NIC XVII

Nuclei in the Cosmos XVII

Science Culture Center, Daejeon, Korea

The status and future of nuclear property experiments at CENS

Sunghoon(Tony) Ahn

Center for Exotic Nuclear Studies

Institute for Basic Science

September 18th, 2023

CENS

ibs 기초과학연구원 Institute for Basic Science

Background: JWST Deepest Infrared Image of Universe by NASA, ESA, CSA, and STScI

Acknowledgement

This work was supported by the Institute for Basic Science (IBS-R031-D1), Ministry of Science and ICT(MSIT), Republic of Korea.

Contents

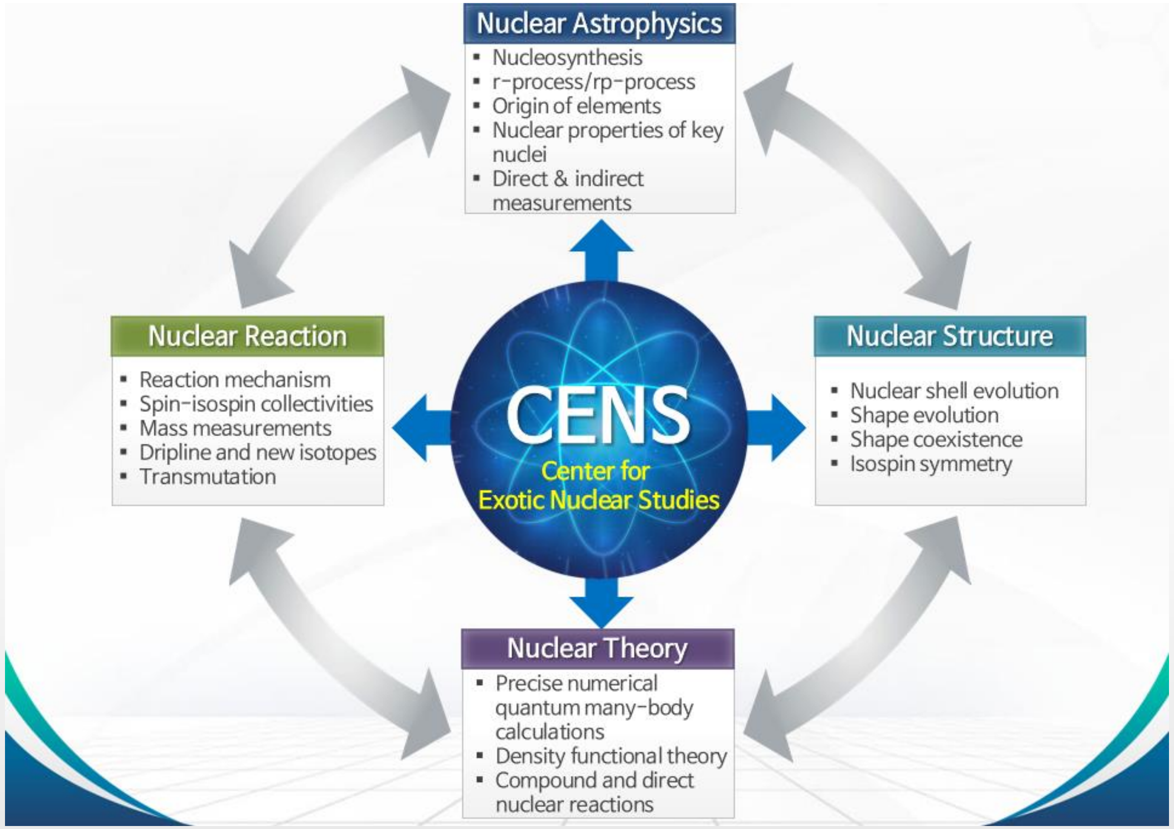
❖ **Introduction of the Center for Exotic Nuclear Studies (CENS)**

❖ **Nuclear astrophysics research activities at CENS**

Introduction of CENS

To study properties of exotic nuclei and origin of heavy elements in the universe

- The Center for Exotic Nuclear Studies (CENS) was launched in December 2019.
- We have 26 researchers and 11 Ph.D. students as of today.



Visions

- To become one of the leading research institutions in nuclear physics
- To explore uncharted regions of nuclei and find important discoveries

Organization of CENS

CENS Director

Advisory Committee

Nuclear Astrophysics

Group Leader

- Nucleosynthesis
- r-process/rp-process
- Origin of elements
- Nuclear properties of key nuclei
- Direct & indirect measurements

Nuclear Structure

Group Leader

- Nuclear shell evolution
- Shape evolution
- Shape coexistence
- Isospin symmetry

Nuclear Reaction

Group Leader

- Reaction mechanism
- Spin-isospin collectivities
- Mass measurements
- Dripline and new isotopes
- Transmutation

Nuclear Theory

Group Leader

- Precise numerical quantum many-body calculations
- Density functional theory
- Compound and direct nuclear reactions

- Interdisciplinary collaborations
- Research using RAON facility with ISOL and IF method
- Detector development

CENS Members (26 researchers)

- D. Kim & S. Kim (2020.02.01.)
- T.-S. Park (2020.03.01.)
- J. Hwang (2020.04.01.)
- J. Park (2020.04.16.)
- C.B. Moon & B. Moon (2020.09.01.)
- S. Ahn (2020.10.01.)
- Z. Korkulu & L. Stuhl (2020.11.01.)

2020 (10)

- S. Choi (2020.11.16.)
- S. Bae & S. Cha (2021.03.01.)
- Q. Zhao (2021.04.16.)
- X. Pereira-Lopez (2021.06.16.)
- D. S. Ahn (2021.10.01.)
- M. Kim (2021.10.16.)

2021 (6)

- Y. H. Kim (2022.01.01.)
- M. L. Bui (2022.01.16.)
- J. Y. Huh (2022.07.01.)
- H. Y. Lee (2022.09.01.)
- I. Mazur (2022.10.16.)

2022 (5)

- Y. Kim (2023.01.01.)
- J. W. Lee (2023.03.01.)
- J . S. Ha(2023.04.01.)
- M.J. Kim (2023.09.01.)
- J.H. Won (2023.04.16.)

2023 (5)

CENS
CENTER FOR EXOTIC NUCLEAR STUDIES

6 Faculty members (4 group leaders)
5 Senior researchers
2 Research engineers
3 YSF(Young Scientist Fellow)
10 Postdoctoral researchers

11 Ph.D. students

Research proposals

- FRIB PAC1 (2022):
  - ✓ 4 proposals and 1 LoI submitted
  - ✓ 2 proposals and 1 LoI accepted
- FRIB PAC2 (2023):
  - ✓ 9 proposals submitted
  - ✓ 2 proposal of spokesperson
  - ✓ 5 (1 CENS) proposals accepted

Argonne NATIONAL LABORATORY, FRIB

- Year 2022:
  - ✓ 1 proposal submitted and accepted
- Year 2023:
  - ✓ 1 proposals submitted

ISOLDE

- ✓ 1 submitted and accepted

GANIL

- Year 2021:
  - ✓ 4 submitted
  - ✓ 1 spokesperson
  - ✓ 2 (1 CENS) accepted

ILL NEUTRONS FOR SOCIETY

- Year 2021:
  - ✓ 2 (CENS) submitted and accepted
- Year 2022:
  - ✓ 9 submitted
  - ✓ 1 spokesperson
  - ✓ 3 accepted

RIKEN NISHINA CENTER

- Year 2020:
  - ✓ 6 submitted
  - ✓ 5 spokesperson
  - ✓ 1 (CENS) accepted
- Year 2021:
  - ✓ 7 submitted
  - ✓ 4 spokesperson
  - ✓ 3 accepted
- Year 2022:
  - ✓ 18 submitted
  - ✓ 12 spokesperson
  - ✓ 5 (2 CENS) accepted

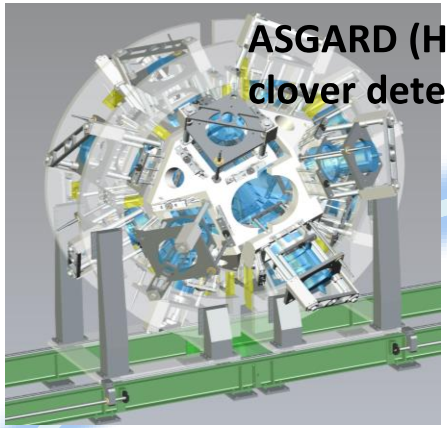
[Summary]

Submitted 67 proposals : Japan(31), Europe(20), USA(16)

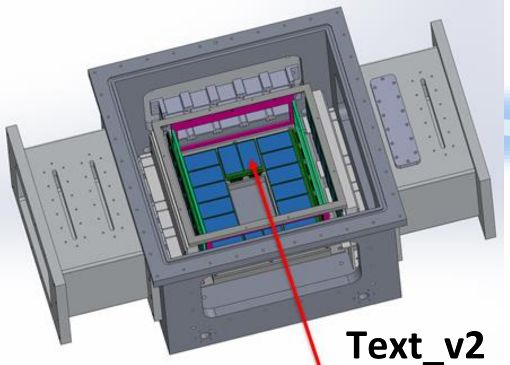
Accepted 29 proposals: Japan(9), Europe(11), USA(9)

CENS spokespersons for 30 proposals, 12 accepted

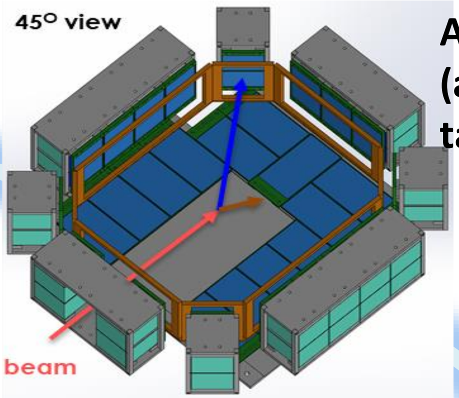
CENS detector and device development



ASGARD (HPGe clover detectors)



Text_v2
(active target TPC)



AToM-X
(active
target TPC)

Decay Spectroscopy Station

A New Plunger Device

Detector System for Internal Conversion Electrons

CENTER FOR EXOTIC NUCLEAR STUDIES

Beam PID

Diagnostics System

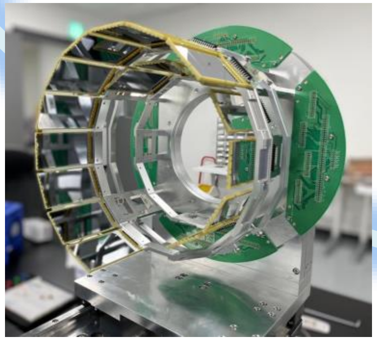
DL-MCP

GAGG Scintillator

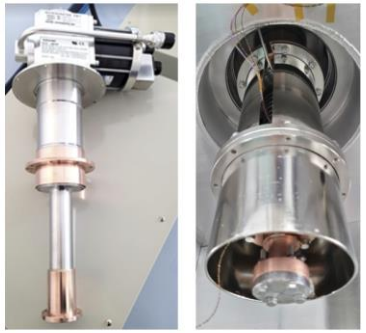
Liquid Organic Scintillator

MUSIC/IC

Gas Jet Target

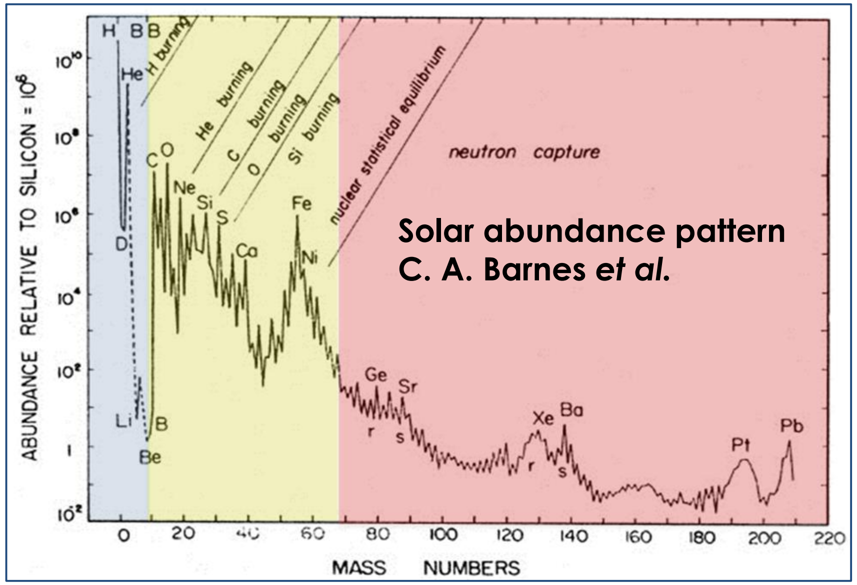


STARK (Si strip array)

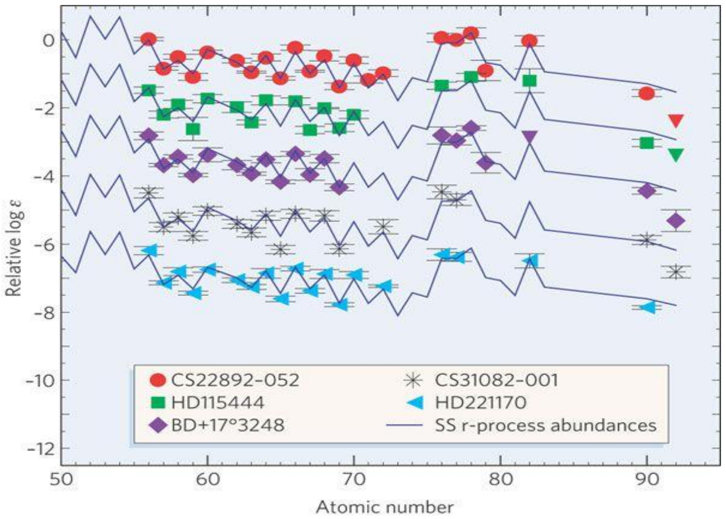


CryoSTAR
(gas target)

Astrophysical Observables and Origin of Elements

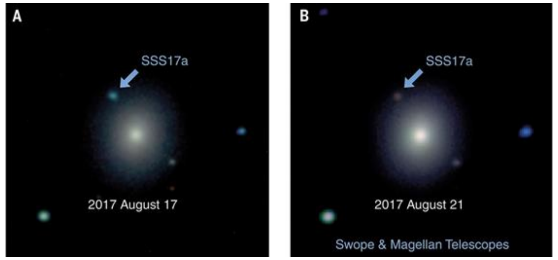


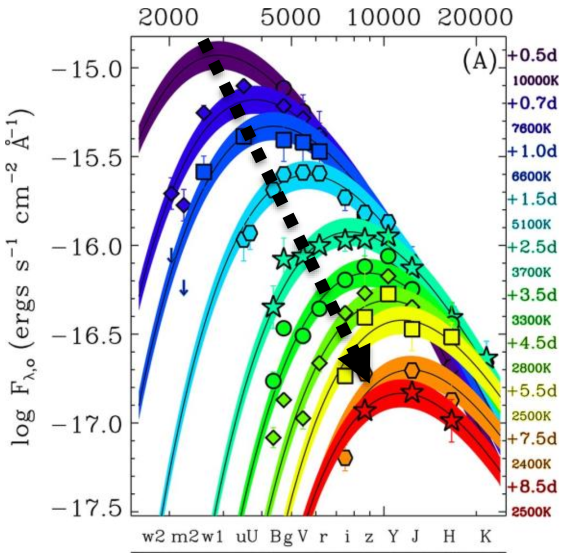
Solar abundance pattern
C. A. Barnes *et al.*

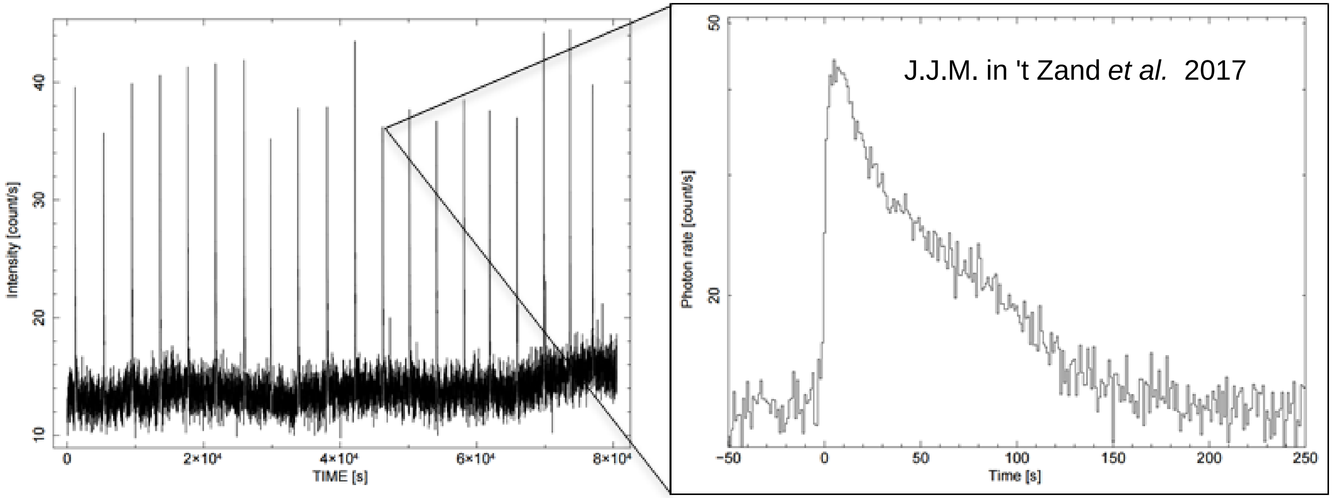


Abundances in metal poor r-stars
J.J. Cowan and C. Sneden, *Nature* 440, 1151 (2006)

Kilo Nova/GW Observations
Drout *et al.* (2017)

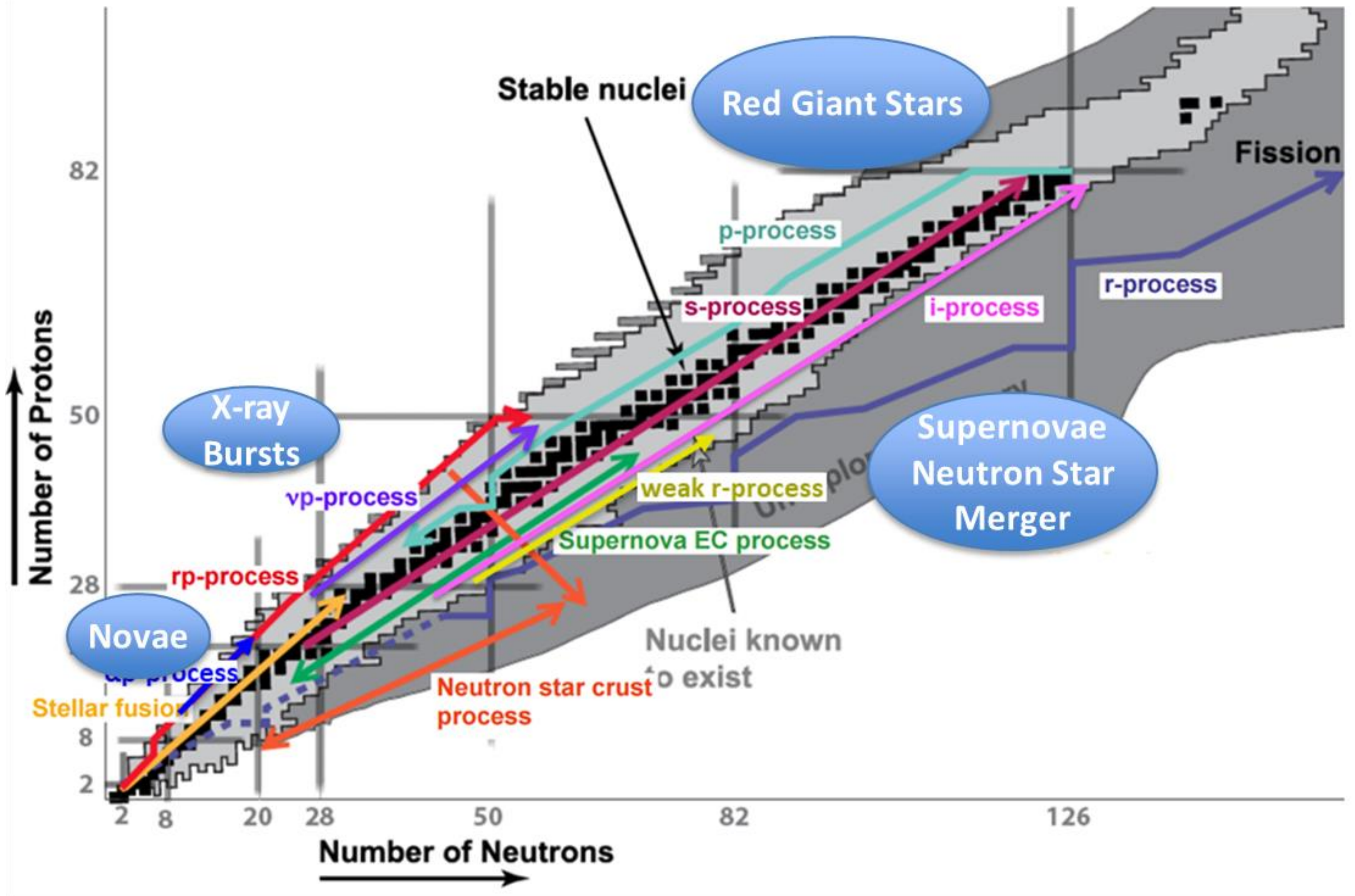




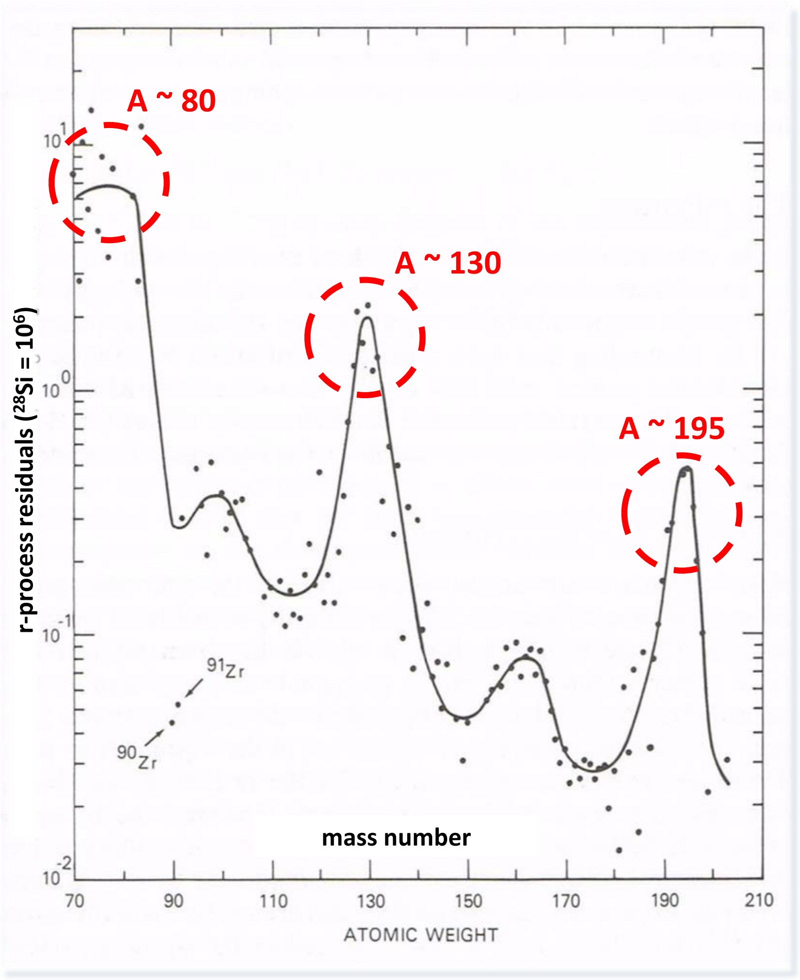


Observed light curves of X-ray burst

Nucleosynthesis Processes



Schematic overview of the nuclear processes on nuclear chart
H. Schatz (2016)

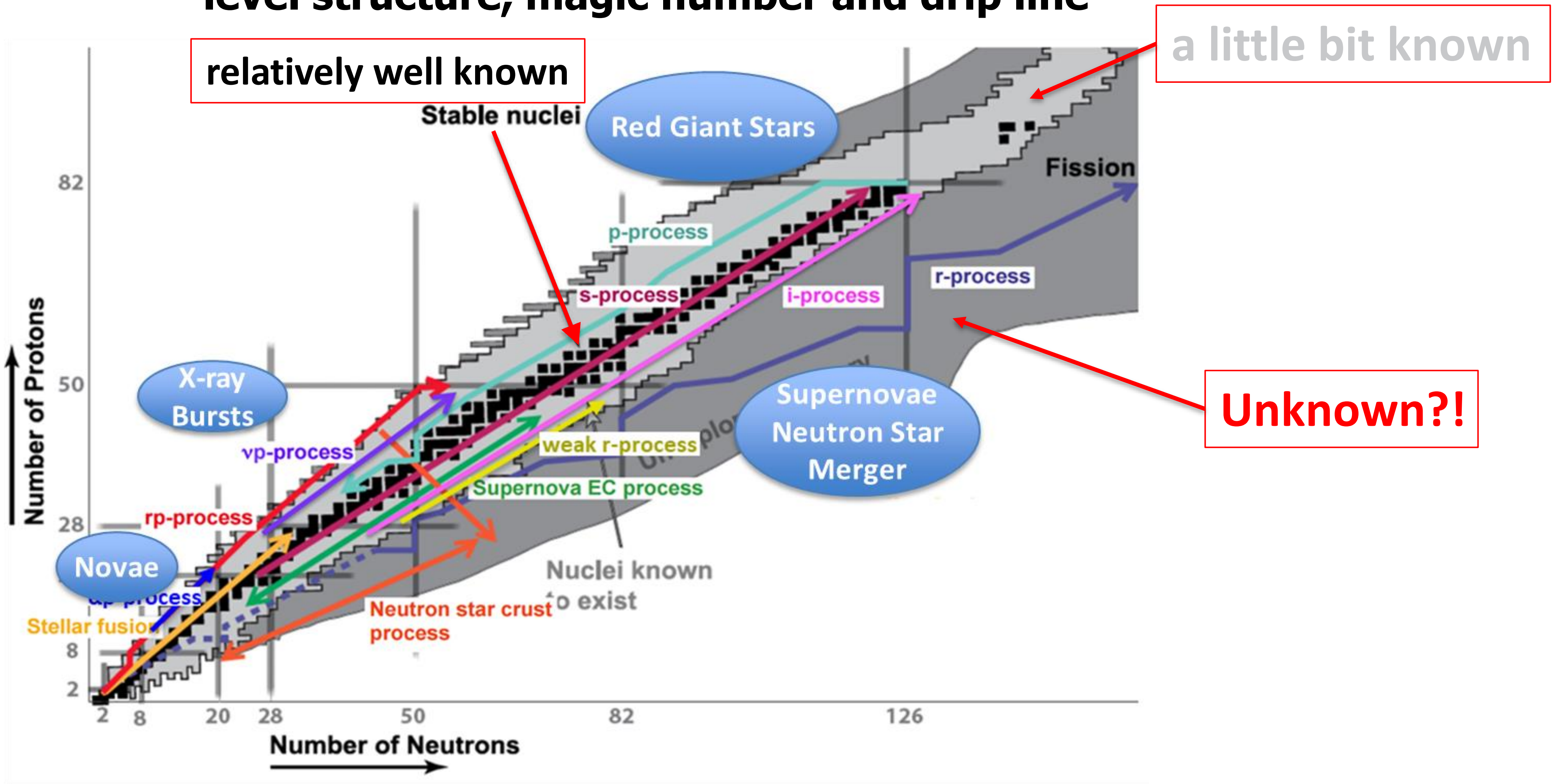


Calculated r-process yields
for solar abundance patterns
F. Kappeler *et al. Rep. Prog. Phys.* 52 945 1989

❖ Nucleosynthesis process can explain the observation.
→ **Nuclear Physics plays an important role!**

What do we need to study?

❖ **Properties of Nuclei: mass, Q-value, $T_{1/2}$, P_n, level densities, reaction rates, level structure, magic number and drip line**

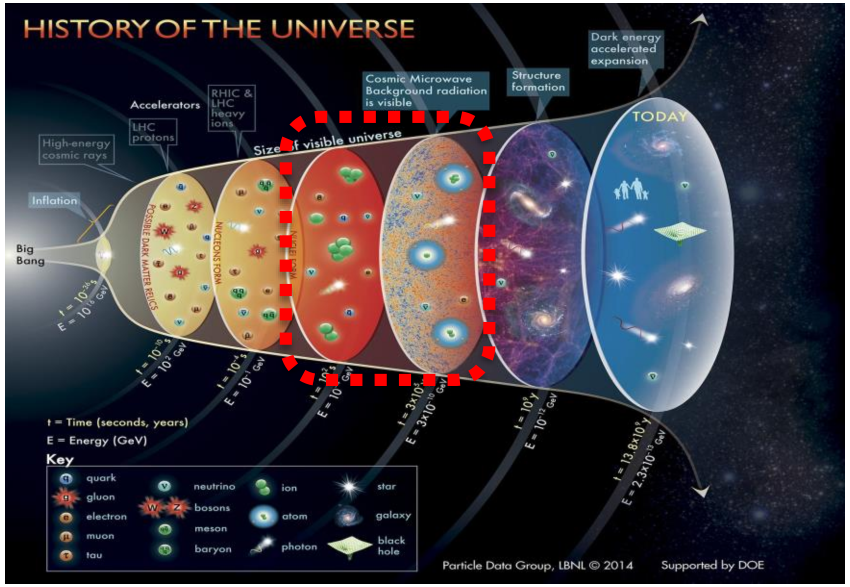


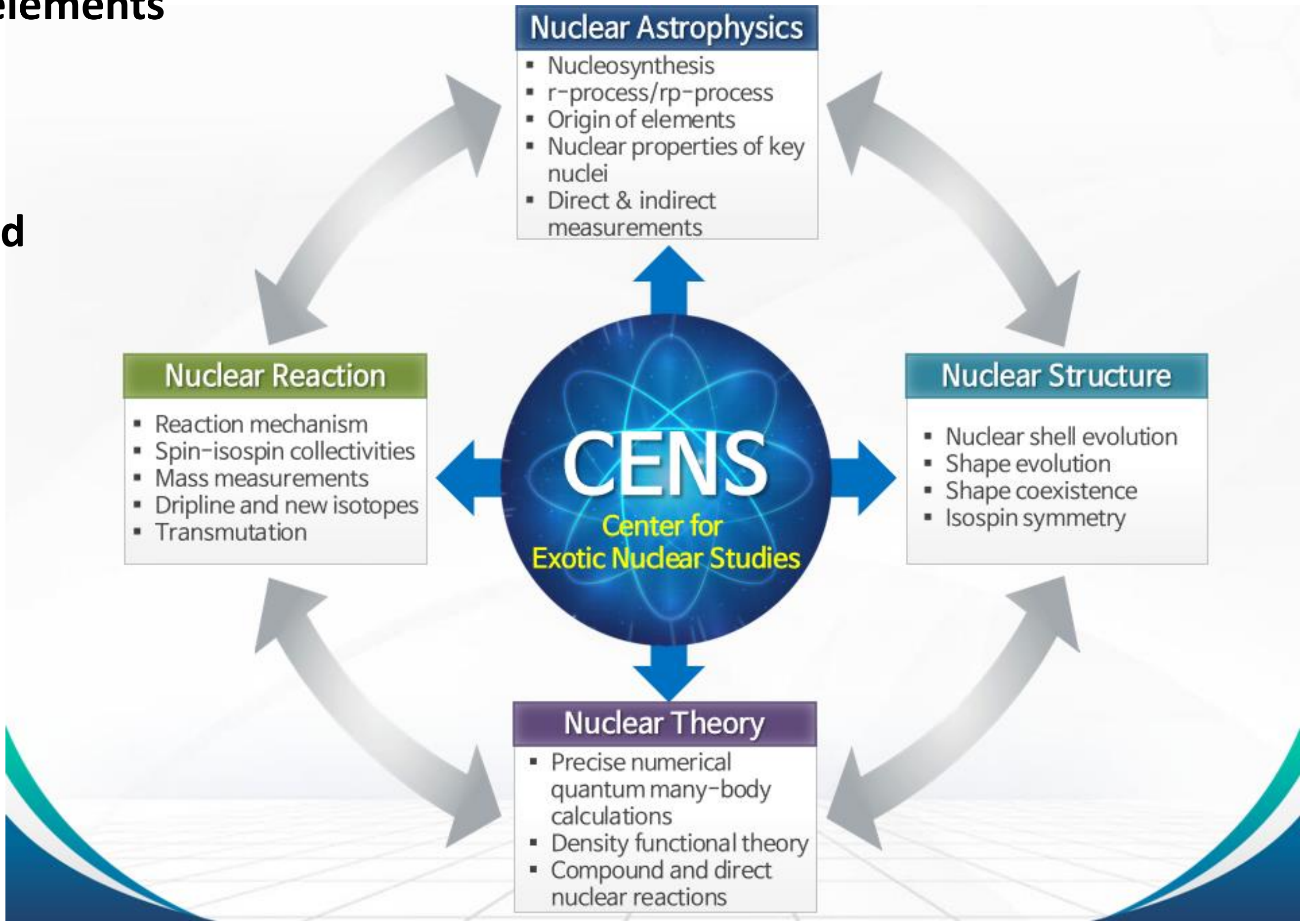
Schematic overview of the nuclear processes on nuclear chart
H. Schatz, *2016*

Nuclear Astrophysics Group at CENS

[Nuclear Astrophysics Research Topics]

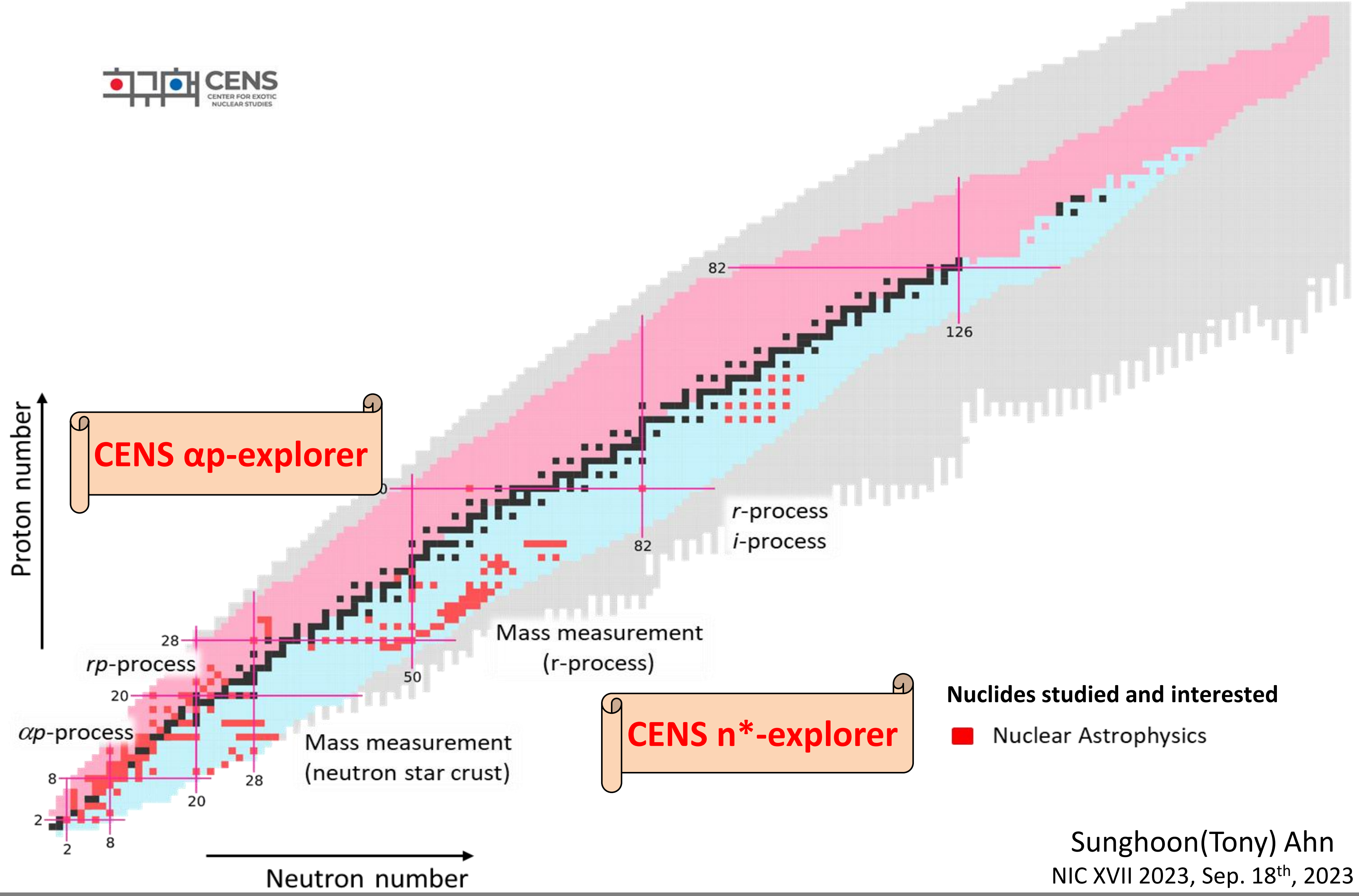
1. **Nucleosynthesis (r-process/rp-process) → Origin of elements**
2. **Nuclear properties of key nuclei**
3. **Direct & indirect measurements**
4. **Interdisciplinary collaborations**
5. **Research using RAON facility with ISOL and IF method**
6. **Detector development**





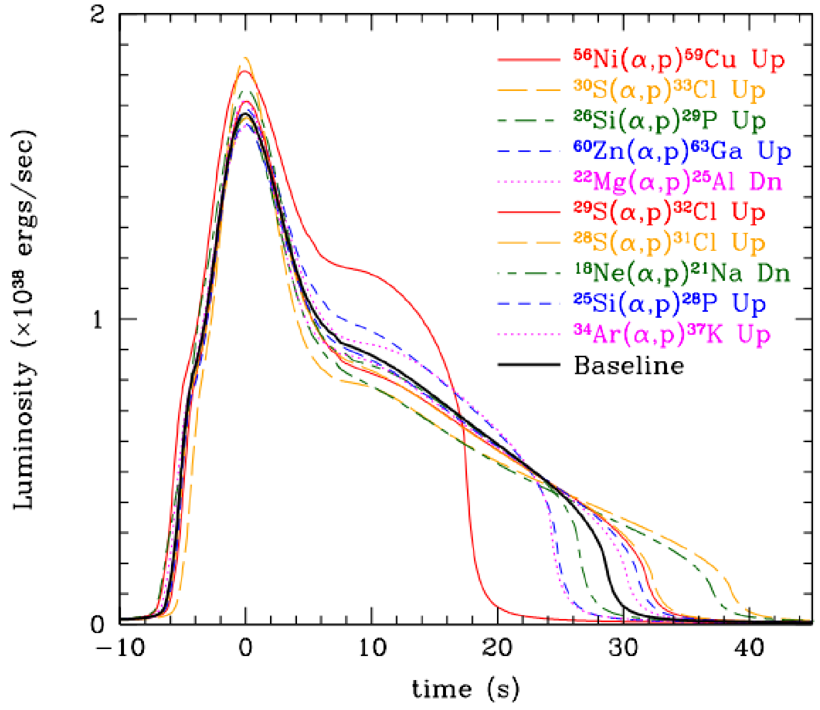
Astrophysically important nuclei on CENS Nuclear Chart

Properties of Nuclei: mass, Q-value, $T_{1/2}$, P_n, level densities, reaction rates, and level structure



Sensitivity Studies on Nuclear Reaction Rates in X-ray burst

- The sensitivity study by R.H. Cyburt *et al.* showed there are important astrophysical reaction rates affecting a large variation of energy generation and final ash in X-ray burst model.
- Limited experimental measurements of (p,ɣ), (α,ɣ) and (α,p) performed to reduce their uncertainties.



Rank	Reaction	Type[a]	Sensitivity[b]	Category
1	^{56}Ni(α, p)^{59}Cu	U	12.5	1
2	^{59}Cu(p, γ)^{60}Zn	D	12.1	1
3	^{15}O(α, γ)^{19}Ne	D	7.9	1
4	^{30}S(α, p)^{33}Cl	U	7.8	1
5	^{26}Si(α, p)^{29}P	U	5.3	1
6	^{61}Ga(p, γ)^{62}Ge	D	5.0	1
7	^{23}Al(p, γ)^{24}Si	U	4.8	1
8	^{27}P(p, γ)^{28}S	D	4.4	1
9	^{63}Ga(p, γ)^{64}Ge	D	3.8	1
10	^{60}Zn(α, p)^{63}Ga	U	3.6	1
11	^{22}Mg(α, p)^{25}Al	D	3.5	1
12	^{56}Ni(p, γ)^{57}Cu	D	3.4	1
13	^{29}S(α, p)^{32}Cl	U	2.8	1
14	^{28}S(α, p)^{31}Cl	U	2.7	1
15	^{31}Cl(p, γ)^{32}Ar	U	2.7	1
16	^{35}K(p, γ)^{36}Ca	U	2.5	2
17	^{18}Ne(α, p)^{21}Na	D	2.3	2
18	^{25}Si(α, p)^{28}P	U	1.9	2
19	^{57}Cu(p, γ)^{58}Zn	D	1.7	2
20	^{34}Ar(α, p)^{37}K	U	1.6	3
21	^{24}Si(α, p)^{27}P	U	1.4	3
22	^{22}Mg(p, γ)^{23}Al	D	1.1	3
23	^{65}As(p, γ)^{66}Se	U	1.0	3
24	^{14}O(α, p)^{17}F	U	1.0	3
25	^{40}Sc(p, γ)^{41}Ti	D	0.9	3
26	^{34}Ar(p, γ)^{35}K	D	0.8	3
27	^{47}Mn(p, γ)^{48}Fe	D	0.8	3
28	^{39}Ca(p, γ)^{40}Sc	D	0.8	3

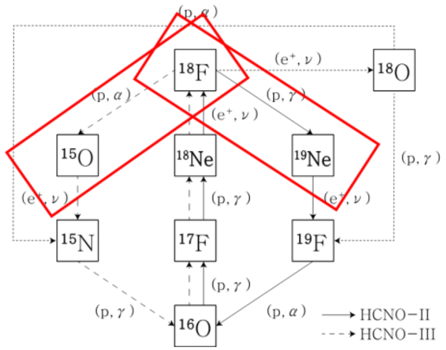
Rank	Reaction	Type[a]	Sensitivity[b]	Category
1	^{15}O(α, γ)^{19}Ne	D	16	1
2	^{56}Ni(α, p)^{59}Cu	U	6.4	1
3	^{59}Cu(p, γ)^{60}Zn	D	5.1	1
4	^{61}Ga(p, γ)^{62}Ge	D	3.7	1
5	^{22}Mg(α, p)^{25}Al	D	2.3	1
6	^{14}O(α, p)^{17}F	D	5.8	1
7	^{23}Al(p, γ)^{24}Si	D	4.6	1
8	^{18}Ne(α, p)^{21}Na	U	1.8	1
9	^{63}Ga(p, γ)^{64}Ge	D	1.4	2
10	^{19}F(p, α)^{16}O	U	1.3	2
11	^{12}C(α, γ)^{16}O	U	2.1	2
12	^{26}Si(α, p)^{29}P	U	1.8	2
13	^{17}F(α, p)^{20}Ne	U	3.5	2
14	^{24}Mg(α, γ)^{28}Si	U	1.2	2
15	^{57}Cu(p, γ)^{58}Zn	D	1.3	2
16	^{60}Zn(α, p)^{63}Ga	U	1.1	2
17	^{17}F(p, γ)^{18}Ne	U	1.7	2
18	^{40}Sc(p, γ)^{41}Ti	D	1.1	2
19	^{48}Cr(p, γ)^{49}Mn	D	1.2	2

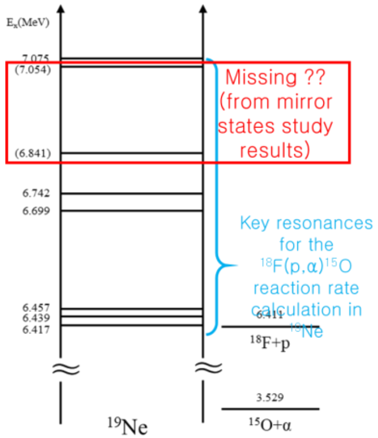
(Left) Calculated light curves of X-ray burst
(Middle) Reactions that impact the burst light curve in the single-zone X-ray burst model
(Right) Reactions that impact the burst light curve in the multi-zone X-ray burst model
R. H. Cyburt *et al.* ApJ 830:55 (2016)

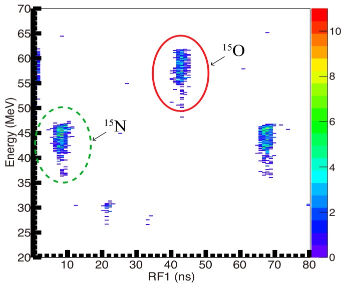
Indirect measurements of (*p,α*)/(*α,p*) reaction cross section

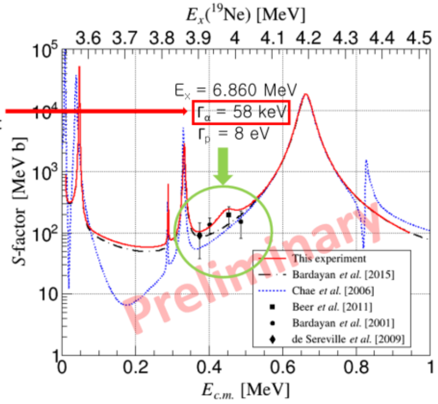
[^{15}O+α elastic resonance scattering]

D. Kim *et al.* PRL in preparation



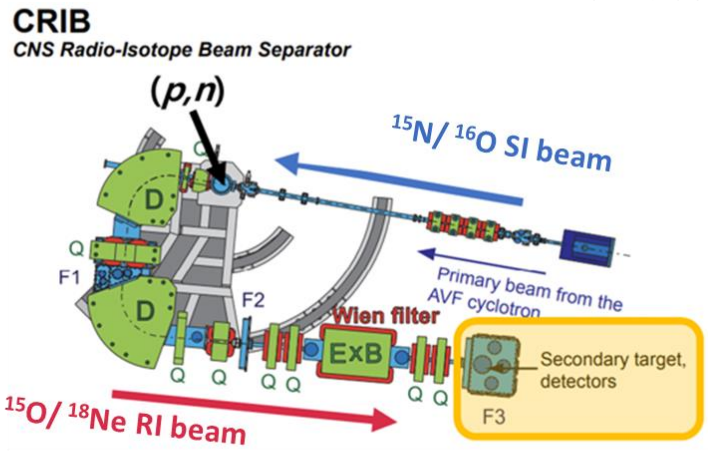






[^{18}Ne+α elastic resonance scattering]

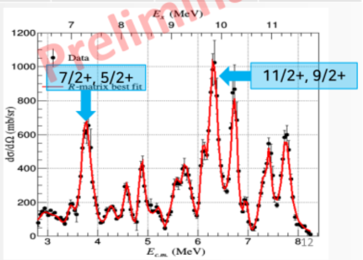
S.M. Cha *et al.* Front. Phys. 11 1163299 (2023)

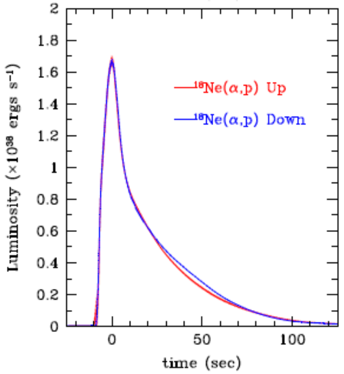


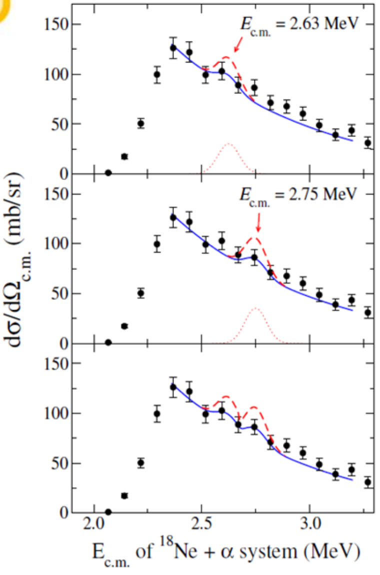
❖ Resonance parameters of alpha cluster state candidates from this experiment

(θ^2 > 0.1) : alpha cluster state

E_x	J^π	Γ_α (keV)	θ^2
7.320(8)	(7/2⁺)	130(3)	0.67
7.420(8)	(5/2⁺)	196(4)	0.89
9.830(8)	(11/2+)	120(3)	0.49
9.880(4)	(9/2+)	133(5)	0.53

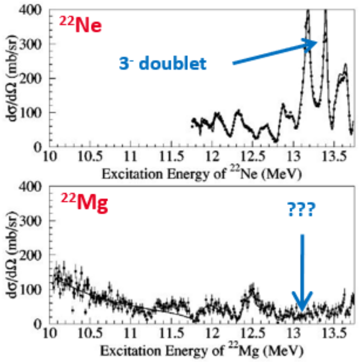


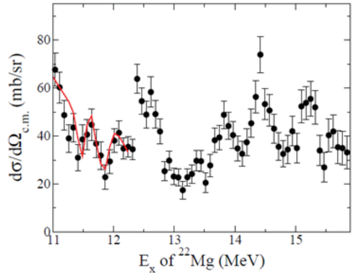




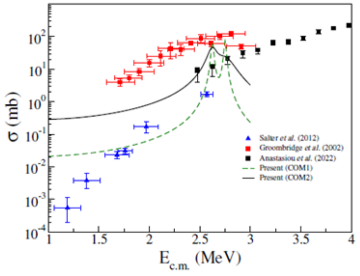
upper limit of the ^{18}Ne(*α,α*)^{18}Ne cross section

Goldberg et al., PRC 69, 024602 (2004)





Excitation function of ^{22}Mg



astrophysically-important ^{18}Ne(*α,p*)^{18}Ne cross section

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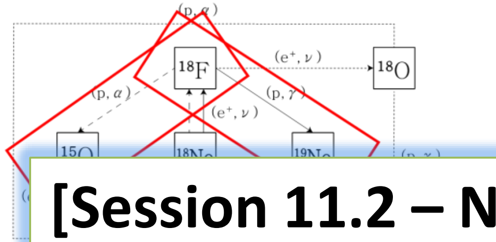
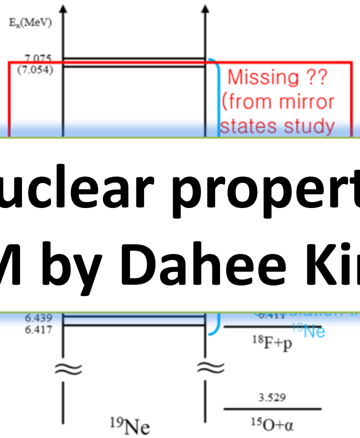
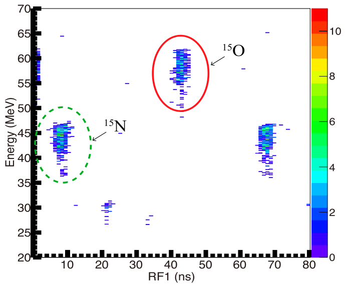
[^{15}O+α elastic resonance scattering]

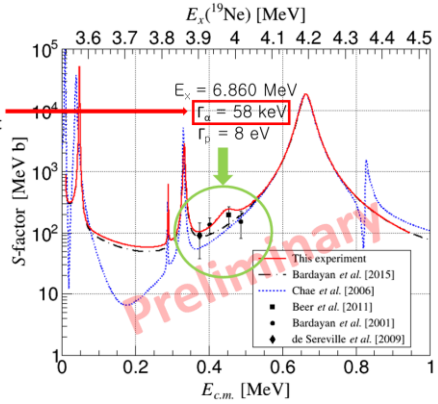
D. Kim *et al.* PRL in preparation





[Session 11.2 – Nuclear properties for astrophysics]
2:45 PM - 3:00 PM by Dahee Kim





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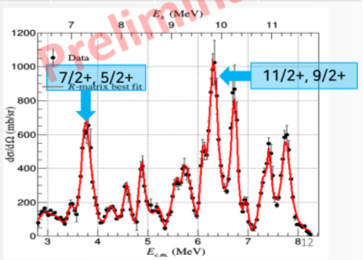
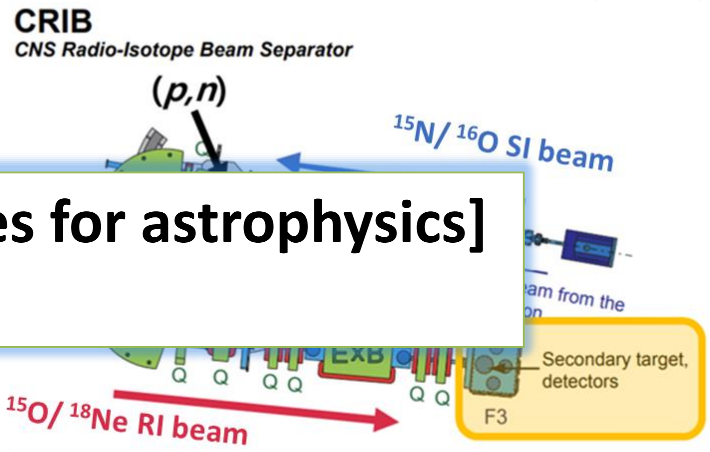
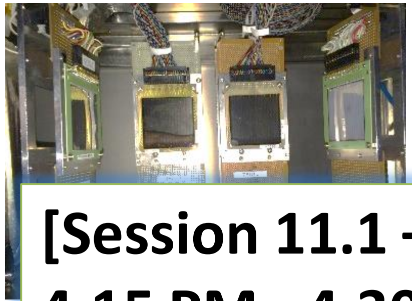
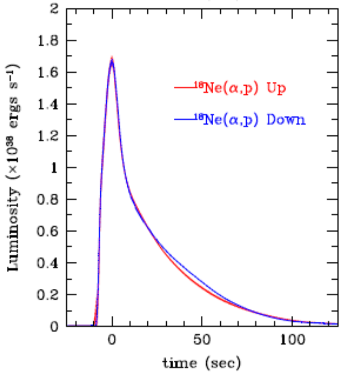


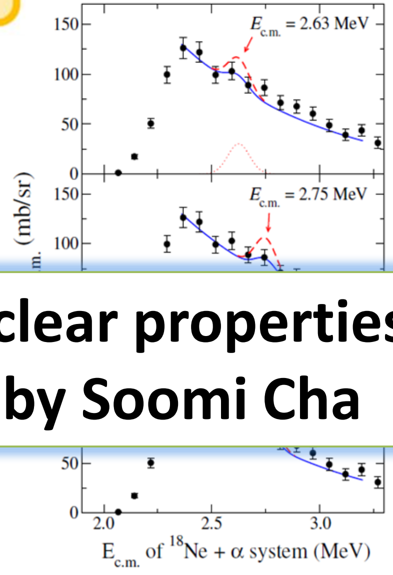




[^{18}Ne+α elastic resonance scattering]

S.M. Cha *et al.* Front. Phys. 11 1163299 (2023)





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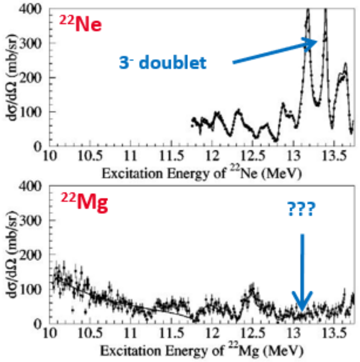
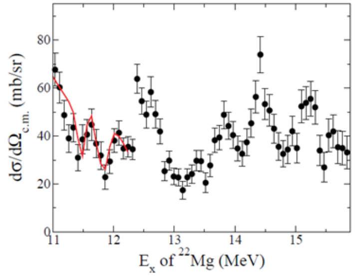
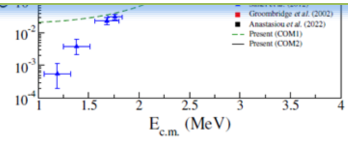




Excitation function of ^{22}Mg

[Session 11.1 – Nuclear properties for astrophysics]
4:15 PM - 4:30 PM by Soomi Cha



astrophysically-important ^{18}Ne(α,p)^{18}Ne cross section

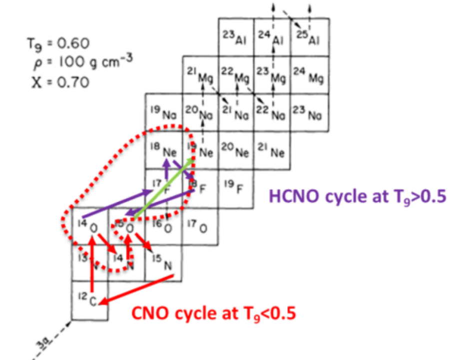
Direct measurement of $^{14}O(\alpha,p)^{17}F$ cross section at CRIB

- "A direct measurement of the $^{14}O(\alpha,p)^{17}F$ reaction with the Texas Active Target detector" approved by RIKEN PAC (2020)
- Beam time was very hard to get due to the Covid-19. We performed the experiment on Mar. 2023.

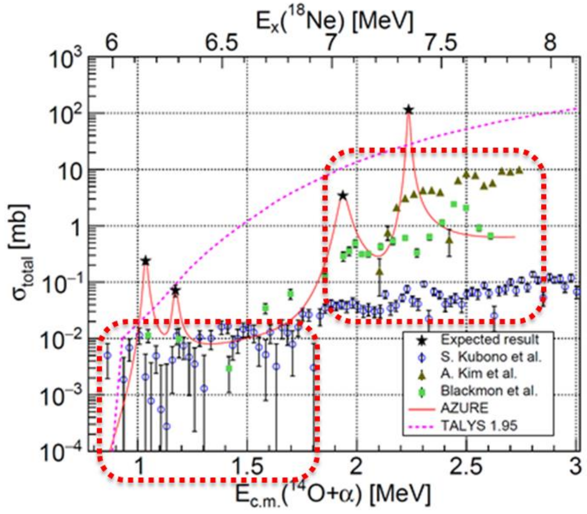
R. H. Cyburt *et al.* 2016

Rank	Reaction	Type	Sensitivity
1	$^{15}O(\alpha,\gamma)^{19}Ne$	D	16
2	$^{56}Ni(\alpha,p)^{59}Cu$	U	6.4
3	$^{59}Cu(p,\gamma)^{60}Zn$	D	5.1
4	$^{61}Ga(p,\gamma)^{62}Ge$	D	3.7
5	$^{22}Mg(\alpha,p)^{25}Al$	D	2.3
6	**$^{14}O(\alpha,p)^{17}F$**	D	5.8
7	$^{23}Al(p,\gamma)^{24}Si$	D	4.6
8	$^{18}Ne(\alpha,p)^{21}Na$	U	1.8
9	$^{63}Ga(p,\gamma)^{64}Ge$	D	1.4
10	$^{19}F(p,\alpha)^{16}O$	U	1.3

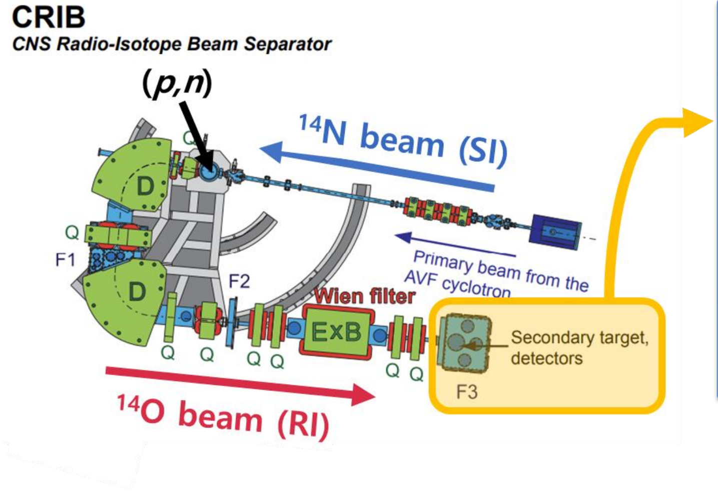
Reactions that impact the burst light curve in the multi-zone X-ray burst model

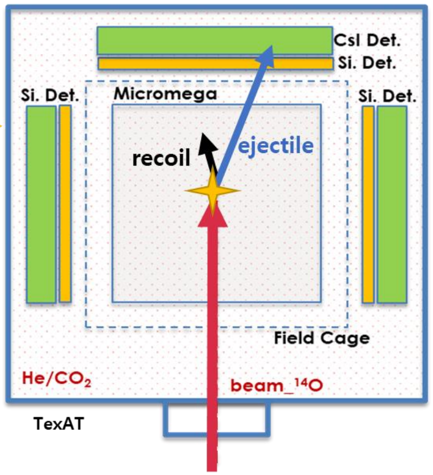


R. K. Wallace and S. E. Woosley, Astro. J. Suppl. Ser. 45, 389 (1981)

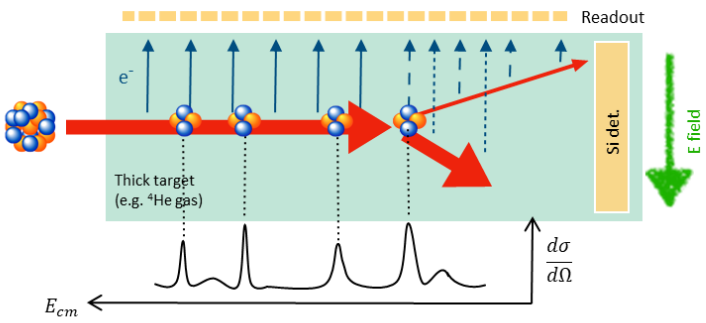


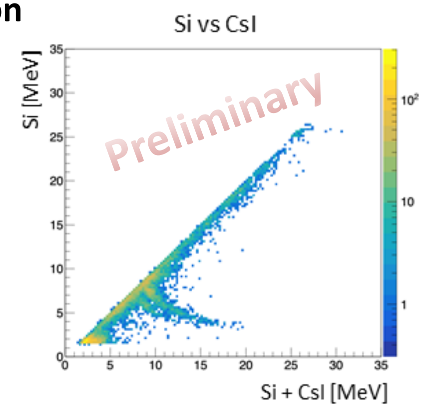
Previous measured data and calculated total cross sections of $^{14}O(\alpha,p)$ reaction

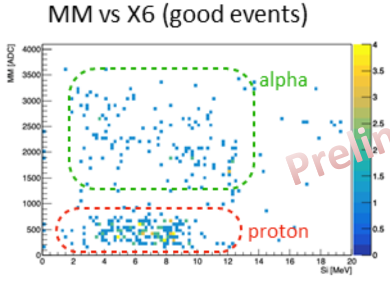


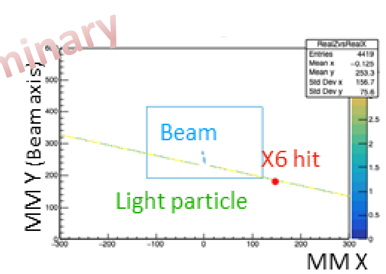


more than 40 participants!









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R. H. Cyburt *et al.* 2016

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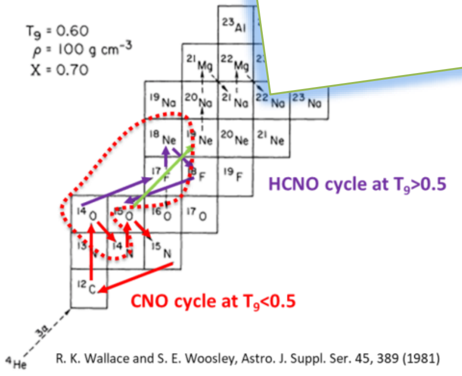
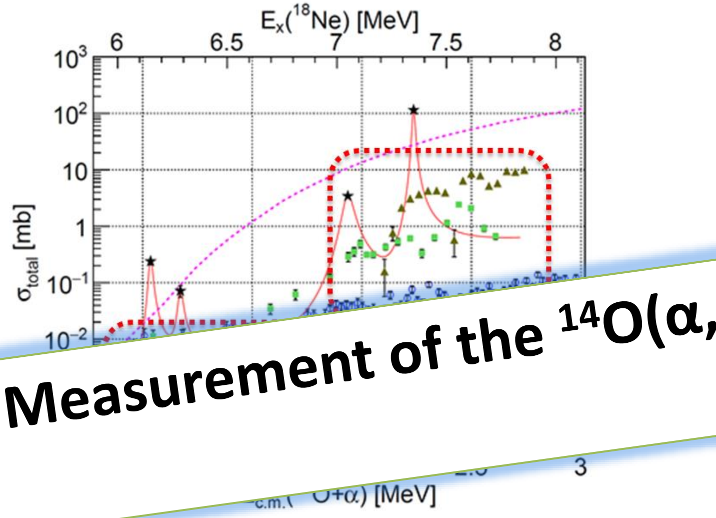
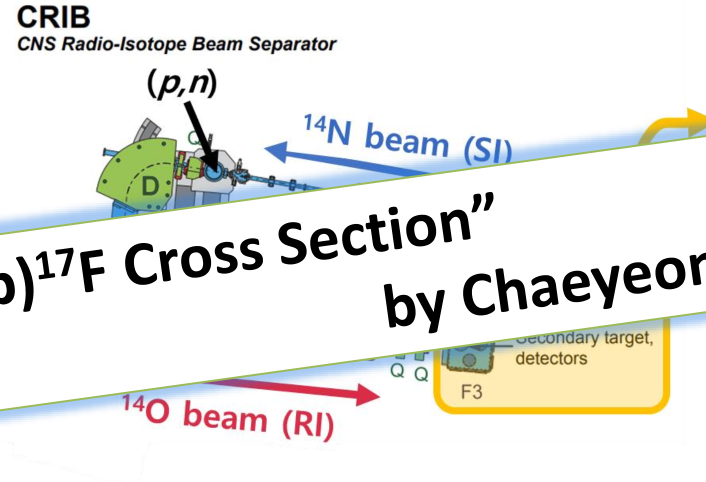


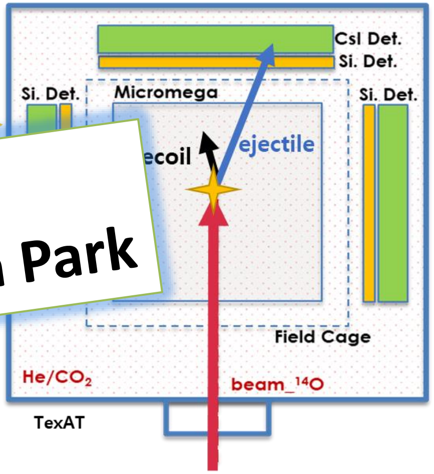
R. K. Wallace and S. E. Woosley, Astro. J. Suppl. Ser. 45, 389 (1981)



Previous measured data and calculated total cross sections of $^{14}O(\alpha,p)$ reaction

P-70 “Direct Measurement of the $^{14}O(\alpha,p)^{17}F$ Cross Section” by Chaeyeon Park





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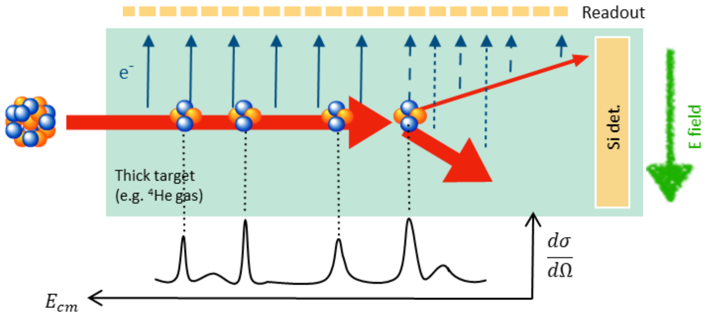
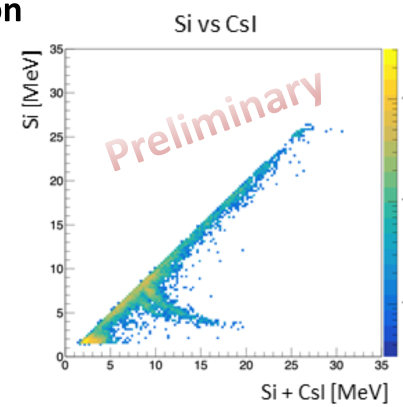
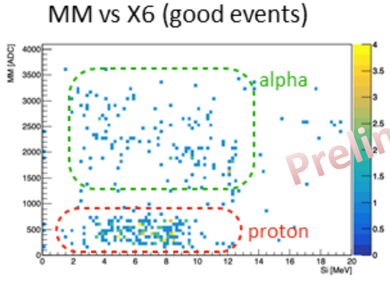
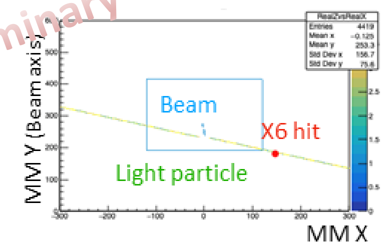


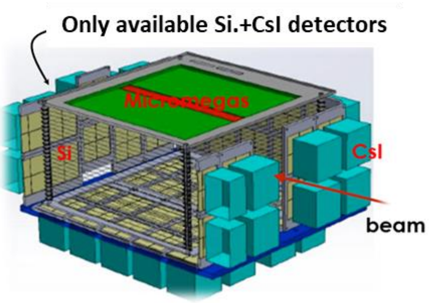


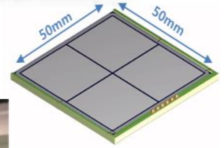




Development of TexAT_v2

- Goals: high beam rate (10^5 pps), large solid angle coverage, high energy and position resolution
- A new field cage built and tested at TAMU: PCB, 50μm tungsten wire and 100MΩ resistors
- High beam rate test: $^{14}N(\alpha,\alpha)$ data with 5×10^5 pps beams taken at TAMU





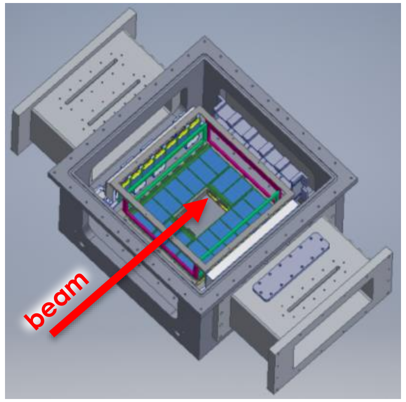
- ✓ E. Koshchiy *et al.*, NIMA **957** (2020) 163398.
- ✓ J. Bishop *et al.*, JPCS **1308** (2019) 012006.
- ✓ J. Hooker *et al.*, PRC **100** (2019) 054618.
- ✓ M. Barbui *et al.*, PRCI (2020).
- ✓ J. C. Zamora *et al.*, PLB **816** (2021) 136256.
- ✓ J. Bishop *et al.*, Nat.Commun. **13** (2022) 2151.
- ✓ J. Bishop *et al.*, PRC **102** (2020) 041303.
- ✓ J. Bishop *et al.*, PRC **103** (2021) L051303.

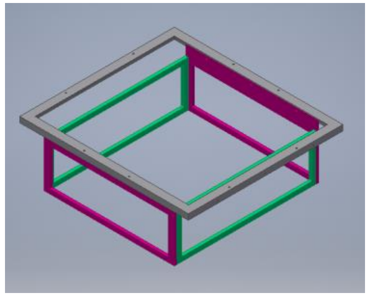
✓ Additional Si. Detectors

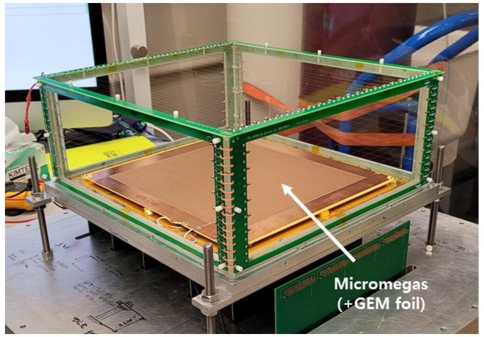
➔ Efficiency increased by a factor of 4.

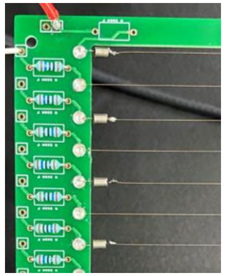
✓ CsI+PIN_diode replaced by CsI+MPPC

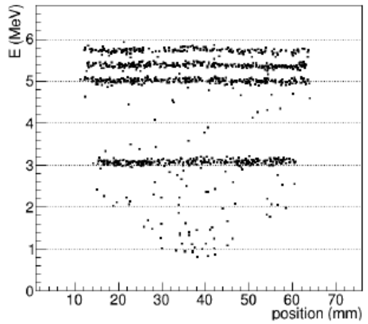
➔ enhanced energy resolution (6%).

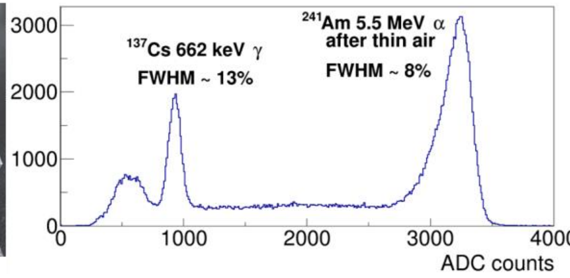












C. Park *et al.*, **541** NIMB (2023) 221.
D. Kim *et al.*, **540** NIMB (2023) 30.
X. Pereira-Lopez *et al.*, NIMB **541** (2023) 134.
S. Bae *et al.*, **541** NIMB (2023) 45.

CENS n*-explorer Project

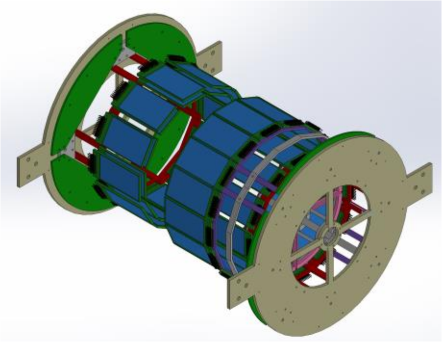
- **Objective:**
  1. **direct measurements of neutron transfer reaction cross sections which are important for i-process and r-process**
  2. **Mass measurement which are important for r-process**
  3. **Direct measurements of (α,n) reaction cross sections which are important for weak r-process**
- **Methods:**
  1. **(d,p) reaction in inverse kinematics using solid target with STARK or ORRUBA**
  2. **New mass measurement using Bρ Time-of-Flight method**
  3. **(α,n) Thick Target in Inverse Kinematics (TTIK) using MUSIC, neutron detector, SECAR or AToM-X**

- **Sensitivity Study #1. "r-process", AIP Advances 4, 041008 (2014) by R. Surman *et al.***
  - ✓ No studies for light particles (Z=30~40) yet.
  - ✓ (n,γ) reaction rates with stable beams near the interest region.
    - (d,p) or (d,pγ) reaction cross sectionss for (n,γ) reactions
    - (d,d) reactions for d-OMP studies
  - ✓ Masses around Z=30~40 and N=50~60
- **Sensitivity Study #2. "s-process reaction flow", Data Nucl. Data Tables, 108, 1 (2016) by A. Koloczek *et al.***
  - ✓ (d,p) or (d,pγ) reactions for (n,γ) reactions: ^{56}Fe, ^{58}Fe, ^{64}Ni and ^{22}Ne
- **Sensitivity Study #3. "i-process reaction flow", PhD. Thesis (2015) by Hampel *et al.***
  - ✓ (d,p) or (d,pγ) reactions for (n,γ) reactions: ^{31}Si, ^{32}Si , ^{34}S, ^{45}Ca and ^{47}Ca

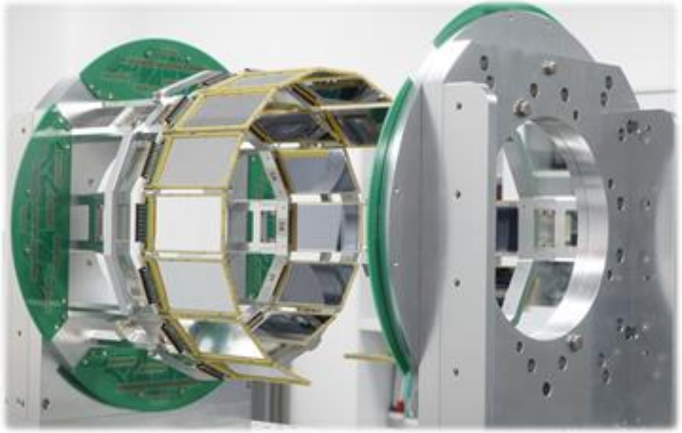
Development of STARK silicon detector array

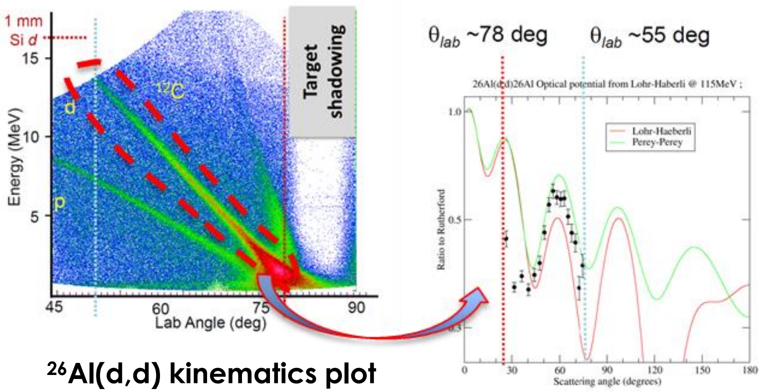
- **STARK: Silicon Telescope Array for Reactions in inverse Kinematics**
- **Three rings with 12-16-12 polygons. 96-116-107 mm from the center of the target**
- **Scattering chamber: 580(X) x 400(Y) x 600(Z) mm3**
- **CryoSTAR compatible**
- **To do: Vacuum test and Commissioning**

→ (α,p) *reaction studies, transfer reaction studies, OMP studies*

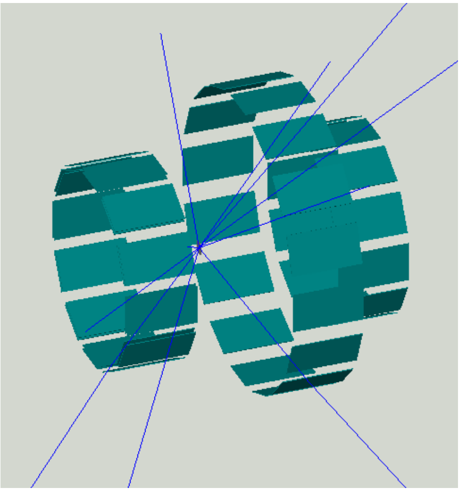


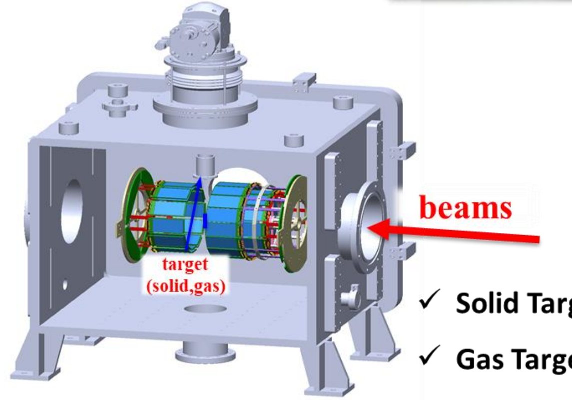
Conceptual Design of STARK





^{26}Al(d,d) kinematics plot

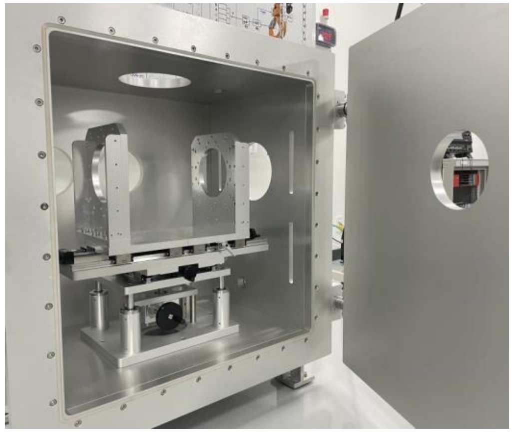




✓ Solid Targets: CH_2, CD_2

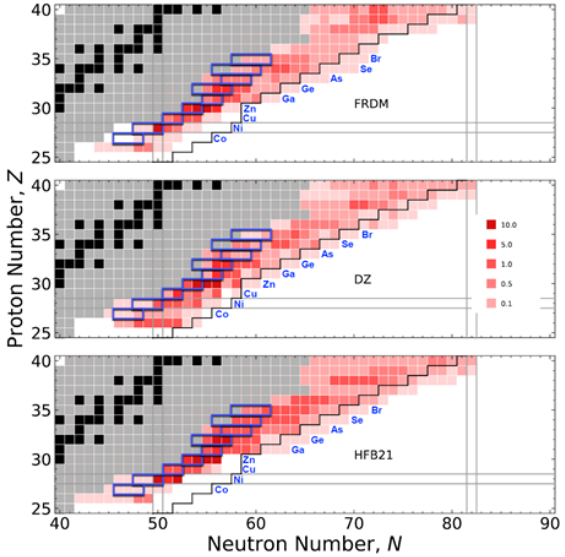
✓ Gas Targets: H_2, D_2, ^4He, ^3He, N_2

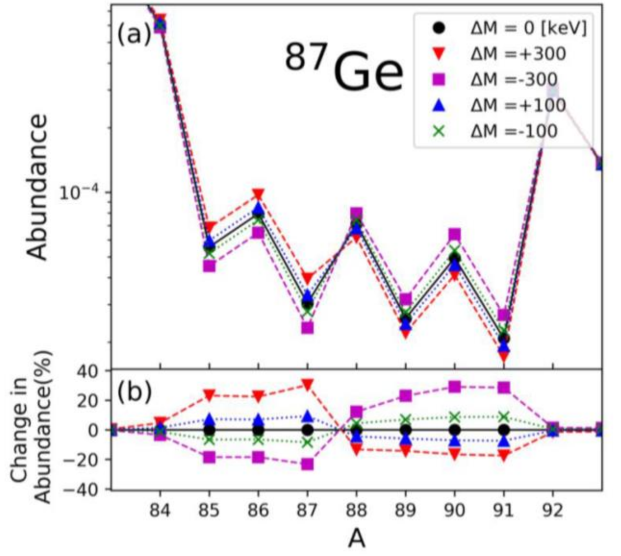
Conceptual Design of STARK chamber

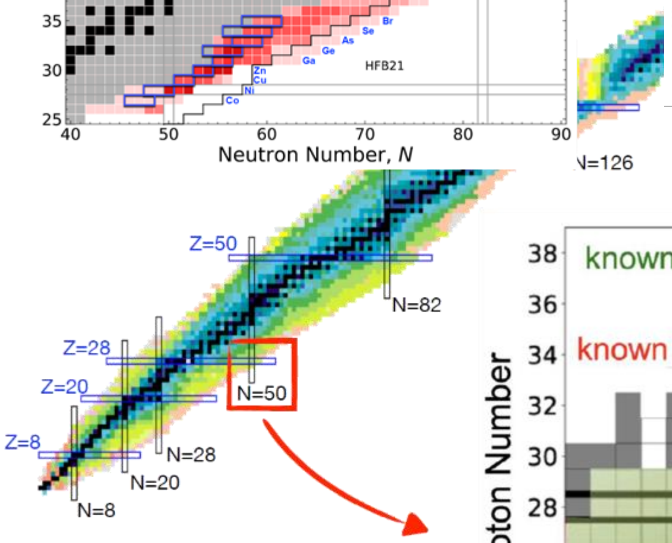


Bρ-Time_of_Flight Mass Measurements at FRIB

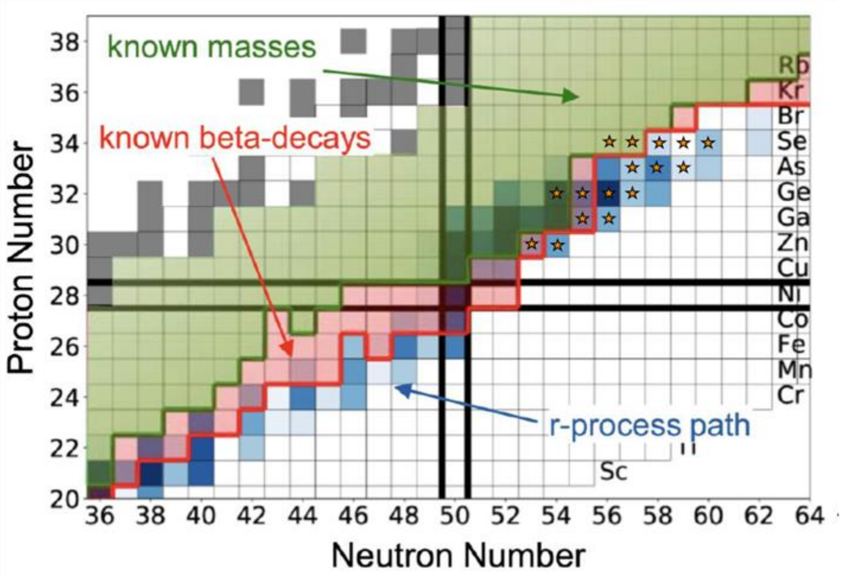
Nuclei that significantly impact final r-process abundances
Mumpower *et al.* (2016)

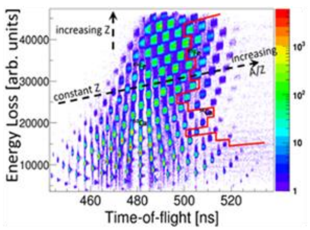


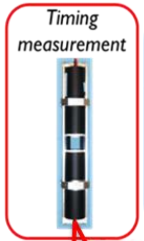


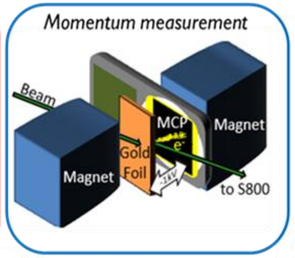


Proposed by Z. Korkulu





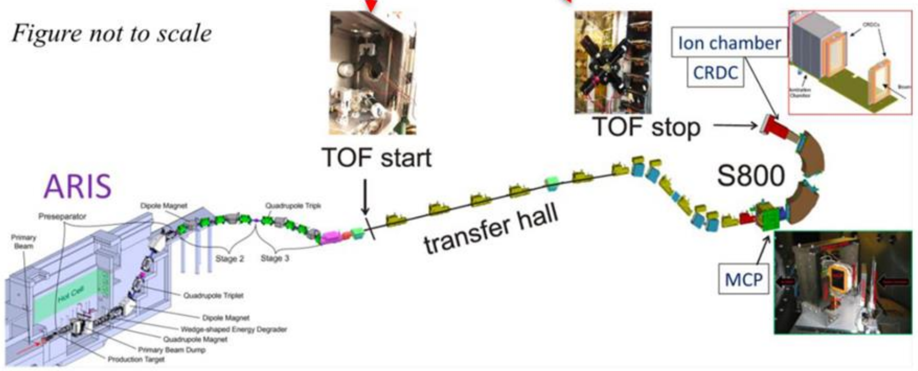




$$m_0 = \frac{(\mathrm{TOF})B\rho}{\gamma L_{\mathrm{path}}}$$

$\rightarrow m_0 = f(A, Z, \mathrm{TOF})$

Length: 60 m
Timing: 80 ps
Tracking: 0.3 mm
→ 1.8×10^{-4} resolution
→ ~100 keV systematic error



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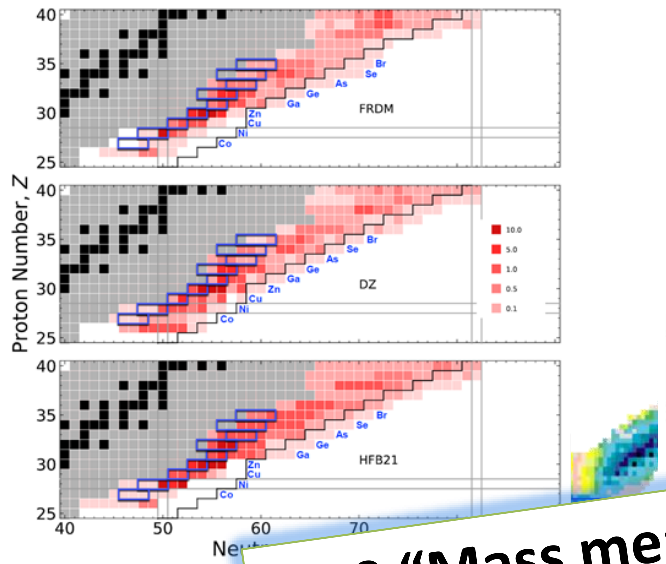

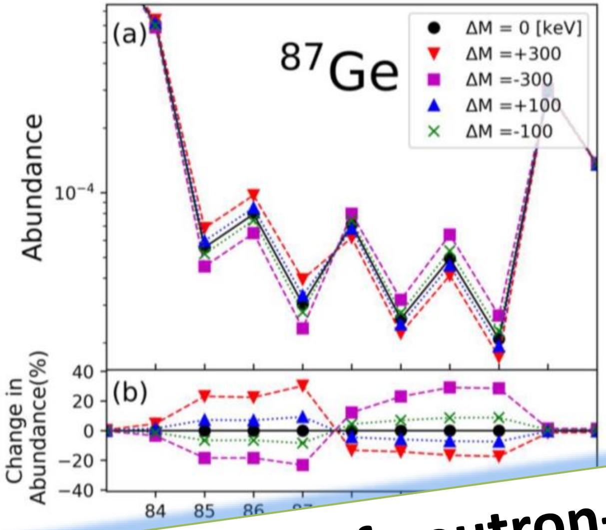

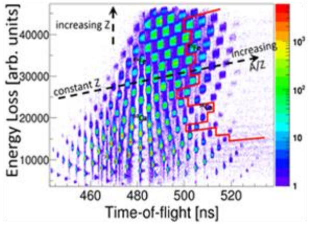

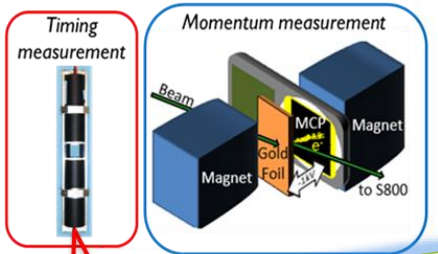

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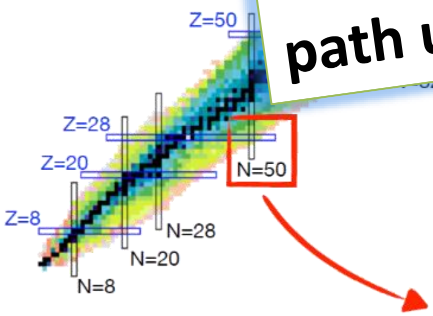
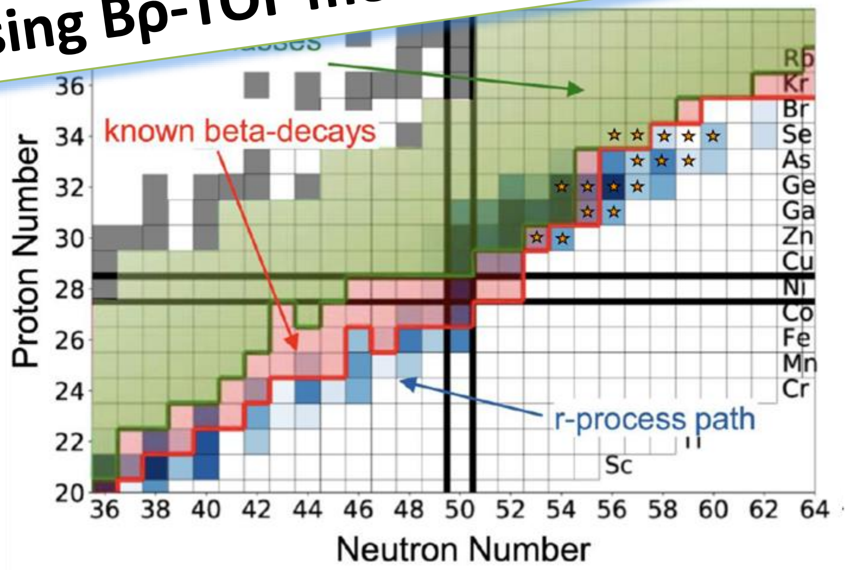
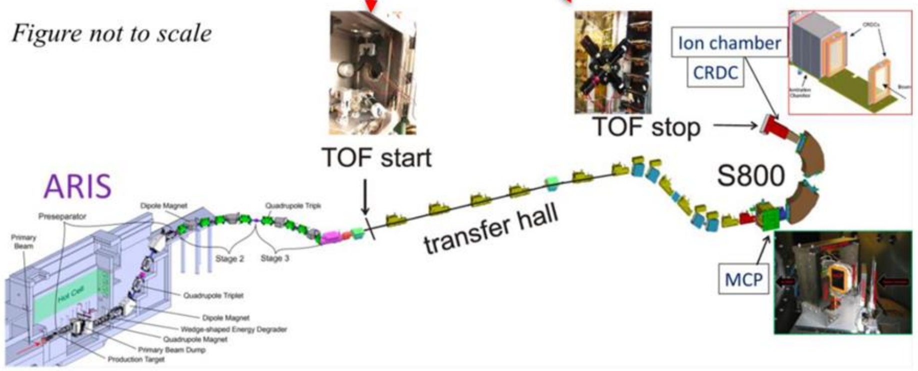
P-60 "Mass measurements of neutron-rich nuclei along the r-process path using Bρ-TOF method" by Zeren Korkulu



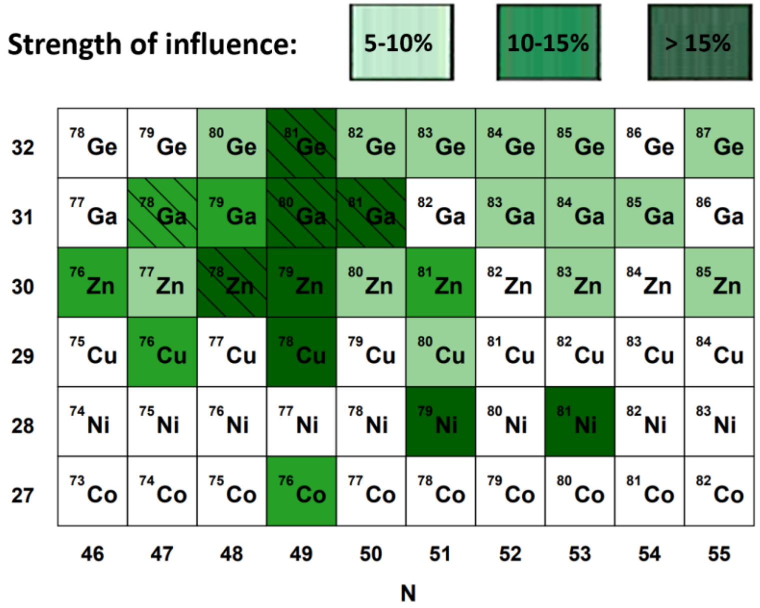


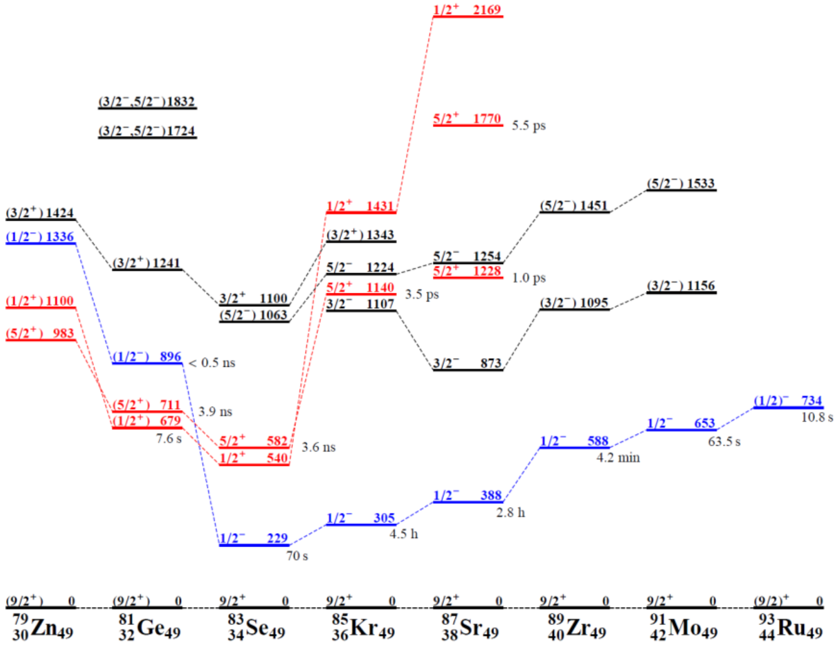


Spectroscopic properties of low-lying states using IDATEN

IDATEN: International Detector Assembly for fast-Timing measurements of Exotic Nuclei

- Array of 84 $LaBr_3$(Ce) detectors
- Collaboration among FATIMA (36), KHALA (36) and SNU (12)
- Construction Proposal approved by RIKEN RIBF PAC22 (2021)
- 3 IDATEN proposals accepted in RIKEN RIBF PAC23 (2022)
- Electronics system development in progress (2023)
- Commissioning experiment planned on 2024

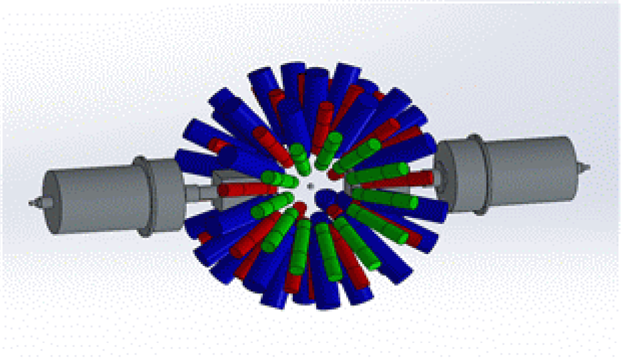




FATIMA

KHALA

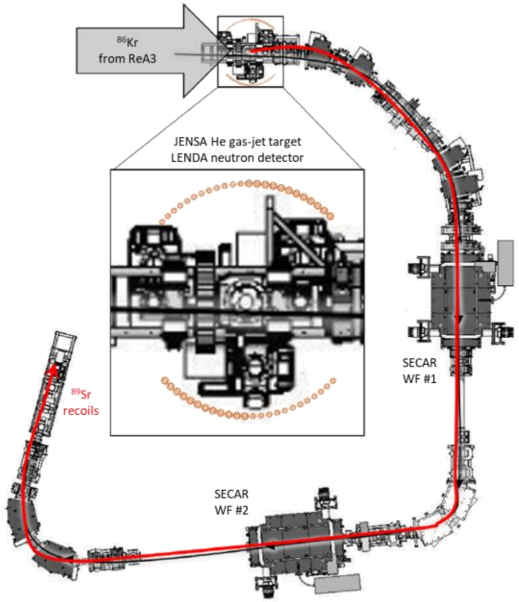
SNU $LaBr_3$(Ce)



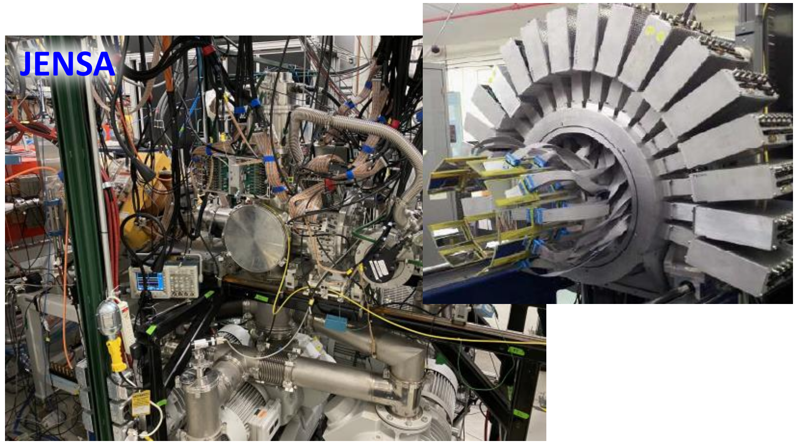
IDATEN Conceptual Design

Research Collaborations at FRIB

- **^{86}Kr(α,xn) cross sections measurement using SECAR at FRIB**
  - Title: "(α,xn) Cross sections for neutrino driven wind nucleosynthesis using SECAR"
- **First JENSA RIB measurement of an X-ray-burst (α,p) cross section close to the Gamow peak at FRIB: ^{26}Al(α,p) ^{29}Si**
  - JENSA gas-jet target and the superORRUBA silicon detector array
- **^{86}Kr(α,n) reaction in the weak r-process using MUSIC and LENDA**
  - Key reaction related to the weak r-process
- **^{20}Mg(βpα)^{15}O reaction measurement using GADGET-II**
  - sensitivity of astrophysical models to the ^{15}O(α,ɣ)^{19}Ne reaction rate.



SECAR beamline



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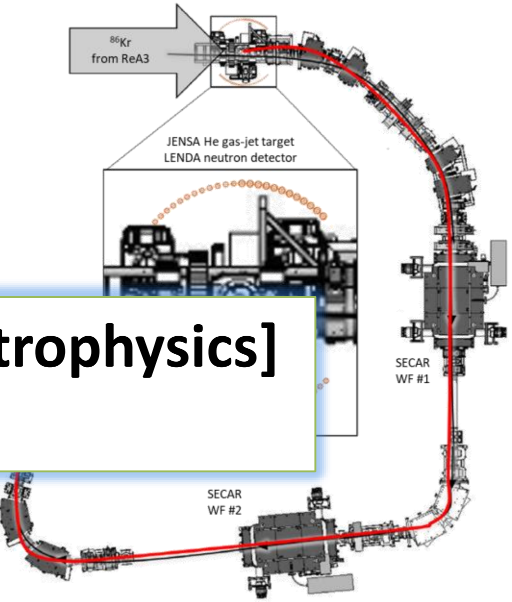
- **First JENSA RIB measurement of an X-ray-burst (α,p) cross section close to the Gamow peak at FRIB: ^{26}Al(α,p) ^{29}Si**
  - JENSA gas-jet target and the superOR
- **^{86}Kr(α,n) reaction in the weak r-process using MUSIC and LENDA**
  - Key reaction related to the weak r-process
- **^{20}Mg(βpα)^{15}O reaction measurement using GADGET-II**
  -

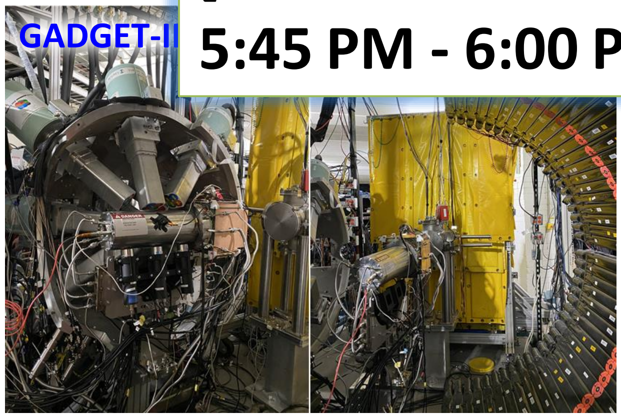
[Session 11.2 – Nuclear properties for astrophysics]
2:00 PM - 2:30 PM by Kelly Chipps

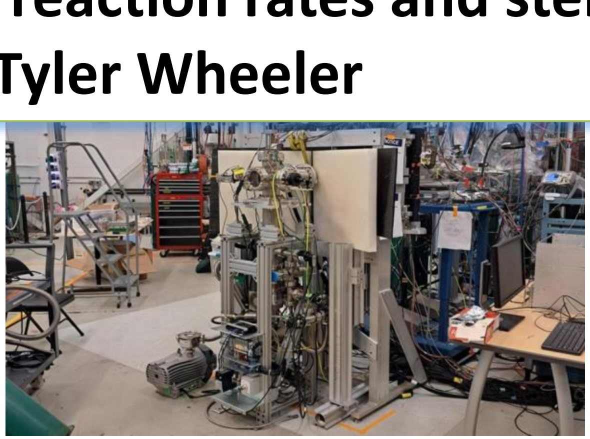


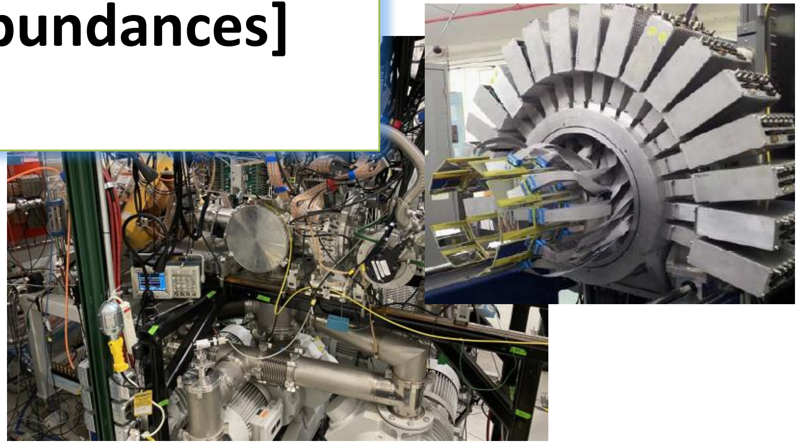
SECAR beamline

[Session 3.1 – Nuclear reaction rates and stellar abundances]
5:45 PM - 6:00 PM by Tyler Wheeler

GADGET-II

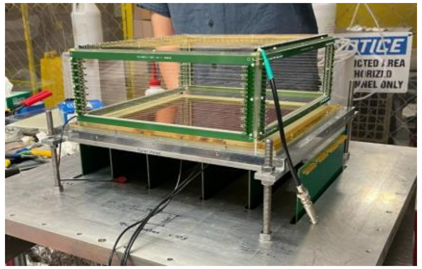
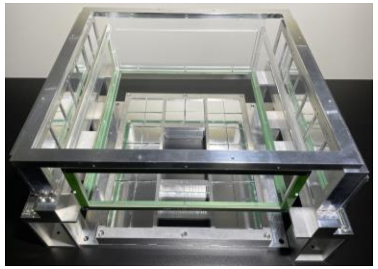
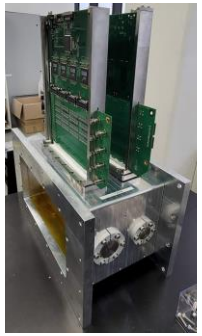
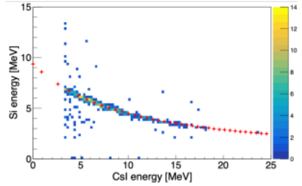


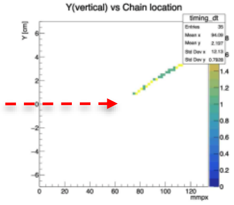




Research Collaborations at Texas A&M

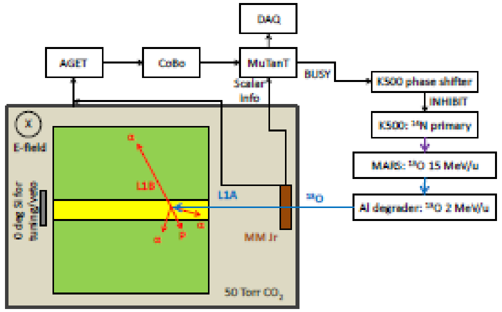
- **TexAT_v2 commissioning experiment using $^{14}N/^{14}O$ beam** C. Park *et al.*, **541** NIMB (2023) 221.
  - ✓ TexAT Upgrade (TexAT_v2)
  - ✓ High beam rate test with the new field cage

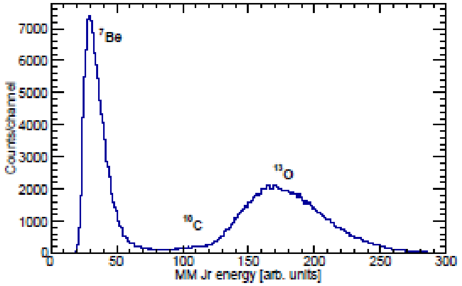





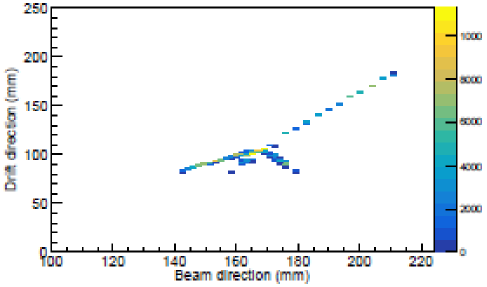


- **beta-delayed charged particle spectroscopy of ^{13}O**
  - ✓ 3α+p events from the decay of excited states in $^{13}N^*$

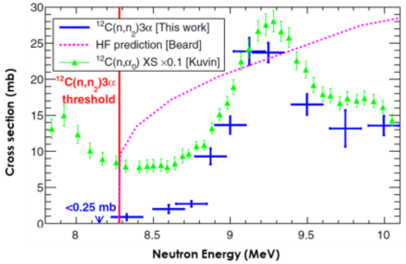
J. Bishop *et al.* PRL **130** (2023) 222501

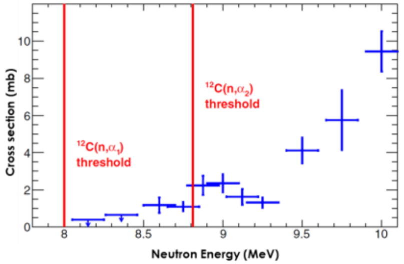






- **Enhancements from neutron/proton Upscattering**
  - ✓ The measured cross sections are significantly suppressed near the threshold in comparison to HF predictions.





J. Bishop *et al.*, Nat.Commun. **13** (2022) 2151.

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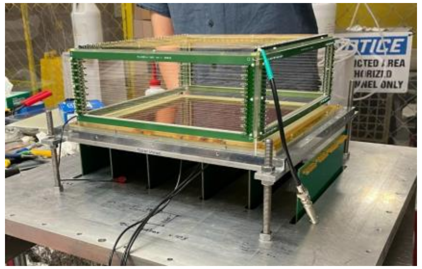
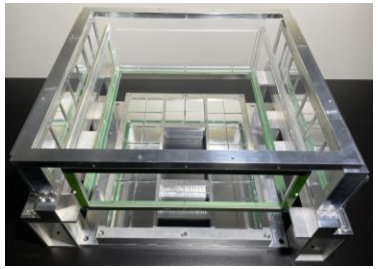
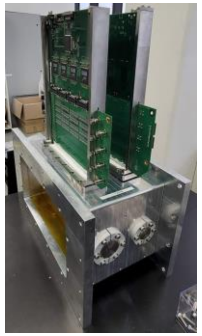
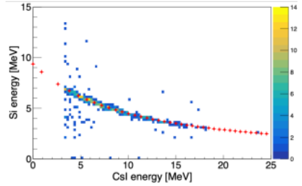
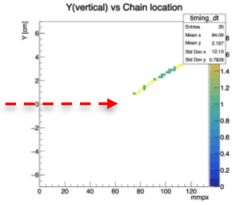
C. Park *et al.*, **541** NIMB (2023) 221.



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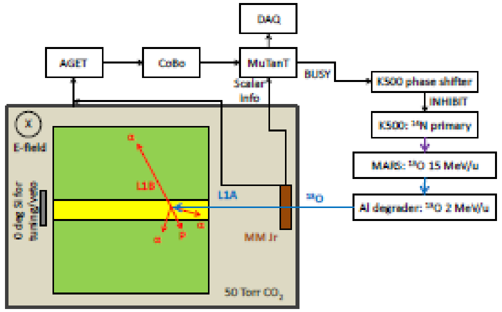
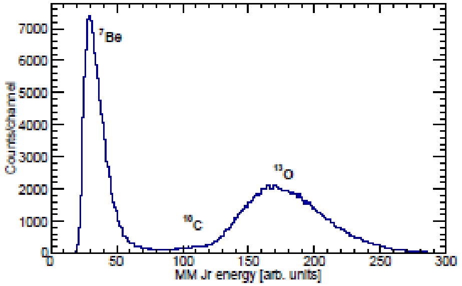
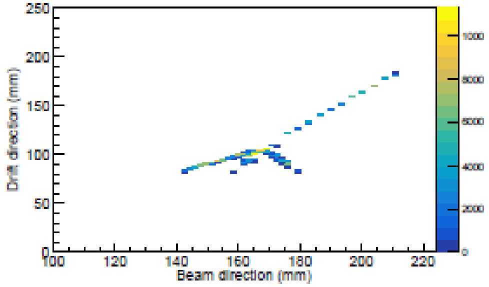
J. Bishop *et al.* PRL **130** (2023) 222501







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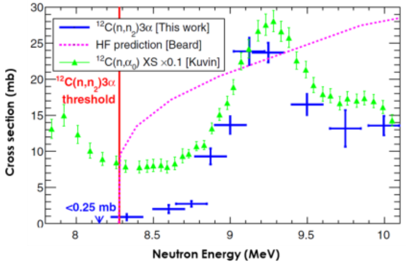
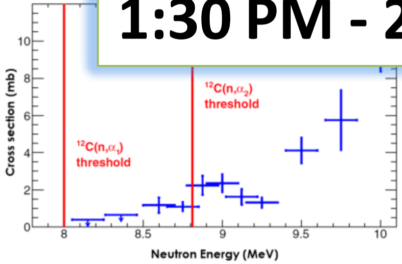
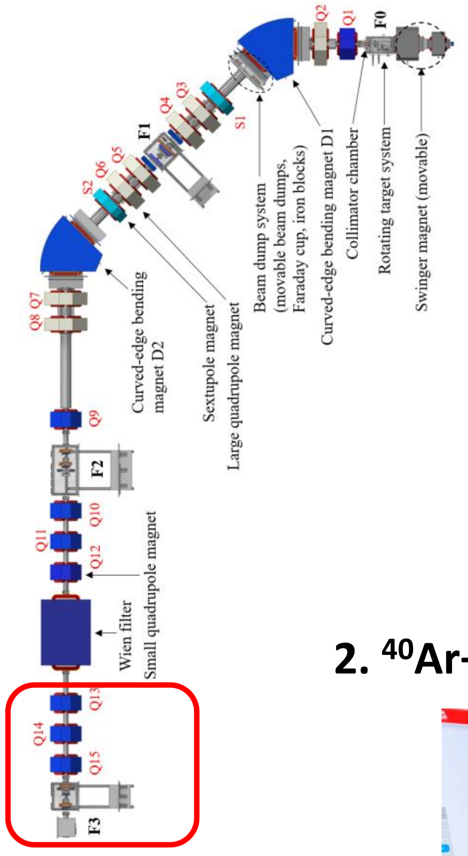
[Session 11.2 – Nuclear properties for astrophysics]
1:30 PM - 2:00 PM by Grigory Rogachev

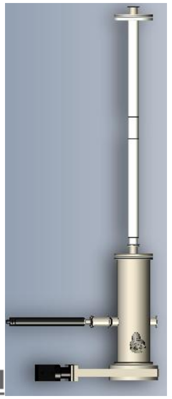




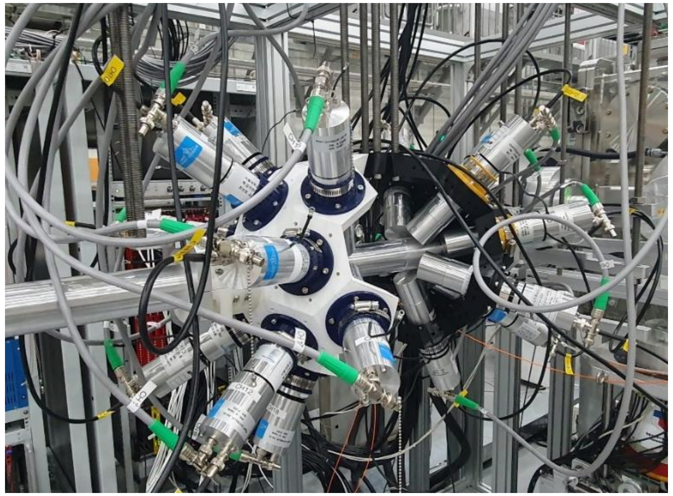
J. Bishop *et al.*, Nat.Commun. **13** (2022) 2151.

Research Collaborations with IRIS, IBS

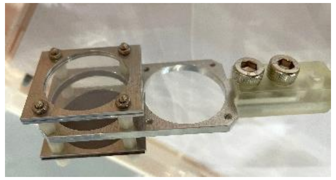




1. Fast-timing measurement with $LaBr_3$ detectors

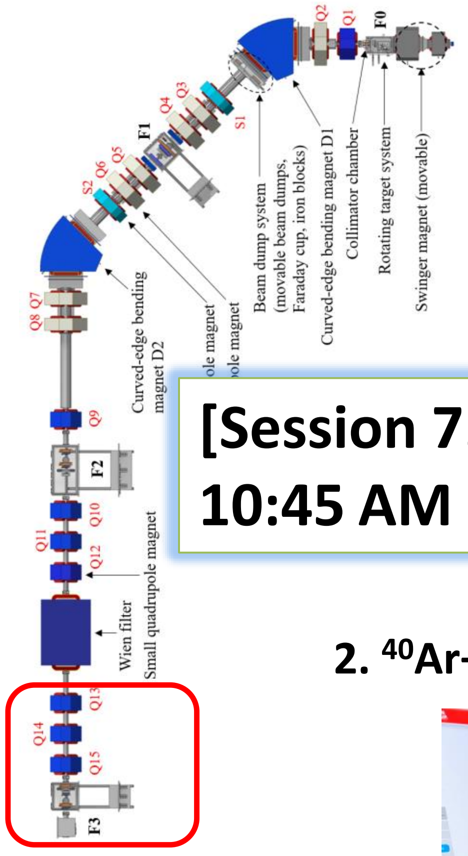


2. ^{40}Ar+p and ^{40}Ar+d elastic scattering studies



3. Activation method method in inverse kinematics for astrophysical studies with ^{39}Cl

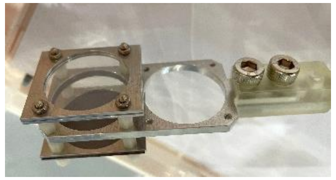
Research Collaborations with IRIS, IBS



1. Fast-timing measurement with $LaBr_3$ detectors

[Session 7.2 – New facilities, instruments and tools]
10:45 AM - 11:15 AM by Taeksu Shin

2. ^{40}Ar+p and ^{40}Ar+d elastic scattering studies



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Summary

- Center for Exotic Nuclear Studies performs RI beam nuclear physics.

"To study properties of exotic nuclei and origin of heavy elements in the universe."

- Nuclear Physics inputs play an important role in nucleosynthesis calculation results.
- Recent sensitivity studies show large uncertainties on the nuclear properties of unstable nuclei.

➔ **Experimental measurements with rare isotopes are very critical to reduce them.**

- **Key experimental studies can be performed with RI beams at RIKEN, FRIB and RAON:**
  1. **CENS αp-explorer**
     - ✓ Direct (α,p) cross section measurements related to *αp*-process: (α,p) with ^{14}O, ^{22}Mg, ^{18}Ne, ^{21}Na, ^{17}F beams
     - ✓ Direct measurement of ^{14}O$(\alpha,p)^{17}$F cross section at CRIB
     - ✓ Experiments at RI facilities using AToM-X, STARK with CryoSTAR
  2. **CENS n*-explorer Project**
     - ✓ Nuclear structures related to neutron capture reaction rates in *s,i,r*-process: e.g. (d,d), (d,p) or $(d,p\gamma)$ wt ^{32}Si, ^{34}Si, ^{32}Mg, ^{28}O beams for *i-process*
     - ✓ Bρ-ToF mass measurements related to r-process: nuclear mass around Z=30~40 and N=50~60
     - ✓ Direct measurements of (α,n) reaction cross sections which are important for weak r-process e.g. (α,n) wt ^{75}Ga, ^{85}Br, ^{84}Se, ^{87}Kr beams using MUSIC, neutron detector, SECAR or AToM-X

- New major horses for nuclear astrophysics studies: **TexAT_v2, AToM-X, CryoSTAR, KoBRA Wien Filter, STARK, ASGARD and IDATEN**.

- Future plan:
  - ✓ **To complete missions of CENS αp-explorer and CENS n*-explorer**
  - ✓ **To build up a interdisciplinary community among nuclear physics, astrophysics and astronomy.**
  - ✓ **To perform many nuclear astrophysics studies using RAON facility.**


Thank you for your attention!