44価及び45価タングステンイオンの電離・再結合断面積の実験的な評価

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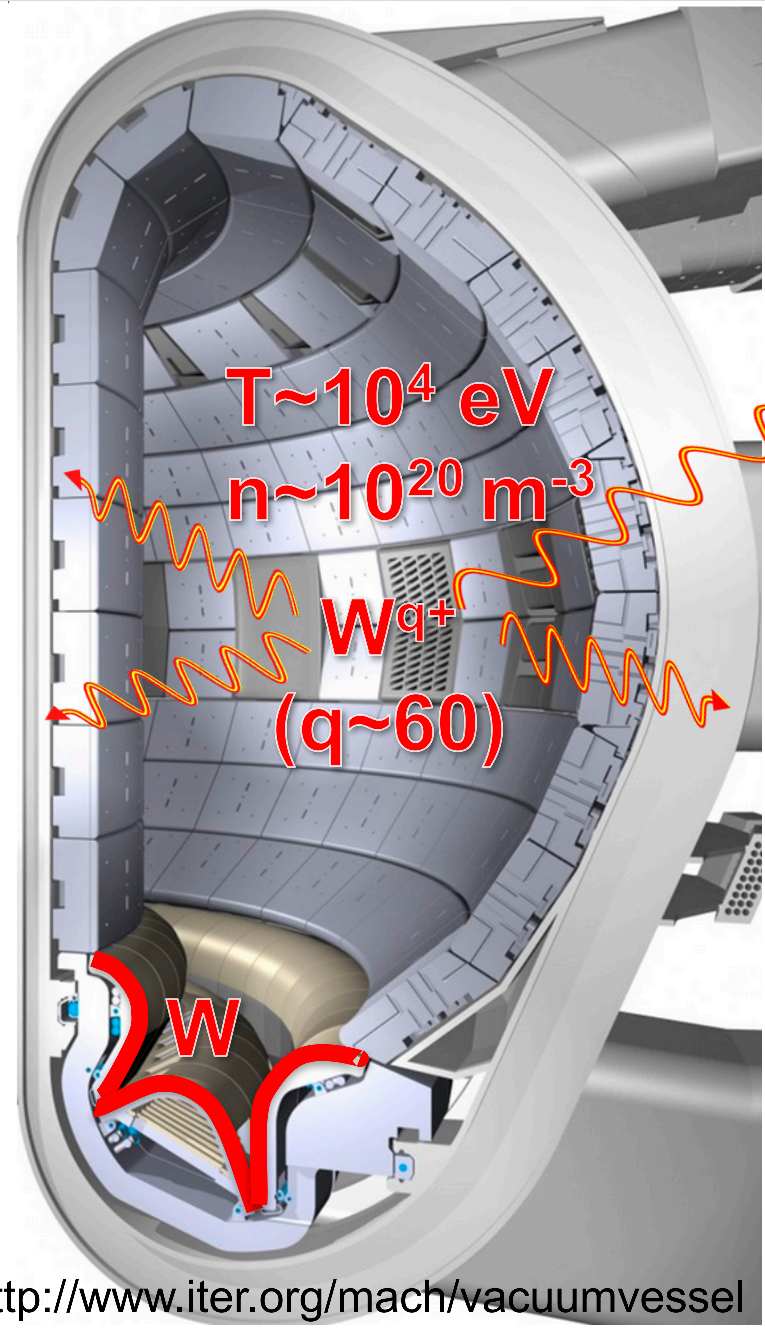
Tungsten: a candidate for PFCs in reactors



http://www.iter.org/mach/vacuumvessel

<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 ($n_W/n_e < 10^{-5}$)

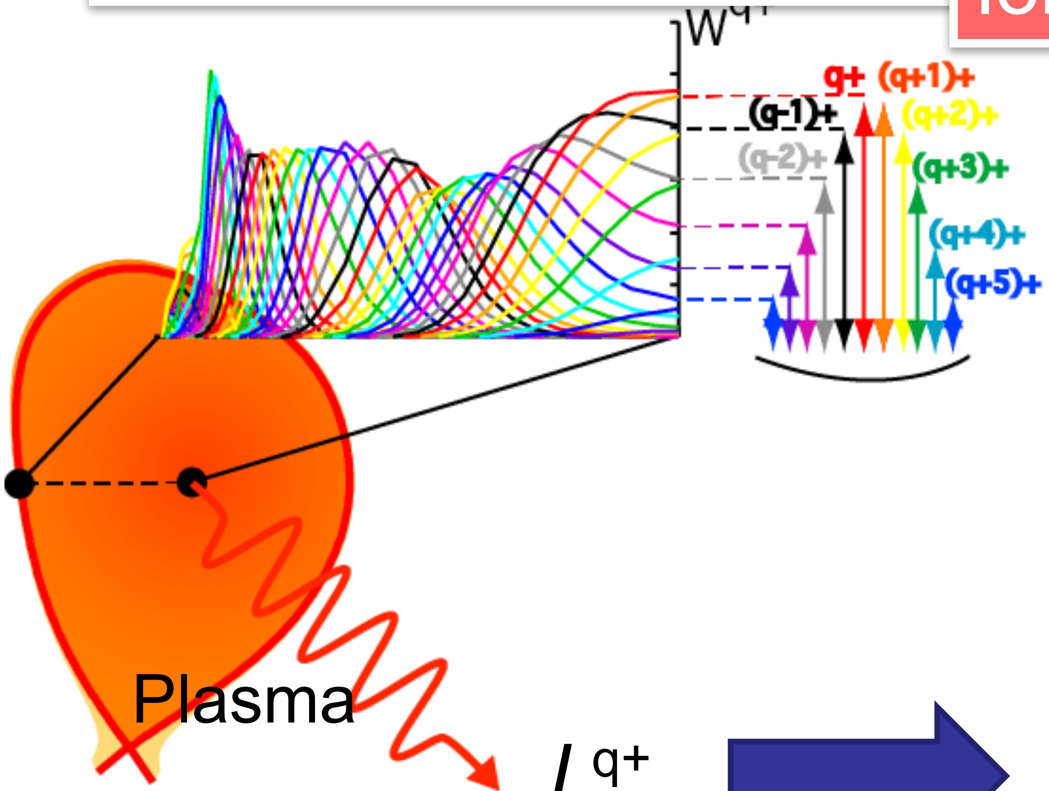
⇒ **W transport in plasmas**

<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)

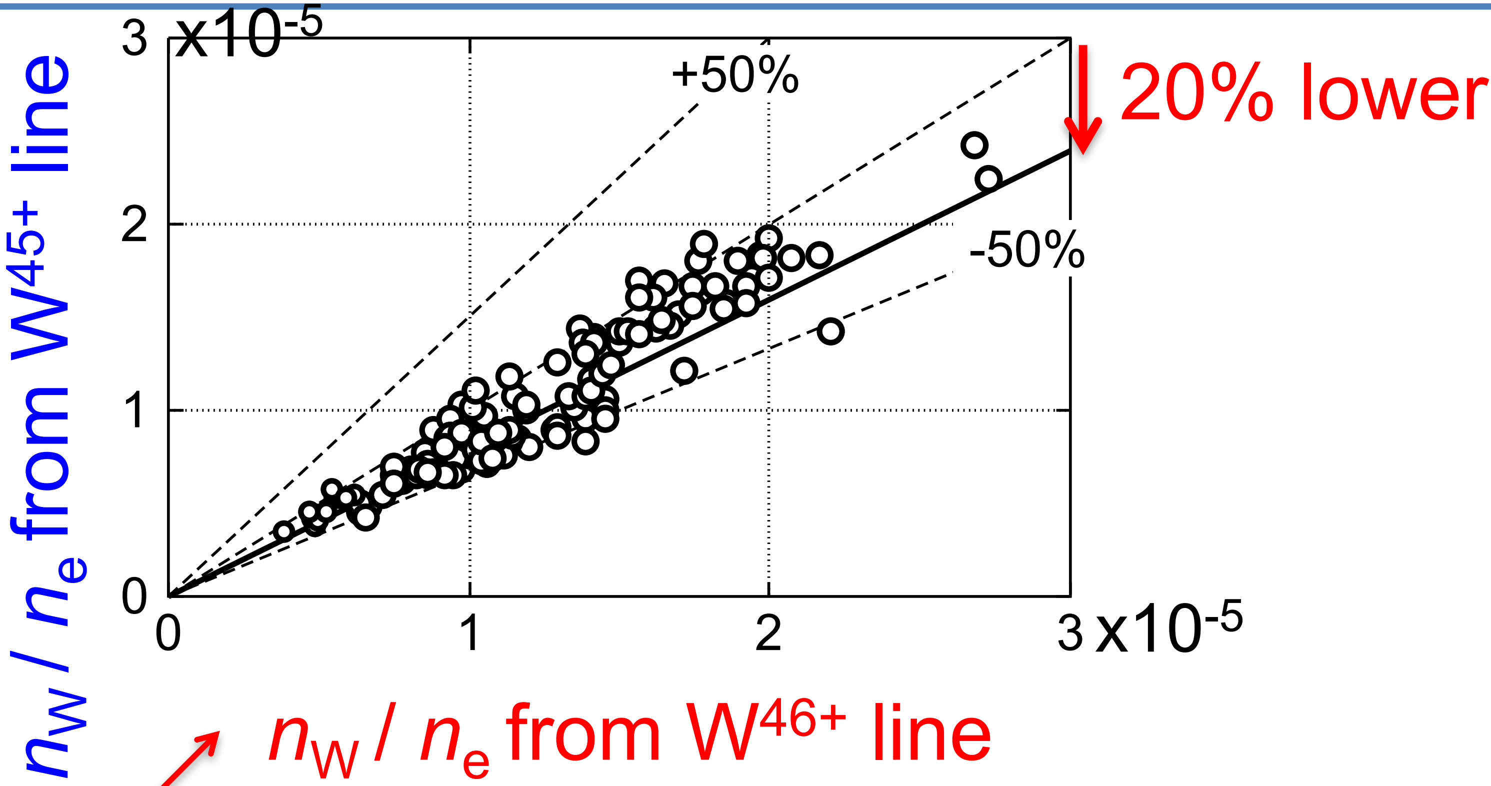
I^{q+} → nW^{q+} (W^{q+} density)

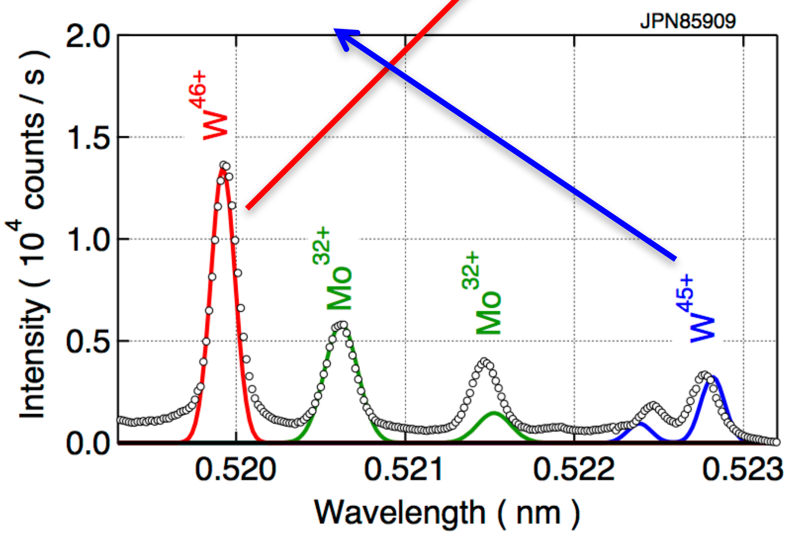
Line identification
<= spectral data

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

Collisional-radiatve model

Issue3: W density measurement





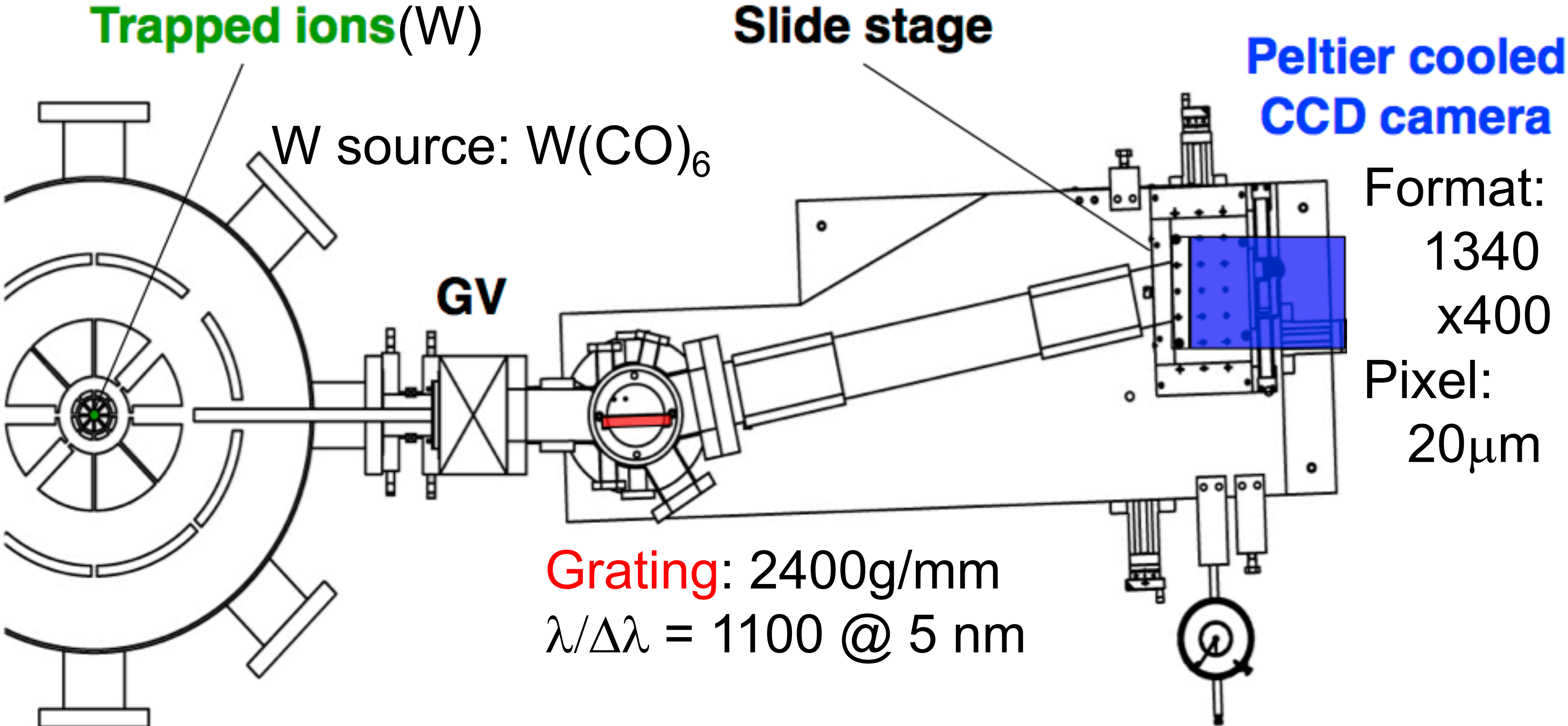
Uncertainty of collisional data
(Ioniz./Recomb. rates) needed

*T. Nakano et al J. Phys. B (2015)

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



Beam Energy : 2.5 – 3.4 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

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

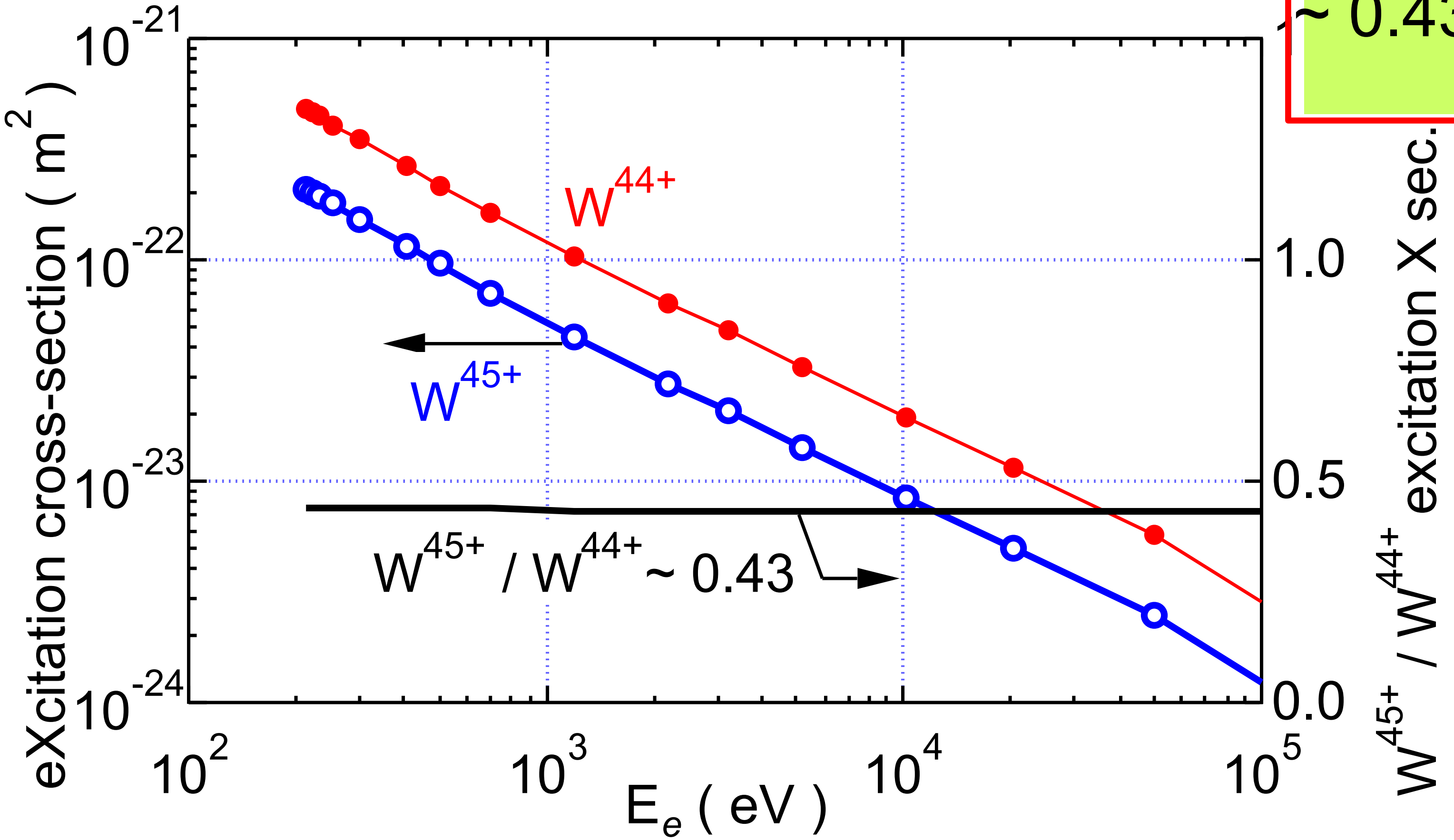
Excitation Xsec

Ioniz. Equi.

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

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

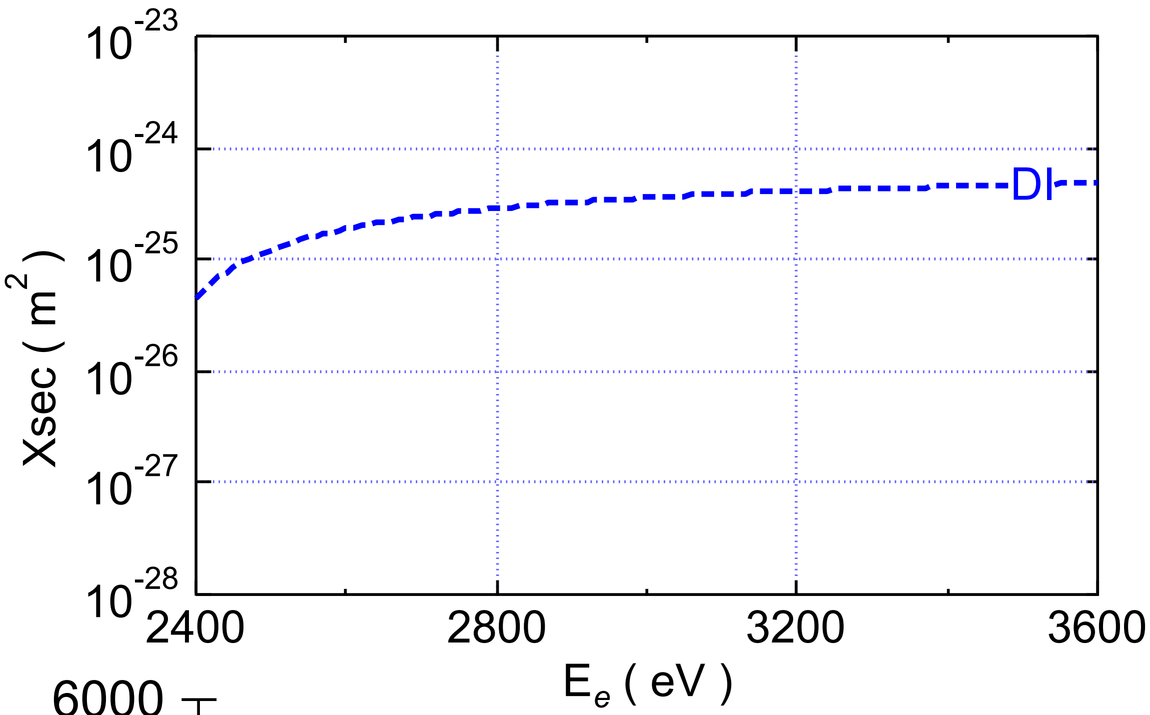
Calculation

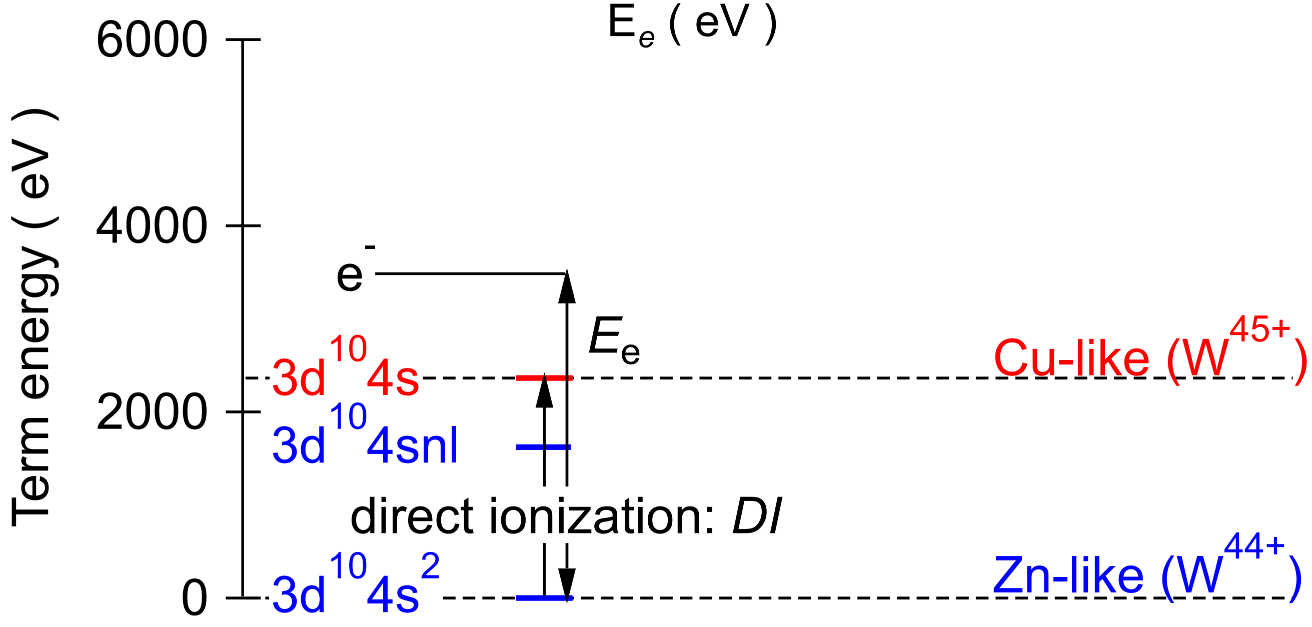


$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\to45+}}{\alpha^{45+\to44+}}$$

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

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

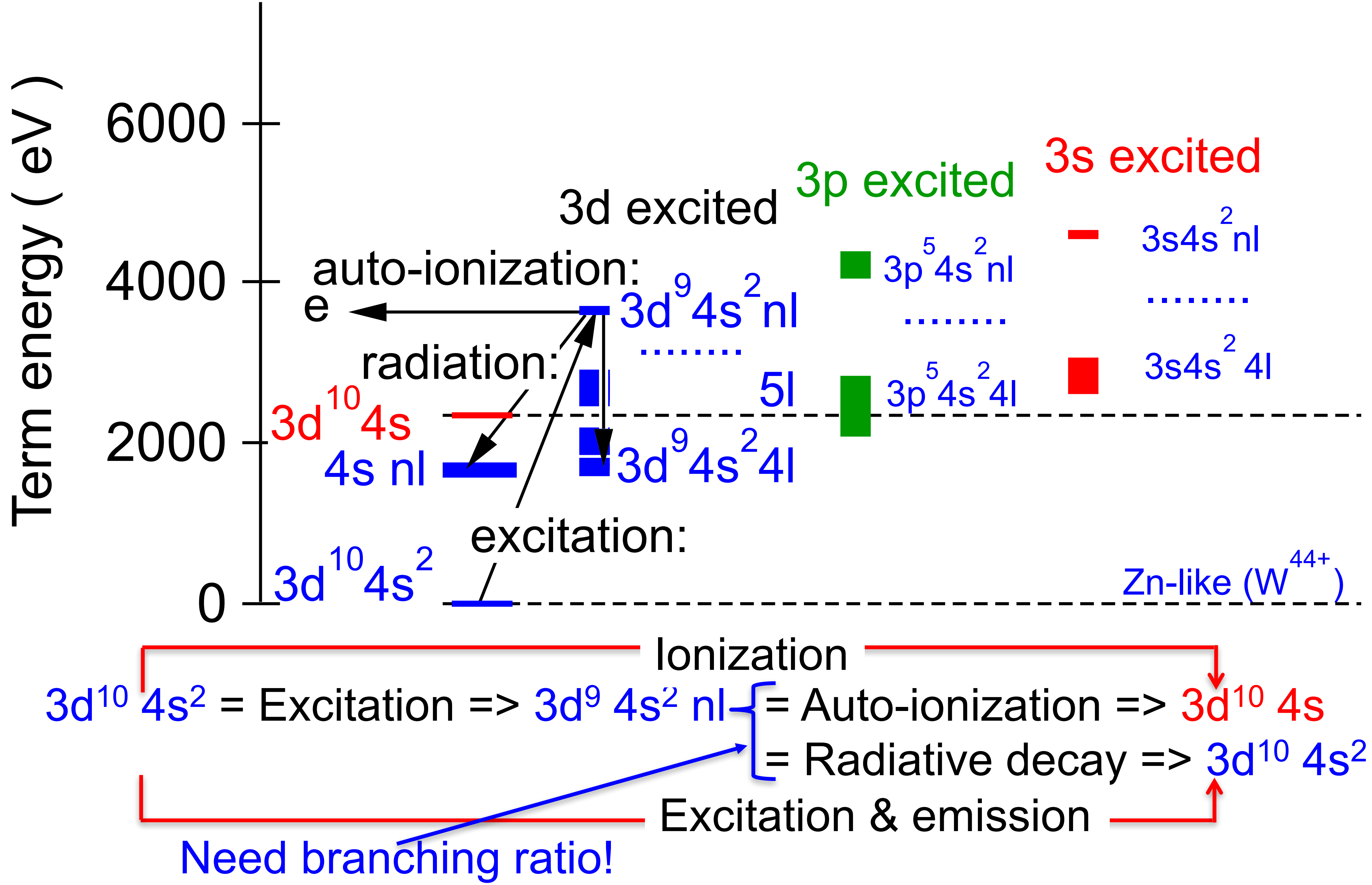




$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\text{->}45+}}{\alpha^{45+\text{->}44+}}$$

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

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



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

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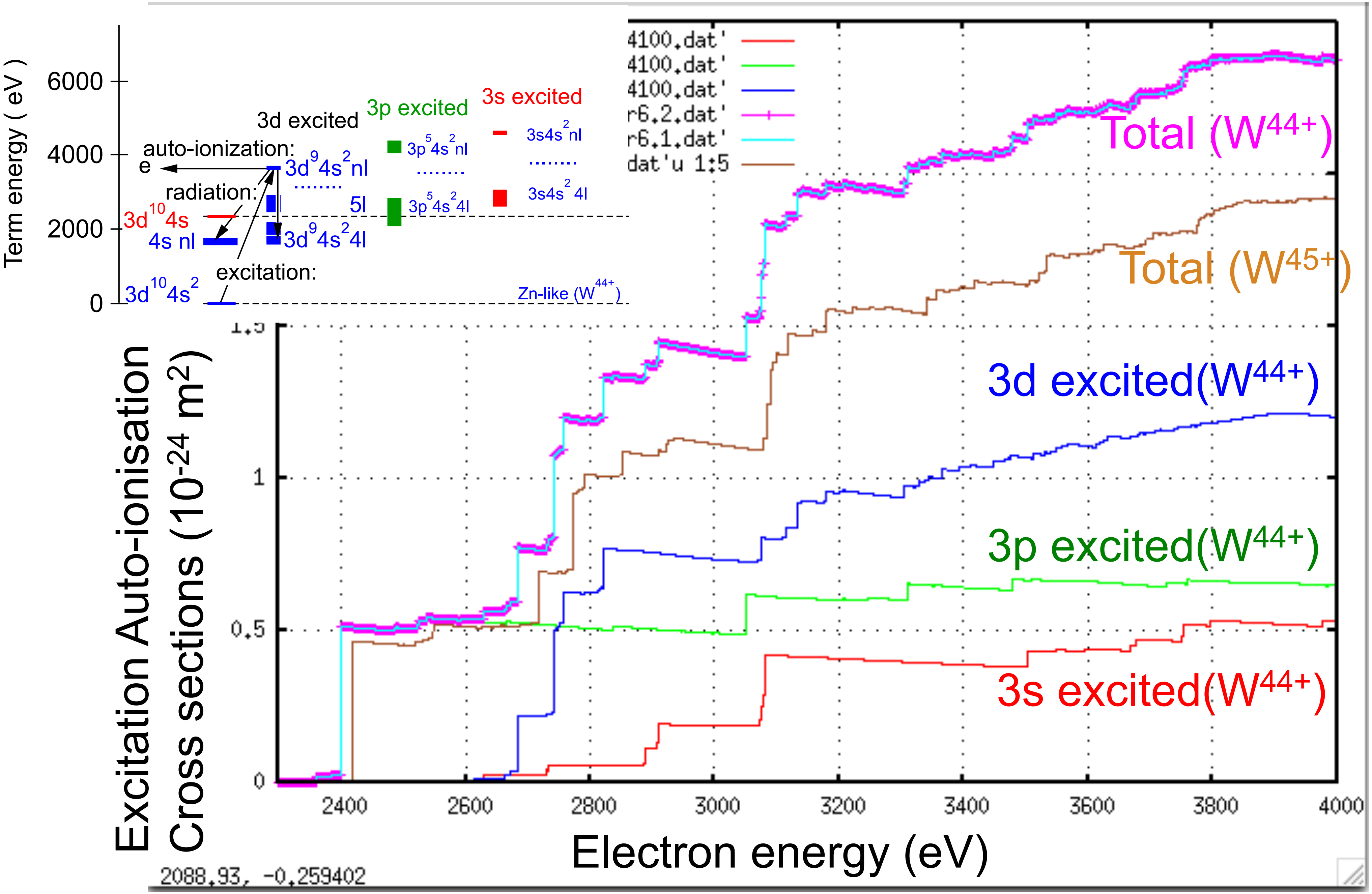
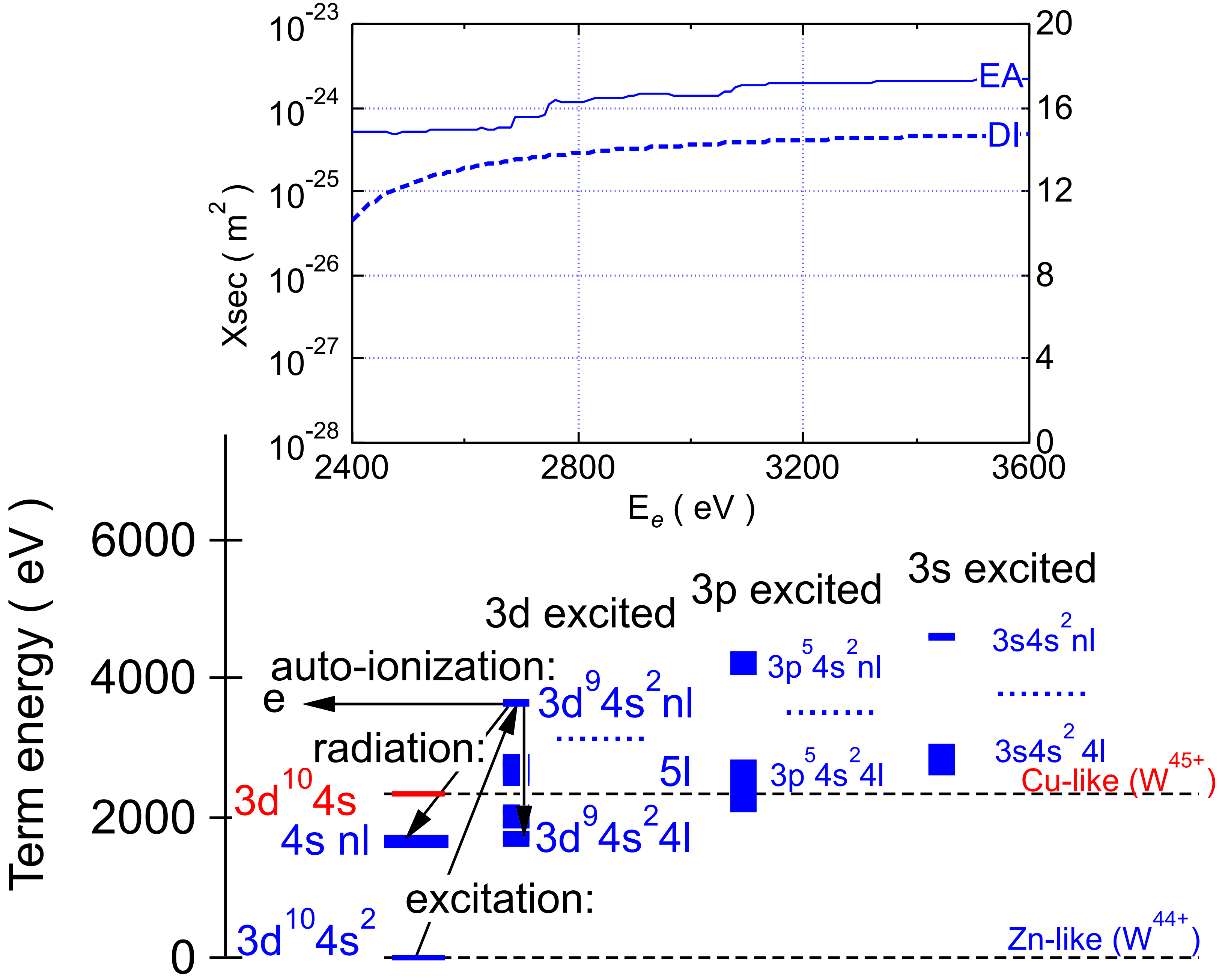


$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\to45+}}{\alpha^{45+\to44+}} \qquad S = S^{\text{direct}}\ (\text{DI}) + S^{\text{excit.autoioniz.}}\ (\text{EA})$$

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



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

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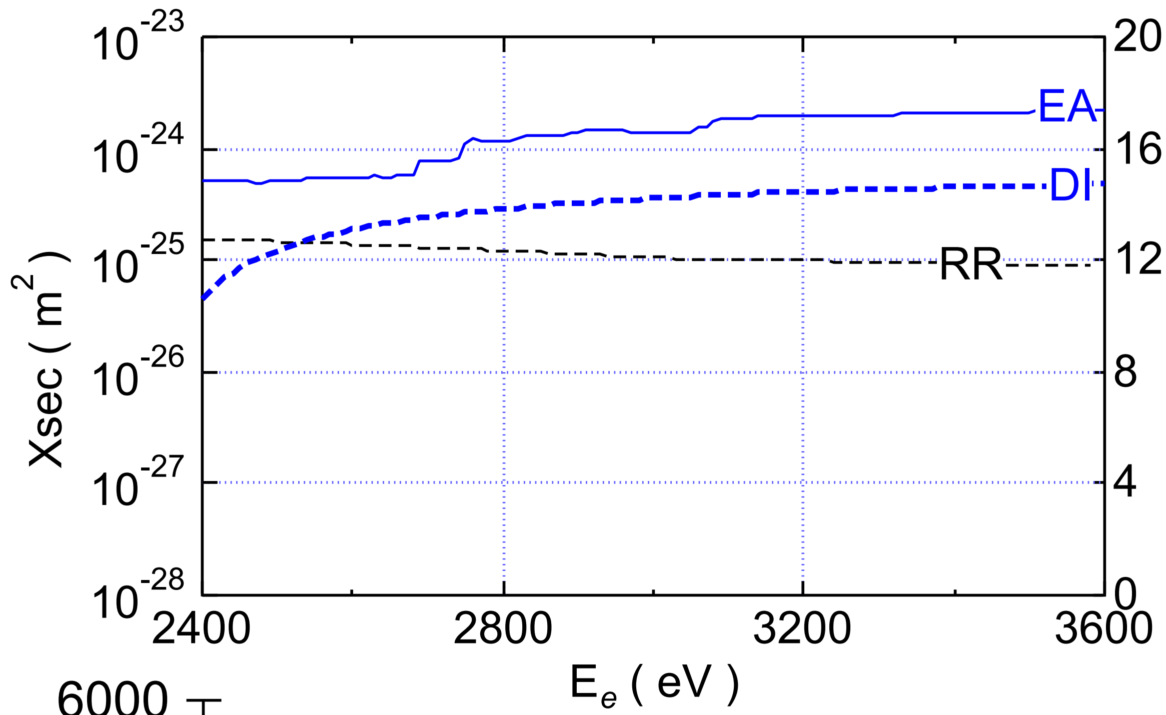

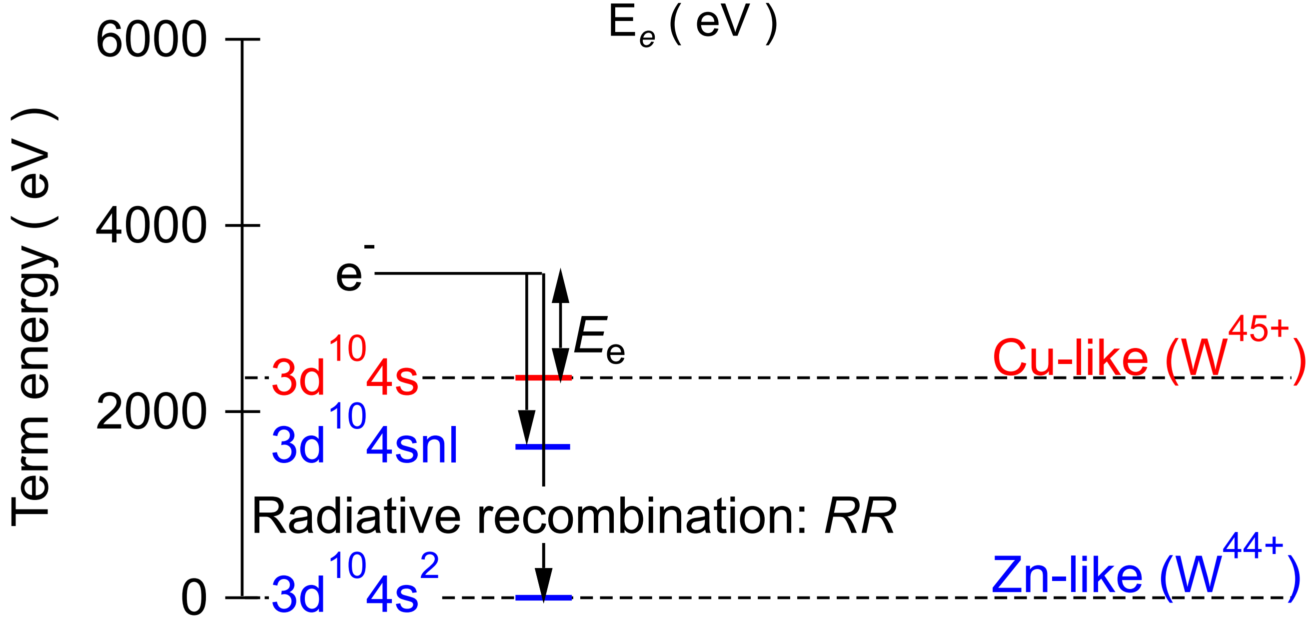

$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\to 45+}}{\alpha^{45+\to 44+}}$$

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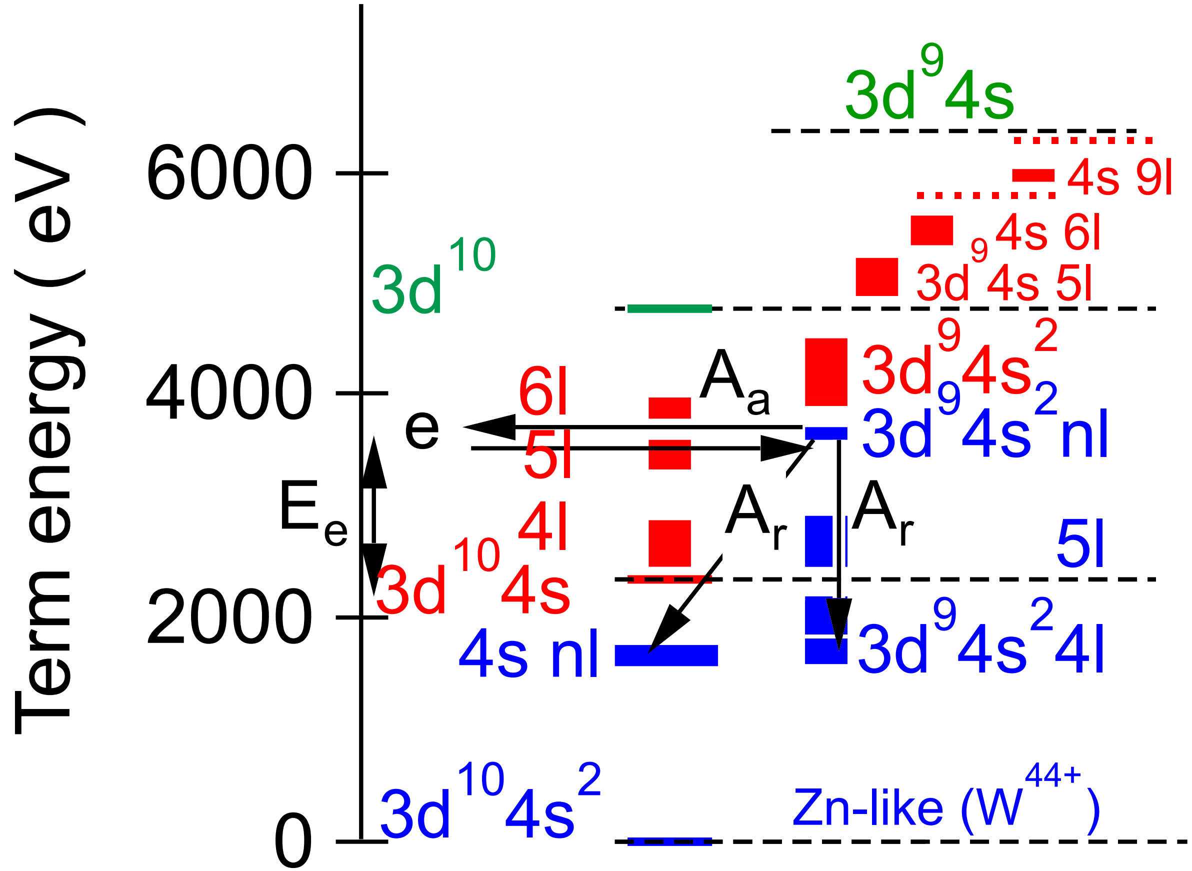

Nothing changes

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

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

DR

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

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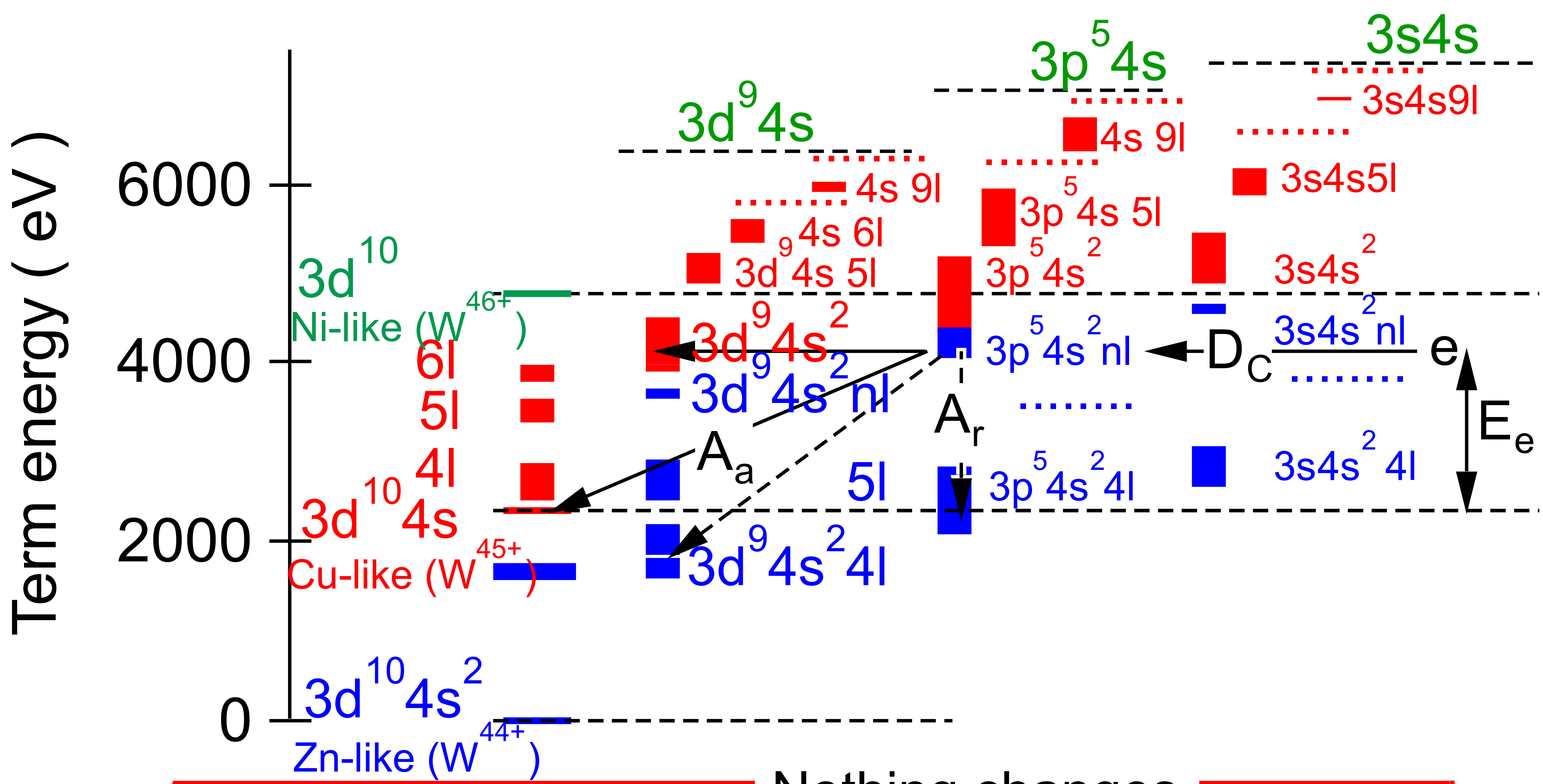
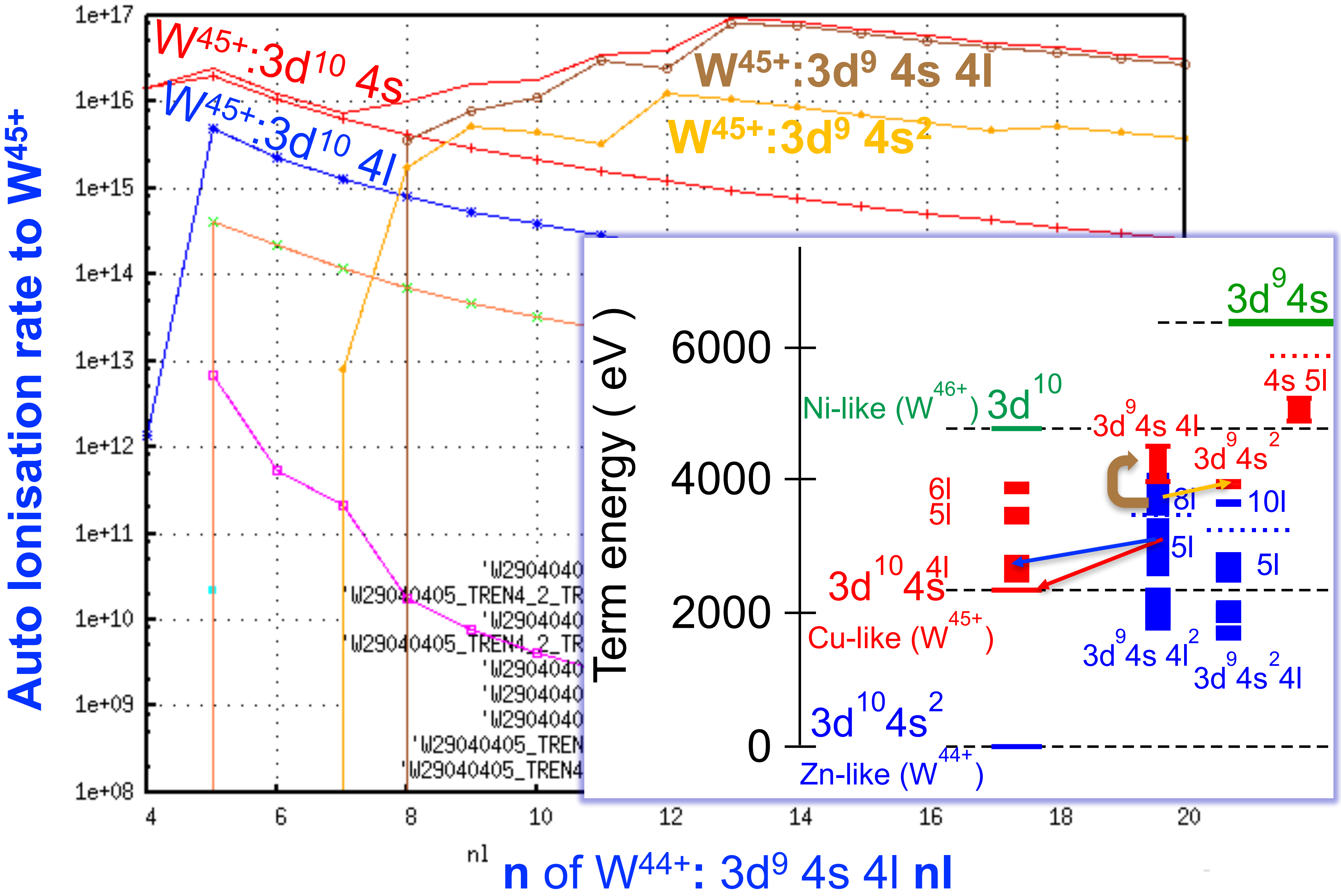


Nothing changes

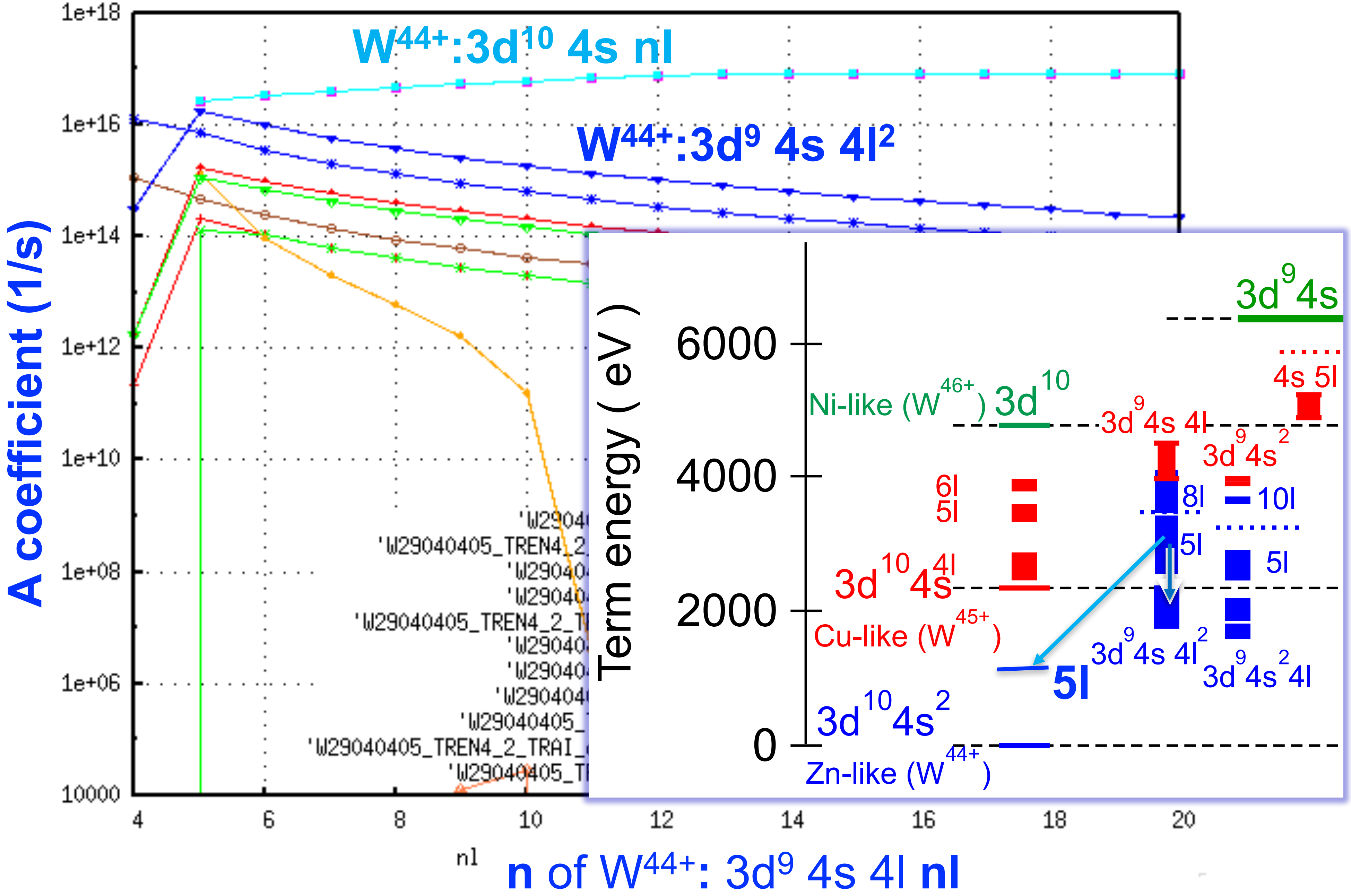
3d^{10} 4s = e capture => 3d^9 4s^2 nl { = Auto-ionization => 3d^{10} 4s
= Radiative decay => 3d^{10} 4s^2

DR

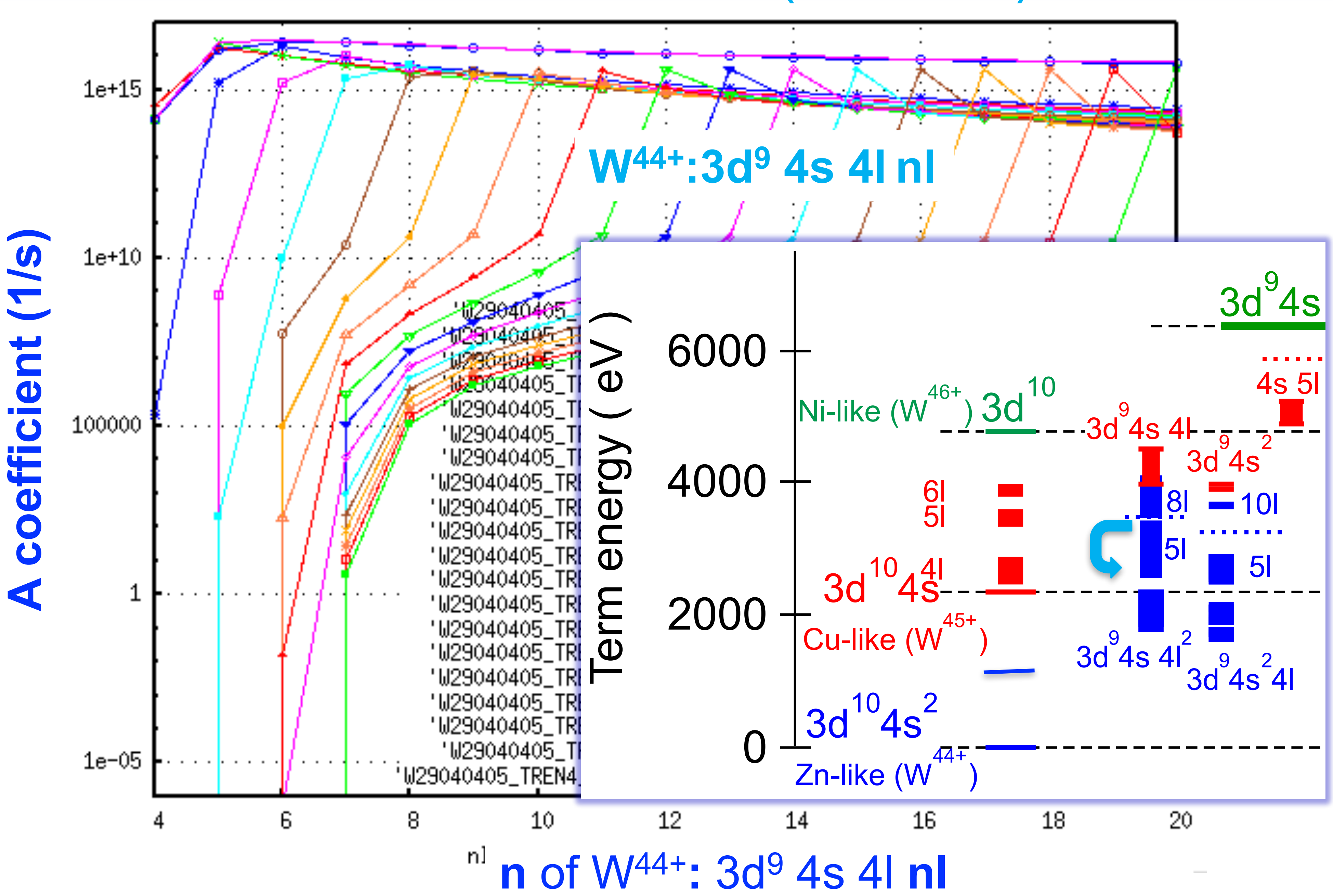
W^{44+}: $3d^9$ 4s 4l nl からの自動電離：
n<8では基底準位へ，n≥8では親準位へ



W^{44+}: $3d^9$ 4s 4l nl からの放射遷移(Ip以下へ)：
$3d^9$ 4s 4l nl -> $3d^{10}$ 4s nl (4l -> 3d) が主要



W^{44+}: $3d^9$ 4s 4l nl からの放射遷移(Ip以上へ)：
$3d^9$ 4s 4l nl -> $3d^9$ 4s 4l nl' (nl -> nl') が主要



$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\text{->}45+}}{\alpha^{45+\text{->}44+}}$$

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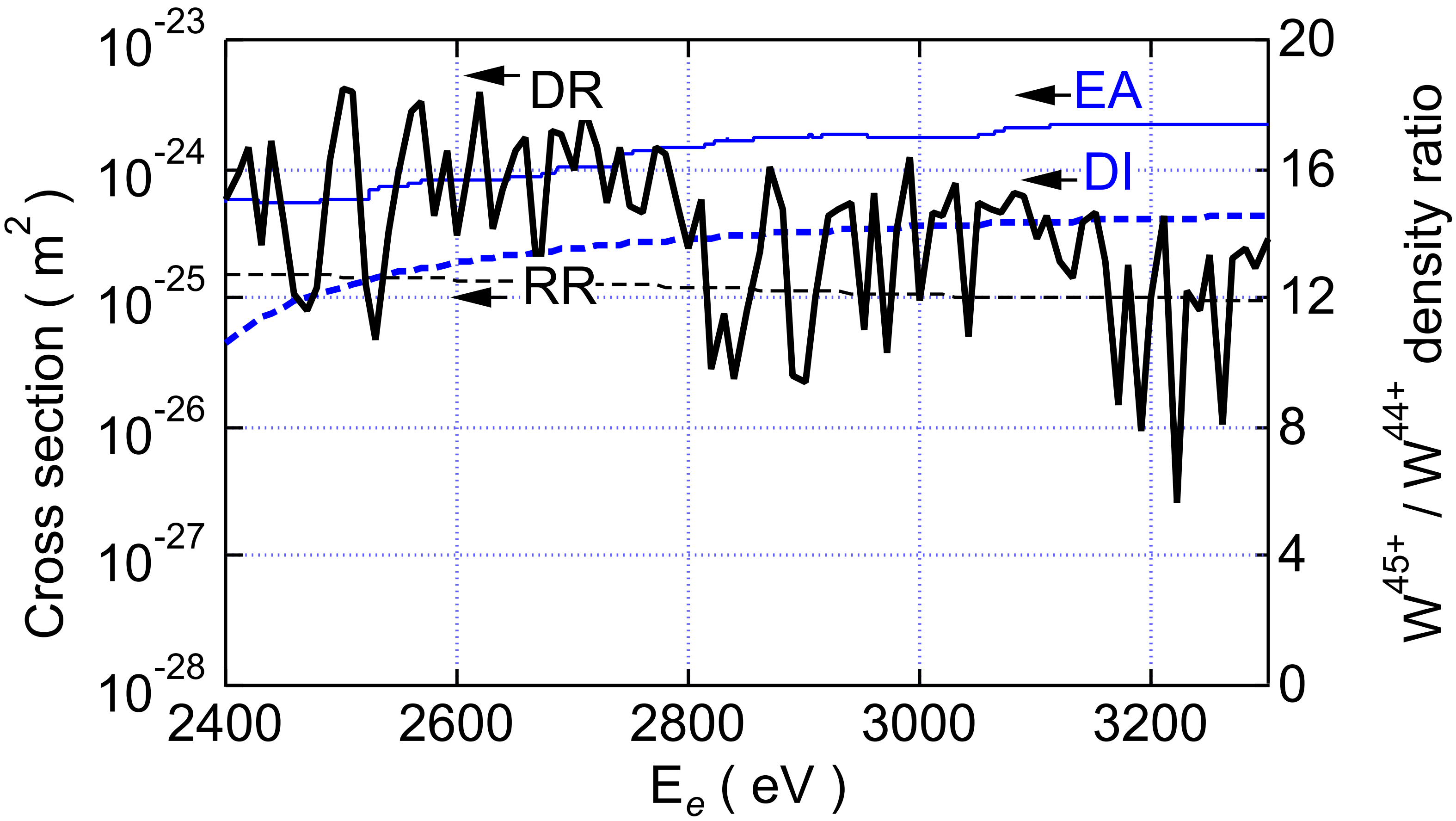

$$\frac{n_W^{45+}}{n_W^{44+}} = \frac{S^{44+\to45+}}{\alpha^{45+\to44+}}$$

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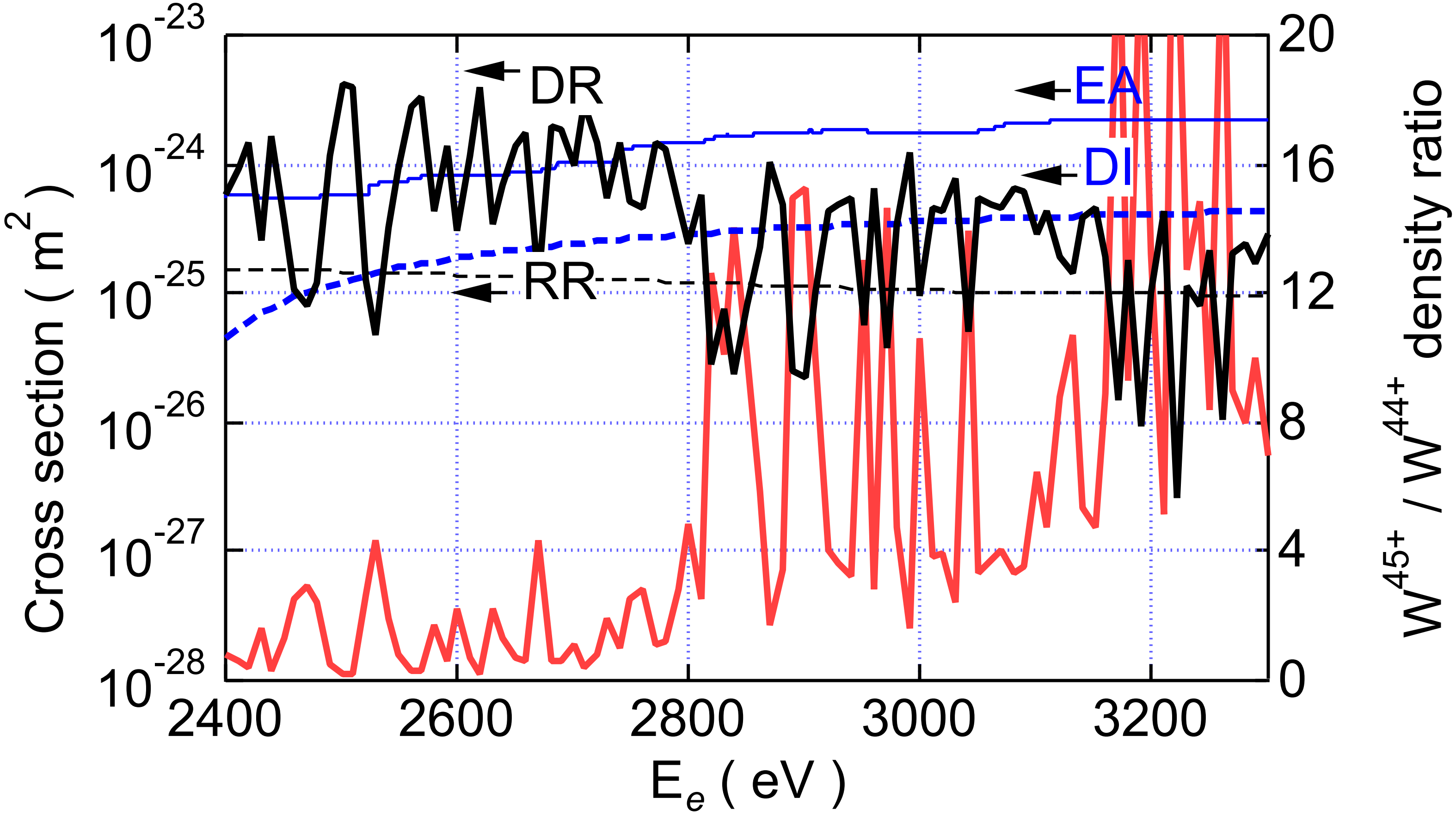

Data evaluation for diagnostic lines for ITER core plasma: W^{62+} and W^{63+} 3s-3p

Measurement

$$\frac{I^{W63+}(7.7\text{nm}):\ 3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}}{I^{W62+}(8.0\text{nm}):\ 3s3s\ ^1S_0 - 3s3p\ ^1P_1} = \frac{Ce^{63+}(3s,3p)}{Ce^{62+}(3s,3p)} \cdot \frac{nW^{63+}(3s)}{nW^{62+}(3s)} \cdot \frac{ne}{ne}$$

Excitation Xsec

Ioniz. Equi.

Close excitation energy (156 ev and 160 eV)
⇒Similar energy dependence of C_e

$$\sim 0.8 \cdot \frac{S^{62+\rightarrow 63+}\ \text{(Ioniz.rate)}}{\alpha^{63+\rightarrow 62+}\ \text{(Recomb.rate)}}$$

Calculation