Determination of $^{118}Sn(p,\gamma)^{119}Sb$ cross-section at astrophysical energies from X-ray emission yields

Manuel Xarepe, Daniel Galaviz, Jorge Sampaio, Pamela Teubig, José Pires Marques, Luís Peralta

Introduction

The stellar synthesis of elements heavier than Fe is explained by slow (s) and rapid (r) neutron captures in explosive events (e.g. supernovae and kilonovae). About 35 proton-rich naturally occurring isotopes between Se and Hg cannot be produced via β^- decay, which means they cannot be produced solely by neutron capture processes. The reaction network for the production of p-nuclei combines (γ, n) and (p, γ) reactions on preexisting s- and r-process seed nuclei.

In view of the huge number of reactions involved, stellar networks will always have to rely on cross-sections obtained with theoretical models. It is of utmost importance to validate these models on a grid of experimental cross-sections spread over the entire reaction network. Such data is crucial since the calculated cross-sections exhibit uncertainties of several hundred percent even for stable isotopes.

In this work, **the Activation Method** is used to measure for the first time the cross-section in the Sn p-process chain – **the radiative proton capture reaction $^{118}Sn(p,\gamma)^{119}Sb$**. The γ-emission associated to the electron capture to the excited state of ^{119}Sb will be used to validate the method.

^{119}Sb decay scheme

Electron capture and γ-emission decay
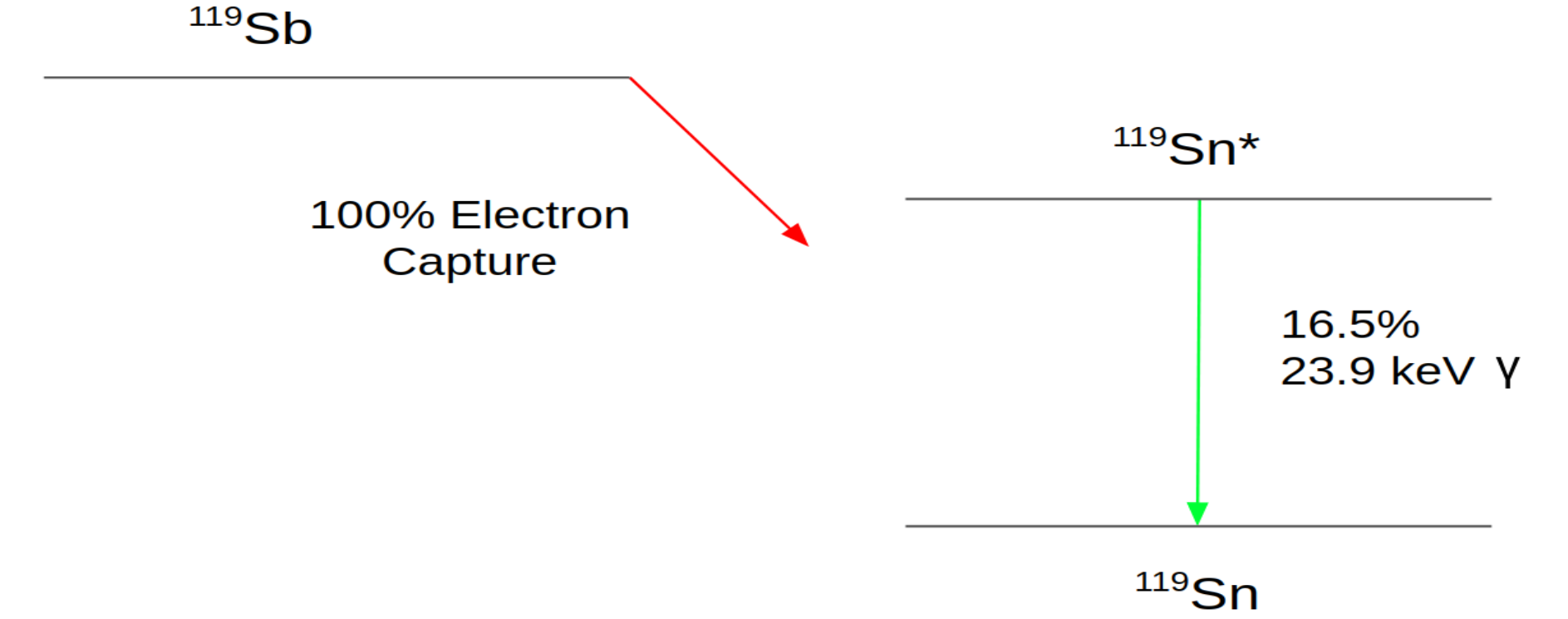
K-line X-ray emissions

| X-ray	Energy [keV]	Relative X-ray intensity per decay [%]
$k\alpha_2$	25.044	21.0 ± 0.5
$k\alpha_1$	25.271	38.9 ± 0.9
$k\beta_3$	28.444	3.53 ± 0.8
$k\beta_1$	28.486	6.80 ± 0.15
$k\beta_2$	29.111	1.86 ± 0.4

Activation Method

The standard method used for cross-section measurements is the **Activation Method** [1, 2, 3]. By irradiating the target, in most cases, radioactive nuclei are created, and even though they are trapped in the target, their decay radiation has enough kinetic energy to escape. By measuring these particles it is possible to calculate the number of produced nuclei, N_D, at the end of the irradiation, see Eq. (1)

$$N_{decay} = N_D \cdot e^{-\lambda t_w} \cdot (1 - e^{-\lambda t_c}), \quad (1)$$

which combined with Eq. (2), can be used to calculate the cross-section.

$$N_D = \sigma \cdot N_A \cdot \phi_b \cdot \frac{1 - e^{-\lambda t_{irrad}}}{\lambda}, \quad (2)$$


Image taken from [4]
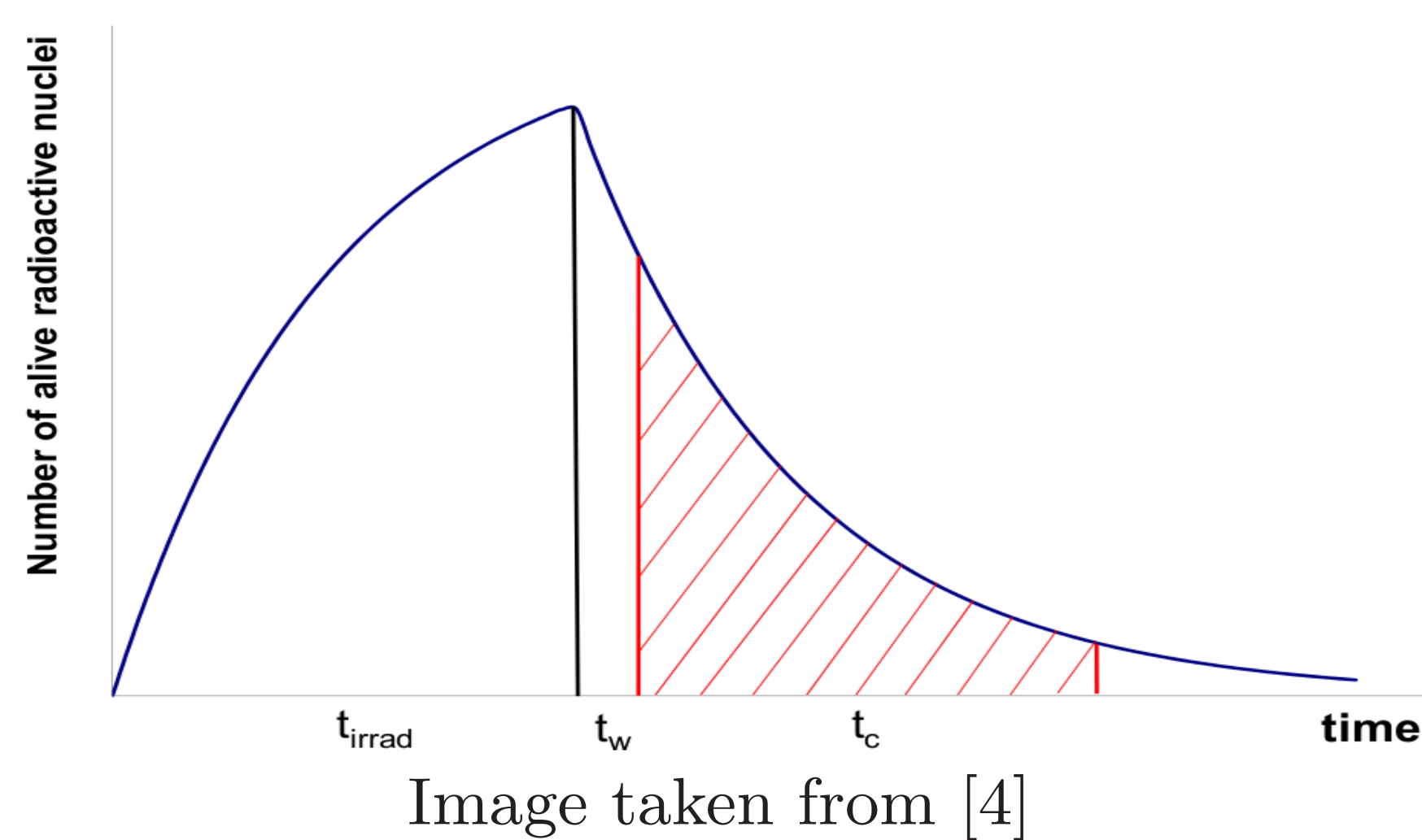
- Both the irradiation and acquisition time depend on the length is the half-life;

- It is impossible to use this method if the nucleus only decays by electron capture with no γ-emission associated;

It was proposed by G.G.Kiss and his team [2] to **measure the decay of X-rays, that are emitted in cascades after the electron capture**.

Experimental methodology

The highly enriched ^{118}Sn (with an Al backing) target will be irradiated at the 3 MV Tandem Accelerator at the CTN/IST facility. Rutherford backscattering spectrometry will be employed to confirm the homogeneity of the target. The target will be irradiated at astrophysical relevant energies (3-4 MeV) corresponding to 2.5 GK. The irradiation time will not exceed two half-life due to long to the long half-life of ^{119}Sb ($t_{1/2} = 38.2$ hours). Special care will be taken to keep a well known constant flux, ϕ_b.

Scheme of the Tandem accelerator at CTN/IST
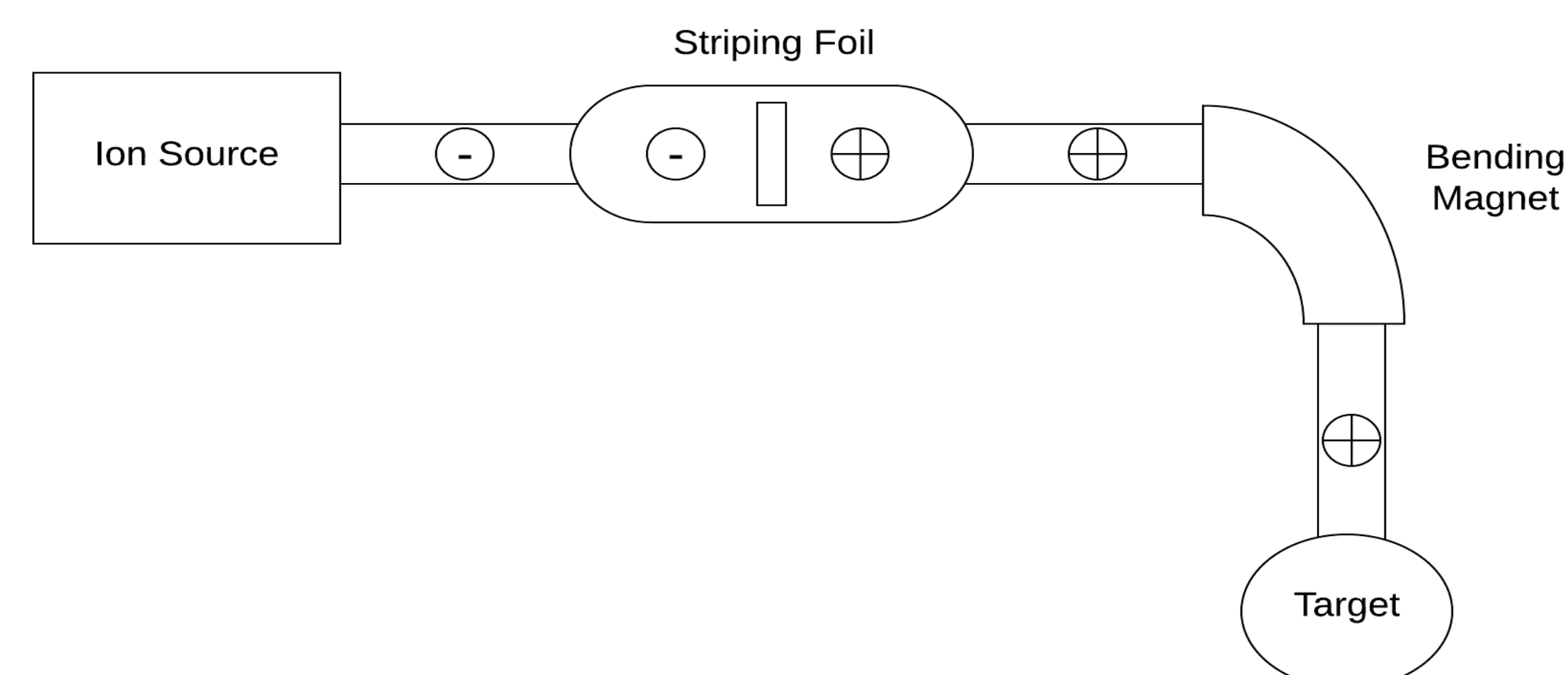
The X-ray emission spectra will be acquired using a the XR-100SDD (Silicon Drift Detector) from Amptek, which has a 125 eV FWHM Resolution at 5.9 keV. The energy calibration and energy dependence of the resolution in the region of interest will be determined using known X-ray emission sources.

Simulations of the emission spectra

Monte Carlo simulations of the experimental setup will be done to determine contributions of the geometry setup to the overall uncertainty and also to obtain the efficiency of the detector. These simulations will be done using Geant4, which is consider to be a state of the art for simulation of particle interaction with matter.

Since the energy of the γ-emission is very close to the Kα emission of ^{119}Sb, we will carry out a simulation of the measured X-ray spectrum in order to accurately deconvolute the two lines. The simulation will use as an input the spectrum of X-ray emission lines calculated using the state-of-the-art relativistic atomic structure code. For this all dipolar radiative transitions between one-hole K-shell configurations and all final configurations in the relevant energy range (20–30 keV) will be calculated with the MCDFGME code [5, 6].

References

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[3] Michael A Famiano, Nuclear Physics A 802(1-4):26–44 (2008)

[4] Gy Gyürky The European Physical Journal A 55(3):41 2019

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Data analysis

A Root-based algorithm is being developed to fit the experimental spectra and determine the peak areas. From the peak area A, the number of decays, N_{decay} can be calculated using, Eq. 1

$$N_{decay} = \frac{A - A_{background}}{\eta \cdot \epsilon}, \quad (3)$$

where ϵ is the detector efficiency and η the relative intensity of the decay. Fitting Eq. (1) to the N_{decay} values as a function of time, the fit parameter N_D is obtained. The cross-section will be estimated using Eq. (2).