STUDY OF VACUUM ARC FORMATION USING A ONE-DIMENSIONAL CPU/GPU PARTICLE CODE

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MOTIVATION

We use a one-dimensional CPU/GPU code to investigate the formation of vacuum arc between two planar metal electrodes. Understanding the physics of arcs is crucial for a wide range of plasma disciplines, including spacecraft propulsion [1]. Plasma acceleration in vacuum arcs has been a topic of study dating back to the 1930s [2]. One unresolved question is the source of high velocity ions: it is unclear if they arise from hydrodynamic pressure or electrostatic fields. Recently, the Benilovs put forth a magnetohydrodynamic model indicating formation of a double layer potential hill [3]. In order to test their hypothesis – and to improve our understanding of the formation process - we have developed a 1D kinetic code to simulate vacuum breakdown. Preliminary results have not yet reproduced a steady double-layer. Instead, the charge separation is quickly neutralized. Simulations with enhanced ionization lead to two stream instability and prey-predator oscillatory discharge.

APPROACH

The simulation utilizes the well-known Electrostatic Particle-in-Cell method (ES-PIC). Planar configuration, as shown in **Fig. 1**, is considered, reducing the computation to 1D3V. Atom and electron particles are introduced at the cathode based on vapor pressure and thermionic emission model. Poisson's equation is used to calculate the electric field between the electrodes. Electrons accelerate towards the anode, gaining energy to ionize the injected neutrals. Direct Simulation Monte Carlo (DSMC) captures neutral-neutral collisions, while a Monte Carlo Collisions (MCC) approach is used for the ion-neutral momentum exchange.

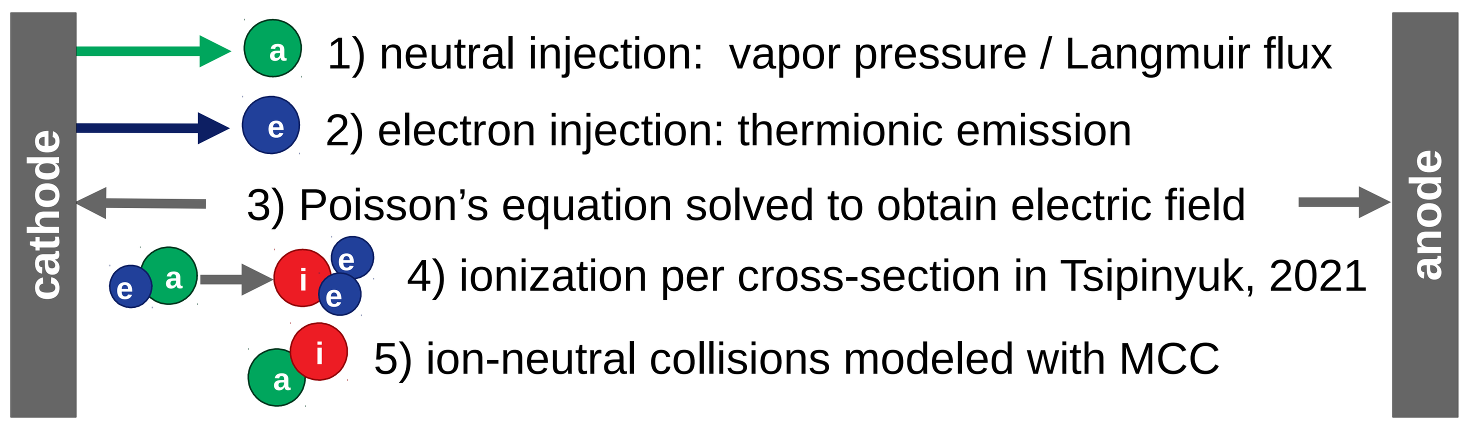
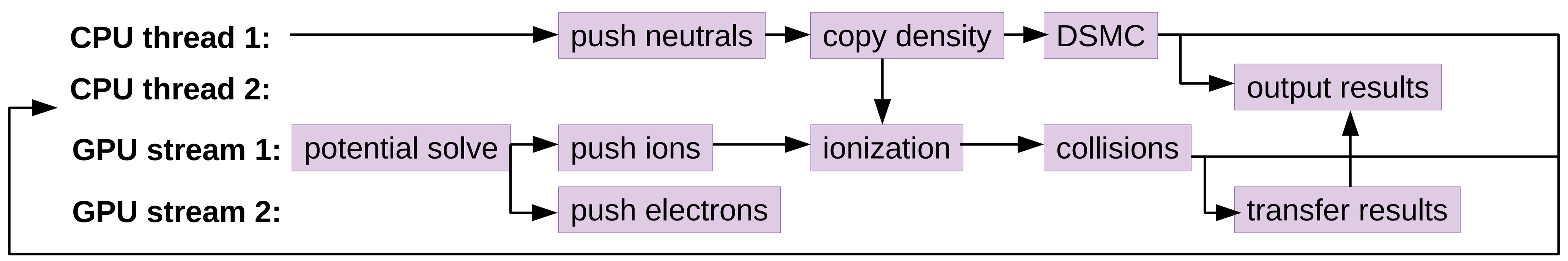


Fig. 1. Numerical model

IMPLEMENTATION

This code is an ideal candidate for GPU computation due to the need to integrate positions and velocities of a large number of simulation particles. To fully utilize the available resources, neutrals are advanced on the CPU concurrently with ion and electron advance on the GPU. Potential is solved on the GPU with a 1D Direct algorithm. Memory transfer is limited to copying neutral density to the GPU for use in ionization and momentum transfer collisions. GPU data is copied to the CPU only for file output, which is performed in parallel using threads and streams.



RESULTS

We have considered several configurations with varying number of mesh nodes, domain size, and cathode temperature. Typical runs consider 2400 cell and 5000K. Simulations ran for 5 million time steps with electrons traveling half cell-length per step. 100 electrons are injected at each time step, with macroparticle weight set according to the emission current. **Fig. 2** shows typical solution results. We notice well neutralized bulk plasma population, with charge separation in the sheath (top left).

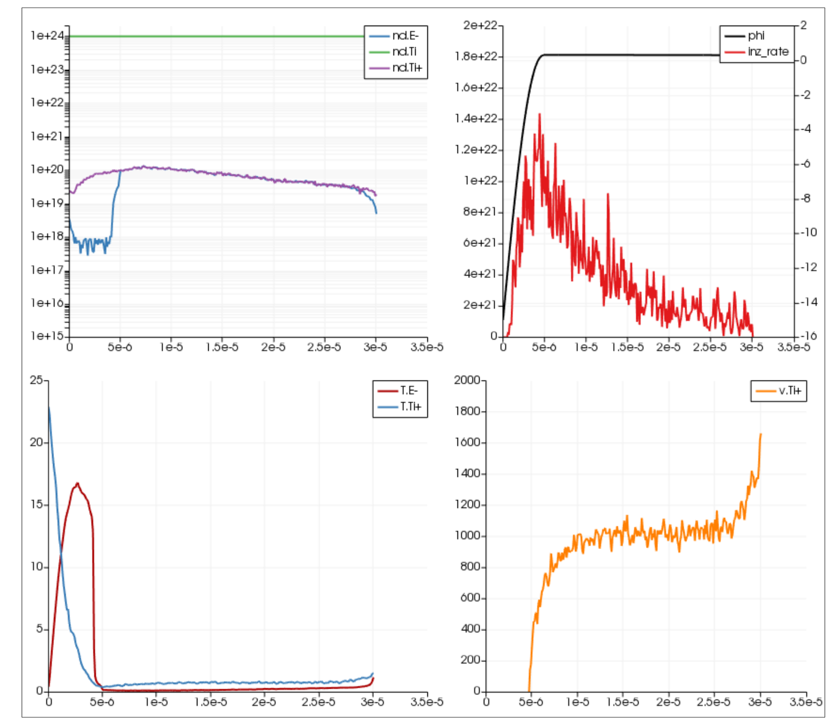


Fig. 2. Snapshot of results at a single time step

Single time-step results are assembled into time-series plots in **Fig. 3**. The cathode is left, and time grows from bottom to top. In this configuration, we notice the formation of a small potential hill, but it quickly vanishes due to electrons neutralizing the space charge. Plasma is well neutralized outside the near-cathode region and ion velocity primarily follows the neutral velocity due to momentum exchange coupling.

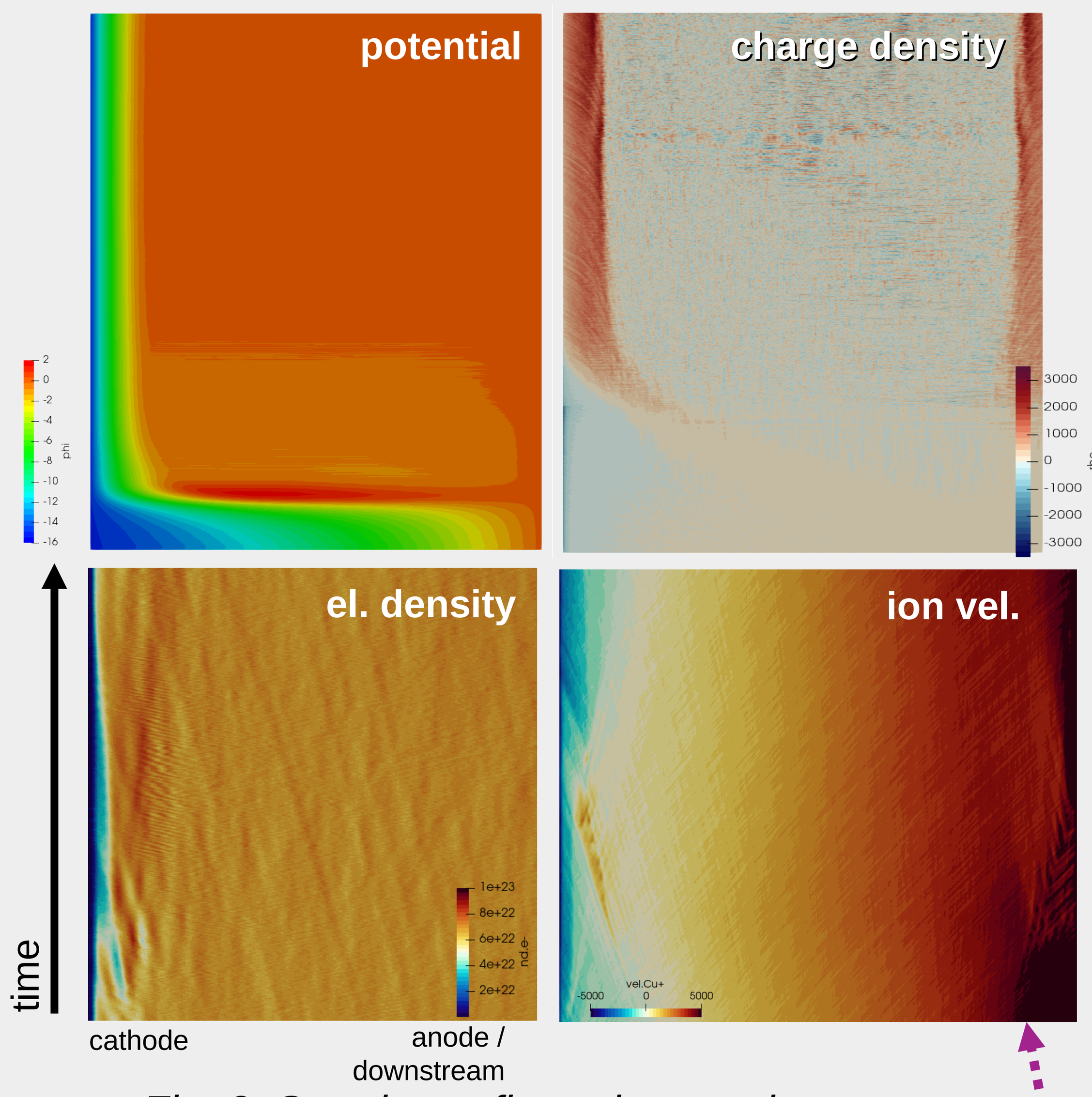
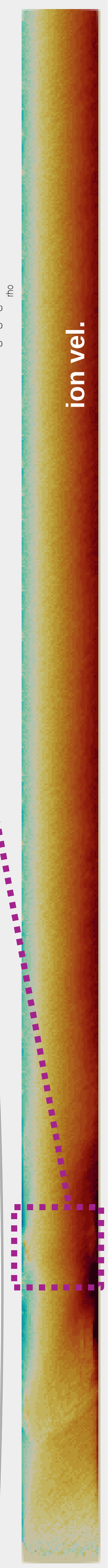
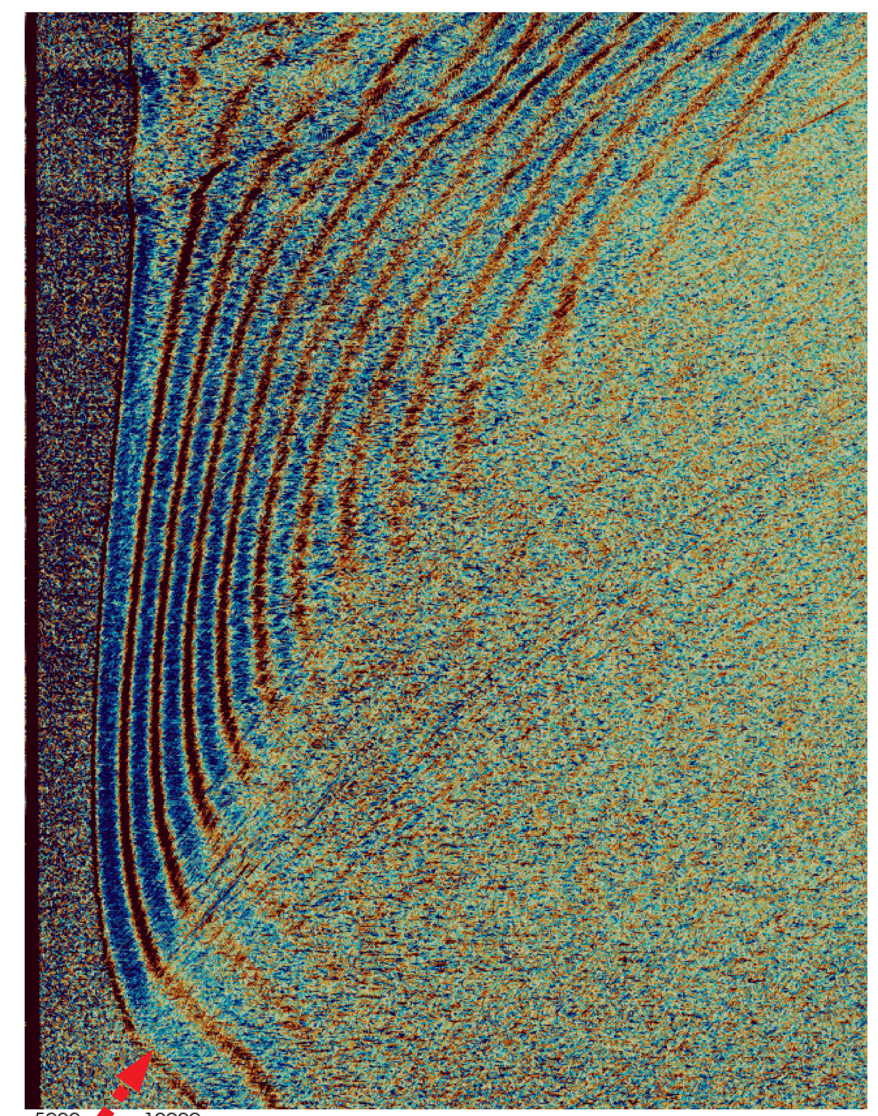


Fig. 3. Steady configuration results



Figs. 4 and **5** show results from a case with an increased injection current and cathode temperature to enhance ionization. Behavior much different from the quiescent case above is observed. Ion density exhibits oscillations reminiscent of prey-predator breathing mode in Hall effect thrusters. We also observe distinct ripples in charge density which seem to be indicative of a two-stream instability. If shown to be physical, it could be a source of energy imparted to the ion population. As part of future work, we plan to further investigate this formation and energy transfer mechanisms.



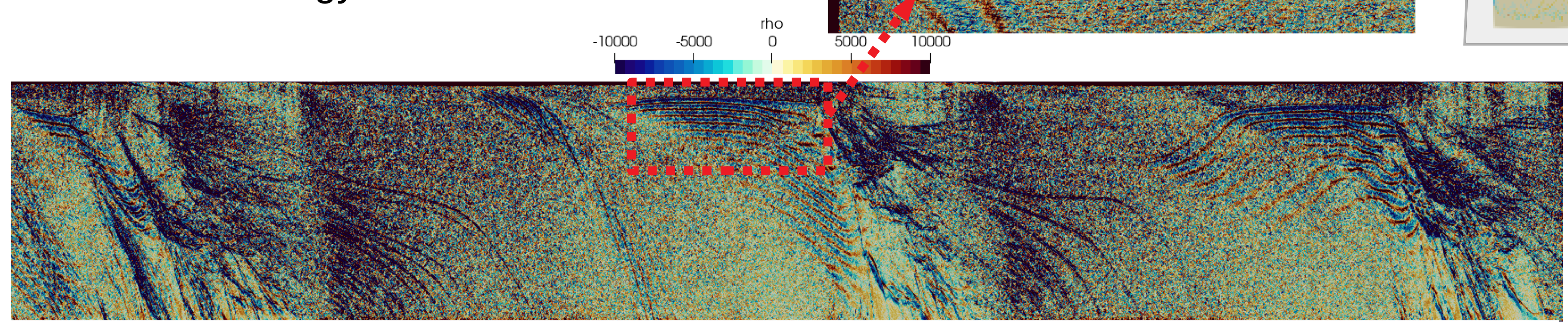
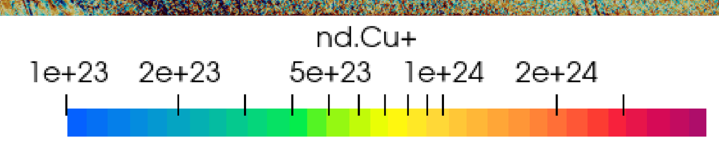
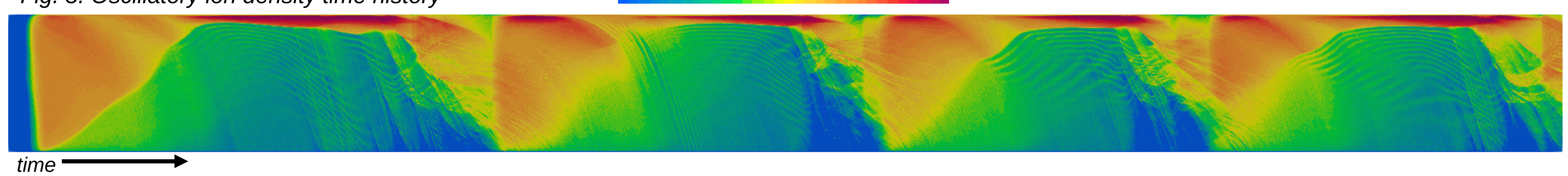


Fig. 4. Instability formation visible in charge density

Fig. 5. Oscillatory ion density time history





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