Precise determination of the ionization potential of astatine by in-source laser spectroscopy

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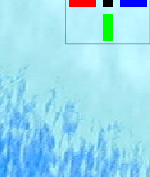
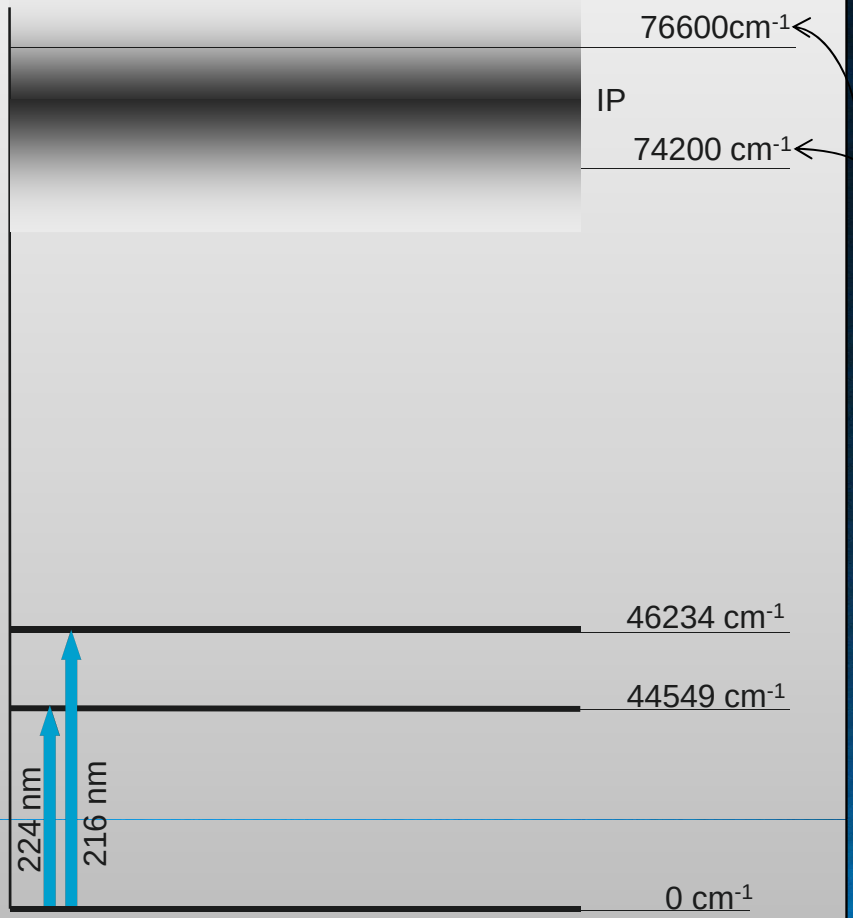
for the Astatine collaboration

Rarest element on earth: Astatine

- Most abundant isotope ^{218}At, ($t_{1/2}$ = 1.5 s)
- I.Asimov: 1st mile of earth's crust : 70mg (~3.5 atoms/ kg)
- Artificial production: ^{209}Bi(α,2n)^{210}At, Corson et al. (1940)
- First optical spectroscopy of ^{210}At, 70 ng sample, (2×10^{14} atoms), McLaughlin (1964)
- Ionization potential (IP) unknown – last in the list of naturally occurring elements





Theoretial predictions of IP(At)

Finkelnburg	1950	9.5 ± 0.2 eV
Varshni	1953	10.4 eV
Finkelnburg	1955	9.2 ± 0.4 eV
Kiser	1960	9.5 eV
Dong	2010	9.35 eV (75412 cm^{-1})

Energy Levels of neutral Astatine (from NIST)

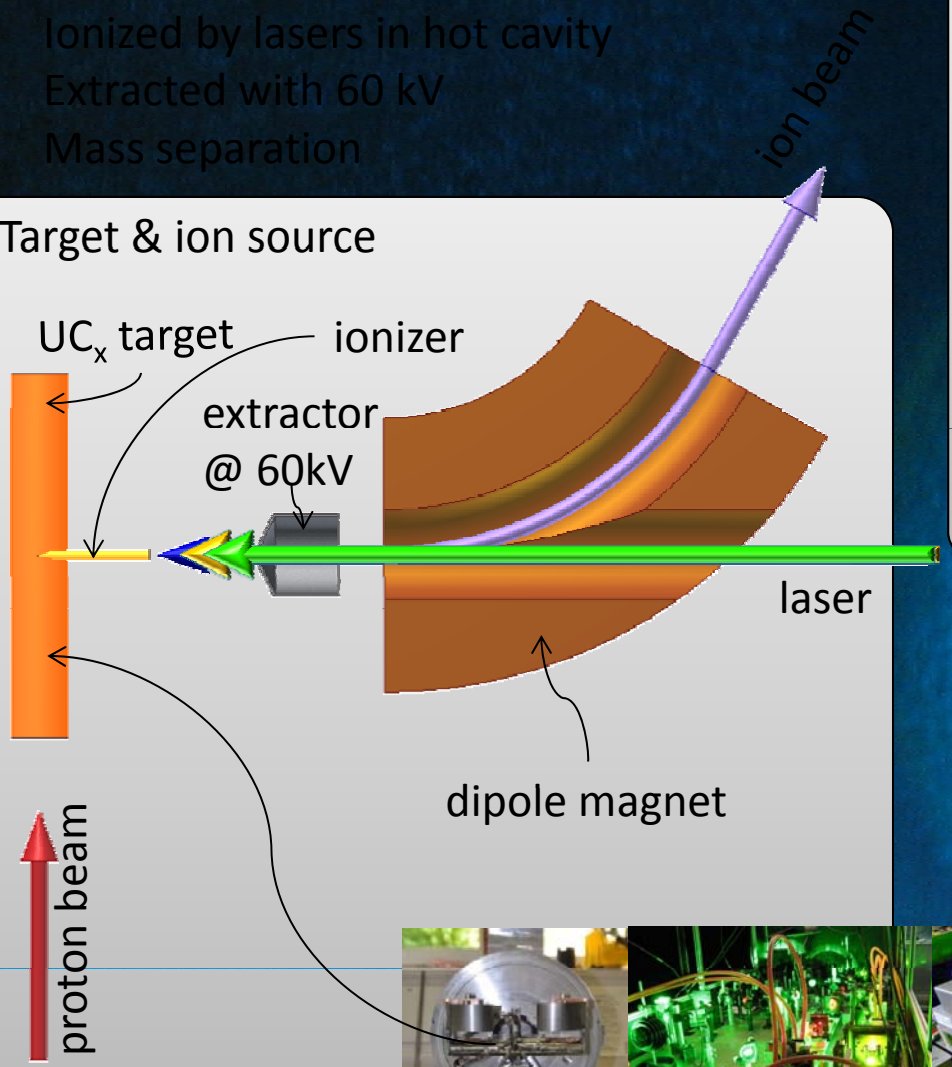
Configuration	Term	J	Level (cm^{-1})	Ref.
$6p^5$	$^2P°$	3/2	0.0	M64a
$6p^4(^3P)7s$	^4P	5/2	44549.3 ?	M64a
		3/2	46233.6 ?	M64a
At II ($^3P_2$)	***Limit***			

[M64a] R. McLaughlin, J. Opt. Soc. Am. 54, 965 (1964)

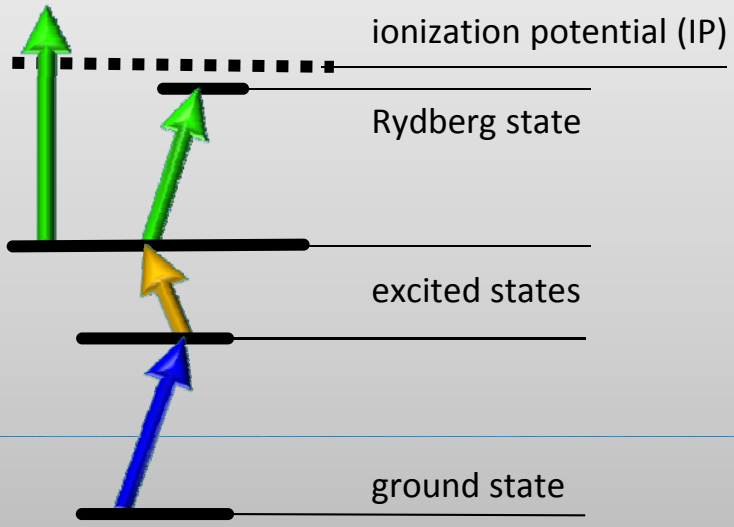
On-line production of astatine using ISOLDE/CERN

- Protons from CERN PS-BOOSTER impinge on a thick UC_x target
- Nuclear reactions produce isotopes
- Products diffuse to ionizer (2000 °C)
- Ionized by lasers in hot cavity
- Extracted with 60 kV
- Mass separation

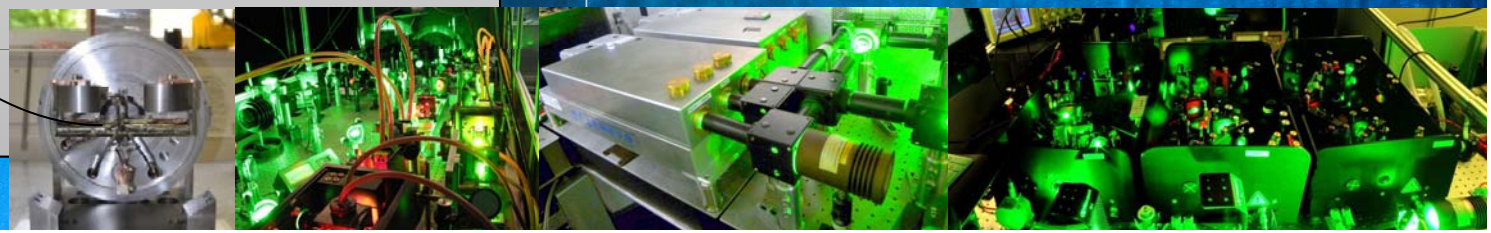
Target & ion source



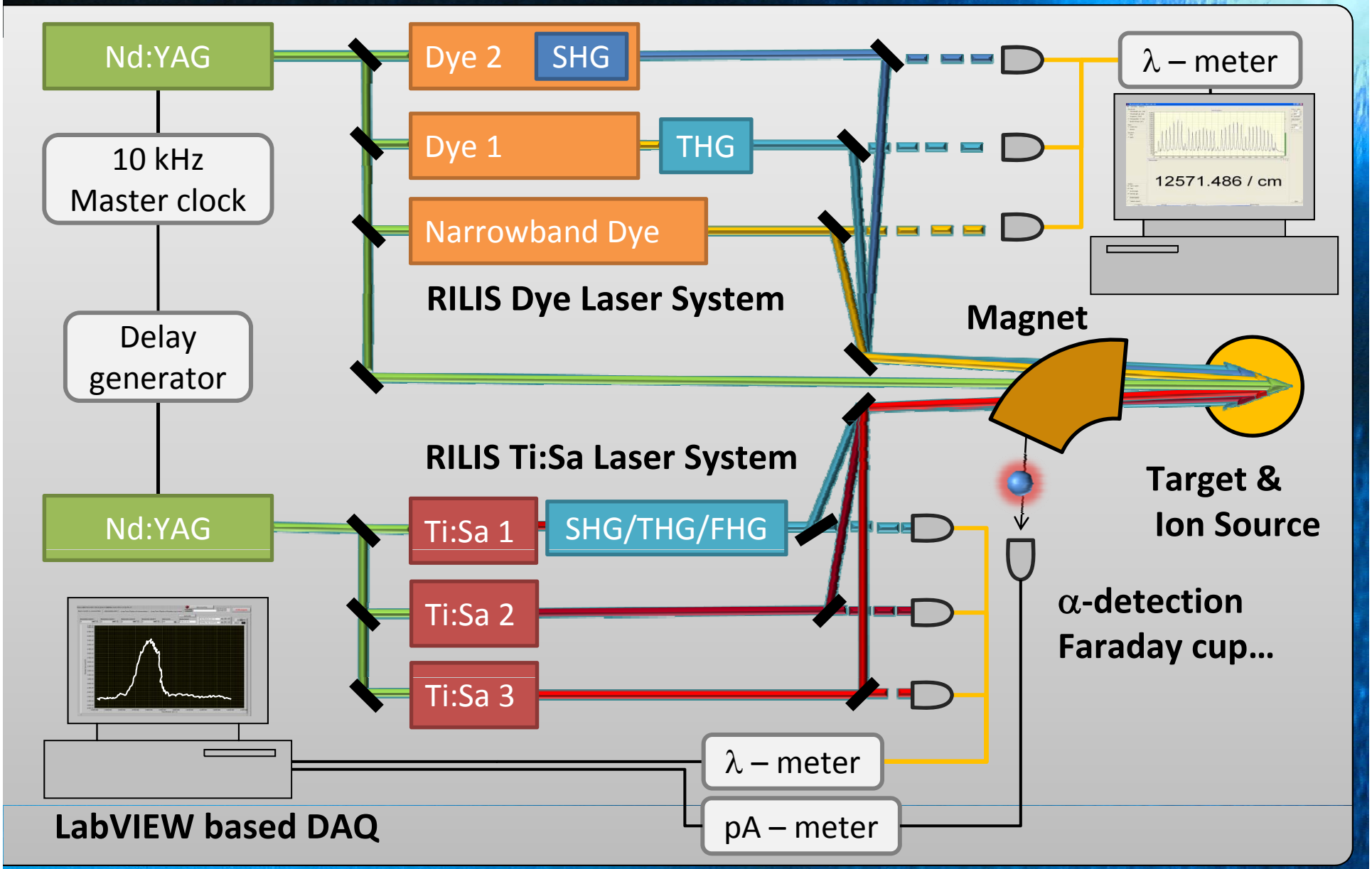
Resonance ionization laser ion source (RILIS)



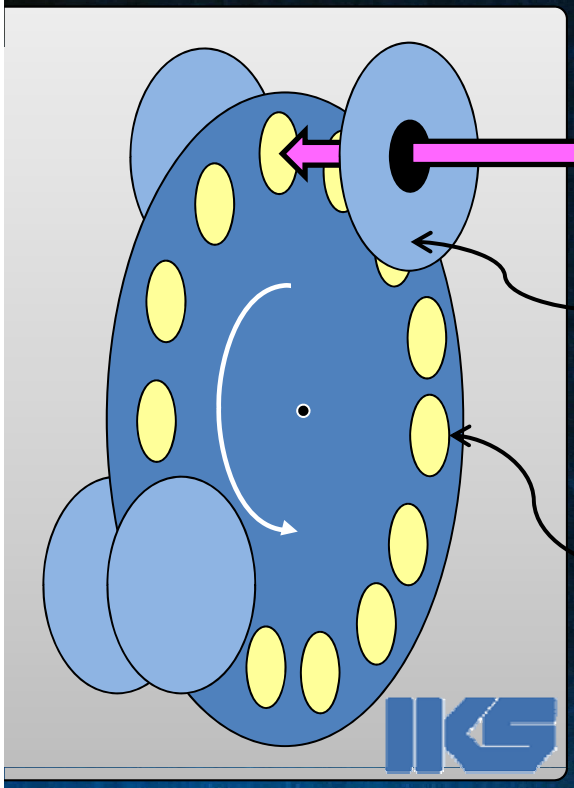
- RILIS is a standard ISOLDE ion source
- Stepwise resonant laser ionization
- Element selective & efficient
- >2500 h of RILIS operation in 2011
- Tool for in-source laser spectroscopy



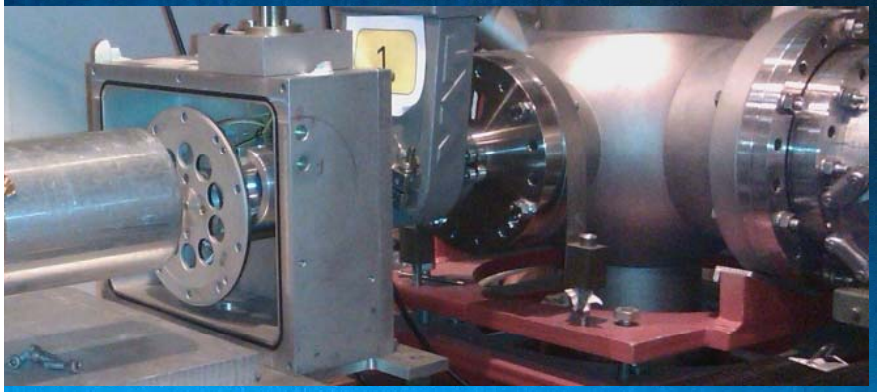
The RILIS laser setup

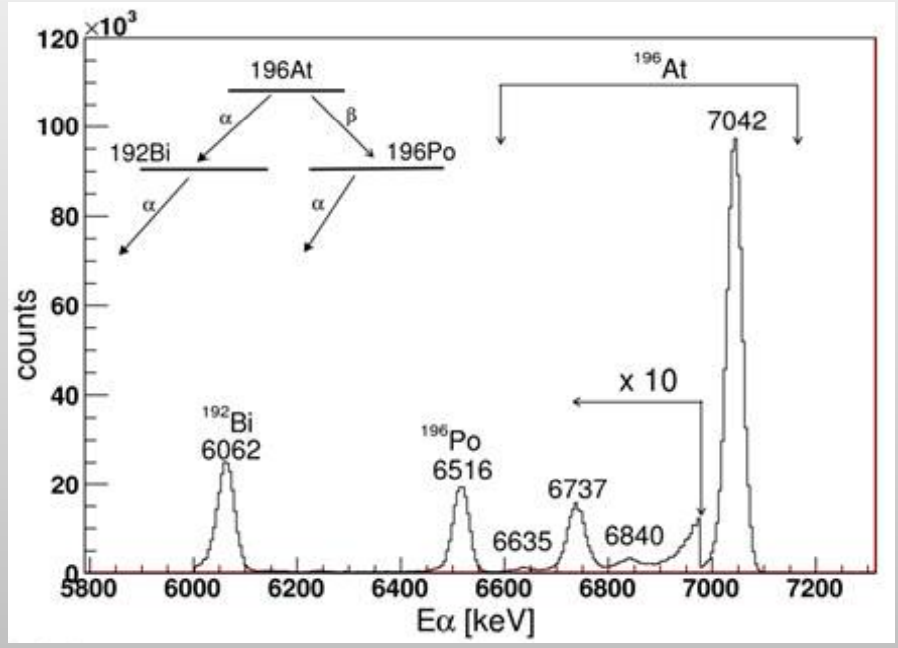


The "Windmill" α-detector



- ion beam implanted into C foil for ~1 min.
- Radioactive isotopes decay
- Characteristic energy spectrum is recorded
- Integral of α-line gives count rate
- Very sensitive: Rates from 0.1 to 1000 s^{-1}



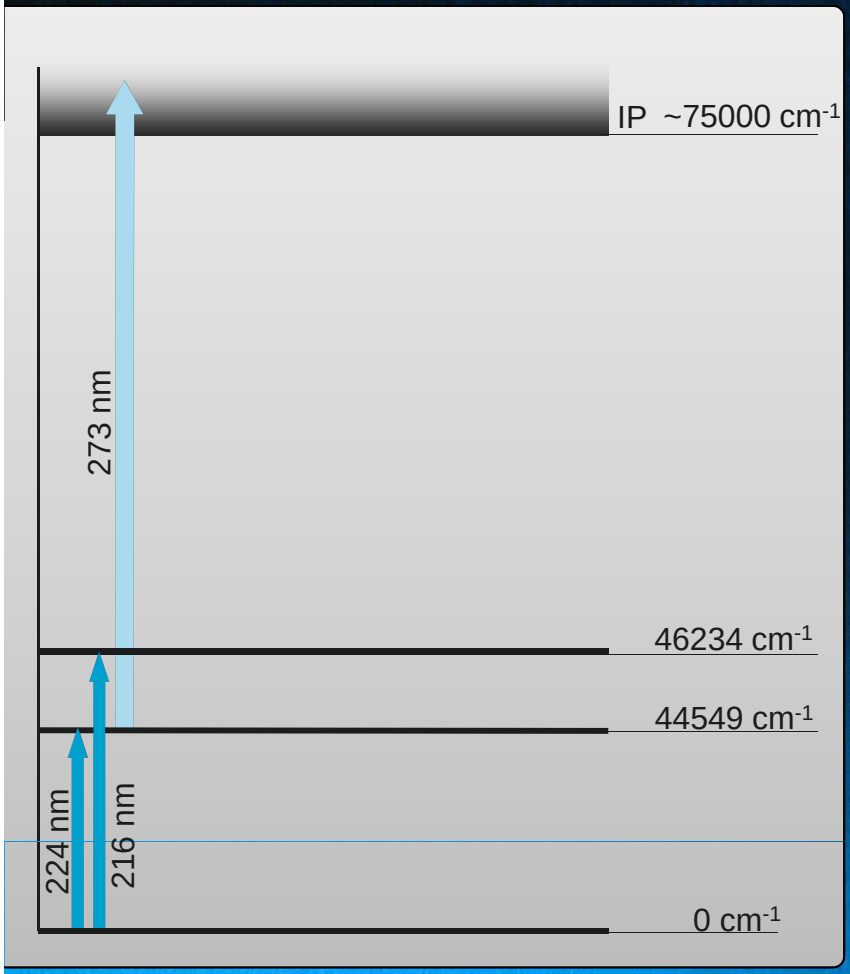


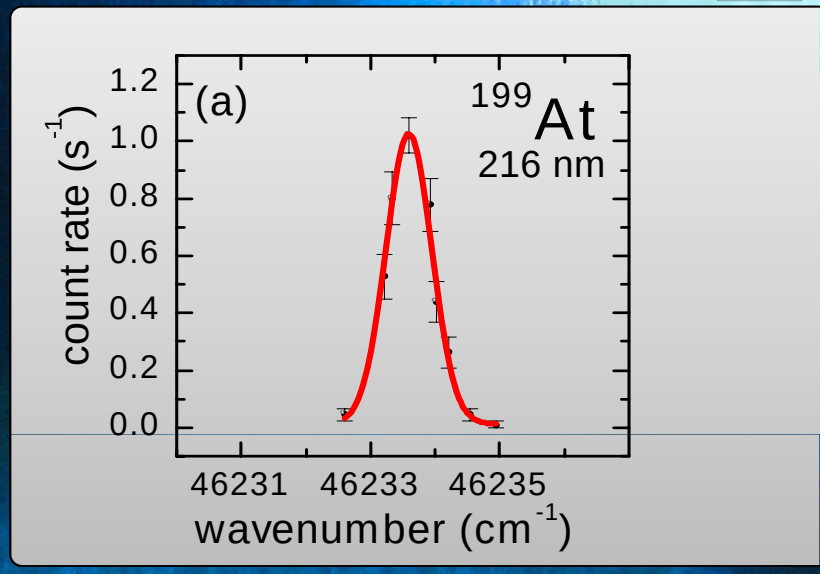
Sample α–decay spectrum.

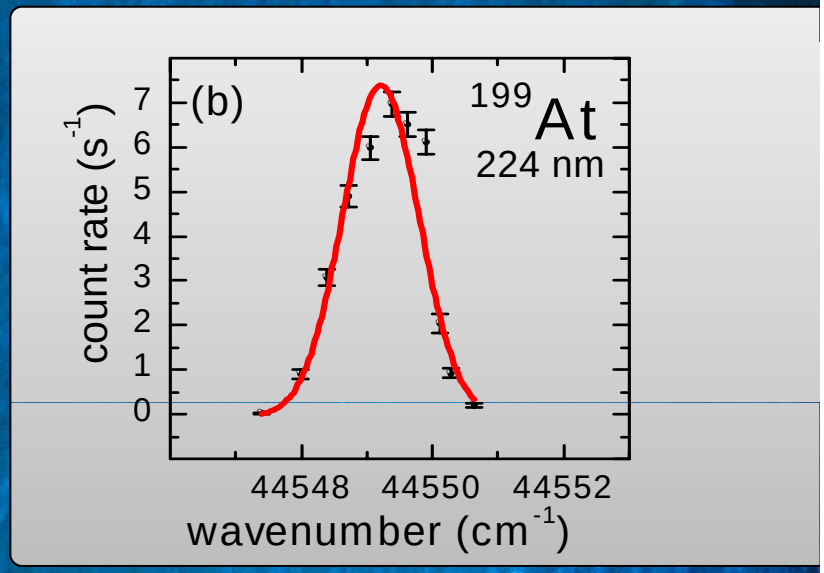
A. Andreyev et al., Phys. Rev. Lett. 105, 1 (2010).

Verification of known transitions

- ~2W @ 273 nm for non-resonant ionization
- Laser scans of 224 nm and 216 nm transitions
- Very low yields 1-10 s^{-1}
- ~5 min per wavelength step



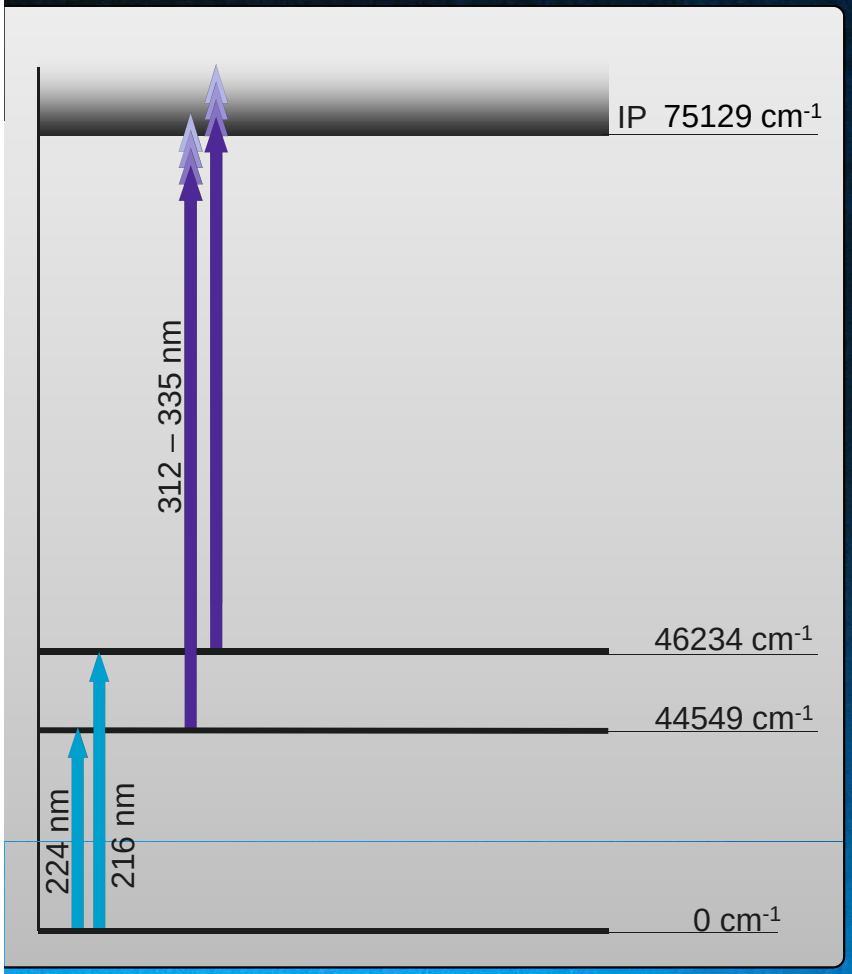


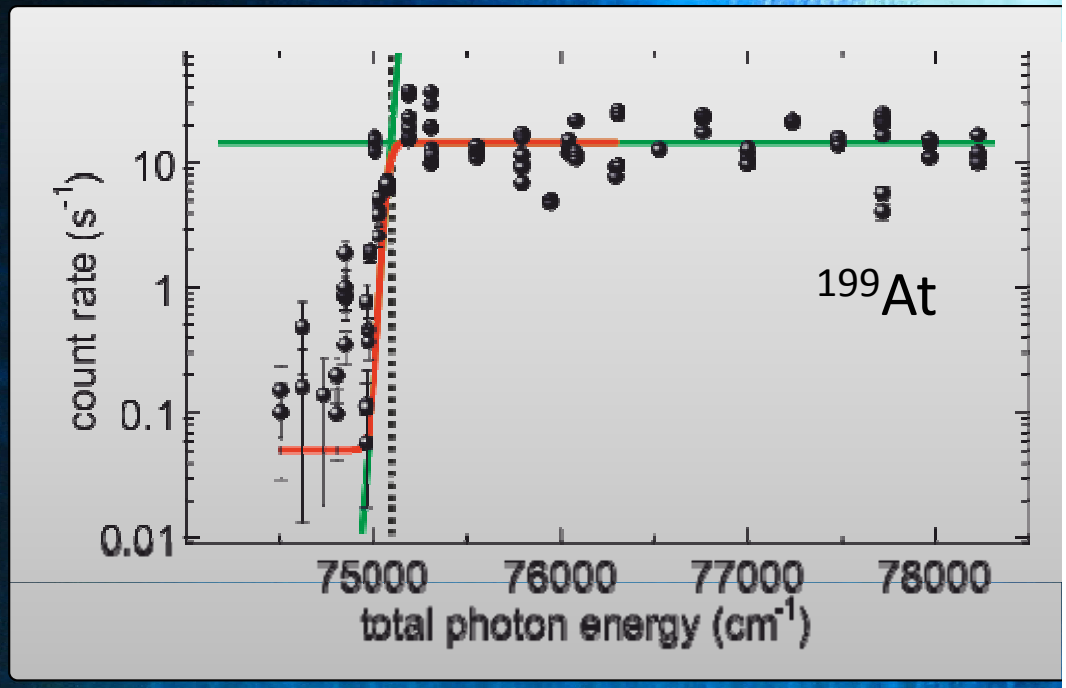


- First laser spectroscopy of At
- Transitions are from ground state

Ionizing threshold of astatine

- Laser scan of second laser
- Low resolution
- Required ~6 h data taking



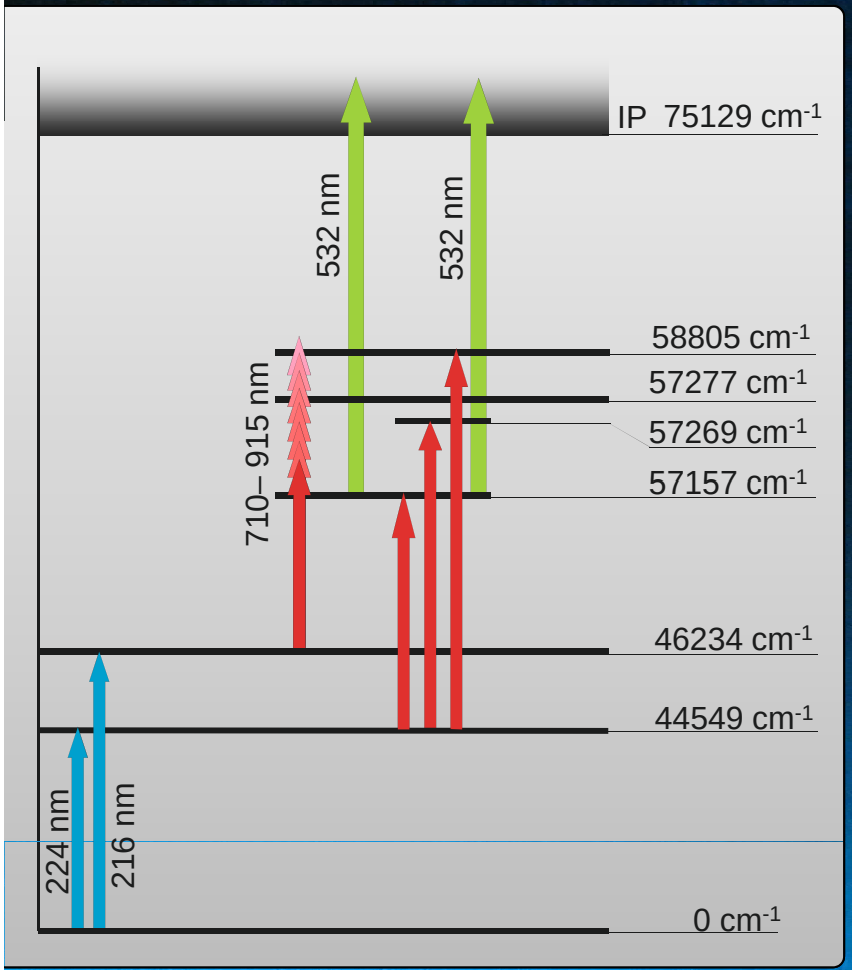


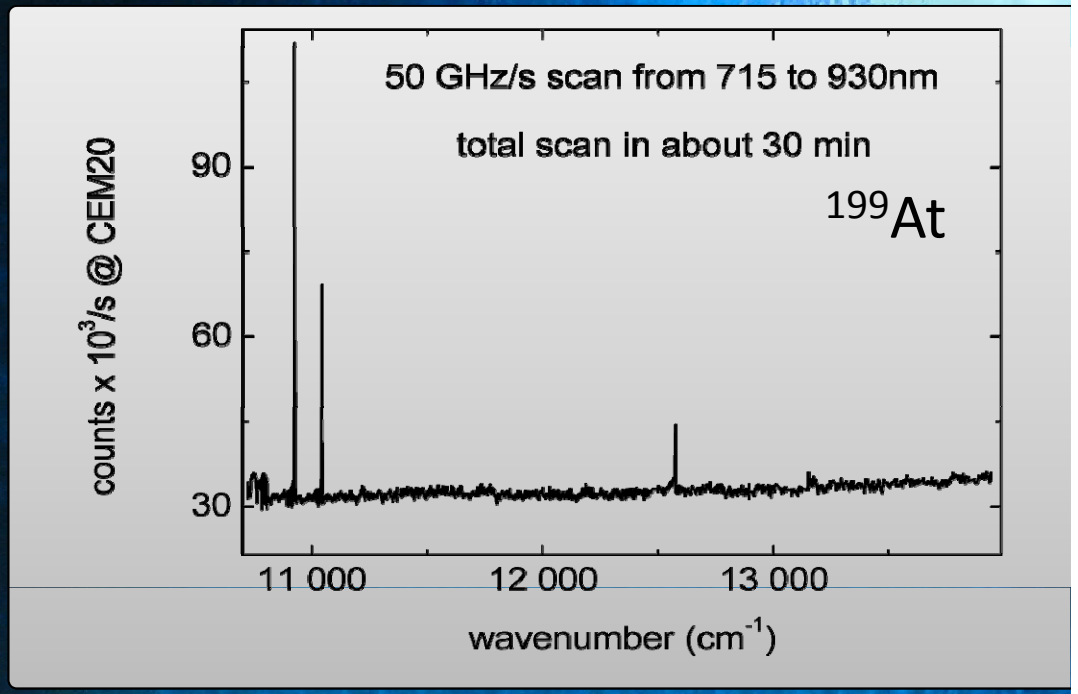
$IP_{threshold}(At) = 75129(95)\ cm^{-1}$

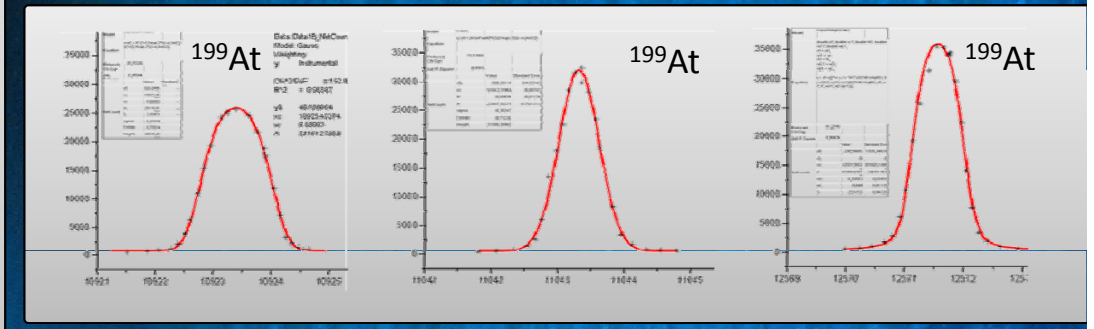
- Higher resolution needed
- low yield due to low laser power in final step
- 3-color scheme allows use of 532 nm (50W)

Towards an efficient ionization scheme

- Spectroscopy at ISAC/TRIUMF (^{199}At)
- cw proton beam from cyclotron
- 200 nm scan: 3 new transitions
- Verified at ISOLDE/CERN (^{205}At)



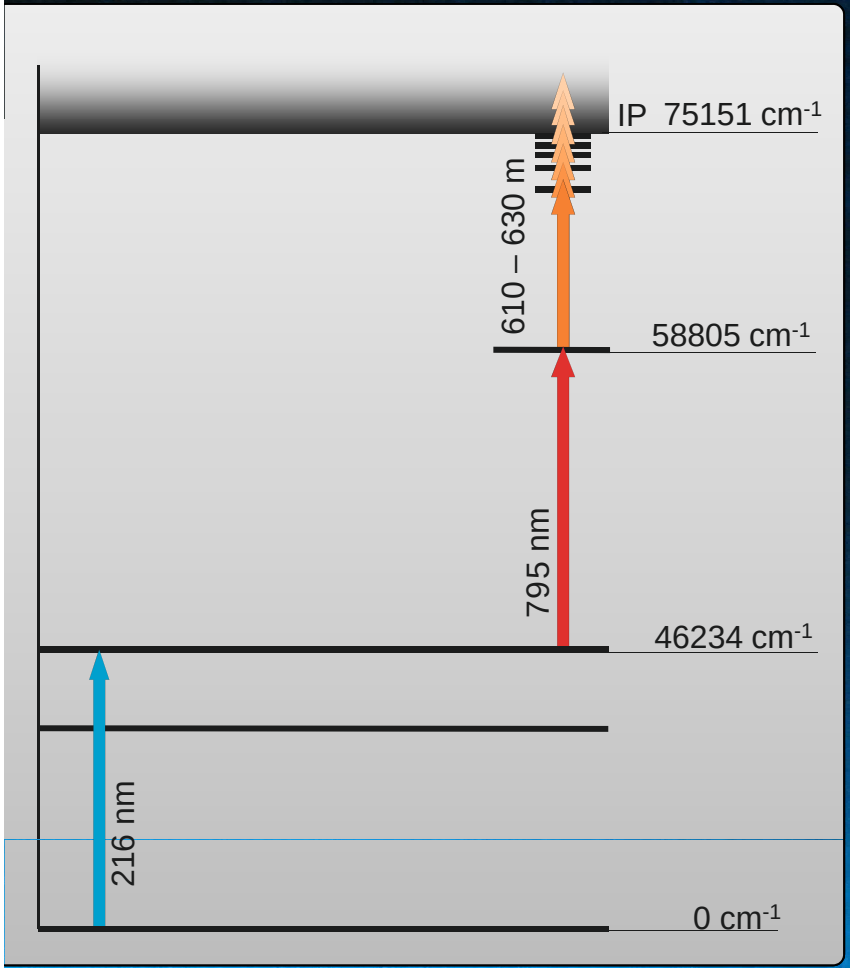


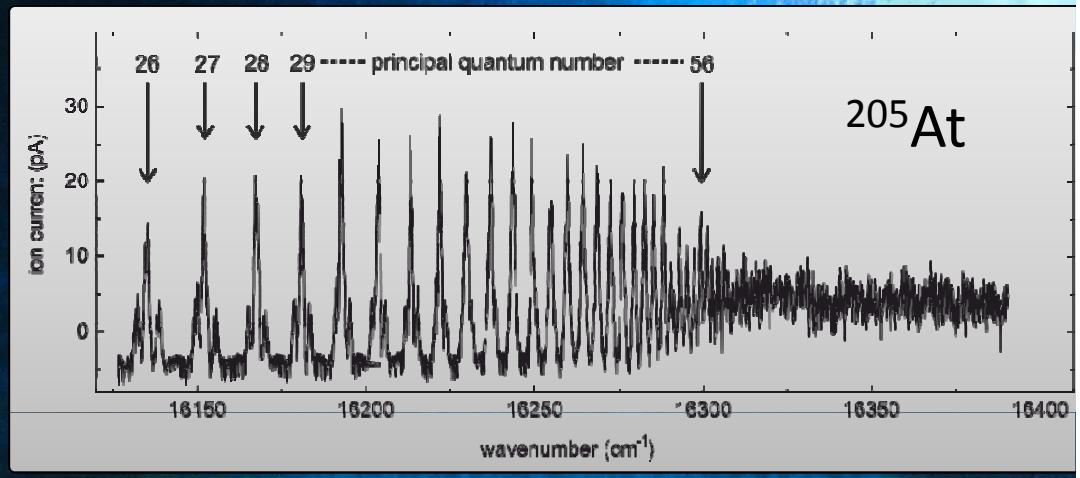


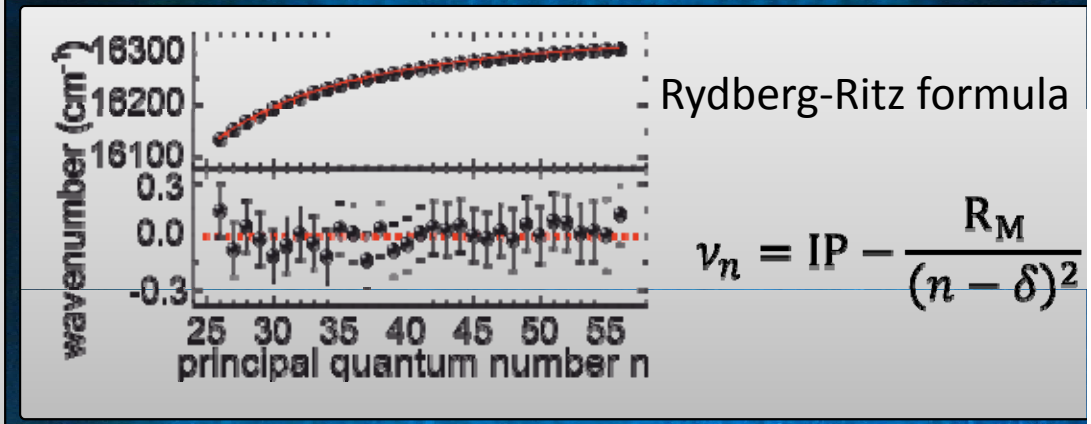
- 6 transitions, 4 new energy levels available
- Up to 150 pA of ^{205}At
- Continuously measurable with Faraday cup

Spectroscopy of Rydberg levels

- $IP_{Threshold}$ allowed choice of laser dye
- High resolution laser scan across the IP
- ^{205}At measured on Faraday cup
- >30 Rydberg levels found







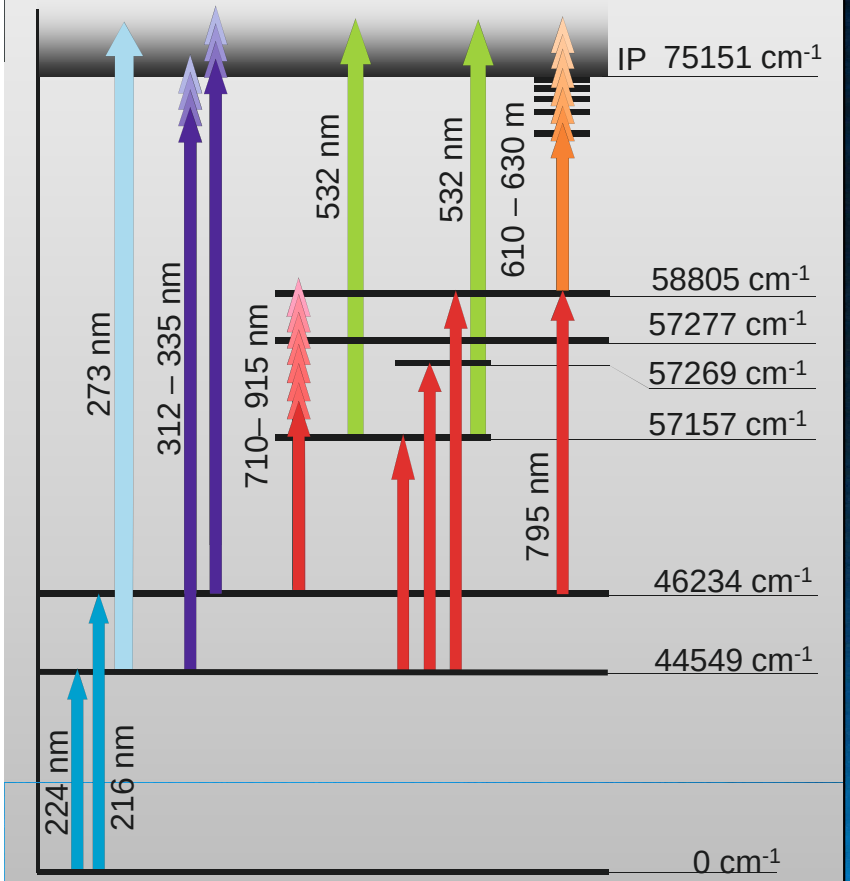
$IP_{Rydberg}(At) = 75151(1)\ cm^{-1}$

$IP_{threshold}(At) = 75129(95)\ cm^{-1}$

- Article submitted

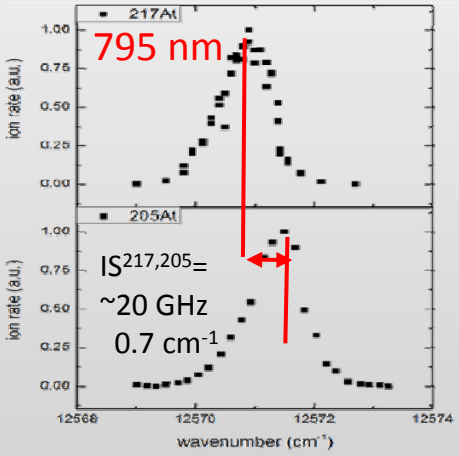
Summary

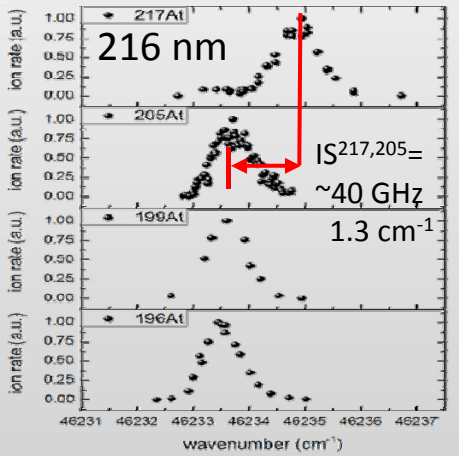
- At isotopes produced at CERN/ISOLDE
- First laser spectroscopy on At
- First measurements of IP
- Efficient 3 step ionization scheme available



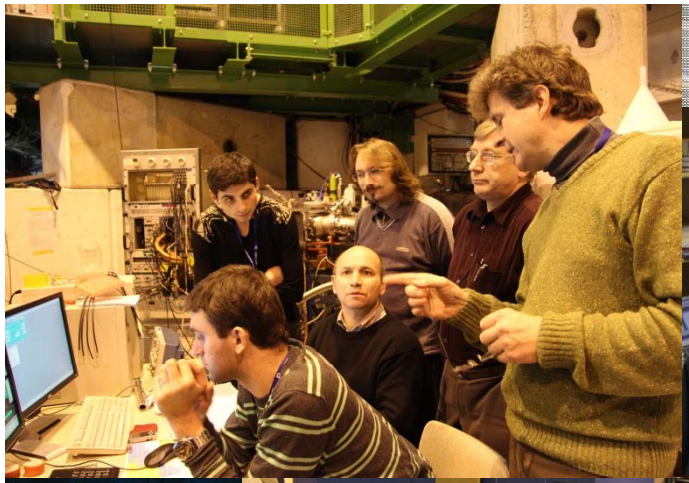
Outlook

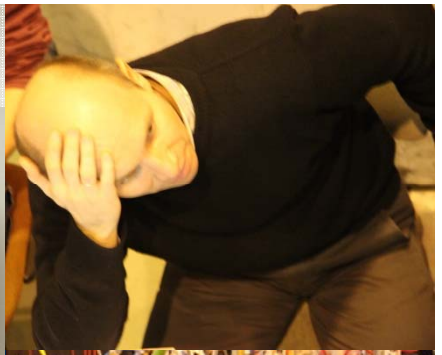
Proposal IS534
Beta-delayed fission, laser spectroscopy and shape-coexistence studies with radioactive At beams
- A. Andreev *et al.* -

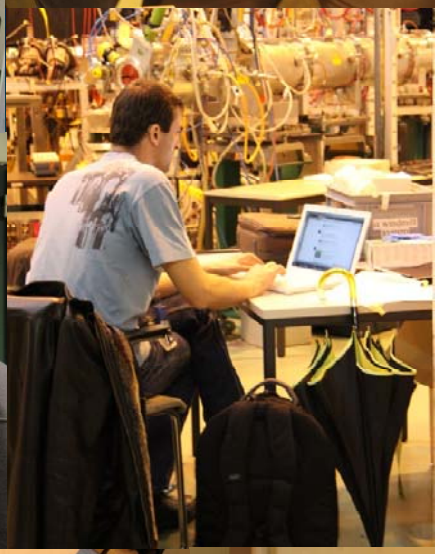
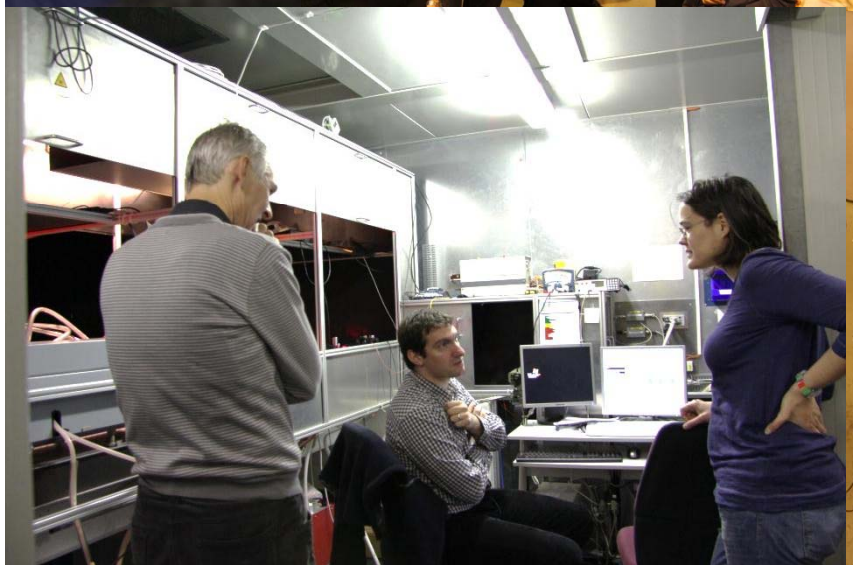


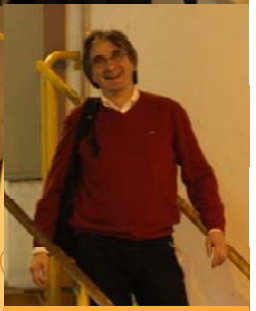
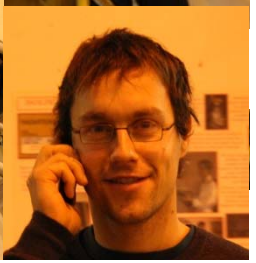


Astatine collaboration





Acknowledgements

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