Saturation Mechanisms in Reduced Simulations of Boundary Turbulence

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Reduced-Model Equations of Evolution in 2D (OM) for Vorticity, Density, Temperature and Zonal Momentum ~ SOLT Code ~

Two Radially Distinguished Regions:

Edge Region

- Sources of Density and Temperature
- Electron Drift Waves
- Curvature-Driven Instability (Blob Birth Zone)

SOL Region

Sheath Absorption Provides a Sink for all Fields

Model Equations

•Vorticity

$$\partial_t \nabla^2 \tilde{\varphi} =$$

$$= \left\{ -\mathbf{v} \cdot \nabla \nabla^2 \varphi + \alpha_{DW} \frac{\overline{T}^{3/2}}{\overline{n}} \left(\varphi - T \ln(n) \right) + \alpha_{sh} T^{1/2} \left(1 - \exp(\varphi_B - \varphi)/T \right) - \frac{\beta}{n} \partial_y (nT) + \mu \nabla^4 \varphi \right\}$$

•Density

$$(\partial_t + \mathbf{v} \cdot \nabla) n = \alpha_{DW} \overline{T}^{3/2} \{ \varphi - T \ln(n) \} - \alpha_{sh} n T^{1/2} \exp\left((\varphi_B - \varphi) / T \right) + D \nabla^2 n + S_n$$

•Temperature

$$(\partial_t + \mathbf{v} \cdot \nabla) T = -\alpha_{sh} s_E T^{3/2} \exp\left((\varphi_B - \varphi) / T \right) + S_T$$

•Zonal Momentum

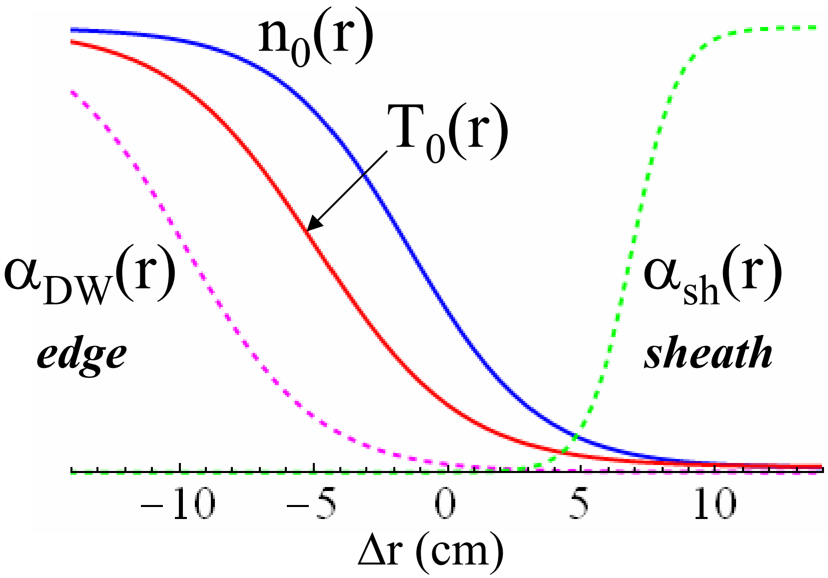
$$\partial_t p_y + \partial_r \overline{n v_r v_y} = \int_r^{L_r} dx\, \alpha_{sh} \overline{n T^{1/2} \left(1 - \exp\left((\varphi_B - \varphi) / T \right) \right)} + \overline{\mu}\, \partial_r^2 \overline{v_y} - \nu_{p_y} p_y$$

$p_y \equiv \overline{n v_y}$, $\overline{v_y} = \partial_r \overline{\varphi}$, and where ν_{p_y} is a constant, varied to control shear.

Boundary Conditions: $p_y = 0$ (*no slip*) and $\overline{\varphi} = \overline{\varphi}_{Bohm}$ at $r = L_r$

Initial and Reference Profiles

(normalized)



No zonal flow initially.

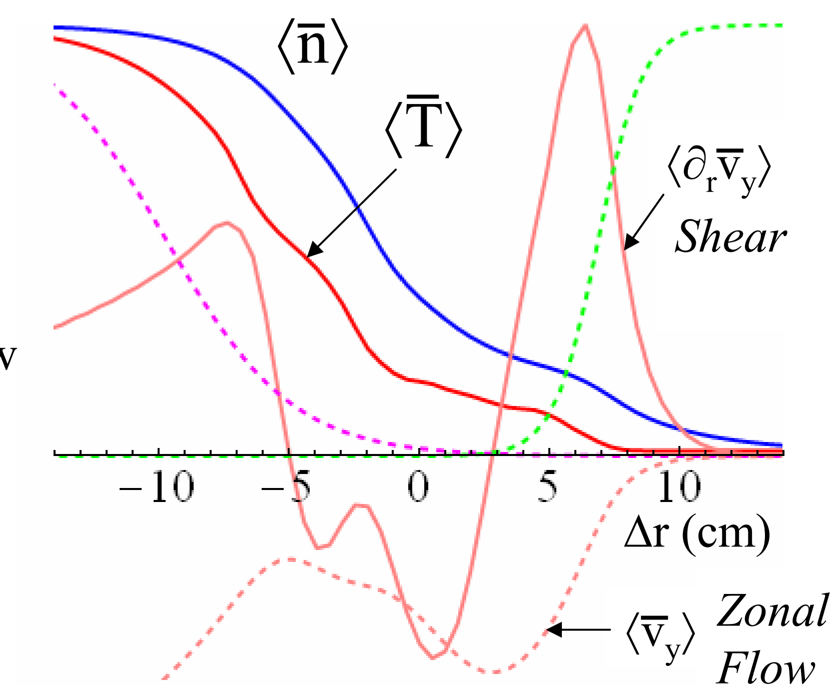
$\nu_{p_y} = 0$ →

Freely Evolved Zonal Flow

Turbulent Profiles

(normalized)

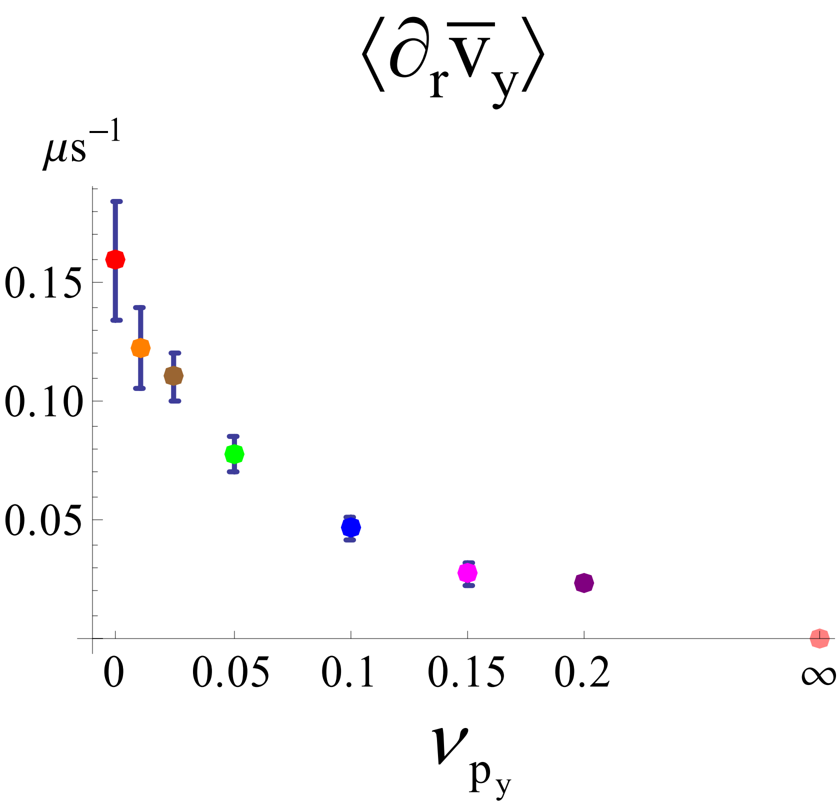
$\langle \ldots \rangle$: Time-Average



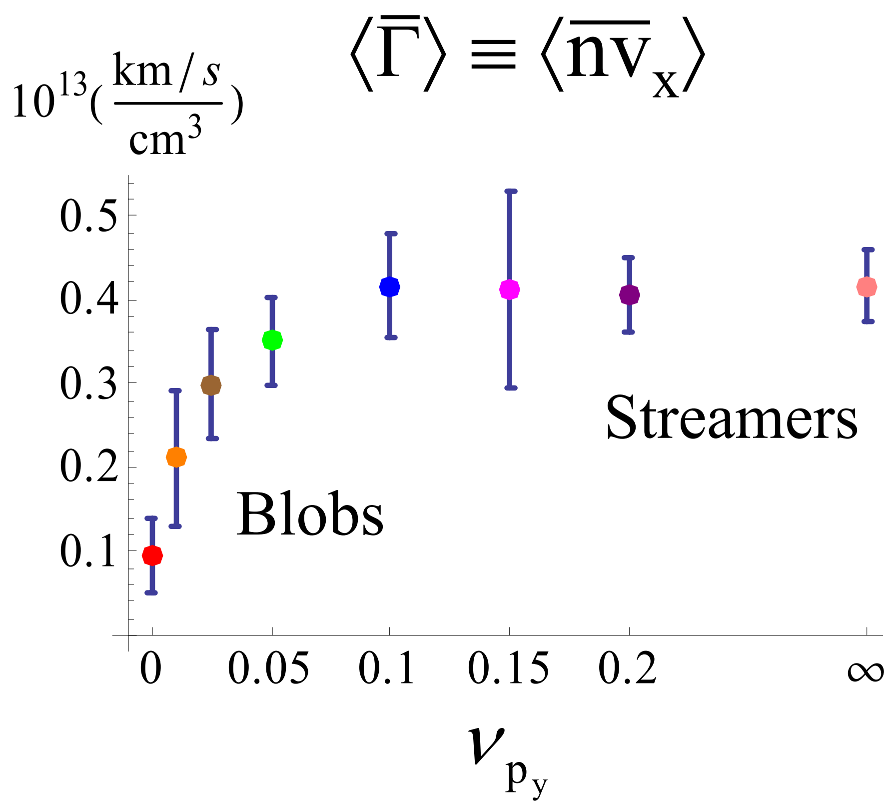
Parameters are NSTX-like.

Zonal Flow Shear Suppresses Transport

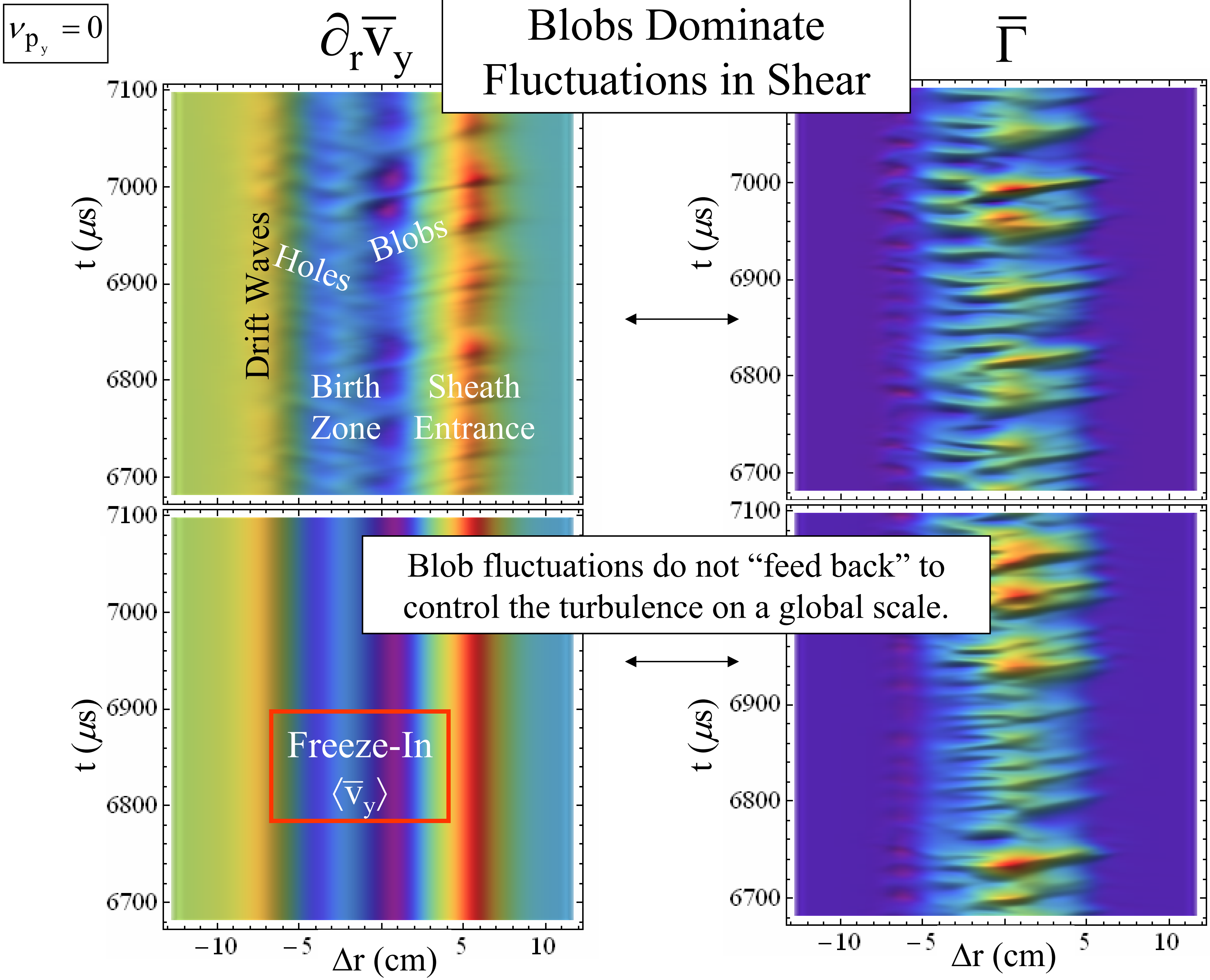
Shear Measured in the Birth Zone



Flux measured at the Sheath Entrance



Blobs Dominate Fluctuations in Shear

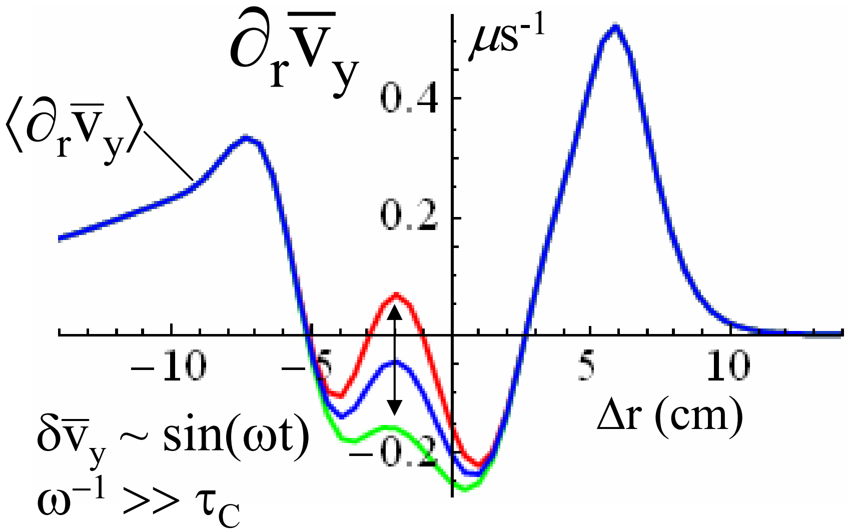


Blob fluctuations do not "feed back" to control the turbulence on a global scale.

Russell TTF 2008

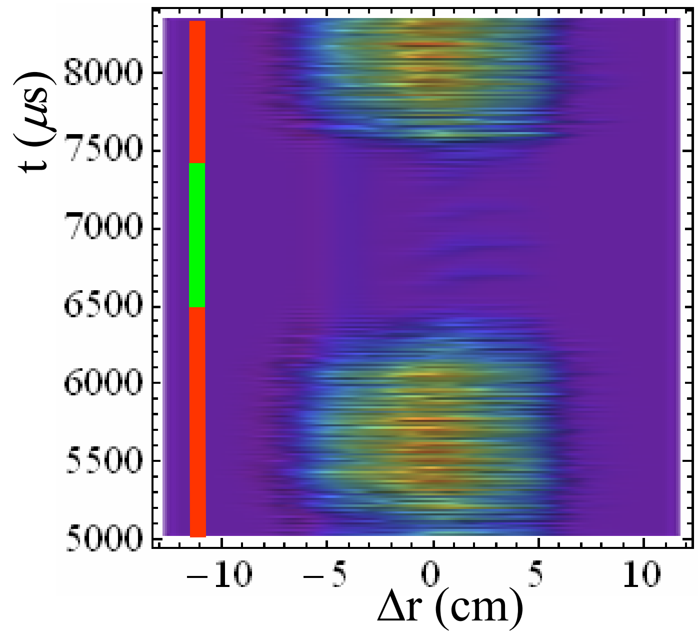
⟨Shear⟩ Controls the Turbulence by Suppressing the Instability

Introduce an artificial perturbation of the shear profile localized to the birth zone:



⇒

$\overline{\Gamma}$



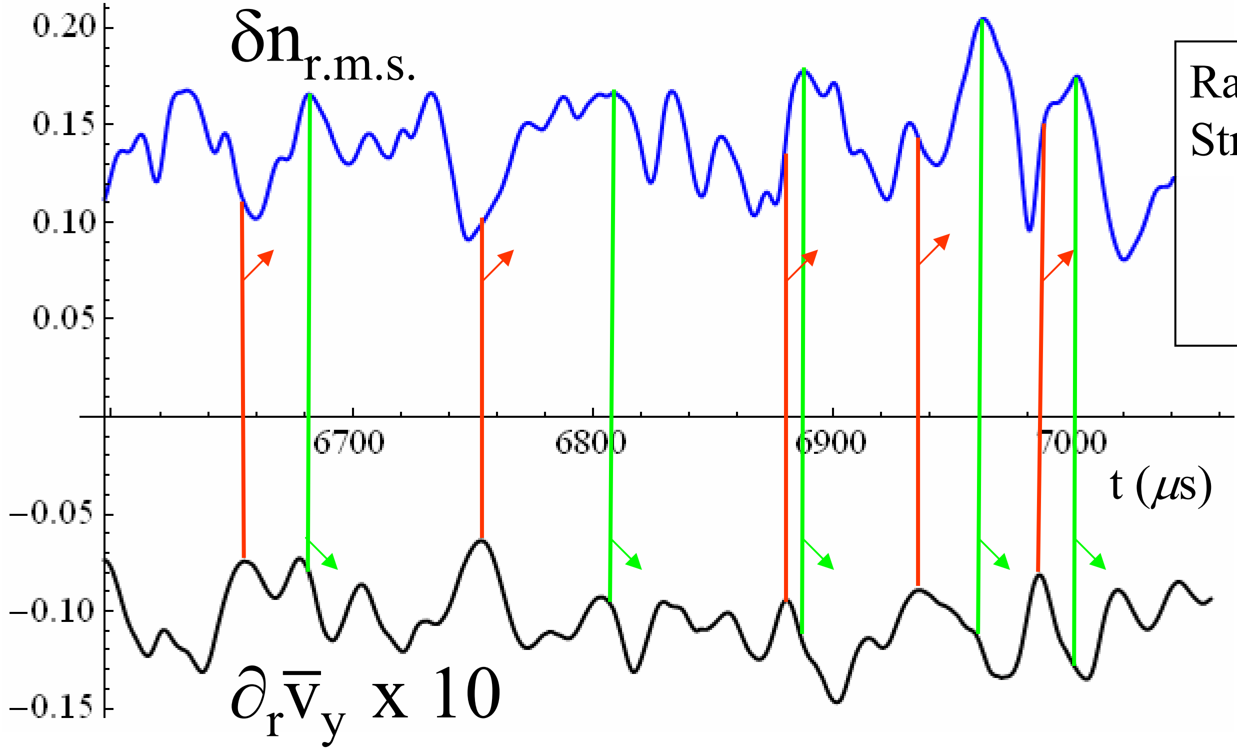
Linear Stability Analysis ⇒ No Unstable Eigenmodes
Localized to the Edge Region in the Green Time Zone

Can we accomplish shear-suppression in the edge region through the core-side b.c.s on $\overline{\varphi}$?

Velocity Shear Fluctuations May Provide a Self-Regulation Mechanism in the Birth Zone

$v_{p_y} = 0$

Free
Zonal Flow
Evolution



Radially Non-Local
Strong Turbulence

$$\frac{\delta n_{r.m.s.}}{\langle \overline{n} \rangle} \sim 1$$

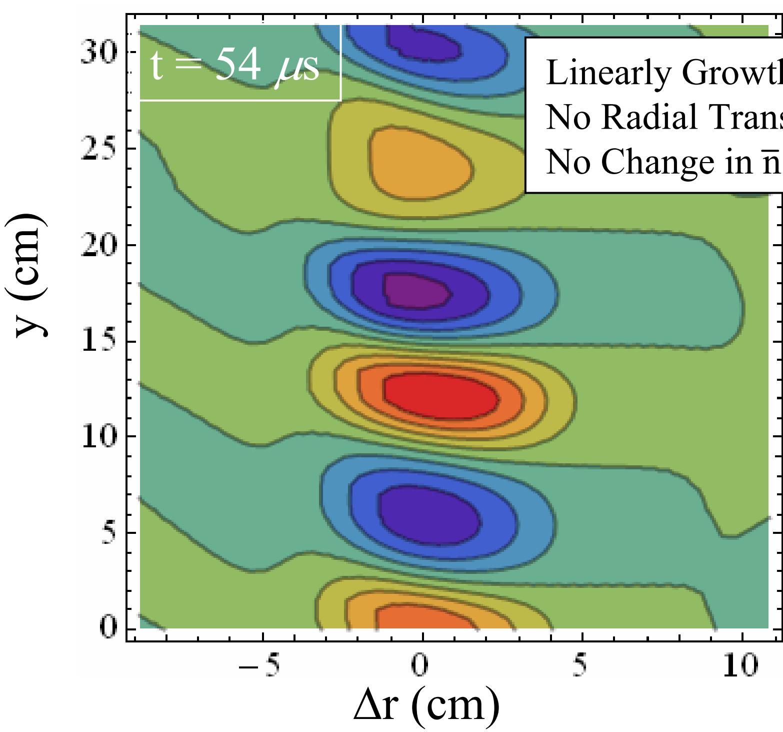
Fluctuations increase following more positive (destabilizing) excursions in shear and decrease when shear is more negative (stabilizing).

But strong fluctuations appear to drive shear more negative.

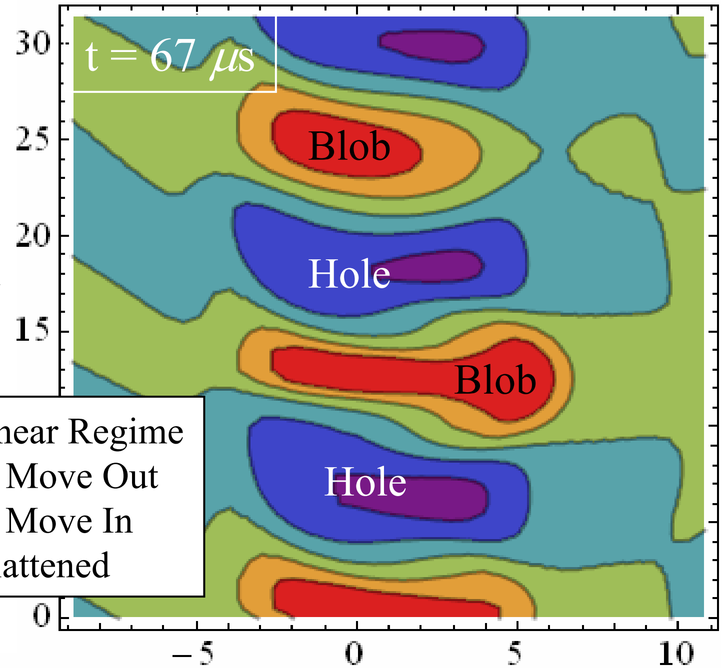
⇒ The turbulence may be locally self-regulated by fluctuations in shear.

Wave-Breaking, or Plateau Formation, is a Saturation Mechanism

$\nu_{py} = \infty$ (No Zonal Flow)

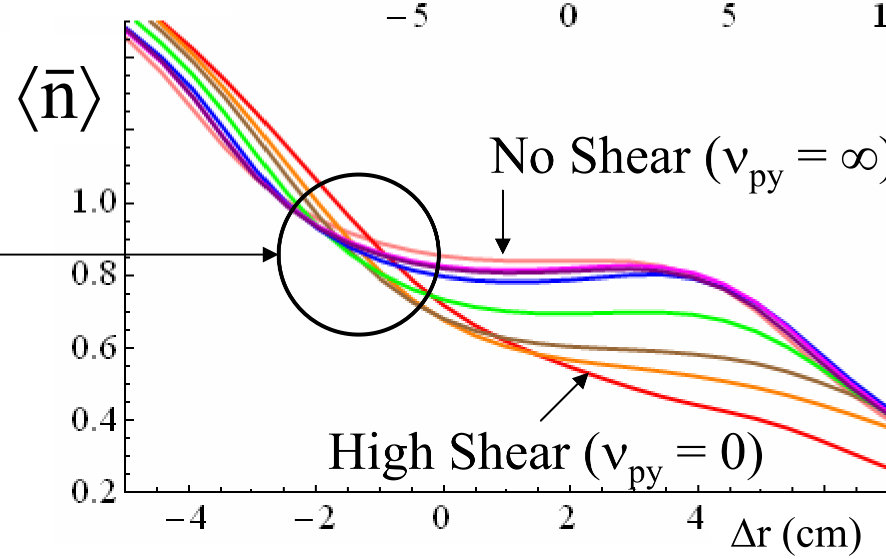


Linearly Growth Regime
No Radial Transport
No Change in $\bar{n}$



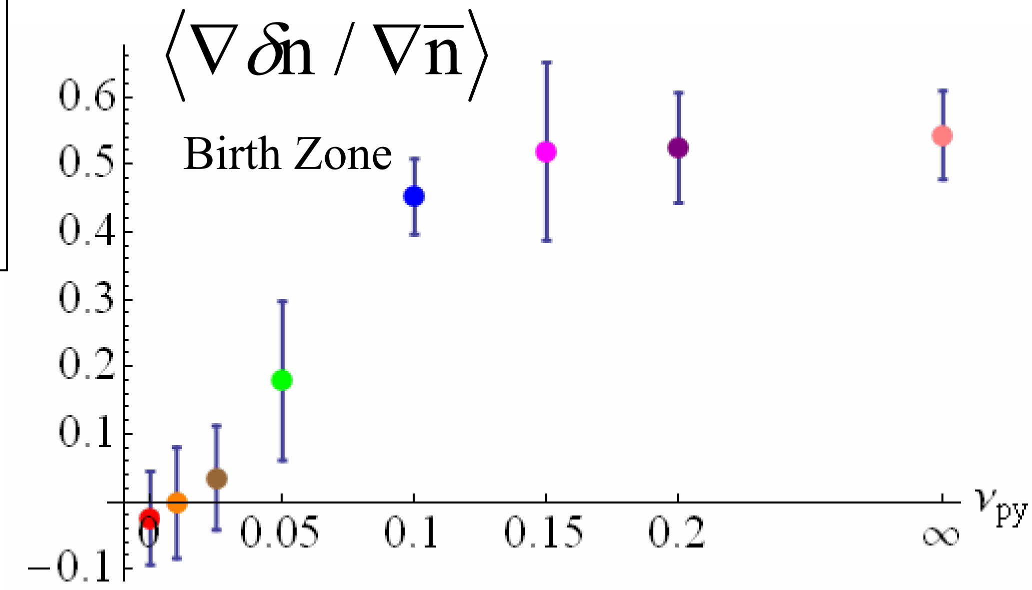
Nonlinear Regime
Blobs Move Out
Holes Move In
$\bar{n}$ is Flattened

Flatter profiles in the birth zone betray the <u>increased</u> role of plateau formation in saturation with <u>decreased</u> zonal flow shear.

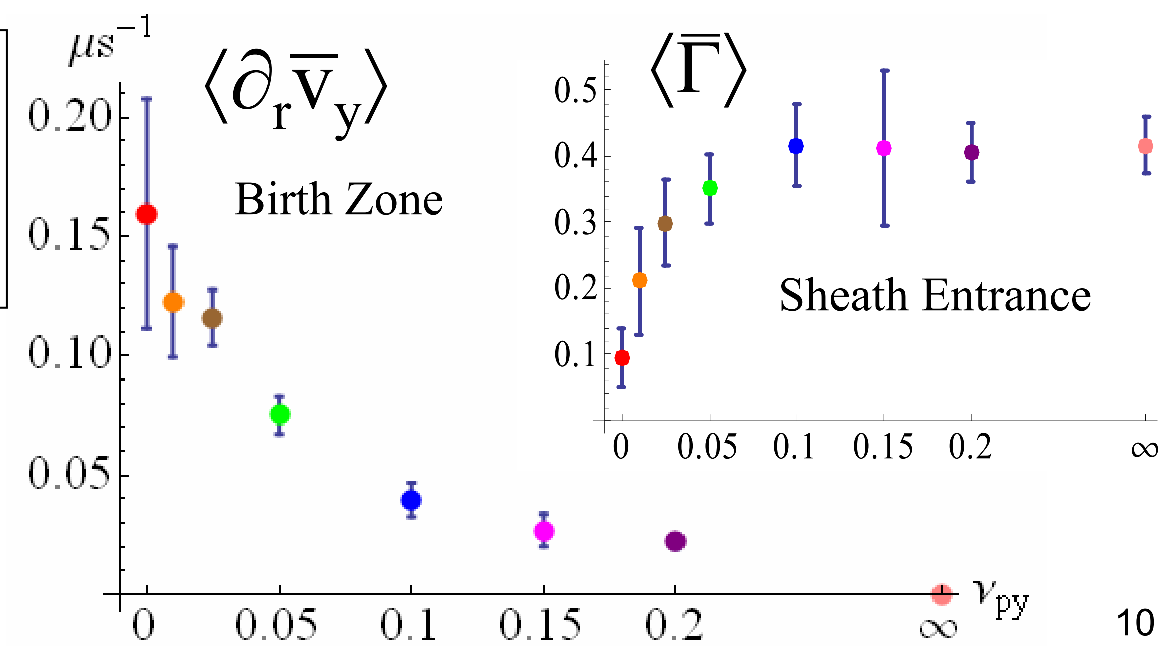


Wave-Breaking (Plateau Formation) and Sheared Zonal Flow Are Complementary Saturation Mechanisms

A Measure of Wave-Breaking



Sheared Flow is the Favored Mechanism because it Reduces Radial Transport



Conclusion

Our Model Includes Radially Distinguished **Edge** and **SOL** Physics,

Blobs, **Streamers** and **Sheared Zonal Flow.**

High Velocity-Shear Regime:

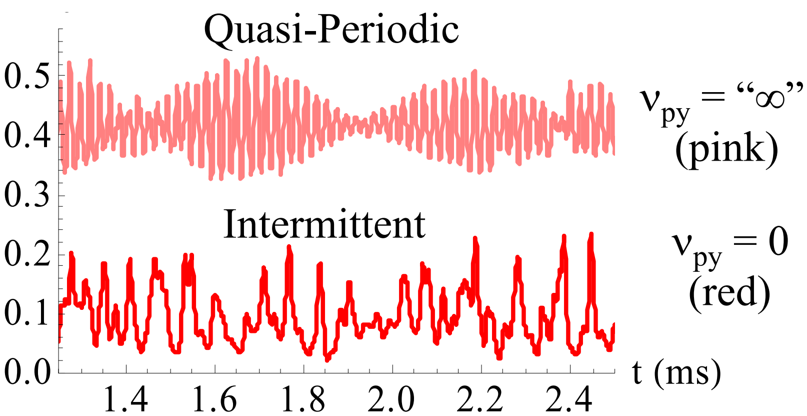
- Transport is Minimized.
- Mean Shear in the Birth Zone Controls the Turbulence by Suppressing the Instability.
- Shear Fluctuations (*blobs*) May Provide a Local Self-Regulation Mechanism.

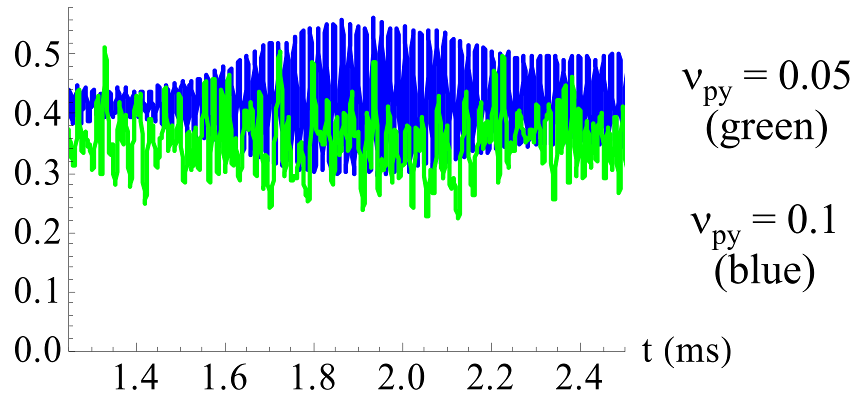
Low Velocity-Shear Regime:

- Transport Increases.
- Wave-Breaking, or Plateau Formation, Compensates Shear Suppression.
- Streamers Dominate, Profiles are Flatter, and SOL Densities are Higher.

Epilogue

Flux Measured at the Sheath Entrance





… and various flavors in-between.