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Development of the Bayesian based Gaussian Process Tomography (GPT) method and its applications to fusion diagnostics

Dong Li[1], J. Svensson[2], T.B. Wang[1], Y.B. Dong[1], Liang Liu[1], W.L. Zhong[1] and Min Xu[1]

[1] Southwestern Institute of Physics, Chengdu, China

[2] Max Planck Institute for Plasma Physics, Teilinstitut, D-17491 Greifswald, Germany

e-mail (speaker): lid@swip.ac.cn

An advanced tomography method (Gaussian Process Tomography, GPT) based on Bayesian probability theory has been developed particularly for the data analysis of line-integrated measurements in fusion diagnostics [1, 2]. The practice of Bayesian formulism in this method allows the uncertainty of the reconstructions to be expressed in the probability form and thus brings benefits to scientists who concern the reliability of their analysis results. The Gaussian process prior is taken as an effective approach to smoothness regularization which can be optimized by the balance between model complexity and data misfit. Furthermore, to address the problem of varying smoothness in pace, a non-stationary version of the Gaussian process has been resolved via a Bayesian hierarchical algorithm model, and for the first time employed to impliment locally adaptive smoothness regularization so that the accuracy of the reconstruction can be improve significantly, as already confirmed by the simulation benchmark and comparison with other tomography methods [3].

The current work is carried out within a large size Bayesian inference framework (Minerva) [4]. The high flexibility of the GPT method enables a wide application in several fusion devices, including the latest implementation for the soft X-ray (SXR) [5, 6] and visible spectroscopic diagnostic on HL-2A tokamak [7]. In the former case, the SXR reconstructions provide important information on the spatial-temporal feature of MHD instability as shown in Fig. 1 and the impurity behavior associated with turbulent and neoclassical transport; in the latter case, reconstructions of the line and bremsstrahlung continuum emission can be used to study the impurity transport mainly related to particle recycling and plasma-wall interaction, and to estimate the effective ion charge Z_{eff} . Based on the previous work, more packets for the non-negative constraint by truncated GP [7] and the physical constraint by integrating magnetic equilibrium information [8] have been developed and applied under some specific circumstances for further accuracy improvement.

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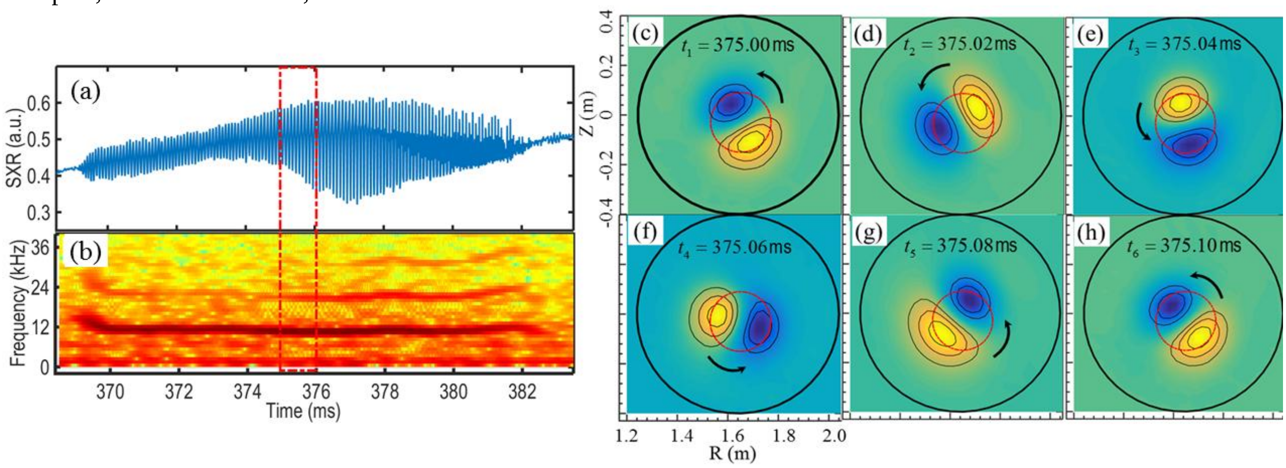

Fig. 1: (a, b) Observation of an internal kink mode in the form of fishbone oscillations in the phase of 0.8 MW NBI heating from shot #22493 on HL-2A. (c-h) Evolution of the m/n=1/1 internal kink mode during a rotation cycle resolved by the SVD analysis technique (The red circles indicate q = 1 surface).