Nucleosynthesis trends of supernovae diagnostics

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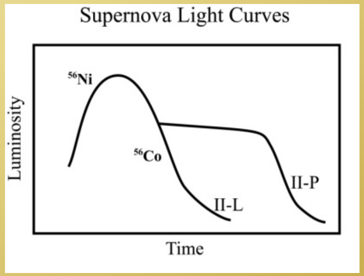
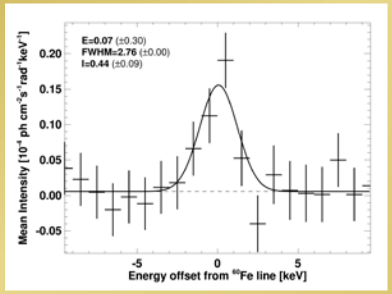
The importance of trace element detection



^{56}**Ni** powers the supernova light curve when produced in massive amounts. The detection of trace elements constrains the modeling uncertainties of massive star evolution.

^{44}**Ti** may be produced primarily in **cc-SN**, but only **Cas A** remnants provide so far the minimum flux required for its detection. Its theoretical yield estimates and trends improve our understanding of the nucleosynthesis process within a supernova explosion.

Credit: NASA, CXC, MIT, U. Mass. Amherst, M.D.Stage et al. (2007)

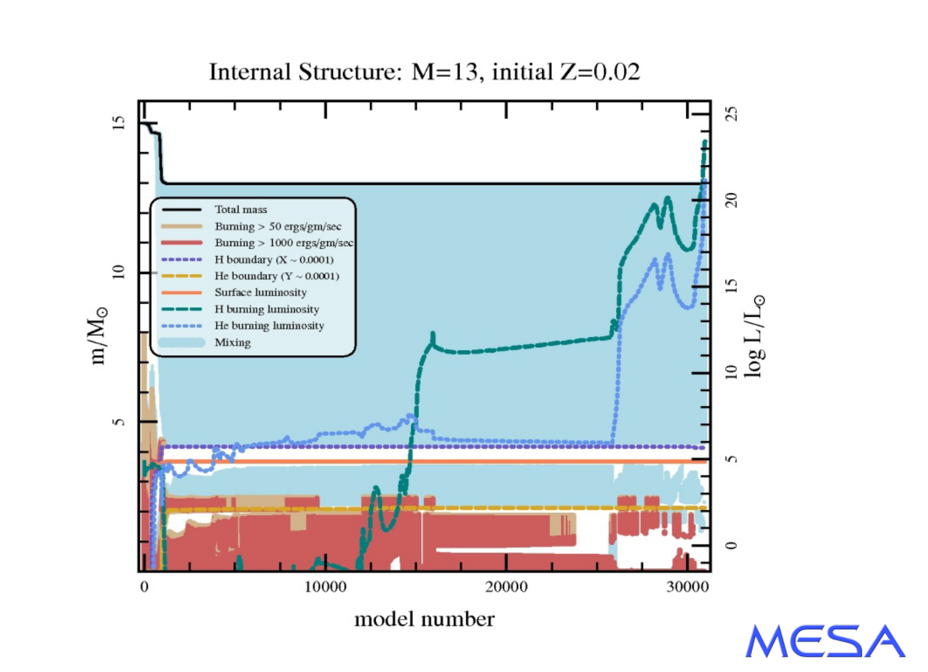


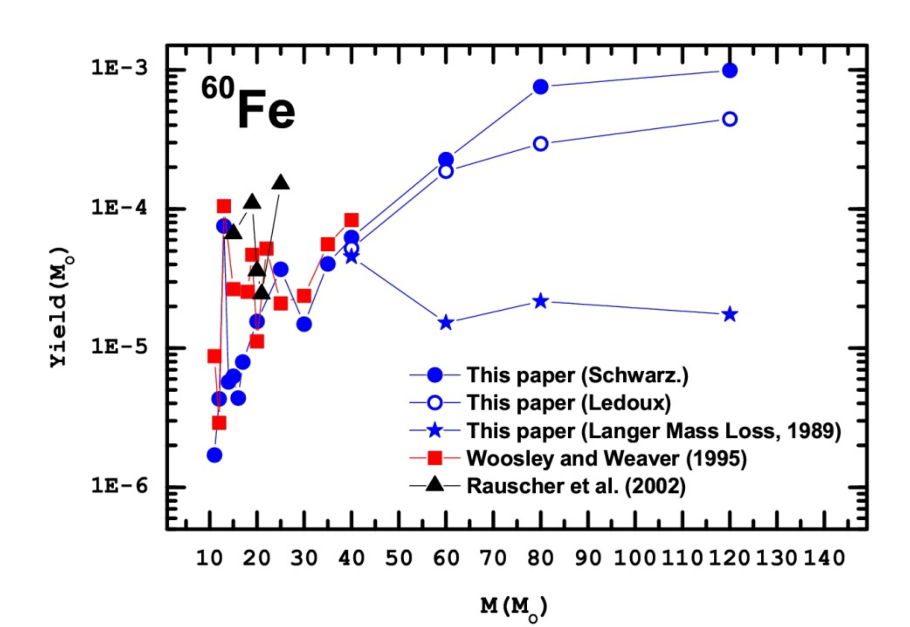
Credit: ESA, INTEGRAL/SPI, Wang et al. (2007)

Following the detection of ^{26}**Al** and ^{60}**Fe** and their ratio prediction by *Timmes et al. (1995)* within massive stars, simulations tend to overproduce ^{60}**Fe** mostly during the hydrostatic evolution. The major uncertainty is believed to originate from nuclear reaction rates.

Progress in nucleosynthesis modeling

Comparisons among stellar evolution surveys have set the basis for nucleosynthesis mechanisms and calibrated average values of theoretical yield estimates.



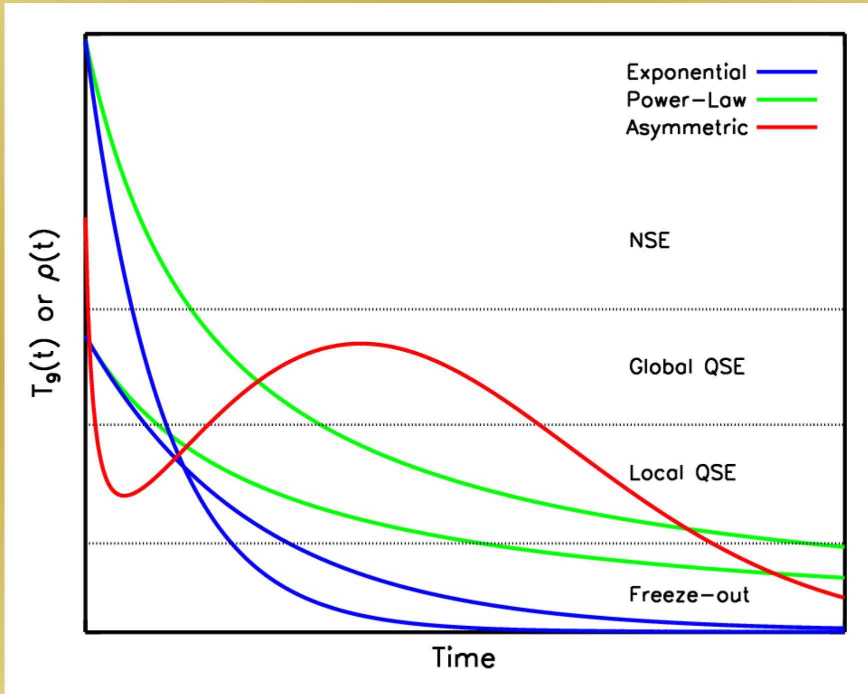


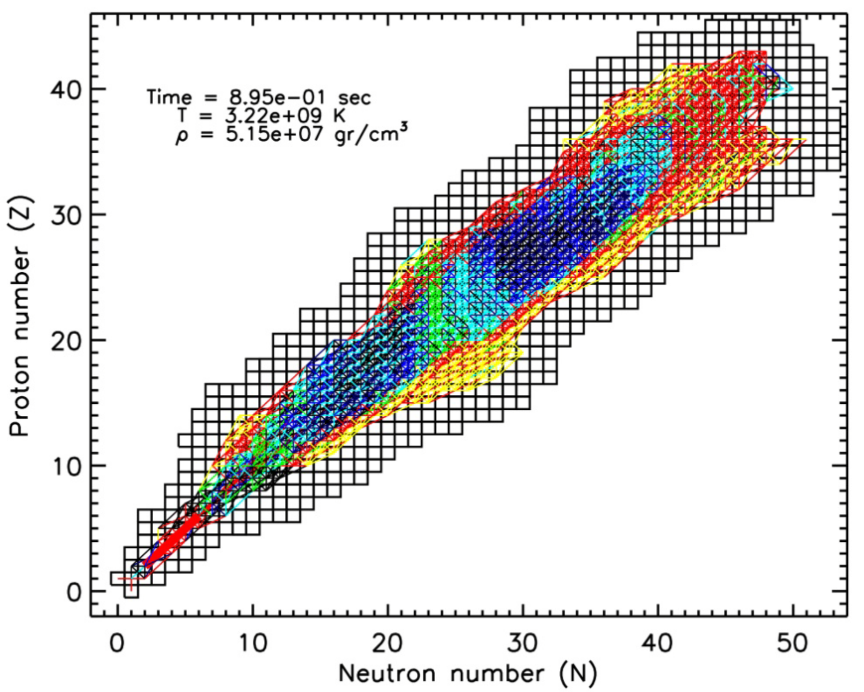
Limongi & Chieffi (2006)

Reaction rate sensitivity studies are the next step to understanding trace element synthesis. Recent studies have varied rates using parameterized expansion profiles [*Hoffman et al. (2010)*] or within stellar evolution simulations [*Tur et al. (2010)*].

Sensitivity study methodology

The extensively studied exponential expansion is augmented by a power-law based on trajectory fits from cc-SN simulations, which mimics a homologous expansion. The newly introduced non-monotonic profile aims to mimic explosion asymmetries.

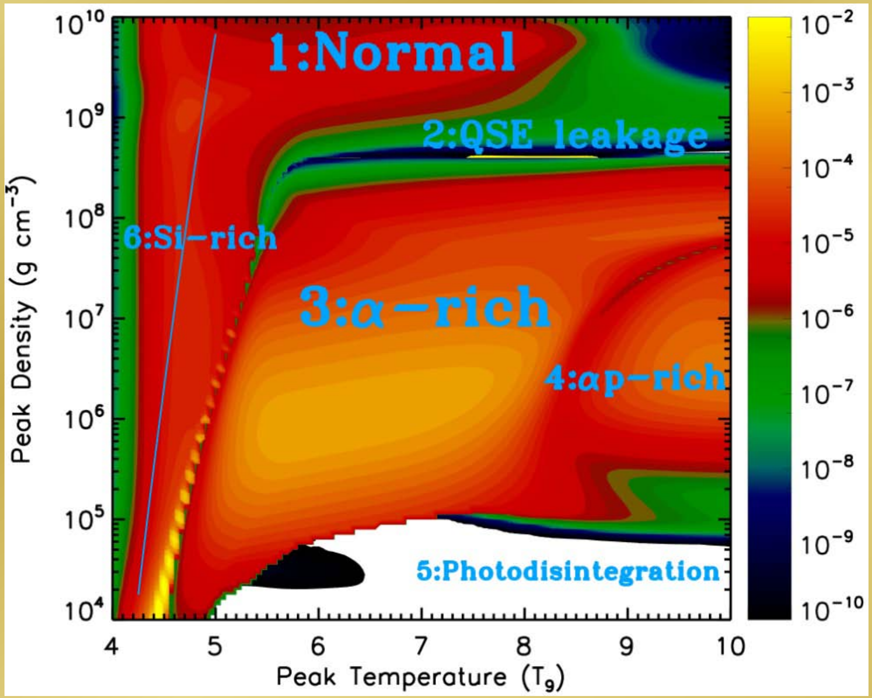


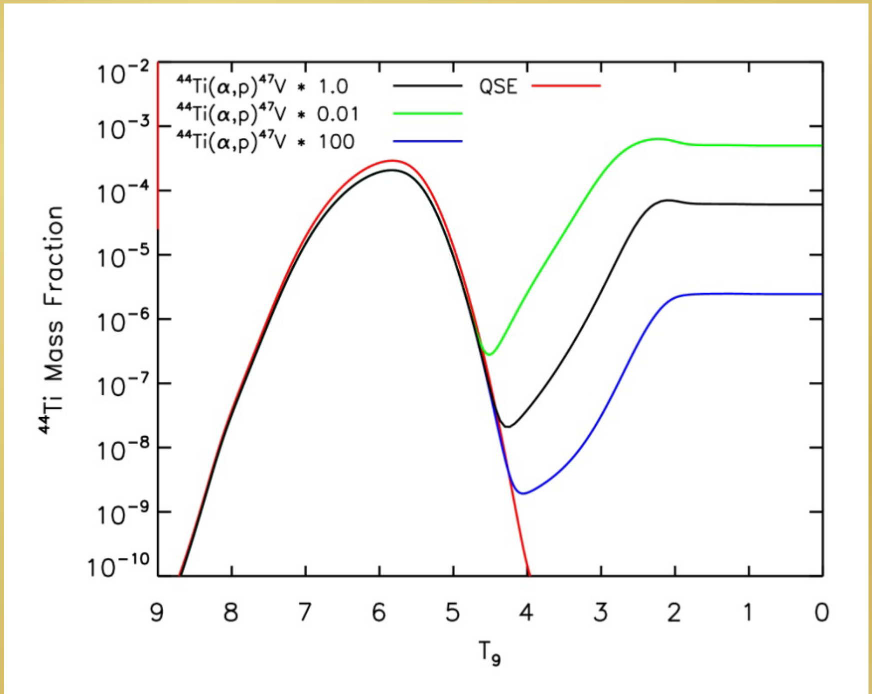


Recorded nuclear flows during the evolution provide a direct view of global and local equilibria patterns, which may be affected by only a few key reactions and result in phase transitions. Each type of freeze-out is characterized by unique transitions.

^{44}Ti trends

^{44}**Ti** may be produced by various types of freeze-out. Depletion regions within our parameter space suggest an answer to the ^{44}**Ti** paradox based on nuclear physics.

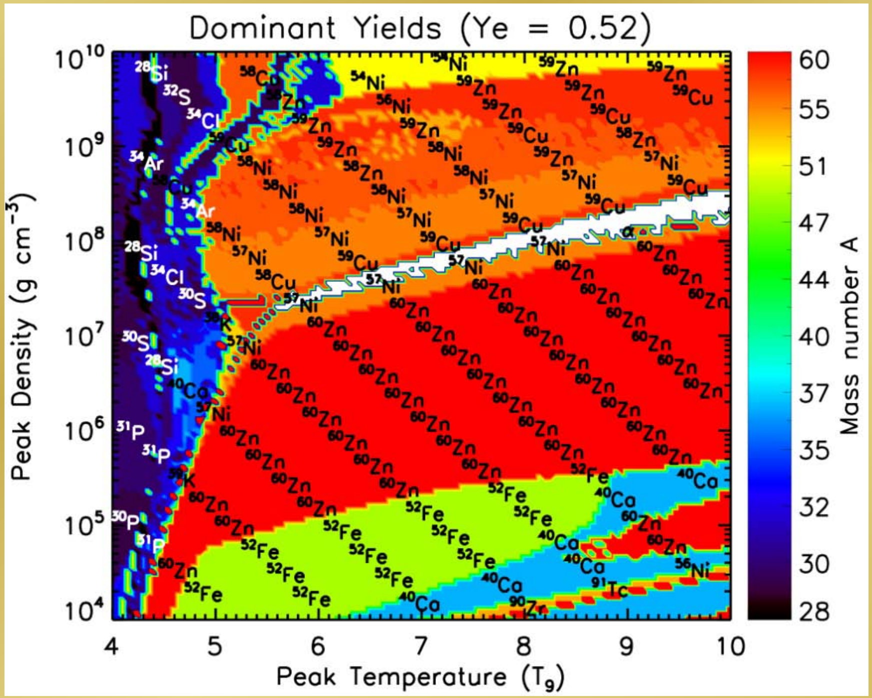


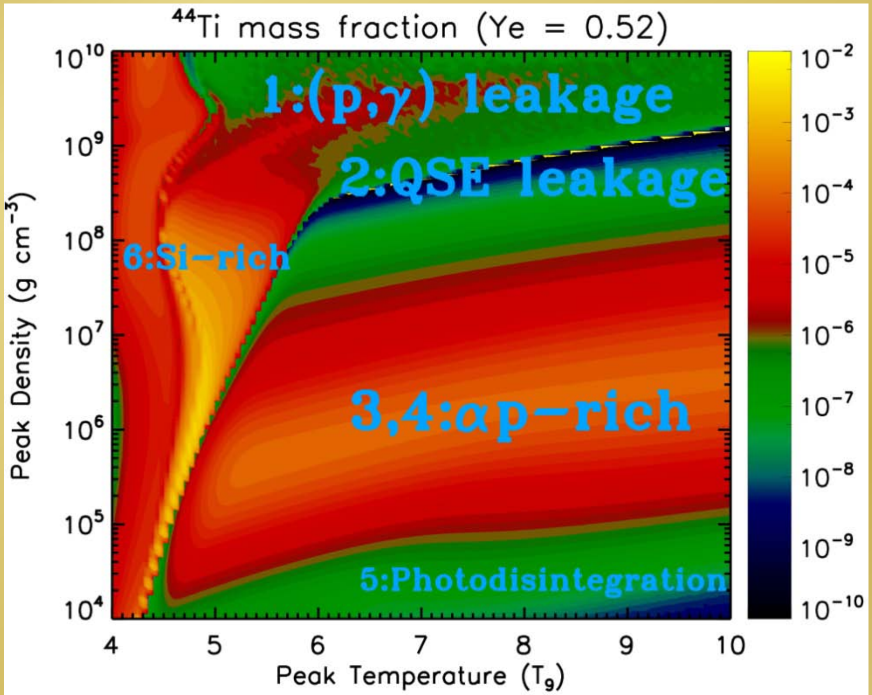


Certain reactions in combination with the expansion timescale impact the topology of the contour plot and shape the mass fraction curves of ^{44}**Ti**. Most of the isotopes in the silicon and iron groups follow the same trends.

Nucleosynthesis at $Y_e > 0.5$

NSE estimates during equilibrium and the subsequent major nuclear flows prevent the appearance of a normal freeze-out. The excess of free protons results in the merging of regions within the contour plots.

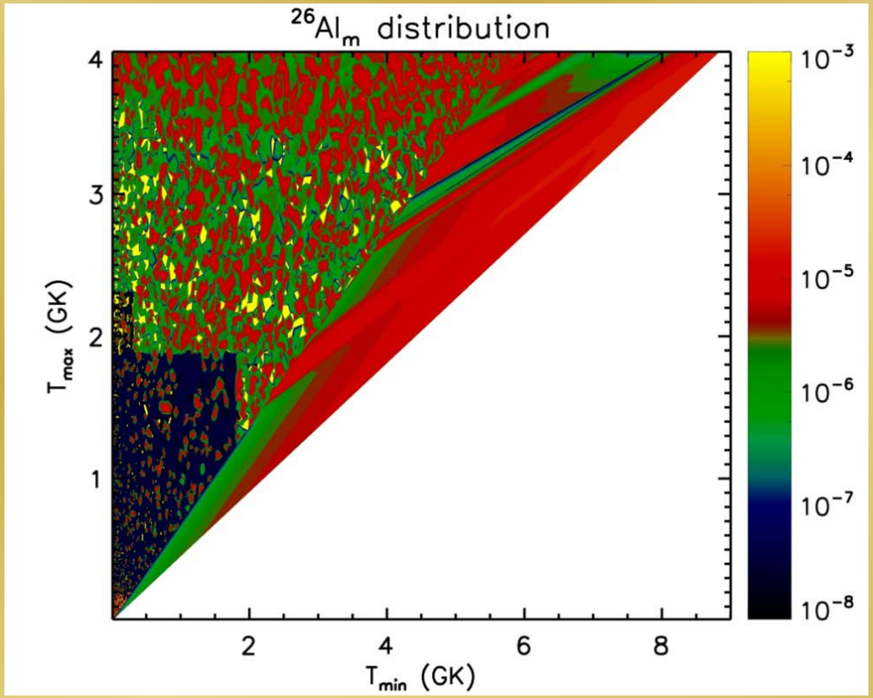


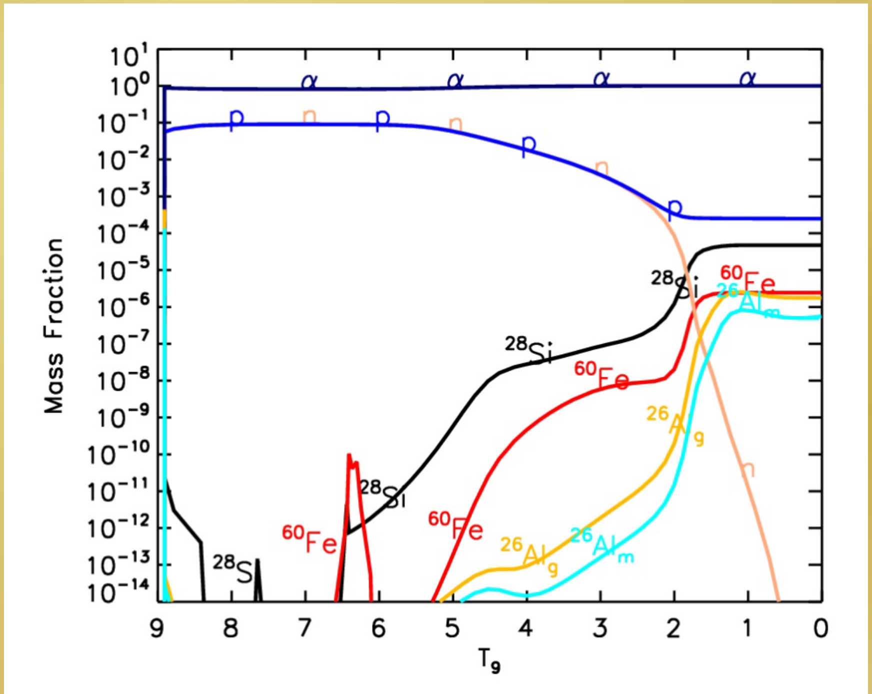


Weak reactions are crucial to the production of all symmetric isotopes such as ^{26}Al and ^{44}Ti. The chasm expands dramatically compared to the $Y_e = 0.5$ case, indicating a possible incorrect bias at the choice of the mass cut location.

^{26}Al and ^{60}Fe preliminary results

This situation is more challenging compared to ^{44}Ti, due to dependencies on the initial composition and mixing. Post-processing thermodynamic trajectories from **MESA** is in progress for the hydrostatic component.





The explosive nucleosynthesis component yields some ^{26}Al during an α-rich freeze-out and an unexplored yet distribution from non-monotonic profiles. The explosive yields of ^{60}Fe are minimal, with the exception of a few scattered fruitful cases.

Outlook

Sensitivity studies are the “next generation” method to study nucleosynthesis trends in massive stars. Stellar evolution simulations in 1D fully coupled to large networks become feasible with increasing computational resources and modern codes.

Recording the partial nuclear flows facilitates the identification of synthesis mechanisms dependent on equilibria patterns. The phase transition related to the chasm is a potential explanation for the absence of $^{44}\mathbf{Ti}$ lines among observed supernovae.

The correlation between $^{26}\mathbf{Al}$ and $^{60}\mathbf{Fe}$ synthesis is still unresolved. ***JINA*** researchers investigate most of the aspects related to their production.