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

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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. The groups at Texas A&M University, the University of Edinburgh and University of Jyvaskyla are 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,γ)^{31}S. 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 [2].

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 were 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 proposed to use a so called “complete spectroscopy” measurement, detecting γ-rays from the reaction ^{28}Si(α,nγ)^{31}S. This would include a γ-γ coincidence measurement at about the highest energy (24 MeV) using the Ge array of IFIN-HH and an excitation function at projectile energies E_α=15-25 MeV. The experiment was approved early in the spring of 2009 and was successfully conducted in summer.

Among the latest efforts is a series of measurements of β-γ and β-delayed proton decay of ^{31}Cl [3] made by the authors of the proposal from Texas A&M University, the University of Edinburgh and the University of Jyvaskyla. 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 β-γ decay without gamma-gamma coincidences. The measurements proposed would complement the ones already made; support the decay scheme and 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 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 [4].

In this experiment we have measured so far γ-γ and n-γ coincidences at E_α=24 MeV on a Si target. The natural Si target was prepared for us by the people at Micron Semiconductor Ltd, UK, from a Si wafer etched down to 20 μm and backed by layers of W (0.9 mm) and Ti (0.1 mm) to stop the recoiling residual nuclei. The un-reacted beam was stopped further downstream in a Faraday cup. We have used the Ge detector array of DFN Bucharest in its maximal configuration (of 2009) (see Fig. 1): seven HPGe detectors and one neutron detector and the associated acquisition system. The neutron detection was useful for channel identification.

FIG. 1. The Ge detector array of DFN Bucharest. The quartz tube (front, left) was used to stop the beam away from the target position. The cylinder at right is the NE213 neutron detector.

The results were only partially analyzed in and 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 to determine their lifetimes in the fs range (see Fig. 2).

Beam intensities of around 1 pnA alpha particles of excellent stability from the newly refurbished FN tandem in Bucharest were used in one week of beam time.

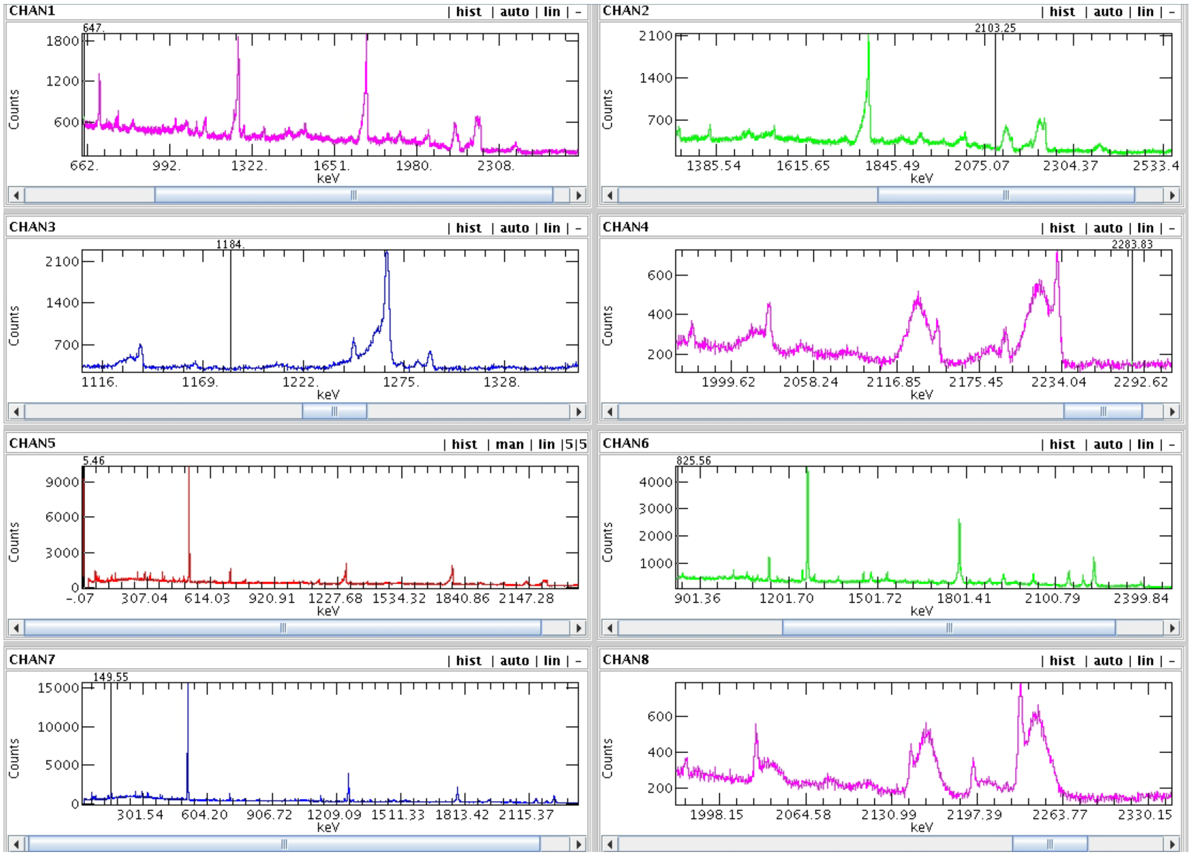

FIG. 2. Spectra from the online analysis. Lines affected by Doppler broadening are clearly visible in a number of detectors (panels 4 and 8), forward or backward oriented.

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