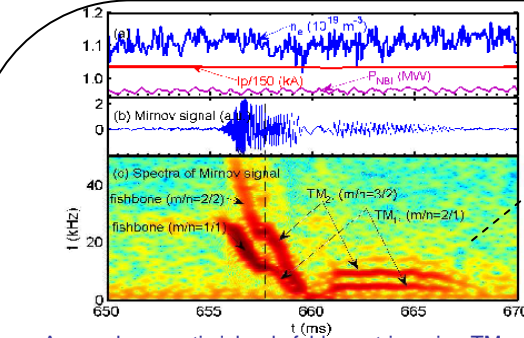
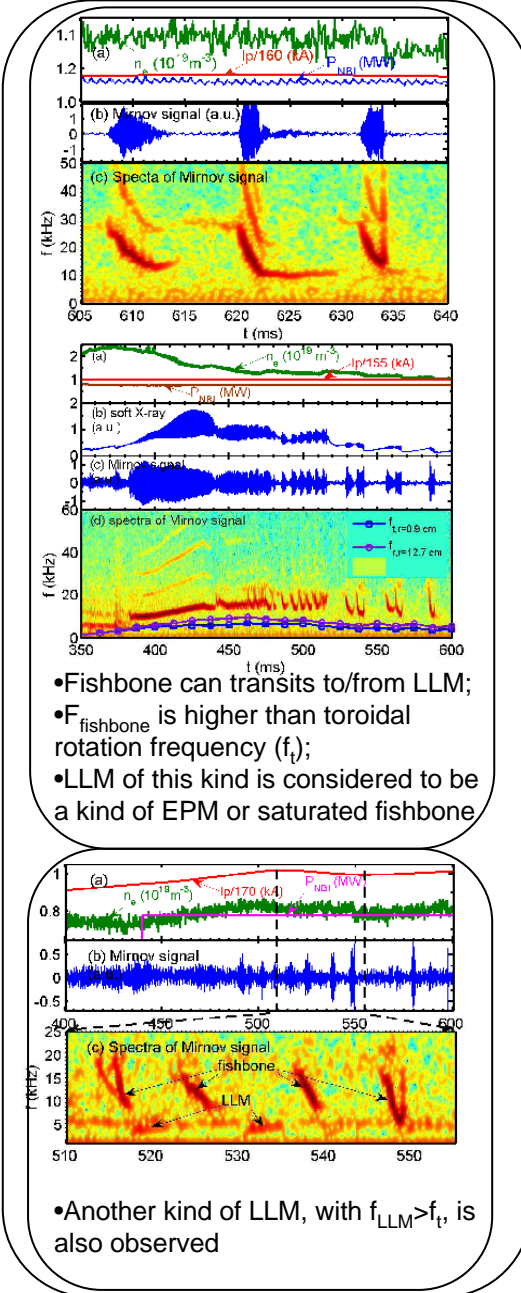


Transition and Interaction of Low-Frequency MHD Modes during NBI Heating on HL-2A

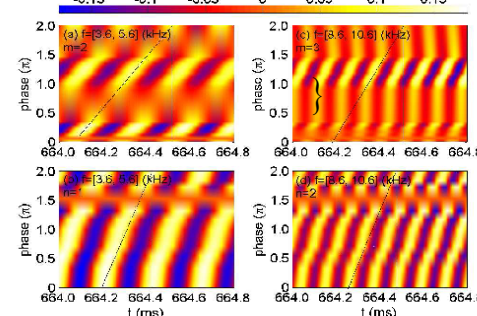


As seed magnetic islands fishbone triggering TMs

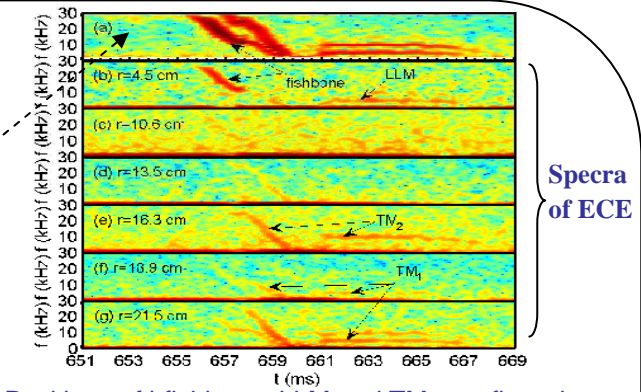
Discharge parameters:

$I_p \approx 154 \text{ kA}$, $n_e \approx 1.2 \times 10^{19} \text{ m}^{-3}$, $B_t = 1.32 \text{ T}$, $P_{\text{NBI}} = 0.95 \text{ MW}$, with $E \approx 40 \text{ keV}$

- TMs follow fishbone tightly and continuously;
- Frequencies of two TMs keeps as 5 and 10 kHz.



- For TM1, $m/n=2/1$; For TM2, $m/n=3/2$;
- TMs propagate ion diamagnetic direction.

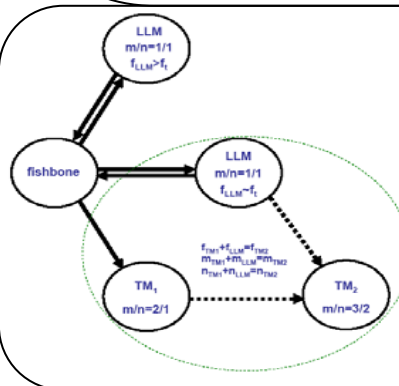


Positions of i-fishbone, LLM and TMs confirmed by ECE

- TM2, $r=16.3 \text{ cm}$; TM1, $r=21.5 \text{ cm}$;
- LLM locates on the core, with $r \approx 4.5 \text{ cm}$, $f_{\text{LLM}} = f_{\text{TM1}}$.

$$\begin{aligned}
 f_{\text{LLM}} &= 5 \text{ kHz} & f_{\text{TM2}} &= 10 \text{ kHz} \\
 f_{\text{TM1}} &= 5 \text{ kHz} & f_{\text{LLM}} + f_{\text{TM1}} &= f_{\text{TM2}} \\
 \text{LLM: } m/n &= 1/1 & \text{TM2: } m/n &= 3/2 \\
 \text{TM1: } m/n &= 2/1 & m_{\text{LLM}} + m_{\text{TM1}} &= m_{\text{TM2}} \\
 & & n_{\text{LLM}} + n_{\text{TM1}} &= n_{\text{TM2}}
 \end{aligned}$$

The $m/n=3/2$ TM may be formed by coupling between $1/1$ LLM and $2/1$ TM.



1. Fishbone and LLM can transit to each other;
2. There are two kinds of LLM:
 - a). EPM or saturated fishbone, with $f_{\text{LLM}} > f_t$, but $f_{\text{LLM}} \sim f_p$ (precessional frequency);
 - b). kink-interchange mode, driven by gradient of pressure, with $f_{\text{LLM}} \sim f_t$;
3. Fishbone and its harmonic as seed magnetic islands can trigger TMs, with $m/n=2/1$ and $3/2$;
4. Nonlinear interaction between fishbone, LLM and TMs are observed.