Annual Report of the ITPA Pedestal and Edge Group, 2011

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The ITPA Pedestal and Edge group has met twice during the year under the chairmanship of Howard Wilson (University of York, UK) and strong guidance from the co-Chairs Naoyuki Oyama (JAEA, Japan) and Alberto Loarte (ITER Organisation). The first meeting was hosted by MIT (US) during 30 March-1 April, and the second at the York Plasma Institute at the University of York (UK) 5-7 October. Each meeting had around 40 participants from EU, US, China, Japan and S Korea. A particularly exciting development, which offers great promise for the further development of pedestal physics, was the results from the Asian tokamaks that have recently achieved H-mode: KSTAR, EAST and HL-2A. Combined with a vast range of results from those tokamaks which already have a well-established H-mode physics basis, as well as advances in theory and modelling, it has been a good year for pedestal physics with substantial progress on a number of important issues for ITER, and fusion in general. This report gives the headlines of the progress and provides a list of publications related to the research for the period June 2008-December 2011. It is not possible to do full justice to the work of the group in such a short note. For further details of the progress, and the individuals who are leading the work, the interested reader is guided towards the group's two summary reports for the year.

Pedestal structure

- The EPED model for pedestal height and width (based on peeling-ballooning and kinetic ballooning mode (KBM) stability constraints) continues to perform well when benchmarked against experiment (273 cases from 5 devices now)
- Rigorous gyrokinetic stability analyses for the pedestal region have provided additional support for the theoretical basis of the EPED model (eg the role of the KBM)
- Experiments between DIII-D, C-Mod and JET have further constrained the scaling of the pedestal width, which remains almost independent of ρ^*, with a dependence $\sim\beta_p^{1/2}$
- The I-mode has been developed further on C-Mod: a weakly coherent mode appears to be responsible for providing density control; a new result is that the amplitude of this mode peaks off the mid-plane.
- Although not a universal result, a number of tokamaks observe that following the pressure gradient rise immediately after an ELM, it can saturate well before the next ELM. There is evidence (eg MAST) that the pedestal width broadens during this phase, and this destabilises the finite-n peeling-ballooning modes, but this results does not appear to be universal.
- Experiments on NSTX have explored the effect of a steady increase of a Li layer. As the layer is increased the pedestal width broadens in both the density and temperature. ELMs are found to be suppressed when the density pedestal width exceeds a certain value; there does not seem to be a correlation with the temperature pedestal width. ELM suppression may also be associated with the movement of the peak gradient region of the pedestal further from the separatrix.

ELM Physics

- Nonlinear MHD codes continue to make advances towards a complete ELM cycle: features of the crash are now produced by several codes (eg JOREK, BOUT++, M3D, NIMROD) but modelling the full ELM cycle remains elusive. Using experimentally relevant Lundquist numbers is important (eg to recover collisionality scaling in JOREK).
- 2D ECE images from KSTAR reveal interesting features of the ELM cycle, including a stage of reduced growth between the initial linear and final explosive states.
- The physics of small ELMs has advanced: ECE images on AUG indicate the presence of fluctuations that limit the pedestal temperature gradient in Type II ELM regimes (cf Type I); the amplitude of the fluctuations peaks off mid-plane (poloidally).

ELM control

- It has been an exciting, if somewhat puzzling, year for ELM control by resonant magnetic perturbations, with new data from AUG and KSTAR.
- AUG have operated with two (above/below midplane) rows of four coils at high collisionality (cf DIII-D). A threshold density is required for ELM mitigation; there is no sign of density pump-out and no evidence for a resonance window in q_{95}. DIII-D experiments at low collisionality do see a density pump-out and q_{95} resonant windows for observing the effect, so there is ongoing work to understand these differences.
- KSTAR have employed an n=1 RMP and observed complete ELM suppression, with an associated density pump-out (although the density begins to recover during the ELM-suppression phase).
- DIII-D have demonstrated ELM control in low collisionality discharges for many confinement times using n=2 RMPs. Sensitivity to shape was also explored: ELM suppression evolves to ELM mitigation as the shape is modified towards double null.
- MAST has operated with an additional 6 coils (12 in total) in the lower ring this year, retaining 6 in the upper ring. ELM mitigation has been achieved with n=4 and n=6 perturbations. The only parameter identified so far that influences pump out is whether the plasma displacement, as predicted by the MARS-F code, is located near the X-point.
- Modelling of RMP field penetration in rotating plasmas shows that the field penetrates when the electron flow is zero. Theory also links terms in the density transport to the electromagnetic torque generated by RMPs.
- Observations of pellet-triggered ELMs (eg on DIII-D) indicate a single dominant filament is initially produced. This is in agreement with JOREK code predictions, but raises concern over the heat-load that such a filament could impart to vessel structures; future work will aim to quantify this experimentally.
- A low field side pellet injector had been installed on DIII-D to mimic ITER by injecting pellets in the vicinity of the X-point. Pellets triggered ELMs before reaching the top of the pedestal.
- Pellet pace-making experiments on JET are on-going with the new high frequency pellet injector now installed and commissioned successfully.

Pedestal transport and LH transition physics

- The contributions to the cross-ITPA-group working group on density transport have been discussed. Areas that the pedestal group will focus on include: edge particle transport; edge particle transport with ELM mitigation (initially focussing on those with no density sources), and fuelling efficiency of shallow pellets (cf ELM pacemaking pellets). Some developments on the challenging issue of density transport are beginning to be addressed through integrated modelling.
- Reflectometer measurements of density fluctuations in the NSTX pedestal indicate an increase in correlation length in the last 40% of the ELM cycle, with correlation lengths broadly consistent with KBMs.
- The working group on LH transition physics has taken on a renewed impetus, with a refocusing on priorities for ITER including, but not restricted to: H-factor as a function of P/P_{th}; susceptibility to back-transitions to L-mode (or transitions to reduced performance); influence of current ramps; isotope dependence. Progress to develop a database for local parameters characterising the transition continues to be made. The new H-mode tokamaks, HL-2A, EAST and KSTAR, are already starting to provide valuable new data that will help us to understand the LH transition

In conclusion, it has been another extremely successful year for the Pedestal and Edge ITPA group with substantial advances in many areas of relevance to ITER and basic tokamak plasma science. Several questions have been answered, and useful collaborative frameworks have been initiated to address remaining urgent issues.

Publications linked to the activities of the ITPA pedestal group; June 2008-December 2011

Publications in refereed journals:

[1] J-W. Ahn, J.M. Canik, R. Maingi, T.K. Gray, A.G. McLean, et. al. *Characteristics of divertor heat and particle deposition with intrinsic and applied 3-D fields in NSTX H-mode plasmas.* J. Nucl. Mater. **415** (2011) S918

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[8] J.M. Canik, et al. *Progress in the development of ELM pace-making with non-axisymmetric magnetic perturbations in NSTX.* Nucl. Fusion **50** (2010) 064016

[9] J.M. Canik, et al. *ELM destabilization by externally applied non-axisymmetric magnetic perturbations in NSTX.* Nucl. Fusion **50** (2010) 034012

[10] Cummings, J., Pankin, A., Podhorszki, N. G. Park, S. Ku, R. Barreto, S. Klasky, C.S. Chang, H. Strauss, L. Sugiyama, P. Snyder, D. Pearlstein, B. Ludascher, G. Bateman, A. Kritz, the CPES Team, *Plasma Edge Kinetic-MHD Modeling in Tokamaks Using Kepler Workflow for Code Coupling, Data Management and Visualization*. Commun. Comput. Phys. **4** (2008) 675-702

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Conference presentations:

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