2013

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J. Paxon Reyes
University of Nebraska-Lincoln

Bradley Allan Shadwick
University of Nebraska-Lincoln, shadwick@unl.edu

Plasma Science (ICOPS), 2013 Abstracts IEEE International Conference on
Year: 2013
Pages: 1 - 1, DOI: 10.1109/PLASMA.2013.6634928

Higher-Order Explicit Numerical Methods for Laser-Plasma Interactions*

J. Paxon Reyes and B. A. Shadwick
Department of Physics & Astronomy
University of Nebraska-Lincoln
Lincoln, NE 68588-0299 USA

The evolution of a short, intense laser pulse propagating in an underdense plasma is of particular interest for laser-plasma accelerator physics. This case is well-modeled by the cold, Maxwell–fluid equations but, using conventional second-order explicit methods, a three-dimensional simulation for experimentally relevant configurations is prohibitively expensive. This motivated a search for numerical methods that might be used to solve the fluid equations more efficiently. Explicit methods tend to suffer from stability constraints which couple the maximum allowable time step to the spatial grid size. If the dynamics of the system evolves on a time scale much larger than the constrained time step, an explicit method may require many more update cycles than is physically necessary. In these circumstances implicit methods, which tend to be unconditionally stable, may be attractive. However, in many physical situations (*e.g.*, Raman processes) it is necessary to fully-resolve the fast dynamics. In this case, implicit methods are unlikely to exhibit much improvement over explicit methods. Thus, we look for methods of higher-order in space that would allow the use of coarser spatial grids and thus larger time steps.

We restrict our discussion to the one-dimensional case and present a comprehensive survey of a wide range of numerical methods one might use to solve the fluid equations, including methods of order two through six in space and two through eight in time. There is no *a priori* way to determine whether a method will work and there are surprisingly many methods that turn out to be unconditionally unstable. We present a systematic approach to determine stability conditions using linear stability analyses of the numerical dispersion relations from these methods. This illustrates how the time step couples with the grid spacing, and we use examples to show how the numerical error of the group velocity depends on the time step. We briefly discuss extensions to two and three spatial dimensions.

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*This work was supported by the U. S. Department of Energy under Contract Nos. DE-FG02-08ER55000 and DE-SC0008382 and by the National Science Foundation under Contract No. PHY-1104683.