

Lecture Notes in Physics

Editorial Board

R. Beig, Wien, Austria
B.-G. Englert, Singapore
U. Frisch, Nice, France
P. Hänggi, Augsburg, Germany
K. Hepp, Zürich, Switzerland
W. Hillebrandt, Garching, Germany
D. Imboden, Zürich, Switzerland
R. L. Jaffe, Cambridge, MA, USA
R. Lipowsky, Golm, Germany
H. v. Löhneysen, Karlsruhe, Germany
I. Ojima, Kyoto, Japan
D. Sornette, Nice, France, and Los Angeles, CA, USA
S. Theisen, Golm, Germany
W. Weise, Trento, Italy, and Garching, Germany
J. Wess, München, Germany
J. Zittartz, Köln, Germany

Springer

Berlin

Heidelberg

New York

Barcelona

Hong Kong

London

Milan

Paris

Tokyo

Physics and Astronomy



ONLINE LIBRARY

<http://www.springer.de/phys/>

The Editorial Policy for Edited Volumes

The series *Lecture Notes in Physics* (LNP), founded in 1969, reports new developments in physics research and teaching - quickly, informally but with a high degree of quality. Manuscripts to be considered for publication are topical volumes consisting of a limited number of contributions, carefully edited and closely related to each other. Each contribution should contain at least partly original and previously unpublished material, be written in a clear, pedagogical style and aimed at a broader readership, especially graduate students and nonspecialist researchers wishing to familiarize themselves with the topic concerned. For this reason, traditional proceedings cannot be considered for this series though volumes to appear in this series are often based on material presented at conferences, workshops and schools.

Acceptance

A project can only be accepted tentatively for publication, by both the editorial board and the publisher, following thorough examination of the material submitted. The book proposal sent to the publisher should consist at least of a preliminary table of contents outlining the structure of the book together with abstracts of all contributions to be included. Final acceptance is issued by the series editor in charge, in consultation with the publisher, only after receiving the complete manuscript. Final acceptance, possibly requiring minor corrections, usually follows the tentative acceptance unless the final manuscript differs significantly from expectations (project outline). In particular, the series editors are entitled to reject individual contributions if they do not meet the high quality standards of this series. The final manuscript must be ready to print, and should include both an informative introduction and a sufficiently detailed subject index.

Contractual Aspects

Publication in LNP is free of charge. There is no formal contract, no royalties are paid, and no bulk orders are required, although special discounts are offered in this case. The volume editors receive jointly 30 free copies for their personal use and are entitled, as are the contributing authors, to purchase Springer books at a reduced rate. The publisher secures the copyright for each volume. As a rule, no reprints of individual contributions can be supplied.

Manuscript Submission

The manuscript in its final and approved version must be submitted in ready to print form. The corresponding electronic source files are also required for the production process, in particular the online version. Technical assistance in compiling the final manuscript can be provided by the publisher's production editor(s), especially with regard to the publisher's own \LaTeX macro package which has been specially designed for this series.

LNP Homepage (<http://www.springerlink.com/series/lnp/>)

On the LNP homepage you will find:

- The LNP online archive. It contains the full texts (PDF) of all volumes published since 2000. Abstracts, table of contents and prefaces are accessible free of charge to everyone. Information about the availability of printed volumes can be obtained.
- The subscription information. The online archive is free of charge to all subscribers of the printed volumes.
- The editorial contacts, with respect to both scientific and technical matters.
- The author's / editor's instructions.

G. Contopoulos N. Voglis (Eds.)

Galaxies and Chaos



Springer

Editors

George Contopoulos
and Nikos Voglis,
Academy of Athens,
Research Centre for Astronomy,
Anagnostopoulou Street 14,
106 73 Athens, Greece

Cataloging-in-Publication Data applied for

A catalog record for this book is available from the Library of Congress.

Bibliographic information published by Die Deutsche Bibliothek

Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie;
detailed bibliographic data is available in the Internet at <http://dnb.ddb.de>

ISSN 0075-8450

ISBN 3-540-40470-8 Springer-Verlag Berlin Heidelberg New York

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

Springer-Verlag Berlin Heidelberg New York
a member of BertelsmannSpringer Science+Business Media GmbH

<http://www.springer.de>

© Springer-Verlag Berlin Heidelberg 2003
Printed in Germany

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: Camera-ready by the authors/editor
Camera-data conversion by Steingraeber Satztechnik GmbH Heidelberg
Cover design: *design & production*, Heidelberg

Printed on acid-free paper
54/3141/du - 5 4 3 2 1 0

Preface

During the last two decades the science of nonlinear and chaotic dynamics has had a spectacular development. Many important ideas and tools appeared in the literature, helping to give a deeper understanding of the role of order and chaos in dynamical systems. One of the most fruitful applications of these ideas and tools has been in the field of dynamical astronomy, namely in galactic dynamics and in the dynamics of the solar system. On the other hand recent observational studies of galaxies and of exosolar systems have come to the point of detecting order and chaos in these systems. For this reason the members of the Research Center of Astronomy of the Academy of Athens decided to organize an international workshop on this subject. This workshop “Galaxies and Chaos. Theory and Observations” was held in Athens in September 16-19, 2002, (see <http://www.cc.uoa.gr/gc2002/>). A total number of 77 participants from 21 countries from all over the World attended the workshop, namely from Europe, U.S.A, Australia, Japan and Chile. There were 45 talks (23 of them invited talks) and 10 posters. The workshop brought together the experience of people working on galactic dynamics and galaxy formation (theory and observations) with the experience of people working on nonlinear dynamical systems. The talks summarized the most recent developments in both theoretical and observational aspects of galactic dynamics with emphasis on the role of chaos in galaxies. Studies of chaos in galaxies use methods similar to those frequently used in celestial mechanics, or other branches of physics and astronomy. For this reason we invited some speakers from related fields of research. A few interesting papers on some of the most up-to-date problems of celestial mechanics are included in this volume.

The Scientific Organizing Committee was composed of: G. Contopoulos (chairman, Academy of Athens), E. Athanassoula (Observatoire de Marseille, France), A. Bosma (Observatoire de Marseille, France), H. Dejonghe (University of Ghent, Belgium), A. Fridman (Russian Academy of Sciences), P. Grosbøl (ESO, Germany), P.O. Lindblad (Stockholm Observatory, Sweden), D. Lynden-Bell (University of Cambridge, UK), D. Merritt (Rutgers University, USA), and N. Voglis (Academy of Athens). The Local Organizing Committee was composed of: N. Voglis (chairman), H. Dara, Ch. Efthymiopoulos, P. Patsis, V. Tritakis and M. Zoulias.

The Academy of Athens covered a considerable part of the expenses of the workshop. But we are grateful also to several other institutions and persons, namely: The University of Athens, in particular the vice-rector Dr. G. Der-

mitzakis, that provided both financial and substructure support, the Hellenic Ministry of Culture, the A.G. Leventis Foundation, the City of Athens, Siemens S.A. in Athens, the European Physical Society and private donors. With their help we could in particular organize an archeological tour of Athens, a closing dinner at the terrace of a hotel in the center of the city, and provide free hotel rooms and free lunches to many participants. We thank heartily all of them.

The Editors
G. Contopoulos, N. Voglis

Contents

Part I Order and Chaos

Order and Chaos in Astronomy

George Contopoulos 3

Critical Ergos Curves and Chaos at Corotation

Donald Lynden-Bell, Jaideep M. Barot 30

Stellar Dynamics and Molecular Dynamics: Possible Analogies

Andrea Carati, Luigi Galgani 44

Waves Derived from Galactic Orbits. Solitons and Breathers

Nikos Voglis 56

Discrete Breathers and Homoclinic Dynamics

Tassos Bountis, Jeroen M. Bergamin 75

Chaos or Order in Double Barred Galaxies?

Witold Maciejewski 91

Jeans Solutions for Triaxial Galaxies

Glenn van de Ven, Chris Hunter, Ellen Verolme, Tim de Zeeuw 101

Nonlinear Response of the Interstellar Gas Flow to Galactic Spiral Density Waves

Edward Liverts, Michael Mond 109

The Level of Chaos in N-Body Models of Elliptical Galaxies

*Nikos Voglis, Costas Kalapotharakos, Ioannis Stavropoulos,
Christos Efthymiopoulos* 117

Low Frequency Power Spectra and Classification of Hamiltonian Trajectories

George Voyatzis 126

Part II Orbit Theory

Disk-Crossing Orbits

Chris Hunter 137

Chaos and Chaotic Phase Mixing in Galaxy Evolution and Charged Particle Beams

Henry E. Kandrup 154

Black Hole Motions

Richard H. Miller 169

Weak Homology of Bright Elliptical Galaxies

Giuseppe Bertin 185

Part III Observations**Observing Chaos in Disk Galaxies**

Preben Grosbøl 201

Observational Determination of the Gravitational Potential and Pattern Speed in Strongly Barred Galaxies

Per A.B. Lindblad, Per Olof Lindblad 213

Observational Manifestation of Chaos in Grand Design Spiral Galaxies

Alexei M. Fridman, Roald Z. Sagdeev, Oleg V. Khoruzii, Evgenii V. Polyachenko 223

Quarter-Turn Spirals in Galaxies

Evgenii Polyachenko 235

Dynamics of Galaxies:**From Observations to Distribution Functions**

Herwig Dejonghe, Veronique De Bruyne 243

Arp 158: A Study of the HI

Mansie G. Iyer, Caroline E. Simpson, Stephen T. Gottesman, Benjamin K. Malphrus 263

Dark Matter in Spiral Galaxies

Albert Bosma 271

A SAURON View of Galaxies

Ellen K. Verolme, Michele Cappellari, Glenn van de Ven, P. Tim de Zeeuw, Roland Bacon, Martin Bureau, Yanick Copin, Roger L. Davies, Eric Emsellem, Harald Kuntschner, Richard McDermid, Bryan W. Miller, Reynier F. Peletier 279

Photometric Properties

of Karachentsev’s Mixed Pairs of Galaxies

Alfredo Franco-Balderas, Deborah Dultzin-Hacyan, Héctor M. Hernández-Toledo 286

Spline Histogram Method for Reconstruction of Probability Density Functions of Clusters of Galaxies

Dmitrijs Docenko, Kārlis Bērziņš 294

Stars Close to the Massive Black Hole at the Center of the Milky Way

Nelly Mouawad, Andreas Eckart, Susanne Pfalzner, Christian Straubmeier, Rainer Spurzem, Reinhard Genzel, Thomas Ott, Rainer Schödel 302

Part IV Formation and Evolution of Galaxies

Angular Momentum Redistribution and the Evolution and Morphology of Bars

Lia Athanassoula 313

Major Mergers and the Origin of Elliptical Galaxies

Andreas Burkert, Thorsten Naab 327

Dynamical Evolution of Galaxies: Supercomputer *N*-Body Simulations

Edward Liverts, Evgeny Griv, Michael Gedalin, David Eichler 340

Formation of the Halo Stellar Population in Spiral and Elliptical Galaxies

Tetyana Nykytyuk 348

Model of Ejection of Matter from Dense Stellar Cluster and Chaotic Motion of Gravitating Shells

Maxim V. Barkov, Vladimir A. Belinski, Genadii S. Bisnovatyi-Kogan, Anatoly I. Neishtadt 357

Direct vs Merger Mechanism Forming Counterrotating Galaxies

Maria Harsoula, Nikos Voglis 365

Pitch Angle of Spiral Galaxies as Viewed from Global Instabilities of Flat Stellar Disks

Shunsuke Hozumi 380

Collisionless Evaporation from Cluster Elliptical Galaxies
Veruska Muccione, Luca Ciotti 387

Part V Solar System Dynamics

Chaos in Solar System Dynamics
Rudolf Dvorak 395

Dynamics of Extrasolar Planetary Systems:
2/1 Resonant Motion
John D. Hadjidemetriou, Dionyssia Psychoyos 412

The “Third” Integral
in the Restricted Three-Body Problem Revisited
Harry Varvoglis, Kleomenis Tsiganis, John D. Hadjidemetriou 433

List of Contributors

Athanassoula Lia

Observatoire de Marseille,
France
lia@obmara.cnrs-mrs.fr

Bacon Roland

Centre de Recherche Astronomique de
Lyon,
France
bacon@obs.univ-lyon1.fr

Barkov Maxim

Space Research Institute,
Russia
barmv@sai.msu.ru

Barot J.M.

Westminster School,
U.K.
jaideep.barot@westminster.org.uk

Belinski Vladimir A.

National Institute of Nuclearphysics
(INFN) and International Center of
Relativistic
Astrophysics (ICRA),
Italy
volodia@vxrmg9.icra.it

Bergamin Jeroen

University of Patras,
Greece

Bērziņš Kārlis

Ventspils International Radio
Astronomy Center,
Latvia
kberzins@latnet.lv

Bisnovaty-Kogan Genadii

Space Research Institute,
Russia
gkogan@mx.iki.rssi.ru

Bertin Giuseppe

Universit'a degli Studi di Milano,
Italy
bertin@sns.it

Bosma Albert

Observatoire de Marseille,
France
bosma@batis.cnrs-mrs.fr

Bountis Tassos

University of Patras,
Greece
bountis@math.upatras.gr

Bureau Martin

University of Columbia,
U.S.A.
bureau@astro.columbia.edu

Burkert Andreas

MPI Heidelberg
Germany,
burkert@mpia-hd.mpg.de

Cappellari Michele

Leiden University,
Netherlands
cappellari@strw.leidenuniv.nl

Carati Andrea

Universita di Milano,
Italy
carati@mat.unimi.it

Ciotti Luca

Universit'a di Bologna,
Italy
ciotti@bo.astro.it

Contopoulos George

Academy of Athens,
Research Center for Astronomy,
Greece
gcontop@cc.uoa.gr

Copin Yannick

Institut de Physique Nucl'eaire de
Lyon,
France
y.copin@ipnl.in2p3.fr

Davies Roger L.

University of Oxford,
U.K.
rld@astro.ox.ac.uk

De Bruyne Veronique

University of Ghent,
Astronomical Observatory,
Belgium
Veronique.DeBruyne@rug.ac.be

De Zeeuw Tim

Leiden University,
Netherlands
tim@strw.leidenuniv.nl

Dejonghe Herwig

University of Ghent,
Astronomical Observatory,
Belgium
Herwig.Dejonghe@rug.ac.be

Docenko Dmitrijs

University of Latvia,
Latvia
dima@latnet.lv

Dultzin-Hacyan Deborah

Instituto de Astronomia de la Univ.
Nacional Autonoma de Mexico,
Mexico
deborah@astroscu.unam.mx

Dvorak Rudolf

University of Vienna,
Austria
dvorak@astro.univie.ac.at

Eckart Andreas

University of Cologne,
Germany
eckart@ph1.uni-koeln.de

Efthymiopoulos Christos

Academy of Athens,
Research Center for Astronomy,
Greece
cefthim@cc.uoa.gr

Eichler David

Ben-Gurion University,
Israel
eichler@bgumail.bgu.ac.il

Emsellem Eric

Centre de Recherche Astronomique de
Lyon,
France
emsellem@obs.univ-lyon1.fr

Franco-Balderas Alfredo

Instituto de Astronomia de la Univ.
Nacional Autonoma de Mexico,
Mexico
alfred@astroscu.unam.mx

Fridman Alexei

Russian Academy of Sciences,
Russia
fxela@online.ru

Galgani Luigi

Universita di Milano,
Italy
galgani@berlioz.mat.unimi.it

Gedalin Michael

Ben-Gurion University,
Israel
gedalin@bgumail.bgu.ac.il

Genzel Reinhard

Max-Planck-Institut für extrater-
restrische Physik,
Germany
genzel@imprs-astro.mpg.de

Gottesman Stephen

University of Florida,
U.S.A.
gott@astro.ufl.edu

Griv Evgeny

Ben-Gurion University,
Israel
griv@bgumail.bgu.ac.il

Grosbøl Preben

ESO,
Garching,
Germany
pgrosbol@eso.org

Hadjidemetriou John

University of Thessaloniki,
Greece
hadjidem@physics.auth.gr

Harsoula Maria

Academy of Athens,
Research Center for Astronomy,
Greece
mharsoul@phys.uoa.gr

Hernández-Toledo Héctor

Instituto de Astronomia de la Univ.
Nacional Autonoma di Mexico,
Mexico

Hozumi Shunsuke

Max-Planck-Institut fuer Astronomie,
Heidelberg,
Germany
hozumi@mpia-hd.mpg.de

Hunter Chris

Florida State University,
U.S.A.
hunter@math.fsu.edu

Iyer Mansie

Florida International University,
U.S.A.
miyer01@fiu.edu

Kalapotharakos Costas

University of Athens,
Greece
ckalapot@cc.uoa.gr

Kandrup Henry Emil

University of Florida,
U.S.A.
kandrup@astro.ufl.edu

Khoruzhii Oleg

Troitsk Institute for Innovation and
Thermonuclear Researches,
Russia
okhor@inasan.rssi.ru

Kuntschner Harald

European Southern Observatory,
Germany

Lindblad Per A.B.

Stockholm University Observatory,
Sweden

Lindblad Per Olof

Stockholm University Observatory,
Sweden
po@astro.su.se

Liverts Edward

Ben-Gurion University,
Israel
eliverts@bgumail.bgu.ac.il

Lynden-Bell Donald

University of Cambridge,
U.K.
dlb@ast.cam.ac.uk

Maciejewski Witold

Osservatorio Astrofisico di Arcetri,
Italy
witold@arcetri.astro.it

Malphrus Benjamin

Morehead State University,
U.S.A.
b.malphr@morehead-st.edu

McDermid Richard

Leiden University,
Netherlands
mcdermid@strw.leidenuniv.nl

Miller Richard H.

University of Chicago,
U.S.A.
rhm@oddjob.uchicago.edu

Miller Bryan W.

Gemini Observatory,
Chile
bmiller@gemini.edu

Mond Michael

Ben-Gurion University,
Israel
mond@menix.bgu.ac.il

Mouawad Nelly

University of Cologne,
Germany
nelly@ph1.uni-koeln.de

Muccione Veruska

Observatoire de Geneve,
Switzerland
veruska.muccione@obs.unige.ch

Naab Thorsten

Institute of Astronomy,
Cambridge,
UK
naab@ast.cam.ac.uk

Neishtadt Anatoly

Space Research Institute,
Russia
aneishta@vm1.iki.rssi.ru

Nykytyuk Tetyana

National Academy of Sciences of
Ukraine, Ukraine,
nikita@mao.kiev.ua

Ott Thomas

Max-Planck-Institut für extrater-
restrische Physik,
Germany
ott@mpe.mpg.de

Peletier Reynier

University of Nottingham,
U.K.
reynier.peletier@nottingham.ac.uk

Pfalzner Susanne

University of Cologne,
Germany
pfalzner@ph1.uni-koeln.de

Polyachenko Evgenii

Institute of Astronomy,
RAS,
Russia
epolyach@inasan.rssi.ru

Psyhoyos Dionysia

University of Thessaloniki,
Greece
dpsyc@skiathos.physics.auth.gr

Sagdeev Roald

University of Maryland,
U.S.A.
rzs@umd.edu

Schödel Rainer

Max-Planck-Institut für extrater-
restrische Physik,
Germany
rainer@mpe.mpg.de

Simpson Caroline

Florida International University,
U.S.A.
simpsonc@fiu.edu

Spurzem Rainer

Astronomisches Recheninstitut,
Germany
spurzem@ari.uni-heidelberg.de

Stavropoulos Ioannis

University of Athens,
Greece
istavrop@cc.uoa.gr

Straubmeier Christian

University of Cologne,
Germany
cstraubm@ph1.uni-koeln.de

Kleomenis Tsiganis

Aristotle University of Thessaloniki,
Greece,
tsiganis@astro.auth.gr

Van de Ven Glenn

Leiden University,
Netherlands
vdven@strw.leidenuniv.nl

Varvoglis Harry

University of Thessaloniki,
Greece
varvogli@astro.auth.gr

Verolme Ellen

Leiden University,
Netherlands
verolme@strw.leidenuniv.nl

Voglis Nikos

Academy of Athens,
Research Center for Astronomy,
Greece
nvogl@cc.uoa.gr

Voyatzis George

University of Thessaloniki,
Greece
voyatzis@auth.gr