Optical Interferometry and Mira Variable Stars

Michael Ireland

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Abstract

This thesis describes the development of a red tip/tilt and fringe detection system at the Sydney University Stellar Interferometer (SUSI), modelling the instrumental performance and effects of seeing at SUSI, making observations of Mira variable stars and finally modelling the atmospheres of Mira variables with physically self-consistent models. The new SUSI tip/tilt system is based around a CCD detector and has been successfully used to both track the majority of tip/tilt power in median seeing at an R magnitude of 4.5, and to provide seeing measures for post processing. The new fringe-detection system rapidly scans 33 to 140 μm in delay and detects the fringes using two avalanche-photodiodes. It has been used to acquire fringe data, provide user feedback and to track the fringe group-delay position. The system visibility (fringe visibility for a point source) and throughput were found to be consistent with models of the SUSI optical beam train. Observations were made of a variety of sources, including the Mira variables R Car and RR Sco, which were observed in two orthogonal polarization states. These measurements were the first successful use of Optical Interferometric Polarimetry (OIP), and enabled scattered light to be separated from bright photospheric flux. Dust scattering was found to originate from a thin shell 2-3 continuum radii from these stars, with an optical depth of 0.1 to 0.2 at 900 nm. Physical model of Mira variables including dust formation were developed, providing consistent explanations for these results as well as many other photometric and interferometric observations.

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Firstly, thank you to all the people that have helped with running the SUSI project and bug-shooting different systems during my thesis period: John Davis, Andrew Jacob, Bob Lucas, Julian North, Steven Owens, Michael Paterson, Gordon Robertson, Bodie Seneta, Bill Tango, Theo ten Brummelaar, Wes Traub and Peter Tuthill. SUSI is a complicated beast, and generally fixing or upgrading existing sub-systems was a team effort: many thanks to everyone.

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Declaration of Originality

This work describes work carried out in the Astronomy group at the University of Sydney, between July 2002 and September 2005. Except where otherwise acknowledged, the work presented in this thesis is my own. Note that in the Chapters on SUSI hardware (Chapters 2 to 4) most of the initial design, purchase and initial of optics had been done by others (John Chow, John Davis, John O'Byrne). Bodie Seneta had done some preliminary work on interfacing a basic linux graphical user interface to the tip/tilt camera. My primary involvement was characterising the optical components and interfacing them with the electronic and computer hardware. Important changes to the initial optical configuration are outlined explicitly. Significant contributions from other people in Chapters 9, 10 and 11 are outlined at the beginning of those chapters.

Michael Ireland　　　　　　　　　　　　Date

Publications

Chapters 7, 9, 10, 11 and Appendix B (partially based on previous work) are all almost exact reproductions of papers published in or submitted to refereed journals:

- Ireland, M. J., Scholz, M., Tuthill, P. G., and Wood, P. R., December 2004, Pulsation of M-type Mira variables with moderately different mass: search for observable mass effects, MNRAS, **355,** 444–450.
- Ireland, M. J., Scholz, M., and Wood, P. R., July 2004, On the observability of geometric pulsation of M-type Mira variables, MNRAS, **352,** 318–324.
- Ireland, M. J., Tuthill, P. G., Bedding, T. R., Robertson, J. G., and Jacob, A. P., May 2004, Multiwavelength diameters of nearby Miras and semiregular variables, MNRAS, **350,** 365–374.
- Ireland, M. J., Tuthill, P. G., Davis, J., and Tango, W., July 2005, Dust scattering in the Miras R Car and RR Sco resolved by optical interferometric polarimetry, MNRAS, **361,** 337–344.
- Ireland, M. J., and Scholz, M., 2005, Observable Effects of Dust Formation in Dynamic Atmospheres of M-type Mira Variables, MNRAS, submitted

In addition, the following publications in conference proceedings partially resulted from work done in this thesis:

- Ireland, M., Tuthill, P., Robertson, G., Bedding, T., Jacob, A., Monnier, J., and Danchi, W., 2004, Interferometry of pulsating red giants from 0.65 to 3.5 microns, in *ASP Conf. Ser. 310: IAU Colloq. 193: Variable Stars in the Local Group,* p. 327.
- Peter G. Tuthill, John Davis, Michael Ireland, Julian North, John O'Byrne, J. Gordon Robertson, William J. Tango,2004, SUSI: recent technology and science, in *Proceedings of the SPIE Vol 5491, ed W. Traub,* 499

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Common Acronymns and Symbols

I_1,I_2	Total intensities of two beams
c_x	x-axis centroid
T_s	Sweep (scan) time
t_s	Sample time
$\boldsymbol{B}$	Baseline vector
$\boldsymbol{\alpha}$	Image-plane vector
$\boldsymbol{u}$	Spatial-frequency vector
r_0	Fried's coherence length
t_0	Atmospheric coherence time
λ	Wavelength
V	Fringe visibility
Q	Object visibility
η	System visibility
I_λ	Monochromatic specific intensity
J_λ	Mean intensity
H_λ	Eddington Flux
$M_\odot$	Solar mass
CGS	Centimetre-Gram-Second units
RMS	Root Mean Square
FWHM	Full-Width Half-Maximum
Var()	Variance
BRT	Beam-Reducing Telescope
LDC	Longitudinal Dispersion Corrector
OPLC	Optical Path Length Compensator
CCD	Charge-Coupled Device
APD	Avalanche Photo-Diode
SUSI	Sydney University Stellar Interferometer
NSII	Narrabri Stellar Intensity Interferometer
OS	Opacity Sampling
OPDF	Opacity Distribution Function
JOLA	Just-Overlapping Line Approximation