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ELM suppression sustained by *n* = 1 radiation-belt oscillations near the X-point by divertor impurity seeding in EAST

G.S. Xu[1*], Y. Ye[1], Y.Q. Tao[1], R. Chen[1], L. Wang[1], H.Y. Guo[2], Z. Sun[3] , et al.

[1] Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China

[2] General Atomics, PO Box 85608, San Diego, CA 92186-5608, USA

[3] Princeton Plasma Physics Laboratory, 100 Stellarator Road, Princeton, NJ 08540, USA

gsxu@ipp.ac.cn

ABSTRACT

- A sustained Edge-Localized-Mode (ELM)-stable/suppressed H-mode scenario compatible with radiation divertor has been discovered in EAST Tokamak using different seeding impurity species over a wide range of conditions;
- An n=1 low-frequency mode are excited along with its harmonics near the X-point, which appears to be the key to maintain the ELM-suppressed state;
- A new model based on impurity-radiation-condensation driven drift instability has been developed to explain the excitation mechanism of this *n*=1 mode;
- The theory predicts that this mode is very likely achievable in future large devices with neon, argon or krypton seeding, which thus offers a highly promising new solution for ELM suppression and divertor detachment compatible operation in future.

BACKGROUND

- Erosion of the first wall of a fusion device due to transient heat pulses from the ELMs is one of the remaining critical issues for tokamak fusion reactors with metal wall;
- In addition to transient heat pulses, long-term steady-state heat fluxes also need to be controlled;
- It is desired to find a physical mechanism to actively excite a mode at plasma edge which can sustain the ELM suppression state, and being compatible with divertor detachment.

EXPERIMENTAL RESULTS

1: Detached ELM-suppressed plasma with CD_4 seeding

- Along with ELM suppression, partial detachment with target electron temperature T_{et}~10 eV have been achieved;
- The pedestal electrostatic coherent mode, ECM, is significant reduced;
- A low-frequency mode (n = 1) near the X-point is excited, which is the key to the steady-state maintenance of this scenario.

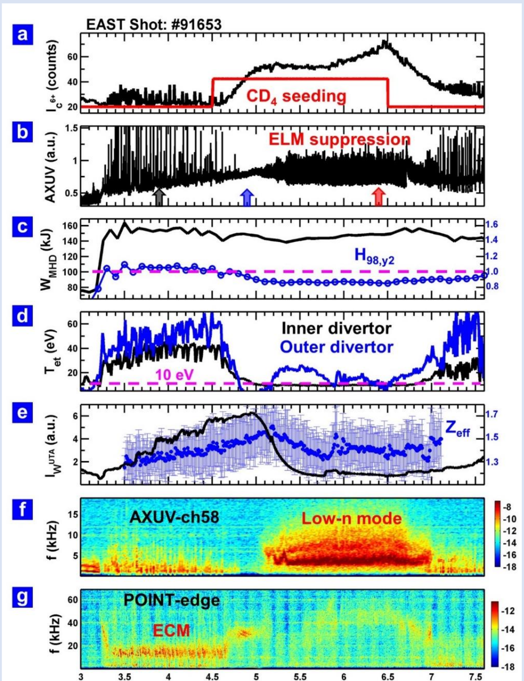

Figure 1

2: Mode location and evidence for particle transport

- The mode locates near the X-point biased towards the high field side as suggested by Absolute eXtreme Ultra-Violet array and visible camera;
- The tungsten line emission intensity and Z_{eff} are significant reduced and maintained at a low level when the mode appears;
- Statistical analysis of 17 adjacent shots shows that there is a clear proportional correlation between the mode amplitude and divertor D_a and target plate probe measurements.

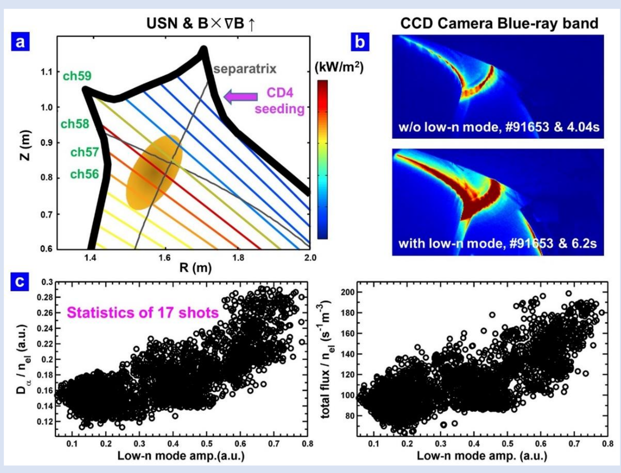

Figure 2

3: Mode excitation is insensitive to specific impurities

- Robust ELM suppression has been achieved with the presence of this mode in a very wide parameter space;
- (a): Boron (very easy), (b): Helium plasma with helium concentration >20%, (c-d) Argon (medium hard) and neon (very hard, in very limited high-power plasma). For CD_4 (easy) with (e) high I_p, (f) low I_p, (g) unfavorable B_t and (h) high heating power with low $v^*_{e,ped}$~1.

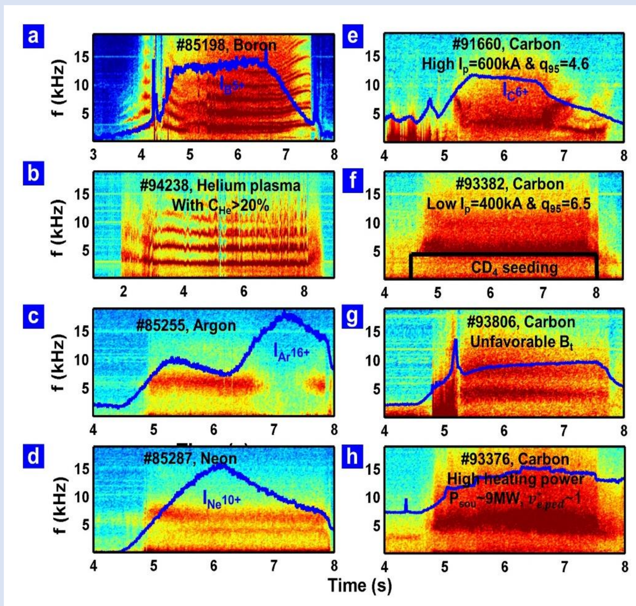

Figure 3

MODELING ANALYSIS

4: Mode excitation mechanism

- A theory for the mode has been proposed based on the impurity radiative condensation instability coupled to drift wave in the tokamak toroidal geometry;
- The mode excitation is due to the negative-slope T_e dependence in the impurity radiation loss function;
- **Growth rate, frequency and transport**

$$\gamma = -\left(1-\frac{1}{\hat{\omega}_r}\right)\frac{2\bar{n}_I}{3}\frac{dL_Z}{dT_e} - \frac{1.71}{\hat{\omega}_r}\frac{2\bar{n}_I}{3}\frac{L_Z}{\bar{T}}$$

$$\omega_r = \left(1.71\frac{L_n}{L_{Te}}+1\right)\omega_{*e}$$

$$\langle\Gamma(t)\rangle = k_\perp \frac{nT}{eB}\hat{\gamma}\hat{n}^2\langle\cos^2(\omega t)\rangle = \frac{1}{2}k_\perp\frac{nT}{eB}\hat{\gamma}\hat{n}^2$$

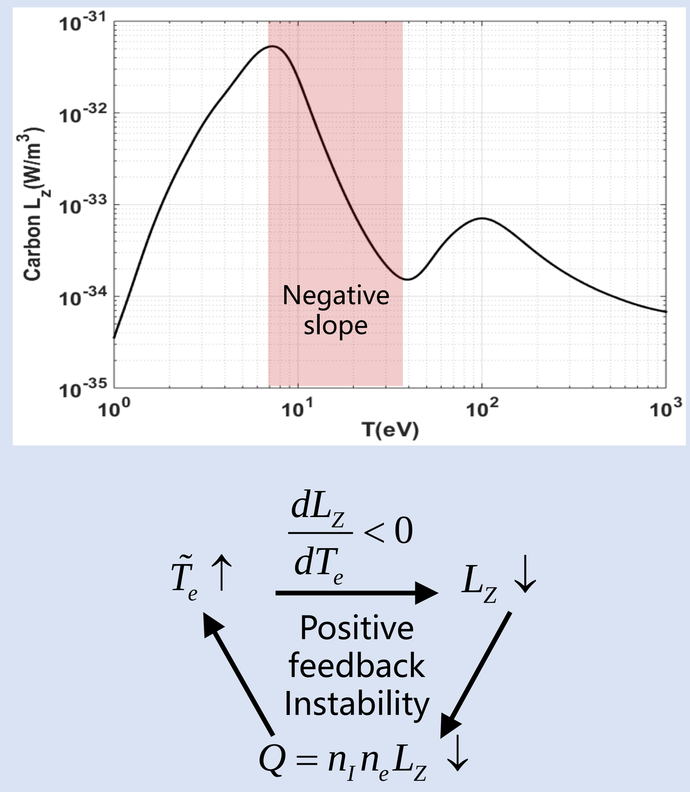

Figure 4

5: Model and experimental comparison

- The mode initially appears near the divertor target plate, then moves to the vicinity of the X point and stay there;
- The mode frequency is consistent with the model and decreases with decreasing T_e;
- Quasilinear analysis indicates that sufficient particle fluxes (~10^{20} $m^{-2}s^{-1}$) can be driven by the mode, comparable to that driven by strong transport mode ECM in EAST;
- Model and experimental results are in good agreement.

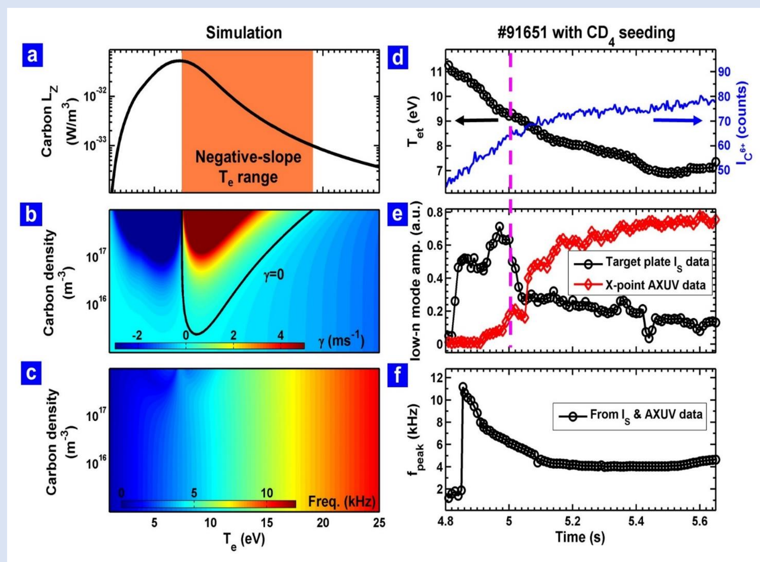

Figure 5

6: Model prediction

- The negative-slope T_e range is different for different impurities, thus the difficulty of mode excitation is different;
- The model predicts that this mode can be excited in ITER parameter range with neon, argon, krypton or other high T_e range impurities.

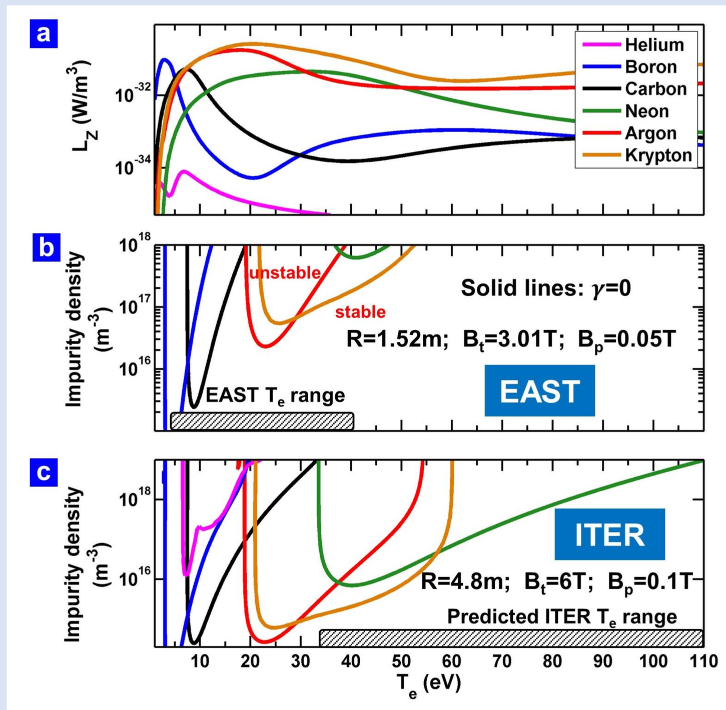

Figure 6

CONCLUSION

- An n = 1 mode, along with its harmonics, can be excited near the X-point with a variety of impurity species over a very wide range of plasma parameters and conditions has been observed in EAST, for the first time;
- This mode appears to be the key to drive particle transport and high-Z impurity exhaust, maintaining the ELM suppressed state;
- A new model coupling the radiation condensation instability and the *ExB* drifts well predicts the experimental observations;
- The model predicts that this mode can be excited in future large devices, such as ITER, compatible with radiative divertor, which thus exhibits an attractive prospect for applications in future fusion reactors.