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Type II Supernovae:

Electro-weak processes during gravitational collapse of massive stars

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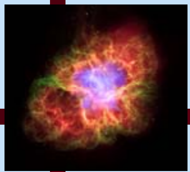
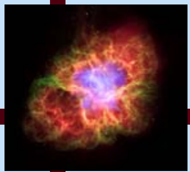


Motivation

- Simulations VS nature: what's missing? → hydrodynamics / nuclear physics
- Nucleosynthesis of heavy elements
- Neutrino physics
- GW signal

Microphysics ⟷ Macrophysics



We investigate …

… electro-weak processes
in core collapse supernova

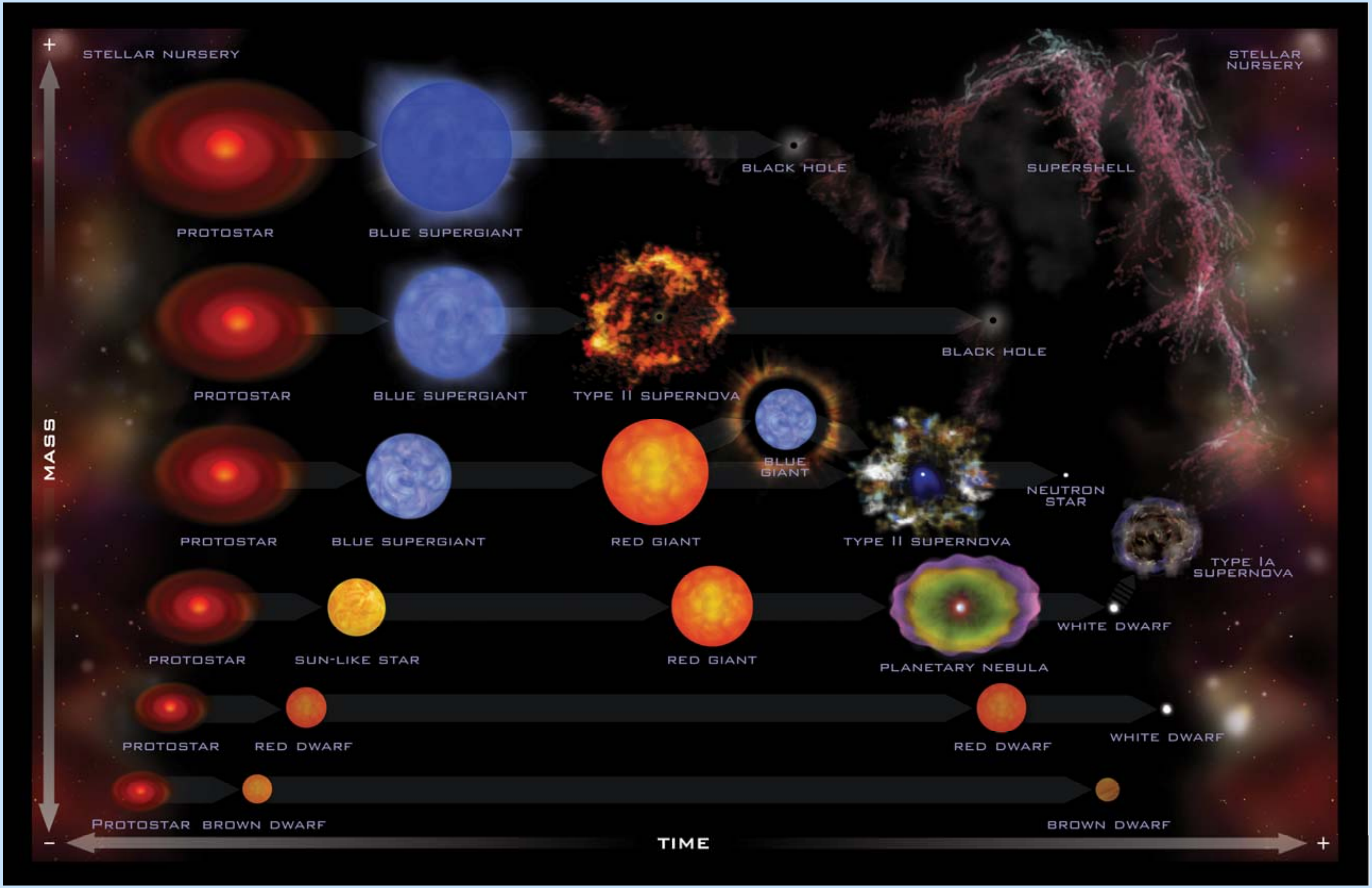
- Nuclear inputs:
  - electron capture rates
  - nucleon effective masses
  - EoS
- Study of the evolution of collapse

→ ***one-zone code*** (A.F.Fantina *et al.*, arXiv:0811.0456 [astro-ph])

→ ***1D Newtonian code*** (P.Blottiau, PhD thesis (1989))

→ ***1D Relativistic code*** (J.Romero *et al.*, Astroph. J. **462**, 839 (1996))

Stellar evolution

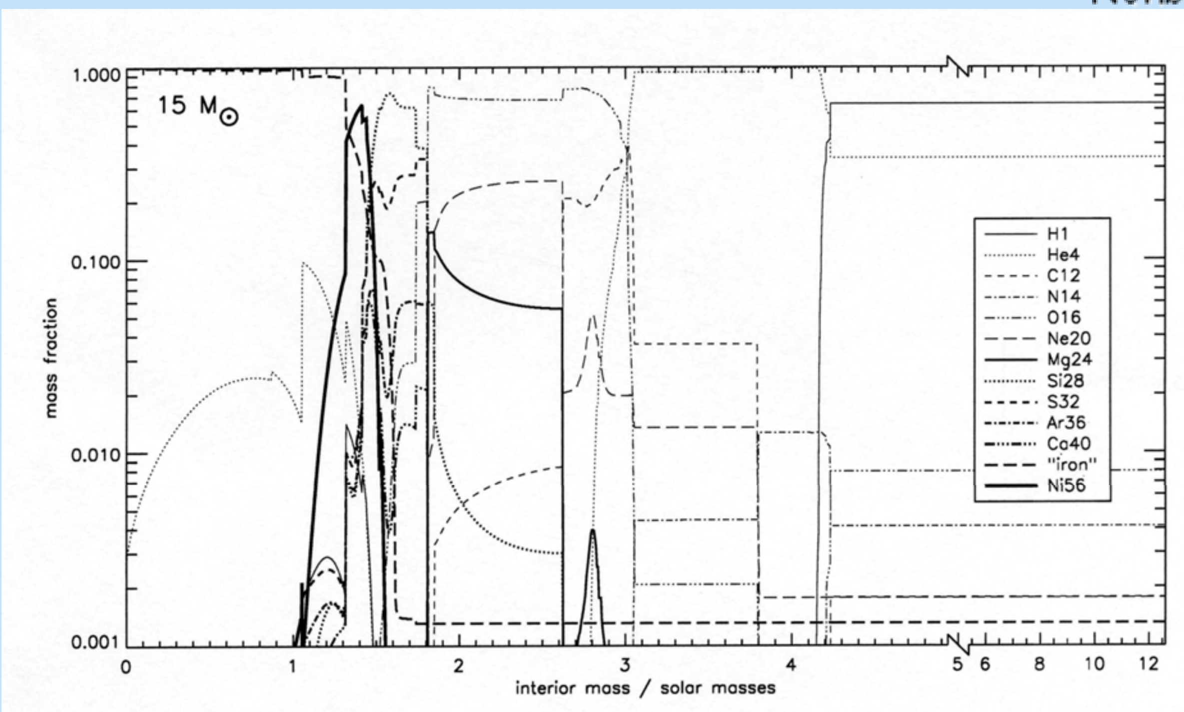


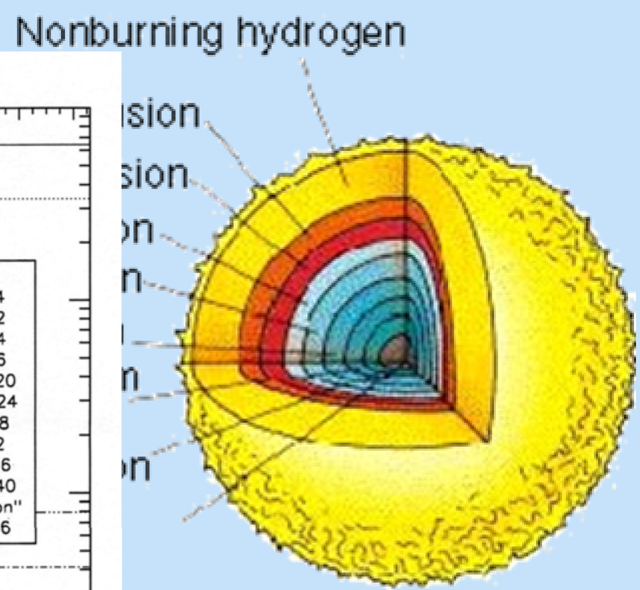
Evolution of a massive star → Type II SN

Type II SN → end point of stellar evolution : $M \gtrsim 8\ M_\odot$

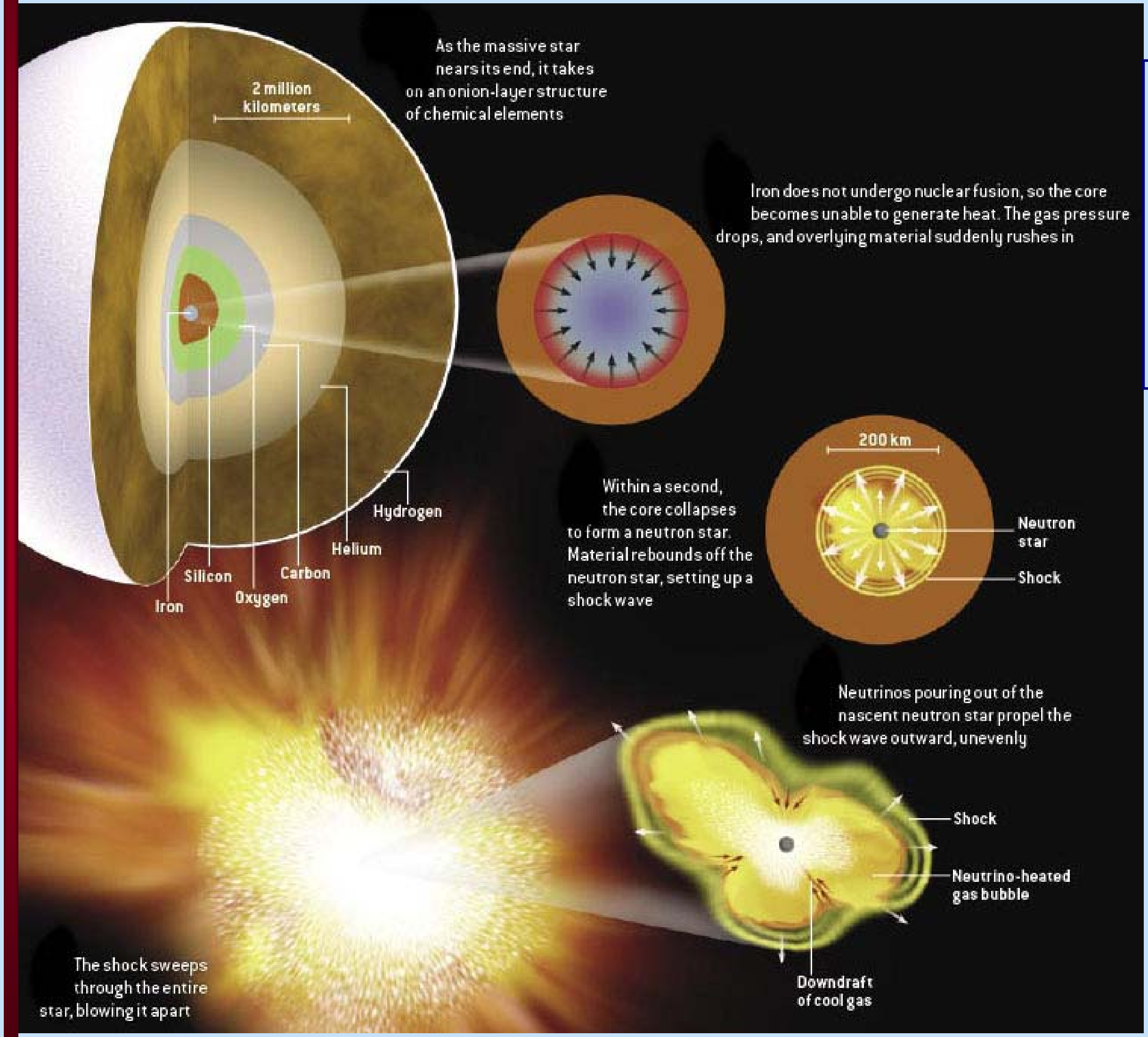
$$\mathrm{H} \xrightarrow{10^7\ \mathrm{yr}} \mathrm{He} \rightarrow \mathrm{C,\ O} \rightarrow \mathrm{Ne,\ Mg,\ Si} \xrightarrow{\text{few days}} \mathrm{Fe}$$

Core: iron and silicon isotopes





SNII – picture of gravitational collapse

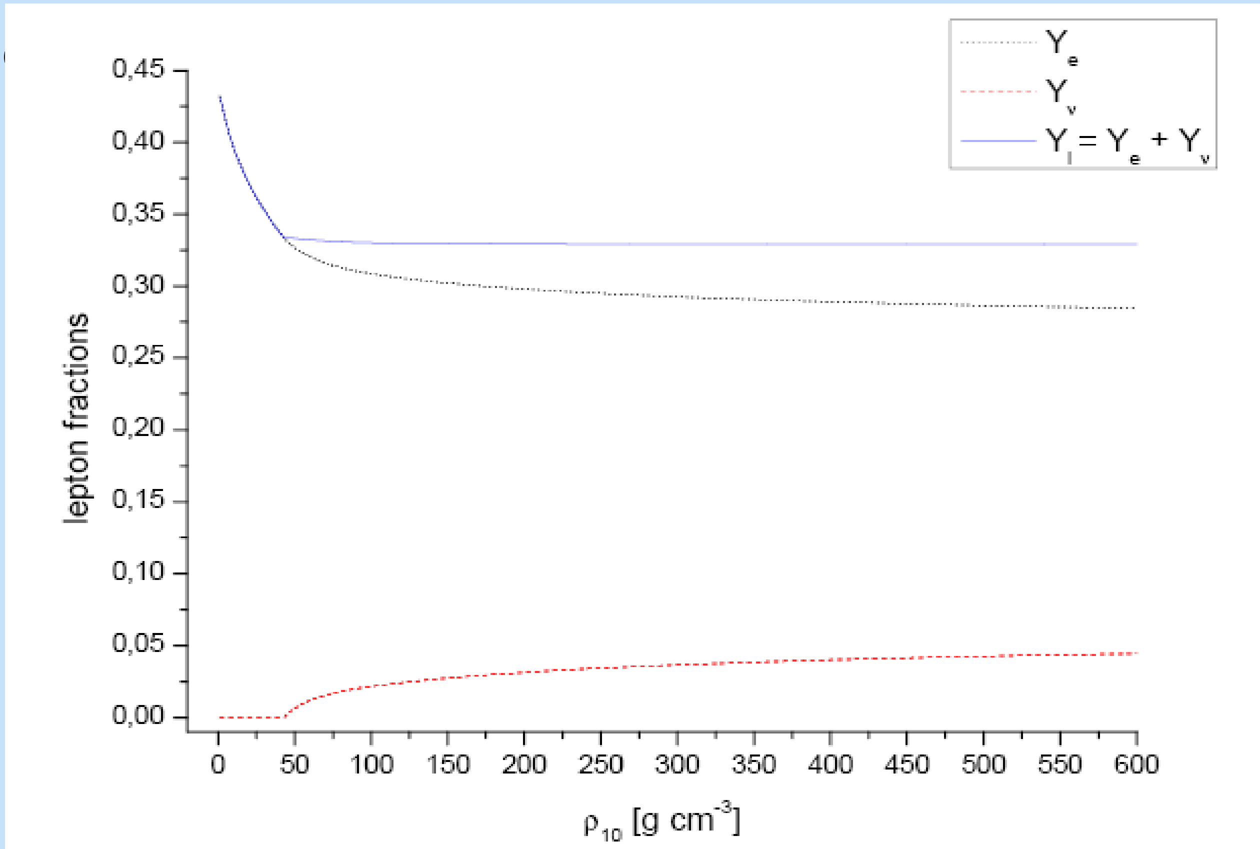


1. *Infall epoch*: compression of the *core* to nuclear density (electron capture)
2. *Core bounce* and formation of shock wave
3. *Explosion*: propagation of shock wave, possible explosion

Physical model

- Nuclear inputs:

$1, A) + \nu_e$



- Evolution of collapse up to neutrino trapping (→ Y_{lept} const!)

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)

$E_{symm}(T)$

$$\begin{cases} E_{sym} = s(T)\left(1 - 2\,\frac{Z}{A}\right) \\ s(T) = s(0) + const\left(\frac{1}{m^*(T)} - \frac{1}{m^*(0)}\right) \end{cases}$$

⇩

reduction of m_ω with T ⇒ increase of E_{symm}

⇩

increase of $\mu_n - \mu_p$ ⟶ Q-value!

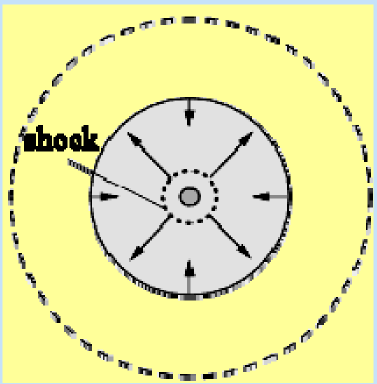
⇩

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

$Y_{lept,tr}$ ⟷ Shock wave energy

Shock wave loses energy while crossing matter.

dissociation energy: $17\ \text{foe}/M_\odot$ $\quad 1\ \text{foe} = 10^{51}\ \text{erg}$



↓

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

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

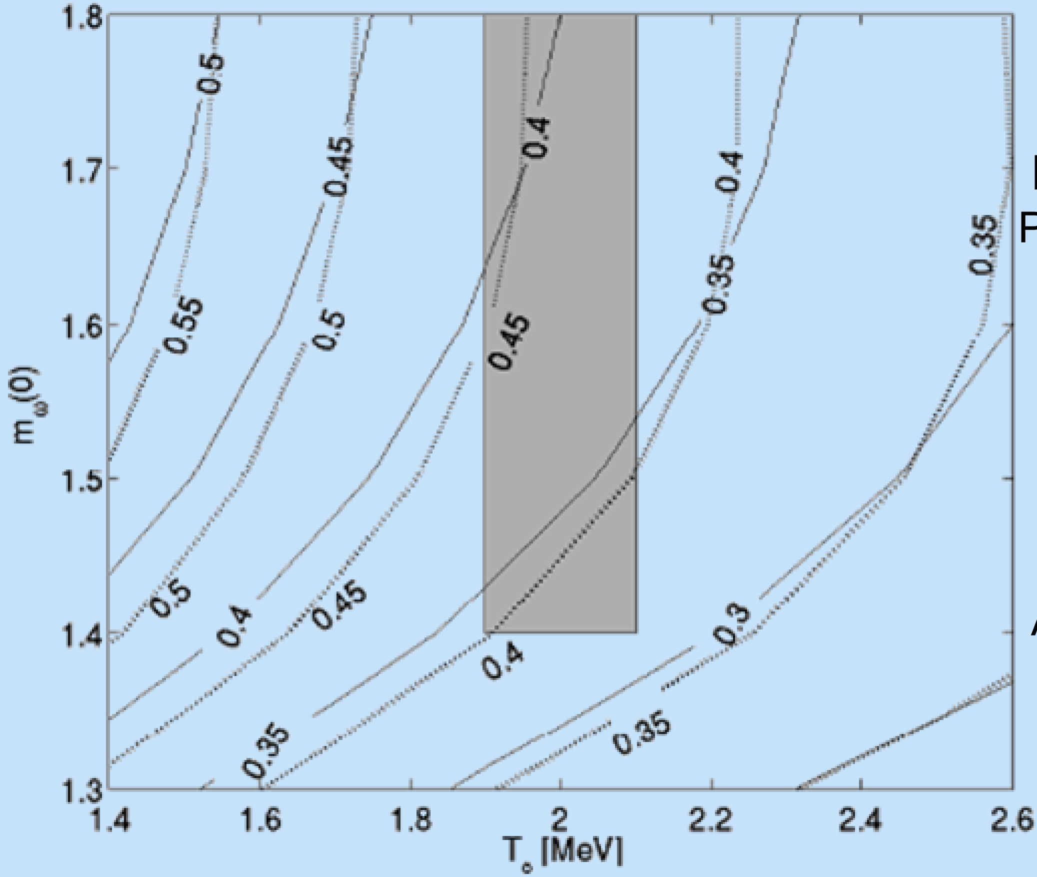
⇩

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

Numerical results of collapse simulation (one-zone code)

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

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



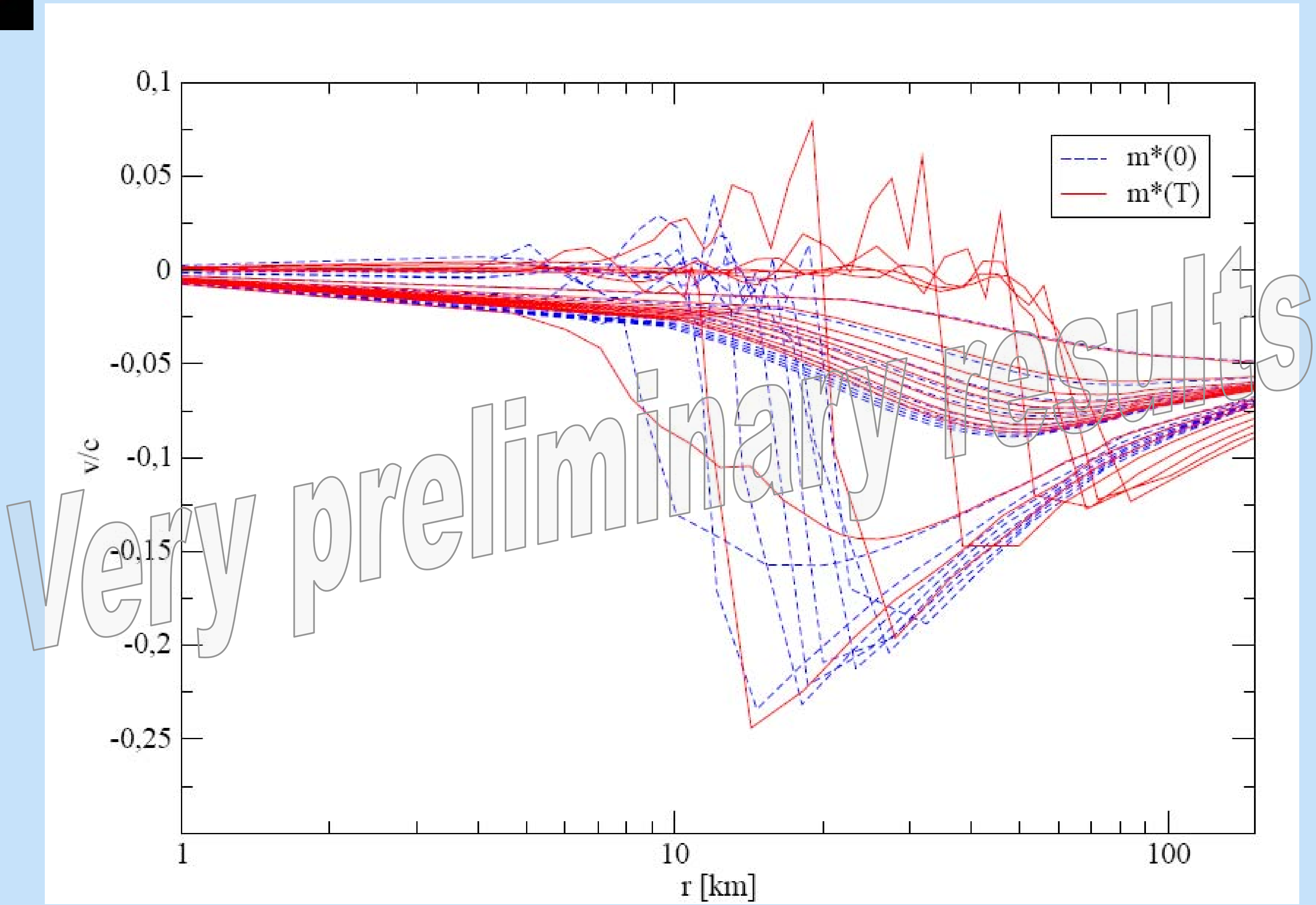
—— $\gamma^2 = 1$

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

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

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

Numerical results of collapse simulation (1D Newtonian code)



Conclusions

- Influence of nuclear physics on the evolution of collapse
  ex. T-dependence of E_{sym}

  → systematic reduction of neutronization of the core
  (increase of final lepton fraction)

  → bigger homologous core & less energy dissipated by shock wave

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

  and: *K* ~ 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!

Outlook

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

  - Electron capture rates on nuclei
    $\rightarrow \gamma^2$

    } IPN Orsay (E.Khan)

  - 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 Bruyeres (P.Blottiau & Ph. Mellor) & LUTh Meudon (J. Novak & M.Oertel)


Thank you