\(^{39}\text{Ar} \) Detection at the \(10^{-16}\) Isotopic Abundance Level with Atom Trap Trace Analysis

Peter Müller
Radioargon Dating - $^{39}\text{Ar}$

cosmogenic isotope; half-life = 270 years; $^{39}\text{Ar}/\text{Ar} = 8 \times 10^{-16}$

Radio-Argon Dating:
- 50 – 1000 year range
- study ocean and groundwater
- previously with LLC and AMS

Dark Matter Searches:
- LAr detectors (WARP, DEAP/CLEAN)
- $^{39}\text{Ar}$ major background
- search for old / depleted Argon

ATTA-2: $^{81}\text{Kr}$ loading rate $\sim$10 atoms/h ($^{81}\text{Kr}/\text{Kr} \sim 5 \times 10^{-13}$)

-> one $^{39}\text{Ar}$ atom every 3 days
## ATTA-3 Loading Rate Improvements

<table>
<thead>
<tr>
<th>Atomic Beam Stage</th>
<th>ATTA-2</th>
<th>ATTA-3</th>
<th>Improvement</th>
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<tbody>
<tr>
<td>LN$_2$ pre-cooling</td>
<td>N.A.</td>
<td>2</td>
<td>x2</td>
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<tr>
<td>Transverse Cooling</td>
<td>70</td>
<td>140</td>
<td>x2</td>
</tr>
<tr>
<td>Sidebands in T.C.</td>
<td>N.A.</td>
<td>3</td>
<td>x3</td>
</tr>
<tr>
<td>2D-MOT</td>
<td>N.A.</td>
<td>3</td>
<td>x3</td>
</tr>
<tr>
<td>New Zeeman Slower</td>
<td>1000</td>
<td>3000</td>
<td>x3</td>
</tr>
<tr>
<td>More Trapping Power</td>
<td>N.A.</td>
<td>1.5</td>
<td>x1.5</td>
</tr>
</tbody>
</table>

- **Loading Rate**: x 160
Argon Atom Level Diagram

Ground-level

Metastable $\tau \approx 40$ sec

12 eV
electron collision

812 nm

4p[5/2]$_3$

4s[3/2]$_2$

3p$^6$
$^{39}\text{Ar} \text{ Hyperfine Structure}$

$^{39}\text{Ar}: I = 7/2$

- $4s[3/2]_2$
- $4p[5/2]_3$

Trapping transition
\(^{39}\text{Ar}\) Hyperfine Structure

\(^{39}\text{Ar}: I = \frac{7}{2}\)

4s[3/2] \text{\(_2\)}

4p[5/2] \text{\(_3\)}

Re-pump transitions

Trapping transition
\( ^{39}\text{Ar Hyperfine Structure} \)

\( ^{39}\text{Ar: } I = 7/2 \)

\( ^{4s}[3/2]_2 \)

\( ^{4p}[5/2]_3 \)

Re-pump transitions

Trapping transition

Frequencies in MHz

W. Williams et al., Physical Review A 83, 012512 (2011)
Argon Single Atom Signals

(a) $^{38}\text{Ar}$

(b) 

Nr. of atoms

(c) $^{39}\text{Ar}$

(d) 

5.5σ

BG

CCD Signal (a.u.)
Ar-39 Single Atom Picture

CCD camera picture

One $^{39}$Ar Atom
$^{39}\text{Ar}$ at Parts-per-quadrillion

Atmospheric $^{39}\text{Ar}/\text{Ar} = 8 \times 10^{-16}$

Depleted $^{39}\text{Ar}/\text{Ar} < 1 \times 10^{-16}$
Radioargon Dating Outlook

Current status of $^{39}\text{Ar}$ ATTA @ Argonne
- $^{39}\text{Ar}$ detected in atmospheric and old water sample
- No isotopic/isobaric interference ($< 1 \times 10^{-16}$)
- Loading rates
  - $^{38}\text{Ar}$: $1.3 \times 10^9$ atoms/s (I.A. 0.063 %)
  - $^{39}\text{Ar}$: 5 atoms/day for atmospheric sample
- Sample consumption rate
  - 10 mL (STP) / day with partial recirculation

Next Steps
- Improve HFS re-pumping, continuous counting
  - $^{39}\text{Ar}$ loading rate 100 atoms/day
- Implement full recirculation
  - 0.5 mL (STP) / day
- Build dedicated argon trap and laser system
Thank You!

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