Results from Numerical Simulation of Magnetic Reconnection

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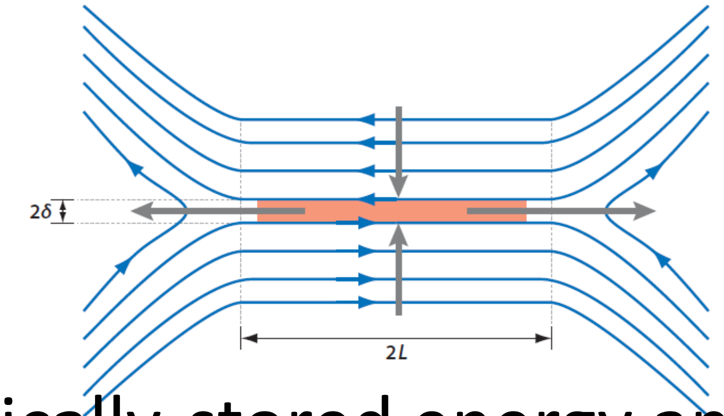
Magnetic Reconnection



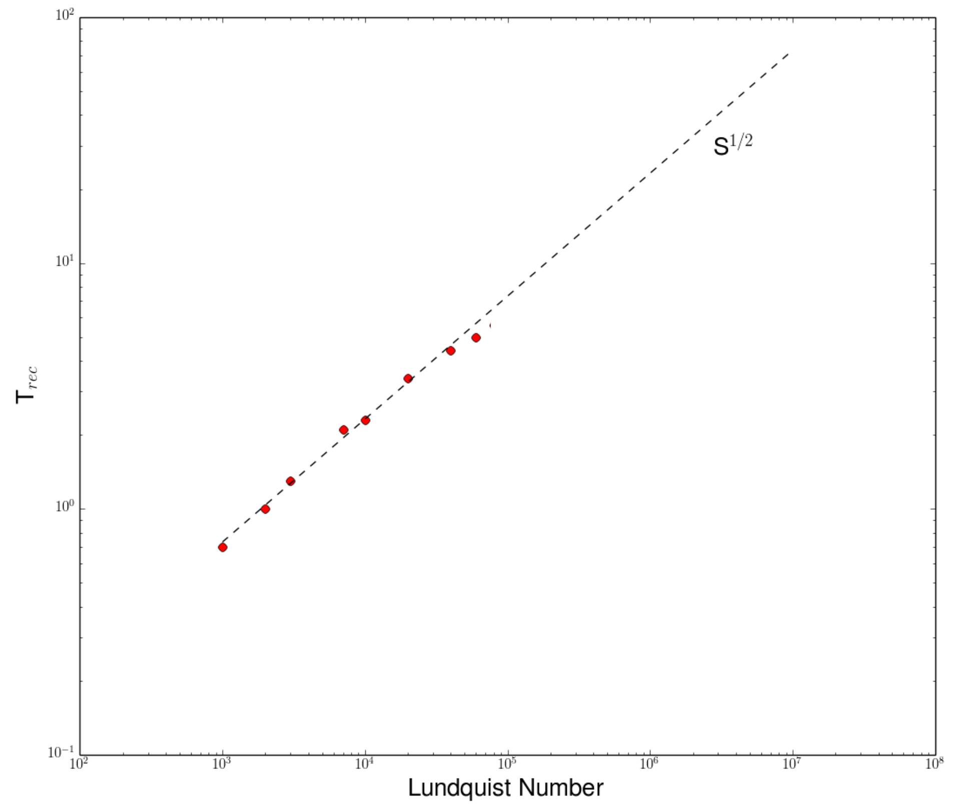
- Rapid rearrangement of magnetic field topology
- Violent release of magnetically-stored energy and its conversion into heat and into nonthermal particle energy
- Observed in numerous physical phenomena such as
  - Solar flares and coronal mass ejections
  - magnetic storms in the Earth's magnetosphere
  - sawtooth crashes in tokamaks

Magnetic Reconnection

The classical Sweet-Parker predicts for the reconnection time scale

$$t_{rec} \sim t_A S^{1/2}$$

where $S = L\, v_A/\eta$ is the *Lundquist number,* η the resistivity of the plasma and $t_A = L/v_A$ is the Alfven transit time.

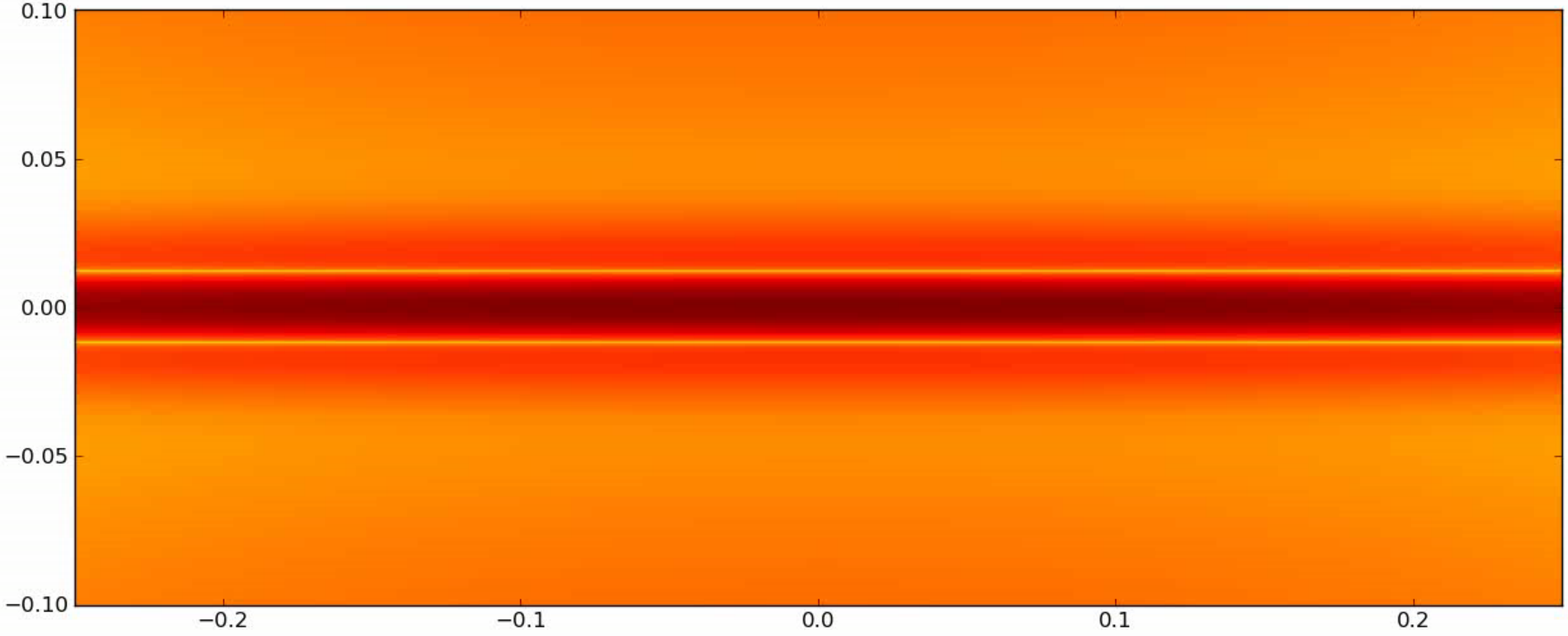


Problem

- S >> 1 (e.g., $S \simeq 10^{12}$ in solar corona)
- The classical Sweet-Parker therefore predicts a very long reconnection time scale
- This is in direct contradiction with the reconnection time observed, that are very short - usually only 10 to 100 times longer that the global Alfven transit time, t_A

When $S > 10^5$ (large aspect ratio) the layer becomes unstable to tearing instability: **production of plasmoids**

(e.g., linear resistive MHD theory, Loureiro et al. 2007)



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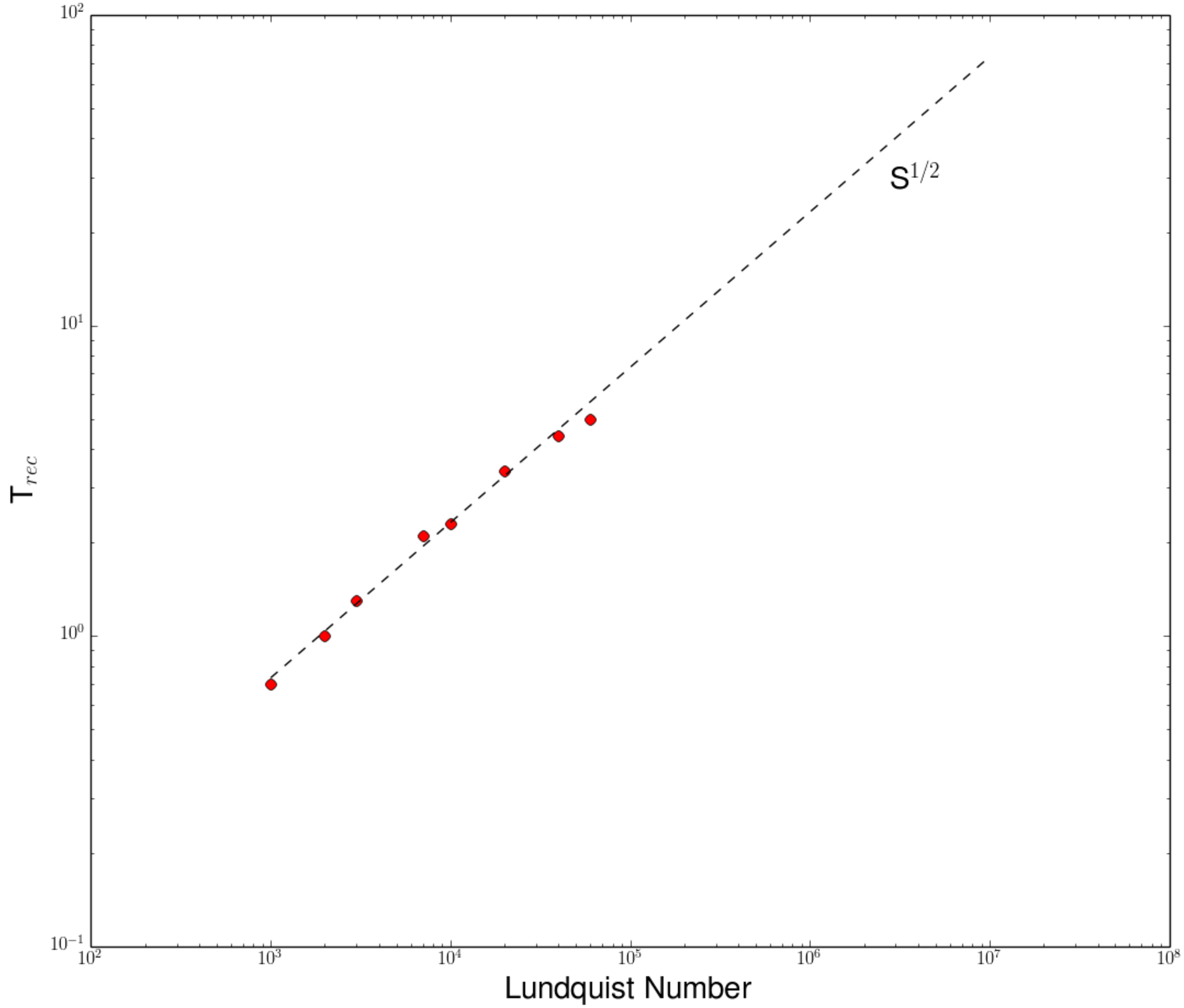
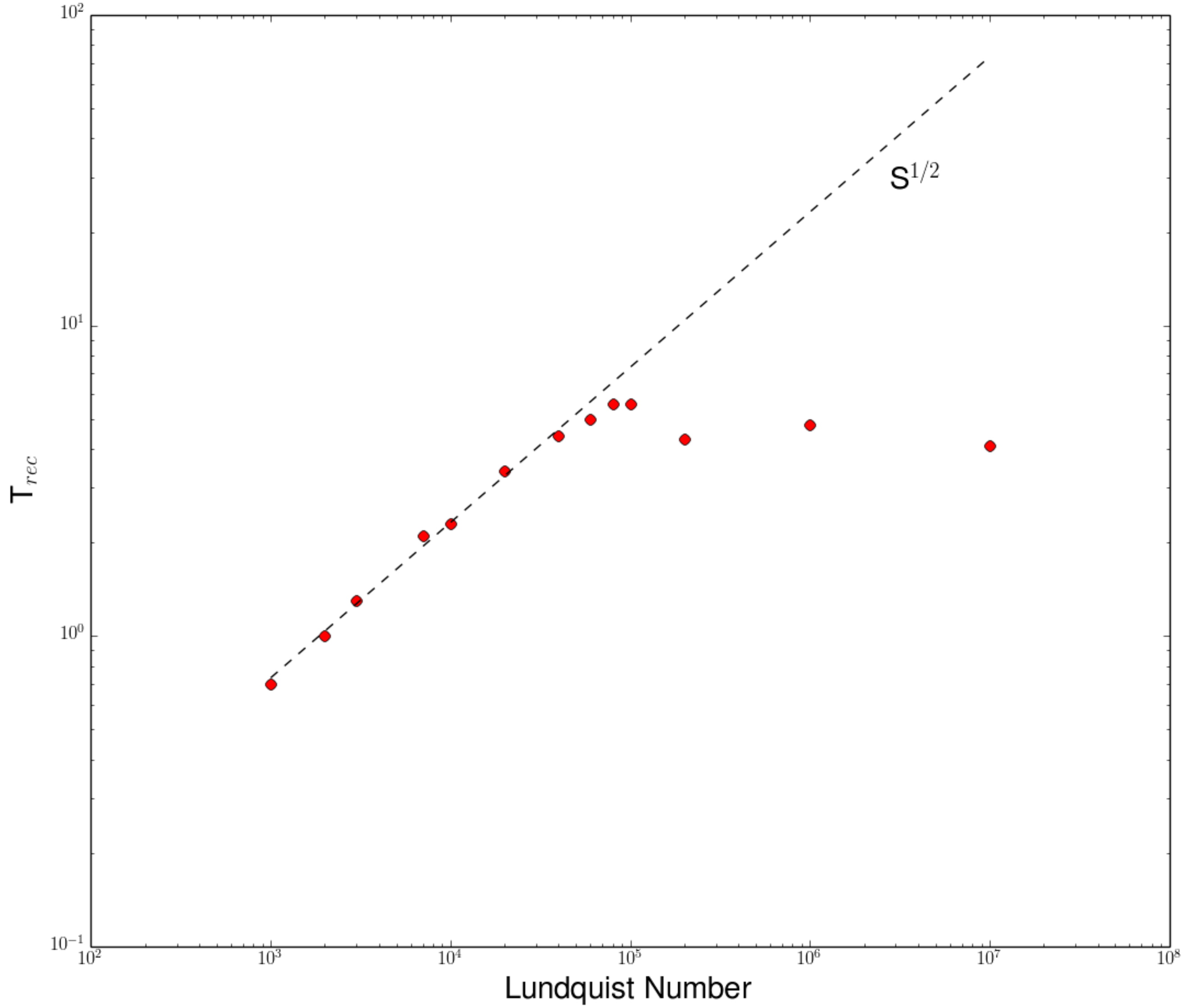
Fast reconnection regime

1. growth rate of the instability scaling as $\gamma t_A \sim S^{1/4}$
2. Effective reconnection rate **indipendent of S**
3. number of plasmoids $\propto S^{3/8}$

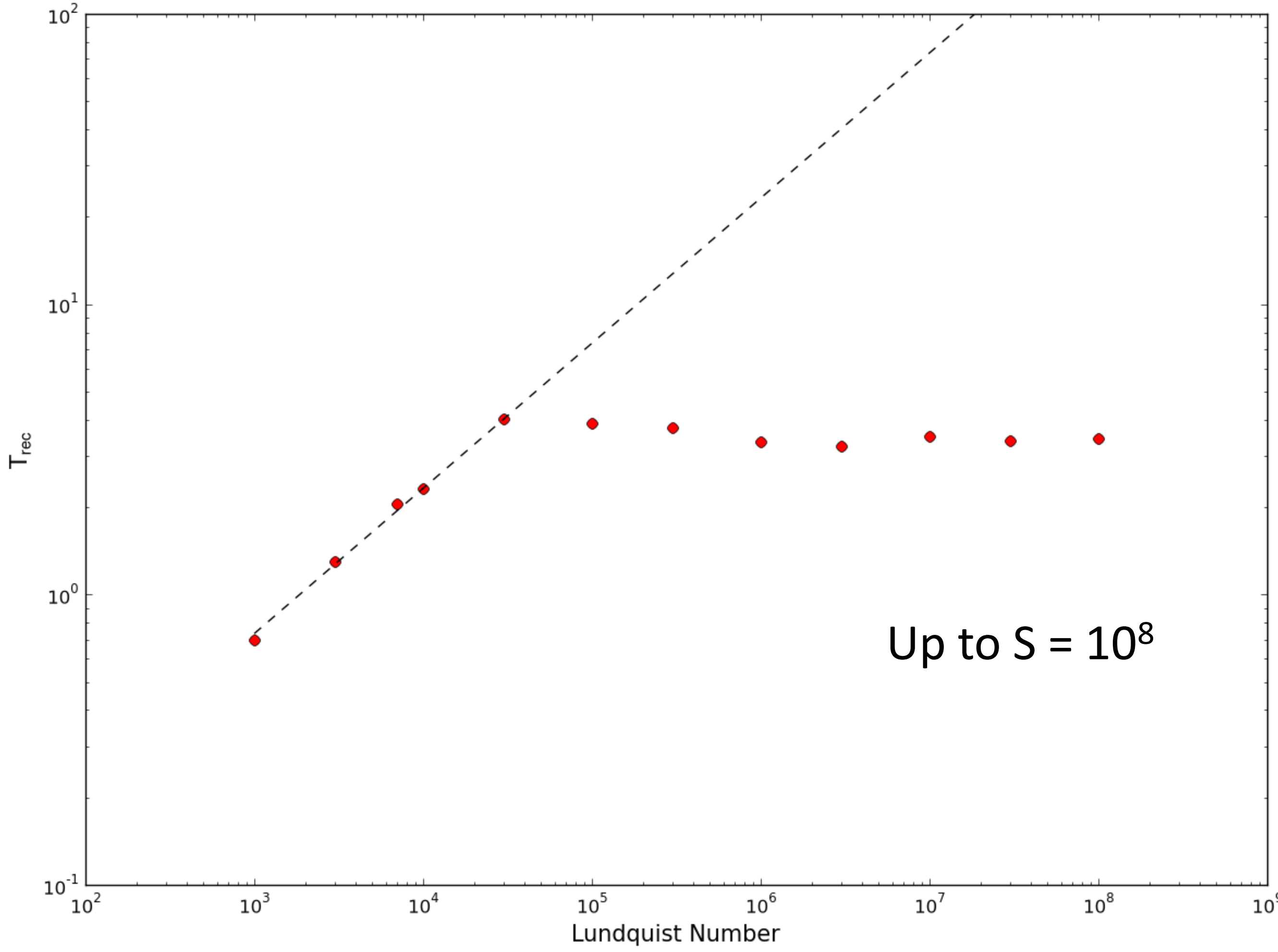
Reconnection Rate



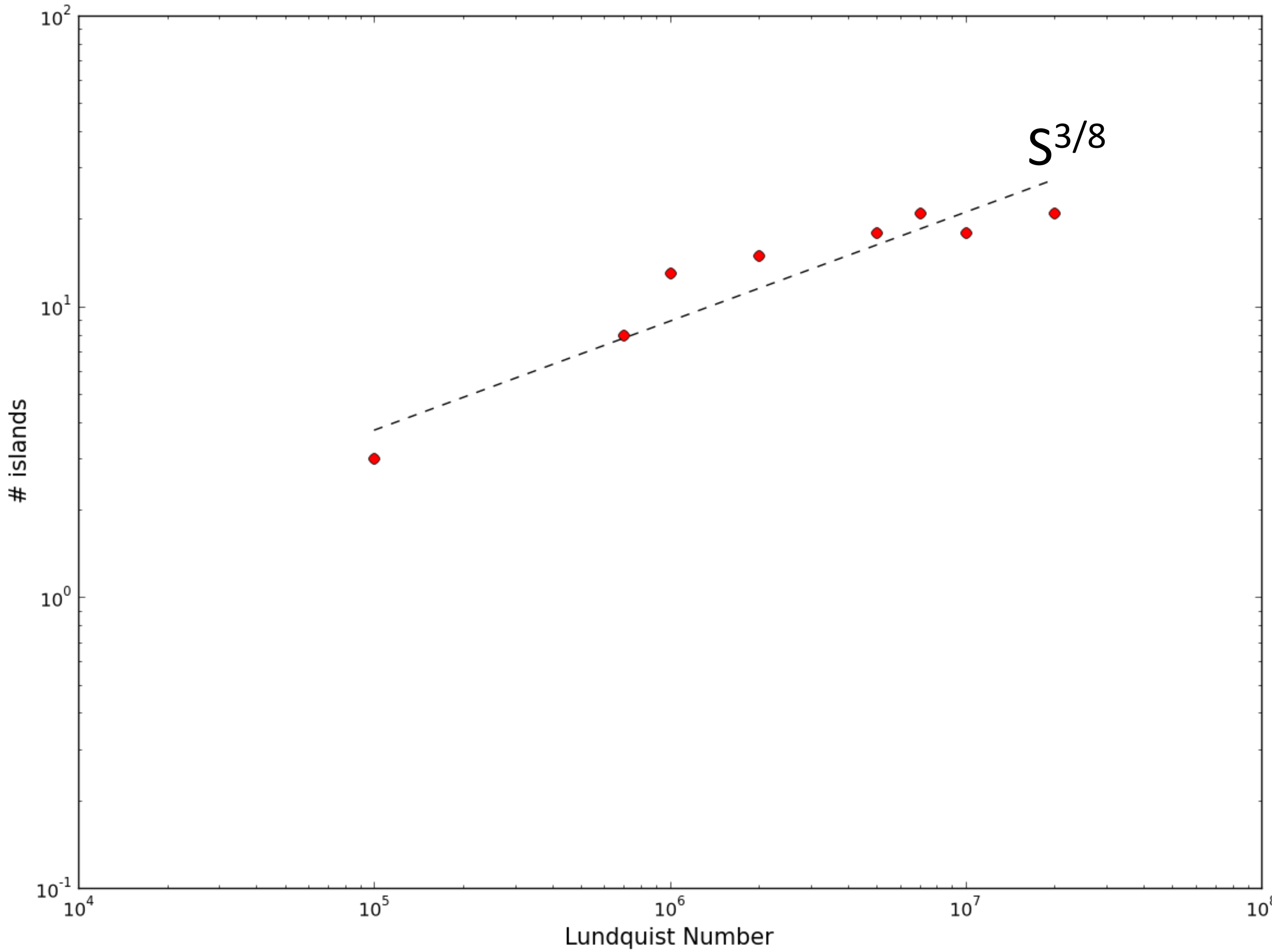
Reconnection Rate



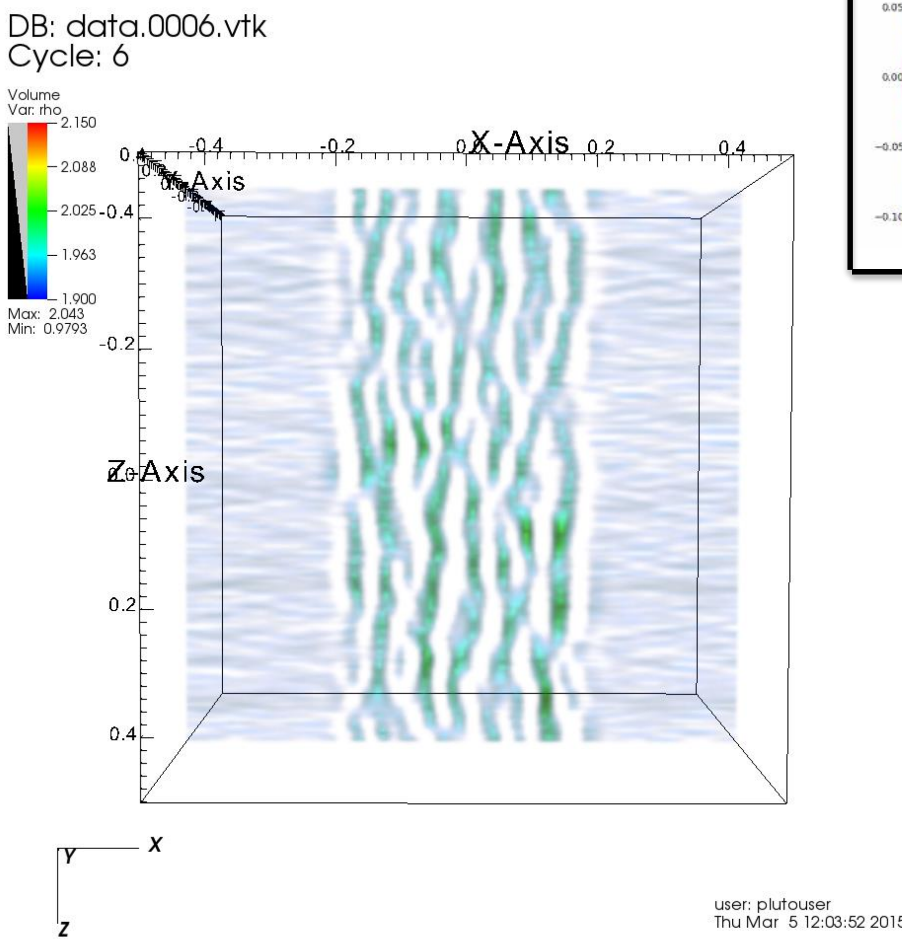
Reconnection Rate

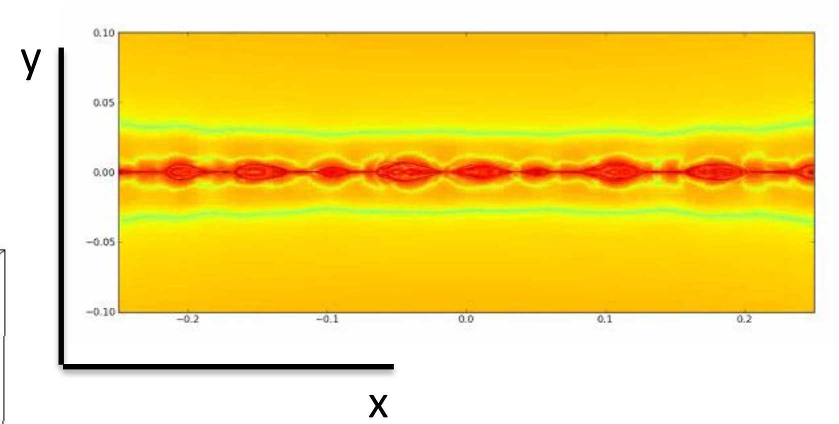


Number of Islands

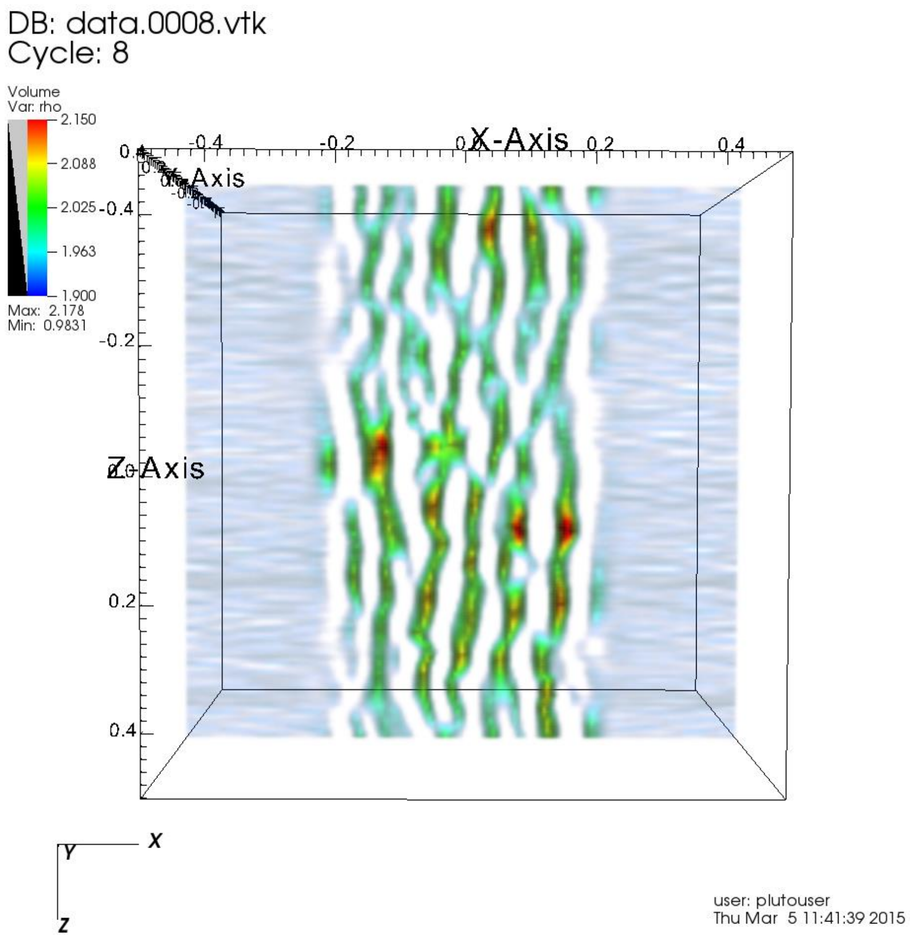


3D simulations of Cartesian Setup

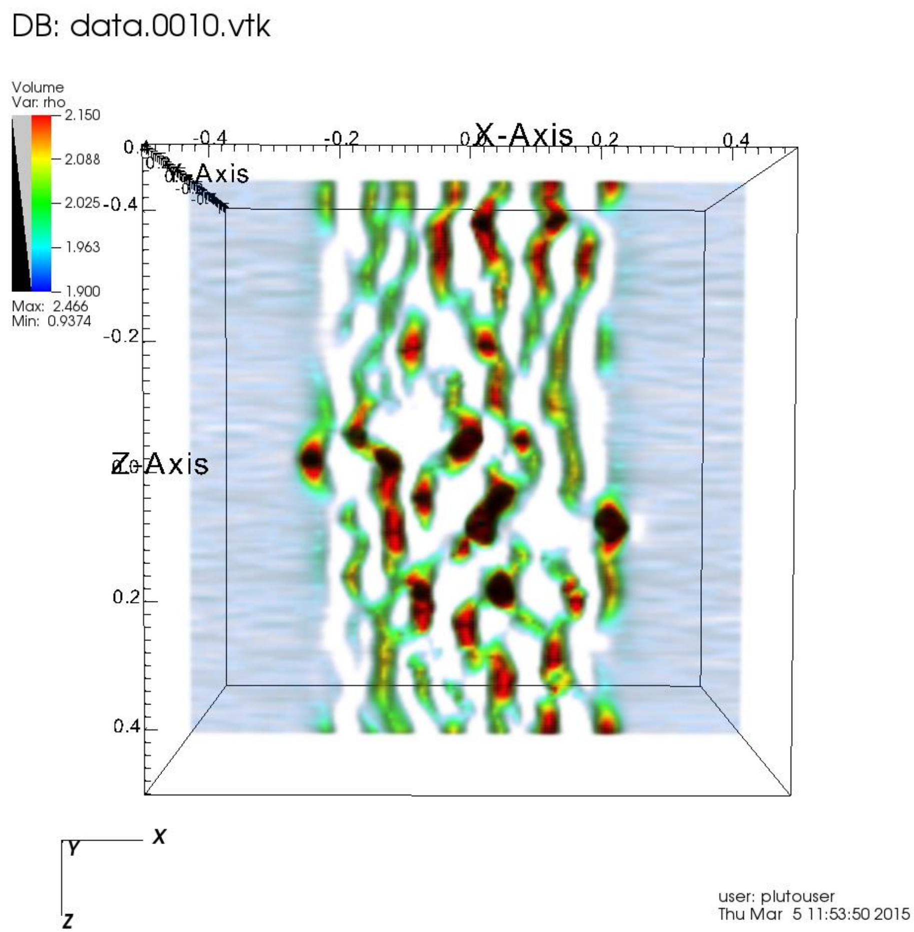




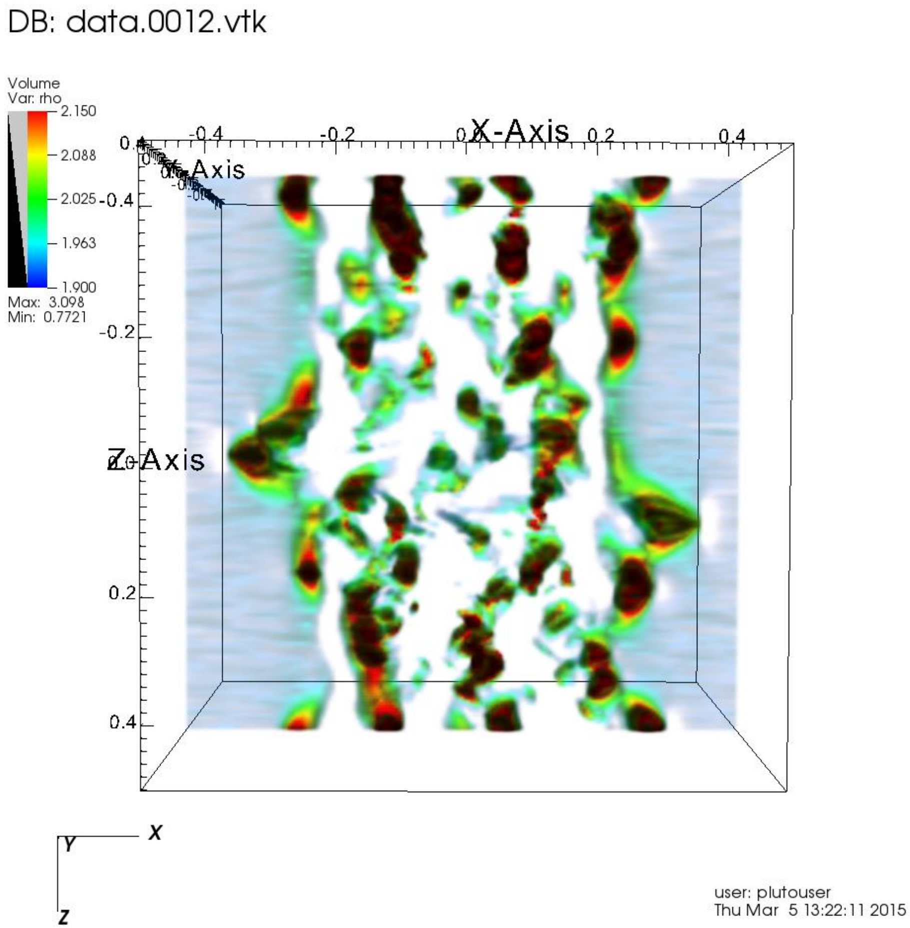
3D simulations of Cartesian Setup



3D simulations of Cartesian Setup



3D simulations of Cartesian Setup



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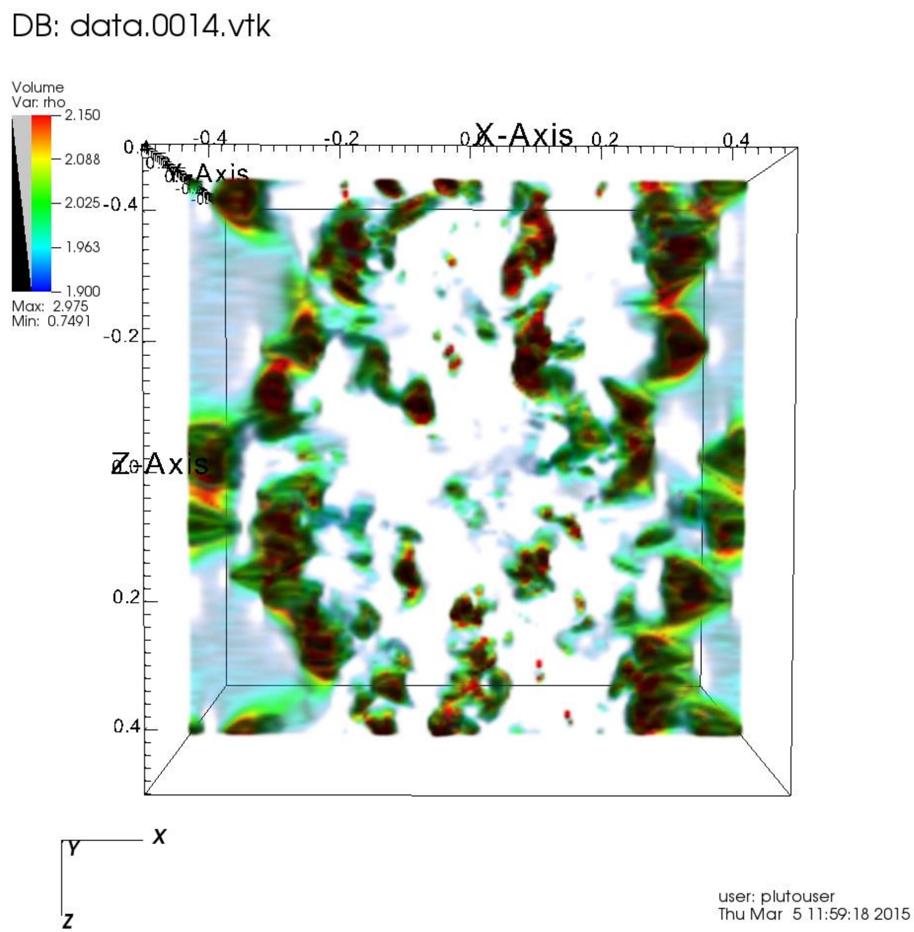
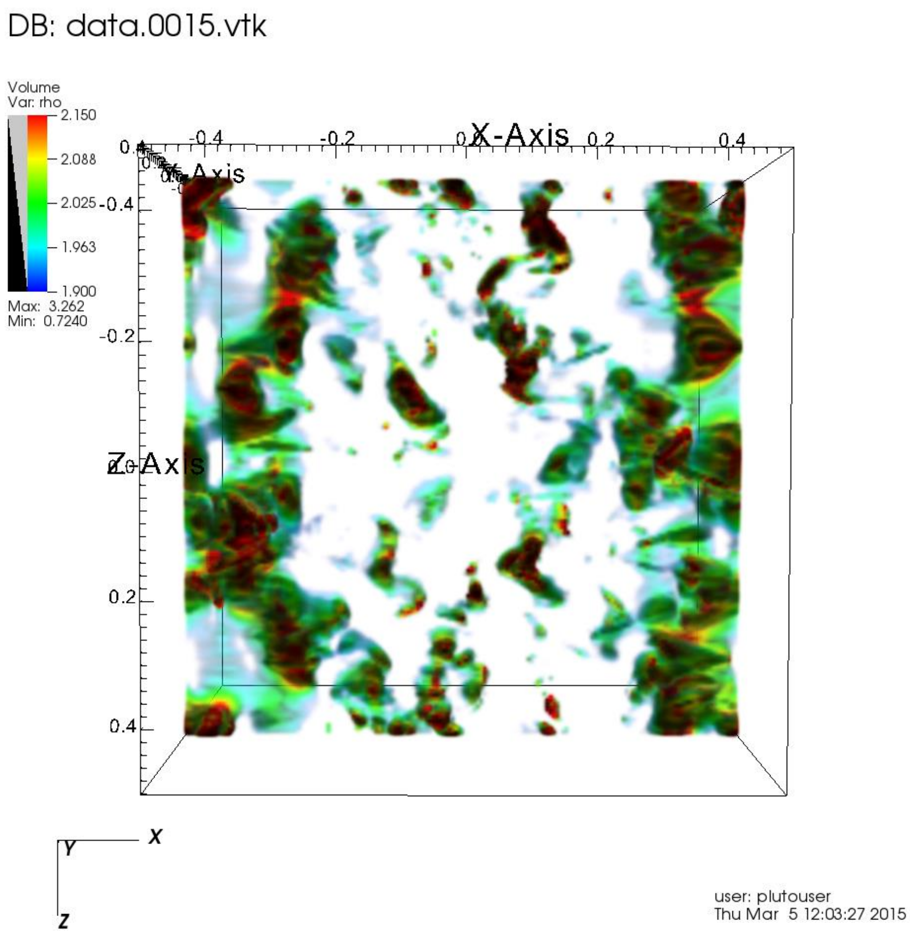
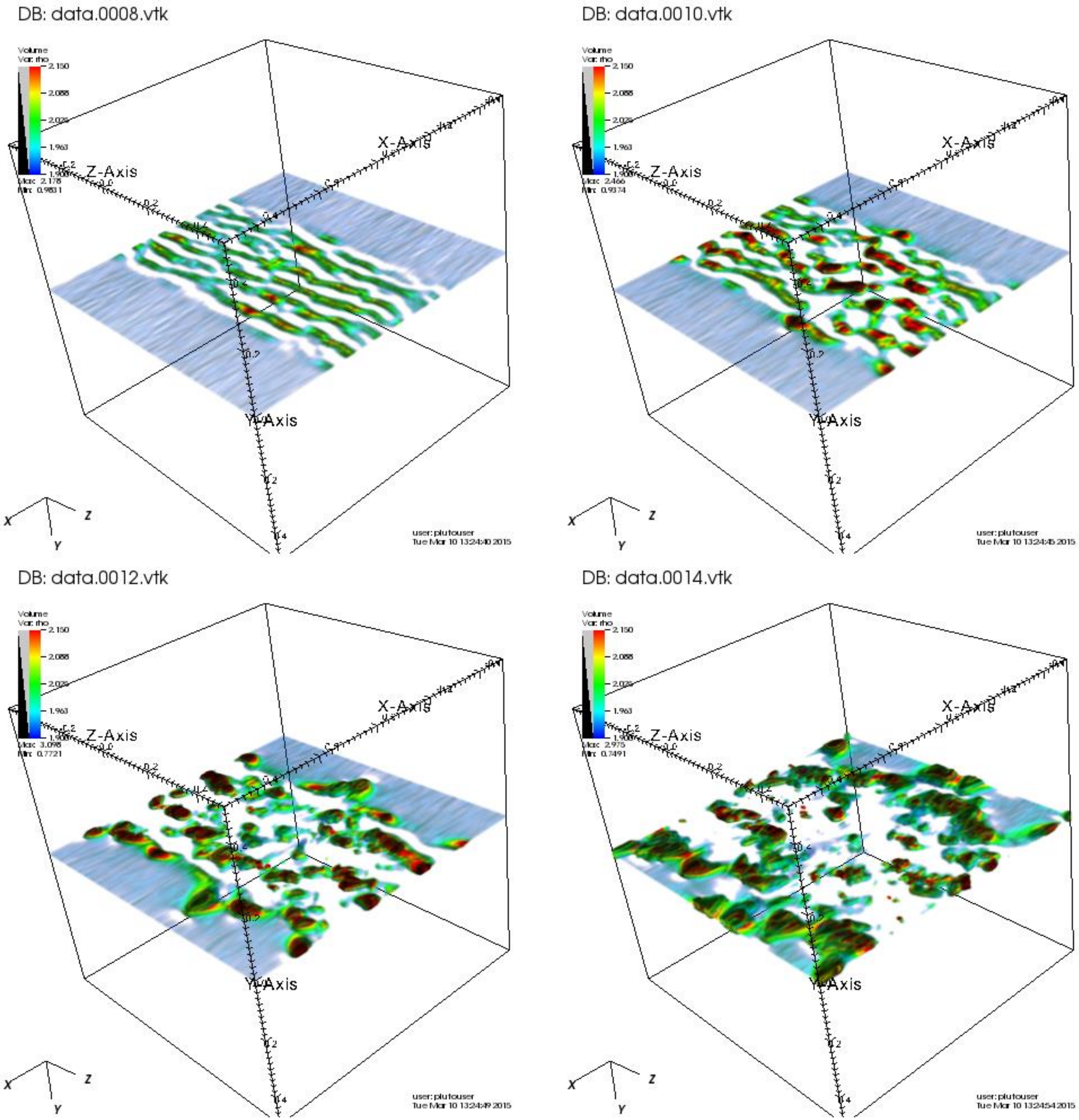


3D simulations of Cartesian Setup





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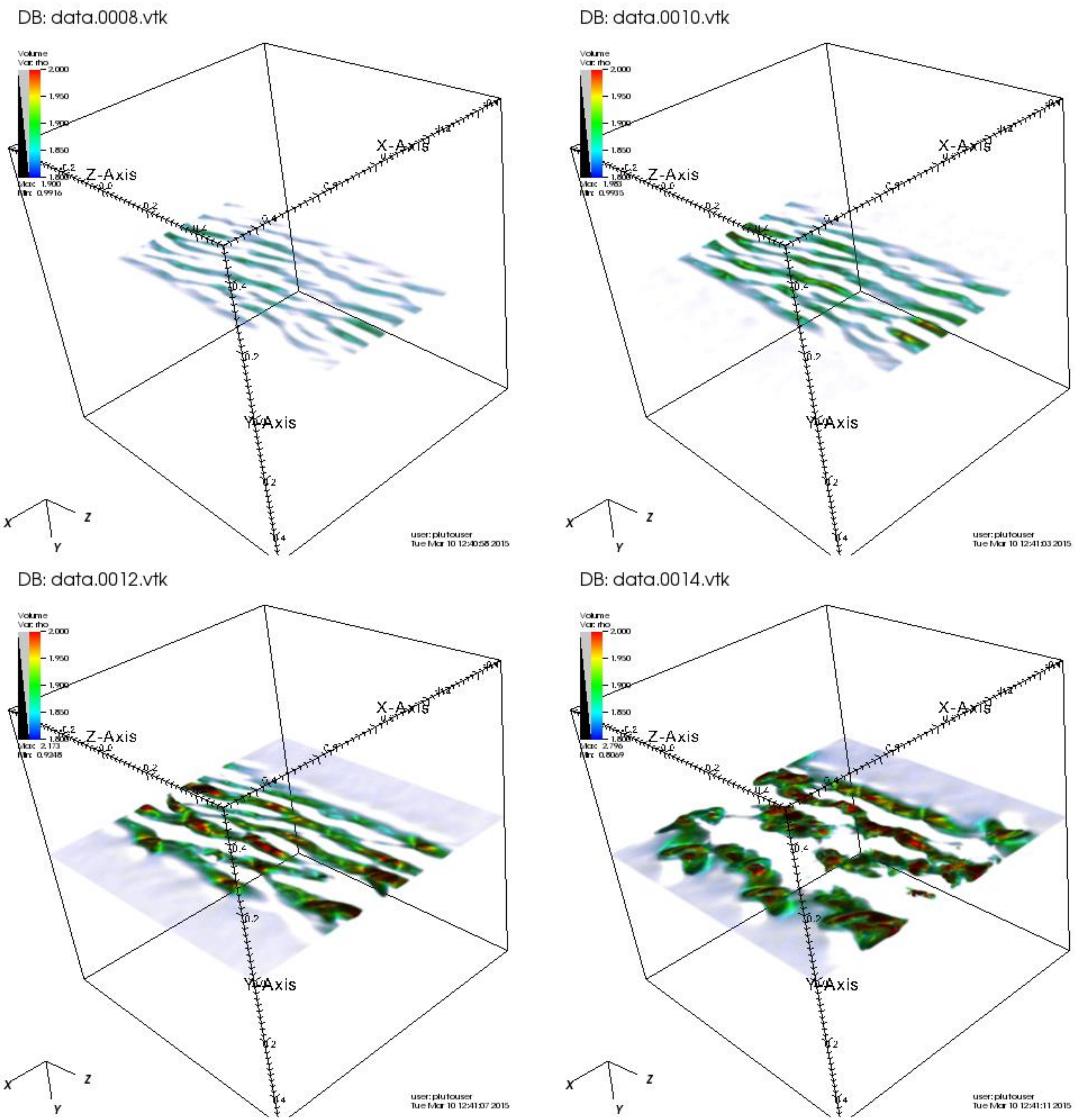
Z-Axis

No Bz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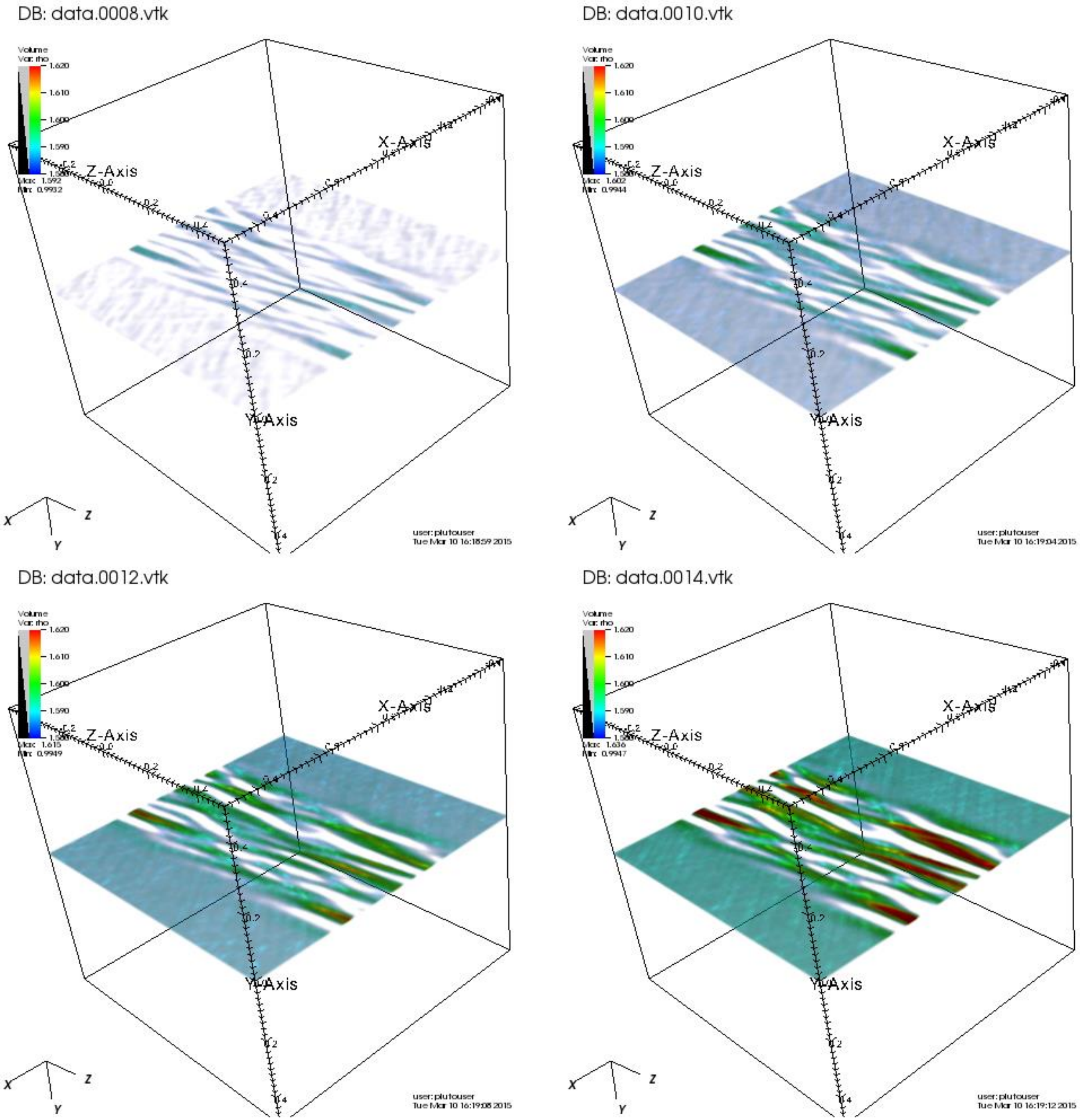
$B_z = 0.25$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Bz = 0.5

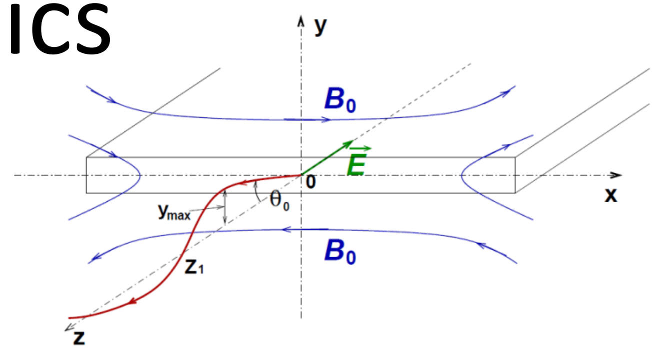
Open questions and work in progress for 3D simulations

- Scalings (reconnection rate and plasmoid formation) in *fast reconnection* regime.

- Effect of the guide field Bz in the time evolution of the current sheet.

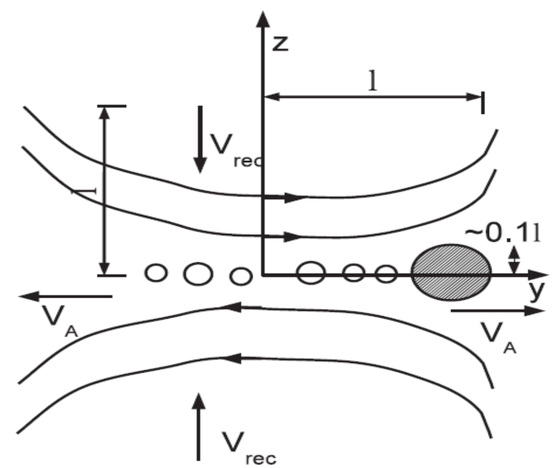
- Morphology of plasmoids in 3D.

Magnetic reconnection and Astrophysics



– Particle acceleration (e.g., Uzdensky et al. 2011)

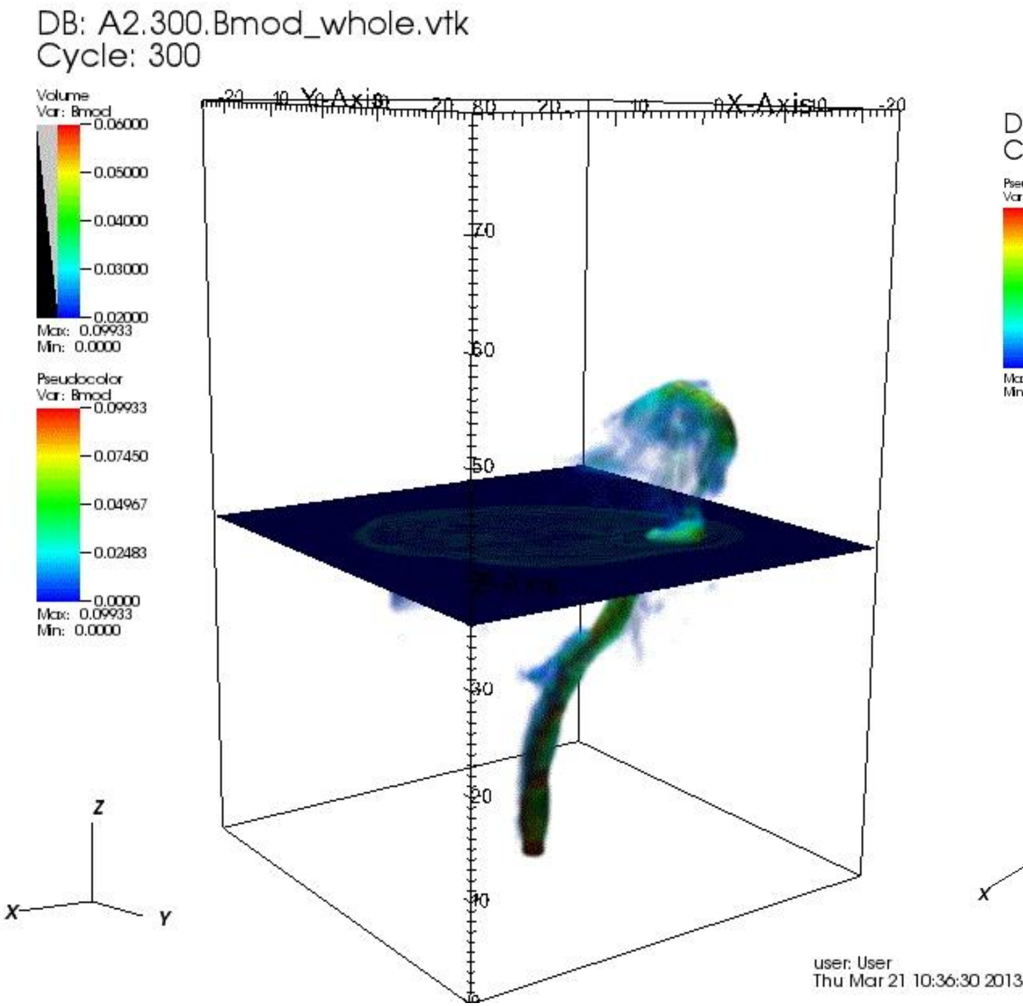
– Magnetic dissipation in PWN (see e.g., Petry & Lyubarsky 2007, Porth et al. 2013)

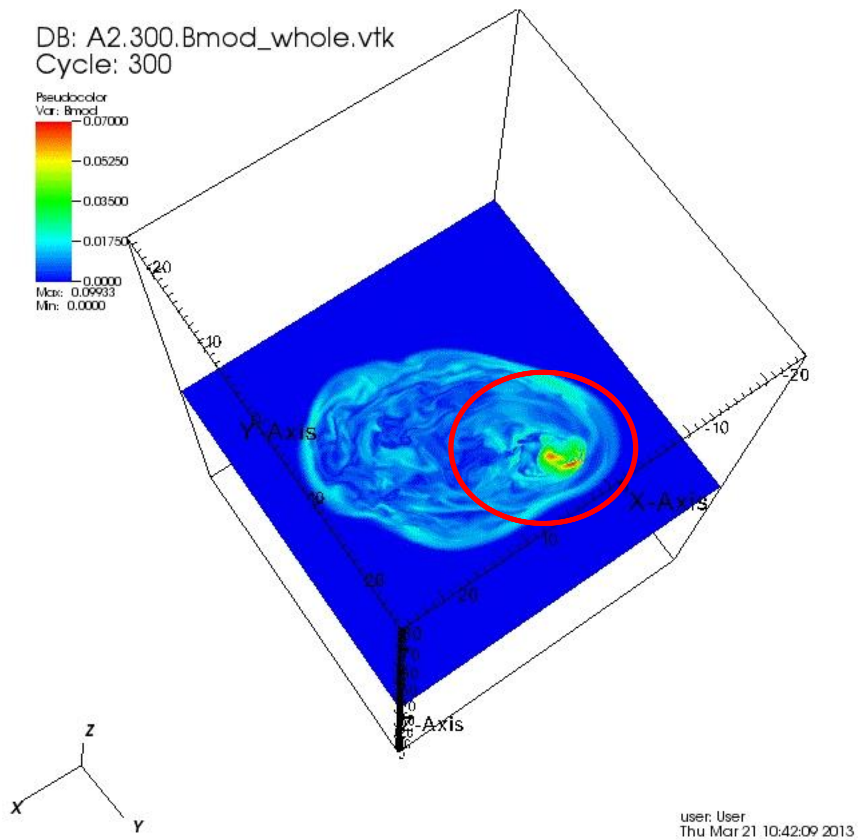


– Flares in AGN (see ***‘monster plasmoid’*** model of Giannios 2013)

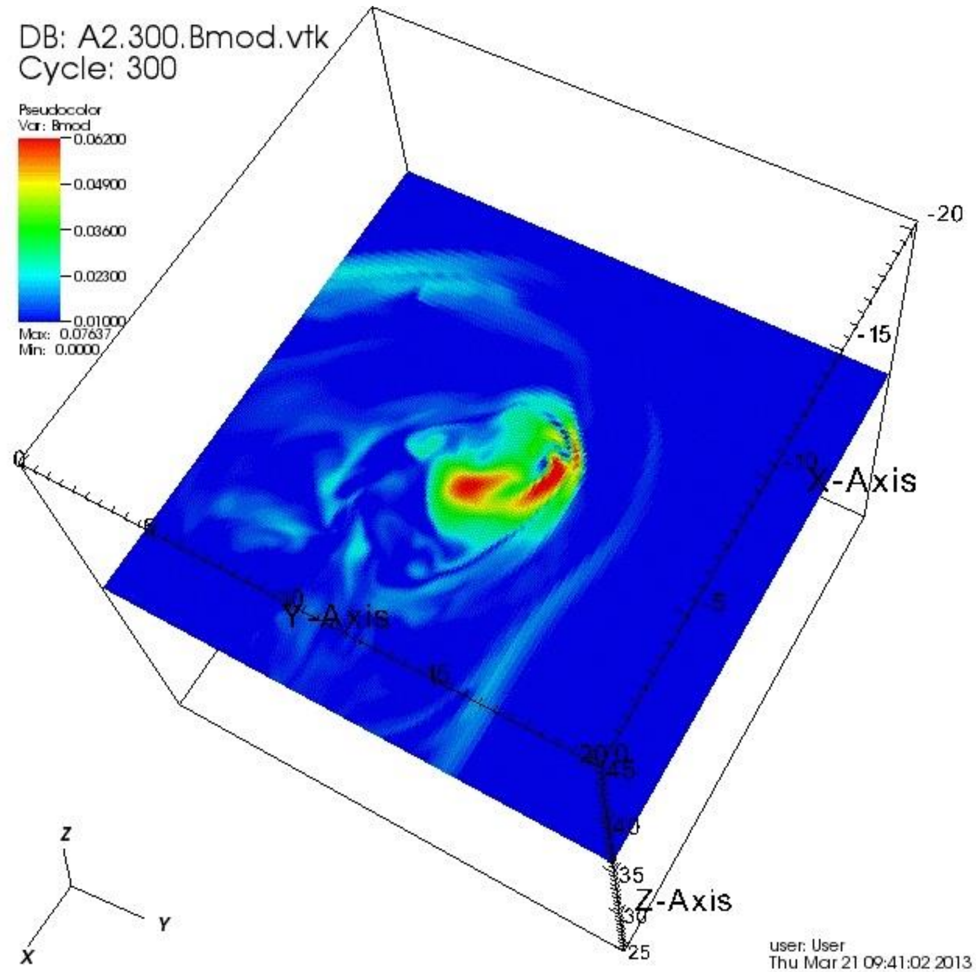
– Crab Nebula gamma-ray flares (see, e.g., Cerutti et al. 2013)

Crab Jet simulations





Mignone, Striani, Tavani, Ferrari 2013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Z
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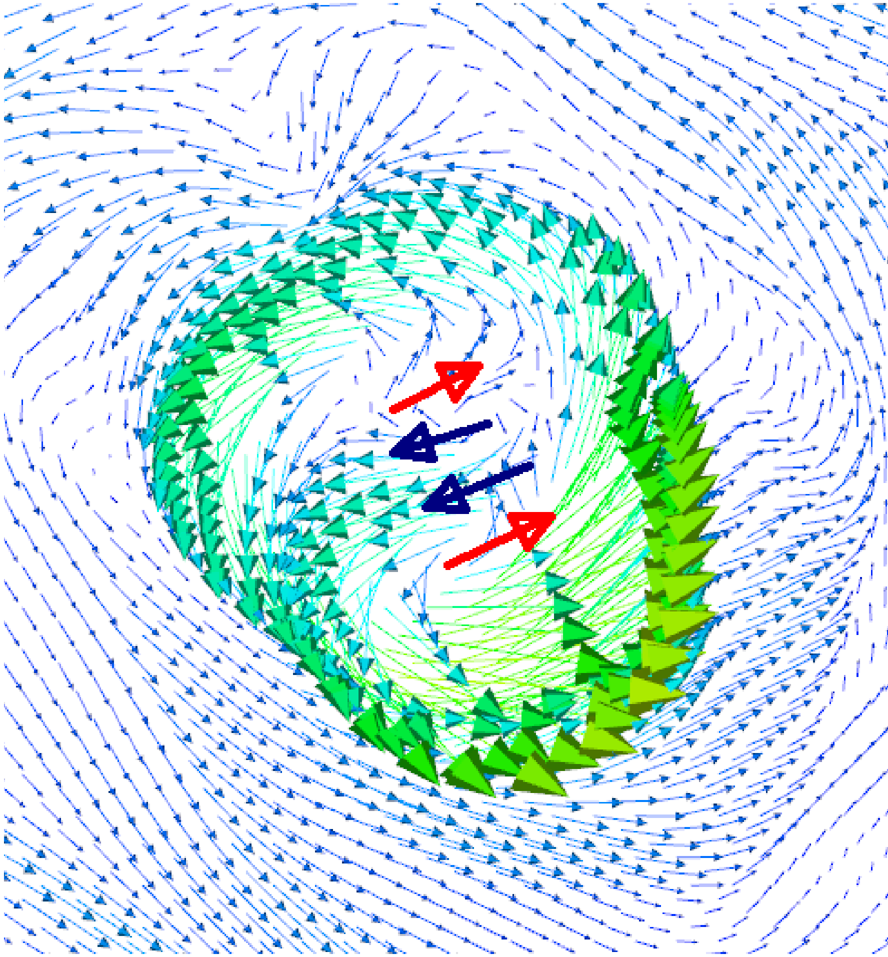
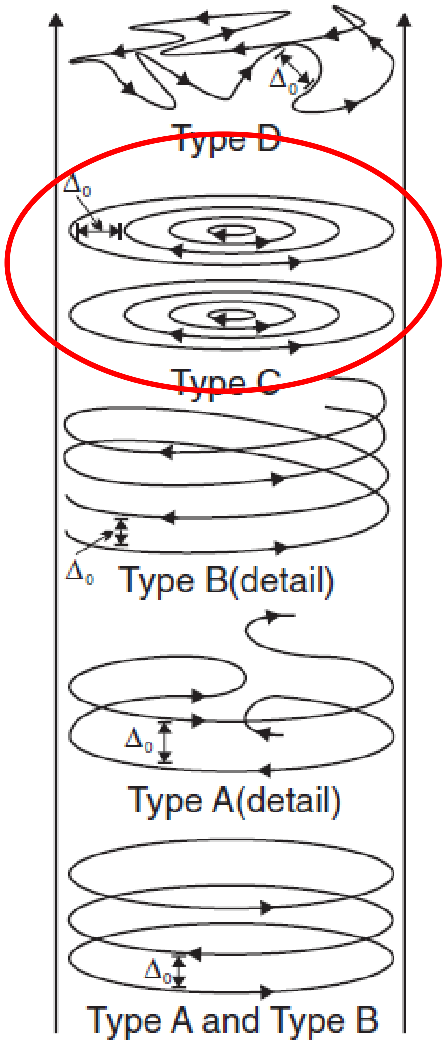
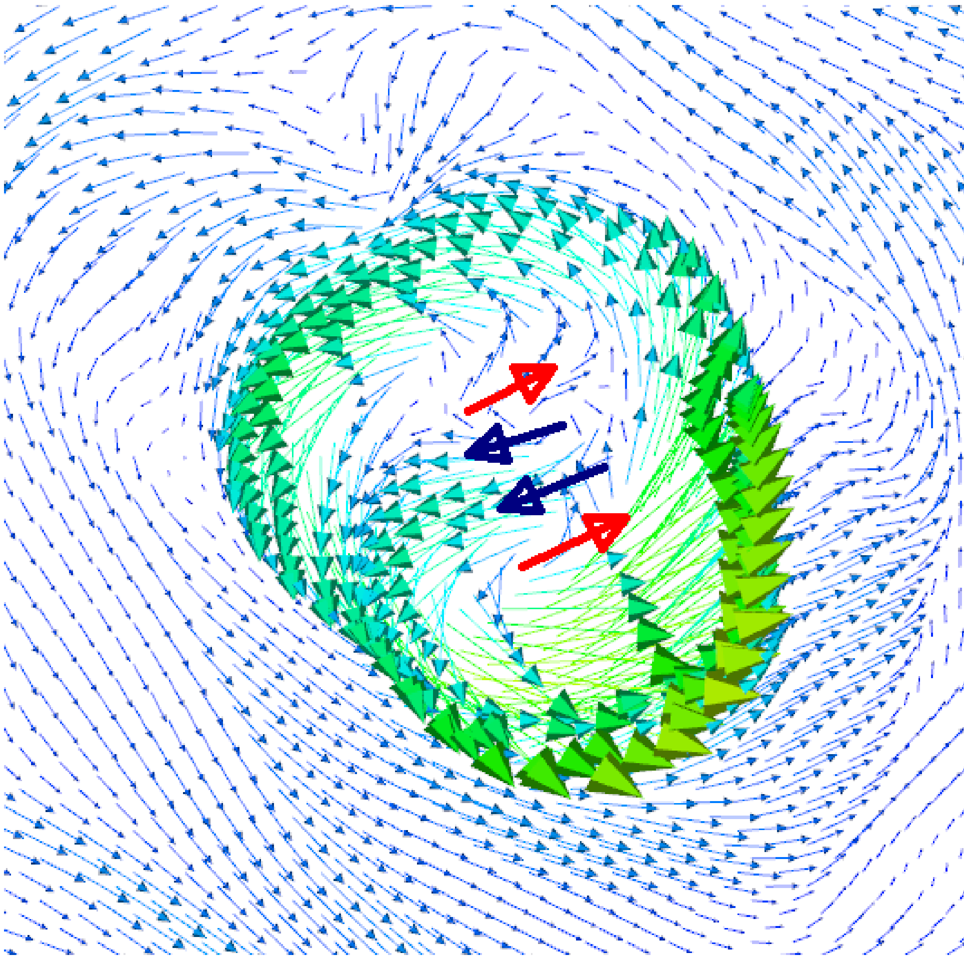
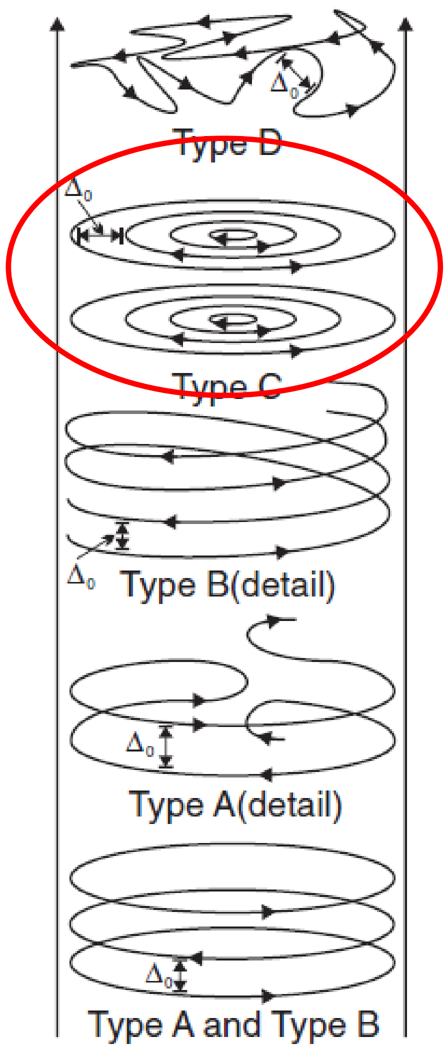
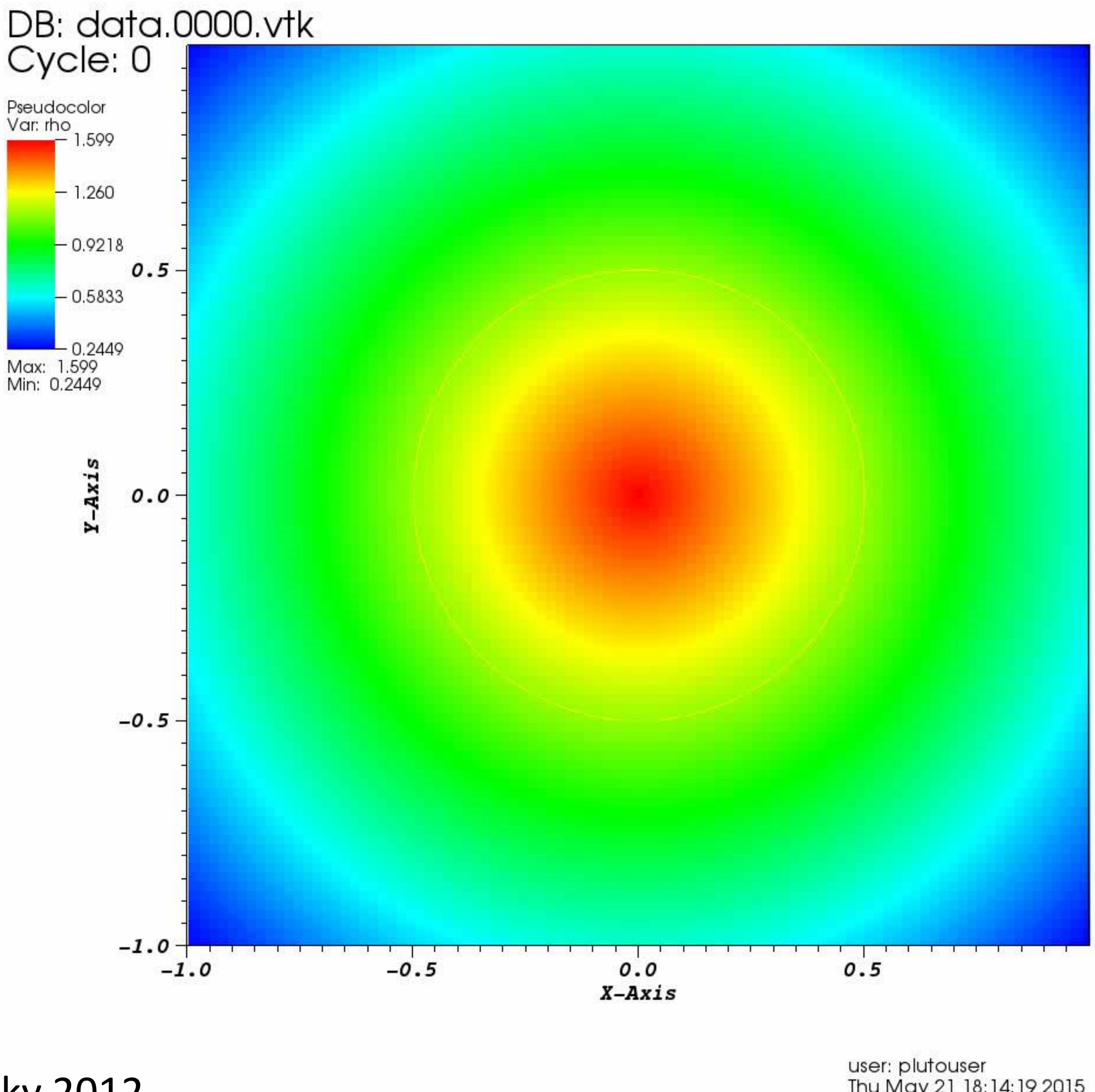
Thu Mar 21 09:41:02 2013




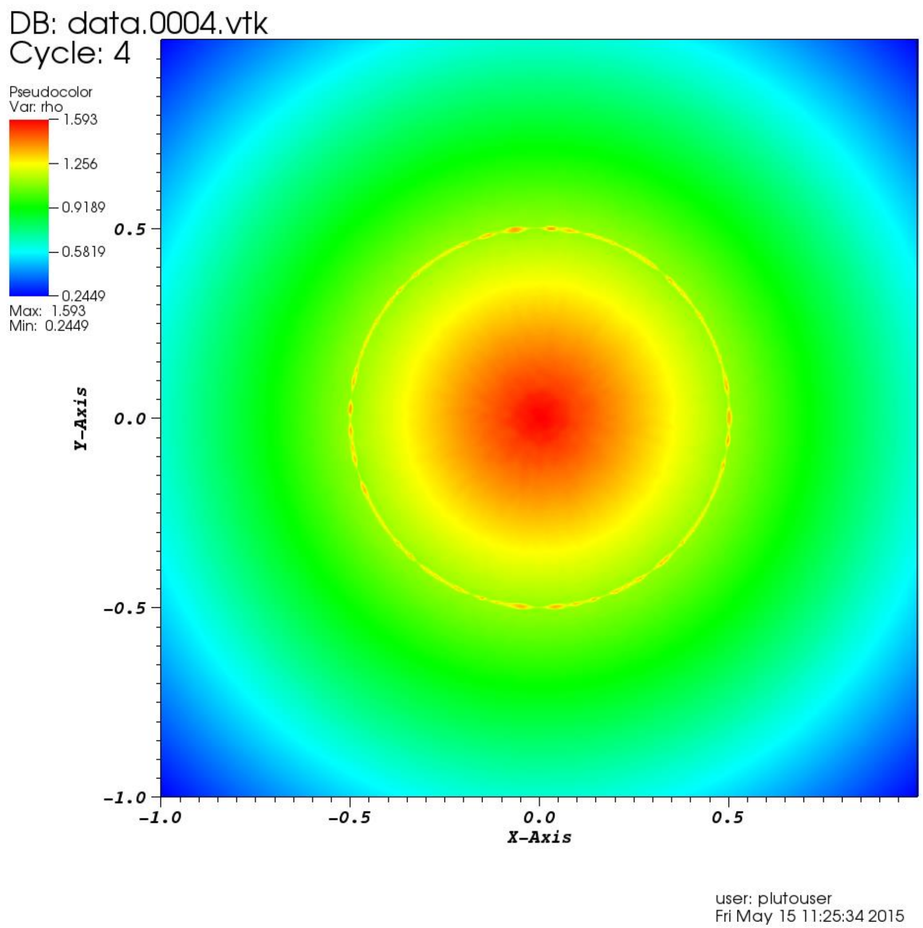


J. McKinney and D. Uzdensky 2012





J. McKinney and D. Uzdensky 2012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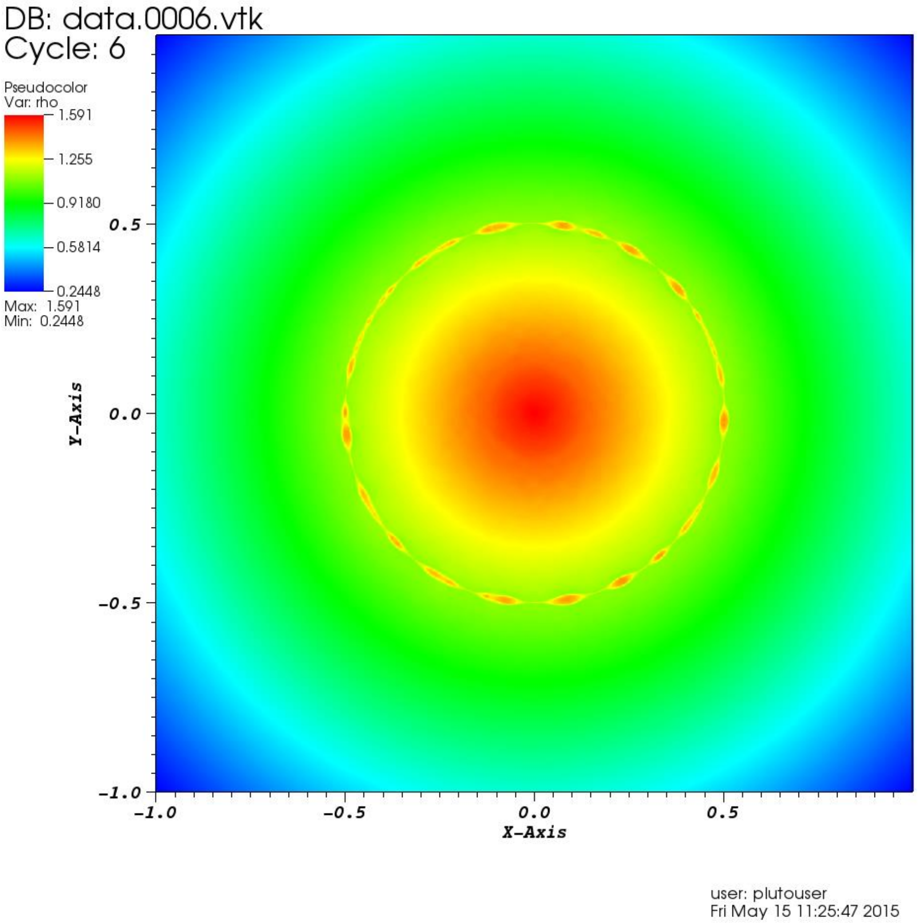
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X-Axis
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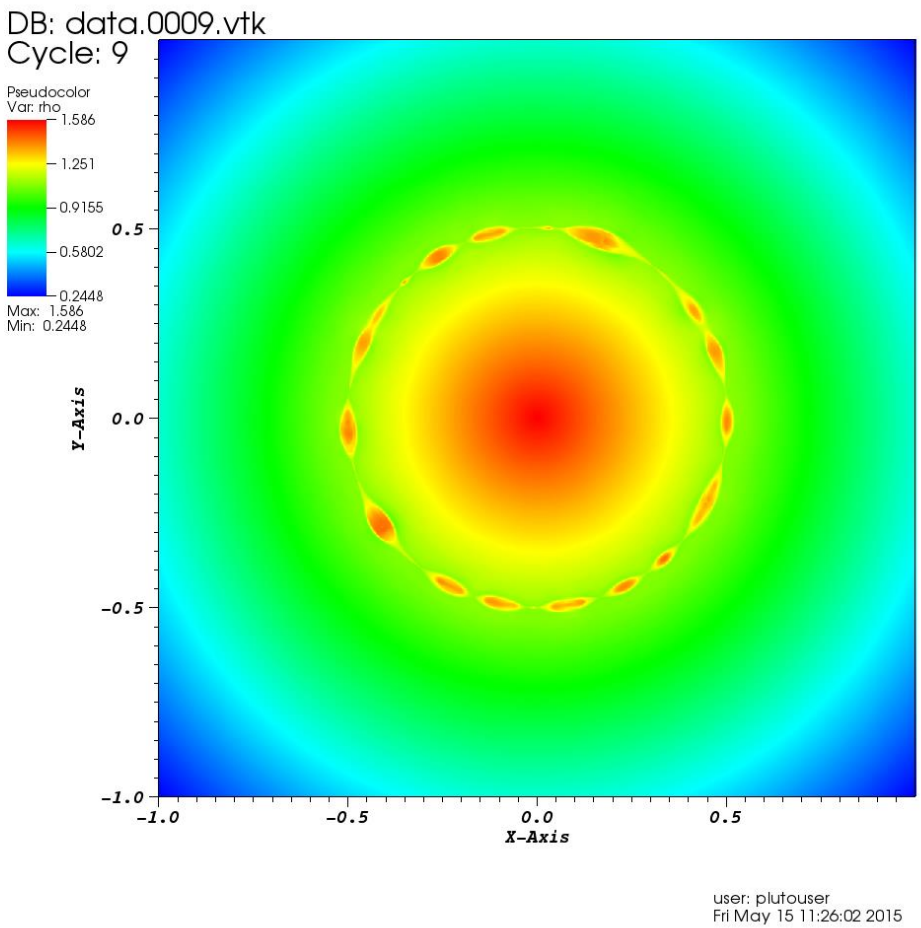
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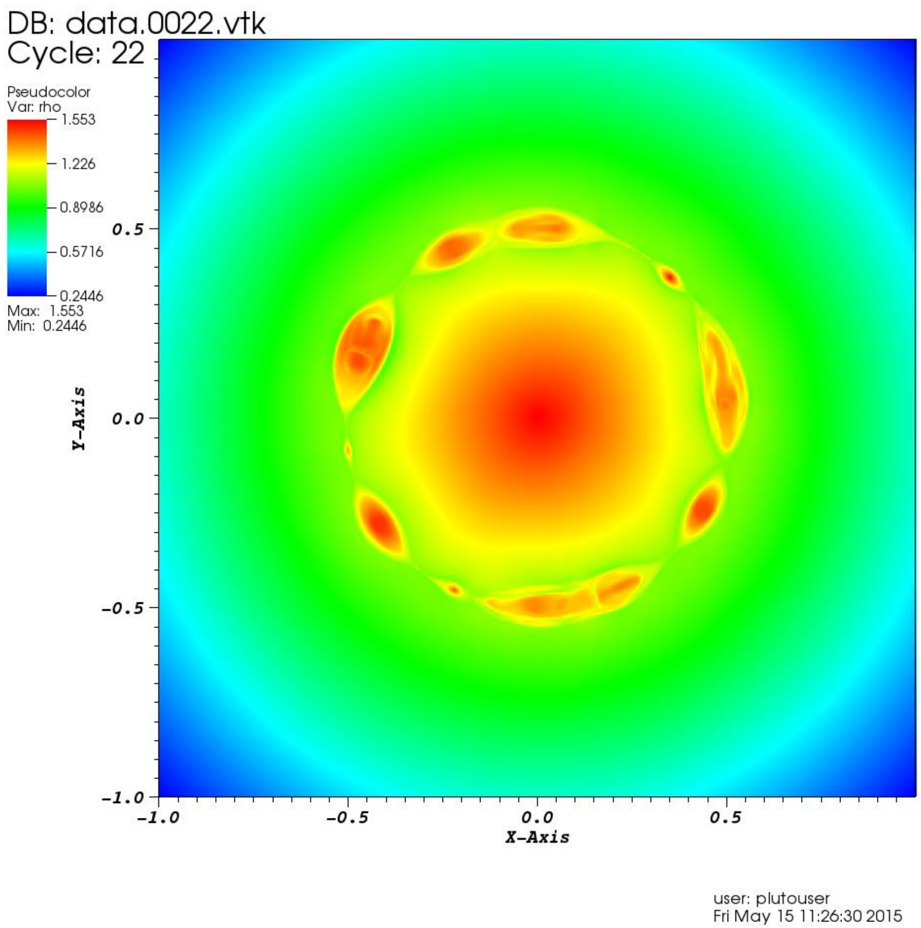
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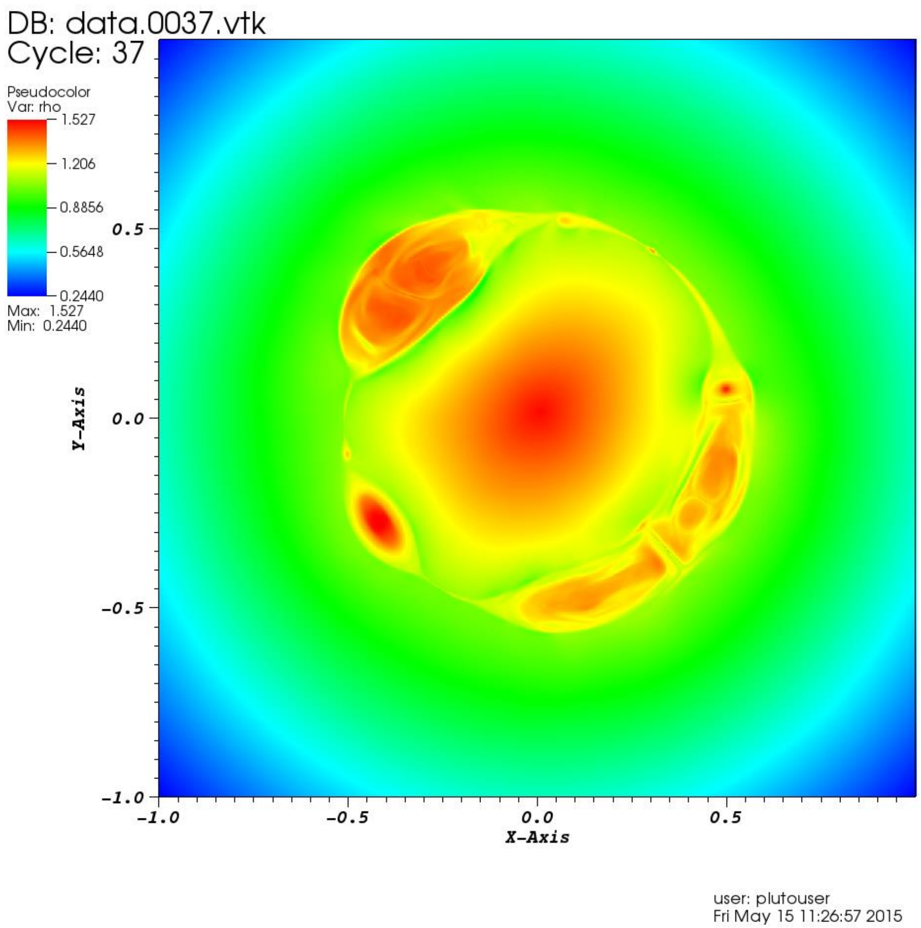
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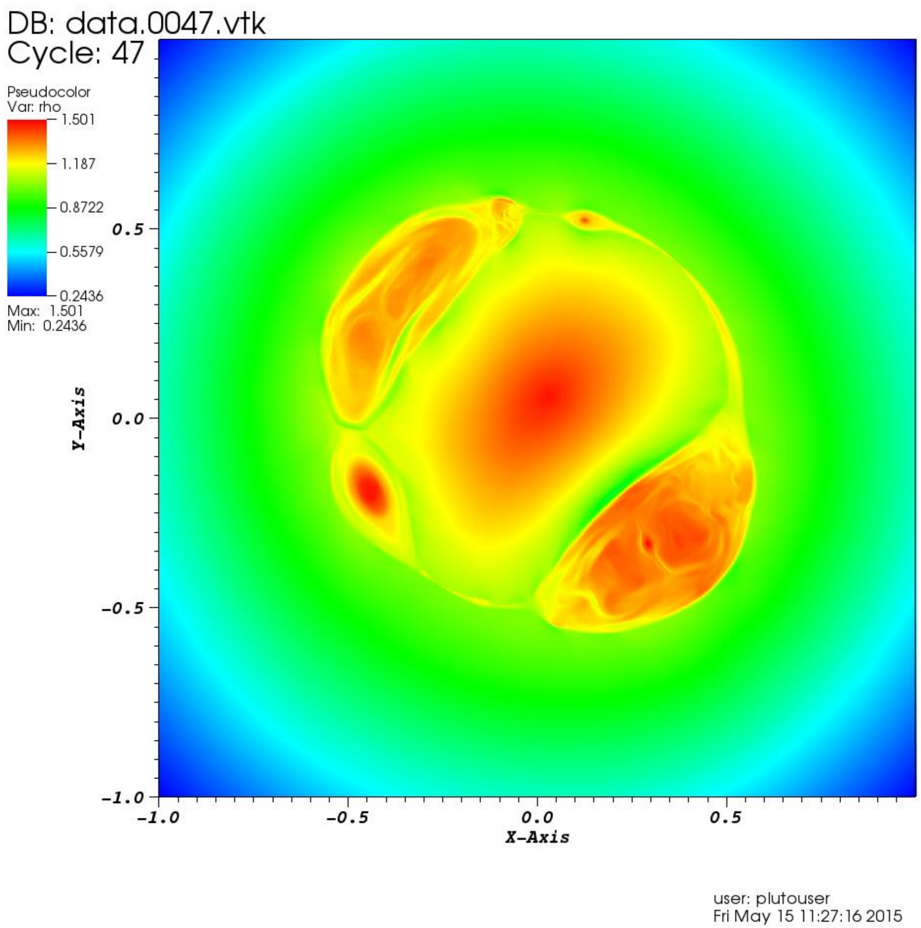
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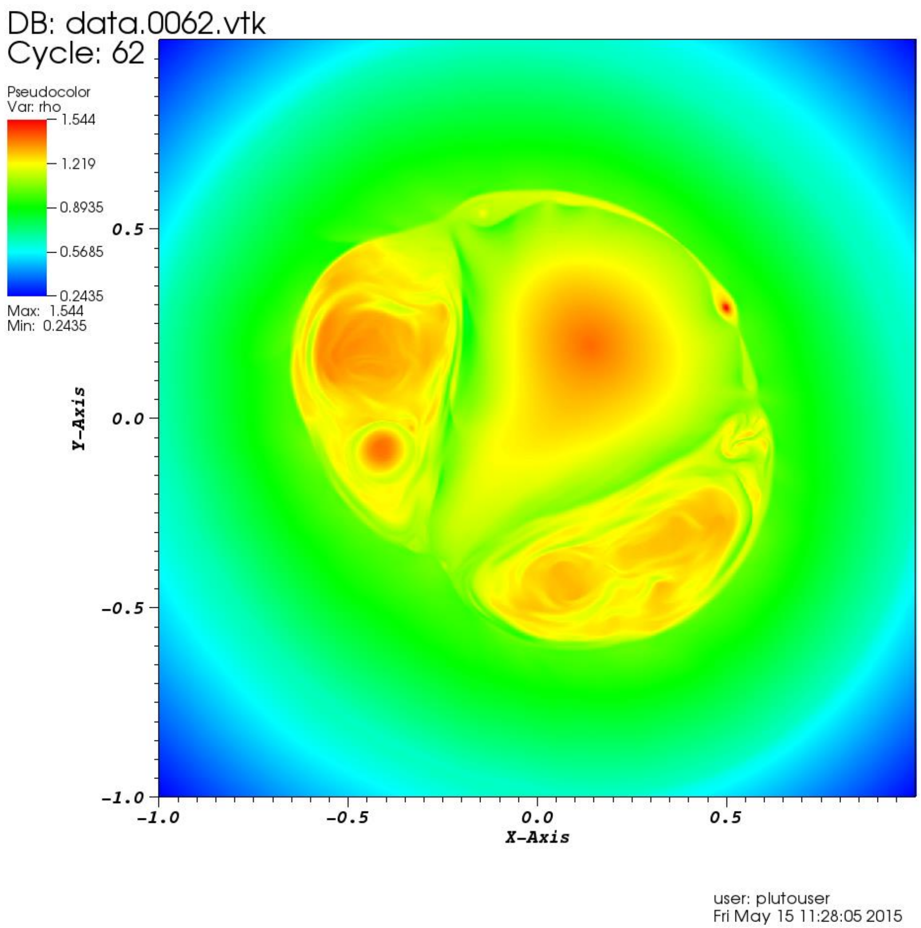
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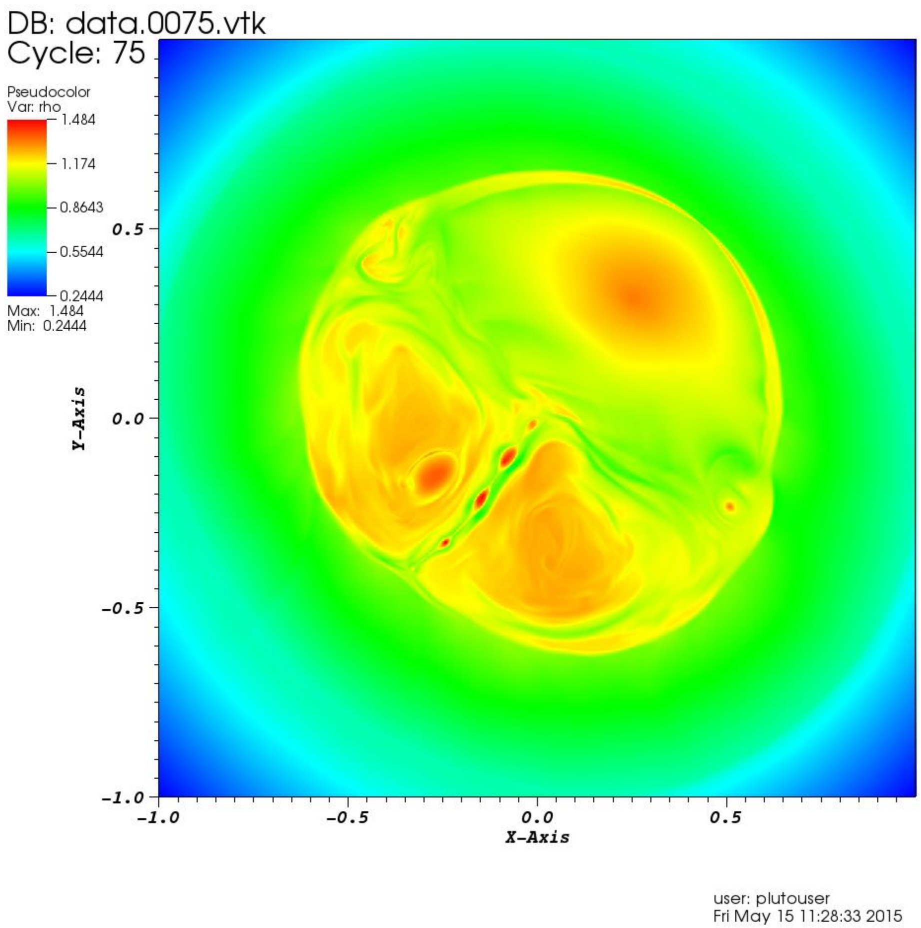
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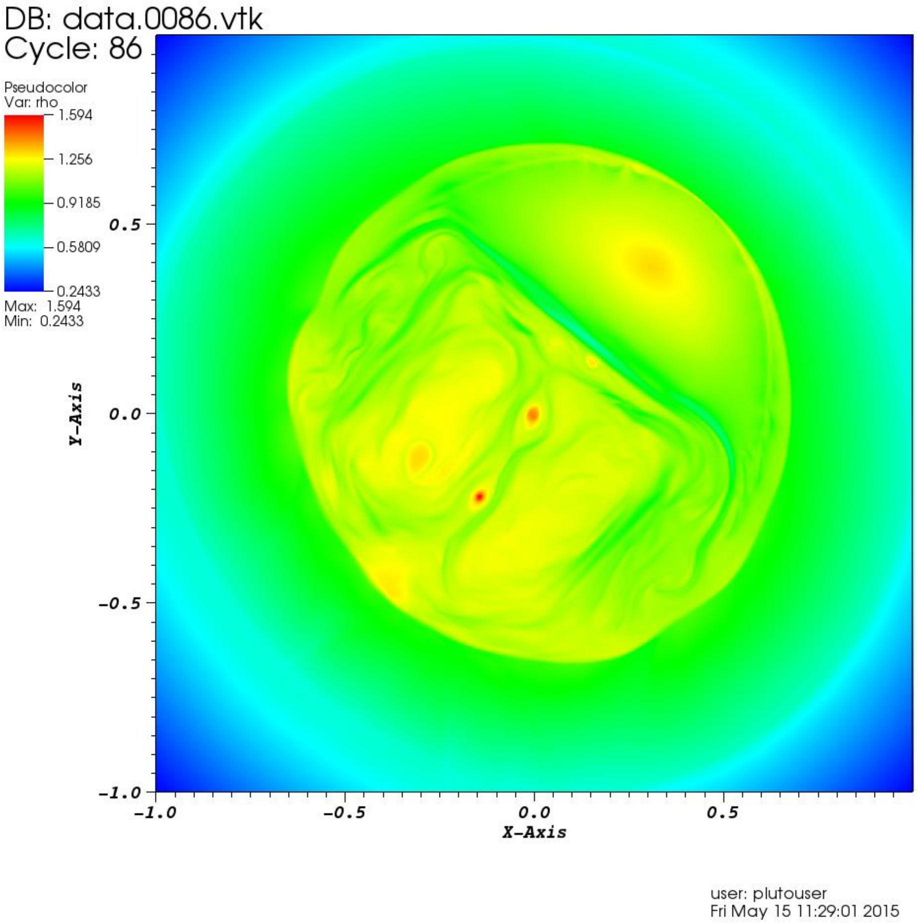

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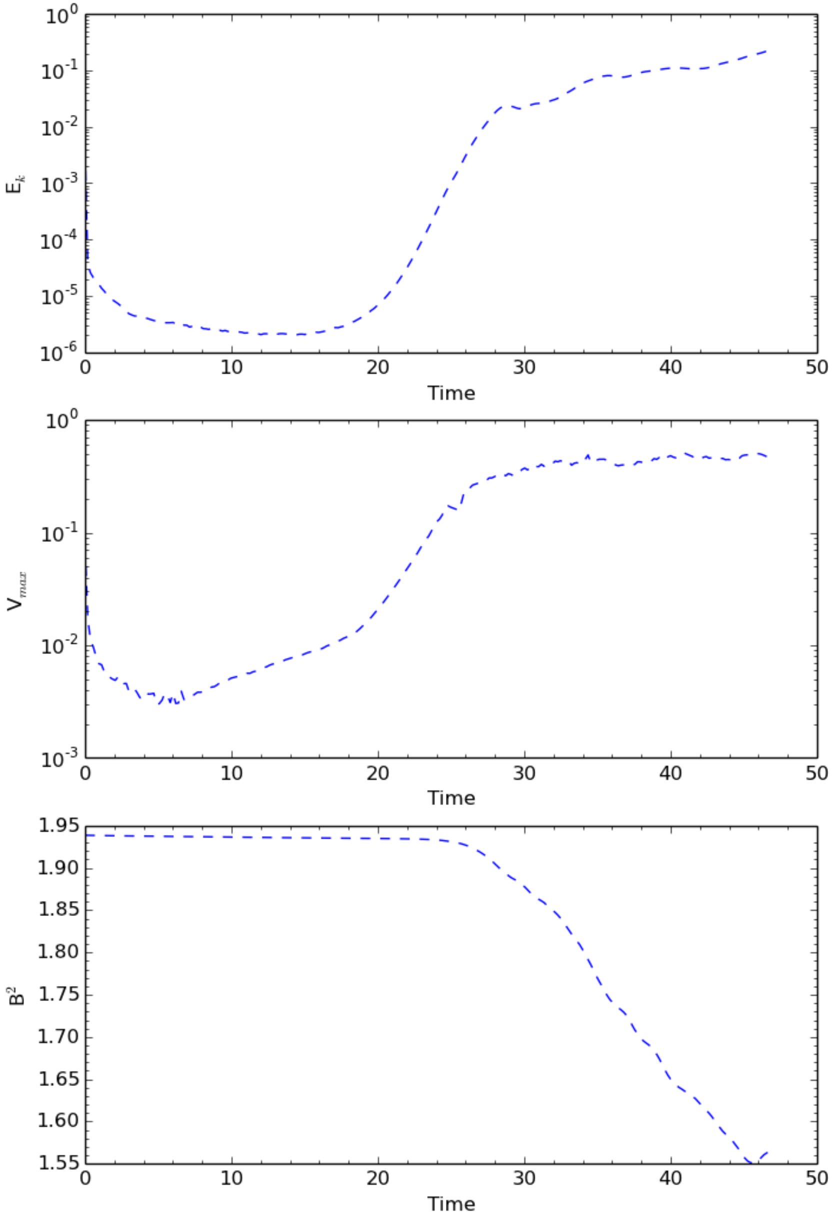
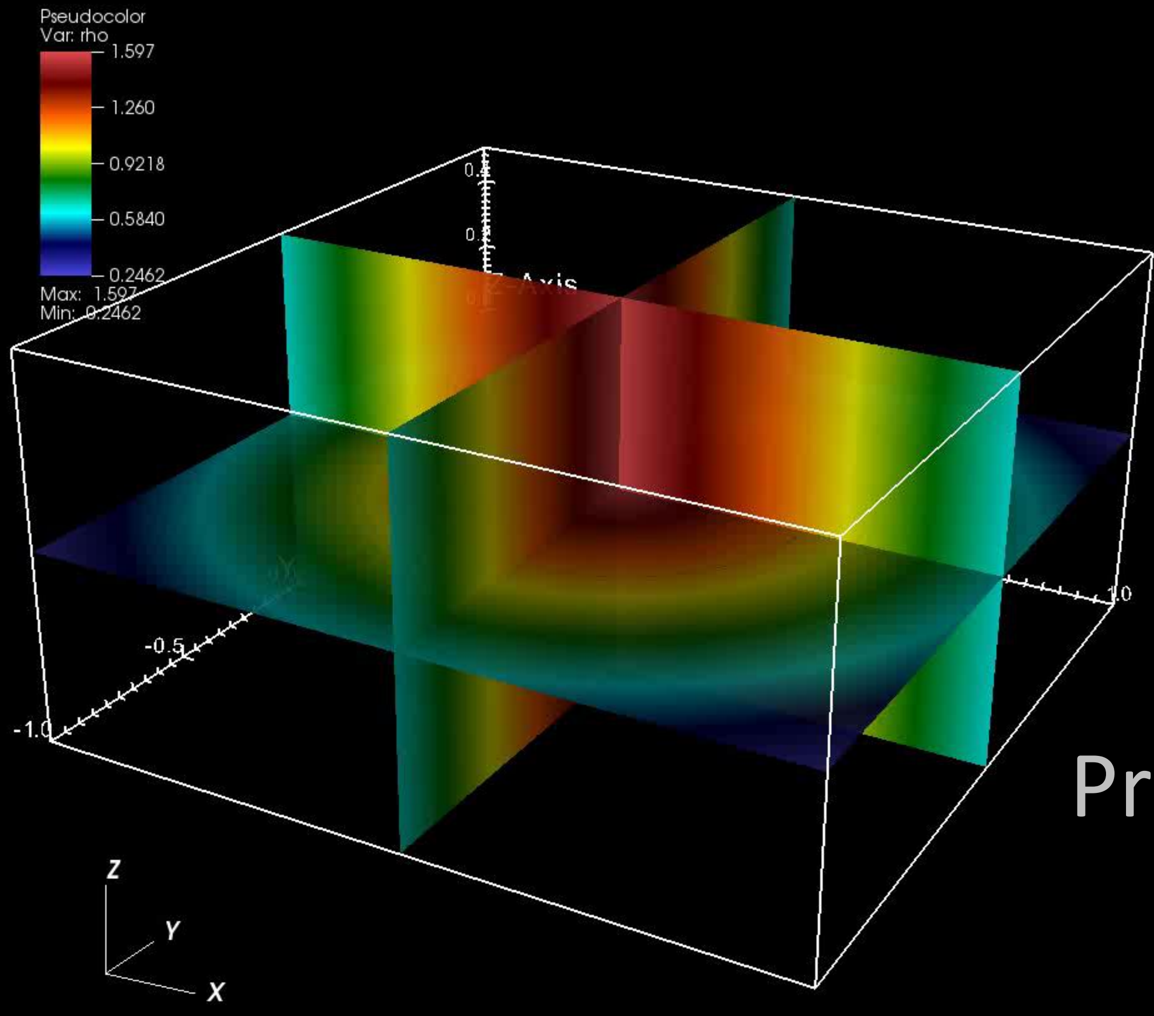
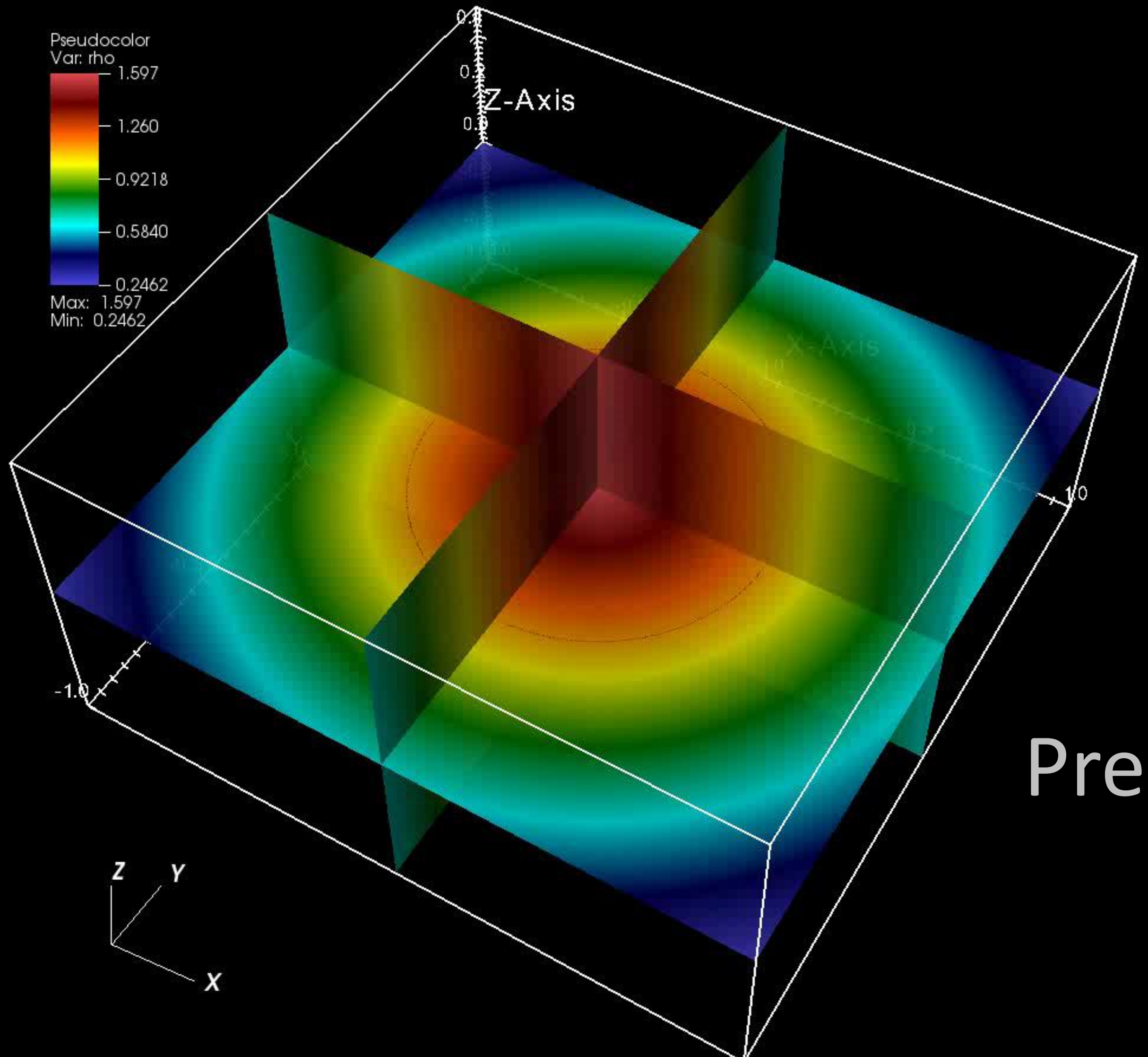


Work in progress:

- Reconnection rate
- Number of plasmoids
- Effect of the plasma beta
- Effect of multiple layers



Preliminary



Preliminary

Conclusions

- MHD reconnection in **large S** systems is fast and dynamic. Sweet-Parker theory inadequate.

- Current sheets predicted by the Sweet-Parker theory are *violently unstable* to the formation of *plasmoid chains.*

- Numerical confirmation of linear theory in the *fast reconnection* regime.

- Formation of *'monster plasmoids'.*

- Work in progress: scaling laws (reconnection rate, number of plasmoids) for 2D and 3D polar configurations.

- Future: 3D simulation of magnetic reconnection in astrophysical jets.

Thank you