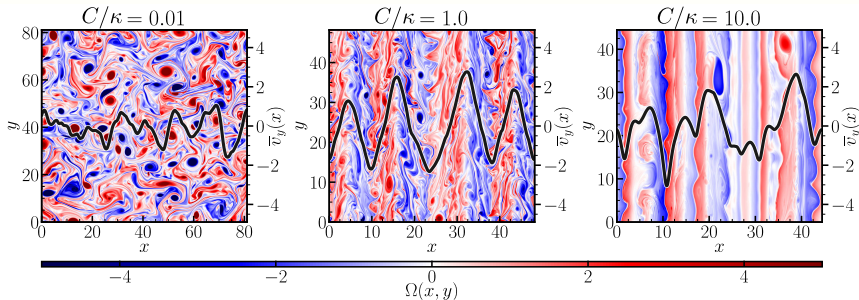


# Phase transition from turbulence to zonal flows

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Hasegawa-Wakatani system: model for **instability-driven 2D turbulence** in tokamaks



Two regimes depending on the ratio of linear parameters  $C/\kappa$

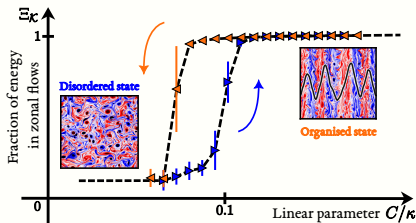
$C/\kappa \ll 1$   
2D turbulence  
Disordered state, "hot"

$C/\kappa \gtrsim 1$   
Zonal flows, quasi-1D  
Organised state, "cold"

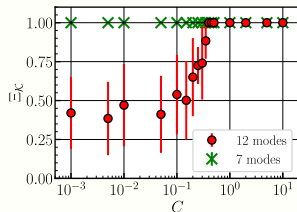
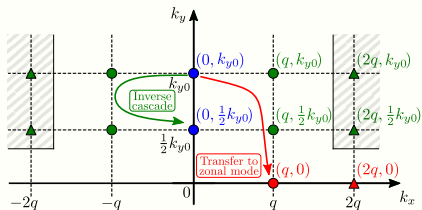
# Phase transition from turbulence to zonal flows

Construct an **order parameter**: fraction of kinetic energy in the zonal flows

- ★ **Hysteresis loop** around the critical point  $C/\kappa \sim 0.1$
- ★ **Zonal flows can survive** once formed
- ★ Need some “latent heat” to destroy them



Reduced model with few Fourier modes to reproduce the transition



[PLG and Ö. D. Gürçan, *Phys. Plasmas*, 2025]