A Special Case of Long-Pulse High Performance Operation in W7-X

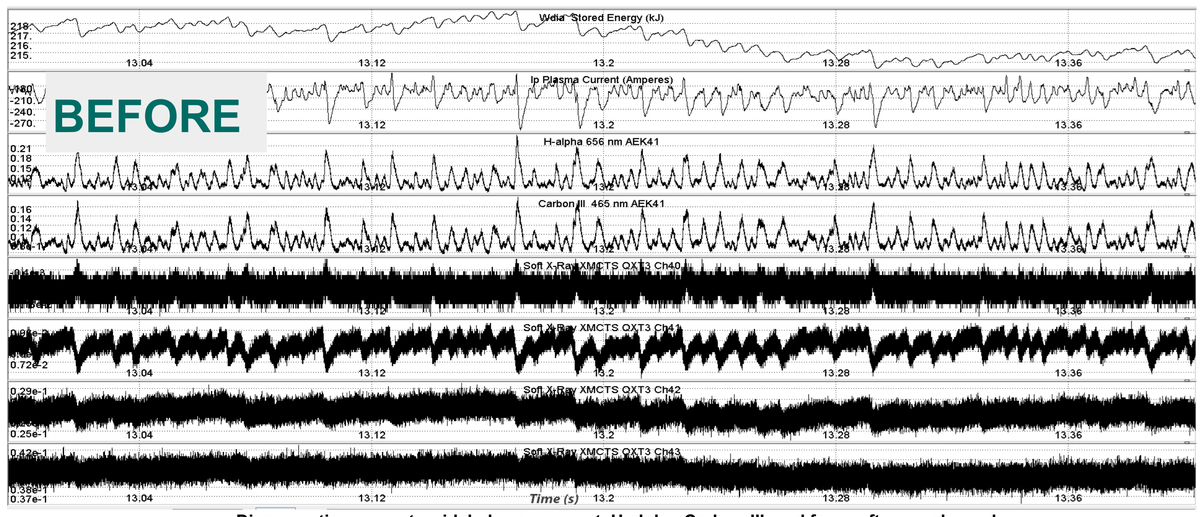
G. A. Wurden*[1], S. Bozhenkov[2] , G. Fuchert[2], D. Zhang[2], S. Jablonski[3], M. Kubkowska[3], A. Von Stechow[2], M. Beurskens[2], C. Brandt[2], K. Brunner[2], B. Buttenschoen[2], N. Chaudhary[2], M. Hirsch[2], P. Kornejew[2], A. Krämer-Flecken[4], Y. Gao[2], M. Krychowiak[2], N. Pablant[5], E. Pasch[2], K. Rahbarnia[2], H. Thomsen[2], T. Windisch[2], V. Winters[2], and the W7-X Team

[1]Los Alamos National Laboratory, [2]Max-Planck-Institut für Plasmaphysik, [3]IPPLM Warsaw, [4]Forschungszentrum Jülich, Germany, [5]Princeton Plasma Physics Laboratory

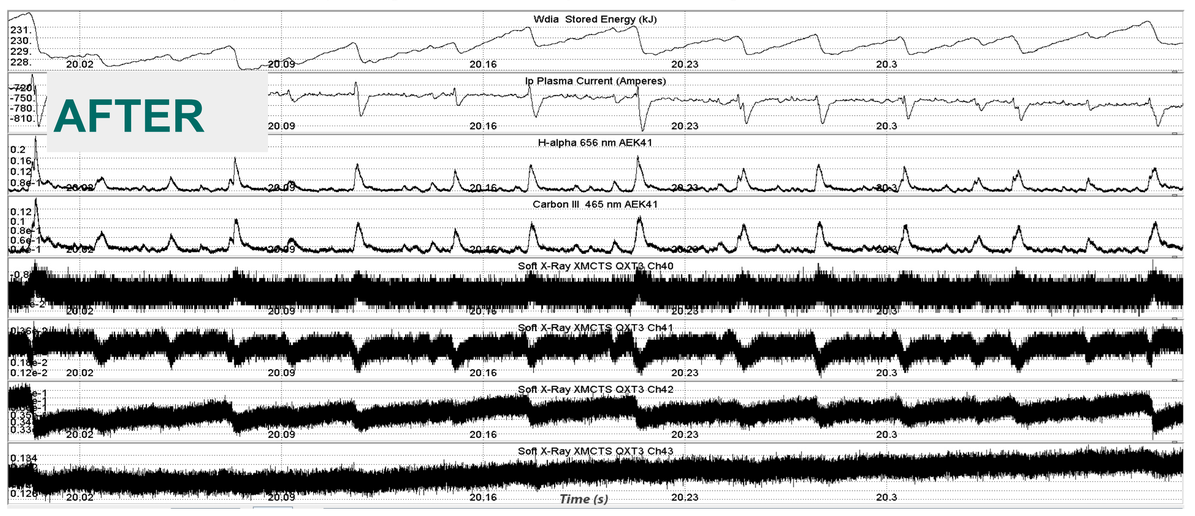
ABSTRACT

In a W7-X discharge (3rd shot of the morning, pulse 20180808.005) an accidental dropout of one of two ECRH heating gyrotrons at 15 seconds into a 55 second planned pulse, allowed a remarkable transition to occur (Figure 1). The plasma stored energy became higher (230 kJ) with only one gyrotron (540 kW) heating the plasma, than it was with two. The plasma density, initially rather flat with core density of 3x10^19 cm^3, peaked (by itself) to ~4.5x10^19 cm^3 during the same time. Turbulence was reduced, and regular island-localized mode (ILM) activity [1], not normally present in high-iota discharges turned on, while the energy confinement time doubled, from 200 msec to 400 msec. The ion temperature climbed to 1.8 keV, approaching the electron temperature, breaking the ion temperature clamping which is often seen in W7-X plasmas [2]. Zeff increased slightly from 1.6 to 1.9, and then held steady for the remainder of the pulse. Bolometery showed an increase in core radiation, which spectroscopy indicates is primarily due to Fe XXII. The edge soft x-rays dropped, but the core soft x-ray emission increased a factor of 5x. Total radiated power increased from 25% initially, to 40%. Line integrated light impurity emission (B, C, O) at the outer regions of the plasma remained constant, or even decreased after the transition. Heat loads on the divertor dropped a factor of 3.7x, consistent with the drop in heating power, and the increase in plasma radiation fraction. The resulting nTTau was within a factor of two of W7-X's best transient performance [3]. A key factor was that the divertor strike points for this high-iota plasma configuration were freshly boronized, and no external gas puffing was enabled. The periodic ILM'ing activity has most of the features of ELM's, which along with the confinement improvement and H-alpha response, suggests the possibility that an H-mode transition occurred.

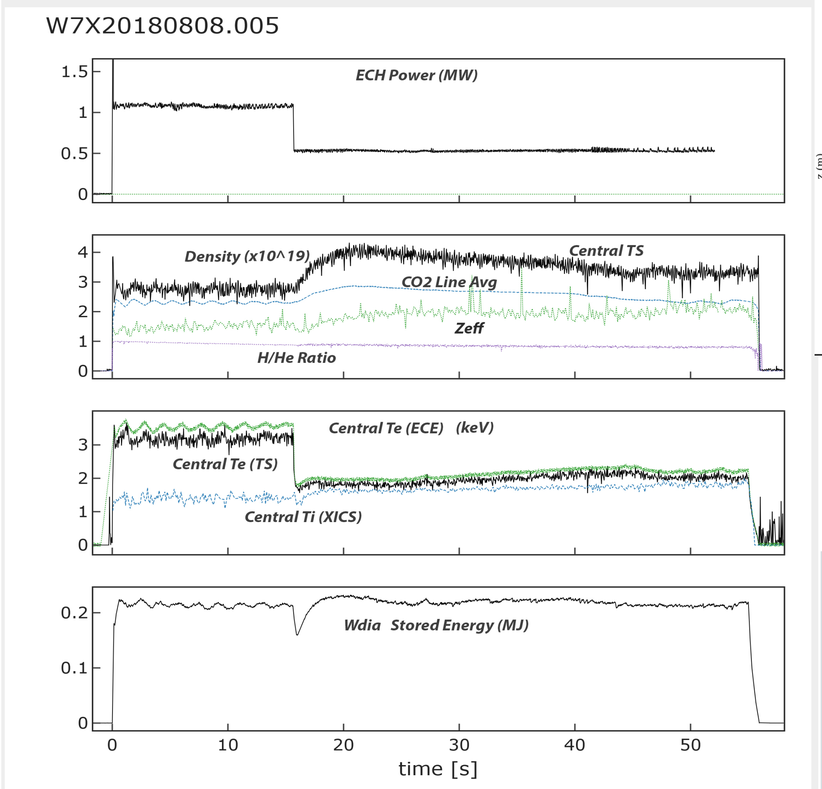
FLUCTUATIONS CHANGE AS DENSITY PROFILE PEAKS



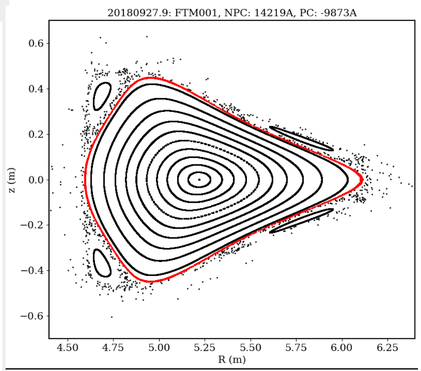
Diamagnetic energy, toroidal plasma current, H-alpha, Carbon-III, and four soft x-ray channels (Camera 3C) viewing from the lower left quadrant of the triangular cross section of W7X



ONE OF TWO ECH GYROTRONS DROPPED OUT AT ~15 SECONDS

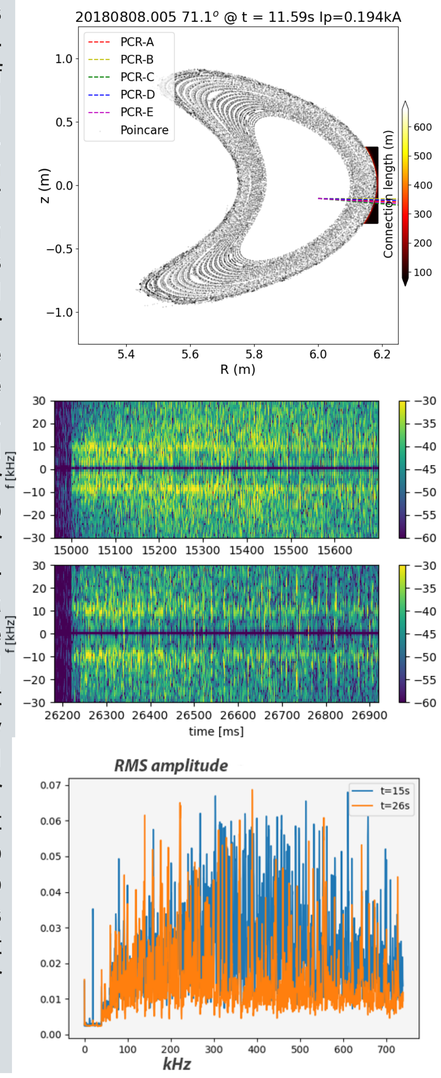


Poincare Plot for High Iota FTM configuration in W7-X, for the triangle cross section, showing the 5/4 island chain, which is normally positioned outside the last closed flux surface.

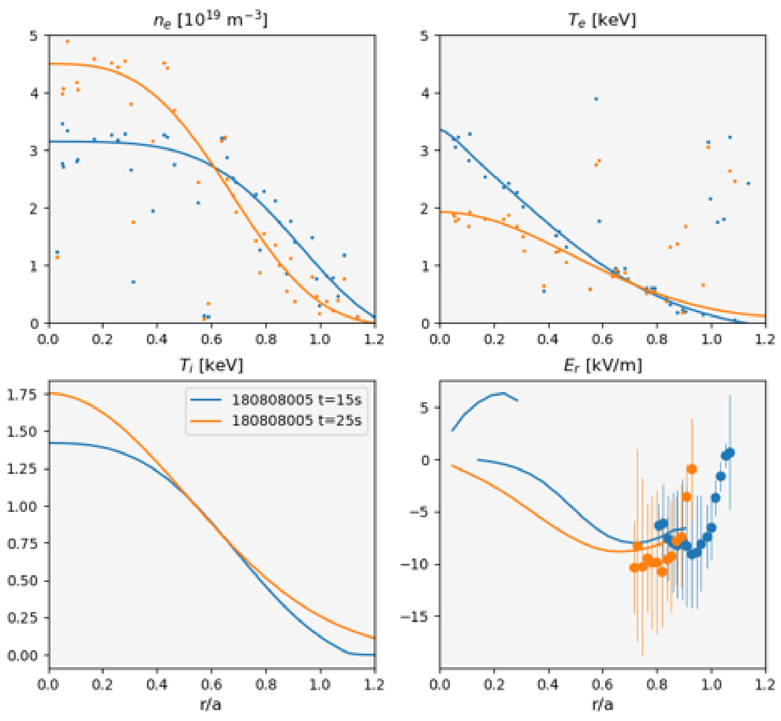


POLOIDAL CORRELATION REFLECTOMETER

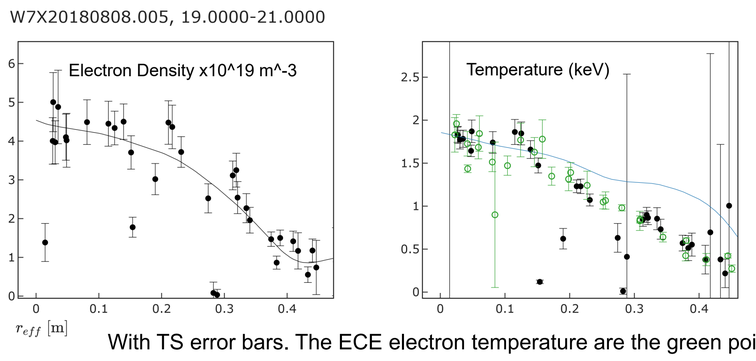
The PCR system is located in the bean-shaped cross section of W7X. There the outboard 5/4 island is very narrow. The vperp-profile for scan 3 (11.2s-11.6s) and scan 7 (26.2s-26.9s) together with the LoS of the PCR is shown. These are local values. The error bars for scan 7 are quite large when averaged for one frequency step of 20ms. Furthermore the shearing rate is much larger for scan 7. A closer look into the temporal behavior shows the burst in the Ip-signal goes along with a sudden change in the rotation and recovers and is followed by the next burst. This is very pronounced for local densities ne<1e19 m^{-3}. For higher densities it is not that much pronounced. So a clear edge effect. Also the 10 kHz mode is weaker in scan 7. It localized in the shear region.



PROFILES

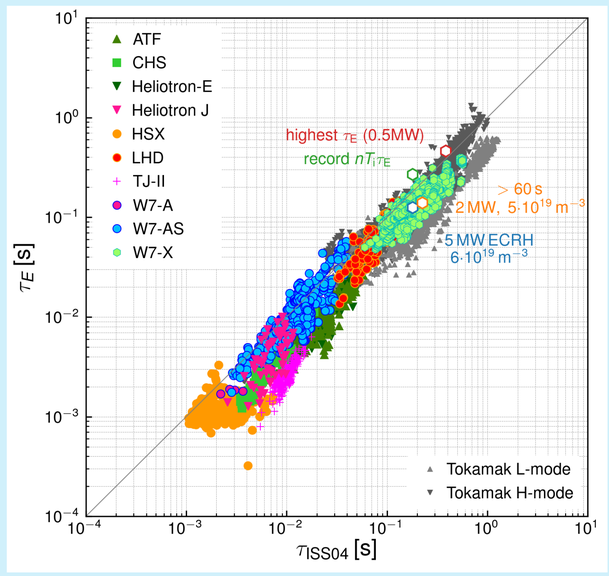


Thomson, X-ray crystal spectrometer, and PCR (E_r) profiles



With TS error bars. The ECE electron temperature are the green points

BEST CONFINEMENT TIME IN W7-X



CONCLUSION

By accident, we found that the plasma can peak its density profile, by itself, during a low power ECH discharge, when the walls have low recycling (fresh boronization) and no additional gas puffing. Core radiation did increase (Fe XXII accumulation) while the transition occurred over a several second period, but did not change substantially for the remaining 40 seconds of the pulse. Z_{eff} increased from 1.6 to 1.9. Light impurity edge radiation (B, C, O) actually remained constant, even though the core plasma density was 50% higher. The profile peaking was marked by a broadband reduction in high frequency edge fluctuations (seen by Poloidal Correlation reflectometer), while the low frequency quasi-continuous modes (normally seen in a high iota configuration plasma) switched over to regular, distinct, periodic island localized modes (ILM's or ELM crashes). Both ECE and X-ray diagnostics show ILM sawtooth crashes localized in the region of the 5/4 island near the plasma edge. In summary, we seem to have all of the conditions to call this a low power H-mode.

ENERGY LOSSES

During the high confinement phase, 40% of the input energy is lost to the walls by radiation, and 15% is lost via the ILM crashes near the plasma edge. Therefore 45% is available for diffusive, turbulent, or neoclassical losses, outside of the island/pedestal.

[1] G. A. Wurden et al. "Structure of island localized modes in Wendelstein 7-X", P2.1068, 46th EPS Conference on Plasma Physics (2019)
[2] M.N.A. Beurskens *et al,* 2022 *Nucl. Fusion* **62** 016015
[3] J Baldzuhn *et al,* 2020 *Plasma Phys. Control. Fusion* **62** 055012
[4] G. A. Wurden, S. Ballinger, Bozhenkov, et al, "Quasi-continuous low frequency edge fluctuations in the W7-X stellarator", P5.1077, 45th EPS Conf. on Plasma Physics, Prague, 2018.

Poster No. 1b.118
48th EPS Conference

*Corresponding author:
glen.wurden@ipp.mpg.de

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.