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Kinetic studies of mildly relativistic magnetized perpendicular shocks

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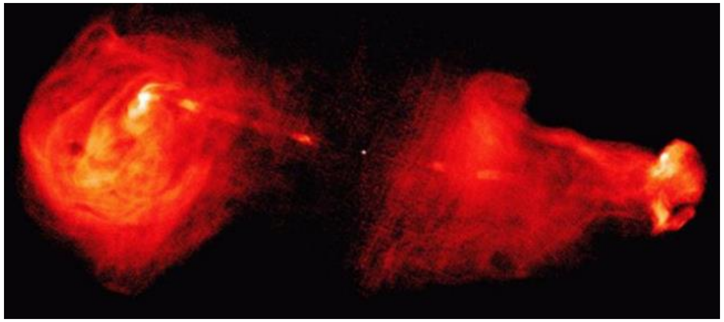
KUKDM 2017 - Zakopane

1. Role of shocks in astrophysics

Plasma shock are thought to be responsible for the emission of many astrophysical objects:

✧ ***Non relativistic shock waves*** → *Supernova Remnants*

✧ ***Relativistic shock waves*** → *Blazars, γ-rays burst, Active Galactic Nuclei, Pulsars*



1. Role of shocks in astrophysics

✧ *<u>Non relativistic shock waves</u> → deeply studied already (see e.g. Artem Bohdan's, Oleh Kobzar's presentations in this event), for different magnetization, magnetic field obliquity…*

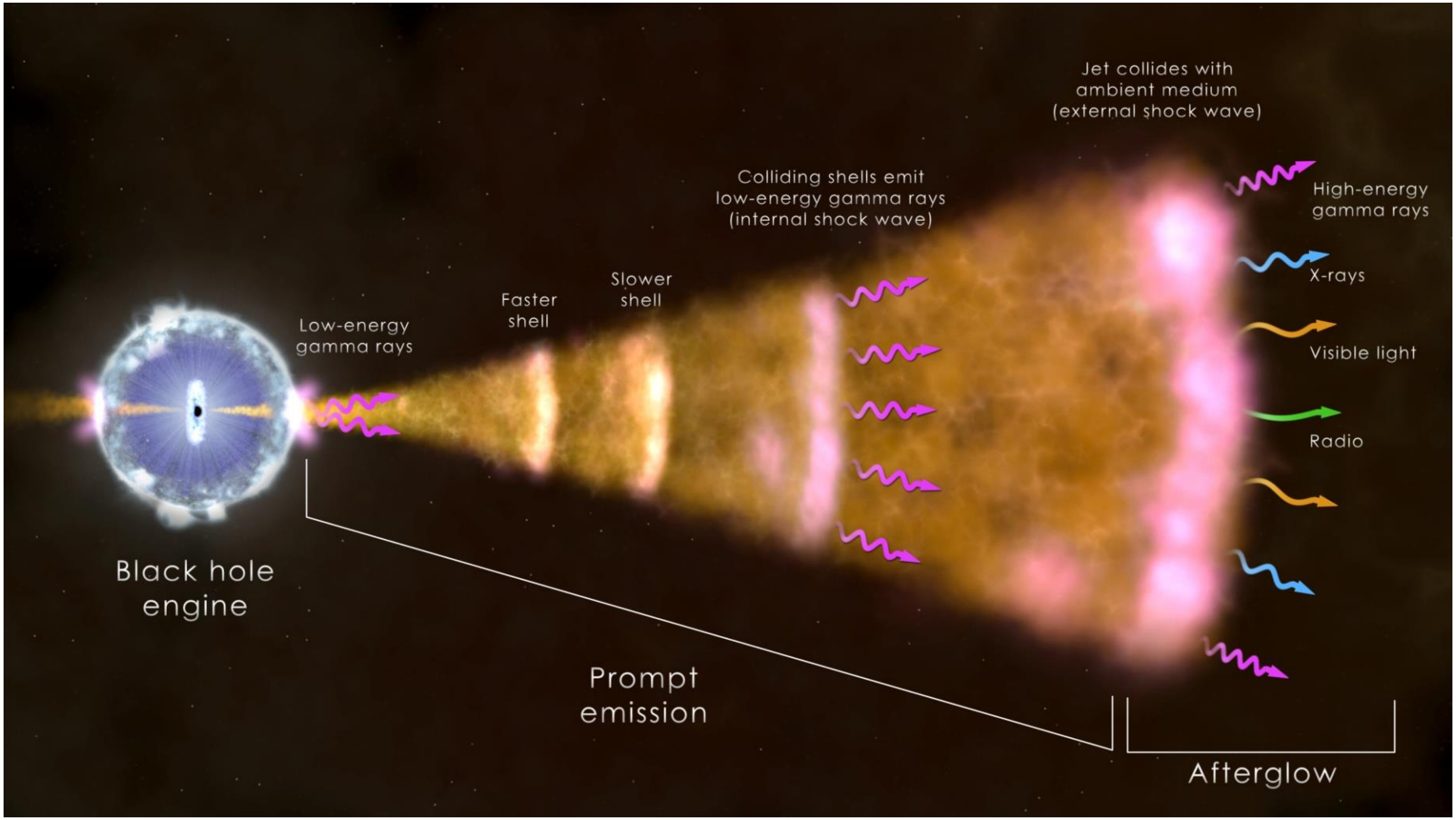
✧ *<u>Mildly relativistic shock waves</u> → very interesting regime! Still not deeply investigated,* ***we dedicate our study to γ~2 regime for perpendicular magnetic field***

✧ *<u>Ultra relativistic shock waves</u> → Many studies in this field, see e.g. Sironi, L. and Spitkowsky, A., 2011, ApJ, 726:75 and Stockem, A., et al., 2012, ApJ, 755:68 with $\gamma \geq 10$*

1.1 Blazars

- *AGN with relativistic jets seen approximately along the jet axis*

- *Dissipation may occur in the jets due to collision of slabs of plasma with different Lorenz factors (Internal Shock model)*



1.2 Superluminal and subluminal shocks

Two classes of shocks depending on the angle between B field orientation and the shock normal,

a) "subluminal" *shocks ($0^\circ \leq \theta \leq \theta_{crit}$), where relativistic particles can escape ahead of the shock along the magnetic field lines*

b) "superluminal" *shocks ($\theta_{crit} \geq \theta \geq 90^\circ$) if particles cannot escape ahead of the shock by sliding along the magnetic field.*

Different mechanism for particle acceleration

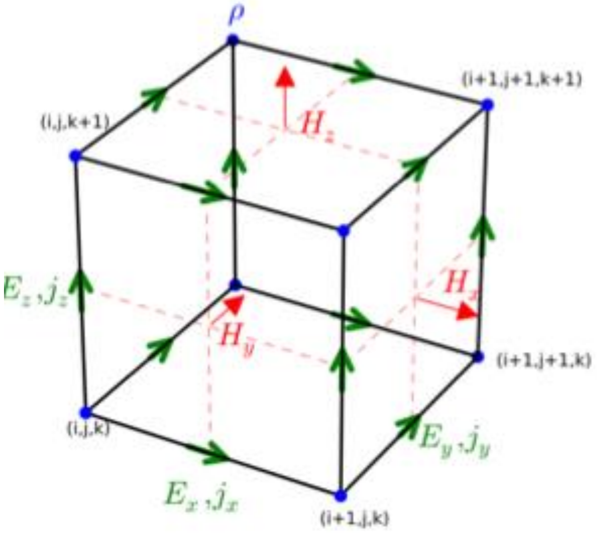
We are studying strictly perpendicular shocks (superluminal shock)

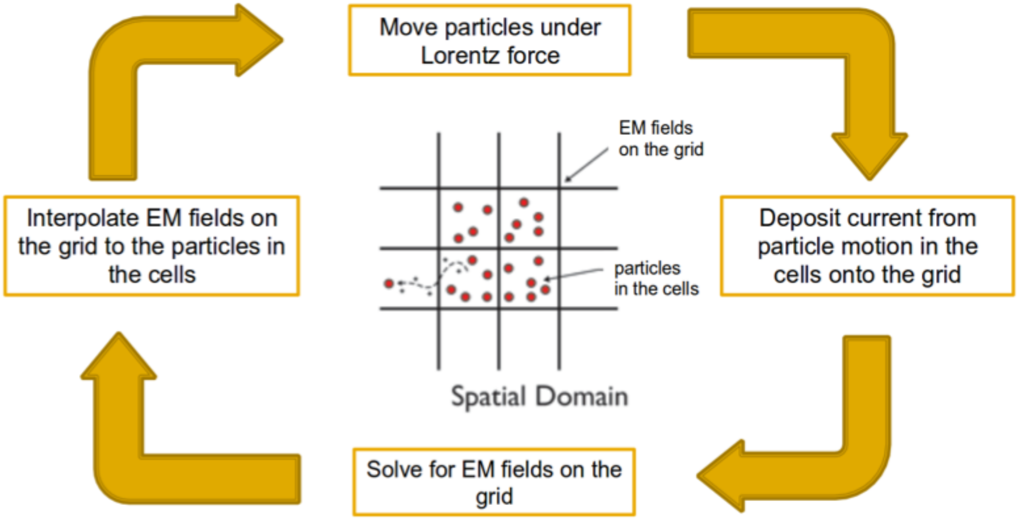
2. Particle-in-Cell Simulation

PIC simulations are an ab-initio method of solving Vlasov equation (a differential eqn. describing time evolution of the distribution function of charged particles plasma with long-range Coulomb interactions) in steps:

1. Solving of Maxwell's equations on a numerical grid

2. Integration of relativistic particle equations of motion in self-consistent EM field



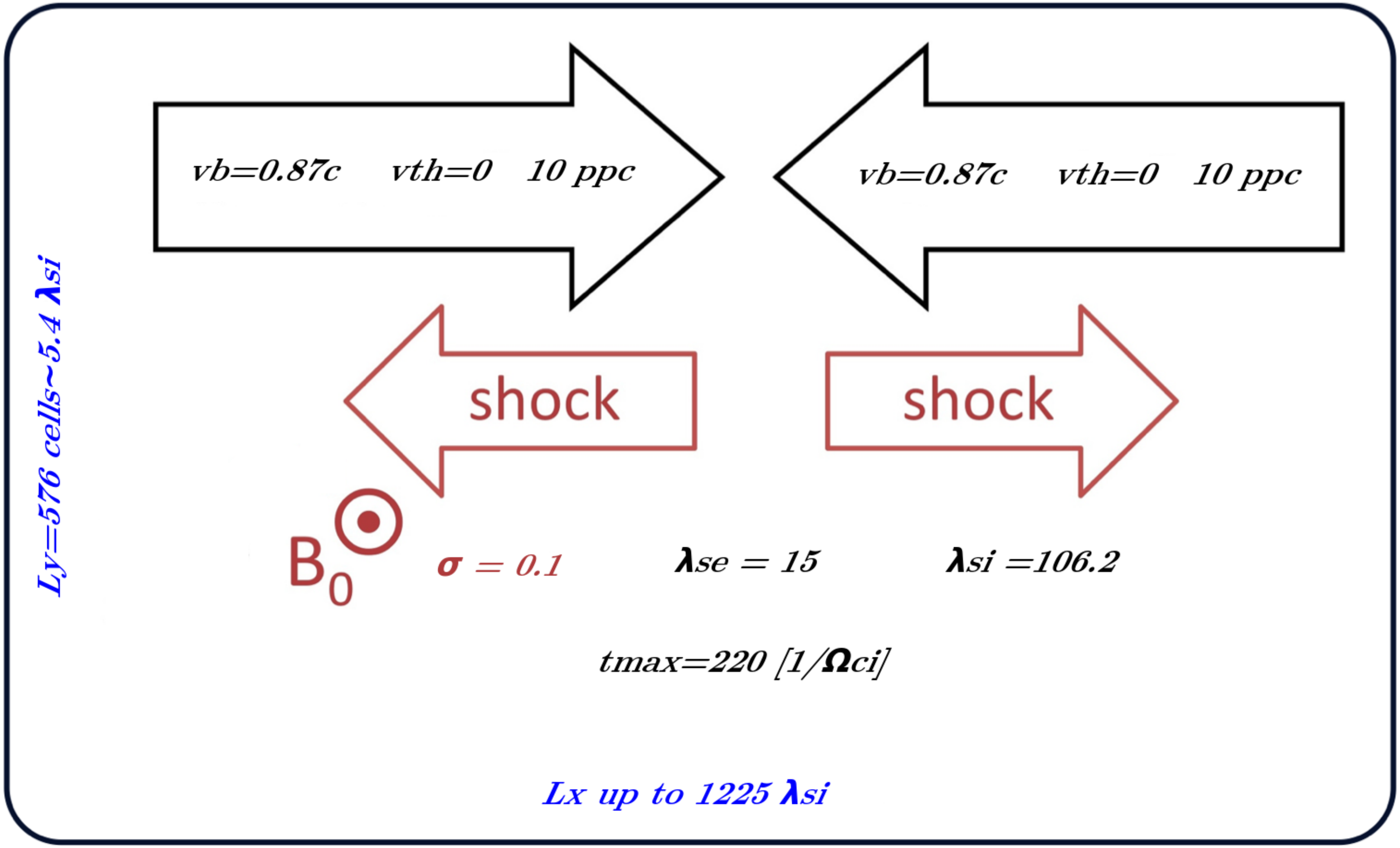

Move particles under Lorentz force

Deposit current from particle motion in the cells onto the grid

Solve for EM fields on the grid

Interpolate EM fields on the grid to the particles in the cells

2.1 Our PIC Simulation Setup



vb=0.87c vth=0 10 ppc

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shock

shock

B_0

$\sigma = 0.1$

$\lambda se = 15$

$\lambda si = 106.2$

tmax=220 [1/Ωci]

Ly=576 cells~5.4 λsi

Lx up to 1225 λsi

Simulations were performed on **`Prometheus`** *system (preliminary results, limited computational and storage resources were used)*

3. Electron Maser instability

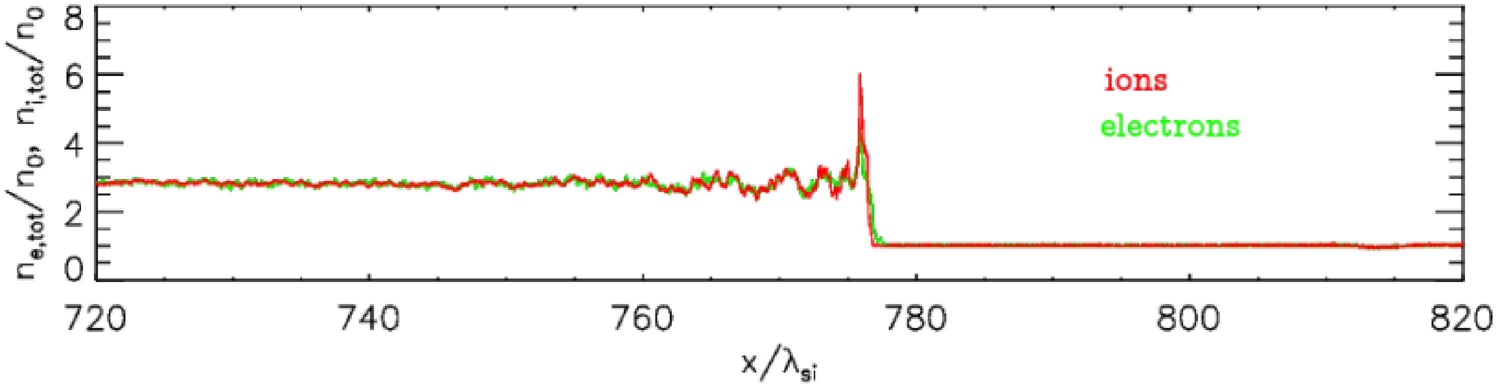
It arises in electron-ion plasma in presence of high obliquity B fields.

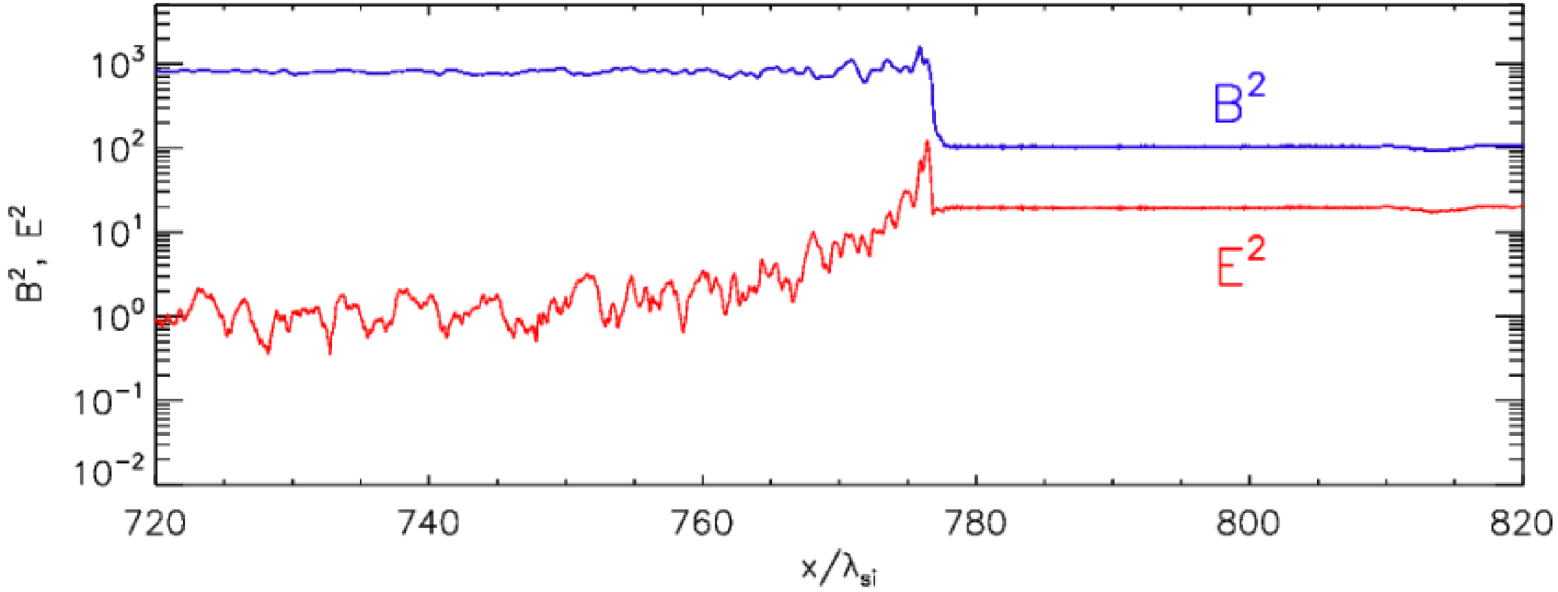
Incoming electrons gyrate in the shock-compressed B field, → a coherent train of intense EM waves is created and propagates upstream.

These oscillations propagate in the incoming plasma and eventually dissipate by ***heating the upstream electrons****, that are primarily* ***boosted toward the shock****.*

4. Profiles of the shock

Snapshot of the shock region, taken at $t=220\ \Omega_{ci}^{-1}$





4. Electron and ion densities

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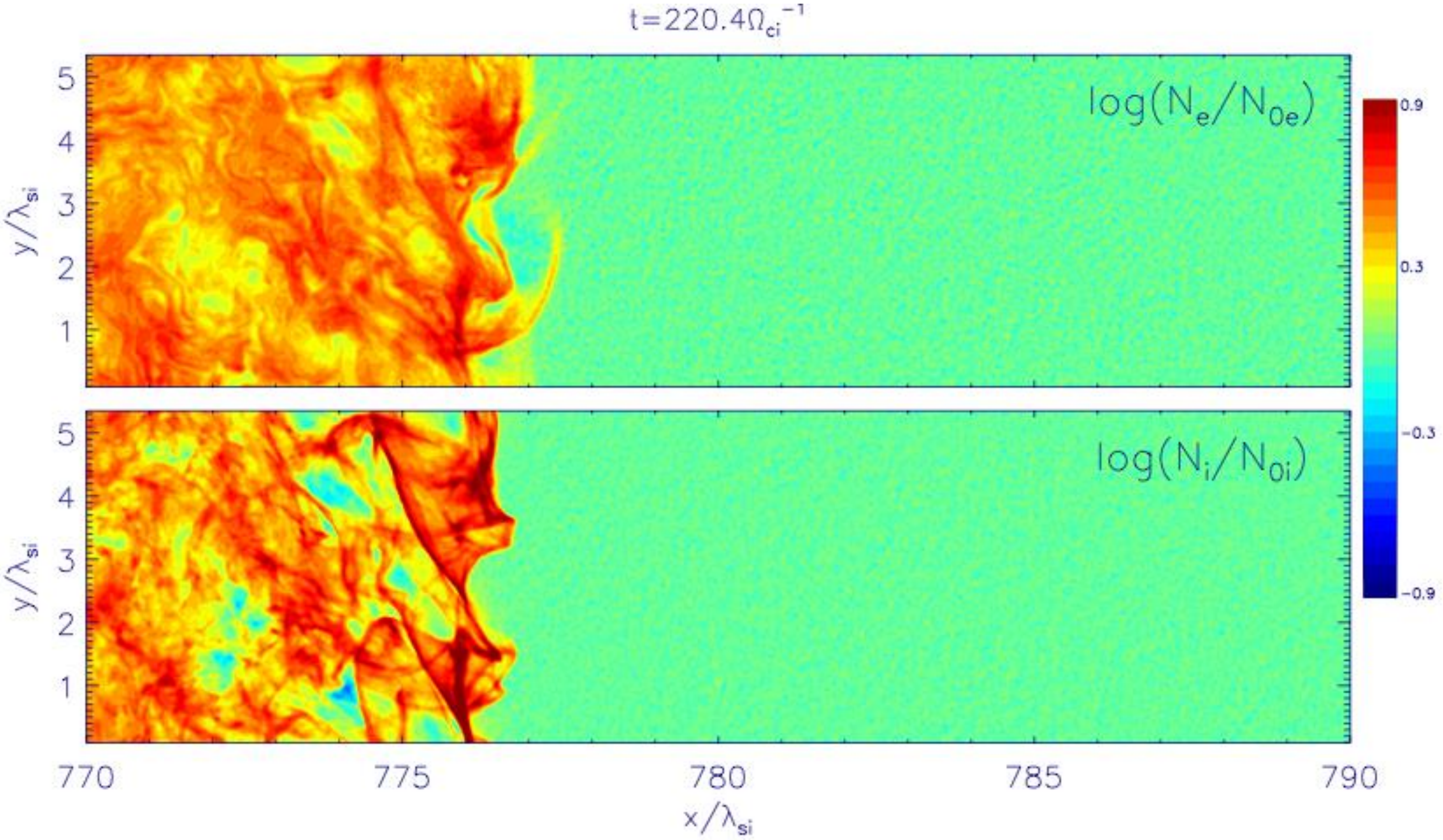
Snapshot of the shock region, taken at $t=220\ \Omega_{ci}^{-1}$

We can see oscillation in the upstream



4. Magnetic field (Bz) map

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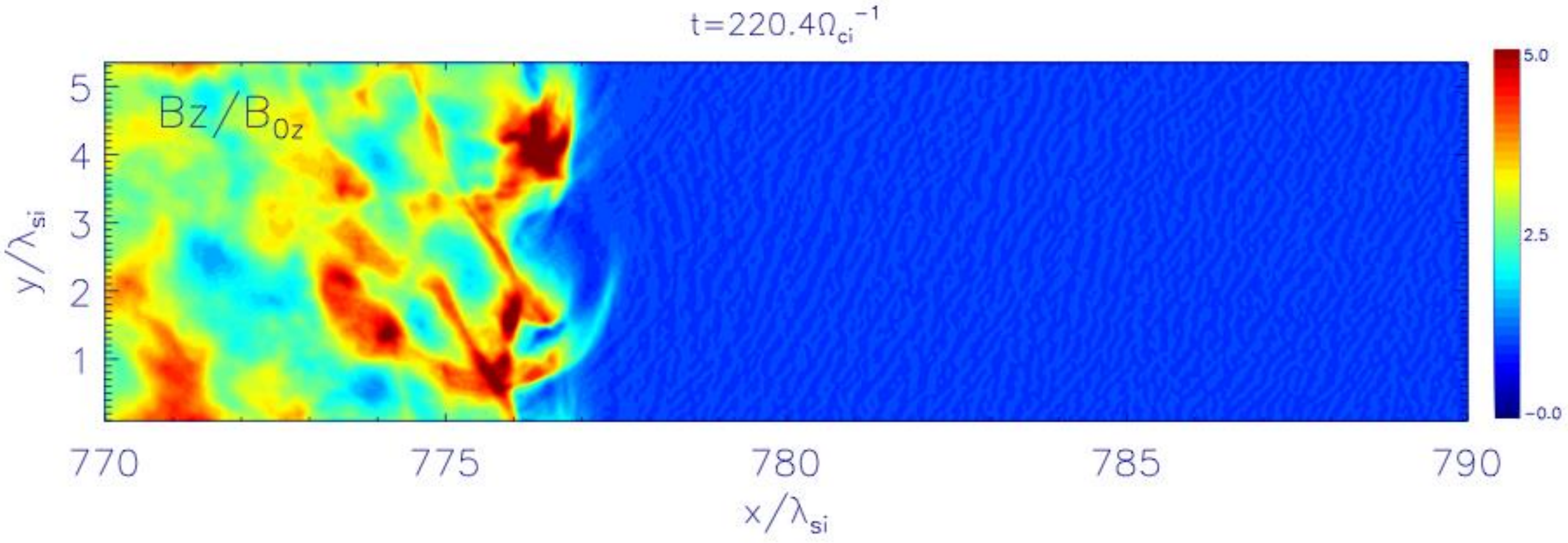
Snapshot of the shock region, taken at t=220 Ω_{ci}^{-1}

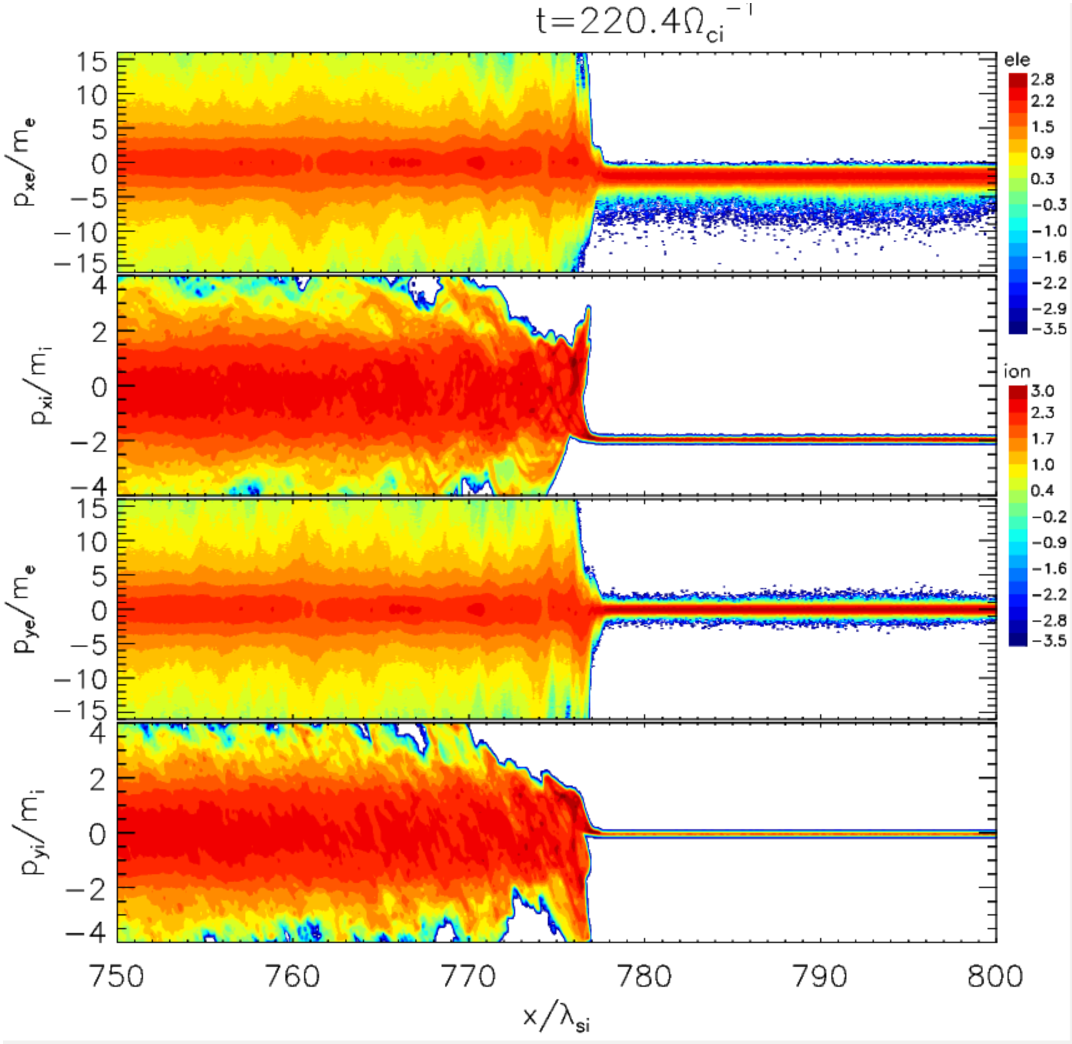
Again are visible in the upstream the oscillation due to electron maser instability



4. Phase space

Snapshot of the shock region, taken at t=220 Ω_{ci}^{-1}

We can notice a heating in upstream electron, boosted towards the shock



ele, x

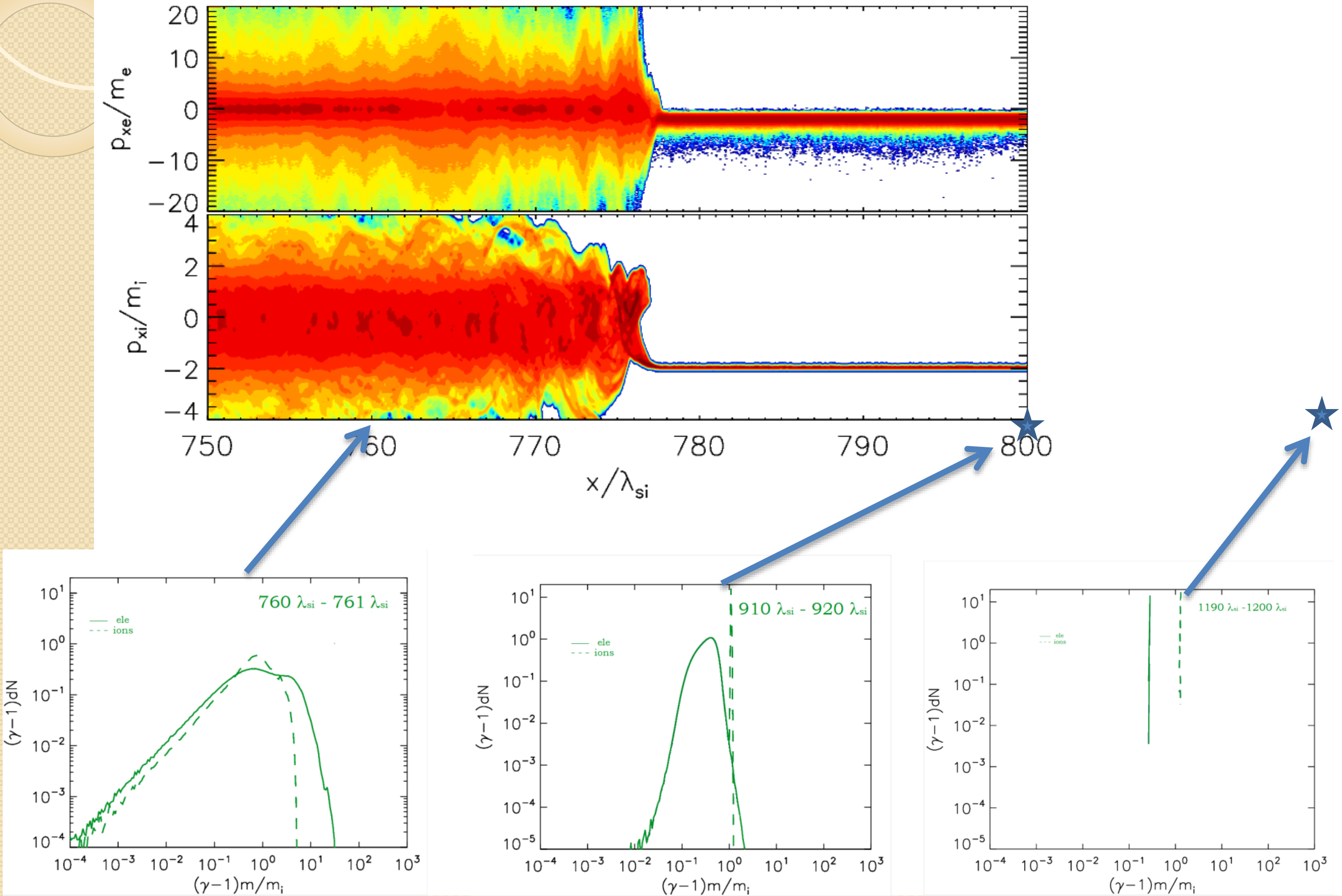
ions, x

ele, y

ions, y

4. Spectra

$t=220\ \Omega_{ci}^{-1}$



5. Summary

Our preliminary studies on mildly relativistic shock show some similarities with the high-γ case, i.e.:

1. *The shock proceeds due to* ***magnetic reflection*** *of the incoming plasma on shock-compressed magnetic field*
2. *The* ***synchrotron maser instability plays a role****: EM oscillation generated in this process create a population of upstream heated electrons boosted to the shock.*
3. *This mechanism may be responsible for energy transfer from ions to electrons*
4. *A* ***strong coupling*** *between electrons and ions appear*

Deeper studies are necessary to investigate further the similarities and difference between high-γ and mildly relativistic cases

6. Future plans

1. ***More extensive simulation*** *with this set of parameters (longer simulation time, bigger box up to* $L_y=25\,\lambda_{si}$*)*

2. Testing of ***different sets of parameters*** *(increase mass ratio, difference in densities of plasma flows, variate plasma magnetization, ...)*

3. Introduction of a ***positron component*** *in the plasma*

This future full-scale simulation will exploit the optimized ***HDF version*** *of the code developed by Andrzej Dorobisz, and may require up to approximately 20 million CPU-hours of computing time*

Thanks