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Modelling magnetic reconnection events relevant for solar physics with the new Energy Conserving Moment Implicit Method

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Fully kinetic simulations of magnetic reconnection events in the solar environment are especially challenging due to the extreme range of spatial and temporal scales that characterises them. As one moves from the photosphere to the chromosphere and the corona, the temperature increases from sub eV to $10 - 100\,eV$, while the mass density decreases from 10^{-4} to $10^{-12}\,kg/m^3$ and further. The intrinsic scales of kinetic reconnection (inertial length and gyroradius) are tremendously smaller than the maximum resolution available in observations. Furthermore, no direct information is available on the size of reconnection regions, plasmoids and reconnection fronts, while observations suggest that the process can cascade down to very small scale [**?**]. Resolving the electron and ion scales while simulating a sufficiently large domain is a great challenge facing solar modelling. An especially challenging aspect is the need to consider the Debye length. The very low temperature of the electrons and the large spatial and temporal scales make these simulations hard to implement within existing Particle in Cell (PIC) methods. The limit is the ratio of the grid spacing to the Debye length. PIC methods show good stability and energy conservation when the grid does not exceed the Debye length too much. Semi-implicit methods [**?**, **?**] improve on this point. Only the recently developed fully energy conserving implicit methods have solved the problem [**?**, **?**], but at a high computational cost.

Very recently, we have developed an efficient new semi-implicit algorithm, which has been proven to conserve energy exactly to machine precision [**?**]. In this work, we illustrate the main steps that enabled this great breakthrough and report the implementation on a new massively parallel three dimensional PIC code, called ECsim [**?**]. The new approach is applied to the problem of reconnection in the solar environment. We compare results of a simple 2D configuration similar to the so-called GEM challenge for different ranges of electron temperature, density and magnetic field, relative to different distances from the photosphere, demonstrating the capability of the new code. Finally, we report on the first results (to the authors' knowledge) of realistic magnetic 3D reconnection simulations in the solar environment, considering a large domain sufficient to describe the interaction of large scale dynamics with the reconnection process.

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