RIS in dysprosium and erbium for scheme development and determination of the first ionization potential

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Overview

1. Motivation
2. Experimental Setup
3. Methodic background & application on spectroscopic data in erbium
4. Spectroscopic results in dysprosium
5. New ionization schemes for Dy and Er
6. Conclusion & Outlook

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Motivation

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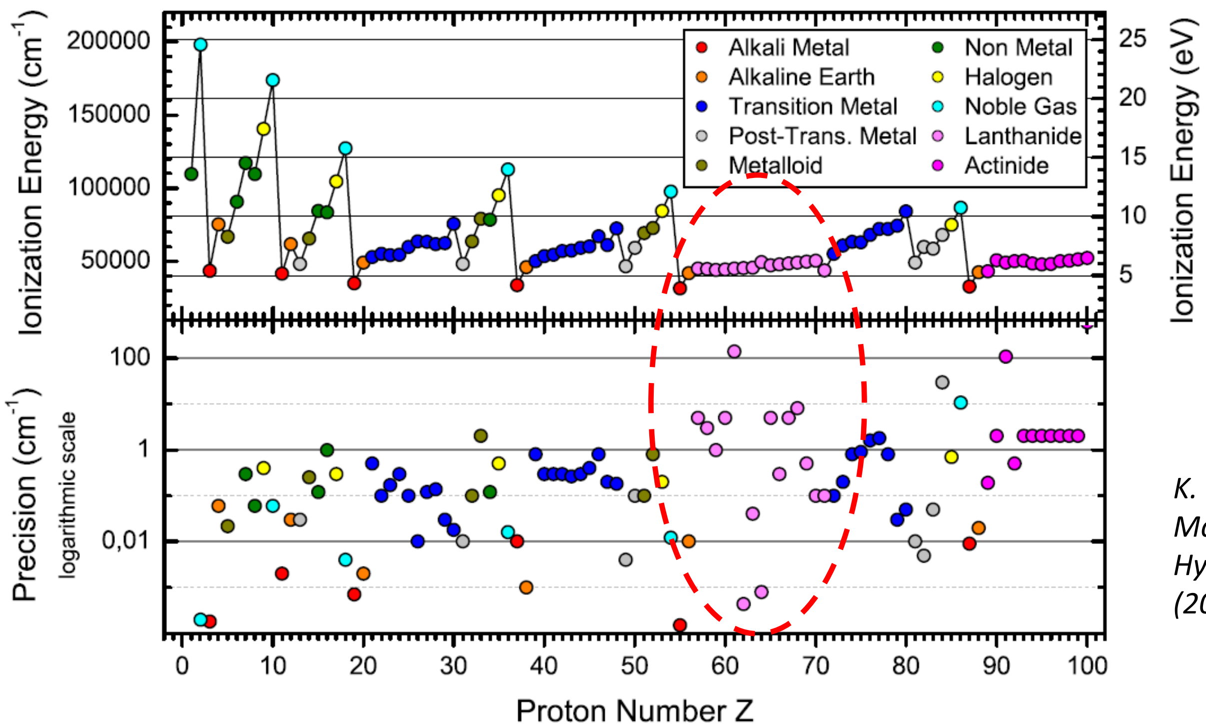
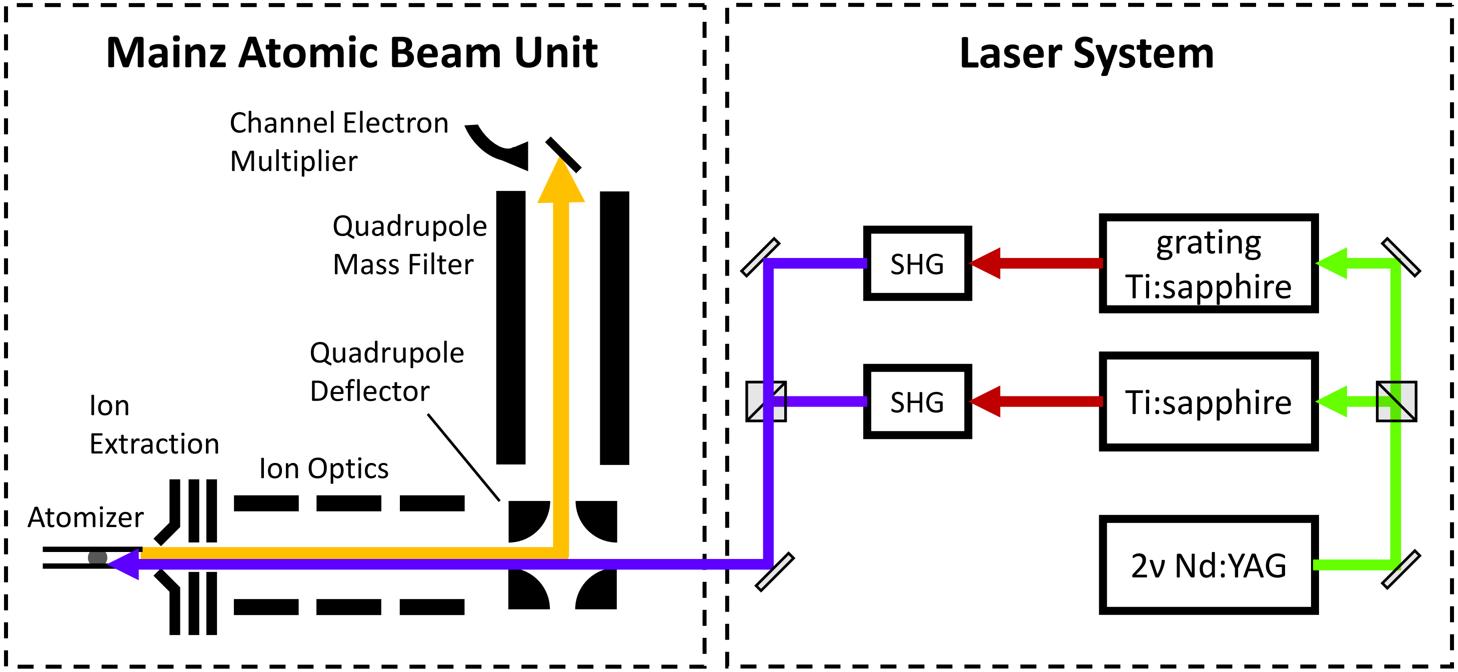
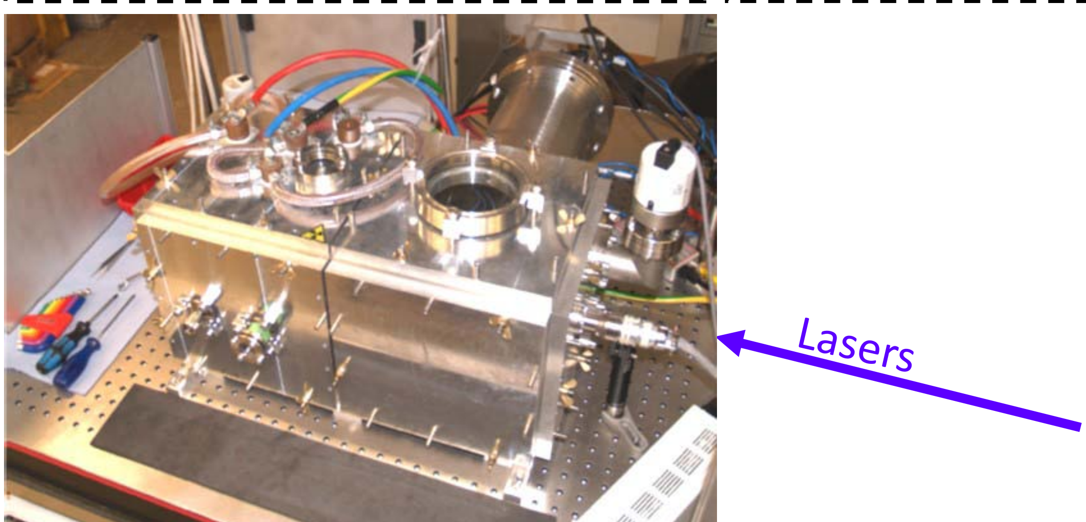
- Limited knowledge of high-lying energy levels for most lanthanide elements
- Laser excitation scheme development for efficient ionization
  - → radioisotope production for medical applications (see talk of V. Gadelshin)
  - → studies of nuclear structure via high-resolution spectroscopy in rare isotopes
- Re-determination of the first ionization potential with high precision



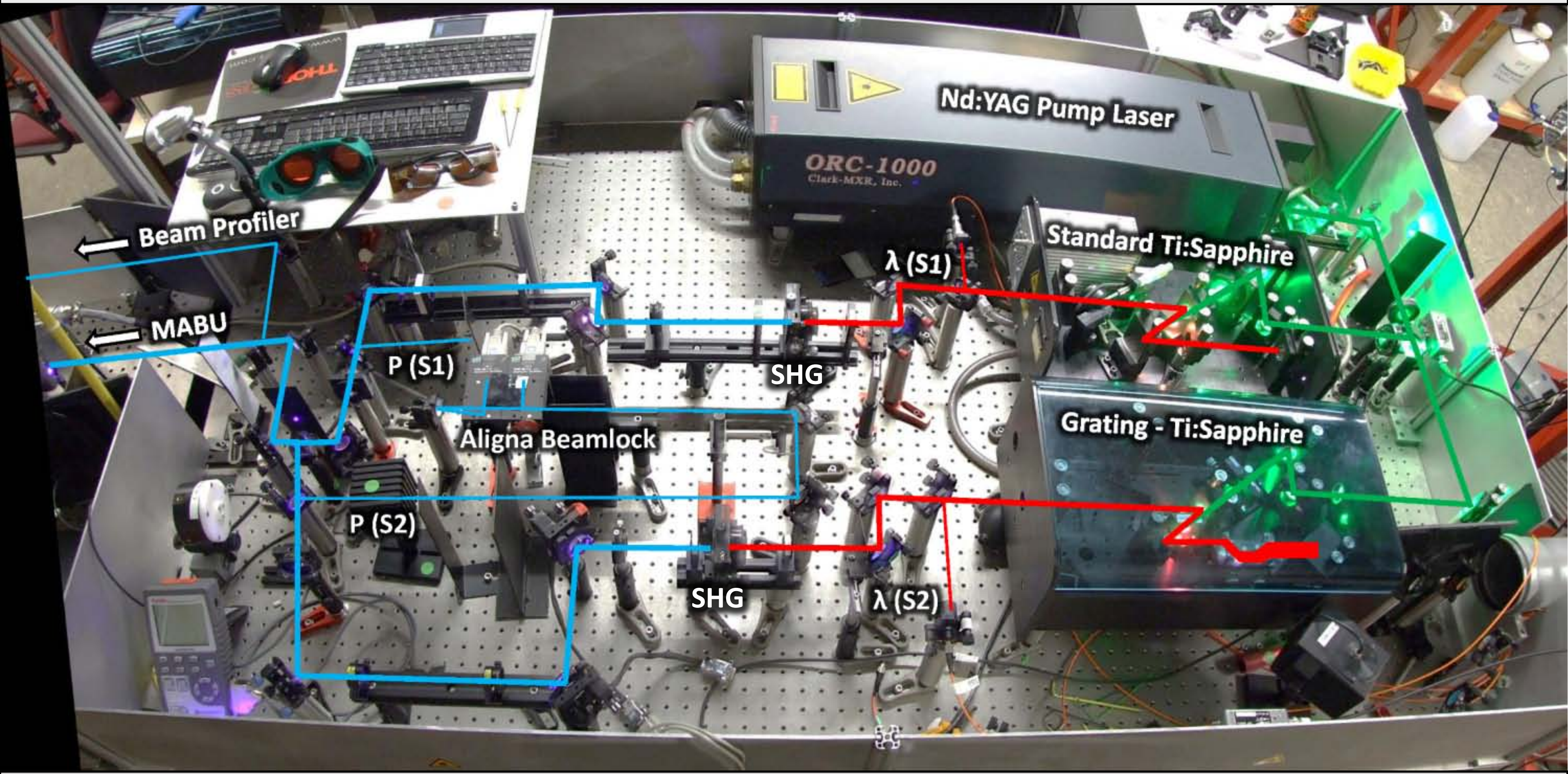
K. Wendt, T. Gottwald, C. Mattolat and S. Raeder, Hyperfine Interactions 227, 55 (2014)

Experimental Setup





Laser System

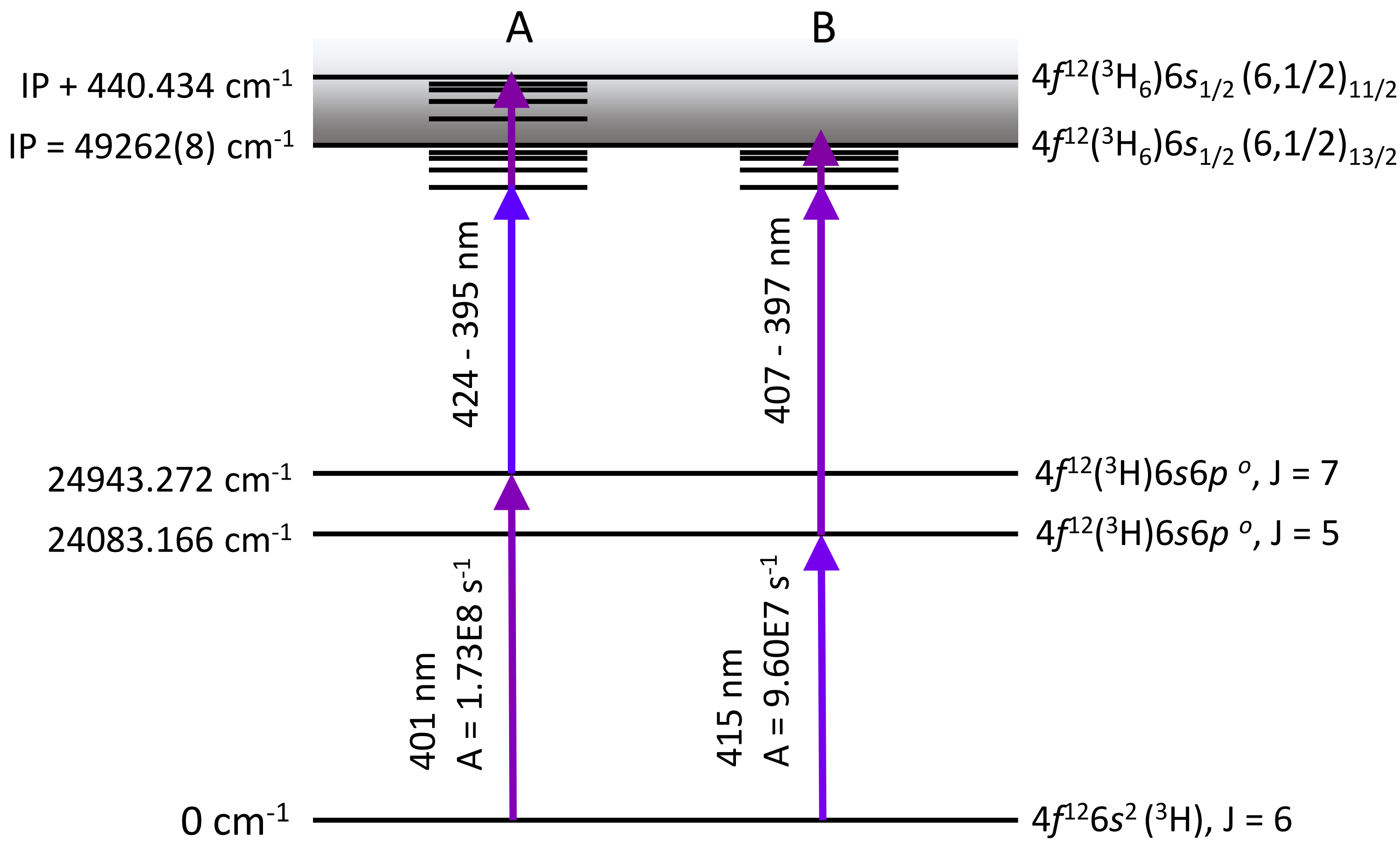


Titanium:sapphire laser specifications:

- Spectral range of 690 to 960 nm
- SHG: 345 to 480 nm
- Mode-hop-free tuning with grating Ti:Sa
- Linewidth of 3 – 8 GHz
- Output power of up to 4 W
- Repetition rate 3 – 10 kHz
- 50 ns pulse length

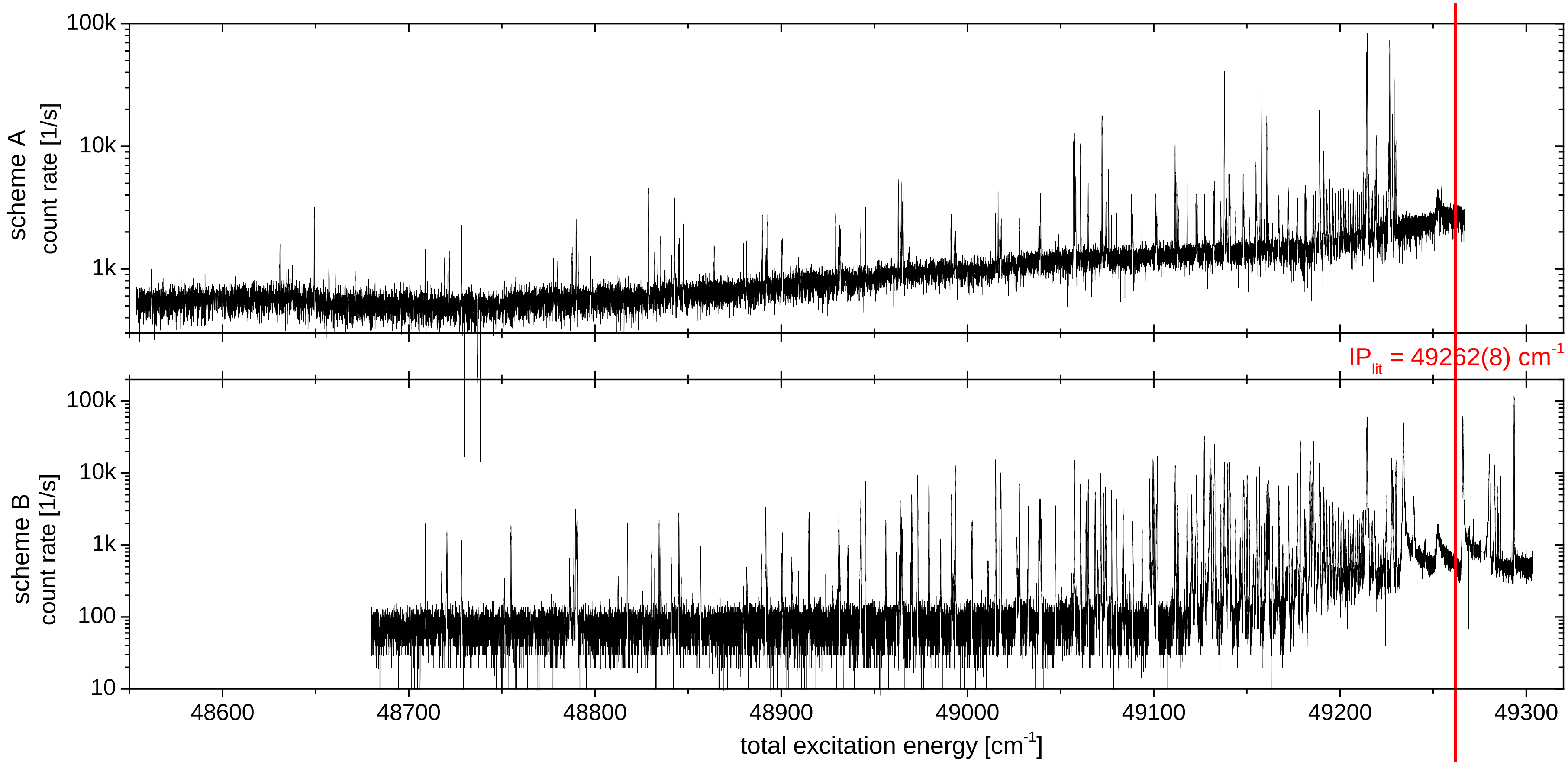
Erbium Excitation Schemes

Erbium (Z = 68) two-step schemes



E. F. Worden, R. W. Solarz, J. A. Paisner, and J. G. Conway, Journal of the Optical Society of America 68, 52 (1978)
W. C. Martin, R. Zalubas, and L. Hagan, NSRDS-NBS, Washington: National Bureau of Standards, US Department of Commerce (1978)

Spectroscopic Data in Er



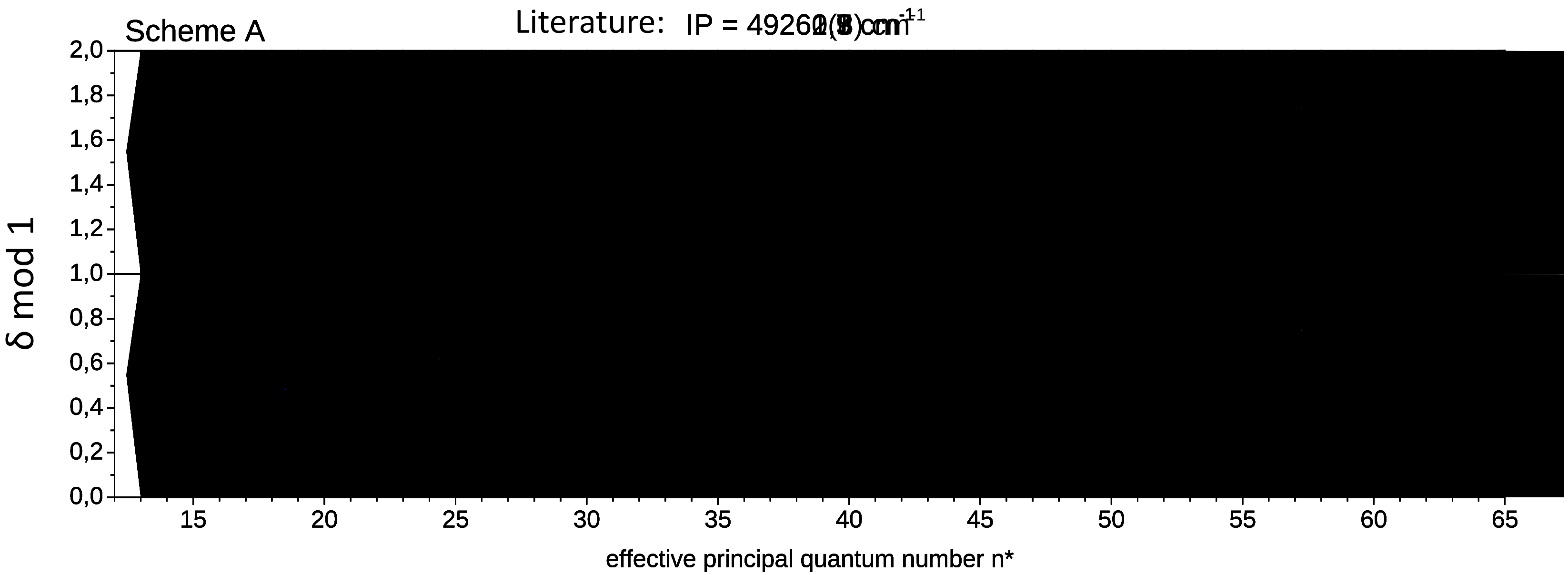
- Total number of 335 peaks (including AI spectrum of scheme A) observed
- Resonances partly appear as fine-structure multiplets
- Interloper states shift energy positions of Rydberg-states and influence their intensity

Graphic Analysis of Rydberg Series

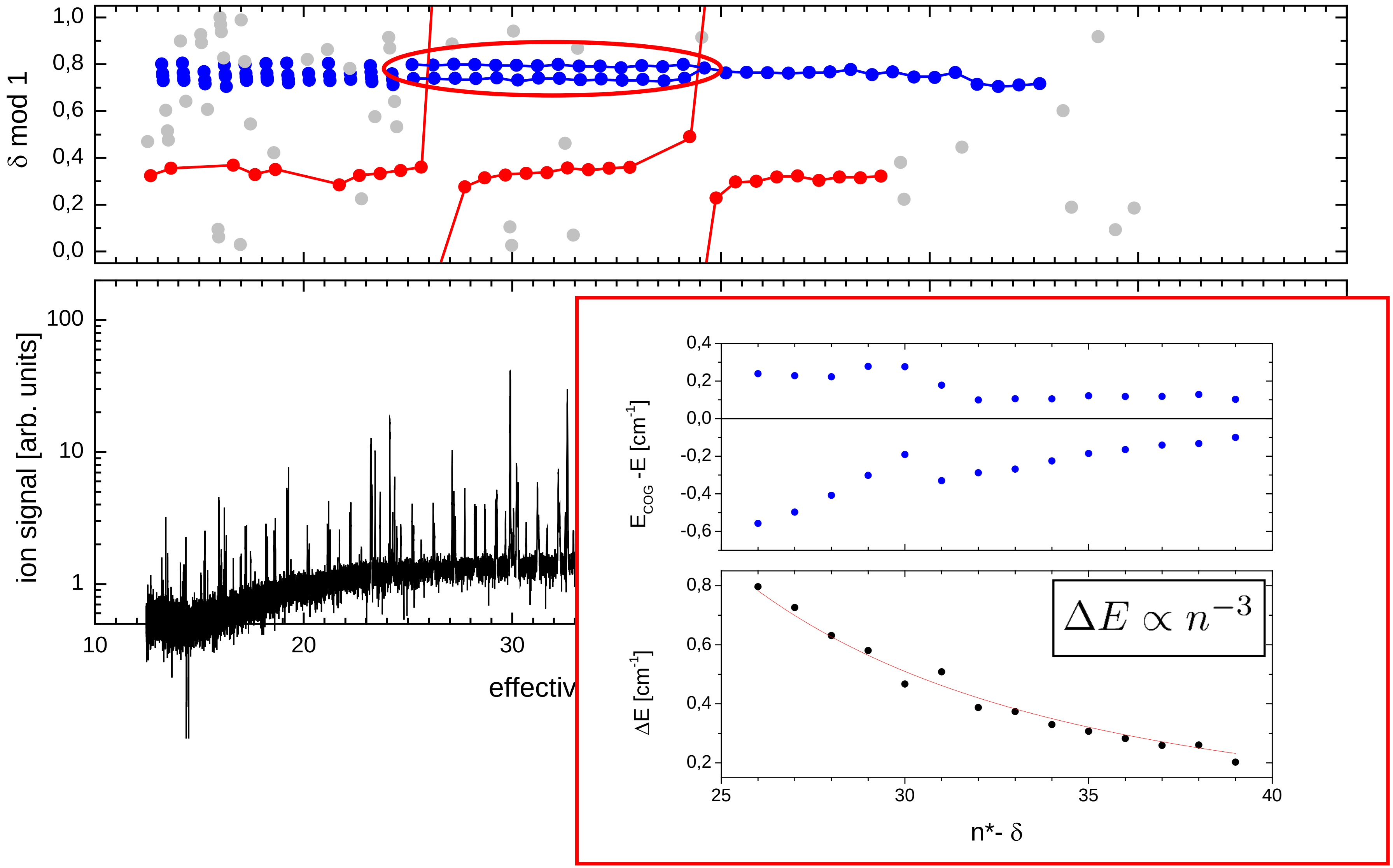
- Assignment of n^* and δ to each energy channel
- Visualization of intensity by color code
- Minimization of slope of δ for Rydberg-series

$$E_n = E_\infty - \frac{R_\mu}{(n-\delta(n))^2}$$
$$= E_\infty - \frac{R_\mu}{(n^*)^2}$$

$$\delta(n) = \delta_0 + \frac{\delta_1}{(n-\delta_0)^2} + \frac{\delta_2}{(n-\delta_0)^4} + \ldots$$



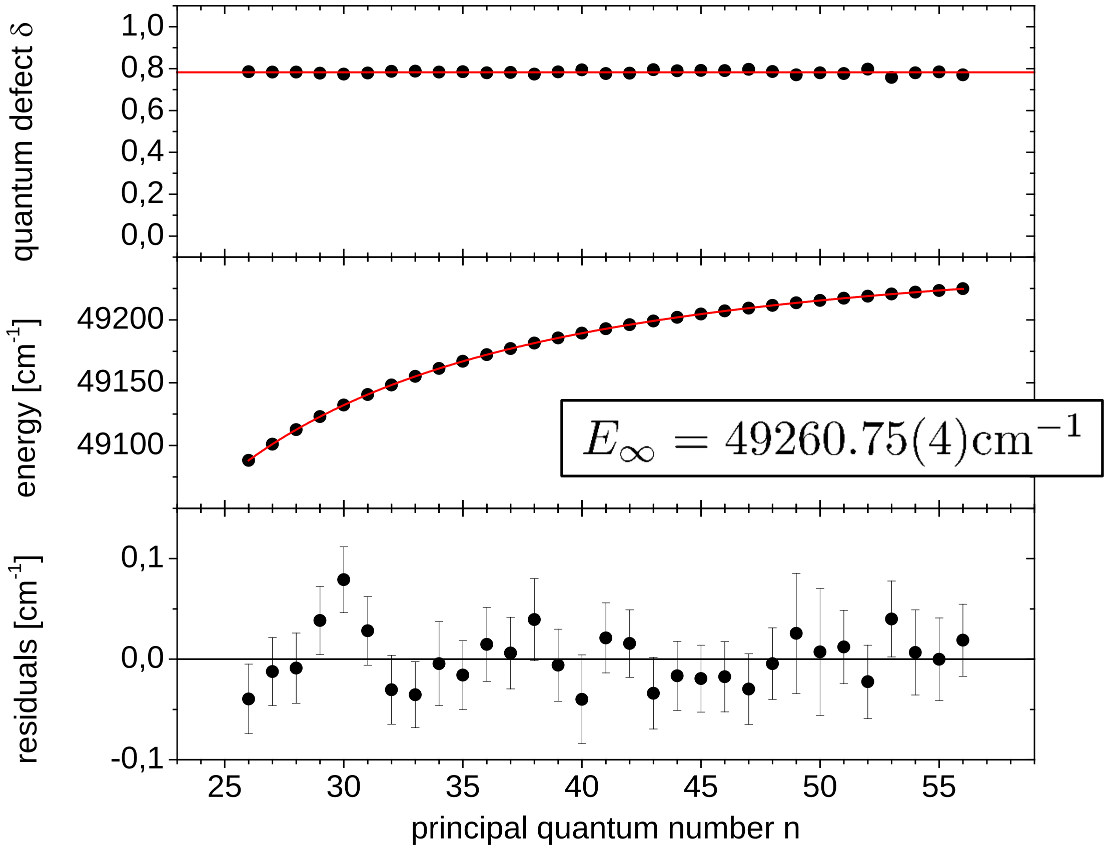
Identification of Rydberg series in Er



Analysis of the 6*snd*-series

$$E_n = E_\infty - \frac{R_\mu}{(n-\delta(n))^2}$$

$$\delta(n) = \delta_0 + \frac{\delta_1}{(n-\delta_0)^2}$$

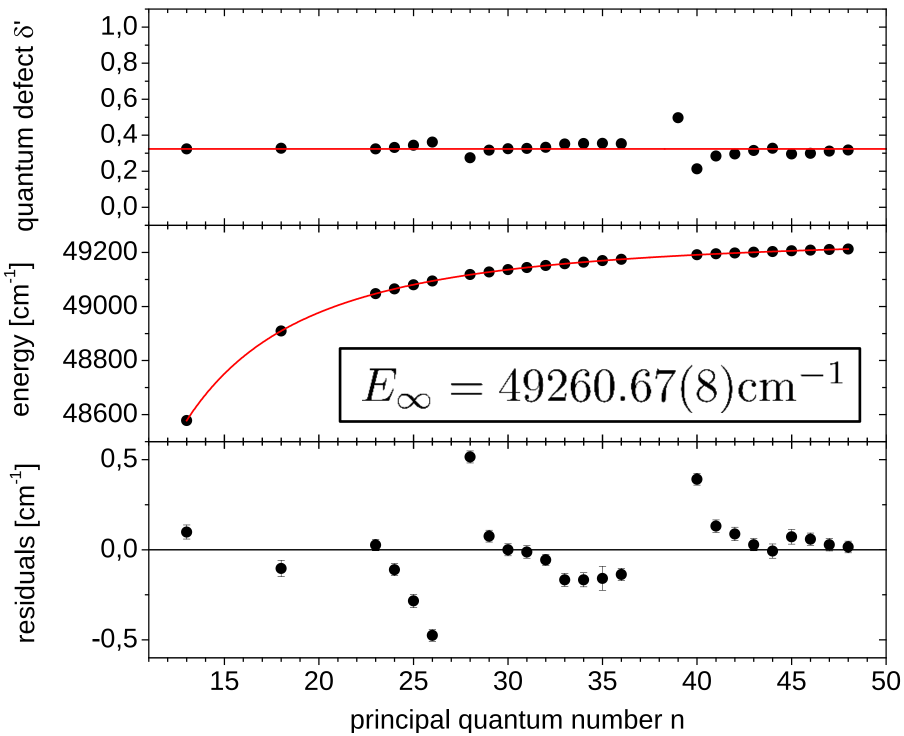


low energy FS component: $E_\infty = 49260.71(7)\ \text{cm}^{-1}$

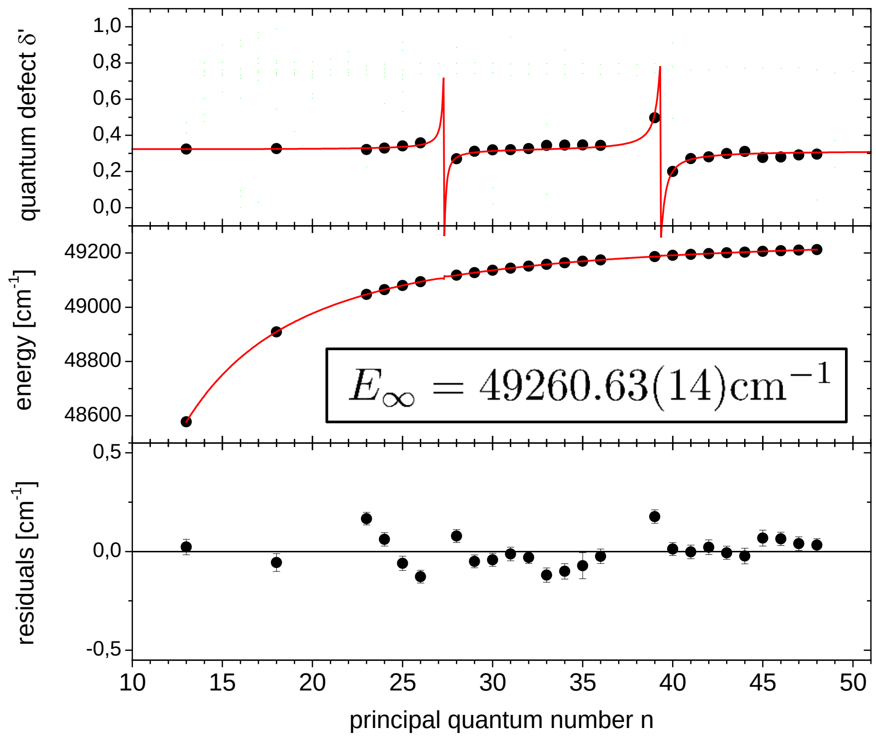
high-energy FS component: $E_\infty = 49260.73(7)\ \text{cm}^{-1}$

Analysis of the 6*sns*-series

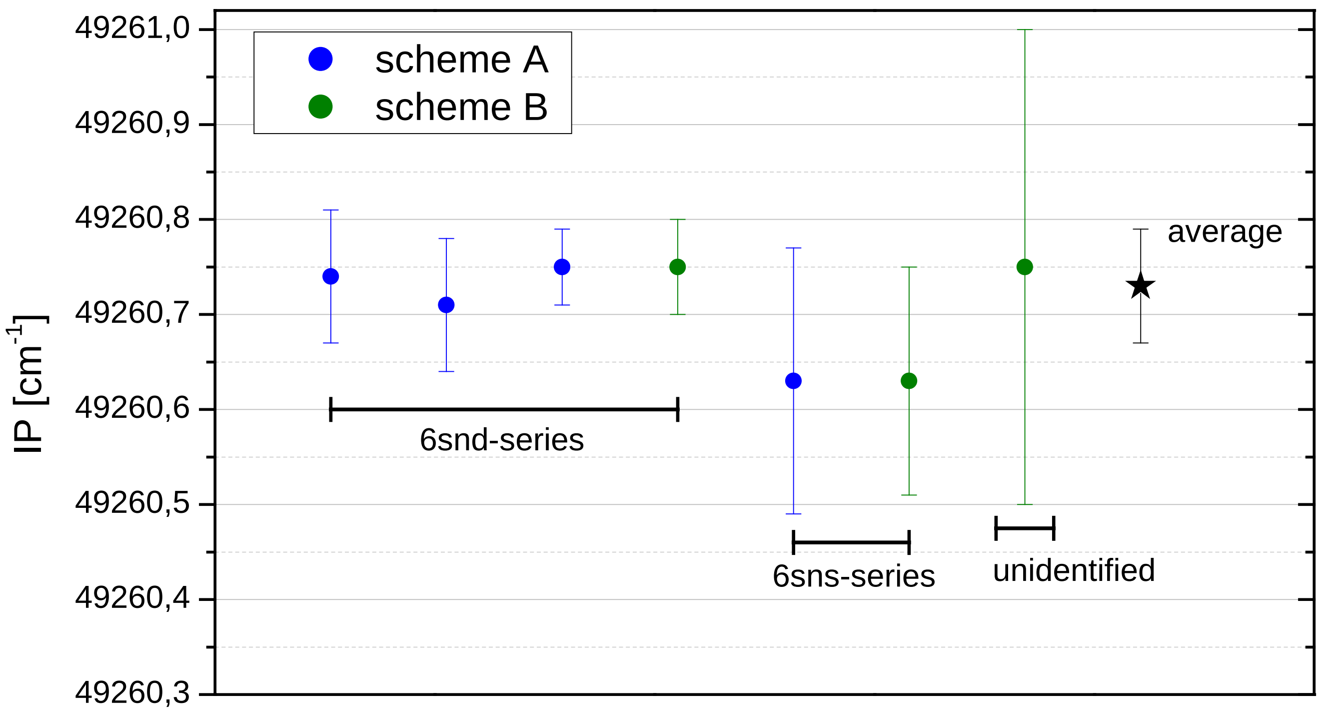
No perturbation corrections



$$\delta_{\mathrm{shift}}(n) = \delta(n) - \frac{1}{\pi}\arctan\left(\frac{\Gamma_I/2}{E-E_I}\right)$$



Determination of the IP in Er

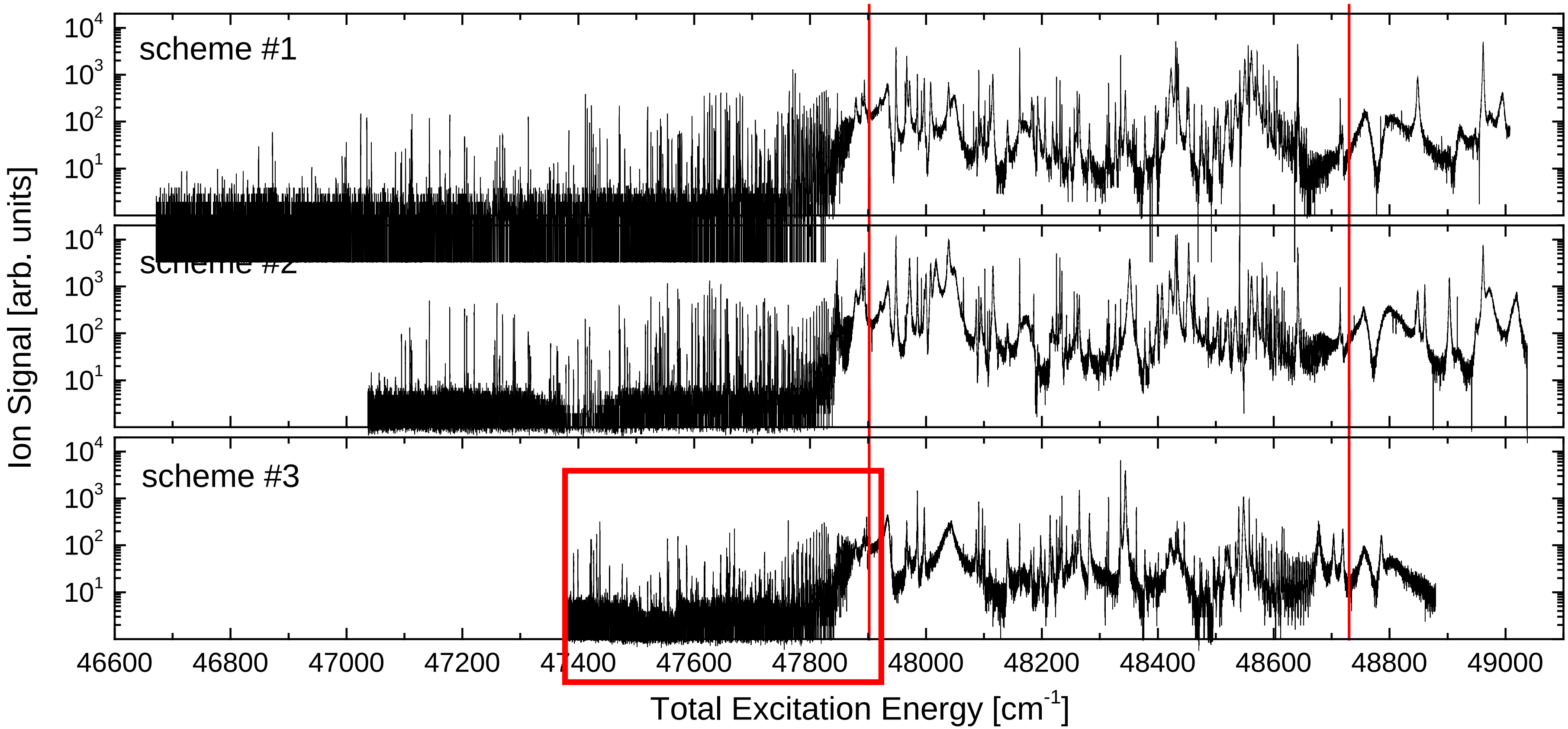


$IP_{Er}^{lit} = 49262(8)\ cm^{-1}$

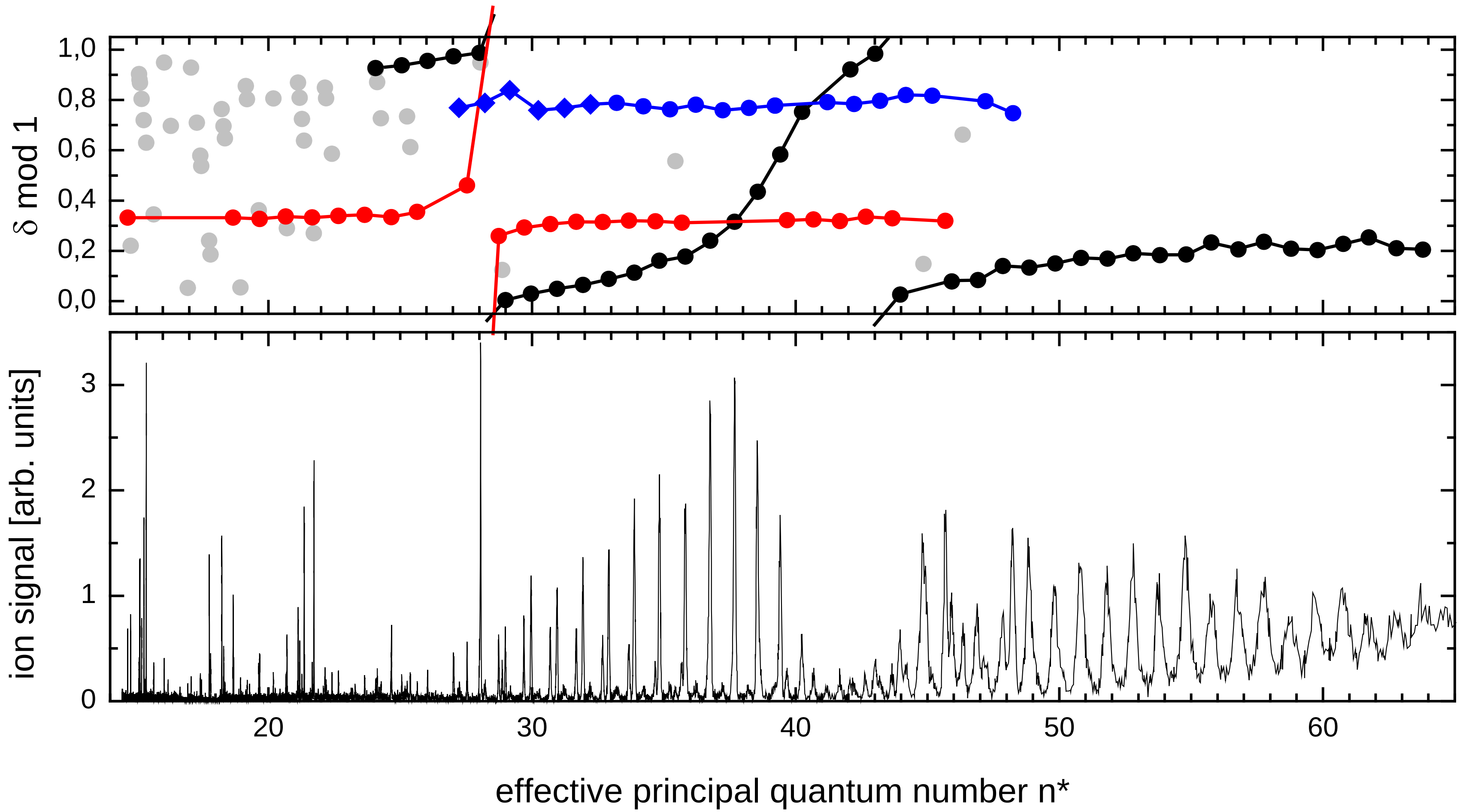
E.F. Worden, R.W. Solarz, J.A. Paisner, J.G. Conway, J. Opt. Soc. Am. 68(1), 52 (1978)

Spectroscopic data in Dy

#	λ_1 [cm^{-1}]	FES	λ_{scan} [cm^{-1}]
1	23877.74	$4f^{10}(^5I_8)6s6p(^1P_1^o)\ (8,1)_8^o$	$22800 \rightarrow 25130$
2	23832.07	$4f^9(^6H^o)5d^2(^3F)6s\ (^8K^o)_8$	$23150 \rightarrow 25200$
3	23736.60	$4f^{10}(^5I_8)6s6p(^1P_1^o)\ (8,1)_9^o$	$23640 \rightarrow 25420$

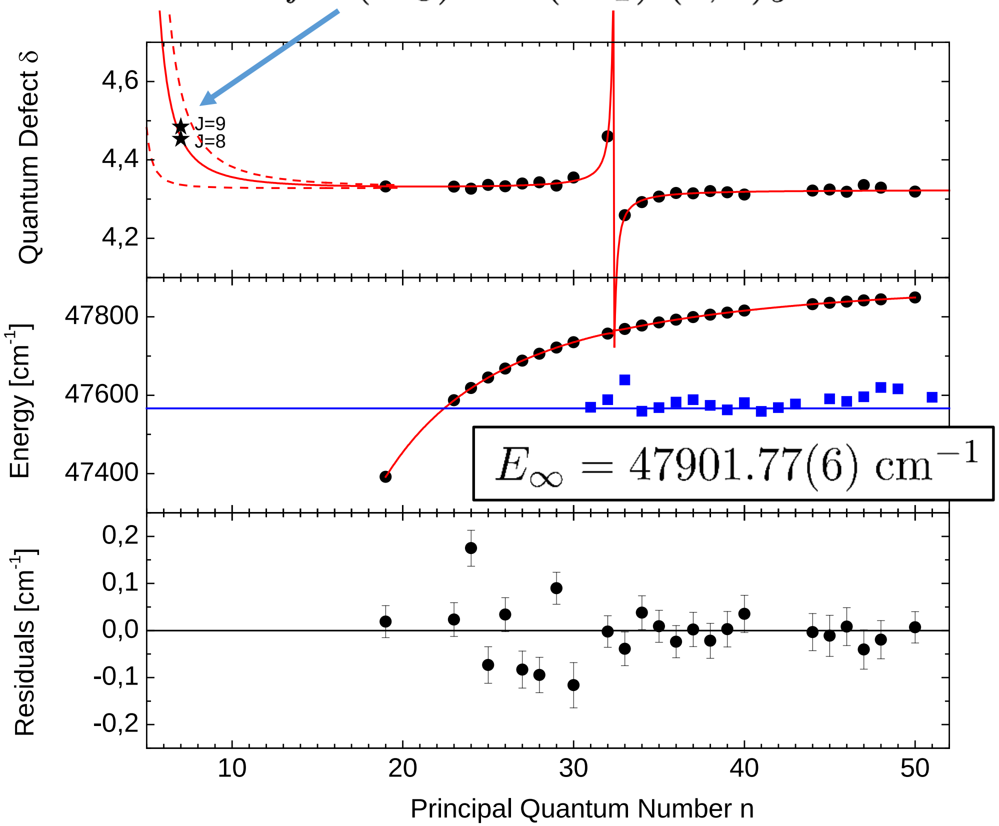


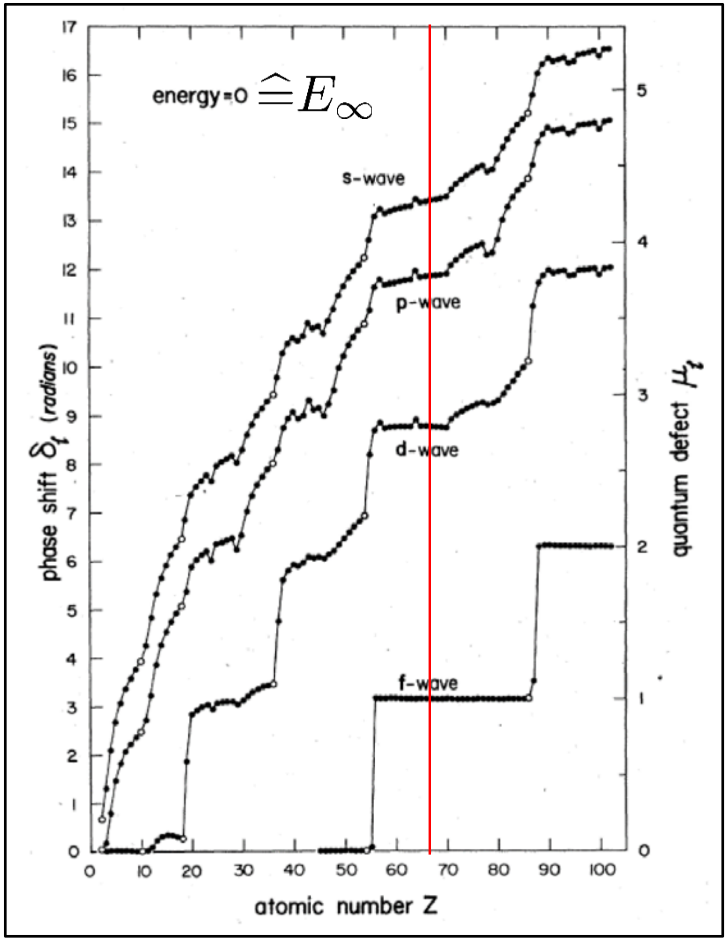
Identification of Rydberg series in Dy



Spectroscopic results in Dy

band heads: $4f^{10}(^5I_8)6s7s(^3S_1)\ (8,1)_J$



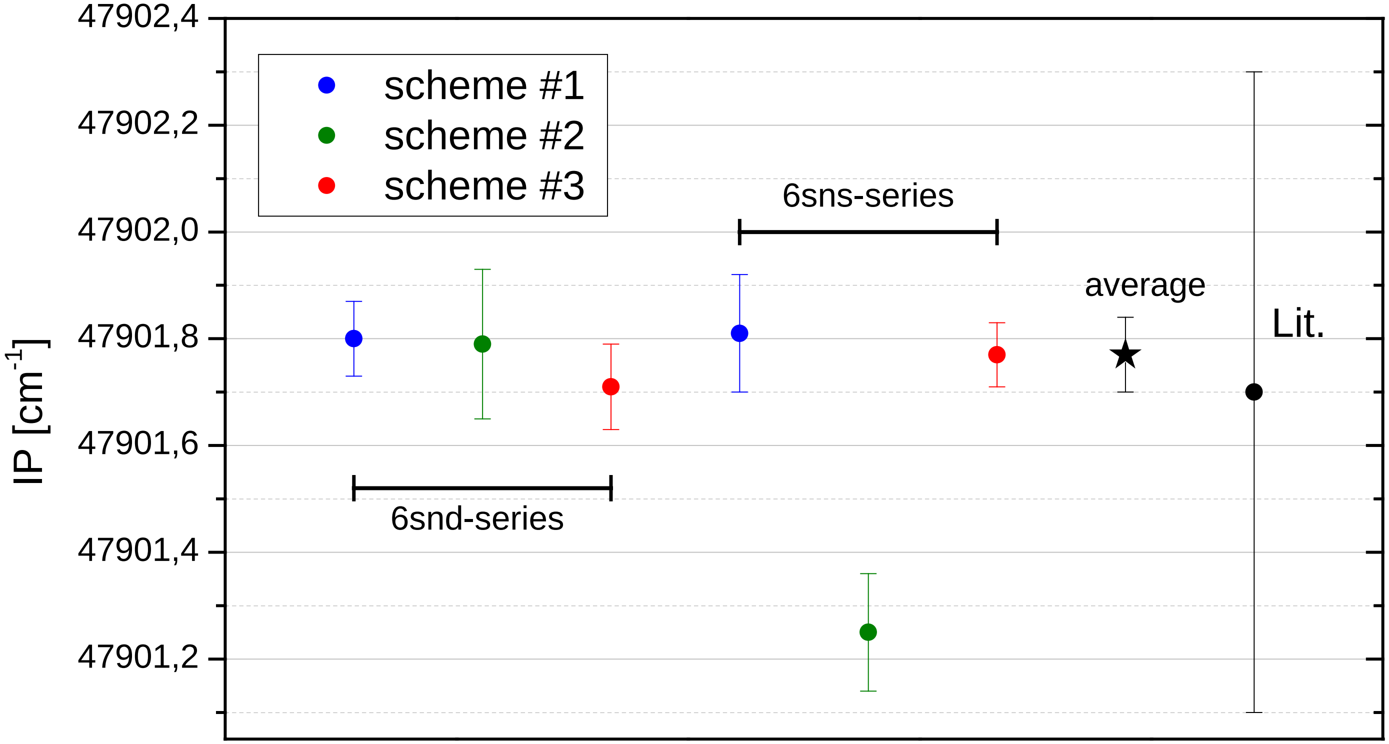


$$\delta_{\text{shift}}(n) = \delta(n) - \frac{1}{\pi}\arctan\left(\frac{\Gamma_I/2}{E-E_I}\right)$$

$$\delta(n) = \delta_0 + \frac{\delta_1}{(n-\delta_0)^2}$$

U. Fano, C. E. Theodosiou, and J. L. Dehmer, Reviews of Modern Physics 48, 49 (1976)

Determination of the IP in Dy

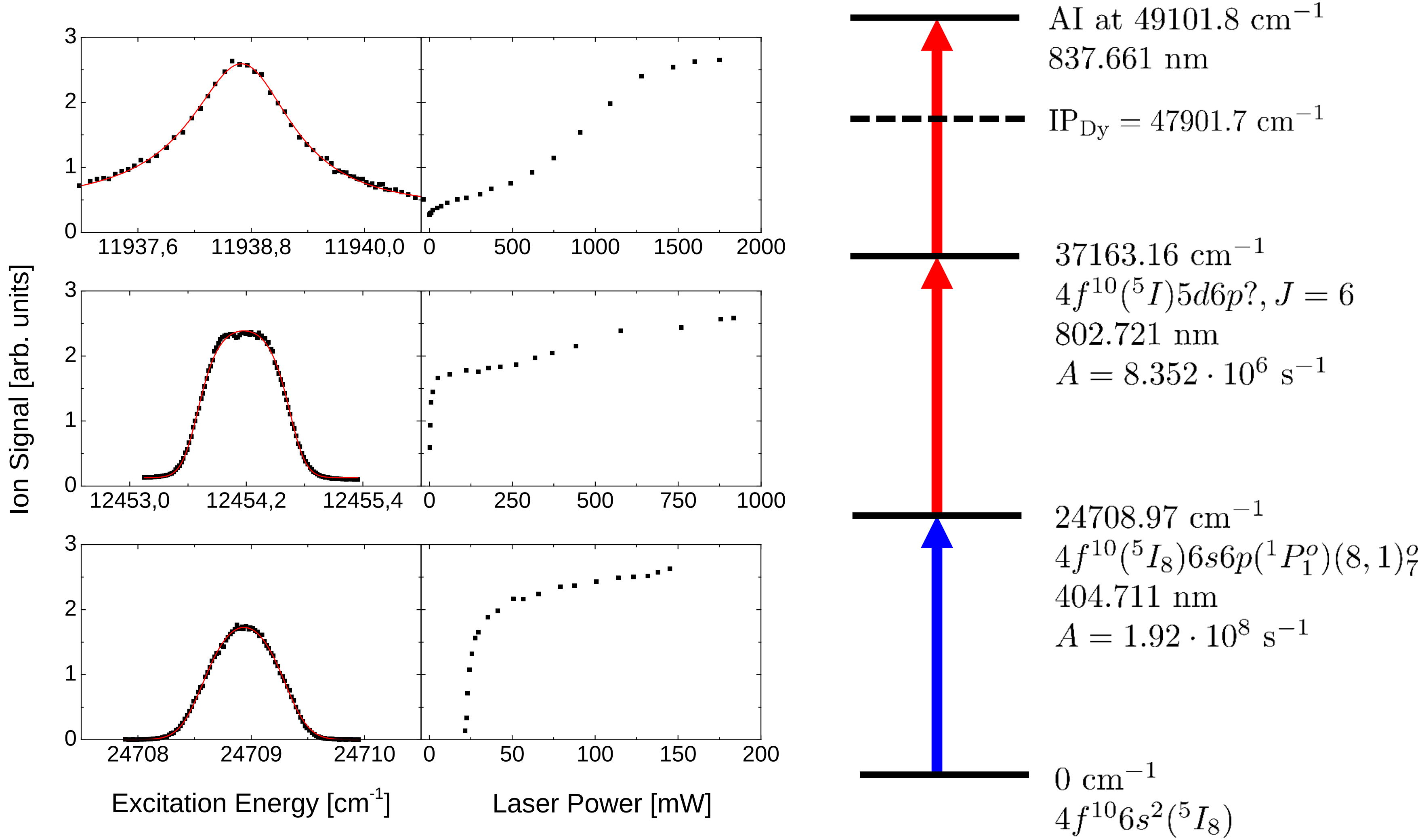


IP_{Dy}^{lit} = 47901.7(6) cm^{-1}

H.J. Zhou, X.Y. Xu, W. Huang, D.Y. Chen, Acta Physica Sinica (Overseas Edn) (1), 19 (1992)

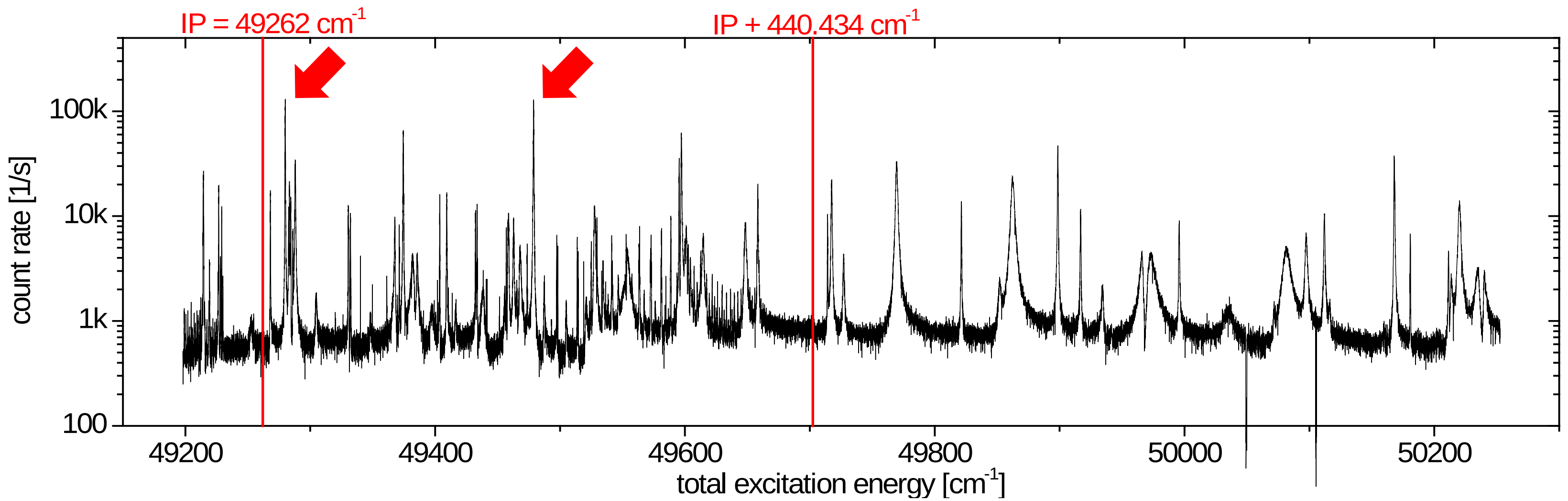
new value: 47901.77(7) cm^{-1}

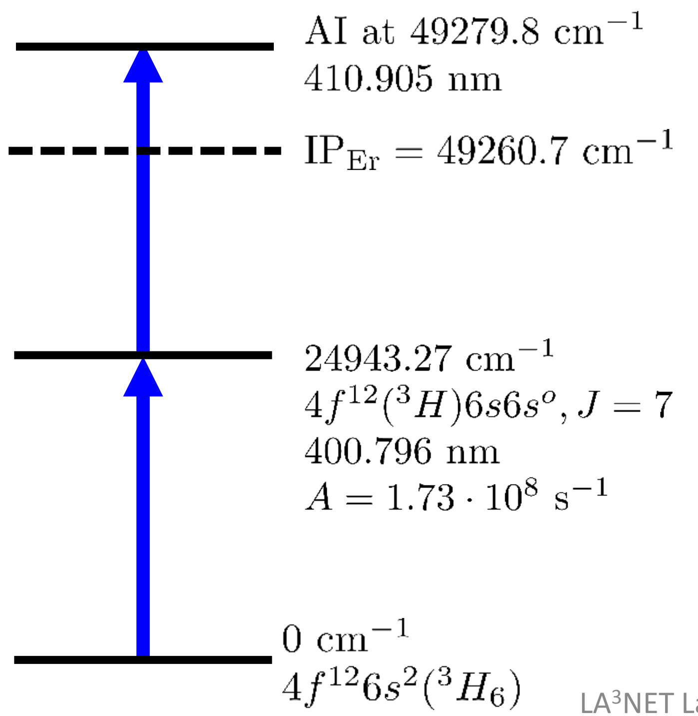
New ionization scheme for Dy



Efficiency measurements at RISIKO: 28%, 26%, 18%, 27%

New ionization scheme for Er





- Two high-intensity resonances identified as auto-ionizing Rydberg states
- Ionization effieciency is to be measured

Conclusion & Outlook

- First ionization potential of Dy and Er re-detemined with high-precision

IP(Dy): 47901.7(6) cm^{-1} → **47901.77(7) cm^{-1}**
IP(Er): 49262(8) cm^{-1} → **49260.73(6) cm^{-1}**

- Ionization efficiency of 24% for Dy demonstrated at RISIKO mass separator with new three-step excitation scheme
- New two-step excitation scheme for Er successfully tested in the ToF reference cell at GANIL

Outlook:

- Test three-step excitation in erbium
- Efficiency measurements for erbium at RISIKO

Thank you for your attention.