



Universiteit
Leiden
The Netherlands

Untangling cosmic collisions: a study of particle acceleration and magnetic fields in merging galaxy clusters

Osinga, E.

Citation

Osinga, E. (2023, November 1). *Untangling cosmic collisions: a study of particle acceleration and magnetic fields in merging galaxy clusters*. Retrieved from <https://hdl.handle.net/1887/3655893>

Version: Publisher's Version

[Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

License: <https://hdl.handle.net/1887/3655893>

Note: To cite this publication please use the final published version (if applicable).

UNTANGLING COSMIC COLLISIONS

A STUDY OF PARTICLE ACCELERATION AND MAGNETIC FIELDS IN
MERGING GALAXY CLUSTERS

UNTANGLING COSMIC COLLISIONS

A STUDY OF PARTICLE ACCELERATION AND MAGNETIC FIELDS IN MERGING GALAXY CLUSTERS

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden,
op gezag van de rector magnificus prof.dr.ir. H. Bijl,
volgens besluit van het college voor promoties
te verdedigen op woensdag 1 november 2023
klokke 12.30 uur

door

Erik OSINGA

geboren te Amsterdam, Nederland
in 1995

Promotor:

Prof.dr. H.J.A. Röttgering

Co-promotor:

Dr. R.J. van Weeren

Promotiecommissie:

Prof.dr. H. Hoekstra

Prof.dr. I.A.G. Snellen

Dr. A. Bonafede (University of Bologna, Italy)

Prof.dr. M. Brüggen (University of Hamburg, Germany)

Prof.dr. K. Dolag (Ludwig Maximilian University Munich, Germany)

Dr. J. Hlavacek-Larrondo (University of Montréal, Canada)

Cover:	<i>Cosmic yarn ball collision. A collision of galaxy clusters as yarn balls, digital art style.</i> Generated with the assistance of DALL-E 2 and edited in GIMP by the author.
Style:	TU Delft template, with modifications by Moritz Beller and the author. https://github.com/Inventitech/phd-thesis-template
ISBN:	978-94-6419-933-8
Printed by:	Gildeprint

An electronic version of this dissertation is available at
<http://scholarlypublications.universiteitleiden.nl/>.

Wetenschap is voortgezette twijfel

Opa Piet

To Tjissa, my Universe

CONTENTS

1	Introduction	1
1.1	Large scale structure	1
1.2	Galaxy clusters	3
1.3	Radio observations of galaxy clusters.	5
1.3.1	Instrument: The Low Frequency Array.	10
1.4	Cluster magnetic fields	12
1.4.1	Instrument: The Karl G. Jansky Very Large Array	14
1.4.2	Technique: Faraday rotation and depolarisation	14
1.5	This thesis	16
1.6	Future outlook	18
2	Alignment in the orientation of LOFAR radio sources	21
2.1	Introduction	22
2.2	The data	23
2.3	Source selection	23
2.4	Statistical methods	24
2.4.1	Parallel transport	24
2.4.2	Statistical test	26
2.5	Results	28
2.5.1	Two-dimensional analysis	29
2.5.2	Three-dimensional analysis	30
2.6	Discussion	35
2.6.1	Robustness of the results	35
2.6.2	Interpretation of the results	36
2.6.3	Scale of the alignment	39
2.7	Conclusion	40
3	Diffuse radio emission from galaxy clusters in the LoTSS Deep Fields	43
3.1	Introduction	44
3.2	Data	45
3.3	Methods	46
3.3.1	Target extraction and imaging	48
3.3.2	Measuring radio halo properties	49
3.4	Verification on simulated halos.	51
3.5	Results	53
3.5.1	PSZ2G147.88+53.24.	53
3.5.2	PSZ2G149.22+54.18.	54
3.5.3	PSZ2G084.69+42.28.	56
3.5.4	MCXCJ1036.1+5713	57

3.5.5	SpARCS1049+56	58
3.5.6	SDSSC4-3094.	59
3.5.7	Upper limits on non-detections.	60
3.6	Discussion	66
3.7	Conclusion	69
4	Probing particle acceleration in Abell 2256: from 16 MHz to gamma rays	77
4.1	Introduction	78
4.2	Data	82
4.2.1	LOFAR HBA	82
4.2.2	LOFAR LBA	82
4.2.3	Gamma-ray data	84
4.3	Results - Radio analysis	86
4.3.1	Radio halo	87
4.3.2	Radio shock	89
4.3.3	AGN related emission	91
4.4	Radio - Gamma-ray comparison	96
4.4.1	Theoretical framework	96
4.4.2	Gamma-ray upper limits	98
4.5	Discussion	101
4.5.1	Spectral properties of the halo	101
4.5.2	Testing a hadronic origin.	103
4.5.3	Diffusive shock acceleration in the radio shock.	104
4.5.4	Origin of AGN related sources	105
4.6	Conclusion	106
5	The detection of cluster magnetic fields via radio source depolarisation	115
5.1	Introduction	116
5.2	Data	117
5.2.1	Chandra-Planck ESZ sample	117
5.2.2	Observations and data reduction	118
5.3	Methods	123
5.3.1	Polarised source finding	123
5.3.2	Fractional polarisation measurement	125
5.3.3	Optical counterparts	129
5.3.4	Redshift estimation.	129
5.4	Magnetic field modelling	131
5.5	Results - Observations	132
5.5.1	Full sample.	134
5.5.2	Background versus cluster members	134
5.5.3	Dynamical state	136
5.5.4	Cluster mass and redshift	138
5.5.5	Presence of a radio halo	139

5.6	Results - Modelling	143
5.6.1	Effect of density profiles	143
5.6.2	Effect of the magnetic field strength and fluctuation scales	144
5.6.3	Comparison with observations	145
5.7	Discussion	150
5.7.1	Cluster members versus background sources	150
5.7.2	Magnetic field parameters	151
5.7.3	Cluster properties	151
5.7.4	Possible caveats	153
5.8	Conclusion	156
6	Probing cluster magnetism with embedded and background radio sources in Planck clusters	171
6.1	Introduction	172
6.2	Chandra-Planck ESZ sample	173
6.3	Methods	174
6.4	Results	175
6.4.1	Average magnetic field strength	175
6.4.2	Radially declining magnetic field	177
6.4.3	Cluster members vs background sources	182
6.4.4	Merging vs relaxed clusters	183
6.4.5	Comparison to models	184
6.5	Discussion	191
6.6	Conclusion	193
Bibliography		203
English Summary		221
Nederlandse Samenvatting		227
Fryske gearfetting		233
List of Publications		239
Curriculum Vitæ		241
Acknowledgments		243

