Core Thermal Ion Energy Transport and Transport Simulation Issues

BPO Transport/Confinement Breakout Session

Oak Ridge, TN, December 8, 2005

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- How rigorously can we predict χ_i and T$_i$ in ITER standard H-mode plasmas?
- Approaches:
  1. Extrapolations from experiments
  2. Predictions from semi-empirical models
  3. Predictions from theory
- There are large uncertainties about χ_i in some ITER-relevant experiments

χ_i extrapolations from present experiments

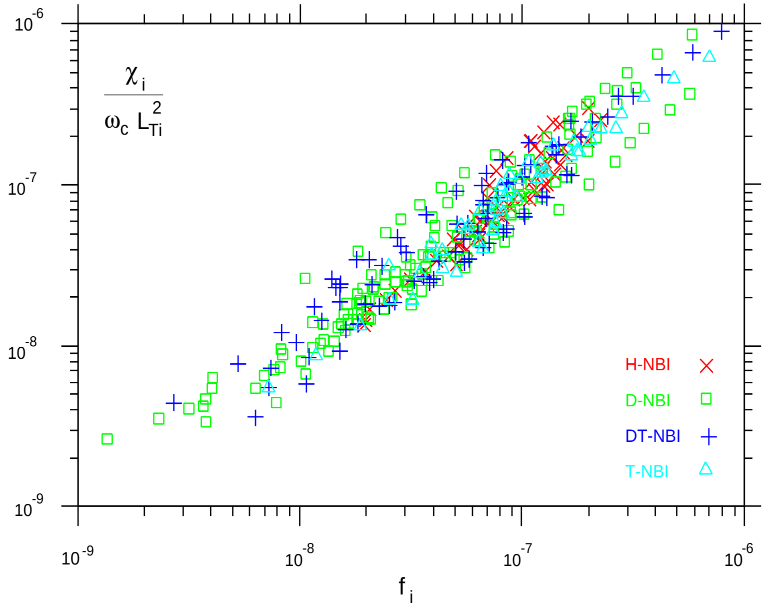
- Warning: Burning Plasmas will be very different
  1. self-heated, weakly-rotating, $T_i \simeq T_e, \cdots$
  2. low ρ_*, ν_*, $\cdots$
  3. DT
- History of controlled fusion experiments is full of surprises
  1. L-mode in ISX-B, PDX
  2. H-mode in ASDEX
  3. Supershots, ERS in TFTR
  4. Hot-ion H-mode in JET
- Therefore we should expect surprises in ITER

Limitations of present experiments for predicting χ_i in ITER

- JT-60U has NNBI, but large ripple effects need to be clarified
  - Time evolution and Z_{eff} profiles often not available
- JET made many ITER-relevant H-modes, but mostly with co-NBI
  - CX T_i difficult in high n_e
  - T_i not available with RF only
- US experiments have good fluctuation data and may be Demo-relevant, but less ITER-relevant?
  - Need high Temperature, high density H-mode plasmas with balanced NBI and ICRH
- How do we extrapolate χ_i from present experiments to ITER?
  - Study scaling of χ_i with dimensionless variables: ρ_*, ν_*, β, isotopic mass, $\cdots$

Dimensionless scaling of χ_i from a database of JET ELMy H-mode

- r/a = 0.3-0.7 in T, DT, D, and H plasmas
- Fit: $\chi_i/(\omega_c L_{Ti}^2) \propto \rho_*^{2.2}\beta^{-0.75}\nu_*^{0.74}M^{-0.84}$
- See shift from Bohm ($\propto \rho_*^2$) to gyroBohm ($\propto \rho_*^3$) as ρ_* decreases
- Budny, *et al*, PoP **7** (2000) 5038



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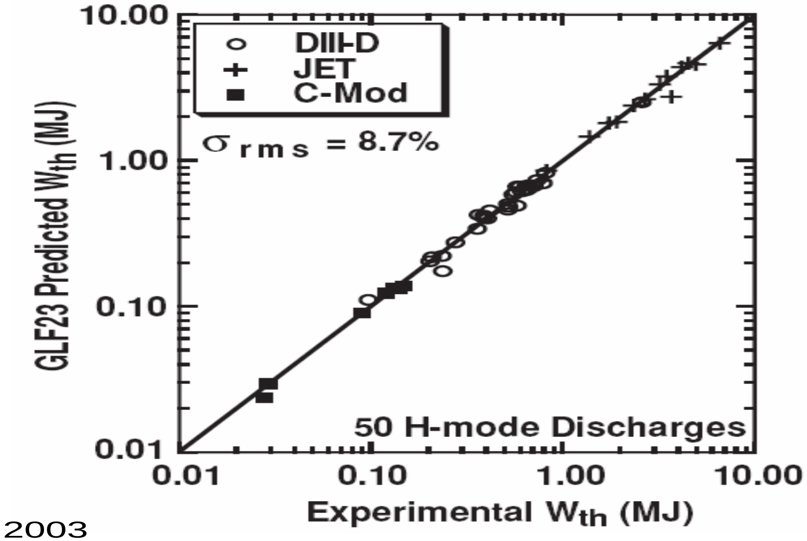
χ_i predictions from semi-empirical models

- Calibrated with exp data or gyrofluid and gyrokinetic calculations
- Examples of models:
  - IFS-PPPL
  - GLF23
  - MMM
  - Weiland
  - Mixed Bohm / gyro-Bohm
  - CDBM
- Do they agree with each other? Generally not
- Do they agree with existing data?
- How do they extrapolate to Burning Plasmas?

Example of GLF23 results for H-mode experiments

Comparison of experiments with 1-D transport model GLF23 based on gyrofluid & gyrokinetic simulations

Caveats: core turbulence simulations use observed or empirical boundary conditions near edge. Need more complicated edge turbulence code to make fully predictive & sufficiently accurate. Edge very challenging: wider range of time and space scales, atomic physics, plasma-wall interactions…



Kinsey, Bateman, et al., Nucl. Fus. 2003

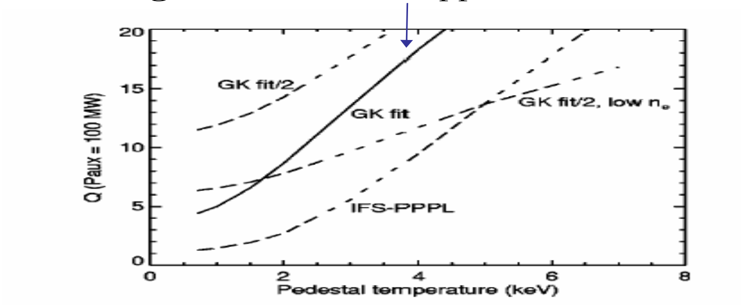
Marginal stability with Stiff Response

- Gyrofluid and gyrokinetic results are stiff, i.e., rapid increase of χ_i and q_i with $\nabla(T_i) \geq \nabla(T_{crit})$
- Comparisons of calculations with measurements indicate that plasmas are pinned near $\nabla(T_{crit})$
- T_i depends sensitively on boundary conditions (T_{ped})
- T_i depends insensitively on χ_i
- Early results (Kotschenreuther and Dorland IAEA 1996) gave χ_i for ITER higher than current results by x2.5, but T_{ped} close to current results $\simeq$4.5keV

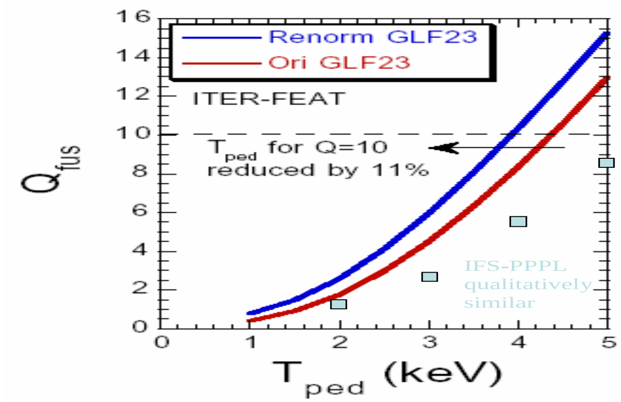
Comparison of results for ITER

Latest renormed GLF23 (used at Snowmass) shows only small difference from original GLF23 (which is similar to original IFS-PPPL) because reduction in ITG due to Dimits shift offset by increase in ETG

I.e., this curve may be too optimistic because it neglects ETG and trapped electron effects.



From Dimits, et.al. Phys. Plasmas 2000
Predictions for 1996 ITER.



From Kinsey, Staebler, Waltz, Sherwood 2002.
Predictions for 2001 ITER-FEAT.

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χ_i predictions from Theory

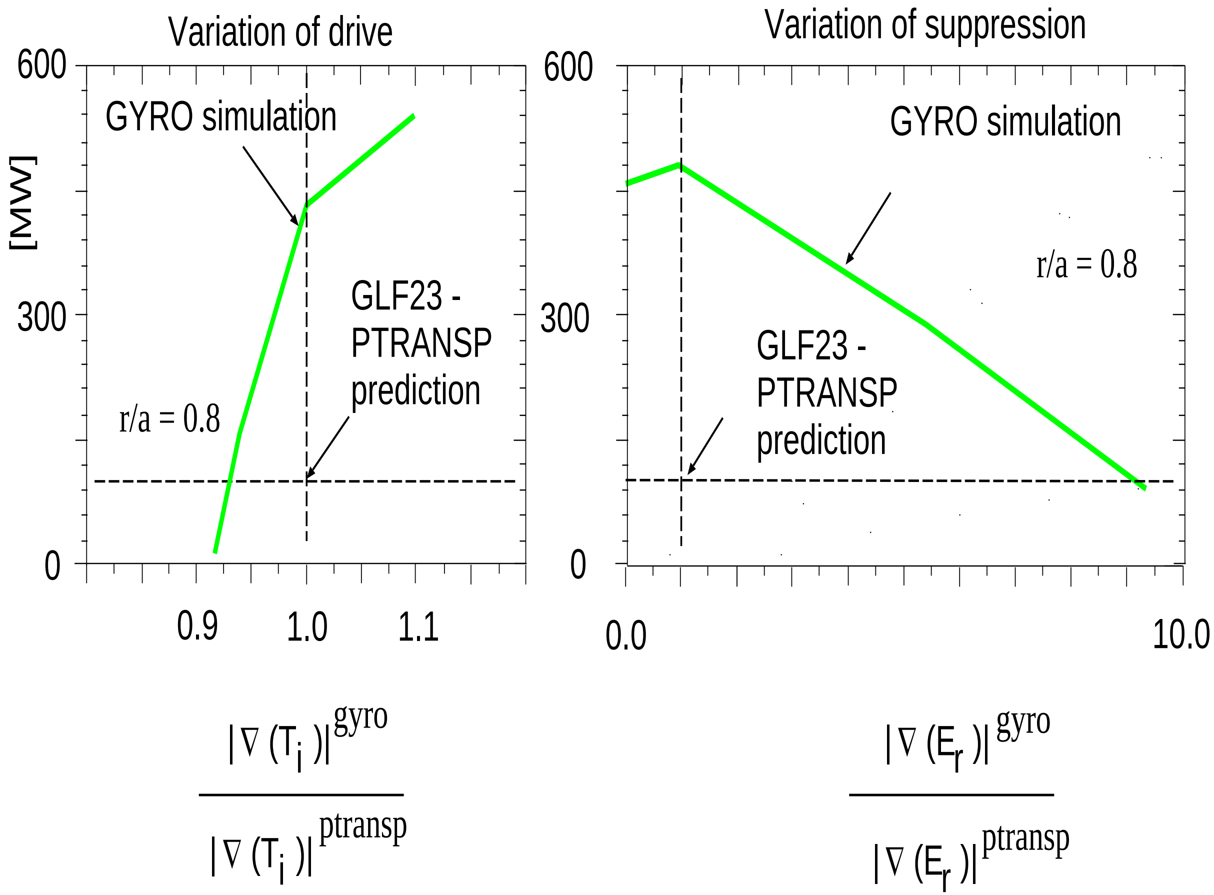
- Generally assumed that ITG / TEM turbulence determines χ_i, but also need to know:

  1. ELMs (indirect effects on core)
  2. MHD
  3. NTM (island flattening?)
  4. Sawteeth (3D effects?, observe δT_i)
  5. Neoclassical (applications with large v_{tor}, fast ions?)
  6. Ripple (ASCOT code results)
  7. Alfv$\acute{e}$n eigenmodes (indirect and possibly direct effects on χ_i)

State-of-the-art gyrokinetic simulations of ITG/TEM turbulence

- Nonlinear codes: GYRO, GS2, GTC,..
- Remaining controversies about Cyclone case (ex, particle noise)
- GYRO code gives qualitative χ_i, but with hyper-sensitivity to $\nabla(T_i)$, $\nabla(E_r)$, $\cdots$
  1. overestimate χ_i in DIII-D H-mode plasmas
  2. underestimate χ_i in JET H-mode plasmas
  3. overestimate χ_i in TFTR supershots
- try GYRO on ITER plasmas with GLF23-predicted tmperatures

Nonlinear GYRO results for ITER



Why doesn't the GYRO flow agree with the GLF23-predicted flow?

- GLF23 based on gyrofluid and gyrokinetic simulations
- Time-dependent integrated modeling using TSC / TRANSP with ITER shaping
- Plasma profiles and Miller equilibrium used in GYRO
  1. shaping? not modeled in GLF23
  2. sensitivity of GYRO results
- Want to close loop: gyrokinetic -> GLF23 -> Integrated ITER Modeling -> gyrokinetic

How can we improve T_i predictions for ITER

- More experiments with ELMy H-mode plasmas (ITER base regime)
  1. want high density, low ρ_*, low ν_*
  2. balanced NBI and ICRH
  3. DT experiments in JET
- More measurements of fluctuations to test turbulence simulations
- Improved semi-empirical predictions
  1. robust solvers of stiff equations
- Improved turbulence calculations
  1. multiple kinetic ion species
  2. plasma shaping
  3. improved checks with fluctuation measurements
  4. calculate T_i from flows instead of flows from profiles
  5. improved data for E_r

Another way to improve T_i predictions for ITER

- Collect predictions of ITER plasmas in the ITPA
  1. Test bed to compare codes
  2. Reference cases for applications
- Five ITER plasmas are in profile working database
  1. One standard ELMy H-mode
  2. Four hybrid cases