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Transport and Turbulence TSG Discussion on PAC and the 5-year Plan

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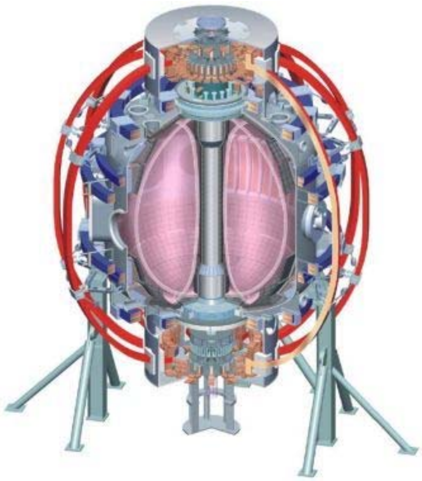
Yang Ren
On behalf of T&T TSG

B252 Feb. 14th, 2012



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Goals of the Meeting

- Prepare T&T FY12-13 research plan
  - NSTX data analysis, modeling, physics design
  - Collaborations with other facilities, e.g. CMOD, DIII-D, MAST
- Develop T&T 5-year plan for FY14-18
  - Two thrusts identified
  - Develop the yearly plans
- Gather ideas for the upcoming theory brainstorming
  - Theories/ models experimentalists want
  - Experiments theorists want

NSTX FY12-13 Research Planning

- NSTX data analysis, modeling and physics design
  - Fulfilling FY 12 JRT with data available
    - Target shots identified and data analysis ongoing
    - Some linear stability analysis performed/ongoing
    - Need to identify target shots for nonlinear simulations
  - Analyzing existing turbulence data, e.g. BES, High-k, reflectometer, backscattering, coupled with linear and nonlinear simulations
  - Applying TGLF to various NSTX scenarios coupled with linear and nonlinear parametric scans
  - Integrated physics and optical design of the new high-k_θ FIR scattering system (NSTX-U FY13 milestone)
- Collaboration with other Facilities
  - DIII-D : explore micro-tearing regime with multiple-field measurement, in particular with polarimetry and BES (proposing)
  - MAST: explore micro-tearing mode with BES measurement (proposing)
  - CMOD on FY12 JRT (exploring)
  - Others?

Preparing PAC Talk (I)

- Overview – goals and/or milestones for your TSG – 1 slide
  - Defining goals +FY12 JRT/NSTX FY13 milestone
- FY2011-12 research highlights/progress from your research area (newest/most important/best since last PAC in Jan 2011) – 6 slides
  - APS invited talks (Guttenfelder; Peterson; Ren); BES data analysis; Impurity transport and more
- Collaboration plans (NSTX team wide) in your respective research area for 2012-2013 – 1-2 slides
  - DIII-D : explore micro-tearing regime with multiple field measurement, in particular with polarimetry (Guttenfelder)
  - MAST: explore micro-tearing mode with BES measurement (Guttenfelder and Ren)

Preparing PAC Talk (II)

- Outline of plans for first 1-2 years of research on NSTX-U (FY2014-2015) – 2 slides
  - To be discussed
- Discuss linkages between collaboration and first 1-2 years of NSTX-U operation – 1 slides
  - Exploring micro-tearing mode with polarimetry and BES on DIII-D and with BES on MAST in preparation for NSTX-U operation
- Discussion of key diagnostics and facility upgrades needed to achieve FY2014-15 research goals – 2 slides
  - BES, High-k, polarimetry and others?
- Brief overview of research goals for 2016-2018 (last 3 years of 5 year plan) – 1-2 slides
  - To be discussed
- Brief overview of major diagnostics and facility upgrades needed to support research goals for 2016-2018 – 1-2 slides
  - To be discussed

Two Thrusts and Three Radial Regions Identified from the 5-year Plan

- Two thrusts for the 5-year plan
  - Identify instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport in L and H mode plasmas
  - Establish and validate reduced transport models (0D and 1D) for NSTX-Upgrade plasmas
- Three spatial regions of concern in NBI H-modes relevant to NSTX-U and beyond
  - Core gradient region (r/a~0.4-0.9) – inside pedestal where significant gradients in thermal plasma exist (→microinstabilities predicted unstable) (also applies to L-mode plasmas)
  - Core flat region (r/a<~0.4) – approaching magnetic axis where thermal gradients become small (→microinstabilities predicted stable) but significant fast ion pressure ($P_{fast}/P_{tot} \leq 50\%$) (Alfvenic modes important)
  - Pedestal (r/a>0.9) - pedestal height plays an important role in global H-mode confinement (BP TSG)

Overview of Tasks of the Two Thrusts

- Identify instabilities responsible for anomalous transport (thermal, momentum, and particle/impurity)
  - Focus on most relevant scenarios: low ν^* H-mode plasmas; fully non-inductive plasma; ITER-relevant plasmas
  - Measure scaling of local transport (χ_e, χ_φ, D_d, D_c) with relevant parameters (ν_e, I_p, B_T, γ_E, s, q, …)
    - Steady state analysis and perturbative experiments
  - Measure turbulence characteristics (δn_e, δB_r, …) and scaling with parameters
    - k_θ spectra (k_r~0) highest priority, most relatable to transport
    - Multi-scale spectrum of modes possible ($k_\theta \rho_s$=0.1-20+), would like complete k-space coverage
    - Focus on parameter regimes where instabilities are expected to be isolated
      - Use 2nd NB and 3D field coils as controlling tools
  - Compare with linear and non-linear predictions to discriminate theoretical modes
    - k spectra and transport fluxes
- Establish and validate reduced transport models for NSTX-Upgrade plasmas
  - Explore 0D confinement scalings (ν_e, β_e, I_p, B_T, …) in NSTX-Upgrade parameter regime: higher Bt, Ip and lower ν^* and project to FNSF/Pilot
  - Develop profile database for most relevant scenarios
  - Focus on developing reduced transport model for ion thermal transport
    - Validate TGLF against gyrokinetics for NSTX/NSTX-U parameters for low-k turbulence
    - Validating neoclassical transport models (pretty good prediction just using)
  - Validate reduced ion thermal transport model for NSTX/NSTX-U/MAST
  - Will attempt to develop electron thermal transport model
    - Start with analytic fits to linear and non-linear GK simulations (*a la* IFS-PPPL for ITG) for μ-tearing and ETG
    - Validate TGLF against gyrokinetics for NSTX/NSTX-U parameters for μ-tearing and ETG

FY14 Goals

- BES and polarimeter are expected to be available; high-k not available; 2nd NBI available-> focus on low-k turbulence
- Implement high-k scattering in FY14
- Thrust 1:
  - Measure low-k turbulence in and out of expected micro-tearing dominant regime in H-mode plasmas with transport measurements and compare with low-k gyro-kinetic simulations
    - Determine transport channels correlated with low-k turbulence
    - Vary q and flow profiles using 2nd NB to differentiate/control low-k turbulence
  - Similar experiments in ITG/TEM dominant L-mode plasmas

- Thrust 2:
  - Start applying TGLF against gyrokinetics for NSTX-U parameters for low-k turbulence
  - Validate gyrokinetic codes with turbulence and transport measurement

FY15 Goals

- Shaking down the high-k scattering system; expecting higher Bt and Ip (lower ν^*)
- Thrust 1:
  - Measure low-k turbulence and take preliminary high-k turbulence measurement in H-mode plasmas in lower ν^* regime with higher Bt and Ip with transport measurements and compare with low-k/high-k gyro-kinetic simulations and neo-classical transport calculations
    - Determine whether ion thermal transport is still near neo-classical level
    - Determine transport channels correlated with low-k turbulence
    - Correlate transport channels with high-k turbulence
- Thrust 2:
  - Establish/Validate 0D confinement scalings with higher Bt, Ip and lower ν^*
  - Use 0D confinement scaling to predict 0D performance of FNSF/Pilot
  - Validate gyrokinetic codes with turbulence and transport measurement
  - Start analytic fits to linear and non-linear GK simulations (*as* IFS-PPPL for ITG) for μ-tearing and ETG

FY16-18 Goals

- Full availability of the high-k system
- Thrust 1:
  - Identify responsible k ranges for different transport channels in H-mode plasmas by correlating measured local transport trends (against ν_e, I_p, B_T, γ_E, s, q, …) with low-k and high-k measurements and theoretical predictions
    - Using the unique properties of the high-k system to identify ETG and its operational regime
    - Identify micro-tearing mode and its relation with transport by combining low-k and high-k measurements and its operational regime
  - Use steady state transport analysis and perturbative techniques
  - Compare with gyrokinetic simulations to identify responsible instabilities
- Thrust 2:
  - Validate 0D confinement scalings with the full range of Bt, Ip and lower ν^*
  - Use validated 0D confinement scaling to predict 0D performance of FNSF/Pilot
  - Validate gyrokinetic codes with turbulence and transport measurement
  - Validate (and update as necessary) TGLF against gyrokinetics in improved NSTX-U parameter regimes
  - Start validation of predictive transport simulations for NSTX/NSTX-U/MAST

Ideas for Theoretical Brainstorming Topcis

- Presentations
  - Simulation Study of Turbulence and Transport by Gyro-Center Shift Theory (KC Lee)
  - EP(enhanced pedestal) H-mode transition on NSTX (KC Lee)
  - Modeling needs (Guttenfelder)

Ion Thermal Transport

- Thrust 1: Identify instabilities responsible for anomalous ion thermal transport
  - Determine whether ion thermal transport is still neo-classical in NBI H-mode plasmas in the NSTX-Upgrade regime
  - Measure full k range turbulence with BES, Doppler backscattering and high-k system
  - Determine turbulence parametric dependence, e.g. on Ip, Bt, q, ExB shear rate, and associated ion-thermal transport trends using TRANSP
  - Investigate the role of zonal flow in regulating low-k turbulence
  - Compare with linear and nonlinear gyrokinetic simulation to identify observed instabilities
- Thrust 2: Establish and validate reduced transport models for NSTX-Upgrade plasmas
  - Validate neoclassical transport models
  - Identify responsible instabilities and their operating regimes; develop reduced mode for ion thermal transport
  - Validate reduced ion thermal transport model for NSTX/NSTX-U/MAST
  - Update TGLF against gyrokinetics for NSTX/NSTX-U parameters for low-k turbulence and validate predictive simulations again NSTX/NSTX-U

Electron Thermal Transport

- Thrust 1: Identify instabilities responsible for anomalous electron thermal transport and their operating regimes
  - Measure full k range density fluctuations with BES, Doppler backscattering and high-k system
  - Combination of BES and polarimetry /Doppler backscattering for the identification of micro-tearing instability
  - Use Ip, Bt, q and ExB shear to isolate instabilities and establish parametric trends
    - Control ν^*_e and β_e to distinguish micro-tearing and ETG
    - Control ExB shear to distinguish low-k and high-k contributions
  - Infer electron diffusivity with steady-state analysis (TRANSP) and perturbative experiments, e.g. heat/cold pulse propagation
  - Compare with linear and nonlinear gyrokinetic simulation to identify observed instabilities
- Thrust 2: Establish and validate reduced transport models for NSTX-Upgrade plasmas
  - Develop reduced model, start with analytic fits to linear and non-linear GK simulations (*a la* IFS-PPPL for ITG) for μ-tearing and ETG

Momentum Transport

- Thrust 1: Identify instabilities responsible for anomalous momentum transport
  - Use perturbative momentum injection to measure momentum diffusivity and pinch
  - Measure full k range turbulence with BES, Doppler backscattering and high-k system and identify responsible k range
  - Compare with linear and nonlinear gyrokinetic simulation to identify observed instabilities
- Thrust 2: Establish and validate reduced transport models for NSTX-Upgrade plasmas
  - Update TGLF against gyrokinetics for NSTX/NSTX-U parameters for low-k turbulence and validate predictive simulations again NSTX/NSTX-U

Particle/ Impurity Transport

- Thrust 1: Identify instabilities responsible for anomalous particle/impurity transport
  - Determine impurity transport with ME-SXR and impurity seeding
    - Whether impurity transport is still neo-classical in the core of NBI H-mode plasmas in the NSTX-Upgrade regime
    - Focus on impurity transport at plasma edge
  - Determine particle transport with SGI gas puffings and reflectometer measurements
  - Measure full k range turbulence with BES, Doppler backscattering and high-k system
  - Compare with linear and nonlinear gyrokinetic simulation to identify observed instabilities
- Thrust 2: Establish and validate reduced transport models for NSTX-Upgrade plasmas
  - Validate neoclassical transport models
  - Update TGLF against gyrokinetics for NSTX/NSTX-U parameters for low-k turbulence and validate predictive simulations again NSTX/NSTX-U

Turbulence – What diagnostic should be used to measure?

- ITG - χ_i, χ_e, χ_φ, D
  - driven by ∇T_i; suppressible by ∇n, E×B shear (ion thermal transport often neoclassical)
  - δn_e - $k_\theta \rho_s$ ~0.2, $k_r \rho_s$~0, isotropic eddies, L_θ~L_r~5-8 ρ_s (BES, high-k)
- TEM - χ_e, χ_φ, D
  - Driven by ∇T_e, ∇n_e; suppressible by E×B shear, reduced by collisionality
  - δn_e - Similar to ITG, maybe slightly higher $k_\theta \rho_s$~0.5+, especially electron heat transport (BES, high-k)
- KBM - χ_i, χ_e, χ_φ(?), D
  - Driven by $\beta' = \beta \cdot a/L_p$; suppressible by E×B shear
  - δn_e - ~similar to ITG, narrower k_θ spectrum (broader L_θ) (BES, high-k)
- **ETG** - χ_e
  - Driven by ∇T_e, low s/q; suppressible by ∇n_e, Z_{eff}, E×B shear; weak dependence on collisionality
  - δn_e - $k_\theta \rho_s$~10, $k_r \rho_s$~0, anisotropic, L_θ~3*L_r~0.5 ρ_s (high-k, …)
- **MT** - χ_e
  - Driven by ∇T_e, increasing s/q, sufficient β_e, peak around $Z_{eff} \nu_{ei}/\omega_{*e}$~5; suppressible by E×B shear
  - δn_e $k_\theta \rho_s$~0.2, $k_r \rho_s$ larger, anisotropy opposite to ETG **(maybe not BES, …)**
  - δB_r $k_\theta \rho_s$~0.2, $k_r \rho_s$~0, very broad, strongly ballooning, $\delta B/B_0$<1% **(polarimetry of some sort?)**

- **BES** and **high-k** are high priority for almost all modes (ITG/TEM/KBM/ETG) and are expected to be available
- **Not clear what will be useful for microtearing, both δn and δB_r**

Transport – What measurements are required to discriminate theoretical mechanisms?

- Local steady state transport coefficients vs. parameter scans
  - TS, CHERS, TRANSP analysis
- Local perturbative measurements, flux-gradient relationships
  - Impurity seeding, ME-SXR
  - Heat/cold pulse propagation, ME-SXR
  - n=3 braking and 2nd NBI, CHERS, UF-CHERS
  - SGI, reflectometery
- What diagnostics are needed to validate transport models?
- Seems like biggest new diagnostic priority is identifying modes present through turbulence measurements
- What more transport tools do we need?