Current status and future plans for CASPAR underground lab

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CASPAR & University of Notre Dame

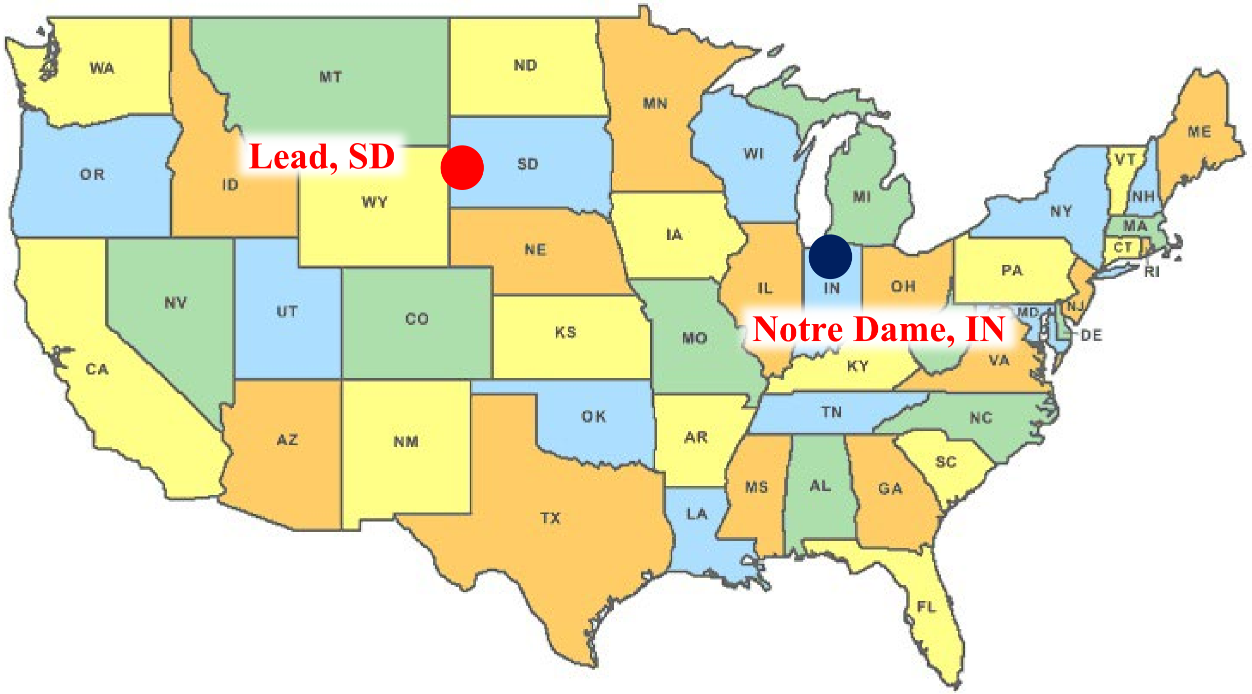
HELIUM-25, Dresden, Aug. 2025

Compact Accelerator System for Performing Astrophysical Research

UNIVERSITY OF NOTRE DAME

SOUTH DAKOTA MINES
An engineering, science and technology university

CASPAR Location

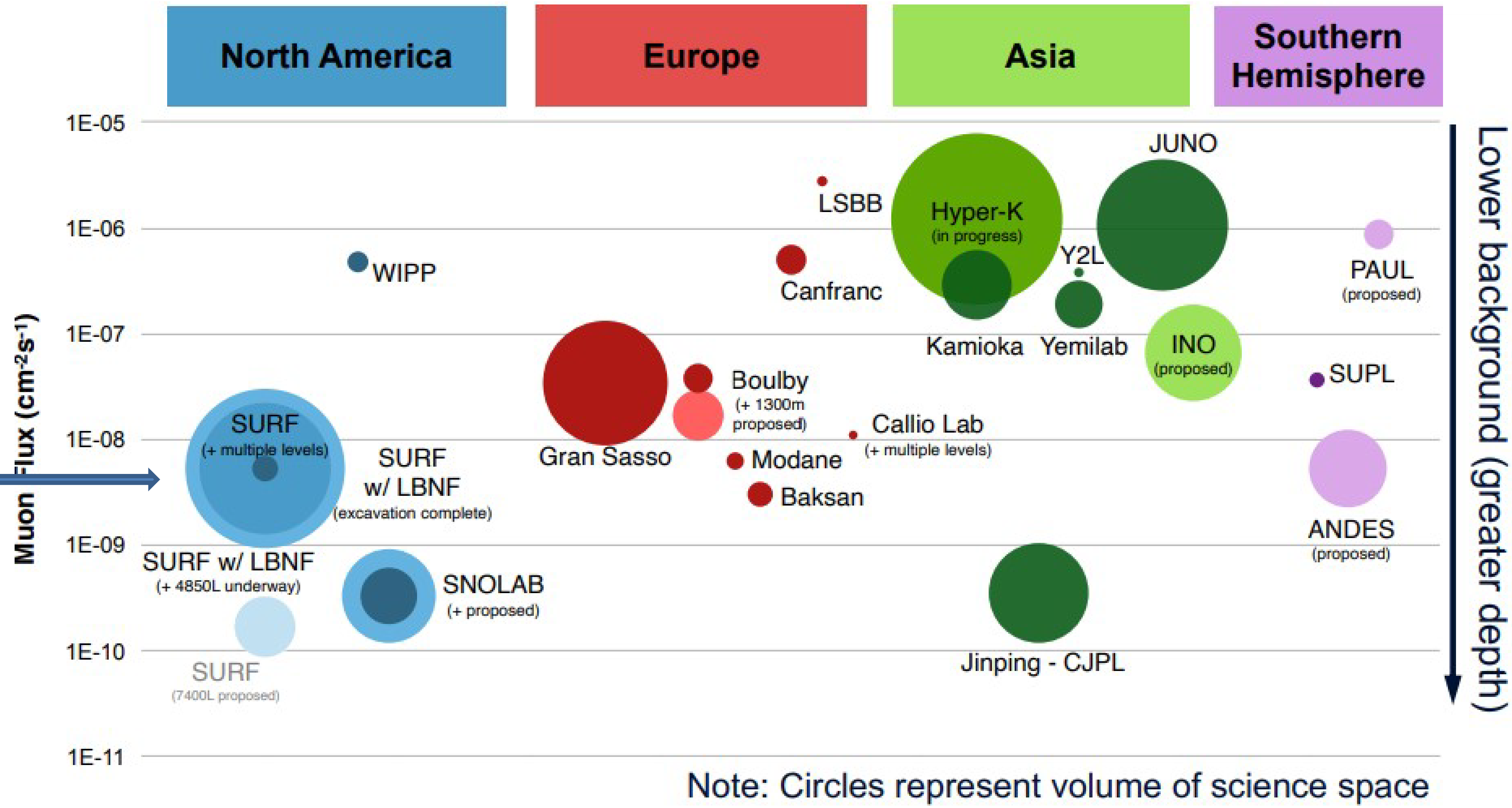


Sanford Underground Research Facility

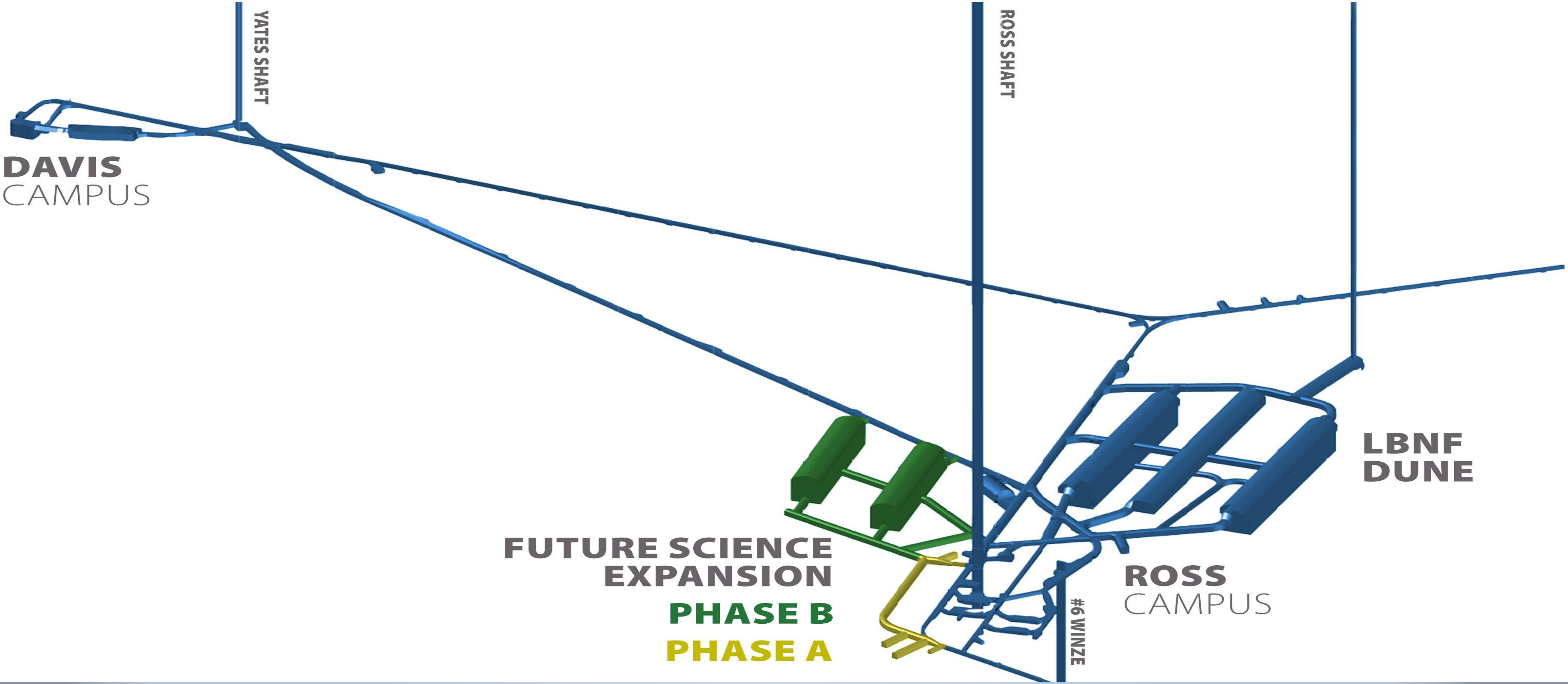
Location and Background Suppression

CASPAR

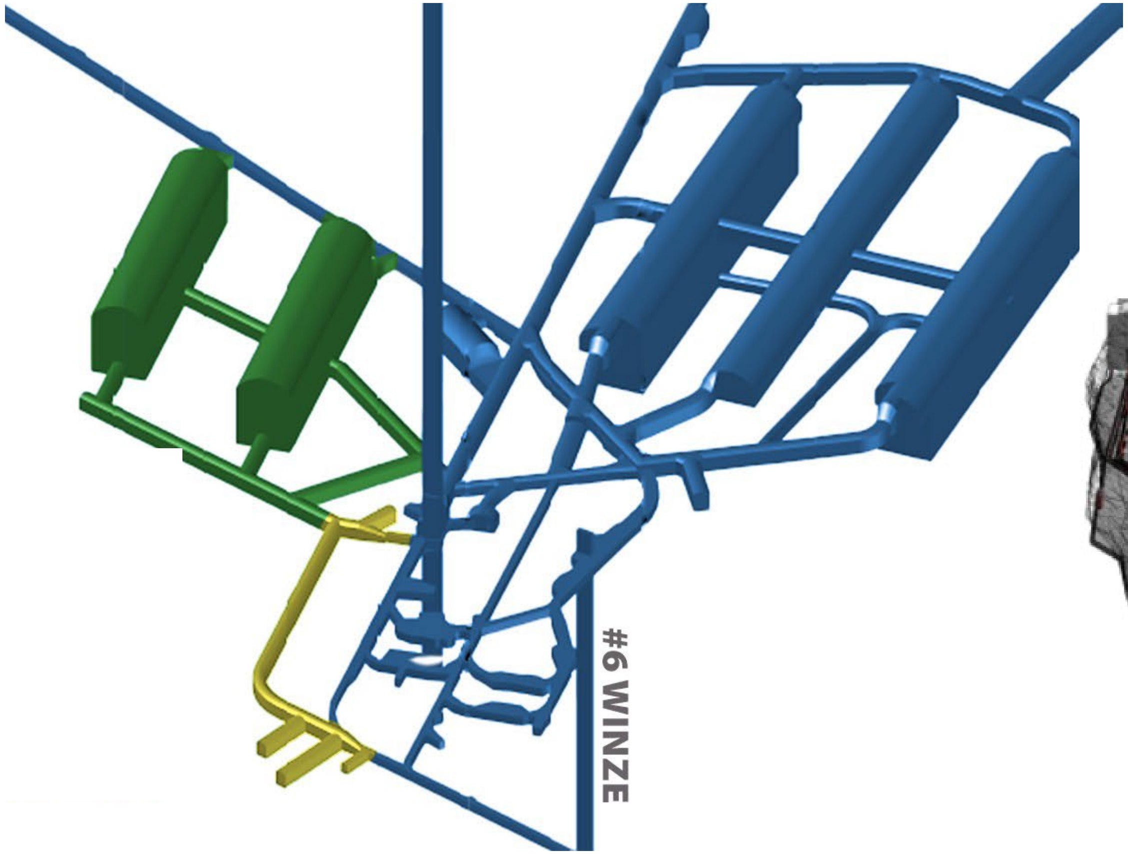
4,300 meters water equivalent
Muon flux 4.4 x 10^{-9} /(cm^2s)



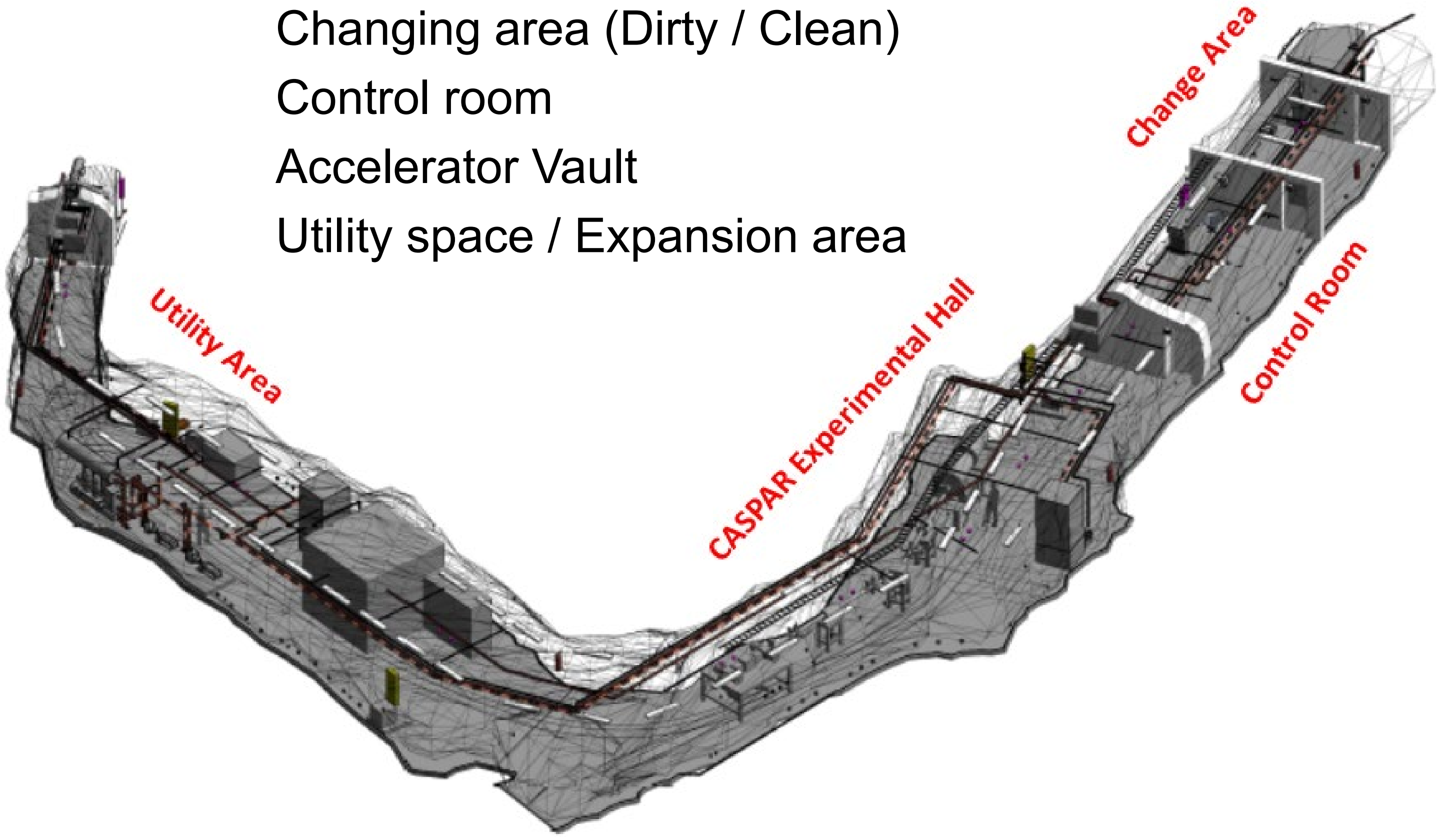
CASPAR Location On The 4850



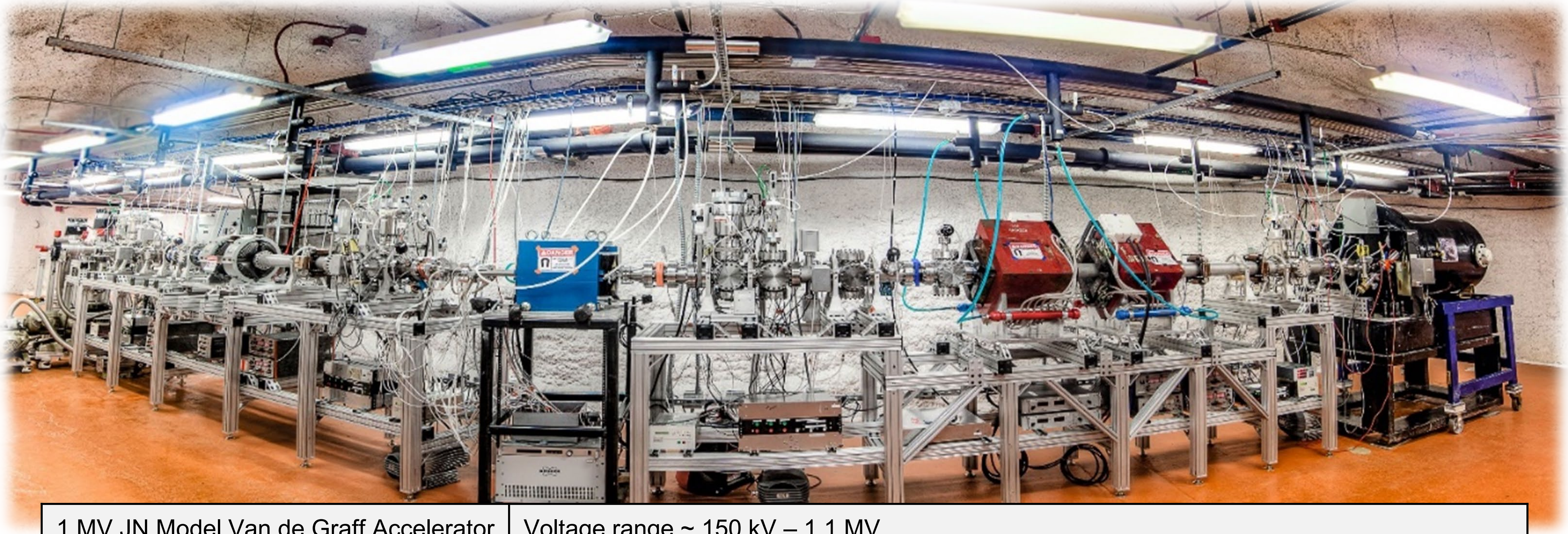
CASPAR Location On The 4850



- Changing area (Dirty / Clean)
- Control room
- Accelerator Vault
- Utility space / Expansion area

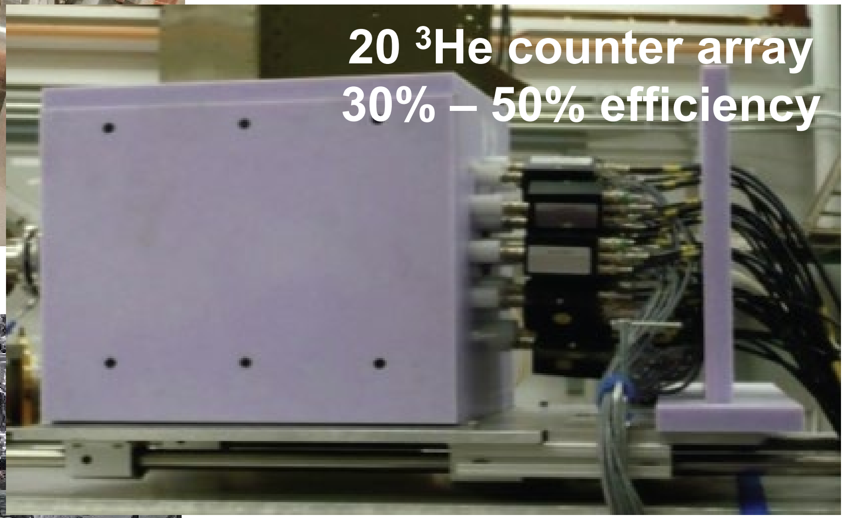


CASPAR Overview



1 MV JN Model Van de Graff Accelerator	Voltage range ~ 150 kV – 1.1 MV
Gas fed radio frequency source	Proton beam and alpha beam to target, 200 – 250 μA
Analyzing magnet	25-degree, with 0-degree and “mass-2” ports
Beamline and pumping	All conflat system with magnetic levitation turbo pumps and dry scroll backing pumps
Typical vacuum operating range	5 x 10^{-9} Torr
Target stations	Extended, recirculating, windowless gas target & Solid target stations interchangeable
Workforce	Graduate student, postdoc and faculty driven. No operators.

Detection Choices



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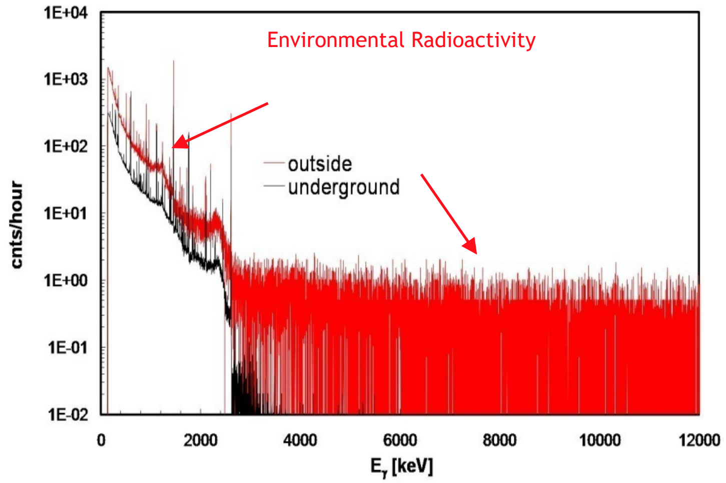
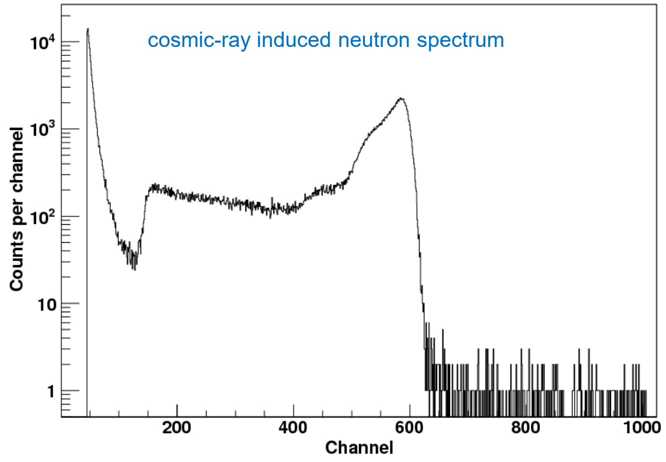
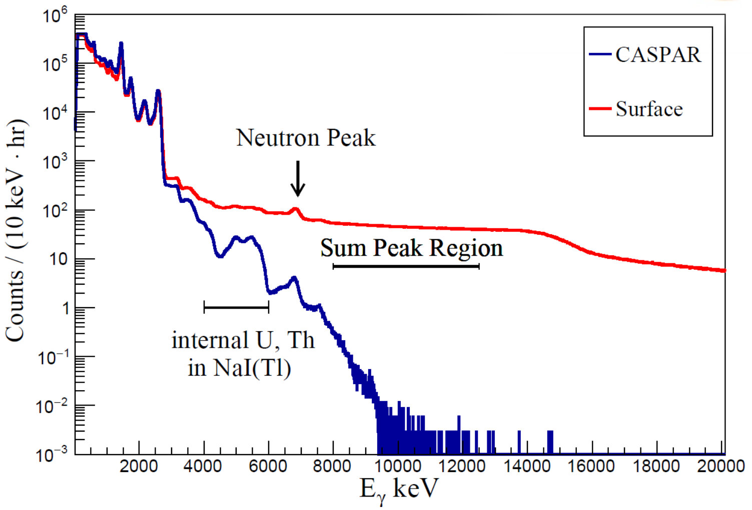
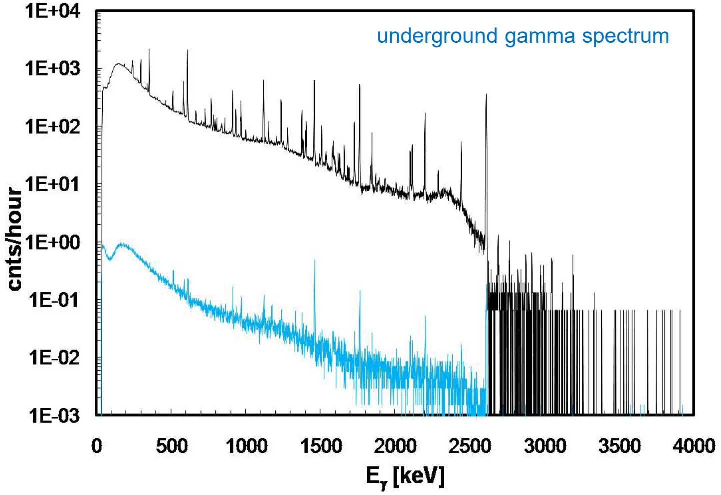
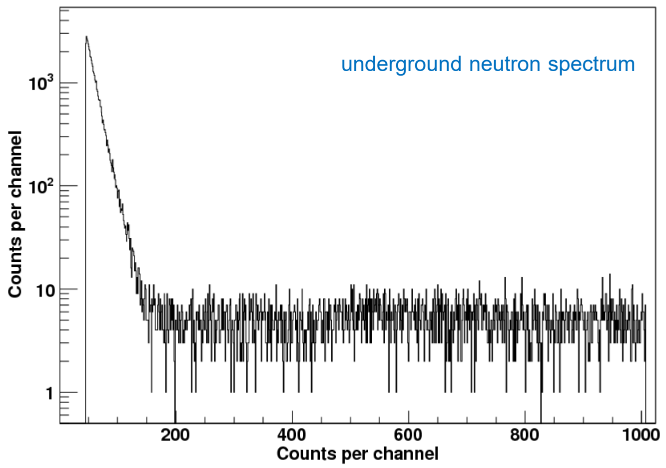


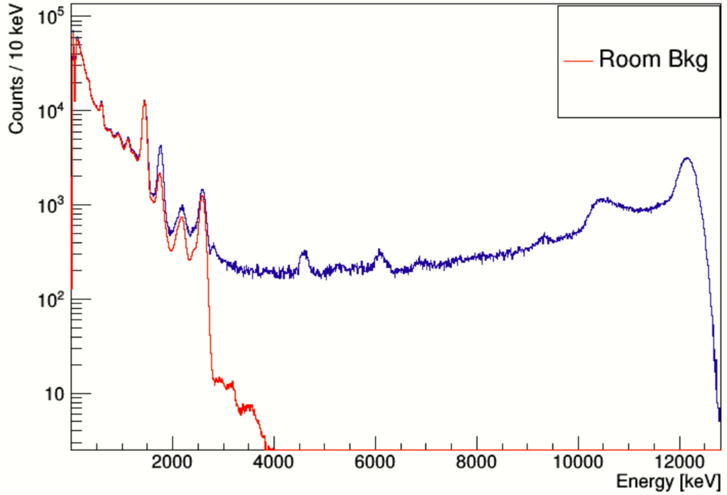








^{27}Al(p,γ)^{28}Si 632 keV resonance

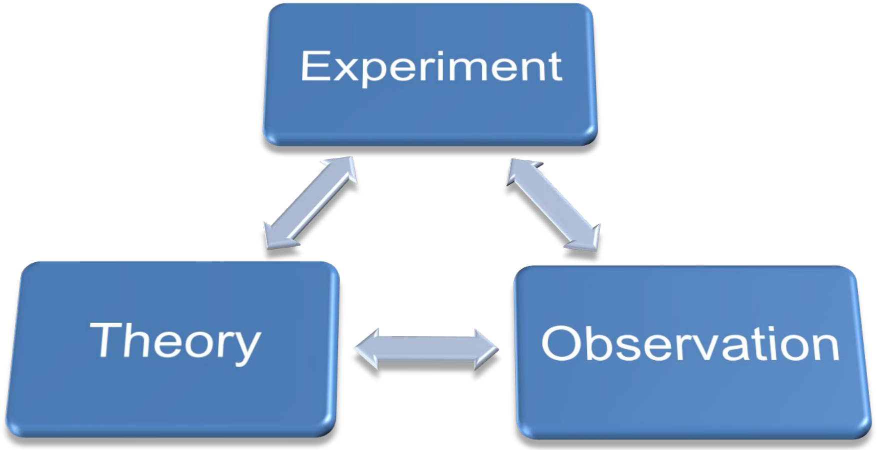


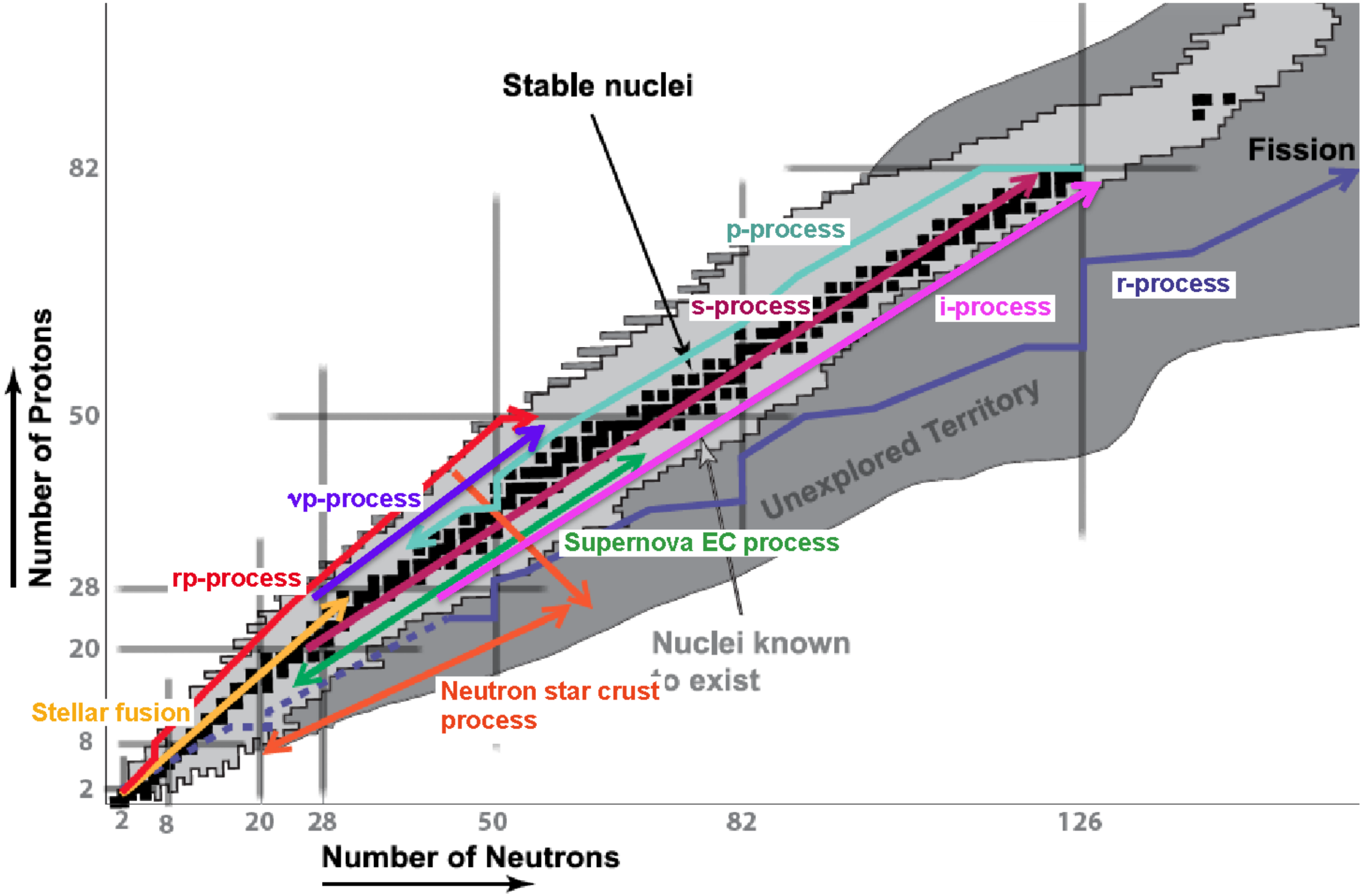
Astrophysics Is Messy

Multiple processes all interacting

Competing interactions
- Decays
- Poisons
- Disassociations

Site specific process flows





For Example 2019 – 2021 Campaign

$^{7}Li(\alpha,\gamma)^{11}B$
PhD Thesis

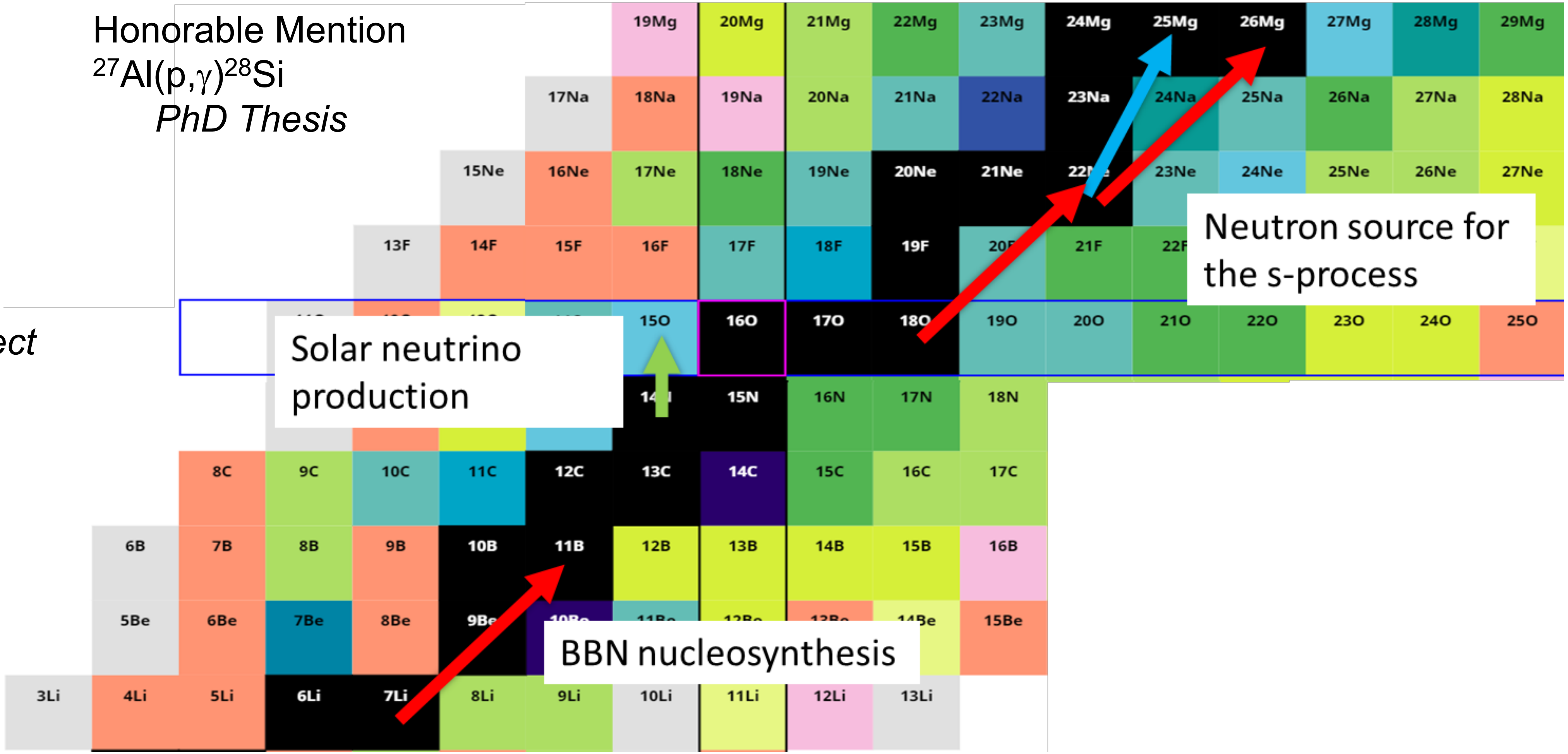
$^{14}N(p,\gamma)^{15}O$
PhD Thesis

$^{18}O(\alpha,\gamma)^{22}Ne$
Postdoc Project

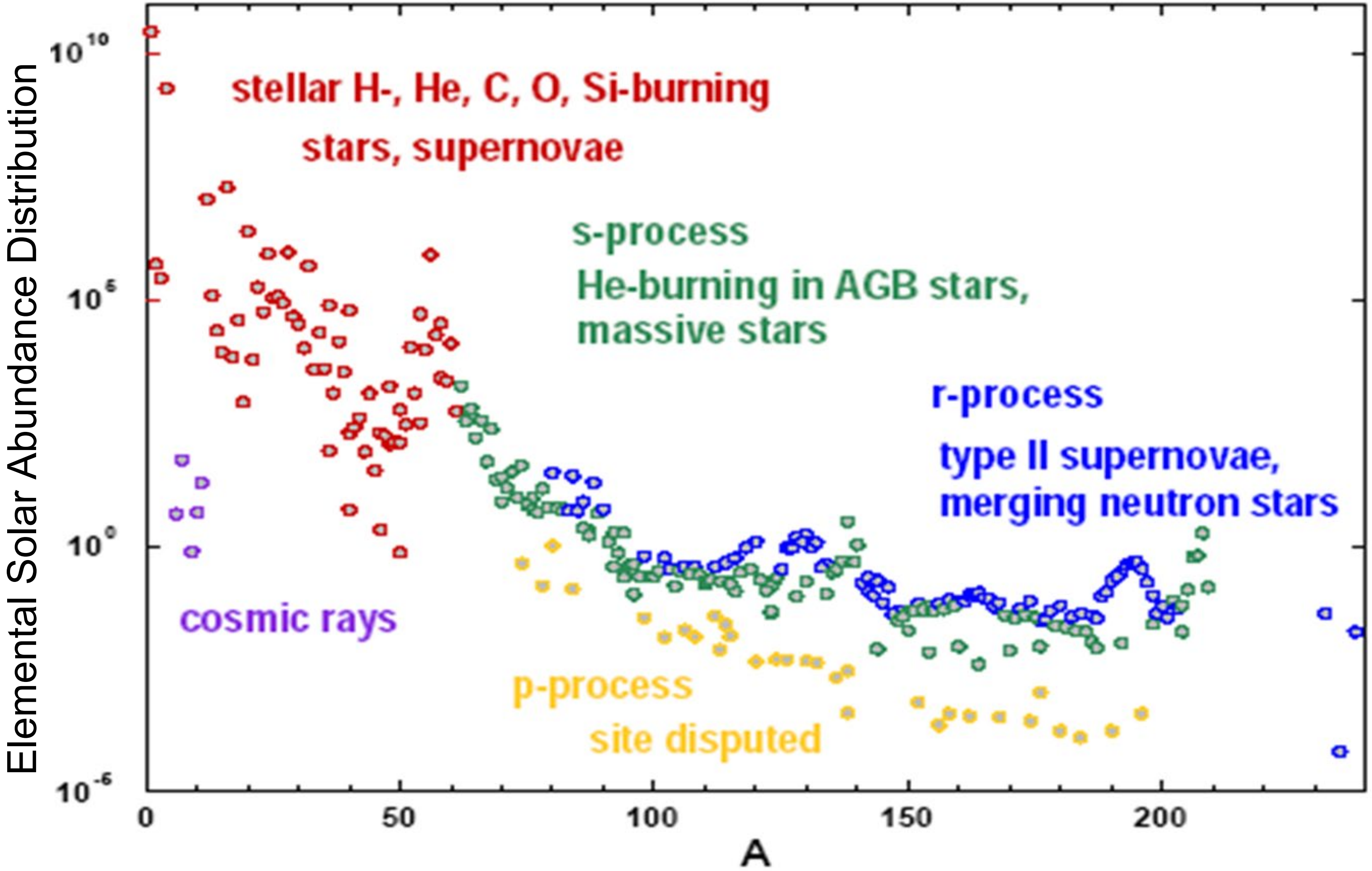
$^{22}Ne(\alpha,n)^{25}Mg$
PhD Thesis

$^{22}Ne(\alpha,\gamma)^{26}Mg$
PhD Thesis

Honorable Mention
$^{27}Al(p,\gamma)^{28}Si$
PhD Thesis



Elemental Abundances – How Does This Affect Me?



Base Veiw

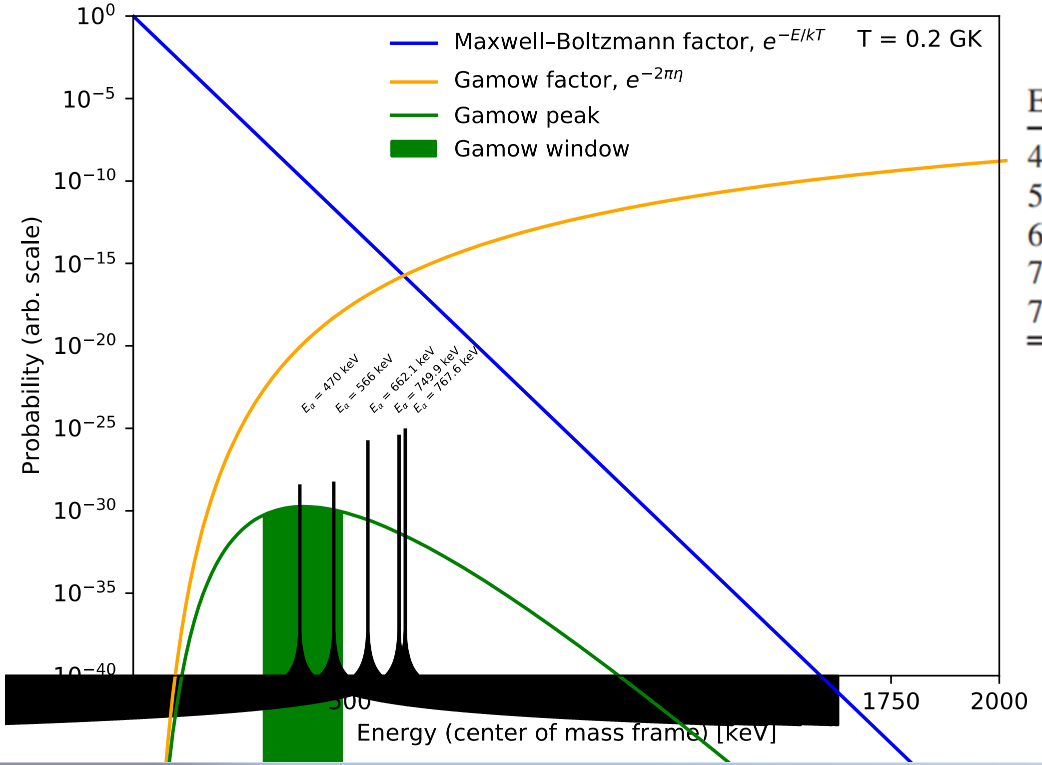
A < 58 Fusion processes
- p-p chains
- He burning
- CNO cycles
- C fusion

A > 58
- r-process (~ 50% elements)
- s-process (~50% elements)
- p-process (35 nuclides)

$^{18}O(a,\gamma)^{22}Ne$ – Path To Neutron Source

- Process flow to ^{22}Ne as a neutron source for both weak and main s-process

  $^{14}N(\alpha,\gamma)^{18}F(\beta+\nu)\mathbf{^{18}O(\alpha,\gamma)^{22}Ne}(\alpha,n)^{25}Mg$
- Within the Gamow window rate is dominated by 5 resonances at 767, 750, 662, 569 and 472 keV
- $Ta_2{}^{18}O_5$ target (prepared via electrolysis),



Ref [7] Dababneh, Phys. Rev. C **68** 025801 (2003)

Energy (keV)	$\omega\gamma_{partial}$ (μeV) Ref. [7]	$\omega\gamma$ (μeV) Ref. [7]	$\omega\gamma$ (μeV) This Letter: Statistical	$\omega\gamma$ (μeV) This Letter: Decay scheme
472 ± 18^a	0.24 ± 0.08^c	0.48 ± 0.16^c	0.26 ± 0.05	
569 ± 15^a	0.63 ± 0.09^c	0.71 ± 0.17^c	0.63 ± 0.30	
662.1 ± 1.0^b		229 ± 19^c	221 ± 12	225 ± 12
749.9 ± 1.0^b		490 ± 40^c	564 ± 35	553 ± 34
767.6 ± 1.0^b		1200 ± 120^b	1438 ± 86	1306 ± 77

Measured all 5 resonances

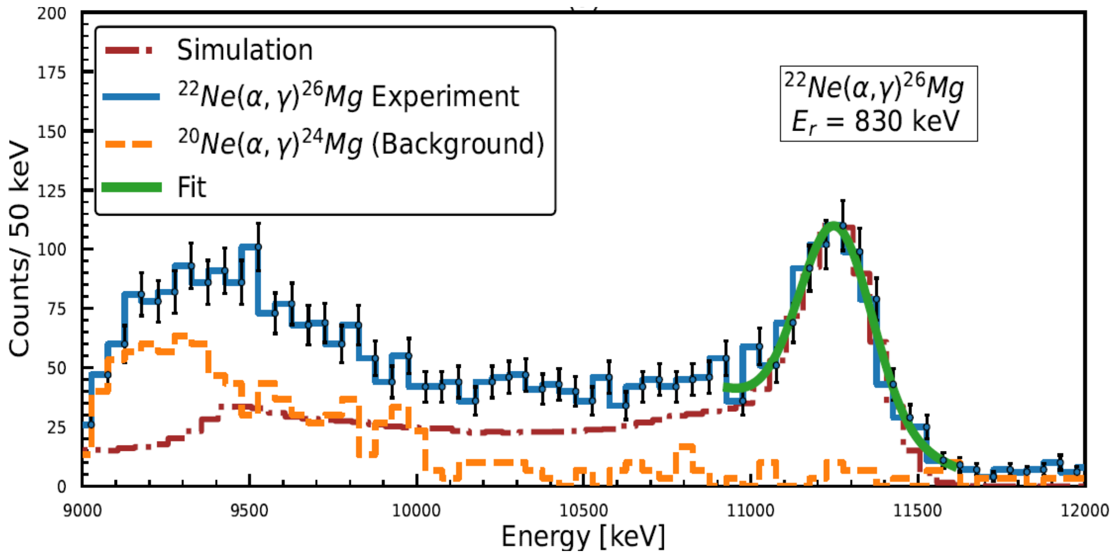
- 770 keV (~ 50 μA)
- 750 keV (~ 50 μA)
- 662 keV (~ 70 μA)
- 566 keV (~ 140 μA)
- 470 keV (~ 140 μA) ← 12 hour run

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

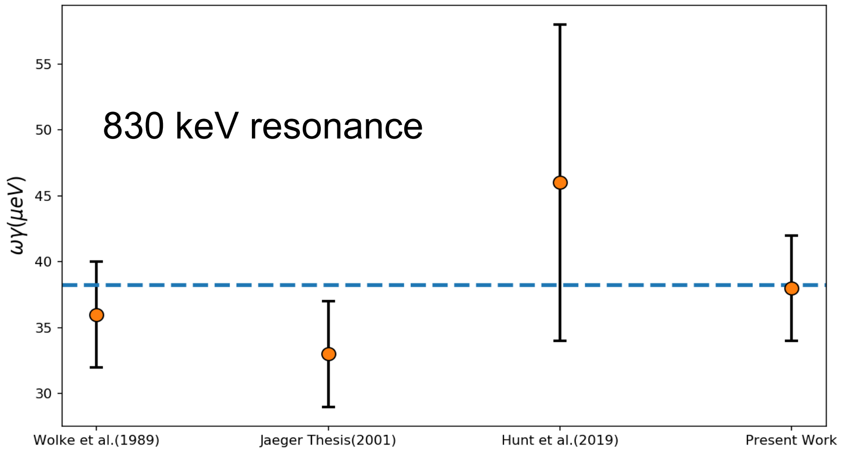
Alex Dombos, UND

$^{22}Ne(\alpha,g)^{26}Mg$ – Competition

- 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 830 and 650 keV
- Ne-target implanted in tantalum @ UND



Upper limit of $\omega\gamma$ < 0.2 μeV obtained for the low energy resonance, determined relative to the 830 keV resonance strength obtained in this experiment.



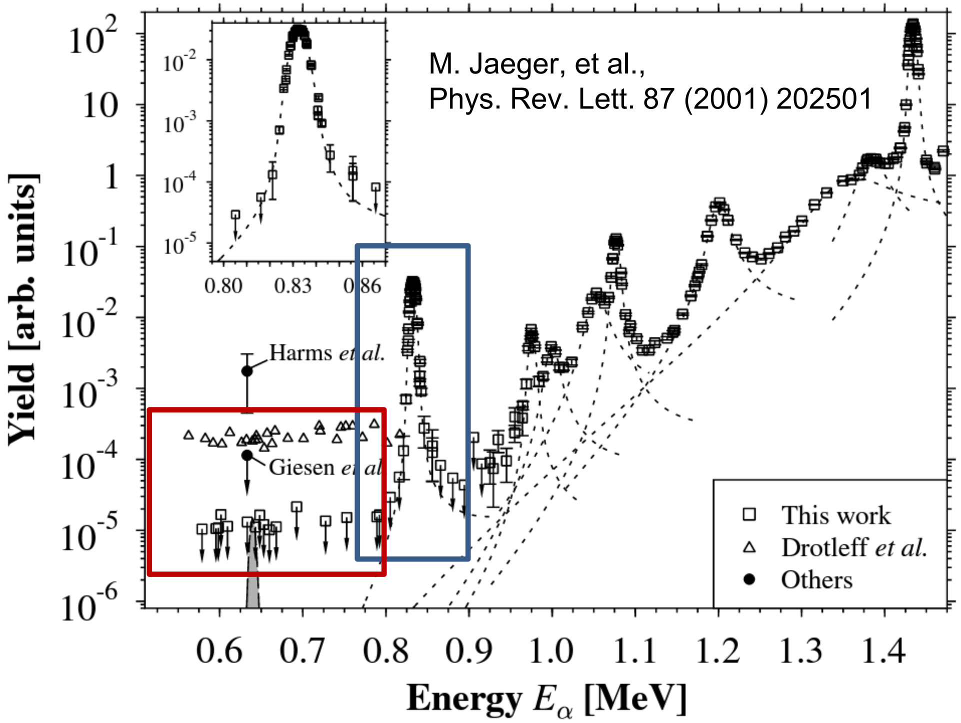
Work	$\omega\gamma$ (μeV)
Wolke *et al.* [5]	36 ± 4
Jaeger (Thesis) [26]	33 ± 4
Hunt *et al.* [6]	46 ± 12
This work	35 ± 4
Weighted average [a]	35 ± 2

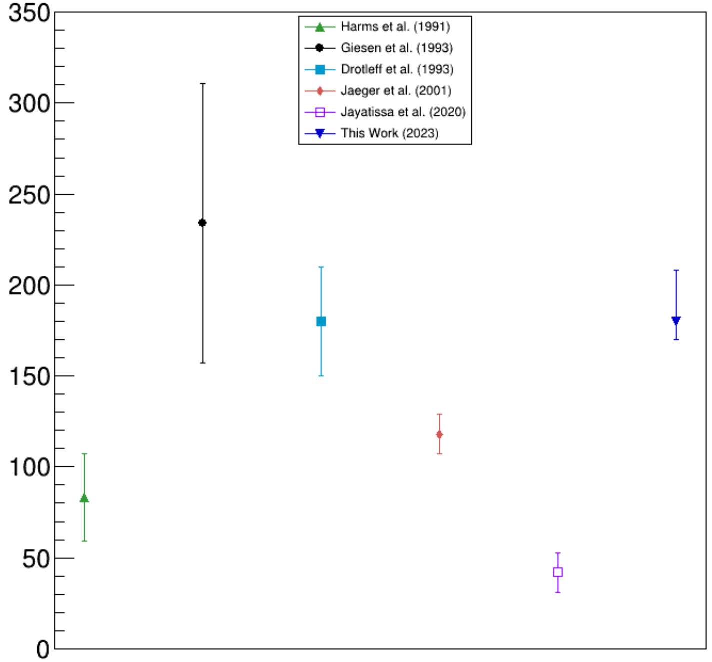
Shahina *et al*, *Phys. Rev. C.* ***106***, *025805 (2022)*

Shahina, UND

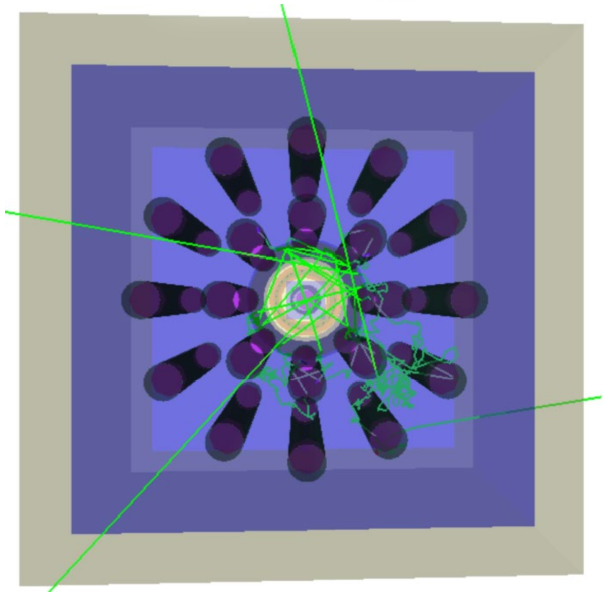
$^{22}Ne(\alpha,n)^{25}Mg$ – Neutron Source

- $^{22}Ne(\alpha,n)^{25}Mg$ is a neutron source for weak and main s-process
- Regions of interest are centered on 830 keV resonance
- Using windowless recirculating gas target and He-3 detectors





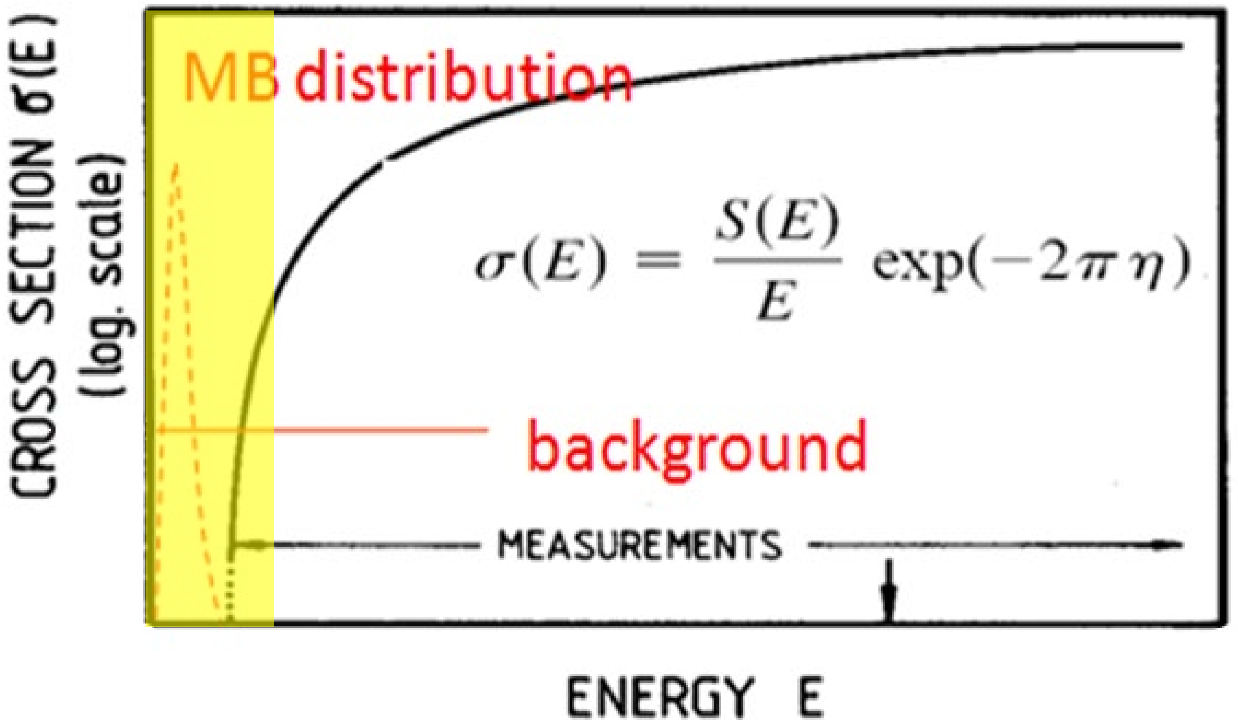
- 16 He-3 filled counters
- Borated poly shielding
- Poly moderator
- Pros / Cons



Thomas Kadlecek, SDSMT

Scale Of The Problem In The Lab

$$N_A\langle\sigma v\rangle = \sqrt{\frac{8}{\pi\cdot\mu}}\cdot(kT)^{-3/2}\cdot\int_0^\infty E\cdot\sigma(E)\cdot\exp\left(-\frac{E}{kT}\right)dE$$



Yield = N_p × N_t × cross section × efficiency

- 10^{14} pps (~ 100 μA)
- 10^{19} atoms/cm^2
- 10^{-13} barn (10^{-9} to 10^{-15})
- ~ 10%

1 cts/day

Solutions And Work Arounds

Increase reaction products

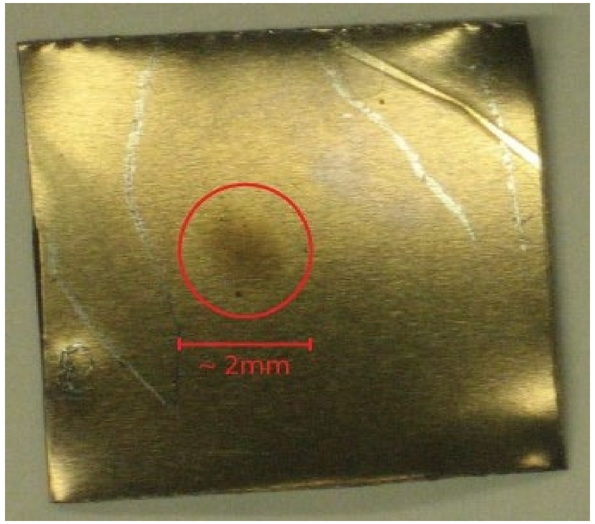
- Increasing accelerated beam intensity
- Longer measurements
- Improving target stability

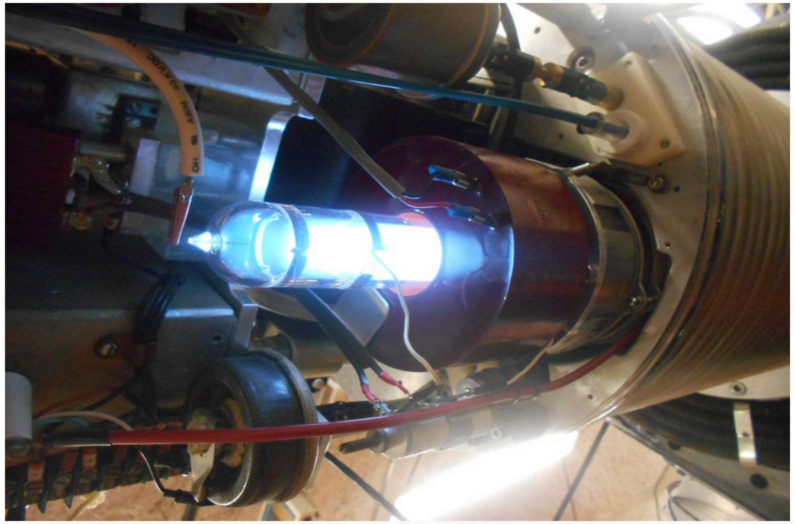
Detection sensitivities & tricks

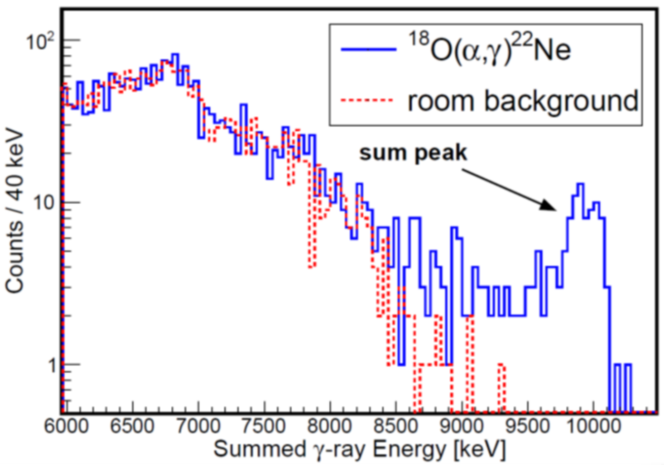
- Higher efficiencies
- Cleaner materials
- Better discrimination

Background reduction

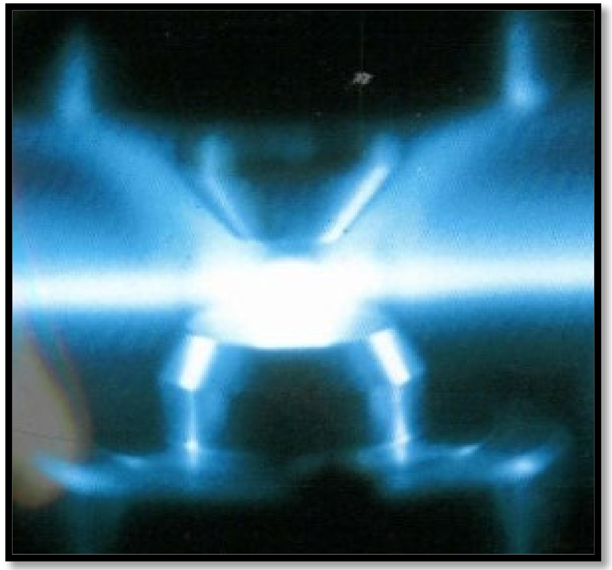
- Cosmic radiation background
- Environmental decay background
- Beam induced background







Other Options For Interference

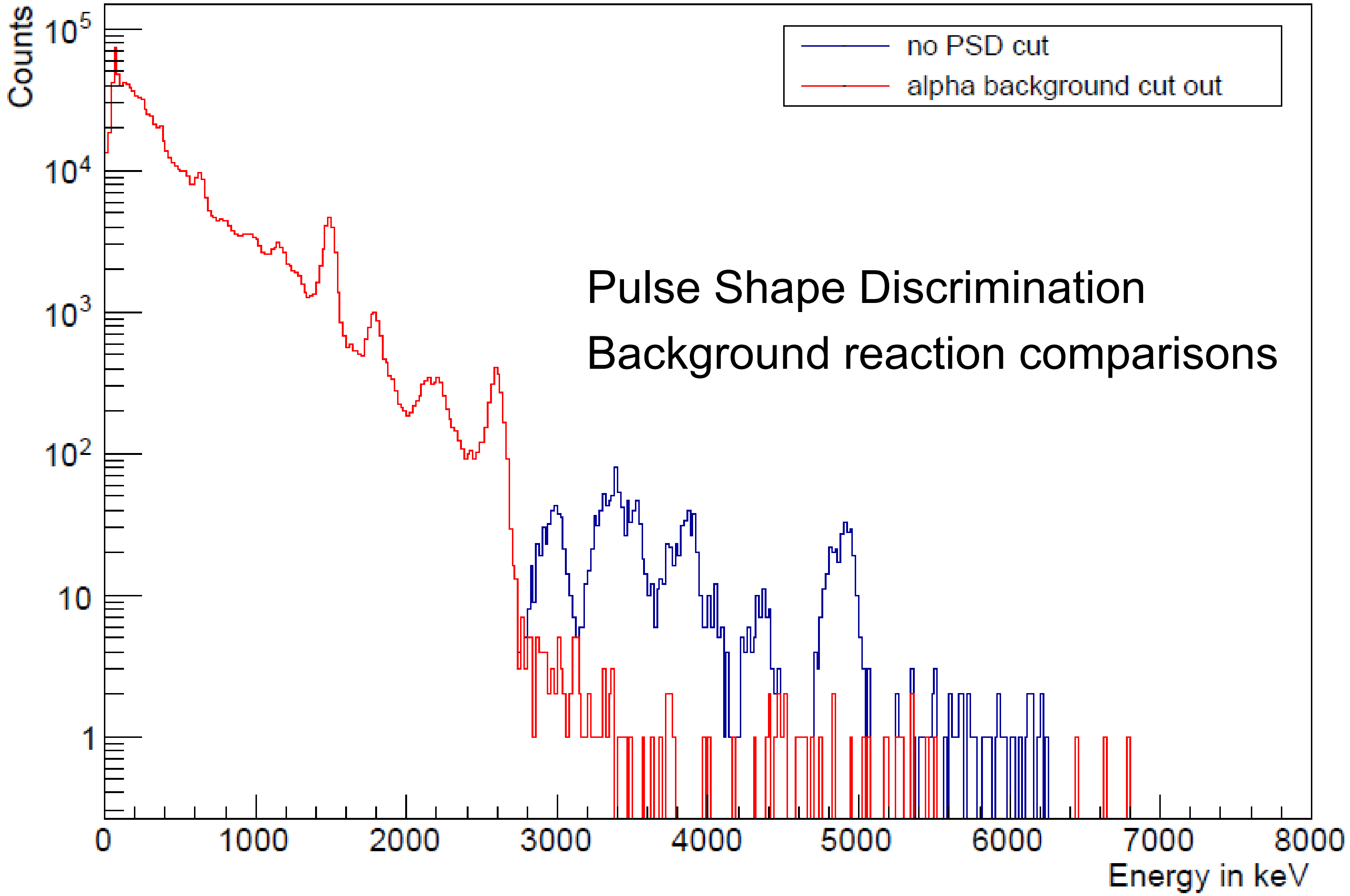


Enhanced material purity

Material assay

Gaseous targets

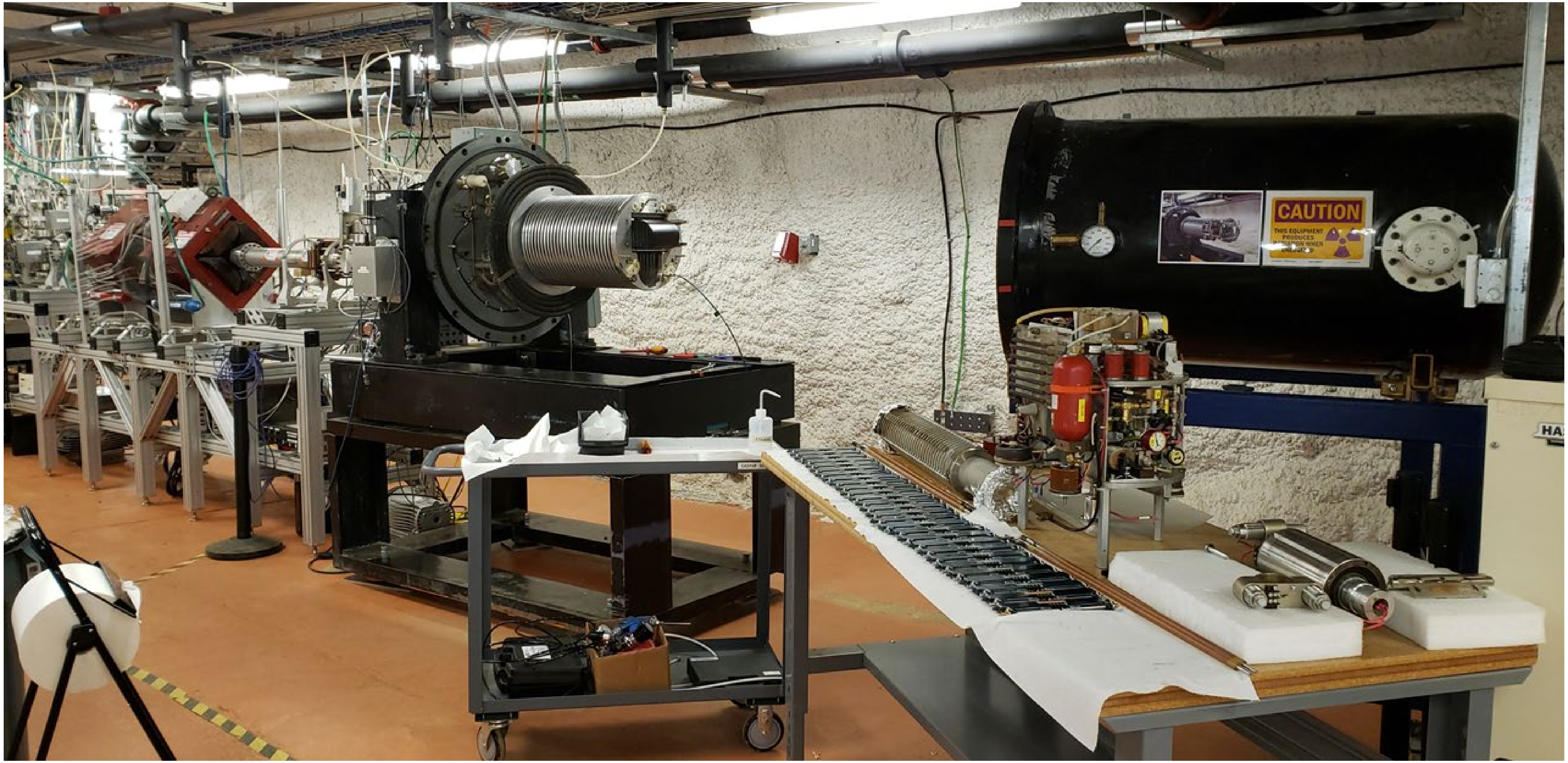
Simulation and testing



Pulse Shape Discrimination

Background reaction comparisons

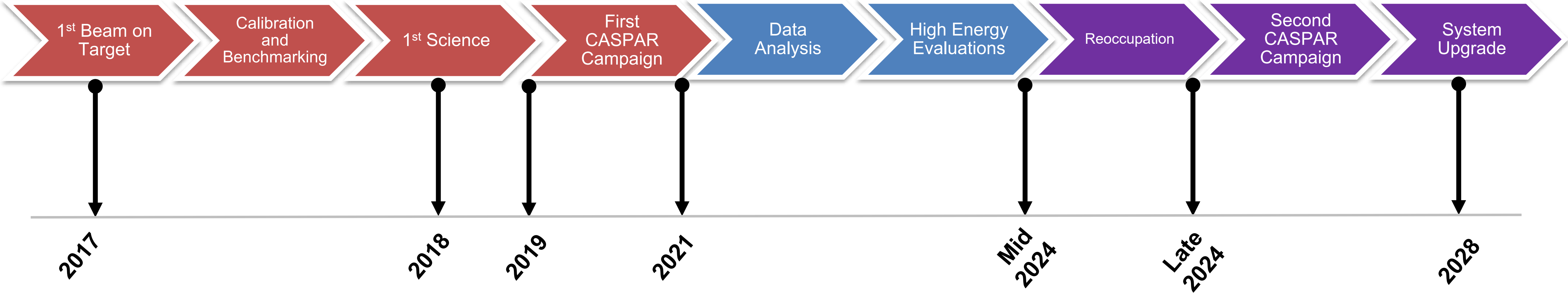
Forced Into Hibernation Mode



Forced Into Hibernation Mode

Forced Into Hibernation Mode

Timeline In Flux



First CASPAR Campaign

Resulted in 6 projects that are now completed or the analysis is in progress

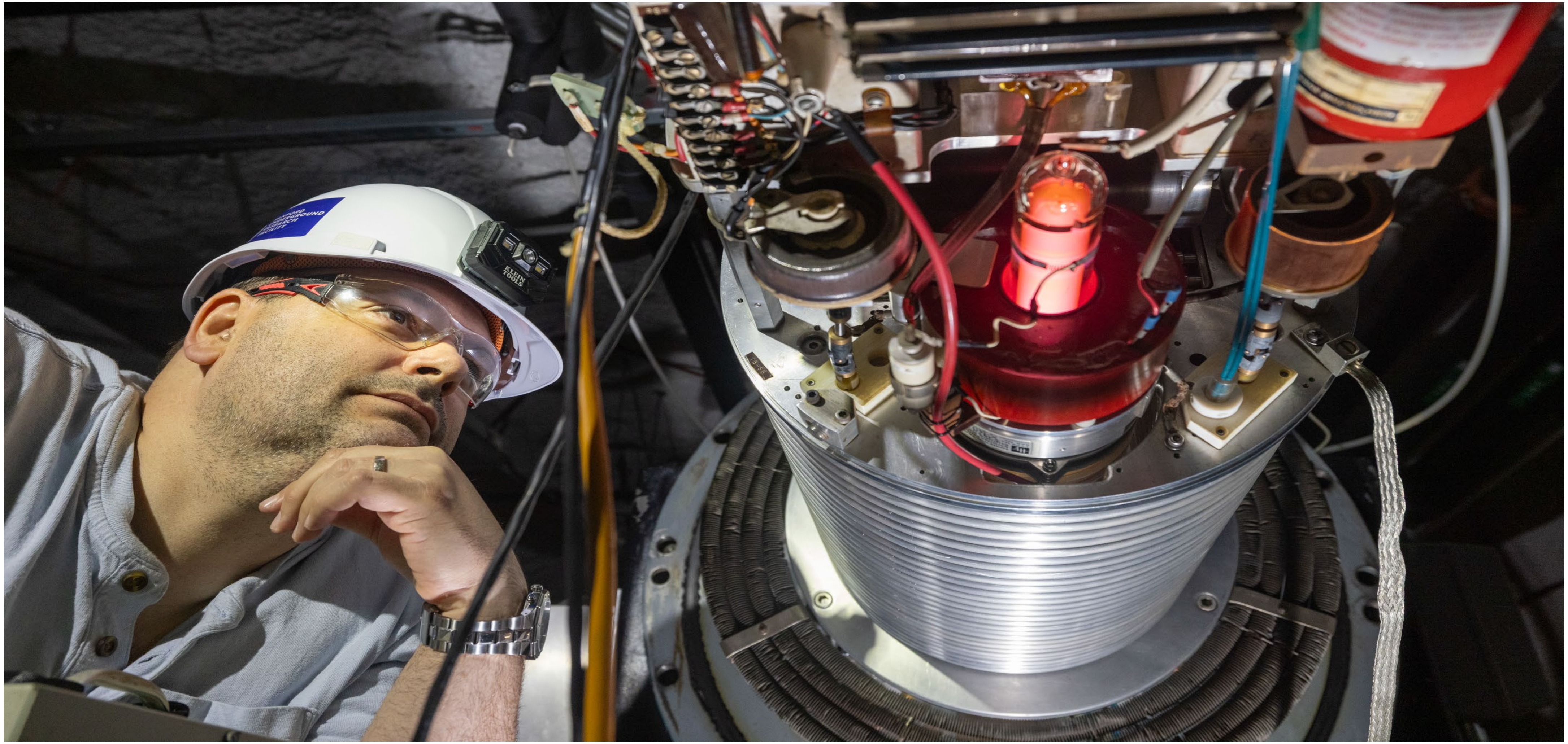
Second CASPAR Campaign

Upgraded passive shielding for γ & n detection

Better signal evaluation eg PSD for neutron and new gating for gammas

Investigation of upper and lower voltage limits

Where We Are Now



Path Forward

- Continued new NSF funding
- Continued focus on (p,γ), (α,γ) & (α,n)
- Increase focus next campaign
  - New detection
  - Increased shielding
  - New target purity and techniques
- 5 Grad projects underway
- Focus on future system upgrade

With Thanks To

Dr. Manoel Couder

Experimenter (UND)

Abbi Elger

Graduate Student (SDSMT)

Dr. Joachim Goerres

Experimenter (UND)

Mark Hanhardt

Graduate Student (SDSMT & SDSTA)

Dr. Anna Simon-Robertson

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Dr. Edward Stech

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Dr. Frank Strieder

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Dr. Michael Wiescher

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Leah Zimmer

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This work was supported by the NSF under grant numbers PHY-2412807, PHY-1913746 & PHY-2310059 and the Sanford Underground Research Facility through the DOE under DE-SC0020216

Questions ?

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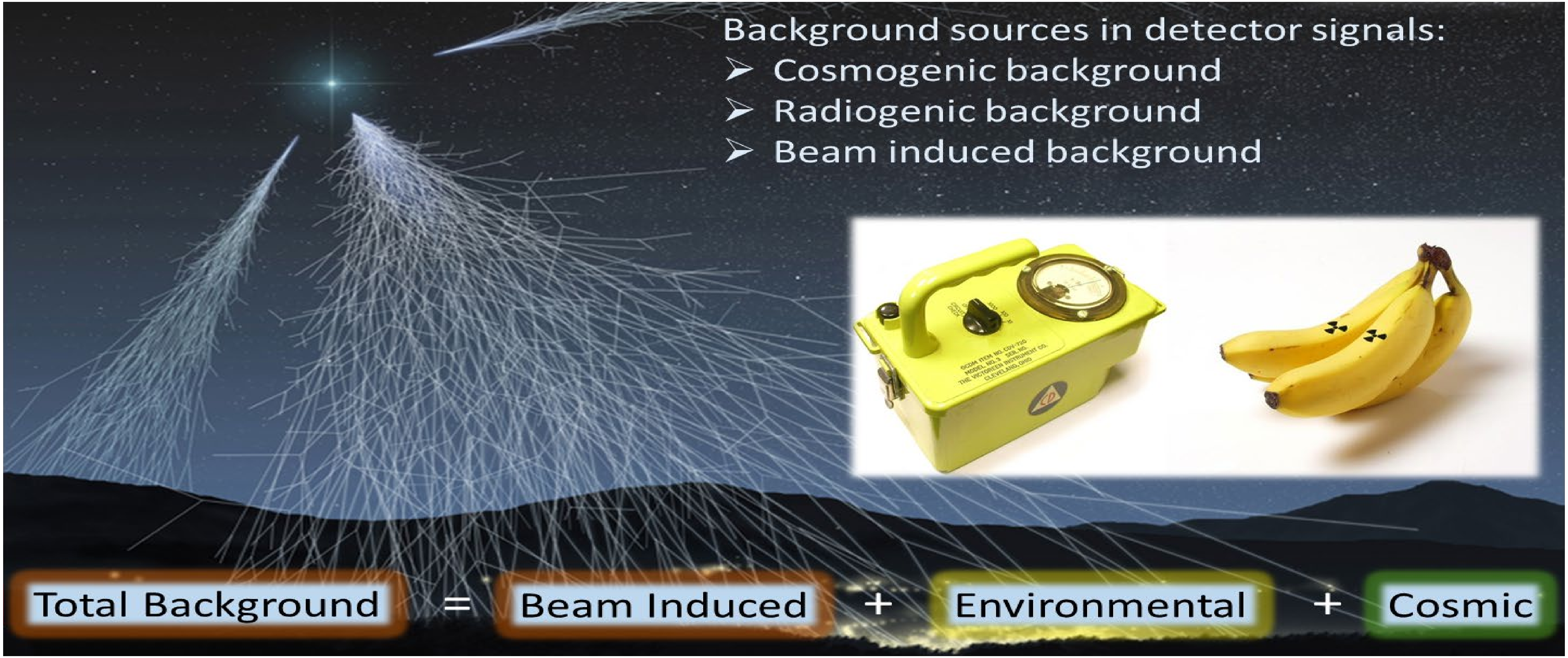
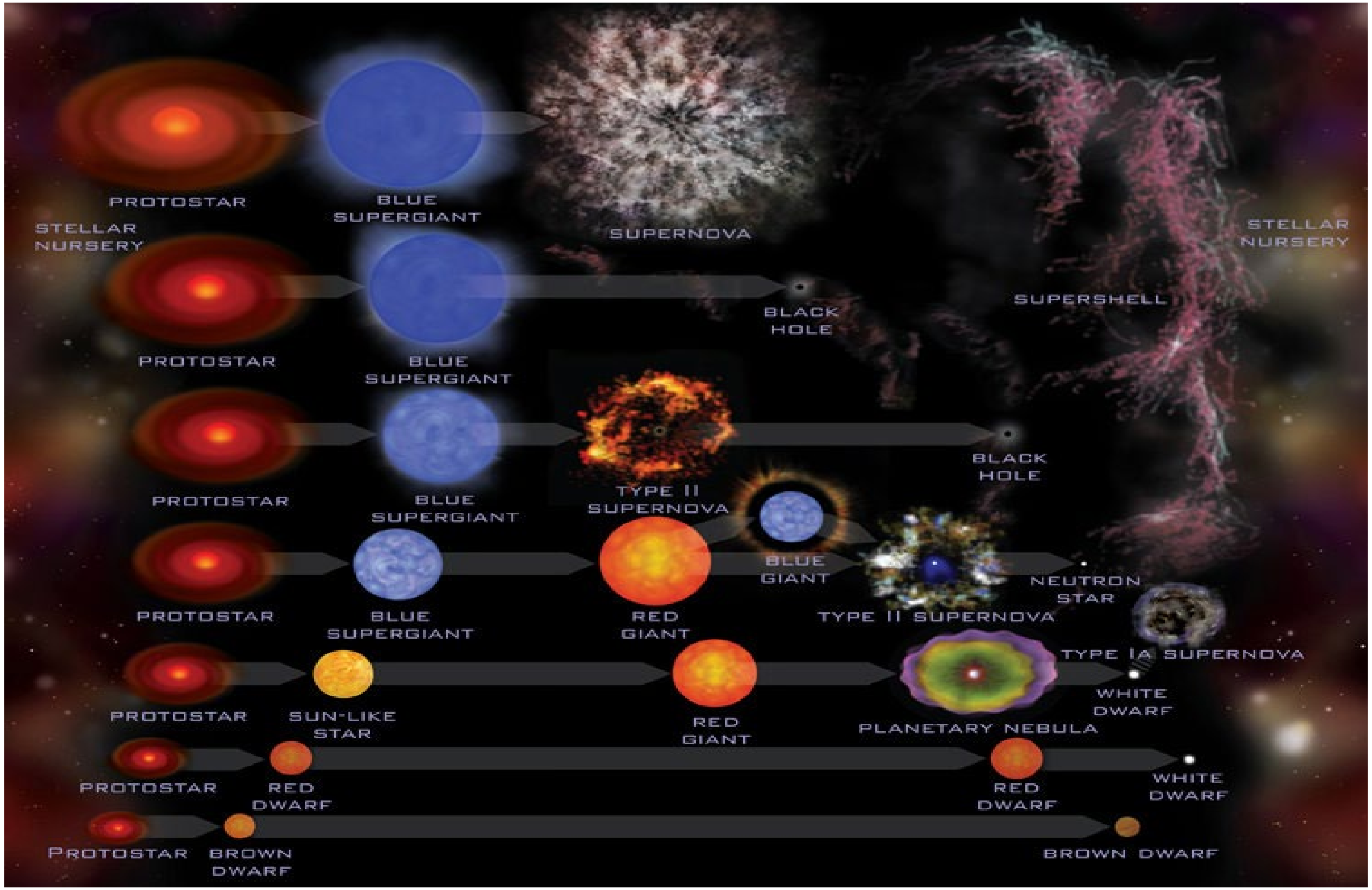
Backgrounds As The Hot Topic



Stellar Life Cycles & Nuclear Burning Regimes



Ignoring first 400 million years after BB

Each path dominated by key features

Every transition adds to the equation

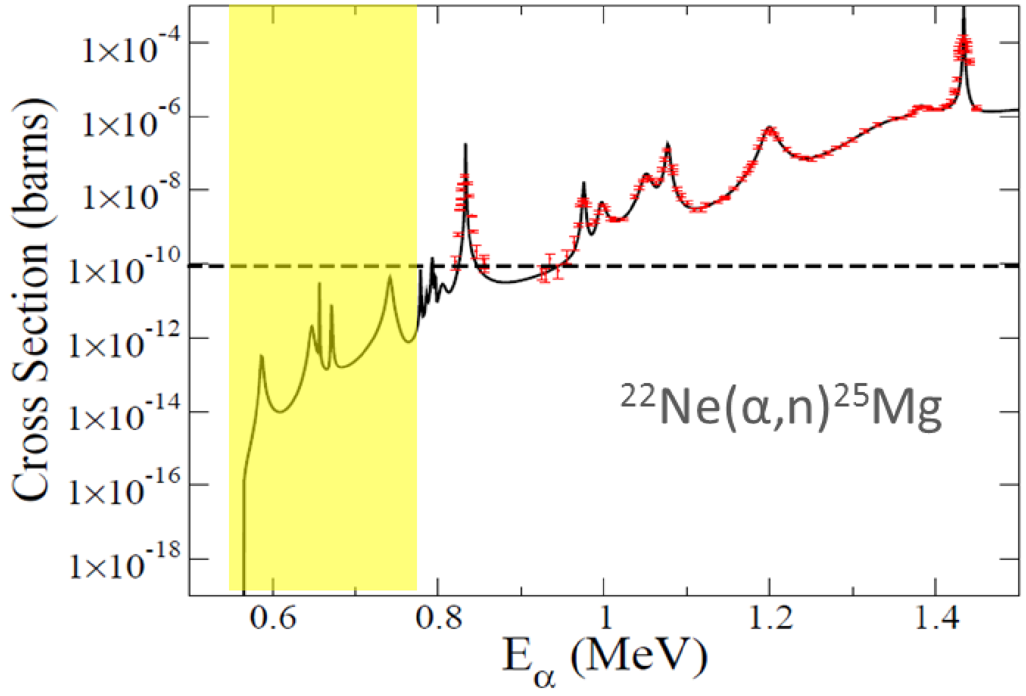
Resultant material seeds the next phase

Means: Massive amounts of material

Motive: Energy production holds off gravity

Opportunity: Time scales and location

“Real World” Examples



$^{22}Ne(\alpha,n)^{25}Mg$ & $^{13}C(\alpha,n)^{16}O$

Issues with theoretical extrapolations

Large uncertainties in burning window

Seeds for the s-process
Measurements above and below