

D. Boccaletti G. Pucacco

Theory of Orbits

Volume 1:
Integrable Systems and Non-perturbative Methods

With 71 Figures



Springer

Dino Boccaletti

Università degli Studi di Roma “La Sapienza”
Dipartimento di Matematica “Guido Castelnuovo”
Piazzale Aldo Moro, 2, 00185 Roma, Italy
e-mail: boccaletti@uniroma1.it

Giuseppe Puccio

Università degli Studi di Roma “Tor Vergata”
Dipartimento di Fisica
Via della Ricerca Scientifica, 1, 00133 Roma, Italy
e-mail: puccio@roma2.infn.it

Cover picture: A wide-field view of the Carina region in the Southern Sky, kindly supplied by ESO (European Southern Observatory), with an insert from a miniature of the XII century *God architect of the cosmos*, miniature from “Bible moralisée”, Cod. 2554 f. 1v (Österreichische Nationalbibliothek, Vienna)

Cataloguing-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>

Corrected Third Printing 2004

ISSN 0941-7834

ISBN 978-3-642-08210-8

ISBN 978-3-662-03319-7 (eBook)

DOI 10.1007/978-3-662-03319-7

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 Berlin Heidelberg GmbH.

Violations are liable for prosecution under the German Copyright Law.

<http://www.springer.de>

© Springer-Verlag Berlin Heidelberg 1996

Originally published by Springer-Verlag Berlin Heidelberg New York in 1996

Softcover reprint of the hardcover 1st edition 1996

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: Data conversion Frank Herweg,

Cover design: *design & production* GmbH, Heidelberg

Printed on acid-free paper SPIN 10955321 55/3141/ba - 5 4 3 2 1 0

Contents

Introduction – The Theory of Orbits from Epicycles to “Chaos”	1
Chapter 1. Dynamics and Dynamical Systems – Quod Satis	15
<i>A. Dynamical Systems and Newtonian Dynamics</i>	16
1.1 Dynamical Systems: Generalities	16
1.2 Classification of Critical Points – Stability	20
1.3 The n -Dimensional Oscillator	26
<i>B. Lagrangian Dynamics</i>	32
1.4 Lagrange’s Equations	32
1.5 Ignorable Variables and Integration of Lagrange’s Equations	37
1.6 Noether’s Theorem	43
1.7 An Application of Noether’s Theorem: The n -Dimensional Oscillator	50
1.8 The Principle of Least Action in Jacobi Form	57
<i>C. Hamiltonian Dynamics and Hamilton–Jacobi Theory</i>	61
1.9 The Canonical Equations	61
1.10 The Integral Invariants – Liouville’s Theorem	65
1.11 Poisson Brackets and Poisson’s Theorem – The Generation of New Integrals	73
1.12 Canonical Transformations	76
1.13 Generating Functions – Infinitesimal Canonical Transformations	82
1.14 The Extended Phase Space	85
1.15 The Hamilton–Jacobi Equation and the Problem of Separability	90
1.16 Action–Angle Variables	98
1.17 Separable Multiperiodic Systems – Uniqueness of the Action–Angle Variables	106
1.18 Integrals in Involution – Liouville’s Theorem for Integrable Systems	113
1.19 Lax’s Method – The Painlevé Property	117

Chapter 2. The Two-Body Problem	125
2.1 The Two-Body Problem and Kepler's Three Laws	126
2.2 The Laplace–Runge–Lenz Vector	136
2.3 Bertrand's Theorem and Related Questions	141
2.4 The Position of the Point on the Orbit	147
2.5 The Elements of the Orbit	156
2.6 The Problem of Regularization	162
2.7 Topology of the Two-Body Problem	171
Chapter 3. The N-Body Problem	177
3.1 Equations of Motion and the Existence Theorem	178
3.2 The Integrals of the Motion	184
3.3 The Singularities	192
3.4 Sundman's Theorem	198
3.5 The Evolution of the System for $t \rightarrow \infty$	200
3.6 The Virial Theorem	209
3.7 Particular Solutions of the N -Body Problem	216
3.8 Homographic Motions and Central Configurations	229
Chapter 4. The Three-Body Problem	237
4.1 The General Three-Body Problem	238
4.2 Existence of the Solution – Sundman and Levi-Civita Regularization	244
4.3 The Restricted Three-Body Problem	256
4.4 The Stability of the Equilibrium Solutions	265
4.5 The Delaunay Elements for the Restricted Three-Body Problem	272
4.6 The Regularization of the Restricted Three-Body Problem	279
4.7 Extensions and Generalizations of the Restricted Problem	284
Chapter 5. Orbits in Given Potentials	301
5.1 Introduction	302
5.2 Orbits in Spherically Symmetric Potentials	306
5.3 Orbits in Isochronal Potentials	316
5.4 Elliptical Coordinates and Stäckel's Theorem	323
5.5 Planar Potentials	334
5.6 The Problem of Two Fixed Centres in the Plane	341
5.7 Axially Symmetric Potentials – Motion in the Potential of the Earth	349
5.8 Orbits in Triaxial Potentials	352
5.9 Configurational Invariants	359
Mathematical Appendix	363
A.1 Spherical Trigonometry	364

A.2 Curvilinear Coordinate Systems	365
A.3 Riemannian Geometry	370
Bibliographical Notes	375
Name Index	385
Subject Index	389