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Super-Alfvénic ion instabilities and transport

E. Fredrickson *for the NSTX Team*

NSTX PAC-19 meeting

Feb. 22-24, 2006

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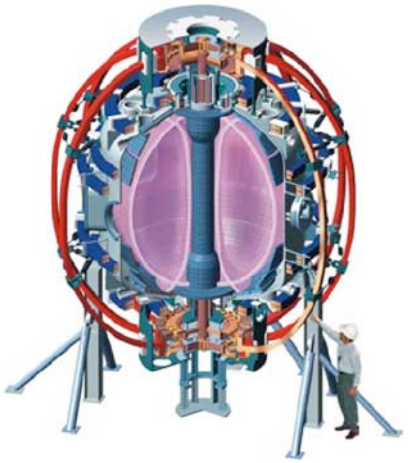
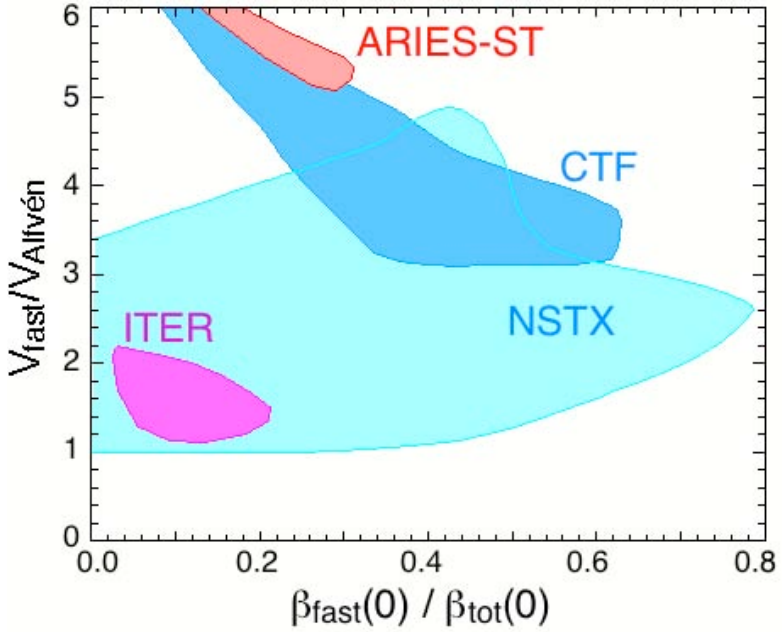
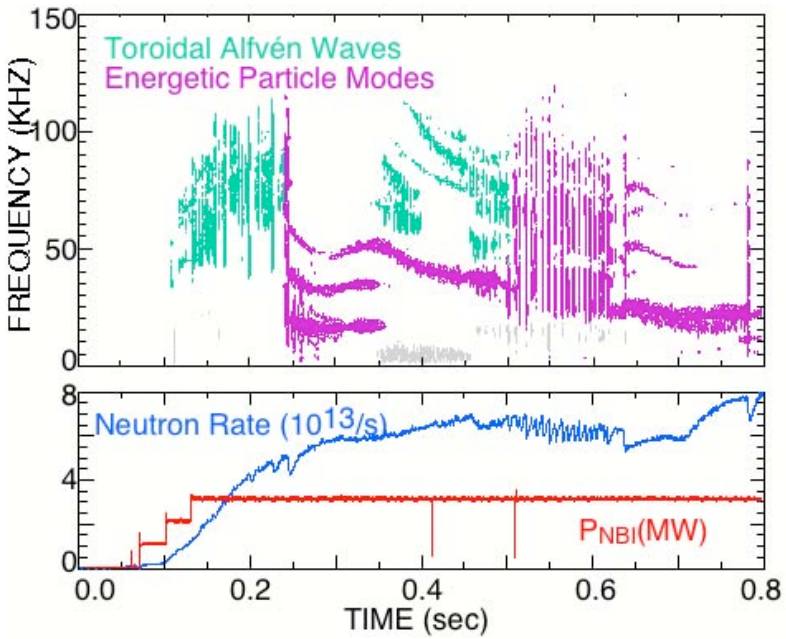


NSTX accesses ITER-relevant regime of phase-space island overlap

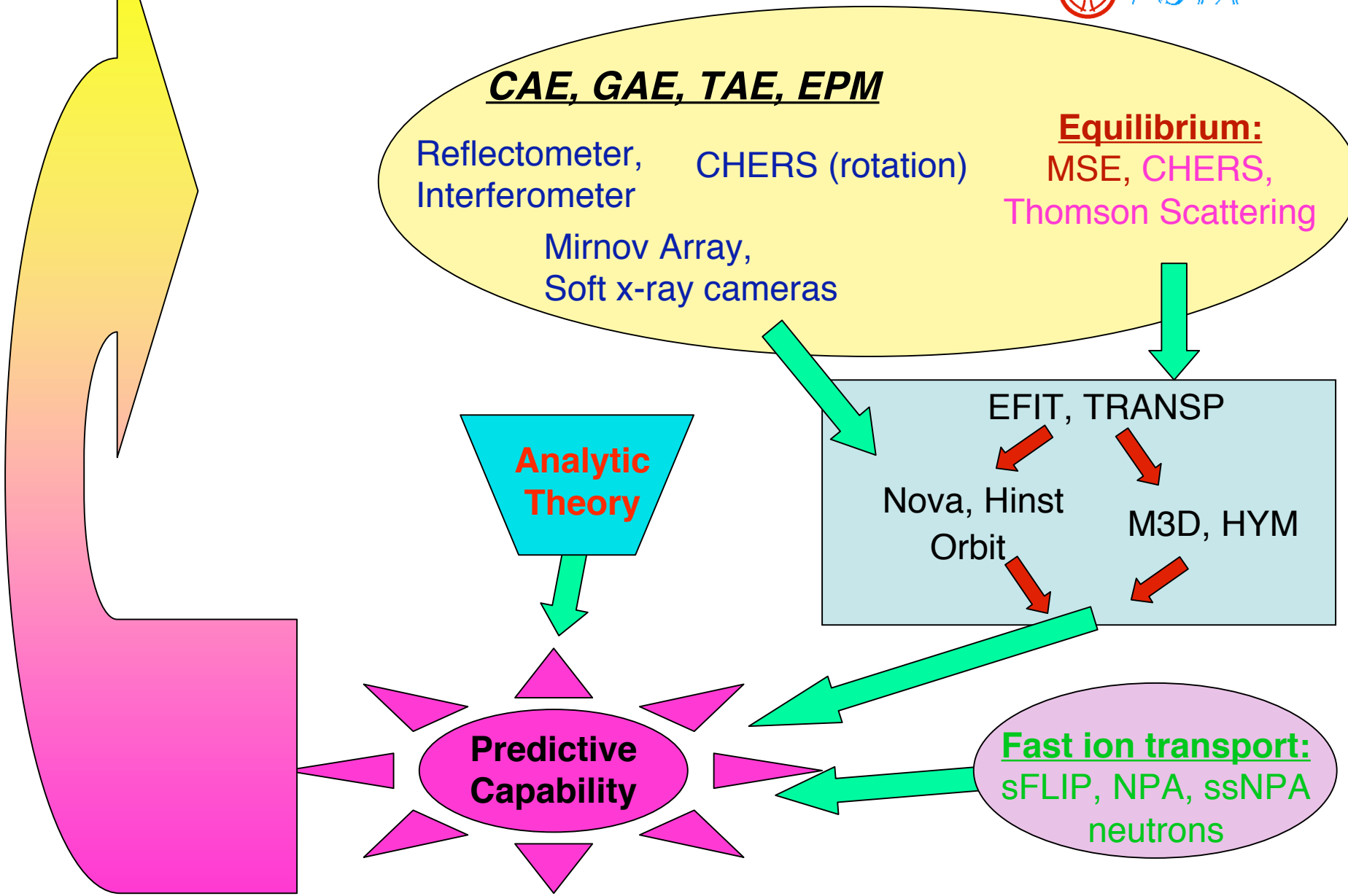
- ITER in new, small ρ^* regime for fast ion transport
  - $k_\perp \rho \approx 1$ means "short" wavelength Alfvén modes
  - fast ion transport from interaction of many modes (MDC-9)





- NSTX also routinely operates with super-Alfvénic fast ions *with q-profile measured*
- 'Avalanche' or 'sea-of-TAE' transport seen
- Predicting effect of fast ion transport on beam driven currents is high priority

NSTX can study nonlinear dynamics



Physics goals for fast ion physics studies

(To achieve 2007 milestone supporting ITPA MDC-9)

- 2006 (MSE, sFLIP, ssNPA, polarization diagnostic)
  - Determination of TAE Avalanche threshold, ORBIT simulations of fast ion losses
    - Measurement of internal mode amplitude and structure,
    - *together* with current profile and fast ion loss measurements
  - Validate bootstrap/beam-driven current models
    - Develop fast -ion MHD-quiescent discharge
    - Compare J(r) evolution in plasmas with energetic particle MHD
- 2007 (fast FireTip, faster scanning reflectometer?)
  - Study parameter scaling of mode structure, amplitude, stability and fast ion losses
  - Dedicated experiment to compare J(r) evolution with/without fast-ion MHD.

Physics goals for 2008

- 2008 - Fast Ion D_{alpha} (FIDA) diagnostic
  - Improved radial profile measurement of Fast Ion MHD induced redistribution
  - Continuation EPM/TAE physics studies
- Contingency/piggy-back experiments:
  - Stochastic heating threshold for CAE/GAE
  - GAE/CAE phase-space structures (hole-clumps)
    (Doppler-shifted cyclotron resonance & universal drive)
  - External excitation of CAE/GAE (TAE?)
  - Role of "saturated" EPMs
  - Non-linear mode coupling (3-wave coupling)

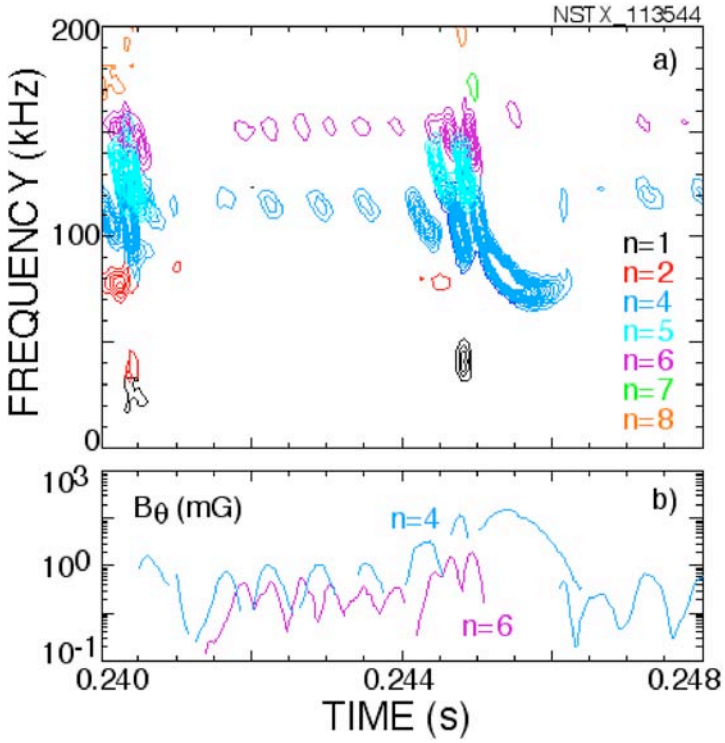
2006: Experiment to study fast-ion interactions with TAE and EPM

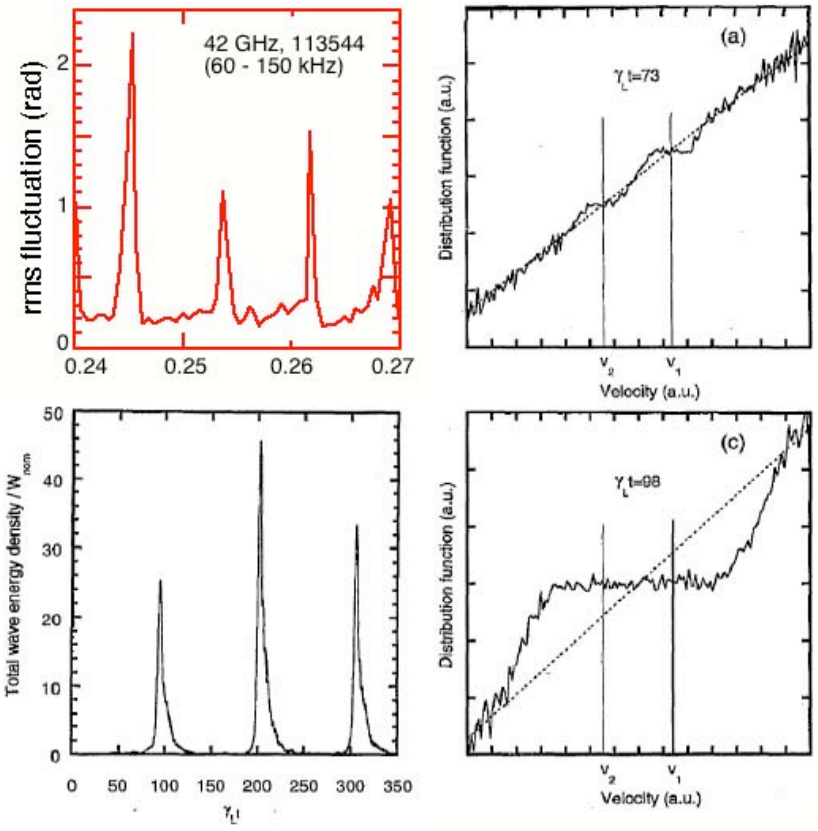
- Test models for EPM-induced fast ion loss:
  - Detailed structure of mode, frequency
- Test models for EPM stability:
  - Bounce or precession-drift resonance?
- Study "sea-of-TAE"-induced fast ion losses
  - Measurements of multiple mode amplitudes
- Test non-linear models of TAE stability
  - Avalanche or domino model (Berk, et al., PoP **2** '95, 3007)
- Develop models for non-linear mode interactions (3-wave coupling)

TAE bursts suggest "Avalanche" physics

NSTX

- No correlation of repetitive small bursts; increased amplitude leads to strong multiple mode burst

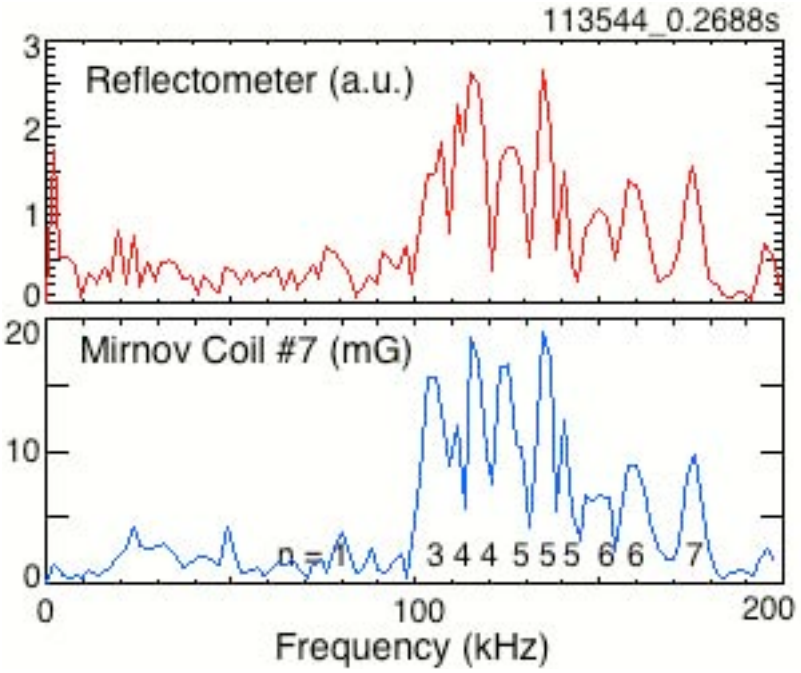




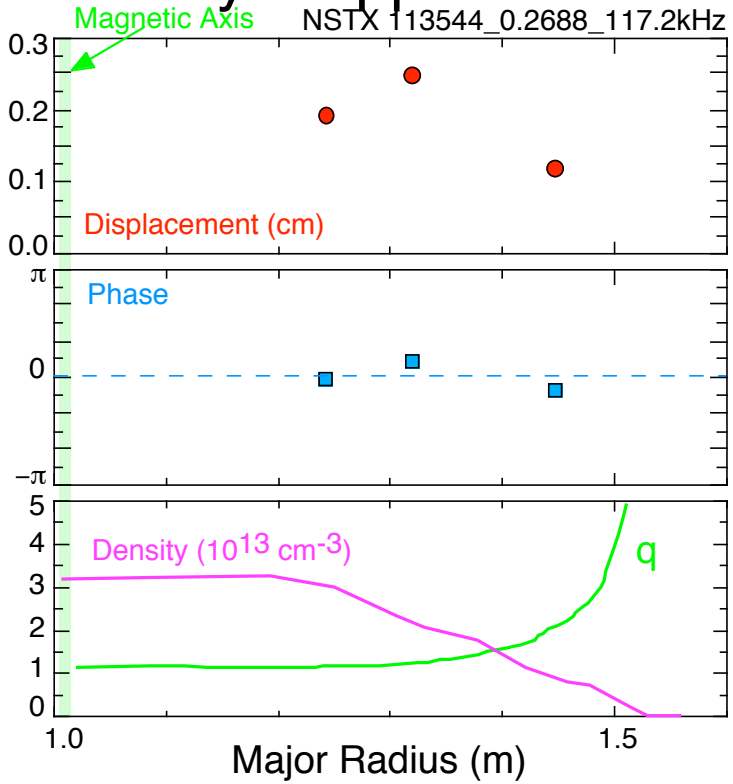
Berk, et al., PoP **2** 3007

- Weak chirping/bursting simulated with M3D-K (Fu)
- Strong bursts consistent with model of "island" overlap in fast ion phase space
- TAE have multiple resonances, more complex physics

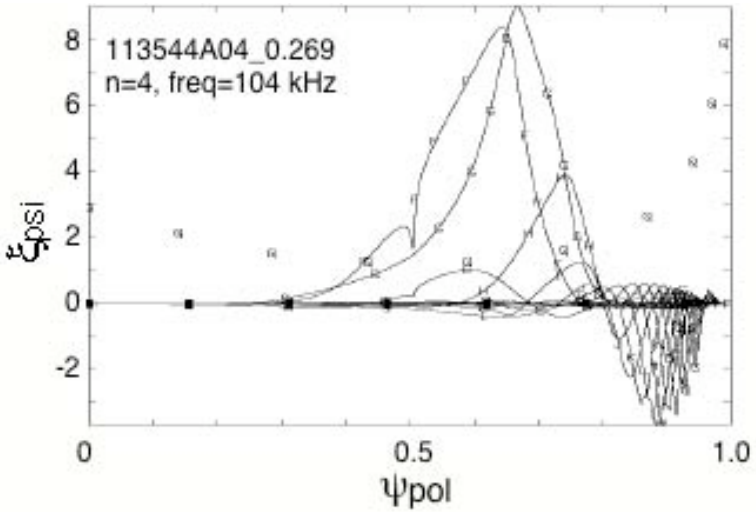
Reflectometer shows "sea of TAE"



- Mode amplitude can be used to infer size of phase space island
- Data from before MSE available; great uncertainty in q-profile



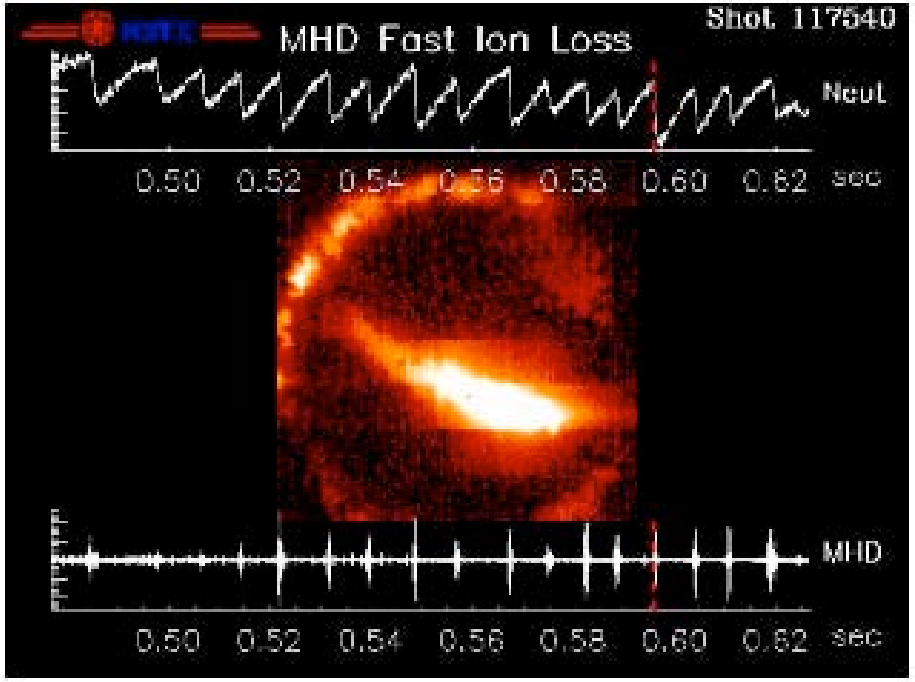
- Nova often shows phase inversion - seen for higher n's

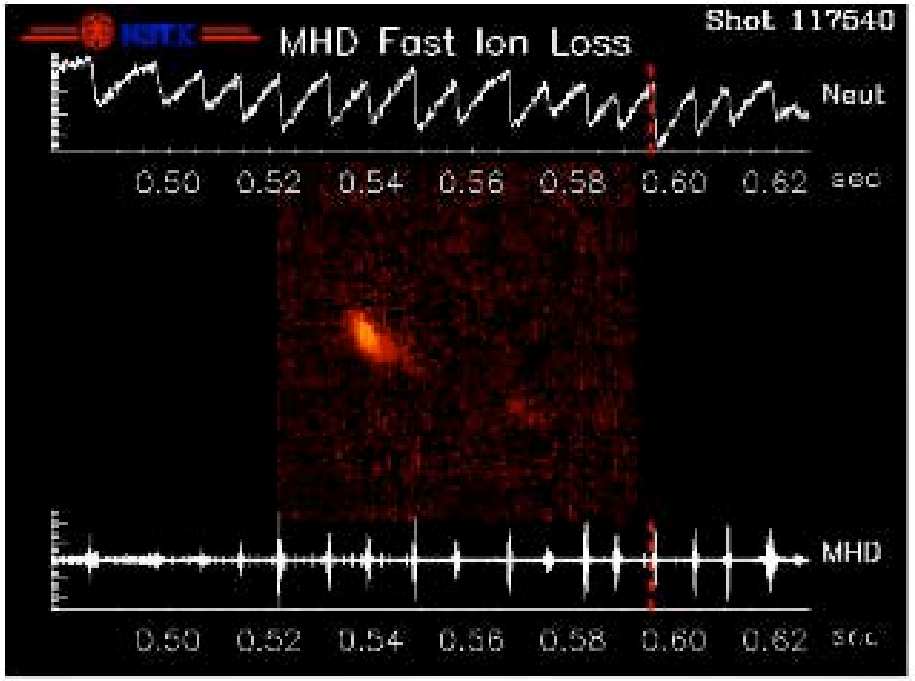


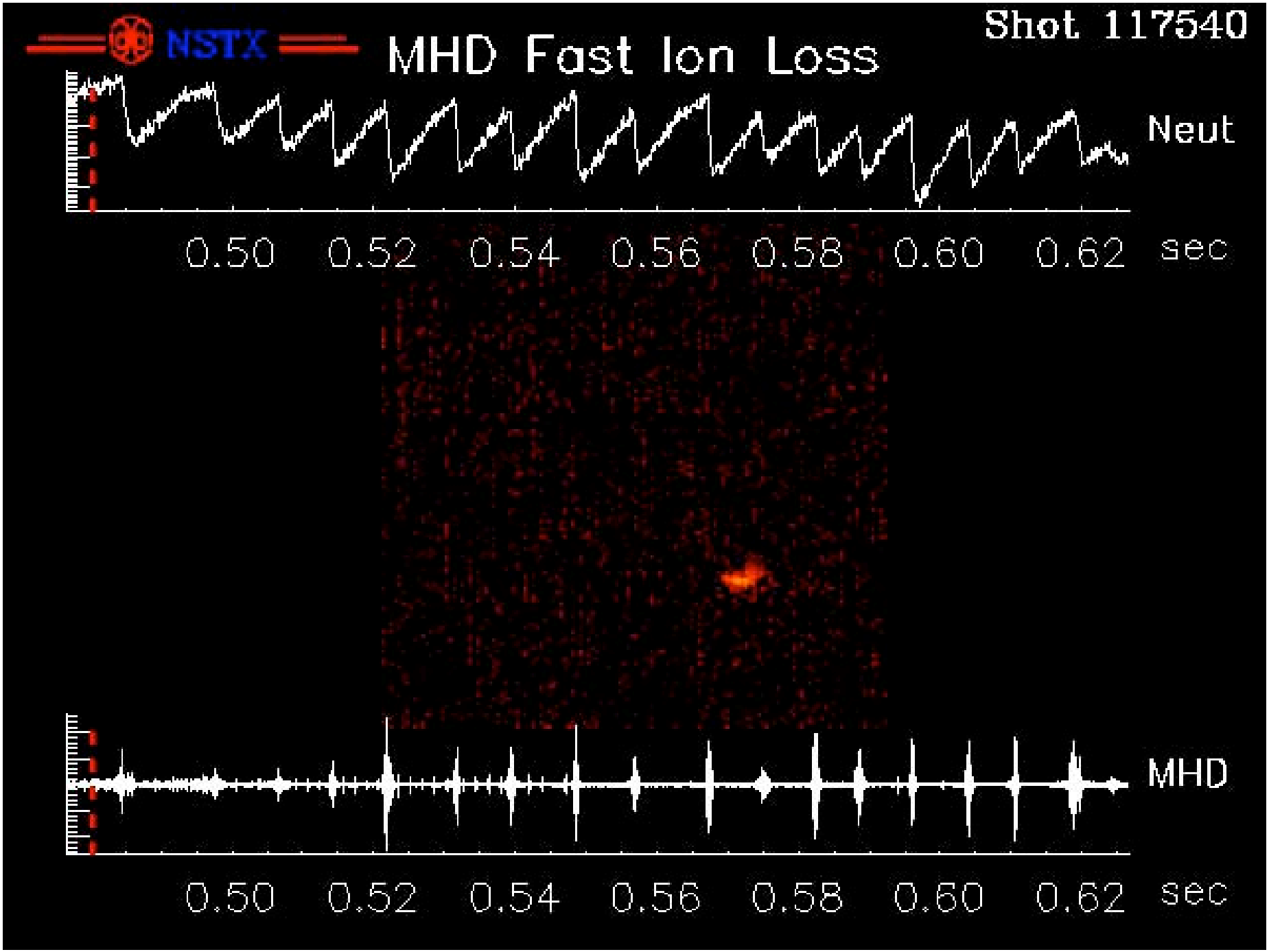
sFLIP data can be used to benchmark ORBIT simulations

- Relatively new capability
- Pitch angle, energy of lost fast ions is measured
- Loss at highest beam energy, range of pitch angles
- Correlate with ORBIT or M3D/HYM simulations

(Fast camera provided by JAEA)



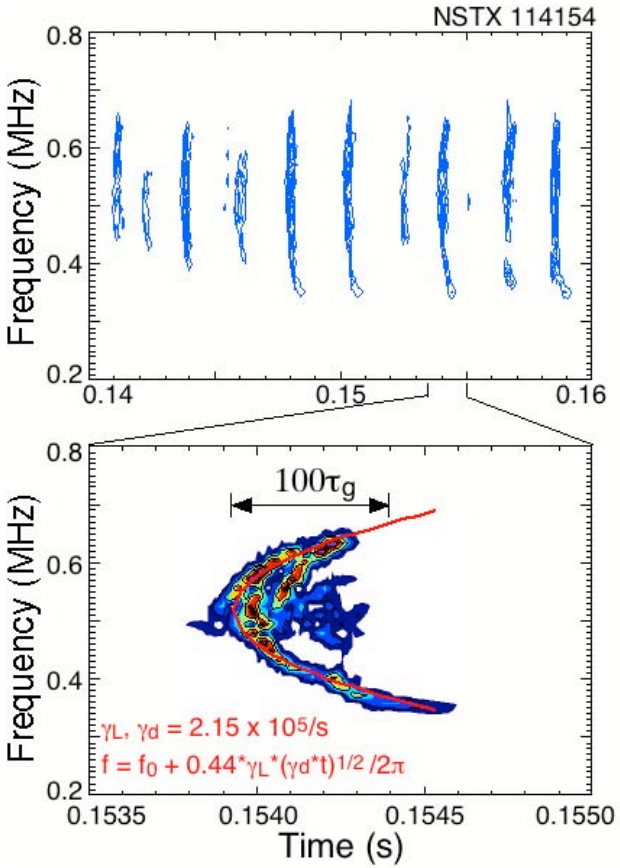



NSTX
MHD Fast Ion Loss
Shot 117540
Neut
0.50 0.52 0.54 0.56 0.58 0.60 0.62 sec
MHD
0.50 0.52 0.54 0.56 0.58 0.60 0.62 sec

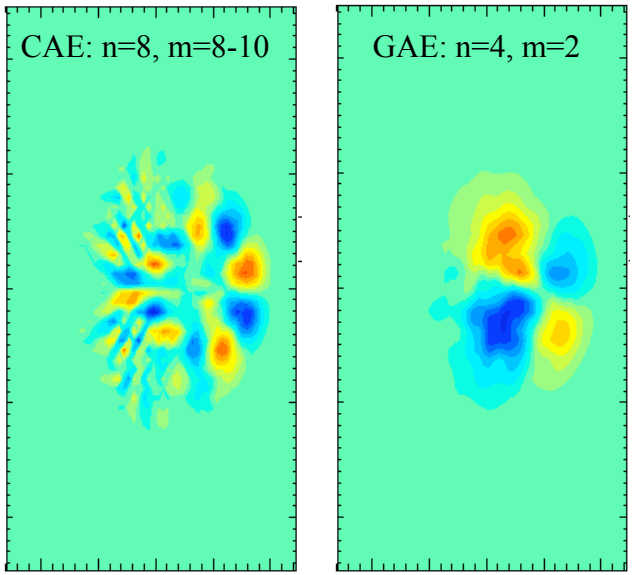
2006: Validate beam-driven and bootstrap current models

- Validate bootstrap/beam driven current physics
  - Develop fast-ion-MHD-quiescent target plasma
  - Document current profile evolution with MSE
- Identify stability thresholds for EPM/TAE
  - Determine MHD-free operational range
- Provides basis for interpretation of effect of TAE/EPM on beam-driven current - feeds into 2007 milestone

Non-linear interactions through phase space structures



- HHFW stabilization observed
  - Introduces effective collisionality operator on fast ion distribution
  - Potential to disrupt avalanche



- Window onto phase space structures in realistic, multi-dimensional phase space.
- HYM code (E. Belova) capable on non-linear CAE/GAE simulations.

NSTX uniquely suited to study non-linear multi-mode interactions relevant to ITER

- NSTX fast ion loss occur with multiple modes, "sea of TAE", as predicted for ITER
- NSTX has comprehensive diagnostic set in the super-Alfvénic fast ion regime
- 2006 experiments address ITPA MDC-9, fast ion redistribution by Alfven modes
- In 2007 will complete experiments to measure effect of TAE/EPM on beam-driven current profile.
- TAE/EPM (CAE) interact, perhaps synergistically
  - Interactions can be through non-linear phase-space coupling
  - Direct non-linear coupling is also being investigated
  - Study of CAE-induced phase-space structures provide window on realistic, multi-dimensional phase space resonances