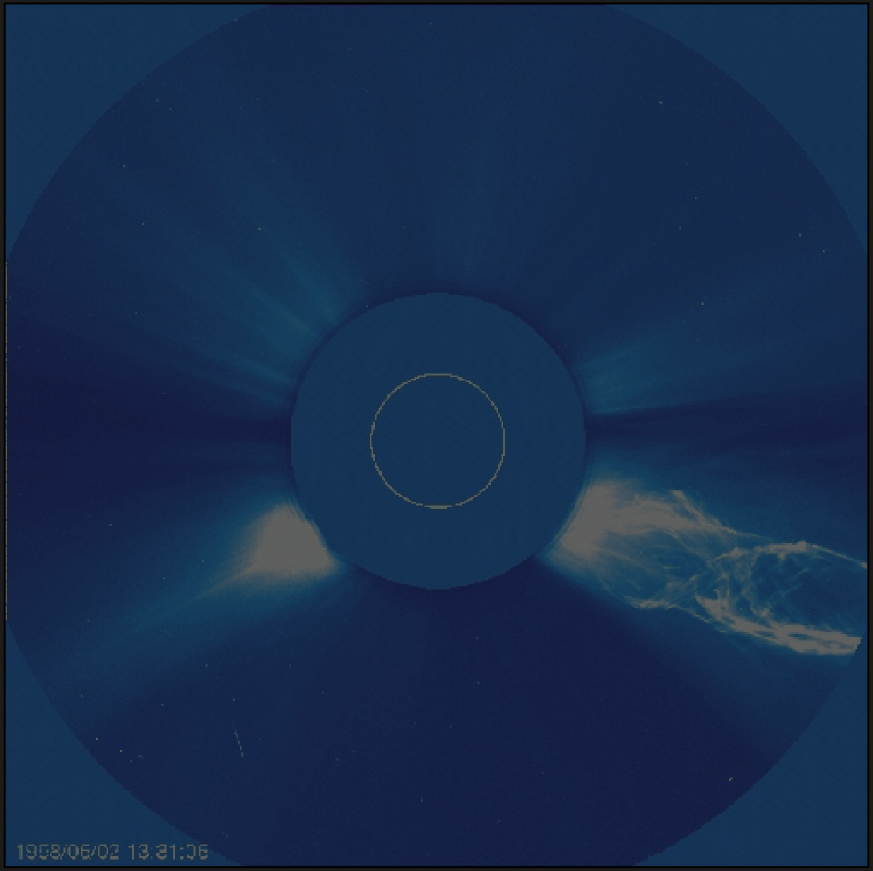
Magnetic helicity measurements in the solar wind

Y. Narita

Space Research Institute,
Austrian Academy of Sciences
Graz, Austria



Helical CME, June 2, 1998
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G. Kleindienst, Ph. Bourdin,
E. Marsch, S. P. Gary, and N. Yokoi

Take-home messages

Magnetic helicity (density) ... A dot B

* unambiguous observation as a challenge!

* apparently random (in sign) in a typical solar wind
(judging from time series data in the ecliptic plane)

* plasma-physical effects interfering helicity transport
(L-mode exciattion, damping, polarization reversal)

* Parker Solar Probe, Solar Orbiter, BepiColombo missions

Evaluating the helicity

Magnetic helicity

$$H^M = \int \boldsymbol{A} \cdot \boldsymbol{B} \, dV$$

Coulomb-gauge relation

$$\nabla \times \boldsymbol{B} = -\nabla^2 \boldsymbol{A}$$

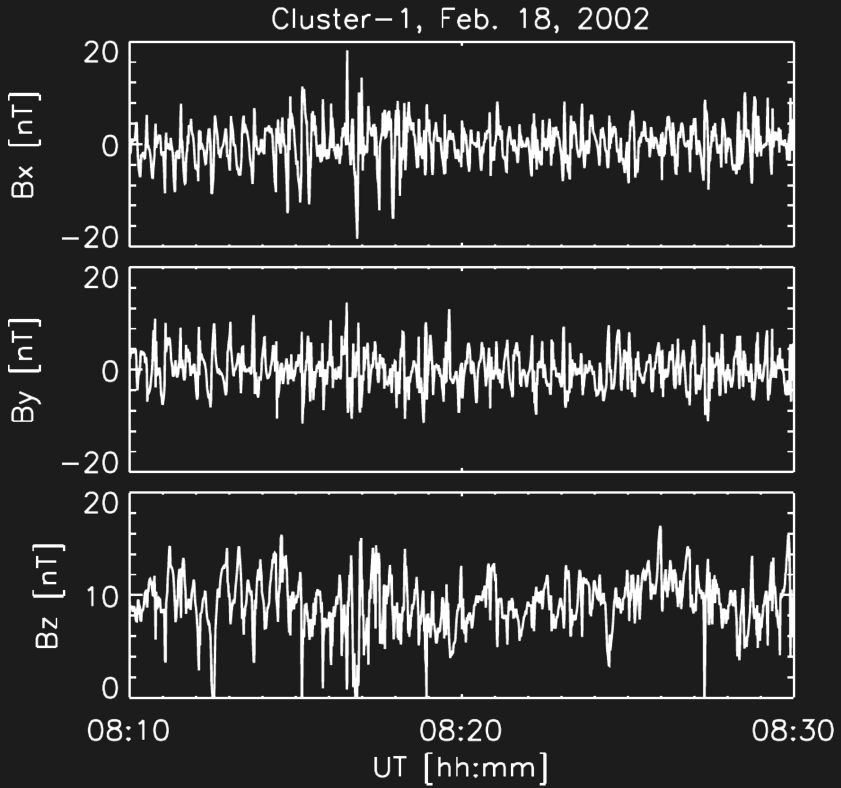
Un-curling in the Fourier space

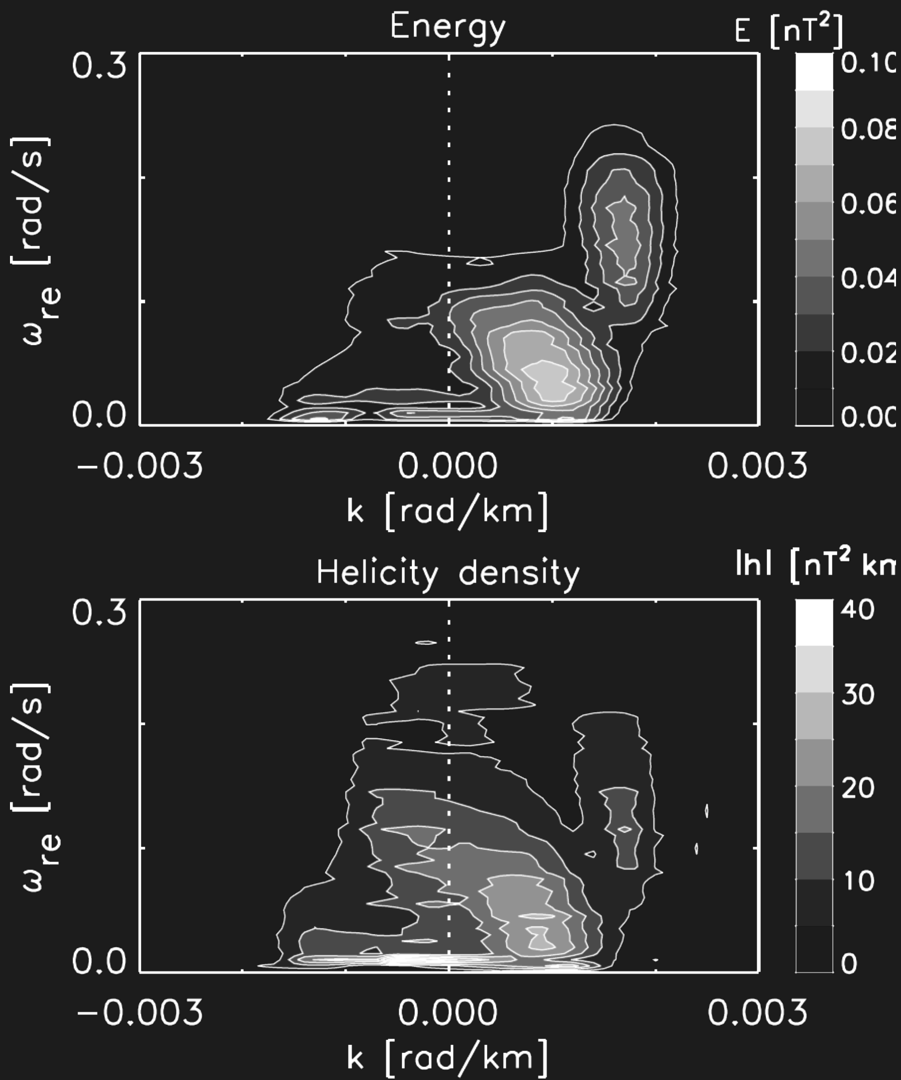
$$\boldsymbol{a} = -\frac{i}{k^2} \boldsymbol{k} \times \boldsymbol{b}$$

Helicity density in the Fourier space

$$\langle \boldsymbol{a}^\dagger \cdot \boldsymbol{b} \rangle = -\frac{i}{k^2} \Big[k_x \Big(\langle b_y^* b_z \rangle - \langle b_z^* b_y \rangle \Big) + k_y \left(\langle b_z^* b_x \rangle - \langle b_x^* b_z \rangle \right) + k_z \Big(\langle b_x^* b_y \rangle - \langle b_y^* b_x \rangle \Big) \Big].$$

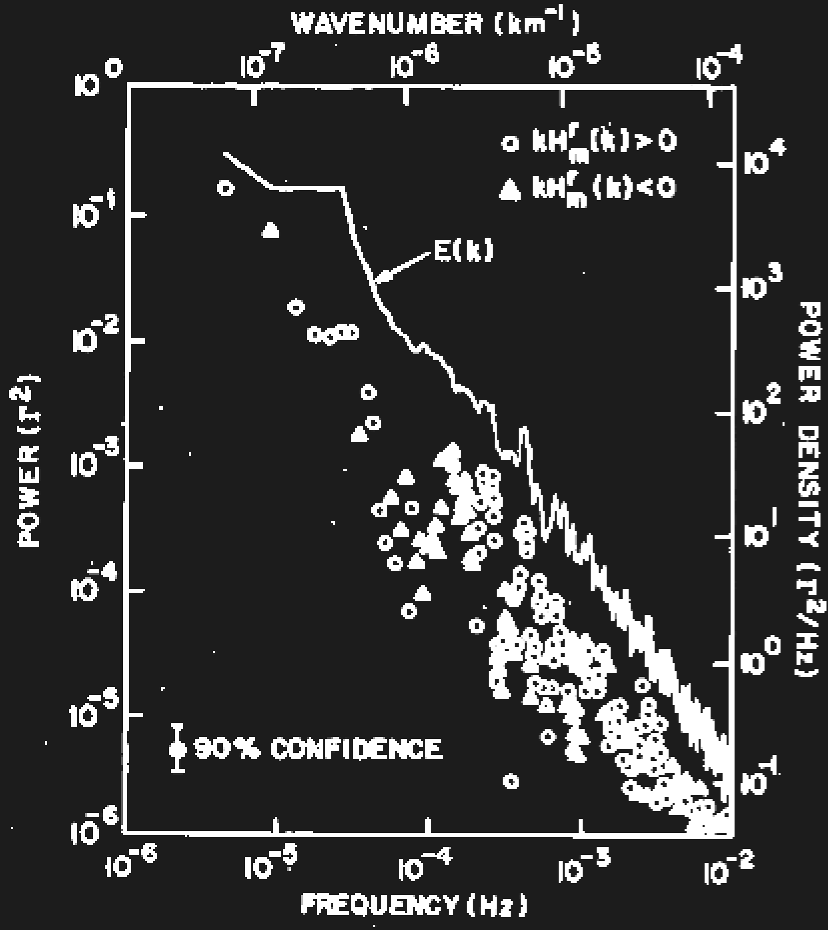
Helicity using 4-point data



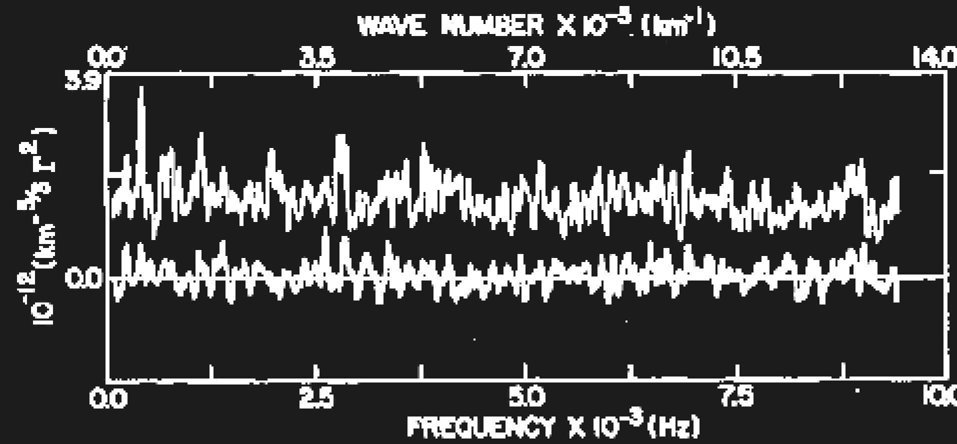


Narita et al., Ann. Geophys. 2009

One-point data (more conventional)

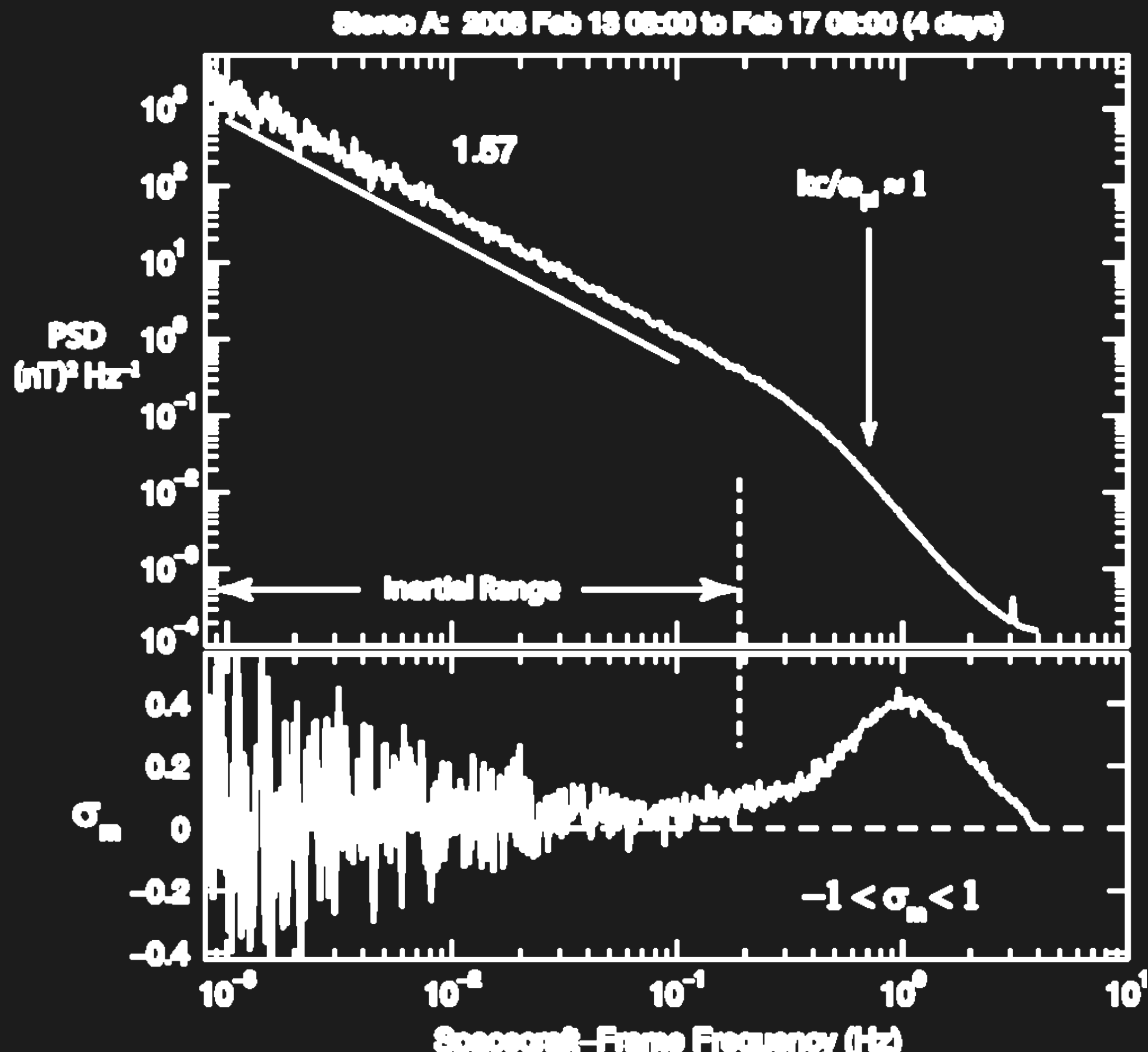


Voyager-2, 2.8AU, 1978



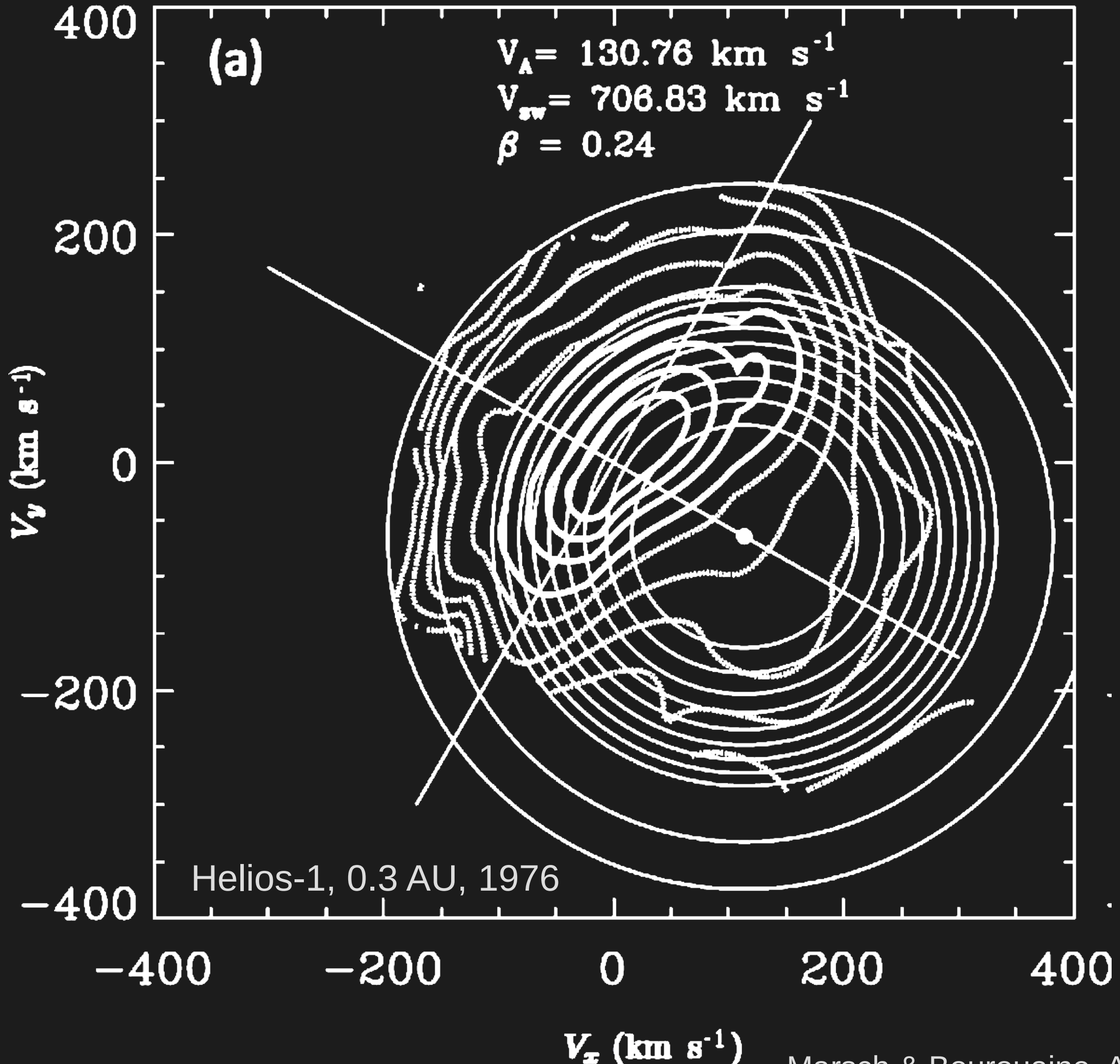
Matthaeus et al., Phys. Rev. Lett. 1982

L-mode disappears on 100-km scale



Podesta, Solar Phys. 2013

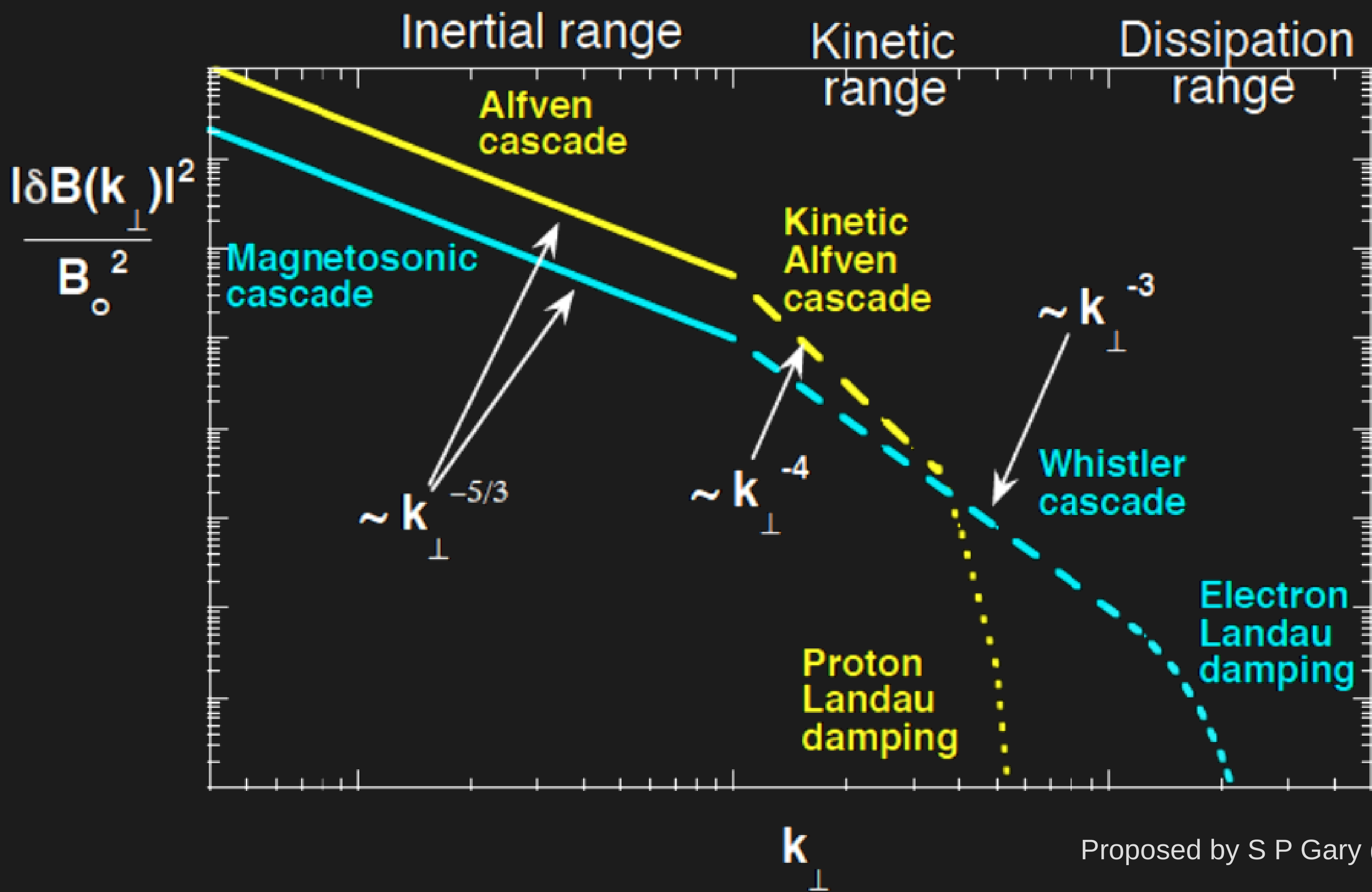
Pitch-angle scattering by L-mode waves



Marsch & Bourouaine, Ann. Geophys. 2011

Marsch, Ann. Geophys. 2018

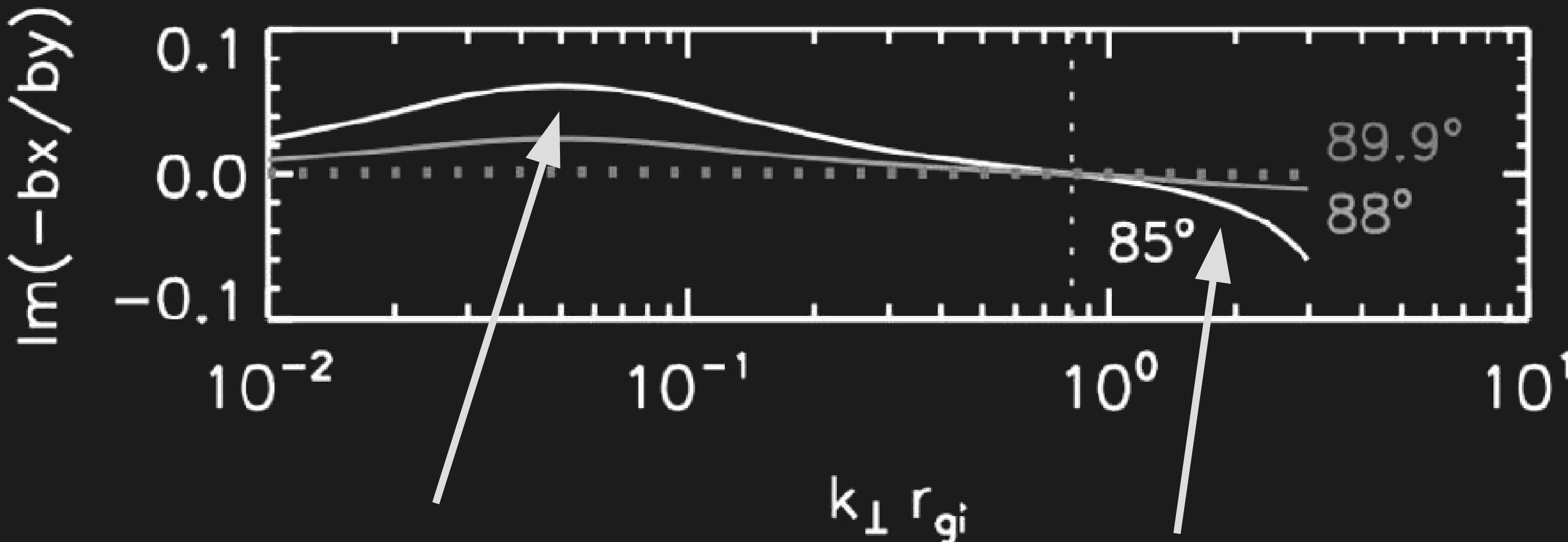
A model of turb. energy spectrum



Proposed by S P Gary (2016)

Polarization reversal by linear mode

Linear Vlasov theory, kinetic Alfven mode



Hall current dominates

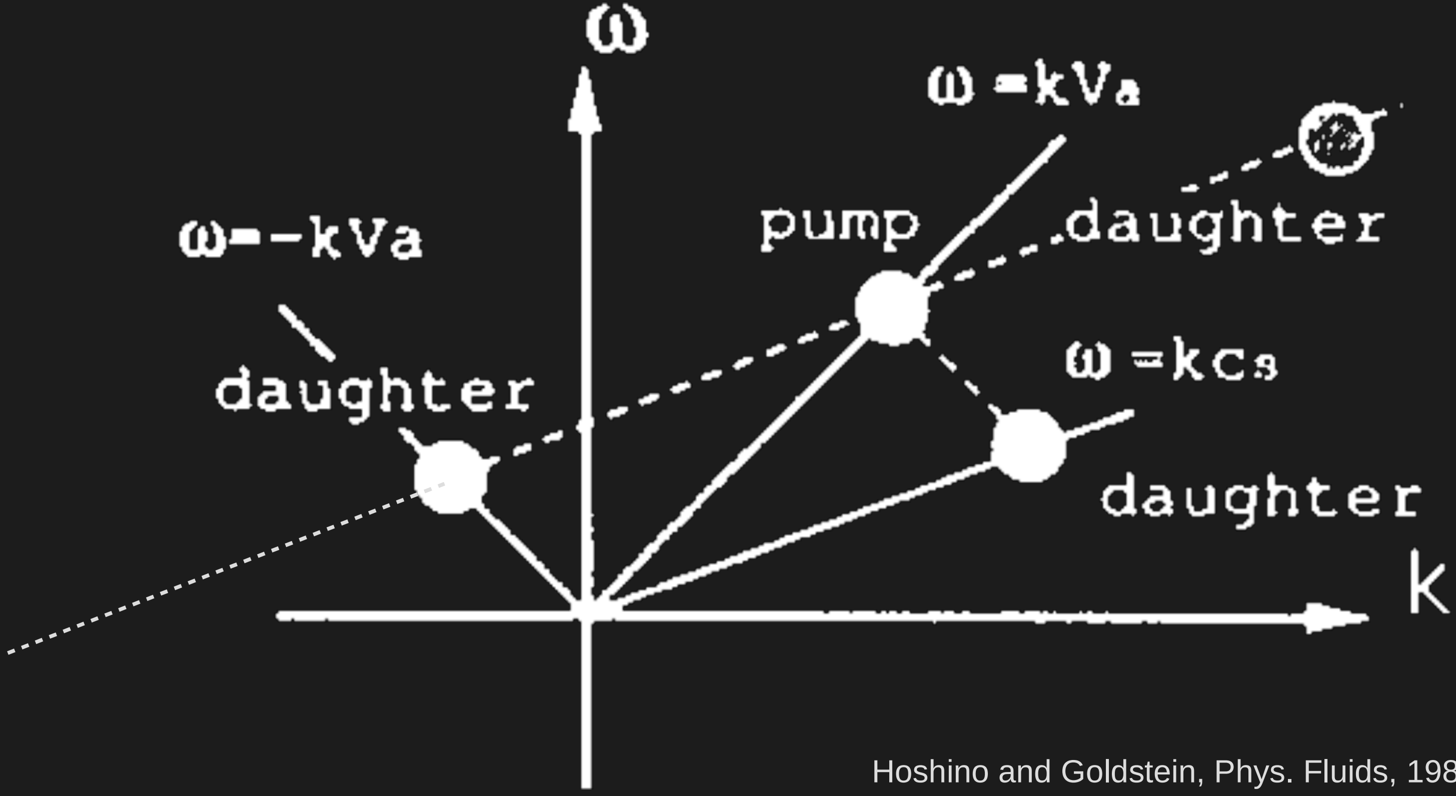
$$E_y = -\frac{1}{n_e e} j_x B_0$$

Diamagnetic current dominates

$$\vec{j} = \frac{\vec{B} \times \nabla p}{B^2}$$

Narita et al., Frontiers Phys. 2020

Polarization reversal by nonlinear mode



Hoshino and Goldstein, Phys. Fluids, 1989