Perspectives on Magnetic Fusion Turbulent Transport Studies and Issues

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Presented at the
Stanford Global Climate and Energy Program
Fusion Workshop
May 1-2 2006
Princeton NJ USA

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Acknowledgements

- Experimental Collaboration on DIIID with UW-Madison BES Group
- Collaboration w/ P. Diamond (UCSD), K. Itoh (NIFS), S. Itoh (Kyushu)
- Materials Obtained from Others:
  - IPP-MPG Plasma Turbulence Summer School 2005
  - IPP-MPG K. Lackner Talk at DEISY Symposium, Paris May 2005
  - K. Itoh 2005 APS-DPP Invited Talk on Zonal flows

The Basic Picture of Turbulent Transport

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Ref: T. Ribiero IPP-Garching 2005 Summer School

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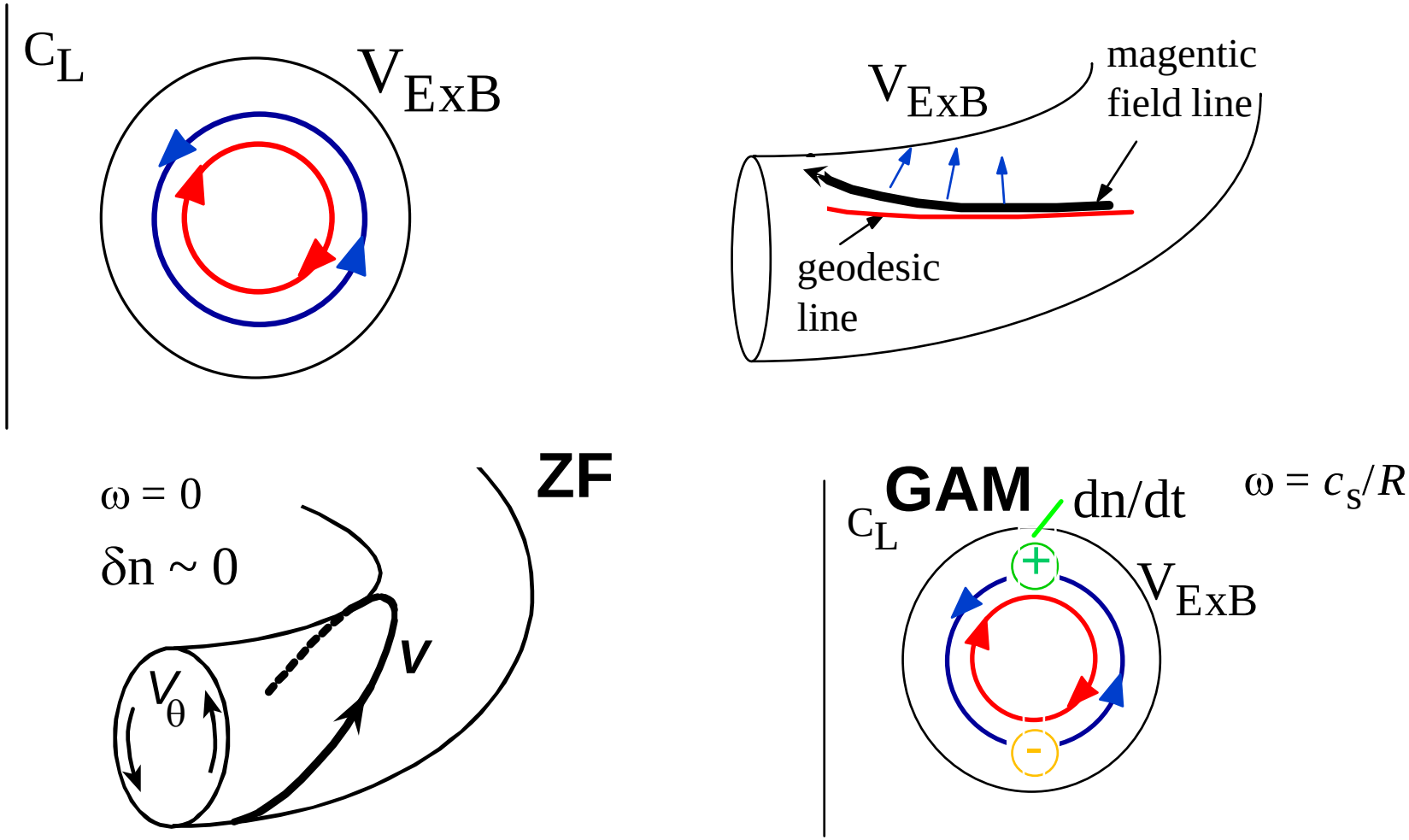
Result: Turbulent Transport in Confined Plasmas

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Ref: Lackner, DEISY Talk 2005

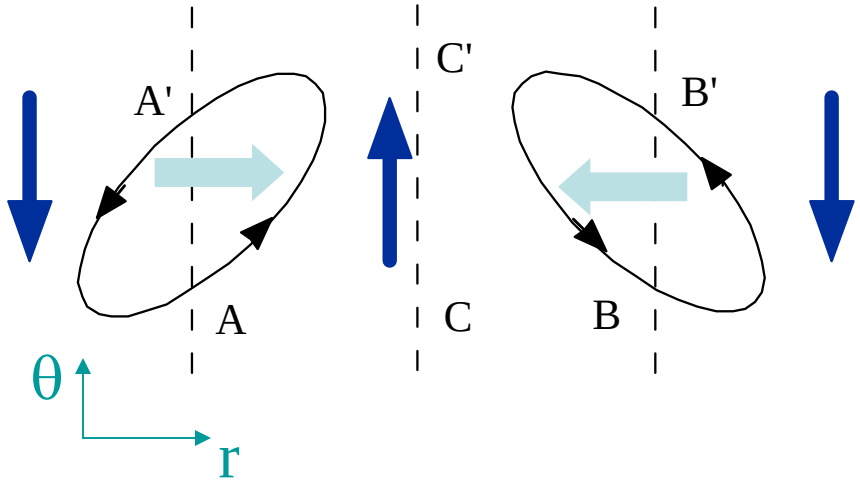
Low Freq. ZFs and GAM: - in toroidal plasmas



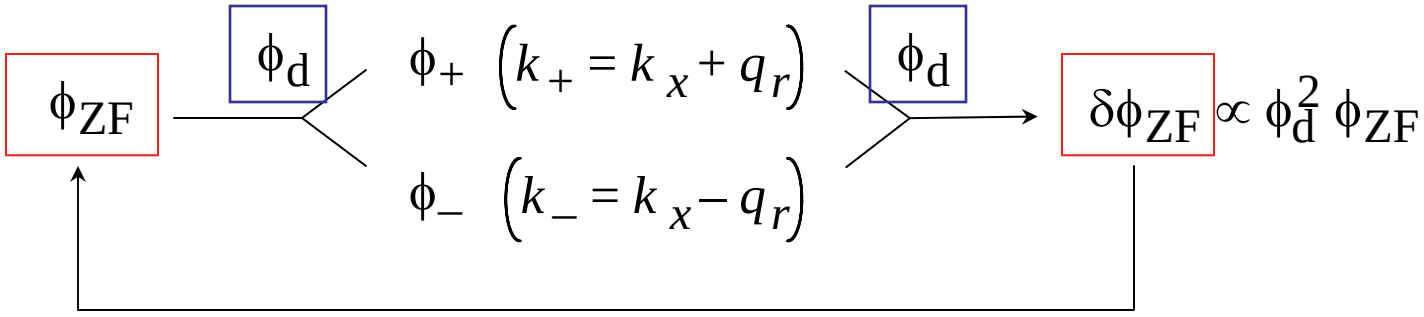
New feature: geodesic acoustic coupling (GAC)

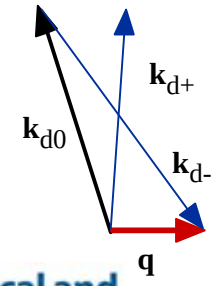
Generation Mechanism

(1) Tilt of convection cell by a sheared flow

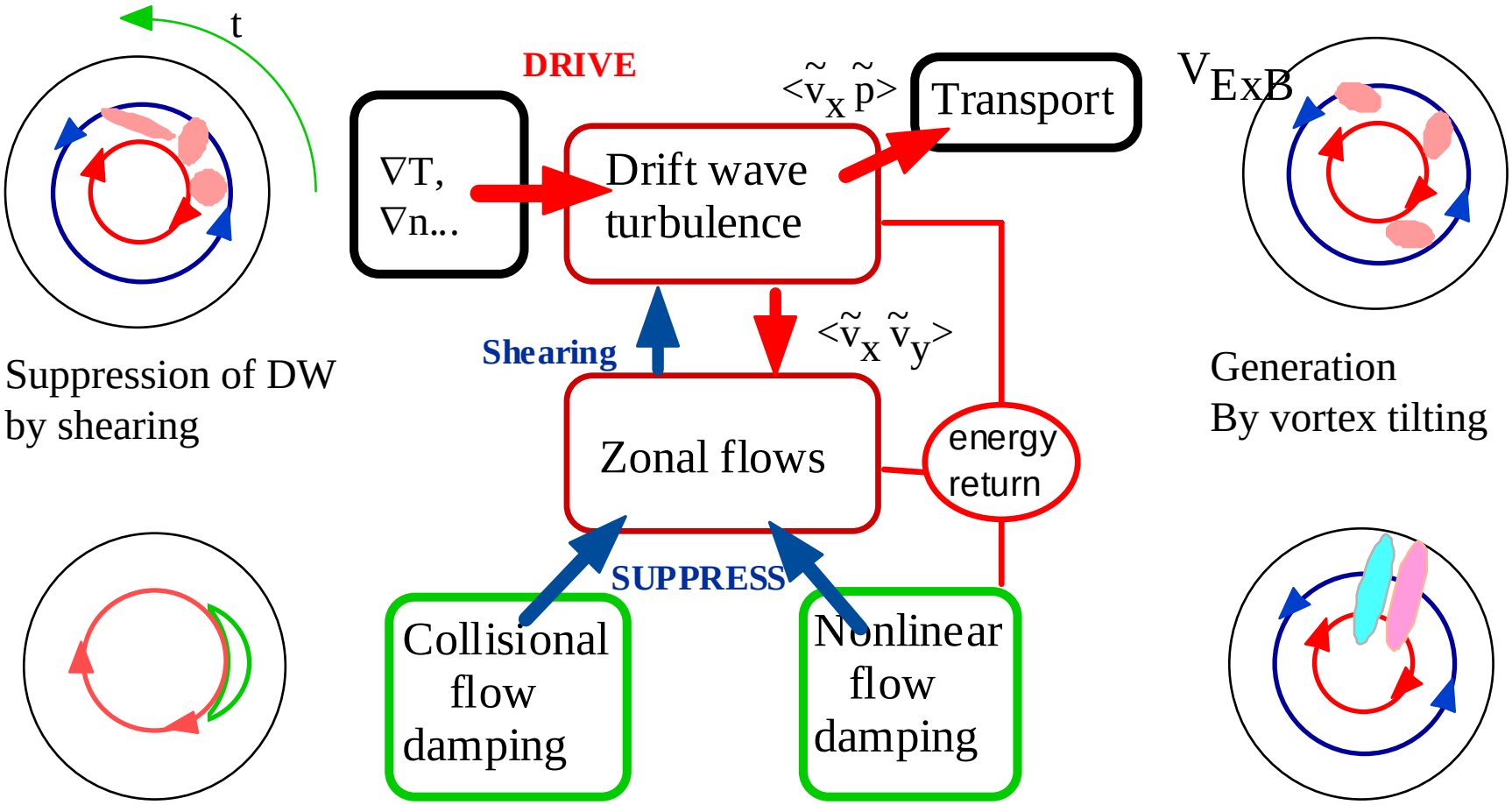


(2) Modulational Instability





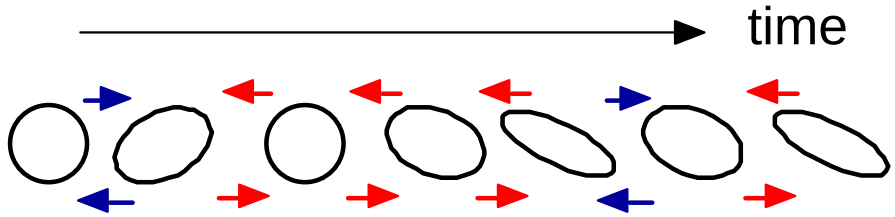
Basic Physics of a zonal flow



Impact of ZFs on Turbulence

Suppression of turbulence - linked to modulational instability

Random stretching of DW eddies



$$\left\langle \delta\, k_r^2 \right\rangle \sim D_k\, t$$

$$D_k \sim k_\theta^2 \left\langle \tilde{V}_{ZF}'^{\,2} \right\rangle \tau_c$$

k_r^2 of DW packet ⬆

DW energy $W_k = \omega_k N_k$ ⬇

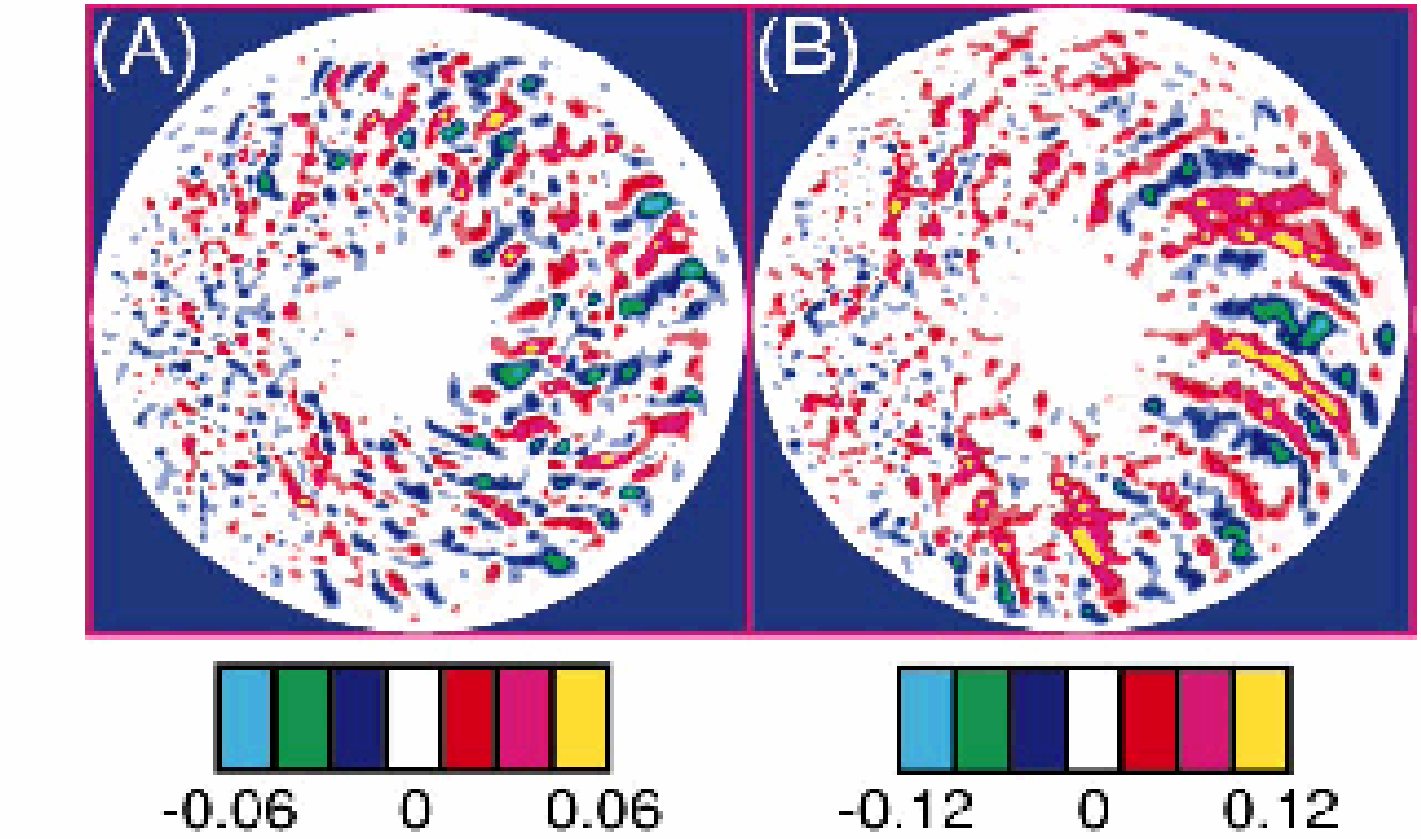
$$\omega_k = \frac{k_\theta V_d}{1 + k_\perp^2 \rho_s^2}$$

Energy for ZFs excitation is extracted from DWs

Note: Conservation energy between ZF and DW

Zonal Flows Thought to Regulate Radial Correlation Length of Turbulent Perturbations & Thereby Regulate Transport

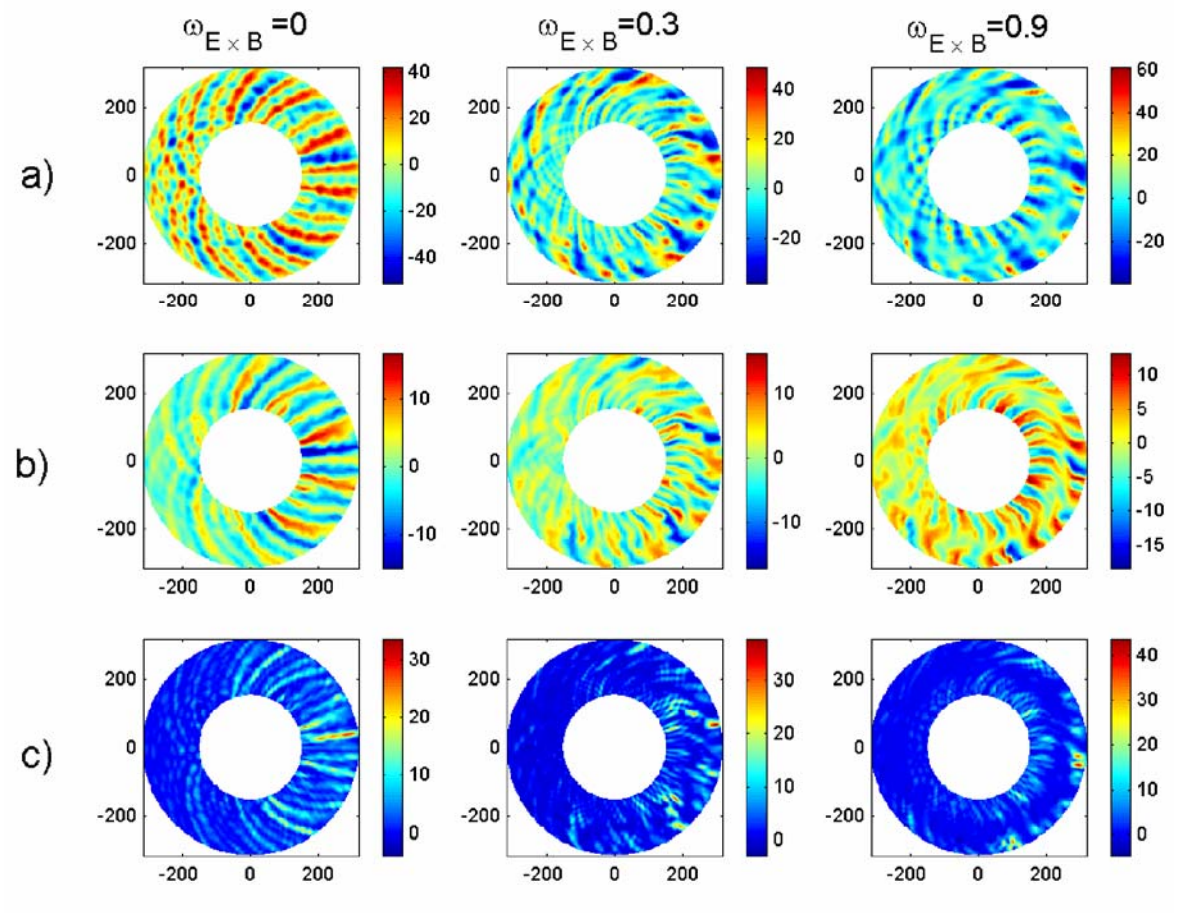
With Z-flow **Z-flow Artificially Quenched**



Lin et al , Science 281, 1835 (1998)

External shear flow breaks streamers

RBM *[Beyer et al, 00]*



Potential

Pressure

Flux

Increasing velocity shear V_E'

Result: Plasma Sits At/Near Marginal Stability

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Ref: Lackner DEISY Symposium 2005

What do the experiments say?

The Good…

- Flows consistent w/ Zonal flows observed in confinement devices
- Lab plasmas show zonal flows sustained by turbulence
- Shear flows can inhibit transport

Zonal flow in confinement devices

McKee etal PoP 2001

QuickTime™ and a
TIFF (LZW) decompressor
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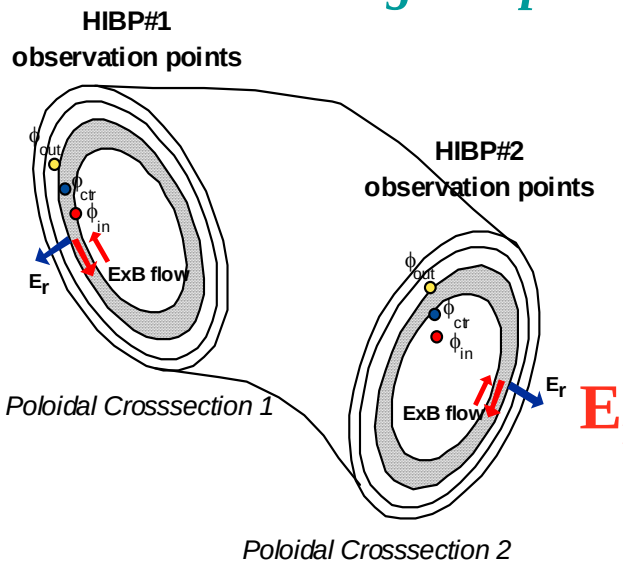
Zonal flows really do exist !

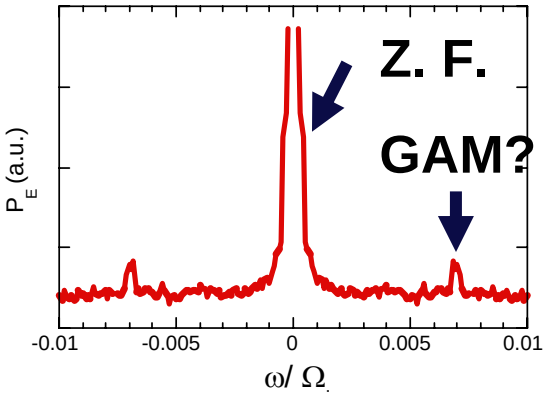
A. Fujisawa,
PRL 2004

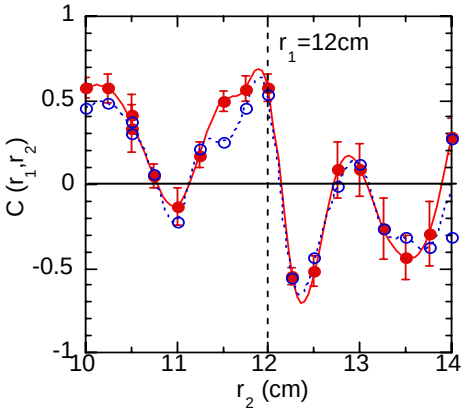
CHS Dual HIBP System

90 degree apart



$E_r(r,t)$





Radial distance

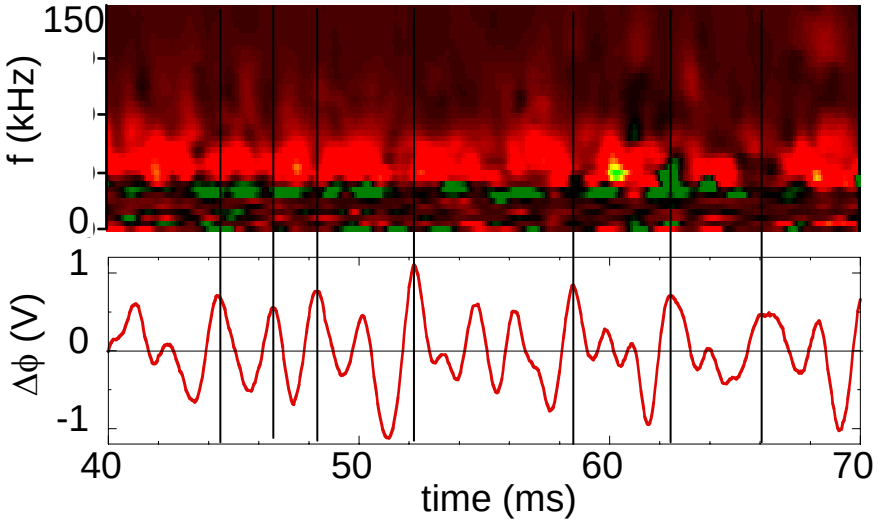
$E_r(r,t)$ {
- High correlation on magnetic surface,
- Slowly evolving in time,
- Rapidly changing in radius.

Suppression of transport by ZF

$$\Gamma(\omega) = \frac{1}{B}\left\langle \tilde{\tilde{E}}_{\theta,\omega}\, \tilde{n}_{\omega} \right\rangle$$

ZF

HIBP on CHS



Fujisawa,
PPCF in press

Regulation of transport by GAMs

GAMs

DW

$\Gamma(t)$

QuickTimeý Ç²
TIFFÅiLZWÅj êLíÉÉvÉçÉOÉâÉÃ
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Time (ms)

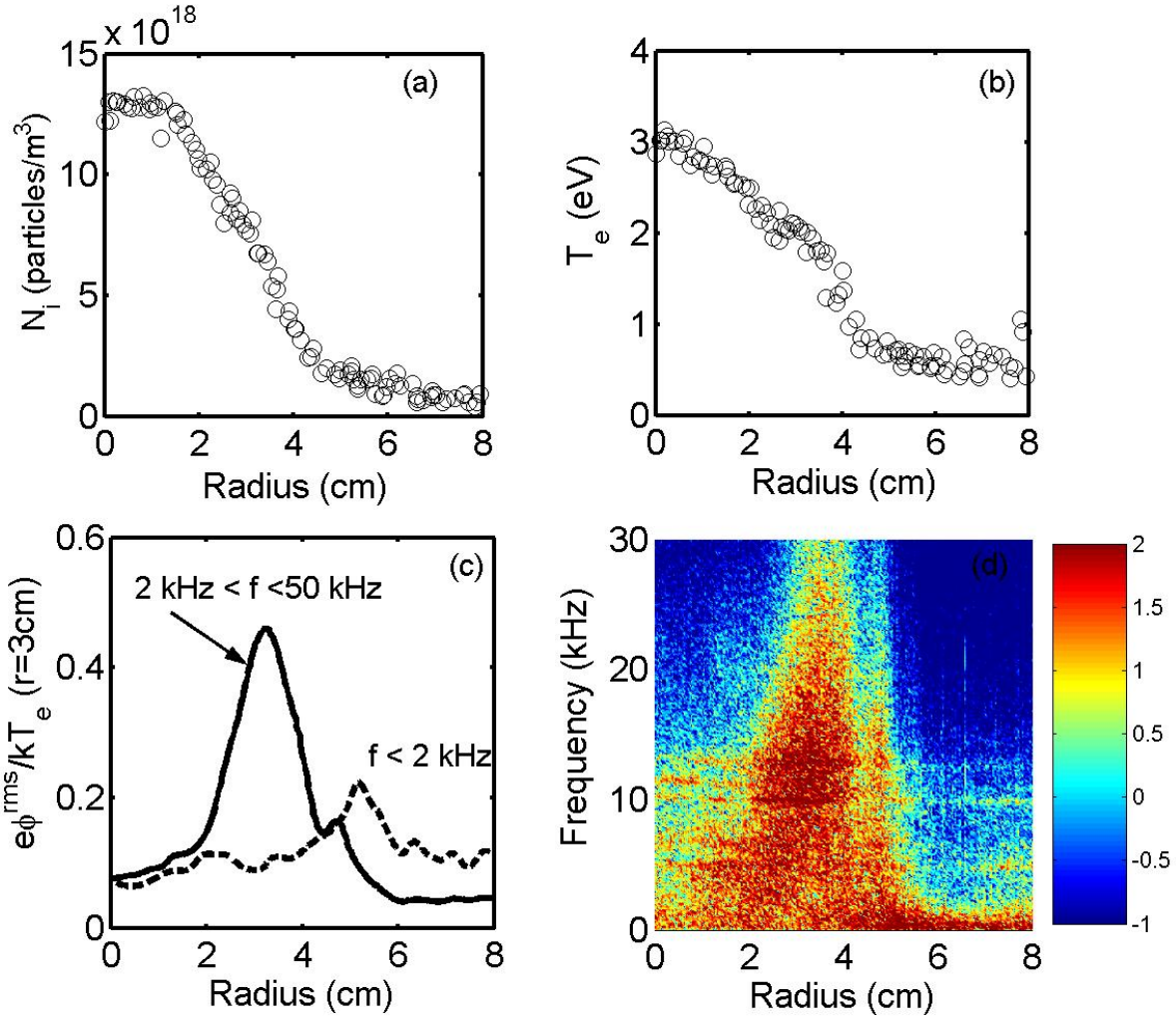
HIBP on JFT-2M

Modulation of envelope and transport by GAMs were confirmed.

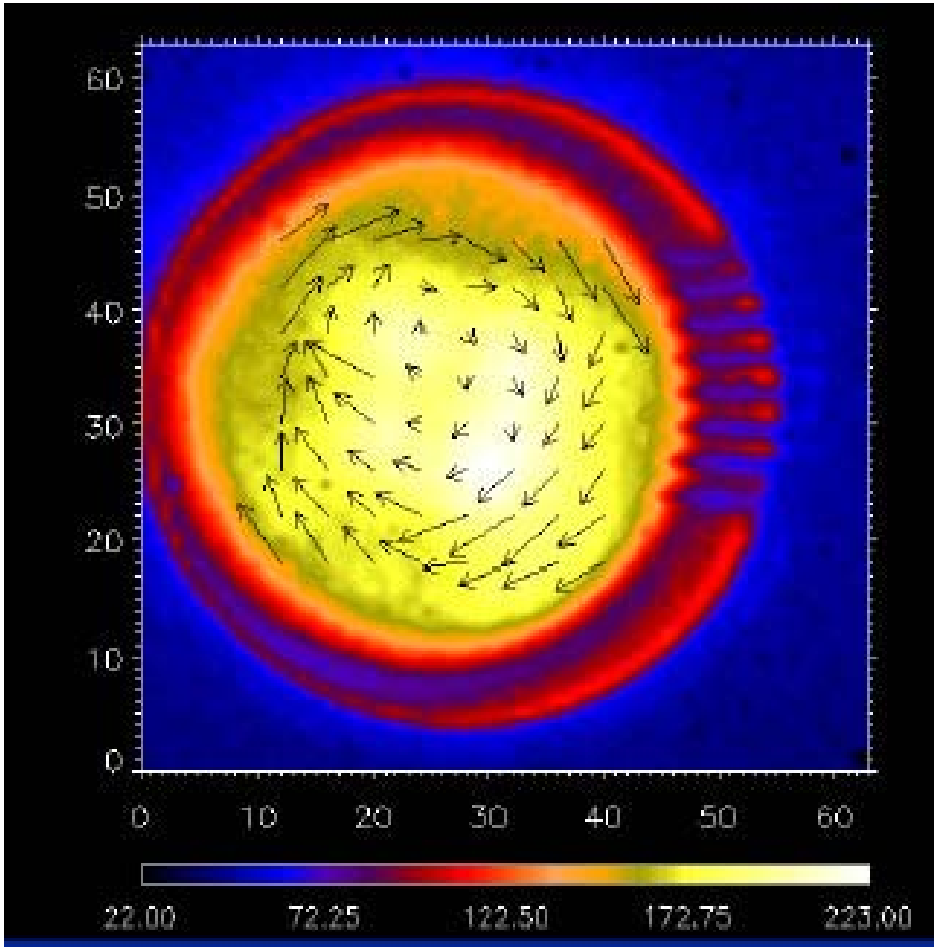
Ido, submitted to NF

Zonal flow in confinement devices

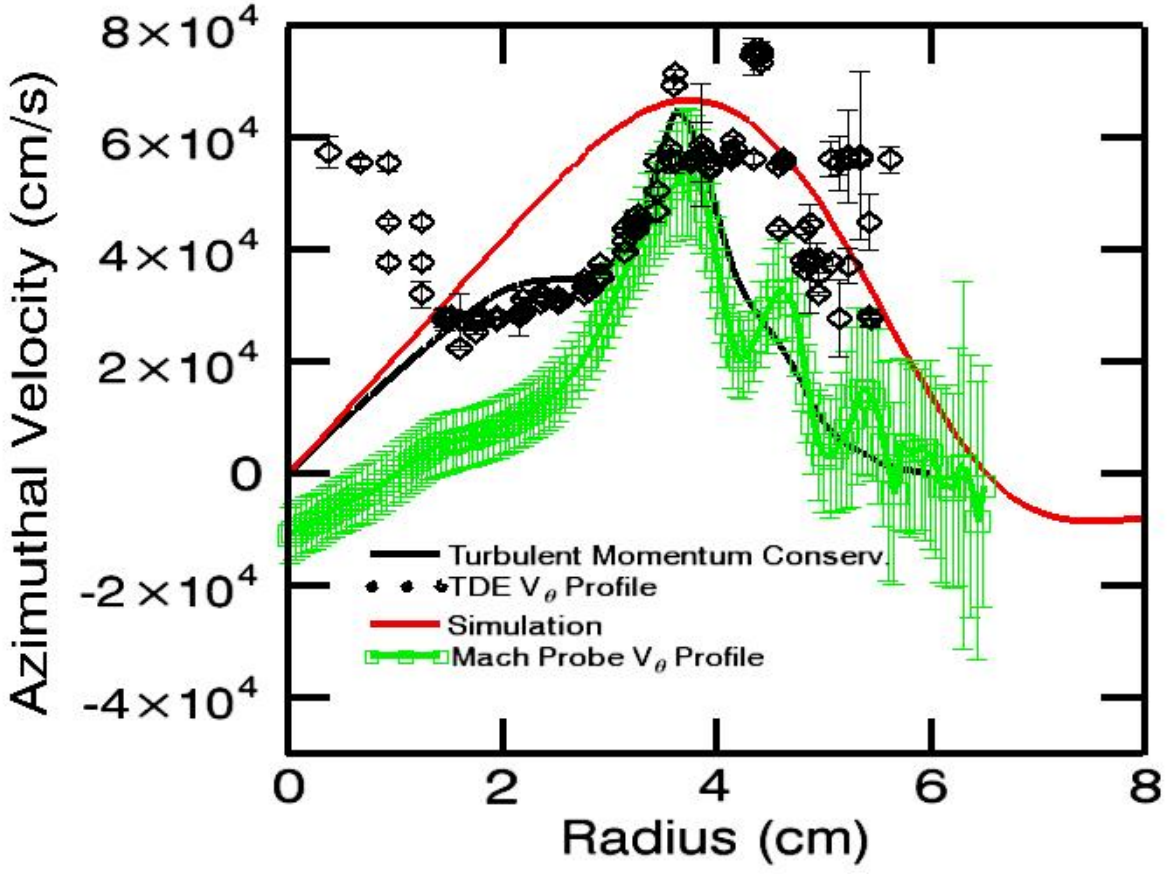
Drift-Turbulence/Zonal Flow Interactions Also Being Studied in Laboratory-scale Plasma Experiments



Lab Plasma Shows Radially Sheared Azimuthal Flow

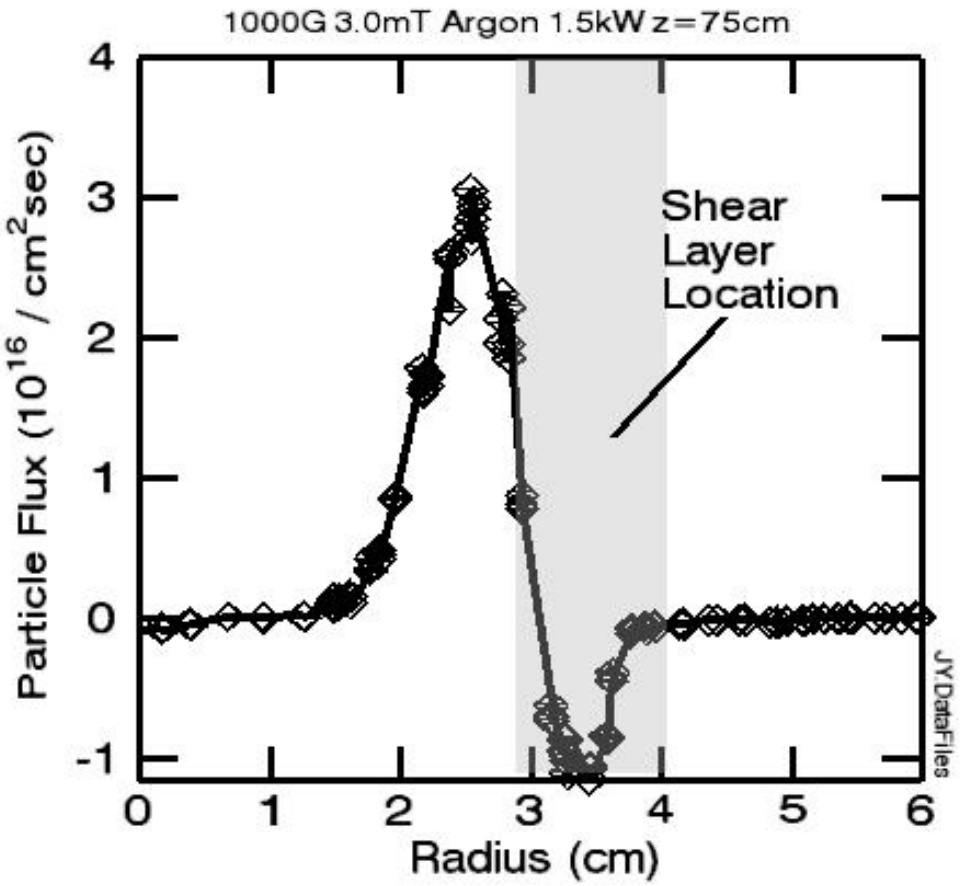


Sheared Flow Consistent with Turbulent Momentum Balance



Tynan et al, April 2006 PPCF, Holland et al, in press, PRL

No Turbulent Particle Transport Across Zonal Flow



Tynan et al, April 2006 PPCF, Holland et al, In press, PRL

Simulations Zonal Flow Forms from Vortex Merging

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

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Open Experimental Issues

- What Triggers Bifurcations to Strong Mean Shear Flow States?
- Why Does Electron Heat Transport Respond Differently Than Ion Transport?
- Do Streamers Really Exist?
- Is the Drift Turbulence/Zonal Flow/Streamer State Consistent w/ Marginal Stability Picture?
- What do these effects say for the ρ^* scaling needed for ITER Q=10?

Suggestions for GCEP

- Could Address Some Issues in Well-thought out Lab Plasma Experiments
  - e.g. Streamer/Z-flow interactions in the LAPD Device at UCLA
- Improve existing core plasma imaging diagnostics
  - Increase BES Channel Count on DIIID
- Develop Te fluctuation diagnostic in core plasma
  - High rep-rate (100-1000kHz) TS for short bursts
- Directly Measure L-H & ITB Trigger Mechanisms in Core Plasma
  - Relocate NIFS HIBP System to DIIID, NSTX, ASDEX-UG after CHS Shutdown