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

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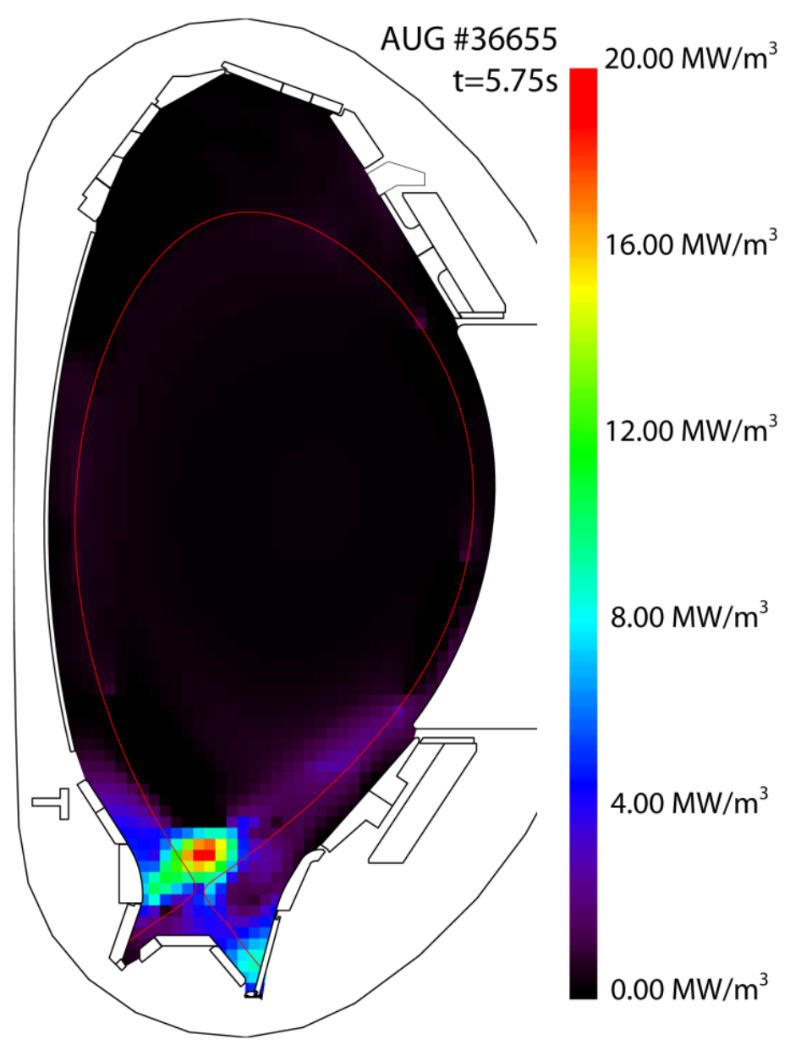
[+] See: B. Labit et al 2019 Nucl. Fusion 59 086020
[++] See: H. Meyer et al 2019 Nucl. Fusion 59 112014

Motivation

- Detachment is essential for ITER & DEMO
  - Partial to pronounced detachment
  - High dissipated power fraction $f_{diss} \geq 95\%$
- Detachment is induced by impurity seeding
  - Balance between reattachment & radiative collapse

➔ Control is crucial
  - Still requires a stable scenario
  - Can ELMs also be avoided?

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%

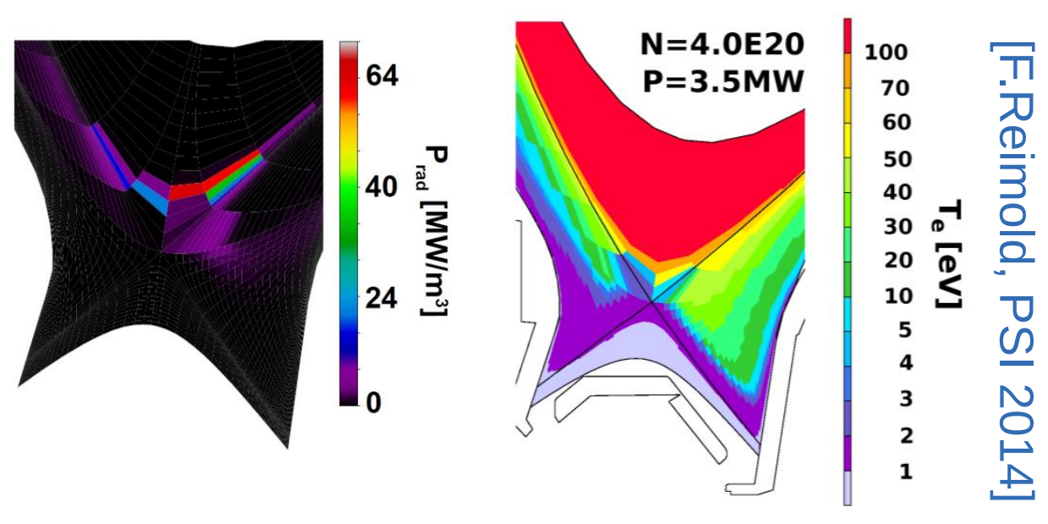
  XPR radiates up to 1/3 of the heating power

- X-point radiation (XPR) is:
  → Stable scenario
  → Existing with N or Ar seeding (at ASDEX Upgrade)
  → Existing in a wide range of heating power:

P_{heat} [MW] = 2.5 – 20
P_{heat}/P_{LH} = 1 – 5

- Radiator reproduced by SOLPS [Reimold, NF 2015]
- Temperature reduction within confined region
  - D line radiation → efficient recombination
  - T_e = 1-2 eV, $n_e \geq 3 \cdot 10^{20}$ m^{-3}

    → **Parallel temperature gradients inside confined region!**

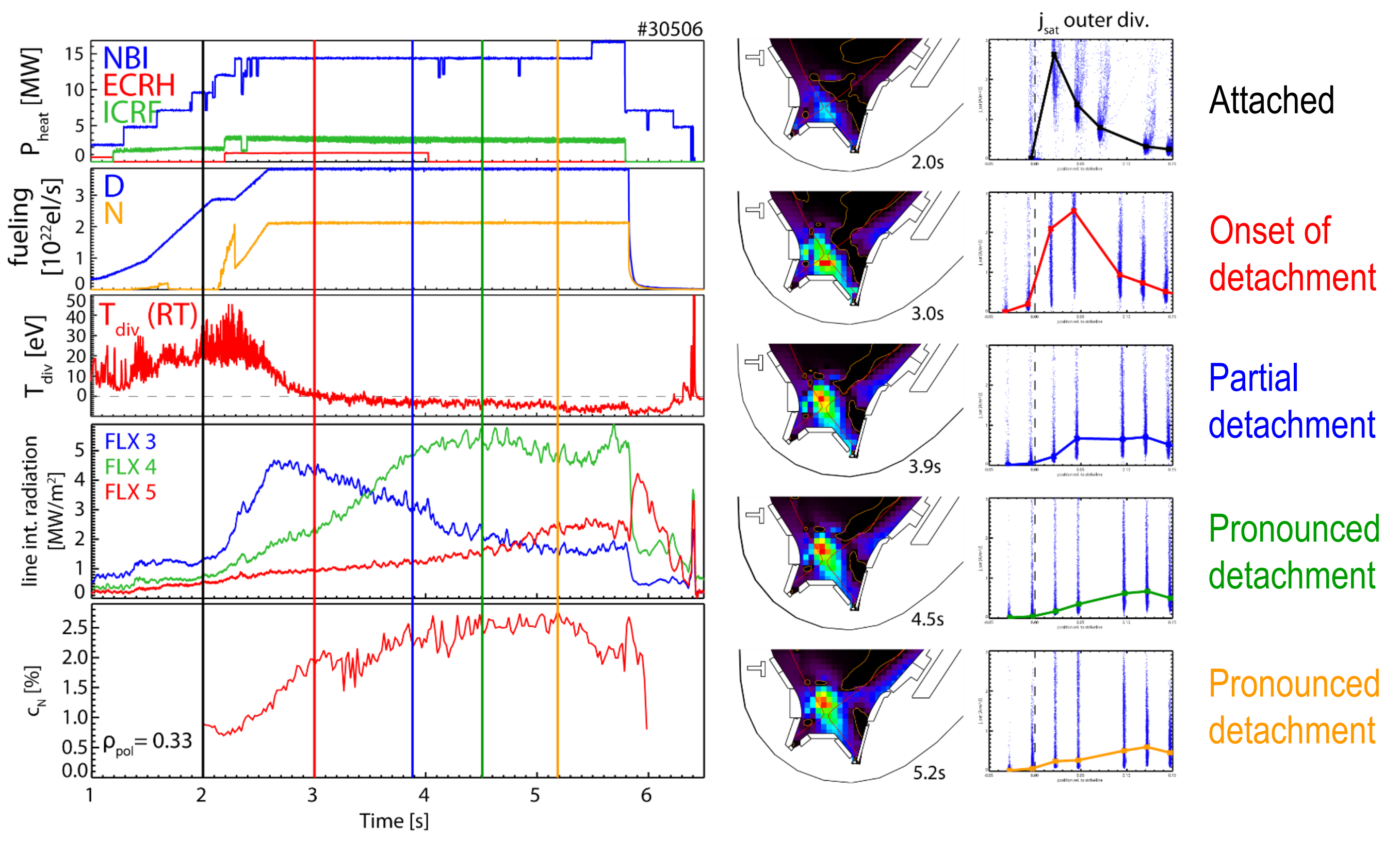


[F. Reimold, PSI 2014]

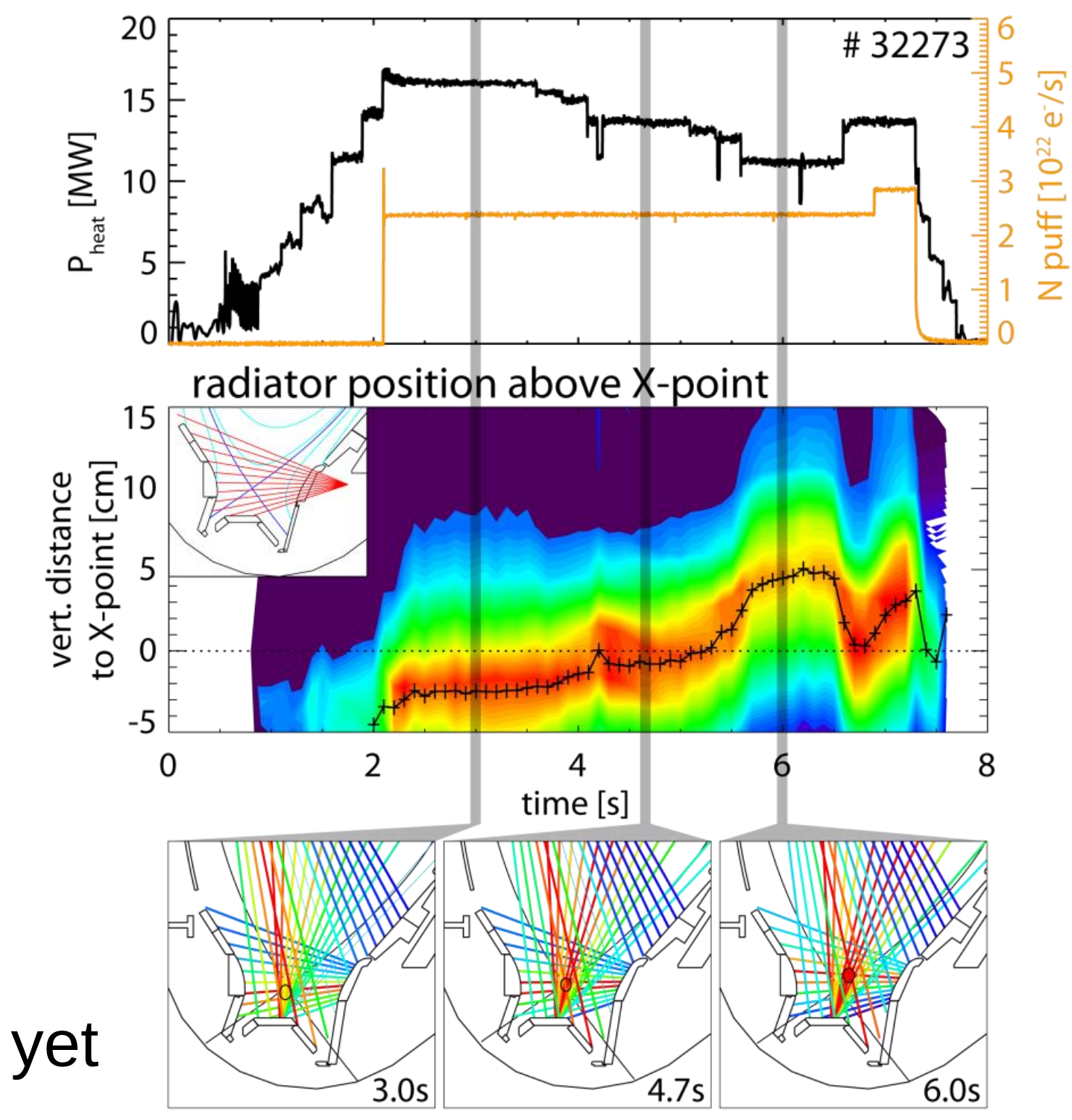
Why is it stable here? Hypotheses:

- Highest flux expansion ↔ longest connection length to midplane
  →Low, sustainable parallel temperature gradients
  →Power flux driven parallel to magn. 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 ($\rho_{pol} \approx 0.99$) observed

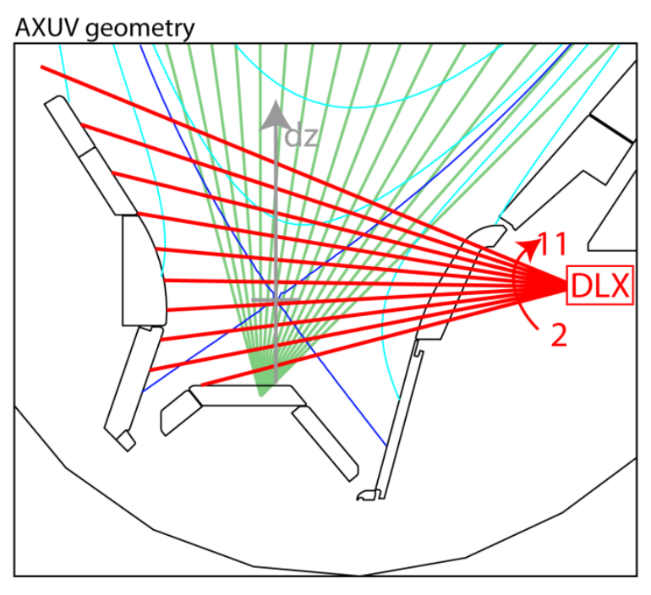


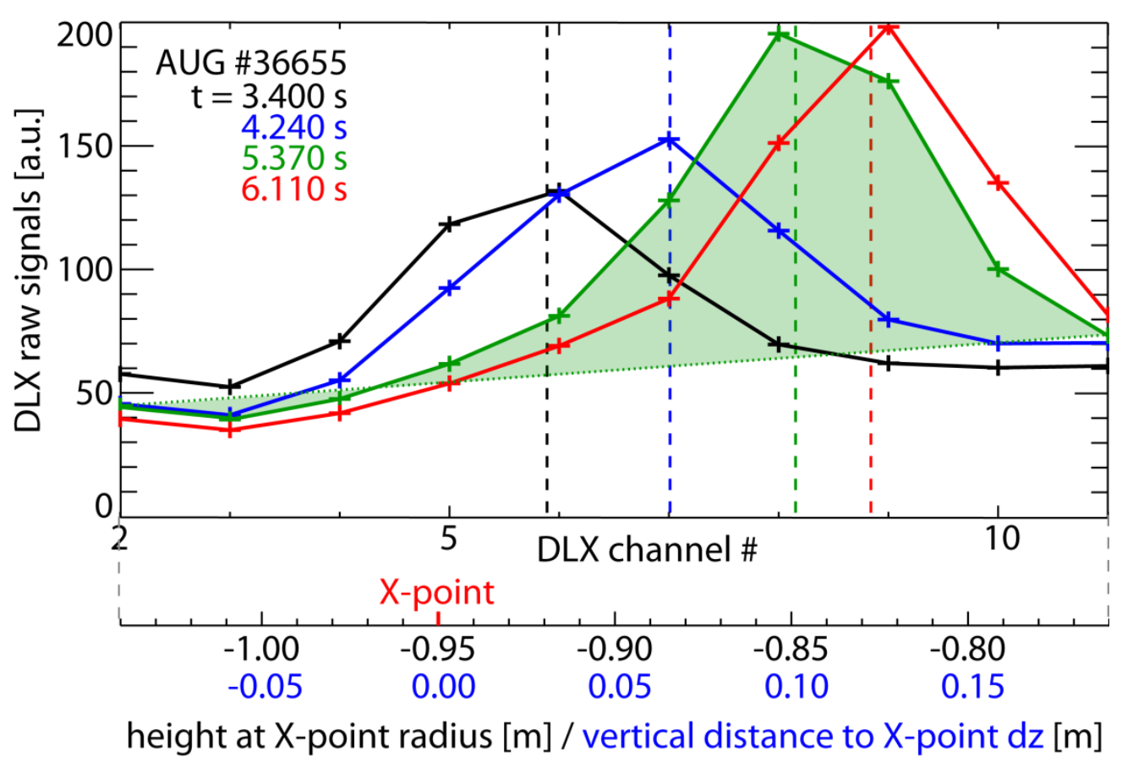
Location of the XPR can be actively influenced

- Location observed with AXUV camera →
- Moves inwards with
  - Lower heating power
  - Higher N seeding
- No clear scaling of position with c_N / Γ_N / P_{heat} yet

Real-time control of the XPR position

Sensor: AXUV diodes →
- SIO2 real time data acquisition
- ELM filter: 20 ms median
- Offset subtraction of measured profile
- Peak detection by calculation of 1st moment (dashed lines)



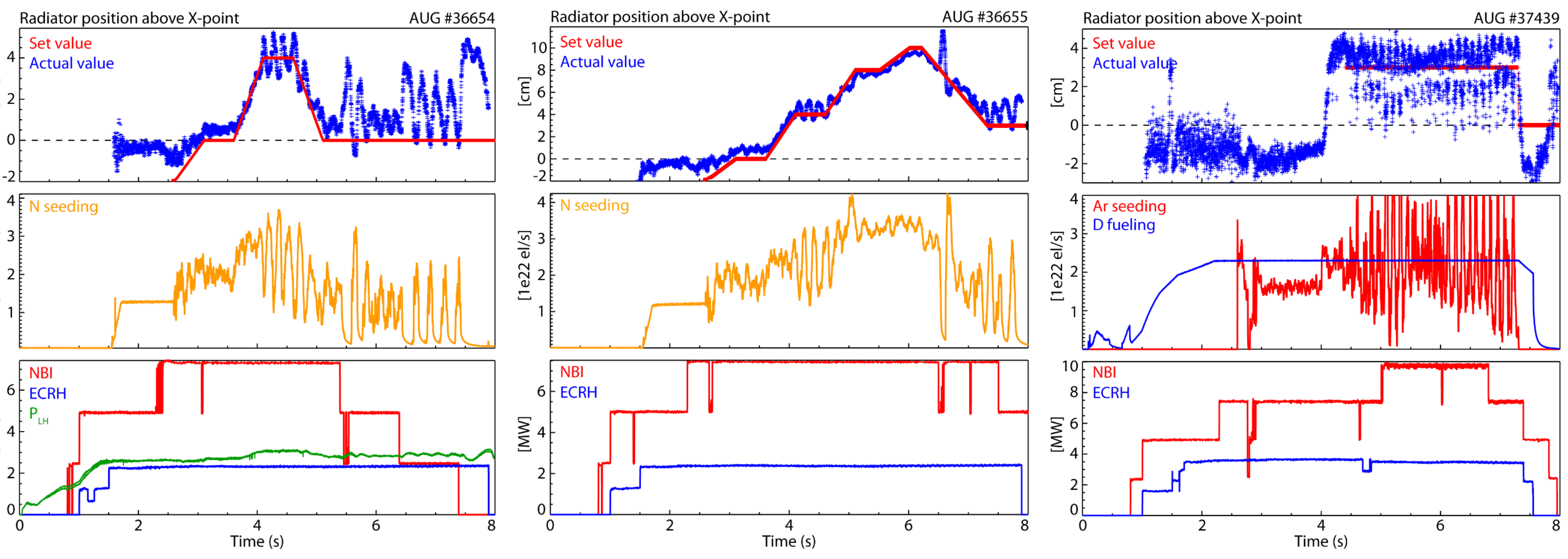


Actuator: N or Ar seeding
- PI controller on vertical distance of detected peak to X-Point
- Further possibility as actuator: Heating power (not implemented yet)

Application of the controller

- Controller tested by variation in:

Heating power | XPR location | Ar seeding as actuator

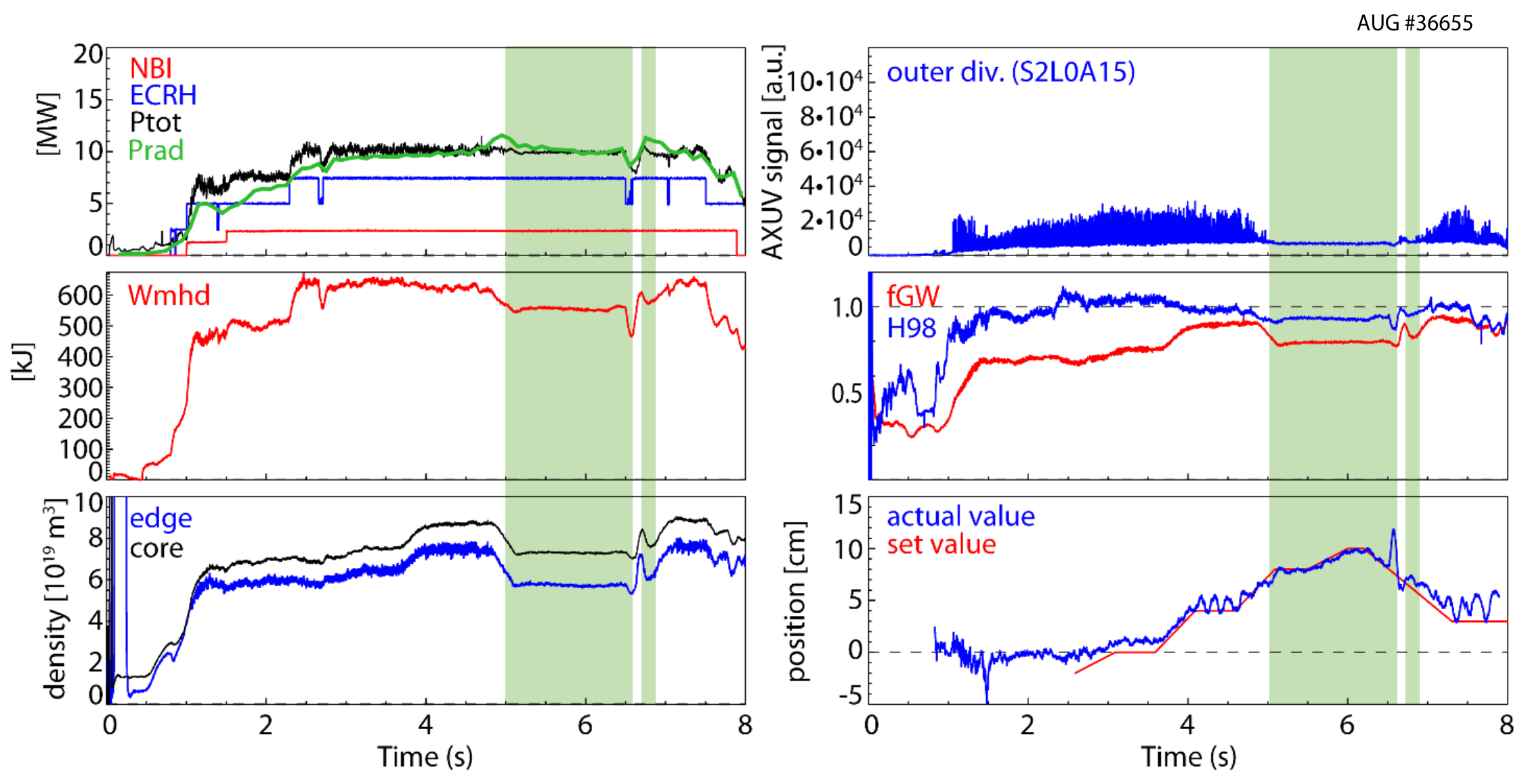


- Detection within 5 mm
- Power steps well compensated
- Controller unstable at:
  - Location around 4 cm
  - Low heating power
- Tested for N seeding with 2-18 MW
  - ELMy H-mode stable for $P_{heat} \approx P_{LH}$
- Applicable also to Ar seeding:
  - Adjusted gains
  - → noisy signal and noisy feedback

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%
  - W_{MHD} reduced by ~10%
  - Increased divertor neutral compression
  - Reduced W content
  - $H_{98} \approx 0.95$
  - $f_{GW} \approx 0.8$
  - $c_N \approx$ 2-4%
- Cold (T_e≈1-2 eV) and dense ($n_e \leq 3 \cdot 10^{20}$ m^{-3}) plasma at X-point inside confined region!

- Pedestal gradients reduced
- Characteristics between L- & H-mode:
  - E_r-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 observer for the control
- ✓ ELM suppression at high density and moderate confinement

➡ Applicability for a future reactor to be further investigated

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