transport studies in the basic plasma physics device TORPEX

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Blob control by convective cells

- Basic plasma physics devices can help understanding electrode biasing effects
- In TORPEX, we achieved control of profiles and blobs using toroidal/poloidal asymmetric biasing
- Radial and vertical blob velocities are significantly modified
- Biasing generates a convective cell that
  - is fairly uniform along B
  - is shifted w.r.t. the position of the biased flux tube due to plasma flows
  - is limited in magnitude (i.e., $\delta V_{fl} << V_{bias}$) due to a high level of effective cross-field currents

C. Theiler et al, PRL 108, 065005 (2012); C. Theiler et al., Phys. Plasmas (2012)

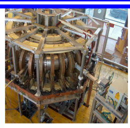
Suprathermal ion dynamics

- Suprathermal ion transport in ideal interchange-mode unstable plasmas is characterized in the simple toroidal plasma device TORPEX using a dedicated suprathermal ion source and detector
- Using numerical fluid simulations, we discover that depending on suprathermal ion energy and turbulence fluctuation level, the transport may exhibit a nature ranging from sub- to super- diffusive
- First experimental data reveal the presence of sub-diffusive and super-diffusive transport

A. Bovet et al., Nucl. Fusion 52 (2012) 094017
K. Gustafson et al., PRL 108, 035006 (2012); K. Gustafson et al., PoP 19, 062306 (2012)

The biasing experimental setup

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



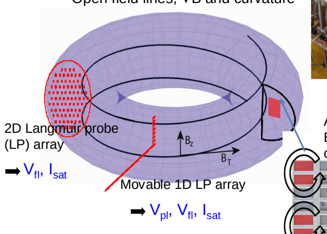
$|B_T| \approx 76mT$

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

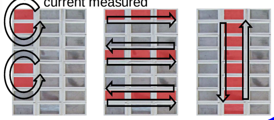
$n_e \leq 10^{17} m^{-3}$

$T_e \leq 15eV$

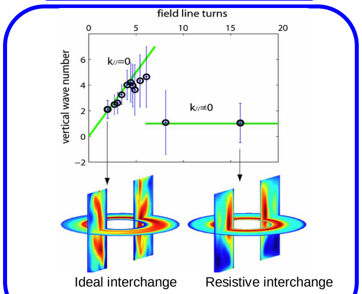
$T_i << T_e$



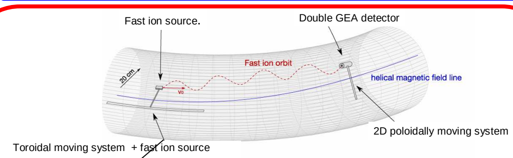
Array of 24 electrodes
Each can be biased individually and the current measured

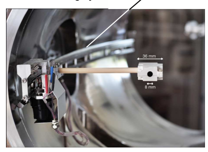


Turbulence regime



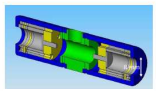
Suprathermal ion experiment - setup



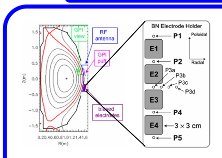


Suprathermal ion source:
- Thermo-ionic emitter, Li^{6+} ions
- Two grid accelerating system
- 50 eV ≤ E ≤ 1 keV, I ≈ 10 μA
- Mounted on a toroidally movable system
- Modulated bias for synchronous detection

Double Gridded Energy Analyzer:
- Differential detection to background noise
- Mounted on a 2D poloidal moving system
- Lock-in detection with a "dead time" to remove capacitively coupled noise



Motivation for asymmetric biasing



NSTX, Zweben et al., PPCF 2009

Idea[1]: induce convective motion in the Scrape-Off Layer (SOL) to increase its width and reduce peak heat loads onto the divertor.

[1] Cohen and Ryutov, NF 1997.

Can we generate convective cells in simple magnetized toroidal plasmas? What is their effect on blob dynamics?

Code validation

➔ *see P. Ricci's poster TH/P4-14*

- Observables and primacy hierarchy: 0th level: I_{sat}^{exp}, T_e^{model},... ; 1st level: I_{sat}^{model}, n_e^{exp}, ...; 2nd level: T_e^{exp}, blob size^{model}, Γ_{blobs}^{exp} .... ; 3rd level: Γ_{blobs}^{model},...
- Ex. of global metric $\chi = \Sigma_i R_i H_i S_i / (\Sigma_i H_i S_i)$

Agreement/disagreement

1/[1 + hierarchy level$_i^{exp}$+hierarchy level$_i^{model}$]

Sensitivity/weight

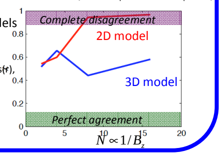
$$S_i = \exp\left(-\frac{<\Delta obs_i^{model}> + <\Delta obs_i^{exp}>}{<obs_i^{model}> + <obs_i^{exp}>}\right)$$

P. Ricci et al., PoP 2011

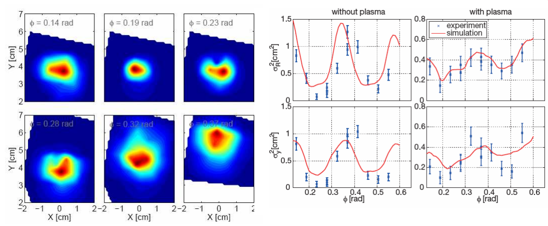
Ex. 2D and 3D fluid models

11 observables

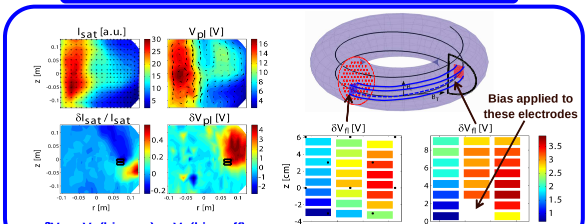
- n(r), T(r), Φ(r), skewness(r), kurtosis(r), δn(r), I_{sat}(r), fluctuation pdf, psd, k_z spectrum, k_{tor}



Experimental results



Generation of convective cells

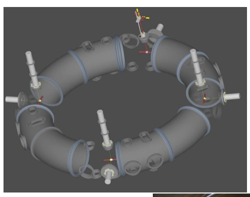


$\delta V_{pl} \equiv V_{pl}$(bias on) – V_{pl}(bias off)

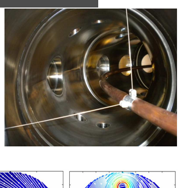
OUTLOOK

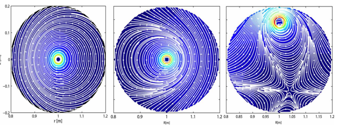
At present, TORPEX can produce SMT configurations. To better mimic the scrape-off-layer and edge magnetic geometry of tokamaks, twisted field line configurations will be created using a toroidal copper wire.

The wire is suspended inside the chamber through four insulated 1mm diameter stainless steel wires.



1kA-10V supply.
Flat top ~1s, ~1kA
~100 discharges/day





Magnetic geometries with single and double magnetic null-lines as well as, for particular combinations of currents in the existing set of poloidal coils, snowflake divertor.

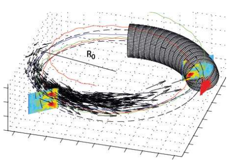
This work is partly supported by the Swiss National Science Foundation

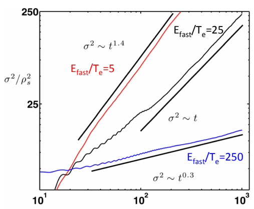
Theory and transport regimes

Suprathermal ion tracers are injected in simulated 2D ideal interchange driven turbulence.

Trajectories are solved using Lorentz force equation in SMT configuration.

Comparison with experiment is made with a synthetic diagnostics.



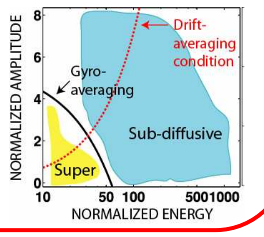


The radial/vertical suprathermal ion beam variance is computed and a dispersion exponent is extracted:

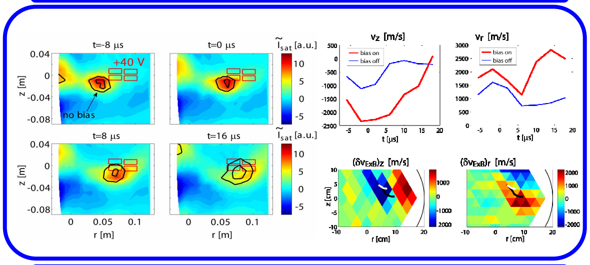
γ = 1	"diffusive"
γ < 1	"sub-diffusive"
γ > 1	"super-diffusive"

Different transport regimes are investigated as a function of ion energy and fluctuations amplitude

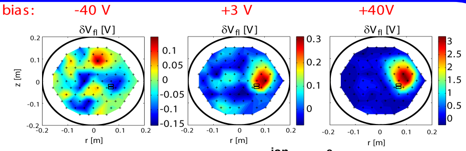
- Dispersion can be sub-diffusive or super-diffusive
- Gyro- and drift-averaging reduces the transport

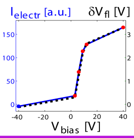


Blob velocity changes consistent with ExB



Perpendicular currents are important





$|I_{sat}^{ion}| << I_{sat}^{e}$

$\delta V_{fl} << V_{bias}$

$\delta V_{fl} \propto I_{electr}$

➡ Problem not 1D, cross-field currents important

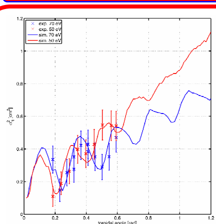
Perpendicular current estimates do not explain observed effect

Analytical estimates for TORPEX parameters yield perpendicular currents too small compared to experimental data.

2D fluid simulations show that polarization drift, ion-neutral collision, or diamagnetic drift cannot explain observed cross-field currents.

Kinetic simulations of the biasing experiments will be attempted.

Evidence of sub- and super- diffusion



Measurements at E=70eV and 50eV are consistent with simulations and indicate ion sub-diffusion and super-diffusion.

Systematic measurements are being performed for wide ranges of E_{fast}/T_e, fluctuations regimes/amplitudes, and source location (wave or blob region).

Suprathermal ion transport will also be studied in different magnetic topologies.