Quantification of Tungsten Sputtering at W/C Twin Limiters in TEXTOR with the Aid of Local WF_6 Injection

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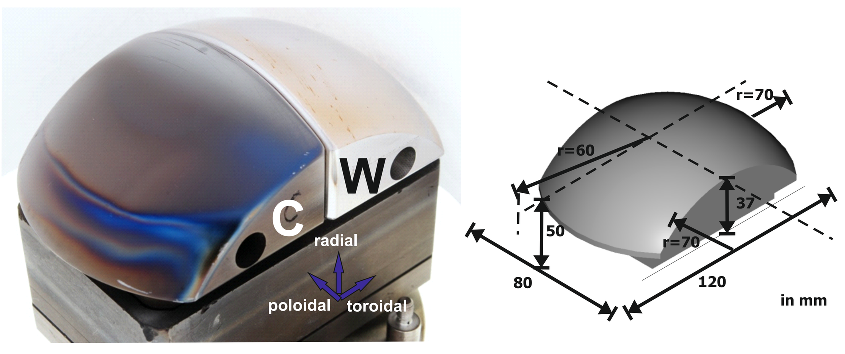
Introduction

Tungsten is the most promising material candidate for the divertor plasma-facing components in the activated operation phase of ITER. An important issue for the qualification of W as plasma-facing material is the quantification of the W source strength, which is connected to the components lifetime and, finally, to the W core accumulation. W sputtering is dominated by impinging intrinsic impurities such as O or C or seeding species like N.

A dedicated experiment to study the W and C sputtering under plasma impact was carried out in TEXTOR with the aid of a spherical limiter in twin limiter design: one half made of W and the other of C. The limiter, installed in the PWI-facilty and positioned in the near scrape-off layer, was exposed to a set of plasma discharges with variations of edge plasma parameters with T_e from 30 to 85 eV owing to strong gas fuelling. Neutral W light was recorded and transferred to W sputtering fluxes and erosion yields by means of measured effective photon efficiencies. The later have been determined experimentally by local WF_6 injection and observation of WI emission in TEXTOR under comparable experimental conditions. Experimental and modelled photon efficiencies (GKU code) are compared.

Experiment: W sputtering at W/C twin limiters in TEXTOR

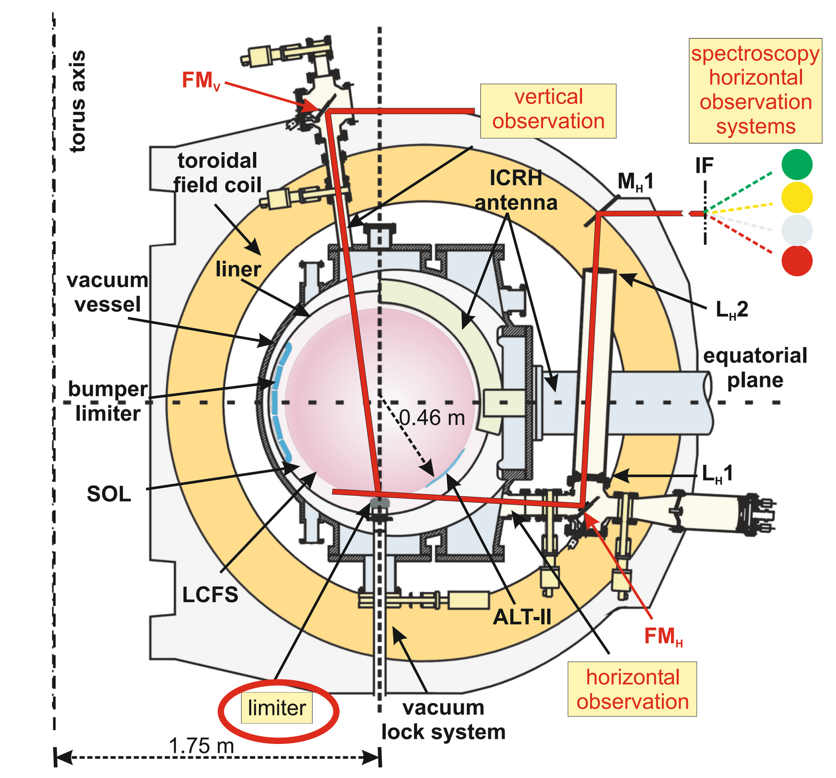
W/C twin limiter



Experimental settings

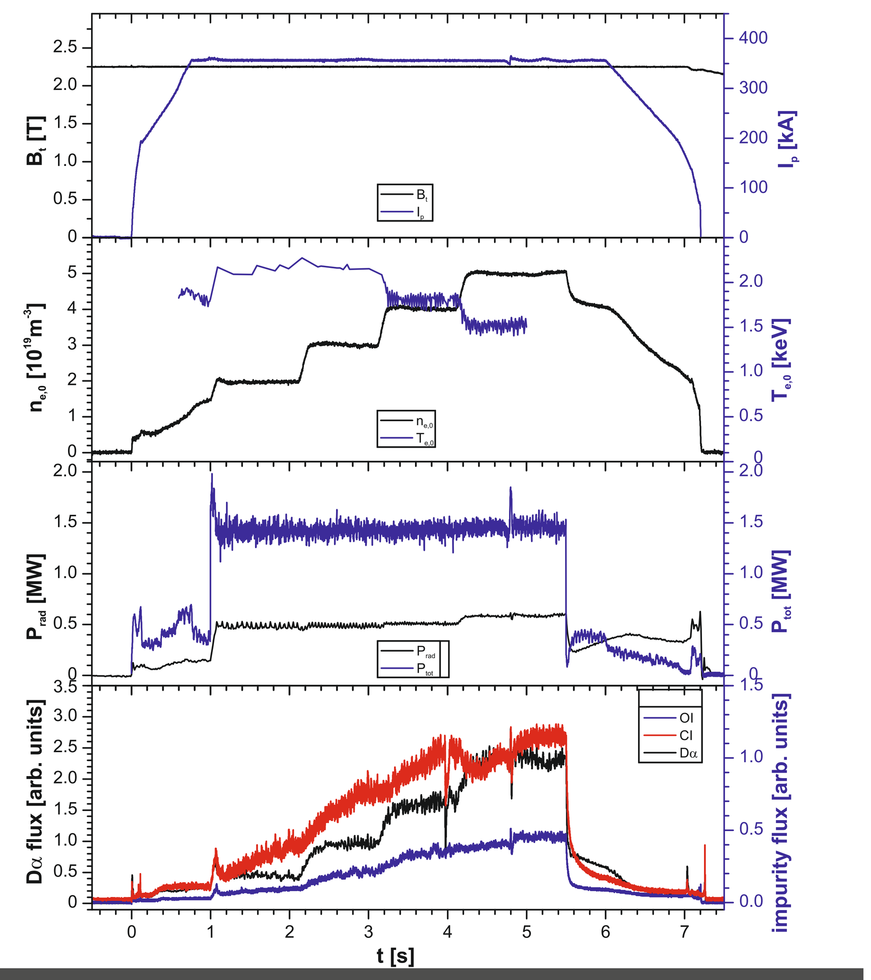
- Sperical limiter design: C and W halves (rotatble)
- Limiter installed in the vacuum lock system
- Limiter positioned close to the LCFS in the near SOL
- Deuterium fuelling
- L-mode plasmas with 1.5 MW NBI (H beams)
- B_t=2.25 T, I_p=0.35 MA
- 4 density steps per discharge (2,3,4,5x10^{19}m^{-3})
- Repetition of discharges for full diagnostic coverage

TEXTOR - poloidal cut and lock system



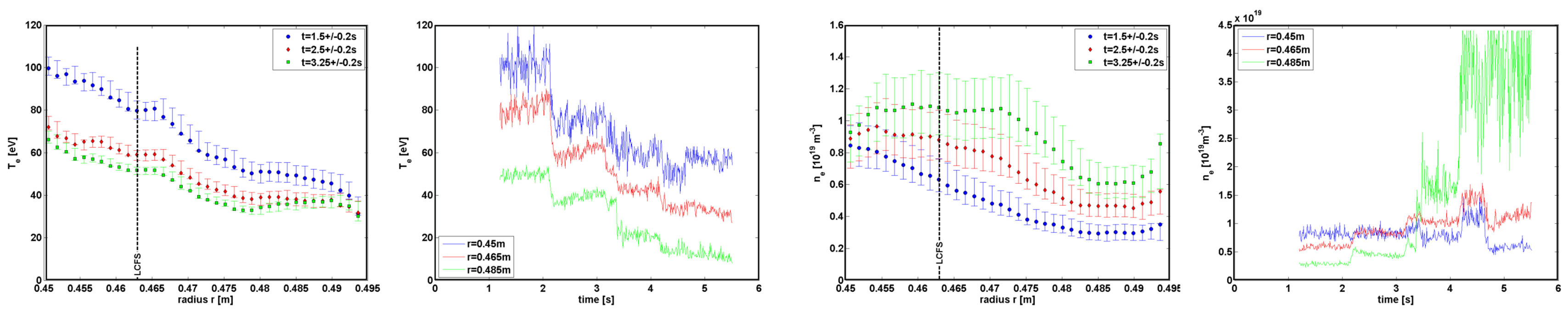
- 2D ICCD camera with interference filters
- 1D radially resolved spectrometer at injection
- Overview spectrometer: photon flux distribution
- Compact spectrometers: temporal flux evolution

Global parameter - twin limiter experiment



Edge plasma conditions

- Edge plasma parameters determined by He-beam diagnostic at outer midplane

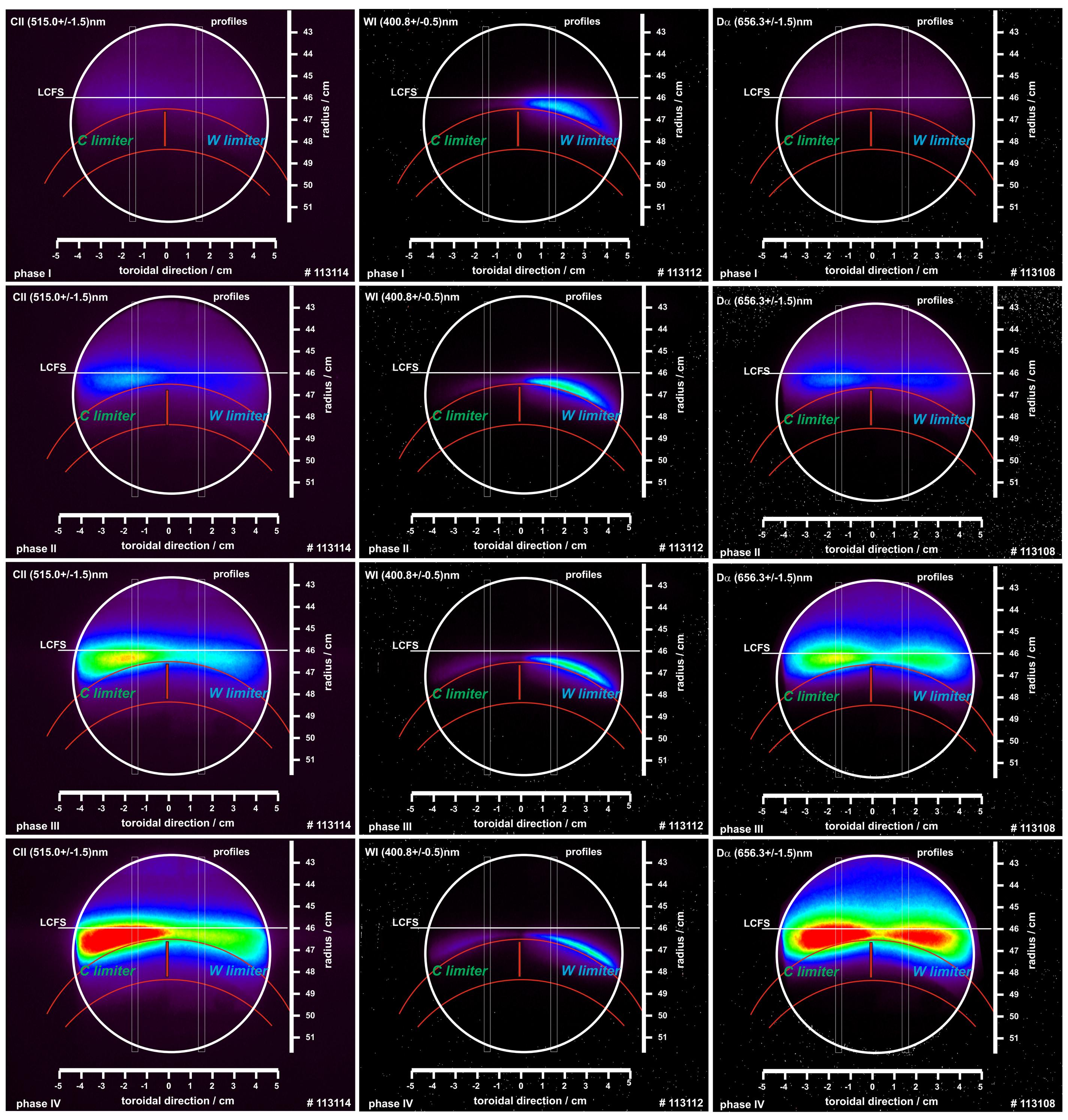


- Four plateaus with different pairs of edge T_e and n_e:
phase I: T_e~85 eV ▪ phase II: T_e~60 eV ▪ phase III: T_e~45 eV ▪ phase IV: T_e~30 eV

Experimental results: Spatial distribution with filtered cameras (side view)

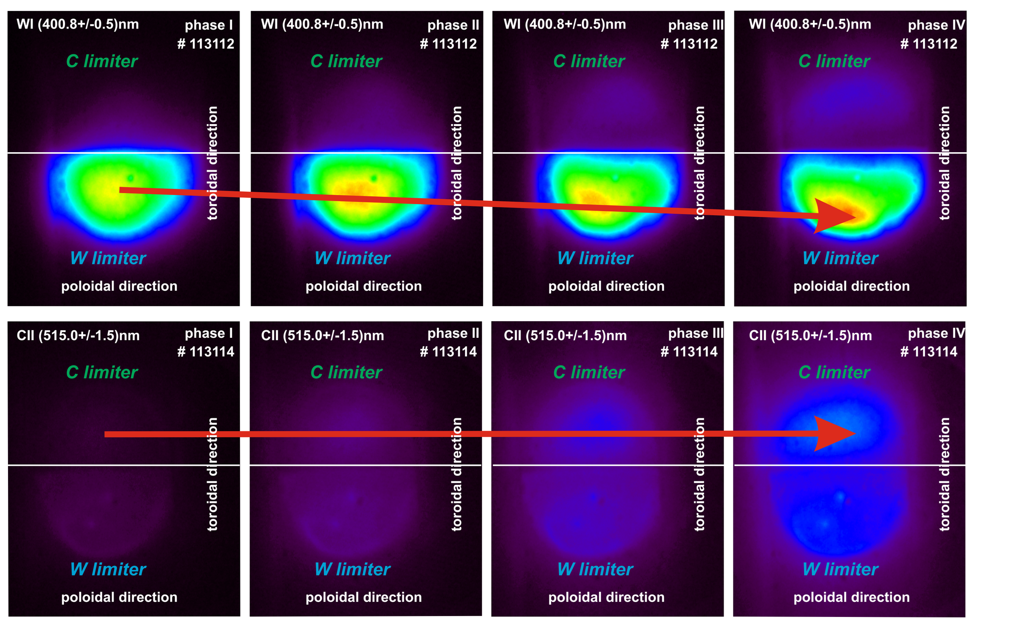
- Decrease of WI emission with decrease of local electron temperature, but with increase of impurity flux (~CII) and ion flux (~Dα)
- Short penetration depth of WI emission (<0.4mm), peaked close to the surface
- Shift of interaction zone to larger impact angle with decreasing T_e and increasing Γ_i

Here:
C is facing the ids: ion drift side
W is facing the eds: el. drift side

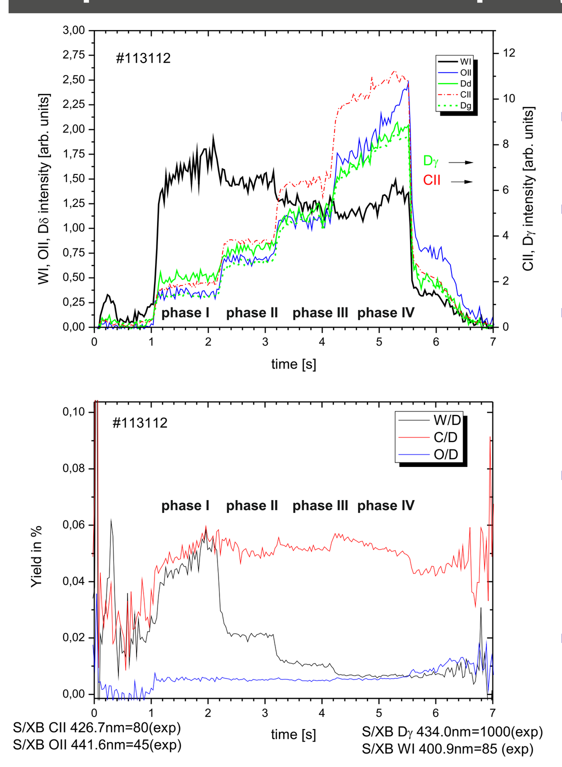


Experimental results: Spatial distribution with filtered cameras (top view)

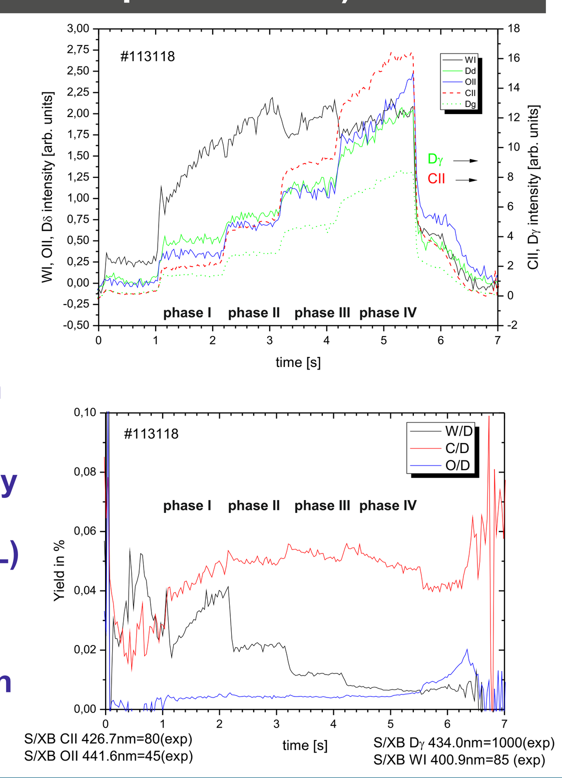
- C limiter faces ids and W limiter faces eds
- CII emission increases from phase I to IV with increasing ion flux: C sputtering by D
- Peak erosion zone remains at same position on the limiter (15mm away from apex)
- WI emission decreases from phase I to IV with increasing ion flux and impurity flux
- WI emission decreases with reduction of local plasma temperature: sputtering by C,O
- Cooling not sufficient to reach threshold for physical sputtering of W by impurities
- Peak erosion zone shifts to the location with larger impact angle (due to limiter curvature)



Experimental results: Impurity fluxes and erosion yields (integral from spectrometer)



- S/XB for CII assumed constant in exp. range: carbon impurity flux ~5.2%
- S/XB for OII assumed constant in exp. range: oxygen impurity flux ~ 0.5%
- S/XB for WI assumed constant in exp. range: W sputtering yields drops from ~5.0 % to ~0.6% with decrease of T_e from 85eV to 30eV
- W measurement in line with sputtering by an equivalent of C^{4+} ions (representing the sum of C and O impurities in the SOL) => V. Philipps JNM 1998
- Full analysis and modelling necessary to include variation in sputtering location and temperature profiles

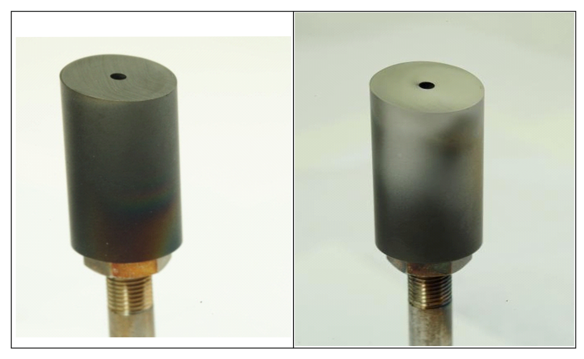


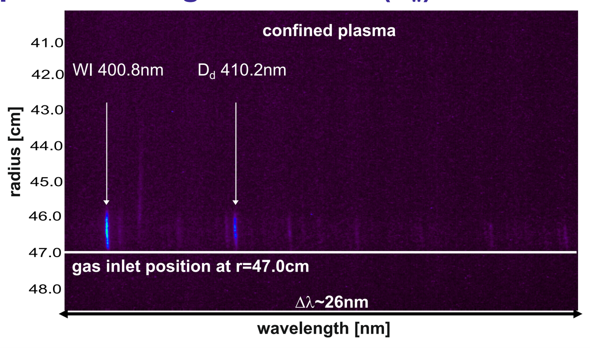
Experiment: WF_6 injection for W sputtering calibration

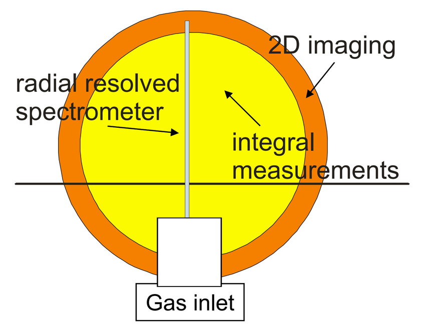
Photon efficiency calibration: WF_6 injection

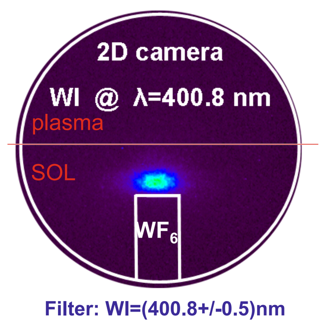
- Photon flux proportional to particle flux
- Proportionality factor: inv. photon efficiency S/XB
- Simulate W source by calibrated WF_6 injection
- Full ionising plasma conditions in TEXTOR edge
- Assumption: WF_6 dissociates quickly and produces W atoms comparable to sputtered W
- Analyse W line ratios to qualify initial population in the complex atomic ground state (T_w)

Diagnostic set-up

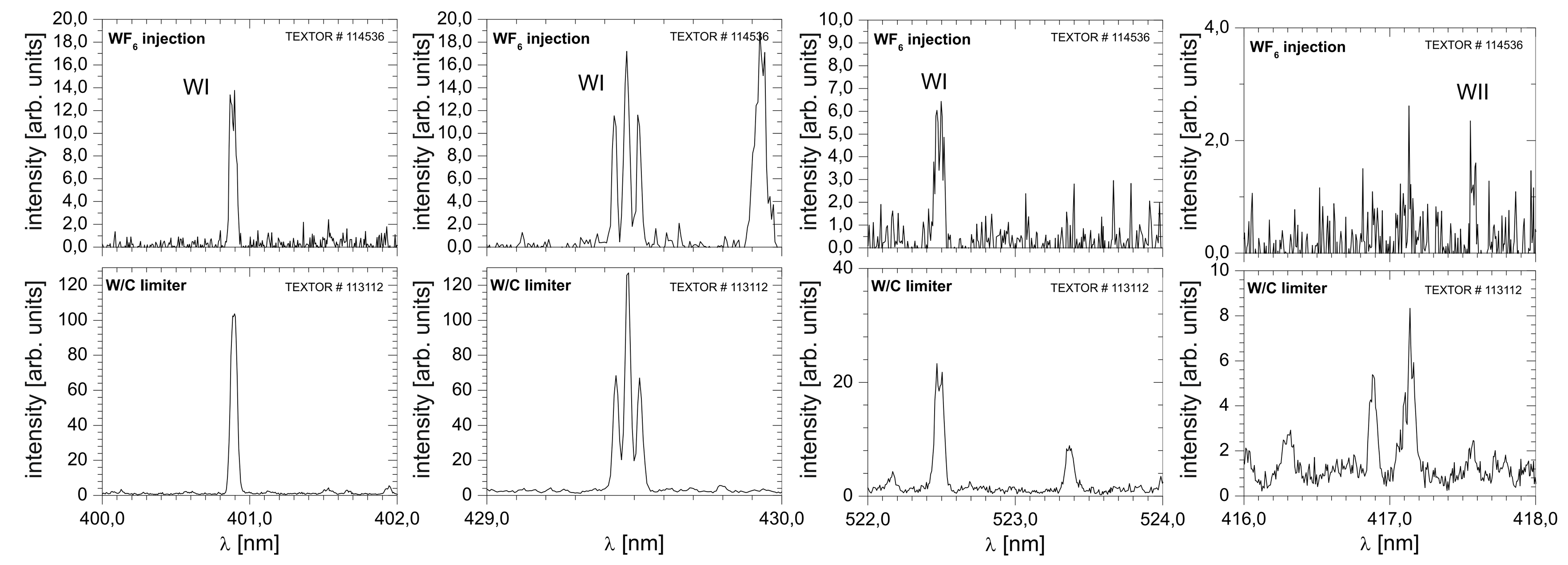








WI and WII spectra comparison between injected and sputtered W



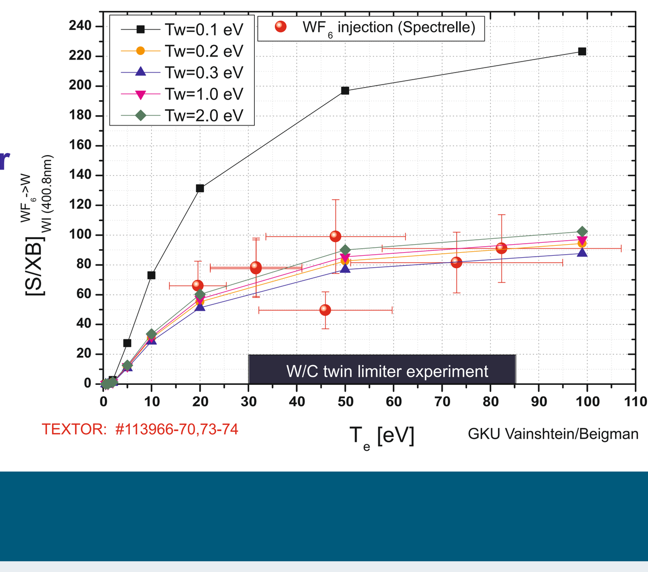
- Complete spectrum coverage from 363 nm-715 nm. More WI lines identified and quantified: model benchmark
- WII lines identified and quantified at 434.8 nm, 417.5 nm, 385.2 nm
- Line ratio of WI to WII lines is different between injected and sputtered W => issue of prompt redeposition

Effective photon efficiency for WI (400.8 nm) ouf of WF_6

- Measured eff. photon efficiencies show moderate reduction with T_e in the TEXTOR experimental range
- Averaged value for W/C twin limiter experiment is for WI at 400.8 nm

about 85 = $[S/XB]^{WF6\rightarrow W}_{WI\ at\ 400.8nm}$

- Fraction of injected WF_6 could be dissociated and deposited in gas inlet => eff. S/XB is upper limit



- Normalisation on WI at 400.8 nm
- The effective photon efficiencies

WI at 429.5 nm => ~80

WI at 505.2 nm => ~245

are in fair agreement with GKU modelling but higher than values deduced in PISCES-B [Nishijima 2010]

Summary

W/C twin limiter exposed in the PWI facility to TEXTOR edge plasma with four T_e steps between 30eV and 85eV
Impurity fluxes and erosion yields deduced in-situ by spectroscopy:
- Reduction of the W sputtering yield from ~5.0% to ~0.6% with decrease in T_e
- Increase of C and O fluxes in the four steps. Flux ratio of C/D and O/D remains almost constant
- W sputtering mainly by impinging C and O ions. Seeding required to reach physical threshold for W
- Pentetration depths and emission pattern of W, C, D determined. Input for ERO modelling

WF_6 injected through a gas inlet inthe PWI facility in TEXTOR to mimic W source
- WF_6 dissociates quickly and provide well-known source of W atoms (population to be determined)
- Effective photon efficiencies for various WI lines obtained and compared with GKU modelling
- Effective photon efficiencies applied to W/C twin limiter experiment

Experiments with impurity seeding by nitrogen started to reduce the local T_e further

This work was done in the frame of the IEA-TEXTOR Agreement on Plasma-Wall Interaction and the EU Task Force on Plasma-Wall Interaction