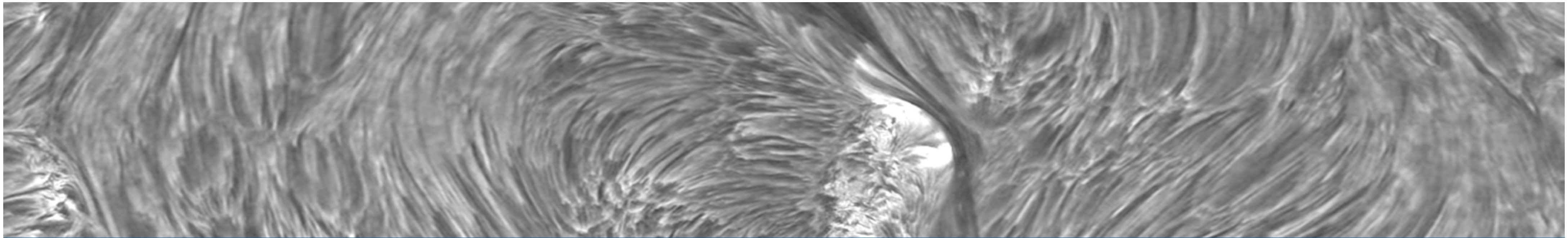

How does numerical diffusion affect high resolution two-fluid simulations of magnetized turbulence?

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References to related presentations Ids: 391, 327, 502, 444

TURBULENCE

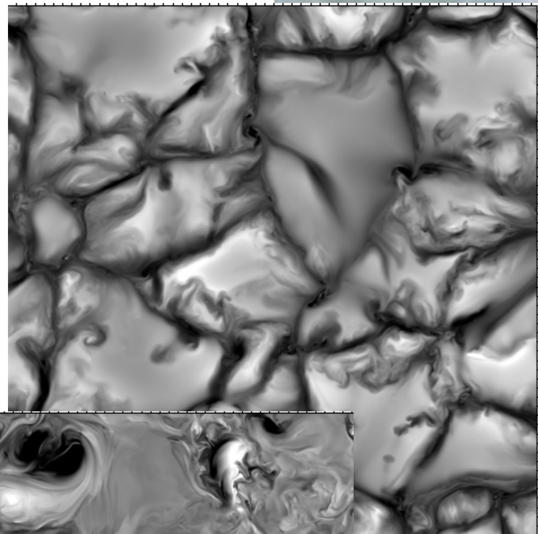
Turbulence in weakly ionized plasmas is common in astrophysical environments

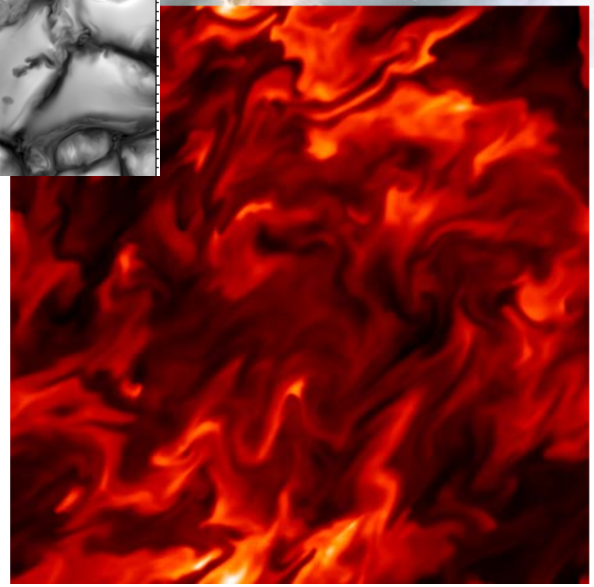
(*) Molecular clouds ::
ionization degree 10^{-7}, weak collisional coupling

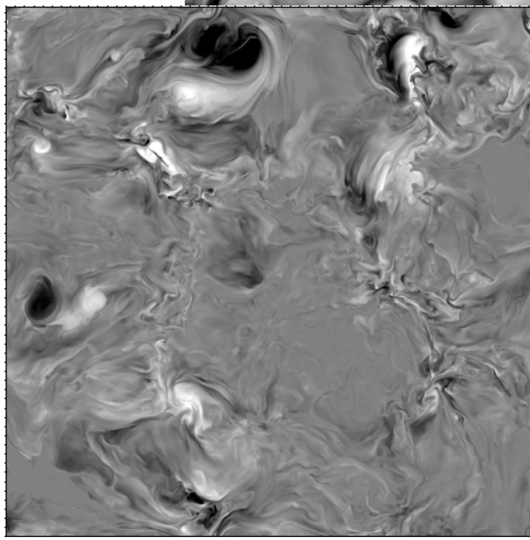
(*) Solar photospheric turbulent convection ::
ionization degree 10^{-4}, strong collisional coupling

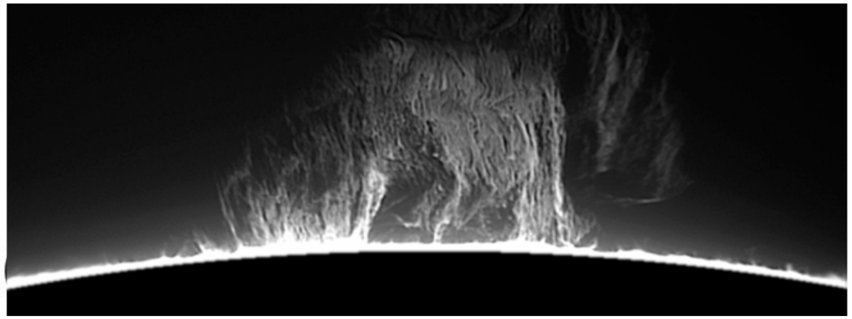
(*) Solar chromosphere ::
ionization degree 10^{-2}, intermediate collisional coupling

(*) Turbulence associated to solar prominences ::
conditions similar to the chromosphere









TWO-FLUID APPROACH

Mancha-2F :: *Popescu Bralieanu et al 2019*

	Neutrals	Charges
Momentum evolution x 2=	Advection Hydrodynamic forces Viscose force Collisional force	Advection Hydrodynamic forces Magnetic force Viscose force Collisional force

+ not easy to determine numerical diffusivity of the code

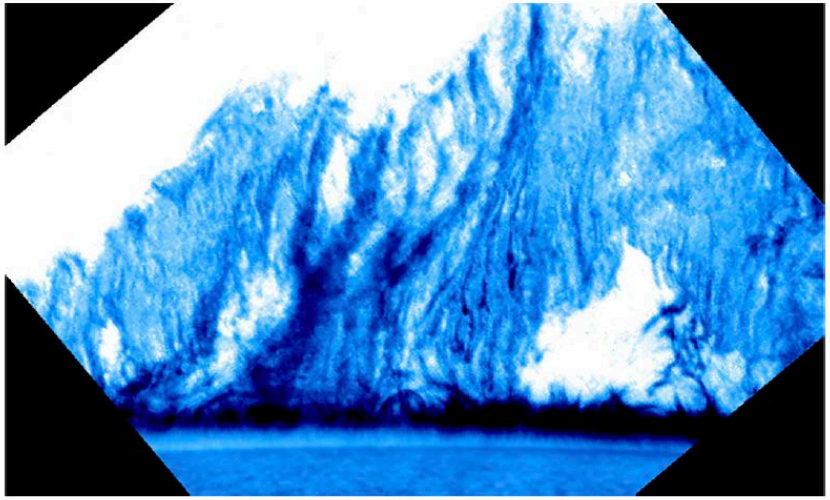
	Neutrals	Charges
Energy evolution x 2 =	Advection Radiation Frictional heating Thermal exchange	Advection Radiation Ohmic heating Frictional heating Thermal exchange

OBJECTIVES & METHODS

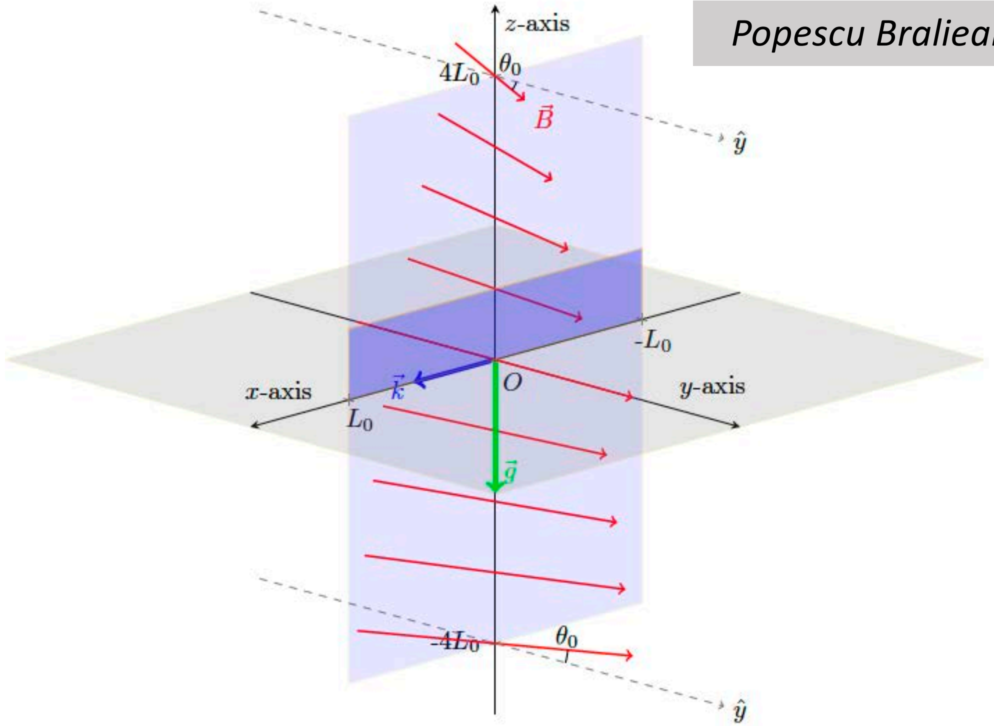
OBJECTIVES ::

(*) Evaluate an equivalent of the Ohmic-like numerical diffusion coefficient for multi-fluid simulations

(*) Estimate the order of dissipation of the numerical scheme.



Popescu Bralieanu et al 2021a, b



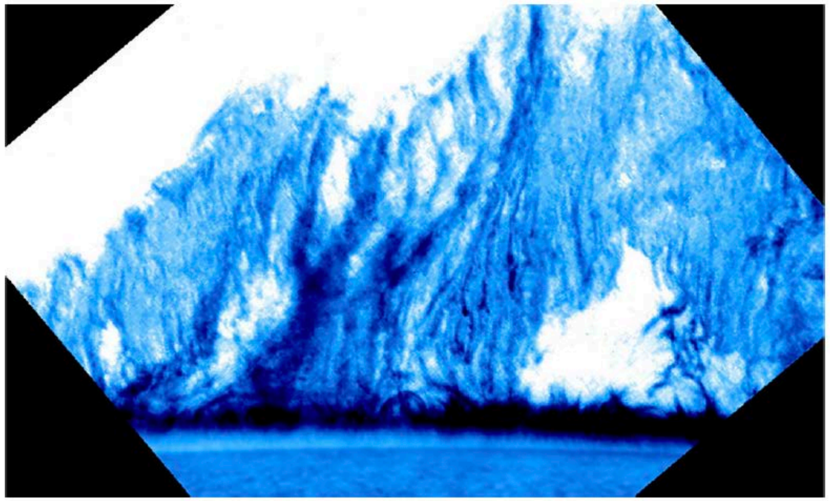
- Numerical box 2048 x 8192 grid; dx=dz=1 km
- Smooth prominence – corona interface
- Magnetic field out of plane and sheared
- **3 sets of numerical diffusion parameters for Mancha-2F code**

OBJECTIVES & METHODS

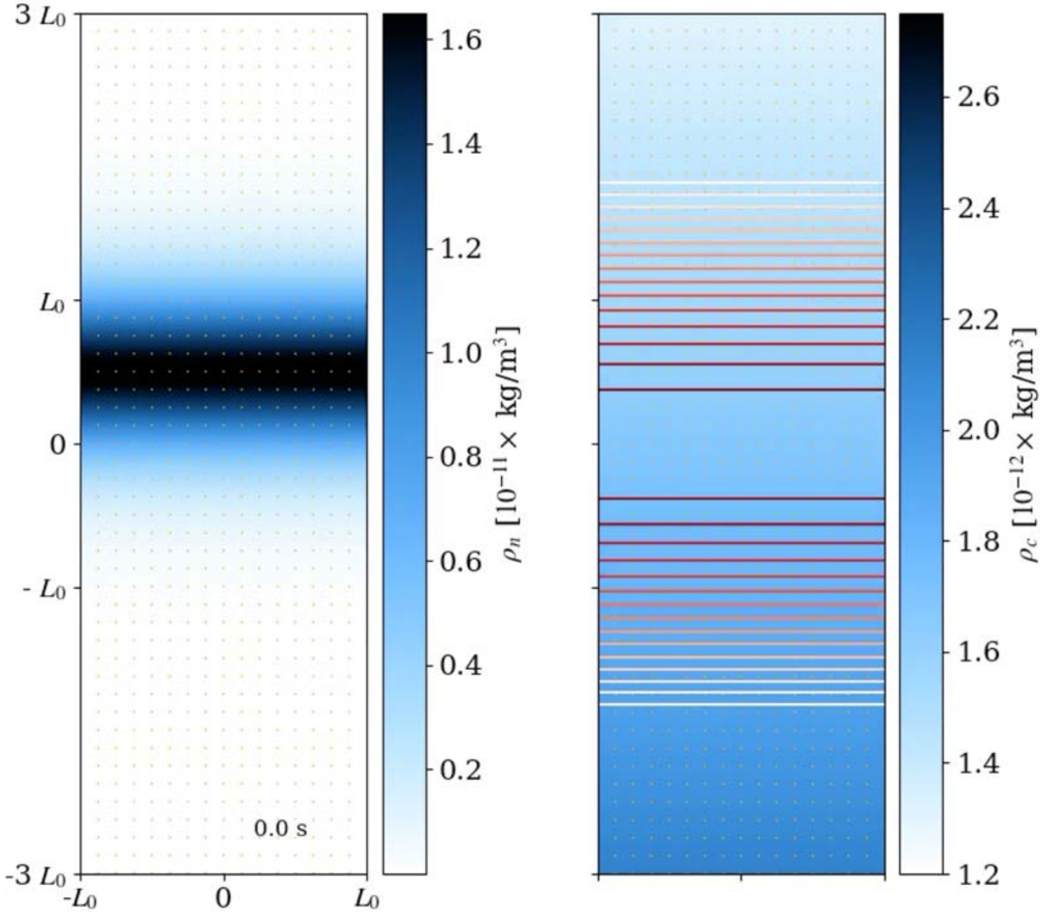
OBJECTIVES ::

(*) Evaluate an equivalent of the Ohmic-like numerical diffusion coefficient for multi-fluid simulations

(*) Estimate the order of dissipation of the numerical scheme.

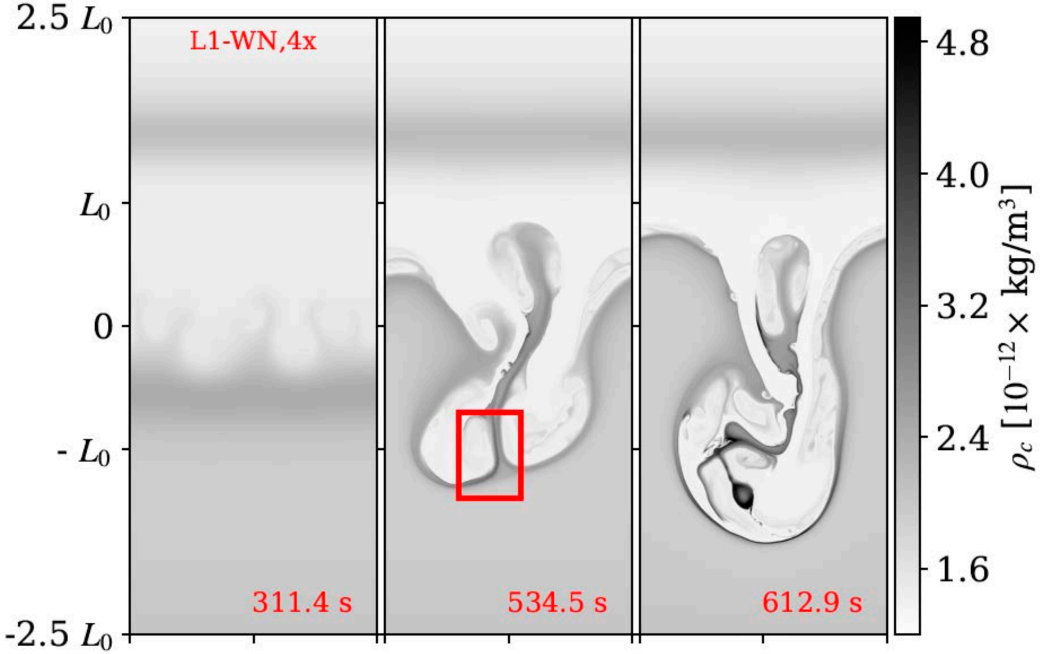


EVOLUTION of NEUTRAL & PLASMA DENSITIES

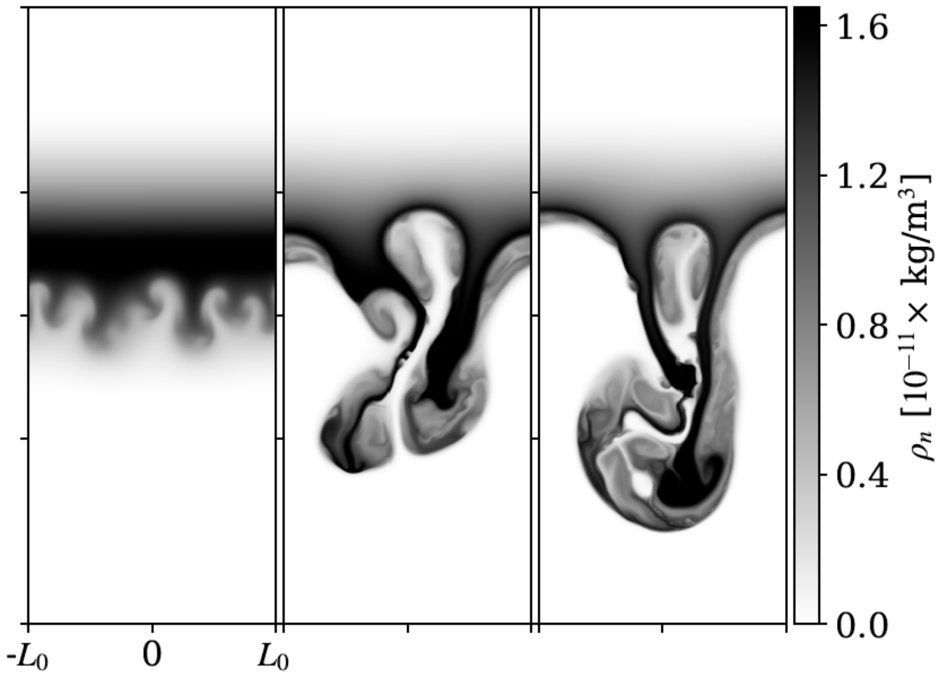


DYNAMICS

PLASMA DENSITY



NEUTRAL DENSITY

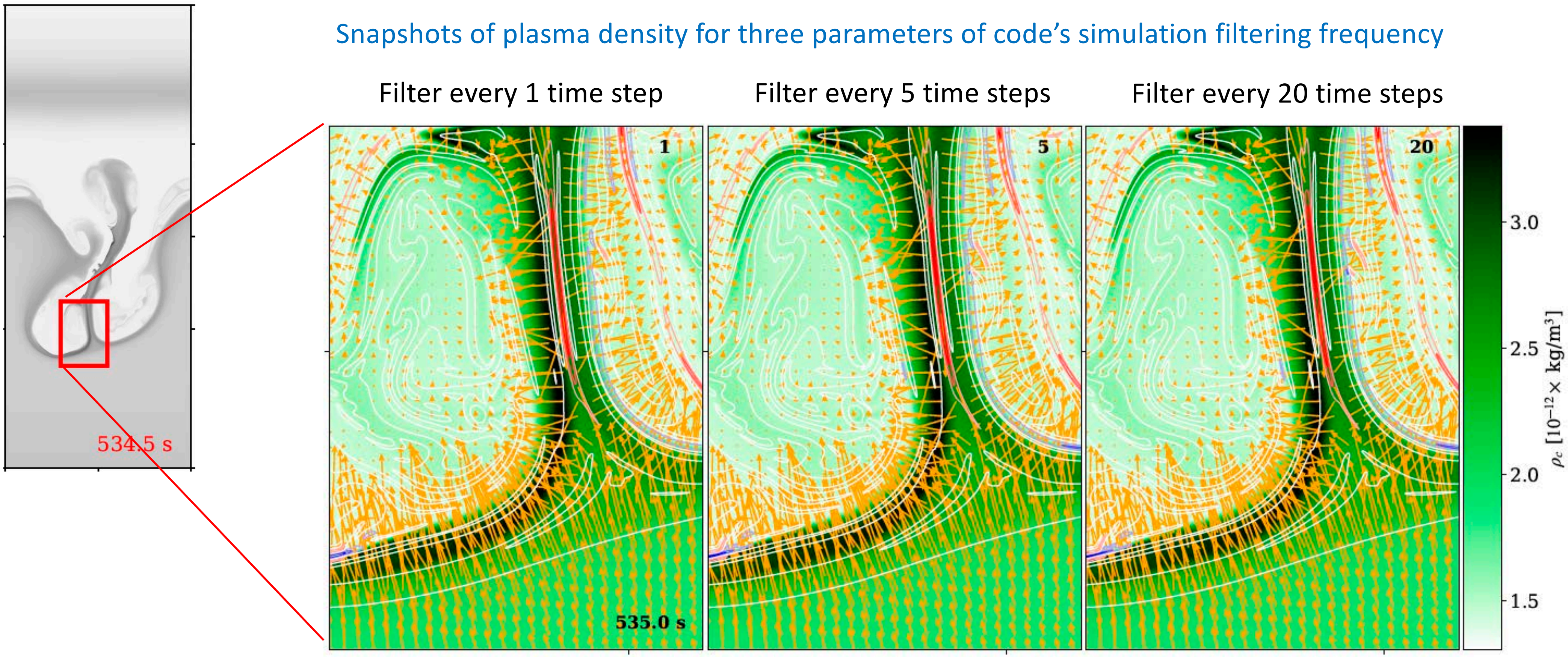


- Neutral drops are brought together by plasma dynamics
- Current sheet formation in between
- Reconnection and formation of magnetic islands filled with coronal material

DYNAMICS of the CURRENT SHEET :: 3 NUMERICAL SETS

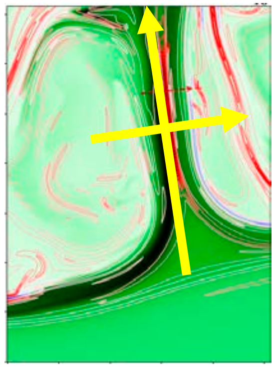
Snapshots of plasma density for three parameters of code's simulation filtering frequency

Filter every 1 time step | Filter every 5 time steps | Filter every 20 time steps

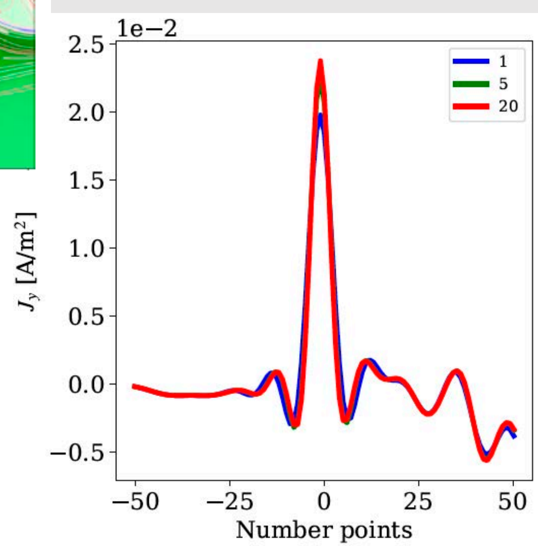


- Slight, but important differences after running with different filtering for a short time

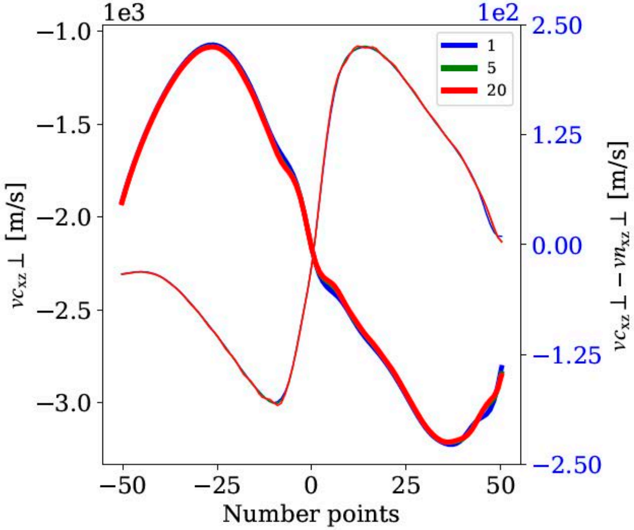
DYNAMICS of the CURRENT SHEET :: 3 NUMERICAL SETS



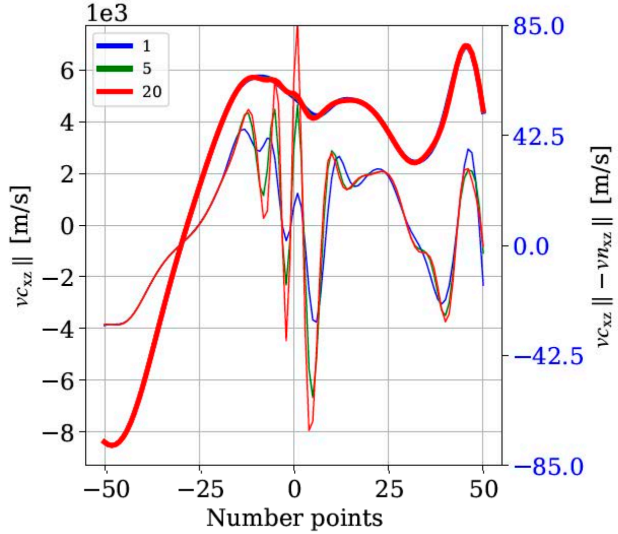
Out of plane current density



Velocity & velocity decoupling
perpendicular to the current sheet



Velocity & velocity decoupling
parallel to the current sheet



Filter every 1 time step

Filter every 5 time steps

Filter every 20 time steps

- Slight, but important differences after running with different filtering for a short time
- Differences in the strength of J_y and in the outflow decoupling

EVALUATION of EFFECTIVE DIFFUSIVITY

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times \left[\mathbf{v} \times \mathbf{B} \right] + \left(\frac{\partial \mathbf{B}}{\partial t} \right)_{\mathrm{diff}}$$

Assume diffusivity is Ohmic-like & constant in space

$$\left(\frac{\partial \mathbf{B}}{\partial t} \right)_{\mathrm{diff}} = \nabla \times \left[-\eta_{\mathrm{scheme}} \mathbf{J} \right] = \eta_{\mathrm{scheme}} \Delta^2 B$$

$$y = \eta_{\mathrm{scheme}} x + c,$$

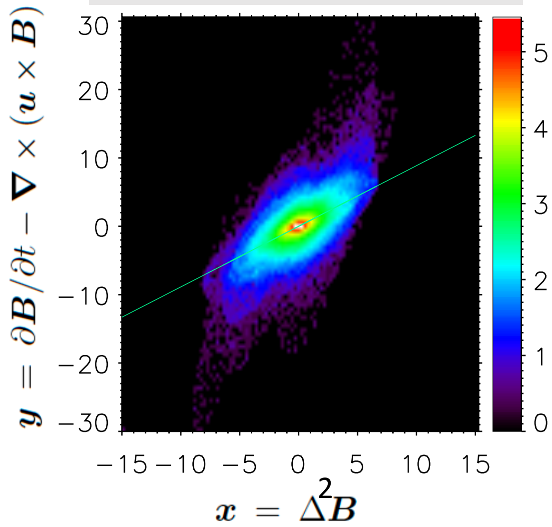
where

$$x = \Delta^2 B,$$

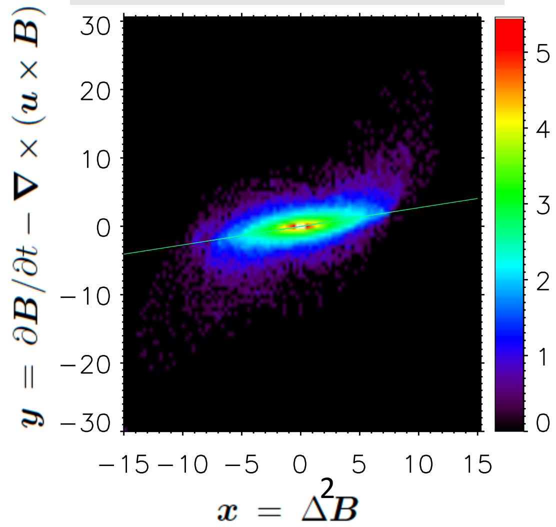
$$y = \partial B / \partial t - \boldsymbol{\nabla} \times (\boldsymbol{u} \times \boldsymbol{B}).$$

$$\eta_{\mathrm{scheme}} = \left\{ \begin{matrix} 0.9 \\ 0.3 \\ 0.08 \end{matrix} \right\} \times 10^6 \ \mathrm{m^2/s}$$

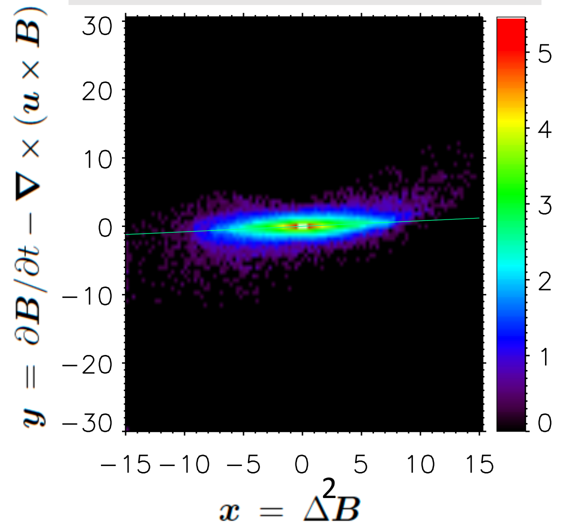
Filter every 1 time step



Filter every 5 time steps



Filter every 20 time steps



EVALUATION of EFFECTIVE DIFFUSIVITY

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times \left[\mathbf{v} \times \mathbf{B}\right] + \left(\frac{\partial \mathbf{B}}{\partial t}\right)_{\mathrm{diff}}$$

Assume hyper-diffusivuty constant in space

$$\left(\frac{\partial \mathbf{B}}{\partial t}\right)_{\mathrm{diff}} = \eta_{\mathrm{hyper}} \; \overset{4}{\Delta} B$$

$$y = \eta_{\mathrm{hyper}}\, x + c$$

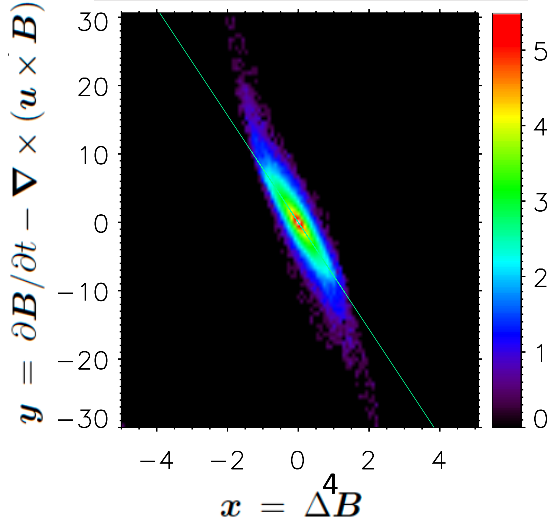
where

$$x = \overset{4}{\Delta} B,$$

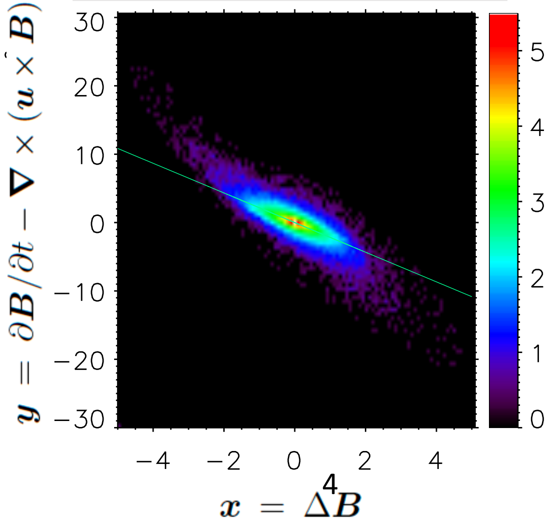
$$y = \partial B/\partial t - \boldsymbol{\nabla} \times (\boldsymbol{u} \times B).$$

$$\eta_{\mathrm{hyper}} = \begin{Bmatrix} 7.8 \\ 2.2 \\ 0.63 \end{Bmatrix} \times 10^{12}\ \mathrm{m^4/s}$$

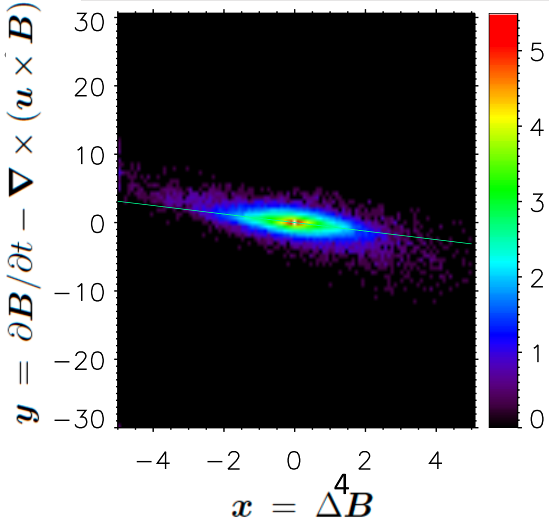
Filter every 1 time step



Filter every 5 time steps



Filter every 20 time steps



SUMMARY

- Simulations of magnetized turbulence are frequently affected by numerical properties of the code
- Two-fluid simulations require scales of plasma-neutral interactions to be resolved
- We propose how to evaluate the numerical diffusion in the explicit two fluid code Mancha-2F
- Our method is clearly sensitive to the numerical parameters of the simulation (filtering frequency)
- The method allows to estimate the order of dissipation of the numerical scheme

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