



Spontaneous Turbulent Magnetic Reconnection and Particle Acceleration in Non-relativistic Perpendicular Shocks

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Main collaborators:

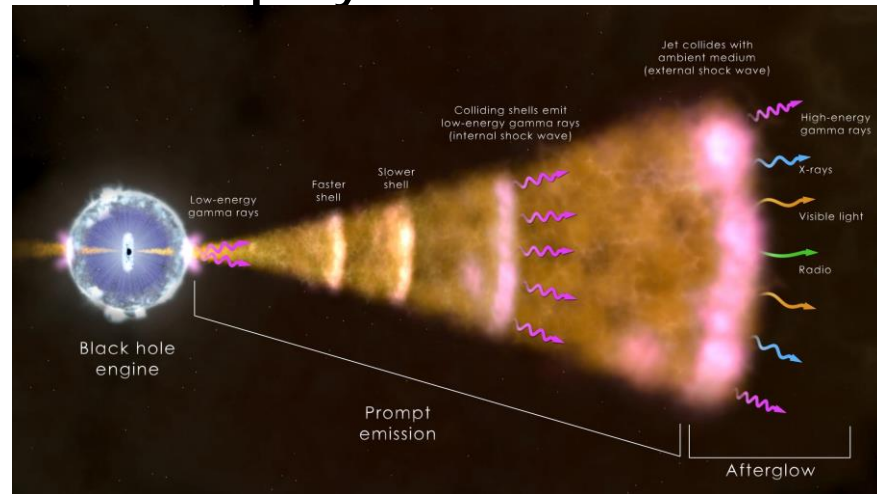
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Plasma shocks in astrophysics



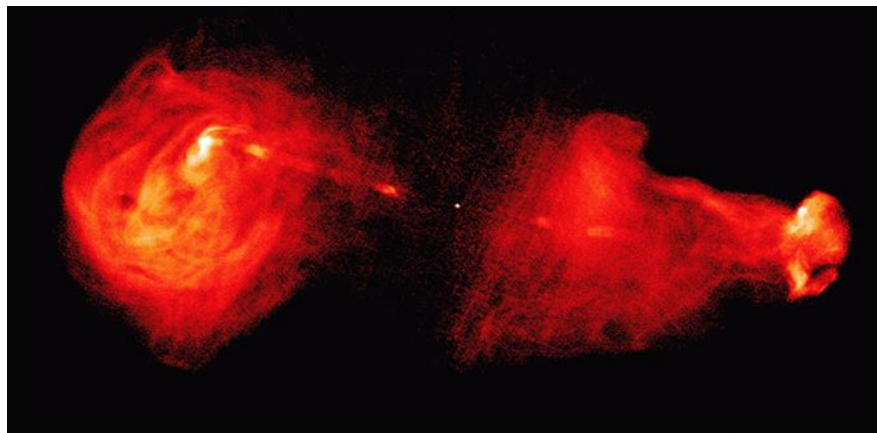
G299 Supernova Remnants - nonrelativistic shock waves

Gamma-ray burst - relativistic shock waves



Crab Nebula - ultrarelativistic terminal shock in pulsar wind

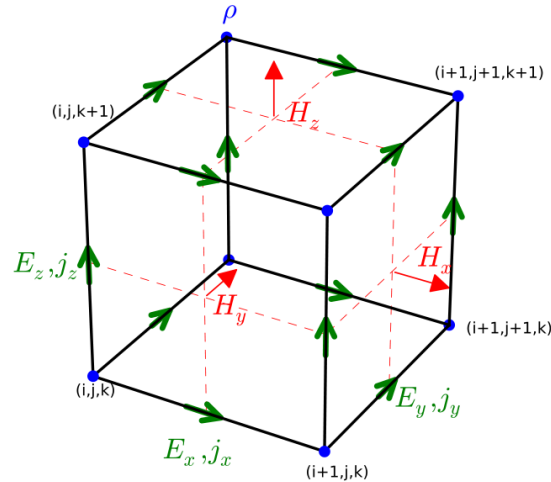
Radio Galaxy 3C353 - active galaxy, relativistic shocks in "hot spots"



Particle-In-Cell Simulations

Particle-In-Cell modeling - an ab-initio method of Vlasov equation solution through:

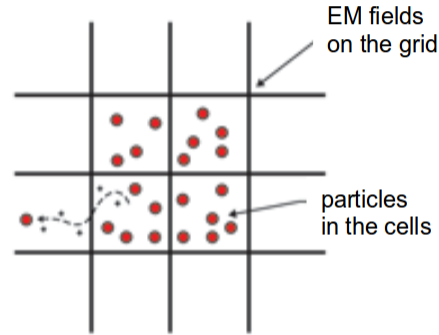
- integration of Maxwell's equations on a numerical grid
- integration of relativistic particle equations of motion in collective self-consistent EM field



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

Move particles under Lorentz force

Deposit current from particle motion in the cells onto the grid



Solve for EM fields on the grid

Particle-In-Cell Simulations

Large-scale high-resolution PIC simulations must be performed at high-performance supercomputing centers. Useful systems:

- massively parallel processors (MPP)
- distributed computing platforms (clusters)

Fast interconnect between nodes, large RAM/core, direct high-capacity scratch disk access is essential.



Facilities currently used:

Prometheus (Poland, Intel Xeon E5-2680v3, 53,568-core, 2.4 PFlop/s)

HLRN (Germany, Intel Xeon IvyBridge and Haswell, 85,248-core, 2.7 PFlop/s)

Stampede (USA, Intel Xeon E5-2680, 102,400-core, 9.6 PFlop/s)



Run	Nproc	Time	Computer	Nppc	Mass ratio
1	432	2 days	HLRN	10	50
2a	432	2 days	Stampede	10	50
3t	448	2 days	Stampede	10	50
4a	1728	3 days	HLRN	40	50
5	1728	3 days	HLRN	40	50
6t	1728	3 days	Stampede	40	50
7	9600	4 days	Prometheus	20	100
8t	9600	4 days	Prometheus	20	100
9	2400	4 days	Prometheus	20	100

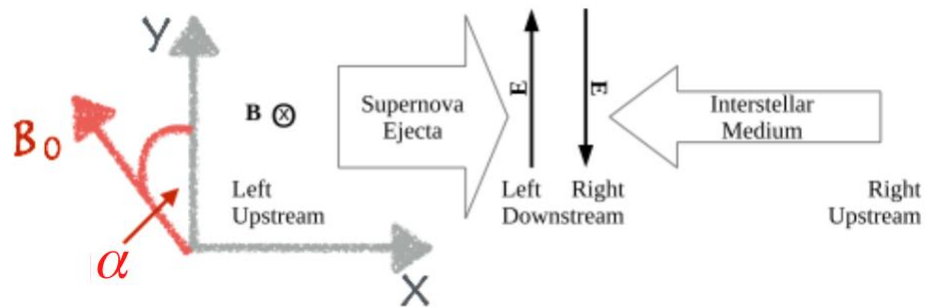
Diffusive Shock Acceleration

Diffusive Shock Acceleration (DSA) process at young SNR shocks assumed to provide the main part of Galactic cosmic-ray flux. Possibly relevant for mildly-relativistic flows in AGN jets.

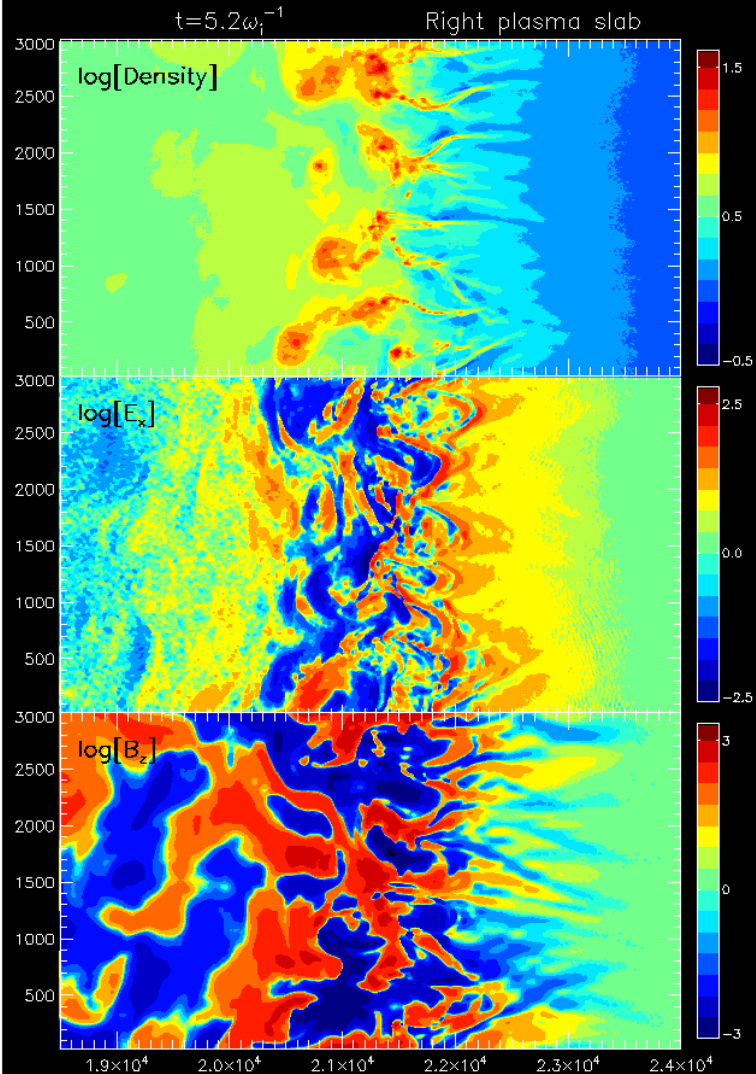
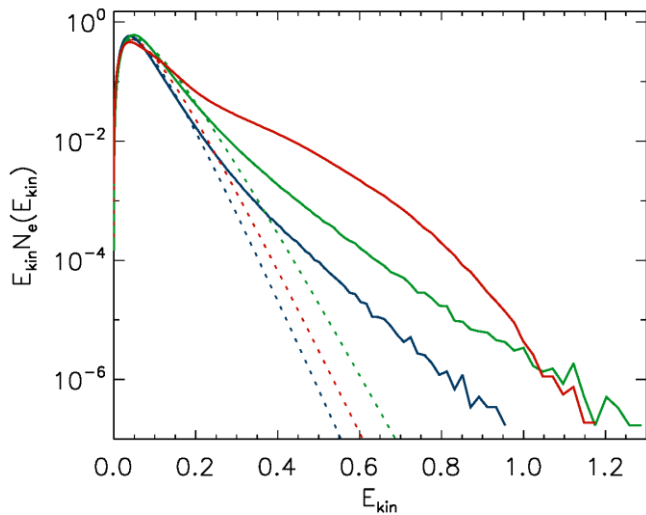
Attributes relevant for DSA:

- shock structure: ion driven but electron dynamics important
- EM field amplitudes
- particle pre-acceleration processes: electron injection constitutes the central unresolved issue

Perpendicular Shocks



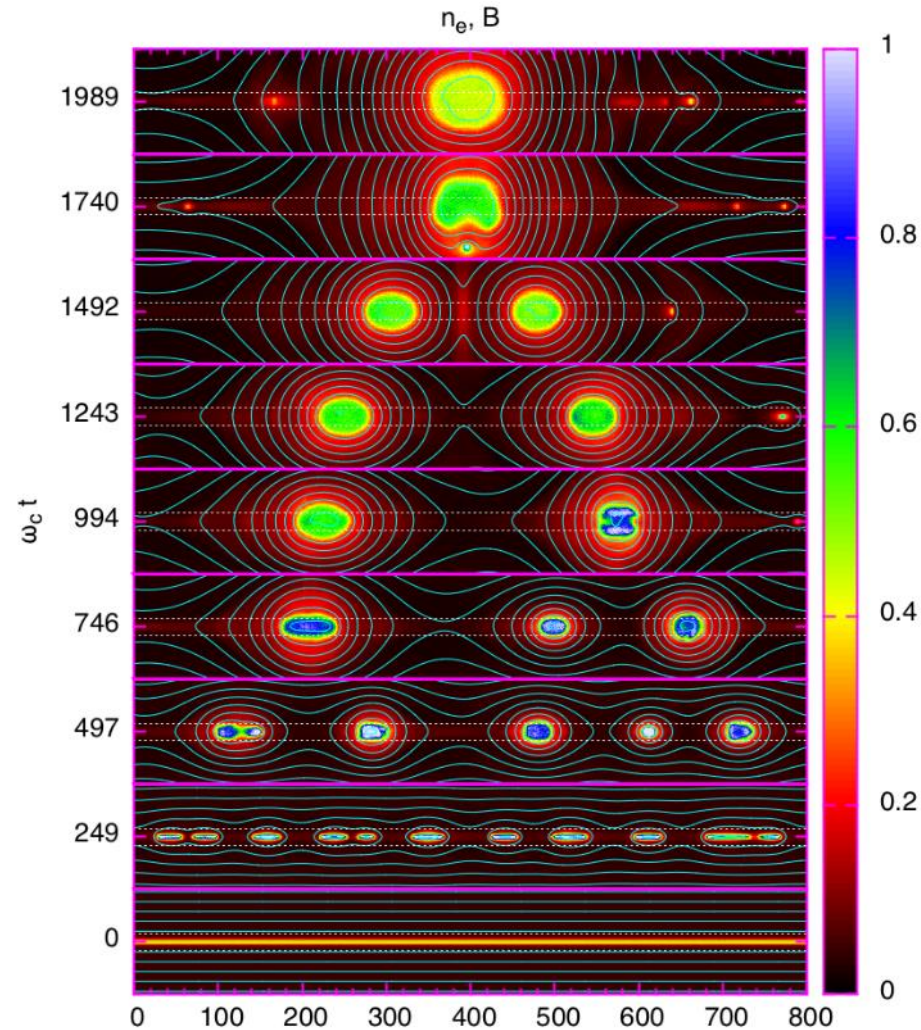
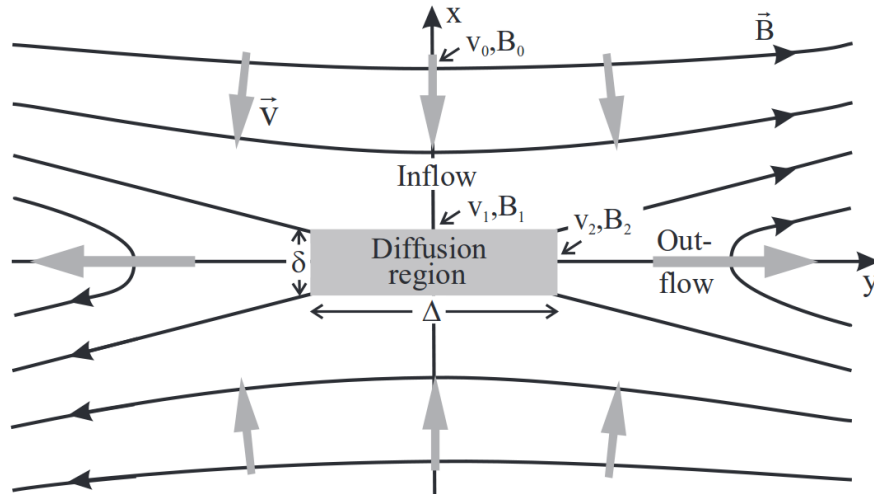
2D3V
 $m_i/m_e=50, 100$
 $\alpha=0, 45, 90$
 $N_{ppc}=10, 20, 40$
up to 9600 Nproc
4 CPU days



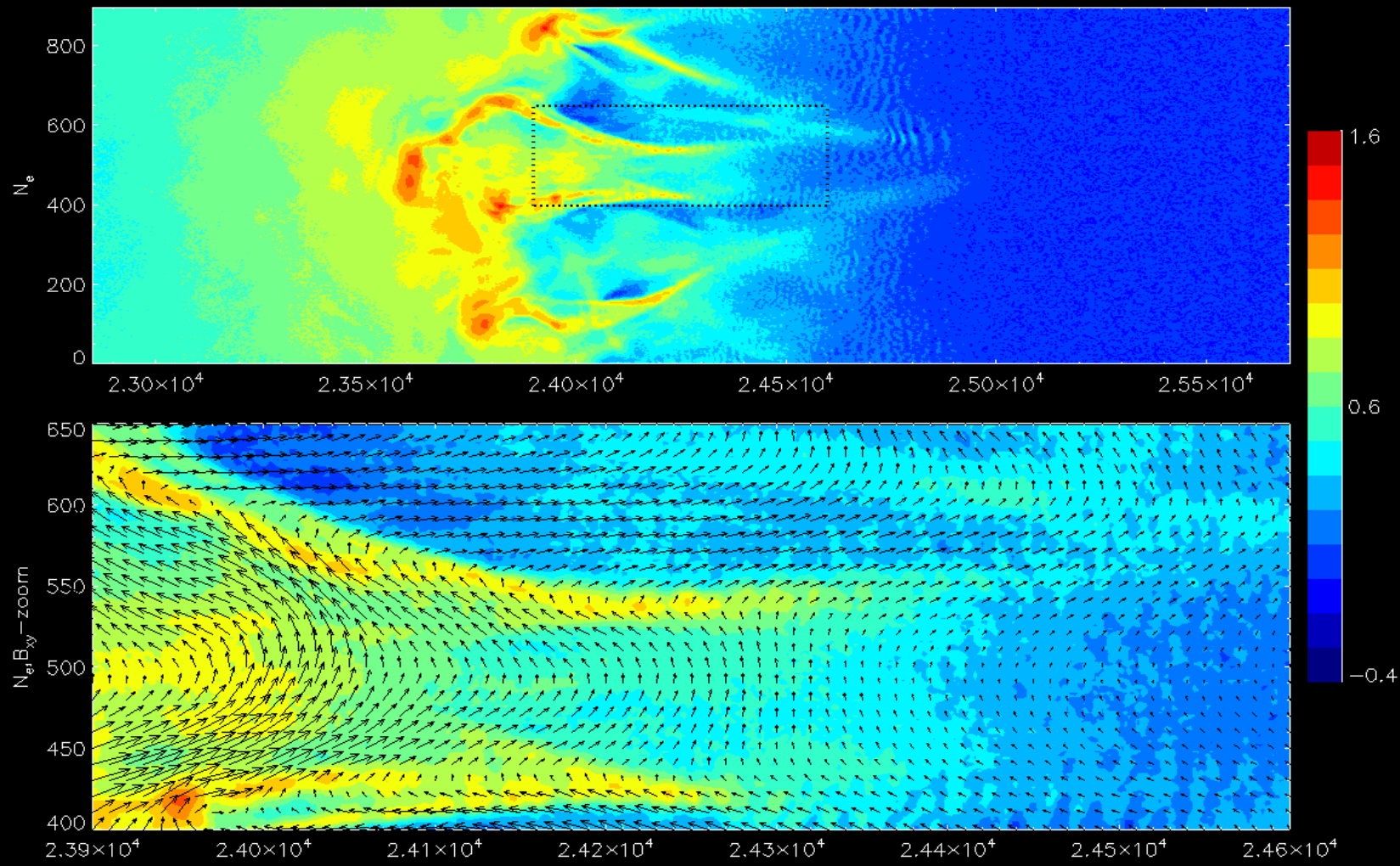
Magnetic reconnection

Ubiquitous plasma process which refers to the breaking and reconnecting of oppositely directed magnetic field lines in a plasma.

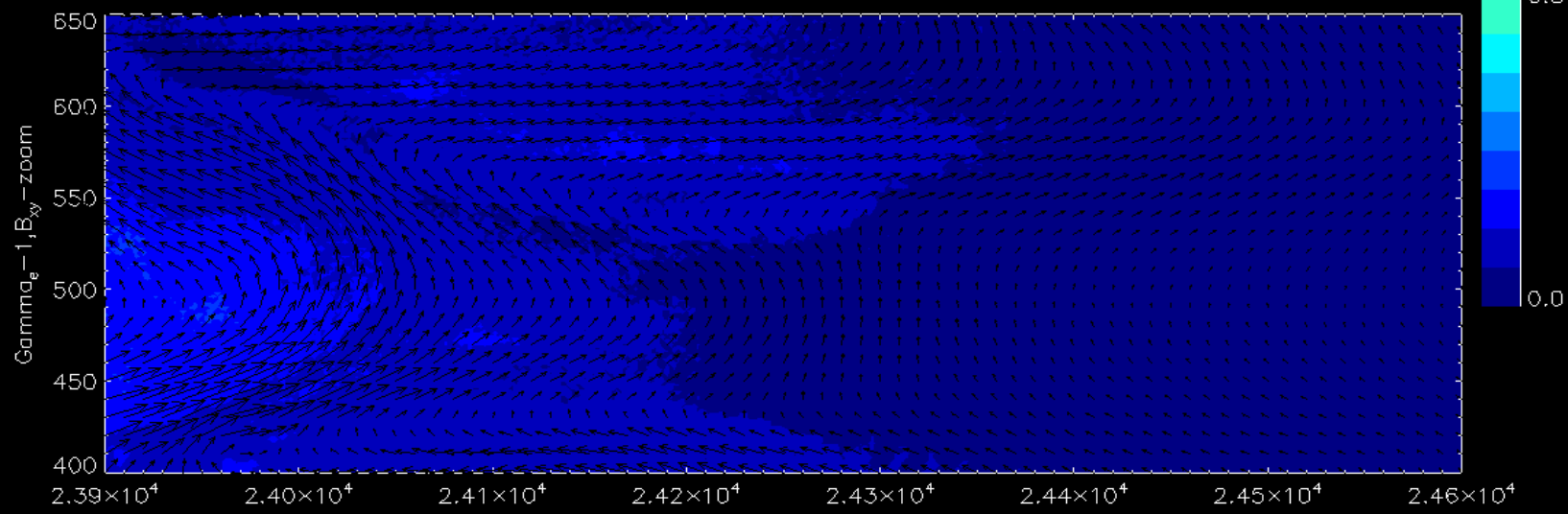
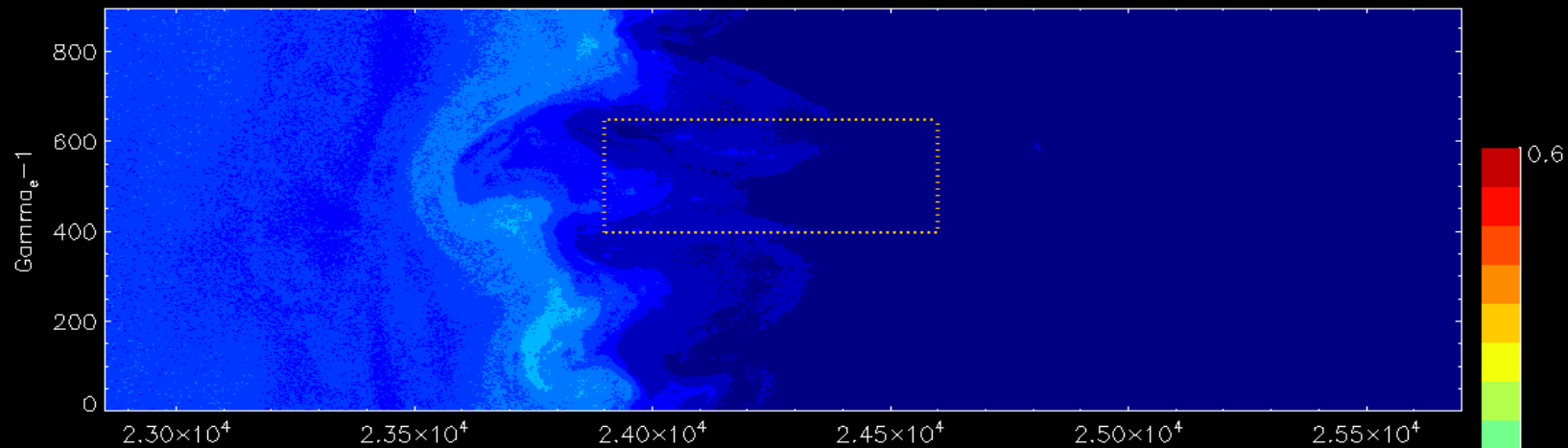
Magnetic energy is converted to kinetic energy, thermal energy and particle acceleration.



$t=141000$

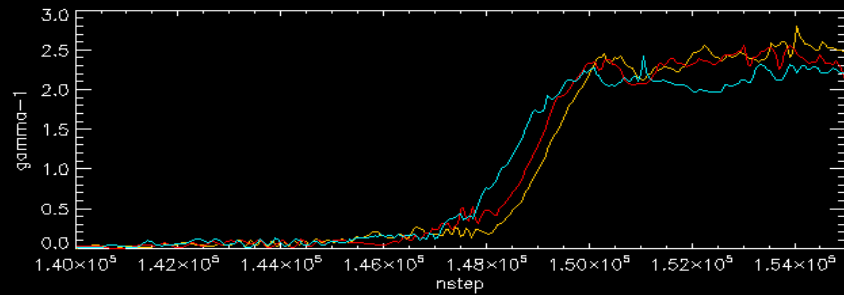
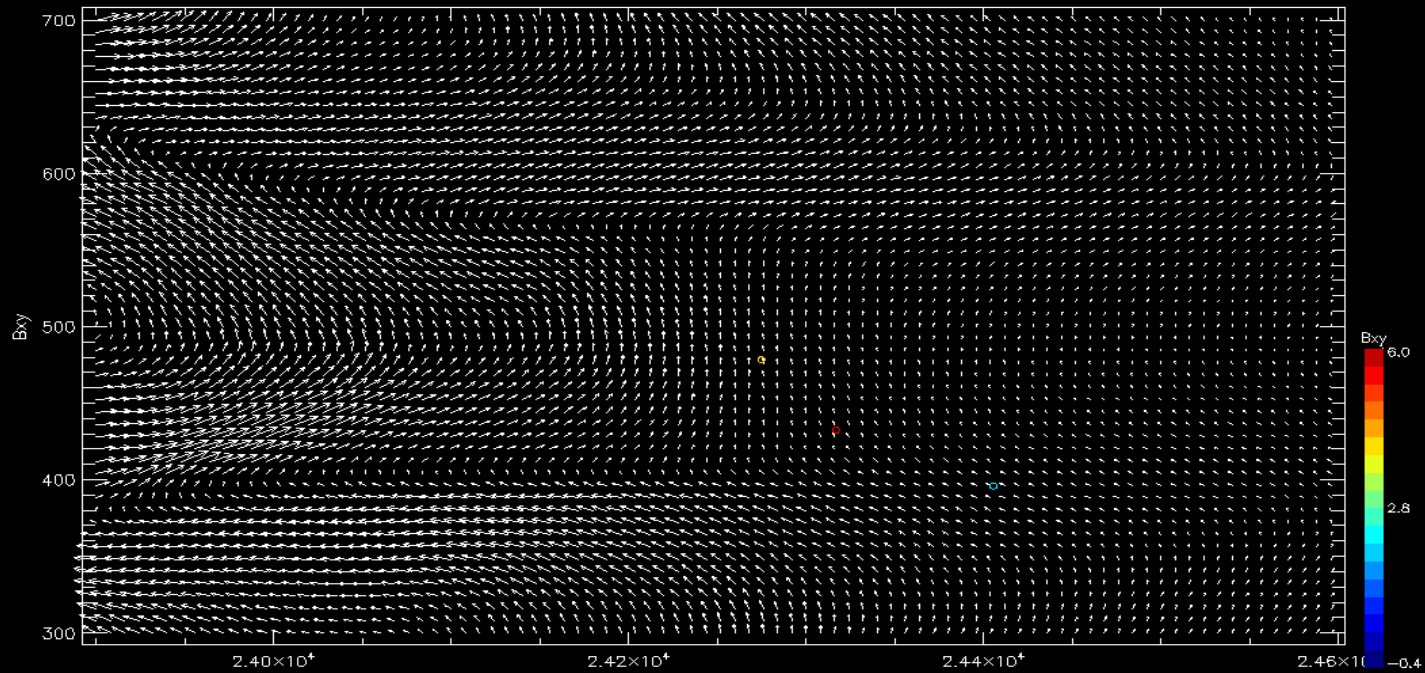


$t=141000$



nstep=140000

$t=5.8\Omega_1^{-1}$



Future plans

1. GPU code
2. 3D simulations (few weeks of calculations with 10 000 Nproc)

Thank you for your attention