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Numerical investigation of energetic particle driven interchange mode in LHD

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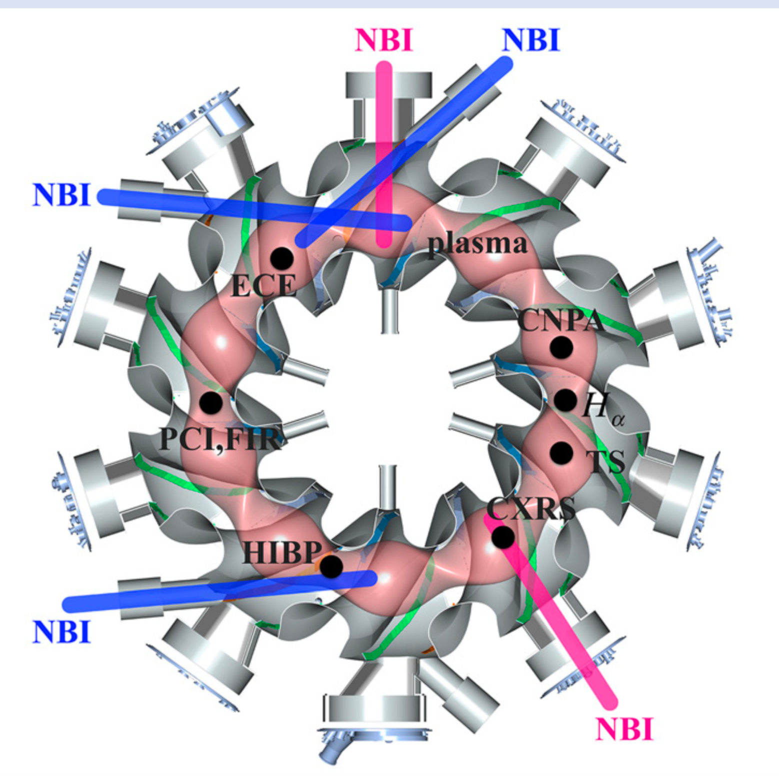
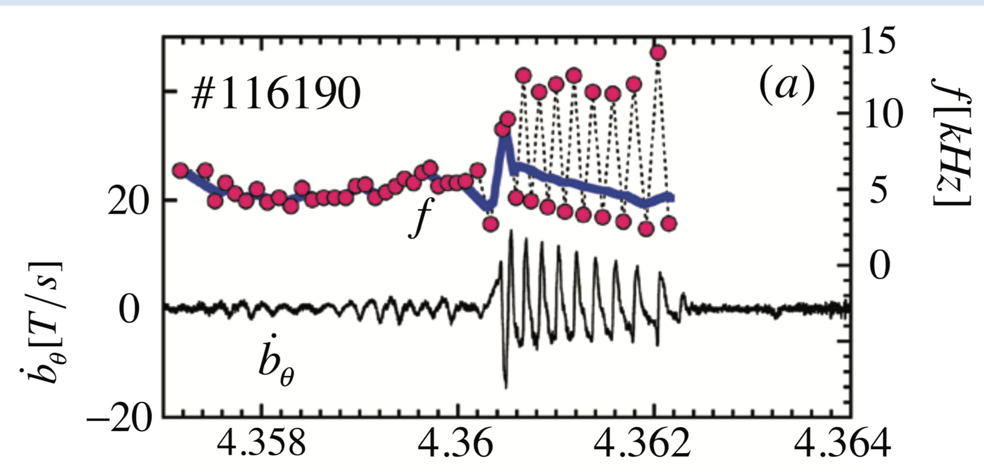
Abstract

- Energetic particle driven Interchange mode (EIC) recently observed in LHD, causing energetic ion losses
- Mode investigated with hybrid code MEGA,
- An m/n=2/1 is observed, inducing a strong energetic particle perpendicular pressure redistribution,
- Frequency chirping is observed at mode saturation.

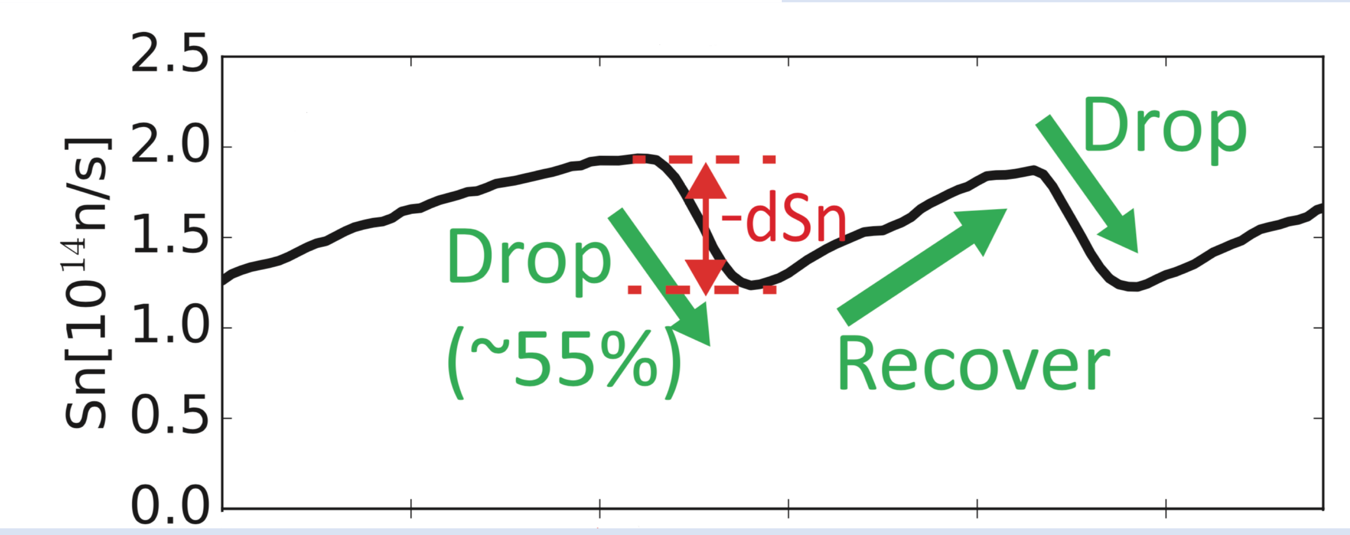
Context

- Energetic particle driven Interchange mode (EIC) recently observed in LHD [1] with perpendicular NBI active
- m/n=1/1 mode with a frequency consistent with helical precession frequency, and observation of frequency chirping.
- Significant losses of energetic ions observed through the drop in neutron emission in deuterium experiment.





Up - Time evolution of magnetic probe signal and temporal frequency [2]
Left - Arrangement of NBI lines [2]



Left - Neutron emission rate [3]

Numerical simulation code

- Numerical code used: hybrid code MEGA [4]
  - Thermal plasma described with MHD equations:

$$\frac{\partial \rho}{\partial t} = -\nabla\cdot(\rho\mathbf{v}) + \nu_n\Delta(\rho-\rho_{\mathrm{eq}})$$

$$\rho\frac{\partial}{\partial t}\mathbf{v} = -\rho\mathbf{v}\cdot\nabla\mathbf{v} - \nabla p + (\mathbf{j}-\mathbf{j}'_h)\times\mathbf{B} + \frac{4}{3}\nabla(\nu\rho\nabla\cdot\mathbf{v}) - \nabla\times(\nu\rho\boldsymbol{\omega})$$

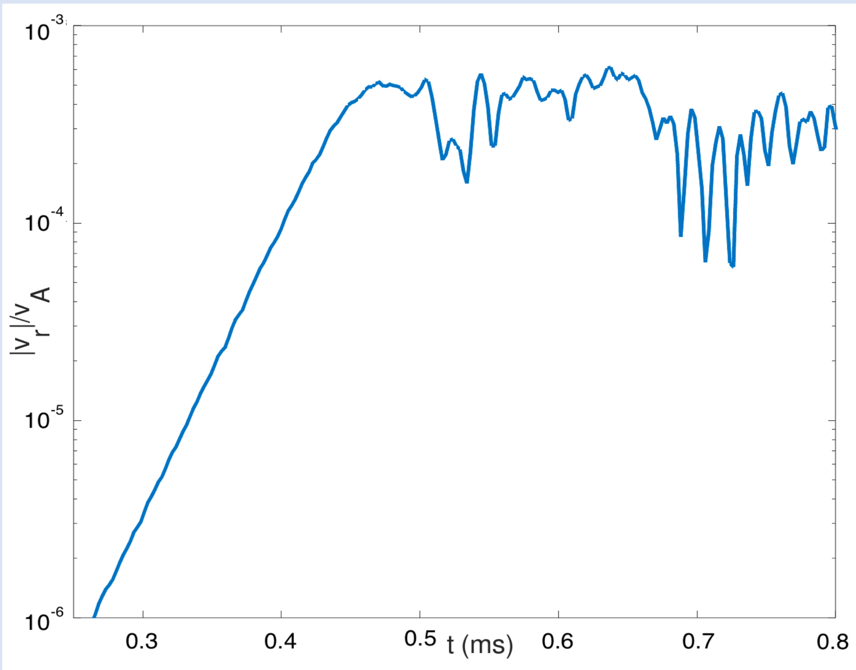
$$\frac{\partial p}{\partial t} = -\nabla\cdot(p\mathbf{v}) - (\gamma-1)p\nabla\cdot\mathbf{v} + (\gamma-1)\left[\nu\rho\omega^2 + \frac{4}{3}\nu\rho(\nabla\cdot\mathbf{v})^2 + \eta\mathbf{j}\cdot(\mathbf{j}-\mathbf{j}_{\mathrm{eq}})\right] + \chi\Delta(p-p_{\mathrm{eq}})$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla\times\mathbf{E},\ \mathbf{j} = \frac{1}{\mu_0}\nabla\times\mathbf{B},\quad \mathbf{E} = -\mathbf{v}\times\mathbf{B} + \eta(\mathbf{j}-\mathbf{j}_{\mathrm{eq}}),\quad \boldsymbol{\omega} = \nabla\times\mathbf{v}$$

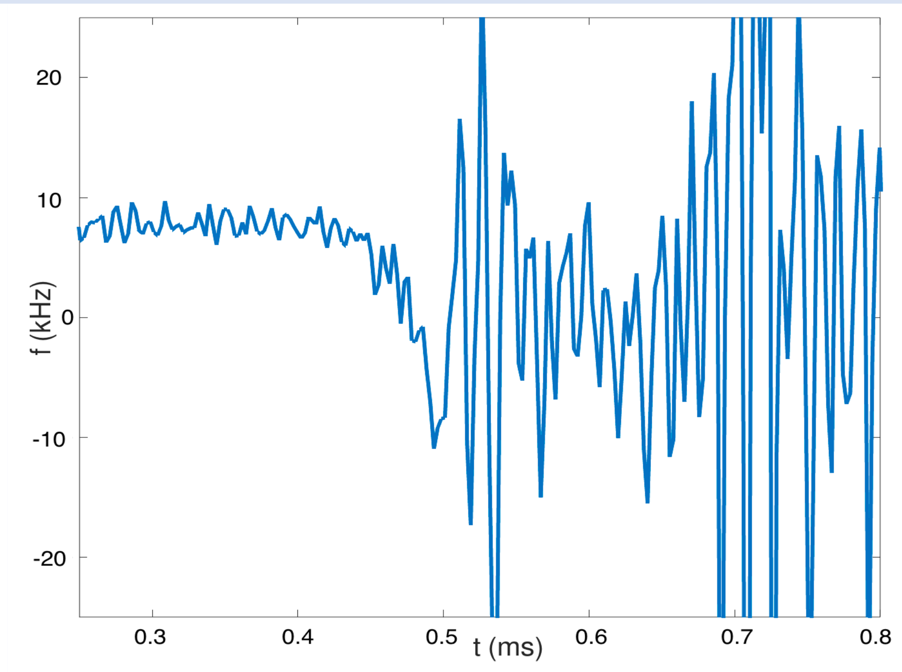
  - Energetic particles described by the drift kinetic equations, and their contribution to the MHD equations enters in $\mathbf{j}'_h$

Results

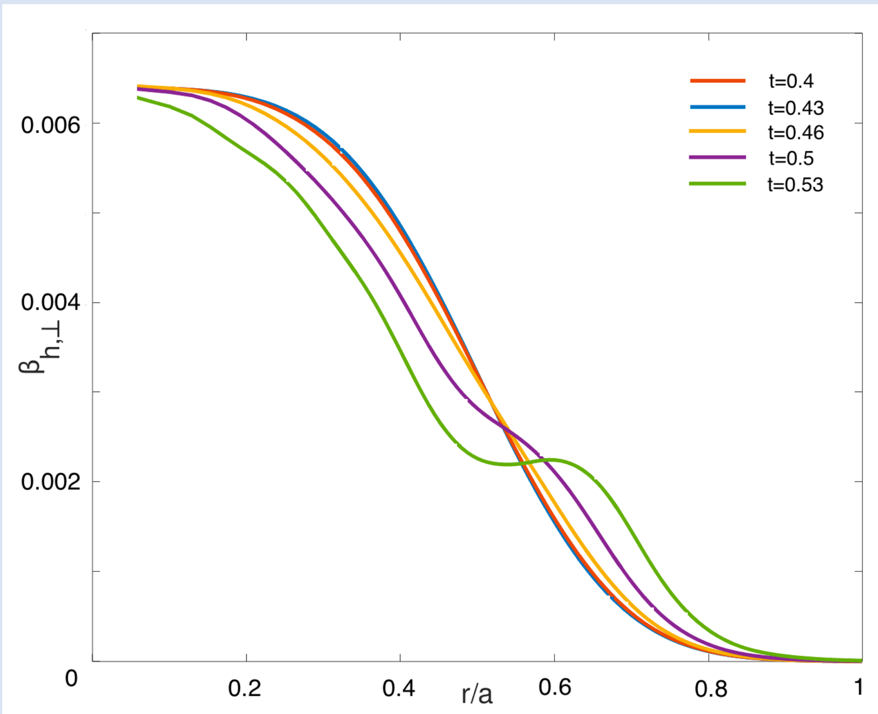
- Observation of a m/n=2/1 mode
  - Saturation at ~0.5ms, with $v_r/v_A \sim 10^{-3}$, with $\beta_h = 1\%$
  - Mode frequency $f \sim 9.3kHz$, and frequency chirping from 0.44ms to 0.5ms, going to a negative frequency for a short time
  - Strong perpendicular pressure redistribution at saturation, with decrease of central pressure
  - Change of the radial velocity profile in the nonlinear phase associated with the inversion of mode frequency

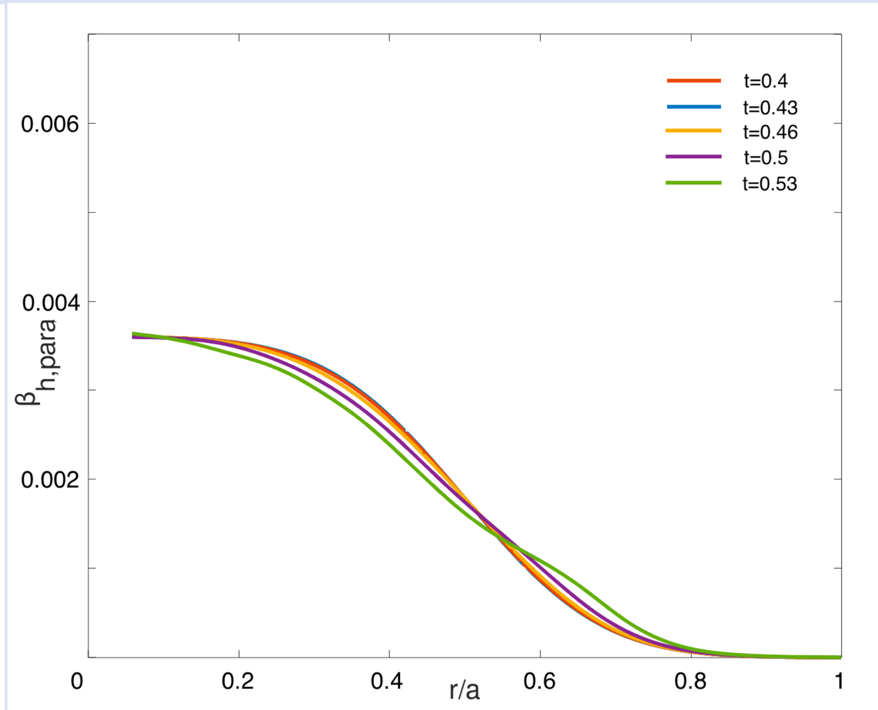


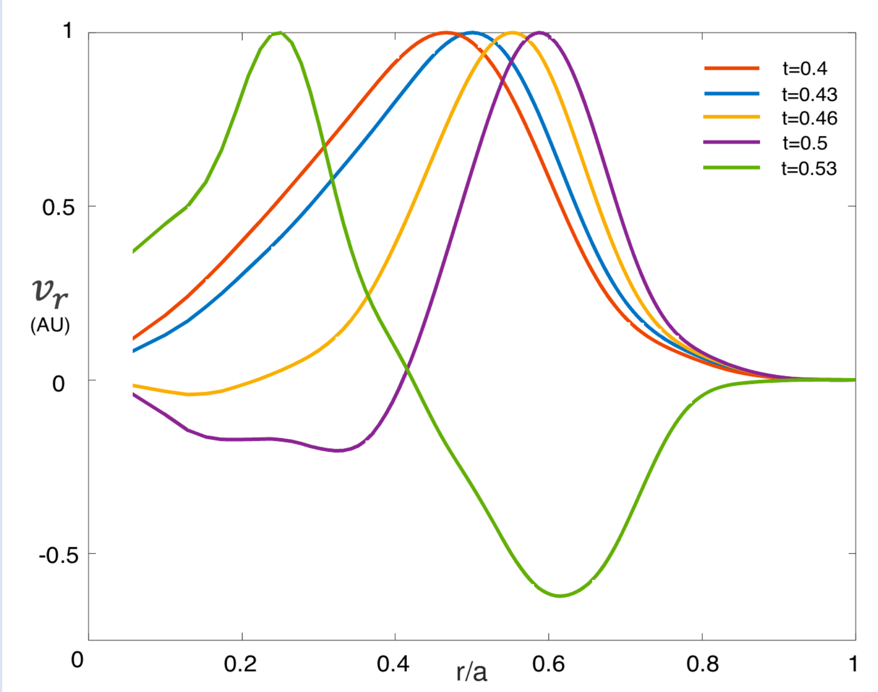
m/n=2/1 mode amplitude



m/n=2/1 mode frequency







Pressure profile snapshots during saturation.
Top left: perpendicular pressure,
Top *right:* parallel pressure.
Left – m/n=2/1 radial velocity profiles
(Snapshot times t=0.4; 0.43; 0.46; 0.5; 0.53ms)

Conclusion

- A numerical investigation of the EIC mode in LHD is attempted using the code MEGA
- An energetic particle driven m/n=2/1 mode is found in the core plasma, showing:
  - a strong perpendicular pressure redistribution.
  - a rapid frequency chirping
- Further investigation is required in order to find an energetic particle driven m/n=1/1 interchange mode located at the plasma edge.

REFERENCES

- [1] X. D. Du *et al.*, Phys. Rev. Lett. **114**, 155003 (2015)
- [2] X. D. Du *et al.*, Nucl. Fusion **56**, 016002 (2016)
- [3] T. Bando *et al.* Nucl. Fusion **58**, 082025 (2018)
- [4] Y. Todo, Phys. Plasmas **13**, 082503 (2006)