Wide Field Aperture Synthesis Radio Astronomy

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Abstract

This thesis is focussed on the Molonglo Observatory Synthesis Telescope (MOST), reporting on two primary areas of investigation. Firstly, it describes the recent upgrade of the MOST to perform an imaging survey of the southern sky. Secondly, it presents a MOST survey of the Vela supernova remnant and follow-up multiwavelength studies.

The MOST Wide Field upgrade is the most significant instrumental upgrade of the telescope since observations began in 1981. It has made possible the nightly observation of fields with area ~ 5 square degrees, while retaining the operating frequency of 843 MHz and the pre-existing sensitivity to point sources and extended structure. The MOST will now be used to make a sensitive (rms ≈ 1 mJy beam^{-1}) imaging survey of the sky south of declination $-30°$. This survey consists of two components: an extragalactic survey, which will begin in the south polar region, and a Galactic survey of latitudes $|b| < 10°$. These are expected to take about ten years. The upgrade has necessitated the installation of 352 new preamplifiers and phasing circuits which are controlled by 88 distributed microcontrollers, networked using optic fibre. The thesis documents the upgrade and describes the new systems, including associated testing, installation and commissioning.

The thesis continues by presenting a new high-resolution radio continuum survey of the Vela supernova remnant (SNR), made with the MOST before the completion of the Wide Field upgrade. This remnant is the closest and one of the brightest SNRs. The contrast between the structures in the central pulsar-powered nebula and the synchrotron radiation shell allows the remnant to be identified *morphologically* as a member of the composite class. The data are the first of a composite remnant at spatial scales comparable with those available for the Cygnus Loop and the Crab Nebula, and make possible a comparison of radio, optical and soft X-ray emission from the resolved shell filaments. The survey covers an area of 50 square degrees at a resolution of $43'' \times 60''$, while imaging structures on scales up to $30'$. It has been used for comparison with Wide Field observations to evaluate the performance of the upgraded MOST.

The central plerion of the Vela SNR (Vela X) contains a network of complex filamentary structures. The validity of the imaging of these filaments has been confirmed with Very Large Array (VLA) observations at 1.4 GHz. Unlike the situation in the Crab Nebula, the filaments are not well correlated with Hα emission. Within a few parsec of the Vela pulsar the emission is much more complex than previously seen: both very sharp edges and more diffuse emission are present. It has been postulated that one of the brightest filaments in Vela X is associated with the X-ray feature (called a 'jet') which appears to be emanating from the region of the pulsar. However, an analysis of the MOST and VLA data shows that this radio filament has a flat spectral index similar to another more distant filament within the plerion, indicating that it is probably unrelated to the X-ray feature.

Preface

It has been MOST enjoyable and satisfying to be part of the major upgrade of the Molonglo Observatory Synthesis Telescope. This project has involved all the staff of the Astrophysics Department in the School of Physics, and much of the material in the early chapters is an account of the collective effort.

I must especially thank my supervisor and co-supervisors. Michael Large has been instrumental not only to my contribution to the project, but also conceived of the Wide Field upgrade, identifying the existing features of the MOST that made it possible. Tony Turtle planned the initial observations and provided continued advice for the MOST Vela SNR survey. Anne Green helped me expand my horizons into multiwavelength studies and gave me extra encouragement while I was writing this thesis. Dale Frail introduced me to observing at the VLA and was a wealth of information on SNRs. All made helpful comments on drafts of this thesis.

The Wide Field upgrade could not have taken place without the extraordinary dedication of the staff at Molonglo: Duncan Campbell-Wilson, Jeff Webb, Mick White and Boyd Smithers, who worked in trying conditions to install the new hardware and keep the telescope in good order. In Sydney, Ralph Davison, Fred Peterson, Barbara Piestrzynski and the workshop staff kept up supplies of vital components for the project. Ralph particularly helped me with electronics. The foresight of one of the great radio astronomers, Bernard Mills, has made the MOST an instrument which continues to be productive today.

I thank also many people with whom I had helpful discussions or who read and commented upon drafts of parts of this thesis, including Lewis Ball, Lawrence Cram, David Crawford, John Dickel, Bryan Gaensler, Richard Hunstead, Tom Landecker, Phil Lukins, Bruce McAdam, Vince McIntyre, Doug Milne, Gordon Robertson, Elaine Sadler, Bob Sault, Ian Skillen and many others at the School of Physics, ATNF and NRAO.

I am grateful to be able to include data obtained by several others in this thesis. Mike Bessell and Andrew Walker made and reduced the Hα observations of the Vela shell and Vela X. Vince McIntyre and Tanya Hill helped with additional reduction. Doug Milne, Berndt Aschenbach and Craig Markwardt kindly provided electronic versions of their data. I acknowledge the support provided by software authors both within and outside the School of Physics, including Lawrence Cram, David Crawford, Richard Gooch, Neil Killeen, Bob Sault and Taisheng Ye. Dick Manchester, Matthew Bailes and Peter McCulloch provided Vela pulsar timing data.

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My family and close friends have always been supportive of my study. My brother Timothy helped me with statistics. I particularly thank my mother who, apart from proofreading this thesis, made many sacrifices to ensure that my brothers and I received an excellent education.

This thesis was typeset by the author using the LaTeX document preparation system (Lamport 1994).

Statement of originality

The work contained in this thesis is the result of the sole and original endeavours of myself, Douglas Carl-Johan Bock, except where noted otherwise. The latter exclusions include some of the work contained in chapters 2, 3 and 8, which was undertaken in collaboration with others. In each case a statement explaining the extent to which the work was my own is incorporated within the chapter.

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Next to our own sun, Vela X was probably the most important star in the history of humanity.

George Michanowsky, 1977, The Once and Future Star: Exploring the Mysterious Link Between the Great Southern Supernova (Vela X) and the Origins of Civilization, (New York: Hawthorn).

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Acronyms, Abbreviations and Conventions

A list of acronyms and abbreviations used frequently in this thesis is given below. A reference to the section where they are introduced is given in parentheses, where usage of the terms is peculiar to the MOST.

A700	The HP-A700 observing computer (3.2.2)
`AIPS`	Astronomical Image Processing System
ADC	Analogue-to-Digital Converter
ARC	Arc (zenithal equidistant) projection
ATCA	Australia Telescope Compact Array
BC	Bay Controller (2.5.2)
BL	Bay Linker (2.5.4)
BP	Bay Phaser (2.4.2)
Dec., δ	Declination
EPROM	Erasable Programmable Read Only Memory
FITS	Flexible Image Transport System
FWHM	Full Width at Half Maximum
HA	Hour Angle
HPBW	Half-Power Beam Width
ISM	Interstellar Medium
IF	Intermediate Frequency (2.4.3)
Jy	Jansky, a unit of flux density; $1\,\mathrm{Jy} = 10^{-26}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$
LED	Light Emitting Diode
LNA	Low Noise Amplifier (2.4.1)
LO	Local Oscillator
MC	Master Controller (2.5.1)
MD	Meridian Distance (2.1)
`MIRIAD`	Multichannel Image Reconstruction Image Analysis and Display
MOST	Molonglo Observatory Synthesis Telescope
MVS	MOST Vela Supernova Remnant Survey
NCP	North Celestial Pole (slant orthographic) projection
NRAO	National Radio Astromomy Observatory[1]
RA	Right Ascension
RF	Radio Frequency

SN(e)	Supernova(e)
SNR	Supernova Remnant
TCC	Telescope Control Computer (3.2.2)
VLA	Very Large Array
WF	Wide Field (2.3)

Typography notes When referring to computer software, I have used the `typewriter` style, capitalised or not as indicated by common usage, for example `AIPS HGEOM` but `MIRIAD regrid`. Algorithms such as CLEAN are given in Roman type. I introduce new terms in *italics.*

Epoch usage I have tried, as far as possible, to use J2000 coordinates throughout this thesis. However, the MOST uses exclusively B1950 coordinates for observing and data archiving. To avoid confusion I have retained B1950 coordinates in discussions of MOST observing parameters.

Spectral indices All radio spectral indices, α, in this thesis are quoted assuming the relationship $S_\nu \propto \nu^\alpha$.