Progress in understanding suprathermal ion transport in a toroidal plasma through theoretical modeling and experiments in TORPEX

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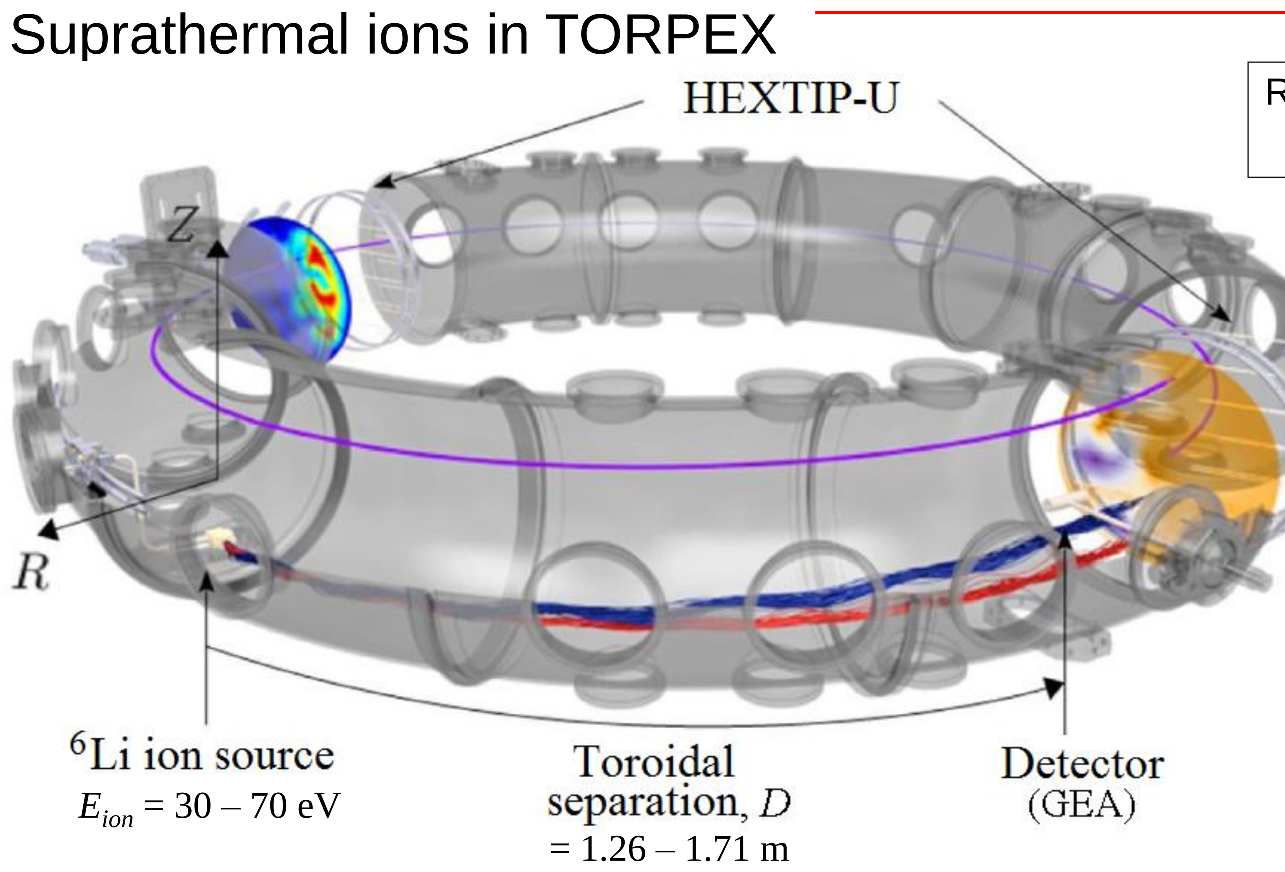
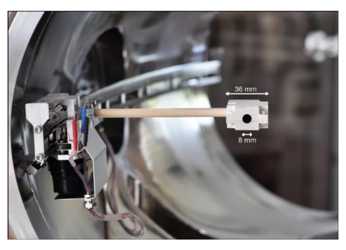
Abstract

The TORPEX device is a basic toroidal plasma physics experiment located at the Swiss Plasma Center in Lausanne. Thanks to its ample diagnostic coverage and its flexibility of operation, it has allowed several studies of interest to tokamak physics. A key research topic has been suprathermal ions, where TORPEX has made important contributions to the understanding of non-resonant interactions of the suprathermal ions with turbulent plasmas. Indeed, past studies demonstrated the non-diffusive character of the transport across-magnetic field lines.

In recent years, we have further pursued this research with major efforts devoted to time-resolved experiments and modelling. We have developed models of transport as well as of time-variability of the detection signals, and have successfully applied them to data from simulations and experiments. Here, we review our recent progress in the understanding of suprathermal ions in TORPEX.

Suprathermal ions in TORPEX



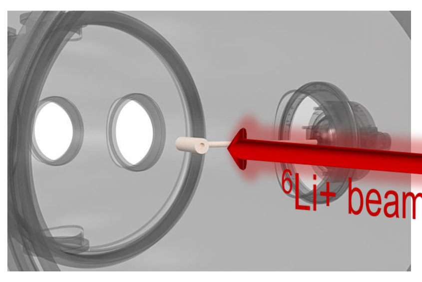


Thermionic emitter of ^{6}Li+ ions, I ≈ 10 μA, into SMT plasma.

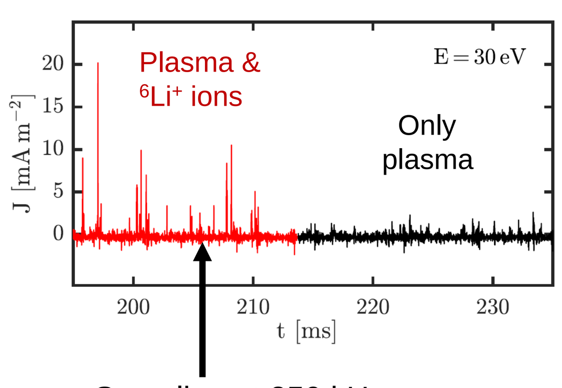
B-field in Simple Magnetized Torus (SMT) configuration.

Dual LP array (HEXTIP-U) for turbulent structure identification [1].

Time-resolved experiments and modelling [2]



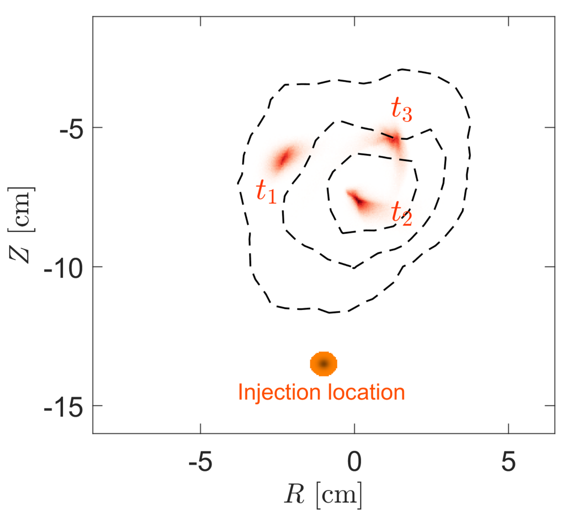
Ions arrive at the GEA after propagating through the plasma and produce a current signal with time-intermittent features.

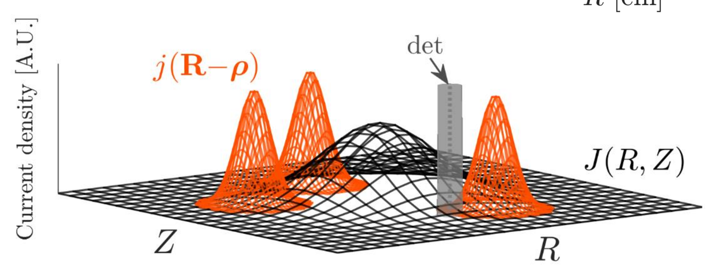


Sampling at 250 kHz

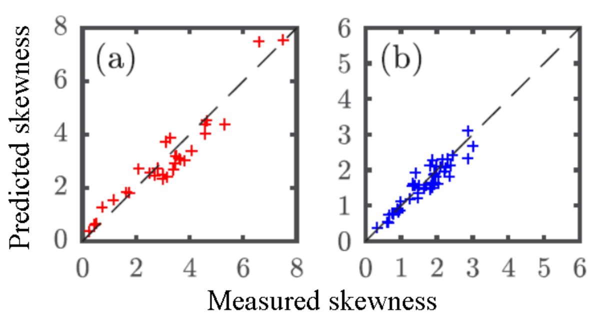
We compute statistics of the time series (mean, variance σ^2 and skewness) taking into account both plasma *on* and plasma *off* states.

Particle tracing simulations using V_{float} measured on the turbulent SMT plasma suggest [2, 3] that intermittency results from the meandering motion of a concentrated current density $j(R, Z)$ on the poloidal plane RZ.



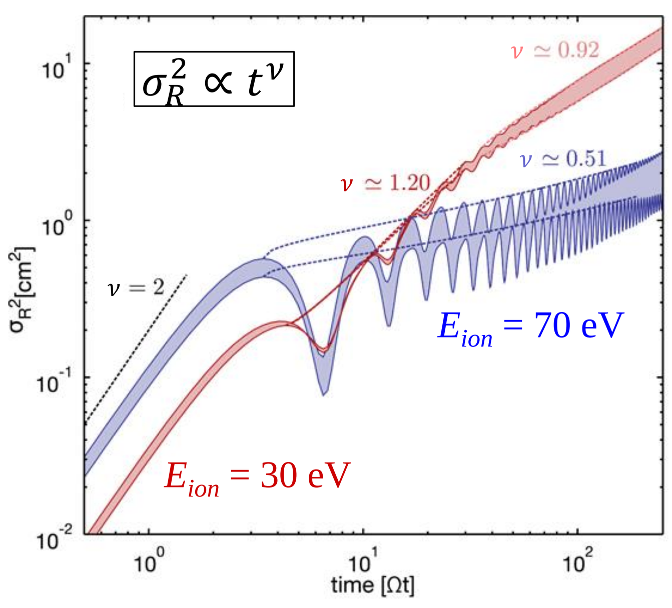


We developed a meandering beam model that yields a link between the time-averaged profile $J(R, Z)$ and all higher order moments of detection time series (including the skewness) at any location on the RZ plane [3].



The skewness determined from experimental GEA signals for D = 171 cm and (a) 30eV or (b) 70eV ions, and the skewness predicted from $J(R, Z)$ using the model show very good agreement [2].

Non-diffusive transport of suprathermal ions [4]



Previous studies focused on the 2D time-averaged profiles of suprathermal ions detected with the GEA at different locations (R, Z).

From the profiles, the radial width σ^2_R can be determined. By looking at the scaling $\sigma^2_R \sim t^\upsilon$ (t is proportional to D in our experiments), different cross B-field suprathermal ion transport regimes can be observed, including sub-diffusive (υ<1), quasi-diffusive ($\upsilon \approx 1$) and super-diffusive ($\upsilon > 1$).

These results were enabled by comparisons with numerical simulations using GBS.

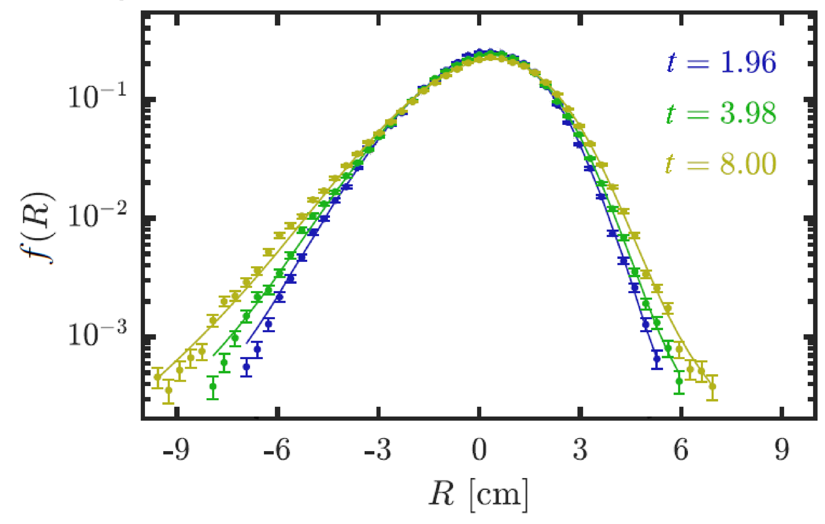
Truncated asymmetric fractional Levy motion model [5]

The evolution of the radial distribution (not only its variance σ^2_R) of suprathermal ions can be described using an asymmetric fractional Levy motion model (AFLM).

The use of Levy distributions, however, allows extremely large increments that are difficult to justify in spatially bounded systems.

We developed a spatial truncation for AFLM that addresses this issue.

Application of the truncated AFLM (TAFLM) model to histograms of simulated data gives a very good description of the system in different non-diffusive transport regimes.



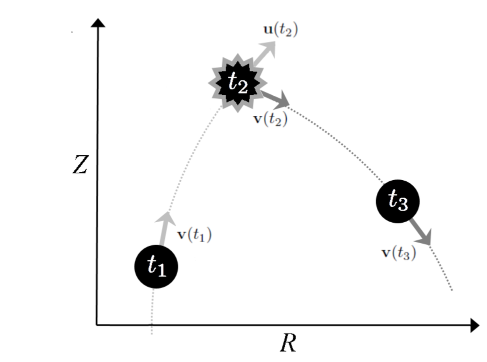
TAFLM fits (solid lines) of histograms of radial locations of simulated suprathermal ions with injection energy 30eV (points). The error bars are determined via bootstrapping, as described in Ref. [5]. Different colors refer to different propagation times t, here in units of gyro-motion periods.

Persistent random walk model [6, 7]

An alternative to address the problem of large increments in AFLM is to use random walks where collisions cause instantaneous changes in *velocity*.

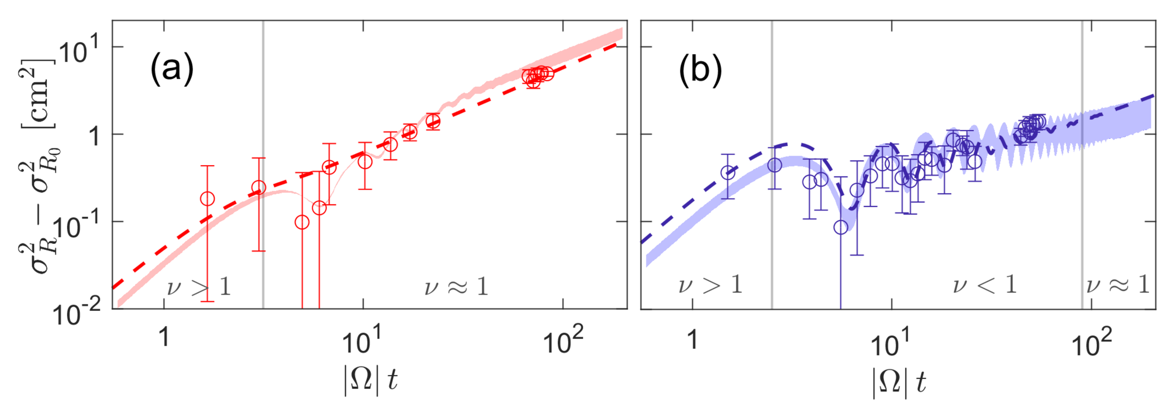
We used this persistent random walk (PRW) approach to develop a model for the motion of the suprathermal ions across magnetic field lines.

The model yields analytic expressions for σ^2_R that capture the main features of simulations and experimental data.



Schematic of the PRW model. A charged particle moves in a magnetic field applied perpendicular to its motion. Collisions do not change the speed.

Experimental data (points), simulations based on GBS (bands), and $\sigma^2_R(t)$ from a PRW model assuming a random initial motion that has equal probability to be in any direction (dashed lines) . The suprathermal ions are injected into TORPEX at (a) ≈30 eV and (b) ≈70 eV.



Conclusions

- Suprathermal ions are a continuing research effort in TORPEX.
- Time-resolved experiments have motivated the development of a model based on a meandering concentrated current density profile. These studies have led to an improved understanding of the time-variability features of the suprathermal ion detection signals.
- Modelling of cross B-field transport has focused on addressing the issue of large increments introduced by the use of Levy distributions in past studies.
- We developed a truncation for the AFLM model that has great potential for applications in plasma physics and in other fields of science.
- We also developed a PRW model capable of capturing the time evolution of transport across the different regimes observed in our studies.

References
[1] M. Baquero-Ruiz et al., Rev. Sci. Instrum. 87, 113504 (2016).
[2] F. Manke et al., Phys. Rev. E 99, 053208 (2019).
[3] M. Baquero-Ruiz et al., Phys. Rev. E 98, 032111 (2018).
[4] A. Bovet, et al., Phys. Rev. E 91, 041101(R) (2015).
[5] F. Manke, et al., Phys. Rev. E 100, 052122 (2019).
[6] M. Baquero-Ruiz, et al., Phys. Rev. E 100, 052134 (2019).
[7] M. Baquero-Ruiz, et al., Phys. Rev. E 102, 053206 (2020).

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Swiss Plasma Center

EUROfusion

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