Commun. Comput. Phys.
doi: 10.4208/cicp.OA-2020-0117

Vol. **29**, No. 3, pp. 955-978
March 2021

A Simple Solver for the Two-Fluid Plasma Model Based on PseudoSpectral Time-Domain Algorithm

Benoit Morel[1], Remo Giust[1], Kazem Ardaneh[1] and Francois Courvoisier[1,*]

[1] *Institut FEMTO-ST, Universite Bourgogne Franche-Comte, 15B Avenue des Montboucons, 25030 Besancon cedex, France.*

Received 24 June 2020; Accepted (in revised version) 9 September 2020

Abstract. We present a solver of 3D two-fluid plasma model for the simulation of short-pulse laser interactions with plasma. This solver resolves the equations of the two-fluid plasma model with ideal gas closure. We also include the Bhatnagar-Gross-Krook collision model. Our solver is based on PseudoSpectral Time-Domain (PSTD) method to solve Maxwell's curl equations. We use a Strang splitting to integrate Euler equations with source term: while Euler equations are solved with a composite scheme mixing Lax-Friedrichs and Lax-Wendroff schemes, the source term is integrated with a fourth-order Runge-Kutta scheme. This two-fluid plasma model solver is simple to implement because it only relies on finite difference schemes and Fast Fourier Transforms. It does not require spatially staggered grids. The solver was tested against several well-known problems of plasma physics. Numerical simulations gave results in excellent agreement with analytical solutions or with previous results from the literature.

AMS subject classifications: 35L02, 35L03

Key words: Two-fluid plasma model, 3D Hydrodynamic code, Lax-Wendroff, composite scheme, PSTD, laser-plasma interaction.

---

1 Introduction

Since the early 1960s, the interaction of laser light with a plasma has revealed to be an extremely rich topic: laser-plasma accelerators, inertial fusion, X-Ray sources, nonlinear plasmonics or laser materials processing [1]. A number of plasma effects have been characterized in laser-plasma experiments, but many challenging problems remain [2]. Simulations in laser-plasma interaction domain are essential for the understanding of

*Corresponding author. *Email addresses:* `francois.courvoisier@femto-st.fr` (F. Courvoisier), `benoit.morel@femto-st.fr` (B. Morel), `remo.giust@univ-fcomte.fr` (R. Giust), `kazem.ardaneh@femto-st.fr` (K. Ardaneh)

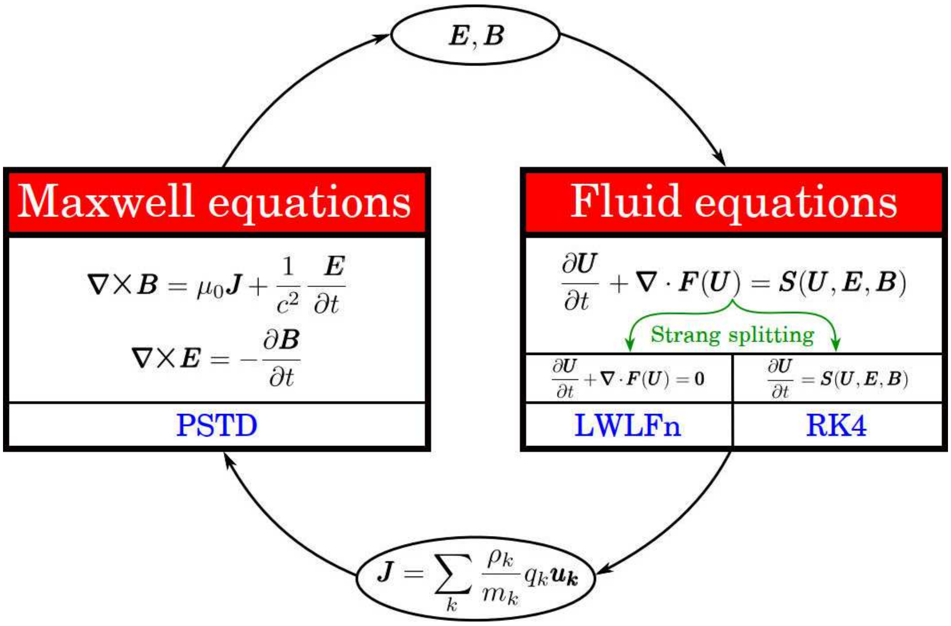

Figure 1: General overview of the algorithm.

the physical phenomena in high-intensity laser interactions. However, this requires efficient and precise numerical simulations. The hydrodynamic approach is particularly interesting to save computational effort when each of the species can be assumed in local thermodynamic equilibrium [3].

The most fundamental approach for hydrodynamic code is the set of multi-fluid plasma equations [4]. These equations can be derived by taking moments of the Vlasov equation with respect to velocity and truncating moment equations by making additional assumptions. Here, we will consider a two-fluid system of electrons and ions. The closure of the system of equations is performed via ideal gas closure. This model describes the evolution in space and time of the density, mean velocity and pressure of electrons and ions fluids. The two-fluid plasma equations therefore consist of two sets of Euler equations with source term, as well as Maxwell's equations. More conventional plasma models, e.g., two-temperature plasma equations, single-fluid equations and MagnetoHydroDynamic (MHD) are derived from the two-fluid plasma model but require additional assumptions.

Until now, only few numerical codes solve the complete two-fluid plasma equations [5]. However, their implementation is often complex for non-specialist groups. ANTHEM code was the first two-fluid plasma algorithm [6, 7]. It is based on a flux-corrected transport (FCT) algorithm for fluids equations and a Finite-Difference Time Domain (FDTD) algorithm for the evolution of the fields. This code was used to simulate high-density plasmas out of reach to Particle-In-Cell (PIC) codes. It was although difficult to extend to arbitrary geometries because of the staggered grid of the FDTD scheme in