Global two-fluid simulations of tokamak Scrape Off Layer turbulence

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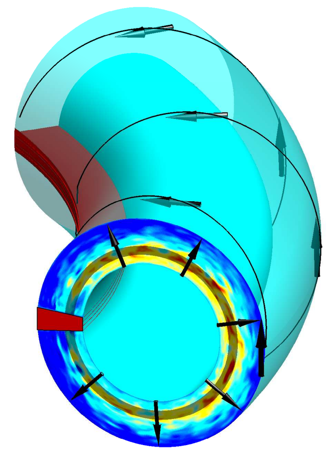
Introduction

- the Scrape Off Layer (SOL) turbulence is studied by means of a linear eigenvalue solver and the non-linear Global Braginskii Solver (GBS) code
- the linear and non-linear results are compared in order to investigate the linear phase and the non-linear saturation mechanism related to the two main instabilities, the Drift Wave (DW) and the Resistive Ballooning (RB)
- the effect of the magnetic shear on both the linear and the non-linear evolution is analyzed

The Global Braginskii Solver (GBS) code

- the code is based on the non-linear, drift-reduced two-fluid Braginskii equations
- self-consistent global evolution of the equilibrium and the fluctuations
- we study the SOL turbulence as the self-consistent result of plasma source from the core and losses at the divertor or limiter
  - open magnetic field lines, ending on a limiter
  - $T_i \ll T_e$, cold ion limit
  - $\beta \ll 1$, electrostatic approximation
  - simple, circular magnetic geometry
  - $\epsilon \ll 1$, large aspect ratio approximation
  - coordinates: $x \to$ radial, $y \to$ binormal, $z \to$ parallel



The drift-reduced Braginskii equations [1]

Continuity: $$\frac{\partial n}{\partial t} = \frac{c}{B}[\Phi, n] + \frac{c}{eRB}\left(\hat{C}p_e - n\hat{C}\Phi\right) - \frac{\partial \left(nV_{\|e}\right)}{\partial z}$$

Vorticity: $$\frac{\partial \nabla_\perp^2 \Phi}{\partial t} = \frac{c}{B}\left[\Phi, \nabla_\perp^2\Phi\right] + \frac{B}{m_i c n R}\hat{C}p_e - V_{\|i}\frac{\partial \nabla_\perp^2\Phi}{\partial z} + \frac{m_i\Omega_{ci}^2}{e^2 n}\frac{\partial j_\|}{\partial z}$$

Ohm's law: $$m_e n\frac{\partial V_{\|e}}{\partial t} = m_e n\frac{c}{B}\left[\Phi, V_{\|e}\right] - m_e n V_{\|e}\frac{\partial V_{\|e}}{\partial z} - T_e\frac{\partial n}{\partial z} + en\frac{\partial \Phi}{\partial z} - 1.71n\frac{\partial T_e}{\partial z} + \frac{en}{\sigma_\|}j_\|$$

Parallel ion velocity: $$\frac{\partial V_{\|i}}{\partial t} = \frac{c}{B}\left[\Phi, V_{\|i}\right] - V_{\|i}\frac{\partial V_{\|i}}{\partial z} - \frac{1}{nm_i}\frac{\partial p_e}{\partial z}$$

Electron temperature: $$\frac{\partial T_e}{\partial t} = \frac{c}{B}[\Phi, T_e] + \frac{2c}{3eRB}\left(\frac{7}{2}T_e\hat{C}T_e + \frac{T_e^2}{n}\hat{C}n - T_e\hat{C}\Phi\right) + \frac{2T_e}{3en}0.71\frac{\partial j_\|}{\partial z} - \frac{2}{3}T_e\frac{\partial V_{\|e}}{\partial z} - V_{\|e}\frac{\partial T_e}{\partial z}$$

red: v_{ExB} convection

magenta: v_{ExB} convection (curvature contribution)

green: v_{de} convection

blue: $v_{\|e}$ convection

Curvature operator: $$\hat{C} = -2\left[\sin\theta\frac{\partial}{\partial x} + \left(\sin\theta\frac{y\hat{s}}{a} + \cos\theta\right)\frac{\partial}{\partial y}\right]$$

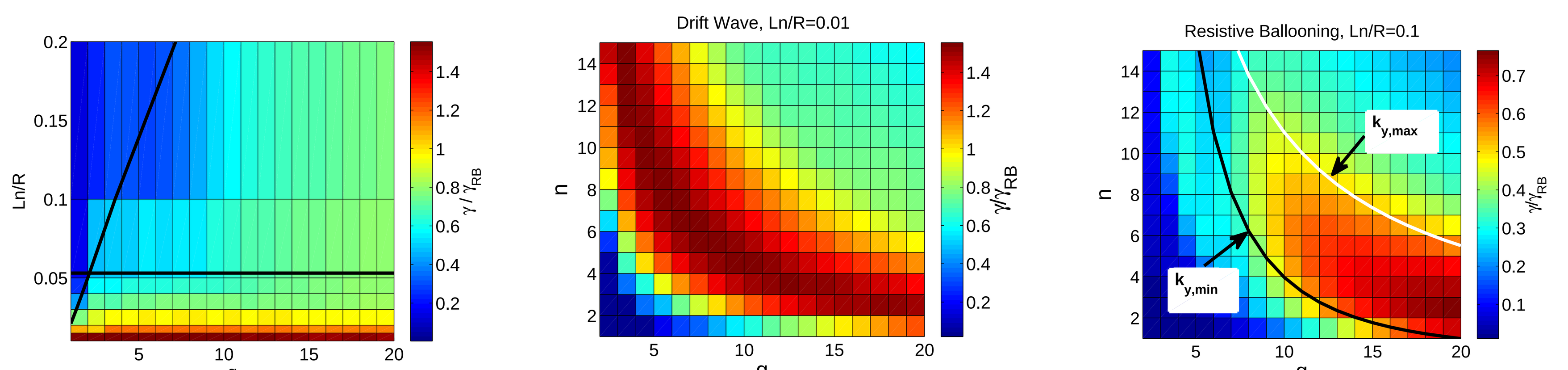
Laplace operator: $$\nabla_\perp^2\Phi = \frac{\partial^2\Phi}{\partial x^2} + 2\frac{y\hat{s}}{a}\frac{\partial^2\Phi}{\partial x\partial y} + \left[1 + \left(\frac{y\hat{s}}{a}\right)^2\right]\frac{\partial^2\Phi}{\partial y^2}$$

Poisson Bracket: $$[f, g] = \frac{\partial f}{\partial x}\frac{\partial g}{\partial y} - \frac{\partial g}{\partial x}\frac{\partial f}{\partial y}$$

linear analysis

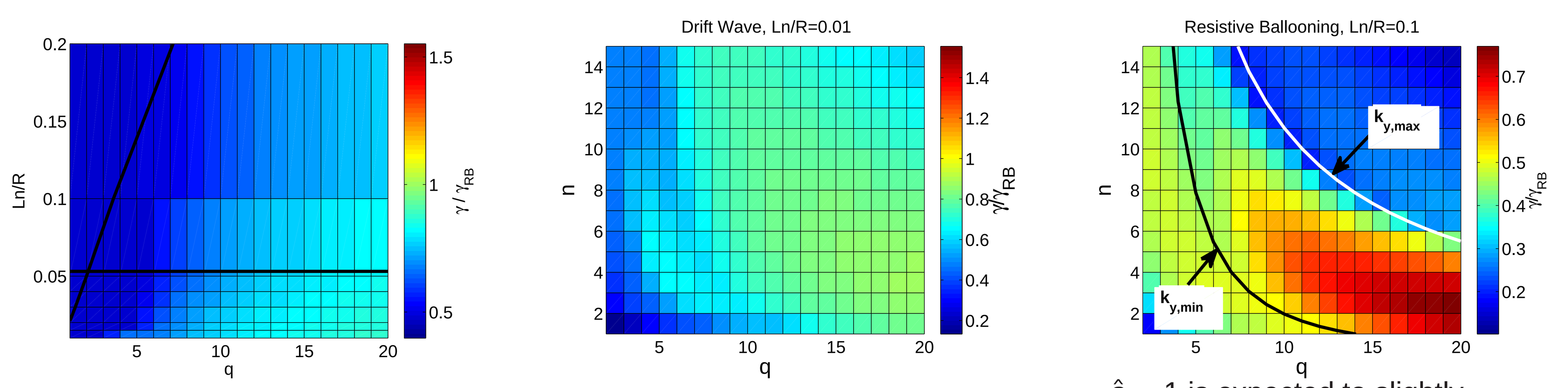
	Resistive Ballooning (RB)	Drift wave (DW)
drive	∇p & R	$\mathbf{E}\times\mathbf{B}$ & ∇p
growth rate	$\sim c_s\sqrt{\frac{2}{RL_n}}$	$\sim \frac{c_s}{L_n}$
parallel dynamics	$k_\| \sim \frac{1}{qR}$	$k_\| \neq 0$
perpendicular dynamics	$k_{min} < k_y < k_{max}$	$k_y\rho_s \approx 1$
physical properties	destabilized by resistivity (non adiabatic electrons)	destabilized by resistivity or electron inertia (non adiabatic electrons)

$shear = 0$



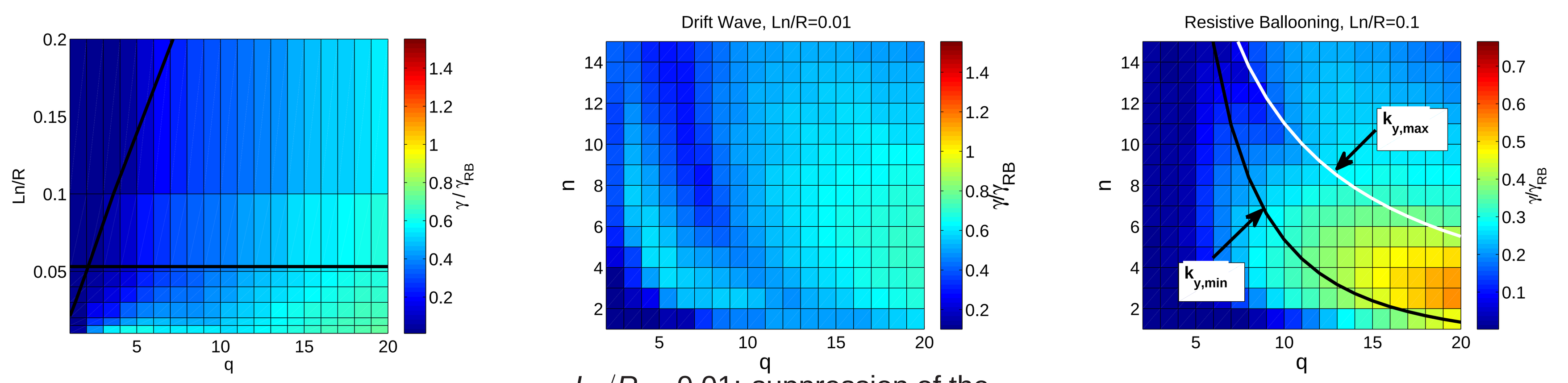
- identification of the RB and DW instabilities in the $q - L_n/R$ plane
- $L_n/R = 0.01$: identification of the DW instability for steep gradients
- $L_n/R = 0.1$: identification of the RB instability for weak gradients

$shear = +1$



- enhancement of the RB zone of influence due to the positive shear
- $L_n/R = 0.01$: suppression of the DW instablity due to the magnetic shear
- $\hat{s} = 1$ is expected to slightly enhance the RB growth rate (linear results with a simplified model for the RB instability)

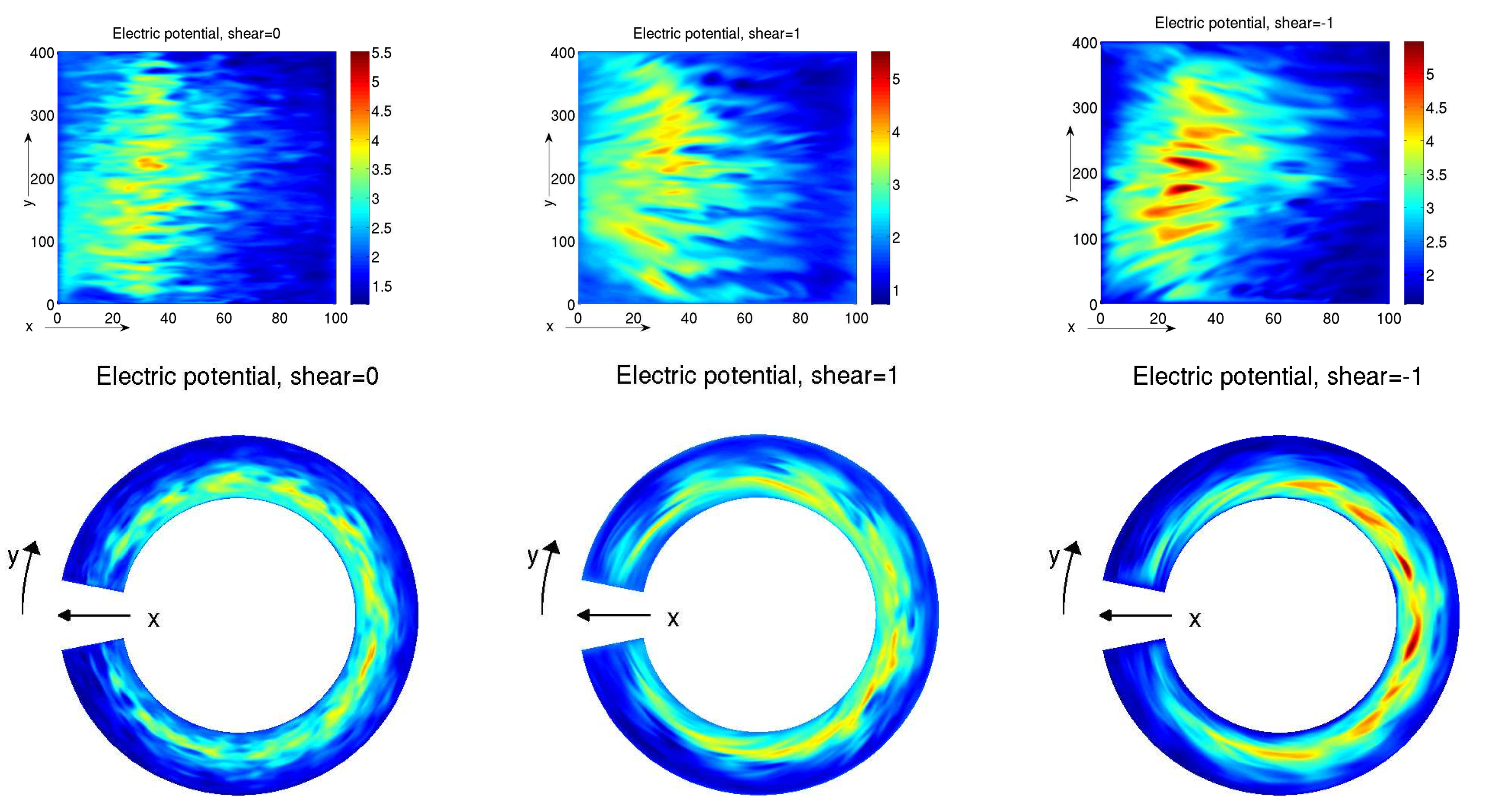
$shear = -1$



- suppression of the RB zone of influence due to the negative shear
- $L_n/R = 0.01$: suppression of the DW instability due to magnetic shear (symmetry in the shear influence on the DW instability)
- $L_n/R = 0.1$: suppression of the RB instability due to negative magnetic shear

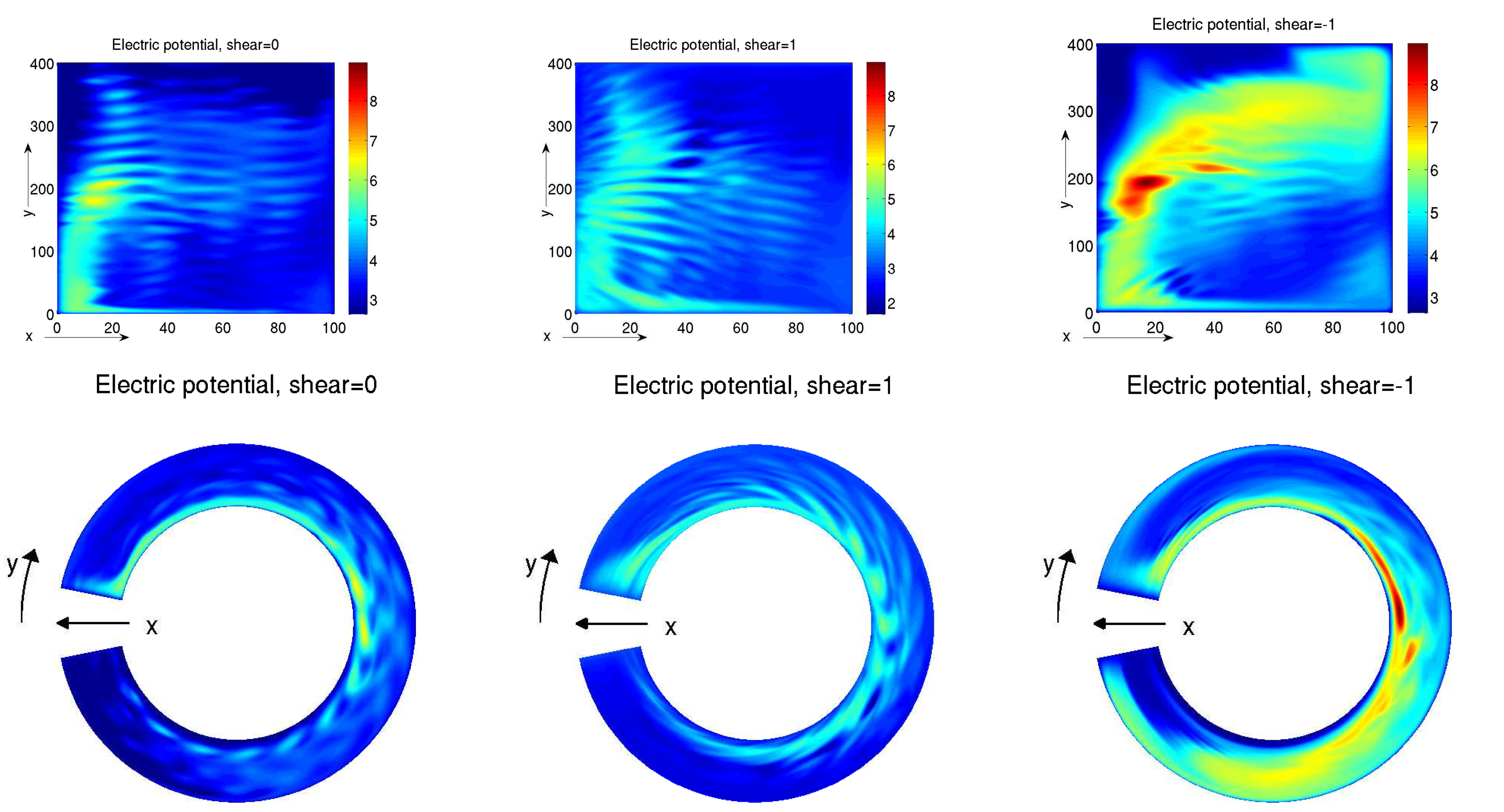
non-linear simulations

Drift Waves



- simulation parameter: $q = 4$, $\nu = 0.01$, $m_i/m_e = 200$, $L_y/\rho_s = 400$, $R/\rho_s = 500$
- $k_y \approx 0.3$, identification of the DW, but still presence of a ballooning component, $L_n/R \approx 0.07$
- difference between the linear and the non-linear case: the DW is not completely damped by the shear, as expected from the linear analysis: what is the mechanism driving the non linear DW instability? Possible explanations currently under investigation [2]

Resistive Ballooning



- simulation parameter: $q = 16$, $\nu = 0.01$, $m_i/m_e = 200$, $L_y/\rho_s = 400$, $R/\rho_s = 500$
- $k_\| \approx 0 \to m \approx nq = 16 \to k_y \approx 0.25 \to$ identification of the RB regime, $L_n/R \approx 0.15$
- the positive shear causes a spread of the instability along the poloidal angle, while the negative shear localizes the instability in the unfavourable curvature region [3]

Conclusions

- linear suppression of the DW due to magnetic shear and linear suppression of the RB due to negative shear
- discrepancies between linear and non-linear simulations for DW under investigations
- agreement between the linear and the non-linear simulations for RB

References :

[1] A. Zeiler *et al.*, *Phys. Plasmas*, Vol. 4, Issue 6, 1997

[2] J. F. Drake *et al.*, *Phys. Rev. Lett.*, Vol. 75, Issue 23, 1995

[3] T. M. Antonsen *et al.*, *Phys. Plasmas*, Vol. 3, Issue 6, 1996

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