Following the Fusion Network in the Crust of Accreting Neutron Stars

Amber Lauer, Louisiana State University Dept. of Physics & Astronomy, Baton Rouge, LA, 70802
Fei Yuan, Michigan State University Dept. of Physics & Astronomy, East Lansing, MI, 48824
Tsunghan Yeh, University of Illinois, Dept. of Physics, Urbana-Champaign, IL, 61801

Abstract

Xnet uses various methods to solve the nuclear network differential equation. We applied this method to the X-ray burst using the formulation devised by Fisker in 2007[1]. The major component of this formulation was the temperature profile, which is created using various observables and basic physics arguments. Using this profile, we varied the initial abundances to observe the nucleosynthesis over time as well as gauge burst efficiency in the form of the ratio of initial and final H abundance. In addition, previously created python scripts for reading the special binary output file were modified and refined to a useful and valuable tool to complement XNet. In addition the files necessary to run the specific XRB example were modified and repackaged to be a standalone version of Xnet suitable for reuse.

X-ray Burst Scenario

- H and ^{4}He-rich material falling from companion star
- Burning through steady fusion process while sinking
- Heating up the NS surface to ignite ^{15}O(α;γ)^{19}Ne
- Gateway between
  hot CNO cycle and rp-process
- Powering a bright X-ray flash

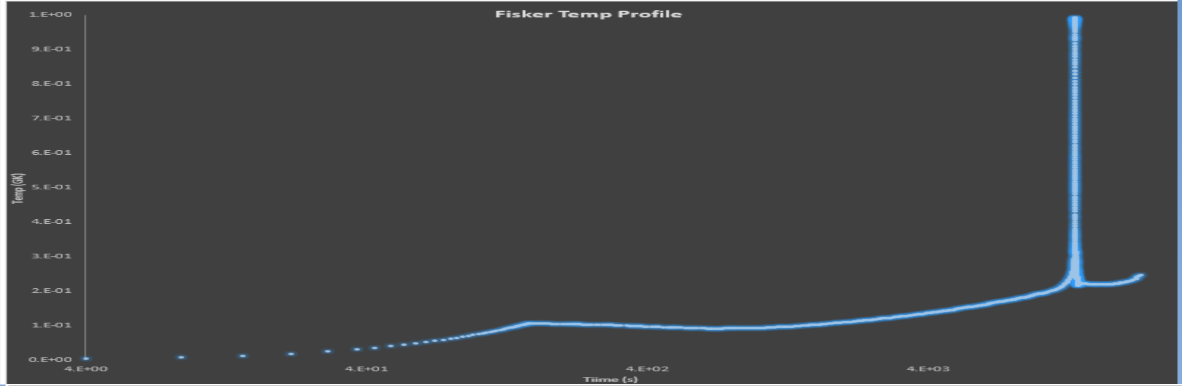
thermonuclear explosion
Photo Credit: David A. Hardy & PPARC

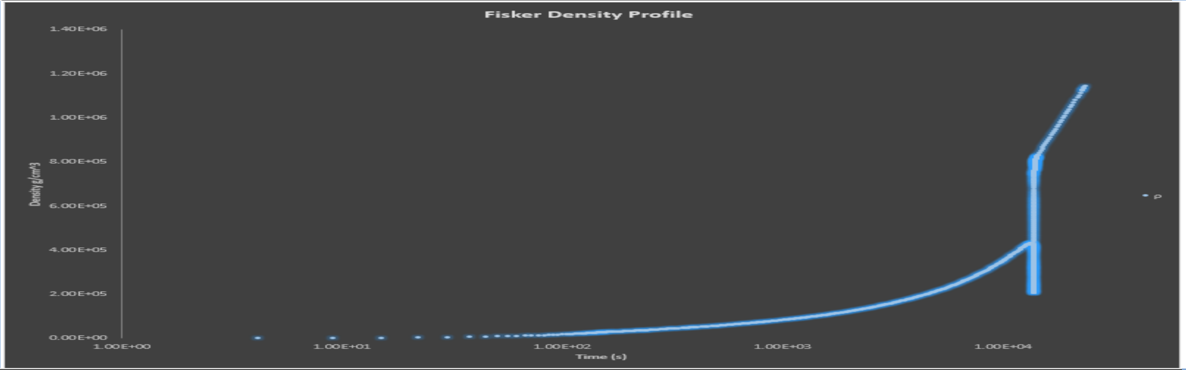
Temperature Profile Theory

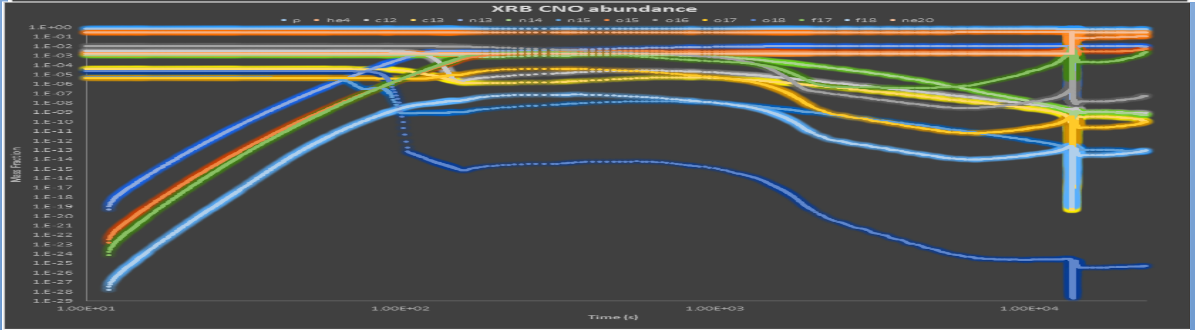
Radiative flux: $F \sim \sigma T^4$

- Upper & lower limit: flux & heavy burning
- $>3\alpha$ heavy Coulomb-suppressed
- basic shape from assumptions & observables
- H & He hot CNO
- ramp up
- hot CNO$\longrightarrow$ burst
- radiative cooling/H burning

Temperature & Density Profiles







[1]

Experimental Design: Code

- XNet: differential equation (DE) solver implemented using matrix operations
- Choice of DE solver:
  - **Backward Euler method**
  - Bader-Deufelhard
- Choice of matrix solver:
  - **Lapack**
  - Pardiso
  - MA28
  - MA48
  - GPU
- Parallelization:
  - MPI
  - OpenMP
  - GPU

Experimental Design: Code

- Took existing Python scripts for rendering graphs and nuclide chart animation[3,4] streamlined compiling and rendering
- Reorganized and modified code and control files for a standalone X-ray burst (XRB) implementation of XNet
- Wrote makefile for both Xnet and Reactionlib to unify installation

Experimental design: Inputs

- Networks:
  - `sunet`
  - `sunet.xrb`
  - `sunet` provided by W. R. Hix
- Thermal profile:
  - Fisker et al. (2007): "xnet folder"`/test/Test_Problem/`
- Reaction rate library:
  - https://groups.nscl.msu.edu/jina/reaclib/db
- Multiple abundance files
  - solar abundance data by Lodders et al. (2009)
  - half solar metallicity (various ratios H/He)
  - no metallicity (various ratios H/He)
  - full abundance file provided by W. R. Hix

Goal

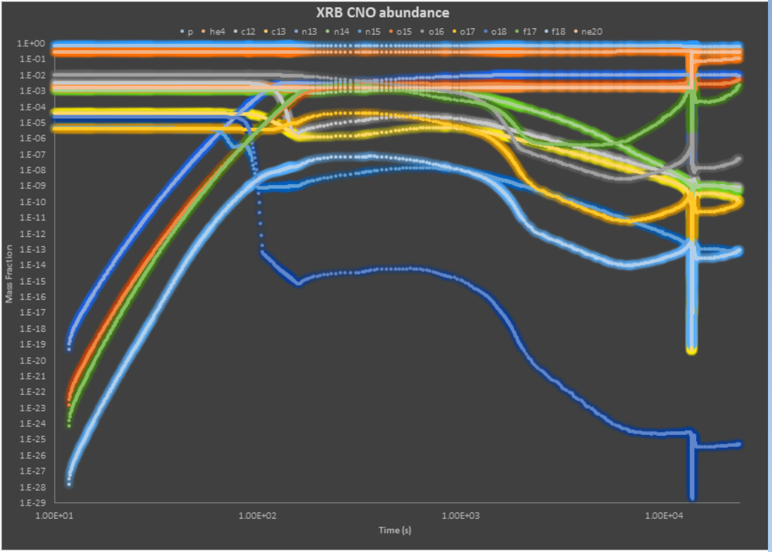
How do the initial abundances affect the reactions in an X-ray burst?

Can we model a full reaction network burst?

Output files

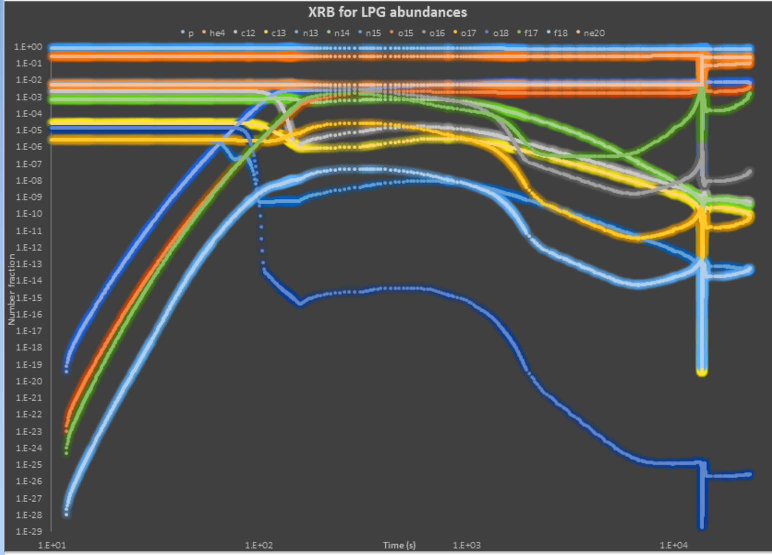
- `ev*:` ASCII, max 14 nuclides
- `tso*:` binary, all nuclides
- decoded with Python (tip-o-hat → Kevin)
  https://github.com/xrf/talent-astro-proj2/blob/master/tso_reader.py
- plot with Matplotlib
- generate animation (tip-o-hat → Kaitlin)
  https://github.com/xrf/talent-astro-proj2/blob/master/plot-chart
- uses (A, Z) data (tip-o-hat → Alison)

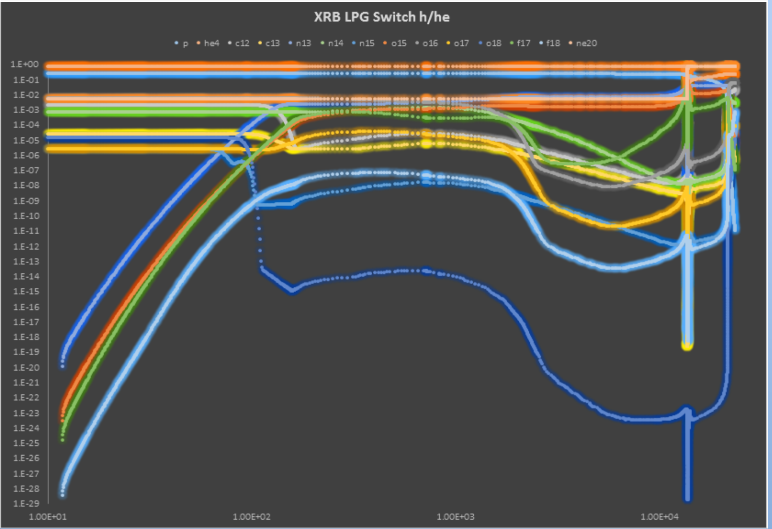
Toy Models



← Small CNO network

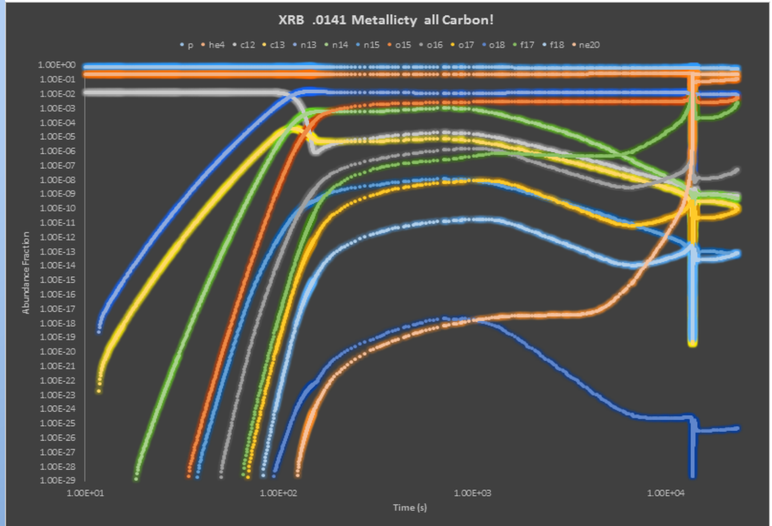
Updated Solar Abundances →



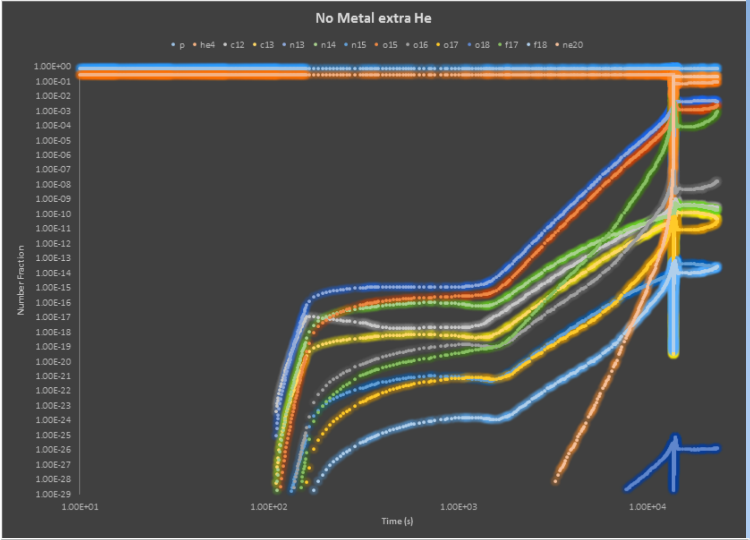


← Updated solar abundances switch H/He

Solar metallicity all carbon →

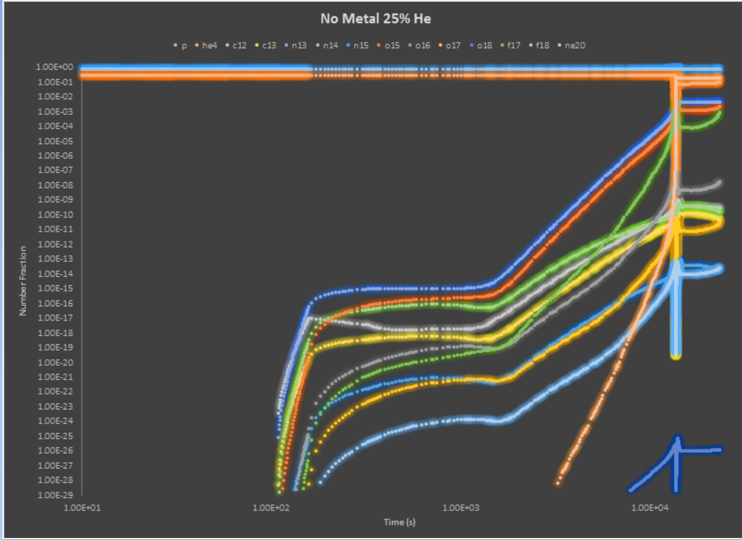


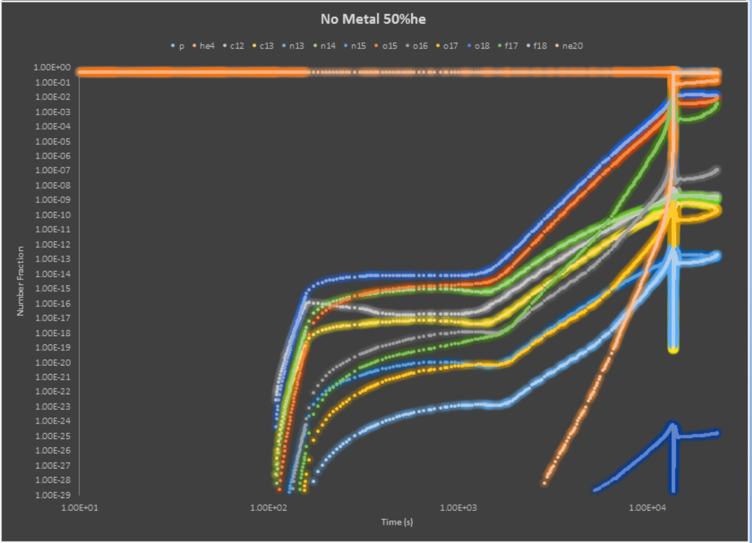
No Metal Toy Model



<=Extra number fraction in He

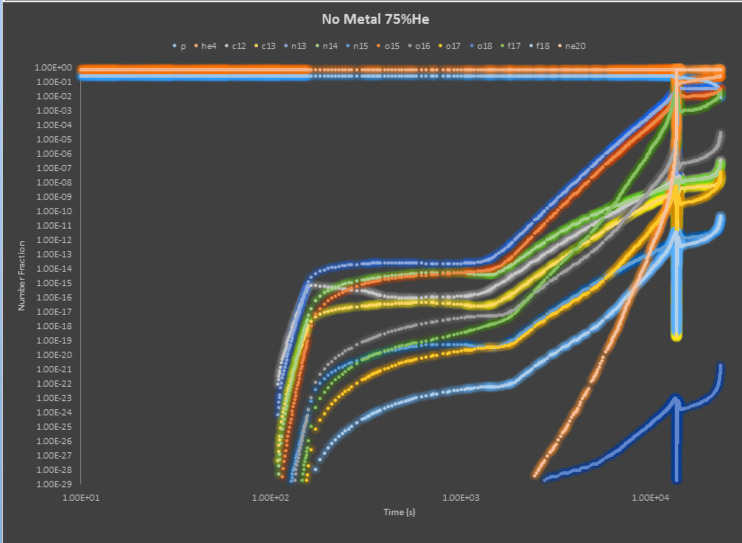
25% He=>

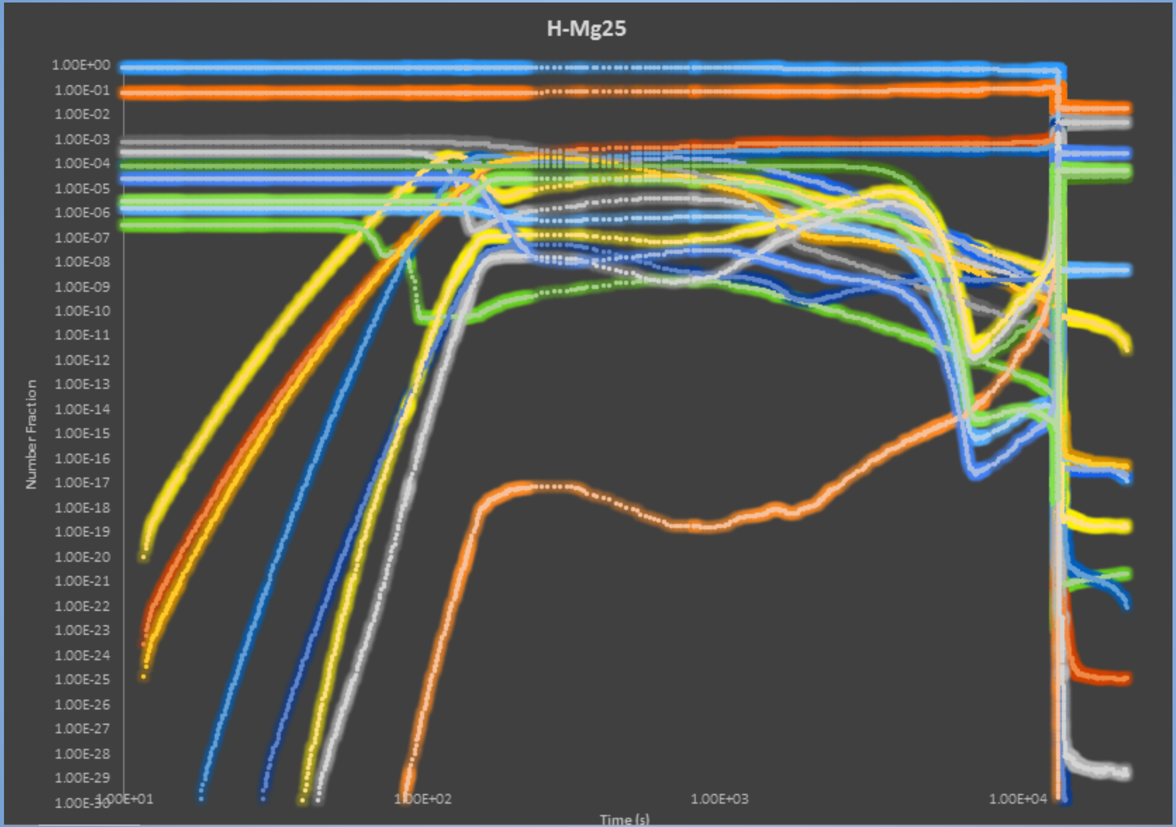




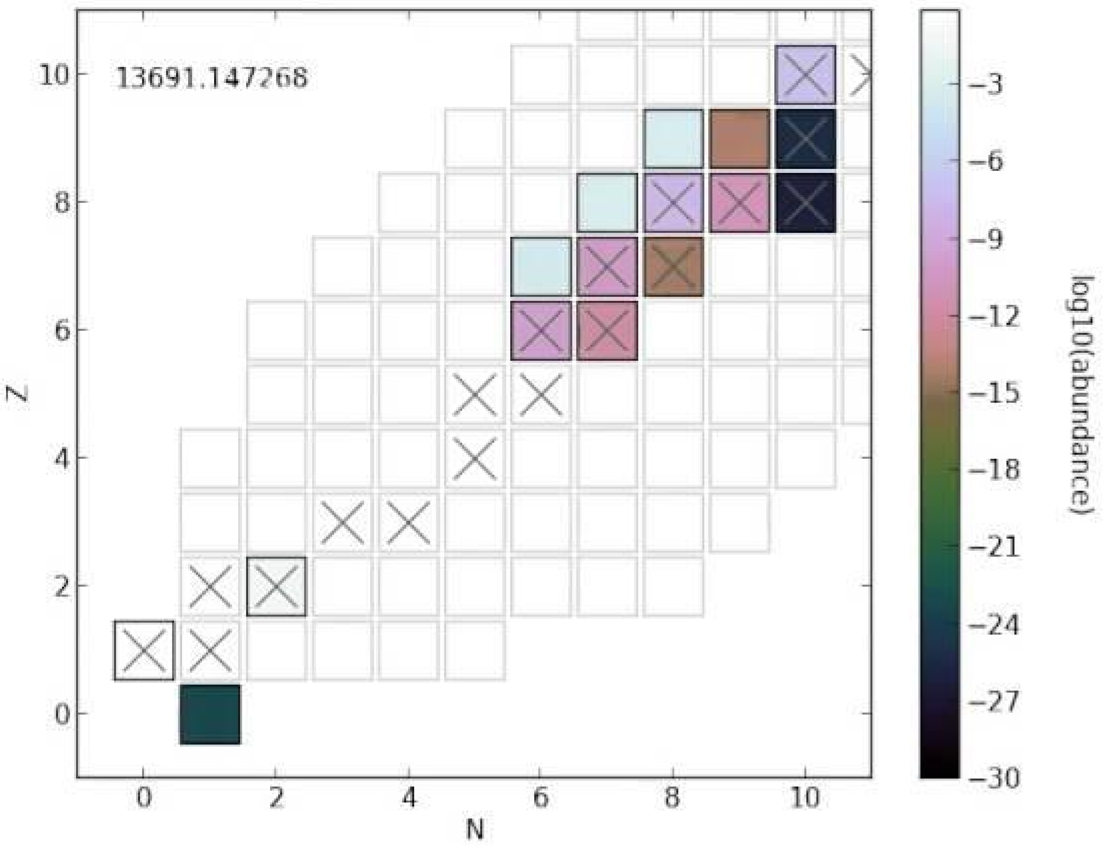
<=50% He

75% He=>

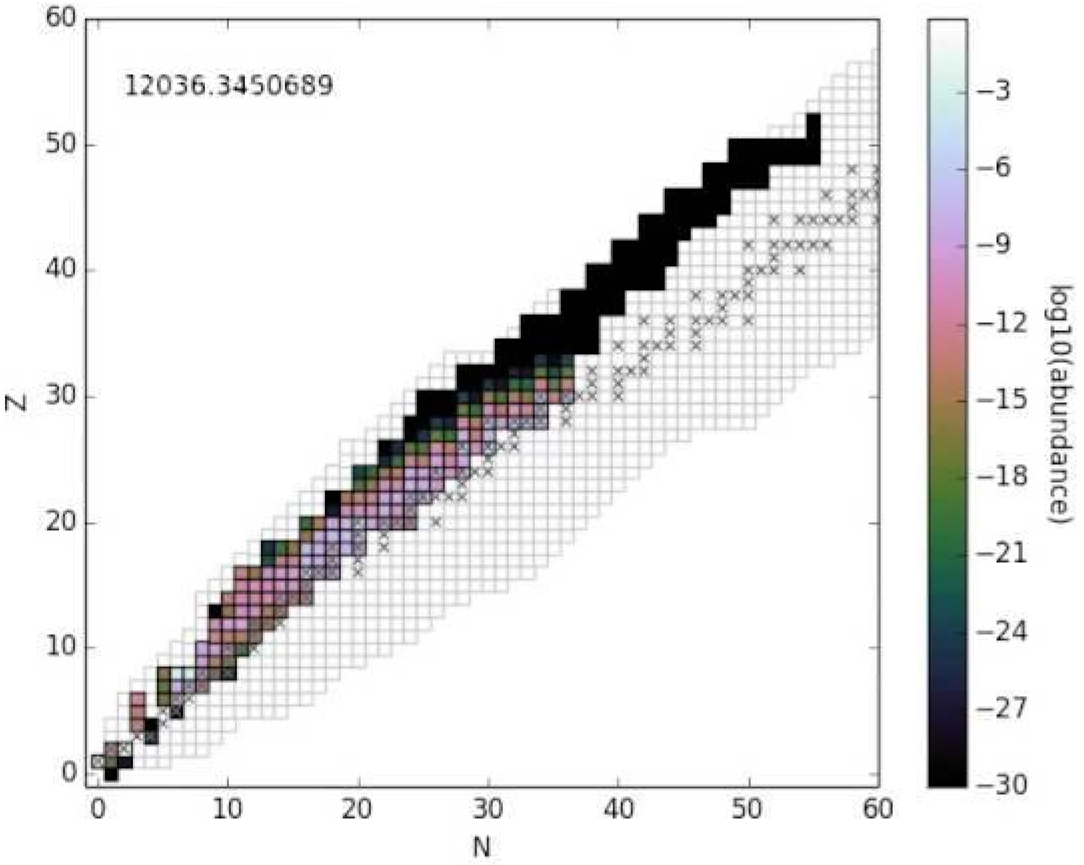




H-Mg25
Number Fraction
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1.00E-17
1.00E-18
1.00E-19
1.00E-20
1.00E-21
1.00E-22
1.00E-23
1.00E-24
1.00E-25
1.00E-26
1.00E-27
1.00E-28
1.00E-29
1.00E-30
1.00E+01
1.00E+02
1.00E+03
1.00E+04
Time (s)



13691.147268
Z
N
0
2
4
6
8
10
−3
−6
−9
−12
−15
−18
−21
−24
−27
−30
log10(abundance)



12036.3450689
Z
N
0
10
20
30
40
50
60
log10(abundance)
−3
−6
−9
−12
−15
−18
−21
−24
−27
−30

Conclusions

Since the initial X-ray burst is dependent on so few nuclei, almost no configuration can stop the burst behavior in a toy model.

References

[1] J. L. Fisker, W. Tan, J. Görres, M. Wiescher, and R. L. Cooper, *The Astrophysical Journal* **665**, 637 (2007).
http://dx.doi.org/10.1086/519517

[2] Kaitlyn Cook, https://github.com/KJCook/sedov-solution

[3] Kevin Siegl, http://goo.gl/ghtj51

[4] K. Lodders, H. Palme, and H.-P. Gail, (2009).

[5] Alison Dreyfuss, http://goo.gl/JF78Yu