Experimental study of ^{26}Al nucleosynthesis in classical novae

Nicolas de Séréville

Institut de Physique Nucléaire (Orsay)

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^{26}Al observations

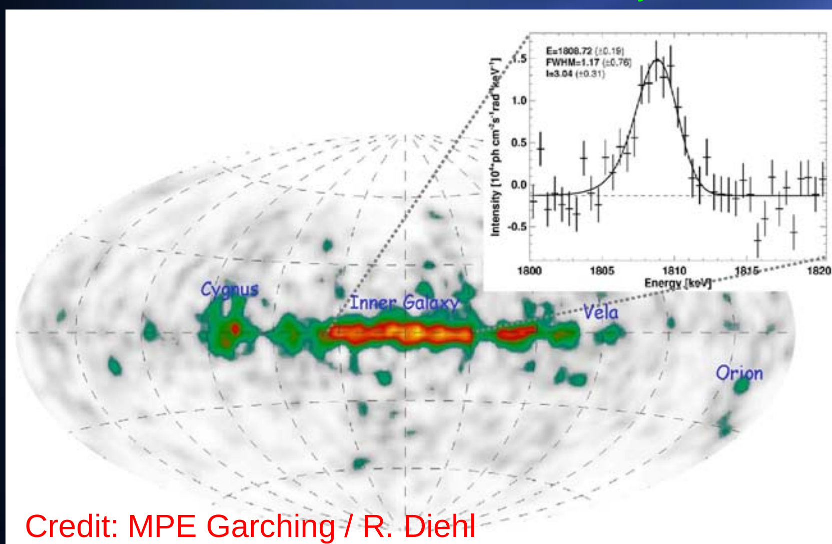
^{26}Al ($T_{1/2}$ = 7.4 10^5 yr): $^{26}\mathrm{Al} \xrightarrow{\beta+} {}^{26}\mathrm{Mg}^* \xrightarrow[1.809\ \mathrm{MeV}]{\gamma} {}^{26}\mathrm{Mg}$

Sources: ccSN, Wolf-Rayet, AGB, classical novae

γ-ray observations

- 1979-1980: Galactic center emission

Mahoney et al. 1982



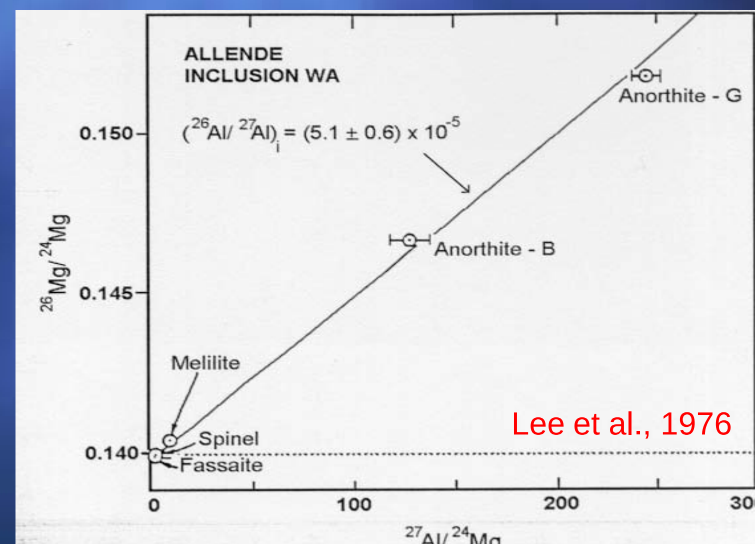
- cumulative emission in the galactic plane
- steady state mass of ^{26}Al: 2.8 ± 0.8 $M_\odot$

Source of ^{26}Al? Star formation rate

meteoritic observations

- 1976: Allende meteorite

Lee et al., 1976



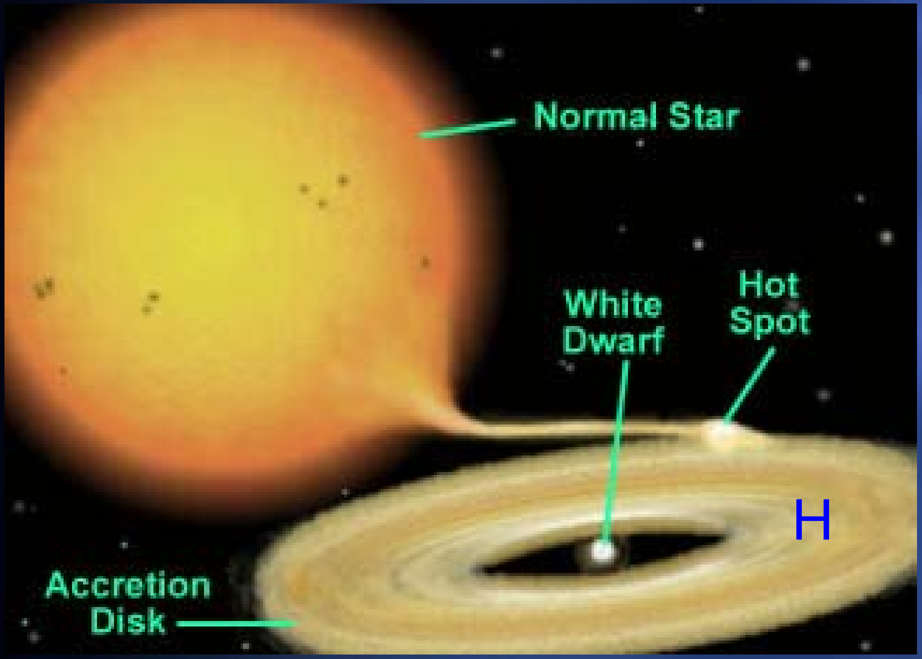
- refractory phases: CAIs
- ratio ^{26}Al/^{27}Al = 5 10^{-5} in Early SS

Astrophysical context of SS formation

Good quality yields needed → nuclear physics input

Classical novae explosion

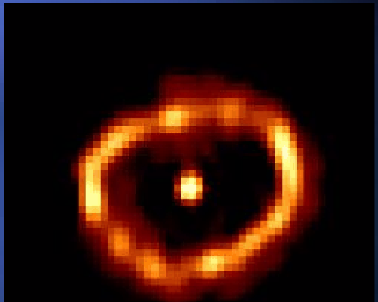
Final evolution of a close binary system



- Accretion of H-rich material on the White Dwarf from the companion

- Ignition of the combustion at the base of the envelope (degenerate conditions)
  T ≈ 50 – 300 MK

- Expansion and shell ejection



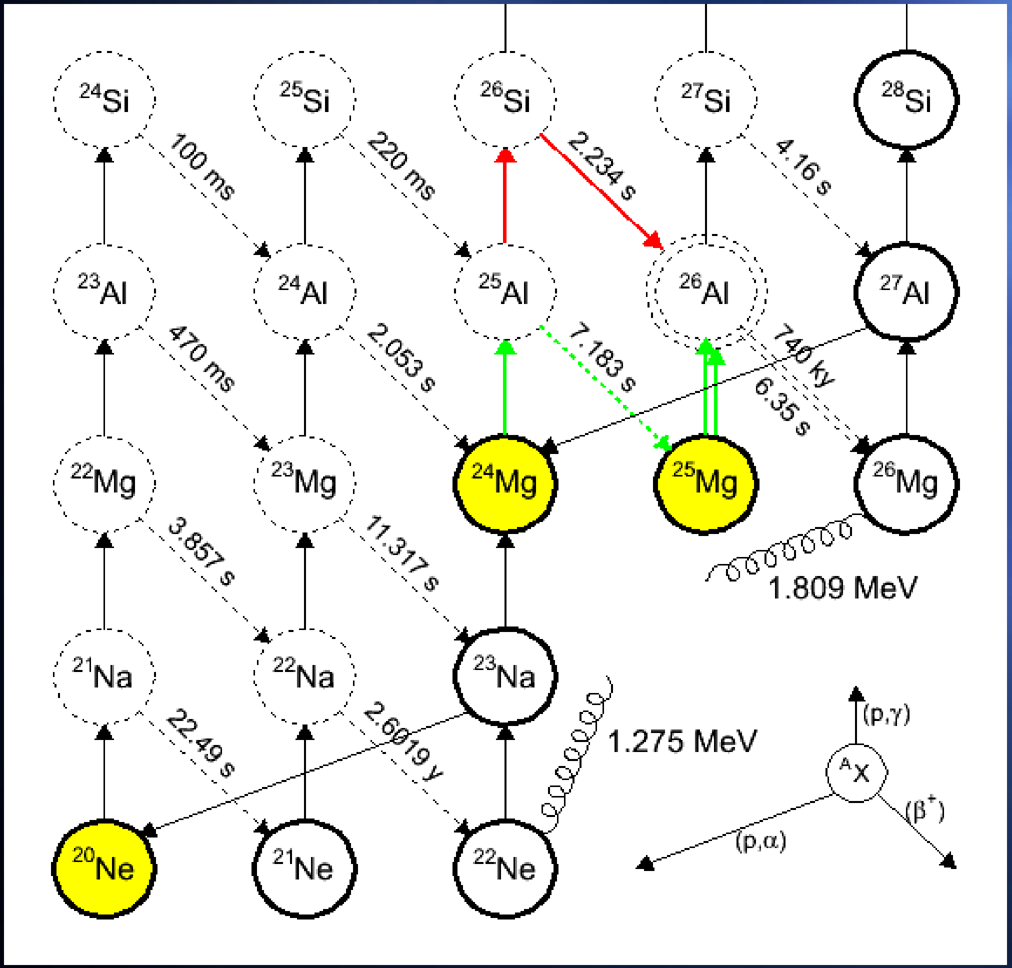
Nova Cygni 1992

- Mechanism well established but:
  → ejected mass < observed mass
  → mixing accreted material / White Dwarf

	Novae	SN II
M_{ej} (M_O)	~ 10^{-5}	~ 10
f (yr^{-1} $galaxy^{-1}$)	~ 30	~ 10^{-2}
L (L_O)	~ 10^5	~ 10^{11}
Nucleosynthesis	^{13}C, ^{15}N, ^{17}O	~ all

Novae $^{12}C^{16}O$ / $^{16}O^{20}Ne$ ($M_{WD} < 1.4\ M_{\odot}$)
→ Different properties (nucleosynthesis...)

^{26}Al nucleosynthesis and γ-ray emission at 1.809 MeV

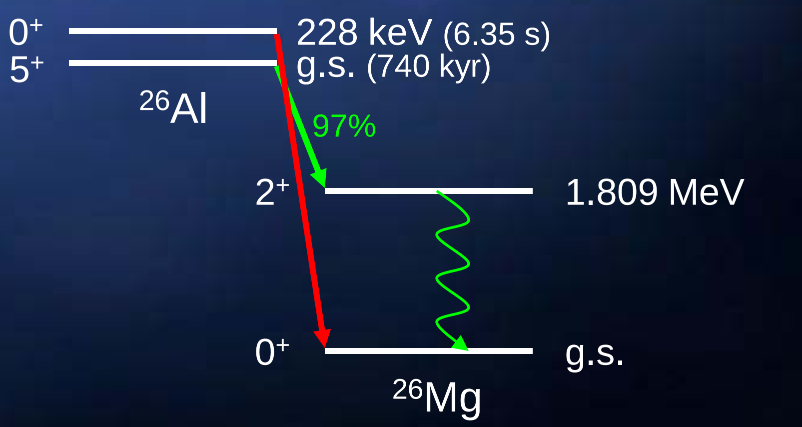


- Seed nuclei: ^{24,25}Mg
  → ONe novae

- Explosive hydrogen burning at the white dwarf surface
  → (p,γ) reactions

- Hydrodynamical calculations
  → SHIVA code (1D) José et al., 2001

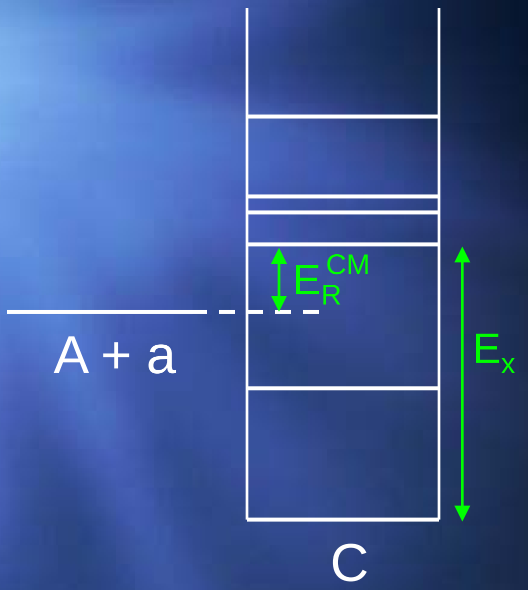
- Main nuclear uncertainty: ^{25}Al(p,γ)^{26}Si



Reaction rates & Gamow peak

Reaction rates (case of narrow resonance)

$$<\sigma v> = \left(\frac{2\pi}{\mu kT}\right)^{3/2} \hbar^2 \sum_i (\omega\gamma)_i \exp\left(-\frac{E_{R,i}^{CM}}{kT}\right)$$



Determine:

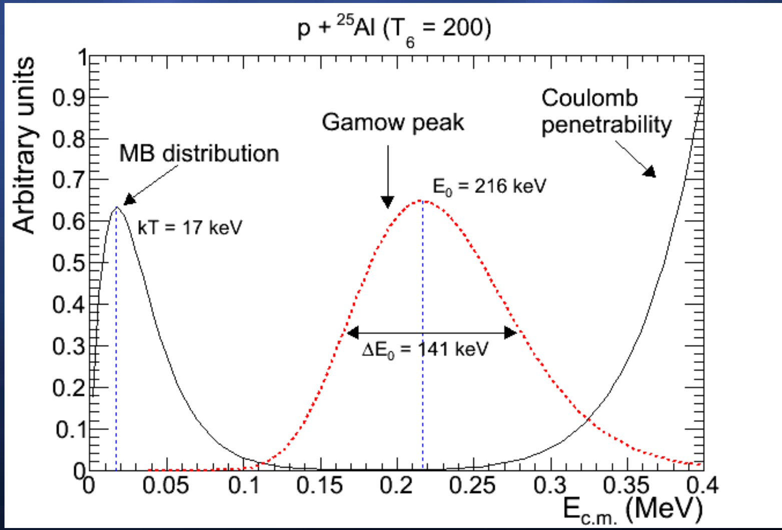
- $E_R = E_x - S_a$
- $\omega\gamma \rightarrow$ spin/parity and partial widths

Gamow peak

Two effects:

- Maxwell-Boltzman velocity distribution
- coulomb barrier

→ define C.M. energy region of interest



$^{25}Al(p,\gamma)^{26}Si$ status

1) Before 90's

(S_p = 5512 keV)

- Very little spectroscopic information available above ^{26}Si proton threshold
- Iliadis et al. 1996: shell model calculations for ^{26}Mg - ^{26}Al - ^{26}Si

→ Prediction 3+ resonance (l = 0) in novae temperature range

2) Recent high energy resolution experiments

$^{28}Si(p,t)^{26}Si$ | $^{29}Si(^3He,^6He)^{26}Si$ | $^{24}Mg(^3He,n)^{26}Si$ | ^{26}P β+ decay | $^{28}Si(p,t)^{26}Si$

QuickTime™ and a
BMP decompressor
are needed to see this picture.

DWBA | Shell-model | Compound nucleus | Shell-model | DWBA

3) Objectives

- Locate 3+ level
- determine spins of first three proton-unbound levels
- determine branching ratio $\Gamma_\gamma / \Gamma_{tot}$

Experimental method

Populate ^{26}Si levels above proton threshold: $^{24}Mg(^{3}He,n)^{26}Si^{*}(\gamma)^{26}Si_{g.s.}$

- High cross-section (50-130 μb / sr)
- Three levels of interest populated (CN mechanism)

n - γ coincidence measurement

1) Spin/partiy determination

- angular momentum selection rules
- comparison with known γ-ray decay from ^{26}Mg
- n-γ angular correlations

$\rightarrow$ Rolfs et al., 1968: spins of 5 first ^{26}Si excited states

QuickTime™ and a
BMP decompressor
are needed to see this picture.

2) Determination of branching ratio $\Gamma_{\gamma}/\Gamma_{tot}$

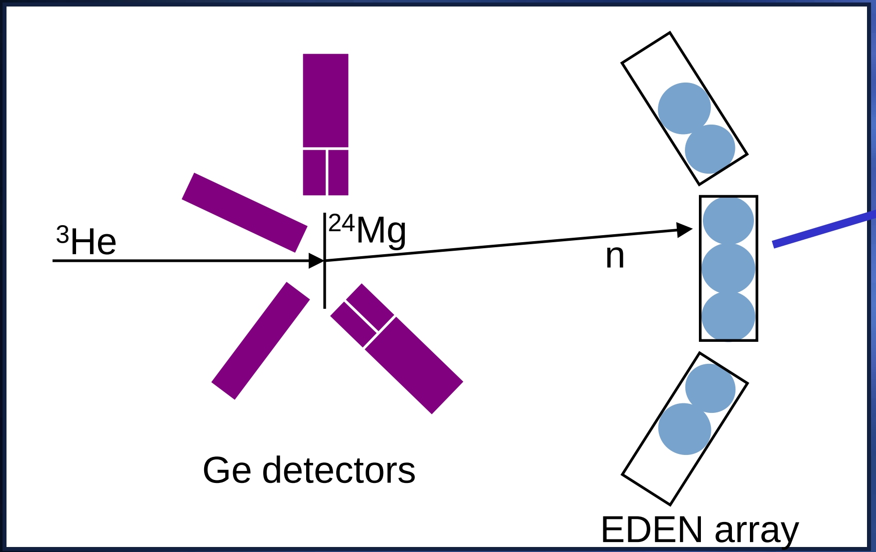
- Compare coincidence / single neutron spectra
- For the doublet E_X = 5.912 - 5.946 MeV

$\rightarrow$ Population from Parpottas et al. 2004

QuickTime™ and a
decompressor
are needed to see this picture.

Experimental set-up

$^{24}Mg(^{3}He,n)^{26}Si^{*} \rightarrow \gamma + {}^{26}Si_{g.s.}$



^{3}He beam @ TANDEM Orsay

- E = 7.9 MeV
- I = 25 nAp

EDEN neutron detector array

- 36 modules @ 1.75 m
  - → energy resolution
  - → $\Delta\Omega$ = 350 msr

Ge detectors

- 2 coaxials (Eurogam)
- 2 clovers

^{24}Mg targets

- high purity: 99.85%
  - → $^{12}C, {}^{16}O(^{3}He,n)$ high cross-section
- backing: 0.2 mm Ta
  - → stop the beam
  - → small neutron absorption
- thickness: 150 μg/cm^2 + 250 μg/cm^2
  - → Counting rate v.s. energy resolution

Properties of EDEN detectors

Detector characteristics (Laurent et al., NIM A326 (1993), 517)

- NE213 organic liquid scintillator
- ϕ 20 cm x L 5 cm
- E_n ~ 1 MeV - 6 MeV
- ε ~ 50% - 30%

Neutrons identification

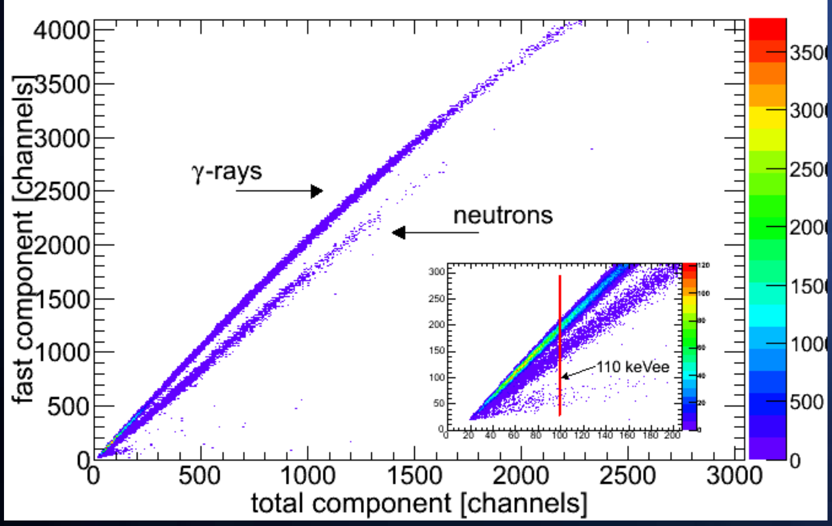
- n + p, n + ^{12}C
- γ + e- (Compton, low Z material)

→ Pulse shape analysis

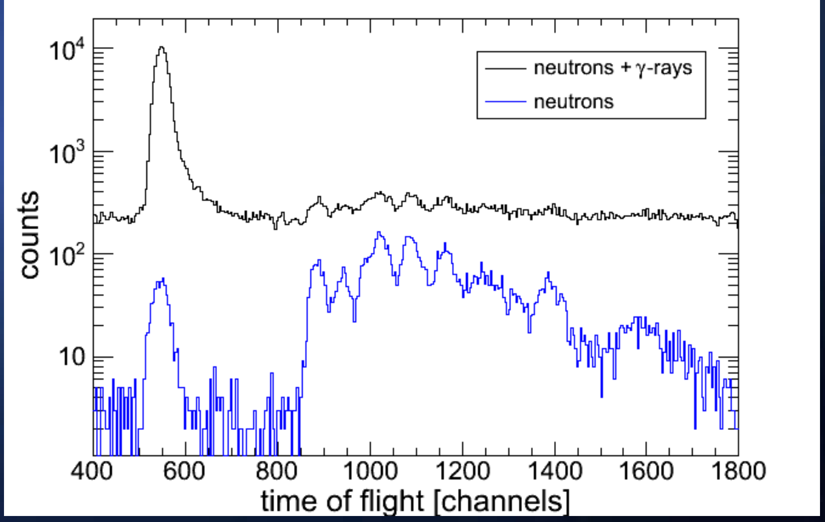
Energy measurement

- time of flight measurement
- Δt ≈ 1 ns

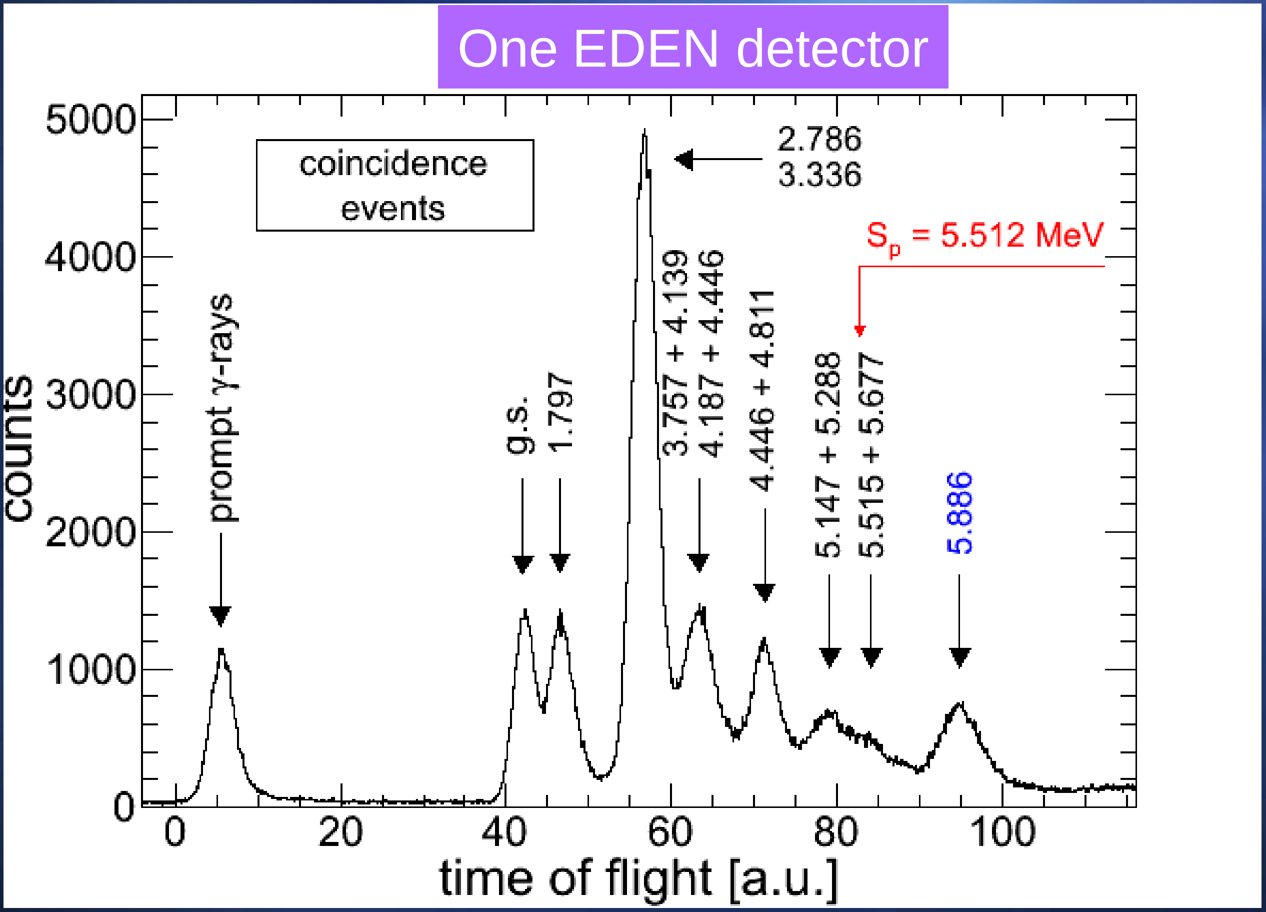
Identification spectrum



Time of flight spectrum



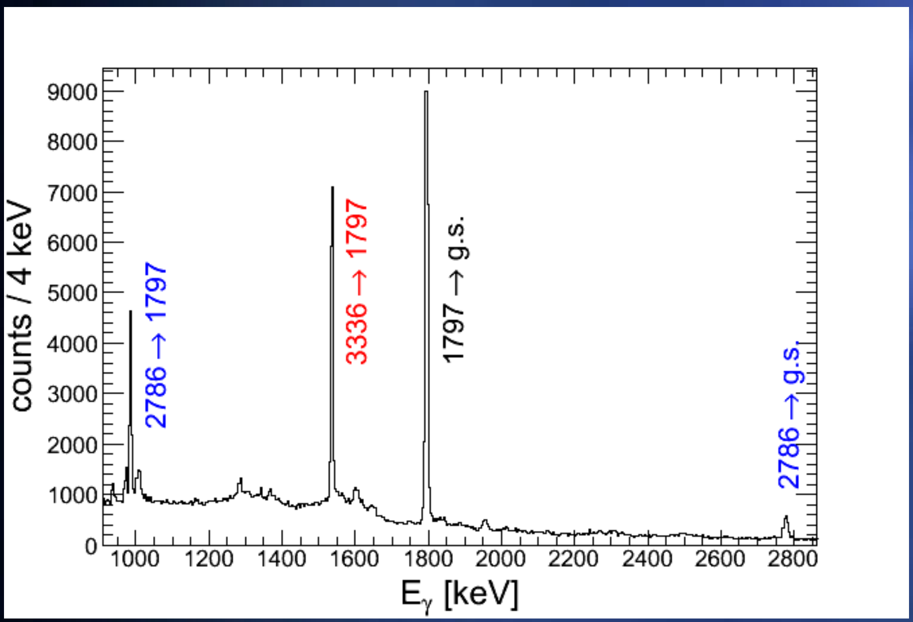
Neutron time of flight spectrum



- All ^{26}Si levels below proton are populated
- No indication of states at E_x = 3.842 MeV and E_x = 4.093 MeV as previously reported by Bell et al., 1969.

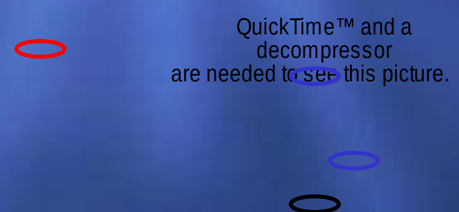
^{26}Si bound states

Coincidence γ-ray spectrum



- One Ge detector in coincidence with all EDEN array
- More intense neutron peak selected
  → Clean γ-ray spectrum

^{26}Si level scheme



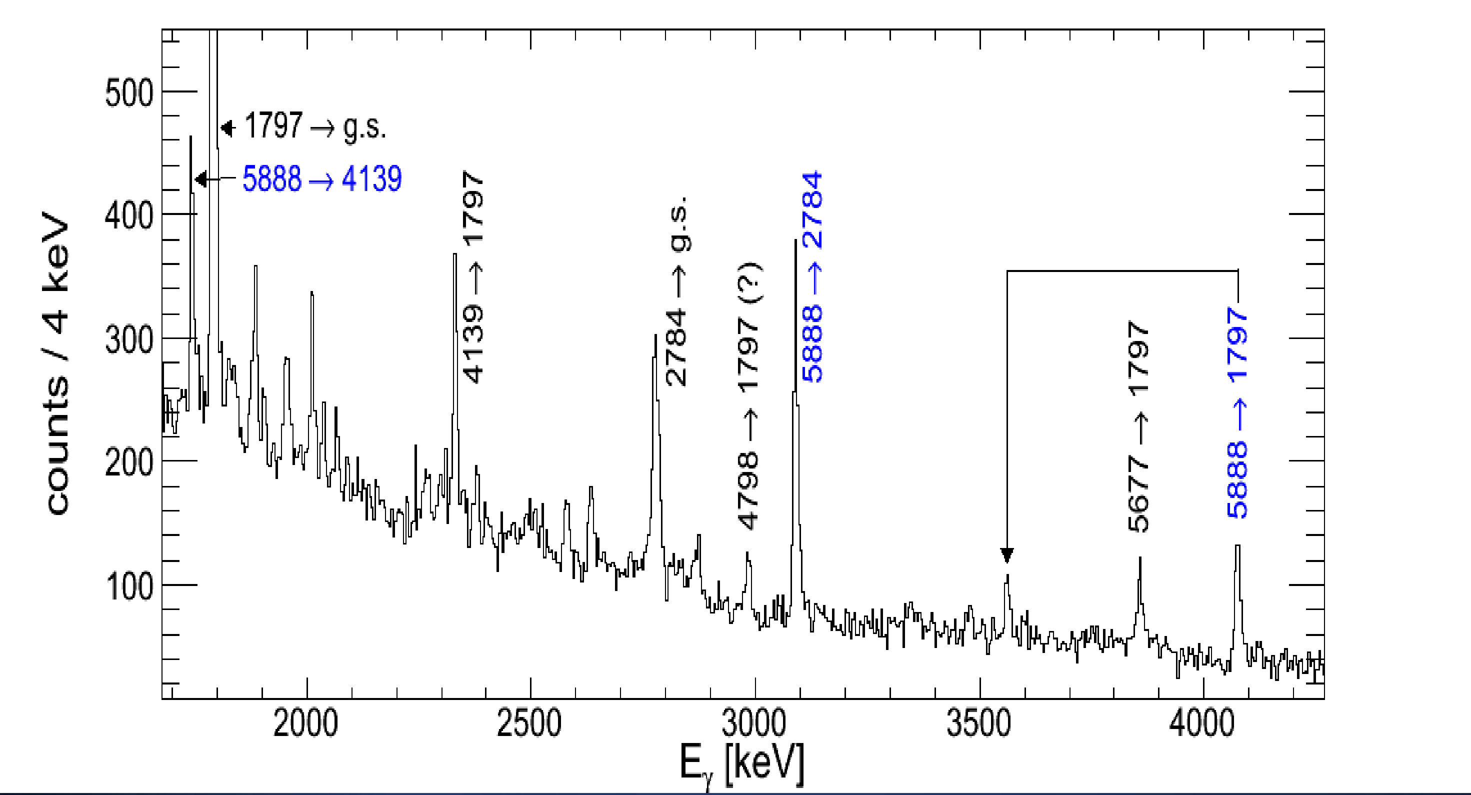
(Seweryniak et al., 2007)

In-beam γ-ray spectroscopy with Gammasphere: $^{12}C(^{16}O,2n)^{26}Si$

All known γ-ray transitions are observed

^{26}Si proton-unbound states

Coincidence γ-ray spectrum



- First two resonances at E_X = 5517, 5677 keV observed
- New γ-ray transitions at 1.749 (2), 3.102 (2), 4.091 (2) MeV

→ New proton-unbound state at E_X = 5.888 (2) MeV (E_R = 376 keV)

(also reported by Komatsubara et al., OMEG10)

Summary & On-going analysis

^{26}Al nuclei important both in γ-ray astronomy and pre-solar grains
→ classical novae are potential contributors

Major uncertainty for the 1.809 MeV γ-ray emission: $^{25}Al(p,\gamma)^{26}Si$
→ location of l = 0 (J^{π} = 3+) resonance

Present experiment: coincident measurement $^{24}Mg(^{3}He,n\gamma)^{26}Si$
→ new resonance in the Gamow peak region

- Extract γ-ray angular distribution / correlation
- Determine spin and parity of new resonance
- Search for higher energy proton-unbound states

Collaboration

N. de Séréville, M. Assié, I. Bahrini, D. Beaumel, M. Chabot, M. Ferraton, S. Fortier, S. Franchoo, S. Giron, F. Hammache, M. Lebois, F. Marechal, A. Matta, B. Mouginot, C. Petrache, P. Roussel, J.A. Scarpaci, I. Stefan, D. Verney
(IPN, Orsay, France)

A. Coc, I. Deloncle, J. Duprat, C. Hammadache, J. Kiener, A. Lefebvre-Schuhl
(CSNSM, Orsay, France)

F. De Oliveira, F. de Grancey, J.C. Thomas
(GANIL, Caen, France)

M. Fallot, L. Giot
(Subatech, Nantes, France)

L. Lamia, R. G. Pizzonne, S. Romano
(LNS, Catania, Italy)