SMNA 2022 - Lecture 8B-maxi - Helium-burning Nuclear Reaction Rates in Models of Massive Stars

We are going to walk through how to leverage STARLIB temperature-dependent nuclear reaction rate uncertainties in models of massive stars. We will work to focus on core He-burning reactions and determine their impact of the progenitors of core-collapse supernovae.

This exercise is based on the ApJ article **The Impact of Nuclear Reaction Rate Uncertainties on the Evolution of Core-collapse Supernova Progenitors** which can be found online.

Learning objectives

- Methods for utilizing STARLIB reaction rate library.
- Producing temperature-dependent uncertainty reaction rates.
- Analyzing MESA output for models using *many* sampled rates.
- Impact of He-burning rate uncertainties in massive stars.

Task 0 - Getting Started

1. Download the work directory 8B-maxi.zip!
2. Ensure that you can compile and run work directory:

```
cd pgstar
 ./mk && ./rn
```

This example will be evolving a 15 $M_\odot$ star using a simplified network starting from core H depletion! Note the first model will take a few hundred retries to converge. That is okay!

Task 1 - Using randomly sampled nuclear reaction rates with STARLIB

STARLIB provides temperature-dependent estimates for the uncertainty of the nuclear reaction rate. The library provides the median rate ($\langle\sigma v\rangle_{\text{med.}}$) and factor uncertatinty (f.u.) - a measure of the estimated 1 sigma uncertainty.

$$\langle\sigma v\rangle_{\text{samp.}} = \langle\sigma v\rangle_{\text{med.}} f.u.^{p_{i,j}}.$$

Here, $p_{i,j}$ is a single Gaussian deviate drawn from a normal distribution of standard deviation of unity and mean of zero. See Equation 4 of Sallaska et al 2013. The i index corresponds has to do with the number of samples/Gaussian deviates and j corresponds to the number of rates sampled in the grid.

The complete STARLIB library can be found online. The website provides a tool `reduceNet.f` to truncate the library. `PySTARLIB` has also been used in the past to search for and extract large batches of rates from the STARLIB library. For this exercise, I have pulled the `r_he4_he4_he4_to_c12` and `r_c12_ag_o16` rates from STARLIB and placed them in `supp/starlib_raw_rates`.

Using this information we can produce a *sampled* reaction rate that is within the uncertainty bounds given by f.u.

First, navigate to `supp` and run:

```
python example.py
```

using N = 1 sample. This should produce two sampled reaction rates in `rate_tables` and will tell you the $p_{i,j}$ value used. Because we are sampling two rates with N=1 sample, in `rate_variation_factors.txt` we will have $p_{1,0}$ and $p_{1,1}$ and their values in column 2. See `rate_list.txt` for which rate corresponds to which.

1. Once the new sampled rates are produced and in `rate_tables`, enable them as we did in Task 2 or 8B-mini using tables and point to the location of your newly generated rates.
2. Set a custom stopping condition based on the central mass fraction of he4=0.5.
3. Run the stellar model to this stopping condition and record the `center_c12` at this point here.

Task 2 - Using randomly sampled nuclear reaction rates with STARLIB - end of He-burning

1. Rerun `example.py` to produce two new sampled rates.

2. Change the stopping condition to central mass fraction of he4=1d-6.
3. Rerun the model and record the value here.
4. Discuss the results as they are populated.

Task 3 (Optional) - Determining the key reaction rates

A method for computing if a rate has an impact on a measured quantity is the Spearman Rank Order Correlation Coefficient.

1. Open `compute_sroc.ipynb` and compute r_S for A = p{*1,0} and then for A = p*{1,1} using the values from the spreadsheet for Task 1 (at X(he4)=0.5).
2. Repeat for the values computed in Task 2.
3. Compare your results with those found in the bottom left subplot of Figure 11 from Fields et al 2018 ApJS.