Theme: Codes Verification/Validation Should be a Collective Effort

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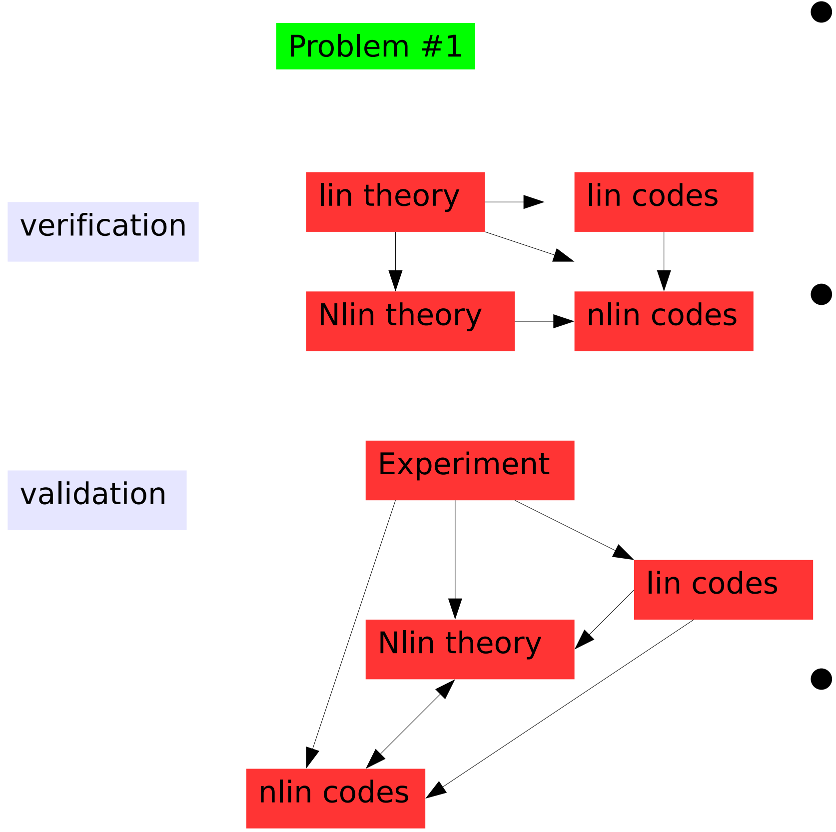
General scheme for problem oriented V&V



- identify problem(s)
  - identify properties and requirements for the model,
  - apply codes.
- There are some missing links:
  - linear global codes with FLR effects,
  - multiple AE instability codes.
- GKM code is the ultimate goal $\Rightarrow$ should be kept in mind while developing the plasma scenarios.

Proper plasma conditions are required on initial runs.
Information should be shared (project website?).

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  - frequency
  - structure
  - polarization
  - plasma parametric dependencies

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- Instabilities/modes we see in codes has to be identified based on mode properties:
  - frequency
  - structure
  - polarization
  - plasma parametric dependencies
- Nonlinear benchmarks, validations are challenging, need cross (nonlinear) code comparisons - fewer examples exist, less agreement?
  - saturation of modes: single to multiple,
  - DIII-D, NSTX transport problems,
  - predictive simulation is the goal.

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  - dominant single m, analytically treatable including kinetic physics
    - (potentially more) important for EP transport.

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- RSAEs/Alfven cascades
  - dominant single m, analytically treatable including kinetic physics
    - $*$ (potentially more) important for EP transport.
- BAE/BAAEs
  - coupling to acoustic wave, not well understood.
  - although may not be expected in ITER.

Candidate problems (part 2)

- $m = 1$ kink modes (IFS lead) - ITER is interested:
  - sawtooth, fishbones,
  - a lot of studies, existing benchmarks (Porcelli, Mcclements, NOVA-KN, M3D)
  - complicated nonlinear dynamics (Odblom),
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- Plasma turbulence vs alphas.
- Ion Cyclotron Emission - cyclotron range of frequency.
- Integrated modeling.
- α-channeling.

First year work

- Large aspect ratio circular plasma, analytical pressure, q, density profiles $\rightarrow$ to realistic plasma (see later)
  - TAEs, RSAEs *(Gorelenkov, PPCF'06)*
    - $*$ Linear theory is applicable in ideal MHD limit plus perturbative kinetic effects.
    - $*$ Linear codes are applicable. FLR can be included in some codes, LIGKA may be involved.
    - $*$ Nonlinear theory can be applied for single mode saturation via NOVA evaluation of theoretical results. ORBIT also can be used for cross benchmarks.
  - $m = 1$ mode (IFS), NOVA(-KN) to be applied.

Further work

Alfven - acoustic coupling, effect on $m = 1$, low - f modes.

Validation against experiments:

- TAE, RSAE in DIII-D, TFTR, NSTX ... for saturation BAAE/BAE

Further work

Some missing links:

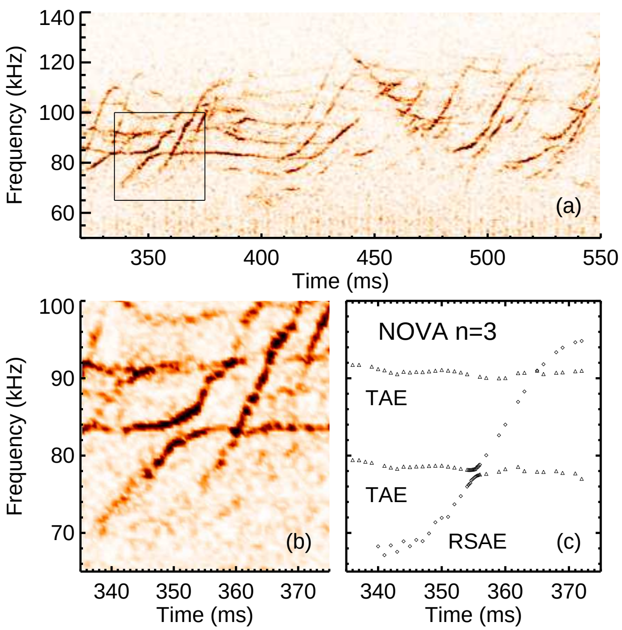
- kinetic global non-perturbative code for high-, medium- n modes,
- can modify NOVA and use its infrastructure,
- two fluid approach should give Pade like kinetic effects.

Some examples

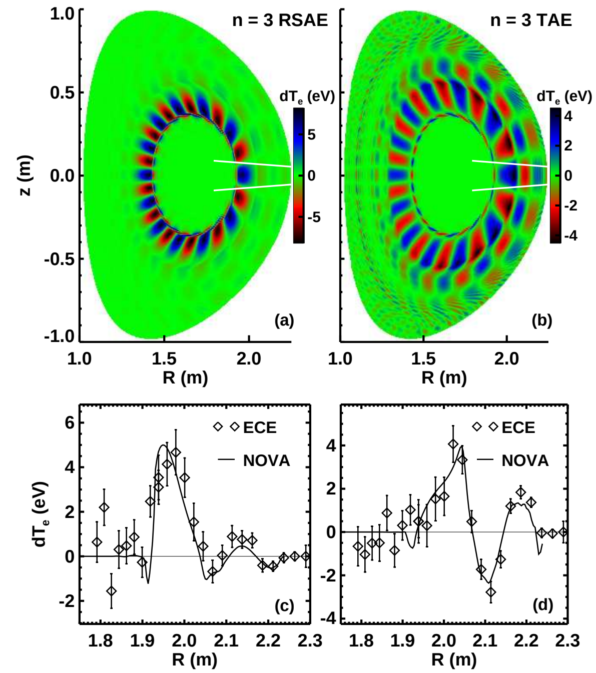
Make use of present documented cases (M.Van Zeeland)
MHD TAE structure seems to agree with measurements in DIII-D

Internal TAE/RSAEs mode structures measured by ECE, compared with NOVA

<u>RSAE & TAE frequencies crossover</u>



<u>RSAE & TAE structures</u>



Saturation is measured, single, multiple mode saturation can be obtained. Transport is not explained.

ORBIT comparison with quasilinear theory (IFS) using NOVA-K

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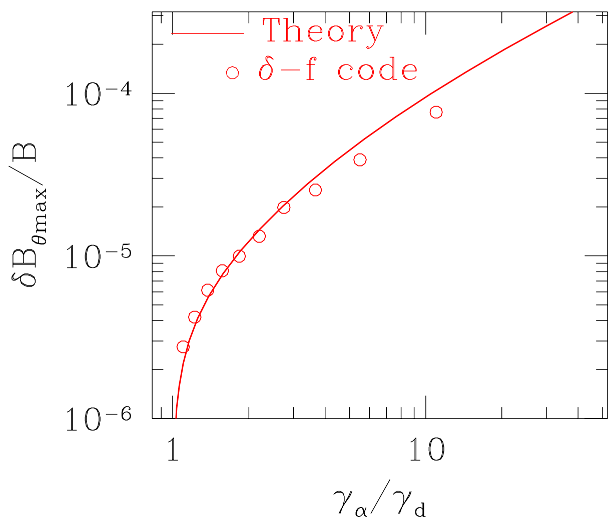

- Single mode saturation via EP response can be compared with theory.
- Improved NOVA-K simulation could include mapping techniques.
- Can be used for validation with single mode XPs.

*Some modeling challenges for *AE instabilities*

- Beams, ICRH ions are often superalfvenic. How does their distribution evolve?
- How well do we know (XP & theory) the mode structure? (Carolipio'01, Heidbrink'97)
- What about thermal ions? Will they drive modes as in DIII-D experiments (Nazikian'06)?
- Non-ideal damping mechanism can be addressed in MHD codes only perturbatively.
- Damping models need to be validated against experiments for medium to high toroidal, n, numbers.
- High-n ideal MHD codes need high poloidal harmonic number up to $m = 100$ or high poloidal grid resolution.

*Some modeling challenges for *AE instabilities*

NOVA/NOVA-K is hybrid kinetic/MHD code with perturbative treatment of various kinetic effects.

Its development is based on multi-institutional collaborations and includes experimental validations:

- NOVA uses TRANSP output for plasma parameters
- Mode structure is computed within ideal MHD (NOVA)
- Perturbative kinetic mode analysis is performed with NOVA-K code
- Fast ion drive includes: finite orbit width (FOW) and FLR effects
- Damping mechanisms included are
  - ion/electron Landau
  - radiative, non-ideal
  - trapped electron collisional
  - continuum damping
- Nonlinear saturation quasilinear model is available...

Typical experimental conditions: multiple modes are present

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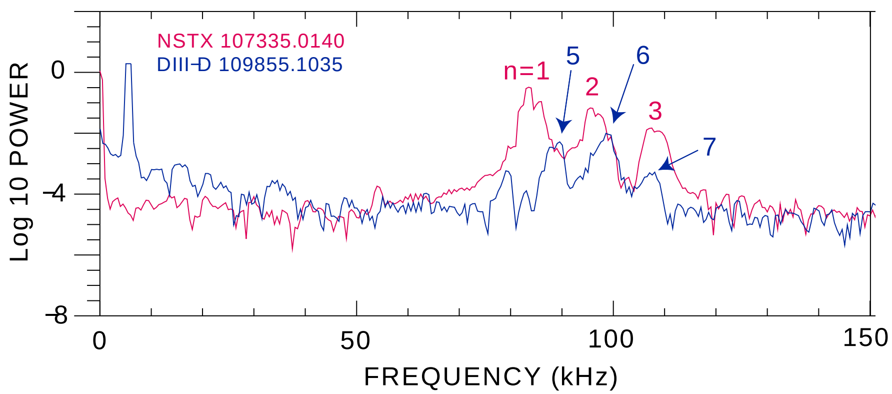
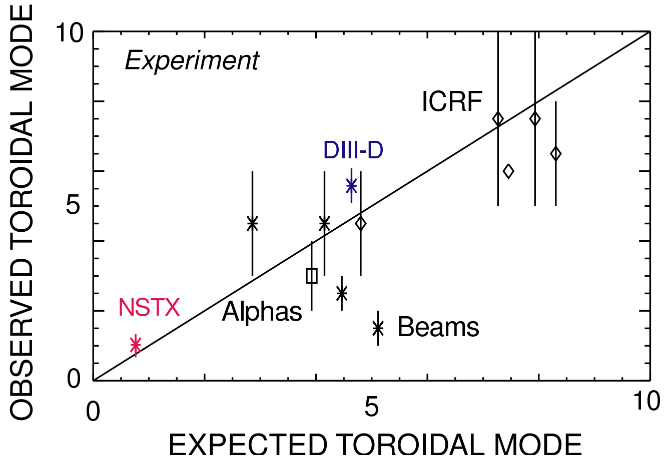
DIII-D/NSTX similarity experiments were designed to study machine size scaling predictions (W. Heidbrink, PPCF '03):

- The same minor radius in NSTX and DIII-D but different major radii.
- Use similar NBI features: injection geometry, energy, trapped to passing particle ratio.





Most unstable mode number (larger amplitude at the edge) scales as $n \sim a/q^2$.

How do we model EP distribution function (df)

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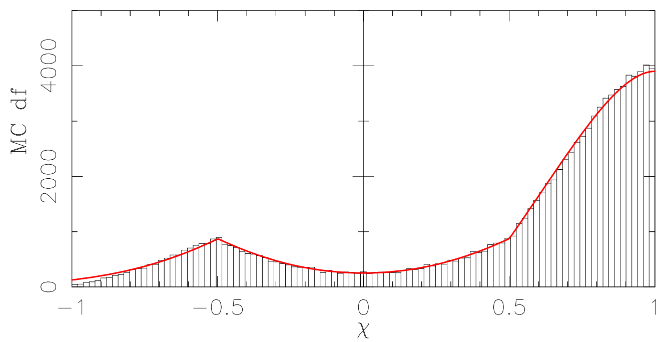
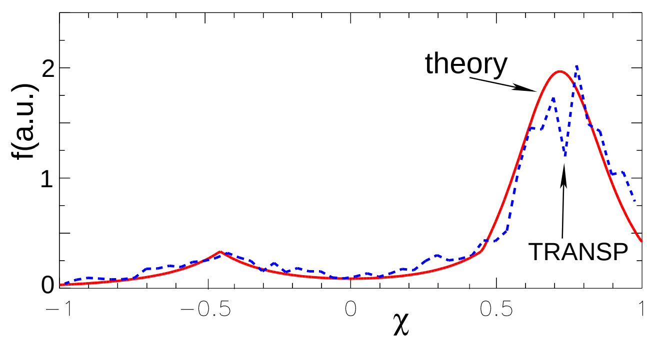
- Alphas in burning plasma (BP) will have slowing down df.
- ICRH df is an issue.
- NBI EP df model exists, should be used.

Truncated image method vs. Monte-Carlo



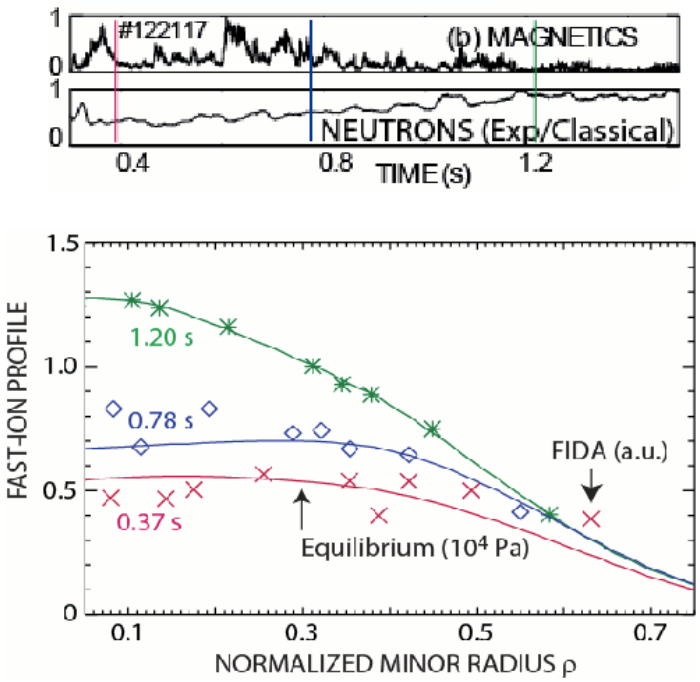
TRANSP Lorentz diffusion operator is consistent with image method (ITER NBI)



Great reduction of Monte-Carlo noises in TRANSP simulations. Analytical derivatives can be taken.

DIII-D recent RS plasma XP (W.W. Heidbrink, IAEA'06)

The Fast-ion Density Gradient is Flattened



- The profile remains flat during the strongest Alfven activity
- As the activity weakens the profile peaks but is still broader than classically predicted

**For this comparison, the FIDA density profile is normalized to the equilibrium profile at 1.20 s.*

NSTX multi-mode transport XPs

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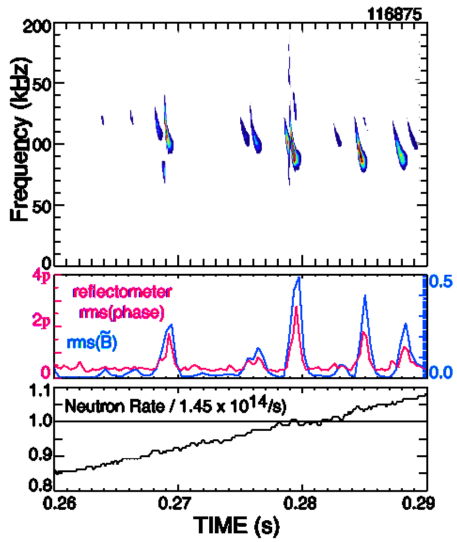
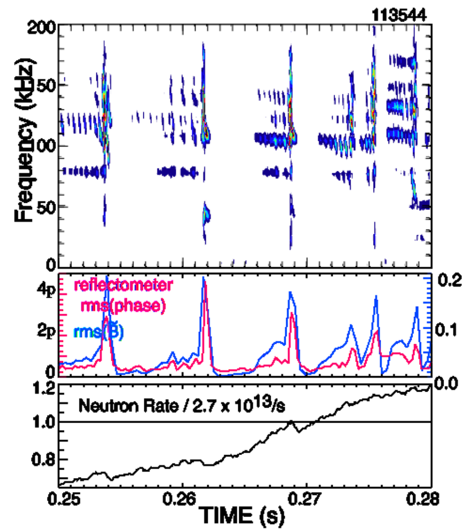
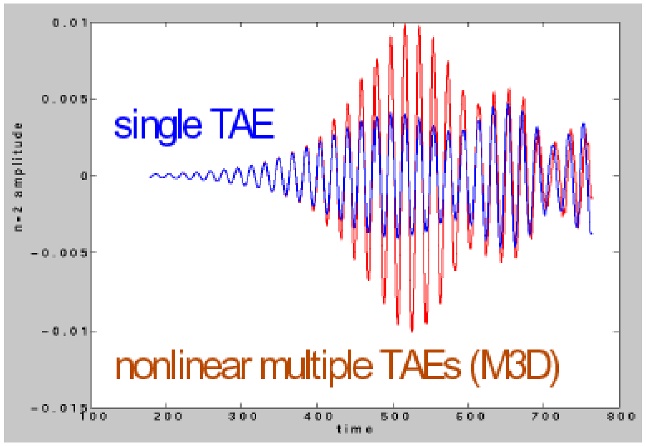
Multi-mode driven transport is targeted on NSTX

M3D study is in progress







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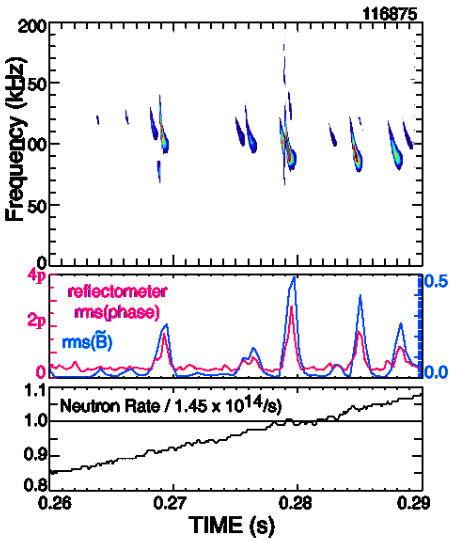

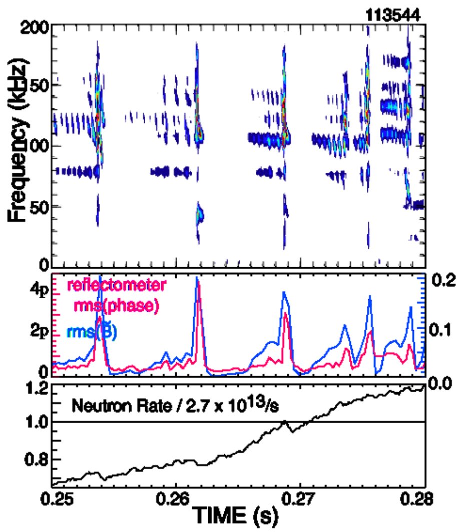

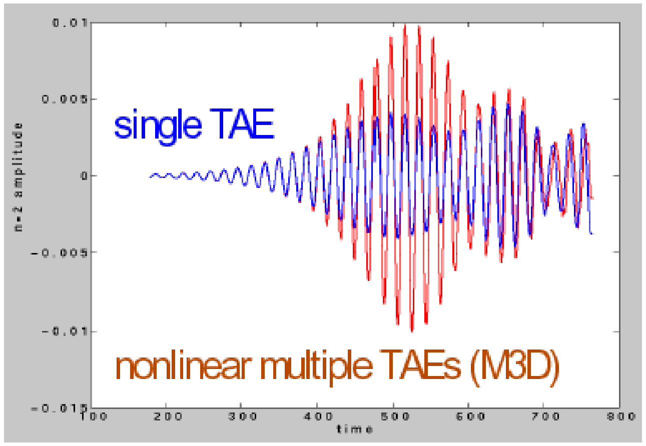

At the moment the diagnostic has to be advanced for better internal measurements.

NSTX is committed for EP effects studies: multi-mode effects on EP transport and current drive.

Summary of what NOVA-K can do

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- Linear theory with various driving and damping mechanisms of *AEs
  (1st year).
- Employs quasilinear theory (IFS) for TAE saturation
  (2nd-3rd year).
- Relatively fast, easy to modify.