# Investigation of the Extreme-UV background emission in WEST tokamak

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## Background & Motivations

➤ Tungsten (W) density can be determined experimentally from its spectral line brightness [1]:

$$B_{ij} = \int n_e N_W f_z C_{ij}\, dl$$

- Errors in line brightness determination due to background estimation.

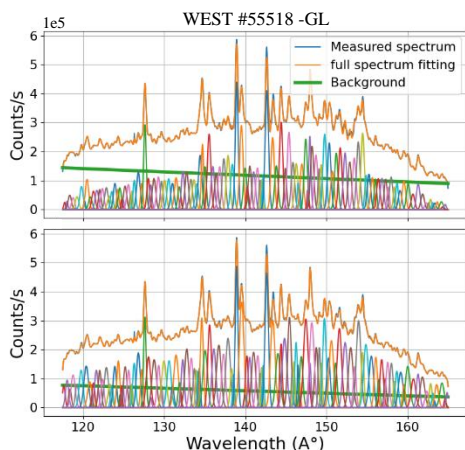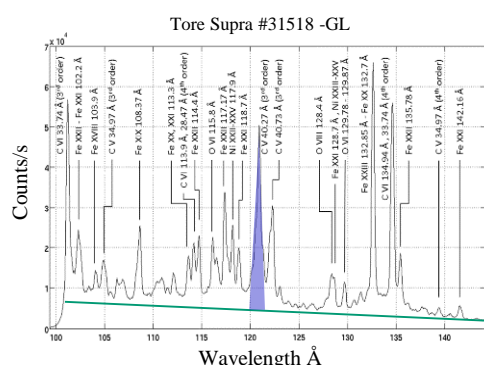• Low Z spectra (Tore Supra):

- Small background compared to lines.

➡ Minor role on brightness values. Uncertainties are small.

• High Z spectra (WEST):

- Apparent background is not small.
- Fitting procedure results depend strongly on the initial guesses.

➡ What is the background real value ?


Tore Supra #31518 -GL


WEST #55518 -GL

We attempt to answer this question by assuming that the measured spectrum $B_{tot}$ (in the wavelength region 115-165 Å) is composed of:

$$B_{tot} = B_{line} + B_{ff} + B_{fb} + B^{m>1}$$

Bremsstrahlung — Recombination radiation — Higher diffraction orders emission

## Higher diffraction orders emission

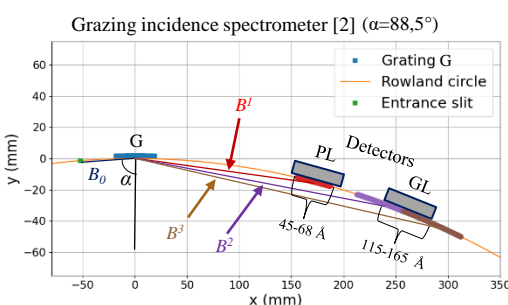➤ Light propagation Inside the spectrometer:

$$B^m(m\lambda) = B_0 E_G^m(\lambda) E_D(\lambda)$$

Measured brightness — Grating efficiency — Detector efficiency

$$\frac{B^{m>1}(m\lambda)}{B^1(\lambda)} = \frac{E_G^{m>1}(\lambda)}{E_G^1(\lambda)} \frac{E_D^{GL}(\lambda)}{E_D^{PL}(\lambda)} = K^{m>1}(\lambda)$$
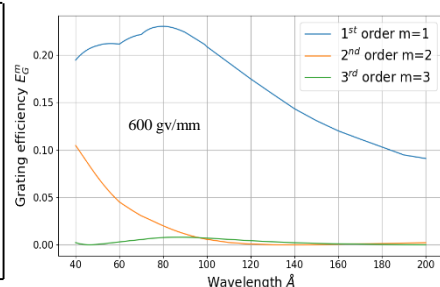
$$B^{m>1}(m\lambda) = B^1(\lambda) K^{m>1}(\lambda)$$

Higher orders — First order


Grazing incidence spectrometer [2] ($\alpha$=88,5°)

### Grating efficiency simulation

• Differential method [3]
• Wavelength region : $\lambda = 40 - 200$ Å
• Grating parameters:

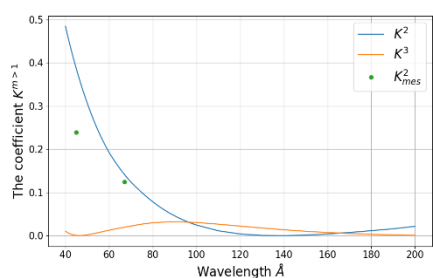| Grating length | Grating radius | Incidence angle $\alpha$ | Blaze angle | Coating |
|---|---|---|---|---|
| 35 mm | 1999.5mm | 88.50° | 1.5° | Gold |



➤ $K^{m>1}(\lambda)$ coefficient :

relates the spectrum brightness of a particular order m $B^{m>1}$ to the first order spectrum $B^1$.

- Identical detectors (their efficiency ratio ~1)
- Good agreement:
  2nd order $K^2$ calculations and measurements.
- Errors : concave grating aberrations (5-15 %).
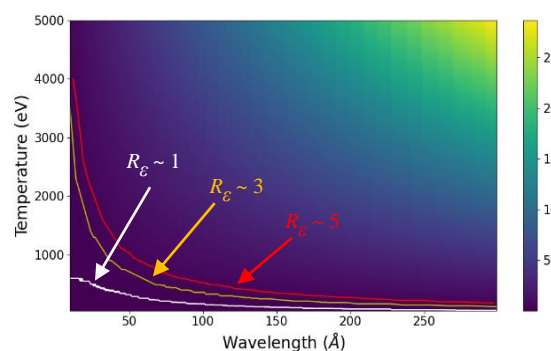


## Bremsstrahlung & recombination radiation

### Continuum emission calculations (ff, fb)
• Maxwellian emission coefficients ($C_{ff}$, $C_{fb}$) [4].
• Impurity : tungsten (Z=74).
• Wavelength range : $\lambda = 10 - 300$ Å.
• Temperature range : $T_e = 50 - 5000$ eV.

➡ Reasonable and fast estimation of the two processes

➤ The comparison of Bremsstrahlung (ff) and radiative recombination (fb) is done by calculating the local emissivity ratio $R_\varepsilon$ of the two processes:

$$R_\varepsilon = \frac{\varepsilon_{ff}}{\varepsilon_{fb}} = \frac{\sum_z f_z C_{ff}^z}{\sum_z f_z C_{fb}^z}$$



- $\lambda < 50$ Å: fb is not negligible and can be dominant below 500 eV.
- $\lambda > 50$ Å: fb is negligible with respect to ff for almost all temperatures ($\lambda$=115-165 Å in particular).

➤ Total Bremsstrahlung [5] :

$$\varepsilon_{ff}(\lambda) = 9.584.10^{-14} \frac{n_e^2}{\lambda \sqrt{T_e}} Z_{eff} \overline{G_{ff}} \exp\left(-\frac{hc}{\lambda T_e}\right)$$

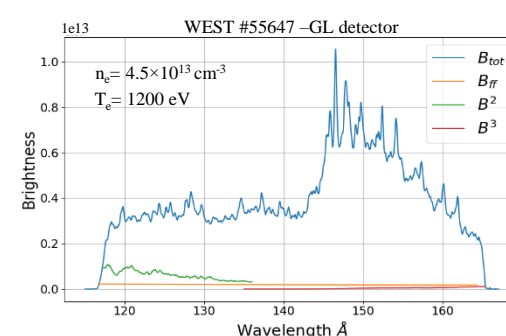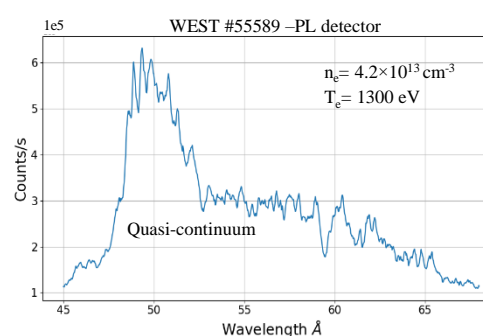## Analysis of a low temperature spectrum ($T_e \sim 1$ keV)

➤ Application to spectrum measured by GL (115-165 Å) during the discharge #55647:

Higher diffraction orders $B^2$ and $B^3$
- Estimated using a spectrum measured by PL (45-68 Å) during the discharge #55589.

Bremsstrahlung $B_{ff}$
- Evaluated using #55647 plasma parameters and $Z_{eff}$=2.5.


WEST #55589 –PL detector


WEST #55647 –GL detector

➤ Bremsstrahlung ($B_{ff}$) is negligible.   ➤ 2nd order $B^2$ may contribute to the spectrum.
➤ spectral lines dominate the emission (merge into an apparent background ?).
➤ Individual lines wavelengths above 145 Å correspond very well with those of 47-53 Å quasi-continuum, which casts some doubt on the 3rd order calculation.

➡ Uncertainties in line brightness (therefore W density) determination may not be small.

## Conclusion & Perspectives

➤ In the wavelength region 115-165 Å at low temperatures (Te ≈ 1 keV) :
- Continuum emission (Bremsstrahlung and recombination) is very weak.
- Higher diffraction order emission may contribute to the spectra.
- Spectral lines dominate the emission.

$$B_{tot} = B_{line} + \cancel{B_{ff}} + \cancel{B_{fb}} + B^2 + B^3$$

➤ What about spectra measured in different wavelength and temperature ?

References:
[1] R. Guirlet, et al. Plasma Physics and Controlled Fusion, 2022.
[2] J.L. Schwob, et al. Review of scientific instruments 58.9: 1601-1615, 1987.
[3] E. Popov, M. Neviere. J. Opt. Soc. Am. A, 18, 2886–2894, 2001.
[4] A. Burgess, H.P. Summers, Monthly Notices of the Royal Astronomical Society, 226(2):257–272, 1987.
[5] M.E. Foord, et al, Review of Scientific Instruments, 53(9), 1407-1409, 1982.