Evolution of progenitors for electron capture supernovae

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Electron Capture Supernova?

- Core-collapse of an ONe core triggers ECSN (~10 Msun)

Crab nebula (Satterfield et al. 2012)

SN 2008S (Botticella et al. 20**)

- ECSN can explain the Crab
  - small explosion energy (~0.1 foe)
  - large X(He), small X(C), X(O)

- SN 2008S (SN IIIn) may be ECSN
  - the progenitor star of ~10 Msun
  - surrounded by dense CSM
ECSN?

- ECSN can be reproduced by 1D simulations
  - delayed explosion by $\nu$-heating is reported (Kitaura et al. 2006)
- There is ONLY one progenitor model for ECSN
  - Nomoto’s evolutionary calculation was done 26 years ago

- PURPOSE: to provide new progenitor model for ECSN explosion simulation by stellar evolutionary calculations
Electron capture reactions

(Oda+ 1994)

$^{20}\text{Ne} \leftrightarrow ^{20}\text{F}$

$^{23}\text{Na} \leftrightarrow ^{23}\text{Ne}$

$^{24}\text{Mg} \leftrightarrow ^{24}\text{Na}$

$^{25}\text{Mg} \leftrightarrow ^{25}\text{Na}$

$^{26}\text{Mg} \leftrightarrow ^{26}\text{Na}$

$^{27}\text{Al} \leftrightarrow ^{27}\text{Mg}$
The Coulomb correction for electron capture rates

\[ \lambda_{ec} = \frac{1}{\pi^2 h^2} \sum \int_{\varepsilon_{thr} + \Delta\varepsilon_{thr}}^{\infty} p_e^2 \sigma_{ec} f(\varepsilon_e - \mu_e) \, d\varepsilon_e \]

\[ \Delta\varepsilon_{thr} = \mu_{ion}(Z-1) - \mu_{ion}(Z) \]

\[ \mu_{ion}(Z) = -kT\left(\frac{Z}{\bar{Z}}\right) \]

\[ \{ \Gamma z[0.9 + c_1(\frac{Z}{\bar{Z}})^{1/3} + c_2(\frac{Z}{\bar{Z}})^{2/3}] \]

\[ + [d_0 + d_1(\frac{Z}{\bar{Z}})^{1/3}] \} \]

(Couch & Loumos 1974; DeWitt et al. 1973)
New electron capture rates for NSE compositions

- electron capture by neutron-rich isotopes

(Juodagalvis+ 2010)
Results

- 3 (of 5) models finally reach the initiation of O+Ne deflagration

- **ONe cores are formed** after nuclear burning of H, He, and C
Contrasting stellar structure

- A \sim 1.37 \text{Msun} \text{ ONe core with diffuse H+He envelope}
Core contraction

- O+Ne deflagration initiates at ~2 GK

- 3 mechanisms
  1. ν cooling
  2. Core mass growth
  3. Electron capture

- O+Ne deflagration

\[ \text{log } T_c \ (K) \]
\[ \text{log } \rho_c \ (g/cm^3) \]
Propagation of the deflagration front

- NSE is achieved behind the deflagration front
- in the NSE region, intense electron capture reduces $Y_e$
- electron capture by n-rich isotopes
- Finally, the core will collapse
Convergent evolution

- ONe core evolution is independent from parameters (3 $M_{\text{ZAMS}}$ & 3 $\dot{M}_{\text{core}}$)
- Extremely degenerate ONe core should have a unique structure
Influence of n-rich electron captures

- difference in the lower limit of Ye
  ← by protons
  + n-rich isotopes
  only by free-protons →

- More central-concentrated structure for n-rich electron captures
Concluding remarks
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- We calculate a progenitor evolution for ECSNe for the first time in 26 years.
- There are 3 mechanisms for core contraction. (ν-cooling, core growth, electron capture)
  - Electron capture in the NSE region finally triggers core-collapse.
- ONe cores for ECSNe have similar structure owing to electron degeneracy.
- Electron capture by n-rich isotopes affects core density profiles.