Summary:
Edge Working Group

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Key Issues in Edge Physics

- SOL transport
  - How do we characterize SOL turbulence?
  - What is origin of SOL flows?
- L-H threshold
  - What is physics of L-H threshold?
  - Do SOL flows affect L-H threshold? How?
- Pedestal boundary conditions
  - Need to calculate edge particle source
  - How do SOL flows affect flows inside LCFS?
- Pedestal structure
  - Need predictive model for pedestal height
  - What is physics of pedestal width?
  - How do 3D magnetic fields affect edge particle transport?
- ELMs
  - Need non-linear theory for ELM evolution

There are several reasons to be optimistic

- Looking back 4-5 years, much progress is evident
  - Much improved data
  - Many new measurements
  - Simultaneous measurements of multiple quantities are much more available
  - New computational tools now available or under development

- The participation of ECC continues to enrich edge group
  - Number of theory/modeling talks has risen markedly over last several years

- And, the plasma edge appears to be slowly (if begrudgingly) giving up a few of its secrets

SOL Turbulence:
How do we characterize SOL turbulence?

- A paradigm shift in last few years (LaBombard, Myra, Cziegler, Pace, Russell)
  - smooth, continuous, small-scale transport model does not hold (LaBombard, Myra, Russell, Pace)
  - Transport on open field lines is highly intermittent – this is a robustly and ubiquitously observed (in all plasma confinement devices)

- Transport just inside last closed flux surface has strong outward ballooning character

- Intermittent structures (BLOBS, streamers?) are formed at periphery of confined plasma near outer midplane

- Plasma ejected at outer midplane tends to flow along field lines and at velocities approaching mach 1

How do we characterize SOL turbulence? - 2

- There are a range of scales for structures that are produced
- There is really no steady state in SOL
- Plasma configuration affects flows - flows can be blocked
- These flows may affect core momentum, L-H threshold, fuelling,...
- Big issue: How is circulation loop closed?
- Very long correlation lengths observed in fluctuating potential in improved confinement modes in TJ-II (Hidalgo)

SOL Turbulence: What is origin of SOL flows?

- Joint session with momentum group to discuss this
- ExB can drive flows – ion orbit loss gives positive potential in SOL, which perhaps drive flows (Chang)
- Momentum transported across LCFS by ejection of blobs (LaBombard, Myra, Diamond)
  - Symmetry-breaking required: more momentum ejected in one direction than in the opposite direction

L-H Threshold: What is physics of L-H threshold?

- Transition may be mainly due to a reduction of convective loss more than a change in conductive loss (Moyer)
  - Te fluctuations at edge remain unchanged or even rise at L-H

- We have known that reduction of turbulent particle transport in H-mode is partly due to a change of cross phase between potential and density fluctuations
- New observations show that cross phase already changed a short time before amplitude of fluctuations is reduced – that is, this change occurs shortly before L-H transition (Moyer)
- Cross phase of potential and density fluctuations may be more sensitive to changes in Er than is amplitude of density fluctuations
  - Perhaps small changes in Er due to small changes of Grad P in L-mode are sufficient to do this and to initiate the transition
- Analytic model and simulations of long wavelength modes leads to identification of improved confinement in TORPEX (Ricci)

L-H Threshold:
Do SOL flows affect L-H threshold?

- Configuration effects on L-H threshold are very common
  - e.g., B X ∇B drift effect

- SOL flows are strongly implicated in playing a role in these configuration effects (LaBombard)
  - Configuration may block flows in one direction and cause a change in boundary condition on rotation

Pedestal boundary conditions: Need to calculate edge particle source

- Edge particle source needed for core transport modeling as well as pedestal modeling

- Had a significant discussion of edge modeling codes (Stacey, Rafiq, Canik, Callen)
  - A low key benchmarking exercise has used several codes to examine same pedestal data sets

- These codes typically use transport coefficients as part of machinery to match profiles and then perform source calculations
  - However, there is no unique set of transport coefficients
  - Also, differences in grids have evidently contributed to differences in reported χ where no differences expected
  - Do we need χ and D and V? Why not stick closer to the primitives that are measured – fluxes?

Pedestal boundary conditions: Need to calculate edge particle source - 2

- What is real uncertainty in calculation of poloidally-averaged particle source?
- Do we need to understand SOL flows to do this correctly?
- What is happening near inner divertor leg, where circulation loop for plasmas flows must close?

Pedestal boundary conditions: How do SOL flows affect flows inside LCFS?

- Strong evidence that SOL flows are providing a boundary condition for toroidal rotation inside LCFS (LaBombard, Brooks)
  - C-Mod data show core rotation going up and down in response to changes in SOL rotation
  - DIII-D data show that changing sign of core toroidal rotation does not have much effect on SOL flows

- One possible scenario: SOL flow exerts a stress on core (Diamond)
  - Needs SOL flow speed to increase with radius (which is observed)
  - Needs symmetry breaking
  - (A deep linkage between momentum transport and particle transport?)

Pedestal structure: Need predictive model for pedestal height

- A predictive model for pedestal height in ELMing H-mode has been developed (Snyder)
  - Uses peeling-ballooning constraint on pressure profile with an empirical width scaling
  - Has successfully predicted an order of magnitude variation of pedestal height in DIII-D
    - Prediction was made before experiment was done

Pedestal structure: Need predictive model for pedestal height

- Continuing work on edge gyrokinetic codes
  - Turbulence being added

- Some careful verification has been done (Rognlien/Xu)
  - Damping of GAMs has provided a good test case of neoclassical physics
  - Generally good agreement between analytic theory, TEMPEST, XGC and GYRO

- Coupling of codes has been initiated
  - XGC + GEM allows initial studies of edge turbulence (Chen)
  - XGC0 + ELITE + NIMROD allows simulation of pedestal buildup, ELM onset and ELM non-linear evolution (Pankin)

Pedestal structure: What is physics of pedestal width?

- Ever improving pedestal measurements are allowing us to start seeing some new trends in pedestal parameters

- Good evidence of "critical" pressure gradient in C-Mod $\nabla P \sim I_p^2$ (Hughes)

- Edge CER measurements in C-Mod have been used for systematic studies of E_r and contributions from rotation and pressure gradient terms (McDermott)
  - Large vpol observed
  - Very negative E_r values observed
  - Machine size scaling study initiated

Pedestal structure: What is physics of pedestal width? – 2

- Evidence that pedestal width increases with increasing pedestal pressure in ELMing H-mode discharges (DIII-D)

- Analytic pedestal model predicts temporal growth of pedestal width (Malkin)
  - This is observed in density width during ELM-free H-mode (Groebner)

- "Neoclassical" pedestal model reproduces characteristics of pedestal buildup in ELM-free H-mode
  - Model also predicts $\Delta_n \sim \mathrm{sqrt}(T_i)$ during pedestal buildup (C.S.)
  - This also observed

- Several analytic transport models compared against experiment (Stacey)
  - ITG, ETG perhaps best in H-mode

Pedestal structure: How do 3D magnetic fields affect edge particle transport?

- EDA H-modes, QH-modes and RMP H-modes all exhibit increased particle transport linked to 3D edge magnetic fields
  - Thus, 3D fields provide opportunities for pedestal control

- Fast density measurements show that application of RMP initiates a prompt (within ~ 5 ms) reduction of core density – increase of SOL density (Zeng)
  - RMP reduces decay time of injected pellets
  - Conclude that particle xport is increased

Pedestal structure: How do 3D magnetic fields affect edge particle xport? -2

- Rapid density drop due to magnetic fluctuations in RFP is well diagnosed and nicely explained (Ding)
  - Measurements and modeling show why Rechester/Rosenbluth over-estimates electron thermal transport relative to particle transport
  - Does same physics apply to RMP or other perturbations in tokamak edges?

- Modeling with 3D magnetic geometry in XGC is being used to study RMP effects (G. Park)

- M3D non-linear MHD code shows that plasma rotation provides some shielding of applied edge stochastic magnetic field (Strauss)

Other Important Issues from ITPA

- ELM control on ITER
  - Recent studies have led to a significant reduction in estimated ELM energy loss that ITER can tolerate
  - Need for ELM mitigation well recognized
  - The mainline ELM mitigation technique is pellet-pacing
  - However, community does not have high confidence in this
  - RMP ELM control is strongly supported by community
  - However, ITER has not accepted this recommendation due to lack of physics understanding, cost and impact on schedule
  - But, ITER now seems to be considering this quite seriously

A Few Other Thoughts

- There has been interest in "validation" efforts within the Edge
  - But, by and large, it appears to be a bit too early for this
  - There are some possibilities; e.g. data presented by Tynan may be ripe for comparisons with BOUT
  - Well-focused, small scale efforts perhaps are appropriate
  - Also, verification test cases being set up at ECC website www.lehigh.edu/~inecc
- However, some experimental studies could benefit from increased modeling support
  - But, it appears that we do not have the people to do this in a significant way
  - Code-experiment comparison work requires dedicated people

And Finally …

- This was a very good meeting for the Edge

THANKS to all who participated!