Radio Interferometric Studies of Cool Evolved Stellar Outflows

A dissertation submitted to the University of Dublin
for the degree of Doctor of Philosophy

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Declaration

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Summary

You should write a nice summary here...

A dedication if you wish...

Acknowledgements

Some sincere acknowledgements...

List of Publications

Refereed

1. **O'Gorman, E.**, Harper, G. M., Brown, J. M., Brown, A., Redfield, S., Richter, M. J., and Requena-Torres, M. A.
   "CARMA CO(J = 2 - 1) Observations of the Circumstellar Envelope of Betelgeuse"
   The Astronomical Journal, 144, 36 (2012)

2. Sada, P. V., Deming, D., Jennings, D. E., Jackson, B. K., Hamilton, C. M., Fraine, J., Peterson, S. W., Haase, F., Bays, K., Lunsford, A., and **O'Gorman, E.**
   "Extrasolar Planet Transits Observed at Kitt Peak National Observatory"
   Publications of the Astronomical Society of the Pacific, 124, 212 (2012)

3. Sada, P. V., Deming, D., Jackson, B. K., Jennings, D. E., Peterson, S. W., Haase, F., Bays, K., **O'Gorman, E.**, and Lundsford, A.
   "Recent Transits of the Super-Earth Exoplanet GJ 1214b"
   The Astrophysical Journal Letters, 720, L215 (2010)

Non-Refereed

1. **O'Gorman, E.**, & Harper, G. M.
   "What is Heating Arcturus' Wind?",
   Proceedings of the 16th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun. Astronomical Society of the Pacific Conference Series, 448, 691 (2011)

Contents

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1
Scientific Overview

Here is the introduction of the thesis, complete with a few references (Prothero & Buell, 2007; Sagan, 1997). Section 3.1 contains Equation 1.1, Section 3.2 has Figure 1.1 and Section 3.3 has Table 1.1. Chapter 2 has pretty much nothing in it.

1.1 First Section

This section has an equation. Here it is:

$$L_\odot = 4\pi R_\odot^2 \sigma T_e^4 \tag{1.1}$$

which is a nice way of describing the luminosity.

1.2 Second Section

So this section has a figure in it[1]. That figure depicts the basic structure of a red giant.

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[1] And also a footnote.
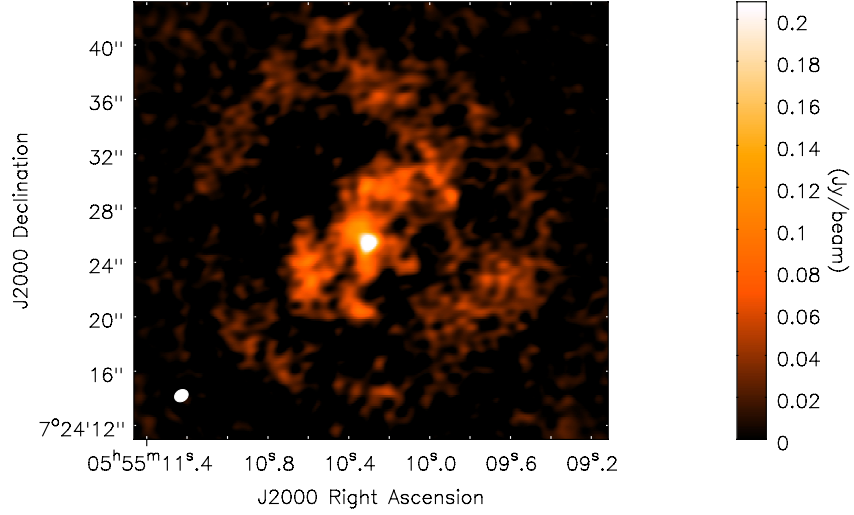
Figure 1.1: Red Giant and Asymptotic Giant Branch Stars. The left side of the figure shows the basic structure of a star on the giant branch of the HR diagram, while the right side shows a similar star after it has evolved to ascend the asymptotic giant branch. *Image Credit: Australian Telescope National Facility.*

1.3   Second Section

This section contains a basic table.

Table 1.1: Physical Properties of α Boo and α Tau.

Property	α Boo	α Tau	Reference
HD Number	124897	29139	. . .
Spectral Type	K2 III	K5 III	1, 2
ra (ICRS: ep=J2000)	$14^{\rm h}15^{\rm m}39.672^{\rm s}$	$04^{\rm h}35^{\rm m}55.239^{\rm s}$	3
dec (ICRS: ep=J2000)	$+19\ 10\ 56.673$	$+16\ 30\ 33.489$	3
pm-ra (mas yr^{-1})	-1093.39 ± 0.44	63.45 ± 0.84	3
pm-dec (mas yr^{-1})	-2000.06 ± 0.39	-188.94 ± 0.65	3
π (mas)	88.83 ± 0.54	48.94 ± 0.77	3
Distance (pc)	11.3±0.1	20.4±0.3	3
M ($M_\odot$)	0.8±0.2	1.3±0.3	6, 4
$\theta_{\rm UD}$ (mas)	21.0±0.2	20.2±0.3	5
$\theta_{\rm LD}$ (mas)	21.0±0.2	20.2±0.3	5
L ($L_\odot$)			
R ($R_\odot$)	25.4±0.3	44.4±1.0	. . .
Log g			
$T_{\rm eff}$ (K)	4294±30	3970±49	5
$v_{\rm rad}$ (km s^{-1})	$+5.19 \pm 0.04$	$+54.11 \pm 0.04$	9
$v_{\rm esc}$ (km s^{-1})	110	106	. . .
v_∞ (km s^{-1})	$\sim$40	$\sim$30	7, 8
$T_{\rm wind}$ (K)	$\sim$10,000	<10,000	7, 8
$\dot{M}$ ($M_\odot$ yr^{-1})	2×10^{-10}	1.6×10^{-11}	7, 8
H ($H_\odot$)			. . .

References.-(1);(2)Gray *et al.* (2006); (3)van Leeuwen (2007); (5)di Benedetto (1993); (6)Kallinger *et al.* (2010); (7)Drake (1985); (8)Robinson *et al.* (1998) (9)Massarotti *et al.* (2008)

2

Introduction to Radio Interferometry

The need....

2.1 Radio Antenna Basics

The quality and properties of the final radio image produced from a synthesis array are partially dependent on the properties of the the individual antennae in the array. The most important such properties are discussed in the following sections and include aperture size, aperture efficiency, pointing accuracy, sidelobe level and noise temperature. We define the radio antenna as the piece of equipment which converts the electromagnetic waves emitted from the observed source into an electric current ready to be input into to the first low noise amplifier where the signal is at the radio/sky frequency, ν_{RF}.

2.1.1 Radio Antenna Formulae

The power gain of a transmitting antenna is a measure of the antenna's capability of converting power into radio waves in a specific direction. In radio astronomy, the receiving counterpart of transmitting power gain is the effective collecting area of an antenna, $A(\nu,\theta,\phi)$, where ν is frequency and θ and ϕ are direction

coordinates. An ideal radio antenna would collect all incident radiation from a distant point source and convert it to electrical power. The total spectral power P_ν, collected by it would then be a product of its geometric area and the incident spectral power per area, or flux density F_ν. By analogy then, the effective area of a real radio antenna is defined

$$A(\nu, \theta, \phi) = \frac{P_\nu}{F_\nu} = \frac{P}{I(\nu, \theta, \phi)\Delta\nu\Delta\Omega} \qquad (2.1)$$

where $I(\nu,\theta,\phi)$ is the source brightness in units W m^{-2} Hz^{-1} sr^{-1} that the antenna is pointing at (see Figure x) and P is the power (in Watts) received by the antenna in bandwidth $\Delta\nu$ from element $\Delta\Omega$ of solid angle.

2.1.2 Antenna Structural Design

2.1.3 Anetnna Performance Parameters

2.2 Fundamentals of Astronomical Interferometry

Young's Slits

2.3 The Synthesis Telescope

2.4 The Measurement Equation

3
Instrumentation and Observations

So this Chapter has nothing really, apart from a shout out to Appendix A, and maybe a few more sample references (Harper & Brown, 2006; Seaquist & Taylor, 1990).

3.1 CARMA

3.1.1 The Basic Instrument

3.1.2 The CARMA Electronic System

3.1.3 Observations

3.2 VLA

3.2.1 The Basic Instrument

3.2.2 The VLA Electronic System

3.2.3 Observation Preparation

3.2.4 Observations

3.3 GMRT

A

A Nice Appendix

This is where the appendix would go...

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