Measurements of the W concentration in the low- and mid-temperature range

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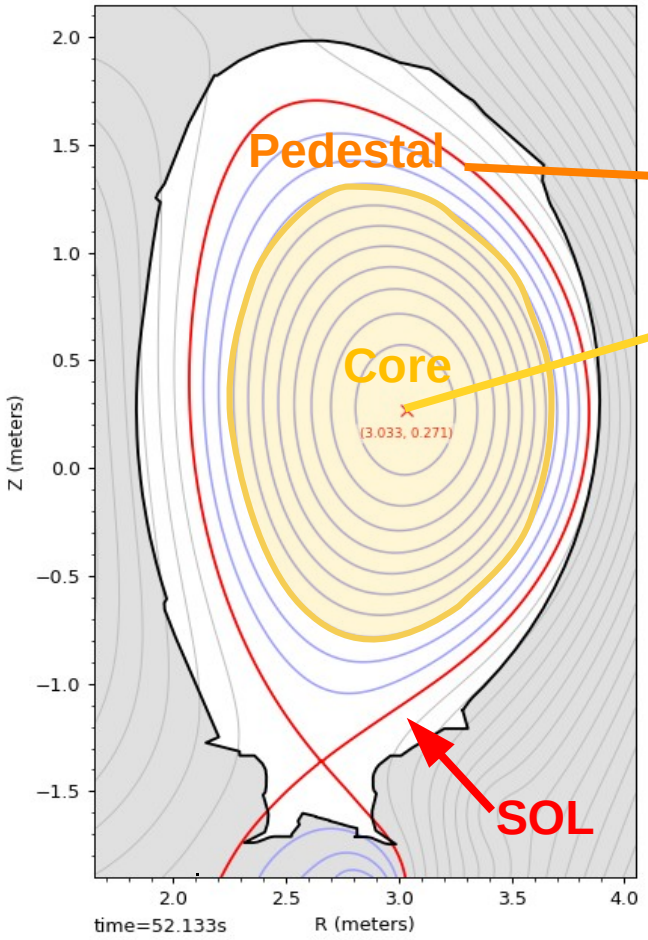
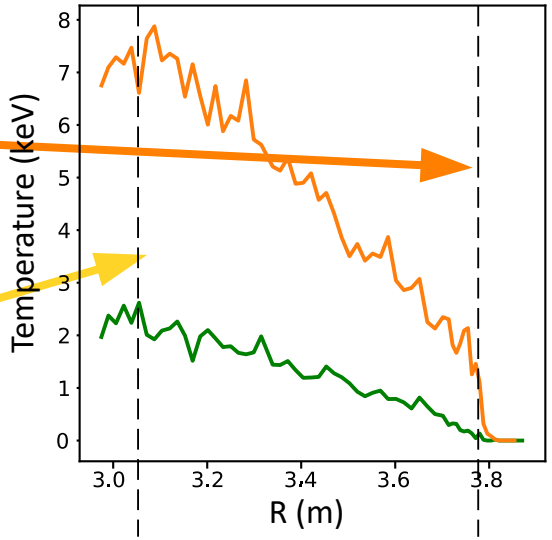
Outline

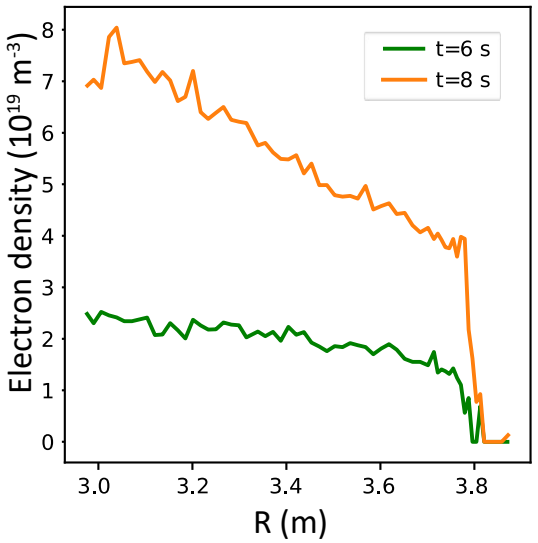
- **Temperature regions in JET tokamak plasma**
- **Overview of the XUV and VUV diagnostics in JET**
- **Mid-temperature W structures used in JET diagnostics**
  - XUV UTA – 4-7 nm measurements and density estimation
  - VUV UTA – 14-40 nm – utilization in fusion plasma
- **Low-temperature W lines:**
  - Transient and ELM measurements of W VI to W VIII line spectra
  - Estimation of temperature and W density in the outer SOL region

JET plasma – shape and parameters



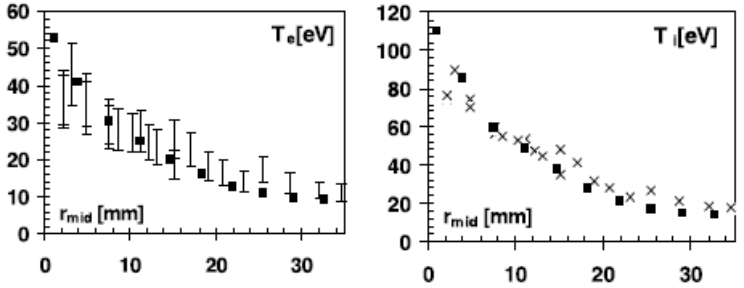
T_e and n_e in the core and pedestal region (JET PPF)





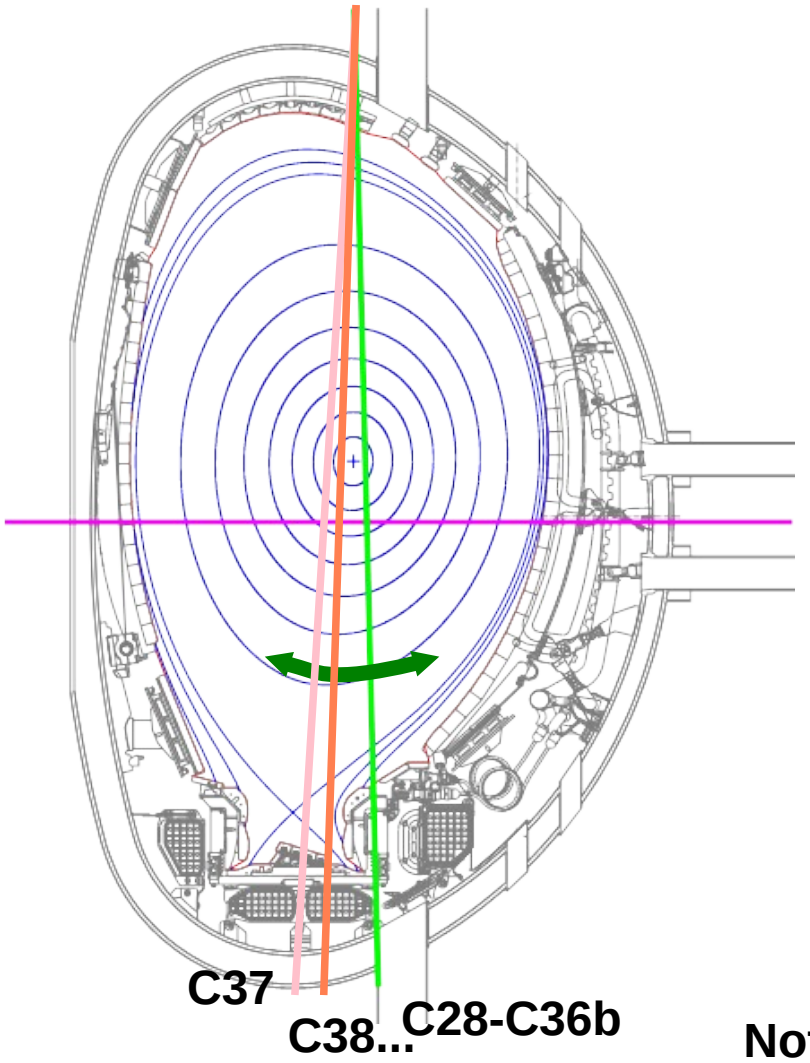
#97018: 6 s, 8 s

T_e and T_i in SOL



(Fundamenski et al, JNucMat 2001)

JET VUV and XUV spectrometers



- **Horizontal l-o-s:**
  - One VUV spectrometer:
    - 10-100 nm with a resolution of ~0.5 nm
- **Vertical l-o-s**
  - Two VUV spectrometers:
    - 14.8-148.5 nm with a resolution of ~0.5 nm
    - 14-44.4 nm with a resolution of ~0.1 nm
  - One XUV spectrometer:
    - 4-7 nm

Note – vertical l-o-s spectrometers are a scarce resource during T campaigns

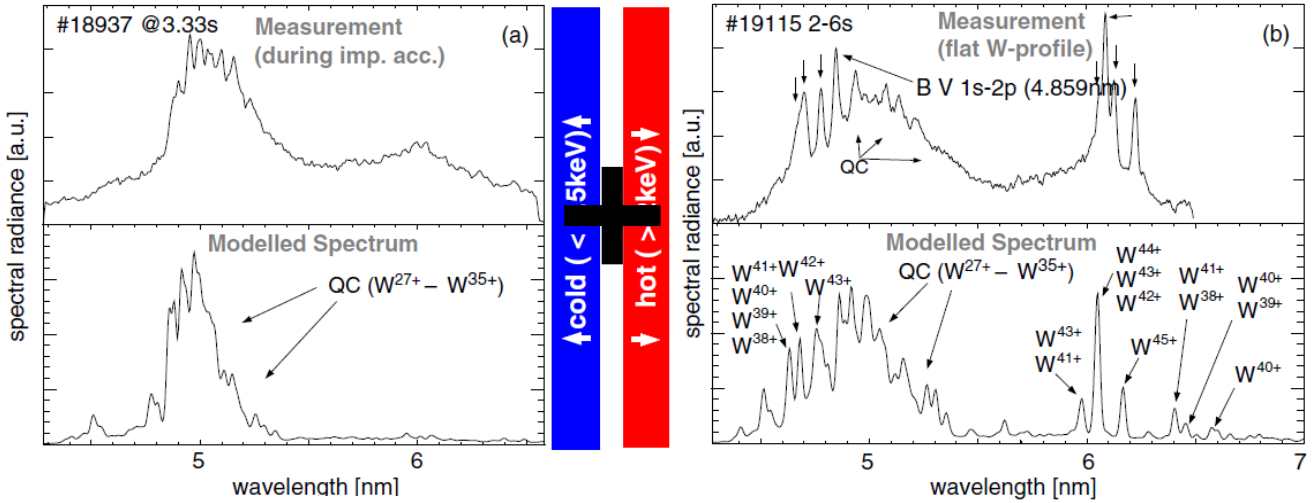
Mid-temperature range (pedestal, L-mode core)

ASDEX and theory

XUV UTA

Temperature dependence

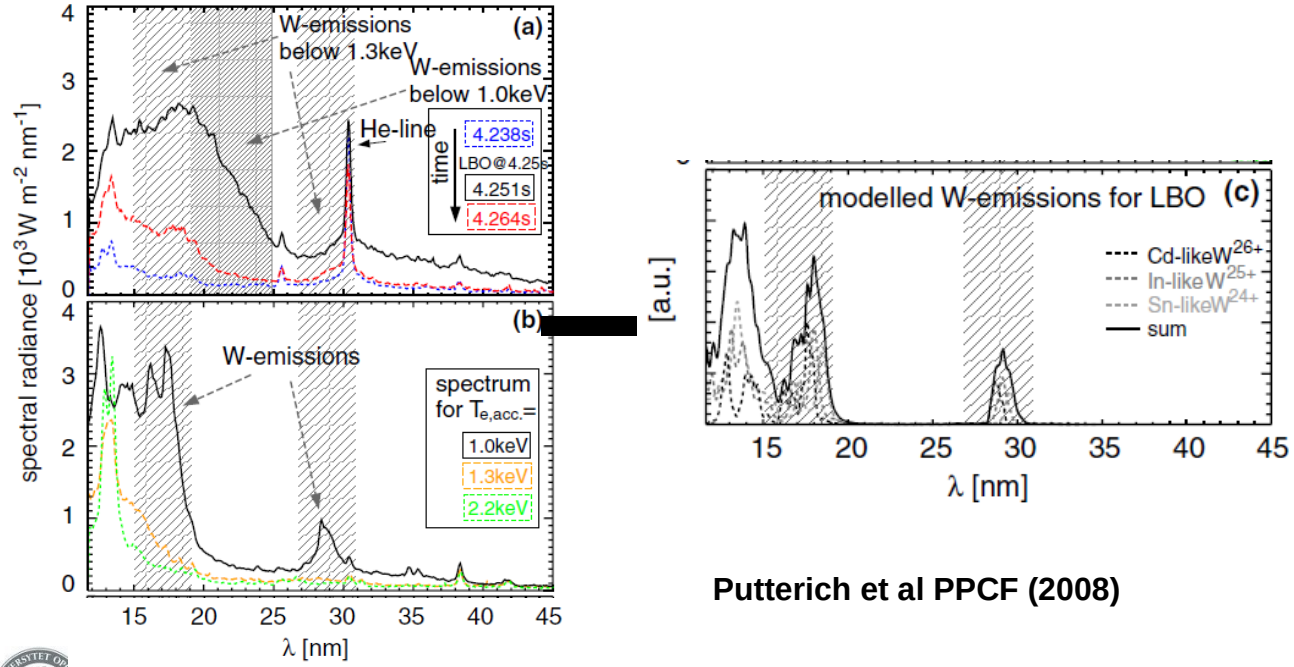
Continuum without visible lines (below 2 keV)
Continuum with overlapping lines (over 2 keV)



VUV UTA

Temperature dependence

short wave - 15-19 nm
– 1-1.3 keV
middle - 19-28 nm
- < 1 keV
long wave to 45 – 1-1.3 keV

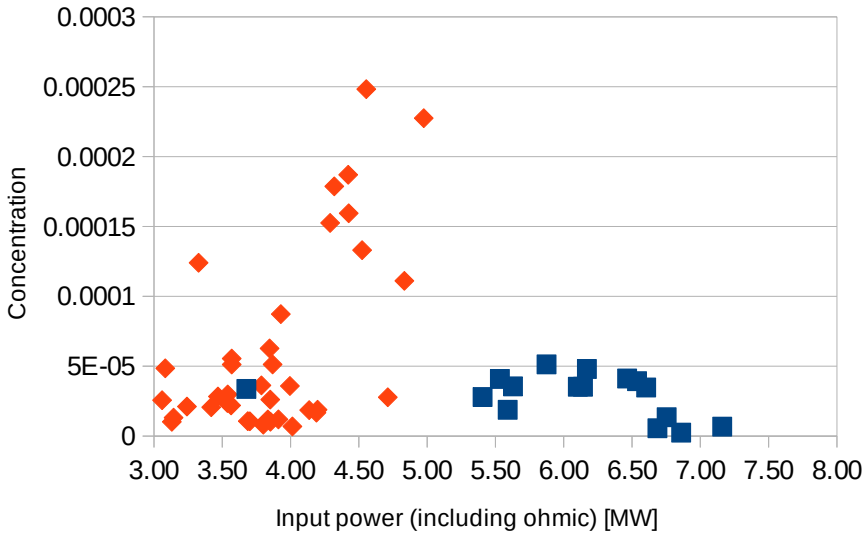


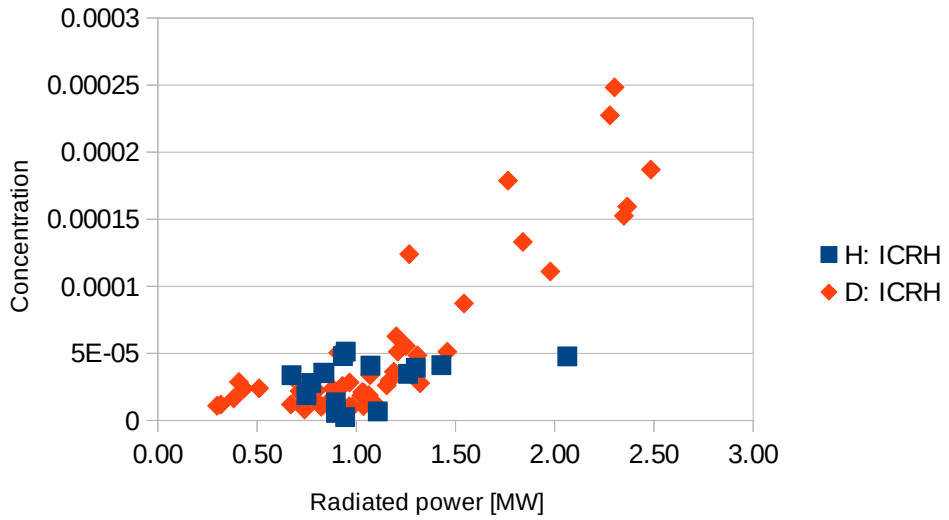
Putterich et al PPCF (2008)

Using XUV c_W – L-H transition study

- **Study of an isotope (and heating type) dependence of the L-H threshold has to include radiative power loss**
- **Radiative power loss – impurities (mostly tungsten)**

c_W during ICRH heating (isotope dependence)



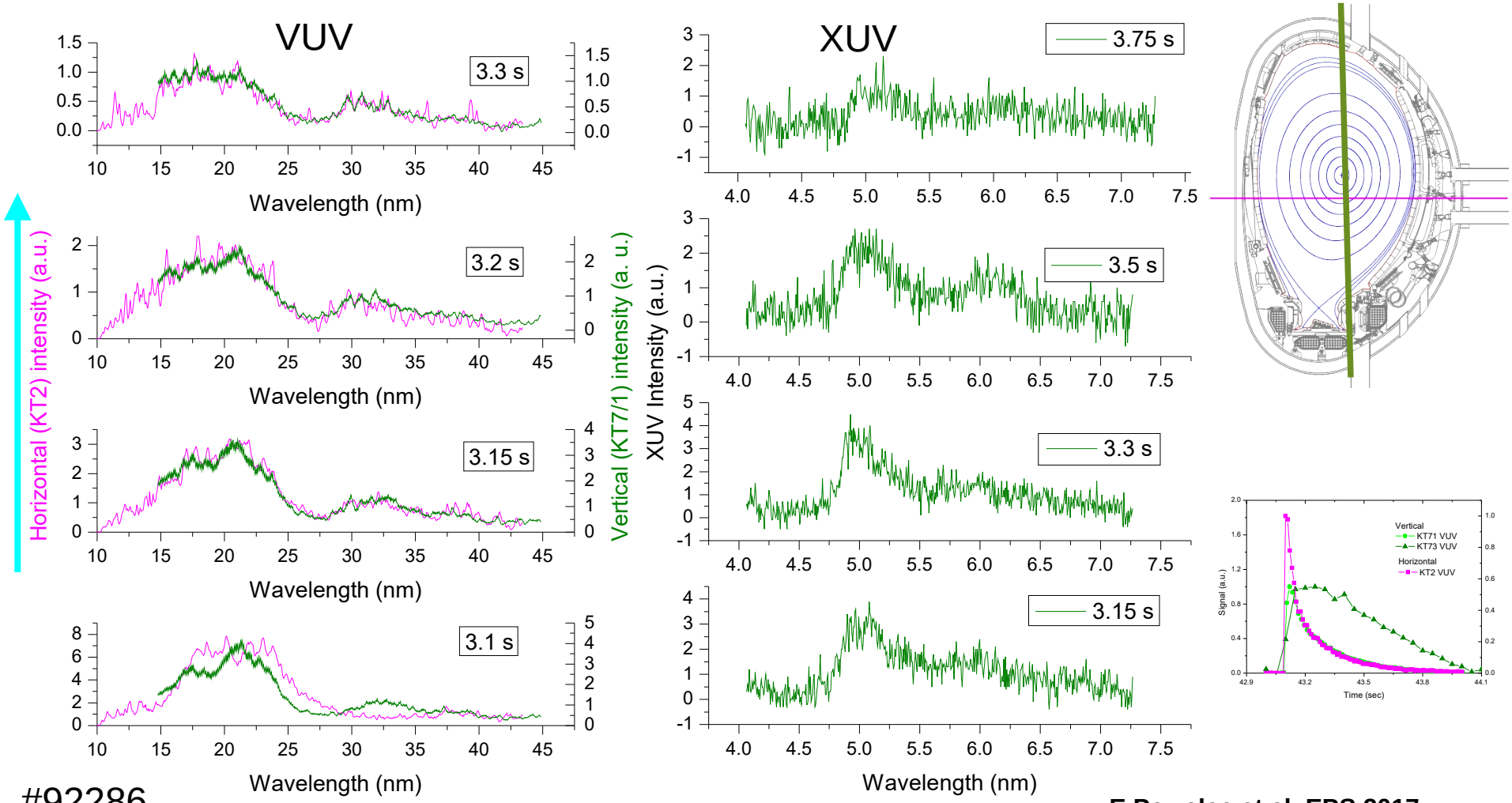


For most L-H transitions we get c_W of the order of 10^{-4} for ICRH ramps and much less (an order of magnitude or more) for NBI ramps (data for D) – studies of the source of W in those two heating types

E Solano, in prep.

JET VUV and XUV spectra

- **L-mode W ablation spectra (ablation at 3.1 s)**



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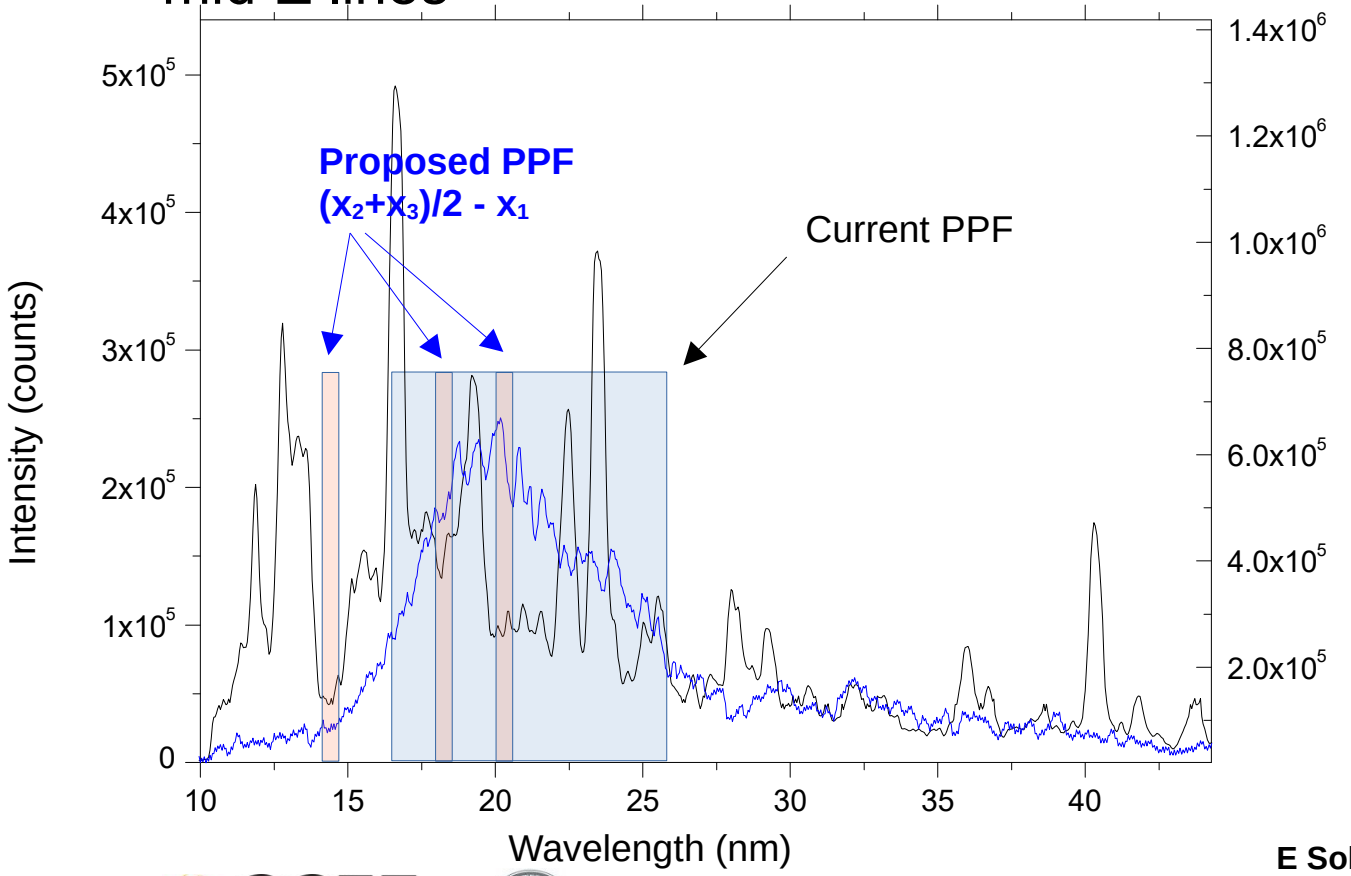
E Pawelec et al, EPS 2017
A Czarnecka et al PPCF 2019

Using the spectra – VUV PPF creation

- **PPF – processed file (intensity vs time, c_W vs time)**
  - Current: integration over a part of the UTA
  - Proposed: using characteristic points inside UTA to exclude mid-Z lines



Only intensity, No c_W

E Solano, in prep.

Summary

C_W from XUV
(only with the vertical l-o-s)
for > 1 keV

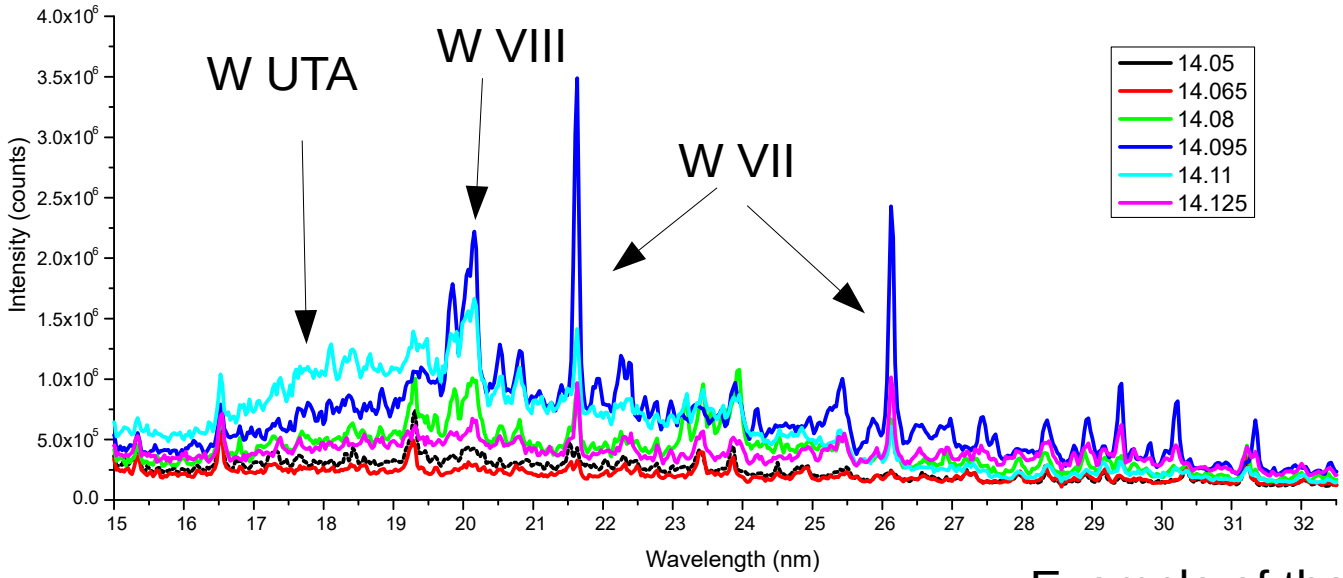
SXR signals
(many l-o-s, tomographic reconstruction)
- high temperature

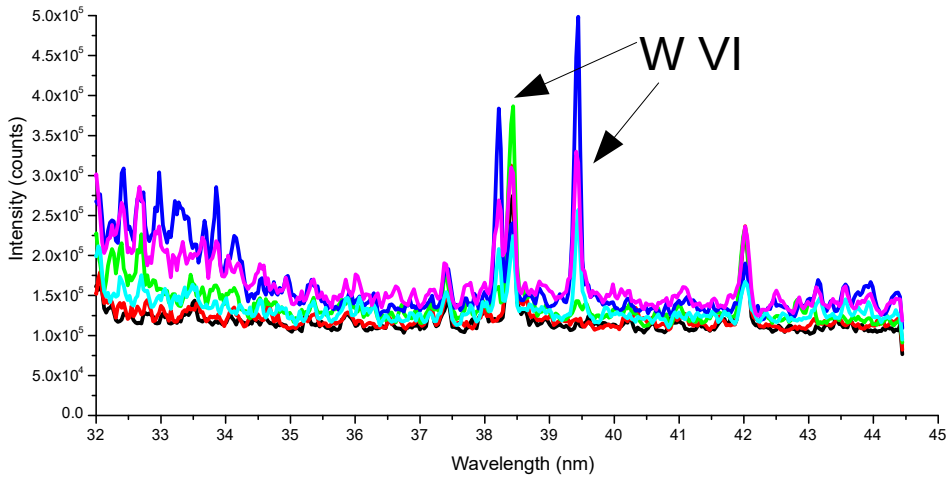
Combination with bolometry, z_{eff} and other data in Sertoli et al (J of Pl Phys, 2019)

VUV signal,
both l-o-s
for T ~ 1 keV and less
- no data for estimation

Low temperature range (SOL)

Transient event – W VI and W VII lines





Example of the tungsten spectrum from W event in JET pulse #94605
(H-mode C-C phase, 15 MW NBI)

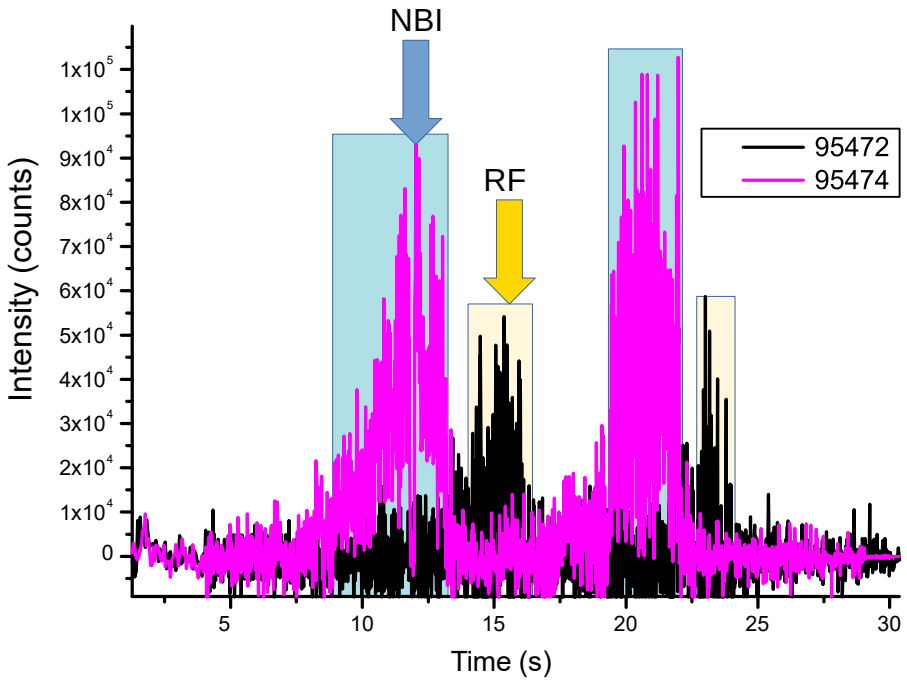
Strongest lines:

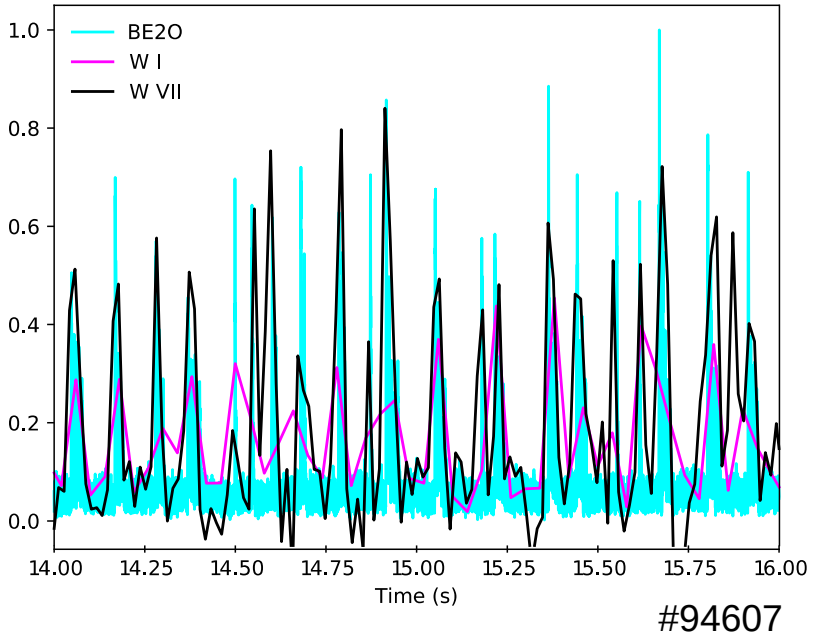
21.6218 nm W VII,
$4f^{14}5p^5(^2P_{1/2})5d\ (1/2,3/2)\ 1 \rightarrow 4f^{14}5p^6\ ^1S_0$

26.1168 nm W VII,
$4f^{14}5p^5(^2P_{3/2})5d\ (3/2,5/2)\ 1 \rightarrow 4f^{14}5p^6\ ^1S_0$

Intensity of the W VII lines – mode

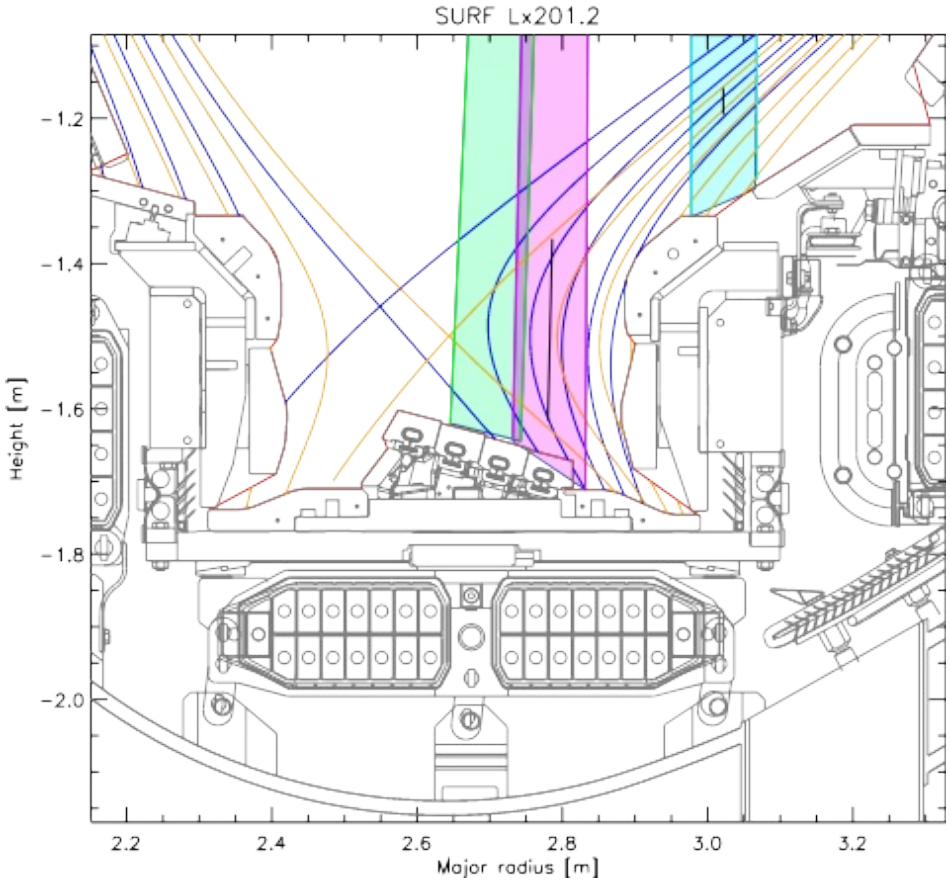
- Lines are visible predominantly in H-mode plasma
- More prominent during NBI heating than RF heating, (not always, depend on the origin of W)
- Synchronized with ELMs



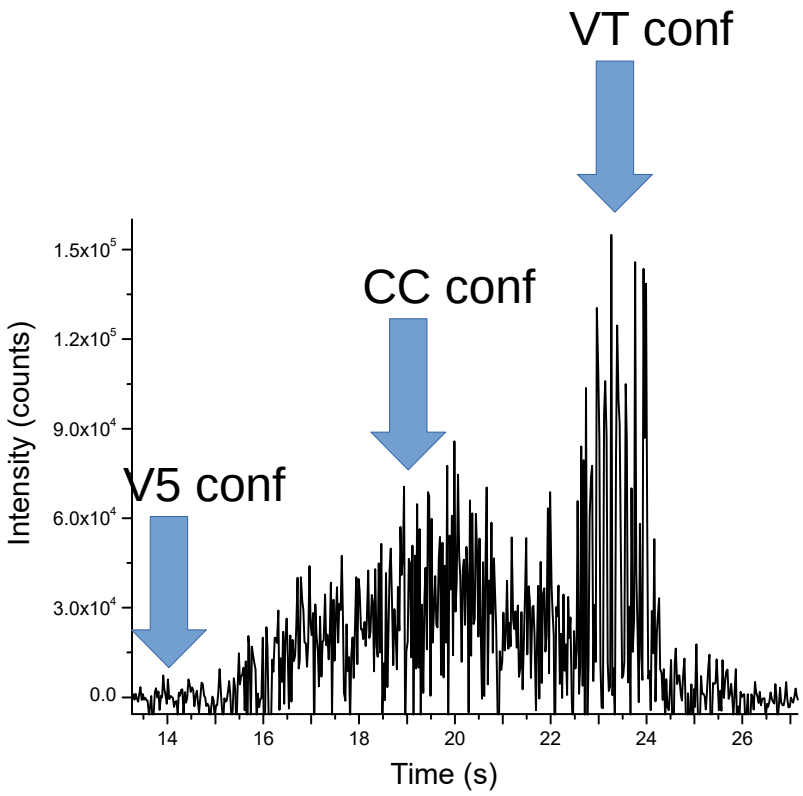


Why did we see it now, not before?

- **Changes in the vertical line of sight position**



- **W VII intensity dependent on configuration**



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W Temperature and density

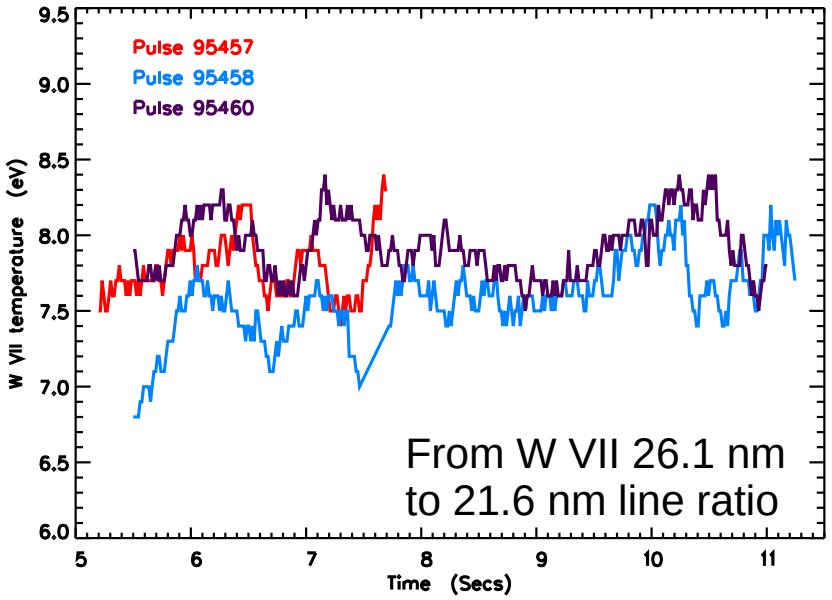
- **Temperature estimation from W VII line ratio**
  - 3.3T, 2 MA, from 6.6 to 18.7MW NBI, from 3 to 6.4 MW RF

$$I_{ij} = n_e n_g \varepsilon_{ij}(T_e, n_e)$$

PEC (ADAS)

$$c_W = \frac{4\pi I_{ij}}{n_e^2 l \varepsilon_{ij}}$$

$n_e = 10^{20}$ m^{-3}
l = 0.1 m



94605	94645	95460	95463
Electron temperature of **W VII** plasma emitting region (eV)			
9.68	9.50	9.09	9.03
W concentration from **W VII** line intensities			
$2.77 \cdot 10^{-3}$	$9.42 \cdot 10^{-4}$	$1.15 \cdot 10^{-3}$	$1.15 \cdot 10^{-3}$
Electron temperature of **W VI** plasma emitting region (eV)			
3.93	3.46	3.89	3.87
W concentration from **W VI** line intensities			
$1.13 \cdot 10^{-1}$	$7.83 \cdot 10^{-2}$	$2.54 \cdot 10^{-2}$	$2.56 \cdot 10^{-2}$

Estimated W concentration of 10^{-3} to 10^{-1} too high – atomic constants?

Conclusions

- **XUV UTA spectrum**
  - Temperature dependent, estimation working and widely used
- **VUV UTA spectrum**
  - Used as an indicator, no data about temperature dependence, no data for concentration estimation
  - Overlaps with lines from different elements
  - In JET – the only one available for horizontal l-o-s
- **VUV W lines (W VI to W VIII)**
  - New-observed SOL feature visible by vertical l-o-s
  - T_e estimation is reasonable, but W density most probably overestimated
- **Experimental problem – vertical l-o-s spectrometers are a scarce resource in T campaigns**