

## Low-Temperature Plasma Turbulence in the Torsatron TJ-K

N. Krause, C. Lechte, S. Niedner<sup>1)</sup>, U. Stroth,  
IEAP, University of Kiel, 24098 Kiel, Germany,  
E. Ascasibar,  
EURATOM-CIEMAT Association, Madrid, Spain  
A. Kendl, B. Scott

<sup>1)</sup>MPI für Plasmaphysik, EURATOM Association, Garching, Germany

**Abstract:** The torsatron TJ-K has a magnetic configuration as used in fusion experiments but it is operated with a low-temperature plasma. This allows for turbulence diagnostics with high spatial and temporal resolution using Langmuir probes. It is planned to compare the data with turbulence simulations done with a 2-fluid drift-Alfvén code taking into account the realistic magnetic configuration of TJ-K. Here first experimental results from TJ-K and from the simulations are presented.

**The Torsatron TJ-K:** Since 2000, the TJ-K torsatron is operated at Kiel University with a low-temperature plasma. TJ-K is the former TJ-IU built and operated at Ciemat [1]. It is a  $l=1$ ,  $m=6$  torsatron with a major plasma radius of  $R = 0.6$  m, a minor radius of 0.1 m and a low shear rotational transform of about 0.3. It was built to run at a magnetic field of  $B = 0.6$  T and is now used at  $B \leq 0.2$  T with the benefit of long discharge durations of a few minutes.

The objective of the project is the investigation of turbulence in a magnetically confined plasma at parameters which are at the same time comparable with high temperature plasmas and which are such that the plasma can be well diagnosed with Langmuir probes. The envisaged plasma parameters are summarized in the table and compared with typical values for the edge of a fusion device.

$B$ (T)	$T_e$ (eV)	$n_e$ (m <sup>-3</sup> )	Gas	$\omega_{ci}$ (MHz)	$\omega_{ce}$ (GHz)	$\rho_{Li}$ (cm)	$\rho_s$ (cm)	$\hat{\beta}$	$\hat{\nu}$	$\hat{\mu}$
0.1	10	$1 \times 10^{17}$	Ar	0.23	17.5	0.95	2	0.04	1.5	0.02
0.1	10	$1 \times 10^{17}$	He	2.3	17.5	0.30	0.6	0.04	0.5	0.3
0.1	10	$1 \times 10^{17}$	H	9.5	17.5	0.15	0.3	0.04	0.2	1.1
0.1	10	$1 \times 10^{18}$	H	9.5	17.5	0.15	0.3	0.73	2.2	2.01
0.05	10	$1 \times 10^{17}$	H	4.8	8.8	6.7	0.6	0.16	0.2	1.1
0.05	10	$1 \times 10^{18}$	H	4.8	8.8	6.7	0.6	1.6	2.1	1.1
2.5	100	$1 \times 10^{19}$	H	238	437	0.06	0.04	0.32	0.26	5.4

The measurements will be closely compared with simulation results from the drift-Alfvén code DALF [2]. The code will calculate two-fluid drift wave turbulence in the realistic 3D geometry of TJ-K. The parameters which govern the fluid equations are shown in the Table. Except for the normalized Larmor radius  $\rho_s$ , all parameters can be brought in the region of a fusion plasma. The situation is similar to predicting ITER with present day fusion experiments.

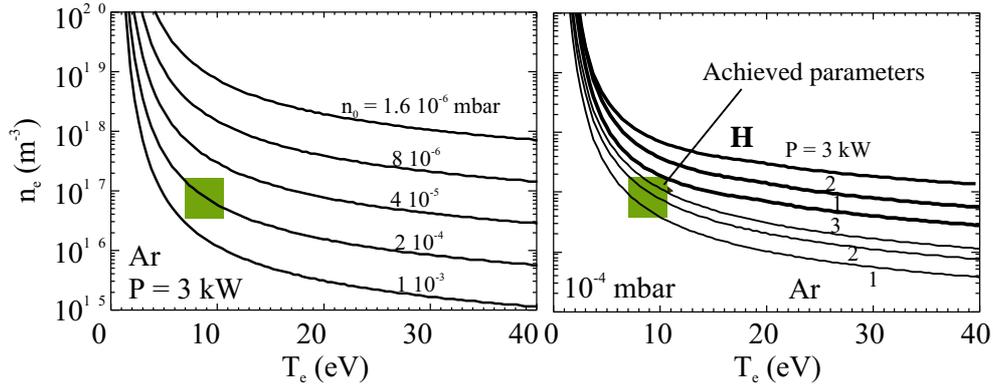


Abbildung 1: Achievable plasma parameter regime from a combined particle and power balance for various values of the control parameters  $n_0$ ,  $P$  and working gas.

**The Helicon-Wave Heating System:** Helicon waves are used for plasma heating. A RF amplifier in the range from 2 to 30 MHz with a continuous power of 3 kW was installed. First experiments were done using a small (4 cm diameter, 10 cm length) half-turn test antenna of the type Nagoya III. In the final setup, the antenna will encompass the entire plasma cross-section. Recently, the full power could be successfully coupled to the plasma. The amplifier was coupled to the antenna with a  $\Pi$  network with two variable vacuum capacitors. Matching was achieved at 27.12 MHz with a load capacitor of 150 pF and a tune with 250 pF. In a recent campaign data were taken a power of 2.5 kW coupled to the plasma at a reflected power of 150 W.

**Plasma parameters:** The achievable plasma parameters were studied with a combined particle and power balance analysis. The plasma density was used as a parameter and thermal conduction was neglected. The steady state particle flux  $\Gamma$  through a surface  $S$  at given neutral density background  $n_0$  and electron temperature  $T_e$  was calculated from a particle balance of the form

$$\Gamma = S(Q_{ion} - Q_{rec}). \quad (1)$$

Ionization by electron collisions,  $Q_{ion} = V \langle \sigma v \rangle_{ei} n_e n_0$  and recombination  $Q_{rec} = V \langle \sigma v \rangle_{rec} n_e^2$  were taken into account. The rate coefficients were calculated from charts of cross-sections for Helium and Argon and fitted into an analytic form.

At a given heating power  $P$ , the electron temperature was calculated from an energy balance of the form

$$P = P_{ion} + P_{rad} + P_{con} + P_{rec}. \quad (2)$$

Losses are due to ionization,  $P_{ion} = V \langle \sigma v \rangle_{ei} n_e n_0 E_{ion}$ , excitation of ions and neutrals,  $P_{rad} = V \langle \sigma v \rangle_{ei} n_e n_i E_{ex} + V \langle \sigma v \rangle_{e0} n_e n_0 E_{ex}$ , recombination  $P_{rec} = V \langle \sigma v \rangle_{rec} n_e^2 T_e$  and convective particle transport,  $P_{con} = 3/2 T_e (a) \Gamma$ . The resulting accessible plasma parameter regimes as a function of the control parameters heating power, neutral density and working gas are shown in Fig. 1.

**Turbulence simulation:** For future comparison with experiment, turbulence simulations are done with the DALF code [2]. DALF is a two-fluid drift-wave code taking into

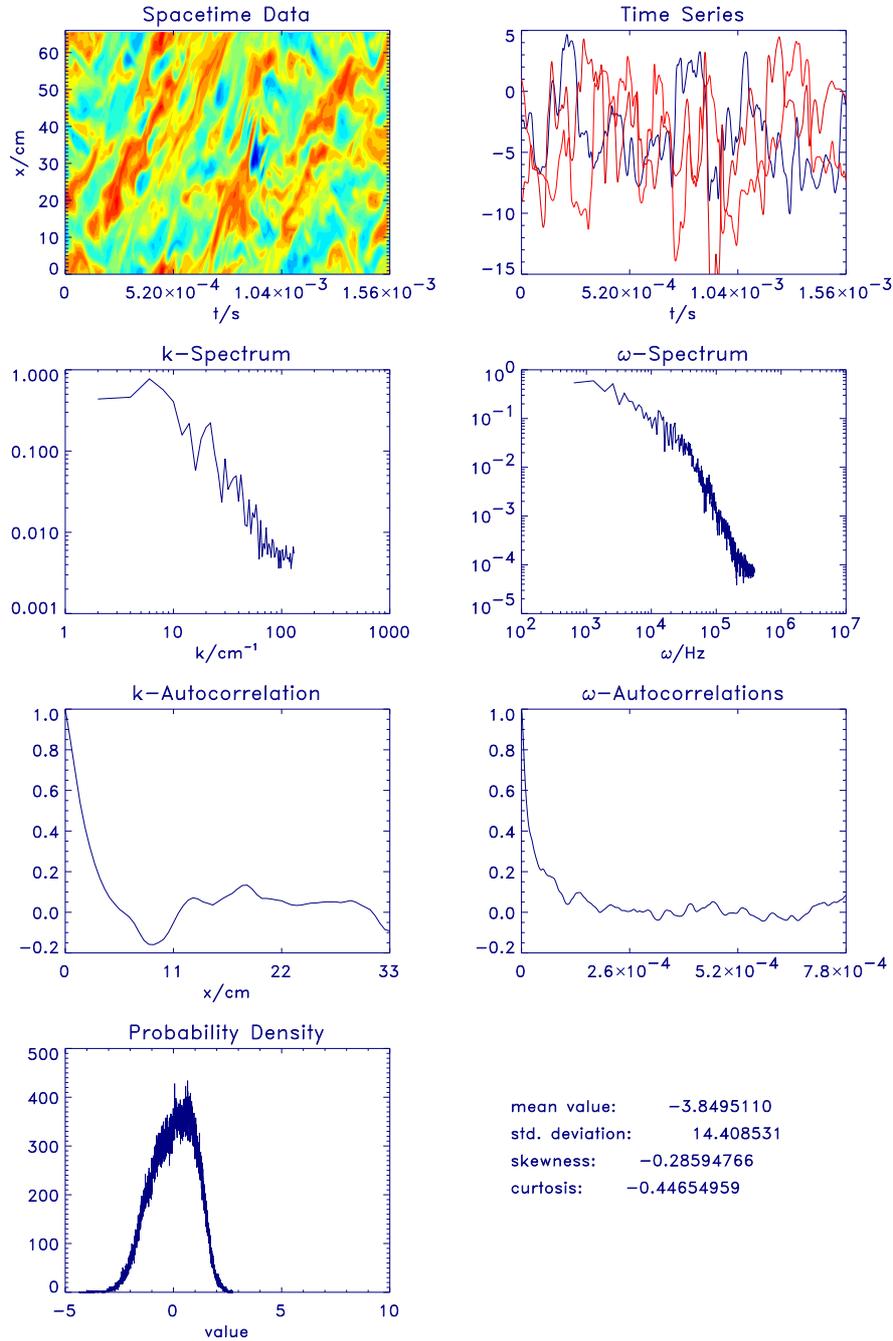


Abbildung 2: Overview of the statistical properties from a turbulence simulations with the DALF code using the parameters quoted in the text.  $x$  denotes the radial co-ordinate.

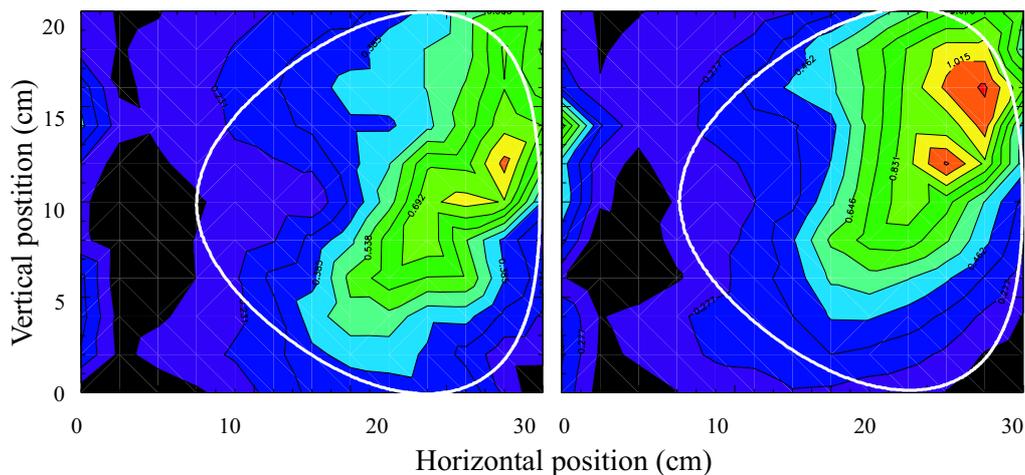


Abbildung 3: First results from a mobile poloidal probe. The ion saturation current is plotted in the frame of the probe position. The white contour is the approximate position of the separatrix.

account coupling to Alfvén waves in the full geometry along a flux tube. The ultimate goal is to simulate the turbulence on an entire flux surface in the realistic geometry of TJ-K.

At present, the simulations were only done in tokamak geometry with TJ-K plasma parameters. The results compiled in Fig. 2 were obtained for Helium with  $B = 0.1$  T,  $T_e = 10$  eV,  $n_e = 10^{18}$  m $^{-3}$ . A long (7 m) but finite parallel correlation length is found. The poloidal and radial correlation lengths are about 10 cm. The spectra show the usual behavior for turbulent systems. Poloidal and radial correlation lengths are both about 5 cm and the time correlation of about 50  $\mu$ s. Since the poloidal correlation length found here is about 1/5<sup>th</sup> of the poloidal circumference, the structure might change when neighboring flux tubes interfere after one toroidal turn (4 m) in a simulation of an entire flux surface. Also the strong modulation of local magnetic parameters like shear and curvature due to the field coils is likely to change the turbulence behavior.

**First experimental results:** Plasma was produced with a cathode and with the helicon antenna. The helicon discharge was diagnosed on an entire plasma cross-section by a mobile poloidal Langmuir probe. From the Langmuir probe characteristic, electron temperature, density and plasma potential  $\Phi_{pl}$  were measured for two values of the magnetic field,  $B \approx 0.05$  and 0.1 T. The ion saturation current was measured at  $B \approx 0.07$  T and  $P \approx 0.8, 1.5, 2.1$  and 2.5 kW. The profiles of the saturation current are shown in Fig. 3. The results can be summarized as follows: Maximum values of  $T_e$ ,  $n_e$  and  $\Phi_{pl}$  are found in the region of the helicon antenna. The temperature is about 8 eV. The plasma potential is positive and of the order of 50 V. The plasma density doubled when  $B$  was increased from 0.05 to 0.1 T. As shown in Fig. 1, the achieved parameters fit rather well with the estimates from the energy balance.

## References

- [1] Ascasibar, E., IAEA Conference, Sevilla, 1994, p. 794
- [2] Scott, B., Plasma Phys. Contr. Fusion, **39**(1997)1635.