What to expect for beam ion driven instabilities in NSTX-U

N.N. Gorelenkov, E. Fredrickson, S. Gerhard, S. Kaye,...
PPPL, Princeton University

This work supported in part by DoE contract No. DE-AC02-09CH11466

PPPL, February 27, 2012

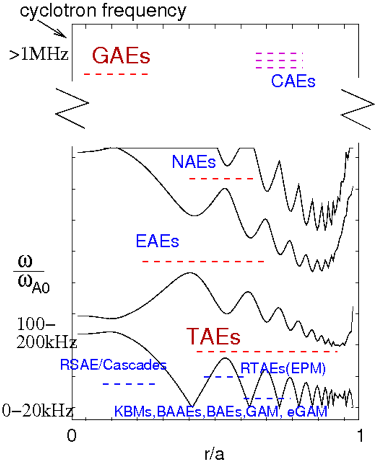
3 categories of FI (fast ion) issues in fusion research

EP instabilities are important for reactor planning

- single particle confinement: *drift motion, collisions, distribution function*
- effects on existing MHD modes, non-driven by fast ions: *internal kink, ballooning, NTM, ripples, RMP ...*
- induced collective effects:
    - *excited instabilities, their effects, ... e-transport.*
        - *low-f modes (still need to learn, nonlinear phys...)*
        - *high-f modes (less studied)*
    - *EPM - energetic particle modes ("over-excited" instabilities)*

beam ions (EPs) drive a variety of instabilities in NSTX

- NBI is source of EPs in both NSTX and NSTX-U



"Sea" of *AEs in NSTX:

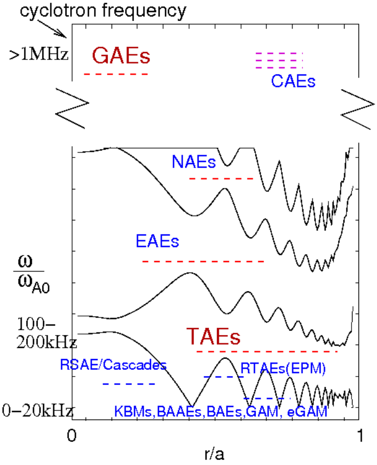
- high-f modes
  CAEs, GAEs
- low-f modes
  TAEs, BAAEs, RSAEs, ω_b-fishbones...
- Key EP parameters/ratios:
  $v_{fast}/v_A = 5-1$,
  $\beta_{fast}/\beta_{pl} = 0.1-1$,
  $a/\rho_{fast} = 5-10$.

unique opportunities

studies, VV efforts

beam ions (EPs) drive a variety of instabilities in NSTX

- NBI is source of EPs in both NSTX and NSTX-U



"Sea" of *AEs in NSTX:

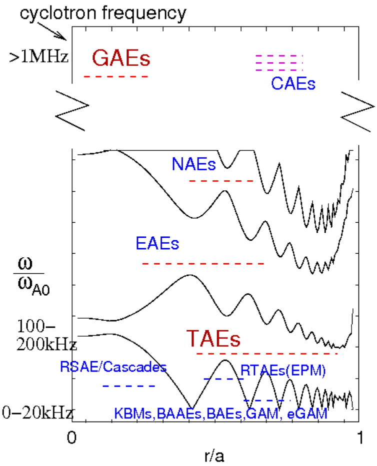
- high-f modes
  CAEs, GAEs
- low-f modes
  TAEs, BAAEs, RSAEs, ω_b-fishbones...
- Key EP parameters/ratios:
  $v_{fast}/v_A = 5 - 1$,
  $\beta_{fast}/\beta_{pl} = 0.1 - 1$,
  $a/\rho_{fast} = 5 - 10$.

unique opportunities

studies, VV efforts

beam ions (EPs) drive a variety of instabilities in NSTX

- NBI is source of EPs in both NSTX and NSTX-U



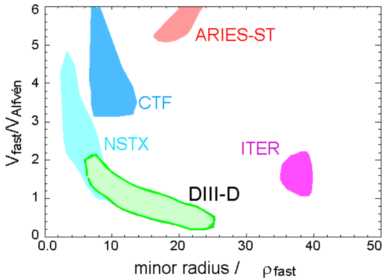
"Sea" of *AEs in NSTX:

- high-f modes
  CAEs, GAEs
- low-f modes
  TAEs, BAAEs, RSAEs, ω_b-fishbones...
- Key EP parameters/ratios:
  $v_{fast}/v_A = 5-1$,
  $\beta_{fast}/\beta_{pl} = 0.1-1$,
  $a/\rho_{fast} = 5-10$.

unique opportunities

studies, VV efforts

Uniqueness of NSTX was explored



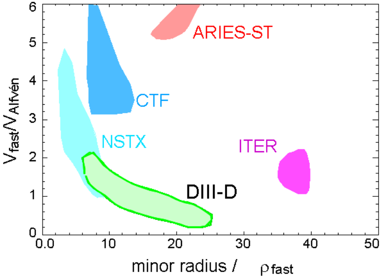
E.Fredrickson

- broadened VV $\Downarrow$
- new (sort of) discoveries: CAEs, α-channeling, e-transport, BAAEs...

NSTX

led EP physics in STs
advanced ST EP physics towards (ST) reactor

Uniqueness of NSTX was explored



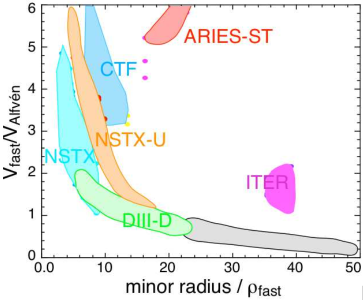
E.Fredrickson

- broadened VV $\Downarrow$
- new (sort of) discoveries: CAEs, α-channeling, e-transport, BAAEs...

NSTX

led EP physics in STs
advanced ST EP physics towards (ST) reactor

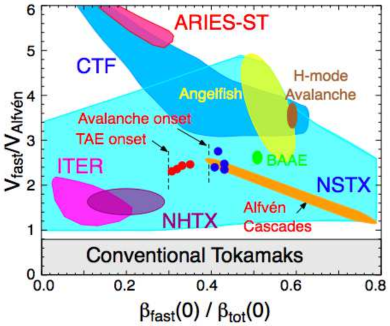
Uniqueness of NSTX-U to explore?



E.Fredrickson, S.Gerhard

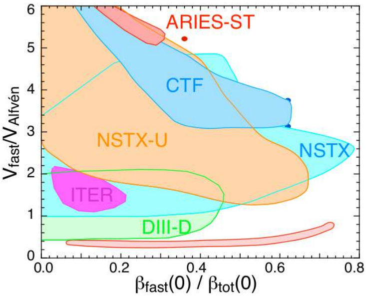
- continue EP research
- similar"ity" param. regimes ⇒ study "smooth" transitions in XPs?
- given the opportunity for diagnostic upgrade, position the program around urgent tasks, <u>CAE antennae, phase space engineering</u>...

Broad coverage of NSTX in $\left(\frac{V_{fast}}{V_{Alfven}}, \frac{\beta_{fast}}{\beta_{tot}}\right)$ space



Broad parameter space $\Rightarrow$ many (typical) EP effects are reproduced:
multiple AE modes, EPM.
direct ITER relevance (res.overlaps, multimodes).

Broad coverage of NSTX-U in $\left(\frac{V_{fast}}{V_{Alfven}}, \frac{\beta_{fast}}{\beta_{tot}}\right)$ space?

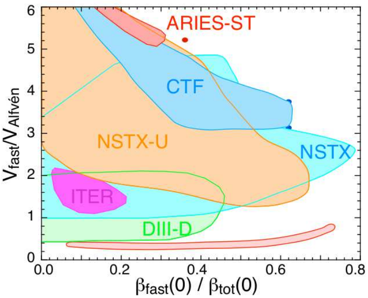


E.Fredrickson, S.Gerhard

NSTX-U

parameter space is still broad
and yet close(?) to ITER plasmas, relevant physics (res.overlap, multimode exc.)...

Broad coverage of NSTX-U in $\left(\frac{V_{fast}}{V_{Alfven}}, \frac{\beta_{fast}}{\beta_{tot}}\right)$ space?



E.Fredrickson, S.Gerhard

NSTX-U

parameter space is still broad
and yet close(?) to ITER plasmas, relevant physics (res.overlap, multimode exc.)...

Implications: low-f modes, TAEs, RSAEs, BAAEs...

Major shifts in n per theory expectations (TAEs, Berk et.al. PLA '92.)

$$k_\perp \rho_f \sim 1 \Rightarrow \frac{nq}{a}\frac{v_f}{\omega_{cf}} \sim 1 \Rightarrow n \sim B \Rightarrow n = 2 - 10$$

Other expectations:

- RS plasmas most unstable (q,s??!!, DIIID)
- more valid transport, QL theory
- codes are readily applicable
- EP should be better confined, less losses
- BAAEs to expore, similarity with DIIID.

Quasi-linear diffusion

see K. Ghantous talk next

Implications: low-f modes, TAEs, RSAEs, BAAEs...

Major shifts in n per theory expectations (TAEs, Berk et.al. PLA '92.)

$$k_\perp \rho_f \sim 1 \Rightarrow \frac{nq}{a}\frac{v_f}{\omega_{cf}} \sim 1 \Rightarrow n \sim B \Rightarrow n = 2 - 10$$

Other expectations:

- RS plasmas most unstable (q,s??!!, DIIID)
- more valid transport, QL theory
- codes are readily applicable
- EP should be better confined, less losses
- BAAEs to expore, similarity with DIIID.

Quasi-linear diffusion

see K. Ghantous talk next

Implications: low-f modes, TAEs, RSAEs, BAAEs...

Major shifts in n per theory expectations (TAEs, Berk et.al. PLA '92.)

$$k_\perp \rho_f \sim 1 \Rightarrow \frac{nq}{a}\frac{v_f}{\omega_{cf}} \sim 1 \Rightarrow n \sim B \Rightarrow n = 2-10$$

Other expectations:

- RS plasmas most unstable (q,s??!!, DIIID)
- more valid transport, QL theory
- codes are readily applicable
- EP should be better confined, less losses
- BAAEs to expore, similarity with DIIID.

Quasi-linear diffusion

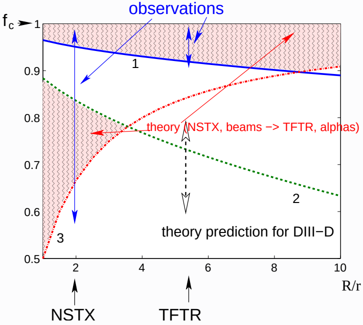
see K. Ghantous talk next

subcyclotron frequency modes (α-channeling, e-transport)

What should we expect? Why on NSTX CAEs have $f \sim f_{cf}/2$?

α-channeling arguments:

relate STs and tokamaks



To describe the drive:

- introduce continuous transition from NSTX (NBI) to TFTR (αs), $v_{\|}/v_A = 4r/R$.
- low electron damping $\Rightarrow$ outside of curves 1 and 2
- avoid AE resonance at the edge $\omega_{CAE} > \omega_{KAW} \Rightarrow k_{\|}/k_{\perp} < v_A/v_{Aedge}$ $\Rightarrow \omega > \omega_c/(1+4r/R)$.

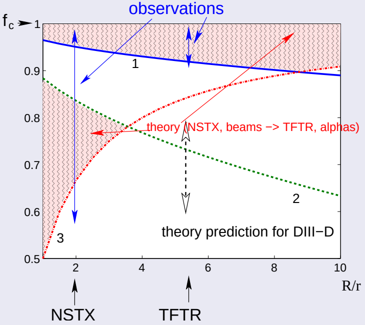
NSTX-U resembles tokamaks:
(i) less modes for e-transp. (ii) antenna for α-ch.

subcyclotron frequency modes (α-channeling, e-transport)

What should we expect? Why on NSTX CAEs have $f \sim f_{cf}/2$?

α-channeling arguments:

relate STs and tokamaks



To describe the drive:

- introduce continuous transition from NSTX (NBI) to TFTR (αs), $v_{\|}/v_A = 4r/R$.
- low electron damping $\Rightarrow$ outside of curves 1 and 2
- avoid AE resonance at the edge $\omega_{CAE} > \omega_{KAW} \Rightarrow k_{\|}/k_{\perp} < v_A/v_{Aedge}$ $\Rightarrow \omega > \omega_c/(1+4r/R)$.

NSTX-U resembles tokamaks:

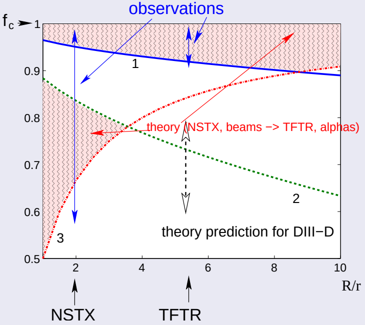
(i) less modes for e-transp. (ii) antenna for α-ch.

subcyclotron frequency modes (α-channeling, e-transport)

What should we expect? Why on NSTX CAEs have $f \sim f_{cf}/2$?

α-channeling arguments:

relate STs and tokamaks



To describe the drive:

- introduce continuous transition from NSTX (NBI) to TFTR (αs), $v_{\parallel}/v_A = 4r/R$.
- low electron damping $\Rightarrow$ outside of curves 1 and 2
- avoid AE resonance at the edge $\omega_{CAE} > \omega_{KAW} \Rightarrow k_{\parallel}/k_{\perp} < v_A/v_{Aedge}$ $\Rightarrow \omega > \omega_c/(1+4r/R)$.

NSTX-U resembles tokamaks:

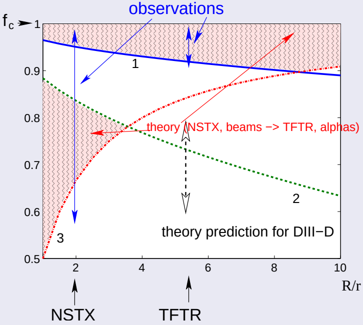
(i) less modes for e-transp. (ii) antenna for α-ch.

subcyclotron frequency modes (α-channeling, e-transport)

What should we expect? Why on NSTX CAEs have $f \sim f_{cf}/2$?

α-channeling arguments:

relate STs and tokamaks



To describe the drive:

- introduce continuous transition from NSTX (NBI) to TFTR (αs), $v_\parallel/v_A = 4r/R$.
- low electron damping $\Rightarrow$ outside of curves 1 and 2
- avoid AE resonance at the edge $\omega_{CAE} > \omega_{KAW} \Rightarrow k_\parallel/k_\perp < v_A/v_{Aedge}$ $\Rightarrow \omega > \omega_c/(1+4r/R)$.

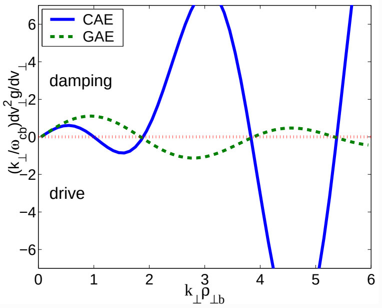
NSTX-U resembles tokamaks:
(i) less modes for e-transp. (ii) antenna for α-ch.

Drive is sensitive to f and $k_\perp$

In contrast to DIII-D and TFTR ($v_\parallel / v_A \sim 1$), in NSTX the drive is large ($v_\parallel / v_A \gg 1$),

- (FLR effect) low energy ions can have weaker interaction with the AEs, and thus only high energy ions release their energy even if $\partial f / \partial v < 0$.

N.N.Gorelenkov, NF'03.



For the drive we need:

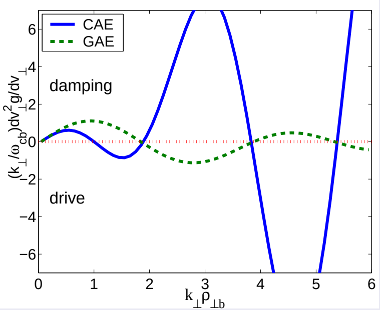
- $1 < k_\perp \rho_{\perp f} = (\omega/\omega_{cf})(v_{\perp f0}/v_A) < 2$ for CAEs and $2 < k_\perp \rho_{\perp f} < 4$ for GAEs.
- In NSTX-U $(\omega/\omega_{cf})(v_{\perp f0}/v_A) \downarrow$.
  - should expect less effects on e-transport

Drive is sensitive to f and $k_\perp$

In contrast to DIII-D and TFTR ($v_\parallel/v_A \sim 1$), in NSTX the drive is large ($v_\parallel/v_A \gg 1$),

- (FLR effect) low energy ions can have weaker interaction with the AEs, and thus only high energy ions release their energy even if $\partial f/\partial v < 0$.

N.N.Gorelenkov, NF'03.



For the drive we need:

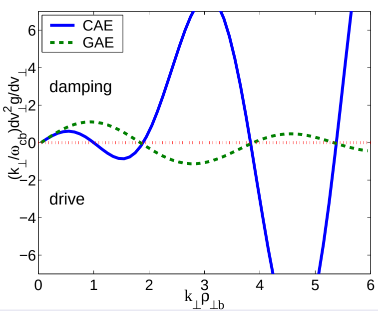
- $1 < k_\perp\rho_{\perp f} = (\omega/\omega_{cf})(v_{\perp f0}/v_A) < 2$ for CAEs and $2 < k_\perp\rho_{\perp f} < 4$ for GAEs.
- In NSTX-U $(\omega/\omega_{cf})(v_{\perp f0}/v_A)\downarrow$.
  - should expect less effects on e-transport

Drive is sensitive to f and $k_\perp$

In contrast to DIII-D and TFTR ($v_\parallel/v_A \sim 1$), in NSTX the drive is large ($v_\parallel/v_A \gg 1$),

- (FLR effect) low energy ions can have weaker interaction with the AEs, and thus only high energy ions release their energy even if $\partial f/\partial v < 0$.

N.N.Gorelenkov, NF'03.



For the drive we need:

- $1 < k_\perp\rho_{\perp f} = (\omega/\omega_{cf})(v_{\perp f0}/v_A) < 2$ for CAEs and $2 < k_\perp\rho_{\perp f} < 4$ for GAEs.
- In NSTX-U $(\omega/\omega_{cf})(v_{\perp f0}/v_A)\downarrow$.
  - should expect less effects on e-transport

What should we expect from $-U$?

- low-f instabilities are expected
  - continue VV, transport studies: *AE
  - MHD spectroscopy can be used to sharpen q-measurements
- high-f instab spectrum should be less broad, less unstable
  - pay attention to "core localized" CAEs
  - phase space engineering.
- e-transport is possible
- α-channeling - new opportunities