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Using the Transition to Action Variables of the Newtonian Problem in the Numerical Solution of the N-Body Problem

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Abstract—We propose an approach for overcoming the problem of close encounters in collisional systems, globular and open star clusters. As is well known, the numerical integration step in such systems, for example, during the formation of close binary stars, begins to fragment and the rate of calculations goes down to a complete stop. We show that using the perturbation theory in the proposed approach, one can isolate the singularity and to increase considerably the integration step without losing the physical effects that affect significantly the evolution of star clusters.

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INTRODUCTION

Solving the problem of many bodies in the gravitational field produced by them is of great importance for astrophysical applications. The many-body problem is fundamental in solving various problems of stellar dynamics, the dynamics and evolution of star clusters, galaxies, and clusters of galaxies. The many-body problem is known to have no exact analytical solution if the number of bodies exceeds 2. In all these cases, only an approximate numerical solution is possible. The growth in the number of bodies increases considerably the requirements for computational resources. Two main approaches to solving the many-body problem are known: the direct solution of differential equations of motion and the statistical method. In the first method, the greatest difficulties arise in simulating close encounters of bodies and the possible formations of close, gravitationally bound pairs (binary systems). When the dynamics of dense globular clusters is calculated, allowance for the formation of such pairs is needed in view of their direct influence on the physics of the process: in many cases, such binary stars when the remaining stars are scattered by them become closer, transferring some of their energy to the star being scattered. The so-called gravothermal collapse of clusters occurs precisely through close pairs (Lynden-Bell and Wood 1968). The method of overcoming the computational difficulties in simulating close encounters and the formation of close pairs is considered in this paper.

The problem of two bodies in the gravitational field produced by them has an exact solution dating back to Newton and is considered in any course of mechanics (see, e.g., Landau and Lifshitz 1988). If the number of bodies exceeds 2, one has to use computational methods, whose wide variety is presented in review papers (see, e.g., Dehnen and Read 2011). In this paper, we will consider the method of directly solving the differential equations of motion.

The complete Lagrangian L for a system of N gravitationally interacting bodies is

$$L = \sum L_i. \tag{1}$$

Here, L_i is the Lagrangian of the ith particle:

$$L_i = \frac{m_i v_i^2}{2} + \frac{G}{2} \sum_{j=1, i\neq j}^{N} \frac{m_i m_j}{r_{ij}}, \tag{2}$$

where v_i is the magnitude of the velocity for the ith body, m_i is the mass of the ith body, G is the gravitational constant, and r_{ij} is the magnitude of the distance between the ith and jth bodies. This Lagrangian leads to the equations of motion

$$\frac{d^2\mathbf{r}_i}{dt^2} = -G \sum_{j=1, i\neq j}^{N} \frac{m_j \mathbf{r}_{ij}}{r_{ij}^3}, \tag{3}$$

where $\mathbf{r}_i$ is the radius vector of the ith body and $\mathbf{r}_{ij}$ is the vector drawn from the ith body to the jth body. At fixed initial coordinates and velocities of all bodies, the

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Numerical Solutions Of The Nbody Problem

Roman Trobec,Boštjan Slivnik,Patricio Bulić,Borut Robič

Numerical Solutions Of The Nbody Problem:

Numerical Solutions of the N-Body Problem A. Marciniak,2012-12-06 Approach your problem from the right It isn t that they can t see end and begin with the answers the solution Then one day perhaps you will find It is that they can t see the the final question problem G K Chesterton The Scandal The Hermit Clad in Crane Feathers in of Father Brown The Point of R van Gulik s The Chinese Maze Murders a Pin Growing specialization and diversification have brought a host of monographs and textbooks on increasingly specialized topics However the tree of knowledge of mathematics and related fields does not grow only by putting forth new brancheq It also happens quite often in fact that branches which were thought to be completely disparate are suddenly seen to be related Further the kind and level of sophistication of mathematics applied in various sciences has changed drastically in recent years measure theory is used non trivially in regional and theoretical economics algebraic geometry interacts with physics the Minkowsky lemma coding theory and the structure of water meet one another in packing and covering theory quantum fields crystal defects and mathematical programming profit from homotopy theory Lie algebras are relevant to filtering and prediction and electrical engineering can use Stein spaces And in addition to this there are such new emerging subdisci fI plines as experimental mathematics CFD completely integrable systems chaos synergetics and large scale order which are almost impossible to fit into the existing classification schemes Numerical Solutions of the Euler Equations for Steady Flow Problems Albrecht Eberle,Arthur Rizzi,Ernst Heinrich Hirschel,2013-04-17 The last decade has seen a dramatic increase of our abilities to solve numerically the governing equations of fluid mechanics In design aerodynamics the classical potential flow methods have been complemented by higher modelling level methods Euler solvers and for special purposes already Navier Stokes solvers are in use The authors of this book have been working on the solution of the Euler equations for quite some time While the first two of us have worked mainly on algorithmic problems the third has been concerned off and on with modelling and application problems of Euler methods When we started to write this book we decided to put our own work at the center of it This was done because we thought and we leave this to the reader to decide that our work has attained over the years enough substance in order to justify a book The problem which we soon faced was that the field still is moving at a fast pace for instance because hyper sonic computation problems became more and more important **Numerical Solution of Ordinary Differential Equations** L.F. Shampine,2018-10-24 This new work is an introduction to the numerical solution of the initial value problem for a system of ordinary differential equations The first three chapters are general in nature and chapters 4 through 8 derive the basic numerical methods prove their convergence study their stability and consider how to implement them effectively The book focuses on the most important methods in practice and develops them fully uses examples throughout and emphasizes practical problem solving methods *Library of Congress Subject Headings* Library of Congress. Cataloging Policy and Support Office,2009 **Library of Congress Subject Headings** Library of Congress,Library of Congress.

Subject Cataloging Division,Library of Congress. Office for Subject Cataloging Policy,2013 *Library of Congress Subject Headings: P-Z* Library of Congress. Subject Cataloging Division,1988 Solving Problems in Scientific Computing Using Maple and MATLAB® Walter Gander,Jiri Hrebicek,2004-06-07 Teaches problem solving using two of the most important mathematical software packages Maple and MATLAB This new edition contains five completely new chapters covering new developments Symposium on Computer Simulation of Plasma and Many-Body Problems ,1967 A Graduate Introduction to Numerical Methods Robert M. Corless,Nicolas Fillion,2013-12-12 This book provides an extensive introduction to numerical computing from the viewpoint of backward error analysis The intended audience includes students and researchers in science engineering and mathematics The approach taken is somewhat informal owing to the wide variety of backgrounds of the readers but the central ideas of backward error and sensitivity conditioning are systematically emphasized The book is divided into four parts Part I provides the background preliminaries including floating point arithmetic polynomials and computer evaluation of functions Part II covers numerical linear algebra Part III covers interpolation the FFT and quadrature and Part IV covers numerical solutions of differential equations including initial value problems boundary value problems delay differential equations and a brief chapter on partial differential equations The book contains detailed illustrations chapter summaries and a variety of exercises as well some Matlab codes provided online as supplementary material I really like the focus on backward error analysis and condition This is novel in a textbook and a practical approach that will bring welcome attention Lawrence F Shampine A Graduate Introduction to Numerical Methods and Backward Error Analysis has been selected by Computing Reviews as a notable book in computing in 2013 Computing Reviews Best of 2013 list consists of book and article nominations from reviewers CR category editors the editors in chief of journals and others in the computing community **Applied Mechanics Reviews** ,1974 **Solving ODEs with MATLAB** L. F. Shampine,I. Gladwell,S. Thompson,2003-04-28 This concise text first published in 2003 is for a one semester course for upper level undergraduates and beginning graduate students in engineering science and mathematics and can also serve as a quick reference for professionals The major topics in ordinary differential equations initial value problems boundary value problems and delay differential equations are usually taught in three separate semester long courses This single book provides a sound treatment of all three in fewer than 300 pages Each chapter begins with a discussion of the facts of life for the problem mainly by means of examples Numerical methods for the problem are then developed but only those methods most widely used The treatment of each method is brief and technical issues are minimized but all the issues important in practice and for understanding the codes are discussed The last part of each chapter is a tutorial that shows how to solve problems by means of small but realistic examples **The Navier-Stokes Equations Theory and Numerical Methods** John G. Heywood,Kyuya Masuda,Reimund Rautmann,Vsevolod A. Solonnikov,2006-11-14 These proceedings contain original refereed research articles by specialists from many countries on a wide variety of aspects of Navier Stokes equations

Additionally 2 survey articles intended for a general readership are included one surveys the present state of the subject via open problems and the other deals with the interplay between theory and numerical analysis Innovative Computational Methods In Nuclear Many-body Problems - Towards A New Generation Of Physics In Finite Quantum Systems Hisashi Horiuchi,Hiroshi Toki,Yoshikazu Fujiwara,M Kamimura,Masayuki Matsuo,Y Sakuragi,1998-09-02 The recent rapid innovations in supercomputer technology are changing the concepts of numerical calculations employed in solving a wide variety of nuclear many body problems The purpose of the XVII RCNP International Symposium on Innovative Computational Methods in Nuclear Many Body Problems INNOCOM97 was to discuss the frontiers of various computational methods and to exchange ideas in wide fields of nuclear physics The subjects discussed at the symposium covered almost all the areas of nuclear physics **A Course in Mathematical Methods for Physicists** Russell L. Herman,2013-12-04 Based on the author s junior level undergraduate course this introductory textbook is designed for a course in mathematical physics Focusing on the physics of oscillations and waves A Course in Mathematical Methods for Physicists helps students understand the mathematical techniques needed for their future studies in physics It takes a bottom u *Scientific and Technical Aerospace Reports* ,1991 Lists citations with abstracts for aerospace related reports obtained from world wide sources and announces documents that have recently been entered into the NASA Scientific and Technical Information Database Numerical Methods for Ordinary Differential Equations J. C. Butcher,2008-04-15 In recent years the study of numerical methods for solving ordinary differential equations has seen many new developments This second edition of the author s pioneering text is fully revised and updated to acknowledge many of these developments It includes a complete treatment of linear multistep methods whilst maintaining its unique and comprehensive emphasis on Runge Kutta methods and general linear methods Although the specialist topics are taken to an advanced level the entry point to the volume as a whole is not especially demanding Early chapters provide a wide ranging introduction to differential equations and difference equations together with a survey of numerical differential equation methods based on the fundamental Euler method with more sophisticated methods presented as generalizations of Euler Features of the book include Introductory work on differential and difference equations A comprehensive introduction to the theory and practice of solving ordinary differential equations numerically A detailed analysis of Runge Kutta methods and of linear multistep methods A complete study of general linear methods from both theoretical and practical points of view The latest results on practical general linear methods and their implementation A balance between informal discussion and rigorous mathematical style Examples and exercises integrated into each chapter enhancing the suitability of the book as a course text or a self study treatise Written in a lucid style by one of the worlds leading authorities on numerical methods for ordinary differential equations and drawing upon his vast experience this new edition provides an accessible and self contained introduction ideal for researchers and students following courses on numerical methods engineering and other sciences *Few-Body Problems in Physics '93*

Bernard Becker,R.van Dantzig,2012-12-06 It is apparent from the history of science that few body problems have an interdis ciplinary character Newton after solving the two body problem so brilliantly tried his hand at the Sun Earth Moon system Here he failed in two respects neither was he able to compute the motion of the moon accurately nor did he understand the reason for that It took a long time to understand the fundamental importance of Newton s failure and only Poincare realised what was the fundamental difficulty in Newtons programme Nowadays the term deterministic chaos is associated with this problem The deep insights of Poincare were neglected by the founding fathers of Quantum Physics Thus history was repeated by Bohr and his students After quantising the hydrogen atom they soon found that the textbook case of a three body problem in atomic physics the 3He atom did not yield to the Bohr Sommerfeld quantisation methods Only these days do people realise what precisely were the difficulties connected to this semi classical way of treating quantum systems Our field as we know it today began in principle in the early 1950 s when Watson sketched the outlines of three body scattering theory Mathematical rigour was achieved by Faddeev and thereafter at the beginning of the 1960 s the quantum three body prob lem at least as far as short range forces were concerned w s tamed In the years that followed through the work of others who first applied Faddeev s methods but later added new techniques the three and four body problems became fully housebroken

Transactions of the International Astronomical Union: Reports on Astronomy C. de Jager,2012-12-06 This volume contains the fifteenth tri annual reports of the Presidents of the forty Commissions of the International Astronomical Union it refers to the progress in our discipline during the three years 1970 1971 and 1972 As compared to earlier volumes a gradual change in character is unmistakable The ever increasing flow of publications combined with the obvious necessity to keep the Reports at a reasonable size and price level has gradually forced the Commission Presidents to be more selective than before in drafting their Reports I have certainly stimulated them into that direction in order that Reports like these be valuable and lasting it seems imperative that the individual contributions have the character of a critical overall review where a fairly complete summary is given of the major develop ments and discoveries of the past three years and in which the broad developments and new trends be clearly outlined while at the same time essential problems for future research are identified With respect to the latter item I have suggested the Commission Presidents to add to their reports a brief section on scientific priorities for future research in the field of their Commissions In order to save space I have suggested to Commission Presidents that references to published papers are given on the basis of their number in the published issues of Astronomy and Astrophysics Abstracts For instance the indication 06 078 019 or AAA 06 078 **Three Body Dynamics and Its Applications to Exoplanets** Zdzislaw Musielak,Billy Quarles,2017-07-22 This brief book provides an overview of the gravitational orbital evolution of few body systems in particular those consisting of three bodies The authors present the historical context that begins with the origin of the problem as defined by Newton which was followed up by Euler Lagrange Laplace and many others Additionally they consider the modern works from the 20th and 21st centuries that describe the

development of powerful analytical methods by Poincare and others The development of numerical tools including modern symplectic methods are presented as they pertain to the identification of short term chaos and long term integrations of the orbits of many astronomical architectures such as stellar triples planets in binaries and single stars that host multiple exoplanets The book includes some of the latest discoveries from the Kepler and now K2 missions as well as applications to exoplanets discovered via the radial velocity method Specifically the authors give a unique perspective in relation to the discovery of planets in binary star systems and the current search for extrasolar moons *Few-Body Problems in Physics '02* Rajmund Krivec,Mitja Rosina,Bojan Golli,Simon Širca,2012-12-06 In this Supplement we have collected the invited and contributed talks pre sented at the XVIII European Conference on Few Body Problems in Physics organised by the Jozef Stefan Institute and the University of Ljubljana Slove nia The Conference sponsored by the European Physical Society took place at the lakeside resort of Bled from 8 to 14 September 2002 This meeting was a part of the series of European Few Body Conferences previously held in Evora Portugal 2000 Autrans France 1998 Peniscola Spain 1995 Our aim was to emphasise to a larger extent than at previous Conferences the interdisciplinarity of research fields of the Few Body community To pro mote a richer exchange of ideas we therefore strived to avoid parallel sessions as much as possible On the other hand to promote the participation of young scientists who we feel will eventually shape the future of Few Body Physics we wished to give almost all attendees the opportunity to speak

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