TRIUMF

The Impact of ^{17}O alpha captures on the weak s-process

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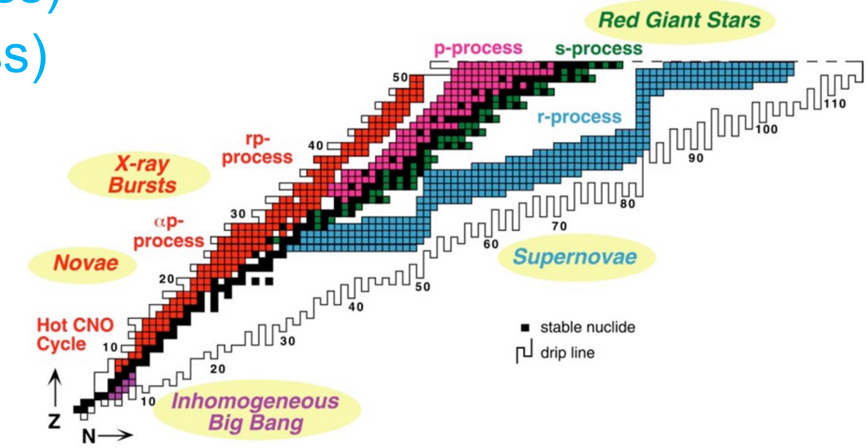
Astrophysical Background

- Two main nucleosynthesis processes for heavier-than-iron elements:
  - Rapid neutron capture (*r*-process)
  - Slow neutron capture (s-process)

- *r*-process is primary
- *s*-process is secondary

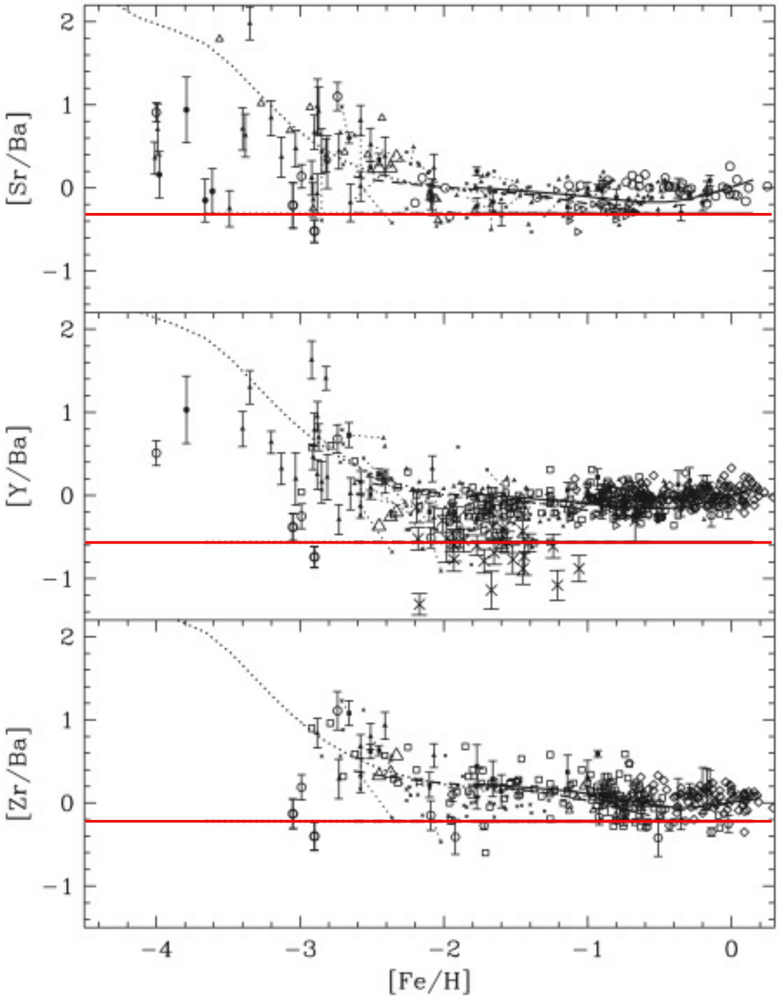
- Abundances of heavier-than-iron elements in the oldest stars are dominated by *r*-process



M. S. Smith and K. E. Rehm (2001) Annual review of Nuclear and Particle Science 51:91-130

Astrophysical Motivation

- Comparing theoretical predictions to astronomical observations
- Ultra metal poor (UMP) stars are very old so can be used to test *r*-process models
- Generally, in agreement for heavy element abundances
- However, more elements with 26 < Z < 47 than expected!



C. Travaglio et al. (2004) ApJ. ***601*** *864*

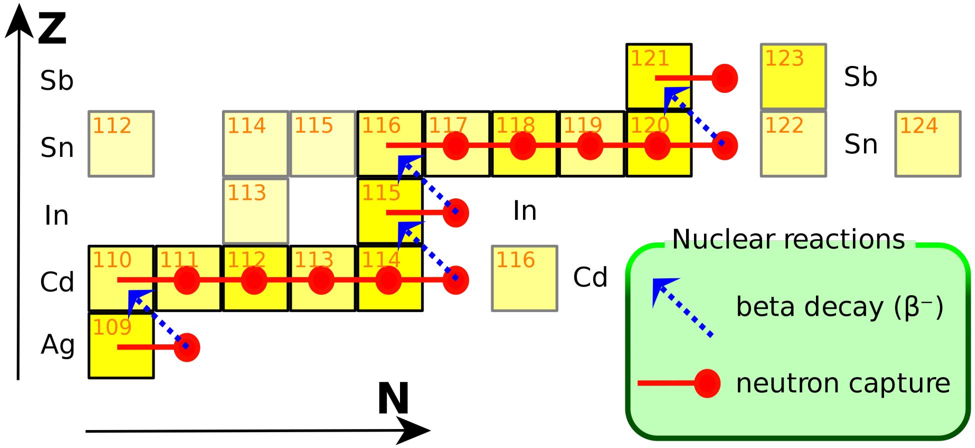
The previously discounted *s*-process

- Responsible for ~1/2 of heavier-than-iron elements

- $t_n < t_\beta$

- Asmptotic giant branch (AGB) stars and massive stars

- Secondary nucleosynthesis process = requires pre-existing ‘seed’ nuclei



https://commons.wikimedia.org/w/index.php?title=File:S-process-elem-Ag-to-Sb.svg&oldid=701241899

Rotating Metal-poor Stars

- ^{12}C produced in He core burning
- Rapid rotation mixes ^{12}C into H-burning shell stimulating ^{14}N production via CNO cycle
- ^{14}N engulfed by expanding He core increases production of ^{22}Ne via successive α captures
- ^{22}Ne(α,n)^{25}Mg – major source of neutrons for the *s*-process
- Potential to produce significant quantities of intermediate mass elements

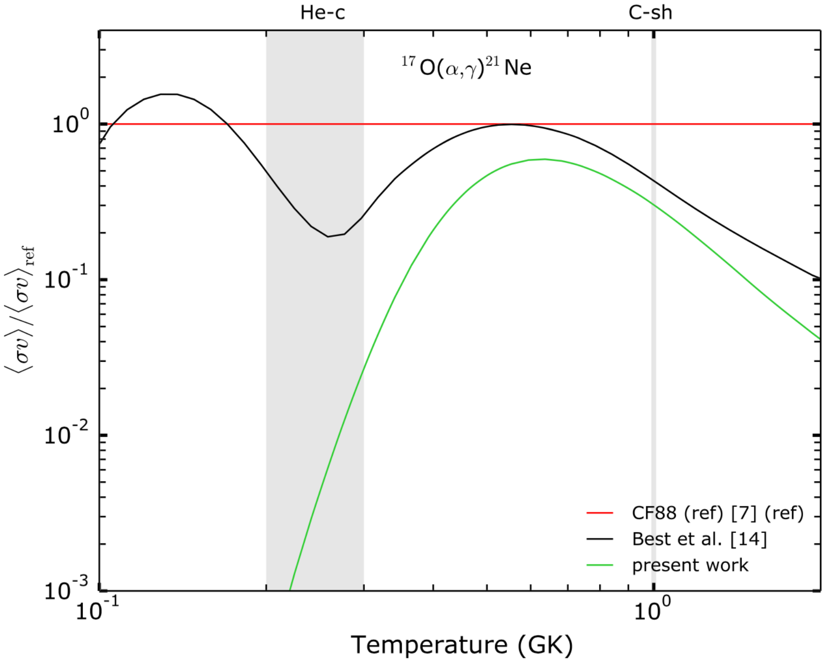
Image Credit: HST, NASA and ESA

Neutron poisoning

- ^{16}O captures neutrons, reducing *s*-process rate

- Neutrons may be liberated again in subsequent $^{17}O(\alpha,n)^{20}Ne$ reaction

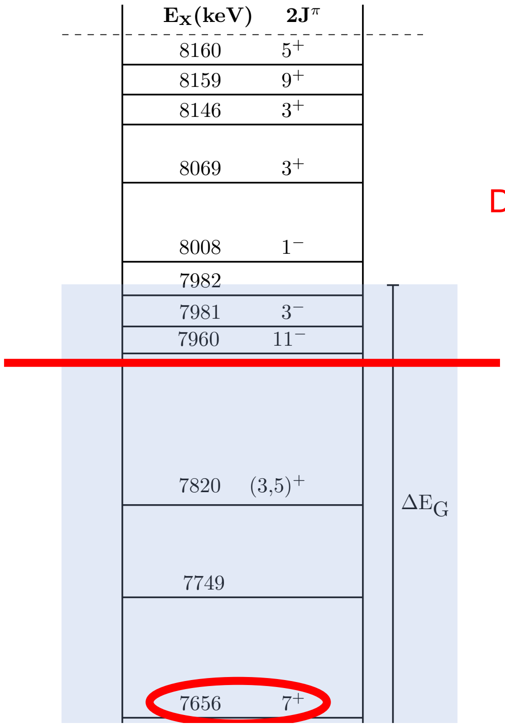
- Efficiency of the ‘weak’ *s*-process depends on $^{17}O(\alpha,n)^{20}Ne/^{17}O(\alpha,\gamma)^{21}Ne$ reaction rate ratio



Taggart et al. (2019) Phys. Let. B.

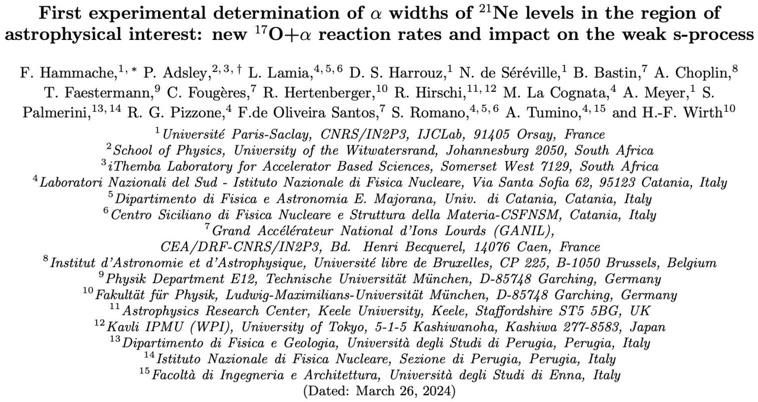
Energy levels of ^{21}Ne

- Reaction cross sections too low to measure directly
- Reaction rate dominated by narrow resonances in compound nuclear ^{21}Ne
- Several unknowns about important energy levels
  - Spin-parity, resonance strengths, neutron partial widths (Γ_n)…



Direct measurement at DRAGON

Taggart et al. (2019) Phys. Let. B.



First experimental determination of α widths of ^{21}Ne levels in the region of astrophysical interest: new ^{17}O+α reaction rates and impact on the weak s-process

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(Dated: March 26, 2024)

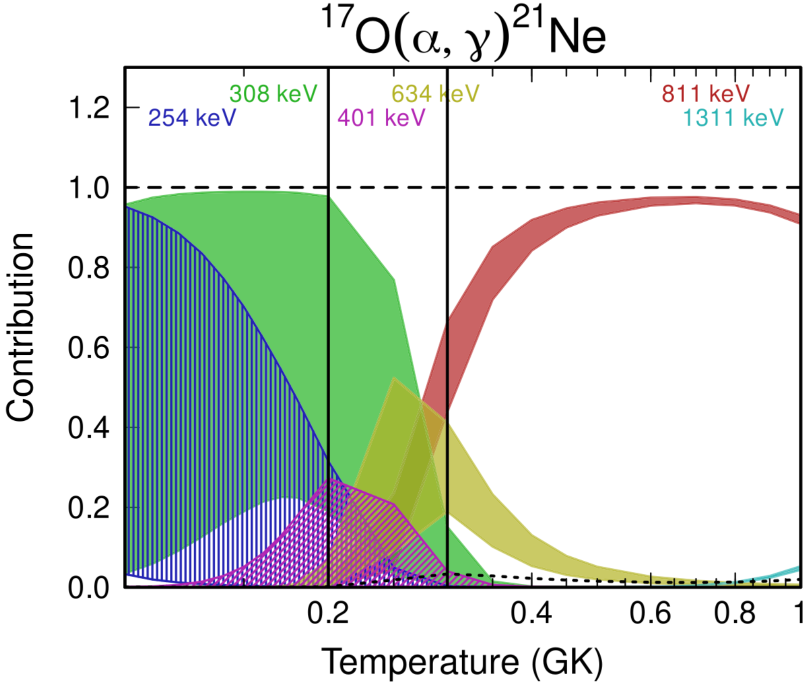
Taggart et al. (2019) Phys. Let. B.

Experiment

- Aim to determine the resonances that significantly contribute to the $^{17}O(\alpha, \gamma)^{21}Ne$ reaction rate and measure their absolute resonance strengths

- Used $^{17}O(7Li,t)^{21}Ne$ reaction to populate relevant energy levels

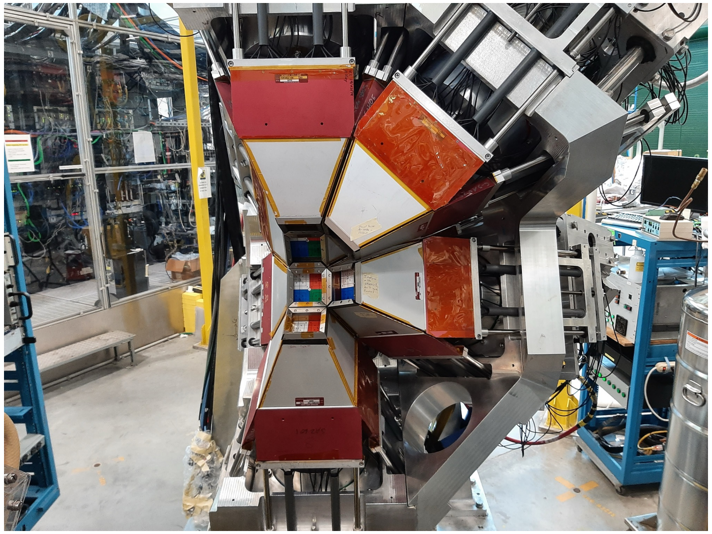
- 4.5 AMeV ^{17}O beam impinged on 100 $\mu g/cm^2$ LiF foil with a 30 $\mu g/cm^2$ carbon backing

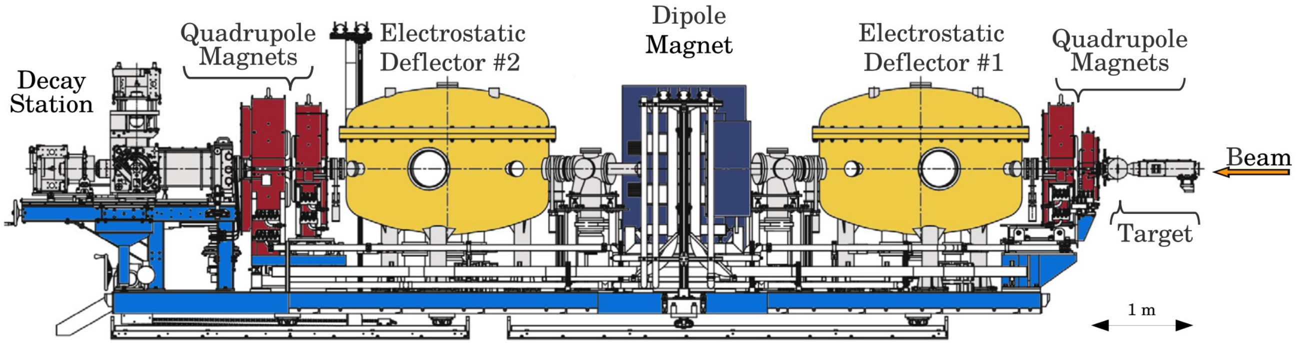


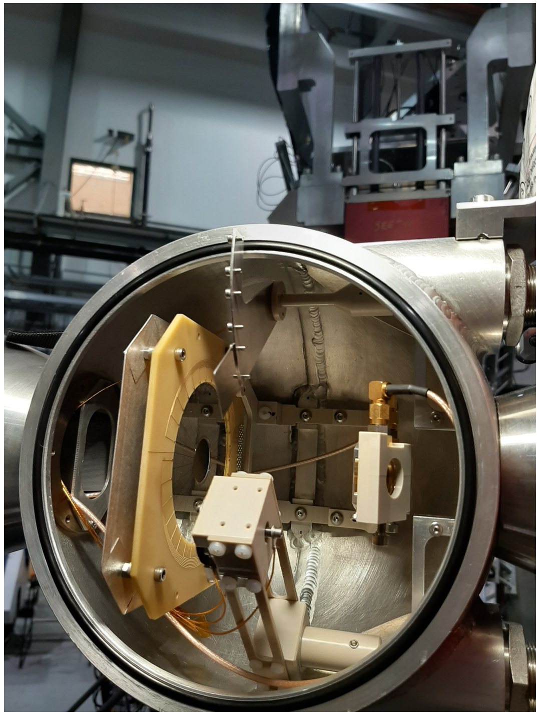
Frost-Schenck et al. (2022) MNRAS.

Experiment

- Dec 2019 & Nov 2020
- Electromagnetic Mass Analyzer (EMMA)
  - S3 annular detector in target chamber
- Triumf-ISAC Gamma-Ray Escape Suppressed Spectrometer (TIGRESS)



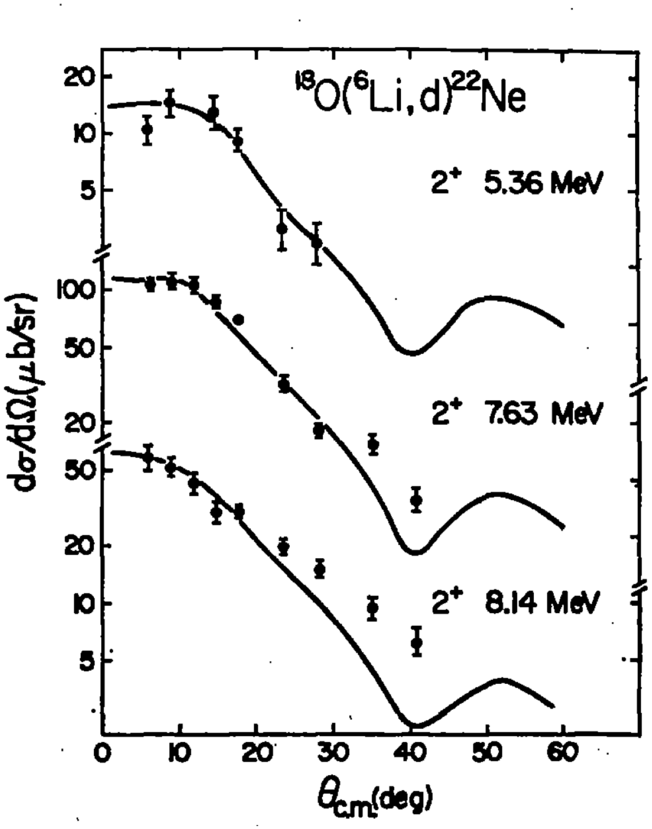




B. Davids et al. (2019) NIM. A. **930** 191-195

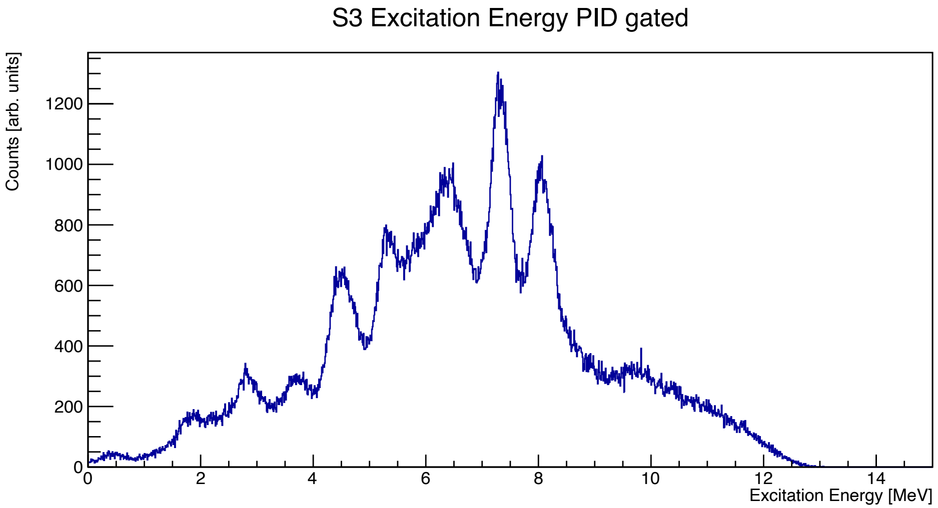
Experiment

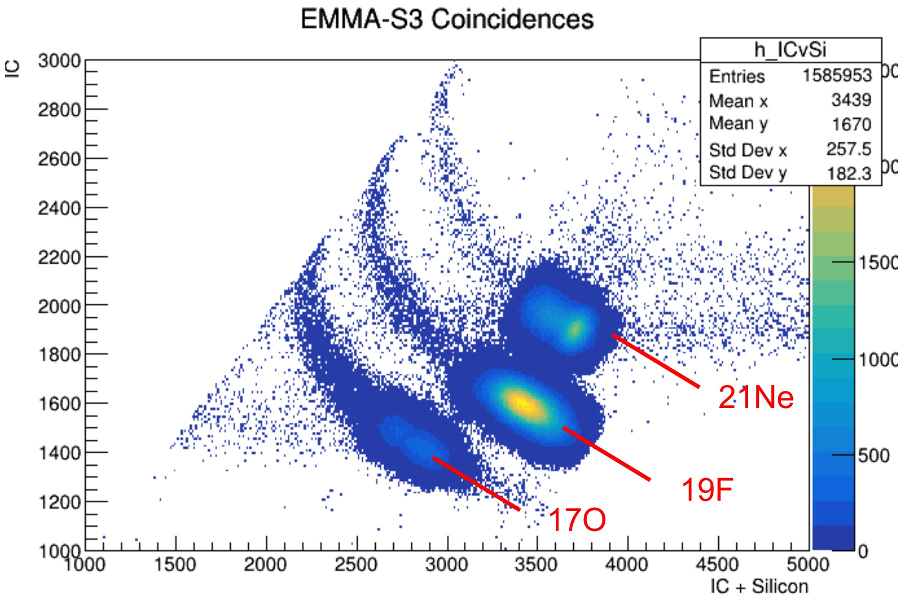
- S3 measured the tritons ejected from the reaction (16° – 37°)
- Angular distribution of tritons compared to Distorted Wave Born Approximation (DWBA) predictions to determine spin-parity and
- TIGRESS used to gate on gamma-rays associated with the de-excitation of specific energy levels
- EMMA used to detect ^{21}Ne recoils

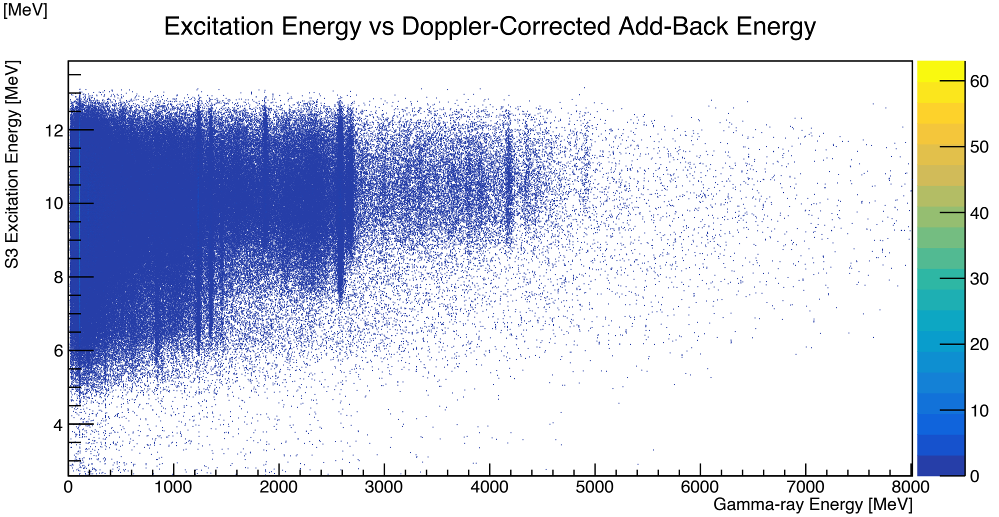


*N. Anantaraman, H. E. Gove and J. P. Trentelman (1977) Nuclear Physics **A276** 119-129.*

Analysis


S3 Excitation Energy PID gated


EMMA-S3 Coincidences


Excitation Energy vs Doppler-Corrected Add-Back Energy

Summary

- EMMA+TIGRESS has been used to measure the ^{17}O(^{7}Li,t)^{21}Ne reaction at TRIUMF/ISAC
- Motivation was to measure the strength of resonances that are the main source of uncertainty in the calculated rate of the $^{17}\mathrm{O}(\alpha, \gamma)^{21}\mathrm{Ne}$ reaction
- Needed to determine the effects of ^{16}O neutron poisoning of the weak s-process
- Weak s-process in rotating massive stars a possible site for early nucleosynthesis of intermediate mass elements
- Analysis ongoing…

Thank You for Listening!

And a big thank you to all my collaborators

A. M. Laird[1], M. Williams[1,2,4], B. Davids[2], C. Aa. Diget[1], S. Bhattacharjee[2], S. Gillespie[2], J. Williams[2], D. Yates[2,3], G. Hackman[2]

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