The KADoNiS databases - progress and future plans

T Szücs[1], **I Dillmann**[2,3], **R Plag**[2,4] **and Zs Fülöp**[1]
[1]Institute of Nuclear Research (ATOMKI), Debrecen, Hungary
[2]GSI Helmholtzzentrum fr Schwerionenforschung GmbH, Darmstadt, Germany
[3]II. Physikalisches Institut, Justus-Liebig-Universität, Giessen, Germany
[4]Institut für Angewandte Physik, Goethe-Universität, Frankfurt am Main, Germany

E-mail: `tszucs@atomki.hu`

Abstract. The KADoNiS (**K**arlsruhe **A**strophysical **D**atabase **o**f **N**ucleosynthesis **i**n **S**tars) project is an online database (`www.kadonis.org`) for cross sections relevant for s-process and the p-process nucleosynthesis. Recently, the p-process part of the KADoNiS database has been extended, and now includes almost all available experimental data from (p,γ), (p,n), (p,α), (α,γ), (α,n) and (α,p) reactions in or close to the respective Gamow window.

1. Introduction

The nuclei heavier than iron are produced by the three processes called s-, r-, and p-process [1]. The first two involve neutron capture reactions and β-decays. The main difference is the neutron density and therefore the time scale of the neutron capture. For the s-process the capture time scale is much longer (one capture per 100−1000 years) than the β-decay half-lives, therefore the reaction flow is running along the valley of stability up to ^{209}Bi. Here the next neutron capture and β-decay lead to the α-instable ^{210}Po, forcing the material to loop back to ^{206}Pb. The two sites of the s-process are low mass thermally pulsing asymptotic giant branch starts (TP-AGB) for the main s-process ($A\geq90$) [2] and massive stars for the weak s-process (A=60−90) [3].

In the r-process the neutron density is so high ($\gg 10^{20}$ cm^{-3}), that subsequent neutron captures drive the material far away from the line of stability close to the neutron drip-line. When the neutron density drops and the temperature decreases ("freeze out"), the material decays back to stability via long β-decay chains. Such high neutron densities and temperatures requires an explosive stellar environment. The exact r-process scenario is still under discussion, but the presently favoured candidates are core collapse supernovae [4] and merging neutron stars [5].

There are about 35 isotopes between ^{74}Se and ^{196}Hg on the proton-rich side of the valley of stability, which cannot be produced via neutron capture reactions. These so-called "p-nuclei" are responsible for only less than 1% of the total solar abundance in mass range heavier than iron, and are mainly produced in a mechanism called "γ-process" [6]. It proceeds by photon-induced reactions starting from pre-existing s- and r-process seed nuclei. First (γ,n) reactions drive the material towards the neutron-deficient region, before charged-particle emitting reactions like (γ,α) and (γ,p) become more probable and divert the reaction flow towards lower masses. Recent simulations revealed that proton-induced reactions are important in the lower mass region, whereas α-induced reactions are important in the higher mass region [7].

However, astrophysical network calculations cannot fully reproduce the observed abundances of all p-nuclei within one scenario [8] and call for additional processes for single isotopes. These reaction network calculations involve thousands of stable and unstable isotopes and tens of thousands of reactions [9]. Only the minority of these reactions are known experimentally, whereas the cross sections for the largest fraction have to be inferred from statistical model calculations.

The fact that self-consistent γ-process studies have problems in synthesizing p-nuclei in the mass regions A <124 and 150< A <165 may result from difficulties related to the astrophysical models as well as from systematic uncertainties of the nuclear physics input. Therefore improvements of nuclear reaction cross sections are crucial for further progress in γ-process models, either by directly replacing theoretical predictions by experimental data or by testing and improving the reliability of statistical models, if the relevant energy range (the so called Gamow window) is not accessible by experiments. For this effort the build-up of an user friendly database from the existing experimental data is needed. The current status and the future aspects of such a database are presented here.

2. Past and present of the KADoNiS database

The first version of the "Karlsruhe Astrophysical Database of Nucleosynthesis in Stars" (KADoNiS, `www.kadonis.org`) database was released in 2005 and was an updated sequel to the previous Bao et al. [10] compilations for (n, γ) cross sections relevant to Big Bang and s-process nucleosynthesis. These compilations contained mainly Maxwellian averaged (n, γ) cross sections (MACS) relevant to the s-process, and KADoNiS provided until now there were three updates [11], [12]. The current version v0.3 contains evaluated Maxwellian-Averaged (n,γ) Cross Section (MACS) at kT=30 keV for 357 datasets between ^{1}H and ^{210}Po, out of which 77 are semi-empirical estimates because only theoretical data exists. The present average experimental uncertainty for all experimental reaction rates at kT=30 keV is ±6.5% (Fig. 1). For the s-only isotopes the uncertainty is ±3.8% (Fig. 2), while the aim is to reach the 1% level. The s-process database contains also the previous recommended values (KADoNiS history), a list of experimental and theoretical values, MACS for energies between kT=5 and 100 keV, reactions rates vs. kT, and Stellar Enhancement Factors (SEF).

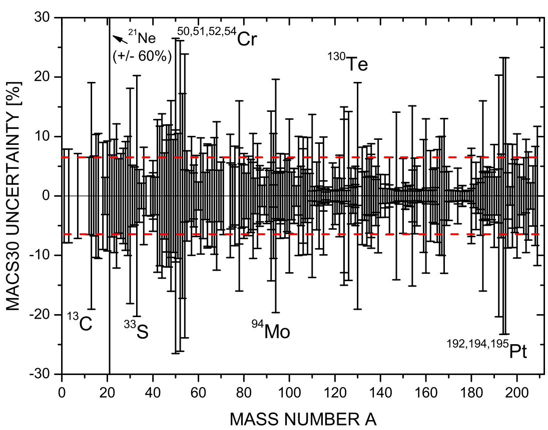

Figure 1. Uncertainties at kT= 30 keV of all experimental datasets. The average value is ±6.5%.

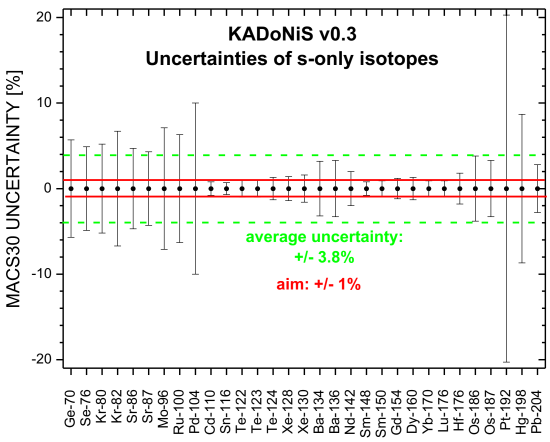

Figure 2. Uncertainties at kT= 30 keV of s-only isotopes. The average value is ±3.8%.

3. The new p-process database

The aim of the p-process database is the collection of all available experimental cross sections in or close to the respective Gamow window and the comparison with various theoretical models. In 2006 a first draft for a p-process database within the KADoNiS project was launched, but it lasted until 2010 until this part was improved in collaboration with the ATOMKI Debrecen and the updated p-process database was published [13].

The basis of the new p-process compilation was the EXFOR database [14], which has the advantage that it contains (almost) all available experimental cross sections and is regularly updated. We scanned it for experimental data from (p,γ), (p,n), (p,α), (α,γ), (α,n), and (α,p) reactions for targets heavier than ^{70}Ge and energies down to 1.5$\times$ the upper end of the respective Gamow window for T= 3 GK. This upper cut-off energy was arbitrarily chosen because most available data was measured above the astrophysically relevant Gamow windows, which lie (for T= 3 GK) at E= 3−6 MeV for proton-induced and between E= 7−14 MeV for α-induced reactions.

In the KADoNiS data sheet of each isotope an interactive chart of nuclides is shown, where the nuclei with experimental cross sections in the database are highlighted. After selection of the isotope and the reaction, the data sheet provides the calculated Gamow window (using approximations as discussed in Ref. [15]) for T=2−3 GK for the respective reaction. It is planned to replace these approximated location of the Gamow window with the more accurate numerical solutions provided by Ref. [16]. One can also select one or more datasets and plot these with an online plotter and obtain tabulated datasets. The tabulated datasets contain the center-of-mass energy of the reaction in MeV with uncertainties (if available), the cross sections (in μbarn) and the experimental uncertainties (if available), and then the respective calculated astrophysical S-factor (in units of MeV barn).

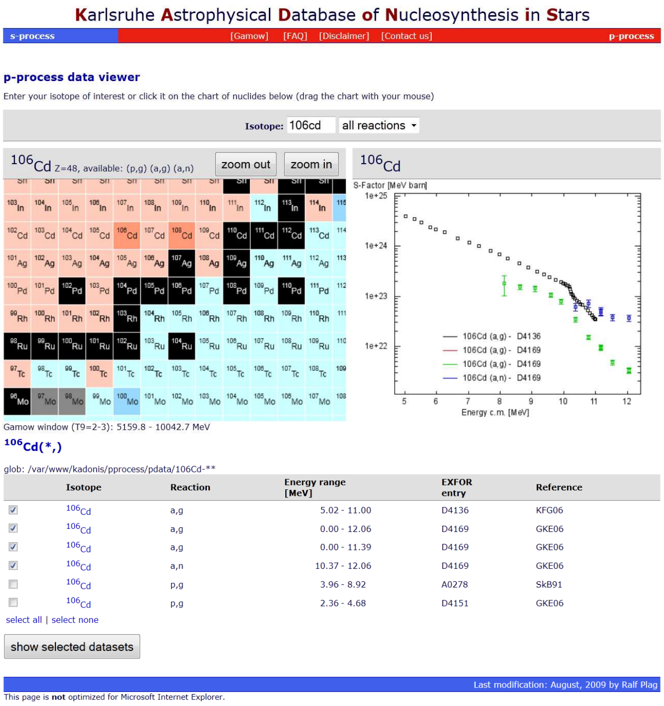

Figure 3. Screenshot of the KADoNiS p-process database.

The experimental basis for (p,γ), (p,n), (p,α), (α,γ), (α,n), and (α,p) cross sections are very different with respect to the energy window for p-process nucleosynthesis. The criteria for the KADoNiS p-process database are fulfilling 34 (p,γ), 15 (α,γ), 70 (p,n), 42 (α,n), and 8 (α,p) reactions. No (p,α) cross section exists within our defined upper cut-off energy, whereas for the inverse (α,p) channel eight reactions are available (^{92,94}Zr, ^{92,98}Mo, ^{96}Ru, ^{106}Cd, and ^{112,124}Sn). However, both reactions play no or only a negligible role in present γ-process models. The most information over the whole mass region can be found for the (α,n) and (p,n) reactions. A lot of effort with respect to astrophysical measurements in the last 15 years was put in determining radiative capture cross sections, which can be related to the photo-induced reactions by detailed balance. For (p,γ) reactions up to now 34 datasets are available, most of them in the lower mass region where their influence was found to be largest [7].

The situation for (α,γ) is much worse, and it was stated by many authors before that more effort should be put in measuring this type of reaction with heavier targets. Up to end of 2009 only 15 isotopes had been measured (and published): ^{70}Ge, ^{91}Zr, ^{96}Ru, ^{106}Cd, ^{107}Ag, ^{113,115}In, ^{112,118}Sn, ^{127}I, ^{136}Xe, ^{139}La, ^{144,154}Sm, and ^{197}Au. All of these measurements do not reach the lower end of the Gamow window, and in the higher mass range, where they have real impact for the network calculations, none of them reach the upper end of the Gamow window.

4. Further plans

The implementation of theoretical data is in progress, which helps to compare the reliability of different theoretical calculations. For each reaction we will give recommended reaction rates and derive fit parameters, which can easily be included in reaction libraries. The database will also be updated regularly (every 1 to 2 years) with new published data. The next step are then paper publications for both databases, still in 2011 for the s-process database, and in 2012 for the p-process database.

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