JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Laser spectroscopy of Neptunium

- excitation schemes, atomic structure and the ionization potential -

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LISA Academic Day/ *17 June 2022*

LISA
LASER IONISATION AND SPECTROSCOPY OF ACTINIDES

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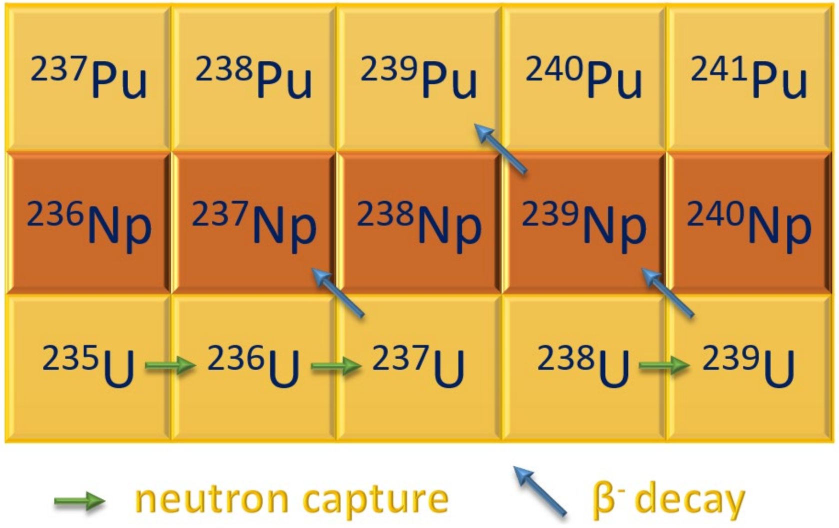
Neptunium production

Np
93

- Radioactive actinide
- Long half-life - *^{237}Np - 2.14 · 10^6 y*
- High radiotoxicity



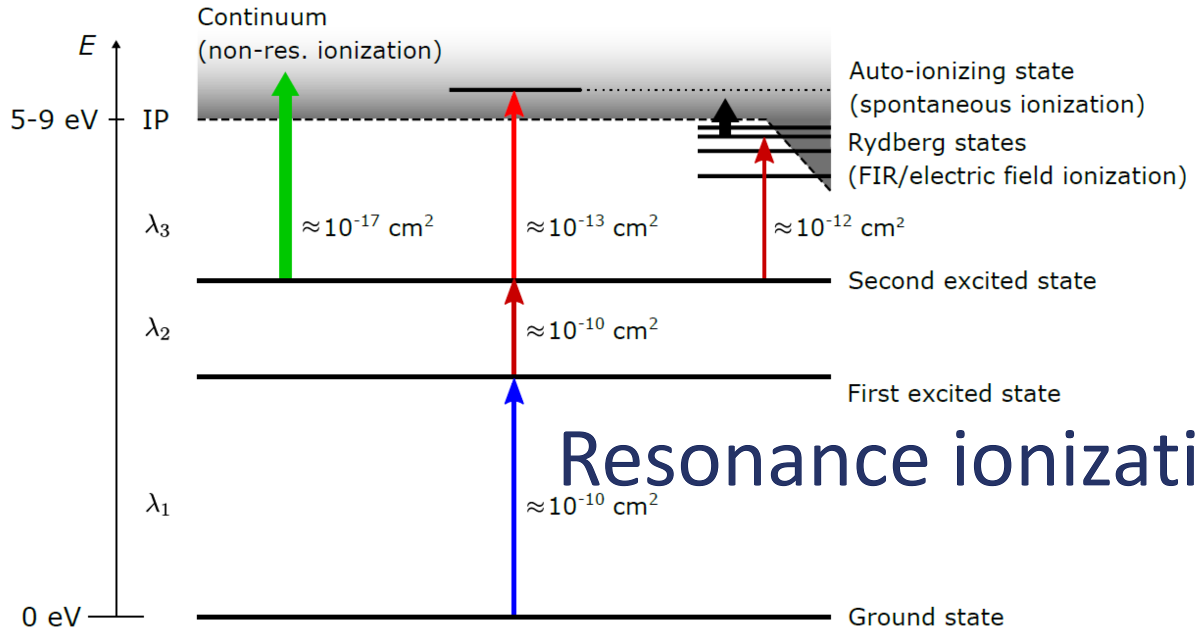
Neptunium

- Ionization potential 50535(2) cm^{-1} [1]
- 462 atomic levels [2]

The development of efficient and selective laser ionization schemes plays an important role for Np spectroscopy and ultratrace analysis.

[1] Kohler, S ; Deissenberger, R ; et al. Spectrochim. Acta B,52, 717 – 726, (1997)
[2] Kazakov, V. V.; Kazakov, V. G.; et al. Phys. Scr., 92, 10, (2017)

Resonance ionization mass spectrometry



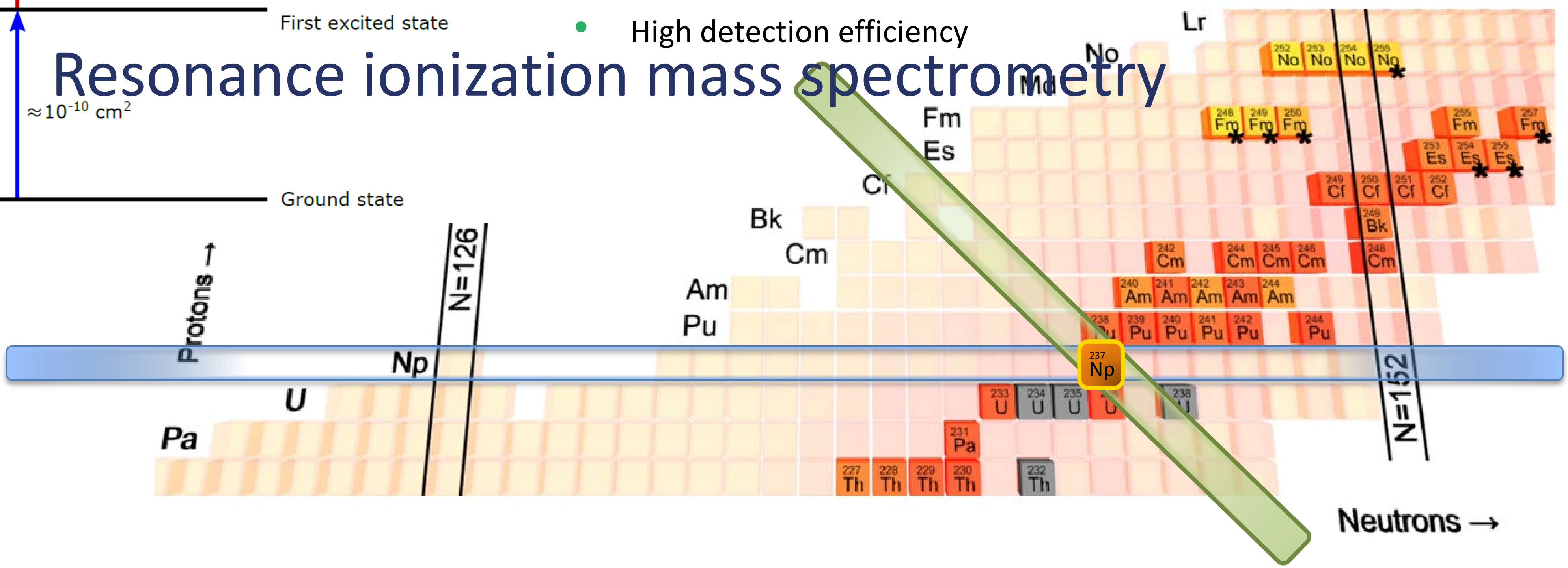
Mass spectrometry

- Separation of m/q
- High detection efficiency

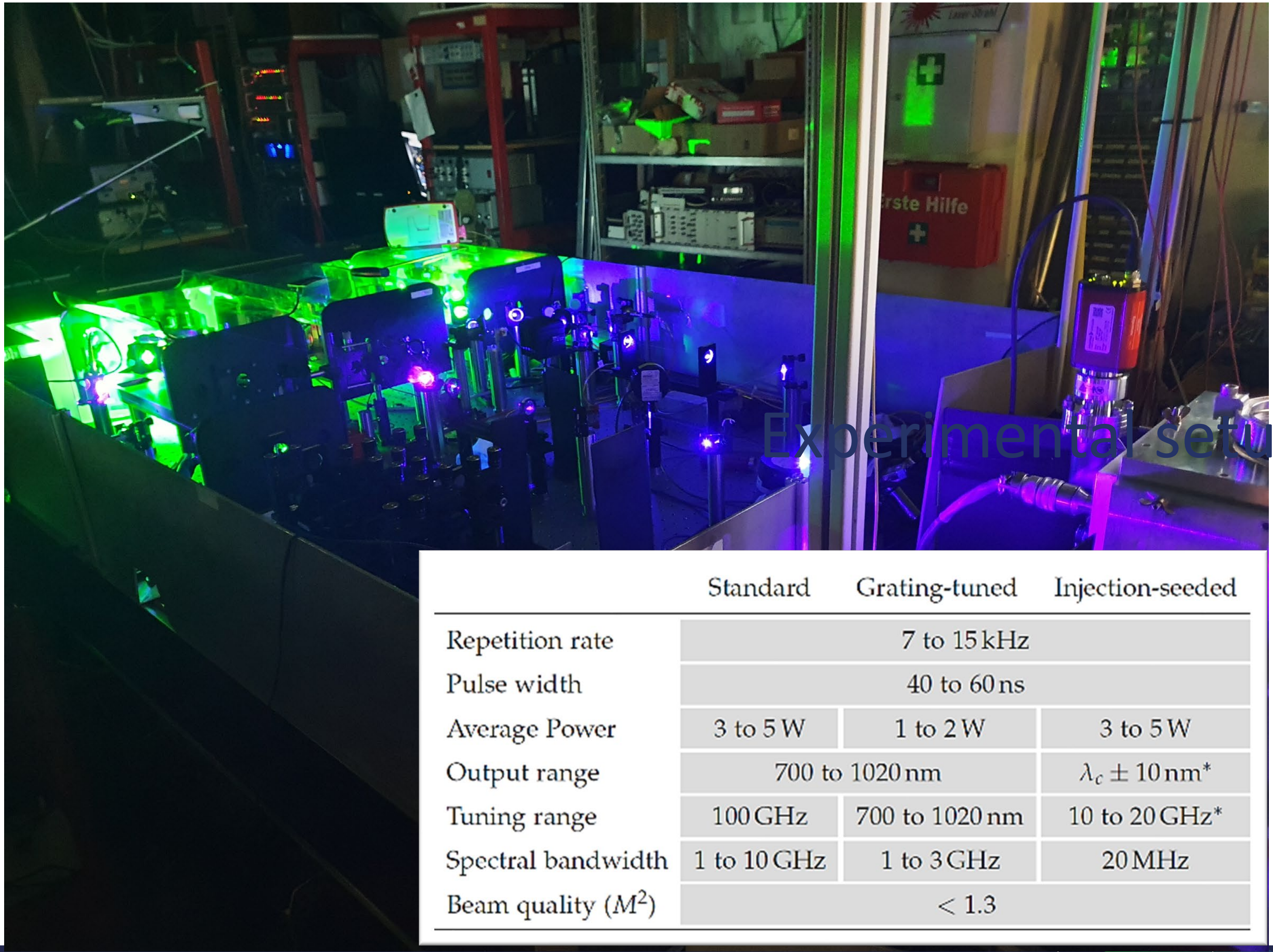
Laser ionzation and spectroscopy

- Highly efficient process
- High isotopic selectivity

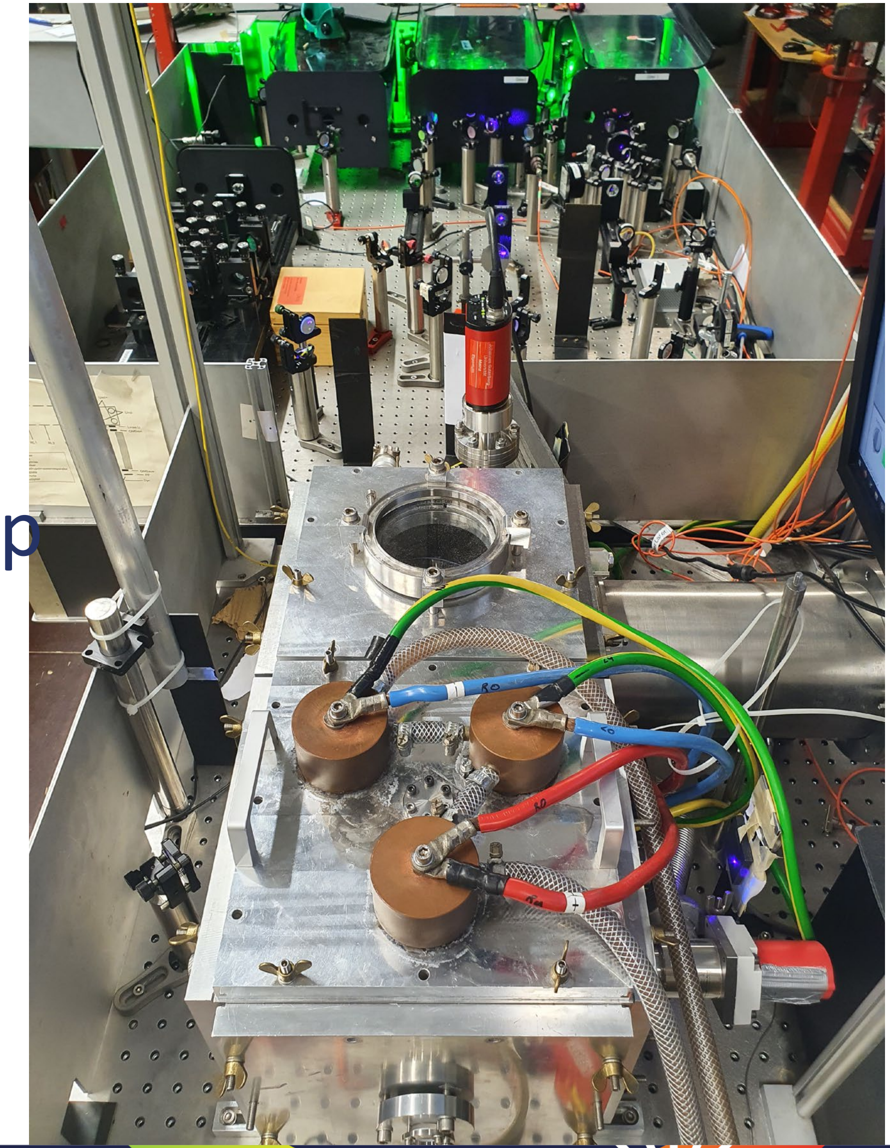
Indicated isotopes:
long lived, studied by laser spectroscopy
Yellow: online at GSI
Orange: offline at RISIKO/MABU



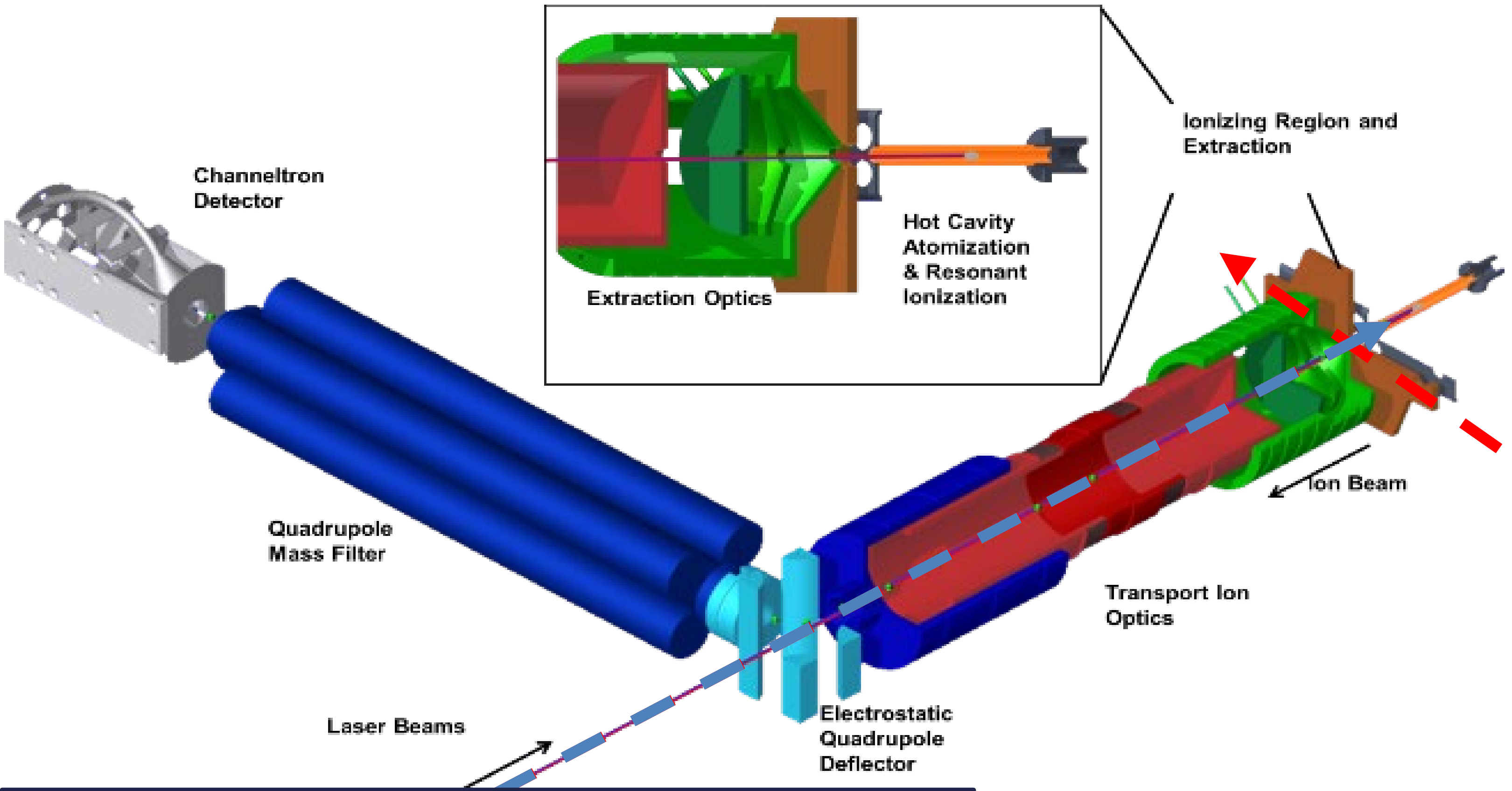
Experimental setup

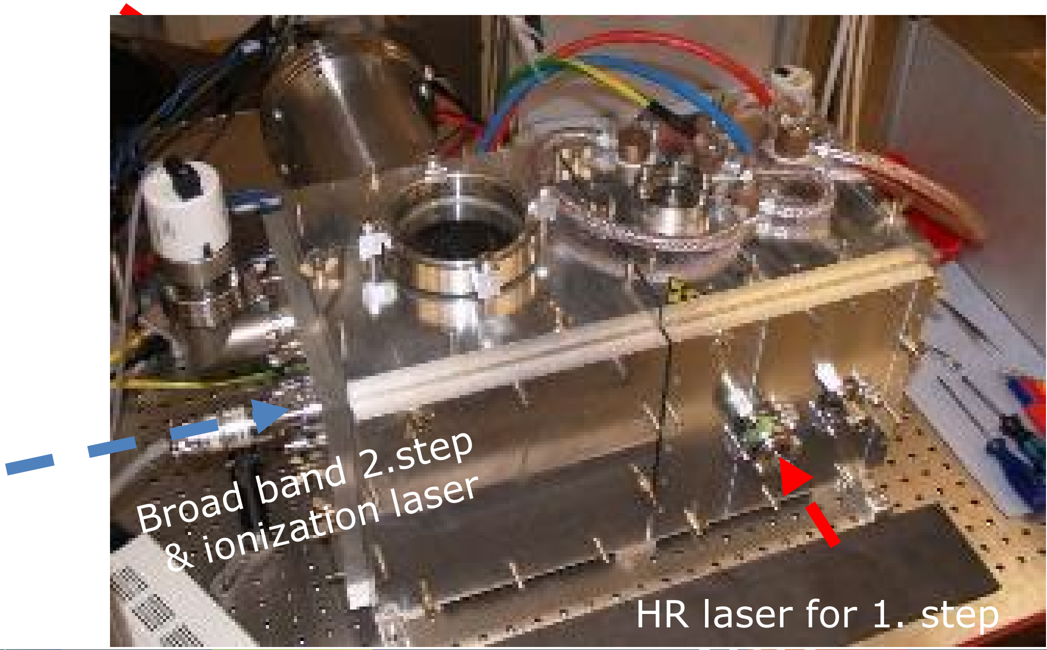


	Standard	Grating-tuned	Injection-seeded
Repetition rate	7 to 15 kHz		
Pulse width	40 to 60 ns		
Average Power	3 to 5 W	1 to 2 W	3 to 5 W
Output range	700 to 1020 nm		$\lambda_c \pm 10$ nm*
Tuning range	100 GHz	700 to 1020 nm	10 to 20 GHz*
Spectral bandwidth	1 to 10 GHz	1 to 3 GHz	20 MHz
Beam quality (M^2)	< 1.3		



Mainz Atomic Beam Unit - MABU

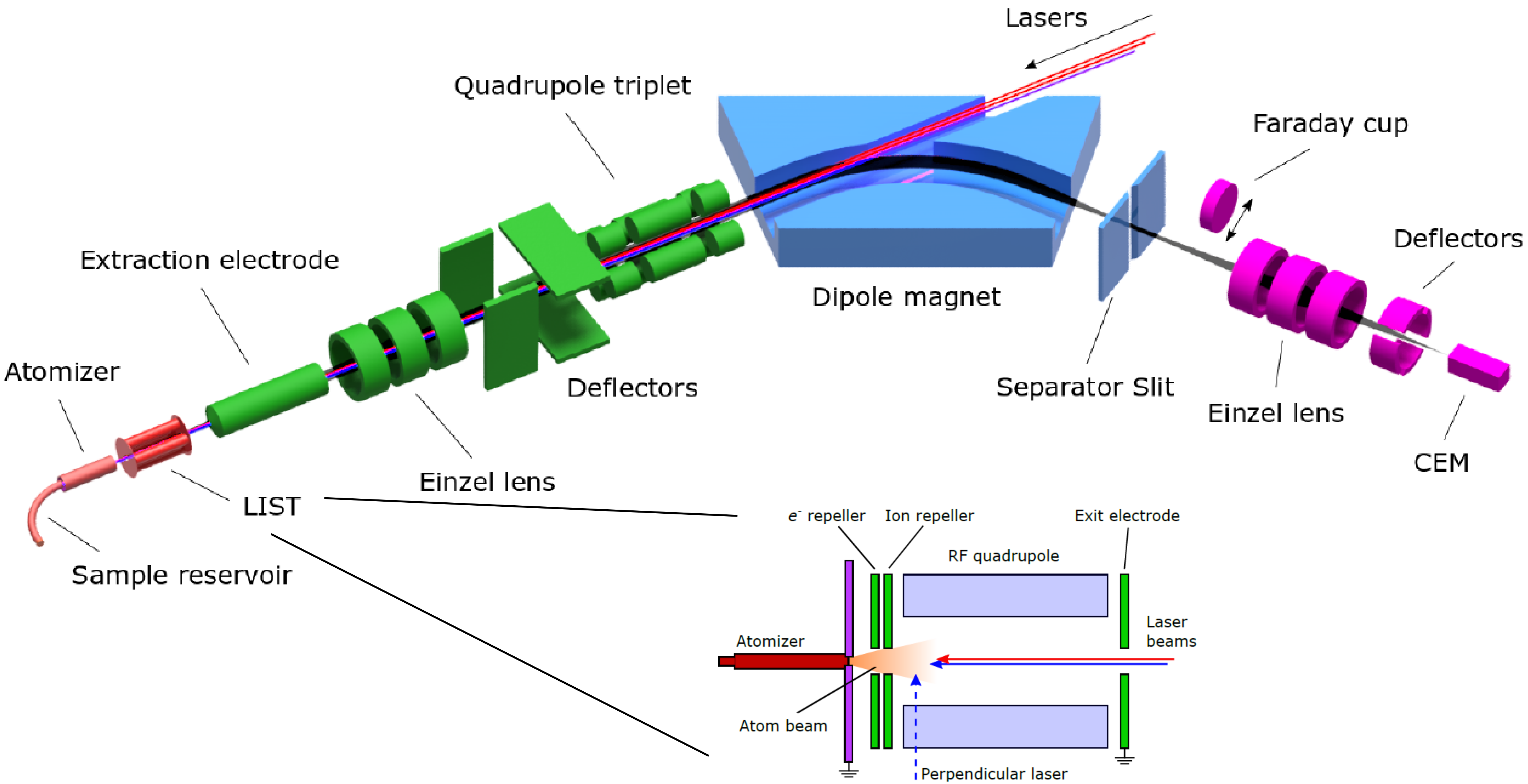




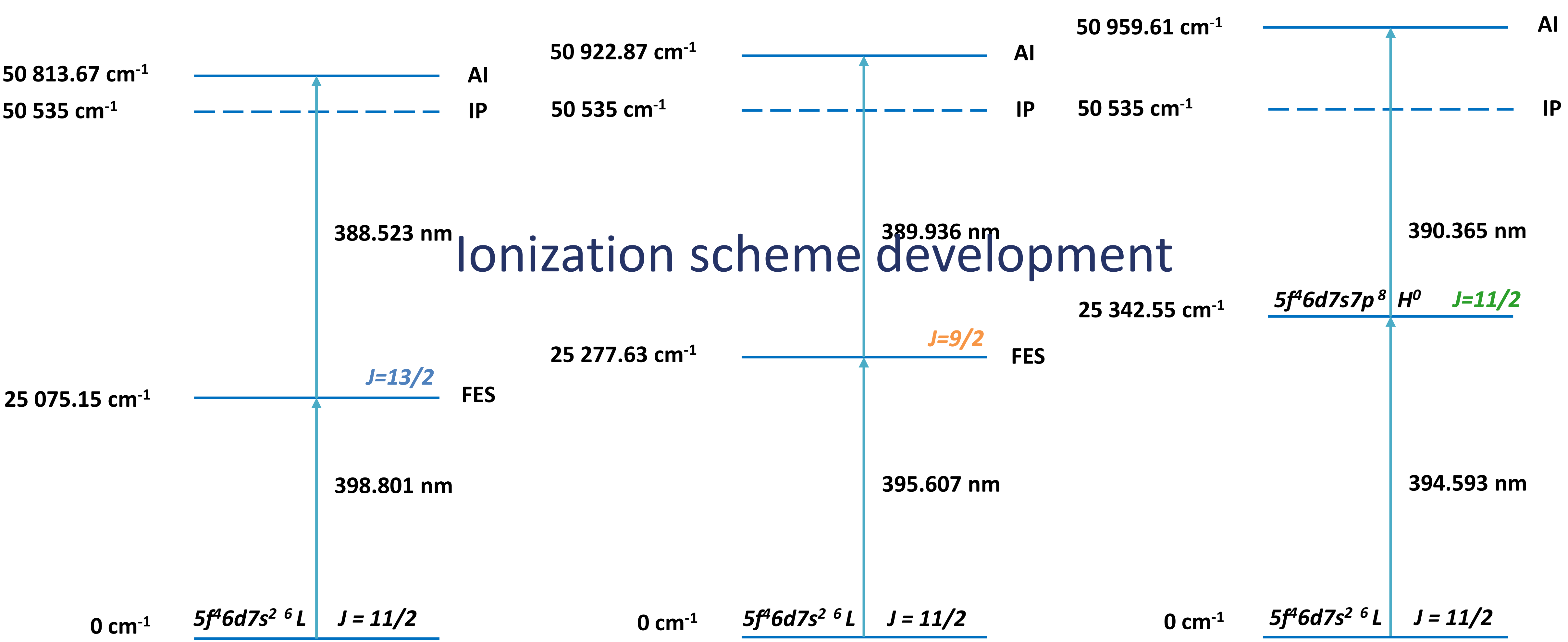
MABU - Quadrupole Mass Spectrometer

- Low acceleration voltage ~100 V
- In-source or HR crossed beam laser ionization
- QMS mass resolution $\frac{m}{\Delta m} \approx 500$

RISIKO mass separator



Ionization scheme development



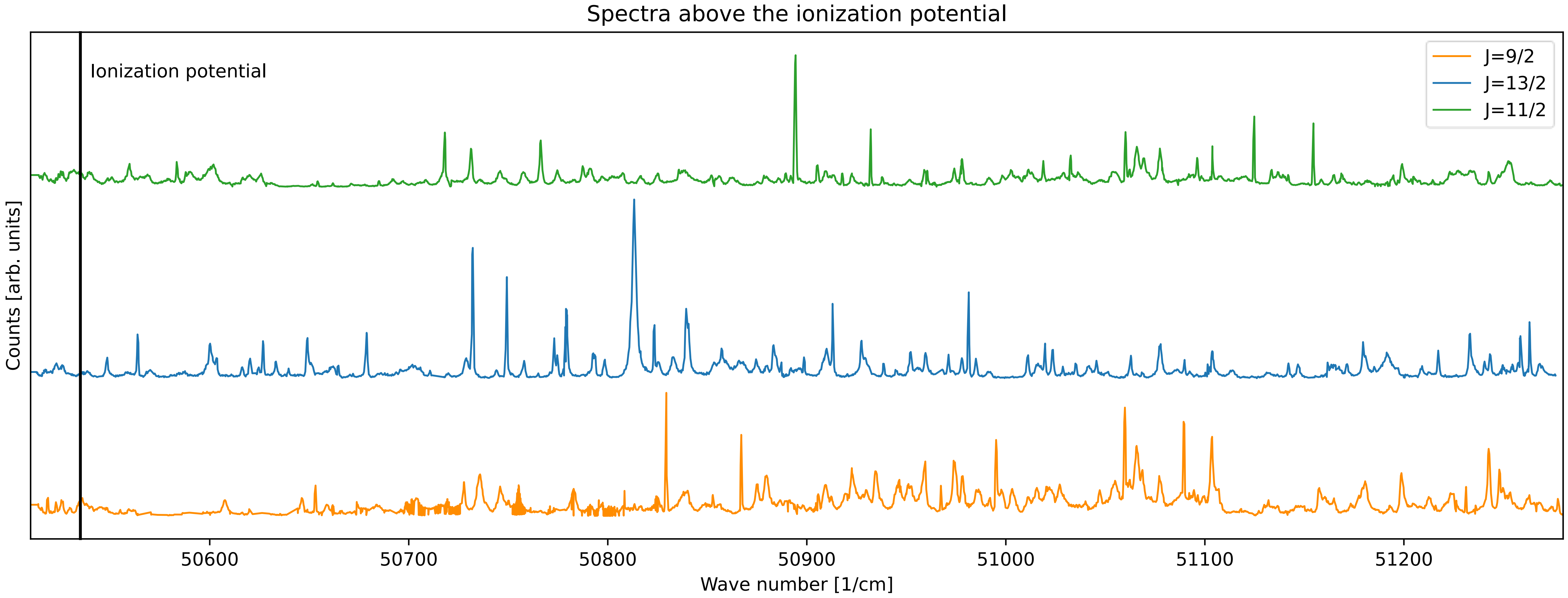
FES: Raeder, S; Stoebener, N; et al.;
Spectrochim. Acta B, 66, 242 – 247, (2011)

Scheme : Berg, F; Kneip, N; et al.;
J. Am. Chem. Soc. TO BE PUBLISHED

FES: Fred, M; Tomkins, F. S.; et al.;
J. Opt. Soc. Am., 67, 1, (1977)

Ionization scheme development

FES = 25 075.15 cm^{-1} (J=13/2)
FES = 25 277.63 cm^{-1} (J=9/2)
FES = 25 342.55 cm^{-1} (J=11/2)



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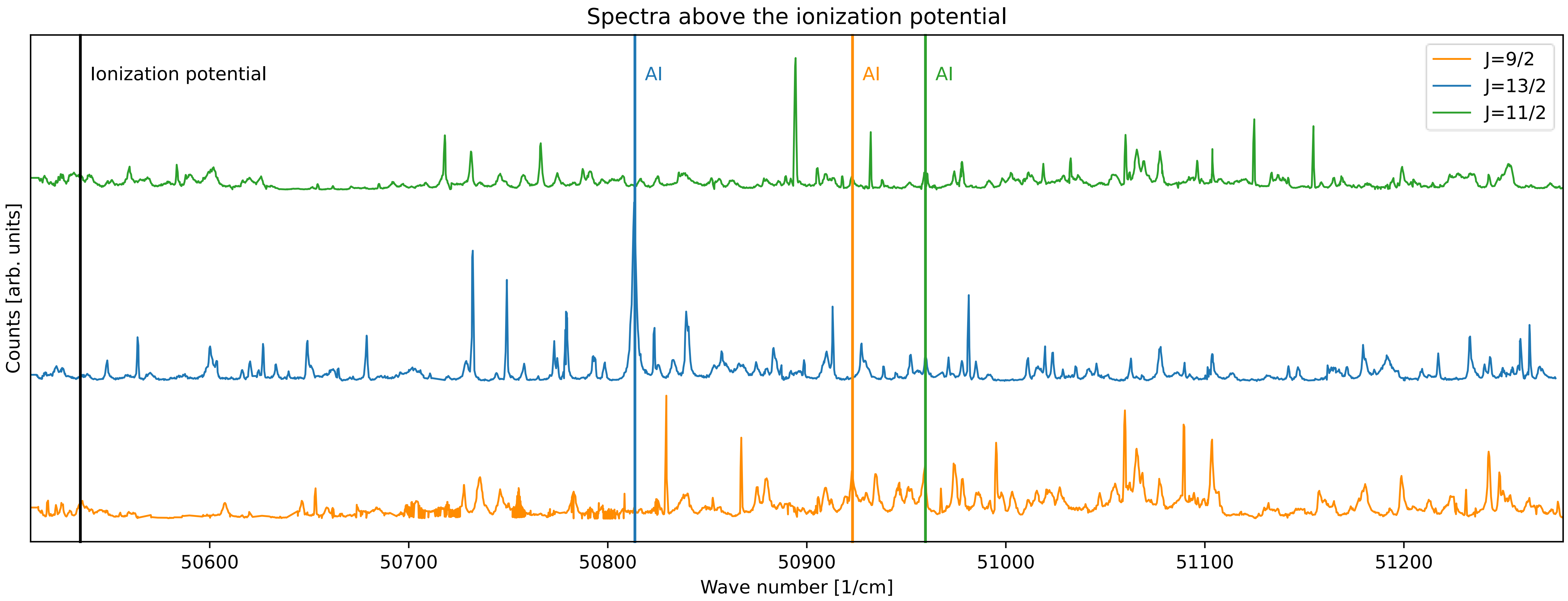

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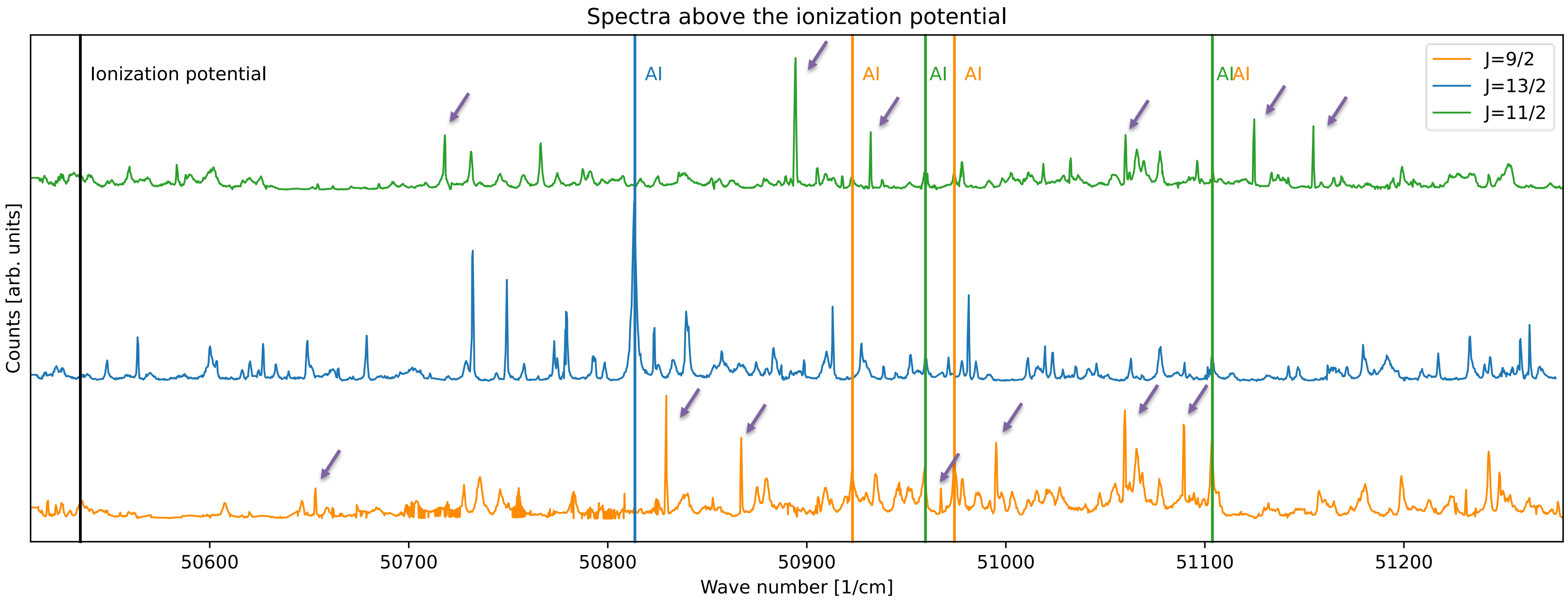
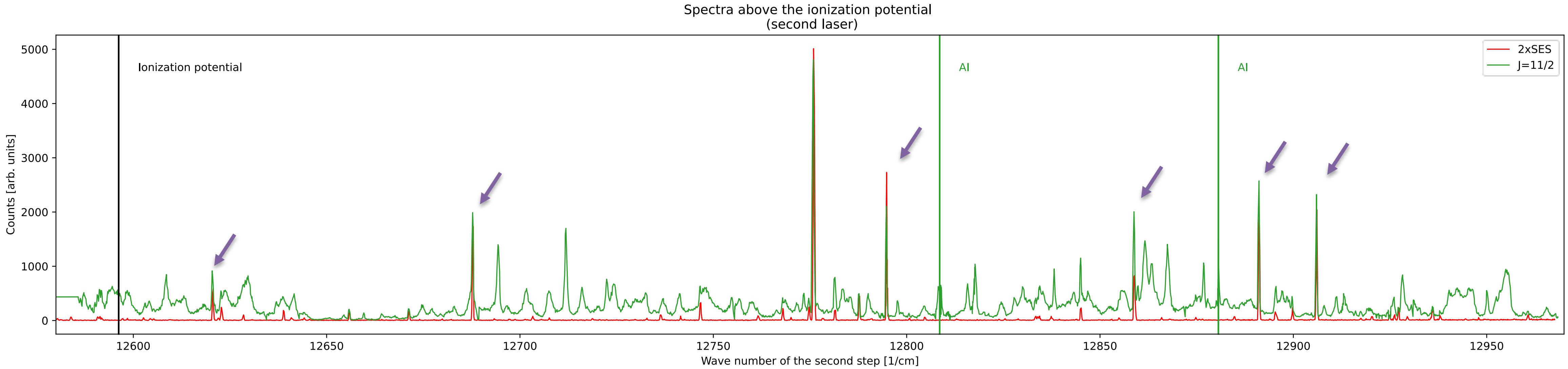
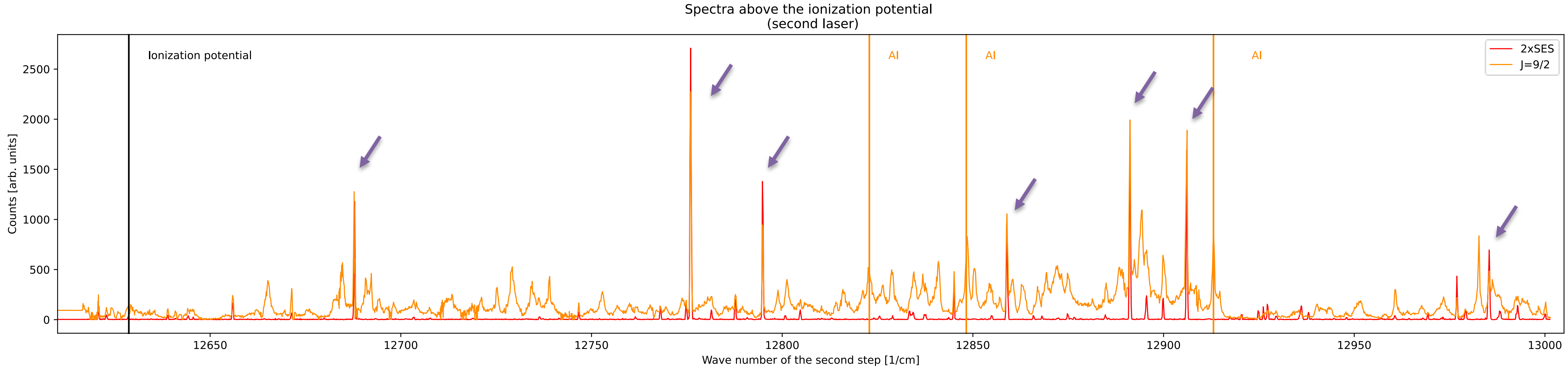
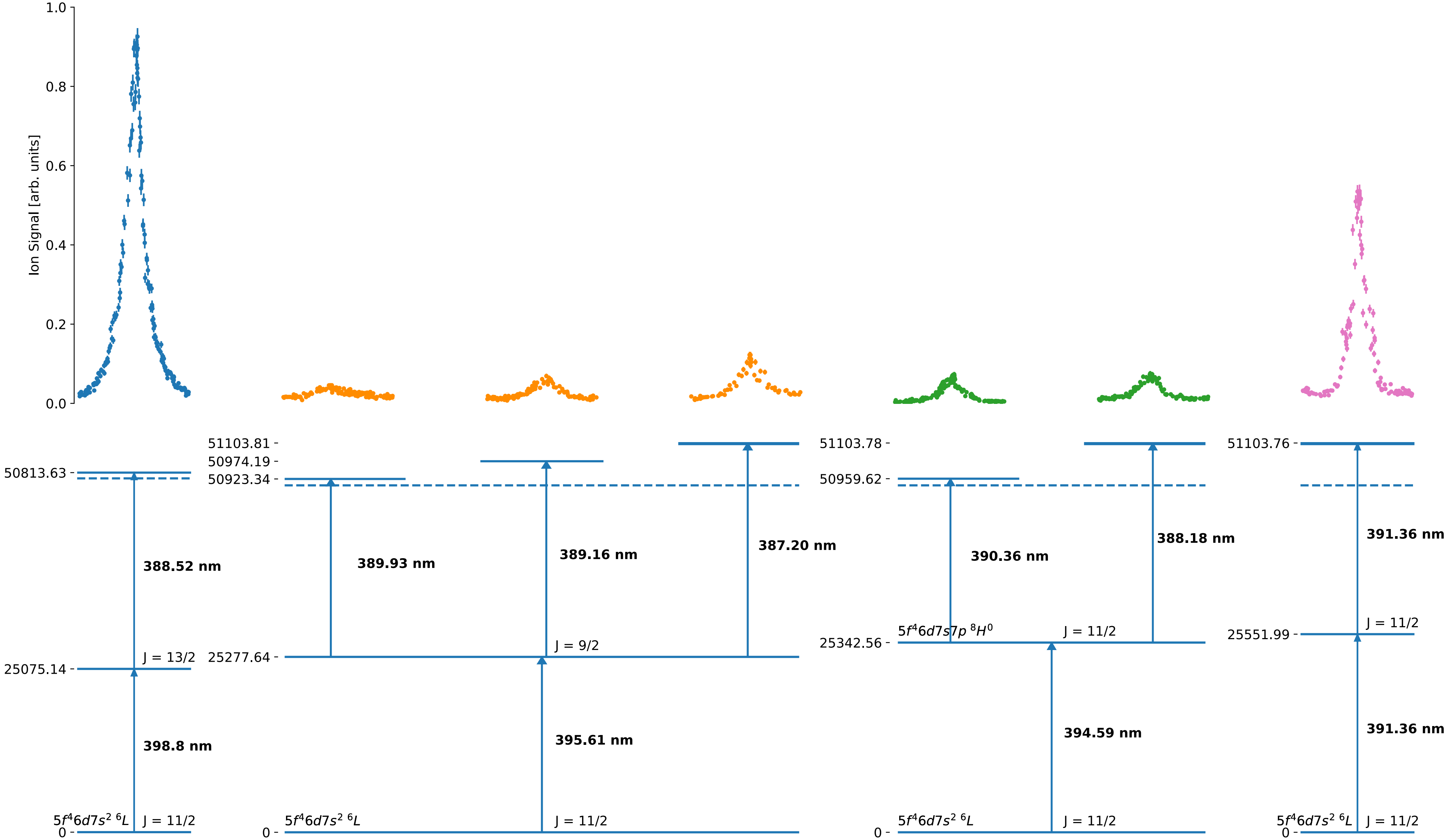


Two-step excitations with just the second laser 2 + 2





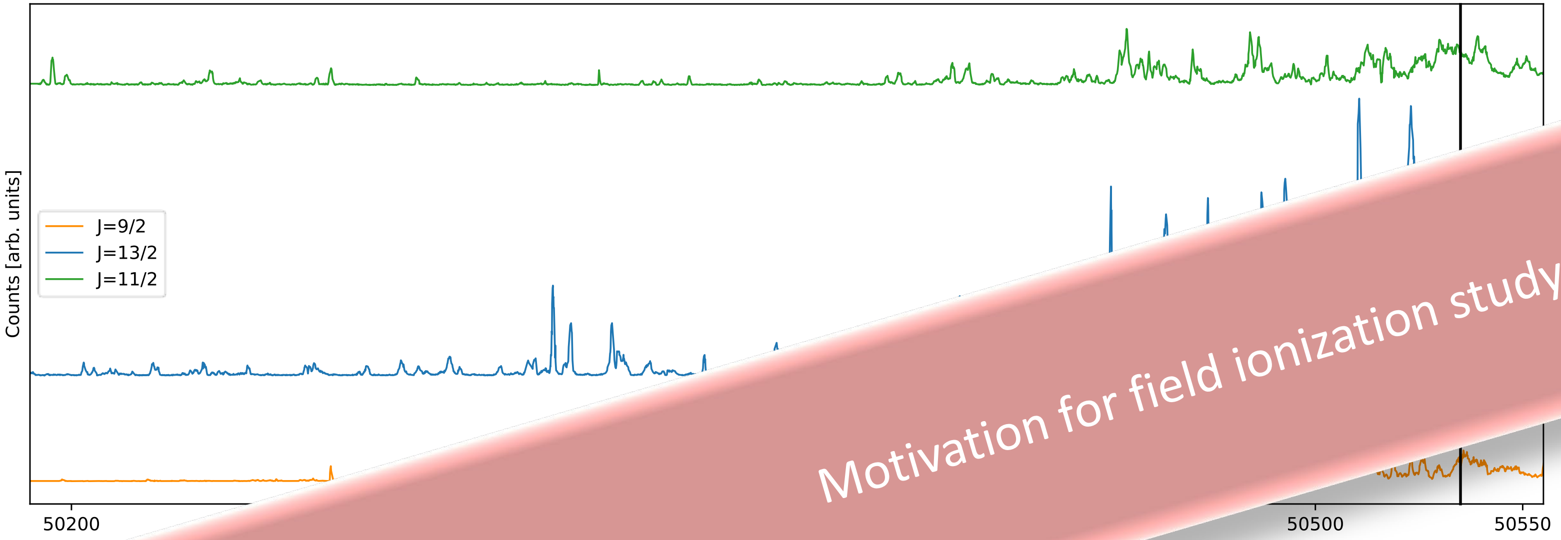
Ionization scheme development – intensities comparison



In source spectroscopy of neptunium

FES = 25 075.15 cm^{-1} (J=13/2)
FES = 25 277.63 cm^{-1} (J=9/2)
FES = 25 342.55 cm^{-1} (J=11/2)

Spectrum below the ionization potential **IP = 50 535 (2) cm^{-1}**



Motivation for field ionization study

Rydber…

… $\delta(n,l))^2$

…al quantum number

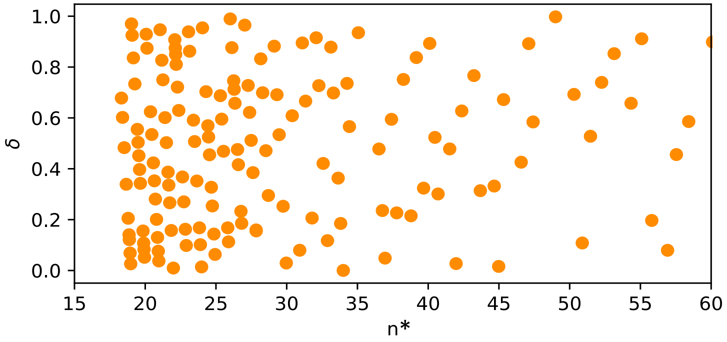
…tum

…$_\mu$ – reduced R…

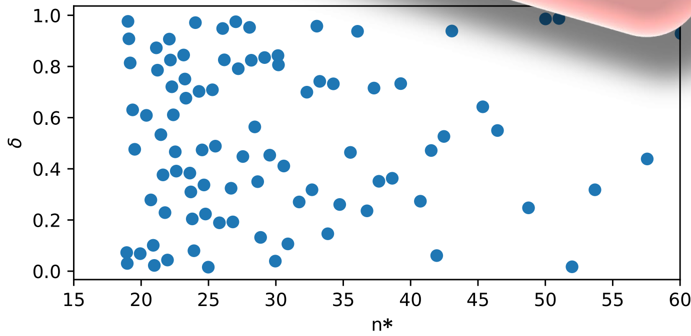
Do you see any obvious Rydberg series?
Not really

The quantum defect for IP from Kohler[1] (…
as a function of the effective principal quantu…

FES = 25 277.63 cm^{-1}



FES = 2…

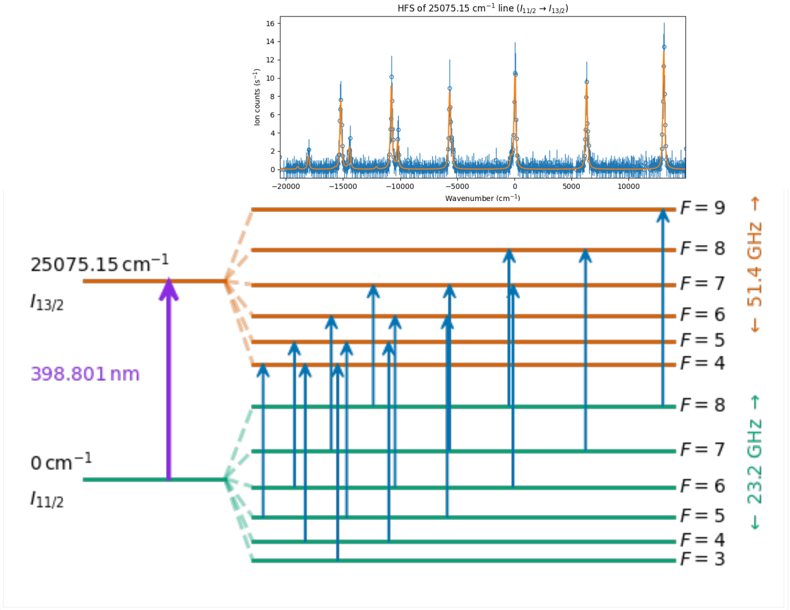


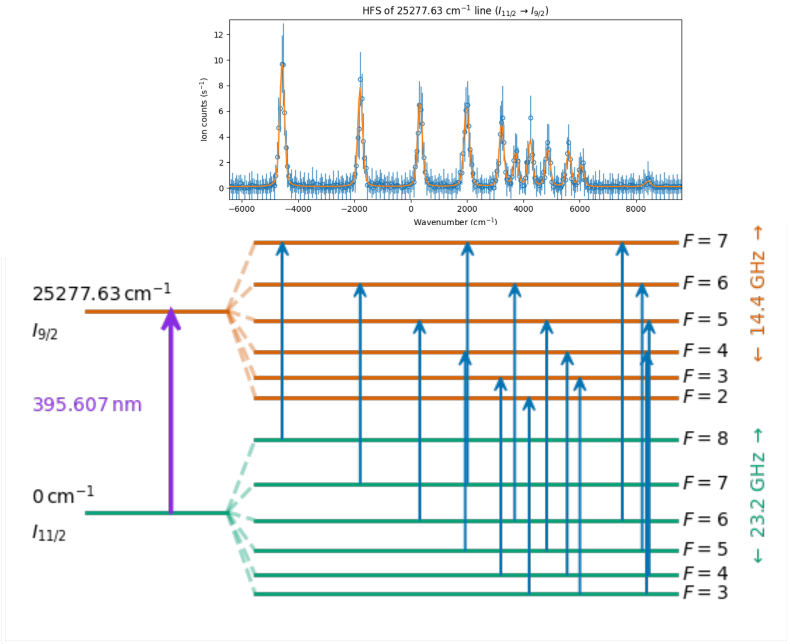
Qua… defect of the energy level n:
$\delta(n,l)$ = -n* mod 1

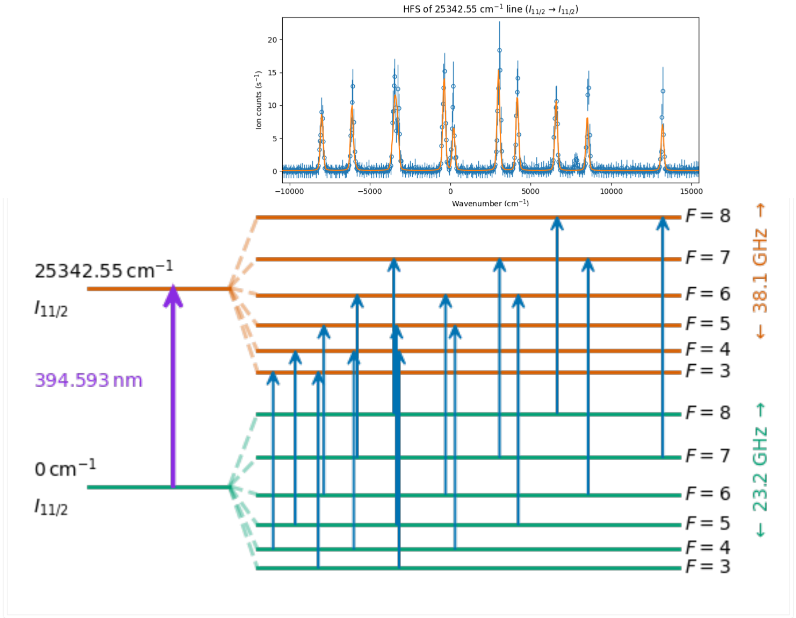
[1] Kohler, S ; Deissenberger, R ; et al.
Spectrochim. Acta B,52, 717 – 726, (1997)

Outlook

- Perform electric field ionization
- Narrow-band spectroscopy at RISIKO in the PI-LIST ion source (^{239}Np)
- Spectroscopy of berkelium and protactinium








LARISSA