Towards Realistic Solar Flare Models

Particle-In-Cell simulations in the exascale era

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Background

Solar flares are multi-scale phenomena. The overall structure evolves on slow timescales where the MHD approach can be used. Near magnetic reconnection sites, the timescales are much faster, and a kinetic approach, such as Particle-In-Cell (PIC), is needed. It is too computationally expensive to fully model a flare using only PIC.

We here present the preliminary validation results of a new PIC solver based on the Photon-Plasma[1] code. The solver is implemented in the DISPATCH[2] framework which allows dynamic switching of solvers in each 'patch'.

My UIO webpage

SCAN ME

Concurrent MHD and PIC

Each 'patch' in DISPATCH has a local timestep and may run different solvers.

With AMR different temporal and spatial scales can be run concurrently in the same simulation.

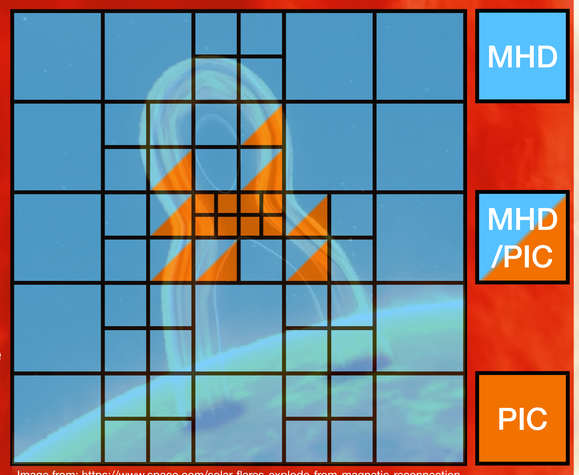
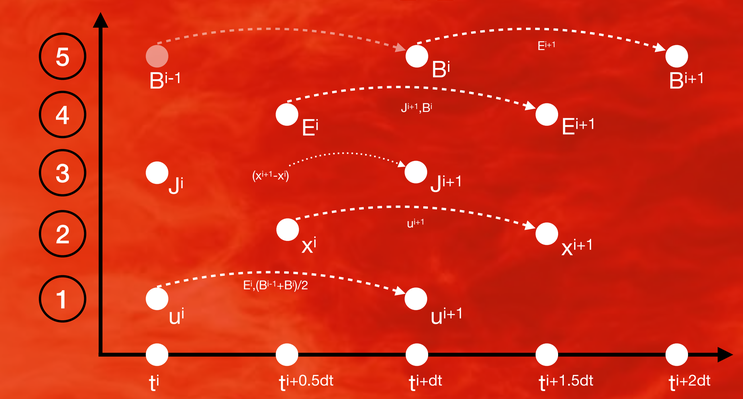


Image from: https://www.space.com/solar-flares-explode-from-magnetic-reconnection

Variables are staggered in time



Timestepping is performed in 5 steps.

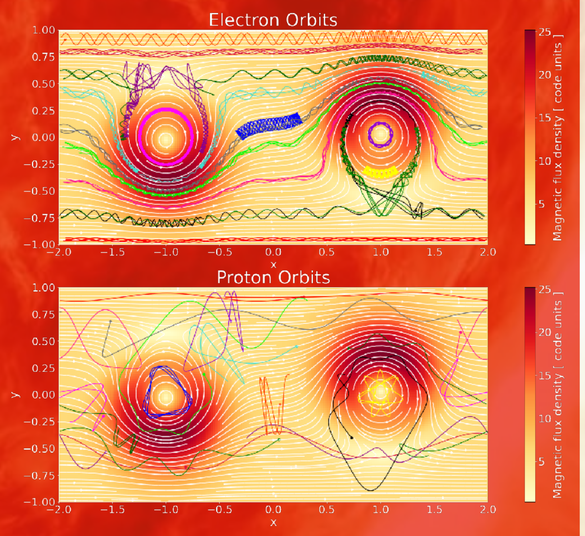
- First, particle velocity is updated from u^i to u^{i+1} using field values.
- Particle position is then updated using u^{i+1}.
- Change in position is used to calculate the charge density.
- The electric field is updated using the new current density and the old magnetic flux density.
- Finally, the magnetic field is updated based on the new electric field value.

Relativistic particle pusher

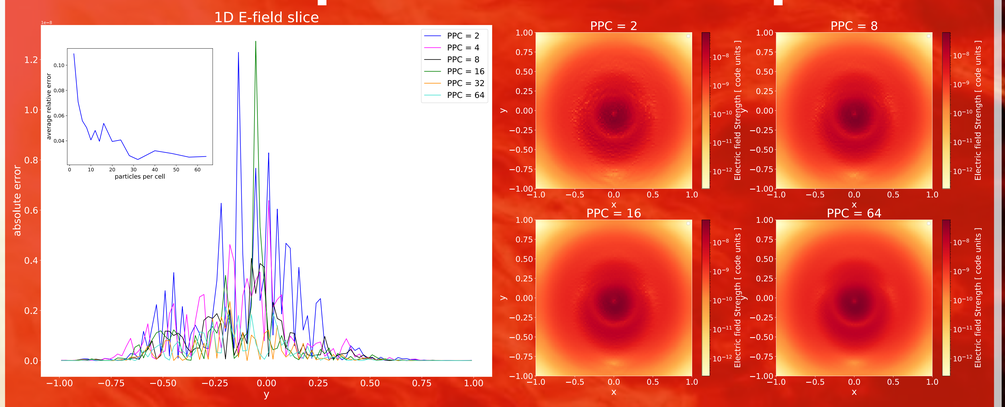
Some particles are expected to reach relativistic velocities in solar flares.

The relativistic Vay Particle Pusher[3] is used to update particle velocity and position.

Early validation with a double plasmoid setup shows expected particle behavior.



Particles per cell sweet spot?



The PIC solver was run for 50 iterations with no electric field initially.
To the right is shown the resulting E-field, for different values of particles per cell (PPC). The four figures show the same overall structure, but with more noise in low PPC runs.
To the left, the absolute error is shown for a 1D slice through the center of the domain. The smaller plot shows the average error.
For this setup, there seems to be a sweet spot around 32PPC, where the error is the lowest.

References:
[1] T. Haugbølle, J. T. Frederiksen, Å. Nordlund, Photon-Plasma: A modern high-order particle-in-cell code, Physics of Plasmas 20 issue 6 (2013)
[2] Å. Nordlund, J. Ramsey, A. Popovas, M. Kuffmeier, Dispatch: A numerical simulation framework in the exa-scale era - i. Fundamentals, Monthly Notices of the Royal Astronomical Society 477 (2018)
[3] J. L. Vay, Simulation of beams or plasmas crossing at relativistic velocity, Physics of Plasmas 15 issue 5 (2008)