Plasma radiation behavior approaching high-radiation scenarios in W7-X

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ABSTRACT

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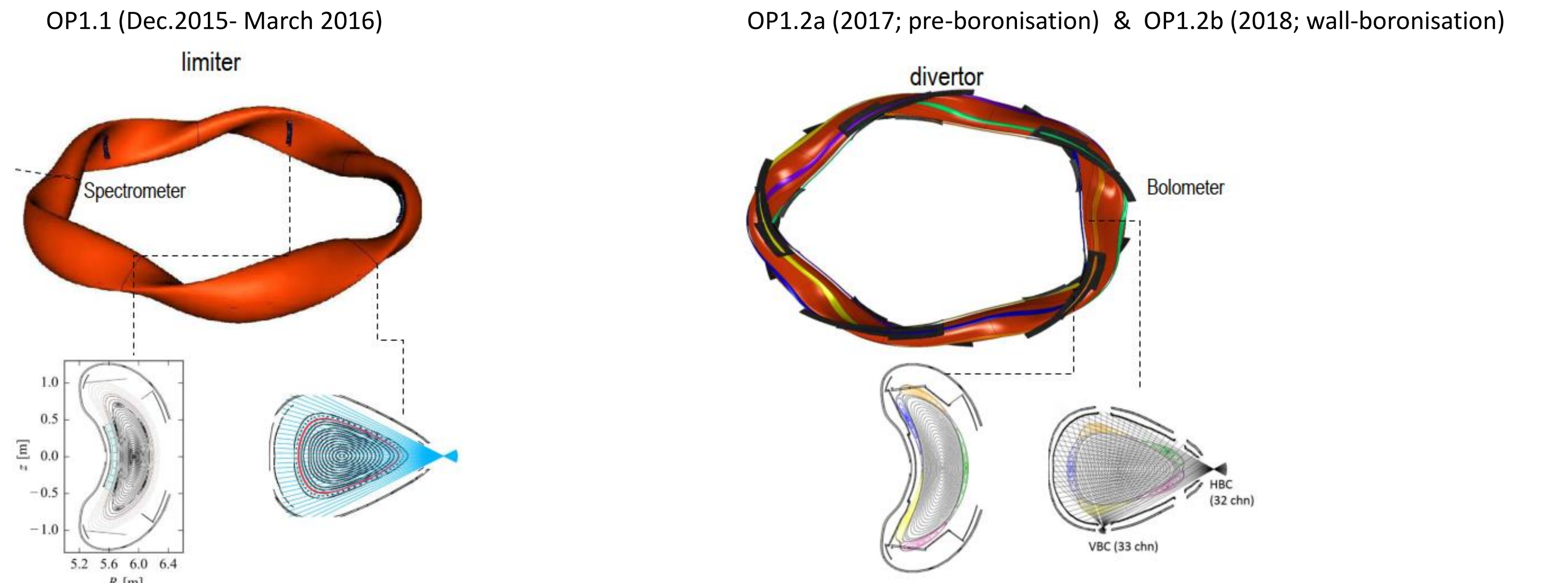
- The present work first summarizes the radiation loss fraction f_{rad} achievable in the quasi-stationary state of the hydrogen plasma in the W7-X stellarator in both limiter and diverotr operational phases.
- Using representative discharge examples, the work shows how the impurity radiation behaves in these plasmas with different boundary conditions as density increases.
- Beneficial effects (with respect to impurity radiation) of the magnetic island divertor are demonstrated:
  - the intense radiation is located at the edge (r/a > 0.8) even at high radiation;
  - the plasma remains stable up to f_{rad} approaching unity (with uncertainties of 10%), which normally signifies plasma detachment.
  - Moreover, beyond the critical density with f_{rad} ~1, the divertor plasma can maintain its stability with only a small reduction in the plasma stored energy.
- After wall boronisation, impurity radiation profiles becomes narrow requiring higher plasma density (by a factor of ~3) for reaching the same f_{rad} value.

BACKGROUND

❑ W7-X operational phases [1-7]

OP1.1 (Dec.2015- March 2016) OP1.2a (2017; pre-boronisation) & OP1.2b (2018; wall-boronisation)



- Hydrogen plasma: mostly generated by ECR-heating with powers up to 6.5 MW;
- low-Z impurities: mainly carbon and oxygen, released from the graphite targets and plasma facing components; Wall-boronisation reduces impurity contents [15].

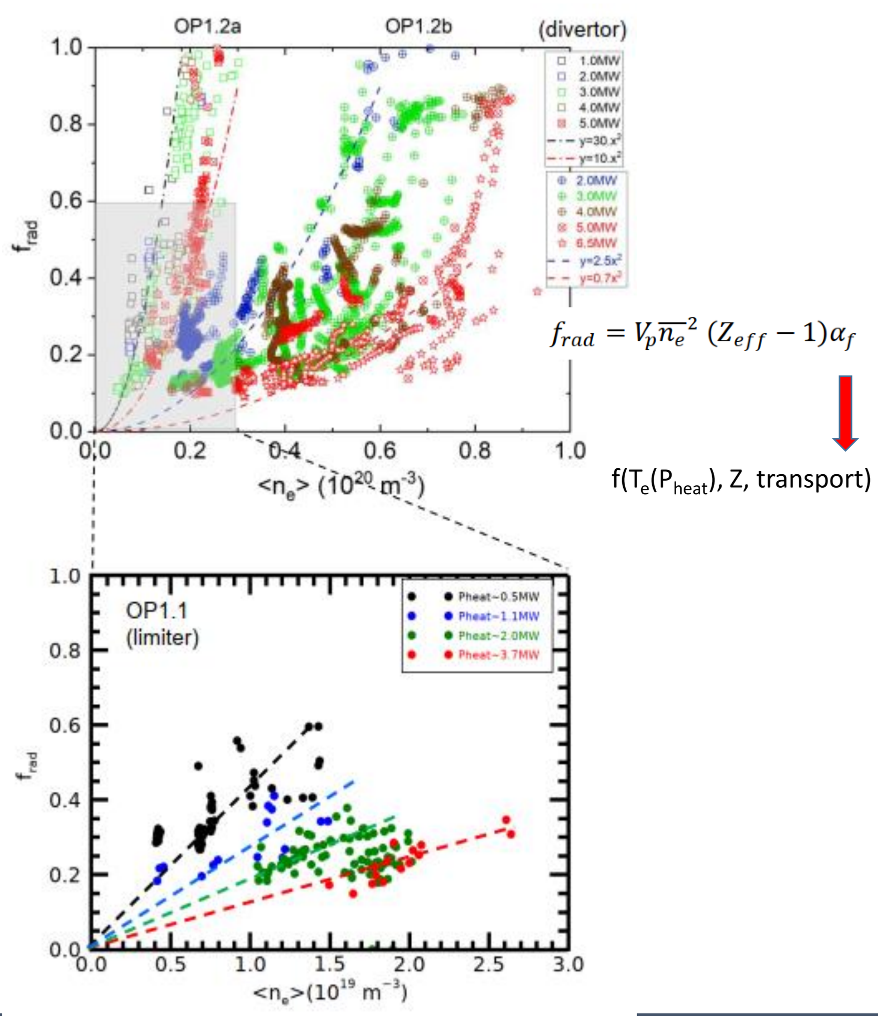
❑ GENERAL OBSERVATIONS

- most of the steady-state limiter plasmas have a radiation loss fraction f_{rad} < 45% , where

$$f_{rad} = P_{rad}/P_{heat}$$

with P_{rad} measured by bolometers [11].

- At higher radiation fractions, the limiter plasmas are usually unstable and thermal instabilities occur.
- By contrast, the plasma in divertor configuration can stably maintain its energy at high radiation with f_{rad} ~1 accompanied by detachment [9-10].

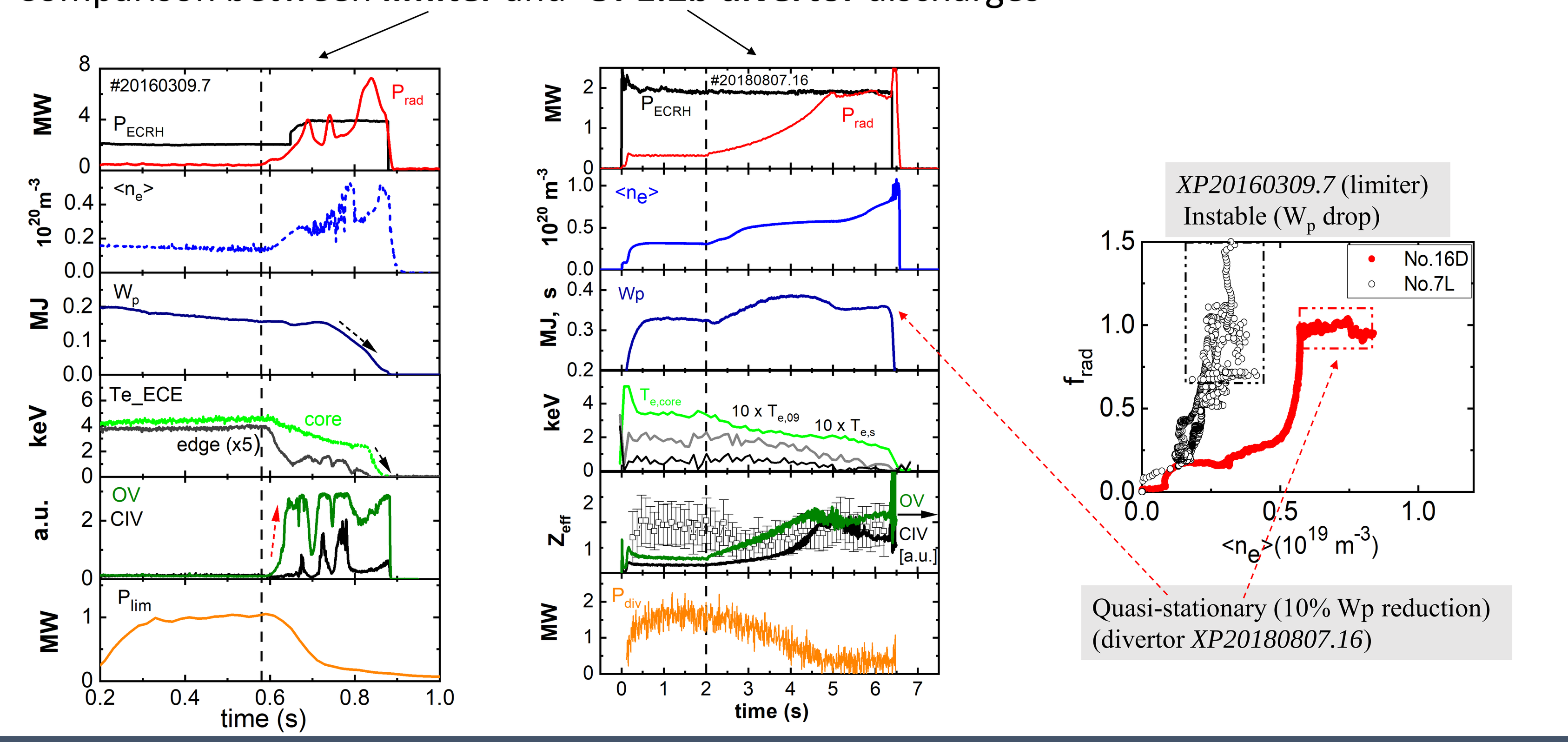


OUTCOME

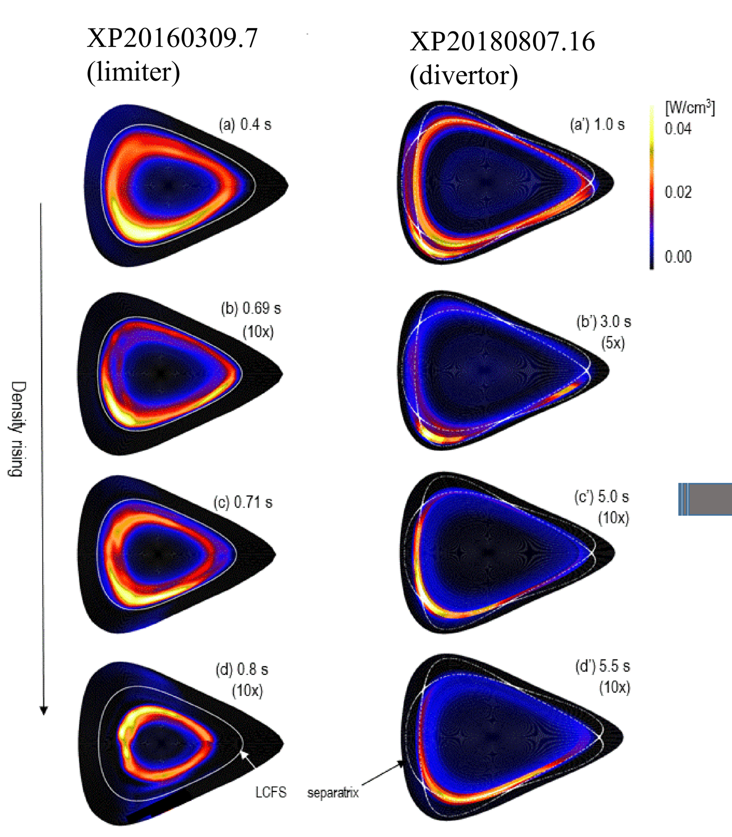
❑ Beneficial effects of the island divertor vs. limiter configuration

- Intensive radiation is located at the edge (r/a > 0.8) even at high radiation levels.
- The plasma remains stable up to a radiation fraction of ~0.9-1.0 (with uncertainties of 10%).

Comparison between **limiter** and **OP1.2b divertor** discharges



The radiation intensity distributions (based on bolometer tomography [12-13])

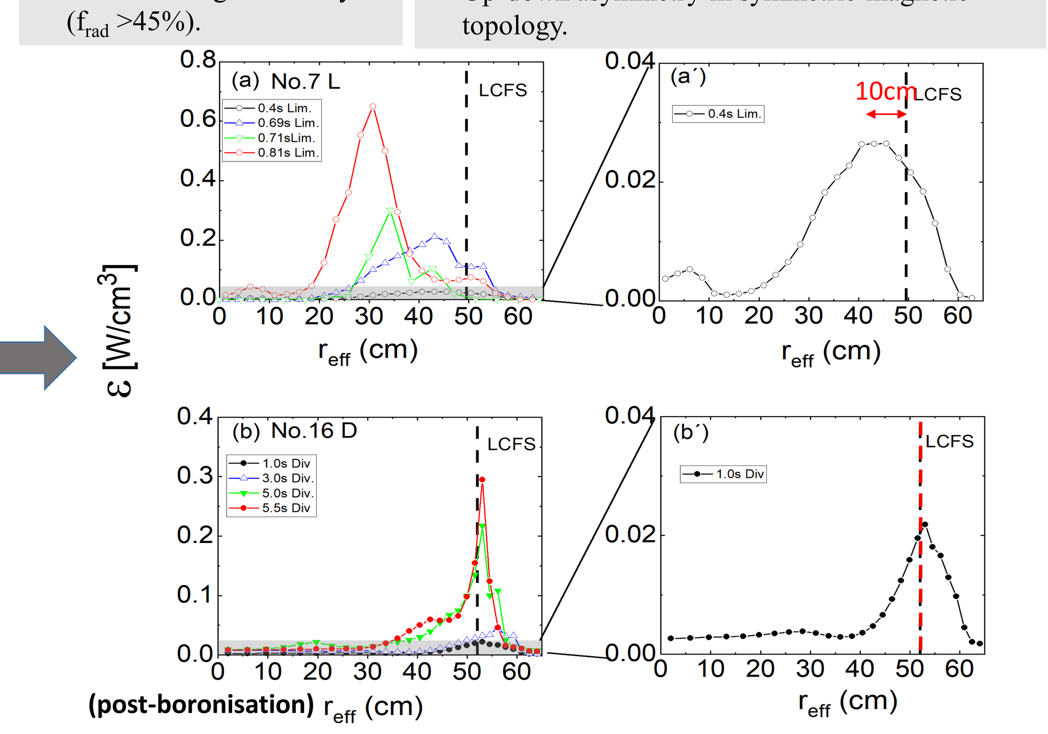


OP1.1 limiter plasma:

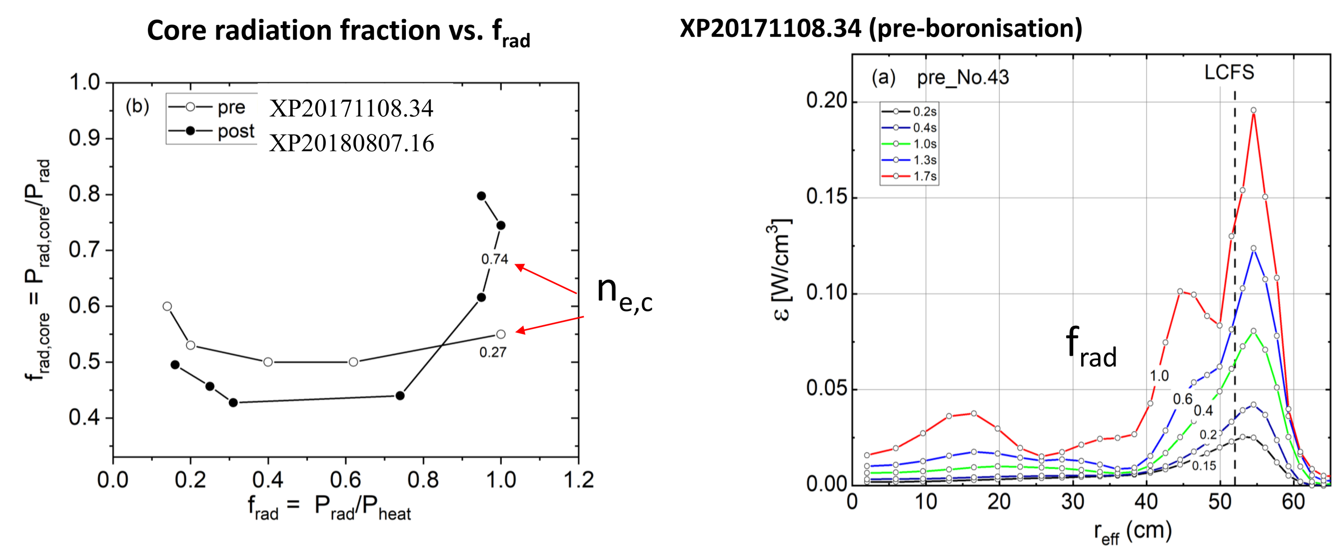
- Radiation peak ~10cm inside the LCFS in the low-density case;
- Instable at higher density (f_{rad} >45%).

OP1.2b divertor plasma:

- the "double emission zone" in the low-n_e case;
- X-point with intensive radiation for detached plasma;
- Up-down asymmetry in symmetric magnetic topology.



Boronisation effect on the radiation distribution



After boronisation:
- narrower profile;
- double emission zone shown in Fig. 4 (a´), smears into one (see Ref. [13]).

CONCLUSION

- The island divertor concept at W7-X provides a large operating window up to high-density, high-radiation scenarios compared to the limiter configuration, and is already showing its beneficial effects in terms of power removal capability due to impurity radiation [8-9, 17-19].
- However, a deeper understanding of the experimental observations, such as the asymmetry in the radiation distribution and its influence on the edge plasma parameters as well as the plasma performance, requires further investigation.

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