

Chapter 17

Numerical Methods for Astrophysics

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ABSTRACT

The physical laws astrophysicists use to describe their phenomena are believed to have been understood in many cases. Thus modelling astrophysical phenomena is focussed on the numerical implementation of these models. The main issue astrophysicists have to overcome is the large range of spatial, temporal and density scales.

The models typically are the compressible inviscid Euler equations or magnetohydrodynamic equations in three space dimensions coupled with many source terms. The numerical methods used often are finite volume methods or particle methods. Numerical methods that deal with the large range of scales need to be addressed individually for each problem at hand. Examples of these methods are the introduction of subgrid scale models, using time implicit methods or moving mesh methods.

These notes are strongly indebted to discussions with Fritz Röpke from Heidelberg University and the Heidelberg Institute of Technological Science, <http://www.h-its.org/en/research/pso/people/>.

Numerical Astrophysics

Frank Graziani



Numerical Astrophysics:

Numerical Astrophysics Shoken M. Miyama, Kohji Tomisaka, Tomoyuki Hanawa, 2012-12-06 These are the proceedings of international conference on Numerical Astrophysics 1998 NAP98 held at National Olympic Memorial Youth Center in Tokyo Japan in the period of March 10-13 1998 and hosted by the National Astronomical Observatory Japan NAOJ In the last decade numerical simulations have grown up as a major tool for astrophysics Numerical simulations give us invaluable information on complex systems and physical processes under extreme conditions which can be neither realized by experiments nor directly observed Super computers and special purpose computers may work as very large telescopes and special purpose telescopes for theoretical astrophysics respectively Numerical astrophysics ranks with other tool oriented astronomy such as radio astronomy infrared astronomy ultraviolet astronomy X-ray astronomy and gamma-ray astronomy This conference NAP98 was planned to explore recent advances in astrophysics aided by numerical simulations The subjects of the conference included the large scale structure formation galaxy formation and evolution star and planets formation accretion disks jets gravitational wave emission and plasma physics NAP98 had also sessions on numerical methods and computer science The conference was attended by 184 scientists from 21 countries We enjoyed excellent talks posters videos and discussions there are 40 oral presentations 96 posters and 16 video presentations We hope that these proceedings and accompanying CD-ROM replay the friendly but inspiring atmosphere of the conference

Numerical Methods in Astrophysics Peter Bodenheimer, Gregory P. Laughlin, Michal Rozyczka, Tomasz Plewa, Harold W. Yorke, 2006-12-13 Numerical Methods in Astrophysics An Introduction outlines various fundamental numerical methods that can solve gravitational dynamics hydrodynamics and radiation transport equations This resource indicates which methods are most suitable for particular problems demonstrates what the accuracy requirements are in numerical simulations and

Numerical Astrophysics Shoken M. Miyama, Kohji Tomisaka, Tomoyuki Hanawa, 1999-03-31 This book contains all the oral and poster sessions presented at the Numerical Astrophysics 1998 symposium held in Tokyo on March 10-13 1998 It covers a wide variety of research fields from the large scale structure of the Universe to planetary systems Astrophysics employing all kinds of supercomputers such as massive parallel computers parallel vector machines and special purpose computers are included Recent progress in numerical methods remote data analysis and special purpose computers are also reviewed This book is suitable for researchers and graduate students in astronomy astrophysics who want an overview of the present research fronts based on supercomputing

Numerical Modelling of Astrophysical Turbulence Wolfram Schmidt, 2013-09-20 In this SpringerBrief the author considers the underlying problems and questions that are common to numerical models of turbulence in different astrophysical systems Turbulence has emerged as an important research topic in several areas of astrophysics Understanding and modeling turbulence is particularly important for the dynamics of the interstellar medium but also for the intergalactic medium as well as in stars The advancement of methods for numerical simulations of

astrophysical turbulence however is still challenging because of gravity strong compressibility magnetic fields and other effects The book begins with a review of general aspects of numerical simulations of turbulence In the main part the author presents findings from his numerical studies on astrophysical turbulence and discusses the astrophysical implications He also explains in detail the numerical schemes utilized Readers will find that this book offers a compact yet comprehensive introduction

Numerical Astrophysics Joan M. Centrella, James M. LeBlanc, Richard L. Bowers, 1985

Numerical Python in Astronomy and Astrophysics Wolfram Schmidt, Marcel Völschow, 2021-07-14 This book provides a solid foundation in the Python programming language numerical methods and data analysis all embedded within the context of astronomy and astrophysics It not only enables students to learn programming with the aid of examples from these fields but also provides ample motivation for engagement in independent research The book opens by outlining the importance of computational methods and programming algorithms in contemporary astronomical and astrophysical research showing why programming in Python is a good choice for beginners The performance of basic calculations with Python is then explained with reference to for example Kepler's laws of planetary motion and gravitational and tidal forces Here essential background knowledge is provided as necessary Subsequent chapters are designed to teach the reader to define and use important functions in Python and to utilize numerical methods to solve differential equations and landmark dynamical problems in astrophysics Finally the analysis of astronomical data is discussed with various hands on examples as well as guidance on astronomical image analysis and applications of artificial neural networks

Computational Methods for Astrophysical Fluid Flow Randall J. LeVeque, Dimitri Mihalas, E.A. Dorfi, Ewald Müller, 2006-04-18 This book leads directly to the most modern numerical techniques for compressible fluid flow with special consideration given to astrophysical applications Emphasis is put on high resolution shock capturing finite volume schemes based on Riemann solvers The applications of such schemes in particular the PPM method are given and include large scale simulations of supernova explosions by core collapse and thermonuclear burning and astrophysical jets Parts two and three treat radiation hydrodynamics The power of adaptive moving grids is demonstrated with a number of stellar physical simulations showing very crispy shock front structures

Handbook of Numerical Methods for Hyperbolic Problems Remi Abgrall, Chi-Wang Shu, 2017-01-16 Handbook on Numerical Methods for Hyperbolic Problems Applied and Modern Issues details the large amount of literature in the design analysis and application of various numerical algorithms for solving hyperbolic equations that has been produced in the last several decades This volume provides concise summaries from experts in different types of algorithms so that readers can find a variety of algorithms under different situations and become familiar with their relative advantages and limitations Provides detailed cutting edge background explanations of existing algorithms and their analysis Presents a method of different algorithms for specific applications and the relative advantages and limitations of different algorithms for engineers or those involved in applications Written by leading subject experts in each field the volumes provide breadth and depth of

content coverage **Explorations in Computational Physics** Devang Patil, 2025-02-20 Explorations in Computational Physics delves into the intricate world of computational physics offering a comprehensive guide from fundamental theories to cutting edge applications This book serves as an indispensable companion for both novice learners and seasoned researchers We cover a diverse array of topics meticulously unfolding layers of computational techniques and their applications in various branches of physics From classical mechanics simulations elucidating celestial mechanics to quantum mechanics computations unraveling atomic and subatomic realms the book navigates through the vast landscape of computational methodologies with clarity and precision Furthermore we delve into electromagnetic field simulations statistical mechanics and thermodynamics equipping readers with tools to model complex physical phenomena with accuracy and efficiency High performance computing techniques data analysis and visualization methodologies are elucidated empowering readers to harness modern computational resources in their research With lucid explanations illustrative examples and insightful discussions on emerging technologies like quantum computing and artificial intelligence Explorations in Computational Physics fosters a deeper understanding of computational methodologies and their transformative impact on physics research

Astronomy and Astrophysics Abstracts S. Böhme, U. Esser, H. Hefele, I. Heinrich, W. Hofmann, D. Krahn, V. R. Matas, L. D. Schmädel, G. Zech, 2013-12-14 From the reviews Astronomy and Astrophysics Abstracts has appeared in semi annual volumes since 1969 and it has already become one of the fundamental publications in the fields of astronomy astrophysics and neighbouring sciences It is the most important English language abstracting journal in the mentioned branches The abstracts are classified under more than hundred subject categories thus permitting a quick survey of the whole extended material The AAA is a valuable and important publication for all students and scientists working in the fields of astronomy and related sciences As such it represents a necessary ingredient of any astronomical library all over the world Space Science Reviews 1 Dividing the whole field plus related subjects into 108 categories each work is numbered and most are accompanied by brief abstracts Fairly comprehensive cross referencing links relevant papers to more than one category and exhaustive author and subject indices are to be found at the back making the catalogues easy to use The series appears to be so complete in its coverage and always less than a year out of date that I shall certainly have to make a little more space on those shelves for future volumes The Observatory Magazine 1

Nuclear Astrophysics Md A. Khan, 2018-02-13 In this volume the physics involved in various astrophysical processes like the synthesis of light and heavier elements explosive burning processes core collapse supernova etc have been critically addressed with minimum mathematical derivations so as to suit all faculties of the readers For graduate students there are solved problems with exercises at the end of each chapter for researchers some recent works on the calculation of physical parameters of astrophysical importance like the calculation of S factors at low energies have been included and for amateur readers there are lot of history information and discussion on the astronuclear phenomenon Please note Taylor Francis does not sell or distribute the Hardback in India Pakistan Nepal

Bhutan Bangladesh and Sri Lanka *Astrophysics* İbrahim Küçük,2012-03-30 This book provides readers with a clear progress to theoretical and observational astrophysics It is not surprising that astrophysics is continually growing because very sophisticated telescopes are being developed and they bring the universe closer and make it accessible Astrophysics Book presents a unique opportunity for readers to demonstrate processes do occur in Nature The unique feature of this book is to cover different aspects in astrophysics covering the topics Astronomy Theoretical Astrophysics Observational Astrophysics Cosmology The Solar System Stars Planets Galaxies Observation Spectroscopy Dark Matter Neutron Stars High Energy Astrophysics **Cellular Automata: Prospects In Astrophysical Applications - Proceedings Of The Workshop On Cellular Automata Models For Astrophysical Phenomena** A Lejeune,J M Perdang,1993-11-23 This book provides a survey of the basic ideas of the cellular automaton CA modelling environment emphasising the relevance of this framework to astrophysical applications It contains introductory level lectures on lattice gases and on CA turbulence diffusion reaction processes percolation and self organised criticality Further it gives a variety of astrophysical applications including stellar oscillations galactic evolution distribution of luminous matter in the universe etc **The Grid 2** Ian Foster,Carl Kesselman,2004 The Grid is an emerging infrastructure that will fundamentally change the way people think about and use computing The editors reveal the revolutionary impact of large scale resource sharing and virtualization within science and industry and the intimate relationships between organization and resource sharing structures **NASA Thesaurus** ,1998 Contains the authorized subject terms by which the documents in the NASA STI Database are indexed and retrieved

Astrophysical Radiation Hydrodynamics Karl-Heinz A. Winkler,Michael L. Norman,2012-12-06 This NATO Advanced Research Workshop was devoted to the pre presentation evaluation and critical discussion of numerical methods in nonrelativistic and relativistic hydrodynamics radiative transfer and radiation coupled hydrodynamics The unifying theme of the lectures was the successful application of these methods to challenging problems in astrophysics The workshop was subdivided into 3 somewhat independent topics each with their own subtheme Under the heading radiation hydrodynamics were brought together context theory methodology and application of radiative transfer and radiation hydrodynamics in astrophysics The intimate coupling between astronomy and radiation physics was underscored by examples from past and present research Frame dependence of both the equation of transfer plus moments and the underlying radiation quantities was discussed and clarified Limiting regimes in radiation coupled flow were identified and described the dynamic diffusion regime received special emphasis Numerical methods for continuum and line transfer equations in a given background were presented Two examples of methods for computing dynamically coupled radiation matter fields were given In 1 d and assuming LTE the complete equations of radiation hydrodynamics can be solved with current computers Such is not the case in 2 or 3 d which were identified as target areas for research The use of flux limiters was vigorously discussed in this connection and enlivened the meeting Parallel Computational Technologies Leonid Sokolinsky,Mikhail

Zymbler,2022-07-18 This book constitutes the refereed proceedings of the 16th International Conference on Parallel Computational Technologies PCT 2022 held in Dubna Russia during March 29 31 2022 The 22 full papers included in this book were carefully reviewed and selected from 60 submissions They were organized in topical sections as follows high performance architectures tools and technologies parallel numerical algorithms supercomputer simulation **Adaptive Mesh Refinement - Theory and Applications** Tomasz Plewa,Timur Linde,V. Gregory Weirs,2005-12-20 Advanced numerical simulations that use adaptive mesh refinement AMR methods have now become routine in engineering and science Originally developed for computational fluid dynamics applications these methods have propagated to fields as diverse as astrophysics climate modeling combustion biophysics and many others The underlying physical models and equations used in these disciplines are rather different yet algorithmic and implementation issues facing practitioners are often remarkably similar Unfortunately there has been little effort to review the advances and outstanding issues of adaptive mesh refinement methods across such a variety of fields This book attempts to bridge this gap The book presents a collection of papers by experts in the field of AMR who analyze past advances in the field and evaluate the current state of adaptive mesh refinement methods in scientific computing eScience on Distributed Computing Infrastructure Marian Bubak,Jacek Kitowski,Kazimierz Wiatr,2014-08-25 To help researchers from different areas of science understand and unlock the potential of the Polish Grid Infrastructure and to define their requirements and expectations the following 13 pilot communities have been organized and involved in the PLGrid Plus project Acoustics AstroGrid PL Bioinformatics Ecology Energy Sector Health Sciences HEPGrid Life Science Materials Metallurgy Nanotechnologies Quantum Chemistry and Molecular Physics and SynchroGrid The book describes the experience and scientific results achieved by the project partners Chapters 1 to 8 provide a general overview of research and development activities in the framework of the project with emphasis on services for different scientific areas and an update on the status of the PL Grid infrastructure describing new developments in security and middleware Chapters 9 to 13 discuss new environments and services which may be applied by all scientific communities Chapters 14 to 36 present how the PLGrid Plus environments tools and services are used in advanced domain specific computer simulations these chapters present computational models new algorithms and ways in which they are implemented The book also provides a glossary of terms and concepts This book may serve as a resource for researchers developers and system administrators working on efficient exploitation of available e infrastructures promoting collaboration and exchange of ideas in the process of constructing a common European e infrastructure *Computational Methods in Transport* Frank Graziani,2006-02-17 There exist a wider range of applications where as igni cant fraction of the momentum and energy present in a physical problem is carried by the transport of particles Depending on the specific application the particles involved may be photons neutrons neutrinos or charged particles Regardless of which phenomena is being described at the heart of each application is the fact that a Boltzmann like transport equation has to be solved The complexity and hence

expense involved in solving the transport problem can be understood by realizing that the general solution to the 3D Boltzmann transport equation is in fact really seven dimensional 3 spatial coordinates 2 angles 1 time and 1 for speed or energy Low order approximations to the transport equation are frequently used due in part to physical justification but many in cases simply because a solution to the full transport problem is too computationally expensive An example is the diffusion equation which effectively drops the two angles in phase space by assuming that a linear representation in angle is adequate Another approximation is the grey approximation which drops the energy variable by averaging over it If the grey approximation is applied to the diffusion equation the expense of solving what amounts to the simplest possible description of transport is roughly equal to the cost of implicit computational fluid dynamics It is clear therefore that for those application areas needing some form of transport fast accurate and robust transport algorithms can lead to an increase in overall code performance and a decrease in time to solution

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