Cross helicity sign reversals in the dissipative scales MHD turbulence

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Kinetic helicity in the planetary boundary layer

Kurgansky et al. 2018, Doklady Earth Sciences

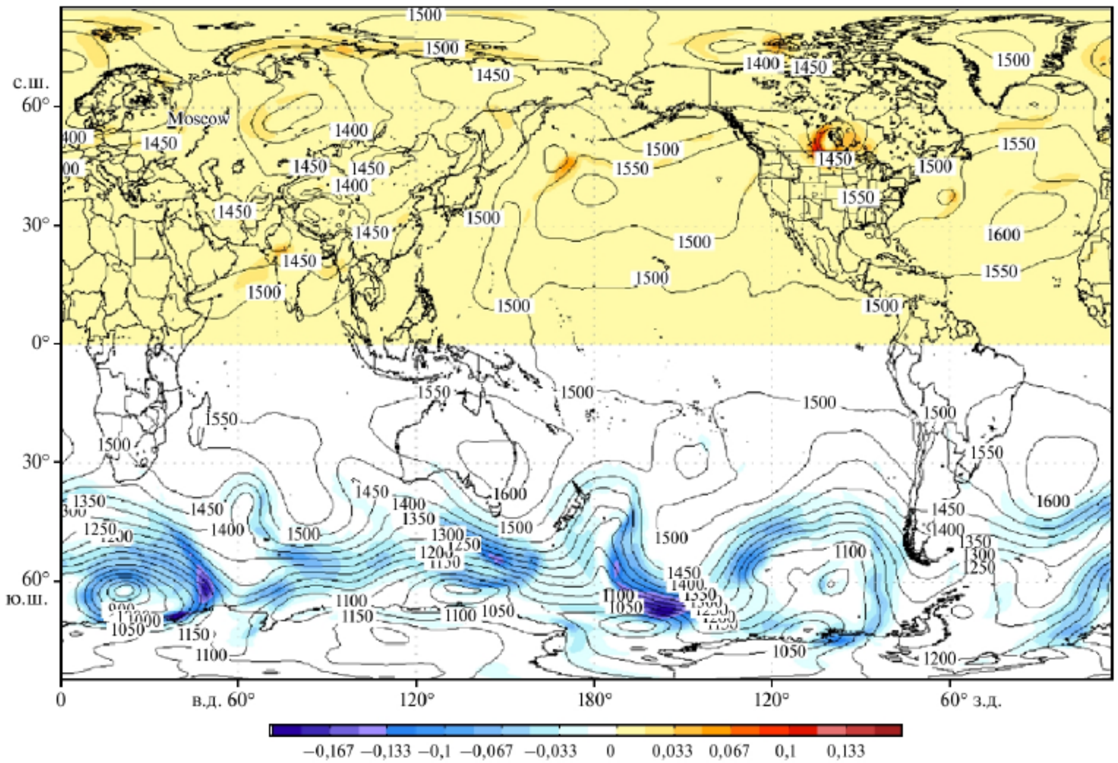
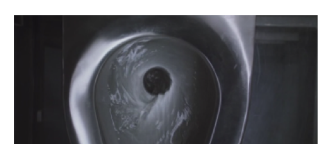


Fig. 1. Distribution of the helicity flux density ($m^2\ s^{-3}$) through the surface of 850 hPa for the NH and SH at 06:00 AM UTC on July 29, 2015. A solid line shows the 850 hPa surface isohypses (gpt m).

The movie «Escape Plan»

Sink vortex flow

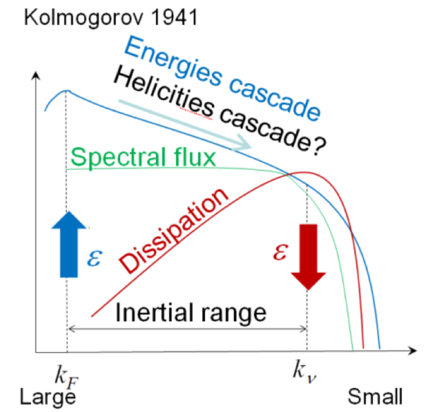


Effect of cross helicity in homogeneous isotropic MHD turbulence

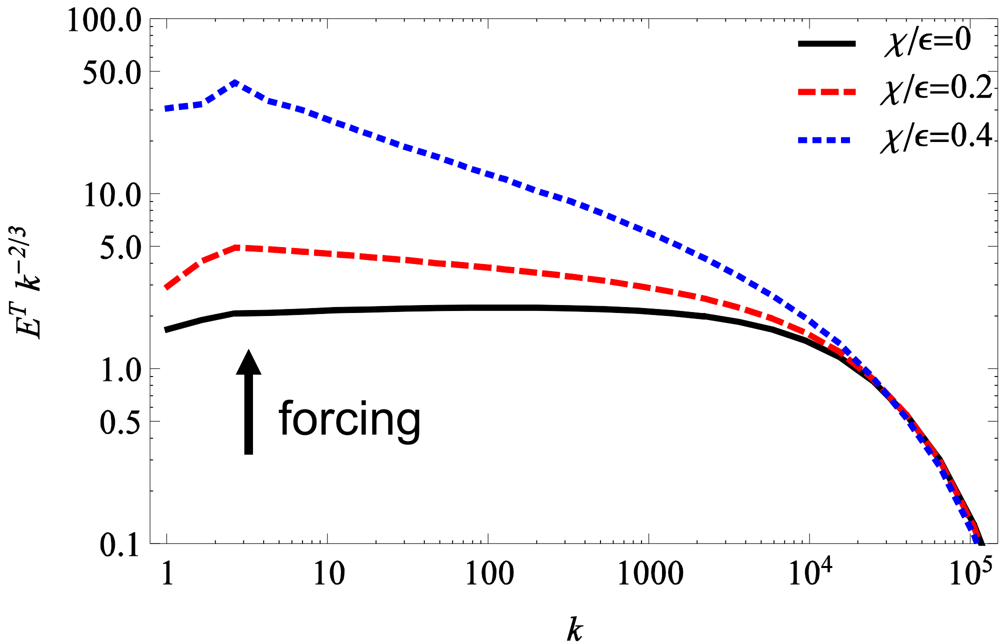
$$H_m = \int_V \mathbf{A} \cdot \mathbf{B} dV$$

$$H_c = \int_V \mathbf{u} \cdot \mathbf{B} dV$$

$$E = \int_V \rho \mathbf{u}^2/2 + \mathbf{B}^2/(2\mu) dV$$



Shell model simulations of MHD turbulence with cross helicity



Energy injection rate: ε=1

Cross-helicity injection rate: χ<1

$$\mathrm{Re} = \mathrm{Rm} = 10^6$$

Mizeva et al, 2009, Doklady Physics

DNS of MHD turbulence with cross helicity injection

$$
\begin{aligned}
\partial_t \mathbf{u} + (\mathbf{u}\cdot\nabla)\mathbf{u} &= (\mathbf{b}\cdot\nabla)\mathbf{b} + \mathrm{Re}^{-1}\,\nabla^2\mathbf{u} + \mathbf{F}_u - \nabla p,\\
\partial_t \mathbf{b} + (\mathbf{u}\cdot\nabla)\mathbf{b} &= (\mathbf{b}\cdot\nabla)\mathbf{u} + \mathrm{Rm}^{-1}\nabla^2\mathbf{b} + \mathbf{F}_b,\\
\nabla\cdot\mathbf{u} = \nabla\cdot\mathbf{b} &= 0,
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{F}_u(\mathbf{k}) &= ((\varepsilon-\varepsilon_c)^{1/2}\mathbf{e}_u(\mathbf{k}) + \varepsilon_c^{1/2}\mathbf{e}_c(\mathbf{k}))\\
\mathbf{F}_b(\mathbf{k}) &= ((\varepsilon-\varepsilon_c)^{1/2}\mathbf{e}_b(\mathbf{k}) \pm \varepsilon_c^{1/2}\mathbf{e}_c(\mathbf{k}))
\end{aligned}
$$

Solver - pseudospectral code TARANG

(M. K. Verma et al. Pramana, 2013)

Control parameter: $C = \varepsilon_c/\varepsilon$

- ratio of cross helicity injection rate to total energy injection rate

Simulation parameters:

Periodic domain with a grid 512^3

$\mathrm{Re} = \mathrm{Rm} \approx 2094$

Forcing at $1 < |\mathbf{k}| \leq 3$

$\varepsilon = 2$

C=0, 0.3, 0.6

Results

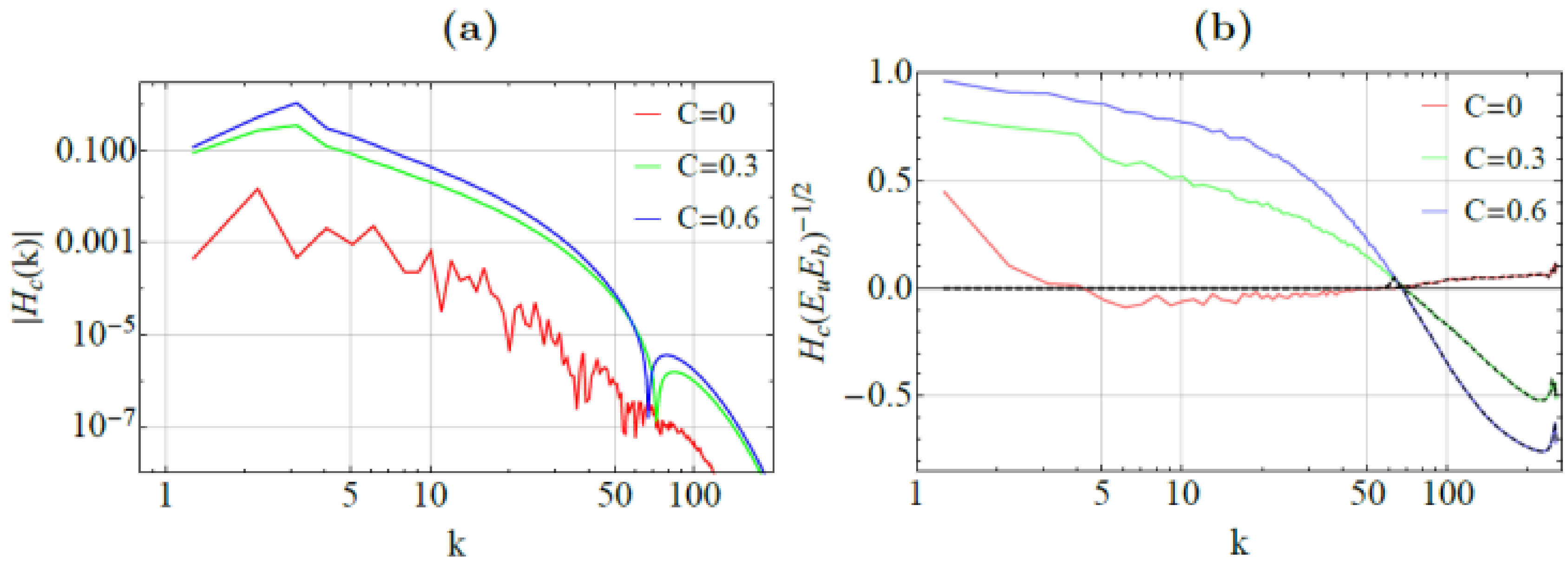
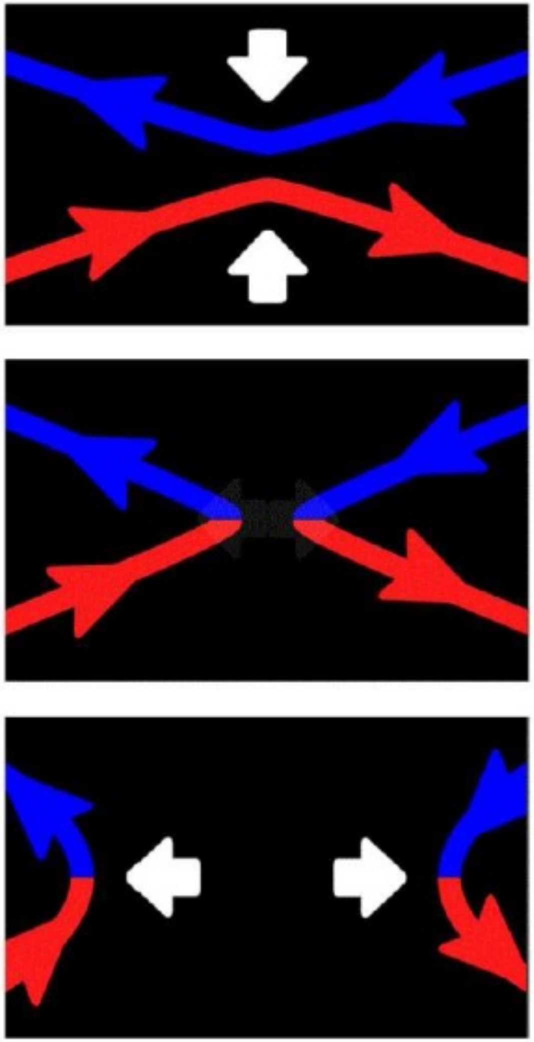


Figure 2: (a) Absolute value of cross helicity spectra; (b) compensated relative spectra of cross helicity. Dashed lines represent remnants after high pass filtering.

Silimar effect was observed but not undertood in McKay et al. Phys. Rev. Fluids, (2017)

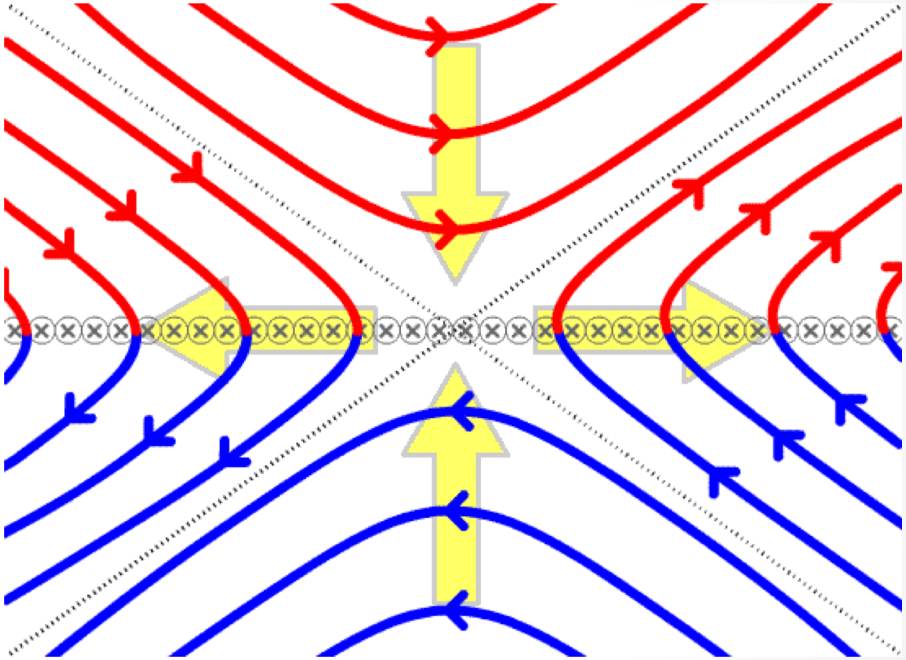
Magnetic reconnection?!

Magnetic reconnection (2D)

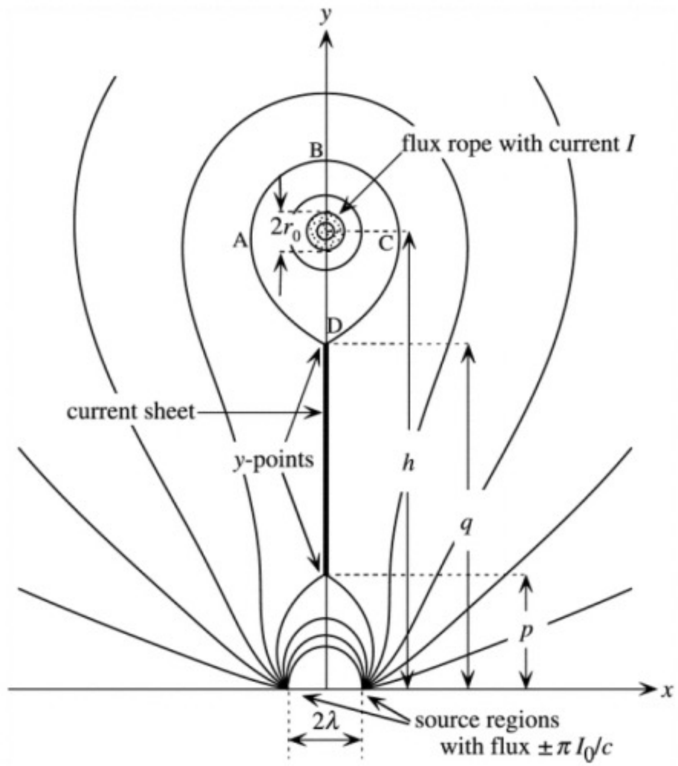


Credits: Center for Visual computing, Univ. of California Riverside

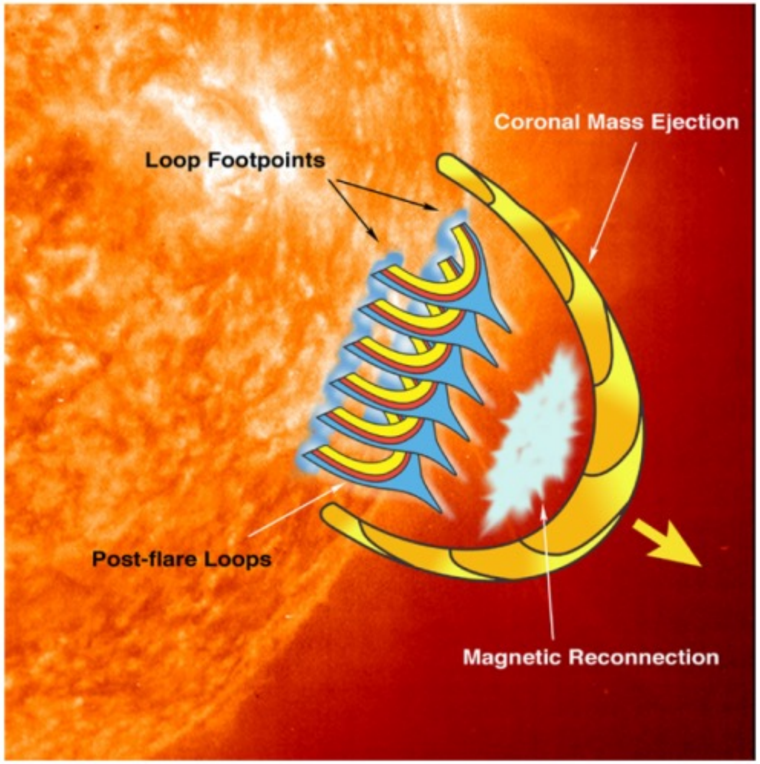
Reconnection – abrupt topology change

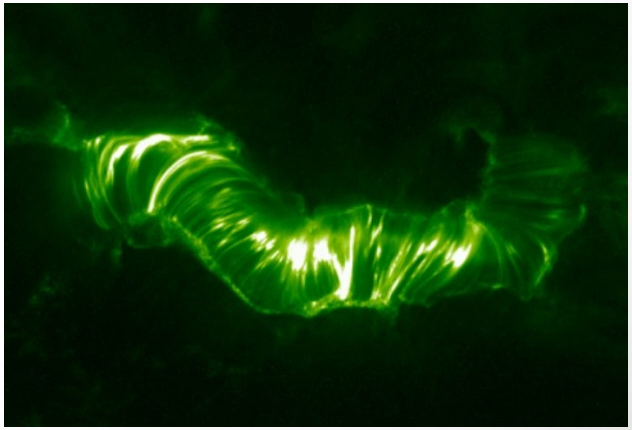


The Sun flaring



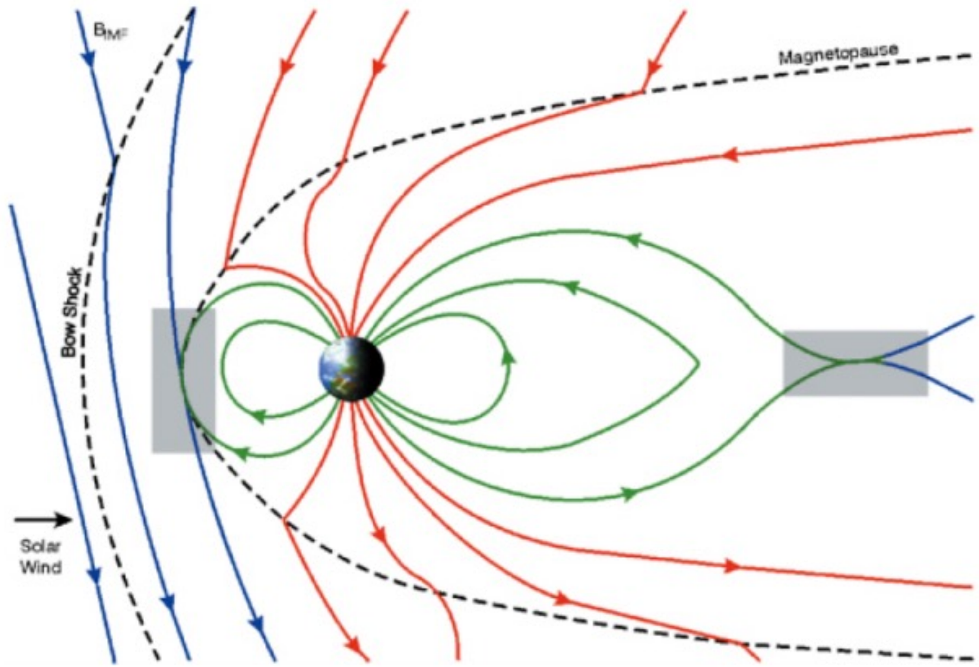
Lin & Forbes (2000)





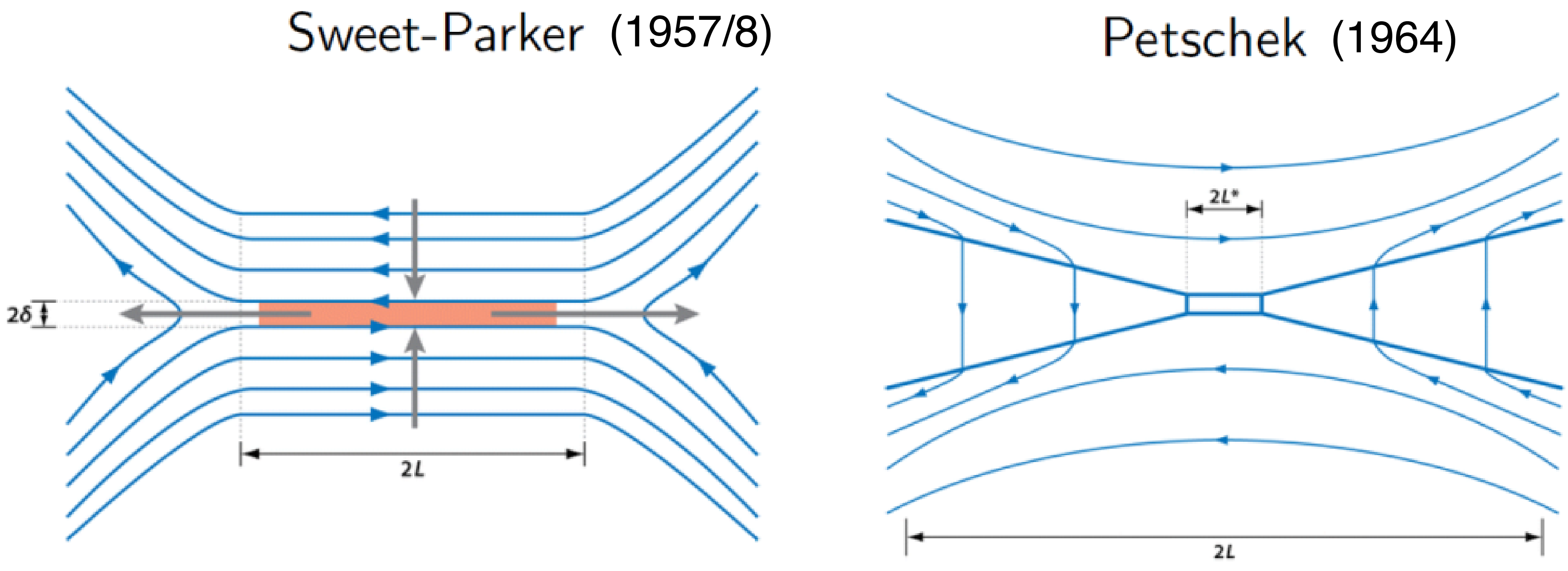
Reconnecting current sheet behind a rising flux rope

Magnetic reconnection in Earth's magnetosphere



- Magnetic reconnection occurs in two primary locations in Earth's magnetosphere in response to driving from solar wind
  - Dayside magnetopause: solar wind plasma reconnecting with magnetospheric plasma
  - Magnetotail: in response to magnetic energy building up in lobes due to solar wind driving

Reconnection models



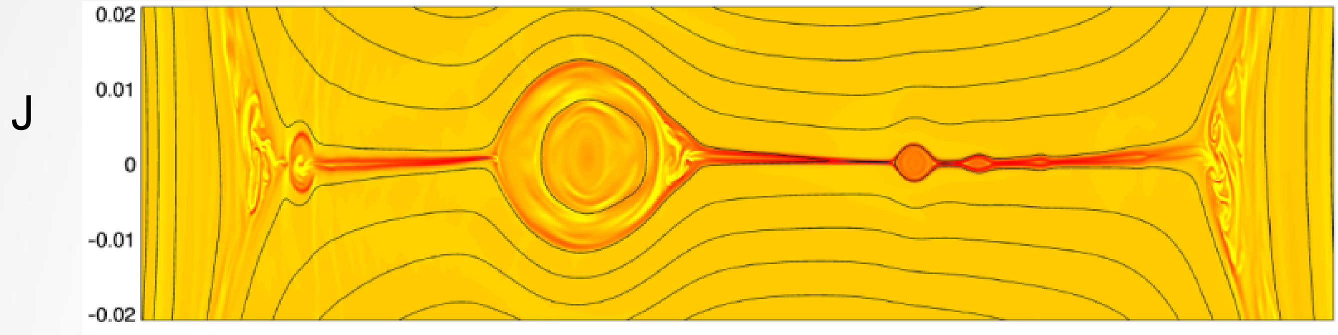
Zweibel & Yamada (2009)

The Lundquist number $S = \mu_0 L_e v_{Ae} / \eta$

$$M_{Ae} = \frac{v_e}{v_{Ae}} = \frac{E}{v_{Ae} B_e} = \begin{cases} \frac{1}{\sqrt{S}} & \text{“Sweet-Parker”} \quad \overset{S=10^8}{=} 10^{-4} \\ \frac{\pi}{8 \ln S} & \text{“Petschek”} \quad \overset{S=10^8}{=} 2 \cdot 10^{-2} \end{cases}$$

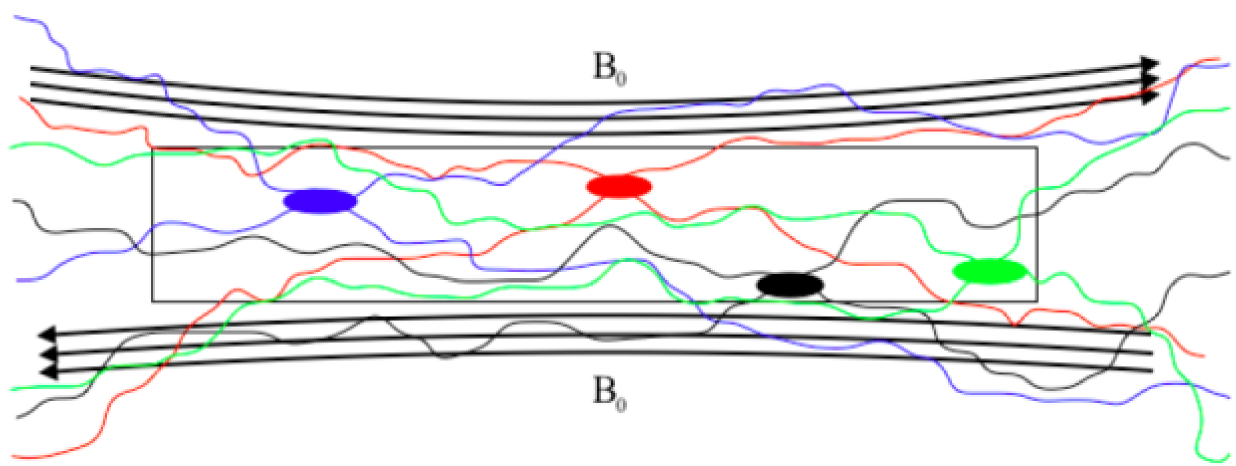
Reconnection models with instability

Plasmoid instability (the tearing-like)
(Loureiro et al. 2007) (first known from Bulanov et al 1979)



Bhattacharjee et al. (2009)

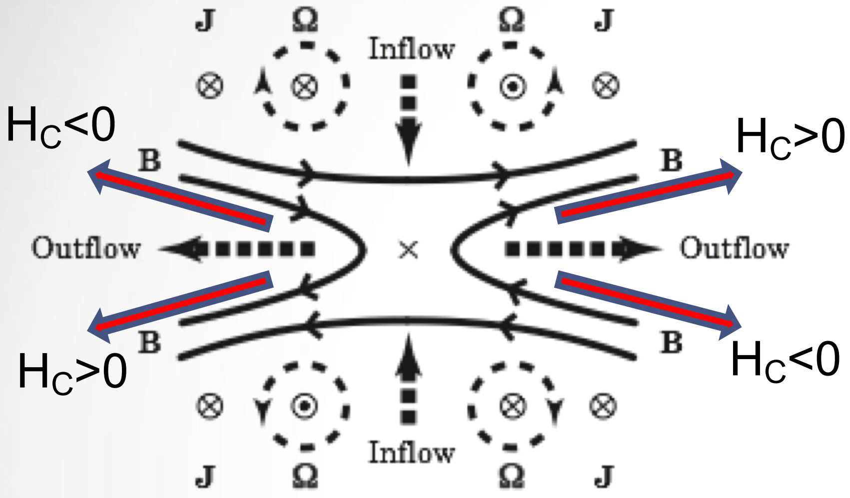
Turbulent reconnection (Lazarian and Vishniac, 1999)



Open questions in magnetic reconnection

- What sets the reconnection rate?
- Why is there often a sudden onset to fast reconnection?
- What is the interplay between small-scale physics and global dynamics?
  - Including collisionless/kinetic effects
- How are particles accelerated and heated?
- What are the roles of turbulence, instabilities, and asymmetry?
- How does 3D reconnection occur?
- How does reconnection behave in extreme astrophysical environments?
  - Neutron star atmospheres, supernovae, gamma ray bursts, black hole accretion disks
  - Weakly ionized plasmas such as the solar chromosphere and protoplanetary disks

Cross helicity and reconnection

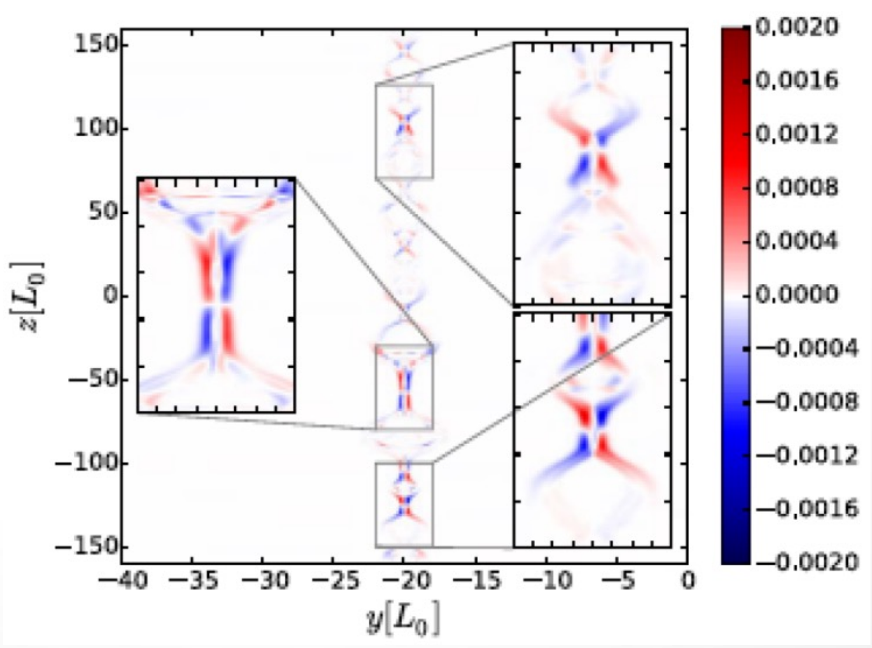


Yokoi & Hoshino, PoP 2011

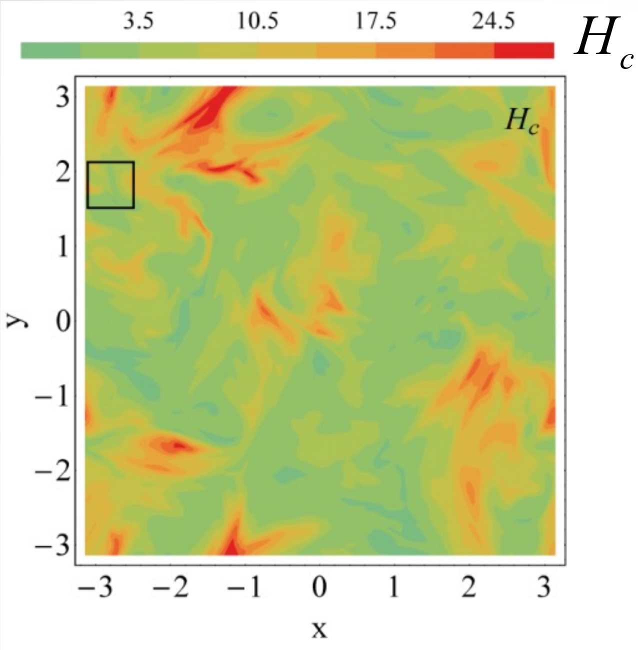
Higashimori, Yokoi & Hoshino, PRL 2013

Yokoi, Higashimori & Hoshino, PoP 2013

From DNS



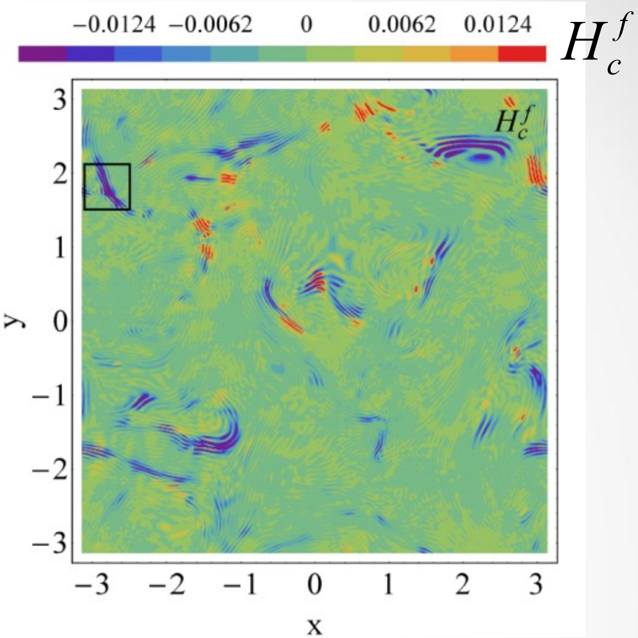
Cross helicity and reconnection in MHD turbulence

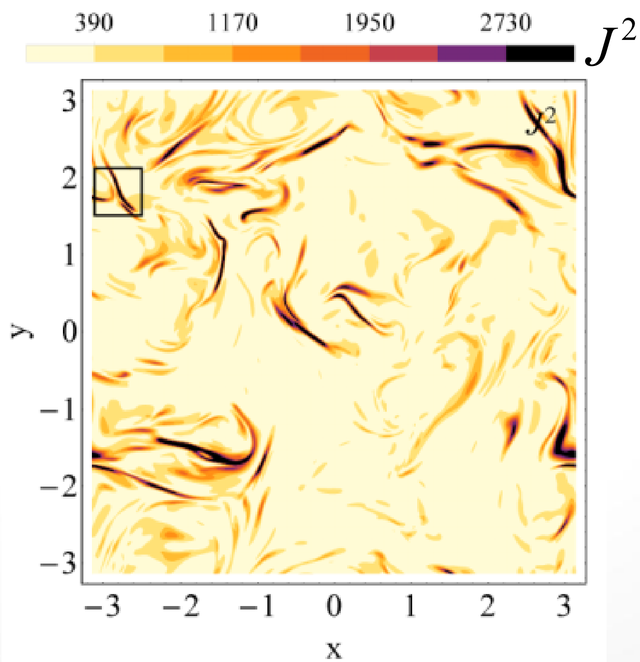


Fourier filtering

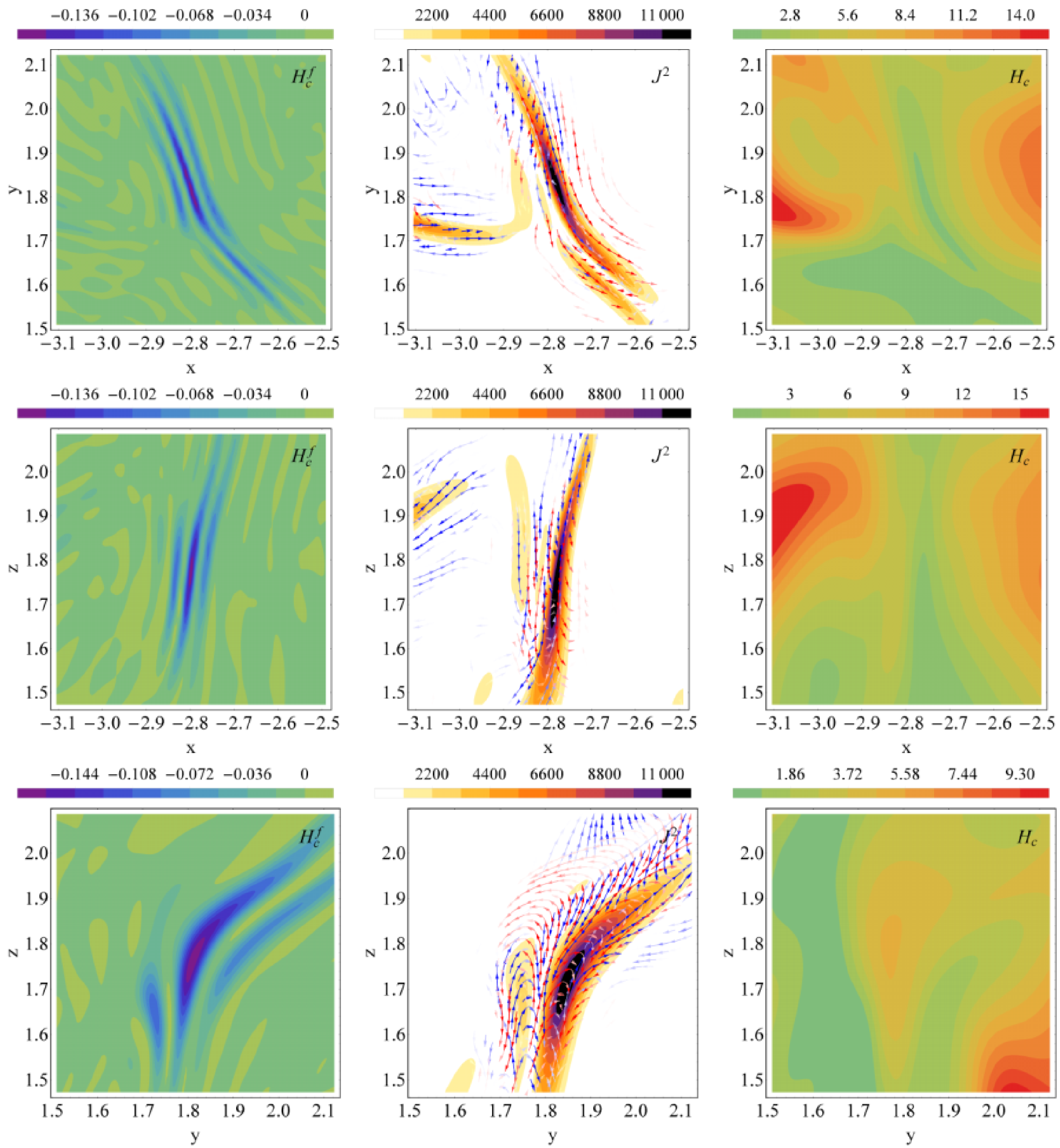
$$\mathbf{x}^f(\mathbf{k}) = \mathbf{x}(\mathbf{k})\mathrm{e}^{-(k_r - k)/k_f}$$

$k_r = 70$





Magnetic dissipation field


−0.136 −0.102 −0.068 −0.034 0
2200 4400 6600 8800 11 000
2.8 5.6 8.4 11.2 14.0
H_c^f
J^2
H_c
3 6 9 12 15
−0.144 −0.108 −0.072 −0.036 0
1.86 3.72 5.58 7.44 9.30
x
y
z
−3.1 −3.0 −2.9 −2.8 −2.7 −2.6 −2.5
1.5 1.6 1.7 1.8 1.9 2.0 2.1

Conclusion

- Cross helicity cascades in MHD turbulence and reverses its sign at particular scales in dissipation range.

- Magnetic reconnections occur at the regions of cross helicity reverses its sign.

Titov et al. arXiv:1902.08253

Future study:

- DNS for Pm≠1
- 3D structure of X-point
- Phenomenology to explain for k_r