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Experimental indications of high-recycling and the role of plasma pressure and power dissipation in the detachment evolution at Wendelstein 7-X

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ABSTRACT

- Spectroscopic measurements in Wendelstein 7-X (W7-X) reveal high electron densities in the divertor, which are an indication for a high-recycling regime. Scaling of divertor densities with power and upstream density is observed.
- Power scaling is in line with recent modeling on power starvation driven detachment in W7-X.
- Reduced pressure losses compared to W7-AS can be inferred by existence of high-recycling in W7-X. Variation of losses with detachment is insufficient to avoid upstream pressure losses with detachment.

BACKGROUND

- Important mission of W7-X is to demonstrate the performance and applicability of the island divertor concept for power and particle exhaust.
- Stability against radiation collapses and increased importance of perpendicular transport are beneficial for power exhaust.
- Neutral densities in the W7-X divertor are limited to low values (0.1 Pa) that are not sufficient for reactor particle exhaust.

→ Understanding of density build up and recycling properties is required to assess and optimize the island divertor capabilities for particle exhaust

EXPERIMENTAL SETUP & DIAGNOSTICS

Density ramp experiments

Two approaches of achieving heat flux detached divertor targets have been followed:

- Density ramp experiments using a feedback controlled gas puff system.
- Impurity seeding of N and Ne to increase the radiated power.

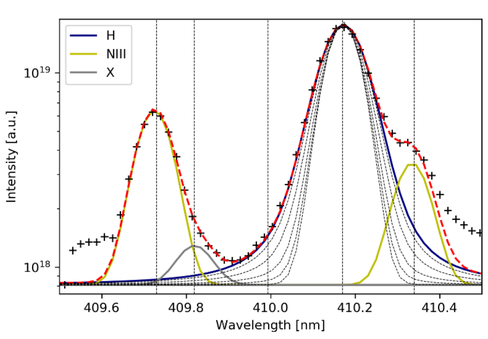
→ We focus here on density ramp experiments.

Main observations

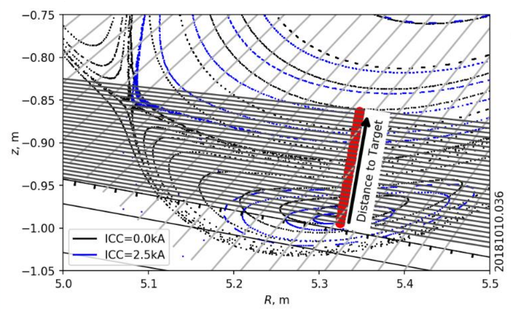
- High divertor densities measured by spectroscopy (10^{20} m^{-3}).
- Complete detachment (q_{tar} < 150 kW/m^2) achieved with density ramps.
- Increased density correlated to strong radiation increase to $f_{rad} \approx 0.90$.
- Compression loss in detachment not due to divertor pressure drop for density controlled experiments with $f_{rad} < 0.9$.

Spectroscopy: Stark broadening & Impurity line emission

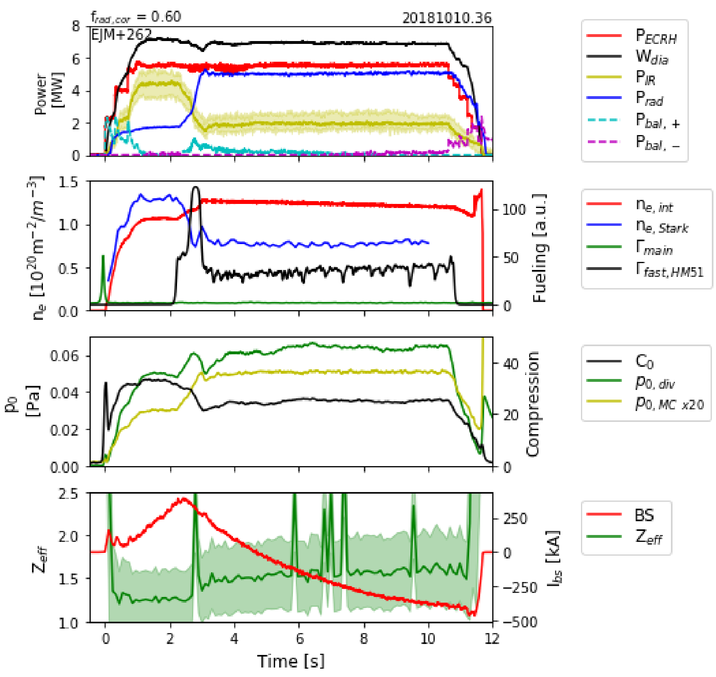
- Lines of sights parallel to divertor target (high-resolution spectrometer).
- Density measurement via Stark broadening of Balmer n=6-2 transition.
- Instrument functions allows measurements down to 2.5x 10^{19} m^{-3}.



Balmer (n=6-2) line with a NIII doublet. The dashed lines indicate the Balmer line shape for reference densities of 0.1/1.0/2.5/5.0/7.5 10^{19} m^{-3}.



Line-of-sight viewing geometry of divertor spectroscopy system. The magnetic equilibrium of the standard configuration is shown for two different control coil currents (black, blue).

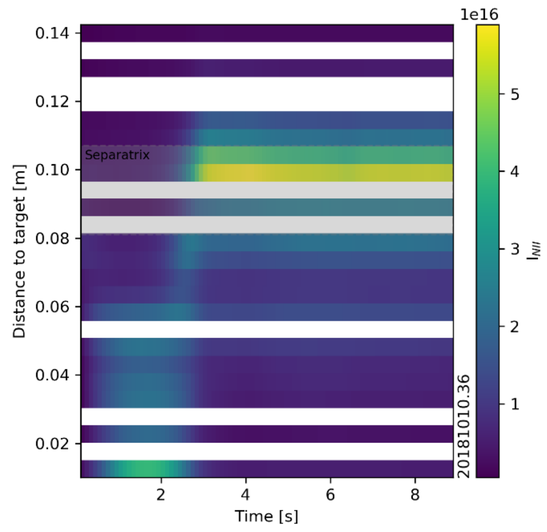


Discharge parameters of 20181010.36. A detachment experiment with constant heating power using a feed-back density ramp to detach the targets.

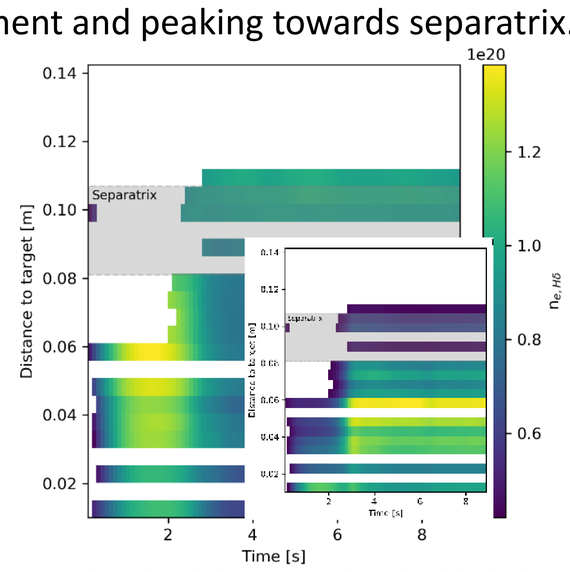
SPECTROSCOPIC OBSERVATIONS

- Bolometers and spectroscopy show movement of emission zones from target towards the separatrix. Detailed localization of radiation in proximity of separatrix is difficult and work in progress.
- N^+ emission region (T_e=3-5 eV) indicative of ionization front. Similar movement of Balmer emission zone.
- Electron density peaks 5-6 cm above target before detachment.

Reduction in divertor with detachment and peaking towards separatrix.



With detachment the N^+ emission region (399.5 nm) moves from the target towards the separatrix.

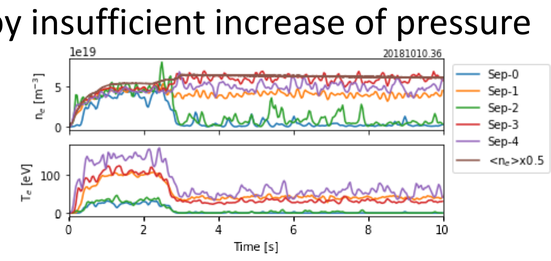


Vertical electron density distribution in the W7-X divertor (HM51). The inlay show the measured Balmer n=6-2 intensity distribution.

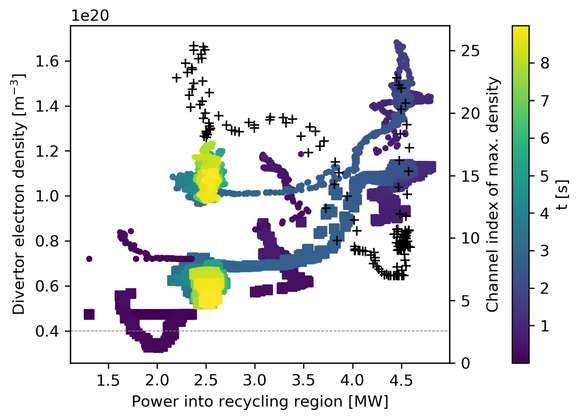
RECYCLING & DETACHMENT OBSERVATIONS

- Divertor density significantly larger than upstream density.
- Divertor density increase with upstream density & available power.

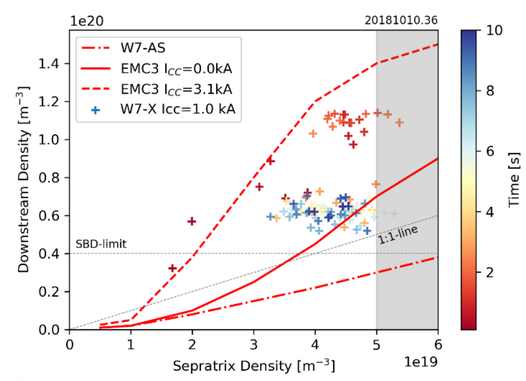
  → **High-recycling regime in W7-X**
- Power starvation detachment consistent with dominant role of power losses in setting the particle balance in the divertor.
- Lower pressure losses/dissipation in W7-X than in W7-AS.
- Upstream pressure drop induced by insufficient increase of pressure losses with detachment.



Thomson measurements around the separatrix. The density behavior is different for channels measuring on the low-field and high-field side of the separatrix.



The divertor density scales with power into the divertor ($P_H - P_{rad}$). The squares are measured directly above the target. Circles are maximum densities in the divertor. The black crosses show the LOS index of the measured maximum density.



Divertor density evolution. Red curves are modelling predictions for W7-X and W7-AS from EMC3.

CONCLUSION

- Dominant processes for density build-up and detachment different than in tokamaks (pressure conservation, power starvation).
- W7-X shows reduced momentum losses due to transport compared to W7-AS and thus high-recycling is possible .
- Spectroscopic density measurements ($n_{e,div}$=1x10^{20} m^{-3}) that show scaling with upstream density and available power in the divertor confirm high recycling behavior.
- Power balance in divertor important to set particle dynamics.

→ **Need to characterize the perpendicular transport in the SOL/divertor.**

ACKNOWLEDGEMENTS / REFERENCES

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