Direct RF heating of thermal ions using HHFW antenna

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PPPL, 2007

Particle orbits in large amplitude waves may become stochastic

- Theoretical concept dates back to 70's; was applied to a variety of modes*

- First(?) and only(?) experimental observations of stochastic heating were from current driven drift-Alfvén wave using LIF Ti measurement.

- Key question: How much power to reach threshold?

- Early theoretical history
  - '75 Smith&Kaufman proposed stochastic ion heating by oblique ES wave
  - '77 Karney&Bers, stochastic ion heating by perpendicular ES wave
  - '78 Karney, ion heating in lower hybrid wave
  - '79 Hsu,Matsuda,Chu&Jensen, parallel standing wave
  - '81 Drake&Lee, Lower hybrid drift wave and multiple waves

- Experimental documentation of stochastic thermal ion heating:
  - '87&'91 McChesney,Stern&Bellan, stochastic ion heating with drift-Alfvén wave
  - '93&95 Bailey,Bellan&Stern, thermal-ion equilibrium distributions
  - '98 Sanders,Bellan&Stern, transport effects on distribution function
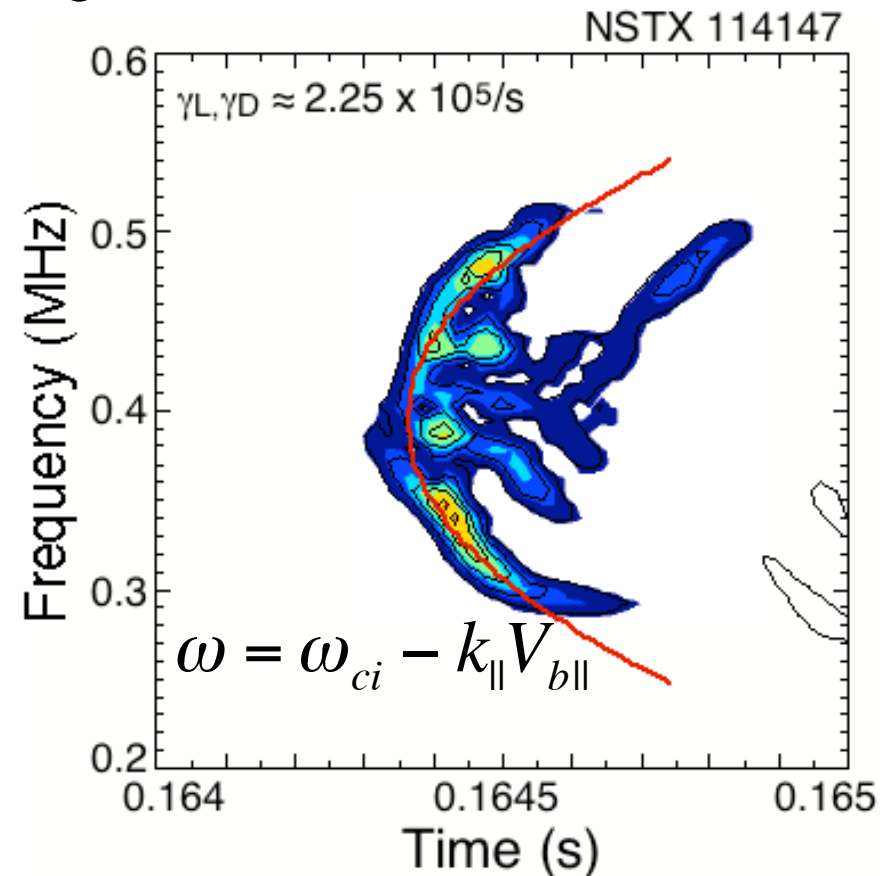
Stochastic Heating Milestones

- Phase I
  - Identify eigenmode spectrum and damping rates.
- Phase II
  - Measure antenna coupling to eigenmodes
  - Excite and measure eigenmode amplitudes
  - Estimate power required to reach stochastic ion heating threshold.
- Phase III
  - Construct stochastic heating RF system

Technique to measure damping rates has been developed

- Growth rate, $\gamma_L/\omega \approx 5.3\%$ in agreement with Nova $\gamma_L/\omega \approx 4\%$.

- More extensive scaling of damping rate to be done.

- Mode amplitude
  - $\delta n/n \approx 1\text{-}5 \times 10^{-4}$,
  - $\delta B_{rms} \approx 1\text{-}5$ G
- Damping rate, 2×10^5/s
- Estimate 10's kW to excite present modes.
  - Most power goes to electrons

NSTX 114147

$\gamma_L, \gamma_D \approx 2.25 \times 10^5$/s

$$\omega = \omega_{ci} - k_{\parallel} V_{b\parallel}$$

Frequency (MHz) vs Time (s)

Linear damping sets threshold heating power to reach stochastic level

- Linear damping rate determines power level required to reach stochastic threshold

- Low linear damping rate also important to reduce fraction of power heating electrons.

- Stochastic threshold is ≈20 modes with amplitude of 2-4 G, $\delta B_{rms} \approx$ 10-20 G. (Gates, et al.),

- Power to reach stochastic threshold is 0.25 MW to 1 MW?

Next Steps:

- Measure mode coupling to antenna.
- Launch waves by beatwave excitation in ohmic plasma?
  - Provides measure of damping rate.
- Launch waves at low power - document with reflectometers.
  - Provide direct measure of coupling efficiency.
- Develop better estimate of stochastic threshold amplitude.