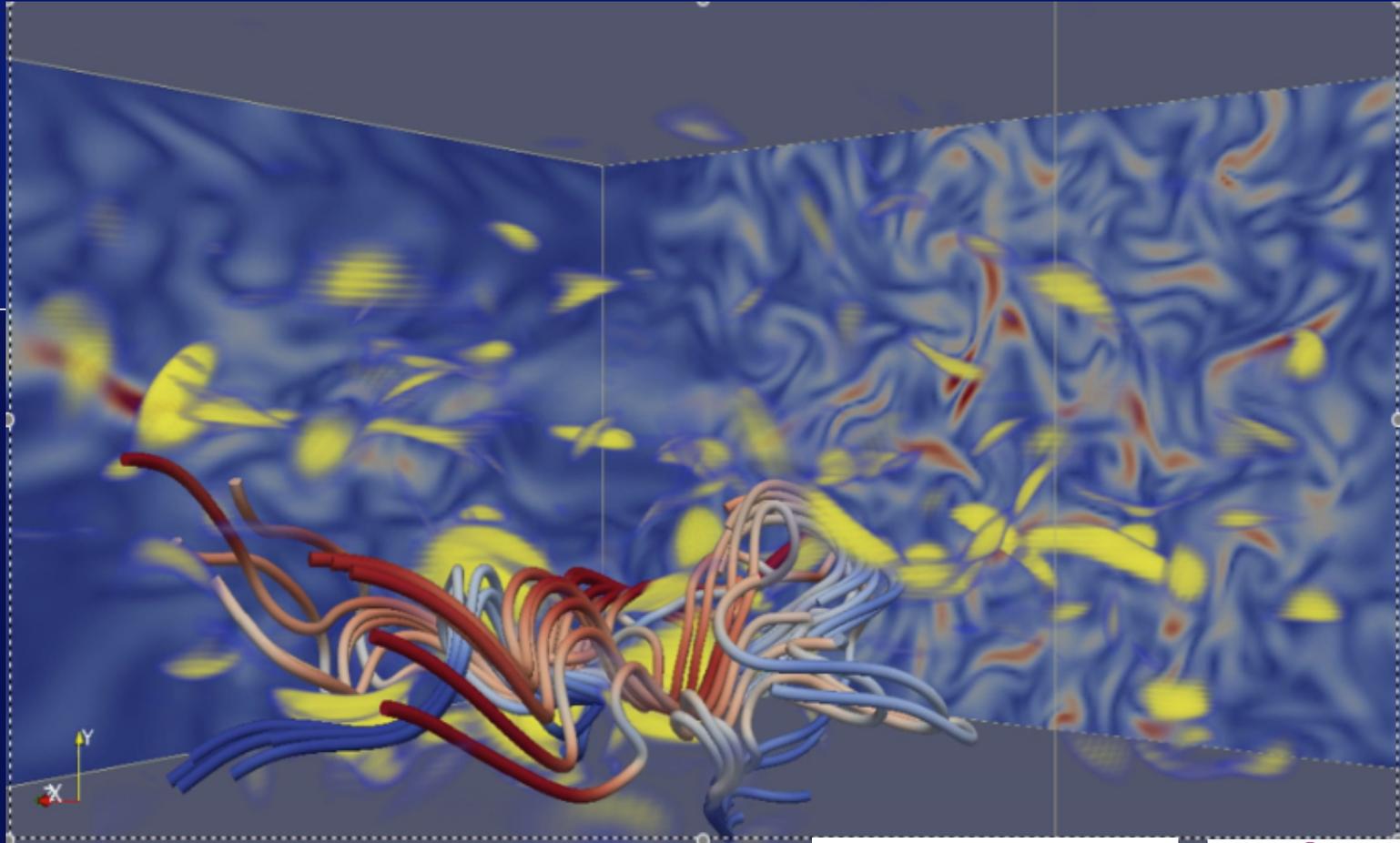


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# Parallel and Perpendicular Acceleration of Particles in Astrophysical Reconnection



**Alex Lazarian (Astronomy, Physics and CMSO)**

*Special Thanks to G. Eyink, E. Gouveia dal Pino, G. Kowal, E. Vishniac, K. Otmianowska-Mazur*

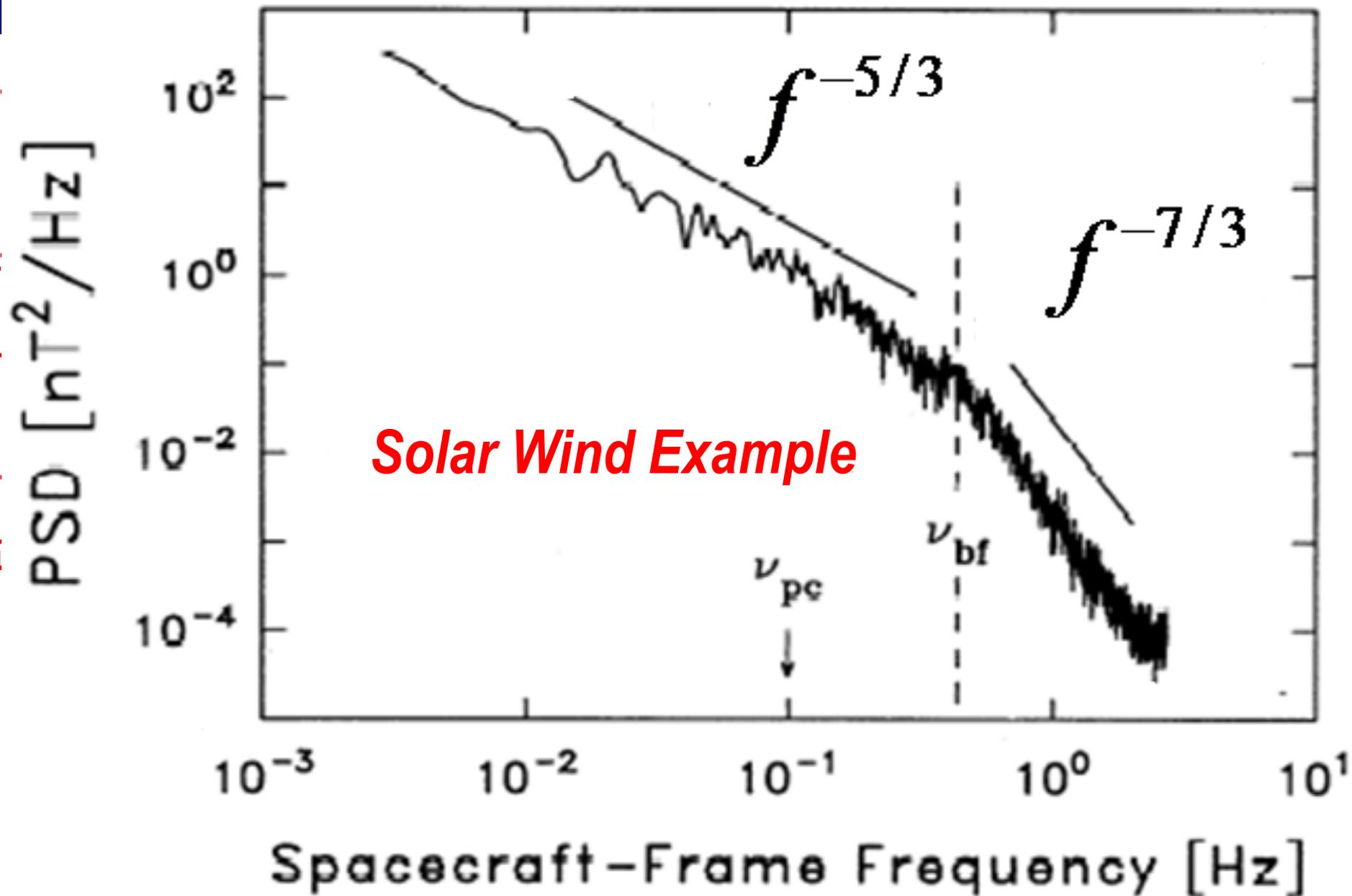


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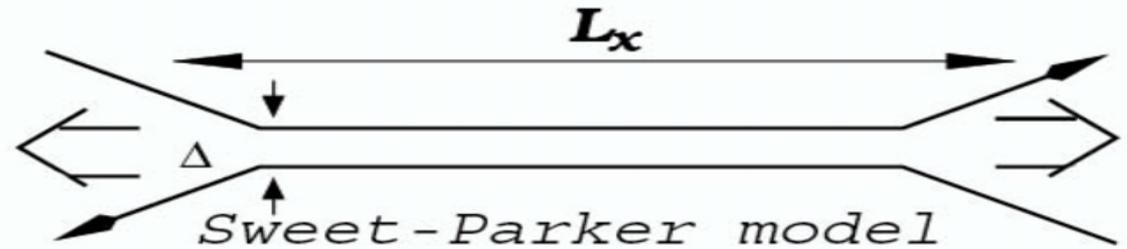
# Astrophysical fluids are turbulent



# LV99 model extends Sweet-Parker model for realistically turbulent astrophysical plasmas

## LV99 reconnection:

1. Outflow is determined by field wandering.
2. Reconnection is fast with Ohmic resistivity only.



$$V_{rec} = V_A \frac{\Delta}{L_x}$$

Lazarian & Vishniac (1999)

henceforth referred to as LV99

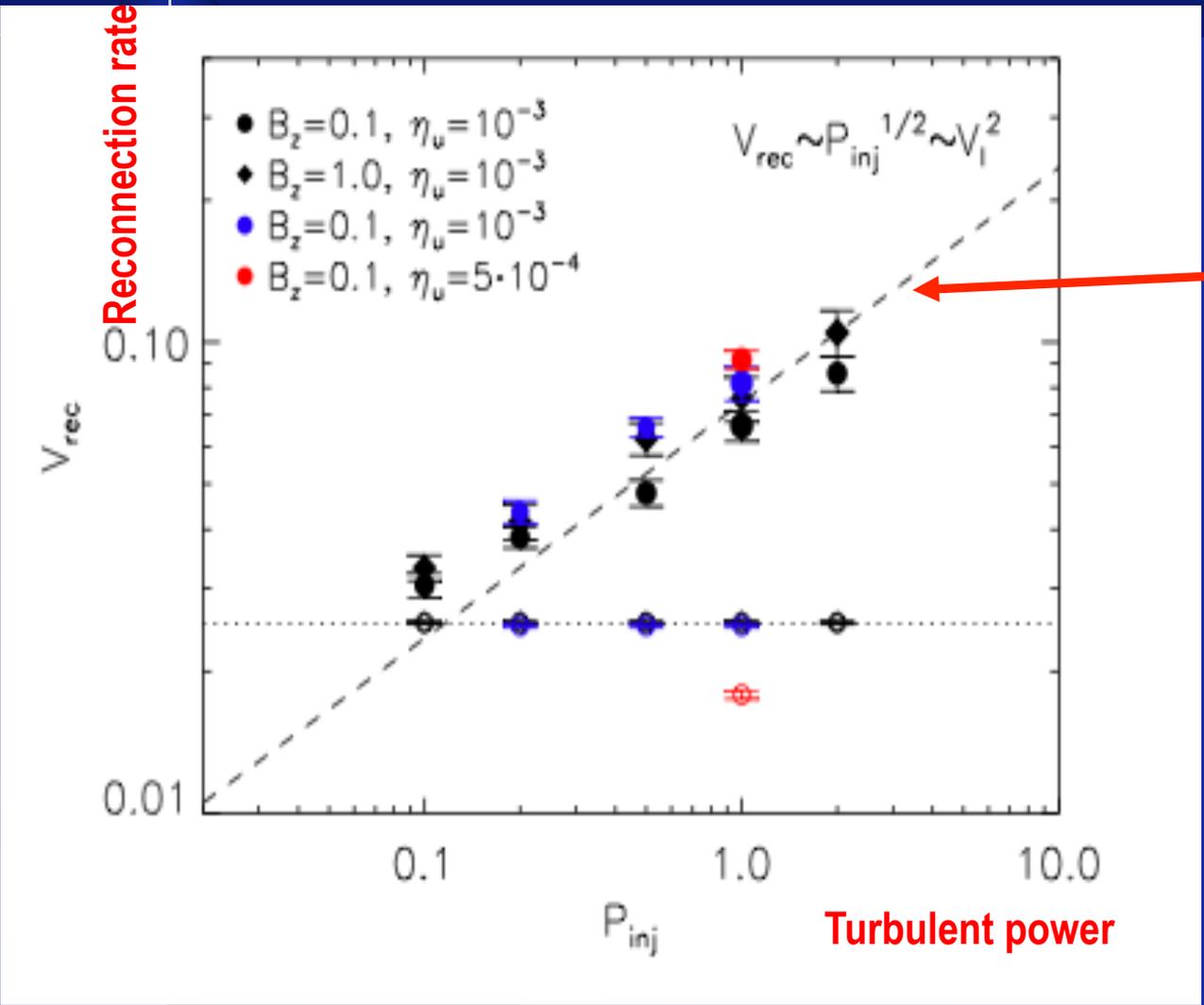
**Big Implication: LV99 means that magnetic field in *turbulent fluids* is not frozen in**



Hannes Alfvén

***Violation of magnetic field frozen in condition in turbulent fluids discussed in Eyink (2010, 2011). The equivalence of this and LV99 approach was demonstrated in Eyink, Lazarian & Vishniac 2011.***

# Simulations with \*different\* types of driving confirm LV99 predictions

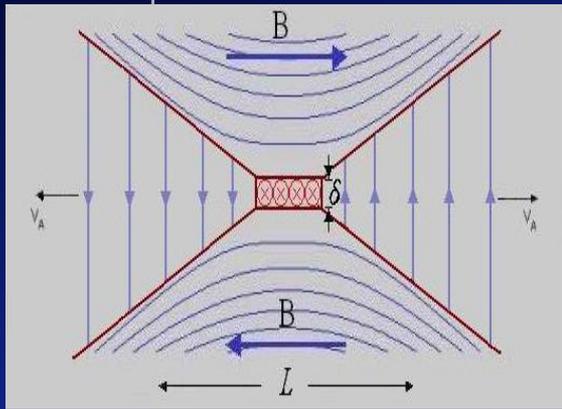


Lazarian & Vishniac (1999) prediction is  $V_{rec} \sim P_{inj}^{1/2}$

*New simulations*

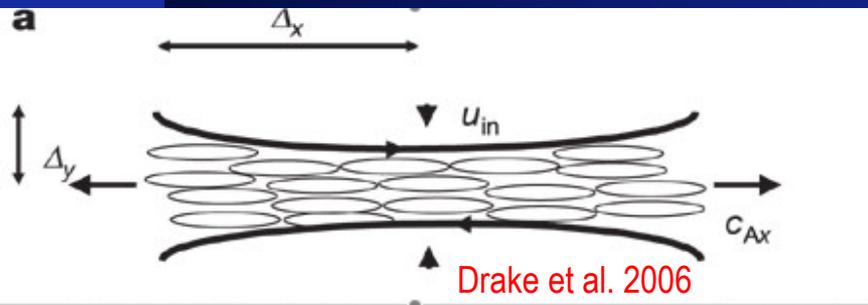
# Within the last decade convergence between the accepted paradigm and LV99 model took place

## Paradigm 1999



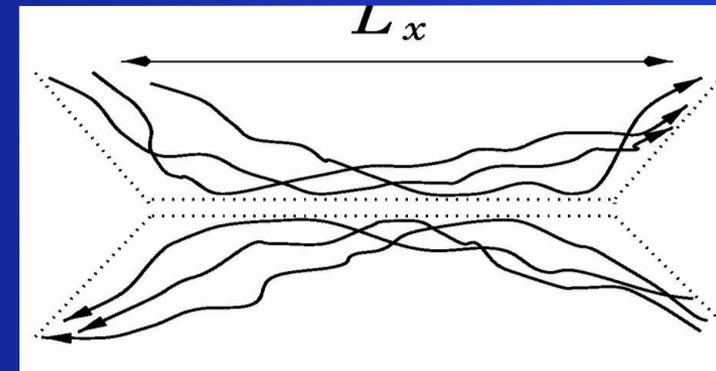
Hall effect is **required**

## Paradigm 2012



Tearing reconnection (Hall effect is **not required**)

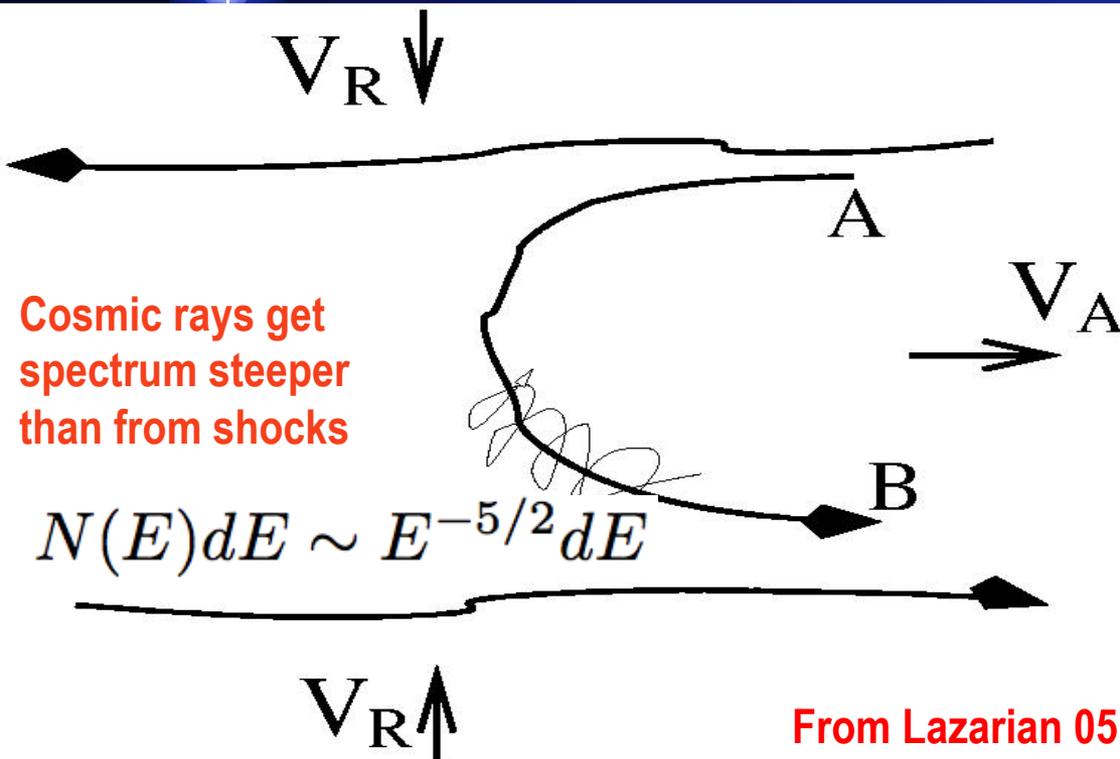
## LV99 model



Hall effect is **not required**  
(Fully 3D, turbulence)

*Current tendency is to study 3D effects and transition to turbulence, i.e. further convergence.*

# In LV99 reconnection model energetic particles get accelerated by First Order Fermi mechanism

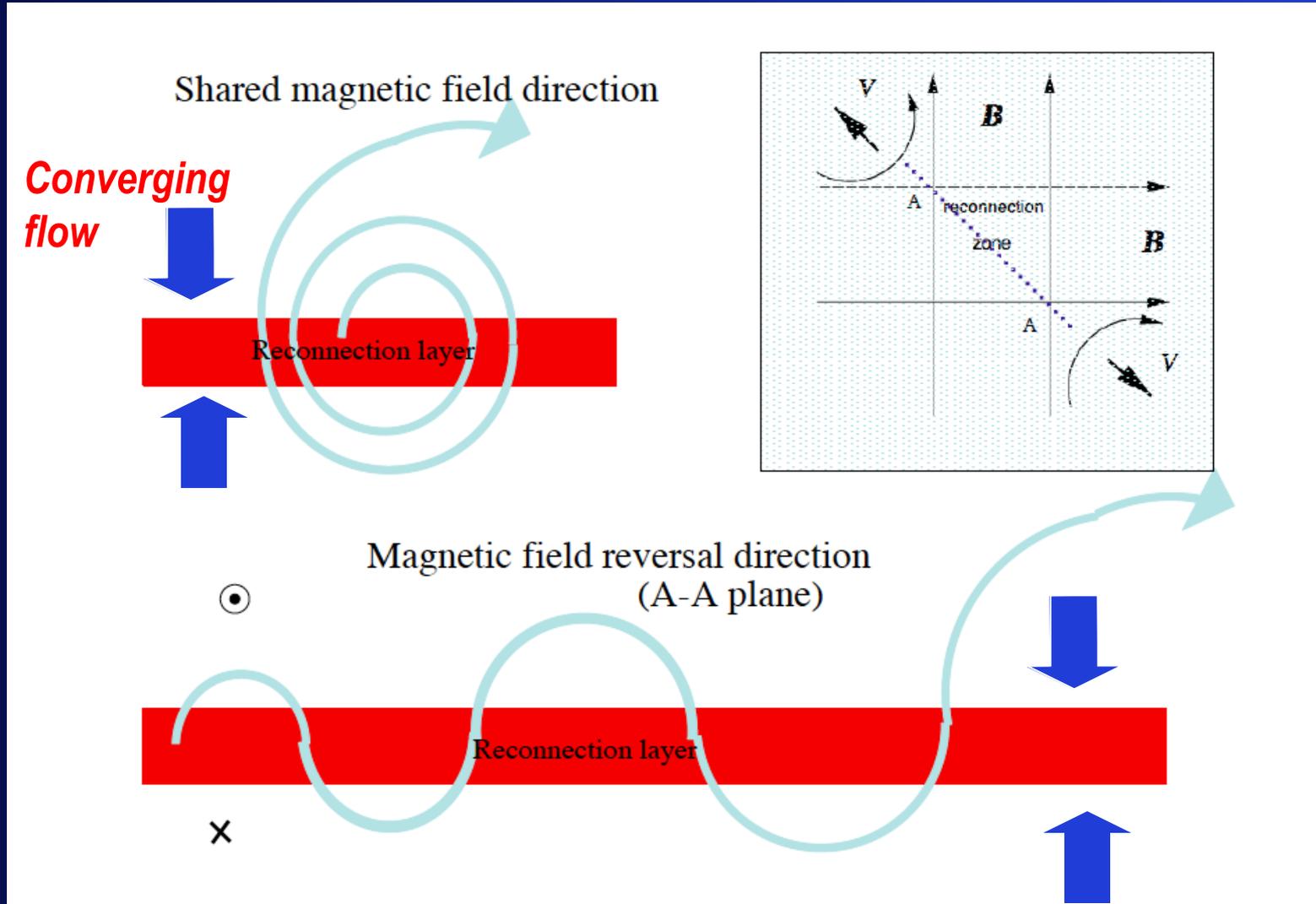


(Similar to Drake 2006).

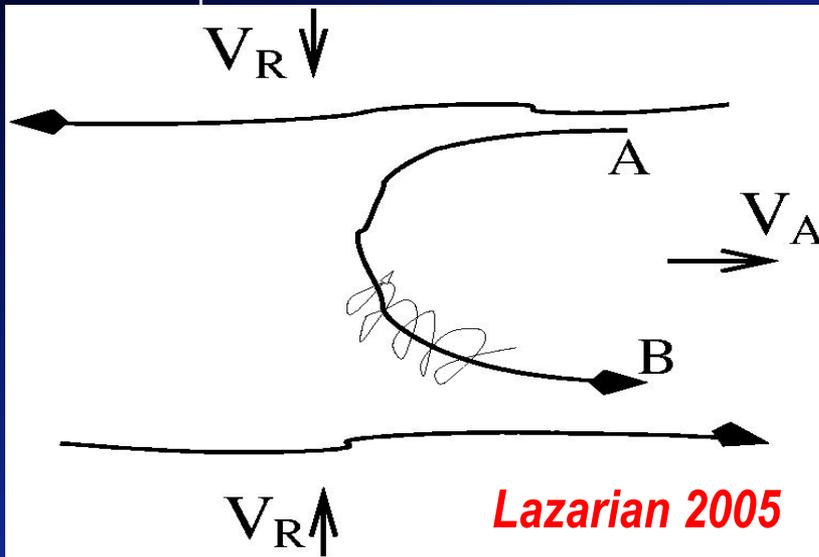
From Lazarian 05

Published in De Gouveia Dal Pino & Lazarian 2003

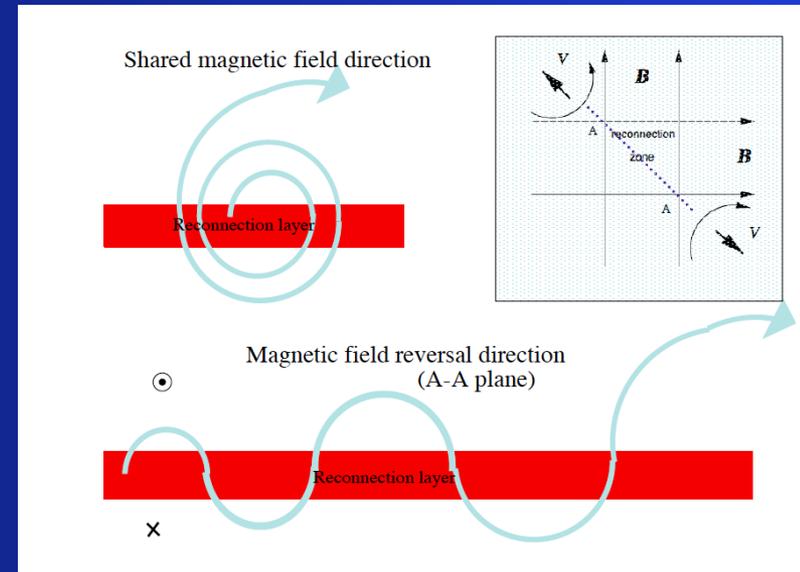
# First order Fermi acceleration happens also for perpendicular components



# What does happen: parallel or perpendicular First order Fermi acceleration?

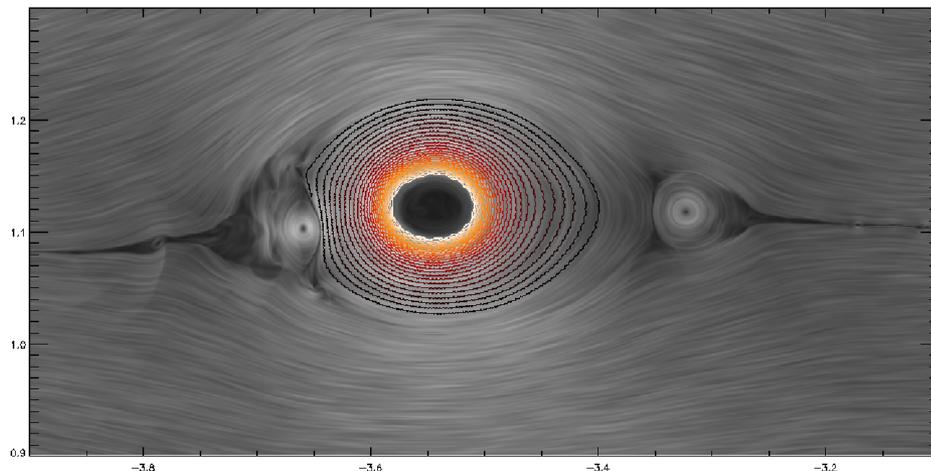
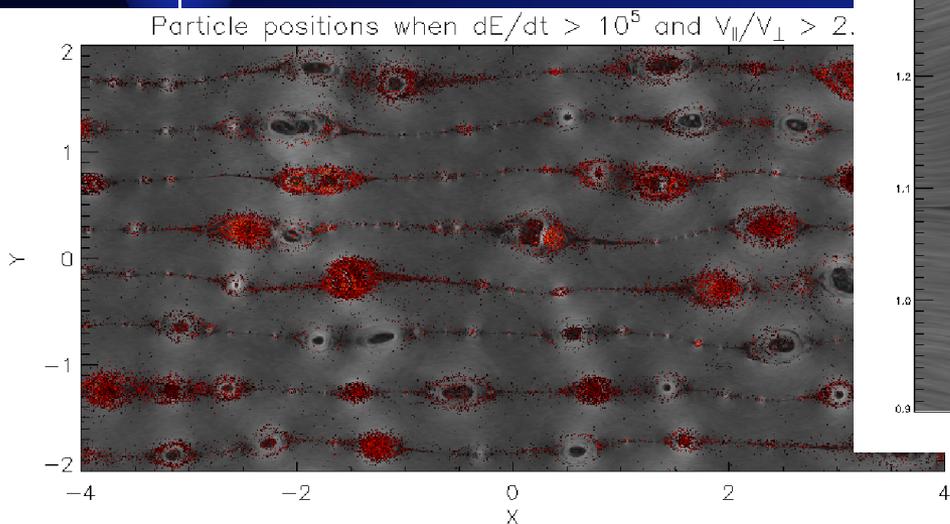


*Parallel acceleration (similar to that  
In Drake et al. 2006)*

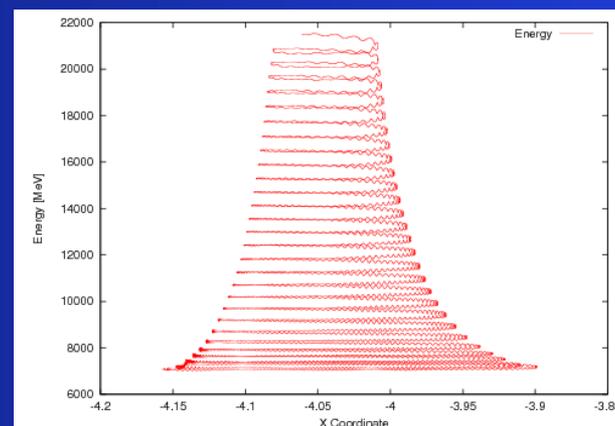


*Perpendicular acceleration*

# MHD calculations reproduce parallel acceleration in 2D PIC calculations by Drake et al and go beyond



Zoom in into itrajectories



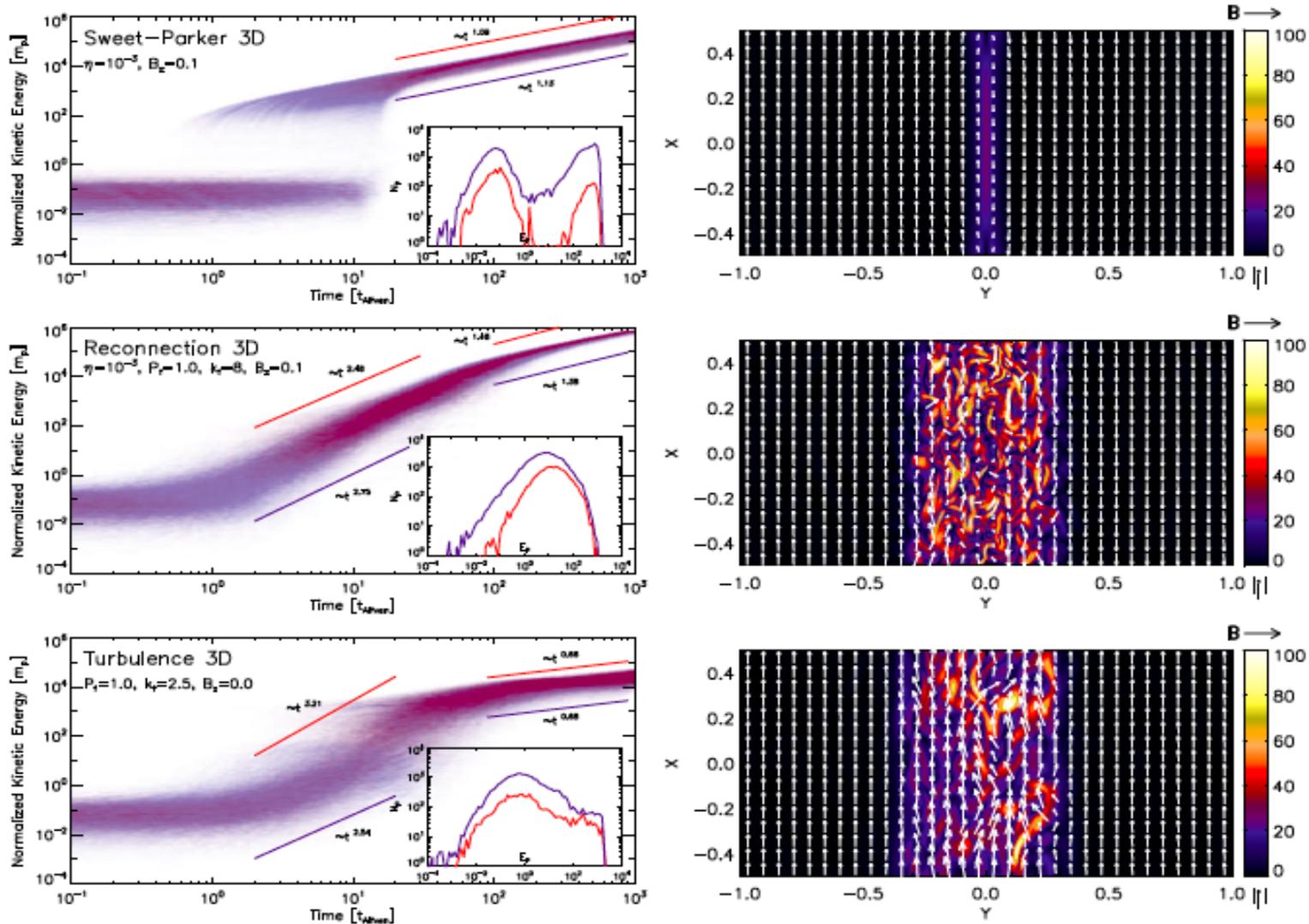
Regular energy increase

Multiple reconnection layers are used to produce volume reconnection.

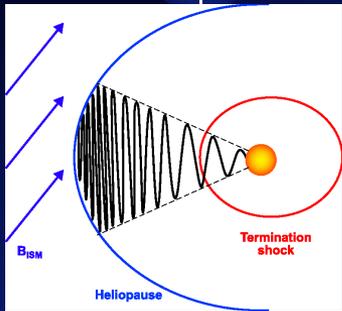
Kowal et al. 2010

# Perpendicular First order Fermi acceleration may dominate in 3D reconnection in the presence of turbulence

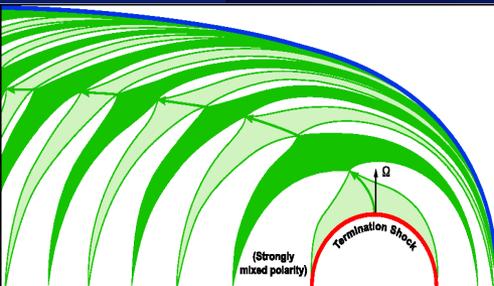
Kowal et al. 2012



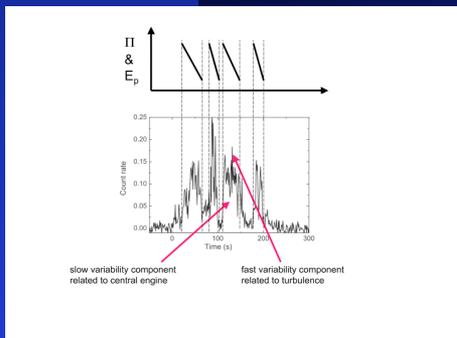
# Perpendicular acceleration in reconnection sites may be important for many astrophysical settings. *\*Selected\* ones:*



*Acceleration of anomalous cosmic rays (Lazarian & Opher 2009, Drake et al. 2010)*

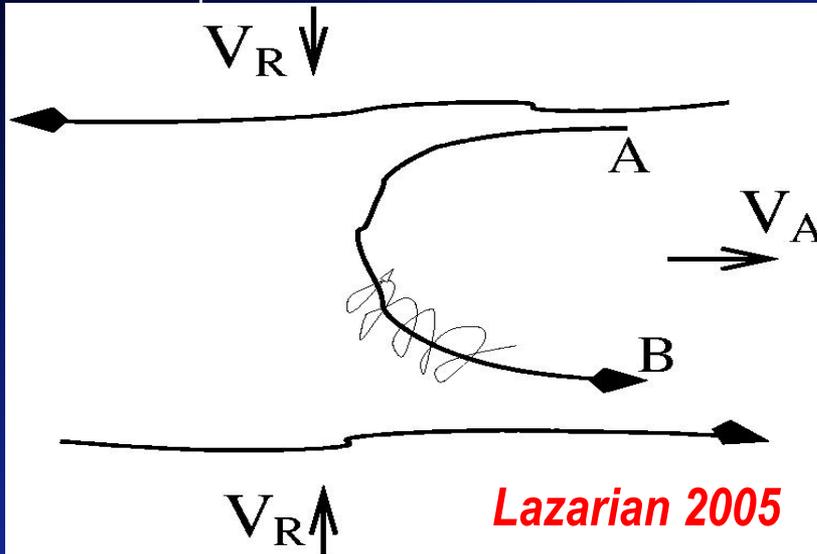


*Acceleration of cosmic rays in heliotail (Lazarian & Desiati 2010)*

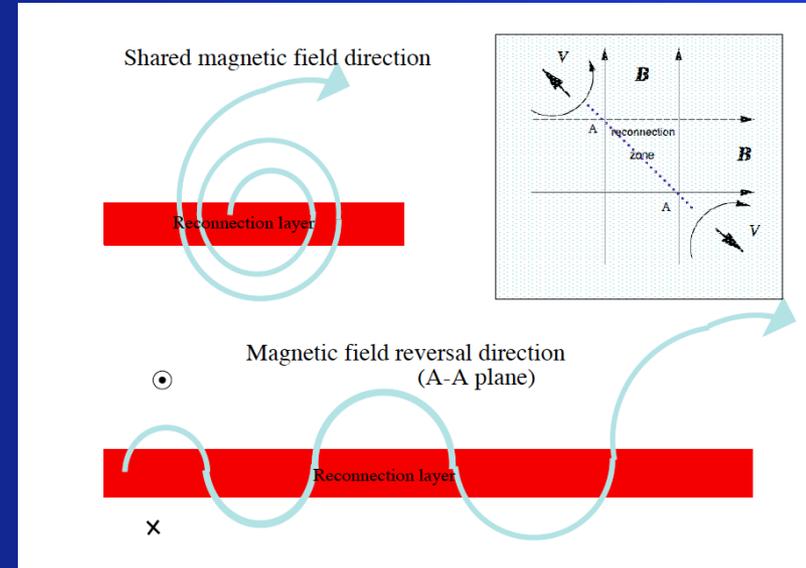


*Acceleration of particles during gamma ray bursts (Lazarian et al. 2003, Zhang & Yan 2011)*

# Further research should clarify the role of parallel and perpendicular First order Fermi acceleration



*Parallel acceleration (similar to that  
in Drake et al. 2006)*



*Perpendicular acceleration*

*And I do hope for the contribution from Yamada-san!*