3-mode zonal coupling part of [Sherwood 2000 Poster

Aspects of Zonal Flow Dynamics, and Gyrofluid Simulations of Electromagnetic Effects on ITG Turbulence*

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Results are presented from three dimensional gyrofluid simulations of ITG-drift-Alfvén turbulence using a new, numerically efficient model which includes self-consistent magnetic fluctuations and non-adiabatic electron dynamics[1]. It employs a $k_{\parallel} v_{te} \gg \omega$ ordering to eliminate fast electron transit time scales while including a model of electron Landau damping perturbatively. A transition from electrostatic ITG turbulence to Alfvénic turbulence is seen at modest values of the plasma pressure. Significant electromagnetic effects on heat conductivity are observed, including a significant increase as the ideal ballooning threshold is approached, particularly when electron Landau damping is included. Turbulent spectra show some similarities to experimental measurements.

The importance of small-scale turbulence-driven zonal flows in the regulation of core plasma turbulence has been widely confirmed in gyrofluid and gyrokinetic simulations. We present a simple 3-mode coupling paradigm problem that illustrates some of the features of nonlinear secondary instabilities that can drive zonal flows, following a treatment by Drake et.al.[2]. The basic physics is related to early work by Kraichnan and by Hasegawa et.al., on negative eddy viscosity at low k and on inverse cascades of energy in 2-D turbulence. Some modifications to the gyrofluid closures have recently been developed [3, 4], to try to improve their treatment of certain neoclassical effects, including the Rosenbluth-Hinton residual undamped component of the flow. This modified gyrofluid closure is able to reproduce part of the Dimits nonlinear upshift[4]. If time permits, we may investigate ideas to further improve the closure.

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References

[1] P.B. Snyder, Princeton Ph.D. Thesis (1999). w3.pppl.gov/~pbsnyder/

[2] J.F. Drake, J.M. Finn, P. Guzdar, et.al., Phys. Fluids B **4**, 488 (1992).

[3] M.A. Beer and G.W. Hammett, Proc. of the Joint Varenna-Lausanne Int. Workshop on Theory of Fusion Plasmas (August 1998), p.19 (Varenna, Italy 1998).

[4] A.M. Dimits, G. Bateman, M.A. Beer, et.al. UCRL-JC-135376, 8/24/1999; to be published in Phys. Plasmas (2000).

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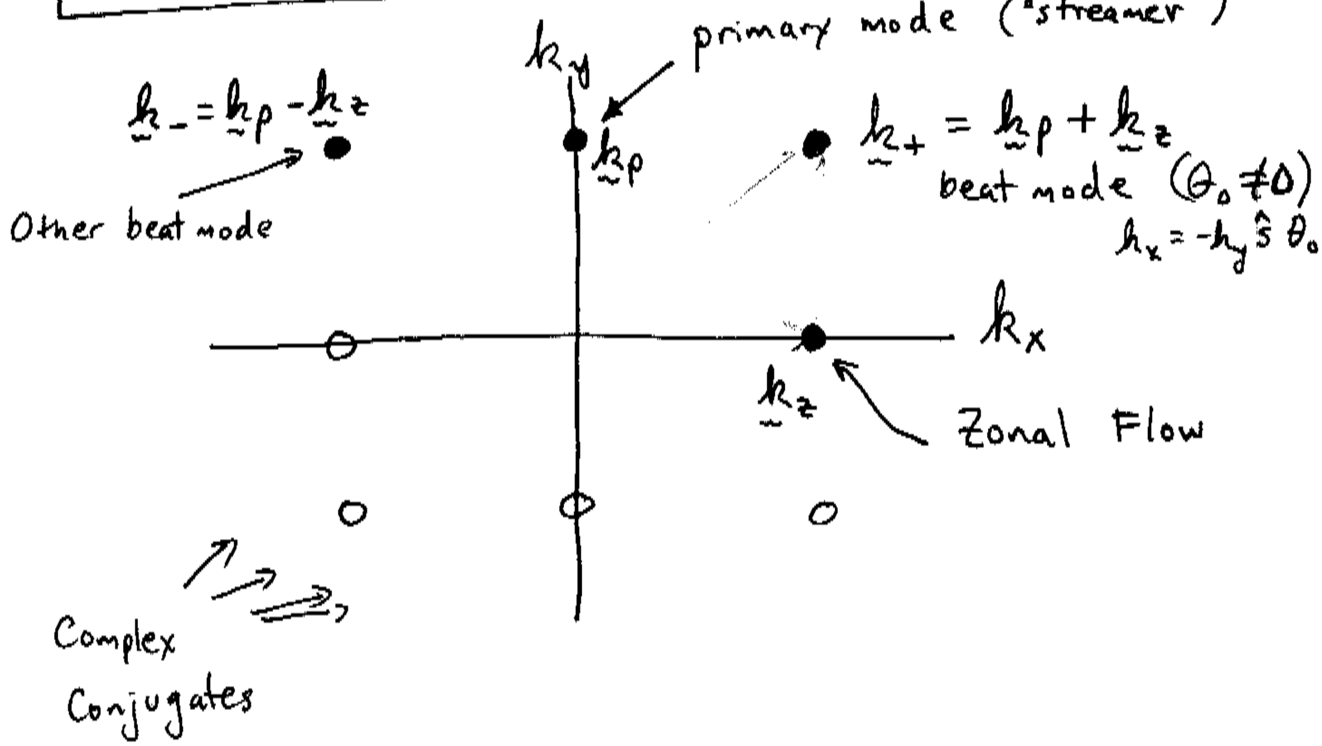
Sherwood 2000

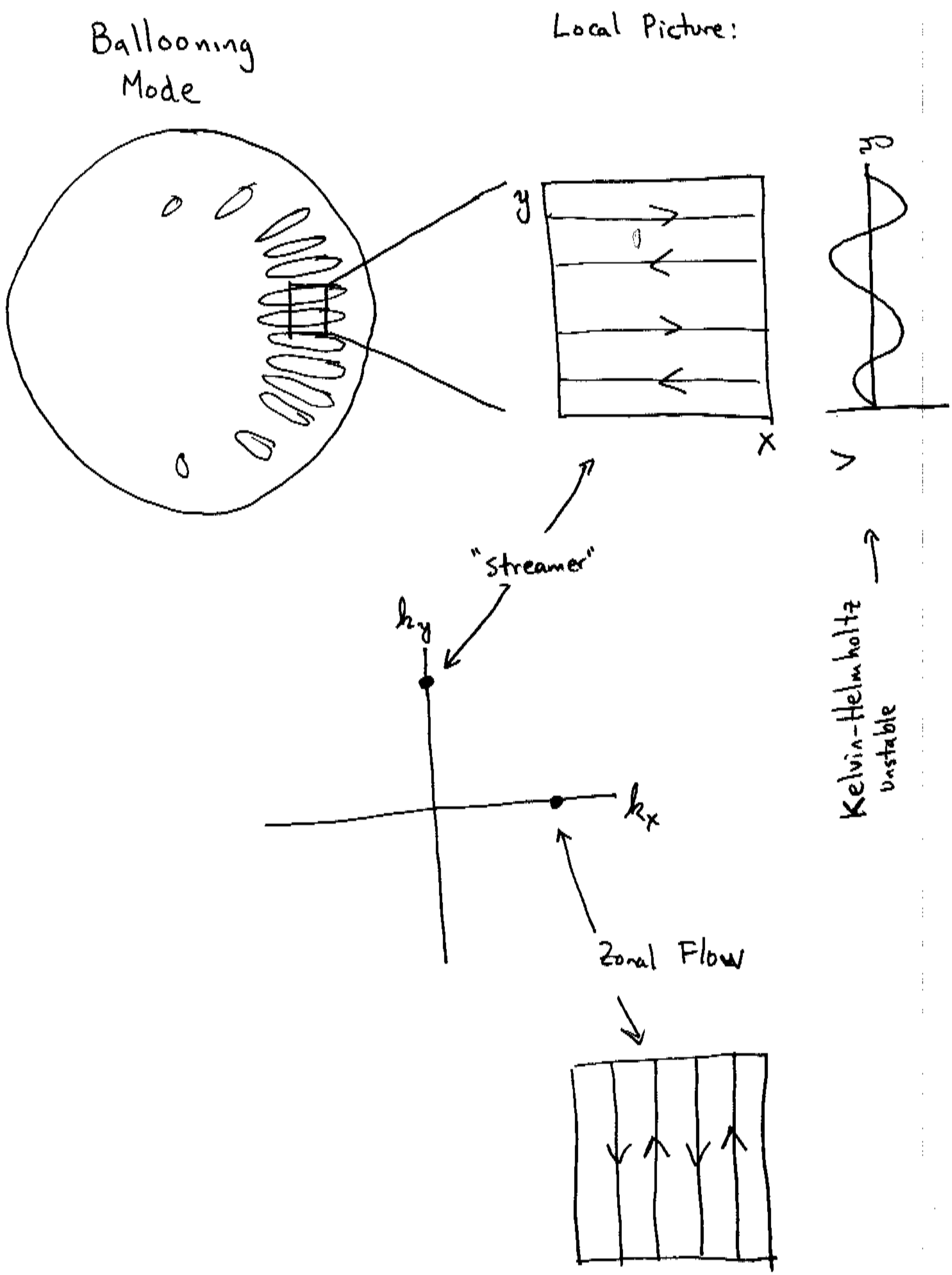
Nonlinear Instabilities Driving Zonal Flows

Simple version of Drake, Finn, Guzdar, et. al., PF B4, 488 (1992)
Similar to inverse cascades of zonal flows of Hasegawa et. al.

Simple 2-D picture:

$\boxed{\text{Secondary instability of primary modes (drift/ITG "streamers") drives zonal flows. Like Kelvin-Helmholtz } \gamma \sim \nabla v_{\bullet}.}$





Ballooning Mode
Local Picture:
y
x
y
"streamer"
k_y
k_x
Zonal Flow
Kelvin-Helmholtz unstable

* Simple cold-ion Hasegawa-Mima-like drift waves (with modified electron response for zonal flows)

$$\frac{\partial n_{igc}}{\partial t} + \underset{\sim}{v}_{\underset{\sim}{E} \times \underline{B}} \cdot \nabla n_{igc} = 0$$

with standard ~~no~~ drift normalizations:

$$\frac{\partial \tilde{n}_{igc}}{\partial t} + \hat{z} \times \nabla \Phi \cdot \nabla \tilde{n}_{igc} + i\omega_* \Phi = 0$$

GK Poisson Eq.: $\tilde{n}_{ig} - \underset{\text{(polarization)}}{k_\perp^2 \Phi} = \tilde{n}_e = (1 - \delta_k)\Phi$

or $\tilde{n}_{igc} = D_{\underset{\sim}{k}} \Phi$

$$D_{\underset{\sim}{k}} = 1 - \delta_k + k_\perp^2$$

$$\delta_k = \begin{cases} 0 & \text{for all modes (standard adiabatic electrons) } \underline{\text{except}} \\ 1 & \text{for zonal mode } (k_y = k_z = 0) \end{cases}$$

Drake's paper simplifies to 2-D hydro: $\delta_k = 1$ for all modes.

Can model Rosenbluth-Hinton neoclassical shielding of zonal flows by increasing $k_\perp^2 \rho_s^2 \rightarrow k_\perp^2 \rho_b^2 \sqrt{\epsilon}$ for zonal modes.

$$\Phi(\underset{\sim}{x},t) = \sum_{\underset{\sim}{k}} \Phi_{\underset{\sim}{k}}(t)\, e^{i \underset{\sim}{k}\cdot \underset{\sim}{x}}$$

$$D_{\underset{\sim}{k}} \frac{\partial \Phi_{\underset{\sim}{k}}}{\partial t} = \sum_{\underset{\sim}{k}_2+\underset{\sim}{k}_3=\underset{\sim}{k}} \left(\hat{z}\times \underset{\sim}{k}_2\cdot \underset{\sim}{k}_3\right) D_{\underset{\sim}{k}_3}\, \Phi_{\underset{\sim}{k}_2}\, \Phi_{\underset{\sim}{k}_3} - i\omega_* \Phi_{\underset{\sim}{k}}$$

Consider case where the primary mode Φ_{kp} is very large, much larger than all other modes. (such as in an initial value simulation, just before onset of nonlinear saturation).

We will discover the zonal + beat modes are unstable with growth rates $\gamma_z \propto |\Phi_{kp}|$, + so consider limit where $|\Phi_{kp}|$ is constant on the time scale $\frac{1}{\gamma_z}$.

Assume $\gamma_z \gg \omega_*$. Focus on standard 3-wave interactions:

$$D_{k+} \frac{\partial \Phi_{k+}}{\partial t} = \hat{z}\times \underset{\sim}{k}_z \cdot \underset{\sim}{k}_p\, \Phi_{kz}\, \Phi_{kp} \left(D_{kp} - D_{kz}\right)$$

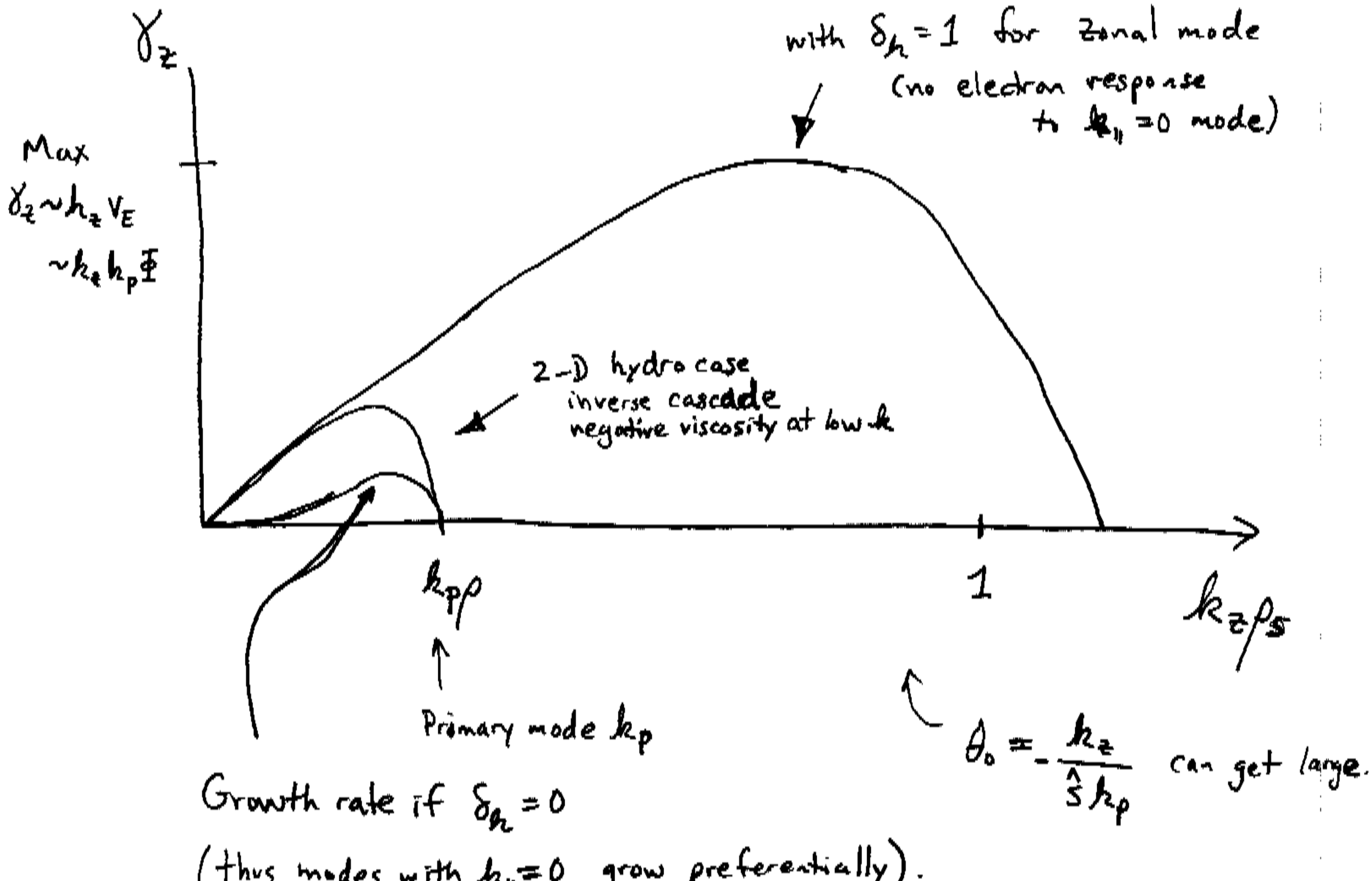
Similar Eq. for Φ_{k-}. Zonal mode:

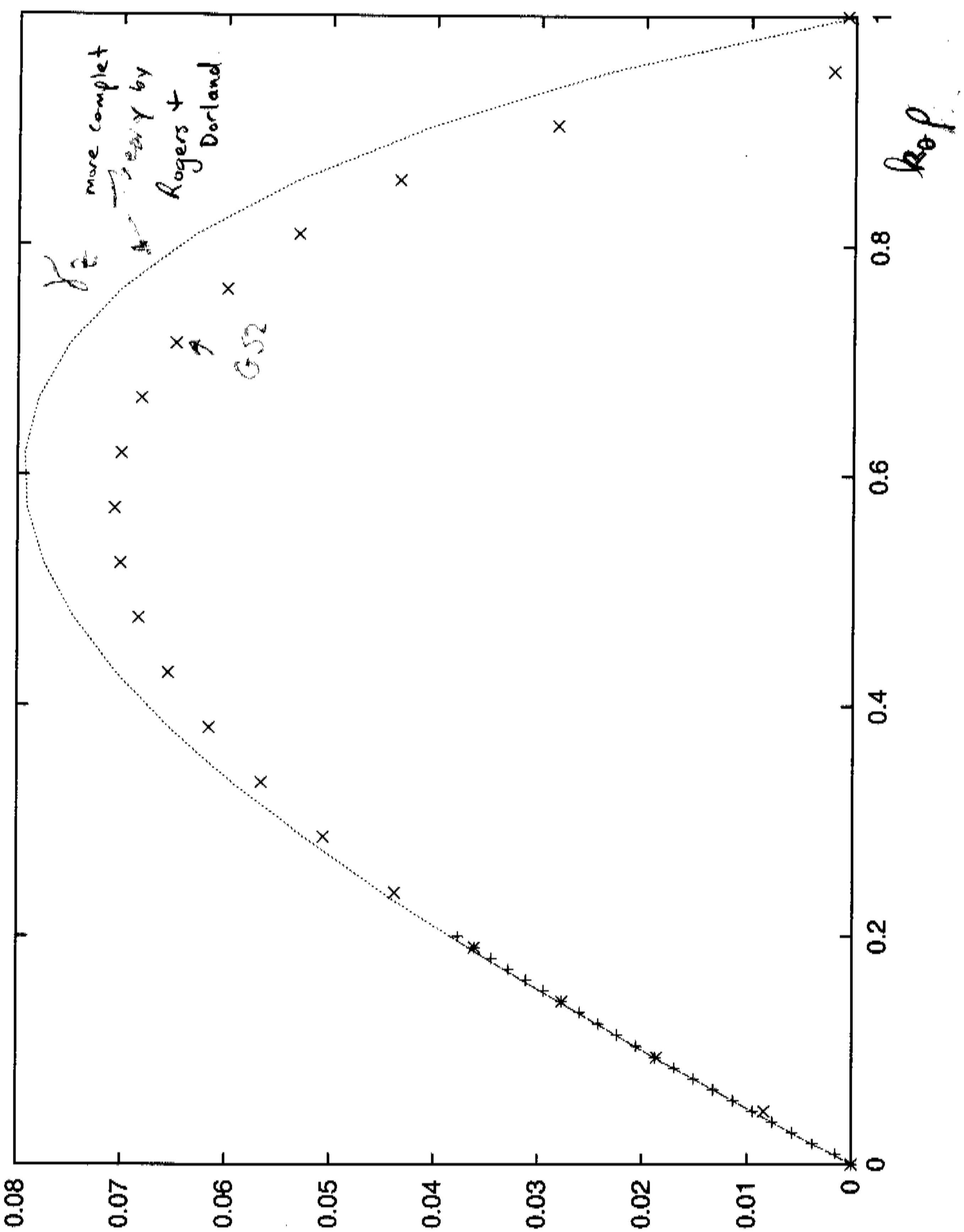
$$D_{kz} \frac{\partial \Phi_{kz}}{\partial t} = \hat{z}\times \underset{\sim}{k}_+ \cdot (-\underset{\sim}{k}_p)\, \Phi_{k+}\, \Phi_{kp}^* \left(D_{kp} - D_{k+}\right)$$
$$+ \hat{z}\times (-\underset{\sim}{k}_-)\cdot \underset{\sim}{k}_p\, \Phi_{k-}^*\, \Phi_{kp} \left(D_{kp} - D_{k-}\right)$$

Take $\frac{\partial}{\partial t}$ of last Eq., $\frac{\partial^2 \Phi_{kz}}{\partial t^2} = \ldots$, & solve:

$$\boxed{\gamma_z^2 = 2\left|\hat{z}\times \underline{k}_z \cdot \underline{k}_p\right|^2 \left|\Phi_{kp}\right|^2 \frac{\left(D_{k+} - D_{kp}\right)\left(D_{kp} - D_{kz}\right)}{D_{kz}\, D_{k+}}}$$

Zonal Flow Growth Rate γ_z




0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.2
0.4
0.6
0.8
1
$k_\theta \rho$
γ_E
more complet theory by Rogers + Dorland
GS2