FUSION ENERGY RESEARCH AT UT

François Waelbroeck

Fusion Power Association Annual Symposium
Dec 17, 2020

Outline

1. Introduction to IFS
2. Experimental program
   - Negative triangularity
3. Theory program
   - Confinement: pedestal transport
   - Macro-Stability: RMP ELM-suppression
   - Energetic particles: pellet ablation

INTRODUCTION

The Institute for Fusion Studies

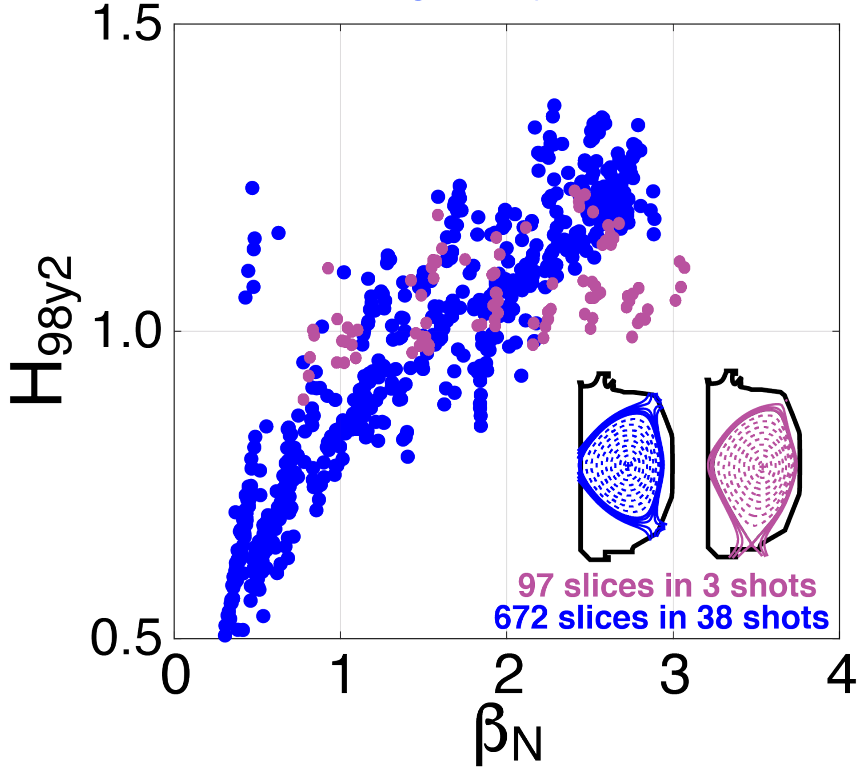
- IFS is a Physics Department center for research in fusion energy science
  - Its mission is to serve as a national center for theoretical and experimental studies
- IFS activities:
  1. EDUCATION AND WORKFORCE DEVELOPMENT
     - Physics Dept. Undergraduate and Graduate program
  2. CONNECTIVITY & EXCHANGE
     - Local: Aerospace & Mechanical Engineering, Mathematics
     - National: PPPL, GA, Woods Hole, Parker solar probe
     - International: JIFT, ICTP
  3. RESEARCH & DEVELOPMENT
     - Theory: Mathematics Dept (RE SciDAC), IPP Garching (GENE)
     - Experiments: ECE on DIII-D, EAST, COMPASS-U
     - Computing: Exascale Project at the Oden Inst. Comp. Eng. Sciences
     - Applied Math: SapientAI, IPP Garching, Aerospace Engineering
     - Technology: ITER-ECE with the UT Center for Electromechanics

EXPERIMENTAL PROGRAM

Negative triangularity is a promising candidate for core-edge Integration

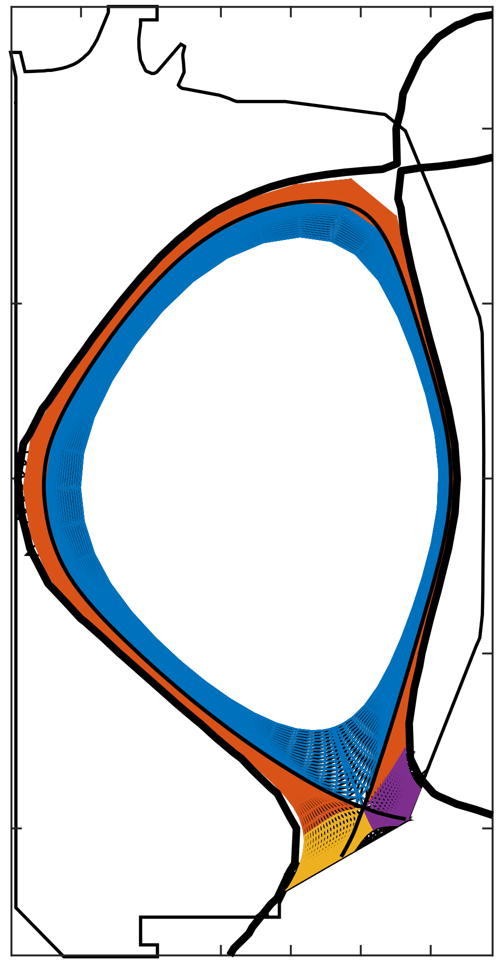
- IFS scientist Max Austin has led a program investigating NT on DIII-D
- Shown that Neg. triangularity discharges at significant β_N achieve H-mode level confinement
  - Combination of shape-related effects that weaken turbulent transport
- Diverted NT discharges remained in L-mode, but with high confinement, at 5x P_{LH}
  - Only got H-mode at relaxed neg. triangularity (δ_{up} -0.36 ➔ -0.18)
- NT is a promising candidate for core-edge integration with low P_{SEP}
  - Robustly ELM-free with divertor at large *R*

DIII-D Negative Triangularity Shots



Future: Negative triangularity core-edge integration with armored DIII-D vessel wall

- Currently the DIII-D outer wall cannot withstand high-power diverted plasmas
- DoE recently approved incr. funding to armor low-field side wall to permit divertor operation in up-down symmetric negative triangularity
- This will make it possible to maintain strong shaping for good core confinement with high power (L-mode) edge
- The growing database of shots shows neg. triangularity has promising features for advanced tokamak operation
  - H98y2 ≤ 1.3
  - Reactor-relevant beta: $\beta N \sim 3.0$
  - Significant bootstrap current
  - ELM-free operation
  - Hints of wider λq's



Planned:
Add carbon armor tiles

DIII-D NATIONAL FUSION FACILITY

THEORY PROGRAM

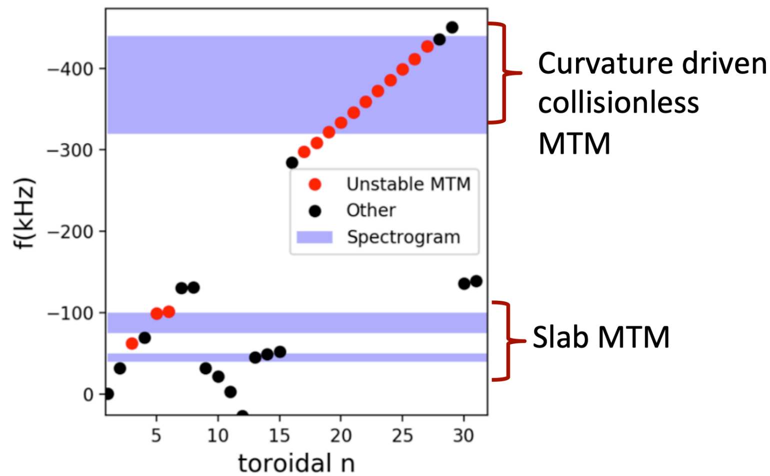
Understanding Pedestal Transport through Gyrokinetic and Edge Modeling

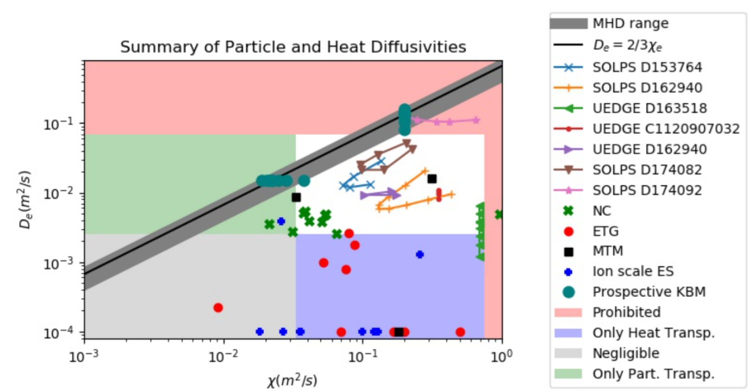
- Compare with the characteristic **'fingerprints' of prospective transport mechanisms** determined by theory + simulation (Kotschenreuther *et al*. NF 2019).
- Interpretive edge modeling (SOLPS and UEDGE):
  - Best possible **estimates of heat and particle diffusivities**
- Survey eight discharges spanning multiple machines (mostly DIII-D), broad range in dimensionless parameters, multiple operating scenarios (I-mode, QH mode, etc.), different wall materials, scans in fueling, etc.
- **Compare gyrokinetic simulations with experimental transport levels (including channels), fluctuation data**
- Final report: DOI: 10.2172/1615233

SciDAC MGK

Major Conclusions

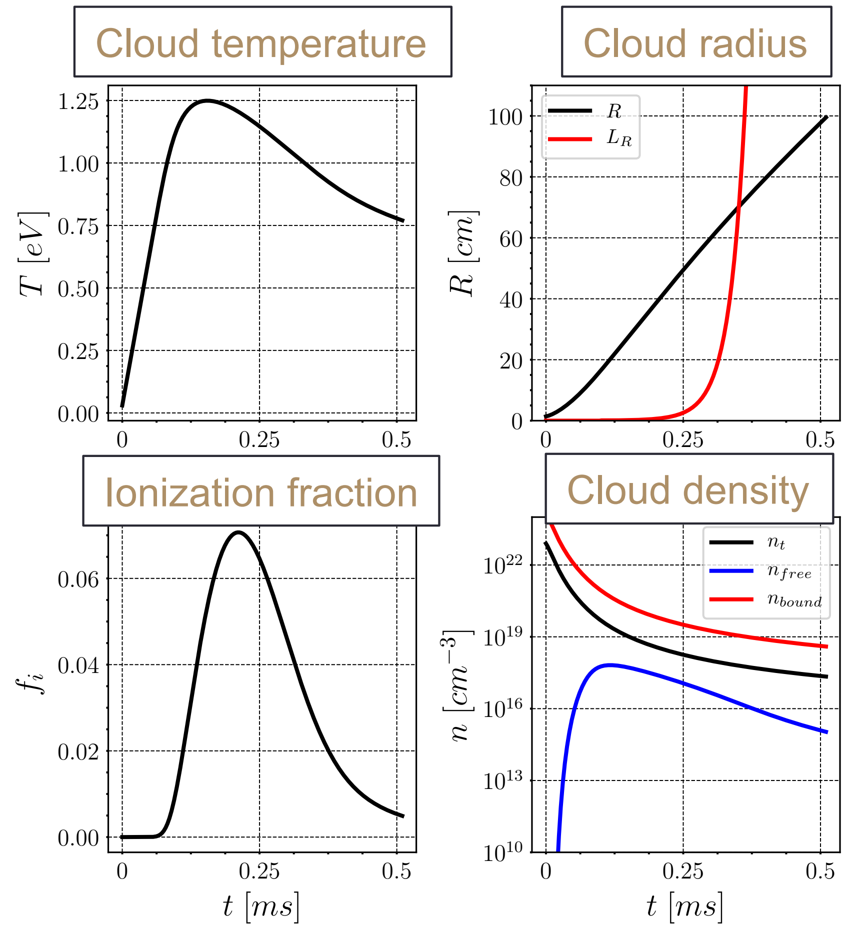
- Edge modeling: **De/χe ≪ 1** is typical.
- **ETG and MTM are important** mechanisms for electron heat transport.
- Close quantitative agreement between distinctive bands in **magnetic spectrograms** and corresponding bands of unstable **MTM** in gyrokinetic simulations.
- Due to the observed disparity between De and χ, **KBM** cannot simultaneously account for all transport in both channels, but, rather, **must be limited largely to the particle channel (not inconsistent with EPED)**.
- **Neoclassical, MTM, ETG, and ITG** can all produce relevant **electron particle transport** levels (the latter two in either positive or negative directions), but generally the combination is too low. **This suggests that an additional particle transport mechanism, like KBM, may be necessary.**
- When **ion scale electrostatic fluctuations** are active, **the pedestal is generally modified** from standard H-mode (in positive or negative ways).





Pellet assimilation under runaway electron flux

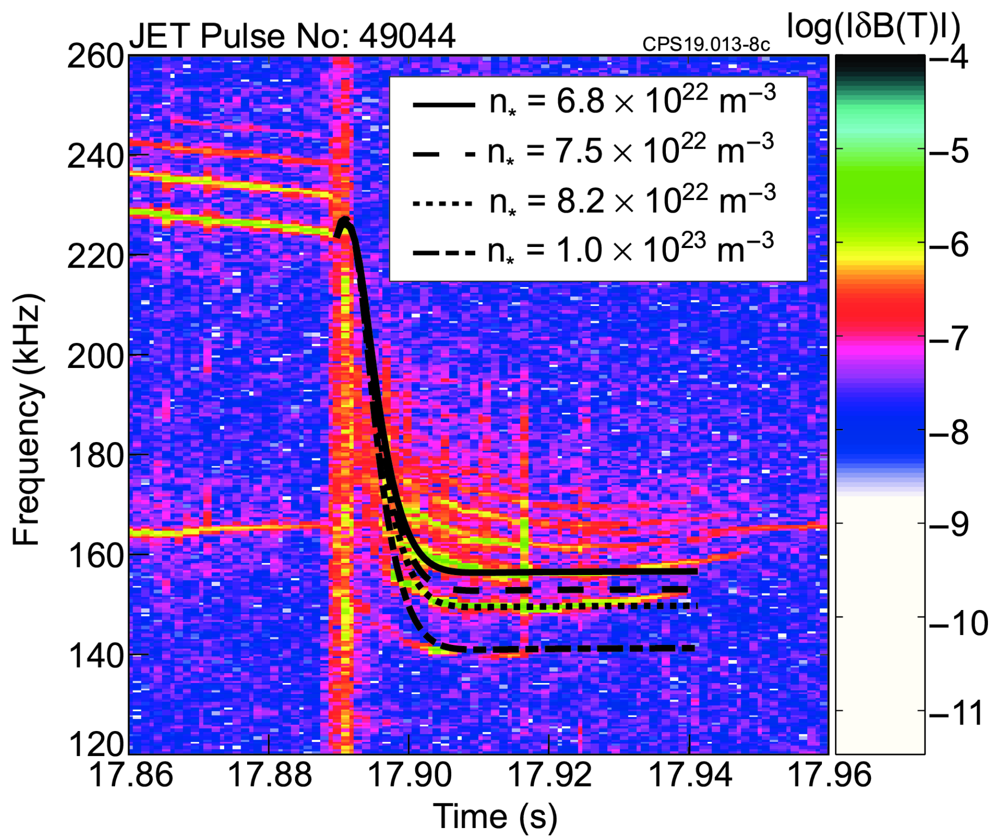
- Runaway electrons heat the pellet volumetrically
- The pellet sublimates immediately when the RE carry a large fraction of the current
- The gas cloud remains weakly ionized and spreads over the poloidal cross-section on a millisecond time scale
- This scenario explains recent experiments by D. Shiraki et al., Nucl. Fusion 58, 056006 (2018).



Pellet assimilation under runaway electron flux, D. I. Kiramov and B. N. Breizman *Nucl. Fus.* **60,** 084004 (2020)

Alfvén eigenmodes respond to transient pellet-induced density rise

- MHD spectroscopy of the pellet plume
- We find the pellet plume density at the TAE and EAE locations by matching the calculated frequency evolution of the modes to the experimental data



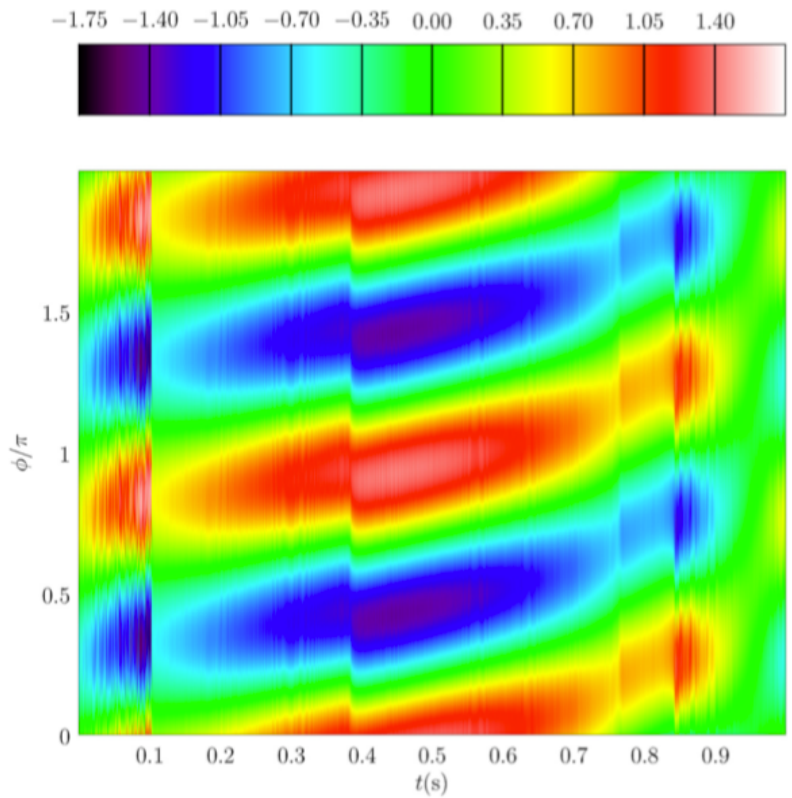
H.J.C. Oliver *et al.*, Nucl. Fusion **59** (2019) 106031.

EPEC Code Models plasma response to Resonant Magnetic Perturbation

- The EPEC code [Fitzpatrick 2020] employs an asymptotic matching approach to model the dynamics of multiple magnetic island chains interacting with an externally applied resonant magnetic perturbation in a rotating toroidal tokamak plasma equilibrium.
- Code can simulate complete time history of discharge in matter of minutes of real time.
- Code requirements: plasma equilibrium (e.g., a g-file); plasma profiles (temperature, density, rotation, Zeff); neutral data.
- Code has already been used to analyze data from DIII-D and KSTAR. [Fitzpatrick Phys. Plasmas **27**, 042506, 072501,102511 (2020)].
- Plans to analyze data from NSTX, NSTX-U, MAST, MAST-U, and ASDEX-U.

Results confirm that island penetration is responsible for ELM suppression

- Modeling of DIII-D ELM suppression data confirms standard scenario, according to which ELM suppression is a direct consequence of inducing a relatively wide magnetic island chain at the top of the pedestal.
- EPEC modeling of DIII-D data seems to indicate that the E × B rotation frequency is the important one. It will be interesting to see whether this result is consistent with KSTAR and ASDEX-U data.
- Obtaining accurate neutral data is a major problem. Plans to use SOLPS-ITER modeling to obtain better data.



Simulated integrated Mirnov signal detected by a toroidal array of pickup when an n=2 I-coil current of 4.2 kA is applied to our model DIII-D plasma equilibrium. The relative phase between the currents flowing in the upper and the lower sections of the I-coil is ramped linearly on a time-scale of 1 s.

IFS looks forward to participating in the LRP program recommended by FESAC

- IFS was an active participant in the Community Planning Process, hosting one of the preliminary meetings.
- We look forward to participating in the closure of the Integrated Tokamak Exhaust and Performance gap using existing and forthcoming experiments including DIII-D, NSTX-U, ITER, the EXCITE experiment and ultimately the FPP.
- Thank you for your attention