Visualization of complex physics of the MHD instabilities in tokamak via 2D Electron Cyclotron Emission Imaging

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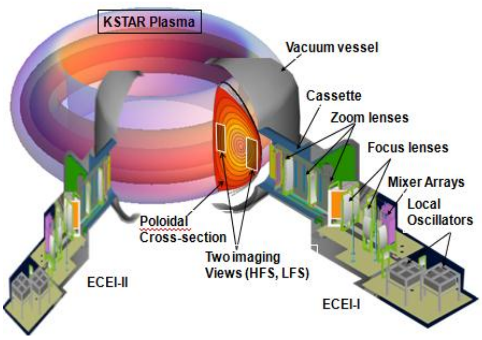
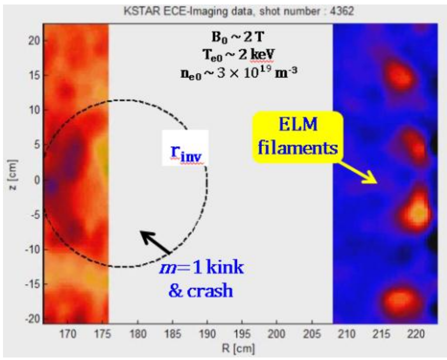
Following the first observation of the crash at the high field side in TEXTOR [1] provided the basis for the *random* 3-D local reconnection model for the sawtooth crash phenomenon, the 2D structure of Alfvén eigenmodes from the reverse shear regime in DIII-D discharge is a significant outcome. The results from the 2010 Korean Sueperconducting Tokamak Advanced Research (KSTAR) campaign confirmed the results obtained from DIII-D as well as TEXTOR. On KSTAR, there are two toroidally separated multi-point (one system has 24 poloidal $\times$ 8 radial positions and the other has two of 24x8 channels) Electron Cyclotron Emission Imaging (ECEI) capable of measuring 3-D images of the temperature fluctuation as shown in Fig.1a. In addition Microwave Imaging Reflectometry (MIR) capable of measuring 2D density fluctuations is commissioned in 2012. Both systems demonstrated the unprecedented advantage of high temporal and spatial resolution of 2-D images over the conventional 1-D data in studies of the physics of density turbulence and various MHD physics such as the sawtooth crash, tearing mode and edge localized modes (ELM). The first simultaneous measurement of the core m=1 mode and edge localized mode (ELM) as illustrated in Fig.1b, opened the door for study of interrelationship between spatially separated MHDs.



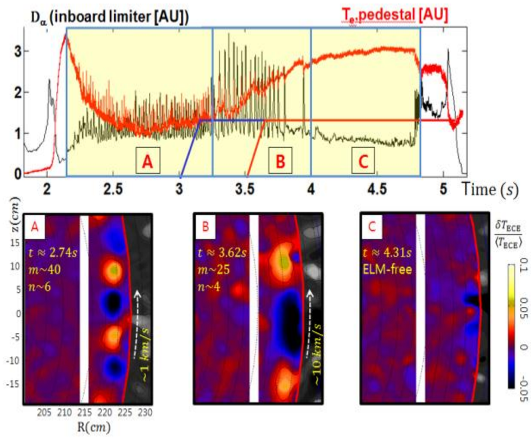
(a)



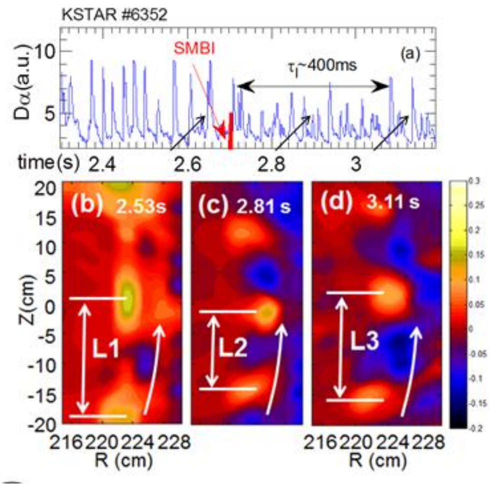
(b)

Fig.1 (a) Two toroidally separated ECEI systems on KSTAR. ECEI-I has two independent views that are capable of measuring two views simultaneously. ECEI-II has a single view of ECEI and MIR system to measure 2D density fluctuations. (b) Simultaneous measurement of the core m=1 mode and edge localized mode (ELM) by the ECEI-II system.

The 2-D ECEI system in KSTAR successfully characterized the real time dynamics of the entire evolution of the ELM [2] in KSTAR campaigns (2010 and 2011). This includes the growth, saturation and bursting process of this instability. In the 2011 KSTAR campaign, the external actuators such as Resonant Magnetic Perturbation (RMP) coils with n=1 structure and Supersonic Molecular Beam Injection (SMBI) has been applied to suppress or mitigate the instability. In KSTAR H-mode operation, the experimentally observed dynamics of ELMs revealed a semi-exponential growth rate of ~100 μs before it is saturated. During the saturation phase, the observed rotation speed was ~1km/s in the electron diamagnetic direction. Note that the observed rotation speed can be a combination of poloidal, toroidal and flow speed of the mode. After a relatively long saturation period of ~10 ms where the average mode size does not grow, the mode goes into a bursting process. The bursting process is observed to be highly non-linear and localized in poloidal and toroidal plane.



(a)



(b)

Fig.2 (a) The time evolution of the ELM during RMP experiment. Upper time traces: D_α signal and edge T_e. (A)-Image of the ELM before the RMP power is applied, (B)-intensified ELM image during RMP phase, (C)-Image during the suppression phase of the ELM. (b) The time evolution of the ELM during SMBI experiment. (b) D_α signal(a) Image of the ELM prior to the SMBI(b) EM structure during the SMBI(c) Recovery phase of the ELM(d)

For ELM control in KSTAR, actuators such as the RMP coils with various toroidal mode numbers and SMBI have been introduced and the responses have ranged from mitigated state to full suppression. In the KSTAR 2011 campaign, significant efforts were made to control the ELMs. The observed base line ELM dynamics were identical to those discussed in previous section and are shown in phase A of Fig.2. When the current level in the RMP coil with an n=1 configuration was increased above a critical value of ~1.5 kA, a significant alteration of the ELM mode structure was observed as shown in phase B in this figure. As the RMP power is applied, the size and intensity of the ELM are increased and the toroidal mode number is changed from n~10 to n=5. Initially, the pedestal temperature is increased and this is an indicative of a broadened pedestal width that can allow more room for the ELM to grow in size and intensity. Through the altered stage of ELMs, the instability is completely suppressed as shown in phase C. When SMBI was introduced to control the ELMs, there was a clear indication of a mitigation process in which the intensity was reduced and the ELM mode structure was changed as shown in Fig. 2b. Note that such change of the poloidal mode spacing can be interpreted as a sensitive dependence of the mode number on the local q value change due to the bootstrap current induced by changes of the pressure gradient and collisionality

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References:

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[2] G.S. Yun, et al., Phys. Rev. Lett., Vol. **107**, 045004, 2011