



Detection of Magnetic Fields and Diffuse Radio Emission in Abell 3667 and other Rich Southern Clusters of Galaxies

Melanie Johnston-Hollitt

Department of Physics & Mathematical Physics
University of Adelaide

*A thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy*

July 2003

© 2003 Melanie Johnston-Hollitt

Abstract

This thesis investigates the properties of magnetic fields in galaxy clusters via both statistical Faraday rotation measures and diffuse source polarimetry, and investigates the nature and generation mechanisms for diffuse radio emission in the ACO cluster A3667. Chapter one gives an introduction to galaxy clusters and discusses both their history and emission processes. Chapter two provides a detailed discussion of the instruments used during the course of this research. Chapter three presents the results of a statistical study into cluster magnetic fields via Faraday rotation measurements (RMs). The results agree well with previous findings and support cluster fields of 1–2 μG . Chapter four presents an interpolated all-sky rotation measure map generated to allow for more accurate modelling of the Galactic contribution to calculated rotation measures. Large scale features in the RM sky are discussed and good agreement is found between these results and previously observed magnetic field directions in the spiral arms. These data do not suggest a field reversal in the outer spiral arm. Chapter five gives an analysis of multifrequency radio observations of the ACO cluster A3667, presenting a detailed investigation into the diffuse emission in the cluster. Major results presented include the discovery of filamentary structure with a power-law spectral index and high polarisation. Generation mechanisms for this emission are discussed in light of these results. Chapter six presents analysis of redshift data for objects in A3667 down to a magnitude of $m_B = 18.3$. The previously reported secondary subgroup in the north of the cluster is less obvious and no subgroup structures are evident in the velocity data. This suggests that if a merger is present in A3667 it must be entirely within the plane of the sky. Chapter seven presents the conclusions and future directions.

Contents

List of Tables	xvii
List of Figures	xix
1 Introduction	1
1.1 Magnetic Fields: an Introduction	1
1.2 Measurement of Magnetic Fields	1
1.3 Magnetic Fields in Galaxies: An Historical Perspective	3
1.4 Clusters of Galaxies	5
1.4.1 Emission Mechanisms in Clusters of Galaxies	9
1.5 Notation and Conventions	15
1.6 Summary	16
2 Instrumentation and Analysis Techniques	17
2.1 Introduction	17
2.2 The Australia Telescope Compact Array	17
2.2.1 ATCA Design Aspects	18
2.3 ATCA Observing Techniques	19
2.3.1 Continuum Observations	19
2.3.2 Multifrequency Synthesis	20
2.3.3 Earth-Rotation Synthesis	21
2.3.4 Short Observations	21
2.3.5 Mosaicing	21
2.3.6 Polarisation Mosaicing	22
2.4 Interferometric Polarisation with the ATCA	24
2.4.1 Polarimetry at the ATCA	25
2.4.2 In the Not-so-ideal World	27
2.5 ATCA calibration	28
2.5.1 Standard Calibration on the ATCA	28
2.6 ATCA Imaging	31
2.6.1 Transforming to the Image Plane	31
2.6.2 Removing the Sidelobe Pattern	32
2.7 The 2dF Spectroscopic System	33
2.7.1 Observing Set-up	33

2.8	Summary	36
3	Rotation Measure Studies in Clusters	37
3.1	Introduction: Magnetic Fields in Clusters	37
3.2	Faraday Rotation	37
3.3	Sources of Error in Rotation Measure Fits	39
3.3.1	Error due to Noise	40
3.3.2	$n\pi$ -Ambiguity	41
3.3.3	Depolarisation	42
3.3.4	Effect of Off-axis Polarisation Errors	45
3.4	Previous RM studies in Clusters	45
3.5	Current Study	48
3.5.1	Source Selection	48
3.5.2	Observations of Southern X-ray Luminous Clusters of Galaxies	50
3.5.3	Observations	52
3.5.4	Polarisation Data	56
3.5.5	RM Fitting	57
3.5.6	Comparison to Other Data	57
3.6	Summary	63
4	An Estimated All-Sky Rotation Measure Map	65
4.1	Introduction	65
4.2	Interpolation	66
4.3	Evaluation	67
4.4	Structure Analysis	67
4.5	Source Statistics	72
4.6	Discussion	76
4.7	Summary	76
5	Diffuse Radio Emission in A3667	77
5.1	Introduction	77
5.2	Diffuse Radio Emission in Galaxy Clusters	77
5.3	A3667	79
5.3.1	Physical Picture of A3667	79
5.4	Diffuse Emission in A3667	84
5.4.1	This Study	85
5.5	Observations	86
5.5.1	Mosaicing at 20 and 13 Centimetres	86
5.5.2	6 Centimetre Observations	87
5.6	Total Intensity 1.4 GHz Imaging	88
5.6.1	Low Resolution Imaging	88
5.6.2	Other Sources	93
5.7	Total Intensity 4.8 GHz Imaging	100
5.8	Spectral Indices	101

5.9	Polarimetry	106
5.9.1	Rotation Measure Data	108
5.10	Comparison to Other Diffuse Sources	116
5.11	Discussion	119
5.12	Summary	120
6	Optical Data for A3667	121
6.1	Introduction	121
6.2	Previous Optical Observations	122
6.3	2dF Observations	124
6.4	Data Reduction	128
6.5	Results	130
6.5.1	Redshift Distribution	133
6.5.2	Bimodality Testing	135
6.5.3	Galaxy Type Information	136
6.6	Discussion	139
6.7	Summary	141
7	Conclusions and Future Prospects	143
7.1	Conclusions	143
7.2	Future Work	145
A	Cluster RM data and Additional Observations	147
A.1	Cluster Pilot Survey Data	147
B	Rotation Measure Catalogue	167
B.1	RM Data used to produce Interpolated All-Sky RM Map	167
B.2	Two Dimensional Solutions to Poisson's Equation	187
C	2dF Redshift Information	191
C.1	Redshift Data for A3667	191
C.2	Cross-correlation	201
	Bibliography	203