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# MHD-kinetic Modeling of Partially Ionized Plasma Flows: Solar Wind Interaction with the Interstellar Medium

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**Minisymposia:** Numerical methods in astrophysics

**Abstract** A common element across multiple, often independent, disciplines is that almost all complex systems occurring in geophysical, space, astrophysical, engineering, and even biological environments comprise multiple gas, fluid, or plasma components that are mutually coupled across many spatial and temporal scales via collision-like integral terms. The "collisional terms" may incorporate processes as diverse as chemical kinetics, charge-exchange, coagulation, etc. The range of scales found in complex systems often requires that some constituents must be modeled using a Boltzmann-like transport equation rather than a continuum system of equations. Continuum, or fluid-dynamics-like, systems of equations have been explored computationally for a variety of applications in considerable depth over the past 15 years but the development of models that incorporate a multiplicity of temporal and spatial scales and collision-like integral terms have received very little attention despite their considerable importance.

Flows of partially ionized plasma are frequently characterized by the presence of both thermal and nonthermal populations of ions. Such flows cannot be modeled using traditional MHD equations. When non-thermal ions are formed due to charge exchange and/or collisions between the thermal (core) ions and neutrals, they experience the action of magnetic field, their distribution function is isotropized by wave-particle interaction, and they soon acquire the velocity of the ambient plasma flow without being thermodynamically equilibrated with the core plasma. This occurs, e. g., in the outer heliosphere – the part of interstellar space beyond the solar system whose properties are determined by the solar wind (SW) interaction with the local interstellar medium (LISM). Collisions between atoms and ions in heliospheric plasma are so rare that they should be modeled kinetically. On the other hand, PUIs born when LISM neutral atoms charge-exchange with SW ions represent a hot, non-equilibrium component and also require a proper kinetic treatment.

Using Chombo as an adaptive mesh refinement (AMR) framework, we have implemented a suite of numerical codes (Multi-Scale Fluid-Kinetic Simulation Suite, MS-FLUKSS) that allows to perform high resolution simulations of MHD, multi-fluid, and MHD-kinetic flows. The AMR implemented in both Cartesian and curvilinear

coordinate systems allows us to perform a detailed analysis of discontinuous flows in the presence of shocks, tangential discontinuities, and current sheets [1]. Our physical model assumes that charged and neutral particles are governed by different sets of equations (MHD and kinetic Boltzmann) self-consistently connected by a vector source term responsible for charge-exchange collisions between these particles. The MHD subsystem consists of the conservation laws for the ion-electron mixture and is solved with the Godunov-type schemes accompanied by an efficient implementation of the far-field boundary conditions [2]. The Boltzmann equation is solved by a Monte Carlo method using a variable-weight particle approach, which increases the efficiency of the method substantially [3, 4]. A level-set method is implemented to describe the evolution of flow separation surfaces and current sheets.

We describe the peculiarities of coupling the MHD and Boltzmann equations and present numerical results of the SW–LISM interaction modeling obtained with MS-FLUKSS. The emphasis is on high-resolution time-dependent simulations requiring AMR simulations on leadership supercomputers. The influence of the interstellar magnetic field and directions covering the range from sub- to super-fast MHD flows is analyzed by comparing numerical simulations with observations. It is shown that the presence of ion-neutral interactions can dramatically change the character of the stream interaction. The results of the shock-turbulence interaction simulations are presented obtained with numerical schemes of the second to sixth order of accuracy.

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Interaction of the Solar Wind with the Local Interstellar Medium: A Theoretical Perspective. Article. Full-text available.Â  A model of such type should, on the one hand, involve a kinetic treatment of the neutral component in the [Show full abstract] partially ionized SW and local interstellar medium plasmas and, on the other hand, take advantage of adaptive mesh refinement (AMR) techniques for resolving the heliospheric discontinuities (the TS, the heliopause, the bow shock, and additional transients) sharply enough so that they can be meaningfully compared with the spacecraft observations. 47 Izmodenov V. Kinetic-MHD modeling of the stellar/solar wind interaction with the local interstellar medium (LISM): eects of stellar and interstellar magnetic elds . . . 48 Kalinin A., Sokolo D. Dynamo resonances in a simple dynamo model . . . 49 Kantorovich S. Self-propelled magnetic laments . . .Â  Pavlov V., Triaskin J. Inuence of shock wave on a weakly ionized gas . . . 100. Pelevina D., Naletova V., Turkov V. Lifting of magnetic and non-magnetic uids over a magnetizable body in a uniform magnetic eld . . .Â  particular with the solar source, the waste recoveries,etc at level of temperature between 200 up to 1000â—¦ C, and the power level can reach more than 100 kW. ALEMANY A.