Intermittency and blob dynamics in the TORPEX device

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Outline

- Mechanism for blob generation from interchange waves
- Detailed study of blob propagation
- First measurements of 2D parallel current inside a blob
- Conclusions and outlook
Plasma produced by EC-waves
Open field lines - no plasma current
Extensive diagnostic coverage for turbulence and plasma response (electrost., magnetic probes)

R = 1 m, a = 0.2 m

$H_2, He, Ne, Ar$ plasmas

$B_{tor} \leq 100$ mT; $B_z \leq 10$ mT; $\rho_s/a \approx 0.02$

$T_e = 2 – 20$ eV; $n_e = 0.1–5 \times 10^{16}$ m$^{-3}$

Instability diagram

\[ N \propto \frac{1}{B_z} \]

Drift wave

Resistive Interchange

\[ k_{\text{toroidal}} = 0, \quad \lambda_z = N \Delta \]

\[ k_{\parallel} \neq 0 \text{ due to resistivity} \]

Ideal Interchange

\[ N \sim 2 \]

\[ k_{\parallel} = 0, \quad \lambda_z = \Delta \]

Ideal interchange regime: waves and blobs
Blob generation mechanism

- Time resolved 2D profiles of $n_e$, $T_e$, $\phi_{pl}$ from conditional sampling
- Interchange wave moves with $v_{ExB}$
- Radially elongated structures form from positive cells
- $ExB$ flow shear breaks off the structures and forms blobs
  - Structures form in $\sim 100 \mu s$ estimated shearing time
    \[
    \frac{1}{\tau_{sh}} = \frac{k_z L_r}{2\pi} \frac{\partial V_{ExB,z}}{\partial r} \sim (100 \mu s)^{-1}
    \]
    H. Biglari et al., PF B (1990)
- Energy is transferred from shear flow to blobs

I. Furno et al., PRL 100, 055004 (2008); C. Theiler et al., PoP (2008); A. Diallo et al., PRL (2008)
Motion of filaments/blobs in simple geometry

- Steel limiter on low-field side, defining region with
  - Constant curvature along field lines and connection length (~$2\pi R$)
  - Near-perpendicular incidence of B-field lines, no magnetic shear

- Blobs identified by pattern recognition, providing
  - Radial velocity $\Rightarrow v$
  - Vertical size $\Rightarrow a$
  - Density $\Rightarrow \delta n_e, n_e$

C. Theiler et al., PRL 103, 065001 (2009); S. H. Müller et al., PoP 2006.
Joint probability of blob velocity – size

- Similar sizes in all gases
- Similar values of $\delta n/n$
- Mean velocity of blobs over their entire trajectory
- Significant differences in the typical velocity, ranging from 500 m/s (Ar) to 2000 m/s (He)

Range of blob sizes below diagnostic resolution
Generalization of 2D blob models and scaling laws

Key question to understand blob motion is which mechanism compensates curvature-driven charge separation

Vorticity equation

\[- \text{sign}(B_z) \frac{2c_s^2 m_i}{RB} \frac{\partial n}{\partial z} = \frac{ne^2 c_s}{T_e L} \phi \nabla \phi + \frac{nm_i D}{B^2} \nabla^2 \phi + \frac{nm_i}{B^2} v_{in} \nabla^2 \phi\]

velocity \(= \left(\frac{2L\rho_s^2}{R^3}\right)^{1/5} c_s\)

size \(= \left(\frac{4L^2}{\rho_s R}\right)^{1/5} \rho_s\)

Fig. from Krasheninnikov et al.

\[\tilde{v}_{blob} = \frac{\sqrt{2\tilde{a}}}{1 + \sqrt{2\tilde{a}}^{1/2}} + \tilde{\eta} \sqrt{\tilde{a}} \frac{\delta n}{n}\]

C. Theiler et al., PRL 103, 065001 (2009).
Comparison with 2D scaling laws

Experimental data in normalized units

Damping due to ion-polarization currents
O. E. Garcia et al., PoP 2005
J. R. Myra et al., PoP 2005

Damping due to parallel currents
S. I. Krasheninnikov, PLA 2001
Two methods to measure $J_{//}$ inside a blob

- Flat one-directional LP (8 mm diam.)
  - at limiter potential $\Rightarrow J_{//}$ is measured
  - 3 cm away from the limiter

- Current probe $\Rightarrow \partial B_{r,z,t} / \partial t \Rightarrow J = \nabla \times B / \mu_0$

  M. Spoladore, N. Vianello et al, PRL 102, 165001 (2009)

Conditional sampling $\Rightarrow$ time resolved 2D profiles of $J_{//}$
Dipolar structure of $J_{//}$ is observed inside a blob in $H_2$ and $He$.

The dipole is not perfectly balanced.
How important is $J_{||}$ for the blob dynamics?

Vorticity equation

$$- \text{sign}(B_z) \frac{2Lc_s^2 m_i}{RB} \frac{\partial n}{\partial z} = -2 \cdot J_{||,\text{sheath}}^{L/2}$$

**Hydrogen**

**Helium**

Charge separation **IS MOSTLY** damped by parallel currents to the sheath

Charge separation **IS NOT** damped by parallel currents to the sheath
Conclusions

- In TORPEX, blobs form from an interchange wave crest that radially elongates and is eventually sheared off by the $\mathbf{E} \times \mathbf{B}$ flow.

- Agreement between data and a generalized 2D model for blob speed and size.
  - Parallel currents to the limiter, cross-field ion polarization currents, and ion-neutral collisions

- First detailed 2D measurements of parallel current inside a blob have been obtained.
  - Parallel currents to the limiter are important in balancing charge separation in hydrogen, but not He

- Outlook: blob control through boundary conditions