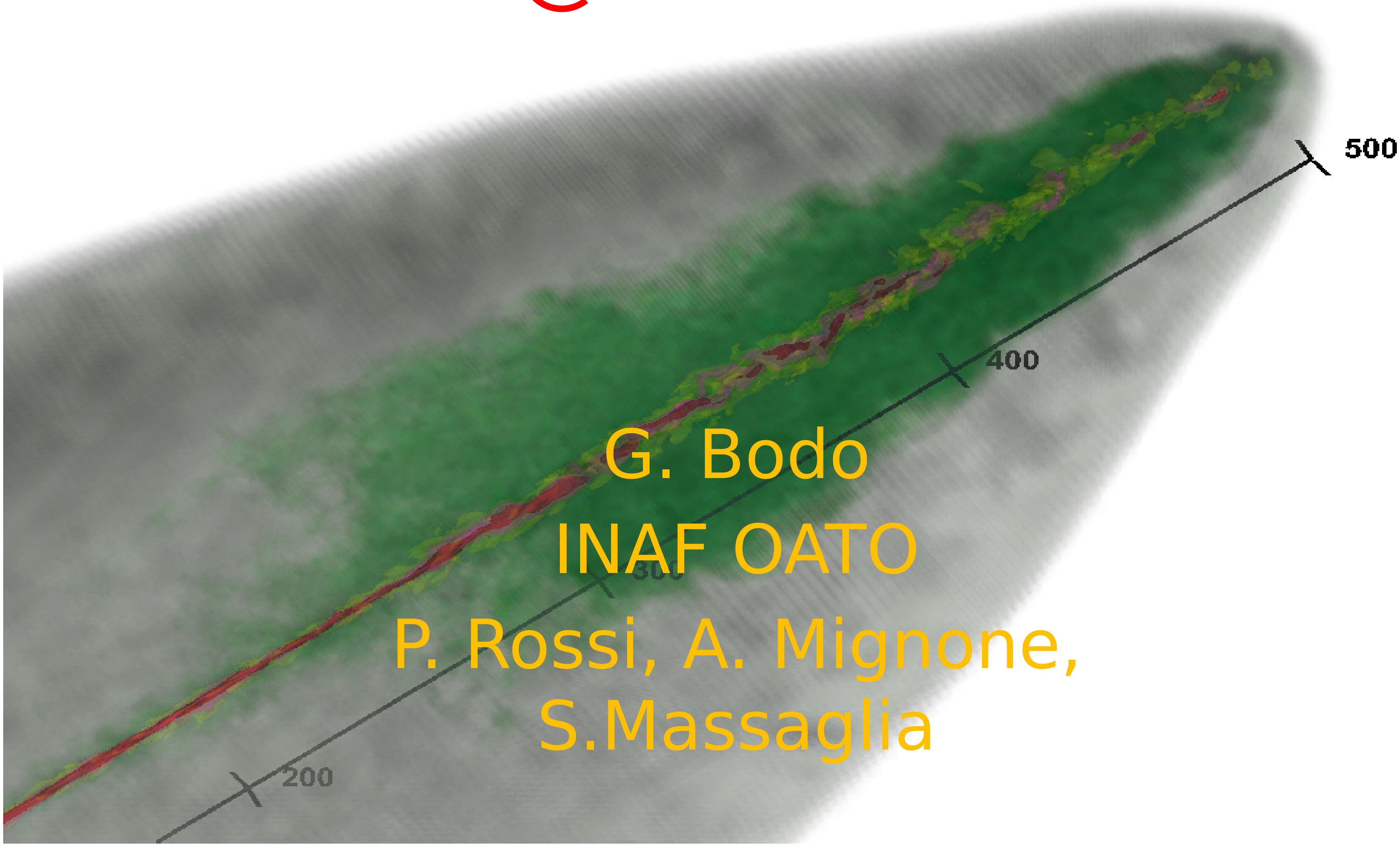
Relativistic jet simulations @CINECA



G. Bodo

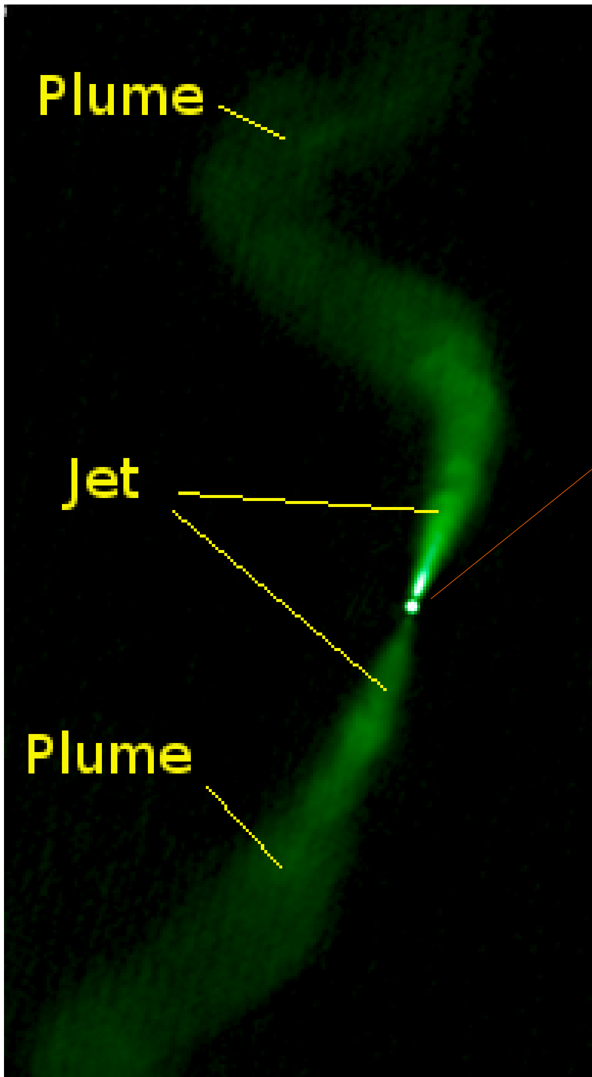
INAF OATO

P. Rossi, A. Mignone, S.Massaglia

Observed morphologies: The Fanaroff-Riley classification

FR I or jet dominated

FR II or lobe dominated (classical doubles)



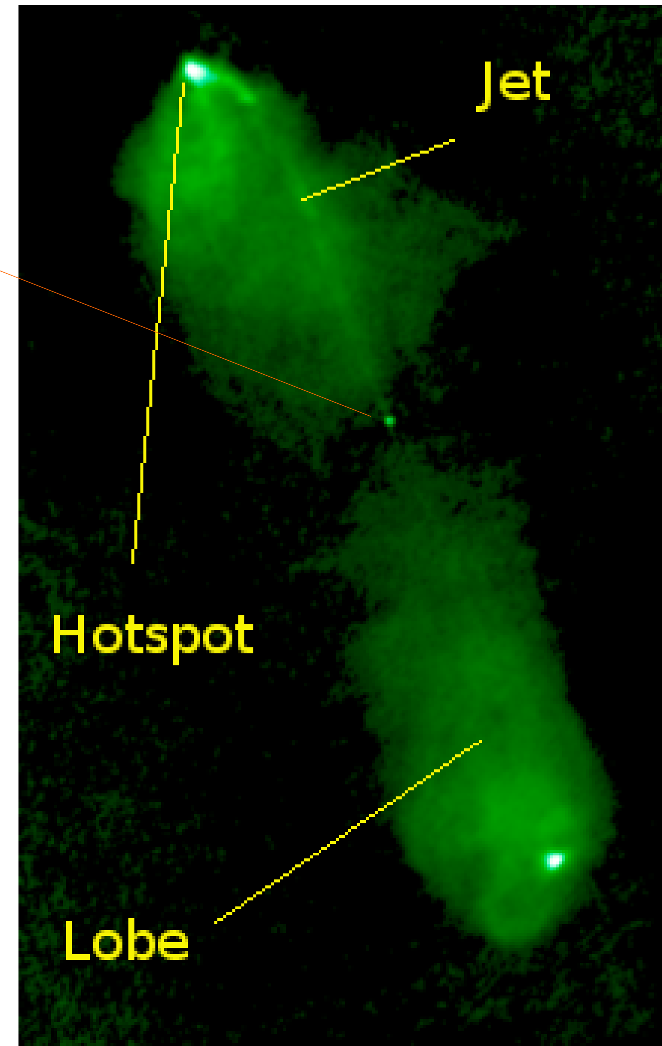
3C 31
VLA

Active Nuclei

3C 98
VLA

FR II only have Hot-spots!

Transition jet power about 10^{43} erg/s

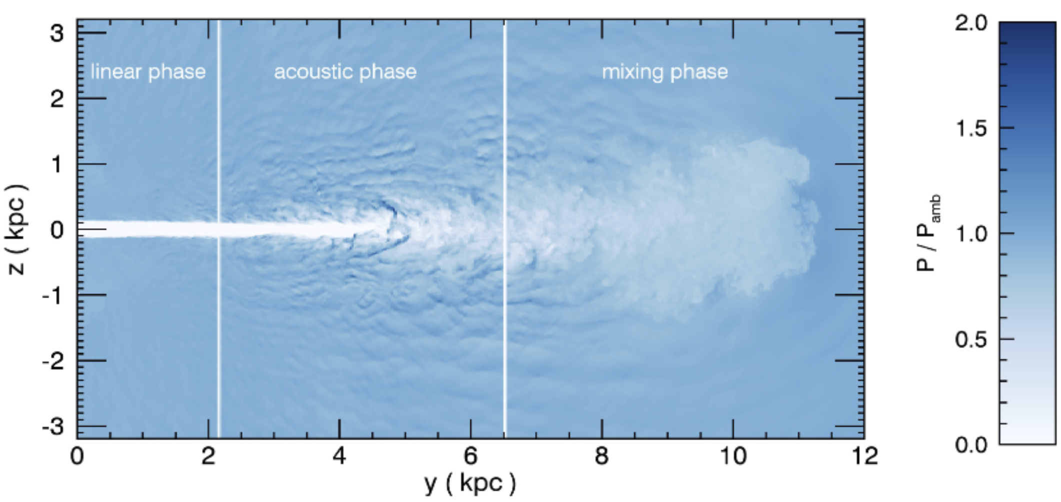


- **There are observational evidences that In both kind of sources the jet at their base are relativistic**
- **The morphology of FRI jets show turbulent plumes, at large scales they have to be non relativistic**

JETS IN FRI HAVE TO DECELERATE

- **How?** **Turbulent entrainment**
- **Where?** **In the first kpc**

S. Massaglia et al.: Making Faranoff-Riley I radio sources. I.

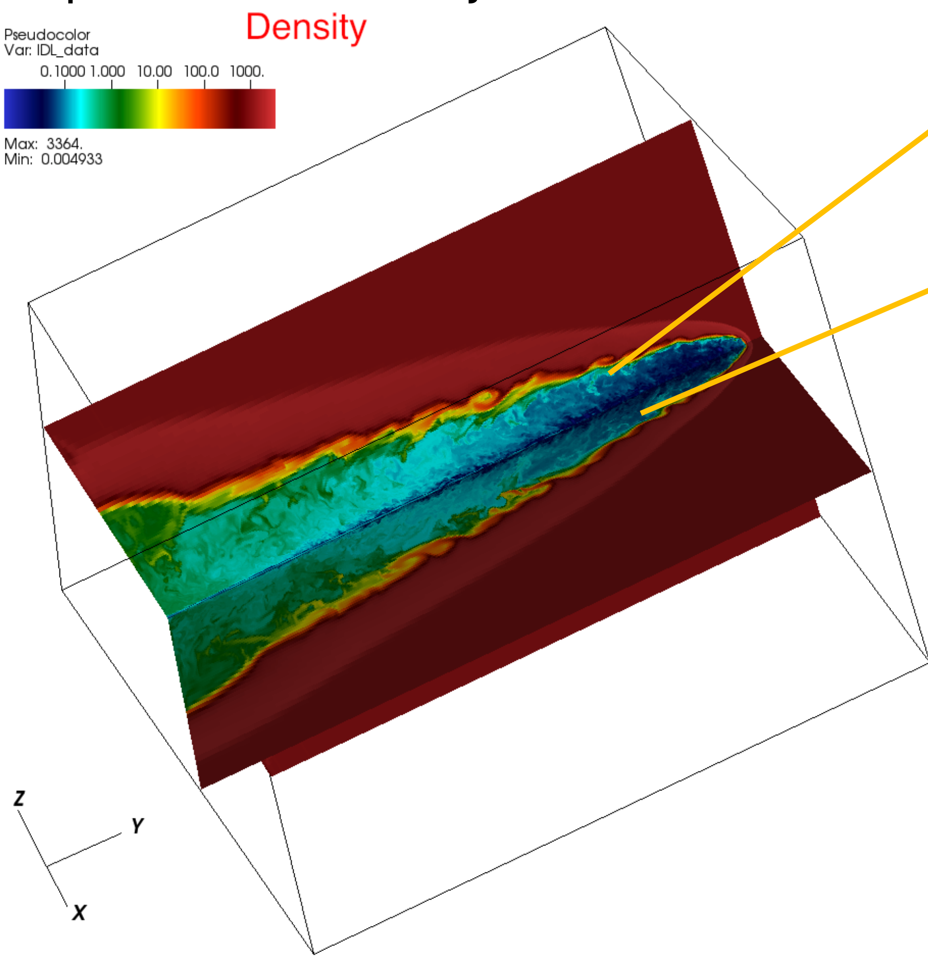


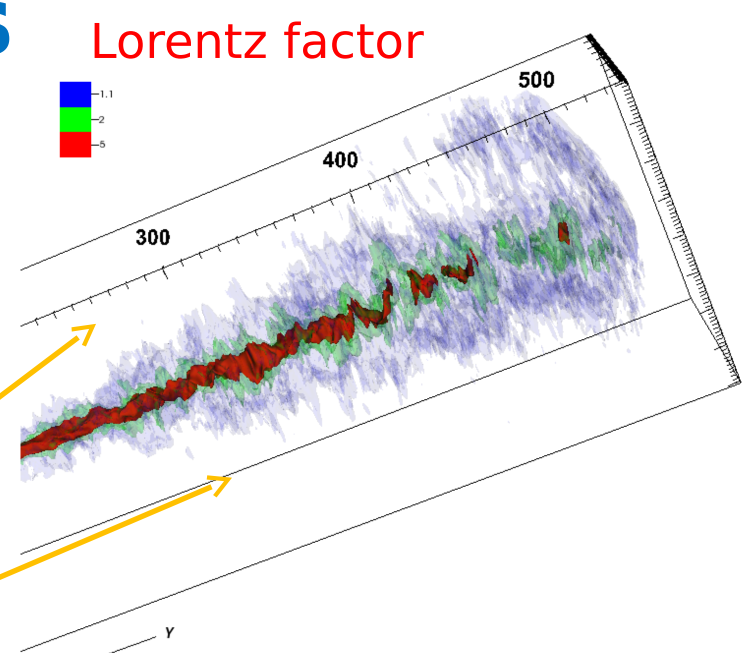
Preliminary results

Grid 500x2500x500 stretched in the Transverse direction

Domain 300x500x300

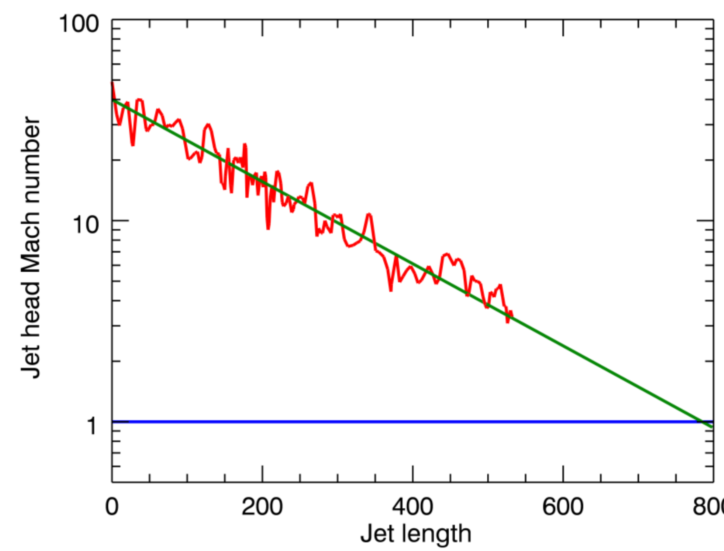
20 points cover the jet





Jet power $< 10^{43}$ erg/s

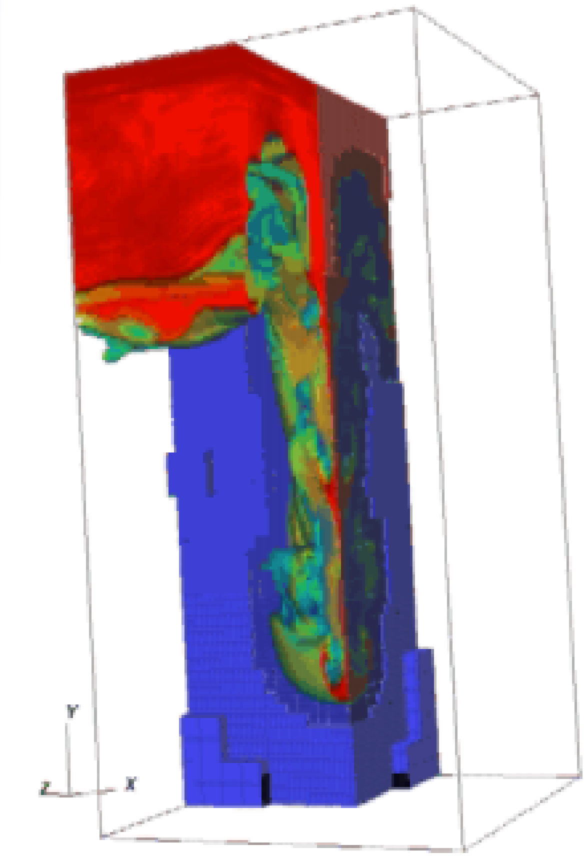
Jet power <



What is PLUTO ?

- PLUTO[1,2] is a modular parallel code providing a *multi-physics* as well as a *multi-algorithm* framework for solving the equations of gas and plasma dynamics in astrophysics;

- *Target*: multidimensional *compressible* plasma with high Mach numbers:
  - Compressible Euler/Navier Stokes;
  - Newtonian (ideal/resistive) magnetohydrodynamics (MHD);
  - Special Relativistic hydro and MHD;
  - Heating/cooling processes, chemical network, …



- Freely distributed at http://plutocode.ph.unito.it (v. 4.2)

[1]Mignone et al. ApJS (2007), 170, 228-242; [2]Mignone et al, ApJS (2012), 198, 7

Available Physics Modules

Advection Physics (Hyperbolic PDE)
- Hydrodynamics (HD)
- Magnetohydrodynamics (MHD)
- Relativistic Hydrodynamics (RHD)
- Relativistic MHD (RMHD)

Thermodynamics
- Isothermal
- Ideal
- Non-constant gamma
- Synge Gas (relativistic)

Dissipation Physics (Parabolic PDE)
- Viscosity (Navier-Stokes)
- Thermal conduction (hydro and MHD)
- Hall MHD, Ambipolar diffusion, Magnetic resistivity[2]
- Radiation Hydrodynamics (FLD[1], 2 temp)

Geometry
- Cartesian (1D, 2D, 3D)
- Cylindrical (1D, 2D, 3D)
- Spherical (1D, 2D, 3D)

Source Terms
- Gravity / Body forces
- Heating / optically thin cooling
- Chemical networks

Particle Physics
- Lagrangian particles Dust
- Cosmic Rays → MHD-PIC

Available Algorithms

- PLUTO supports 2nd order Finite-Volume as well as 5th order finite difference algorithms in multiple dimensions.

Time Stepping

- RK2, RK3
- MUSCL-Hancock
- Characteristic Tracing

Dimensionally split or fully unsplit methods.

Interpolation

- Piecewise Linear
- Piecewise Parabolic
- WENO 3rd – 5th order

Primitive or characteristic fields

Riemann Solver

- Two-shock
- AUSM
- Roe
- HLL / HLLC / HLLD
- TVDLF
- MUSTA

Parabolic Solver

- Explicit
- Super-Time-Stepping
- Runge-Kutta-Legendre

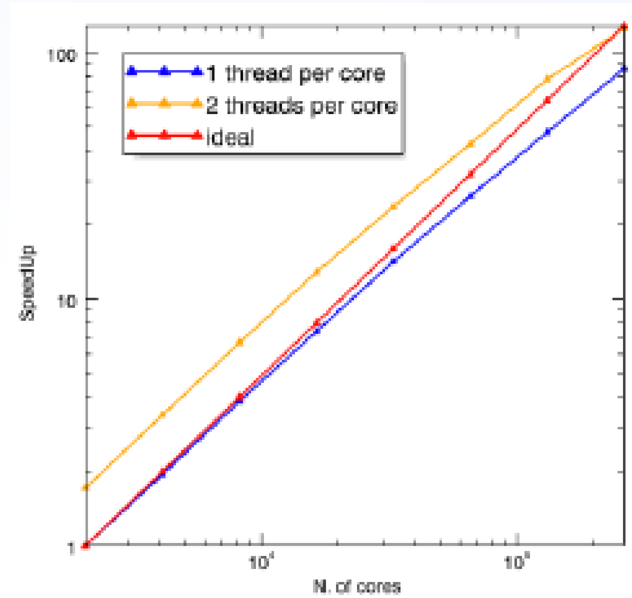
$\nabla\cdot B$ control

- 8-wave
- Constrained Transport
- Hyperbolic Divergence Cleaning

Introducing the PLUTO Code

- PLUTO is written in C (~80,000 lines) and C++ (12,000 lines);

- Support multi-dimensional parallel (MPI) computations from single processor to a large number of cores (tested up to 262,144);

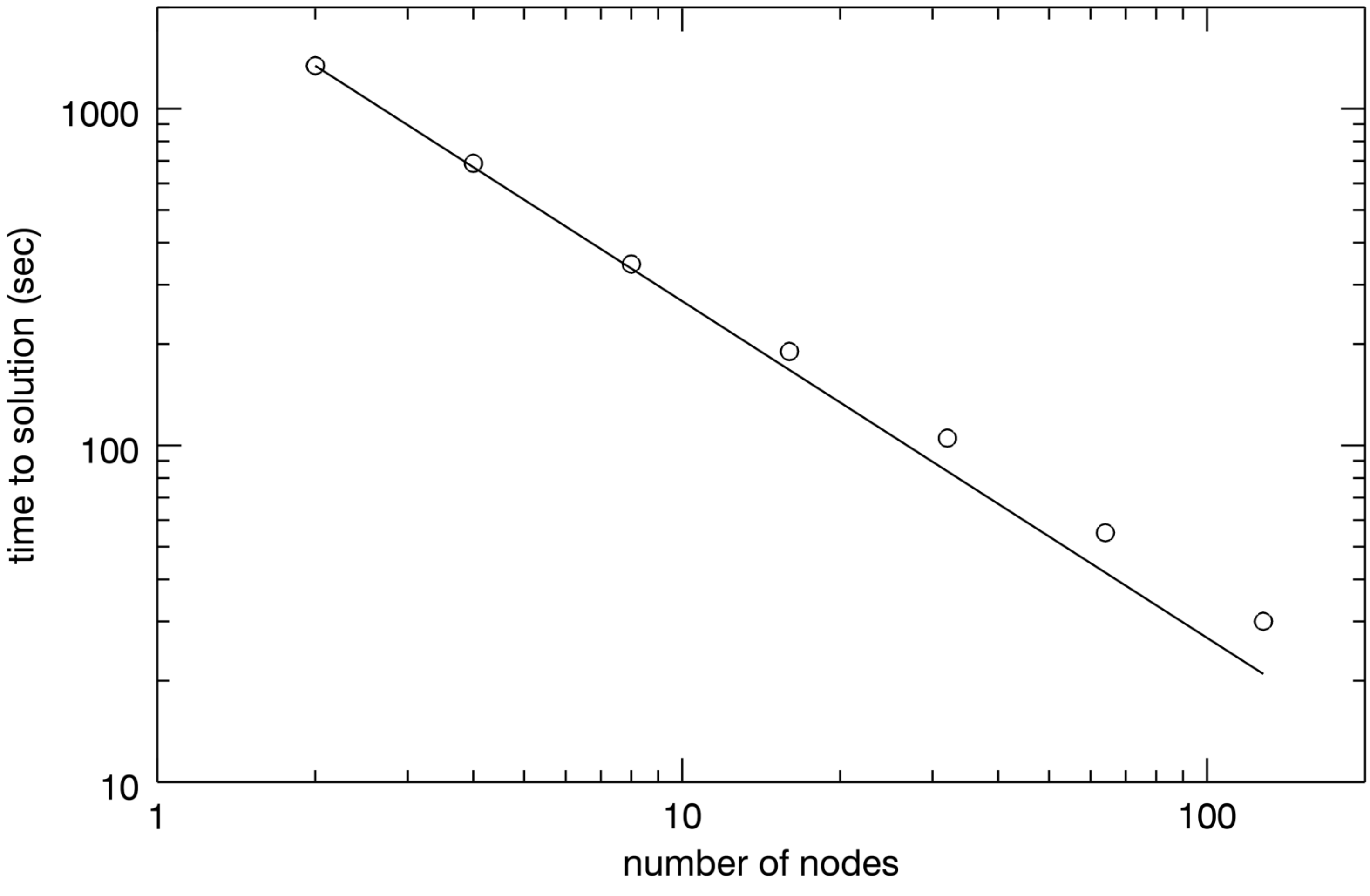


- Tested on several platforms (Linux/Mac OS/ SP6/Blue Gene Q,P, Cineca Tier-0 system, ...);

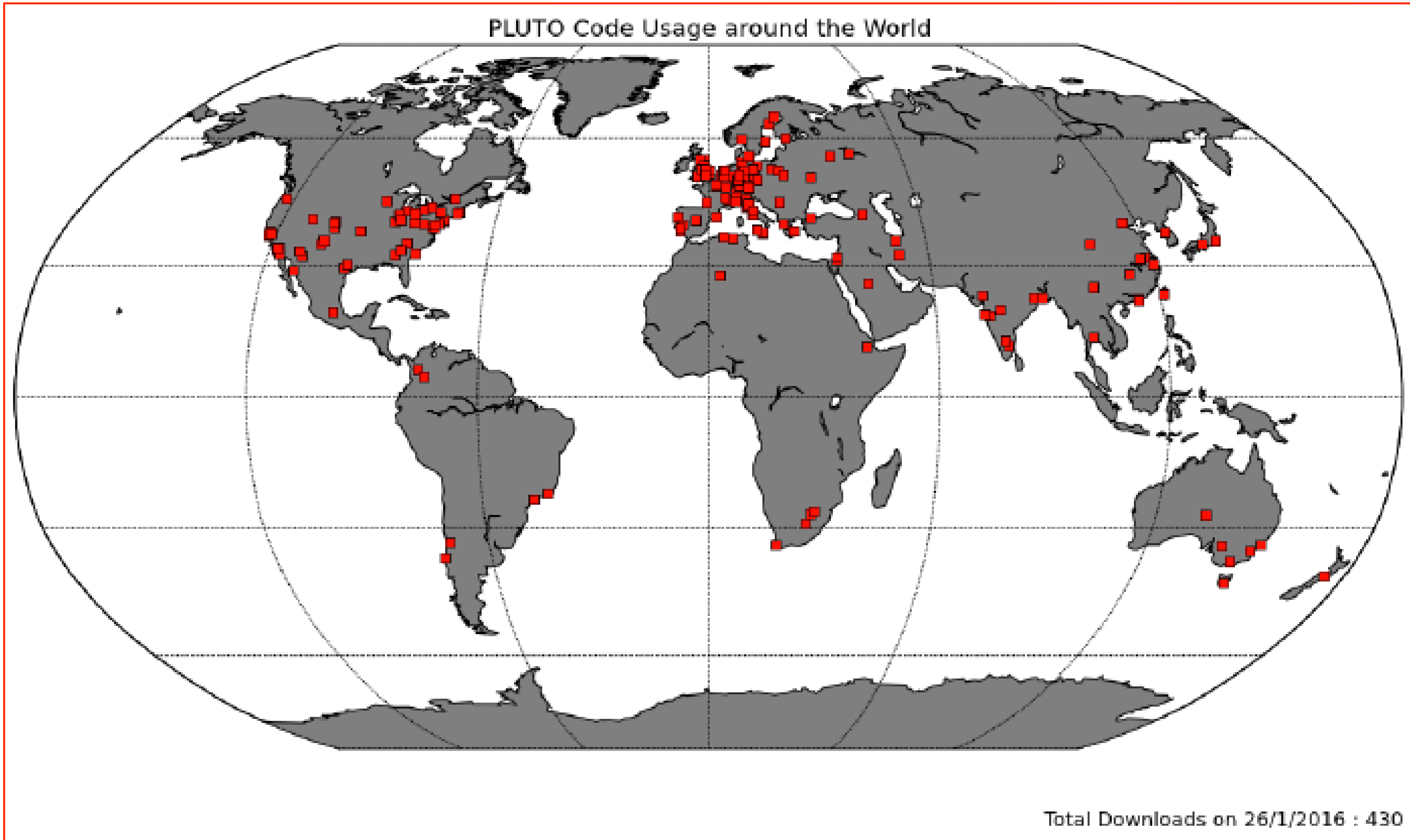
- Computations may be performed on

  - Static grid : single fixed grid;
  - *Adaptive grid*: multiple refined, block-structured nested grids following and adapting to the solution (Chombo library)

Scaling su Marconi KNL

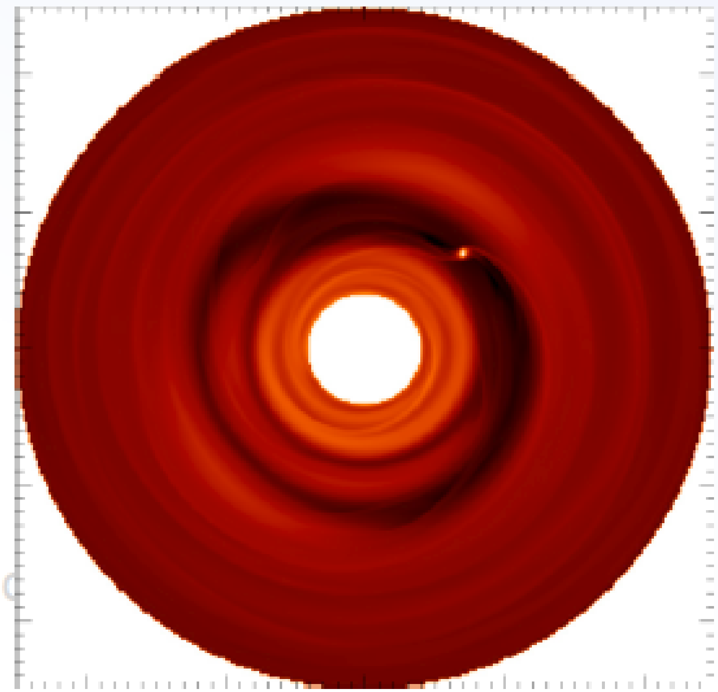


PLUTO Worldwide Distribution



PLUTO Application Gallery

- Planet Formation
- Stellar Jets
- Radiative shocks
- Extragalactic Jets
- Jet Launching
- Magnetospheric accretion & star-disk Interaction
- Magneto-rotational instability (MRI) & ac
- Relativistic Shock dynamics
- Fluid instabilities CD, KH, RT, etc…



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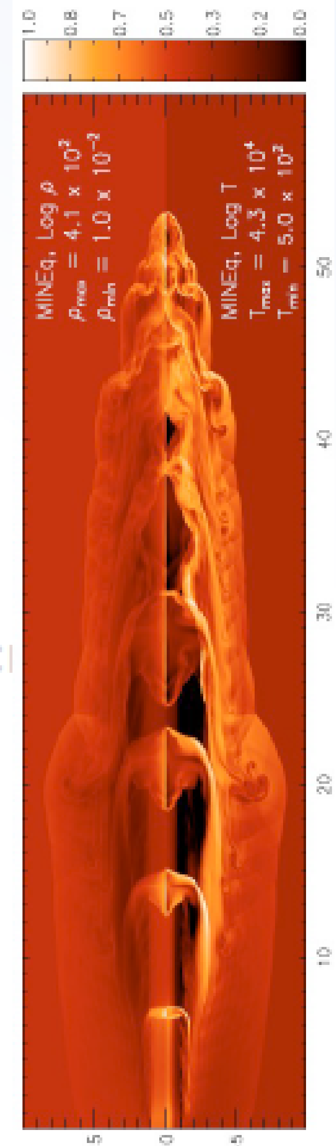

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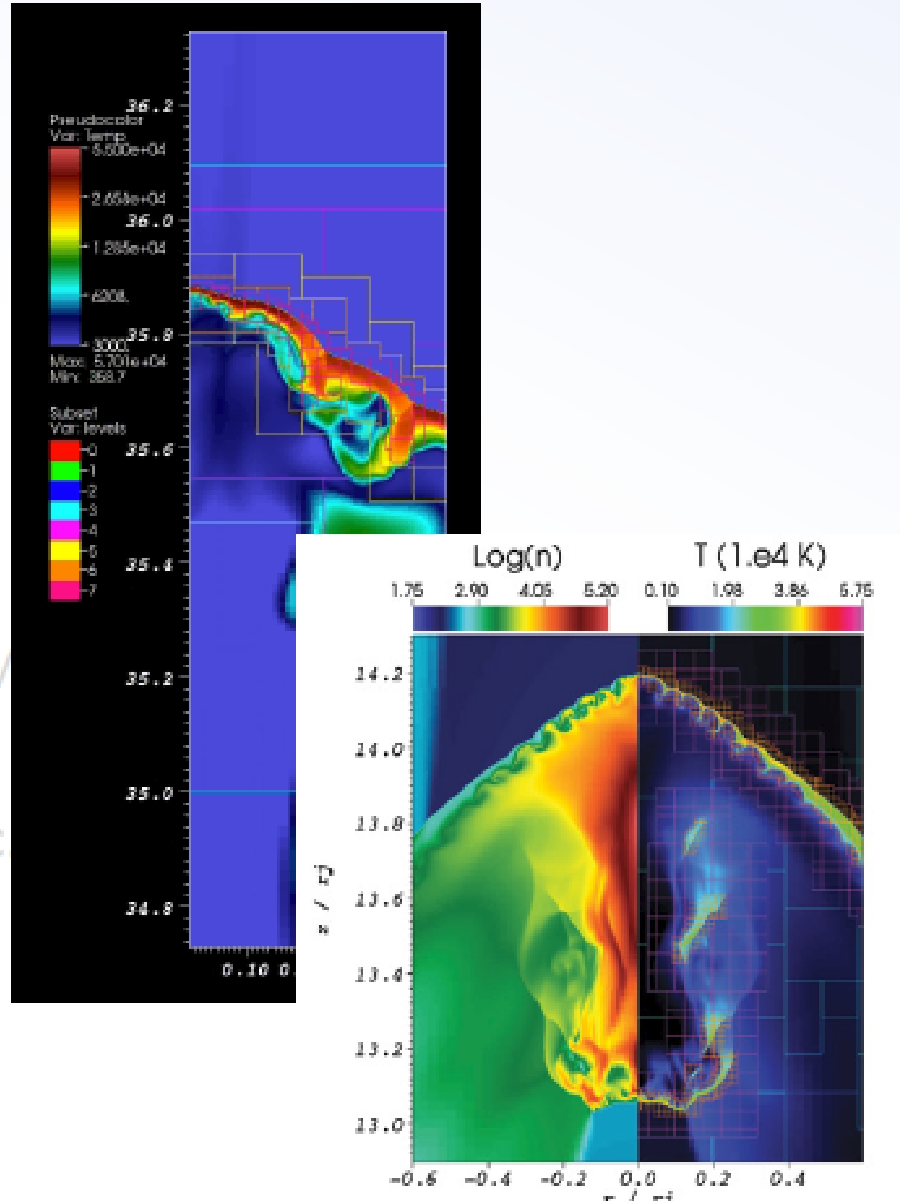

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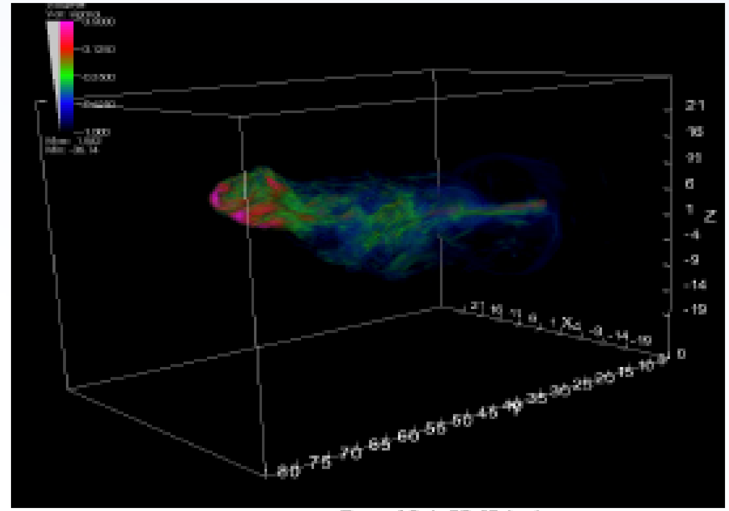

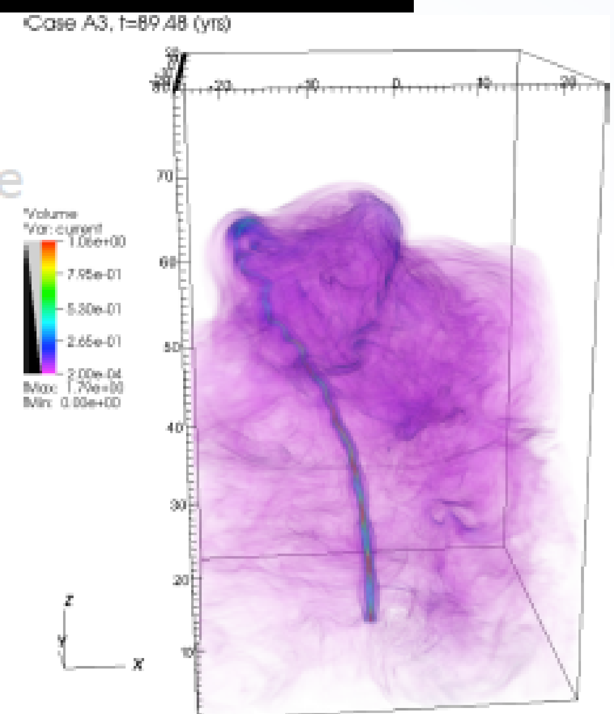

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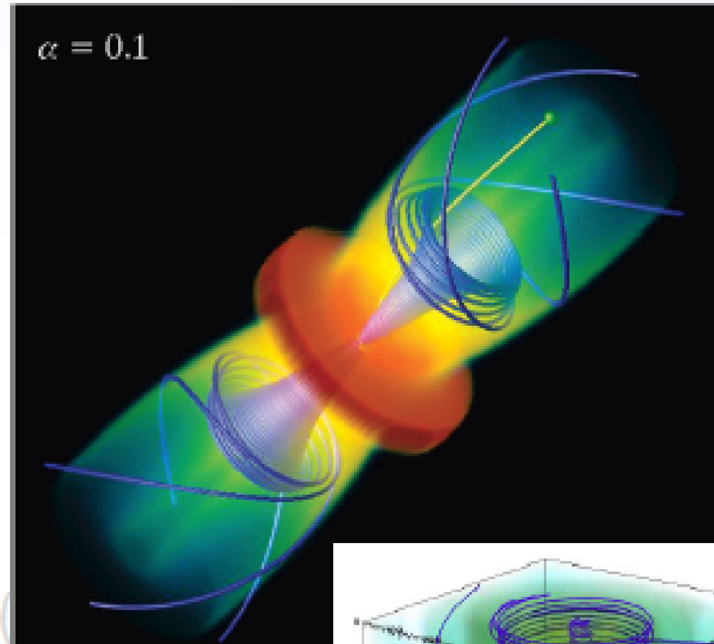

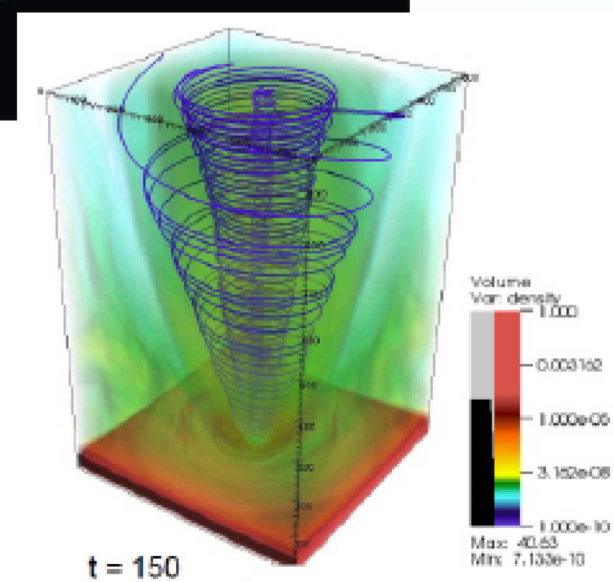

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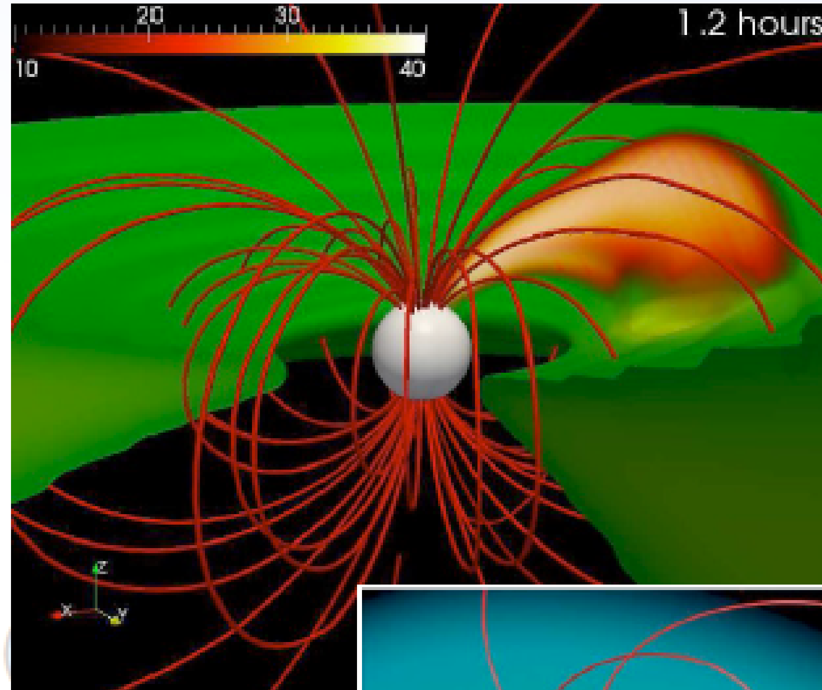

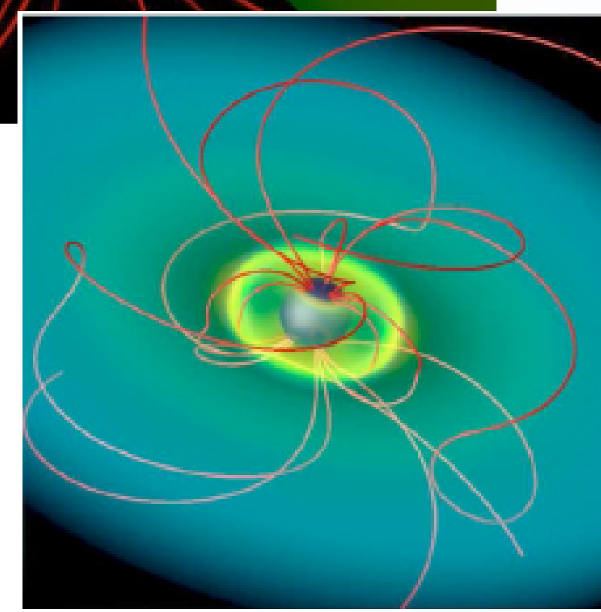

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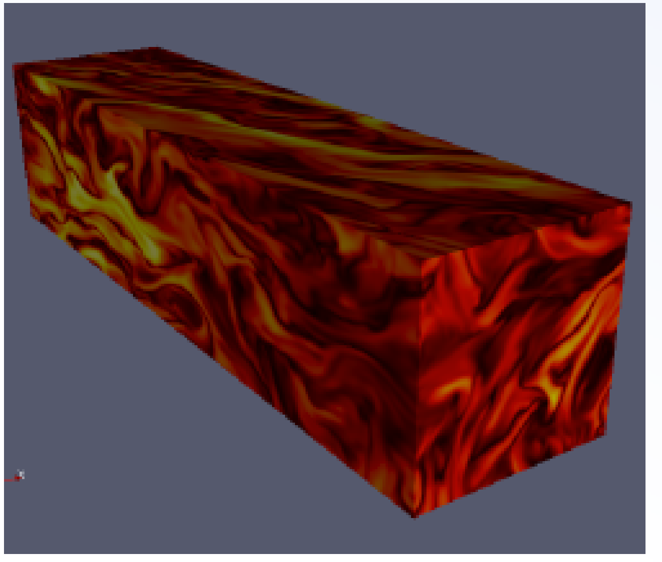

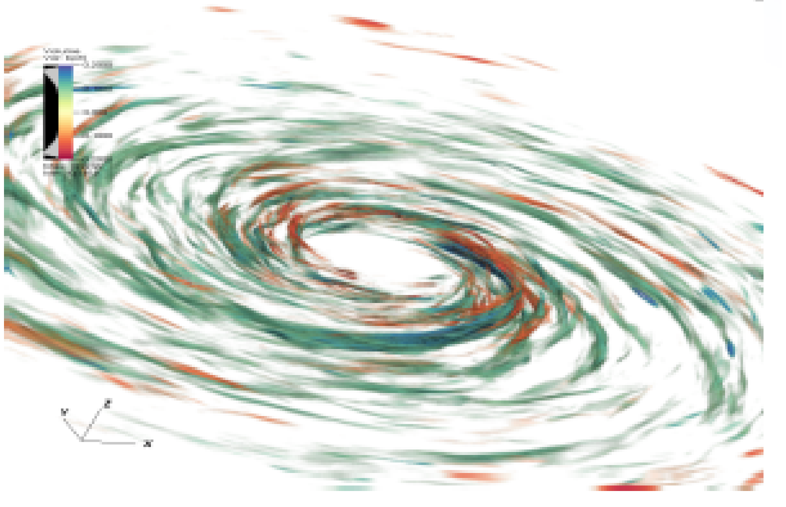

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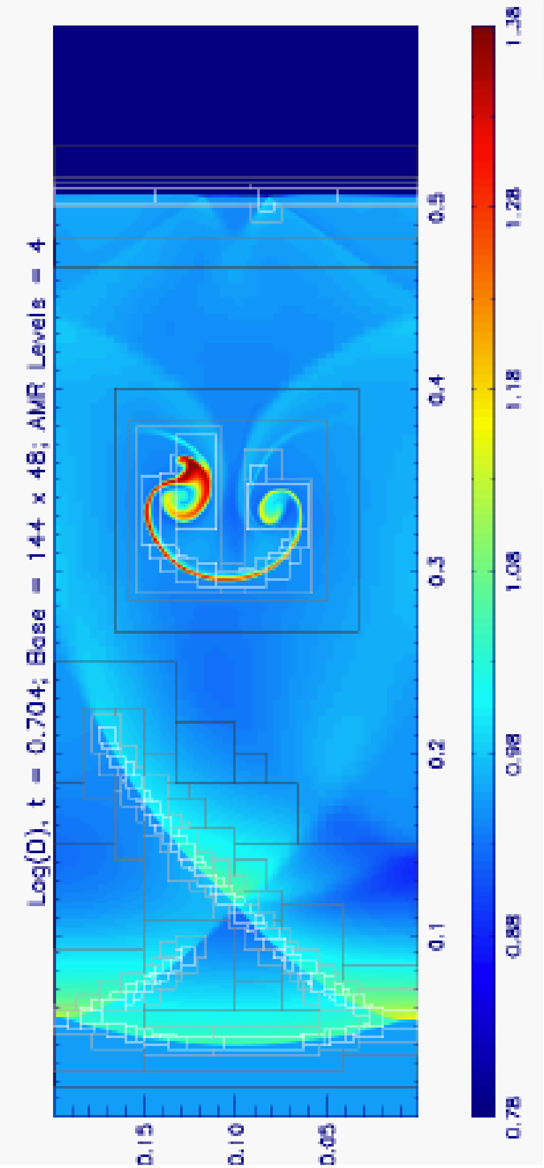

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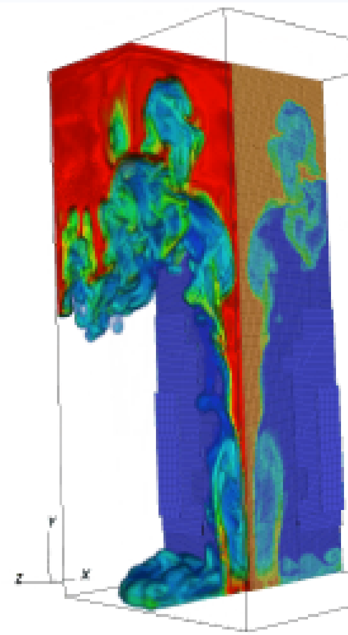
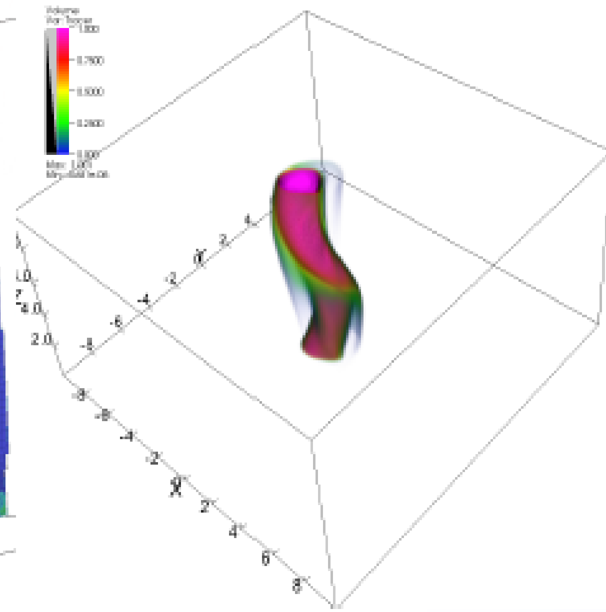
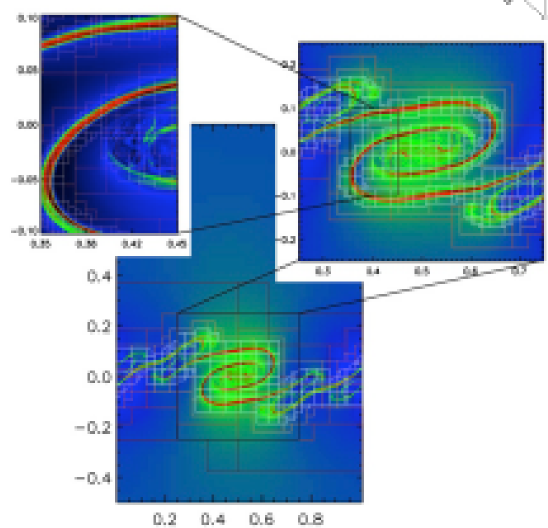


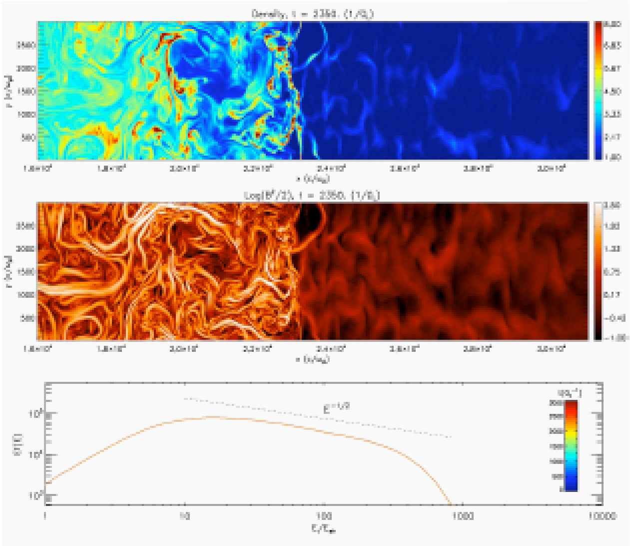




Hybrid module

Particle Acceleration at Shocks

- CR scattered by local turbulent magnetic field irregularities. Accelerated CRs drift with respect to the upstream fluid and the instability typically quickly enters its strongly nonlinear stage.
- Particles spectrum broadens in time, extending substantially to the high energy side.
- A high-energy power-law tail builds up, with spectral slope consistent with -3/2.
- The high-energy tail extends to higher energies with time, with a roughly exponential energy cutoff.



- Assegnate 5 Mh   --   3.5 Mh   + 1.5 Mh

- Marconi KNL

- Progetto iniziato a metà maggio

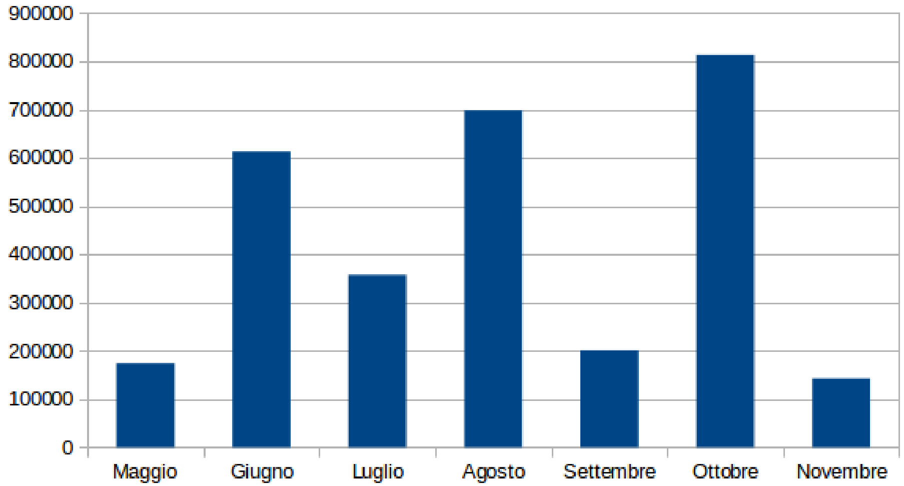
- Principalmente utilizzati 32 nodi -- 2176 cores
  -- 2 threads per core – 4352 mpi tasks

- Tempi di attesa in coda < qualche ora

- Utilizzate 3 Mh

Totale utilizzato 3000000 ore

Consumi mensili



Giorni sospensione CINECA (dai mail HPC-News)