Type II Supernovae:
Impact of electro-weak processes during core-collapse phase

Anthea F. FANTINA & Patrick BLOTTIAU

Dr. E. Khan, Dr. J. Margueron (IPN Orsay)
Dr. Ph. Mellor (CEA, DAM, DIF)
Dr. J. Novak, Dr. Micaela Oertel (Luth, Meudon)

Prof. P. Pizzochero & Dr. P. Donati
(Univ. Milano & INFN)

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We investigate …

… influence of T-dependence of nuclear symmetry energy during core-collapse phase

  - study of $m^*(T)$: $^{98}$Mo, $^{64}$Zn, $^{64}$Ni in the range $0 < T < 2$ MeV (QRPA)
    - decrease of $m^*(T)$ in the range $0 < T < 2$ MeV
    - increase of $E_{sym}$ ($\sim 8\%$)
    - effects on gravitational collapse not negligible

  - study of $E_{sym}(T)$: A = 56-66 in the range $0.33 < T < 1.23$ MeV (SMMC)
    - increase of $E_{sym}$ ($\sim 6\%$) consistent with Donati et al.
    - “not significant changes for the collapse trajectory”
Effective mass $\leftrightarrow$ Symmetry energy $\leftrightarrow Y_{\text{lept,tr}}$

\[
\frac{m^*}{m} = \frac{m_k}{m} \frac{m_\omega}{m} \\
\frac{m_\omega(T)}{m} = 1 + \left[ \frac{m_\omega(0)}{m} - 1 \right] e^{-T/T_0}
\]


\[
E_{\text{symm}}(T) = s(T) \left( 1 - 2 \frac{Z}{A} \right)^2 \\
s(T) = s(0) + \text{const} \left( \frac{1}{m^*(T)} - \frac{1}{m^*(0)} \right)
\]

1.4 < \frac{m_\omega(0)}{m} < 1.8

1.9 MeV < k_B T_0 < 2.1 MeV

reduction of $m_\omega$ with $T \Rightarrow$ increase of $E_{\text{symm}}$

increase of $\mu_n - \mu_p : \Rightarrow$ Q-value of electron capture rates!

less neutronization $\Rightarrow$ larger values of $Y_{\text{lept}}$ at trapping

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\[ Y_{\text{lept, tr}} \quad \text{Shock wave energy} \]

Shock wave loses energy while crossing matter.

dissociation energy: \( 17 \ \text{foe}/M_\odot \)

\[ M_{\text{ch}} = 5.8 \ Y_{\text{lept}}^2 \]

\[ E_{\text{diss}} = 98 \ [Y_{l, i}^2 - Y_{l, \text{tr}}^2] \ [\text{foe}] \]


larger values of \( Y_{\text{lept}} \) at trapping \( \Rightarrow \) less deleptonization

\( \Rightarrow \) less energy dissipated

\[ m^*(T) \rightarrow E_{\text{sym}} \rightarrow Y_{l, \text{tr}} \rightarrow \text{Shock wave energy} \]

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Numerical results of collapse simulation (one-zone code)

\[ \delta_T E_{\text{diss}} = \left[ E_{\text{diss}}|_0 - E_{\text{diss}}|_T \right] > 0 \]

\[ E_{\text{diss}} = 98 \left[ Y_{l,i}^2 - Y_{l,tr}^2 \right] \text{[foe]} \]

\[ \gamma^2 = 1 \]

Langanke K. et al.,

\[ \gamma^2 = 0.1 \]

Fuller G.M.,

Fantina A.F. et al.,
Numerical results of collapse simulation (one-zone code)

\[ \delta T E_{\text{diss}} \propto Y_{l, tr} \bigg|_0 \delta T Y_{l, tr} \]

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Preliminary results of collapse simulation at trapping density (1D Newtonian code)


Preliminary results of collapse simulation at bounce (1D Newtonian code)


Conclusions

• Influence of T-dependence of $E_{sym}$ on the evolution of collapse
  → systematic reduction of neutronization of the core
    (increasing of final lepton fraction) & less energy dissipated by shock wave
    - one zone model -
  → position of shock wave formation: bigger homologous core
    - 1D Newtonian code -

• Gain in shock wave dissociation energy if we consider $m^*(T)$:
  $\delta_T E_{diss} \sim 0.4$ foe (estimation with one-zone code, within reasonable physical ranges of parameters)

and: $K \sim 1 – 1.5$ foe (Bethe H.A. & Pizzochero P., Astrophys. J. 350, L33 (1990))

⇒ even if no dramatic effect on dynamics of the collapse is expected
  (see fluid instabilities, SASI, magnetic field, …) effects are not negligible!

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Outlook

- **Nuclear point of view**: *Microscopic calculation of nuclear inputs*
  - Electron capture rates on nuclei → $\gamma^2$
  - Calculation of $m^*(T)$ & $E_{sym}(T)$:
    → systematic calculations on more nuclei
    → level density parameter (experiments?!) → dependence on $\rho$, $A$, $Z$, $T$
  - EoS
    → Lattimer & Swesty, Nucl. Phys. A535, 331 (1991), with $m^*(\rho, x, T)$

- **Astrophysical point of view**: *Hydrodynamics*
  - multizone / multi-D code → test in 1D
  - Newtonian & Relativistic
  - more accurate treatment of neutrinos and shock formation

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Thank you