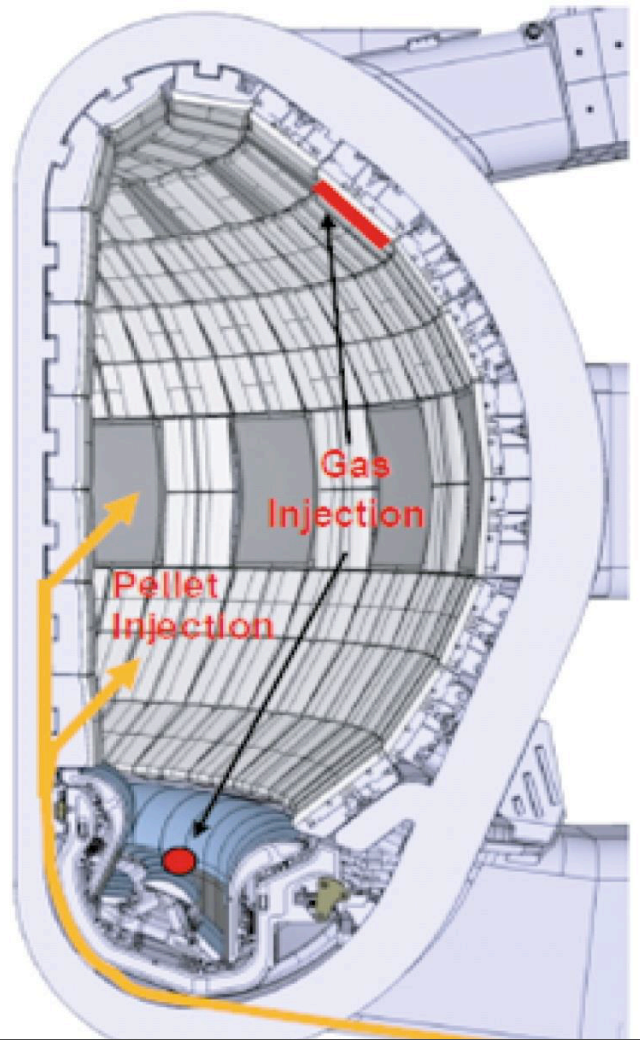
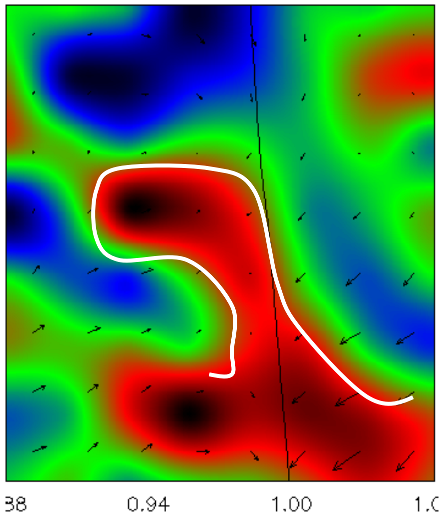
ITPA Transport & Confinement Meeting: Summary to the US Burning Plasma Organization

G. McKee, University of Wisconsin
G. Staebler, General Atomics





BPO Webinar

December 9, 2013

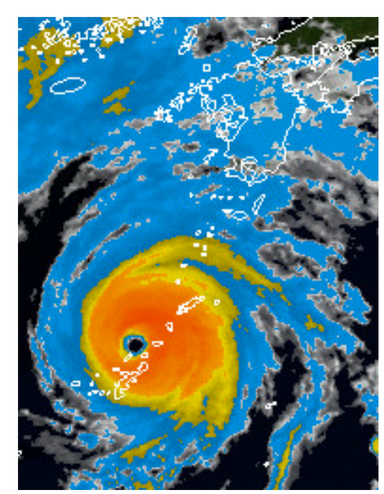
Overview of ITPA Transport & Confinement Topical Group

- **Scope to develop fundamental understanding of transport processes, emphasizing those relevant to ITER/Burning Plasmas**
  - Confinement and L-H Threshold databases
  - Particle, energy, momentum transport
  - Barrier formation, rotation physics
  - Coordinate Inter-Machine experiments and comparisons
  - Validating transport models and developing predictive capability
  - Interfacing with other TGs (e.g., IOS, pedestal/edge)
- **40 International Members from 7 country/entities + ITER**
  - 7 US Members: Diamond, Doyle, Kaye, McKee, Mikkelsen, Petty, Rice (4)
    - *70 Contributing Experts*
  - Any and all scientists welcome to meetings: don't need to be official member!
  - ITER: A. Loarte

- **https://portal.iter.org/departments/POP/ITPA/TC/**

11th ITPA Transport & Confinement Meeting

- **Held in conjunction with International Workshop on H-Mode Physics and Transport Barriers**
  - Kyushu University, Fukuoka, Japan
  - October 7-9, 2013
- **Topics of focus (session chairs):**
  - L-H transition physics (P. Diamond)
  - Rotation physics (M. Yoshida)
  - Turbulent transport (R. Jha)
  - 3D physics (K. Tanaka)
  - L-Mode edge (C. Bourdelle)
  - Multi-ion physics impact (G. Staebler)
  - Profile Stiffness (P. Mantica)
  - Joint sessions with IOS/Pedestal groups
    - *Energy transport in integrated modeling*
    - *Integrated modeling of fueling/impurity transport*
    - *Pedestal projections/impact on integrated modeling*

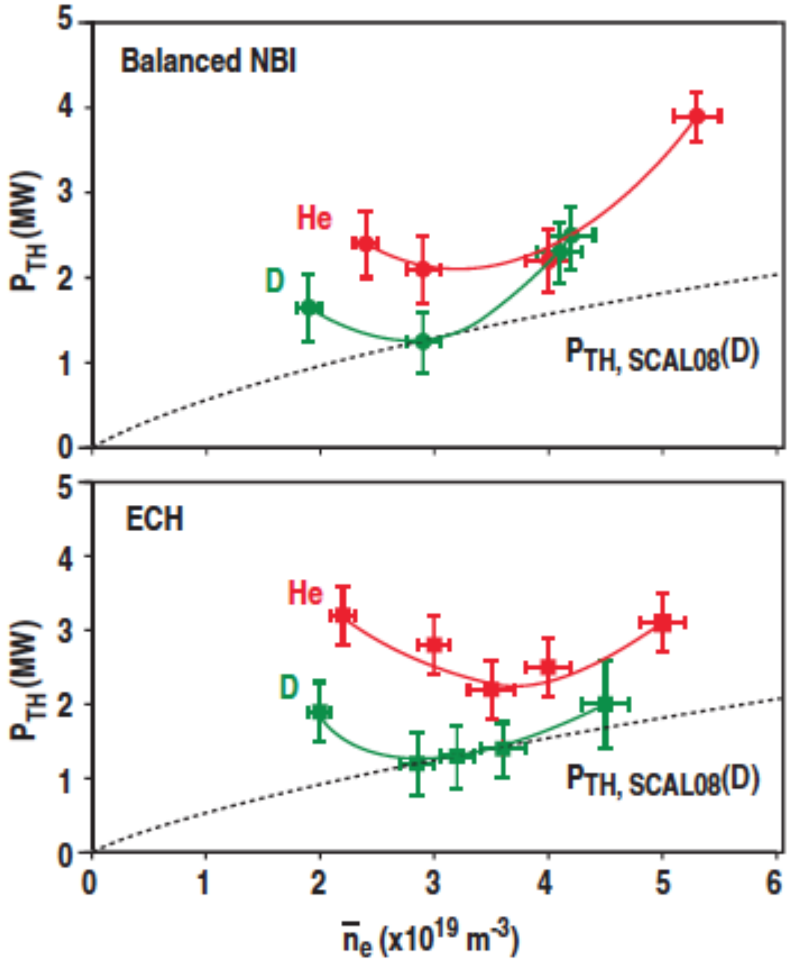


Typhoon Danas

Sakurajima Volcano

L-H Transition Physics

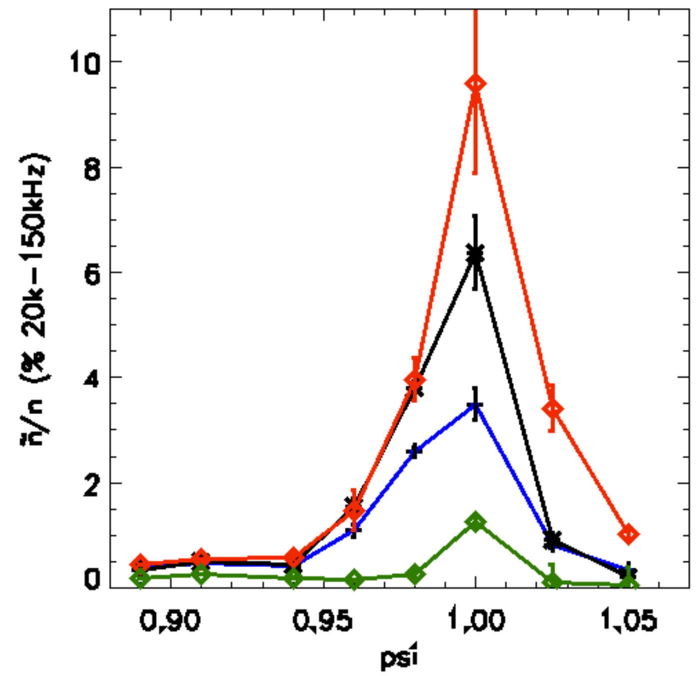
- **Issues addressed**
  - Role of turbulence-driven flows
  - Threshold physics: low-n branch, collisionality
  - Developing models that aim for prediction
  - Motivating simulations…
- **Presentations**
  - Dynamics of Turbulence & Shear Flow Across L-H Transition (Z.Yan-UW/DIII-D)
  - Stimulated Transitions on KSTAR (S.H. Hahn-NFRI)
  - Transition simulations (L. Chone)
  - ETB Formation Simulations (G. Park)
  - Zeff effects in threshold calculations (C. Bourdelle-CEA)
  - Developments in 1D Model (P. Diamond-UCSD/WCI)

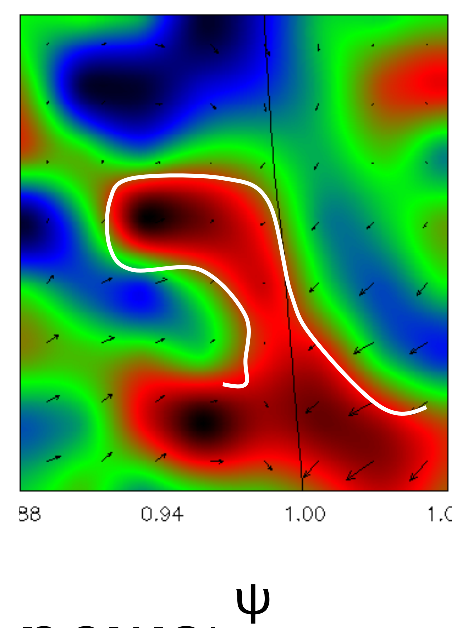


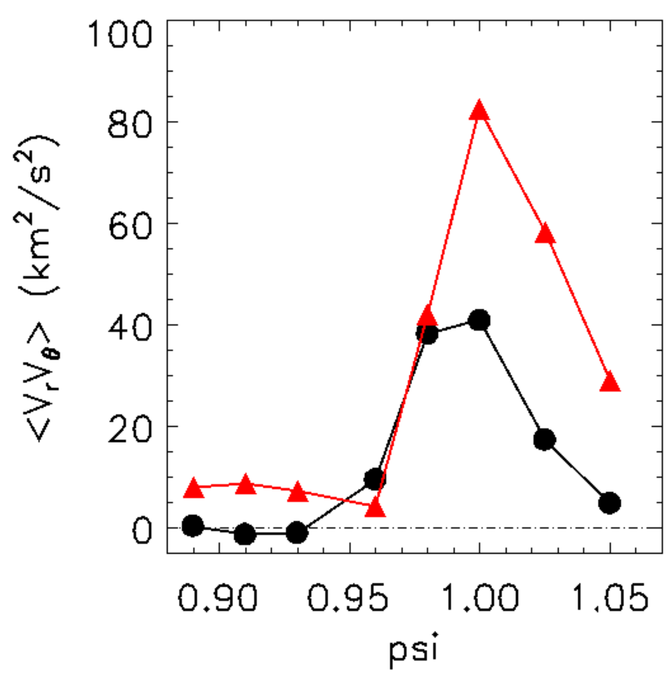
Turbulence and Flow Dynamics Across L-H Transition

- **Experimental data and analysis shows:**

Increased power flux
⇩
Increased turbulence
⇩
Increased turbulent Reynolds stress driving m=0,n=0 flow V_{pol}
⇩
Increased kinetic energy transfer $\tilde{n} \rightarrow V_{pol}$
$\gamma_{shearing} > \gamma_{decorrelation}$
⇩
Turbulence suppressed
⇩
Triggers transition







- **Similar dynamics at lower B_T at lower power**
  - Suggests connection to BT-dependence of P_{TH}

Yan, submitted to PRL

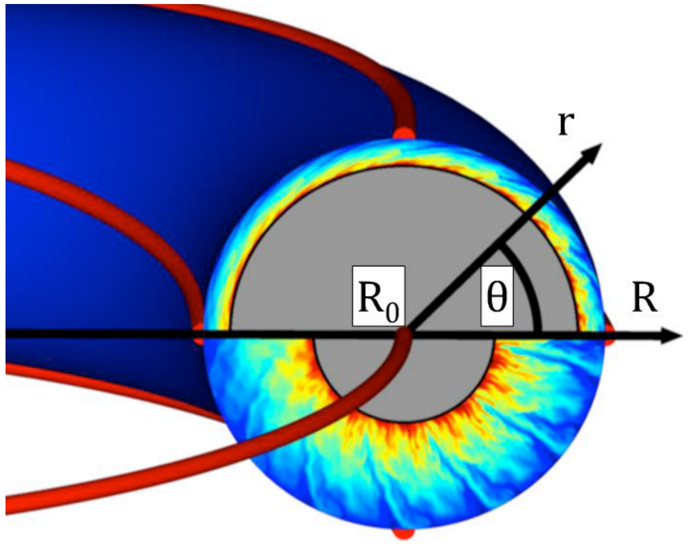
Z. Yan, UW-DIII-D (APS-13, Invited talk)

Altering L-H Power Threshold via SMBI (S.G Hahn)

- **Supersonic Molecular Beam Injection (SMBI) pulse can decrease P_{LH}**
- **SMBI can cause transition to Limit-Cycle-Oscillations (LCO) on "low-density" branch of P_{TH} curve**
- **Indications that profile modification and changes in edge velocity shear cause changed threshold**
- **Mechanism at low-density branch appears distinctly different from high-density branch**
  - Transfer of turbulent energy to zonal flow and/or mean flow

New Simulations Demonstrating Transition Features

- **Simulations of Resistive Ballooning Mode turbulence (EMEDGE3D)**
  - Relevant to cooler, dense edge region, incorporating neoclassical friction
  - Spatiotemporal analysis of turbulence flux, poloidal velocity demonstrate formation of barrier at higher heat flux (radial variation of collisionality)
  - L. Chone (Marseilles Université, CEA)
- **Edge Transport barrier formation in BOUT++ (G. Park, NFRI)**
  - Self-consistent heat source (inside), sink (beyond separatrix)
  - Electrostatic RBM turbulence shows formation of edge transport barrier
  - Er shear layer, positive feedback from diamagnetic flow
  - First-order phase transition observed in Power vs. Pressure gradient



Modeling on Implications of Z_{EFF} on P_{LH}, and SMBI Effects

- **Experimental observations: higher Z_{eff} --> Higher P_{LH} (C. Bourdelle)**
  - Model examines $\gamma_{turb}/\gamma_{ExB}$ as determining parameter
  - GENE simulations suggest RBM dominant near rho=0.97
  - Larger growth rates for higher BT, lower isotope mass
    - *Consistent with threshold trends*
- **Diamond/Miki Model**
  - Edge $\langle V_E \rangle'$ critical parameter
  - No zonal flow in stimulated transition (SMBI)
  - Interaction of Turbulence, Zonal Flow, Mean Flow is critical

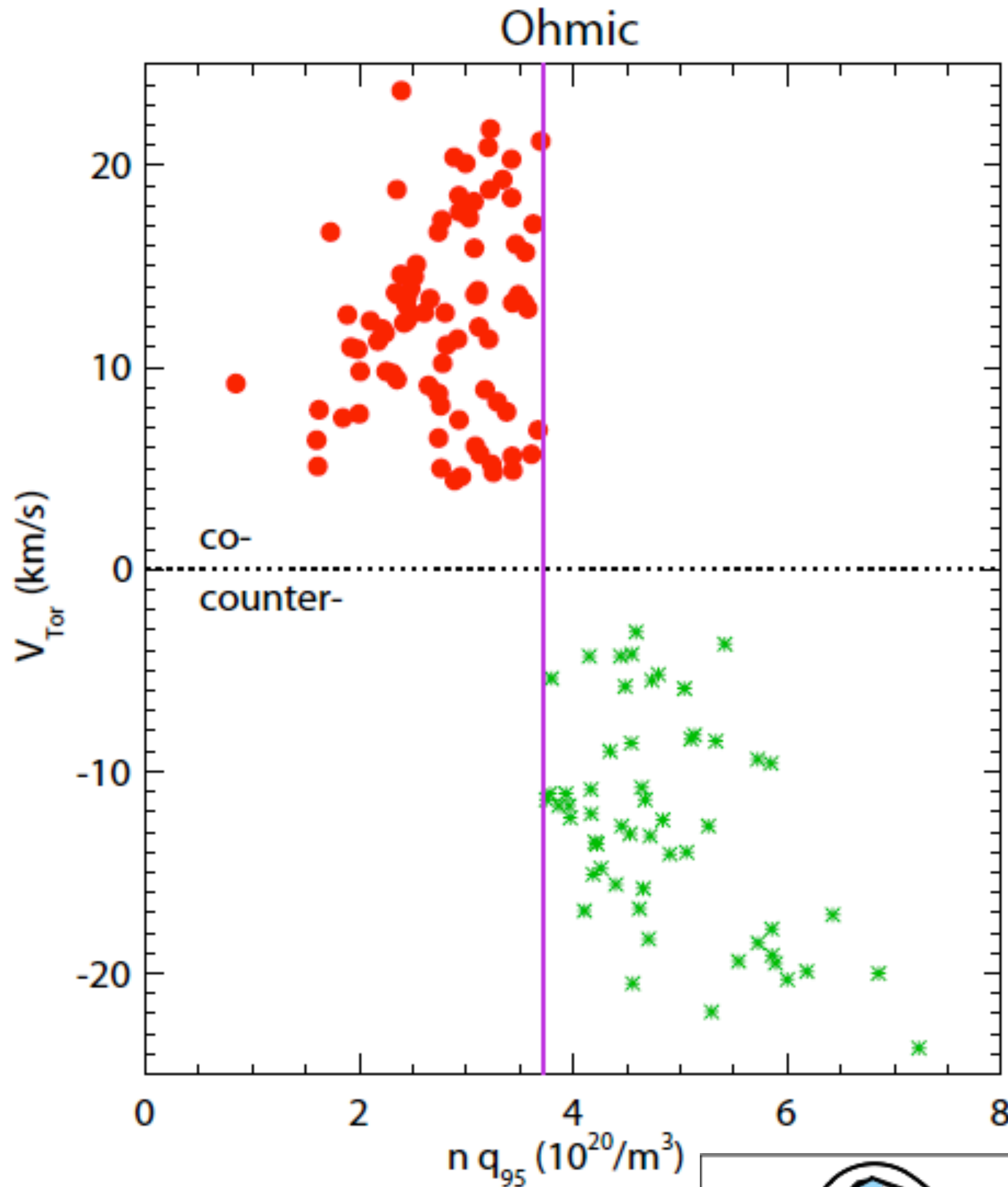
- **Strong interaction of experimental observations, threshold dependences and new models and simulations**
  - Leading to deeper understanding of which edge parameters, gradients are important, aiming towards first principles understanding of threshold, possible techniques to reduce P_{LH}

Rotation Physics (M. Yoshida)

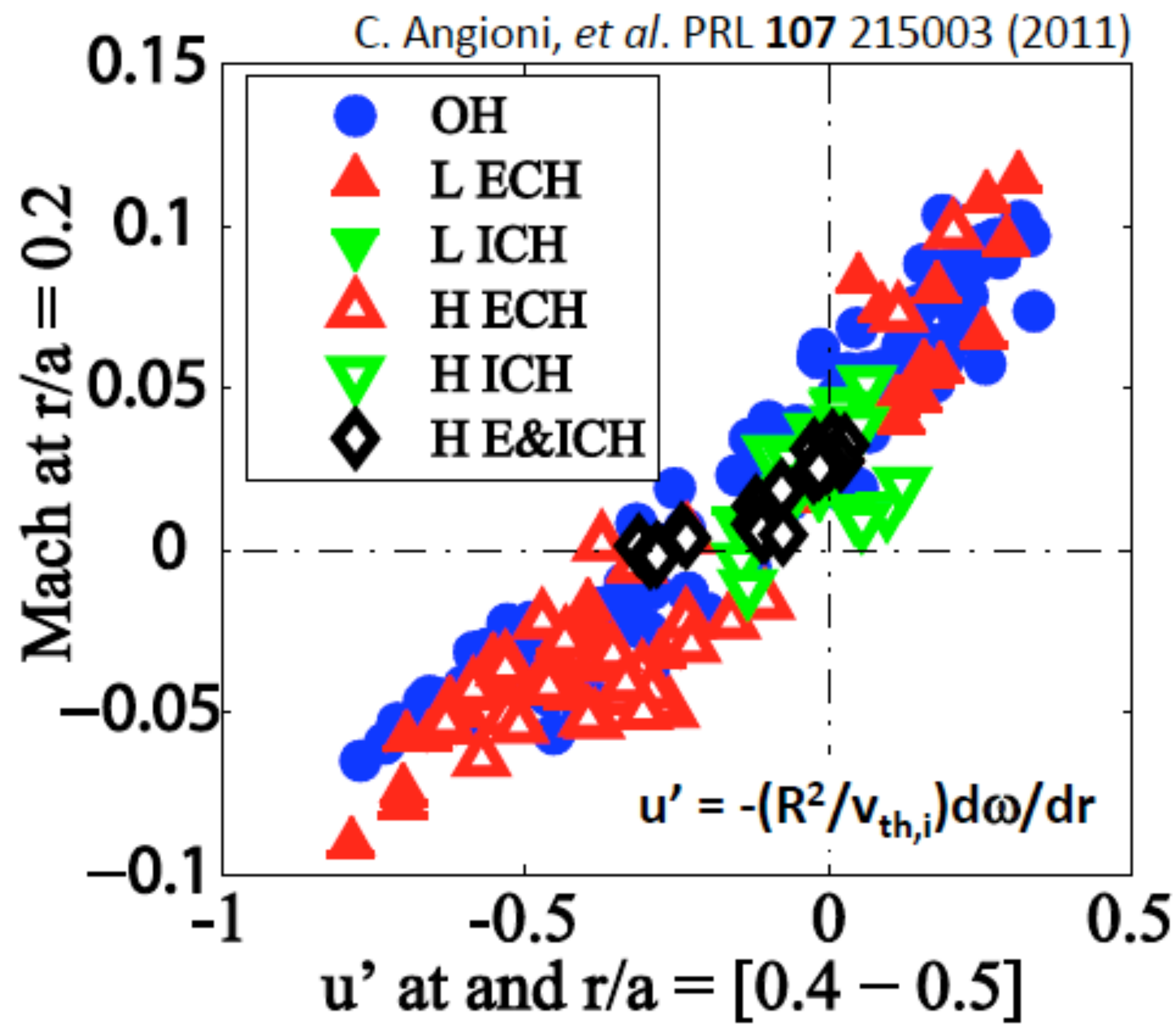
- **Key Issues**
  - Intrinsic Rotation: Will ITER rotate? Which Ip direction? How fast?
    - *Can we predict?*
  - Collisionality and beta dependence of rotation transport
  - Angular momentum transport modeling
- **Intrinsic Rotation (TC-9)- J. Rice, C-MOD**
  - L and H-mode exhibit different intrinsic rotation scalings:
    - *H-mode: co-current rotation increases with stored energy*
    - *L-mode: complex rotation profile response to ne, B_T, I_P , magnetic config.*
    - *LOC-SOC transition: rotation reversal, confinement scaling change, turbulence changes*
    - *LHCD Rotation Direction and magnitude depends on q-profile*
  - Rotation source at edge
    - *Propagates in from edge after L-H , L-I transitions*
  - Residual stress and momentum pinch offers unifying mechanism
    - *Paradigm: TEM to ITG transition may cause different torque drive*
    - *Velocity fluctuation measurements required (==> attempt at DIII-D)*
  - AUG and C-MOD: Mach # increases with velocity gradient at mid-radius

Intrinsic Rotation Physics

C-MOD Rotation
Reversal with nq_{95}



AUG
Similar trends across regimes



ASDEX Upgrade

Alcator C-Mod

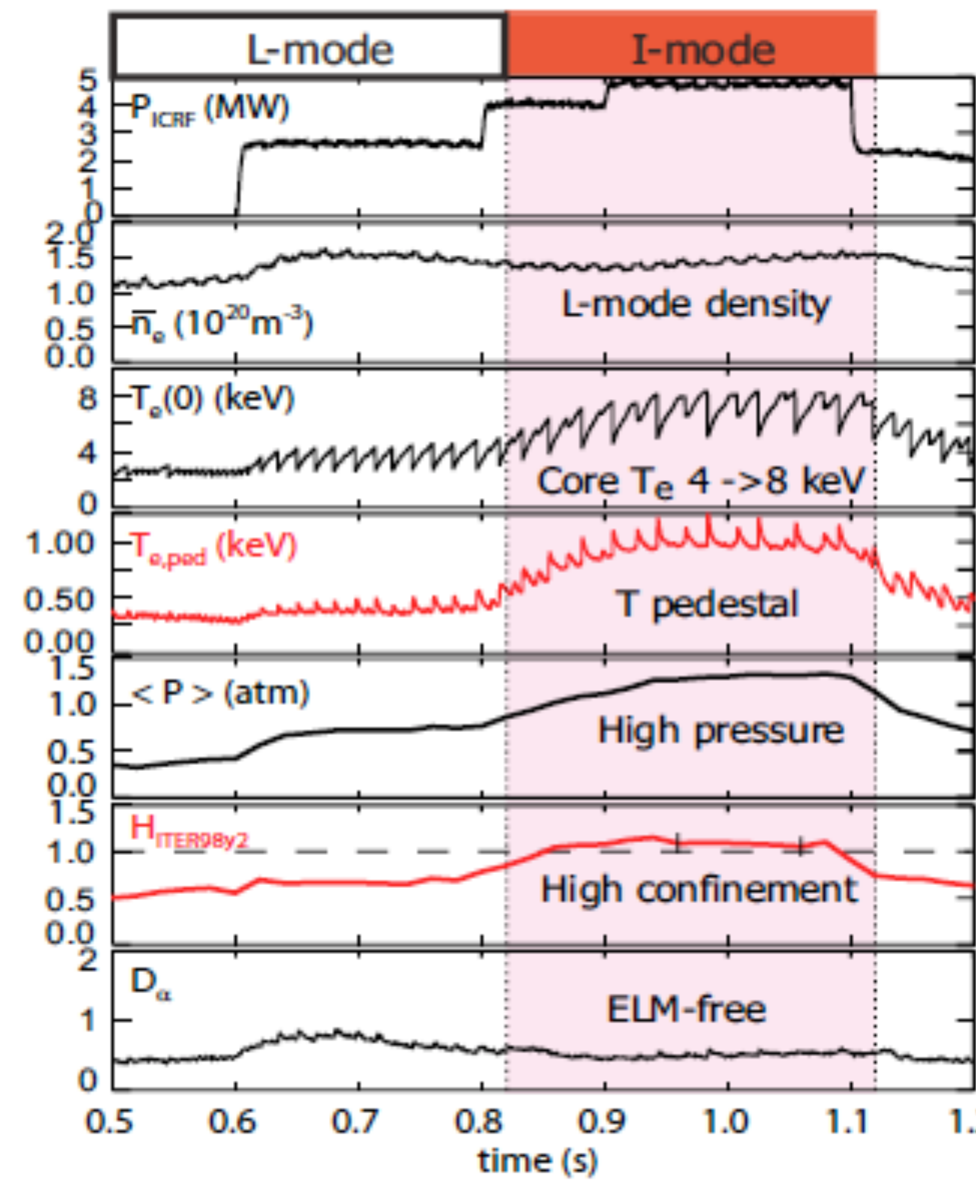
C-MOD data looking generally similar

ASDEX-U (R. McDermott) and Tore Supra (Bourdelle) Results

- **Non-diffusive momentum transport identified: momentum pinch**
  - Similar to JET results
- **Edge-localized torque source**
  - Similar magnitude as NBI
  - Scales with pedestal height
- **LOC/SOC transition**
  - Similar to C-MOD, TCV, KSTAR
  - Not connected to turbulence regime change (linear growth rates)
  - Profile dependences of R/L_{ne}, nu_{eff}, R/L_{Ti} in TEM appear more important
- **Lower-Hybrid Current Drive on Tore Supra**
  - Similar to C-MOD: Co-Ip at low Ip, Counter-Ip at higher Ip
  - Consistent with JET and EAST at low Ip (not high Ip)
- **QuaLiKiz: gyrokinetic model (Bourdelle)**
  - Estimate Momentum transport (plus heat, particle); validated by GKW
  - Parallel velocity gradient: destabilizing; ExB shear: stabilizing; like GKW

Turbulent Transport

- **Characteristics of I-Mode (TC-19, J. Rice)**
  - Good energy confinement, ~L-mode density
  - Access power, transition dynamics, profile shapes
    - *Characterized Weakly Coherent Mode (WCM) and GAM*
    - *Core fluctuations reduce before WCM (A. White)*
  - AUG demonstrated I-Mode
    - *Including turbulence feature (Weakly-Coherent Mode)*
  - DIII-D demonstrated I-Mode-Like features
    - *I-H occurred readily; different Ti/Te, rotation regimes*
    - *Pedestal below P-B limits*
  - Experiments in 2014 at AUG, D3D, EAST
- **TC-23: Physics of Non-locality (Rice)**
  - Cold-pulse observed at low collisionality (TEM)
  - Correlates with LOC-SOC transition
  - Collisionaltiy appears to be critical: nqR~nu*=constant
  - Linear GYRO: TEM dom. in LOC; ITG dom. in SOC
  - SOC: diffusive; LOC: heat pinch



C-Mod, Hubbard, IAEA-2012

Alcator C-Mod

Turbulent Transport

- **Ion Temperature Gradient Scale with Equilibrium Parameters on MAST (Y-C Ghim)**

$$\frac{R}{L_{Ti}} = \left(\frac{q}{\varepsilon}\right)^{\alpha_1} \bar{\gamma}_E^{\alpha_2} \nu_{*i}^{\alpha_3} \left(\frac{R}{L_{Te}}\right)^{\alpha_4} \hat{s}^{\alpha_5} \left(\frac{R}{L_n}\right)^{\alpha_6} \left(\frac{T_i}{T_e}\right)^{\alpha_7}$$

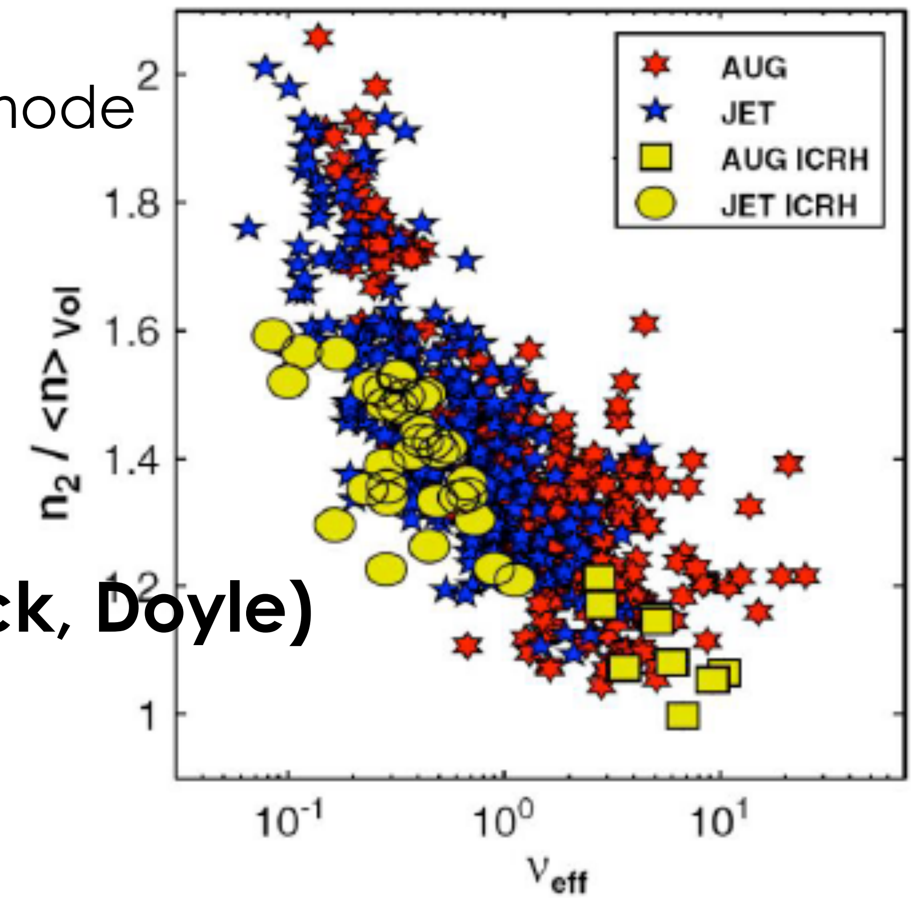
  - Correlates most strongly with q/e (inverse) and shear (direct)
  - Inverse correlation of Q_{TURB} with R/L_{Ti} from BES ($\tilde{n}/n$, L_c): counter-intuitive
    - *Theoretically consistent if R/L_{Ti} is near a critical value*
- **KSTAR finds that T_I and V_{TOR} reduced with ECRH (H.H. Lee)**
  - More significant rotation degradation compared with Ti reduction
  - Flat core rotation not explained by confinement/transport degradation
  - ECRH-driven internal kink modes causes counter-Ip NTV torque?

3D PHYSICS (TC-24)

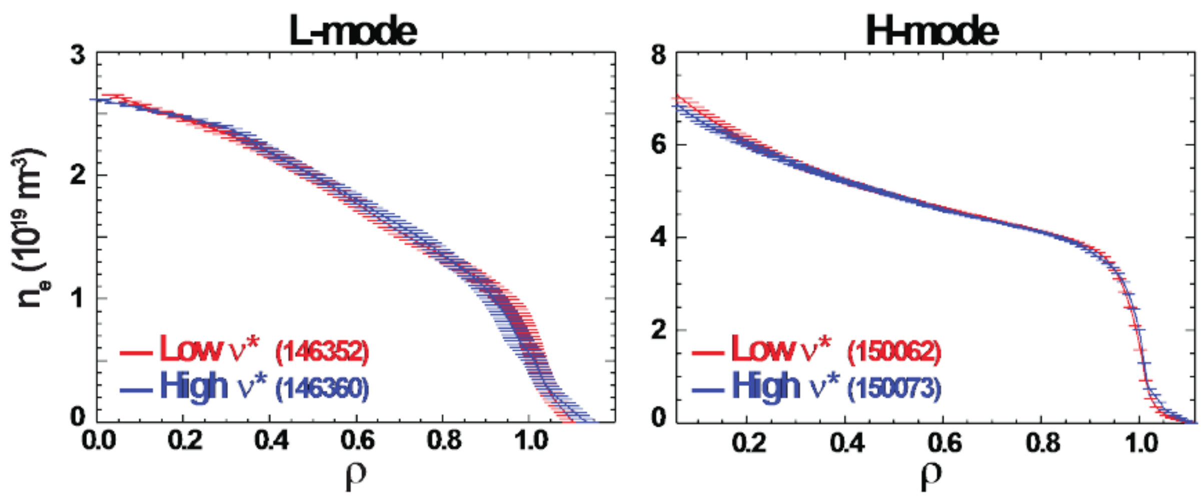
- **Goal: understand transport effects from 3D-fields**
  - RMP ELM suppression, RWM control, NTV
  - Exploit synergy of tokamak and stellarator experiments
- **3D working group**
  - Hidalgo-TJII, Jakubowski-IPP, Dinkleage-IPP, Tanaka-LHD, McKee-D3D
- **q (iota) influence on Long-Range Corr. and Zonal Flows (Hidalgo)**
  - LRC enhanced by edge shear flows/ER; affected by q-scan
  - LRC reduced by DED (TEXTOR)
  - Viscosity reduces ZF; affected by topology, rationals; isotope effects (H/D)
  - Magnetic perturbations expected to impact L-H transition (ZF-effects)
- **Particle transport changes w/RMP in AUG (M. Jakubowski)**
  - Density increase with Resonant MP; decrease with Non-Resonant MP
  - MAST observes Density Pump-Out by RMP (sensitive to resonance)
- **Turbulence responds rapidly (~ms) to RMP in DIII-D (McKee)**
  - Fluctuation amplitude clearly correlated with low-order rational surfaces
    - *q_{90}=8/3, 9/3, 10/3 in pedestal/inboard region*
- **Consistency between iota effects in TJ-II, q_{90} in D3D**

Parallel Joint Session: Particle & Impurity Transport (w/IOS)

- **Particle and Fueling ad-hoc group**
  - Valovic, Angioni, Chang, Doyle, Garzotti, Lang, Loarte, Wang, Weisen
- **ITER Density: HFS pellets and ELM-mitigation (RMP, pacing pellets)**
  - Strong density profile peaking at low nu*
  - D3D shows self-similar ne profiles w/nu* (contrast)-L&H-mode
    - *Doyle, Mordijck, Zeng*
  - Recommended models:
    - *Core (r/a<0.7): GLF23 (moderate pinch)*
    - *Edge (r/a>0.7): working on models for ELM-loss, inter-ELM -NGPS, JOREK*



- **D, v (perturb) derived from gas-puff-mod (Mordjick, Doyle)**
  - TGLF does reasonable job predicting density profs.



Doyle, Mordjick, APS-2013

Tungsten Transport and Accumulation in ITER - C. Angioni

- **Neoclassical and turbulent transport essential (NEO, GKW)**
  - W density not constant on flux surface (high-Z): 2D modeling
    - *beyond diffusive transport (D,v)*
  - Centrifugal, rotation effects considered
  - ICRH impacts high-Z impurities: poloidal asymmetries
- **Validating with JET kinetic profiles, equilibrium**
  - Qualitative/quantitative comparisons with JET SXR tomography of W emiss.
  - W accumulation from inward neoclassical convection
  - Using NEO (Belli, Candy) critical (inc. rotation and poloidal asymmetries)
  - MHD effects need to be considered (not done here)

Preliminary results-to be published

Active Joint Expements

- TC-9: Scaling of Intrinsic Plasma Rotation with no Momentum input
- TC-10: Turbulence and transport in the L-mode core-edge region
- TC-11: He and impurity profiles and transport coefficients
- TC-12: H-mode transport and confinement at low aspect ratio
- TC-13: Ion and electron critical gradient and profile stiffness
- TC-14: RF Rotation Drive
- TC-15/16: Dependence of the Momentum Pinch
- TC-17: Scaling of intrinsic torque
- TC-18: Dimensionless Identity Experiments in I-Mode
- TC-19: Characteristics of I-Mode
- TC-20: Validation of transport models in ITER-similar current ramps
- TC-21: Characteristics of the LOC/SOC transition
- Evolution of transport during and immediately after H-L transitions
- TC-23: Physics of Non-Locality Phenomena
- TC-24: Impact of RMP on transport and confinement

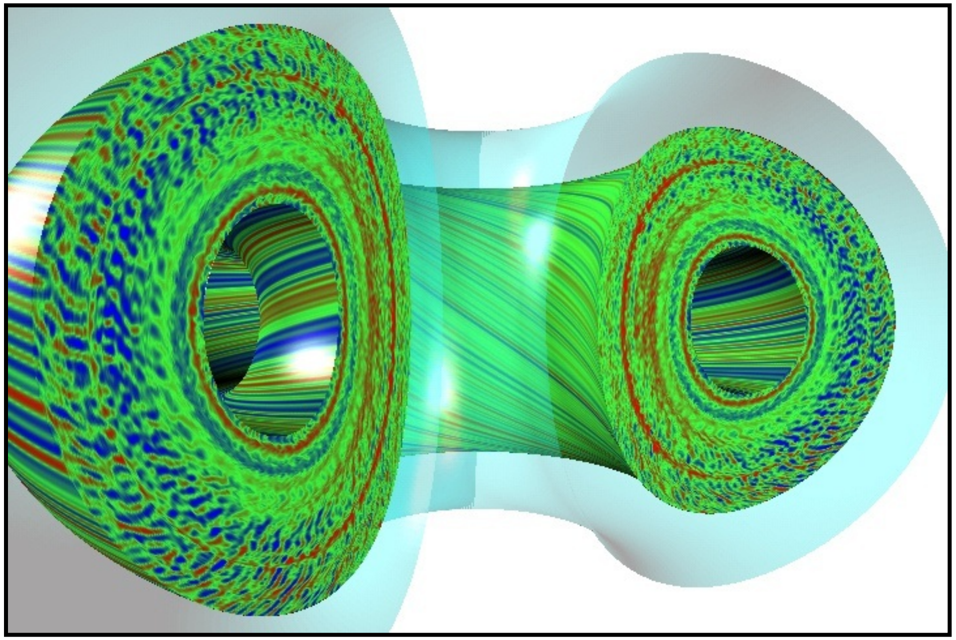
Report on the ITPA Transport and Confinement Group Meeting of October 7-9, 2013

by

G.M. Staebler

General Atomics

San Diego, CA



Presented at the

USBPO webinar

Dec 9, 2013

L-Mode Edge Session: C. Bourdelle TC-10

- **M. Nakata – Validation Study with GKV and TGLF against JT-60U L-mode Plasmas**
  - 3D Ripple can shield the ZF potential, and leads to the lower residual level compared to the purely 2D case. [cf. Sugama PFR2008]
- **E. Fable – Update on the code validation against ASDEX-U L-mode edge**
  - At least in the region up to r/a ≈ 0.9 there is not much short-fall in the non-linear calculations for current ramp discharges.
  - Comparison with TGLF shows that, there is an underestimate of electron transport when moving to higher values of *q*.
- **F. Jenko – more on ASDEX validation: Spotlight for DIII-D case**
  - Collision operators (impact on subdominant TEMs)
  - External ExB shear flows (periodic vs Dirichlet boundary conditions)

L-Mode Edge Session: C. Bourdelle TC-10 cont.

- **C. Holland – Update on code validation for DIII-D L-mode edge**
  - A publically accessible wiki page was created by Chris Holland (chholland@ucsd.edu) to track and co-ordinate cross-code comparisons for shortfall case: https://fusion.gat.com/theory/shortfall
  - Multi-code linear comparisons show excellent agreement with pitch angle electron scattering only (GYRO, GENE, GKW, GS2, GEM).
  - Significant differences in linear stability are seen with energy scatttering between GENE and GKW. (not the same models)
  - GENE gives significantly higher (x2) energy fluxes than GYRO non-linearly even for the pitch-angle only case with ExB shear.
- **L. Chone – Drift waves versus RBM in L-mode edge non-linear modeling**
  - Preliminary turbulence simulations with extended MHD to include a drift-wave branch were presented.

Session on Multi-ion Physics: G. Staebler

- **N. Howard – Validation of impurity transport with GYRO on C-mod**
  - Trace impurity transport of laser blow off calcium injection is used to determine and effective diffusion and convection coefficients.
  - The result have been found to compare favorably with GYRO turbulence simulations.
- **Y. Ren – Initial Results from model validation studies on NSTX**
  - Lithium treatment of NSTX discharges results in improved electron energy confinement and reduction of electron scale (ETG) turbulence.
  - There are complex changes to the ion mix and recycling conditions of NSTX with Lithium injection making transport analysis challenging.
  - The mix of linear instabilities was found to change after Lithium injection.
- **T. S. Hahm – On the isotope dependence of Zonal flows and confinement**
  - The ion species can impact the higher-kr residual zonal flows in a way that moves the transport scaling closer to what is observed in experiment.

Session on Profile Stiffness: P. Mantica TC-13

- **J. Citrin - Nonlinear stabilization of tokmak microturbulence by fast ions in low beta plasmas**
  - GENE nonlinear gyrokinetic simulations show that pure toroidal flow shear provides insufficient ion heat transport stabilization at ρ =0.33
  - The key factor found to lead to agreement between simulation and experiment is nonlinear electromagnetic stabilization of ITG enhanced by suprathermal pressure gradients.
- **J. Garcia – Fast ion impact on microturbulence in high beta plasmas**
  - Linear analysis shows that a mix ITB/KBM plasma for 75225 discharge due to high electron beta
  - Fast ions provide a clear reduction of ITG linear growth rates
  - **This mechanism allows for transport thermal improvement in ITER in the absence of significant external torque**
- **C. Petty – Critical gradient and transport stiffness studies on DIII-D**
  - Contact Craig Petty <petty@fusion.gat.com> for a copy.

Final report on TC-20 : D. Mikkelsen

- **D. Mikkelsen – Validation of transport models in ITER similar current ramp plasmas (TC-20)**
  - Final report draft is being circulated.
  - ITER-similar current ramp data obtained from C-MOD, DIII-D, JET.
  - No models work from center to separatrix.
  - Critical plasma control parameter ℓ_i sensitive to edge temperature.
  - TGLF with edge enhancements (paleo-classical or Scott model) works better but additions are not extensively validated.

Joint Session on Energy Transport in Integrated modeling: T. Luce/G. Sips

- **G. Staebler – Introduction and TGLF validation**
  - Answers to specific questions from IOS on readiness of TGLF given.
- **C. Bourdelle – QuaLiKiz**
  - A new way of including the ExB shear radial wavenumber shift in the linear eigenmodes shows promise (P. Cottier)
  - QuaLiKiz and TGLF benchmarks underway (s-alpha geometry).
  - Both QuaLiKiz & TGLF share the same design philosophy: quasilinear models of non-linear gyro-kinetic turbulence fit only to simulations not experiment.
  - QuaLiKiz & TGLF are independently developed with very different numerical techniques.

Answers to IOS questions for TGLF

- Does TGLF capture properly the dependences of:
  - Fast ions: Yes, fast ion dilution and pressure gradient are important stabilizing effects that have been shown to contribute to a good agreement for predicted profiles. ITER will have little dilution but significant fast ion pressure.
  - Finite beta: Yes, finite beta is weakly stabilizing linearly and in TGLF. The linear threshold for KBM is accurate in TGLF. No, non-linear gyro-kinetic simulations often show a lower effective beta threshold for KBM turbulence thought to be due to zonal (n=0) pressure gradient corrugations (Waltz). No, the compressional MHD fluctuations (B-parallel) important for STs are not accurate in TGLF due to a problem with the curvature drift closure.
  - Parallel velocity shear: Yes, this is accurately included in TGLF. Torodial momentum transport predictions will be extensively validated with data soon. No, Parallel flows are restricted to low mach number neglecting centrifugal effects.
  - Magnetic shear: Yes, TGLF tracks the magnetic shear dependence of gyro-kinetic simulations very well. $\left(-3 \leq \hat{s} \leq 3\right)$

DIII-D NATIONAL FUSION FACILITY

Answers to IOS questions for TGLF cont.

- Does TGLF capture properly the dependences of:
  - Geometry: Yes, TGLF has general flux surface geometry or shaped Miller model. Finite aspect ratio is destabilizing and is the primary reason that TGLF gives lower performance projections for ITER than GLF23 for the same pedestal pressure. This was validated by TFTR data showing better agreement with the finite aspect ratio predictions.
  - ExB velocity shear: Yes, the TGLF model for shear in the ExB Doppler shift has recently been improved to achieve greater fidelity to gyro-kinetic simulations.
  - Collisions: Yes, TGLF is an accurate model of fluxes with electron pitch angle scattering. No, TGLF does not have energy scattering of electrons or any ion-ion collisions.
  - Multi-ion plasmas: Yes, TGLF can handle multiple ion species as dynamic species. Using kinetic carbon impurity ions is found to be essential for high zeff >2.5 discharges. ITER is a multi-ion plasma and it is necessary to have a model like TGLF that is valid for fuel and impurity ions. (D,T,He,Neon, Argon, W, etc.)

Joint Session on Energy Transport in Integrated modeling: T. Luce/G. Sips cont.

- **J. Garcia – Comparison of TGLF and QuaLiKiz predictions for JET discharges**
  - The first temperature profile predictions with QuaLiKiz have been made using the CRONOS code.
- **R. Budny – ITER modeling with PTRANSP**
  - TGLF has been installed in PTRANSP with a new solver.
  - First results predicting temperatures, density and rotation in a hybrid JET discharge were presented.
- **TGLF has now been installed in many of the integrated modeling transport codes.**
  - PTRANSP, CRONOS, ASTRA, FASTRANS
  - TGLF+NEO out to the top of the H-mode pedestal + EPED1 to predict the pedestal top pressure boundary condition is the best predictive model for transport at present.
  - The sawtooth region is unpredictable by TGLF.