GA–A27239

IMPROVED UNDERSTANDING OF PHYSICS PROCESSES IN PEDESTAL STRUCTURE, LEADING TO IMPROVED PREDICTIVE CAPABILITY FOR ITER

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APRIL 2012

GENERAL ATOMICS

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R.J. GROEBNER, C.S. CHANG,* J.W. HUGHES,† R. MAINGI,‡ P.B. SNYDER and X.Q. XU£

This is a preprint of a paper to be presented at the 24th IAEA Fusion Energy Conference, October 8–13, 2012 in San Diego, California and to be published in Proceedings.

*Princeton Plasma Physics Laboratory, Princeton, New Jersey USA
†Massachusetts Institute of Technology, Cambridge, Massachusetts USA
‡Oak Ridge National Laboratory, Oak Ridge, Tennessee USA
£Lawrence Livermore National Laboratory, Livermore, California USA

Work supported in part by
the U.S. Department of Energy
under DE-FC02-04ER54698, DE-AC02-09CH11466,
DE-FC02-99ER54512, DE-AC05-00OR22725
and DE-AC52-07NA27344

GENERAL ATOMICS PROJECT 30200
APRIL 2012

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Joint experiment/theory/modeling research has led to increased confidence in predictions of the pedestal height in ITER. This work was performed as part of a US DOE Joint Research Target in fiscal year 2011 and included experimental research from C-Mod, DIII-D and NSTX as well as interpretation of experimental data with several theory-based modeling codes. This coordinated work provides confidence that the newest version of the EPED model [1] can be used to predict pedestal pressure height in ITER to within ~20%. The research provides new benchmarking of physics models used within the EPED model, including models for peeling-ballooning (P-B) modes, pedestal bootstrap current and kinetic ballooning modes (KBM). In studies of other physics processes, modeling provides evidence that there is a particle pinch in the pedestal, but there is also experimental evidence that neutral fuelling may be important. Studies of models for neoclassical and paleoclassical transport find that these mechanisms may be significant in the pedestal but that additional transport is needed to describe the fully developed pedestal.

The new version of the EPED model contains no adjustable or fitted parameters and predicts values of pedestal pressure height and width that agree within ~20% of measurements in Type I ELMy discharges on C-Mod and DIII-D, as shown in Fig. 1. The C-Mod data increase the maximum pressure for which EPED has been tested by a factor of two [2]. The test of the width predictions has been improved with new data from DIII-D that provide widths in the range of 0.06-0.08 in ψ_N [Fig. 1(b)], filling a gap in previous data sets. As shown in Fig. 1, the EPED prediction for the width of the ITER pedestal (baseline operation) is within the range of existing pedestal widths and prediction of the height is an extrapolation of about a factor of 3 over the current data, spanning more than a factor of 10.

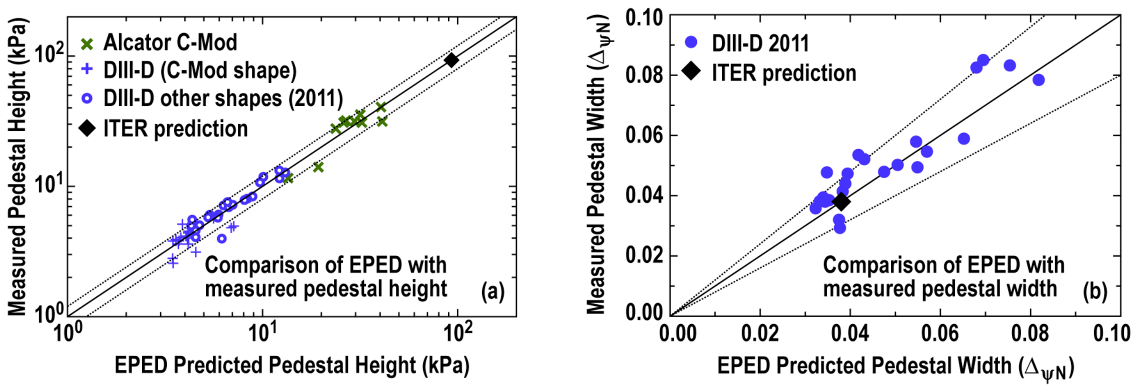

Fig. 1. (a) Measured pedestal pressure height ($2n_eT_e$) vs predicted height. Data from 2011 experiments in C-Mod and DIII-D. (b) Measured pedestal width (average of n_e and T_e widths) vs predicted width for DIII-D. For (a) and (b), darkest solid line is unity line; upper and lower lines are ±20%.

Validation studies performed with BOUT++ and ELITE (used in EPED) increase confidence that P-B modes limit the pedestal height obtained in H-mode discharges, with the discharges usually reaching the predicted peeling limit rather than the ballooning limit. These models provide good predictions of pedestal height observed at the onset of Type-I ELMs in C-Mod, NSTX and DIII-D. Kinetic calculations with XGC0 and NEO, using realistic collision operators, have been used to benchmark analytic bootstrap current models, required for P-B calculations. The results show that analytic models of bootstrap current (used in EPED) are accurate to ~10–15% for C-Mod and DIII-D and to ~40% in NSTX.

The pedestal width scales approximately as expected if the pedestal p´ is limited by KBMs. A simple KBM model predicts that the pedestal width scales with the square root of the pedestal beta poloidal. This scaling is a good description of scalings observed in systematic parameter scans in all three devices. The proposed KBM width scaling data quantitatively agrees with DIII-D and C-Mod data within ~20%. Fluctuation measurements in DIII-D have shown that coherent modes exist in near QH-mode conditions and that these modes have characteristics expected for linear KBMs. It remains an open question whether KBM fluctuations or turbulence cause the observed transport.

Careful comparisons of the electromagnetic gyrokinetic codes, GYRO, GEM and GTC have been performed to study the linear gyrokinetic stability of one well-diagnosed DIII-D pedestal. These codes find electron drift modes and KBMs (with expected onset) within the pedestal and ion temperature gradient modes (ITGs) on the pedestal top [3]. XGC1 finds that ITGs spread from the core into the pedestal [4]. Experimental and modeling results suggest that electron temperature gradient (ETG) modes may play a role in the pedestal structure of all three machines. These results indicate that fluctuation-driven transport may play a role in pedestal structure, but much more research is needed.

Experimental and modeling evidence suggest that both atomic physics and a pinch play a role in controlling the density pedestal. A pedestal similarity experiment between C-Mod and DIII-D matched the pedestal T_e profiles [Fig. 2(b)] whereas the n_e pedestal in DIII-D was wider than in C-Mod [Fig. 2(a)], consistent with a role for atomic physics in the density pedestal. Application of lithium coatings in NSTX provided much wider density pedestals than obtained without the coatings [Fig. 2(c)], suggesting an important role for atomic physics. However, the paleoclassical model, in which pinch physics is much more important than fuelling physics, matched the shapes of n_e profiles with and without lithium coatings [Fig. 2(c)] [5]. Other modeling calculations on DIII-D and C-Mod provide evidence that physics other than atomic physics plays a role in the density pedestal.

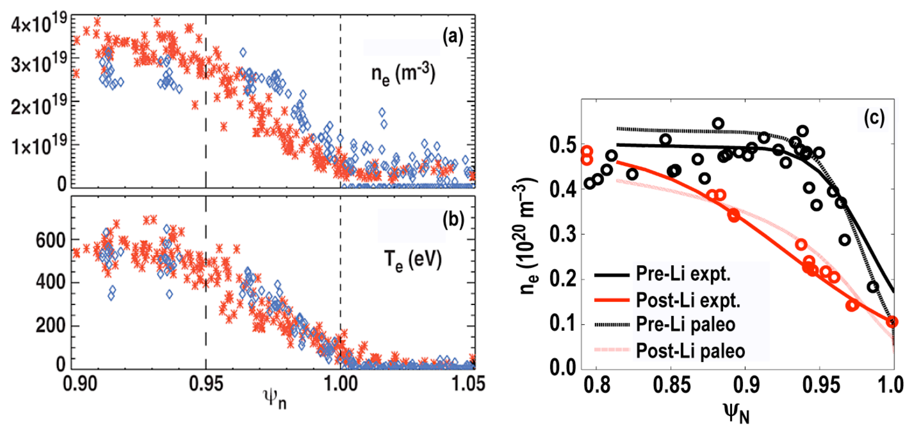

Fig. 2. (a) n_e and (b) T_e pedestals from similarity match between C-Mod (blue diamonds) and DIII-D (red stars). C-Mod data scaled to DIII-D temperatures and densities. (c) n_e pedestals in NSTX from pre- and post-lithium wall coating. [Fig. 2(c) from Ref. 5.]

Overall, these results provide increased confidence that some elements of pedestal structure (P-B stability, bootstrap current, p´ limits) are sufficiently well understood to allow for better predictions of pedestal height in ITER. The results of these and other studies strongly indicate that several physics processes control the pedestal structure and must be understood for a predictive capability of all profiles.

This work was supported in part by the US Department of Energy under DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FC02-99ER54512, DE-AC05-00OR22725 and DE-AC52-07NA27344.

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