Rapid response of turbulence to ECRH power modulation in the TJ-II stellarator

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Abstract

ECRH heating is known to have a strong impact on turbulence levels [1]. In this work, we use data from Langmuir probes at the edge of TJ-II plasmas to quantify the response of turbulence to fast changes in heating power. TJ-II is a flexible Heliac ($R = 1.5$ m, $a \approx 0.2$ m, $B_0 \leq 1$ T). It disposes of two ECRH gyrotrons that can deliver up to 300 kW each. In these pure ECRH experiments, performed at low electron density ($(3.9 \pm 0.2)10^{19}m^{-3}$ - electron root plasmas), one gyrotron was kept at 300 kW while the second one was modulated with a square wave between 0 kW and 300 kW with a duty cycle of 50% and a modulation period of 40 mS.

Probe configuration and measured quantities

TJ-II has two movable probe arrays in sectors B and D located at ($\phi = 195°, \theta = 294°$) and ($\phi = 38.2°, \theta = 107°$) respectively. Probe B has 3 poloidally separated tips which were configured to measure floating potential, V_f, with tips pointing in radial direction. A staircase probe was used in sector D with innermost row w.r.t. the plasma of 4 pins. Pin 1 providing bias voltage, V_+, pins 2 and 4 measuring floating potential, $V_{f2,4}$ and pin 3 - ion saturation current, I_s. Plasma potential was estimated from measurements of floating potential in combination with obtained electron temperature: $V_{pl} \approx V_f + 2.5T_e/e$, where electron temperature is in units of eV and e is the electron charge. Temperature profile from probe D was interpolated to be interpret potential measurements in probe B. By taking gradients of spatially sampled plasma potential radial and poloidal electric fields, E_r, E_θ, are estimated.

Mean profile response

Figure 1 presents the response of radial profiles to the ECRH power modulation averaged over 5 ms with error bars indicating a standard deviation. As ECRH power increases plasma potential, Figs. 1a, 1b, grows towards the core of the plasma. Calculated radial electric field profiles in Figs. 1e, 1f both have a maximum at $\rho \approx 0.95$. However, neither V_{pl} nor E_r profiles between B and D match exactly, suggesting that assumption of equality in temperature profiles between the probes is questionable. Ion saturation current, Fig. 1c, and thus density, changes by up to 25% during ECRH modulation. Electron temperature profile in D, Fig. 1d, is not affected by power modulation. Changes in poloidal phase velocity of potential fluctuations, calculation of which will be discussed further, for probes B and D, Figs. 1g, 1h accordingly, coincide with the shape of radial electric field profiles, agreeing with estimation for $v_{\mathbf{E}_r \times \mathbf{B}_0}$. No noticeable change in the mean level of turbulent transport, $\Gamma_r = \langle \tilde{n}_e \tilde{E}_\theta \rangle_t \approx \langle \tilde{I}_s \tilde{E}_\theta \rangle$, and effective radial velocity, $v_r = \dfrac{\Gamma_r}{\langle I_s \rangle}$ measured by the probe D are observed. However, the amplitude of the fluctuations of these quantities increases with the input power, Figs. 1j, 1i.

Poloidal phase velocity of potential fluctuations and turbulent transport

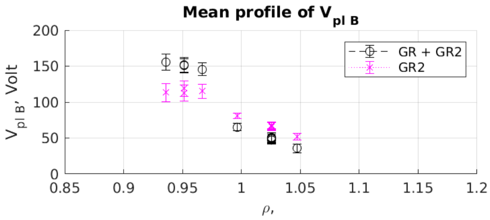
Poloidal propagation of fluctuations and turbulent transport were analysed using S(k,f) technique [2]. From cross-phase of two polidally separated signales velocity was calculated in the following manner: $v_\theta(f,t) = \frac{2\pi f d}{\varphi(f,t)}$, where d is the spatial separation between two measurement points. In order to obtain mean phase velocities demonstrated in Figs. 1g, 1h averaging was performed over frequencies using coherence as a statistical weight. Analysis for the probe D at $\rho = 0.9$, Fig. 2a, reveals non-linear dispersion relationship with a "knee" at 150 kHz. Coherence above 150 kHz increases with ECRH power. Same analysis was conducted for signals of ion saturation current and poloidal electric field, $E_\theta \approx (V_{f2} - V_{f4})/d$. Abrupt change in coherence level of turbulent radial transport, Γ_r, especially above 200 kHz happens somewhere within $0.92 \leq \rho \leq 0.96$, but no significant effect from ECRH modulation is observed, Fig. 2b. This allows to conclude that turbulent radial transport in the plasma edge a) is not directly driven by the ECRH power input, b) has a well defined radial structure and c) a broadband (50-750 kHz) spectral composition with maximum at 200 kHz.

Characteristic response time of the radial profiles

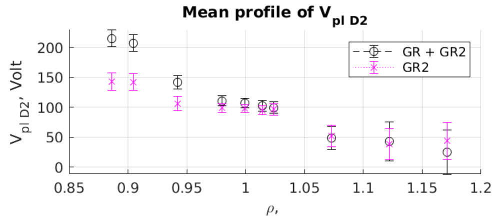
To study radial dependence and determine characteristic response timescales of V_f and I_s and their running RMS values (over 20 μs window) were fitted with an exponential curve, $C_1 + C_2 e^{(t-t_0)/\tau}$, where t_0 is the transition time. From Fig. 2c no clear radial dependence is observed in V_f, however, RMS values have a consistently faster (below 0.5 ms) rise time with a minimum at $\rho = 0.9$. Response times for ion saturation current, Fig. 2d are the same on average, but have a distinctive minimum in rise time of both I_s and it's RMS value at $\rho = 0.95$. RMS rise times are similarly below 0.5 ms for both V_f and I_s.

Conclusion

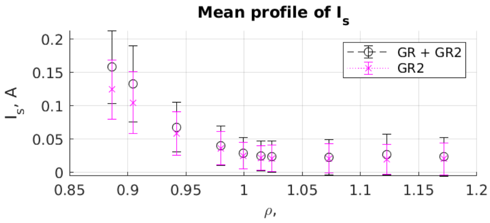
Higher input ECRH power causes steepening of I_s and V_{pl} profiles in the edge and latter causing a localised increase in E_r and v_θ. However, v_r, T_e and Γ_r are not affected by the modulation. Increased poloidal velocity shear coincides with a peak in v_r at $\rho \approx 0.94$. Spectral



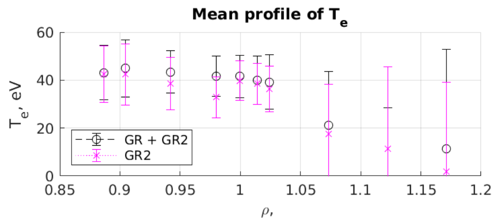
(a) Plasma potential profile in probe B



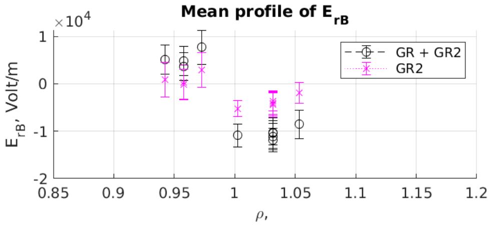
(b) Plasma potential profile in probe D



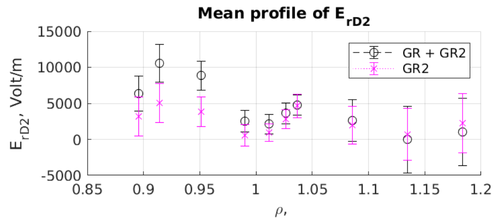
(c) Ion saturation current profile



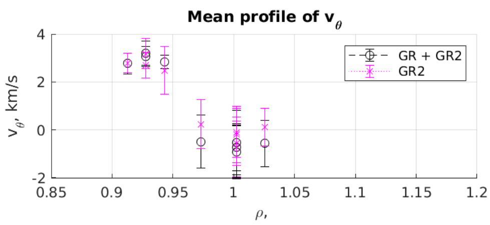
(d) Electron temperature profile



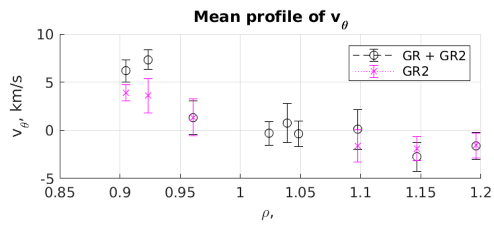
(e) Radial electric field at probe B



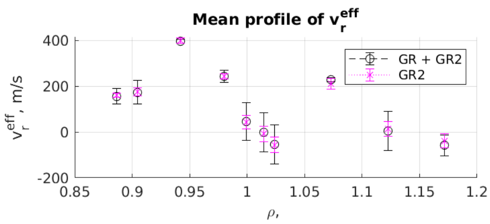
(f) Radial electric field at probe D



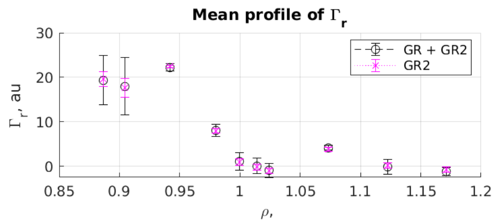
(g) Poloidal phase velocity profile measured with probe B



(h) Poloidal phase velocity profile measured with probe D



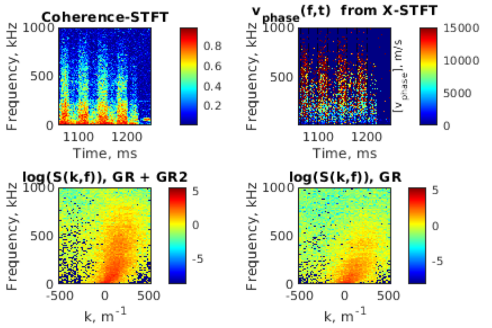
(i) Effective radial transport velocity



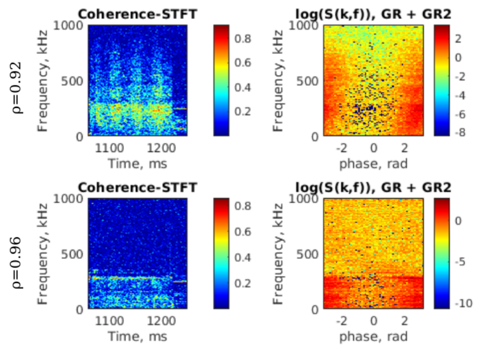
(j) Turbulent radial transport profile

Figure 1: Response of the radial profiles to the ECRH modulation

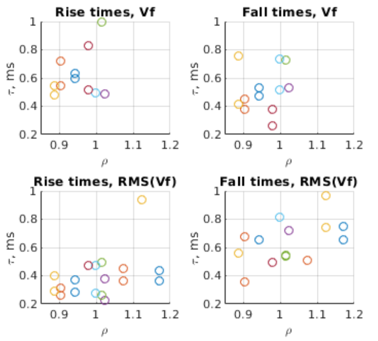
analysis reveals change in coherence levels between E_θ and I_s implying de-correlation of turbulent transport outside of the shear layer. Non-linear dispersion relation of v_θ should be also noted. Response times of the V_f and I_s are on order of 1 ms and do not have a clear radial dependence, apart from minimum in I_s and RMS(I_s) at $\rho = 0.94$. RMS level rises faster for both and has an average rise time below 0.5 ms, suggesting that turbulence levels respond before profiles



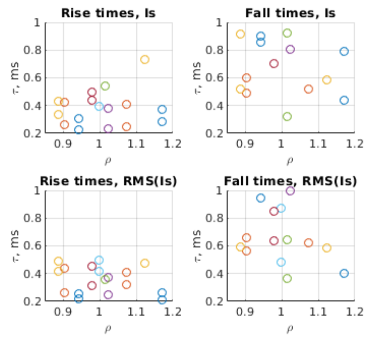
(a) S(k,f) analysis of poloidally separated floating potentials in probe D at $\rho = 0.9$



(b) Change in coherence between I_s and E_θ with radius



(c) Characteristic response time of V_f and RMS(V_f)



(d) Characteristic response time of I_s and RMS(I_s)

Figure 2: Spectral and temporal analysis

adjust to the increase in input power.

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References

[1] A. Melnikov, L. Krupnik, E. Ascasibar, A. Cappa, A. Chmyga, G. Deshko, M. Drabinskij, L. Eliseev, C. Hidalgo, P. Khabanov, S. Khrebtov, N. Kharchev, A. Komarov, A. Kozachek, S. Lysenko, A. Molinero, J.L. de Pablos, M. Ufimtsev, V. Zenin, Plasma Physics, Controlled Fusion **8**, 60 (2018)

[2] C. Ritz, E. Powers, T. Rhodes, R. Bengtson, K. Gentle, H. Lin, P. Phillips, A. Wootton, D. Brower, N. Luhmann, W. Peebles, P. Schoch, and R. Hickok, Rev. Sci. Instrum. **59(8):1739**, 1988.