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# Application of super - resolution method to Langmuir probe arrays

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**Abstract**

To study turbulence, high spatio - temporal resolution is required to resolve the involved processes. Experimentally, spatio - temporal diagnostic rely on 2D probe array. They are characterized by low spatial and high temporal resolution. This contribution describes a super-resolution (SR) algorithm which uses the high temporal resolution of the system to enhance the spatial resolution. The experiments have been conducted in a linear, magnetized low $\beta$ plasma device and investigate weak drift wave turbulence. To benchmark the SR - method a systematic comparison with traditional two point techniques (Conditional Averaging and Cross - Correlation Functions) is presented.

## Introduction

The plasma turbulence simulation have shown that high spatial and temporal resolution are needed to understand the various transport processes being involved in e.g. fusion devices [1]. Experimentally the plasma turbulence diagnostics is a difficult task. Common spatio-temporal diagnostics rely on electrostatic probes, i.e. 2D-probe arrays [2]. Their spatial resolution is limited by probe size, number of recording channels and plasma disturbance. Recently it was shown that a post processing Super-Resolution algorithm is able to improve the spatial resolution of turbulence [3]. It was shown that amplitude, trajectory and shape of structures involved in turbulence process are significantly improved by application of super-resolution algorithms.

At the moment, a sufficiently high resolution can be also obtained by statistical techniques, e.g. conditional averaging, cross correlation functions [4, 5]. However, the averaging process implies a loss of information namely only the average temporal evolution is observed which can be quite different. Besides this, the method has severe limitations, i.e. to detect small structures, to resolve correct amplitudes and hence to quantify transport properties [6].

In this paper super-resolved results from real experimental data sets (weak drift waves turbulence from KIWI experiment [7]) are systematically compared with traditional two point techniques (Conditional Averaging and Cross - Correlation Functions) results. All methods are applied to the same data set to allow for a quantitative comparison.

## Experimental setup

The experiments have been conducted in a linear, low magnetized plasma device (KIWI - Kiel Instrument for Waves Investigations) and investigate saturated drift waves modes as well as weak drift waves turbulence. The important feature of the KIWI is its steady state operation with stable plasma conditions for several hours which permits long time measurements with high temporal resolution [2, 7].

For spatio-temporal information about the plasma fluctuations a circular probe array consisting of 63 regular spaced probes is used (Fig. 1). In order to minimize the errors due to the probe size and position a calibration of the probe array is done. The position of the individual probe is estimated using a plasma beam created by a movable emissive probe inside of the vacuum vessel. A simple scaled pictures of the probe array is used to prove the probe position. The probes sizes are calibrated using the direct experimental information from monochromatic drift waves.

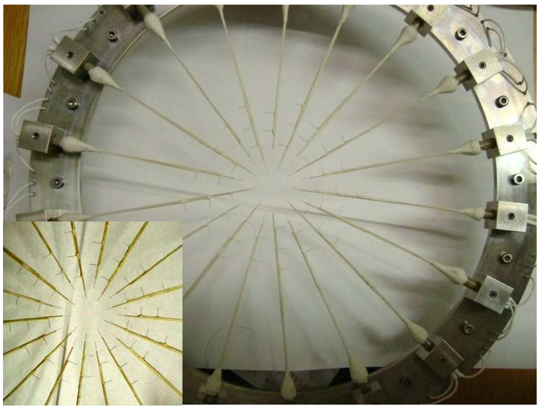

Figure 1: Picture of the 2D probe array. The 63 Langmuir probes are adjusted for a uniform spatial distribution.

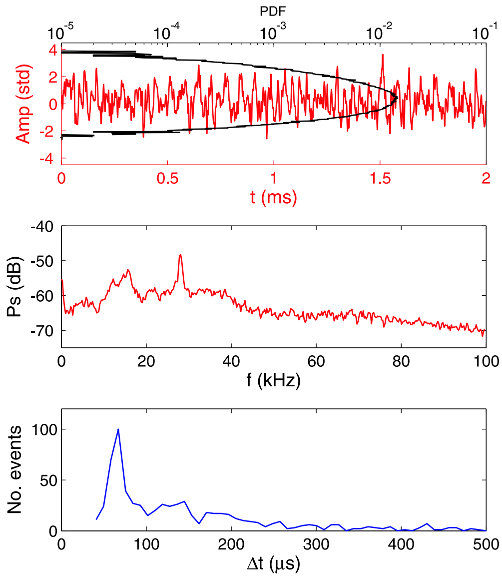


Figure 2: a) The normalized reference signal and probability density function (PDF) b) power density spectrum (Ps) c) the events statistics of the reference signal in CA processing

**Results**

The weak turbulence regime from KIWI experiment is analyzed using the super-resolution technique [3] and standard statistical methods, Conditional-Averaging (CA) and Cross- Correlation Functions (CC) on 2D probe array. The Probability Density Function (PDF) and the Power Density Spectrum (Ps) for the reference signal indicate the weak turbulence regime, Fig. 2. The Ps shows two main peaks, a broad peak at about 17kHz and a narrow peak at 30kHz. The 17kHz peak corresponds to the the peak of about 60$\mu$s (time delay) in the events statistics and indicate weak mode-like behavior of the turbulence regime.

Fig. 3 presents snapshots of turbulence evolution using these three methods. For the CC and CA images the reference signal is situated to the maximum amplitude fluctuations position at $\tau$=0$\mu$s in CC picture. The trigger condition for CA is chosen by considering a trigger level $\geq 2*\sigma$ (large events) and the positive signal slope.

The CA results shows a pronounced monopole-like structure having a maximum amplitude of about 0.04. The live time of the monopole (the time when the structure decays to half maximum amplitude value), is of about 20$\mu$s. CC, Fig. 3b, shows similar results with CA, [4] having the same monopole-like shape. The small time lag between CC an CA is caused by the trigger condition.

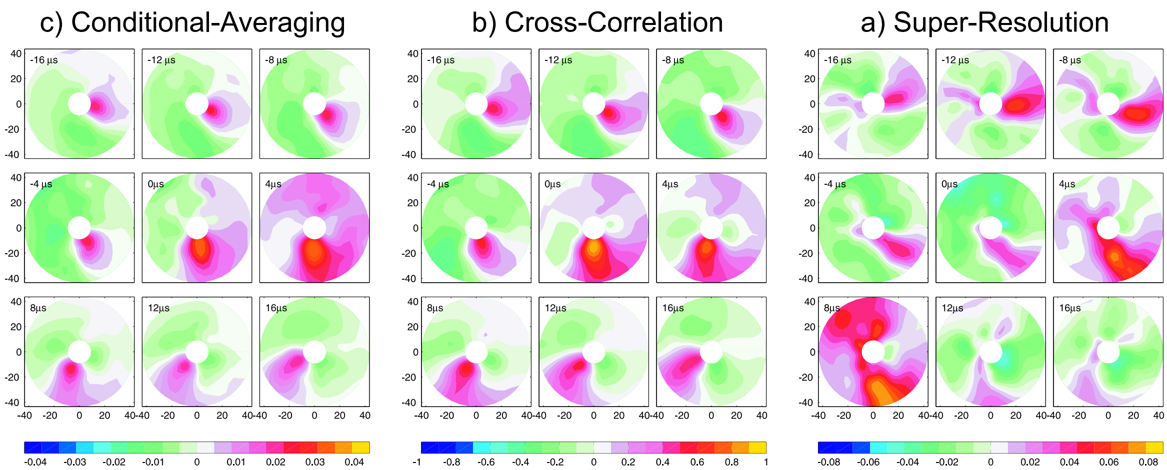


Figure 3: Snapshots on weak turbulence evolution in the KIWI experiment using: a) CA having the reference signal situated to the maximum amplitude fluctuations at about $\tau$=4$\mu$s b) CA having similar reference signal c) Super-Resolution. The color bars encode the absolute amplitude value with exception of CC. There, it represents the value of the cross-correlation function.

Super-resolution results shows a different time evolution with more that a structure (no monopole) having higher amplitudes (two time higher than CA result). If the monopole-like structure obtained by CA and CC have smooth circular shape by SR the shape is different.

As predicted [6] by CA and CC structures are smoothed and damped during the average process and smaller scale structures can not be seen any more. A similar analysis for CA and CC for different radial position of the the reference signal was done and we have found that the structure trajectory was changed. The super-resolved structure trajectory is not similar with CA and CC result. Dependence of the structure trajectory on reference signal spatial position is an other limitation of statistical techniques.

**Summary**

This paper presets a systematic comparison between the well known statistical techniques (Conditional-Averaging and Cross-Correlation Functions) and the novel method of Super- Resolution on weak turbulence experimental data sets from KIWI. It was shown that the super-resolution can be applied to improve the spatial resolution for a 2D probe array. The similarity between CC an CA results and the effects of the averaging process are visible.

**Acknowledgment**

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