Recent Experimental Results in ADITYA Tokamak

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Abstract. Recent studies on measurements of edge turbulence in ADITYA are reported. The measured particle flux in the edge plasma shows bursty nature. The Lévy analysis of plasma fluctuations and the fluctuation induced transport shows self-similarity over a time scale 3 times the auto-correlation time. In the short time scaling range, the Lévy scale index, α = 1.1-1.3 and α=2 in the long-time scaling range. The results indicate that the transport due to small-scale fluctuations is convective whereas that due to large scale is diffusive. The observed bursty transport can be explained in terms of Lévy flights. In addition, several new diagnostics have become operational which have allowed experiments on low-Z impurity injection, gas-puff and limiter biasing with a common goal of improving energy confinement time.

1. Introduction

The ADITYA tokamak has been in operation for about a decade. Several new diagnostics have become operational in the last year, which allow us to carry out studies of plasma confinement. The new diagnostics which have become operational are measurement of electron temperature (T_e) profile using ECE (electron cyclotron emission) and soft X-ray, single point measurement of core T_e using Thomson scattering, impurity radiation power using bolometry, edge density and temperature using Lithium blow-off and hydrogen ionization rate using H_α intensity and density fluctuation measurement using µW reflectometry at 22.4 GHz. In addition, a 20-40 MHz, 200 kW Ion Cyclotron Resonance Heating (ICRH) system has been integrated with ADITYA and experiments to measure coupling efficiency have been carried out. Similarly a 28 GHz, 200 kW gyrotron based Electron Cyclotron Resonance Heating (ECRH) system has been successfully commissioned and experiments to initiate plasma discharge have been carried out. In ohmically heated ADITYA discharges, we have carried out new measurements on the nature of plasma turbulence in the edge. It is observed that floating potential and density (ion saturation current) fluctuations exhibit self-similarity of short time scales (up to 3 times the auto-correlation time) and simultaneous absence of long-range correlation. The observation implies the existence of self-similar coherent structures in the edge plasma. The measured particle fluxes exhibit bursty nature and self-similarity of small scales. In the following we summarize these activities.

2. Turbulence studies

The floating potential and ion saturation current are measured using a poloidal array of Langmuir probes made up of molybdenum wires (length = 3.5 mm, diameter = 1 mm, separation= 3 mm). The probes on a movable shaft are mounted on the top port, toroidally 72^{O} away from the limiter in the electron side. The 24 kB data are acquired at a sampling rate of 1 MHz in the time window (25-49 ms or 40-64 ms) where the mean plasma parameters are nearly constant. In the present experiment the probe array is located at 3 mm behind the limiter. The instantaneous particle flux is determined from the measurements of ion-saturation current and floating potential at alternate probes in the probe array. The odd number probes measure the floating potential, whereas the even number probes measure the ion saturation current. Granular structures propagating in the poloidal direction can be seen in both measurements.

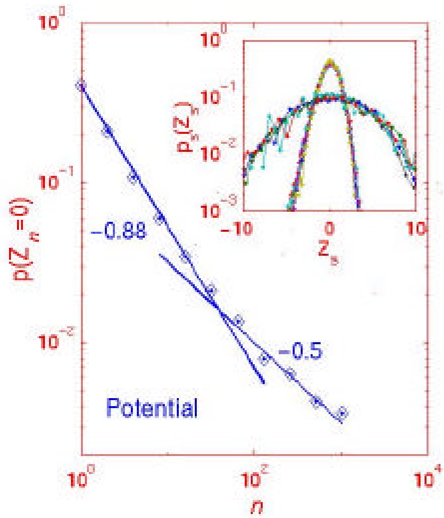


FIG 1: Results for floating potential. The probability of return to the origin $p(Z_n=0)$ vs. n graph shows two distinct scaling ranges: n=1-40 and n>40. The Lévy scale indices in the two scaling ranges are: 1.2 and 2 respectively. The re-scaled PDFs for the two scaling ranges are shown in the inset (larger width for the long time scaling range).

The instantaneous value of fluctuation induced particle flux = $\delta n_e \delta v_r$, where the radial velocity, δv_r is obtained from the poloidal electric field, δE_θ and the plasma density, δn_e is assumed to be proportional to the ion saturation current. The δ sign indicates fluctuation in different quantities. The poloidal electric field at the location of an even number probe is determined from the difference of floating potentials at the adjacent probes. The fluctuation induced particle flux shows bursty nature. The bursty enhancement over the mean flux (=0.25) is by a factor of 2-20.

The floating potential, ion saturation current and the particle flux show non-Gaussian behaviour as indicated in excess kurtosis. We have carried out Lévy analysis of these data with an objective to search for self-similarity of non-Gaussian stochastic process. It has been shown by Lévy that the sum of *n* independent stochastic variables, with a probability distribution having power-law wings, converges to a stable process characterized by the Lévy distribution [1]. The process is stable because the PDF of the sum, $Z_n = \sum_1^n X_i$, of the stochastic variables {X}, has the same functional form as the PDF of X_i. The PDF of a symmetrical Lévy stable process is given by [2]:

$p(Z_n) = (1/p)\int_0^\infty \exp(-ngq^a)\cos(qZ_n)dq$ where α ($0 < \alpha \leq 2$) and γ(>0) are the scale index and scale factor respectively. If the central region of the distribution is well described by a Lévy stable process, then the probability of return to the origin is given by: $p(Z_n = 0) = \Gamma(1/a)/[pa(ng)^{1/a}]$, where Γ is a Gamma function. The Lévy stable symmetrical distributions rescale under the following transformations: $Z_s = Z_n / n^{1/a}$ and $p_s(Z_s) = n^{1/a}\, p(Z_n)$ Although Lévy stable process is characterized by infinite variance, the existence of finite variance in physical systems is treated by using a truncated Lévy distribution (TLD) where an exponential tail is imposed on the values of the stochastic variable. The TLD is a Lévy stable process. Further details can be found in [2].

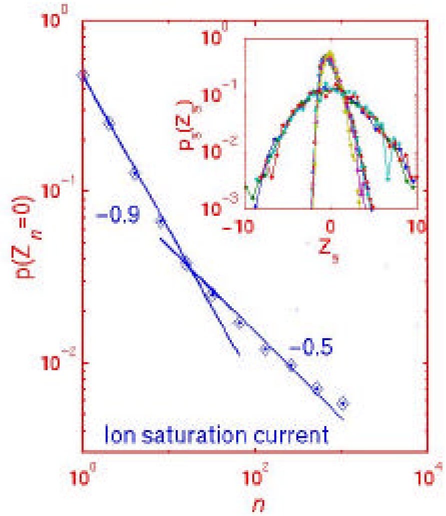


FIG. 2 : Results for ion saturation current. Other details are same as in FIG. (1).

FIG. 1 shows the probability of return to the origin, $p(Z_n=0)$ as a function of the number of convolution (n) for the floating potential fluctuations. There are two scaling ranges n= 1-32 and $n \geqslant 64$ with well defined slopes: -0.9 and -0.5 respectively. The corresponding Lévy indices are 1.11 and 0.5 respectively. In the inset, we have plotted the re-scaled PDFs, $p_s(Z_s)$ and it is observed that the PDFs collapse to distinct PDFs in the two scaling ranges. The difference of $\log[p_s(Z_s=0)]$ values in the first and the second scaling regimes provides a measure of the \`distance', Δ between the two scaling regimes. The Δ≅ 0.6 for the results shown in Fig.(1) indicates that the 'distance' is significantly large. *FIG. 2* shows the probability of return to the origin, $p(Z_n=0)$ as a function of n for ion saturation current. The self-similarity is present and the Lévy scale parameters (α) in the short and the long scaling ranges are 1.2 and 2.0 respectively. The short scales are skewed and non-Gaussian whereas the long scales are Gaussian. The two scales are well separated with Δ≅ 0.6.

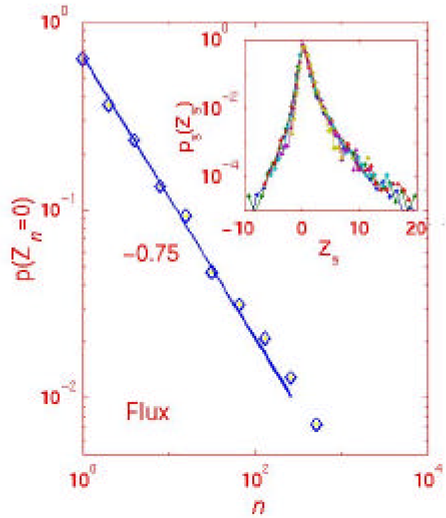


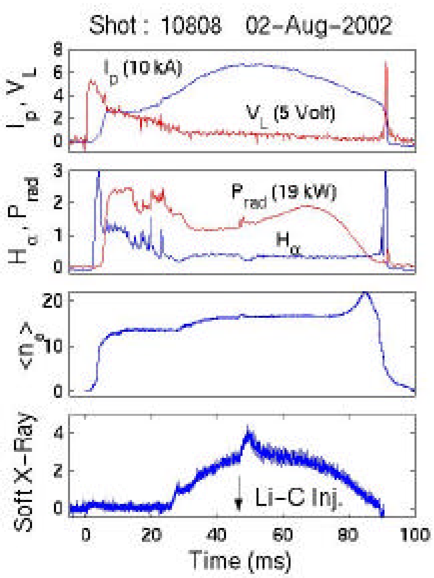
FIG. 3: Results for particle flux. Other details are as in Fig. (1). The re-scaled PDFs of only scales 1-32 μs are shown in the inset. For higher time scales, the PDFs do not collapse to a single PDF as shown in the insets of FIG. (1) and FIG. (2).

FIG. 3 shows peak of $p(Z_n)$ vs. n for the particle flux. For the first six scales, the peak is close to $p(Z_n=0)$. For larger scales, the peaks move towards the positive Z_n values, and hence

$p(Z_n =) \approx n^{-1/a}$ relation is not applicable. The re-scaled PDFs with α =1.33 for the first six scales are shown in the inset.

3. Confinement characteristics

The discharge parameters in the present experiments are: B_f= 0.75 T, *R*= 0.75 m, *a*=0.25 m, I_p=50-80 kA, $\langle n_e \rangle$= (8-16) x 10^{19}} m^{-3} and discharge duration of 50 to 100 ms. The plasma current is nearly constant during 35-65 ms. The energy confinement times, τ_E determined from the measured Ohmic power (200-300) kW, the radiated power (20-50 kW) and the heat content (300-600 J) are in the range 1-2.5 ms. The estimate of the total number of electrons in the discharge [(5-11)x10^{18}] is obtained from the μW-interferometry and that of the ionization rate [(2-6)x10^{21} s^{-1}] is obtained from the H_α intensity. The particle confinement time, τ_p determined from these estimates is typically 2 times the energy confinement time (τ_E).



Several other experiments have been carried out towards a common goal of improving plasma confinement. These are limiter biasing, gas puff and low-Z impurity injection. *FIG. 4* shows diagnostic signals when Li-C impurity has been injected at 46 ms into the ADITYA discharge. Increase in plasma density and impurity radiation and Soft X-ray emission can be observed simultaneously with decrease in H_α intensity for a duration of 4-5 ms. It is not yet confirmed that the increase in density is due to improvement in the confinement time. Similarly we have carried out limiter biasing experiment in which there is a clear reduction of fluctuations in floating potential measured by Langmuir probes. Detailed studies are being carried out and will be reported separately.

FIG. 4: Diagnostic signals in an experiment with Li-C impurity injection at 46 ms. The $\langle n_e \rangle$ unit is 10^{18} m^{-3}.

3. Preliminary RF Experiment

Ion Cyclotron Resonance Heating system at 20.0 – 40.0 MHz and 200 KW has been installed on ADITYA. Initial experiments relate to optimization of matching conditions at different frequencies. Antenna system is matched with RF generator using matching unit comprising stubs and phase shifters. Voltage probes (20 nos.) are placed in between antenna system and matching unit where VSWR is quite high. RF power coupled to the antenna has been optimized at 25.5 MHz. This is done off-line based on the signal obtained from the directional coupler positioned at load end and the signals from the twenty probes to measure the VSWR. Antenna current is measured using a calibrated current loop placed at the back plate of the antenna box.

A probe assembly consisting of electric dipoles, magnetic loops, Langmuir probes and capacitive probe is placed inside ADITYA vacuum chamber through radial port. This assembly can be moved by 50 mm to scan mainly SOL region. RF electric and magnetic field components are measured using dipoles and magnetic loops. The same heating system is being used in experiments of plasma breakdown and for preionization assisting ohmic breakdown. *FIG. 5* shows successful plasma breakdown with 100 kW ECRH system installed on ADITYA. The diagnostic signatures from optical light and Langmuir probe measurements show a plasma density of 5×10^{11} cm^{-3}.

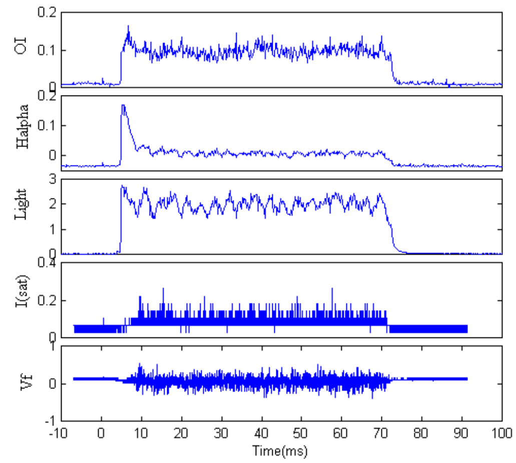


FIG. 5: Plasma breakdown in ADITYA using ECRH.

5. Concluding remarks

In conclusion, we have reported results of some recent experiments in ADITYA tokamak. The direct measurement of particle flux shows bursty nature. It is shown that edge fluctuations and fluctuation induced particle flux exhibit different scaling behaviors at short- and long-time scaling ranges. In the short time scaling ranges, the Lévy scale index, α=1.1-1.3. This indicates the dominance of coherent structures at these scales which can lead to convective transport. At longer scales, the value of α is close to 2 indicating that at those scales, fluctuation lead to diffusive transport. In addition, some new diagnostics have become operational which allow confinement studies. The measured τ_E is in the range 1-3 ms and τ_p is 2 times longer. Several experiments with limiter biasing, gas-puff and low-Z impurity injection is being carried out.The initial RF experiments demonstrates the launching of RF into ADITYA and feasibility of using it for initiation of discharge which may be of importance in our next generation tokamak (SST-1).

References

[1] P. Lévy , "Théorie de lAddition des Variables Aléatoires", Gauthier-Villars, Paris, (1937).
[2] R. Jha et al., "Evidence of Lévy stable process in tokamak edge turbulence", Submitted to Phys. Plasmas.