Frequency slowly-sweeping Alfvenic modes on the HL-2A tokamak

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Abstract

- Two kinds of frequency slowly-sweeping Alfvenic modes, i.e., reversed shear Alfven eigenmodes (RSAEs) and high frequency modes ranging 500-100kHz, have been found on the HL-2A Tokamak.
- The RSAE with frequency sweeping-up or down are drive unstable by passing fast ions and those modes resonant with thermal ions, then lead to a heat transport process, and finally cause a drop in ion temperature.
- The high frequency modes are usually excited in the high density discharges and characterized by multiple bands of modes with mean frequency decreasing steadily in time. The mode evolution may be determined by formation of ITB and play a role on particle transport.

Background

- Interactions between energetic particles (EPs) and shear Alfven wave (SAW) have become a major concern in magnetically confined fusion researches. Amount of energetic particle driven Alfvenic modes, have been predicted and confirmed in both theoretical or experimental frames and found to played a negative or a positive role in the performance of fusion plasmas. To better understand of Alfvenic events and reveal their effects on plasma confinement, more attentions should be paid to the underlying mechanisms of excitation, saturation and damping through experimental verification associating with numerical simulations and analytical theory.

Reversed Shear Alfven Eigenmode and MHD spectroscopy

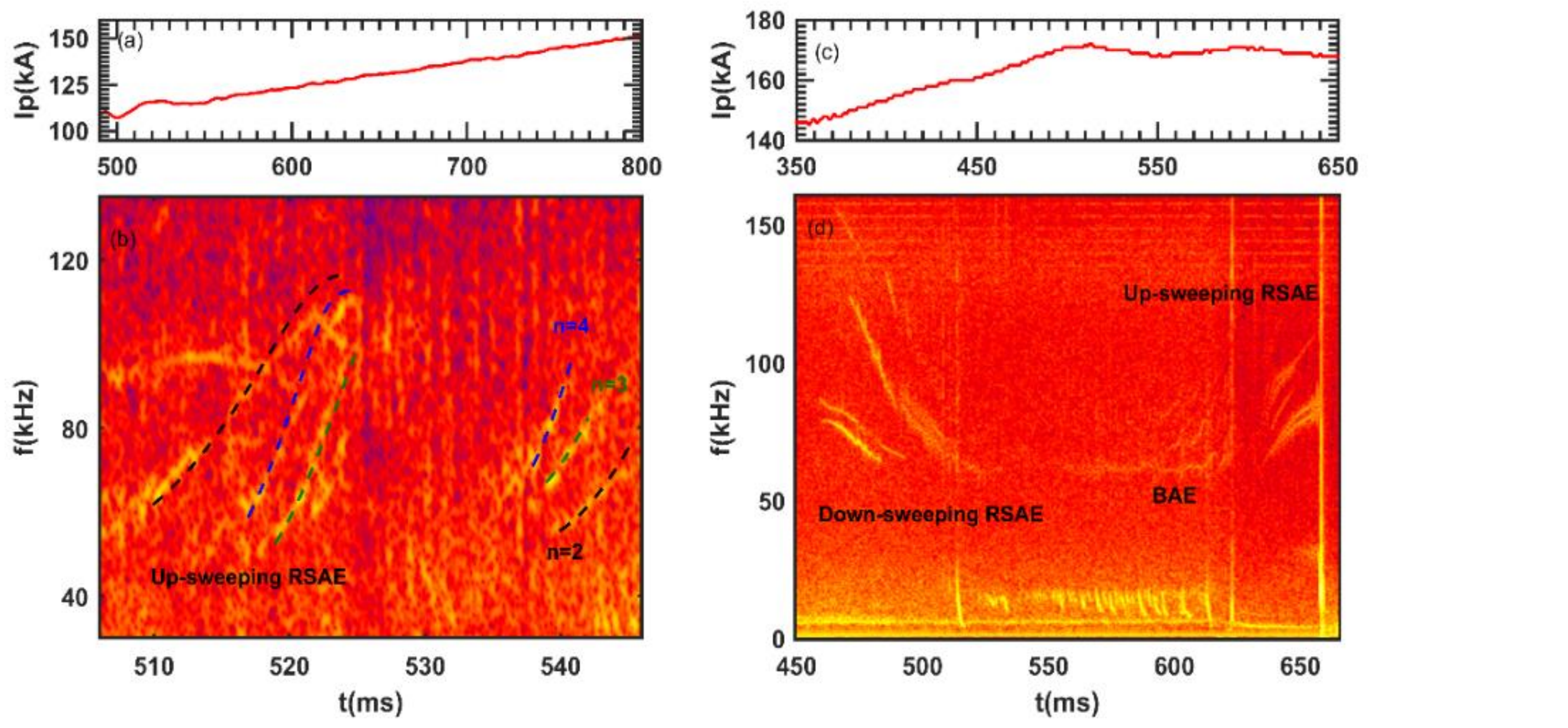


FIG.1. Up-sweeping and down-sweeping RSAEs during plasma current ramp-up phase on HL-2A tokamak. The plasma currents are plotted at (a) and (c) , respectively.

- Both down sweeping and up sweeping RSAEs have been observed during current ramp-up phase in HL-2A neutral beam injection heated plasma.
- The RSAEs are driven unstable by passing fast ions and localized nearby q=1 rational surface. The most unstable toroidal mode numbers are n= 2-4 for the up-sweeping RSAEs while n=2-6 for the down-sweeping modes.
- Kinetic Alfven eigenmode code analysis suggests that the down-sweeping modes are kinetic RSAEs and the up-sweeping modes are conventional RSAEs.

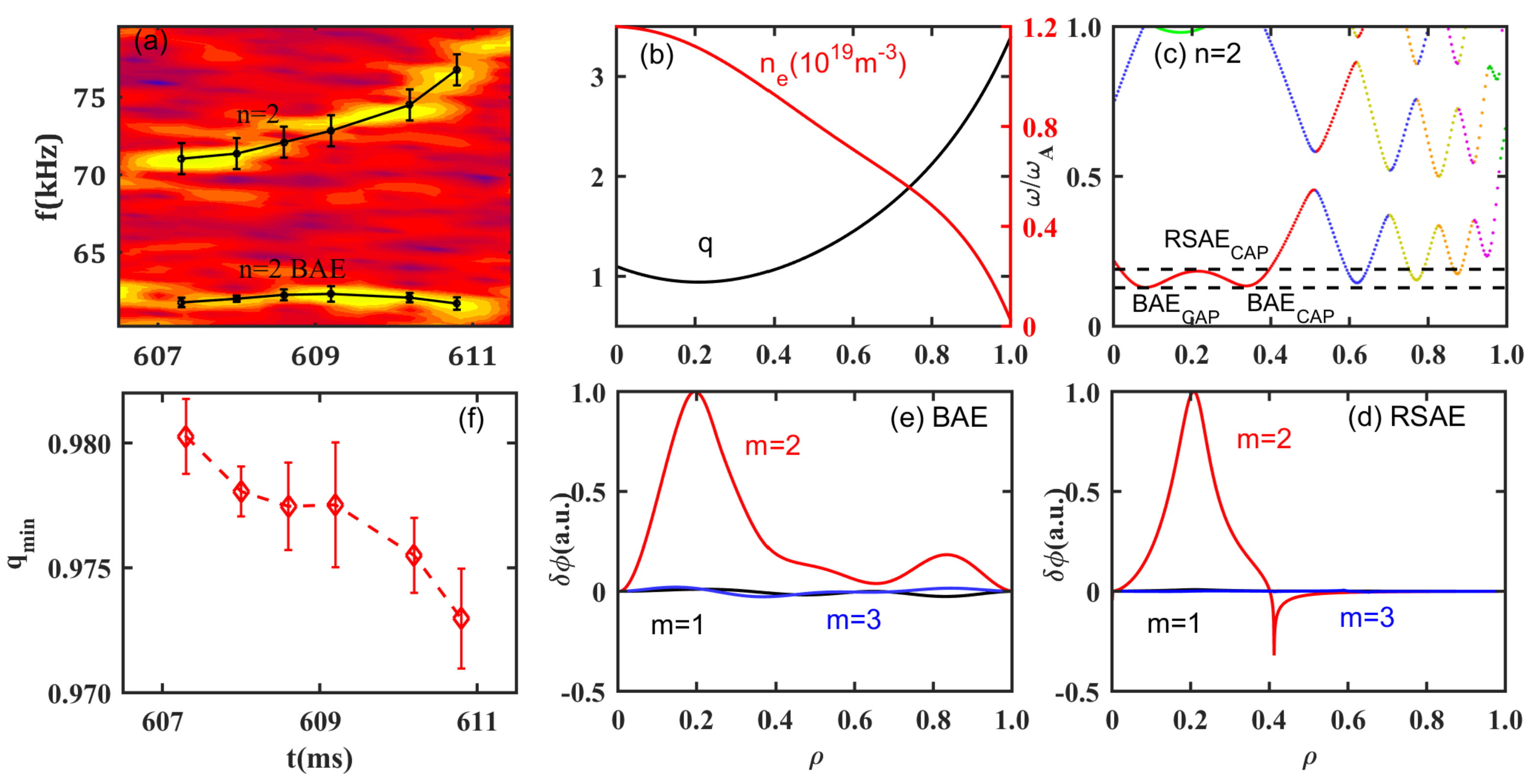


FIG.2. (a)Close-up image of Fig.1(d) during 606.5-611.5ms, (b)electron density and safety factor profile, (c) Alfven continuum calculated with toroidal mode number of n=2, radial mode structure of (d) RSAE and (e) BAE, (f)the minimum safety factor obtained from during coexistence of bate induced Alfven eigenmode and RSAE.

- The RSAE frequency is expressed by $\omega_{RSAE}^2 = \frac{{V_A}^2}{R^2}(n - \frac{m}{q_{min}})^2 + \omega_{BAE}^2 + \delta\omega^2$.
- The m/n=2/2 BAE indicates the existence of q=1 rational surface and the RSAE signifies the change of q_{min}. the q_{min} are below unity and decline from 0.98 to 0.972 during coexistence of BAE and RSAE.

Thermal Ion Heat Transport Induced by RSAE

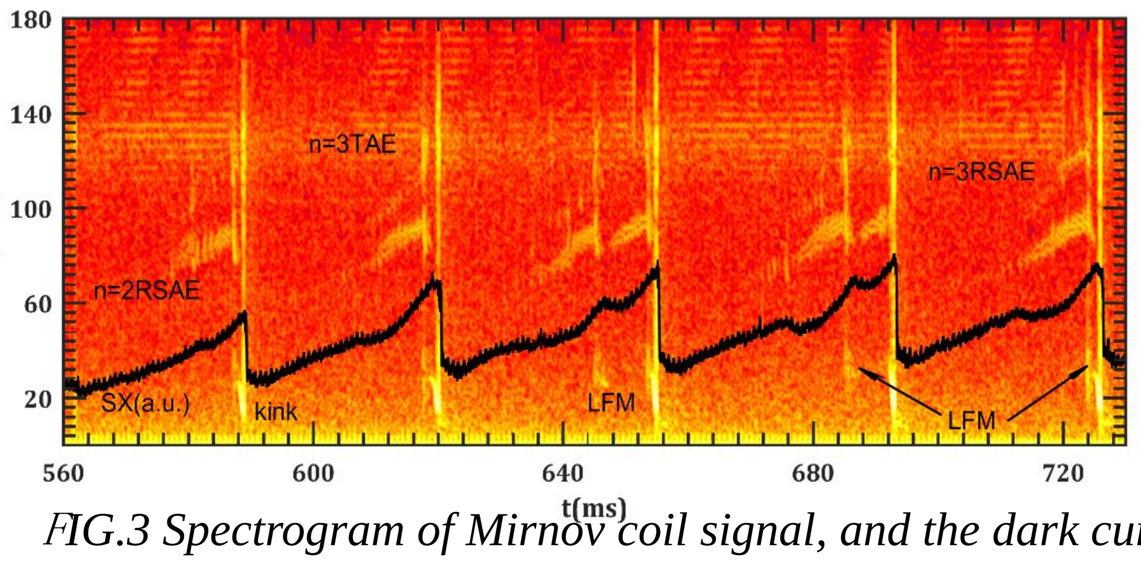
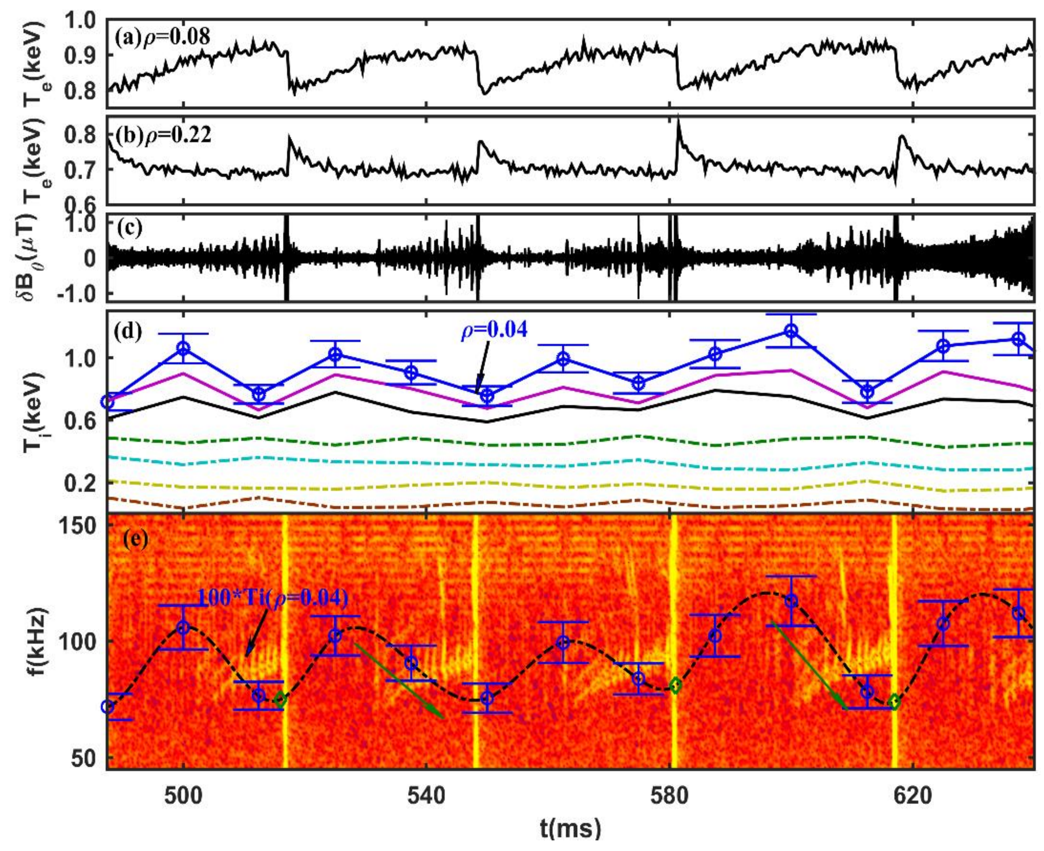


FIG.3 Spectrogram of Mirnov coil signal, and the dark curve is the soft-x signal. TAEs, RSAEs, kink modes and low frequency modes have been marked out.

- The soft-x signal fall down when the RSAEs are driven unstable in core. And bremsstrahlung radiations change may indicate redistribution of thermal particles.



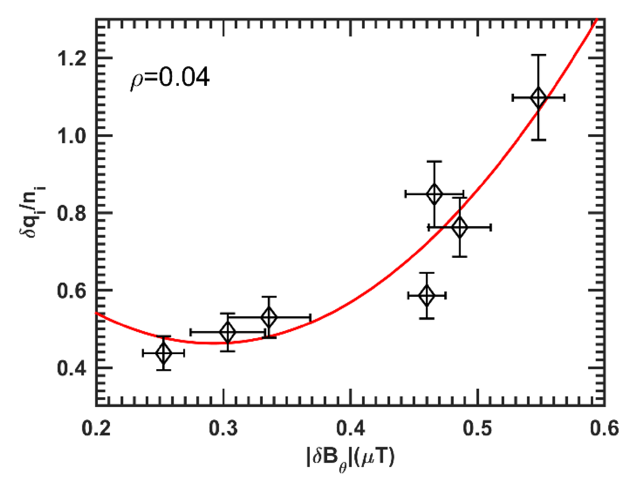


FIG.5. The relation of ion heat flux perturbation at $\rho = 0.04$ normalized by the ion density $\delta q_i/n_i$ to amplitude of magnetic fluctuation δB_θ

FIG.4. The temporal electron temperatures detected by ECE radiometer at locations of (a) $\rho = 0.08$ and (b) $\rho = 0.22$. (c)Magnetic signal filtered by the numerical filter with frequency of 65-85kHz. (d)Ion temperatures obtained from CXRS at multiple positions. (e)Spectrogram of Mirnov coil signal for shot 22484, the ion temperature ($\times 100$) at $\rho = 0.04$ and the corresponding fitting curve are also plotted.

- T_i declines when the RSAEs are driven unstable during sawtooth activities.
- the resonance condition between RSAEs and thermal ions $\omega_0 - k_\parallel V_\parallel - \iota\omega_{ti} = 0$ is satisfied and the change rate of energy and angular momentum $\frac{\dot{E}/E}{\dot{P}_\phi/P_\phi} = 0.45\text{-}0.64$ suggest the thermal transport play a dominant role during RSAEs evolution.
- The ion heat flux perturbation evaluated by $\delta q_i = -\frac{1}{r}\int_0^r \frac{3}{2} n_i \frac{\partial \delta T_i(r,t)}{\partial t}\rho d\rho$ shows a quadratic dependence on amplitude of magnetic fluctuation induced by RSAE.

High Frequency Slowly-Sweeping Alfvenic Mode

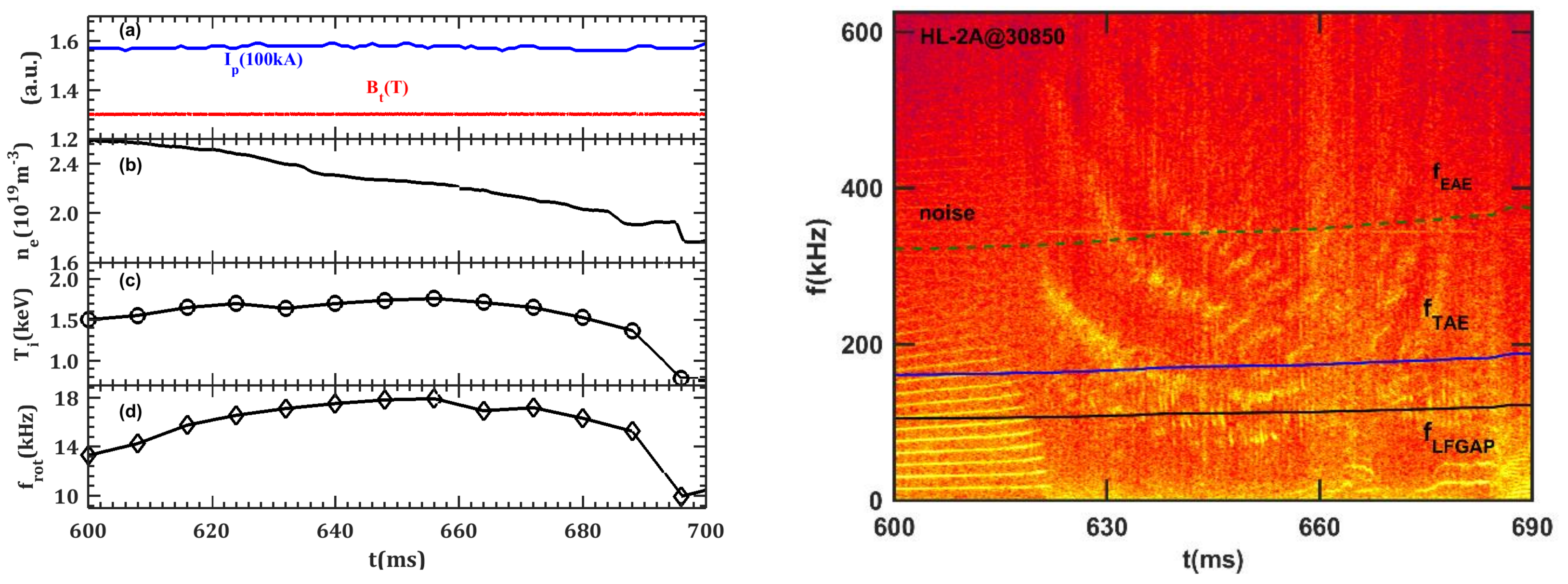
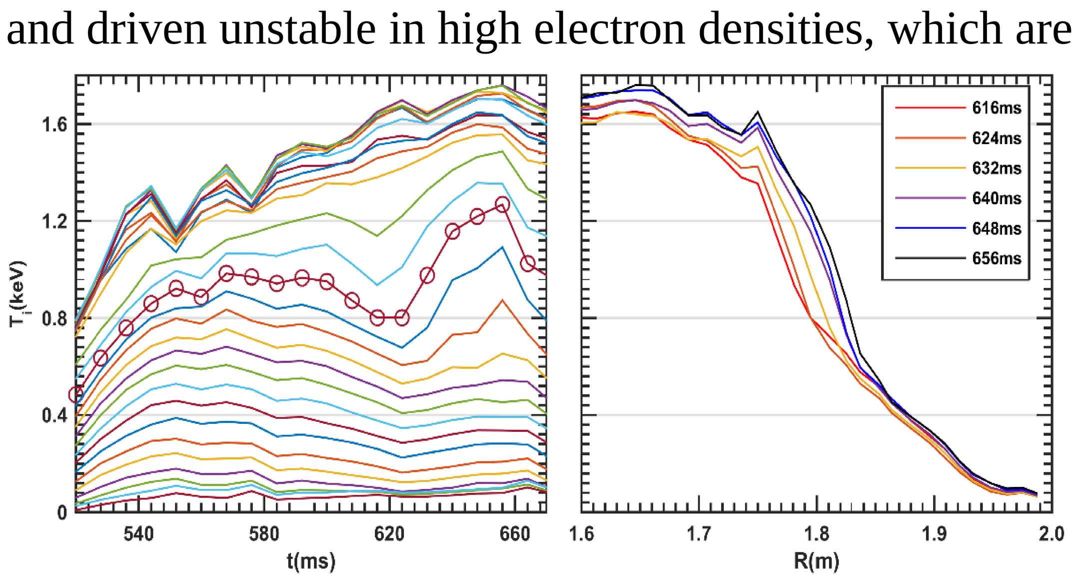


FIG.6. The temporal evolution of discharge parameter and the spectrogram of W-band microwave interferometer.

- Those modes are characterized by multiple bands of modes with mean frequency decreasing steadily (from 500kHz to lower frequency gap accumulation point) in time and driven unstable in high electron densities, which are higher than $0.7n_{GW}$.



- The ion temperature and its gradient increases when the high frequency modes slowly sweep down during 616-656ms. Meanwhile, the ITB root spread outside gradually.

FIG.7. Temporal evolution of ion temperature and its profiles during 616-656ms

Conclusion

- Thermal ions heat transport induced by energetic particle driven RSAE was firstly observed on HL-2A tokamak.
- The high frequency characterized by multiple bands of modes with mean frequency decreasing steadily in time may closely relate to formation of ITB and further study are needed in the future.

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