Coronal oscillations, the Kelvin-Helmholtz instability and magnetic reconnection

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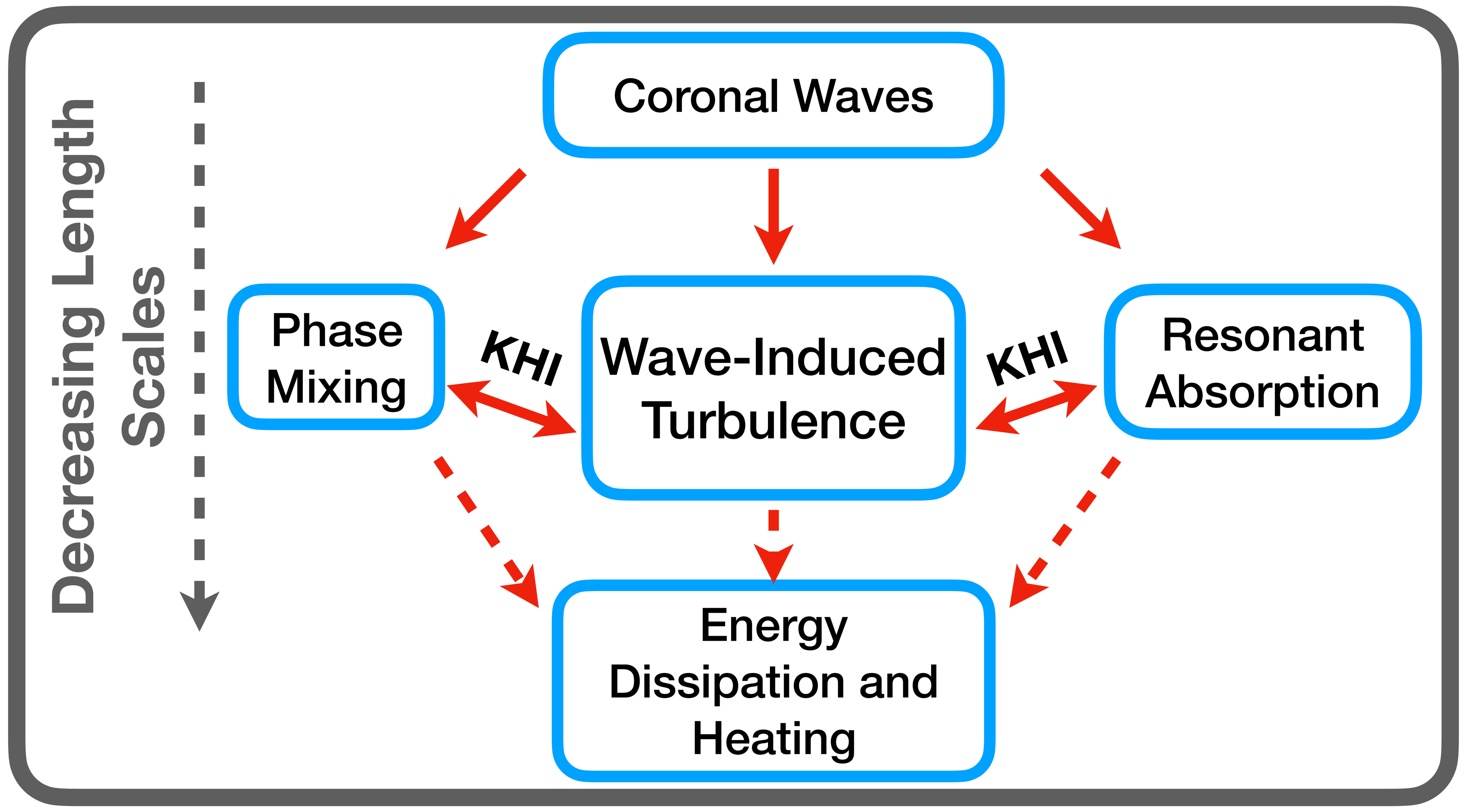
Context

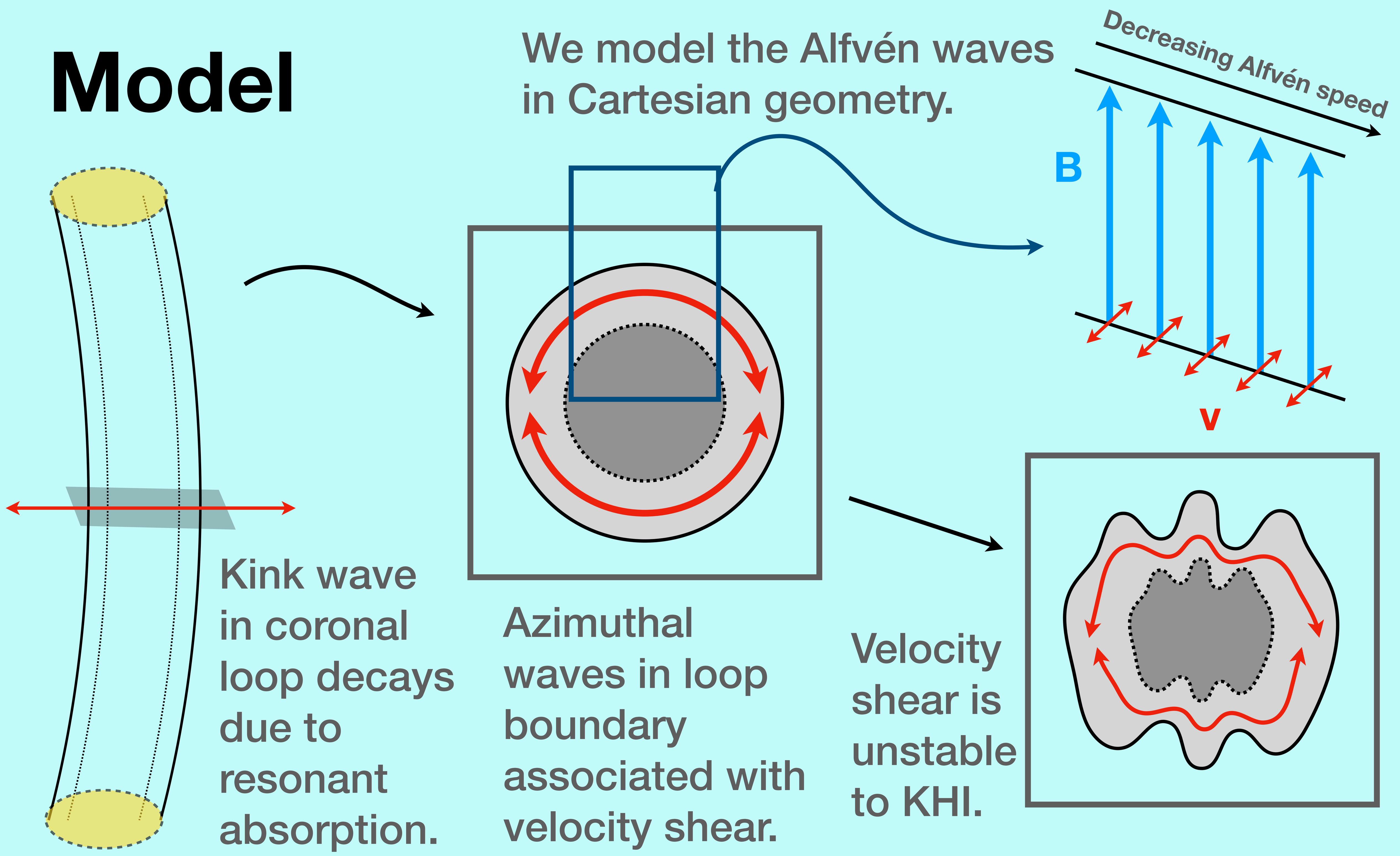
Many studies (e.g. [1], [2]) have shown that the Kelvin-Helmholtz instability (KHI) can develop during the decay of coronal loop oscillations. This is interesting for the coronal heating problem as the instability causes energy to cascade to dissipation length scales.



Questions and Answers

1. Can the KHI trigger reconnection in the corona? **Yes**
2. Under what conditions is the reconnection rate greatest? **When the instability growth rate is largest (e.g. long, unsheared field lines).**
3. Do we see that the instability releases energy stored in the background field? **Not efficiently.**

Model

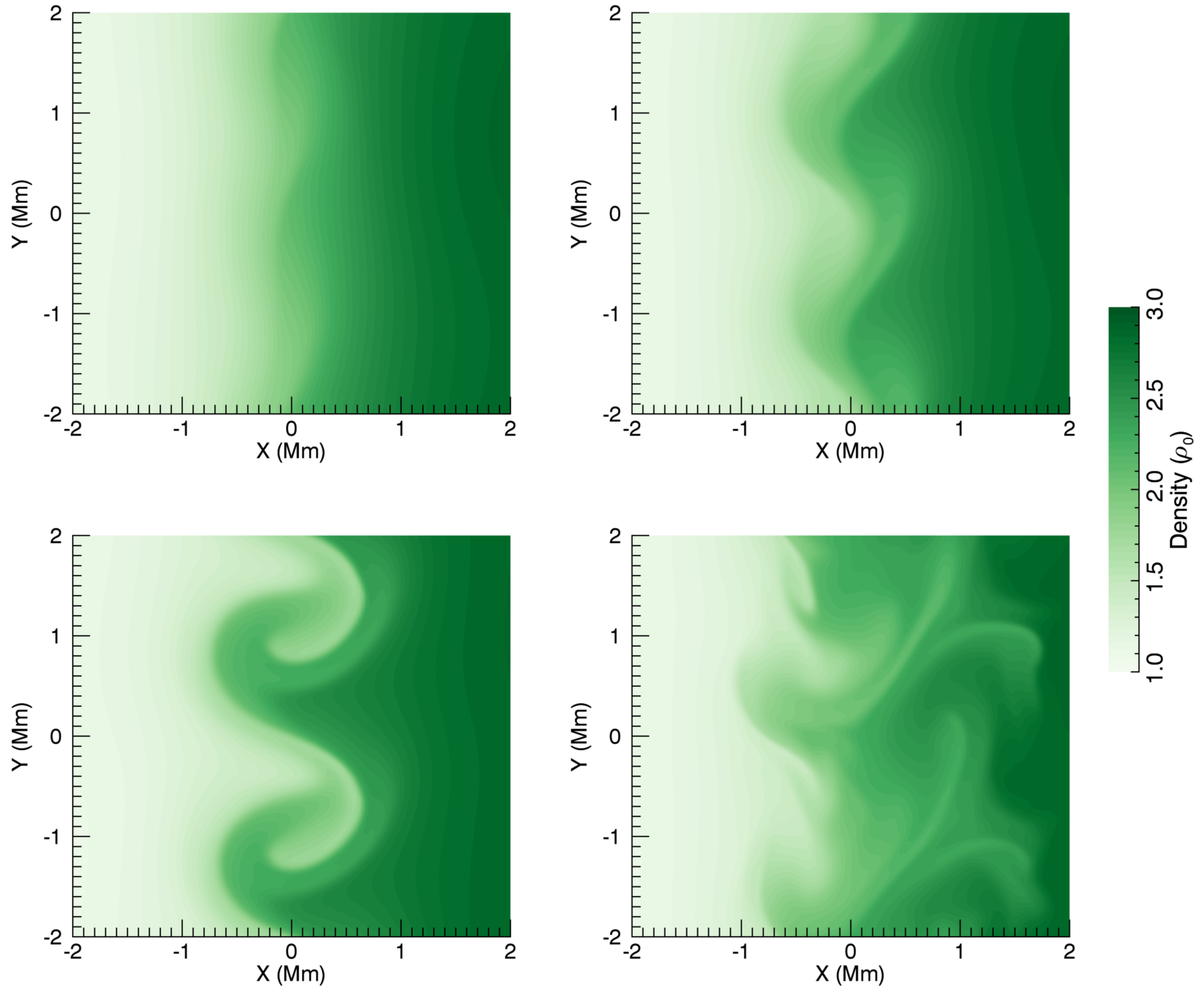


Summary: Will the KHI lead to reconnection in the corona? Yes, but we find that it does not extract significant energy from the background field.

Kelvin-Helmholtz Instability

KHI Development

Density Evolution



1. Wave driver excites velocity shear at x=0.

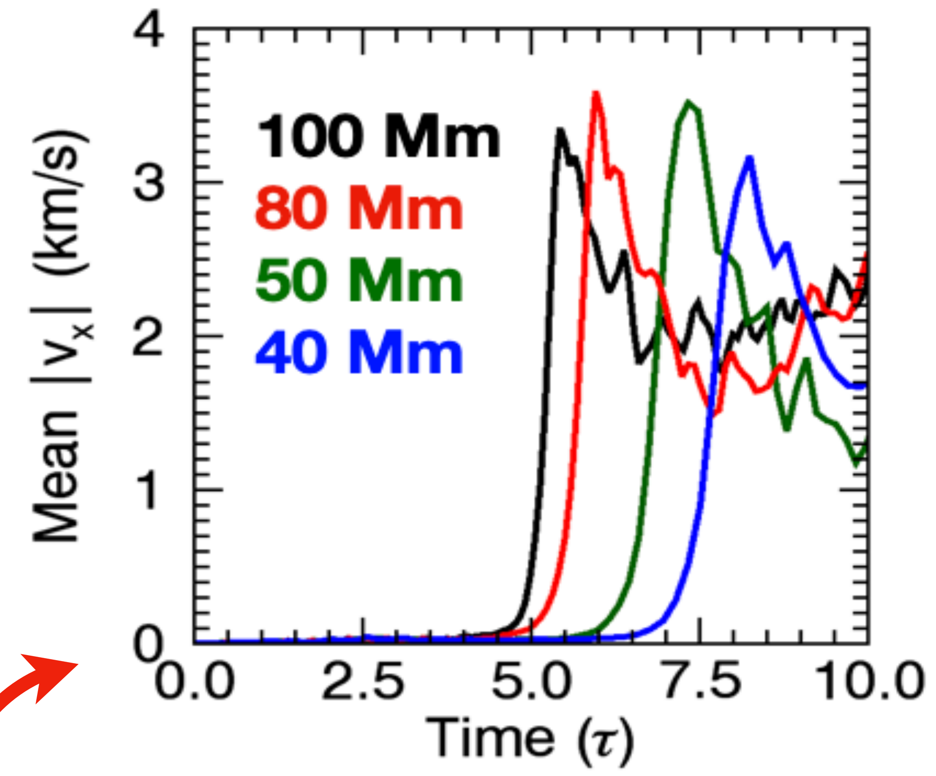
2. System becomes unstable to KHI.

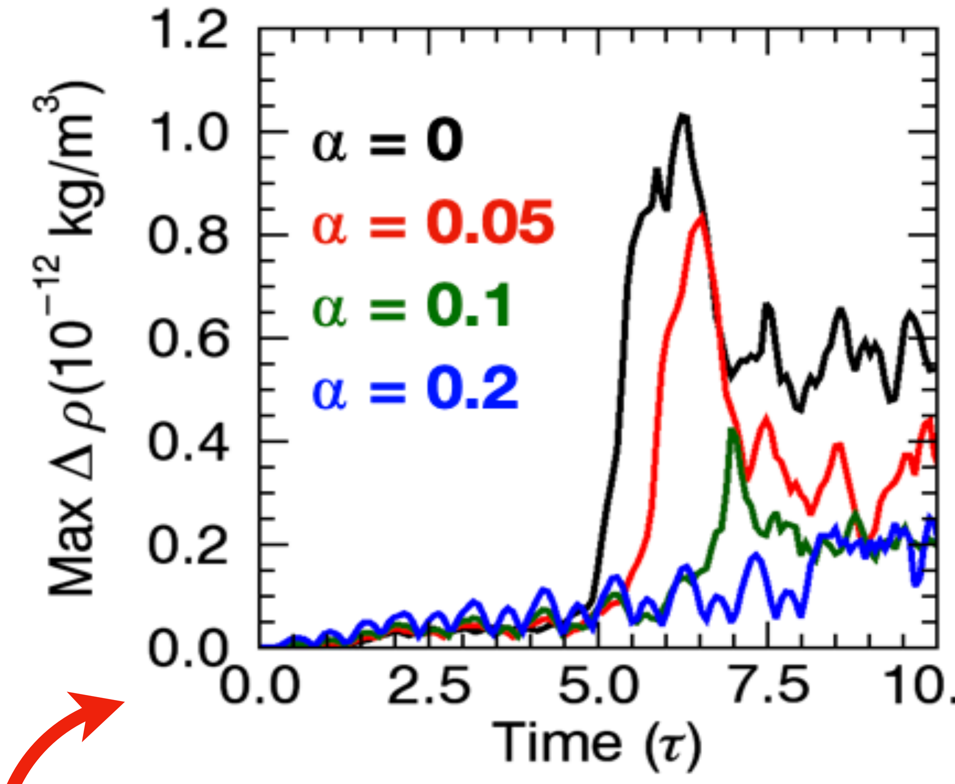
3. Density profile deformed by KH vortices.

4. Field frozen into plasma so currents form throughout mixing layer.

5. Turbulent-like regime develops.

Growth Rates

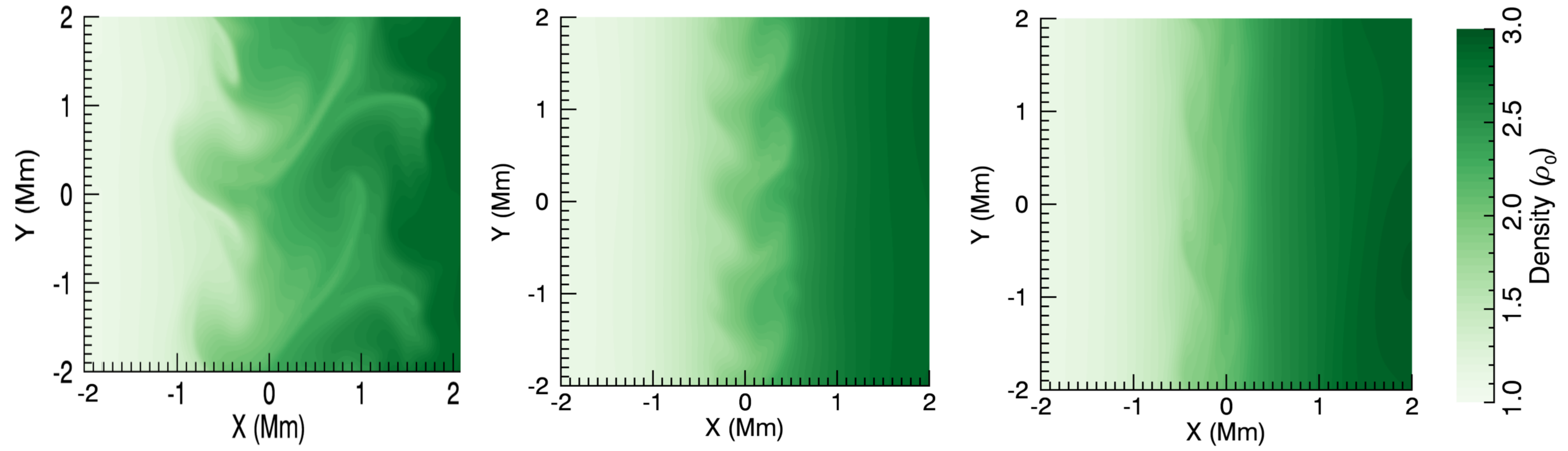




KHI delayed (in terms of wave periods) for short field lines.

Growth rate reduced for sheared field lines [3, 4].

Unsuppressed **Short field lines** **Sheared field lines**



Vortex formation and extent of mixing region significantly reduced for short [5] and sheared field lines.

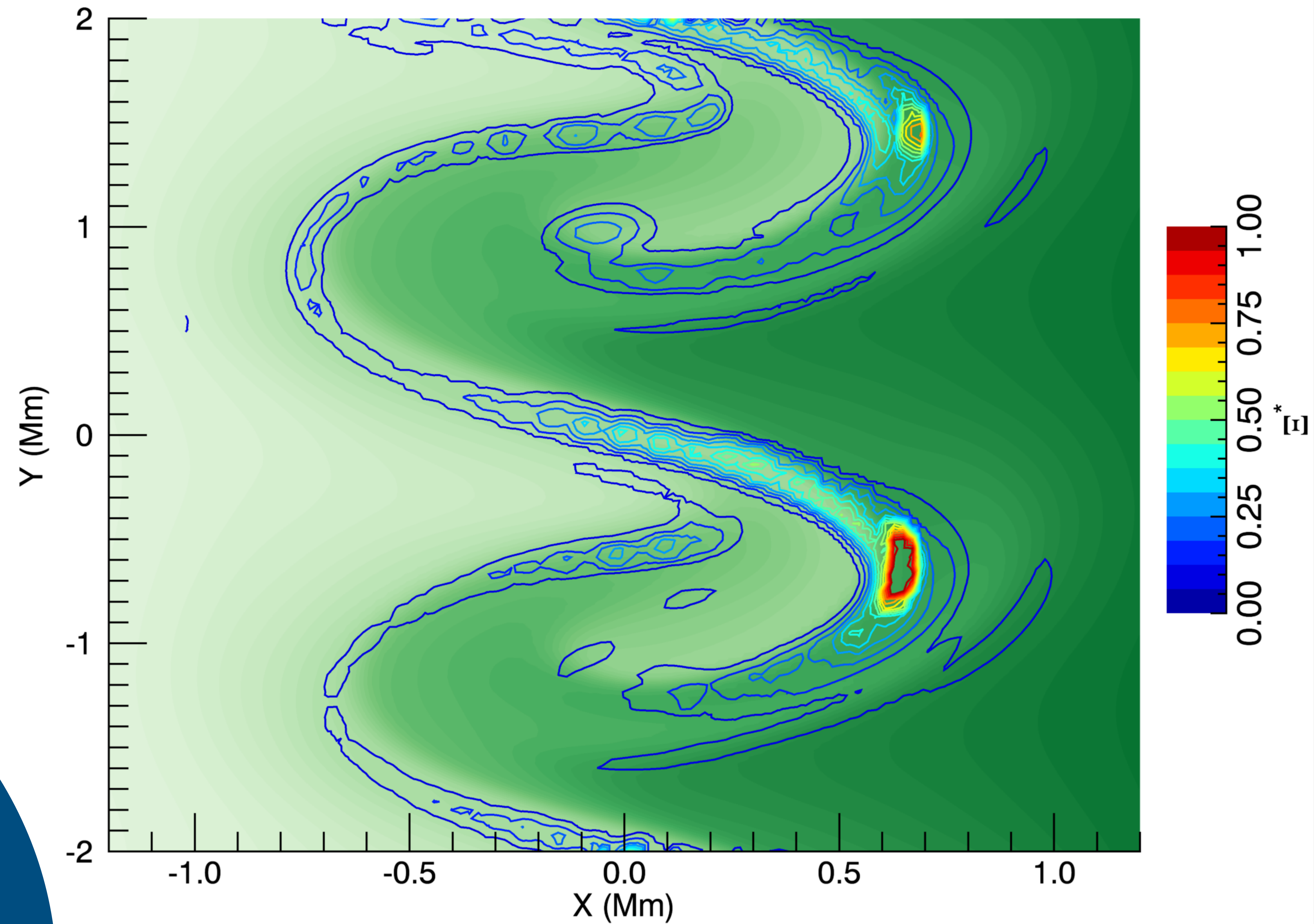
Summary: KHI leads to small scales in the magnetic and velocity fields. Growth rate is reduced for short or sheared field lines.

Magnetic Reconnection

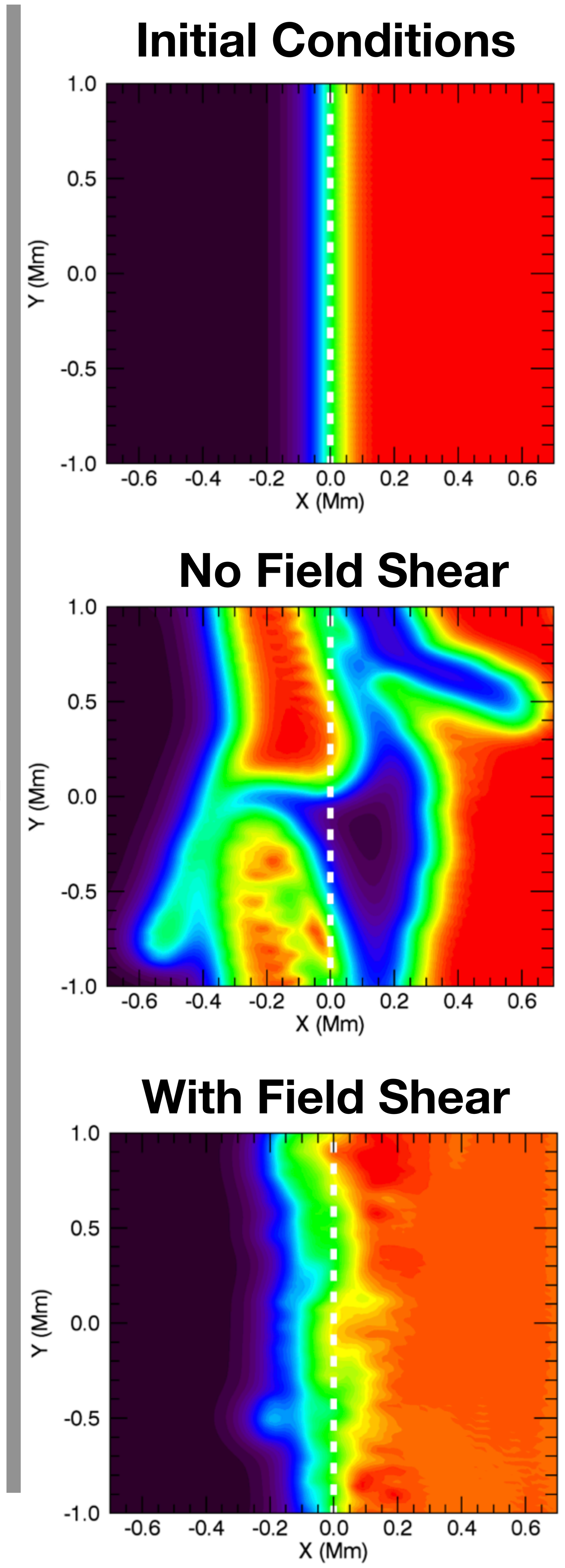
KHI generates a parallel component of the electric field —> **magnetic reconnection.**

We require: $$\Xi = \int_l E_{\parallel} \, \mathrm{d}l \neq 0.$$

Vortices and Parallel Electric Field



Large electric fields form as the KHI develops which allow magnetic reconnection.



Field Line Connectivity

Reconnection allows field lines to change connectivity across shear layer (white line).

Large change in field line connectivity (red zones in x < 0) for unsuppressed cases.

Little change in connectivity when KHI growth rates are lower (e.g. sheared field).

Summary: Parallel electric field largest around KH vortices. Connectivity change greatest with high KH growth rates.

Reconnection Rates

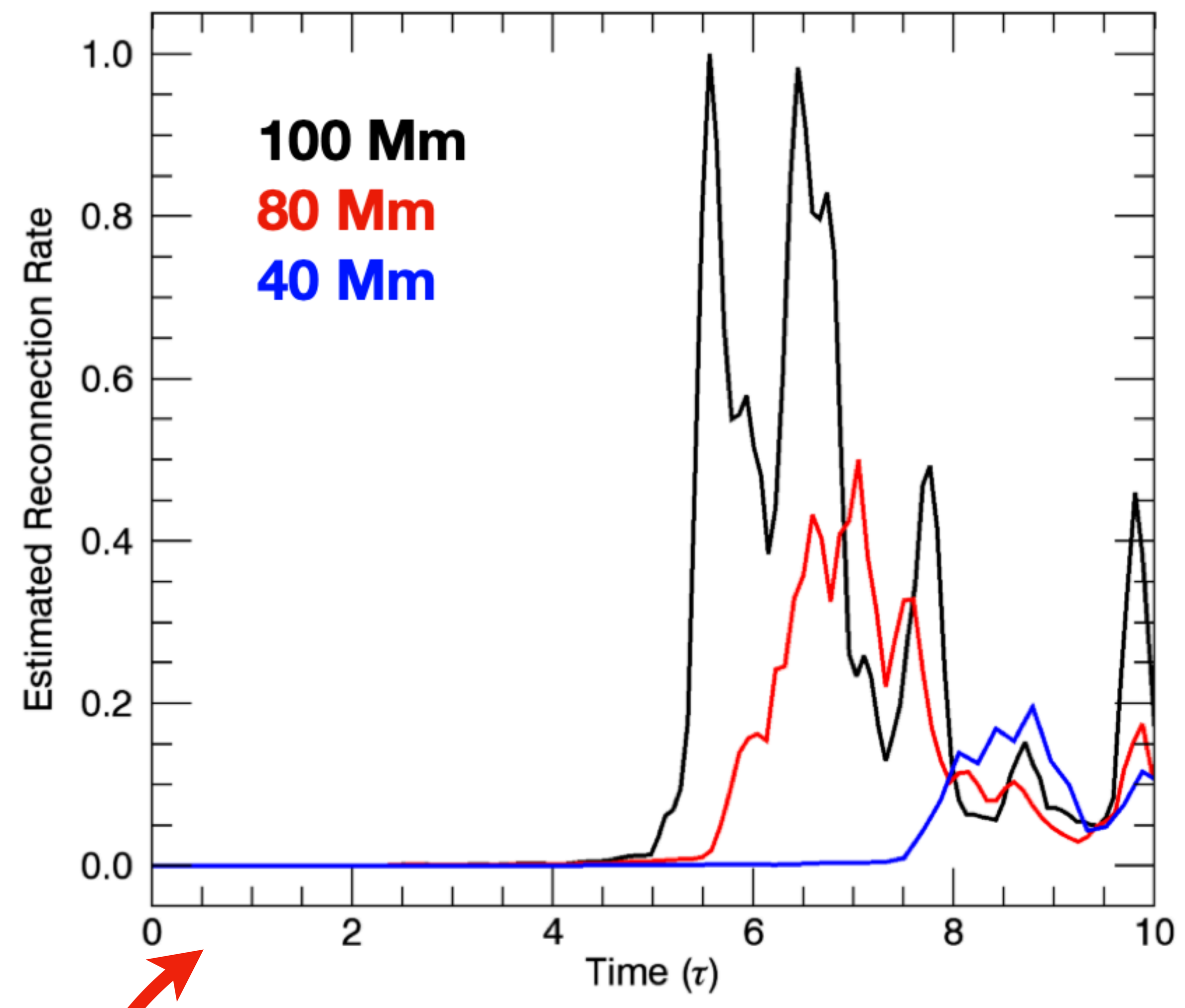
In a turbulent-like regime, [6] calculate a global reconnection rate as

$$|\Xi_{\mathrm{max}}| + \sum |\Xi_{\mathrm{l.m.}} - \Xi_{\mathrm{s.p.}}|.$$

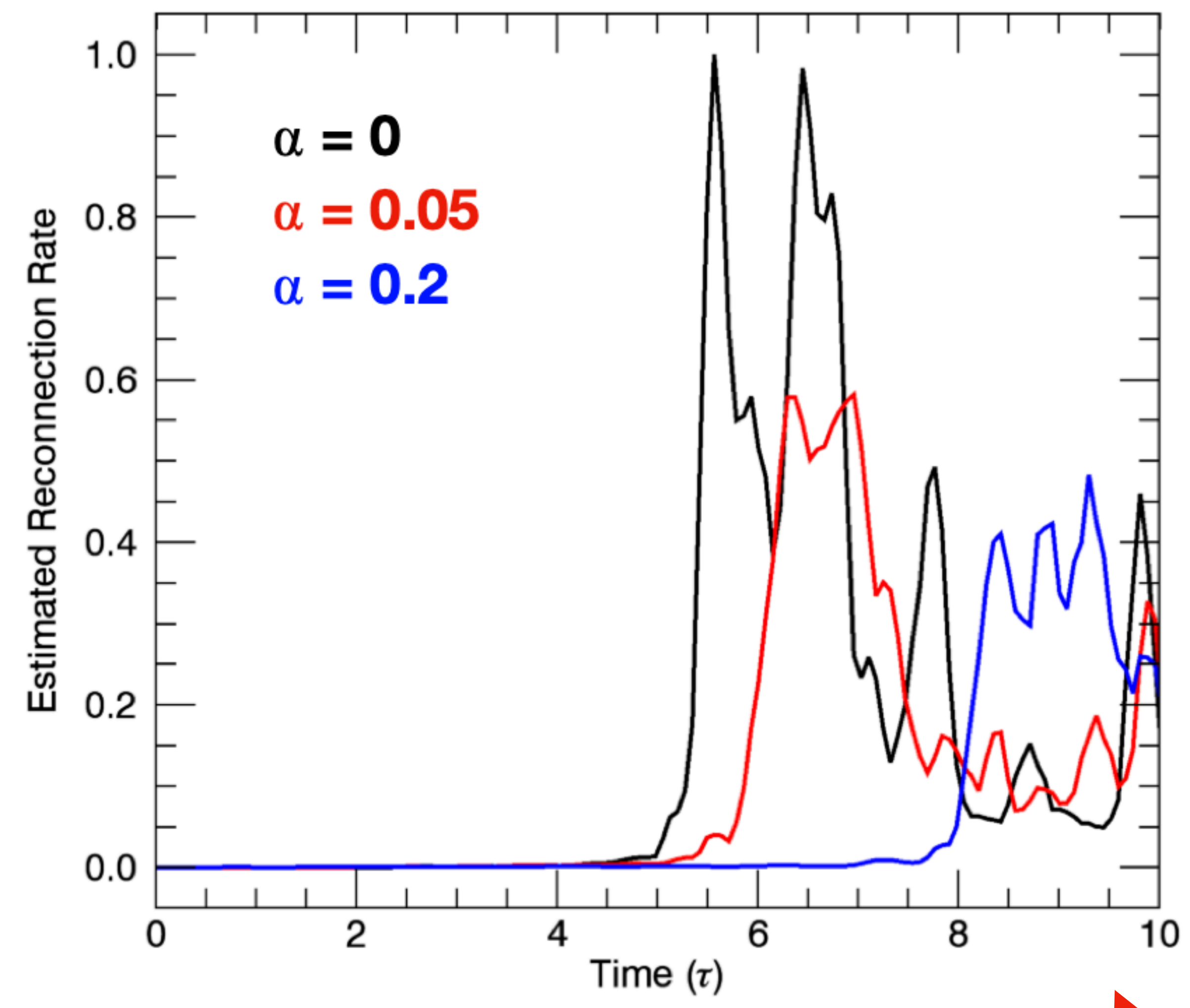
Method:

1. Trace 10^4 field lines from domain boundary.
2. Calculate $\int_l E_{\|}\, \mathrm{d}l$ on all field lines.
3. Identify all local maxima and use above formula
4. Repeat for all times during each simulation.

Field Line Length



Field Line Shear



In all cases, the global **reconnection rate increases significantly** during growth of instability. **Highest rate found during initial phase.**

Reconnection rate is reduced and peak occurs later for sheared field lines. Free energy in non-potential background field does not compensate for the reduced growth rate.

Reconnection rates are reduced for shorter field lines. In terms of wave periods, the peak reconnection rate occurs later due to delayed KHI.

Summary: Reconnection rate is greatest during the initial phase of instability and when the growth rate is largest (long unsheared field lines).

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References [1] Terradas, J., Andries, J., Goossens, M., et al. 2008, ApJ, 687, L115; [2] Antolin, P., Yokoyama, T., & Van Doorsselaere, T. 2014, Astrophys. J. Letts., 787, L22; [3] Howson, T. A., De Moortel, I., & Antolin, P. 2017, A&A, 607, A77; [4] Terradas, J., Magyar, N., & Van Doorsselaere, T. 2018, ApJ, 853, 35; [5] Hillier, A. & Arregui, I. 2019, ApJ, 885, 101; Wyper, P. F. & Hesse, M. 2015, Physics of Plasmas, 22, 042117.