Fluorine nucleosynthesis: measurement of $^{15}\text{N}(\alpha,\gamma)^{19}\text{F}$

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Origin of $^{19}$F: a long standing issue

three the possible **astrophysical sites** proposed:

1. **type II Supernovae**: via spallation of $^{20}$Ne by $\nu_\mu$ and $\nu_\tau$

3. **Wolf Rayet stars**: massive stars experiencing large mass loss episodes, where the material exposed to the He burning can be ejected before the fluorine destruction occurs via the $^{19}$F($\alpha,p$)$^{22}$Ne reaction

5. **Asymptotic Giant Branch (AGB)** stars via the chains

$$^{14}N(n,p)^{14}C(\alpha,\gamma)^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$$

$$^{14}N(\alpha,\gamma)^{18}F(\beta^+)^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$$

neutrons from $^{13}C(\alpha,n)^{16}O$, protons from $^{14}N(n,p)^{14}C$

in the convective zones generated by recurring He-burning thermonuclear runaways (thermal pulses). **Most promising**: observational evidence of $^{19}$F in outer envelope
Sensitivity to nuclear inputs

Updated nuclear network cross sections, models computed with FUNS. Main uncertainty related to $^{13}\text{C}(\alpha,n)^{16}\text{O}$ and $^{14}\text{N}(p,\gamma)^{15}\text{O}$

However, playing a little with unlikely options:

\[
\begin{align*}
^{14}\text{C}(\alpha,\gamma)^{18}\text{O} \\
^{18}\text{O}(\alpha,\gamma)^{22}\text{Ne} \\
^{14}\text{N}(\alpha,\gamma)^{18}\text{F} \\
^{13}\text{C}(\alpha,n)^{16}\text{O} \\
^{15}\text{N}(\alpha,\gamma)^{19}\text{F} \\
^{19}\text{F}(\alpha,p)^{22}\text{Ne}
\end{align*}
\]

Table 3. Scaling factors $sf$ of the computed tests with the corresponding $^{19}\text{F}$ and $^{18}\text{O}/(\text{s})$ surface ratios with respect to the reference case.

<table>
<thead>
<tr>
<th>Reaction rate</th>
<th>$sf$</th>
<th>$R^{(19}\text{F})$</th>
<th>$R(\text{F}/(\text{s}))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{13}\text{C}(\alpha,n)^{16}\text{O}$</td>
<td>0.01</td>
<td>4.70</td>
<td>2.80</td>
</tr>
<tr>
<td>$^{13}\text{C}(\alpha,n)^{16}\text{O}$</td>
<td>100</td>
<td>0.62</td>
<td>0.67</td>
</tr>
<tr>
<td>$^{14}\text{C}(\alpha,\gamma)^{18}\text{O}$</td>
<td>0.01</td>
<td>1.03</td>
<td>1.59</td>
</tr>
<tr>
<td>$^{14}\text{C}(\alpha,\gamma)^{18}\text{O}$</td>
<td>100</td>
<td>1.04</td>
<td>1.61</td>
</tr>
<tr>
<td>$^{14}\text{N}(\alpha,\gamma)^{18}\text{F}$</td>
<td>0.01</td>
<td>3.03</td>
<td>5.14</td>
</tr>
<tr>
<td>$^{14}\text{N}(\alpha,\gamma)^{18}\text{F}$</td>
<td>100</td>
<td>0.64</td>
<td>1.10</td>
</tr>
<tr>
<td>$^{15}\text{N}(\alpha,\gamma)^{19}\text{F}$</td>
<td>0.01</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td>$^{15}\text{N}(\alpha,\gamma)^{19}\text{F}$</td>
<td>100</td>
<td>0.96</td>
<td>1.50</td>
</tr>
<tr>
<td>$^{18}\text{O}(\alpha,\gamma)^{22}\text{Ne}$</td>
<td>0.01</td>
<td>2.21</td>
<td>2.01</td>
</tr>
<tr>
<td>$^{18}\text{O}(\alpha,\gamma)^{22}\text{Ne}$</td>
<td>100</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>$^{19}\text{F}(\alpha,p)^{22}\text{Ne}$</td>
<td>0.01</td>
<td>1.05</td>
<td>1.19</td>
</tr>
<tr>
<td>$^{19}\text{F}(\alpha,p)^{22}\text{Ne}$</td>
<td>100</td>
<td>0.08</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Recoil separators for Nuclear Astrophysics

- DRAGON
- Saint George
- SECAR
- ARES
- ERNA@CIRCE
- Caltech
- DRS
- ERNA@Bochum
- KUTL

Old facilities
Active facilities
Future facilities
Recoil Mass Separator ERNA
ERNA at CIRCE
Cross section determination

\[
\sigma(E) = \frac{1}{T_q \phi_q(E) \varepsilon N_{\text{target}} N_{\text{projectiles}}} \cdot Y(R^{q+})
\]

typical uncertainty

\begin{align*}
T_{4q} & \quad \text{transmission to end detector (acceptance)} \\
\phi_{4q}(E) & \quad \text{charge state probability} \\
\varepsilon & \quad \text{detection efficiency} \\
N_{\text{target}} & \quad \text{number of target atoms} \\
N_{\text{projectiles}} & \quad \text{number of projectiles} \\
Y(R^{q+}) & \quad \text{number of detected recoils}
\end{align*}

1\% 3\% 0.5-2\% 5\% 1\% 2\%
Intense N ion beam production

Nitrogen ion beam generation with a source of negative ions by cesium sputtering (SNICS) suffers difficulties connected with its low electron negativity, which hampers the formation of a stable negative ion.

Di Leva et al. NIMA 689(2012)98
$^{4}\text{He}$ extended gas target

Measurements overlapped with $^{7}\text{Be}(p,\gamma)^{8}\text{B}$, target chamber was adapted for a shorter gas cell. Target fully characterized.

$P_{4\text{He}}$: 4 mbar
Effective length: ...
Thickness: $(0.54\pm0.03)$ atoms/cm$^2$
The use of an additional layer of a different gas can make charge state independent of reaction coordinate within the target.
Separator acceptance

![Graph showing the relationship between $Y / Y_0$ and $E_{\text{set}} / E_{\text{uning}}$. The graph has a scatter plot with error bars, indicating variability at different points on the x-axis.]
1323 keV resonance

\[ \Gamma_\gamma = (1.62 \pm 0.09) \text{eV} \]
\[ \Gamma_\alpha = (2.51 \pm 0.10) \text{keV} \]
1487 keV resonance

\[ \Gamma_\gamma = (2.2 \pm 0.2) \text{eV} \]
\[ \Gamma_\alpha = (6.0 \pm 0.3) \text{keV} \]
Influence on reaction rate

Before

After
Outlook

need:
- end detector with lower detection threshold: ToF-E (see poster J.G. Duarte #…);
- $^4$He jet gas target (see poster D. Rapagnani #…);

aim:
- measurement of narrow resonances $E_{cm} = 536\text{keV} \div 1093\text{keV}$ (not difficult)
- measurement of non resonant component (DC) (challenging)
- measurement of 365keV resonance (very challenging)

Using values from:
Thank you for your attention