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The NSTX Theory and Modeling Research Plan

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For the NSTX National Team

DOE Review of
NSTX Five-Year Research Program Proposal
June 30 – July 2, 2003

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OUTLINE

- Introduction
- Modalities
- MHD
- Turbulence and transport
- Energetic particle physics
- RF wave heating and current drive
- Coaxial helicity injection - CHI
- Boundary physics

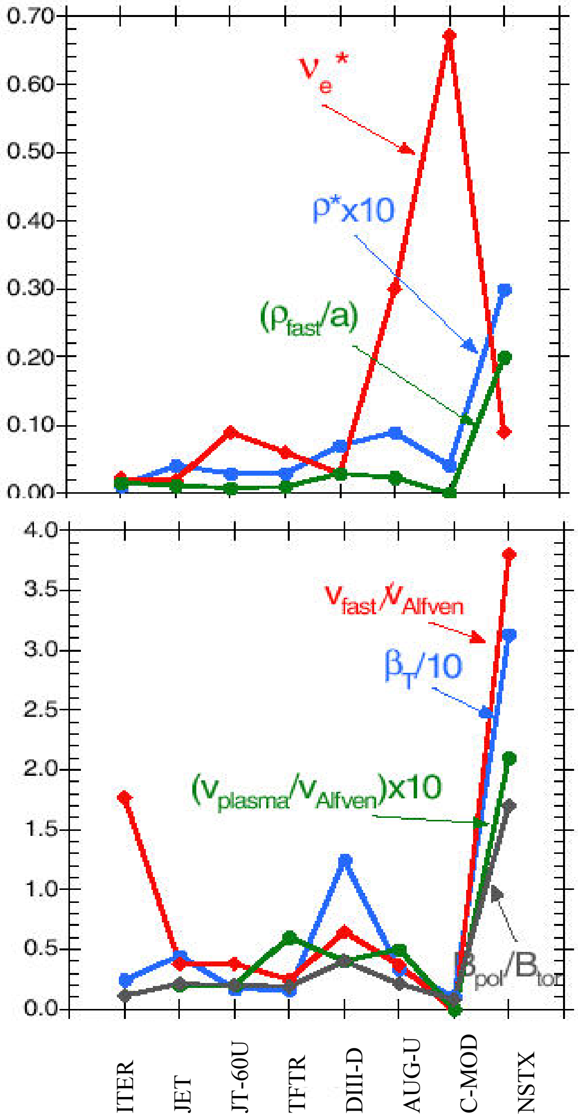
NSTX provides the opportunity to advance plasma science

Assess the attractiveness of the ST concept
Exploit ST characteristics to expand knowledge base

- NSTX provides access to unique regimes of parameter space that present a challenge to theory/models
  - *New regimes ⇨ new physics*
- Successful comparison of experiment with theory-based models will extend their range of applicability
  - *Synergism of experiment and theory*
- The over-arching goal is to define a valid physics model for the ST and achieve predictive capability
  - *Need for comprehensive and computationally efficient models*
- Success in the ST modeling effort will strengthen the predictive capability in other devices

NSTX accesses new regimes in parameter space

- Large Shafranov shift
  - High trapping fraction, mirror effects
- Larmor radius
  - Neoclassical, turbulence, RF modeling, Edge physics
- Plasma flow ~ C_s ~ V_{Alfven}
  - Equilibrium, micro and macro-stability
- $V_{fast} >> V_{alfven}$
  - Energetic particle driven MHD
- High β_T, β_{pol}
  - MHD stability, EM electrons, high dielectric constant



The theory modeling effort builds on existing codes

- The team is multi-institutional
- Benchmark and adapt where possible
- Development of new theory and codes as needed
- Benefit from other OFES programs and initiatives
  - SciDAC (ongoing)
  - Fusion Simulation Project (proposed)
- The interpretive codes EFIT & TRANSP serve as a paradigm of this approach

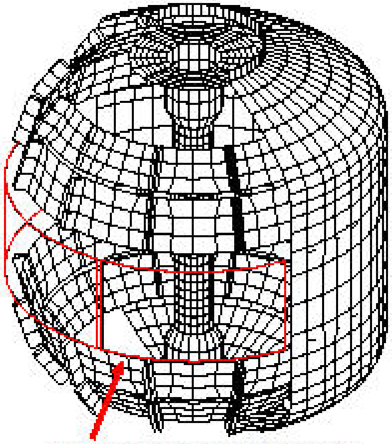
ST features which challenge the modeling of macroscopic stability physics

- Toroidal effects
  - High beta, Shafranov shift, poloidal mode coupling
- Large plasma flow, comparable to C_s and V_{Alfven}
  - Equilibrium, stability – RWMs,
  - Flow shear stabilization of internal kink and ballooning
- Nonlinear physics
  - Rotation damping and error fields
- Kinetic effects
  - FLR, ballooning modes, NTMs

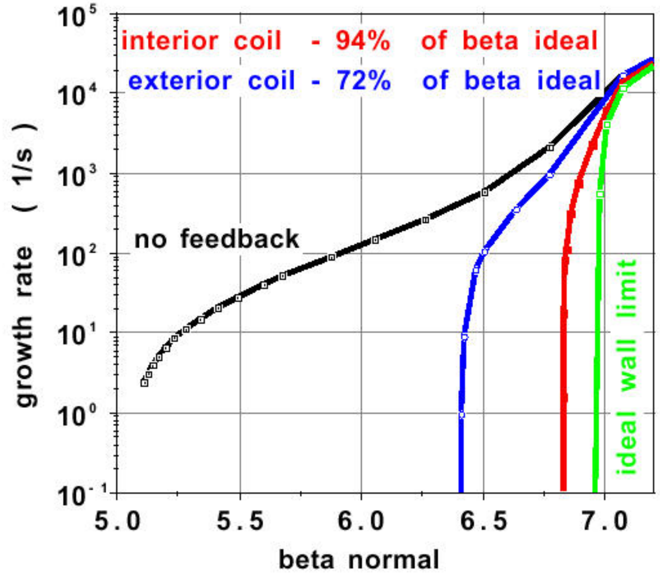
MHD codes are enabling tools for present and future experiments

- Ideal MHD stability
  - DCON, GATO, M3D, NIMROD, PEST, VACUUM
- Resistive wall modes
  - MARS, M3D, NOVA-F
- Feedback stabilization
  - VALEN, VACUUM, MARS

Some of these codes are already in routine use



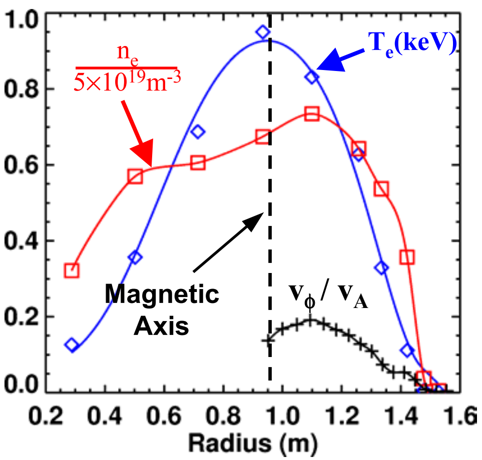
Modeled active feedback coils

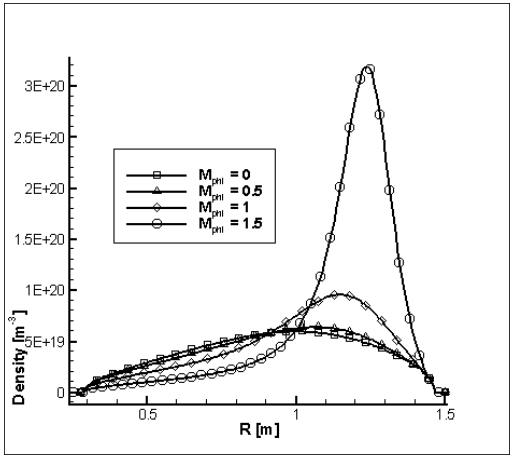


VALEN/Columbia

Experimental observations have motivated advances in equilibrium and stability modeling with rotation

Shot 105051 at t=0.211s





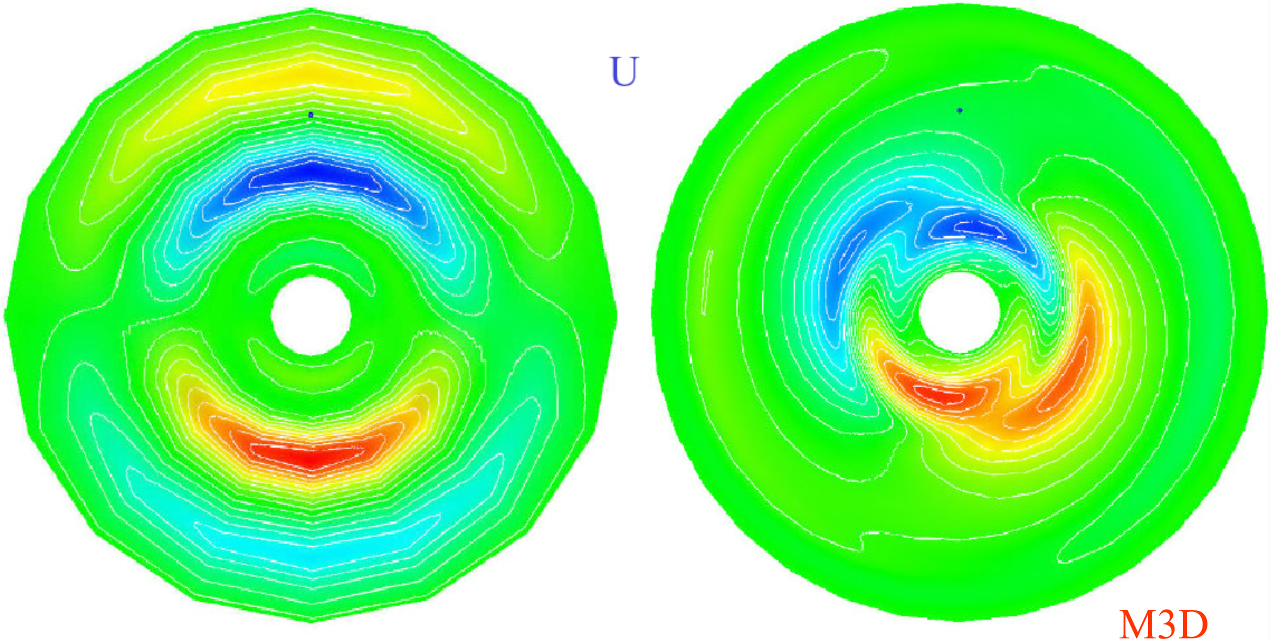
FLOW - U. Rochester

Equilibrium code reproduces in/out density asymmetry

Stability analysis shows reduced γ of n=1 internal mode

M_A=0
Ωm=0

With shear flow: M_A=0.2
Rotating mode: Ωm=0.13



M3D

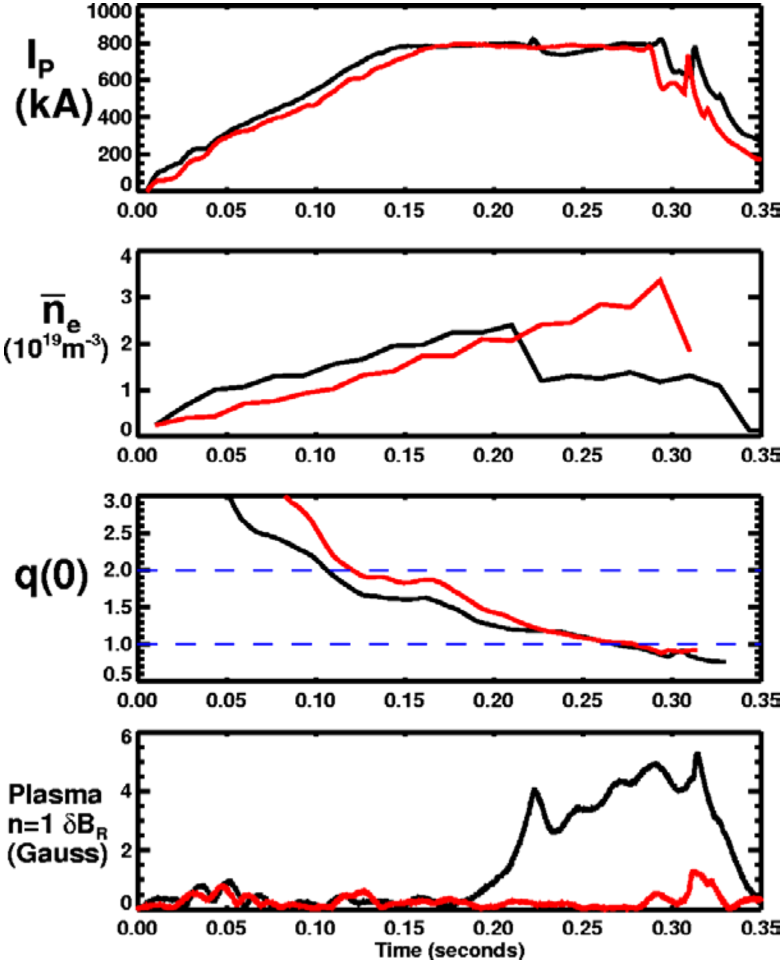
NSTX will benefit from and help advances in non-linear and kinetic MHD modeling

- Rotation damping and error fields
- Non-linear and kinetic MHD

Error field modeling requires 3D codes

- PIES, VMEC
- M3D, NIMROD
- TERPSICHORE

Reducing the error field reduces mode locking



NSTX features will extend the scientific understanding of turbulent transport

- High beta
  - Electromagnetics, $\delta B_\perp$ & $\delta B_\parallel$,
- Toroidal effects
  - Trapped particles, mode coupling
- High ExB flow (compared to C_s)>200 km/sec,
  and high flow shear (10^5 to 10^6/sec)
  - μ–instability thresholds, neoclassical theory, low-*k* turbulence
- Finite Larmor radius effects in general geometry
  - Neo-classical theory- experimental modeling

Advance the understanding of the physics, underlying confinement, transition physics

Transport physics research plans are guided by theory

Microstability and turbulence simulations are done with, FULL, GS2, GYRO. GTC

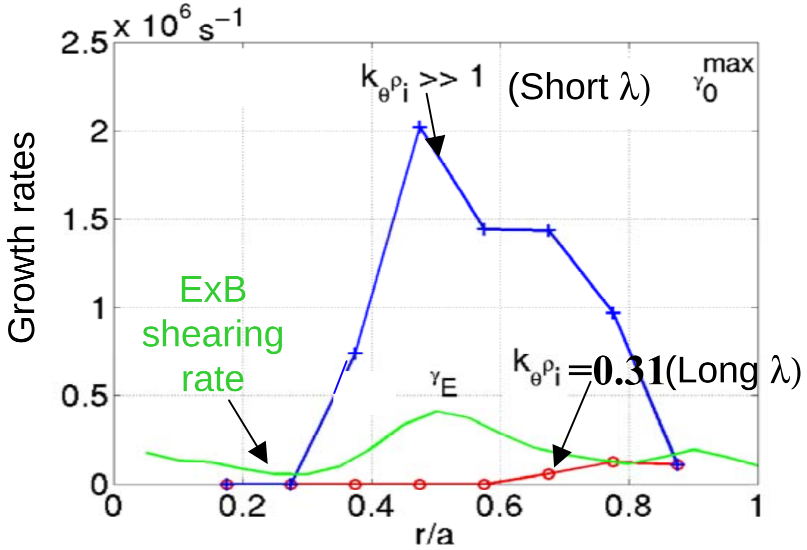
GS2 linear analyses shows that

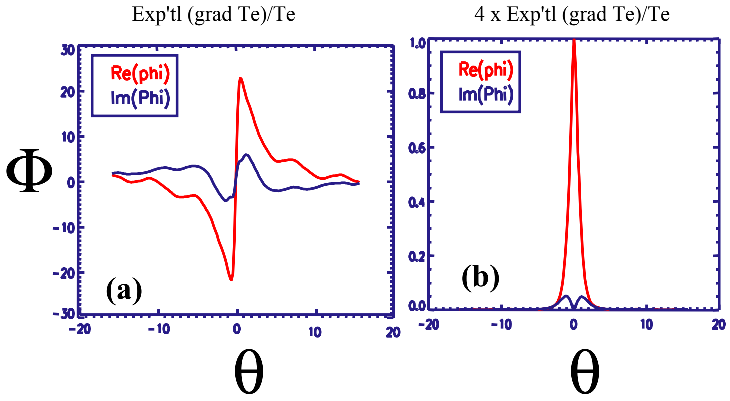
- ExB shearing rate stabilizes long λ, ITG modes, in NBI plasmas
- short λ ETG modes not stabilized, may dominate transport
- Modes that are usually sub-dominant, (tearing parity), may play a role

Diagnostics and localized heating, EBW, will test theory

Non-linear studies – GS2

+ global (GTC & GYRO) in future



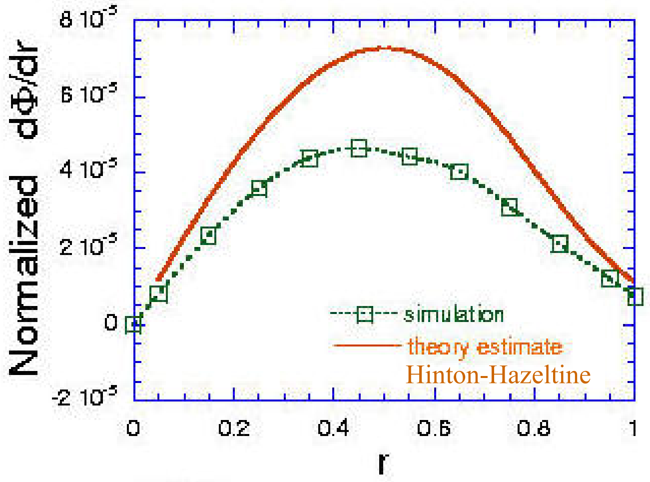


GS2 - U. Maryland

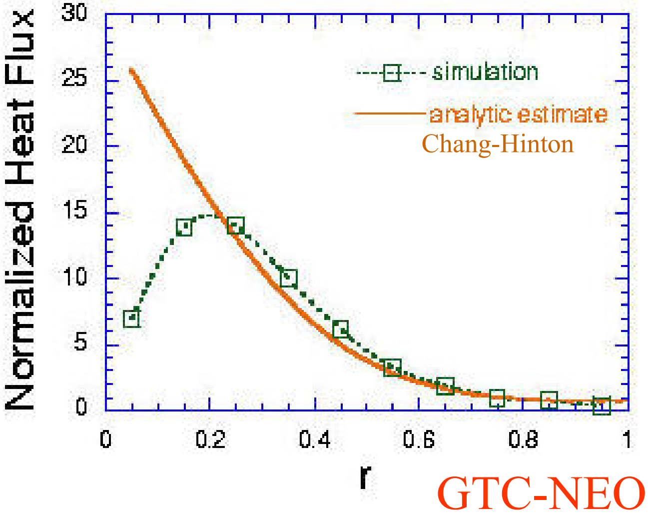
Tools to identify low-A transport physics are being developed and applied

- Neoclassical transport studied using GTC-NEO (PIC code)
  - Sheared rotation and FLR may affect bootstrap current
  - Analytic model of electric field differs significantly from the numerical result in ST geometry
- NCLASS (model)
  - Compare with GTC-NEO
  - NCLASS is being modified to account for beam-thermal ion friction

Benchmarking will be followed by applications



A NSTX case



GTC-NEO

NSTX data challenges existing models

Scaling expressions for L-H transition are inconsistent with NSTX data

Need to include the effect of fast ion loss, radial electric field and shear on turbulence suppression

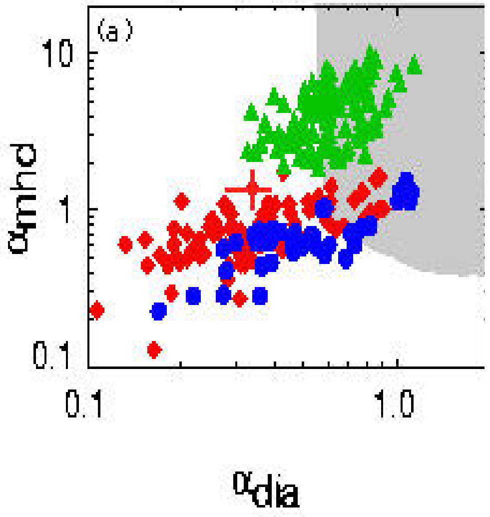
Rotation effects – equilibrium and stability

Finite ρ* - GTC, GYRO

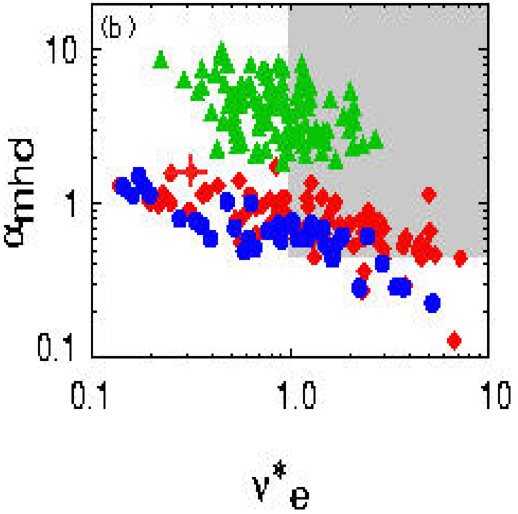
Non-linear physics

● L-mode ♦ L→ H ▲ H-mode

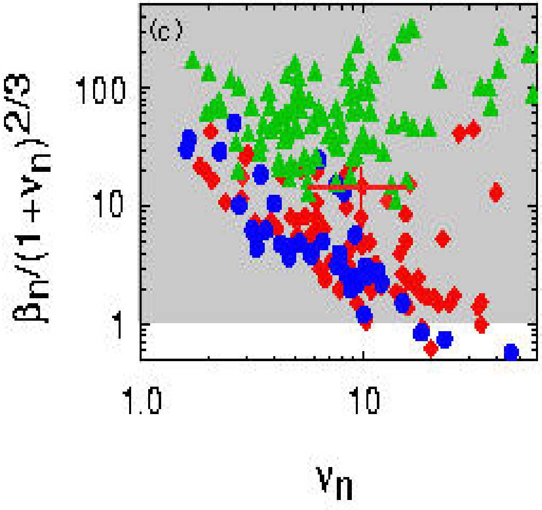
Drift resistive ballooning
Rogers et al., PRL 81(1998) 4396



Peeling
Wilson et al., Phys. Plasma 6(1999)1925



Drift Alfven
Pogutse et al., Proc. 24th EPS 21A (1997) 1545

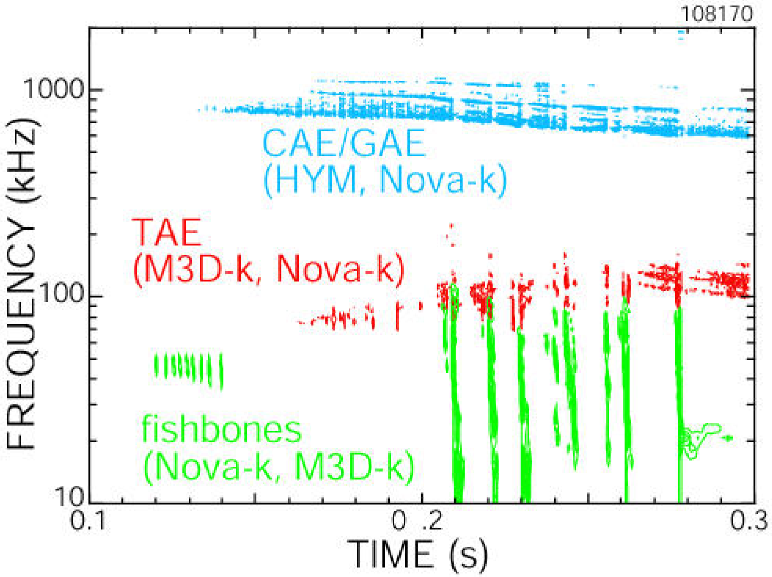


ST features test the physics understanding of fast particle confinement and wave-particle interactions

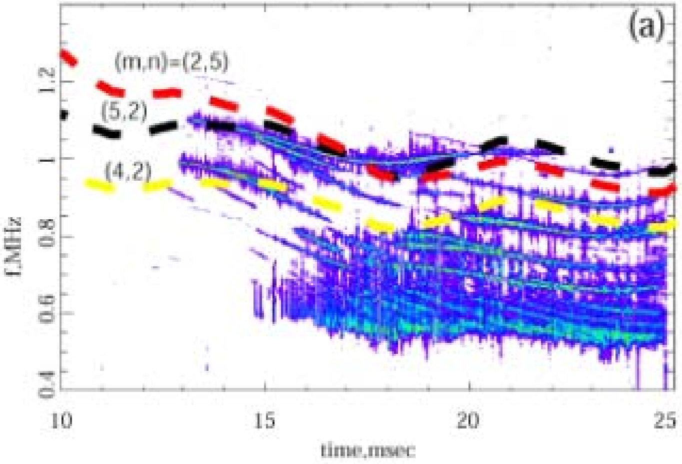
- Large Larmor radius, drift orbit radial width
  - Non-adiabaticity, possible enhanced prompt loss
- $V_{fast} >> V_{Alfven}$
- High β (thermal and/or fast-ion)
  - non-perturbative models
- Toroidal effects
  - High-q , poloidal mode coupling, challenges the ballooning approximation
- Electric fields due to NBI
  - Particle loss
- Alfven mode turbulence
  - Linear and nonlinear modeling

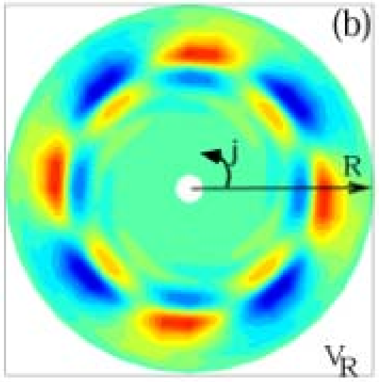
The tools which model/guide energetic particle physics are being developed to span a wide range of frequency

- Low frequency (<200 kHz)
  - NOVA-KN, HINST, M3D-K, HYM, ORBIT
- High frequency(>200 kHz)
  - HYM, NOVA
- Particle confinement
  - Non-adiabaticity, EIGOL



The HYM code will be used to self consistently model multi-mode wave-particle interactions i. e. Alfven mode turbulence





HYM

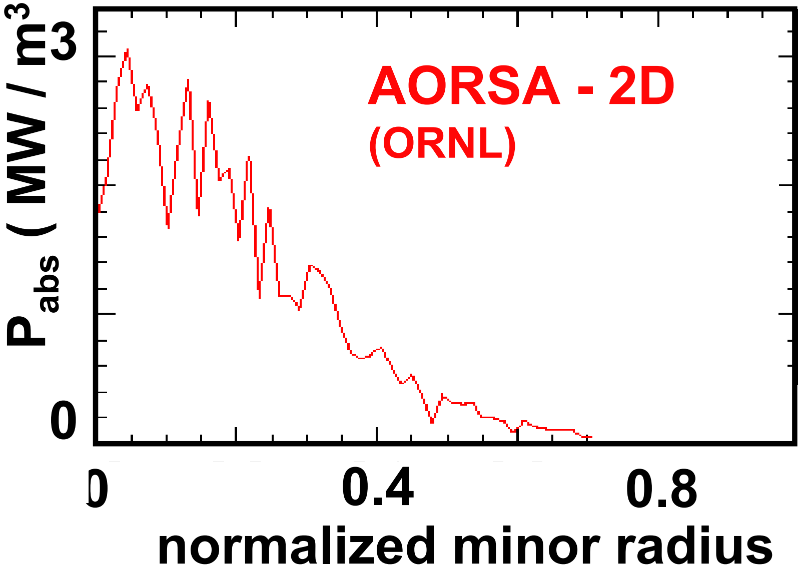
RF wave particle interaction physics issues challenge present models and codes

- Models which rely on finite Larmor radius expansions may not be accurate
- Scale lengths are similar
  - $\rho_i \sim$ banana width $\sim \Delta\, \rho_{\omega c}$
- $B_{pol} \sim B_T$
  - 2D modeling, $k_{||}$ variation
- Non-Maxwellian distributions
  - Trapping, Fokker-Planck models are needed
- High β – HHFW
- High dielectric constant

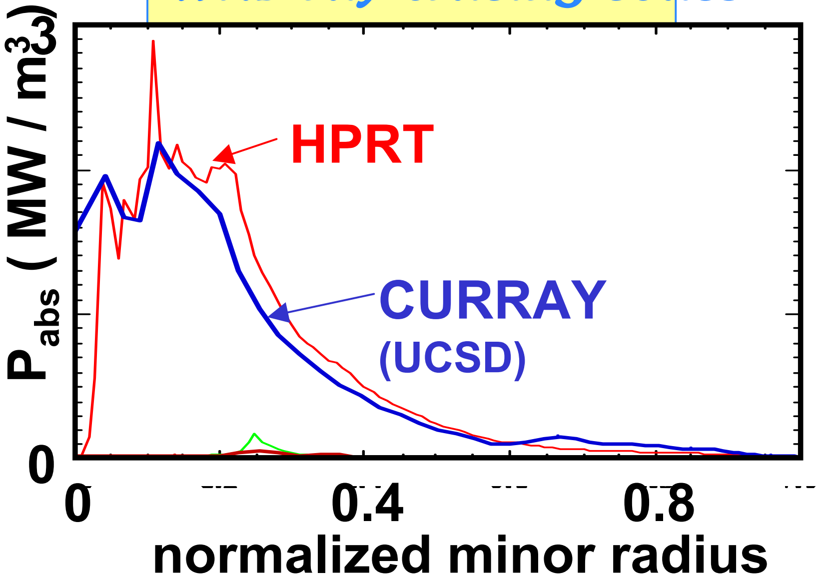
Both comprehensive and approximation based approaches are needed

- Physics exploration
- Benchmark
- Experimental modeling
- Parameter studies

Full wave code



WKB ray tracing codes

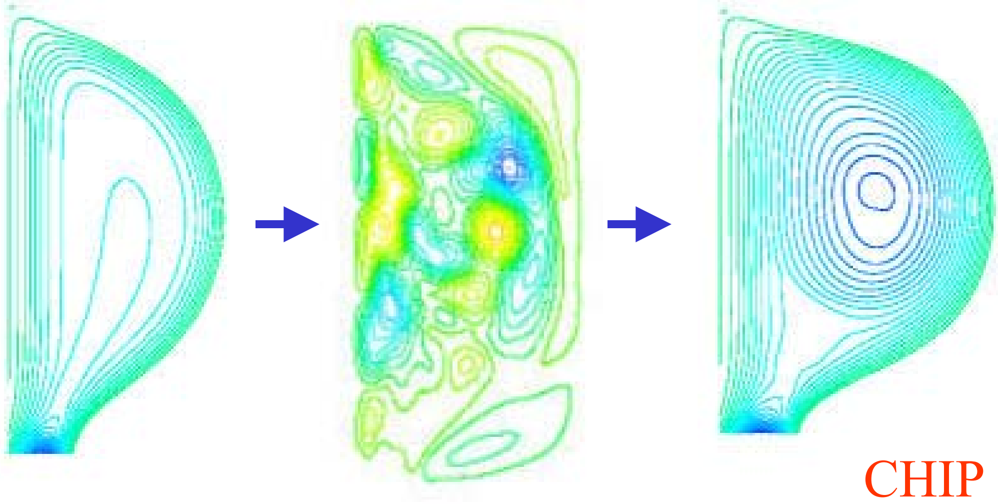


We are addressing various aspects of RF wave physics for both HHFW and EBW to successfully model NSTX

- Antenna modeling
  - GLOSI, RANT3D – Consistent equilibria
- Wave propagation
  - GENRAY, CURRAY, HPRT, TORIC, METS plasma model, 2D effects
- Non-Maxwellian distributions
  - METS, CQL3D, generalized dielectric, collisions
- Current drive
  - Ehst-Karney, Full adjoint, Fokker-Planck
- Time dependent transport modeling
  - Speed, accuracy

Modeling requirements and tools for Coaxial Helicity Injection

- Assessing and modeling flux surface evolution
  - EFIT, MFIT, ESC, TSC
- Current drive optimization, transient
  - TSC
- Flux closure and reconnection
  - CHIP, M3D, NIMROD



CHIP - LANL

Boundary Physics Issues and Modeling requirements to assess power and particle handling at steady state

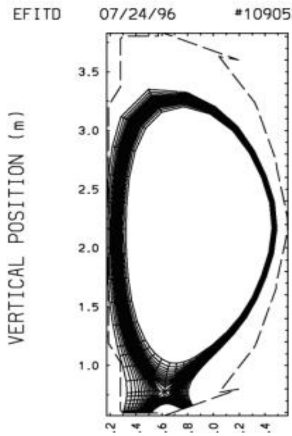
"The tail that wags the dog"

Physics

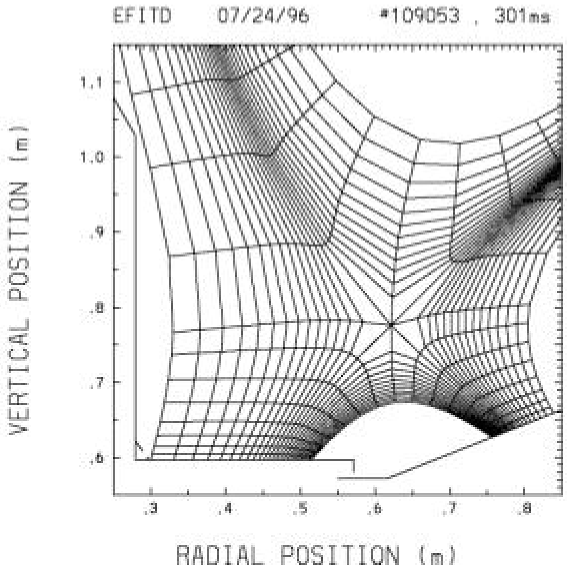
- Magnetic topology
  - mirror ratio, $f_{trapped}$
- Larmor radius
  - Kinetic codes, connection length

Modeling

- High heat flux
  - Dispersal techniques
- Transport
  - Convective vs. diffusive



UEDGE - LLNL



Tools that are being used to address boundary physics issues

- Density control
  - Neutral and plasma density profiles in SOL
  - UEDGE, DEGAS-2
  - Cryopump optimization, Lithium modeling
- Power handling
  - Assess power flux, UEDGE, DEGAS2
  - Assess the importance of kinetic effects – FPI (1D ⇨ *2D*)
- Edge turbulence
  - BAL, BOUT, UEDGE

Integrated scenario modeling

The goal of achieving predictive modeling requires coupling codes and models from different topical areas. [Kessel talk]

As the codes and theories improve they will contribute to refining the total package.

Comparisons with the experiment will help to validate the models

Summary

The theory and modeling research plan addresses all the topical areas of relevance to NSTX

Theory activities address the experimental modeling needs as well as the underlying physics of STs

Advances made here will extend our understanding of toroidal physics, supporting both the tokamak and ICC development lines