Recent results on tungsten spectra obtained with a compact electron beam ion trap

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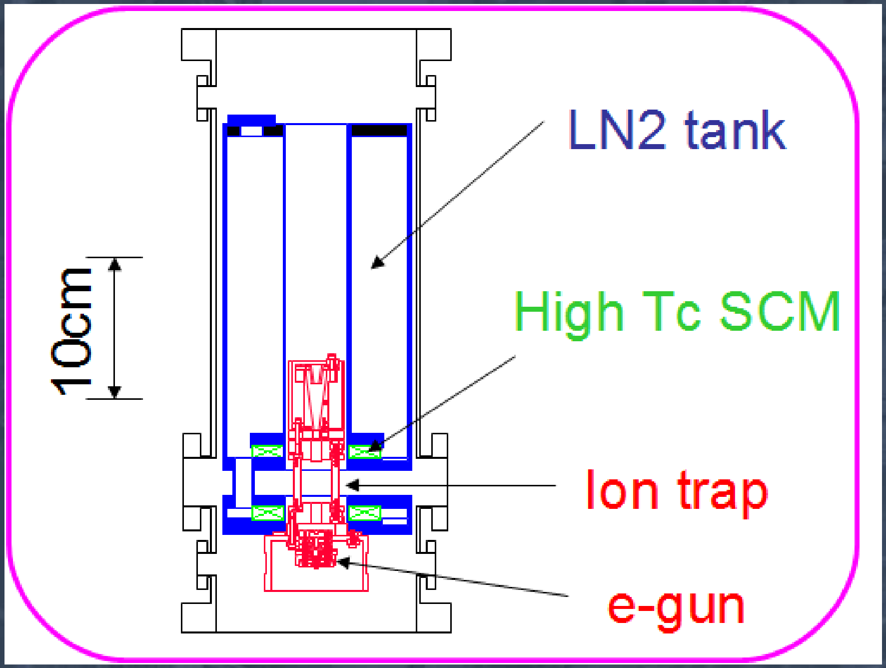
Contents

- Electron Beam Ion Trap, CoBIT
- Recent studies
  - EUV and visible spectra for W^{q+} (q=6-13)
  - E3 transitions in Ag-like W^{27+}
- Summary

CoBIT (compact EBIT)



Specifications

e-beam energy 50 - 1000 eV

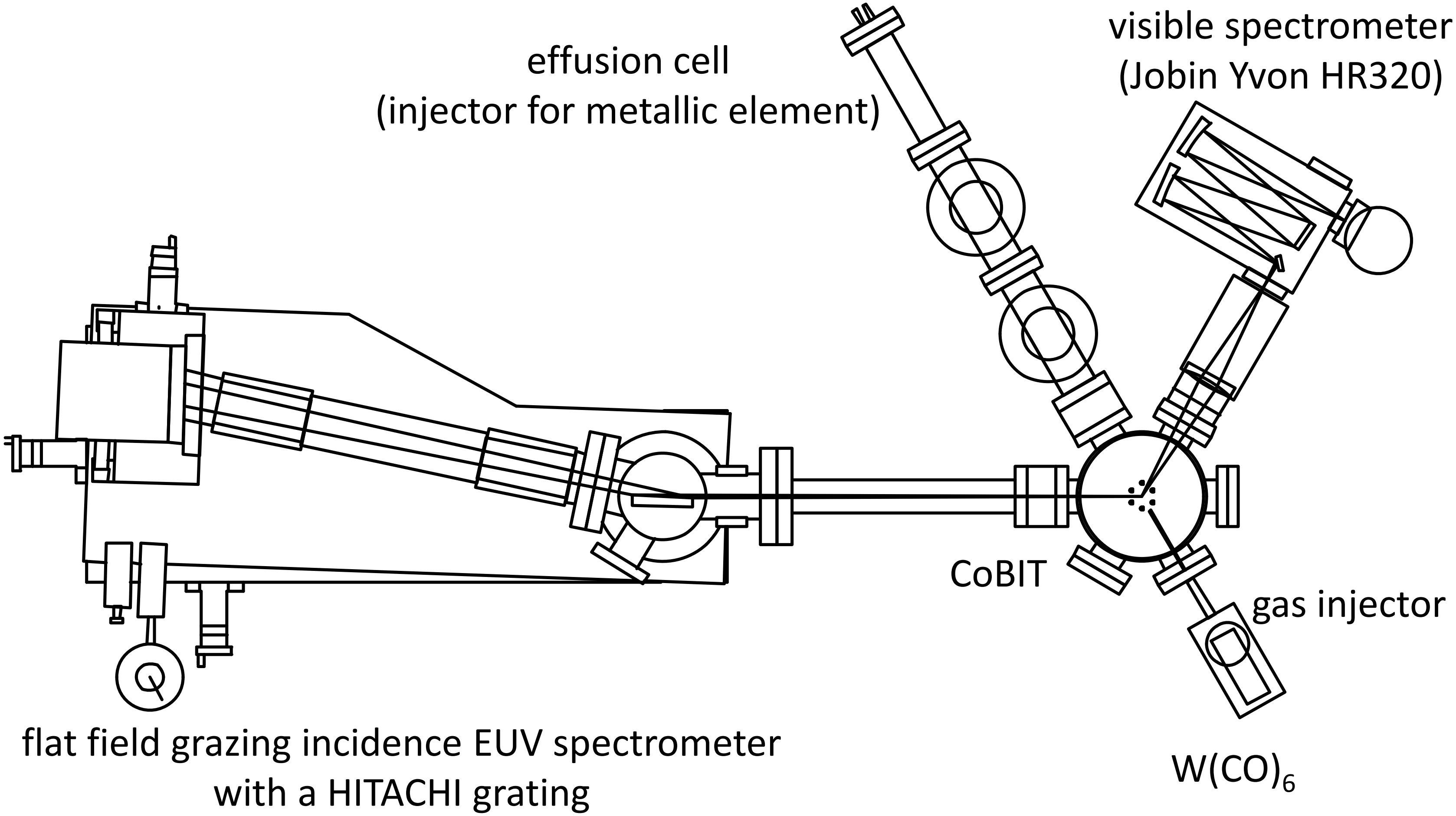
e-beam current 20 mA (max)

electron density 10^{9-10} cm^{-3} (typ)

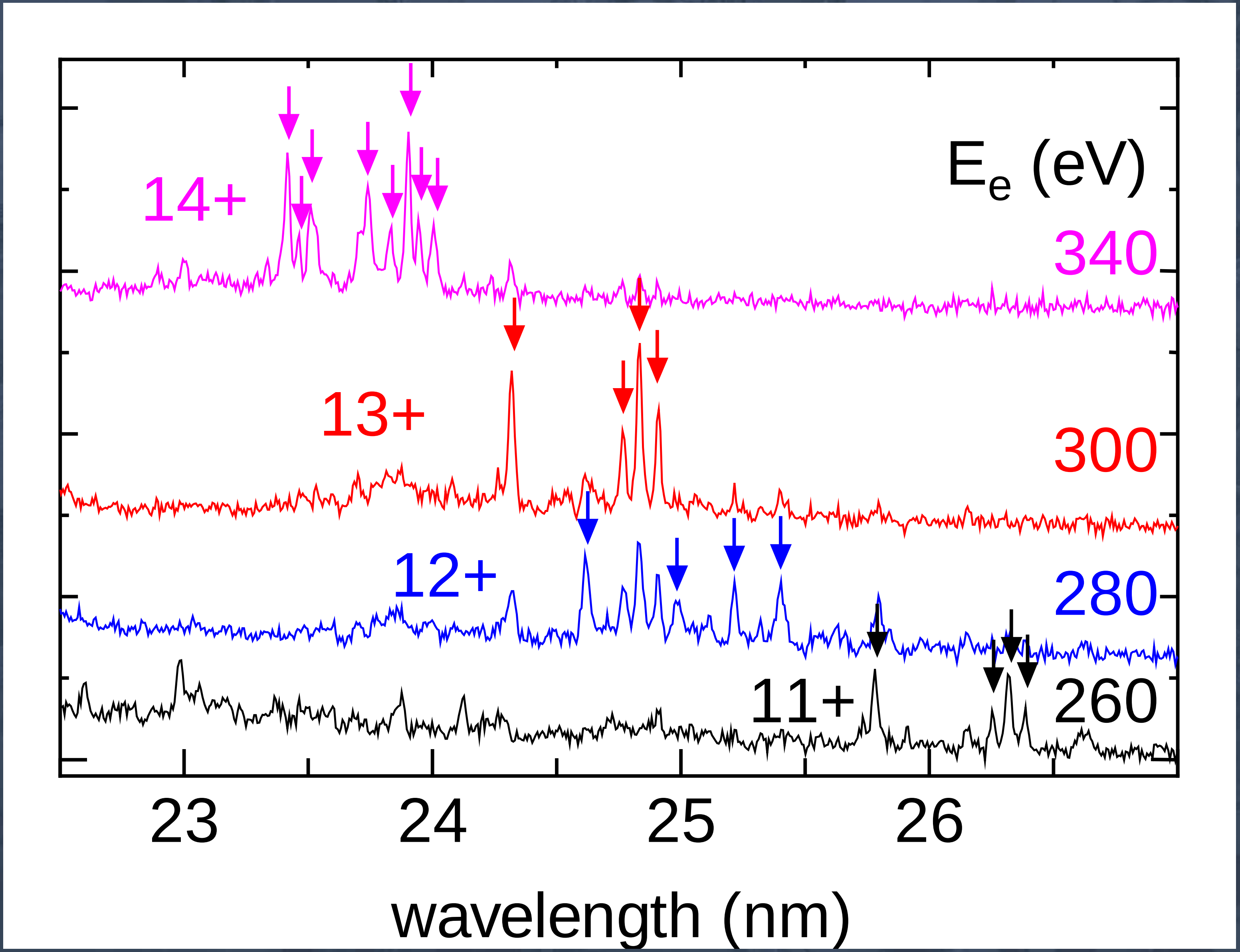
Magnetic field 0.2 T (max)

Temperature 77 K (High-Tc SCM)

Experimental setup



Typical spectra of CoBIT



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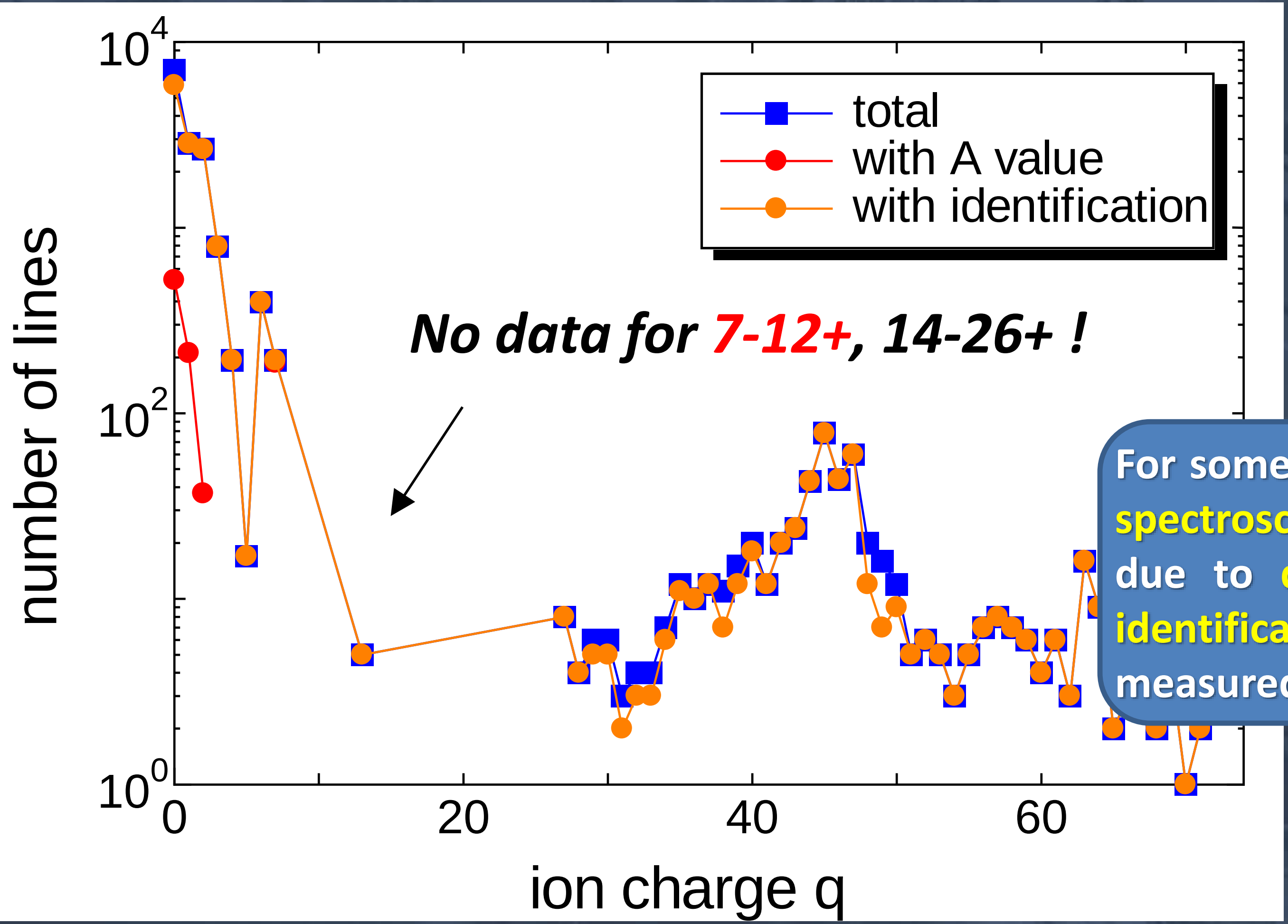
Why we study q=6-13?

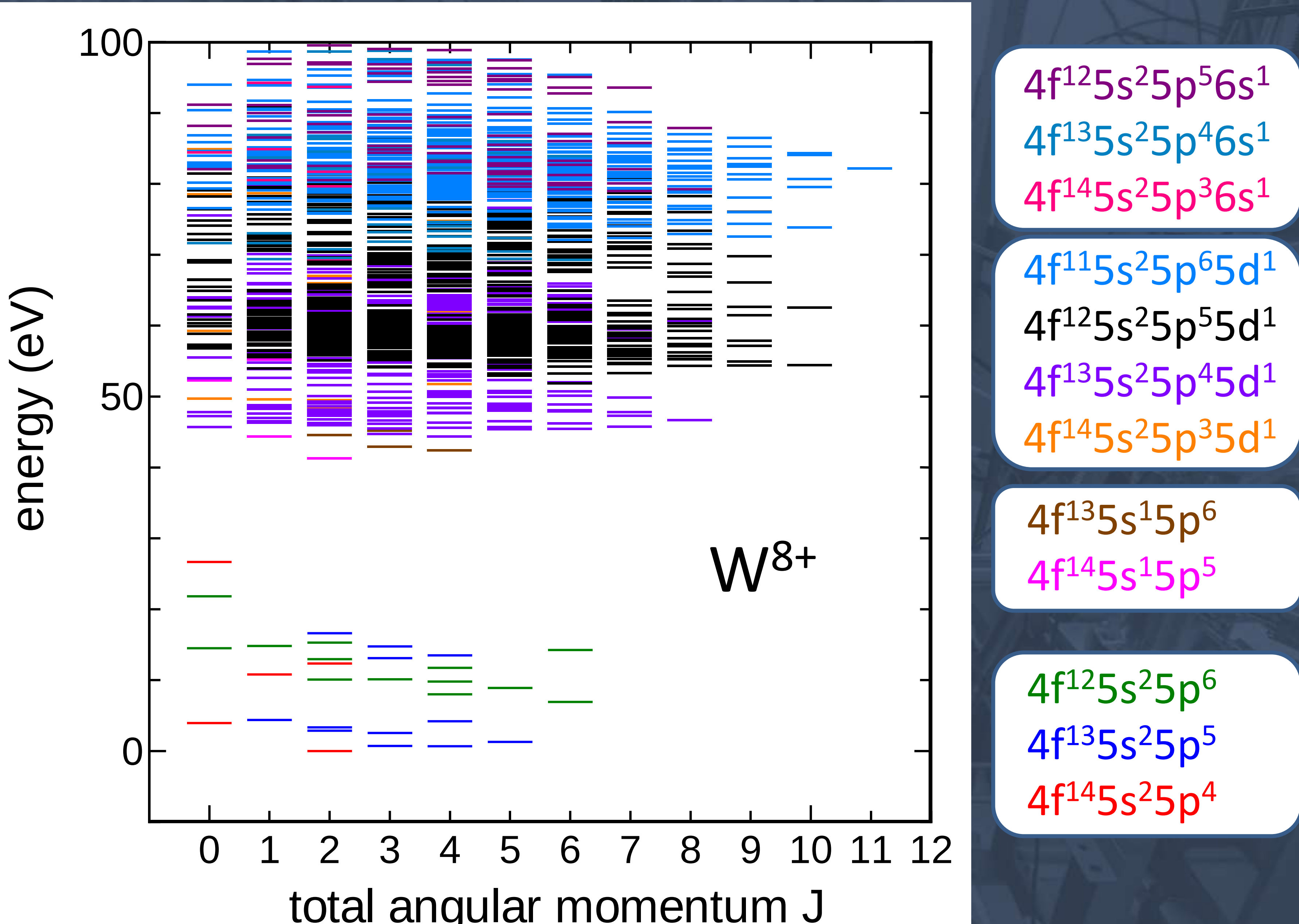


For some ions ASD contains **no spectroscopic data** primarily due to **difficulties in reliable identification** of the few measured **complex spectra.**

Yuri RALCHENKO

PFR 8 (2013)2503024

Why we study q=6-13?



Why we study q=6-13?

PRL **106,** 210802 (2011) PHYSICAL REVIEW LETTERS week ending 27 MAY 2011

Electron-Hole Transitions in Multiply Charged Ions for Precision Laser Spectroscopy and Searching for Variations in α

J. C. Berengut, V. A. Dzuba, V. V. Flambaum, and A. Ong

School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia

(Received 14 March 2011; published 27 May 2011)

TABLE III. Energy levels and sensitivity coefficients (q) relative to the ground state for W^{7+} (cm^{-1}).

W^{7+}

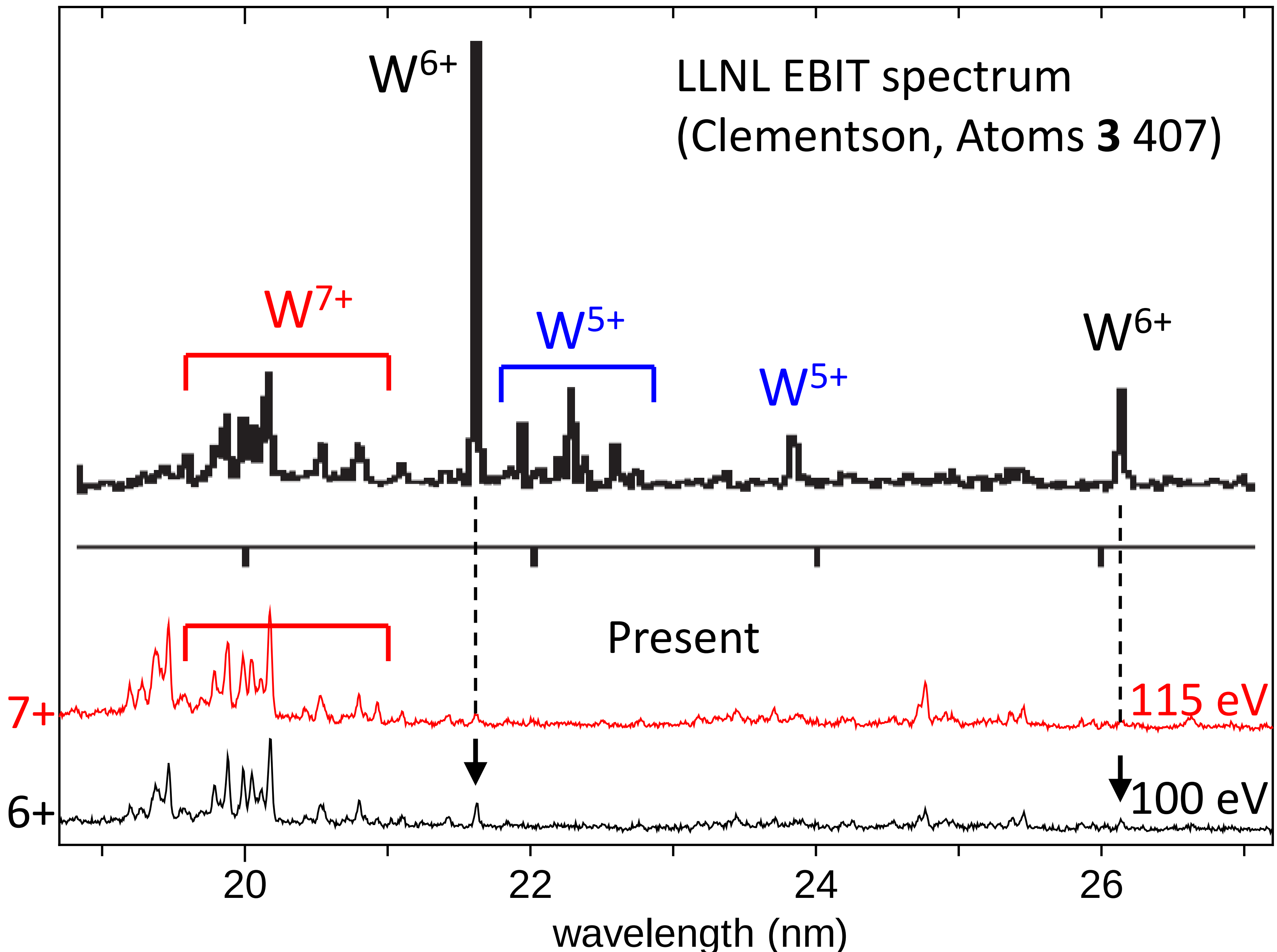
Configuration	J	Energy: This work	Energy: [15…	
$4f^{13}5p^{6}\,^2F^o$	7/2	0	0	0
	5/2	18 199	17 440	
$4f^{14}5p^{5}\,^2P^o$	3/2	4351	800 (700)	
	1/2	93 908	87 900 (700…	

TABLE IV. Energy levels and sensitivity coefficients (q) for W^{8+} (cm^{-1}). Energies between terms are uncertain at the level ~6000 cm^{-1}.

W^{8+}

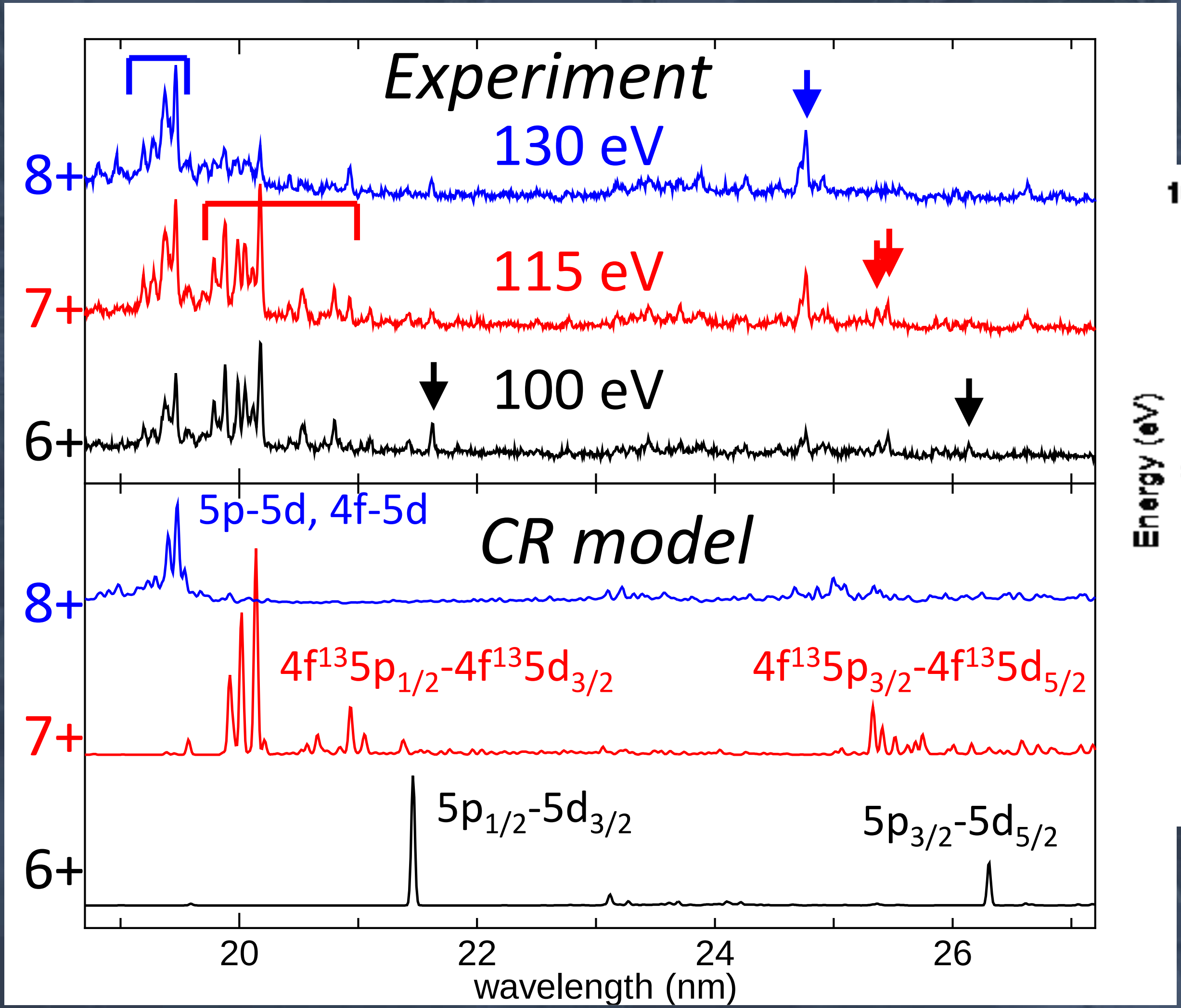
Configuration	J	Energy	q
$4f^{14}5p^{4}\,^3P$	2	0	0
$4f^{13}5p^{5}\,^3F$	4	6075	−81 564
$4f^{13}5p^{5}\,^3G$	3	6357	−81 480
$4f^{13}5p^{5}\,^3G$	5	11 122	−82 880
$4f^{13}5p^{5}\,^3F$	3	21 905	−66 489

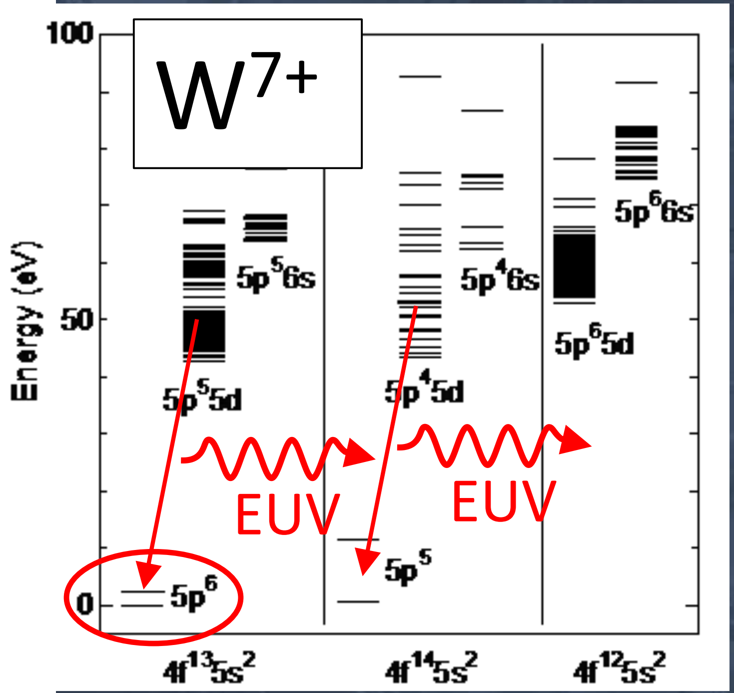
EUV spectra



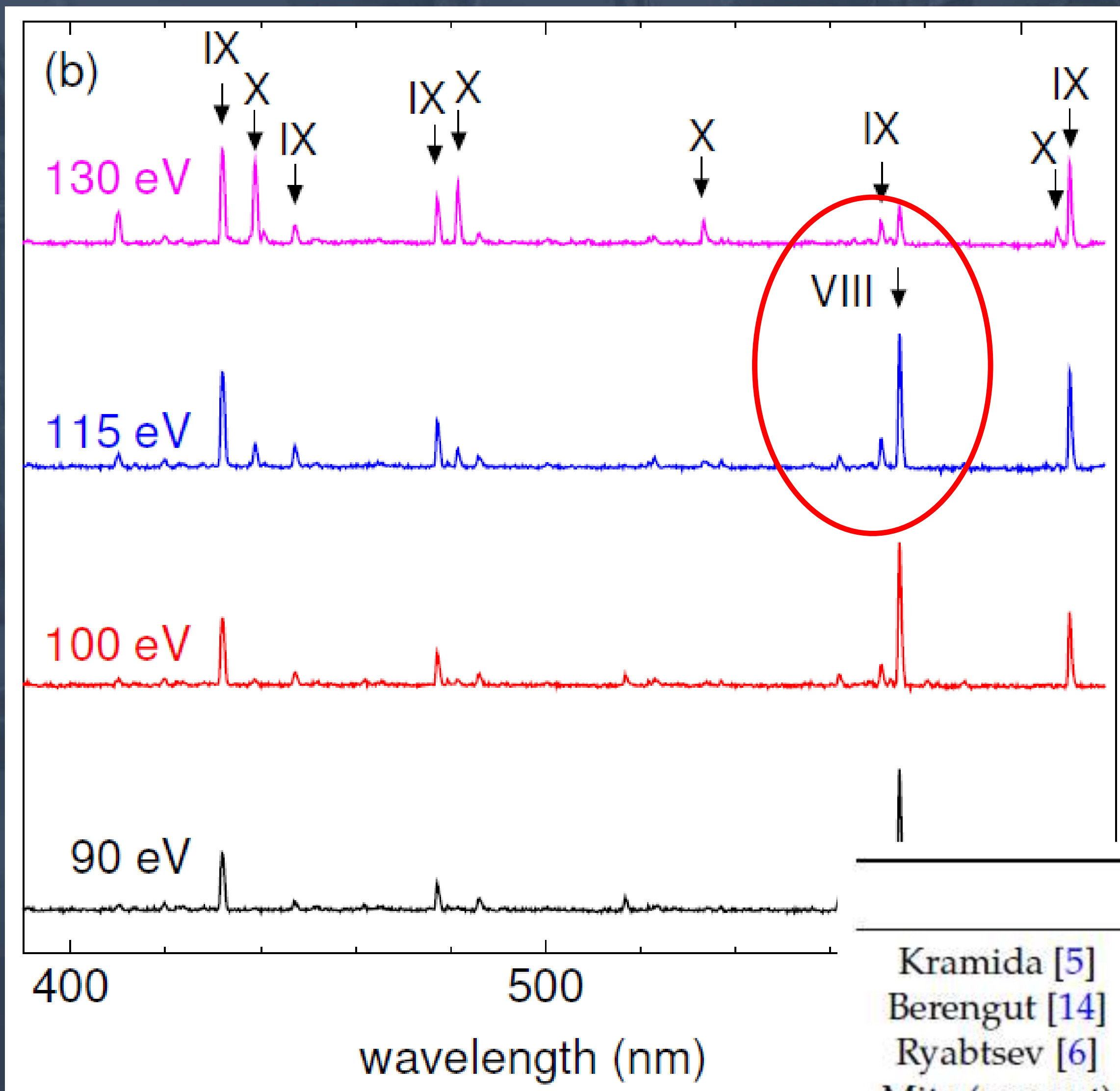
W6+
LLNL EBIT spectrum
(Clementson, Atoms **3** 407)
W7+
W5+
W5+
W6+
Present
7+
115 eV
6+
100 eV
20
22
24
26
wavelength (nm)

EUV spectra

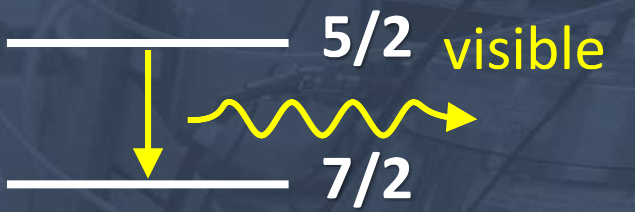

Experiment
130 eV
115 eV
100 eV
8+
7+
6+
CR model
5p-5d, 4f-5d
$4f^{13}5p_{1/2}$-$4f^{13}5d_{3/2}$
$4f^{13}5p_{3/2}$-$4f^{13}5d_{5/2}$
$5p_{1/2}$-$5d_{3/2}$
$5p_{3/2}$-$5d_{5/2}$
20
22
24
26
wavelength (nm)


W^{7+}
Energy (eV)
100
50
0
$5p^5 5d$
$5p^5 6s$
$5p^4 5d$
$5p^4 6s$
$5p^6 5d$
$5p^6 6s$
$5p^6$
$5p^5$
EUV
EUV
$4f^{13}5s^2$
$4f^{14}5s^2$
$4f^{12}5s^2$

Visible spectra



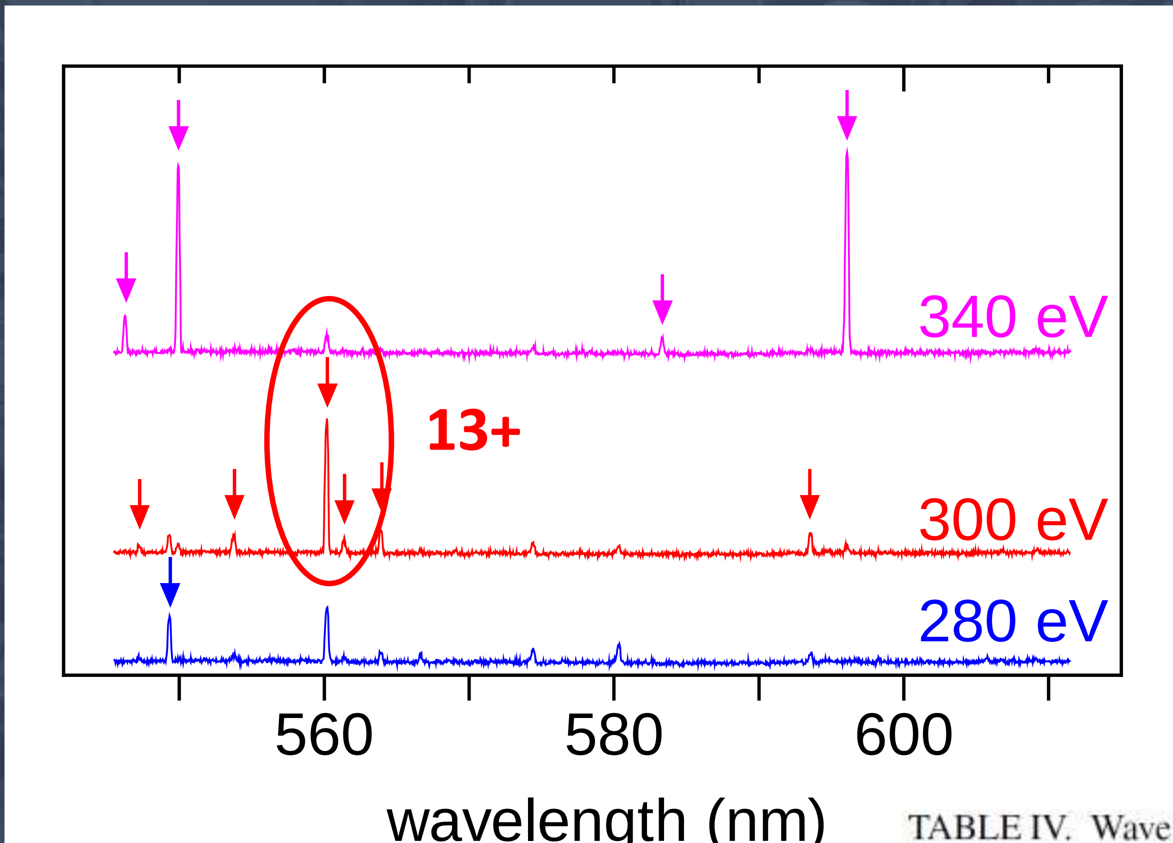
W^{7+} $(4f^{13}5s^25p^6)$ ^2F



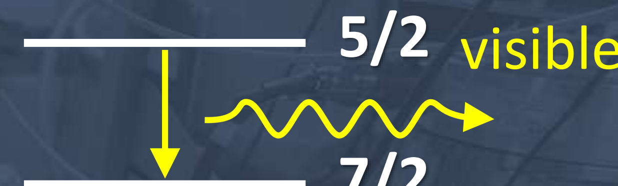
M. Mita et al., Atoms 5 (2017) 13

	year	exp or th	energy (cm^{-1})
Kramida [5]	2009	theory	17440 ± 60
Berengut [14]	2009	theory	18199
Ryabtsev [6]	2015	experiment	17410 ± 5
Mita (present)	2016	experiment	17402.5 ± 0.9

Visible spectra



W^{13+} ($4f^{13}5s^2$) ^2F



Kobayashi et al., PRA 92, 022510

TABLE IV. Wavelength λ (nm in air) and transition probability A (s^{-1}) for the $[4f^{13}5s^2]_J$ ($J = 7/2{-}5/2$) transition in promethiumlike tungsten and gold.

Ion	λ_{exp}	λ_{th}				A
W^{13+}	560.25	567.8[a]	538[b]	568[c]	552[d]	83.9[a]
Au^{18+}	324.39	327.4[a]				437[a]

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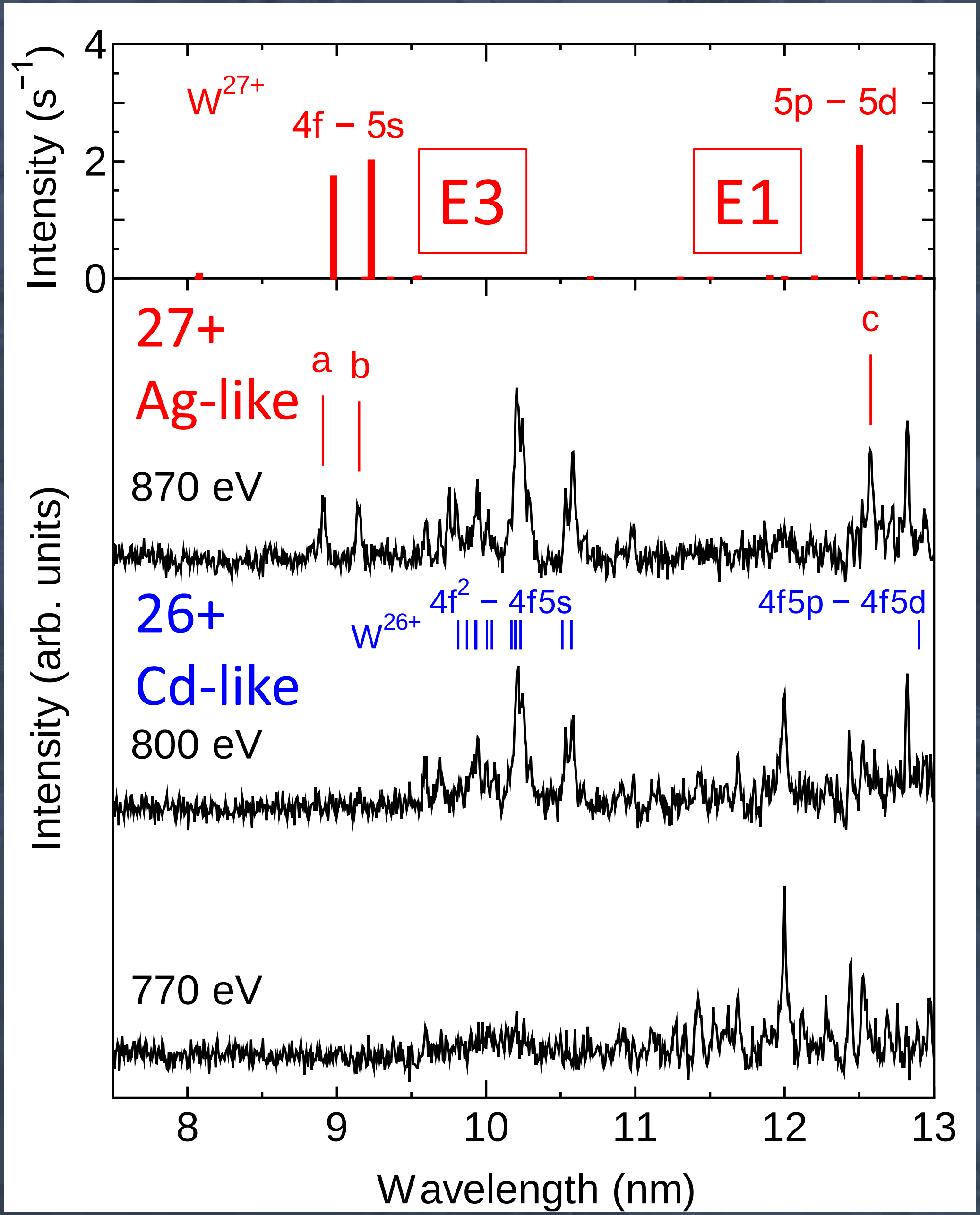
EUV spectra of W^{q+} (q=25-27)



I.P.

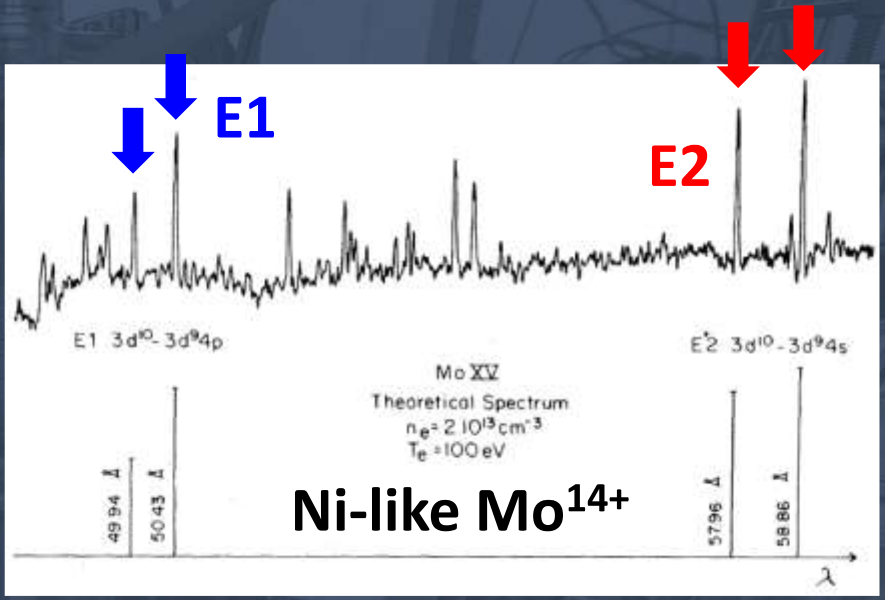
25+→26+: 784 eV

26+→27+: 833 eV

Examples of multipole radiations

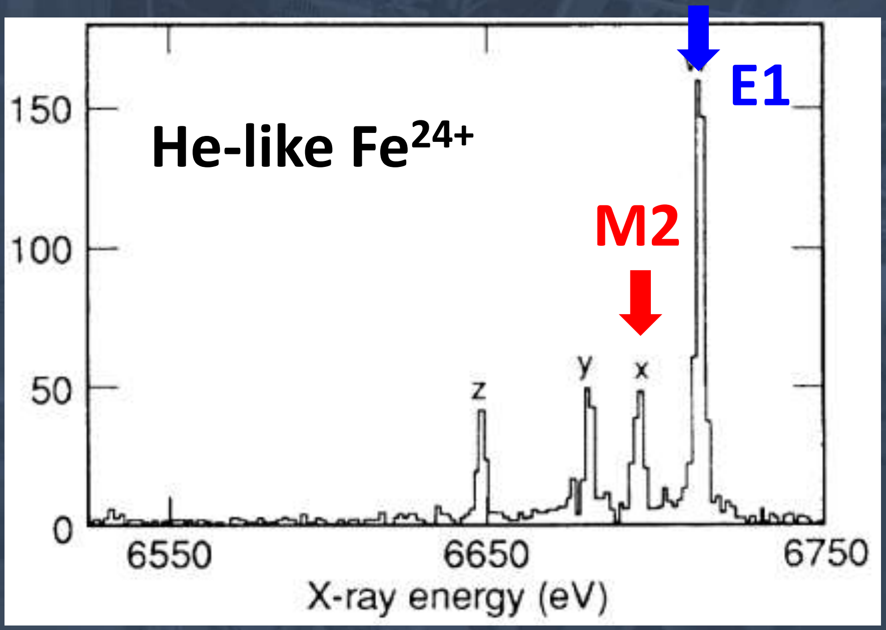
- **Electric quadrupole (E2)**
  $[3d^{10}]_{J=0}$ – $[3d^{9}4s]_{J=2}$ in Ni-like

  Klapisch et al., PRL 41 403 (1978)



- **Magnetic quadrupole (M2)**
  $1\ ^1S_0 – 2\ ^3P_2\ (x)$ in He-like

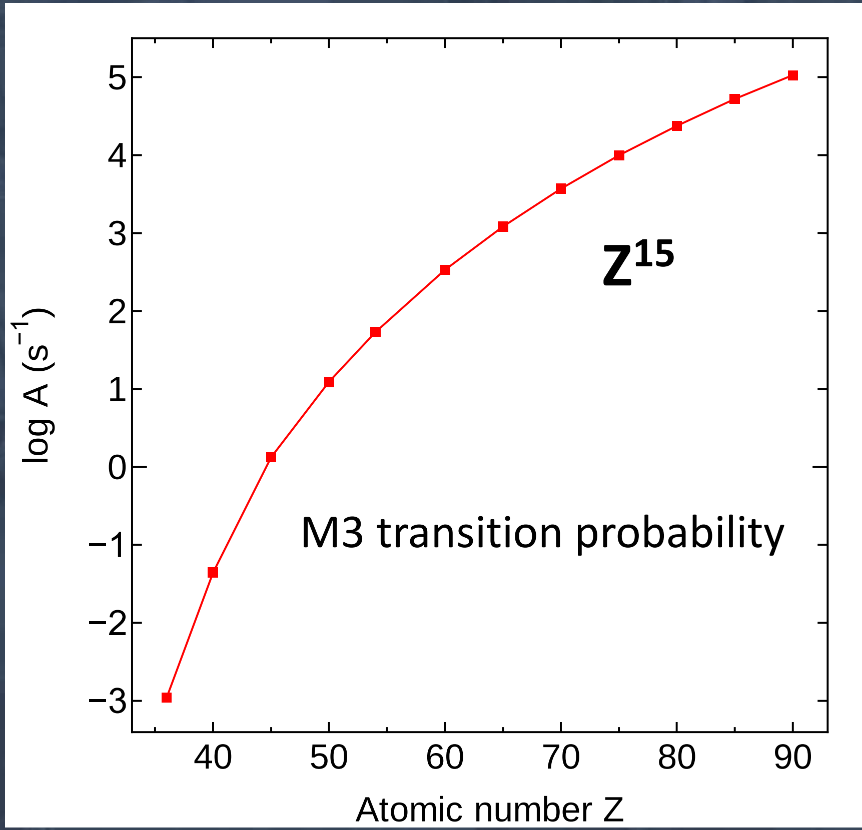
  Beiersdorfer et al., PRA 46 3812 (1992)



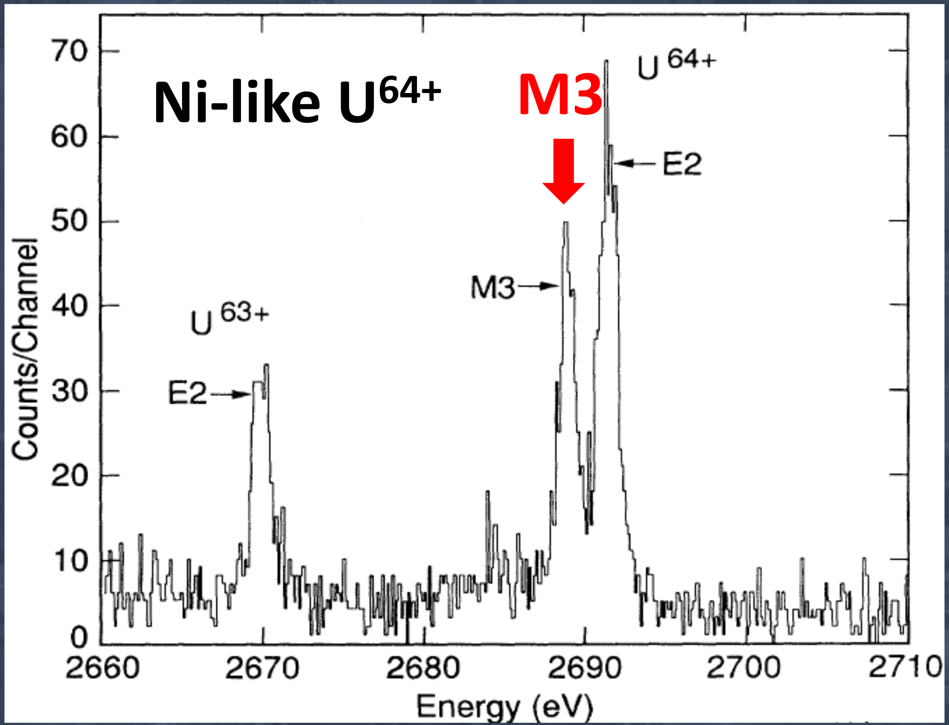
Examples of multipole radiations

- **Magnetic octupole (M3)**
  $[3d^{10}]_{J=0} – [3d^9 4s]_{J=3}$ in Ni-like

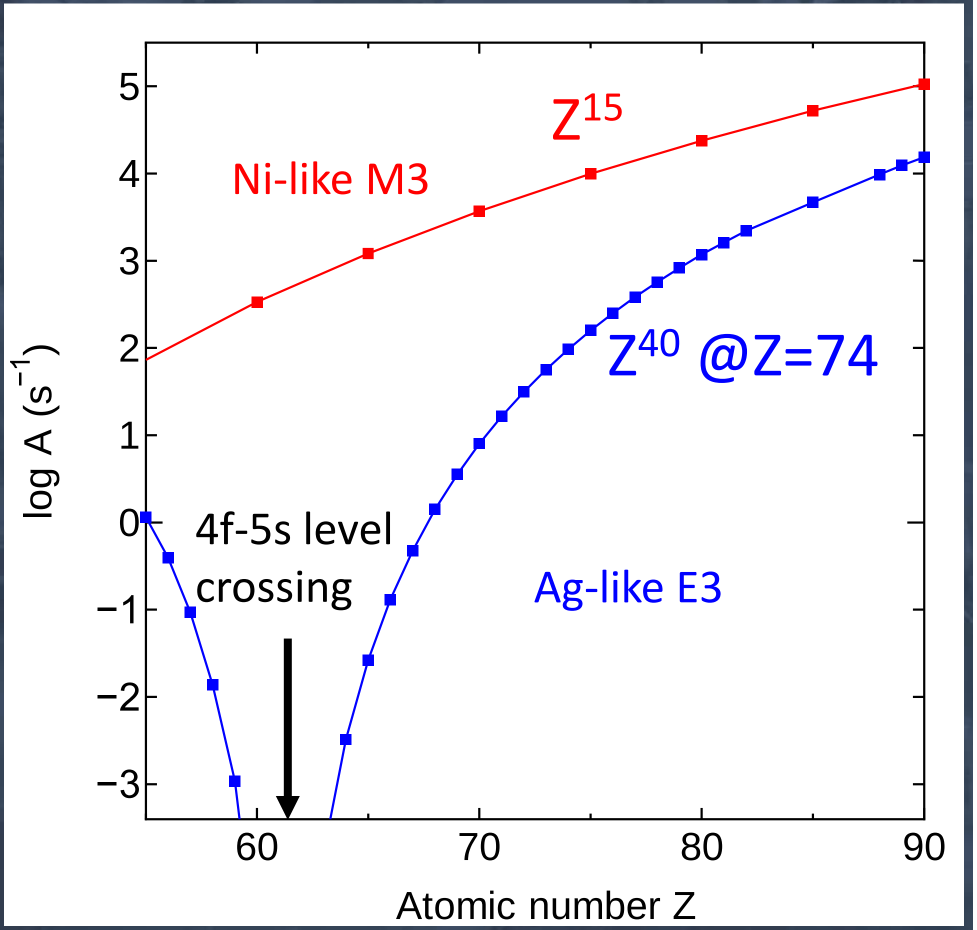
Safronova et al., ADNDT 92 47 (2006)

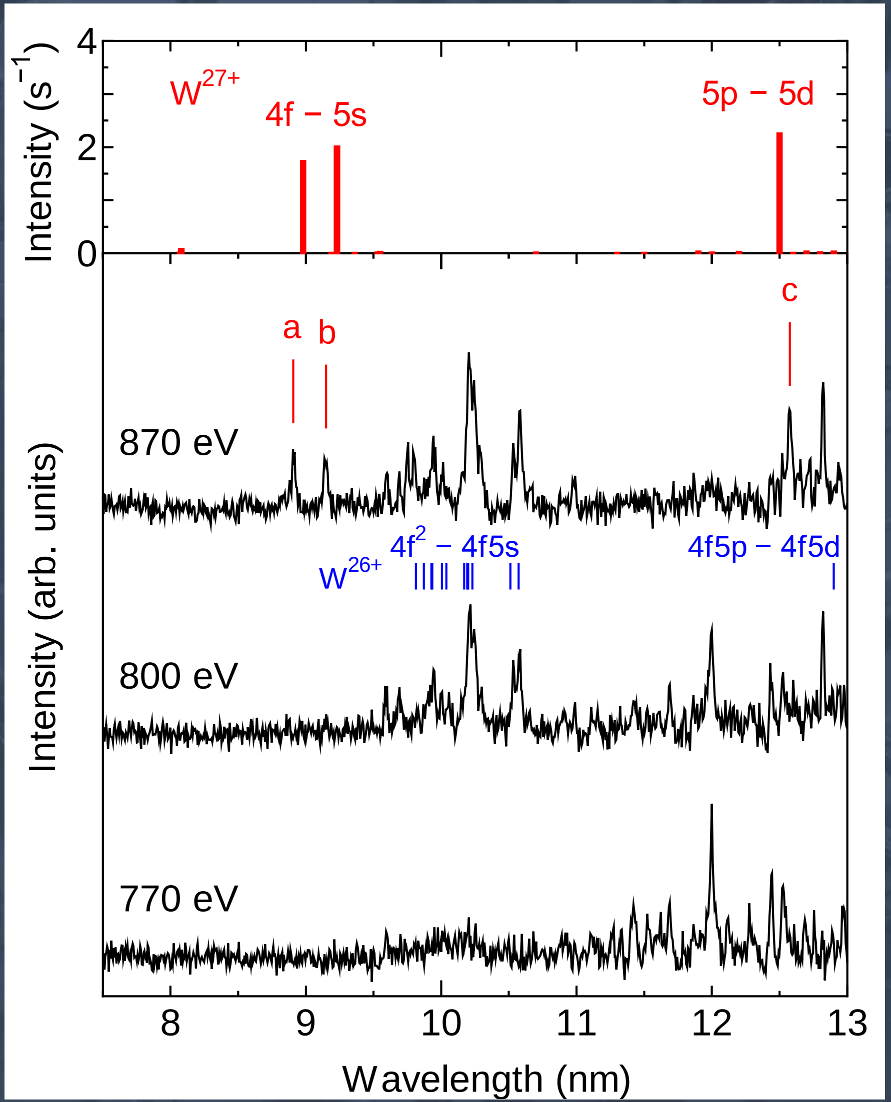


Beiersdorfer et al., PRL 67 2272 (1991)



E3 transition probability





Collisional radiative modelling

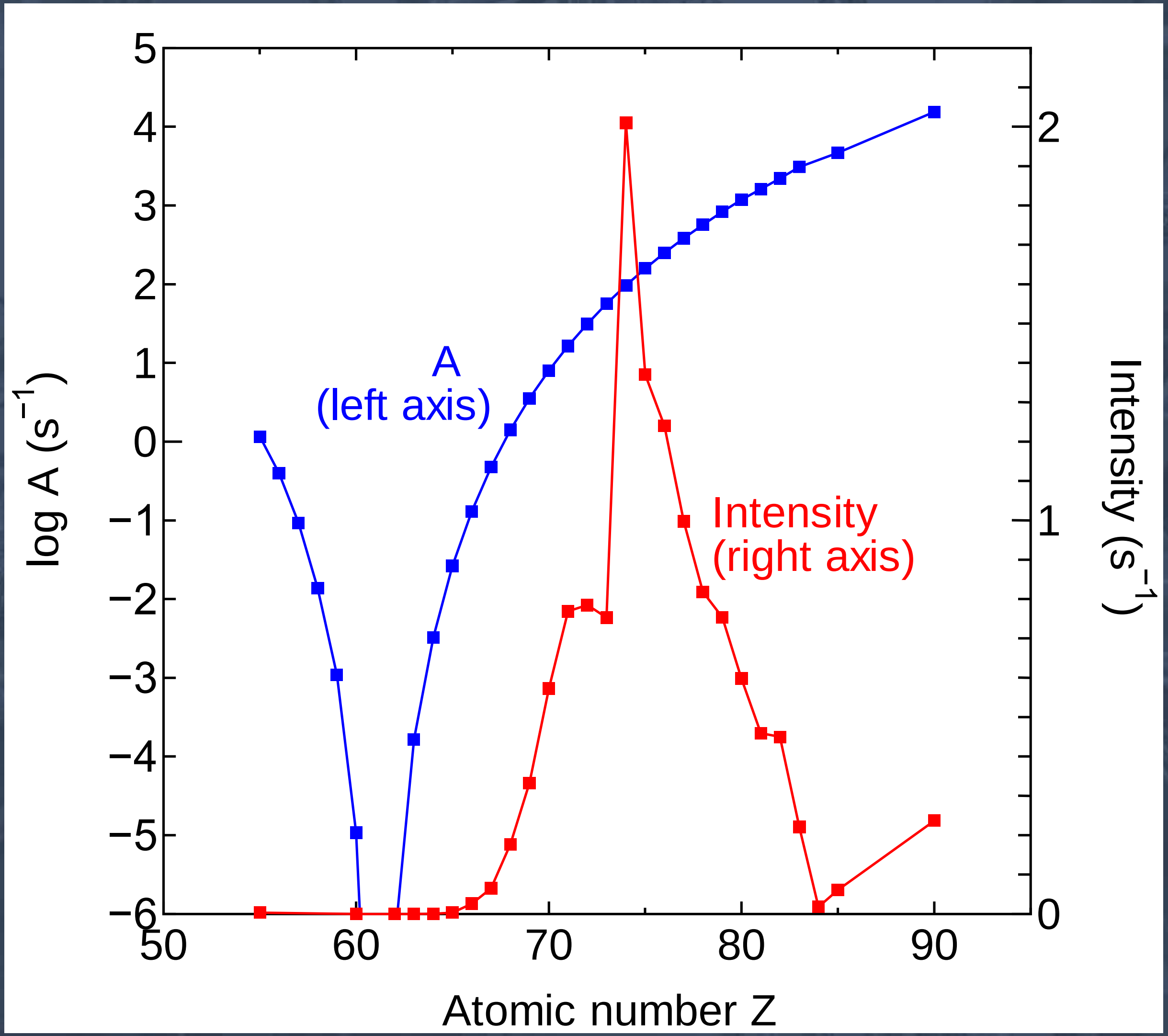
$$n_i = \frac{n_e \sum_{j\neq i} C_{ij} n_j + \sum_{j>i} A_{ij} n_j}{n_e \sum_{j\neq i} C_{ji} + \sum_{j<i} A_{ji}} \equiv \frac{C_{\text{in}} + R_{\text{in}}}{c_{\text{out}} + r_{\text{out}}} \equiv \frac{F_{\text{in}}}{f_{\text{out}}}$$

n_i : fractional population of level i
C_{ij} : electron impact (de)excitation rate coefficient
A_{ij} : radiative transition rate
n_e : electron density

included levels:
$4d^{10}4f$, $4d^{10}nl$ (n=5-6), $4d^9 4f^2$, $4d^9 4f5l$, $4d^9 5l^2$, $4d^8 4f^3$, $4d^8 4f^2 5l$

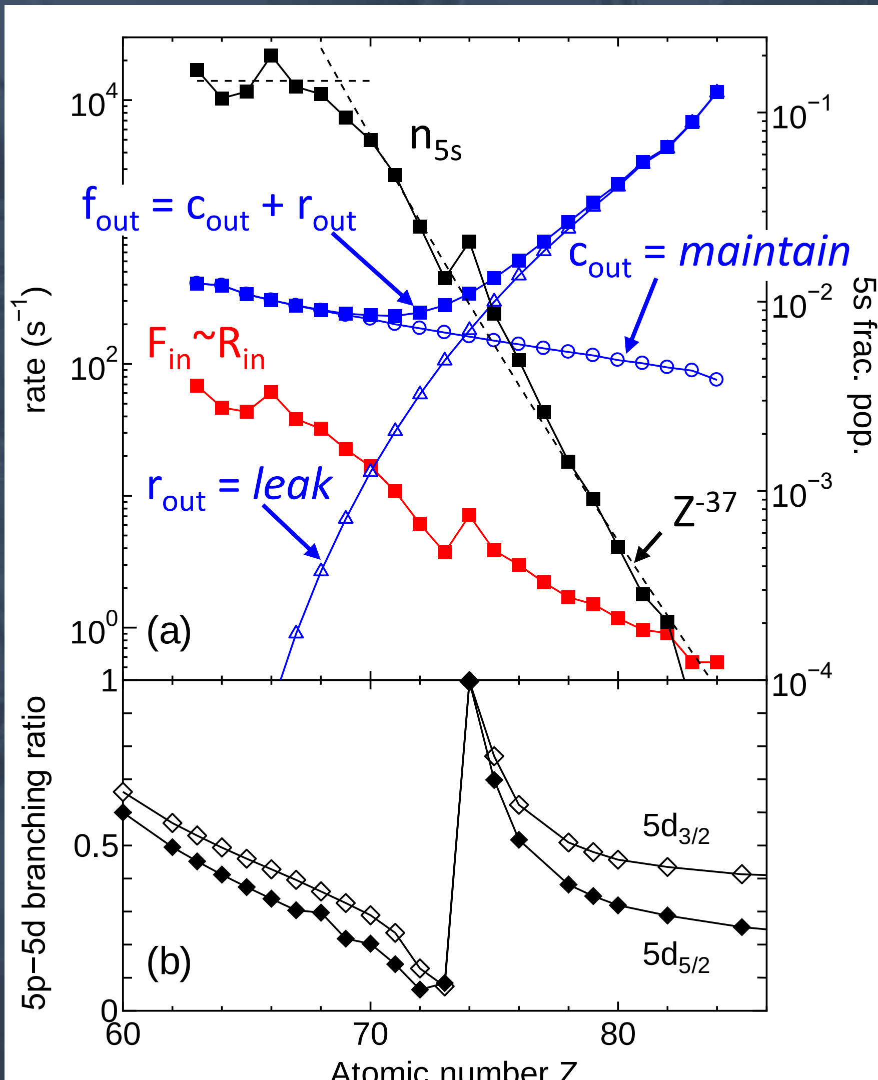
CRM results

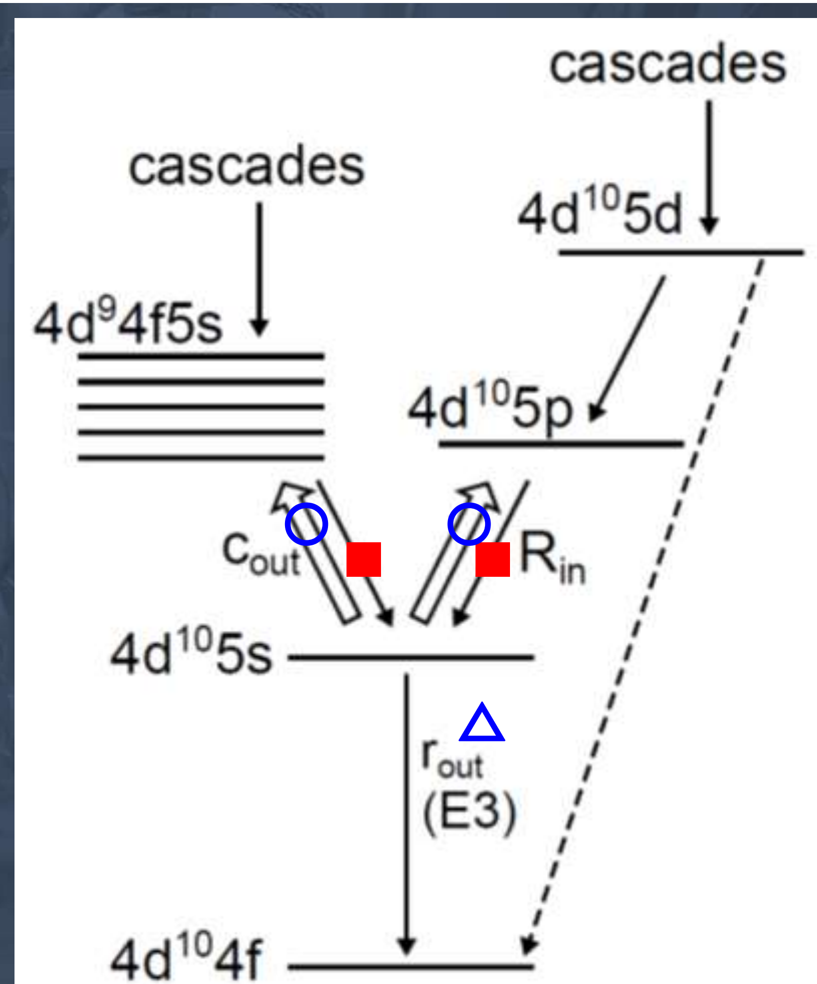
E3 intensity = $n_{5s} \times A_{4f \leftarrow 5s}$



Population kinetics for the 5s level

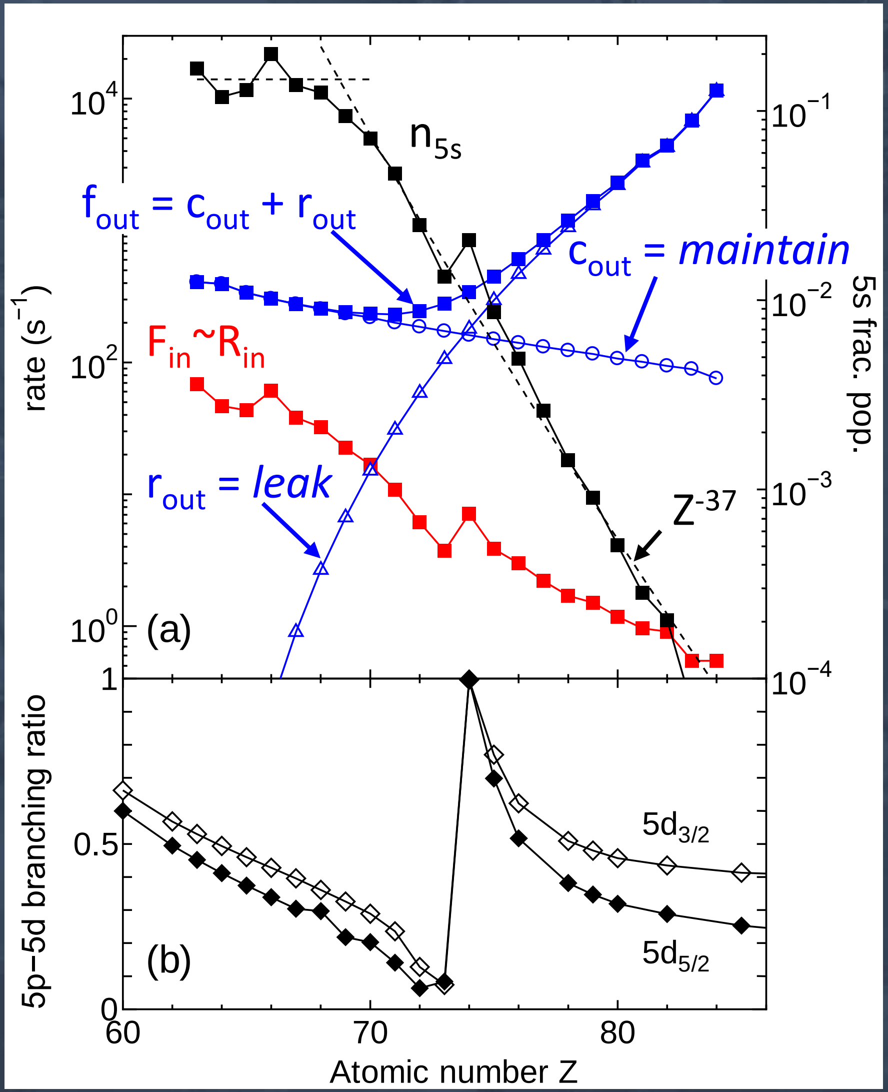
$$n_i = \frac{\cancel{C_{\text{in}}} + R_{\text{in}}}{c_{\text{out}} + r_{\text{out}}} \equiv \frac{F_{\text{in}}}{f_{\text{out}}}$$



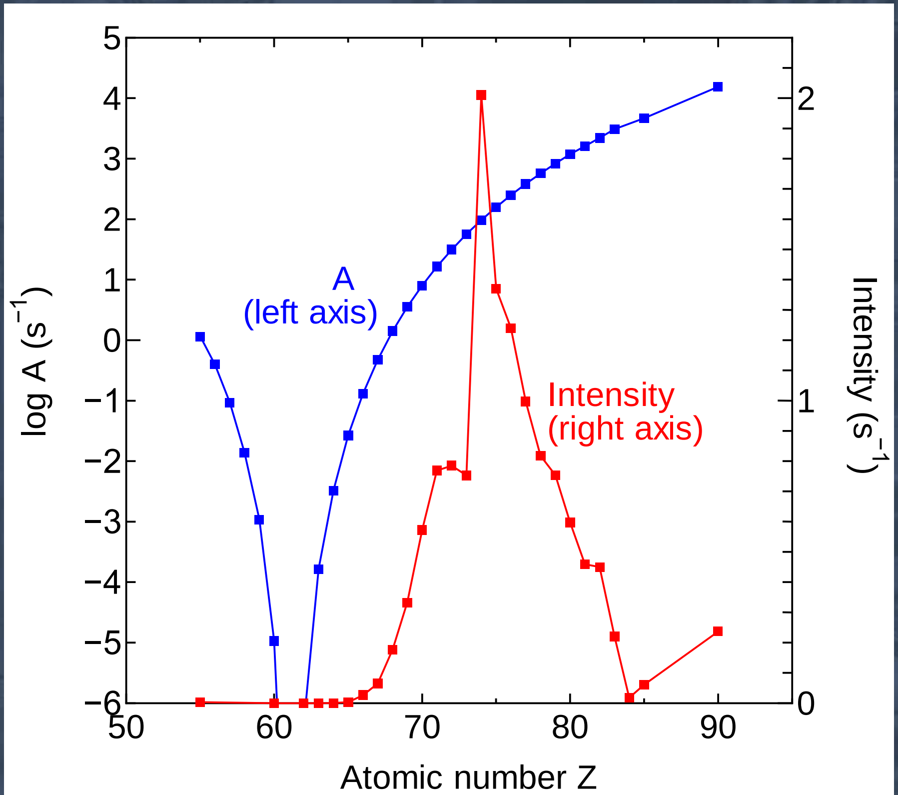


cf) Safronova et al., PRA 68, 062505

Population kinetics for the 5s level



E3 intensity = $n_{5s} \times A_{E3}$



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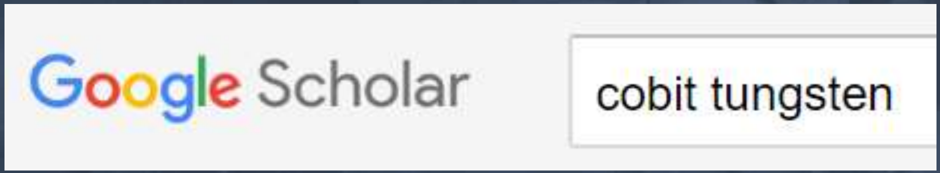
Summary

- CoBIT is a compact but powerful device for observation and identification of previously unreported lines of tungsten.
- EUV and visible spectra of W^{q+} (q=6-13) have been recently observed and compared with CRM calculations.
- In the EUV spectra of Ag-like W^{27+}, 4f-5s transitions have been identified as the first observation of E3 emission.
- Please search our work with “cobit tungsten” in Google scholar.



Collaborators

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