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"An expanding hadronic supercritical model for γ-ray burst emission"

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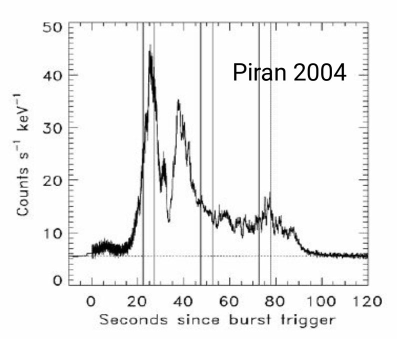
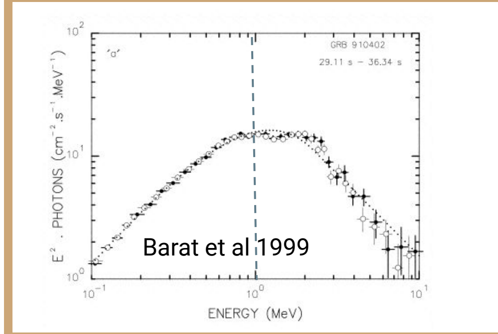
The GRB phenomenology

- Brief flashes of gamma rays
- Large amounts of energy E= $10^{51\text{-}54}$ ergs
- Duration 0.01 sec-100 sec
- Highly variable light curves: (Usually) many pulses (~10-100) with typical width 10 msec-1 sec each
- Spectra with energy peaks ~100 keV-1 MeV





The GRB prompt emission models

Deduced from observations :

- Source Radius R< 10^{13} cm
- Magnetic Field B>10^{3} G
- Bulk Lorentz Factor $\Gamma>10^{2}$

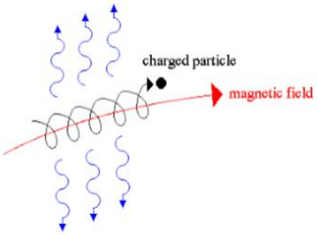
Non thermal

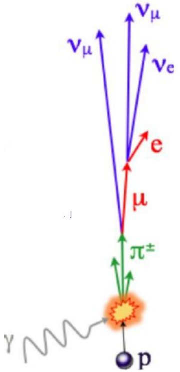
✓ Hadronic

Leptonic

Proton synchrotron

Photo-hadronic interactions



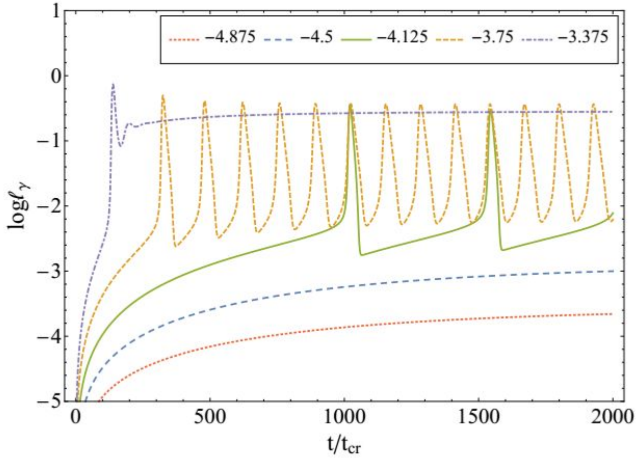


✓ Hadronic supercriticality

Feedback processes give rise to non linearity

What is hadronic supercriticality?

When relativistic protons reach a critical density they release all their energy with high radiative output in short timescales

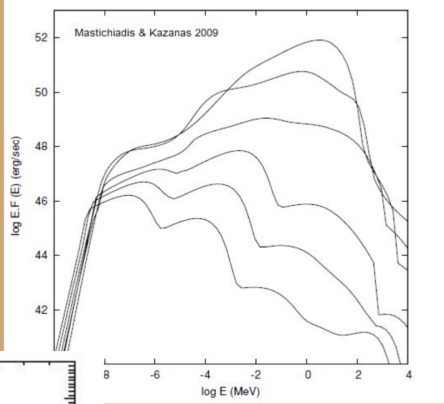


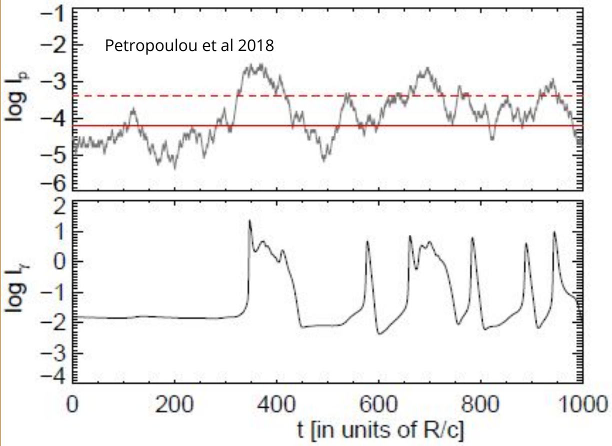
Mastichiadis et al 2020

Hadronic supercriticality has been already applied to GRBs

(Mastichiadis & Kazanas 2004, Petropoulou et al 2014, Petropoulou & Mastichiadis 2018)

Common assumption : Constant emitting region





The novelty of this project:

We have developed a numerical code that solves the kinetic equations of particle populations inside an expanding volume taking into account all the radiative processes as well as adiabatic losses

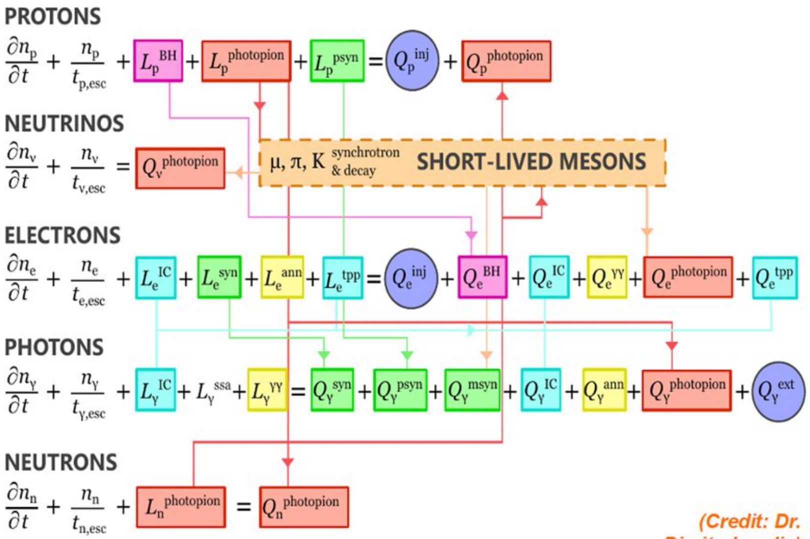
Expanding spherical volume with a constant expansion velocity

$$u_{\exp}\frac{\partial n_j}{\partial r} + u_{\exp}\frac{3n_j}{r} + \frac{n_j}{t_{esc,j}} + \mathcal{L}_j = Q_j$$

Free parameters:

1. Initial Source Radius
2. **Expansion velocity**
3. Initial Magnetic field / **Time Profile**
4. Proton luminosity / **Time Profile**
5. Maximum proton energy
6. Proton Distribution/ **Injection rate**

$$\ell_p = \frac{\sigma_T L_p}{4\pi r m_p c^3} = \ell_{p,in}\left(\frac{r}{r_{in}}\right)^{s-1} \qquad \ell_\gamma = \frac{\sigma_T L_\gamma}{4\pi r m_e c^3}$$

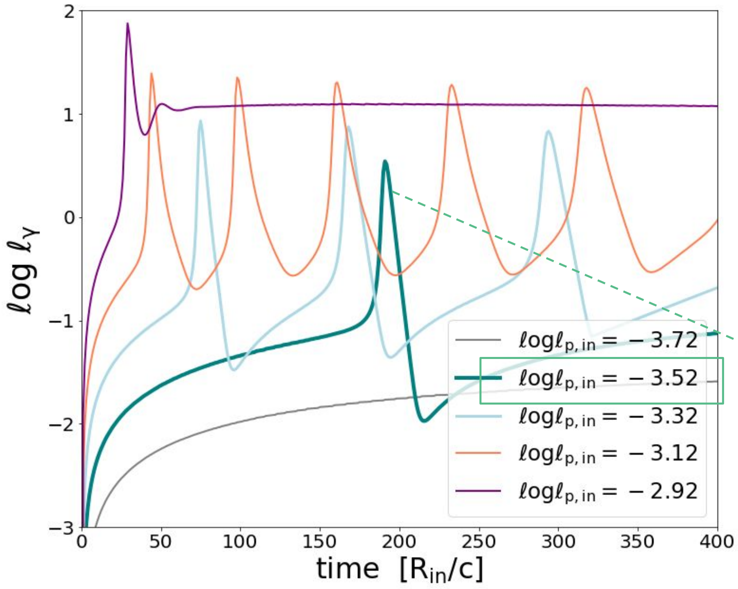


(Credit: Dr. Dimitrakoudis)

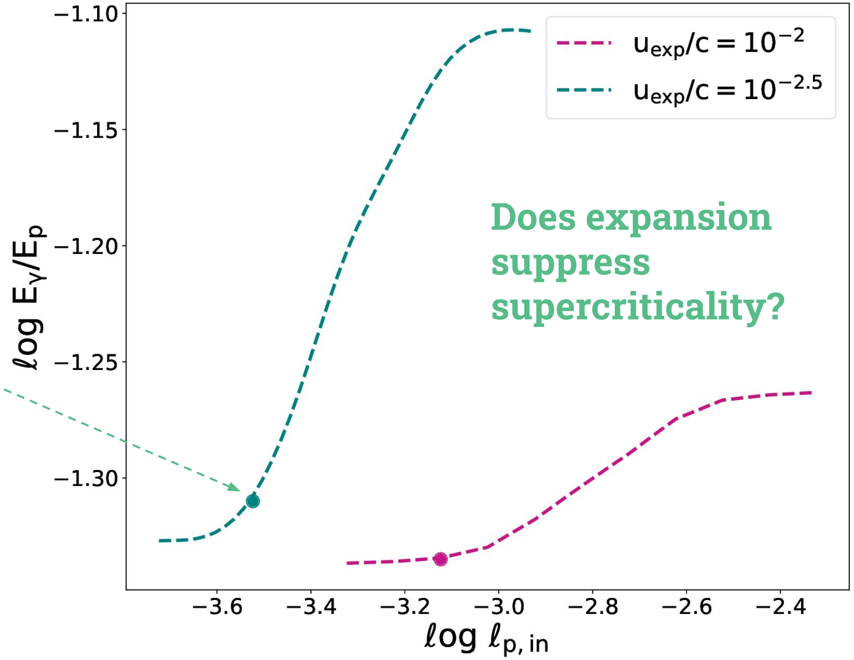
The transition to supercriticality

Initial Supercritical Parameters non expanding scenario → Expanding numerical code

$u_{exp}=10^{-2.5}c$ $R_{in}=10^{11}$ cm $B=10^4$ G $\gamma_{max}=10^8$ $l_{p,in}=10^{-4.25}c$



Radiative efficiency

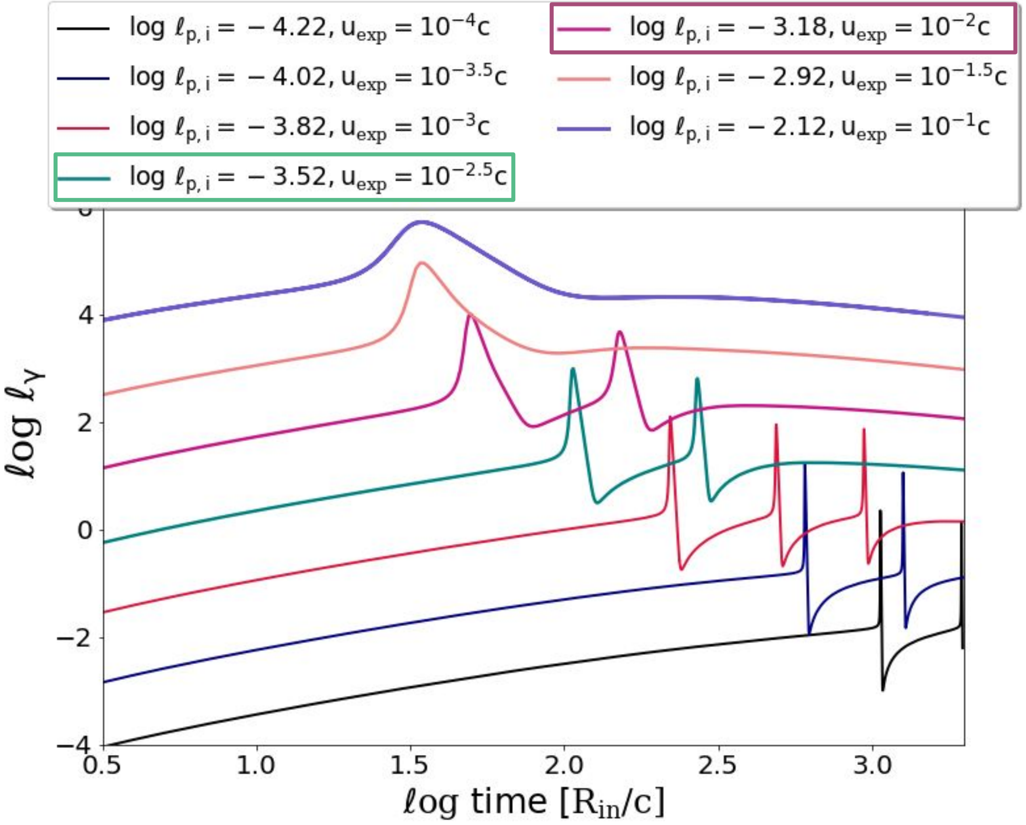


Does expansion suppress supercriticality?

Constant B, adiabatic losses included

Florou, Mastichiadis, Petropoulou 2021 in prep.

The role of expansion velocity in the manifestation of supercriticality



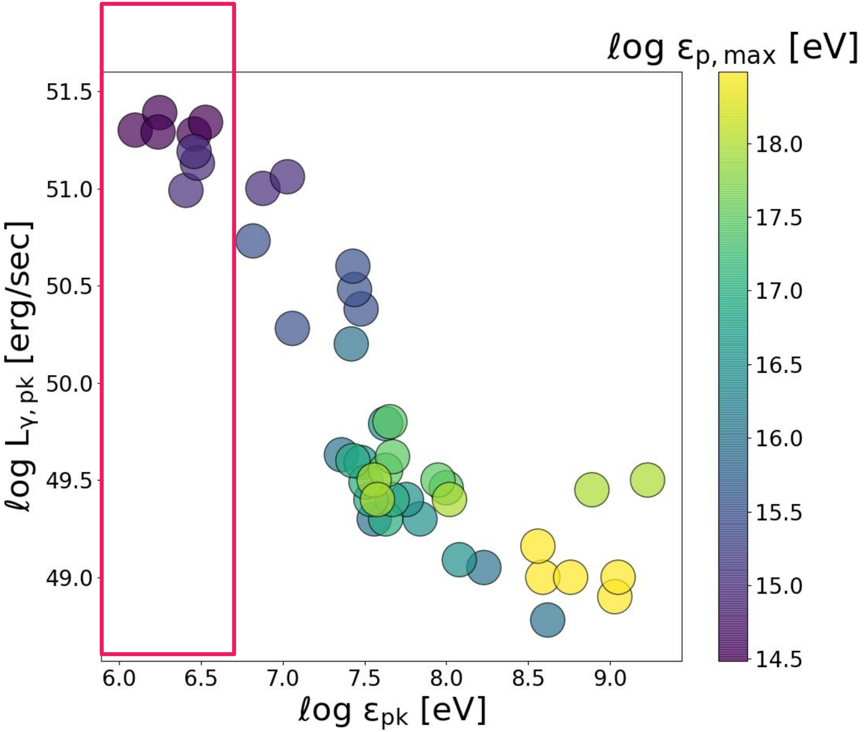
As the expansion velocity is increased:

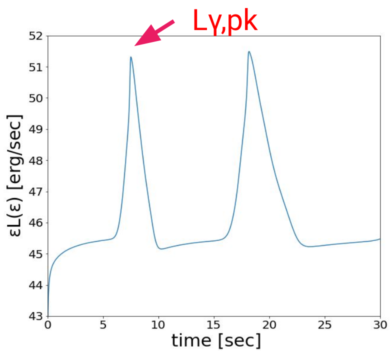
- ➔ Lower radiative efficiencies
- ➔ Broader light curves
- ➔ Multiple bursts vanish

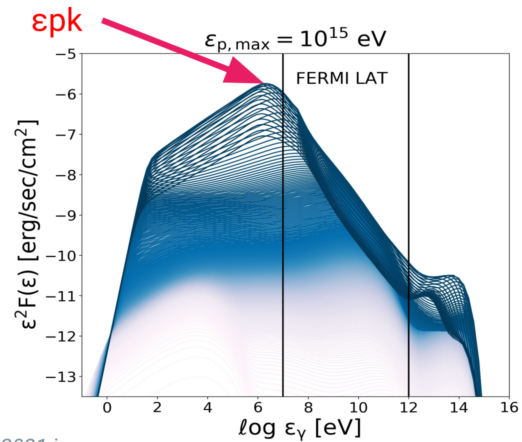
Florou, Mastichiadis, Petropoulou 2021 in prep.

Energetics that fall in the case of GRBs

R_{in}= 10^{11} cm B_{in}=10^4 G u_{exp}=$10^{-2.5}$c
Magnetic field ~1/R
Proton luminosity injected ~R
Power law distribution p=2, Γ=100, z=2







small values of proton energy preferable - γ_{max}~10^4 -10^5

Florou, Mastichiadis, Petropoulou 2021 in prep.

The Blob tracking model

Discrete number (N) of blobs emitted randomly from a central engine every 2 sec

The blobs do not collide and expand with the same velocity

Initial parameters that lead to HS-fall in the GRB case

Light curve construction

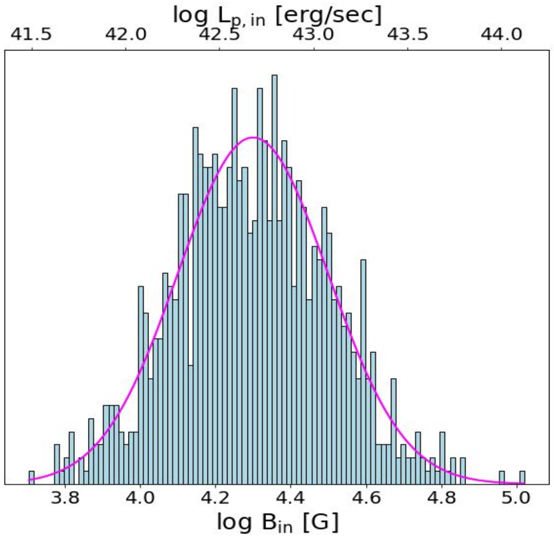
Assumptions

1. Equipartition between initial magnetic energy and proton luminosity injected, κ=80
2. Maximum proton energy : equation of the acceleration and synchrotron cooling timescale
3. Monte Carlo simulation- Random Select N=10

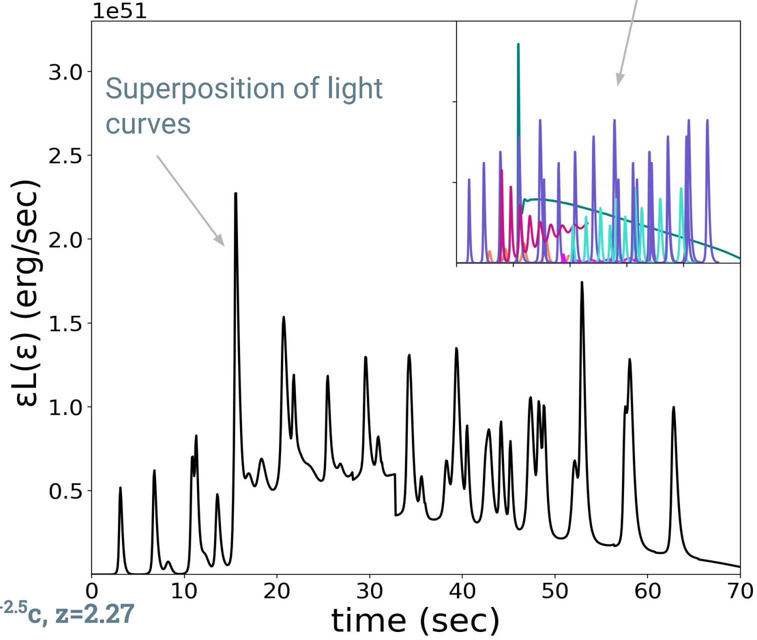
Parameters of the Gaussian Distributions (comoving frame)

$B_{in}=10^{4.3}$ G , $\gamma_{max}=10^5$

$Lp_{in}=10^{42.8}$ erg/sec , logσ=0.2



Contribution from each blob



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Γ=100, $u_{exp}=10^{-2.5}c$, z=2.27

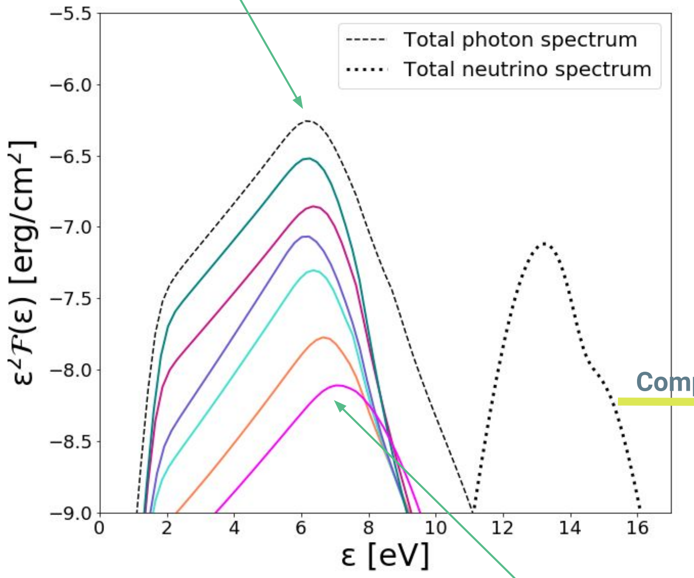
Photon & neutrino spectra

Results / Typical values of GRB phenomenology

Γ	$\epsilon_{\rm eff}$ %	$E_{\rm iso}$ [erg]	$\varepsilon_{\rm pk}$ [eV]	$\varepsilon_{\nu\rm pk}$ [eV]	$\mathcal{F}_{\gamma,\rm pk}/\mathcal{F}_{\nu,\rm pk}$	T_{90} [sec]
100	23.7	5.68×10^{51}	9×10^{5}	1.6×10^{13}	7.9	60

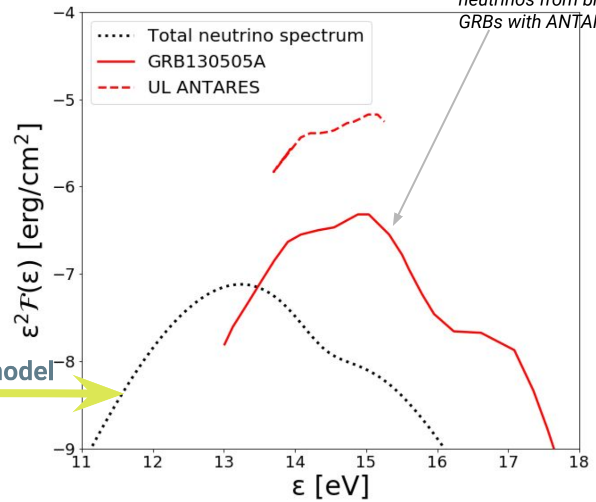
$$E_{\rm iso} = 4\pi d_{\rm L}^2 \int_{\varepsilon_{\rm min,obs}}^{\varepsilon_{\rm max,obs}} \mathcal{F}_\gamma(\varepsilon)d\varepsilon$$

Photon spectra superposition



Comparison with a neutrino internal shock model

Albert et al 2017
"Search for high-energy neutrinos from bright GRBs with ANTARES"



Contribution from each blob

Florou, Mastichiadis, Petropoulou 2021 in prep.

Conclusions

- Supercriticality is manifested even in expanding sources. There are initial parameters that can reproduce the GRB prompt emission

- Important!- low values of γ_{max} required in order to reproduce a GRB photon spectrum
- The resulting energetics and spectra of the “Blob Tracking Model” fall in the GRB case

- The produced neutrino spectra peak at lower energies compared to those of a standard neutrino internal shock model