Supported by Office of Science

NSTX

Theory – NSTX Synergy

College W&M
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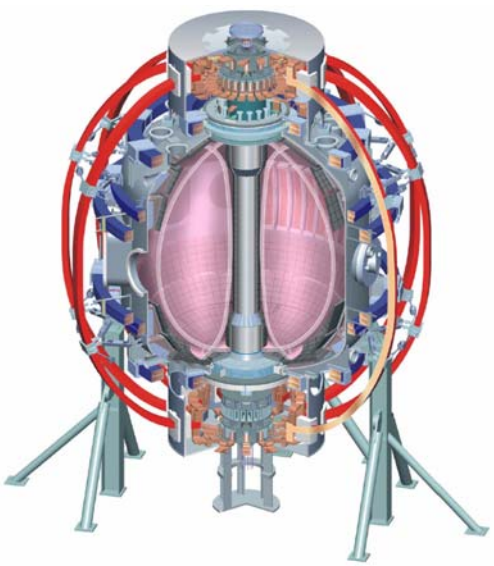
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

Stanley M. Kaye
For the NSTX Team

Theory Review
Oct 10 – 11, 2005
PPPL



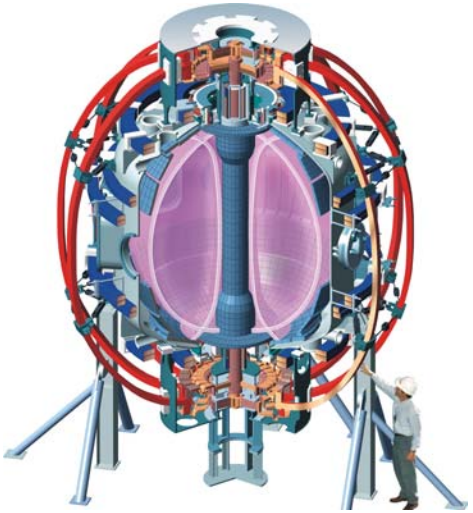
Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAERI
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

The Mission of NSTX is Broad

- Extend the understanding of toroidal physics to high-β, low-collisionality regimes at low aspect ratio (R/a≤1.4)
  - High-β equilibrium and stability
  - Thermal and fast ion confinement
  - Non-inductive current generation and sustainment
  - Edge physics

  - *Development of the Spherical Torus (ST) as a reactor and/or Component Test Facility (CTF) concept*

- Address physics issues in parameter space relevant to burning plasmas (ITER)
  - NSTX has unique capabilities to do this in several areas



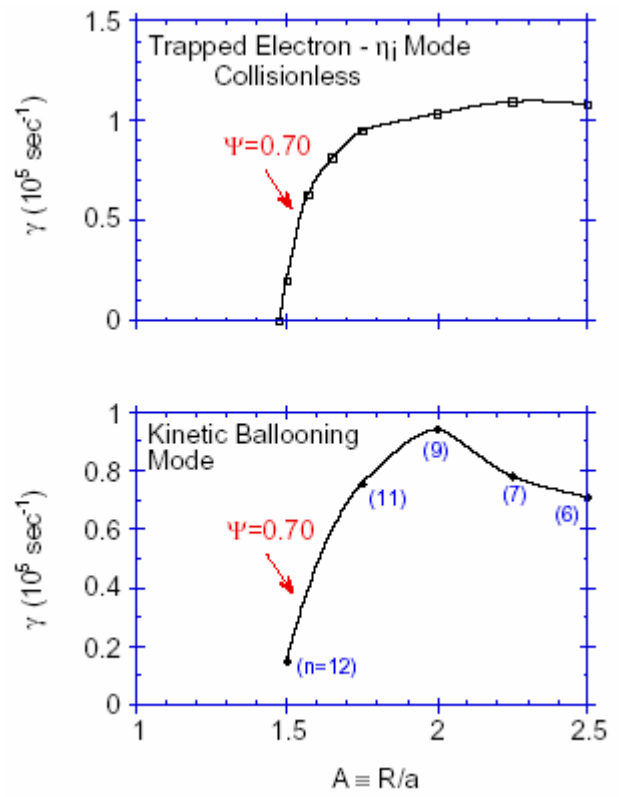
Aspect ratio A	1.27
Elongation κ	2.5
Triangularity δ	0.8
Major radius R_0	0.85m
Plasma Current I_p	1.5MA
Toroidal Field B_{T0}	0.6T
Pulse Length	1s
Auxiliary heating:	
NBI (100kV)	7 MW
RF (30MHz)	6 MW
Central temperature	1 – 3 keV

Theory – NSTX Synergy is Strong

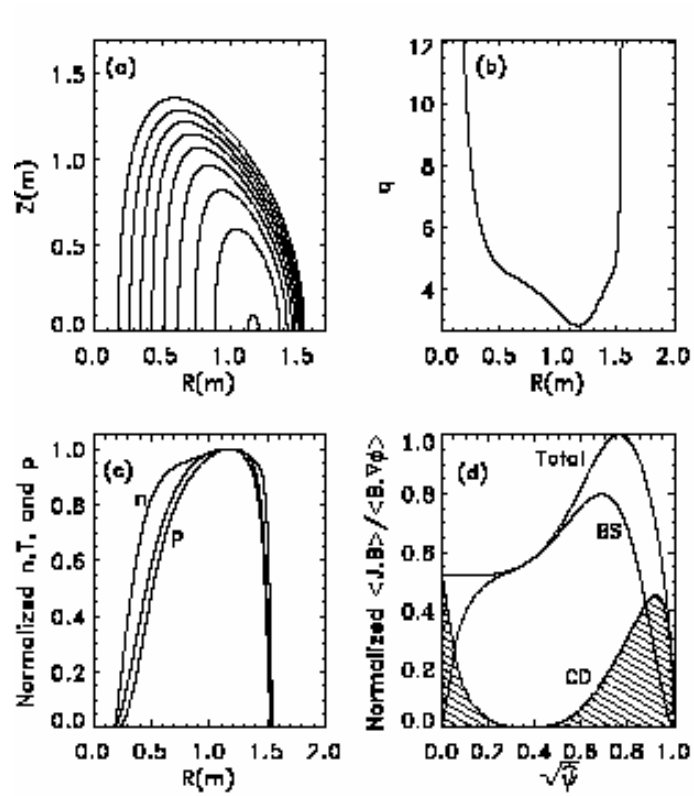
- NSTX is an excellent test bed for validating and extending theory to new regimes
- The Theory – NSTX collaboration is helping to establish the basis for
  - Fundamental understanding of toroidal physics
  - Design and operation of future devices (ITER, CTF and beyond)
- Synergy between Theory and NSTX helps drive experiments and diagnostic development
- Talk will focus on key aspects of Theory – NSTX collaboration
  - Background (physics design)
  - Selected elements in areas of Equilibrium and Stability, Transport and Turbulence, Fast Particles, Non-Inductive Current Drive, Boundary Physics
- *NSTX needs are well integrated in the Theory Five Year Plan*

Enhanced Performance in NSTX Predicted by Theory During Physics Design Phase

Suppression of long & medium-λ μinstabilities predicted by FULL (Rewoldt)



JSOLVER, PEST used to determine optimized profiles for high-β, high-non-inductive current (Menard, Jardin)

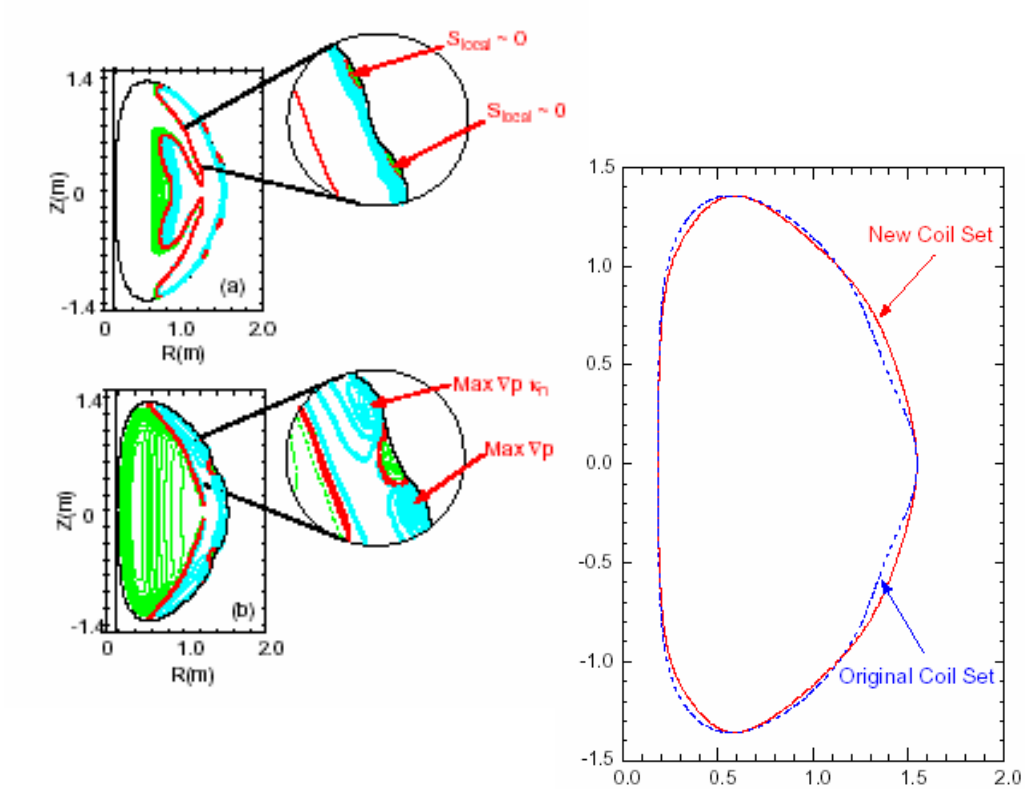


Ion transport observed to be subdominant

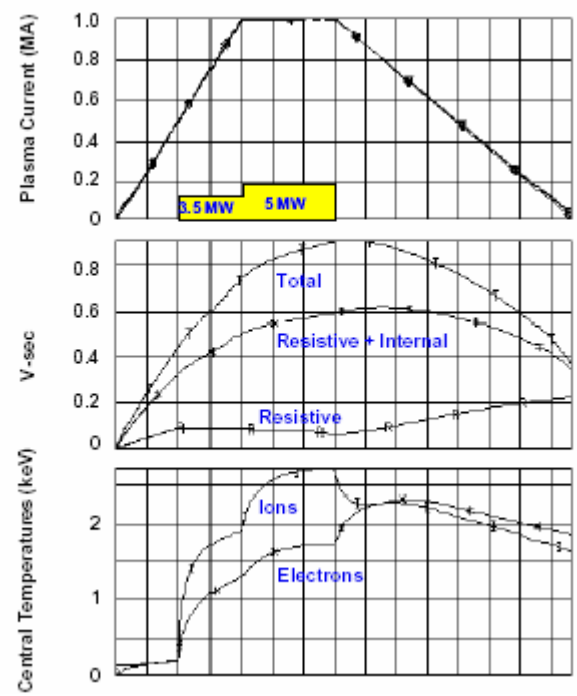
β_T near 40%, 75% NICD achieved

Theory Made Crucial Contributions to Machine and Experiment Design

PEST showed that plasmas produced by existing PF placement would have poor high-n stability properties (Manickam, Paoletti [Columbia U.])



TSC used to develop breakdown requirements and operational scenarios (Pomphrey, Jardin, Kessel, Kaye)

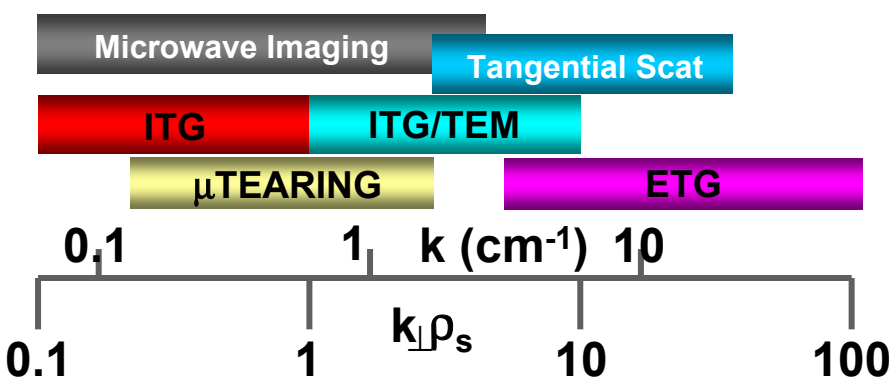


New coil wound to eliminate "dimple"

Initial NSTX plasma achieved on first attempt

Theory Shows That NSTX Offers a Unique View into Plasma Transport and Turbulence Properties

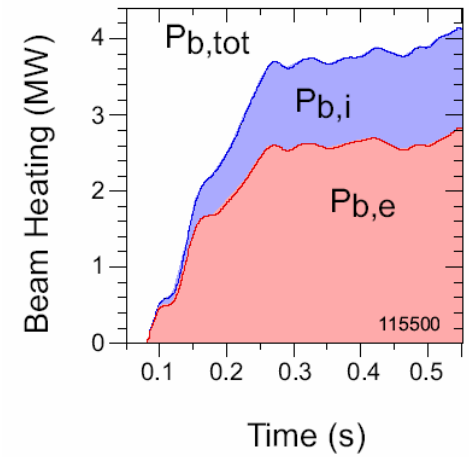
- Low B_T
  - Larger scale sizes (ρ), turbulence amplitudes: electron turbulence measurable
  - Large rotational shear (ω_{ExB}): can reduce or suppress long-λ turbulence
  - High trapped particle fraction: impacts μinstability drive
- High β_T
  - Spans range from electrostatic to electromagnetic turbulence
  - Impacts electron transport
- Greater toroidicity
  - Strong poloidal mode coupling, large variations along field
  - Low magnetic shear in central region, high at edge
- Theory motivated plan for turbulence measurements on NSTX



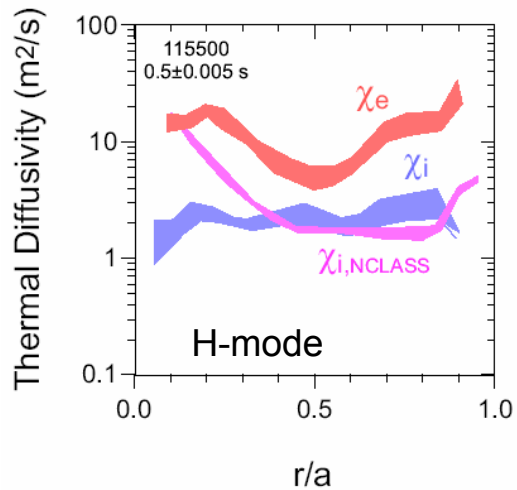
FULL (Rewoldt)

Electron and ETG Physics is a Critical Theory – NSTX Collaboration Area

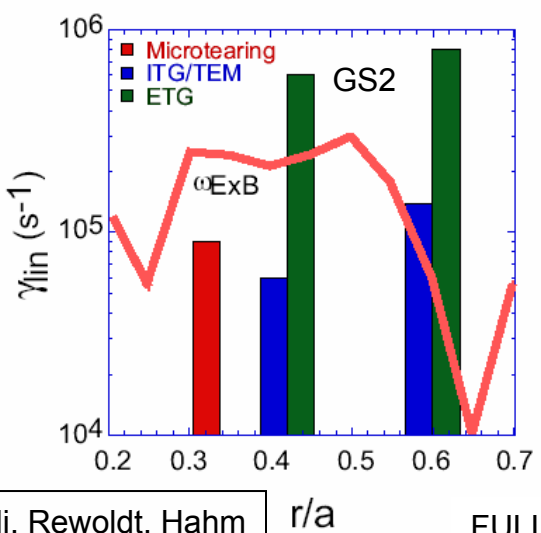
Predominant electron heating (relevant to α-heating in ITER)



Electron transport dominant in most NSTX regimes (TRANSP) – ions near neoclassical



ETG possible source of electron transport



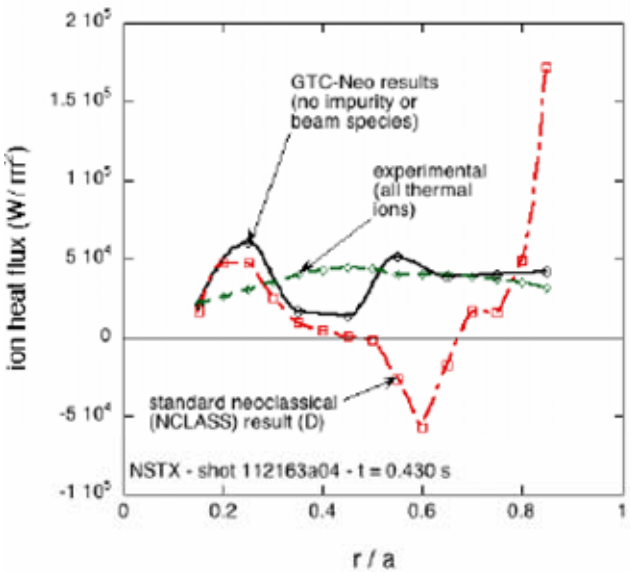
Redi, Rewoldt, Hahm

FULL, GS2 results agree

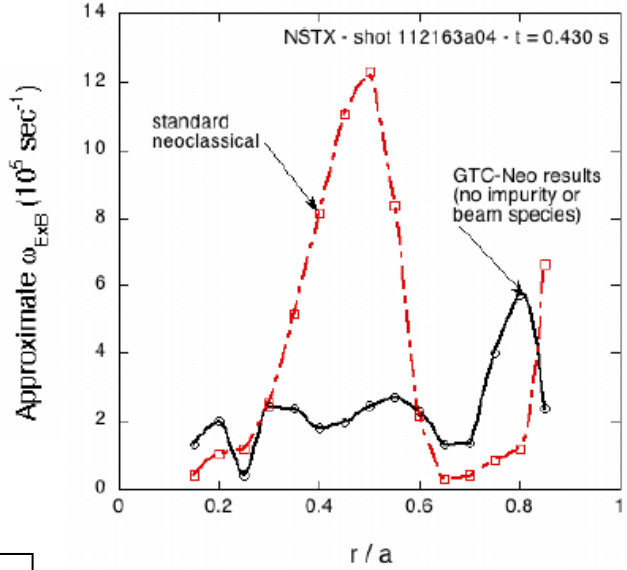
- *Non-linear gyrokinetic simulations necessary*
  - *Effect of flow shear on ETG growth*
  - *Non-linear saturation of ETGs – generation of radial streamers?*
  - *Calculate and correlate predicted $\tilde{n}$ and k-spectra with ion vs electron scale measurements*
  - *Regularly scheduled theory/exp't discussions*

Theory Has Shown That Non-Local Effects are Important in the Study of Both Ion and Electron Transport

GTC-Neo yields a more physical picture of neoclassical transport with finite Δ_b effects



ExB shear differences can impact μinstability suppression



Wang, Rewoldt

- Further address non-local effects over wide range of ν_*, T_{i0}/T_{e0}

- Assess impact on long and short-λ modes in non-linear gyrokinetic calculations

Understanding Fast Particle Physics Will Have Direct Application to ITER and CTF

- V_f/v_A~1-4, β_f/β_T~0-0.8
  - Resonance and instability drive for a range of fast particle modes
  - Large mode amplitudes results in ITER-like mode overlap
- Low B_T, high-β
  - Compressional terms important for modes
- Wide range of diagnostics available for investigating fast ion distributions and instabilities

Fast particle loss

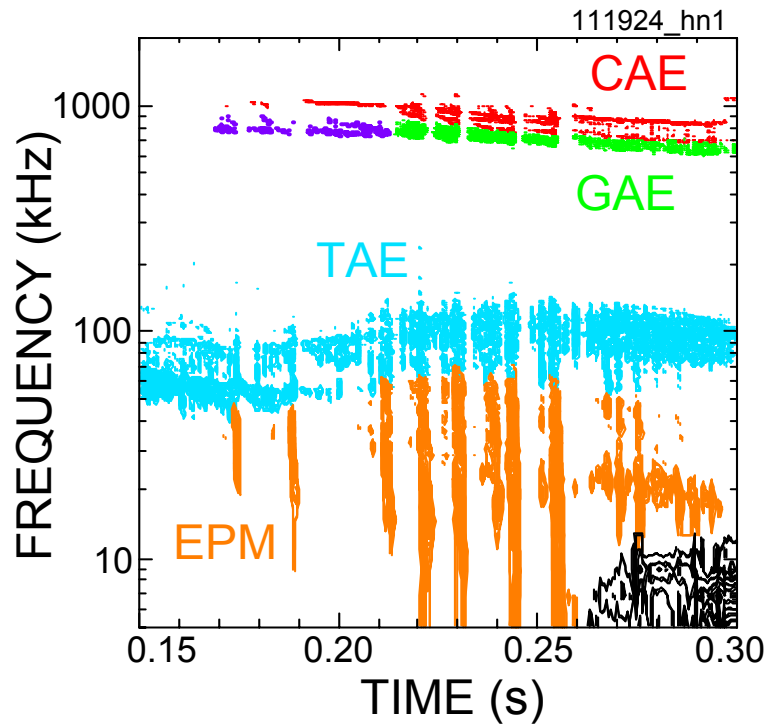
Fast Lost Ion Probe
sFLIP
Neutral Particle Analyzer
Solid State NPA

Fluctuations

Reflectometer
Tang FIR polarimeter
High-f Mirnov coils
Fast SXR camera

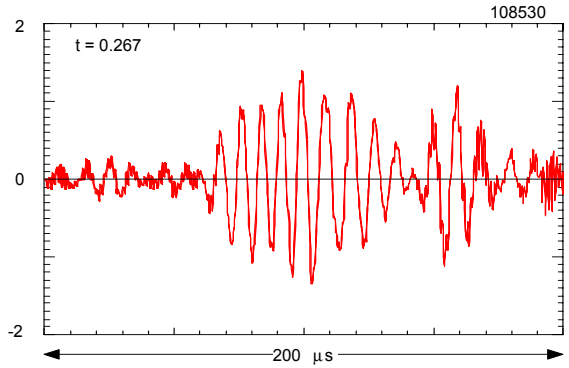
NSTX is only device that has MSE for j(r,t) measurement at high V_f/V_A
- Mode stability
- Effect on fast ion driven current

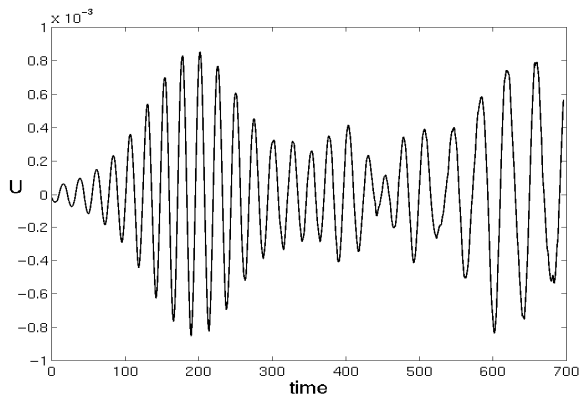
Fast particle modes can occur over a wide range of frequencies



Broad spectrum of TAEs due to extreme toroidicity was predicted (Gorelenkov)

Non-Linear TAE Simulations Reproduce Observed Bursting/Chirping Behavior

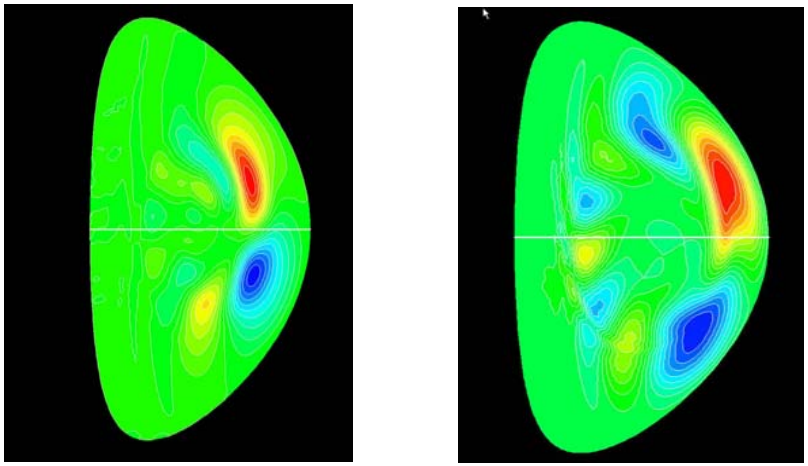




Fu

Nonlinear M3D-K simulations (kinetic effects included)

- Mode growth and decay times 50-100 μsec
- B/C results from non-linear modifiction of fast ion distribution, change in mode structure



Fu

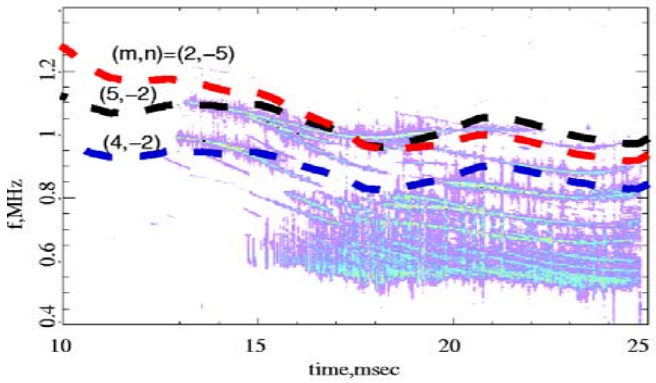
Further understand non-linear interactions between TAE mode and fast ions with more comprehensive models and codes

NSTX results have direct bearing on ITER

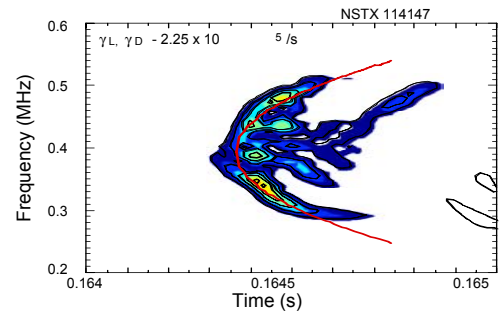
High Frequency Mode Activity on NSTX is an Area of Intense Theory Collaboration

GAE mode characteristics agree with predictions

Gorelenkov



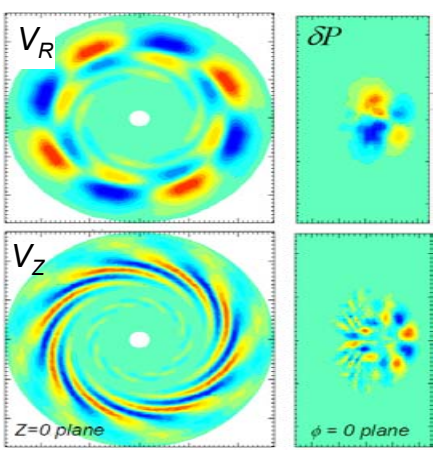
Observed frequency splitting at high-f consistent with 1D hole-clump theory



Observation

Non-linear simulations (HYM)

Belova

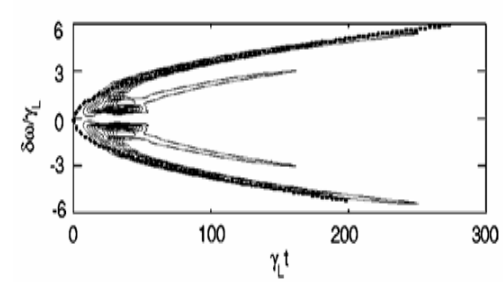


GAE (most unstable)

- Low n, near R_{mag}
- $dB_{||} < dB_{\perp}$

CAE

- Higher n, near outboard midplane
- $dB_{||} > dB_{\perp}$



Theory
Berk – UTexas ('99)

Extend to multi-dimensions

NOVA, ORBIT (Gorelenkov, White)
M3D-K (Fu)

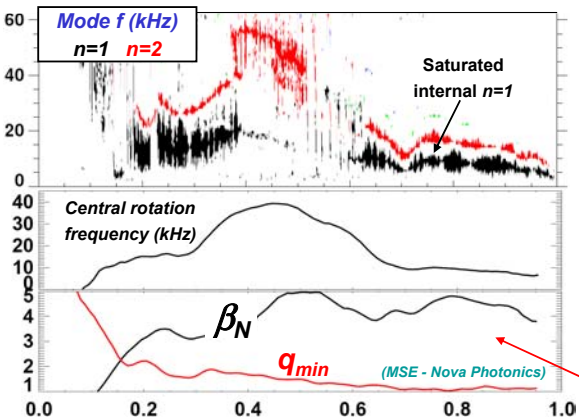
CAE modes identified through Theory – NSTX collaboration

Predicted for ITER

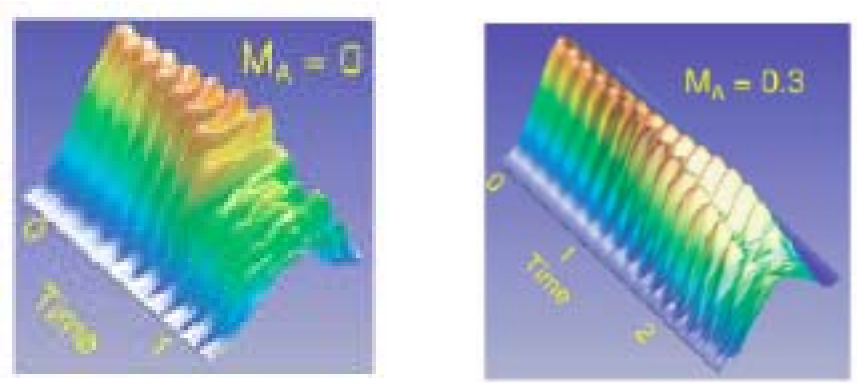
Strong Plasma Flow Has Significant Effect on Internal Mode Growth

High plasma rotation with M_A~0.4, M_s~1.0
Being incorporated into equilibrium/transport codes by CPPG

High-β sustained during periods of saturated 1/1 activity



M3D resistive MHD
Sheared rotation slows mode growth by factor of 2 to 3



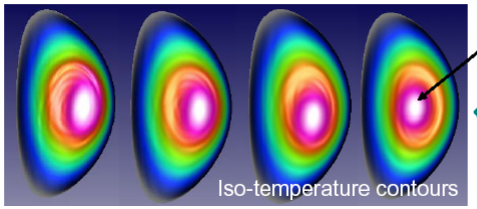
Possible approach to understanding ITER hybrid scenario

Park, Breslau

Non-linear 2-fluid M3D simulations w/ kinetic stabilization

Saturation with hot spot pulled away from x-point

Co-injection w/ 2-fluid
M_A=+0.3

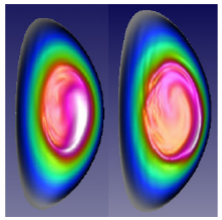


Displaced core "hot-spot"

Nonlinear 2-fluid MHD simulations
(M3D – PPPL, NYU, MIT)

Mode crashes faster than single-fluid MHD

Counter injection w/ 2-fluid
M_A=-0.3



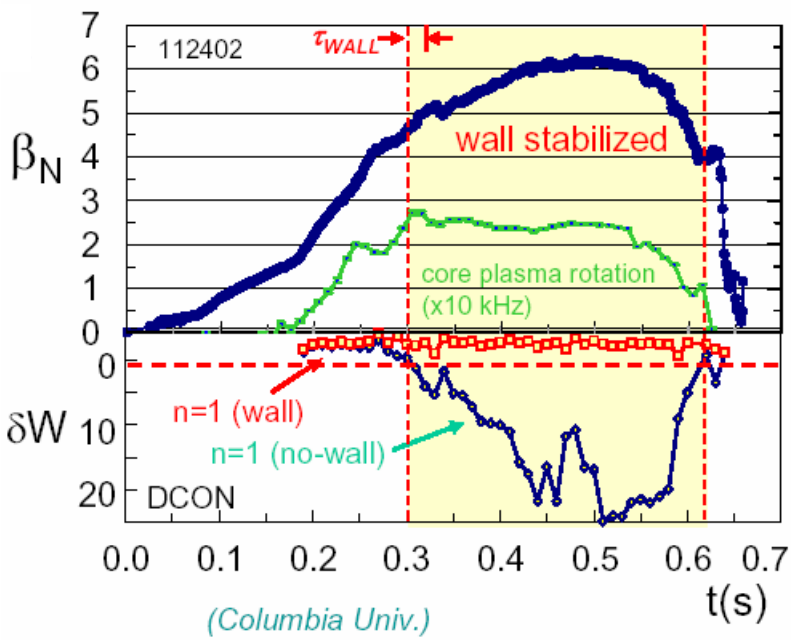
Specific experiment to be performed to test theory

Park, Breslau

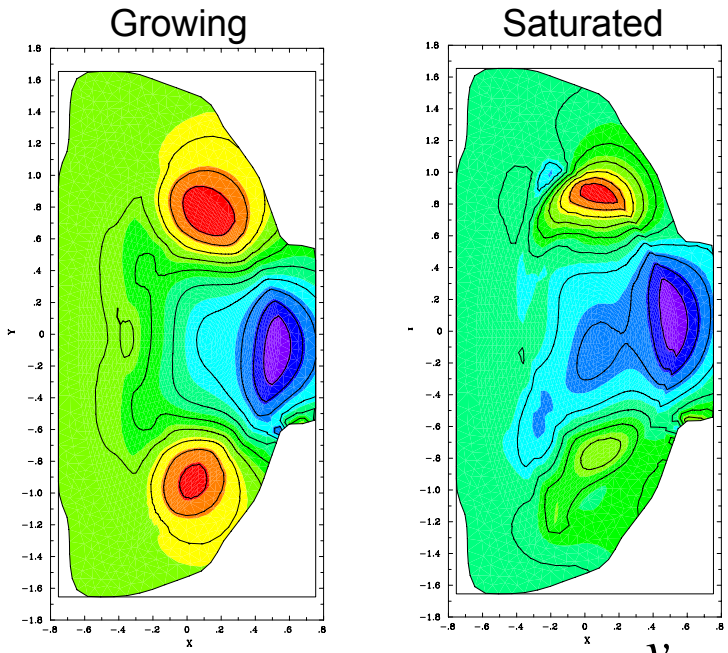
External Mode (RWM) Growth Can Be Reduced by Plasma Rotation

Sustained high-β_N operation 30% above the no-wall limit

- Operation at highest β_N is sustained for >> τ_{wall} with β_N / $\beta_N^{no\text{-}wall}$ > 1.3



Resistive plasma/resistive wall simulations with M3D show the external mode is partially stabilized by rotation



$$\Omega = 0 \qquad \Omega = .05\frac{v_A}{R}$$

Study RWM in context of possible β-limiting mode in ITER

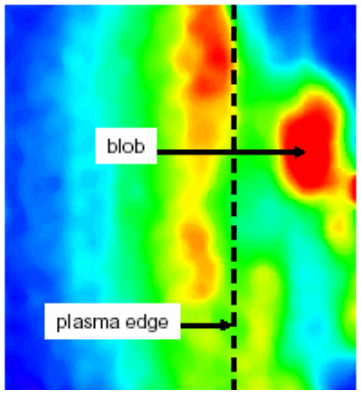
- *Understanding of linear and non-linear mode dynamics crucial to developing optimized control scenarios*
- *NSTX error field/mode control coil design similar to that planned for ITER*

Park, Strauss (NYU)

Gas Puff Imaging Diagnostic/DEGAS-2 Synergy Being Used to Study Blob Physics

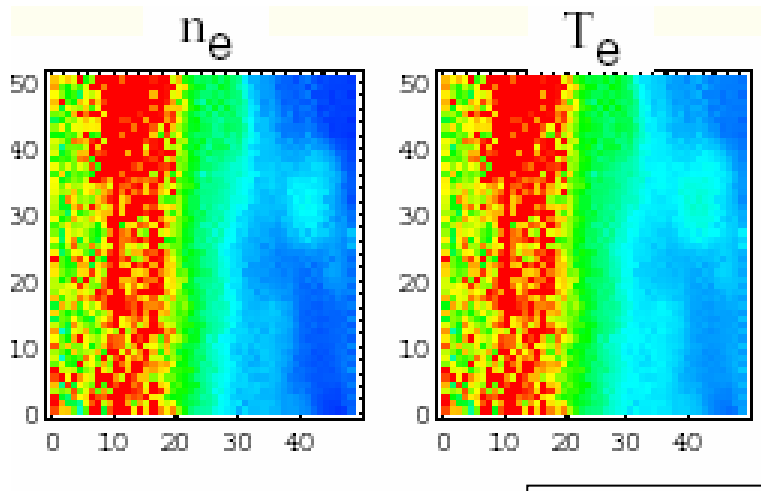
- GPI data modeled by DEGAS-2 to determine n_0
- n_0 used to infer T_e, n_e of blob → blob birth location

GPI Emissivity



n_0 from DEGAS-2

Stotler



Myra (Lodestar), Stotler

- Blob stability (Myra [Lodestar], Stotler)
- Understand turbulence-related flows, coherent structure formation (Krommes + grad student)

Theory – NSTX Synergy is Strong and is Essential to the Success of the NSTX Research Program

- NSTX is an excellent testbed for validating and extending theory to new regimes
- Theory – NSTX synergy is longstanding
  - Critical to NSTX physics design
  - Helps motivate experiments and diagnostic development
  - Helps to establish fundamental understanding as well as contributing to the design and operation of future devices
- NSTX needs are well-integrated into the Theory Five Year Plan
  - T&T (neoclassical physics, turbulence-induced transport, including ETG and electron physics)
  - Fast particles (wave-particle interactions over full frequency range)
  - E&S (plasma flow, kinetic effects on internal and external modes, NTMs at low R/a and high-β, diagnostic simulation)
  - NICD (equilibrium and dynamics of CHI)
  - Edge physics (edge turbulence, fueling and edge recycling, Li particle control)
- Strong ITER component to Theory – NSTX collaboration