Analysis of spectra from multiply ionized W ions by atomic structure code FAC
原子構造計算プログラムFACによる多価タングステンイオンのスペクトル解析

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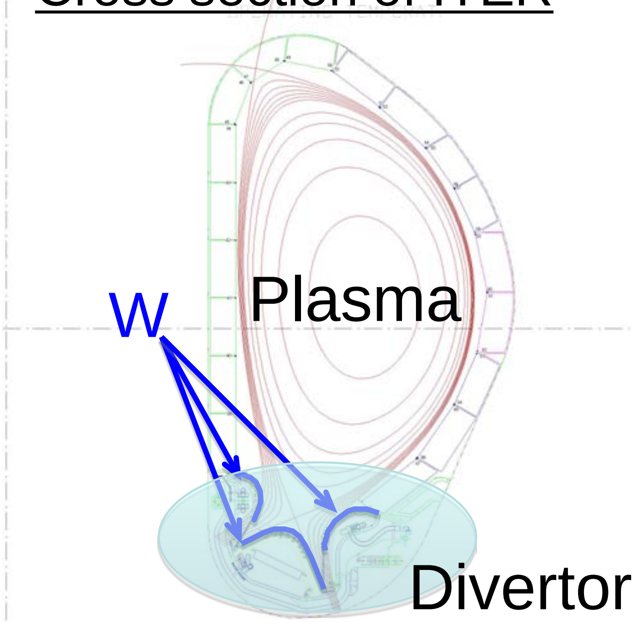
Tungsten in Fusion Research

Tungsten as a plasma-facing component

- Pros : high melting point => compatible with high temperature fusion plasma
  : low hydrogen (T) retention => safety, economy
  : low sputtering yield => long lifetime
  : low dust production
- Cons : high Z (74)
  ⇒ highly radiative (allowable $n_W/n_e < 10^{-5}$)
  ⇒ accumulation in the core plasma

Cross section of ITER

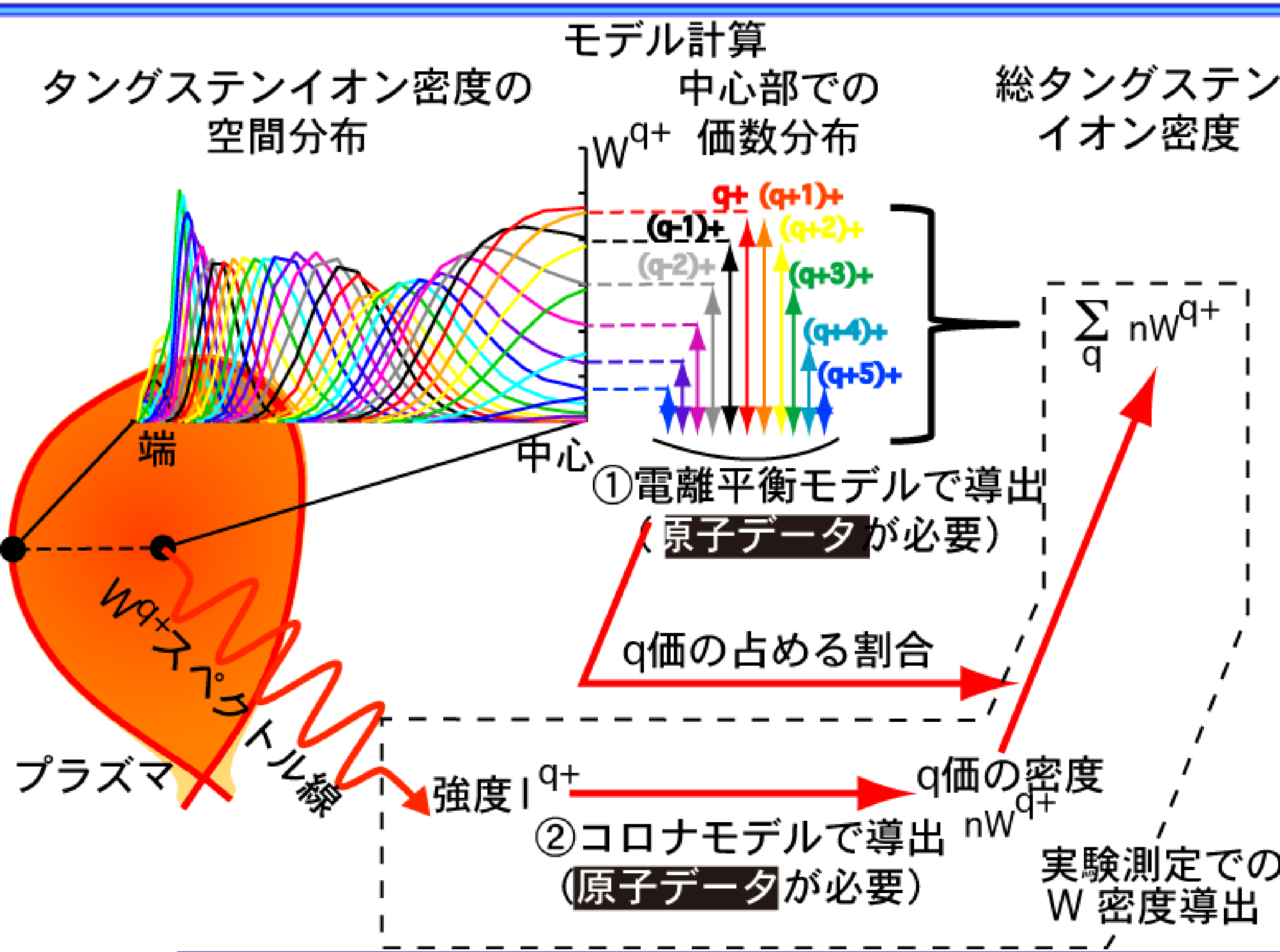


Issues of W transport study

- Understanding of
  Transport in core plasma*
  => accumulation mechanism in core plasma
  Local transport in divertor, global migration,,,
- Control of
  W generation, W penetration, W accumulation,,,
- Preparation of diagnostics at high T_e ~ 15 keV (~ W^{q+} : q > 60)
- Evaluation of W density, W ion distribution*, radiative power,,,

*present study

Requirement for W atomic data =>calculation with an atomic structure code,FAC*

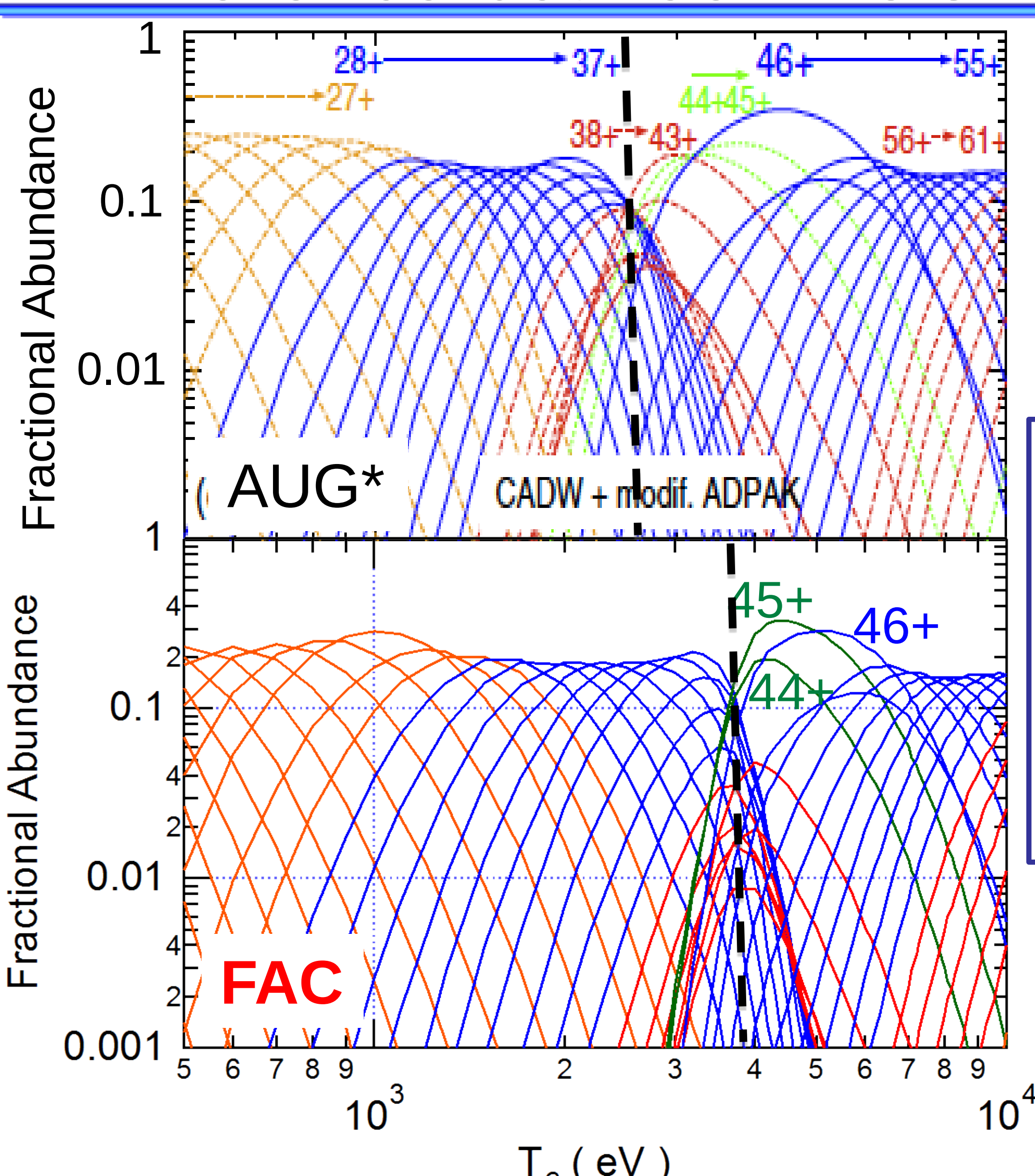


① Calculation of Dielectronic recombination

② W Spectrum analysis (JT-60U, LHD)

*) M.F.Gu *et al.*, *Astrophys. J.* **582** (2003) 1241. http://sprg.ssl.berkeley.edu/~mfgu/fac/

Ionization equilibrium:
Difference between AUG* and FAC calculation



Still different:
Shift to lower T_e
in AUG calculation

Ionization equilibrium:

$$S^{q+=>(q+1)+} \cdot n_W^{q+} = \alpha^{(q+1)+=>q+} \cdot n_W^{(q+1)+}$$

$$S = S^{direct} + S^{excit.autoioniz.}$$

$$\alpha = \alpha^{radiative} + \alpha^{die\text{-}electronic}$$

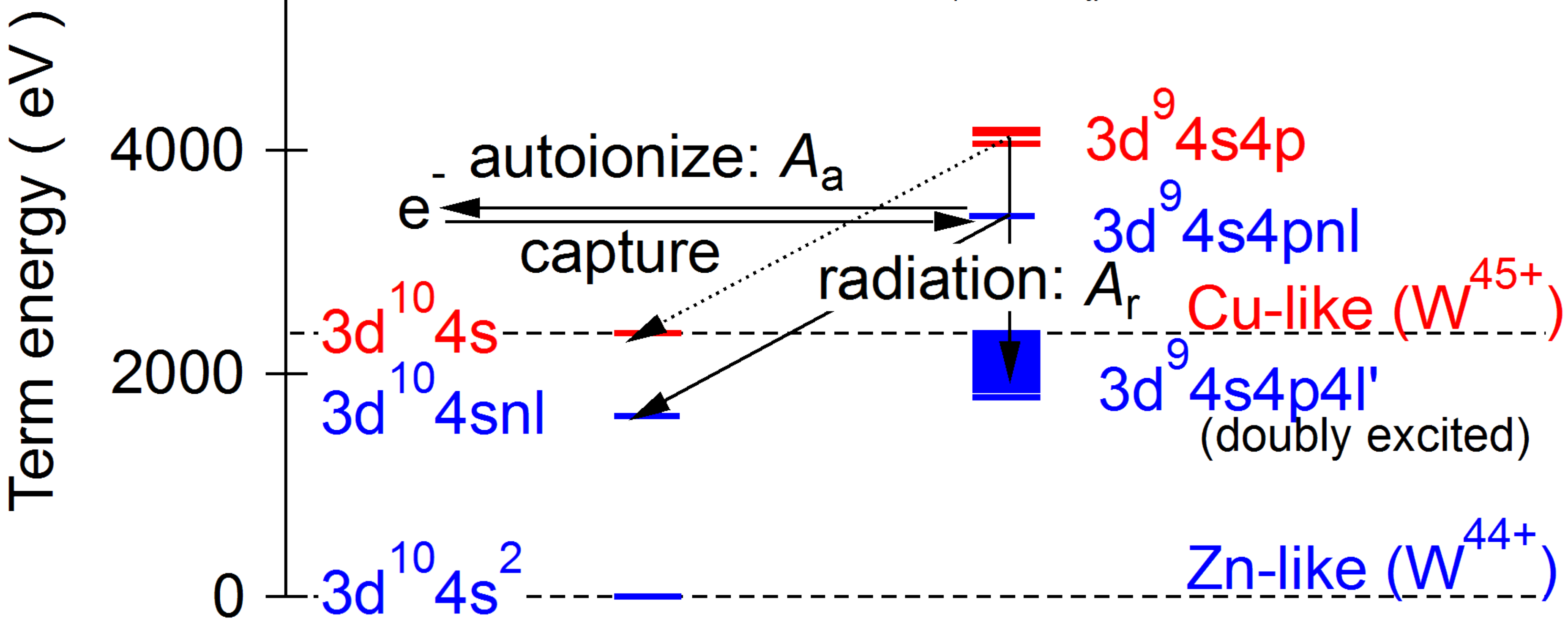
*present study

*T Putterich *et al Plasma Phys. Control. Fusion* **50** (2008) 085016

Calculation of Dielectronic Recombination rate: Example for DR for $W^{45+} \Rightarrow W^{44+}$

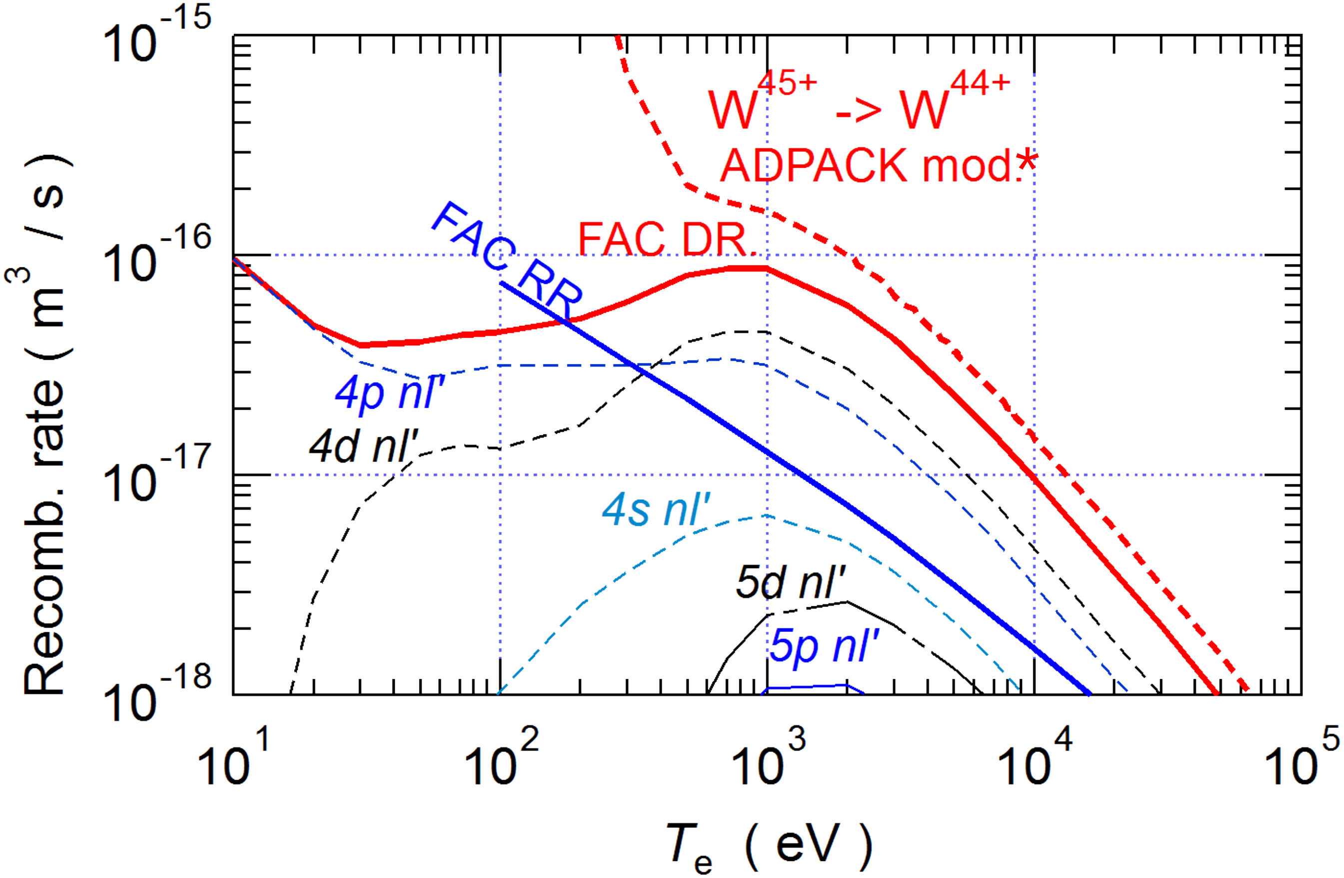
$$\alpha_{DR}(T_e) = \frac{h^3}{(2\pi m_e T_e)^{3/2}} \sum_i \frac{g_i}{g_f} A_a(i \to f) B(i) \exp\left(-\frac{E_{if}}{T_e}\right)$$

Branching ratio: $B(i) = \dfrac{\Sigma A_r}{\Sigma A_r + \Sigma A_a}$



A_a and A_r are calculated with FAC

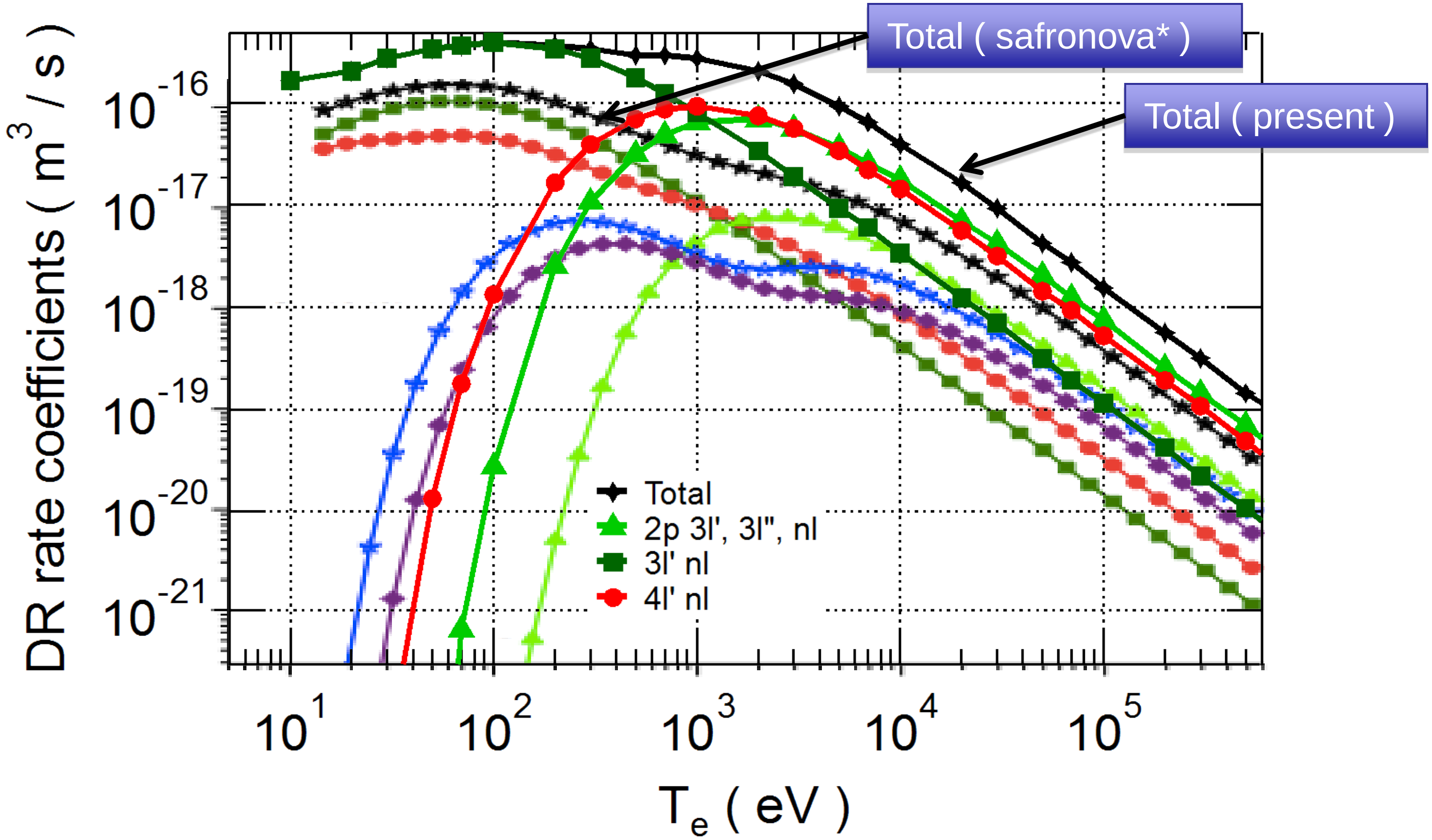
Dielectronic Recombination rate for W^{45+}



Evaluation of calculated α_{DR} in EBIT experiments is in progress

*T Putterich *et al., Plasma Phys. Control. Fusion* **50** (2008) 085016

Dielectronic Recombination rate for W^{63+}: Na-like $2p^6\ 3s$ => W^{62+}:Mg-like $2p^6\ 3s^2$



Evaluation of calculated α_{DR} in EBIT experiments is under consideration

*U Safronova *et al., J. Phys. B* **42** (2009) 165010

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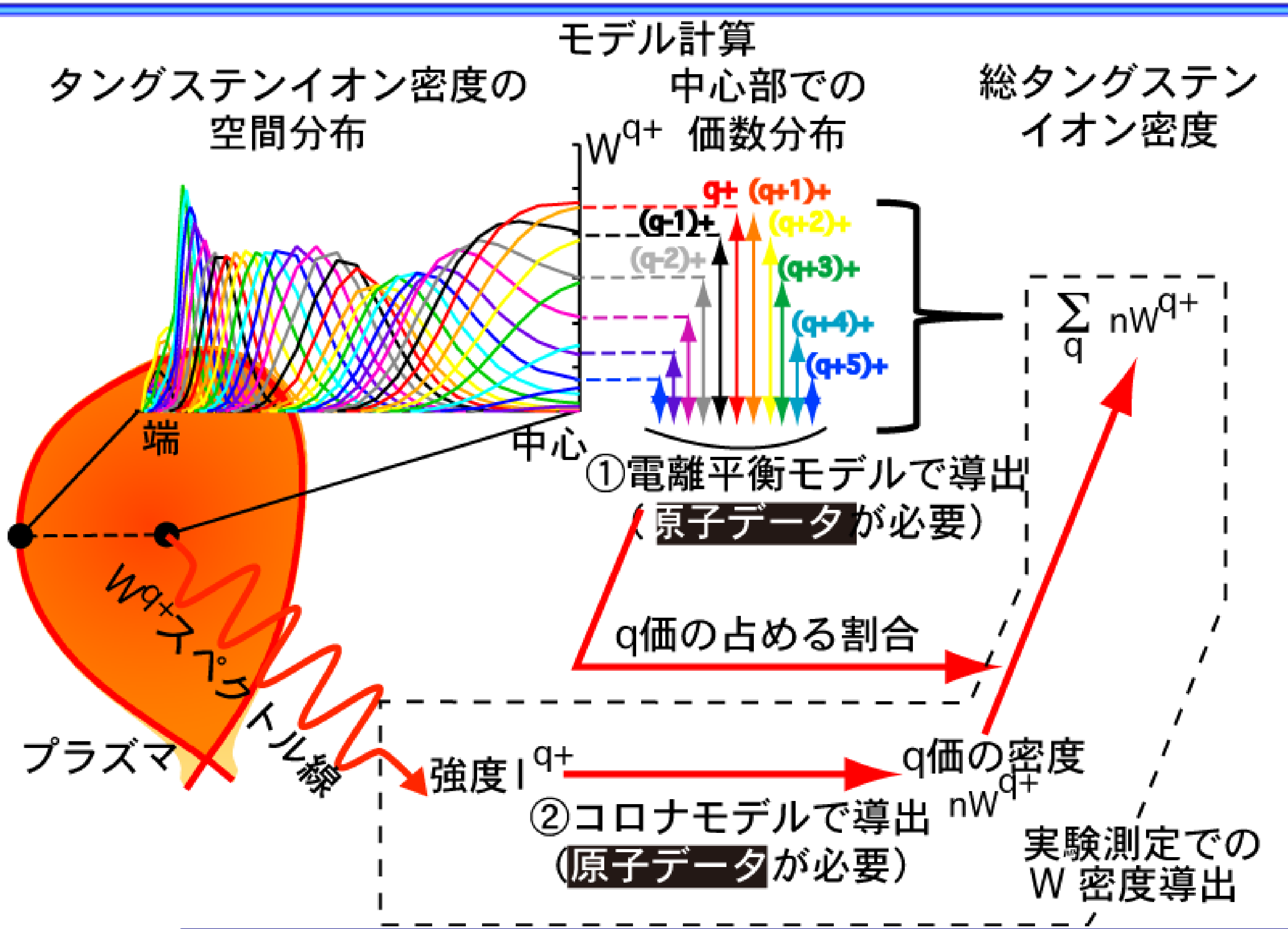
=>calculation with an atomic structure code,FAC*



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Calculation model: Example for W^{15+}

Electron configuration:

4d10 4f11 5s2

4d10 4f11 5s1 5*1;5s=0

4d10 4f12 5s1

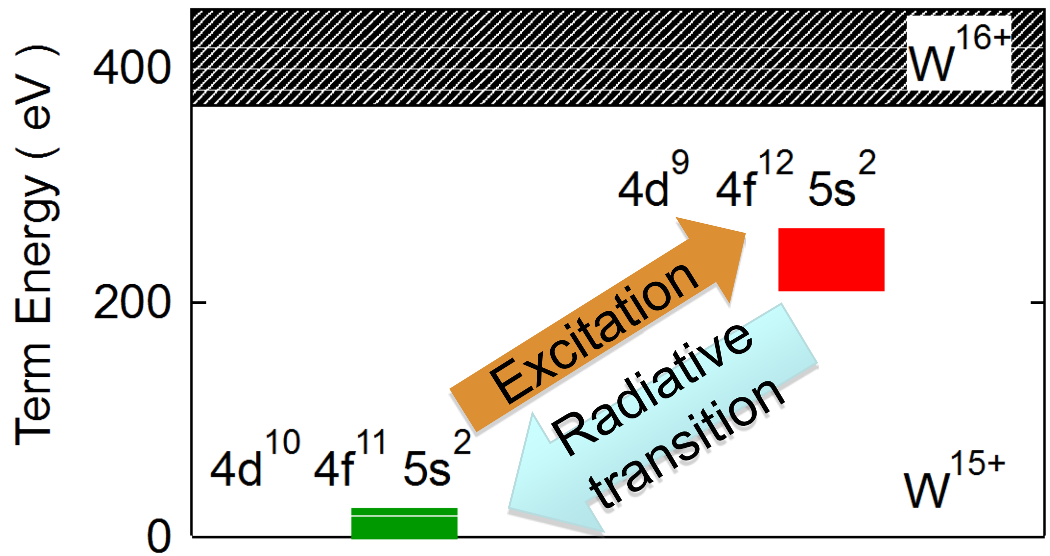
4d10 4f11 5s1 6*1

4d9 4f12 5s2

Atomic structure calculation

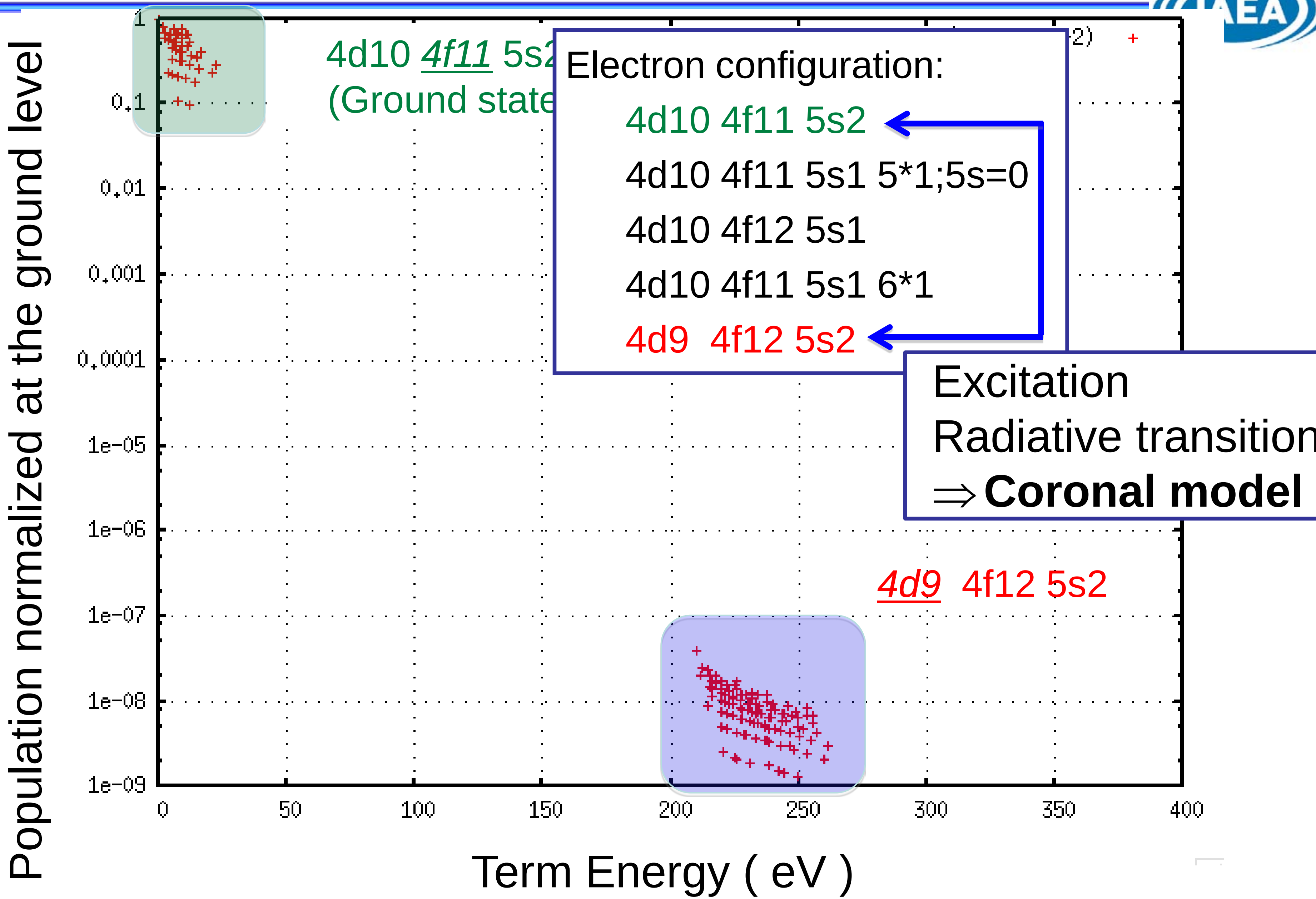
Energy level:

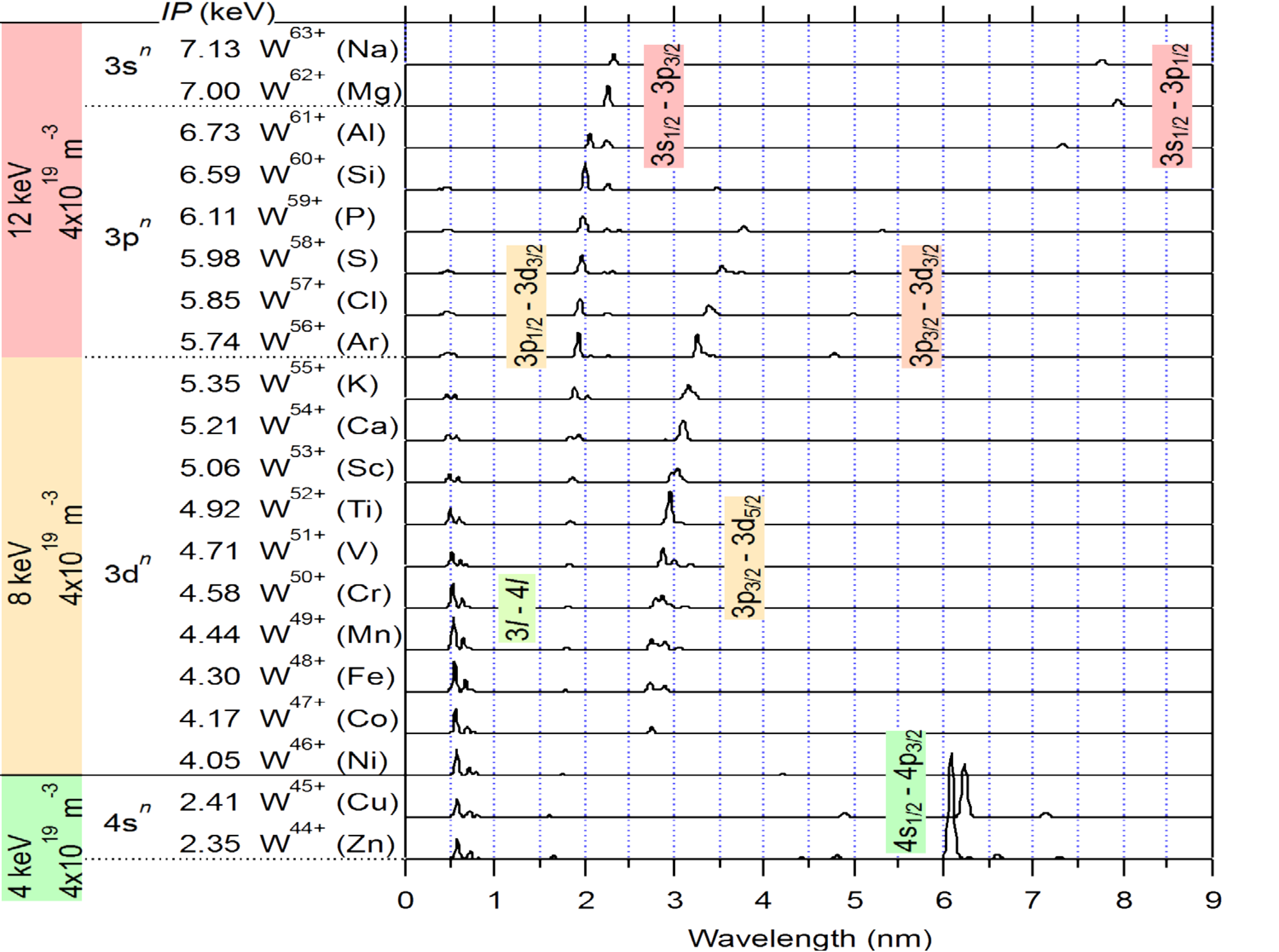
Excitation rate:
Radiative transition
r



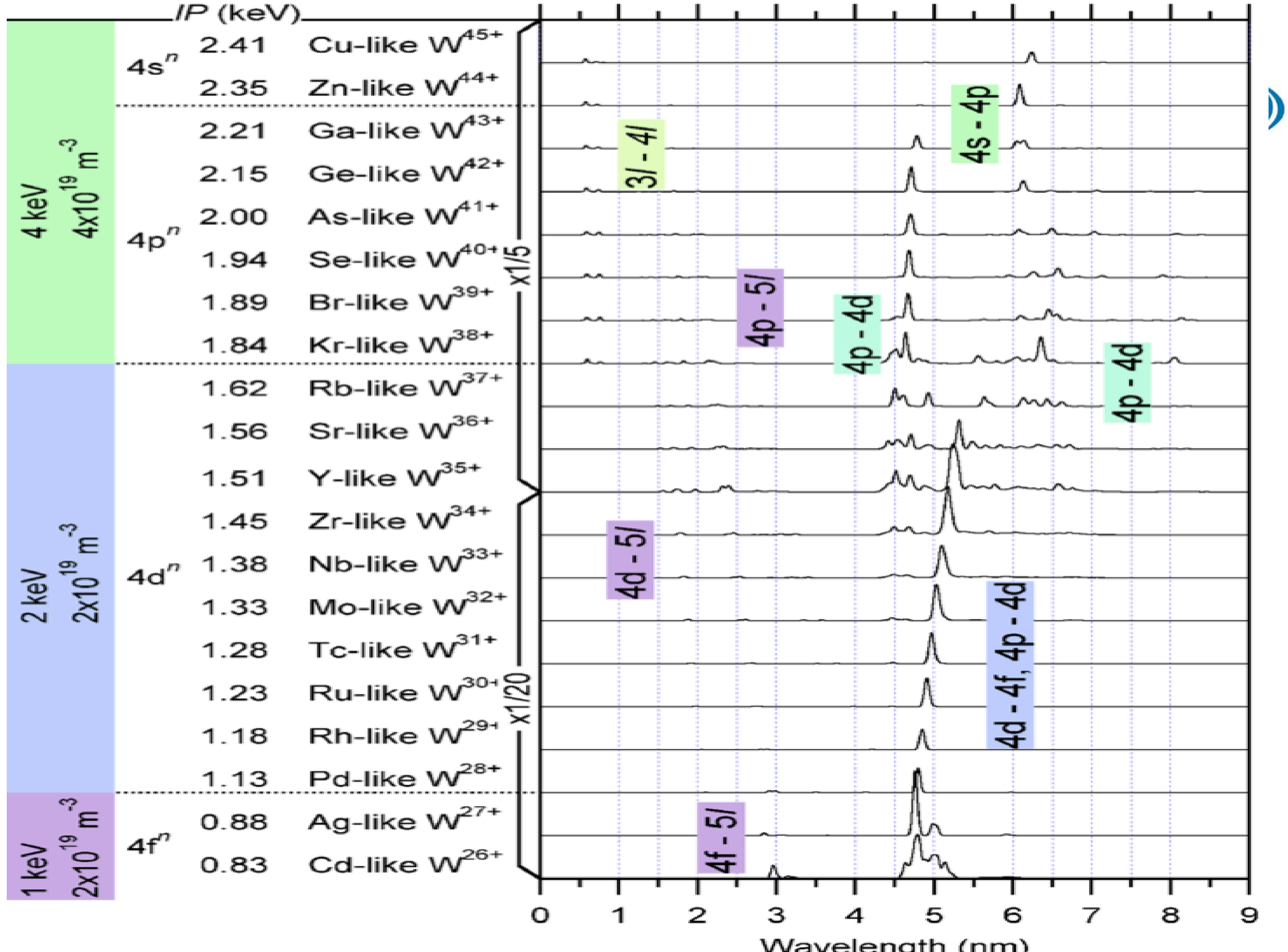
Coronal model

Calculated population: Example for W^{15+}



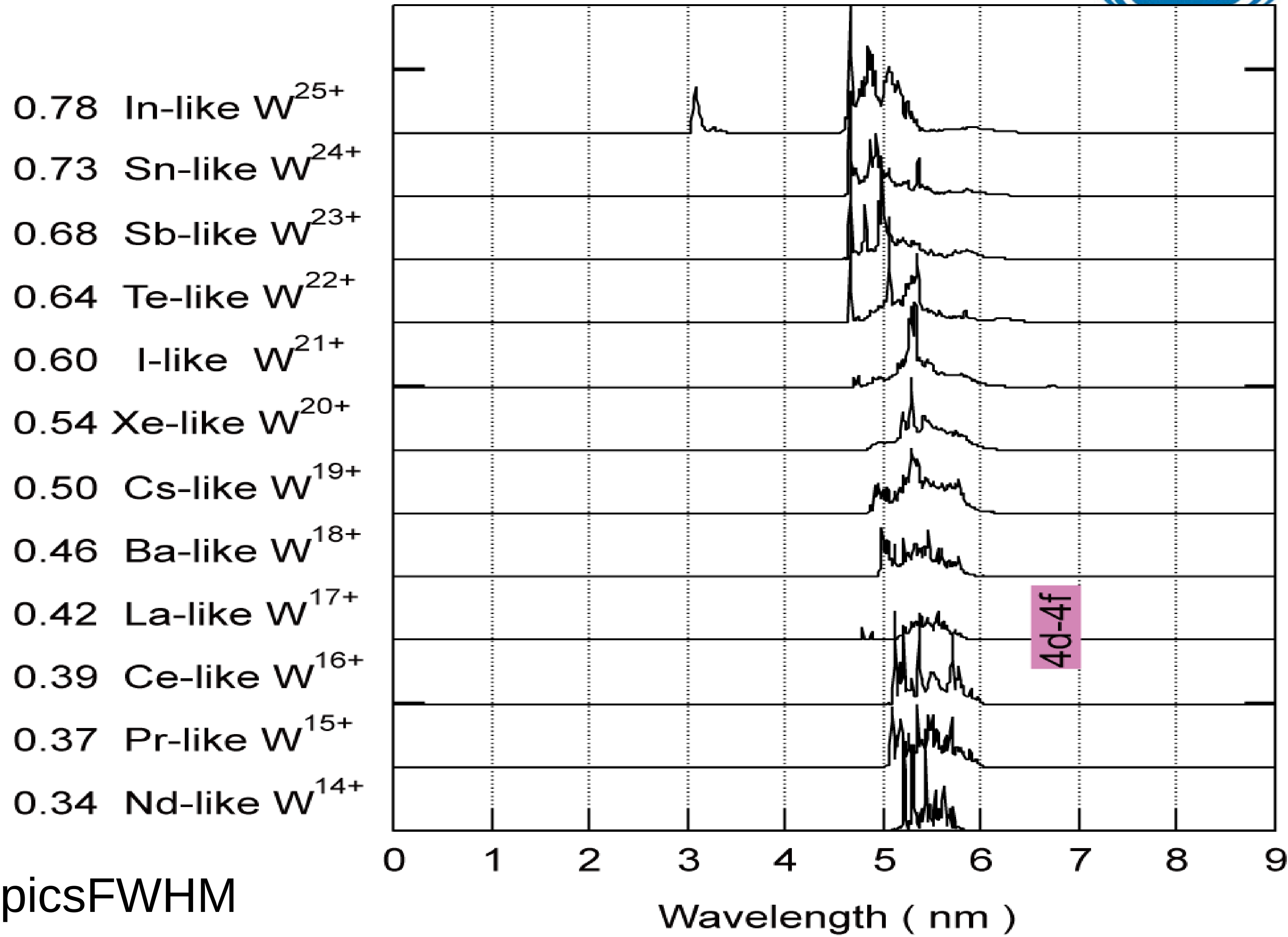


IP (keV)
12 keV
4x10^19 m^-3
8 keV
4x10^19 m^-3
4 keV
4x10^19 m^-3
3s^n
3p^n
3d^n
4s^n
7.13 W^63+ (Na)
7.00 W^62+ (Mg)
6.73 W^61+ (Al)
6.59 W^60+ (Si)
6.11 W^59+ (P)
5.98 W^58+ (S)
5.85 W^57+ (Cl)
5.74 W^56+ (Ar)
5.35 W^55+ (K)
5.21 W^54+ (Ca)
5.06 W^53+ (Sc)
4.92 W^52+ (Ti)
4.71 W^51+ (V)
4.58 W^50+ (Cr)
4.44 W^49+ (Mn)
4.30 W^48+ (Fe)
4.17 W^47+ (Co)
4.05 W^46+ (Ni)
2.41 W^45+ (Cu)
2.35 W^44+ (Zn)
3s1/2 - 3p3/2
3s1/2 - 3p1/2
3p1/2 - 3d3/2
3p3/2 - 3d3/2
3p3/2 - 3d5/2
3l - 4l
4s1/2 - 4p3/2
0
1
2
3
4
5
6
7
8
9
Wavelength (nm)



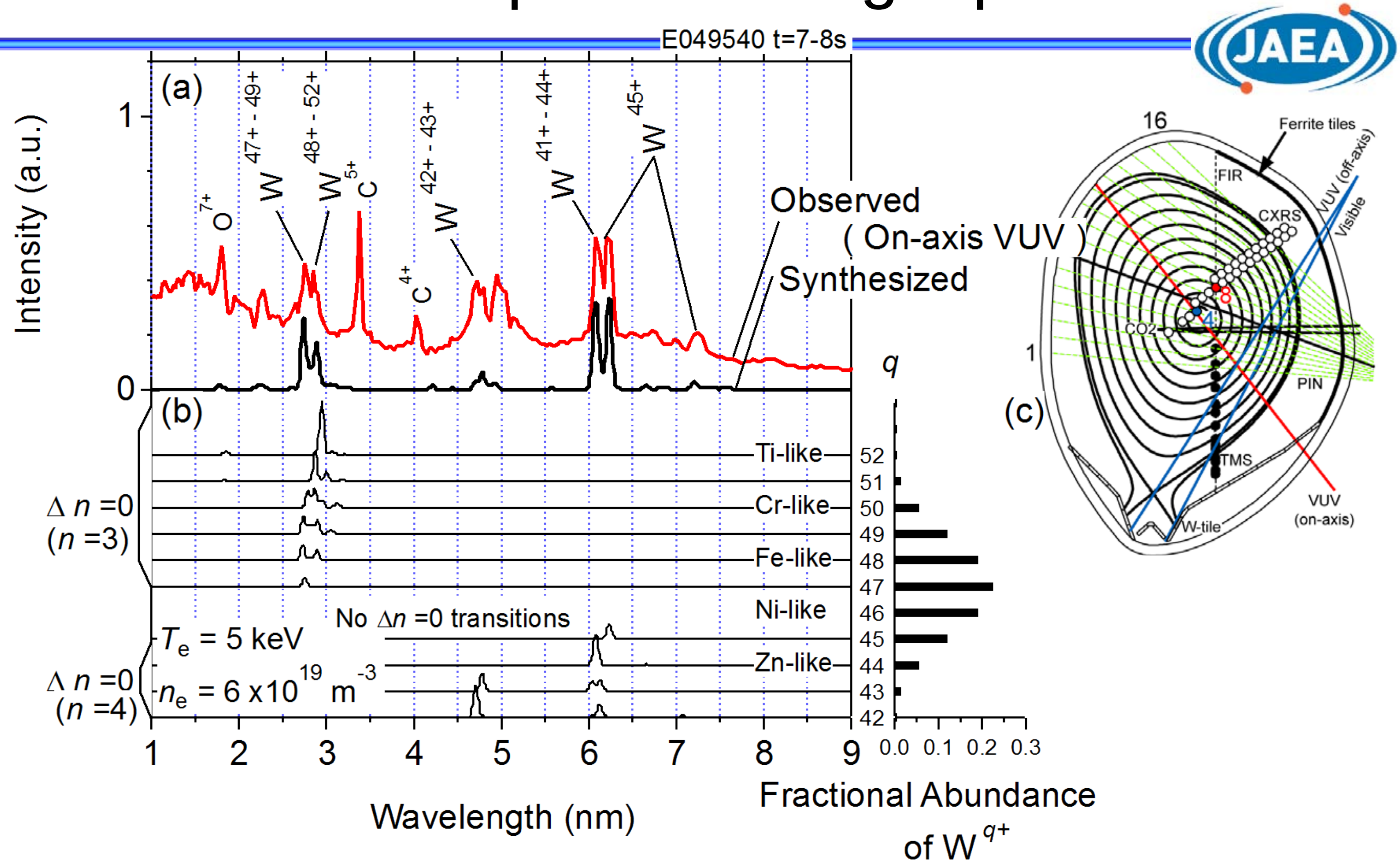
IP (keV)
4 keV
4x10^19 m^-3
2 keV
2x10^19 m^-3
1 keV
2x10^19 m^-3
4s^n
4p^n
4d^n
4f^n
2.41 Cu-like W^45+
2.35 Zn-like W^44+
2.21 Ga-like W^43+
2.15 Ge-like W^42+
2.00 As-like W^41+
1.94 Se-like W^40+
1.89 Br-like W^39+
1.84 Kr-like W^38+
1.62 Rb-like W^37+
1.56 Sr-like W^36+
1.51 Y-like W^35+
1.45 Zr-like W^34+
1.38 Nb-like W^33+
1.33 Mo-like W^32+
1.28 Tc-like W^31+
1.23 Ru-like W^30+
1.18 Rh-like W^29+
1.13 Pd-like W^28+
0.88 Ag-like W^27+
0.83 Cd-like W^26+
x1/5
x1/20
3l - 4l
4s - 4p
4p - 5l
4p - 4d
4p - 4d
4d - 5l
4d - 4f, 4p - 4d
4f - 5l
0
1
2
3
4
5
6
7
8
9
Wavelength (nm)

0.5 keV
4×10^{19} m^{-3}



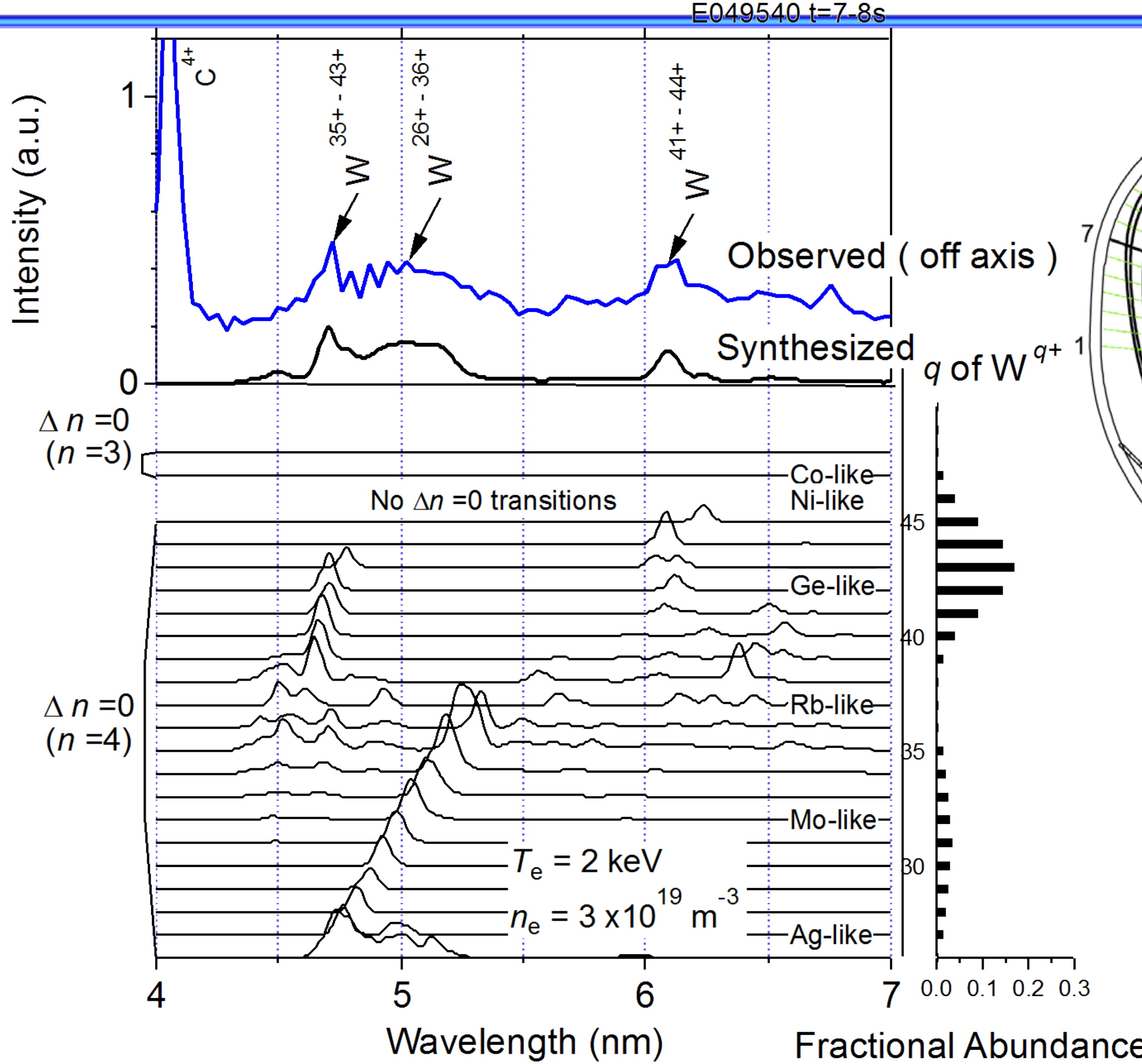
* ¼ picsFWHM

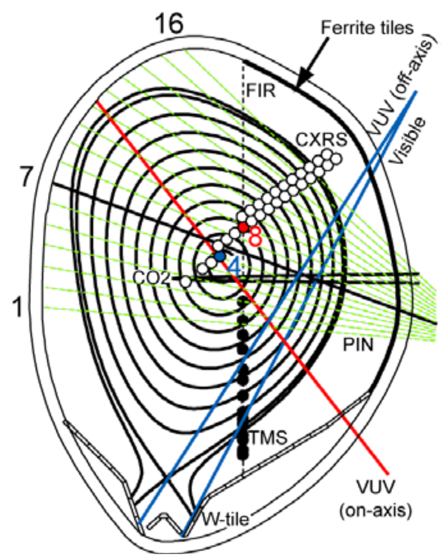
JT-60U core plasma: single peak



*) T. Nakano *et al*., *Nucl. Fusion* **49** (2009) 115024.

JT-60U peripheral plasma: two peaks





*) T. Nakano *et al.*, *Nucl. Fusion* **49** (2009) 115024.