Direct Measurement of Resonances in $^7$Be($\alpha,\gamma$)$^{11}$C With DRAGON

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Direct Reactions with Exotic Beams
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Outline

• Motivation

• Experimental technique

• Analysis and Preliminary results

• Future plans
Heavy Element Nucleosynthesis

• Isotopic abundances of elements heavier than Fe explained by s-process, r-process and p-process nucleosynthesis

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• $\nu p$– process thought to occur in ejecta of CCSN, probable site of synthesis of $p$-nuclei
$^7\text{Be}(\alpha, \gamma)^{11}\text{C}$ and the $\nu p$-process

- $^7\text{Be}(\alpha, \gamma)^{11}\text{C}$ competes with $3\alpha$ in breakout from $p$-$p$ chain
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- Recent sensitivity study found that altering $^7\text{Be}(\alpha,\gamma)^{11}\text{C}$ rate significantly alters $p$-nuclei abundances
- $^7\text{Be}(\alpha,\gamma)^{11}\text{C}$ reaction rate poorly known over temperature range of interest (1.5 – 3 GK)

## Previous Measurements

<table>
<thead>
<tr>
<th>$E_x$ [MeV]</th>
<th>$E_r$ [MeV]</th>
<th>$J^\pi$</th>
<th>$\Gamma_\alpha$ [eV]</th>
<th>$\Gamma_p$ [eV]</th>
<th>$\omega\gamma$ [eV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.900$^3$</td>
<td>1.355</td>
<td>$9/2^+$</td>
<td>8 keV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.699(2)$^{2,3}$</td>
<td>1.154</td>
<td>$5/2^+$</td>
<td>15(1) keV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.654(4)$^{2,3}$</td>
<td>1.109</td>
<td>$7/2^+$</td>
<td>$\leq 5$ keV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.420(2)$^1$</td>
<td>0.877</td>
<td>$5/2^-$</td>
<td>12.6(3.8)</td>
<td>3.1(1.3)</td>
<td>3.80</td>
</tr>
<tr>
<td>8.105(17)$^1$</td>
<td>0.560</td>
<td>$3/2^-$</td>
<td>$6^{+12}_{-2}$</td>
<td>0.350(56)</td>
<td>0.331</td>
</tr>
</tbody>
</table>

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**Experiment**

**ISAC-I**

- 50 μA 500 MeV $p^+$ from main cyclotron
- Ta target
- $A = 7$ extracted from target using TRIUMF Resonant Ionization Laser Ion Source (TRILIS)
- Transported to high resolution mass separator
- Reaccelerated to 454 A keV by ISAC-I accelerators (RFQ & DTL)
- Delivered to DRAGON gas target
- $I_{\text{avg}} = 2.0(1.4) \times 10^7$ pps
• 3 main parts:
  • Head
    • Differentially-pumped windowless gas target
    • High geometric efficiency BGO γ-ray array
    • Detects prompt γ emissions of excited recoil nuclei
  • Body
    • High-suppression electromagnetic mass separator
    • 2 stages of separation (MD, ED, MD, ED)
  • Tail
    • Suite of heavy ion detectors
    • Dual MCP for TOF
    • DSSSD, IC, or Hybrid for E-loss / deposition
• Performed $^6,^7\text{Li}(\alpha,\gamma)^{10,11}\text{B}$ yield measurements for background / acceptance characterization

• Performed Yield measurements of $E_r = 1.155\ \text{MeV}$ and $E_r = 1.109\ \text{MeV}$ resonances
Analysis

- $E_r = 1.155$ MeV
- Candidate recoils identified via TOF between coincident $\gamma$ and heavy ion signals
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• Candidate recoils identified via TOF between coincident $\gamma$ and heavy ion signals
• Gating on TRILIS signal provides further discrimination of $^{11}$C / $^{11}$B
• 8 candidate $^{11}$C recoils pass gates on Separator TOF, TRILIS, $E_{BGO}$, $E_{DSSSD}$
\( \frac{(m_{7Be} - m_{7Li})}{m_{7Be}} = 0.00013 \rightarrow \text{expect significant } ^7\text{Li contamination} \)

- Average \(^7\text{Li} / ^7\text{Be} \) ratio = 520:1
- Observed total of 172 candidate recoil events (signal + bg region)
- Given detection efficiencies, number or signal / bg events and ratio of signal / bg regions yields an upper limit\(^1\) of 15 detected \(^{11}\text{C} \) recoils (given detection efficiencies and ratio of signal / bg regions)

\[
Y = \frac{N_{rec}}{N_b \eta_{DRA}} = 6.39 \times 10^{-11}
\]

→ Preliminary \((1 - \sigma) \) upper limit \((E_r = 1.155 \text{ MeV resonance})\)

\[
\omega \gamma = \frac{2 Y_\infty}{\lambda_r^2} \frac{m_{7Be}}{m_{7Be} + m_\alpha} \epsilon_{lab} = 0.64 \text{ eV}
\]

\(^1\)W. A. Rolke et al., Nucl. Instrum. Meth. A 551, 493 (2005)
Further analysis of current data

→ upper limits on $E_r = 1.155$ MeV and $E_r = 1.109$ MeV resonances

Post-experiment $^7$Be beam development on UC$_x$ target yielded intensities as high as $2.4 \times 10^8$ pps

• Suggests use of pure SiC target could yield intensities $\sim 10^9$ pps
• Possible to post-strip in HEBT beamline at these intensities
  → pure $^7$Be on target by selecting $q = 4$
• Reperform previous measurements of $E_r = 1.109$ MeV and $E_r = 1.155$ MeV resonances with pure $^7$Be on target
• Probe possible existence of $E_r = 1.355$ MeV resonance
Summary

• $^7\text{Be}(\alpha,\gamma)^{11}\text{C}$ reaction rate impacts isotopic abundances of $\rho$-nuclei in $\nu_p$-process nucleosynthesis

• 2 resonances in $^7\text{Be}(\alpha,\gamma)^{11}\text{C}$ were directly measured with DRAGON $E_r = 1.155$ MeV and $E_r = 1.109$ MeV
  • Preliminary $(1 - \sigma)$ upper limit 0.64 eV ($E_r = 1.155$ MeV resonance)

• Beam Development suggests use of pure SiC target could yield a background-free measurement
Thank You!

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