New developmental methods in nonlocality study

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1. Experimental background

Phenomena suggesting fast, apparently "non-local" response of core plasma parameters to edge perturbations have been observed in many tokamak experiments. Here, by 'non-local', we mean that a rapid response in the core is observed to follow from an edge perturbation on a time scale far shorter than any standard approximation to a global or diffusion model confinement time. The first and most striking example of these is the cold pulse experiment, in which edge cooling by pellet injection, impurity blow-off, Supersonic Molecular Beam Injection (SMBI), etc, induces a rise in central electron temperature on time scales far shorter than any of those characteristics of local transport[1-8]. These experiments are a strong challenge to the standard concepts and models of transport, which, despite a few exceptions, remain diffusive or at least local in their basic formulation. Till now, few, if any, credible dynamical models have been proposed to substantively address the main features of nonlocality phenomena.

2. Experiment results

2.1 Sustained Nonlocal Response induced by SMBI on HL-2A

For density lower than 2×10^{19} m^{-3}, a transient rise of the core electron temperature has been observed when repetitive SMBs are injected to induce fast cooling of the peripheral region ($\rho \geq 0.7$), as shown in figure 1. The core temperature rise has strong density dependence: it is more than 600 eV when the electron density n_e is around 0.7×10^{19} m^{-3}, it decreases to 150 eV when n_e is around 1.36×10^{19} m^{-3} and disappears when n_e is larger than 1.5×10^{19} m^{-3}. Sequential firing of SMBI on the HL-2A tokamak can sustain the increase in the core temperature in response to the edge perturbation.

The O-mode reflectometers are introduced to measure density fluctuation. Figure 2 and

figure 3 show the spectrum evolutions of the density fluctuations with sequential SMBI. In fugure 2, repetitive non-local effect has been triggered by SMBI, while no nonlocality appears in figure 3 because the density is higher. In figure 2, the line averaged density is about $(0.8\text{-}1.1)*10^{19}\text{m}^{-3}$, the cutoff surface is estimated at $r/a = 0.3\text{-}0.5$ The central turbulence is suppressed after SMBI during non-local effect. In figure 3, the line averaged density is around 1.5×10^{19} m^{-3} and SMBI failed in triggering nonlocality. The central turbulence increased after SMBI in this case. This suggests that the steepening of core ∇Te and the rise in the central temperature are due to a local reduction in turbulence and the associated transport.
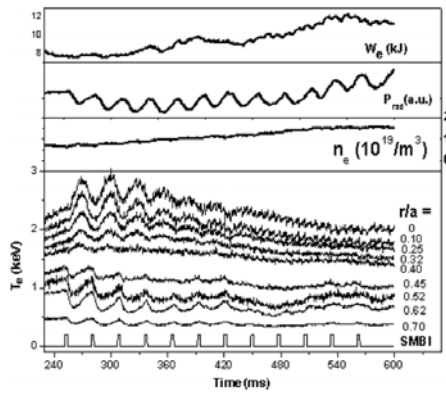

Figure. 1 Evolution of parameters in shot 8363 with SMBI. From top to bottom: the storage energyWe, the bolometer signal, the electron density, ECE temperature at different radii and the SMBI signal in the ohmic regime (Bt = 1.45 T, ne = (0.7–1.5) $\times 10^{19}$ m^{-3}, Ip = 190 kA).

2.2 Off-axis ECRH switch-off

In addition to normal cold pulse injection (i.e. Pellet injection, SMBI, impurity injection, etc), far off-axis ECRH switch-off can be also used to create inward cold pulse propagation. One would expect similar non-local effects with the edge cooling by off-axis ECRH switch-off. This was tested on HL-2A in experiments with various ECRH depositions by scanning the toroidal magnetic field. When the power deposition was moved to plasma edge ($\rho \approx 0.7$) after the off-axis ECRH switch off, the core electron temperature did not decrease immediately. Instead, the core temperature increased for several tens of milliseconds before it started to decrease. In contrast, the edge temperature decreased just after the ECRH switch off, as shown in figure 4. This phenomenon is quite similar to the non-local effect induced by SMBI. Here, the core response appears more slowly than the usual cold pulse case, and the time delay is several msec.

Figure 5 shows the power spectra of the density fluctuations of the same discharge in figure 4 which is measured by 35GHz reflectometer before (380 ms), during (480 ms) and 25

ms after (540 ms) ECRH. The cutoff surface is estimated to be located at r/a = 0.1-0.5 in this shot since the line averaged density is about $(1-1.4)*10^{19}m^{-3}$. The power spectrum after ECRH switch-off is much lower than that before or during ECRH. This suggests that the central turbulence is suppressed after ECRH is turned off.
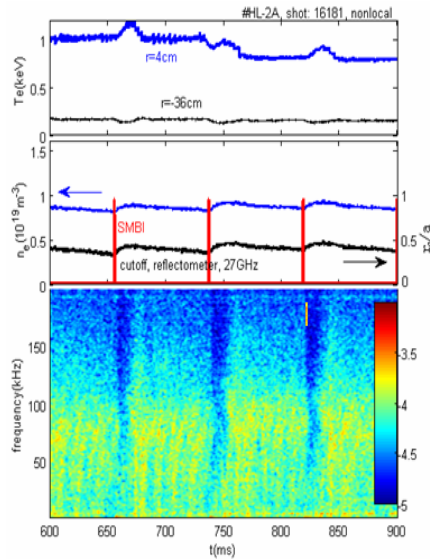

Figure 2 shot 16181, sequential SMBI induces nonlocal effect. From top to bottom: the core and edge Te, line averaged density and cutoff surface of reflectometer, power spectrum of density fluctuation. Power spectrum shows the central turbulence suppression during nonlocal effect measured by 27GHz reflectometer.
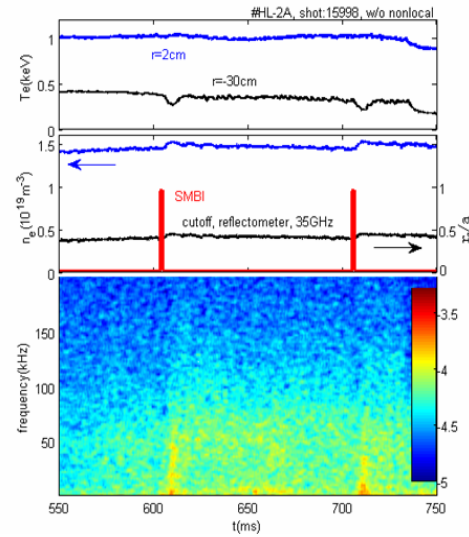
Figure 3 shot 15998, normal cold pulses induced by SMBI, without nonlocal effect. From top to bottom: the core and edge Te, line averaged density and cutoff surface of reflectometer, power spectrum of density fluctuation. Power spectrum shows the increase of the central turbulence after SMBI

3. Summary

Experiments using SMBI and off-axis ECRH switch-off as peripheral cooling methods in the HL-2A tokamak confirm and extend the observations of nonlocality made in other machines. Sequential firing of the SMBI can effectively sustain the increased core temperature which appears to follow in response to the edge perturbation. The period of central temperature increase can be extended to several global energy confinement times by repetitive SMBI. The duration of the core temperature increase can be prolonged until the density reaches the nonlocal cut-off density. The central turbulence is suppressed after the nonlocal response suggesting that the interpretation of the phenomenon as 'ITB-like' is

plausible. Experiments on off-axis ECRH switch-off shows that the deposition location of initial perturbation is important in achieving a non-local response. On HL-2A, the deposition position of ECRH should be outside $\rho \approx 0.7$ so it can trigger non-local response. It seems like $\rho \approx 0.7$ is a 'special' location for non-local transport phenomenon. On HL-2A, the location is related to the radius of the q=2 surface.
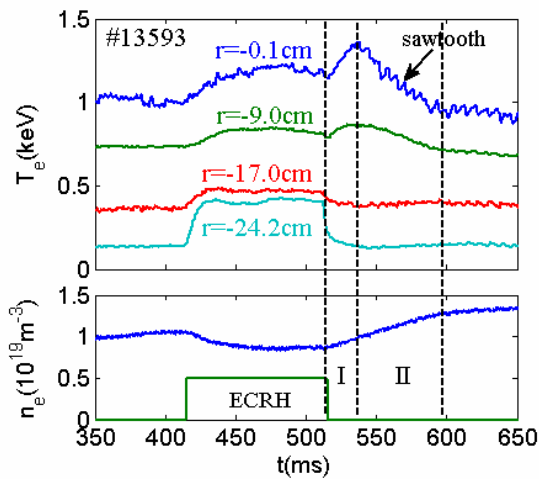

Figure 4. Time evolution of the electron temperature and density after ECRH switch-off (at 515 ms) (shot#13593, B_t=1.42 T, I_p=170 kA, P_{ECRH}=740 kW). The ECRH resonance is at 27.8cm (r_{dep}/a ~ 0.69).
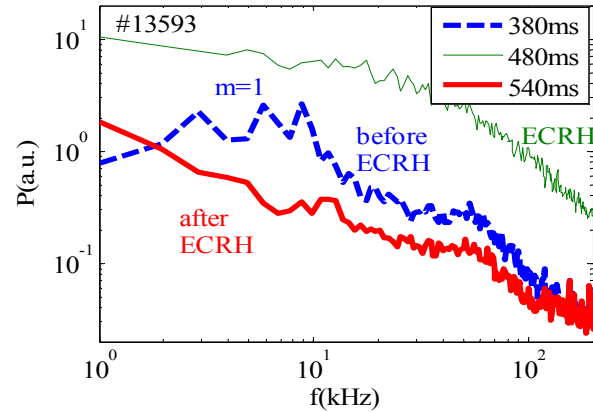

Figure 5 power spectrum showing the turbulence suppression after ECRH switch-off. The ECRH power deposited at 27.8cm (r_{dep}/a ~0.7).

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