FLORIDA STATE UNIVERSITY

Nuclear Astrophysics, Near-threshold Resonances and Continuum Effects

Sergio Almaraz-Calderon

NSF Site Visit, John D. Fox Laboratory, Florida State University

Outline

- Development of a ^{44}Ti beam at FSU for a measurement of the ^{44}Ti(α,p)^{47}V reaction with Encore.

- Contribution of low-lying isomers to stellar nucleosynthesis ^{26}Al and ^{34}Cl.

- Detailed spectroscopy studies using CATRiNA + Clarion-2 arrays for Nuclear Astrophysics.

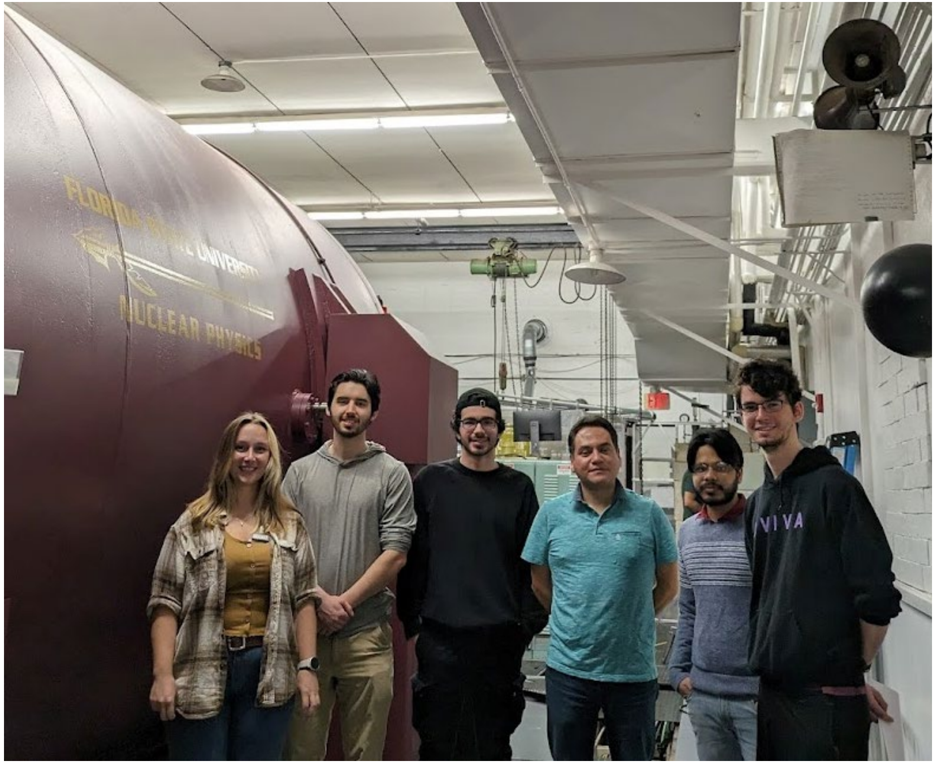
- Near-threshold resonances and continuum effects.

My research group …

2020

Fabio (ug), Ashton, Ben, Eilens, Jesus, Nate

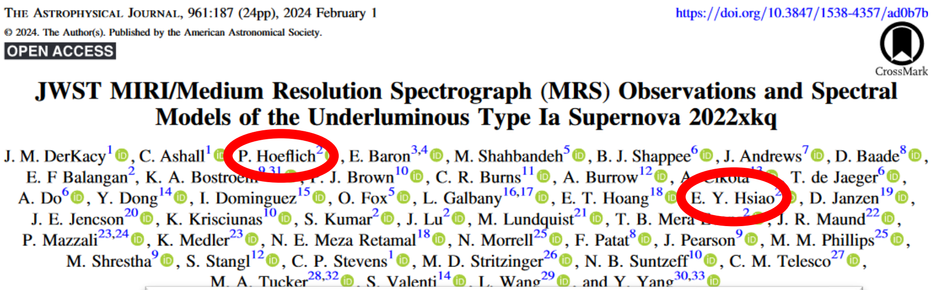
2024



(Ashton), Mat, Andrew, Rajat, Santiago (ug)

^{44}Ti in Supernova explosions

Satellite based observations of ^{44}Ti help understand the physics in SN explosions. ^{44}Ti is produced near the core, in α-rich regions and can be link to the hydrodynamics of the star.


The Astrophysical Journal, 961:187 (24pp), 2024 February 1 https://doi.org/10.3847/1538-4357/ad0b7b

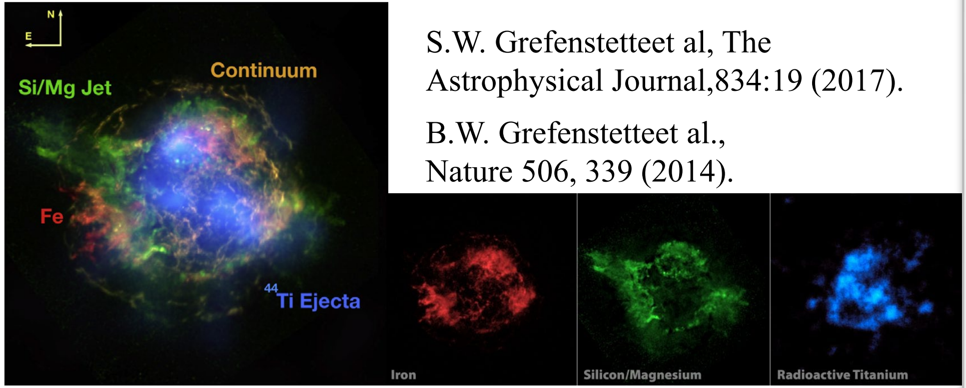
CrossMark

JWST MIRI/Medium Resolution Spectrograph (MRS) Observations and Spectral Models of the Underluminous Type Ia Supernova 2022xkq

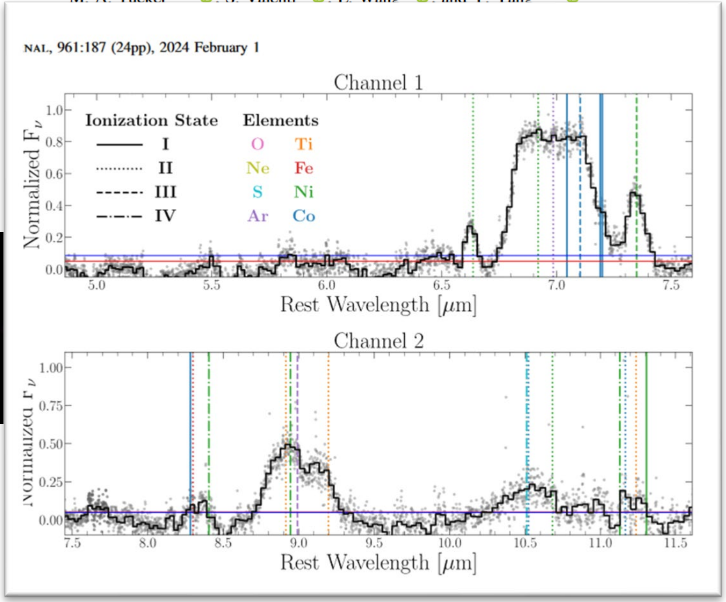
J. M. DerKacy[1], C. Ashall[1], P. Hoeflich[2], E. Baron[3,4], M. Shahbandeh[5], B. J. Shappee[6], J. Andrews[7], D. Baade[8], E. F Balangan[2], K. A. Bostroem[9,31], T. J. Brown[10], C. R. Burns[11], A. Burrow[12], A. Cikota[13], T. de Jaeger[6], A. Do[6], Y. Dong[14], I. Dominguez[15], O. Fox[5], L. Galbany[16,17], E. T. Hoang[18], E. Y. Hsiao[2], D. Janzen[19], J. E. Jencson[20], K. Krisciunas[10], S. Kumar[2], J. Lu[2], M. Lundquist[21], T. B. Mera Evans[2], J. R. Maund[22], P. Mazzali[23,24], K. Medler[23], N. E. Meza Retamal[18], N. Morrell[25], F. Patat[8], J. Pearson[9], M. M. Phillips[25], M. Shrestha[9], S. Stangl[12], C. P. Stevens[1], M. D. Stritzinger[26], N. B. Suntzeff[10], C. M. Telesco[27], M. A. Tucker[28,32], S. Valenti[14], L. Wang[29], and Y. Yang[30,33]

S.W. Grefenstetteet al, The Astrophysical Journal,834:19 (2017).

B.W. Grefenstetteet al., Nature 506, 339 (2014).



The spatial distribution of ^{44}Ti in ***Cas A*** compared with the other bright X-ray features as seen by *NuSTAR.*



^{44}Ti in Supernova explosions

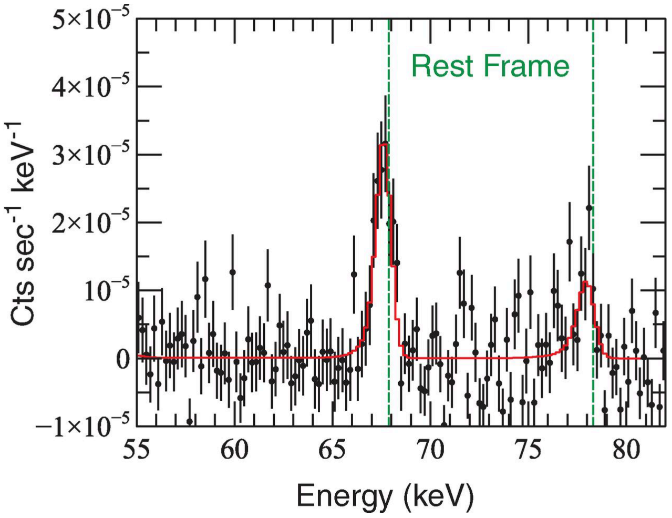
The amount of ^{44}Ti ejected is a gauge for the position of the mass cut of the star. The final amount of ^{44}Ti depends mostly on the ^{44}Ti(α,p)^{47}V reaction.

ORDER OF IMPORTANCE OF REACTIONS PRODUCING ^{44}Ti AT $\eta = 0.002$

	REACTION RATE MULTIPLIED BY 1/100		REACTION RATE MULTIPLIED BY 100	
RANK	Reaction	^{44}Ti Change (percent)	Reaction	^{44}Ti Change (percent)
1	^{44}Ti(α, p)^{47}V	+208	^{44}Ti(α, p)^{47}V	−93
2	^{12}C(α, γ)^{16}O	−72	^{44}Ti(α, γ)^{48}Cr	−66
3	^{40}Ca(α, γ)^{44}Ti	−66	^{27}Al(α, n)^{30}P	−60
4	^{20}Ne(α, γ)^{24}Mg	−16	^{30}Si(α, n)^{33}S	−33
5	^{30}Si(p, γ)^{31}P	−9.2	^{12}C(α, γ)^{16}O	+18
6	^{36}Ar(α, p)^{39}K	−7.9	^{40}Ca(α, γ)^{44}Ti	+15
7	^{59}Ni(p, n)^{59}Cu	−4.7	^{23}Na(α, p)^{26}Mg	−4.7
8	^{59}Ni(p, γ)^{60}Cu	−4.7	^{39}K(α, p)^{42}Ca	+4.7
9	^{44}Ti(α, γ)^{48}Cr	+2.8	^{27}Al(p, γ)^{28}Si	+4.3
10	^{27}Al(α, n)^{30}P	+2.7	^{24}Mg(α, γ)^{28}Si	+4.2

The et al. Astrophy. J., 504, 500 (1998).
Magkotsios et al. Astrophys. J. Supl. Ser. 191, 66 (2010).

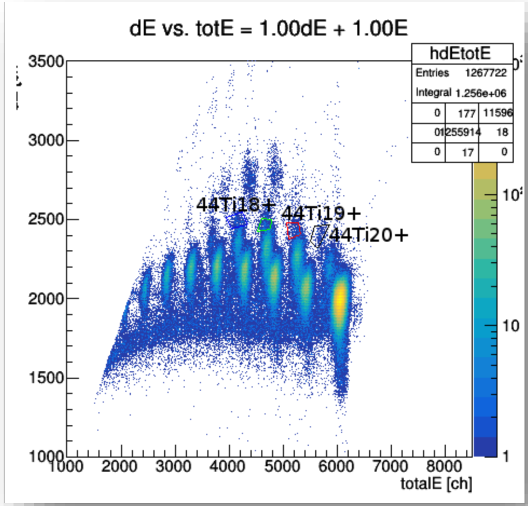
S.E. Boggs et al. Science 348, 670 (2015).



SN1987A 55- to 80-keV background-subtracted spectrum measured with NuSTAR.

Development of a ^{44}Ti beam at FSU

Several unsuccessful attempts at ANL for making a ^{44}Ti beam
[In-flight production ANL#1659
ECR2 and ECR3 ANL#1876]



VOLUME 84, NUMBER 8 PHYSICAL REVIEW LETTERS 21 FEBRUARY 2000

The ^{44}Ti(α, p) Reaction and its Implication on the ^{44}Ti Yield in Supernovae

A. A. Sonzogni,[1] K. E. Rehm,[1] I. Ahmad,[1] F. Borasi,[2] D. L. Bowers,[1] F. Brumwell,[1] J. Caggiano,[1] C. N. Davids,[1] J. P. Greene,[1] B. Harss,[1] A. Heinz,[1] D. Henderson,[1] R. V. F. Janssens,[1] C. L. Jiang,[1] G. McMichael,[1] J. Nolen,[1] R. C. Pardo,[1] M. Paul,[3] J. P. Schiffer,[1] R. E. Segel,[2] D. Seweryniak,[1] R. H. Siemssen,[1] J. W. Truran,[4] J. Uusitalo,[1] I. Wiedenhöver,[1] and B. Zabransky[1]

$^{45}Sc(p,2n)^{44}Ti$

was mixed with 50 mg of $^{nat}TiO_2$ and placed inside a copper insert for a negative-ion Cs-sputter source. The ^{44}Ti activity from the pellet was measured to be ~38 μCi.
From the ion source a beam of $^{44}TiO^-$ was extracted and injected into the tandem accelerator at ATLAS. After stripping in the terminal of the tandem, a $^{44}Ti^{8+}$ beam was

Development of a ^{44}Ti beam at FSU

Several unsuccessful attempts at ANL for making a ^{44}Ti beam

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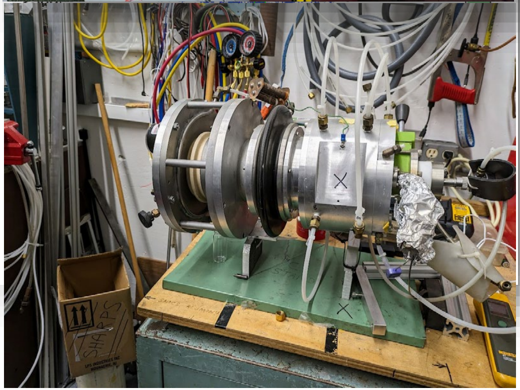
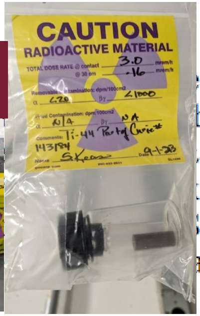


We will use SNICS source + Tandem accelerator at FSU to produce an ^{44}Ti beam using the original cathodes from (~20 yrs ago) for a measurement of the ^{44}Ti(α,p) reaction.

^{45}Sc(p,2n)^{44}Ti

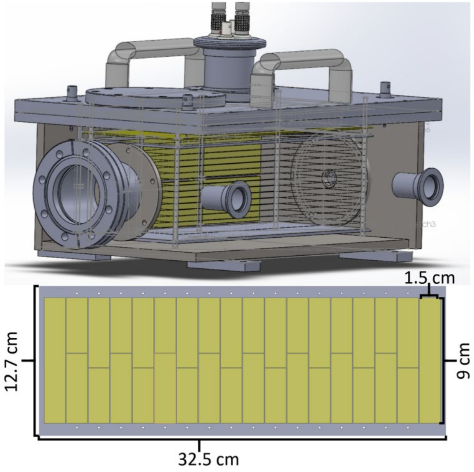
Ready to be shipped to FSU!

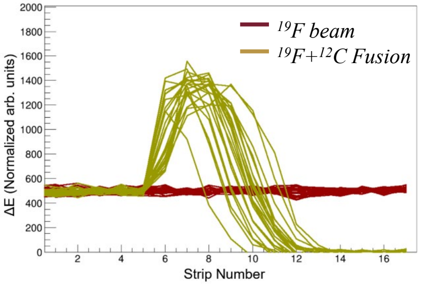
... a cop-
per insert for a ... the ^{44}Ti
activity from the ... Ci.
From the ion ... tracted
and injected into ... . After
stripping in the t... am was

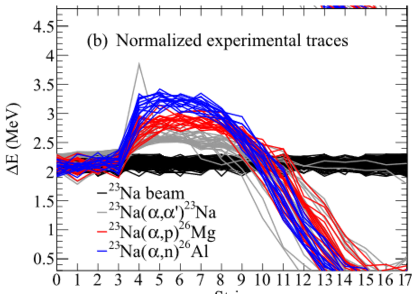


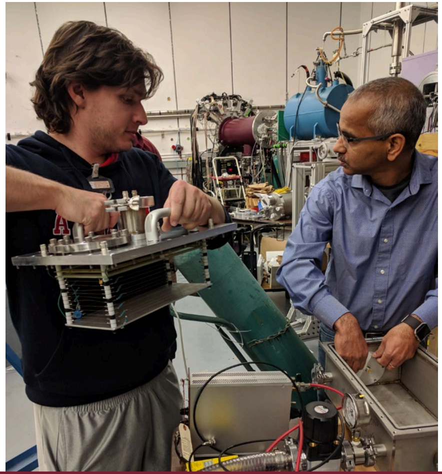
Measurement of the $^{44}Ti(\alpha,p)^{47}V$ reaction with Encore at FSU

- Encore active target was developed at FSU (B. Asher), it has been used to measure fusion and (α,p) reactions.
- MUSIC at ANL has been successfully used to measure several (α,p) reactions.







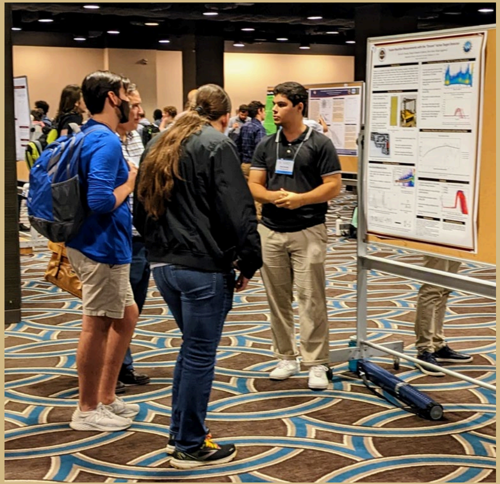


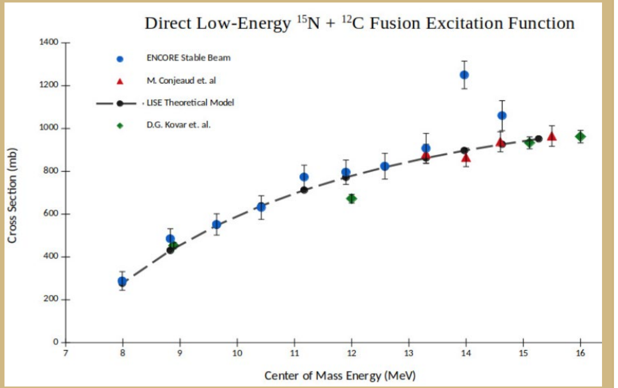
Ben Asher is now a staff scientists at PNNL

B.W. Asher, SA, et al. Phys. Rev. C 103, 044615 (2021).
B.W. Asher, SA, et al. NIM A 1014, 165724 (2021).
B.W. Asher, SA, et al. Eur. Phys. J. A 57, 272 (2021).

Measurement of the $^{44}Ti(\alpha,p)^{47}V$ reaction with Encore at FSU

Undergraduate Research

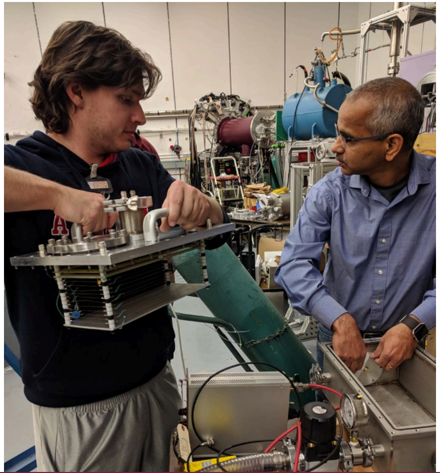




Bajron Alvin Zenelaj, FSU Honor’s thesis 2023. “Fusion Reaction Measurements with the Encore Active Target Detector”.

Attended CEU @ APS-DNP in New Orleans, LA.

Alvin is now a grad student at University of North Carolina (UNC).

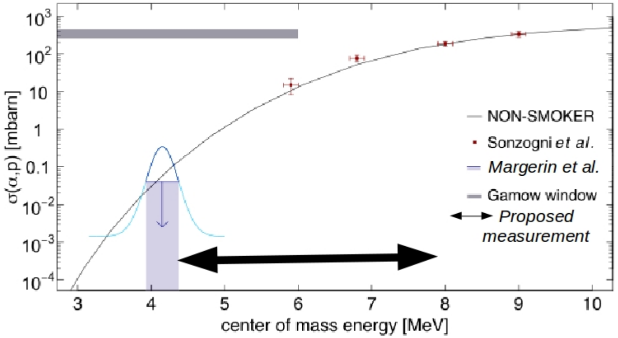


Ben Asher is now a staff scientists at PNNL

SA, et al. Phys. Rev. C 103, 044615 (2021).
SA, et al. NIM A 1014, 165724 (2021).
SA, et al. Eur. Phys. J. A 57, 272 (2021).

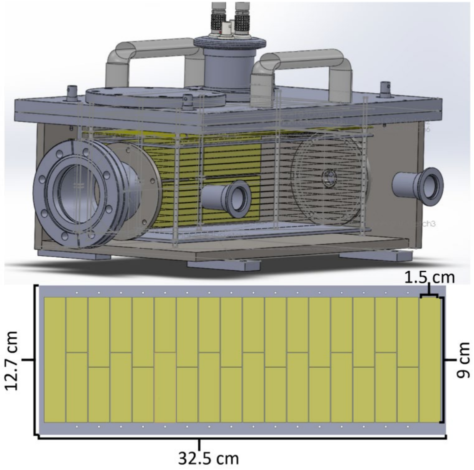
Measurement of the $^{44}Ti(\alpha,p)^{47}V$ reaction with Encore at FSU

In the proposed measurement, the ^{44}Ti beam will be delivered to the Encore detector which will be filled with helium gas for a direct measurement of the $^{44}Ti(\alpha,p)^{47}V$ reaction in the Gamow window.
^{4}He @ 400 Torr.
^{44}Ti @ ~ 4 MeV/u with an expected beam rate of a few kHz.



A. Sonzogni et al. Phys. Rev. Lett.84, 1651 (2000).
V. Margerin et al. Phys. Lett B, 7321, 358 (2014).

G.S. Andrew Peters



Isomeric contributions to stellar nucleosynthesis: ^{26}Al

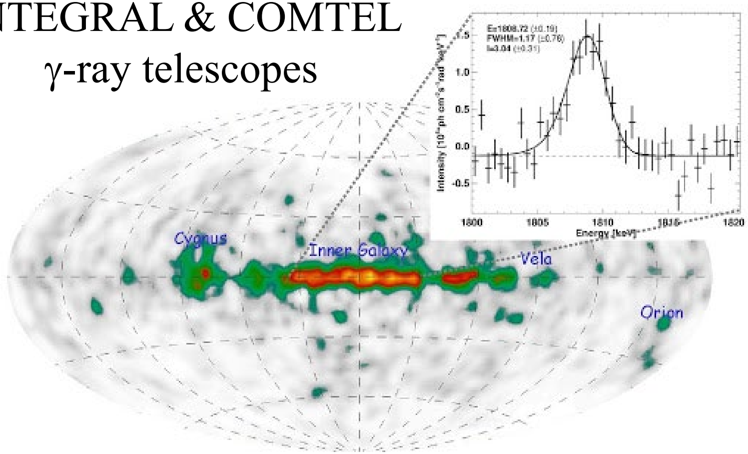
Galactic γ-rays

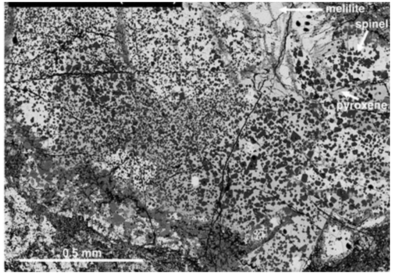
Decay chain	Mean life* (yr)	Line energies (MeV) (Branching ratios)	Site [Detected]	Nuclear process
^{7}Be $\rightarrow$ ^{7}Li	0.21	0.478 (0.1)	Novae	Expl.H
^{56}Ni $\rightarrow$ ^{56}Co^{+} $\rightarrow$ ^{56}Fe	0.31	0.847 (1.0) 1.238 (0.68) 2.598 (0.17) 1.771 (0.15)	SN [SN1987A] [SN1991T]	NSE
^{57}Co $\rightarrow$ ^{57}Fe	1.1	0.122 (0.86) 0.136 (0.11)	SN [SN1987A]	NSE
^{22}Na^{+} $\rightarrow$ ^{22}Ne	3.8	1.275 (1.0)	Novae	Expl.H
^{44}Ti $\rightarrow$ ^{44}Sc^{+} $\rightarrow$ ^{44}Ca	89	1.157 (1.0) 0.068 (0.95) 0.078 (0.96)	SN [Cas A]	α-NSE
^{26}Al^{+} $\rightarrow$ ^{26}Mg	1.04×10^{6}	1.809 (1.0)	WR, AGB Novae SNII [inner Galaxy, Vela, Cygnus, Orion]	St.H Expl.H St.Ne Expl.Ne ν
^{60}Fe $\rightarrow$ ^{60}Co $\rightarrow$ ^{60}Ni	2.2×10^{6}	1.332 (1.0) 1.173 (1.0)	SN [Galaxy]	n-capt
e^{+}	10^{5}–10^{7}	0.511	SNIa... [Galactic bulge]	β^{+}-decay

R. Diehl, et al. A&A 522, A51 (2010).

R. Diehl, et al. Nucl. Phys. A 777, 70 (2006).

INTEGRAL & COMTEL
γ-ray telescopes

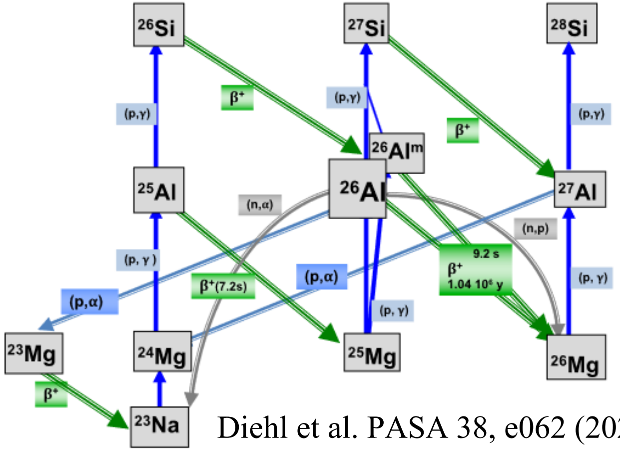




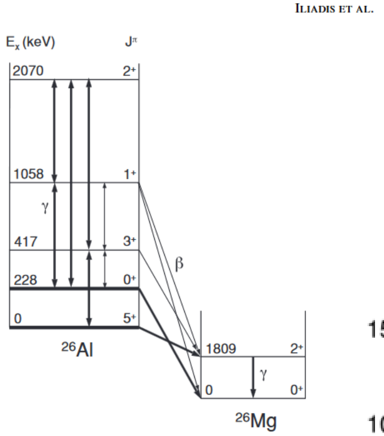
Allende Meteorite – Large ^{26}Mg content

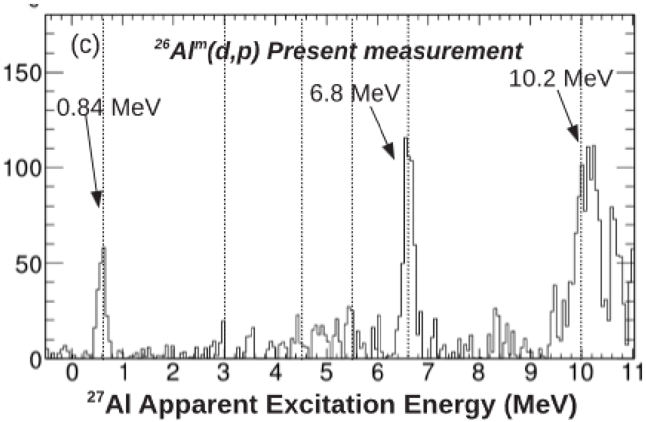
Isomeric contributions to stellar nucleosynthesis: ^{26}Al

Study of the $^{26m}Al(p,\gamma)^{27}Si$ via the $^{26m}Al(d,p)^{27}Al$ reaction



Diehl et al. PASA 38, e062 (2021).





Nuclear Inst. and Methods in Physics Research, A 899 (2018) 6–9

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Development of an Isomeric beam of ^{26}Al for nuclear reaction studies

B.W. Asher[a], S. Almaraz-Calderon[a,*], O. Nusair[b], K.E. Rehm[b], M.L. Avila[b], A.A. Chen[d], C.A. Dickerson[b], C.L. Jiang[b], B.P. Kay[b], R.C. Pardo[b], D. Santiago-Gonzalez[c,b], R. Talwar

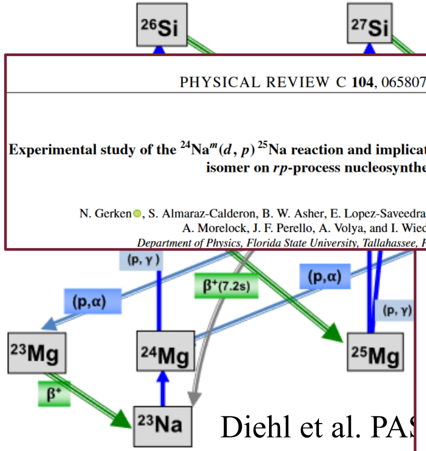
PRL 119, 072701 (2017) PHYSICAL REVIEW LETTERS

Study of the ^{26}Al^m(d, p)^{27}Al Reaction and the Influence of the $^{2(}$ Isomer on the Destruction of ^{26}Al in the Galaxy

S. Almaraz-Calderon,[1,*] K. E. Rehm,[2] N. Gerken,[1] M. L. Avila,[2] B. P. Kay,[2] R. Talwar,[2] A. S. Bottoni,[2] A. A. Chen,[3] C. M. Deibel,[4] C. Dickerson,[2] K. Hanselman,[1] C. R. Hoffmar S. A. Kuvin,[5] O. Nusair,[2] R. C. Pardo,[2] D. Santiago-Gonzalez,[4,2] J. Sethi,[2] and C.

Isomeric contributions to stellar nucleosynthesis: ^{26}Al

Study of the ^{26m}Al(p,γ)^{27}Si via the ^{26m}Al(d,p)^{27}Al reaction



PHYSICAL REVIEW C **104**, 065807 (2021)

Experimental study of the ^{24}Na^m(d, p)^{25}Na reaction and implications for the influence of the ^{24}Al^m isomer on rp-process nucleosynthesis

N. Gerken, S. Almaraz-Calderon, B. W. Asher, E. Lopez-Saveedra, L. T. Baby, K. W. Kemper, A. Morelock, J. F. Perello, A. Volya, and I. Wiedenhöver
Department of Physics, Florida State University, Tallahassee, Florida 32306, USA

Diehl et al. PAS

Nuclear Inst. and Methods in Physics Research, A 899 (2018) 6–9

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Nuclear Inst. and Methods in Physics Research, A

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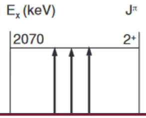
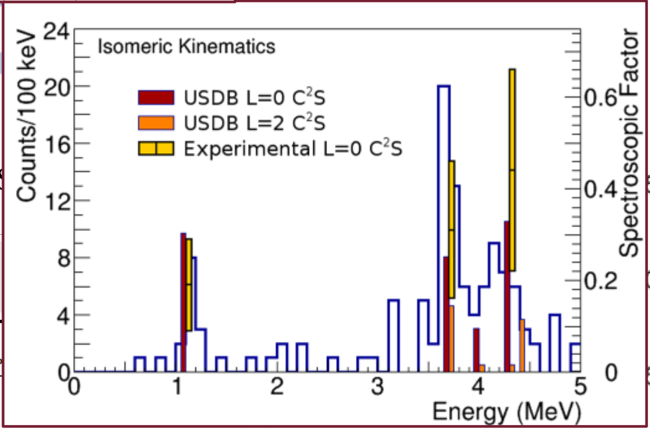
journal homepage: www.elsevier.com/locate/nima

Development of an Isomeric beam of ^{26}Al for nuclear reaction studies

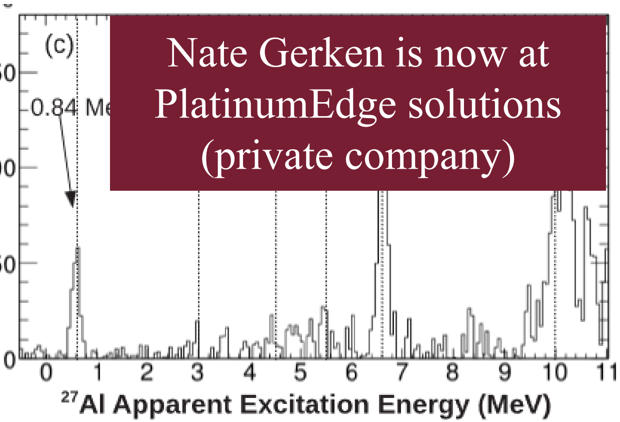
B.W. Asher [a], S. Almaraz-Calderon [a,*], O. Nusair [b], K.E. Rehm [b], M.L. Avila [b], A.A. Chen [d], C.A. Dickerson [b], C.L. Jiang [b], B.P. Kay [b], R.C. Pardo [b], D. Santiago-Gonzalez [c,b], R. Talwar





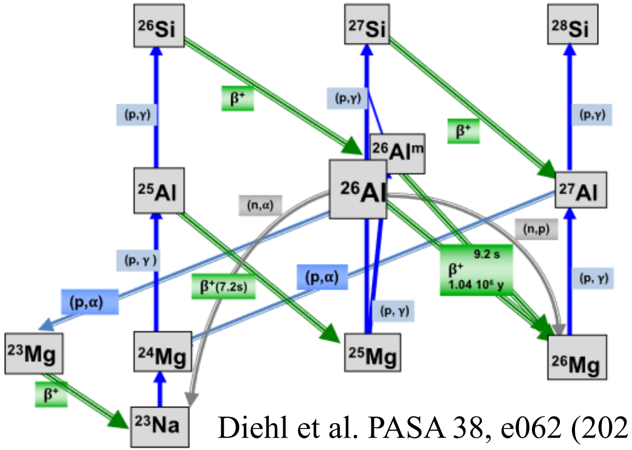
Isomer on the Destruction of ^{26}Al in the Galaxy

S. Almaraz-Calderon,[1,*] K. E. Rehm,[2] N. Gerken,[1] M. L. Avila,[2] B. P. Kay,[2] R. Talwar,[2] A. S. Bottoni,[2] A. A. Chen,[3] C. M. Deibel,[4] C. Dickerson,[2] K. Hanselman,[1] C. R. Hoffman S. A. Kuvin,[5] O. Nusair,[2] R. C. Pardo,[2] D. Santiago-Gonzalez,[4,2] J. Sethi,[2] and C.

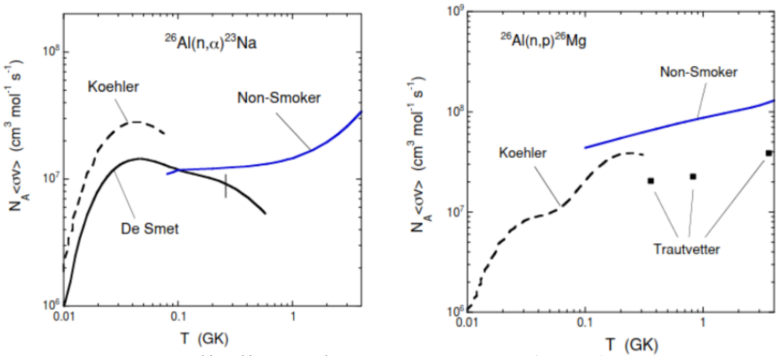


Nate Gerken is now at PlatinumEdge solutions (private company)

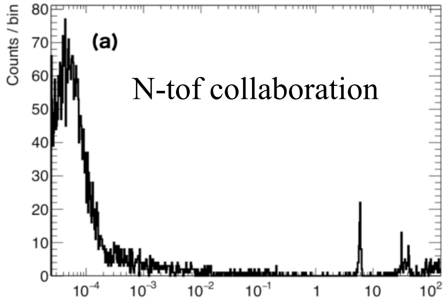
Constraint of the $^{26}Al^{g}(n,p)^{26}Mg$ and $^{26}Al^{g}(n,\alpha)^{23}Na$ reactions



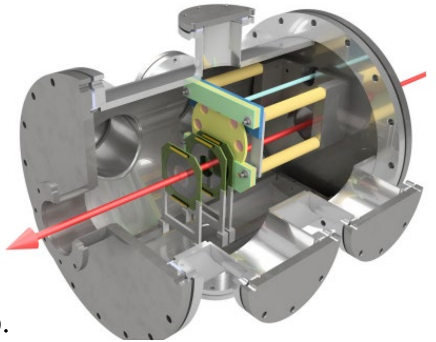
Diehl et al. PASA 38, e062 (2021).



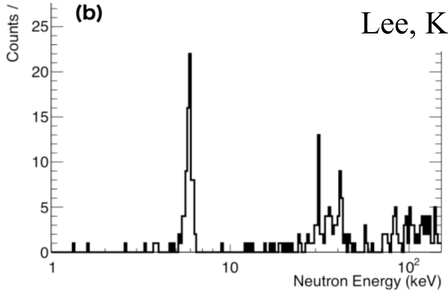
Iliadis et al. AJSS 193, 16 (2011).



N-tof collaboration



Lederer-Woods et al. PRC 104, L022803 (2021).



Lee, Kuvin, et al. PRC109, 014601 (2024).

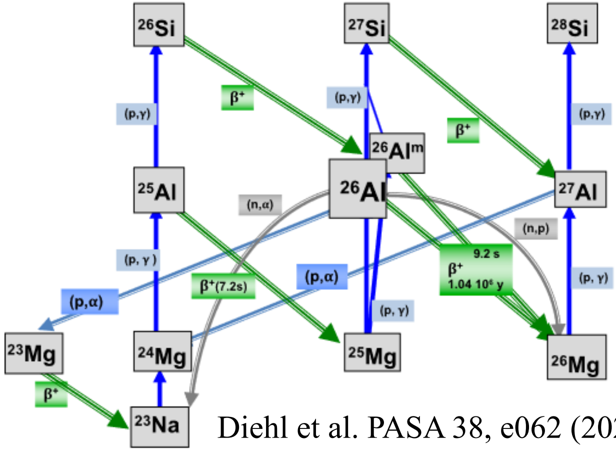
S. Kuvin, H.Y. Lee experiments at LANL

PHYSICAL REVIEW C **105**, 044608 (2022)

Direct measurement of $^{59}Ni(n,p)^{59}Co$ and $^{59}Ni(n,\alpha)^{56}Fe$ at fast-neutron energies from 500 keV to 10 MeV

S. A. Kuvin,* H. Y. Lee, B. DiGiovine, C. Eiroa-Lledo, A. Georgiadou, M. Herman, T. Kawano, V. Mocko, S. Mosby, C. Vermeulen, D. Votaw, M. White, and L. Zavorka†
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

Constraint of the $^{26}Al^{m}(n,p)^{26}Mg$ and $^{26}Al^{m}(n,\alpha)^{23}Na$ reactions



Diehl et al. PASA 38, e062 (2021)

Production of a $^{26}Al^{m}$ target is not feasible!

Proposal at ANL to measure the $^{26}Al^{m}(d,p)^{27}Al^{*}\rightarrow p/\alpha$ reaction with HELIOS as an indirect way to study the neutron capture in the ^{26}Al isomer.

Argonne NATIONAL LABORATORY | Physics Division

1983x	Almaraz-Calderon	A high-quality isomeric 26mAl beam to constrain the neutron destruction channels of 26Al in the Galaxy

ADOPTED LEVELS, GAMMAS for ^{27}Al

Author: M. Shamsuzzoha Ba… …utoff date: 30-Nov-2010

$^{26}Al(d,p)^{27}Al^{*}\rightarrow p/\alpha$

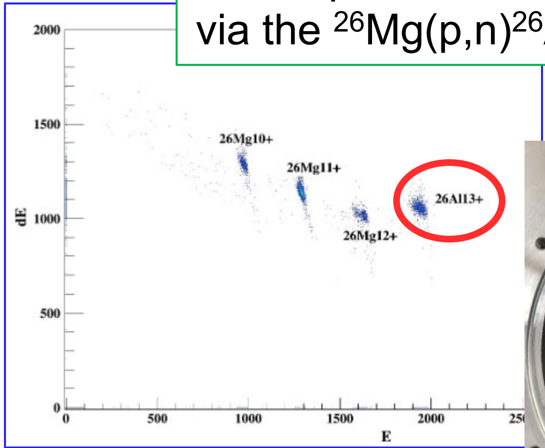
Q(β-)=-4812.36 keV …0 S(n)= 13057.95 keV 12 S(p)= 8271.17 keV 11 Q(α)= -10091.8 keV 1

Reference: 2012WA38

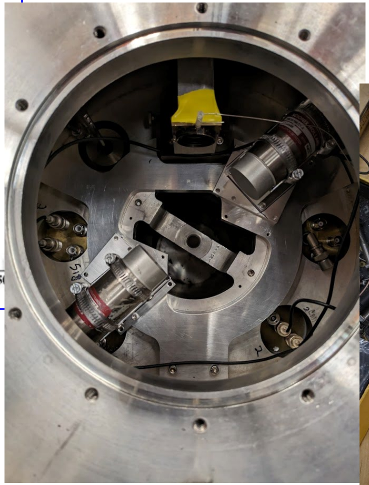
Constraint of the $^{26}Al^{m}(n,p)^{26}Mg$ and $^{26}Al^{m}(n,\alpha)^{23}Na$ reactions

Beam development at ANL

Development of a 9.5 MeV/u ^{26}Al beam using the in-flight method via the $^{26}Mg(p,n)^{26}Al$ reaction and characterize its isomeric content.



Nov. 2023

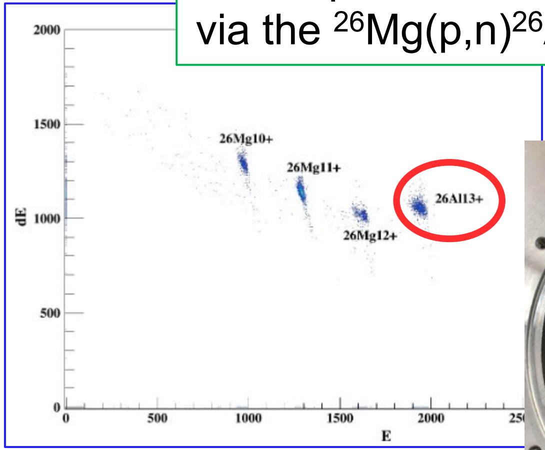


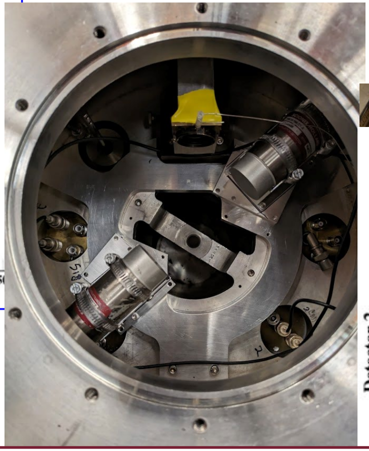
G.S. Rajat Aggarwal

Constraint of the $^{26}Al^{m}(n,p)^{26}Mg$ and $^{26}Al^{m}(n,\alpha)^{23}Na$ reactions

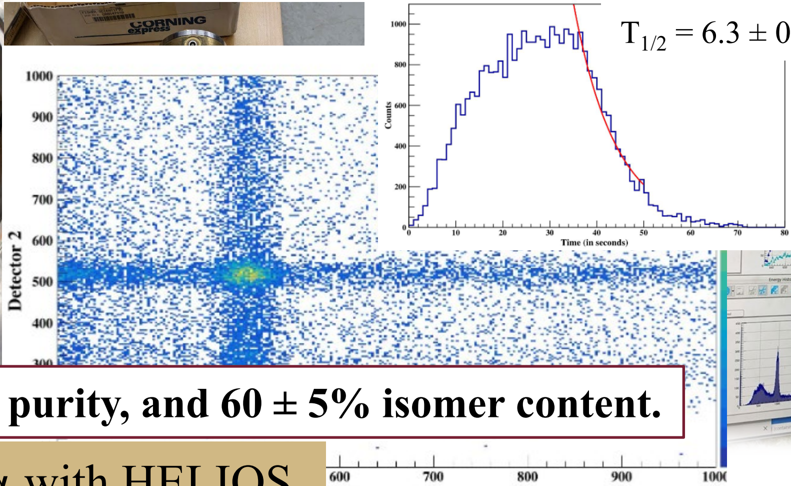
Beam development at ANL

Development of a 9.5 MeV/u ^{26}Al beam using the in-flight method via the $^{26}Mg(p,n)^{26}Al$ reaction and characterize its isomeric content.





G.S. Rajat Aggarwal



$T_{1/2} = 6.3 \pm 0.3$ s

Nov. 2023

~ 10^4 ^{26}Al per 1 pnA of ^{26}Mg, with ~ 90% purity, and 60 ± 5% isomer content.

$^{26}Al(d,p)^{27}Al^{*} \rightarrow p/\alpha$ with HELIOS

Isomeric contributions to stellar nucleosynthesis: ^{34}Cl

The ^{34}Cl(p,γ)^{35}Ar reaction relevant in nova environments and in the classifications of presolar grain. (Sulfur isotopic ratios, production of ^{34}S)

Argonne NATIONAL LABORATORY — Physics Division

1983x	Almaraz-Calderon	A high-quality isomeric 26mAl beam to constrain the neutron destruction channels of 26Al in the Galaxy
2056	Almaraz-Calderon	Constraining isomeric contributions to nova nucleosynthesis: A study of the 34g/mCl(d,p)35Cl reaction

https://www.phy.anl.gov/atlas/pac/app_exp.html

33Ar 173.0 ms ε = 100.00% εp = 38.70%	34Ar 844.5 ms ε = 100.00%	35Ar 1.7756 s ε = 100.00%	36Ar STABLE 0.3336%	37Ar 35.04 d ε = 100.00%
32Cl 298 ms ε = 100.00% εα = 0.05% εp = 0.03%	33Cl 2.511 s ε = 100.00%	34Cl 1.5264 s ε = 100.00%	35Cl STABLE 75.76%	36Cl 3.01E+5 y β⁻ = 98.10% ε = 1.90%
31S 2.5534 s ε = 100.00%	32S STABLE 94.99%	33S STABLE 0.75%	34S STABLE 4.25%	35S 87.37 d β⁻ = 100.00%
30P 2.498 min ε = 100.00%	31P STABLE 100%	32P 14.268 d β⁻ = 100.00%	33P 25.35 d β⁻ = 100.00%	34P 12.43 s β⁻ = 100.00%

Ground and isomeric state information for $^{34}_{17}$Cl

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	0+	-24440.09 *5*	1.5264 s *14*	ε = 100.00%
0.1464	3+	-24293.69 *5*	32.00 min *4*	ε = 55.40% IT = 44.60%

The Astrophysical Journal Supplement Series, 252:2 (17pp), 2021 January https://doi.org/10.3847/1538-4365/abc41d

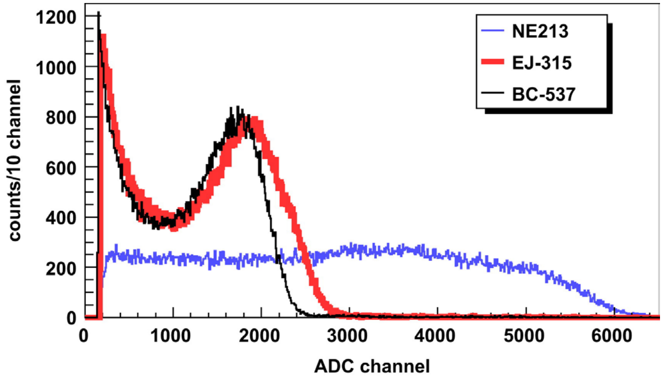
CrossMark

Astromers: Nuclear Isomers in Astrophysics*

G. Wendell Misch[1,2,3,4], Surja K. Ghorui[5,3], Projjwal Banerjee[6], Yang Sun[3,7,8], and Matthew R. Mumpower[1,2,4]

The CATRiNA neutron detector array

32 - C_6D_6 liquid scintillators detectors (EJ315).
Pulse shape discrimination.
E_n via Time-of-flight.
Structure in the Pulse-height.



Nuclear Inst. and Methods in Physics Research, A 930 (2019) 196–202

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Characterization of the CATRiNA neutron detector system

J.F. Perello, S. Almaraz-Calderon *, B.W. Asher, L.T. Baby, N. Gerken, K. Hanselman
Department of Physics, Florida State University, Tallahassee, FL 32306, USA

APSNews

March 2023 (Volume 32, Number 3)

Now a Nuclear Physicist at Los Alamos, APS Bridge Program Grad Says Nuclear Security is His Calling

"[My mom] was my savior," says Jesus Perello. "She said, 'Listen, you did not go this far just to quit."

By Liz Boatman | February 16, 2023

Credit: Jesus Perello

Jesus Perello, who earned his doctorate in physics from Florida State University in 2021, is now a physicist at Los Alamos National Lab.

March 2023 (Volume 32, Number 3)

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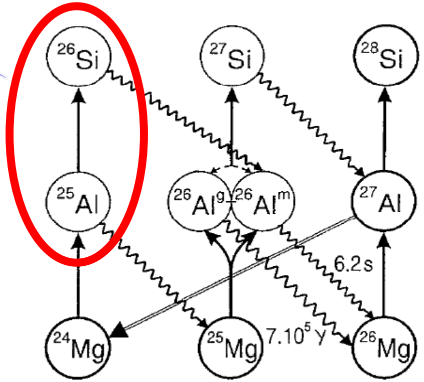
Articles in this Issue

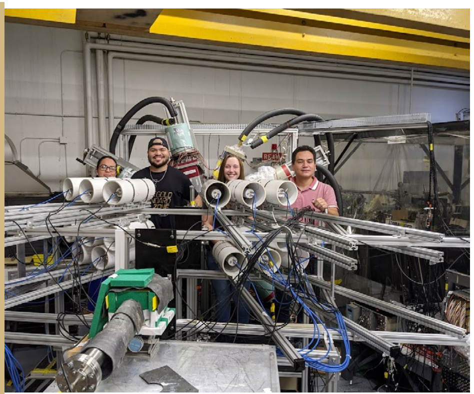
- New Technique Generates Non-Flickering Flames at Normal Gravity and Atmospheric Pressure
- This Month in Physics History
- Meenakshi Narain, 1964-2023
- How Do You Study Quantum Materials That Don't Yet Exist? Ask AI.
- Wikipedia Has a Problem That Physicists Can Help Solve
- Now a Nuclear Physicist at Los Alamos, APS Bridge Program Grad Says Nuclear Security is

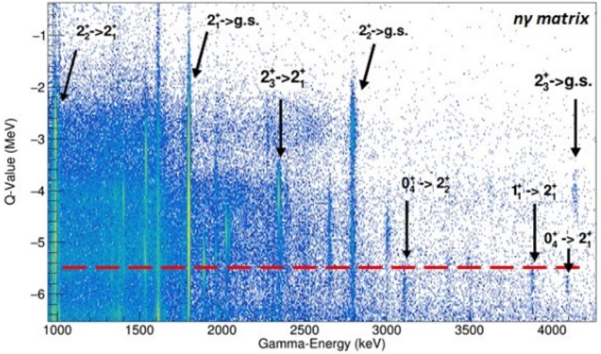
Jesus Perello is currently a postdoc fellow at LANL

Nuclear Astrophysics studies with CATRiNA



- Detailed resonance spectroscopy of ^{26}Si needed for determination of the ^{25}Al(p,γ)^{26}Si reaction rate.
- States in ^{26}Si were populated via the ^{24}Si(^{3}He,n) reaction.
- A n/γ coincidence measurement was performed using CATRiNA detectors and a set of HPGe detectors.





PHYSICAL REVIEW C
covering nuclear physics

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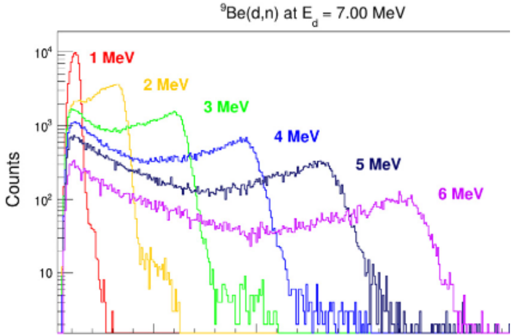
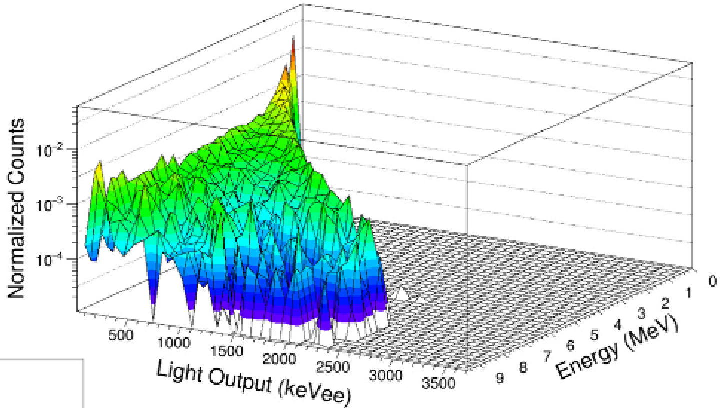
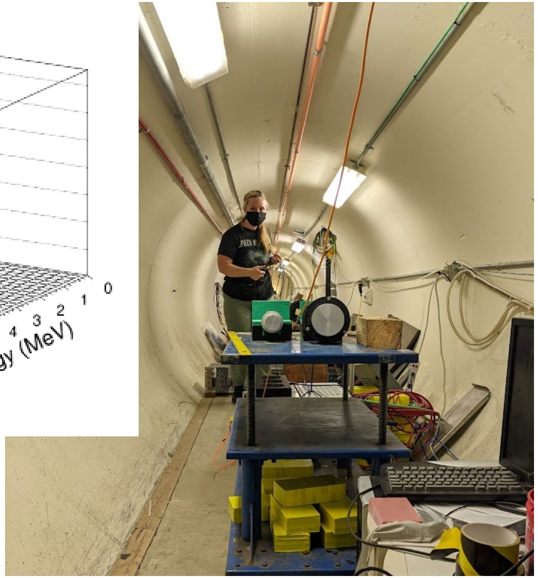
Low-lying resonances in ^{26}Si relevant for the determination of the astrophysical ^{25}Al(p,γ) ^{26}Si reaction rate

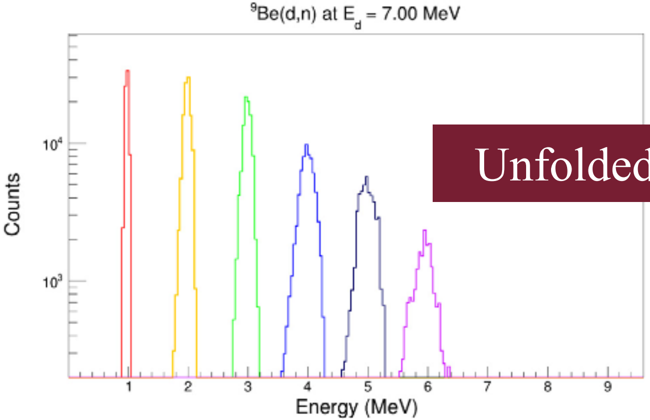
J. F. Perello, S. Almaraz-Calderon, B. W. Asher, L. T. Baby, C. Benetti, K. W. Kemper, E. Lopez-Saavedra, G. W. McCann, A. B. Morelock, V. Tripathi, I. Wiedenhöver, and B. Sudarsan
Phys. Rev. C **105**, 035805 – Published 24 March 2022

Spectrum unfolding with CATRiNA









Unfolded neutron energy spectra

Using a statistical Bayesian inference method to analyze the pulse-height spectra.

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/nima

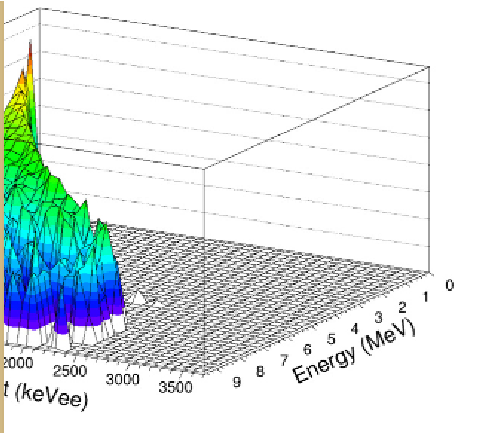
Characterization and description of a spectrum unfolding method for the CATRiNA neutron detector array

A.B. Morelock [a,*], J.F. Perello [a], S. Almaraz-Calderon [a], B.W. Asher [a], K. Brandenburg [b], J. Derkin [b], G. Hamad [b], Y. Jones-Alberty [b], E. Lopez Saavedra [a], T. Massey [b], Z. Meisel [b], N. Singh [b], D. Soltesz [b], S.K. Subedi [b], A. Voinov [b], J. Warren [b]

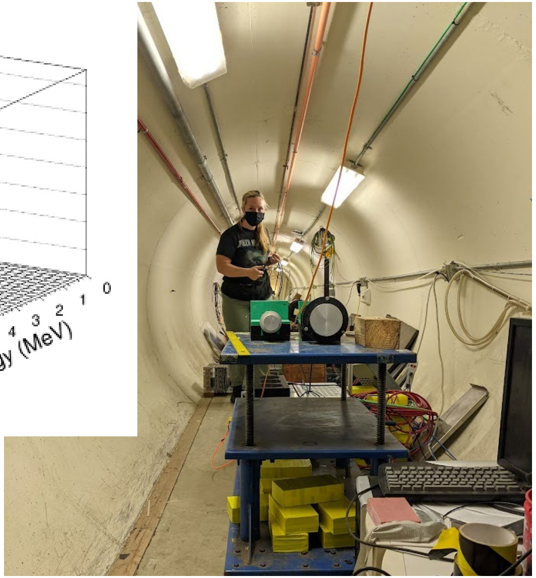
Spectrum unfolding with CATRiNA

Undergraduate Research

Fabio Rivero, FSU Honor's thesis, 2020.
"Neutron Spectrum Unfolding with Deuterated Liquid Scintillator Detectors".
Fabio is now a grad student at University of Notre Dame (ND).



energy spectra



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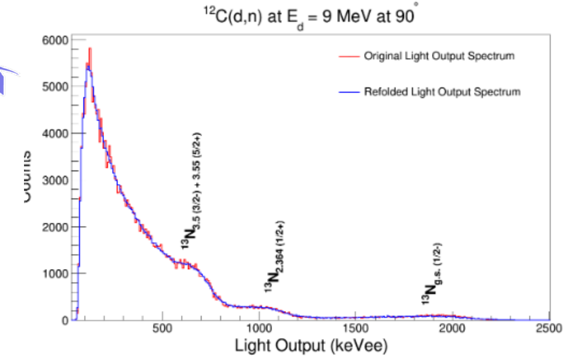
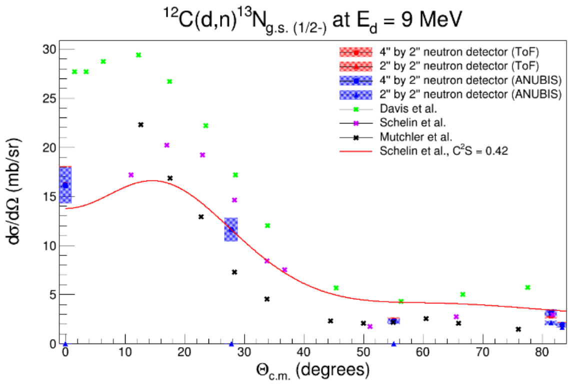
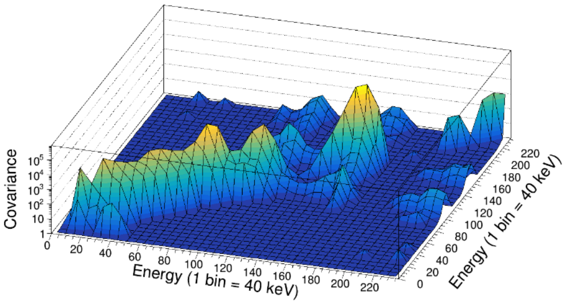
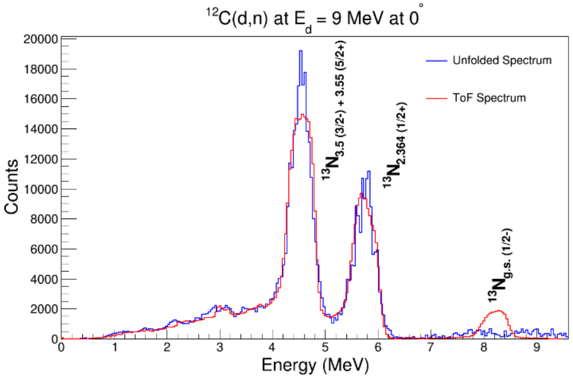
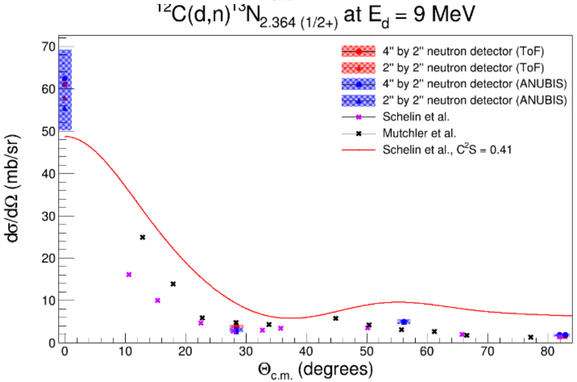
Unfolding vs ToF with CATRiNA







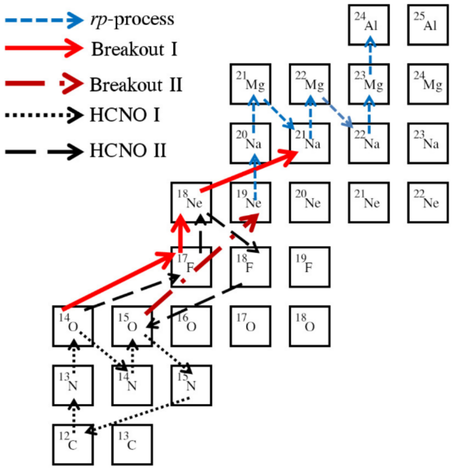




Ashton is currently a postdoc at UTK/FSU

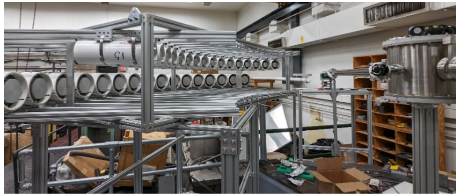
Resonance spectroscopy, CATRiNA + CHARON

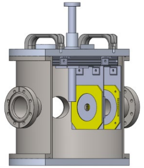
Breakout of the Hot CNO cycle via the ^{14}O(α,p)^{17}F → resonances in ^{18}Ne.

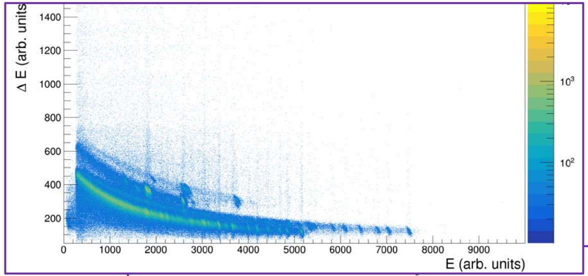


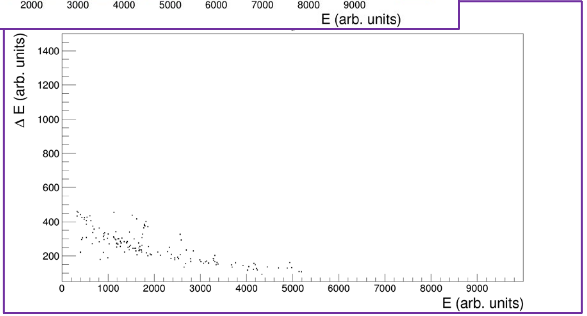
SA et al. PRC 86, 025801 (2012).

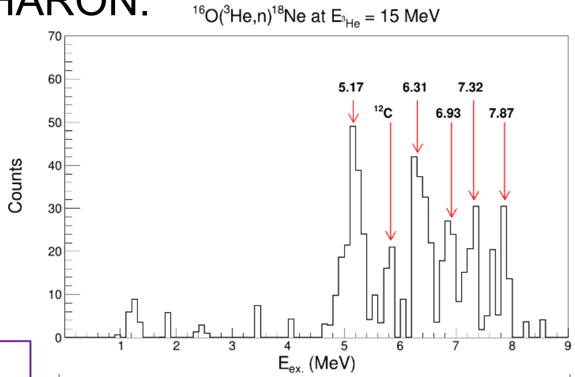
- States in ^{18}Ne were populated via the ^{16}O(^{3}He,n) reaction.
- Neutron and charged-particles were measured in coincidence with CATRiNA + CHARON.

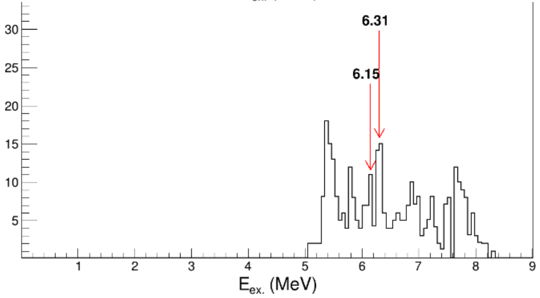












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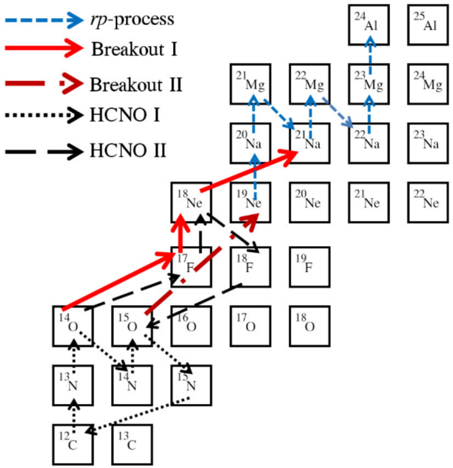
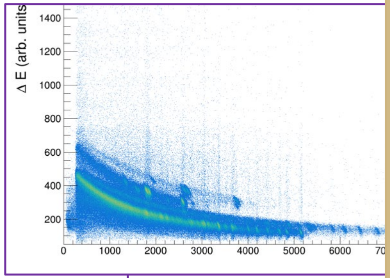
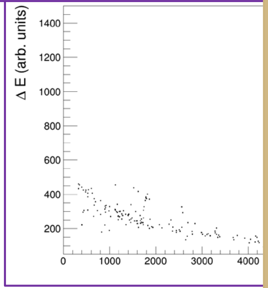
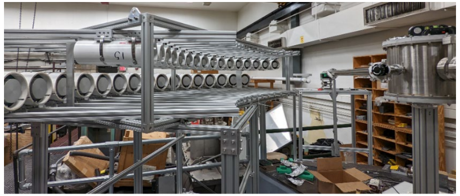


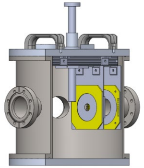
SA et al. PRC 86, 025801 (2012).

- States in ^{18}Ne w
- Neutron and cha
  coincidence with

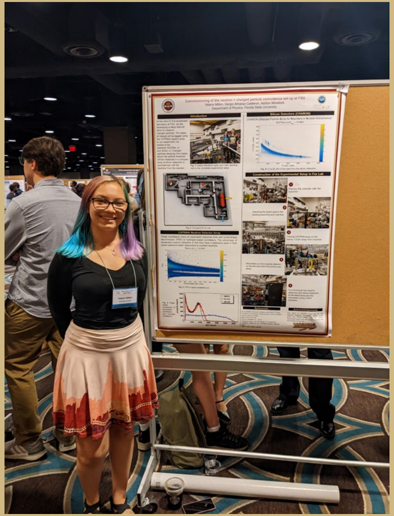








Undergraduate Research

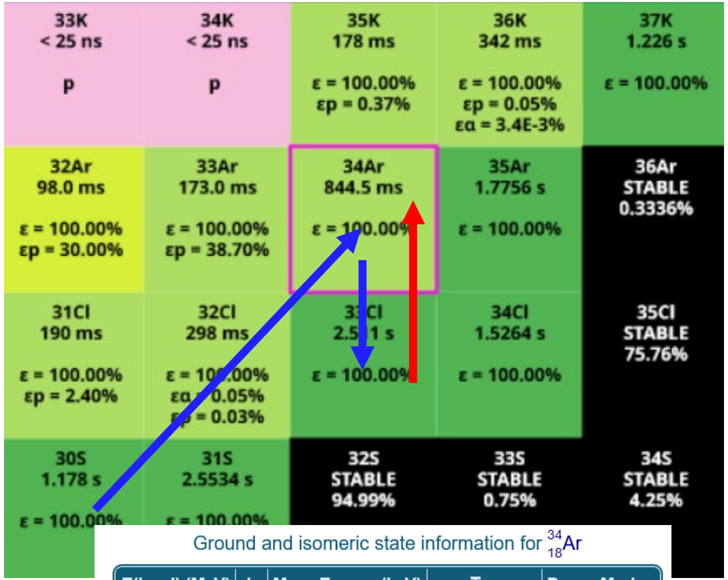


Valarie Milton, FSU BSc. 2023.
"Commissioning of the neutron - charged-particle coincidence setup at FSU".
Attended CEU @ APS-DNP in New Orleans, LA.
Valarie is now a grad student at Louisiana State University (LSU).

Resonance spectroscopy, CATRiNA + Clarion-2

- ^{34}Ar → Waiting point in the rp-process (^{33}Cl(p,γ)^{34}Ar) and αp-process (^{30}S(α,p)^{33}Cl).
- Presolar grain characterization.
- Final abundances and energy output in XRBs.

→ Resonance parameters largely undetermined!



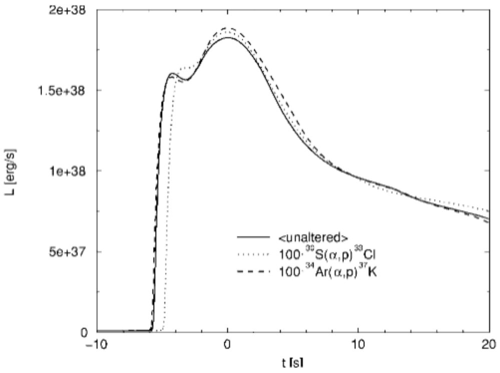
Ground and isomeric state information for $^{34}_{18}$Ar

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	0+	-18378.29 *8*	844.5 ms *34*	ε = 100.00%

The Astrophysical Journal, 608:L61–L64, 2004 June 10

THE NUCLEAR REACTION WAITING POINTS: ^{22}Mg, ^{26}Si, ^{30}S, AND ^{34}Ar AND BOLOMETRICALLY DOUBLE-PEAKED TYPE I X-RAY BURSTS

Jacob Lund Fisker and Friedrich-Karl Thielemann



Deibel et al. PRC 84, 045802 (2011).
Long et al. PRC 97, 054613 (2018).
Kennington et al. PRL 124, 252702 (2020).

Resonance spectroscopy, CATRiNA + Clarion-2

- ^{34}Ar → Waiting point in the rp-process (^{33}Cl(p,γ)^{34}Ar) and αp-process (^{30}S(α,p)^{33}Cl).
- Presolar grain characterization.
- Final abundances and energy output in XRBs.

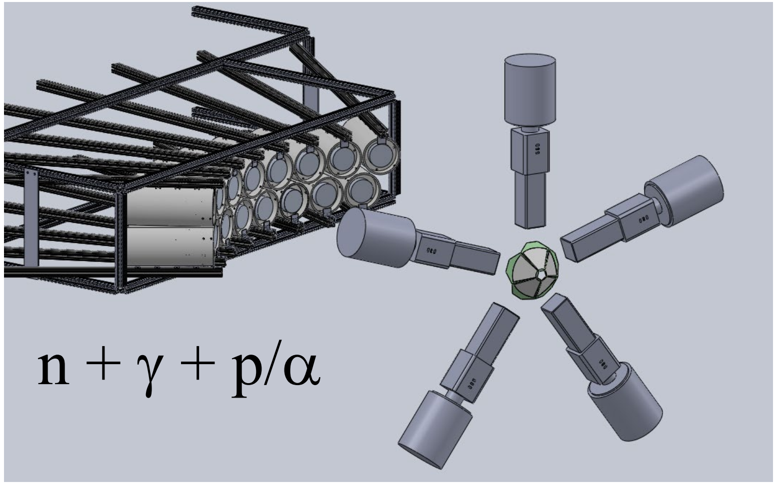
→ Resonance parameters largely undetermined!

G.S. Matthew Mestayer

→ Perform a measurement of the ^{32}S(^{3}He,n)^{34}Ar reaction.

→ ^{3}He beam and ~200 μg/cm^2 ^{32}S(ZnS)

Use ***CATRiNA + Clarion + Charged-particle*** coincidences to study the resonance structure in ^{34}Ar.



Near-threshold resonances and continuum effects

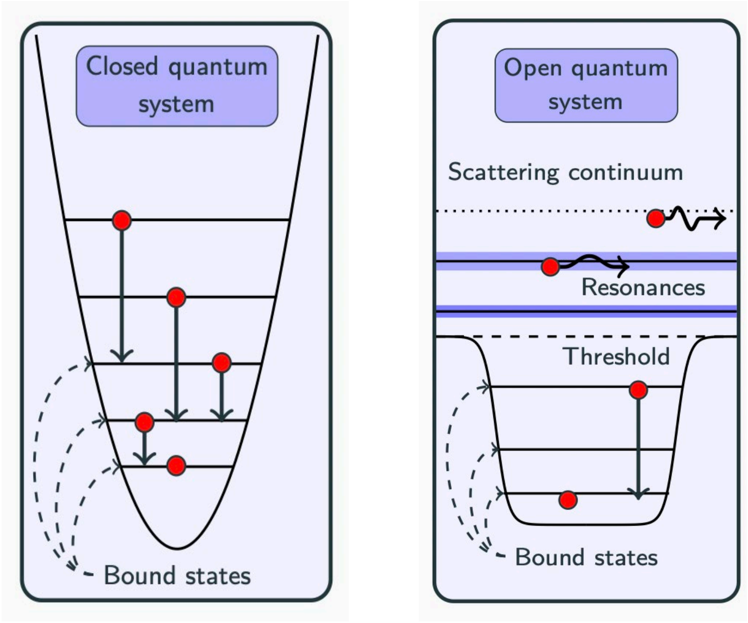


Figure from K. Fossez.

At low excitation energies, well-bound nuclei can be considered as closed quantum systems.

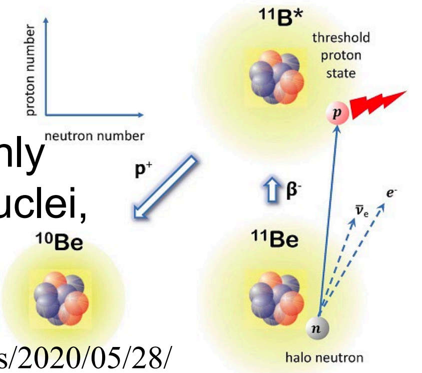
Moving towards drip lines, or higher in excitation energy, the continuum coupling becomes gradually more important, changing the nature of weakly bound states.

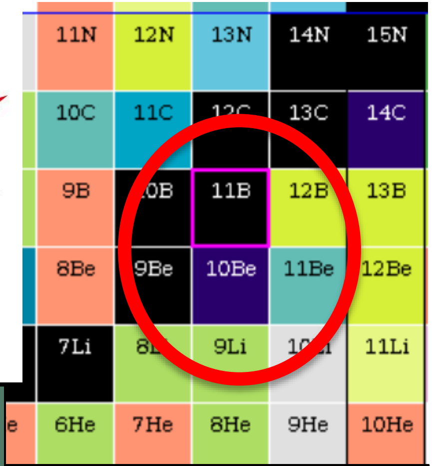
Couplings to the continuum states play a significant role in the structure and reactions of these systems.

Near-threshold resonance in ^{11}B

A puzzling exotic decay

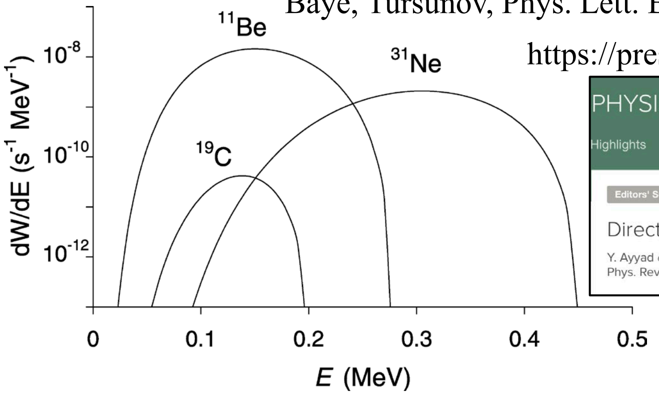
- Can neutron rich nuclei emit a proton?
- **beta-delayed proton emission ($\beta^- p^+$)** is only energetically allowed for a handful of light nuclei, ^{11}Be the most accessible.

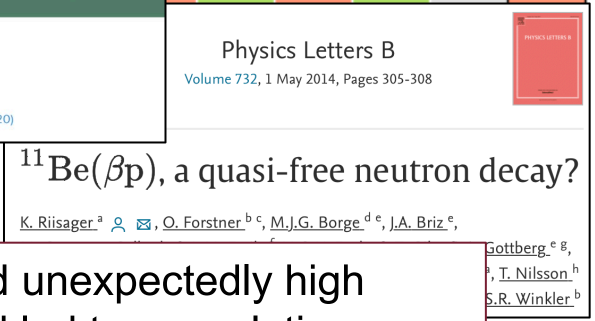




Baye, Tursunov, Phys. Lett. B 696, 464 (2011).

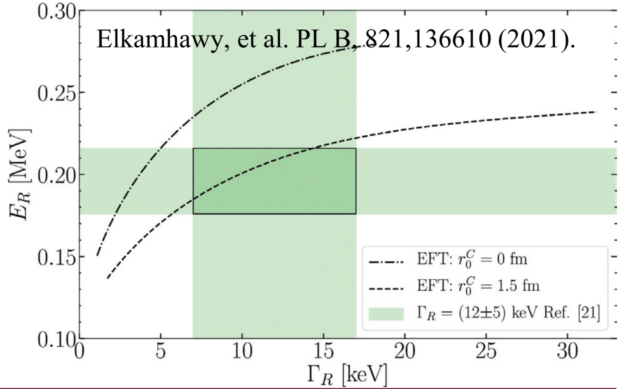
https://press.ifj.edu.pl/en/news/2020/05/28/





Experimental studies of the ^{11}Be/^{10}Be branching ratio obtained unexpectedly high results that raised questions about the decay mechanism and led to speculations about a possible nuclear dark decay channel.

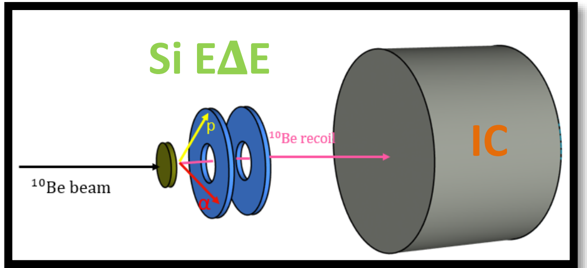
Near-threshold resonance in ^{11}B

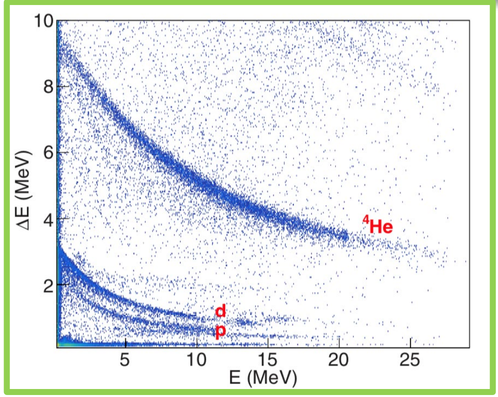


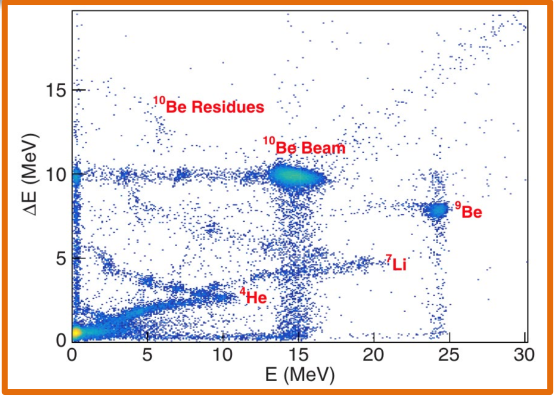
The ^{11}B resonance at FSU

Measurement of the ^{10}Be(d,n)^{11}B*→p/α reaction in Inverse Kinematics at Florida State University.

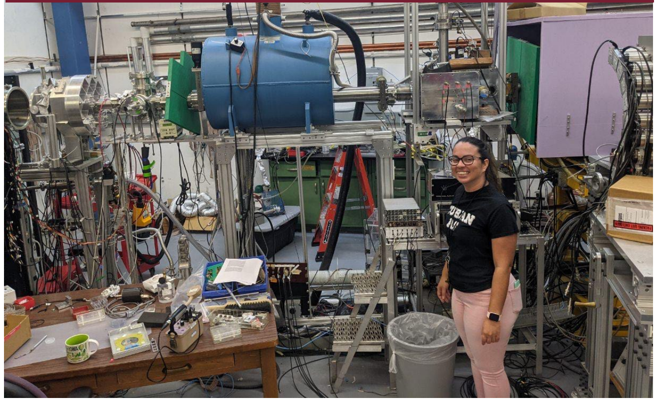
Using a ^{10}Be beam from RESOLUT produced via the ^{9}Be(d,p) reaction.







Eilens Lopez-Saavedra is currently a postdoc at ANL



Near-threshold resonance in ^{11}B

The ^{11}B resonance at FSU

PHYSICAL REVIEW LETTERS **129,** 012502 (2022)

Observation of a Near-Threshold Proton Resonance in ^{11}B

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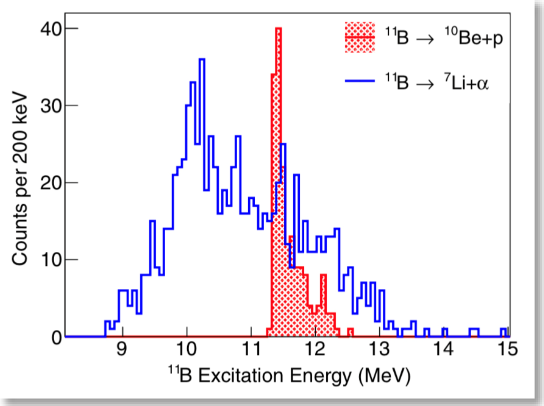
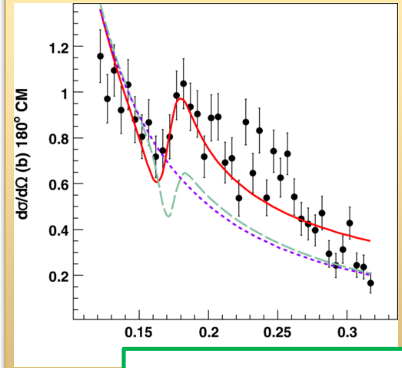
Nuclear Physics

Near-Threshold Resonance Helps Explain a Controversial Measurement of Exotic Decay in Beryllium-11

SEPTEMBER 28, 2022

$$E_{ex} = 11.44 \pm 0.04\ \text{MeV}, (1/2^{+}),$$
$$\Gamma_{sp} = 20\ \text{keV},\ \Gamma_p = 5.4\ \text{keV}$$





PHYSICAL REVIEW LETTERS **129,** 012501 (2022)

Evidence of a Near-Threshold Resonance in ^{11}B Relevant to the β-Delayed Proton Emission of ^{11}Be

Y. Ayyad,[1,2,*] W. Mittig,[2,3] T. Tang,[2] B. Olaizola,[4] G. Potel,[5] N. Rijal,[2] N. Watwood,[2] H. Alvarez-Pol,[1] D. Bazin,[2,3] M. Caamaño,[1] J. Chen,[6] M. Cortesi,[2] B. Fernández-Domínguez,[1] S. Giraud,[2] P. Gueye,[2,3] S. Heinitz,[7] R. Jain,[2,3] B. P. Kay,[6] E. A. Maugeri,[7] B. Monteagudo,[2] F. Ndayisabye,[2,3] S. N. Paneru,[2] J. Pereira,[2] E. Rubino,[2] C. Santamaria,[2] D. Schumann,[7] J. Surbrook,[2,3] L. Wagner,[2] J. C. Zamora,[2] and V. Zelevinsky[2,3]

The ^{11}B resonance at NSCL

$$(E_x = 11.4\ \text{MeV},\ J^{\pi} = 1/2^{+},\ \text{and}\ \Gamma_p = 4.4\ \text{keV})$$

Near-threshold resonance in ^{11}B

LETTER • OPEN ACCESS

$\beta^{-}p$ and $\beta^{-}\alpha$ decay of the ^{11}Be neutron halo ground state

J Okołowicz[4,1], M Płoszajczak[2] and W Nazarewicz[3]

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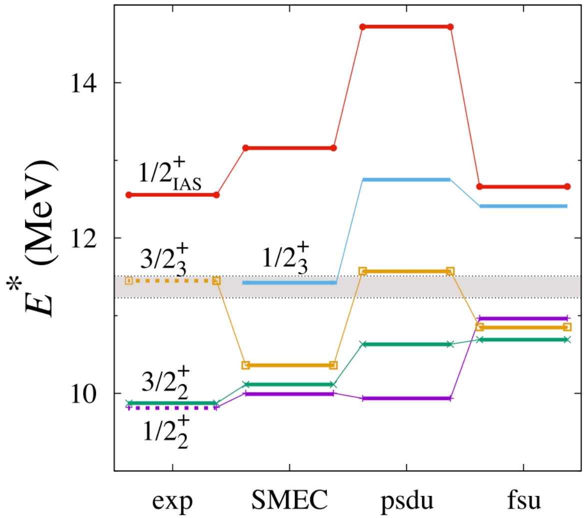
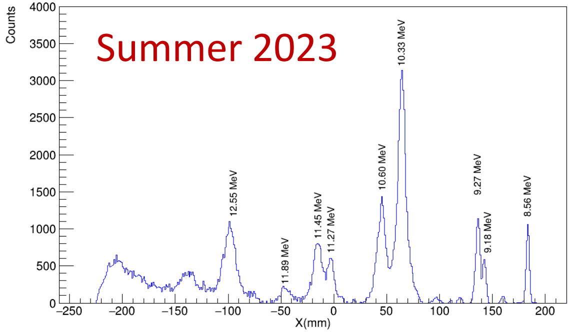
Open questions

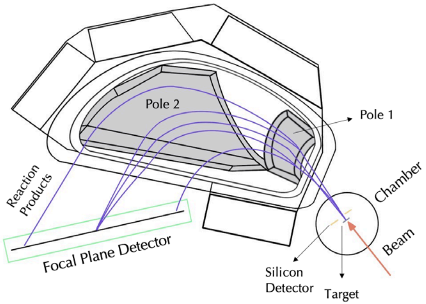
- Does the p-resonance have an alpha strength?
- Is there a close $3/2^{+}$ state responsible for the $\beta^{-}\alpha$ decay?
- Is it a threshold effect consequence of coupling with the continuum?

→ **New Experiments to study the mirror nucleus ^{11}C**



The ^{7}Li(^{7}Li,t)^{11}B reaction with Super Enge Split Pole Spectrograph (SE - SPS) at FSU.



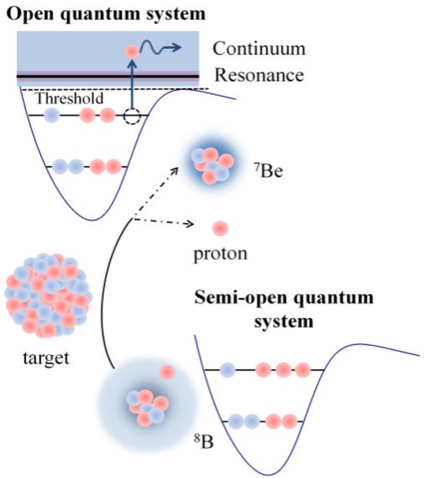


To be continued … Further studies on ^{11}B and ^{11}C

Near-threshold resonances and continuum effects

Halo structure of ^{8}B

The proton dripline nucleus ^{8}B has a very small Sp ~ 138 keV.
→ it presents an ideal case to study nuclear OQS, and continuum effects!



G.S. Rajat Aggarwal

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Halo structure of ^{8}B determined from intermediate energy proton elastic scattering in inverse kinematics

G.A. Korolev[a,*], A.V. Dobrovolsky[a], A.G. Inglessi[a], G.D. Alkhazov[a], P. Egelhof[b], A. Estradé[b], I. Dillmann[b], F. Farinon[b], H. Geissel[b], S. Ilieva[b], Y. Ke[b], A.V. Khanzadeev[a], O.A. Kiselev[b], J. Kurcewicz[b], X.C. Le[b], Yu.A. Litvinov[b], G.E. Petrov[a], A. Prochazka[b], C. Scheidenberger[b], L.O. Sergeev[a], H. Simon[b], M. Takechi[b], S. Tang[b], V. Volkov[b], A.A. Vorobyov[a], H. Weick[b], V.I. Yatsoura[a]

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https://doi.org/10.1038/s41467-022-34767-8

Breakup of the proton halo nucleus ^{8}B near barrier energies

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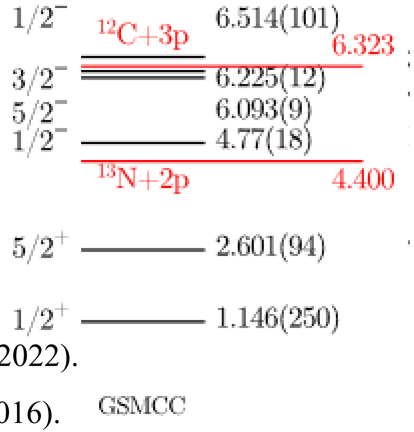
L. Yang[1,2], C. J. Lin[1,3], H. Yamaguchi[2,4], A. M. Moro[5,6], N. R. Ma[1,2], D. X. Wang[1], K. J. Cook[7,8,21], M. Mazzocco[9,10], P. W. Wen[1], S. Hayakawa[2], J. S. Wang[11], Y. Y. Yang[12], G. L. Zhang[13], Z. Huang[13], A. Inoue[14], H. M. Jia[1], D. Kahl[15], A. Kim[16], M. S. Kwag[17], M. La Commara[18], G. M. Gu[17], S. Okamoto[19],

A ^{7}Be beam from RESOLUT to measure the ^{7}Be(d,n)^{8}B reaction and the decay from resonances in halo nucleus ^{8}B.

Collaboration with FSU theorist A. Volya and K. Fossez.

Near-threshold resonances and continuum effects

Structure of a triplet of Near-threshold resonances in ^{15}F



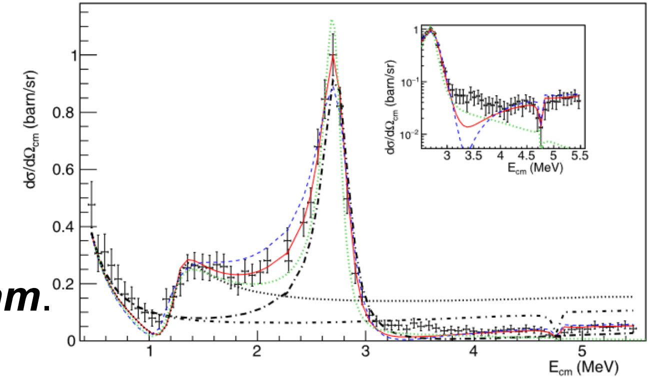
The observation of a unique triplet of narrow resonances between 2p- and 3p-emission thresholds in ^{15}F requires further characterization to understand their properties.

Girad-Alcindor et al. PRC 105, L051301 (2022).

F. de Grancey et al. Physics Letters B 758, 26 (2016).

A measurement of the ^{14}O(d, n)^{15}F reaction and subsequent charged-particle decays with RESOLUT. Beam production via the ^{14}N(p,n)^{14}O reaction.

A study on the mirror ^{15}C will also be pursued via the ^{13}C(t,p) reaction using the newly developed ***triton beam***.



Collaboration with FSU theorist A. Volya and K. Fossez.

FLORIDA STATE UNIVERSITY

Summary

- Development of a ^{44}Ti beam at FSU for a measurement of the ^{44}Ti(α,p)^{47}V reaction with Encore.
- Contribution of low-lying isomers to stellar nucleosynthesis ^{26}Al and ^{34}Cl.
- Detailed spectroscopy studies of the ^{34}Ar waiting point nucleus using CATRiNA + Clarion-2 arrays.
- Near-threshold resonances and continuum effects ^{11}B, ^{8}B, and ^{15}F.

Thank you!