associated with both quiet and active regions, and wider interests in MHD wave theory, tachocline stability, and flares (studies of populations of particles accelerated from flares, simulations of impact of flares on the chromosphere and photosphere). Data from SOHO/MDI, SDO/HMI, RHESSI, GONG, and other instruments are extensively used by the group. Research highlights from the *Clique* include an extensive development of the theory of MHD mode conversion, and the discovery of many new sunquakes. Papers of central importance include Cally, Crouch & Braun (2003), Schunker & Cally (2006), Donea & Lindsey (2005), and Donea et al. (2006), with many subsequent developments. Research partners include the High Altitude Observatory (HAO) and Colorado Research Associates (CoRA) in Boulder Colorado, the Space Sciences Laboratory (SSL) Berkeley, the Max Planck Institute for Solar System Research (MPS) in Germany, the Instituto de Astrofísica de Canarias (IAC) in Spain, the Institute of Geodynamics of the Romanian Academy, and the University of Hawaii.

Monash doctoral graduates since 2003 currently working in solar physics include Ashley Crouch (CoRA), Hannah Schunker, Ray Burston, and Hamed Moradi (MPS), Diana Beşliu-Ionescu (Romanian Academy), and Juan Carlos Martinez-Oliveros (SSL

Berkeley). Hamed Moradi will return to Monash as a postdoctoral researcher in September 2011.

2.3 James Cook

Dr Aimee Norton, previously of HAO and the National Solar Observatory (NSO), is now a lecturer and researcher with the Centre for Astronomy at James Cook University in Townsville, Queensland. Her interests include the sunspot cycle and the solar dynamo, magnetohydrodynamic waves in the solar atmosphere, the development of instruments to observe solar magnetic fields, and the Sun-Earth connection. Aimee maintains collaborations with Stanford University and NSO, and is currently supervising three PhD students.

3. Murchison widefield array

Australia is currently undertaking a huge investment in radio astronomy that will be multiplied manyfold if it is chosen in 2012 as the site of the Square Kilometre Array (SKA). Amongst this new generation of instruments is the Murchison Widefield Array (MWA), co-located with the Australian Square Kilometre Array Pathfinder (ASKAP) at the Murchison Radioastronomy Observatory (MRO), 315 km north east of Geraldton in Western Australia. MWA is an international project led by MIT Haystack Observatory, with strong collaboration from a large array of other institutions from the U.S., Australia, and India. The major research foci of MWA are the Epoch of Reionization; Galactic/Extragalactic; Transients; and Solar-Heliospheric-Ionospheric (SHI). Recent Australian leaders of the SHI collaboration include Iver Cairns (U. Sydney) and Merv Lynch (Curtin U. Technology).

The characteristics of MWA that make it very suitable for SHI research include its low frequency range (80–240 MHz), wide field of view (15°–50°), very good angular resolution, rapid imaging cadence, great frequency and pointing agility, wide bandwidths, polarization measurements, and considerable signal processing capabilities. Its low frequency range (80–300 MHz) makes it particularly useful for studies of metric type II and III bursts and of radio waves propagating through the magnetized coronal, solar wind, and ionospheric plasmas from astrophysical sources or spacecraft radio beacons. Coronal mass ejections (CMEs) will be imaged using interplanetary scintillation (IPS) techniques and their complex magnetic structures probed remotely using Faraday rotation. These techniques should be crucial in predicting the paths and space weather implications (since these are crucially dependent on the magnetic field direction and strength just upstream of Earth's magnetopause) of CMEs headed for the Earth. MWA's high temporal and frequency resolution and novel imaging and polarization capabilities should be ideally suited to studying thermal and non-thermal coronal emission associated with CMEs and solar flares within 5 solar radii of the Sun, in particular metric type II and III radio bursts.

MWA has been developing its systems using a 32 tile (32-T) array with 16 dipole antennas per tile for about two years, and completion of a 128-T array is expected by the end of 2012. Oberoi et al. (2011) recently reported the first spectroscopic images of solar radio transients from the 32-T instrument at 171–202 MHz, revealing the spatial, spectral, and temporal evolution of events simultaneously and in unprecedented detail. In summary, MWA will offer a powerful new tool allowing us to probe the solar-terrestrial link more completely than ever before.

4. Conclusions

It is likely that Australia will retain important niche capabilities in international solar research, but a return to the major solar focus of the 1950s to 1970s is unlikely. This is because solar physics is only one part (albeit a vital part) of space science and because the country's astronomical focus lies in areas served by the natural advantages of southern vista and huge empty spaces. Nevertheless, Australia sees itself as the "sunburnt country" (to quote a famous poem by Dorothea MacKellar), and there is always an underlying fascination with our star. A new generation of Australian solar physicists is emerging, and though currently largely based overseas, it has the ambitions and the talent to carry on the country's proud traditions in solar research. It is to be hoped that they will manage to do so in their own country.

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