PROCEEDINGS OF SCIENCE

STARLIB: A Website Tutorial

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STARLIB is a new, next-generation reaction-rate library that provides a tabular, up-to-date database that supplies not only the recommended rate and its factor uncertainty but also the rate distribution (i.e., its probability density function). The library structure is based on Monte-Carlo method to calculate reaction rates. This method uses experimental nuclear physics data as inputs and yields the reaction rate output probability density function at a given temperature. From the cumulative distribution of rate probability densities, the low, median, and high rates are rigorously defined. Here, we detail a method for accessing STARLIB on the Internet at starlib.physics.unc.edu. The three main components of the website include the Rate Library, Rate Calculator, and Details. Within the Rate Library, one may access STARLIB itself. Monte Carlo reaction rate simulations may be run on our server from the Rate Calculator page. Pertinent information on STARLIB is given on the Details page. In this article, an overview of STARLIB is presented, and each website component is discussed in depth.

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1. Introduction

STARLIB is a tabular, stellar reaction rate library for stellar modelers and is described in detail in Refs. [1, 2]. This library includes not only uncertainties on rates but also the information to build *realistic* probability density functions (PDFs). Its structure is based on a Monte Carlo method to calculate experimental reaction rates [3]. The reaction rate, $N_A\langle\sigma v\rangle$, at a temperature T for two interacting charged particles whose velocities are distributed according to Maxwell-Boltzmann is given by [4]:

$$N_A\langle\sigma v\rangle = N_A\left(\frac{8}{\pi\mu}\right)^{1/2}\frac{1}{(kT)^{3/2}}\int_0^\infty E\,\sigma(E)e^{-E/kT}\,dE, \tag{1.1}$$

where N_A is Avogadro's number, μ is the reduced mass of the particles in the entrance channel, E is the center-of-mass energy of the interaction, and σ is the reaction cross section. The Monte Carlo method assigns physically motivated distributions to each nuclear physics input parameter and randomly samples Eq. 1.1 until the desired precision is reached. The output is the rate PDF, an example of which is shown in Fig. 1. The top panel displays the red PDF histogram, and the bottom panel shows the cumulative probability distribution. From this, the low, median, and high rates are rigorously defined as the 16th, 50th, and 84th quantiles. The black curve is the lognormal approximation to the rate (see Refs. [1, 2, 3] for more information).

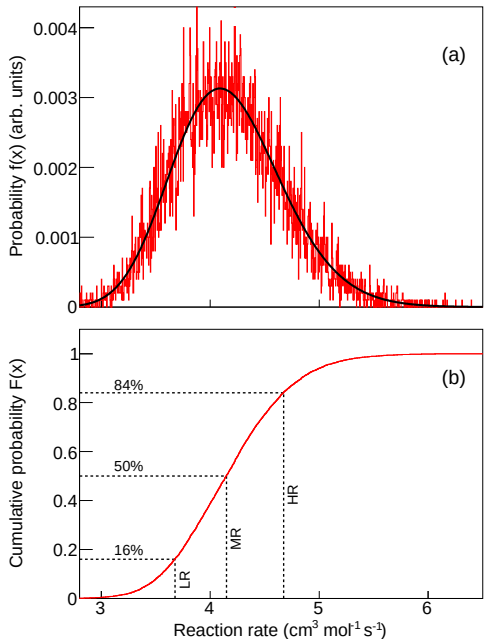

Figure 1: Sample Monte Carlo output for a hypothetical resonance in ^{22}Na$(p,\gamma)^{23}$Mg at a fixed temperature for 10,000 samples ($\omega\gamma = 1.7 \pm 0.2$ eV at $E_r = 430 \pm 1$ keV). Panel (a): reaction rate probability density. Red histogram: output of simulation. Black curve: lognormal rate approximation. Panel (b): cumulative probability distribution.

Each entry in the STARLIB library consists of a single-line header followed by three columns. The header includes the chapter number (i.e., the chapter number of JINA REACLIB [5]), interact-

ing nuclei, source, and Q-value. Column 1 is a grid of 60 temperatures between 1 MK and 10 GK (in units of GK). Column 2 is the rate, either the thermonuclear rate (in units of $\mathrm{cm}^3\ \mathrm{mol}^{-1}\ \mathrm{s}^{-1}$) or the decay constant of photodisintigration or β decay (in units of s^{-1}). Column 3 is the factor uncertainty, $f.u.$, explained below.

The approximate rate probability density function can be derived for each STARLIB entry. For all rates x, we assume a lognormal distribution given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\frac{1}{x}e^{-(\ln x-\mu)^2/(2\sigma^2)} \qquad \text{for} \quad 0 < x < \infty. \tag{1.2}$$

As discussed in Refs. [1, 2, 3], the lognormal parameters μ and σ may be derived from STARLIB Columns 2 and 3, such that:

$$\text{Column 2} \equiv x_{med} = e^{\mu} = \sqrt{x_{high}x_{low}}, \qquad \text{Column 3} \equiv f.u.(68\%\ \text{coverage}) = e^{\sigma} = \sqrt{x_{high}/x_{low}}, \tag{1.3}$$

where x_{med} is the median rate. The high (x_{high}) and low rates (x_{low}) for 68% coverage are given by:

$$x_{low} = e^{\mu}/e^{\sigma} = x_{med}/f.u., \qquad x_{high} = e^{\mu}e^{\sigma} = x_{med}\ f.u. \tag{1.4}$$

Thus, by supplying the temperature, rate, and factor uncertainty, one can obtain not only the high and low rates but also the parameters μ and σ. With this information, the probability density function can be computed for any given temperature grid point.

In this article, we discuss the website that has been constructed for STARLIB and how to use it. The three main components are the Rate Library, Rate Calculator, and Details.

2. Homepage: `starlib.physics.unc.edu`

Each page allows navigation to all other pages, both as buttons at the top of the page and as links at the bottom. Additionally on the homepage, there are three menu items directing to the main components of the site. A screen capture of the top and bottom of the homepage is shown in Fig. 2.

3. Rate Library: `starlib.physics.unc.edu/RateLib.php`

Three elements may be accessed on our Rate Library page:

- Display an individual rate
- Download the entire library
- Download a subset of the library

A screenshot of the Rate Library homepage is shown in Fig. 3, and Fig. 4 displays is a screenshot as one scrolls down.

First, one may display an individual rate. As shown in the top half of Fig. 4, there are three menus in which to enter the desired reaction. Each menu includes a “?” button that, upon clicking multiple times, presents various examples directly in the boxes. There is also a master “Reset" button to clear all fields. Allowed formatting of nuclei is also shown. Lowercase and uppercase

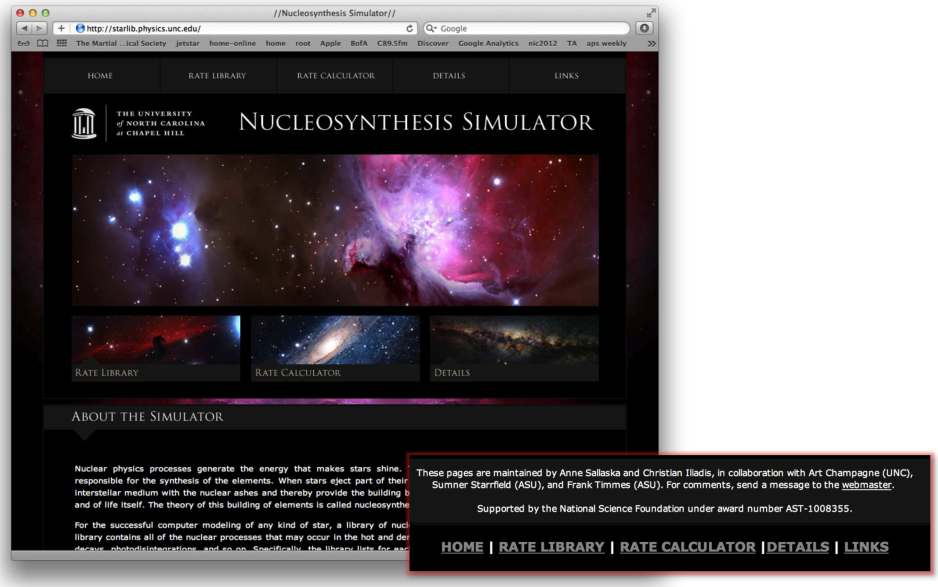

Figure 2: STARLIB homepage.

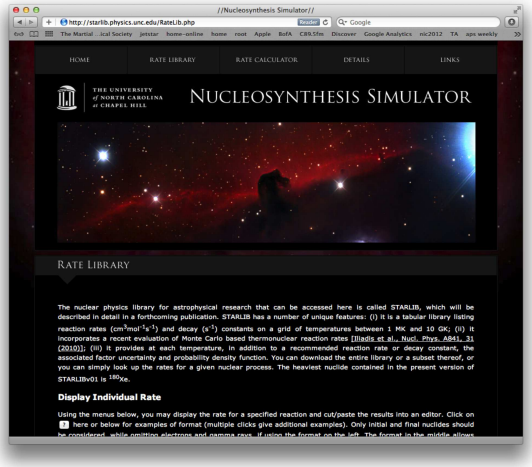

Figure 3: Rate Library, homepage.

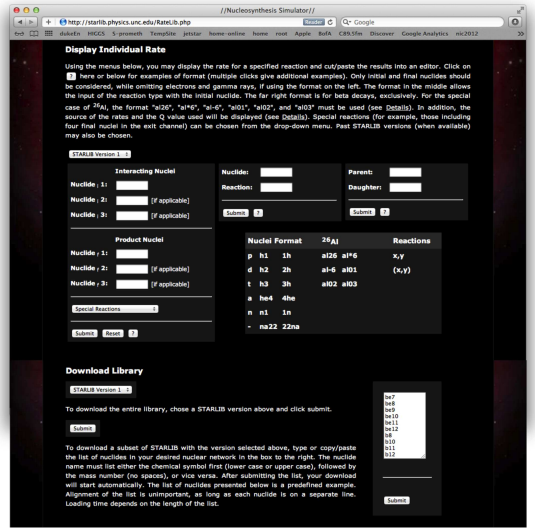

Figure 4: Rate Library, main details.

letters are permissible, and chemical symbol and mass number may be entered in any order, with no spaces or dashes. In addition, formats of “n”, “p”, “d”, “t”, and “a” may be used for neutron, proton, deuteron, triton, and alpha particle, respectively. ^{26}Al is a special case, wherein several formats are allowed, with meanings described on our Details page (Sec. 5). Archived versions of STARLIB may also be accessed by selecting the desired version.

The left menu requires that every nuclide involved be entered, up to three interacting and three product nuclei (i.e., omitting electrons, gamma rays, etc). A drop-down menu highlights special reactions and reactions that have more than three nuclei in one channel. The middle menu requires

the input of the initial nuclide and the type of reaction, in "(x,y)" or "x,y" format. The right menu is specifically for decays, with boxes for parent and daughter nuclide. Clicking "Submit" in any of the three menus displays the desired rate, shown in Fig. 5. The version is shown, as well as the header, including reaction, reference source, and Q-value. The source is a hyperlink to our Details page, where one may view the publication from which the data is taken or derived. Information on STARLIB's structure is discussed in Sec. 1.

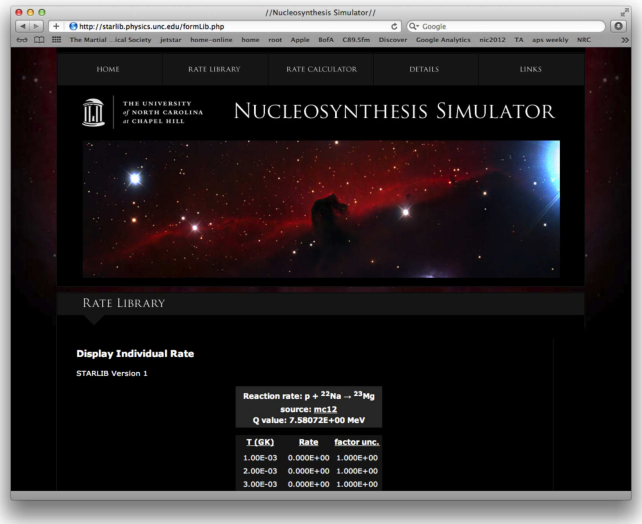

Figure 5: Rate Library, individually displayed rate.

The bottom half of Fig. 4 illustrates how to download the entire library or a subset. Again, archived versions of STARLIB will still be available, as we continue to update the library. Clicking the "Submit" button automatically downloads the full version to the user's computer. If only a subset is required, a list of nuclei to include may be copied and pasted into the text box at the right. Accepted formatting is the same as above, and right or left alignment of the list is allowed. The subset is downloaded upon clicking of the "Submit" button under the list of required nuclei.

4. Rate Calculator: `starlib.physics.unc.edu/RateCalc.php`

The Rate Calculator section allows users to run our Monte Carlo code to calculate their own reaction rates on our server. This is especially useful if one has measured new nuclear physics parameters and would like to calculate the resulting reaction rate. Details on this calculation can be obtained in Ref. [3] and in the forthcoming publication on STARLIB [1]. The components of this section include how to:

- Display our input files
- Run the Monte Carlo simulation on our server
- Monitor simulation progress
- Download output files

Figure 6: Rate Calculator, homepage.

A screen capture of the Rate Calculator homepage is shown in Fig. 6. Scrolling down this page shows our repository of current input files, shown in Fig. 7. Each input file includes *all* information needed to calculate the reaction rate, such as masses, spins, Q-values, information on direct capture, resonances, and interferences. Because formatting is very important, we suggest displaying an existing input file and editing it with the new information. Details on the formatting of the input file are discussed in Refs. [1, 3]. Two menu options are available for accessing our input files, and the formatting is the same as for the library, discussed in Sec. 3. Additionally, for the reaction ^{25}Mg$(p,\gamma)^{26}$Al, one may select a check box that displays the input file for only the metastable state of ^{26}Al. Selecting the “Total" check box for this reaction includes both the ground state and the metastable state. Leaving both check boxes blank for this reaction shows the input file for the ground state only. Again, clicking the “?” button multiple times cycles through various examples of acceptable formats. The input file is displayed in the text box below the two menu options. Alternatively, the file may be copied and pasted directly into the text box.

Once an input file is selected, the user simply needs to supply an email address and click “Run simulation" below the input file, shown in Fig. 8. This takes the user to the page where simulations may be monitored, output files may be download, and a job ID is issued (Fig. 9). This number allows tracking of the simulation and identification of the simulation’s output files, as each file is tagged with both job ID and reaction name for clarity. The STARLIB server employes a priority queue system. If the input file includes any resonances to be integrated, the simulation is filtered into the default queue and will be started when other simulations complete, if the queue is full. However, if no resonances require integration, the simulation is filtered into a separate queue where it will be run immediately, bypassing all waiting simulations in the default queue.

Shown in the middle of Fig. 9, one may view the status of *all* simulations currently running (i.e., this is for the entire server, not only one user’s simulations). The status is given, either as an “R” for running or “Q” for waiting in the queue, as well as total run time, progress through

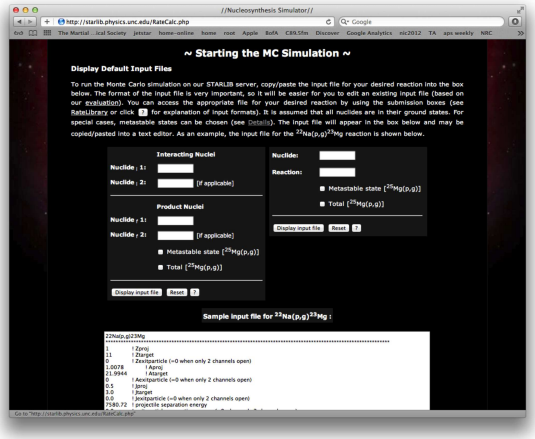

Figure 7: Rate Calculator, displaying existing input files.

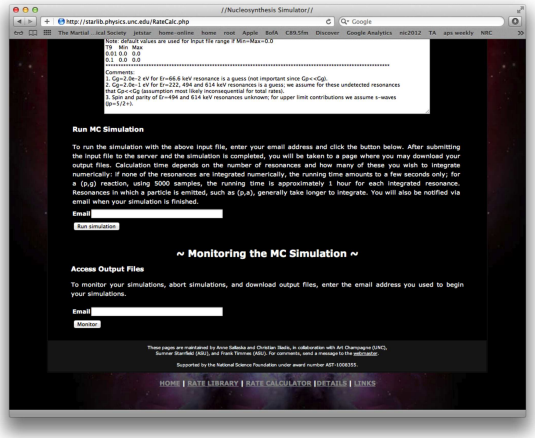

Figure 8: Rate Calculator, starting the Monte Carlo simulations and accessing output files.

the simulation in percent, and an estimate of remaining time. Below the status shown in Fig. 9 is a section in which one may abort simulations, if need be. Scrolling farther down the page displays the available output files, shown in Fig. 10. These may also be accessed from the main Rate Calculator page by submitting the email address used to start the simulations (see bottom of Fig. 8). Output files are tagged with both reaction name and job ID and may be sorted by name, size, or date. A "Refresh" button is included to update available output files. To aid bookkeeping, the original input file (*.in) has been copied here and tagged with the same information to correlate to the output file (*.out). The output file *.out includes all information on temperature, recommended rate, lower and upper rates. Examples of *.in files and *.out files are shown in Fig. 11. A detailed description of the format is in Refs. [1, 3]. Also given are the rate in a convenient latex format (*.latex) and a histogram of the rate probability density function at each temperature (*.hist). Unwanted output files may be deleted by entering in the job IDs at the bottom of the page.

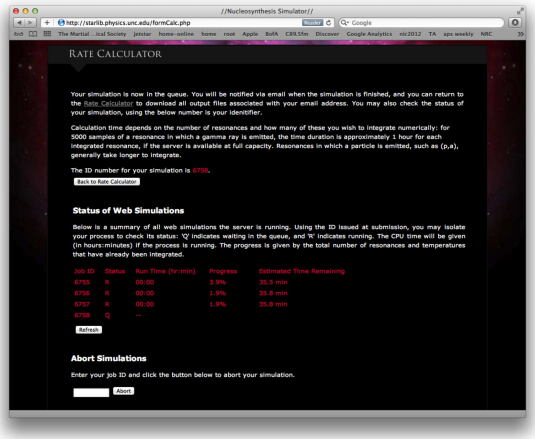

Figure 9: Rate Calculator, upon submission of a simulation.

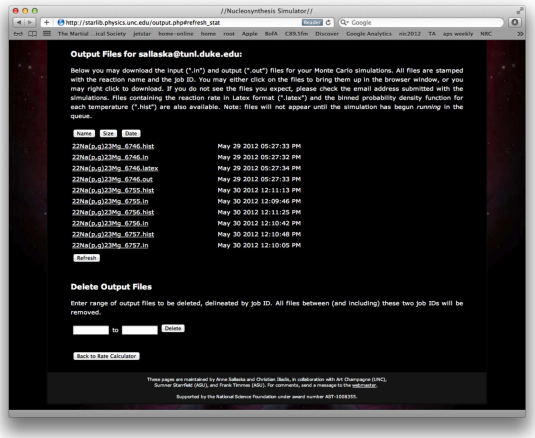

Figure 10: Rate Calculator, accessing output files.

Upon completion of each simulation, an email alert is sent to the address provided, indicating by job ID which simulation has been finished. The user may click the link in the email to return to our main Rate Calculator page, where inputting the email address will take the user to his/her output file repository. The user may also return to this page to monitor simulation progress at any time.

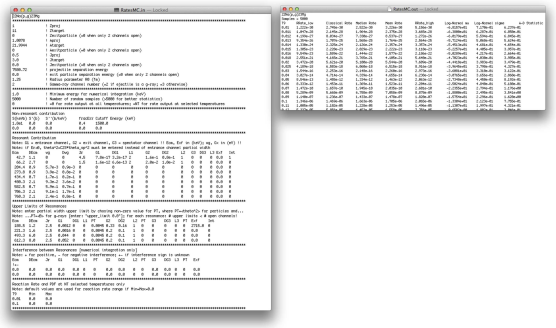

Figure 11: Examples of input files (left) and output files (right). For explanation of formatting, see Refs. [1, 3].

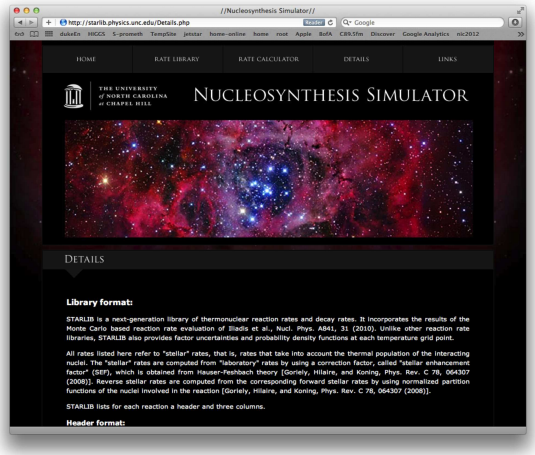

Figure 12: Details, homepage.

5. Details: `starlib.physics.unc.edu/Details.php`

Topics on this division of the webpage include construction of the library, library formatting, references and links to original papers, information on STARLIB updates, and details on the special case of ^{26}Al. A screen capture of this page is shown in Fig. 12.

Acknowledgments

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