

Observation of Radial Propagation of Electrostatic Fluctuations in Edge Plasma of the Sino United Spherical Tokamak *

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Radial propagation of electrostatic fluctuations in the edge plasma of Sino-United Spherical Tokamak (SUNIST) has been measured using Langmuir probes. The propagation characteristics of the floating potential fluctuations are analysed by the two-point correlation technique. The results show radially outward propagation of the turbulent fluctuations at all measured radial positions. The power-average wave number profile is approximately constant in plasma edge region and suddenly increases to the limiter. These results are in good agreement with the model predictions proposed by Mattor which suggests that the drift wave propagation may be a source of edge turbulence.

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The goal of the Sino-United Spherical Tokamak (SUNIST) at Tsinghua University is to extend for understanding of toroidal plasma physics at a low aspect ratio (R/a approximate to 1.3) and to demonstrate maintainable target plasma by non-inductive startup. Initial discharges with 52 kA of plasma current, 6 ms of pulse length and 50 MA/s of ramp rate have been achieved easily with pre-ionized filament. As the first physical experiment in SUNIST, the electrostatic fluctuations in the edge plasma of SUNIST have been measured. The pilot study of the propagation of electrostatic fluctuations will be the first accumulation of database of edge experimentations.

The radial propagation of electrostatic fluctuations and the turbulence structure in magnetically confined fusion plasma and its role in cross-field transport have been a central topic over the past years.^[1,2] There have been a number of indirect^[3-7] and direct^[8,9] measurements. As one of the simplest but effective tools in edge plasma diagnostics, Langmuir probe has been used in many edge measurements^[6,8-10] for its high spatial-temporal resolving power and little disturbance to the plasma. In this Letter, we report the measurements of the radial propagation of the edge plasma turbulence by a hand-moveable Langmuir probe array in the edge of SUNIST.

The SUNIST has a major radius of 30 cm and minor radius of 23 cm. The normal ohmic hydrogen discharge parameters are toroidal magnetic field $B_T \approx 0.1$ T, plasma current $I_p \approx 20$ kA, and loop voltage $V_l \approx 4-6$ V. The edge plasma parameters vary with $n_e \approx 1-9 \times 10^{18} \text{ m}^{-3}$ for electron density and $T_e \approx 10-50$ eV for electron temperature.^[11]

The fluctuations of the floating potential were measured using the Langmuir probe array, consisting

of three Langmuir probes, as shown in Fig. 1. Probes 1 and 2, separated radially by 3 mm, were used to monitor the radial correlations in plasma floating potentials, and probes 2 and 3 were used to measure the poloidal correlations. All the probes are mounted on a moveable shaft. Each probe tip is made of tungsten, 1mm in diameter and 3 mm in length. All the tips were orientated off the field lines to avoid shadowing with each other. The probe array was mounted on the equatorial plane, the data were digitized at sampling rate of $0.5 \mu\text{s}$ with 12-bit resolution, using a multi-channel digitizer. The radial reach of the measurement spans from the scrape-off layer (SOL, $R \sim 60$ cm, here and hereafter R is the major radius) to the plasma edge ($R \sim 51$ cm).

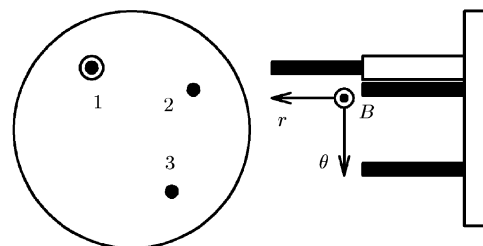


Fig. 1. Configuration of the probe arrays used to simultaneously measure the poloidal and radial wave number spectra.

Fluctuations of the plasma floating potential in ohmic discharges have been analysed with fast-Fourier-transform-based (FFT) technique, the wave number spectrum and the power spectrum, which are calculated by using the standard two-point cross-correlation technique method.^[12] Figure 2 shows the frequency spectra of the float potential fluctuations measured at two different radial positions (one from

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the edge $R = 51$ cm and the other from SOL $R = 57$ cm). Each spectrum is resulted from averaging over 20–40 samples from 10–15 shots. It clearly shows that the fluctuation power is primarily confined to frequencies $f \leq 200$ kHz, and for both the edge and the SOL cases the power spectra decay nearly in the same way. This feature can also be seen from Figs. 3(a)–3(d), which show the radial power-averaged statistical relation $k_r(f)$ and the wave-number spectral width $\sigma_r(f)$ at the same radial positions. In Fig. 3, both $k_r(f)$ and $\sigma_r(f)$ from two radial positions behave themselves in nearly linear function and there is $k_r(f) \sim \sigma_r(f)$ in the whole frequency regime. This indicates that the edge fluctuations on SUNIST are the fully developed turbulence.

Figure 4 indicates some evidence of the radial propagation of fluctuations. Here the positive radial wavenumber corresponds to the outward propagation direction. We can see that at all the measured radial positions the power-averaged wave number $\bar{k}_r > 0$, suggesting the radially outward propagation at all radial positions. This can also be seen from the radial profile of the radial phase velocity V_{phr} . Furthermore, we can see from Fig. 4 that the profile of k_r is approximately constant in the plasma edge and suddenly increases to the limiter. This trend seems to be consistent with the predictions of the drift wave propagation theory proposed by Mattor^[13] that an initially linear wave from core propagation to a low-density edge region breaks most possibly and becomes

turbulence in the edge.

Generally, the edge turbulence exhibits as a turbulent cell with some radial and poloidal size. This structure can be illustrated with the radial-poloidal wave-number spectrum and the radial and poloidal correlations lengths. Figure 5(a) shows a typical $S(k_r, k_\theta, f)$ spectrum at the radial position $R = 51$ cm. In the poloidal direction the fluctuations mainly propagate in the electron diamagnetic direction (positive poloidal direction). In the radial direction, the spectrum has components in both outside direction and inside

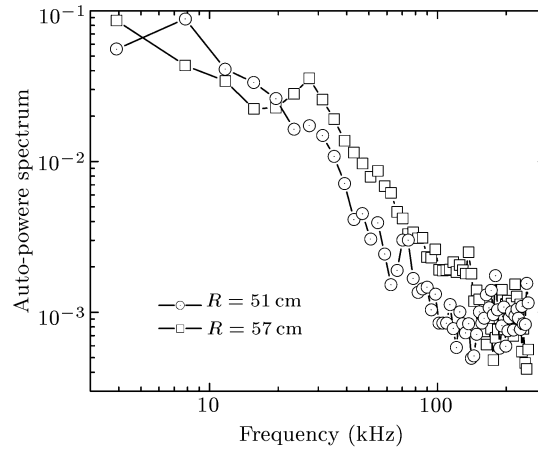


Fig. 2. Typical power spectra at $R = 51$ cm (edge) and $R = 57$ cm (SOL).

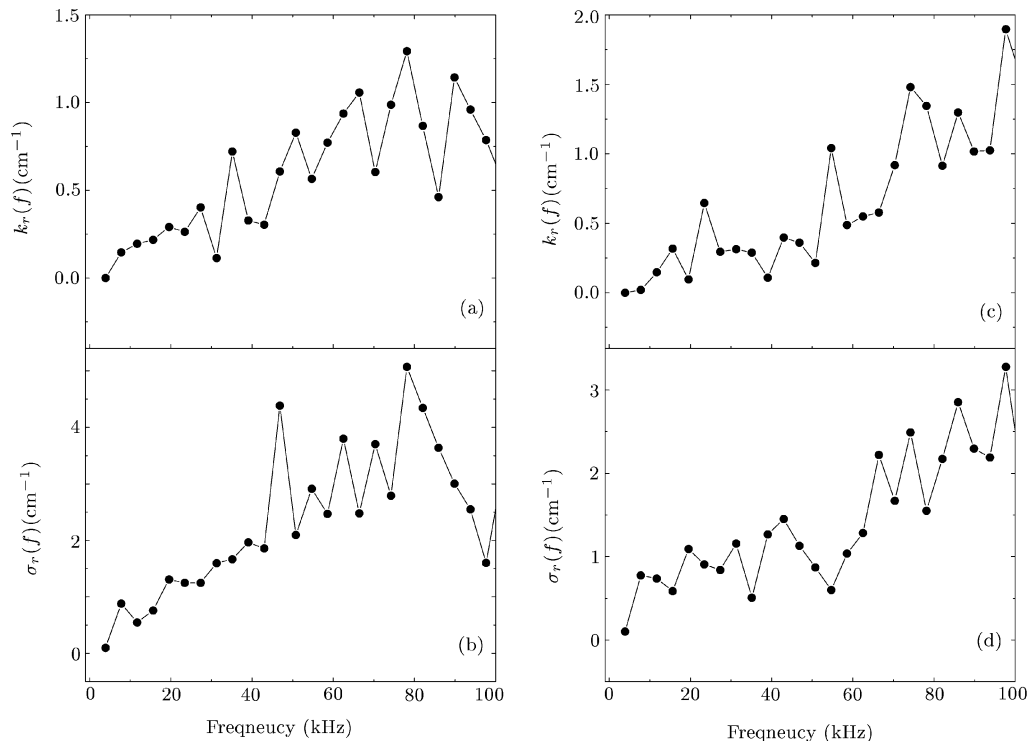


Fig. 3. (a) Radial power-averaged statistical relation $k_r(f)$ and (b) wave-number spectral width $\sigma_r(f)$ at the edge $R = 51$ cm; (c) $k_r(f)$ and (d) $\sigma_r(f)$ at the SOL $R = 57$ cm.

direction but most radially outwards. In other words, the turbulence indicates an anisotropy property in the plane perpendicular to magnetic field. This feature can be quantitatively described with the radial and poloidal correlation lengths (inverses of the wave number spectral widths, σ_{kr} and $\sigma_{k\theta}$, respectively). Figure 5(b) shows the profiles of the radial and poloidal correlation lengths l_{cr} and $l_{c\theta}$. It can be seen that throughout all the measured radial positions, there exists $l_{c\theta} > l_{cr}$. The turbulence is anisotropy in the plane perpendicular to magnetic field. Whereas $l_{cr}/l_{c\theta} \approx 1$ near the velocity shear layer ($R = 54$ cm). This may be related to the suppression effect of the $E_r \times B$ shear on the turbulence structure, as observed on the other tokamaks.^[8–10] The further analysis is underway.

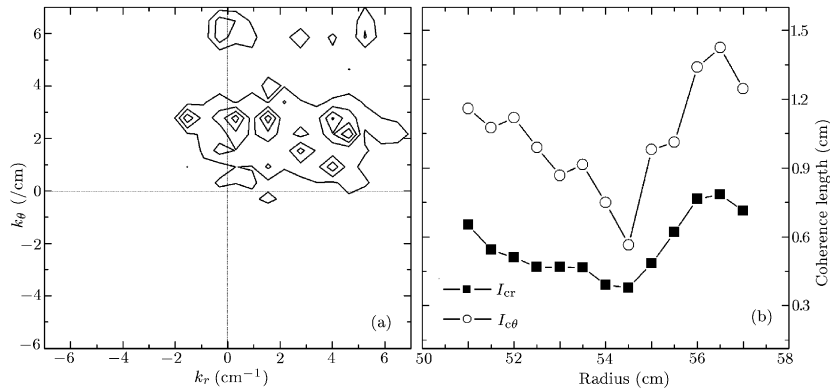


Fig. 5. (a) Contour plot of $S(k_r, k_\theta, f)$ at $R = 51$ cm. (b) Radial profiles of the radial and poloidal correlation lengths l_{cr} and $l_{c\theta}$.

It is noticed that a radial component of the poloidal propagation may contribute to the radial propagation under the conditions that the probes are set on different poloidal positions of the flux surfaces, as pointed out by Bleuel^[6] and Mattor.^[13] In our case, the probes are set on the outer side of the equatorial plane of the device, and the tips separation is much smaller than the device structure size, so the orientation of the poloidal tips is almost perpendicular to the radial plane and this error can be minimized.

In conclusion, we have observed the radial propagation of electrostatic fluctuations in the plasma edge of SUNIST. Similar to those found on other tokamaks, the radial average wave number distributes within $\bar{k}_r \leq 3$ cm⁻¹ for all the measured radial positions, suggesting a net radial outward propagation of the electrostatic turbulences. The results are in good agreement with the model prediction that the inner drift wave propagation could be a source of edge turbulence, and indicate the common characteristic of dif-

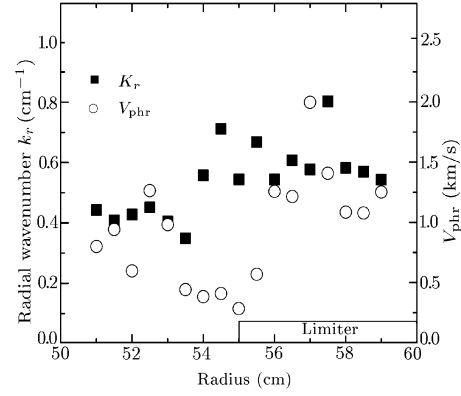


Fig. 4. Radial profiles of the power-averaged wave number \bar{k}_r and the radial phase velocity V_{phr} .

ferent magnetic confined devices.

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