Discovery of Stationary Operation of Quiescent H-mode Plasmas with Net-Zero NBI Torque and High Energy Confinement on DIII-D*

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Recent experiments on the DIII-D tokamak have discovered a technique to control edge turbulence to achieve stationary, high confinement operation without Edge Localized Mode (ELM) instabilities and with no external torque input. Eliminating the ELM-induced heat bursts and controlling plasma stability at low rotation represent two of the great challenges for fusion energy. Stationary operation with improved pedestal conditions is highly significant for future burning plasma devices, since operation without ELMs at low rotation and good confinement is key for tokamak fusion energy production. By exploiting edge turbulence in a novel manner, we achieved outstanding tokamak performance, well above the H98 international tokamak energy confinement scaling (H98 up to 1.6), thus meeting an additional confinement challenge that is usually difficult at low torque. The new regime is triggered in double null plasmas by ramping the injected torque to zero and then maintaining it there. This lowers ExB rotation shear in the plasma edge, allowing low-k, broadband, electromagnetic turbulence to increase. An example of the oscillating magnetic field associated with this turbulence is shown in Fig. 1.

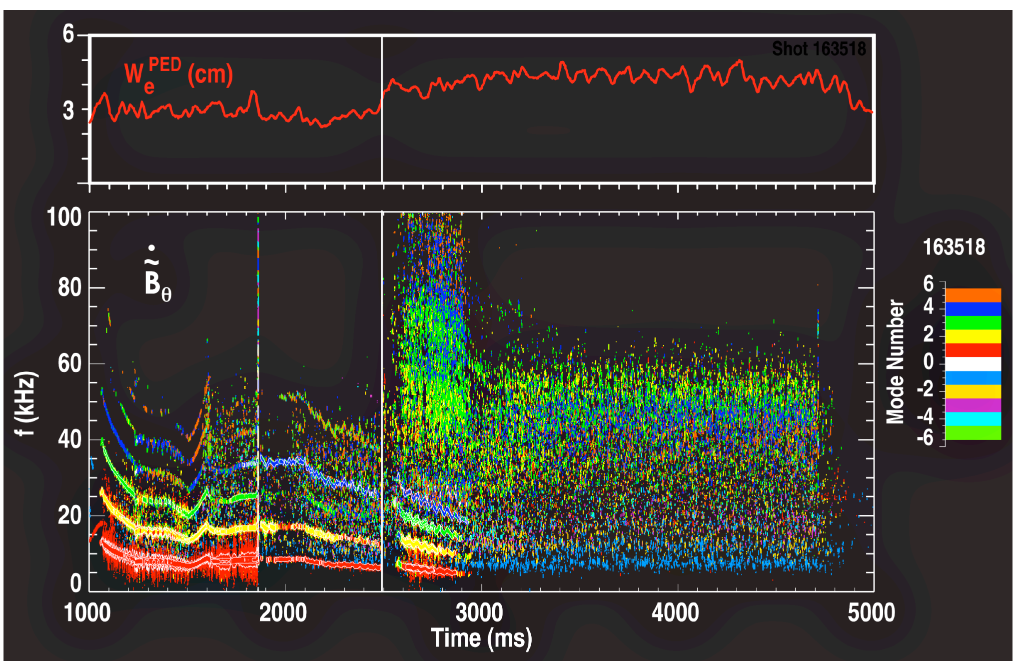

Fig. 1 This figure illustrates the change in the edge turbulence when the edge pedestal width increases. The lower box shows color-coded spectrogram of the magnetic fluctuations from the plasma as a function of time in the discharge while the upper box shows the width of the edge pedestal region. When the pedestal width increases, the magnetic fluctuations switch from several coherent modes to a more incoherent spectrum with greater frequency spread.

In the H-mode edge plasma, a narrow transport barrier usually grows until MHD instability (a peeling ballooning mode) leads to the ELM heat burst. However, the increased turbulence reduces the pressure gradient, allowing the development of a broader and higher transport barrier. This increase in height is consistent with MHD stability calculations. As can be seen in Fig. 2, a 60% increase in pedestal pressure and 40% increase in energy confinement result. Strong double-null plasma shaping raises the threshold for the ELM instability, allowing the plasma to reach a transport-limited state near but below the explosive ELM stability boundary. The resulting plasmas have burning-plasma-relevant β_N=1.6-2.3 and $\nu^*{}_e^{PED}$ = 0.16-1.0. To date, stationary conditions have been produced for 2 s or 12 energy confinement times, limited only by external hardware constraints.

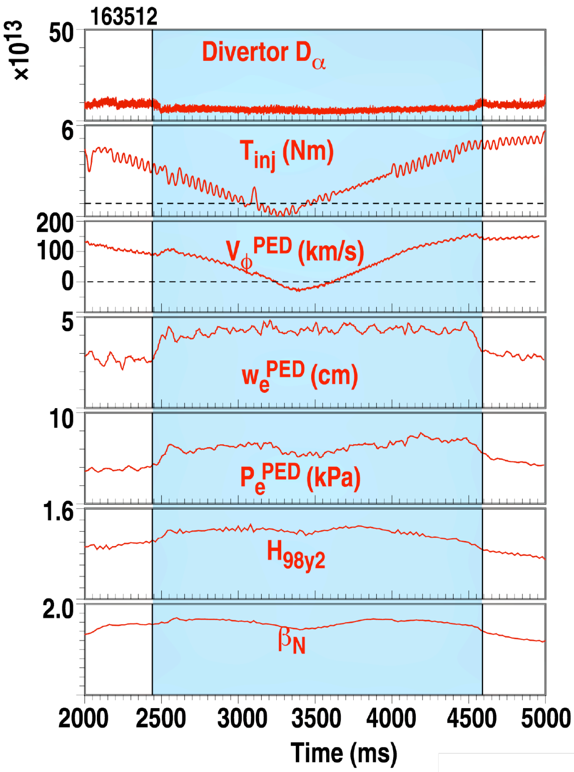

Fig. 2 The wide pedestal state has significant improvement in edge pressure and in global energy confinement. The figure shows time histories of the H98 confinement factor, the input torque from the neutral beams, the width of the edge pedestal region and the pressure at the top of the edge pedestal. When the input torque is decreased sufficiently, the plasma rapidly switches to the wide pedestal state with a corresponding increase in pedestal pressure and H98 confinement factor.

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