14SEP2015
IAEA CM on W
Deajeon, KAERI, Korea

Experimental evaluation of W^{45+} recombination and W^{44+} Ionization cross-sections

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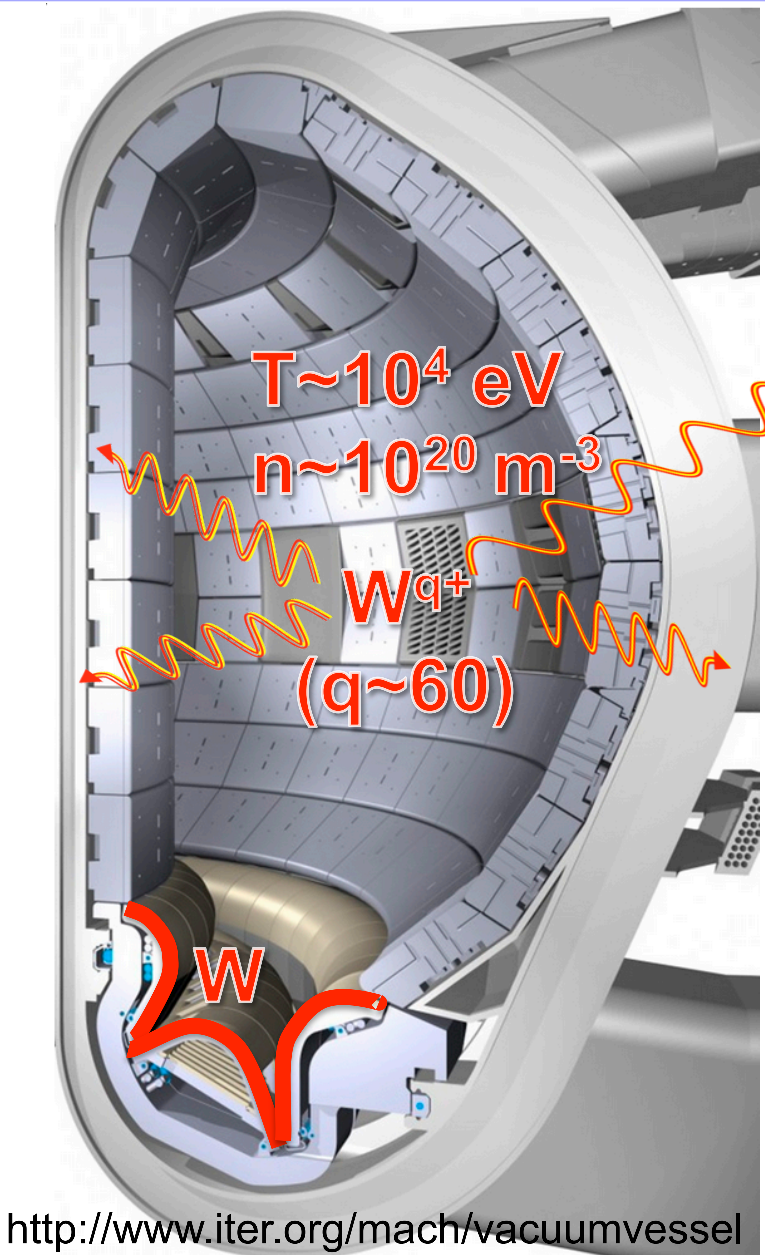
Acknowledgements
Dr. N. Nakamura (Univ. of Electro-Communications)
Dr. H. Ohashi (Toyama Univ.)

Tungsten: a candidate for PFCs in reactors



<u>W plasma-facing component</u>

- Merit : high melting point
  : high heat conductivity
  : low sputtering yield
  : low hydrogen (T) retention
  ⇒ safety, economy
- Demerit : melting
  : cracking (Bulk W)
  : **high Z (74)**
  ⇒ accumulation in plasma core
  ⇒ highly radiative ($n_W/n_e < 10^{-5}$)

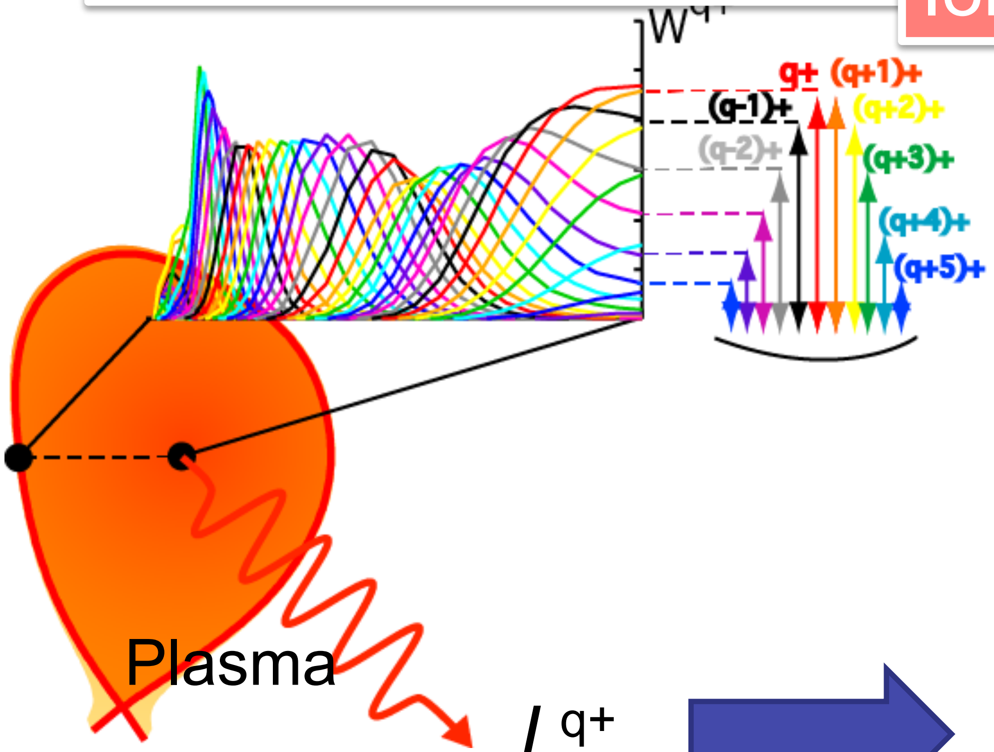
⇒ **W transport in plasmas**

<u>For quantitative transport study, absolute W density is required.</u>

Various W atomic data needed for W density measurement

W spatial / charge state distribution
<= Ioniz/recomb. rates

Ioniz.Eq / Transport model



(Fractional abundance of W^{q+})

$$\frac{nW^{q+}}{nW}$$

nW (total W density)

I^{q+} → nW^{q+} *(W^{q+} density)*

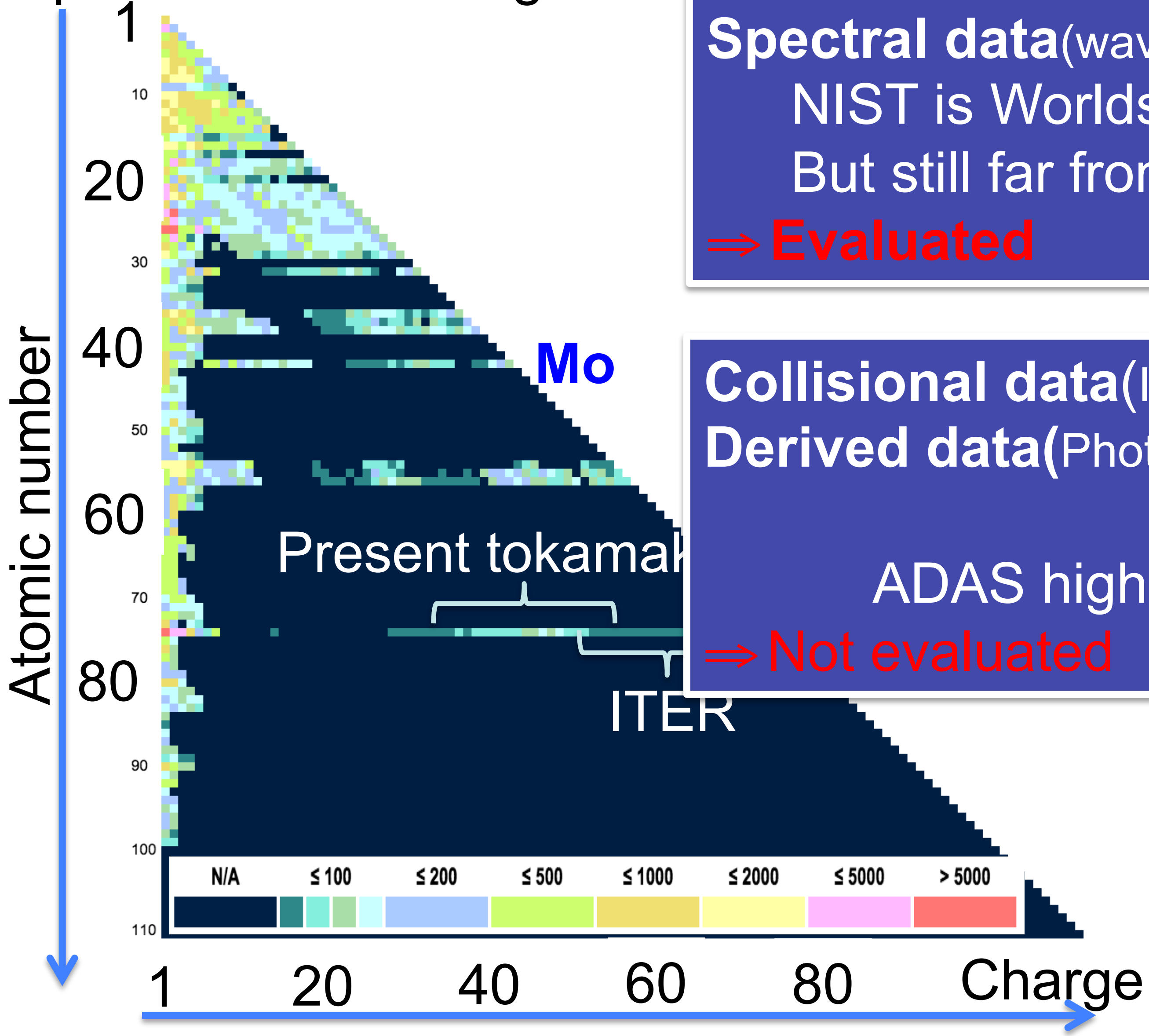
Line identification
<= spectral data

Photon Emission Coefficient
<= excitation rate, A coef, Energy level

Collisional-radiatve model

Availability of W atomic data

Spectral data holdings at NIST*



Spectral data(wavelength, Acoef)**:**

NIST is Worlds' standard database

But still far from 'a complete set'

⇒ **Evaluated**

Collisional data(Ioniz./recomb. Rates)**:**

Derived data(Photon emission coef,

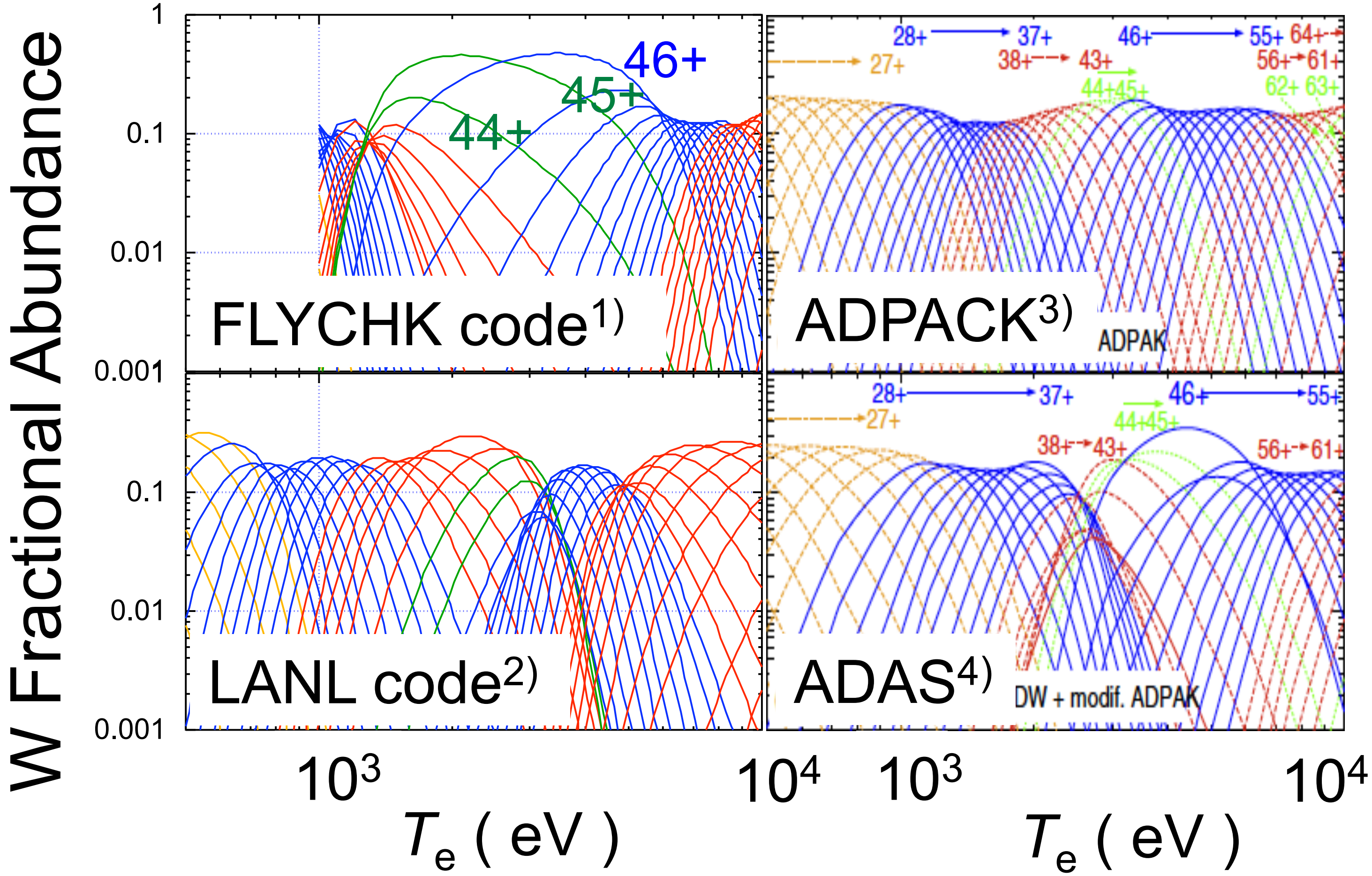
Cooling rates)**:**

ADAS high availability

⇒ Not evaluated

*) NIST ASD version5.
http://physics.nist.gov/ASD

W fractional abundance under Ionization equilibrium still different amongst datasets



Uncertainty of collisional data (Ioniz./Recomb. rates) needed
⇒ Evaluation

1)http://nlte.nist.gov/FLY/
2)http://aphysics2.lanl.gov/tempweb/lanl/
3)K. Asmussen, et al., Nucl. Fusion **38** (1998) 967-986.
4)T. Puetterich *et al PPCF* **50** (2008) 085016.

Issue 1: W density measurement

W spatial / charge state distribution
<= Ioniz/recomb. rates

Ioniz.Eq / Transport model

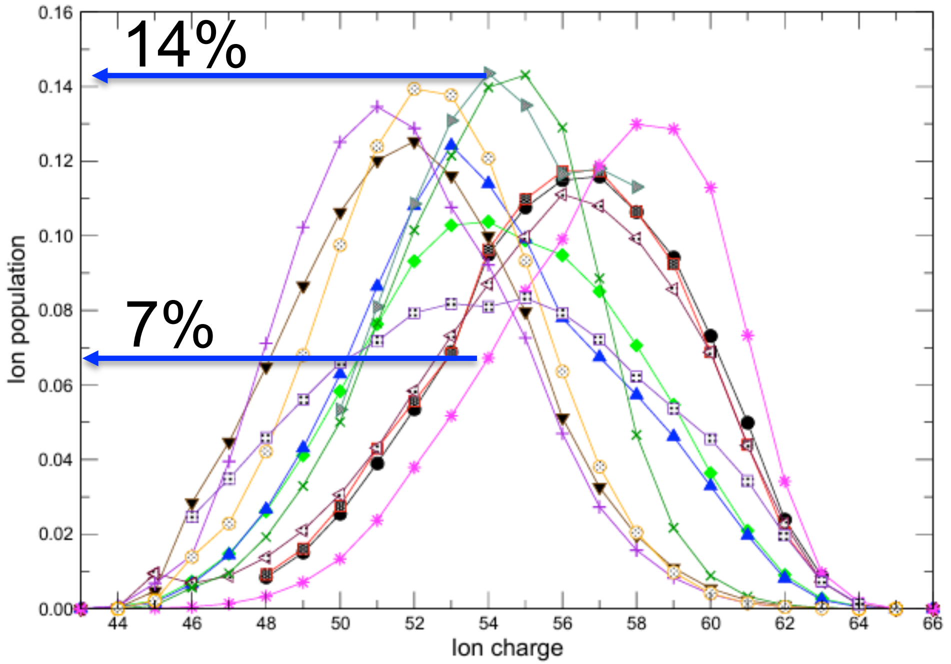


Fig. 11. Ionization distribution of W ions at 7 keV and 10^{14} cm^{-3}.

(Fractional abundance of W^{54+})

$$\frac{nW^{54+}}{nW}$$

nW (total W density)

Factor of 2 deviation

nW^{54+}

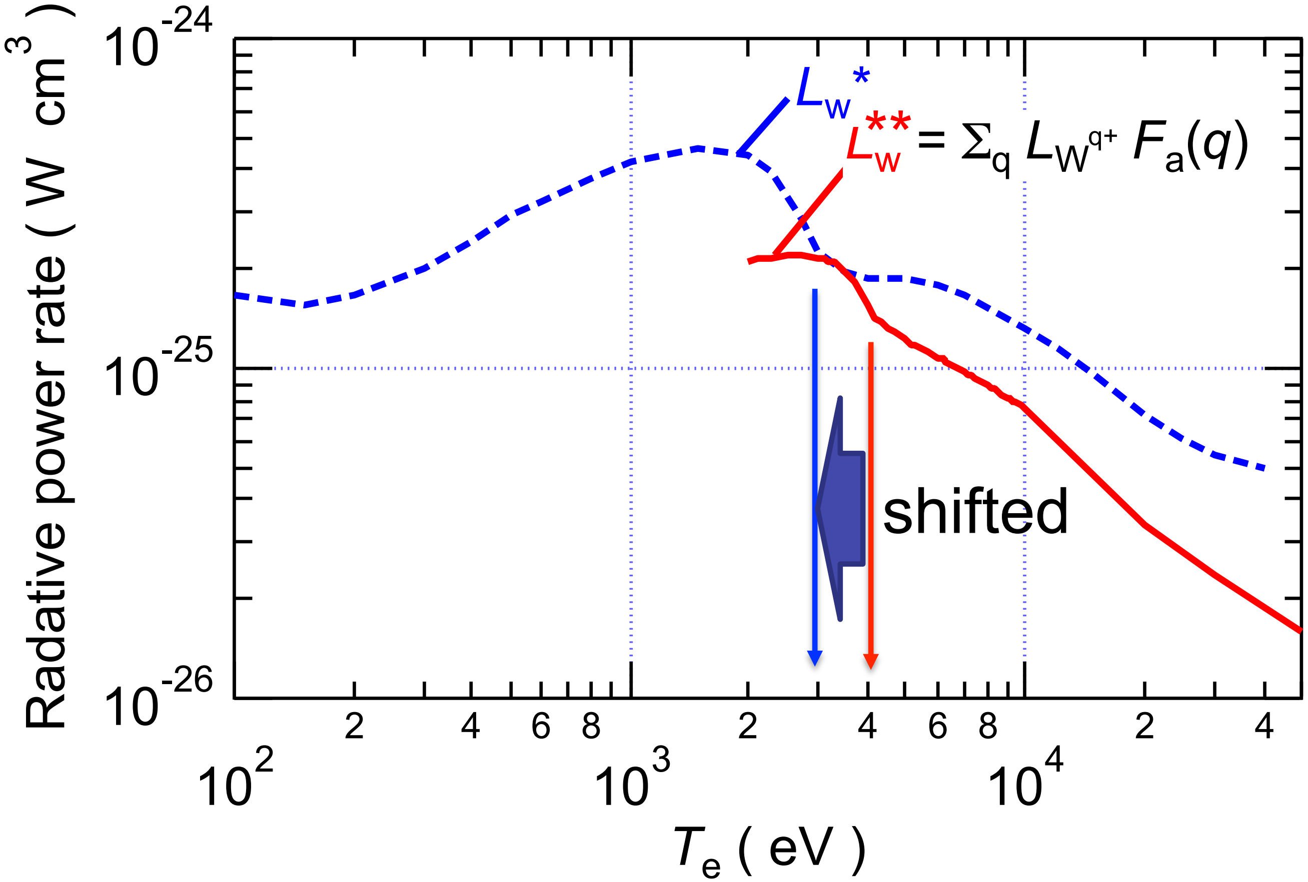
Line identification
<= spectral data

Photon Emission Coefficient
<= excitation rate, A coef, Energy level

Collisional-radiatve model

*H.-K Chung et al., HEDP 9 (2013) 645.

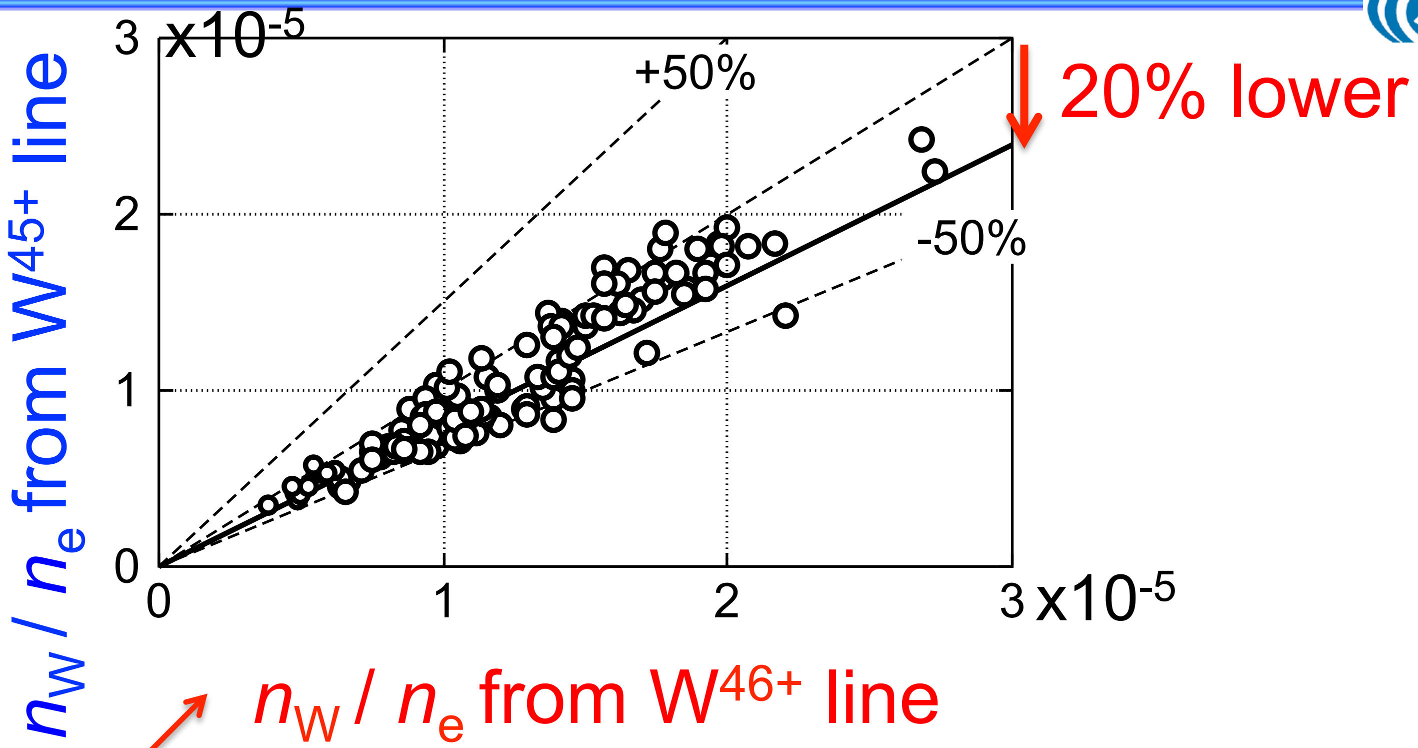
Issue 2: W cooling rate

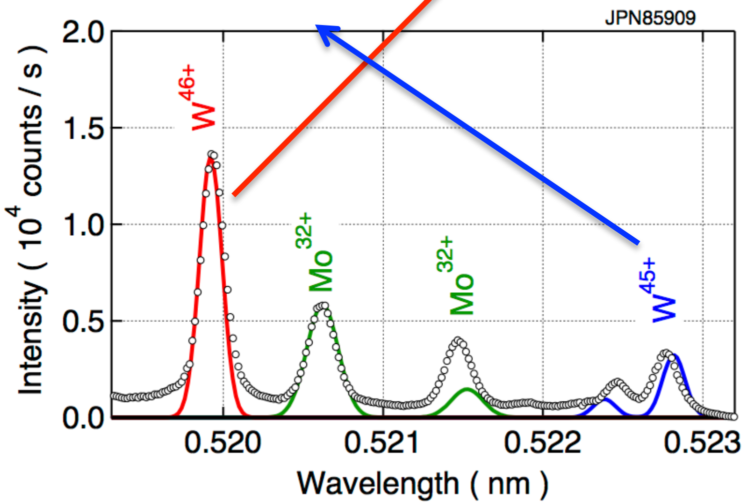


Shift of the cooling rates originates from ioniz. Eq calculation

*T Puetterich *et al Nucl. Fusion* **50** (2010) 025012
T Nakano et al J. Nucl. Mater **415 (2010) S327

Issue 3: W density measurement





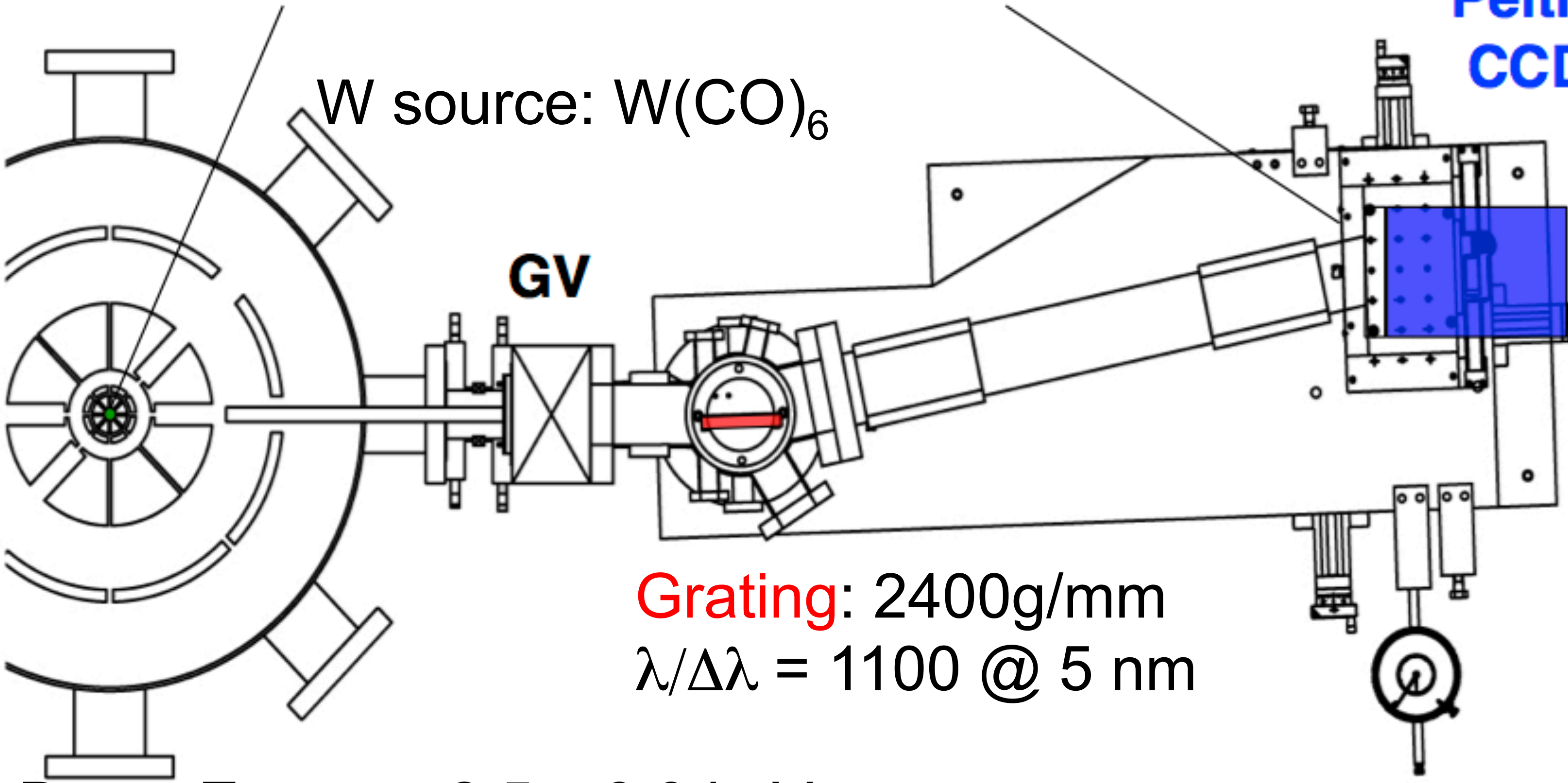
Uncertainty of collisional data
(Ioniz./Recomb. rates) needed

*T. Nakano et al 41st EPS conference (2014), submitted to J. Phys. B

Outline

- Introduction
- Motivation
- Evaluation of W^{44+} ionization / W^{45+} recombination
  - -Experiment in Tokyo EBIT device
  - -Calculations for Excitation Auto-ionization and Dielectronic Recombination by FAC
  - -Comparison
- Conclusions

Experimental setup



Format:
1340
x400
Pixel:
20μm

Grating: 2400g/mm
$\lambda/\Delta\lambda$ = 1100 @ 5 nm

Beam Energy : 2.5 – 3.3 keV
Energy width : ~ 10 eV
Beam Current: 20 – 50 mA

*) H. Ohashi et al, Rev. Sci. Instrum. **82** (2011) 083103

Constant excitation rate ratio of W^{44+} and W^{45+} useful for direct comparison btw Exp and Theory

Measurement

$$\frac{I^{W45+}(6.2\ \text{nm}):\ 4s\ ^2S_{1/2} - 4p\ ^2P_{3/2}}{I^{W44+}(6.1\ \text{nm}):\ 4s4s\ ^1S_0 - 4s4p\ ^1P_1} = \frac{C_e^{45+}(4s,4p)}{C_e^{44+}(4s,4p)} \cdot \frac{nW^{45+}(4s)}{nW^{44+}(4s)} \cdot \frac{n_e}{n_e}$$

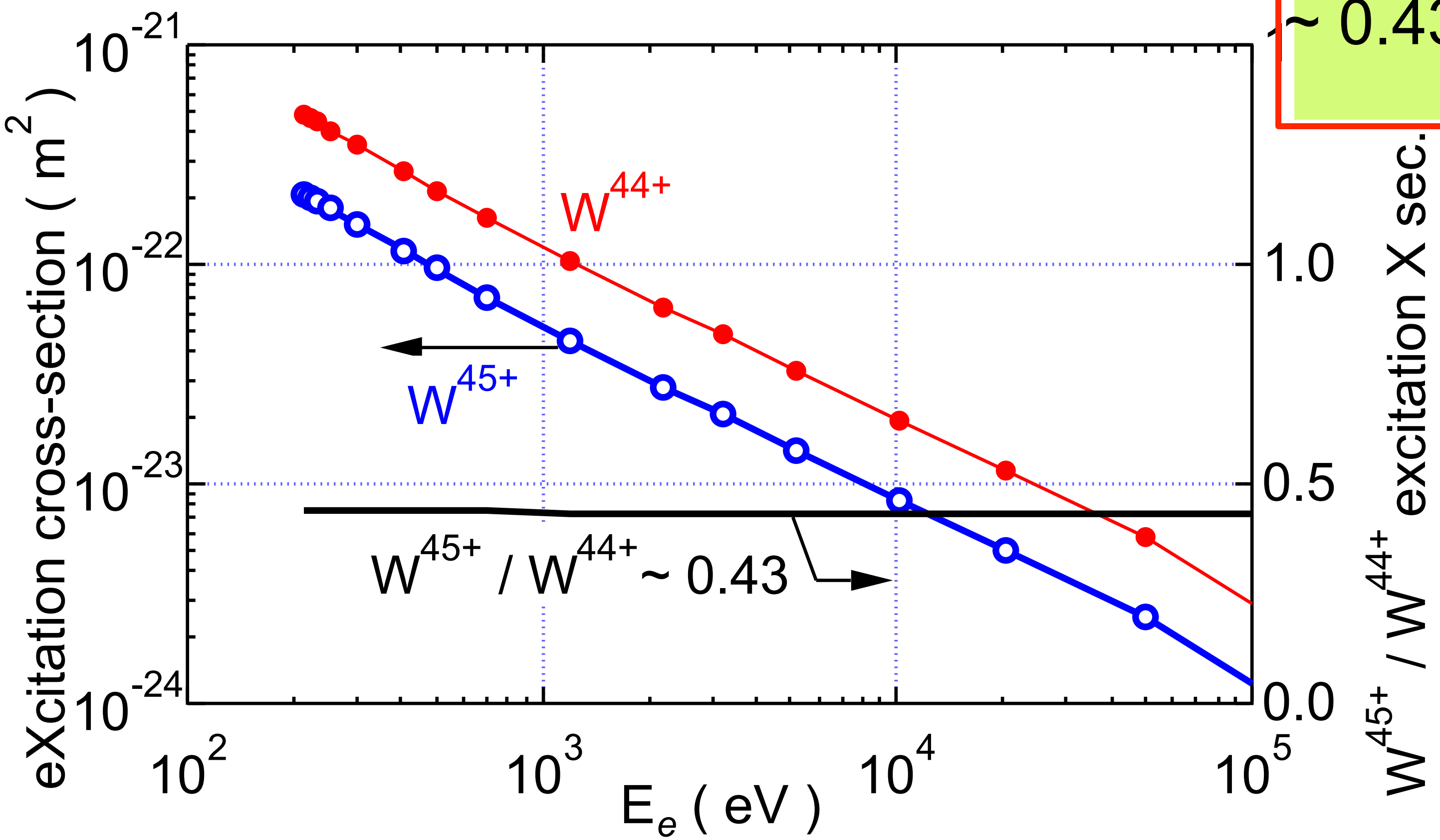
Excitation Xsec

Close excitation energy (199 ev and 204 eV)
⇒ Similar energy dependence of C_e

Ioniz. Equi.

$$\sim 0.43 \cdot \frac{S^{44+\to 45+}\ (\text{Ioniz.Xsec})}{\alpha^{45+\to 44+}\ (\text{Recomb.Xsec})}$$

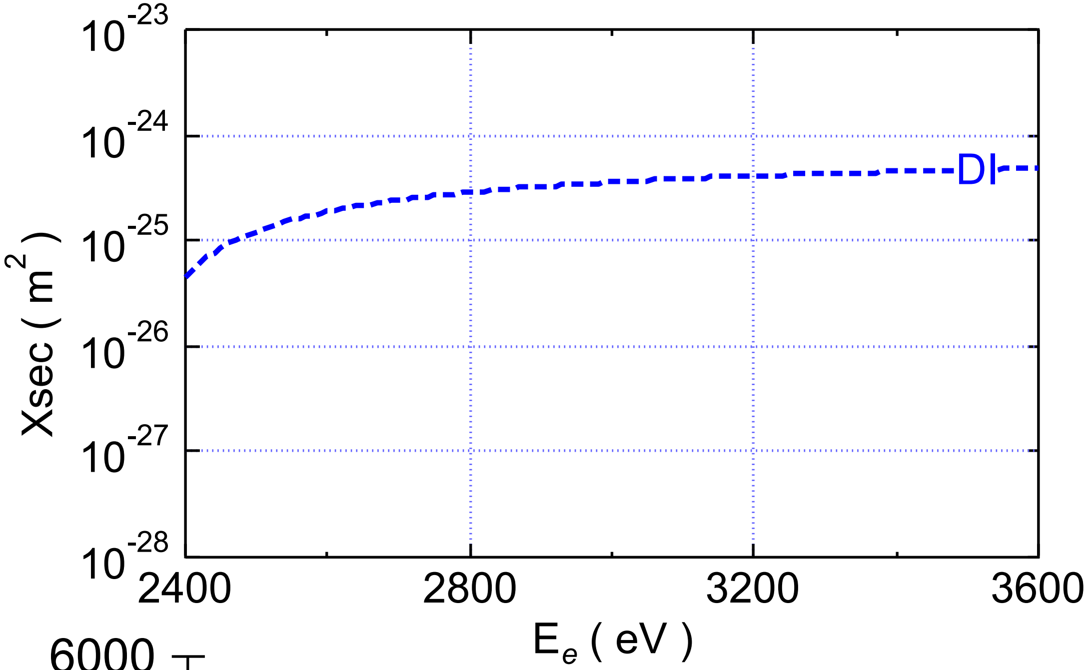
Calculation

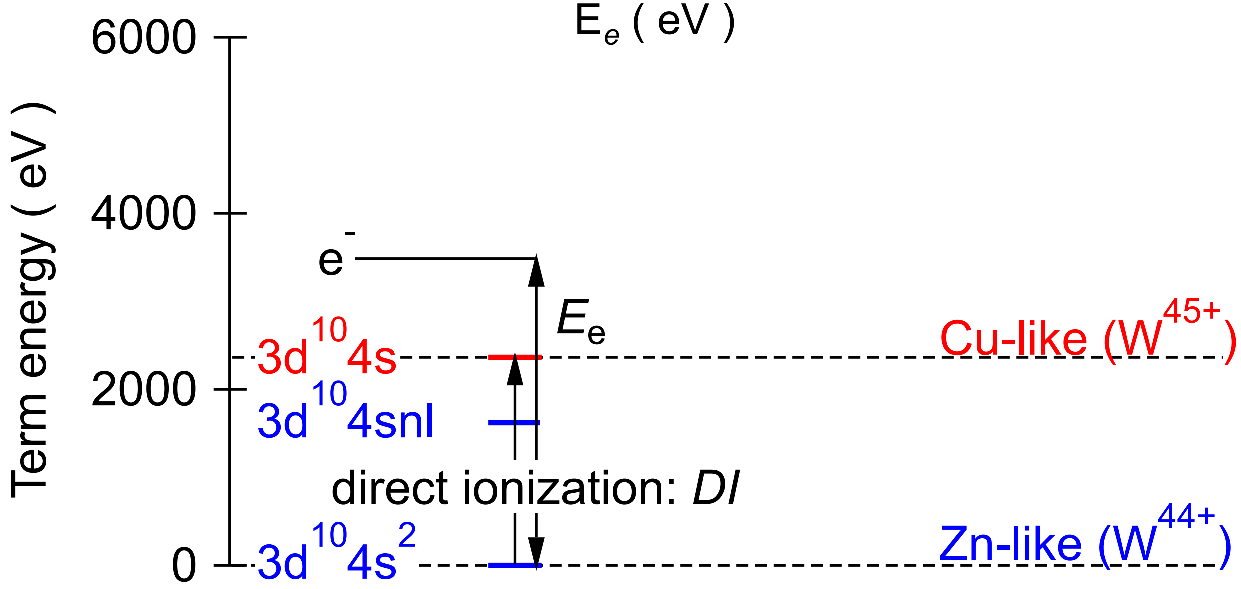


$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\to45+}}{\alpha^{45+\to44+}}$$

$S = S^{direct}$ (DI) + $S^{excit.autoioniz.}$ (EA)

$\alpha = \alpha^{radiative}$ (RR) + $\alpha^{die\text{-}electronic}$ (DR)





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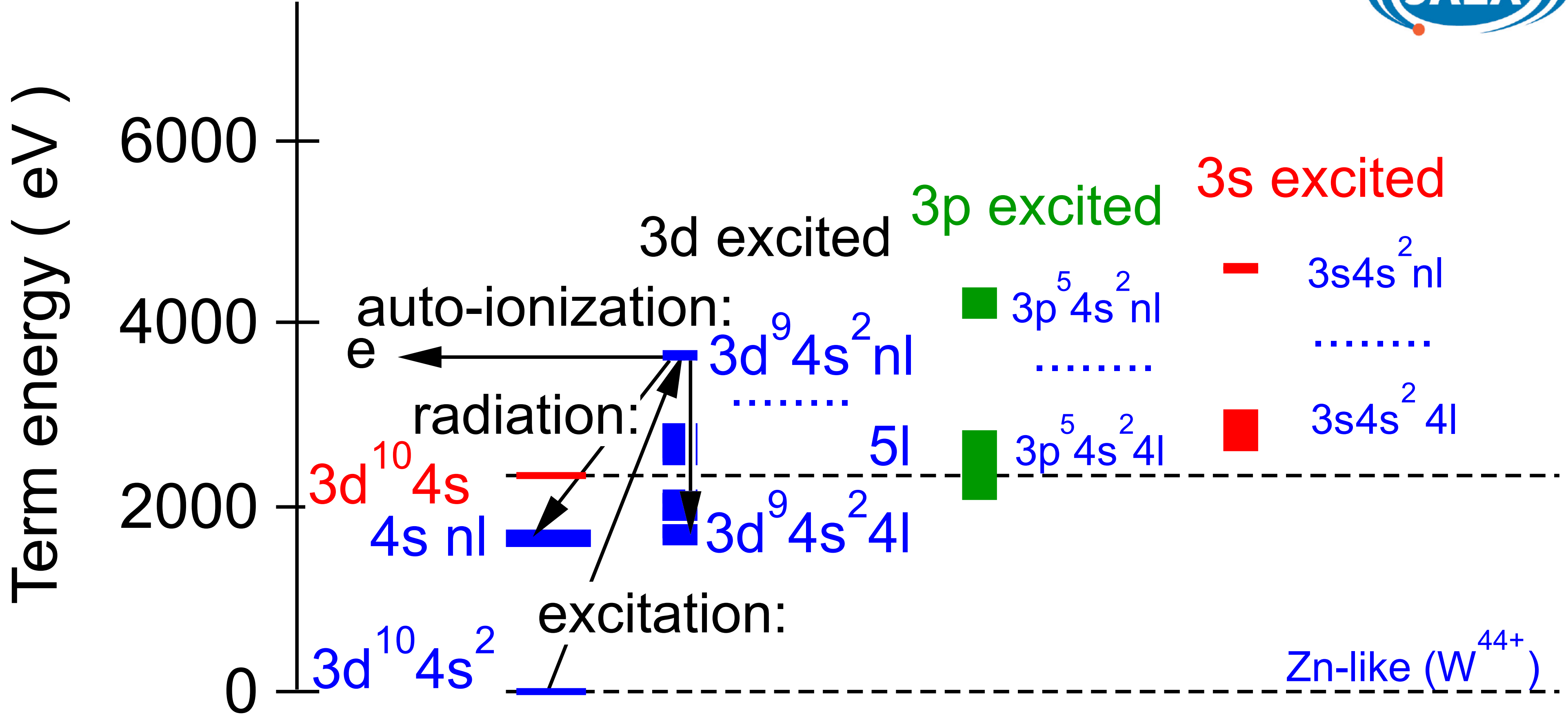

Ionization

$3d^{10}\,4s^2$ = Excitation => $3d^9\,4s^2\,nl$ { = Auto-ionization => $3d^{10}\,4s$

= Radiative decay => $3d^{10}\,4s^2$

Excitation & emission

Need branching ratio!

$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\to 45+}}{\alpha^{45+\to 44+}}$$

$$S = S^{direct}\ (DI) + S^{excit.autoioniz.}\ (EA)$$

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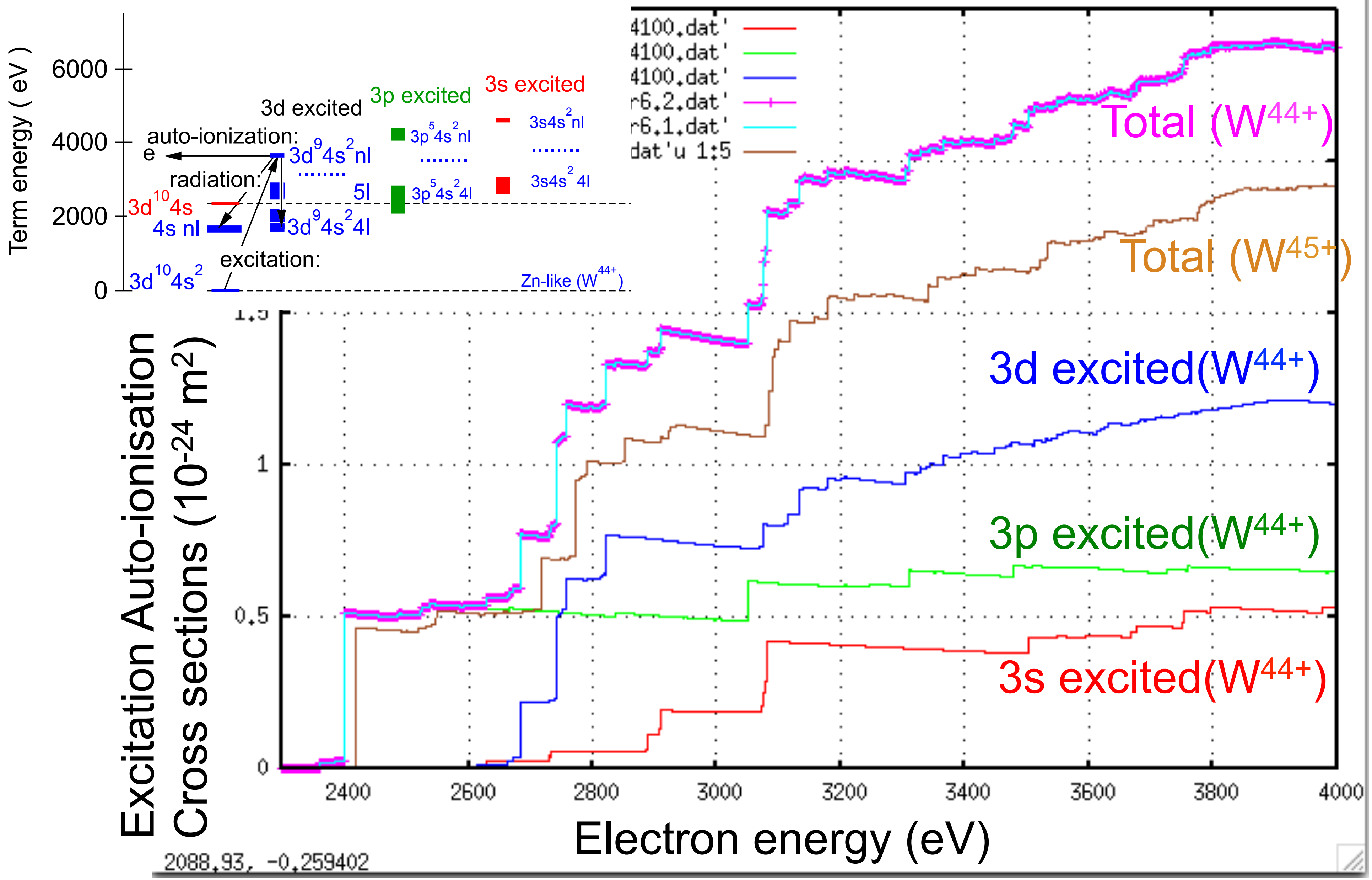

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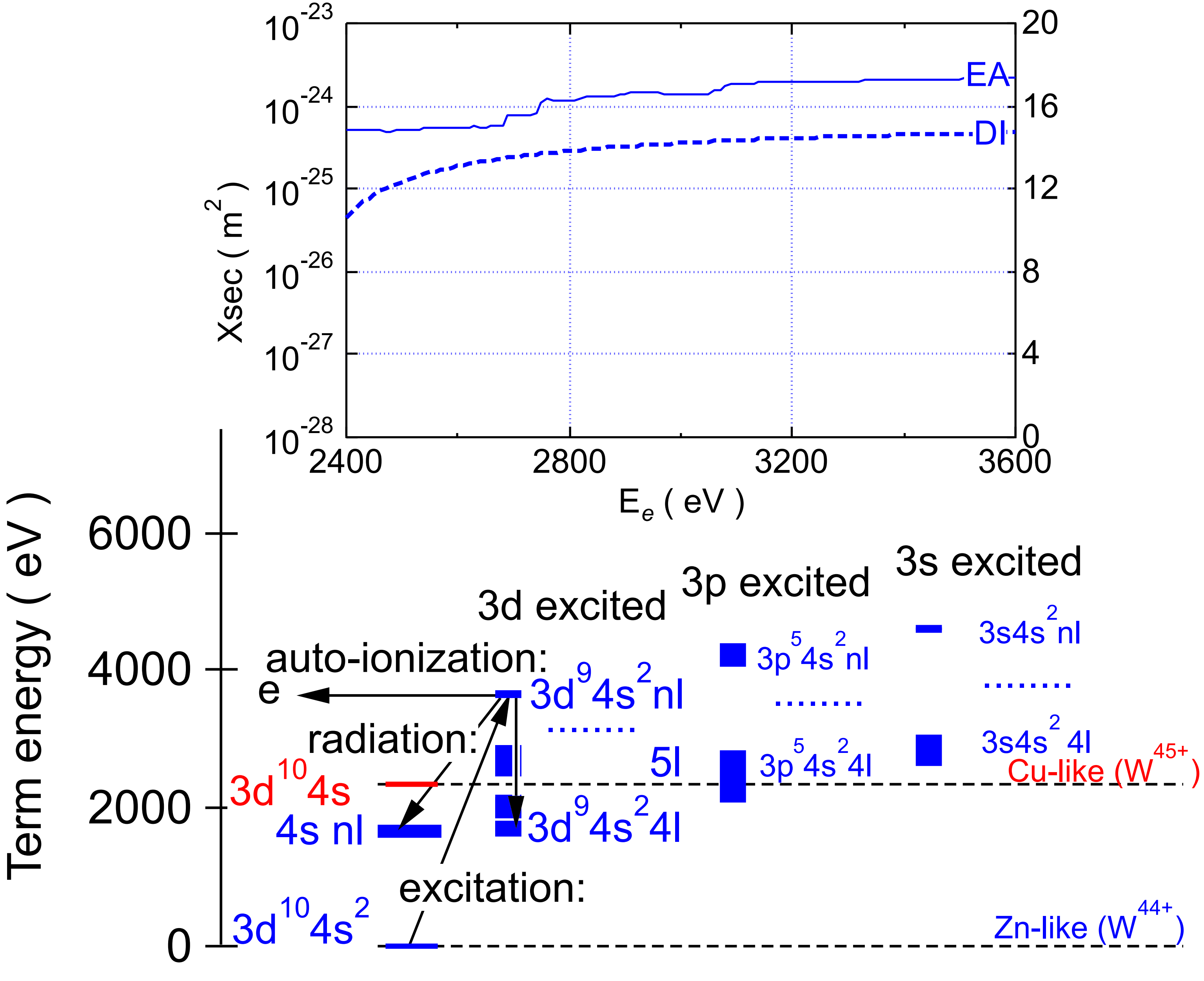

$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\text{->}45+}}{\alpha^{45+\text{->}44+}} \qquad S = S^{\text{direct}}\,(\text{DI}) + S^{\text{excit.autoioniz.}}\,(\text{EA})$$

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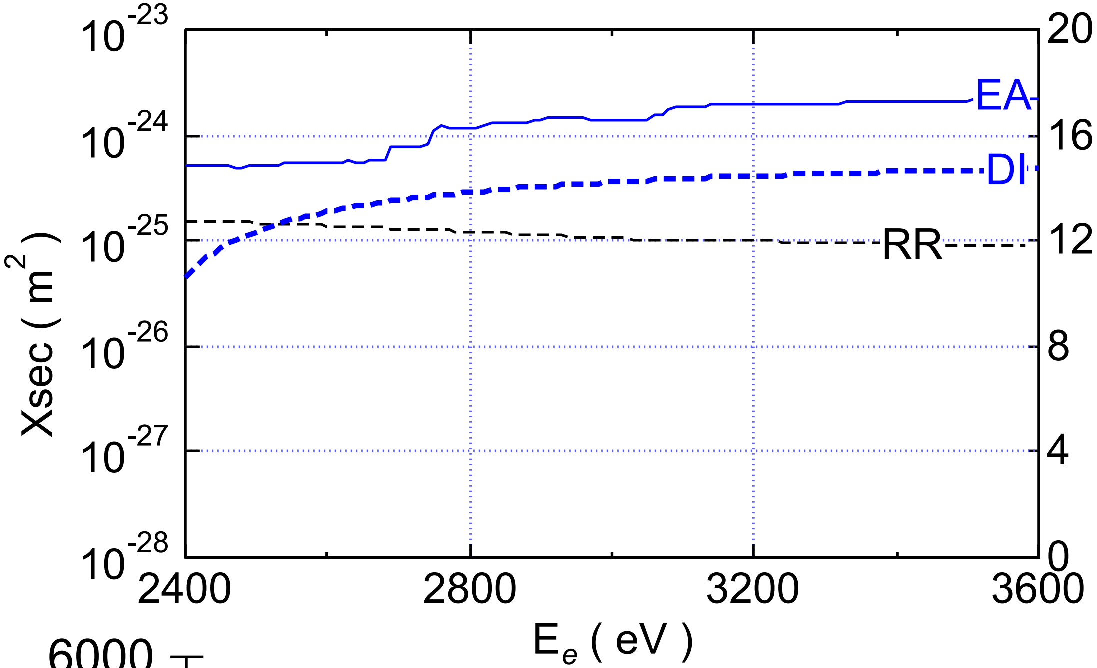

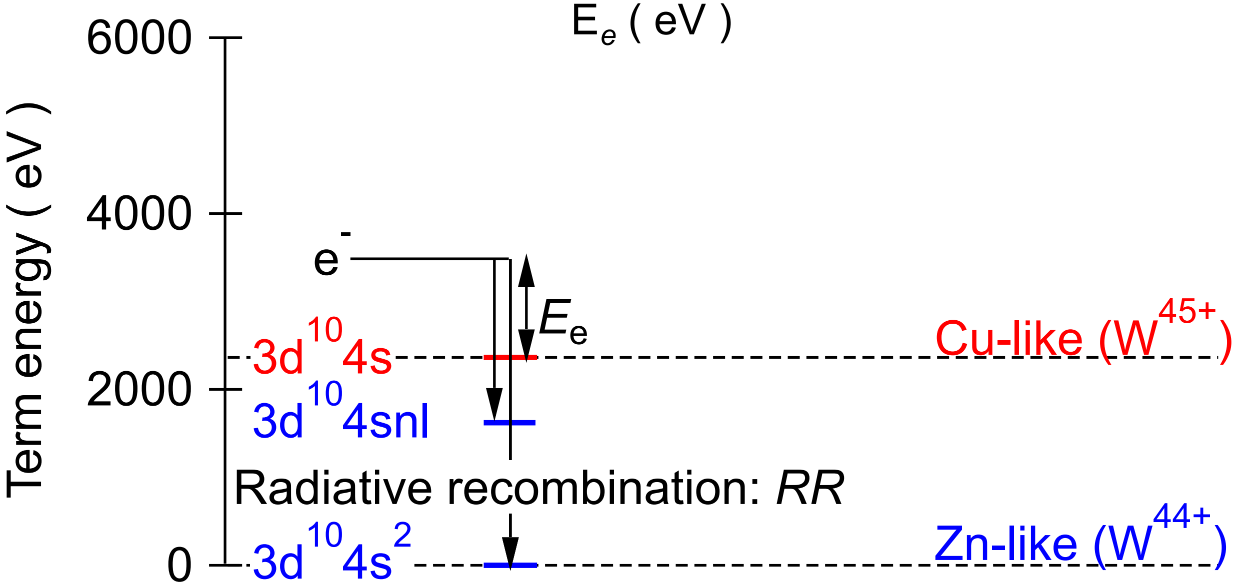

$$\frac{n_W{}^{45+}}{n_W{}^{44+}} = \frac{S^{44+\text{->}45+}}{\alpha^{45+\text{->}44+}} \qquad S = S^{\text{direct}}\ (\text{DI}) + S^{\text{excit.autoioniz.}}\ (\text{EA})$$

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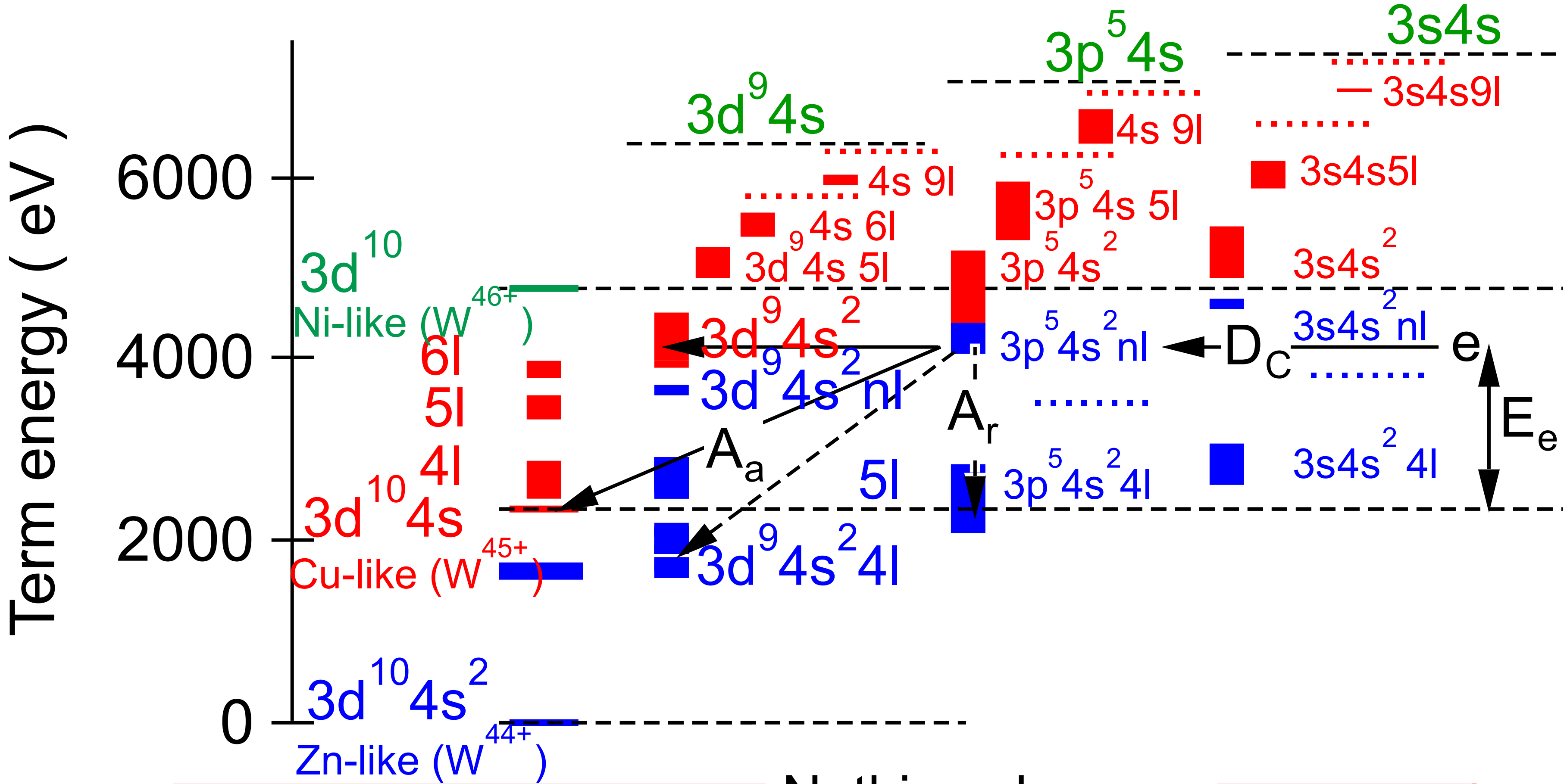
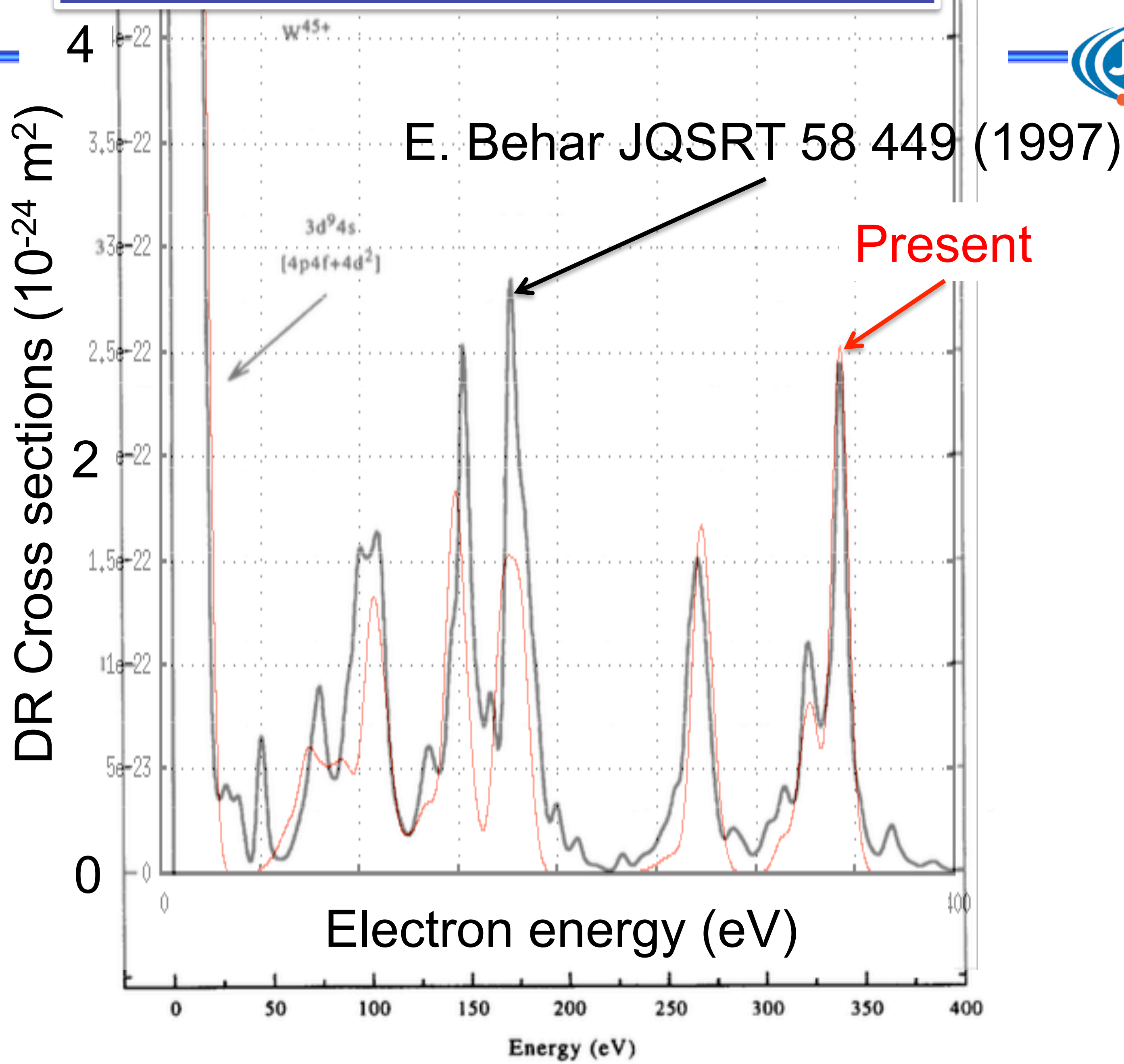


Nothing changes

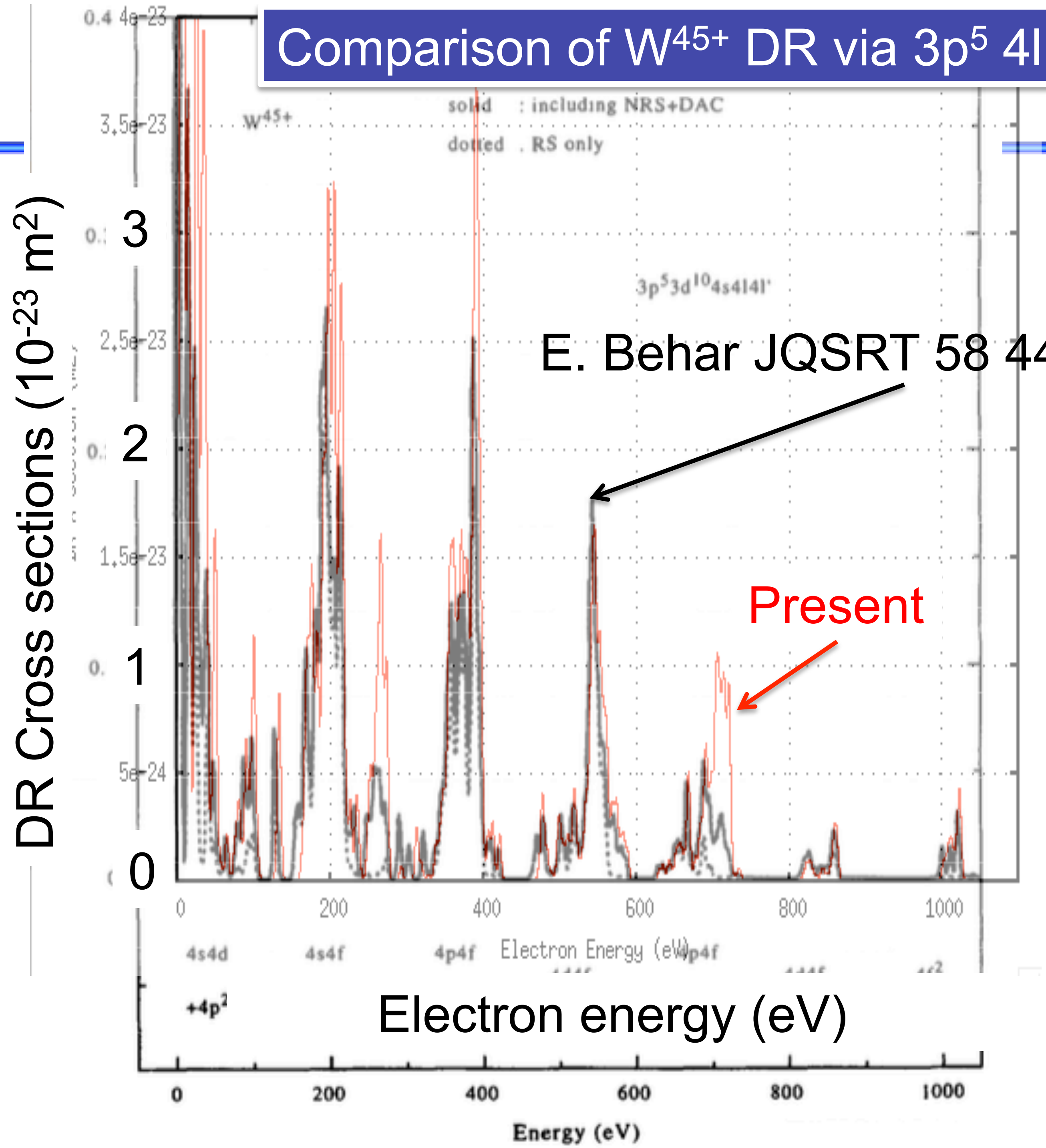
3d¹⁰ 4s = e capture => 3d⁹ 4s² nl { = Auto-ionization => 3d¹⁰ 4s
= Radiative decay => 3d¹⁰ 4s²

DR

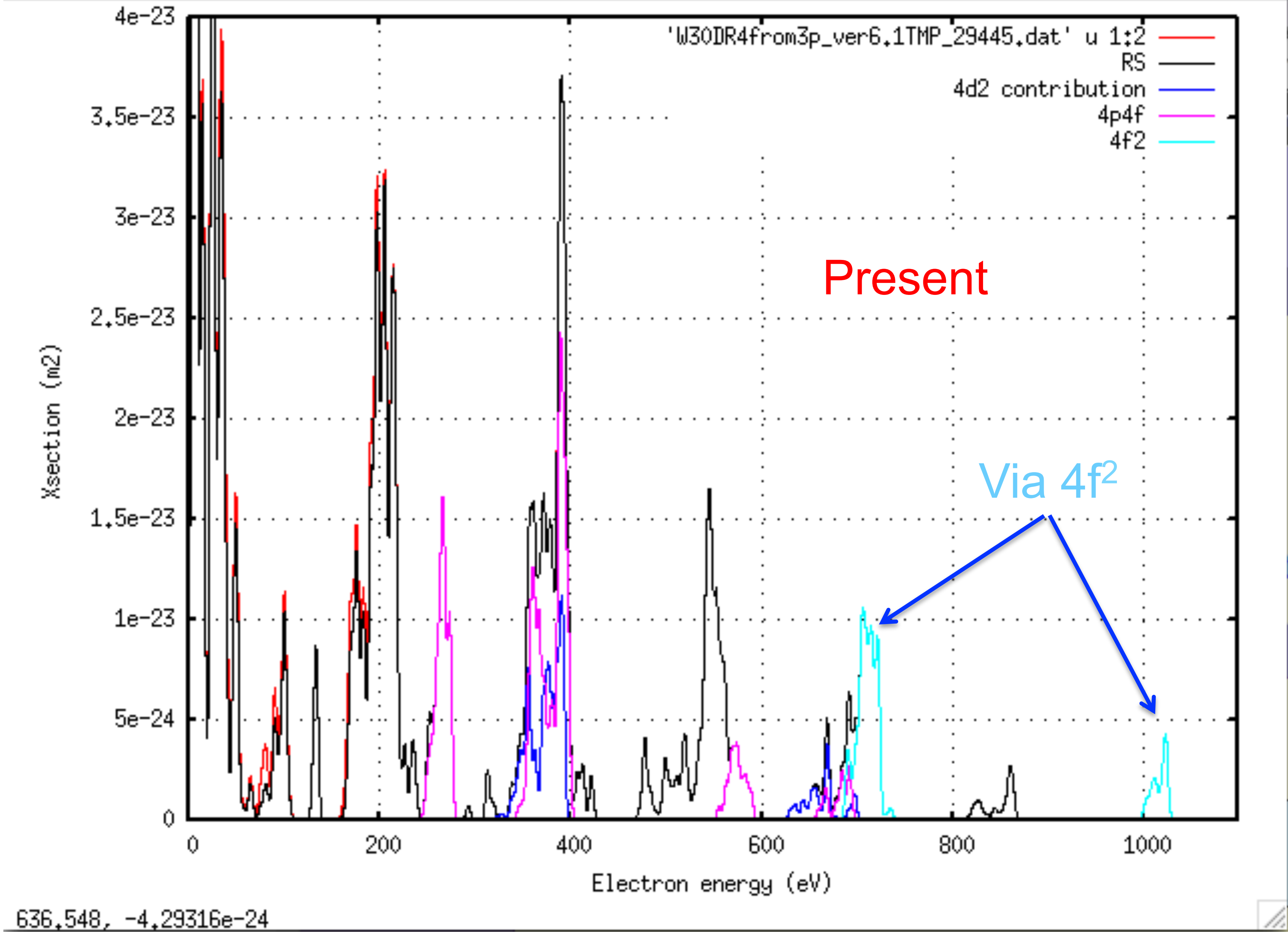
Comparison of W^{45+} DR via $3d^9$ 4l 4l'



Comparison of W^{45+} DR via $3p^5\ 4l\ 4l'$



Present : Two peaks via $4f^2$
Ref : One peak via $4f^2$



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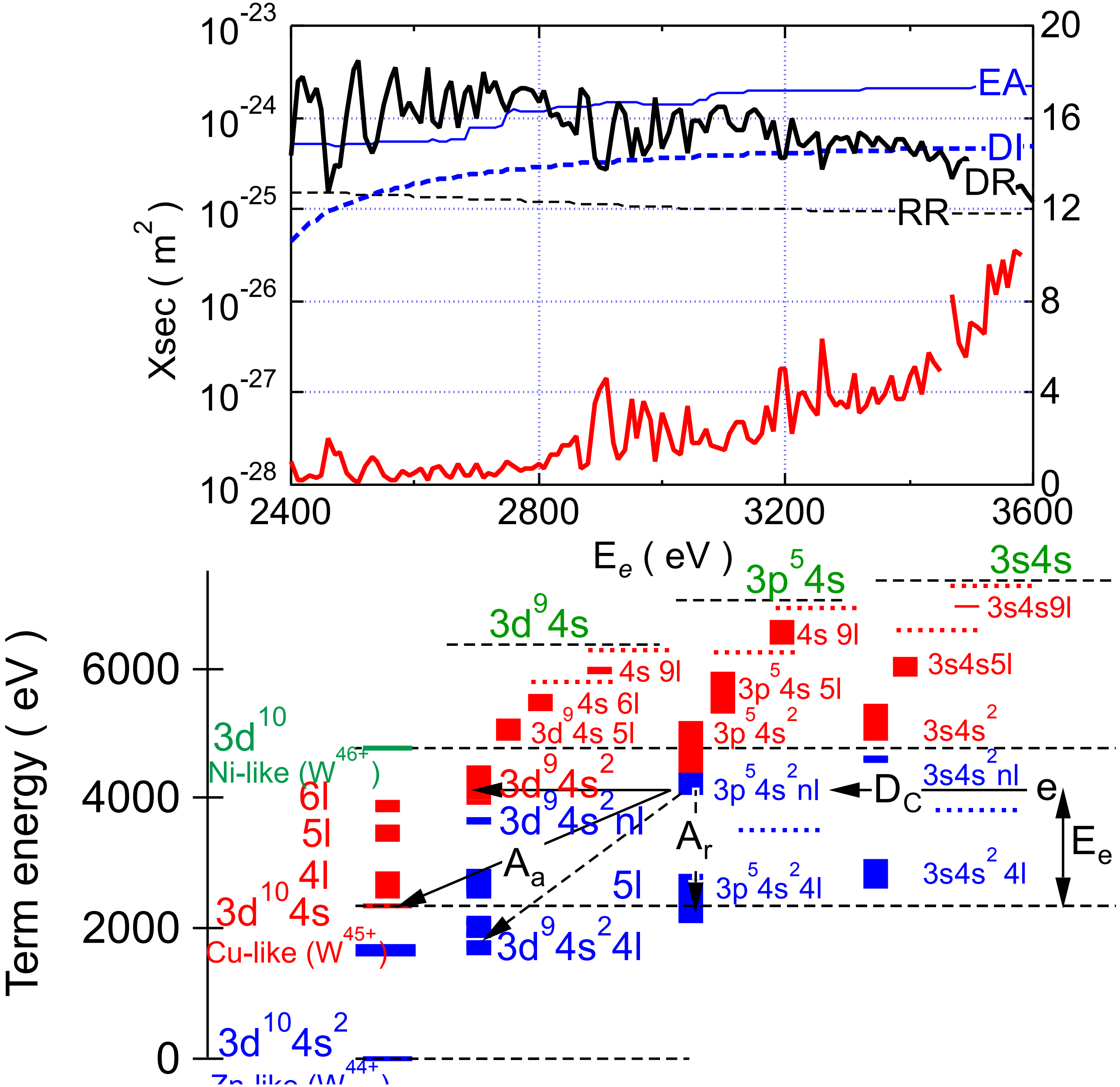
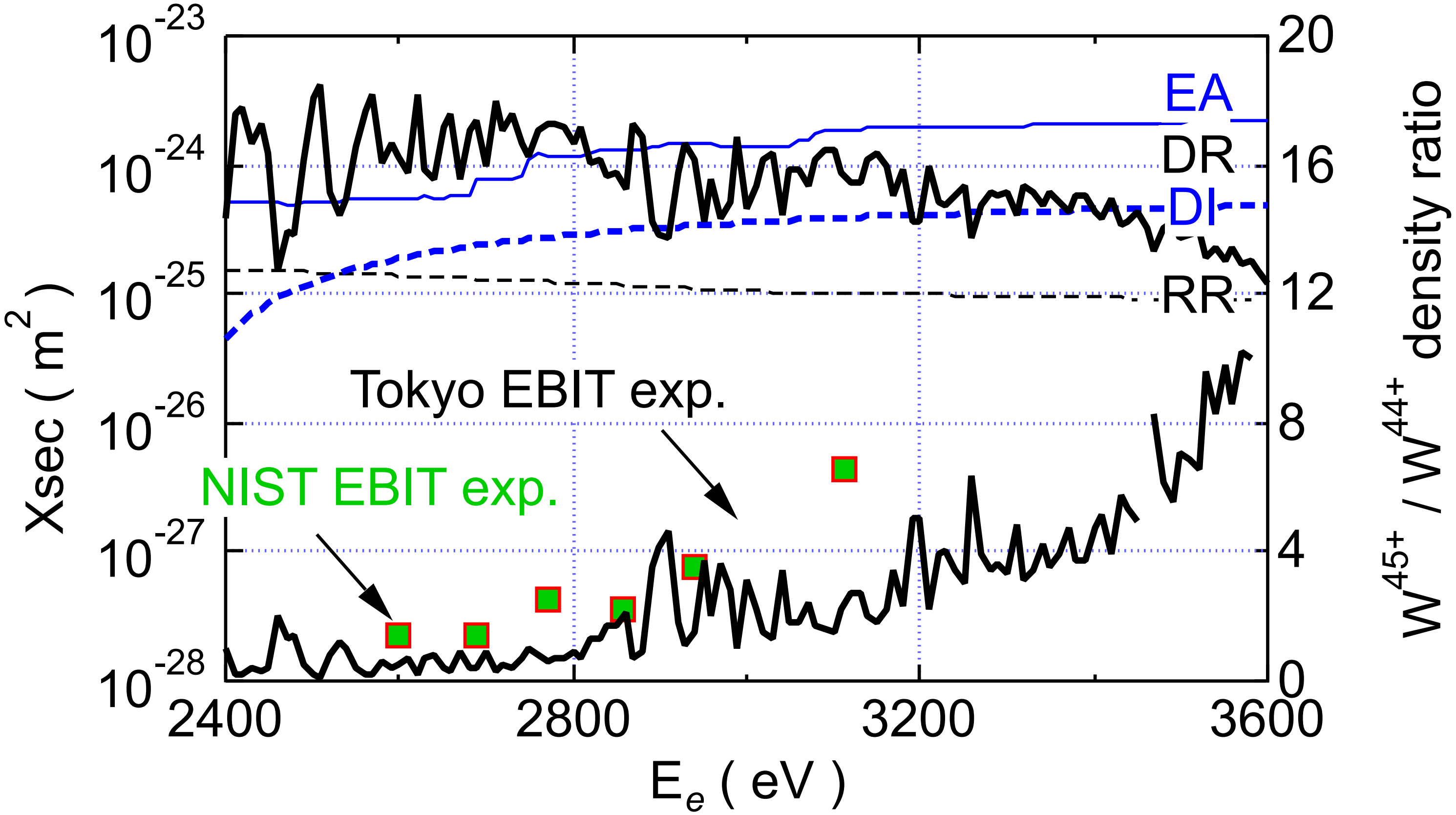


$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\text{->}45+}}{\alpha^{45+\text{->}44+}} = \frac{1}{0.43}\,\frac{I^{W45+}(6.2\text{ nm}):\quad 4s\ ^2S_{1/2}\ -\quad 4p\ ^2P_{3/2}}{I^{W44+}(6.1\text{ nm}):\ 4s4s\ ^1S_0\quad -\ 4s4p\ ^1P_1}$$



Comparison of Experiment and Calculation shows:

- Quantitatively ~ 2x difference

⇒ Need 2x higher EA, or 2x lower DR.

*) Y. Ralchenko, et al., J. Phys. B **40** (2007) 3861.

Comparison of DR & EA rates