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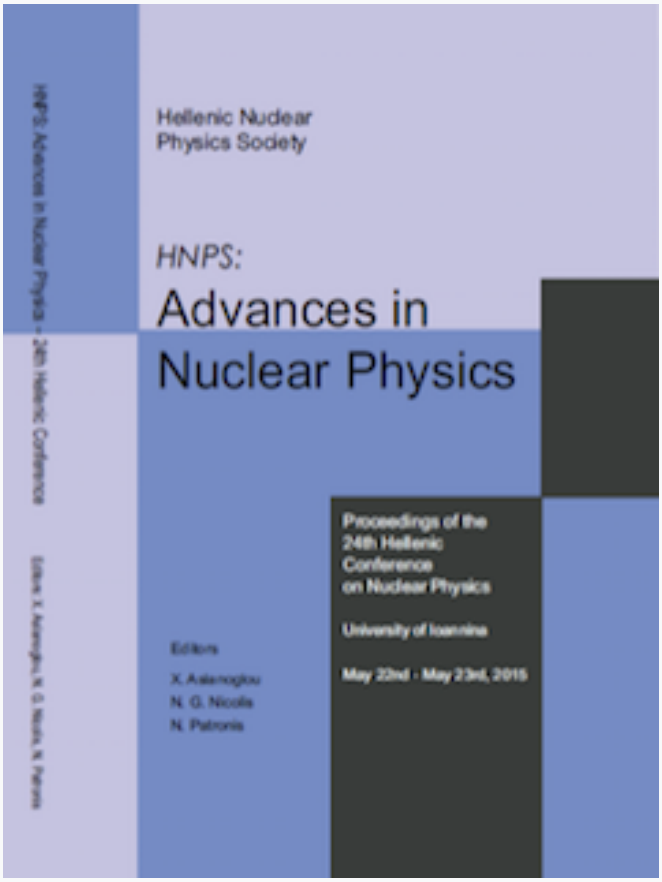

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Modeling radiative proton-capture reactions in mid-heavy nuclei

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Abstract A systematic study of (p,γ) reactions was carried out using the reaction codes EMPIRE, TALYS and NON-SMOKER (web). The calculated (p,γ) cross sections of seed nuclei ^{89}Y, ^{107,109}Ag, ^{106,108,110}Pd, ^{112}Cd, ^{121,123}Sb, ^{127}I, and ^{133}Cs can be used in a three-fold way: (a) perform an intercomparison of the models in a low-energy regime (b) compare existing experimental data to the theoretical predictions and (c) predict cross sections of reactions planned to be studied experimentally in the near future by our group. The results of the study are presented in a concise way focusing on the experimental conditions.

Keywords proton capture, cross section, modeling, EMPIRE, TALYS

INTRODUCTION AND MOTIVATION

Nuclear processes at explosive astrophysical sites play a central role in the creation of the elements in the universe. Measured elemental abundances in the solar system is an important input in modeling the nucleosynthetic processes. The vast reaction network calculations needed to describe the dynamic phenomena rely on statistical theory, such as the Hauser-Feshbach (HF) theory, which requires the knowledge of nuclear cross sections. Data of experimental nuclear cross sections for such studies are rather scarce. As a consequence, theoretical predictions are often used to provide information on the nuclear processes.

In this work, proton-capture radiative (p,γ) reactions have been investigated in a few mid-heavy isotopes, in the area of nuclear chart where the p-process is important, using three different reaction codes. Details of the calculations performed are described below. Results are compared to experimental data, if available in literature at the time of the study.

METHODOLOGY AND RESULTS

A systematic test was carried out with the theoretical models EMPIRE, TALYS and NON-SMOKER, using their default settings (Table 1) for three specific nuclear parameters: the *Optical Potential*, the *Nuclear Level Density* and the *γ-Strength Function*. The codes are generally optimized at different energy

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regimes, therefore differences are expected. Comparison with existing published datasets is expected to improve our understanding on the predictive power of each code in particular energy and mass regions.

The study was focused on ^{89}Y, ^{107,109}Ag, ^{106,108,110}Pd, ^{112}Cd, ^{121,123}Sb, ^{127}I, and ^{133}Cs seed isotopes, lying in the neutron-deficient part of the nuclear chart. In all cases, isotopes were studied at the low energy regime, E ≤8 MeV in an attempt to overlap with the Gamow window, which -according to HF theory- provides favorable conditions for nucleosynthesis with the p-process, and is around 3 MeV for most of the nuclei in our study.

Three codes were used: EMPIRE [1], TALYS [2] and NON-SMOKER(web) [3]. The latter is considered obsolete, however, it was included for the sake of intercomparison. In all cases, default settings were used, as listed in Table 1.

Table 1 Default settings for the three theoretical codes used in the present study

	Optical Model Potential	**Nuclear Level Densities**	**γ-Strength Function**
EMPIRE	Koning-Delaroche	EGSM	Plujko MLO RIPL-2
TALYS-1	Koning-Delaroche	CTFG	Kopecky-Uhl
TALYS-2	Bauge-Delaroche-Girod	Goriely-Demetriou	Hartree-Fock-BCS
TALYS-3	Bauge-Delaroche-Girod	Hilaire-Goriely	Hartree-Fock-Bogolyubov
NON-SMOKER	Jeukenne et al. (1980)	Rauscher et al. (1997)	Cowan et al. (1991)

Cross sections for radiative proton captures by the seed nuclei listed above were calculated and plotted as a function of energy in Figs. 1 & 2. In Fig. 1, existing experimental data have been added for comparison. Fig. 2 shows the results for reactions with no data available in literature at the time of the study.

CONCLUSIONS

Direct comparison of selected published experimental data with the three different theoretical models attests a very good agreement between them. Any discrepancies between the models are located at energies where the neutron emission channel is surpassed, and are likely caused by the different model inputs. For the case of ^{106}Pd, at energies lower than the (p,n) channel threshold, theoretical predictions need to be scaled, but when $E \geq E_{thresh}$, TALYS-3 seems to fit the data better. Concerning ^{121}Sb, NON-SMOKER(web), though a rather outdated code, seems to best fit the experimental data. For the rest of the isotopes studied with published datasets (^{89}Y, ^{112}Cd, ^{123}Sb), a very good agreement was found. These cross sections will potentially be exploited for future experimental work and provide a starting point for a more detailed systematic study in p-nuclei.

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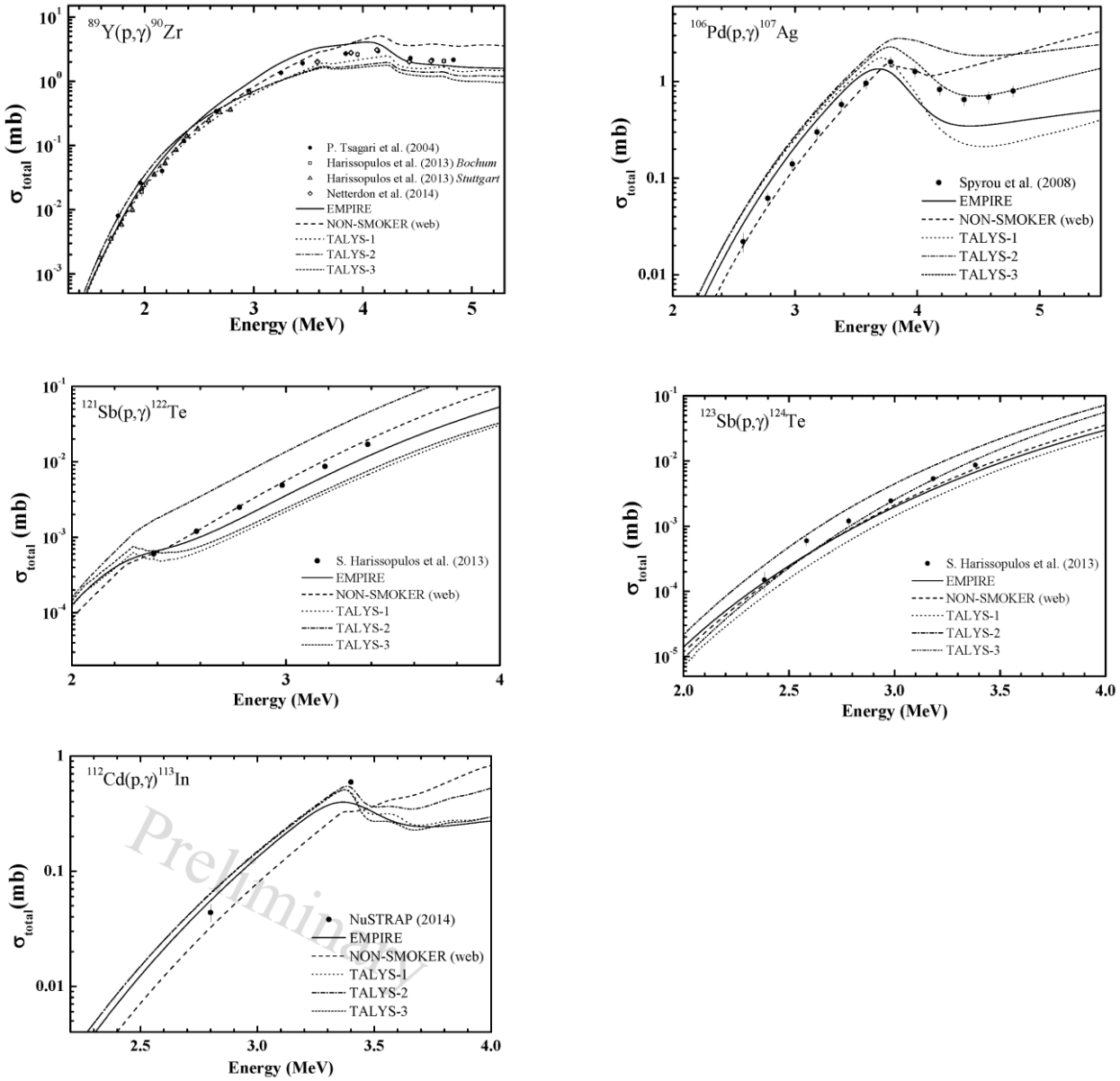

Figure 1 Cross section predictions for the (p,γ) reactions with ^{89}Y, ^{106}Pd, ^{112}Cd, and ^{121,123}Sb. Data points correspond to published works, except for ^{112}Cd(p,γ) that has been recently measured by our group.

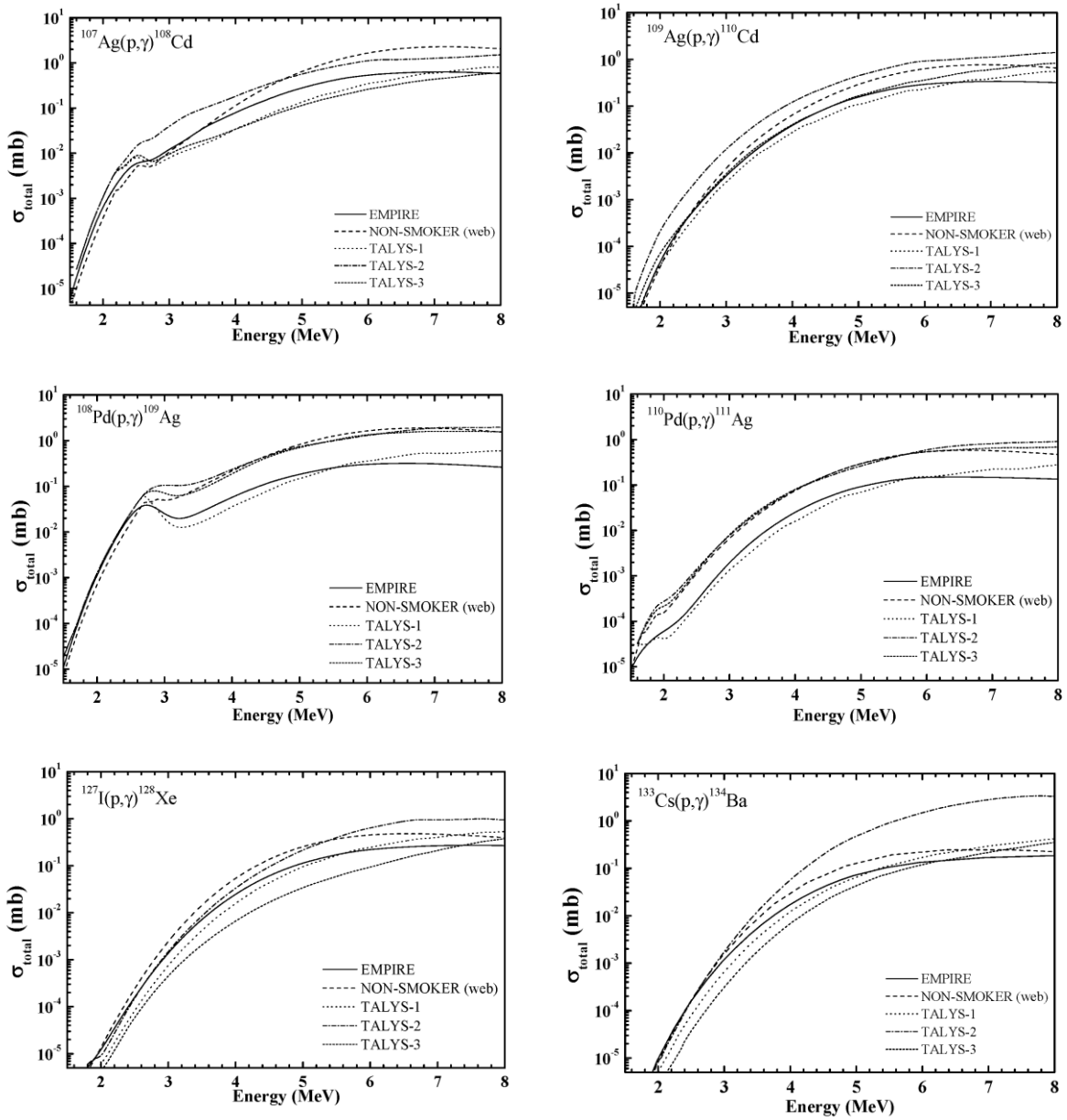

Figure 2 Cross section predictions for (p,γ) reactions with ^{107,109}Ag, ^{108,110}Pd, ^{127}I and ^{133}Cs. For these nuclides, no experimental data were available at the time of the study.