

095.M
S9794



Cosmic Ray Propagation Through Turbulent Magnetic Fields

Eliza Switalska

*Submitted in fulfilment of the requirements for the degree of
Master of Science*

*School of Chemistry and Physics
(Faculty of Sciences)*

The University of Adelaide

September 2006

CONTENTS

Abstract	8
Preface	9
CHAPTER 1	
Cosmic Rays	12
1.1 Introduction	12
1.2 Overview of Cosmic Rays	13
1.2.1 Cosmic Ray Arrival Directions	16
1.2.2 GZK Cut-off	16
1.2.3 High-Energy Cosmic Ray Propagation	17
1.2.4 Cosmic Ray Acceleration	19
CHAPTER 2	
Magnetic Fields	21
2.1 The Galactic and Extragalactic Magnetic Fields	21
2.2 The origin of the Galactic Magnetic Field	21
2.3 Methods in Determining Magnetic Field Strengths	23
2.3.1 The Zeeman Effect	23
2.3.2 Optical Dust Absorption and Polarization of Sub-mm and mm Emission	24
2.3.3 Synchrotron Radiation	25
2.3.4 Radio Faraday Rotation	28
2.3.5 Factors in the Determination of the Rotation Measure of Galaxies	32
2.3.6 Faraday Depolarization	34
2.3.7 Energy Equipartition between Magnetic Fields and Cosmic Rays	35
2.5 Magnetic Field Turbulence	36
2.5.1 Kolmogorov Scale Turbulence	37
2.6 Magnetic Fields in Galaxy Clusters	39
2.6.1 The Local Group of Galaxies	41
2.6.2 The Virgo Cluster and Nearby Superclusters	43
2.6.3 Radio and X-Ray Methods for Probing Cluster Magnetic Fields	46
CHAPTER 3	
RADIO ASTRONOMY	49
3.1 Introduction	49
3.2 Observational Techniques and Instruments Used	49

3.2.1	The Very large Array (VLA)	51
3.2.2	The Australia Telescope Compact Array	53
3.3	Radio Synthesis Imaging	54
CHAPTER 4		
Estimation of the Scale of the Turbulent Magnetic Field in Galaxy Clusters		55
4.1	Introduction	55
4.2	Galaxy Clusters and the A3667 Cluster	56
4.2.1	Radio Interferometer - Amplitude vs Baseline Length	57
4.2.2	Amplitude vs Baseline plot of A3667	58
4.3	Procedure	60
4.3.1	Modified A3667 Plot	60
4.3.2	Analysis of the Modified Spectrum	61
4.3.3	Results	61
CHAPTER 5		
Modelling of Cosmic Ray Propagation in a Magnetic Field		64
5.1	Previous Studies in Propagation Simulations	64
5.2	Generation of Random Magnetic Fields	66
5.3	Simulation of a Turbulent Magnetic Field	68
CHAPTER 6		
Processes Involved in Generating Simulated Turbulent Magnetic Fields and a Study of the Effects of Field Scale Variations		70
6.1	Introduction	70
6.2	Random Magnetic Field Component	71
6.3	Results of Scale Length Variation	71
6.3.1	Properties of the Magnetic Field Model	72
6.4	Effects of Clumpiness on the Magnetic Field	83
6.4.1	Small-Scale Clumpiness Results	83
6.4.2	Large-Scale Clumpiness Results	86
6.4.3	Conclusion	88
CHAPTER 7		
Cosmic Ray Propagation Through Turbulent Magnetic Fields		90
7.1	Computer Simulation of Propagation	90

7.2	Procedure	90
7.3	Results	92
7.3.1	Results for Propagation through Large Scale Turbulence	92
7.3.2	Results for Propagation through Small Scale Turbulence	93
7.3.3	Comments on the Results	94
 CHAPTER 8		
	Conclusion	96
	References	99
	Bibliography	101
 APPENDIX A		
	Diffusion	102
 APPENDIX B		
	Programs	105

Abstract

This study begins with an overview of cosmic ray literature in relation to the origin and propagation of high-energy particles in extragalactic space. It follows with a review of recent methods used in the observation and measurement of extragalactic magnetic fields and describe the radio astronomy techniques used. The later chapters describe computer simulations, which were used for producing turbulent magnetic field models and then follow on to show how these can be used to estimate the probable turbulent scales of such fields. These models are then applied to data from an actual galaxy cluster, where the turbulence spectrum of the Abell galaxy cluster (using data from a recent observational study of A3667) is estimated. The final part of this thesis is concerned with the study of cosmic ray propagation within such turbulent magnetic fields. This is achieved by altering the turbulent scale-lengths and observing the behaviour of cosmic rays within, both large and small-scale magnetic fields, thereby giving an indication as to the actual paths they may follow in space and consequently providing some clues as to their origins.