Nuclear Astrophysics Research with the MUSIC Detector

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March 2, 2018







Nuclear reactions are important for understanding many different astrophysical phenomena

X-ray superbursts (NS binary)



Novae (WD binary)



P. Mróz et al. (2016) Nature **537**, p649–651

Neutrino-driven Winds (Core-Collapse Supernovae)



A. Arcones, A. and F. K. Thielemann. (2012) *J. Phys. G: Nuclear and Particle Physics* **40**: 013201



²⁶Al production



The Multi-Sampling Ionization Chamber (MUSIC)

MUSIC is an active-target ionization chamber with a segmented anode







Beam

Advantages of the MUSIC detector

MUSIC can make simultaneous measurement over wide energy range
Can make viable rate measurements with much lower beam rates (low kHz)
Portable, small (can be surrounded by auxiliary detectors at close distance)
Self-normalizing (does not require other beam monitors)





How do X-ray superbursts ignite? (hint: something to do with Carbon fusion)

 2×10^{4} $5 \times 10^{\circ}$ ¹³C+¹²C 15C+12C 5×10^{4} PCUs) cts/sec (5 PCUs) 104 MUSIC Kovar et al 1979 9 Coupled-channels 104 cts/sec São Paolo 5000 18 18 10 12 16 1014 16 5000 E_{c.m.} (MeV) *E*_{c.m.} (MeV) P. Carnelli et al. (2015) NIM A 799 197 \bigcirc 1.5×10⁴ 10^{4} 10^{4} 1.5×10⁴ 5000 5000 \cap 0 Time (sec) Time (sec)

Superbursts are probably triggered by fusion of neutron-rich isotopes of C (maybe O).

E. Kuulkers. (2004) Nuc. Phys. B-Proceedings Supplements 132: 466-475.



¹⁶C (from RAISOR) on ¹²C (¹²CH₄ gas at 450 Torr)



Figures courtesy of Ashley Hood (LSU)

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How is ²⁶Al produced?

The ²³Na(α ,p)²⁶Mg and ²³Na(α ,n)²⁶Al reactions

- The ²³Na(α,p)²⁶Mg reaction directly influences the production of ²⁶Al in massive stars
- Important proton source for the ²⁵Mg(p,γ)²⁶AI

- The ²³Na(α,n)²⁶Al reaction important for the production of ²⁶Al in massive stars
- ²⁶Al(n,α)²³Na is one of the dominant destruction mechanisms of ²⁶Al



²³Na(a,n) (a,p) measurements

Identification of events from different reactions occurring in strip 4







²³Na(a,n) (a,p) measured in one day!





Where are the r-process nuclei made?

Neutrino-driven wind in Core-Collapse Supernova?





Neutron star mergers



S. Wanajo and Y. Ishimaru (2005) IAU Symposium 228: 435-438



R-process nucleosynthesis in the neutrino-driven wind

a,n reactions are important, but suffer from orders of magnitude uncertainty





¹⁰⁰Mo(a,n) measurement demonstrates we can successfully measure a,n for nuclei in first r-process peak (Z of 34-47)



LLNL-PRES-XXXXX



The Future of MUSIC - pushing to tougher measurements

- 1. Digital MUSIC (decreases dead-time, increases efficiency)
- 2. GEANT4 simulations (informs future upgrades, machine learning analysis)

Machine Learning Preview (Machine-Enhanced Learning in Nuclear Astrophysics?)

MUSIC data from ¹⁷F+⁴He reactions

- Used the dimension reduction technique
- Unsupervised learning
- Studied 35 quantities from data
- ¹⁷F(α,p) points were previously identified with standard analysis technique



Courtesy of P. Balaprakash, M. Avila and D. Santiago (ANL)

Fully utilise CARIBU and RAISOR beams for nuclear astrophysics measurements!



Thanks!

