Low-Temperature Plasma Turbulence in the Torsatron TJ-K

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Abstract The torsatron TJ-K, which is the former TJ-IU [1], is operated to study turbulence and wave propagation in a toroidal low-temperature plasma. Turbulence measurements with multi-probe arrays are compared with results from drift-Alfvén turbulence simulations. From simulations, wave-number spectra of density and potential fluctuations and their phases were identified to be the relevant method to disentangle different turbulence driving mechanisms. Typical sizes and frequencies of the measured turbulence are in reasonable agreement with the simulations. The plasma is produced by a helicon wave heating system. Wave field measurements are consistent with the assumption of a toroidally propagating m=1 helicon mode.

The Torsatron TJ-K TJ-K is an $l = 1$, $m = 6$ torsatron operated with a low temperature plasma at densities up to 2 10^{18} m^{-3} and electron temperatures up to 15 eV. The magnetic field is 0.2 T, minor and major radii are 0.1 and 0.6 m, respectively. Working gases are Helium and Argon. The plasma is created by RF heating at a frequency of 27 MHz and powers up to 3 kW. In this range helicon waves propagate in the plasma.

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. Experimental knobs to change plasma parameters are the working gas, neutral gas pressure, heating power and magnetic field. The latter does not enter the power balance since transport is neglected. From the modeling follow hyperbolic curves $T_e(n_e)$ with high temperatures (T_e) for low densities (n_e) and vice versa. The temperature increases at lower neutral pressure and high heating power and ionization energy. In Fig. 1, experimental results from swept Langmuir probes are shown for different neutral pressures and magnetic fields. The dependence on pressure is consistent with the power balance results. The field dependence indicates reduced transport with increasing field. It has to be investigated whether this trend is due to a reduced turbulence scale length.

Helicon Wave Studies Helicon waves in the frequency range from f = 2 to 30 MHz are used for plasma heating at a continuous power of up to 3 kW. At these frequencies ($\omega_{ci} \ll \omega \ll \omega_{ce}$) the right-handed helicon wave propagates in the plasma. It corresponds to the whistler wave in a bounded plasma with a simplified dispersion relation, which is in proper units (10^{18} m^{-3},T,m,MHz)

$$n_e \approx 31 \frac{B}{\lambda^2 f}. \tag{1}$$

The wave is coupled to the plasma with a double-half-turn Nagoya-type-III antenna. The RF amplifier is coupled to the antenna via a Π network with two variable vacuum capacitors. Matching was achieved with 1% of reflected power.

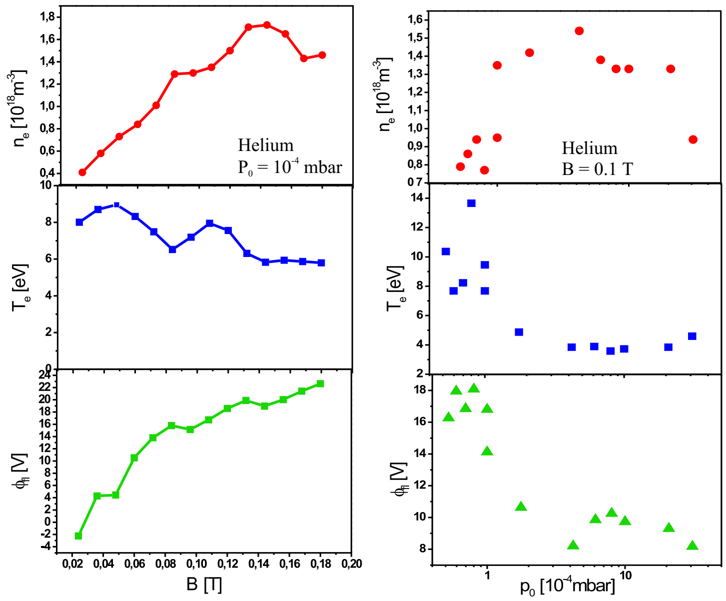

Fig. 1: Plasma parameters (density, temperature and floating potential) from a swept Langmuir probe for different magnetic fields and gas pressures in Helium at a heating power of 1.5 kW.

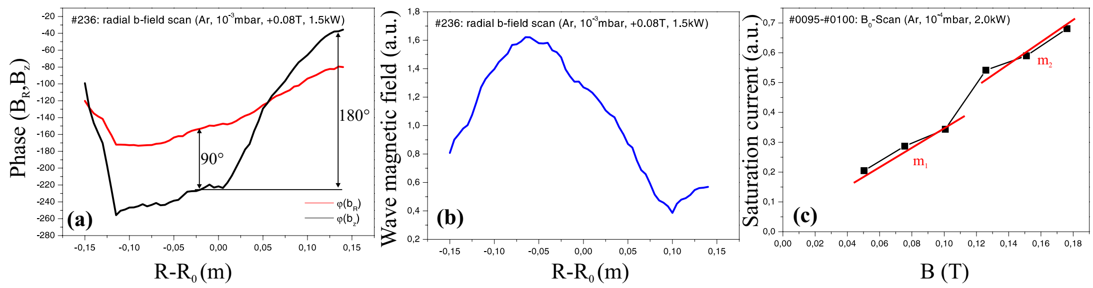

Fig. 2: Phase between horizontal and vertical magnetic field components (a) and the field amplitude (b) as function of R and the ion saturation current ($\approx n_e$) as function of magnetic field (c).

Experiments were carried out to measure the wave field, power absorption profile and the dispersion relation. The preliminary results are consistent with an $m = 1$ right-handed wave propagating parallel to the magnetic field. Vertical and radial magnetic field components, B_z and B_R, have a phase of $\pi/2$ in the plasma core (Fig. 2a). At the plasma edge a general phase change by π is found, which would be consistent with an $m = 1$ mode. However, the relative phase of the two components vanishes. As expected for $m = 1$, the wave amplitude is peaked in the plasma center (Fig. 2b). Power modulation experiments indicate a broad power deposition profile. In Fig. 2c measurements of the dispersion relation (1) are presented. Since the wave has to interfere coherently around the torus ($2\pi R = N\lambda$), the discontinuity can be interpreted as a change in wave number from N to $N + 1$. From the slopes of the indicated lines $N = 16$ can be interfered. Consequently, the wavelength would be 24 cm and the plasma density 2 10^{18} m^{-3}. Both are reasonable results.

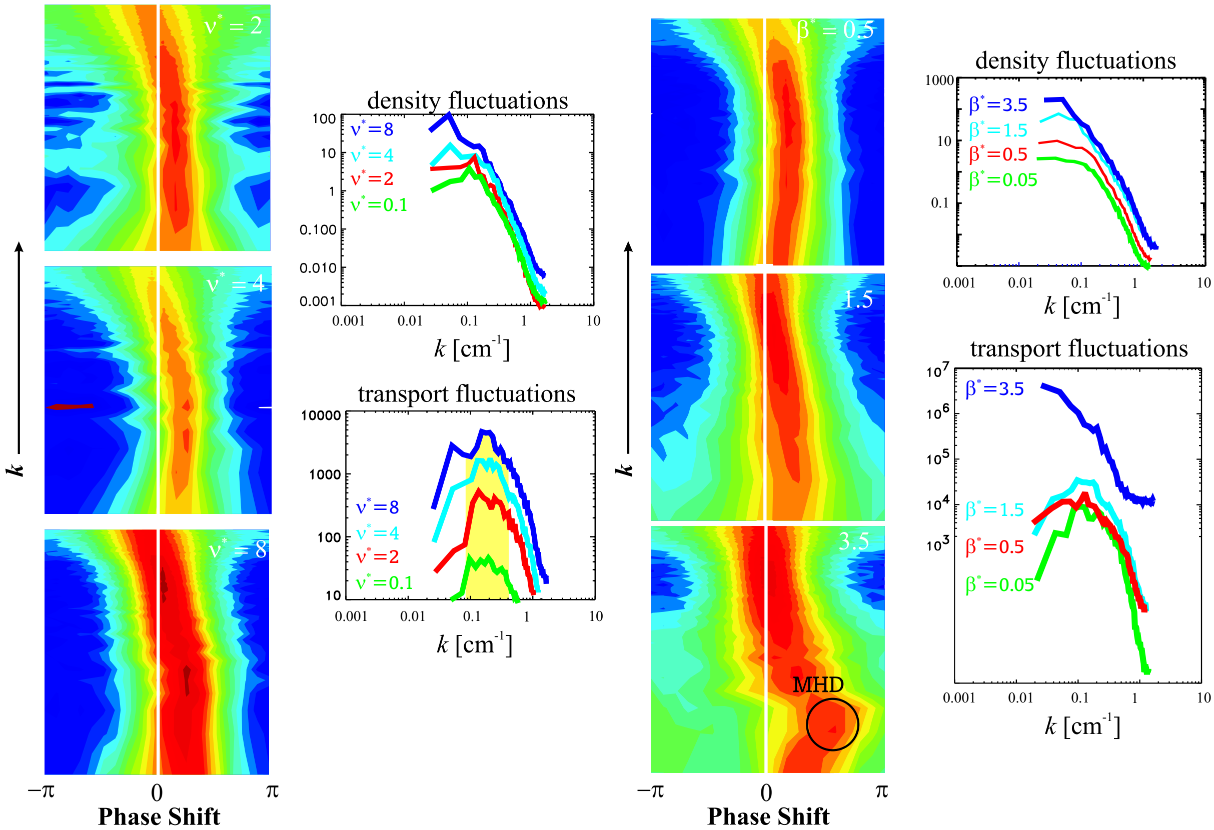

Fig. 3: Poloidal wave number resolved density-potential phase spectra of a ν^* (at $\beta^* = 0.7$, left) and a β^* scan (at $\nu^* = 4$, right) as well as the corresponding density and transport fluctuation k spectra.

Turbulence Simulations Turbulence measurements are closely compared with simulation results from the drift-Alfvén code DALF [1]. The parameters which govern the fluid equations are the normalized β^*, collisionality ν^* and gyro radius ρ^*. Except for ρ^*, which just scales the size of the turbulent eddies, TJ-K can produce plasmas in a parameter range which overlaps with the parameters of a fusion plasma scrape-off layer. With simulations, the scaling of the turbulence properties with the dimensionless plasma parameters were studied. In Fig. 3, data from a ν^* and a β^* scan are presented. The results allow to disentangle the influence of different driving mechanisms. With increasing collisionality the phase between density and potential fluctuations increases at all wavelengths (Fig. 3). Consequently, transport, which is concentrated in the transition from injection to inertia region of the spectra, increases without an concomitant increase of the density fluctuation amplitude. This behavior is typical for drift-wave turbulence. An increase of β^* only effects the long-wavelength turbulence. At high β^* values, large scale events develop with a phase of $\pi/2$, as it is characteristic for MHD turbulence. The enhanced transport can be attributed to these events. The turbulence in the interia range is not modified. Furthermore, MHD turbulence, which is driven by the magnetic field curvature, exhibits strong asymmetries on high and low-field sides of the plasma while drift-wave turbulence is almost symmetric.

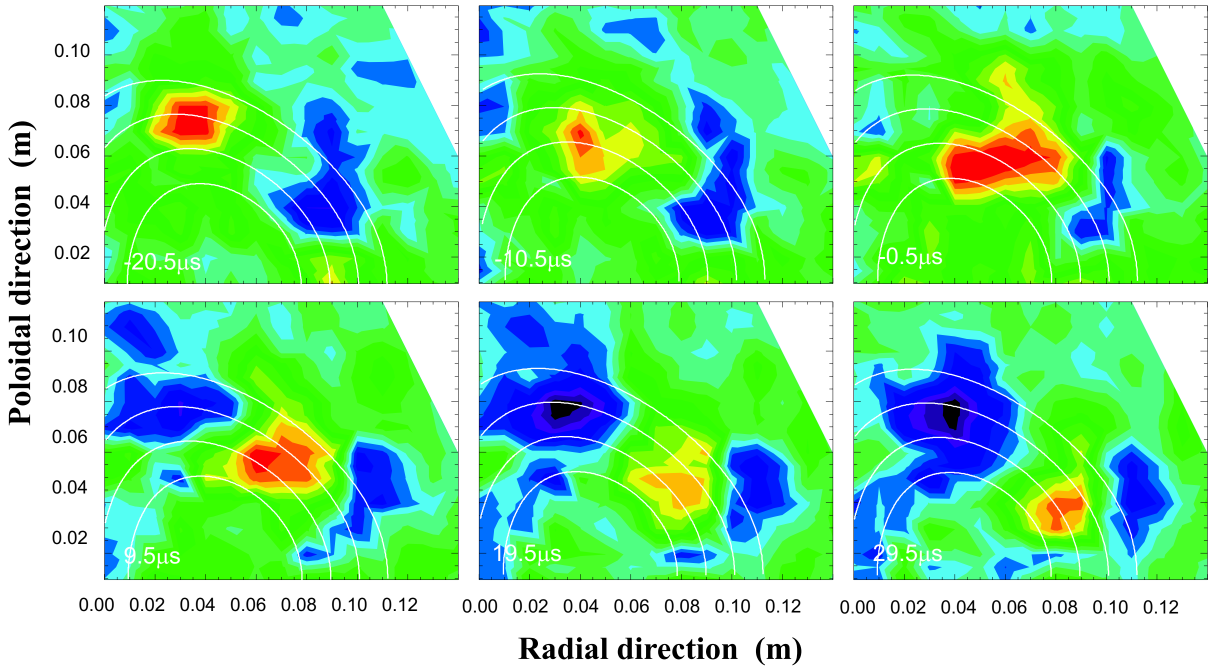

Fig. 4: Correlation of ion saturation current fluctuations in a poloidal cross-section between a 2D movable probe and a fixed probe for time delays from -20 μs to +30 μs. Red corresponds to positive and blue to negative correlation. Flux surfaces are overlayed.

Comparison with Turbulence Measurements The fluctuations in density and potential are measured by a Langmuir probe arrays. The probes are scanned through the poloidal plasma cross-section and correlated with a fixed probe. The spectra are typical for plasma turbulence with an injection range up to about 20 kHz and an intertia range up to 300 kHz. The slopes in the spectra are between -2.5 and -3.5, the simulation yield -3. Both measured and simulated probability density functions (PDF) for density and potential are gaussian. As typically observed in fusion plasmas too, the transport PDF is peaked. These statistical features are reasonably well reproduced by the turbulence simulations using DALF at the experimental equilibrium parameters. Details will be published elsewhere.

The correlation measurements between a movable array and a fixed probe yield spatio-temporal information on the large turbulent events. A sequence of correlation measurements in the poloidal cross-section for different time delays is shown in Fig. 4. The size of the event is about 3 cm and the duration 80 μs. The simulation yields a size of 5 cm in poloidal and radial direction. The motion coincides with the flux surfaces and the electron diamagnetic drift direction. The maximum is accompanied by minima on both sides. Correlation with the potential fluctuations are not yet available.

References

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