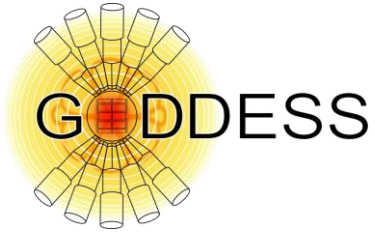


ORNL Instrumentation Development for Astrophysics Measurements

Matthew Hall
ATLAS Workshop
7/13/19

Outline

- ^{3}He beam experiments with GODDESS
  - Previous experiments
    - ^{19}F(^{3}He,t)^{19}Ne
    - ^{40}Ca(^{3}He,α)^{39}Ca
- (α,p) reactions with gas jets
  - Previous measurements with JENSA
  - SOLSTISE for HELIOS and SOLARIS

Recipe for Reaction Rate Calculations

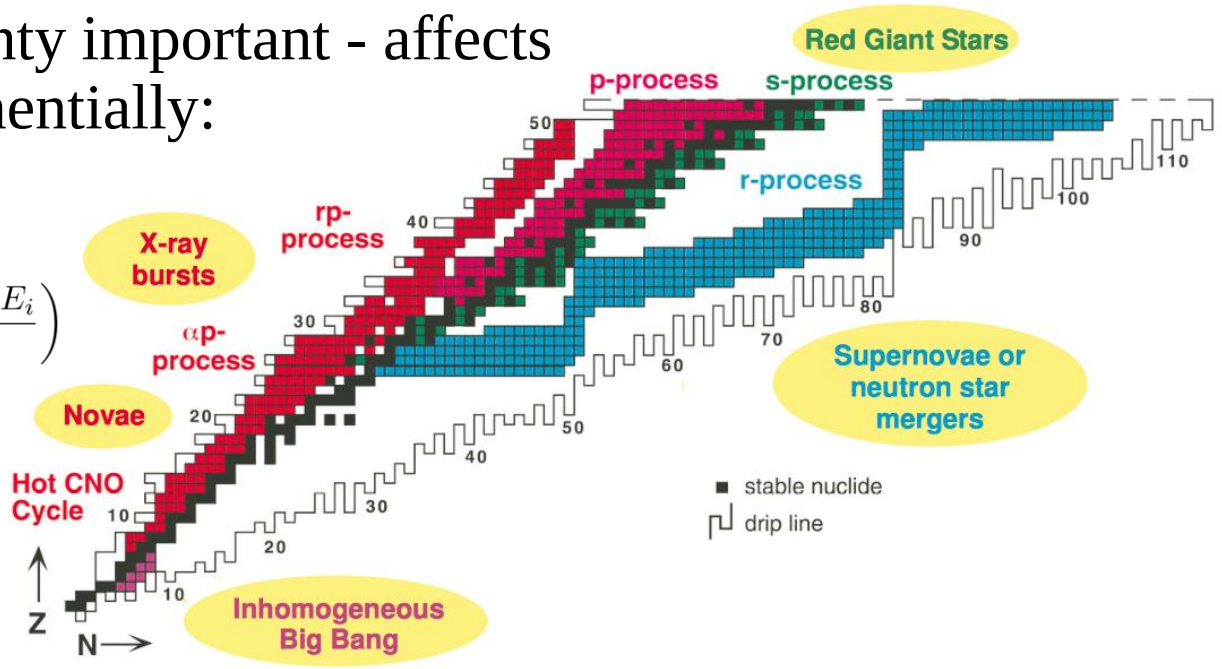
OAK RIDGE National Laboratory

- Resonance Strengths
  - Typically need one of Γ_p, Γ_α, Γ_γ
  - Need J^π of excited states in compound nucleus

- Excitation energies
  - Reducing uncertainty important - affects reaction rate exponentially:

$$N_A\langle\sigma v\rangle_r = \frac{1.5399\times10^{11}}{T_9^{3/2}}\left(\frac{M_0+M_1}{M_0M_1}\right)^{3/2} \times\sum_i(\omega\gamma)_i\exp\left(\frac{-11.605E_i}{T_9}\right)$$

- Interference?



D. W. Bardayan 2016 *J. Phys. G: Nucl. Part. Phys.* **43** 043001

Recipe for Reaction Rate Calculations

OAK RIDGE National Laboratory

- Resonance Strengths
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Many of these can be measured with GODDESS

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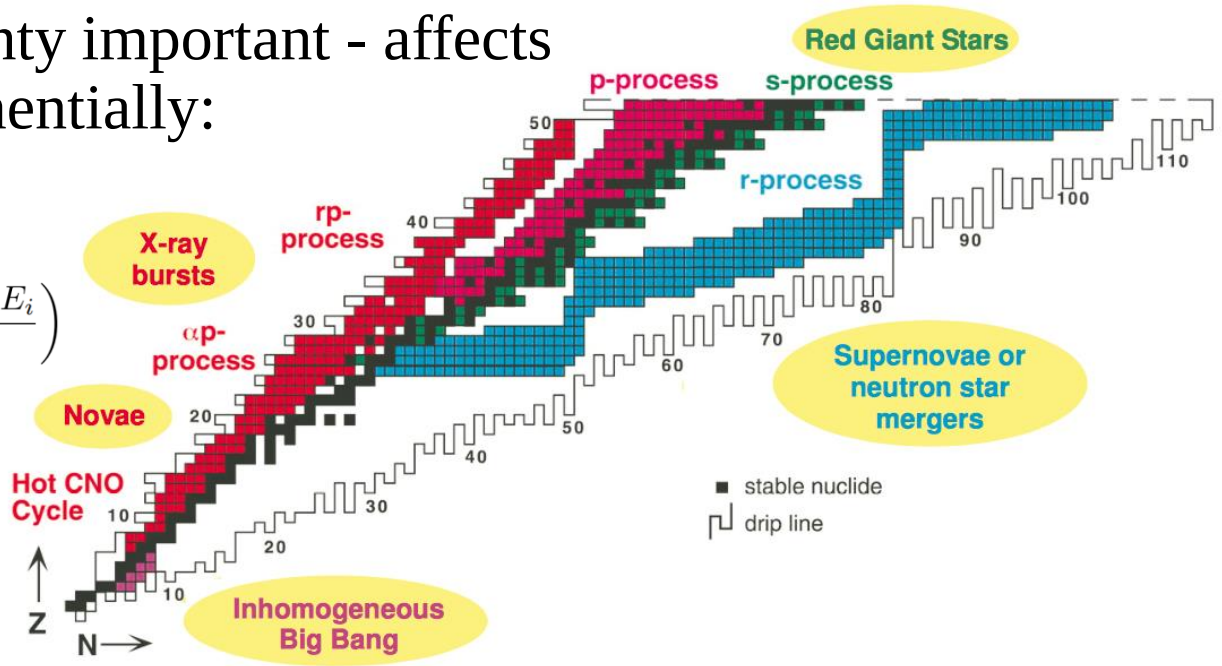

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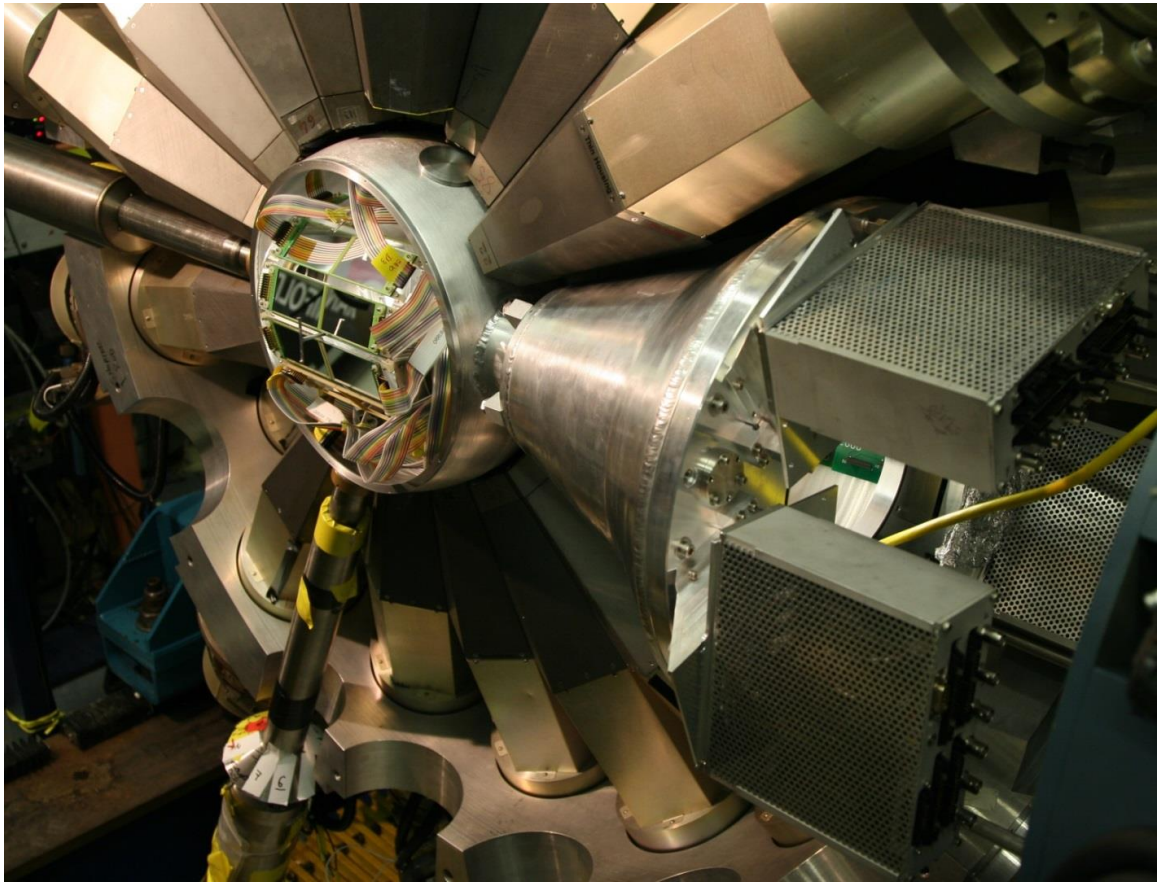
GODDESS Summary

- ORRUBA + Gretina/Gammasphere

- Previous Experiments:
  (Gammasphere)
  - ^{95}Mo(d,p)^{96}Mo
  - ^{134}Xe(d,p)^{135}Xe
  - **^{19}F(^{3}He,t) / ^{40}Ca(^{3}He,α)**

  (Gretina)
  - ^{56}Fe(p,p')
  - ^{30}P(d,p)^{31}P
  - ^{134}Te(d,p)^{135}Te



^{3}He Beams with GODDESS

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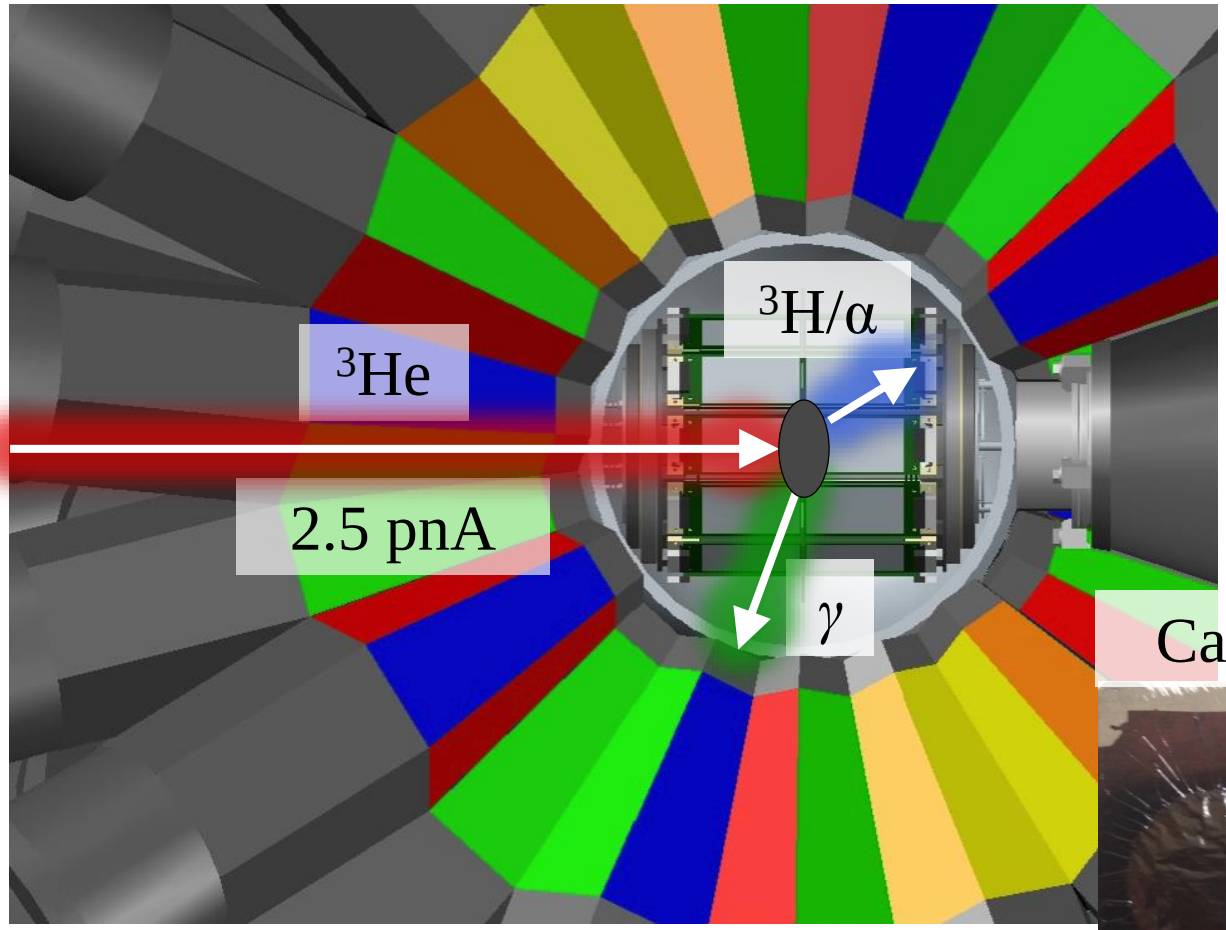

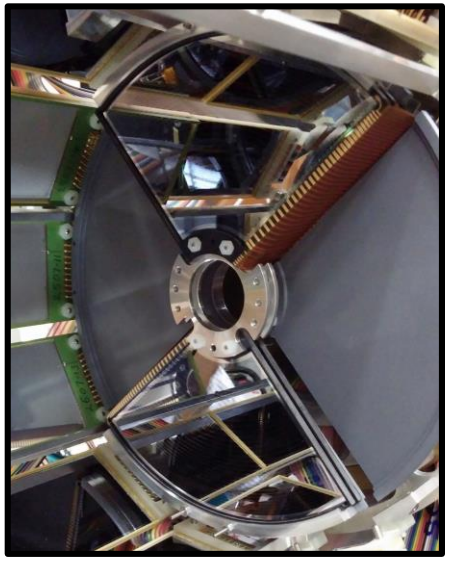

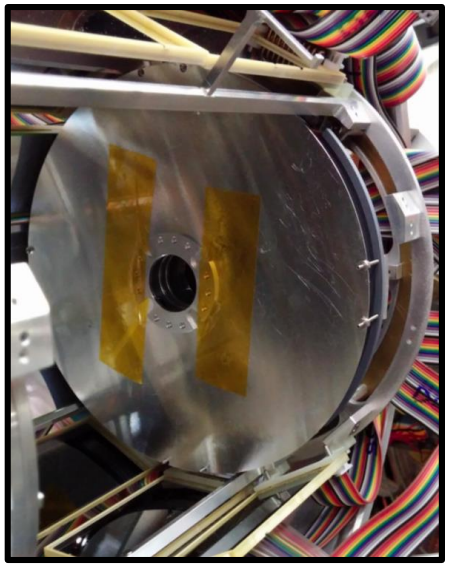

Adapted from A. Ratkiewicz *et al.* AIP Conf. Proc. 1525, 487 (2013).

$^{19}F(^3He,t)^{19}Ne$ for $^{18}F(p,\alpha)^{15}O$

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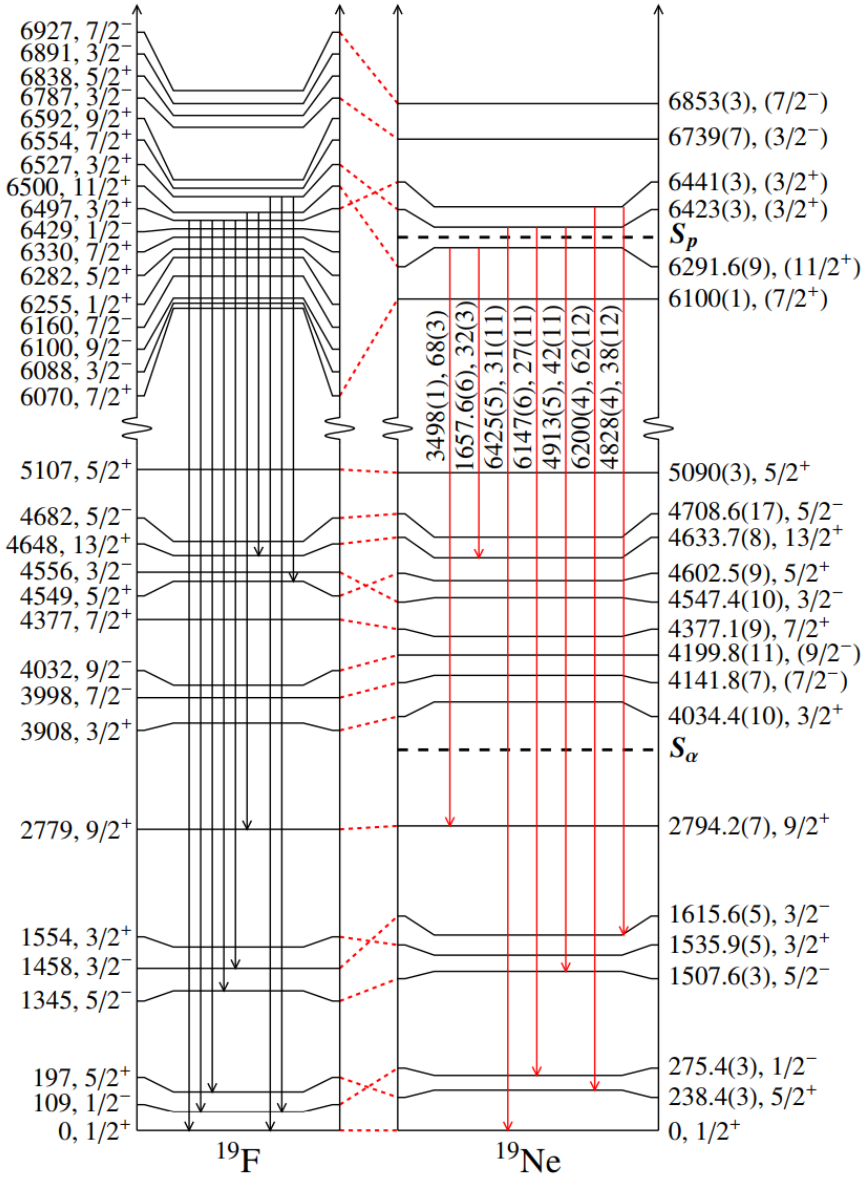
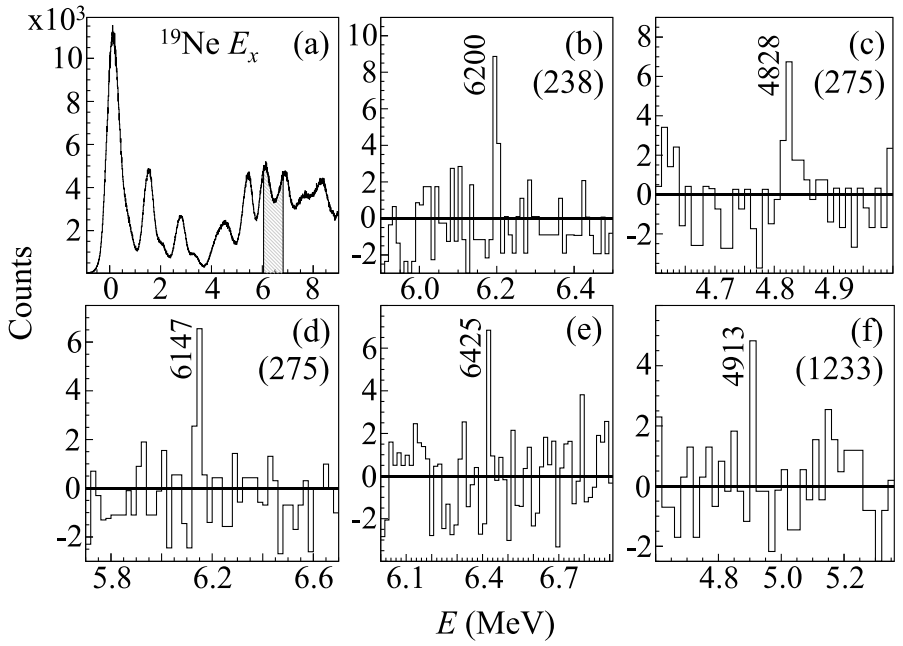


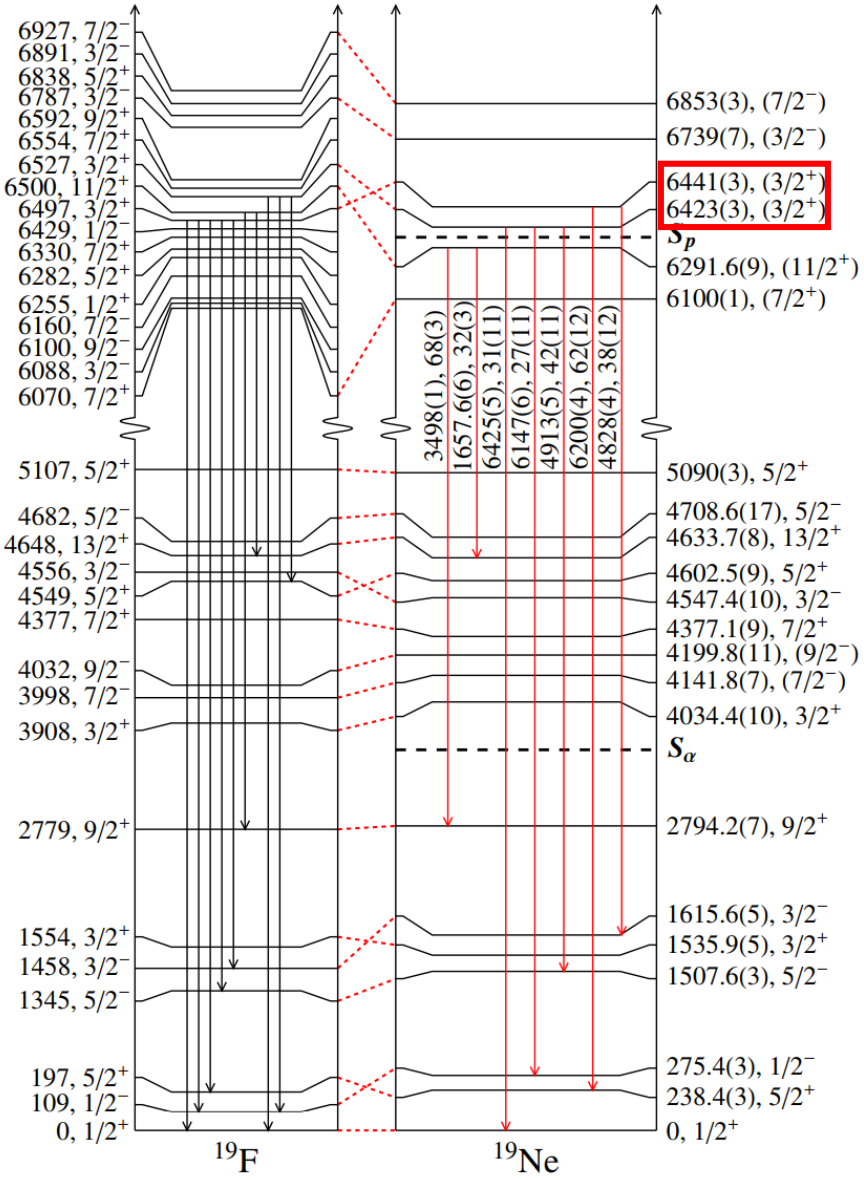
- $^{18}F(p,\alpha)^{15}O$ important for nova nucleosynthesis.
- Interference between $3/2^+$ states near S_p and resonance at $E_x \sim 7$ MeV
- Found gamma rays for two potential $3/2^+$ states in ^{19}Ne – resonances in $^{18}F(p,\alpha)^{15}O$



M. R. Hall *et al.* Phys. Rev. Lett. **122**, 052701

$^{19}F(^3He,t)^{19}Ne$ for $^{18}F(p,\alpha)^{15}O$

OAK RIDGE National Laboratory



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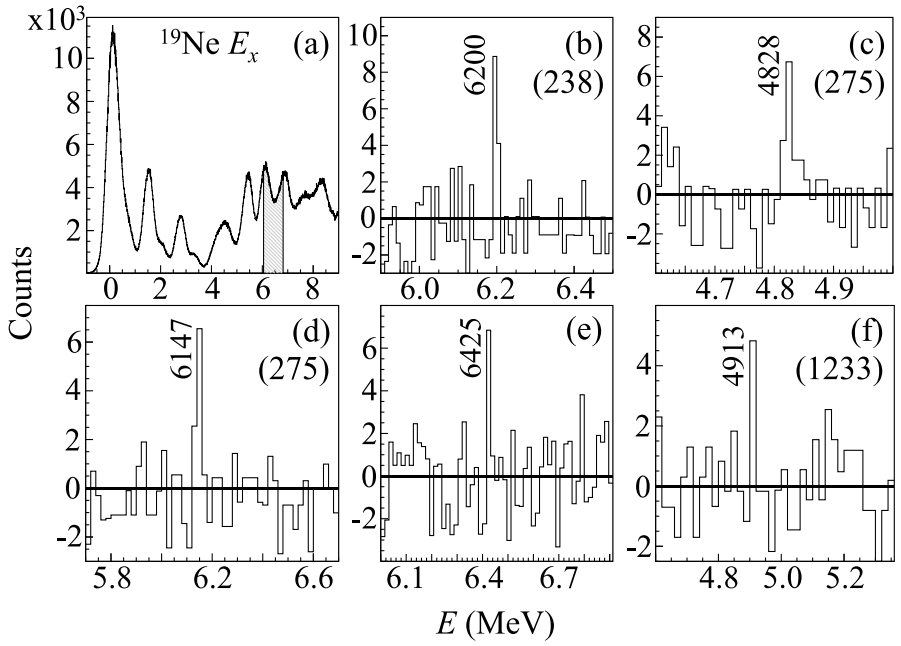

M. R. Hall *et al.* Phys. Rev. Lett. **122**, 052701

$^{40}Ca(^{3}He,\alpha)^{39}Ca$ with GODDESS

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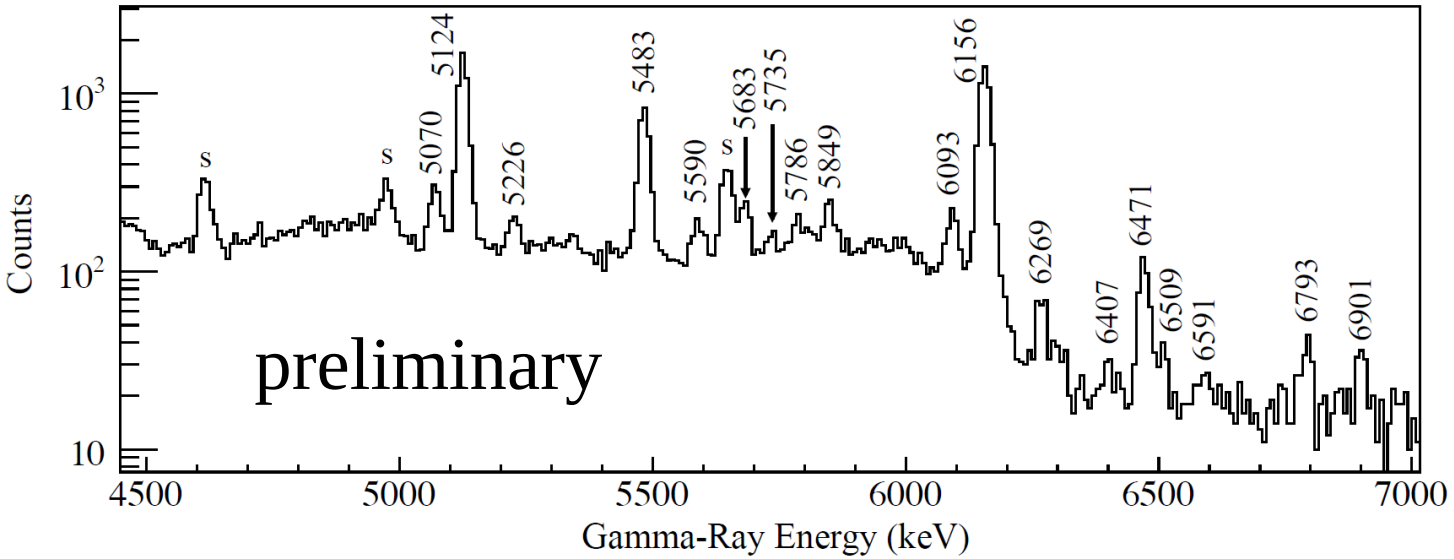
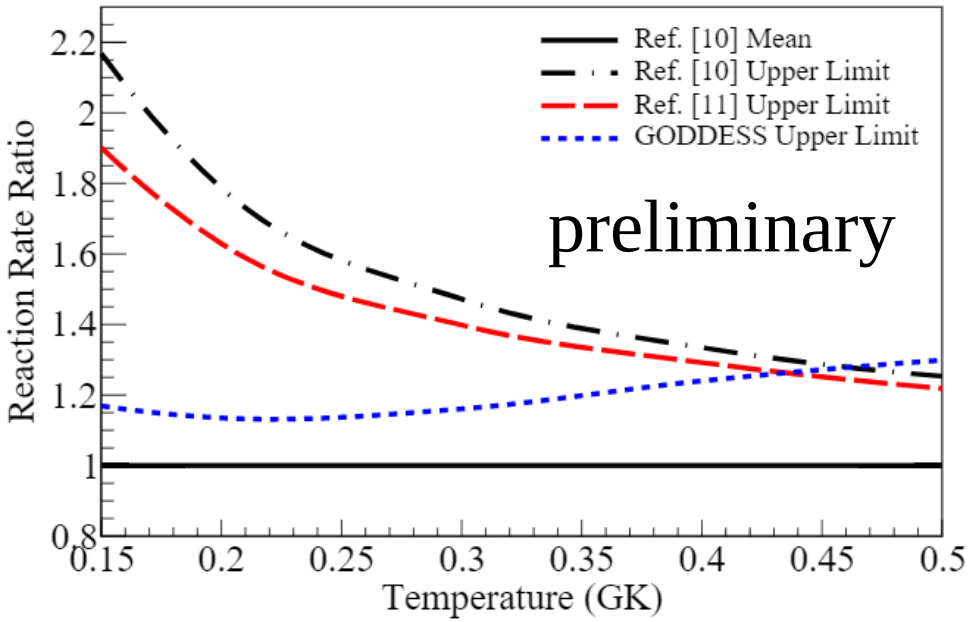


- $^{38}K(p,\gamma)^{39}Ca$ important at endpoint of nova nucleosynthesis – disagreement between theory and observation.
- Previously studied directly with DRAGON and via $^{40}Ca(^{3}He,\alpha)$ at TUNL.
- 23 new ^{39}Ca transitions found including three potential resonances for $^{38}K(p,\gamma)$



(α,p) reactions with SOLSTISE

(SOLenoid and Supersonic Target In Structure Experiments)

(α,*p*) Reactions and Nucleosynthesis

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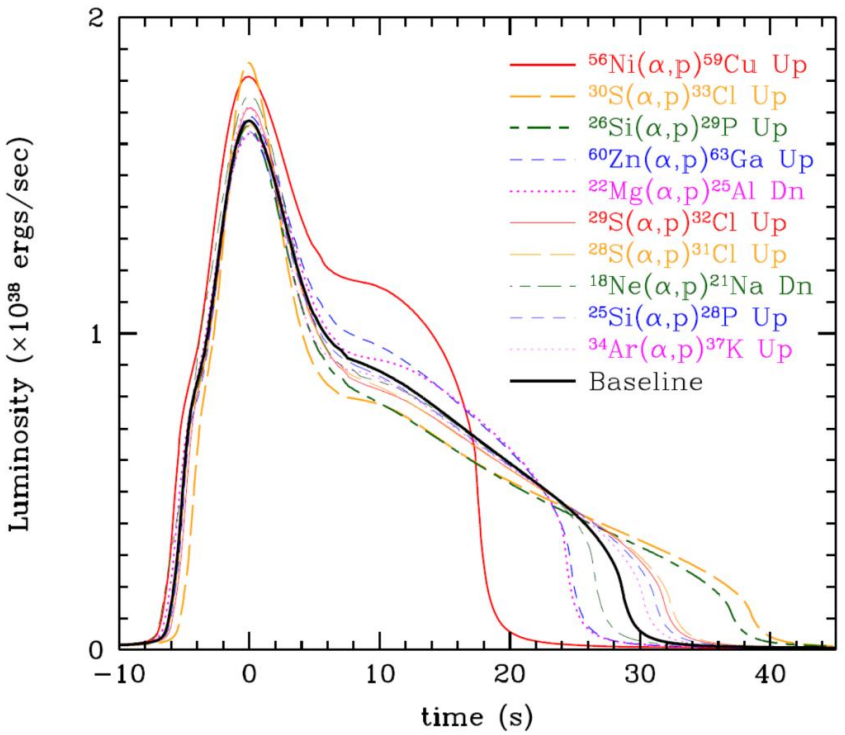
TABLE 1
REACTIONS THAT IMPACT THE BURST LIGHT CURVE IN THE SINGLE-ZONE X-RAY BURST MODEL.

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

[a] Up (U) or down (D) variation that has the largest impact
[b] $M_{LC}^{(i)}$ in units of 10^{17}ergs/g/s

- (α,*p*) reactions important reactions for *αp*-process and astrophysical sites like XRBs, Type Ia SN, etc.
- Not easy to measure, especially on radioactive nuclei where He target needed.
- Gas target (jet/cell) necessary for many of these:



(α,p) Reactions with JENSA

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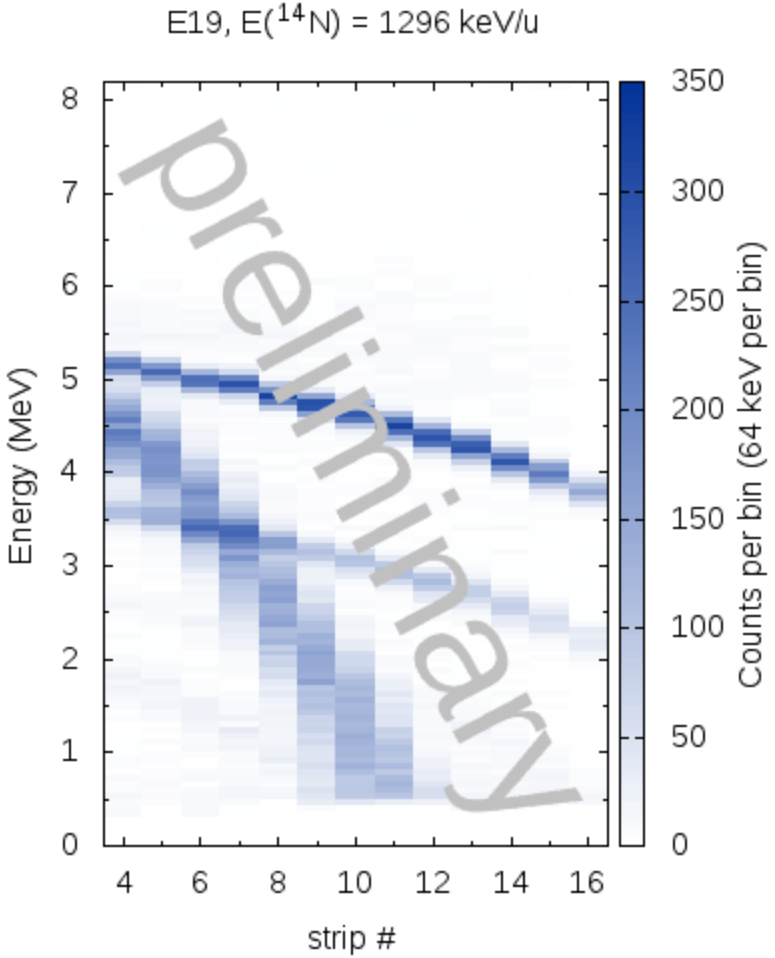
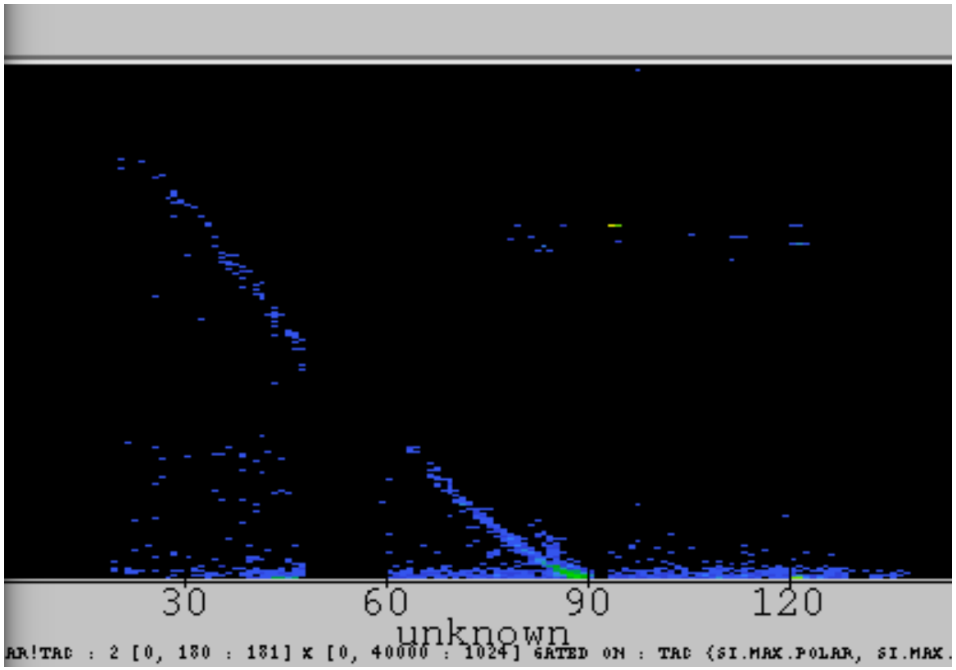
- ^{14}N(α,p) – first inverse kinematics experiment with gas jet.
- Large level spacing in ^{18}F, nice test case:



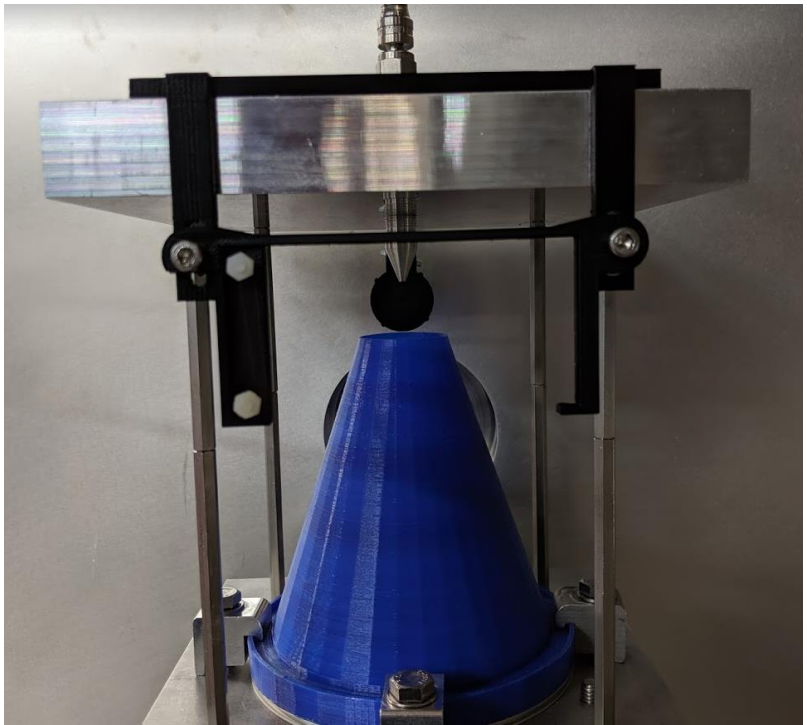
- ^{56}Ni(α,p) – performed for time inverse ^{59}Cu(p,α) – important in XRBs.

- Density of states also not an issue here because p_0 dominates.



(α,p) Reactions with a Solenoid/Gas Jet

- Many of these experiments could be improved in a solenoid especially if the level density is higher.
- SOLSTISE (gas jet + HELIOS/SOLARIS)
- Jet currently being tested at ORNL/simulations in progress (more at LECM).



Test nozzle/receiver cone

Test chamber with long pipe

Advantages of (α,p) with SOLSTISE

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- Potentially less elastic scattering – less DAQ dead time and higher beam rates for more statistics.

- Kinematic compression in inverse kinematics not an issue: in A=30-40 region solenoid may especially be useful due to high density of states.

Design considerations:

- Investigating different nozzle designs
  - Gas jet "sheet" or smaller (~1 mm) jet to improve position resolution?
    - For high level densities that can't be resolved in silicon, thicker jet may be more useful for increased statistics.

  - Gas jet "sheet" would also be useful for RAISOR beams/beams with larger spot size.

Summary and Outlook

- GODDESS has had successful measurements using stable ^{3}He beams
  - ^{19}F(^{3}He,t) & ^{40}Ca(^{3}He,α)

- Some astrophysics measurements may require new target technologies (SOLSTISE)
  - SOLSTISE will be particularly useful for (α,p)
  - JENSA has already had some success
  - Solenoid may solve some issues present in regular inverse kinematics experiments (kinematic compression, etc)…

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