

## Australian PhD Theses in Astronomy: Abstracts

### UNIVERSITY OF ADELAIDE

#### Search for Very High Energy Gamma-rays from PSR 1706–44 using the Atmospheric Cerenkov Imaging Technique

Gavin P. Rowell

1995

High energy astrophysics is concerned with the understanding of energetic extraterrestrial phenomena. Gamma-ray astronomy is a subset of this discipline and this thesis documents work by the author in this field. Data were collected from the isolated  $\gamma$ -ray pulsar PSR1706–44 employing a ground-based method: The Atmospheric Cerenkov Imaging Technique, which is sensitive to  $\gamma$ -rays of energy  $\sim 10^{12}$  to  $10^{14}$  eV.

Chapter 1 provides an introduction to  $\gamma$ -ray astrophysics, in particular to some of the questions that can be answered by studying the origins of extraterrestrial  $\gamma$ -rays. The observational and theoretical histories of  $\gamma$ -ray pulsars are presented. Summaries of observational techniques and results from satellite and ground-based methods are also given.

Chapter 2 discusses the atmospheric Cerenkov imaging technique itself. Beginning with an outline of extensive air showers created by  $\gamma$ -rays and cosmic rays after interaction with the Earth's atmosphere, this chapter describes how the Cerenkov image from these showers can be used to enhance a  $\gamma$ -ray signal over the much greater background of cosmic rays. The imaging method employed in this work is one of three background rejection techniques currently utilised, and has been successful in establishing a number of sources. A first principles approach to telescope design leads to a full description of current procedures used in the background rejection process.

A short discussion of current imaging systems and their analysis procedures is given in Chapter 3. Emphasis is devoted to successful results in the field.

Chapter 4 describes the Woomera Bicentennial Gamma RAY Telescope (BIGRAT) which was used for data collection. This telescope is the Australian contribution to the CANGAROO (Collaboration of Australia and Nippon for a GAMMA Ray Observatory in the Outback) project. Sections are devoted to the imaging camera, electronics, telescope optical quality

and typical operating procedures and conditions.

Monte Carlo simulations were used to evaluate the performance of the BIGRAT imaging camera in selecting  $\gamma$ -ray events out of the background of cosmic ray events. Extensive air showers originating from the vertical and a zenith angle of  $30^\circ$  were considered. Using the differences in Cerenkov images between  $\gamma$ -rays and cosmic rays, a set of selection criteria or cuts was determined. The simulation model is described in detail along with results of these cuts in Chapter 5.

Chapter 6 details the analysis of data taken from the isolated radio and  $\gamma$ -ray pulsar PSR1706–44 during the 1993 and 1994 observing seasons. A DC analysis was performed which was sensitive to steady and pulsed  $\gamma$ -ray emission. Systematic effects were present, and the data were separated into two blocks (A & B) according to the severity of these effects, each of which are described. A discussion of the various methods used to cope with these effects forms a major part of this chapter. The equalisation of skynoise levels for ON source and OFF source data was necessary for both data blocks and was a major problem. The *software padding* technique of Cawley was partially successful in achieving this, and adjustments applied to this technique indicated definite improvement. Two adjustments were made, one purely empirically based, and the other based on an approximation of the detector behaviour to pure skynoise. Both methods provided improved results in each data block. However, one block appeared to suffer from further systematic effects as a result of large time differences between ON and OFF source runs. Only one block was therefore considered in obtaining a final result.

Chapter 7 provides a discussion of the analysis and suggestions for further work to improve the performance of BIGRAT. Using a variety of image cuts, the ON–OFF excess for the accepted data block was not found to be significant. A  $3\sigma$  upper limit on the steady  $\gamma$ -ray flux from PSR1706–44 of  $6.0 \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$  ( $>500$  GeV) was determined using a cut. This upper limit and the previous detection above 1 TeV of  $0.8 \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$  (see Kifune) imply a spectral break in going from EGRET (see Thompson) to TeV energies.

Finally, this thesis is concluded with a brief section devoted to the future status and directions of the field.

## The Cosmic Ray Anisotropy at High Energies

Andrew G. K. Smith

1995

This thesis is primarily involved with the study of the cosmic ray anisotropy. Following a brief introduction to the field of cosmic ray astrophysics, Chapter 1 discusses extensive air showers (EAS) as a tool for studying primary cosmic radiation at high energies. EAS are examined in terms of their ability to provide information on the cosmic ray energy spectrum, anisotropy and composition.

The anisotropy is discussed in some detail in Chapter 2 including a critical discussion of harmonic analysis as applied to practical situations. Chapter 3 then discusses our understanding of the Milky Way galaxy as a source of cosmic rays and modelling of the propagation process is used to predict the cosmic ray anisotropy.

The remainder of the thesis is concerned with two experiments to measure the anisotropy over the energy range from about  $3 \times 10^{-13}$  to  $3 \times 10^{-15}$  eV. The author reanalysed data from the Buckland Park EAS array during the period 1984 to 1989 for anisotropy and modelled the behaviour of the array for comparison. The bulk of the work concerned the construction of a new small array specifically designed for anisotropy studies. This array ran for one year with high reliability and good stability. The resulting data were analysed for evidence of anisotropy in right ascension and a search was made for any bursts which may have been correlated with BATSE bursts.

## Design and Feasibility Studies for a High Energy Neutrino Detector

Janice L. Reid

January 1996

The design of a high energy neutrino detector intended to observe astrophysical point sources is developed. The first two chapters contain an introduction to the field of neutrino astrophysics which is presented along with a review of neutrino astronomy.

Chapter 3 describes the selection of a suitable site for the proposed detector. Factors which are considered are the physical properties of the site and the optical properties of the water in the site with respect to the transmission of Cerenkov light. This involves a detailed analysis of the attenuation length of water using a spectrometer and also a specifically built transmissometer.

In Chapter 4, the design of a detector to be located in the Blue Lake is optimised, using Monte

Carlo techniques, with respect to the rate of signal events, the signal to noise ratio and the angular resolution.

The final chapter describes in situ measurements taken using a custom-built device to track individual muons and record their Cerenkov light. This was used to assess the feasibility of detecting muons in the Blue Lake via Cerenkov light and also to investigate the level of background light and the effect of this light on the detection process.

## AUSTRALIAN NATIONAL UNIVERSITY

### Distribution of Matter in Clusters of Galaxies

Haida Liang

February 1996

We present observations of the Sunyaev-Zel'dovich (SZ) effect in five clusters of galaxies with a Fourier synthesis telescope—the Australia Telescope. A synthesis telescope has the advantage of simultaneously imaging the discrete radio sources and the SZ effect. Observations were made at 8.8 GHz and in an ultra-compact 122.4 m array configuration. Extended emission, either due to radio halo sources or a blend of weak radio sources below the detection threshold, limited our ability to detect the SZ effect. However, upper limits to the SZ effect obtained for the cluster MS2137-23 were useful in constraining the cluster gas temperature when combined with the X-ray measurements and gravitational lensing constraints.

The advantages of a multi-wavelength analysis of cluster mass density distributions and the properties of the intra-cluster medium were demonstrated through the examples of MS2137-23 and Abell 2218. Both clusters possess a giant arc that constrains the cluster central mass. In the case of Abell 2218 where there is a large amount of good data available in various wave-bands, we combined gravitational lensing constraints, optical photometry, measurements of the SZ effect, X-ray surface brightness and temperature to constrain the cluster potential  $H_0$  and test the usual assumptions of mass-follows-light and hydrostatic equilibrium.

### Dwarf Galaxies in Nearby Southern Groups

Stéphanie Côté

September 1995

This thesis describes a successful survey to find dwarf irregular galaxies in the two most nearby southern groups of galaxies, the Sculptor group at 2.5 Mpc

and the Centaurus A group at 3.5 Mpc. Candidates were selected from a visual search on ESO SRC J films, then observed in neutral hydrogen (HI) at Parkes, as well as in  $H\alpha$ . In the Sculptor group 12 dwarfs are detected, and in Centaurus A 20 (from which 21 were already known members), yielding a dwarf-to-giant ratio of roughly 3. Some of the detected dwarfs in Sculptor are amongst the faintest dwarf irregulars ever found. The spatial and velocity distributions of these dwarfs are studied, and their radial velocities used to deduce the dynamical state of each group.

Surface photometry in B, R, I of these dwarfs is presented. The structural properties of the dwarfs of each group are compared. The dwarfs are shown to follow a surface-brightness-magnitude relation, and their effective radii are shown to decrease with magnitude over the whole range of 7 magnitudes. The luminosity function for the two groups is found to be still rising much fainter than previously believed, down to  $M_B = -12.5$ . But despite the large number of dwarfs detected the slope is  $\alpha = -1.1$ .

For a subsample of eight dwarfs, high resolution HI imaging with the VLA and the AT is presented. Two objects are found to have peculiar kinematics (NGC 625, ESO 245-G05), possibly due to interactions. For the remaining objects (UGCA 442, SDIG, ESO 381-G20, DDO 161, ESO 444-G84, ESO 325-G11), rotation is clearly supporting these systems. Multi-component mass-models are calculated, revealing dark matter accounts for between 50% and up to 90% of the total mass in these galaxies. Scaling laws for the dark halo parameters are inspected, and it is shown that the total mass-to-light ratio is increasing for fainter bluer dwarfs, reaching up to  $(M/L_B)_{dyn} = 90$ .

## Binary and Millisecond Radio Pulsars

Jon Bell

February 1996

Deep optical searches for the companions to several of the binary millisecond pulsars found in the Parkes survey were conducted. The companions to PSRs J0337-4715 and J2145-0750 were found. Both companions are cool white dwarfs with effective temperatures of  $4000 \pm 350$  K and  $3850 \pm 350$  K respectively. This is evidence that the remnant companions to millisecond pulsars are white dwarfs as predicted by evolutionary models. Using white dwarf cooling models, the ages of both companions are shown to be several Gyr. This is the first direct evidence that millisecond pulsars are so old and therefore that their magnetic fields do not decay on time scales shorter than 1 Gyr. These companions are amongst the coldest and oldest white dwarfs known.

A deep limit on the companion to PSR J0034-0534 was used to show that the initial period of the pulsar was less than 1.6 ms and possibly as low as 0.6 ms. If matter had been accreted at the Eddington rate during spin up, the initial period would have been close to the minimum period of 0.6-1.6 ms. The range of minimum initial periods results from the many equations of state for neutron stars. The limit on the initial period of PSR J0034-0534 therefore challenges some of the harder equations of state.

Timing data collected for PSR J0437-4715 show that the proper motion of the pulsar is  $135 \pm 4$  mas yr<sup>-1</sup> at a position angle of  $122^\circ \pm 2^\circ$ . This agrees well with the proper motion of the optical companion, putting the association beyond doubt. An  $H\alpha$  pulsar wind nebula was discovered around PSR J0437-4715. The dimensions and orientation of the nebula bow shock agree well with the direction and magnitude of the pulsar's proper motion.

The first observations of the radial velocity variations resulting from the binary motion of a companion to a radio pulsar are presented. These results demonstrate that the companion to the Small Magellanic Cloud pulsar J0045-7319 is a B1V star. The mass of the companion was found to be  $8.8 \pm 1.8 M_\odot$ , consistent with the mass expected for a B1V star. The projected rotational velocity of the companion is  $113 \pm 10$  km s<sup>-1</sup>, while the heliocentric radial velocity of the binary system is consistent with that of other stars and gas in the same region of the Small Magellanic Cloud.

The proper motions for 4 millisecond pulsars and upper limits on the proper motions of five others are presented, along with period derivatives accurate to 2-3 significant figures for them. The observed velocities and distances from the Galactic plane of millisecond pulsars appear to be lower than those of low-mass X-ray binaries. As a result of a strong selection effect against finding high velocity millisecond pulsars, it is unclear as to whether this is indicative of formation via accretion induced collapse or recycling in low mass X-ray binaries. Several of the millisecond pulsars have characteristic ages greater than the age of the Galactic disk, indicating that their rotation periods at birth were close to their present periods. The existence of planetary mass companions similar to Earth, Venus and the two largest companions to PSR B1257+12 is ruled out for these 10 millisecond pulsars.

A new method is proposed for obtaining very accurate distance estimates and transverse velocities for some nearby binary pulsars. It is based on the contribution to orbital period derivatives from a time varying Doppler effect. In many cases this method will estimate distance more accurately than is possible by measuring annual parallax, as the relative error in the estimate decreases as  $t^{-5/2}$ . Unfortunately, the uncertainty in the distance limits

the usefulness of nearby relativistic binary pulsars for testing the general theory of relativity.

Some theories of gravity predict violations of local Lorentz invariance and violations of conservation of energy and momentum. General relativity predicts no violations. In the parametrised post-Newtonian (PPN) formalism, the parameters are  $\alpha_1 \equiv \alpha_2 \equiv \alpha_3 \equiv 0$  if these effects do not exist. The period derivatives of millisecond pulsars were used to more tightly constrain the extent of any violations by showing that  $|\alpha_3| < 5 \times 10^{-16}$ . The limit  $|\alpha_1|$  was improved to  $|\alpha_1| < 1.5 \times 10^{-4}$  using the very low eccentricity binary pulsar J2317+1439.

## Dynamics and Excitation of Extended Emission-line Regions in Radio Galaxies

Anton Koekemoer

May 1996

A fraction of elliptical galaxies is known to be associated with powerful radio sources; the radio emission is produced by large lobes of radio plasma, often several times the size of the elliptical galaxy. The plasma in the radio lobes is generally thought to have been deposited by fast, supersonic radio 'jets', which transport the material from the active nucleus of the elliptical galaxy into the lobes. The nucleus is usually considered to harbour a large black hole (about 100 million times the mass of the sun); the jets are 'fed' by gas which accumulates around the nucleus, and this is thought to power the radio source.

The accumulating gas in such elliptical galaxies is often observed as optical line-emitting gas extended on large scales, up to  $\sim 100$  kpc (i.e. sometimes several times larger than the elliptical galaxy). If this gas is what 'feeds' the radio source, then understanding its properties is crucial for understanding how radio galaxies are formed and how they evolve. Two key questions concerning the properties of the gas are: (1) what is its detailed motion, i.e. where did it originate? and (2) what keeps the gas ionised so that we detect it?

This thesis is aimed at a detailed investigation of the gas properties, by studying its dynamics as well as its ionisation state, across its entire spatial extent. This is in order to extend the constraints on the gas physics that have been derived from previous studies, and to complement studies that have been carried out on larger samples, which are usually aimed at investigating global properties of the galaxies and not the detailed processes in the gas.

The principal result from the thesis is that the gas ionisation and kinematics can be explained through a single physical mechanism, involving collisions between streams of gas acquired from a

companion galaxy which is interacting with the elliptical galaxy. It is suggested that the collisions lead to strong shocks, which radiate energy and ionise the surrounding gas; hence the emission that we observe is a combination of emission from the shocked regions and from the surrounding gas. This mechanism accounts for a number of difficulties with other mechanisms; for example, if the gas is ionised by radiation from the active nucleus then it is difficult to account for highly ionised regions that are observed at large distances from the nucleus. Finally, the physical appeal of this mechanism is that it relates all the observable properties of the gas by a single mechanism, thus allowing better constraints to be placed on the physics of the gas.

## UNIVERSITY OF NEW SOUTH WALES

### Construction and Use of the CCD Camera on the Automated Patrol Telescope

Paul Brooks

August 1995

This thesis describes the construction, commissioning and use of a charge-coupled device (CCD) detector system on the Automated Patrol Telescope—a converted Baker–Nunn satellite tracking camera donated to the School of Physics at the University of New South Wales. The work is divided into three distinct areas, entitled 'Hardware', 'Software' and 'Observations'.

'Hardware' covers the construction, operation and measurement of the electronic performance of the CCD camera and the CCD/telescope combination thus formed. The evolution of the system to a working configuration producing images of scientific quality is presented.

'Software' describes two distinct applications and software libraries that were developed for IBM-compatible PC computers running the MS-DOS operating system. One of these is IMLIB, a generic image processing package that implements the low-level details of accessing and viewing FITS-format two-dimensional images, which is the standard format for transferring astronomical images between institutions. The other is the APT CONSOLE, which provides the user-interface for operating and controlling the APT sub-systems, from source selection and tracking to image acquisition, and provides the foundations for operation of the APT in an unattended, automated mode.

'Observations' covers the observation programme and research conducted with the APT during testing. The optical and photometric performance of the telescope is measured using the Harvard E-region photometric standard star fields. Research into algorithms and methods for use in transient object detection, particularly in searches for supernovae,

novae and/or asteroids, is described using asteroids as 'test novae'. A supernova search atlas containing images of nearby galaxies for use as comparison standards was begun. Mosaic images of the Small Magellanic Cloud (SMC) in B, V and Kron-Cousins R, I bands, covering twenty-five square degrees with eight arcsecond resolution, demonstrate the power of the large field of view of the APT. A program and preliminary results for detection and mapping of short-period variable stars over the entire SMC is also described.

## UNIVERSITY OF SYDNEY

### Wave-Particle Interactions in Coherent Electromagnetic Fields

A. Melatos

July 1995

This thesis is concerned with the behaviour of particles in intense, coherent electromagnetic fields. Part I is devoted to the theoretical analysis of transit-time interactions involving nonlinearly-collapsing wave packets in strongly turbulent plasmas. Three applications are investigated: dissipative arrest of wave collapse, auroral strong turbulence, and electron scattering in relativistic-electron-beam experiments. Part II is devoted to energy transport by particles and large-amplitude electromagnetic waves in the winds of rotation-powered pulsars.

In Part I, an introduction to existing theoretical and experimental work on transit-time interactions is presented in Chapter 1. Transit-time interactions occur when particles cross a localised, oscillating, coherent electric field in a time comparable with its period of oscillation. In Chapter 2, the wave-particle energy transfer during one complete interaction is calculated analytically via a perturbed-orbit method to second order in the perturbing fields. In its most general form, the calculation applies to interactions with a non-electrostatic wave packet in a magnetostatic field.

In Chapter 3, the wave-particle energy transfer is evaluated for particular field structures, and the analytic results are compared with numerical test-particle calculations to determine the limits of validity of the perturbation theory. The physical properties of transit-time interactions are also explored by surveying the dependence of the energy transfer on a range of parameters. In Chapter 4, a systematic procedure is given for generating analytic approximations to the wave-particle energy transfer, which yields especially simple results in the physically important limits of small and large Larmor radius, and small and large values of the ratio of the wave frequency to the cyclotron frequency.

In Chapter 5, the transit-time power dissipated locally is calculated as a function of position within

a coherent wave packet in a magnetostatic field. The theory is then applied to compute the arrest scale of collapsing lower-hybrid waves in a thermal electron-ion plasma. It is shown rigorously that damping can be dominated either by unmagnetised ions or by strongly magnetised electrons depending on the physical conditions, contrary to semiquantitative arguments in the literature suggesting that ion damping always predominates. In Chapter 6, this work is combined with recent findings on the structure of lower-hybrid turbulence to interpret in situ observations of lower-hybrid waves and associated density cavities in the Earth's ionosphere at auroral latitudes.

In Chapter 7, an analytic Fokker-Planck theory is developed to describe the diffusion of a beam of relativistic electrons in momentum space as a result of multiple transit-time interactions with a turbulent ensemble of Langmuir wave packets. Approximate solutions are obtained for strongly and weakly collimated beams and various distributions of wave-packet orientations, and are then used to interpret measurements of electron scattering in energy and pitch-angle in relativistic-electron-beam experiments. It is shown that the theory fits the energy scattering data well, but underestimates the pitch-angle scattering. Chapter 7 closes with a brief discussion of possible reasons for this discrepancy.

In Part II, an overview of the theory and observations of relativistic pulsar winds is presented in Chapter 8. Energy transport by particles and large-amplitude electromagnetic waves in these winds is investigated in Chapter 9. It is shown that the theory of ideal magnetohydrodynamics underpinning standard, steady-state wind models does not apply throughout a rotation-modulated wind, and must be replaced by an exact one-fluid description that includes an exact, relativistic generalisation of Ohm's law. It is also shown, via analytic test-particle calculations based on a Hamilton-Jacobi method, that the outer part of the wind is a radiation zone where Poynting flux is transported by nonlinear transverse waves, and that such waves are catastrophically damped in the inner part of the wind. The inner boundary of the radiation zone is calculated to lie well inside the wind termination shock for the Crab pulsar. A self-consistent fluid model of the radiation zone predicts that the kinetic energy flux dominates the Poynting flux if the Lorentz factor of the flow is large. This result agrees with independent studies of the interaction of the Crab pulsar wind with the surrounding nebula.

In Chapter 10, the interaction between a pulsar wind and its environment is studied in the special case of the eclipsing binary pulsar PSR B1259-63, which orbits a Be star. Two models of the circumstellar environment—based on a coronal stellar wind, and

a circumstellar disc—are examined critically to see if they account for the main features of radio observations of the pulsar's 1994 periastron passage. The disc model fits the data; the wind model does not.

## Protection of Optical Surfaces by Thin Films

Wayne Sainty

September 1994

This thesis presents an investigation into several aspects of protective films applied to surfaces sensitive to environmental attack. Primarily, the protection of precision silver mirrors used in a very high angular stellar interferometer, under construction by the Chatterton Astronomy Department of the University of Sydney, was the motivation for the project. The sensitivity of such a complex instrument is ultimately determined by the optical throughput of starlight to the detectors. The lifetime of the numerous mirrors then becomes crucial to the maintenance of optical throughput.

This work reports the development of silver-based mirrors, overcoated with transparent dielectric materials for the dual purpose of boosting the specular reflection while providing acceptable protection against environmental attack. The physical, optical and electrical properties of silver films deposited onto glass were investigated. Accelerated testing of coatings, under controlled environments as well as longer term natural environments, was employed to evaluate the many break-down mechanisms.

Other materials were also investigated which were considered to have relevance to the protection of sensitive surfaces. The microstructural, physical and optical properties of boron nitride was studied. Boron nitride films were deposited by several techniques including ion beam synthesis (IAD), plasma-assisted chemical vapour deposition (PACVD) and ion plating (IP).

A study of phosphorus nitride and silicon oxynitride films produced by PACVD was carried out. The influence of the deposition parameters on the physical and optical properties was investigated. Thin film filter designs using multilayers of discrete, homogeneous materials were demonstrated. Time dependent phenomena related to the residual gas environment were studied. This was shown to impose a limit to the deposition of discrete, homogeneous layers produced by this technique.

The deposition of rugate structures was investigated using the PACVD technique. Computer control of the deposition process was shown to be essential to obtain predictability and repeatability. The use of *in situ* single-wavelength ellipsometric and multi-wavelength optical monitoring of the growth process was used to gain an understanding

of the limitations of the PACVD process to this application.

## Optical Spectroscopy of Supernova 1987A

Raylee Anne Stathakis

September 1994

In this thesis I have described the archive of observations of SN 1987A taken at the AAT. I have provided details of instrumentation used, instrumental setup and observing conditions, and have given indications of the quality of the data. I have described in detail the procedures used to process the optical spectra observed during the first two years. These details help outside users to access the archive, and to understand the usefulness and limitations of the data. The archive will be distributed via the Internet, and will be of use to the astronomical community for the foreseeable future. During the first six months, telescope time was allocated to the observation of SN 1987A by a nightly one hour override of scheduled programmes. The rate of success and productivity of this period is assessed, and some improvements are suggested in the event of another unexpected observing opportunity of similar importance.

In the remainder of this work, I have presented the time evolution of the line flux ratios and spectral line profiles from the optical spectra, highlighting many trends and characteristics. I have used simple analytic models to study the line profile structure in the oxygen and hydrogen lines with greater accuracy, and I have compared the observations and modelling results to current theory on the structure of the envelope of SN 1987A, showing that while there is some agreement, there are many observations which cannot be explained by current theory. By discussing the trends and deriving parameters to describe them, I hope to make the observations more accessible to the theorist, and to provide indicators for useful directions of research.

I have presented a picture of the SN 1987A envelope. This picture is not intended as a serious theory, and cannot be shown to be a unique solution to the observed trends. However, the picture is useful in identifying the complicated nature of the envelope and of the observed spectrum. It is clear from my results that most spectral lines contain emission from a number of spatially separated sources, with a range of physical parameters. While average parameters obtained from the summed emission can be useful, they can also in some cases be misleading. Average temperatures, densities and composition may have no physical relevance if the component source regions differ significantly. Future models of the SN envelope will need to address this issue.

## Some Topics in the Physics of Solar Flares

Michael Wheatland

January 1995

In this thesis the emphasis is on the magnetohydrodynamical description of processes associated with solar flares. A brief review of both the observational and theoretical aspects of solar flare physics is presented in Chapter 1, which provides a context for the individual topics addressed.

In Chapter 2, energy propagation into the site of energy release in a solar flare is studied in detail, in the context of an existing model. The existing model described the unwinding of a twisted magnetic flux tube when a dissipative region turns on somewhere along its length; the dissipative region is a simple model for the primary site of energy release in a flare. It is shown that the evolution of the system after the termination of energy release leads to a resupply of energy to the coronal part of the flux tube, thereby providing a simple model for the phenomenon of homologous flaring. It is also shown that the model can be generalised to describe a time dependent, rather than impulsive, turning on and off of energy release, and the generalisation of the model to describe the same processes in a force-free flux tube is also investigated. Chapter 2 concludes with a critical examination of a particular energy release mechanism, due to Zaitsev and Stepanov (1991, 1992). It is shown that this mechanism does not constitute a tenable flare model.

Chapter 3 of this thesis is concerned with the interpretation of several hard and soft X-ray flare observations made with the Yohkoh spacecraft. A model is presented to account for the loop-top hard X-ray sources found by Masuda (1994) and the soft X-ray observations of Feldman et al. (1994). Electrons accelerated by the flare energy release mechanism near the apex of a coronal loop are assumed to encounter an intermediate thick-thin target in an overdense loop-top region. Some of the energised electrons are stopped at the loop-top, and some precipitate to the footpoints of the loop. The model predicts theoretical photon spectra for the loop-top dense region and the footpoints of the loop which qualitatively agree with the observations of Masuda (1994). The model also accounts for the heating of the dense loop-top region, and provides a natural explanation for Type A flare observations.

In Chapter 4, a simple, two-dimensional model is presented to describe how an externally imposed current closes as a function of time beneath the photosphere. The model shows that currents close in a given layer of the subphotosphere only during an Alfvén propagation time of that layer. The implication is that currents observed at the solar photosphere close along field lines beneath the photosphere a conclusion inconsistent with the

boundary condition of line-tying, often imposed to describe the behaviour of plasma and fields at the photospheric boundary. The implications of this conclusion for the dynamics of coronal magnetic structures are then investigated. A simple model for the shearing of a magnetic arcade is presented, and it is shown that if one side of the arcade is driven continuously, the other row of footpoints is set into motion as well, with a timescale determined by the transfer of momentum between footpoints. The role of the subphotosphere in this process is investigated, and it is shown that if a finite layer of subphotosphere at one footpoint of an arcade is initially set into motion, the propagation of Alfvén fronts into the subphotosphere at that footpoint effectively brakes the driving motion.

Chapter 5 present a circuit model for Alfvén wave propagation in a stratified atmosphere. The model extends the analysis of Scheurwater and Kuperus (1988) to describe vertically propagating Alfvén waves in an atmosphere with arbitrary density and conductivity profiles. By way of example, the model is applied to waves in an infinitely conducting, exponential atmosphere.

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## UNIVERSITY OF TASMANIA

### Class II Methanol Masers in Star Formation Regions

Simon Peter Ellingsen

February 1996

In 1991 maser emission from the transition of CH<sub>3</sub>OH at a frequency of 6.7 GHz was discovered by Menten (1991). This transition is more common and stronger than the 12.2-GHz transition discovered four years previously. This thesis contains the results of a detailed study of 6.7-GHz CH<sub>3</sub>OH maser emission over a wide range of angular resolutions.

The University of Tasmania 26-m radio telescope has been used to perform a sensitive search for 6.7-GHz CH<sub>3</sub>OH masers in a 28.5 square-degree region of the Galactic Plane. The search is complete, within a well defined velocity and flux density range. One hundred and eight 6.7-GHz CH<sub>3</sub>OH masers were detected during the course of the survey, 57 of these being new detections. These new 6.7-GHz CH<sub>3</sub>OH masers are generally weaker than those already known, but otherwise their spectral appearance is

similar to those detected towards OH and 12.2-GHz CH<sub>3</sub>OH masers. The sample of 6.7-GHz CH<sub>3</sub>OH masers has been used to critically evaluate several IRAS-based search techniques and we find that all these techniques fail to detect a large fraction of the masers. Two targeted searches of the Large and Small Magellanic Clouds have been performed, resulting in the detection of three 6.7-GHz CH<sub>3</sub>OH masers.

In addition, a search for 6.7-GHz CH<sub>3</sub>OH megamasers was carried out toward ten extragalactic sources, nearly all of which are known OH or H<sub>2</sub>O megamasers. No CH<sub>3</sub>OH megamasers were detected with a peak flux comparable to the OH or H<sub>2</sub>O megamasers in the galaxies searched.

Single dish spectra of 6.7- and 12.2-GHz CH<sub>3</sub>OH masers are often complicated, with many spectral features spread over a velocity range of 10 km s<sup>-1</sup> or more. High resolution observations of these maser sources show that each of the spectral features arise from a different region in the gas cloud. For OH and H<sub>2</sub>O masers the high resolution spatial morphology typically shows little or no simple structure. Conversely, high resolution observations of 6.7- and 12.2-GHz CH<sub>3</sub>OH masers (Norris et al. 1988, 1993) show that many have a simple curved, or linear morphology. The Australia Telescope Compact Array has been used to observe the radio continuum emission associated with three strong 6.7-GHz CH<sub>3</sub>OH masers. It is shown that the position of the CH<sub>3</sub>OH masers with respect to the continuum emission is consistent with the masers originating in a circumstellar disc.

Very long baseline interferometry (VLBI) has been used to image strong class II CH<sub>3</sub>OH maser emission associated with two star formation regions. The milli-arcsecond resolution images detected many new maser spots, but all of these follow the general morphology revealed by lower resolution observations. Comparison of the 6.7- and 12.2-GHz images for the CH<sub>3</sub>OH masers associated with NGC 6334F shows that five of the spots are coincident to within the positional errors of the observations ( $\approx 4$  milli-arcseconds).

VLBI observations were also used to measure the size of the 6.7- and 12.2-GHz CH<sub>3</sub>OH maser spots. These show that the maser spots contain structure on two different scales, one of the order of tens of astronomical units, the other between a few and ten astronomical units. These findings are supported by the imaging data and the VLBI observations of Menten et al. (1988, 1992). The sizes of the 6.7- and 12.2-GHz spots toward the same sources are similar, which suggests that they are not broadened by interstellar scattering.

This thesis is available on the WWW at: <http://reber.phys.utas.edu.au/~sellings/thesis.html>

## Timing Observations of Southern Pulsars

Franco D'Alessandro

March 1996

Pulse arrival-time measurements made at frequencies near 670 and 800 MHz over a 7-year period have been used to study the timing behaviour of 45 southern pulsars. These measurements have resulted in more accurate estimates of the period, period derivative, position and dispersion measure of most of these pulsars. Changes in some of the dispersion measures have been detected and used to estimate the scale-sizes and electron densities of irregularities in the interstellar medium. The timing measurements also revealed distinct jumps in the rotation rate of five pulsars, most of which have not been reported elsewhere.

Polarimetric data at 670 and 800 MHz are presented for eighteen of the more luminous pulsars. The integrated profiles display properties in general agreement with trends extrapolated from other frequencies. Rotation measures have been derived for these pulsars. Nine are more accurate than previous determinations, and two have changed since they were last measured. These changes suggest a dense, magnetised electron cloud has moved into or out of the line of sight.

It has been confirmed that the level of pulsar timing noise is correlated with spin-down rates. Further analyses have revealed that, in most pulsars, the observed timing noise is due to a mixture of different kinds of activity, such as random walk processes, microjumps, and for one pulsar, free precession of the spin axis. The microjumps are characterised by a variety of signatures, involving both positive and negative changes in the rotation frequency and frequency derivative. The amplitudes of these microjumps form the tail-end of a continuous distribution of amplitudes extending down to microglitch level. An investigation of timing noise in the Vela pulsar has shown that the microactivity during the postglitch recovery period is dominated by microjumps in the rotation frequency and frequency derivative which occur every 30–40 days. This microactivity is also punctuated by less frequent events, such as large steps in the frequency derivative, discrete changes in the frequency second derivative, and in one isolated case, a small glitch. The above results have been discussed in terms of current theories of pulsar timing noise and it was found that no theoretical model, in isolation, is able to explain the range of observed timing activity in the pulsars studied.

Power spectra of the pulsar timing residuals have been derived using a novel technique based on the CLEAN algorithm. Most of the spectra are well described by a single- or double-component power-law model. Some of these spectra can be

interpreted in the context of one or more of the current timing noise models.

## Modelling Cosmic Ray Ground Level Enhancements

Jennifer Cramp

May 1996

Analyses of seven cosmic ray ground level enhancements (GLE) are presented. The first four events were part of the unprecedented sequence of relativistic solar proton events which occurred during 1989. Three of the larger events of the 21st solar cycle have also been modelled. In each case, analysis is based on data from the world-wide network of neutron monitors. Surface muon telescope data have also been used for of the 29 September 1989 event.

A sophisticated model has been developed from that of Smart et al. (1979). Modifications include the calculation of asymptotic directions using a geomagnetic field model which accounts for distortion of the field during geomagnetic disturbances, and the use of a least squares method for determining the best fit parameters. An exponential function used to describe the pitch angle distribution has been further developed to allow bi-directional particle flow and rigidity dependence. The form of the particle spectrum used in most of the analyses was a modified power law in rigidity. An approximation of the Ellison and Ramaty (1985) shock acceleration spectrum has recently been included in the model.

A rigidity dependent pitch angle distribution was required to model the GLE on 29 September 1989 and indicates that, initially, the anisotropy of the particle distribution decreased with increasing rigidity. Significant back-scattering of particles resulted in the observation of a late peak at stations viewing in the anti-sun direction and two peaks at some other stations.

The three GLEs which occurred during October 1989 have been modelled with particular emphasis on the initial spikes seen at some stations for both the 19 and 22 October events. In the case of 19 October 1989, a further spike later in the event appears to have been produced by the same mechanism as the initial spike, which had a significantly different particle distribution and spectrum to that of the main event. Enhancement of the pitch angle distributions in the anti-sun direction during the 22 October event is probably due to scattering by a disturbed plasma region beyond the Earth. The 24 October 1989 event was best modelled using a modified form of the Ellison and Ramaty shock acceleration spectrum. A rigidity dependent pitch angle distribution resulted in only marginal improvement in the fit to the observed data.

The 12 October 1981 GLE has been modelled with a bi-directional pitch angle distribution. This is found to be consistent with results at lower energies and is further evidence for the presence of a looped structure in the interplanetary magnetic field. Further complexity in the interplanetary medium was present during the 7–8 December 1982 GLE. Interplanetary magnetic field data are consistent with a magnetic cloud-like feature situated just beyond the Earth. Observed neutron monitor increases were satisfactorily reproduced by a model with an elliptical deficit region to account for the scattering which impeded some particles approaching the Earth. The derived particle arrival direction for the 16 February 1984 GLE was  $\sim 40^\circ$  from the measured interplanetary magnetic field direction. This could not be satisfactorily explained, however it is found to be consistent with the results of previous studies.

Ellison, D. C., and Ramaty, R. 1985, *Astrophys. J.* 298, 400–408.

Smart, D. F., Shea, M. A., Humble, J. E., and Tanskanen, P. J. 1979, A model of the 7 May 1878 solar cosmic ray event. *Proc. 16th Int. Cosmic Ray Conf.*, Vol. 5, pp. 238–43.

## Modulation of High Energy Cosmic Rays in the Heliosphere

Damian Lindsay Hall

July 1995

The distribution of galactic cosmic ray particles in the heliosphere is influenced (modulated) by the Sun's interplanetary magnetic field (IMF) and the solar wind. The particles diffuse inward, convect outward and have drifts in the motion of their gyro-centres. They are also scattered from their gyro-orbits by irregularities in the IMF. These processes are the components of solar modulation and produce streaming (anisotropies) of particles in the heliosphere. The anisotropies can be investigated at Earth by examining the count rates of cosmic ray detectors. The anisotropic streams appear as diurnal and semi-diurnal variations in the count rates of cosmic ray recorders in solar and sidereal time. Theoretical models of solar modulation predict effects which are dependent on the polarity of the Sun's magnetic dipole ( $A > 0$  or  $A < 0$ ). The solar diurnal and North–South anisotropy can be used to test these predictions.

The yearly averaged solar and sidereal diurnal variations in data recorded by seven neutron monitors and ten muon telescopes for the period 1957 to 1990 have been deduced by Fourier analysis methods. The rigidities of the galactic cosmic rays to which these instruments respond encompass the range 10 to 1400 GeV. The rigidity spectrum of the solar diurnal anisotropy has been inferred to have a mean spectral index extremely close to zero and an idealised

upper limiting rigidity of  $100 \pm 25$  GeV. This is in good agreement with previous determinations. It is shown that this upper limit has a temporal variation between 50 and 180 GeV and is correlated with the magnitude of the IMF. The rigidity spectrum is likely to be dependent on the polarity of the Sun's magnetic dipole, the spectral index being determined as positive in the  $A > 0$  magnetic polarity state and negative in the  $A < 0$  polarity state. It is also shown that the amplitude of the anisotropy varies with an 11-year variation and the time of maximum varies with 22-year variation. Both of these variations are shown to be independent of any change in the rigidity spectrum.

The solar diurnal anisotropy is also used as a tool to calculate the modulation parameters  $\overline{\lambda_{||} G_r}$  (the product of the parallel mean-free path and radial density gradient) and  $G_{|z|}$  (an indicator of the symmetric latitudinal density gradient).  $\overline{\lambda_{||} G_r}$  is found to have a 22-year variation at all rigidities studied and furthermore to only have rigidity dependence when the heliosphere is in the  $A > 0$  magnetic polarity state. It is unlikely that  $\overline{\lambda_{||} G_r}$  has any rigidity dependence in the  $A < 0$  polarity state. Here  $G_{|z|}$  indicates that below 50 GeV the symmetric latitudinal density gradient behaves in accordance with the predictions of current modulation theories. Between 50 and 195 GeV however, the predicted behaviour is only observed when the rigidity spectrum of the solar diurnal anisotropy is assumed to be flat static and have an upper limiting rigidity of 100 GeV.

The sidereal diurnal variation in the data recorded by the instruments has been deduced and used to study the North–South anisotropy. The results indicate that this anisotropy has only a small variation in amplitude. There is strong evidence for heliospheric asymmetric modulation (with respect to above and below the neutral sheet) of a galactic anisotropy in the sense proposed by Nagashima et al. (1982) and that this modulation may have a 22-year variation. From the examination of the North–South anisotropy the radial density gradients ( $G_r$ ) at 1 AU of 17 to 195 GeV particles were determined. The gradient is slightly smaller around times of solar minimum. No magnetic polarity dependence of the radial gradient was observed, in direct conflict with conventional theoretical predictions.

The modulation parameters have been used to determine the parallel mean-free path ( $\lambda_{||}$ ) of galactic cosmic rays with rigidities between 17 and 195 GeV near the Earth. It was found that this parameter depends on magnetic polarity at all the rigidities examined and has a linear relationship with rigidity. Perpendicular diffusion has been examined and shown to have very little contribution to the values of the modulation parameters except for years near solar minimum.

## UNIVERSITY OF WESTERN SYDNEY

### A Multi-frequency Investigation of Discrete Sources in the Magellanic Clouds

Miroslav D. Filipovic

1996

This project involves a detailed study of discrete sources observed in the Magellanic Clouds (MCs) using large scale surveys at radio, infrared, optical, ultraviolet and X-ray wavelengths. As a part of the study, this project resulted in a catalogue of discrete radio sources in the MCs with their positions, fluxes and spectral index. These new surveys were compared with previous results and showed great improvement. Firstly, in improving the number of discrete radio sources towards the Magellanic Clouds and, secondly, in the positions and flux densities of these sources. Classification criteria were established and most of the MCs sources were classified in one of three groups: SNRs, HII regions or background sources. Specific source flux density comparisons were undertaken and source distributions throughout the Clouds were studied.

From observations with the Parkes radio telescope, I am presenting catalogues of radio sources in the Large Magellanic Cloud (LMC) at six frequencies: 1.40, 2.30, 2.45, 4.75, 4.85 and 8.55 GHz. A total of 483 sources has been detected in at least one of these frequencies, 143 of which are reported here for the first time as radio sources. Also, catalogues of radio sources in the Small Magellanic Cloud (SMC) were presented at the same radio frequencies and the total number of catalogued radio sources is 224. Some 60 of these 224 sources are reported here for the first time as radio sources.

A comparison of Parkes radio surveys and the X-ray ROSAT All-Sky Survey (RASS) of the LMC has found 71 discrete sources of both radio and X-ray emission. A flux density comparison of the radio and X-ray sources shows very little correlation, but we note that the strongest SNRs at both radio and X-ray frequencies are young SNRs from Population I. Six new SNR candidates are proposed. From the brightness of the SNRs we have estimated the SNR birth rate to be one every  $100 \pm 20$  years and the star formation rate (SFR) to be  $0.7 \pm 0.2 M_{\text{Sun}}$  per yr. The comparison with the IRAS IR surveys showed 130 sources in common to the LMC and 38 to the SMC. Most of these sources ( $\sim 90\%$ ) are intrinsic to the MCs as HII regions and SNRs. Similar results come from the  $H\alpha$ , VUV and CO comparison. Sources seen in these surveys are believed to be very likely intrinsic. Some 94 sources in the LMC and 12 sources in the SMC are classified on this basis as HII region candidates.

In total, 209 discrete radio sources in the LMC and 38 sources in the SMC are classified here to be either HII regions or SNRs. From the distribution of the LMC sources, spiral structure patterns can be seen with a centre somewhere in 30 Doradus. The SMC source distribution follows the Mathewson (1985) prediction and the sources are generally grouped into three regions: Mini-MC, the SMC Remnant and the Eastern Wing of the SMC.

## MSc Theses in Astronomy: Abstracts

### MONASH UNIVERSITY

#### Simulation of the Monash Spectrograph: A Study of the Radial Velocities of Cool Stars

S. C. Marsden

1996

The author made a computer simulation of the expected performance of a crossed Czerny–Turner spectrograph which is to be installed on the Physics Department's 0.46-m cassegrainian telescope primarily to study radial velocities of cool, active stars. The simulation program determines the effects of exposure time, CCD temperature, stellar magnitude, etc. on the precision of measurements of radial velocities of these stars.

The program is written in Fortran for a PC. Examples of its predictions are that using an exposure time of 1000 s for a cool star of  $mv = 8$  having a projected rotational velocity of 50 km  $s^{-1}$ , the precision in radial velocity is 1.3 km  $s^{-1}$ : this precision becomes 0.7 km  $s^{-1}$  for a star of  $mv = 6$  and 3.0 km  $s^{-1}$  for a star of  $mv = 10$  under the same conditions. Predicted values of the precision for a grid of parameters are provided in the thesis. The program has been tested on existing spectrographs and predictions agree well with their actual performance. Although the program appears to overestimate the precision achievable in radial velocity measurements for reasons which are not clear, it does give a good starting point for use in design studies.

A floppy disk of the program and plotting routines is supplied with the thesis.

### UNIVERSITY OF SYDNEY

#### Diffusive Acceleration at Multiple Shocks

M. Pope

December 1994

The effects of diffusive shock acceleration at a sequence of shocks on a distribution of energetic particles is explored. Particular attention is paid to the particle momentum distribution. The role

of the shock compression ratio, the efficiency with which fresh particles are injected and adiabatic decompression in producing the asymptotic limit  $f(p) \propto p^{-3}$  are examined. Numerical experiments show that the dependence of choice of the injection efficiency on the shock strength does not critically affect the approach to this limit. The shock strength and adiabatic decompression are the main factors which determine how rapidly a distribution will evolve towards the asymptotic limit. A special case of a sequence of pairs of shocks of alternating shock strength is examined analytically.

A model whereby electrons are accelerated by a sequence of shocks is applied to double hot spots in the radio lobes of extragalactic radio jets. The results are consistent with the observations of the radio spectral indices of 3C 196 and 3C 268.4. A similar model is applied to the jets of the Wide-Angled Tailed galaxy NGC 4784. The observed dips in the radio spectral index in two places along each jet, and hydrodynamical models of bent jets, are consistent with acceleration at two shocks along each jet.

### UNIVERSITY OF WESTERN SYDNEY

#### Astronomical Observations of Wide Southern Double Stars

Christina M. Bauer

1995

Observations were made of 309 binary systems comprising 698 'pairs' lying between Right Ascension 17h–07h and Declination  $-70$  to  $-60$  degrees with separations greater than 3 arcseconds and primary magnitude brighter than 14. The images were calibrated against fixed optical doubles which were in turn calibrated against pairs measured specifically for CCD calibration. Measurements were made of separations, position angles and differential magnitudes. The uncertainties in position angle and separation were determined to be  $7.8/r$  degrees (where  $r$  is separation in arcsec) and 0.16 arcseconds respectively. The probability of any given pair being an optical double rather than a true binary was calculated for all possible pairs.

For those pairs with corresponding WDS entries the position angles, separations and differential  $V$  magnitudes were compared with the last recorded WDS figures. It was determined that only  $29 \pm 5\%$  of the observed pairs had undergone significant movement since the previous measurement, which agrees with the results of a survey of the WDS.

It was found that the spread of calculated separations agreed with those found by other authors, while the distribution of periods, while falling within the range(s) calculated by other authors, were significantly longer.

The Dsorb program was adapted for use on the SUN Sparc Stations and several modified versions of this program were produced, including the Rauto program which worked by accepting a set of orbital parameters and modifying them in an attempt to optimise their fit to the observed data. The programs were tested using ideal data derived from

the published orbital parameters of  $\alpha$ -Centauri before being applied to seven observed pairs. Orbits could be calculated for six of these seven pairs, however investigations of the observed motion suggests that for four of these pairs the observed movement may be due to proper motion rather than orbital motion.