Comparing Post Processing Nucleosynthesis (PPN) Codes

An investigation into the impact that different charged particle reaction rate libraries and different PPN codes can have on a variety of different astrophysical environments

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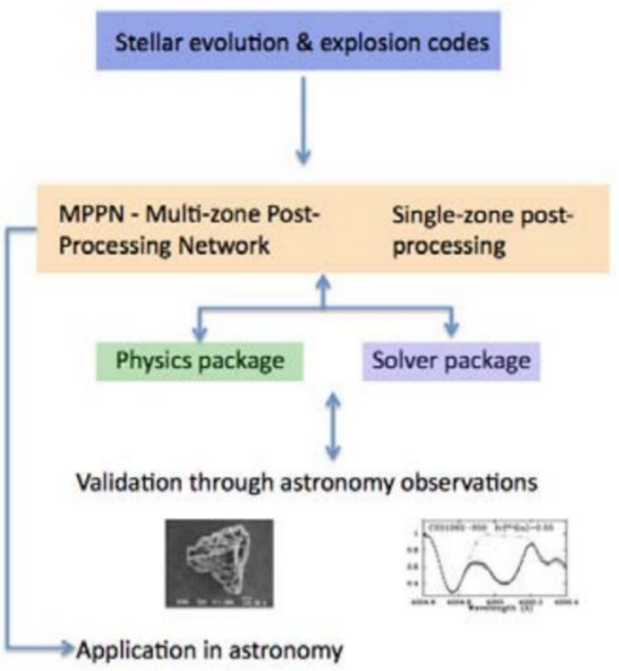
Motivation

- Codes that model astrophysical environments are used throughout the astrophysics community.
- Various different types of software and codes are available with more being developed independently.
    - Post Processing Nucleosynthesis codes are one such example of modeling software.
- These codes depend on theoretically and experimentally obtained data to accurately model astrophysical processes.
- When first examining a new scenario - a neutron star common envelope - we noticed that different codes produced different abundances for the same input trajectory and initial composition.

How do PPN codes work?

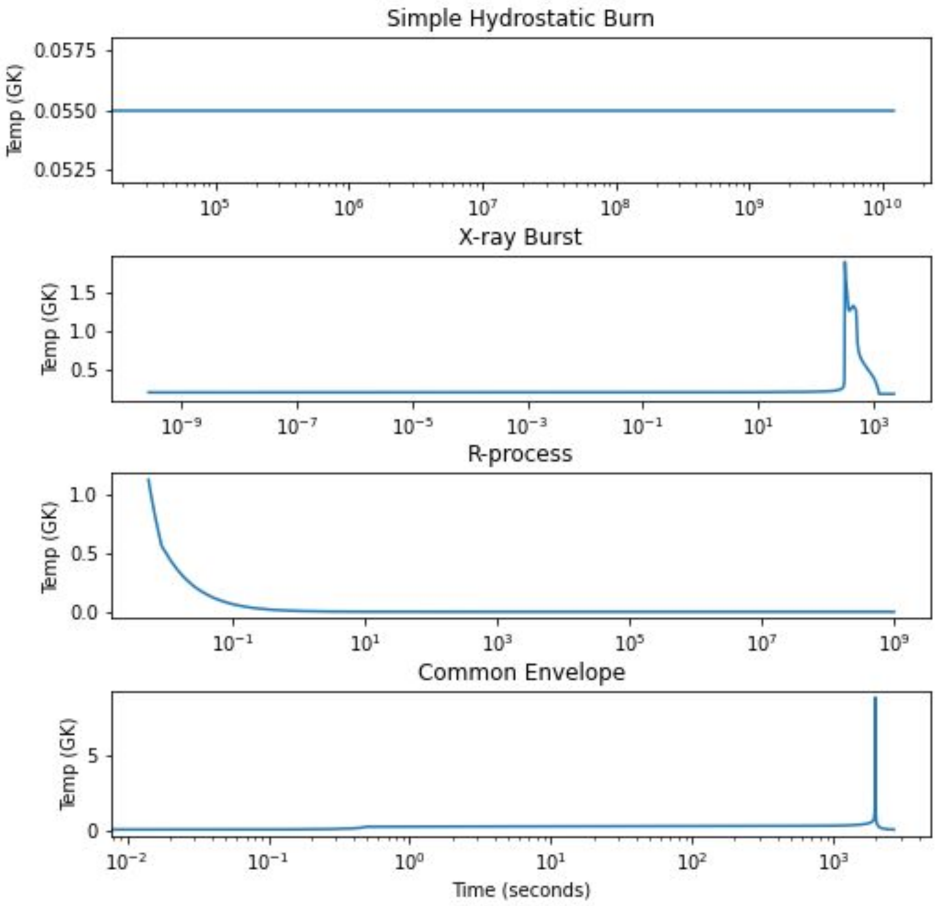
- PPN models nuclear reaction flows (flux) and isotopic abundance changes using differential equations.
- Inputs:
  - Temperature evolution.
  - Density evolution.
  - Initial abundances.
  - Nuclear reaction cross section data.
    - Experimental.
    - Theoretical.



The trajectories

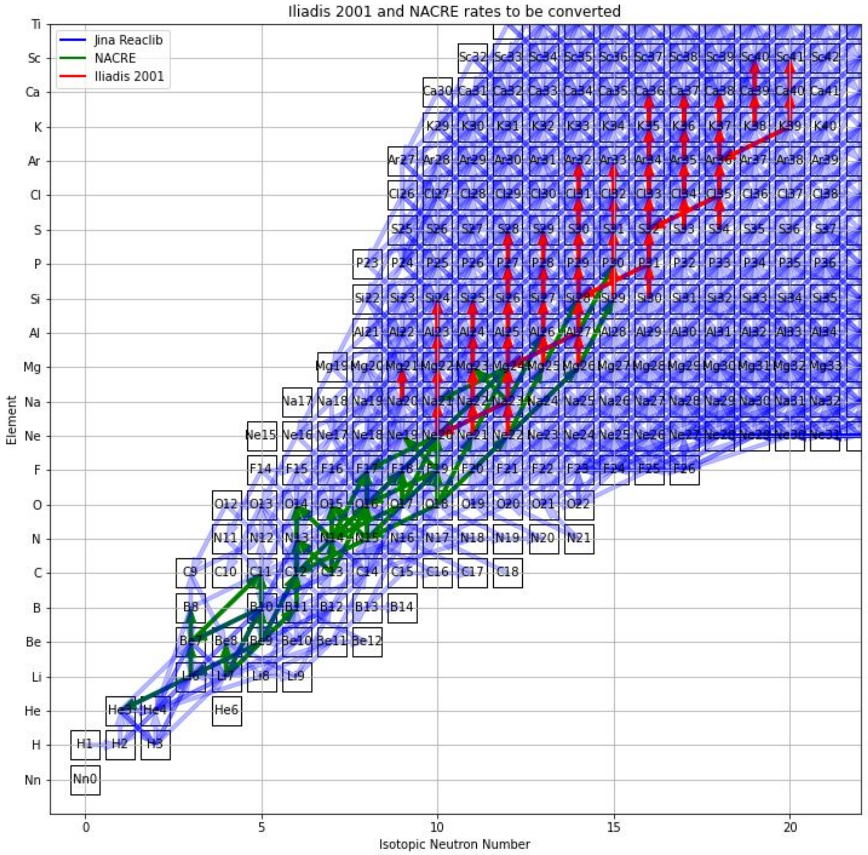
Four trajectories were used to test different scenarios:

- A simple hydrostatic burn.
- An X-ray burst.
- A r-process like trajectory.
- A rapidly accreting neutron star inside a common envelope.



Ensuring a fair comparison

To ensure any differences that are seen in the code comparison don’t come from different input physics only the JINA Reaclib library was used across all of the PPN codes.

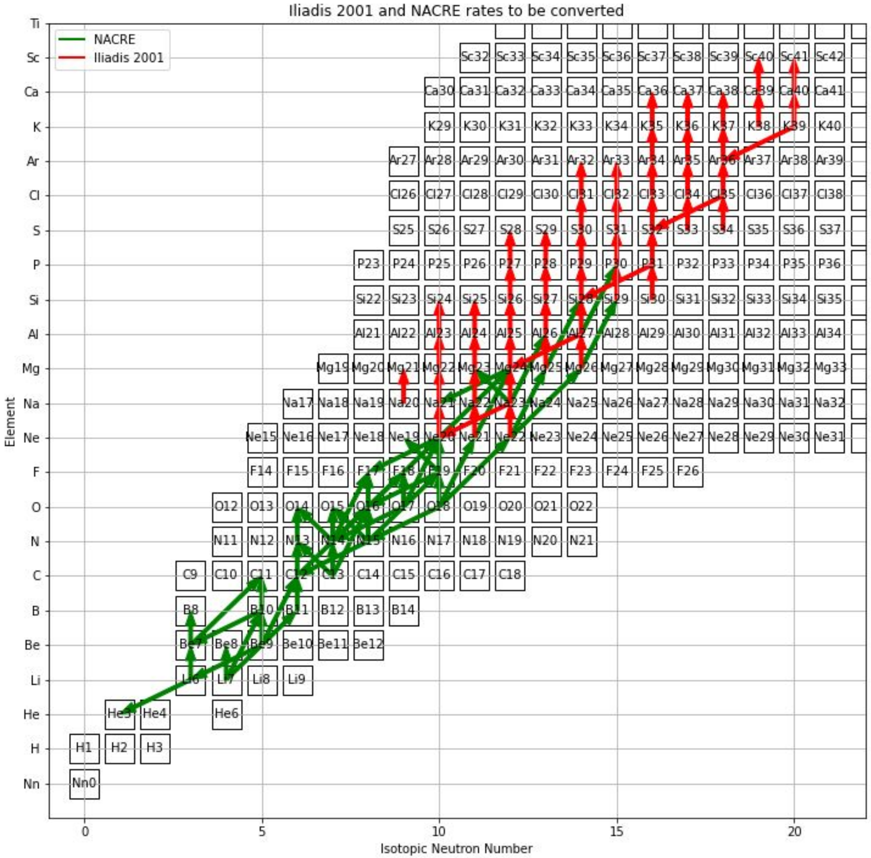


Ensuring a fair comparison

The first code that was investigated was NuGrid.

This code utilises multiple reaction libraries.

For charged particle interactions there are three libraries used: JINA Reaclib v1.1, NACRE and Iliadis 2001 proton capture study



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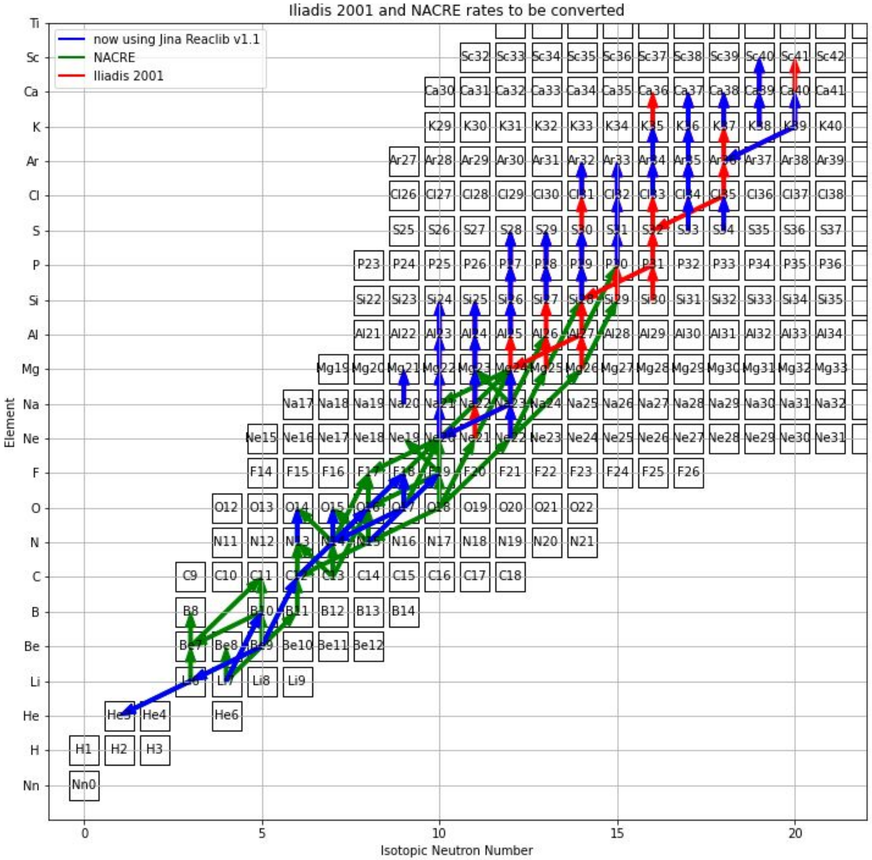

Converting Iliadis 2001 to JINA Reaclib v1.1

For the Simple hydrostatic burn and X-ray burst trajectory we see little impact.

In the common envelope and r-process there are large variations. This could be due to reaclib containing older theory rates that NACRE and the Iliadis 2001 study have measured.

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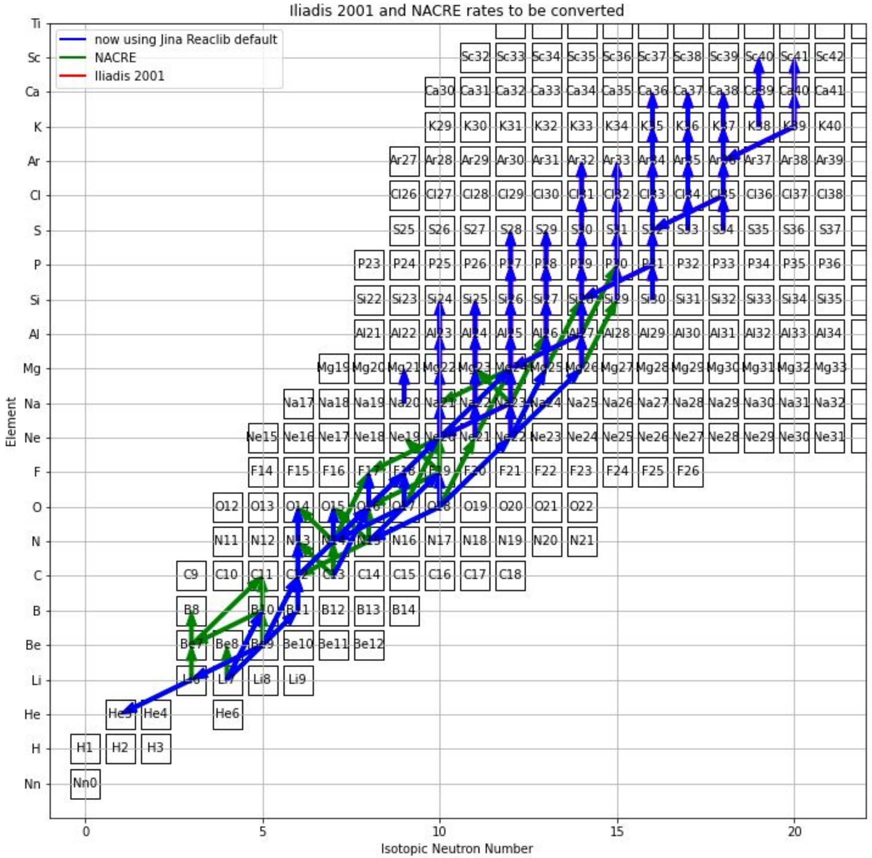
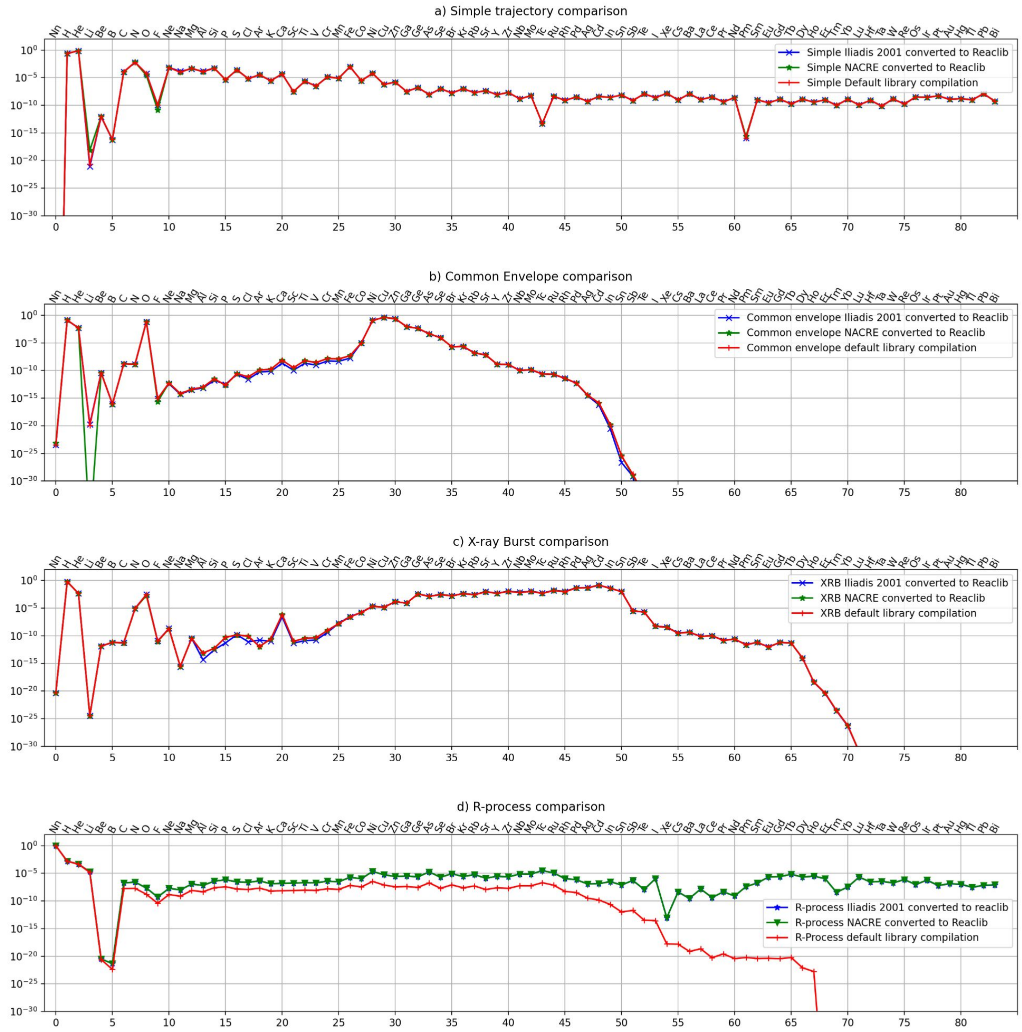


Converting Iliadis 2001 to the default JINA Reaclib (2021)

Using the updated the version of JINA Reaclib, we see that converting the NACRE and Iliadis 2001 rates has almost no impact on the Common envelope trajectory.

The R-process trajectory still shows different elemental abundances. We are still trying to understand why this occurs.



Which codes are included?

Four codes were used in this comparison:

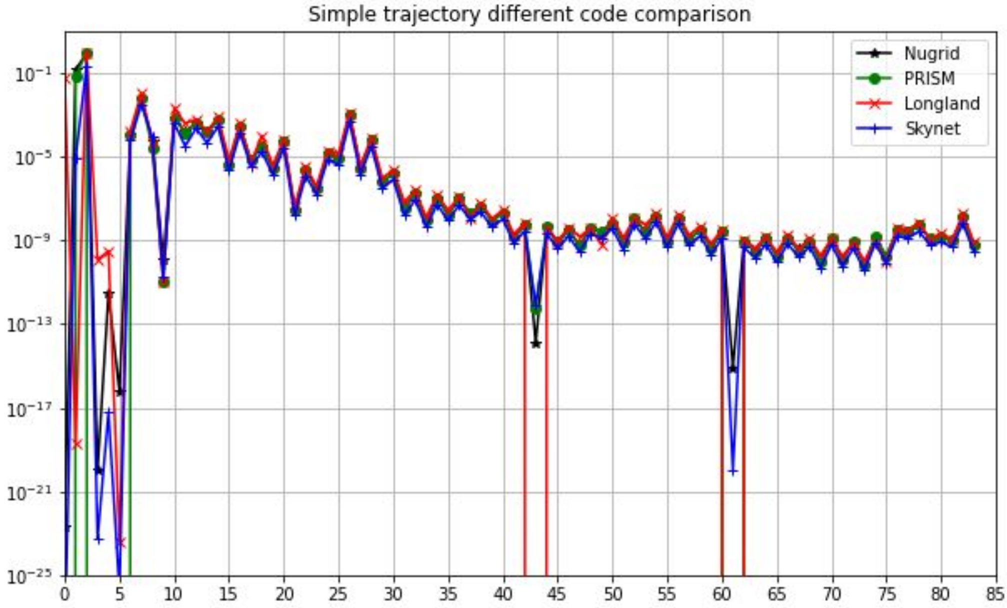
- NuGrid - 5234 isotopes
- PRISM - 5234 isotopes
- SkyNet - 5234 isotopes
- A nucleosynthesis code with performance improvements as presented in [Longland 2014] - 2464 isotopes

The four codes were updated to use the latest version of JINA Reaclib.

The Results - Simple trajectory

For a simple hydrostatic burn we see little difference in the results from each network.

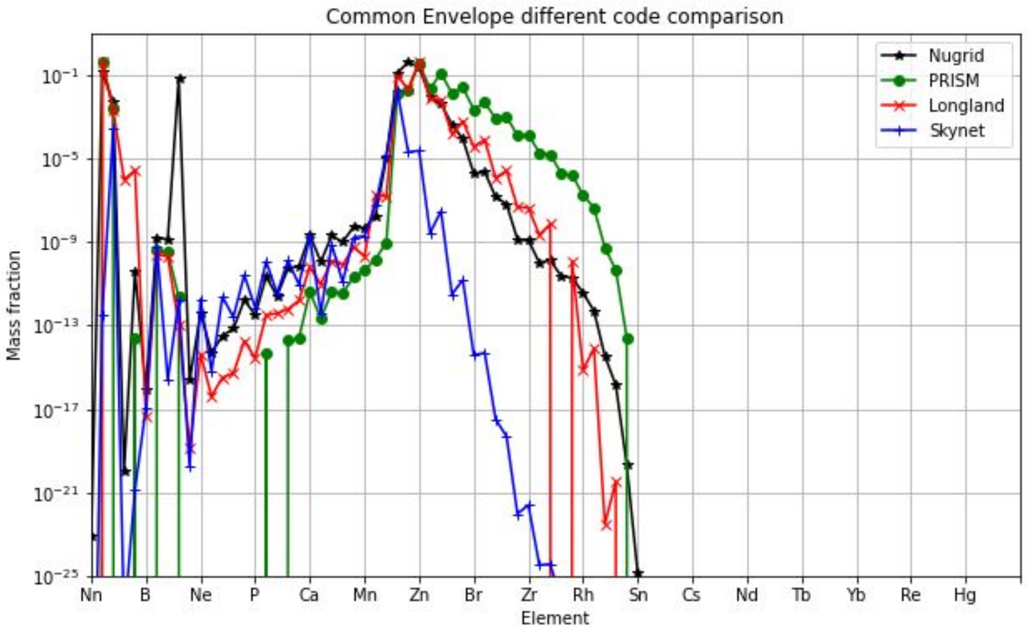
During low temperature and low density hydrogen burning the codes mostly agree with each other.



The Results - Common envelope

Similar abundances in NuGrid and SkyNet are seen up to Nickel

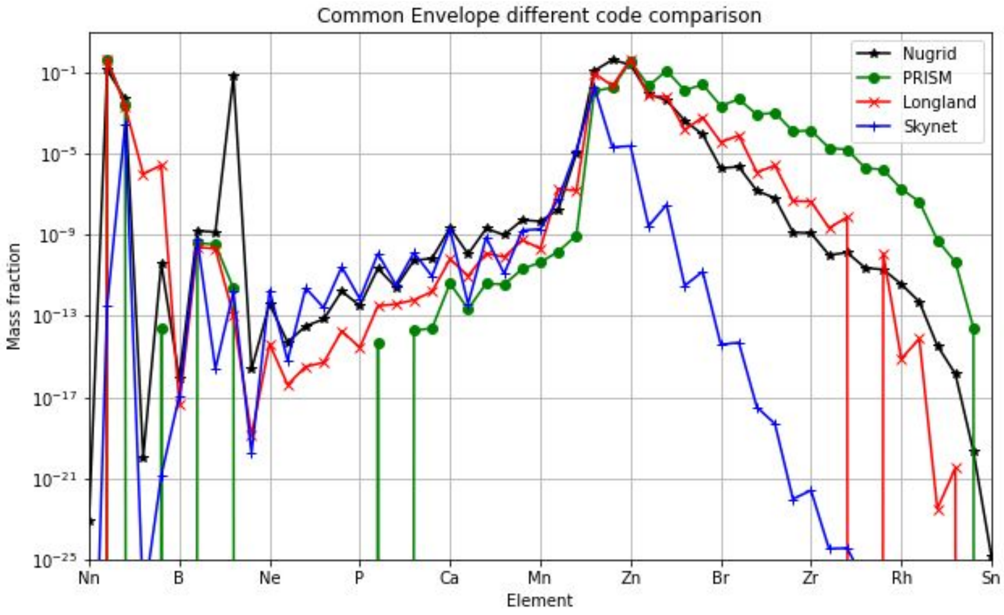
SkyNet under produces elements beyond Nickel compared to the others



The Results -
Common envelope

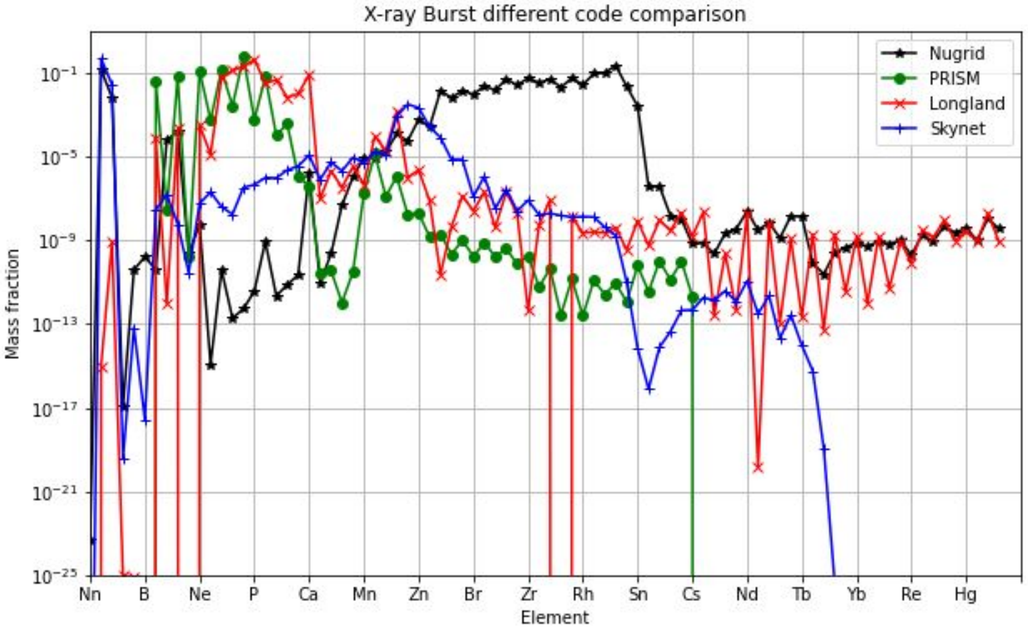
On further investigation the peak at Oxygen produced by NuGrid is due to a network boundary decay issue.

Oxygen 12



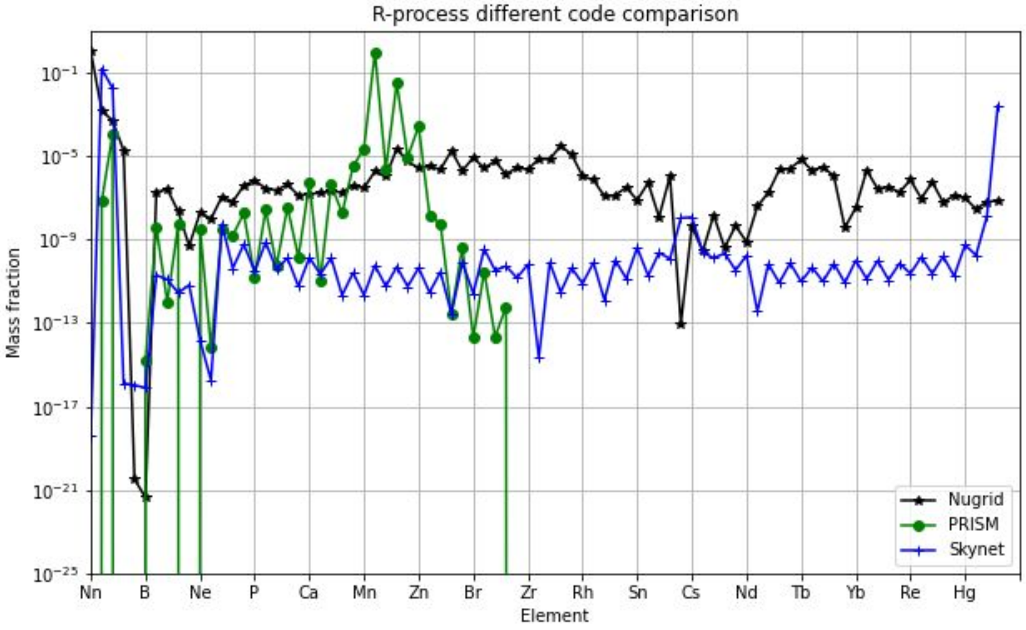
The Results - X-ray burst

Once again we see large differences between all of the codes. With only a few elements around Manganese that have similar mass fractions.



The Results -
R-process trajectory

PRISM doesn't produce any elements beyond Strontium. SkyNet and NuGrid both elements produce up to Bismuth but SkyNet consistently under produces most elements compared to NuGrid.



Conclusion

While we are still trying to understand the exact origin of the difference that can be found in the resulting elemental abundances, we believe that it is due to different implementations of numerical solvers, screening effects and potentially also due to resolution of the temperature grids used inside these networks.

Choice of reaction library and PPN code can impact extreme environments. Care must be taken to ensure that the correct network is chosen for a specific environment, and these environments should be tested in more than one PPN code.

Thank you for listening!

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Dr Chris Fryer - Los Alamos National Laboratory

Sophie Abrahams - The University of York

The NuGrid collaboration

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