# Atom Trap Trace Analysis (ATTA)

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$^{81}$Kr

$^{85}$Kr

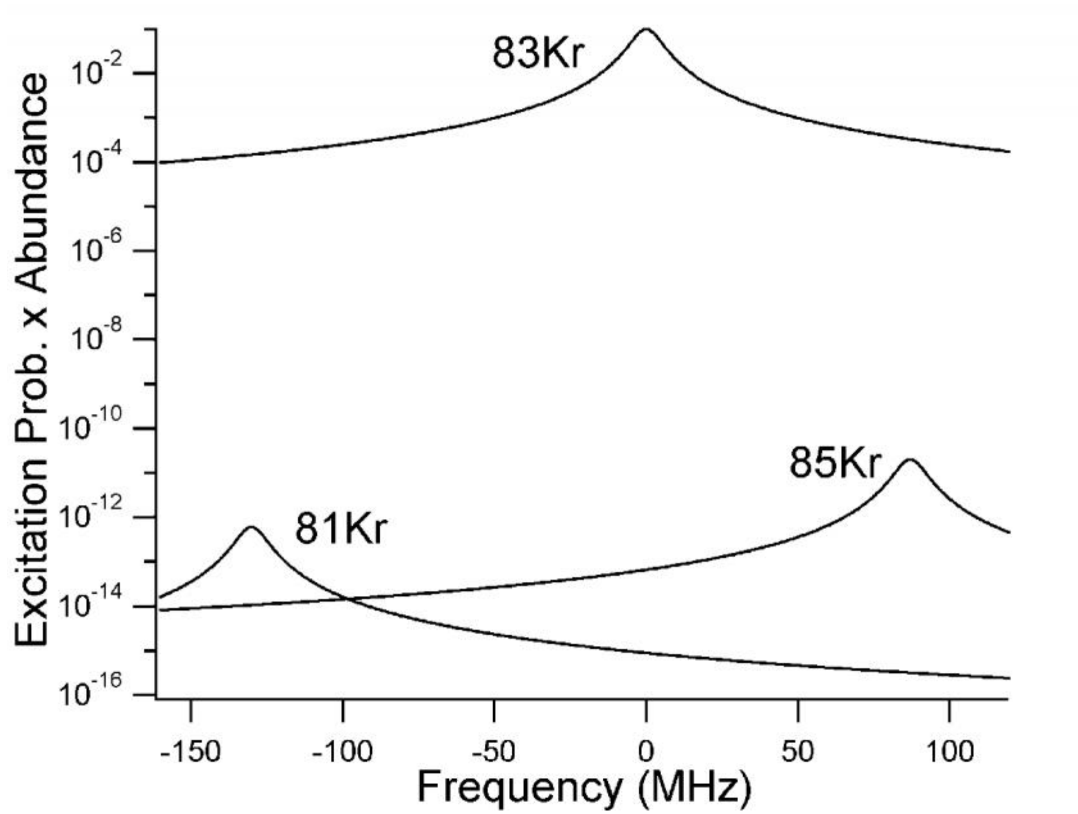
$^{39}$Ar

# Laser Methods Based on Isotope Shifts

Isotope shift due to the change in nuclear mass, charge radii and moments


$1s_5$--$2p_9$ 811nm Laser Frequency (MHz)

Prob x I.A.

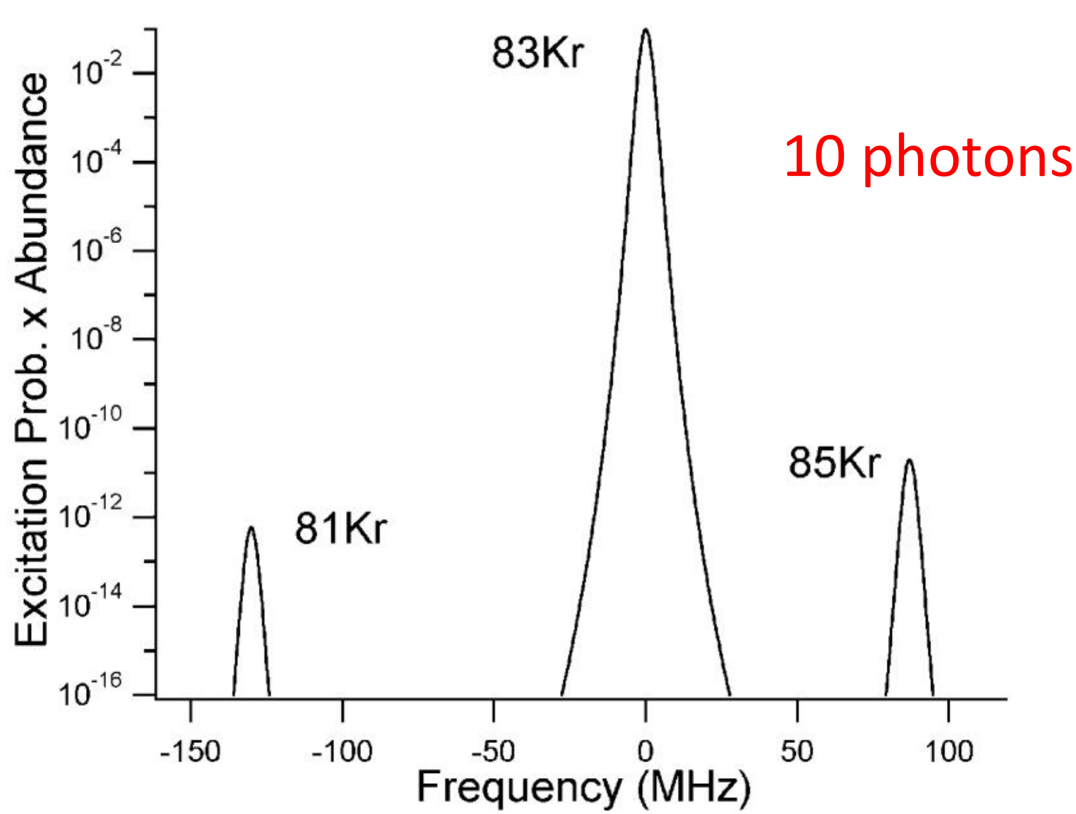


# Laser Methods Based on Isotope Shifts

Isotope shift due to the change in nuclear mass, charge radii and moments

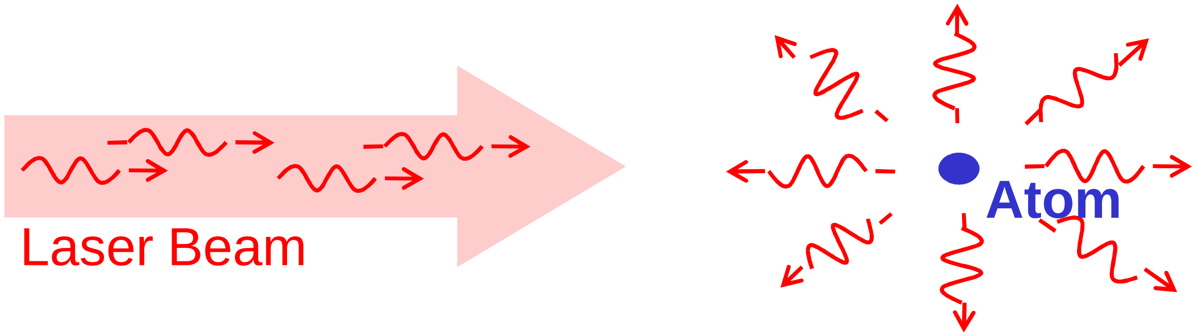

$1s_5$--$2p_9$ 811nm Laser Frequency (MHz)

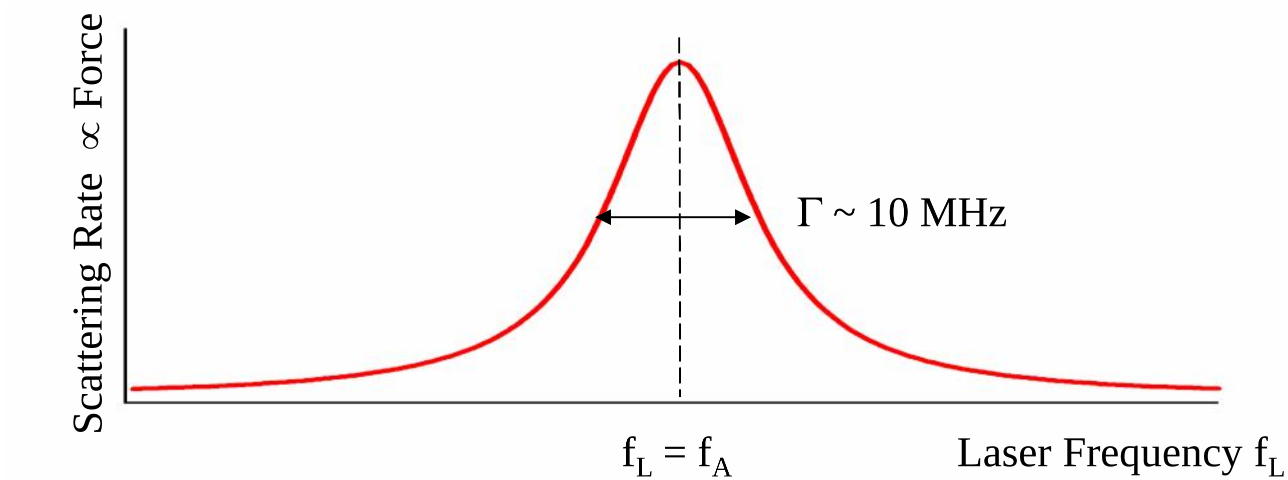
$(Prob)^{10}$ x I.A.



# Spontaneous Scattering Light Force

## Resonance & Repetition



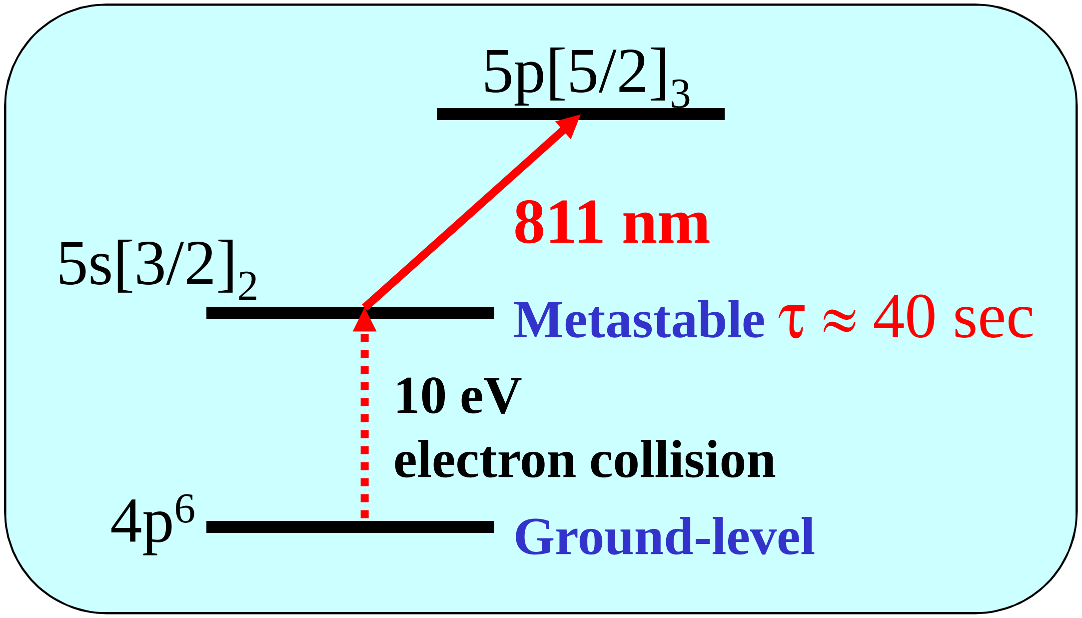

**Krypton Atom (81 amu, 811 nm)**

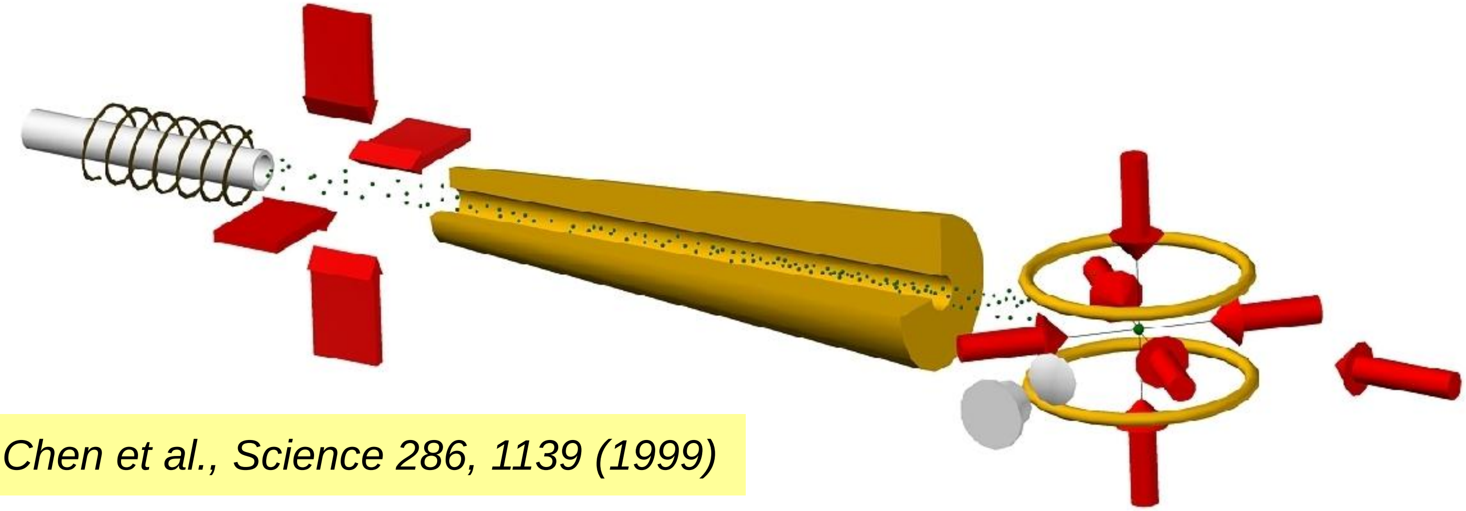
Single photon kick δv: 6 mm/sec

Transition rate: $10^7$ /sec

Acceleration: $6 \times 10^4$ m/sec$^2$

# ATTA - Krypton

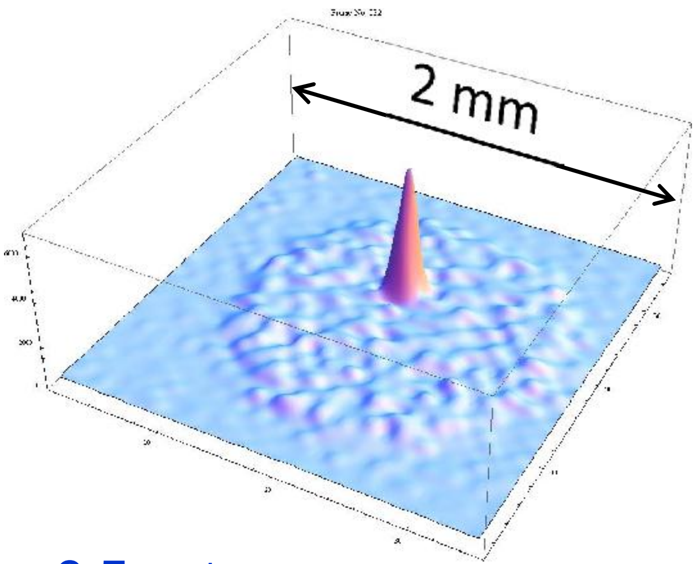


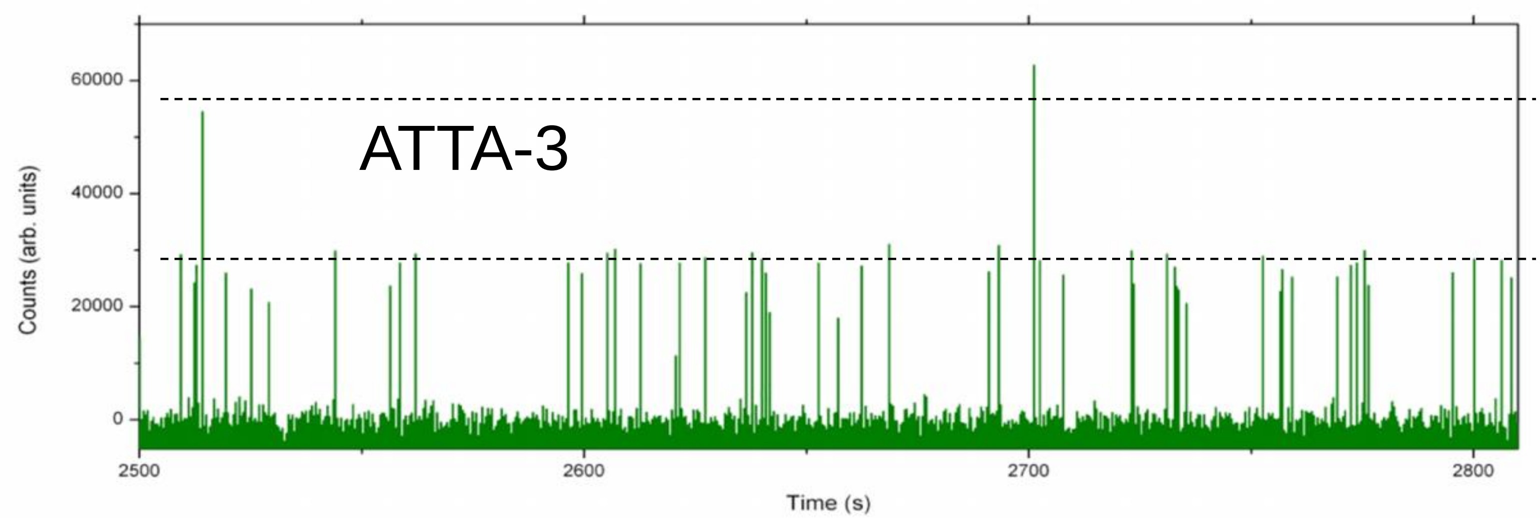
ATTA-1: *Chen et al., Science 286, 1139 (1999)*

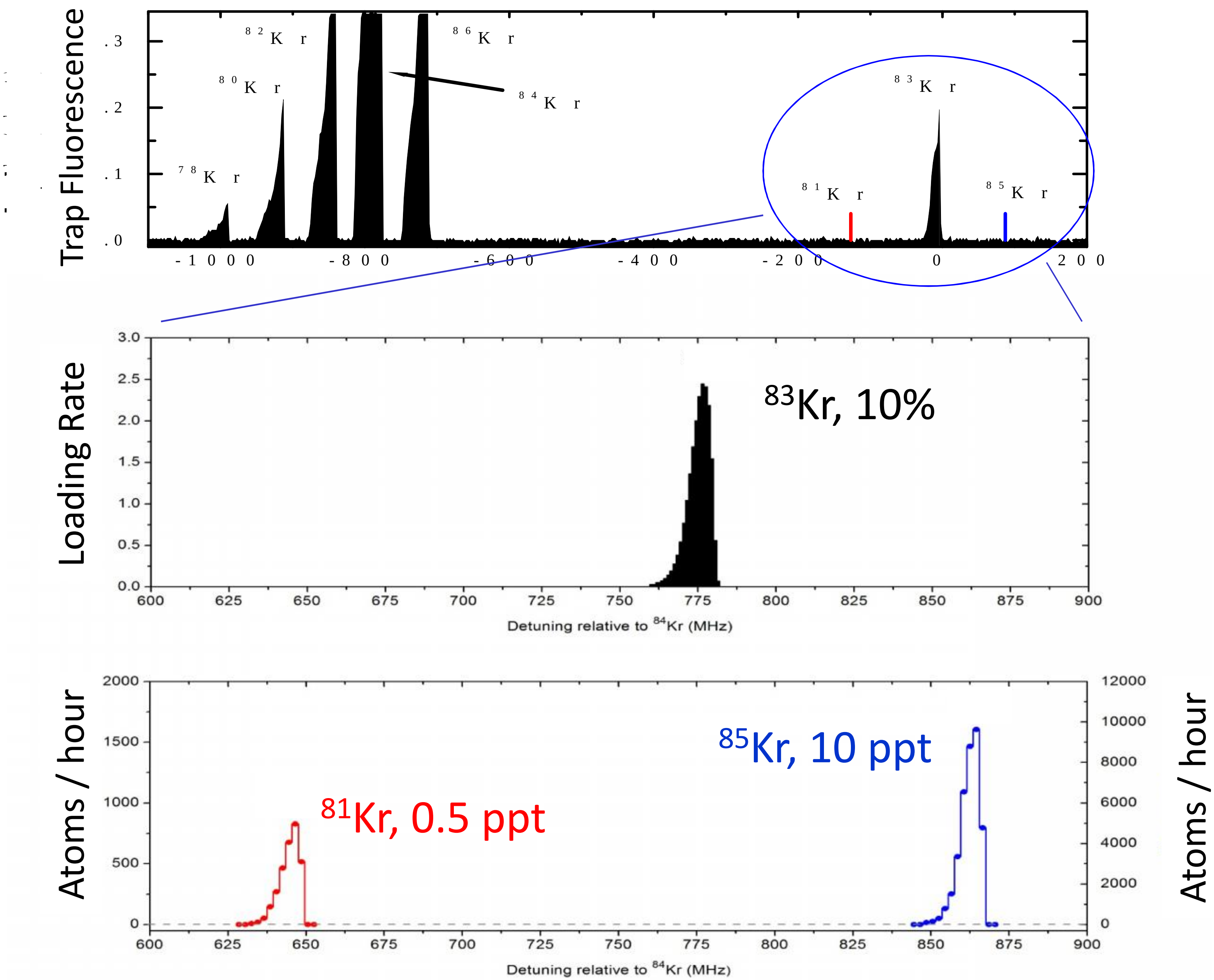
# Single Atom Detection

CCD image profile
of a single $^{81}$Kr atom




$^{81}Kr / Kr = 5 \times 10^{-13} = 0.5$ ppt

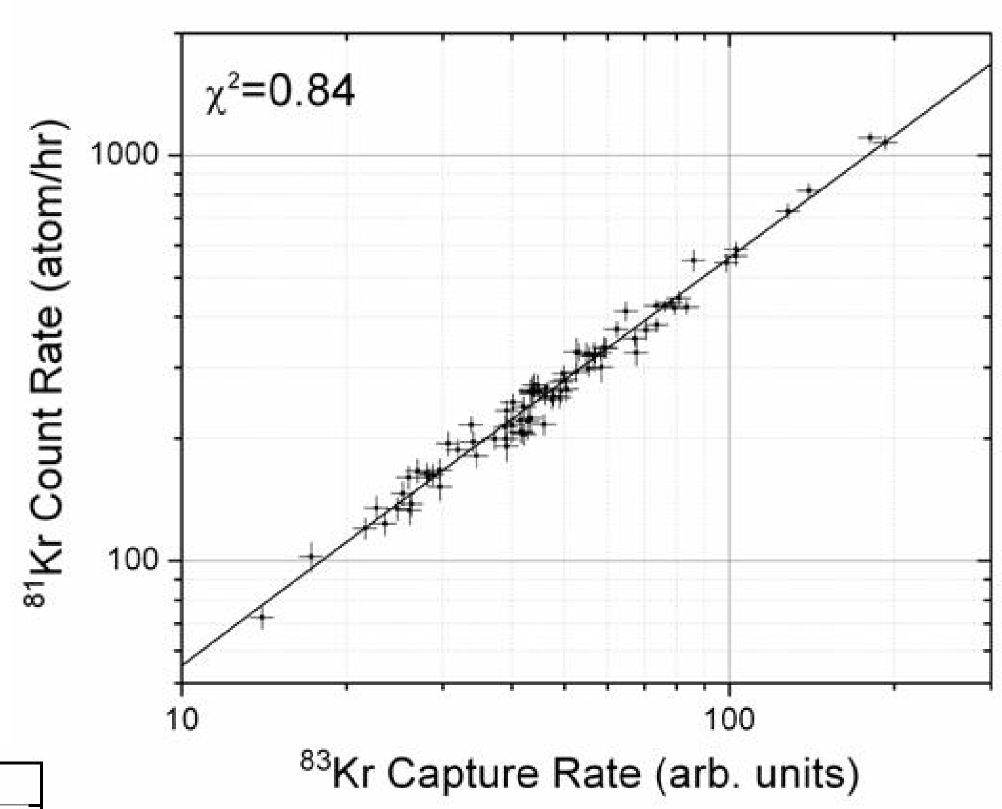


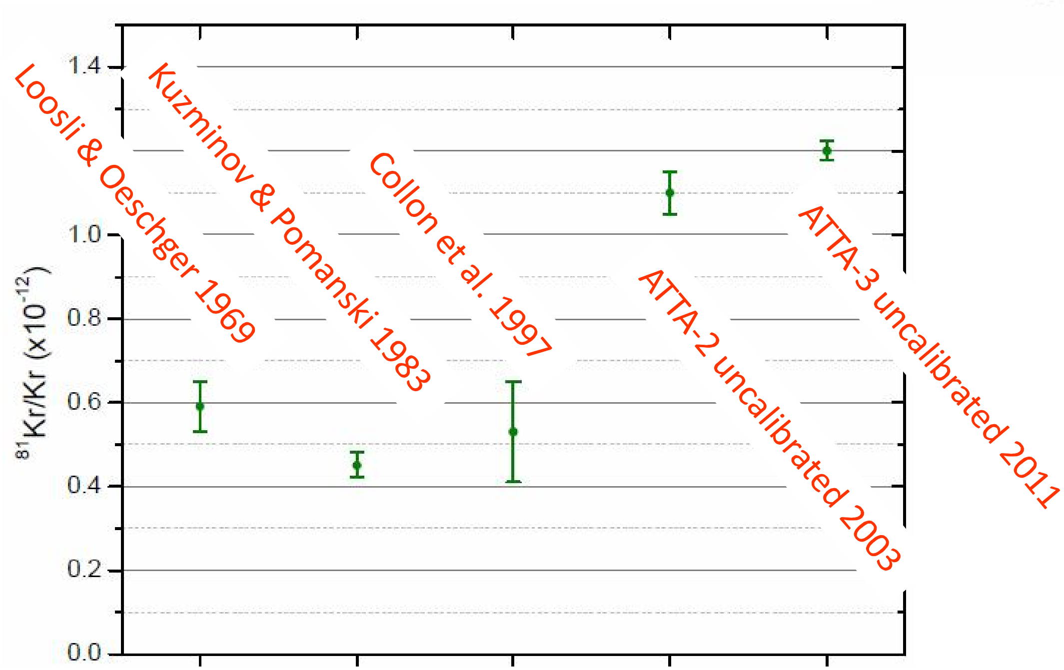


Trap Fluorescence
78Kr
80Kr
82Kr
84Kr
86Kr
81Kr
83Kr
85Kr
.0
.1
.2
.3
-1000
-800
-600
-400
-200
0
200
Loading Rate
83Kr, 10%
Detuning relative to 84Kr (MHz)
Atoms / hour
81Kr, 0.5 ppt
85Kr, 10 ppt
Detuning relative to 84Kr (MHz)
Atoms / hour

## $^{81}Kr$ / $^{83}Kr$ Isotope Ratio

- Test linearity and reliability on relative isotope ratios
- Modern samples measured under different conditions
- Vary laser power, alignment, discharge, pressure …




True isotope ratio:

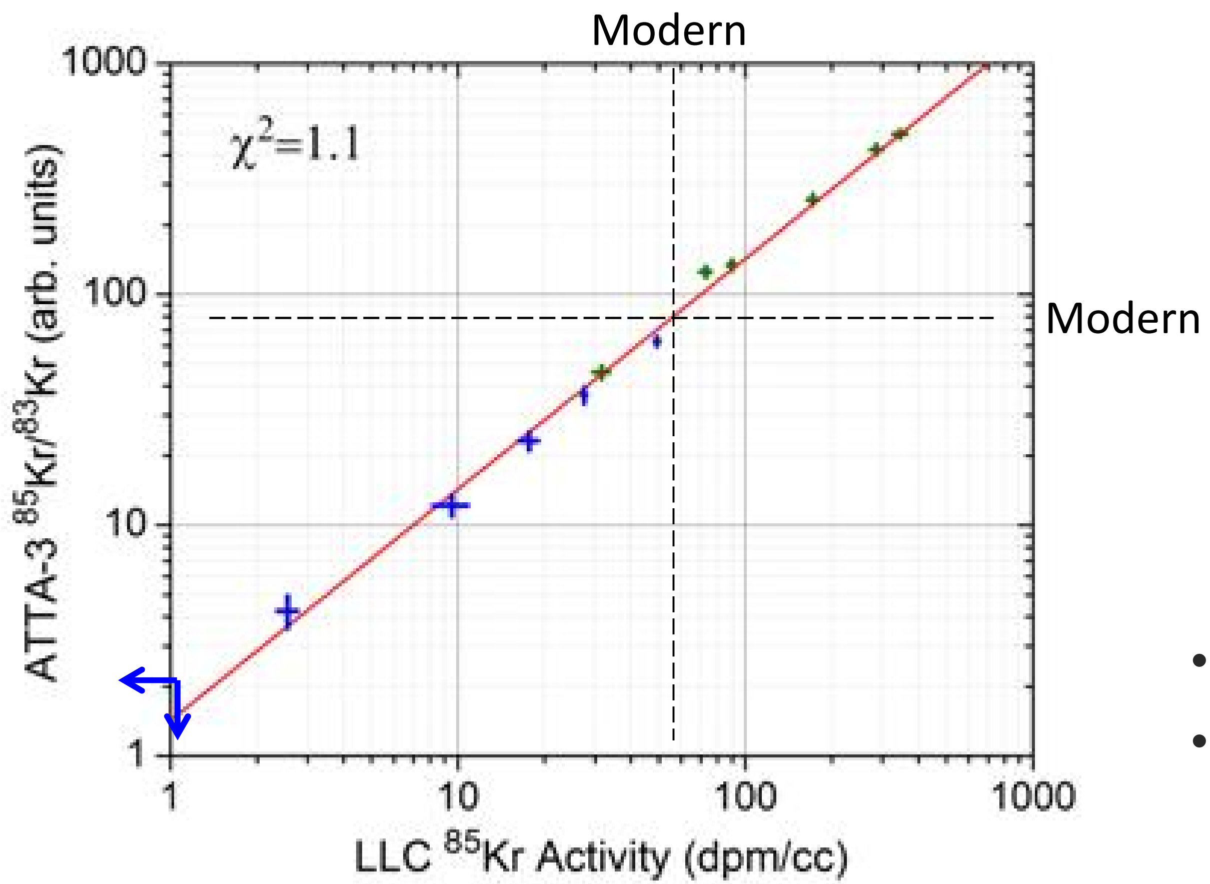
$^{81}Kr / Kr = (5.3 +/- 1.2) \times 10^{-13}$

Collon *et al.* NIM B123 (1997)

$^{81}Kr/Kr$ is the ideal integrator of cosmic-ray flux over ~ 300 kyr.

# ATTA-3 vs. Decay Counting - Roland's Test

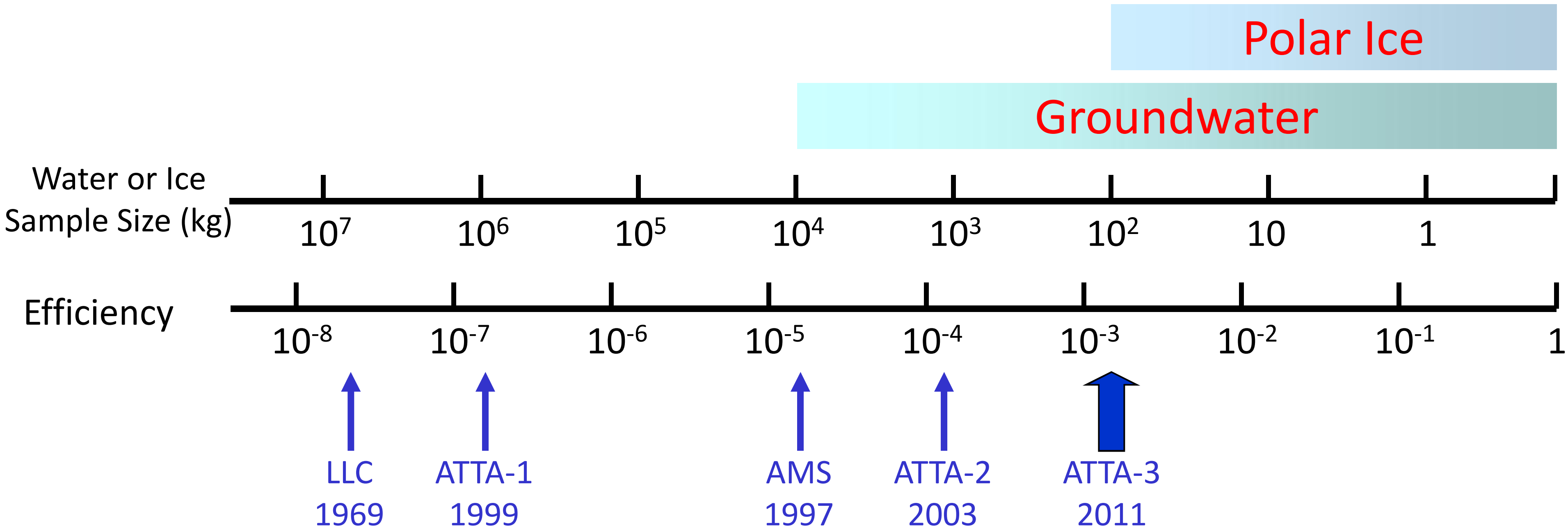
$^{81}Kr / Kr = 5 \times 10^{-13}$ $^{85}Kr / Kr = 10^{-12} – 10^{-10}$




Roland Purtschert
University of Bern

- 6 samples unblind
- 6 samples blind

# $^{81}Kr$ Dating: From Dream to Practice

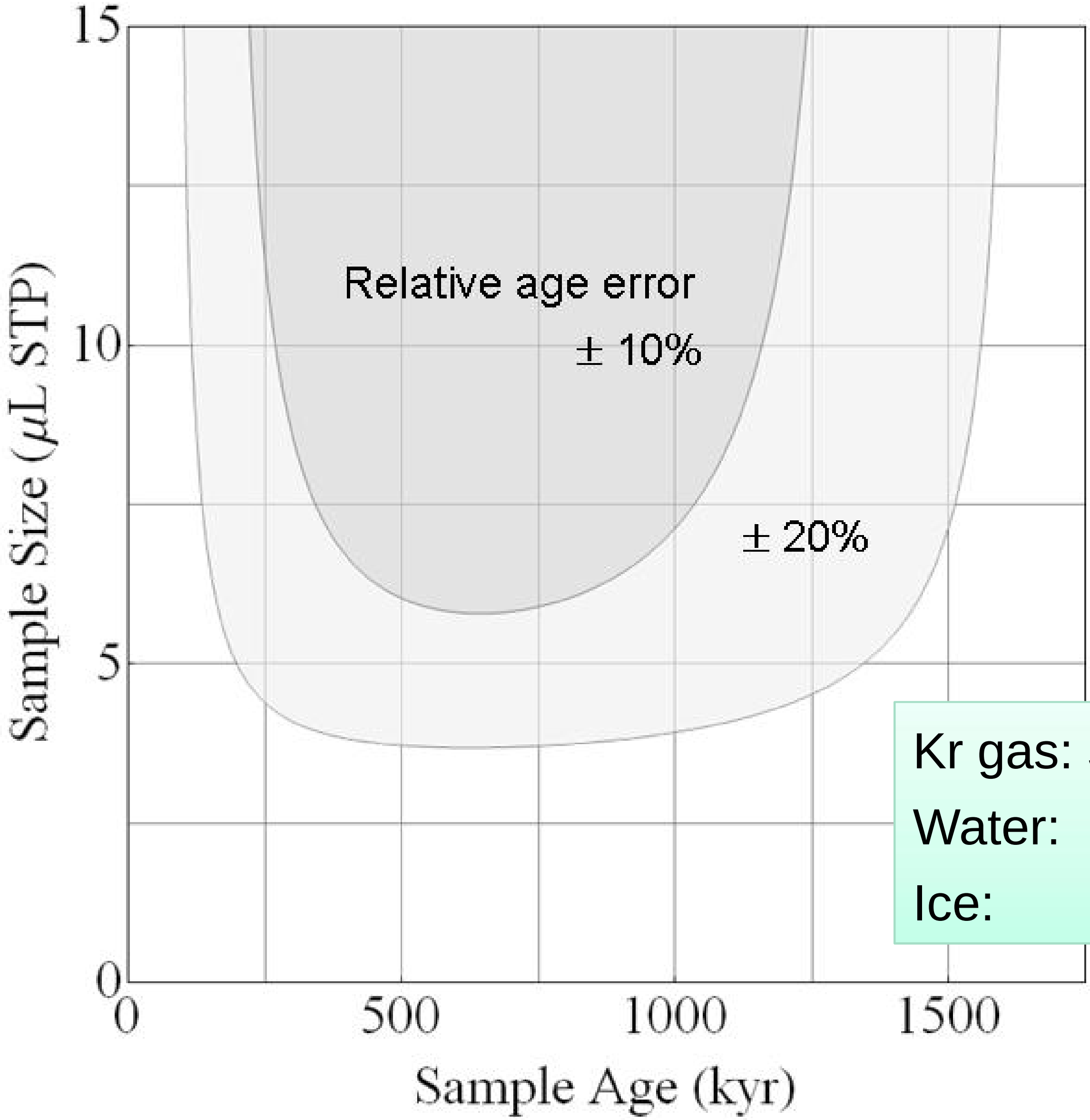



Present Status of ATTA-3:

- Selectivity requirement: Done;
- Efficiency requirements: Practical, but far from perfection


ATTA-1: *Chen et al., Science (1999)*
ATTA-2: *Du et al., Geophys. Res. Lett. (2003)*
ATTA-3: *Jiang et al., Geochim. Cosmochim. Acta (2012)*

# $^{81}Kr$ Dating: Sample Size




Kr gas: 5 - 10 micro-L

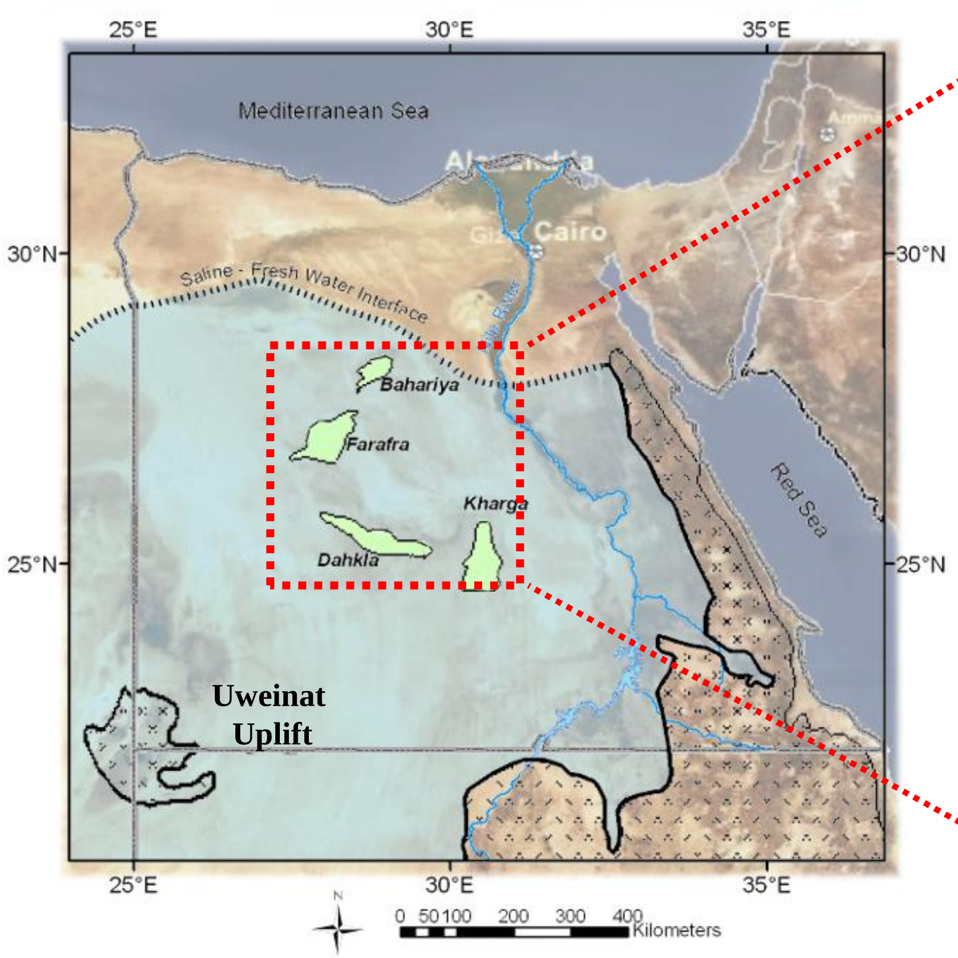
Water: 100 – 200 kg

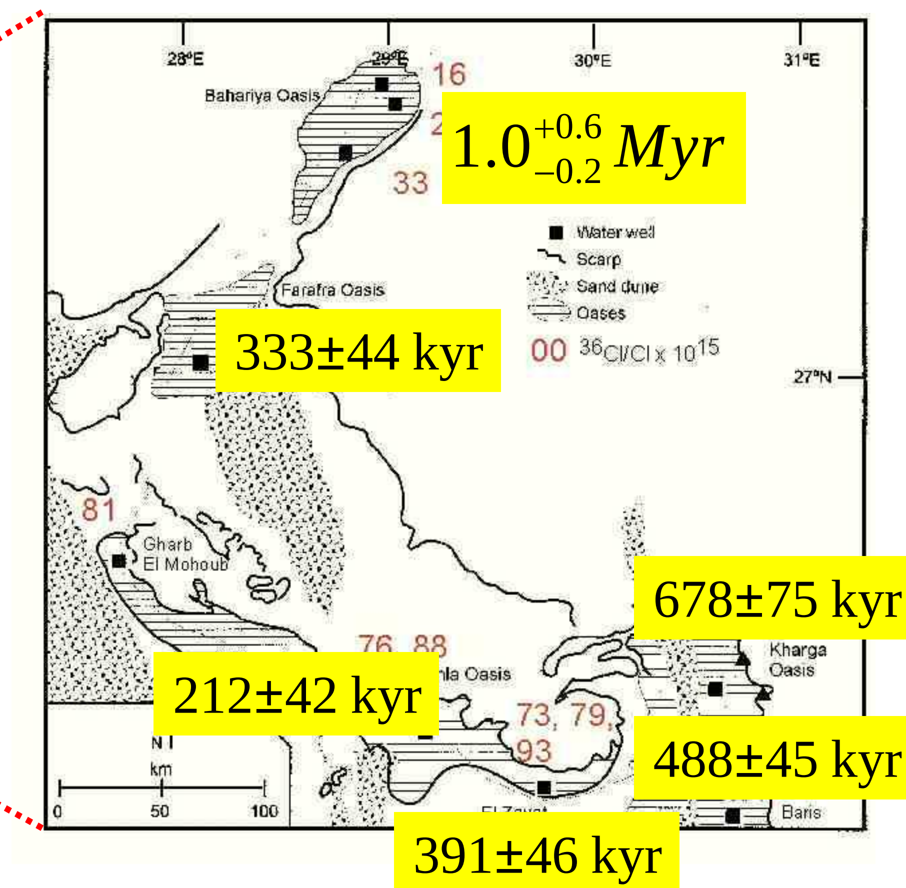
Ice: 40 – 80 kg

# One Million Years of Nubian Aquifer Groundwater History

Neil Sturchio *et al*., Geophys. Res. Lett. (2004)

- Analyses performed with ATTA-2
- Groundwater at six sites dated;
- Flow direction and speed measured.

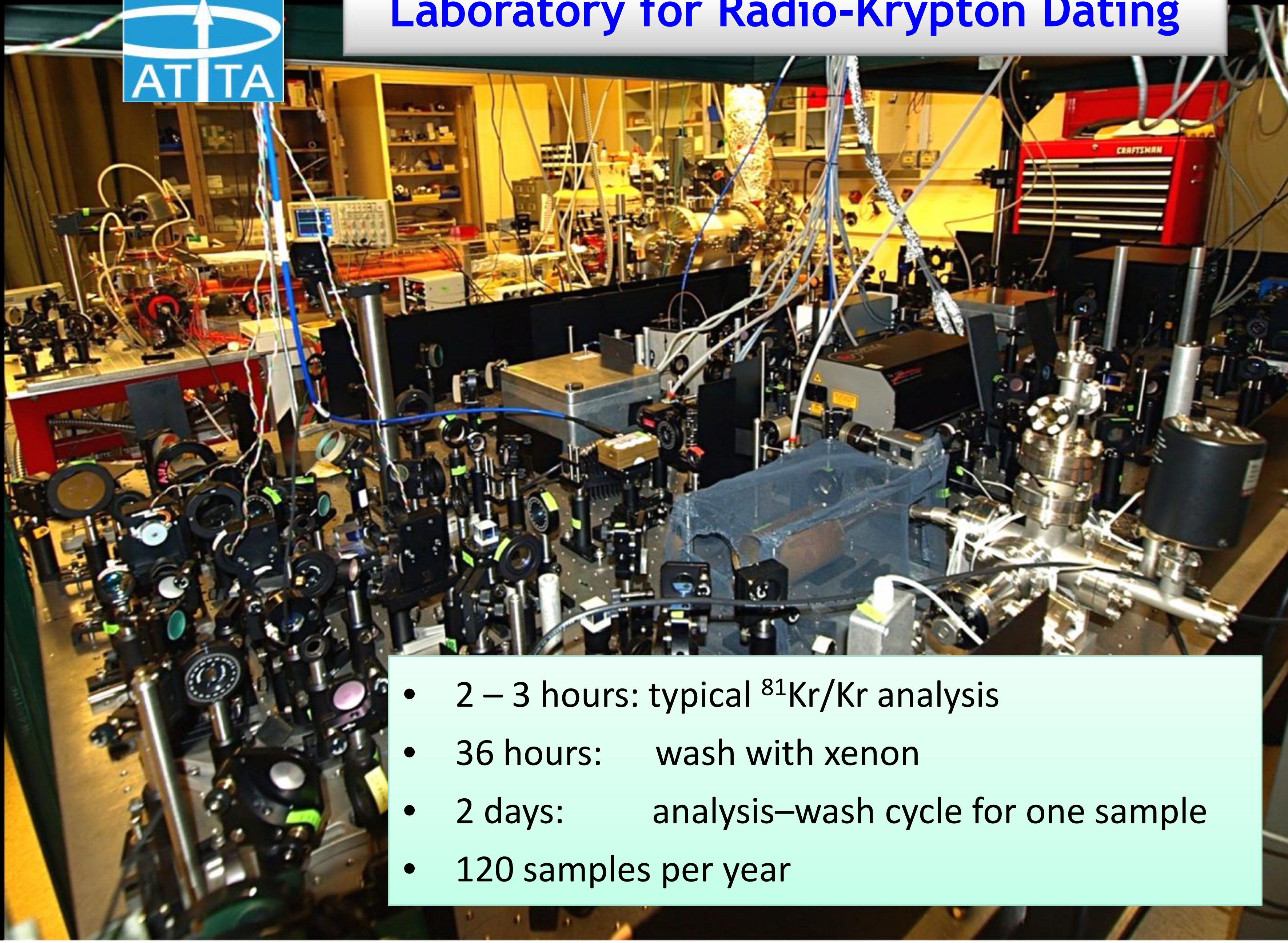


Since Nov 2011, $^{81}$Kr/Kr and $^{85}$Kr/Kr analyzed using ATTA-3

- ✓ Great Artesian Basin, Australia ---- 19 samples
- ✓ Yellowstone National Park ---------- 6 samples
- ✓ Waste Isolation Pilot Plant ---------- 2 samples
- ✓ Guarani Aquifer, Brazil --------------- 5 samples
- ✓ Locust Grove, Maryland ------------- 7 samples
- Antarctic Ice --------------------------- 4 samples
- More samples in preparation at UIC and Bern

# Laboratory for Radio-Krypton Dating



- 2 – 3 hours: typical $^{81}$Kr/Kr analysis
- 36 hours: wash with xenon
- 2 days: analysis–wash cycle for one sample
- 120 samples per year

# Summary

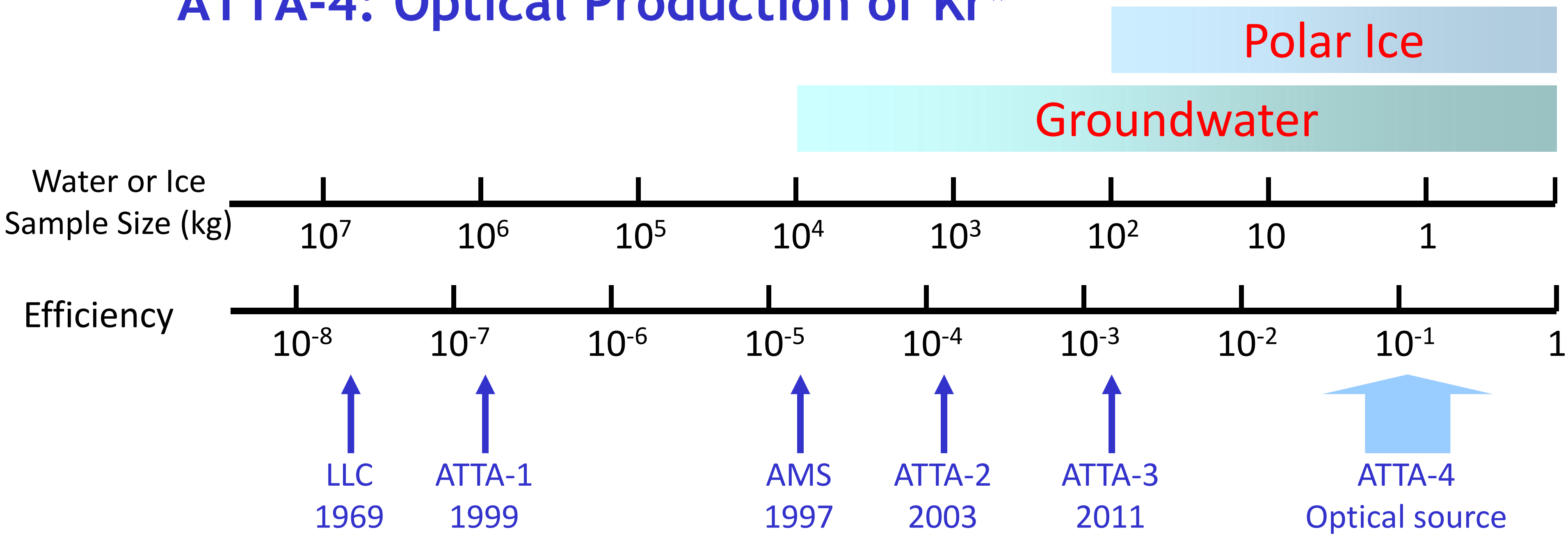
- At present
  - 5-10 micro-l of Kr; 100-200 kg of water; 40-80 kg of ice
  - 120 samples per year

- Assuming no technical advances:
  - an additional beamline → + 120 samples / year

- Incremental technical advances are possible

- Transformational advance (optical production) is under investigation

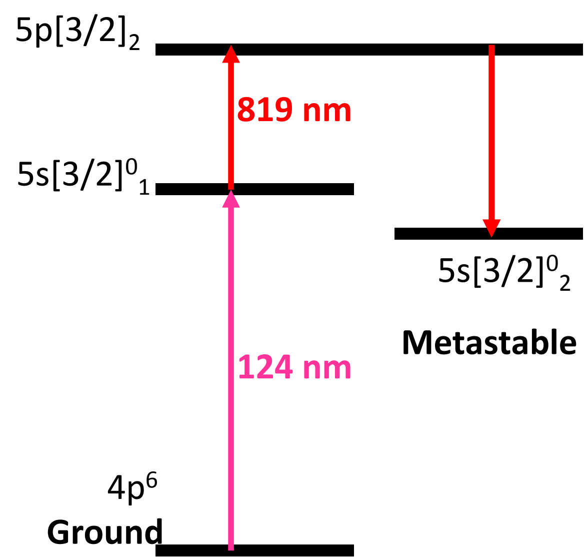
# ATTA-4: Optical Production of Kr*




Optical production of Kr*
via two-photon excitation:

124 nm + 819 nm

Young *et al.*, *J. Phys. B* (2002)
Ding *et al*. *RSI* (2007)




## ATTA Team

Wei Jiang
Will Williams
Kevin Bailey
Zheng-Tian Lu
Peter Mueller
Tom O'Connor

## Collaborators on ATTA Development

| | |
|---|---|
| Andrew M. Davis | University of Chicago |
| L. Young & R. Dunford | Chemistry Division, Argonne |
| Shuiming Hu | University of Science & Technology of China |
| B. Mack Kennedy | Lawrence Berkeley National Lab |
| Roland Purtschert | University of Bern |
| Neil C. Sturchio | University of Illinois at Chicago |
| Charles Sukenik | Old Dominion University |
| Reika Yokochi | University of Chicago |

## Other ATTA Efforts

| | |
|---|---|
| Shuiming Hu | University of Science & Technology of China |
| Markus Oberthaler | Heidelberg University |
| Tania Zelevinsky | Columbia University |
| Martin Kalinowski | Hamburg University |

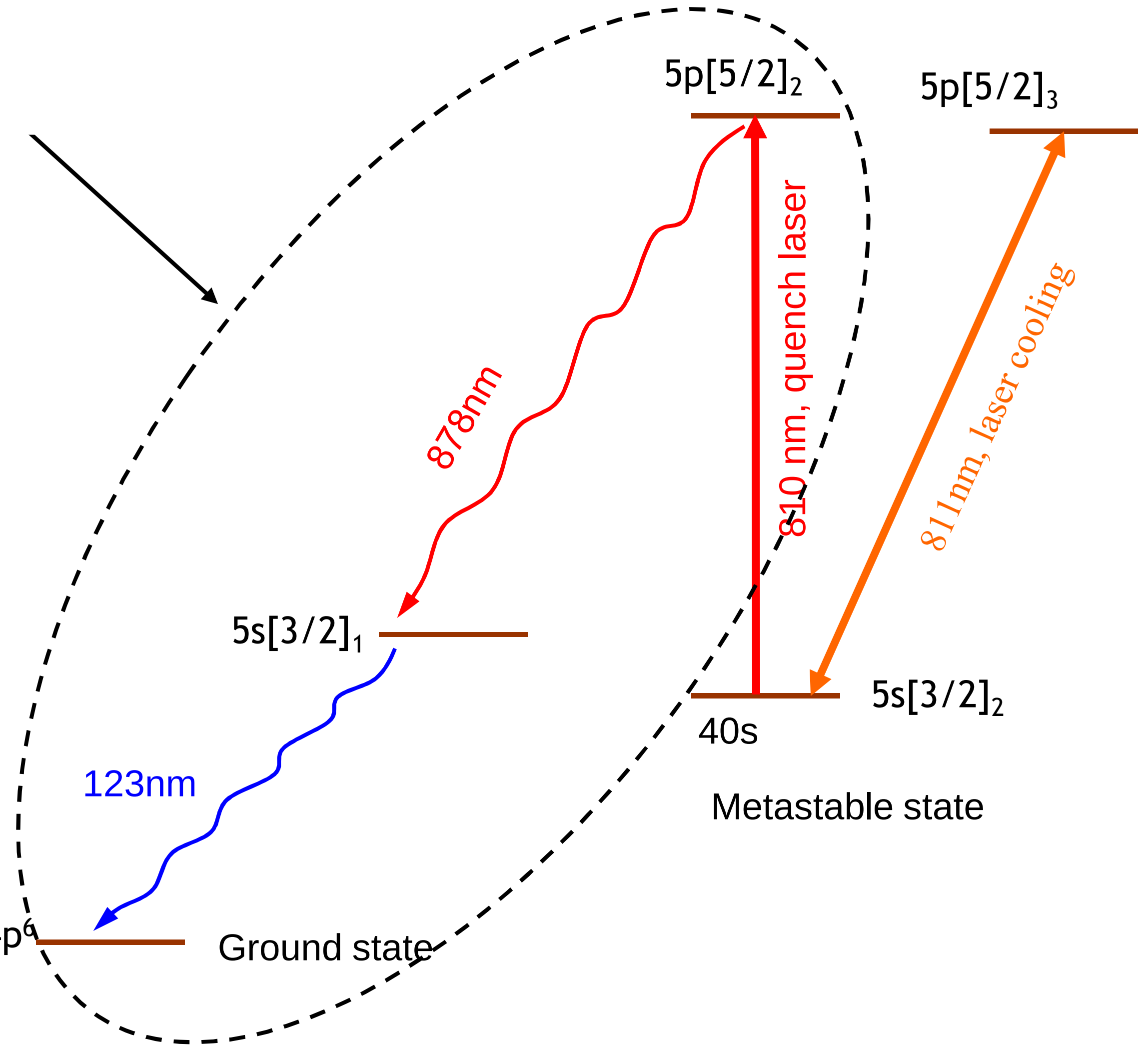
# Determine the Loading Rate of $^{83}$Kr – The Quench Method

$$\frac{dN}{dt} = L - ¥ \ N - \quad N^2$$

Steady state $\quad L \approx ¥_1 N$

$¥_1 >> ¥, \quad N$

$¥_1 \sim 100s^{-1}, ¥ \sim 1s^{-1}, \quad N \sim 2s^{-1}$




One atom can only give one 878nm photon before going back to ground state. Insensitive to laser power and detuning.