Pair-instability supernovae as possible explanation of GRBs

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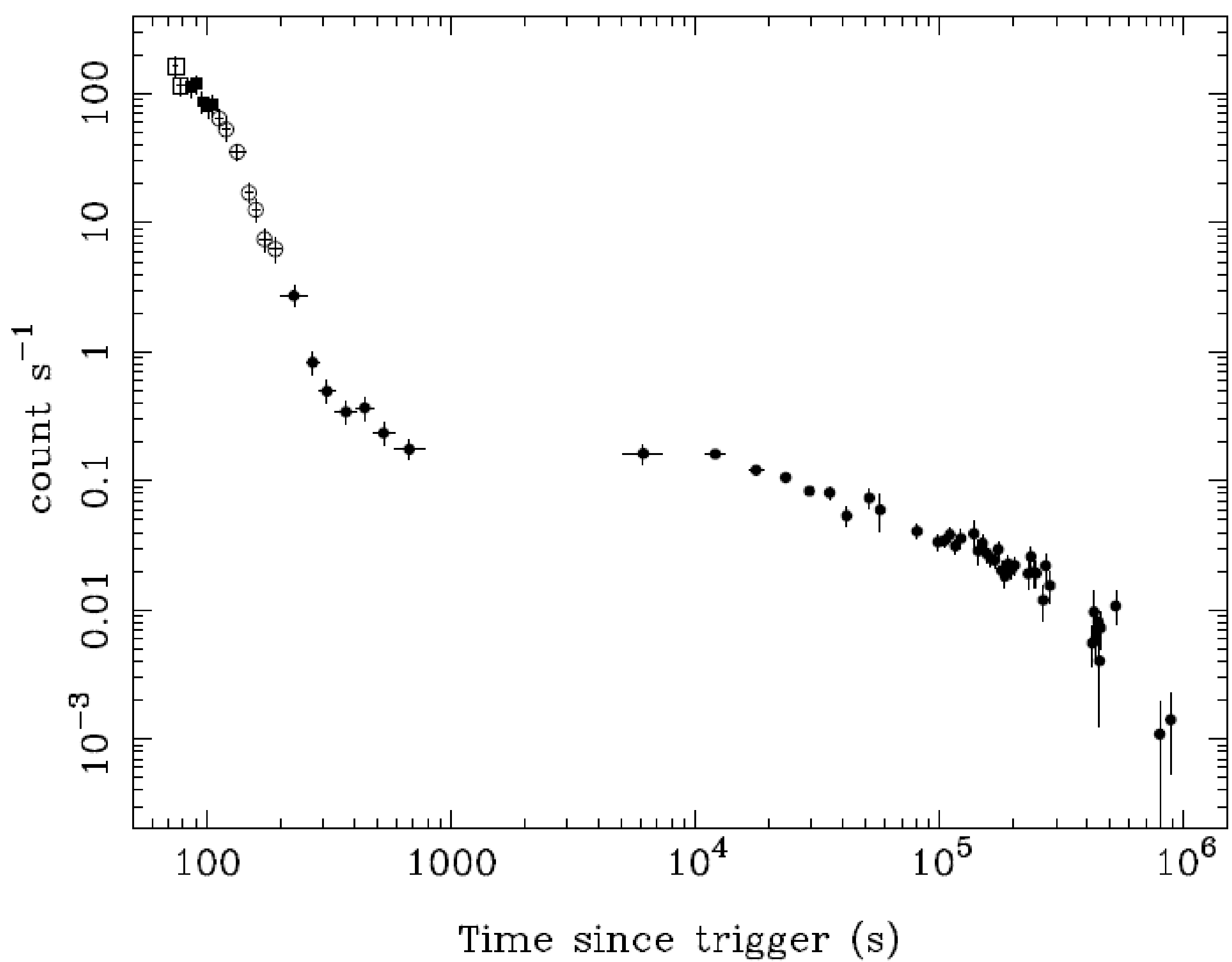
GRB

- Cosmological phenomena
- 1 event every 3 days in average
- Energy budget: 10^{51} - 10^{54} ergs
- Timescale of the prompt emission: 1-100 sec

GRB



[S. Vaughan et al. ApJ (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.

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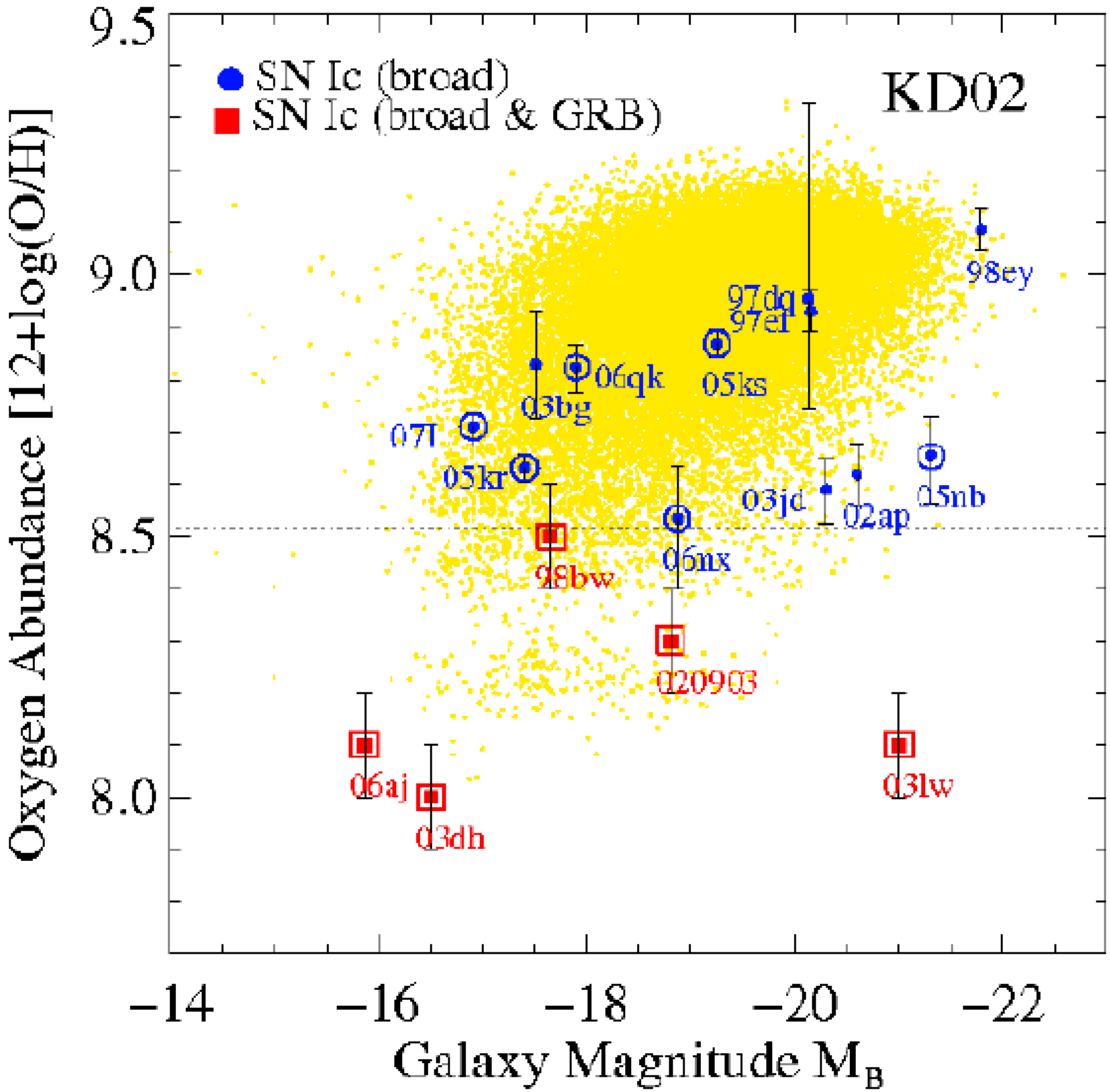
Metallicity

- 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

[Barkat et al., (1967)]

Population III stars could reach masses more than 100 solar masses

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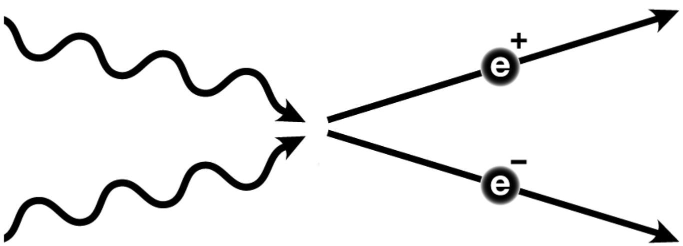

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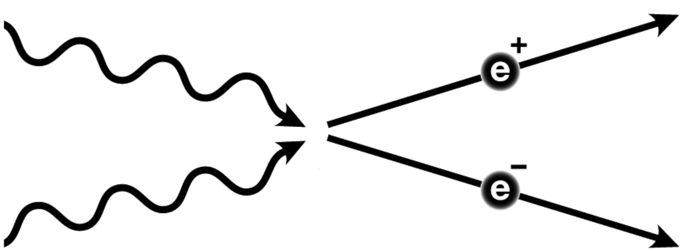
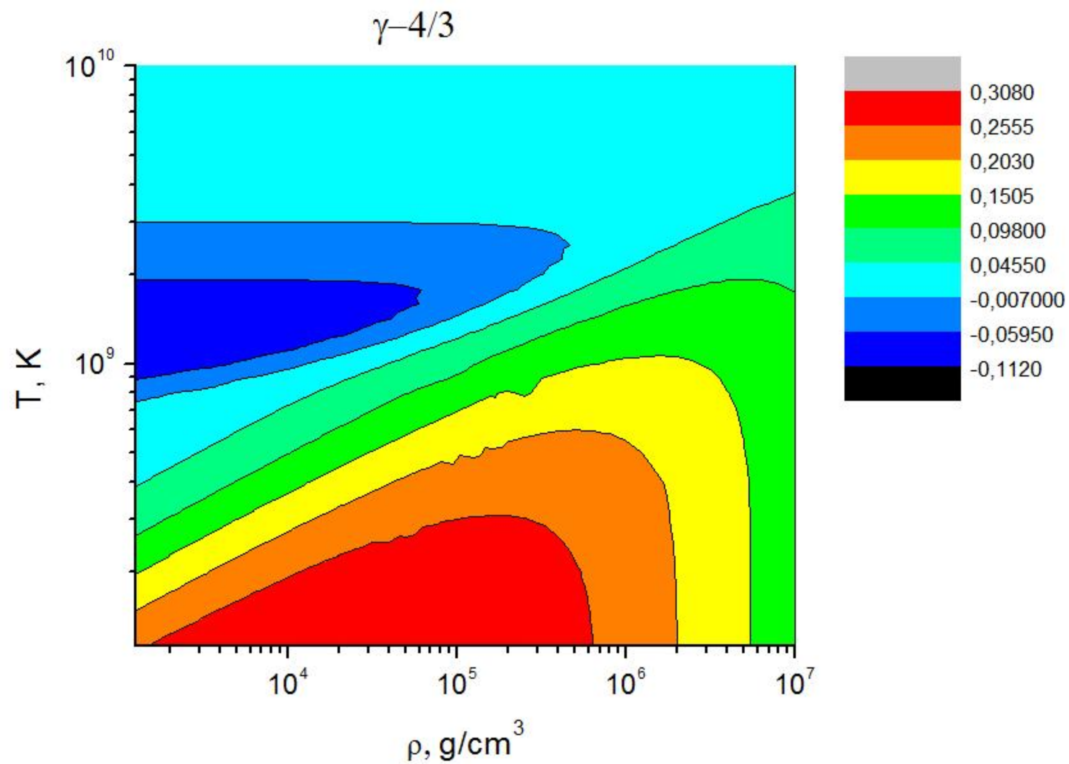


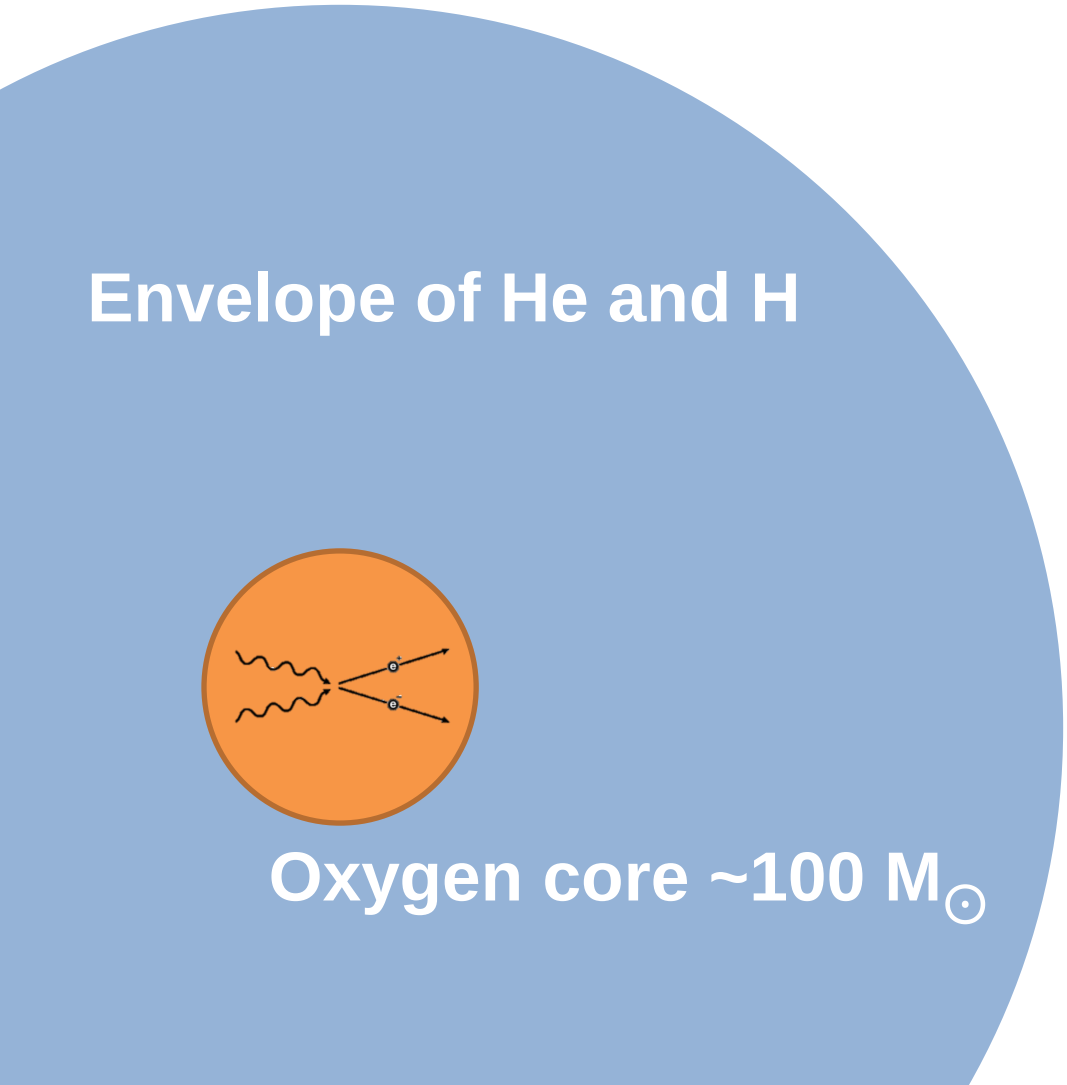


Pair-instability SN as possible candidate

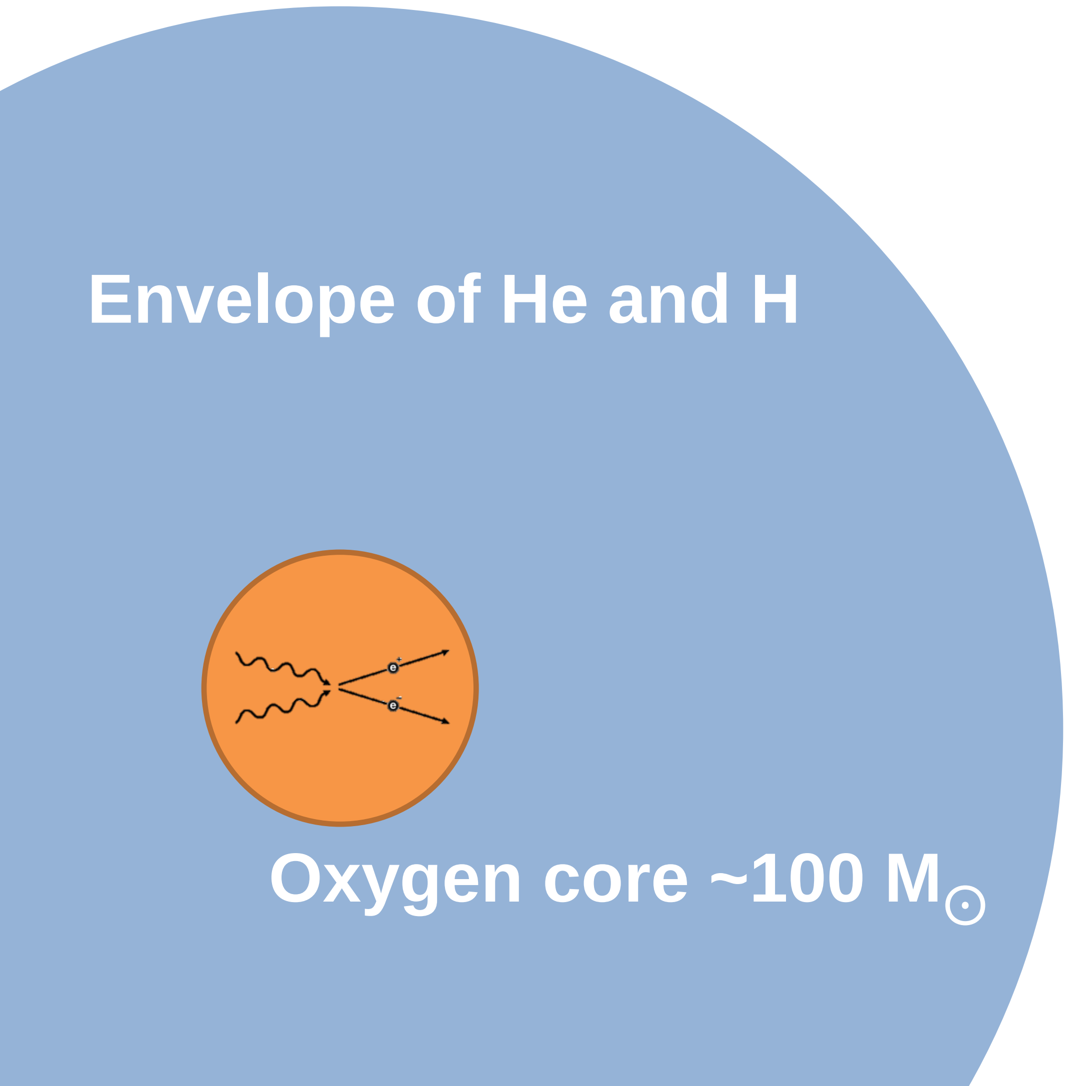
[P. Chardonnet, V. Chechetkin and L.Titarchuk ,2009]

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

Numerical simulations



Numerical simulations



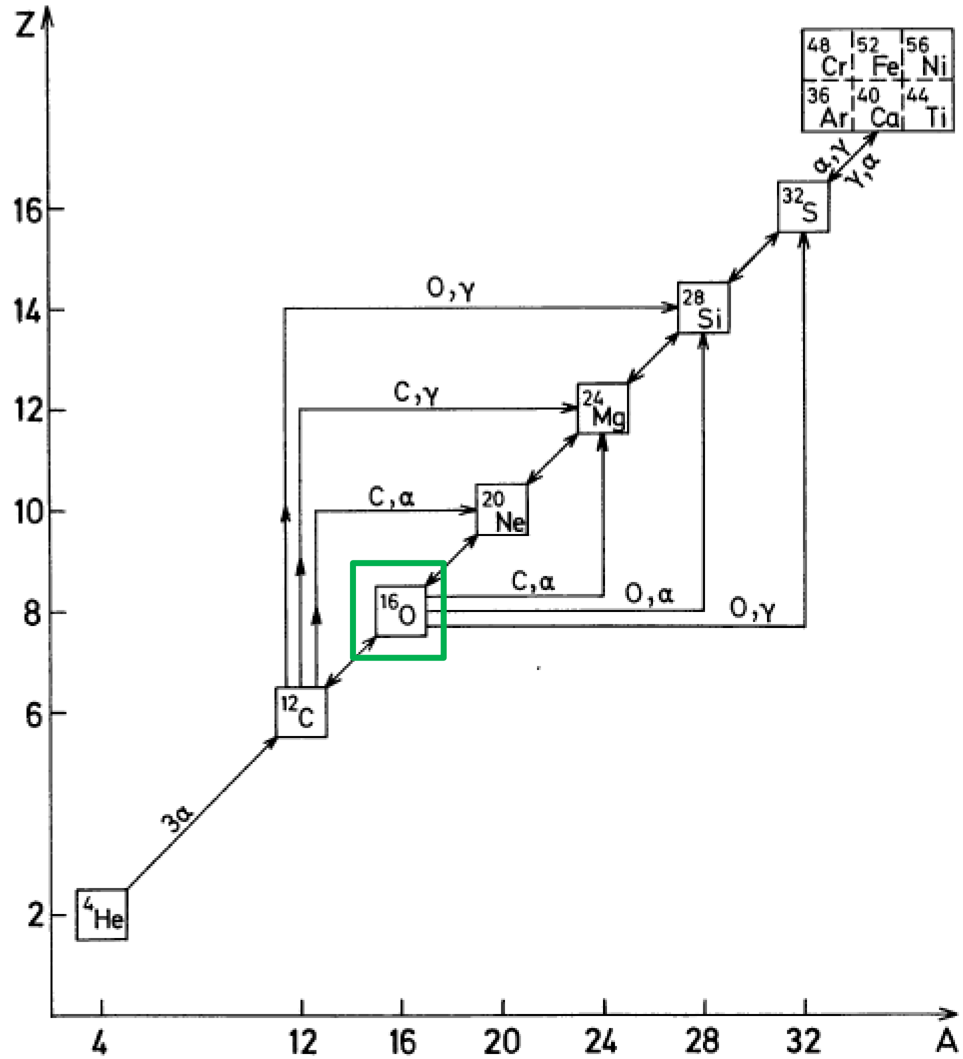
- Spherical symmetry
- Computation of the core only
- Polytrope with γ=4/3

  $P=K\rho^{\gamma}$

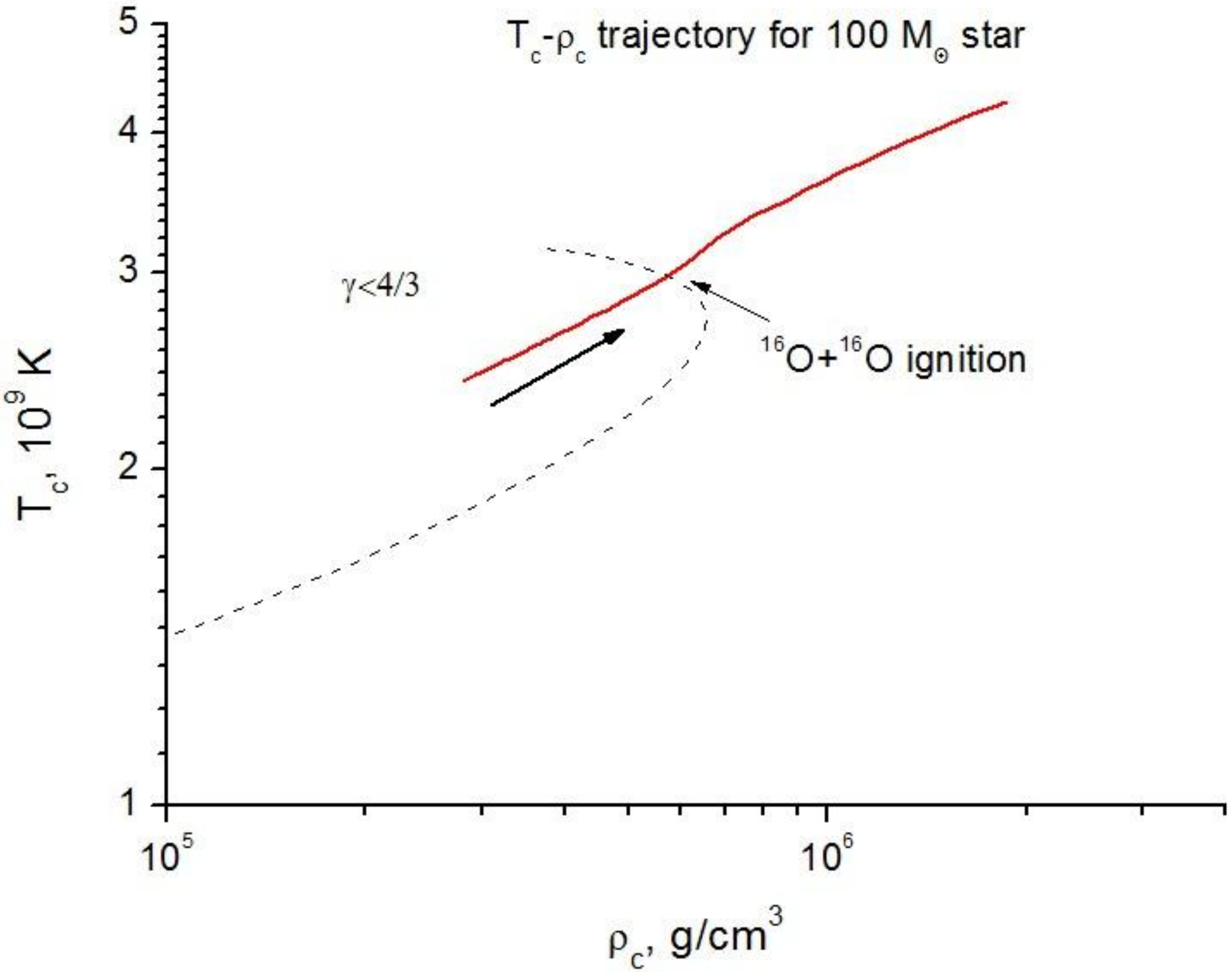
System of equations

$$
\begin{cases}
\partial r/\partial t & = v \\
\partial v/\partial t & = -Gm/r^2 - 4\pi r^2(\partial P/\partial m) \\
\partial T/\partial t & = (-4\pi \frac{\partial(r^2 v)}{\partial m} T(\partial P/\partial T)_\rho + \varepsilon_{nucl} - \varepsilon_\nu)/(\partial E/\partial \rho)_\rho \\
P(\rho, T, Y_i) & = EOS(\rho, T, Y_i) \\
... & \\
dY_j/dt & = Y_k Y_l \rho R_{jk,l} - Y_j Y_l \rho R_{jl,m} + Y_i \lambda_{i,j} - Y_j \lambda_{j,k} \\
... &
\end{cases}
$$

Nuclear reactions

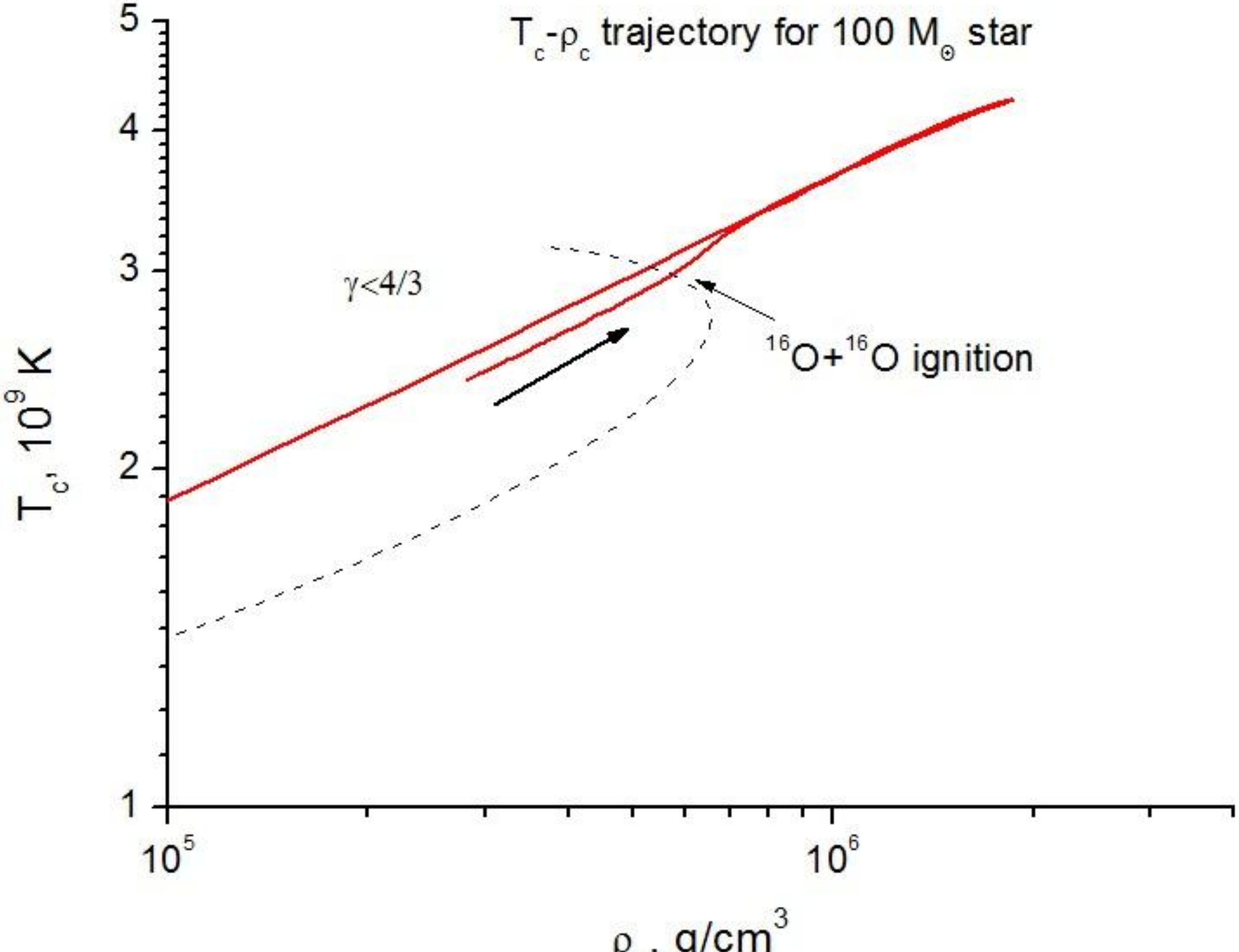


Results



T_c-ρ_c trajectory for 100 $M_\odot$ star
5
4
3
2
1
γ<4/3
$^{16}O+^{16}O$ ignition
T_c, 10^9 K
10^5
10^6
ρ_c, g/cm^3

Results



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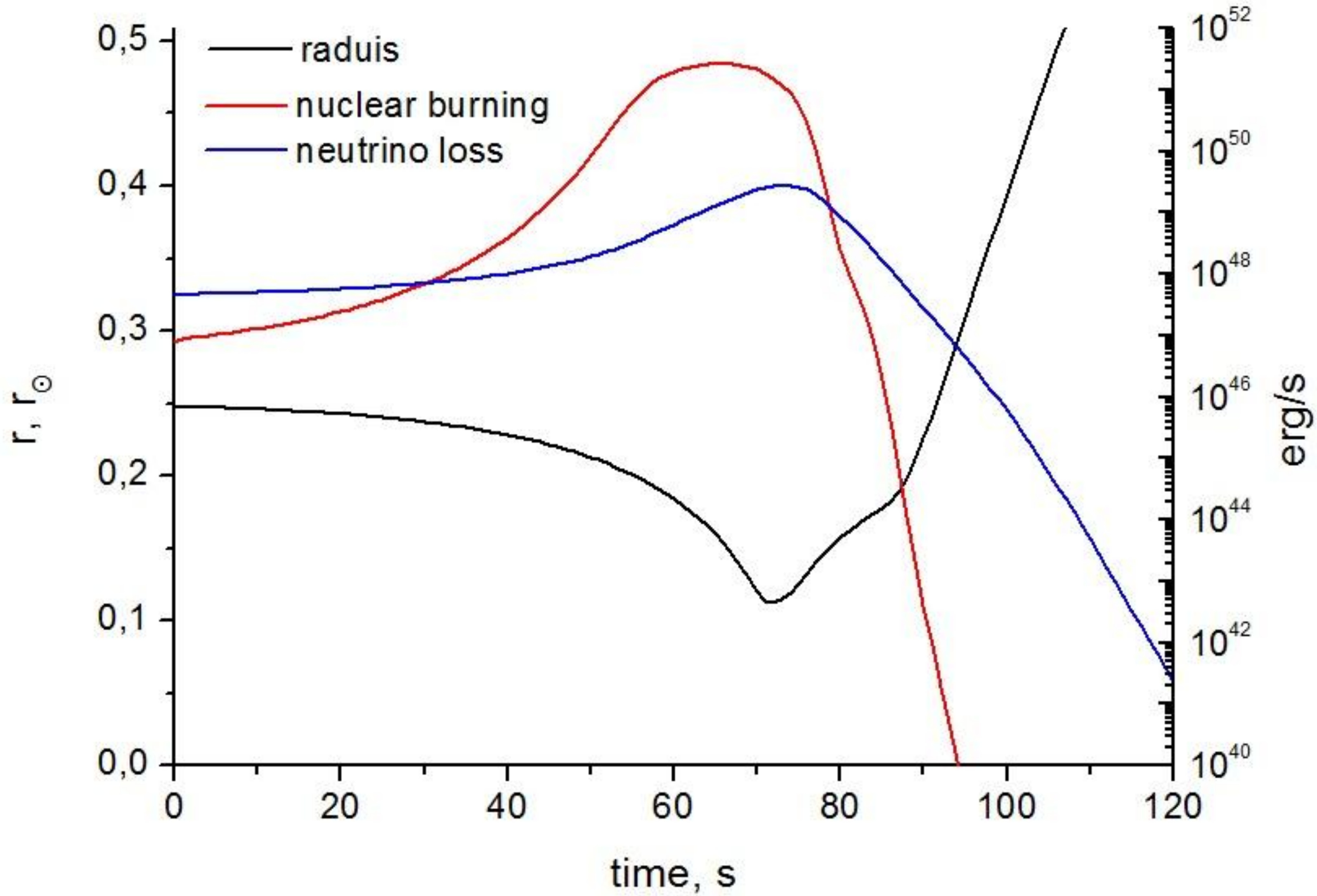
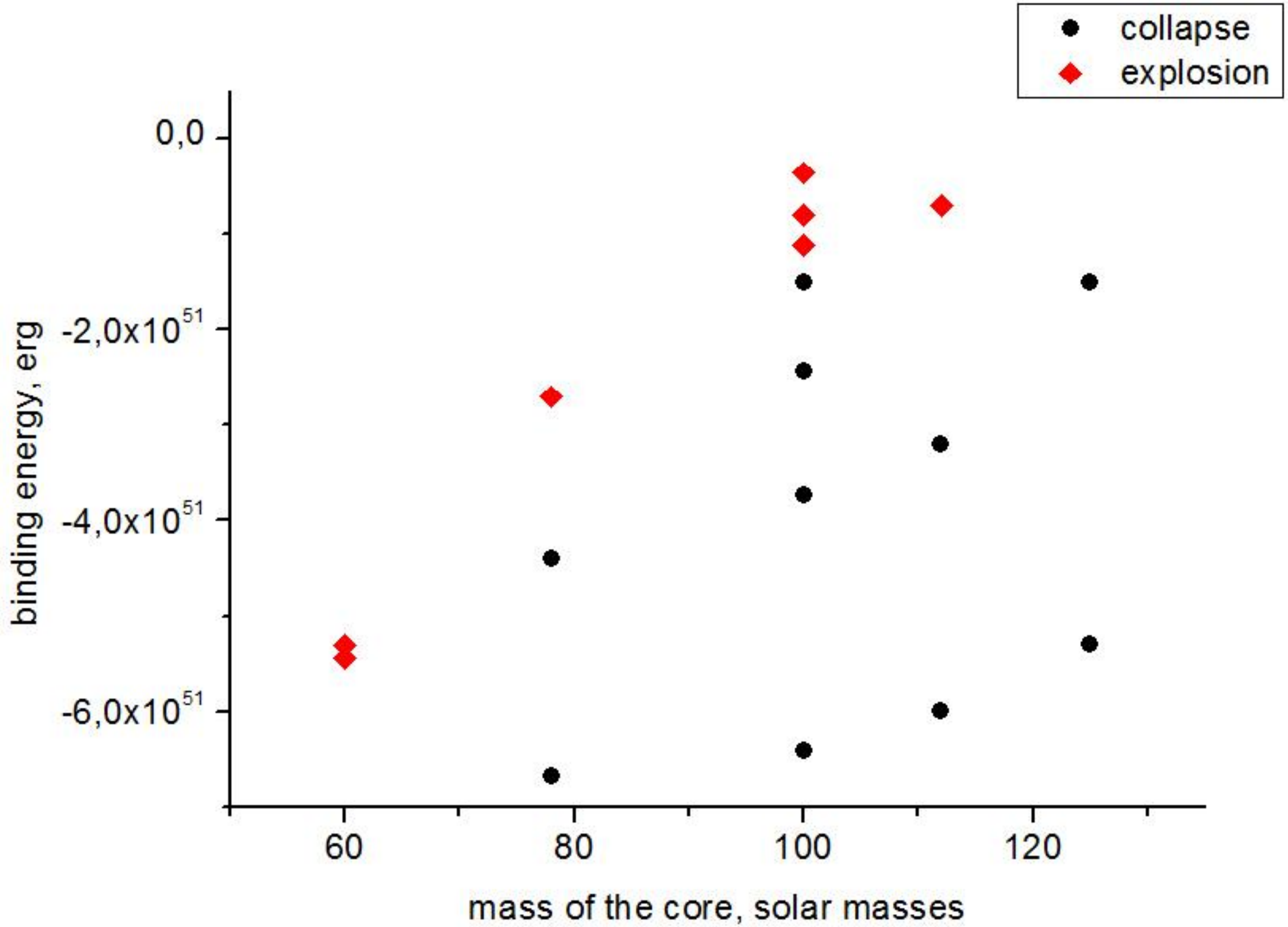


raduis
nuclear burning
neutrino loss
0,0
0,1
0,2
0,3
0,4
0,5
r, r⊙
0
20
40
60
80
100
120
time, s
10^40
10^42
10^44
10^46
10^48
10^50
10^52
erg/s

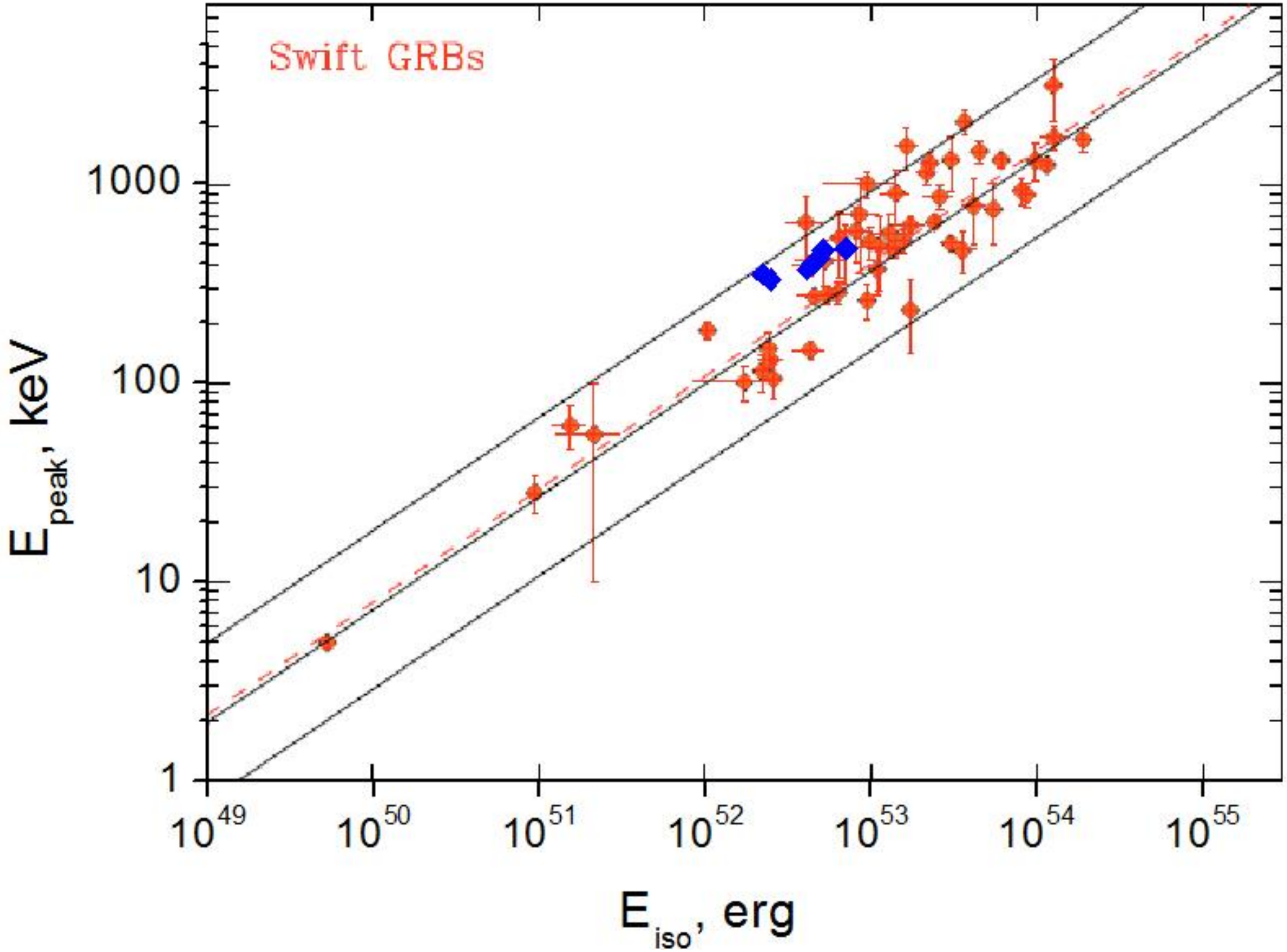
Collapse vs explosion



Results

$M/M_\odot$	$\rho_c, g/cc$	T_{max}, keV	$E_{nuc}, 10^{52}$ ergs
60	$1.15 \cdot 10^5$	351	2.23
78	$3.0 \cdot 10^5$	330	2.46
100	$2.65 \cdot 10^5$	371	4.12
100	$2.5 \cdot 10^5$	421	4.80
100	$2.4 \cdot 10^5$	463	5.11
112	$2.0 \cdot 10^5$	470	7.06

On a physical interpretation of the Amati Relation



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

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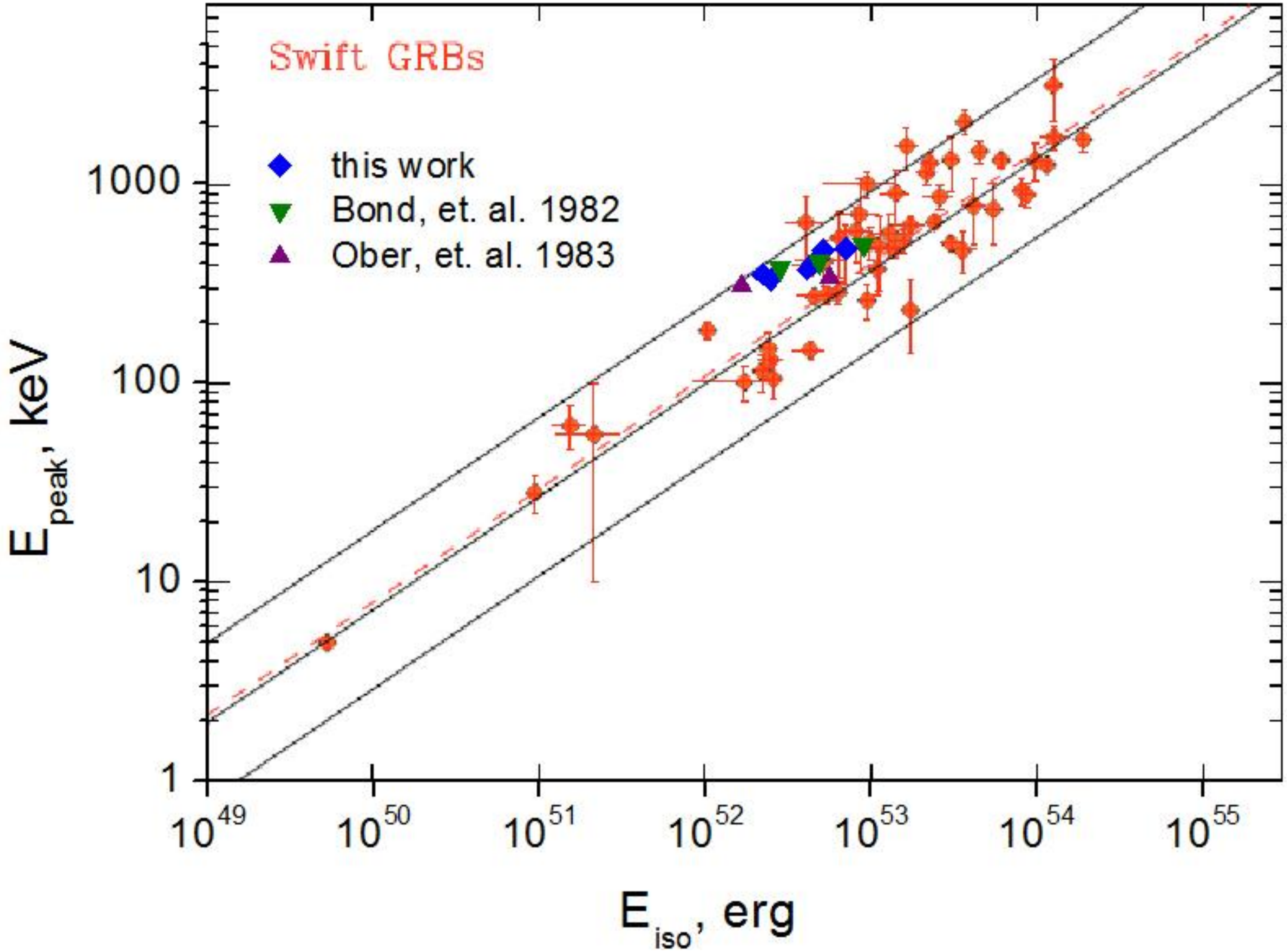

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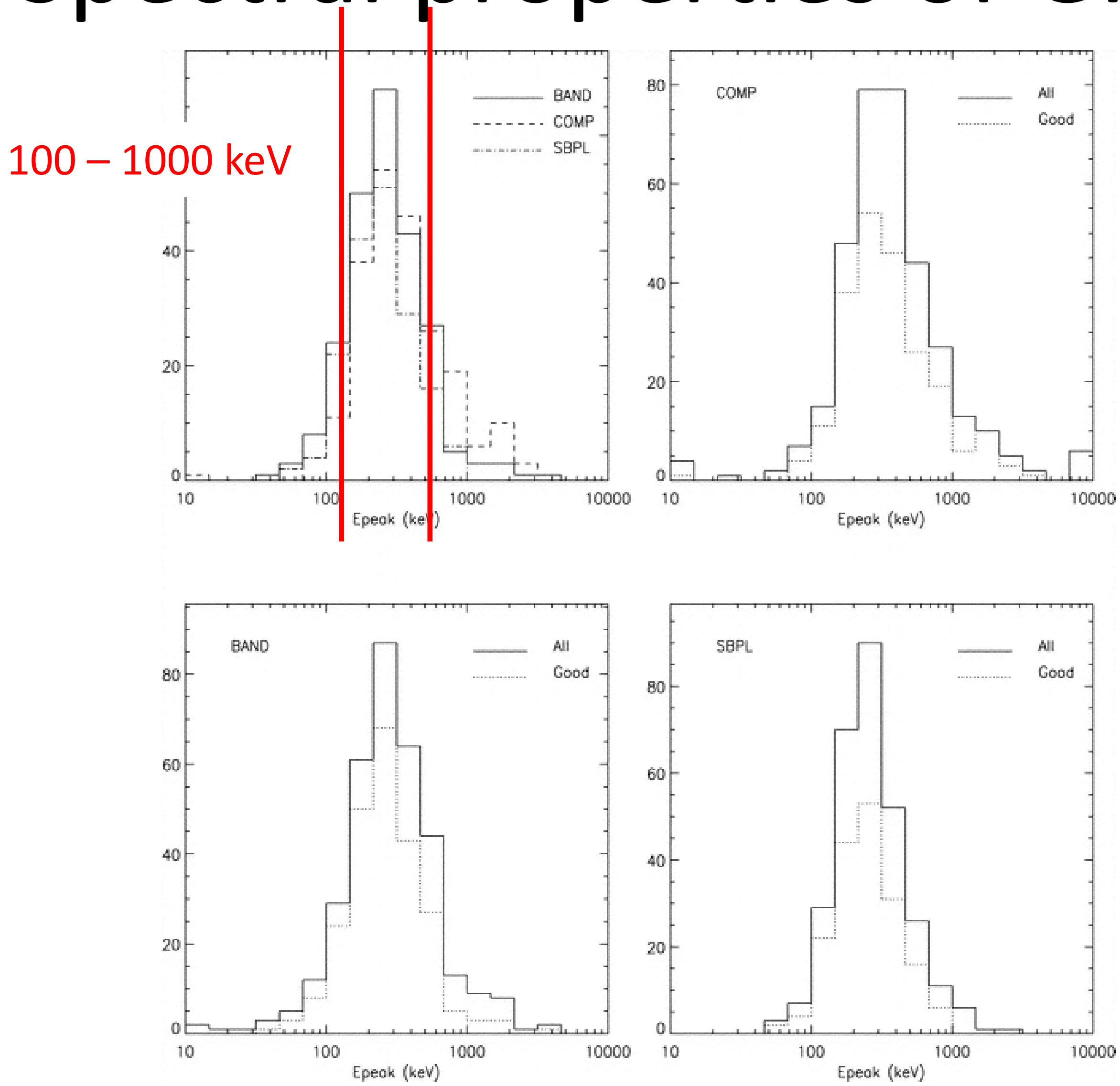
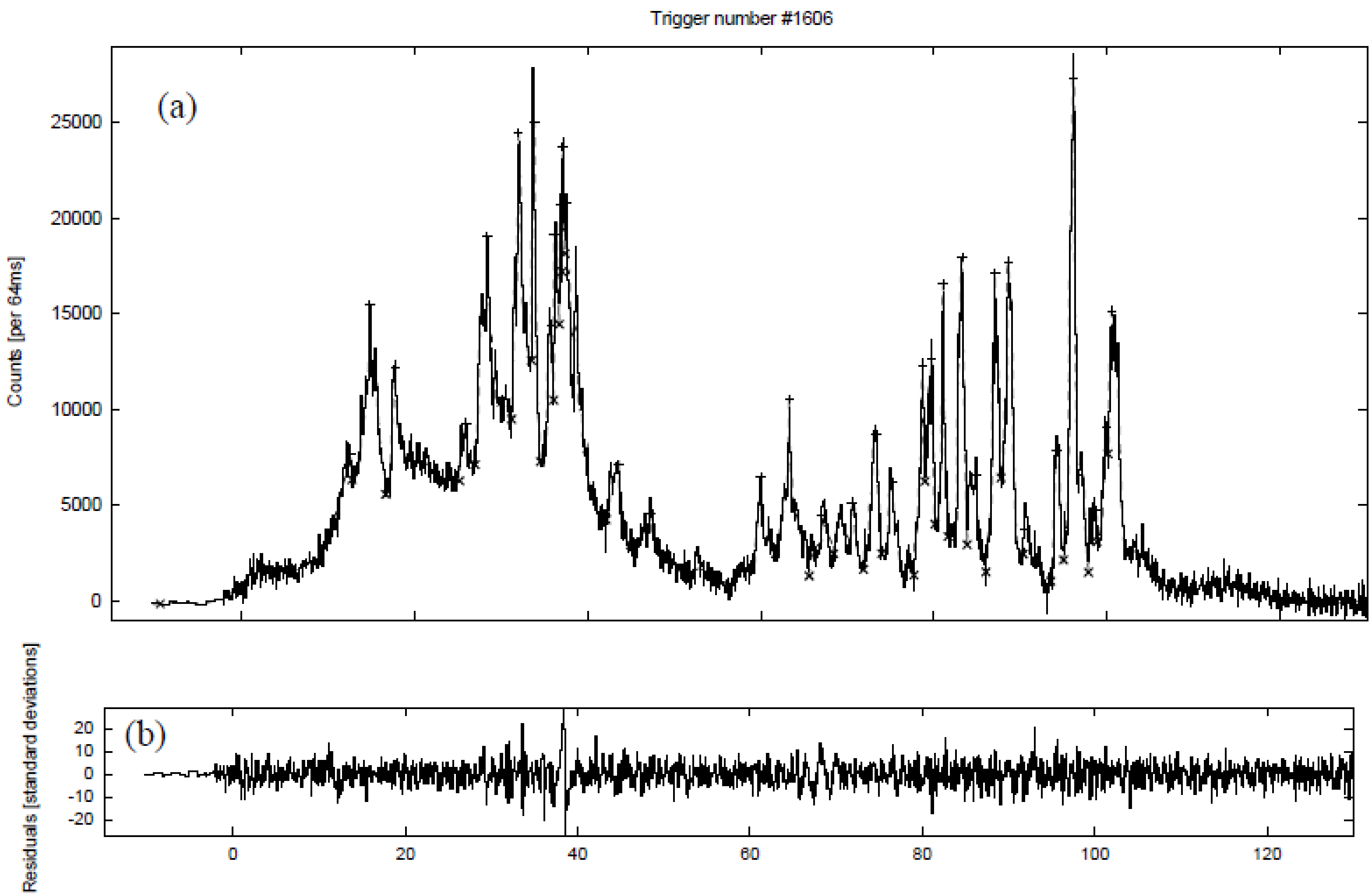
Spectral properties of GRBs



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

Temporal properties of GRBs



[F. Quilligan et al. A&A (2002)]

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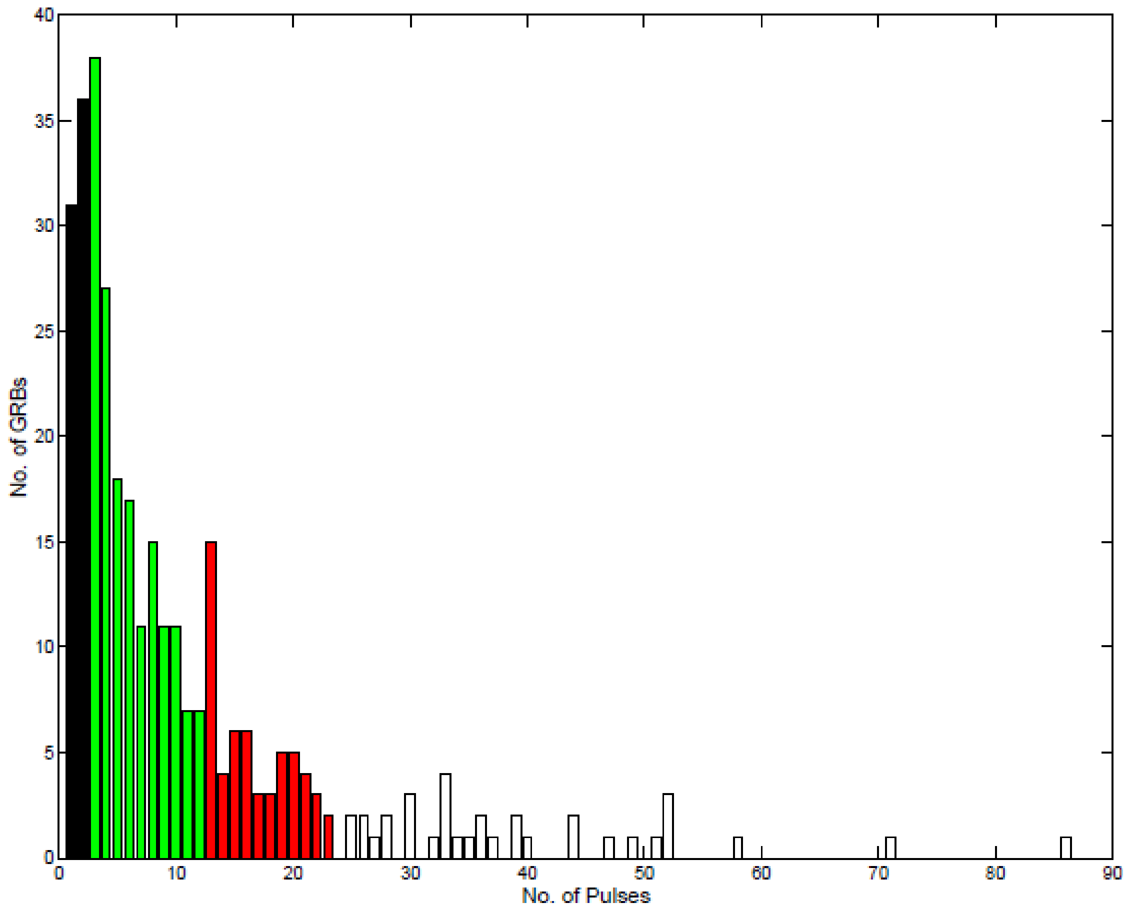

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GRB-SN ratio

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- Using Salpeter's function $dN \propto M^{-2.35}dM$, a typical mass of GRB progenitor $\sim 200M_{\odot}$, and $\sim 20M_{\odot}$ for the SN, one can obtain that the GRB-SNe ratio is about 0.4% [Chardonnet et al. 2009]

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Conclusions

- New scenario of GRBs is proposed. Explosive phenomena different from core-collapse SN
- 1D simulations: 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 for your attention!

Acknowledgments:
Chechetkin V., Filina A., Popov M.