Contribution ID: **1497** Type: **Regular Poster**

[REGULAR POSTER TWIN] Achievements of Actively Controlled Divertor Detachment Compatible with Sustained High Confinement Core in DIII-D and EAST

Tuesday, May 11, 2021 6:25 PM (20 minutes)

Joint research on the tokamaks DIII-D and EAST demonstrates a successful integration control of divertor detachment with excellent core plasma performance, a milestone towards solving the critical Plasma-wall-interaction (PWI) issues for ITER and future reactors. DIII-D has achieved actively controlled fully detached divertor with low plasma temperature ($T_{e,div} \leq 5$ eV across the entire divertor target), low particle flux (DoD > 3) and heat flux reduction > 85%, simultaneous with very high core performance (β_N ~ 3, β_P > 2 and H_{98} ~ 1.5) in the high β_p scenario developed for ITER steady state operation. EAST has achieved actively controlled detachment with $T_{e,div}$ ~ 5 eV and $H_{98} \geq 1.1$ in various H-modes, i.e., normal ELMy H-mode, grassy ELMy H-mode and high β_P H-mode scenarios. The divertor detachment with $T_{e,div} \leq 5$ eV is highly desirable for suppression of the erosion in reactor-grade devices.

In DIII-D, full detachment was achieved, for the first time, with very high H_{98} ~ 1.5 by utilizing feedback controlled impurity seeding in the high β_P scenario [1]. The self-organized with co-existence of internal transport barrier (ITB) and edge transport barrier (ETB, or pedestal) benefits access to detachment without degradation of core performance. The scenario makes detachment easier by optimizing impurity seeding at relatively higher q_{95} and lower separatrix density, with very high core confinement enabled by a large-radius ITB. Fig. 1 shows a fully detached plasma with excellent core confinement in the high β_P scenario on DIII-D with nitrogen seeding. In the full detachment phase, the steady-state peak heat flux measured by infra-red (IR) camera is reduced by > 85%, and the particle flux measured by divertor Langmuir probes is reduced by > 80%. Nitrogen seeding is more efficient for full detachment than neon-seeding experiments and leads to a small reduction of ETB. The demonstration of compatibility with divertor detachment adds to the well-known benefits of high bootstrap current fraction and low disruption risks, positioning the high β_P scenario as a prime candidate for steady-state fusion reactor operation.

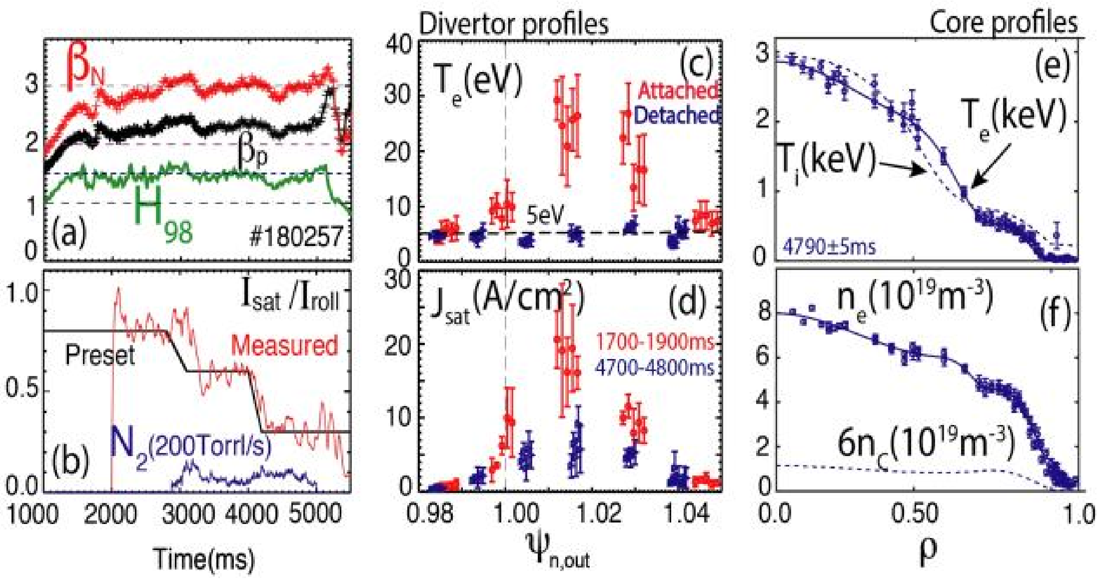

Figure 1: Left: Time histories of (a) normalized beta, poloidal beta, energy confinement factor H_{98}, (b) controlled degree of detachment, feedback impurity puffing; Middle: radial profiles of (c) divertor electron temperature, (d) particle flux for attached (red) and detached (blue); Right: core radial profiles of (e) electron temperature and ion temperature, (f) electron density and carbon density for a fully detached case on DIII-D.

In EAST, actively feedback controlled H-mode detachment with simultaneous $T_{e,div}$ ~ 5 eV and H_{98} > 1.1 was achieved using either divertor neon or argon seeding in USN configuration, i.e. divertor detachment operating on an ITER-like tungsten divertor, was maintained with energy confinement quality higher than the ITER baseline scenario, as shown in Fig. 2. The feedback detachment waveforms follow closely the preset targets. Experiments using injection of different impurity species for radiative divertor and detachment were performed to understand the extrapolation to future burning plasmas on ITER and CFETR. Neon exhibits good core-divertor integration, while argon is more efficient for detachment with a slight loss of confinement. In addition, different detachment feedback controllers including degree of detachment (DoD) via Langmuir probe measured divertor particle flux [2], divertor $T_{e,div}$ [3], plasma radiative power P_{rad} [4], $T_{e,div}$ + P_{rad} have all been developed successfully in EAST.

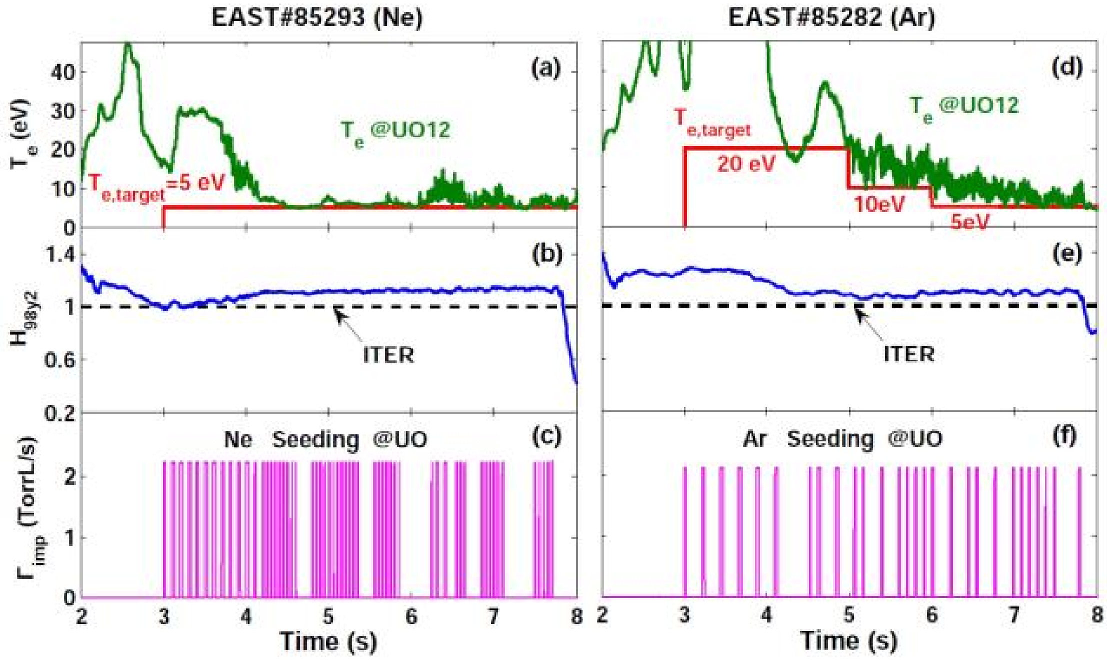

Figure 2: Time traces of the stationary divertor $T_{e,div}$ in the strike point region together with feedback control target (a, d), H_{98} compared with ITER baseline (b, e), and feedback divertor impurity seeding quantity (c, f) during two actively controlled detached H-mode plasmas achieved with neon (left) and argon (right) on EAST, respectively.

The success of actively controlled detachment is achieved with different divertors and benefits from the divertor closure and pumping. A closed divertor is beneficial for neutral trapping and thus detachment access $[5-6]$, as well as the drift effect in the SOL and divertor volume. Furthermore, the sustained detachment compatible with core high performance is independent of plasma heating schemes and divertor materials, i.e., EAST with ITER-like tungsten wall + RF heating and DIII-D with carbon wall + NBI heating, respectively.

The compatibility of efficient divertor detachment with a high-performance core is vital to the realization of magnetically controlled fusion energy. The significant progress in DIII-D and EAST show that the potential for a high-performance core plasma suitable for long pulse operation of fusion reactors can be achieved with controlled PWI. The present joint DIII-D/EAST methodology will be used for minute-time-scale long pulse operation on EAST in near future and thus offers a useful solution for ITER, CFETR as well as future fusion energy power plants.

This work was supported by National Key R&D Program of China under 2017YFE0301300 and the U.S. DOE under DE-FC02-04ER54698, DE-AC04-94AL85000, DE-NA0003525, DE-AC52-07NA27344.

[1] L. Wang, H. Q. Wang*, A. M. Garofalo et al, "First Observation of Fully Detached Divertor Compatible with Improved Core Confinement in Tokamak", to be submitted to PRL
[2] L. Wang* et al., Nucl. Fusion 59, 086036 (2019)
[3] D. Eldon, ⋯, L. Wang et al., this conference (Poster submission)
[4] K. Wu, ⋯, L. Wang* et al., Nucl. Fusion 58, 056019 (2018)
[5] J. B. Liu, L. Wang* et al., Nucl. Fusion 59, 126046 (2019)
[6] X. J. Liu, L. Wang* et al., Phys. Plasmas 16, 102510 (2019)

Country or International Organization

China

Affiliation

Institute of Plasma Physics, Chinese Academy of Sciences

Author: WANG, Liang (Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP))

Co-authors: Dr WANG, Huiqian (General Atomics, San Diego, CA 92186, USA); GAROFALO, A. M. (General Atomics); GONG, Xianzu (Insititute of Plasma Physics, Chinese Academy Sciences); GUO, Houyang (General Atomics); ELDON, David (General Atomics); Ms YUAN, Qiping (Institute of Plasma Physics, Chinese Academy of Sciences); Mr LI, Kedong (Institute of Plasma Physics, Chinese Academy of Sciences); Mr WU, Kai (Institute of Plasma Physics, Chinese Academy of Sciences); XU, Guosheng (Institute of Plasma Physics, Chinese Academy of Sciences); Dr XU, Jichan (Institute of Plasma Physics, Chinese Academy of Sciences); Dr LIU, Jianbin (Institute of Plasma Physics, Chinese Academy of Sciences); Mr MENG, Lingyi (Institute of Plasma Physics, Chinese Academy of Sciences); Dr ZHANG, Bin (Institute of Plasma Physics, Chinese Academy of Sciences); Dr DUAN, Yanmin (Institute of Plasma Physics, Chinese Academy of Sciences); Dr DING, Fang (Institute of Plasma Physics, Chinese Academy of Sciences); DING, Siye (Institute of Plasma Physics, Chinese Academy of Sciences); QIAN, Jinping (Institute of plasma physics, Chinese academy of sciences); HUANG, Juan (CnIPPCAS); BARR, Jayson (General Atomics); WEISBERG, David (General Atomics); HYATT, Alan (General Atomics); LEONARD, Anthony W. (General Atomics); FENSTERMACHER, Max (LLNL @ DIII-D); LASNIER, Charles (Laurence Livermore National Laboratory); Dr WATKINS, Jonathan (Sandia National Laboratory); Dr OSBORNE, Thomas (General Atomics); Dr THOMAS, Dan M. (General Atomics, San Diego, CA 92186, USA); HUMPHREYS, David (General Atomics); BUTTERY, Richard J. (General Atomics); LUO, GUANG-NAN (Institute Of Plasma Physics, Chinese Academy Of Sciences); Prof. XIAO, Bingjia (Institute of Plasma Physics, Chinese Academy of Sciences); LI, Jiangang (Institute of Plasma Physics, Chinese Academy of Sciences); WAN, Baonian (Institute of Plasma Physics, Chinese Academy of Sciences)

Presenter: WANG, Liang (Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP))

Session Classification: P2 Posters 2

Track Classification: Magnetic Fusion Experiments