# PLANS FOR FAST PARTICLE PHYSICS AND ITS MODELING IN NSTX

*presented by*

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# *Issues to consider*



1. Single particle physics

   ✓ Prompt losses

   ✓ Ripple losses

2. Collective phenomena:

   ✓ New, due to fast particles, plasma oscillations:

   – CAEs, TAEs, Fishbones, KBMs.

   ✓ Effects on present phenomena in the plasma & plasma transport

   – sawteeth, tearing modes, energy channeling from NBI to plasma

# *Modeling requirements*



✓ New regimes require recoding of older and meet in new codes:

- Low aspect & Large trapped particle population
- Large Larmor radius $\rho_{Lb}/a \sim 1/5 - 1/3$
- Wide drift orbits $\Delta_b/a \sim (q/\epsilon)(\rho_{Lb}/a) \sim 1/3 - 1/2$
- Low Alfvén speed $v_A \ll v_{b0}$
- Magnetic well presence
- Anisotropic equilibrium

✓ Need to be coupled to experiments (TRANSP, diagnostics).

✓ Fortunate similarity in beam ions in NSTX and Alpha particles in DT ST: $\Delta_b/a$, $v_A/v_b$.

# *Numerical codes at PPPL for hot ion collective effects study*



## Linear analysis

| | Low-n | Med-n | High-n | FOW | FLR | Landau | cont-radiative | perturbative |
|---|---|---|---|---|---|---|---|---|
| NOVA(-K) | x | x | | x | ($\alpha$'s) | x | | Yes |
| HINST | | x | x | | mode | x | x | No |

HINST has been benchmarked against NOVA for medium $n$ numbers.

?? Open question for EPM/RTAE modes at low-n & strong drive.

NOVA is well updated for TAE study in ST.

NOVA needs FLR corrections included & nonperturbative strong drive.

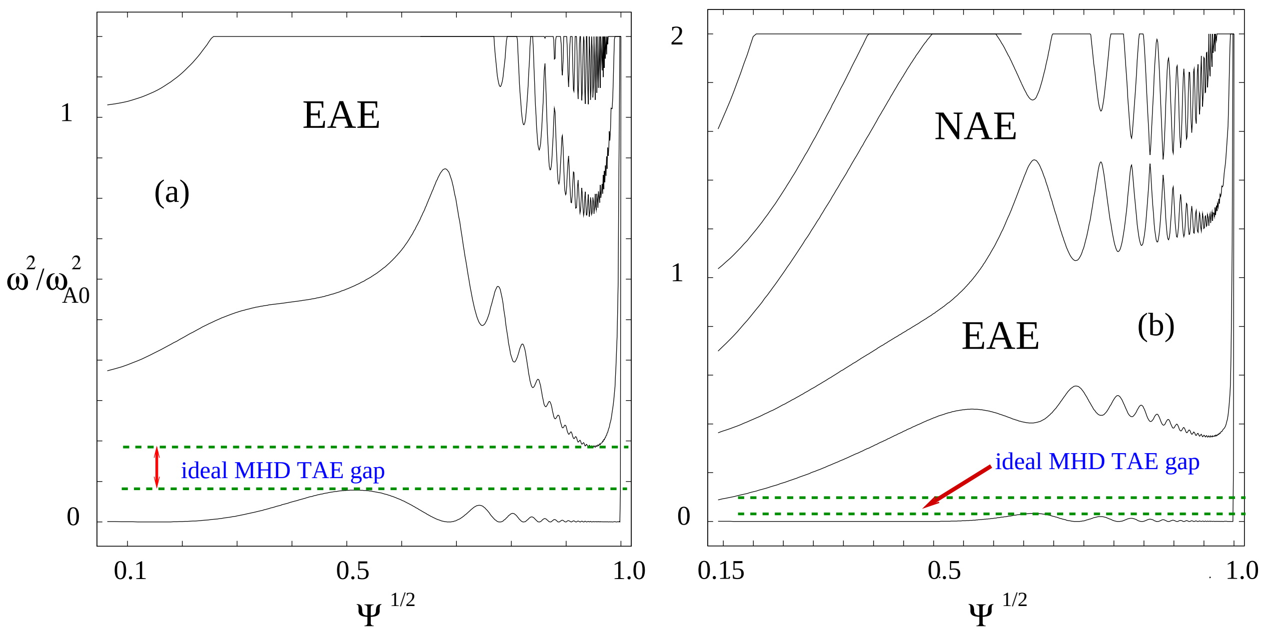
## Nonlinear analysis

| | Low-n | Med-n | High-n | FOW | FLR | perturbative | multimode | method |
|---|---|---|---|---|---|---|---|---|
| ORBIT | x | | | x | | | x | $\delta$-f |
| NOVA-K | x | x | | x | ($\alpha$'s) | x | | nonlinear BB theory |
| MH3D | x | x | | x | | | | fully nonlinear |
| HYM | x | x | | x | x | | x | fully nonlinear |

# *Low frequency modes can cause NBI ion losses*



Low- and high- beta Alfvén Gap Structure for $n = 3$




✓ In high beta $\langle\beta\rangle = 33\%$ plasma TAE gap is not closed.

✓ Recent observations of strong TAE activity in NSTX with multiple modes indicate losses (E. Fredrickson)

# *TAE's effect on beam ions*



Use ORBIT & collisional scattering.

Choose most unstable modes for each case.

TAEs amplitude was taken the same with $\tilde{B}_\theta/B \simeq 10^{-3}$

Low $q_0 = 0.4$, $\langle\beta\rangle = 10\%$

| losses,%$\rightarrow$ | prompt | +$n = 1$ TAE |
|---|---|---|
| no FLR | 9 | 11 |
| with FLR | 29 | 31 |

✓ High $q_0 = 2.8$, $\langle\beta\rangle = 15\%$

| losses,%$\rightarrow$ | prompt | +$n = 1$ | $n = 1$ & $n = 3$ |
|---|---|---|---|
| no FLR | 1 | 2 | |
| with FLR | 24 | 30 | 35 |

Magnetic well and strong edge poloidal magnetic field helps particle confinement at high beta.

# *Plans for codes development for fast ion study in NSTX (Low frequency codes)*



Low frequency modes TAE, KBMs:

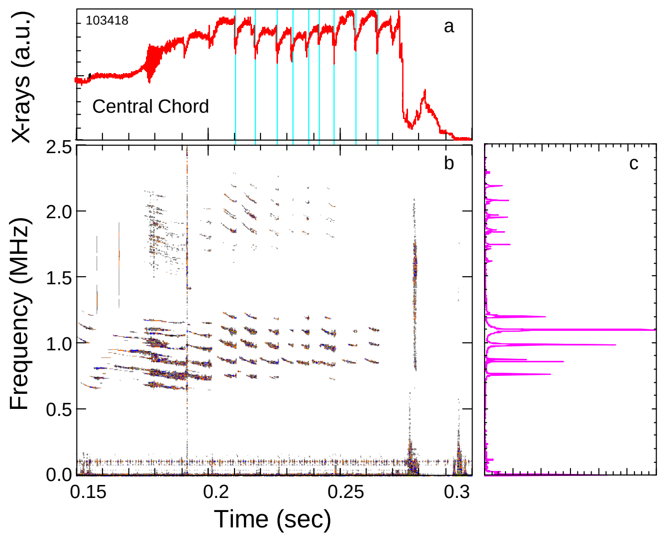
1. Linear codes show growth in case of TAEs $\gamma/\omega > 10\%$ (compare with ITER TAE problem).

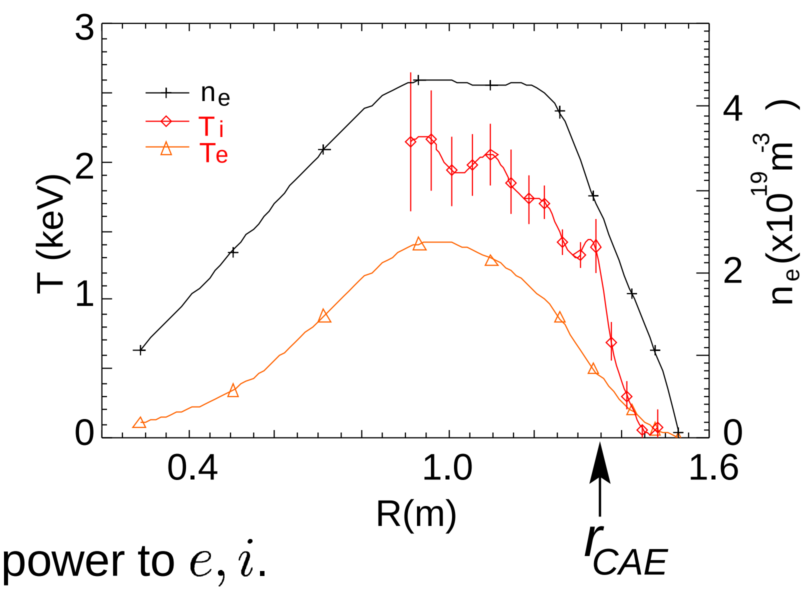
   ✓ Trapped kinetic electron are important as a damping mechanism through $E_{\|}$

2. $\Rightarrow$ nonperturbative linear codes like NOVA2 are required (2-5 years program).
3. HINST for KBM and RTAE with full kinetic treatment (1-3 year).
4. Applications of HYM and M3D for NSTX problems should be broader (near to longer term).
5. ORBIT will include different types of fishbone dispersion relations: precession drift, bounce frequency branches.
6. Couple ORBIT/GYROXY with nonperturbative codes for faster simulations (1-3 year).

# Can CAE explain $T_i > T_e$, observed in NSTX by CHERS?






✓ $P_{NBIe} \simeq 2P_{NBIi}$, where $P_{NBIe,i}$ is NBI power to $e, i$.

✓ Unphysical power balance results with present data set if only classical collisional processes are considered (beam heating, ion-electron coupling).

✓ Experimental study of anomalous ion temperature increase with and without CAEs is in progress.

# *Plans for codes development for fast ion study in NSTX (High frequency codes)*



1. Linear code need to be developed (borrowed) to address and compare with theory CAE types of modes:

   ✓ $\omega_c/\omega$ corrections to MHD

   ✓ resonances with fast particles

   ✓ realistic equilibrium (fast solvers, ESC like)

   ✓ distribution function of beam ions and thermal ions.

2. Nonlinear high frequency code, such as HYM, is needed to correctly model CAE and GAE in NSTX including effects like

   ✓ particle cyclotron resonances with modes

   ✓ multi-mode interaction with background plasma to demonstrate the energy channeling from beam ions to thermal ions.

3. Codes need to be benchmarked against experiments.