Can you create a large-scale vertical field from the KHI? Yup.

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Motivation:

Merging compact objects excite KH unstable shear layers in the plasma between the stars.

Due to a large seperation in shear timescales t_Δ, and merger timescales, $t_{\rm merge}$, shear layer dynamics can be realized. For example, in binary neutron star (BNS) mergers

$$t_\Delta = \frac{\delta_0}{\Delta U} \approx \frac{65\,{\rm m}}{0.2c} = \mathcal{O}(10^{-6}\,{\rm s}) \approx 10^{-3} t_{\rm merge}.$$

In $10^3 t_\Delta$, the shear layer can produce a strong magnetic through the magnetic dynamo. Tripathi et al. (2026) demonstrates the existence of a toroidal (in-plane) dynamo. Gutiérrez et al. (2026) shows a strong fluctuation dynamo. But most important for multimessenger signals of the events is the BZ mechanism, which requires a vertical field dynamo. Here we show, for the first time, a vertical field dynamo that is active in the first $500 t_\Delta$ in the shear layer.

Numerical Setup:

3D, visco-resistive, compressible MHD equation, with KHI ICs:

$$\frac{u_y(x,t_0)}{U_y} = \Delta(x) - 1, \qquad \Delta U = 2U_y, \qquad \text{shear profile}$$

$$\frac{\rho(x,t_0)}{\rho_0} = 1 + \frac{\delta\rho}{2\rho_0}\Delta(x), \qquad \text{stratification}$$

$$\Delta(x) = \tanh\left(\frac{x-x_1}{\delta_0}\right) - \tanh\left(\frac{x-x_2}{\delta_0}\right),$$

$$\frac{u_x(x,y,t_0)}{U_x} = \frac{1}{\sqrt{n_{\max}+1}} \sum_n^{n_{\max}} \sin\left(\frac{2n\pi}{L}y + \phi_n\right) \times \qquad \text{perturbation}$$

$$\left(\exp\left\{-\frac{(x-x_1)^2}{\sigma^2}\right\} + \exp\left\{-\frac{(x-x_2)^2}{\sigma^2}\right\}\right),$$

with initial random magnetic field that satisfies:

$$\widetilde{B}_i(\boldsymbol{k}) = \widetilde{A}(k)(\delta_{ij} - k_i k_j/k^2)\widetilde{g}_j(\boldsymbol{k}) \iff \boldsymbol{k}\cdot\widetilde{\boldsymbol{B}}(\boldsymbol{k}) = 0, \quad k \neq 0,$$

$$\langle \widetilde{g}_i(\boldsymbol{k})\rangle = 0, \qquad \langle \widetilde{g}_i(\boldsymbol{k})\widetilde{g}_j^\dagger(\boldsymbol{k}')\rangle = \delta_{ij}\,\delta_{\boldsymbol{k}\boldsymbol{k}'}.$$

magnetic field breaks z symmetry

discretized on uniform grids: $288^3 \leq N^3_{\rm grid} \leq 4{,}608^3$

Dynamo Results:

Integral energy statistics are dominated by large-scale, diffusing shear layer:

$$\frac{d\ln E_{\rm mag}}{dt} = 2\overline{\hat{B}_i\hat{B}_j\partial_j u_i} \sim \frac{2U_y}{\delta(t)} \sim \frac{2U_y}{\sqrt{\delta_0^2 + C_\nu \nu t}},$$

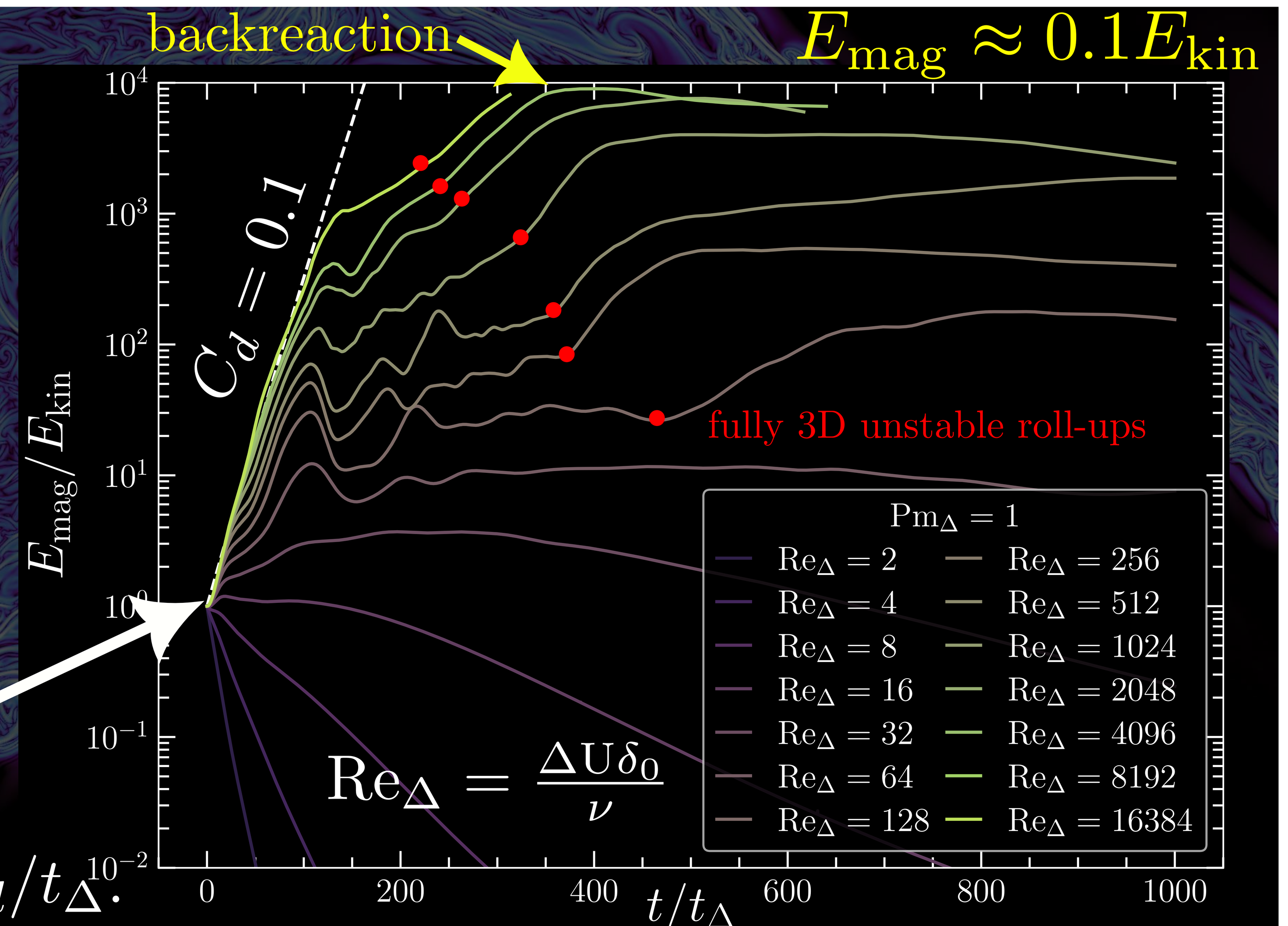
and integrating

$$\frac{E_{\rm mag}(t)}{E_{\rm mag}(0)} = \exp\left(\frac{2C_d{\rm Re}_\Delta}{C_\nu}\left[\sqrt{1+\frac{C_\nu}{{\rm Re}_\Delta}\frac{t}{t_\Delta}} - 1\right)\right),$$

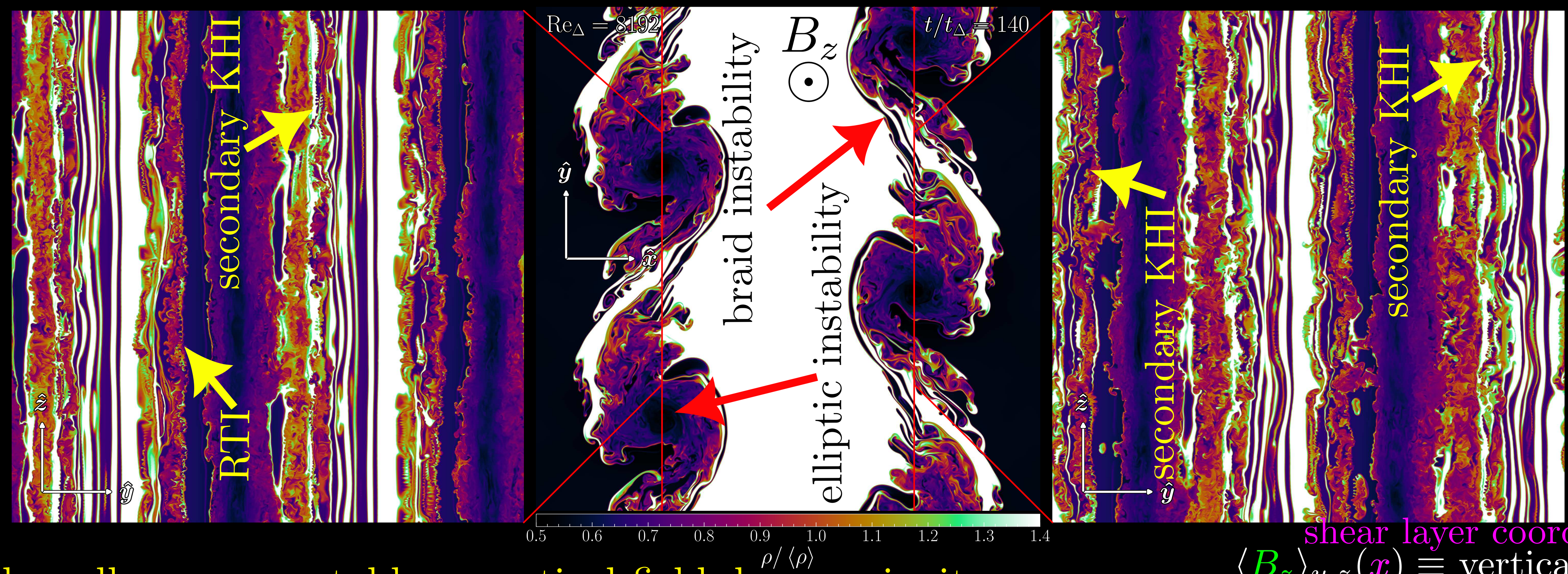
where $C_d = \mathcal{O}(10^{-1})$ is the dynamo efficiency. For $t/t_\Delta \ll {\rm Re}_\Delta/{\rm C}_\nu$,

$$\frac{E_{\rm mag}}{E_{\rm mag}(0)} \approx \exp\left(C_d\frac{t}{t_\Delta}\right),$$

predicts asymptotic Re $\to \infty$ growth rate, $\gamma \approx C_d/t_\Delta$.

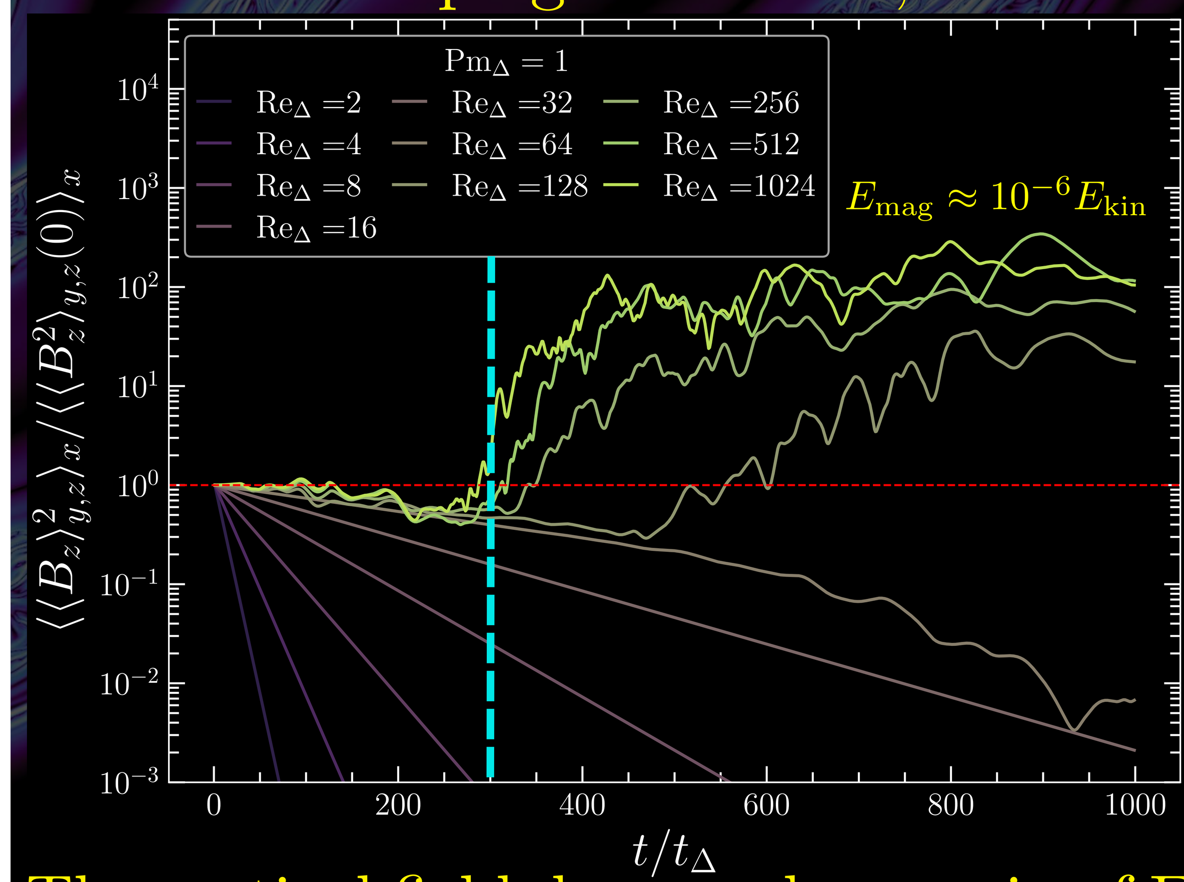


KHI goes nonlinear on $t \gtrsim 1t_\Delta$, creating roll-ups. Roll-ups go 3D unstable via a zoo of instabilities:



shear layer coordinate
$\langle B_z\rangle_{y,z}(x) \equiv$ vertical field
out-of-plane field

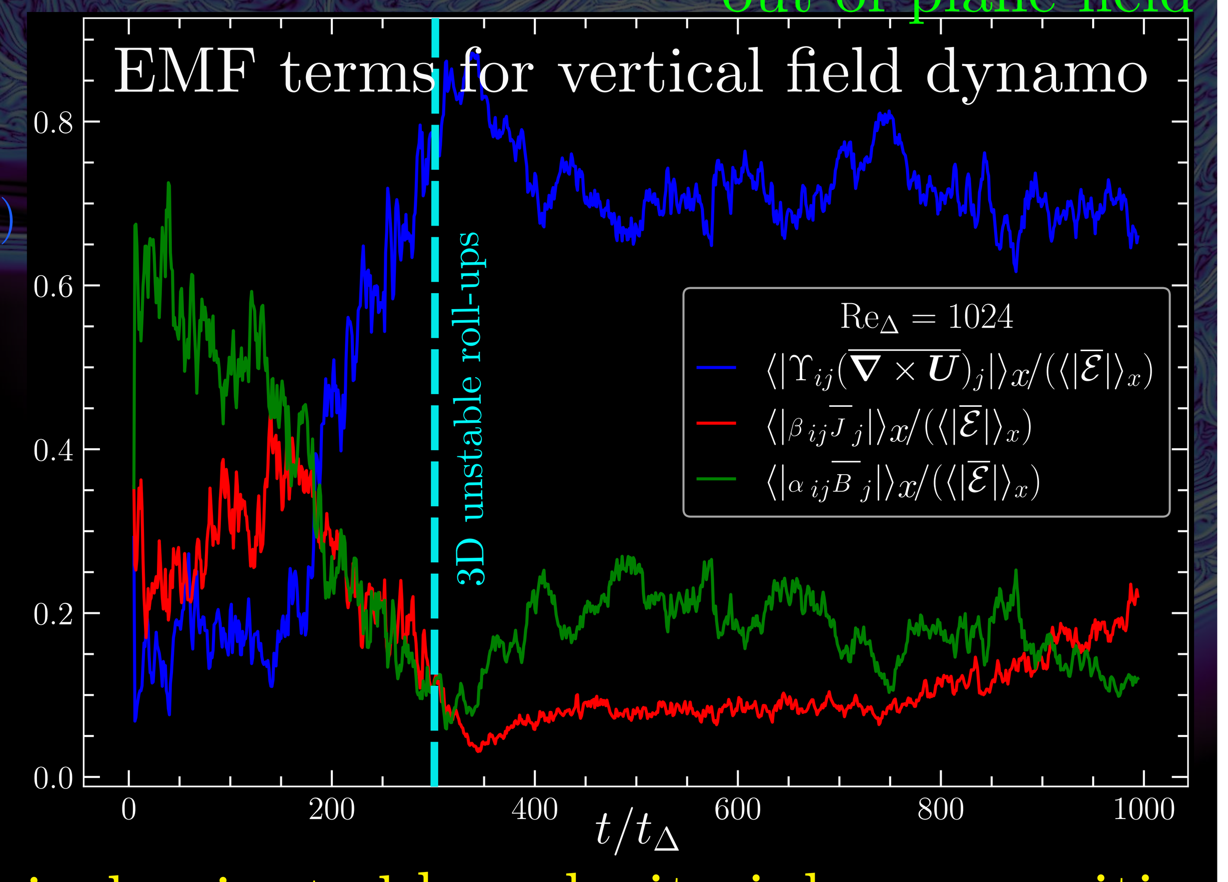
As the roll-ups go unstable, a vertical field dynamo ignites



Upsilon term
(inhomogenous velocity)
Tripathi et al. (2026)
70% flux

Beta term
70% flux

Alpha term
70% flux



The vertical field dynamo has a mix of EMF contributions, but is dominated by velocity inhomogeneities