

Study of plasma filament motion and their active control

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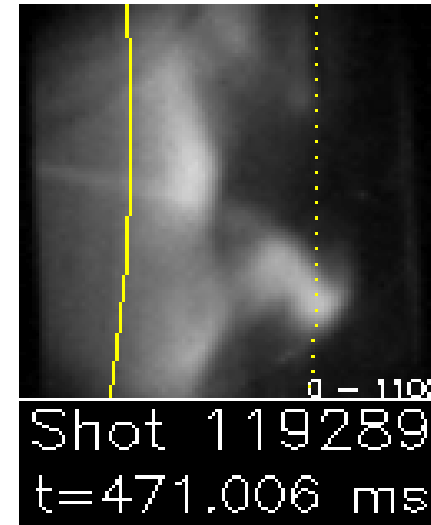
Sofia, Bulgaria

Introduction

Propagating plasma filaments are an important element of edge turbulence.

They influence

- Plasma-wall interactions
- Divertor efficiency
- Confinement?



Courtesy of R. Maqueda

Mechanism of filament/blob motion

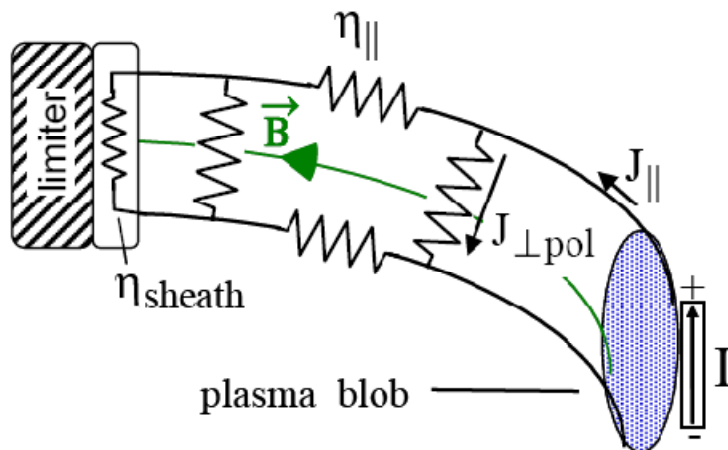
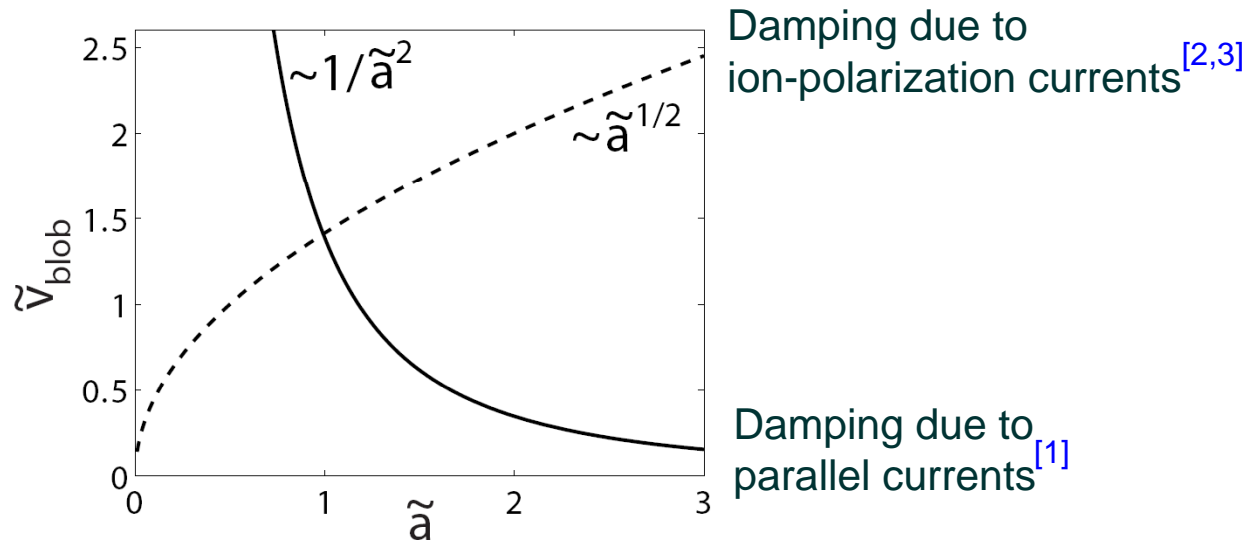


Fig. from Krasheninnikov *et al.*

The radial velocity of a filament/blob is a crucial parameter as it governs the fraction of energy and particles which are transported to the wall

Scaling laws for filament/blob velocity



Normalization:

$$v_{blob}^* = \left(\frac{2L\rho_s^2}{R^3} \right)^{1/5} c_s$$

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

L : connection length
 R : major radius

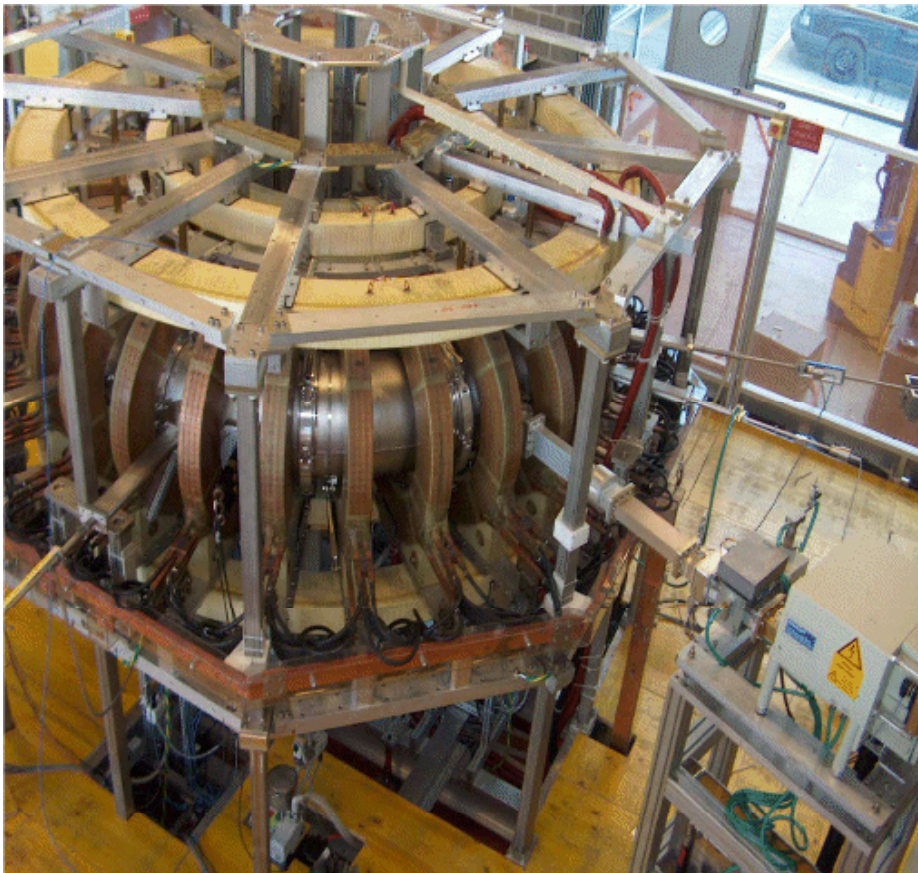
Presentation of:

- In situ measurements of blob motion in a simple geometry
- Wide scan in normalized blob size \tilde{a} by varying ion mass
- Generalization of above scaling laws
- First attempt to actively influence blob motion

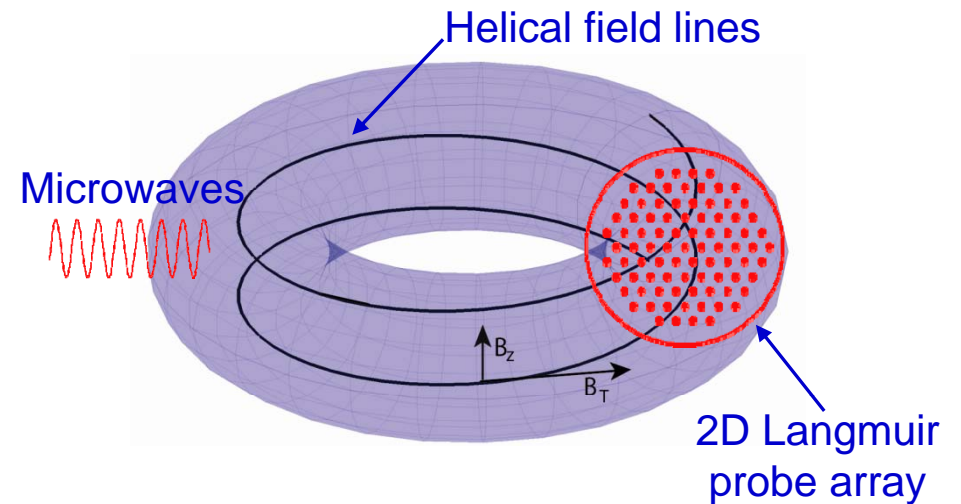
[1] S. I. Krasheninnikov, PLA 2001 [2] O. E. Garcia et al., POP 2005 [3] J. R. Myra and D. A. D'Ippolito, POP 2005

The TORPEX device

- ❑ Toroidal device: $R=1$ m, $a=0.2$ m
- ❑ Open field lines, ∇B and curvature



[A. Fasoli et al., POP 2006]



Parameters

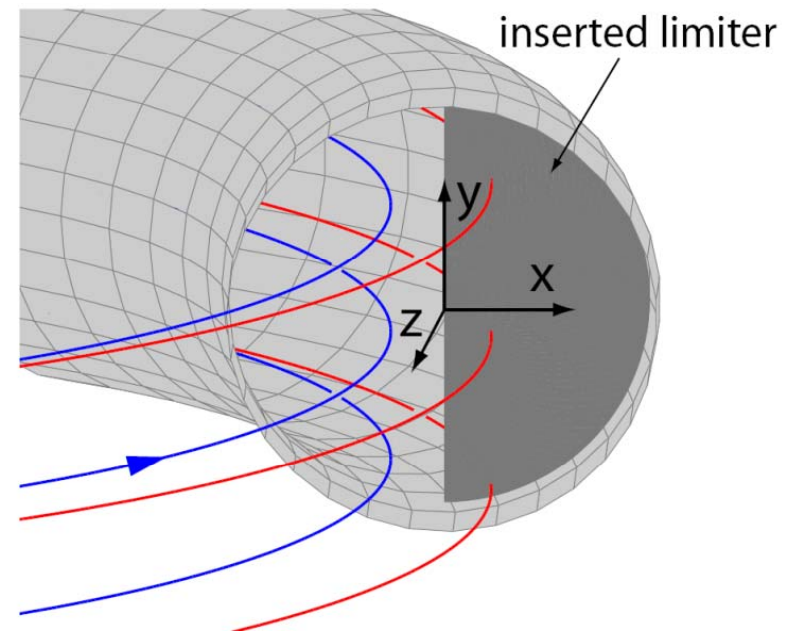
$$|B_T| \approx 76 \text{ mT} \quad n_e \leq 10^{17} \text{ m}^{-3}$$

$$|B_z / B_T| \leq 5\% \quad T_e \leq 15 \text{ eV}$$

$$T_i \ll T_e$$

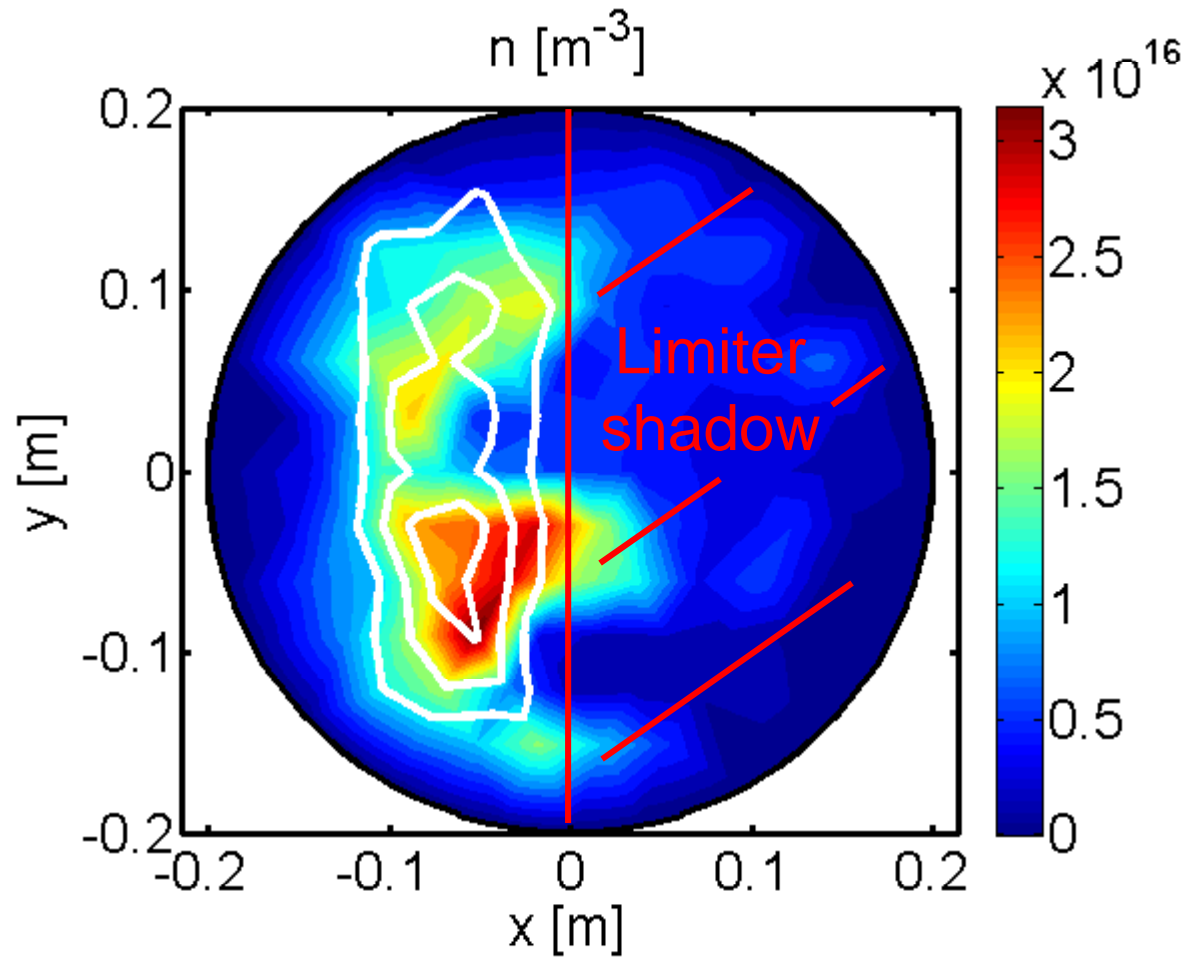
Filaments in a simple geometry

- Steel limiter in low-field side
 - ➔ Region with
 - Constant curvature along field lines
 - Nearly constant connection length
 - Near-perpendicular incidence of magnetic field lines on limiter
 - ➔ No complicating effects such as
 - Magnetic shear
 - Changing field-line curvature
 - Wall tilt
 - Finite beta effects



Target plasma

Snapshot of density profile in H₂ plasma

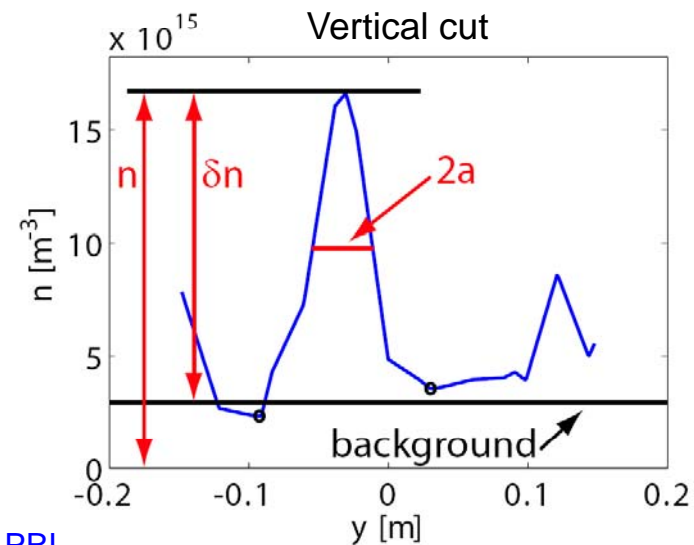
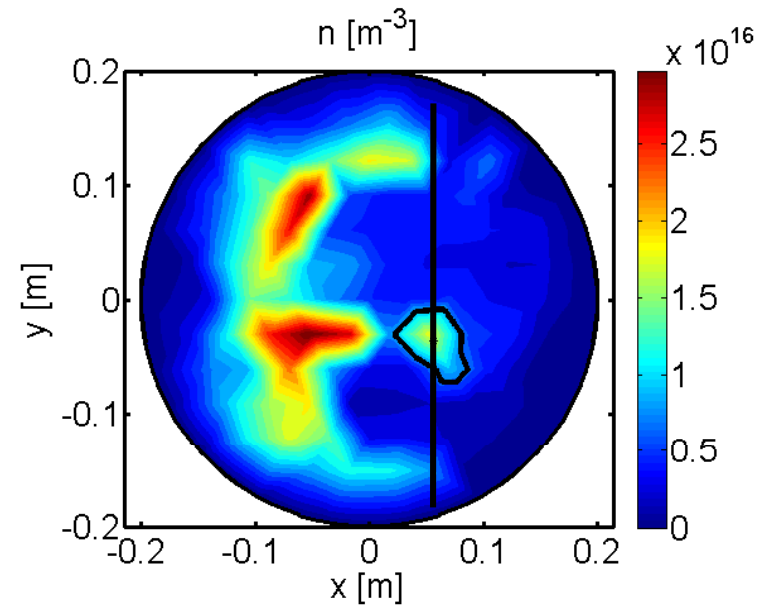


Analysis of filament/blob motion

❑ Blobs identified by pattern recognition^[1]

❑ Automatic evaluation of^[2]

- Radial velocity v
- Vertical size a
- Peak density n
- Peak density above background δn



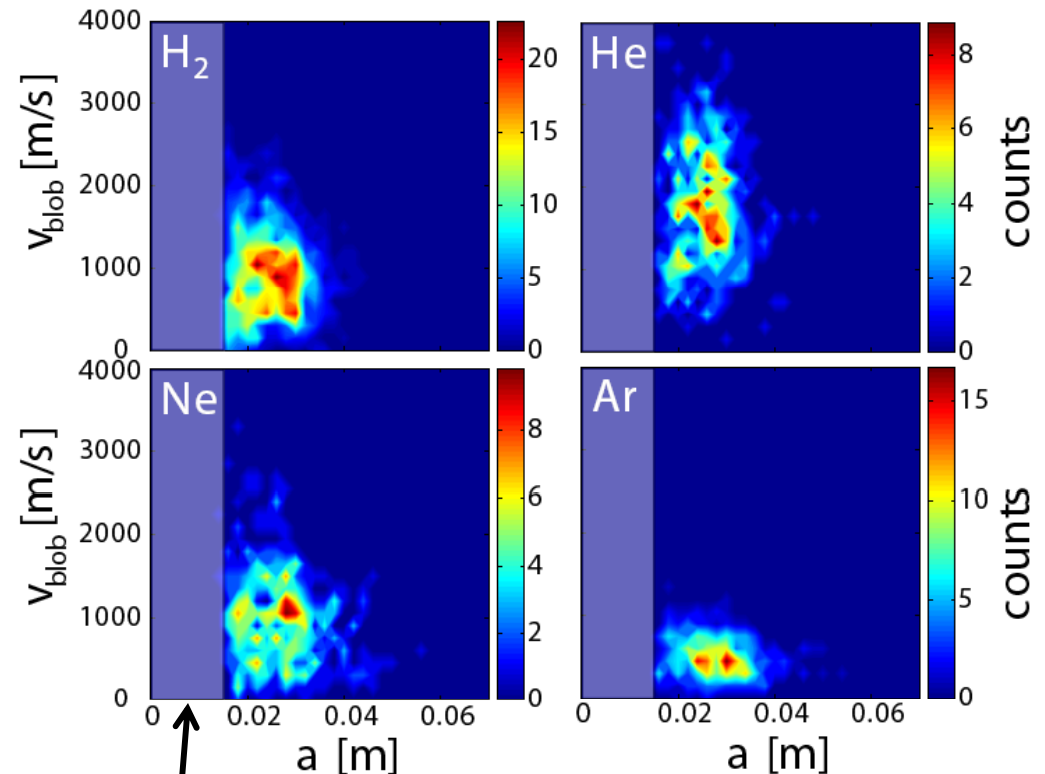
[1] S. H. Müller et al., POP 2006

[2] C. Theiler et al., submitted to PRL

Experimental results

□ Joint probabilities of blob velocity versus vertical size shows a wide distribution with

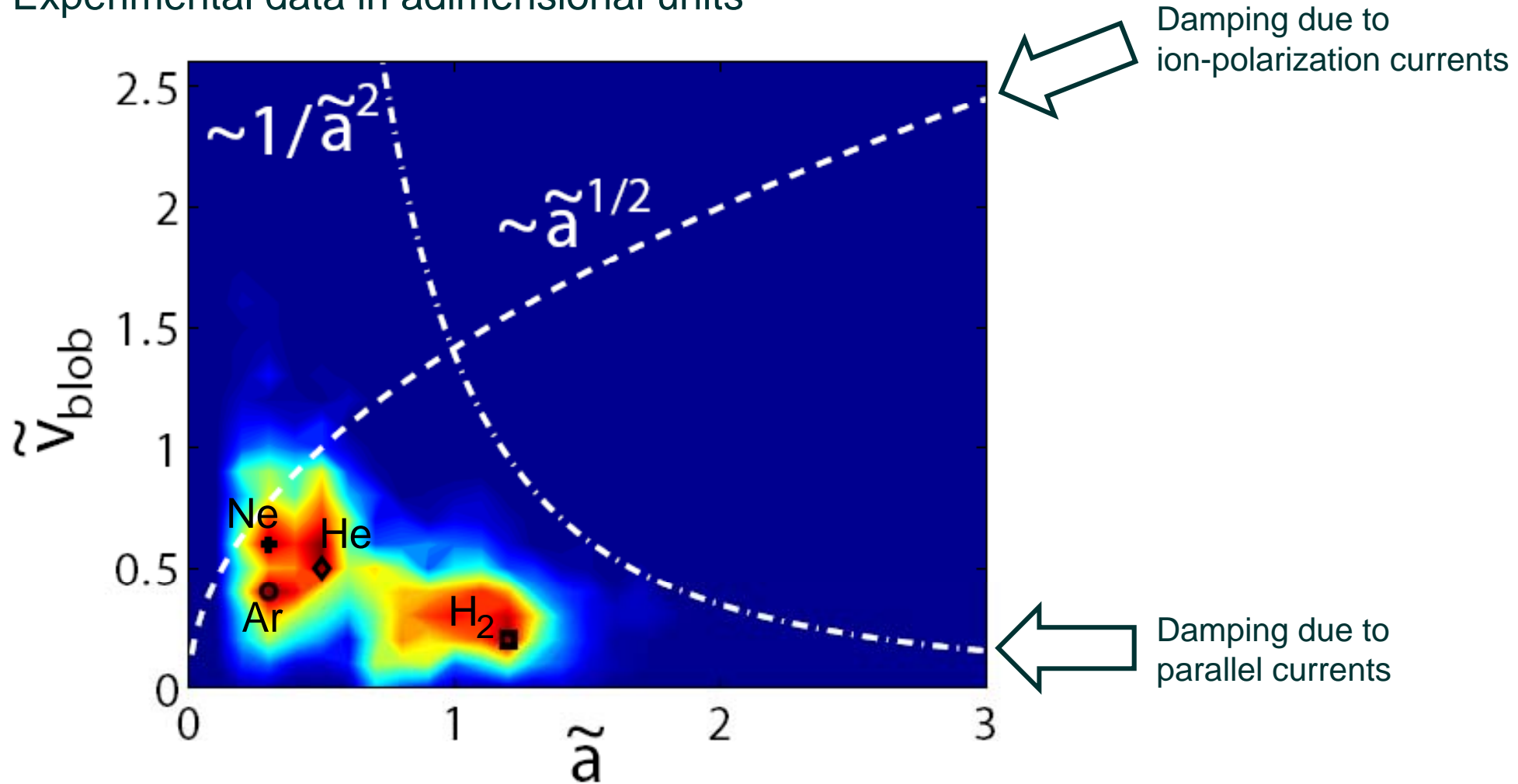
- Similar sizes in all gases
- Similar values of $\delta n/n$
- Significant differences in the typical velocity, ranging from 500 m/s (Ar) to 2000 m/s (He)



Range of blob sizes below diagnostic resolution

Comparison with 2D blob models

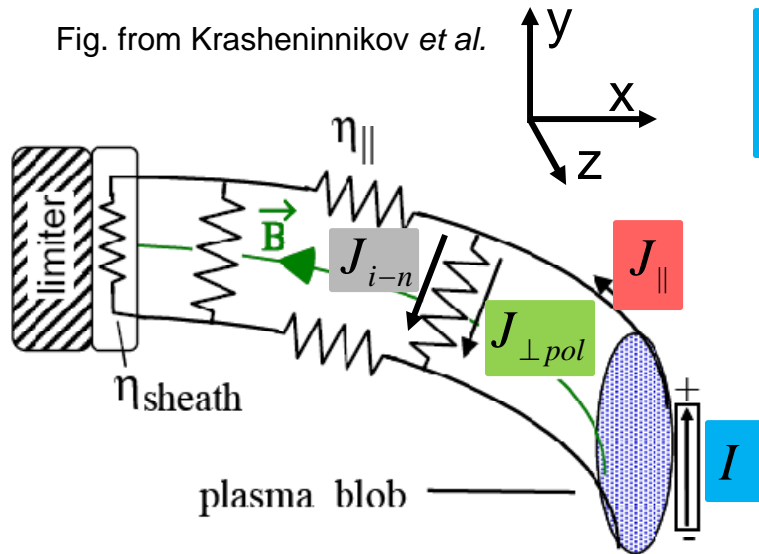
Experimental data in adimensional units



Comparison with 2D blob models

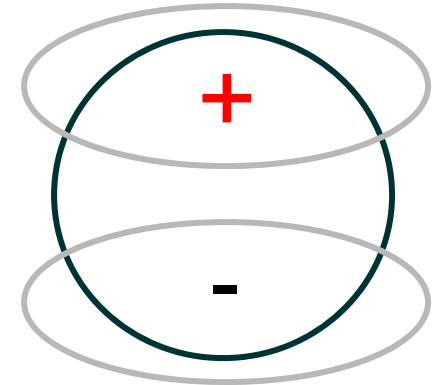
Vorticity equation

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



Estimation of terms

$$\frac{\partial n}{\partial y} \sim \frac{-\delta n}{a} \quad \frac{D}{Dt} \sim \frac{\sqrt{2}c_s}{\sqrt{Ra}} \quad \nabla^2 \phi \sim \frac{-\tilde{\phi}}{a^2} \quad \tilde{\phi} \sim Bv_{blob}a$$



$$\tilde{v}_{blob} = \frac{\sqrt{2\tilde{a}}}{1 + \sqrt{2\tilde{a}}^{5/2} + \tilde{\eta}\sqrt{\tilde{a}}} \frac{\delta n}{n} \quad [5]$$

Limits

$$\tilde{v}_{blob} = \sqrt{2\tilde{a}} \quad [2,3]$$

$$\tilde{v}_{blob} = \frac{1}{\tilde{a}^2} \quad [1]$$

$$\tilde{v}_{blob} = \frac{\sqrt{2}}{\tilde{\eta}} \quad [4]$$

[1] S. I. Krasheninnikov, PLA 2001

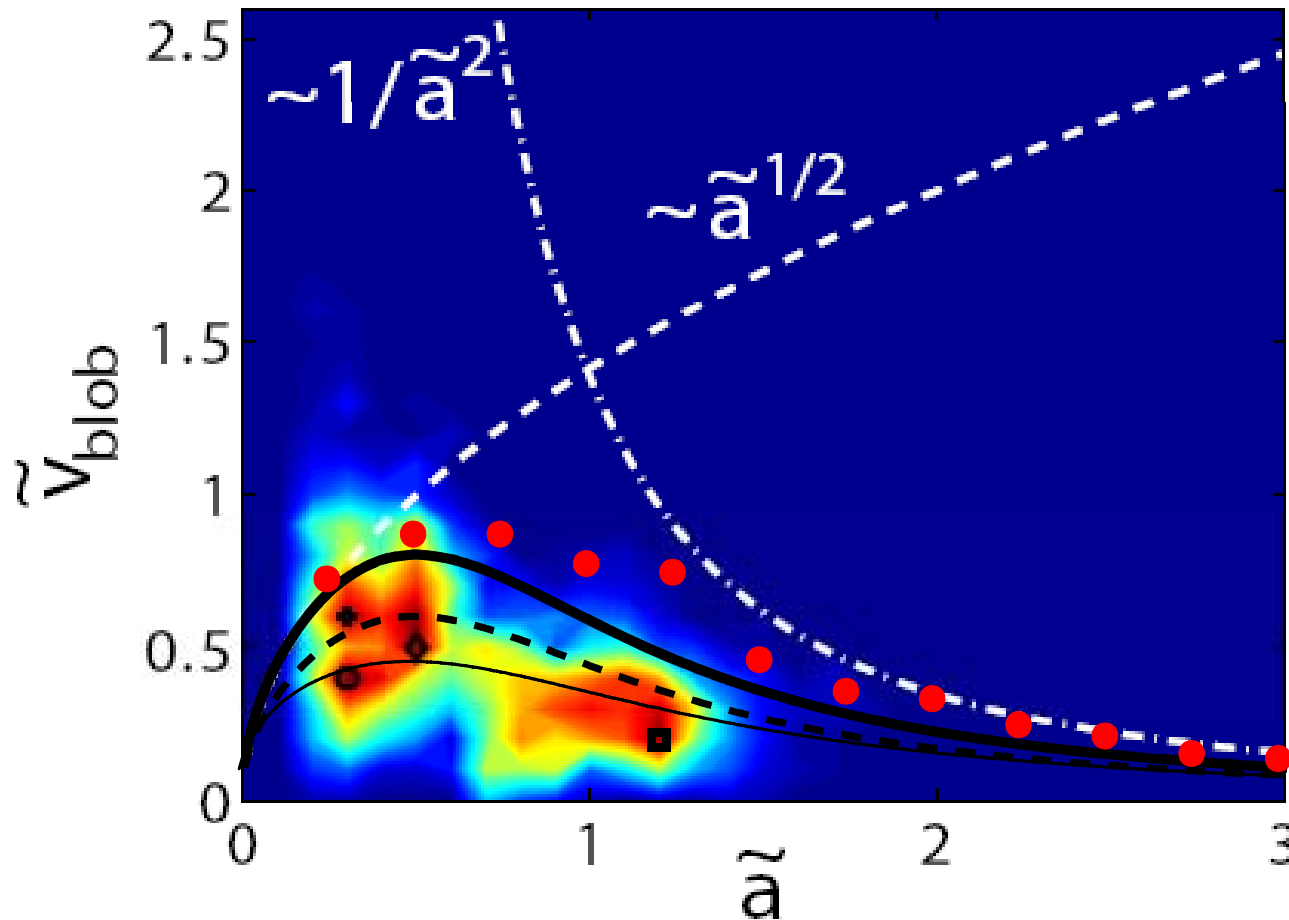
[2] O. E. Garcia *et al.*, POP 2005

[3] J. R. Myra and D. A. D'Ippolito, POP 2005

[4] N. Katz *et al.*, PRL 2008

[5] C. Theiler *et al.*, submitted to PRL

Agreement with 2D blob models



Parallel currents
+
Cross-field currents
+
Background plasma
+
Ion-neutral collisions

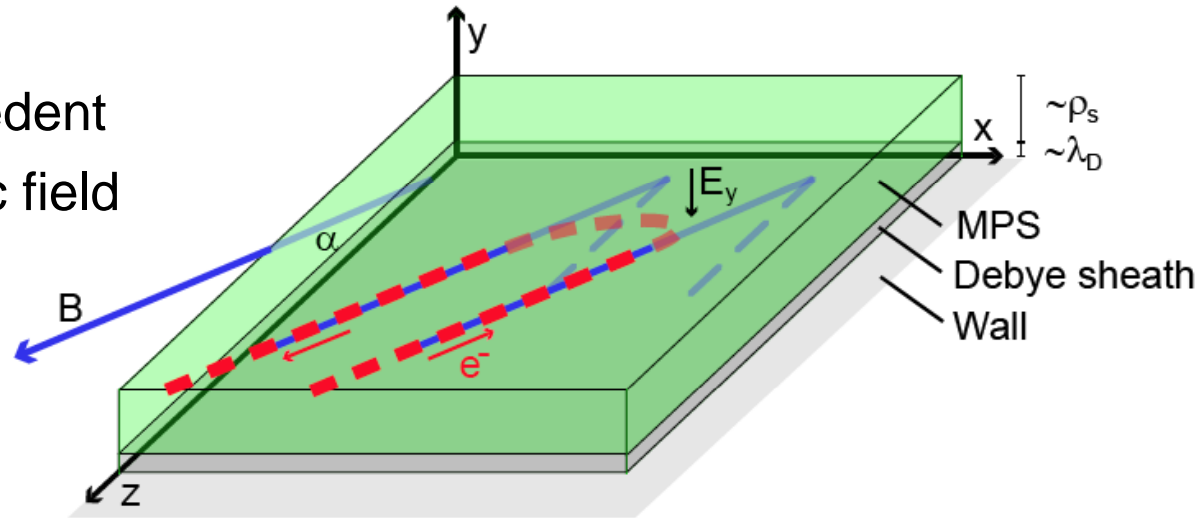
Numerical simulations
from S. SUGITA et al.^[1]

[1] S. Sugita et al., Plasma Fusion Res. 3, 040 (2008)

Effect of wall tilt on blob velocity

Theoretical prediction ^[1,2]

Parallel electron current dependent on angle α between magnetic field lines and wall



$$\alpha = \pi/2 \quad \alpha \ll 1$$

$$j_{\parallel} = \frac{n_{se} e^2 c_s}{T_e} \tilde{\phi} + \text{sign}(B_z) \frac{1}{\alpha B} \frac{\partial p_e^{se}}{\partial x}$$

→ α -dependence of parallel current boundary conditions

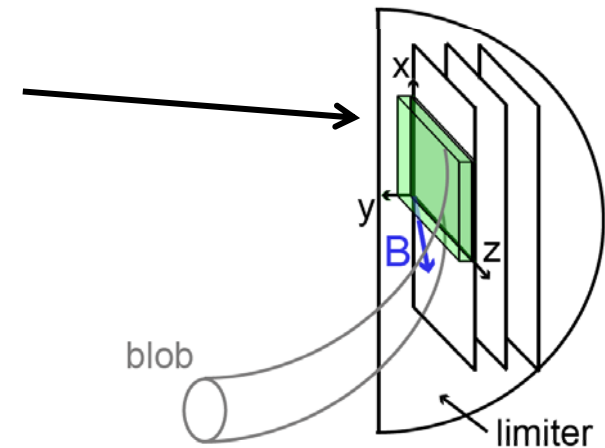
[1] R. H. Cohen and D. D. Ryutov, POP 1995

[2] R. H. Cohen and D. D. Ryutov, CPP 2006

Effect of wall tilt on blob velocity

Idea Attaching plates **vertically** on the limiter

- ➔ In the magnetic pre-sheath, electrons are deviated in the **vertical** direction, in competition with ∇B and curvature drifts.
- ➔ Drive term in vorticity equation changed by a factor $1-R/(2L\alpha)$

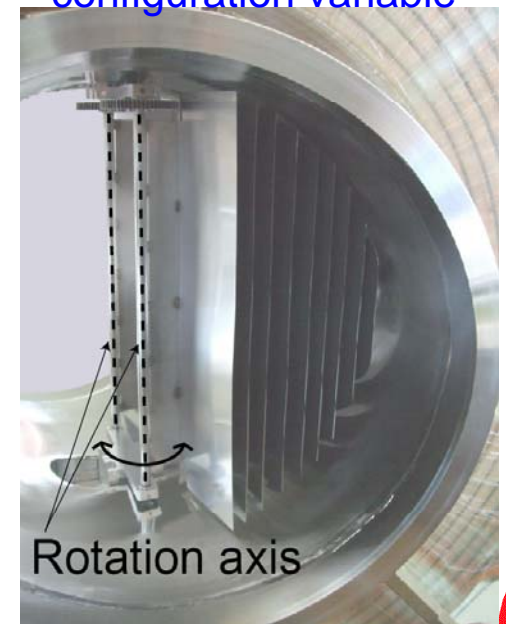
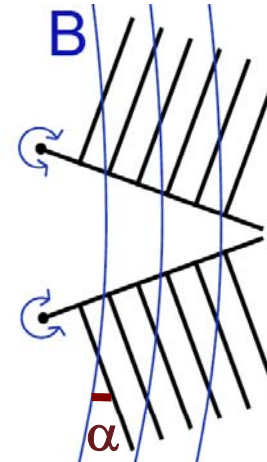


Limiter à configuration variable

Design

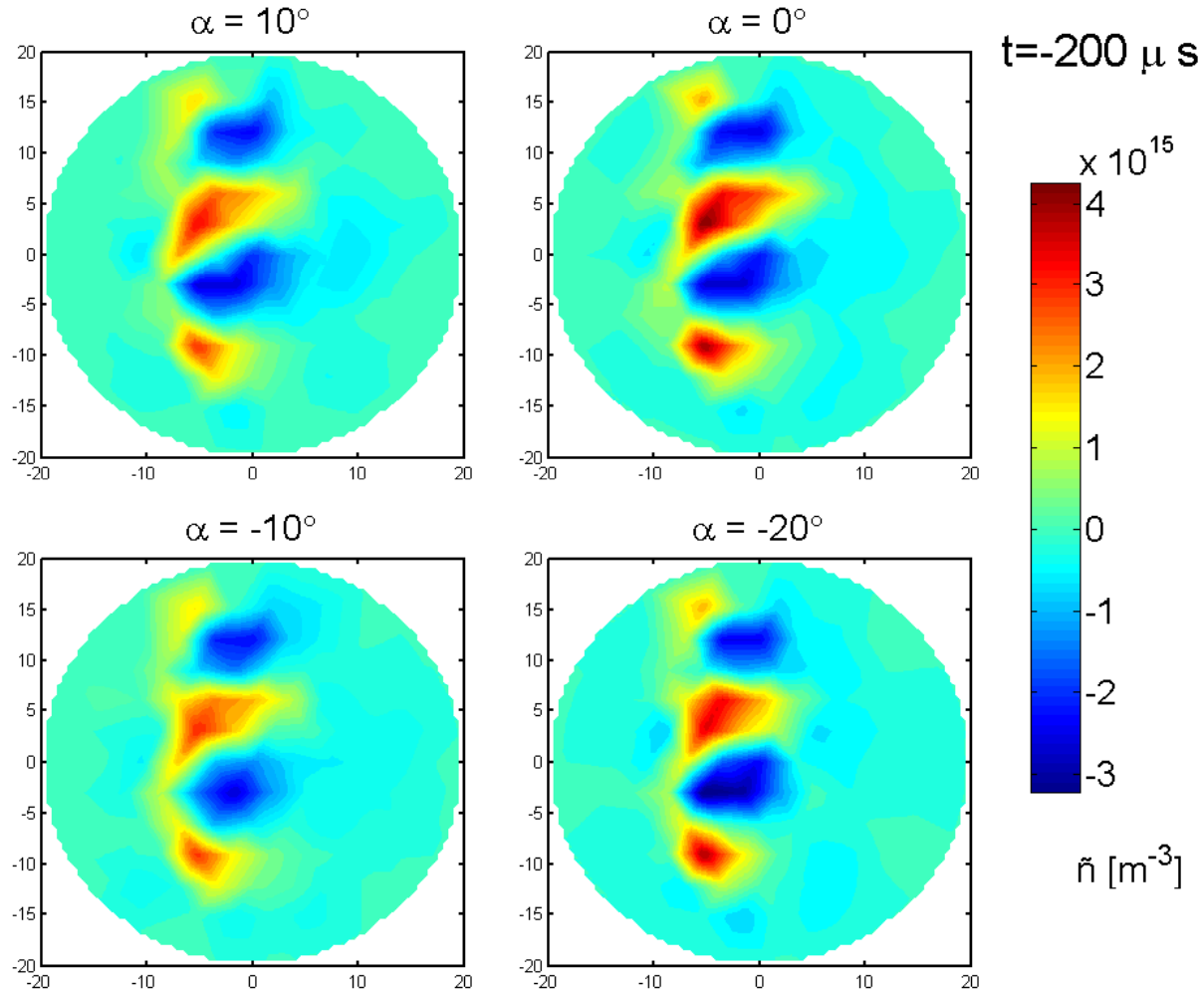
- Several plates are mounted perpendicularly on a limiter
- By pivoting the limiter around a vertical axis, we can achieve $|\alpha| \sim 10^\circ$ and $|R/(2L\alpha)| \sim 0.5$

Schematic top view



First results show no dependence of blob velocity on angle α

Average blob dynamics in H_2 (conditional average over ~350 events) shows no significant difference for different values of α



Summary

- ❑ In situ measurements of blob motion in a simple geometry and a scan in the normalized blob size \tilde{a} allowed for a quantitative comparison with 2D blob models

- ❑ A generalized expression for blob velocity was derived, which shows good agreement with experimental and simulation data. It includes
 - Parallel currents to the limiter
 - Cross-field ion polarization currents
 - Finite background plasma
 - Ion-neutral collisions

- ❑ Preliminary results with new tiltable-plate limiter suggest no effect of the angle between the magnetic field and the limiter on the blob velocity