2
Special relativistic hydrodynamics

2.1 Perfect fluid energy momentum tensor

It is easiest to begin a study of general relativistic hydrodynamics with a discussion of special relativistic hydrodynamics in flat space. A good starting point for any hydrodynamic discussion is the energy momentum tensor. Many astrophysical and cosmological models make use of the hydrodynamics of a perfect fluid. A perfect fluid is simply one in which the velocity field at each point is such that an observer moving with this velocity sees the fluid as isotropic and nonviscous on a small enough local scale. Although we begin our discussion with a perfect fluid, we will add imperfections (viscosity, heat flow, etc.) later.

The stress tensor in Newtonian fluids is a measure of the momentum flux. In relativity (both special and general) one desires a generalization to a measure of not only momentum flux density, but also energy flux density and energy density as observed in different reference frames. In special relativity it is easy to find the form of the energy momentum tensor. Consider a pressureless cloud consisting of a local number density of n particles per unit volume with a rest mass of m_0 each. An observer in an arbitrary frame then measures a fluid mass energy density,

$$\text{mass energy density} = \sum_N \frac{nmm_0}{(1-v^2)}. \tag{2.1}$$

where one factor of $1/\sqrt{1-v^2}$ arises from length contraction and another factor from the mass energy. In special relativity, this quantity represents the flux of mass energy across a t = constant surface. The energy flux density across a spatial surface is the amount of energy transported in various directions as seen by the observer,

$$(\text{energy flux density})_i = (\text{momentum density})_i = \sum_N \frac{nmm_0v^i}{(1-v^2)}. \tag{2.2}$$

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Relativistic Numerical Hydrodynamics

Luciano Rezzolla,Olindo Zanotti

Relativistic Numerical Hydrodynamics:

Relativistic Numerical Hydrodynamics James R. Wilson,Grant J. Mathews,2007-07-02 Calculations of relativistic hydrodynamics are crucial to several areas of current research in the physics of supernovae and stellar collapse This book provides an overview of the computational framework in which such calculations have been developed with examples of applications to real physical systems Beginning with the development of the equations and differencing schemes for special relativistic hydrodynamics the book stresses the viability of the Euler Lagrange approach to most astrophysical problems It details aspects of solving the Einstein equations together with the fluid dynamics for various astrophysical systems in one two and three dimensions **Relativistic Hydrodynamics** Luciano Rezzolla,Olindo Zanotti,2013-09-26 This book provides an up to date lively and approachable introduction to the mathematical formalism numerical techniques and applications of relativistic hydrodynamics The topic is presented here in a form which will be appreciated both by students and researchers in the field *Elements of Numerical Relativity and Relativistic Hydrodynamics* Carles Bona,Carlos Palenzuela-Luque,Carles Bona-Casas,2009-07-24 Many large scale projects for detecting gravitational radiation are currently being developed all with the aim of opening a new window onto the observable Universe As a result numerical relativity has recently become a major field of research and Elements of Numerical Relativity and Relativistic Hydrodynamics is a valuable primer for both graduate students and non specialist researchers wishing to enter the field A revised and significantly enlarged edition of LNP 673 Elements of Numerical Relativity this book starts with the most basic insights and aspects of numerical relativity before it develops coherent guidelines for the reliable and convenient selection of each of the following key aspects evolution formalism gauge initial and boundary conditions and various numerical algorithms And in addition to many revisions it includes new convenient damping terms for numerical implementations a presentation of the recently developed harmonic formalism and an extensive new chapter on matter space times containing a thorough introduction to relativistic hydrodynamics While proper reference is given to advanced applications requiring large computational resources most tests and applications in this book can be performed on a standard PC Relativistic Hydrodynamics Luciano Rezzolla,Olindo Zanotti,2013-09-26 Relativistic hydrodynamics is a very successful theoretical framework to describe the dynamics of matter from scales as small as those of colliding elementary particles up to the largest scales in the universe This book provides an up to date lively and approachable introduction to the mathematical formalism numerical techniques and applications of relativistic hydrodynamics The topic is typically covered either by very formal or by very phenomenological books but is instead presented here in a form that will be appreciated both by students and researchers in the field The topics covered in the book are the results of work carried out over the last 40 years which can be found in rather technical research articles with dissimilar notations and styles The book is not just a collection of scattered information but a well organized description of relativistic hydrodynamics from the basic principles of statistical kinetic theory down to the technical aspects of numerical

methods devised for the solution of the equations and over to the applications in modern physics and astrophysics Numerous figures diagrams and a variety of exercises aid the material in the book The most obvious applications of this work range from astrophysics black holes neutron stars gamma ray bursts and active galaxies to cosmology early universe hydrodynamics and phase transitions and particle physics heavy ion collisions It is often said that fluids are either seen as solutions of partial differential equations or as wet Fluids in this book are definitely wet but the mathematical beauty of differential equations is not washed out **Hyperbolic Problems: Theory, Numerics, Applications** Sylvie Benzoni-Gavage,Denis Serre,2008-01-12 This volume contains papers that were presented at HYP2006 the eleventh international Conference on Hyperbolic Problems Theory Numerics and Applications This biennial series of conferences has become one of the most important international events in Applied Mathematics As computers became more and more powerful the interplay between theory modeling and numerical algorithms gained considerable impact and the scope of HYP conferences expanded accordingly *Relativistic Astrophysics* Harald Riffert,Hanns Ruder,Hans-Peter Nollert,Friedrich W. Hehl,2013-06-29 This book summarizes the lectures given at the 162 WE Heraeus Seminar which took place in the house of the German Physical Society in Bad Honnefin August 1996 Already the number 162 shows the activity and effectiveness of the WE Heraeus Foundation We would like to express our thanks to Jutta Adam and Dr Volker Schafer for the almost incredibly simple and unbureaucratical procedure of funding organization and realization and of course to the founders Similar to the 152 WE Heraeus Seminar Relativity and Scientific Computing Springer Verlag 1996 this seminar was a joint venture of the Astronomical Society AG and of the Section Gravitation und Relativity Theory of the German Physical Society DPG Since Einstein has developed his Theory of General Relativity more than 80 years ago the situation has changed dramatically In the first decades main efforts were untertaken for a better understanding and for the experimental verification of the theory Mean while General Relativity GR is one of the experimentally best confirmed theories with 13 an accuracy better than 10 Consequently GR has become a powerful tool for the investigation of cosmic processes where strong gravitational fields are involved The state of the art of our knowledge is summarized by Jiirgen Ehlers in the first chapter An impressive example of the change of the situation is the gravitational light deflection *Relativistic Fluid Dynamics in and out of Equilibrium* Paul Romatschke,Ulrike Romatschke,2019-05-09 Presents a powerful new framework for out of equilibrium hydrodynamics with connections to kinetic theory AdS CFT and applications to high energy particle collisions

The Conformal Structure of Space-Times Jörg Frauendiener,Helmut Friedrich,2008-01-11 Causal relations and with them the underlying null cone or conformal structure form a basic ingredient in all general analytical studies of asymptotically flat space time The present book reviews these aspects from the analytical geometrical and numerical points of view Care has been taken to present the material in a way that will also be accessible to postgraduate students and nonspecialist reseachers from related fields *Godunov Methods* E.F. Toro,2012-12-06 This edited review book on Godunov methods

contains 97 articles all of which were presented at the international conference on Godunov Methods Theory and Applications held at Oxford in October 1999 to commemo rate the 70th birthday of the Russian mathematician Sergei K Godunov The meeting enjoyed the participation of 140 scientists from 20 countries one of the participants commented everyone is here meaning that virtu ally everybody who had made a significant contribution to the general area of numerical methods for hyperbolic conservation laws along the lines first proposed by Godunov in the fifties was present at the meeting Sadly there were important absentees who due to personal circumstance could not at tend this very exciting gathering The central theme o the meeting and of this book was numerical methods for hyperbolic conservation laws fol lowing Godunov s key ideas contained in his celebrated paper of 1959 But Godunov s contributions to science are not restricted to Godunov s method *Relativistic Kinetic Theory* Gregory V. Vereshchagin,Alexey G. Aksenov,2017-02-16 Relativistic kinetic theory has widespread application in astrophysics and cosmology The interest has grown in recent years as experimentalists are now able to make reliable measurements on physical systems where relativistic effects are no longer negligible This ambitious monograph is divided into three parts It presents the basic ideas and concepts of this theory equations and methods including derivation of kinetic equations from the relativistic BBGKY hierarchy and discussion of the relation between kinetic and hydrodynamic levels of description The second part introduces elements of computational physics with special emphasis on numerical integration of Boltzmann equations and related approaches as well as multi component hydrodynamics The third part presents an overview of applications ranging from covariant theory of plasma response thermalization of relativistic plasma comptonization in static and moving media to kinetics of self gravitating systems cosmological structure formation and neutrino emission during the gravitational collapse

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