The first ionization potential of nobelium

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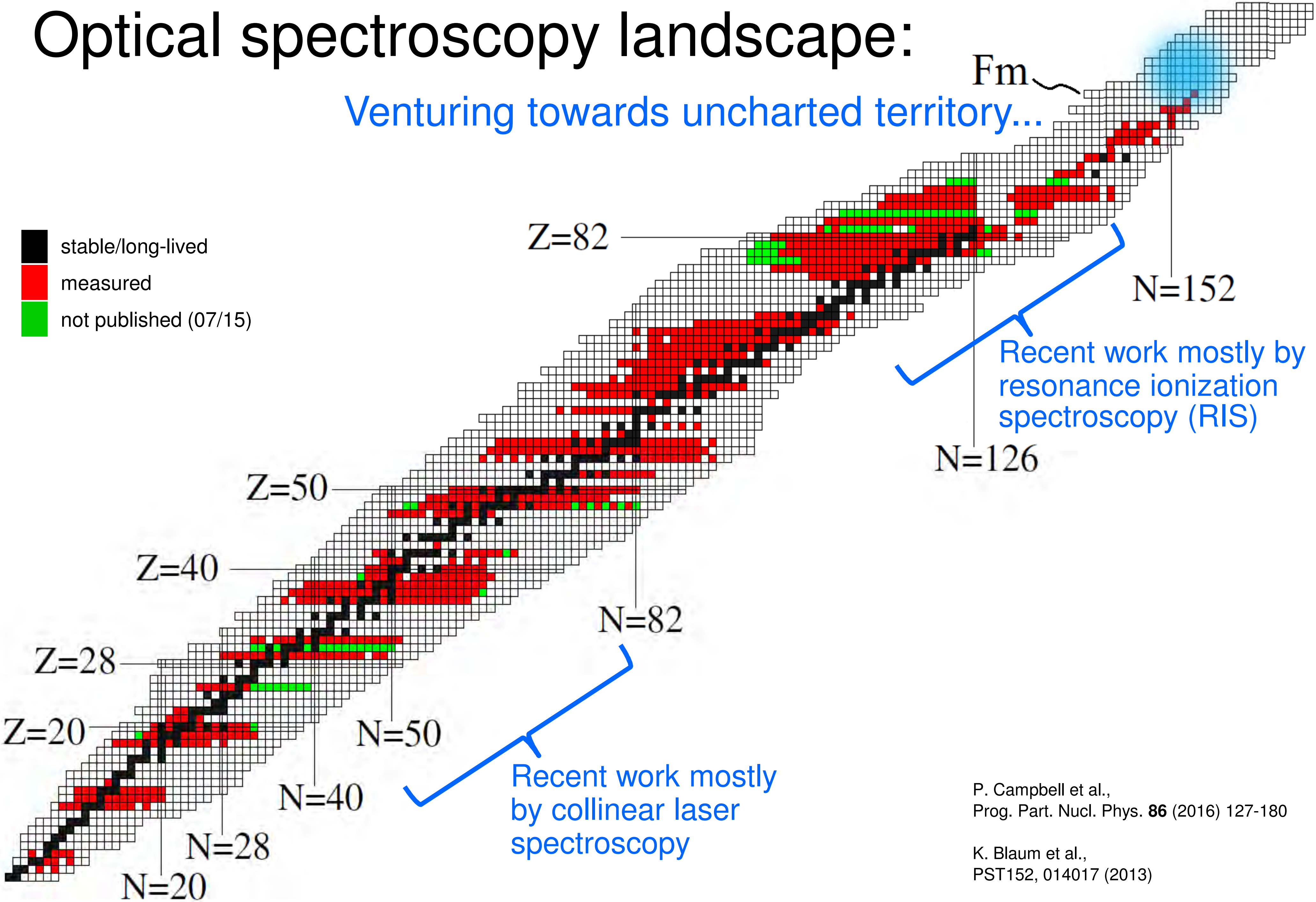
Outline

- Motivation
- Experimental method
- Results
- Conclusions & future prospects

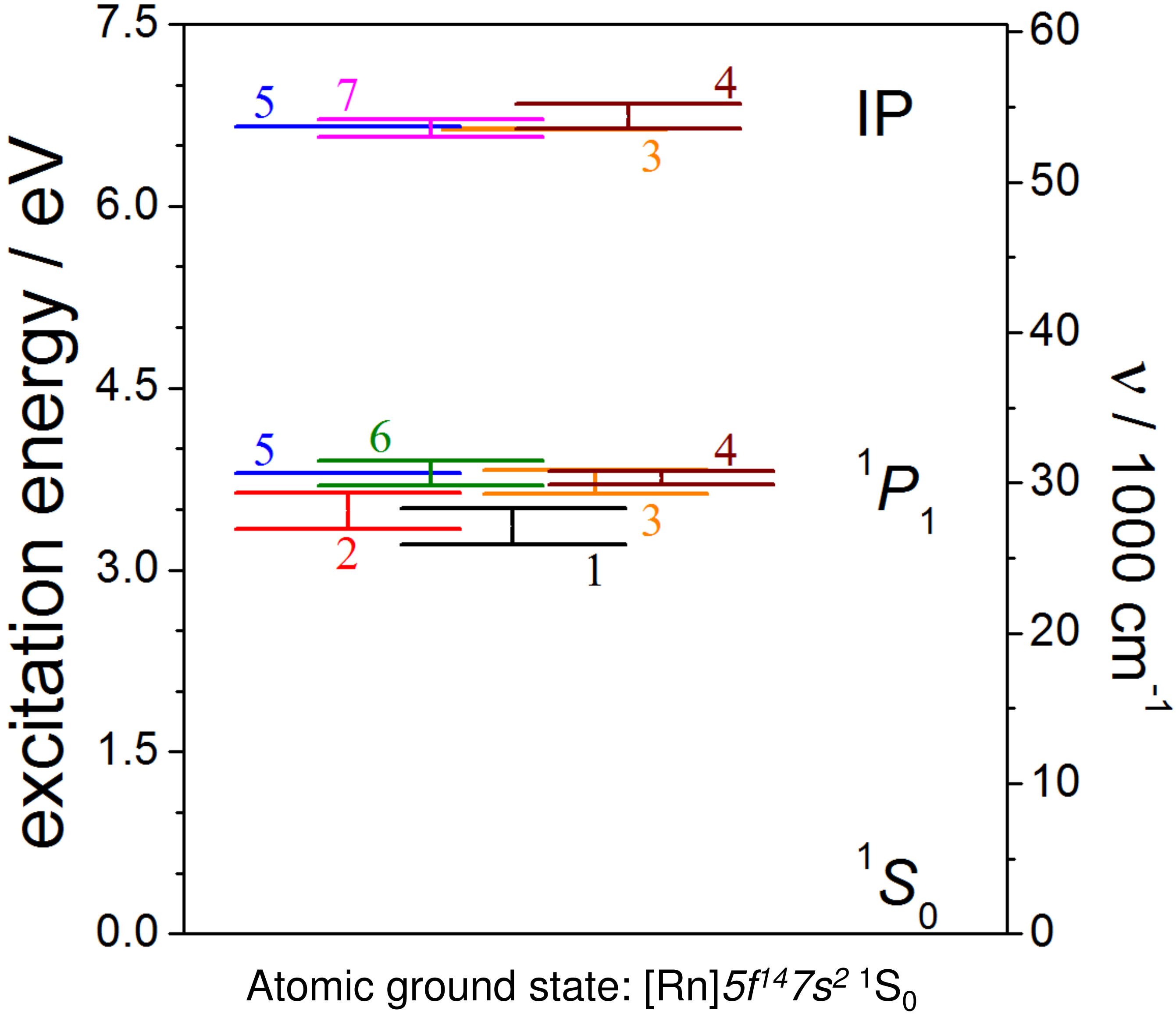
Optical spectroscopy landscape:



P. Campbell et al., Prog. Part. Nucl. Phys. **86** (2016) 127-180

K. Blaum et al., PST152, 014017 (2013)

Theoretical predictions for nobelium



Model calculations:

1 (MCDF): S.Fritzsche, Eur. Phys. J. D 33 (2005) 15

2 (MCDF): S.Fritzsche, Eur. Phys. J. D 33 (2005) 15

3 (IHFSCC): A.Borschevsky et al., Phys. Rev. A 75 (2007) 042514

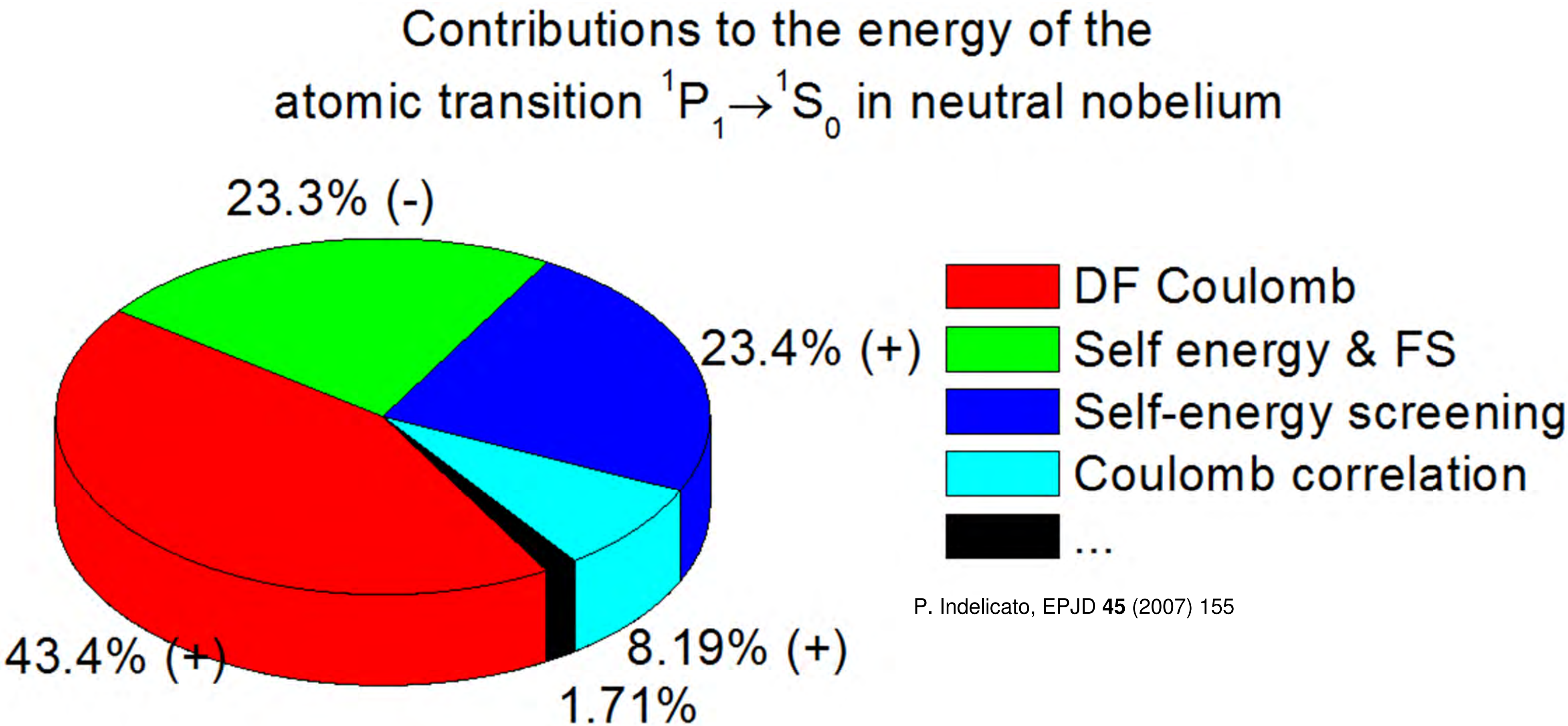
4 (RCC): V.A.Dzuba et al., Phys. Rev. A 90 (2014) 012504

5 (MCDF): Y.Liu et al., Phys. Rev. A 76 (2007) 062503

6 (MCDF): P.Indelicato et al., Eur. Phys. J. D 45 (2007) 155

7 (extrapolation): J.Sugar, J. Chem. Phys. 60 (1974) 4103

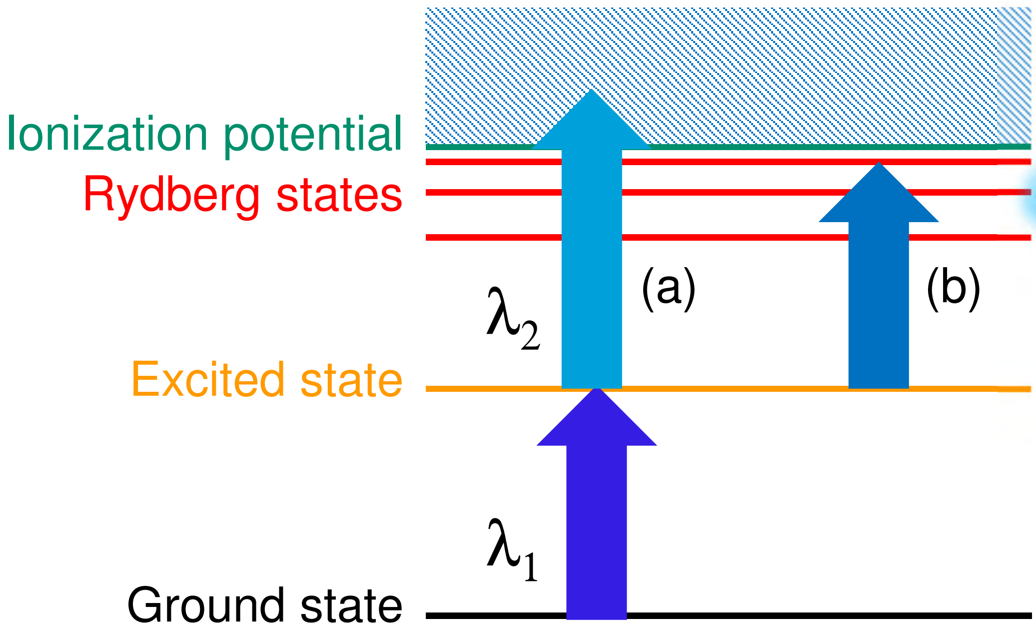
Relativistic, QED etc.

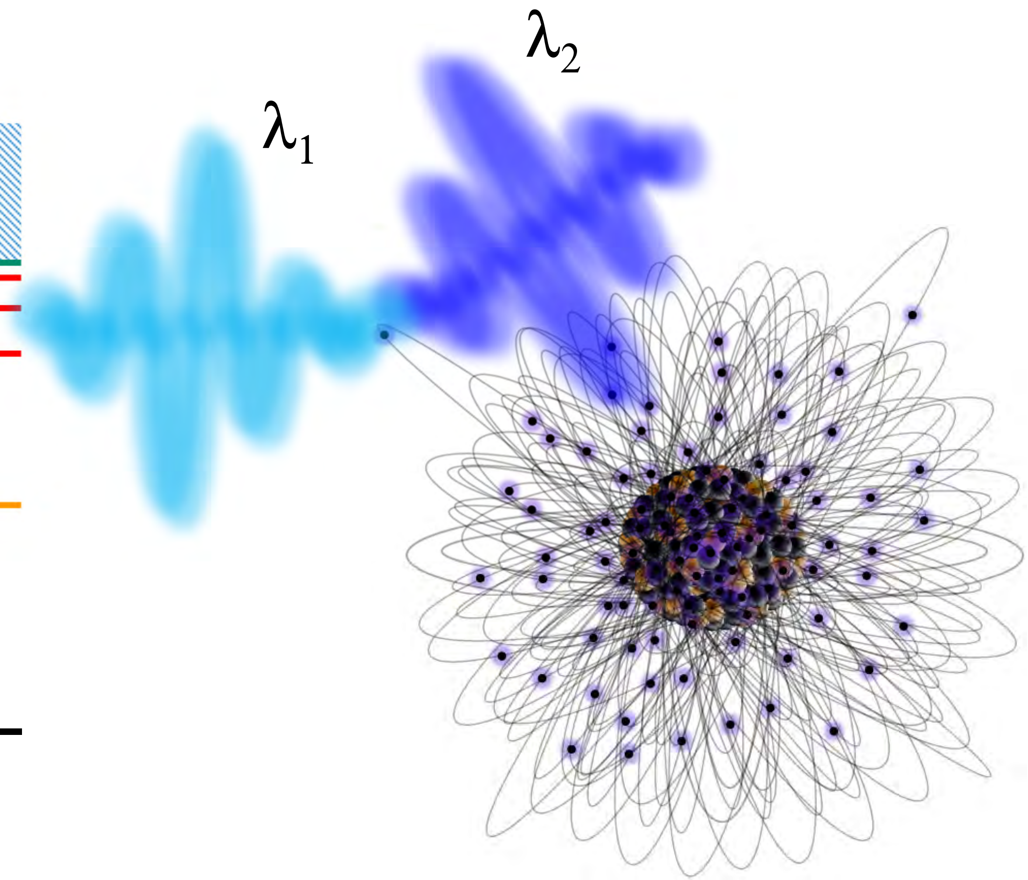


P. Indelicato, EPJD **45** (2007) 155

➔ Feedback to theoreticians concerning treatment of e.g. core correlations (CV,CC)

The tool of choice: 2–Step Resonance Ionization





Nobelium
Atom

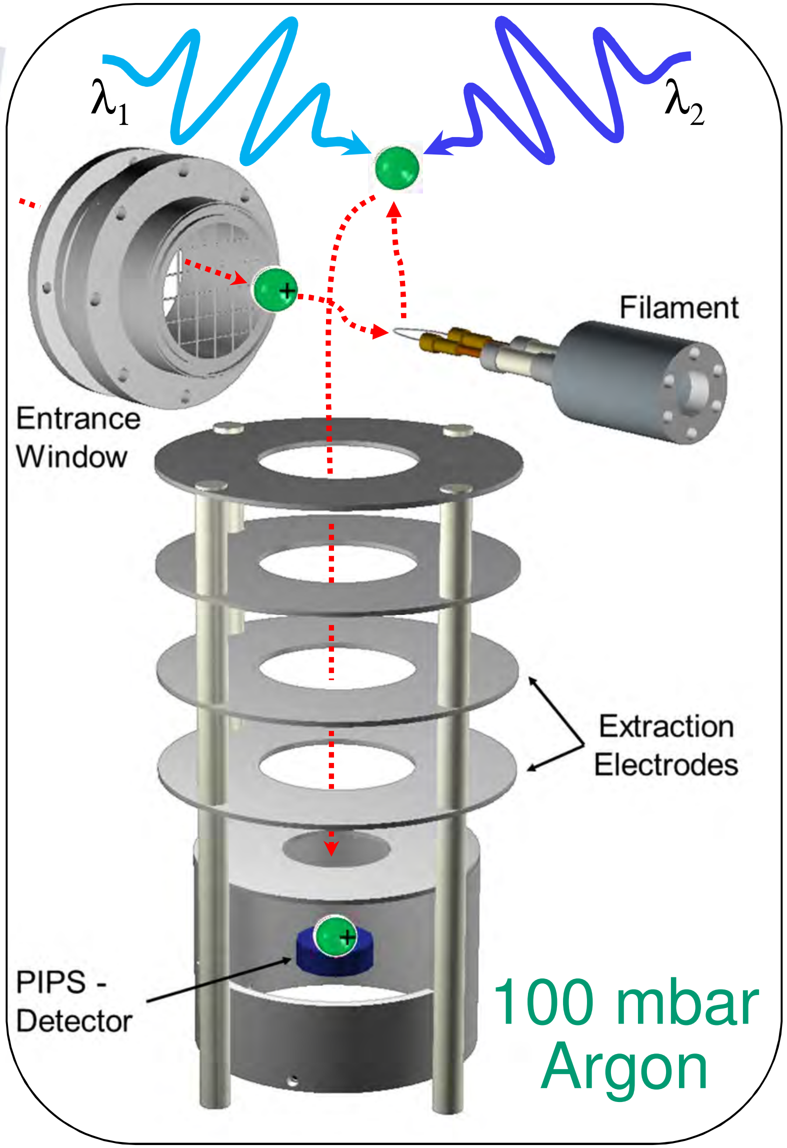
- Scenario (a) about 2 orders of magnitude less efficient compared with (b)

Nobelium isotopes

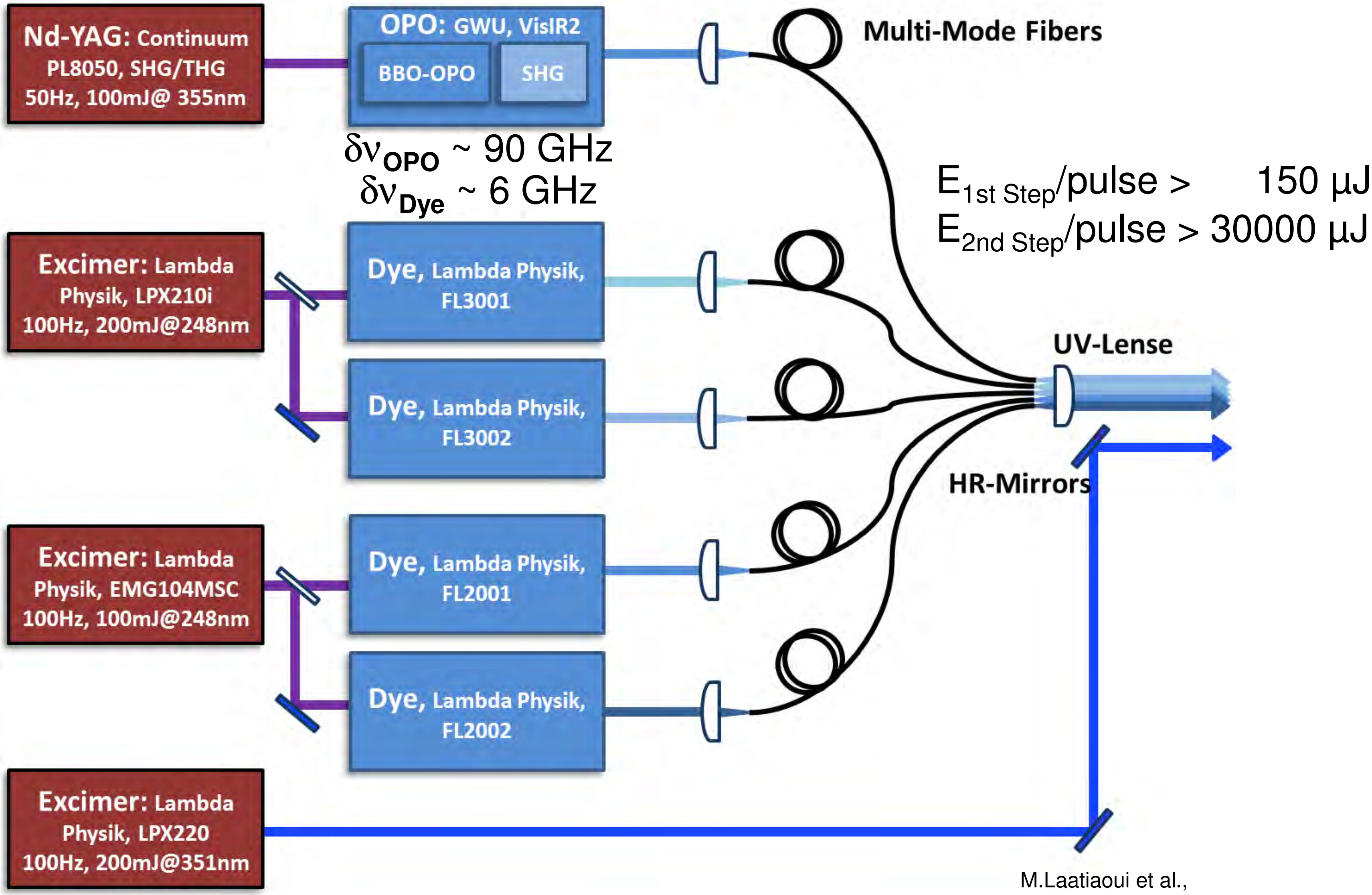
Isotope	I^P	$T_{1/2}$ (s)	Nuclear reaction	Production rate @ 1μA_P (1/s)	α- energy (MeV)
^{252}No	0	2.4	^{206}Pb(^{48}Ca,2n)^{252}No	4	8.42
^{253}No	(9/2$^-$)	102	^{207}Pb(^{48}Ca,2n)^{253}No	11	8.01
^{254}No	0	51	^{208}Pb(^{48}Ca,2n)^{254}No	17	8.10
^{255}No	(1/2$^+$)	186	^{208}Pb(^{48}Ca,1n)^{255}No	2	8.12

Radiation Detected Resonance Ionization Spectroscopy (RADRIS)

SHIP



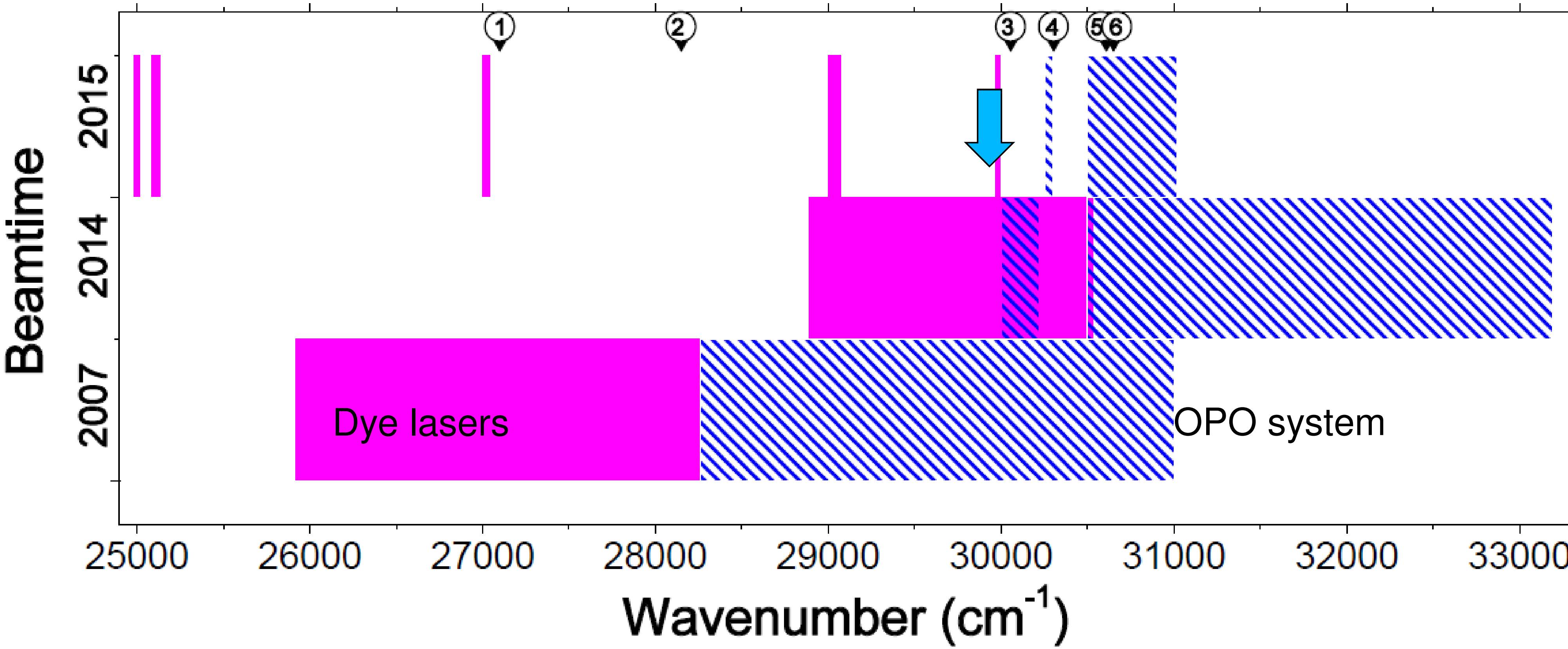
Laser systems



M.Laatiaoui et al.,
Hyperfine Interact. **227** (2014) 69

Level search in ^{254}No

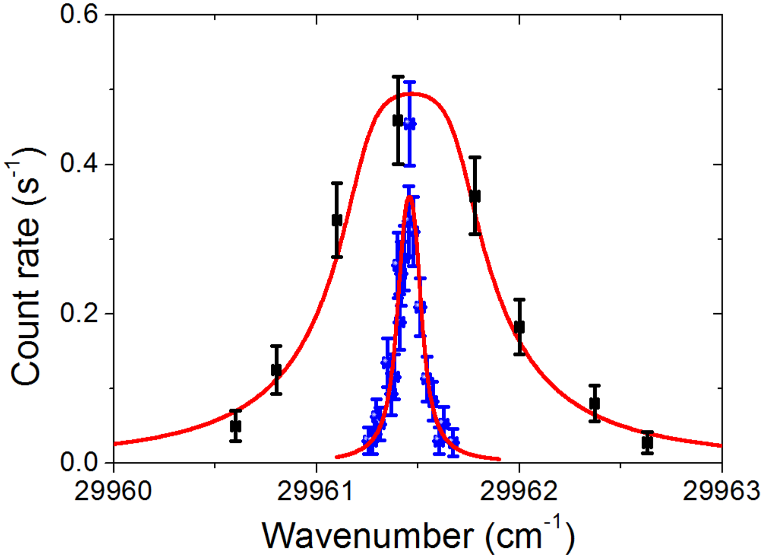
Year	2007	2014
Scan range (cm^{-1})	25920 – 31001	28887 – 33191
Net scan time (h)	39	67

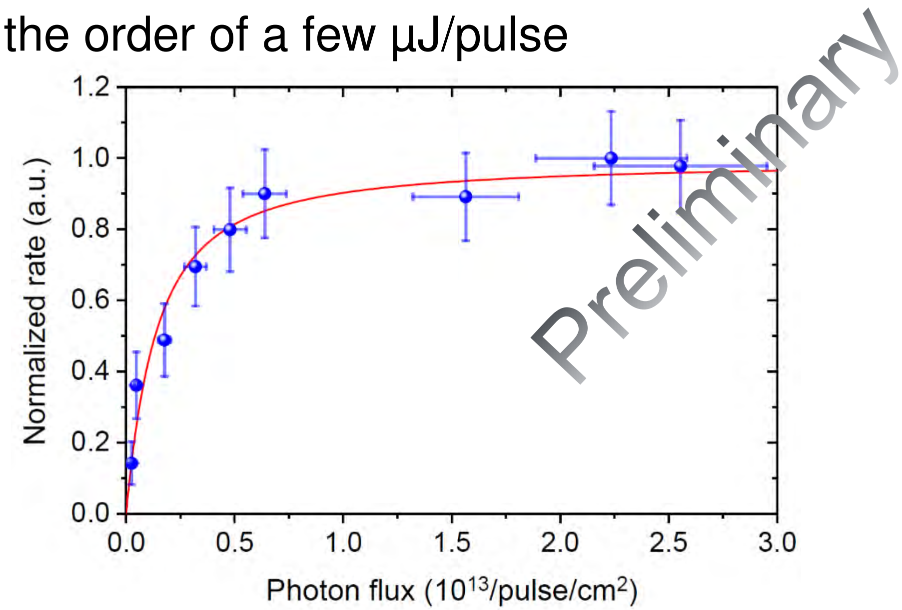


1: MCDF (2005), 2: MCDF (2005), 3: IHFSCC (2007), 4: RCC (2014), 5: MCDF (2007), 6: MCDF (2007)

The ground-state transition

- Strong atomic transition from $^1S_0$ ground state to $^1P_1$ excited state observed.
- Saturation of signal already at energies on the order of a few µJ/pulse

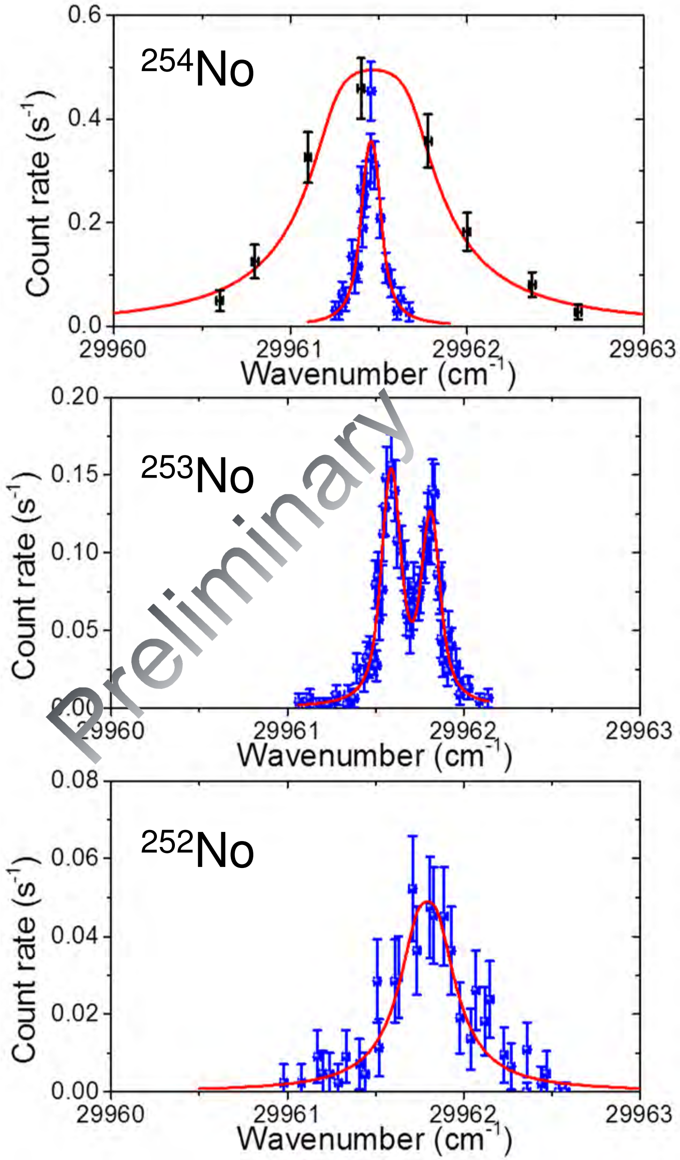




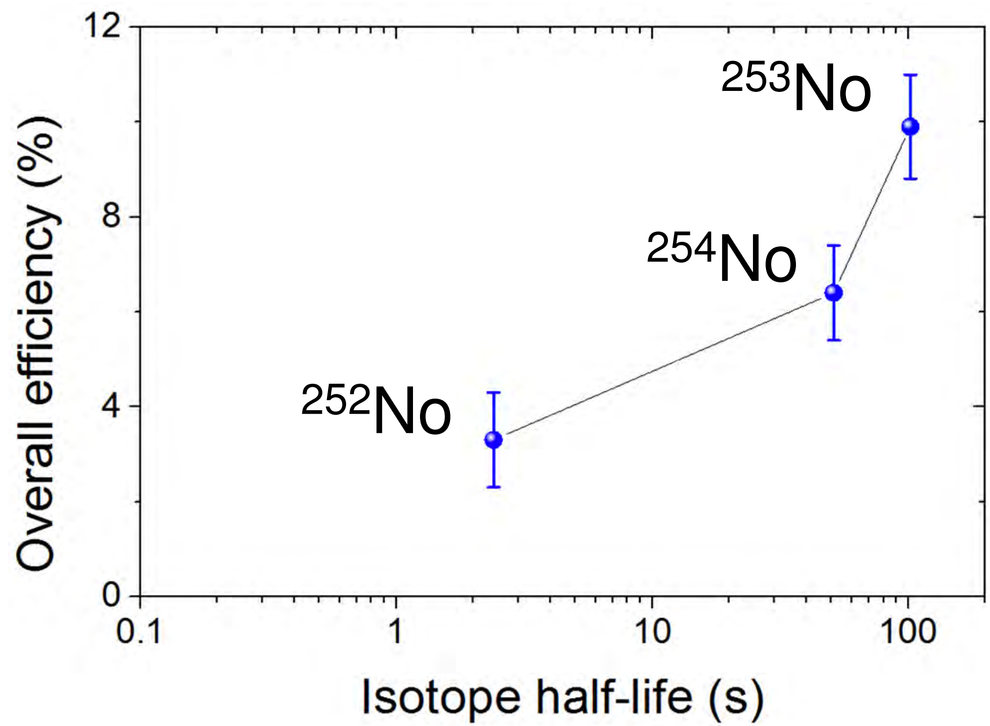
	ν_1 (cm^{-1})	A_{ki} (s^{-1}) x10^8
Experiment [1]	$29{,}961.457(7)_{stat}$	$4.2\ (2.6)_{stat}$
IHFSCC [2]	30,100(800)	5.0
MCDF [3]	30,650(800)	2.7

[1] M. Laatiaoui et al., Nature (in press)
*[2] A. Borschevsky et al., Phys. Rev. A **75** (2007) 042514*
*[3] P. Indelicato et al., Eur. Phys. J. D **45**, (2007) 155*

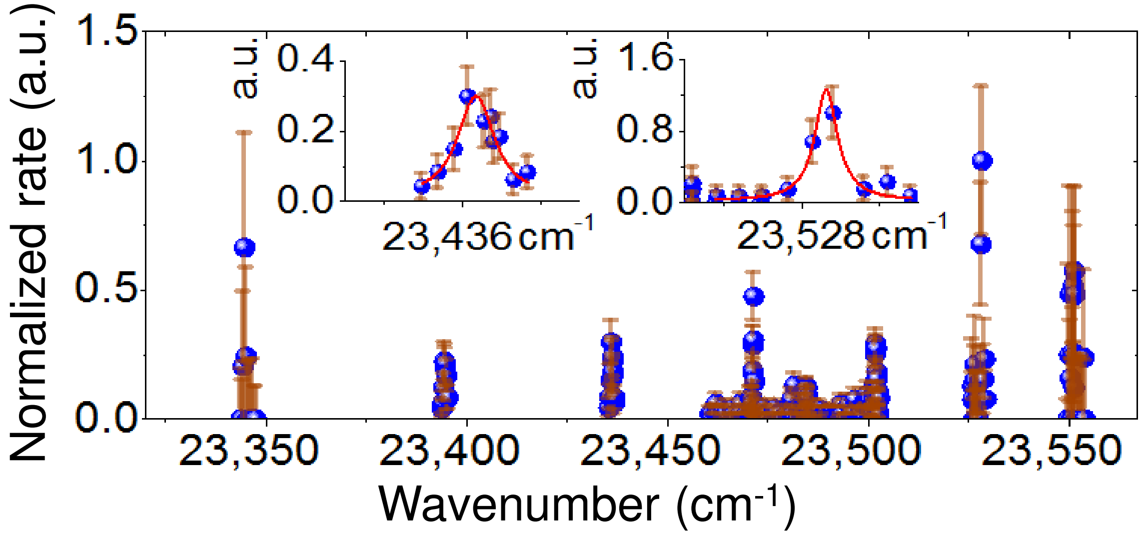
Few words to the overall efficiency:

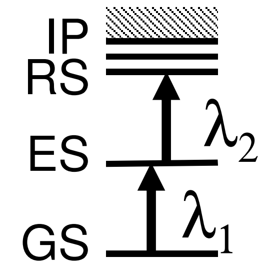


- Laser spectroscopy on ^{252,253,254}No performed
- For ^{252}No with σ= 500 nb, and $T_{1/2}$=2.4s :
  - Less than 1 atom/s delivered to the cell
  - Overall efficiency: 3.3±1.0 %
- RADRIS applicability: $T_{1/2}$-range ~ 0.1 – 200 s



Observed Rydberg states

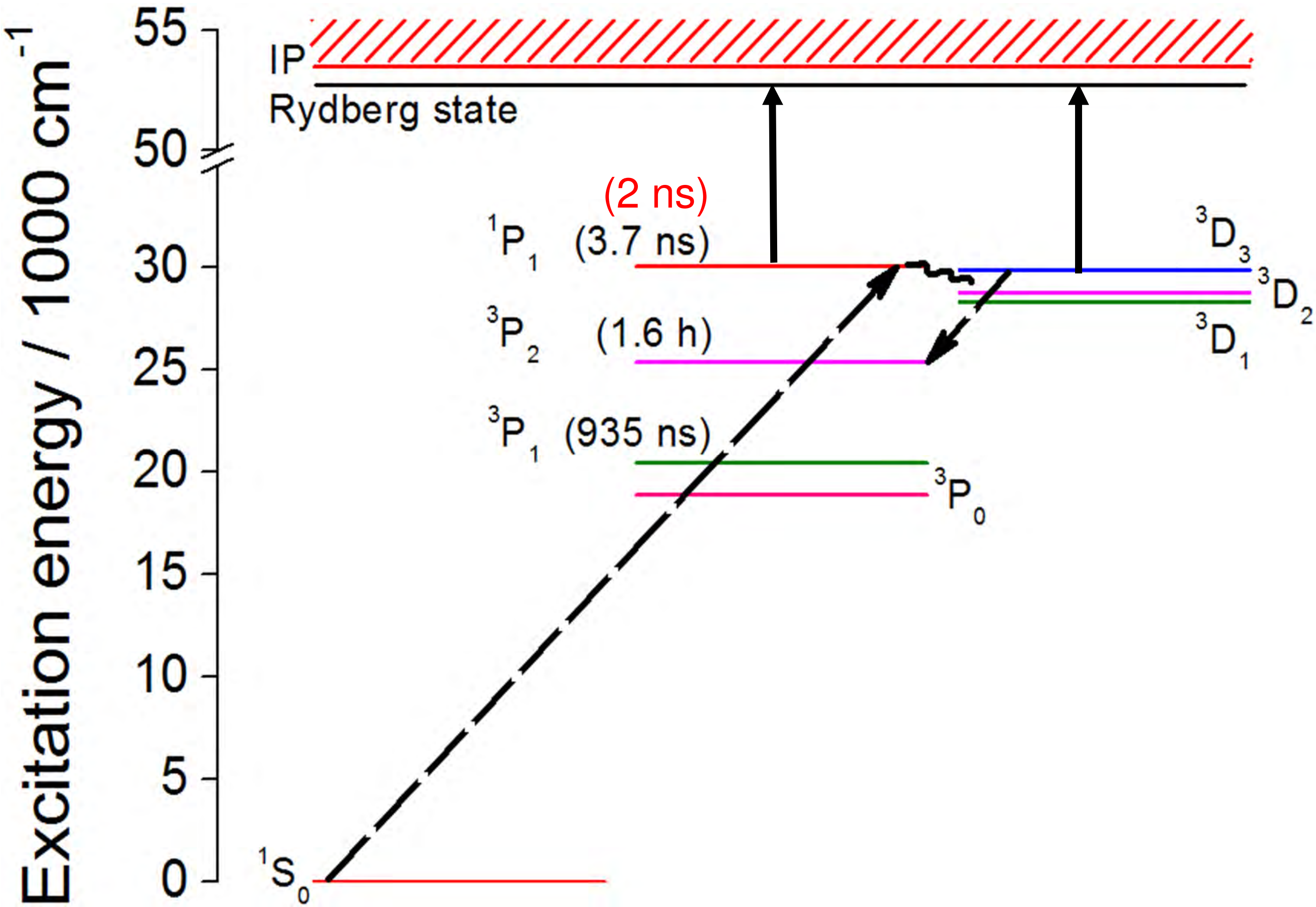




- High resolution scan to identify two members of the same series (low statistics)
- Close look at higher statistics
- Series fitted with Rydberg-Ritz formula

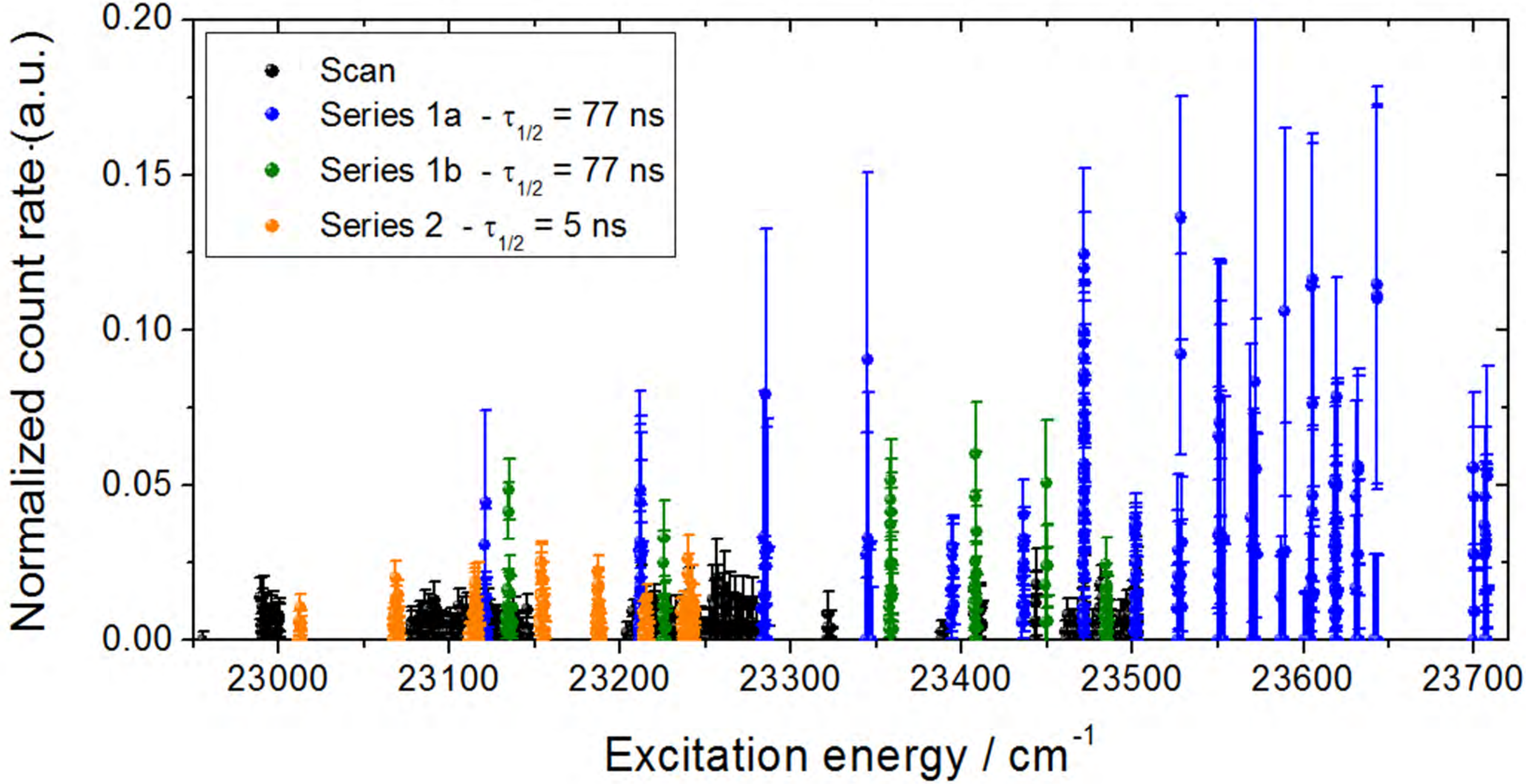
$$E_n = E_{\mathrm{IP}} - \frac{R_\mu}{[n - \delta(n)]^2}.$$

Upper limit for the ionization potential

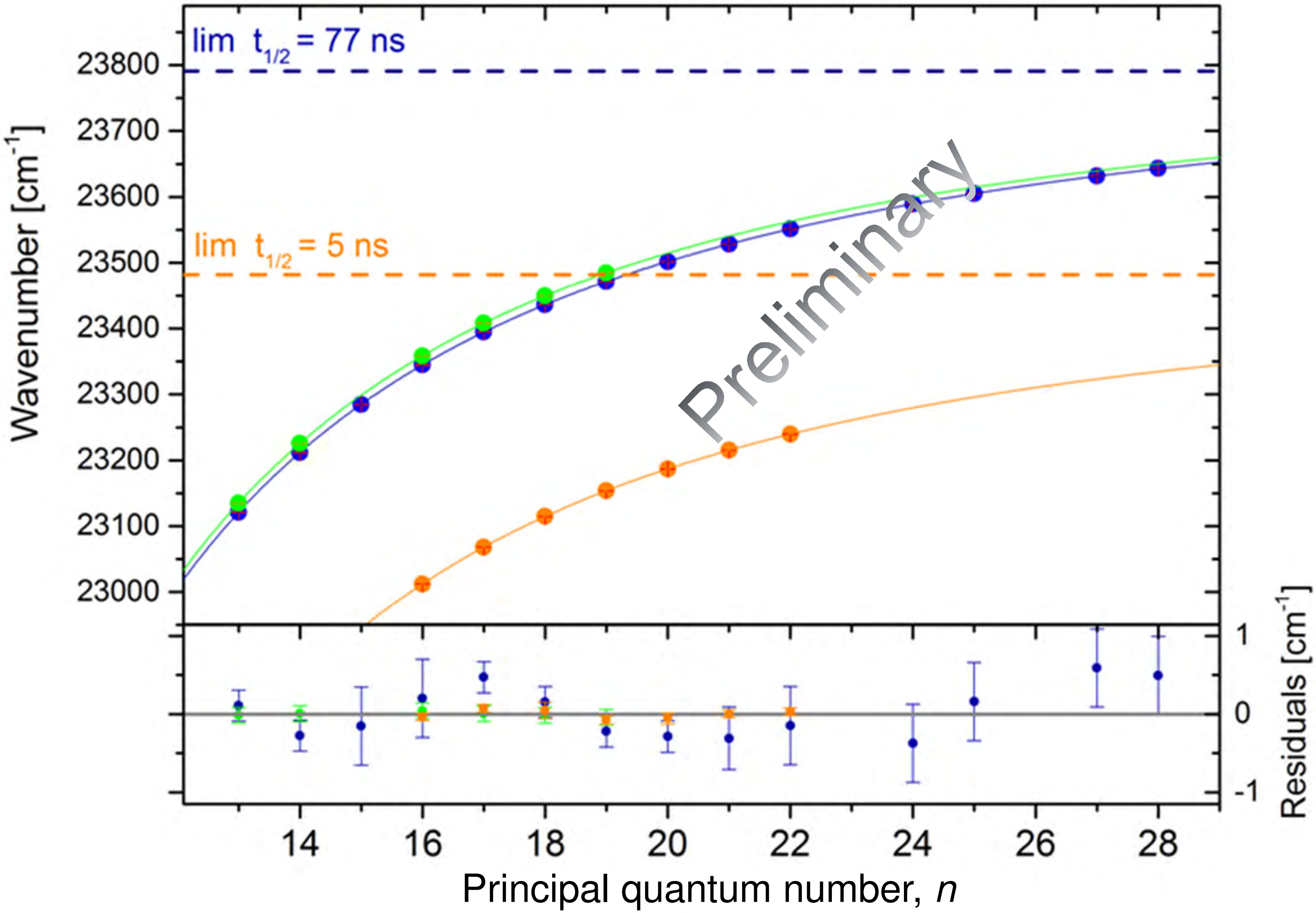


[1] M. Laatiaoui et al., Nature (in press)
*[2] A. Borschevsky et al., Phys. Rev. A **75** (2007) 042514*
*[3] P. Indelicato et al., Eur. Phys. J. D **45**, (2007) 155*

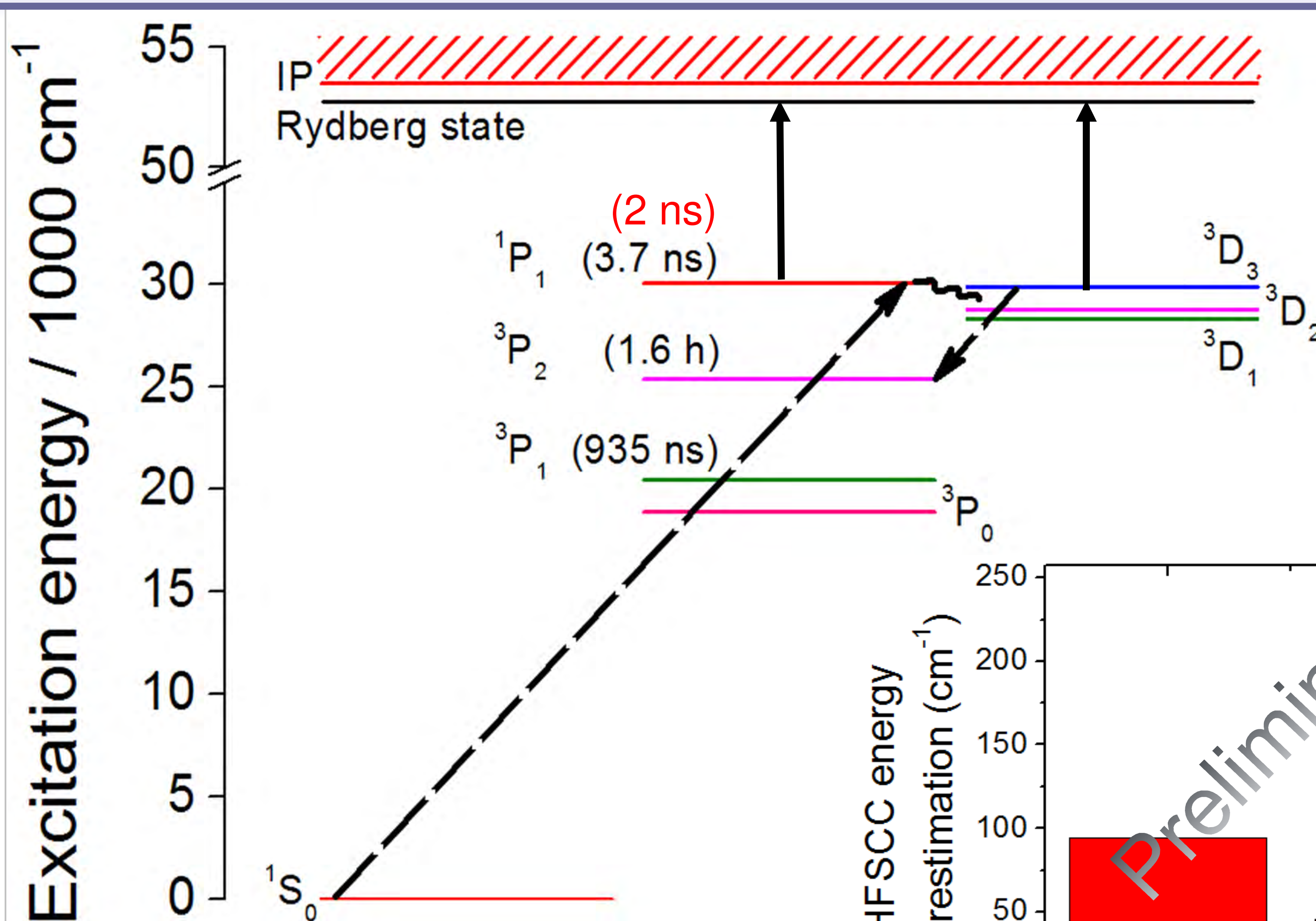
Search for other Rydberg series

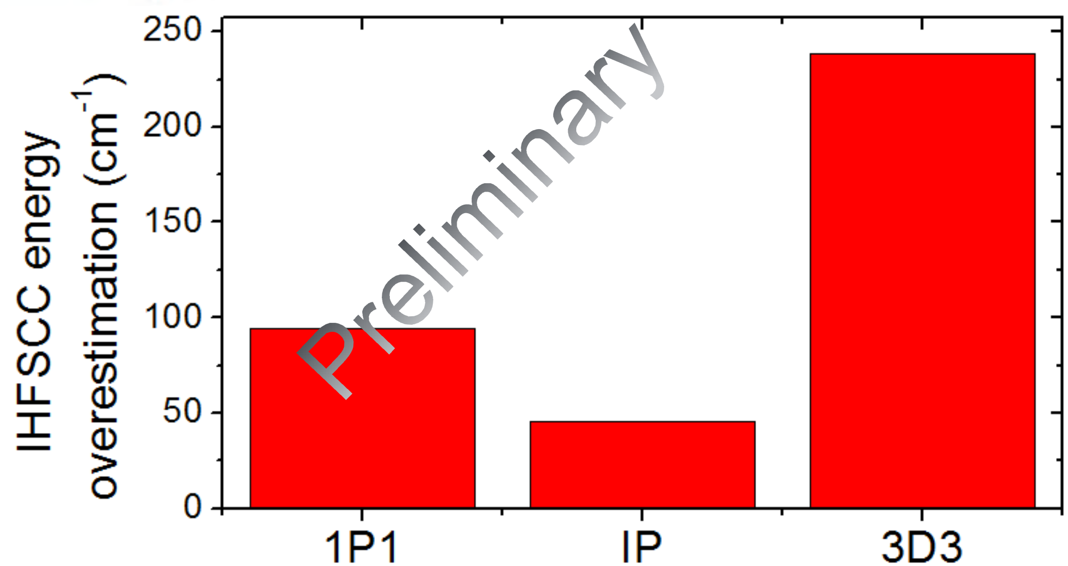


Ionization limits



The first ionization potential





Conclusions

- First successful laser spectroscopy of a transfermium element

- The detected resonance corresponds to the strongest ground-state transition in nobelium (Z=102), the $^1S_0 \rightarrow {}^1P_1$ – transition.

- An overall efficiency up to 10% was achieved for nobelium isotopes.

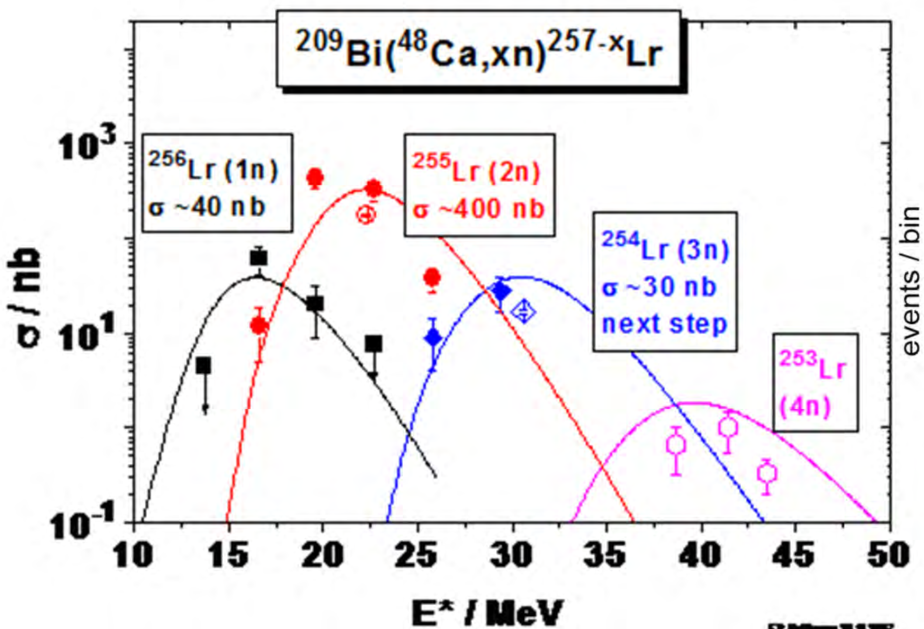
- Hyperfine structure and isotope shift measurements were successfully performed for the isotopes ^{253}No and $^{252-254}$No, respectively (data analysis in progress).

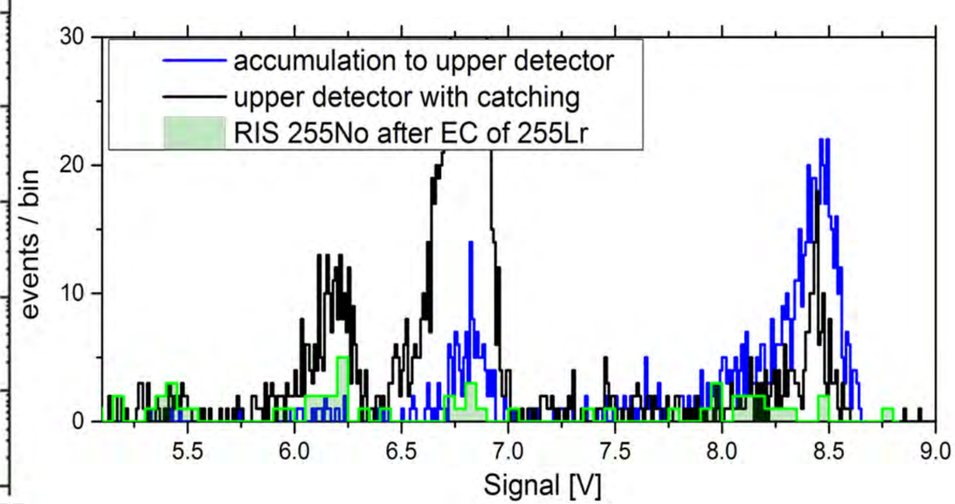
- Different Rydberg series were observed. A very accurate value for the first IP of nobelium was extracted.

- The level energy for the intermediate state $^3D_3$ was obtained.

Future prospects:

- First experiments on the element lawrencium (Z=103) performed
  - Studying desorption and surface ionization mechanisms ...
  - First level search initiated (no resonances found so far)
- Test of laser resonance ionization of ^{255}No (via EC from ^{255}Lr)





Thank you for your attention!

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IPNO
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Motivation

- Atomic Physics:

  ➔ Study relativistic effects and how they influence the electronic structure

  ➔ Provide a benchmark for atomic theories

- Nuclear Physics (via hyperfine structure studies):

$$\Delta E_{HFS} = f(A, B, I, J)$$

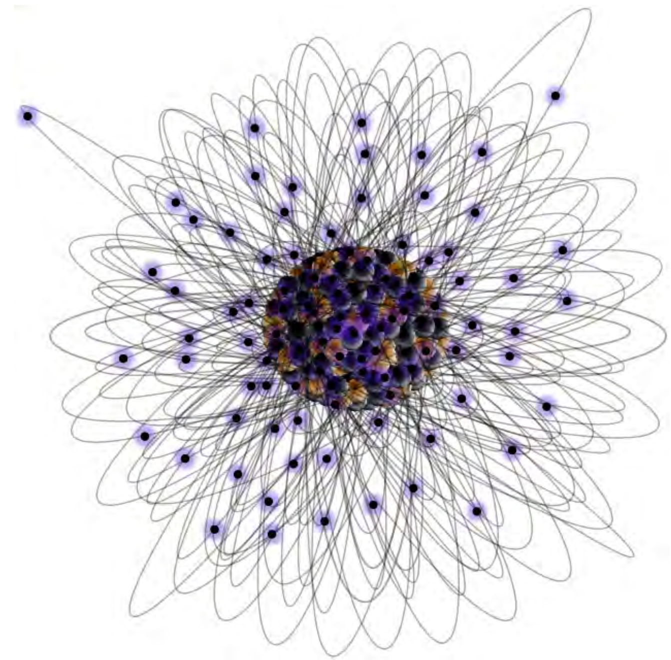
  ➔ Study nuclear spin coupling

  ➔ Extraction of nuclear moments

$$A = \mu \frac{B_e(0)}{IJ} \; ; \quad B = eQ_s \left\langle \frac{\delta^2 V}{\delta z^2} \right\rangle$$

- Nuclear Physics (via isotope shift measurements):

  ➔ Extraction of changes in the mean square charge radii



Nobelium Atom