

# Summary of Transport/Confinement Session

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Presented at  
Burning Plasma Workshop  
Oak Ridge National Laboratory

December 7–9, 2005

# What can the U.S. Do to Address Burning Plasma Related Transport Issues?

- **U.S. is the world leader in all areas of transport research:**
  - ✓ Most flexible, best diagnosed facilities
  - ✓ Superior theory, modeling and simulation capabilities
  - ✓ Unmatched turbulence diagnostics
  - Opportunity for U.S. to lead ITER research in this area, but this requires focus and commitment
- **Transport provides a good mix of short and long term research possibilities, and would engage all segments of U.S. transport community**
  - *i.e.*, theory/simulation, modeling, turbulence and transport measurements

**(Thanks to Ed Doyle)**

# While ITER Extends Operational Space, It is Not an Ideal Vehicle for Transport Studies

- **Answering BP transport questions prior to and during ITER operation will require solid base program with viable experiments**
  - Virtual non-existence of fluctuation diagnostics
  - Next step questions not addressable due to ITER's design realities
  - Our partners tend to view ITER more as an energy project
- **U.S. will need ancillary facilities to ITER for transport studies and to serve as test beds of ideas**
  - Expansion of diagnostic capabilities in existing devices required
  - Measurement capabilities (e.g., profile resolution, turbulence measurements) likely superior to ITER's

# What Transport Issues Should be Resolved by ITER?

- **ITER will provide a comprehensive benchmark of transport understanding and predictive capability for burning plasmas**
  - Test for soundness of transport understanding in low rotation,  $T_e \sim T_i$ , small  $\rho^*$  regime
  - As part of a risk management plan, ITER diagnostic capabilities should be maximized
- **Transport control and control requirements in highly non-linear burning plasmas**
  - Local transport control is the only possibility for controlling pressure and bootstrap current profiles in self-sustained plasma configurations (Snowmass report)
  - Will ITER have the tools required for transport control?

# Electron Thermal Transport Issues

- **Cause of electron anomaly not known, despite importance of electron loss channel in burning plasmas and burn control**
  - Possibilities: ITG mode, TEM, ETG mode
  - Neglected areas: magnetic flutter, MHD, non fluctuation
- **Need aggressive scientific approach with experiment and theory comparison**
  - High  $k$  turbulence diagnostic comparison with simulation, identification of electron streamers
  - Role on magnetic shear in electron ITB
- **Need simulation refinement to give convergence of ETG mode at large scales**
  - Also need to include kinetic ions in simulations

# To further test experimental relevance of ETG

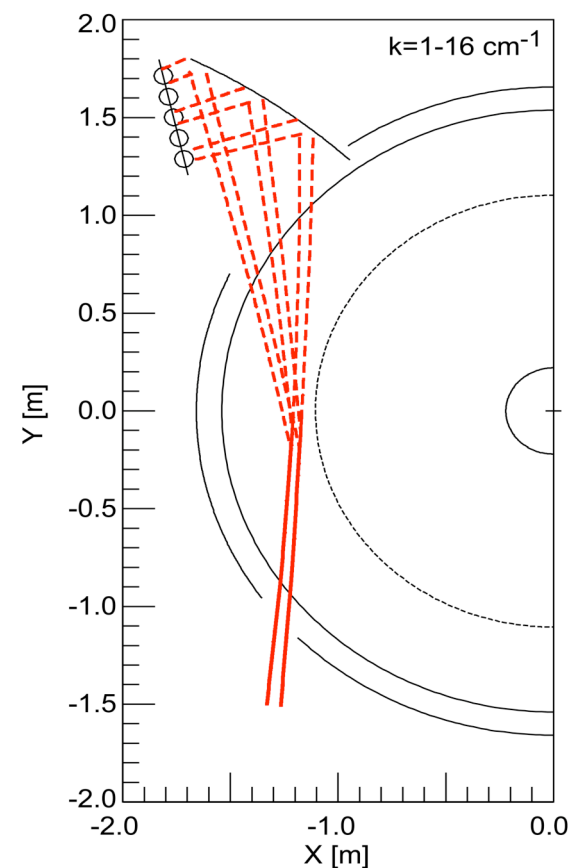
- Measurements and identification of ETG “streamers”

DIII-D (Back-scattering), C-Mod (PCI)

NSTX (Tangential-scattering):

With low B and large  $\rho_e$ , ideal place to look for ETG streamers with good spatial resolution

- Its correlation with transport:  
In HHFW plasmas with high  $T_e$  gradient ?  
From nonlinear simulations, correlation of streamer size and transport still needs to be demonstrated



[Mazzucato, Park]

# Ion Thermal Transport Issues

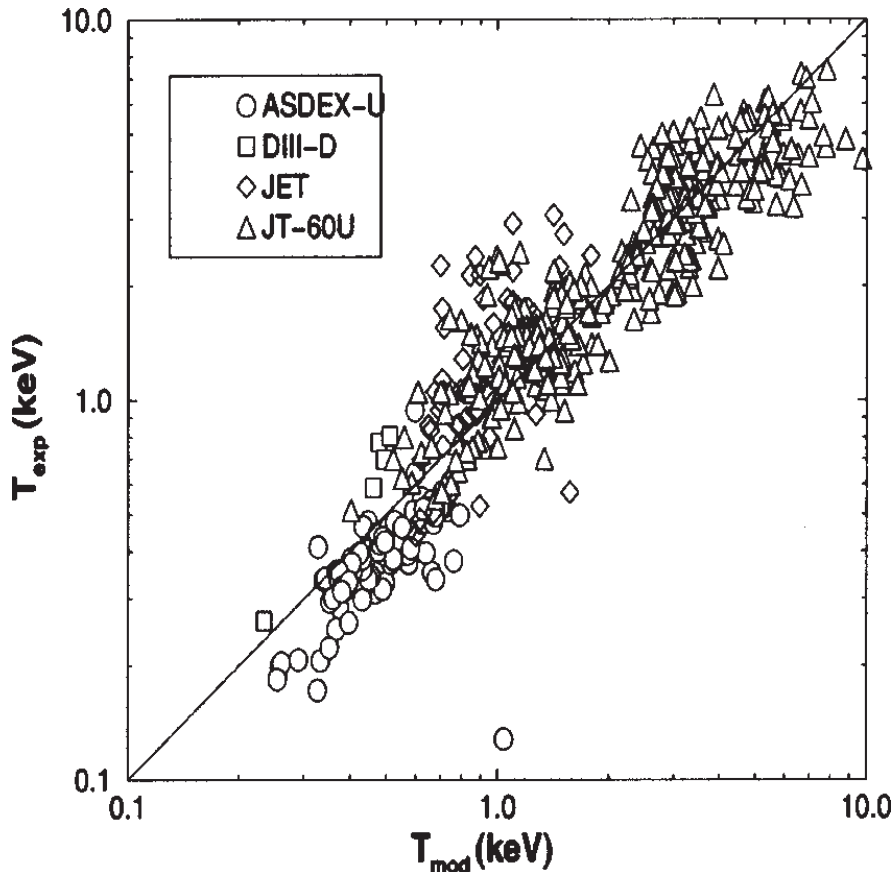
- **Theory of ion thermal transport is the most developed, but...**
  - Disagreements still exist between different codes, and between codes and experiments
  - Predictive capability for BP should be taken to the “next level” (part of risk mitigation for ITER)
    - Extend transport models to plasma boundary
- **Amount of transport stiffness needs to be resolved**
  - Including more precise shaping effects in theory-based models, and comparing with experimental shape scans, should help determine the transport stiffness
- **Need to improve synthetic diagnostics in transport simulations, especially for fluctuation measurements**

# H-mode Threshold and Pedestal Transport Issues

- **Issues that overlap with other topical areas:**
  - Scaling of H-mode pedestal width and height (especially with  $\rho^*$ )
  - L-H threshold (small margin of error for ITER)
- **Need dynamic modeling of pedestal and ELM**
  - Requires well diagnosed pedestal profiles during ELM cycle
  - Models of pedestal width need to be expanded to include multiple physics effects
  - Should study pedestal in vicinity of L-H threshold
- **Need to expand pedestal diagnostic capabilities, and develop new codes and new collaborations**
  - SOL poloidal flows appear to be important

# The ITPA Pedestal Database has been Fit to Several Physical Models

Fit to ITPA Database With Flow Shear Stabilization Constraint



T. Onjun (Phys. Plasmas 2002)

Scaling	Physical Model	RMSE
$\Delta \propto \sqrt{\beta_\theta} R$	Poloidal pressure	33%
$\Delta \propto \rho S^2$	Magnetic and flow shear stabilization	32%
$\Delta \propto \sqrt{\rho R q}$	Flow shear stabilization	31%
$\Delta \propto \rho^{2/3} R^{1/3}$	Diamagnetic stabilization	34%
$\Delta \propto \sqrt{\epsilon \rho_\theta}$	Ion orbit loss	34%
$\Delta \propto 1/n_{ped}^{3/2}$	Neutral penetration	53%

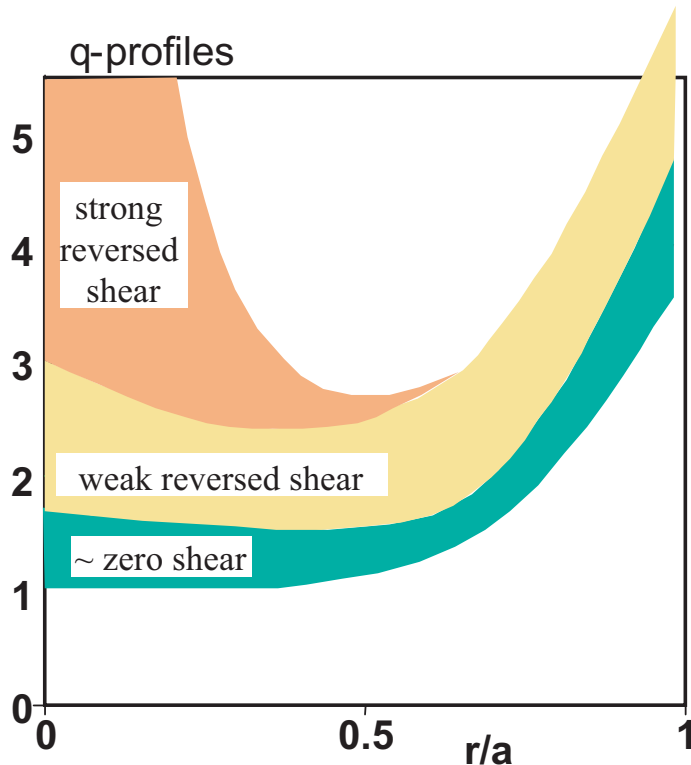
- ◆ Pedestal width is a difficult measurement
- ◆ Pedestal width fit using pedestal top pressure and stability constraint
- ◆ The different possible models ( $\rho^0$  to  $\rho^1$ ) represents a significant range of predicted pedestal pressure
- ◆ Critical issue: Identify physics controlling pedestal temperature width

# Improved H-Mode Transport Issues

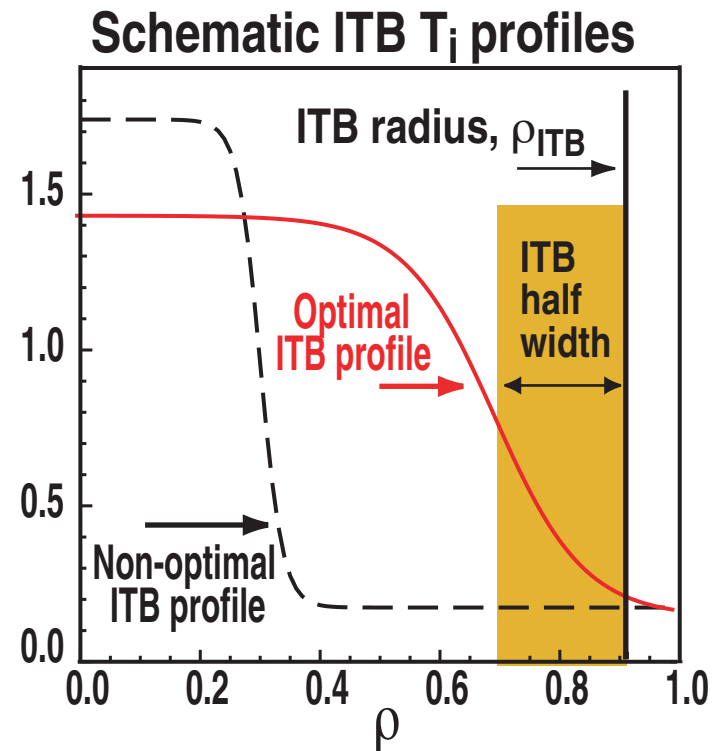
- **Reduced, theory-based transport models are critical to AT scenario modeling**
- **ITER will provide a comprehensive benchmark for transport understanding and predictive capability for AT scenarios**
  - Can improved confinement be obtained for AT modes in BP with low rotation,  $T_e \sim T_i$ , and central power deposition?
  - Does higher  $q_{95}$  limit pedestal height and thus limit  $Q$ ?
- **Existing transport control tools don't readily extrapolate to ITER — we must develop new tools such as**
  - Torque-free or RF-driven rotation
  - RF flow drive (ion cyclotron wave looks promising)
  - Preferential ITB at rational  $q$  location
  - Shafranov-shift stabilization of turbulence

# Need to determine optimal target conditions - what confinement level/profile?

- What is optimal q-profile to generate enhanced confinement consistent with high beta, and high  $f_{NI}$



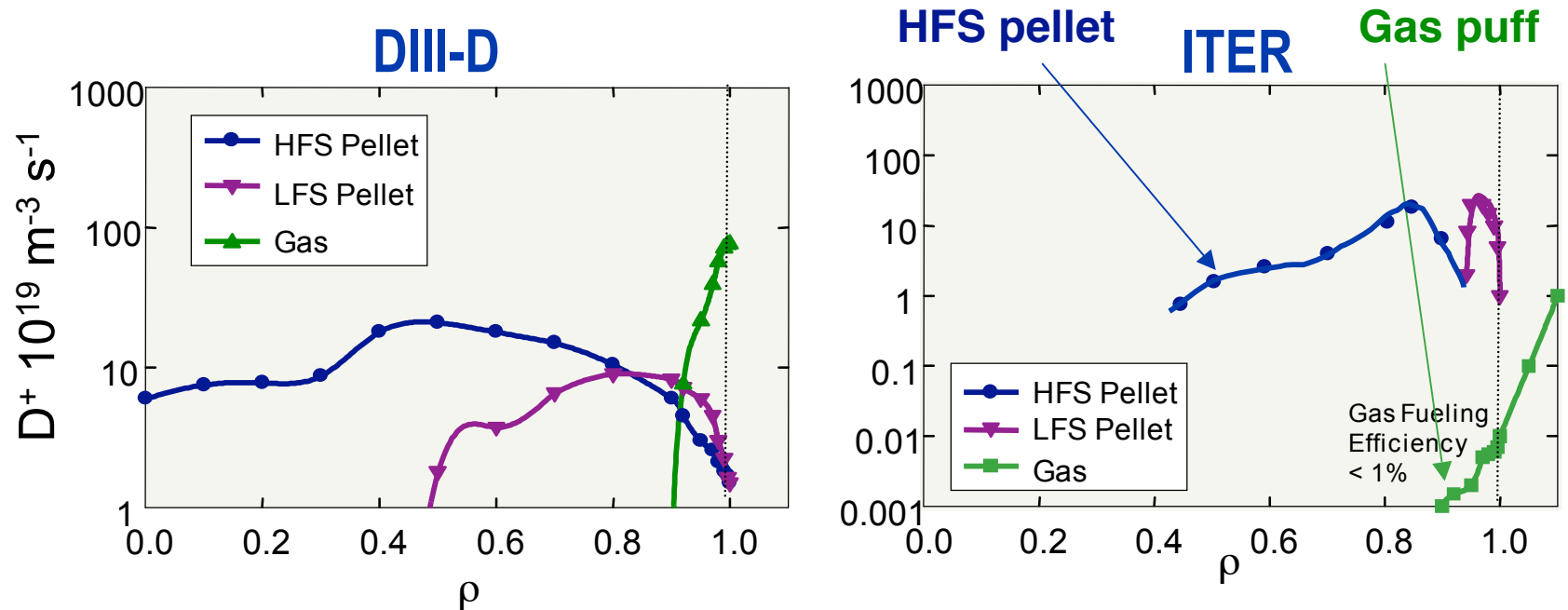
- What is optimal transport regime - no ITB, weak or strong ITB? US favors none to weak



# Particle and Impurity Transport Issues

- **Impurity and main ion density profiles are linked in a complicated manner**
  - Need to understand density peaking and anomalous particle pinch
  - Control of helium ash (*i.e.*,  $\tau_p^*/\tau_E$ ) and other impurities has high leverage on fusion performance
- **Gyrokinetic simulations of turbulent particle transport need to include kinetic particles**
  - Qualitative physics issues remain about effect of zonal flows on particle transport
- **Need to develop credible model of pellet fueling**
- **Study of operational density limit should be extended to (more) collisionless plasmas**

# Pellet Injection is Crucial for Effective Core Fueling in ITER as Shown in H-mode Fueling Source Profile Comparison



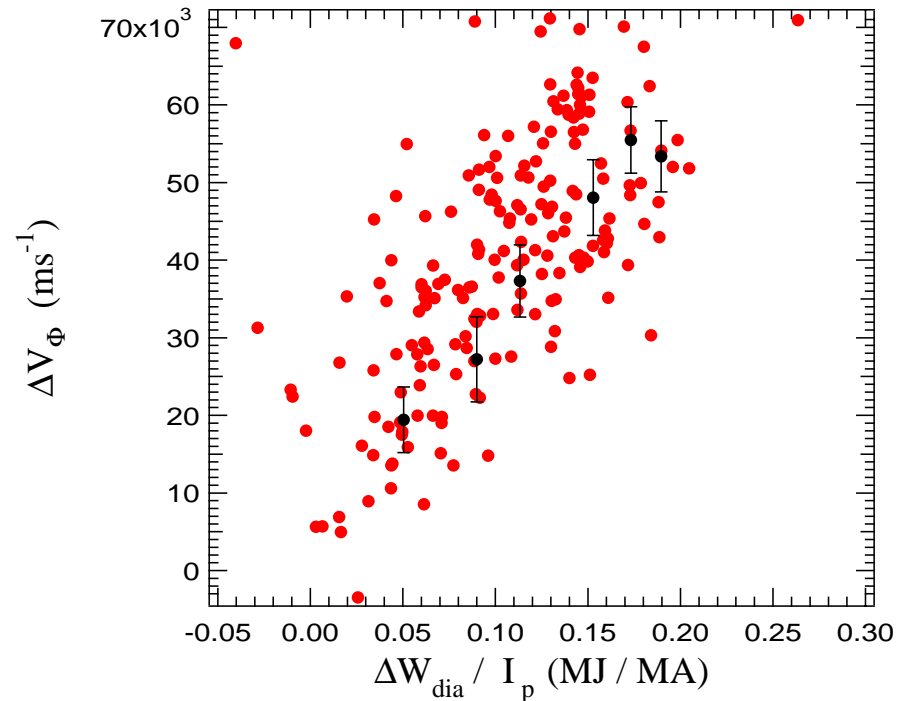
- Gas puff core fueling in ITER will be much less effective than in DIII-D
  - ITER pellet source profiles are from PRL (P. Parks) ( 5-mm @ 16 Hz )
  - Gas fueling rate of ~1000 torr-L/s for ITER case B2-Eirene slab calculation (L. Owen and A. Kukushkin)

# Momentum Transport and Rotation Issues

- **Question of whether a diffusive/convective model is useful or not for momentum transport should be resolved**
  - Gyrokinetic simulation codes should begin addressing momentum transport
  - Need to incorporate effects of non-axisymmetric magnetic fields on rotation studies
- **What is the origin of self-generated flows, and how do they scale to ITER?**
  - Important physics problem outside of tokamak BP
  - What are the dimensionless parameters that govern self-generated flows?
- **Need to understand poloidal rotation measurements**
  - Collisional damping of poloidal flows is an open question

# Self Generated Flows Widely Observed

- Data limited because of NBI perturbations (diagnostic limitation)
- C-Mod, JET, Tore Supra, DIII-D, JT-60
- What is origin of rotation?
- What is origin of scaling seen?  
 $V_\phi \sim W/I_p$  or  $p/I_p$  or  $\nabla p/I_p$
- C-Mod/DIII-D comparisons –Some similarities, but what is origin of differences?
- What will happen on ITER?



*Tore Supra*  
(Assas et al., EPS 2003)

# Discussion of BPO Structure

- **No one spoke against forming a BPO**
- **BPO can provide physics support for ITPA, but it should also allow the U.S. some independence to pursue our own goals**
  - BPO should not focus only on ITER
- **The BPO can identify and recommend areas of research, and sign up advocates to make credible scientific proposals for research on U.S. (and international) facilities**
- **Question raised on how to involve university researchers**
  - Need to reach wide audience using remote participation tools
  - Funding agencies should make it easier for universities to spend their money on BPO activities
  - Need to integrate students into BPO activities

# Discussion of BPO Structure Continued

- **BPO should have a strong “bottom up” component**
  - Topical groups should be the prime movers since they are the most democratic part of the organization
  - Topical groups can spawn task groups for specific problems with well defined deliverables
  - Key is to have effective leadership of topical groups
- **BPO allows community to vet BP issues, which adds weight to getting the important issues funded and implemented**
  - Institutions need to support vetted BPO agenda
  - While the BPO will have some near term deliverables, it also serves as an organization to educate the community on critical BP issues that need to be resolved