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# $^{17}$O HYDROGEN BURNING AT THE ENERGIES OF CLASSICAL NOVA AT LUNA

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Hydrogen burning of $^{17}$O sensitively influences nucleosynthesis in a number of stellar sites, including red giants, asymptotic giant branch (AGB) stars, massive stars, and classical novae. In particular, the ratio between reaction rates of $^{17}$O(p,$\alpha$)$^{14}$N (Q = 1.2 MeV) and $^{17}$O(p,$\gamma$)$^{18}$F (Q = 5.6 MeV) channels on $^{17}$O is one of the most important parameters for the galactic synthesis of $^{17}$O, the stellar production of radioactive $^{18}$F, and for predicted O isotopic ratios in presolar grains. The LUNA collaboration has studied the $^{17}$O(p,$\gamma$)$^{18}$F in a wide energy range (from 167 up to 360 keV) covering completely the energy of the nova scenario and the new results reduce by a factor of 4 the precedent evaluation of the $^{17}$O(p,$\gamma$)$^{18}$F reaction rate. In addition, the 183.3 keV resonance strength has been determined with unprecedented precision solving the discrepancies of previous experimental efforts.

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## 1. Introduction

Hydrogen burning of $^{17}$O is believed to play a key role on the destruction of $^{17}$O and on the formation of $^{18}$F, mainly through the competing reactions $^{17}$O(p,$\gamma$)$^{18}$F and $^{17}$O(p,$\alpha$)$^{14}$N. Thus, the thermonuclear rates of both reactions should be determined with a high degree of accuracy directly in the energy region of hydrogen burning in classical novae. Classical novae are thought to be a major, if not the dominant, source of $^{17}$O in the Galaxy. In addition, they can produce the short-lived radioisotope $^{18}$F ($T_{1/2}$ = 110 min), whose $\beta^+$ decay is followed by $\gamma$-ray emission from positron-electron annihilation, which could be observed with $\gamma$-ray satellites such as the INTEGRAL observatory. At nova temperatures, the $^{17}$O(p,$\gamma$)$^{18}$F reaction rate is dominated by a direct-capture (DC) reaction mechanism despite the presence of two narrow resonances at $E = 66$ and 183 keV above the proton threshold in $^{18}$F [1, 2]. In addition, non-resonant contributions arise from the low-energy tails of two broad resonances at $E = 556.7$ and 676.7 keV. A reliable determination of the total $^{17}$O(p,$\gamma$)$^{18}$F reaction rate thus requires the accurate knowledge of the individual energy dependence of both resonant and non-resonant contributions. The $^{17}$O + p reaction were investigated by Rolfs in 1973 [3] and recently by several groups. The 183.3 keV resonance strength was measured by Fox et al. [1] and Chafa et al. [4] by using two different techniques: the gamma-prompt detection and the activation technique. Those two works reported different values for the $\omega\gamma$ agree only within $2\sigma$. As a matter of fact, Chafa et al. measured $\omega\gamma = (2.2 \pm 0.4)\mu$eV and Fox et al. report $\omega\gamma = (1.2 \pm 0.2)\mu$eV. The source of this disagreement is not understood at present. The non resonant contribution to the cross section has been reported by Newton et al. in 2010 [2] in the energy region from 257 keV up to 470 keV. More recently, the S factor was measured at $E = 260 - 470$ keV using the DRAGON recoil separator at TRIUMF [5] and found to be in fairly good agreement with values by Ref. [2]. In addition a new measurements has been done at the Notre Dame University [6]. This work reports data in a wide energy region from 345 to 1700 keV and an R-Matrix fit is also produced by the authors. Here we report the results obtained by LUNA (Laboratory for Underground Nuclear Astrophysics) [7, 8] on the study of the $^{17}$O(p,$\gamma$)$^{18}$F reaction in the energy range corresponding to Nova explosions. The LUNA facility is placed into the National Gran Sasso Laboratory (LNGS). Thanks to the shielding provided by the Gran Sasso mountain [9, 10] it is possible to reach the uncertainties required by the novae models [11].

## 2. Experimental Setup

The experimental setup used in the experiment is shown in Fig. 1. The beam passed through a cold trap (cooled with liquid nitrogen) to reduce contamination on target surface. The cold trap was placed 2 mm close to the target surface and 300 V negative voltage was applied to the trap to suppress secondary electrons. 100 nm $Ta_2O_5$ targets were used and placed tilted at 55° with respect the beam axis. They were made at LNGS and they were characterized by using Ion Beam Analysis and SIMS (secondary ion mass spectrometry) techniques. The setup used to produce the target is reported in Fig. 2 and the process is described in details in [12].

A HPGe detector in close geometry (1.45 cm from the target position) was used to detect the prompt gammas. It was calibrated by using radioactive sources and the 278 keV resonance of the $^{14}$N(p,$\gamma$)$^{15}$O reaction. The summing effect was taken into account by performing the efficiency

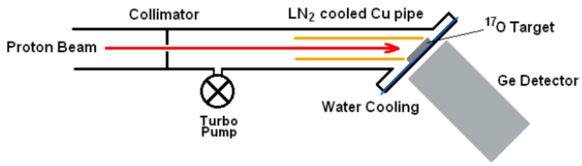


**Figure 1:** Schematic picture of the experimental setup installed at the LUNA400kV accelerator.

at several distances and it contributed for a final systematic error of 3.5%. The detector was surrounded with 10 cm lead in order to reduce the environmental background below 3 MeV in the $\gamma$-spectrum, since the reaction also produced low energy $\gamma$s from the transitions to the 1080 keV and 937 keV $^{18}$F levels. Thanks to the background reduction obtained in the present experiment it was possible to determine also the intensity of low probable branchings leading to an update of the value reported in literature [13].

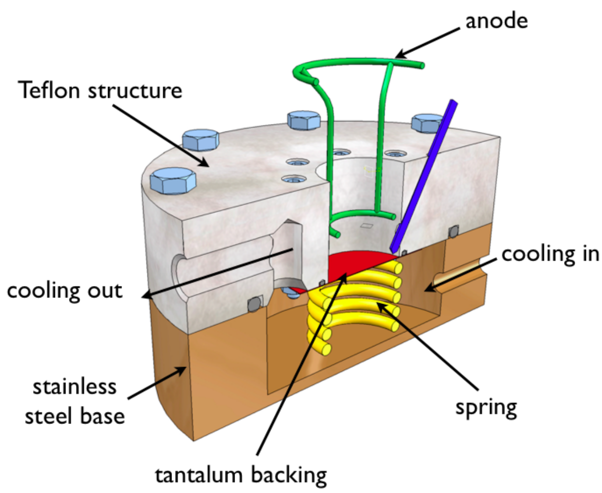


**Figure 2:** The anodization setup used to produce the oxide tantalum targets used in the experiment.

Since the $^{18}$F is a radioactive isotope ($T_{\frac{1}{2}}$ = 109 min) it was also possible to derive the cross section by counting the $^{18}$F produced on the target. The 511 keV $\gamma$ rays emitted in the $^{18}$F $\beta^+$ decay were detected by a fully shielded germanium detector of the STELLA low counting facility of the LNGS. The presence of 511keV emitter contaminates was checked and it was found a small contamination of $^{13}$N ($T_{\frac{1}{2}}$ = 9 min) as shown in Fig.3. The $^{13}$N contributes to the final systematics by less than 1%. For the activation phase the target were irradiated for 6 hours (about 3 lifetimes) and then moved to the STELLA facility were the decays were counted for at least 6 hours.

In Fig. 4 the results for the S-factor are shown in comparison with the previous experimental data. It has to be noted that in the figure only statistical errors are reported and that the data in [5] are affected by 12% systematics. The LUNA data obtained by using both activation and prompt gamma detection at the LUNA accelerator are in perfect agreement and they extend the previous data covering totally for the first time the Gamow peak for Novae explosions. In this experiment we

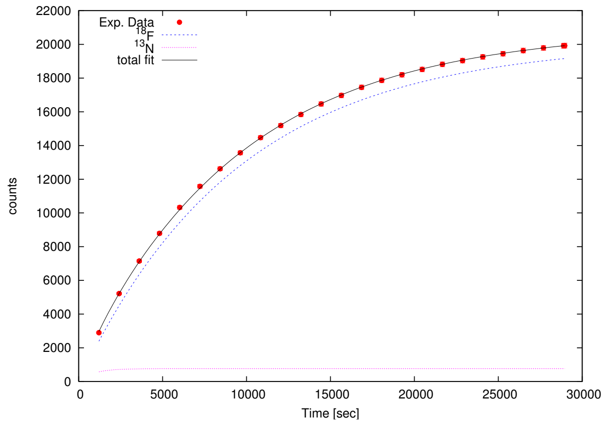


**Figure 3:** The counts in the germanium spectra during time for the 511 keV line. In red the experimental data. The $^{18}$F (blu dashed curve) and $^{13}$N (purple point) contribution included in the fit (black) are reported in the figure.

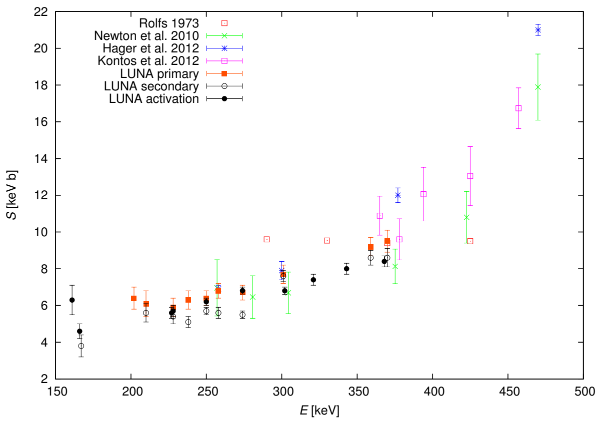


**Figure 4:** Total astrophysical S factor as a function of center-of-mass energy for the $^{17}$O(p,$\gamma$)$^{18}$F reaction [13]. The LUNA data are reported for the primary and secondary prompt $\gamma$ transitions and for the activation measurements separately.

measured also the 183.3 keV resonance strength obtaining a value of $\omega\gamma = (1.67 \pm 0.12)\mu$eV. The LUNA results allow to reduce the uncertainties in the production of oxygen and fluorine isotopes in novae from 50% to 10% reaching the value requested by the stellar models for this astrophysical scenario [15].

### 2.1 Acknowledgements

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