Search for $^{24}\text{Mg}$ resonances inside the Gamow window for $^{12}\text{C} + ^{12}\text{C}$ fusion

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• 3 experiments performed, 1 proposal approved at INFN - LNL
• Objective: search for $^{12}$C+$^{12}$C resonances at $^{24}$Mg excitations 15 -20 MeV and their full characterization: excitation energy, width, spin, parity, partial decay widths
• Low energy data for $^{12}$C+$^{12}$C fusion reaction: quiescent burning of massive starts, super-AGB stars, super-bursts and supernovae type Ia

Important new result is even observation of the $0^+$ state at these excitations which decay into $\alpha+^{20}$Ne and/or $^1$H+$^{23}$Na

\[
\begin{align*}
E_{\text{thr}}(n+^{23}\text{Ne}) &= 16.532 \text{ MeV} \\
E_{\text{thr}}(\alpha+\alpha+^{16}\text{O}) &= 14.044 \text{ MeV} \\
E_{\text{thr}}(^{12}\text{C}+^{12}\text{C}) &= 13.931 \text{ MeV} \\
E_{\text{thr}}(^1\text{H}+^{23}\text{Na}) &= 11.692 \text{ MeV} \\
E_{\text{thr}}(\alpha+^{20}\text{Ne}) &= 9.313 \text{ MeV}
\end{align*}
\]
Explosive phenomena in binary systems
SNIIa: initiates thermonuclear runaway on white dwarf temperature $0.5 - 1.2 \times 10^9$ K $\rightarrow E_{\text{cm}} = 1.5 - 3.3$ MeV
Super-bursts: trigger of $^{12}$C ignition up to $2.5 \times 10^9$ K - 5.7 MeV

Massive stars: $^{12}$C+$^{12}$C fusion is differentiating between the evolutionary paths leading to either white dwarf or heavy elements burning stages
The most relevant quantity: total reaction fusion rate

\[ ^{12}\text{C} + ^{12}\text{C} \rightarrow ^{24}\text{Mg} + \gamma \]
\[ ^{12}\text{C} + ^{12}\text{C} \rightarrow ^{20}\text{Ne} + \alpha \]
\[ ^{12}\text{C} + ^{12}\text{C} \rightarrow ^{23}\text{Na} + \text{p} \]
\[ ^{12}\text{C} + ^{12}\text{C} \rightarrow ^{23}\text{Mg} + \text{n} \]

Existing data show large discrepancies
Low energy resonance?

Experiment at INFN – LNS

Coincident detection of 2 reaction products

\[ ^{12}\text{C} + ^{16}\text{O} \rightarrow ^{4}\text{He} + ^{12}\text{C} + ^{12}\text{C} \quad Q=-7.16 \text{ MeV} \quad E_{\text{thr}}(^{24}\text{Mg})=13.93 \text{ MeV} \]
\[ \rightarrow ^{4}\text{He} + ^{16}\text{O} + ^{8}\text{Be} \quad Q=-7.37 \text{ MeV} \quad E_{\text{thr}}(^{24}\text{Mg})=14.14 \text{ MeV} \]
\[ \rightarrow ^{4}\text{He} + ^{20}\text{Ne} + ^{4}\text{He} \quad Q=-2.54 \text{ MeV} \quad E_{\text{thr}}(^{24}\text{Mg})=9.31 \text{ MeV} \]
\[ \rightarrow ^{4}\text{He} + ^{23}\text{Na} + ^{1}\text{H} \quad Q=-4.92 \text{ MeV} \quad E_{\text{thr}}(^{24}\text{Mg})=11.69 \text{ MeV} \]

\[ ^{16}\text{O} \quad \alpha \]

\[ ^{12}\text{C} \quad ^{24}\text{Mg} \]

\[ ^{16}\text{O} \text{ beam energy 90 MeV} \]

\[ 11 \text{ days of beam-time} \]
Detector telescopes: 50 x 50 mm\(^2\)
20 \(\mu\)m SSSD + 1000/500 \(\mu\)m PSD & DSSD
Particle identification from p to \(^{12}\)C
reaction identification
$^{12}\text{C}(^{16}\text{O},^{4}\text{He}+^{12}\text{C})^{12}\text{C}$

Work in progress: Calibration, re-calibration, calibration checks
Thickness profile of the SSSD: 17 – 27 μm
The first excitation energy spectra very preliminary results

$E_x^{(^{24}\text{Mg})}$

$E_x^{(^{16}\text{O})}$

$^{16}\text{O}$ excitation spectrum
Experiment at GANIL

- Resonant scattering technique: heavy beam particle into thick gas target - $^{20}\text{Ne} + {^4}\text{He} \rightarrow ^{24}\text{Mg}^* \rightarrow \alpha + ^{20}\text{Ne}, \alpha + ^{20}\text{Ne}^*$
• Very complex structure, many overlapping resonances
• Angular distributions & R-matrix fits don’t provide spin information
• There is some $0^+$ strength in peaks below 15 and above 16 MeV

1-day beam-time Setup was not fully optimized for this measurement as it was test/calibration run
Proposal & experiment at INFN-LNL

• improved measurement of the resonant scattering experiment
  \( ^{20}\text{Ne} + ^{4}\text{He} \rightarrow ^{24}\text{Mg}^* \rightarrow \alpha^{^{20}\text{Ne}}, \alpha^{^{20}\text{Ne}^*}, \ p^{^{23}\text{Na}} \)
• we built new beam-line & scattering chamber
• scheduled for May 2013 but PIAVE did not work
• new run in 2014 or look for another facility with \(^{20}\text{Ne}\) beam
• we run \(^{12}\text{C}+^{14}\text{N} \rightarrow ^{2}\text{H}+^{12}\text{C}+^{12}\text{C}, \ ^{4}\text{He}+^{20}\text{Ne}+^{4}\text{He}, \ ^{4}\text{He}+^{23}\text{Na}+p \)
Study of $^{18}$Ne resonances relevant for the $^{14}$O(α,p)$^{17}$F reaction: experiment performed

HCNO breakout: X-ray bursts, cc supernovae, novae
IPN Orsay Nov 2012: study of the isobar analogue nucleus $^{18}$O

$^{13}$C + $^9$Be → α + $^{18}$O* → α + α + $^{14}$C

Work in progress
Conclusion & Prospects
personal view

EuroGENESIS project was important step ahead for Zagreb group
New research programme after successful applications for large investment in research instrumentation - 2 FP7 REGPOT projects, EuroGENESIS, some national funding – in total 500 000 €
1 new PhD student positions – in total 4 PhD in 5 years
It provides funding for 4 experiments – we have data to analyse

Many thanks to all who brought EuroGENESIS into life!
THANK YOU JORDI!

It would be great to have EuroGENESIS successor!