



Universiteit
Leiden
The Netherlands

Seismology of magnetars

Hoven, M.B. van

Citation

Hoven, M. B. van. (2012, February 15). *Seismology of magnetars*. Retrieved from <https://hdl.handle.net/1887/18484>

Version: Corrected Publisher's Version

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

Downloaded from: <https://hdl.handle.net/1887/18484>

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

Seismology of Magnetars

M.B. van Hoven

ISBN 978-94-6191-176-6

Cover by Harry Allaart & Maarten van Hoven

Seismology of Magnetars

PROEFSCHRIFT

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van de Rector Magnificus prof. mr. P. F. van der Heijden,
volgens besluit van het College voor Promoties
te verdedigen op woensdag 15 februari 2012
klokke 11.15 uur

door

Maarten Benjamin van Hoven
geboren te Leiden
op 7 juni 1981

Promotiecommissie

Promotor:

Prof. dr. K.H. Kuijken

Co-promotor:

Dr. Y. Levin (Universiteit Leiden/Monash University)

Overige leden:

Prof. dr. A.M. Beloborodov (Columbia University)

Prof. dr. K.D. Kokkotas (Eberhard Karls Universität Tübingen)

Prof. dr. F.W.M. Verbunt (Universiteit Utrecht)

Dr. A.L. Watts (Universiteit van Amsterdam)

*This is how the world works. All energy flows
according to the whims of the Great Magnet.
What a fool I was to defy him.*

HUNTER S. THOMPSON

Contents

Introduction	1
History	1
Neutron stars	3
Magnetars	5
SGR giant flares and QPOs	7
Seismology of magnetars	9
This thesis	13
Chapter 1	13
Chapter 2	14
Chapter 3	15
Chapter 4	16
Acknowledgements	17
1 Hydromagnetic waves in a superfluid neutron star with strong vortex pinning	19
Abstract	20
1.1 Introduction	21
1.2 Dispersion relations	25
1.3 Hydromagnetic waves in magnetars	28
1.4 Precession of neutron stars	29
1.4.1 Glaberson instability criterion	30
1.4.2 The maximum misalignment angle for fast precession	31
1.5 Discussion	33
Acknowledgements	34

CONTENTS

Appendix 1.A: Dispersion relation for arbitrary drag	35
Appendix 1.B: Instability criterion for non-zero viscosity	36
2 Excitation of f-modes and torsional modes by giant flares	39
Abstract	40
2.1 Introduction	41
2.2 The general formalism	42
2.2.1 Excitation by the EM	42
2.3 f-modes and gravitational waves	46
2.4 Torsional modes	48
2.4.1 Magnetic modes	49
2.5 Discussion	49
Acknowledgements	50
Appendix 2.A: Alternative derivation of the mode excitation	51
Appendix 2.B: Stellar oscillations	52
3 The strongly coupled dynamics of crust and core	55
Abstract	56
3.1 Introduction	57
3.2 An oscillator coupled to a continuum: edge modes	60
3.2.1 Time-dependent behavior	61
3.2.2 Finding eigenmodes	65
3.2.3 Late time behavior of the system	67
3.2.4 The effect of viscosity	69
3.3 Transient and drifting QPOs	71
3.4 More realistic magnetar models	74
3.4.1 The model	75
3.4.2 The continuum	76
3.4.3 Results	82
3.5 Tangled magnetic fields	84
3.5.1 simple model: “square” neutron star	86
3.6 Discussion	92
Acknowledgements	96
Appendix 3.A: Multimodal crust-core system	97

Appendix 3.B: Core continua with a mixed toroidal-poloidal field . . .	98
4 A spectral method for magnetar oscillations	101
Abstract	102
4.1 Introduction	103
4.2 Relativistic MHD equations	106
4.3 Modes of a magnetized crust in General Relativity	110
4.3.1 Magnetic force density in the free crust	114
4.3.2 Relativistic equations for elastic forces	115
4.3.3 The neutron star model	117
4.3.4 Results	118
4.4 Core continuum and the coupling between crust and core . . .	122
4.4.1 The continuum	122
4.4.2 Equations of motion for the coupled crust and core . .	125
4.4.3 Results	129
4.5 Discussion	132
Acknowledgements	133
Appendix 4.A: Damped modes	134
Bibliography	137
Nederlandstalige samenvatting	143
Het heelal in een notendop	144
Het leven en sterven van een ster	148
Neutronensterren	152
Magnetars	155
Oscillaties van sterren	157
Seismologie van magnetars	159
Hoofdstuk 1: Golven in de kern van een neutronenster . . .	161
Hoofdstuk 2: Het ontstaan van ‘magnetarbevingen’	164
Hoofdstukken 3 en 4: Een dynamisch model van een magnetar	166
Curriculum Vitae	171
Nawoord	173

