Current sheets characterized by large shear angles or relatively small thickness, can effectively scatter energetic particles and effect transport beyond the conventional diffusion framework.

Quantification of particle scattering and transport by solar wind current sheets

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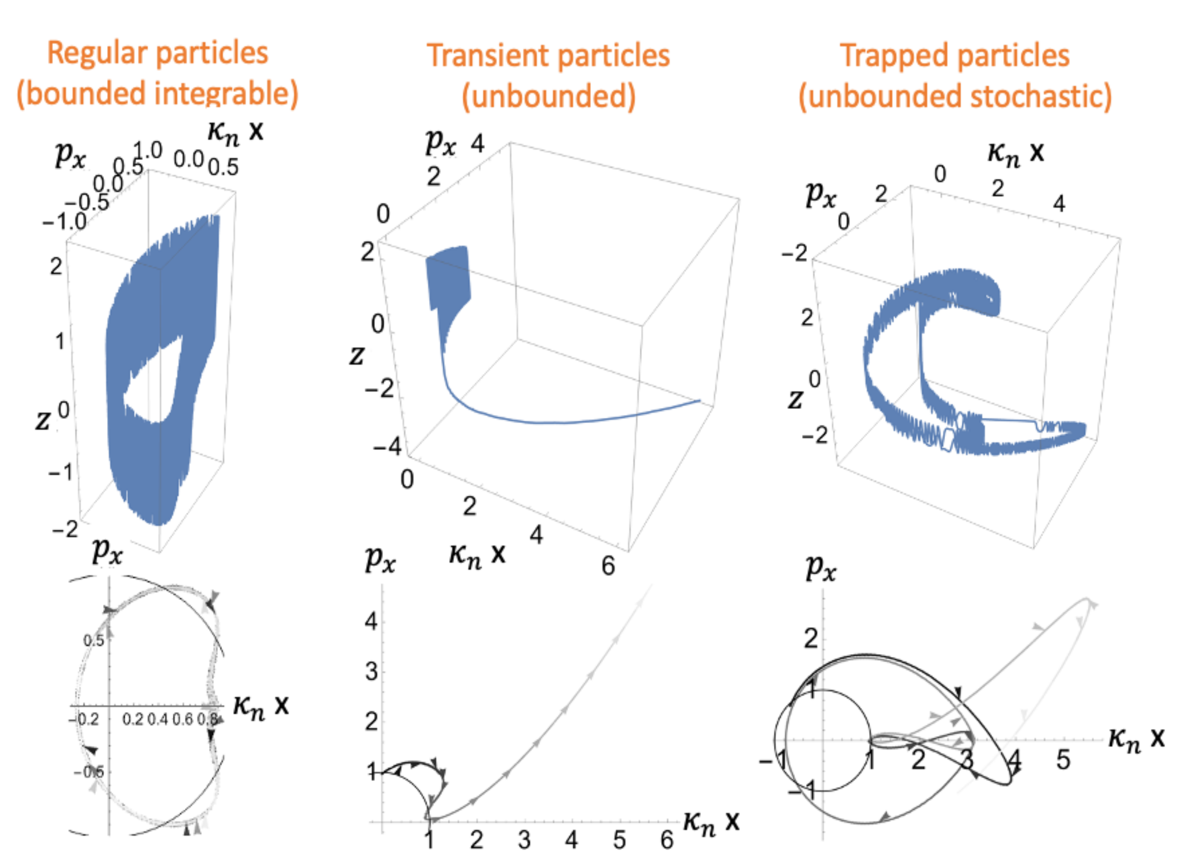
Introduction & Motivation

The transport of energetic particles within the heliosphere is significantly influenced by the turbulent magnetic field present in the solar. Rather than being a simple superposition of random fluctuations, these turbulent fields exhibit a structured nature, frequently observed in the solar wind magnetic field in the form of current sheets, discontinuities, Alfvén vortices, magnetic holes, and other coherent structures. These structures arise from nonlinear energy cascade processes and play a critical role in modulating particle transport.

A. Theory - Hamiltonian system

$$\tilde{H} = \frac{1}{2}\left(\left(\tilde{p_x} - f_1(z)\right)^2 + \left(\tilde{x}\cot\theta + f_2(z)\right)^2 + \tilde{p_z}^2\right)$$

Particle have three types of trajectories in phase space

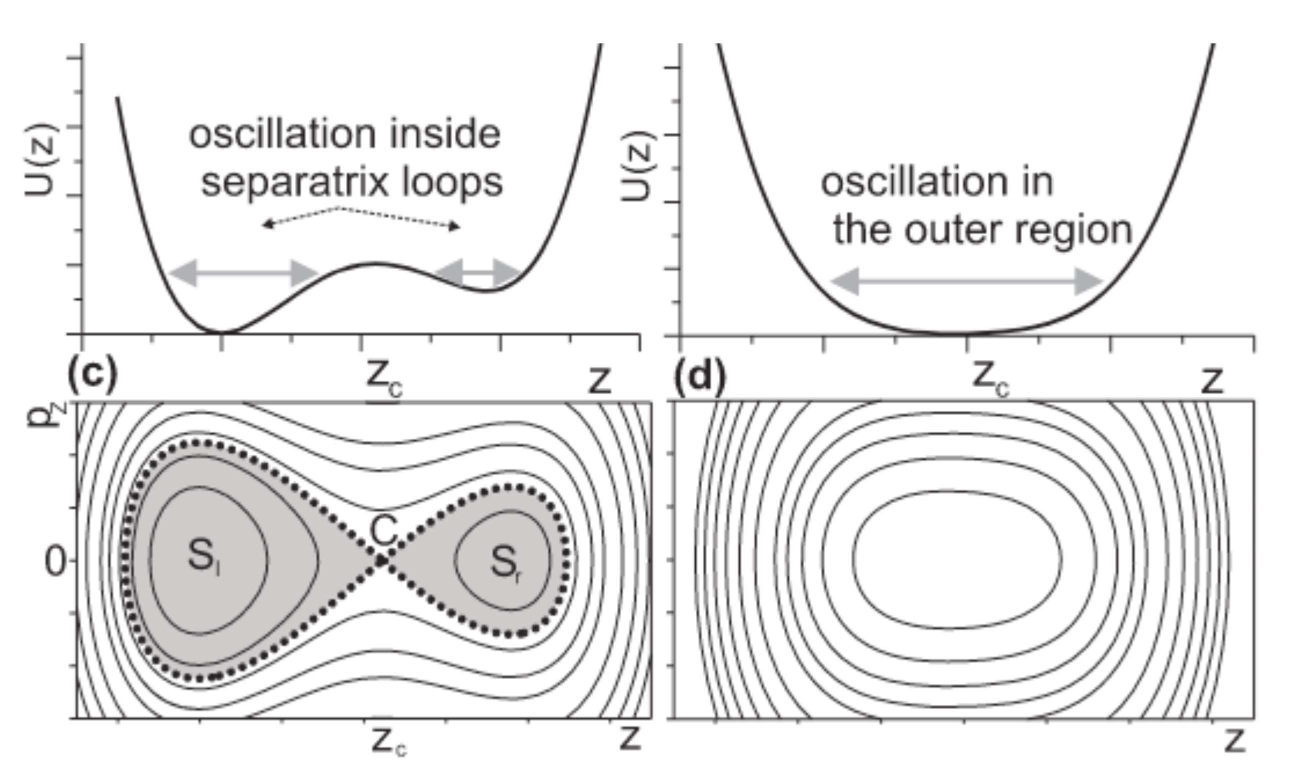


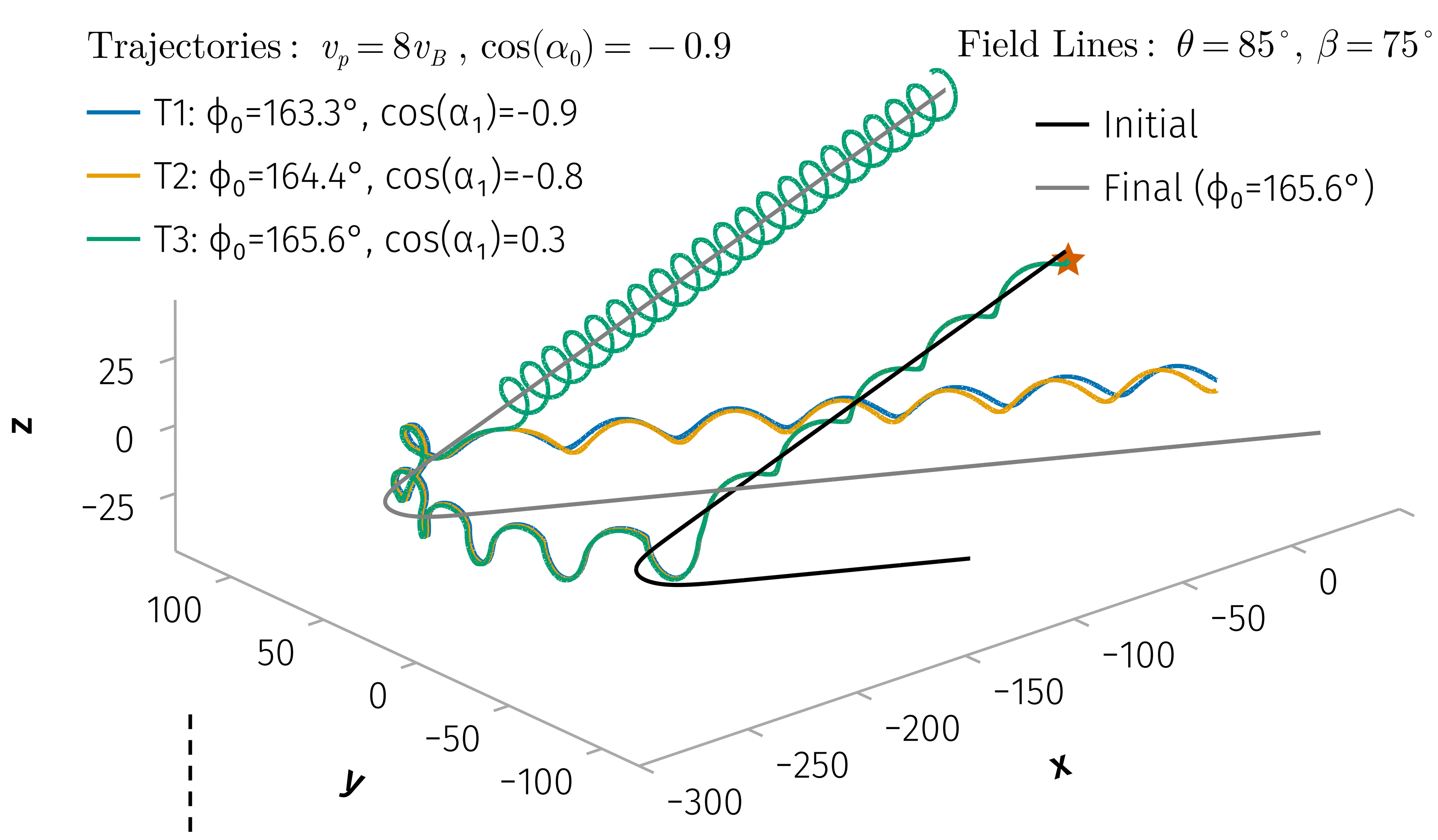
Variables $(\kappa x, p_x)$ change much slower than (z, p_z) (for κ =cotθ << 1)

Generalized magnetic moment $I_z = (2\pi)^{-1}\oint p_z dz$ is conserved as the first **adiabatic invariant**

Simultaneous conservation of energy and I_z fully determines the motion of the particle

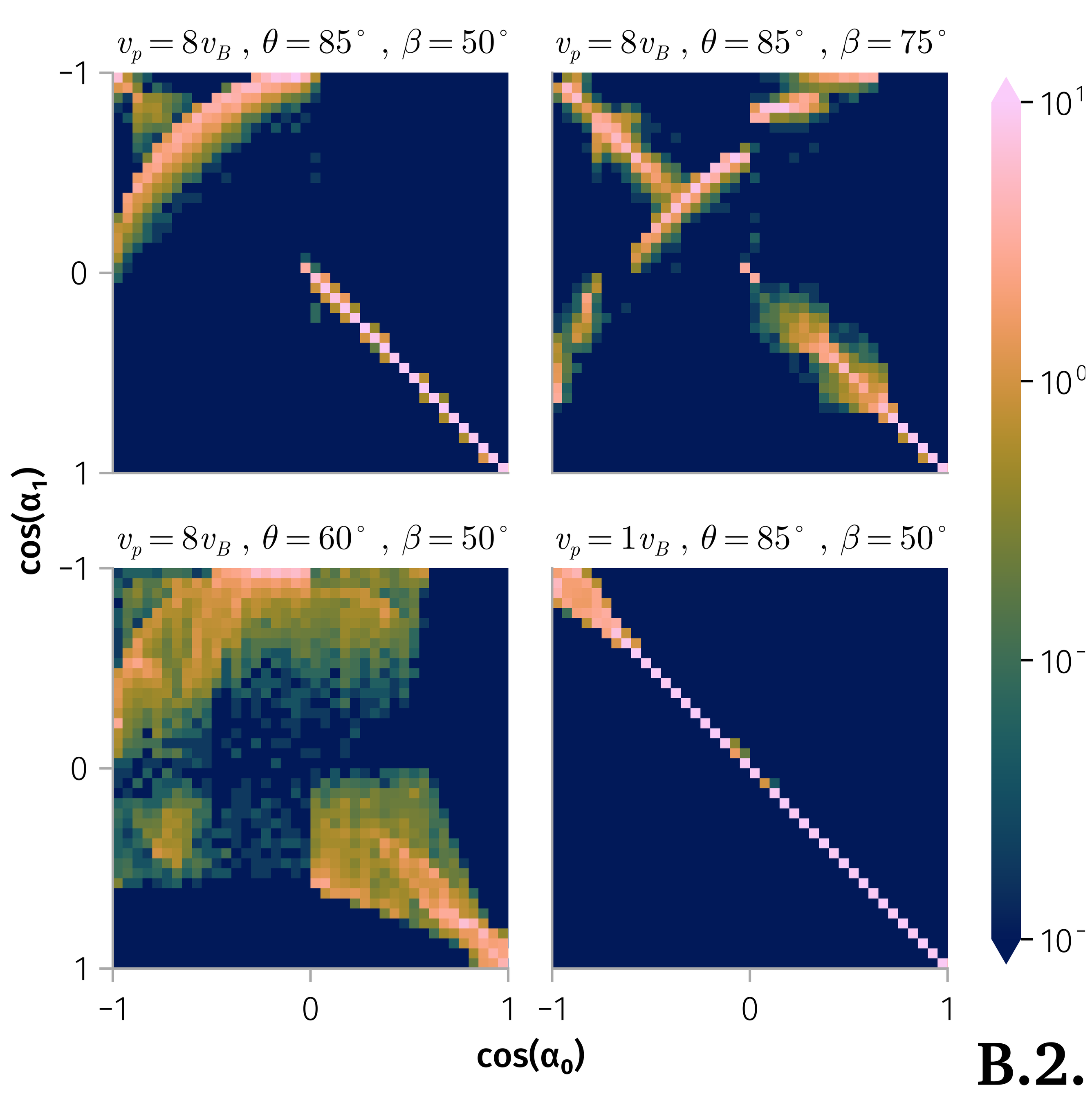
In the absence of $\boldsymbol{I_z}$ **destruction**, there is no pitch-angle scattering



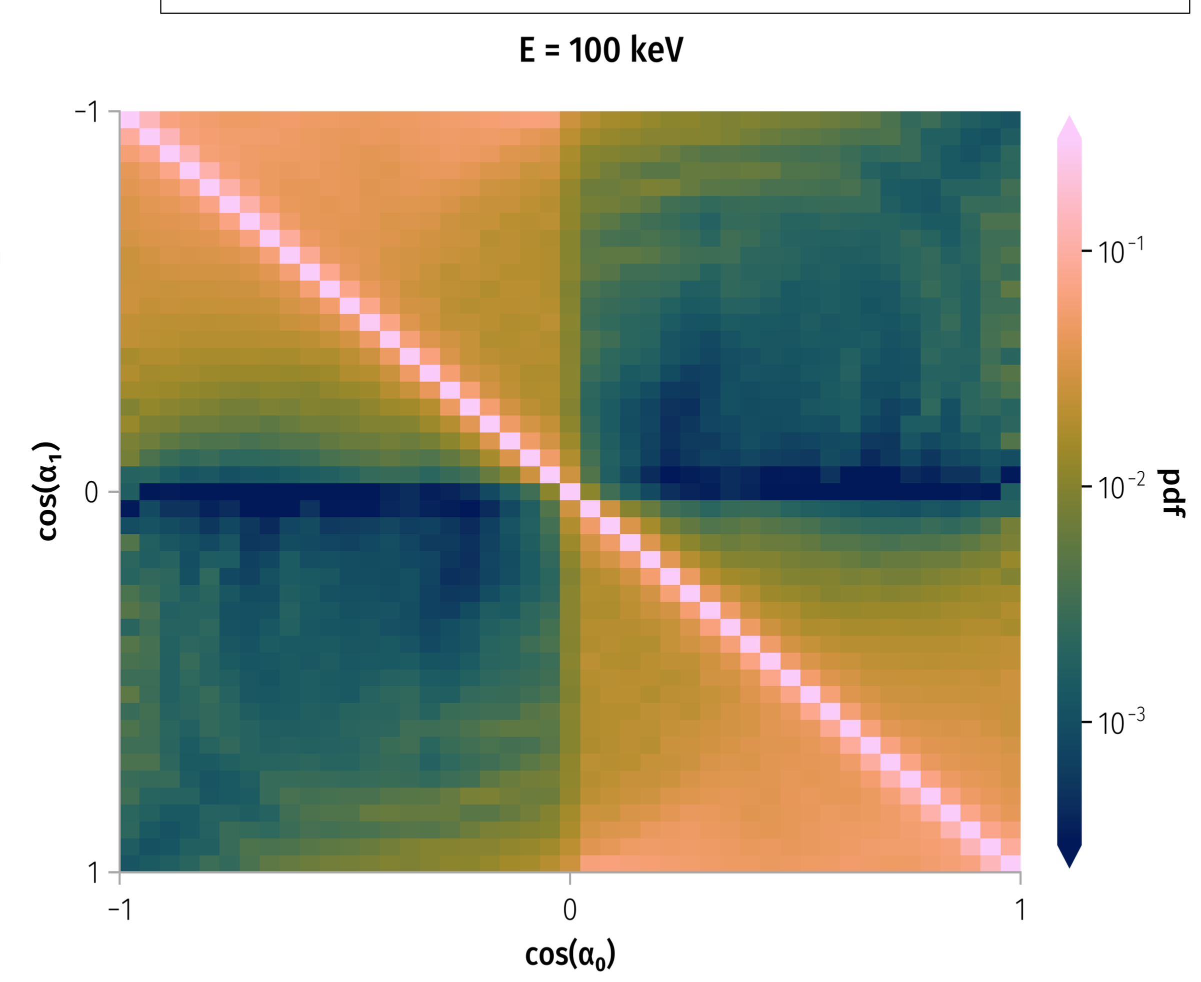


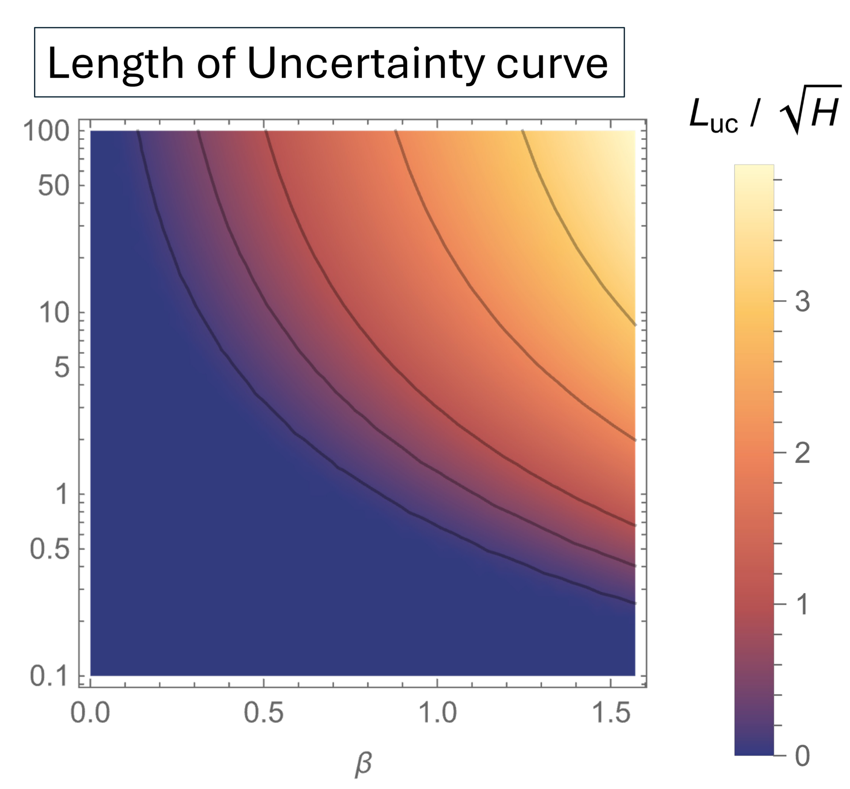
$$\mathbf{B} = B_0\left(\cos\theta\,\mathbf{e_z} + \sin\theta\left(\sin\varphi(z)\,\mathbf{e_x} + \cos\varphi(z)\,\mathbf{e_y}\right)\right)$$

B. Test particle simulation & Mapping



Transition matrix for 100 keV protons under four magnetic field configurations and weighed transition matrix from observed distribution of current sheet at 1 AU.





Two distinct types of particle trajectories in (z, p_z) plane separated by a curve called ***Separatrix***.

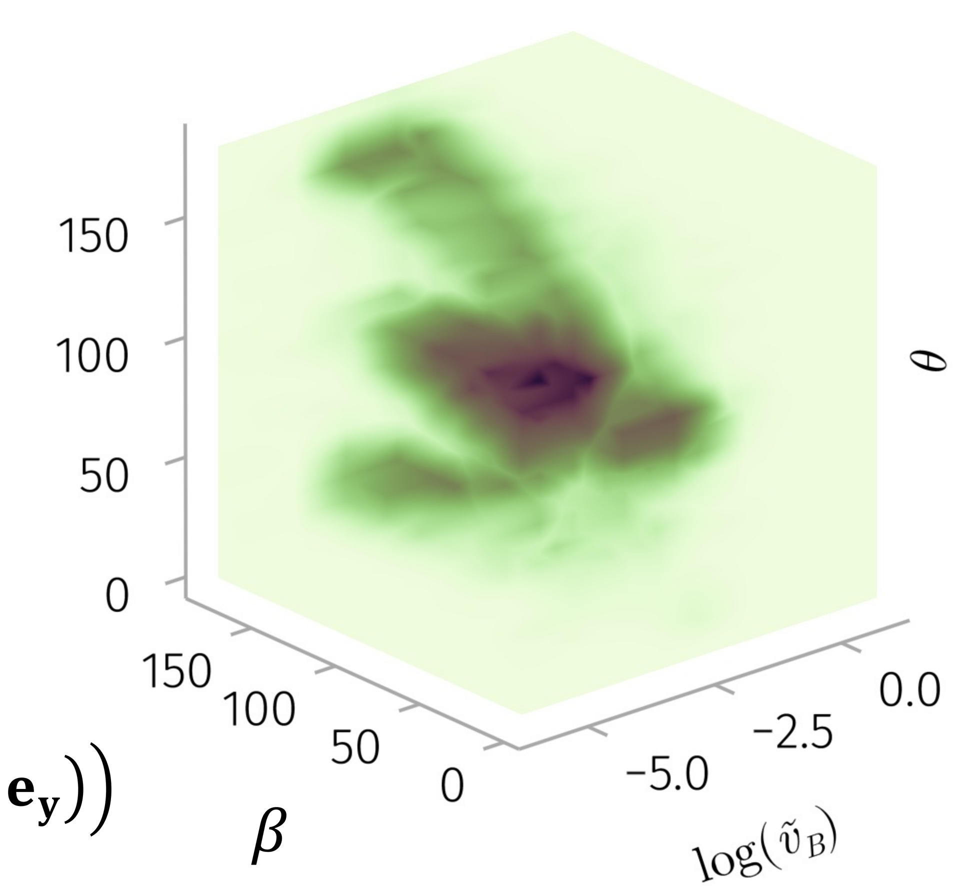
The separatrix corresponds to a point on a certain curve in the $(\kappa x, p_x)$ plane, called ***Uncertainty Curve***.

Near the separatrix, the instantaneous period of motion increases logarithmically.

Particle accumulates a nonvanishing change in the adiabatic invariant: dynamical jump and geometric jump

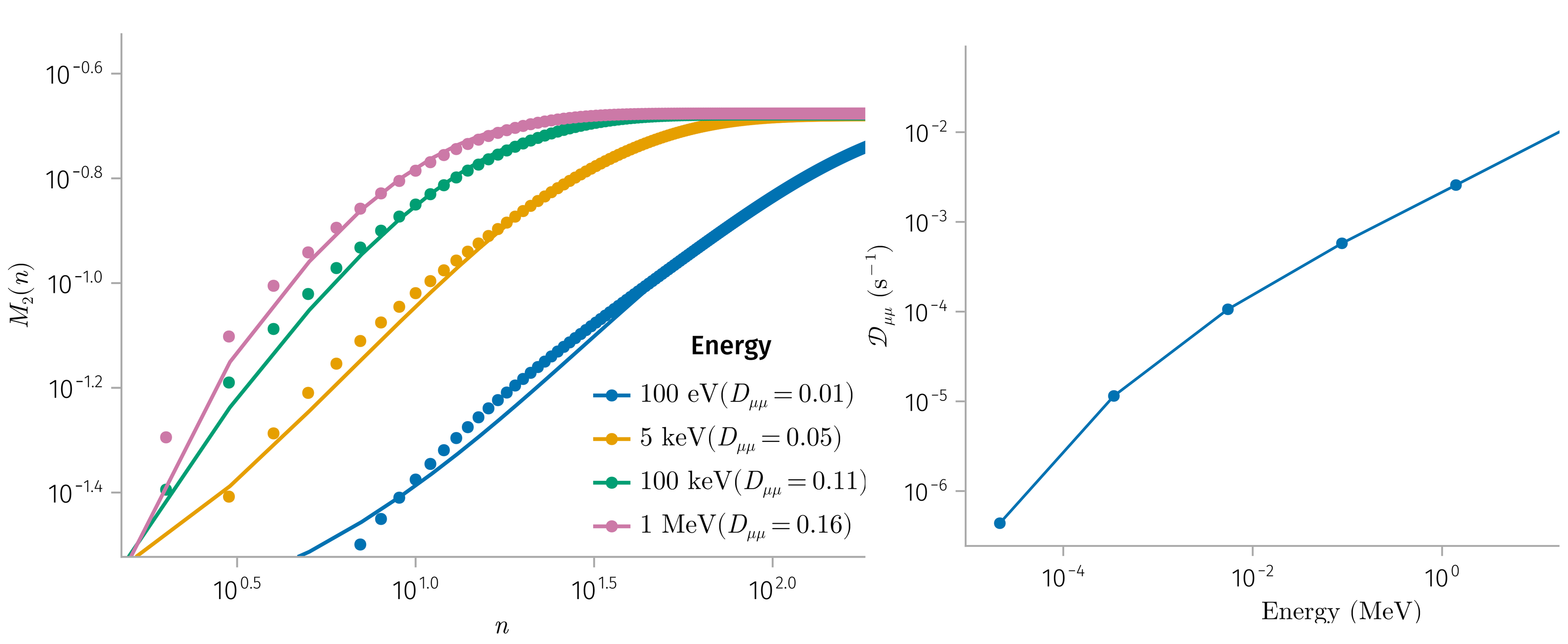
C. Solar Wind Observation

We compiled a dataset of 100,000 current sheets, characterizing the current sheet parameters from the ARTEMIS and Wind missions.

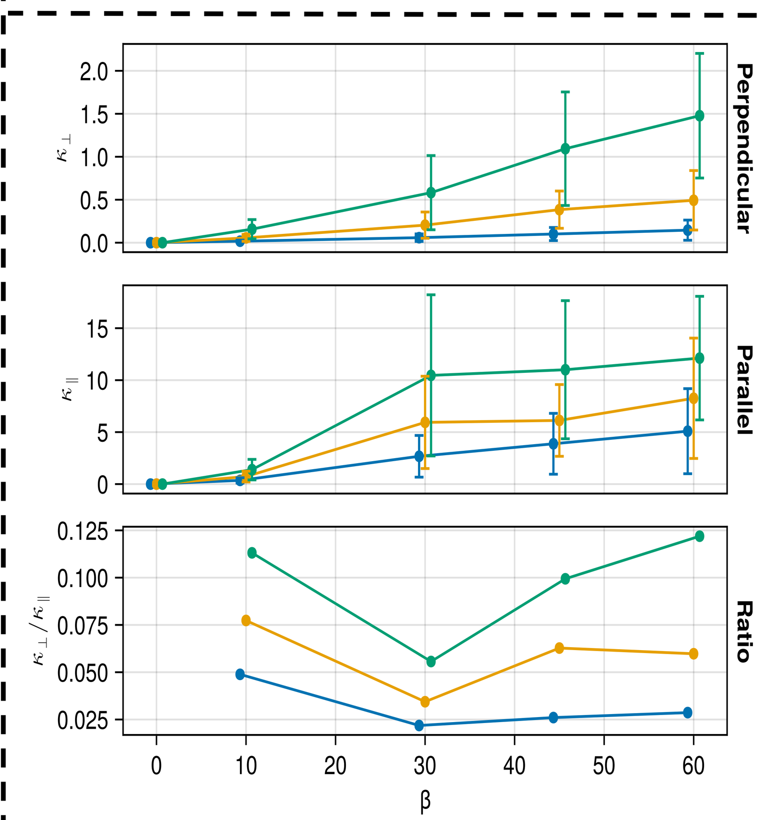


B.2. Long-term pitch-angle evolution

$$\alpha_{n+1,i} = W\left(\alpha_{n,i}, \xi_{n,i}\right)$$



D. Efficient cross-field transport



$$\kappa_\parallel = \sqrt{\frac{1}{\sum w}\sum_{i=1}^{n} w_i \frac{\left(\Delta s_{\parallel,i} - \overline{\Delta s_\parallel}\right)^2}{T_i}}$$

$$\kappa_\perp = \sqrt{\frac{1}{\sum w}\sum_{i=1}^{n} w_i \frac{\left(\Delta s_{\perp,i} - \overline{\Delta s_\perp}\right)^2}{T_i}}$$