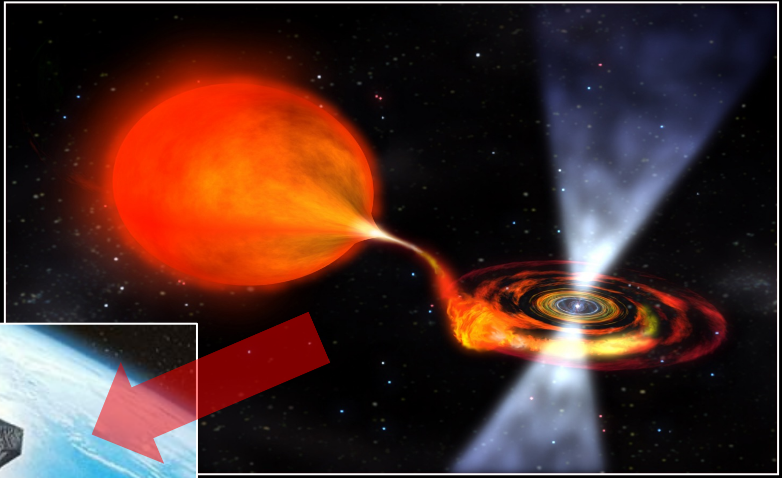
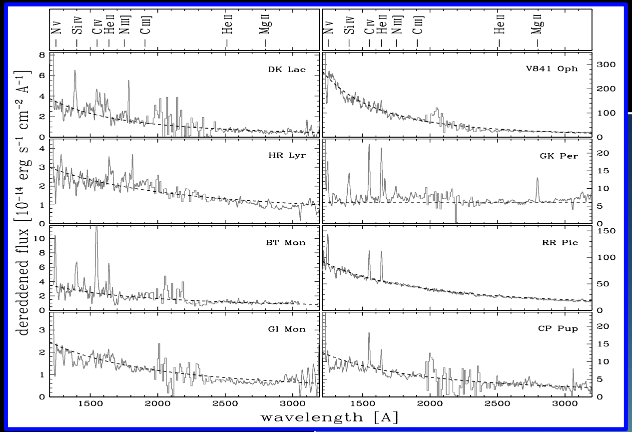
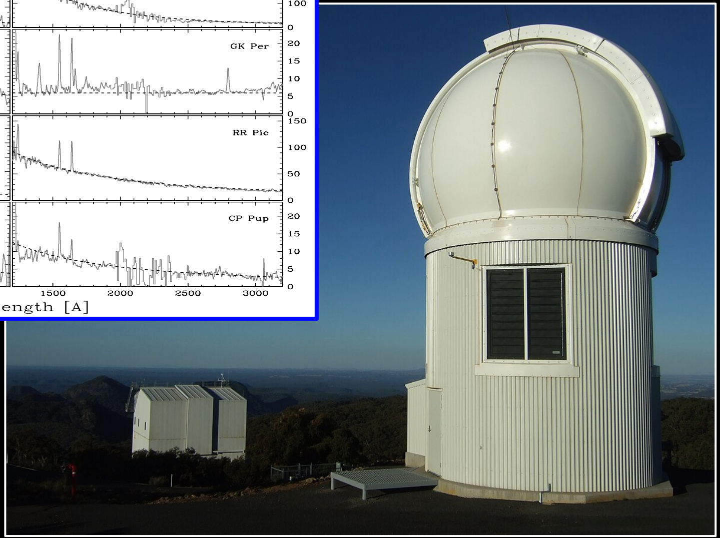
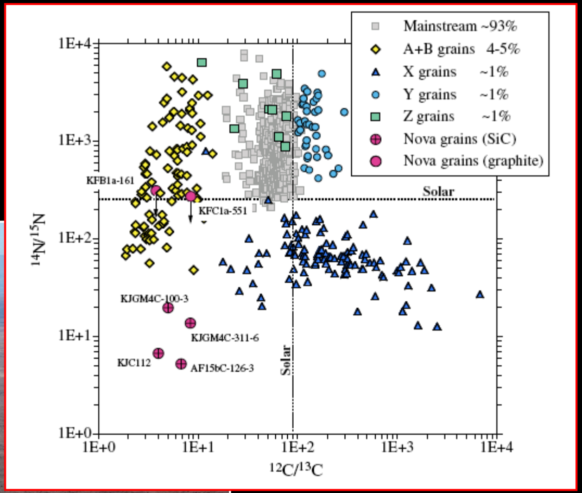
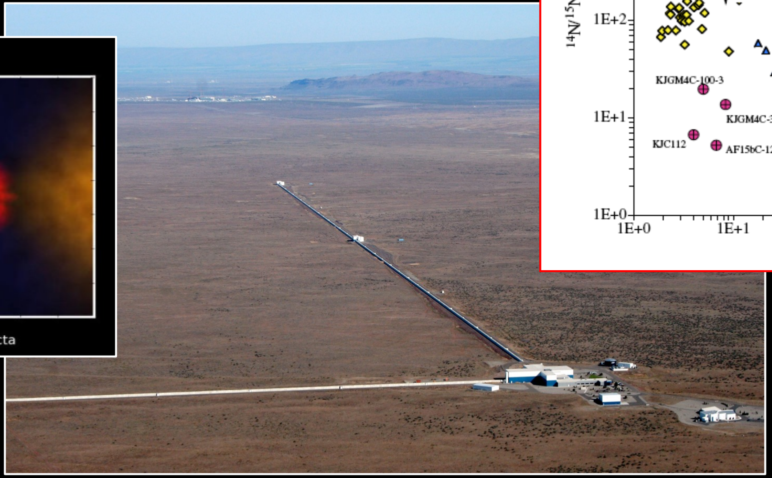
Frontiers in Explosive Nuclear Astrophysics – Gavin Lotay

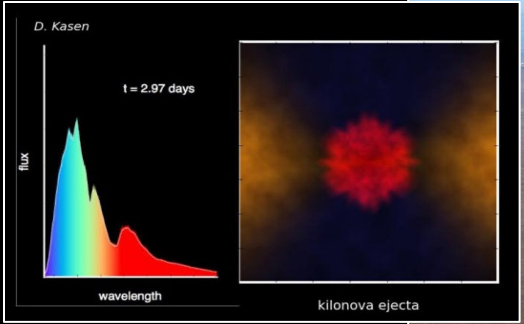


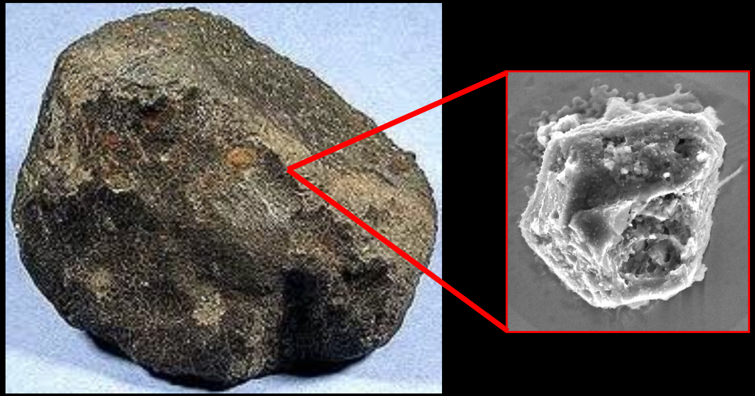




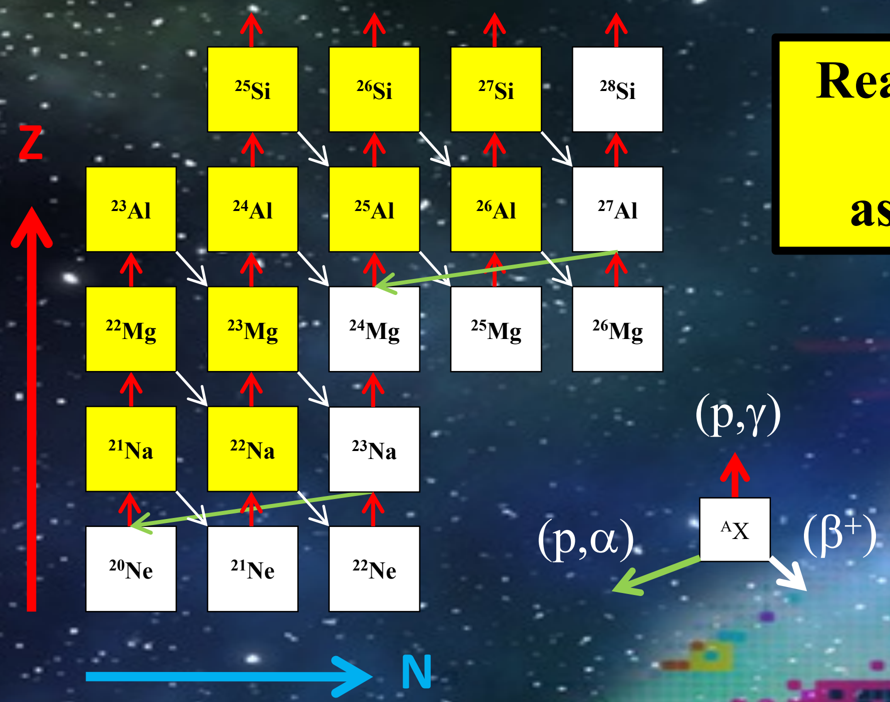








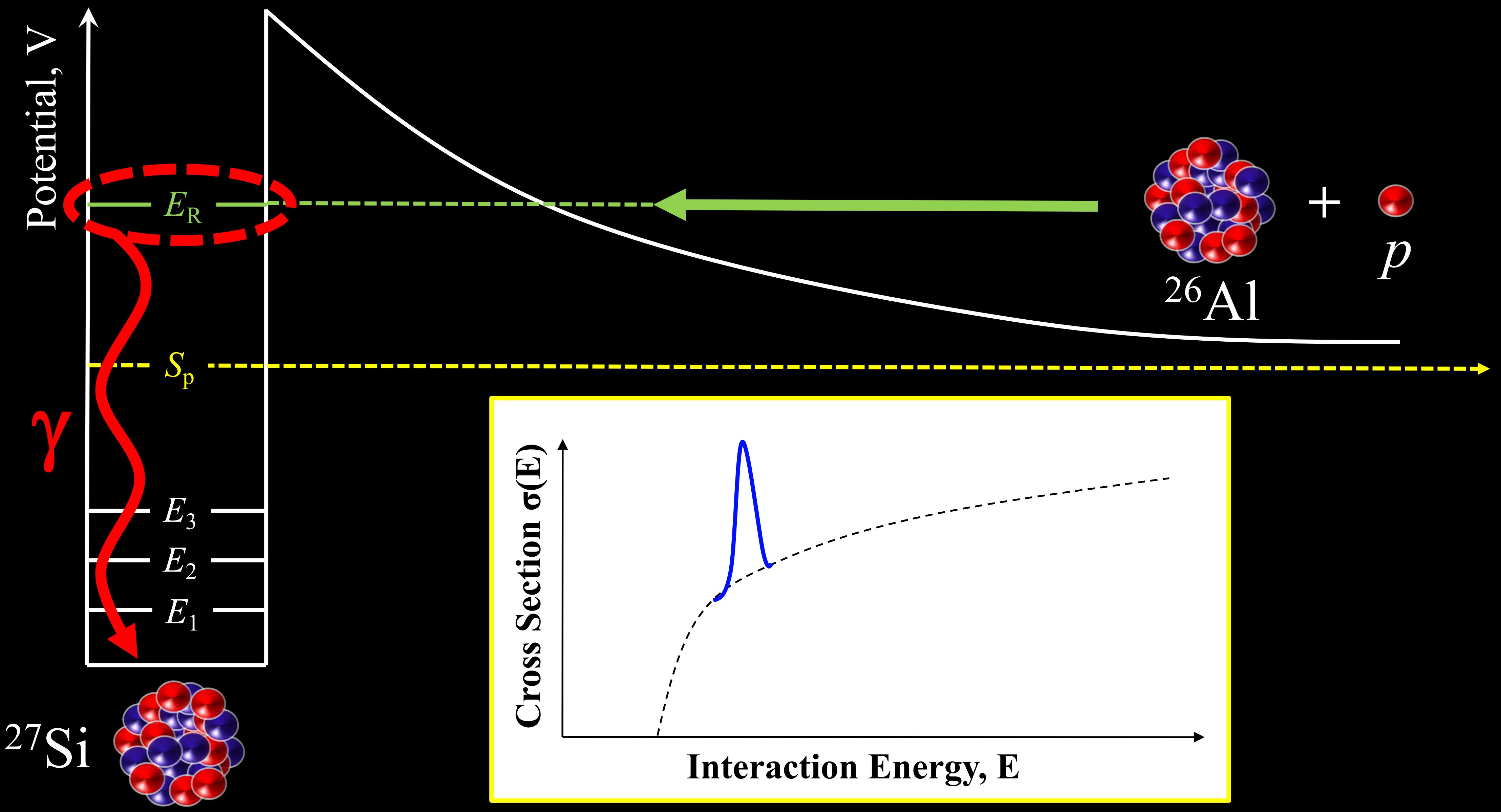
The Need for Nuclear Physics



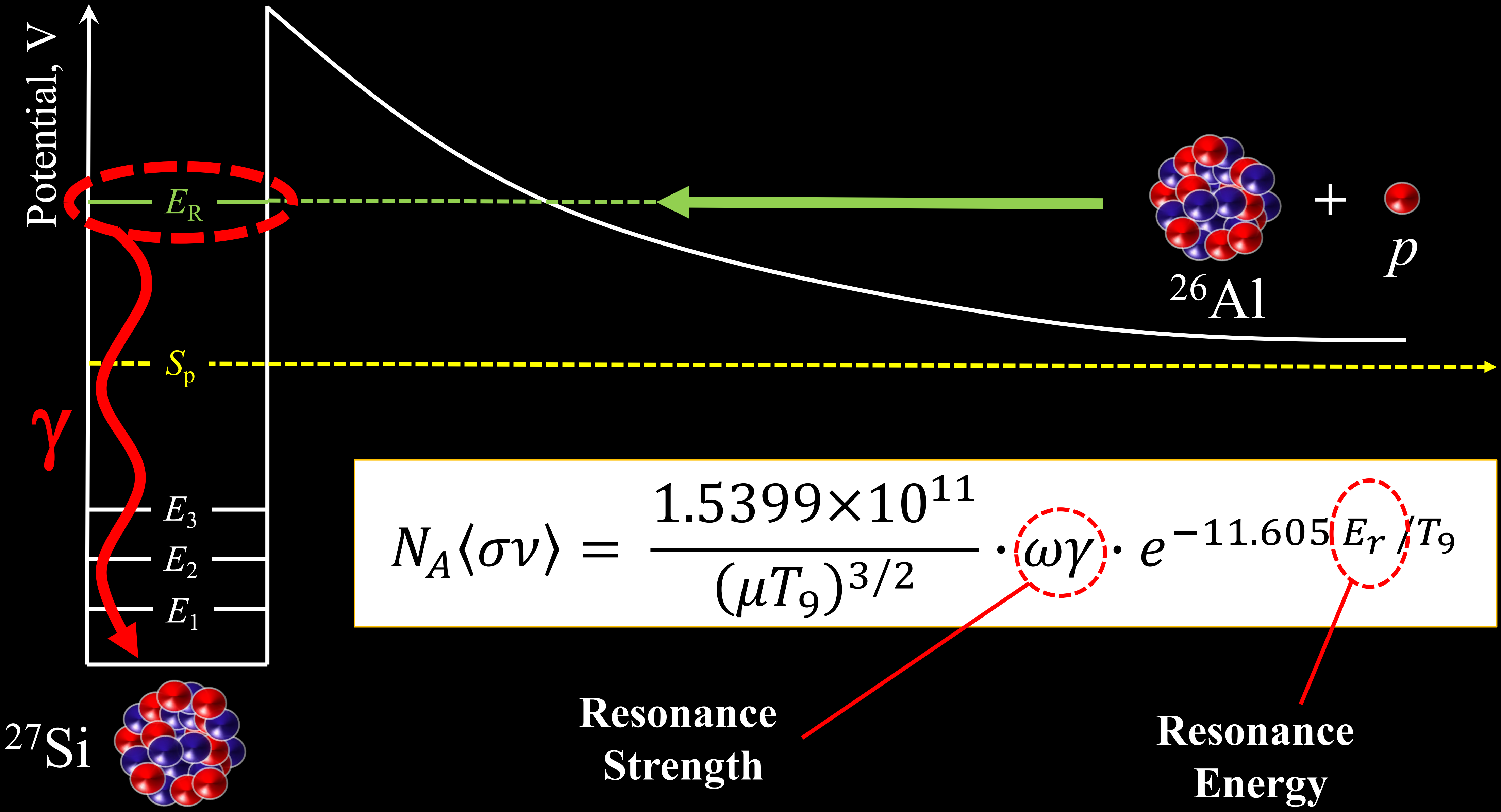
Reactions on RADIOACTIVE nuclei drive explosive astrophysical environments

NUCLEAR ASTROPHYSICS LINKS MICROSCOPIC TO MACROSCOPIC

Stellar Reaction Rates



Stellar Reaction Rates

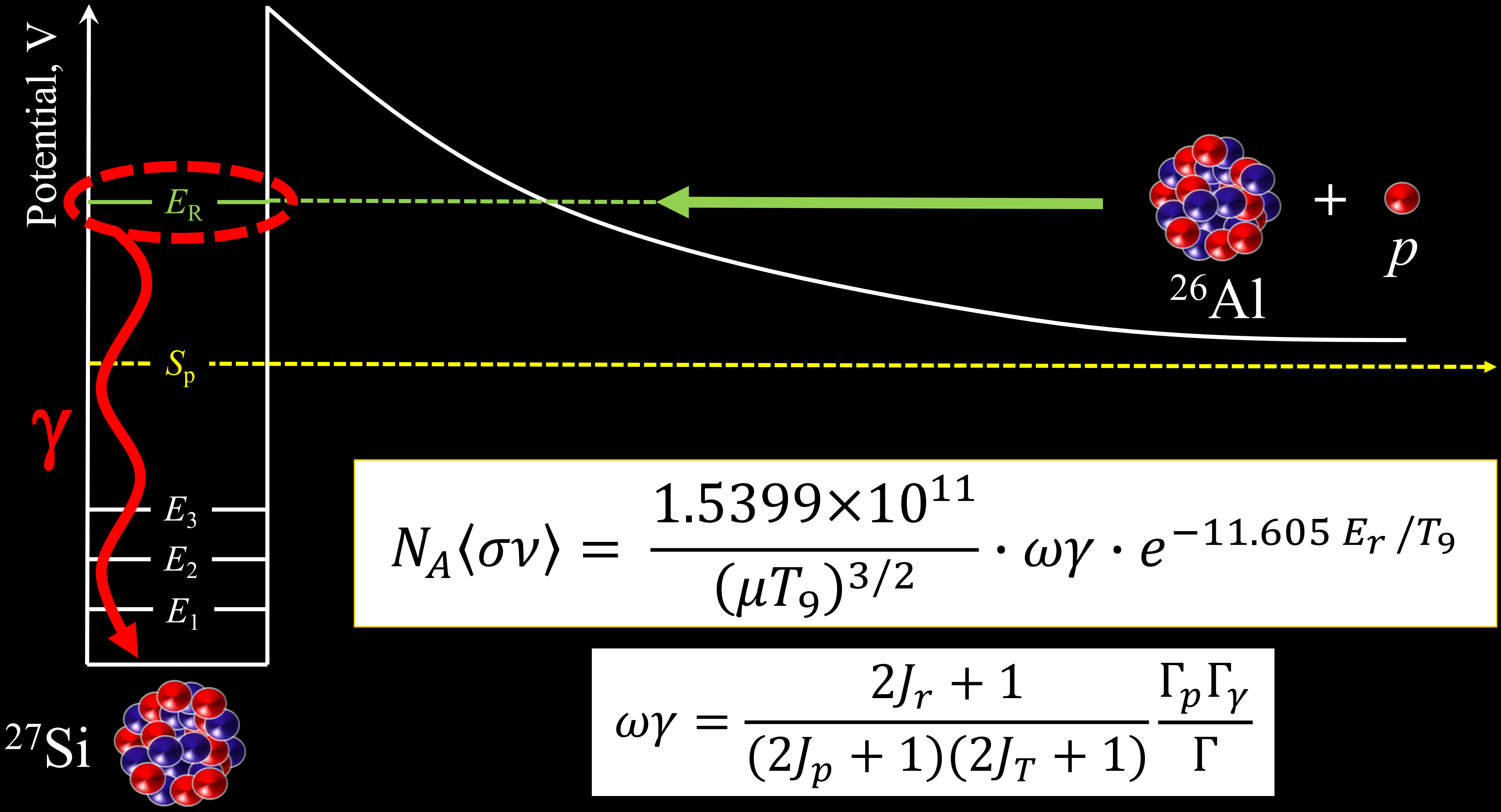


$$N_A\langle\sigma v\rangle = \frac{1.5399\times10^{11}}{(\mu T_9)^{3/2}}\cdot\omega\gamma\cdot e^{-11.605\,E_r/T_9}$$

Resonance Strength

Resonance Energy

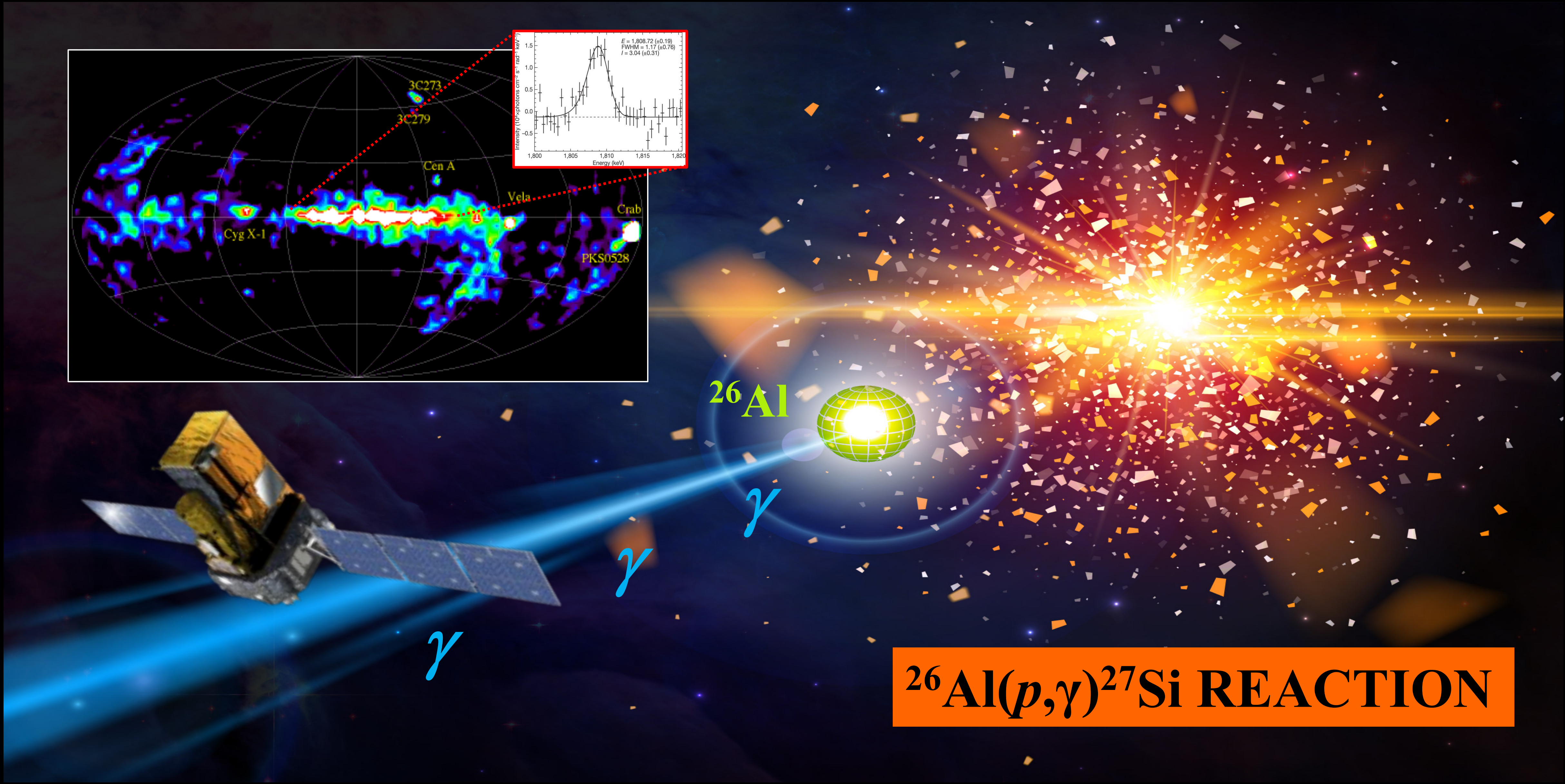
Stellar Reaction Rates



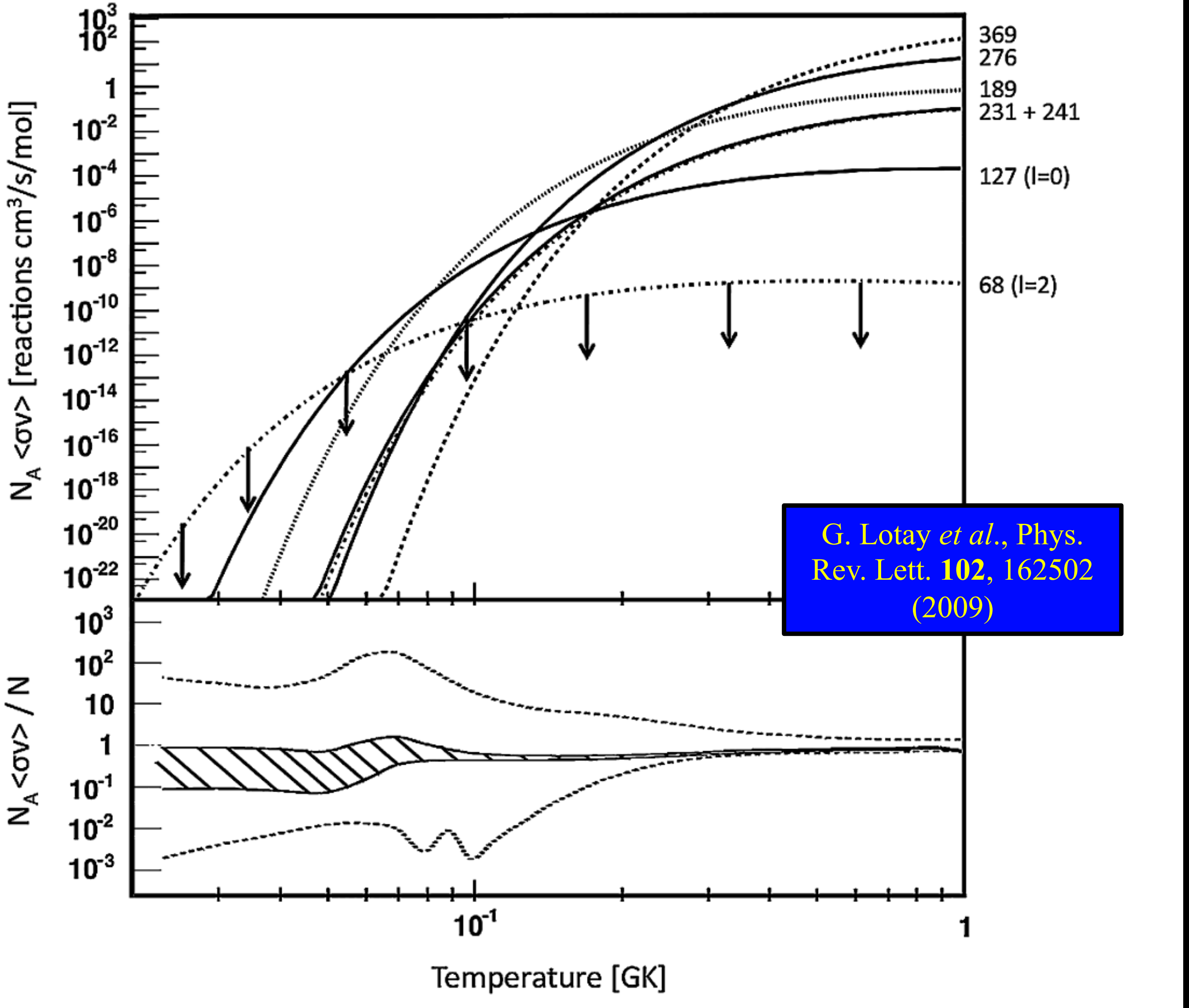
$$N_A\langle\sigma v\rangle = \frac{1.5399\times10^{11}}{(\mu T_9)^{3/2}}\cdot\omega\gamma\cdot e^{-11.605\,E_r/T_9}$$

$$\omega\gamma = \frac{2J_r+1}{(2J_p+1)(2J_T+1)}\frac{\Gamma_p\Gamma_\gamma}{\Gamma}$$

The Origin of Cosmic γ-ray Emitters



Outside the Reach of Direct Measurements – Energies



G. Lotay *et al.*, Phys. Rev. Lett. **102**, 162502 (2009)

7832 9/2$^+$ **[*E*$_r$ = 369 keV]**

7739 9/2$^-$ **[*E*$_r$ = 276 keV]**

7652 11/2$^-$ **[*E*$_r$ = 189 keV]**

7590 9/2$^+$ **[*E*$_r$ = 127 keV]**

7557 3/2$^+$ ***T* = 3/2**

7531 5/2$^+$ **[*E*$_r$ = 68 keV]**

7469 (1/2, 5/2)$^+$ **[*E*$_r$ = 6 keV]**

Comparison with the USD Shell Model Energies

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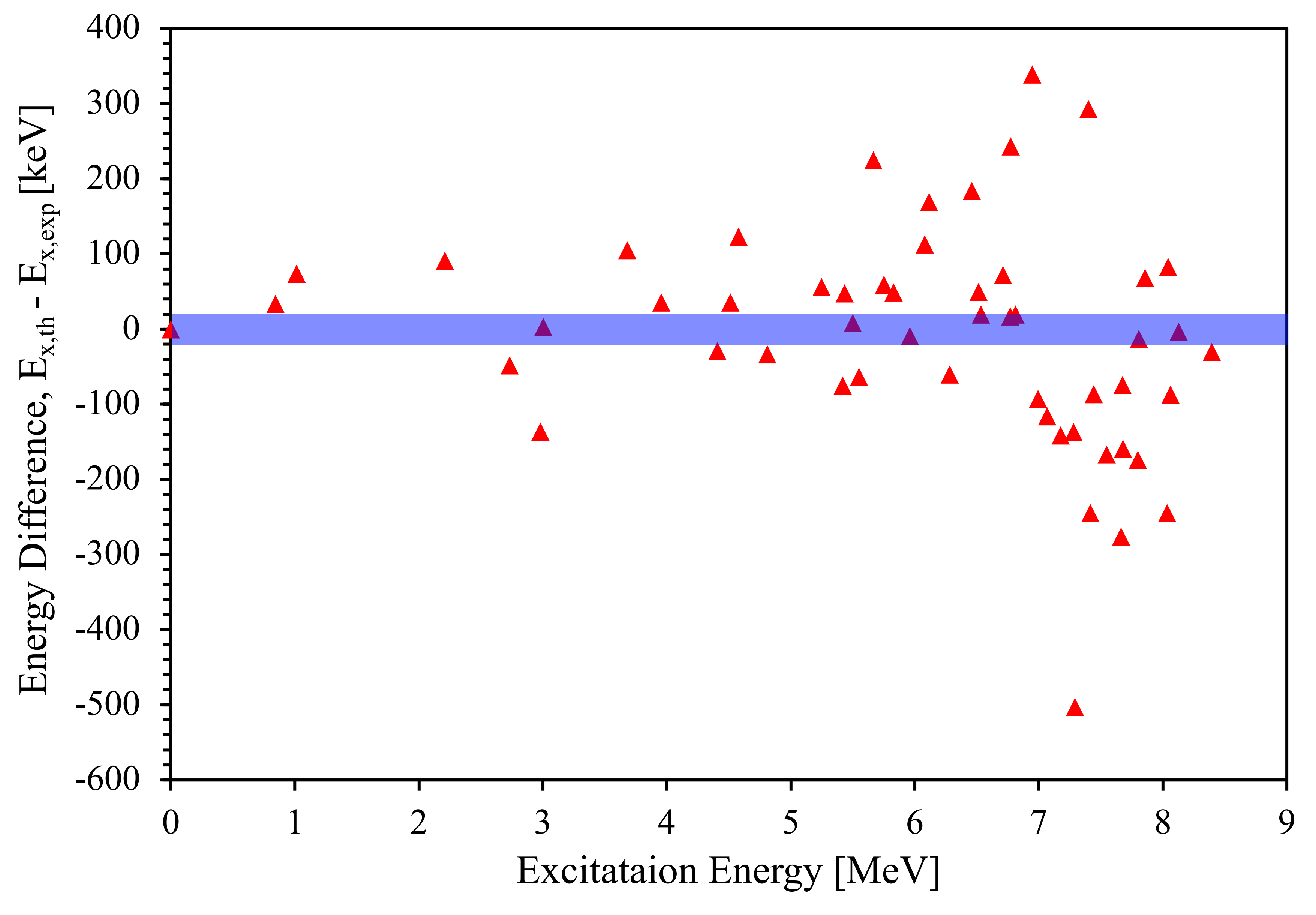
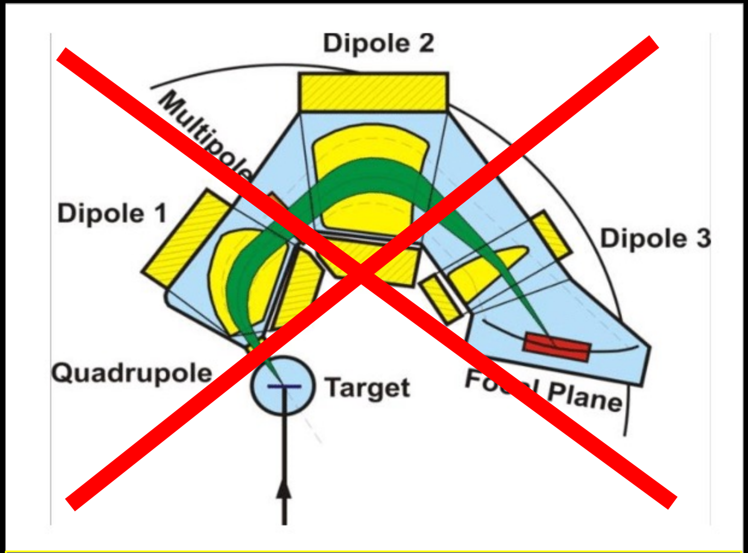


The Shell Model may not (currently) be the best tool to determine resonance energies

Outside the Reach of Direct Measurements – Resonance Strengths



$^{26}Al(^{3}He,d)^{27}Si$

Not the most experimentally favourable reaction for RIBs

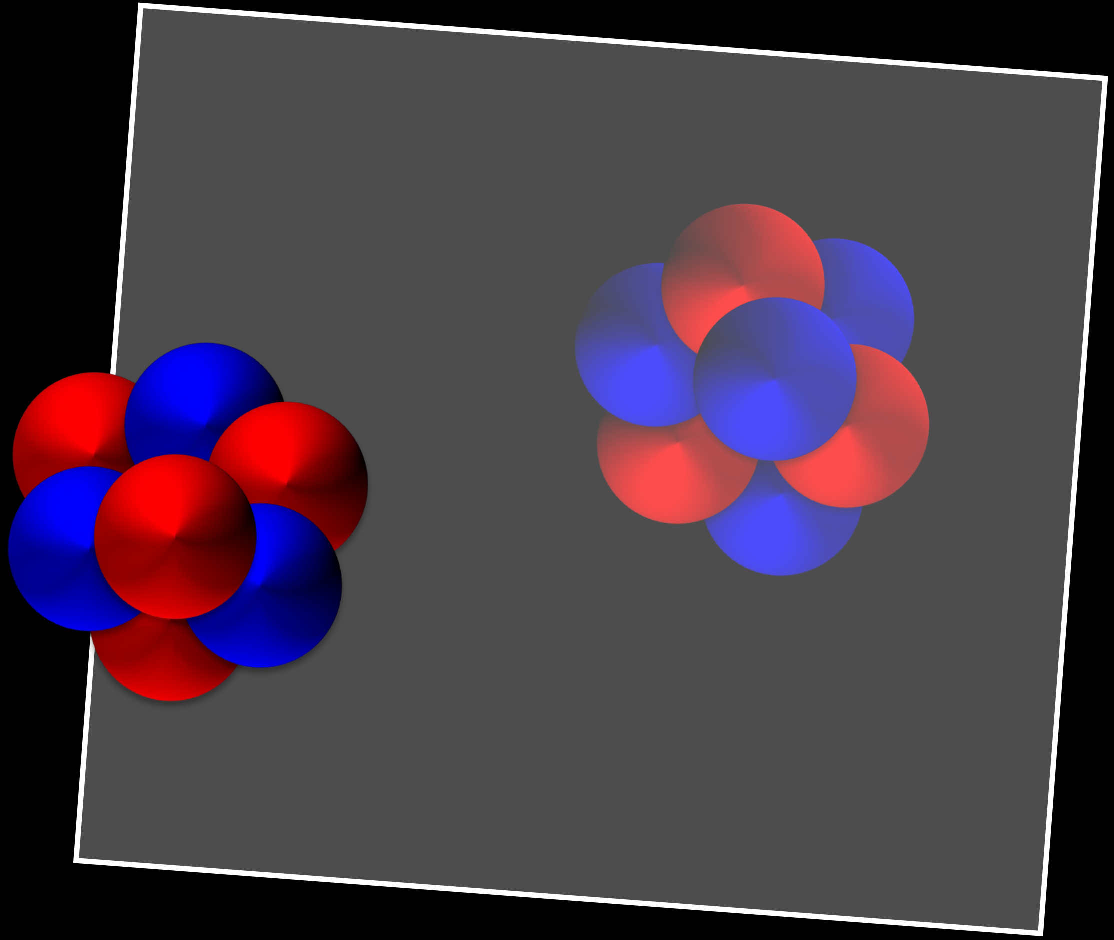
7832	$9/2^+$	**[E_r = 369 keV]**
7739	$9/2^-$	**[E_r = 276 keV]**
7652	$11/2^-$	**[E_r = 189 keV]**
7590	$9/2^+$	**[E_r = 127 keV]**
7557	$3/2^+$	***T* = 3/2**
7531	$5/2^+$	**[E_r = 68 keV]**
7469	$(1/2, 5/2)^+$	**[E_r = 6 keV]**

$$\omega\gamma = \frac{2J_r + 1}{(2J_p + 1)(2J_T + 1)} \frac{\Gamma_p \Gamma_\gamma}{\Gamma}$$

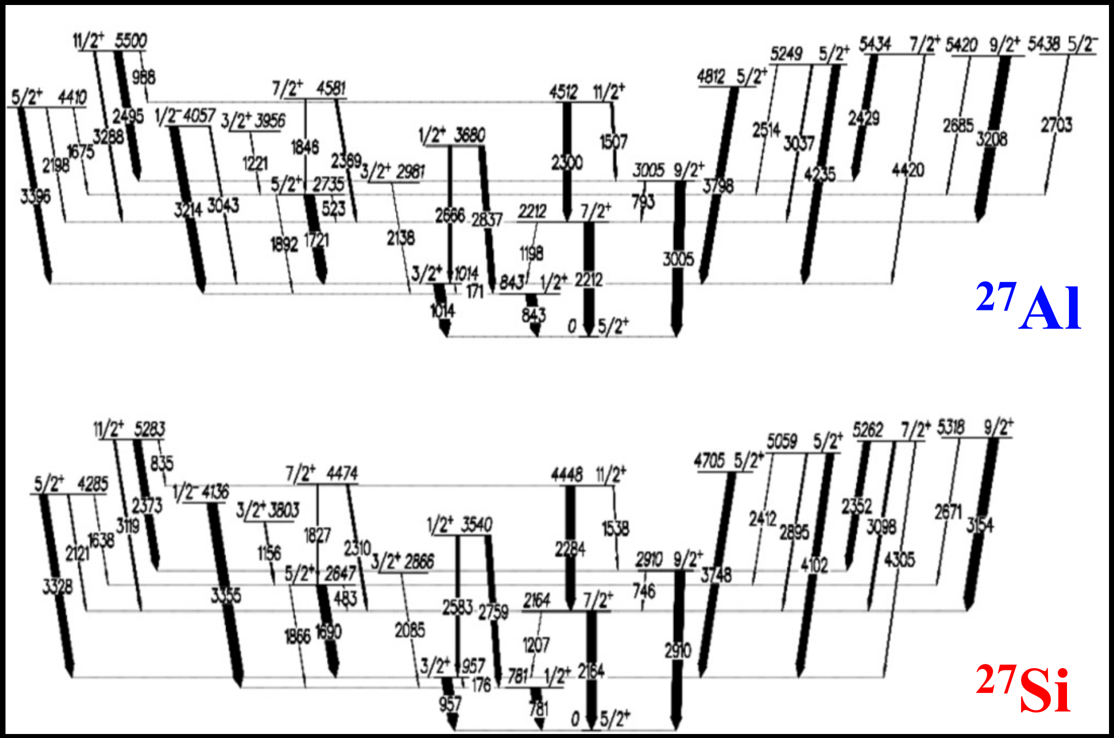
$$\omega\gamma \sim \omega\Gamma_p$$

$$\Gamma_p \sim P_l \cdot C^2S \cdot \theta_p^2$$

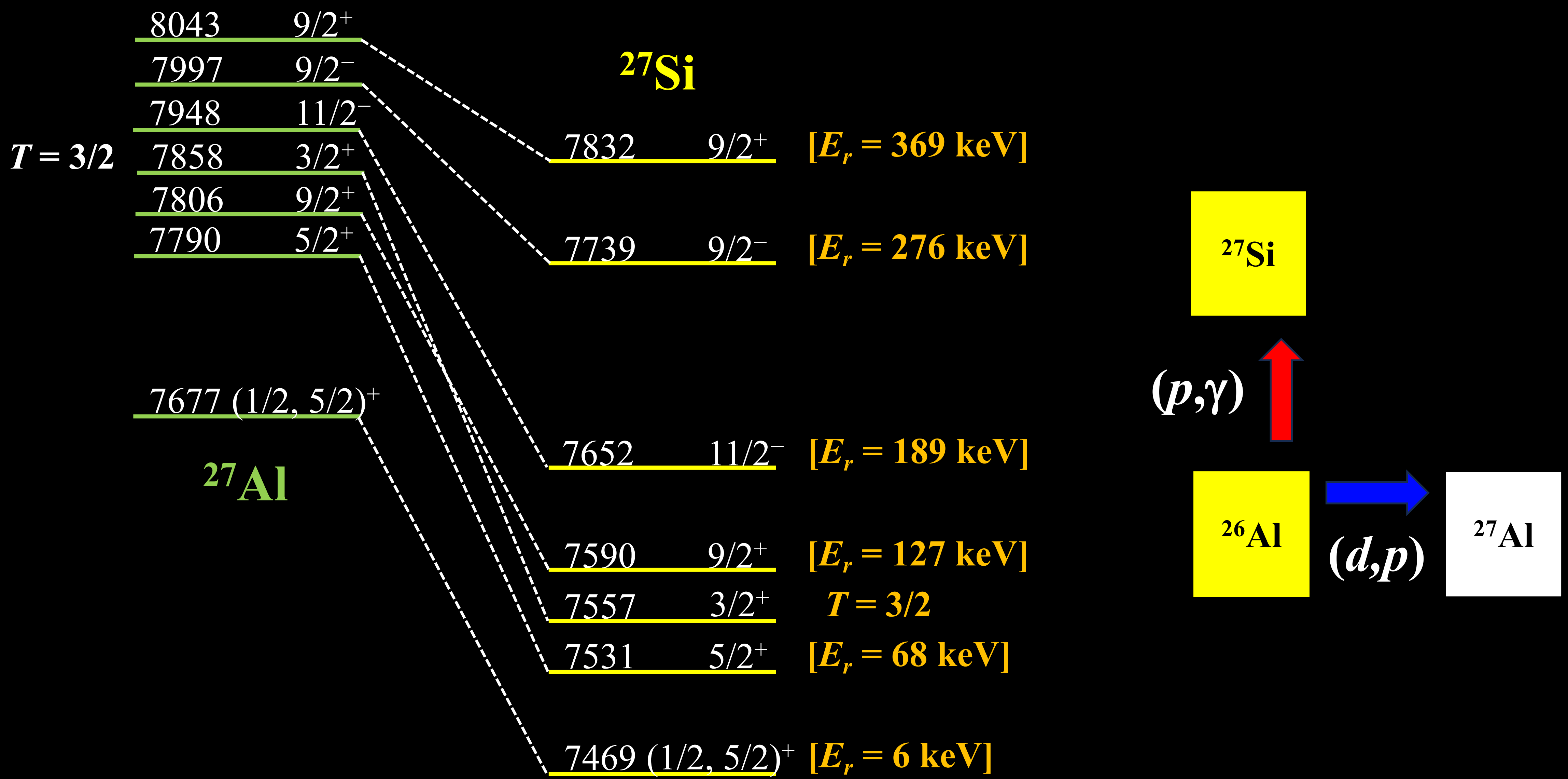
The Use of Mirror Symmetry



The structures of mirror nuclei are found to be nearly identical

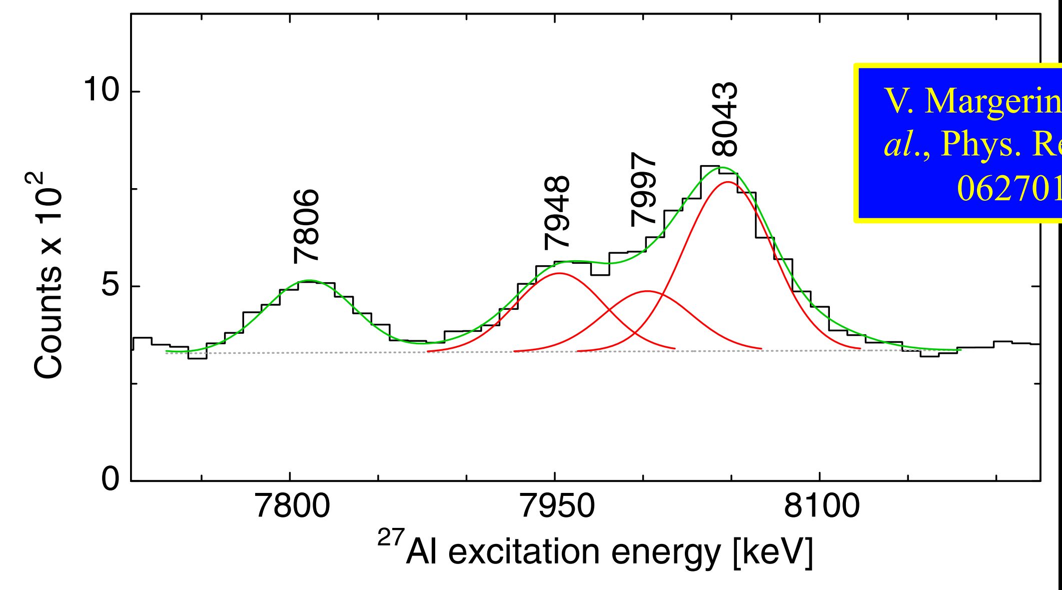


The Use of Mirror Symmetry



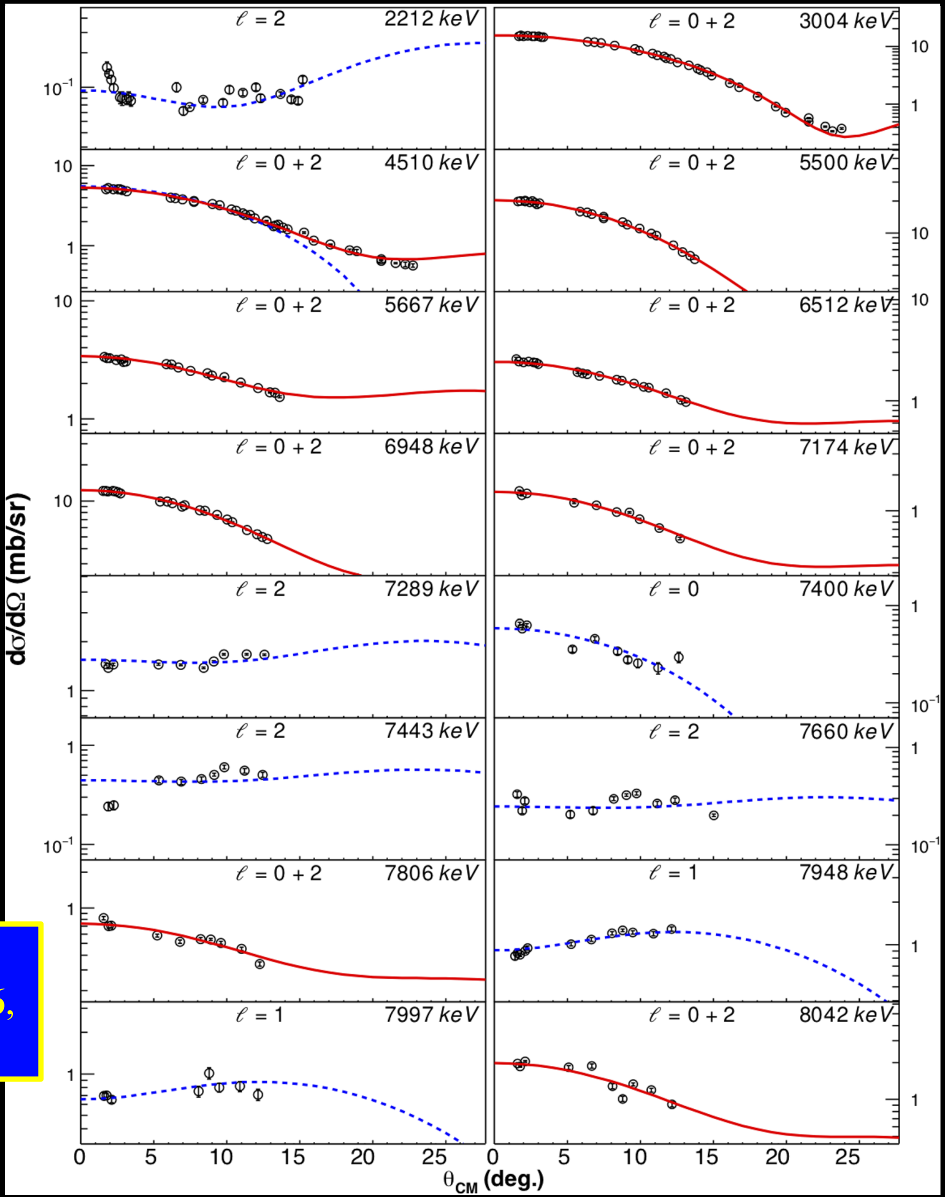
The $^{26}Al(d,p)^{27}Al$ transfer reaction at TRIUMF

E_x [keV]	E_r [keV]	$\omega\gamma_{(d,p)}$ [meV]	$\omega\gamma_{(p,\gamma)}$ [meV]
8043	369	45(22)	69(7)
7997	276	2.3(11)	2.9(3)
7948	189	0.026(12)	0.035(7)



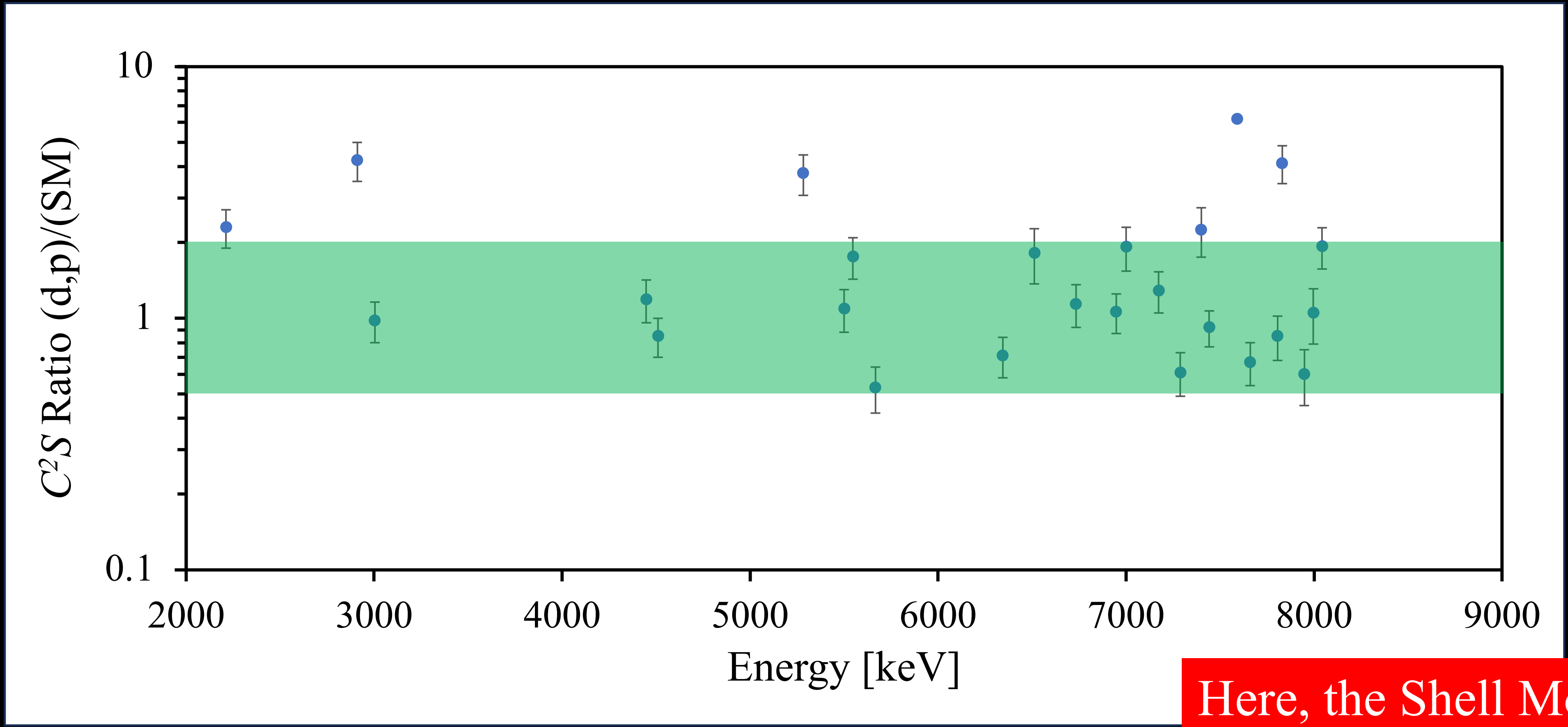
V. Margerin, G. Lotay *et al.*, Phys. Rev. Lett. **115**, 062701 (2015)

G. Lotay *et al.*, Eur. Phys. J. A **56**, 3 (2020)



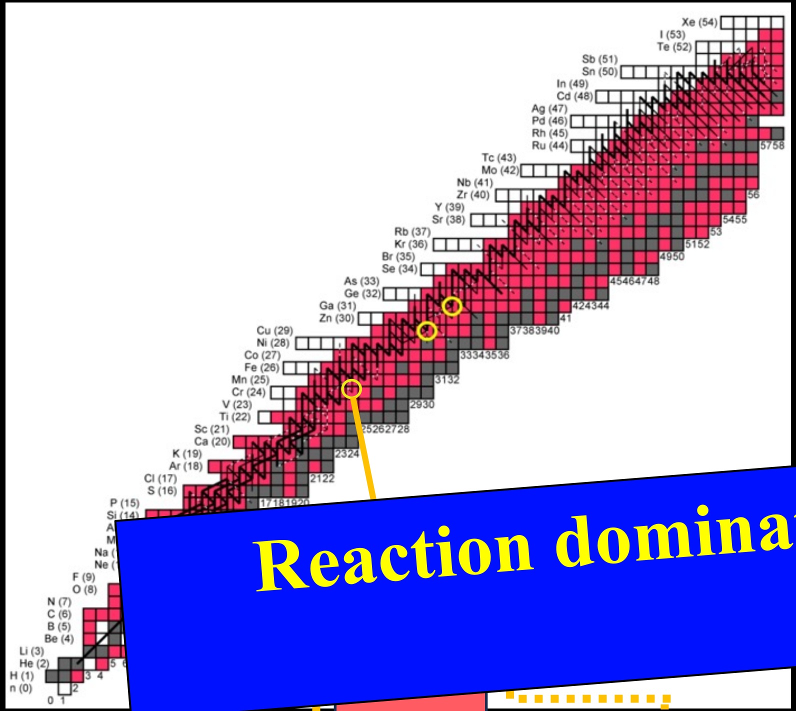
Comparison with USD Shell Model Spectroscopic Factors

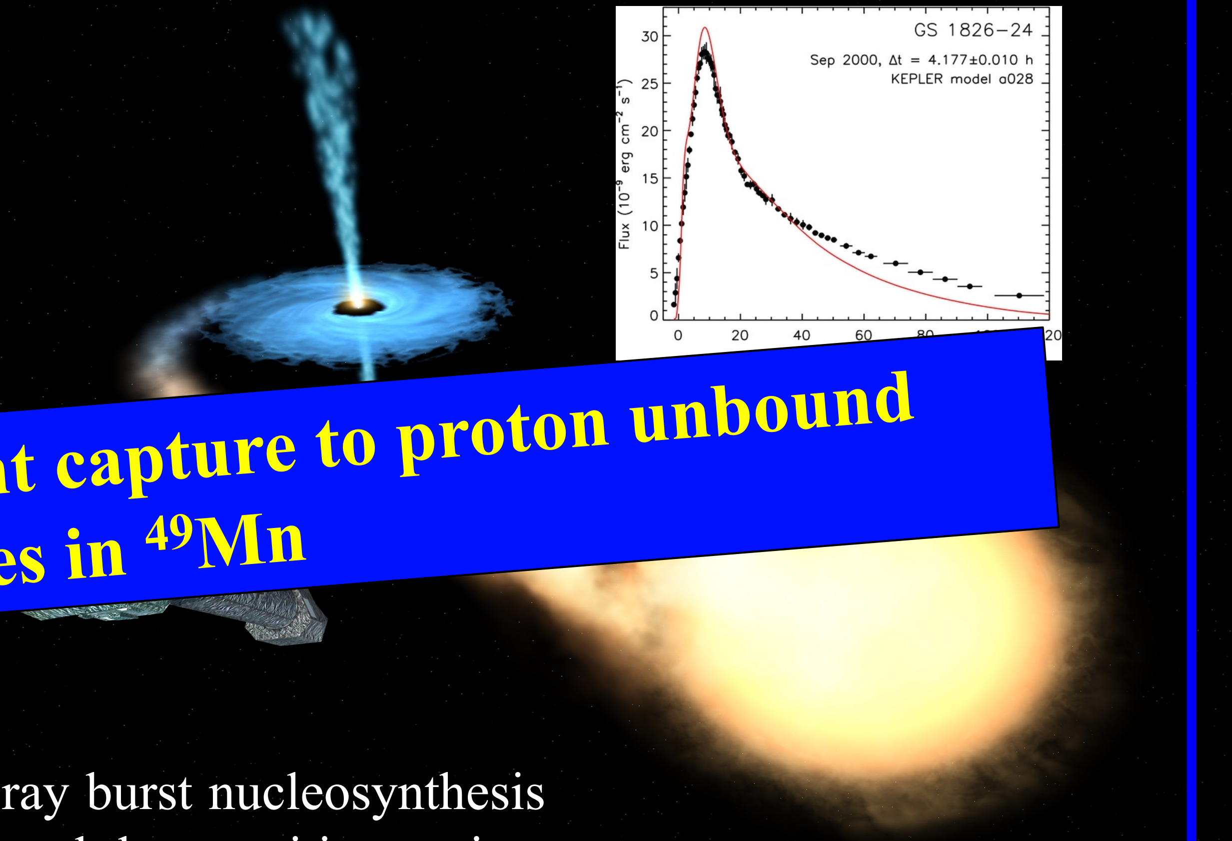
Comparison with USD Shell Model Spectroscopic Factors



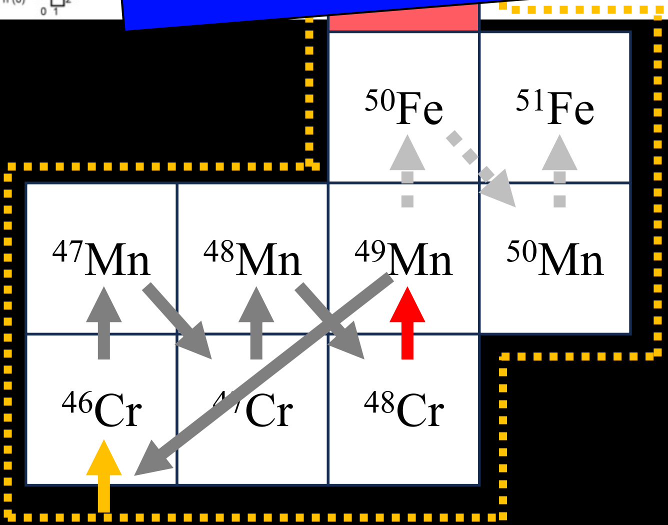
Here, the Shell Model seems to be good at predicting the spectroscopic factors once the states have been identified

Understanding the Light Curves of Type-I X-ray Bursts





Reaction dominated by resonant capture to proton unbound excited states in ^{49}Mn

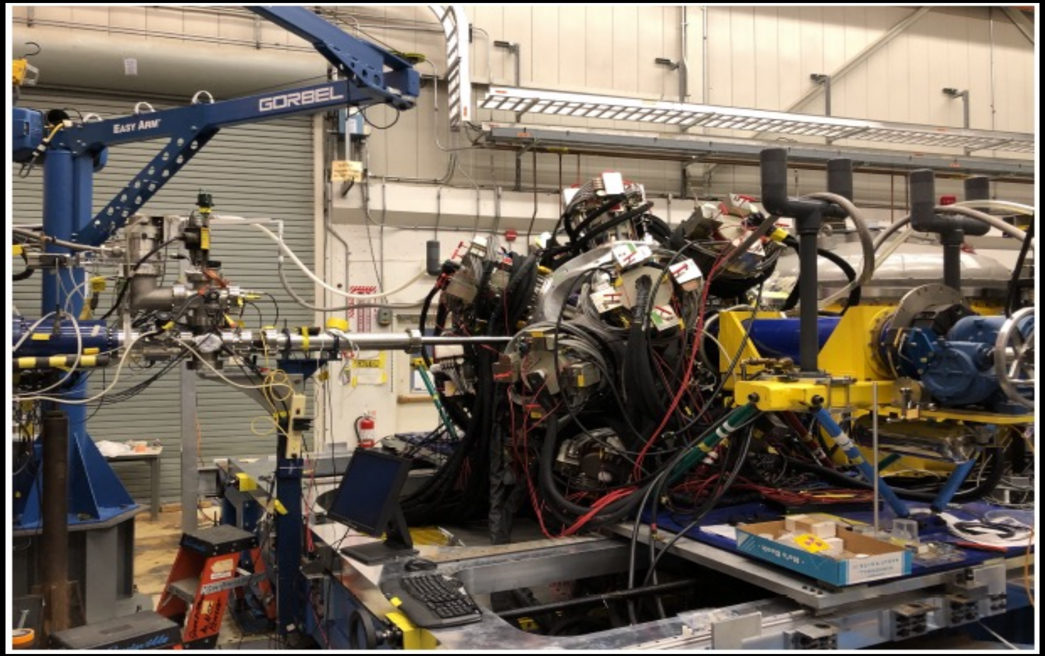


- Detailed models of X-ray burst nucleosynthesis indicate reactions around key waiting points strongly influence the resulting light curves

- In particular, the **^{48}Cr(p,γ)^{49}Mn** reaction has been highlighted as key [R.H. Cyburt et al., ApJ **830**, 55 (2016)]

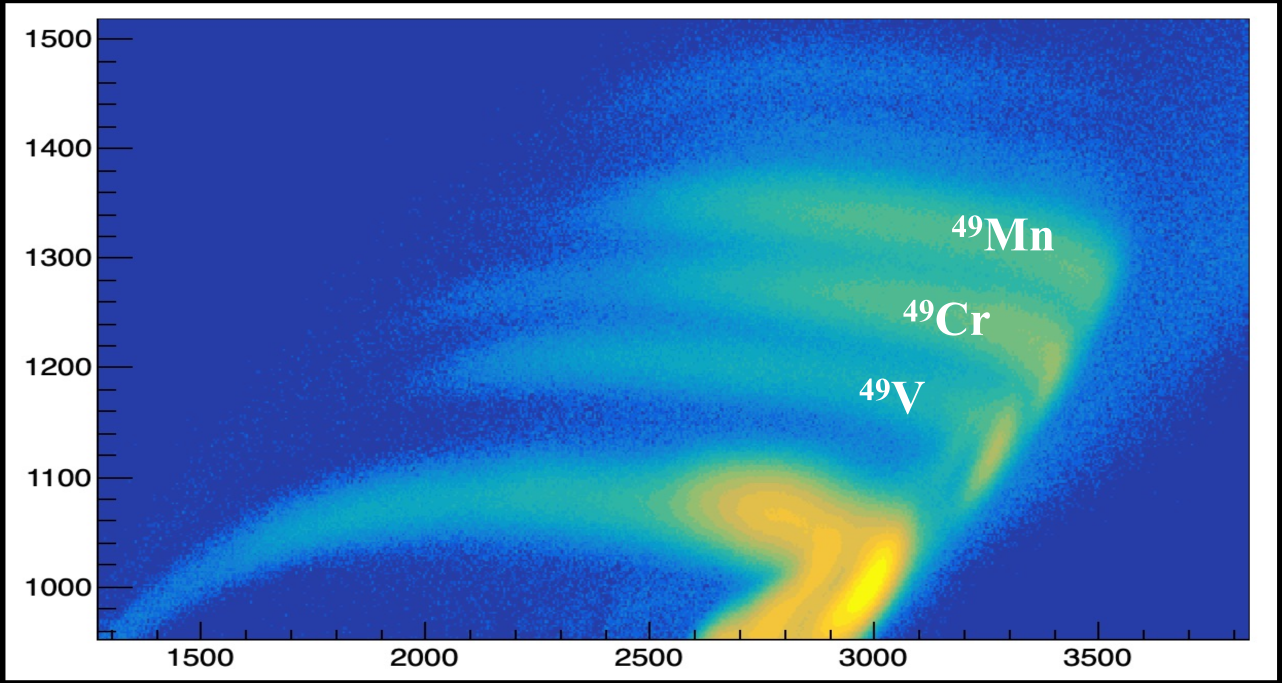
Gamma-ray Spectroscopy Study of ^{49}Mn @ ANL

- A 75 MeV beam of ^{40}Ca ions (~20 pnA) produced by the Argonne ATLAS accelerator was used to bombard a ~200 μg/cm^2 thick target of ^{11}B target to populate excited states in ^{49}Mn via ^{11}B(^{40}Ca,2n) and ^{49}Cr via ^{11}B(^{40}Ca,1p1n)



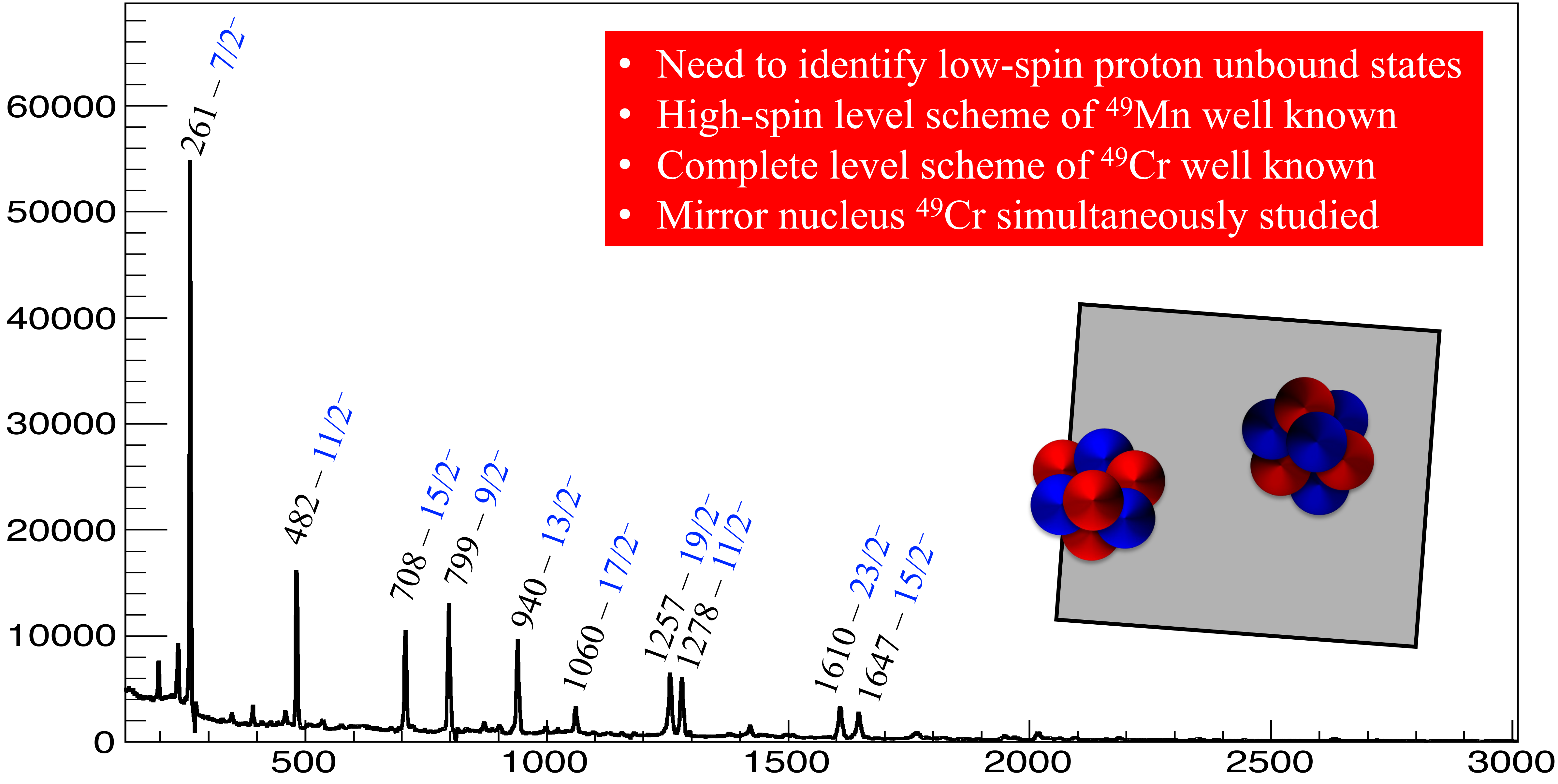
The Argonne Fragment Mass Analyser used to Transmit *A* =49 recoils

GRETINA γ-ray tracking array used to detect prompt γ rays at the target position

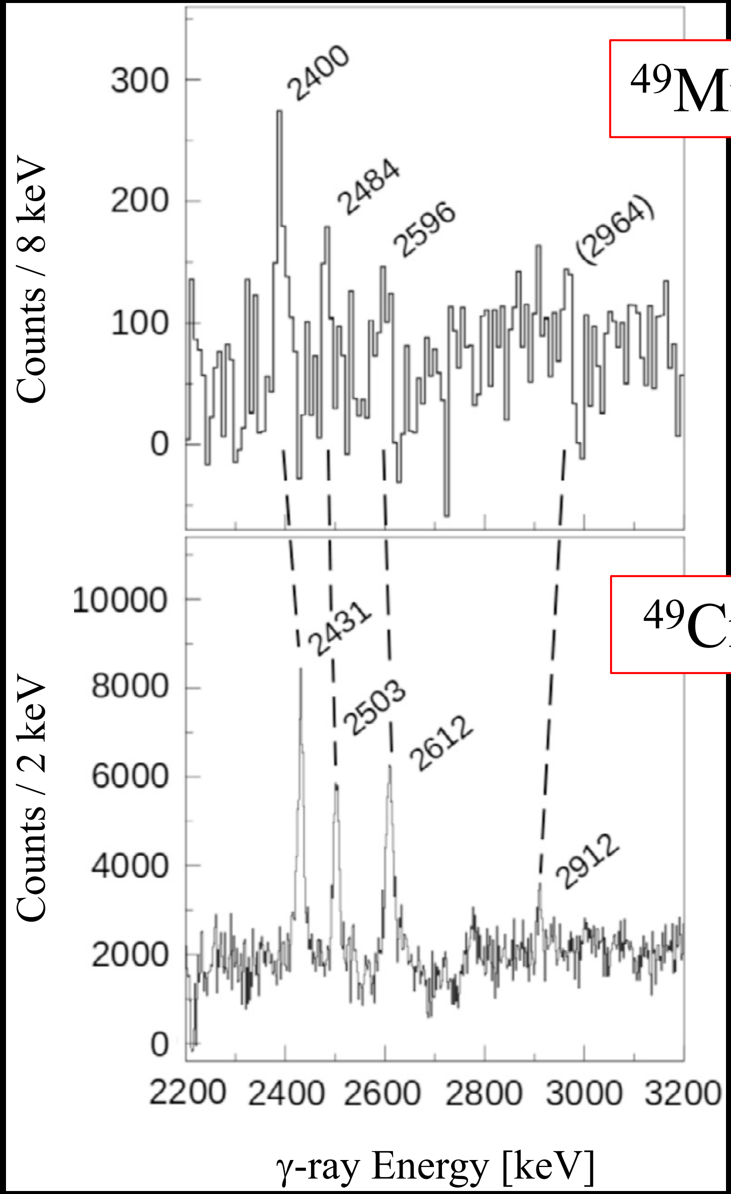


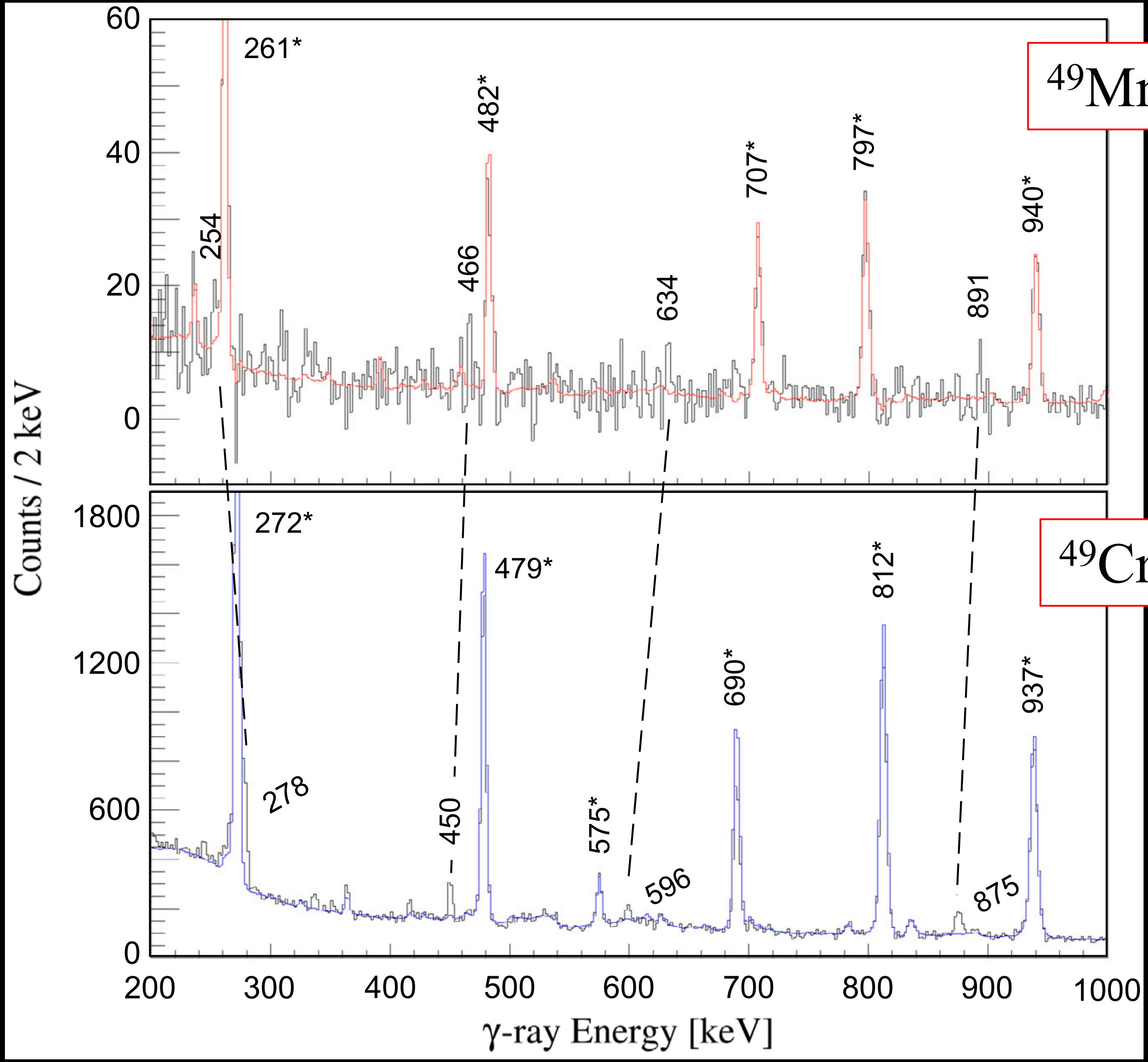
Gamma-ray Spectroscopy Study of ^{49}Mn @ ANL

- Need to identify low-spin proton unbound states
- High-spin level scheme of ^{49}Mn well known
- Complete level scheme of ^{49}Cr well known
- Mirror nucleus ^{49}Cr simultaneously studied

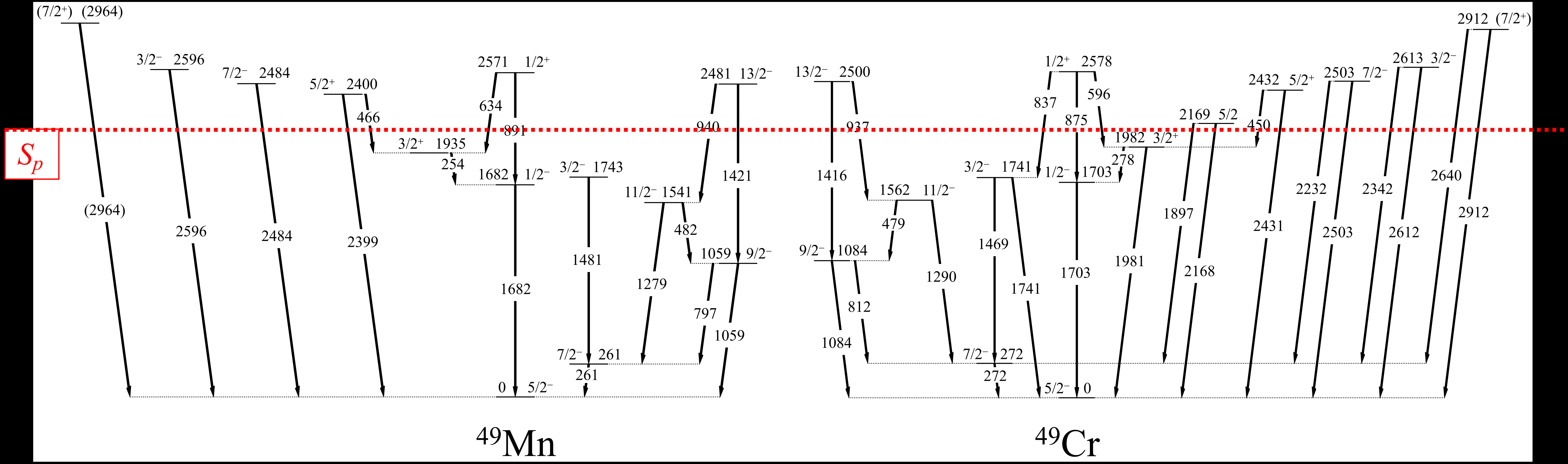


Gamma-ray Spectroscopy Study of ^{49}Mn @ ANL





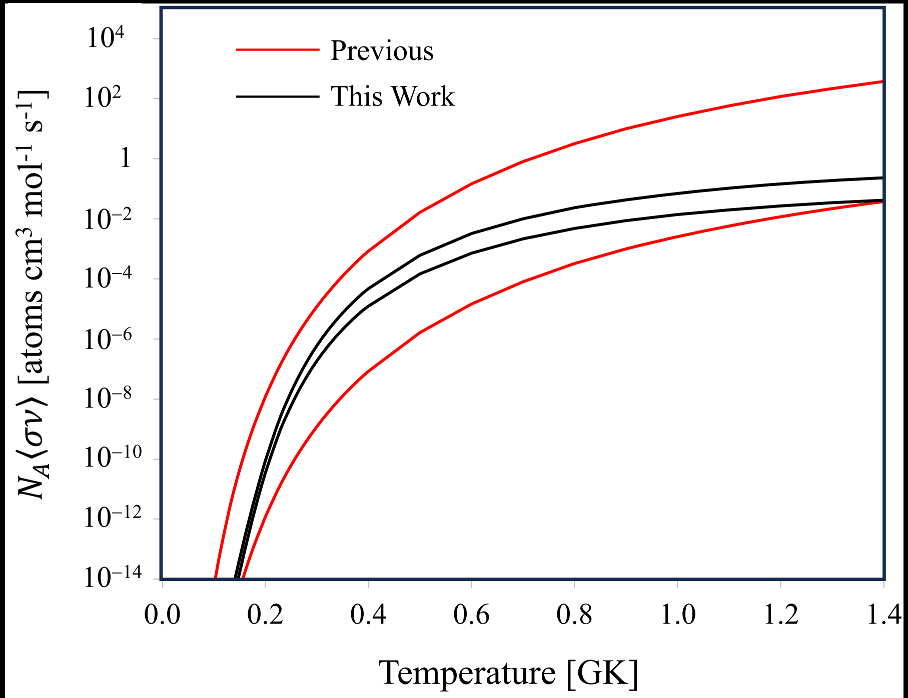
Gamma-ray Spectroscopy Study of ^{49}Mn @ ANL

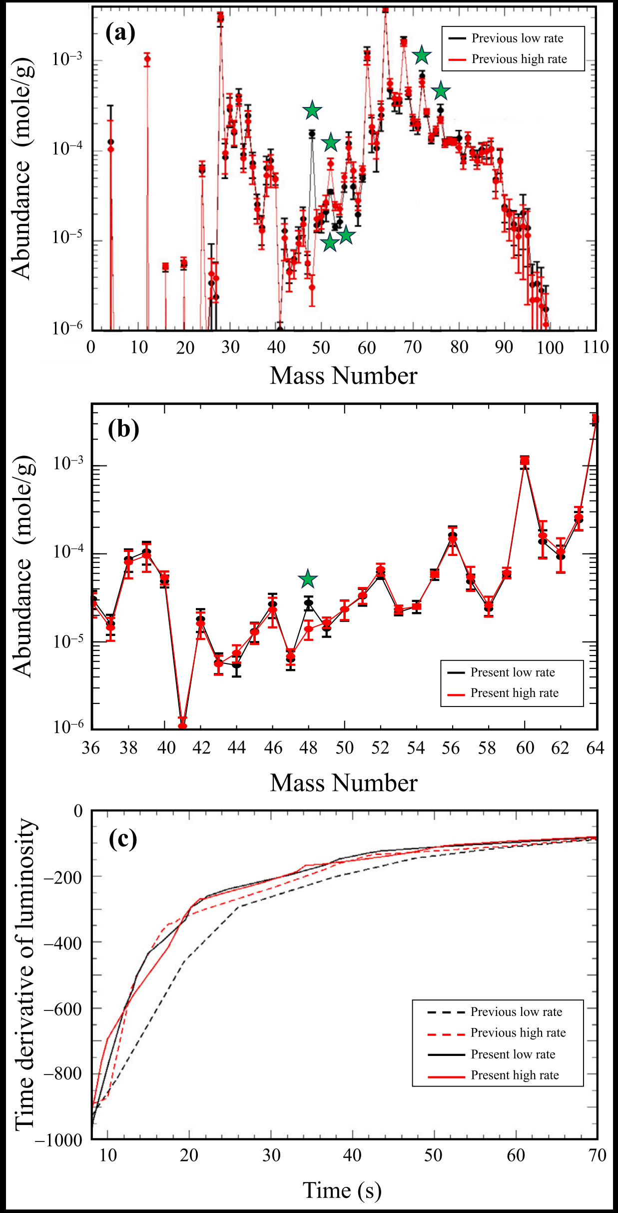


E_x (keV)	E_r (keV)	J^π	C^2S	Γ_p (eV)	Γ_γ (eV)	$\omega\gamma$ (eV)
2400.3(29)	312.3(85)	5/2$^+$	0.01	7.90×10^{-11}	6.91×10^{-4}	2.37×10^{-10}
2484.4(19)	396.4(82)	7/2$^-$	0.01	3.71×10^{-10}	5.70×10^{-2}	1.48×10^{-9}
2570.9(26)	482.9(84)	1/2$^+$	0.03	3.89×10^{-5}	5.70×10^{-4}	3.64×10^{-5}
2595.9(21)	507.9(83)	3/2$^-$	0.01	1.24×10^{-5}	1.01×10^{-2}	2.48×10^{-5}
2964.4(28)	876.4(85)	7/2$^+$	0.01	3.35×10^{-6}	8.77×10^{-4}	1.34×10^{-5}

Spectroscopic factors adopted from shell-model calculations and from comparison with ^{51}Mn

Gamma-ray Spectroscopy Study of ^{49}Mn @ ANL





C. O'Shea, G. Lotay *et al.*, Phys. Lett. B **854**, 138740 062701 (2024)

- The nominal rate is found to be lower than previously expected
- However, newly constrained uncertainties have removed the possibility of a waiting point at A = 48 in the *rp* process