SOUTH DAKOTA MINES

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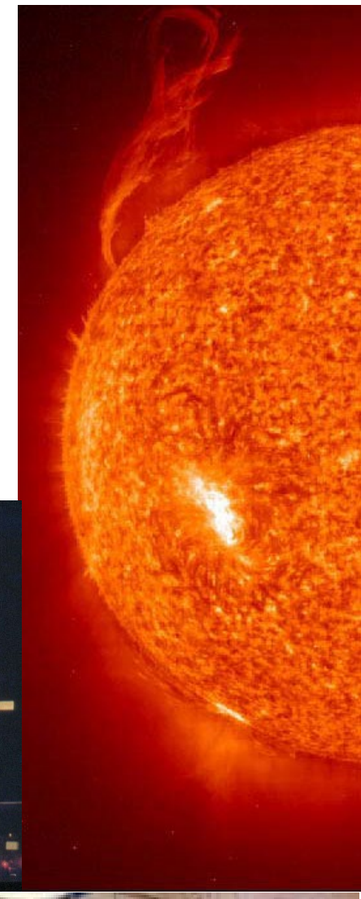
CASPAR

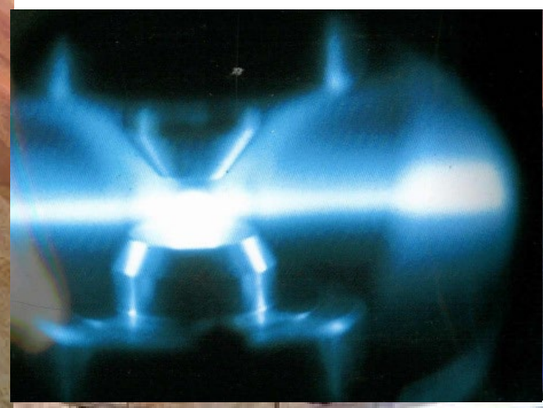
Compact Accelerator System for Astrophysical Reactions

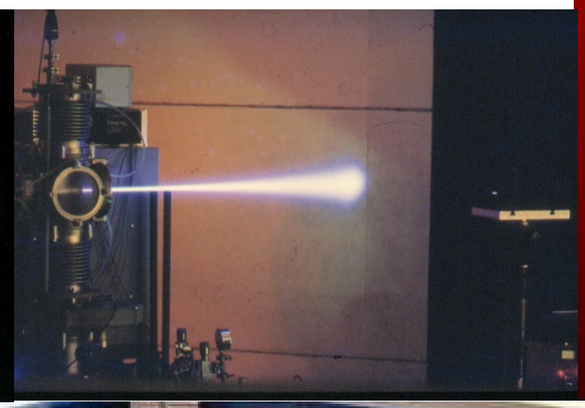
Nuclear Astrophysics Underground

Frank Strieder
South Dakota Mines
for the CASPAR Collaboration

SURF User Association 2022
October 26th, 2022







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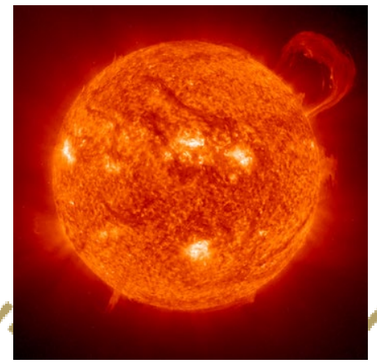
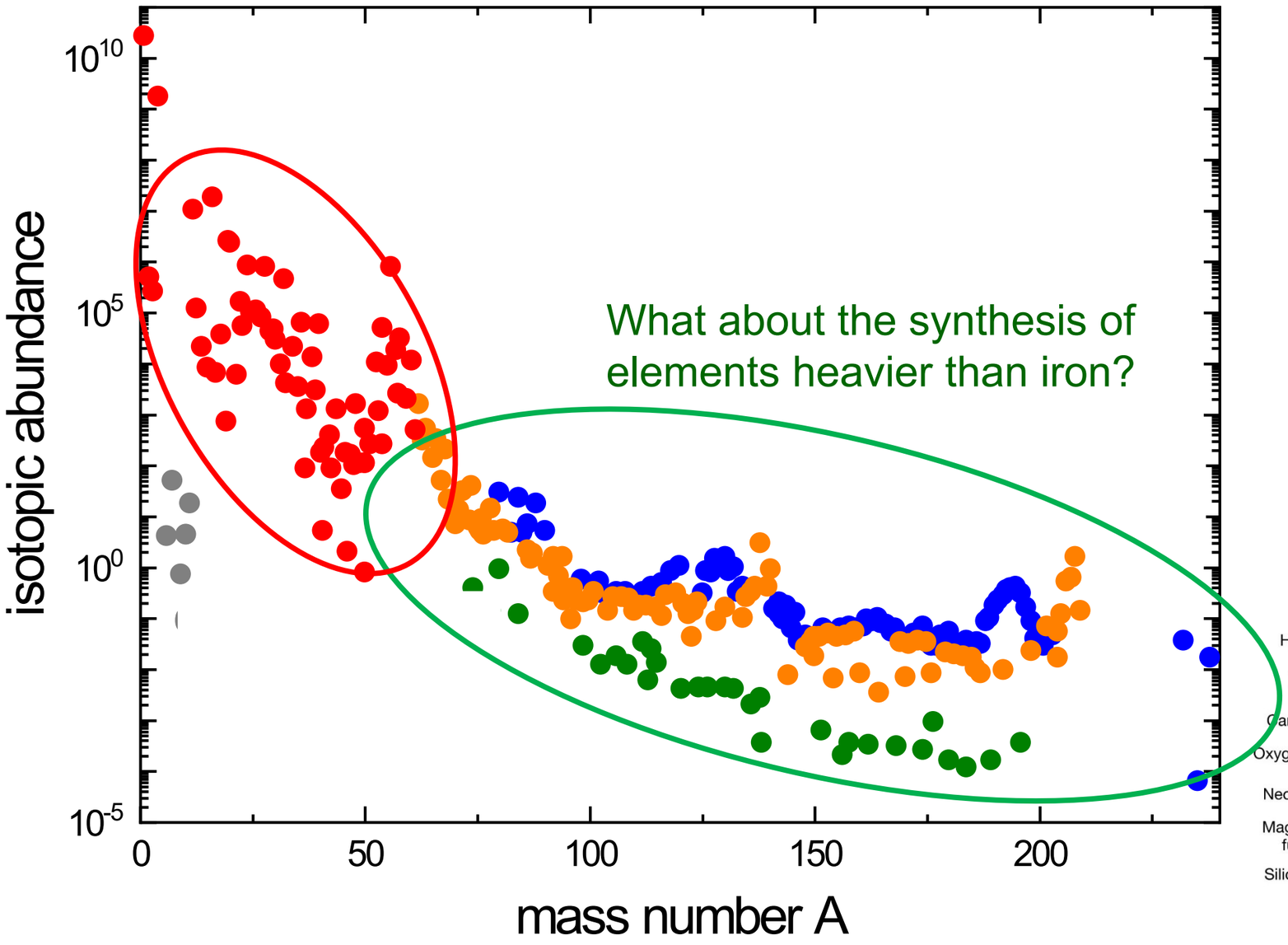
Origin of the Elements?





Hydrogen burning

⬇

Helium burning

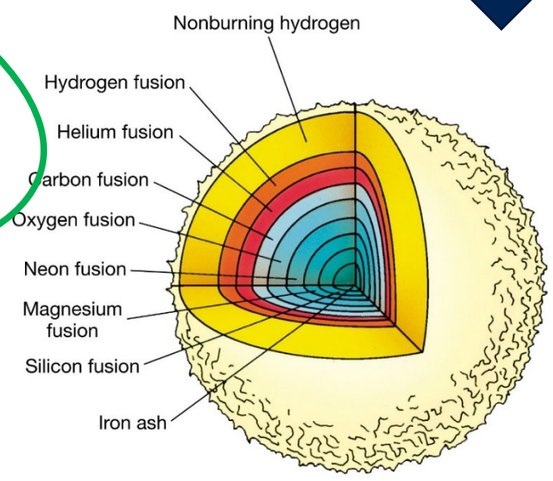
⬇ $M > 8M_{solar}$

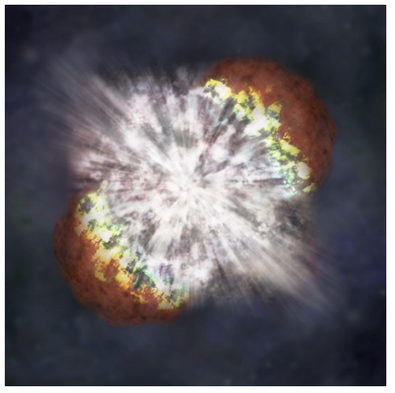
Carbon burning

⬇

advanced burning stage

⬇





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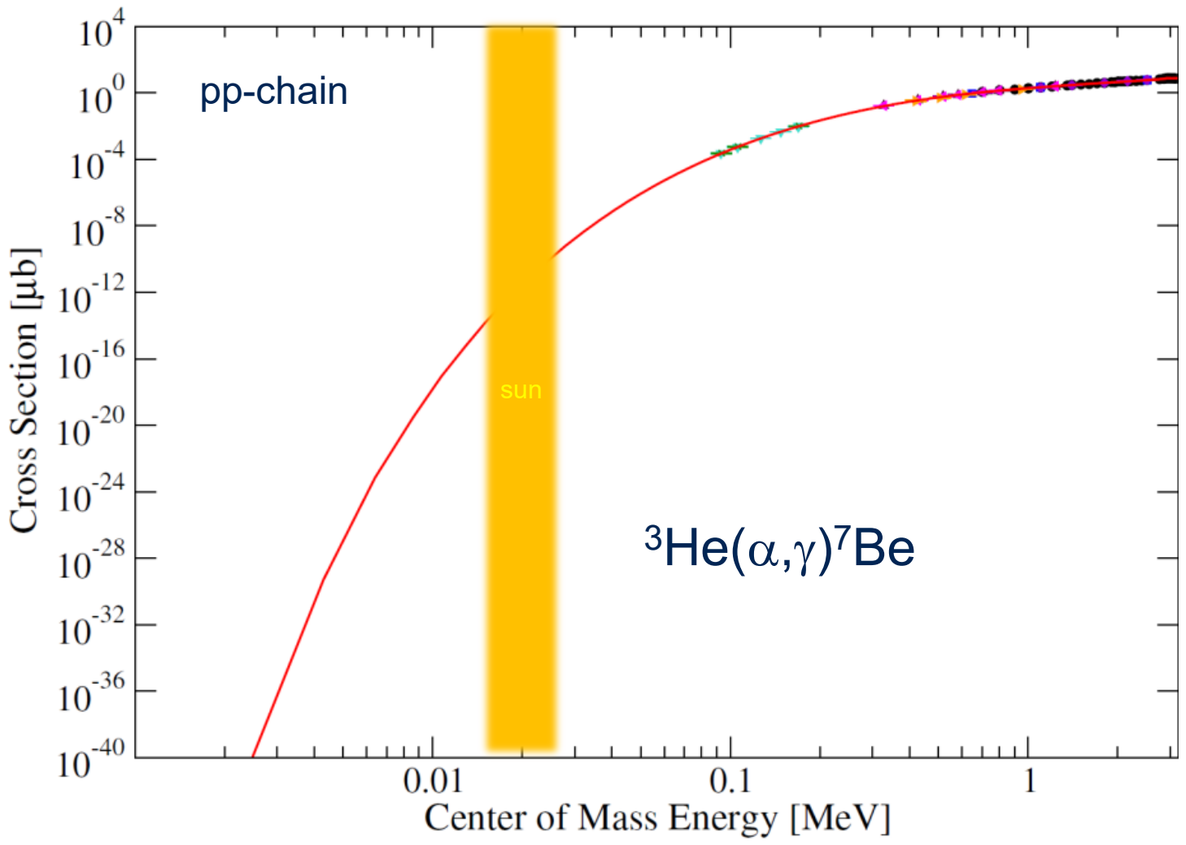
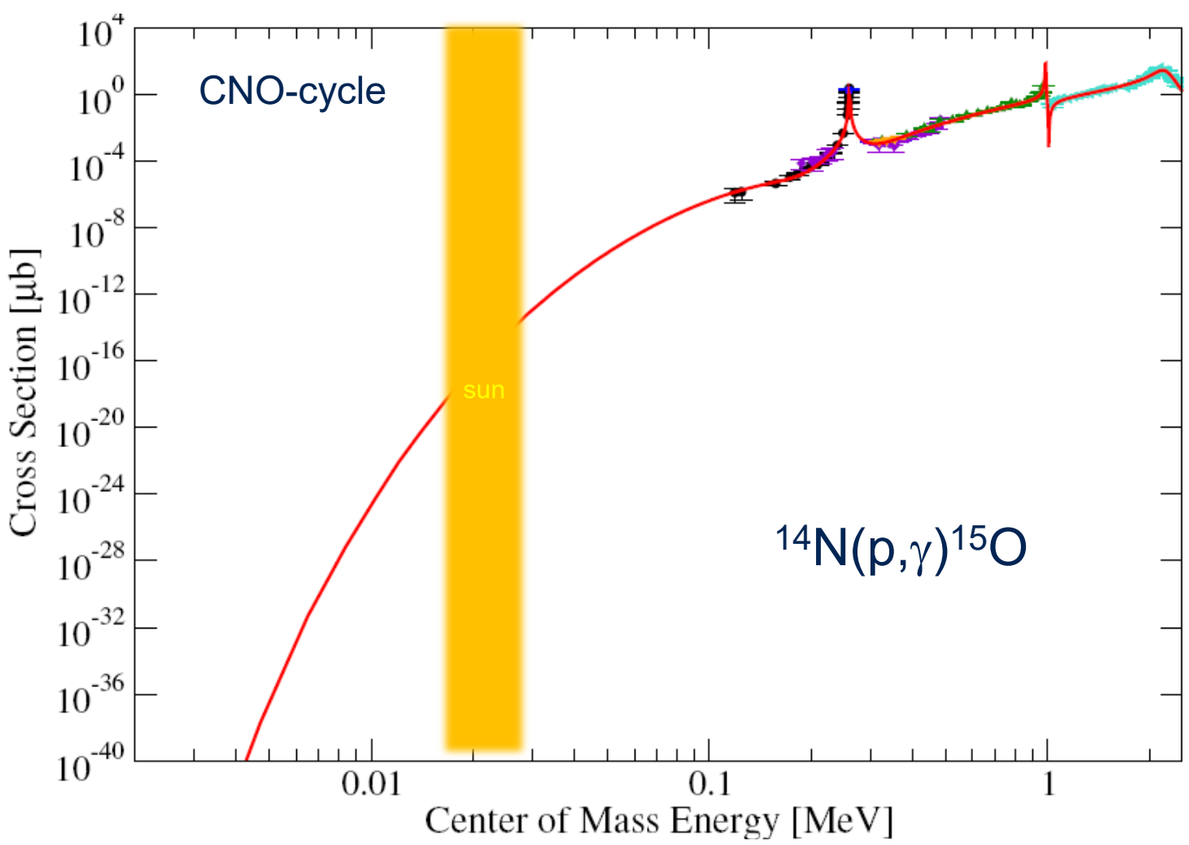
Nuclear Physics of Stars

- Reactions relevant for stellar burning and s-process nucleosynthesis need to be established at very low energies, where cross sections drop rapidly
- Direct measurements at higher energies can be extrapolated using R-matrix analysis
  → it is crucial to provide experimental data as close to the Gamow window as possible
- To achieve this, high-intensity beams need to be combined with high-efficiency detection systems in low-background environments





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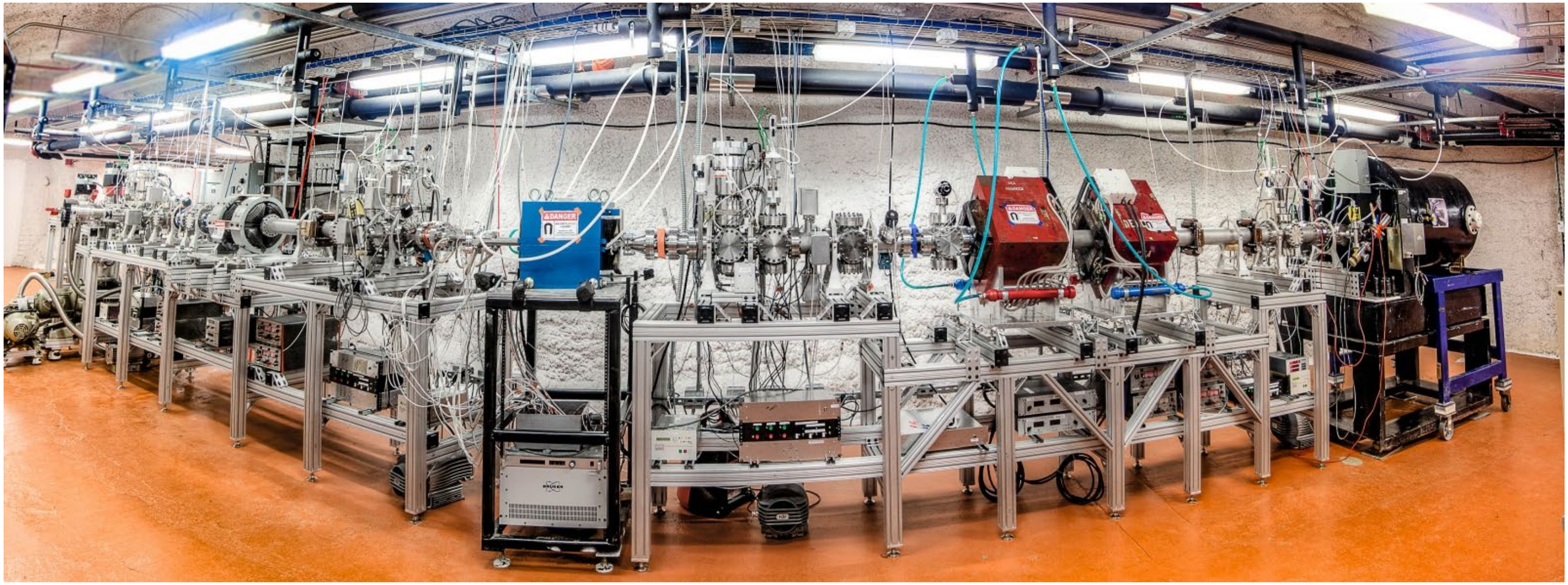

JN Accelerator	Electrostatic accelerator, voltage range 150 kV-1.1 MV
RF Ion Source	Proton Beam ~250 μA, Alpha Beam ~220 μA
Analyzing Magnet	25-degree dipole, 0-degree and "mass 2" lines
Target Station	Extended, recirculating, windowless gas target and solid target stations
Vacuum System	Turbomolecular pumping, conflat system beamlines

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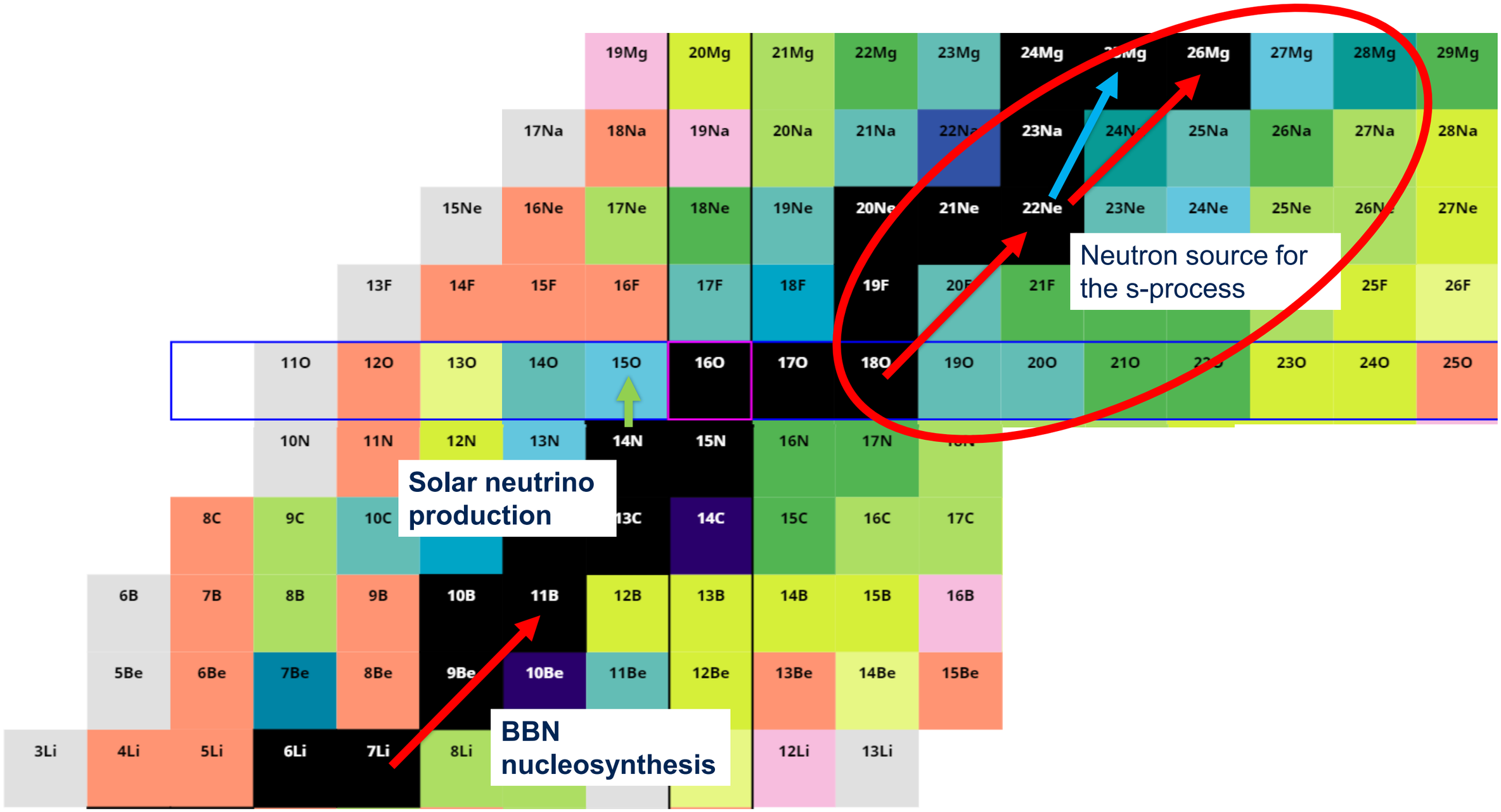
CASPAR - Underground Measurements



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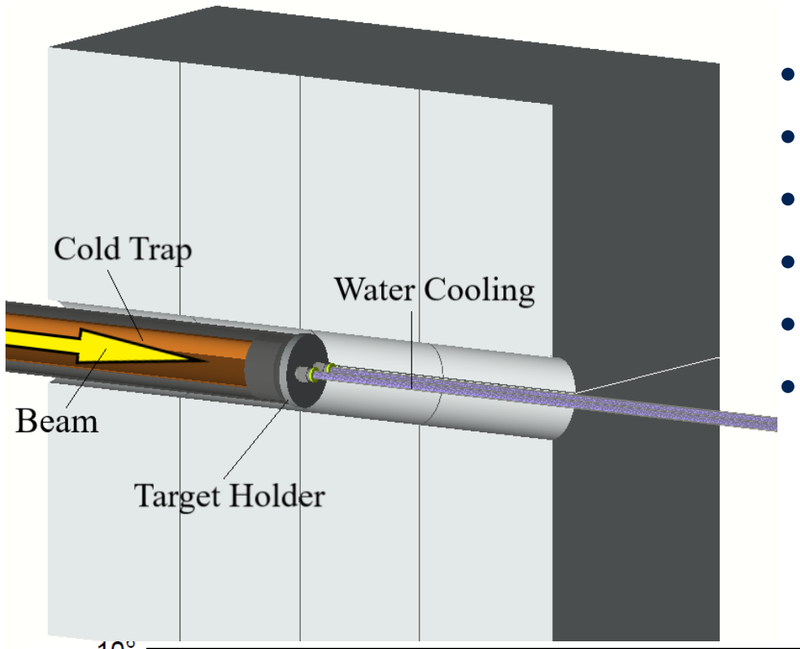
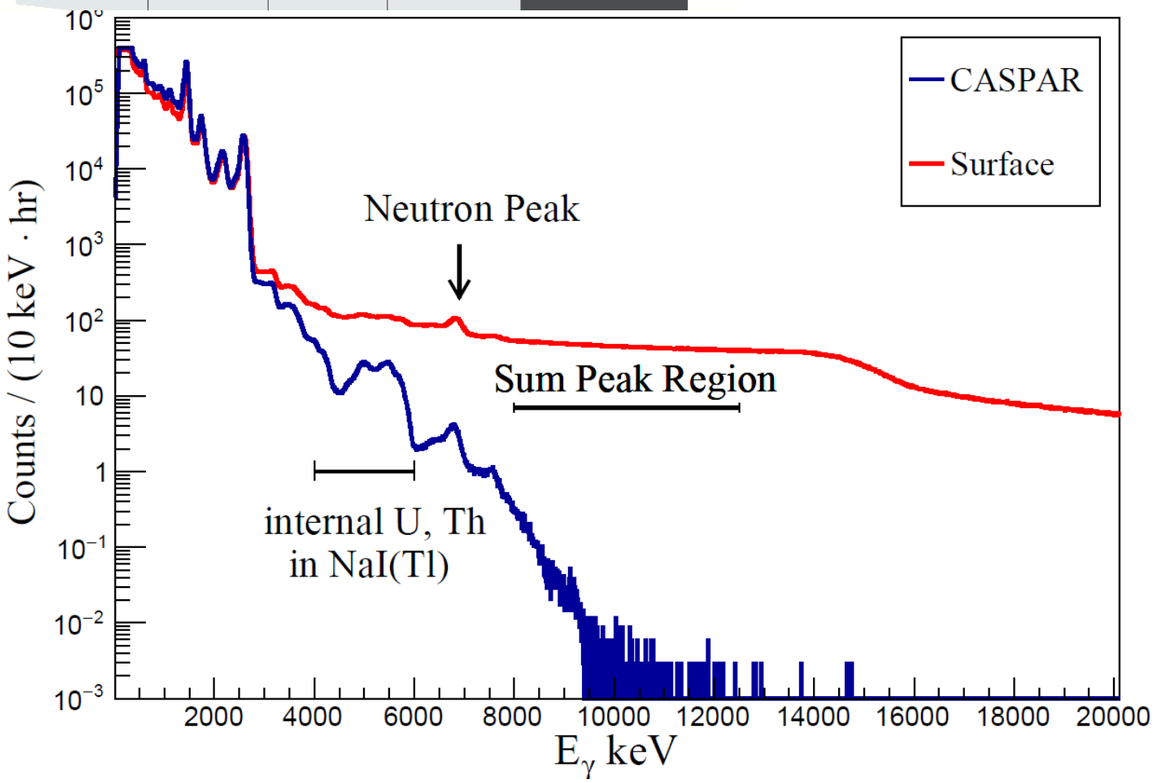
(α,γ) measurements – HECTOR



- 16 segments of NaI(Tl)
- Crystal size: 4” x 8” x 8”
- 2 PMTs per segment
- ∅60 mm borehole
- 52% efficiency for ^{60}Co
- 6% resolution at 1173 keV



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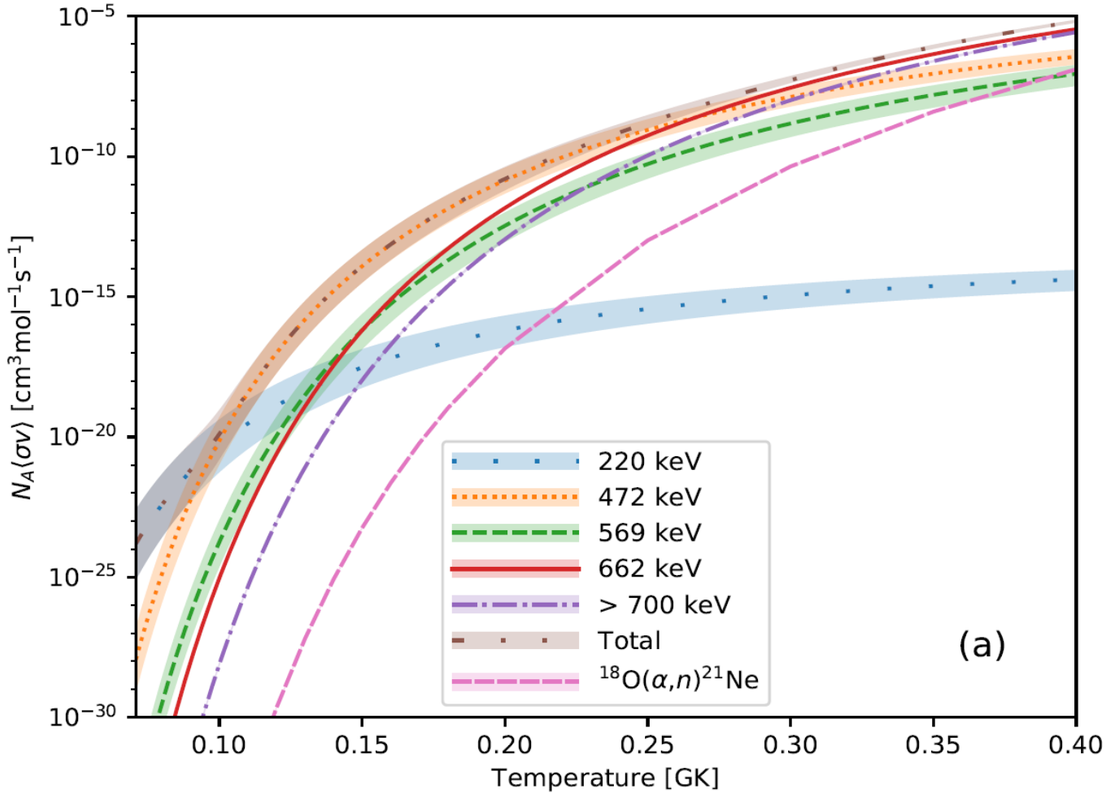
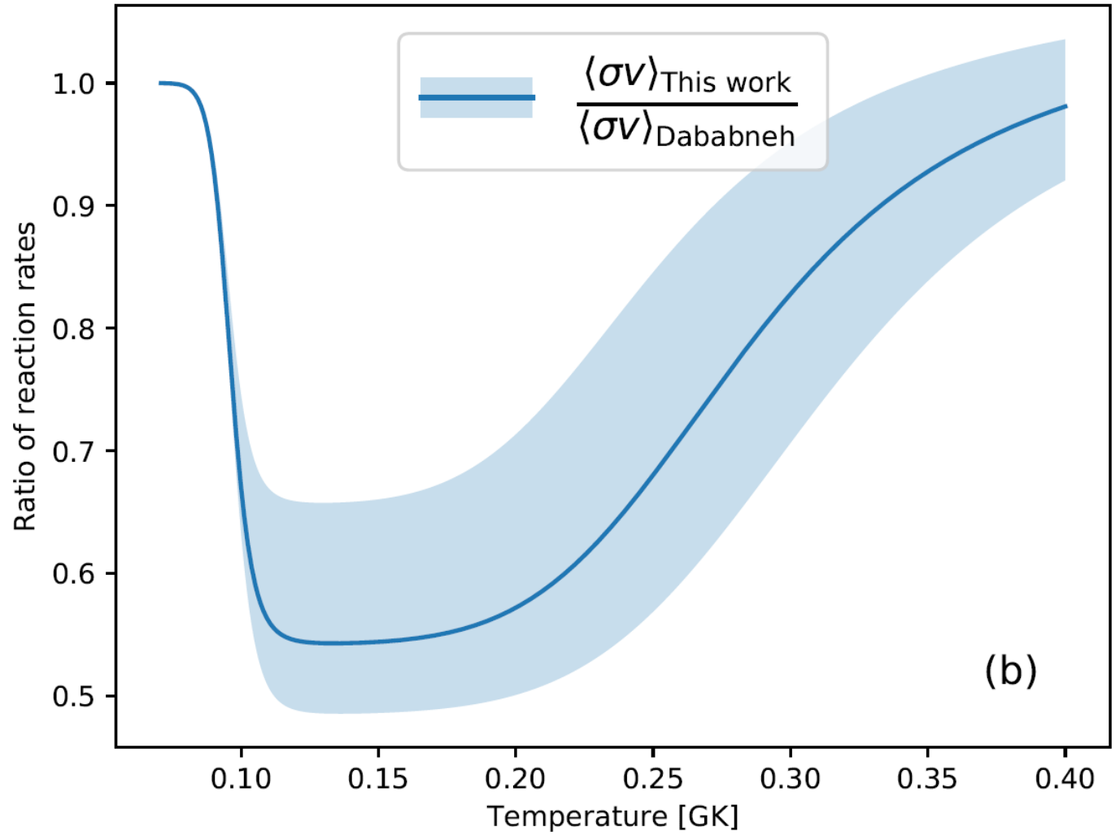
s-process at CASPAR – $^{18}O(\alpha,\gamma)^{22}Ne$

- Neutron source for both the weak and main s-process:
  - $^{14}N(\alpha,\gamma)^{18}F(\beta^{+}\nu)$**$^{18}O(\alpha,\gamma)^{22}Ne$**$(\alpha,n)^{25}Mg$
- **$^{18}O(\alpha,\gamma)^{22}Ne$** reaction not well constrained at the temperatures of interest
- Gamow window rate is dominated by resonances at 767, 750, 662, 569 and 472 keV
- α-beam on $Ta_2{}^{18}O_5$ target (prepared via electrolysis), measurements with HECTOR





A. Dombos et al., Phys. Rev. Lett. 128, 162701 (2022)

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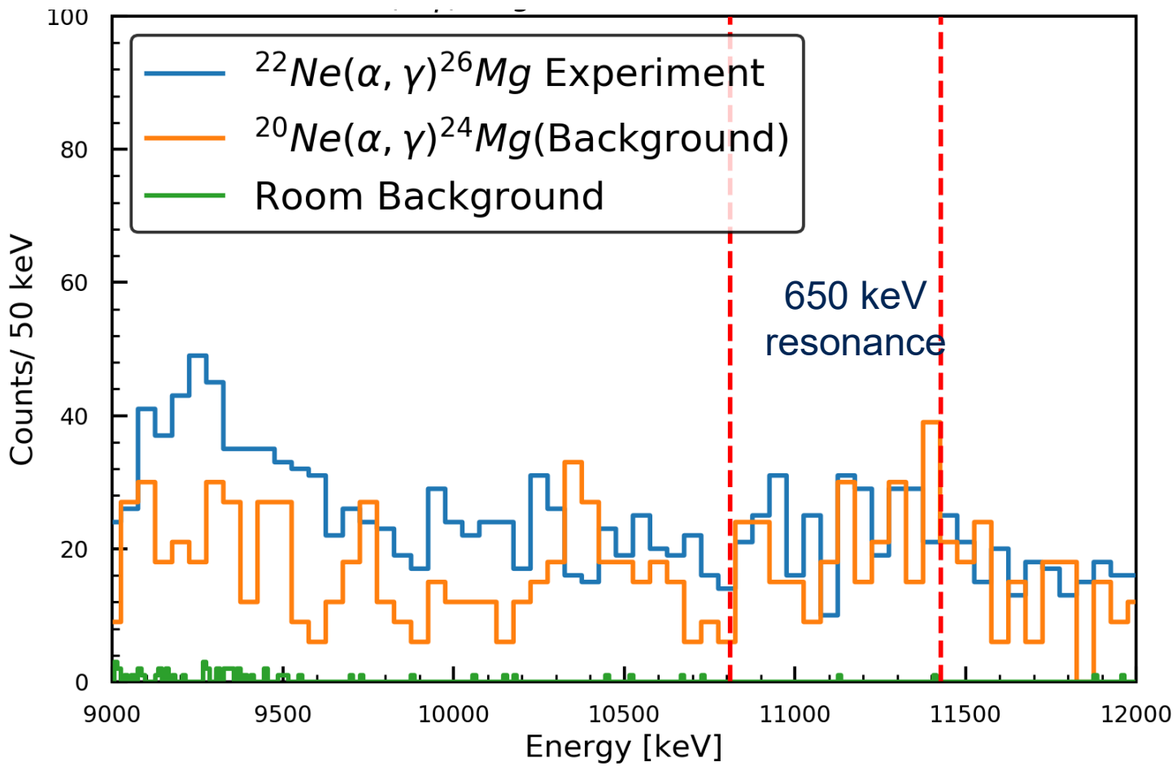
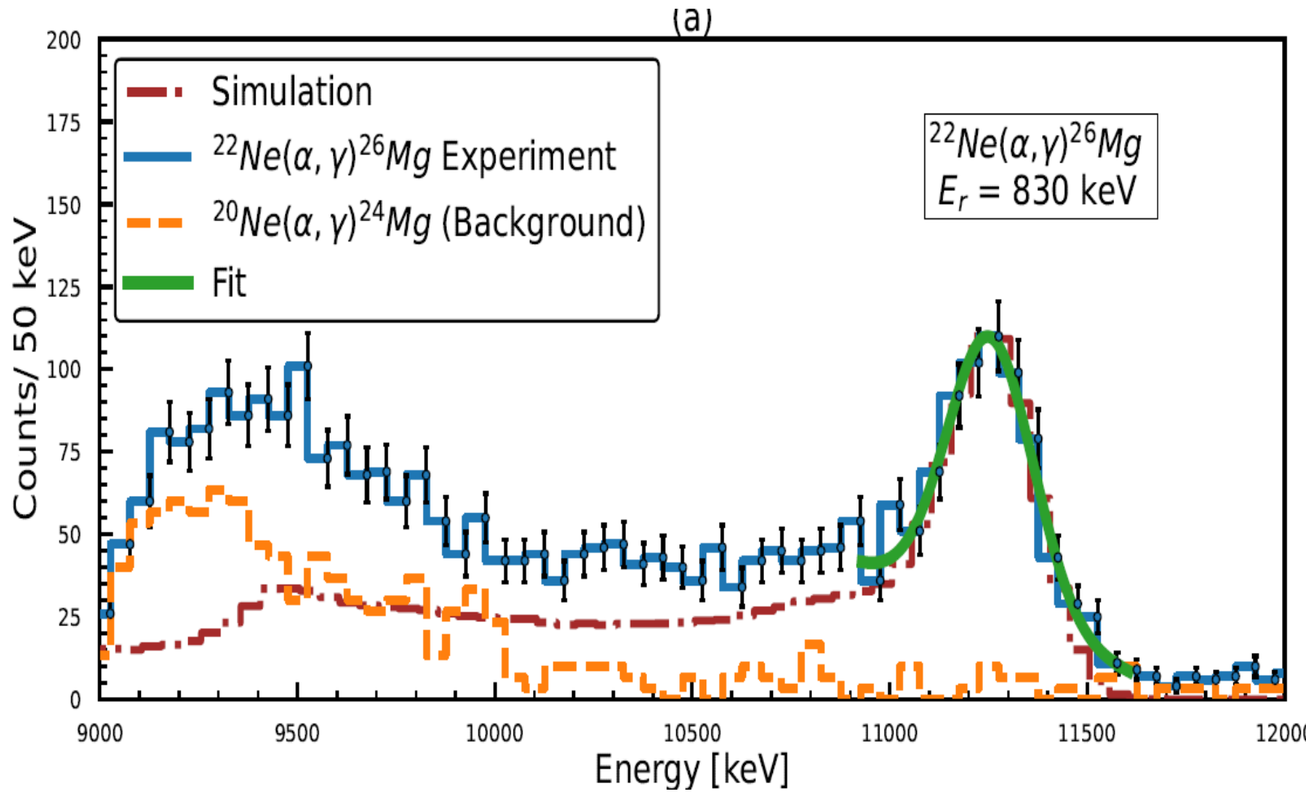
s-process at CASPAR – $^{22}Ne(\alpha,\gamma)^{26}Mg$

- Alpha-capture with a positive Q-value competes with the $^{22}Ne(\alpha,n)^{25}Mg$ reaction
- Reaction rate is dominated by two resonances at 650 and 830 keV
- α-beam on Ne-target implanted in tantalum, measurements with HECTOR





Upper limit of $\omega\gamma < 0.1\ \mu$eV obtained for the low energy resonance, determined relative to the 830 keV resonance strength obtained in this experiment.

Shahina et al., Phys. Rev. C 106, 025805 (2022)

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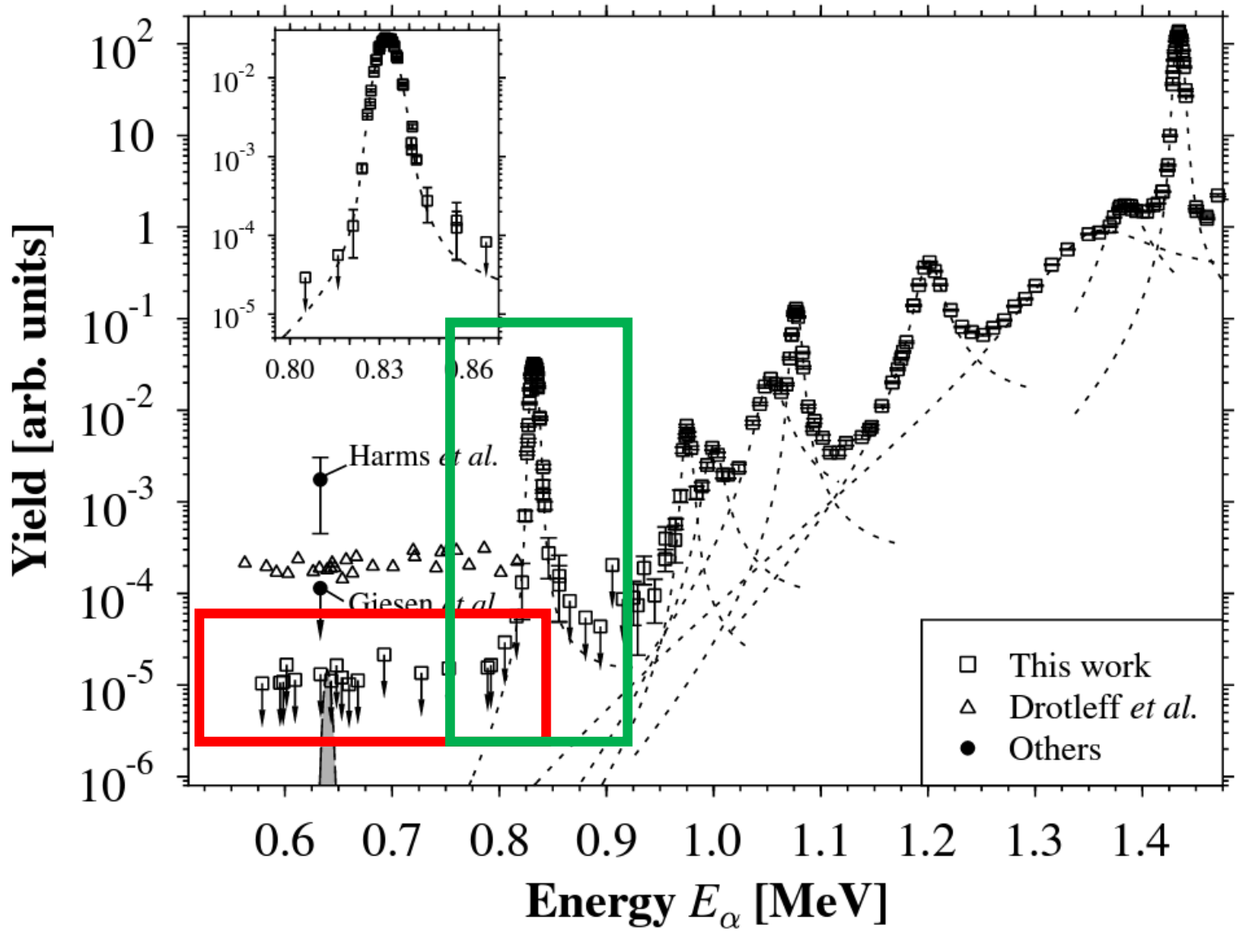
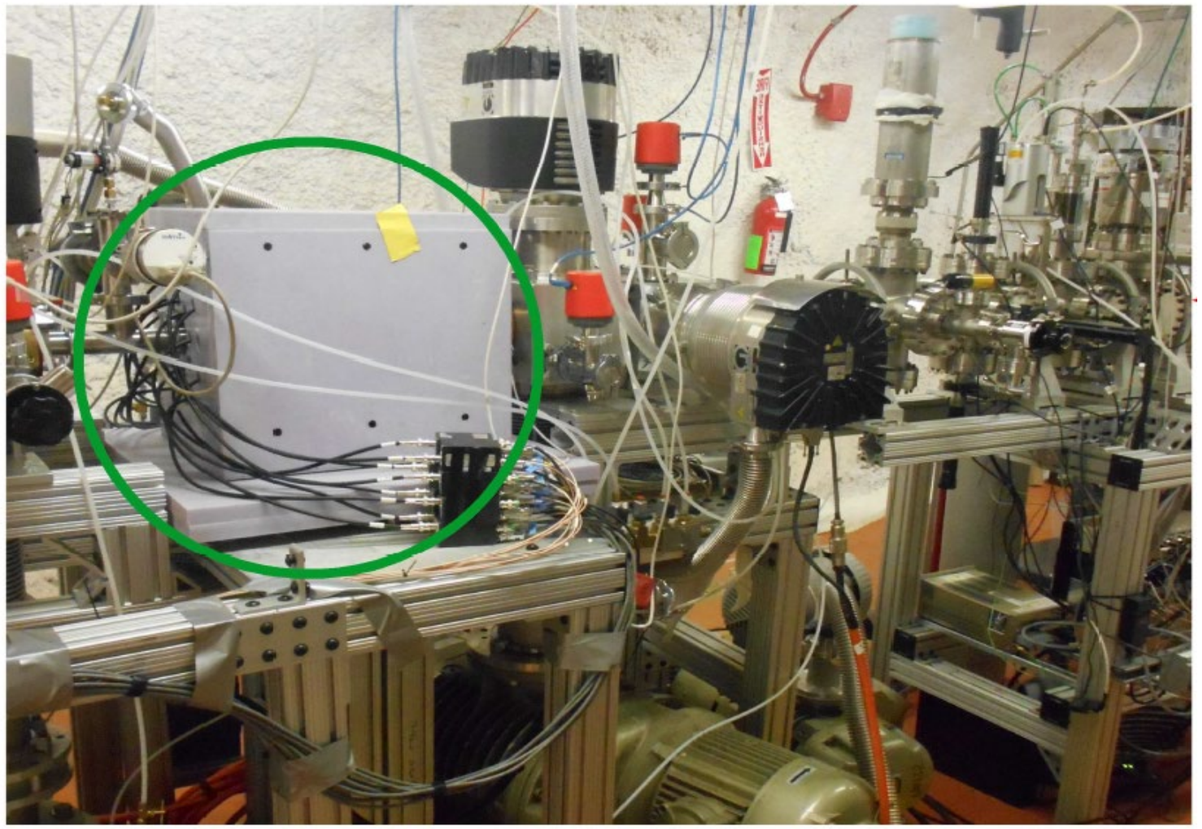
s-process at CASPAR – $^{22}Ne(\alpha,n)^{25}Mg$

- $^{22}Ne(\alpha,n)^{25}Mg$ is a neutron source for the s-process nucleosynthesis
- Measurements performed using a windowless gas target surrounded by 16 He-3 detectors in a borated-polyethylene moderator
- Analysis of the 830 keV resonance and the low-energy region down to ~600 keV almost completed





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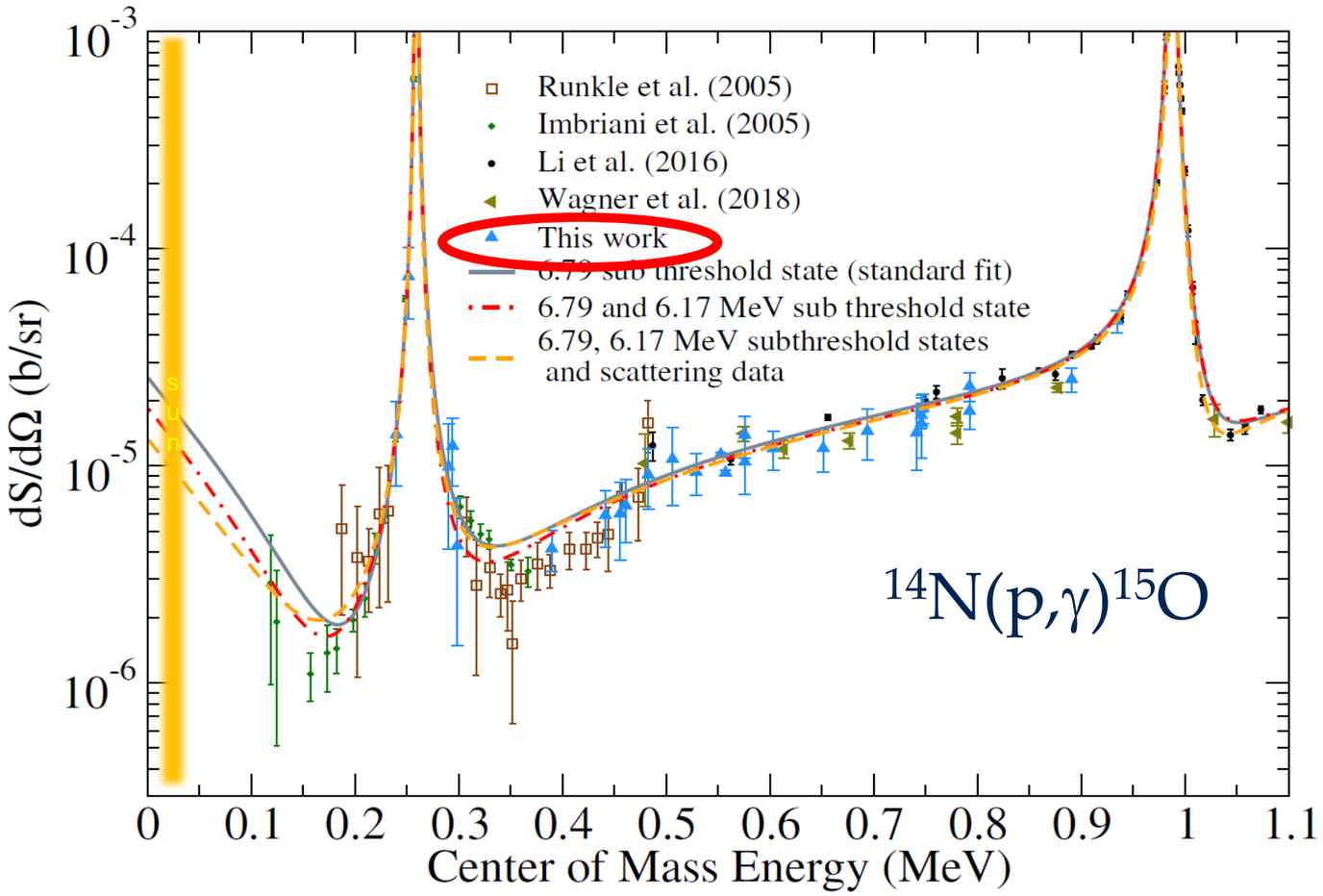
CNO Neutrino Sources – $^{14}N(p,\gamma)^{15}O$

- Inconsistencies between elemental abundances from spectroscopic data and isotope analysis from neutrino flux raise questions about interior structure or metallicity of the sun
- CNO neutrino flux offers an independent measure of the metallicity of the solar core → low energy cross sections of CNO reactions need to be known with high accuracy



- R-matrix calculations indicate inconsistencies in the fit of the cross-section data.
- Missing resonance states or structure information in the region near the threshold might explain the observed discrepancies and lead to a reliable reaction rate!

submitted to Phys. Rev. C (May 2022)

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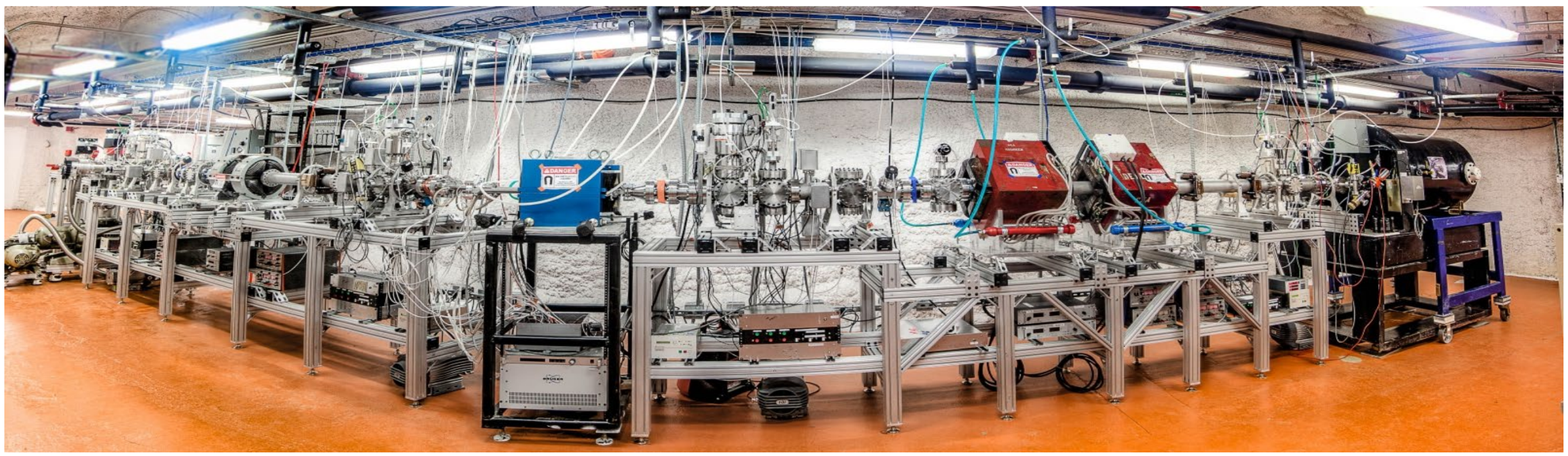
Summary

- Ongoing research program at CASPAR provides data for a variety of nucleosynthesis processes at low-energies
- Last experimental campaign resulted in 6 project that are now completed or the analysis is in progress
- Future plans include measurements both with HECTOR and the He-3 spectrometer → stay tuned for updates!
- Currently, the experiments are hibernating due to DUNE constructions, CASPAR plans to resume activities in late 2023



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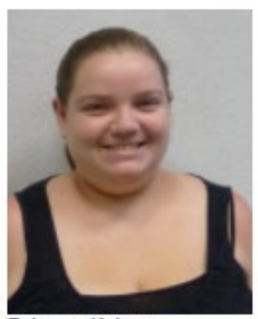
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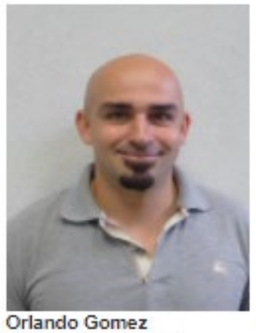
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