Blob motion and control in simple magnetized plasmas

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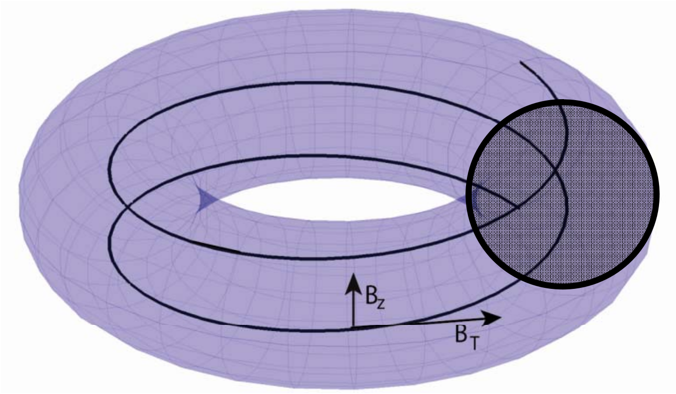
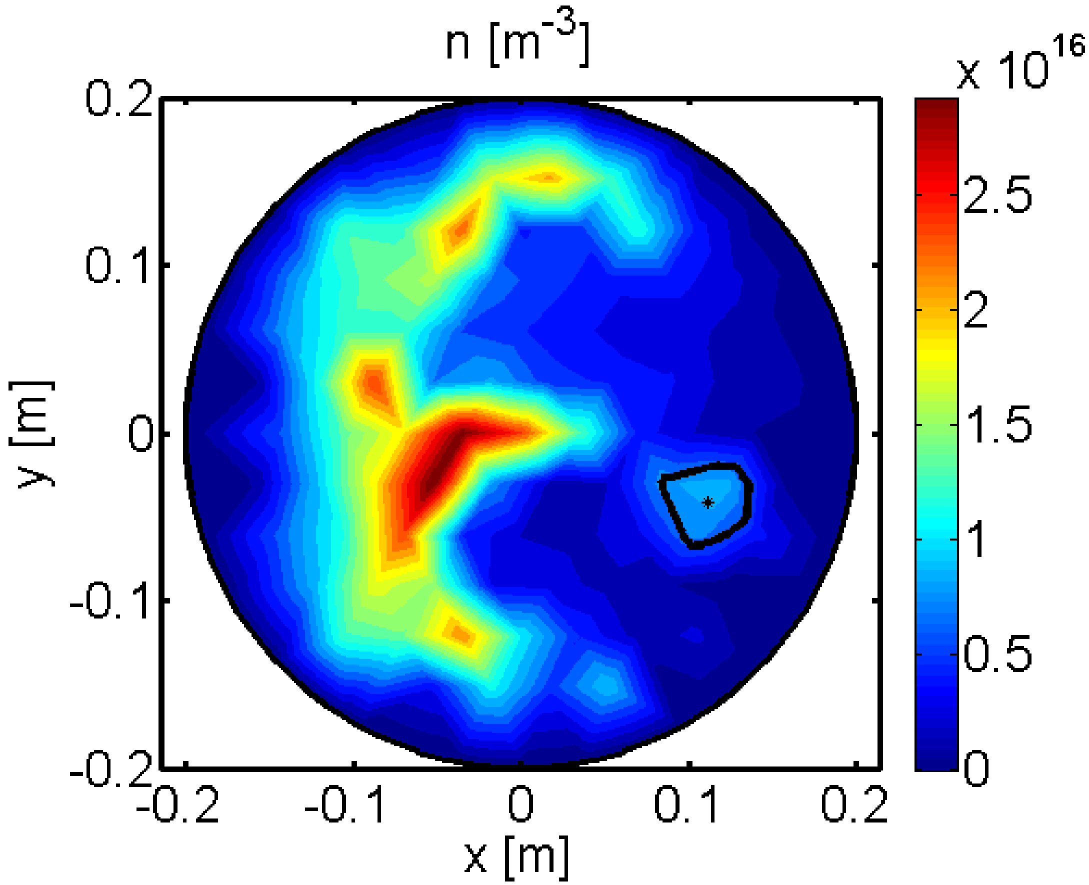
A blob in TORPEX

Torpex geometry



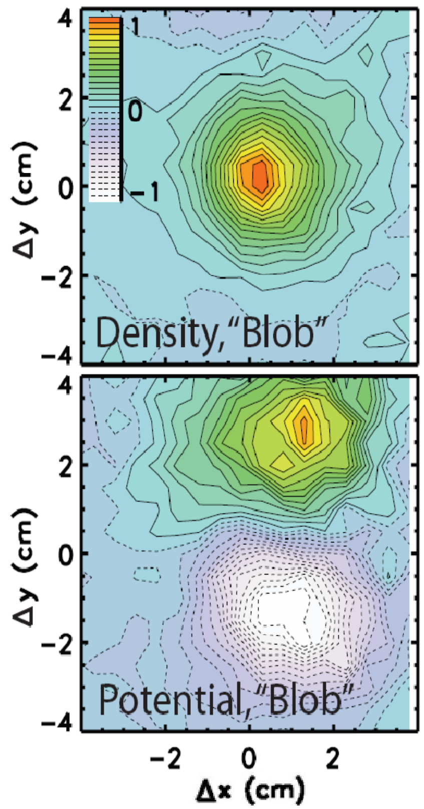
cross-section



Blobs are everywhere…

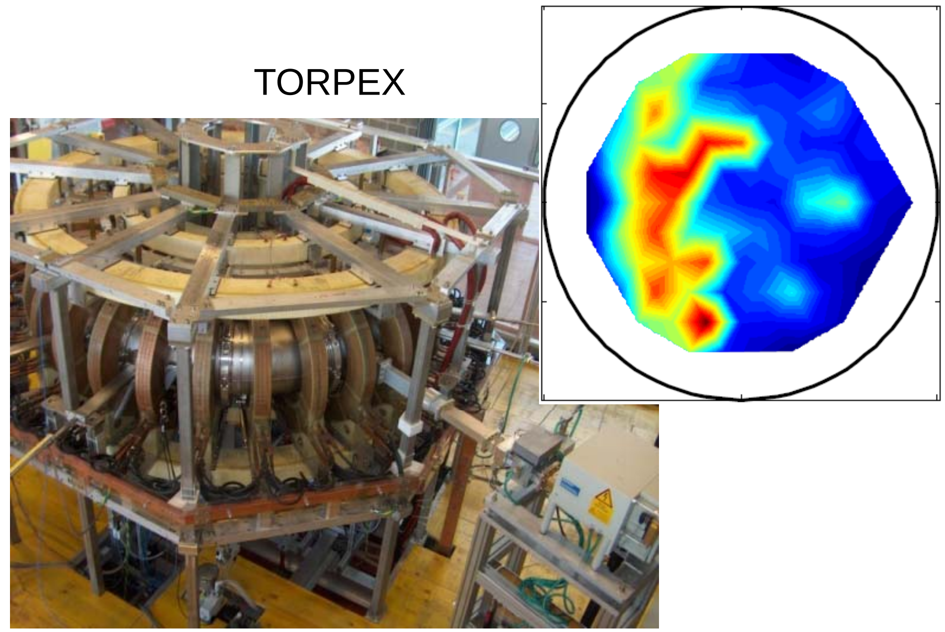
… in linear machines, in simple toroidal plasmas …

LAPD



Carter POP 06

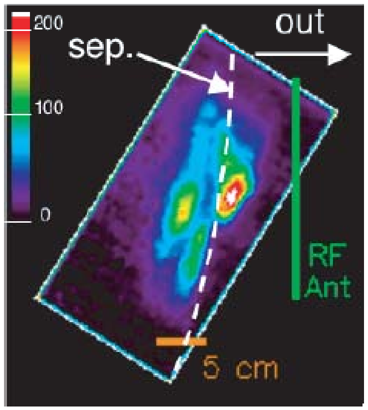
TORPEX



Blobs are everywhere…

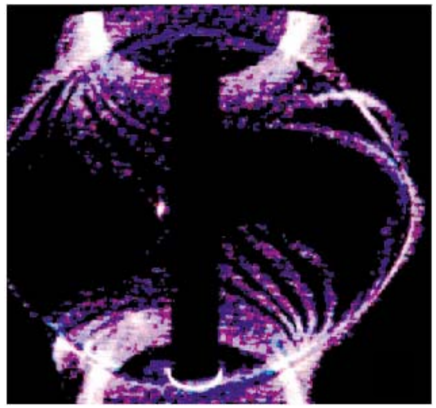
… in tokamaks…

NSTX



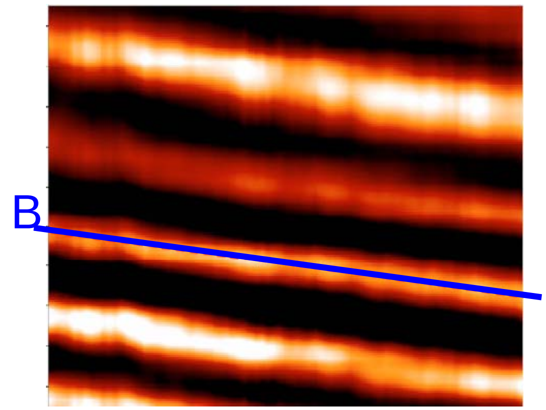
Zweben et al. POP 04

MAST



Kirk et al. PRL 04

C-Mod



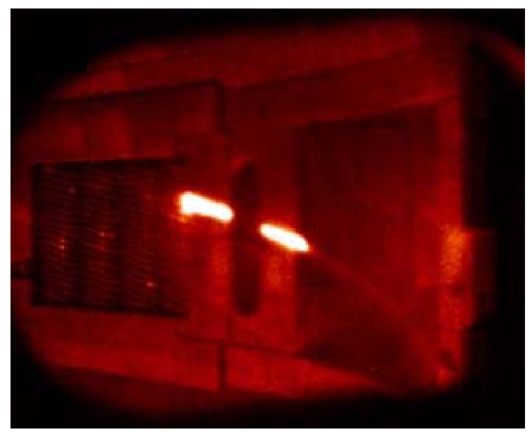
Grulke et al. POP 06

… and they are important for fusion,

they influence

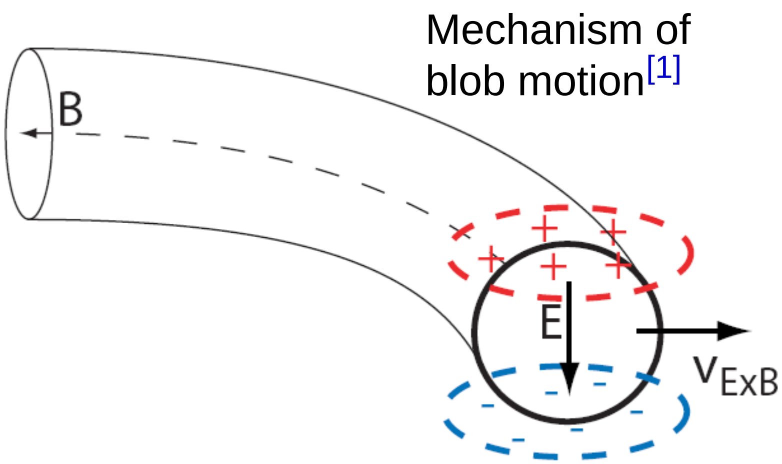
- Confinement
- Divertor efficiency
- Plasma-wall interactions

DIII-D



Yu et al. POP 08

Motivation



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

It is therefore crucial to understand the mechanisms behind blob propagation, the scaling of blob dynamical properties with plasma parameters, and to investigate ways to influence the blob motion

[1] Krasheninnikov PLA 2001

Outline

- Derivation of blob velocity scaling law
- In situ measurements of blob motion in a simple geometry
- Verification of scaling law via a wide scan in (normalized) blob size by varying ion mass
- Control of blob motion by
  - Reduction of connection length
  - Variation of neutral gas pressure
  - Biased electrodes

Generalized scaling law: derivation

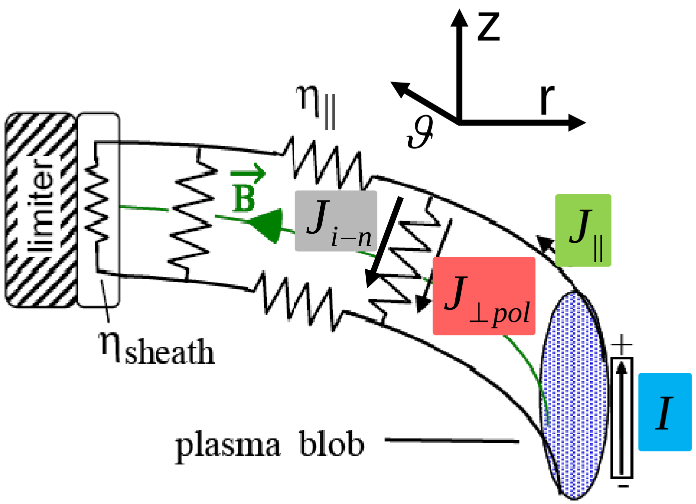


Fig. from Krasheninnikov *et al.* JPP 08

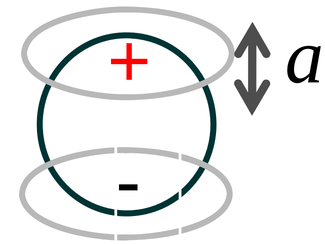
Vorticity equation

$$\frac{2c_s^2 m_i}{RB}\frac{\partial n}{\partial z} = \frac{nm_i}{B^2}\frac{D}{Dt}\nabla^2\phi - \frac{ne^2c_s}{T_e L_c}\tilde{\phi} + \frac{nm_i}{B^2}\nu_{in}\nabla^2\phi$$

Estimate of terms

$$\frac{\partial n}{\partial z} \sim \frac{-\delta n}{a} \qquad \frac{D}{Dt} \sim \frac{\sqrt{2}c_s}{\sqrt{Ra}}$$

$$\nabla^2\phi \sim \frac{-\tilde{\phi}}{a^2} \qquad \tilde{\phi} \sim Bv_{blob}a$$



Generalized scaling law: derivation

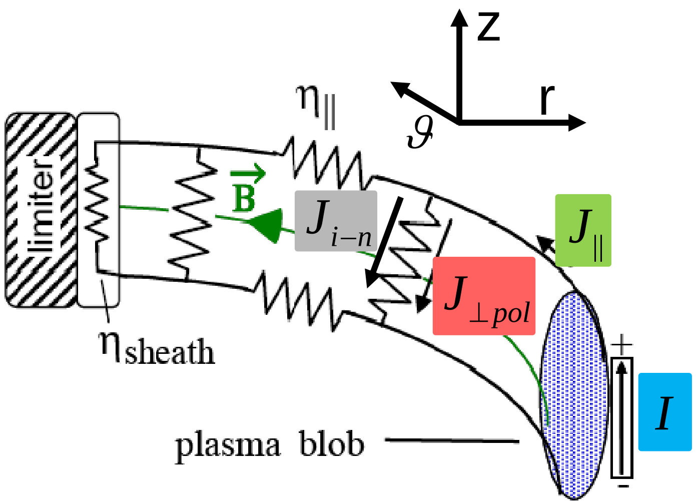
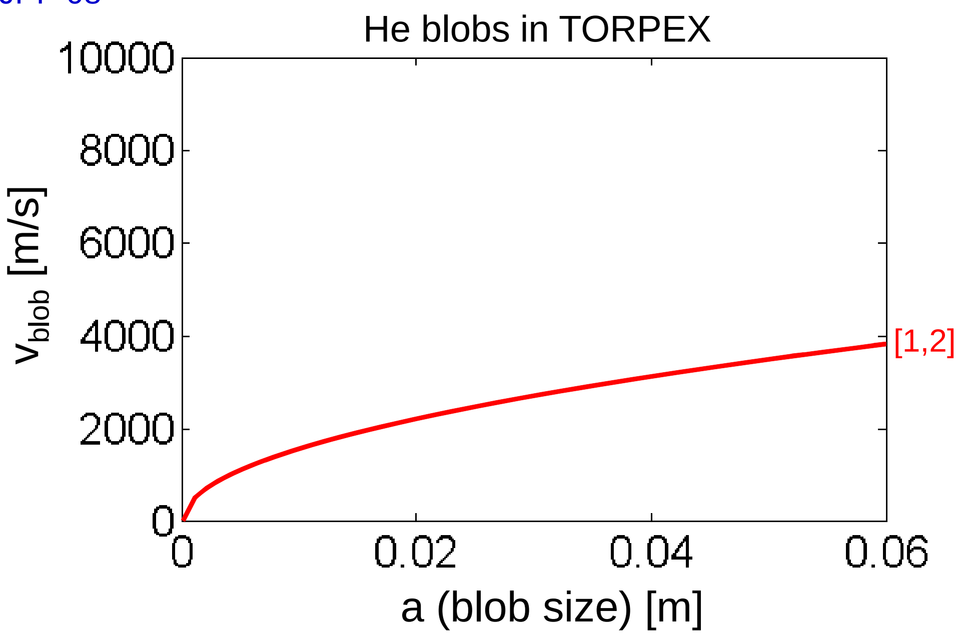


Fig. from Krasheninnikov *et al.* JPP 08

Vorticity equation

$$\frac{2c_s^2 m_i}{RB}\frac{\partial n}{\partial z} = \frac{n m_i}{B^2}\frac{D}{Dt}\nabla^2\phi$$



[1] Garcia et al. POP 2005
[2] Myra and D'Ippolito POP 2005
[3] Krasheninnikov PLA 2001
[4] Katz et al. PRL 2008
[5] Theiler et al. PRL 2009

Generalized scaling law: derivation

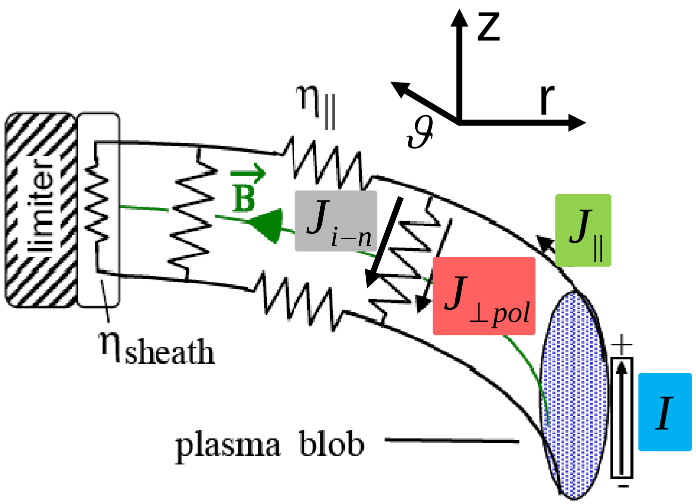
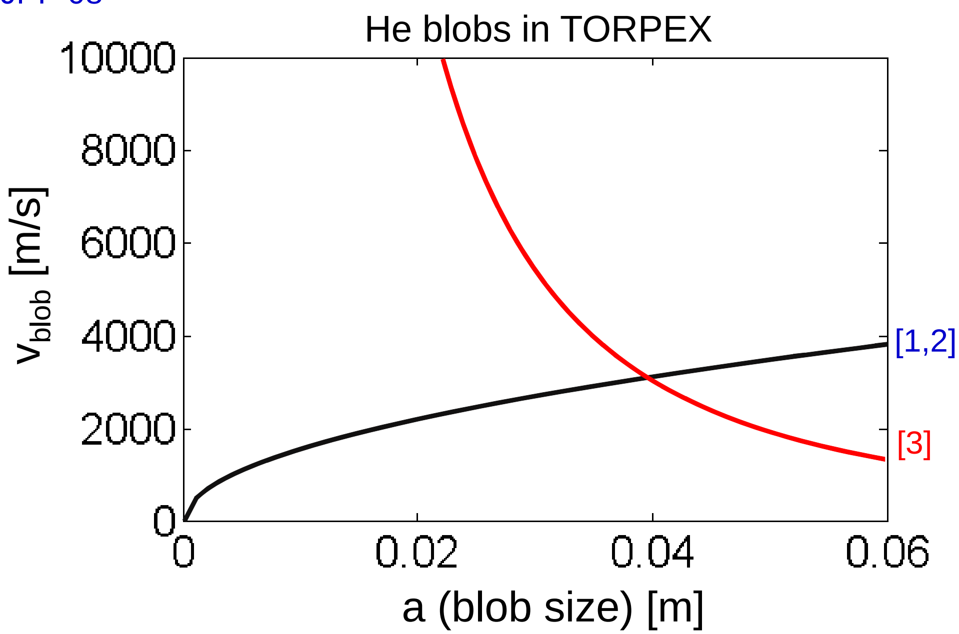


Fig. from Krasheninnikov *et al.* JPP 08

Vorticity equation

$$\frac{2c_s^2 m_i}{RB}\frac{\partial n}{\partial z} = \qquad - \frac{ne^2 c_s}{T_e L_c}\tilde{\phi}$$



[1] Garcia et al. POP 2005
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Generalized scaling law: derivation

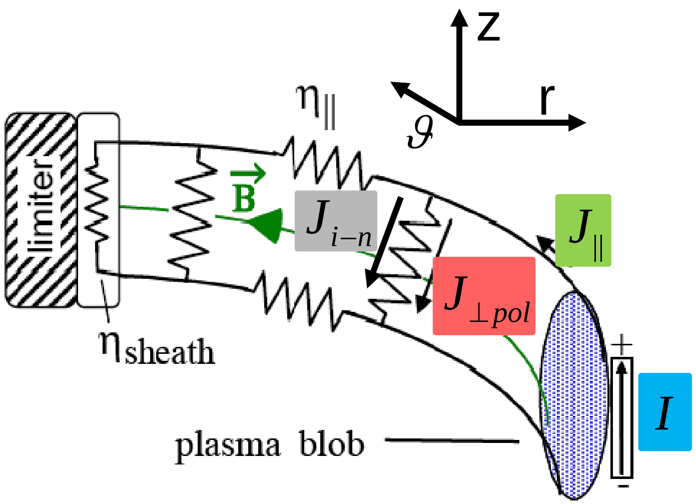
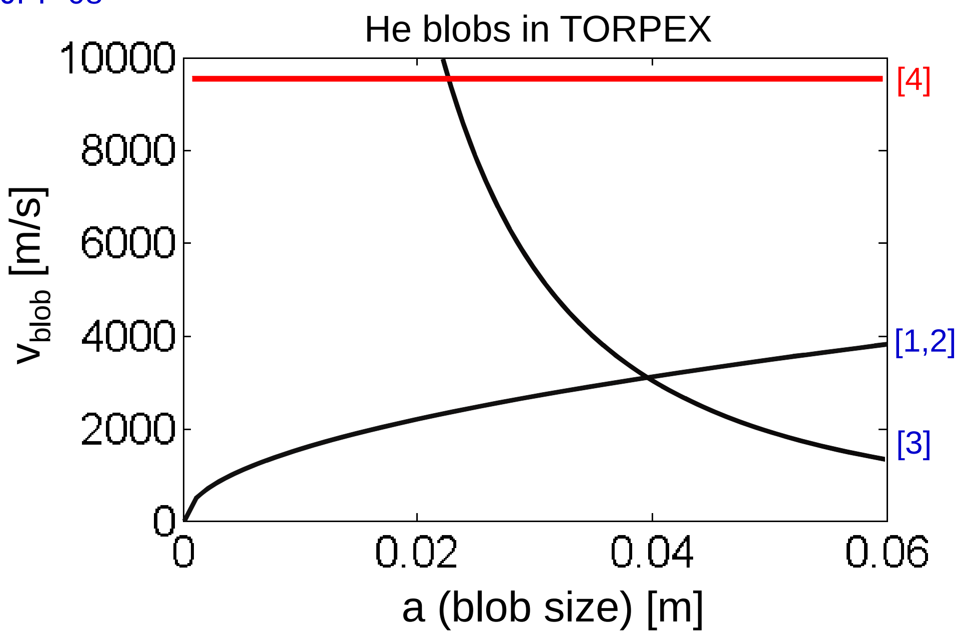


Fig. from Krasheninnikov *et al.* JPP 08

Vorticity equation

$$\frac{2c_s^2 m_i}{RB}\frac{\partial n}{\partial z} = \qquad + \frac{nm_i}{B^2}\nu_{in}\nabla^2\phi$$



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Generalized scaling law: derivation

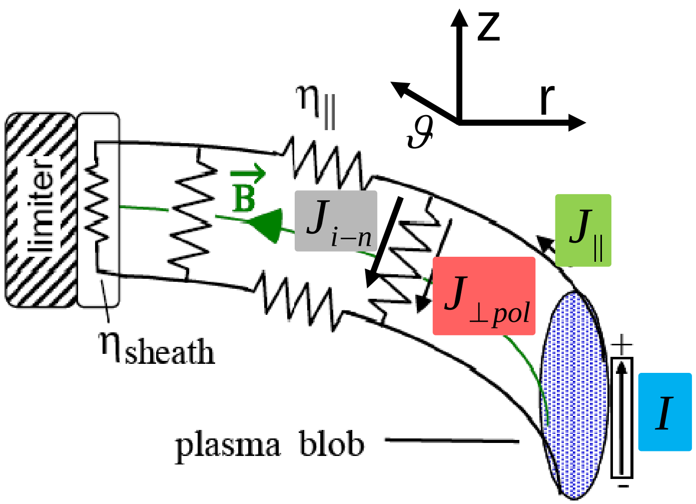
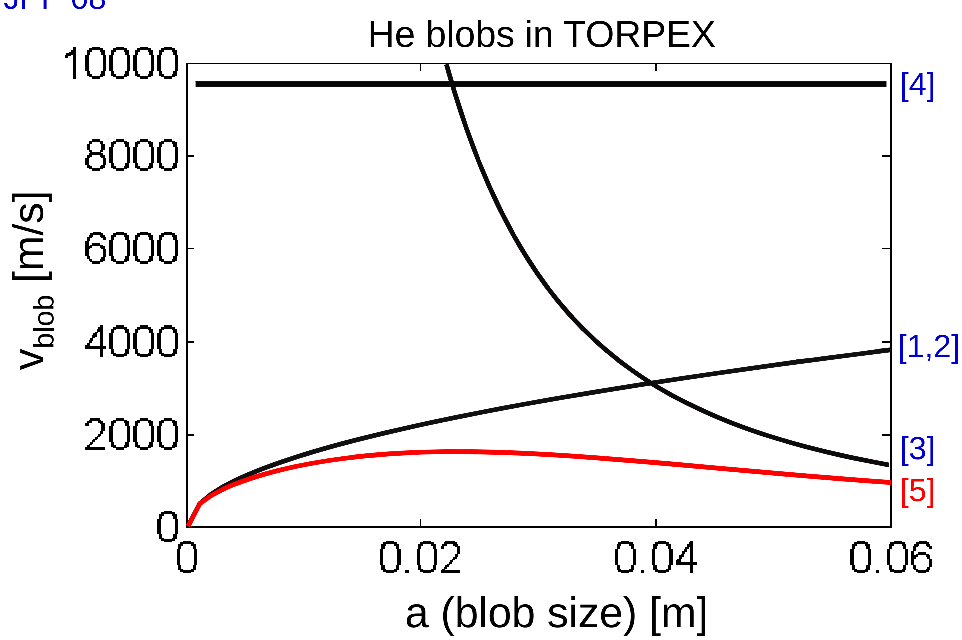


Fig. from Krasheninnikov *et al.* JPP 08

Vorticity equation

$$\frac{2c_s^2 m_i}{RB}\frac{\partial n}{\partial z} = \frac{nm_i}{B^2}\frac{D}{Dt}\nabla^2\phi - \frac{ne^2 c_s}{T_e L_c}\tilde{\phi} + \frac{nm_i}{B^2}\nu_{in}\nabla^2\phi$$



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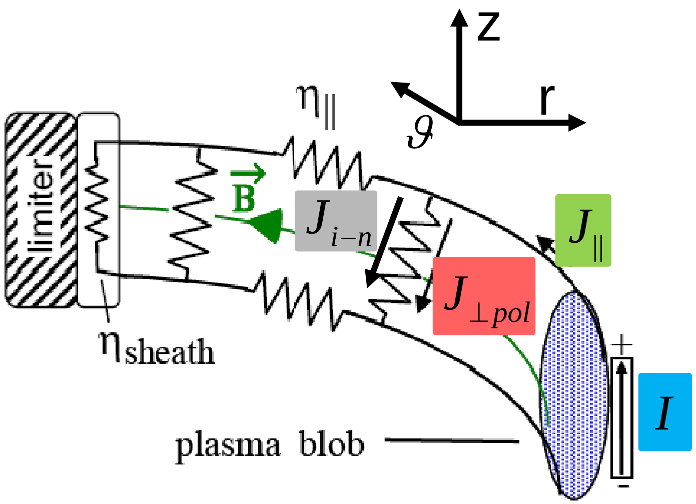

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Vorticity equation

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$$v_{blob} = \frac{\sqrt{\frac{2a}{R}}c_s}{1 + \frac{1}{\rho_s^2 L_c}\sqrt{\frac{R}{2}}a^{5/2} + \frac{\upsilon_{in}\sqrt{Ra}}{\sqrt{2}c_s}}\frac{\delta n}{n}$$

[1,2] [3] [4]

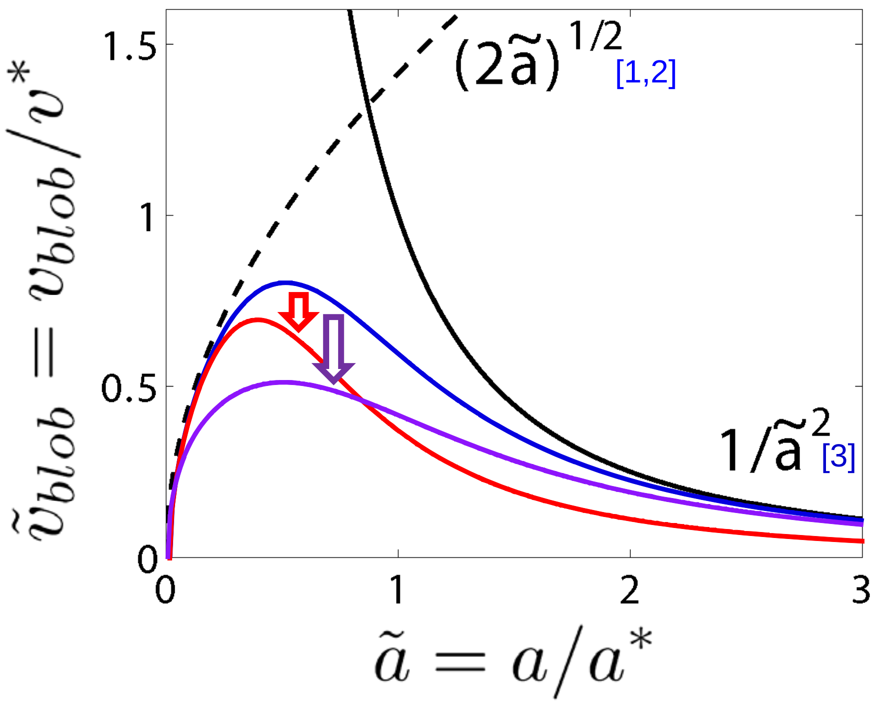
[5]

[1] Garcia et al. POP 2005
[2] Myra and D'Ippolito POP 2005
[3] Krasheninnikov PLA 2001
[4] Katz et al. PRL 2008
[5] Theiler et al. PRL 2009

Generalized scaling law and possible blob control

Normalization:

$$a^* = \left(\frac{4L_c^2}{\rho_s R}\right)^{1/5} \rho_s \qquad v^* = \left(\frac{2L_c\rho_s^2}{R^3}\right)^{1/5} c_s$$



Variation of ã to test scaling law by

- Ion mass scan $a^* \propto m_i^{2/5}$

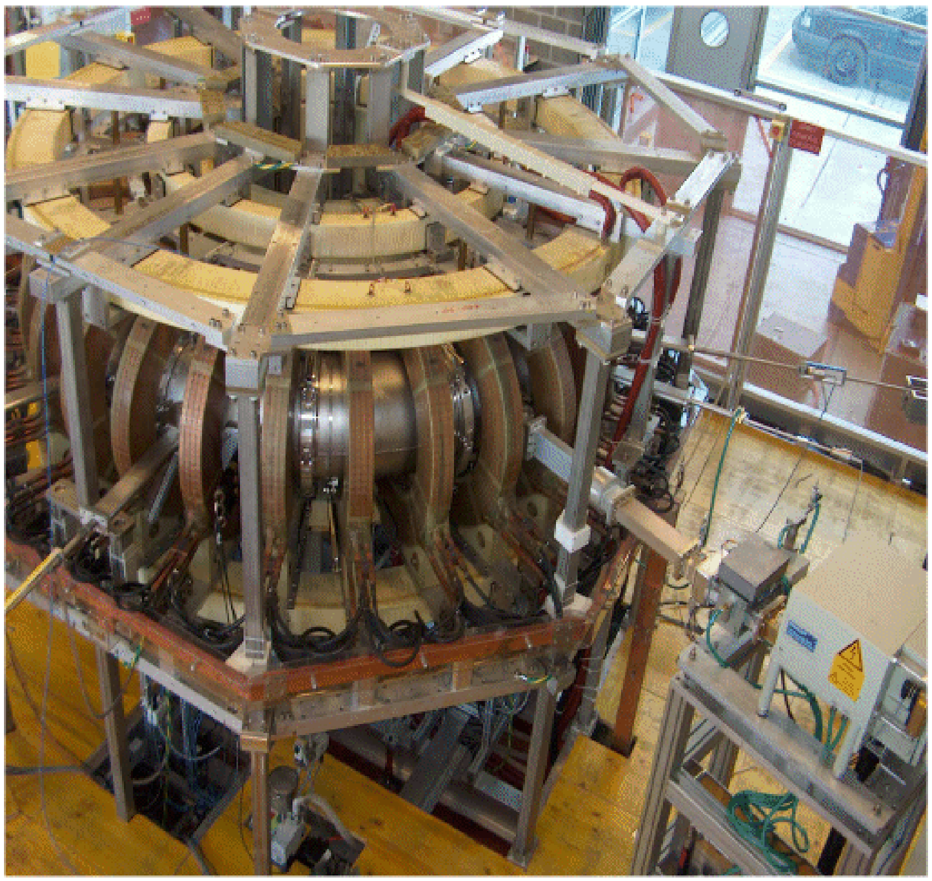
Possibilities of blob control

- reduce connection length
- increase neutral gas pressure[4]

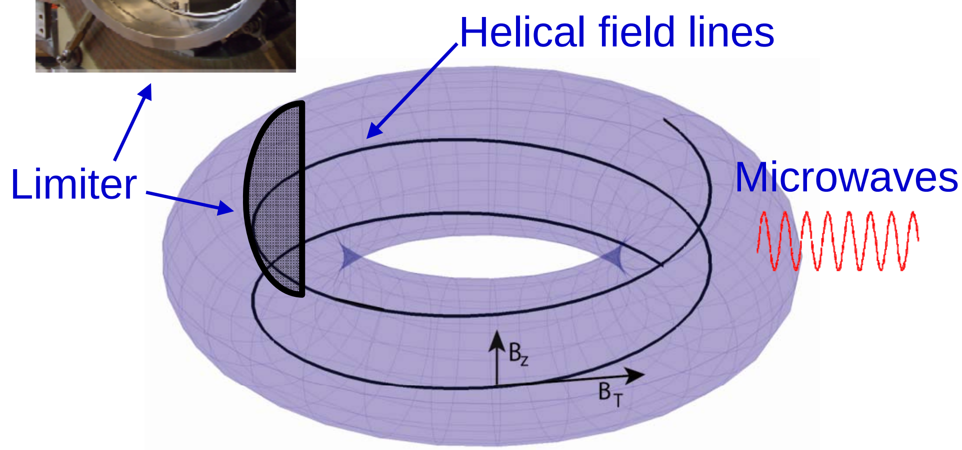
[1] O. E. Garcia et al., POP 2005
[2] J. R. Myra and D. A. D'Ippolito, POP 2005
[3] S. I. Krasheninnikov, PLA 2001
[4] N. Katz et al., PRL 2008

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

$|B_T| \approx 76mT$

$|B_z / B_T| \leq 5\%$

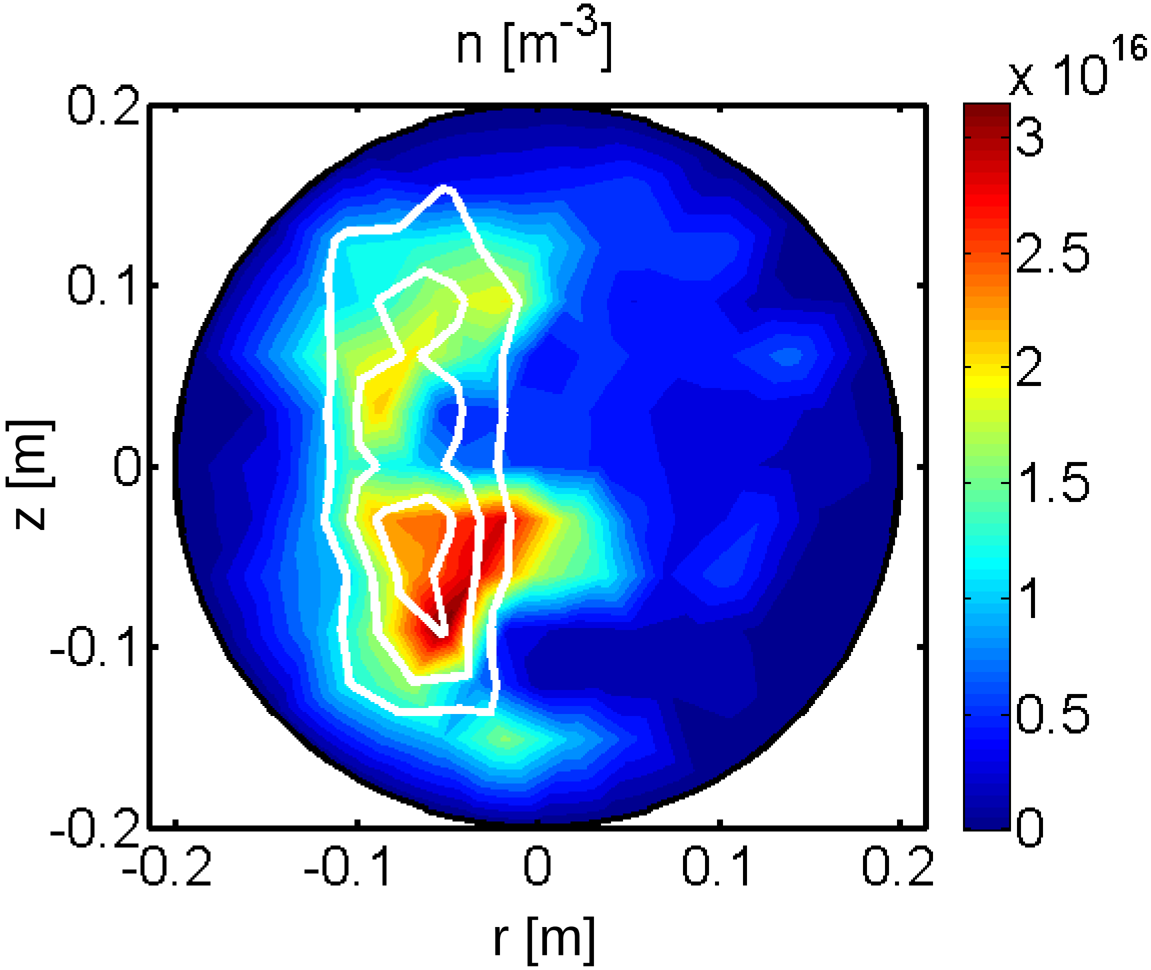
$n_e \leq 10^{17} m^{-3}$

$T_e \leq 15eV$

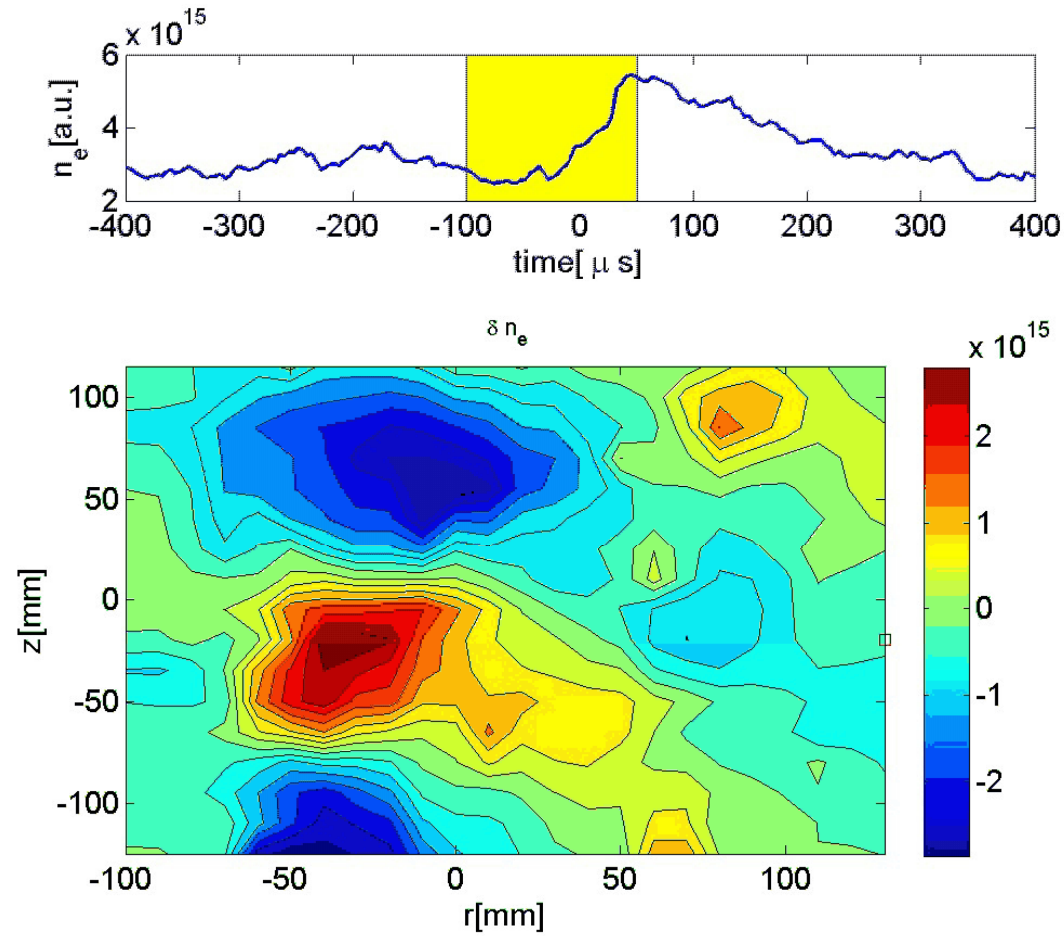
$T_i << T_e$

Target plasma

A simplified model of the tokamak far edge (SOL)



Blob formation



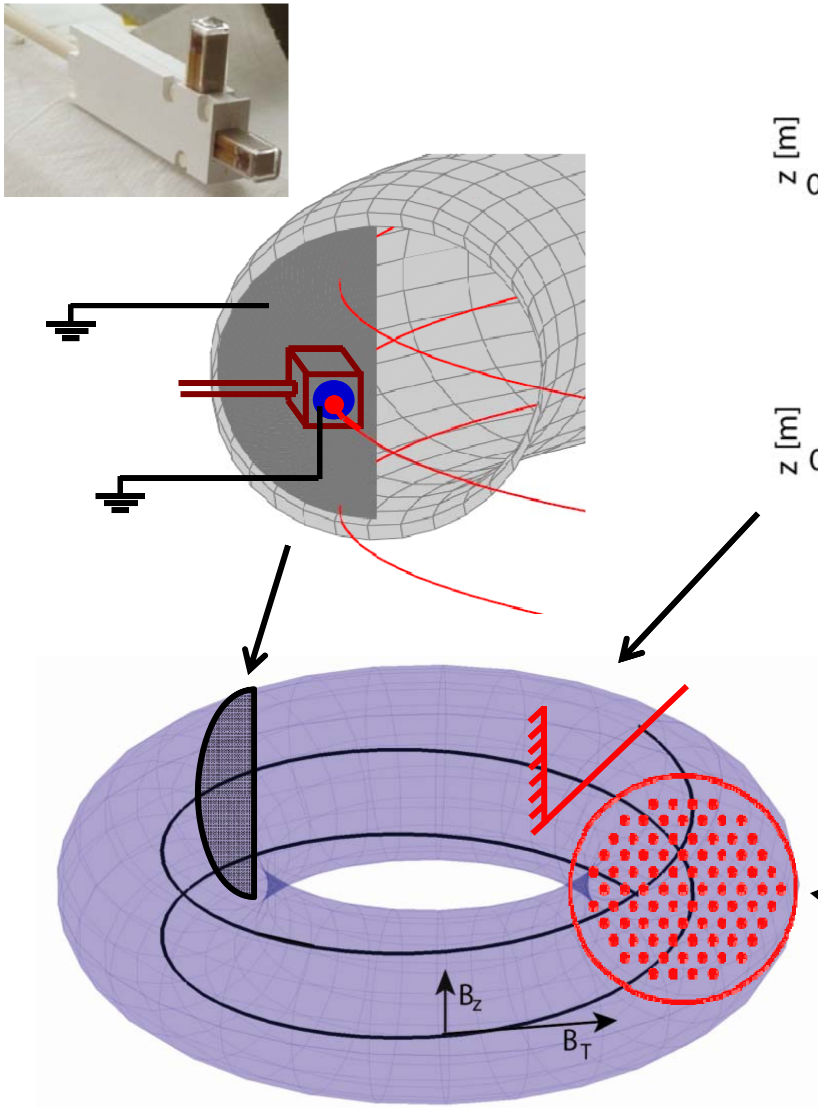
Instability characterization:

- Poli et al. POP 06, POP 08
- Ricci et al. PRL 10

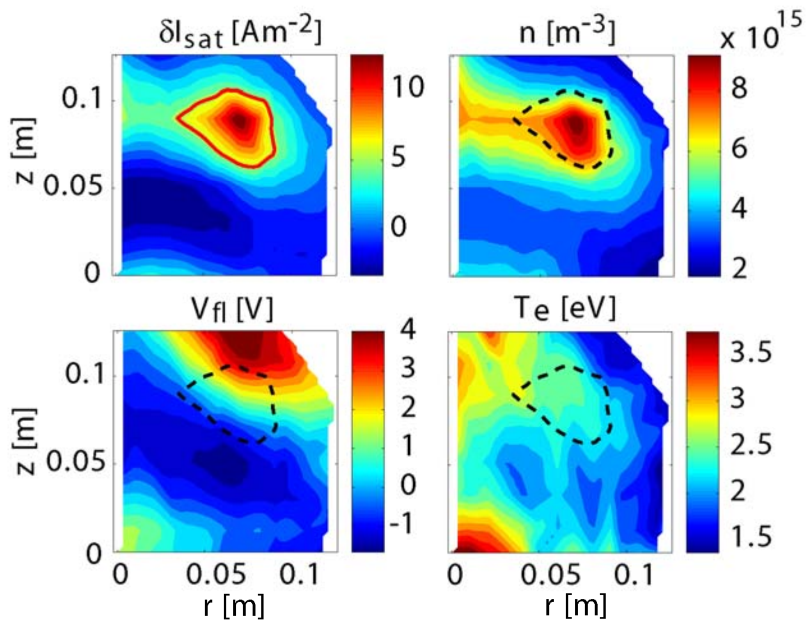
Blob formation, propagation, transport, universal statistical properties of turbulence:

- Furno et al. PRL 08, POP 08
- Müller et al. POP 07, PPCF 09
- Theiler et al. POP 08, PRL 09
- Diallo et al. PRL 08
- Podestà et al. PRL 08
- Labit et al. PRL 07, PPCF 07

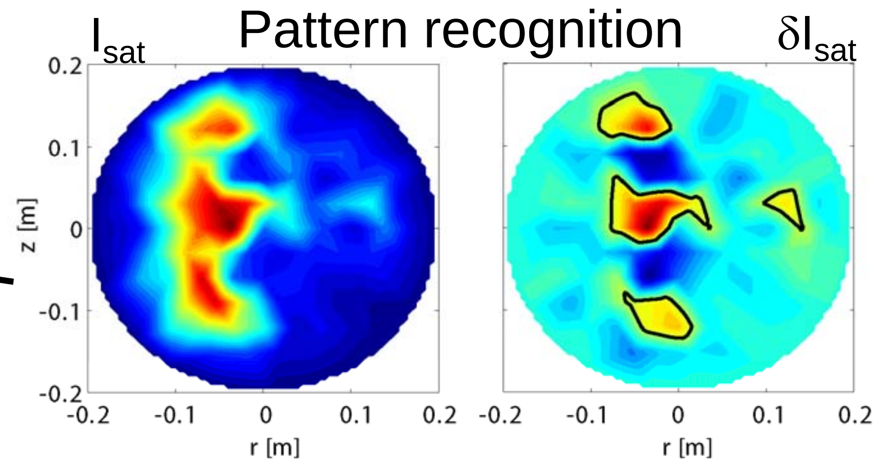
Diagnostics and blob analysis



Conditional sampling



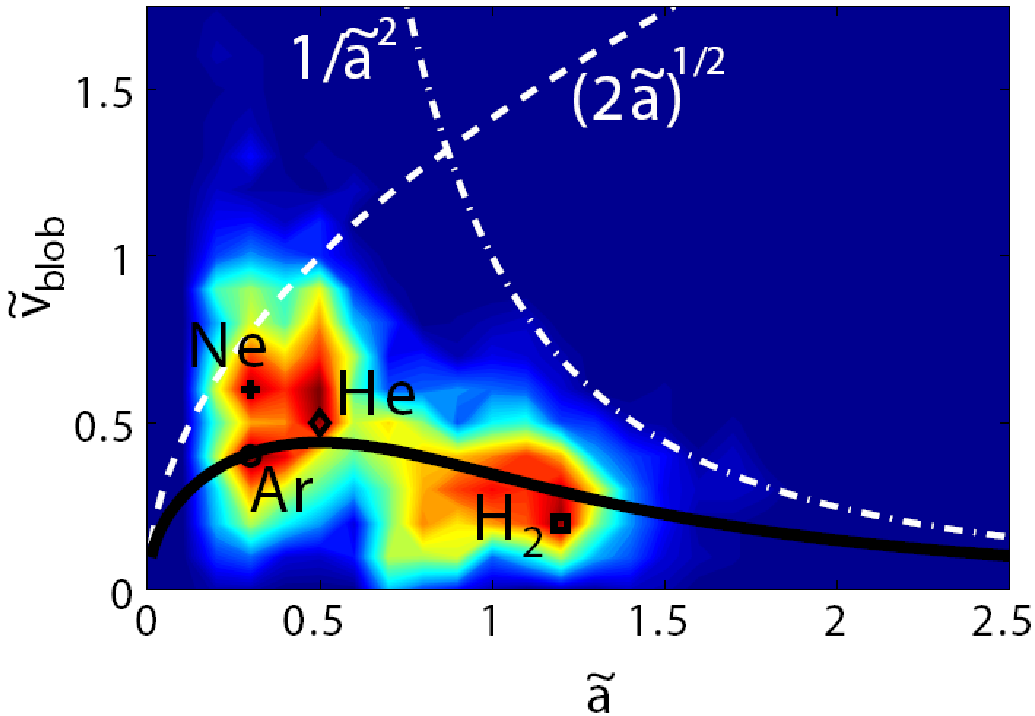
Pattern recognition



C. Theiler, 52nd APS - DPP, Nov 8 - 12, 2010, Chicago, IL

Verification of velocity scaling law: ion mass scan

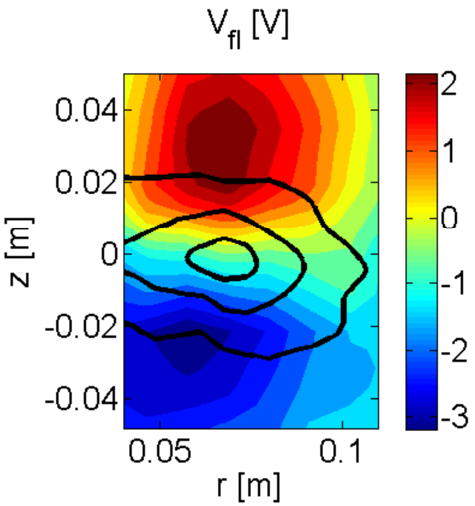
Ion mass scan:
$$1 \le m_i \le 40 \quad [a.m.u.]$$
$$0.2 \le \tilde{a} \le 1.5$$



C. Theiler et al., PRL 2009

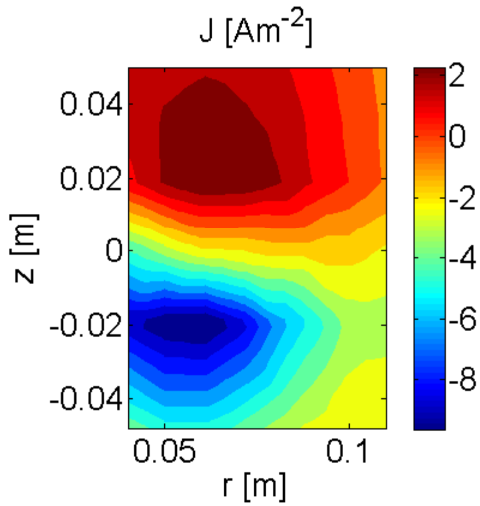
Direct measurement of parallel current

Blob parallel current at limiter: $$j_{\parallel} = j_{sat}\left(1 - \exp^{-\frac{V_{fl}}{T_e}}\right) \approx j_{sat}\frac{V_{fl}}{T_e}$$

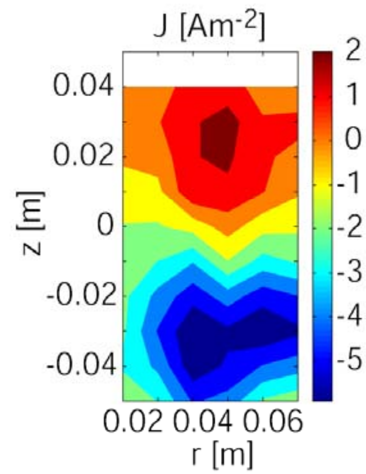


Current measurement at 3cm from limiter

Single sided LP



Array of $\dot{B}$-coils



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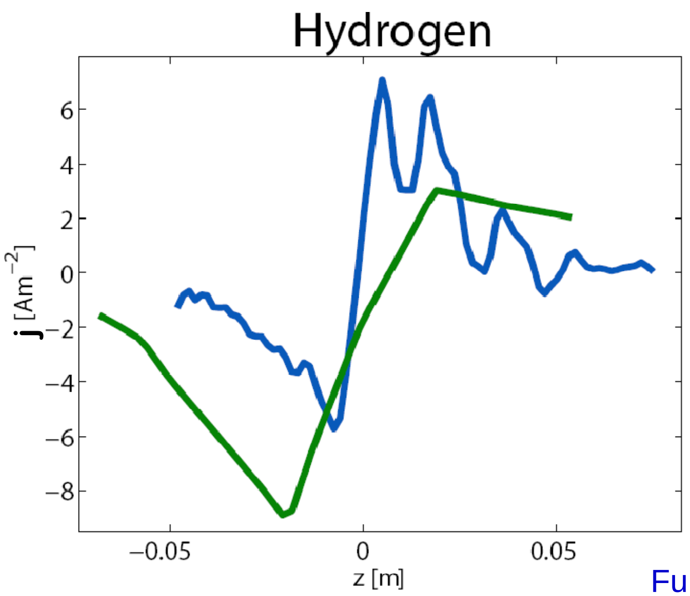
Direct measurement of parallel current

Blob parallel current at limiter: $$j_{\parallel} = j_{sat}\left(1 - \exp^{-\frac{V_{fl}}{T_e}}\right) \not\approx j_{sat}\frac{V_{fl}}{T_e}$$



Furno et al. TTG-TTF 2010

$$\frac{2c_s^2 m_i}{RB}\left.\frac{\partial n}{\partial z}\right|_{L/2} = -2 \cdot J_{//\,sheath}$$

- Current dipole is asymmetric
- Parallel current significant to damp blob propagation in H_2
- More on parallel currents in filaments on RFX, ASDEX, and TORPEX: N. Vianello,Poster XP9.00008, Friday

Short summary

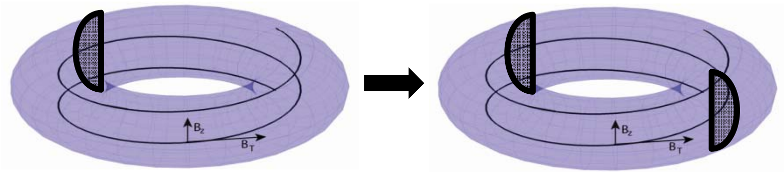
Blob motion

- Different regimes of blob propagation (damping by parallel or cross-field currents) achieved by ion mass scan
- Good agreement between measured blob velocity and generalized scaling law
- 2D structure of parallel current is dipolar with a more pronounced negative pole

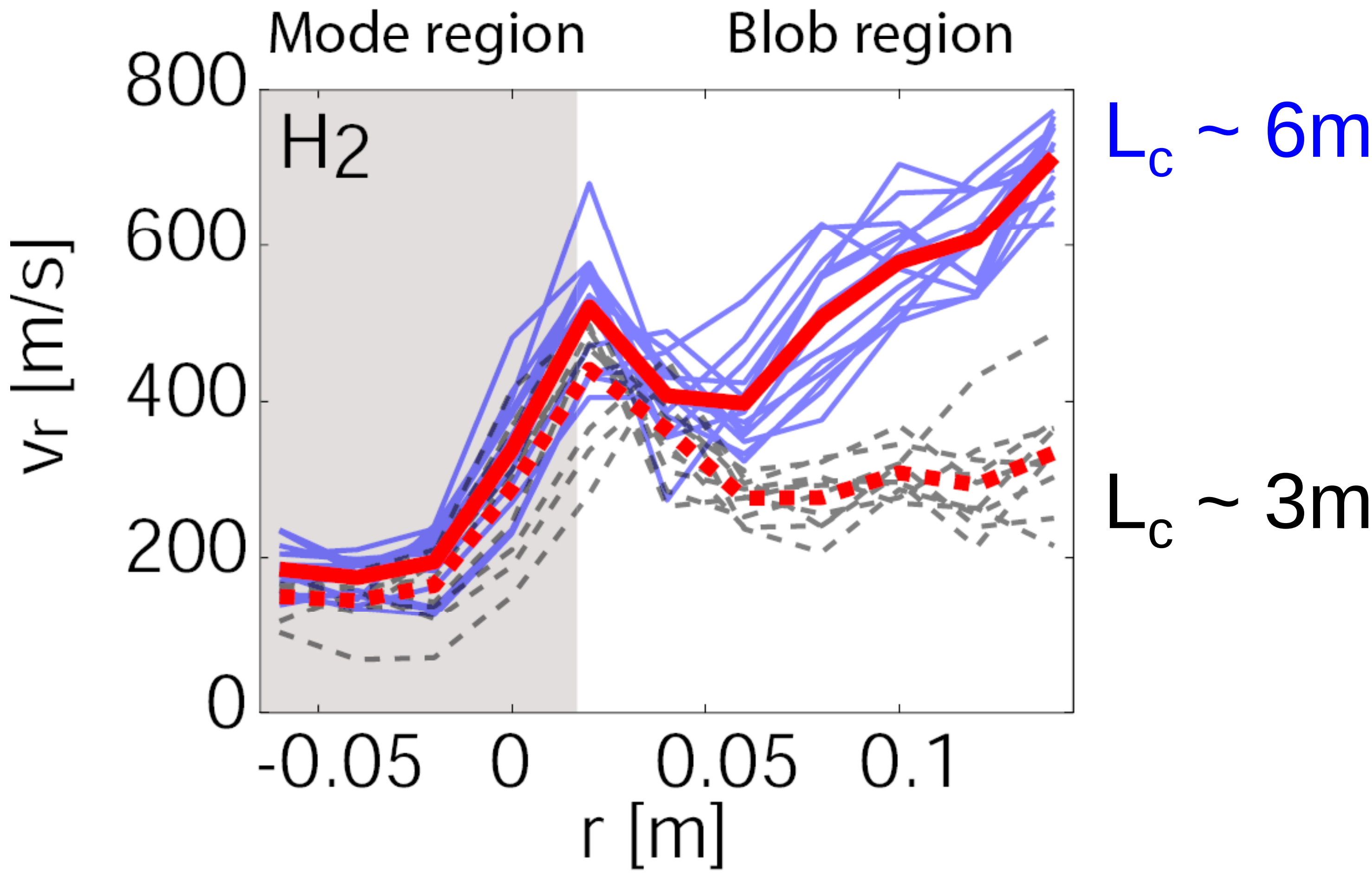
Next: Attempts of blob control by

- Reduction of connection length
- Increase of neutral gas pressure
- Biased electrodes

Blob control: reduction of connection length



- Analysis with pattern recognition
- Data from several experimental sessions



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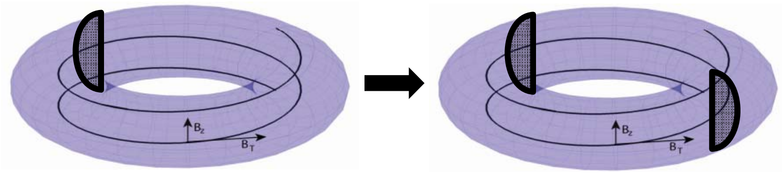
Blob control: reduction of connection length



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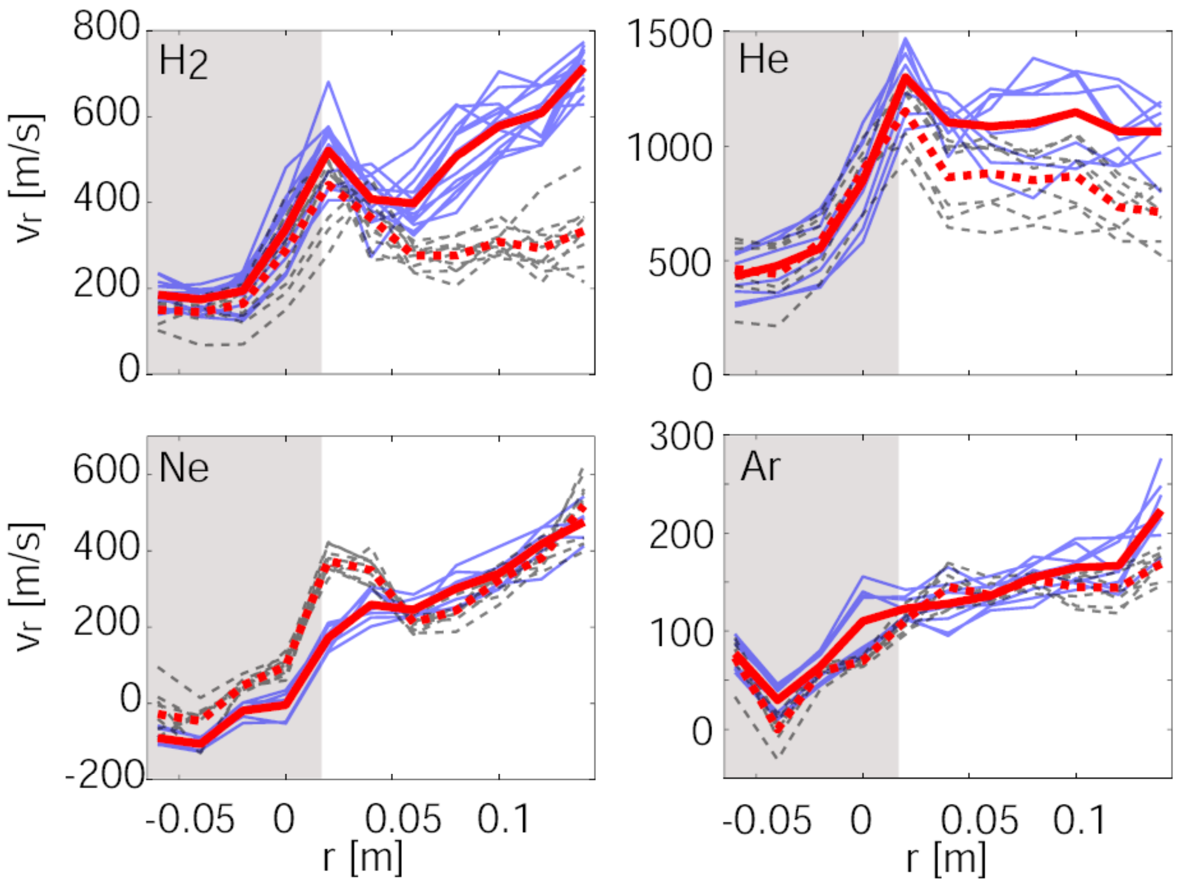
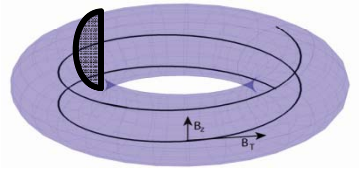
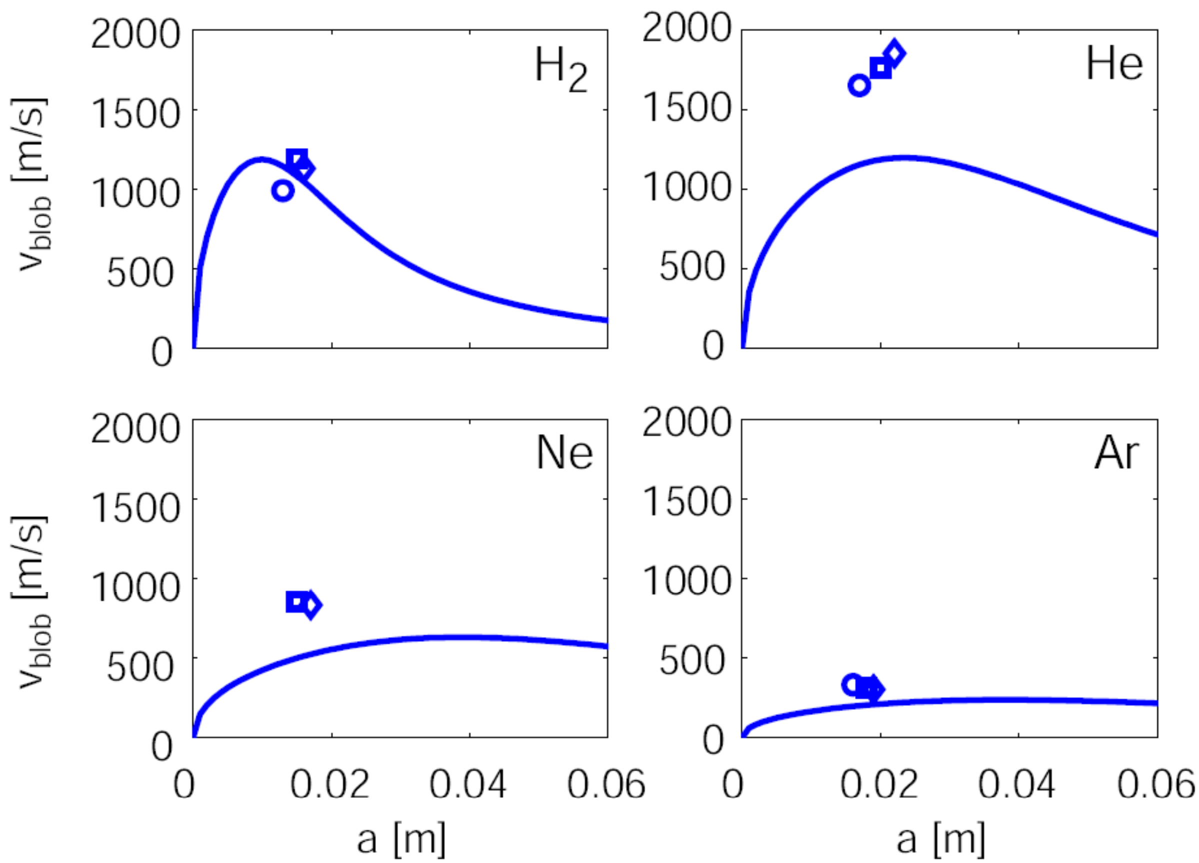
L_c(—) ➡ $L_c/2$ (······)



Blob control: reduction of connection length



- Analysis with conditional sampling
- Data from one single experimental session
- Determination of blob velocity, size, temperature



$L_c \sim 6m$

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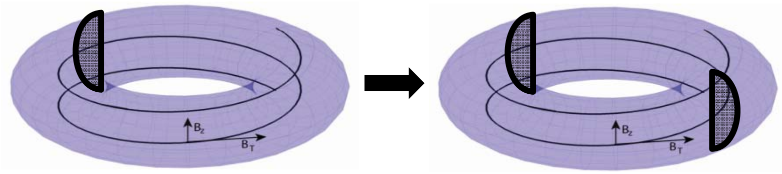
Blob control: reduction of connection length



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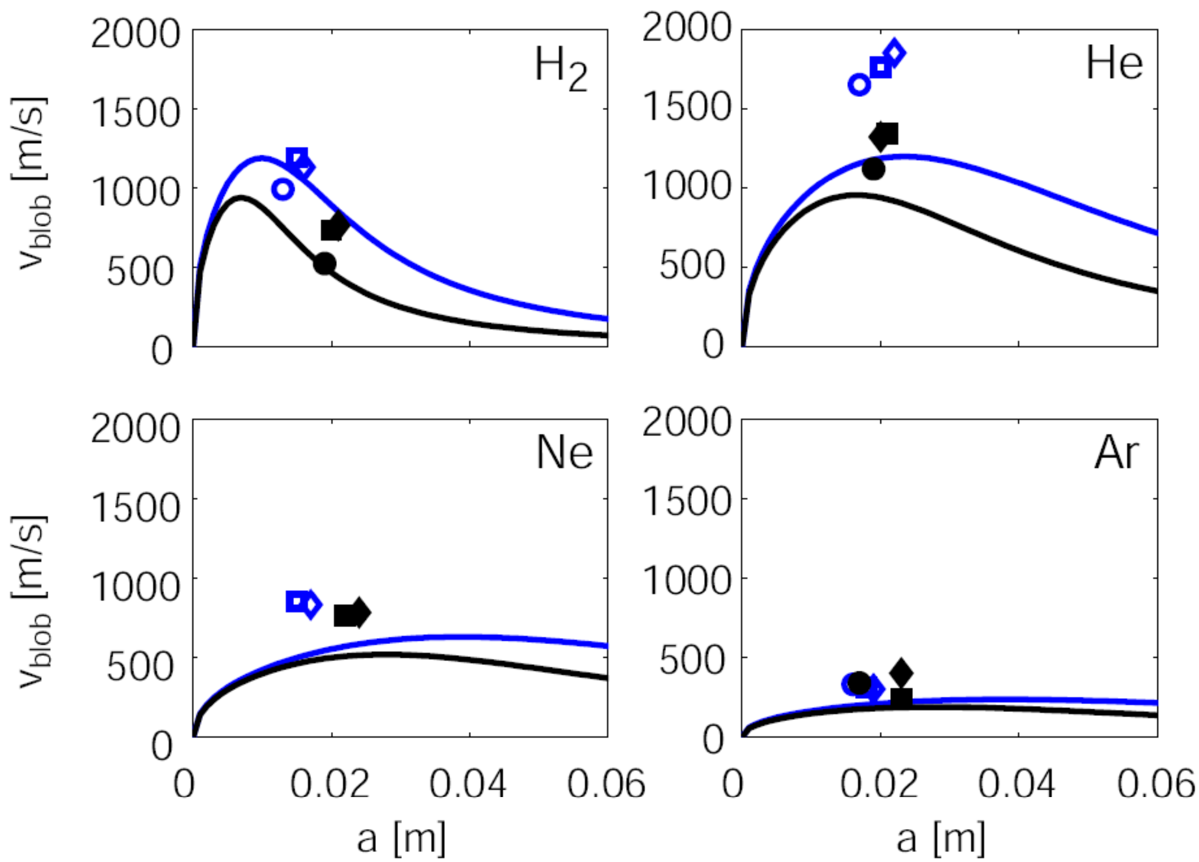
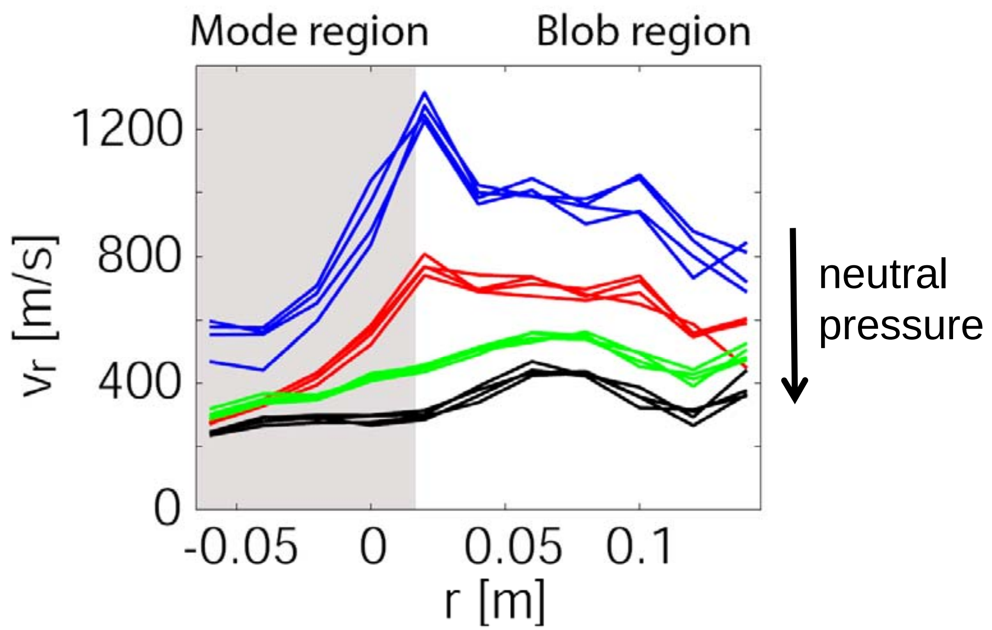


$L_c \sim 6m$

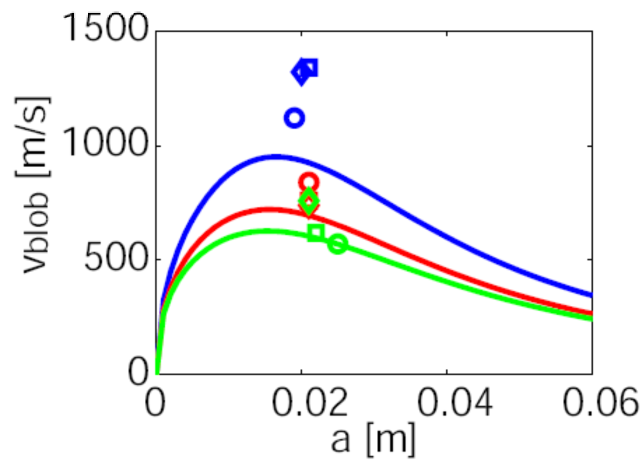
$L_c \sim 3m$

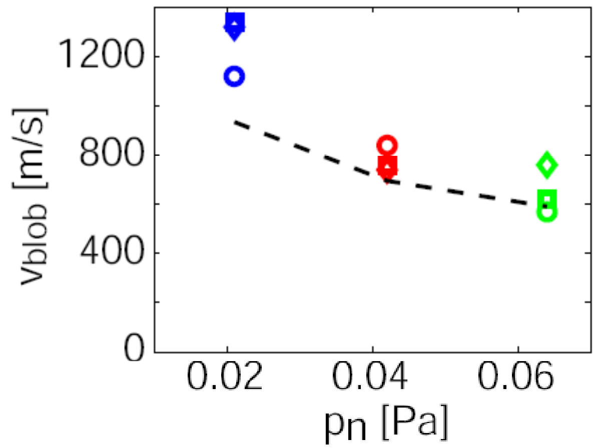
Blob control: variation of neutral gas pressure

Analysis with pattern recognition,
4 different neutral pressures



Analysis with cond. sampling,
3 different neutral pressures



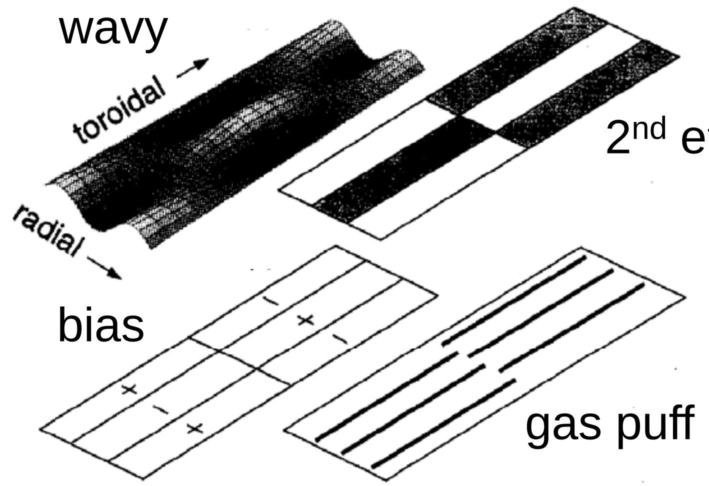


Variation of boundary conditions: biased electrodes

Idea[1]

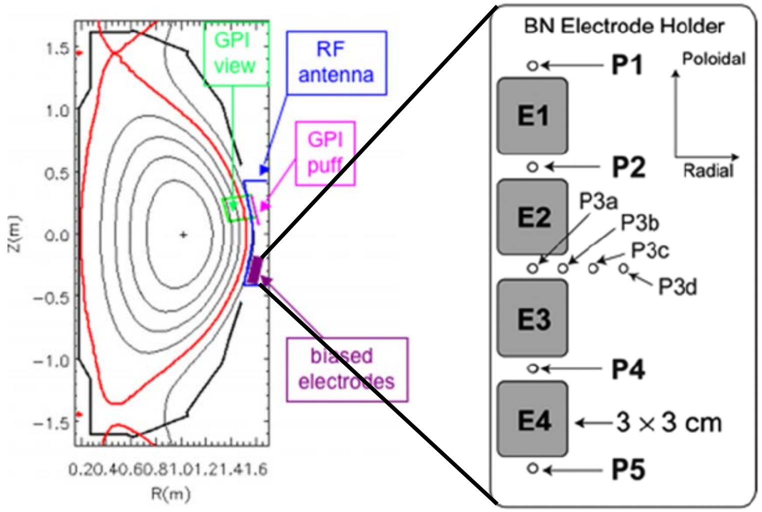
- Induce poloidal electric fields to produce convective cells and thus broadening of SOL and reduction of heat loads on divertor

Use of toroidally asym. divertor:



Tests in NSTX[2]

- Local increase of SOL-width
- No significant effect 1m downstream

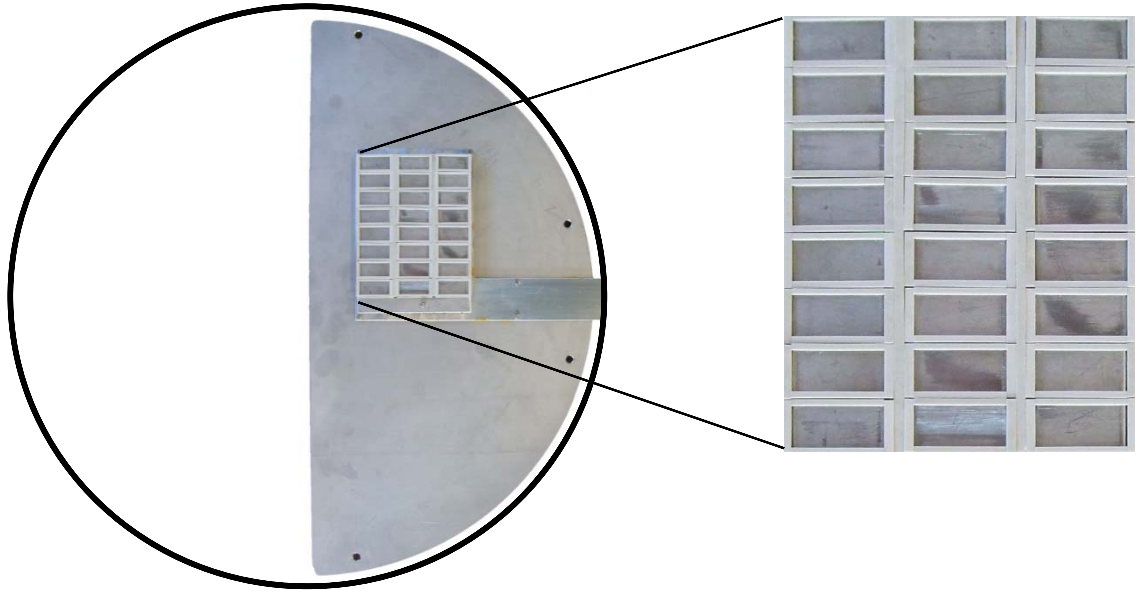


[1] R. H. Cohen, D. D. Ryutov NF 1997

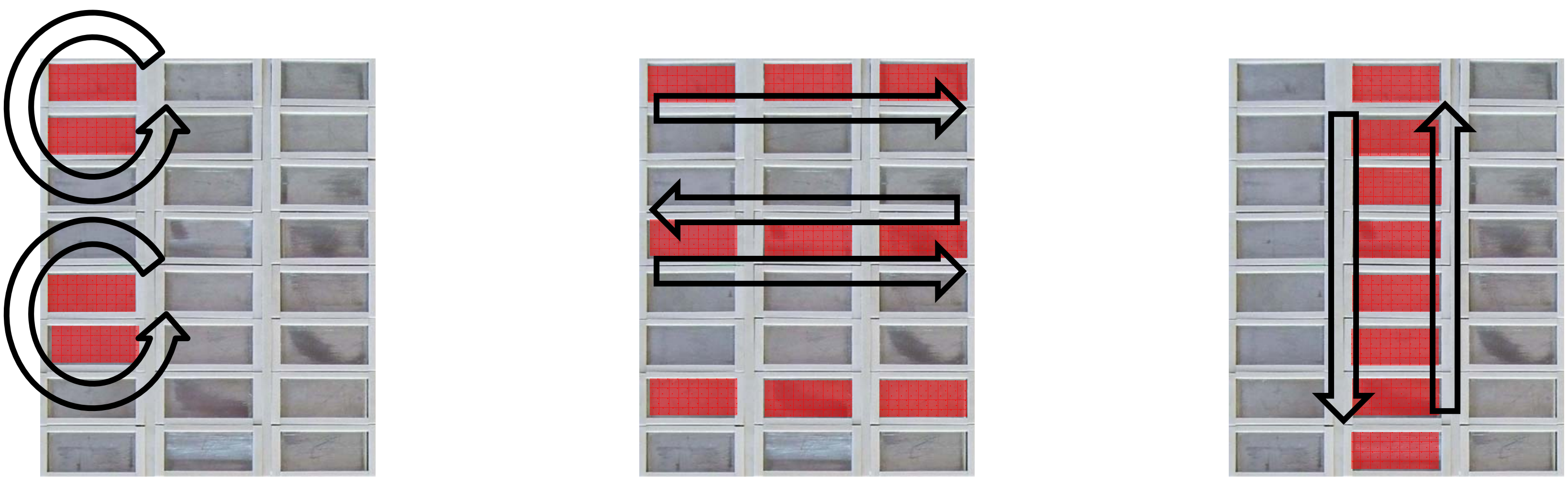
[2] S. J. Zweben et al., PPCF 2009

Biased electrodes: setup in TORPEX

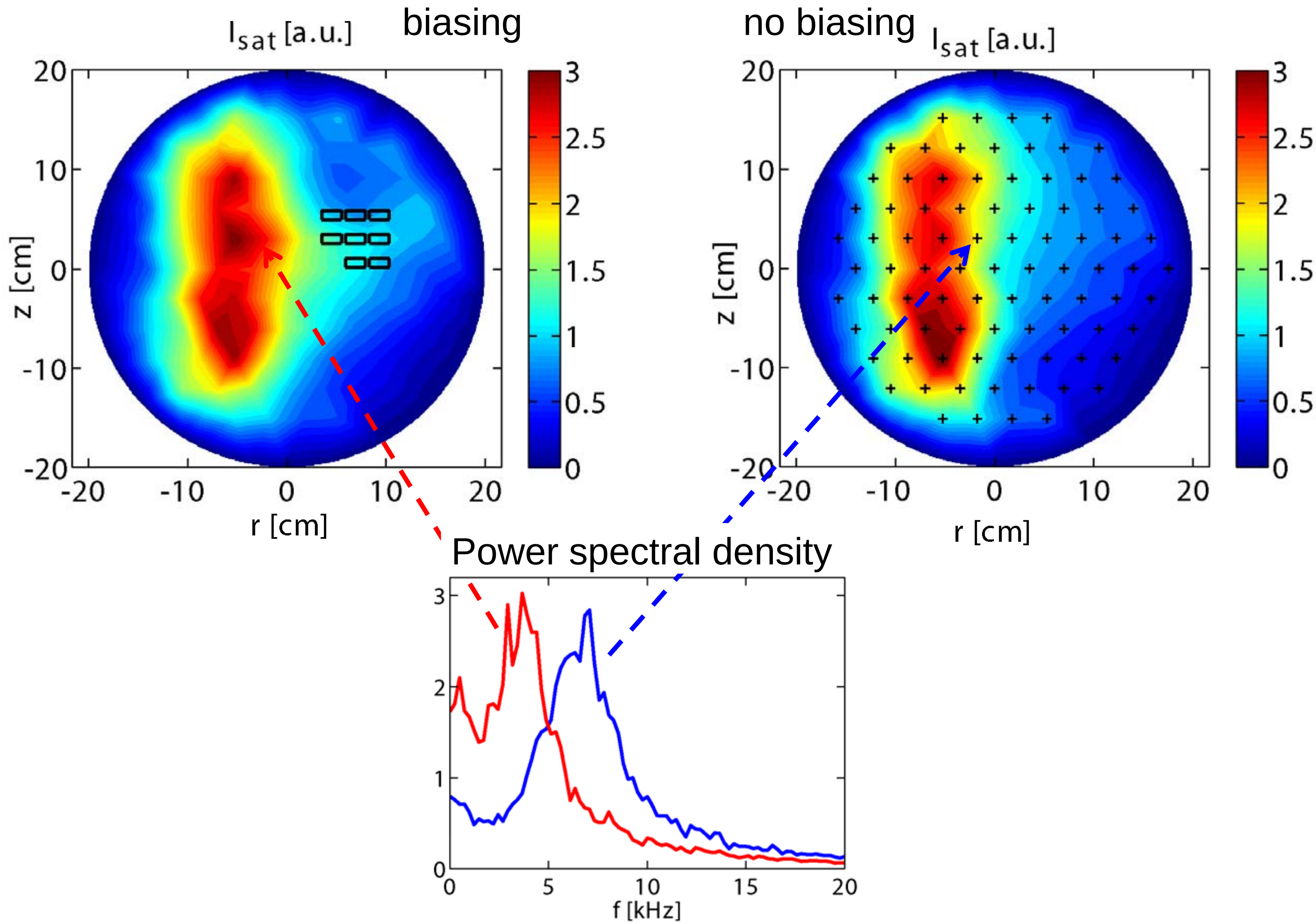
- Array of 24 electrodes
- Each can be biased individually and the current can be measured



Some possible setups:



Biased electrodes: effect on profile and wave



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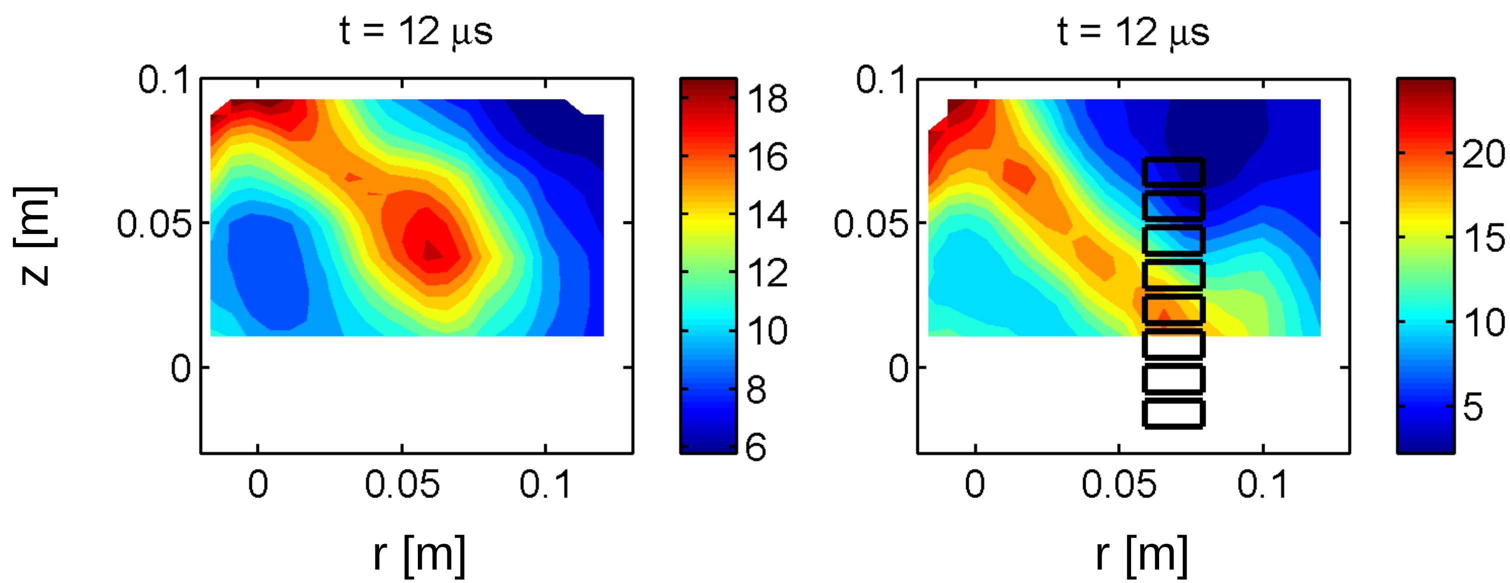
Biased electrodes: effect on blob



Next questions

- On what perpendicular scale can potential be varied
- What is the parallel penetration length of the bias potential
- What is the magnitude of potential variations that can be achieved

Summary

Blob motion

- Different regimes of blob propagation (damping by parallel or cross-field currents) achieved by ion mass scan
- Good agreement between measured blob velocity and generalized scaling law
- 2D structure of parallel current is dipolar with a more pronounced negative pole

Blob control

- As expected, a reduction of connection length reduces blob velocity in H_2 and He and shows little effect in Ne and Ar
- As expected, blob velocity decreases with neutral gas pressure (shown for He)
- A 2D array of biased electrodes has been described and first effects on profiles, mode, and blobs have been presented