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

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Introduction: 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 island localized mode |(ILM) activity has most of the features of edge localized modes (ELM's), which along with the confinement improvement and H-alpha response, suggests the possibility that an H-mode transition occurred.

Experimental Traces:

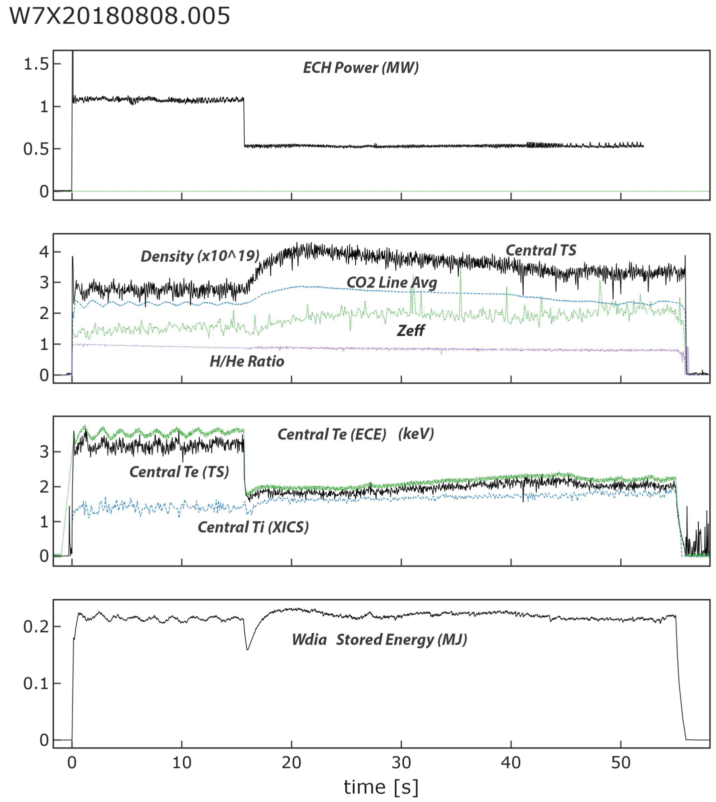


Figure 1: A high iota discharge, after fresh boronization. Time traces (in seconds) showing the gyrotron dropout at 15 seconds, subsequent peaking of the density profile over a 2 second period, and recovery of the stored energy to a higher value (230 kJ) with one gyrotron operating, than with two. With the reduction in ECH power to the electrons, the electron temperature falls, but then the ion temperature quickly approaches the electron temperature (1.8 keV). Zeff increases from ~ 1.6 to ~1.9 as core heavy impurities accumulate. Helium (released from the boronization coating) increases slowly.

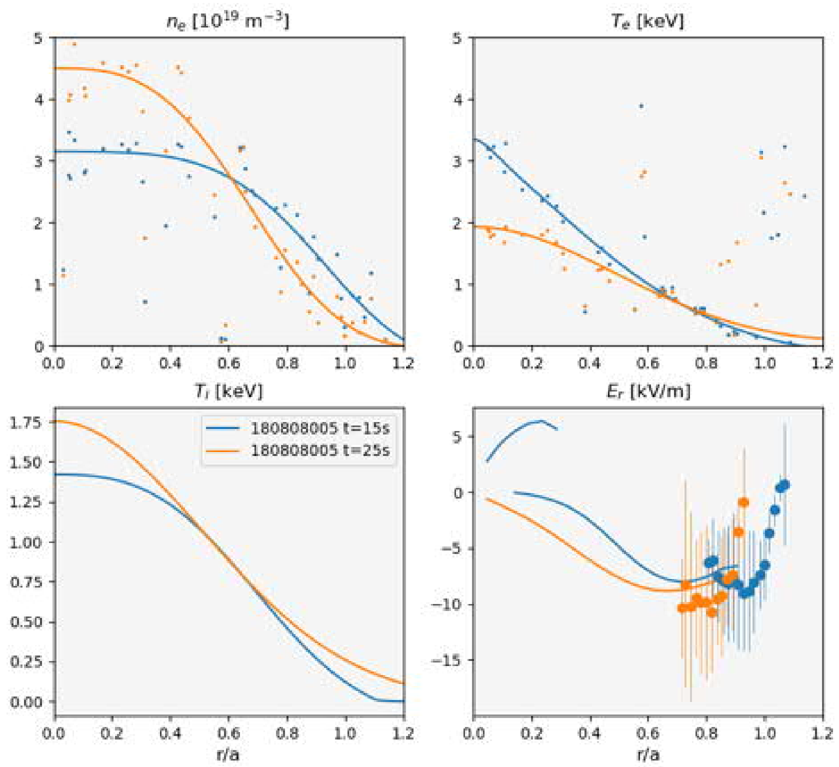
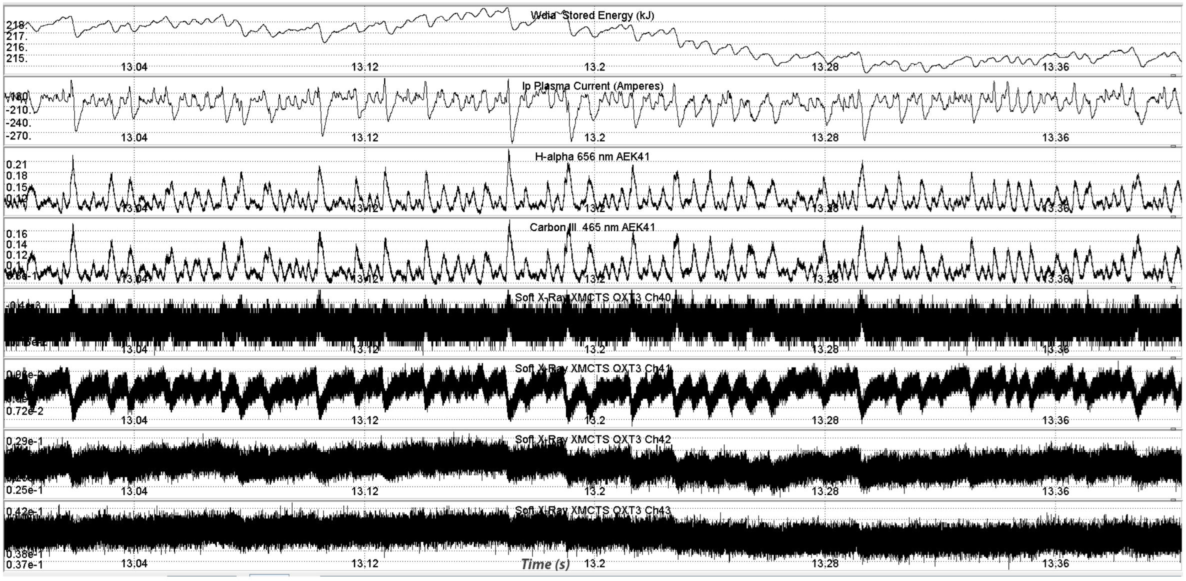
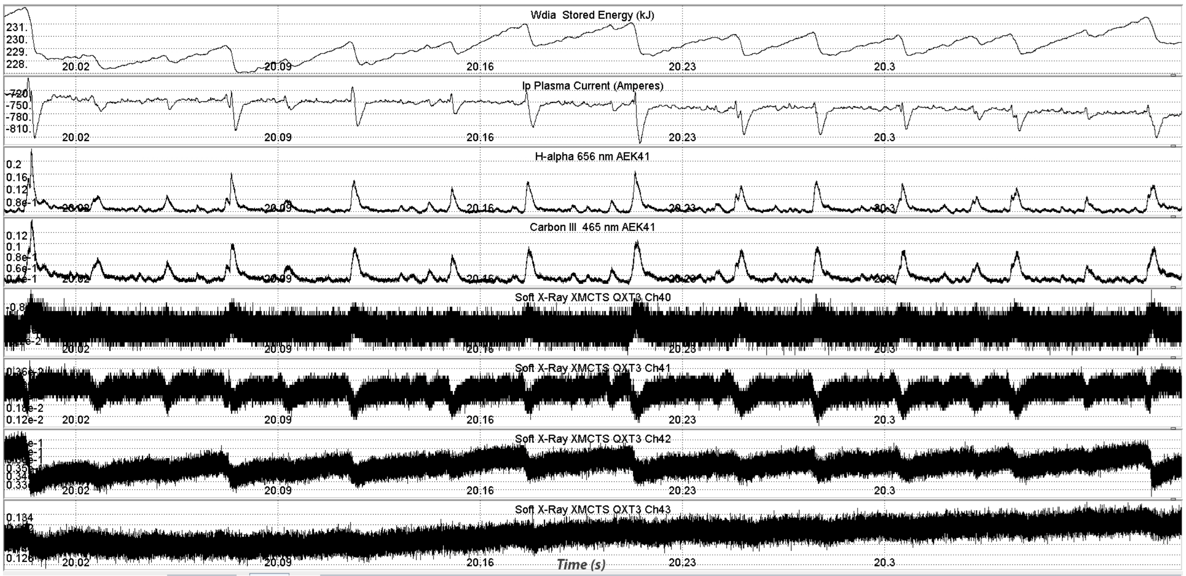


Figure 2: Profile plots versus radius, before (blue) and after (orange) the transition. Data from Thomson scattering, x-ray crystal spectrometer, and Doppler reflectometry. The radial electric field is more negative and shifts inwards after 15 seconds.

Figure 3. Two 400 millisecond time slices (a) before, and (b) after the transition to improved confinement. The nature of the high iota edge fluctuations changes from quasi-continuous oscillatory ones, to regular periodic ILM crashes (ELM's). Only one 18-chord XMCTS x-ray array was operating on this discharge, and four of its chords are shown.



(a). Time slice of fluctuations before the gyrotron dropout at 15 seconds, showing typical high iota quasi-continuous oscillatory behavior [4], although there are unusual occasional small "sawteeth" (perhaps due to very clean wall conditions and low neutral pressure).



(b). Same time window duration as (a), but after the density profile (and stored energy) peak up following the gyrotron dropout. Regular, well-separated, periodic ILM's (ELM's) are seen. These continue until the end of the discharge. XMCTS Camera 3C Ch40 x-ray chord shows inversion, while a more central soft x-ray chord (Ch43) is mostly unaffected. ECE profiles confirm a temperature pedestal which is cyclically crashing in the edge across the 5/4 island location.

Discussion: Although at low power (0.5 MW), this discharge exhibited a transition to high confinement (τ_e > 400 msec), sustained for 40 seconds, concurrent with development of a peaked density profile, along with the presence of periodic island localized modes (ILM's, which are ELM's located at the edge island (5/4 in this case) position). Radial electric fields (by Doppler reflectometry) also became more negative, and there was some high-Z impurity accumulation, although stable for at least 40 seconds. The discharge lies above the ISS04 scaling line (see Figure 4), and is the best confinement time yet seen in W7-X. During the next campaign OP2.1, we will reproduce it with more diagnostics online, study degradation due to additional heating (neutral beam injection (NBI) versus ECH), while also seeing if it can be further enhanced with deep pellet injection.

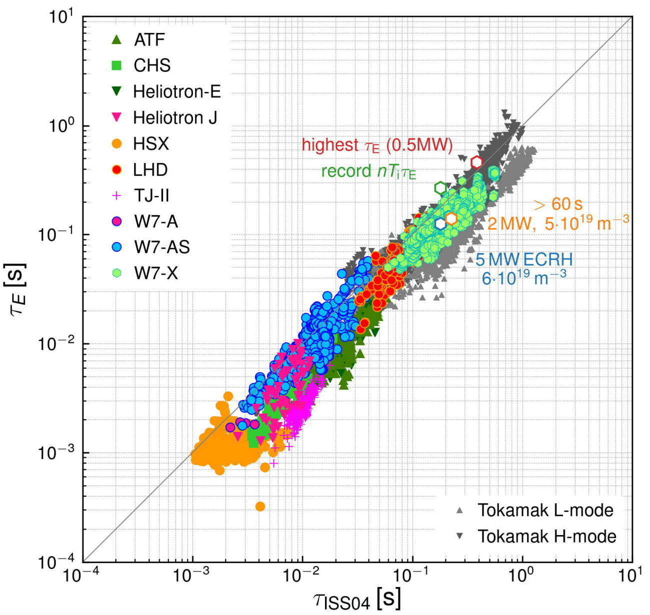


Figure 4. Plot of energy confinement time vs ISS04 scaling, with shot 180808005 marked by the red open circle. At over 400 milliseconds, it is the best energy confinement time achieved in W7-X, while also sustained for 40 seconds.

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