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Bifurcation in Resistive Drift Wave Turbulence

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In this work we report the results of numerical simulation of the modified Hasegawa-Wakatani model, which describes resistive drift wave turbulence in tokamak edge plasmas. The HW model is a simple model, but contains an interesting physics, i.e. turbulence-shear flow interaction. This simulation study also complements the low-dimensional modeling results which we already have.

Modified Hasegawa-Wakatani Model

MHW model describes evolution of density fluctuation n and vorticity $\zeta=\nabla^2\varphi$ (φ : electrostatic potential)

$$\frac{\partial\zeta}{\partial t}+[\varphi,\zeta] = \alpha(\tilde{\varphi}-\tilde{n})-D_\zeta\nabla^4\zeta$$

$$\frac{\partial n}{\partial t}+[\varphi,n] = \alpha(\tilde{\varphi}-\tilde{n})-\kappa\frac{\partial\varphi}{\partial y}-D_n\nabla^4 n$$

$[a,b]=\partial a/\partial x\,\partial b/\partial y-\partial a/\partial y\,\partial b/\partial x,\ \nabla^2=\partial^2/\partial x^2+\partial^2/\partial y^2$

D_ζ, D_n : dissipation coefficients (Prandtl number $P_r=D_\zeta/D_n$)

$\kappa=\frac{-\partial}{\partial x}\ln n_0,\quad \alpha=\frac{T_e k_z^2}{\eta n_0 \omega_{ci} e^2}$

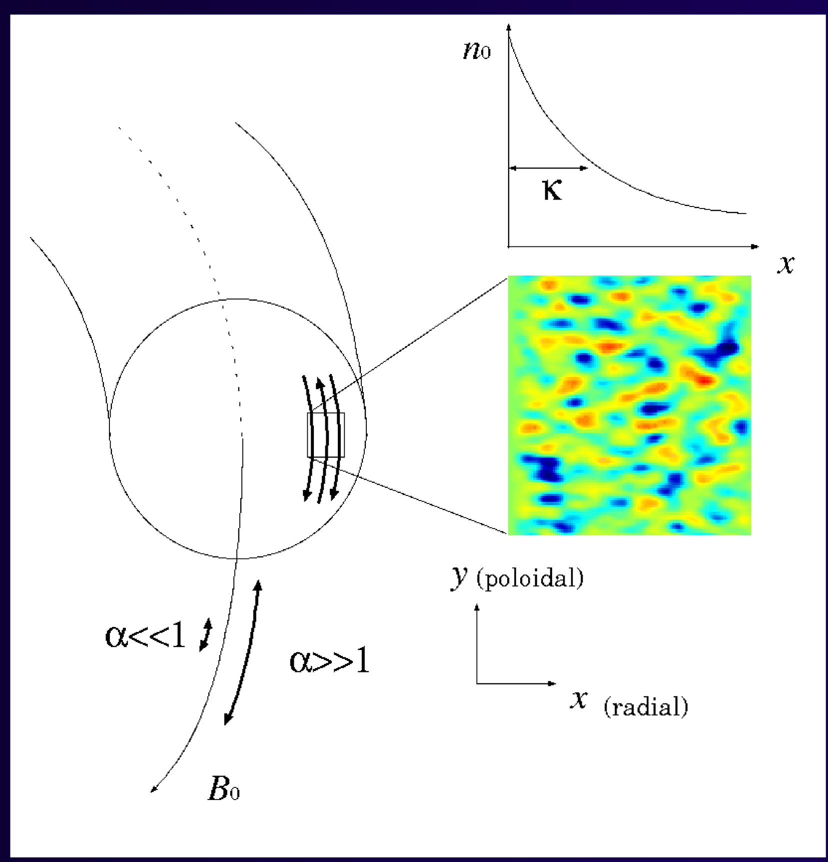
Resistive coupling term which comes from parallel electron response $\partial j_z/\partial z=1/\eta\,\partial^2(\varphi-n)/\partial z^2$ (Ohm's law)

does not act on the zonal components ($k_y=k_z=0$)

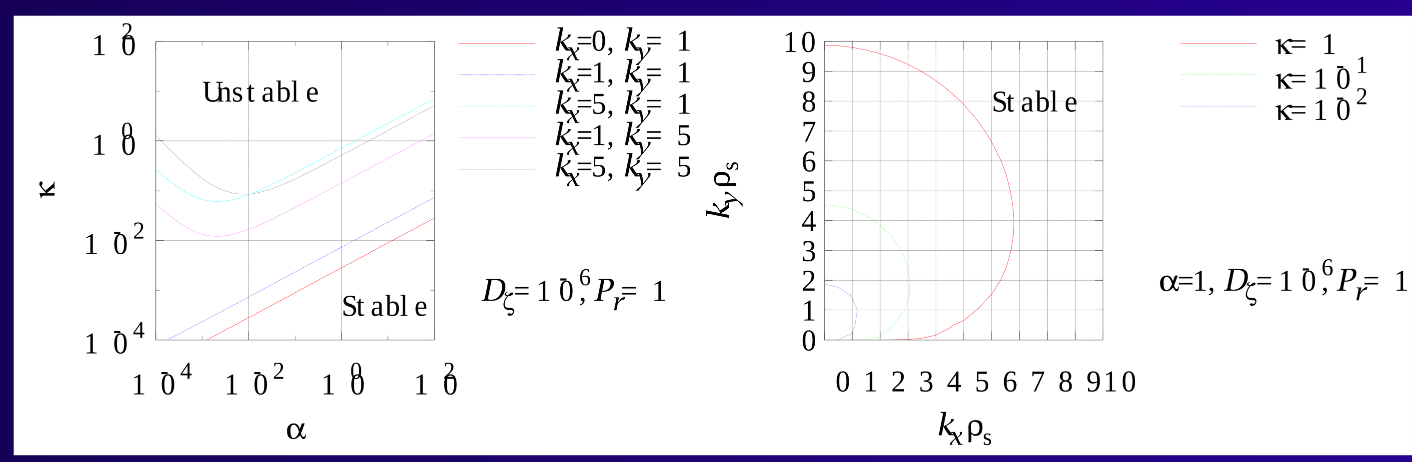
Original HW MHW
$\alpha(\varphi-n)\rightarrow\alpha(\tilde{\varphi}-\tilde{n})$

Zonal: $\langle f\rangle=\frac{1}{L_y}\int f\,dy$ (f stands for φ and n)

Non-zonal: $\tilde{\varphi}=\varphi-\langle\varphi\rangle,\ \tilde{n}=n-\langle n\rangle$



Stability Diagram Indicating 1st Bifurcation Points



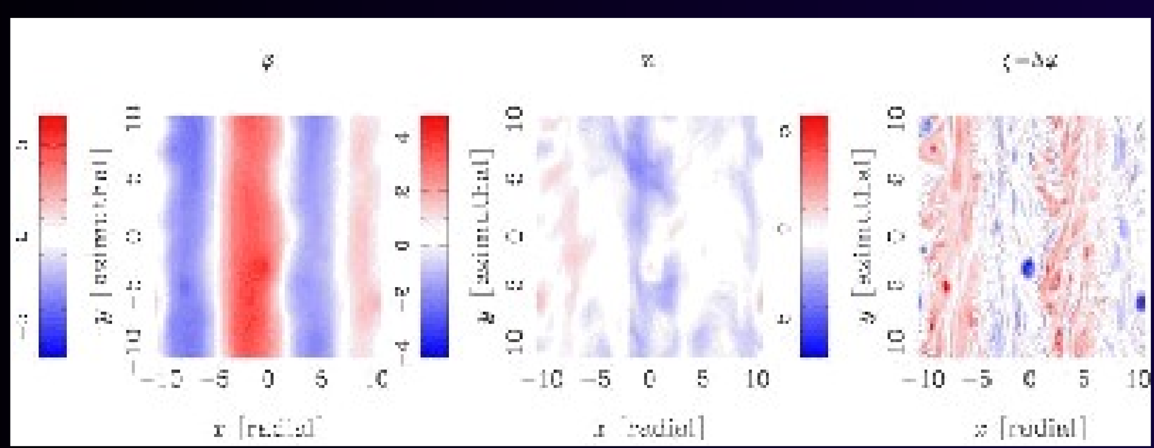
For finite α one positive growth rate if $D=0$ (dissipationless)
large $\kappa\rightarrow$ destabilizing, large $\alpha\rightarrow$ stabilizing
Growth rate monotonically decrease with k_x, peaks at $k_y\sim1$

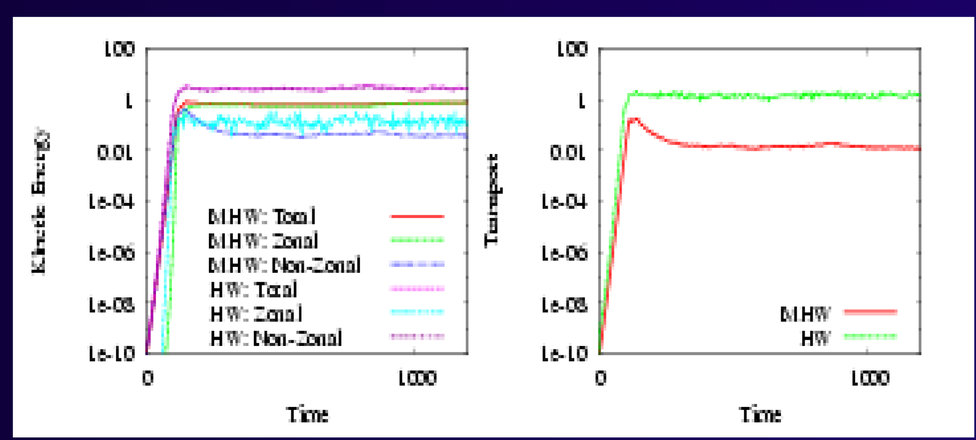
Numerical Algorithm to Solve MHW Model

- MHW model is solved in 2D slab geometry
- Box size L, determined by smallest wavenumber $\Delta k=0.3$ [$(2L)^2=(2\pi/\Delta k)^2$]
- Periodic boundary in both x and y direction
- Time stepping algorithm is a 3rd order explicit linear multistep method
- Finite difference method is used for spatial discretization
- Poisson bracket term evaluated by the Arakawa's method (Arakawa(1966))
- Implemented on APAC-NF SGI Altix 3700 Bx2 Cluster

Zonal Flow Generation and Transport Suppression

Contour plot of saturated variables for $\kappa=1,\alpha=1,D_\zeta=10^{-6},P_r=1$



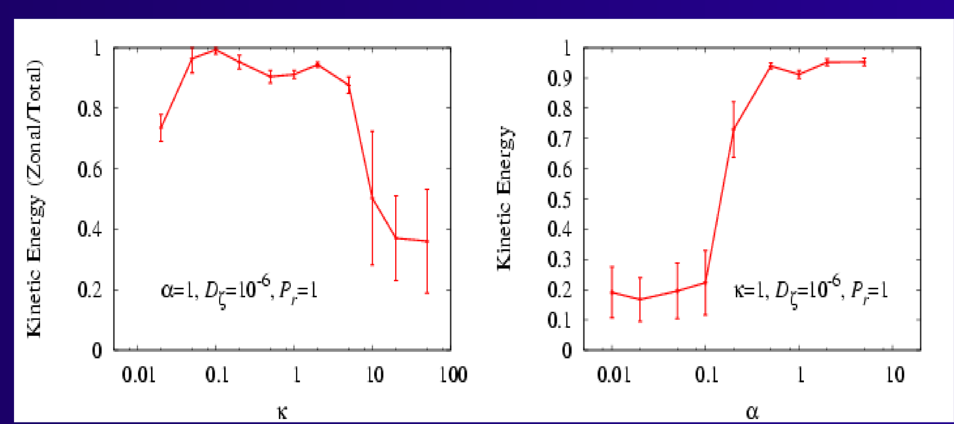


Kinetic energy $E=\frac{1}{2}\int|\nabla\varphi|^2\,dxdy$

Zonal kinetic energy $F=\frac{1}{2}\int\left(\frac{\partial\langle\varphi\rangle}{\partial y}\right)^2 dx\,dy$

Cross-field transport $\Gamma_n=-\kappa\int n\,\partial\varphi/\partial y\,dx\,dy$

Transition to Zonal Flow Suppressed Regime



Sudden transition occurs if we move parameters to linearly more unstable direction

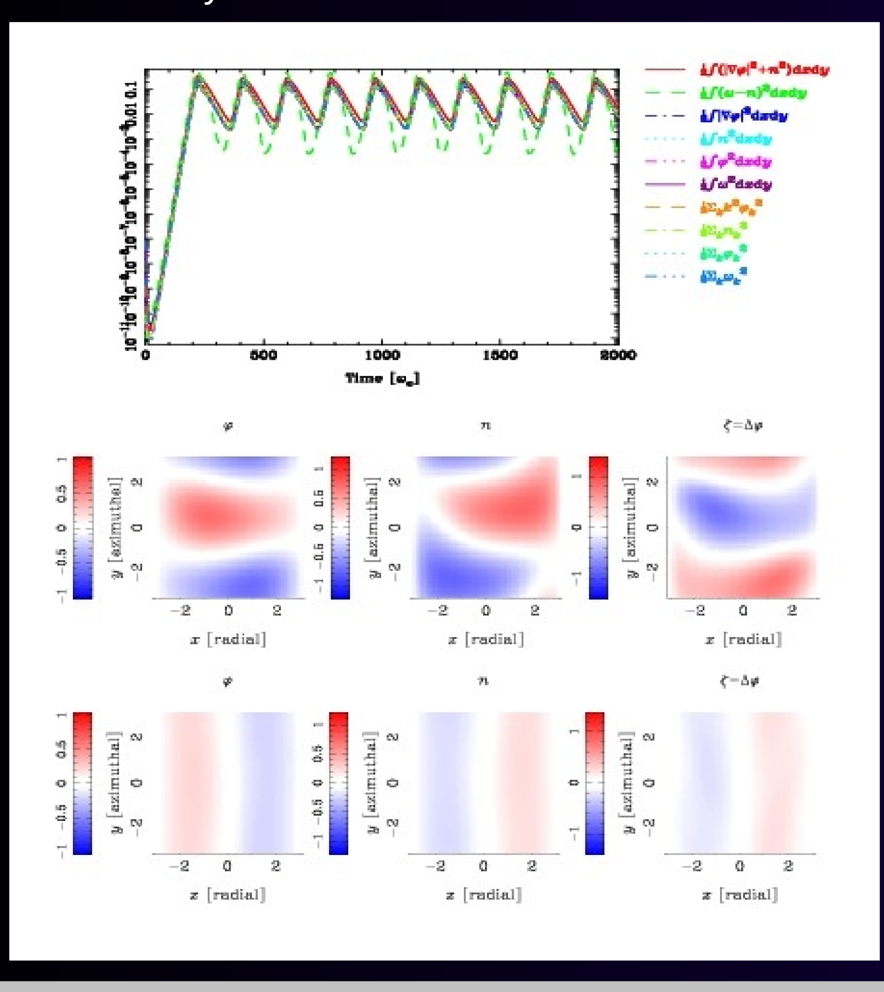
To understand Bifurcation ...

- Stability of Zonal Flow [Kelvin-Helmholtz Instability]

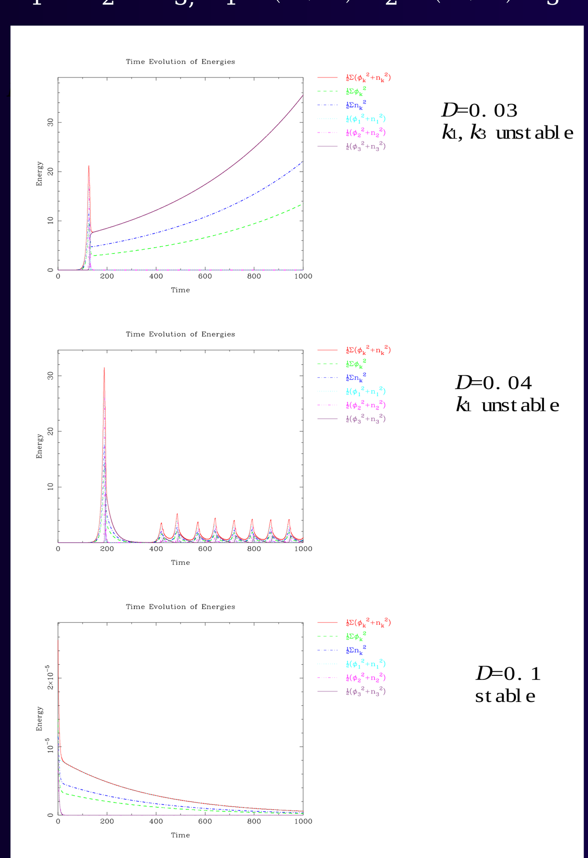
$$\varphi=\varphi_0(x)+\tilde{\varphi}(x)\exp(ik_y y+\gamma t)$$

- What is the 1st destabilized structure which appears just beyond linear threshold?

Fully nonlinear



3 wave interaction
$\vec{k}_1+\vec{k}_2=\vec{k}_3,\ \vec{k}_1=(0,1)\ \vec{k}_2=(1,0)\ \vec{k}_3=(1,1)$



Summary and Conclusion

- We have performed simulations of modified Hasegawa-Wakatani model
- Zonal flows are generated, and the zonal flows suppress cross-field turbulent transport in MHW model
- Transition from zonal flow dominant to zonal flow suppressed state is observed
- Bifurcation points may be understand as destabilization of zonal flow or some other structure. But, what structure?
- To look for the 1st destabilized state, we start to study the behavior near the linear stability boundary where only few modes are involved.
- Oscillatory behavior is observed just beyond linear stability boundary, where drift wave and zonal flow are competing [predator-pray]
- Corresponence of bifurcation diagram obtained from numerical simulation and from low-κ dimensional model should be considered

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