Preface

Modern astronomy reveals an evolving Universe rife with transient sources, mostly discovered—few predicted—in multi-wavelength observations. Our window of observations now includes electromagnetic radiation, gravitational waves and neutrinos. For the practicing astronomer, these are highly interdisciplinary developments that pose a novel challenge to be well-versed in astroparticle physics and data analysis. In realizing the full discovery potential of these *multimessenger* approaches, the latter increasingly involves high-performance supercomputing.

These lecture notes developed out of lectures on mathematical-physics in astronomy to advanced undergraduate and beginning graduate students. They are organized to be largely self-contained, starting from basic concepts and techniques in the formulation of problems and methods of approximation commonly used in computation and numerical analysis. This includes root finding, integration, signal detection algorithms involving the Fourier transform and examples of numerical integration of ordinary differential equations and some illustrative aspects of modern computational implementation. In the applications, considerable emphasis is put on fluid dynamical problems associated with accretion flows, as these are responsible for a wealth of high energy emission phenomena in astronomy.

The topics chosen are largely aimed at phenomenological approaches, to capture main features of interest by effective methods of approximation at a desired level of accuracy and resolution. Formulated in terms of a system of algebraic, ordinary or partial differential equations, this may be pursued by perturbation theory through expansions in a small parameter or by direct numerical computation. Successful application of these methods requires a robust understanding of asymptotic behavior, errors and convergence. In some cases, the number of degrees of freedom may be reduced, e.g., for the purpose of (numerical) continuation or to identify secular behavior. For instance, secular evolution of orbital parameters may derive from averaging over essentially periodic behavior on relatively short, orbital periods. When the original number of degrees of freedom is large, averaging over dynamical time scales may lead to a formulation in terms of a system in approximately thermodynamic equilibrium subject to evolution on a secular time scale by a regular or singular perturbation.

In modern astrophysics and cosmology, gravitation is being probed across an increasingly broad range of scales and more accurately so than ever before. These observations probe weak gravitational interactions below what is encountered in our solar system by many orders of magnitude. These observations hereby probe (curved) spacetime at low energy scales that may reveal novel properties hitherto unanticipated in the classical vacuum of Newtonian mechanics and Minkowski spacetime. Dark energy and dark matter encountered on the scales of galaxies and beyond, therefore, may be, in part, revealing our ignorance of the vacuum at the lowest energy scales encountered in cosmology. In this context, our application of Newtonian mechanics to globular clusters, galaxies and cosmology is an approximation assuming a classical vacuum, ignoring the potential for hidden low energy scales emerging on cosmological scales. Given our ignorance of the latter, this poses a challenge in the potential for unknown systematic deviations. If of quantum mechanical origin, such deviations are often referred to as anomalies. While they are small in traditional, macroscopic Newtonian experiments in the laboratory, they same is not a given in the limit of arbitrarily weak gravitational interactions.

We hope this selection of introductory material is useful and kindles the reader's interest to become a creative member of modern astrophysics and cosmology.

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