CONTROL OF THE X-POINT RADIATOR IN FULLY-DETACHED ASDEX UPGRADE H-MODE PLASMAS

The X-point radiation regime
- Detachment in metal machines achieved with seeding
- With the pronounced detachment of the outer divertor, an intense, localized radiator evolves close to the X-point.
- Most likely radiation condensation (MARFE-like)
- Total radiated power fraction close to 100%

X-point radiation (XPR)
- Stable scenario
- Existing with N or Ar seeding (at ASDEX Upgrade)
- Existing in a wide range of heating power:
  - Radiator reproduced by SOLPS [Friedel, NF 2015]
  - Temperature reduction within confined region
    - D line radiation -> efficient recombination
    - $T_e = 1-2 \text{ eV}$, $n_e \approx 3 \times 10^{19} \text{m}^{-3}$
    - Parallel temperature gradients inside confined region?

Why is it stable here? Hypotheses:
- Highest flux expansion -> longest connection length to midplane
  - Low, sustainable parallel temperature gradients
  - Power flux driven parallel to mag. field
  - Radiator acts as heat sink
- Influence of near divertor (neutral & impurity penetration for local cooling)

Overview of an discharge – movement of the X-point radiator (XPR)
- Constant N seeding programmed -> slow evolution of N concentration
- XPR moves inside confined region:
  - XPR forms close to X-point
  - Moves further inside
  - Up to 15 cm inside confined region ($\rho_{ins} = 0.99$) observed

Location of the XPR can be actively influenced
- Location observed with AXUV camera
- Moves inwards with
  - Lower heating power
  - Higher N seeding
- No clear scaling of position with $c/\Gamma$ or $P_{net}$ yet

Real-time control of the XPR position

Sensor: AXUV diodes
- SICO2 real time data acquisition
- ELM filter: 20 ms median
- Offset subtraction of measured profile
- Peak detection by calculation of 1st moment (dashed lines)

Actuator: N or Ar seeding
- PI controller on vertical distance of detected peak to X-Point
- Further possibility as actuator: Heating power (not implemented yet)

Application of the controller
- Controller tested by variation in:
  - Heating power
  - XPR location
- Tested for N seeding with 2-18 MW
  - ELMs H-mode stable for $P_{net} = P_{LH}$
  - Applicable also to Ar seeding:
    - Adjusted gains
    - Noisy signal and noisy feedback

An ELM suppressed regime for high locations of XPR
- At high locations of the XPR (>7 cm above the X-Point), ELMs are suppressed
- Sudden change of characteristics:
  - ELMs disappear
  - Density reduced by 15% = increased diverter
  - $W_{th}$ reduced by ~10% = Reduced W content
  - $H_\parallel = 0.95$, $f_{\text{LH}} = 0.8$, $c_{\text{LH}} = 2.4%$
- Cold ($T_e \approx 1-2 \text{ eV}$) and dense ($n_e \approx 3 \times 10^{19} \text{m}^{-3}$) plasma at X-point inside confined region?
- Pedestal gradients reduced
- Characteristics between L- & H-mode:
  - E. well depth:
  - Filament characteristics
- Reproducible scenario
  - Existing at heating powers of 2-17.5 MW

Conclusion
- X-point radiation is a stable regime, shown in AUG & JET
- The X-point radiator moves inside the confined region
- The movement can be actively controlled
- First time control of full detachment!
- A high location of the radiator leads to ELM suppression

For a future reactor, this would provide:
- An operational window between detachment and radiative collapse
- A simple sensor for the control
- ELM suppression at high density and moderate confinement

Applicability for a future reactor to be further investigated

Motivation
- Detachment is essential for ITER & DEMO
  - Partial to pronounced detachment
  - High dissipated power fraction $f_{\text{diss}} \approx 95$
- Detachment is induced by impurity seeding
  - Balance between reattachment & radiative collapse
- Control is crucial
  - Still requires a stable scenario
  - Can ELMs also be avoided?