Turbulence Imaging of Spatiotemporal Fluctuation Structures in the Scrape-Off Layer of Alcator C-Mod

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radial transport is characterized by large transport events

- transport is intermittent
- events are associated with fluctuation structures

intense investigation of structure formation in plasma turbulence

- 2D simulation / with statistical methods in experiment
- common result: dynamics of potential vortices
Example: SOL of W7-AS Stellarator

- conditional averaging of large $\Phi_{\text{float}}$ fluctuations
- radial size $\sim 1\text{cm}$
- lifetime a few $10\ \mu\text{s}$

-propagation is poloidal (with background E$x$B)

Grulke et al.
Phys. Plasmas 8(12), 2001
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- transport is intermittent
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in the last few years transport by direct radial propagation observed
Example: SOL of Alcator C-Mod
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intense investigation of structure formation in plasma turbulence
- 2D simulation / with statistical methods in experiment
- common result: dynamics of potential vortices

in the last few years transport by direct radial propagation observed
- intermittent transport event (IPOs), avaloids, blobs propagate radially
  Terry et al., Phys. Plasmas 10(5), 2003
- cause ~50% of radial transport
  Boedo et al., Phys. Plasmas 10(5), 2003

detailed understanding of propagation mechanism / scaling important
Outline

- diagnostics: „gas puff imaging“ (GPI) on Alcator C-Mod
- potential distribution of blobs
- measured radial / poloidal blob velocities
- comparison of propagation speeds with 2D numerical simulations
Ohmic Discharges

\[ I_P = 630 \text{ kA} \]
\[ B_t = 5.4 \text{ T} \]
\[ q_{95} = 6 \]
\[ \int n \, dl = 8 \cdot 10^{19} \text{ m}^{-2} = 30\% n_G \]
SOL Diagnostics on Alcator C-Mod

reciprocating Langmuir probe ⇒ profiles \( n, T_e, \Phi \)

„gas puff imaging“
⇒ camera / diodes

\( D_\alpha \) Intensity \( \sim n_0 f(n_e, T_e) \)

reciprocating Langmuir probe ⇒ fluctuations

\( I_{\text{sat}} \sim n \sqrt{T_e} \)

\( \Phi_f \sim \Phi_P + \alpha T_e \)
Structure of Blobs parallel B

time-averaged emission profile

poloidal-toroidal camera field of view
Structure of Blobs parallel B
Parallel Correlation Measurements

250kHz Movie Camera
interference filter (Dγ)
coherent fiber bundle
300 frame camera

Radial Diode Array
(13 channels)
fast photo-diode
interference filter (Dα)
discrete fibers

Vertically scanning probe

C-Mod - top view
separatrix
limiter
gas-jet
gas-jet nozzle
flux-tube mapping probe to jet at correct 'q'
telescope
Parallel Correlation Measurements

250kHz Movie Camera
interference filter ($D_\alpha$)
coherent fiber bundle

300 frame camera

Radial Diode Array
(13 channels)
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telecscope
gas-jet nozzle

Vertically scanning probe

C-Mod - top view
separatrix
limiter
gas-jet

connection length $\sim$3m

magn. mapping based on EFIT

LCFS
probes plunge

$D_\alpha$ diode array
connecting diode

vertical position [cm] vs. major radius [m]
Parallel Correlation

normalized correlation functions between one probe tip ($I_{sat}$) and connecting diode ($D_\alpha$):
normalized correlation functions between one probe tip ($\Phi_{\text{float}}$) and connecting diode ($D_\alpha$):
Parallel Correlation: phase shift

Relative positions: potential and density structures

- Monopole-like density structure corresponds to dipole-like potential
- Poloidal phase shift $\pi/2 \Rightarrow$ in agreement with blob propagation picture
Parallel Correlation: phase shift

relative positions: potential and density structures

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2D Diagnostic – „turbulence imaging“
Propagation of Blobs

threshold on amplitude & spatial scale

2D correlation function

poloidal $E \times B$

$2\% c_s$
Density Evolution

- formation of blobs
- strong radial propagation
Blob Propagation

blob potential distribution

density

poloidal position \( \| p \| \)

potential

poloidal position \( \| p \| \)

radial position \( \| p \| \)
Blob Propagation

blob potential distribution

$D_\alpha$, reduced res.

potential
Blob Propagation

blob potential distribution

$D_\alpha$, reduced res.

poloidal / radial velocities

Potential

Poloidal position [$p_\parallel$]

Radial position [$p_\|$

PDF

Poloidal velocity [$c_\parallel$]

Radial velocity [$c_\|$

PDF
Summary

- fluctuation structures (blobs) show strong radial propagation
  - over distances larger than auto-correlation length
  - hit first wall / limiter

- potential associated with blob is dipole
  - vertical electric field $\rightarrow$ radial $E \times B$
  - in agreement with blob models

- measured radial velocities on the order of $2-3\% c_s$

- comparison with numerical model shows reasonable agreement
  - formation of blobs
  - similar radial propagation speeds ($\leq 5\% c_s$)
  - suggests fine structure (not resolved with GPI)