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,

$$\text{mass energy density} = \sum_N \frac{n m_0}{(1 - v^2)}. \tag{2.1}$$

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,

$$(\text{energy flux density})_i = (\text{momentum density})_i = \sum_N \frac{n m_0 v^i}{(1 - v^2)}. \tag{2.2}$$

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Relativistic Numerical Hydrodynamics

Sylvie Benzoni-Gavage,Denis Serre

Relativistic Numerical Hydrodynamics:

   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

   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   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 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   **Numerical Relativity** Thomas W. Baumgarte,Stuart L. Shapiro,2010-06-24 Aimed at students and researchers entering the field this pedagogical introduction to numerical relativity will also interest scientists seeking a broad survey of its challenges and achievements Assuming only a basic knowledge of classical general relativity the book develops the mathematical formalism from first principles and then highlights some of the pioneering simulations involving black holes and neutron stars gravitational collapse and gravitational waves The book contains 300 exercises to help readers master new material as it is presented Numerous illustrations many in color assist in visualizing new geometric concepts and highlighting the results of computer simulations Summary boxes encapsulate some of the most important results for quick reference Applications covered include calculations of coalescing binary black holes and binary neutron stars rotating stars colliding star clusters gravitational and magnetorotational collapse critical phenomena the generation of gravitational waves and other topics of current physical and astrophysical significance   **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 Flows in Astrophysics** A.W. Guthmann,M. Georganopoulos,A. Marcowith,K. Manolakou,2008-01-11 1 1 Schematic Picture of AGN Some galaxies are known to emit radiation with extremely high luminosities from a rather small volume in the ray X ray and UV continuum Such active cores are the so called Active Galactic Nuclei AGN and the radiation is commonly believed to be a result of gravitational energy released by matter spiraling around 9 a supermassive central black hole of about 10 M see Fig 1 Though the central engine which produces the enormous observed activity cannot be resolved observationally a standard picture of an AGN has gradually emerged to explain the richness of the radiation spectra an accretion disk with radius from about 2 to 100 gravitational radii R g feeding the central black hole and emitting mainly in the UV and soft X rays the broad line optically emitting clouds BLR

which seem to be absent in 3 some sources e g FRI see hereafter and extend up to a few 10 R from g the center

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 **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 researchers from related fields **Numerical Special Relativistic Hydrodynamics** Weili Zhang,1996 Relativistic Kinetic Theory Gregory V. Vereshchagin,Alexey G. Aksenov,2017-02-16 This book presents fundamentals equations and methods of solutions of relativistic kinetic theory with applications in astrophysics and cosmology **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

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rotational kinematics in the section on uniform circular motion we discussed motion in a circle at constant speed and therefore constant angular velocity however there are times when angular velocity is not constant rotational motion can speed up

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evaluate problem solving strategies for rotational kinematics just by using our intuition we can begin to see how rotational

quantities like θ ω and α are related to one another for example if a motorcycle wheel has a large angular acceleration for a fairly long time it ends up spinning rapidly and rotates through many revolutions

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