

# Renormalization group and instantons in stochastic nonlinear dynamics

## From self-organized criticality to thermonuclear reactors

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**Abstract.** Stochastic counterparts of nonlinear dynamics are studied by means of nonperturbative functional methods developed in the framework of quantum field theory (QFT). In particular, we discuss fully developed turbulence, including leading corrections on possible compressibility of fluids, transport through porous media, theory of waterspouts and tsunami waves, stochastic magneto-hydrodynamics, turbulent transport in crossed fields, self-organized criticality, and dynamics of accelerated wrinkled flame fronts advancing in a wide canal. This report would be of interest to the broad auditorium of physicists and applied mathematicians, with a background in nonperturbative QFT methods or nonlinear dynamical systems, having an interest in both methodological developments and interdisciplinary applications.

*In Memoriam of George M. Zaslavsky (31.05.35–25.11.08), Professor of Physics & Mathematics at the Department of Physics & Courant Institute of Mathematical Sciences, New York University, Doctor honoris causa of the University of Provence.*

## 1 Introduction

In this report, we study the stochastic counterparts of some models in nonlinear dynamics. Deterministic trajectories are replaced by random trial trajectories of some well-defined stochastic processes. The proposed approach is closely related to the Nelson stochastic mechanics, the probabilistic interpretation of dynamical equations, and the critical phenomena theory. We thoroughly use the renormalization group (RG) and the method of instanton—the nonperturbative techniques developed in the framework of quantum-field theory (QFT).

Asymptotic solutions for the models in stochastic dynamics are obtained in the form of a perturbation theory, which can be studied by means of Feynman functional integrals. In the presence of a large parameter in the model, this integral can be estimated directly—two examples are given in the fourth section. Otherwise, diagram series of the perturbation theory can sometimes be studied by means of RG techniques. We apply this method in the theory of turbulence, for the study of tsunami waves, in magneto-hydrodynamics (MHD), and in self-organized criticality.

In statistical mechanics, the RG (which is, in fact, a semigroup since the transformations are not invertible) forms an ensemble of transformations that map a Hamiltonian into another

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# Nonlinear Dynamics And Renormalization Group

**L. Douglas Kiel**



## **Nonlinear Dynamics And Renormalization Group:**

**Nonlinear Dynamics and Renormalization Group** Israel Michael Sigal, Catherine Sulem, 2001 This book contains the proceedings from the workshop Nonlinear Dynamics and Renormalization Group held at the Centre de recherches mathématiques CRM in Montréal Canada as part of the year long program devoted to mathematical physics In the book active researchers in the fields of nonlinear partial differential equations and renormalization group contribute recent results on topics such as Ginzburg Landau equations and blow up of solutions of the nonlinear Schroedinger equations quantum resonances and renormalization group analysis in constructive quantum field theory This volume offers the latest research in the rapidly developing fields of nonlinear equations and renormalization group

**Nonlinear Dynamics and Chaos: Advances and Perspectives** Marco Thiel, Jürgen Kurths, M. Carmen Romano, György Károlyi, Alessandro Moura, 2010-05-17 This book is a collection of papers contributed by some of the greatest names in the areas of chaos and nonlinear dynamics Each paper examines a research topic at the frontier of the area of dynamical systems As well as reviewing recent results each paper also discusses the future perspectives of each topic The result is an invaluable snapshot of the state of the field by some of the most important researchers in the area The first contribution in this book the section entitled How did you get into Chaos is actually not a paper but a collection of personal accounts by a number of participants of the conference held in Aberdeen in September 2007 to honour Celso Grebogi's 60th birthday At the instigation of James Yorke many of the most well known scientists in the area agreed to share their tales on how they got involved in chaos during a celebratory dinner in Celso's honour during the conference This was recorded in video we felt that these accounts were a valuable historic document for the field So we decided to transcribe it and include it here as the first section of the book

**Symmetry and Perturbation Theory in Nonlinear Dynamics** Giampaolo Cicogna, Giuseppe Gaeta, 2003-07-01 has been in the of a Symmetry major ingredient development quantum perturbation and it is a basic of the of theory ingredient theory integrable Hamiltonian and of the the use in context of non Hamiltonian systems yet symmetry general is rather recent From the of view of nonlinear perturbation theory point the use of has become dynamics widespread only through equivariant symmetry bifurcation in this attention has been confined to linear even theory case mostly symmetries in recent the and of methods for diff Also theory practice symmetry years differential has become and has been to a equations increasingly popular applied of the of the book Olver This by variety problems following appearance 2621 with is and deals of nature theory deeply geometrical symmetries general provided that described i.e. in this context there is are vector no they by fields to limit attention to linear reason symmetries In this look the basic tools of i.e. normal book we at perturbation theory introduced Poincaré about and their inter a forms first by century ago study action with with no limitation to linear ones We focus on the most symmetries basic fixed the and i.e. a setting systems having point at origin perturbative around thus is local

**Critical Dynamics** Uwe C. Täuber, 2014-03-06 Introducing a unified framework for describing and understanding complex interacting systems

common in physics chemistry biology ecology and the social sciences this comprehensive overview of dynamic critical phenomena covers the description of systems at thermal equilibrium quantum systems and non equilibrium systems Powerful mathematical techniques for dealing with complex dynamic systems are carefully introduced including field theoretic tools and the perturbative dynamical renormalization group approach rapidly building up a mathematical toolbox of relevant skills Heuristic and qualitative arguments outlining the essential theory behind each type of system are introduced at the start of each chapter alongside real world numerical and experimental data firmly linking new mathematical techniques to their practical applications Each chapter is supported by carefully tailored problems for solution and comprehensive suggestions for further reading making this an excellent introduction to critical dynamics for graduate students and researchers across many disciplines within physical and life sciences

#### **Nonlinear Dynamics of Transcritical Flows** Hermann L.

Jordan, Herbert Oertel, Klaus Robert, 2012-12-06 The German Aerospace Research Establishment DFVLR has initiated a new series of seminars concerning fundamental problems in applied engineering sciences These seminars will be devoted to interdisciplinary topics related to the vast variety of DFVLR activities in the fields of fluid mechanics flight mechanics guidance and control materials and structures non nuclear energetics communication technology and remote sensing The purpose of the series is twofold namely to bring modern ideas and techniques to the attention of the DFVLR in order to stimulate internal activities and secondly to promulgate DFVLR achievements within the international scientific technical community To this end prominent speakers from Germany and other countries will be invited to join in a series of lectures and discussions on certain topics of mutual interest The first colloquium of this series dealt with the dynamics of nonlinear systems especially in relation to its application to fluid mechanics particularly in transcritical flows Of special interest are questions concerning the formation of nonlinear three dimensional structures in classical fluid mechanical stability problems the physical process of transition to turbulence and the appearance of chaotic solutions The scope of lectures reaches from self organization in physical systems to structural stability of three dimensional vortex patterns the treatment of dissipative and conservative systems the formation of nonlinear structures in the region of laminar turbulent transition and numerical simulation of cumulus cloud convection in meteorology The seminar should provide an insight into the extent to which theoretical findings in Non linear Dynamics apply to the comprehension of fluid mechanical problems

#### **Methods of Hilbert Spaces in the Theory of Nonlinear Dynamical Systems** Krzysztof Kowalski, 1994 This book is the first monograph on a new powerful method discovered by the author for the study of nonlinear dynamical systems relying on reduction of nonlinear differential equations to the linear abstract Schrödinger like equation in Hilbert space Besides the possibility of unification of many apparently completely different techniques the quantal Hilbert space formalism introduced enables new original methods to be discovered for solving nonlinear problems arising in investigation of ordinary and partial differential equations as well as difference equations Applications covered in the book include symmetries and first integrals

linearization transformations B cklund transformations stroboscopic maps functional equations involving the case of Feigenbaum Cvitanovic renormalization equations and chaos      **Nonlinear Dynamics in Geosciences** Anastasios A.

Tsonis,2007-09-25 This work comprises the proceedings of a conference held last year in Rhodes Greece to assess developments during the last 20 years in the field of nonlinear dynamics in geosciences The volume has its own authority as part of the Aegean Conferences cycle but it also brings together the most up to date research from the atmospheric sciences hydrology geology and other areas of geosciences and discusses the advances made and the future directions of nonlinear dynamics      **Earthquake Thermodynamics and Phase Transformation in the Earth's Interior** Roman

Teisseyre,Eugeniusz Majewski,2000-10-19 A group of distinguished scientists contributes to the foundations of a new discipline in Earth sciences earthquake thermodynamics and thermodynamics of formation of the Earth s interior structures The predictive powers of thermodynamics are so great that those aspiring to model earthquake and the Earth s interior will certainly wish to be able to use the theory Thermodynamics is our only method of understanding and predicting the behavior of many environmental atmospheric and geological processes The need for Earth scientists to develop a functional knowledge of thermodynamic concepts and methodology is therefore urgent Sources of an entropy increase the dissipative and self organizing systems driving the evolution and dynamics of the Universe and Earth through irreversible processes The non linear interactions lead to the formation of fractal structures From the structural phase transformations the important interior boundaries emerge Non linear interactions between the defects in solids lead the authors to develop the physics of continua with a dense distribution of defects Disclinations and dislocations interact during a slow evolution as well as during rapid dynamic events like earthquakes Splitting the dynamic processes into the 2D fault done and 3D surrounding space brings a new tool for describing the slip nucleation and propagation along the earthquake faults Seismic efficiency rupture velocity and complexity of seismic source zone are considered from different points of view fracture band earthquake model is developed on the basis of thermodynamics of line defects like dislocations Earthquake thermodynamics offers us a microscopic model of earthquake sources Physics of defects helps the authors describe and explain a number of precursory phenomena caused by the buildup of stresses Anomalies in electric polarization and electromagnetic radiation prior to earthquakes are considered from this point of view Through the thermodynamic approach the authors arrive at the fascinating question of possibility of earthquake prediction In general the Earth is considered here as a multicomponent system Transport phenomena as well as wave propagation and shock waves are considered in this system subjected also to chemical and phase transformations      **Nonequilibrium Statistical Mechanics** Gene F. Mazenko,2008-07-11 The present text offers a graduate level treatment of time dependent phenomena in condensed matter physics Conventional ideas of linear response theory and kinetic theory are treated in detail The general emphasis however is on the development of generalized Langevin equations for treating nonlinear behaviour in a wide variety of systems A full treatment is given for the

underpinnings of hydrodynamics for fluids This is the third volume of a four volume set of texts by the same author two of which have already been published *Fluctuations Order and Defects* 0 471 32840 5 *Equilibrium Statistical Mechanics* 0 471 32839 1 While the preceding volume contains material that is a prerequisite for fully understanding the material presented here this volume is self contained and can stand alone from the preceding volume *Statics and Dynamics of Nonlinear Systems* Giorgio Benedek,H. Bilz,R. Zeyher,2012-12-06 The investigation of the properties of nonlinear systems is one of the fast developing areas of physics In condensed matter physics this terra incognita is approached from various starting points such as phase transitions and renormalization group theory nonlinear models statistical mechanics and others The study of the mutual interrelations of these disciplines is important in developing unifying methods and models towards a better understanding of nonlinear systems The present book collects the lectures and seminars delivered at the workshop on Statics and Dynamics of Nonlinear Systems held at the Centre for Scientific Culture Ettore Majorana in Erice Italy July 1 to 11 1983 in the framework of the International School of Materials Science and Technology Experts and young researchers came together to discuss nonlinear phenomena in condensed matter physics The book is divided into five parts each part containing a few general articles introducing the subject followed by related specialized papers The first part deals with basic properties of nonlinear systems including an introduction to the general theoretical methods Contributions to the nonlinear aspects of phase transitions are collected in the second part In the third part properties of incommensurate systems are discussed Here competing interactions lead to charge density waves soliton lattices and other complex structures Another point of special interest illustrated in the fourth part is the chaotic behavior of various systems such as Josephson junctions and discrete lattices *Recent Advances In Applied Nonlinear Dynamics With Numerical Analysis: Fractional Dynamics, Network Dynamics, Classical Dynamics And Fractal Dynamics With Their Numerical Simulations* Changpin Li,Yujiang Wu,Ruisong Ye,2013-01-11 Nonlinear dynamics is still a hot and challenging topic In this edited book we focus on fractional dynamics infinite dimensional dynamics defined by the partial differential equation network dynamics fractal dynamics and their numerical analysis and simulation Fractional dynamics is a new topic in the research field of nonlinear dynamics which has attracted increasing interest due to its potential applications in the real world such as modeling memory processes and materials In this part basic theory for fractional differential equations and numerical simulations for these equations will be introduced and discussed In the infinite dimensional dynamics part we emphasize on numerical calculation and theoretical analysis including constructing various numerical methods and computing the corresponding limit sets etc In the last part we show interest in network dynamics and fractal dynamics together with numerical simulations as well as their applications *Nonlinear Dynamics And Chaos* Nicholas B. Tufillaro,Tyler Abbott,Jeremiah Reilly,1992-05-20 This essential handbook provides the theoretical and experimental tools necessary to begin researching the nonlinear behavior of mechanical electrical optical and other systems The book describes several

nonlinear systems which are realized by desktop experiments such as an apparatus showing chaotic string vibrations an LRC circuit displaying strange scrolling patterns and a bouncing ball machine illustrating the period doubling route to chaos Fractal measures periodic orbit extraction and symbolic analysis are applied to unravel the chaotic motions of these systems The simplicity of the examples makes this an excellent book for undergraduate and graduate level physics and mathematics courses new courses in dynamical systems and experimental laboratories

**Chaos in Dynamical Systems** Edward Ott, 2002-08-22 Over the past two decades scientists mathematicians and engineers have come to understand that a large variety of systems exhibit complicated evolution with time This complicated behavior is known as chaos In the new edition of this classic textbook Edward Ott has added much new material and has significantly increased the number of homework problems The most important change is the addition of a completely new chapter on control and synchronization of chaos Other changes include new material on riddled basins of attraction phase locking of globally coupled oscillators fractal aspects of fluid advection by Lagrangian chaotic flows magnetic dynamos and strange nonchaotic attractors This new edition will be of interest to advanced undergraduates and graduate students in science engineering and mathematics taking courses in chaotic dynamics as well as to researchers in the subject

Knowledge Management, Organizational Intelligence And Learning, And Complexity - Volume I L. Douglas Kiel, 2009-08-25 Knowledge Management Organizational Intelligence and Learning and Complexity is the component of Encyclopedia of Technology Information and Systems Management Resources in the global Encyclopedia of Life Support Systems EOLSS which is an integrated compendium of twenty one Encyclopedias The Theme on Knowledge Management Organizational Intelligence and Learning and Complexity in the Encyclopedia of Technology Information and Systems Management Resources provides the latest scientific insights into the evolution of complexity in both the natural and social realms Emerging perspectives from the fields of knowledge management computer based simulation and the organizational sciences are presented as tools for understanding and supporting this evolving complexity and the earth s life support systems These three volumes are aimed at the following a wide spectrum of audiences from the merely curious to those seeking in depth knowledge University and College students Educators Professional practitioners Research personnel and Policy analysts managers and decision makers and NGOs

*Applications in Physics, Part A* Vasily E. Tarasov, 2019-02-19 This multi volume handbook is the most up to date and comprehensive reference work in the field of fractional calculus and its numerous applications This fourth volume collects authoritative chapters covering several applications of fractional calculus in physics including classical and continuum mechanics

Vibro-impact Dynamics Albert C. J. Luo, Yu Guo, 2013-01-25 Presents a systematic view of vibro impact dynamics based on the nonlinear dynamics analysis Comprehensive understanding of any vibro impact system is critically impeded by the lack of analytical tools viable for properly characterizing grazing bifurcation The authors establish vibro impact dynamics as a subset of the theory of discontinuous systems thus enabling all vibro impact systems to be explored and characterized for applications Vibro impact

Dynamics presents an original theoretical way of analyzing the behavior of vibro impact dynamics that can be extended to discontinuous dynamics All topics are logically integrated to allow for vibro impact dynamics the central theme to be presented It provides a unified treatment on the topic with a sound theoretical base that is applicable to both continuous and discrete systems Vibro impact Dynamics Presents mapping dynamics to determine bifurcation and chaos in vibro impact systems Offers two simple vibro impact systems with comprehensive physical interpretation of complex motions Uses the theory for discontinuous dynamical systems on time varying domains to investigate the Fermi oscillator Essential reading for graduate students university professors researchers and scientists in mechanical engineering **Strange Nonchaotic**

**Attractors** Ulrike Feudel, Sergey Kuznetsov, Arkady Pikovsky, 2006 This book is the first monograph devoted exclusively to strange nonchaotic attractors SNA recently discovered objects with a special kind of dynamical behavior between order and chaos in dissipative nonlinear systems under quasiperiodic driving A historical review of the discovery and study of SNA mathematical and physically motivated examples and a review of known experimental studies of SNA are presented The main focus is on the theoretical analysis of strange nonchaotic behavior by means of different tools of nonlinear dynamics and statistical physics bifurcation analysis Lyapunov exponents correlations and spectra renormalization group The relations of the subject to other fields of physics such as quantum chaos and solid state physics are also discussed Key Features Topics are suitable for various disciplines dealing with nonlinear dynamics mechanics physics nonlinear optics hydrodynamics chemical kinetics etc A variety of theoretical tools is supplied to reveal different characteristics of strange nonchaotic behavior Readership Graduate students and researchers in nonlinear science Statistical Physics of Non-Thermal Phase

Transitions Sergey G. Abaimov, 2015-05-18 This book addresses the application of methods used in statistical physics to complex systems from simple phenomenological analogies to more complex aspects such as correlations fluctuation dissipation theorem the concept of free energy renormalization group approach and scaling Statistical physics contains a well developed formalism that describes phase transitions It is useful to apply this formalism for damage phenomena as well Fractals the Ising model percolation damage mechanics fluctuations free energy formalism renormalization group and scaling are some of the topics covered in Statistical Physics of Phase Transitions **Regularity and Complexity in**

**Dynamical Systems** Albert C. J. Luo, 2013-07-12 Regularity and Complexity in Dynamical Systems describes periodic and chaotic behaviors in dynamical systems including continuous discrete impulsive discontinuous and switching systems In traditional analysis the periodic and chaotic behaviors in continuous nonlinear dynamical systems were extensively discussed even if unsolved In recent years there has been an increasing amount of interest in periodic and chaotic behaviors in discontinuous dynamical systems because such dynamical systems are prevalent in engineering Usually the smoothening of discontinuous dynamical system is adopted in order to use the theory of continuous dynamical systems However such technique cannot provide suitable results in such discontinuous systems In this book an alternative way is presented to



discuss the periodic and chaotic behaviors in discontinuous dynamical systems

### **Multiple Time Scale Dynamics**

Christian Kuehn, 2015-02-25 This book provides an introduction to dynamical systems with multiple time scales The approach it takes is to provide an overview of key areas particularly topics that are less available in the introductory form The broad range of topics included makes it accessible for students and researchers new to the field to gain a quick and thorough overview The first of its kind this book merges a wide variety of different mathematical techniques into a more unified framework The book is highly illustrated with many examples and exercises and an extensive bibliography The target audience of this book are senior undergraduates graduate students as well as researchers interested in using the multiple time scale dynamics theory in nonlinear science either from a theoretical or a mathematical modeling perspective

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