MANCHA: a non-ideal MHD code for realistic simulations of the solar atmosphere.

First public release

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General info

The MANCHA code was originally developed in 2004-2006 by Elena Khomenko and Manolo Collados to study wave dynamics in sunspots.

“Mancha solar” stands for “Sunspot” in Spanish
Multi (purpose/physics/fluids/dimensional) **A**dvanced **N**on-ideal **C**ode for **H**igh-resolution simulation of the solar **A**tmosphere

- Solves non-linear non-ideal MHD equations for perturbations in 3D;
- Magneto-static equilibrium is explicitly removed from the equations;
- Radiative energy losses assuming LTE;
- Realistic equation of state for solar chemical mixture;
- 4th order in space and time;
- Parallel input/output with HDF5 files format;
- MPI parallelized using domain decomposition in all directions

Equations, physics

$$\frac{\partial \rho}{\partial t}+\nabla\cdot(\rho\boldsymbol{u})=\left(\frac{\partial \rho}{\partial t}\right)_{diff}$$

$$\frac{\partial \rho\boldsymbol{u}}{\partial t}+\nabla\cdot\left[\rho\boldsymbol{u}\boldsymbol{u}+\left(\boxed{p}+\frac{\boldsymbol{B}^2}{2\mu_0}\right)\boldsymbol{I}-\frac{\boldsymbol{B}\boldsymbol{B}}{\mu_0}\right]=\rho\boldsymbol{g}+S(t)+\left(\frac{\partial \rho\boldsymbol{u}}{\partial t}\right)_{diff}$$

$$\frac{\partial e}{\partial t}+\nabla\cdot\left[\boldsymbol{u}\left(e+\boxed{p}+\frac{\boldsymbol{B}^2}{2\mu_0}\right)-\frac{\boldsymbol{B}(\boldsymbol{u}\cdot\boldsymbol{B})}{\mu_0}+\boxed{\frac{(\eta_A+\eta)\boldsymbol{J}_{\perp}\times\boldsymbol{B}}{\mu_0}}+\frac{\nabla p_e\times\boldsymbol{B}}{e\,n_e\mu_0}\right]=(\rho\boldsymbol{g}+S(t))\cdot\boldsymbol{u}+\boxed{Q_R}+\left(\frac{\partial e}{\partial t}\right)_{diff}$$

$$\frac{\partial \boldsymbol{B}}{\partial t}=\nabla\times\left[\boldsymbol{u}\times\boldsymbol{B}-\eta\boldsymbol{J}-\boxed{\eta_A\boldsymbol{J}_{\perp}}+\boxed{\frac{\nabla p_e}{e\,n_e}-\eta_H\frac{\boldsymbol{J}\times\boldsymbol{B}}{|B|}}\right]=\left(\frac{\partial \boldsymbol{B}}{\partial t}\right)_{diff}$$

$$e=\frac{1}{2}\rho u^2+e_{internal}+\frac{\boldsymbol{B}^2}{2\mu_0}$$

$$\boldsymbol{J}=\frac{1}{\mu_0}\nabla\times\boldsymbol{B}$$

$$\boldsymbol{J}_{\perp}=\frac{(\boldsymbol{J}\times\boldsymbol{B})\times B}{|B^2|}$$

Artificial diffusivities

Biermann battery and Hall effects

Ambipolar diffusion due to neutrals

The radiative loss term is computed either by solving the radiative transfer equation (with precomputed opacity tables) assuming LTE with the short characteristics method or by the Newton cooling law.

Equation of state (ideal gas law or precomputed lookup tables)

MANCHA features

Split variables for both linear and non-linear equations:

$$\rho = \rho_0 + \rho_1$$
$$e = e_0 + e_1$$
$$\boldsymbol{B} = \boldsymbol{B_0} + \boldsymbol{B_1}$$

PML boudary conditions – simplifies bc for wave simulations

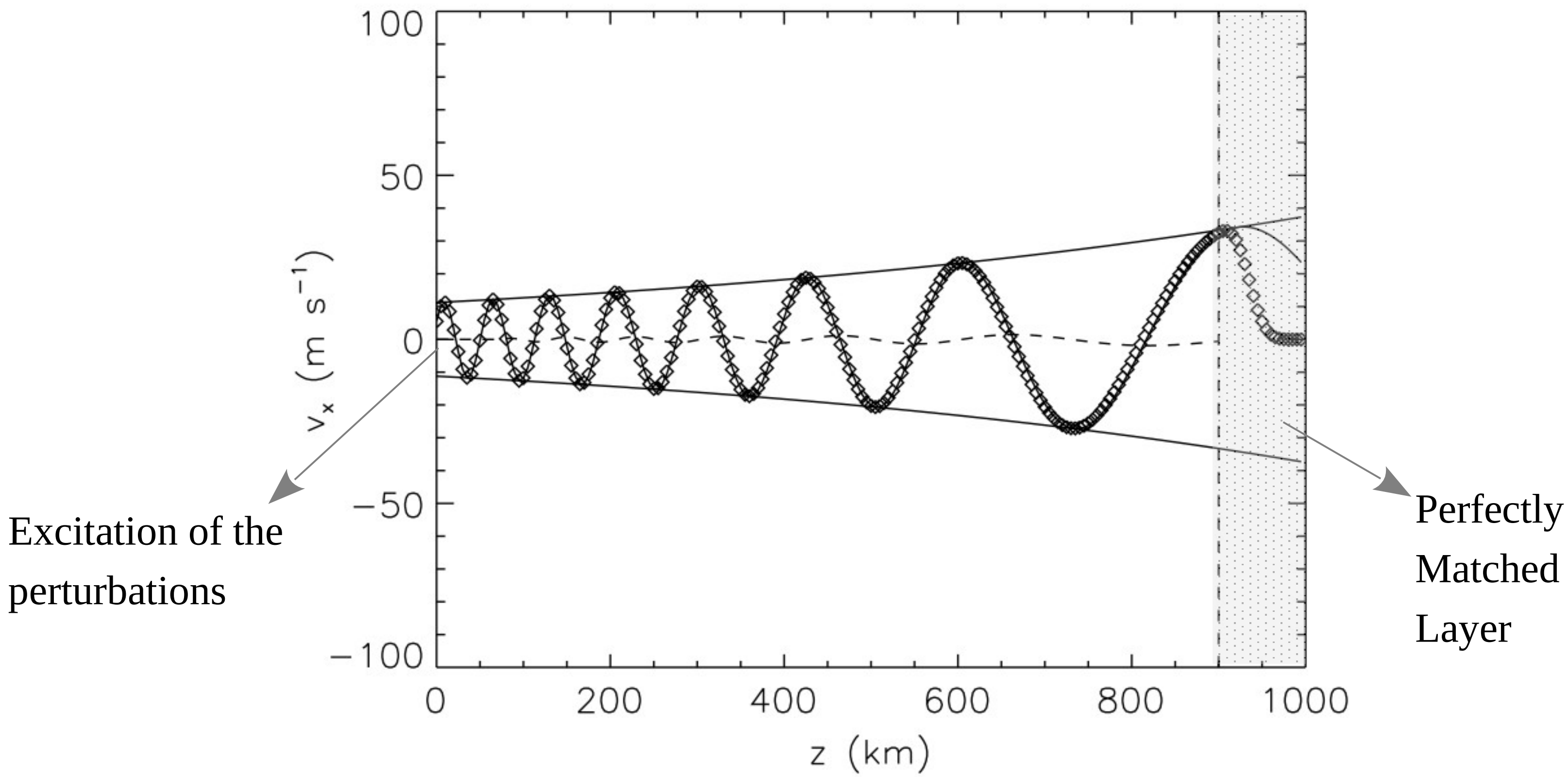
Hyperdiffusion and filtering – stabilization

STS (super-time-stepping) method – speed up simulations with ambipolar diffusion and thermal conduction. HDS (Hall diffusion sceme) is used for Hall effect

”Grey” box – a user modifies only his/her setup (initial, boundary conditions, configuration files) without looking into the main code

Same code for idealized and realistic simulations

Alfven waves

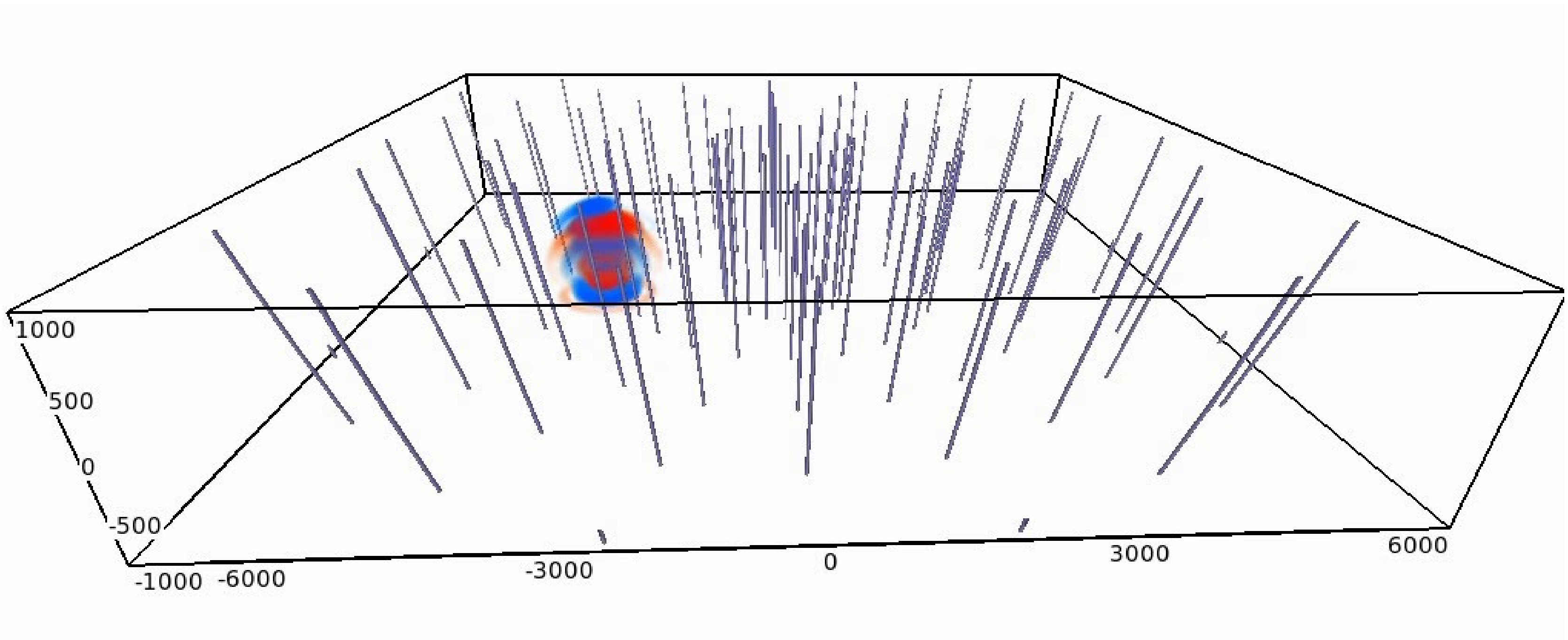


Horizontal velocity profiles of Alfvén waves in an isothermal, stratified atmosphere with a vertical constant magnetic field.

Solid line: exact solution; diamonds: numerical solution. The dashed line is the difference between both solutions. The vertical dashed line indicates the position of the PML interface.

Felipe, T.; Khomenko, E.; Collados, M. "Magneto-acoustic Waves in Sunspots: First Results From a New Three-dimensional Nonlinear Magnetohydrodynamic Code", 2010, ApJ, 719, 1, 357-377

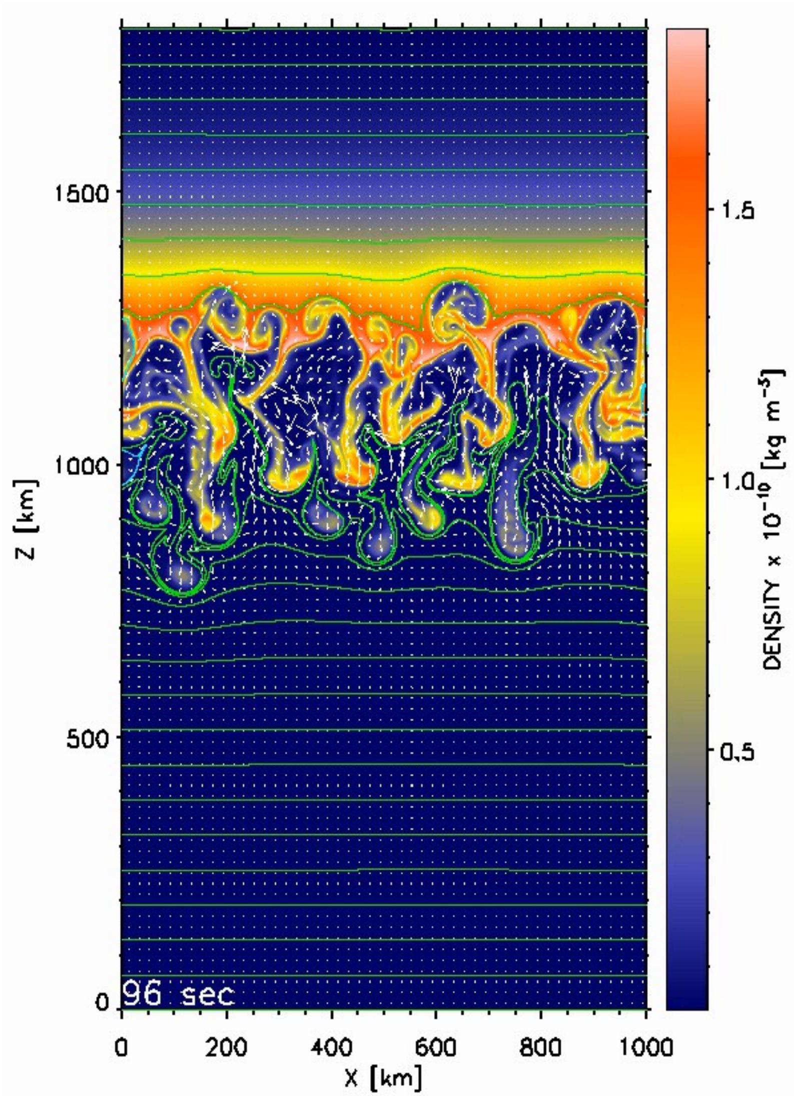
3D acoustic waves in sunspots



3D view of the vertical velocity in the simulation with 50s harmonic force located at the bottom off the sunspot axis.

Felipe, T.; Khomenko, E.; Collados, M. "Magneto-acoustic Waves in Sunspots: First Results From a New Three-dimensional Nonlinear Magnetohydrodynamic Code", 2010, ApJ, 719, 1, 357-377

Rayleigh-Taylor instability in prominence

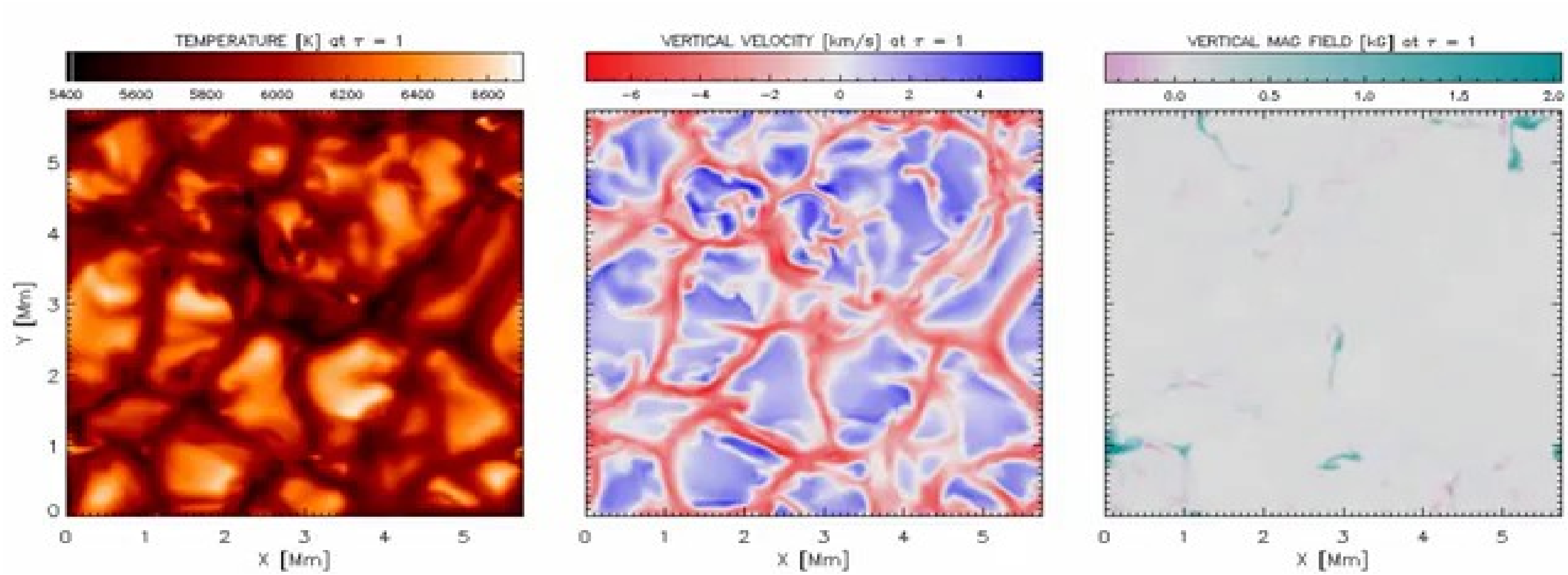


Density evolution together with velocity field in 2D simulation of RTI including partial ionization effects and inclined external magnetic field.

Resolution 1km, 1000x1800 grid points.

E Khomenko, A Díaz, A De Vicente, M Collados, M Luna. A&A 565, A45

Convection 3D



Evolution of the temperature, vertical velocity and magnetic field in the 3D MHD simulation of the solar near-surface convection. Magnetic field is generated by Biermann battery effect and amplified by local dinamo action.

Simulation domain is 5.8×5.8×1.6 Mm^3 domain with resolution 288x288x114 grid points.

E Khomenko, N Vitas, M Collados, A De Vicente, 2017, A&A 604, A66

What do we share

src

Source files

aux

- Manual
- IDL scripts
- Python scripts
- Submission scripts

samples

- Acoustic wave
- Alfven wave
- Ambipolar
- Hall_HDS
- Orszag
- Pulse
- Riemann test
- RTI
- KHI

- Initial condition (.F90)
- Boundary conditions (.F90)
- Control (.trol)
- Submission script (.sub)
- Equilibrium.h5
- Perturbation.h5
- EquilibriumHDF.pro

You need:

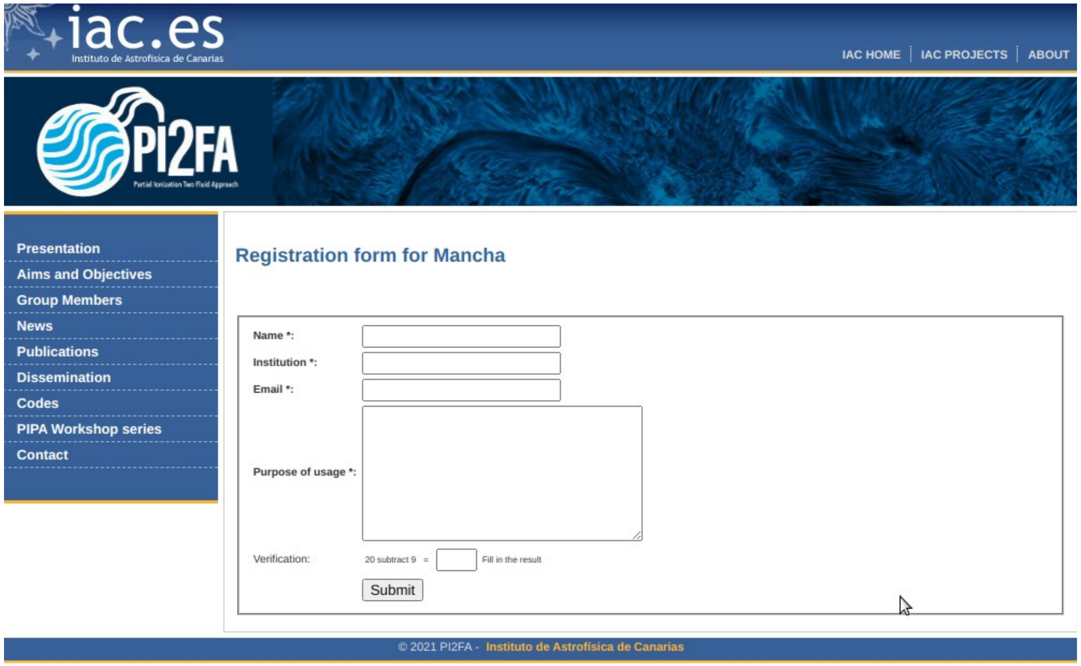
- Fortran compiler (GNU, Intel)
- MPI library (openmpi, impi, mpich, ...)
- HDF5 library
- Cmake package

Registration form

At the first stage the public MANCHA will be distributed via private Gitlab repository

New users will need to fill a simple form to get access to the code

http://research.iac.es/proyecto/PI2FA/pages/codes/mancha-form.php



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Khomenko, E.; Collados, M. "Heating of the Magnetized Solar Chromosphere by Partial Ionization Effects", 2012, ApJ, 747, 2, 87

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González-Morales, P. A.; Khomenko, E.; Downes, T. P.; de Vicente, A. "MHDSTS: a new explicit numerical scheme for simulations of partially ionised solar plasma", 2018, A&A, 615, A67

Khomenko, E.; Vitas, N.; Collados, M.; de Vicente, A. "Three-dimensional simulations of solar magneto-convection including effects of partial ionization", 2018, A&A, 618, A87

Popescu Braileanu, B.; Lukin, V. S.; Khomenko, E.; de Vicente, A. "Two-fluid simulations of waves in the solar chromosphere I: numerical code verification", 2019, A&A 627, A25.

More info on our group webpage:

http://research.iac.es/proyecto/PI2FA

http://research.iac.es/proyecto/PI2FA/pages/codes.php