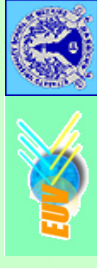


Systematics of Atomic 4d-4f Transitions of Atomic Ions in EUVL source plasmas and Neighboring Atomic Numbers



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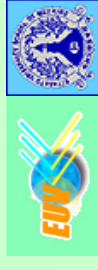
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Abstract:

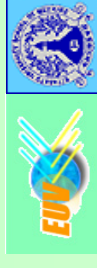
The emissions of EUV lines in the wavelength 13.5nm band is one of the candidates of the EUVL source. The *4d-4f* transition arrays of Sn atomic ions of ionicity ranging from 6+ to 13+ and of the possible satellite lines give emissions in this wavelength range. The *4d-4f* transitions of Sn ions are heavily influenced by the interference with the *4p-4d* transitions that take place simultaneously in the same atomic ionic electronic states. For Sn ions, we have carried out line by line sophisticated calculations and investigated the spectral structure of the *4d-4f* transitions using a set of multi-configuration Dirac-Fock and its adjacent atomic structure codes GRASP and RATIP package.

To clarify the mechanisms and the systematics of the interference structures of *4d-4f* and *4p-4d* transitions, we have also carried out similar calculations for atomic ions with atomic numbers ranging from $Z=48$ to $Z=56$. The atomic number dependence of the spectrum for the ions with iso-electronic structures are investigated in detail.

A peculiar spectral structure that appears on the red wing of the Y-like Sn charge transfer experimental spectra (Tanuma et al 2006)

has been speculated to be of an interference between the electron capture to *4f* and the electron capture to *4d* with *4p* sub-shell excitation.

A part of this work was performed under the auspices of Leading Project performed by MEXT in Japan.



Calculation of energy levels and oscillator strengths by MCDF

GRASP92 (General purpose Relativistic Atomic Structure Program 92)

F.A.Parpia et al., Comput. Phys. Commun. 94, 249 (1996).

CESD99 (a program for the Complete Expansion of *jj*-coupled symmetry Functions into Slater Determinants, A component of RATIP package)

S.Fritzsche et al., Comput. Phys. Commun. 124, 353 (2000).

REOS99 (a program for Relaxed-orbital Oscillator Strength calculations, A Component of RATIP package)

S.Fritzsche et al., Comput. Phys. Commun. 124, 340 (2000).

Within the framework of Löwdin's formalism, the single-photon double-electron excitation can be described as the shake-up process induced by the inner-shell excitation.

P.O.Löwdin, Phys. Rev. 97, 1474 (1955).

GRASP2 (unpublished version of the GRASP package series (1992))

Allows the batch mode calculations, that fits an automatic data production using scripts.



MCDF Calculations of 4d Open Sub-Shell Ions

Configurations Included:

① Ground State: $4p^6 4d^N$

② Excited State: $4p^6 4d^{N-1} 4f^1$

$4p^6 4d^{N-1} 5f^1$

$4p^6 4d^{N-1} 5p^1$

$4p^6 4d^{N-1} 6p^1$

$4p^5 4d^{N+1}$

Optimize All the Possible Levels Simultaneously

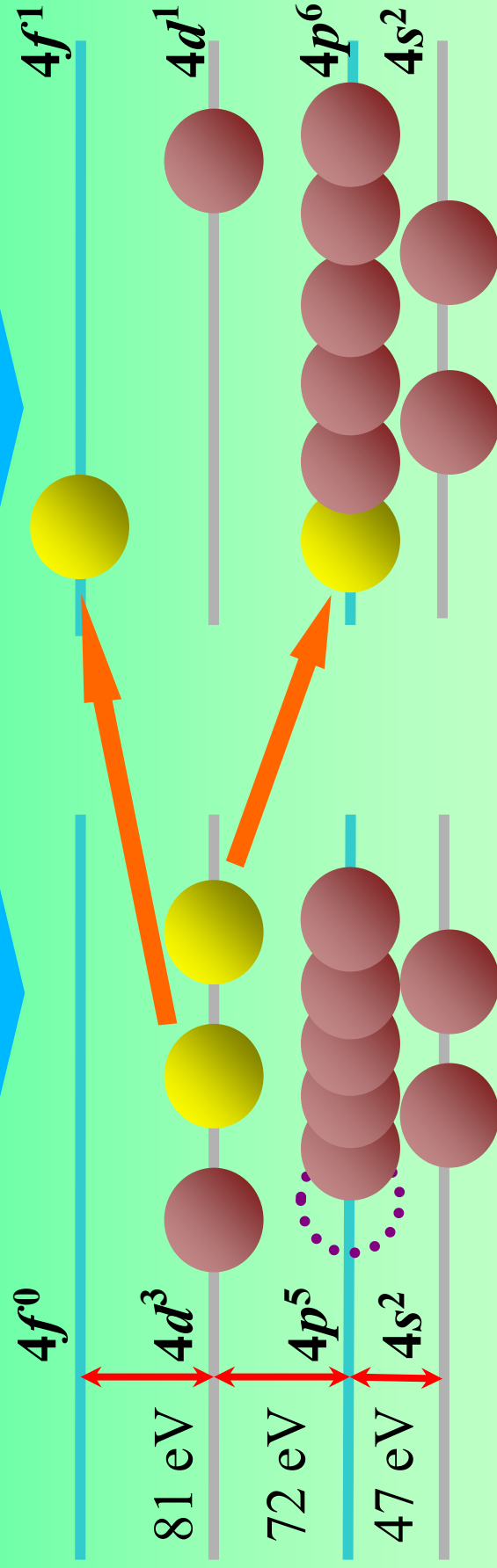


Sn¹²⁺

Electron Configurations in Excited Sn¹²⁺ Ions

- Mixing of $4s^2 4p^6 4d^1 4f^1$ and $4s^2 4p^5 4d^3 4f^0$ --

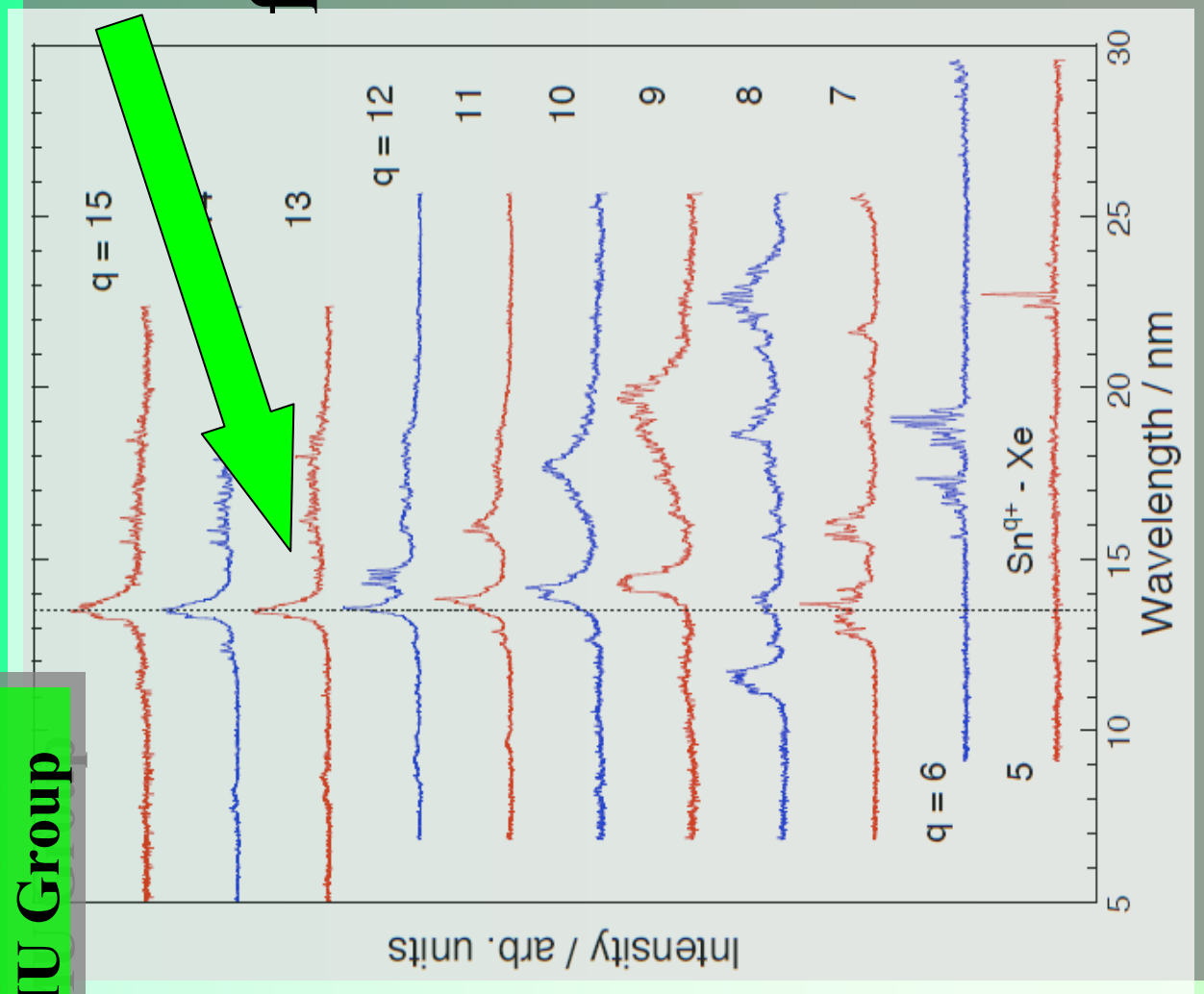
Configuration Mixing



$$\Delta E = 81 - 72 = 9 \text{ eV} \sim 4\% \text{ of } 4d \text{ binding energy } 253 \text{ eV}$$

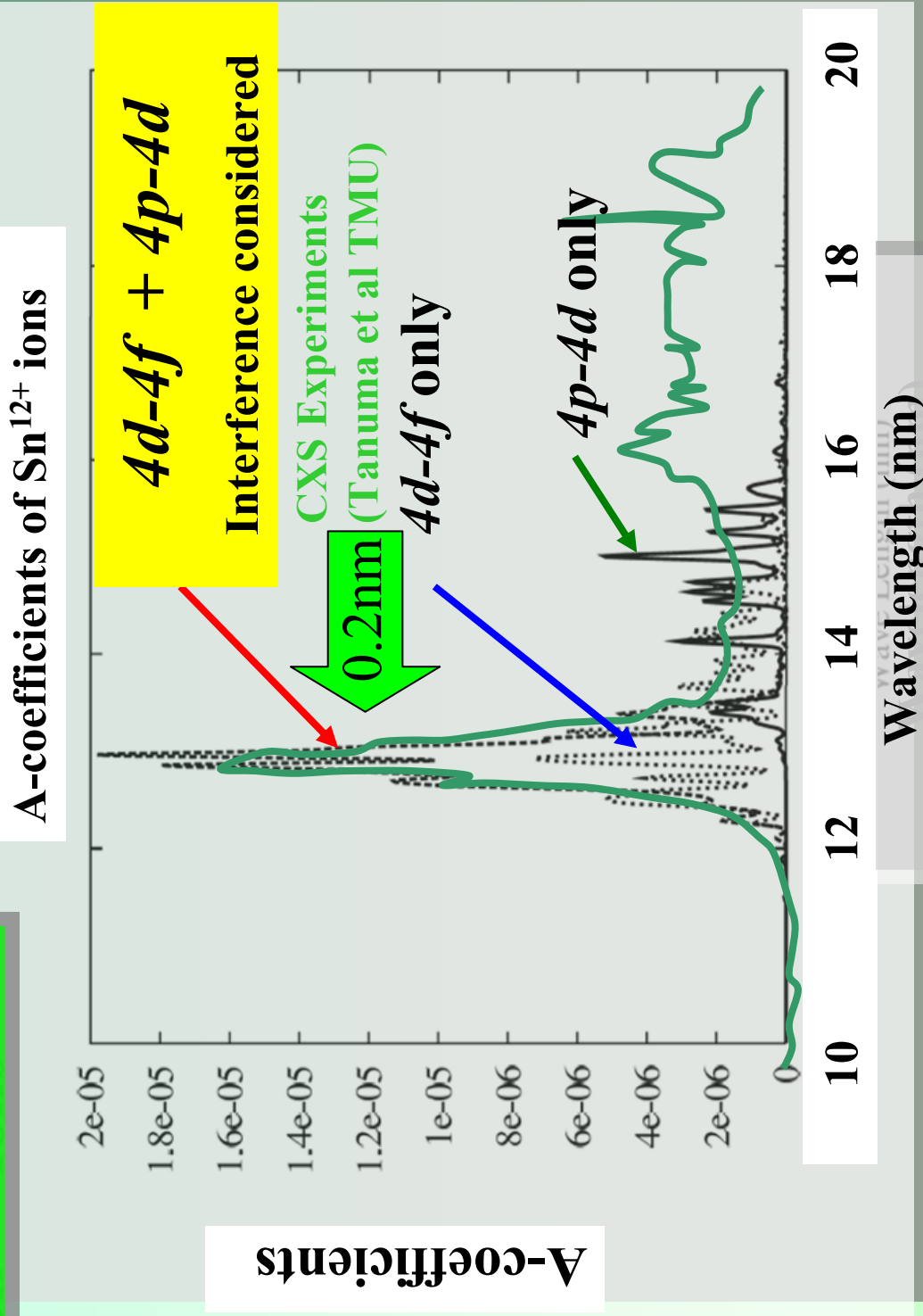


EUV Emission from Sn¹²⁺

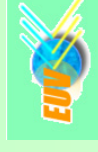
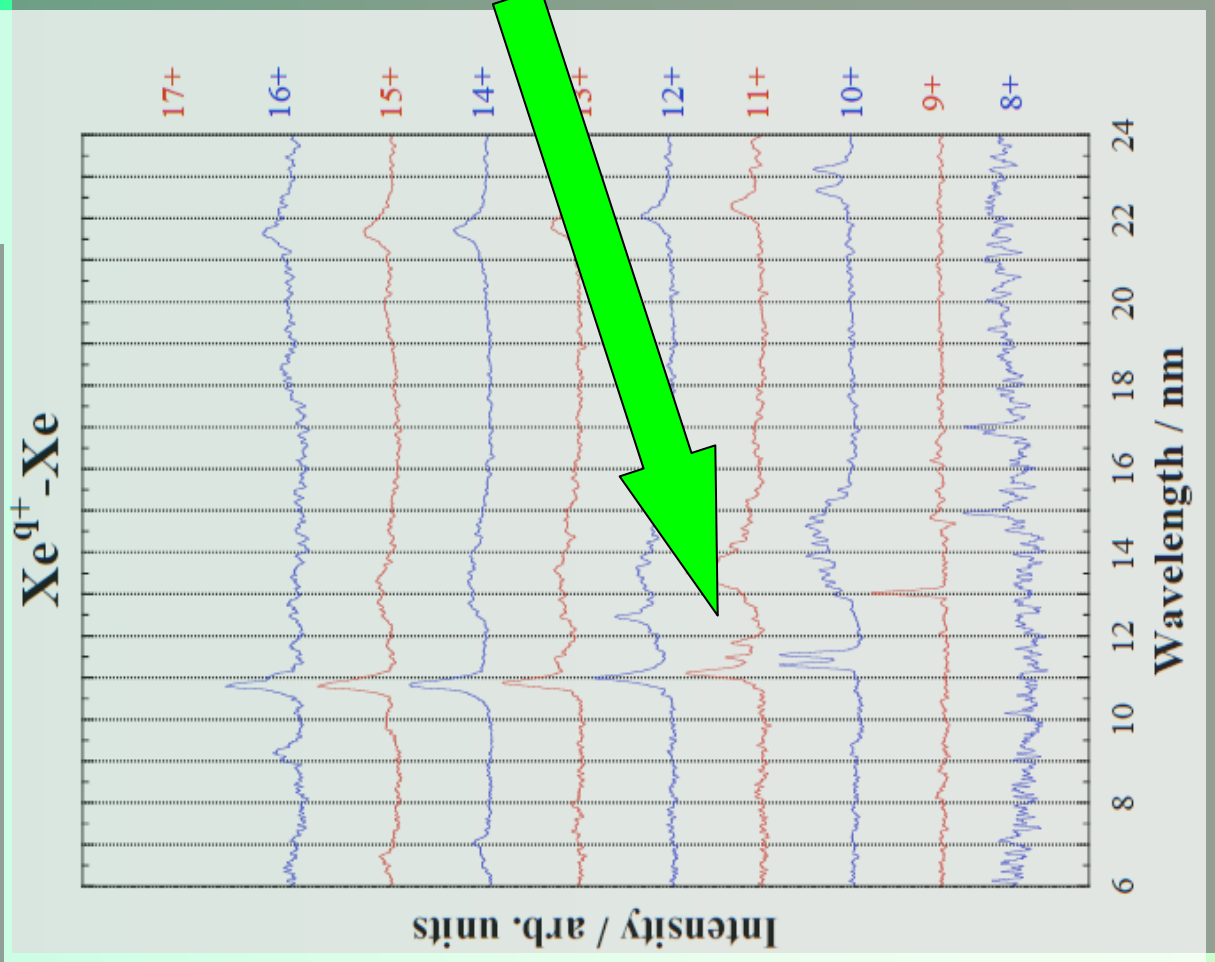


$4d-4f$ & $4p-4d$ Transitions of Sn^{12+} Ions

5th EUVL Workshop, 16-18 September 2006, Barcelona



EUV Emission from Xe¹⁰⁺



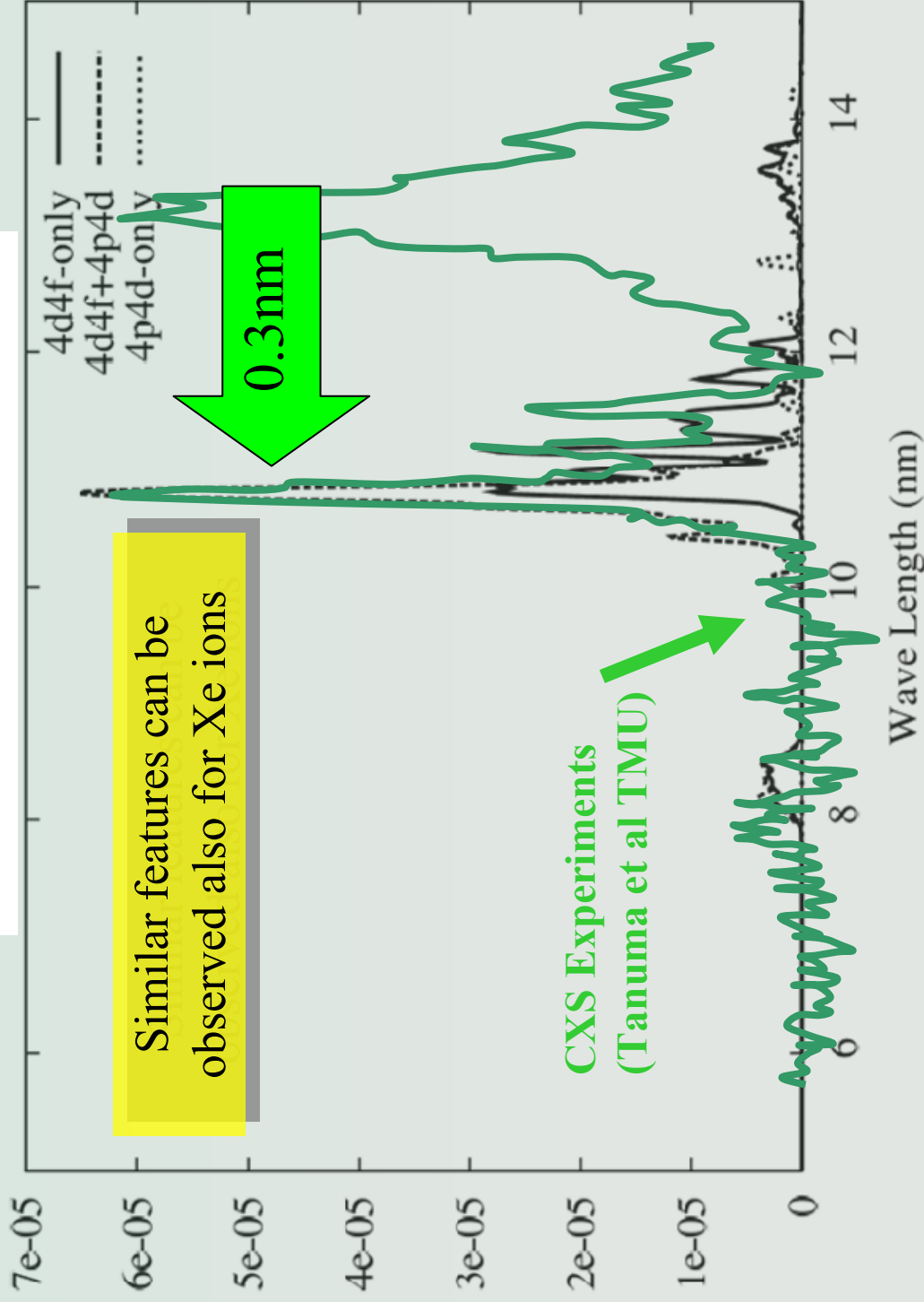
4d-4f & 4p-4d Transitions of Xe^{10+} Ions

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A-coefficients of Xe^{10+} ions

Similar features can be observed also for Xe ions

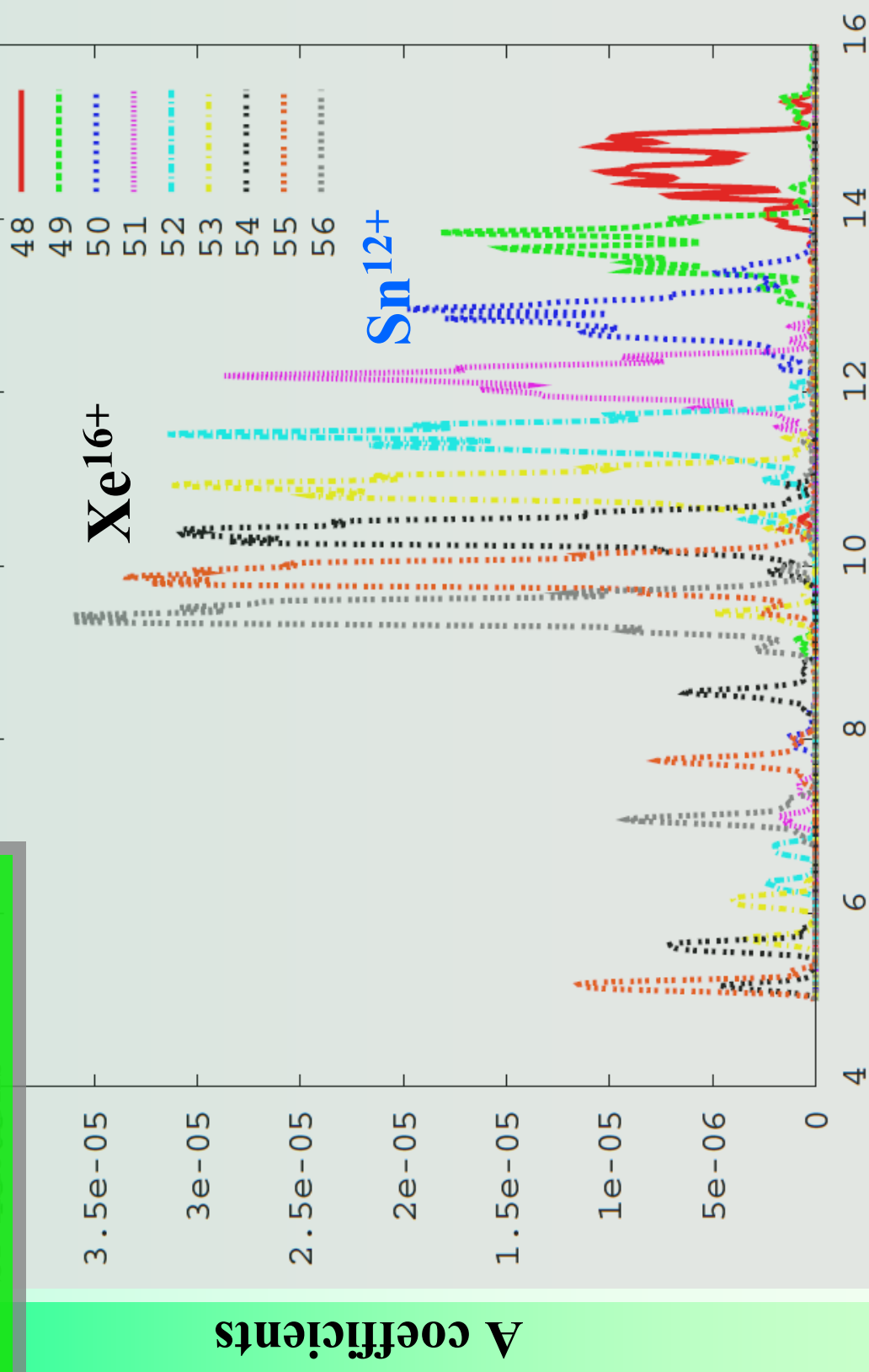
A-coefficients



Atomic Number Dependence of *4d-4f* & *4p-4d* Spectra in Sr-like Ions

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Atomic Number



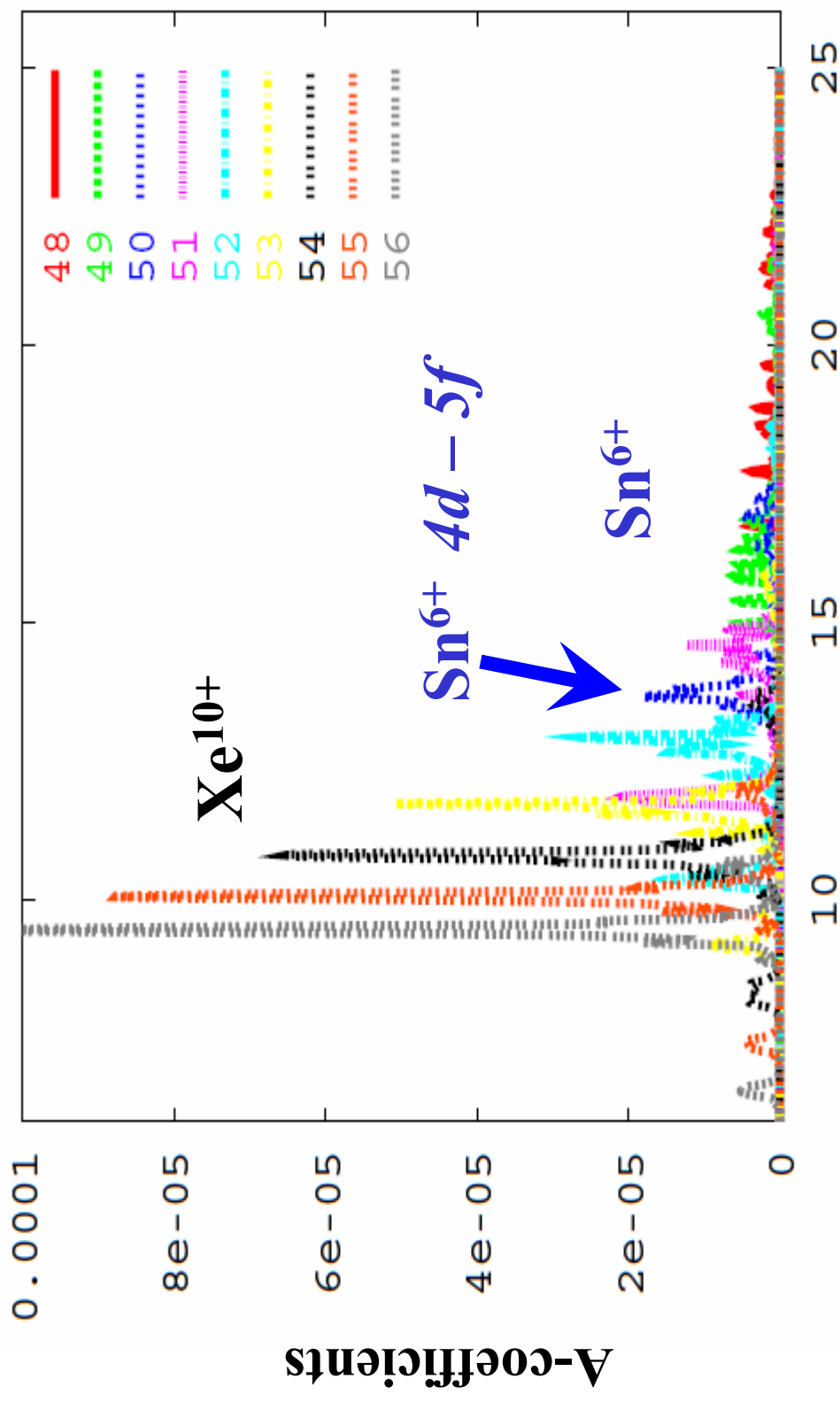
Wave Length (nm)



Atomic Number Dependence of $4d-4f$ & $4p-4d$ Spectra in Ru-like Ions

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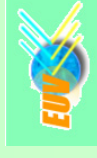
Atomic Number

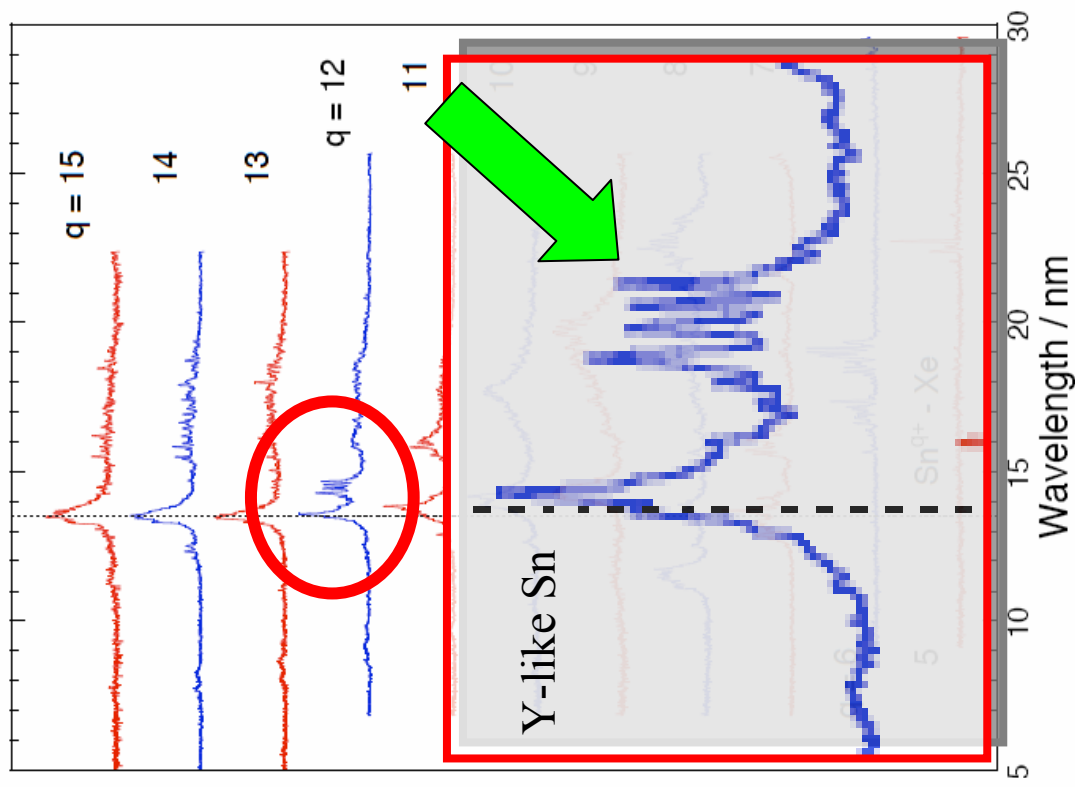
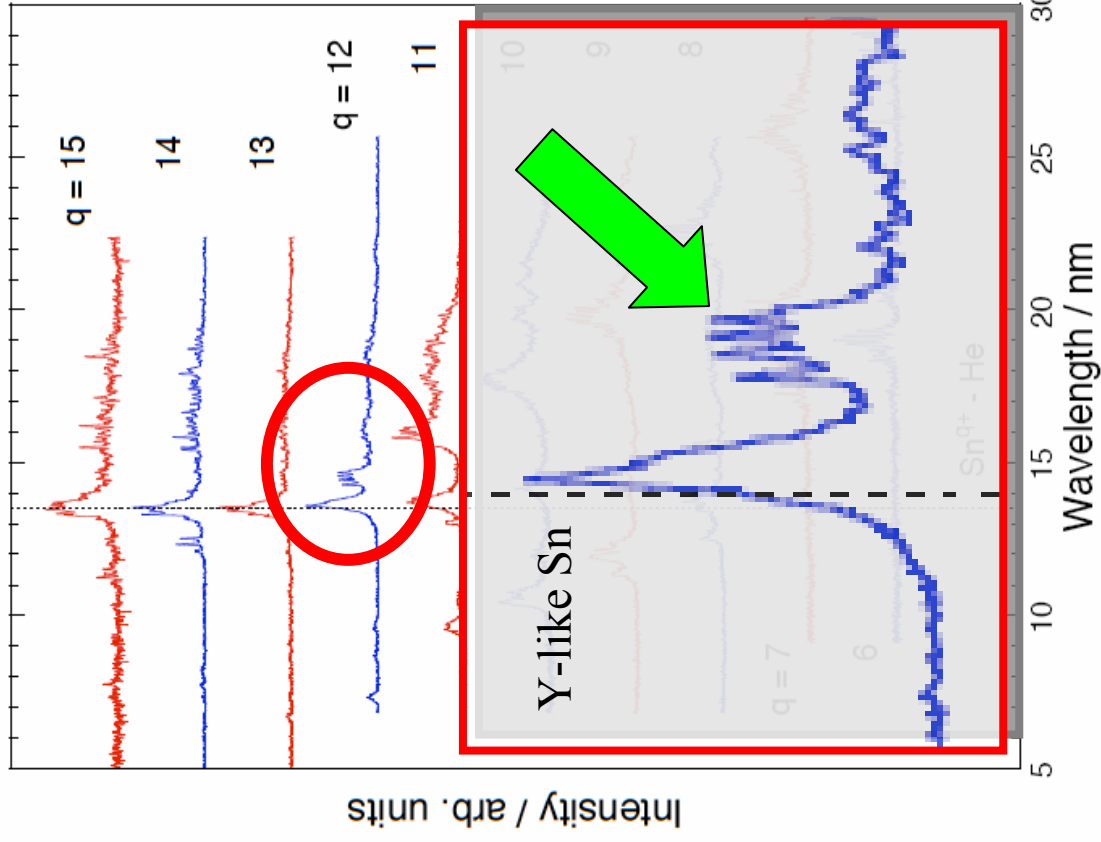


Interference Structure in Y-like Sn Charge Exchange Spectra

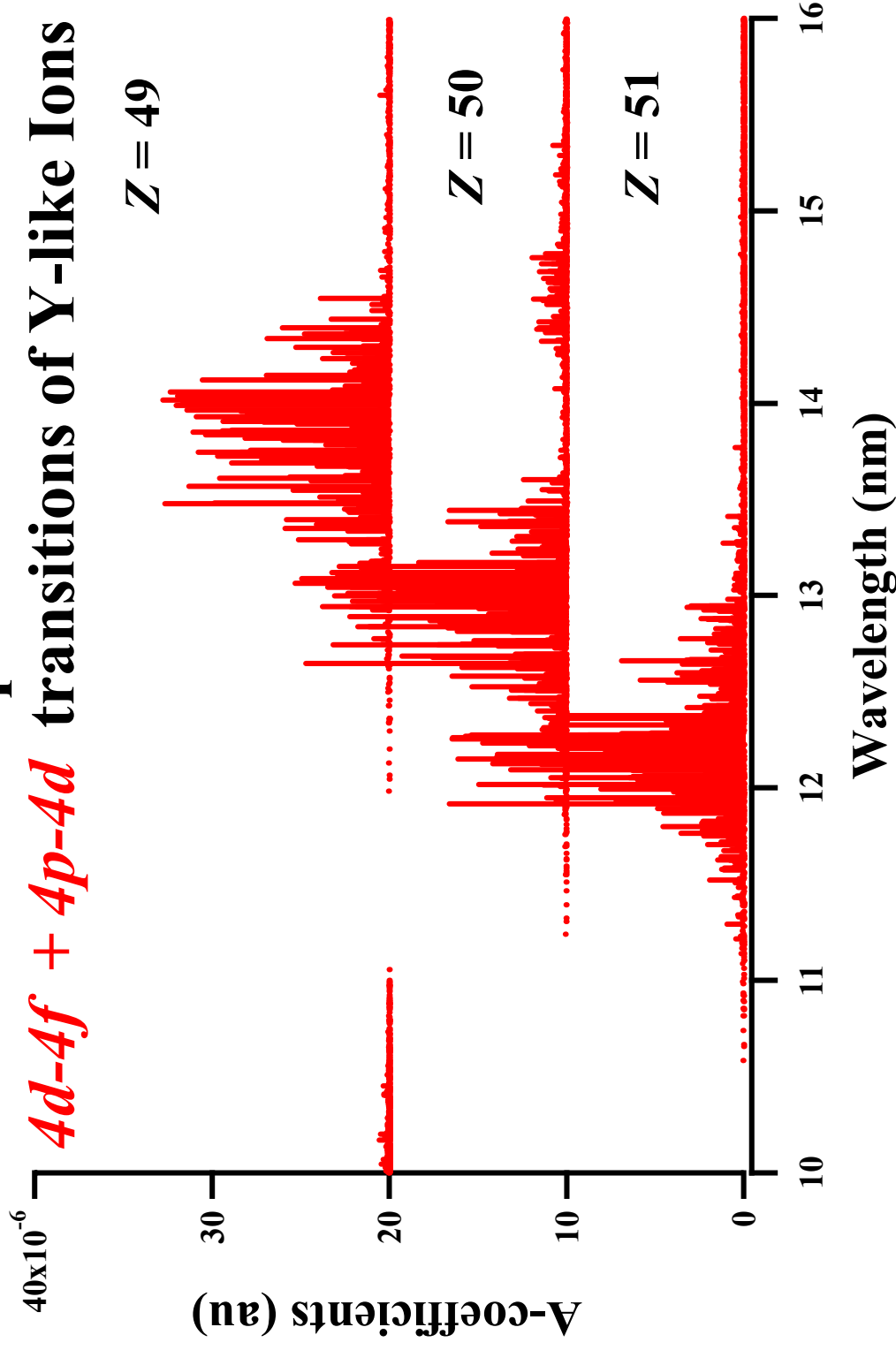
Investigation of peculiar and interesting spectral structures observed in the red wings of the 13.5 nm band. The EUV light emissions are created by electron capture of Sn^{q+} ions from neutral Xe and He atoms.

A simple single electron transfer and a single electron capture accompanied by sub-valence core electron excitation take place simultaneously.

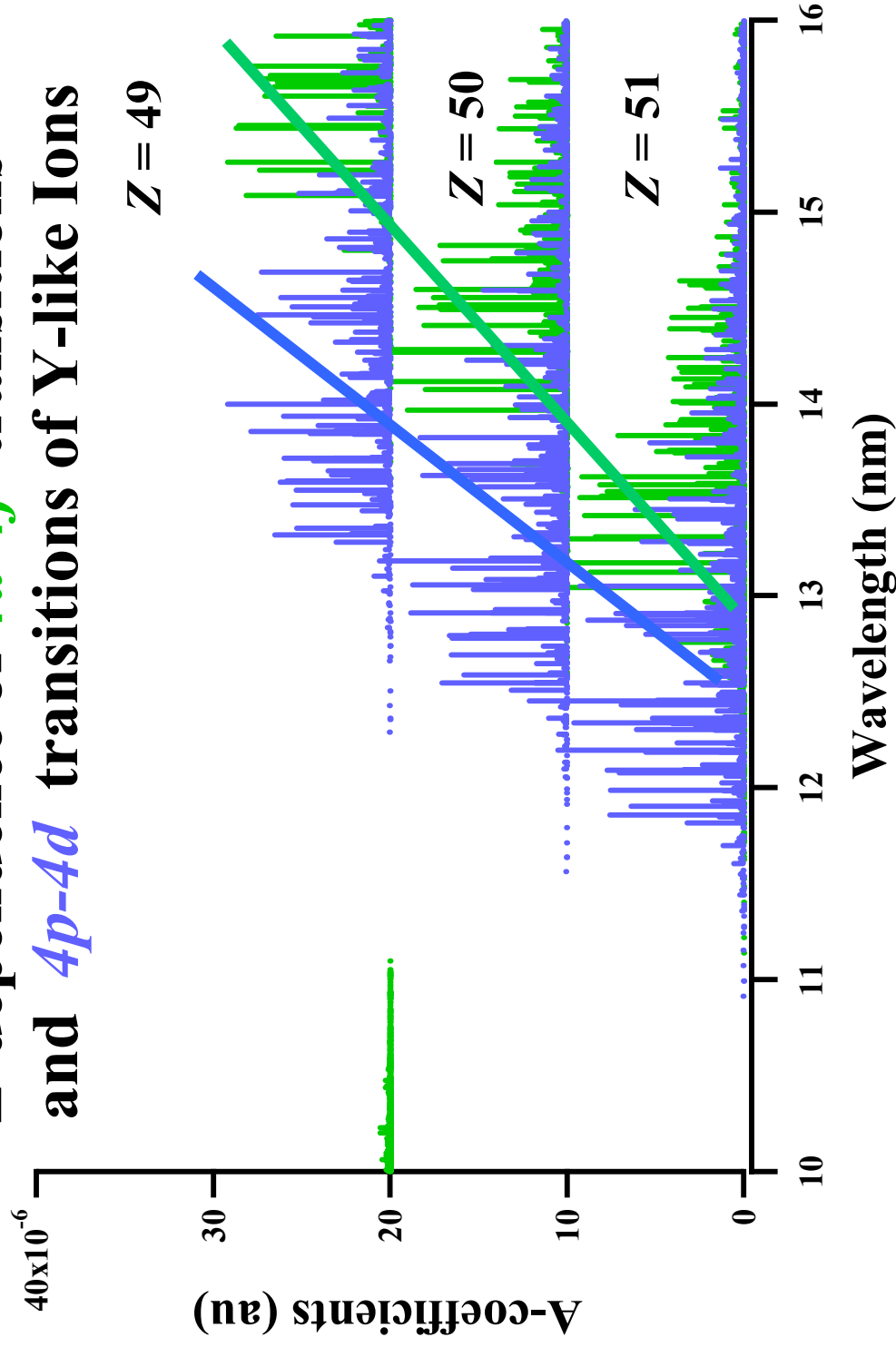




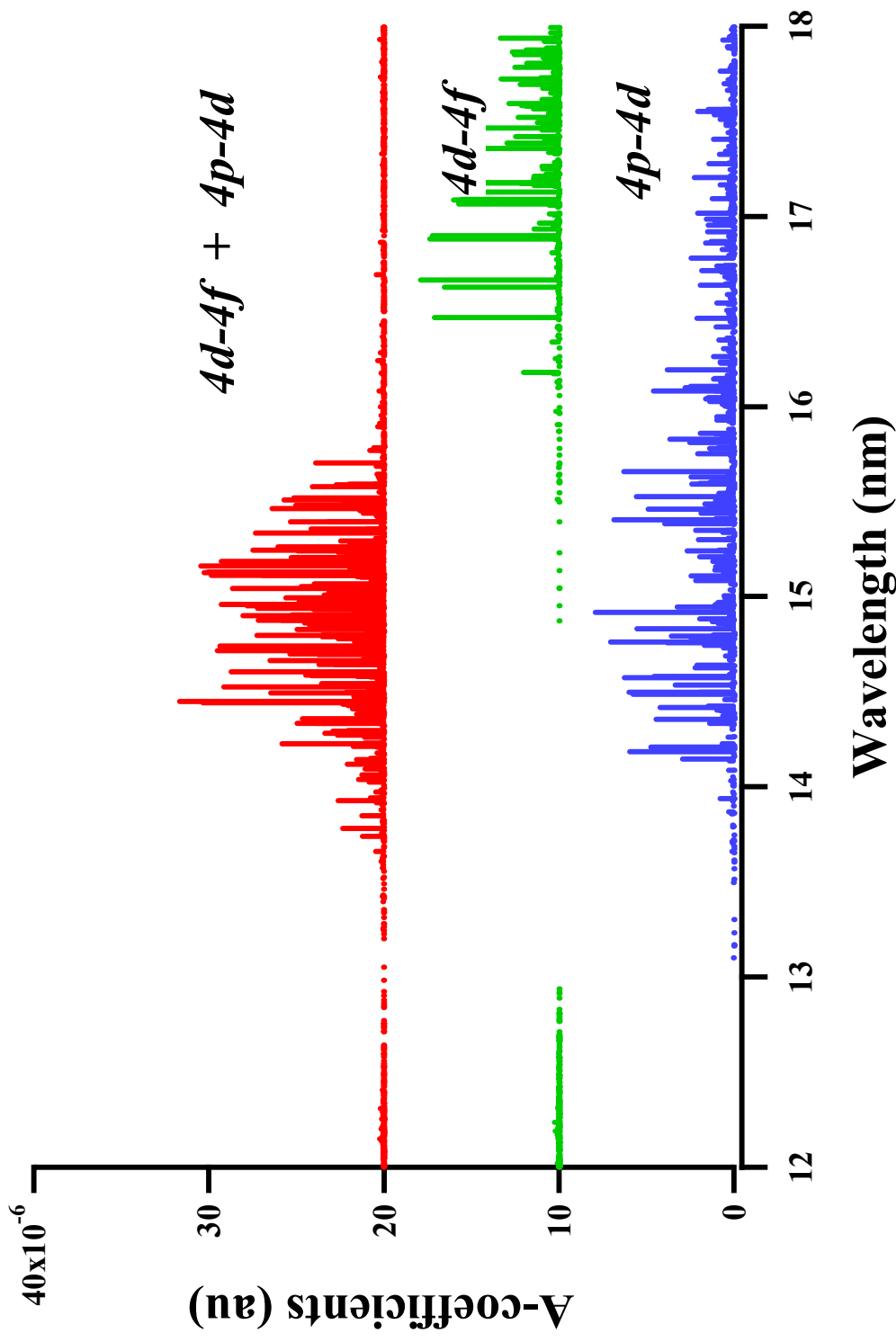
Z-dependence of *4d-4f + 4p-4d* transitions of Y-like Ions



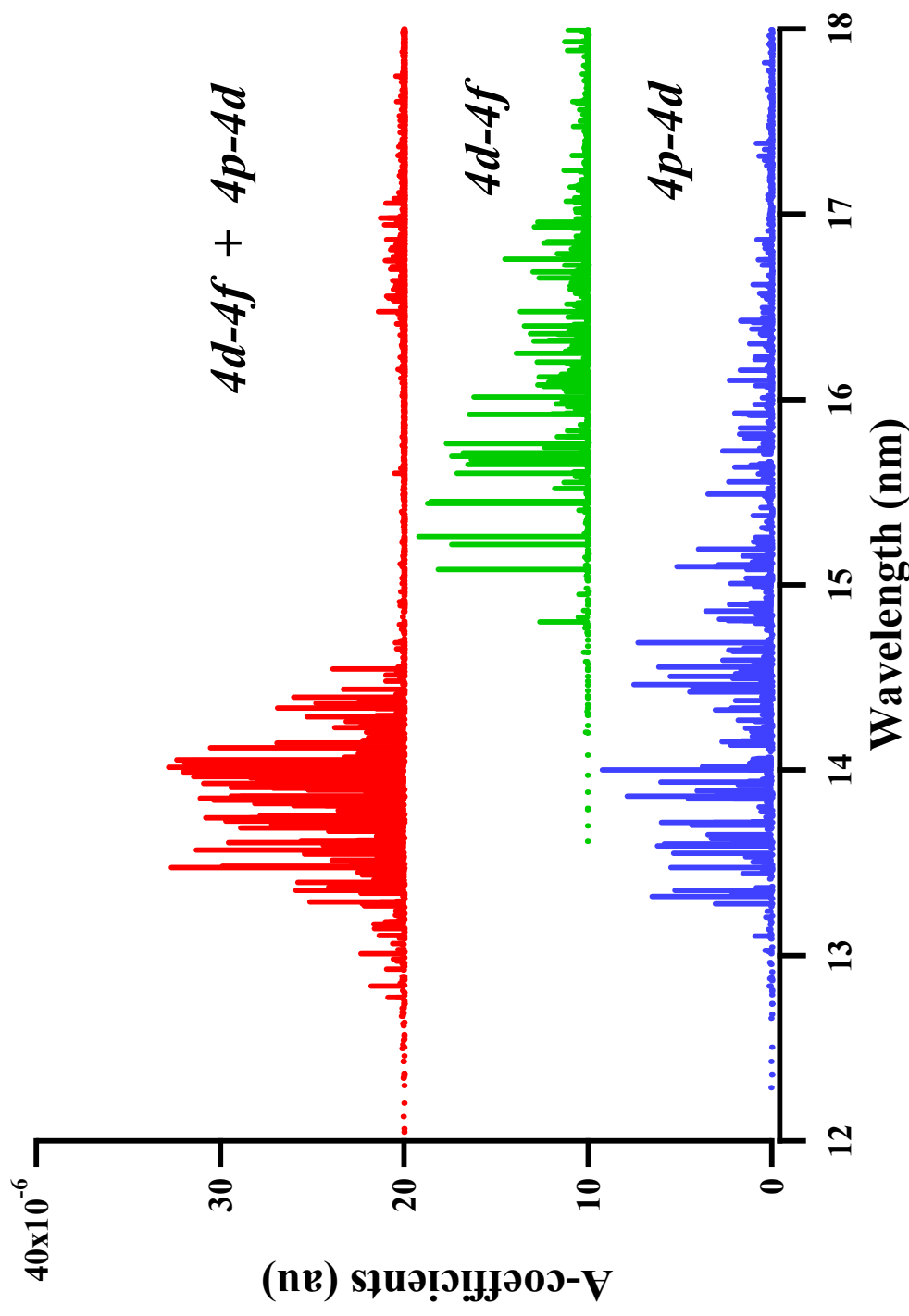
Z-dependence of $4d-4f$ transitions and $4p-4d$ transitions of Y-like Ions



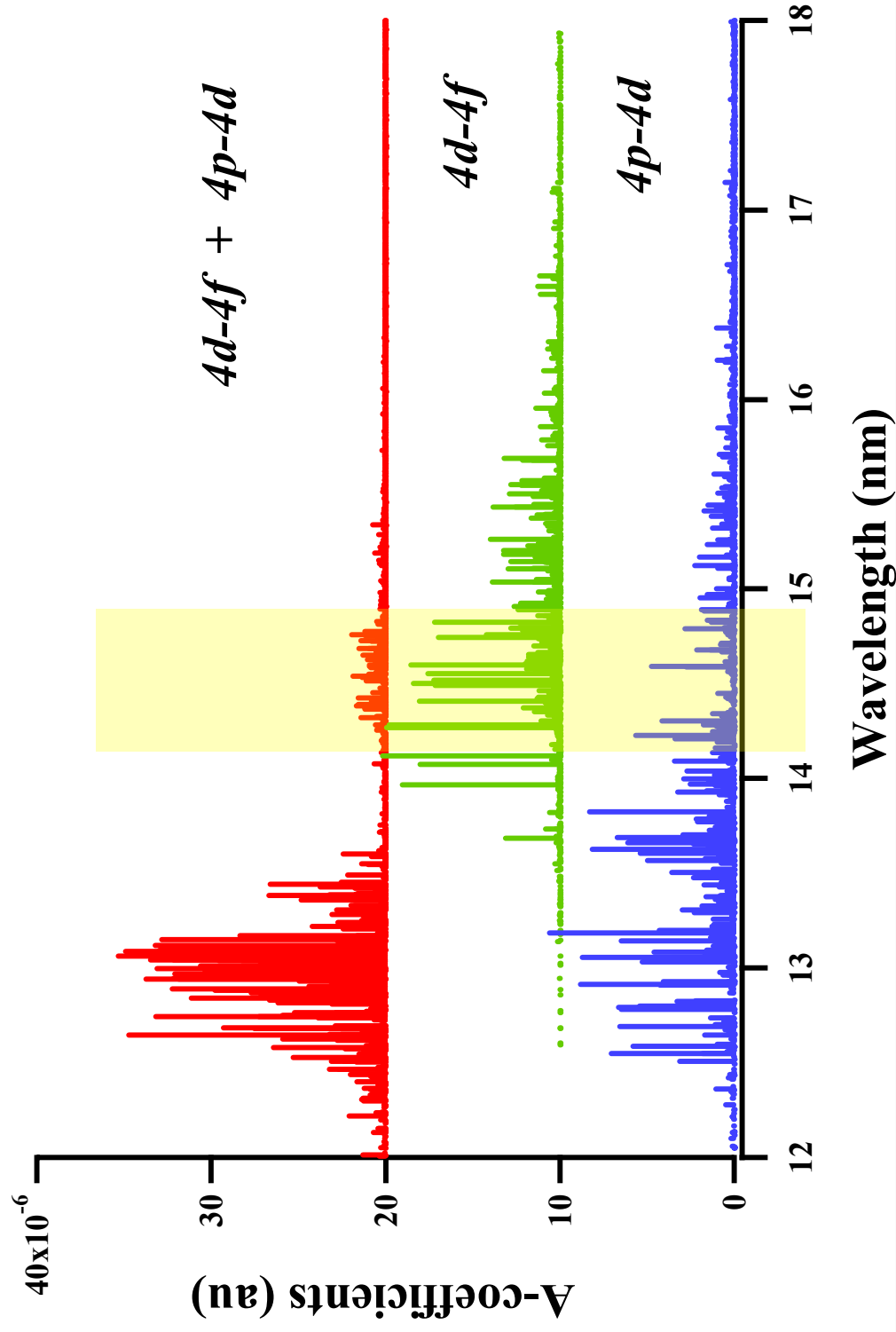
A-coefficients distribution of Y like Z=48



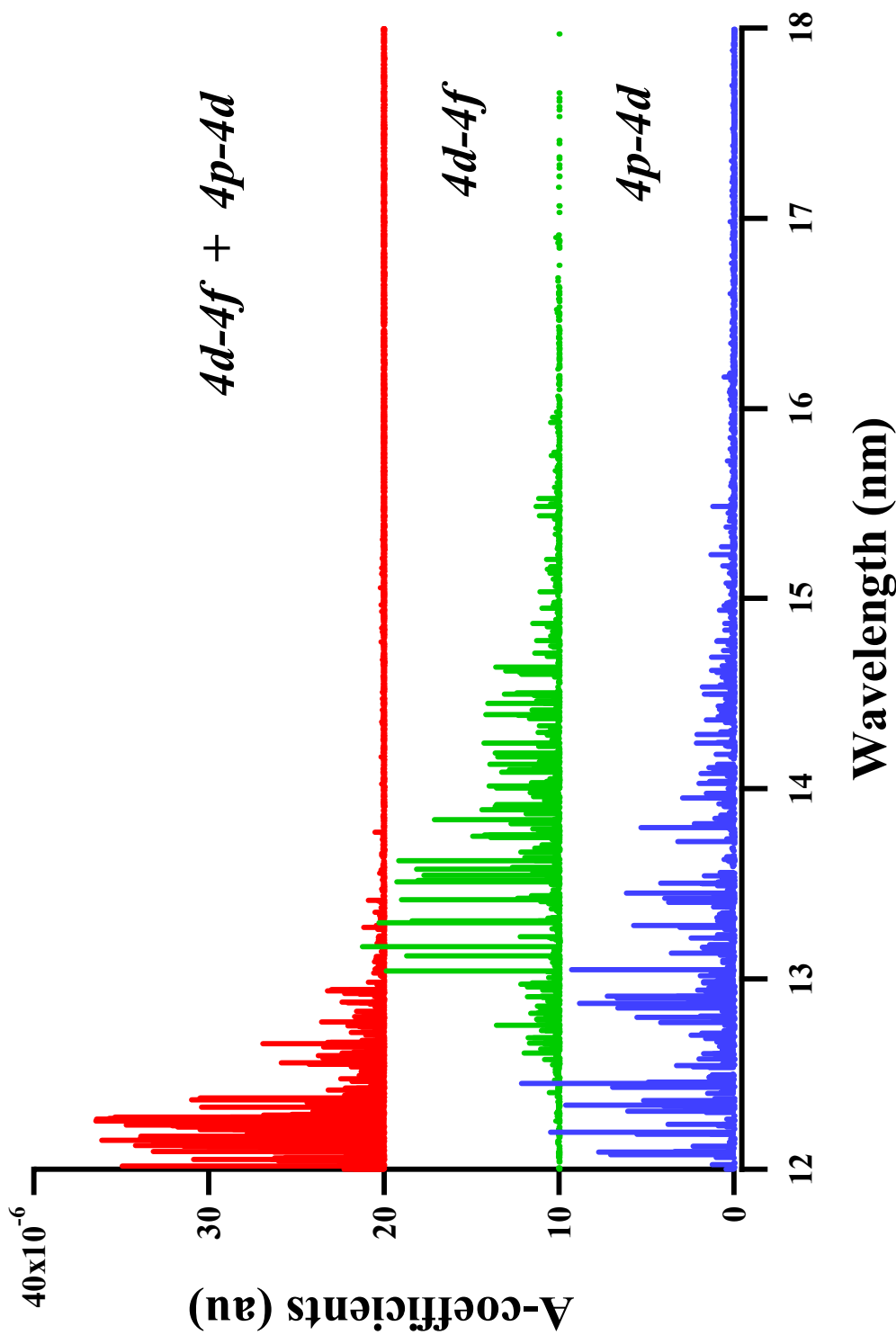
A-coefficients distribution of Y like Z=49



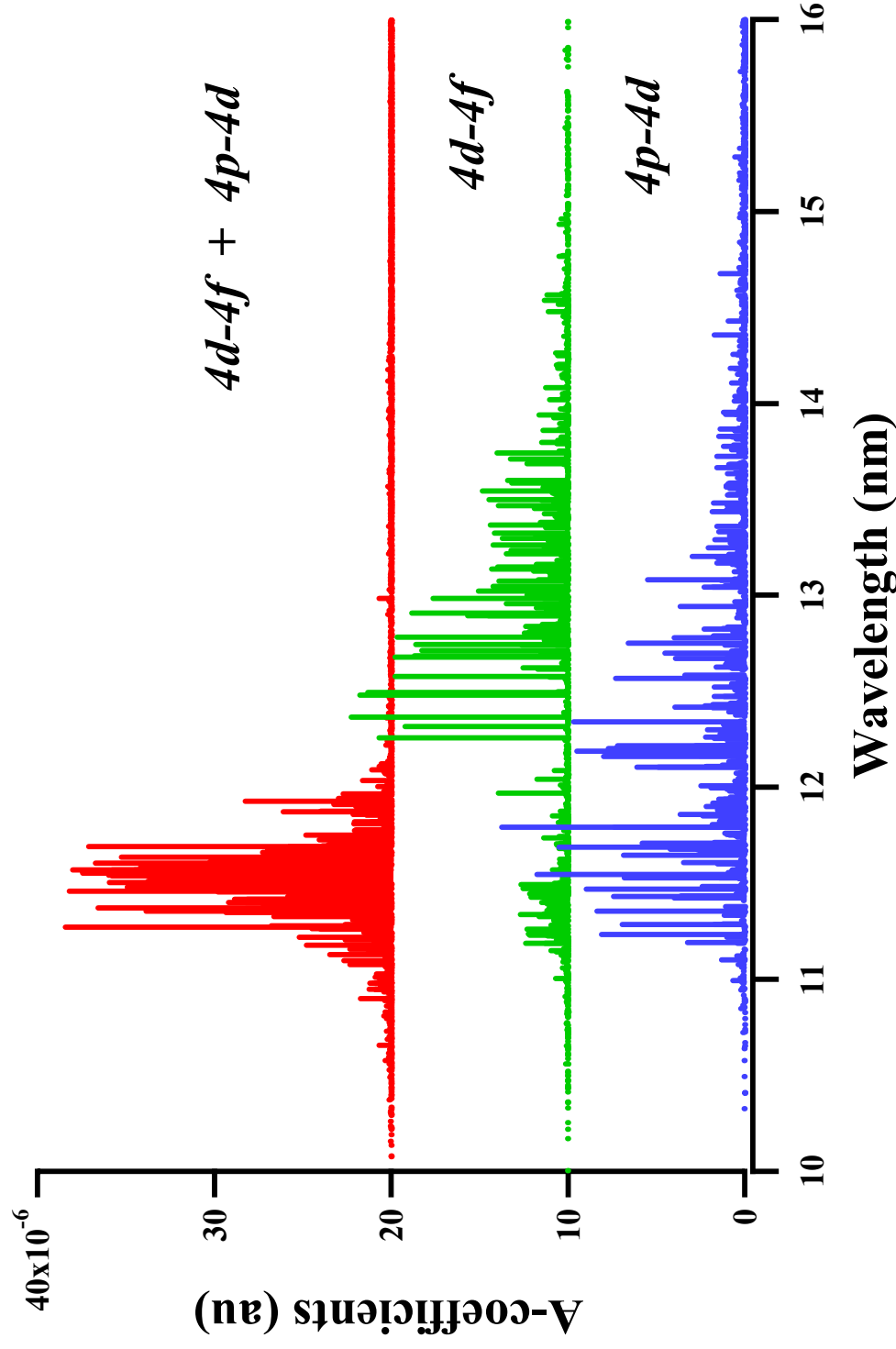
A-coefficients distribution of Y like Z=50



A-coefficients distribution of Y like Z=51



A-coefficients distribution of Y like Z=52



Summary:

- 1. The Structure of Excited States in 4d Open Sub-Shell Atomic Ions are discussed.**
- 2. The Mechanism of Inter Sub-Shell Electron Correlations and The Coherence in 4d-4f and 4p-4d Simultaneous Transitions are discussed.**
- 3. The EUV Spectra of Sn¹²⁺ ions are compared with charge transfer experiments by TMU group.**
- 4. Atomic Number Dependence of Sr-Like Ions are discussed.**
- 5. The EUV Spectra of Y-like In, Sn, and Sb ions are compared. The peculiar structures of Sn¹¹⁺ spectra are discussed.**

