Plasma turbulence studies in the TORPEX basic plasma physics device: from concentric flux surfaces to single-null X-points

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1. Introduction

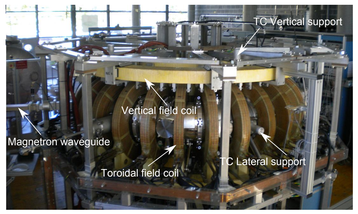
The TORoidal Plasma EXperiment features a Simple Magnetized Torus configuration (SMT) where helical open magnetic field lines results from the superposition of a small vertical magnetic field on the main toroidal component [1].
A **new experimental set-up** based on an in-vessel toroidal copper conductor (TC) has recently been implemented into TORPEX **to produce a poloidal magnetic field**, driving a current with a dedicated external power supply [2].

Motivations:

The new TC allows us to close the magnetic field lines and to perform turbulence studies in the presence of a rotational transform, with **magnetic configurations similar to the tokamak one**:

- Scrape-Off Layer region.
- Core region.
- Closed-to-open magnetic field lines transition.

2. TORoidal Plasma EXperiment



View of the TORPEX device.

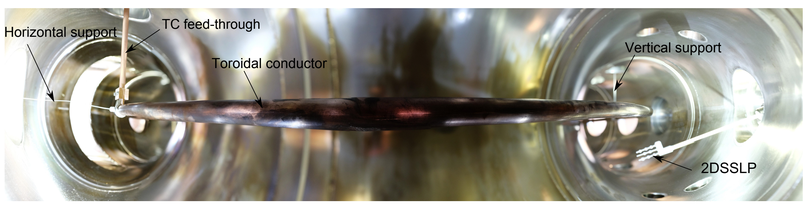
Main parameters:

- $R = 1.0\,\mathrm{m}$
- $a = 0.2\,\mathrm{m}$
- $B_T \approx 76\,\mathrm{mT}$
- $B_V \approx 1\,\mathrm{mT}$ ($I_{B_V} \approx 30\,\mathrm{A}$)
- $n_e \approx 10^{16}\,\mathrm{m}^{-3}$
- $T_e \approx 5\,\mathrm{eV}$
- $f_{\mathrm{microwave}} \simeq 2.45\,\mathrm{GHz}$

Main features:

- Gases: H_2, He, Ne, Ar.
- Density gradients.
- Magnetic field gradients and curvature.
- Direct measurements over the whole plasma volume.
- High plasma reproducibility.
- High flexibility of the control parameters.

3. TORPEX in-vessel toroidal conductor



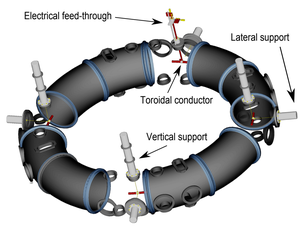
In-vessel view of TORPEX with the TC installed in the middle of the poloidal cross section.

Experimental set-up:

- Toroidal copper conductor of 1 cm radius.
- 1 vertical feed-through actively cooled.
- 3 vertical supports.
- 4 horizontal supports.
- Current up to 1 kA.

Accessible fusion relevant magnetic geometries:

- Wall-limited plasmas.
- Single / Double-null X-points.
- Magnetic snowflakes.



CAD drawing of the in-vessel toroidal conductor system installed on TORPEX.

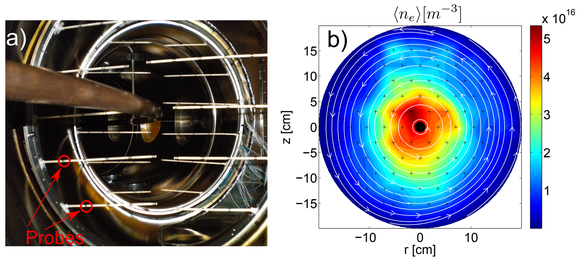
4. Turbulence studies in quasi-circular flux surfaces

2D time-averaged profiles:

Plasmas with quasi-circular concentric flux surfaces are investigated:

$$I_{TC} = 400 - 800\,\mathrm{A} \qquad R_{EC} = -10\,\mathrm{cm} \qquad P_{\mathrm{MAG}} = 300\,\mathrm{W}.$$

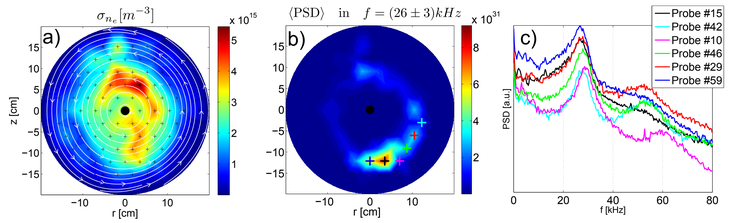
2D time-averaged plasma density profiles using the HEXagonal Turbulence Imaging Probe (HEXTIP): 85 fixed Langmuir probes (LPs) covering the poloidal cross section.



a) View of the TC with the HEXTIP diagnostic. b) 2D density profiles time-averaged in the time-window (150-950) ms. These are obtained assuming a constant electron temperature of 5 eV, with a linear interpolation on HEXTIP data for the case with $I_{TC} = 620$ A. In white the simulated magnetic field lines. The black crosses indicate HEXTIP LPs. The black circle in the center corresponds to the TC.

Quasi-coherent fluctuations spatial localization:

The analysed quasi-coherent modes show a **strong poloidal asymmetry**, with a dominant spatial localization on the low field side, **suggesting a ballooning nature**.



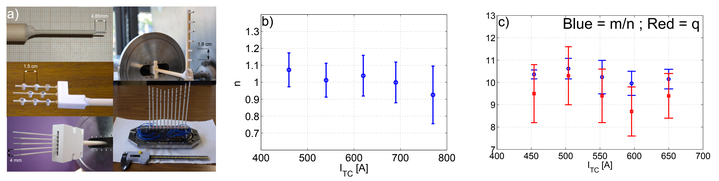
a) Standard deviation of I_{sat} HEXTIP signals. b) Power spectral density (PSD) of fixed Langmuir probe signals averaged in the range 26±3 kHz; the crosses indicate the probes considered for the data shown in c) PSDs of several fixed Langmuir probes.

Quasi-coherent fluctuations spectral characterization:

Two-point correlation technique applied on:

- LPs placed at different toroidal angles → measured **toroidal mode number n = 1** $\forall\, I_{TC}$;
- 2D array of fixed LPs at different poloidal angles → measured poloidal mode number m;

The comparison with the flux surface averaged safety factor obtained from the calculated magnetic field, revealed the **field aligned nature of the analysed instabilities.**



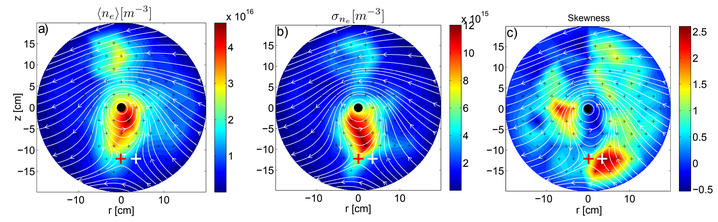
a) Langmuir probes used for the measurement of the toroidal and poloidal mode numbers. b) Measured toroidal mode number n for different TC currents. c) Comparison of measured m/n=m (blue) with the simulated flux surface averaged safety factor q (red).

The linear version of the Global Braginskii Solver (GBS) indicates a dominant ballooning character of the instabilities with respect drift modes.

5. Turbulence studies with a single-null X-point

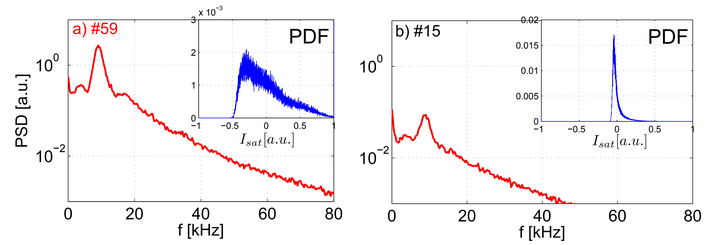
A single null X-point at approximately [r=0,z=-10] cm has been studied:

$$I_{TC} = 600\,\mathrm{A} \qquad R_{EC} = -7\,\mathrm{cm} \qquad P_{\mathrm{MAG}} = 300\,\mathrm{W}.$$



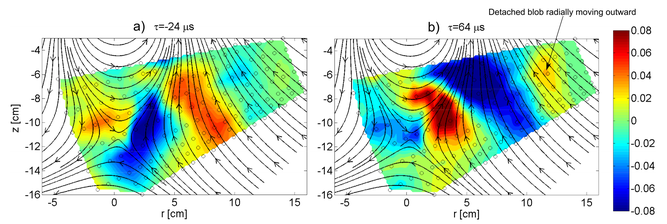
a) 2D time-averaged density profiles from HEXTIP data. b) Standard deviation. c) Skewness.

Plasma fluctuations close to the X-point are present, with a region of quasi-coherent modes and high skewness.



PSD and PDF of HEXTIP I_{sat} signals for the probes #59 and #15.

The Conditional Averaging Sampling technique (CAS) indicates the **presence of blobs detaching from the mode region**.



Time snapshots of 2D plasma fluctuations resulting from the Conditional Averaged Sampling on the 2DSSLP data using as trigger a fixed probe located at [r=-1,z=-9.5] cm. In black the simulated magnetic field lines.

6. Conclusions and outlook

- The spectral characterization of quasi-coherent fluctuations has been performed in TORPEX in the presence of almost circular concentric flux surfaces;
- First studies of plasma turbulence with a single-null X-point have been carried out.

[Outlook]: further studies on the effect of a single-null X-point on blob dynamics will be performed.

References - Acknowledgement

[1] A. Fasoli, et al, *Plasma Physics and Controlled Fusion* **52**, (2010).
[2] F. Avino, et al, *Review of Scientific Instruments* **10**, (2014).

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