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A Bayesian approach for estimating the kinematic viscosity model in reversed-field pinch fusion plasmas

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A fundamental feature of reversed-field pinch fusion plasmas is helical self-organized states. In the past few decades, MHD theory and numerical simulations have played a key role in describing these states. An important parameter is the dimensionless Hartmann number [1], which is determined by the resistivity and the viscosity. It can be interpreted as the electromagnetic equivalent of the Reynolds number and it turns out to be the ruling parameter in the 3D nonlinear visco-resistive magnetohydrodynamics activity. However, there is no consensus regarding the theoretical model for the kinematic viscosity coefficient.
There are five candidate models according to the various momentum transport theories developed for hot magnetized plasmas: three classical viscosities derived from the closure procedure leading to the Braginskii equations, the ion temperature gradient viscosity, describing a mode that damps the velocity fluctuations, and the Finn anomalous viscosity according to the Rechester-Rosenbluth model.
We calculated the viscosities and the Hartmann number using measurements from RFX-mod. A power-law dependence was then sought between the Hartmann number and the amplitude of the m = 0, 1 secondary modes. Our approach, using Bayesian statistics, outperforms the previous analysis based on simple least squares fitting.
First, by computing the Bayes factor [2], we inferred that a constant relative error is a better model for the uncertainty in the regression analysis. Second, errors on the plasma parameters and their role in error propagation were taken into consideration. Third, Bayes factors between the different viscosity models were used to infer the optimal viscosity model, in a more robust way compared to the earlier approach based on correlation coefficients and simulations.
The optimal model, identified through the Bayesian procedure, agrees with physical motivation [3]. More generally, our work has demonstrated the potential of the Bayesian approach in other model selection problems in fusion, using a rigorous and robust statistical methodology.

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References:

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