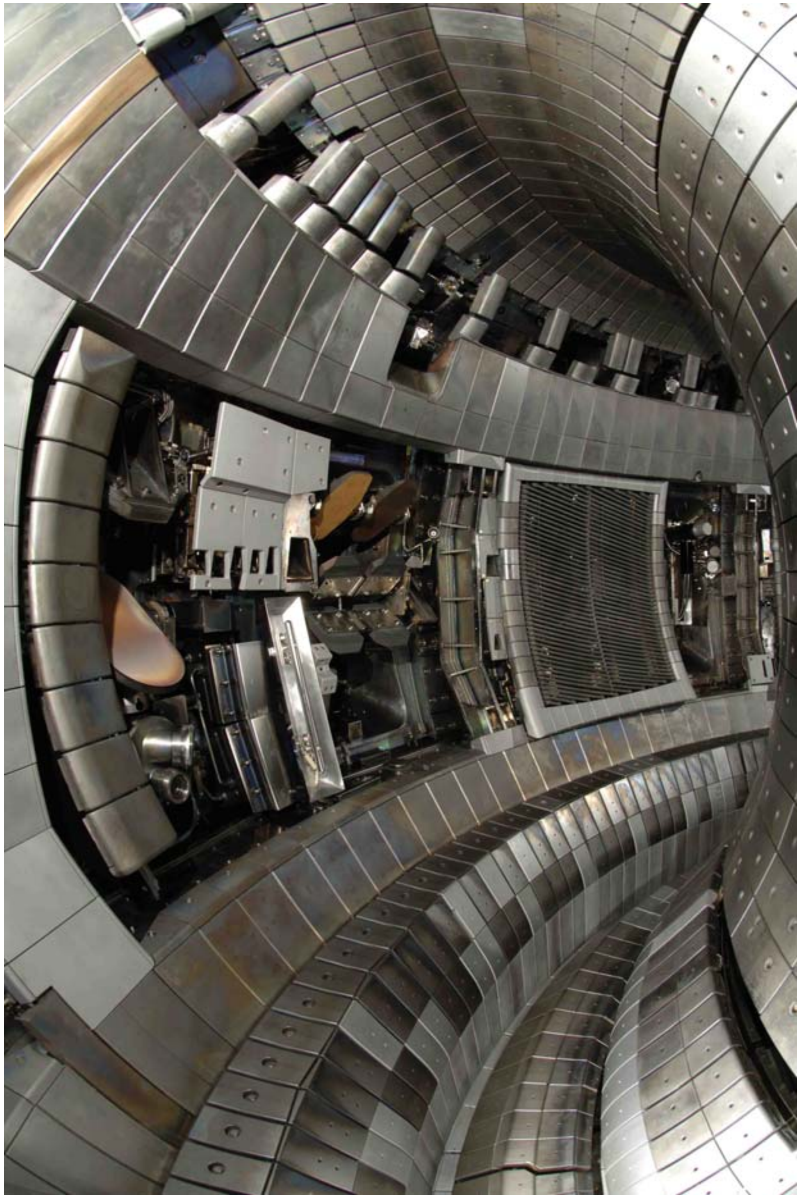
Tungsten Influx Measurements at ASDEX Upgrade

R. Dux,
R. Pugno, T.Pütterich, ASDEX Upgrade Team

AUGD with W-Coated Plasma Facing Components (PFC)



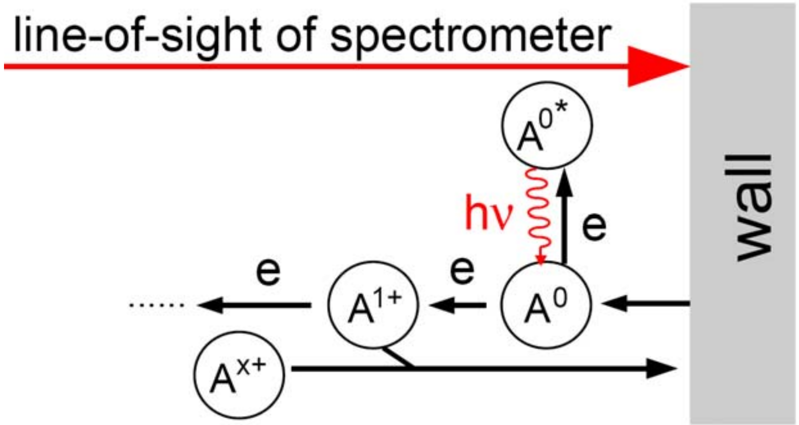
Spectroscopy of W

Quantify W-content inside confined plasma:

- VUV/X-Ray
- W density approx. constant on flux surfaces

Quantify W-influx from various PFCs:

- visible spectroscopy
- Influx density is a local quantity (often toroidal symmetry)
- Many lines-of-sight needed to have full account of the total influx



Present Set-up for Spectroscopic Influx Measurements

Lines-of-Sight (LOS):

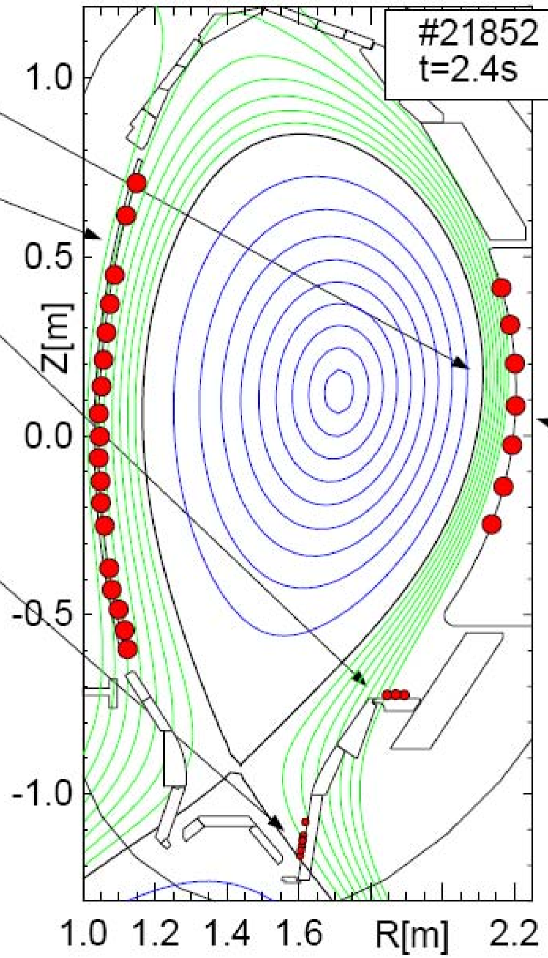
- 17 LOS on ICRH limiter (3.4ms)
- 18 LOS on central column (40ms)
- 6 LOS on horizontal plate (1.9ms)
- 7 LOS near strike point (1LOS:0.2ms, 6 LOS: 8ms)

Spectral Line:

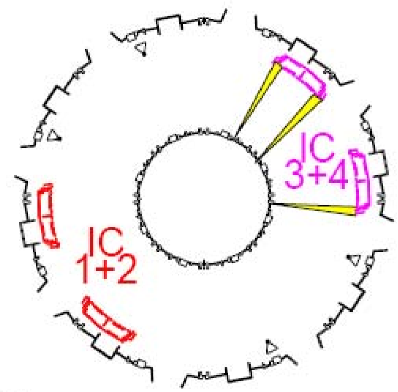
WI: λ=400.9nm [S/XB=20]

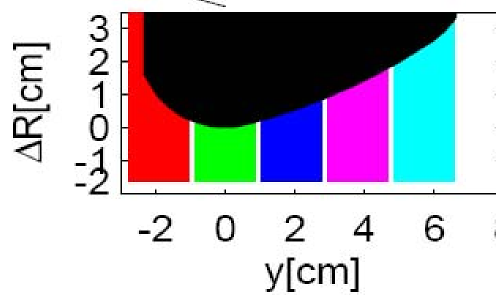
Ion flux:

Γ_ion=Γ_photon x (S/XB)



Observation of ICRH Limiters

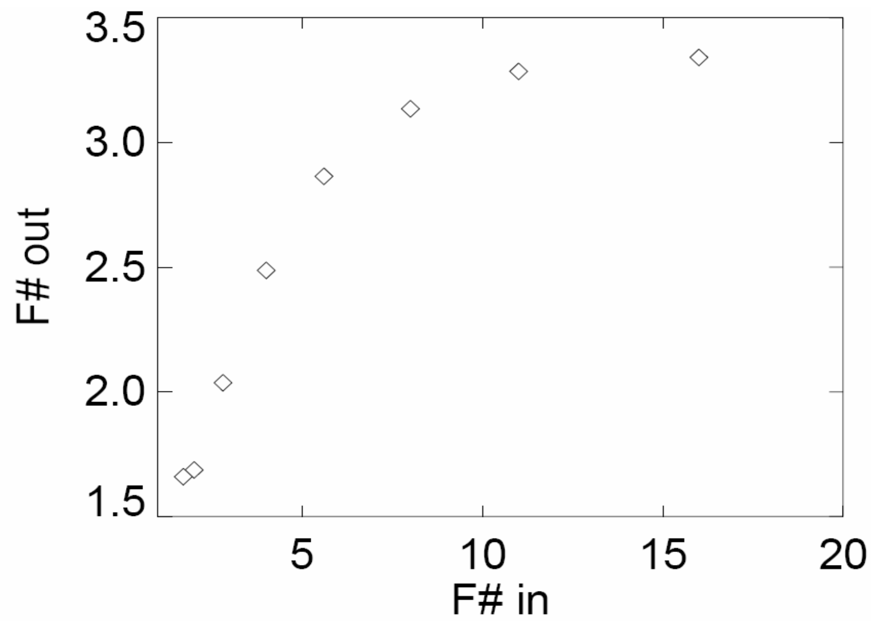


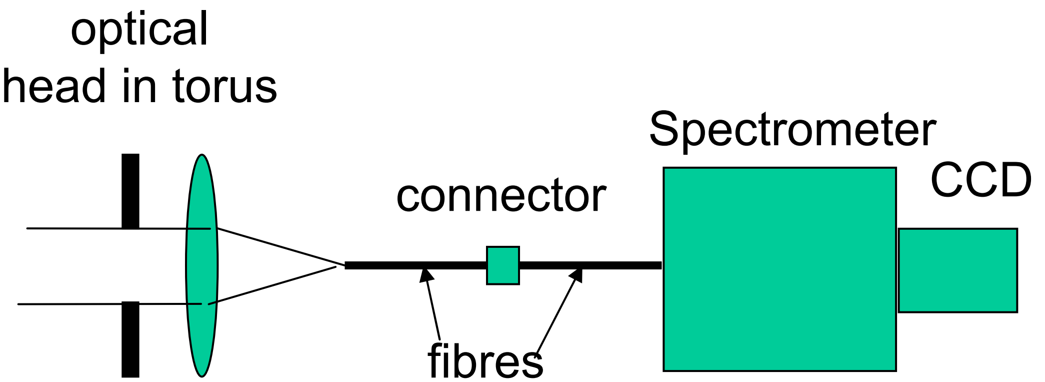


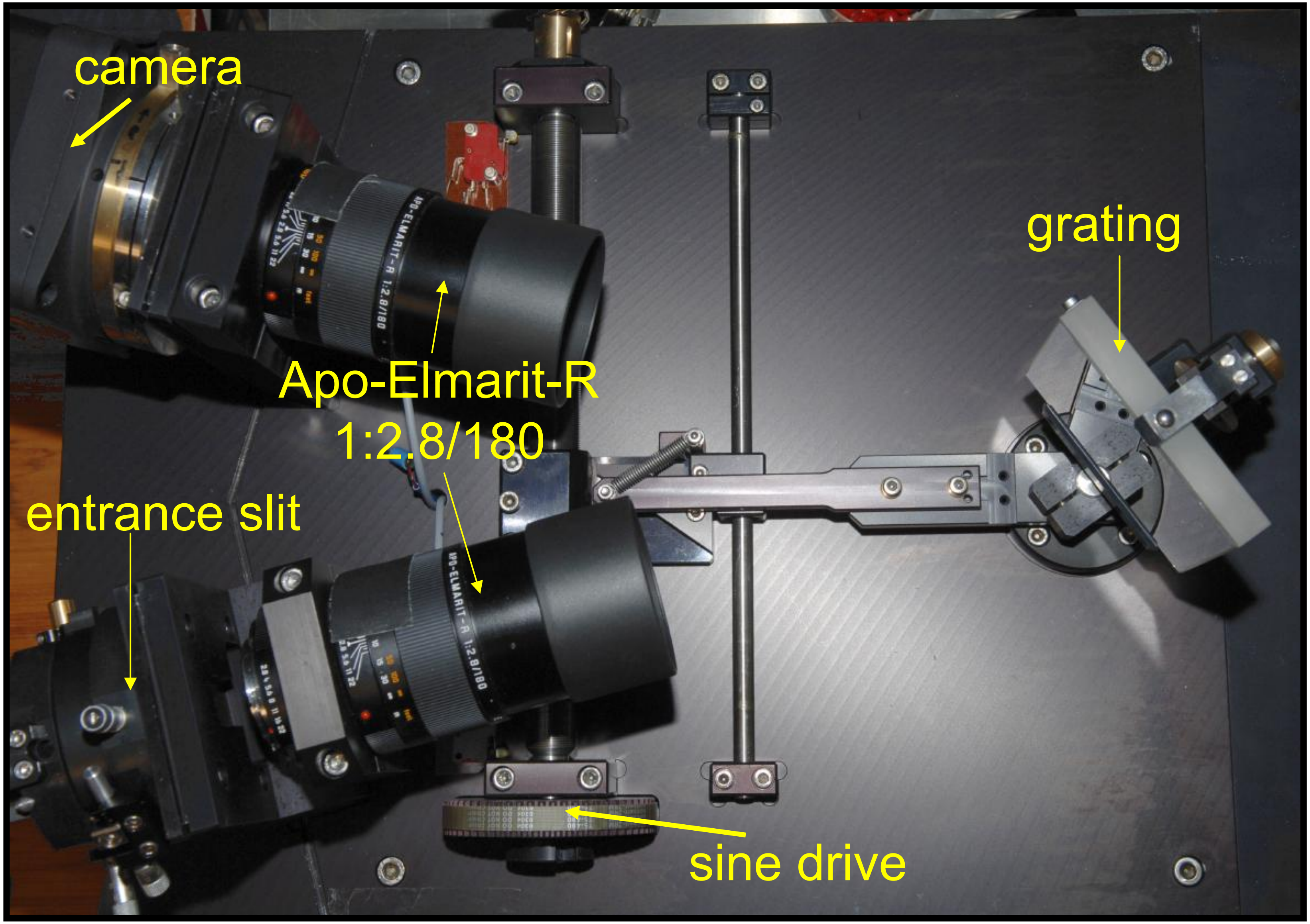
Sensitive detection of W-influx needs spectrometer with low F-number and good imaging quality

fibres: ø 400μm N.A=0.22, F#=2.3

- low f-number → F#=2.8
- good imaging quality
  commercial camera lenses
- moderate spectral resolution
  moderate focal length (180mm)
  open input slit as much as possible



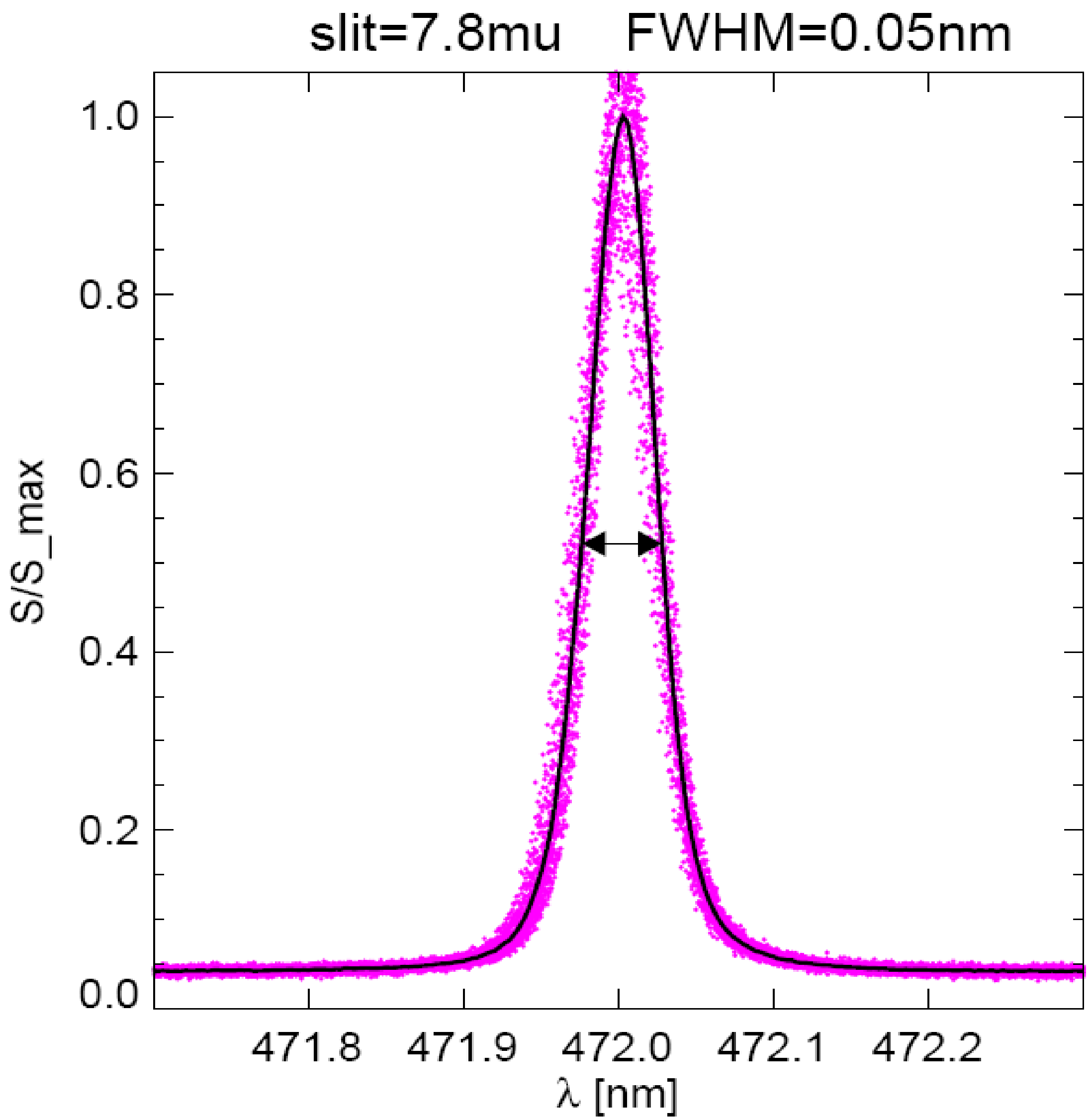



camera
grating
Apo-Elmarit-R
1:2.8/180
entrance slit
sine drive

Minimum line width

FWHM:
minimum image width 25μm

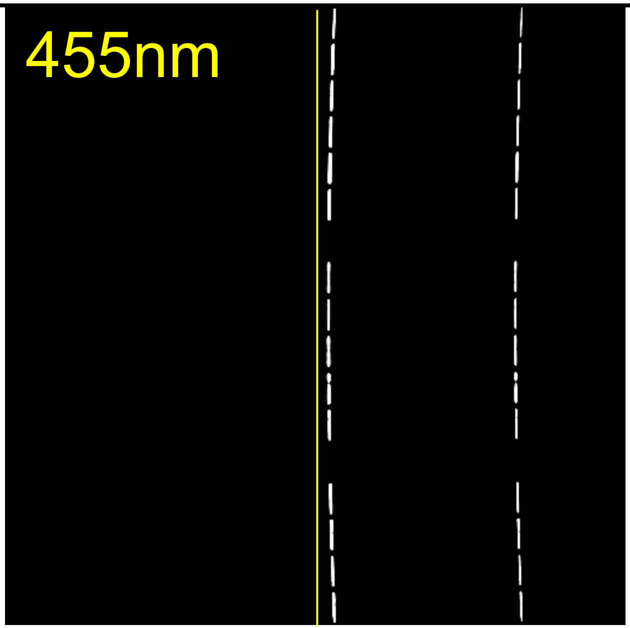
Gaussian profile

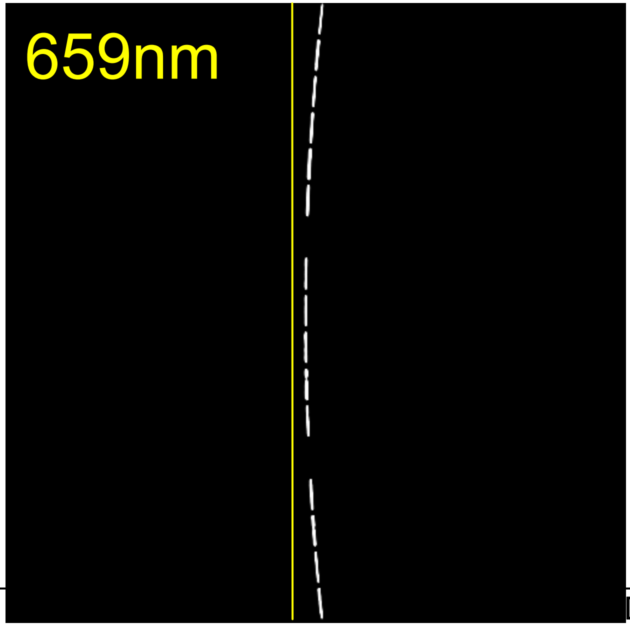


No astigmatism

17 channels on 8x8mm CCD

(line shift in slit direction due to small focal length)



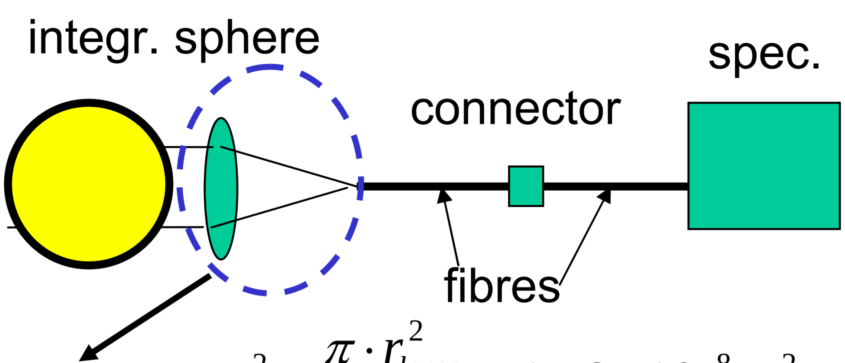


Sensitivity

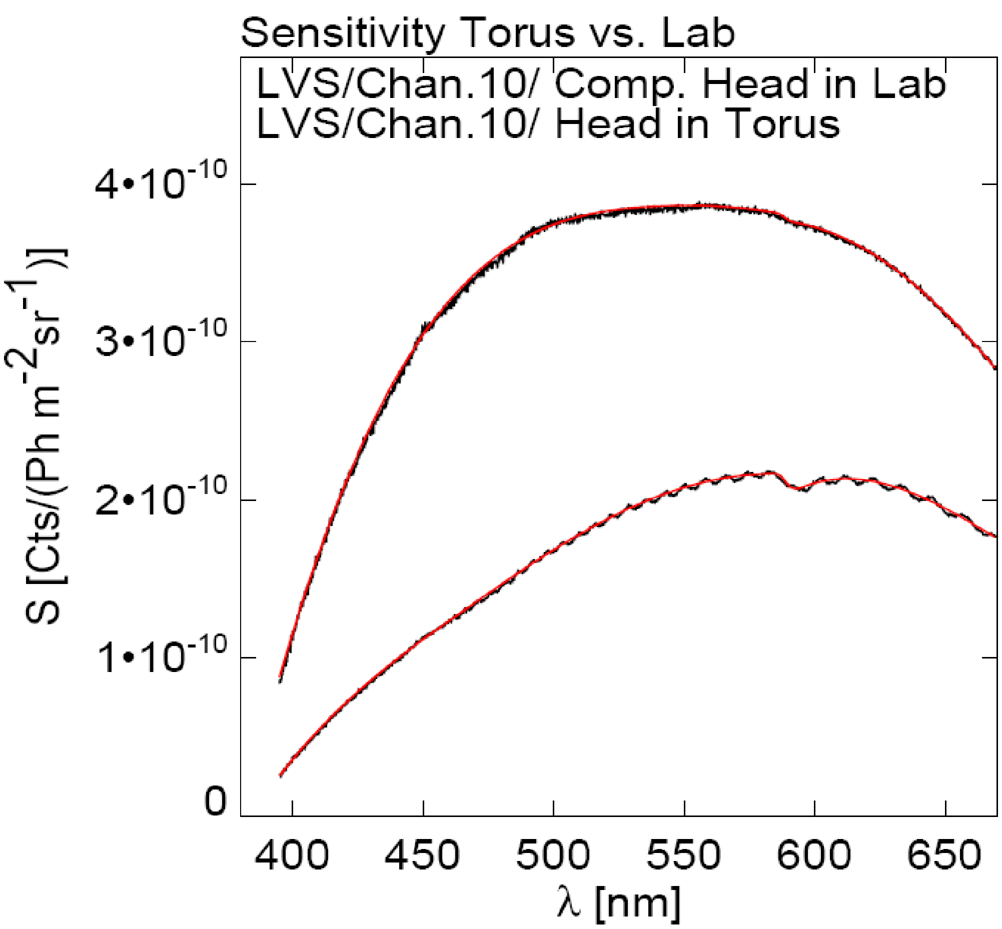
calibration of total setup with integrating sphere (standard for spectral radiance):

$$B_\lambda = \frac{\dot{N}_{ph}}{A \cdot \Delta\Omega \cdot \Delta\lambda} \qquad [B_\lambda] = \frac{\mathrm{Ph}}{\mathrm{m}^2 \cdot \mathrm{s} \cdot \mathrm{sr} \cdot \mathrm{nm}}$$

$$S = \frac{\dot{N}_{cts}}{B_\lambda \Delta\lambda_{pixel}} \qquad [S] = \frac{Cts}{\mathrm{Ph} / \mathrm{m}^2 \cdot \mathrm{sr}}$$



$$e_{\det} = \pi \cdot r_{fibre}^2 \frac{\pi \cdot r_{lense}^2}{f_{lense}^2} = 1.58 \times 10^{-8}\,\mathrm{m}^2\mathrm{sr}$$



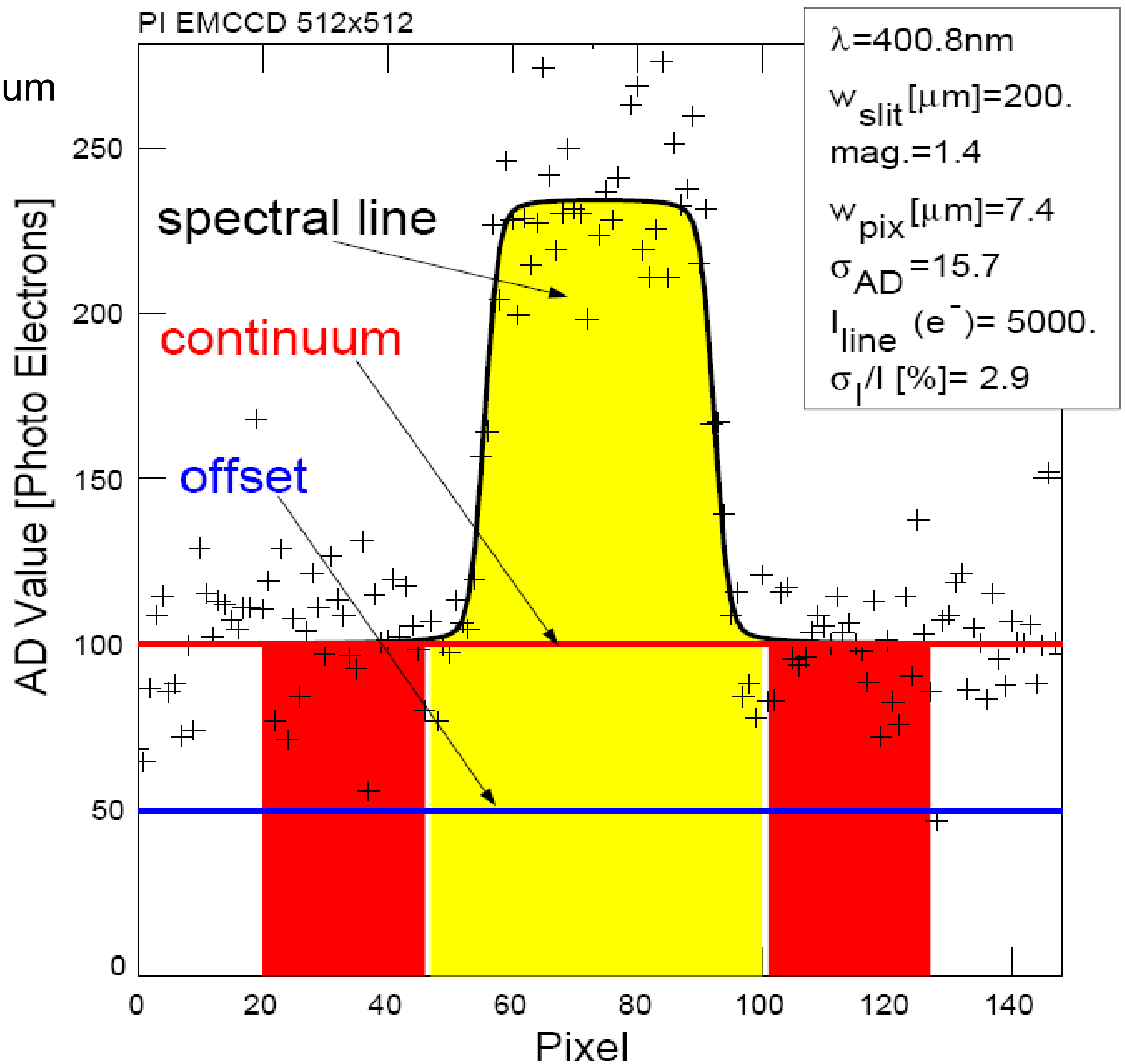
Detection limit: determination of area under spectral line

subtract background=offset + continuum (red intervals)

from

spectral line (yellow interval)

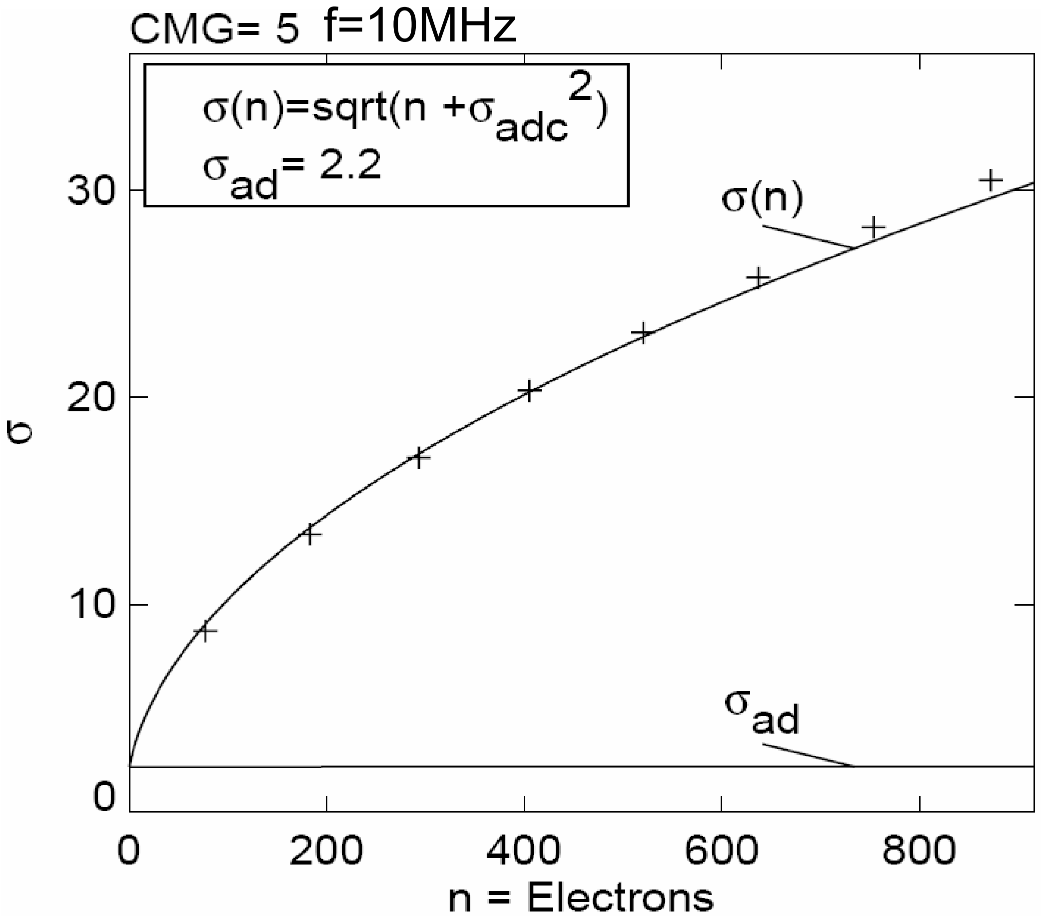
noise due to photon noise and AD-conversion



Detection limit: signal noise

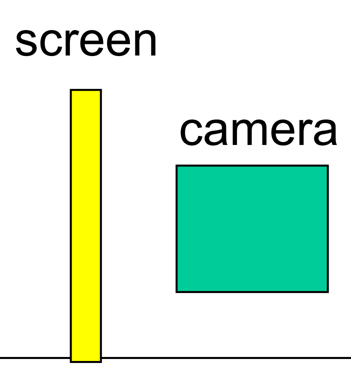
- AD-conversion noise
- photon noise

TI-CCD with charge multiplication

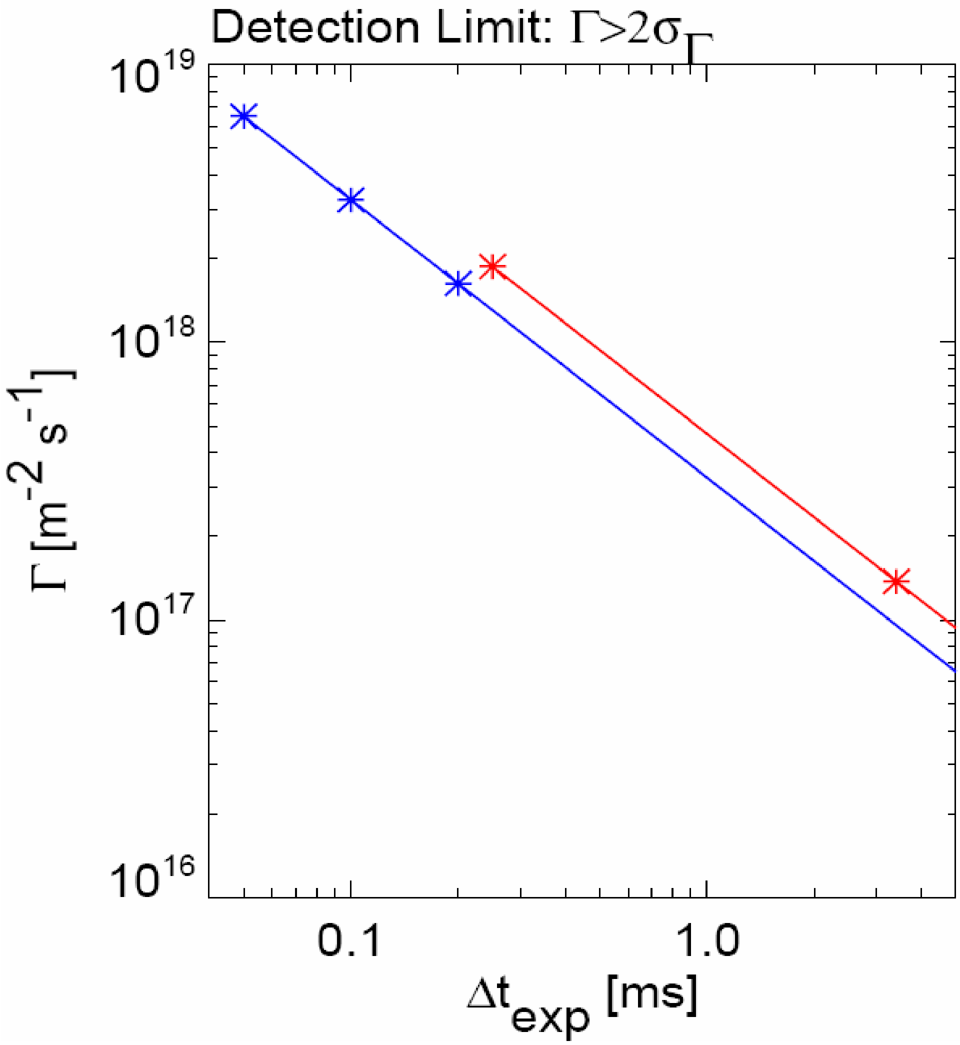


observe homogenously illuminated screen

- vary photon flux
- determine standard deviation
- σ-curve yields: # of AD-counts per photon and ADC noise



Detection limit



λ=401.nm W I S/XB=20.

LVS/L-09-04

npix= 24

σ_{ad}=15.5e$^-$

N_{min}= 216.

S= 1.2e-10e$^-$/(Ph m^{-2}sr^{-1})

DVS/RON014

npix= 50

σ_{ad}= 1.1e$^-$

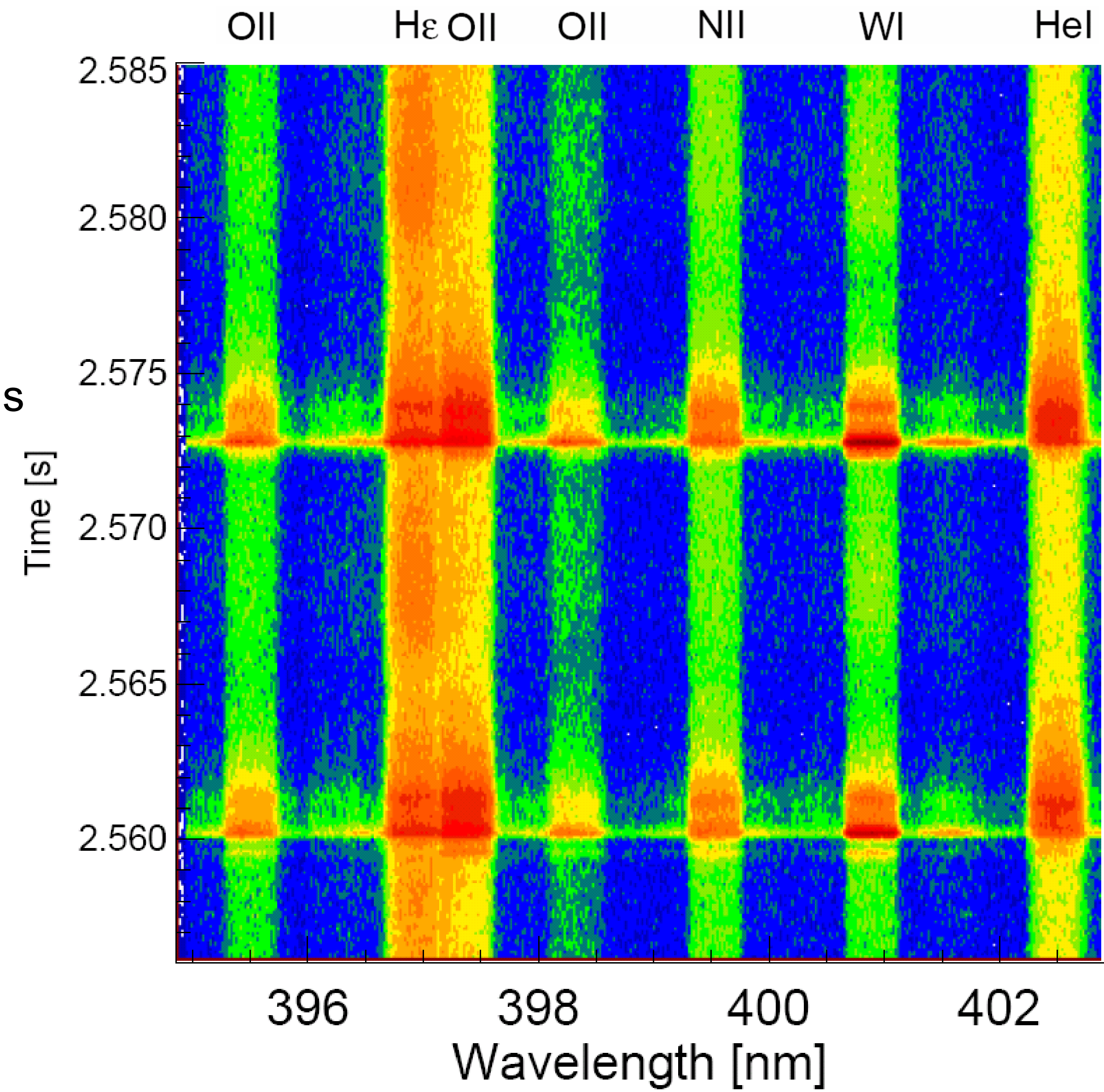
N_{min}= 24.

S= 1.9e-11e$^-$/(Ph m^{-2}sr^{-1})

Example of spectra evolution

spectrometer for fast measurements in divertor (1 line-of-sight)

- wide entrance slit (200μm)
- repetition/exposure time=0.2ms
- Balmer-ε surrounded by OII multiplet



Example of spectra evolution

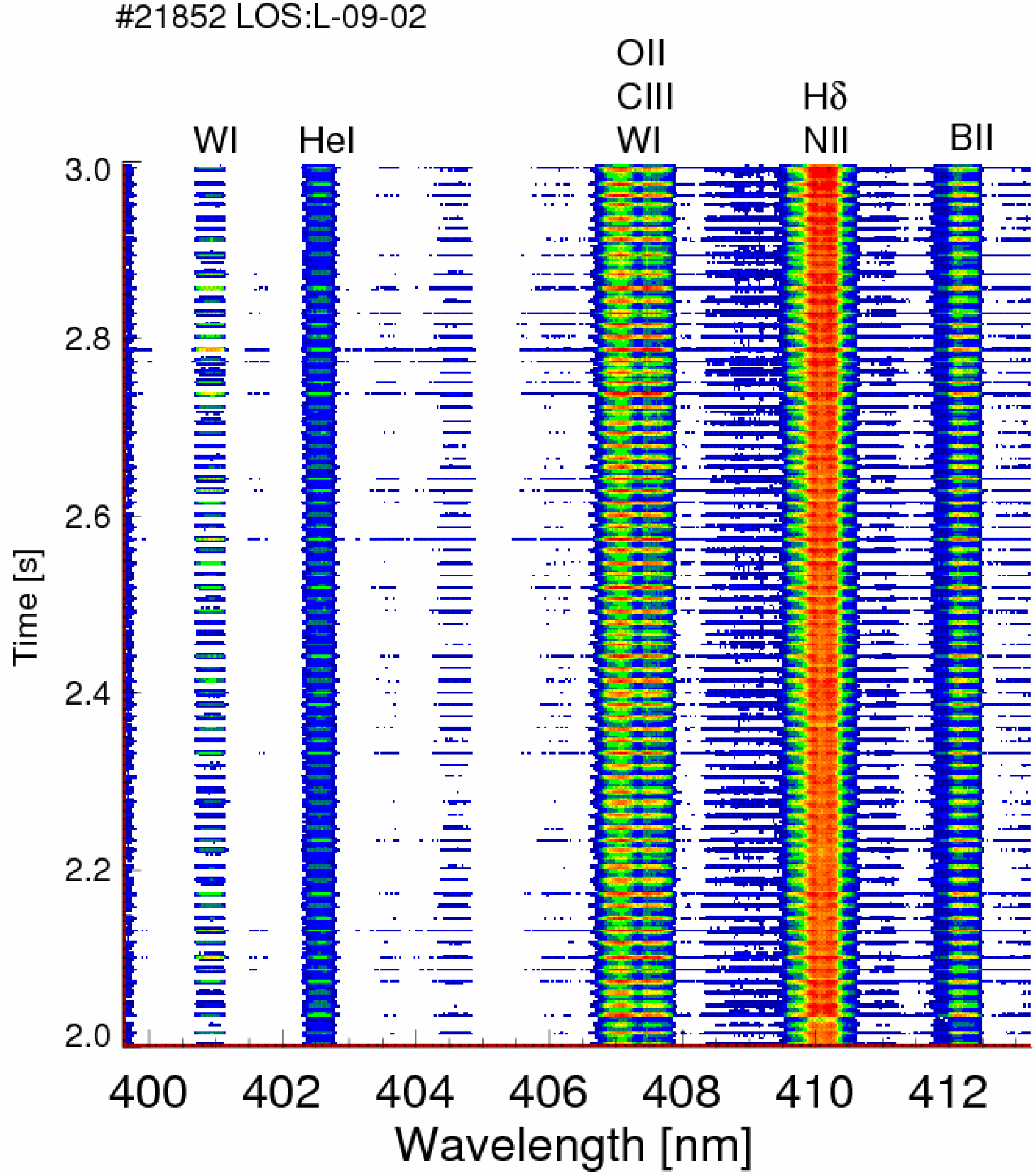
spectrometer for measurement at limiters (17 lines-of-sight)

• wide entrance slit (200μm)

•repetition/exposure time = 3.4ms

• WI line at 400.9nm quite well isolated

• many overlapping lines above 406 nm around Balmer-δ



Data Analysis: Fit of Spectra

Fixed Parameters:

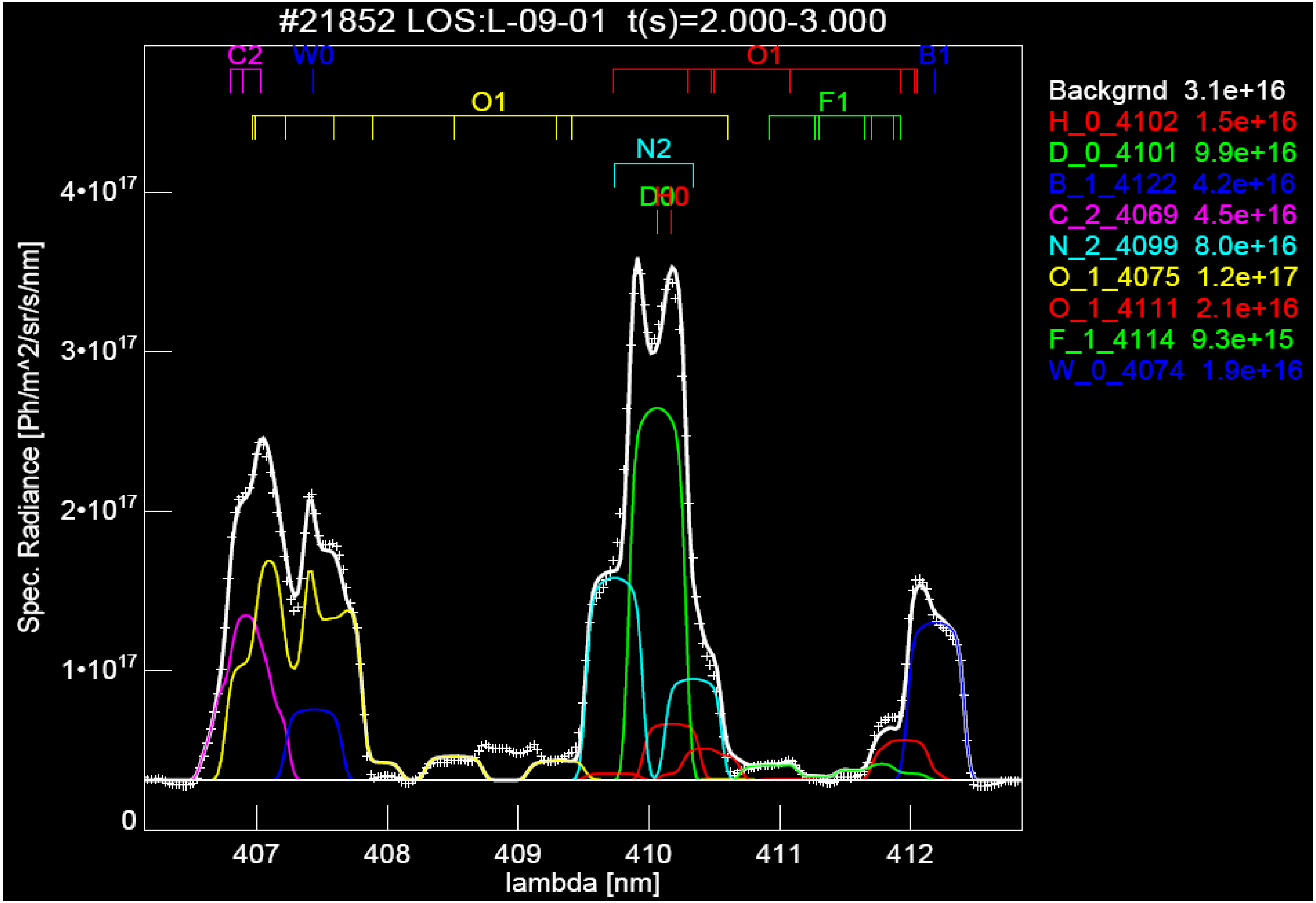
- line centres
- line shape = instrumental line shape (image of fibre area cut out by slit folded with Gaussian)
- relative line strength of lines from same multiplet (pre-computed using assumption of LS-coupling)

Fitted Parameters:

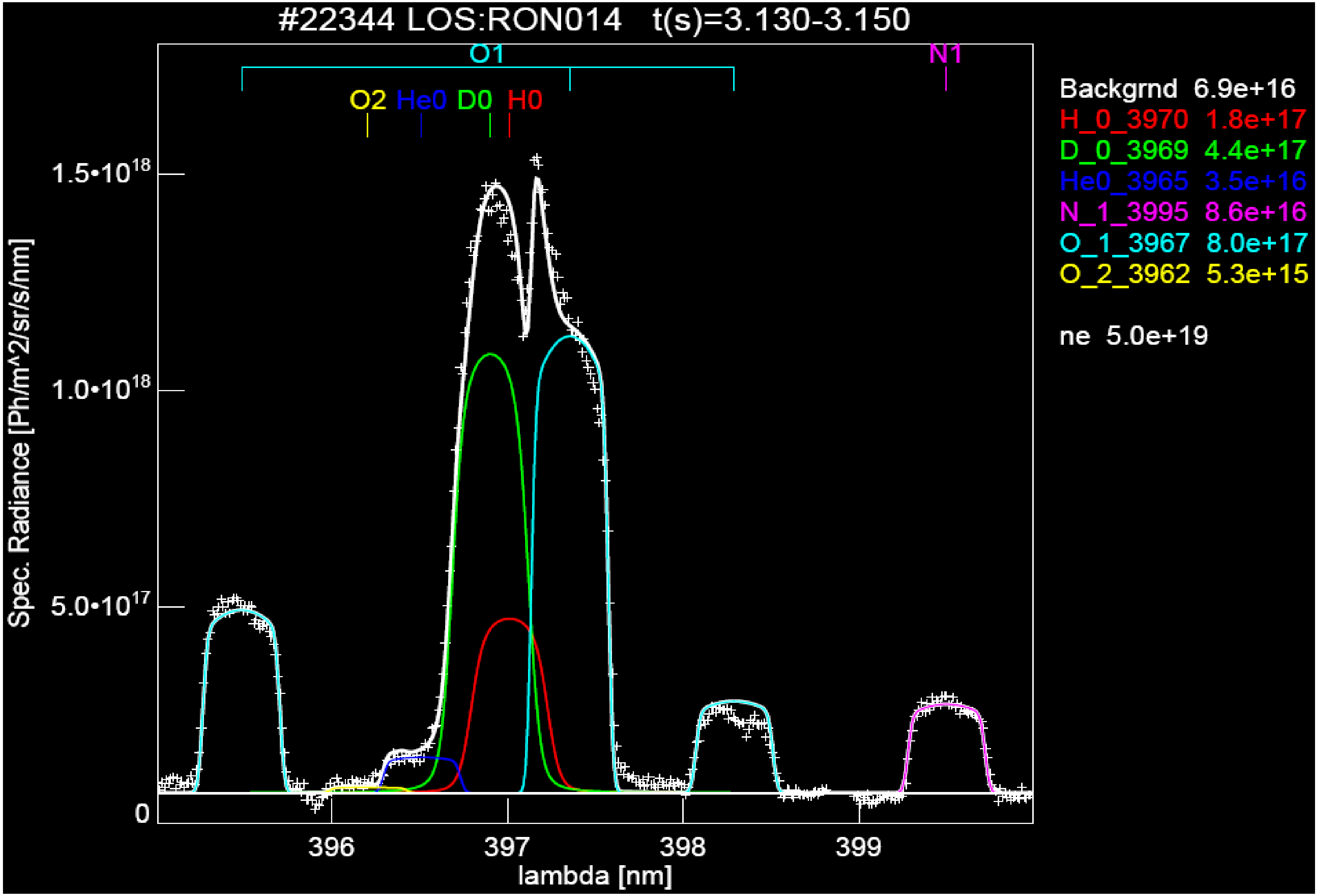
- line strengths of total multiplet
  [direct connection to ADAS data files ADF15(PEC) or ADF13 (S/XB)]
- background level

$\rightarrow$ Linear Model

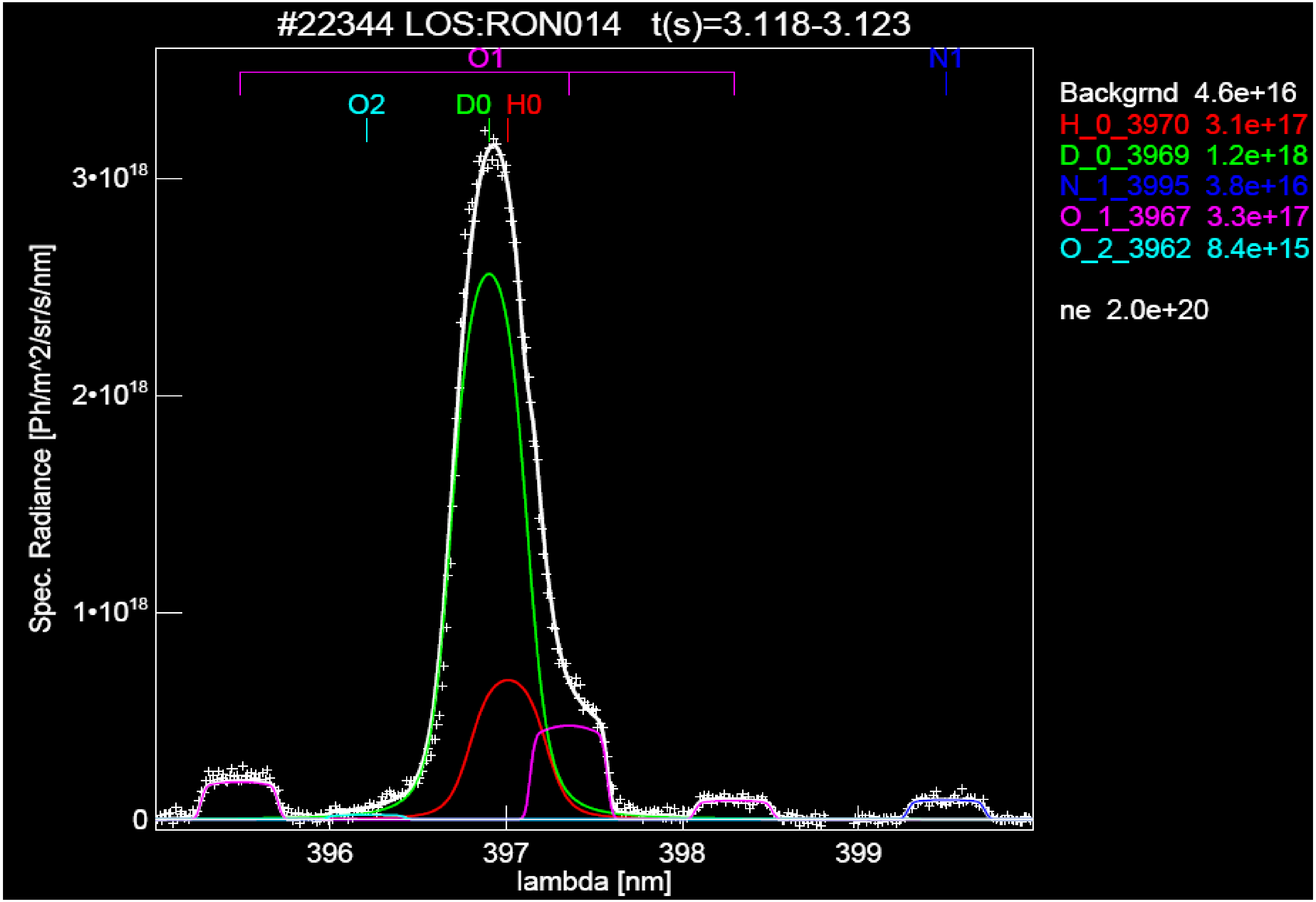
Data Analysis: Fit of Spectra (limiter LOS)



Data Analysis: Fit of Spectra (divertor LOS)



Data Analysis: Fit of Spectra (Divertor LOS)



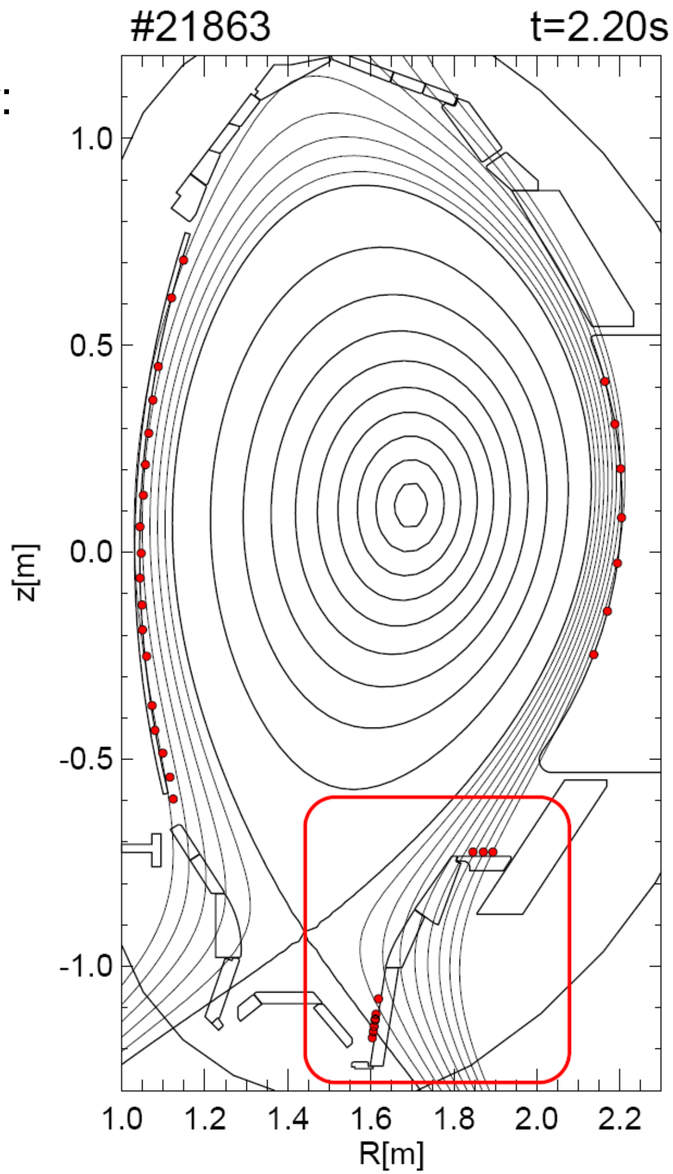
Some Results

Strongest W erosion found in the outboard divertor:

- determination of the total W source
  (temporally averaged - integrating over ELMs)

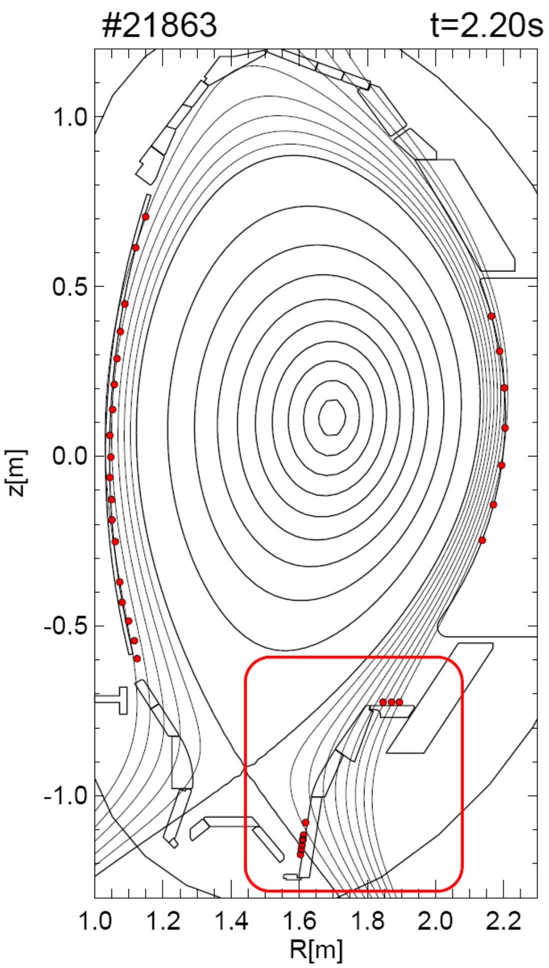
- Effect of ELMs

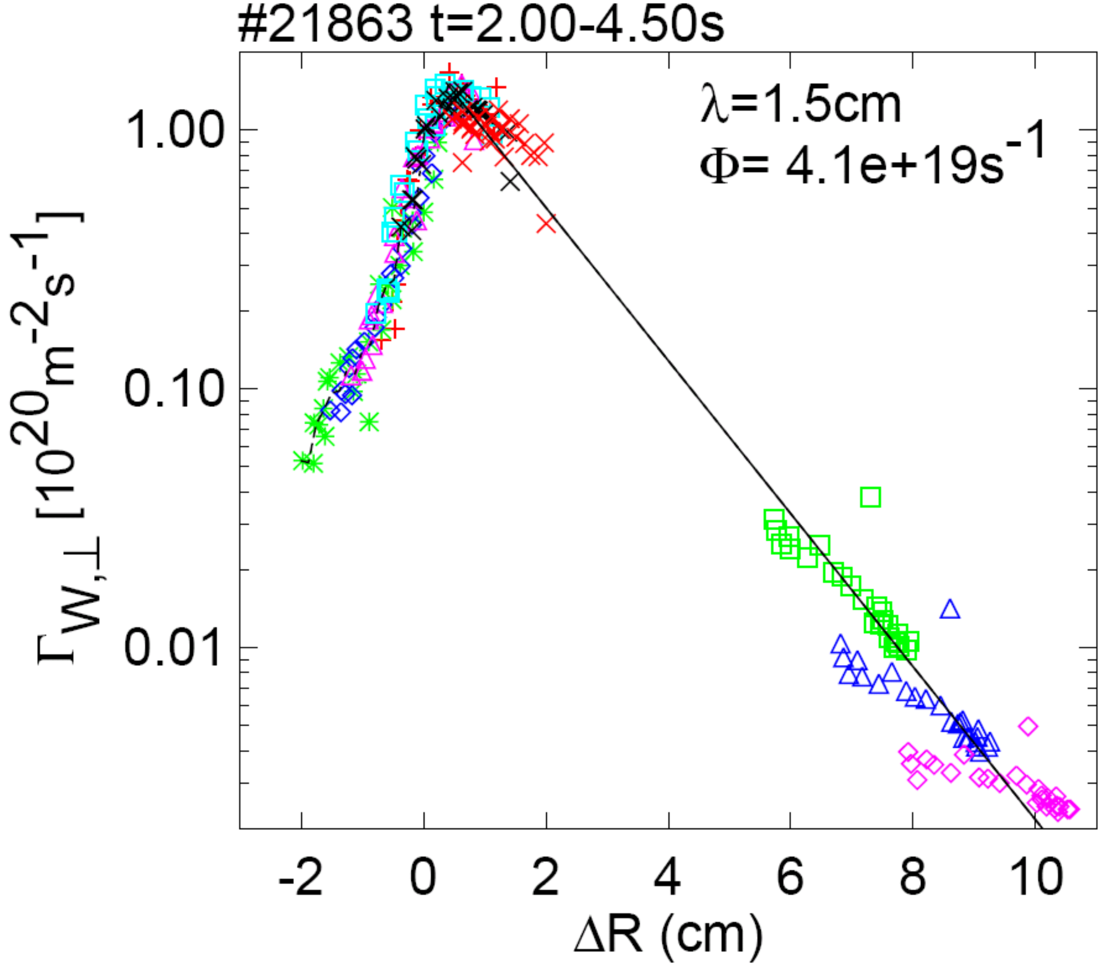
- Effective Erosion Yield



W-influx profile (temporally averaged)

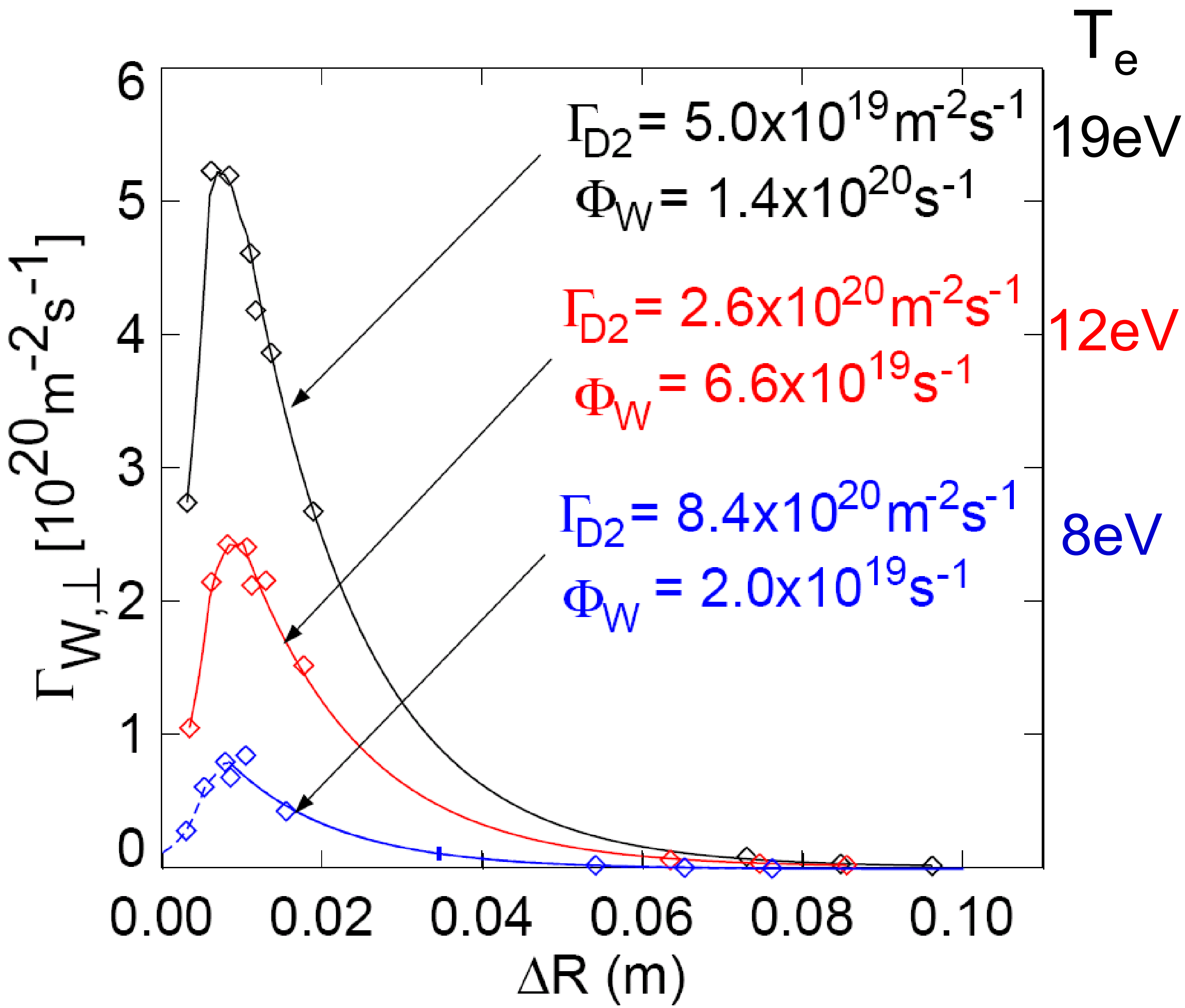
- Map flux densities to outer midplane
- SOL profile follows an exponential decay up to the far SOL
- Interpolation and integration yields total source





Highest W erosion rates for hot divertor conditions

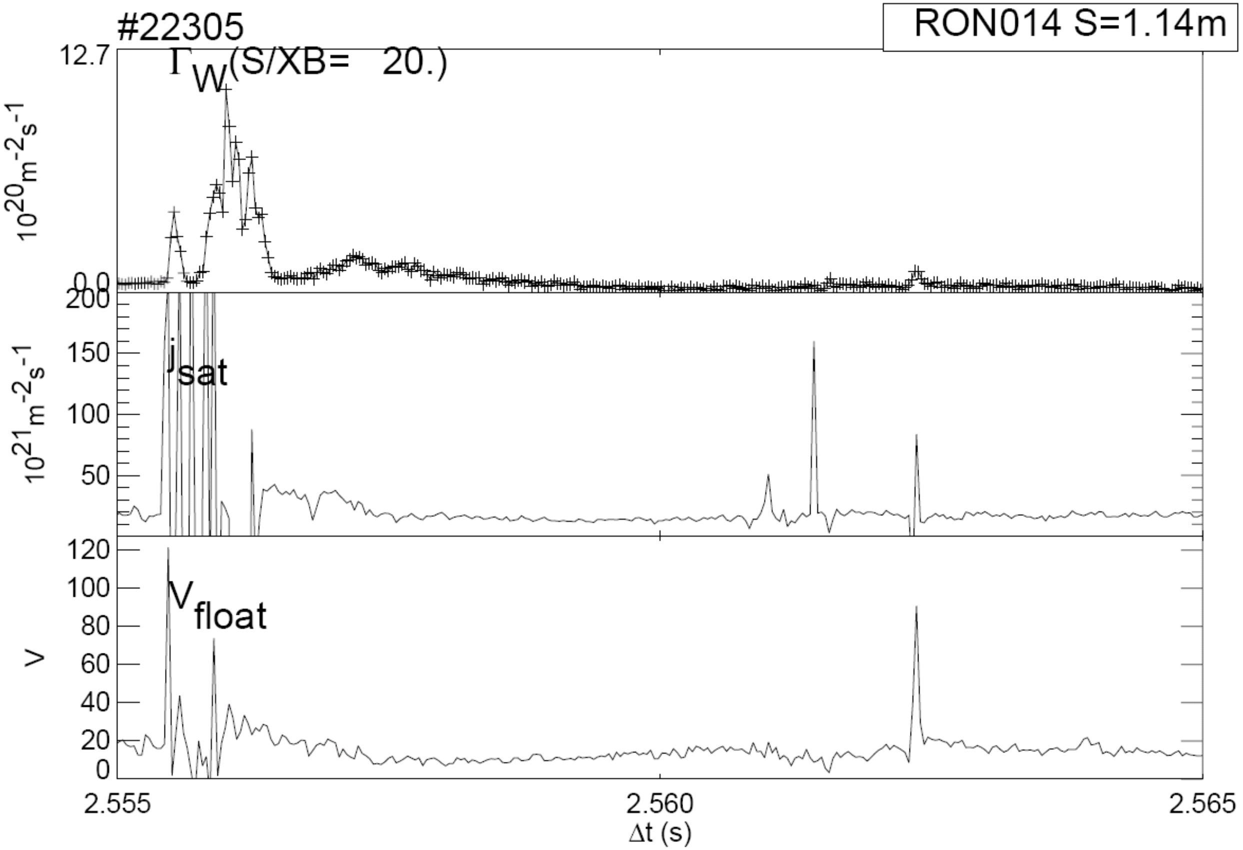
W-erosion decreases with increasing level of gas puff (recycling) leading to lower temperatures in divertor

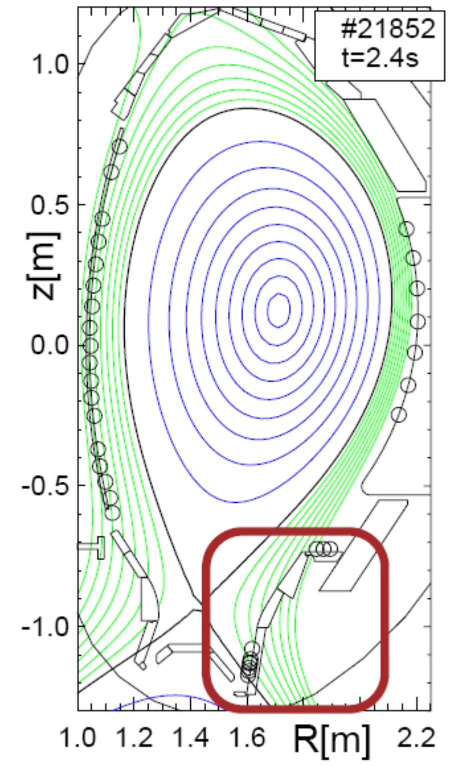


W influx during a single ELM

• W-influx measurements with time resolution down to 40μs

• Langmuir probe data can not be used during ELMs



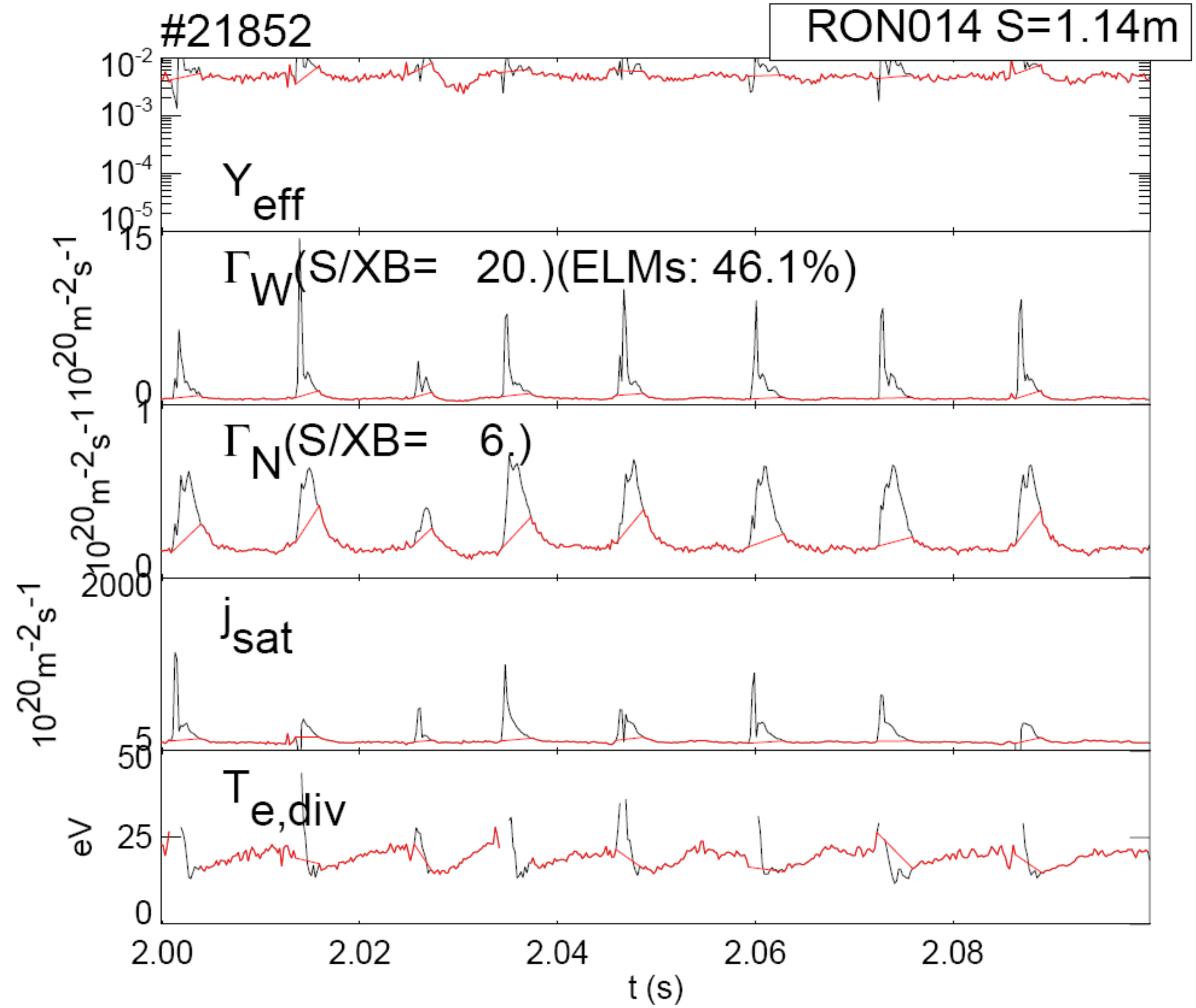


The ELM cycle at low divertor density

At low density

- divertor temperature between ELMs is ≈20eV

- ELMs contribute ≤ 50% to the W-influx

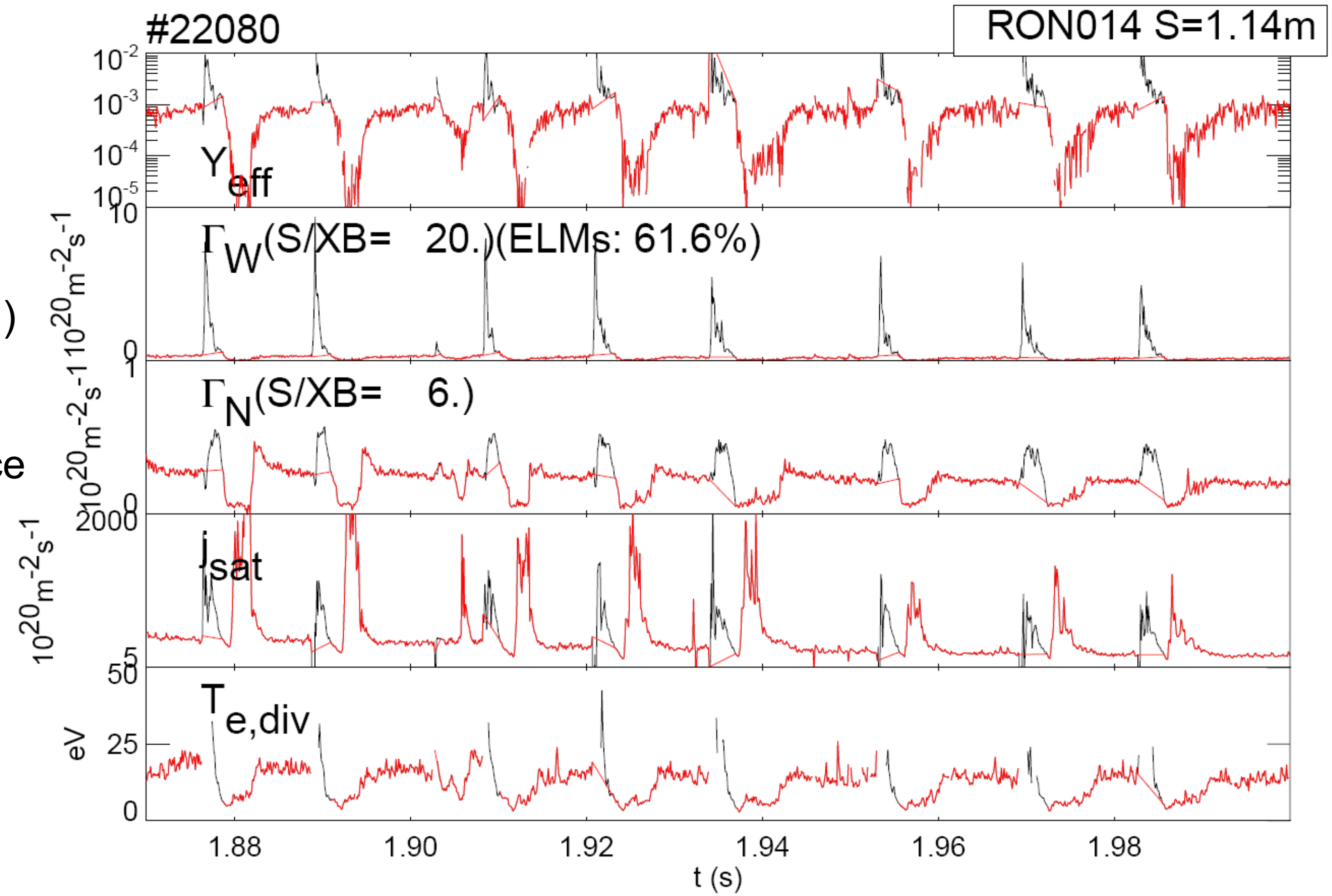


The ELM cycle at higher divertor density

At higher density

- divertor temperature is low after the ELM (detachment, phase with high recycling) and eventually recovers during the ELM cycle depending on the distance to the strike point, the ELM frequency …

- more erosion during ELMs than between ELMs



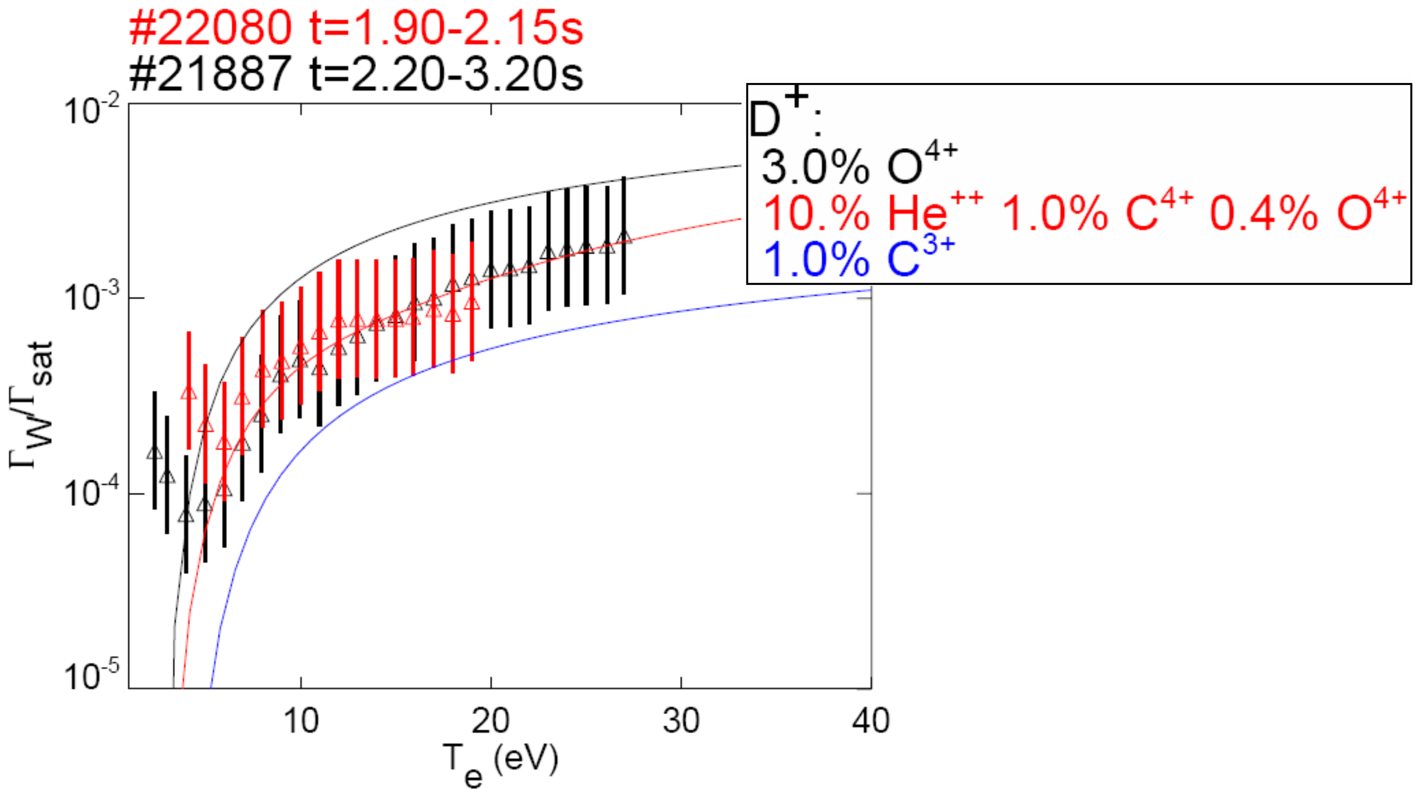
Erosion Yield of Tungsten

data from:

1x H-mode discharge
(only between ELMs)

1 x discharge with
H-L transitions

Erosion yields
can only be explained
with sputtering by
light impurities



Summary

- Diagnostic Equipment
  - spectrometer with low F-number and fast CCD-detectors allow for ELM resolved W-influx measurements in the divertor ($\Delta t \approx 40 \mu s$)
- Atomic Data Needs
  - ionisation rate coefficients, excitation rate coefficients , A-values, collisional radiative models to calculate
    $\rightarrow$ S/XB values for WI, WII and low ion stages of low-Z elements
  - linear Stark broadening of H,D Balmer lines (Zeeman splitting)
  - good diagnostic of electron density and temperature
- Divertor Erosion
  - dominated by impurity sputtering with strong ELM modulation
  - dependence on divertor temperature and impurity composition needs further work