Theory Development in support of NSTX

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Thanks to topical group leaders and forum participants

Sources

- IPPA goals for ST research
- Theory department – Five year plan, FWP
- Spherical Tokamak Theory Development Panel Report
- This Forum

IPPA goals for ST attractiveness

- Assessment of confinement, stability and high-beta
- Non-inductive operation
- Long pulse – Performance extension

Macroscopic Stability-1

How high a beta and low a q can be stably obtained in STs with good plasma confinement?

Theory Challenges:

- Large flow compared to the sound speed and the Alfven speed.
- Edge instabilities and the need to resolve sharp gradients in pressure and current density right up to the edge.
- RWMs – feedback stabilization
- NTMs – feedback stabilization
- What is the appropriate scaling of the β limit ?

  $\beta_N \sim \mathbf{N}\, l_i\,(I/aB)$

  – $2\mu_0\langle p\rangle/\langle B^2\rangle \sim 3.0\ I/(aB)$

Macroscopic Stability-2

Theory needs:

- Ideal MHD theory
  - Equilibrium reconstruction- diagnostics, new physics
  - Between shot stability analysis
- Rotation
  - equilibrium -
    - Betti: toroidal and poloidal flow, next anisotropic pressure
    - M3D: density profile dependence on physics model
    - sheared flow with fast particles
    - stability - M3D - stabilization of internal kink
    - rotation with error field
- Kinetic effects
  - kinetic contributions to δW - trapped particles

Macroscopic Stability-3

Theory needs:

- Resistive wall mode
  - dissipation mechanism - sound wave, shear alfven wave
  - VALEN feedback modeling - multi-mode, plasma rotation
- Resistive MHD
  - M3D - assessing physics models - MHD, 2 fluid(ω*,Hall,NC) and hybrid
  - Ion collisions, electron fluid closure: NC , Landau
  - resistive wall and external coils for RWM, CHI and feedback
  - TM, NTM - Benchmarking and exp.- theory comparison
  - Locked modes

ST Microscopic Turbulence and Transport Issues-1

How can transport be made as small as possible?

- Geometry at A~1, near unity trapped fraction, beta ~1, high toroidal rotation, large ion gyroradii.

Experimental Mysteries:

- What causes high electron heat transport that far exceeds ion heat transport?
- How can ion heat transport be understood? – anomalous ion heating, ion heat pinch, plus residual neoclassical?
- ***Theory Challenges:***
- Large gyroradius and low aspect ratio (A ~ 1) properties of STs require a unified description of classical and neoclassical transport.
- High beta requires electromagnetic treatment of electrons

ST Microscopic Turbulence and Transport Issues-2

- GS2
  - Extensively applied to NSTX - Research opportunities
  - Comparison of theory and experiment-perturbative
  - e.g. ETG, turbulence, electro-magnetic transport, momentum transport, wave-particle interaction
- GYRO
  - Given experimental profiles can infer transport
  - benchmarked and available for use
  - direct comparison with experiment - “synthetic diagnostics”

ST Microscopic Turbulence and Transport Issues-3

- GTC
  - Preparing for application to NSTX
  - neoclassical simulation
  - electro-magnetic electrons - finite and high-β transport
- NCLASS
  - Heat and particle pinches from beam-ion friction
  - comparable to neo-classical effects
- TRANSP
  - GLF23 and MM95
  - Benchmarking in progress

Gyro-kinetic >>>>> <<<<<< Hybrid-MHD

ST Fast particle issues-1

- *Are ripple losses of beam ions and alpha particles tolerable in an ST reactor?*
- *Do collective modes driven by fast particles degrade fast particle confinement?*

Theory Challenges:

- Large gyroradius and low aspect ratio ($A \sim 1$) properties of STs especially relevant for fast particle transport.
- Self-consistent description of mode saturation and fast particle transport in the presence of particle sources and multiple weakly unstable modes (steady-state turbulence versus bursty turbulence).
- This issue is strongly related to the general problem of anomalous transport.

ST Fast particle issues-2

- Single particle physics
  - prompt losses
  - ripple losses
- Collective phenomena
  - fast particles and plasma oscillations - CAE, TAE, fishbones, KBM
  - sawteeth, tearing modes, edge
- Physics extensions from conventional tokamaks
  - low R/a, trapped particles, large larmor radius
  - drift orbits,low Alfven speed, magnetic wells, anisotropic eq.

ST Fast particle issues-3

- Low frequency codes
  - Trapping => non-perturbative linear codes, NOVA2 (2-5 years)
  - HINST for KBM and RTAE with full kinetic treatment (1-3)
  - HYM and M3D (1-3)
  - ORBIT - several fishbone dispersion relations(1)
- High frequency
  - Need linear code with ω/ω_c corrections to MHD
  - arbitrary beam-ion distribution functions
  - fast particle resonances
  - non-linear code HYM to self-consistently model CAE and GAE
- Benchmarking

RF wave heating and current drive issues-1

Theory challenges:

- Many approximations presently used for RF calculations are known to be of questionable validity for STs (geometrical optics, local approximation in conductivity operator, FLR expansion in full wave codes, Maxwellian f_0. Of these, identify which MUST be eliminated, and how can they be eliminated in a computationally feasible way.
- What is the underlying physics of Coaxial Helicity Injection (CHI) current drive?
- How are the large n=1 oscillations during CHI related to the formation of closed flux surfaces?

RF wave heating and current drive issues-2

HHFW:

- Develop comprehensive model of HHFW- Fast ion interaction
  - time dependent, finite orbit and loss cones in CQL3D, self-consistent distribution
  - resonance overlap
- Develop comprehensive model of HHFW- Current drive
  - incorporate in TRANSP - CURRAY
  - 2D Fokker-Planck vs adjoint method
  - DC electric field
  - electron transport effects
- Effect of MHD on CD efficiency

RF wave heating and current drive issues-3

EBW:

- Realistic antenna and refraction at mode conversion, multi-ray, non-linear effects
- Target equilibria, kinetic profiles – antenna design
- CD requirements for NTM suppression
- Parallelise GENRAY/CQL3D for scoping studies, launch angle, $n_{||}$, frequency
- effect of transport and bootstrap current
- edge parametric instabilities at high RF power
- Relativistic effects needed?

Edge and Divertor Issues-1

Theory Challenges:

- The ion gyroradius can be comparable to the radial gradient scale length of the outboard edge plasma.
- Conventional fluid models for turbulence and SOL transport will need kinetic corrections and validation with respect to fully kinetic models and experimental data.
- Low collisionality in the edge plasma changes the pedestal and SOL region parameters of an ST relative to conventional or advanced tokamaks. Turbulent radial transport, the L-H power threshold, ELM characteristics and divertor plate heat loads may be affected.

Edge and Divertor Issues-2

Theory Challenges:

- Kinetic effects in edge codes
  - Connection length
  - High fraction of trapped particles on outboard - mirror
- UEDGE - plasma boundary
  - Code ready for benchmarking – diagnostics – particle fluxes
- BOUT 3D EM turbulent transport uses UEDGE – compare with exp.
- GYRO - core-edge transport
- ELITE – ELMs – intermediate-n

Edge profiles and particle and energy fluxes

Integration issues

- Effect of low A and large gyroradius (fast ion and edge thermal ion) on ideal MHD instabilities consistent with a current profile formed partially by non-inductive means (i.e., bootstrap and RF).

- Self-consistent treatment of effect of RF on both electron and fast ion distribution functions, and the effect of these modified distributions on macro- and micro-stability, including fast ion-driven modes.

Of all the issues the most important ones are those that contribute to making progress on an integrated ST confinement system sustained by non-inductive current drive.

Coaxial Helicity Injection

- Modeling the discharge equilibrium with current on open field lines
  - EFIT-MFIT
  - ESC
- Modeling the evolution
  - 2D TSC
- Flux closure-reconnection
  - CHIP - 2D - current multiplication, 3D- flux closure
  - M3D
- Feedback control in the presence of large asymmetric current

Resources needed

- Identified several code development and application efforts
- Diagnostics – equilibrium and fluctuations
- Benchmarking
- Inter device opportunities
- Manpower limited
- Leverage on SCIDAC – MHD, RF and Transport
- More needed

ST Theory Workshop

There will be an ST theory workshop on
August 2, 2002
following the
Results Review on
July 31 and August 1, 2002