This is the work for the p -process which is a thermonuclear project for stellar astrophysics $ASTR8200$.

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Introduction

The p-process involves proton-rich nuclides that are made by adding one or more protons to an atomic nucleus. This type of nuclear reaction is called the proton capture reaction. (aka p/*gamma* reaction) When one adds a proton to a nucleus, the ratio of the protons and neutrons also change which results in a proton-richer isotope of the next element.

This project will be about the 92-Molybdenum decay in the p process of a thermonuclear supernova. This decay occurs after there is a shockwave generated from a supernova explosion. This shockwave goes through and causes heavier material in the leftover star to breakdown. Then the system cools and freezes out before all of the material breaks down. Here we are looking for a possible shell to get the right temperature. If yhou look at the p process with core collapse and compare the amounts of molecules with respect to the oxygen. (The p process is too low for the solar system so we think the thermonuclear supernovas may be the answer to why we have the amount of oxygen in our solar system. First we will run a simple calcluation. Thjen we will look at doing multiple zones and grid the zones. If there is time we will turn to a core collapse (this uses the p process at two different sites.))

There is a paper that Dr. Meyer wrote as a post doc that you may want to check out. The paper is called **A new site for the astrophysical gamma-process** by W. Howard and B. Meyer.

Computer Requirements

The calculations needed to create the figures can be run on most computers. It is necessary to install the appropriate libraries, as described at `http://sourceforge.net/p/nucnet-projects/wiki/libraries/`. Since the input and output XML data are parsed in with a DOM parser, it is advisable to have at least 2 Gb of RAM.

Getting Help

If you find you need help in installing or compiling the codes, or running the calculations, it is best to create a post on the Nucnet Projects Discussion Board at `http://sourceforge.net/p/nucnet-projects/discussion/`. If you believe you have found a bug in one or more of the codes, please report it as a NucNet Projects Ticket at `http://sourceforge.net/p/nucnet-projects/tickets/`.

Nucleosynthesis Calculations

To make Figure 1, you first need to run the nucleosynthesis calculation. First follow the instructions at `http://sourceforge.net/p/nucnet-projects/wiki/nuclear_mass/` to install and compile the relevant codes.[1]

Once the *nuclear_mass* project is properly installed and compiled, you are ready to run the the nucleosynthesis calculations. To do so, change into the nucnet-tools-code directory that downloaded automatically when you compiled the *nuclear_mass* project and compile the single zone network code:

```
cd ~/projects/nucnet-tools-code/examples/network
```

```
make all_network
```

Next, download the data for the calculation by typing:

```
make data
```

This creates a directory *../../data_pub*. For convenience, create a subdirectory under *../../data_pub* for your output called *coulomb* by typing

```
cd ../../data_pub
```

```
mkdir coulomb
```

Now edit the file *zone.xml* in *data_pub* until it reads

```
<zone_data>
  <zone>
    <optional_properties>
      <property name="tend">1.e10</property>
      <property name="tau">0.2</property>
      <property name="munuekT">-inf</property>
      <property name="t9_0">5.</property>
      <property name="steps">5</property>
      <property name="rho_0">1.e7</property>
    </optional_properties>
    <mass_fractions>
      <nuclide name="si28">
        <z>14</z>
        <a>28</a>
        <x>1</x>
      </nuclide>
    </mass_fractions>
  </zone>
</zone_data>
```

[1] Throughout these instructions, we will assume you have installed the *projects/* directory off your home directory.

Once this is done, you are ready to run the calculation. Return to *~/projects/nucnet-tools-code/examples/network* by typing

```
cd ../examples/network
```

and type (all on one line)

```
./run_single_zone ../../data_pub/my_net.xml ../../data_pub/zone.xml ../../data_pub/coulomb/m
```

This calculation uses the network data in *../../data_pub/my_net.xml* and the run data in *../../data_pub/zone.xml* and places the output in *../../data_pub/coulomb/my_output5.xml*. The

```
"[z <= 35]"
```

selects a network that only includes species up to $Z = 35$, which is certainly adequate for our purposes. (Typical execution time for an x86_64 type processor: ~50 minutes.)

Figure 1

To make Figure 1, first run the nucleosynthesis calculation. Next, compile the NucNet Tools analysis codes by typing:

```
cd ~/projects/nucnet-tools-code/examples/analysis
```

```
make all_analysis
```

Once that is done, return to the nuclear_mass project:

```
cd ~/projects/nuclear_mass
```

and run the code to compute nuclear mass terms during the calculation by typing (all on one line):

```
./compute_mass_terms_in_zones ../nucnet-tools-code/data_pub/coulomb/my_output5.xml ../nucnet
```

Now extract the E_C per nucleon versus time by typing (all on one line):

```
../nucnet-tools-code/examples/analysis/print_properties ../nucnet-tools-code/data_pub/coulom
```

Graph column 3 versus column 2 in *ec_time5.txt*.

Figure 2

To make Figure 2, it is first necessary to compute the radioactive fraction of each isobaric abundance. To do this, checkout and compile the *nuclear_decay* project, as described at `http://sourceforge.net/p/nucnet-projects/wiki/nuclear_decay/`. Once that is done, compute the isobaric abundances. To do so, select the timestep between time $t = 0.19$ and $t = 0.2$ seconds; thus, type (all one one line)

```
./rad_vs_nucleon_number ../nucnet-tools-code/data_pub/coulomb/my_output5.xml a "[optional_pr
```

The output file *yz_rad_stable.txt* gives the isobaric abundances for the indicated number of mass numbers (first line) and at the indicated time, temperature, density (second line). The subsequent lines give the mass number A, the isobaric abundance, and the fraction of the abundance that is radioactive. Graph column 2 versus column 1. Distinguish between the cases where the radioactive abundance fraction is less than or greater than 1/2.

Figure 3

To make Figure 3, change into the *data_pub/coulomb* directory and extract the necessary data by typing

```
cd ~/projects/nucnet-tools-code/data_pub/coulomb

../../examples/analysis/print_properties my_output5.xml time > time.txt

../../examples/analysis/print_mass_fractions_in_zones my_output5.xml he4 si28 ca40 fe54 ni56
```

Graph columns 2 (^{4}He), 3 (^{28}Si), 4 (^{40}Ca), 5 (^{54}Fe), and 6 (^{56}Ni) of *x.txt* versus column 2 of *time.txt*.

Figure 4

To make Figure 4, run the nucleosynthesis calculations as done previously but for the four cases 1) *t9_0* = 6 and rho_0 = 2.e7, 2) *t9_0* = 7 and rho_0 = 3.4e7, 3) *t9_0* = 8 and rho_0 = 5.e7, and 4) *t9_0* = 7 and rho_0 = 1.e7 (Run 2). Then create the data as done previously.

Figure 5

Figure 5 can be made from data computed with the simple_snII project at `http://sourceforge.net/p/nucnet-projects/wiki/simple_snII/`. To make this figure, follow the instructions at `http://nucnet-projects.sourceforge.net/data_pub/2014-02-26/` to make Figure 6 of `http://journals.aps.org/prc/abstract/10.1103/PhysRevC.89.025807`, choosing the appropriate isotopes and stellar interior mass range.

Figure 6

To make Figure 6, it is necessary to retrieve the relevant nuclear data. First, create the *libnucnet* example codes by typing

```
cd ~/projects/nucnet-tools-code/build

make -f Makefile.libnucnet all_libnucnet
```

Next extract the data by typing

```
cd ../libnucnet

./print_nuclides ../data_pub/my_net.xml "[(z >= 12 and z <= 30) and ((a = 2 * z or a = 2 * z
```

The XPath expression selects out only alpha nuclei and their potential daughters. Graph the mass excess (column 4 of *masses.txt*) difference between (Z, A) and $(Z-2, A)$ versus atomic number of the (Z, A) parent (column 2).

Now compute the terms in the nuclear mass formula for the species by typing

```
cd ~/projects/nuclear_mass

./mass_terms ../nucnet-tools-code/data_pub/my_net.xml "[((z >= 12 and z <= 30) and ((a = 2 *
```

The columns of the output file *energies.txt* are 1 (species name), 2 (atomic number), 3 (mass number), 4 (volume energy), 5 (surface energy), 6 (Coulomb energy), 7 (pairing energy), and 8 (shell energy). Subtract the relevant Coulomb energy from the mass excess from *masses.txt* and plot the difference between (Z, A) and $(Z-2, A)$ versus atomic number of the (Z, A) parent.

For more details on running *libnucnet* example codes, see the blog post `http://sourceforge.net/u/mbradle/blog/2012/07/running-libnucnet-examples/`.

Figure 7

To make Figure 7, return to the data directory and run the property printer code on the output you previously created by typing:

```
cd ~/projects/nucnet-tools-code/data_pub/coulomb

../../examples/analysis/print_properties output_terms5.xml time "Volume term" "Surface term"
```

Plot the sum of columns 3, 4, 5, and 6 versus column 2 in terms.txt.

Table 1

To make Table 1, change into the *data_pub/coulomb* directory and extract the necessary data for the first row by typing

```
cd ~/projects/nucnet-tools-code/data_pub/coulomb

../../examples/analysis/print_properties my_output5.xml time t9 rho > props.txt

../../examples/analysis/print_mass_fractions_in_zones my_output5.xml he4 ni56 > x.txt
```

Find the row in *props.txt* corresponding to the time $\sim$ 100 seconds. Compute the photon-to-nucleo ratio ϕ as $\phi = 0.34T_9^3/\rho_5$, where $\rho_5 = \rho/10^5$ g/cc. The ^{4}He and ^{56}Ni mass fractions are in the corresponding row of the file *x.txt*. The Coulomb energy per nucleon can be retrieved from the file *ec_time5.txt* computed previously. Repeat for the other calculations.
