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Type II Supernovae:

Impact of electro-weak processes during core-collapse phase

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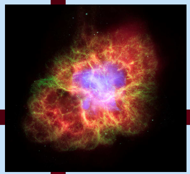
MICRA 2009, NBIA Copenhagen 24th - 28th August



We investigate …

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

❖ Donati P. *et al*, Phys. Rev. Lett. **72**, 2835 (1994)

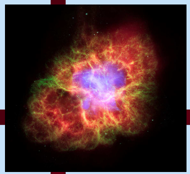
➡ study of $m^*(T)$: ^{98}Mo, ^{64}Zn, ^{64}Ni in the range 0 < T < 2 MeV (QRPA)

- decrease of $m^*(T)$ in the range 0 < T < 2 MeV
- increase of E_{sym} (~ 8%)
- effects on gravitational collapse not negligible

❖ Dean D.J. *et al*, Phys. Rev. **C66**, 31801 (2002)

➡ study of $E_{sym}(T)$: A = 56-66 in the range 0.33 < T < 1.23 MeV (SMMC)

- increase of E_{sym} (~ 6%) consistent with Donati *et al.*
- "not significant changes for the collapse trajectory"



Effective mass ⟷ Symmetry energy ⟷ $Y_{lept,tr}$

$$\frac{m^*}{m} = \frac{m_k}{m}\,\frac{m_\omega}{m}$$

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

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

$$1.9\ \text{MeV} < k_B\, T_0 < 2.1\ \text{MeV}$$

Donati P. *et al*., Phys.Rev.Lett. **74** (1994)

$E_{symm}(T)$

analogy with Fermi gas model

$$E_{sym} = s(T)\,\left(1 - 2\,\frac{Z}{A}\right)^2$$

$$s(T) = s(0) + const\,\left(\frac{1}{m^*(T)} - \frac{1}{m^*(0)}\right)$$

⇩

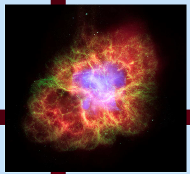
reduction of m_ω with $T \Rightarrow$ increase of E_{symm}

⇩

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

⇩

less neutronization ⇒ larger values of Y_{lept} at *trapping*

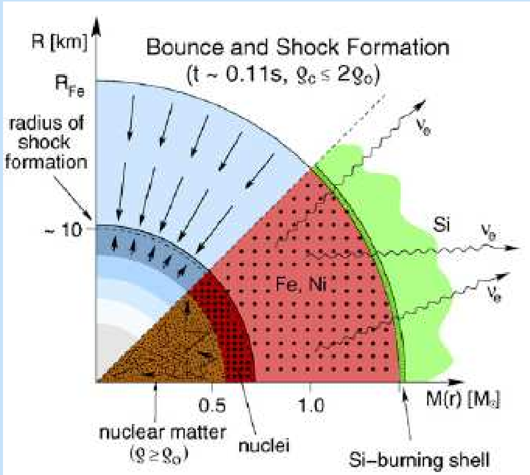


$Y_{lept,tr}$ ⟷ Shock wave energy

Shock wave loses energy while crossing matter.

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

$1\ \text{foe} = 10^{51}\ \text{erg}$



$$M_{ch} = 5.8\ Y_{lept}^2$$

↓

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

Brown G. *et al*,
Nucl. Phys. **A375**, 481 (1982)

⇩

larger values of Y_{lept} at *trapping* ⇒ less deleptonization
⇒ less energy dissipated

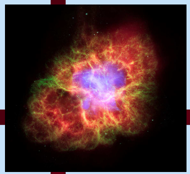
⇩

Stronger shock wave ⟷ explosion

⇩

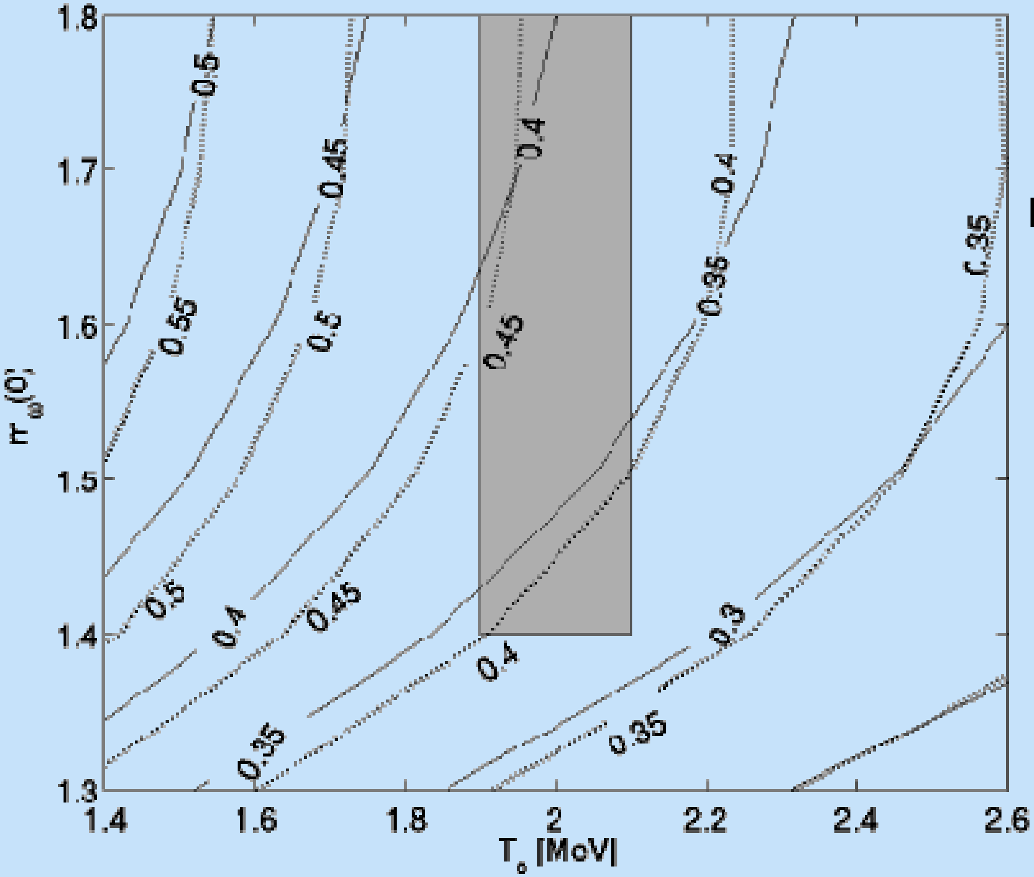
$m^*(T)$ ⟶ E_{sym} ⟶ $Y_{l,tr}$ ⟶ Shock wave energy

Numerical results of collapse simulation (one-zone code)



$$\delta_T E_{diss} = [E_{diss}|_0 - E_{diss}|_T] > 0$$

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



—— $\gamma^2 = 1$

Langanke K. *et al*.,
Phys. Rev. Lett. **90**, 241102 (2003)

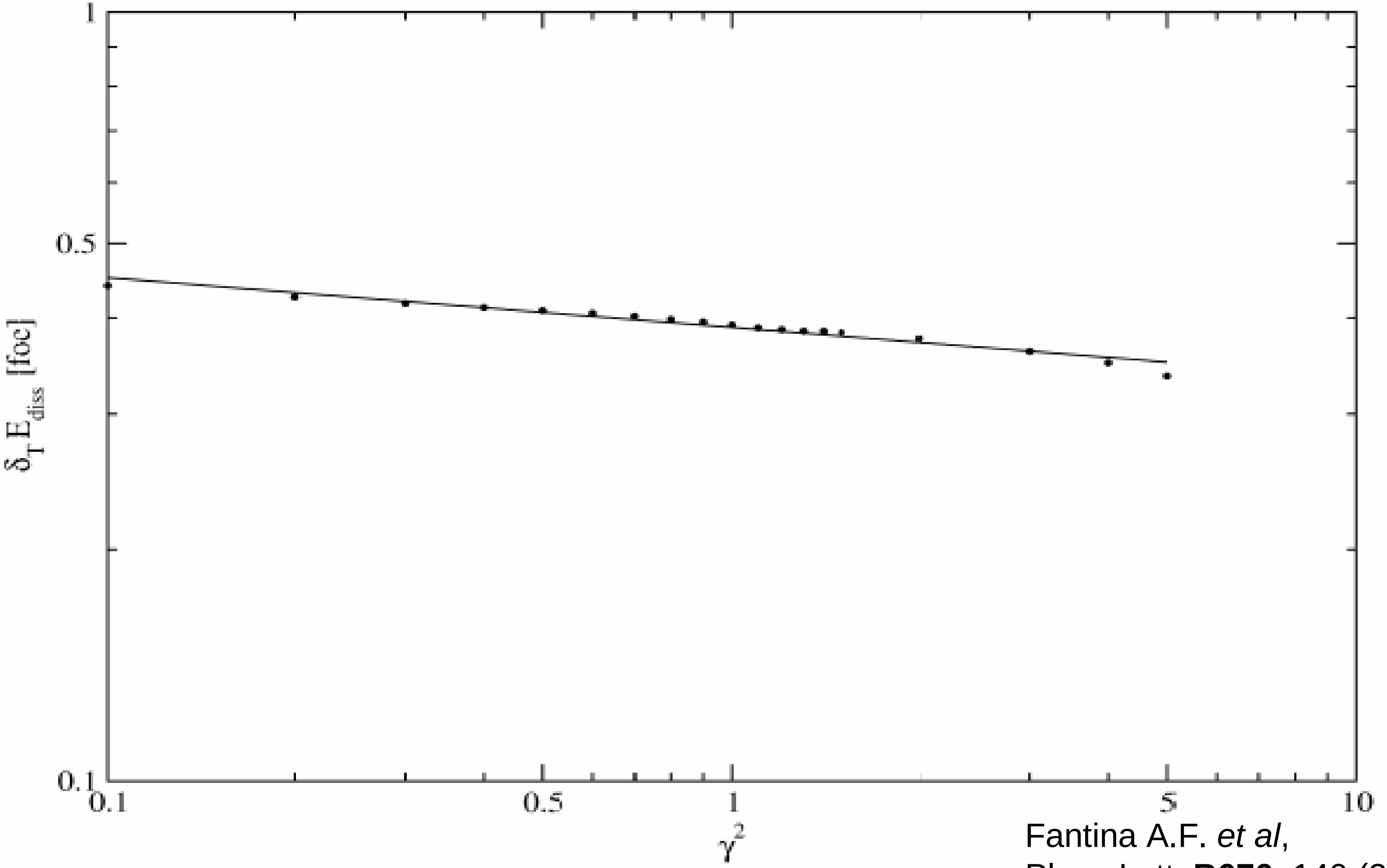
------- $\gamma^2 = 0.1$

Fuller G.M.,
Astroph. J. **252**, 741 (1982)

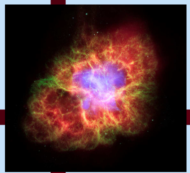
Fantina A.F. *et al*,
Phys. Lett. **B676**, 140 (2009)

Numerical results of collapse simulation (one-zone code)

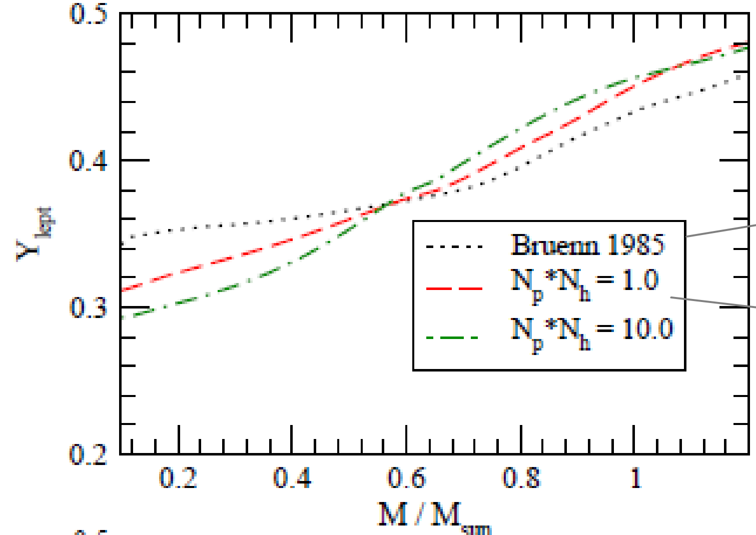
$$\delta_T E_{diss} \propto Y_{l,tr}\Big|_0 \; \delta_T Y_{l,tr}$$



Fantina A.F. *et al*,
Phys. Lett. **B676**, 140 (2009)

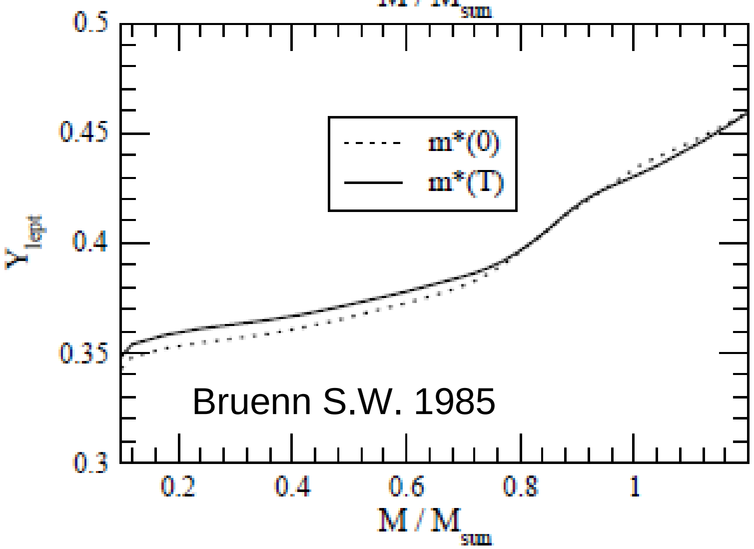


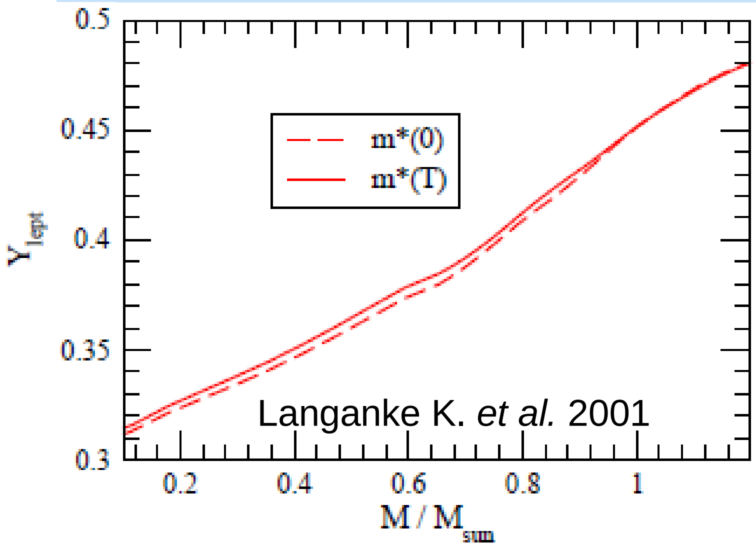
Preliminary results of collapse simulation at trapping density (1D Newtonian code)

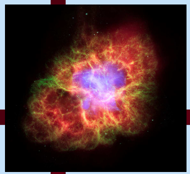


Bruenn S.W.,
Astrophys. J. Suppl. **58**, 771 (1985)

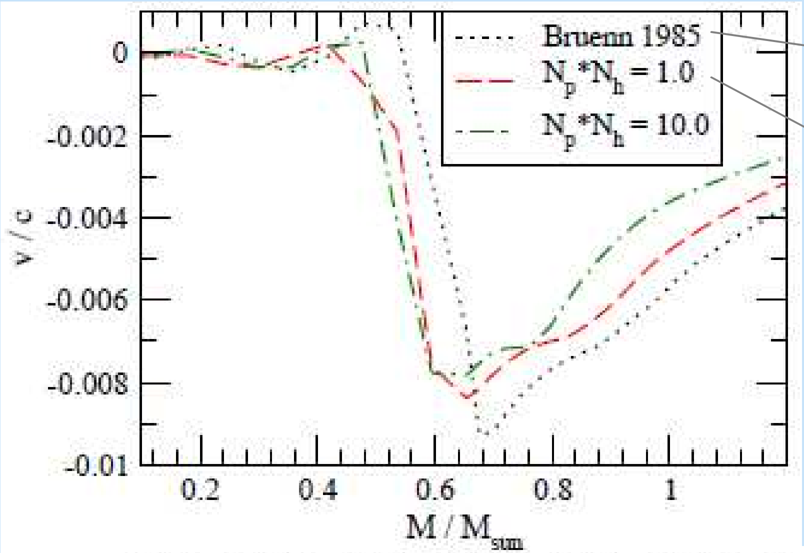
Langanke K. *et al.*,
Phys. Rev. **C66**, 45802 (2001)







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



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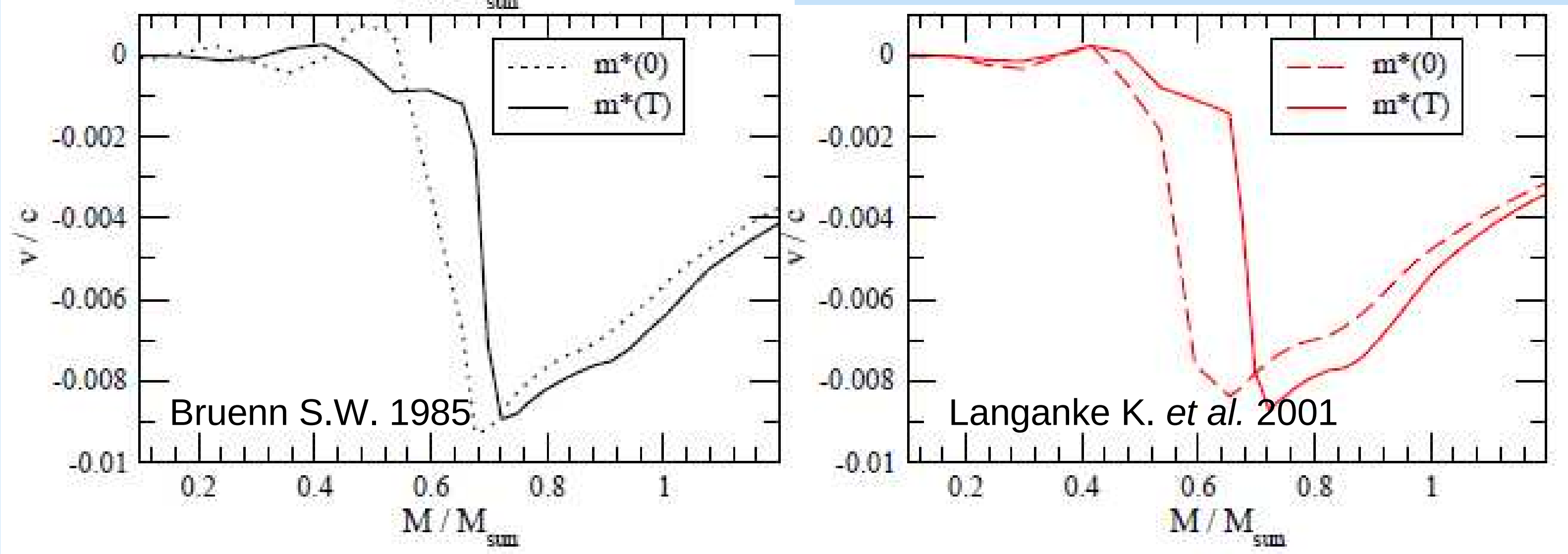
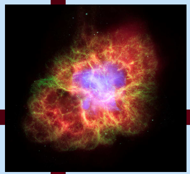




Conclusions

- 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* -

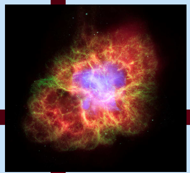
  → position of shock wave formation: bigger homologous core
  - *1D Newtonian code* -

- *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 <u>not</u> negligible!



Outlook

- Nuclear point of view: *Microscopic calculation of nuclear inputs*

  - Electron capture rates on nuclei $\rightarrow \gamma^2$ } IPN Orsay (E.Khan), N. Paar *et al.*, submitted to Phys.Rev. C (2009)

  - Calculation of $m^*(T)$ & $E_{sym}(T)$:
    - $\rightarrow$ systematic calculations on more nuclei
    - $\rightarrow$ level density parameter (experiments?!)
    - $\rightarrow$ dependence on ρ, A, Z, T

    } Milan & IPN Orsay (P.Donati & J.Margueron)

  - EoS
    - $\rightarrow$ Lattimer & Swesty, Nucl. Phys. **A535**, 331 (1991), with $m^*(\rho, x, T)$

- Astrophysical point of view: *Hydrodynamics*

  - multizone / multi-D code $\rightarrow$ test in 1D
  - Newtonian & Relativistic
  - more accurate treatment of neutrinos and shock formation

  } CEA Bruyères (P.Blottiau & Ph. Mellor) & LUTH Meudon (J. Novak & M.Oertel)


Thank you