Particle-in-cell Simulations of Pulsar Polar-cap Discharge

Alexander Y. Chen
Andrei Beloborodov

Department of Physics
Columbia University

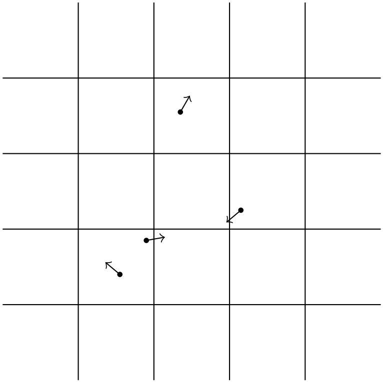
May 12, 2014

A New PIC Code Tailored for Pulsar Simulations

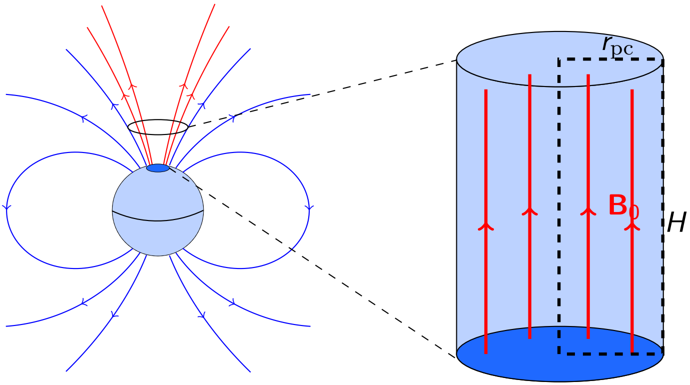
- Attempt to understand Pulsar magnetosphere from first principles
- 2D axisymmetric Particle-in-cell code
- Handles various coordinate systems
- Includes pair creation physics
- Runs on GPUs

Particle-in-Cell

- Fields are evaluated on a grid
- Particles move in the grid cells
- Interpolate particle motion to obtain current on the grid



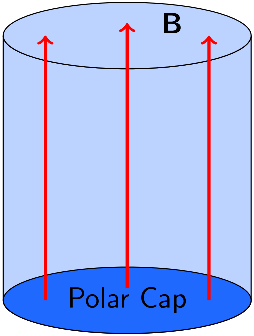
Polar-cap Simulations



Polar-cap Simulations

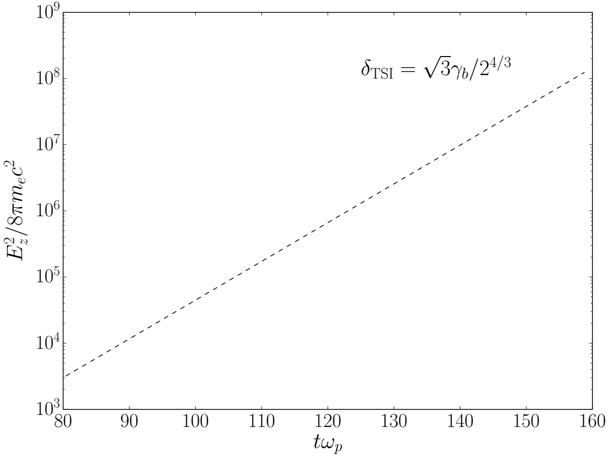
- Grounded cylinder boundary condition
- Escape boundary condition at the top
- Free supply of both signs of charges from the stellar surface
- High energy particles emits photons, which can turn into pairs in strong fields

Open field bundle



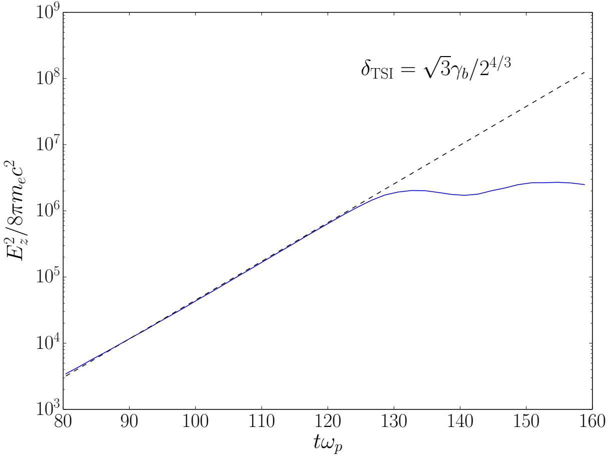
Polar-cap Simulations

Test 1: Two-stream instability



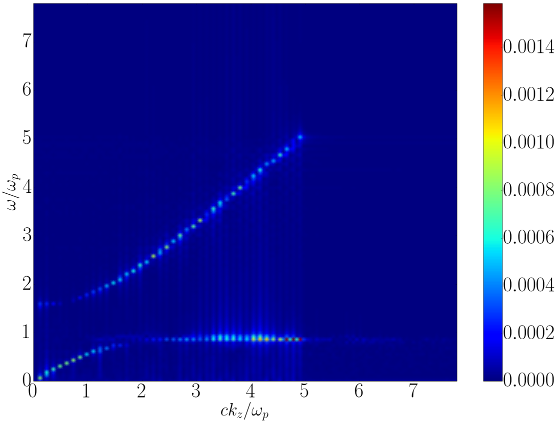
Polar-cap Simulations

Test 1: Two-stream instability



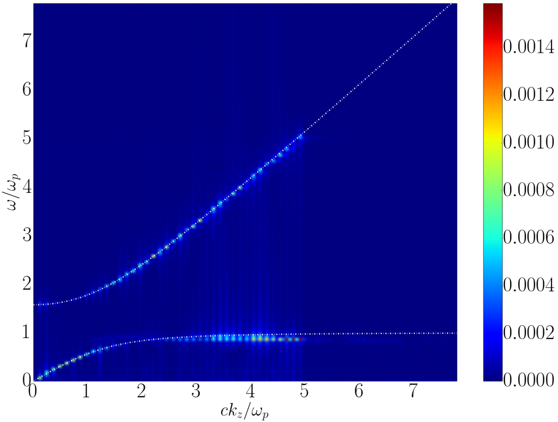
Polar-cap Simulations

Test 2: Dispersion relation



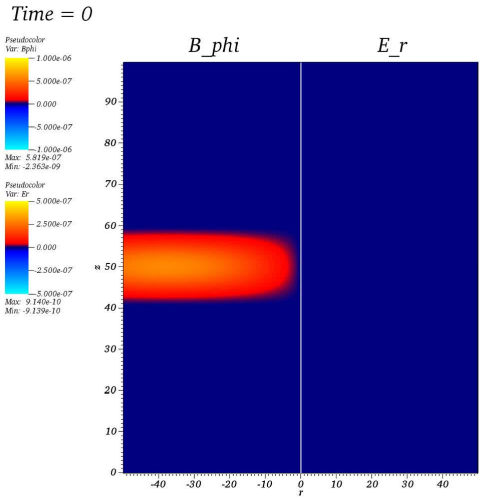
Polar-cap Simulations

Test 2: Dispersion relation

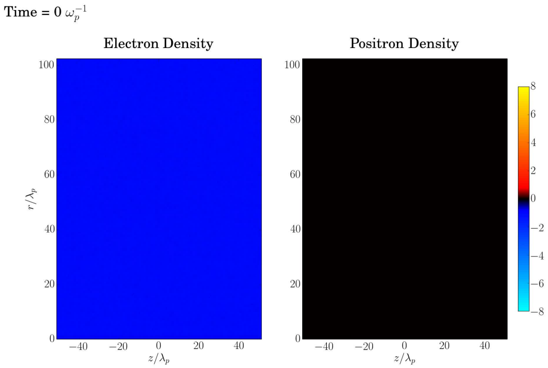


Polar-cap Simulations

Test 3: Propagating Alfven Wave Packet



Polar-cap Simulations with Pair Creation



- Imposing force-free $\alpha = |\nabla \times \mathbf{B}|/4\pi\rho_{\mathrm{GJ}}$ at the upper boundary
- Starting with $\rho = \rho_{\mathsf{GJ}}$

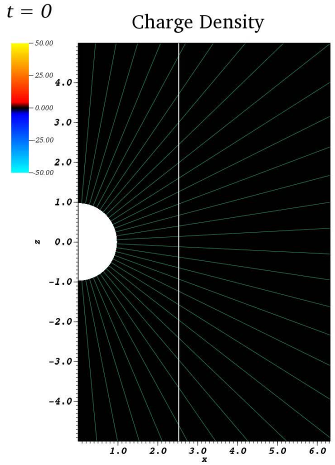
Towards a Global Simulation

Inconsistency in local simulations indicate the need of a global simulation.

- Spherical coordinates, stellar surface being the natural boundary
- Self-consistently determine the current through polar-cap
- Resolving particle gyration
- Self-consistent pair creation

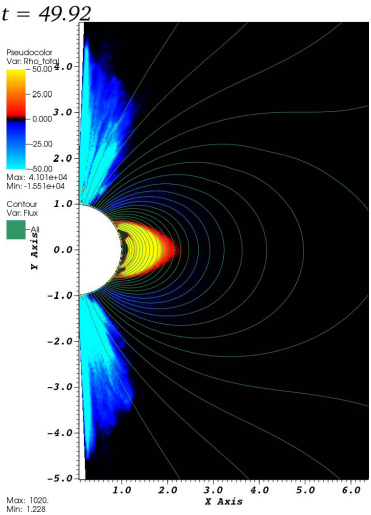
Michel Monopole Solution

- Gradual spinning up of the star, steady extraction of charges
- Charges flow freely across the light cylinder
- Achieved a steady state, as predicted by Michel (1973)



Next Step

- Apply to dipole initial condition
- Already able to reproduce the electrosphere (dome and torus)
- Study self-consistent pair creation in this setting



Conclusion

- A new PIC code designed for pulsar simulations
- Works with curvilinear coordinate systems
- Can handle physical pair creation
- WIP towards a realistic picture of the pulsar

Thank you!