TABLE OF CONTENTS

Chapter I **Introduction** **1**
§ 1 Self-organization far from equilibrium 1
§ 2 Active matter – from flying spins to flocking 2
§ 3 Outline of objectives, methods and structure of this thesis ... 6

Chapter II **Individual dynamics of self-propelled particles** **11**
§ 4 Self-propelled particles in two dimensions 11
§ 5 Taylor-Kubo formula 12
§ 6 Properties of self-propelled particles 14
§ 7 From particles to fields 15
§ 8 A glimpse on coarse-graining 17
§ 9 A geometric view on self-propelled motion in d dimensions .. 20
§ 10 Self-propelled motion in anisotropic environments 24

Chapter III **Diffusion of self-propelled particles with velocity reversal** . **29**
§ 11 Self-propelled particles with velocity reversal 29
§ 12 Reversal as a renewal process 32
§ 13 Resonance – optimal noise maximizes diffusion 36
§ 14 A clock model for velocity reversal 38
§ 15 A perspective on the relevance for microbiology 42

Chapter IV **Derivation of kinetic theories** **45**
§ 16 The objective of kinetic theory 45
§ 17 Fokker-Planck approach 46
§ 18 Microscopic density approach 49
§ 19 Markov chain approach for Vicsek-type models 52
§ 20 Boltzmann approach 54
§ 21 Concluding remarks 56

Chapter V **Mesoscale turbulence** **59**
§ 22 Turbulence at low Reynolds numbers 59
§ 23 Phenomenological theory for mesoscale turbulence 60
§ 24 Self-propelled particles with competing alignment interactions 63
§ 25 Derivation of transport coefficients 66
§ 26 Linear stability of the disordered state 70
§ 27 Langevin simulations 73
§ 28 Perspectives on mesoscale turbulence 82

Chapter VI **Alignment-driven phase separation regulated by reversal . 85**
§ 29 A self-propelled particle model for self-driven rods 85
§ 30 Hydrodynamic limit 89
§ 31 Linear stability of the disordered state 93
§ 32 Reduced hydrodynamic equations & emergence of bands 95
§ 33 Transversal band dynamics 101
§ 34 Linear stability of the ordered state 104
§ 35 Discussion & outlook 107

Chapter VII **Superdiffusion, large-scale order and topological defects .. 111**
§ 36 From self-propelled particles to moving oscillators 111
§ 37 Langevin dynamics of randomly moving oscillators 114
§ 38 Phenomenology: synchronization of moving oscillators 115
§ 39 A roadmap towards macroscopic field equations 119
§ 40 Fluctuating density dynamics 120
§ 41 Derivation of a stochastic field theory 123
§ 42 High density limit I: dynamics close to the transition point .. 127
§ 43 High density limit II: spin-wave approximation 130
§ 44 Concluding remarks 132

Chapter VIII **Summary 135**

Appendix A **Interface dynamics in reaction-diffusion systems 139**

Appendix B **Kuramoto model 145**

Bibliography 149