

# Project SPIRAL2-CZ and nuclear astrophysics collaboration with GANIL/SPIRAL2

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**Nuclear Physics Institute of the CAS, Rez, Czech Republic**

April 26, 2019



EUROPEAN UNION  
European Structural and Investment Funds  
Operational Programme Research,  
Development and Education



MINISTRY OF EDUCATION,  
YOUTH AND SPORTS

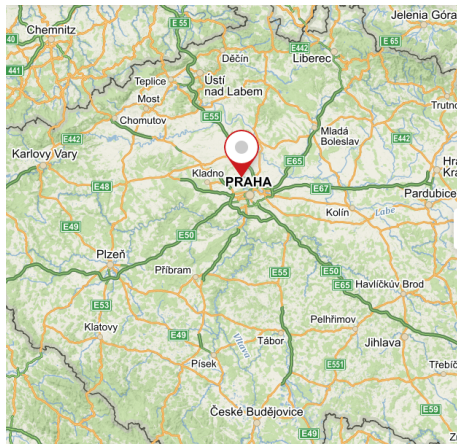
- 1 NPI CAS
  - location and the experimental base
  
- 2 Project SPIRAL2-CZ
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- 3 Nuclear astrophysics in Řež
  - Asymptotic Normalization Coefficients
  - Trojan Horse Method
  - $^{26}\text{Al}$  efforts

# Nuclear Physics Institute of the CAS

- Located near Prague in Řež

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 $p^+ / H^-$ : 5.4–38 MeV,  
 $D^+ / D^-$ : 11–20.5 MeV,  
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- Cyclotron TR24 (new)  
 protons 8 MeV to 24 MeV, CUSP ion source, up to 300  $\mu A$
- Tandatron 4130 MC (3MV)  
 $H^- - Au$  0.4–20 MeV up to tens of mA  
 RBS, RBS-channeling, ERDA, ERDA-TOF, PIXE, PIGE, ion microprobe 1  $\mu m$



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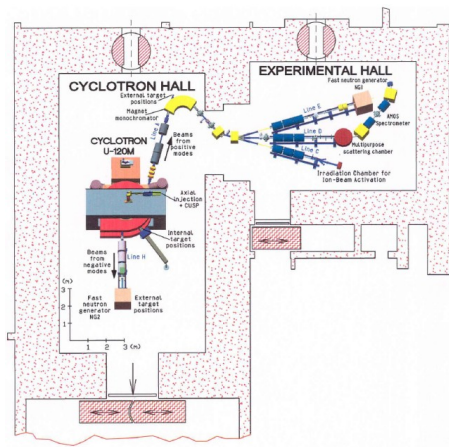
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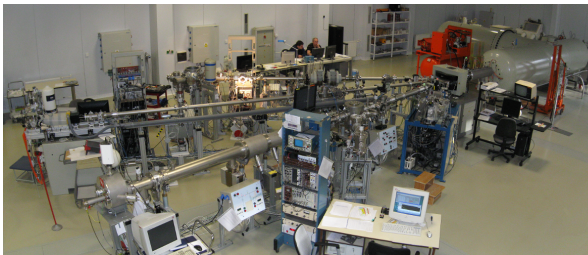
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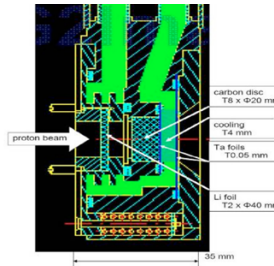
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- Fast Neutron Generators (FNG)

see talk of M. Ansorge





## activation by neutrons

## Measurement on Delayed Neutrons from Fast Fission

David HLADEK

Miroslav HRODINA, Petr ŠTĚPÁNEK, Petr ŠTĚPÁNEK, Petr ŠTĚPÁNEK, Petr ŠTĚPÁNEK

**Abstract**

Measurements were carried out at the Cyclotron Institute of the Czech Academy of Sciences, Brno. The experiment was designed to measure the time distribution of the delayed neutrons from fast fission. The experiment was carried out at the Cyclotron Institute of the Czech Academy of Sciences, Brno.

### Introduction

Small samples of the  $^{235}\text{U}$  were irradiated with quasi-monoenergetic neutrons from the cyclotron U-120M with p-Li converter at several peak neutron energies in the range of 17-55 meV and delayed neutrons (DN) were measured.

BF detectors were chosen for the measurement of time distribution of the DN, but the measurement process needed to be invented to avoid saturation of the detectors as well as detecting even the shortest decay group (in the range of 0.5 s). Arduino Nano is the key unit for controlling the cyclotron as well as the detectors, and prevent the mentioned obstacles.

### Measurement process I

At first, it is needed to set up measurement station, which include Digitizer, Amosco and Pulse generator.

The most important part is the Amosco device with three output signals as shown at Fig. 1.

- Signal for the detectors
- signal for the cyclotron
- Resetting signal

Measuring period is set to 5 weeks of irradiation and 2 weeks of measurement.

Pulse generator is there to provide constant, low amplitude pulse. It is used to synchronize the different channels in the digitizer.

Fig. 1: Three signals generated by Amosco. Amosco is a device that generates three signals: Amosco signal, Pulse generator, and Digitizer. The diagram shows the timing of these signals. Below the diagram is a photograph of the Amosco device.

### Measurement process II

Inside the cyclotron room, there should be only devices that do not need any configuration during the measurement, such as:

- Detector sample
- BF detectors
- Preamplifier + 230 V source

Detectors are laid down in a moderator and connected to the preamplifier, powered by 42 V source. Signals from the preamplifier are sent to the entrance through relays. In case the relays are on, digitizer starts to collect data.

at last, beam gun is placed to the centre of the moderator.

Fig. 2: Scheme of the measurement. The diagram shows the layout of the measurement station. It includes a Cyclotron, Amosco, Digitizer, and BF detectors. The Amosco is connected to the Cyclotron and the Digitizer. The BF detectors are connected to the Amosco and the Digitizer. The Digitizer is connected to a PC. Below the diagram is a photograph of the measurement station.

### Data processing

Output from the digitizer needs several adjustments. As shown at Fig. below, data file contains 3 columns

- Time in microseconds
- Amplitude of the pulse
- Time stamp

Fig. 3: Example of data processing. The diagram shows a data file with three columns: Time (μs), Amplitude, and Time stamp. The data is processed to show a decay curve. Below the diagram is a photograph of the digitizer.

obtained decay curve has to be fitted, using decay law of natural uranium (1). result is shown at Fig. 3.

$$y(x) = a_1 \times e^{-b_1 x} + a_2 \times e^{-b_2 x} + a_3 \times e^{-b_3 x} + a_4 \times e^{-b_4 x} + a_5 \times e^{-b_5 x} + a_6 \times e^{-b_6 x} \quad (1)$$

$b_1$	0.021402
$b_2$	0.021402
$b_3$	0.111048
$b_4$	0.021402
$b_5$	1.184007
$b_6$	1.011488

### Future improvement

Things we would like to implement and improve in the near future:

- Create a measurement stand with fixed moderator layout for irradiated samples and detector
- Compare the resulting decay curve of delayed neutrons with simulations - namely

General Fission Model (GFM)

- measure the ratio between the delayed neutrons and the total fission products
- conduct further research using  $^{235}\text{U}$

see poster of D.Hladik for delayed neutron's measurement

■ Project RAMSES

AMS 300kV

spectrometer to 2020+

Determination of long-lived

radio-nuclides

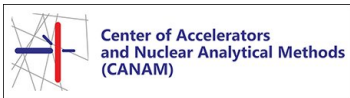
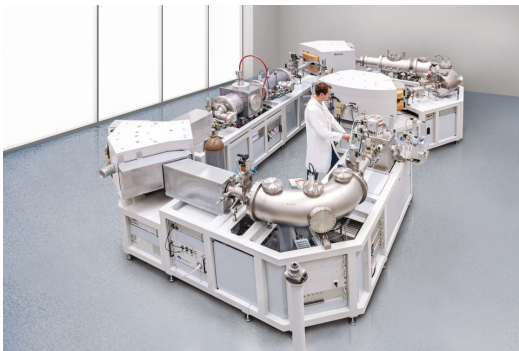
$^{14}\text{C}$ ,  $^{10}\text{Be}$ ,  $^{26}\text{Al}$ , cosmogenic

nuclides

actinides and fission products at

levels or in amounts up to  $10^{-6}$

lower compared to decay counting methods



## Project SPIRAL2-CZ

SPIRAL2-CZ as the project of Czech support to GANIL/SPIRAL2

## Timeline of the project

- 2011 - **LEA NuAG**<sup>1</sup> - first official support of collaboration NPI CAS and GANIL
- **2015**- SPIRAL2 in *Roadmap of Large Infrastructures for Research, Experimental Development and Innovation of the Czech Republic for the years 2016-2022*
- 2015 - **LIA NuAG** - prolongation
- **2016** - **MEYS**<sup>2</sup> financing the international abroad infrastructure SPIRAL2-CZ ~ 8-12 people on the project
- **2017** - **MEYS** and **EU Operational Program - research, development and education** financing the investments to the infrastructure SPIRAL2-CZ OP
- 2019 - green light for the next **LIA NuAG**
- **June 2019** - next call of the **EU OP** program for investments
- **2020** - expecting the continuation of the **MEYS** support for running costs



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<sup>1</sup>Laboratoire Européen Associé - Nuclear Astrophysics and Grids

<sup>2</sup>Ministry of Education, Youth and Sports

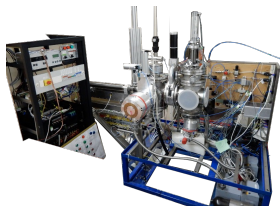
## content of the project

**Two** main activities within the project:

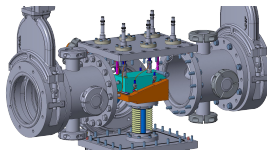
- Nuclear astrophysics
- Activation by charged particles and neutrons

**Three** investments within the project:

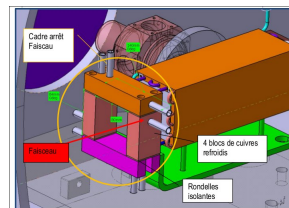
Irradiation Chamber (IC) for activation on NFS



Target for radioisotopes with medical potential



Target for production of radioactive beams



see the poster of Eva Šimečková

yesterday's talk of Gilles and Ondrej

Astrophysics interest

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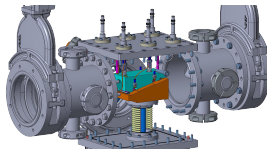
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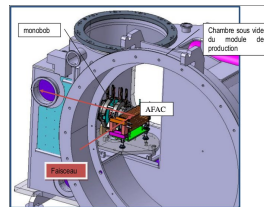


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# activation by charged particles

Irradiation Chamber (IC)  
Pneumatic transport System  
(PTS)

see poster of Eva Šimečková

www.spiral2.cz

## Activation measurements at GANIL/SPIRAL2-NFS

E. Berežná, J. Miksa, R. Bidař, V. Žalozal, M. Pátek, M. Douchay, S. Ševčík, J. Dufek, A. Lebel, M. Beránek, P. Ben, F. Veselý,  
Nuclear Physics Institute of the CAS, Řad. 1, 25068 Řež, Czech Republic [spiral2@nps.jil.go.jp](mailto:spiral2@nps.jil.go.jp)  
A.K.H. U'Fahes, T. Pflaum et al., Karlsruhe Institute of Technology, Karlsruhe 76131, Germany [spiral2@nps.jil.go.jp](mailto:spiral2@nps.jil.go.jp)  
S. Lefebvre et al., GANIL, Bd. Henry Becquerel, Caen, France

**Abstract:** The activation experiments are important for both basic research and nuclear data measurement and validation. The future energy technologies need quality activation data for different construction materials not only by neutrons (ITER) but also by deuterons (PFZ) for central plasma and the superheating, life cycle and decommission phases. The neutron activation results show the need of careful theoretical description of all processes involved in reaction. The advance in the theory is important for cases that are not reachable experimentally and/or for better understanding of the underlying physics. The studies of activation by alpha particles and protons are important also for future development of nuclear technologies.

**The Irradiation Chamber (IC)** developed in NPI CAS is a system of vacuum chambers and mechanics, coupled to a Pneumatic Transfer System (PTS), developed in KIT Karlsruhe, that enables to irradiate samples in a beam of charged particles (in vacuum) and to transfer the irradiated sample to the HPGe detector online. The system will enable systematic activation measurements in SPIRAL2-NFS as well as measurements of isotopes with short half-lives in sub-cycle regime.

Cyclotron U-120M in NPI CAS → GANIL/SPIRAL2 - NFS

**Research will be extended to measurement of activation of isotopes with short half-lives**

**Proposal E714**

**Research will be extended to higher incident energies for deuterons**

**Pilot tests of IC in NPI CAS, Řež**

These were carried in beam tests conducted in NPI CAS Řež:

- mechanical tests and control SW
- integrator function
- current measurement in a Faraday cup
- behavior with the intense beam
- maximum speed of sample transfer

The tests were performed with protons,  $^3\text{He}$  and  $^4\text{He}$  ions. The tests appeared like very important, not only for debugging of the system, but also for finding a proper mode of operation.

**GANIL/SPIRAL2 - NFS**

**The irradiation chamber was developed, constructed and tested in NPI and installed in GANIL/SPIRAL2 - NFS**

**PTS - Pneumatic Transfer System** constructed and built in KIT Karlsruhe - installed in NPI CAS. It transports the sample (with a lead shield) to the HPGe detector, where it is put into a shielded plastic.

**The graphs show selected measurements during the tests in NPI Řež above:**

- 1) On the left-hand side, the dependence of the current on the repetition rate of the cyclotron.
- 2) The full curve shows that the data for short half-lives (tau - red) can be also selected.

Transport and installation of IC in SPIRAL2-NFS - 2017

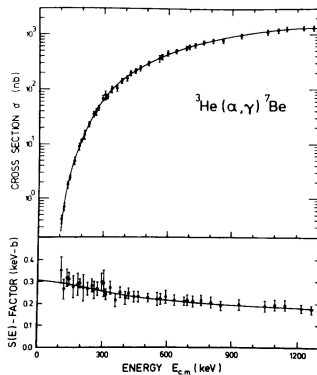
The carrier system is based on the NPI CAS and the active microprocessor with communication by RS-485 and ethernet. The commissioning is progressing in Caen.

## Nuclear astrophysics

# Nuclear astrophysics (in Řež and in collaborations)



The problem of the measurement of charged particle reaction cross sections at low energies  
– is the Coulomb barrier



The problem of the measurement of charged particle reaction cross sections at low energies

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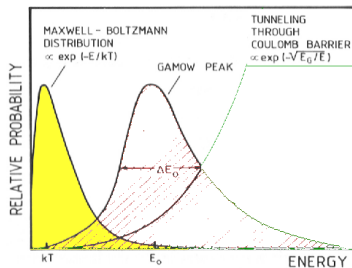
reaction	Coulomb barrier [MeV]
p+p	0.55
$\alpha+^{12}\text{C}$	3.43
$^{16}\text{O}+^{16}\text{O}$	14.7

	T [ $10^6\text{K}$ ]	kT [keV]
Sun - core	15	1
AGB star -(H)	90	8
AGB star (He)	300	38
Classical Nova	100 - 400	10 - 50

The problem of the measurement of charged particle reaction cross sections at low energies

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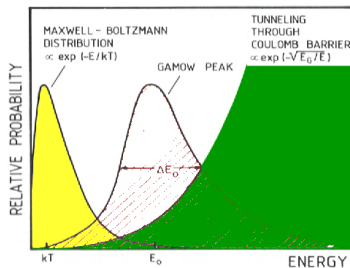
- high energy tail of Maxwell distribution



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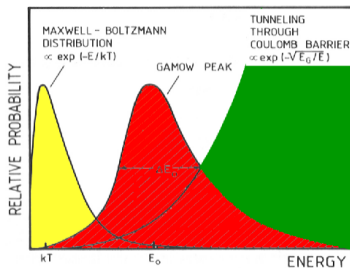
- high energy tail of Maxwell distribution
- tunneling through the Coulomb barrier



The problem of the measurement of charged particle reaction cross sections at low energies

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- high energy tail of Maxwell distribution
- tunneling through the Coulomb barrier
- **Gamow peak**

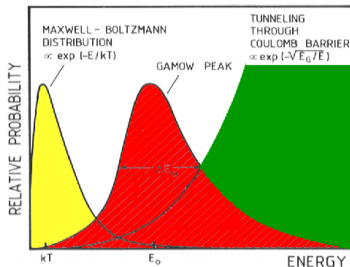


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**How to face the low x.s. in measurements ?**



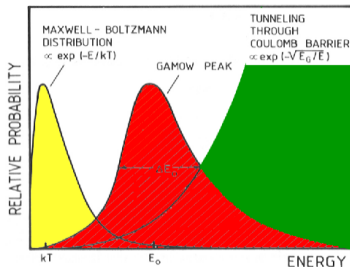
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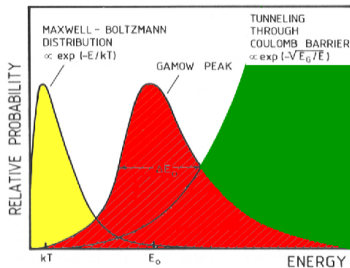
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- **indirect methods**
  - Asymptotic Normalization Coefficients
  - Trojan Horse Method



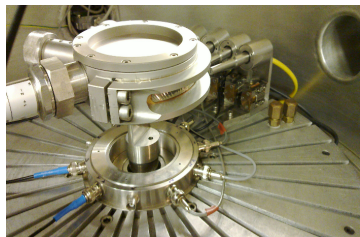
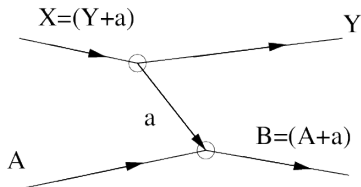


# Asymptotic Normalization Coefficients

**Trick:** Deducing the **direct radiative capture** cross section from direct transfer reaction

**Benefit:** Overcoming the Coulomb barrier

**Conditions:** The reaction must be direct process and be peripheral.



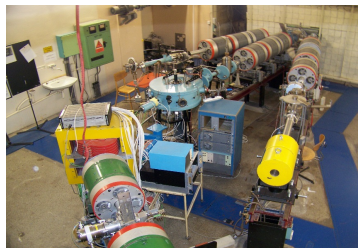
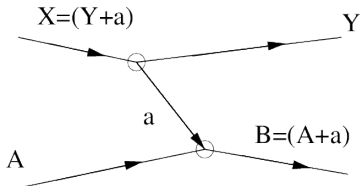
Typical setup of ANC experiment - with gas target

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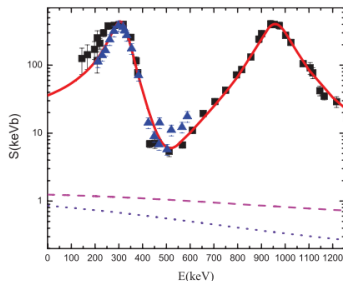
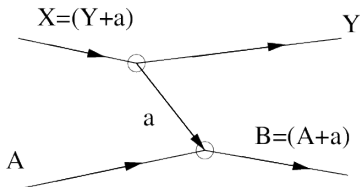
The experimental hall in NPI CAS

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The example of the result applied to the resonances and the R-matrix fit of the resonances in  $^{16}\text{O}$  for  $^{15}\text{N}(p, \gamma)^{16}\text{O}$

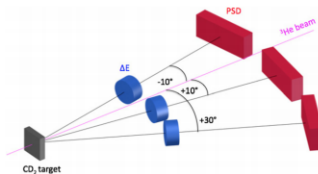
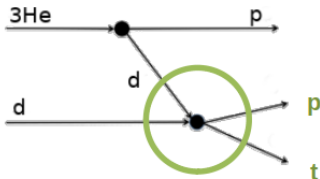
# Trojan Horse Method

collaboration with INFN LNS Catania:  
C.Spitaleri, M.LaCognata, G.Pizzone,  
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**Trick:** extraction of the two-body process from the three-body reaction.

**Benefit:** Overcoming the Coulomb barrier and the electron screening

**Conditions:** careful selection of the quasi-free component of the three-particle process.



Typical setup of THM experiment

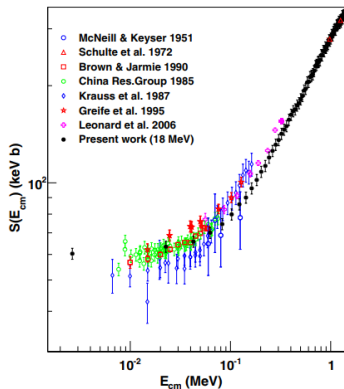
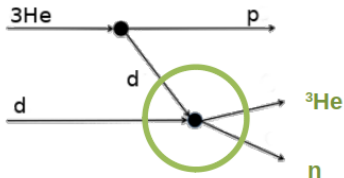
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The extracted S-factor (analog to cross section) for  $d+d \rightarrow {}^3\text{He} + n$

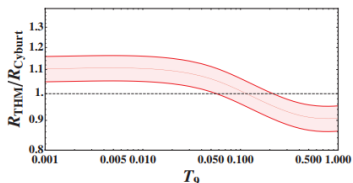
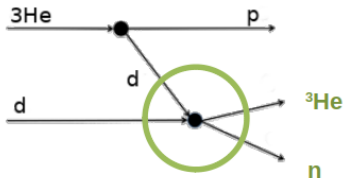
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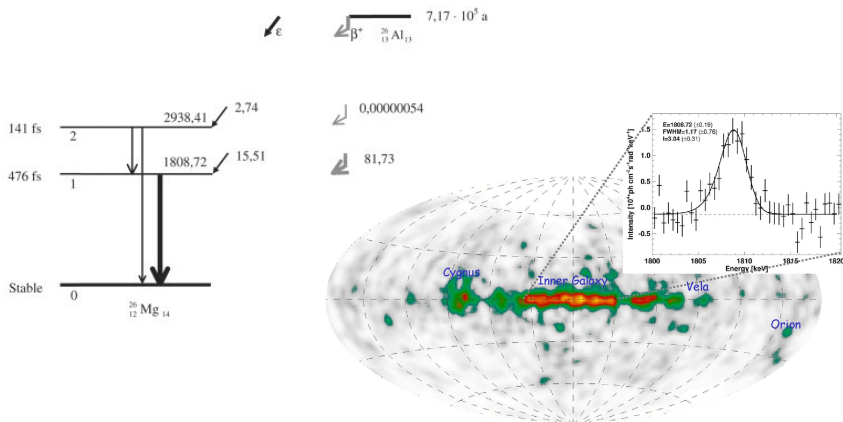
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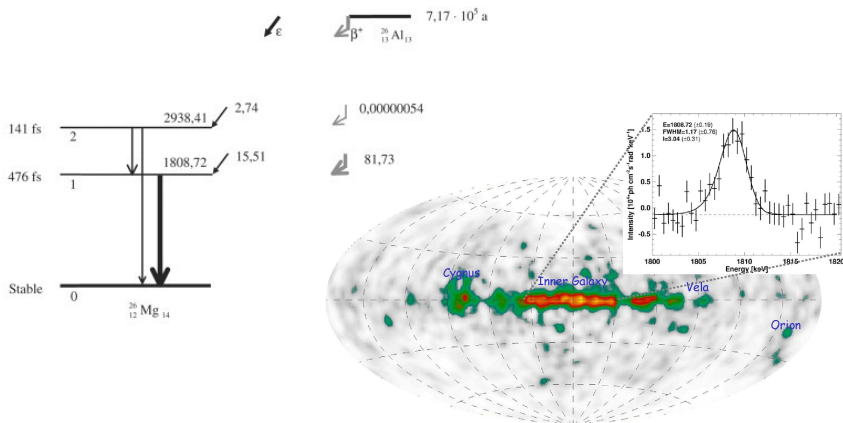
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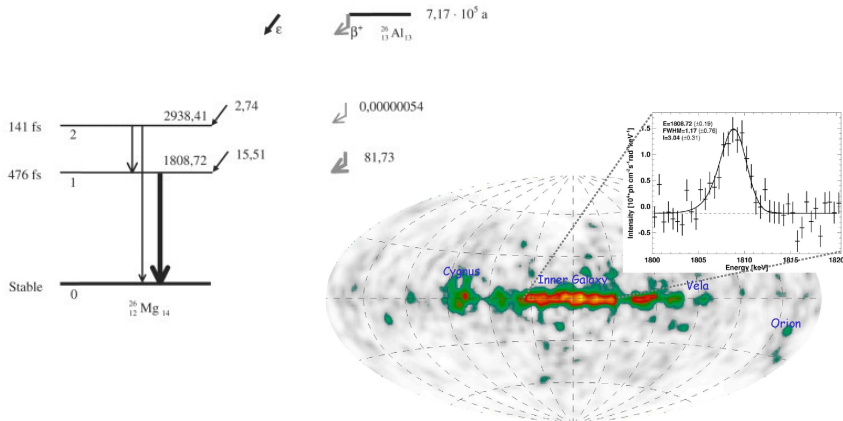
New reaction rate margins relative to the current accepted values from NACRE

COMPTTEL and INTEGRAL/SPI observations of  $^{26}\text{Al}$ 

COMPTTEL and INTEGRAL/SPI observations of  $^{26}\text{Al}$ 

3 solar masses of  $^{26}\text{Al}$  in our galaxy  $T_{1/2} \sim 700$  ky

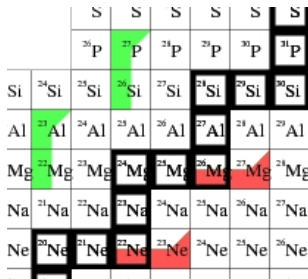
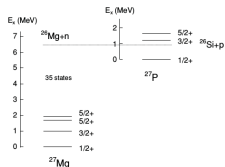


COMPTEL and INTEGRAL/SPI observations of  $^{26}\text{Al}$ 

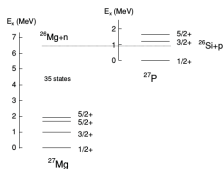
3 solar masses of  $^{26}\text{Al}$  in our galaxy  $T_{1/2} \sim 700$  ky

Conclusions: origin is mostly massive stars (ccSN, Wolf-Rayet stars?)

We analyze reaction  $^{26}\text{Mg}(d,p)^{27}\text{Mg}$  to deduce **ANC** for mirror  $^{26}\text{Si}(p,\gamma)^{27}\text{P}$   
*Bypass of Mg-Al cycle through  $^{25}\text{Al}(p,\gamma)$*   
*(contradicting experimental conclusions)*

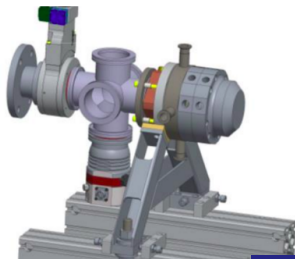


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		S	S	S	S	S	S
		$^{30}\text{P}$	$^{27}\text{P}$	$^{21}\text{P}$	$^{29}\text{P}$	$^{30}\text{P}$	$^{31}\text{P}$
Si	$^{24}\text{Si}$	$^{28}\text{Si}$	$^{26}\text{Si}$	$^{27}\text{Si}$	$^{28}\text{Si}$	$^{29}\text{Si}$	$^{30}\text{Si}$
Al	$^{23}\text{Al}$	$^{24}\text{Al}$	$^{25}\text{Al}$	$^{26}\text{Al}$	$^{27}\text{Al}$	$^{28}\text{Al}$	$^{29}\text{Al}$
Mg	$^{22}\text{Mg}$	$^{23}\text{Mg}$	$^{24}\text{Mg}$	$^{25}\text{Mg}$	$^{26}\text{Mg}$	$^{27}\text{Mg}$	$^{28}\text{Mg}$
Na	$^{21}\text{Na}$	$^{22}\text{Na}$	$^{23}\text{Na}$	$^{24}\text{Na}$	$^{25}\text{Na}$	$^{26}\text{Na}$	$^{27}\text{Na}$
Ne	$^{20}\text{Ne}$	$^{21}\text{Ne}$	$^{22}\text{Ne}$	$^{23}\text{Ne}$	$^{24}\text{Ne}$	$^{25}\text{Ne}$	$^{26}\text{Ne}$

**Project of THM** with INFN LNS and GANIL with  $^{26}\text{Al}$  beam ( $p,\alpha$ )  
 preparation of  $70\mu\text{g}$  of  $^{26}\text{Al}$  from  $^{26}\text{Mg}$   
 using new Hi-Power target developed for neutron generators (see the talk of Martin Ansorge).



Thank you for the attention,  
thanks to the organizers