“Complete spectroscopy” of ^{31}S for nuclear astrophysics

Proposal submitted by:
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Accelerator: 9 MV
Beam: *α*, Energy = 22 MeV, intensity = 1pnA
Time requested: 10 days

Abstract

We propose the study of excited states in ^{31}S at excitation energies up to around E_{exc}=7 MeV using gamma-ray spectroscopy methods, equipment and beam from the 9 MV tandem pelletron of IFIN-HH Bucharest. The measurements are motivated by a nuclear astrophysics problem: the bottle-neck reaction in the chain of reactions in novae is 30P(p,g)31S, which is dominated by low lying resonances. These are excited states in 31S, and the knowledge of these states' spectroscopy is insufficient at this time. We want to complete data from other types of measurements with neutron-gamma coincidences and possibly lifetime measurements for states of interest populated thru $^{28}Si(\alpha,n\gamma)^{31}S$ reaction. We are interested in the “complete spectroscopy” of low spin states in the excitation window Eexc=6.1 – 7.0 MeV.

Classical novae are relatively common events in our Galaxy, and a few per year are actually detected and studied. Space-based gamma-ray telescopes look for discrete gamma-ray lines that may give information about the nuclear processes occurring in these explosive H-burning events. There is considerable progress in the understanding of their dynamics, but there are many problems to solve before we can assess their contribution to the chemical evolution of the Galaxy. Novae are anticipated to become the first type of explosive cosmic events where all nuclear data for nucleosynthesis can be based on experimental data [1]. However, we are still far from reaching that goal. Groups at Texas A&M University, the University of Edinburgh, IPN Orsay and University of Jyvaskyla were engaged, separately or in collaboration, to the study of reactions occurring in novae. Among the key reactions for which the reaction rates are only known with large uncertainties is the radiative proton capture $^{30}P(p,\gamma)^{31}S$ [2]. The reaction rate is dominated by capture through low-energy proton resonances, which correspond to excited states in ^{31}S nuclei. Considerable efforts are made to find these resonances and to determine their parameters (position and resonance strength) by direct or indirect methods, with no conclusive results so far. This leads to an uncertainty of a factor of about 100 in the astrophysical reaction rate [3].

In continuation of our efforts to identify and study the decay of these low spin excited states in ^{31}S, states that are also populated through the β-decay of ^{31}Cl [3] and which may be astrophysically relevant, we proposed the study of states in ^{31}S at excitation energies up to about 7 MeV using gamma-ray spectroscopy methods and the beam from the tandem accelerator of IFIN-HH Bucharest. We are particularly interested in locating and determining the decay paths of the low spin, positive parity states ($1/2^+$, $3/2^+$, …) in the excitation energy window E=6.1-7.0 MeV. We propose to use a so called “complete spectroscopy” measurement, detecting γ-rays from the reaction $^{28}Si(\alpha,n\gamma)^{31}S$. This would include a n-γ–γ coincidence measurement at about the highest energy (24 MeV) using the Ge array of IFIN-HH and neutron detectors. An experiment was approved early in the spring of 2009, but the neutron detection was insufficient at the time. Consequently, the experiment was proposed at Argonne National Laboratory using GAMMASPHERE, where good results were obtained [4]. However, the gamma-rays depopulating the states of interest directly to the ground state in

^{31}S could not be identified at GAMESPHERE, due to the lack of neutron detection. Here, we propose to use the new neutron detectors placed in ROSPHERE at the position of 5 forward Ge detectors.

Among the latest efforts is also a series of measurements of $\beta-\gamma$ and β-delayed proton decay of ^{31}Cl made by the authors of the proposal at the MARS separator of the Cyclotron institute, Texas A&M University, using very thin Si detectors [5, 6] and the new ASTROBOX2 detector [7, 8]. Beta-decay of ^{31}Cl populates states in ^{31}S and those above the proton binding energy Sp=6.133 MeV represent the resonances sought above. However, the rich (preliminary) level scheme was established from $\beta-\gamma$ decay without gamma-gamma coincidences. The measurements proposed would complement the ones already made; support the decay scheme by proton and gammas and help the spin/parity assignments. They will assure a precise determination of the energy of the resonances sought and, hopefully, their spins and parities. The new data will complement also information we have from other studies, including beta-delayed proton decay measurements, transfer reactions and HI induced gamma-ray studies.

In the early 80’s the group of P. von Brentano in Cologne has shown that (α,n) reactions at relatively low bombarding energy from their tandem accelerator can be used to populate non-selectively low-to-medium spin states in nuclei and that standard gamma-ray spectroscopy techniques can be used to determine their decay scheme and spin/parity. The technique was dubbed “complete spectroscopy” for its non-selective population of states and was used later in several places, including at the Bucharest tandem [9].

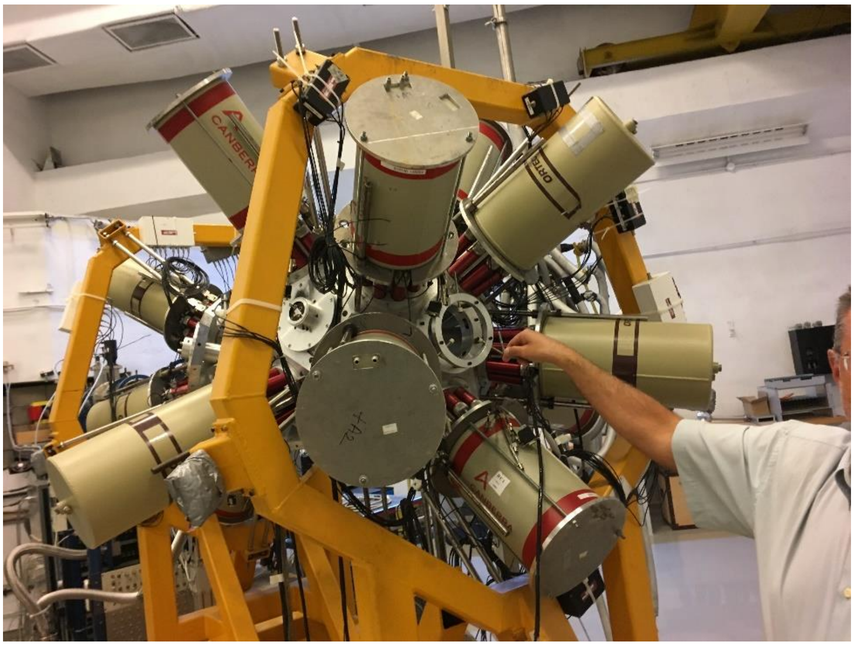

Figure 1. The Ge detector array of DFN Bucharest. We propose to replace the five forward Ge detectors by NE213 neutron detectors with special geometry.

The results of the previous experiments show that the strongest channel was ^{28}Si(α,p) populating states in the mirror nucleus ^{31}P. These are going to be also useful, as we will be able to get more information about those states and use mirror symmetry to find information about the structure of corresponding states in ^{31}S. A large number of lines have Doppler affected shapes that will allow us, hopefully, to determine their lifetimes in the fs range.

Beam intensities of around 1 pnA alpha particles of good stability from the newly refurbished FN tandem in Bucharest are sought and one week of beamtime. Due to high-energy γ rays expected from ^{31}S, we intend to perform a ^{13}C(α,n)^{16}O calibration reaction, through 6.129 MeV line in ^{16}O; this should take for about a day. We intend to use a high-purity ^{28}Si target(over 99% purity). Although in natural silicon, the ^{28}Si has an abundance of over 92%, the other two stable isotopes will open additional neutron channels when interacting with alpha paticles, and we have no desire in that.

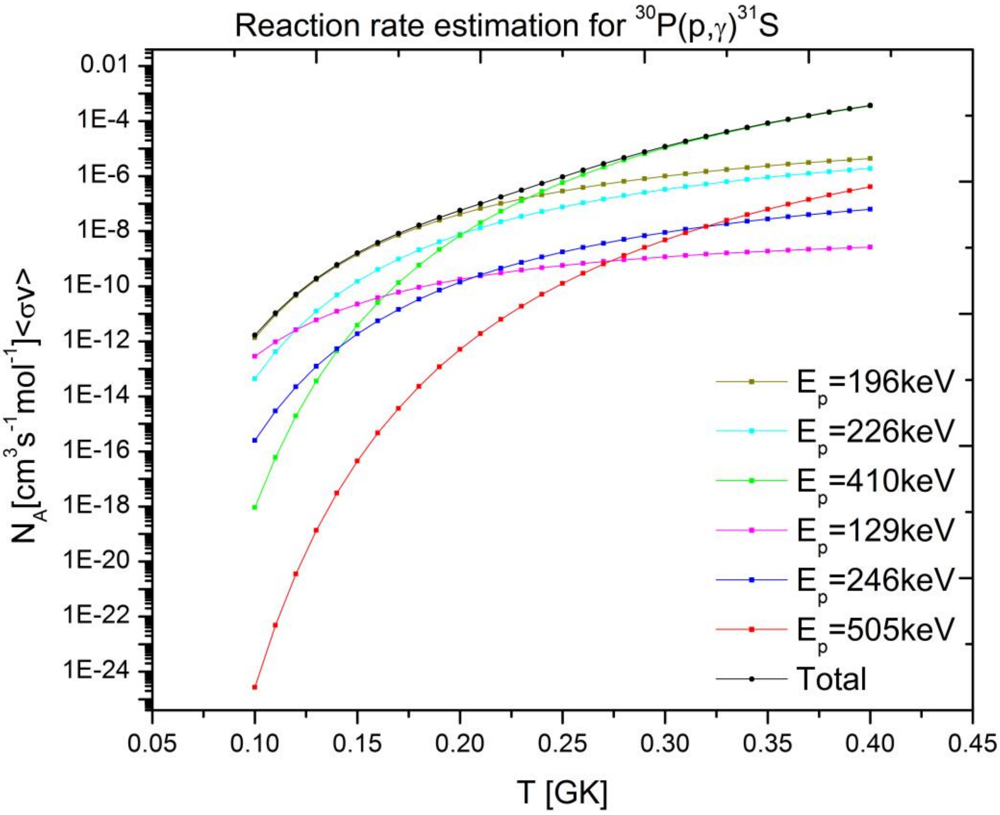

Figure 2. Reaction rate estimation for ^{30}P(p,γ)^{31}S, for different resonance energies

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