Pair-instability supernovae as possible explanation of GRBs

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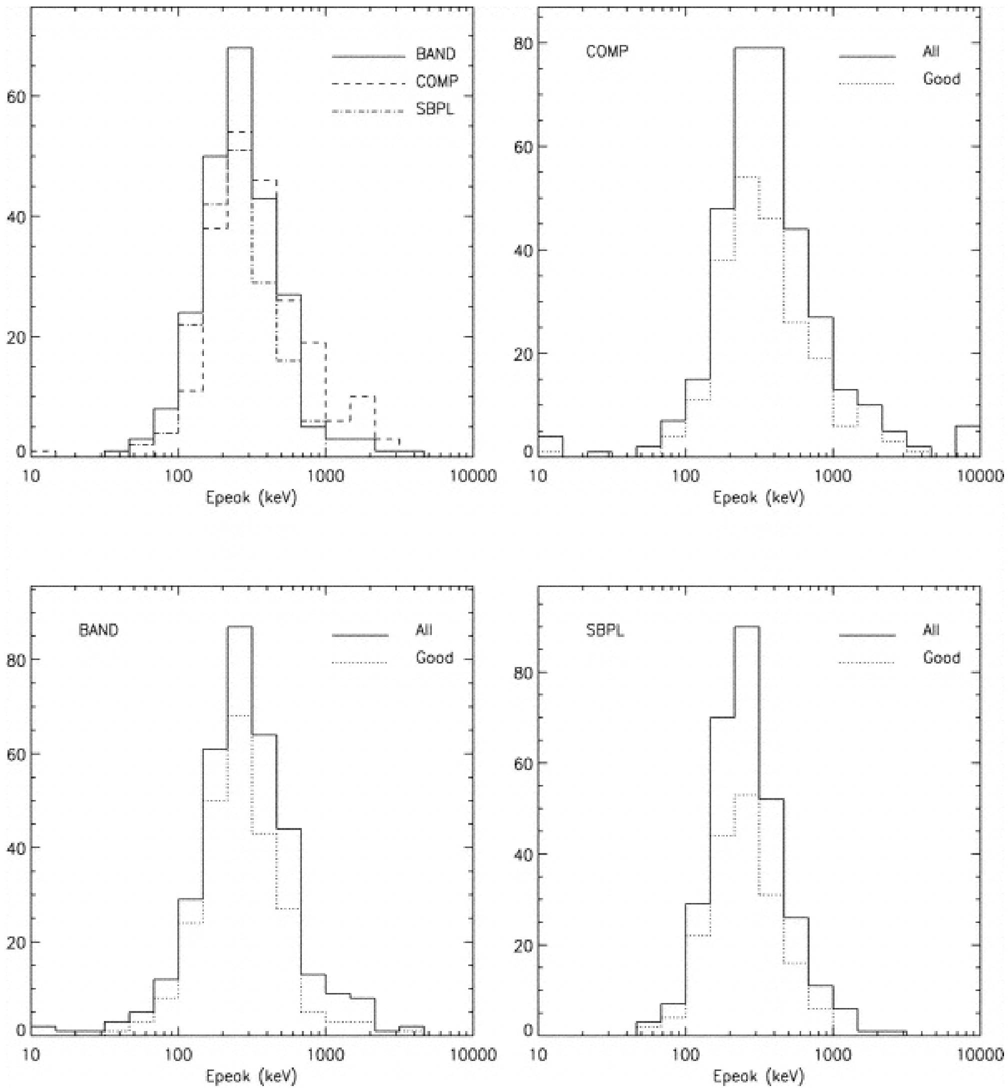
GRB

- Cosmological phenomena
- 1 event every 3 days in average
- Energy budget: 10^{51} - 10^{54} ergs
- Timescale of the prompt emission: 1 -100 sec
- Most of energy is emitted in X-ray or gamma-rays within interval of 100 keV-1000 keV

E_{peak}



Kaneko et al., The Complete Spectral Catalog of Bright BATSE Gamma-Ray Bursts, 2006

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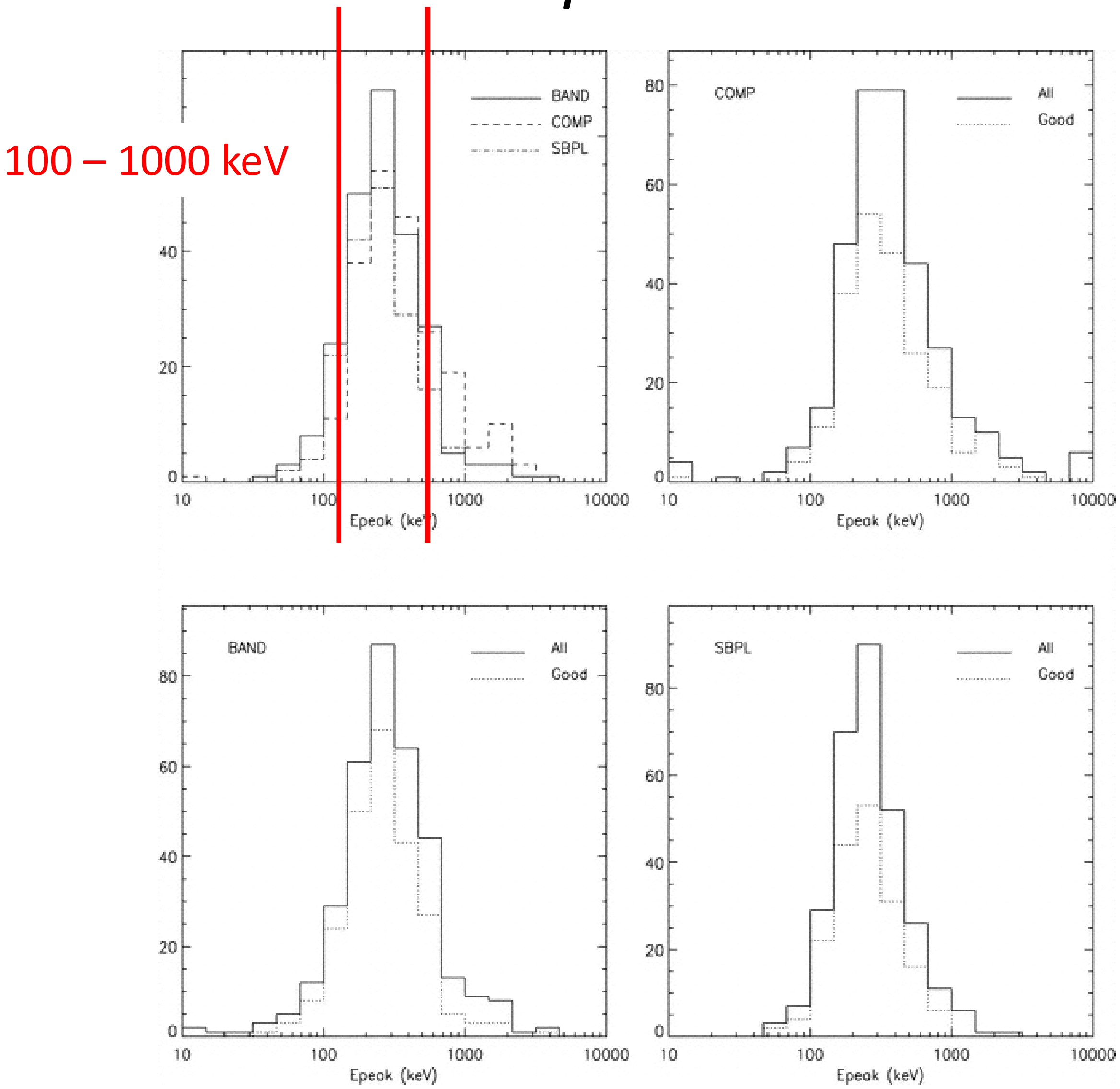


Kaneko et al., The Complete Spectral Catalog of Bright BATSE Gamma-Ray Bursts, 2006

GRB-SN connection

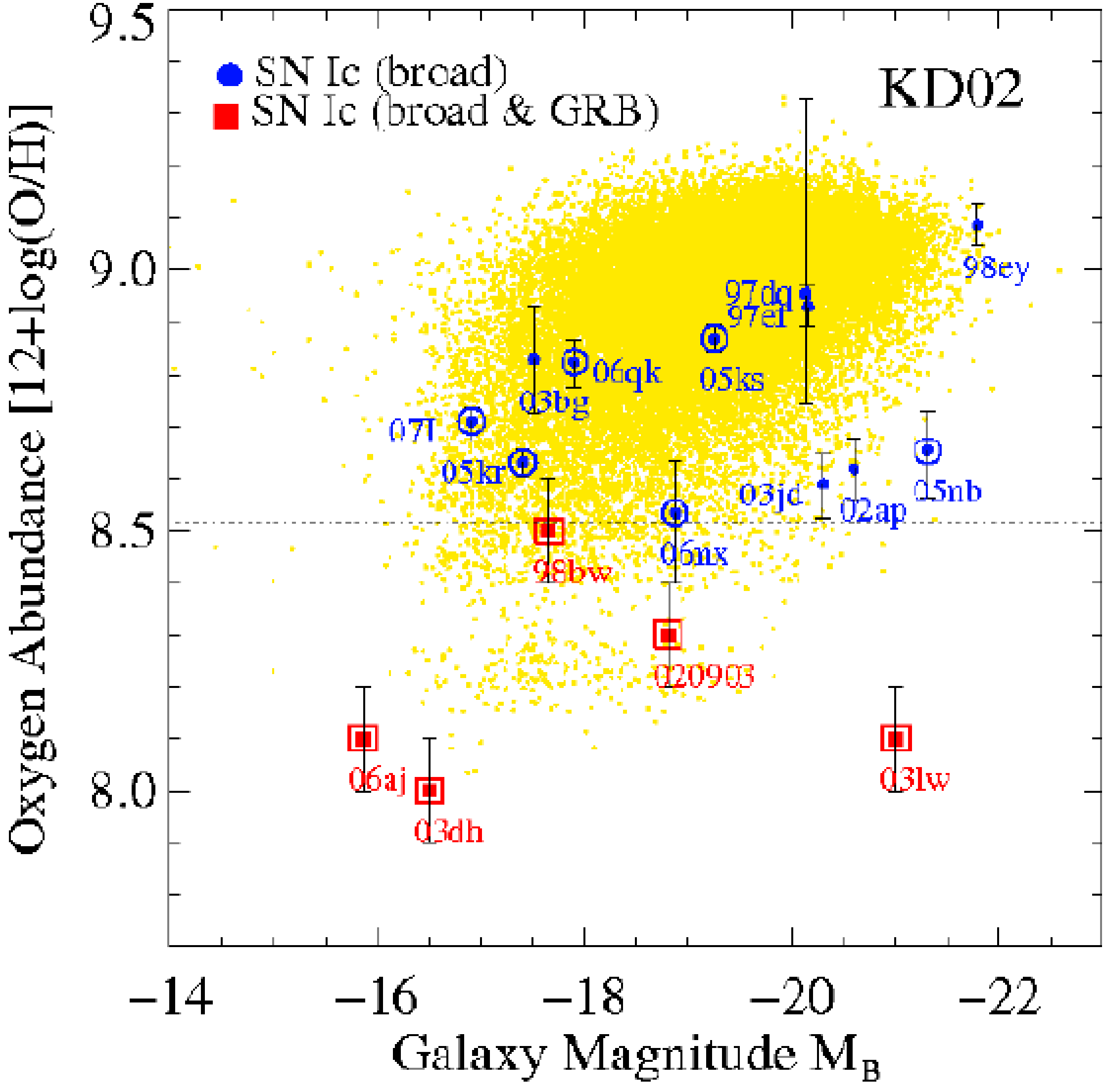
- Relative number of GRBs to Ibc SNe is about 0.4% - 3% [Guetta and Della Valle, 2007]
- Some GRBs are associated with Ic SNe
- Long GRB and core-collapse supernovae have different environments [Fruchter et al. 2006]
- Host environments of GRBs are systematically less metal-rich than host environments of broad-lined SN Ic where no GRB was observed.

Metallicity

- GRB hosts are low in luminosity and low in metal abundances. [Modjaz et al., 2007]

- The environment of every broad-lined SN Ic that had no GRB is more metal rich than the site of any broad-lined SN Ic where a GRB was detected [Modjaz et al., 2007]

Metallicity



Pair-instability SN as possible candidate

[P. Chardonnet, V. Chechetkin and L.Titarchuk ,2009]

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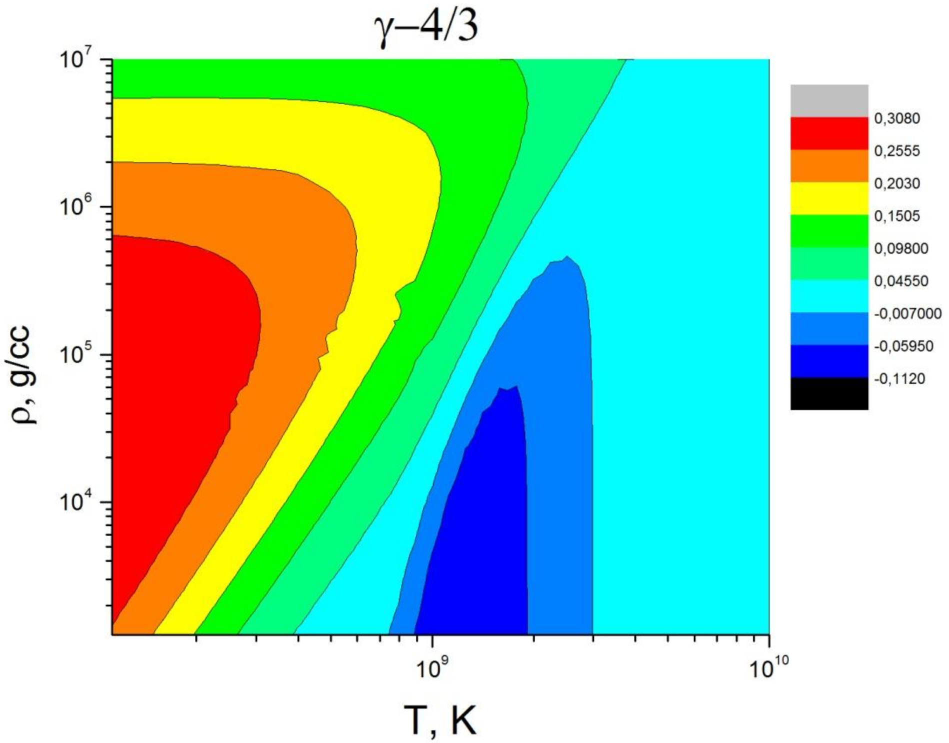
- Explosive process different from core-collapse SN
- Low metallicity
- Energy budget is about 10^{53} ergs

Pair-instability SN

[Barkat et al., 1967]



Numerical simulations

$$
\left\{
\begin{aligned}
\partial r/\partial t &= v \\
\partial v/\partial t &= -Gm/r^2 - 4\pi r^2(\partial P/\partial m) \\
\partial T/\partial t &= \left[- 4\pi \frac{\partial(r^2 v)}{\partial m}(T(\partial P/\partial T)_\rho) + \varepsilon_{\rm nucl} - \varepsilon_\nu\right] / (\partial E/\partial T)_\rho
\end{aligned}
\right.
$$

Numerical simulations

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Nuclear burning

Numerical simulations

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Nuclear burning

Neutrino losses

Numerical simulations

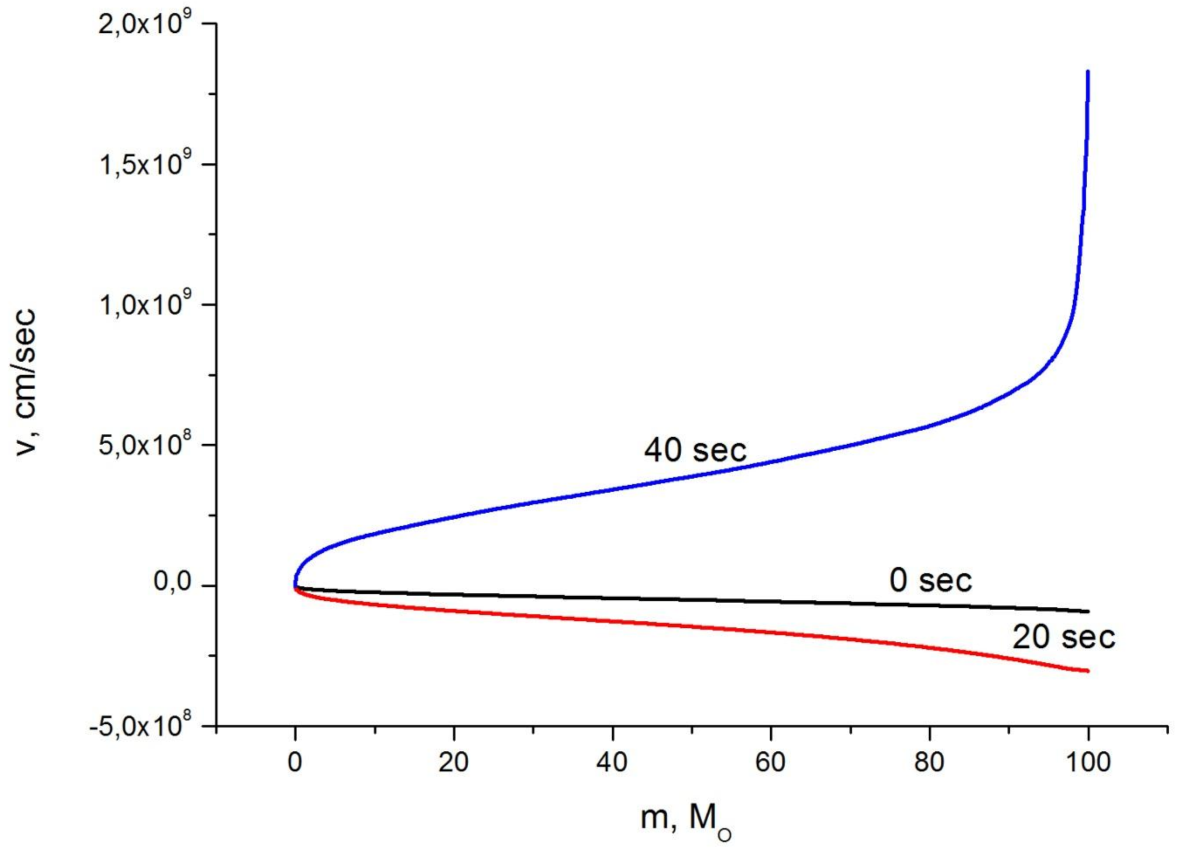
- Neutrino losses [P.J. Schinder et al., 1987]
  - Photo
  - Pair annihilation
  - Plasma

- Nuclear burning

$$2O^{16} \longrightarrow S^{32} + 16.54\ \mathrm{MeV}$$

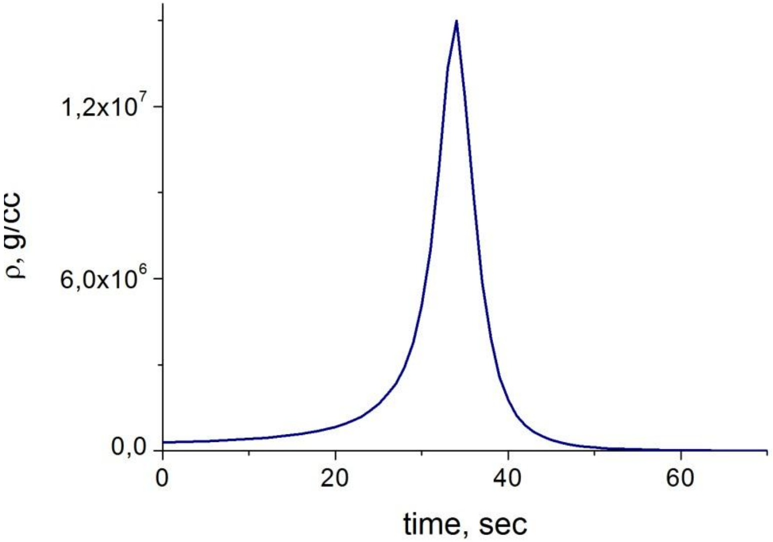
Results

Velocity profiles

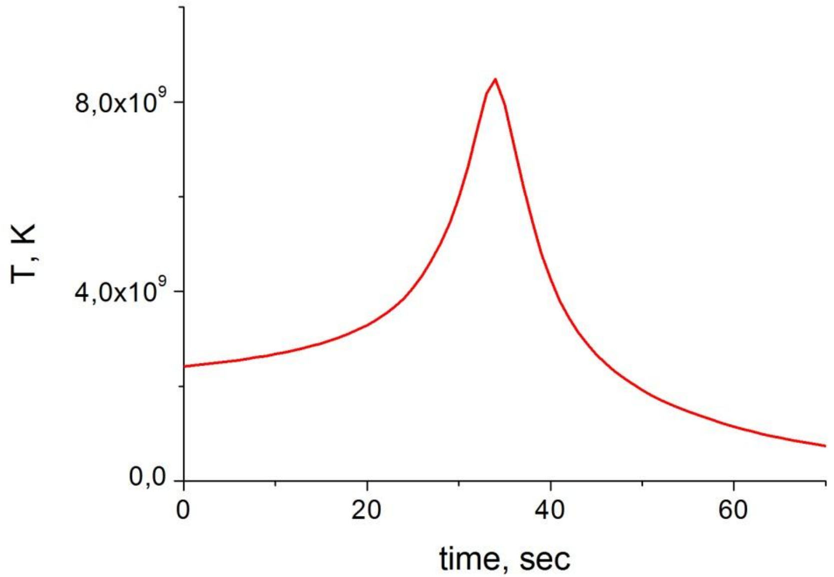


Results

Central density

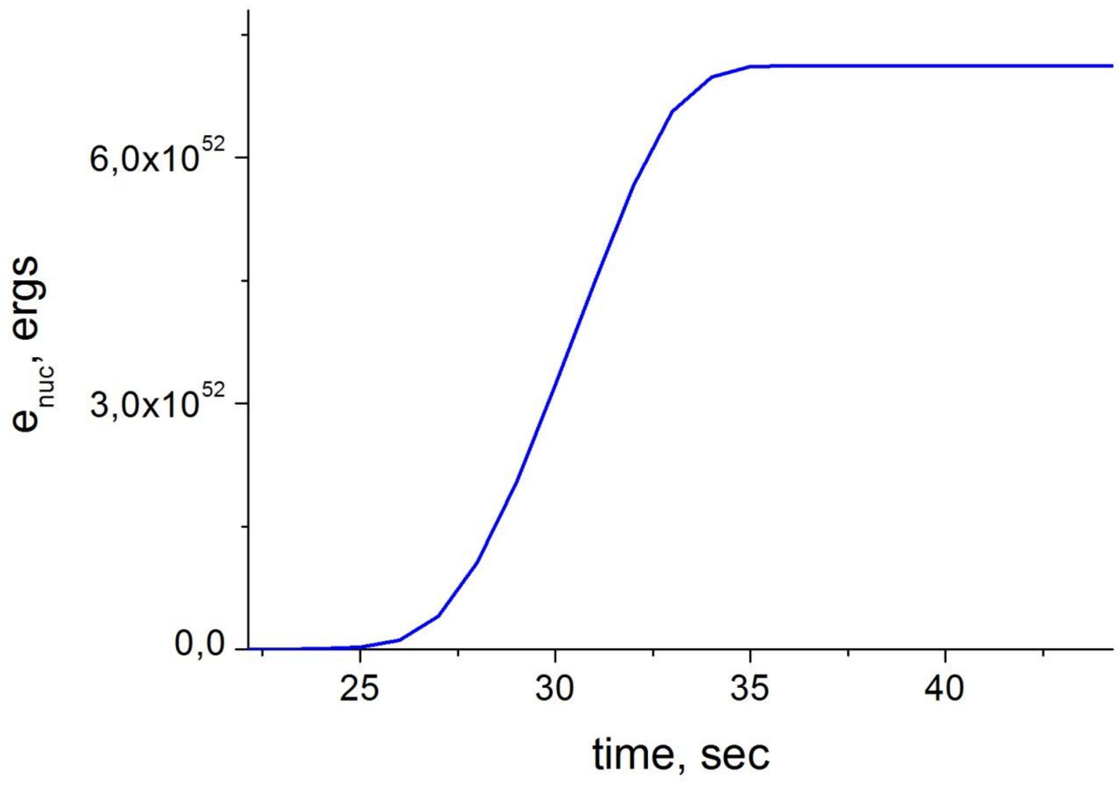


Central temperature



Results

Nuclear burning energy



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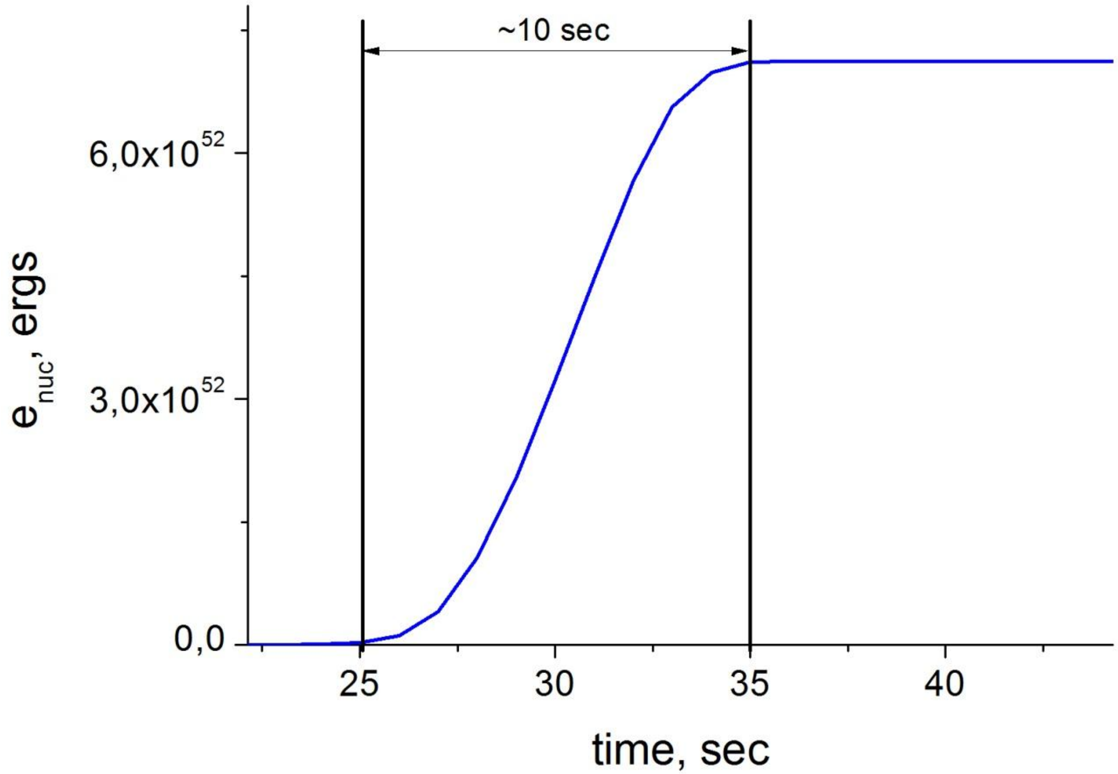

Results

$M/M_\odot$	**50**	**60**	**78**	**100**	**112**	**125**	**179**
$M_i/M_\odot$	108	124	150	180	200	220	300
$\rho_c, g/cc$	$7.55 \cdot 10^4$	$5.77 \cdot 10^4$	$6.0 \cdot 10^4$	$1.65 \cdot 10^5$	$1.0 \cdot 10^5$	$7.0 \cdot 10^4$	$2.70 \cdot 10^4$
T_{max}, keV	489	554	674	720	834	957	—
$E_{nuc}, 10^{52}$ ergs	1.94	3.05	4.99	7.01	8.67	10.3	—

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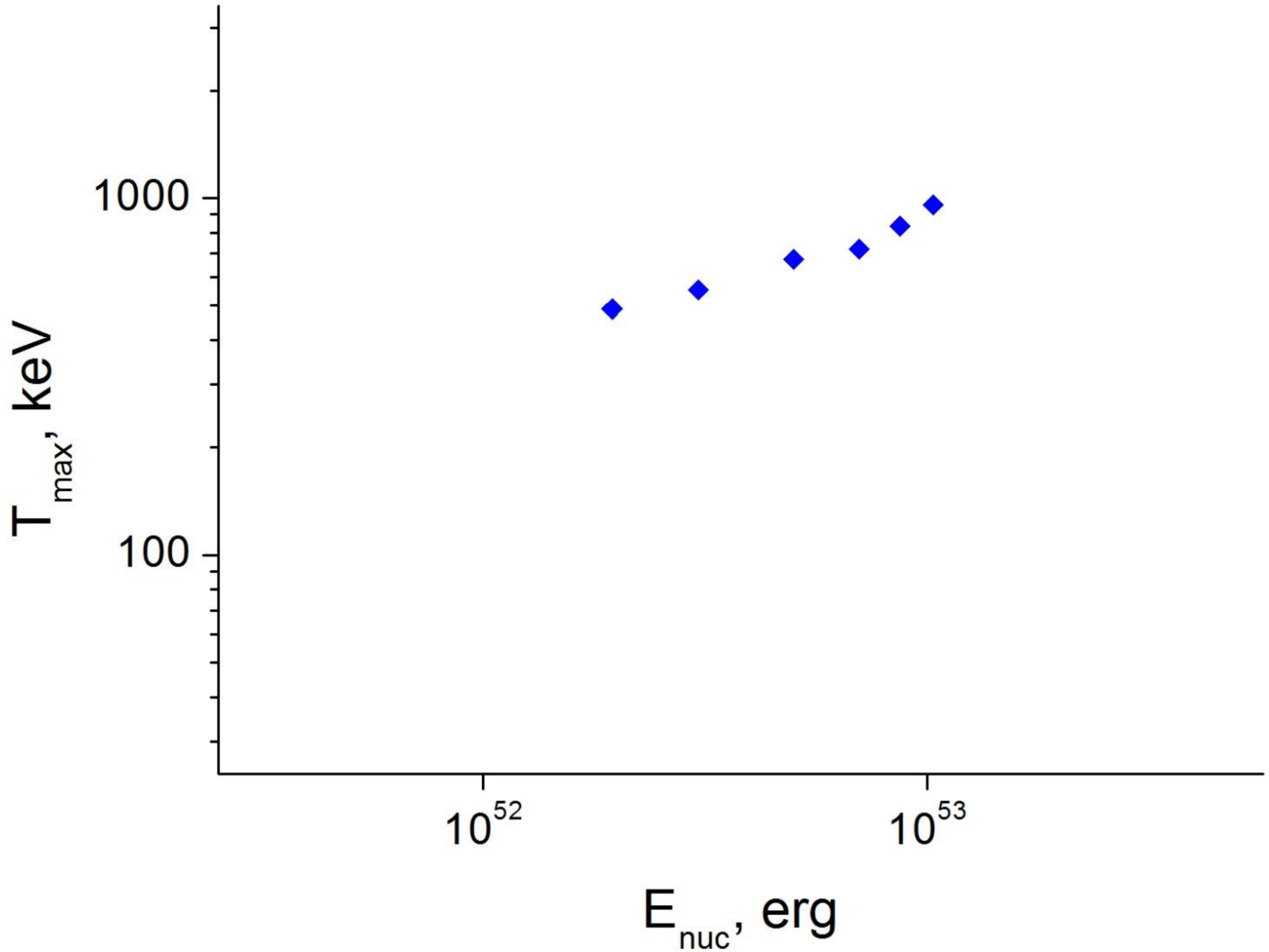
On a physical interpretation of the Amati Relation



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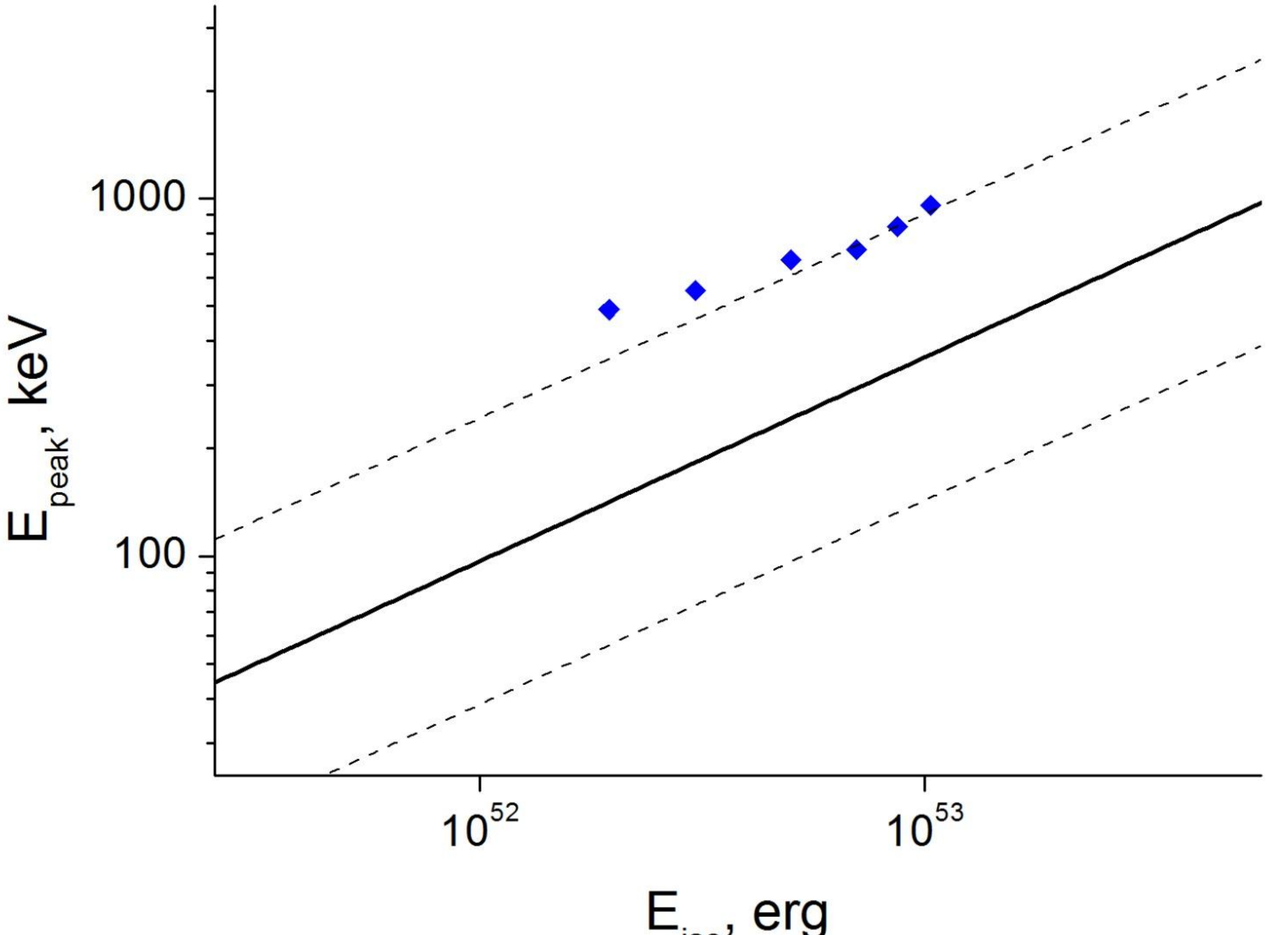

Amati relation from [L. Amati, F. Frontera and C. Guidorzi, 2009]

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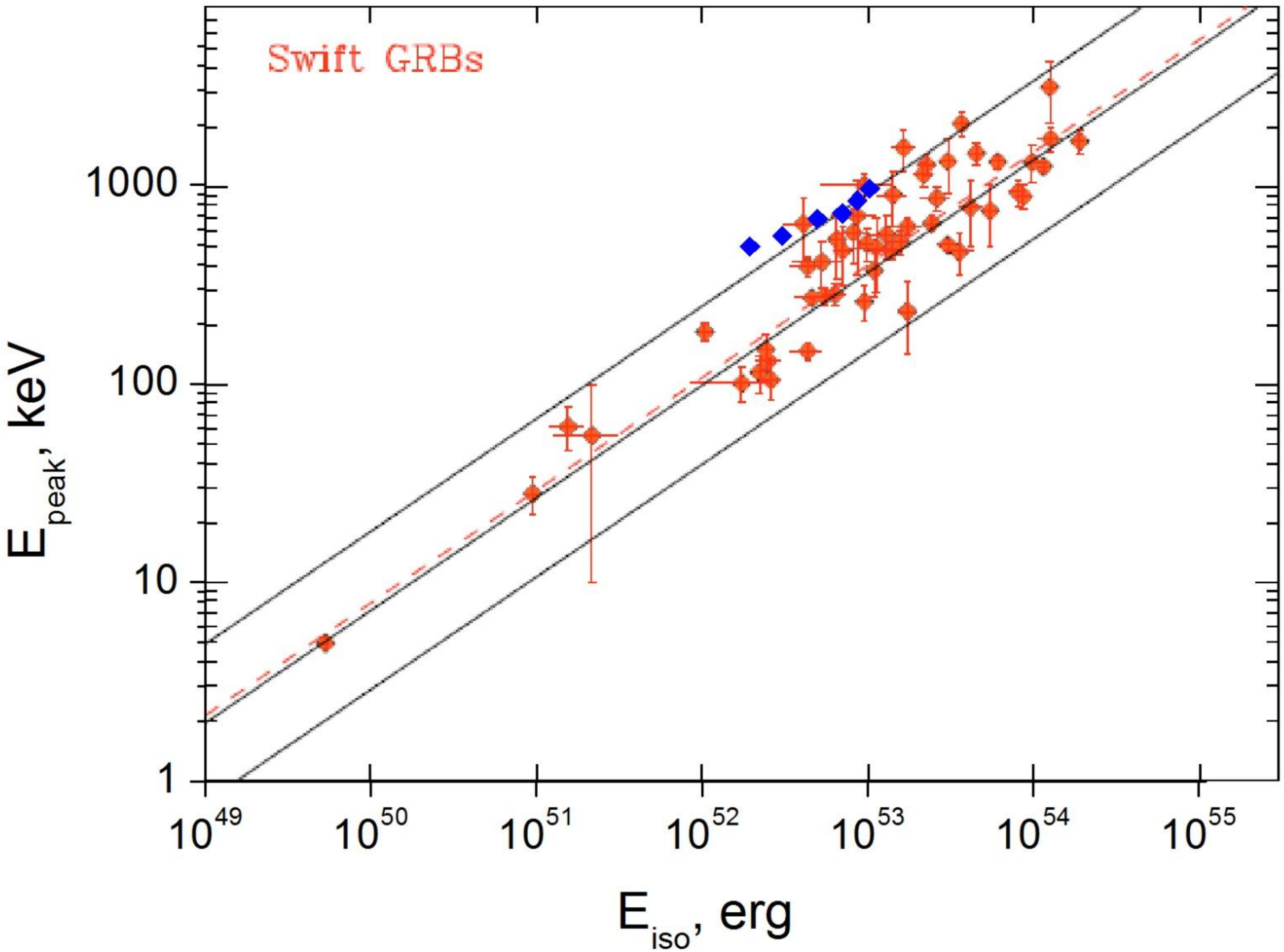

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Conclusions

- Explosive phenomena: timescale and energy budget are OK
- Amati relation could be related to the mass of the progenitor
- This model predicts more GRBs at high z

Thank you!

Acknowledgments:
Chechetkin V., Popov M.