

ISBN: 978-90-367-8946-2 (printed version)
ISBN: 978-90-367-8945-5 (electronic version)

The work described in this thesis was performed at the Van Swinderen Institute for Particle Physics and Gravity of the University of Groningen.

Front cover: “Circle Limit III” by M. C. Escher (computer generated picture by V. Bulatov, <http://bulatov.org>). It represents the Poincaré disk model of a 2-dimensional hyperbolic space. This type of geometry is a central topic of the present thesis, as at the core of the cosmological attractor phenomenon.

Bookmark: “Circle Limit III” by M. C. Escher (computer generated picture by V. Bulatov). It represents a 2-dimensional hyperbolic geometry in half-plane coordinates.

Cover and bookmark realized by Seannamon Design (Giada Maugeri).
Printed by Ipskamp Printing, The Netherlands.



/ university of
groningen

Inflation, Universality and Attractors

PhD thesis

to obtain the degree of PhD at the
University of Groningen
on the authority of the
Rector Magnificus Prof. E. Sterken
and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on

Monday 13 June 2016 at 9:00 hours

by

Marco Scalisi

born on 28 April 1986
in Siracusa, Italy

Supervisors

Prof. D. Roest

Prof. E. A. Bergshoeff

Assessment committee

Prof. A. Achúcarro

Prof. A. Hebecker

Prof. R. van de Weijgaert

to Anika

Contents

1	Introduction	1
1.1	Scientific background	2
1.2	Main subject and challenges	4
1.3	Outline of the thesis	5
2	Standard Cosmology	7
2.1	The expanding Universe	8
2.2	Relativistic cosmology	11
2.2.1	Homogeneity and isotropy	12
2.2.2	Friedmann equations and the cosmic history	14
2.3	Big Bang shortcomings	18
2.3.1	Flatness problem	18
2.3.2	Horizon problem	20
2.3.3	Additional challenges	21
3	Inflationary Cosmology	23
3.1	Inflation and the smooth background	24
3.1.1	Basic idea	24
3.1.2	Decreasing Hubble radius	25
3.1.3	Quasi-de Sitter phase and Hubble flow functions	25
3.1.4	Puzzles resolution and the amount of inflation	26
3.1.5	Scalar field dynamics and slow-roll inflation	28
3.2	Inflation and the background perturbations	30
3.2.1	The inhomogeneous Universe	30
3.2.2	Quantum scalar fluctuations during inflation	32
3.2.3	Classical curvature and density perturbations	35
3.2.4	Primordial gravitational waves	36
3.3	Inflation and observations	36
3.3.1	CMB power spectrum and inflationary observables	37
3.3.2	Planck data	39

4 Universality, Observations and the Inflaton Range	43
4.1 The N -formalism of inflation	44
4.2 Universality classes at large N	45
4.3 The inflaton range and observations	48
4.4 Degeneracy of the inflaton range	50
4.4.1 Chaotic inflation as benchmark	51
4.4.2 Perturbative class	52
4.4.3 Logarithmic class	56
4.4.4 Non-perturbative class	57
4.4.5 Sub-Planckian field ranges	61
4.4.6 Discussion	62
4.5 Universality of the inflaton range	64
4.5.1 Universality at large N	64
4.5.2 Universality at small μ	65
4.6 The Lyth bound with a tilt	67
4.6.1 Strengthening the Lyth bound	68
5 Inflation and Attractors in Supergravity	71
5.1 Inflation in supergravity	72
5.1.1 Basics of 4D $\mathcal{N} = 1$ supergravity	74
5.1.2 The η -problem in supergravity	76
5.1.3 sGoldstino directions and inflation	77
5.1.4 Towards an embedding in string theory	83
5.2 Flat Kähler geometry and arbitrary inflation	85
5.3 Hyperbolic Kähler geometry and attractors	87
5.3.1 Model with $K = -3\alpha \ln(\Phi + \bar{\Phi} - S\bar{S})$	90
5.3.2 Model with $K = -3\alpha \ln(\Phi + \bar{\Phi}) - S\bar{S}$	94
5.4 α -Scale supergravity and attractors	94
5.4.1 No-scale supergravity and de Sitter	95
5.4.2 α -Scale supergravity and stable de Sitter	97
5.4.3 Single superfield α -attractors	99
5.4.4 Flat Kähler limit	101
5.4.5 Discussion	103
6 Inflation and de Sitter Landscape	105
6.1 Introduction and outline	106
6.2 Single superfield inflation and dark energy	108
6.2.1 Inflation and uplifting with a linear superpotential . .	110
6.2.2 Inflation and uplifting with a quadratic superpotential	114
6.2.3 Discussion	118

CONTENTS	III
6.3 Arbitrary inflation and de Sitter landscape	119
6.3.1 The nilpotent superfield	119
6.3.2 Arbitrary inflation, dark energy and SUSY breaking .	120
6.3.3 Fermionic sector after the exit from inflation	122
6.4 Attractors and de Sitter landscape	123
6.4.1 Uplifting flat α -attractors	124
6.4.2 Uplifting geometric α -attractors	127
6.4.3 General inflaton potential from curved Kähler geometry	129
6.4.4 Discussion	130
7 Conclusions	133
7.1 Overview of the results	134
7.2 Outlook	135
List of Publications	139
Bibliography	141
Samenvatting	161
Acknowledgments	165

