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直線プラズマにおけるトモグラフィと Fourier-Bessel 展開を用いた構造解析

Structure analysis using tomography and Fourier-Bessel expansion in the linear plasma

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Plasma turbulence is a system of micro-scale fluctuations and meso- and macro-scale structures generated by the micro-scale fluctuations. Tomography is a method that can observe the fluctuations and structures in every scale. We have made a tomography system on a linear cylindrical device, named Plasma Assembly for Nonlinear Turbulence Analysis (PANTA)[1], and have obtained local emission profiles using a tomography algorithm, Maximum Likelihood-Expectation Maximization (ML-EM). The spatial structure of the ML-EM image can be analyzed using Fourier-Bessel series. Here we present the obtained results of ML-EM image and the decomposition with Fourier-Bessel series.

The experiments were performed in a cylindrical linear magnetized plasma device, PANTA in Kyushu University. The plasma has the diameter of 100 mm and axial length of 4000 mm. The magnetic field is 900 G and filling Ar pressure is 1 mTorr. In this study, we observed ArI emission with the wavelength around 810 nm. The device has four detector arrays that are installed on the position of different azimuthal angles with 45 degree interval. Each detector array contains 33 fiber channels, thus, totally 132 channels are prepared to obtain line-integrated emission of plasma. The channels in an array are aligned with 5 mm interval to face the plasma radially. The range of observation is from L = -80 to 80 mm, where L means distance from the center position of the detector array.

The ML-EM method is tomography algorithm to invert the line-integral data to local emission. The local emission distribution is obtained as the values on 121(=11x11) grids in the observation square (16 cm x16 cm) with the grid width of ~1.45 cm. The reconstructed images are calculated with parallel computing using 120 cores in every 1 μs. The image of ML-EM, $\varepsilon(r,\theta)$, is expanded with the Fourier-Bessel series to decompose mode structure as

$$\varepsilon(r,\theta) = \sum_m \sum_n [a_m^n \cos m\theta + b_m^n \sin m\theta] J_m(k_n, r) \quad (1)$$

where the coefficients a_m^n and b_m^n are found by least square fitting, and $J_m(k_n,r)$ is the Bessel function. k_n is selected for $k_n L$ to be the n-th zero point of the m-th order Bessel function. In the real situation, the number of fitting functions is limited, therefore, the number or the combination of the fitting functions should be optimized. For the purpose, we utilize orthonormal property of Fourier-Bessel function system. The content of a Fourier-Bessel function can be evaluated by the inner production between an ML-EM image vector and a vectorized Fourier-Bessel function. After the inner products are calculated, the least square fitting is carried out with varying the number of the fitting functions in descending order. The optimized number of the fitting function is determined using Akaike Information Criterion (AIC), which is defined as

$$AIC(N) = M \ln(\hat{\chi}^2) + 2N \quad (2)$$

where M and N are the number of data and that of functions, respectively, and χ is the residual error between the ML-EM and vectorized image of the Fourier-Bessel fitting.

Figure 1 shows examples of images obtained with ML-EM and Fourier-Bessel expansion. Based on the images, the inner products in descending order of the content are calculated as shown in Figs.2 (a) and (b), together with the corresponding AIC value and residual error χ^2, respectively. The AIC value takes a minimum at the optimized number N = 18 for this case.

Finally, we present the application result of the Fourier-Bessel series expansion to an MLEM image with a method to optimize the number and selection of the base functions. As a future work, the method should be applied on temporal sequential data of ML-EM images to obtain temporal behavior of spatial modes, *e.g.,* excitation, annihilation, and competition between them.

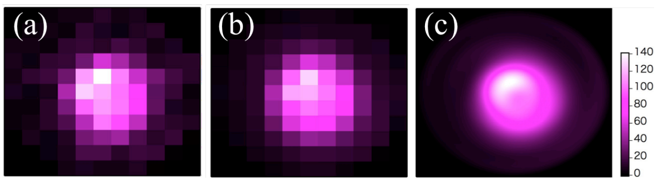

Fig.1(a) Reconstructed image of ML-EM, (b)vectorized image of Fourier-Bessel expansion. (c) Image is fitted Fourier-Bessel function when the AIC has a minimum value.

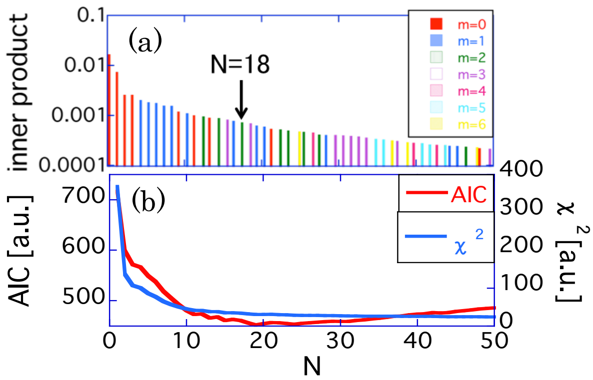

Fig.2(a) Inner products between image of ML-EM and Fourier-Bessel series (b) AIC and residual error ε^2

[1] S.Oldenbürger, et al., Plasma Phys. Control. Fusion **54** 055002 (2012)
[2] Y. Nagayama, J. Appl. Phys. **62**, 2702 (1987)