UNIVERSITY OF Hull

E.A. Milne Centre
for Astrophysics

The Effect of Progenitor Metallicity on Nucleosynthesis in Multidimensional Type Ia Supernova Models

J Keegans[1], M Pignatari[1], D Townsley[2], S Andrews[3], S Jones[4], W Even[4], C Fryer[4]
[1] E. A. Milne Center for Astrophysics, University of Hull, Hull, HU6 7RX
[2] Department of Physics and Astronomy, The University of Alabama
[3] Center for Nonlinear Studies (T-CNLS), Los Alamos National Laboratory, Los Alamos, NM, USA
[4] Computational Methods (CCS-2), Los Alamos National Laboratory, Los Alamos, NM, USA

Introduction:

Type Ia supernovae occur in binary stellar systems, although there is debate over the relative contributions between single-degenerate and double-degenerate scenarios (see, for example, [1] [2] [3]). The multi-dimensional simulations examined here are from the single degenerate case, where material is accreted from a close main sequence companion, as described in Townsley et al. [4].

The effect of metallicity in the progenitor on the SNIa nucleosynthesis in the system is investigated by changing the ^{22}Ne abundance. Similar studies have been undertaken previously for different SNIa models [5][6]. Miles et al [7] investigates the effect of metallicity on 3 SNIa models, and includes the 2D DDT model used here [4]. Comparison with these results will therefore serve as an important benchmark ensuring that the new new tppnp framework is consistent with the literature.

Differences in progenitor metallicity were investigated by Timmes, Brown & Truran [8] and ^{56}Ni production was found to increase linearly with progenitor metallicity. This followed the work of Höflich, Wheeler & Thielemann [9], who found that changing the progenitor metallicity influenced the nucleosynthesis in the outer layers of SNIa explosions,and Iwamoto et al [10].

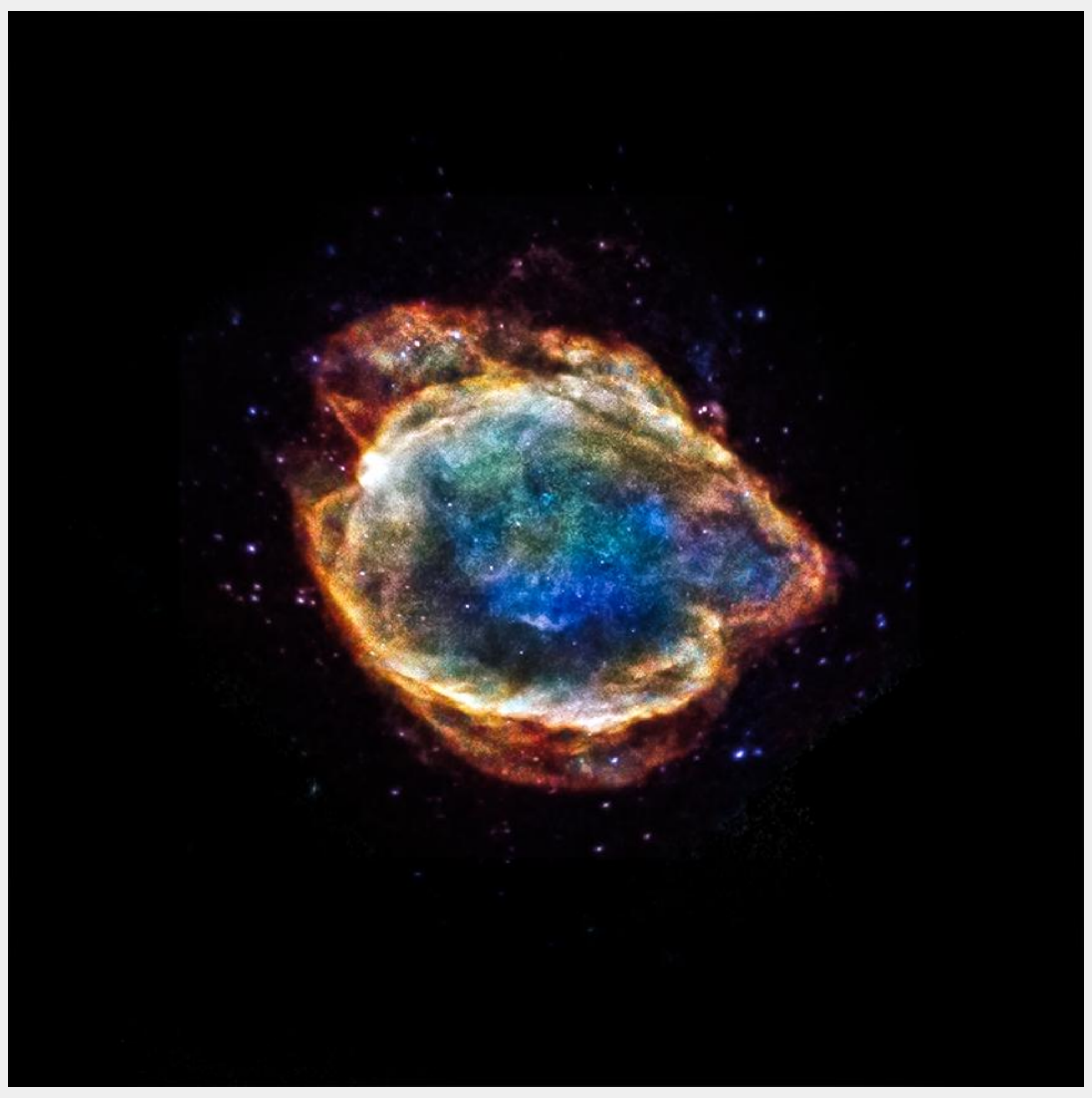

Fig 1 X-ray composite of SNIa remnant G299.2-2.9, detected with Chandra X-ray Observatory.
Credit: NASA/CXC/U.Texas/S.Post et al. G299.2-2.9 shows an inhomogeneous distribution of metals [11]. Initial analysis by Post et al show variations in the Fe/Si abundance throughout the structure, highlighting the importance of multidimensional hydrodynamics modeling in describing the nucleosynthesis during SNIa

Fig 2. VIPER computing cluster at the University of Hull ~5,500 computing nodes utilising Open MPI for parallel computing.

Method: The NuGrid Post Processing Tools

- Nuclear Physics Package:

The nucleosynthesis is followed by the utilisation of an adaptive nuclear reaction network containing 5234 isotopes and ~75,000 reaction rates, from various reaction libraries (see Pignatari et al. 2016 [12] for full details).

- tppnp Framework:

The tppnp framework is a parallel post processing framework designed for post processing of trajectories from multidimensional SN simulations.

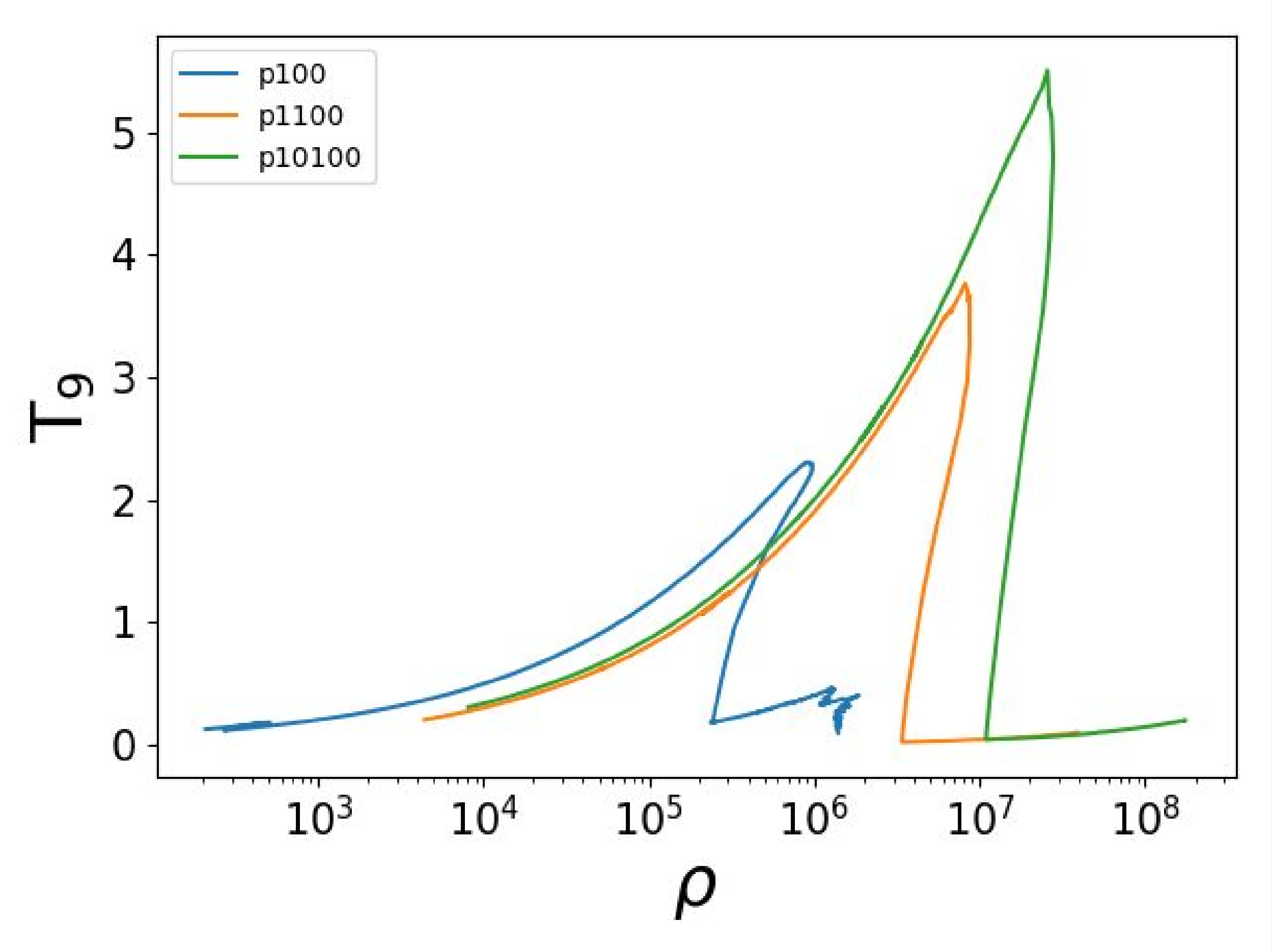

Fig 3. The T ρ profiles or particles 100, 1100 and 10100

Results:

Figure 3 shows the T ρ profile for three sample trajectories, taken from the full set of 10^5 particles. Figure 3 shows the mass of each isotope produced for elements P to Ti. Particles 100 and 1100 showed large variation, for some isotopes more than 100 times larger(e.g. ^{39}K, ^{34}Cl) in production between different metallicities, with particle 100 having the largest dependence over the largest range of atomic number. Particle 10100 appeared to have smaller dependencies on ^{22}Ne, especially for the most abundant isotopes (^{32}S,^{36}Ar and ^{40}Ca). This is due to the more extreme conditions experienced in this trajectory, pushing the system into nuclear statistical equilibrium.

For p100 it can be seen that as the metallicity of the progenitor system is increased, heavier isotopes and elements are produced, many of which are stable. In Fig 4, panel 2 shows an increase in the abundance of 5 Sc isotopes by a factor of 100. Ti isotopes ^{46,47,48}Ti are also enhanced, with abundances between 10^{-8} and 10^{-10}. This may provide a possible way to discriminate between ejecta from SNIa with different progenitor metallicities. In order to make any quantitative statements, a full post-processing of the SNIa trajectories for each metallicity would have to be undertaken. Radioactive isotopes are not completely decayed, as these results are shown at the end of the explosion (t = 4s).

Next Steps

Full post-processing and analysis of the 10^5 trajectories will be undertaken. They may also be compared with the results of Martínez-Rodríguez et al [5] to assess the effect of the multidimensional models on the yields, as compared with their 1D explosions.

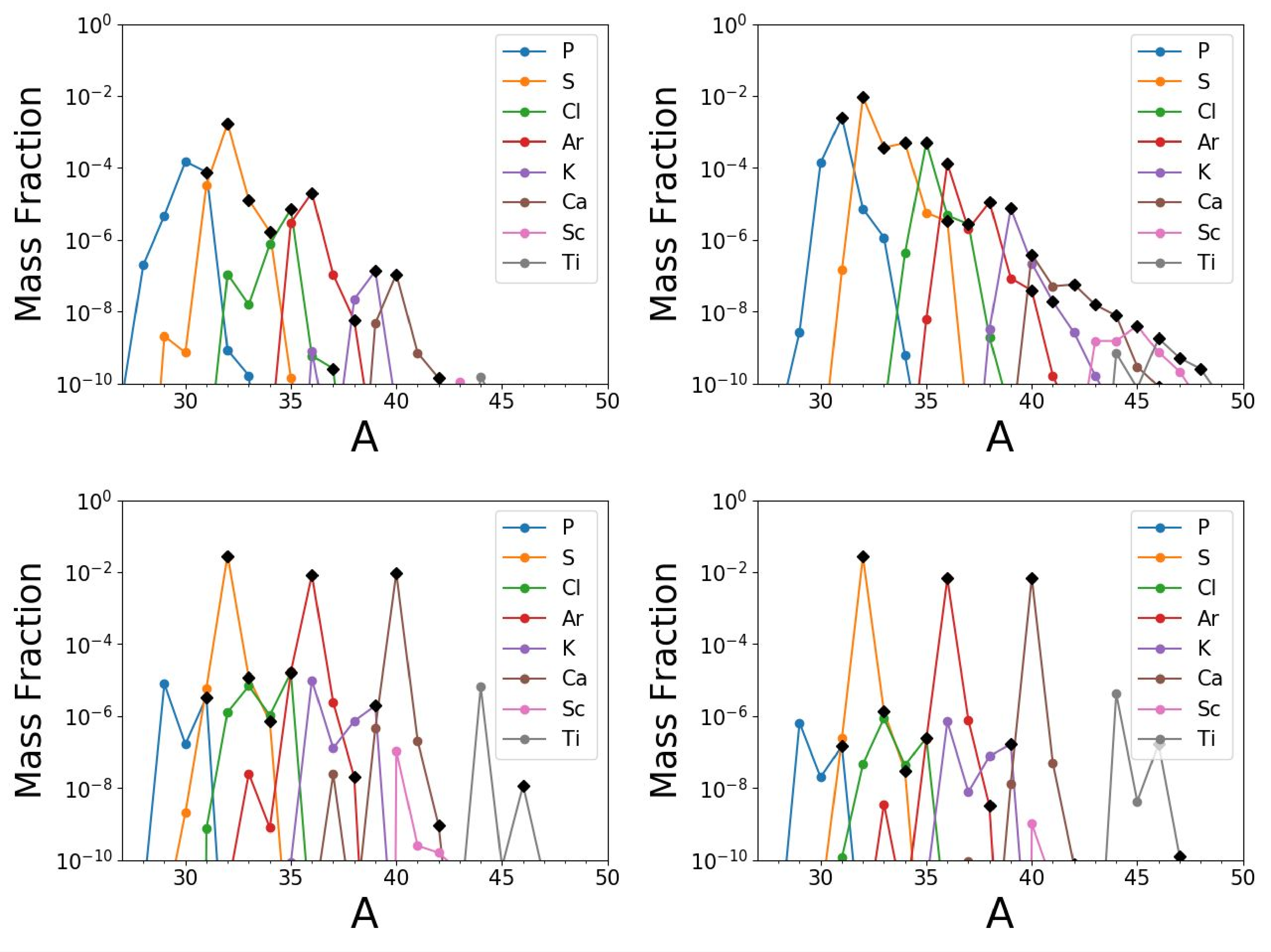

Fig 4 Total mass of each isotope produced in p100 (top row) and p10100 (bottom row) with initial ^{22}Ne content of 0 (left panels) and 0.02 (right panels) by fraction of total mass.

References:
1.Hillebrandt, W., et al. "Towards an understanding of Type Ia supernovae from a synthesis of theory and observations." *Frontiers of Physics* 8.2 (2013): 116-143.
2.Matteucci, F., et al. "The effect of different type Ia supernova progenitors on Galactic chemical evolution." *Astronomy & Astrophysics* 501.2 (2009): 531-538.
3.Seitenzahl, Ivo R., et al. "Solar abundance of manganese: a case for near Chandrasekhar-mass Type Ia supernova progenitors." *Astronomy & Astrophysics* 559 (2013): L5.
4. Townsley, Dean M., et al. "A Tracer Method for Computing Type Ia Supernova Yields: Burning Model Calibration, Reconstruction of Thickened Flames, and Verification for Planar Detonations." *The Astrophysical Journal Supplement Series* 225.1 (2016): 3.
5. Martínez-Rodríguez, Héctor, et al. "Observational evidence for high neutronization in supernova remnants: implications for Type Ia supernova progenitors." *arXiv preprint arXiv:1701.07073* (2017).
6. Piersanti, Luciano, et al. "Type Ia Supernovae keep memory of their progenitor metallicity." *arXiv preprint arXiv:1701.06453* (2017).
7. Miles, Broxton J., et al. "ON MEASURING THE METALLICITY OF A TYPE IA SUPERNOVA'S PROGENITOR." *The Astrophysical Journal* 824.1 (2016): 59.
8. Timmes, Frank X., Edward F. Brown, and J. W. Truran. "On variations in the peak luminosity of Type Ia supernovae." *The Astrophysical Journal Letters* 590.2 (2003): L83.
9.Höeflich, Peter, J. C. Wheeler, and F. K. Thielemann. "Type Ia supernovae: influence of the initial composition on the nucleosynthesis, light curves, and spectra and consequences for the determination of Ωm and Λ." *The Astrophysical Journal* 495.2 (1998): 617.
10. Iwamoto, Koichi, et al. "Nucleosynthesis in chandrasekhar mass models for type ia supernovae and constraints on progenitor systems and burning-front propagation." *The Astrophysical Journal Supplement Series* 125.2 (1999): 439.
11. Post, Seth, et al. "Asymmetry in the Observed Metal-rich Ejecta of the Galactic Type Ia Supernova Remnant G299. 2–2.9." *The Astrophysical Journal Letters* 792.1 (2014): L20.
12. Pignatari, M., et al. "NuGrid stellar data set. I. Stellar yields from H to Bi for stars with metallicities Z= 0.02 and Z= 0.01." *The Astrophysical Journal Supplement Series* 225.2 (2016): 24.

Acknowledgements:

The authors would like to thank the Hull Viper HPC Team, The Nugrid Collaboration, Los Alamos National Laboratory Center for Nonlinear Studies, Los Alamos National Laboratory Computational Methods, JINA-CEE, SNF (MP, Switzerland), NSF grants PHY 02-16783 and PHY 08-22648 (Joint Institute for Nuclear Astrophysics,JINA), the Canadian Advanced Network for Astronomy research (CANFAR), NSF grant PHY-1430152 (JINA Center for the Evolution of the Elements) and Laboratory Directed Research and Development Grant 20160173ER. JK and MP thank the resource allocations on the University of Hull High Performance Computing Facility viper.