DPP20-2020-000208
Abstract for an Invited Paper
for the DPP20 Meeting of
the American Physical Society

**Experimental observations on energy flow from low frequency electromagnetic components to broadband turbulence via nonlinear couplings during ELM crashes**[1]

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It is well known that transport levels during ELM crashes are much larger compared to the inter-ELM phases, which have been explained based on linear stability criteria, e.g. reduction of shear flow rates, and formation of stochastic magnetic fields. In this work, we show that nonlinear coupling is an additional factor causing increased fluctuation levels during the ELM crashes. More specifically, we find that low frequency (<15 kHz) density fluctuations contain electromagnetic components (based on second-order spectral analyses with magnetic field fluctuations), which transfer energies to broadband (<100 kHz) density fluctuations via nonlinear interactions. Such nonlinear interactions are not observed during the inter-ELM phases. Density and magnetic field fluctuations are measured by a 2D beam emission spectroscopy and a Mirnov coil, respectively, in KSTAR. Existence of nonlinear couplings between two different frequencies are identified based on bicoherence, while the direction of energy flow is found using the Volterra series. These findings are based on a conditional ensemble average scheme applied to 2,660 ELMs obtained from three different long ELMy H-mode KSTAR discharges. The results of this study indicate that one must include the effect of nonlinear couplings, which exist only during ELM crashes and not during inter-ELM phases, between low frequency electromagnetic component and broadband fluctuations to understand the transport phenomena during ELM cycles.

[1]This research is supported by National RD Program through the National Research Foundation of Korea funded by Ministry of Science and ICT (Grant Nos. NRF-2020M1A7A1A03016161 and NRF-2017M1A7A1A01015892).