Tungsten Spectroscopy for Measurement of Fluxes

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Present data status

Spectroscopic observations on TEXTOR
- “Standard“ tungsten line
- Other wavelength ranges

Modelling of the corresponding S/XB

Comparison with
- “old” data
- TEXTOR spectroscopic measurements

Conclusions and further needs

Present data status

From new NIST tables (version 3.0)

Yu. Ralchenko, J.R. Fuhr, F.-C. Jou et al. "New Generation of the NIST Atomic Spectroscopic Databases," in *Atomic and Molecular Data and Their Applications*, AIP Conference Proc., Vol. 771 Ed. by E.T. Kato, H. Funaba, and D. Kato (AIP Press, Melville, NY,2005), p. 276-285.

A.E.Kramida, T.Shirai — **W I: 7049 lines, W II: 2838 lines**

(J. Phys. Chem. Ref. Data, Vol. 35, No. 1, 2006) — **522 lines with A_{ik}, term designations not complete**

Wavelengths for *intense* W-lines:

W I (8 eV) UV- visible: up to 5600 Å

W II (15 eV) UV - visible: up to 4200 Å

W III (25 eV) UV: up to 2700 Å

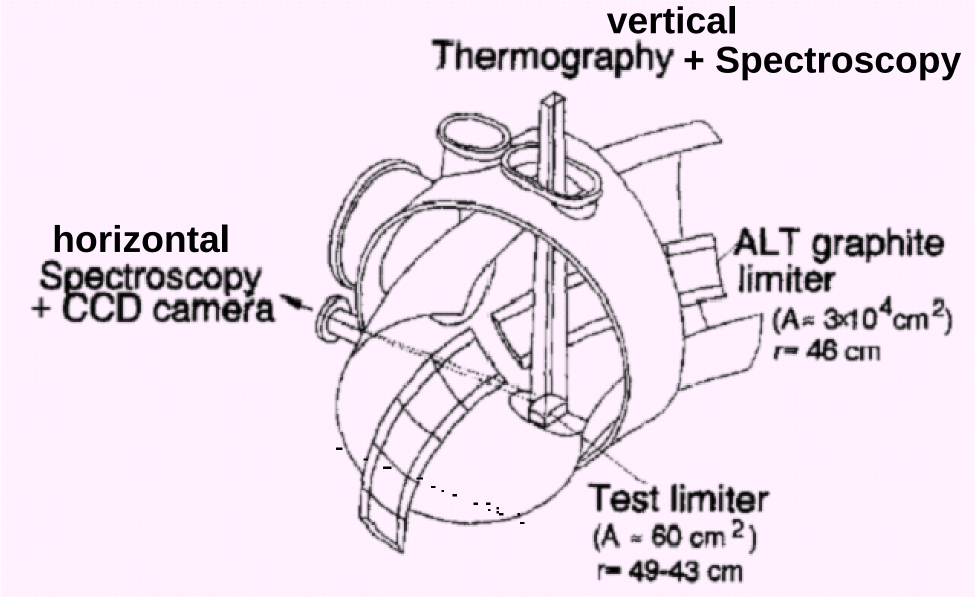
W IV (39 eV) UV: up to 2700 Å

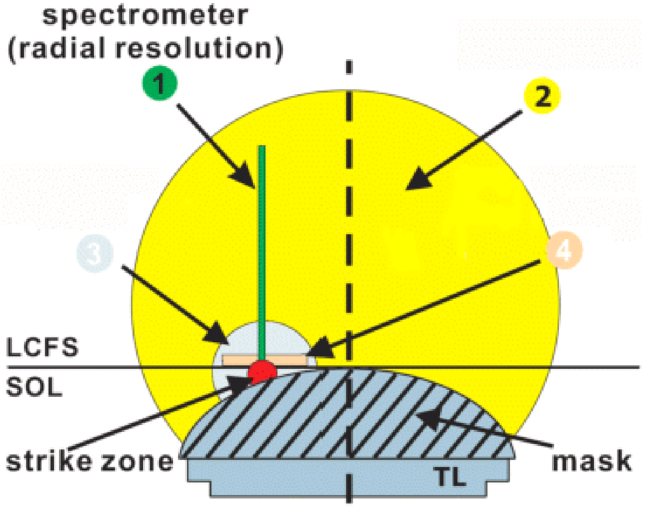
W V (53 eV) UV: up to 2300 Å

W VI VUV: up to 1500 Å

W I and W II lines are often very close to each other => Spectrometers with good resolutions are needed or regions with sufficient separation

Experimental set-up for spectroscopy on a TEXTOR limiter lock





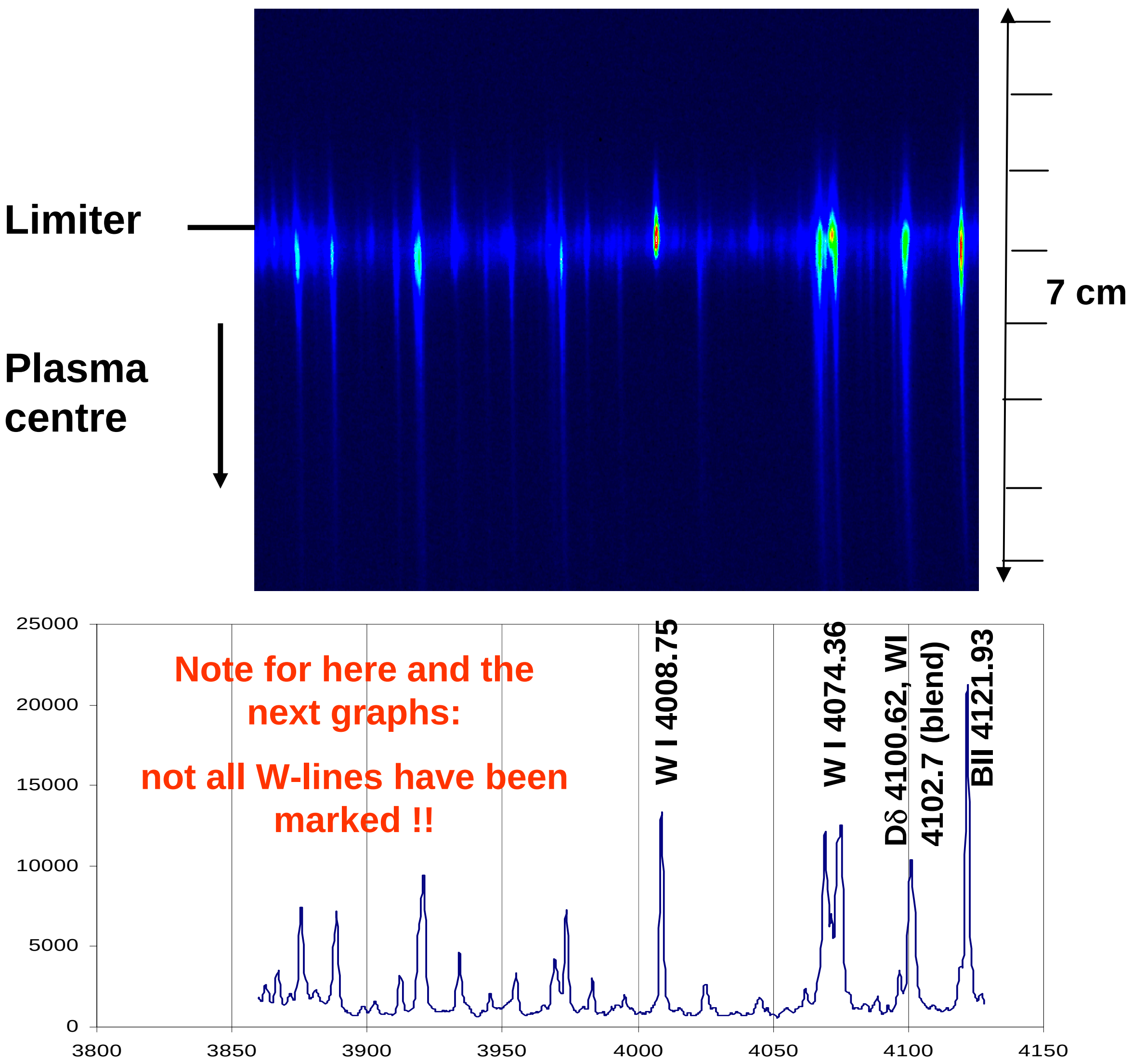
Spectrometers: Overview 200 - 464 nm $\mathscr{R}$:1500 3

Spatially resolving **medium 200 - 750 nm** $\mathscr{R}$:5500 1

Broad band **Echelle (220)375 - 750 nm** $\mathscr{R}$:20000 3

observation of several distant W-lines necessary

4008.75 Å line



well separated line

very intense line

S/XB is known

strong blue => fiber transmission could be low

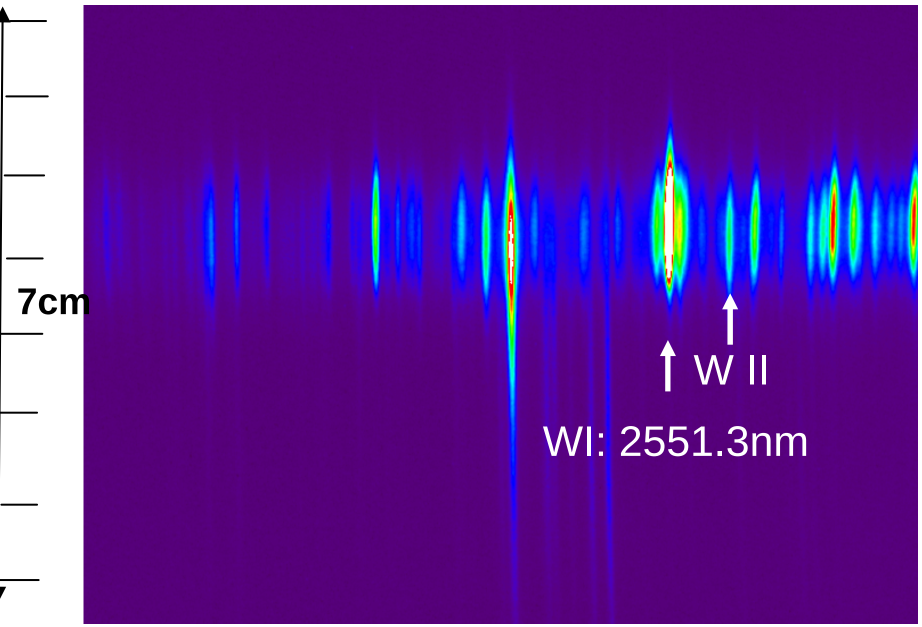
search for W-lines with longer wavelengths

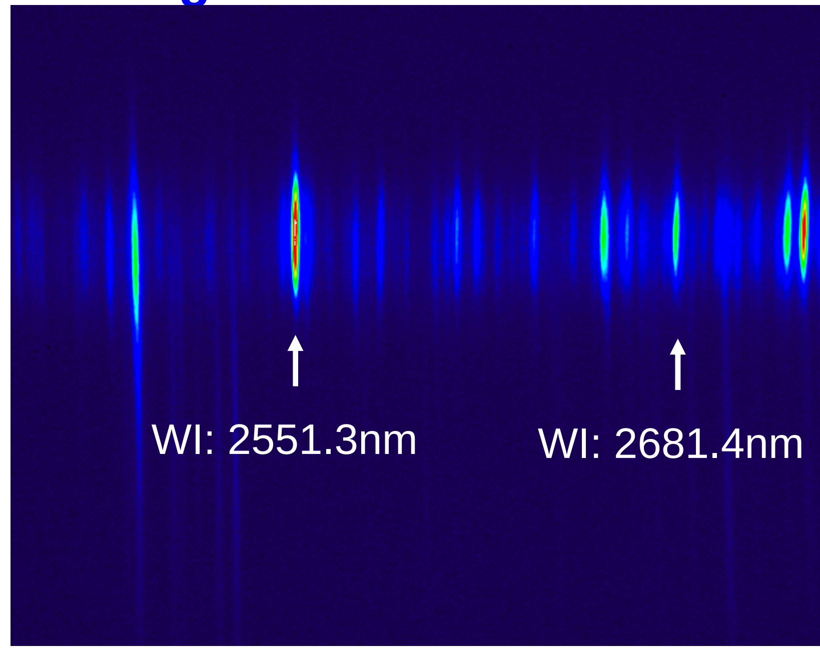
may be still affected during extreme heating

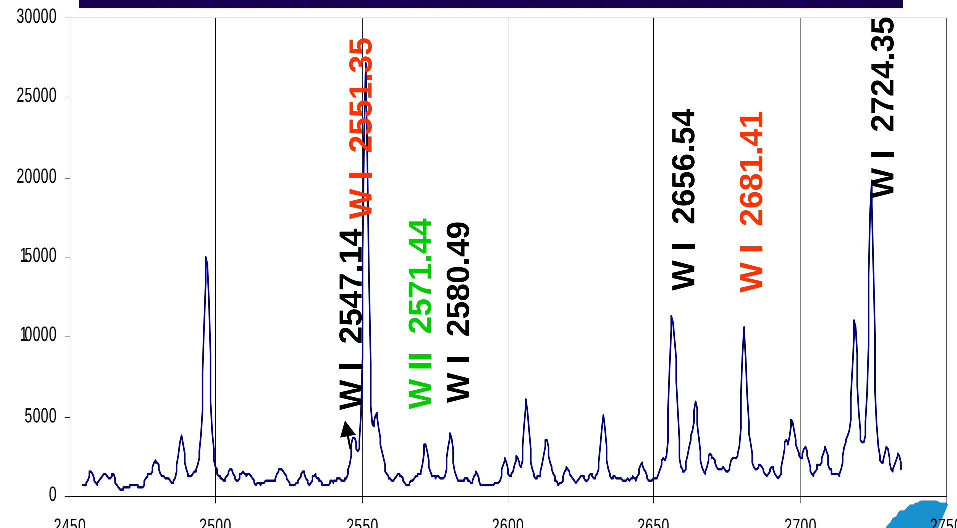
use lines in the UV; direct view needed

both extensions are useful

2350 Å – 2750 Å range

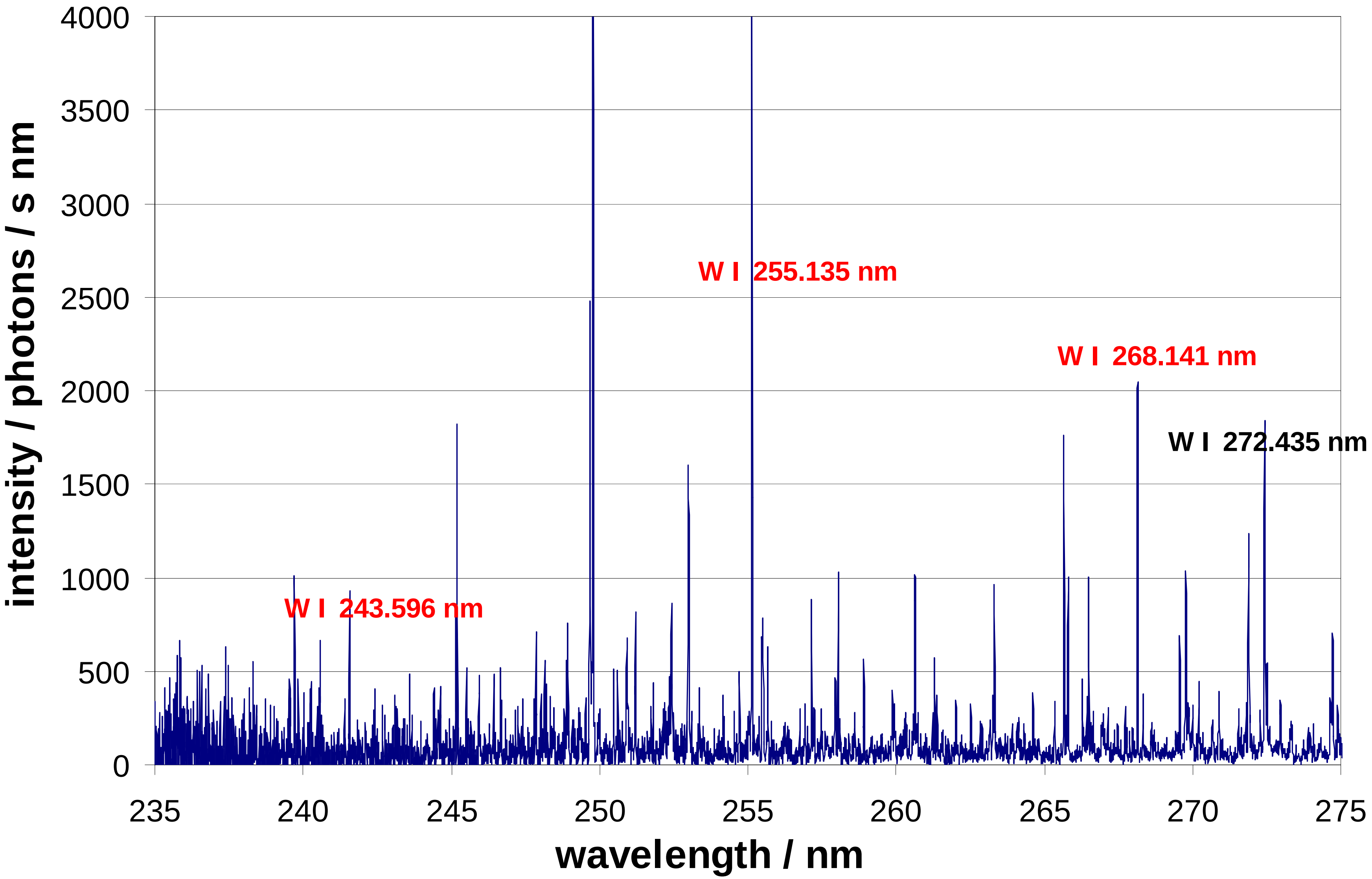




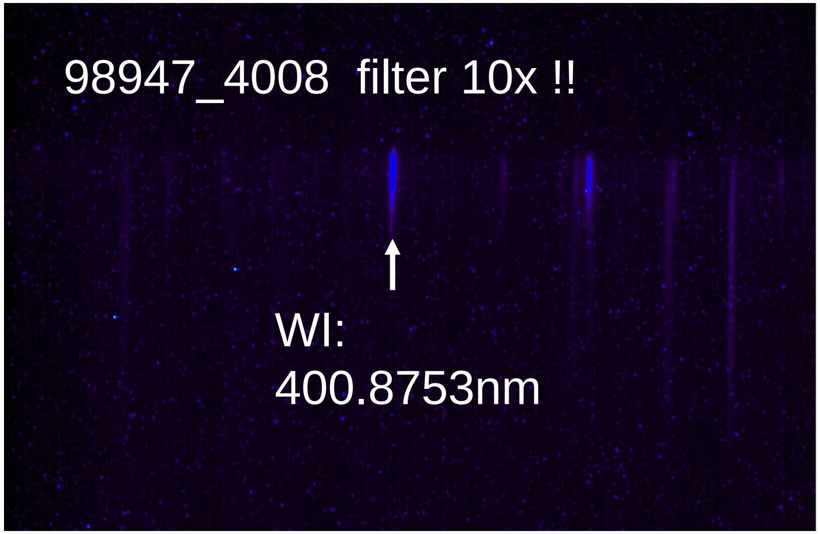


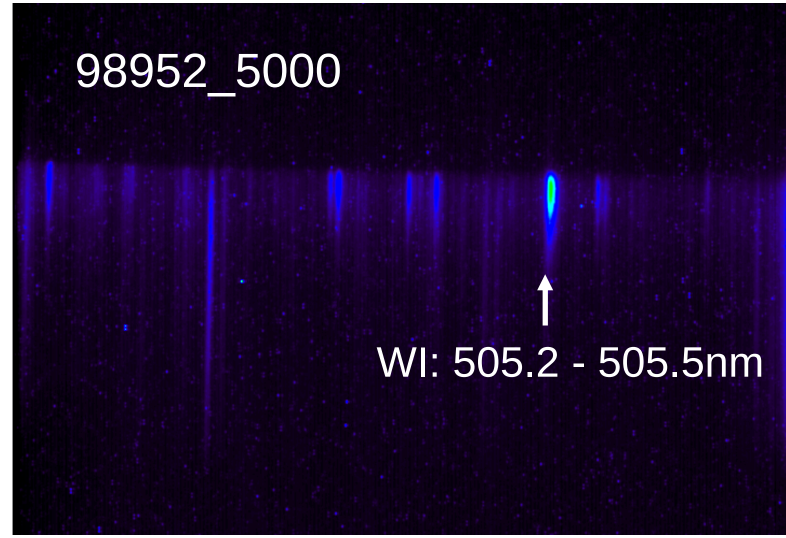
- **strong isolated W I lines exist in the UV range**
- **well separated**
- **not influenced by continuum radiation of T= 3500 ^{0}C**
- **S/XB ?**

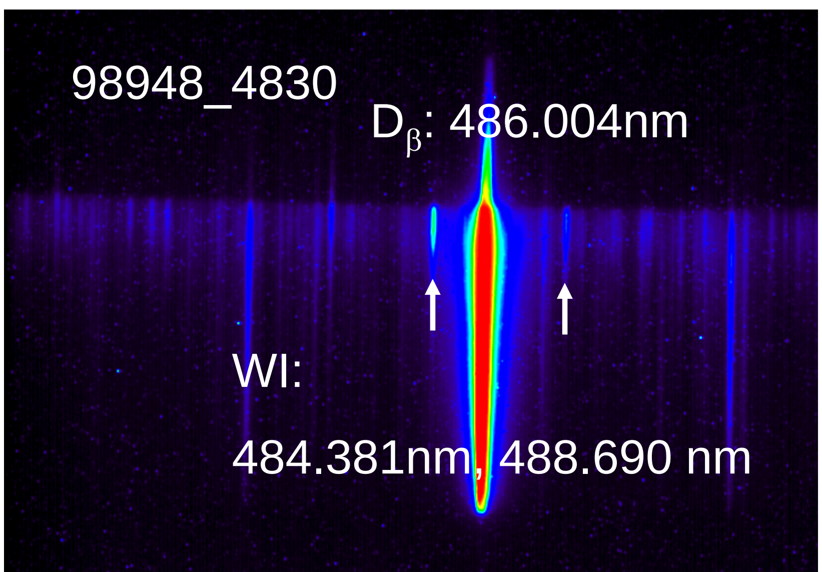
Echelle spectrometer in the same range (radially integrating)

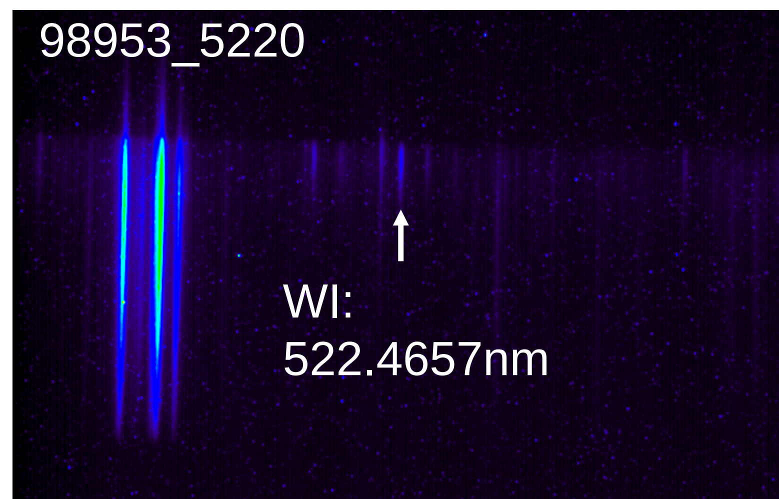


4000 Å – 5300 Å range

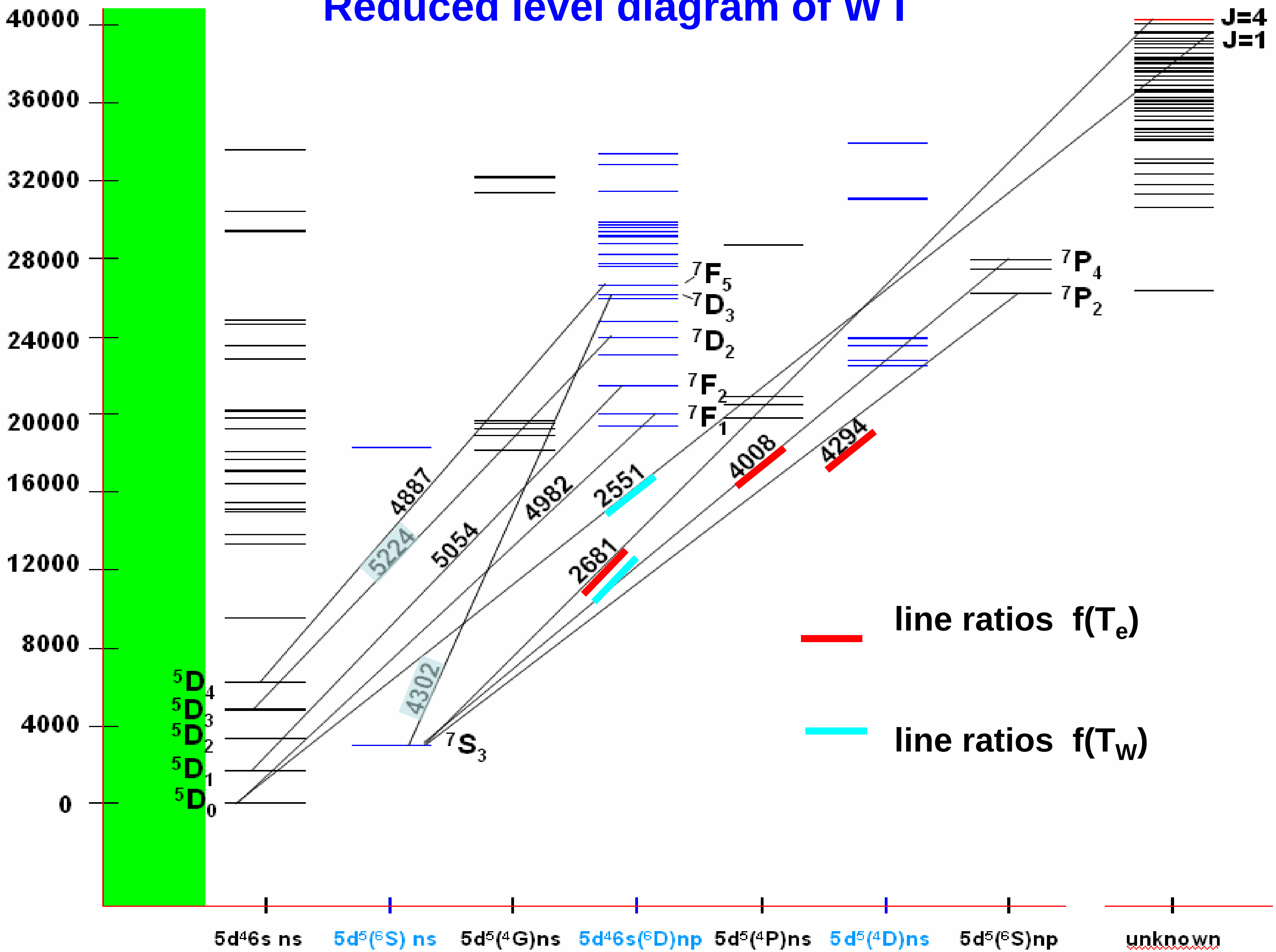








Reduced level diagram of W I



Model Calculations

ionization rate coefficients: from the Code “ATOM” (B & BO appr.) for the lowest configurations $5d^4$ (^{6}S) $6s^2$ and $5d^5$ (^{6}S) $6s$ using

$$\langle v\sigma_{iz}\rangle = 10^{-8} A \frac{\sqrt{\beta}\,(\beta+1+D)}{(\beta+\chi)(\beta+1)\sqrt{\beta_{iz}+1}} e^{-\beta_{iz}} \left[cm^3 s^{-1}\right],$$

$$\beta = Ry/T_e;\ \beta_{iz} = E_{iz}/T_e,$$

E_{iz}=7.864 *eV* ionization energy, T_e is the electron temperature; A=84.9, χ=0.22, D= -0.4 from the code

excitation rates: complicated coupling scheme and configuration mixing. For many levels the identification is unknown: =>semi-empirical van Regemorter formula:

$$\langle v\sigma_{k_0,k}\rangle = 0.11\cdot 10^{-16}\cdot \frac{g_k}{g_{k_0}} A_{k,k_0} \left(\frac{Ry}{\Delta E}\right)^3 u(T_e) e^{-\beta_{ex}} [cm^3 s^{-1}],$$

$$u(T_e) = \beta^{0.5} l\,og(2+1/(1.78\beta_{ex})),\ \beta_{ex} = \Delta E/T_e,\ \beta = Ry/T_e,$$

where $A_{k,k0}$ is the radiative transition probability. Non-dipole collisional transitions were not considered.

Model: *Coronal approximation* with excitation only from the group of "ground" levels

$5d^4$ (^{5}D) $6s^2$ ^5D_J and $5d^5$(^{6}S) $6s$ $^7S_3$

$$Q_{k,k'} = \frac{A_{k,k'}}{A_k} \sum_{k_0} N_{k_0} \langle v\sigma_{k_0,k}\rangle, \qquad S/XB = \langle v\sigma_{iz}\rangle / Q_{k,k'}$$

$$A_k = \sum_{k''} A_{k,k''}.$$ is the total radiative decay probability:

Lines with transition probabilities A(k,k') and A(k,k_0) used if provided in the NIST tables (522 lines)

Assumption: level population (k_0) -> Boltzmann distribution with T_W (free parameter)

W-I lines considered

λ / A	E / cm^{-1}		g_L		Transition		A / s^{-1}	br
	low	Up	low	up	Low	Up		%
2551.35	0.00	39183.20	0.0	1.00	a $^5D_0$	x J=1	1.8e+8	79
2681.42	2951.29	40233.97	1.98	1.50	b $^7S_3$	x J=4	7.4e+7	86
4008.75	2951.29	27889.68	1.98	1.70	b $^7S_3$	d $^7P_4$	1.6e+7	99
4294.61	2951.29	26229.77	1.98	1.84	b $^7S_3$	d $^7P_2$	1.2e+7	94
4886.90	6219.33	26676.48	1.50	1.46	a $^5D_4$	c $^7F_5$	8.1e+5	100
4982.59	0.00	20064.30	0.0	1.54	a $^5D_0$	c $^7F_1$	4.2e+5	79
5053.28	1670.29	21453.90	1.51	2.51	a $^5D_1$	c $^7D_1$	1.9e+6	52

Designations: a=$5d^4(^5D)6s^2$, b=$5d^5(^6S)6s$, c=$5d^4(^5D)6s6p$, d= $5d^5(^6S)6p$,
x means unidentified.

from NIST; other sources: R. Kling, M. Kock JQSRT 62 (1999) 129 - **263 lines**

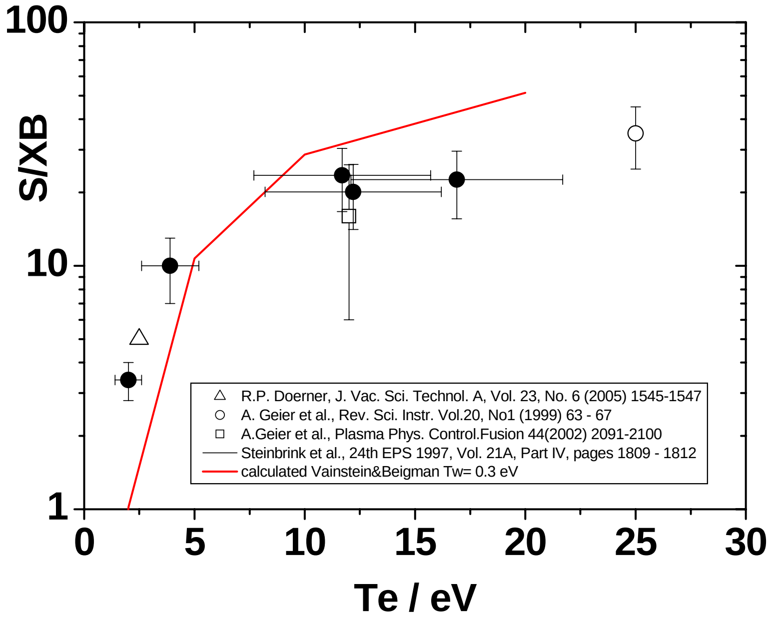
C.H.Corliss, W.R.Bozman NBS 53 (1962) 499 - **261 lines**

note: the large number of W I lines is a strong help for absolute calibrations (via br -> UV)

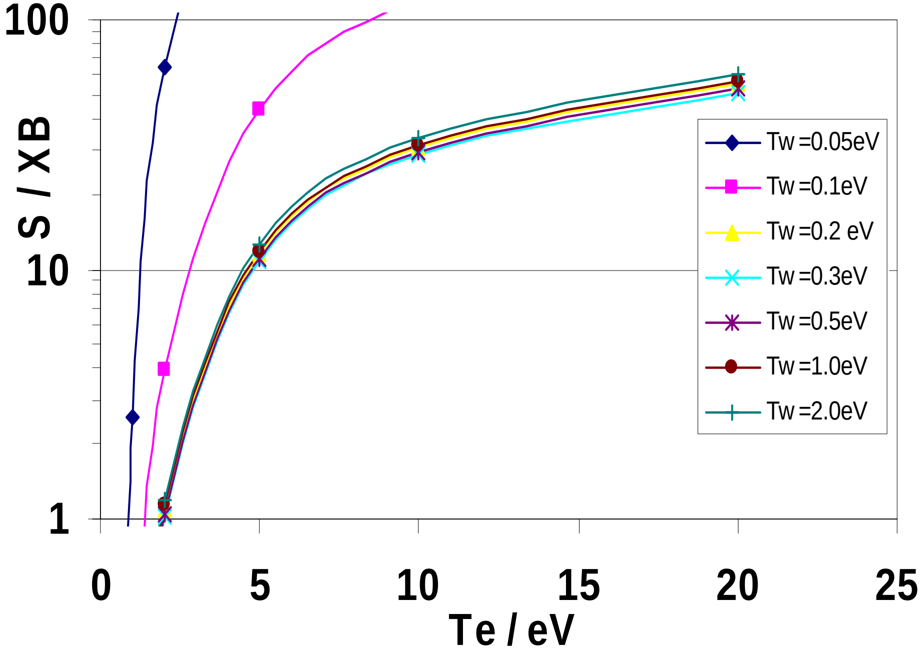
S/XB for 4008 Å

from PSI-1 (Berlin, Germany)

ASDEX-U, PISCES



from Model (B & V)



Interference ??

Very important interference – line is conveniently used for flux measurements

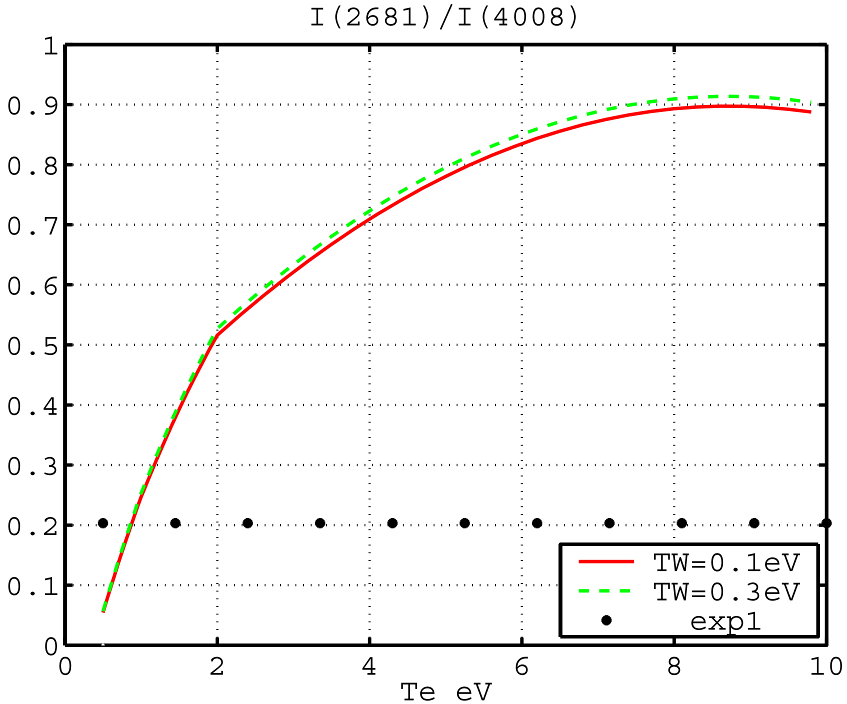
Ion	Observed Wavelength Air (Å)	Ritz Wavelength Air (Å)	Rel. Int. (?)	A_{ki} (s^{-1})	Acc.	E_i (cm^{-1})	E_k (cm^{-1})	Configurations	Terms	J_i - J_k	g_i - g_k	Type	TP Ref.	Line Ref.
W II	4 008.7506	4 008.7075	999m			30 223.744	- 55 162.390			$^3/_2$ - $^5/_2$	4 - 6			K05
W I	4 008.753	4 008.749	1000	1.63e+07	B	2 951.29	- 27 889.68	$5d^5(^6S)6s$ - $5d^5(^6S)6p$	^7S - $^7P°$	3 - 4	7 - 9		K05	K05

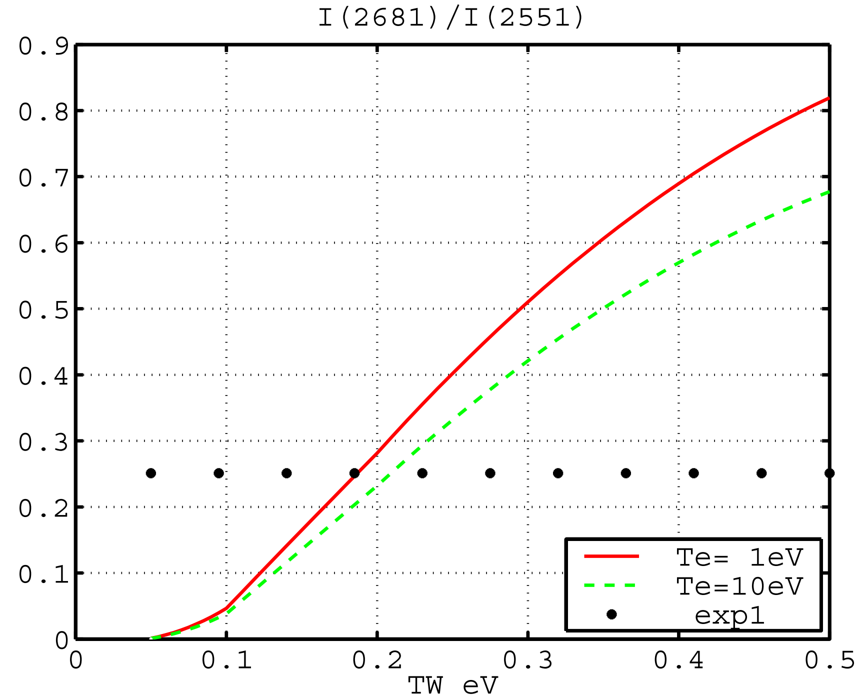
Test other lines for quantitative measurements

Longer wavelengths: **better for fiber transmission**

Shorter wavelengths: **better for hot surfaces**

Determination of T_e and T_W by line ratio measurements





Intensity ratio independent on T_W

dependent on T_e

$T_e \approx 1$ eV

same ground level **$^7S_3$**

Intensity ratio dependent on T_W

independent on T_e

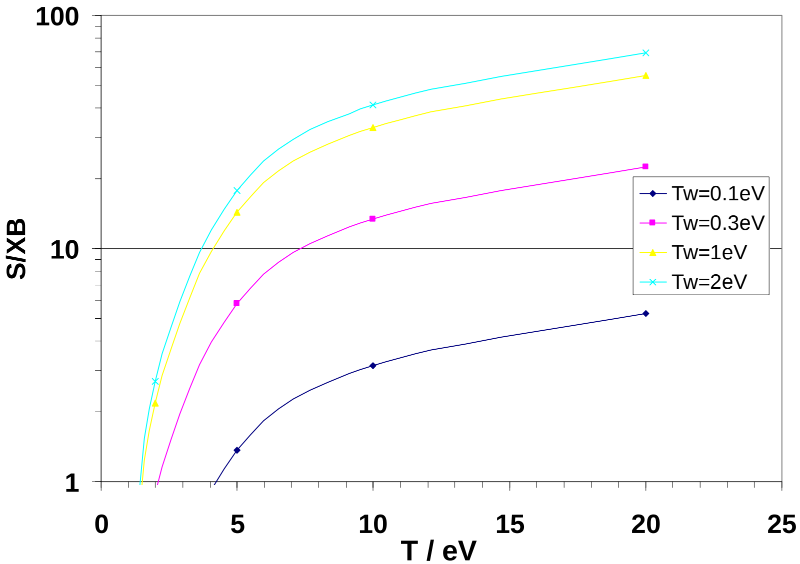
$T_W \approx 0.2$ eV = 2000 K

similar upper levels

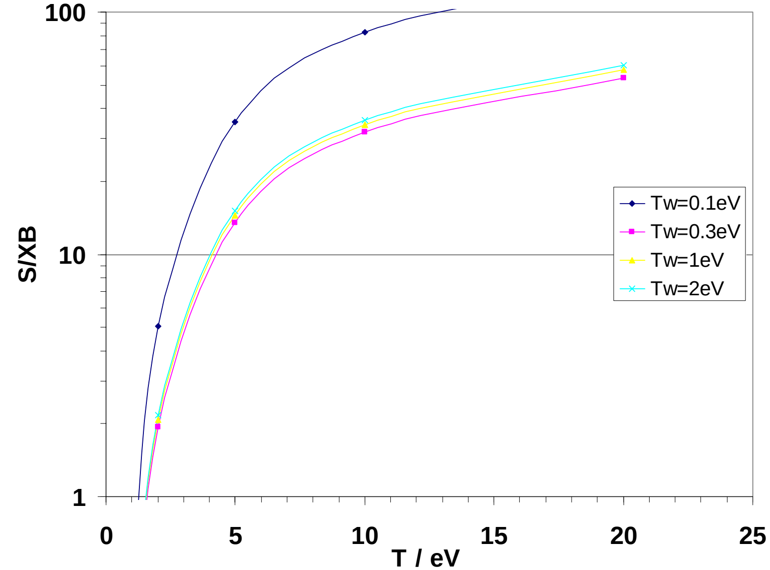
ratios I(4008)/I(4982), I(4008)/I(5053) provide similar numbers

S / XB for all other lines

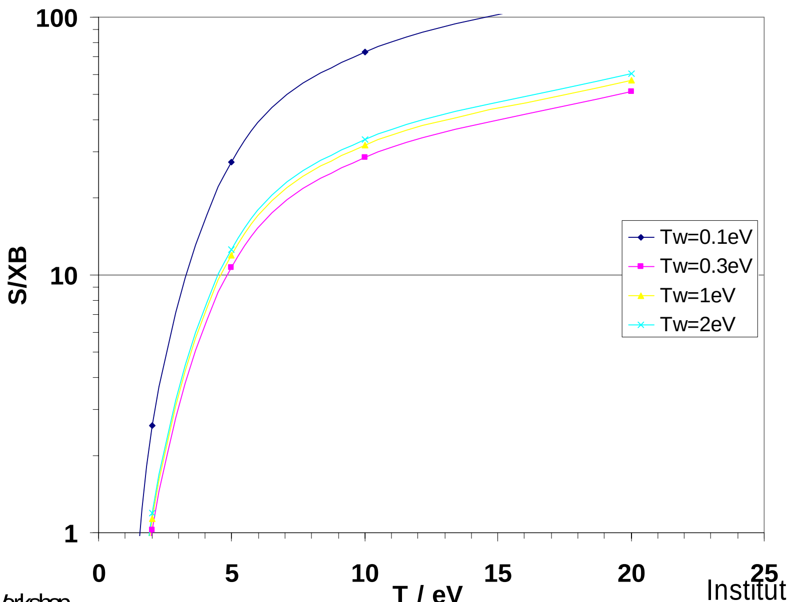
2551 A



2681 A



4008 A

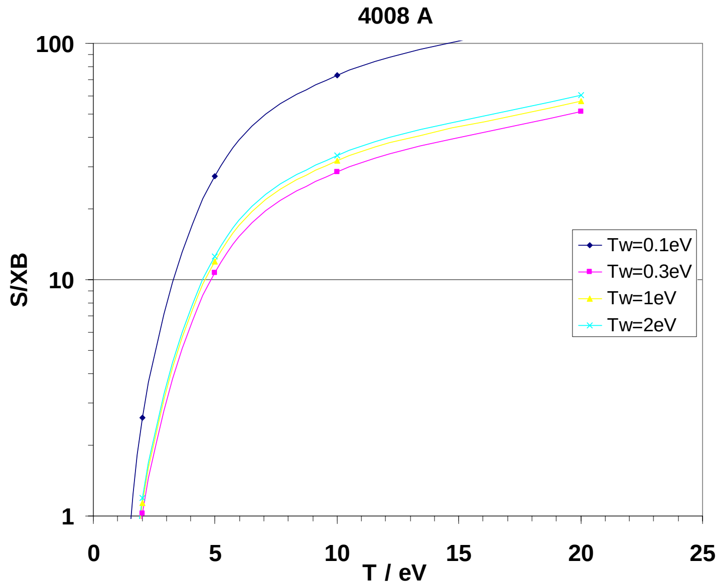


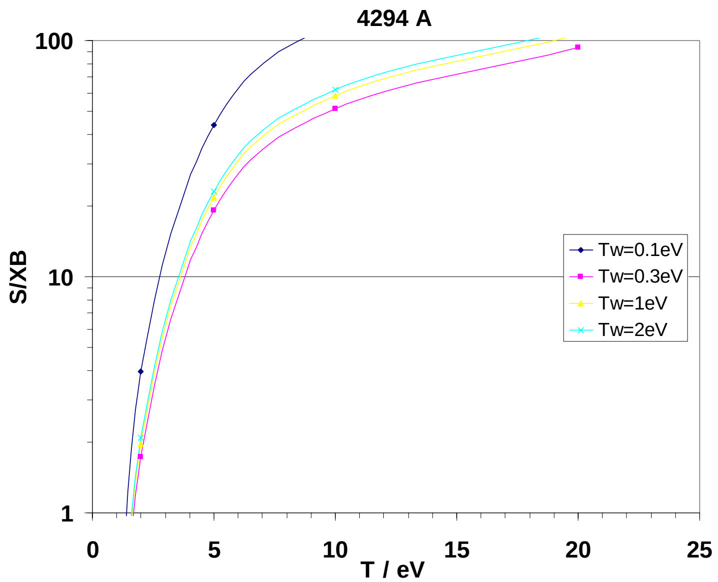
I (2681) / I (2551) is dependent on T_w

I (2681) / I (4008) is dependent on T_e

I (4294)

S / XB for all other lines

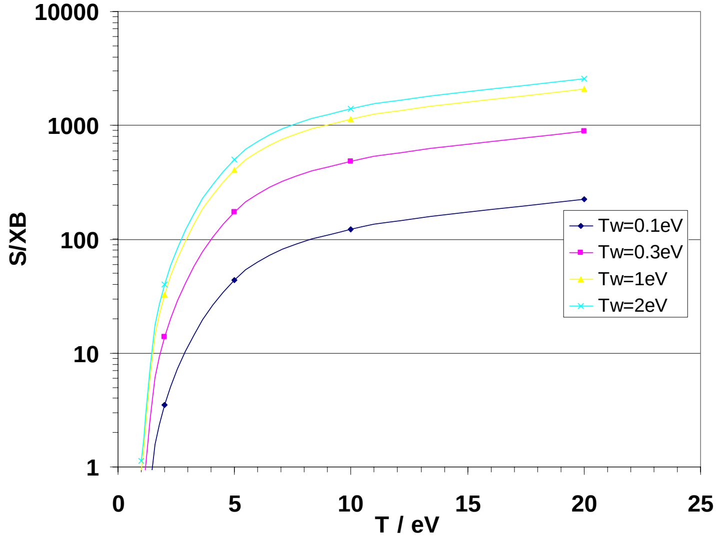




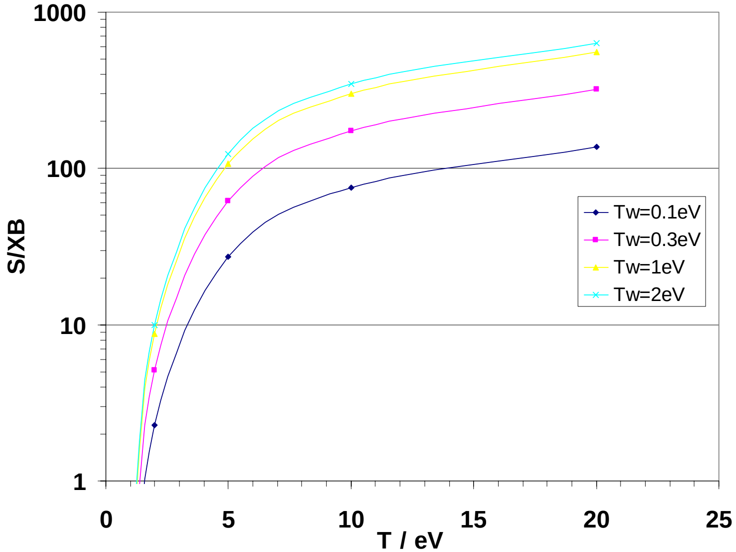
I (4294) / I (4008) is only weakly dependent on all parameters !

S / XB for all other lines

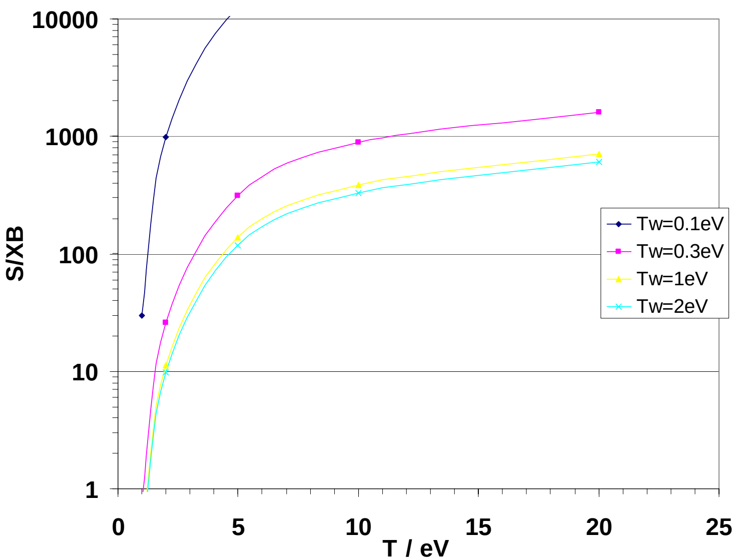
4982 A



5053 A



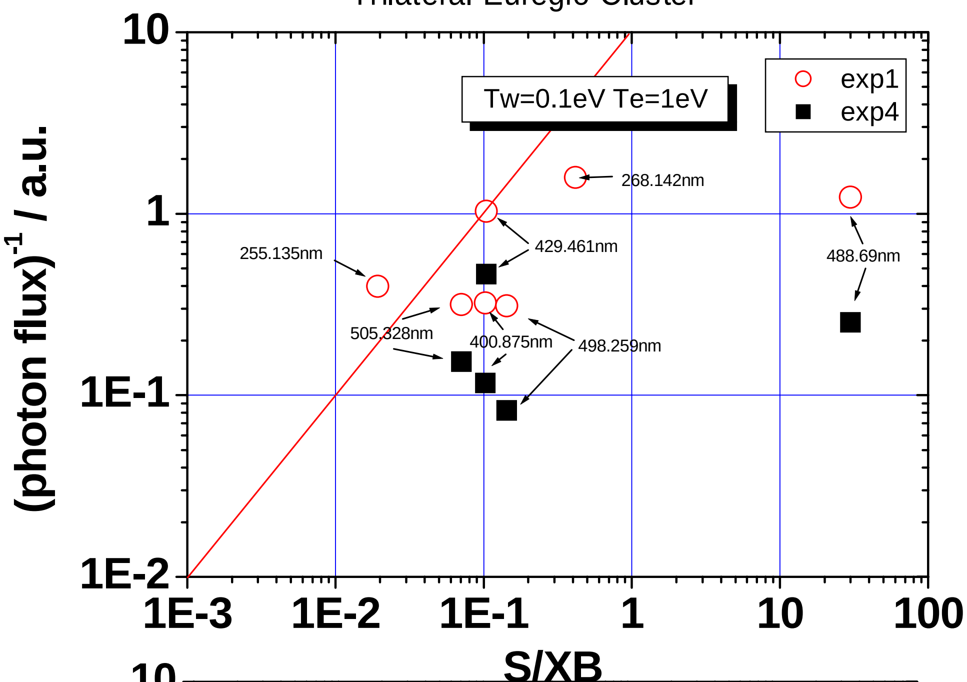
4886 A

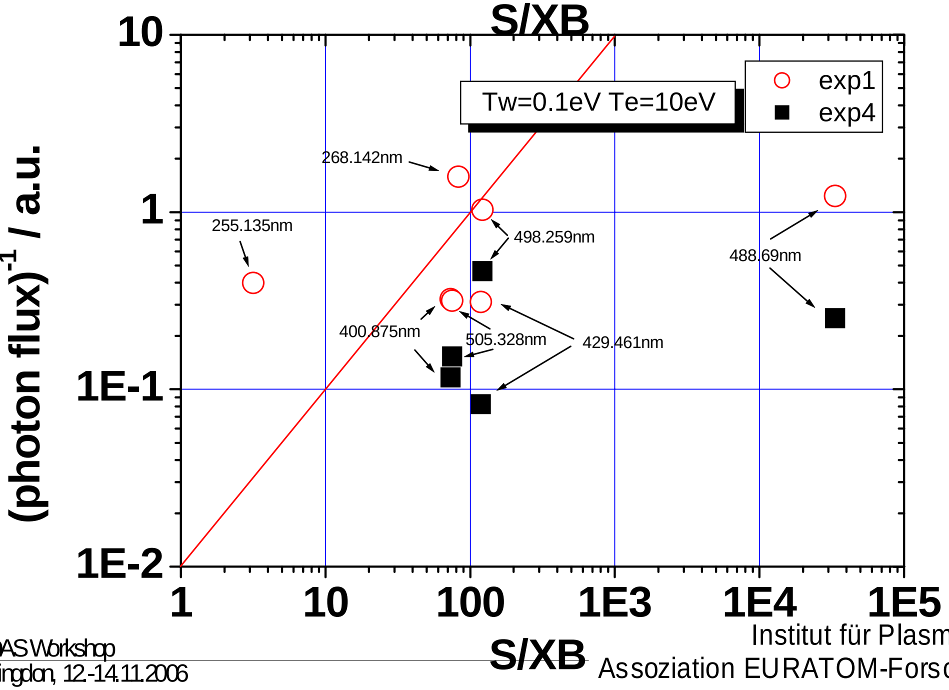


I (4008) / I (4982) is dependent on T_w

/ I (5053)

I (4294) / ....

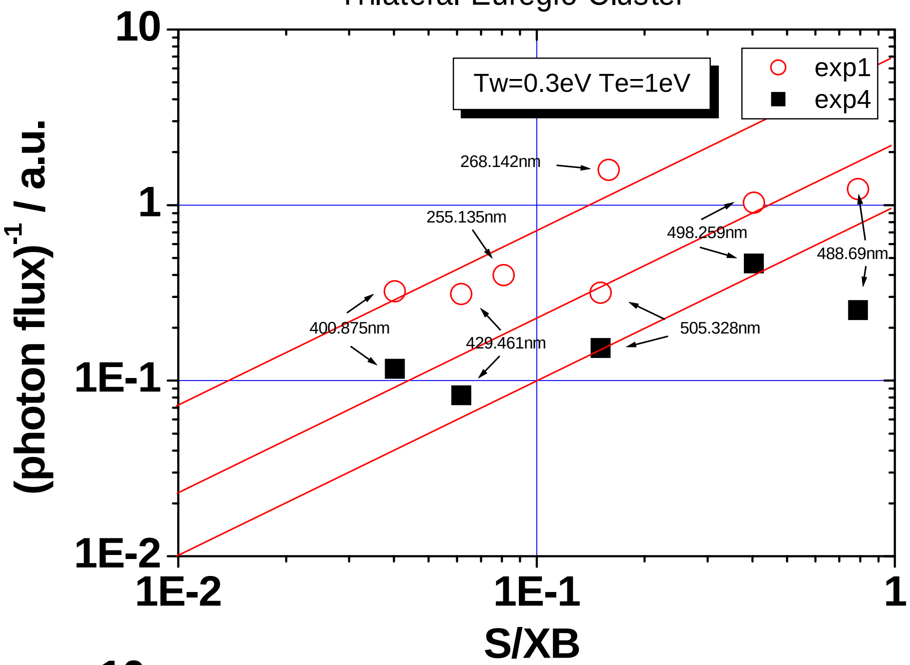


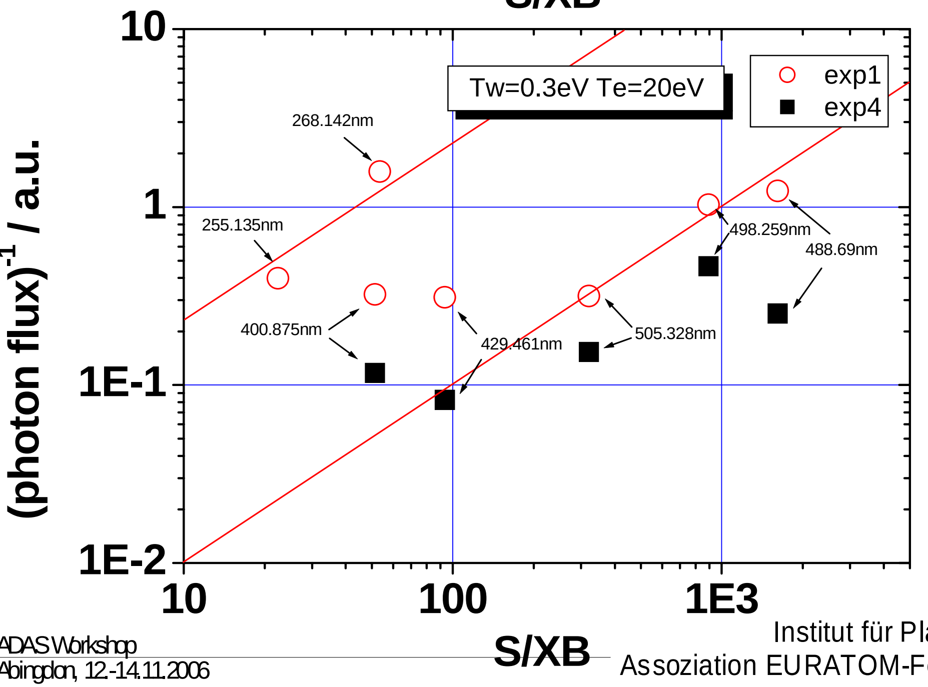


Experimental tests

Γ_p = S / XB × photon flux

T_W = 0.1 eV is obviously not a good choice





Experimental tests

T_W = 0.3 eV is better but yields

T_e = 1 eV

revision of UV calibration

and/or

addition of cascading from higher levels may improve the situation

Conclusions - S/XB

400.8 nm: experimentally obtained values are in good agreement

theoretical values fit quite well – ionisation rate too high, $^7S_3$ pop. too high

429.4 nm: can be used similarly - interferes with CH/D- band !

longer λ : blended (H/D_β) or need good resolution

shorter λ: well suited but need UV optics

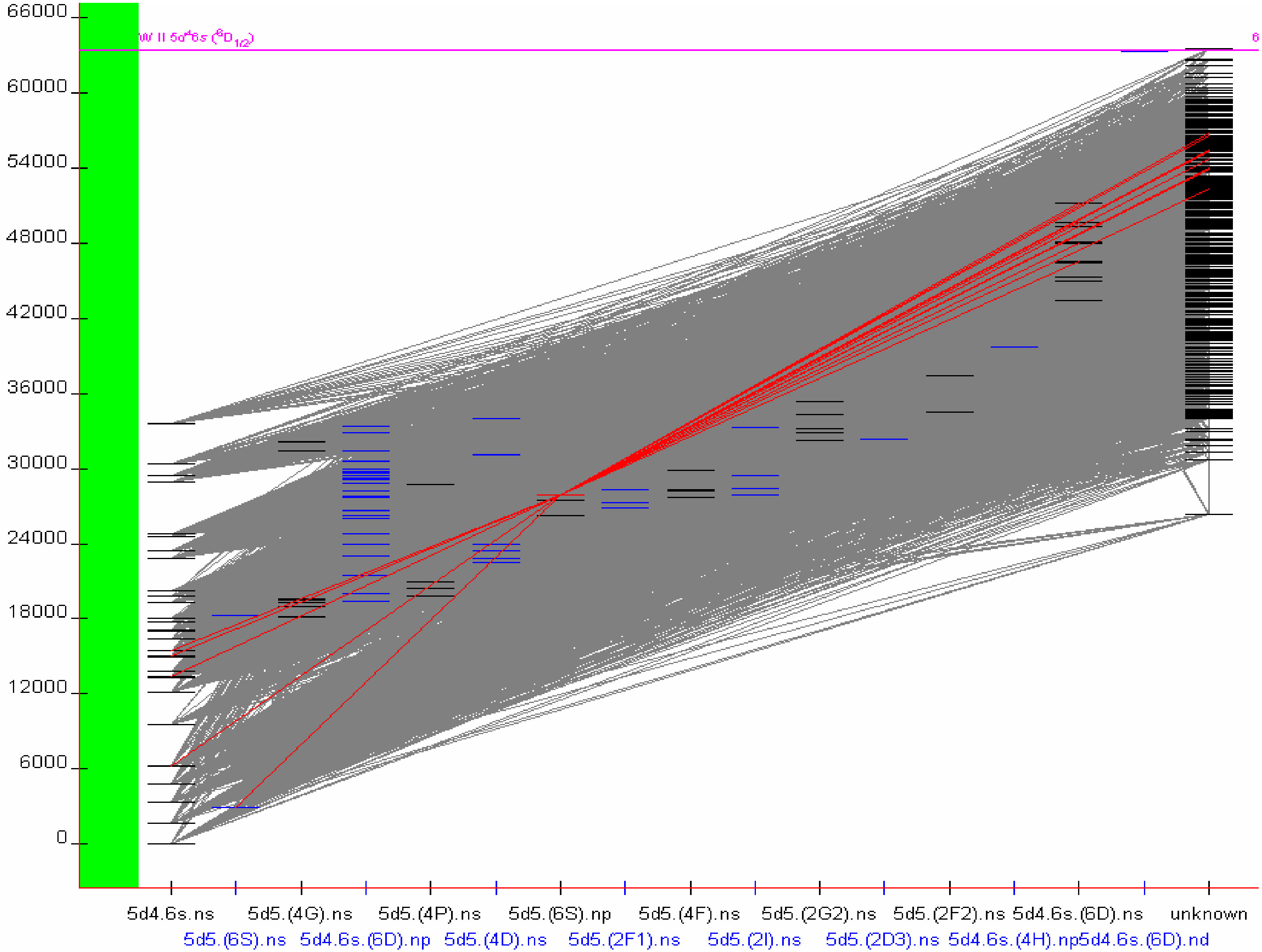
theoretical values require $T_e \approx 1$ eV (?!)

Further plans

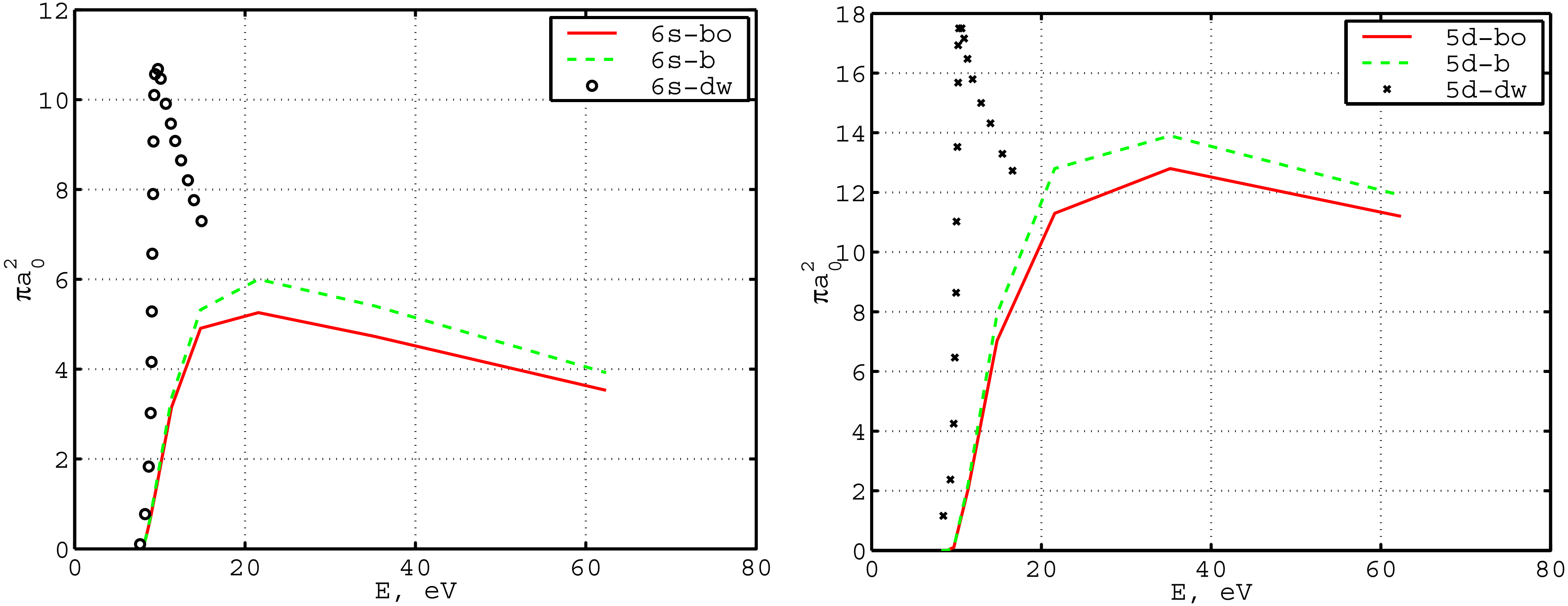
experimental cross calibrations to 400.8 nm

refine level populations (cascading, transfer, ground state) – experimental input

Full Level Diagram of W I NIST (3.0)



ionization cross sections



Ionization cross-section of W I from the shells 6s and 5d

“b” – Born approximation, “bo”- Born-Ochkur approximation, “dw”- distorted wave method

ionization rates