Validation of quasilinear/crit.gradient models for fast ion relaxation due to Alfvén Eigenmodes for burning plasmas

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in collaboration with

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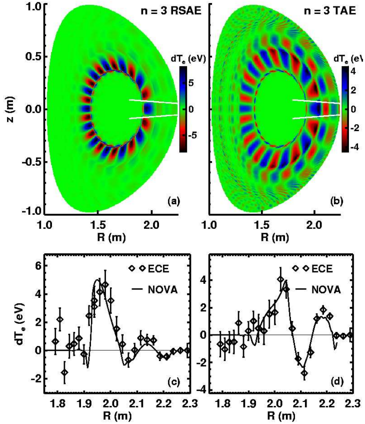
APS DPP, Providence, RI, 1 Nov. 2012

PRINCETON PLASMA PHYSICS LABORATORY

Linear ∗AE theory is well developed



M. Van Zeeland, et.al.PRL06

DIII-D ∗*AE* validation XP:

- TAE/RSAEs computations are validated
  - **whole MHD theory!!!**
- growth/damping rates are consistent
  - predictions (NSTX, TFTR - TAEs, ITER)
- ⇒ address EP transport in a regime when ∗*AE* modes are not virulent [S. Sharapov, IAEA12]

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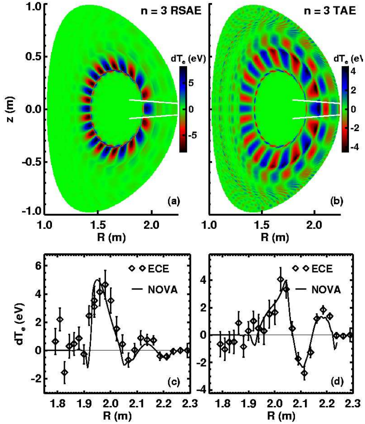

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Motivations for models validations

- Linear theory of EP instabilities is well understood
  - sophisticated codes, theories, confidence in predictions from V&V:
    - NSTX, TFTR, DIII-D ... simulations
- *Can we use them to compute EP profile relaxation?*
- *If so need to validate: DIII-D, NSTX, ... XPs*
- *Is this procedure ready, effective to make predictions?*
  - 1.5D (saturation) versus more complete 2.5D (QL)

Is QL model in need?
If not, what else? should we wait?

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Outline

1. Motivations
2. Formulations
   - qualitative
   - applications
   - DIII-D validations
   - ITER
3. Status and plans

1.5D quasilinear/crit.gradient theory (K.Ghantous et.al.PoP'12)

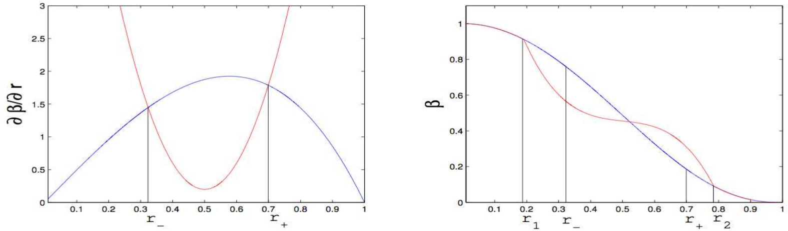
Employ linear theory to compute *AE critical EP gradient +

- assume large number of unstable modes
- fast EP diffusion
- fixed background dampings, plasma profiles
- using analytic theory compute the critical gradient $\partial\beta_{EP}/\partial r$
  - "improve" linear calculations with more accurate evaluation of the growth/damping rates (use comprehensive code NOVA-K)
  - 1.5D procedure employs analyt. expressions to keep the parametric dependence when the codes can not be applied
- integrate critical EP beta to compute
  - (i) relaxed profiles
  - (ii) losses
- account for EP distribution in a simple form as per in *Kolesnichenko, NF'80*, i.e. simple resonance $v_{\parallel} \sim v_A$ (1/2D)

Linear theory sets up the EP critical gradient against *AE instabilities

$$\frac{\partial \beta_{EPcr}}{\partial r} = -\frac{\gamma_{iL} + \gamma_{ecoll} + \gamma_{rad}}{\gamma'_{EP}}, \; \gamma'_{EP} = \gamma_{EP}/\left(\partial \beta_{EP}/\partial r\right)$$

Three damping mechanisms are often dominant in DIII-D, ITER...: ion Landau, electron collisional, radiative.



Use particle conservation law $\int_0^a r\left(\beta_{EP} - \beta_{EPrelax}\right) dr = 0$ to describe **profile broadening:**

limit $\left|\beta'_{EP}\right| \leq \left|\beta'_{EPcrit}\right|$ result in the relaxed EP profile $r_{\pm} \rightarrow r_{1,2}$

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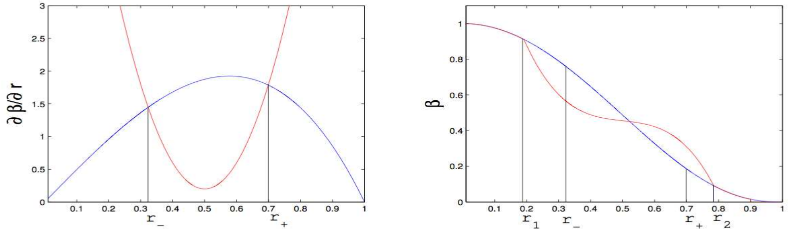

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Similarity to core transport theories

transport model	abbreviation	diff.mechanism	applic.
QL	I/P, GLF23, TGLF	diffusion	transp.codes
transp.thresh.	?	crit.thresh.	-
QL complete	2.5D	diffusion	future
crit.thresh.	1.5D	crit.thresh.	this talk

2.5D EP "true" QL theory application/coding is being developed

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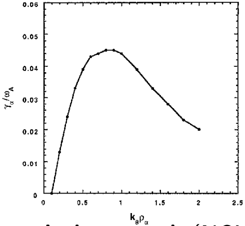
Two ways to apply

1. **Analytic model** relies on
   - TRANSP or analytic profiles
   - analytic distribution for EP αs or beams, slowing down.
   - n is taken at the maximum growth rate $k_\perp \rho_{EP} \sim 1$



G.-Y. Fu, C. Z. Cheng, PoP'92
B. N. Breizman, S. E. Sharapov, PPCF'95.

2. **Numerical approach** (NOVA-K) relies on
   - the localized *AE mode evaluation of the growth rates for normalization of the analytic growth rates
   - scan of n/z_{EP} (from $k_\perp \rho_{EP} \sim 1$) ratio in the growth rate dependence to find maximum
   - use n from the above procedure for growth rate normalization

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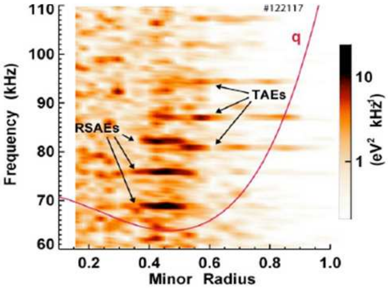
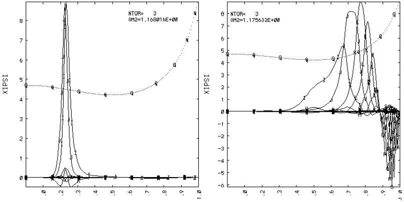
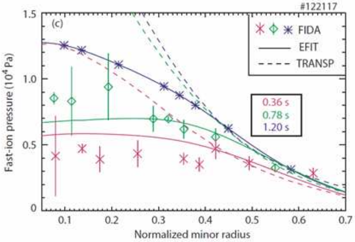


Make use of well documented DIII-D plasmas

TAEs are observed by ECE
FIDA measures beam distribution

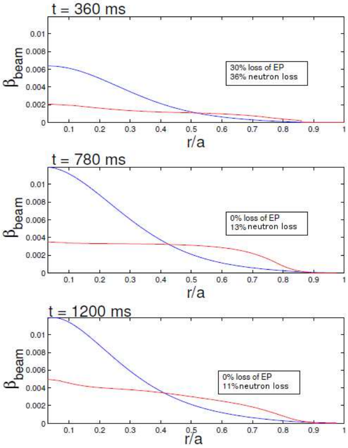
NOVA TAE modes for *normalization*





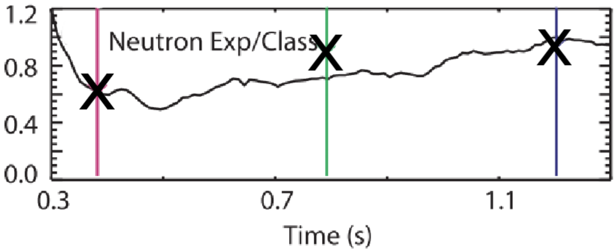
W.W. Heidbrink, NF'08

Internal EP profile dynamics is computed



- 3 times selected
- predict redistribution
- predict losses
- compare with XPs

Compare EP losses with XP via neutron signal



- Assume DD fusion cross-section is broad in energy dependence
- Compute neutron losses
- Some small inaccuracy can be introduced.

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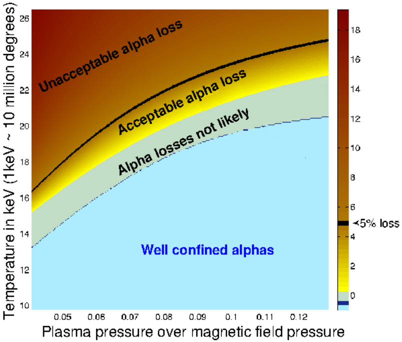
Projections to ITER



- Stability diagram, $\beta_{pl}(0)$, $T_i(0)$
  - plasma source of alphas
  - analytic theory
- α's slowing down d.f., ion Landau and trapped electron collisional dampings.
- predict the loss level, width of the benign region to stable.
  - with NOVA normaliz. crit. thresh. is well determined
  - non-linear relaxation needs further V&V effort

ITER needs to use this QL model for operation planning *(A. Polevoi, EPS'12)*.

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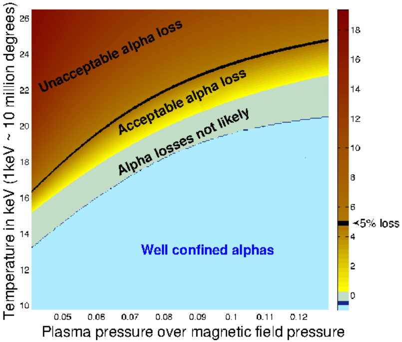

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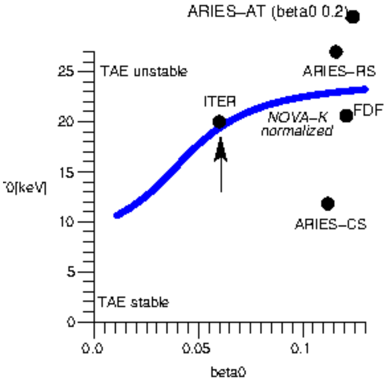
Can compare ITER and other BPs quickly

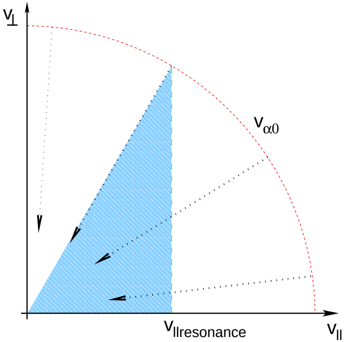


- no error bars for stable/unstable boundary
- further validation against DIII-D experiments could determine the error bars for losses
- can readily apply to future BP plasmas
- help to identify the operational regimes
- important for the guidance

Present status and plans

- 1.5D critical threshold (QL?) model has been validated against DIII-D
  - validations help to understand limitations,
  - further validations are needed (DIII-D)
- applied to ITER, ARIES, other BPs
- motivate further development of QL model, 2.5D (to be similar to TGLF).
- build into the codes like TRANSP.

How much EP/alphas is affected?



Ya. I. Kolesnichenko, NF'80

- expected max effect from instabilities with $v_\parallel = v_A \sim$ shaded area
- $\Rightarrow$ address EP transport in a regime when $*AE$ modes are not virulent
- fraction of effected alpha power $P_{\alpha res} = P_\alpha \left(v_{\alpha 0} - v_\parallel\right) v_\parallel / v_{\alpha 0}^2 \leq 25\%$
- 0.5D part of the QL model

too optimistic? sideband resonances ignored: $v_\parallel = v_A/(1 \pm 2l...)$!!!
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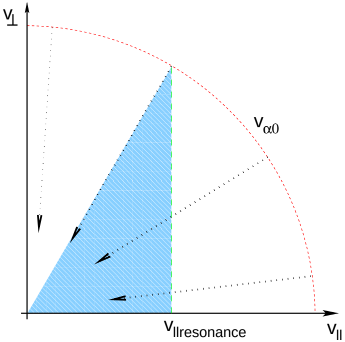

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