Nuclear Theory for Chemical Evolution of Galaxies

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JINA GCE Workshop “Building Virtual Galaxies”

April 30, 2010

(based on review by Janka et al. 2007 in Physics Reports)
Stellar input for chemical evolution of galaxies

- Star formation
- Stellar evolution
- End states
- Type Ia & core-collapse SNe

Nucleosynthesis
Energy injection, mixing
Gas return
Nuclear theory input for chemical evolution

- nuclear reaction rates for:
  - hydrostatic & explosive burning
    - r-process, s-process, p-process, rp-process

- nuclear theory input for core-collapse SNe:
  - weak interaction rates
  - nuclear equation of state
weak rates during pre-SN evolution & core collapse

mass, Ye, entropy of “Fe” core

mass of inner core
nuclear equation of state (EOS)

radius of inner core at bounce

initial shock energy

later neutrino luminosity
nuclear EoS & neutrino processes
neutrino luminosity & spectra
explosion & nucleosynthesis
\[ B_{\text{GT+}} \] for the reaction 
\[ ^{51}\text{V}(d,^2\text{He})^{51}\text{Ti} \]

with \( E_{\text{lab}} = 171 \text{ MeV} \) and \( \Theta_{\text{cm}} < 1^\circ \).

The graph shows a Shell-Model Calculation with energy levels at 2.14 MeV, 3.62 MeV, and 4.88 MeV.
comparison with Fuller, Fowler, & Newman (FFN 1980, '82, '85) for late stages of pre-SN evolution smaller, non-systematic differences for beta-decay further constraints on shell model calculations from FRIB?
detailed GT strength distribution needed

centroid & total GT strength mostly needed

e-capture

beta-decay
e capture during core collapse

- nuclear statistical equilibrium (NSE) has many nuclei with significant abundances
- reduction of Ye depends on the product of nuclear abundance & the corresponding e-capture rate
- decreasing Ye changes NSE composition to favor more n-rich nuclei

when Z<40 & N>40 nuclei have significant abundances, more sophisticated shell model calculations needed, but computational capability forces alternative: Random Phase Approximation (RPA)
Independent Particle Shell Model gives no GT strength for e capture on nuclei with \( Z<40 \) & \( N>40 \)

but finite temperature & residual interaction lead to unblocking
Friday, April 30, 2010

\[ \lambda_{\text{ec}} (\text{s}^{-1}) \]

\[ Q (\text{MeV}) \]

- \( \rho_{11} Y_e = 0.07, T = 0.93 \)
- \( \rho_{11} Y_e = 0.62, T = 1.32 \)
- \( \rho_{11} Y_e = 4.05, T = 2.08 \)
Nuclear theory input for supernova neutrino emission
nuclear EoS, neutrino emission & interaction processes

Qian & Woosley 1996
without neutrinos, nuclear flow ends at $^{64}\text{Ge}$

$$\bar{\nu}_e + p \rightarrow n + e^+$$

$(n, p) \& (p, \gamma)$ lead to heavier nuclei

**$\nu p$-process**

Frohlich et al. 2004, '06

Pruet et al. 2005
Nuclear theory input for the r-process

- during the r-process, assuming $(n, \gamma) \rightleftharpoons (\gamma, n)$ equilibrium
- neutron separation energy, beta-decay rates both depend on nuclear masses
  - macro-microscopic (e.g., FRDM) vs. ab initio (e.g., RMF) mass models
- possible role of fission cycling
- n-induced fission cross sections & yields

- during freeze-out
  - n capture cross sections, beta-delayed n emission
  - possible role of neutrino-induced n emission