Pair-instability supernovae and Gamma-ray bursts

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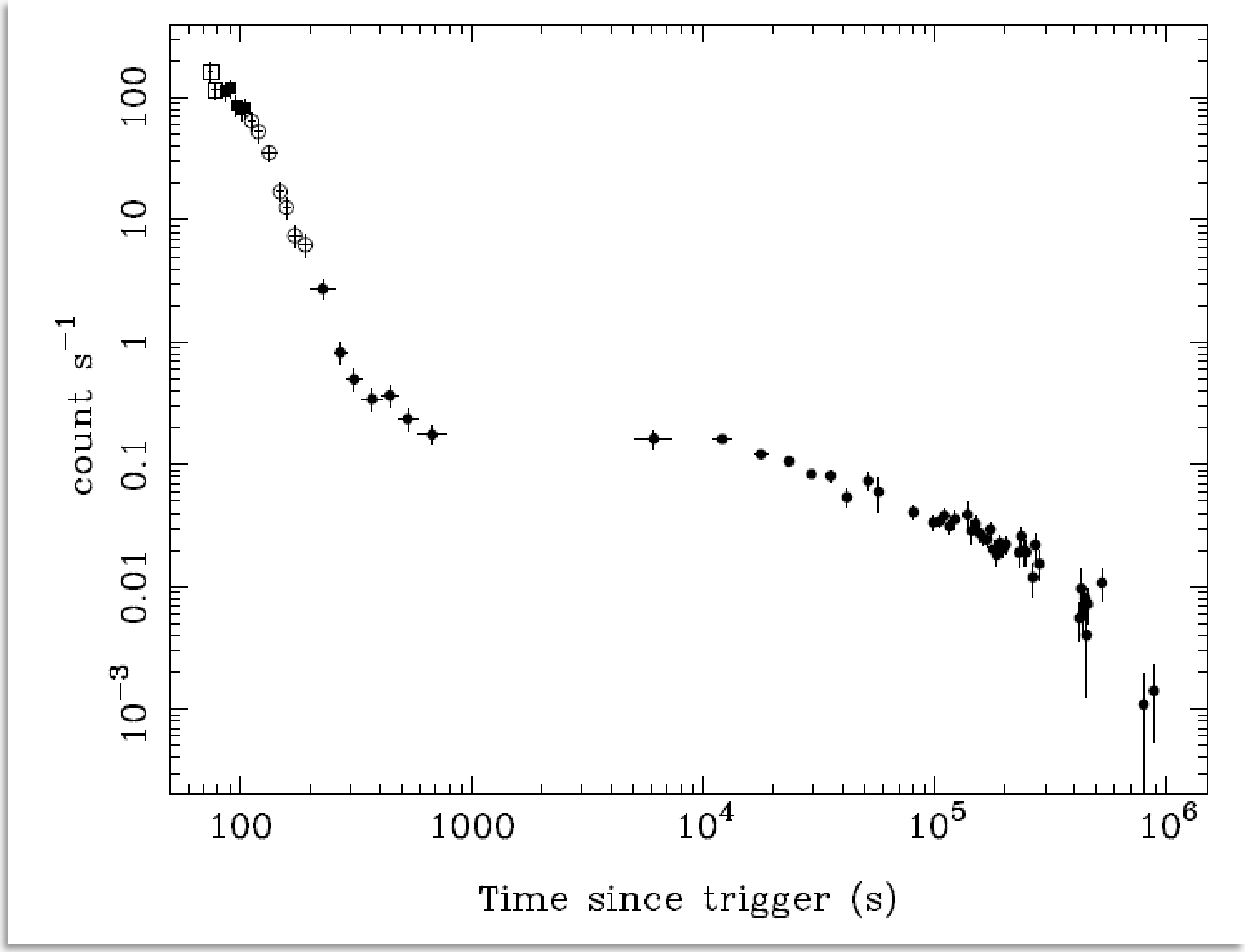
GRB

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

GRB



[S. Vaughan et al. (2006)]

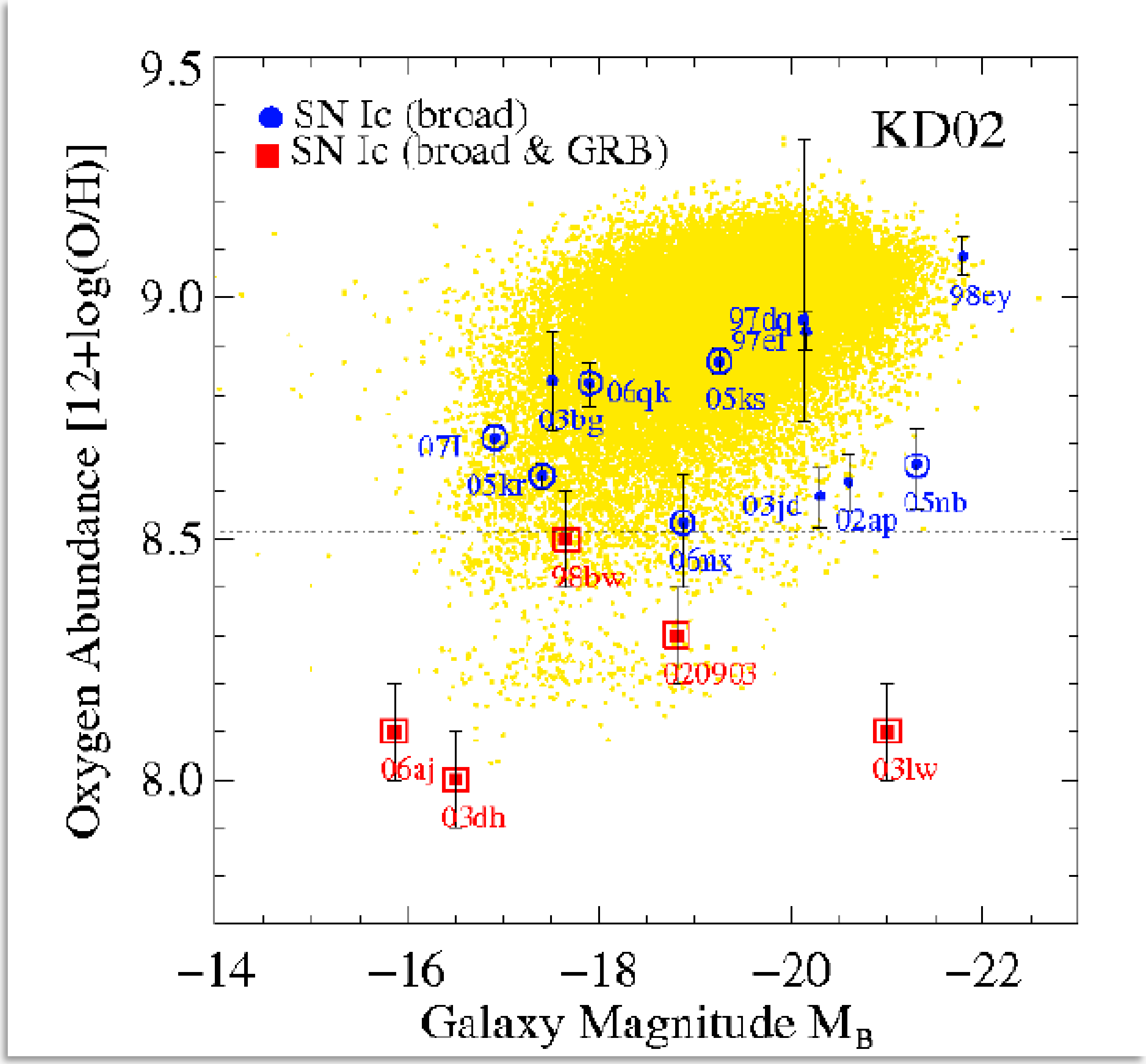
GRB-SN connection

- 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]

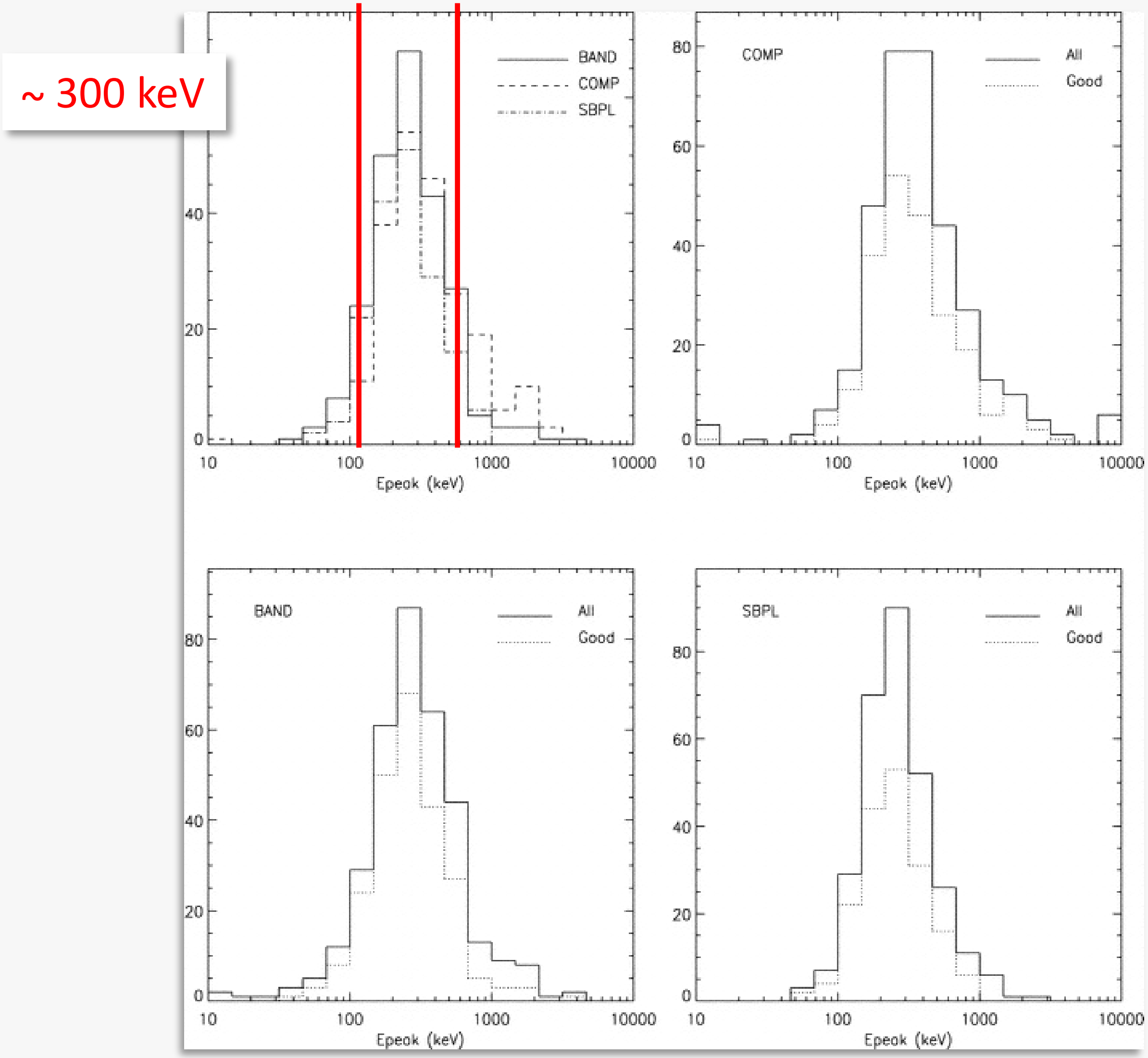
Specific environment of GRBs

- 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

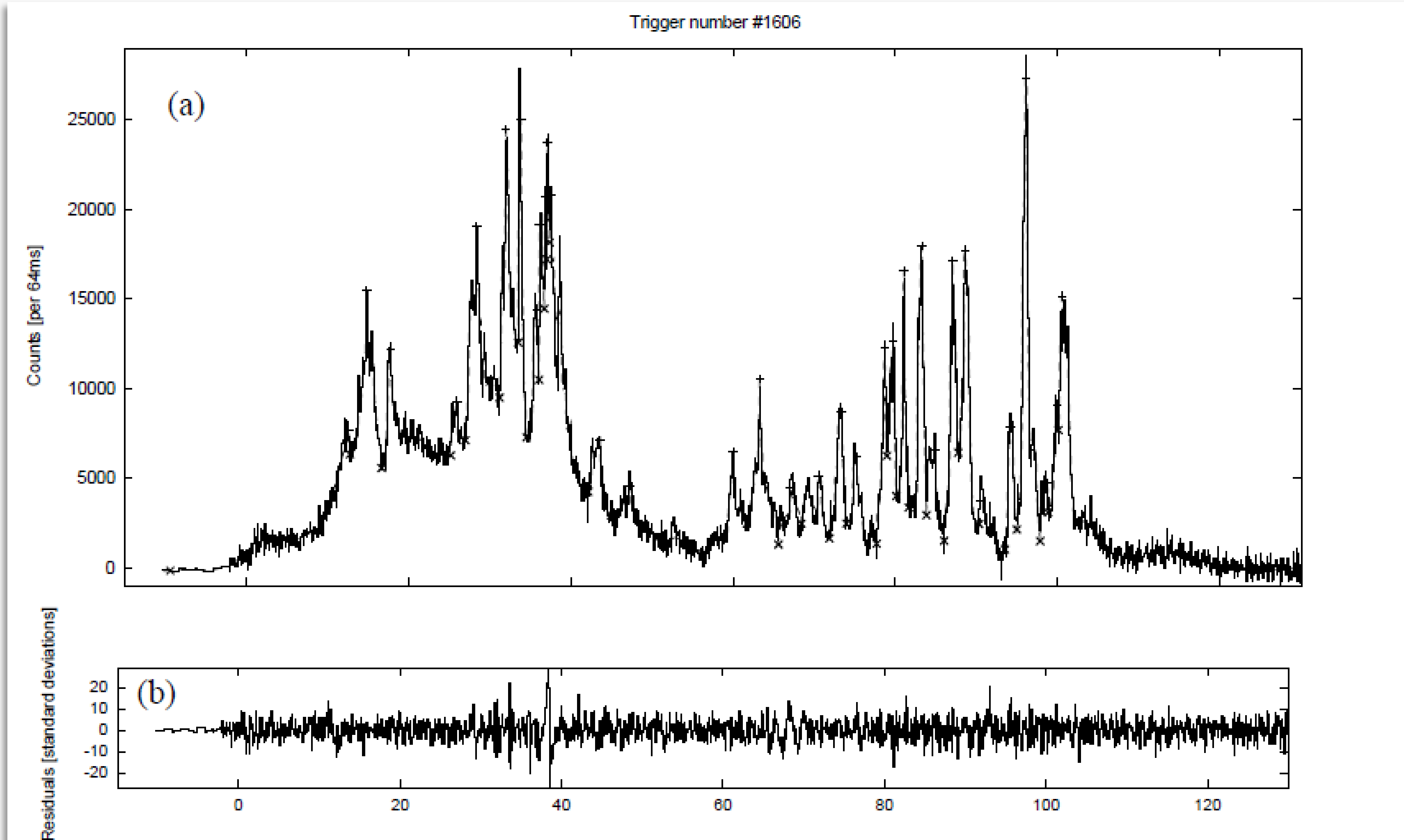


Spectral properties of GRBs



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

Temporal properties of GRBs



[F. Quilligan et al. (2002)]

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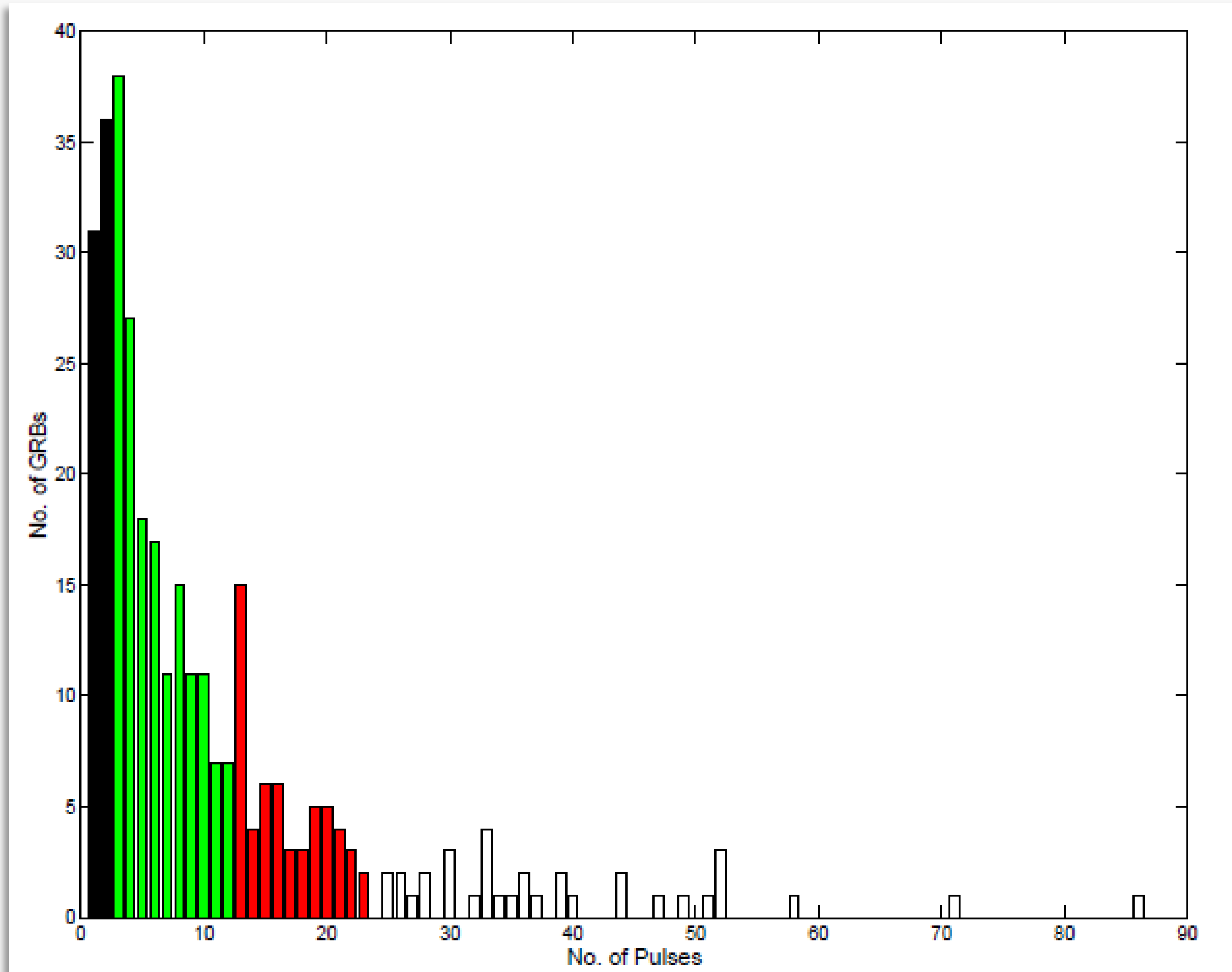

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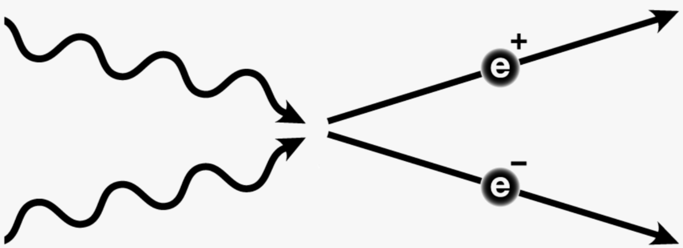
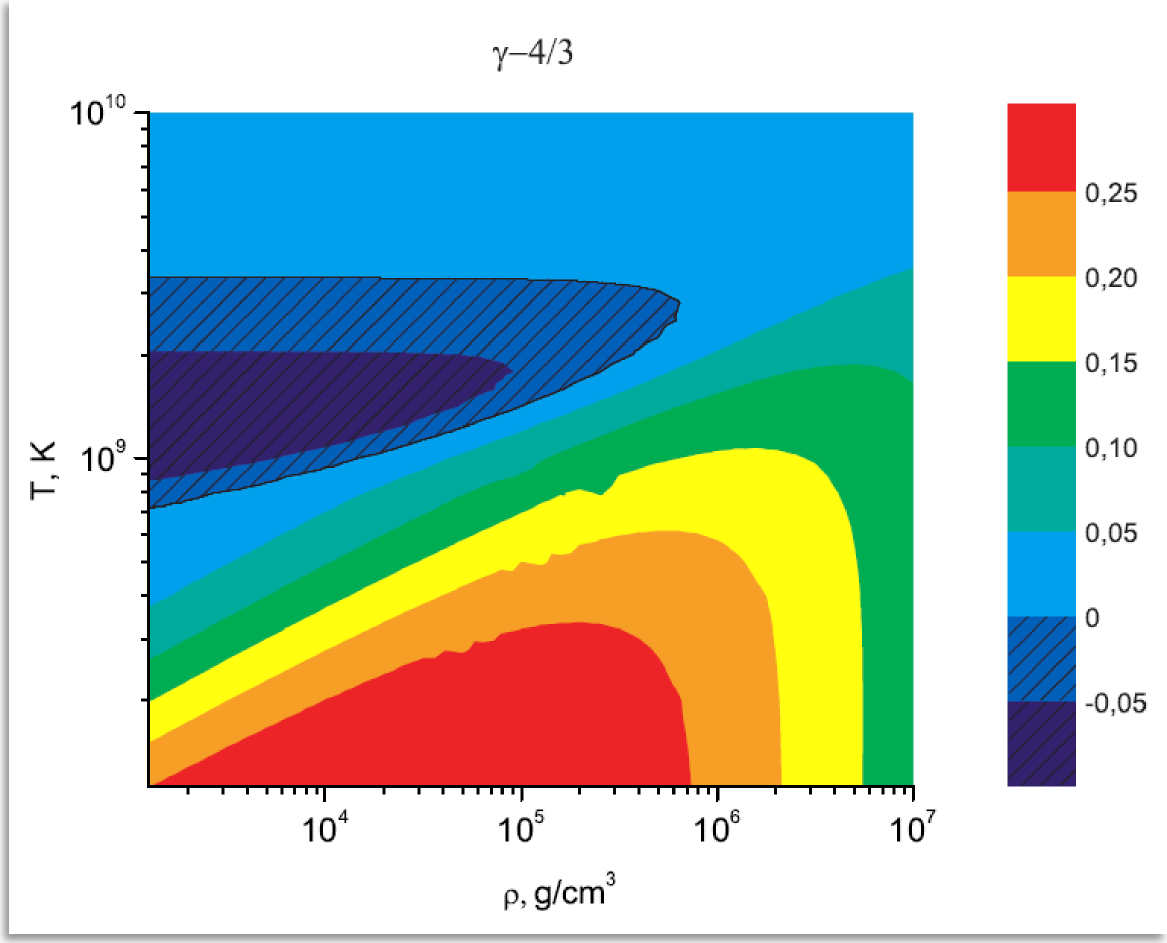
Pair-instability SN as possible candidate

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

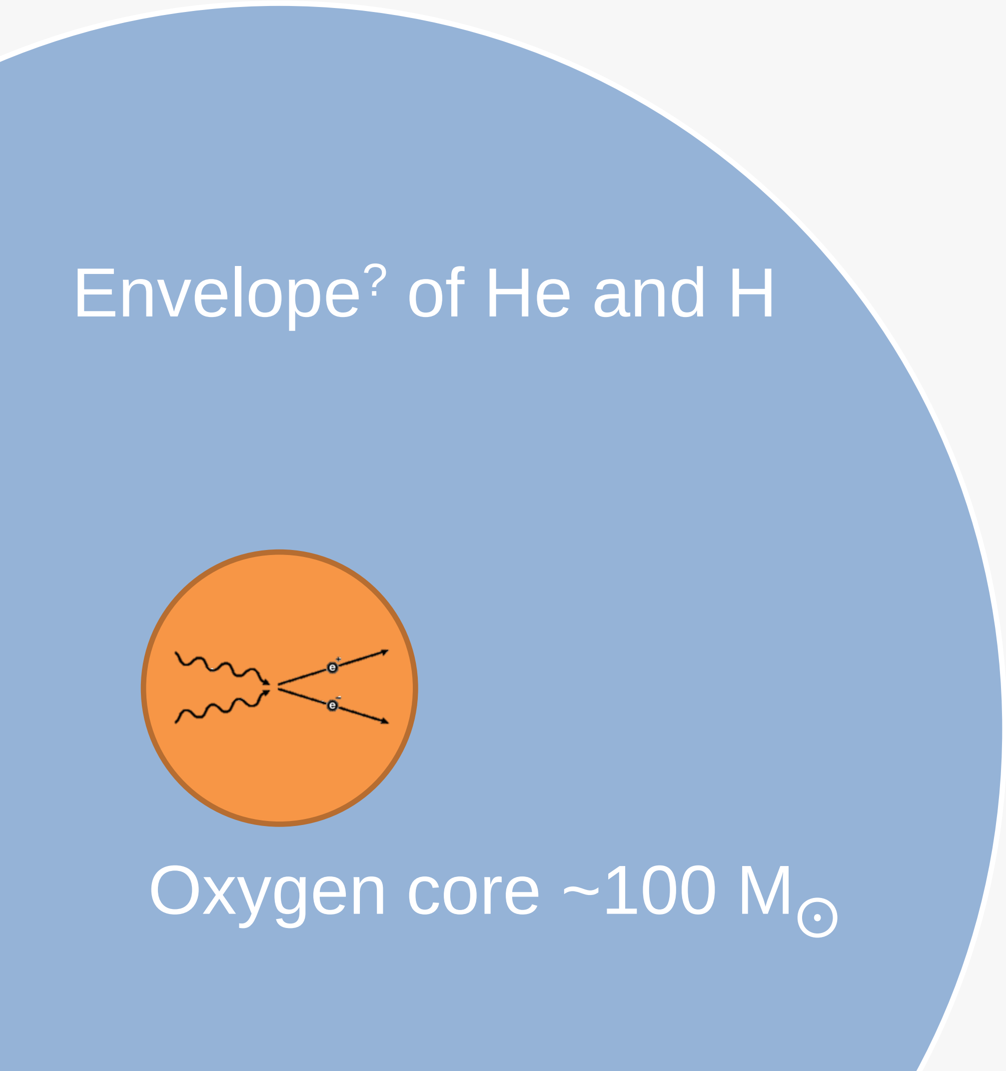
- Explosive process different from core-collapse SN
- Low metallicity environment
- Energy budget is about 10^{53} ergs

Pair-instability SN





Numerical simulations



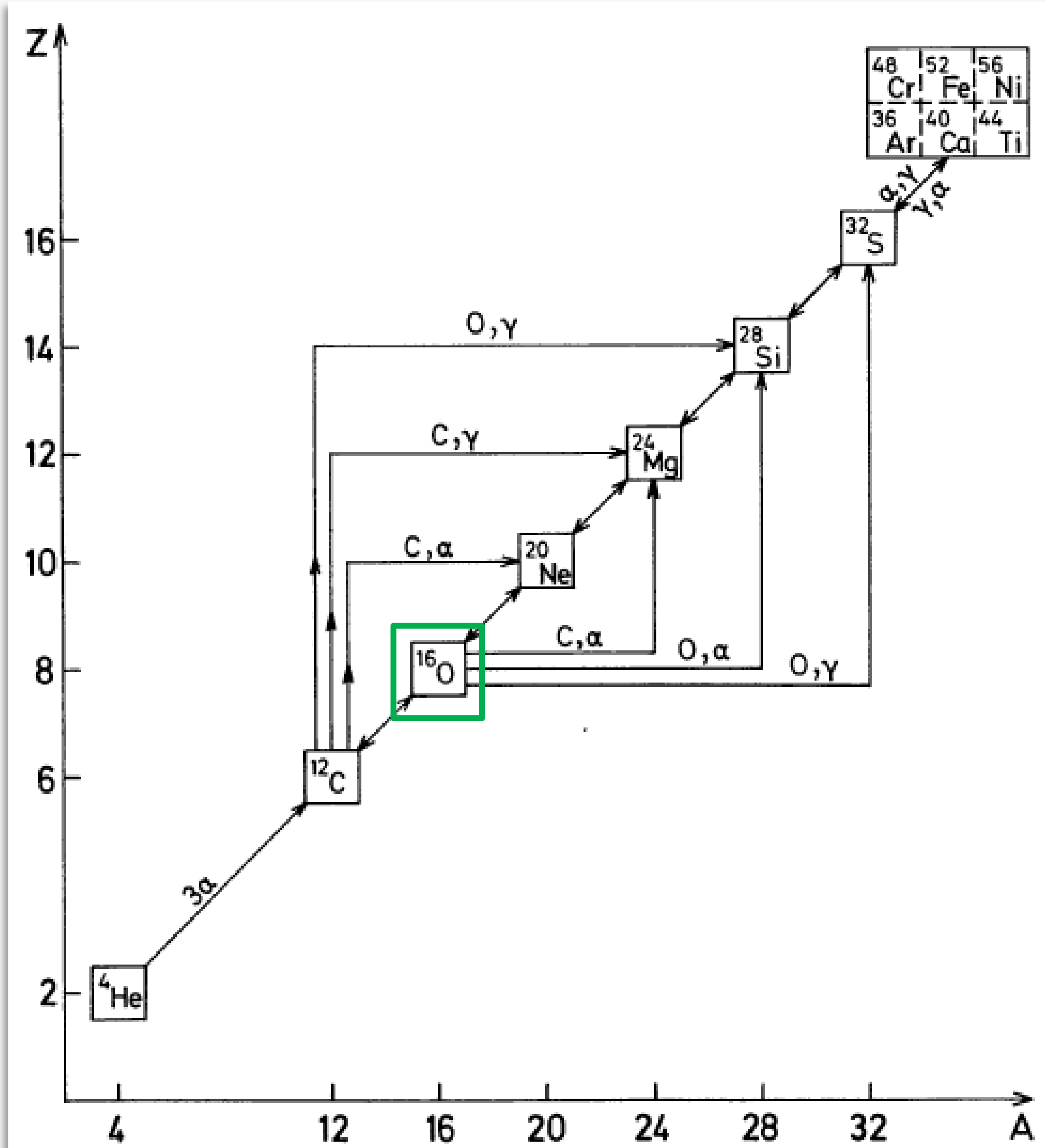
- Spherical symmetry
- Computation of the core only
- Polytrope with γ=4/3

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

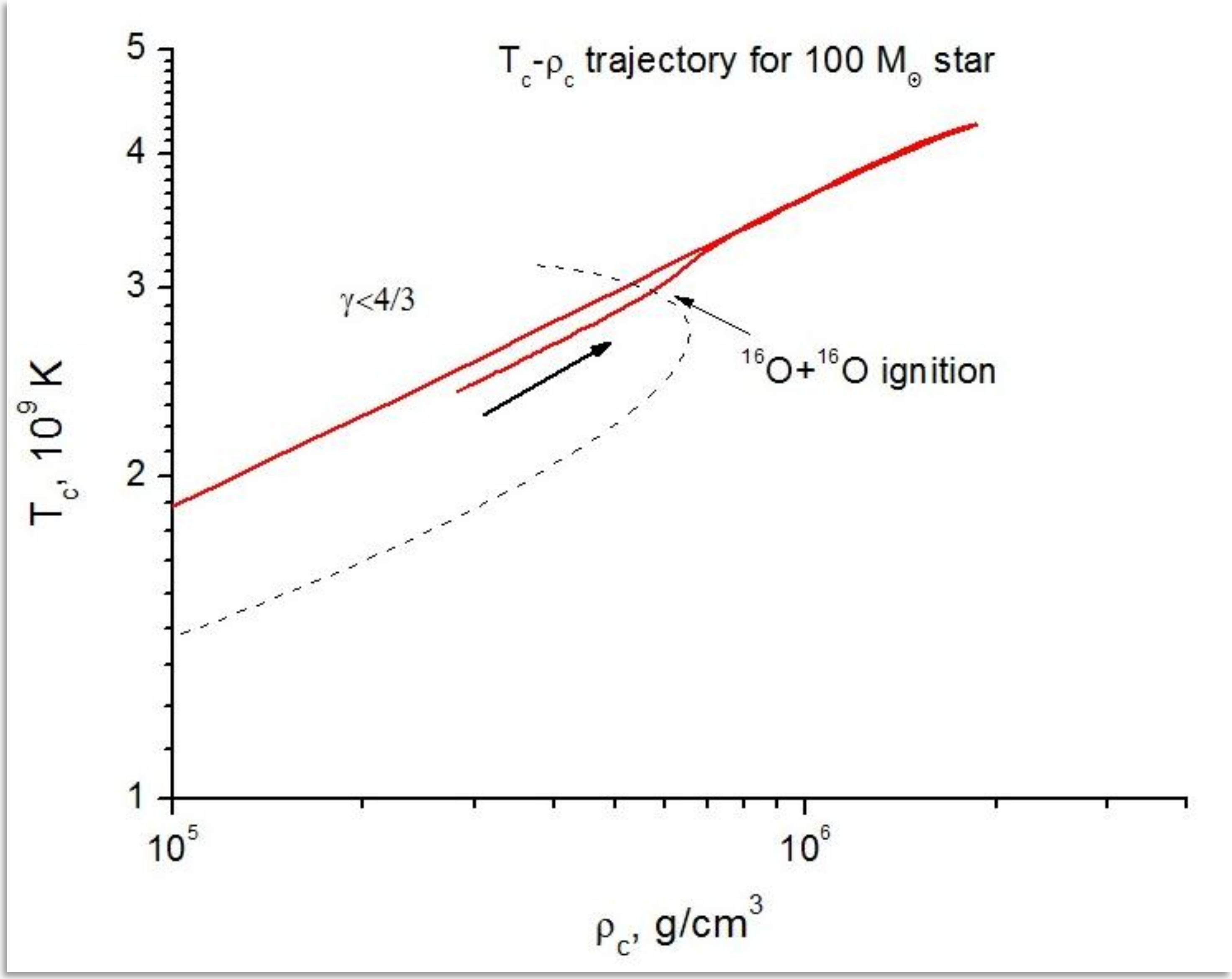
System of equations

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

Nuclear reactions



Results



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

Results

$M/M_\odot$	$\rho_c, 10^5 g/cc$	T_{max}, keV	$E_{nucl}, 10^{52}$ ergs	fate
60	0.87	352	2.23	explosion
60	1.15	351	2.25	explosion
78	0.60	—	—	collapse
78	2.00	—	—	collapse
78	3.00	330	2.46	explosion
100	1.00	—	—	collapse
100	1.65	—	—	collapse
100	2.00	—	—	collapse
100	2.25	—	—	collapse
100	2.40	463	5.11	explosion
100	2.50	421	4.80	explosion
100	2.65	371	4.12	explosion
112	1.00	—	—	collapse
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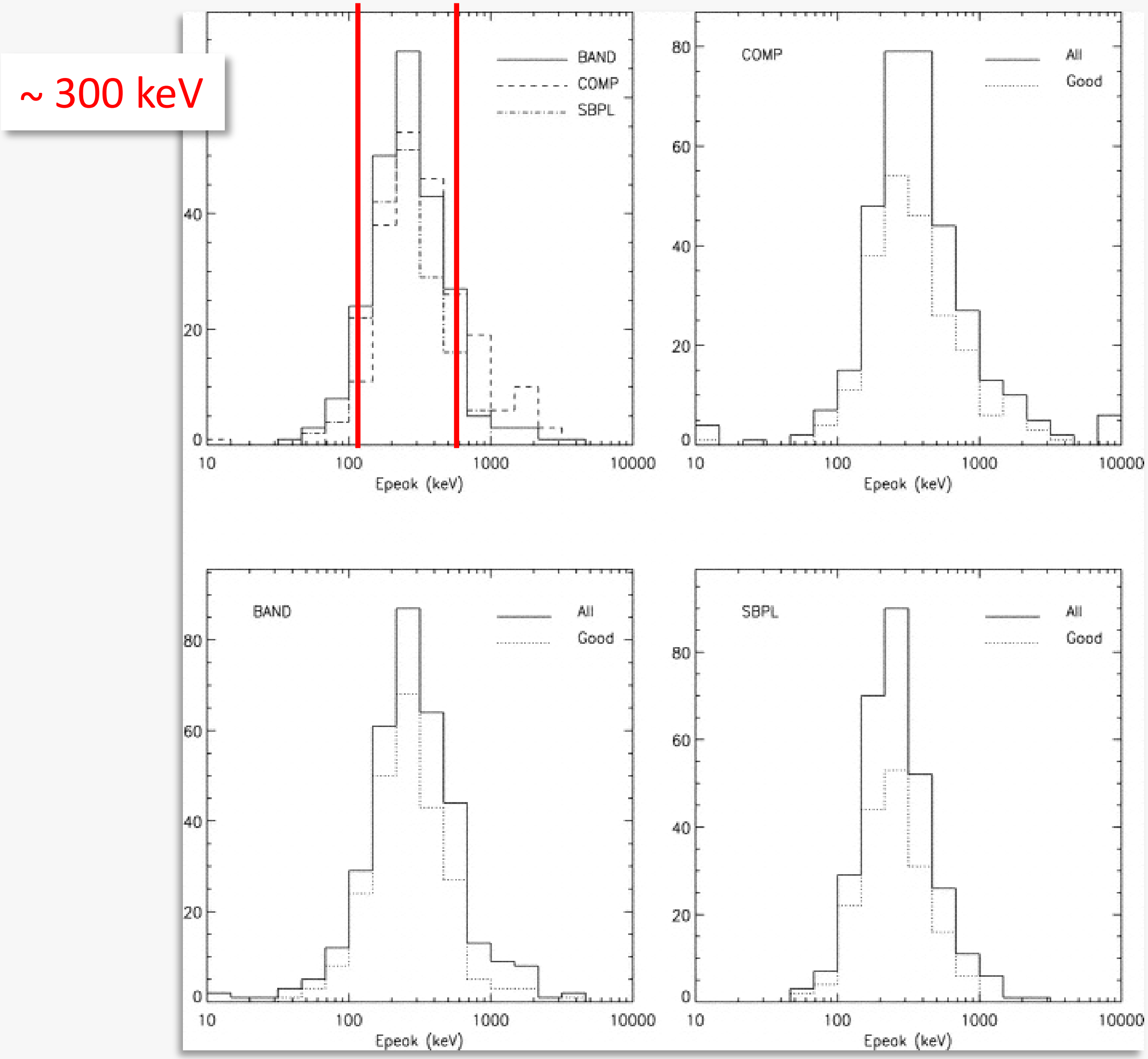
Spectral properties of GRBs



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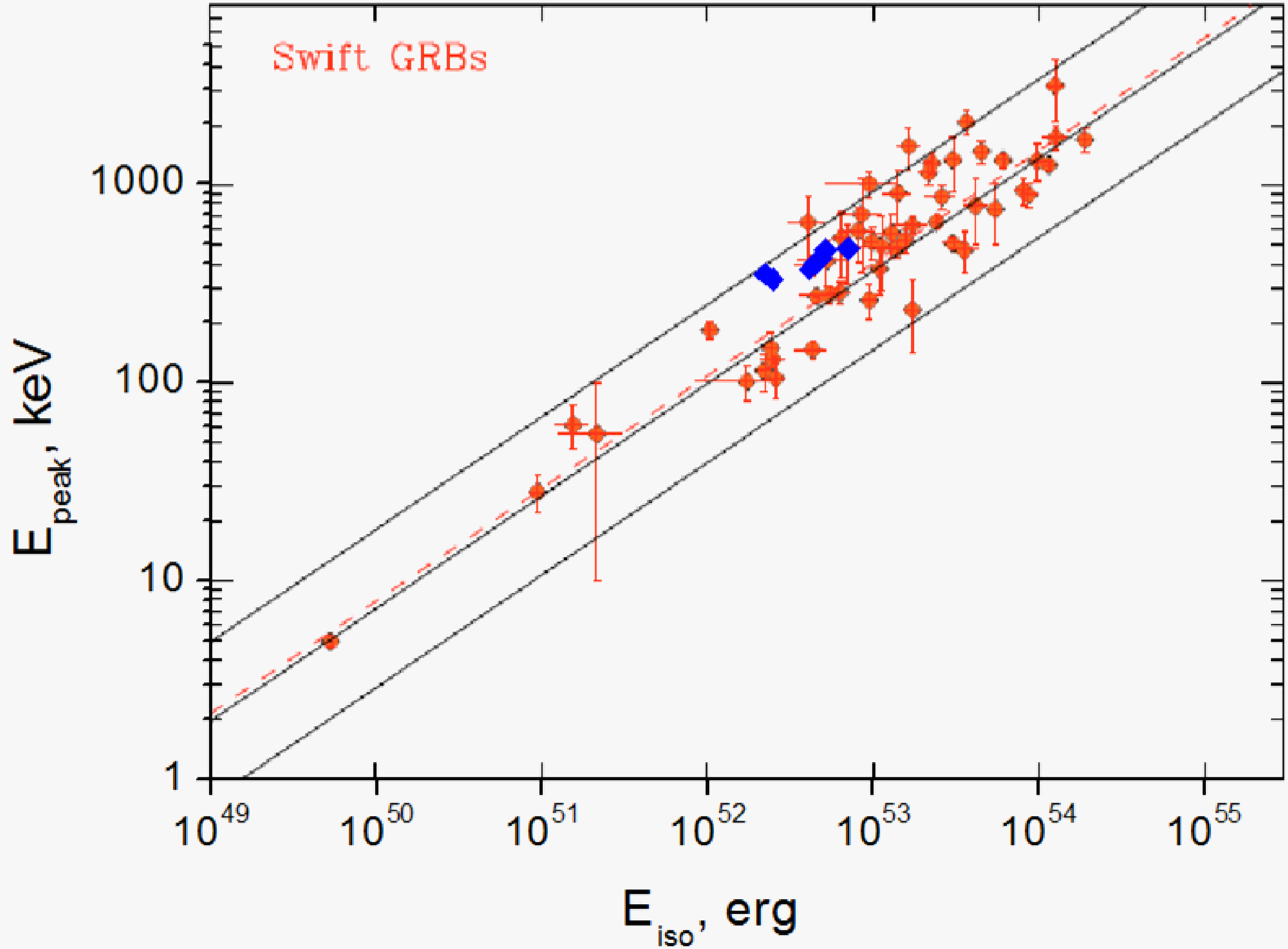
On a physical interpretation of the Amati Relation



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

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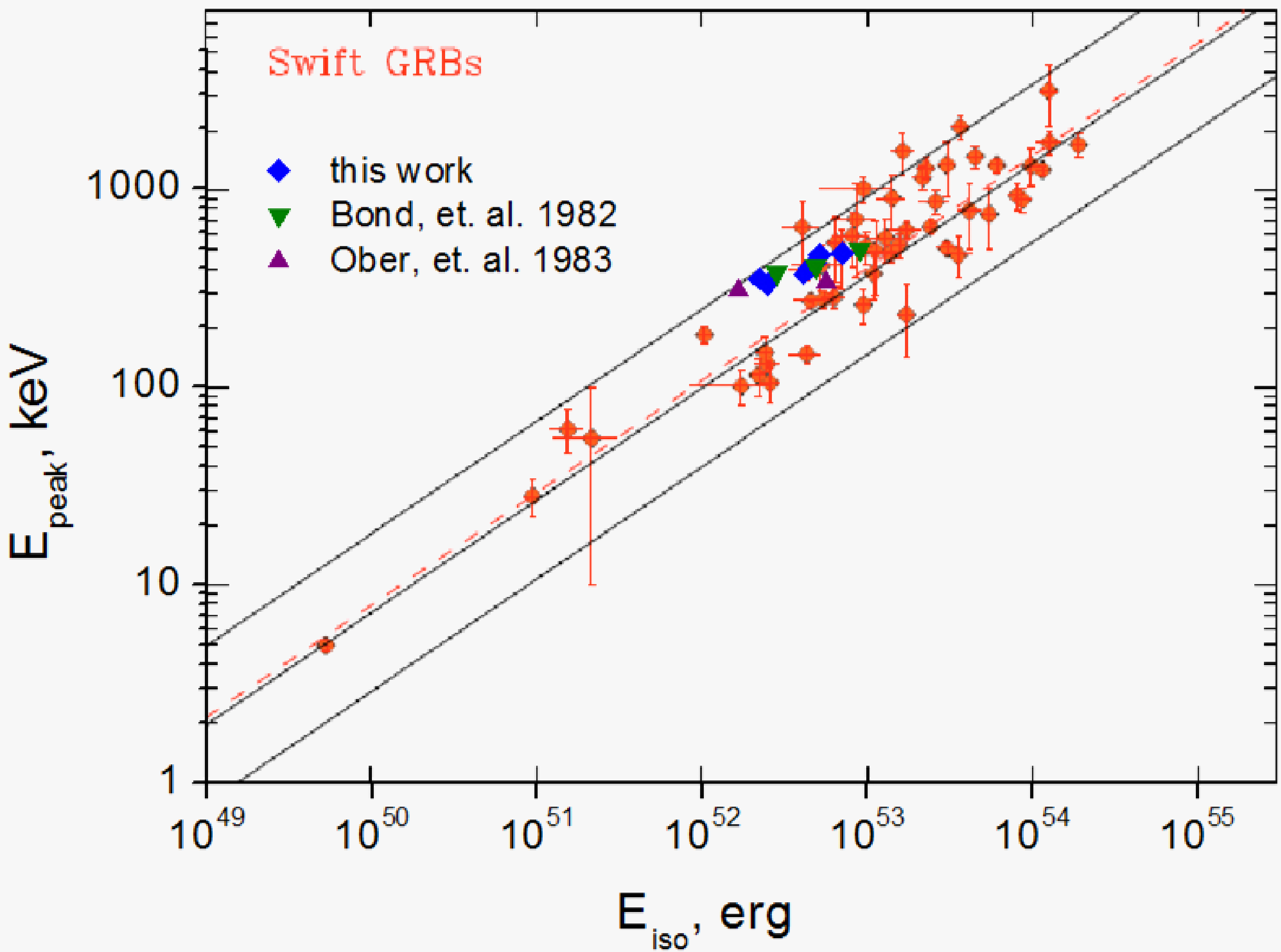

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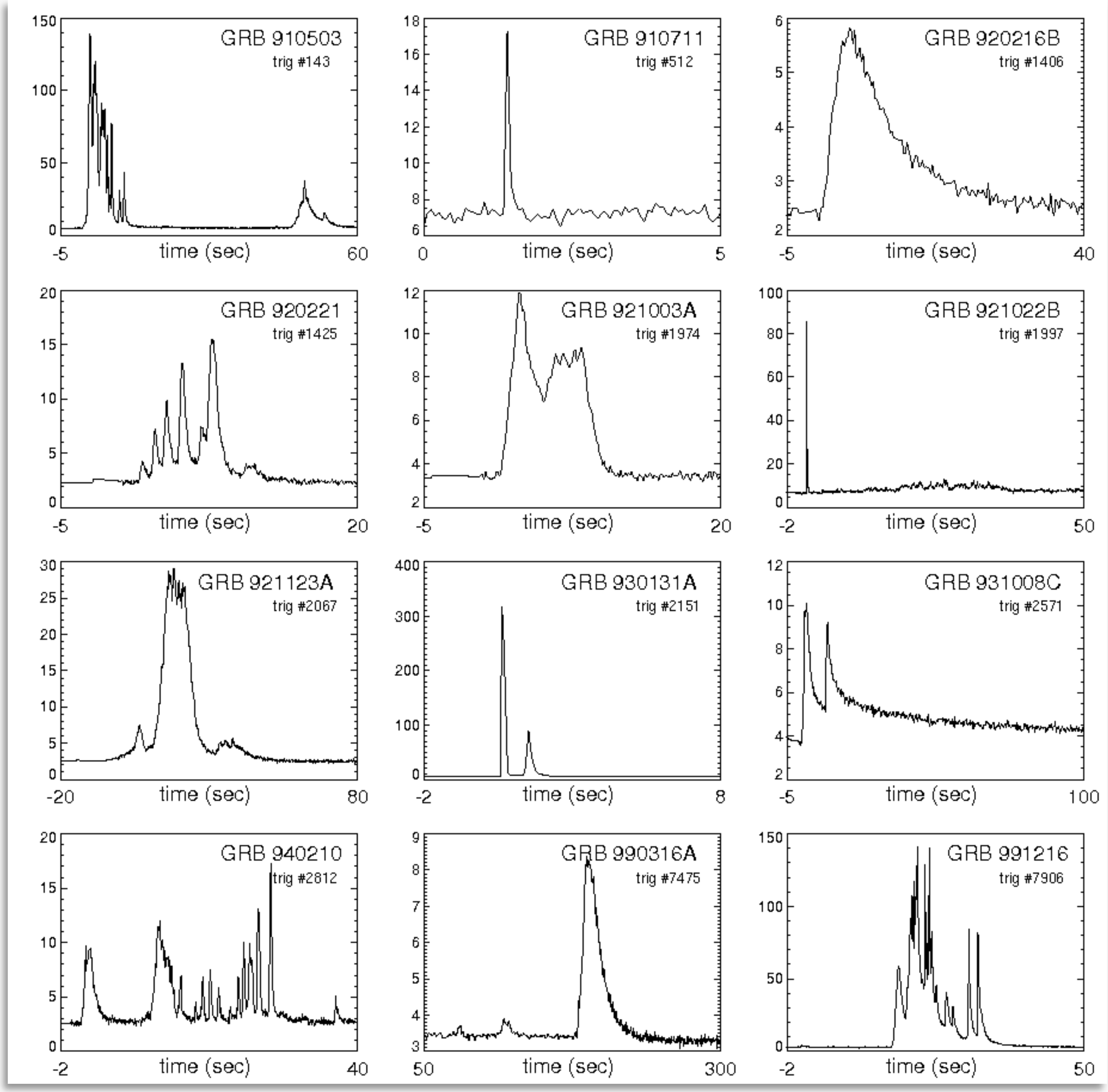
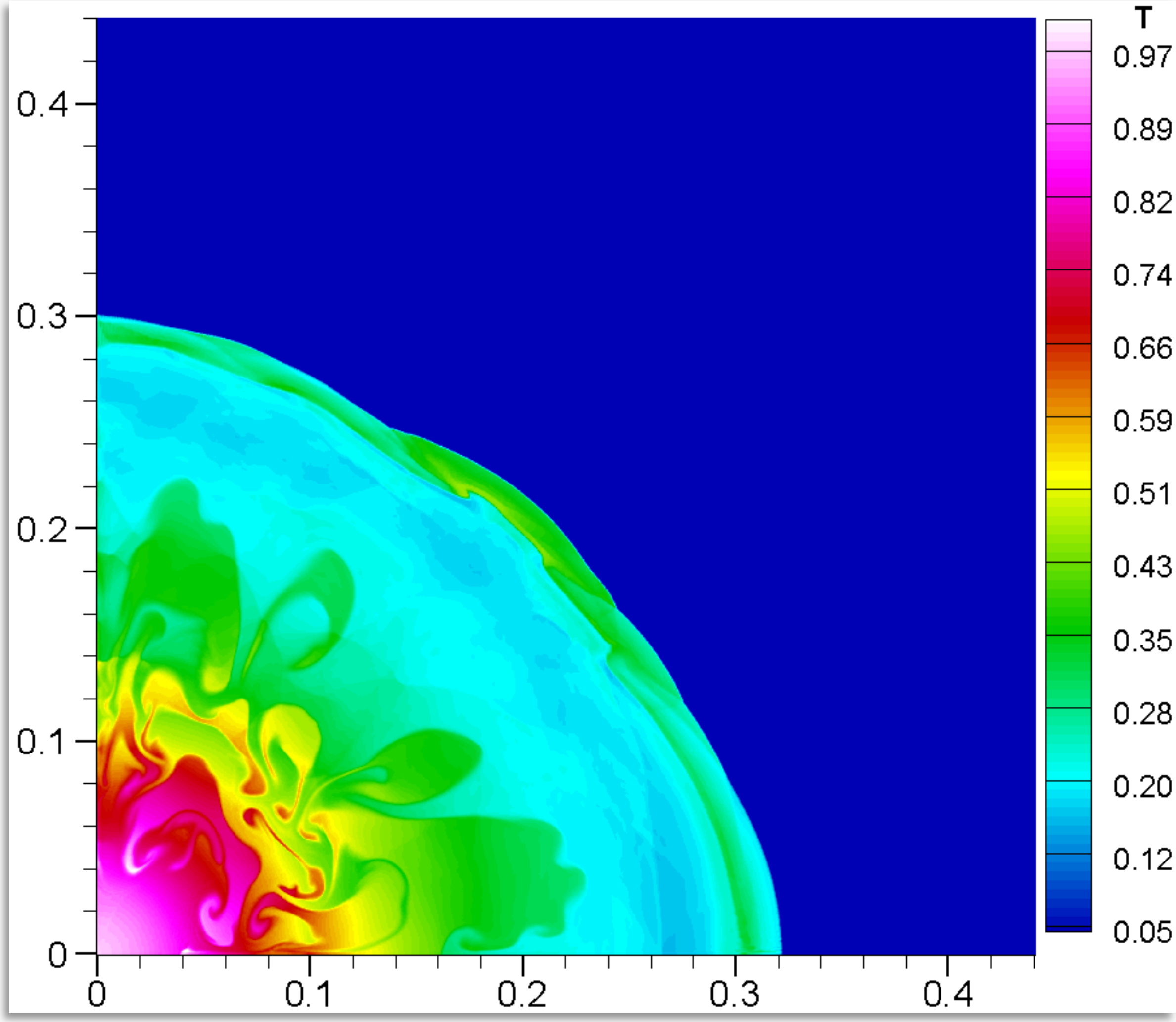
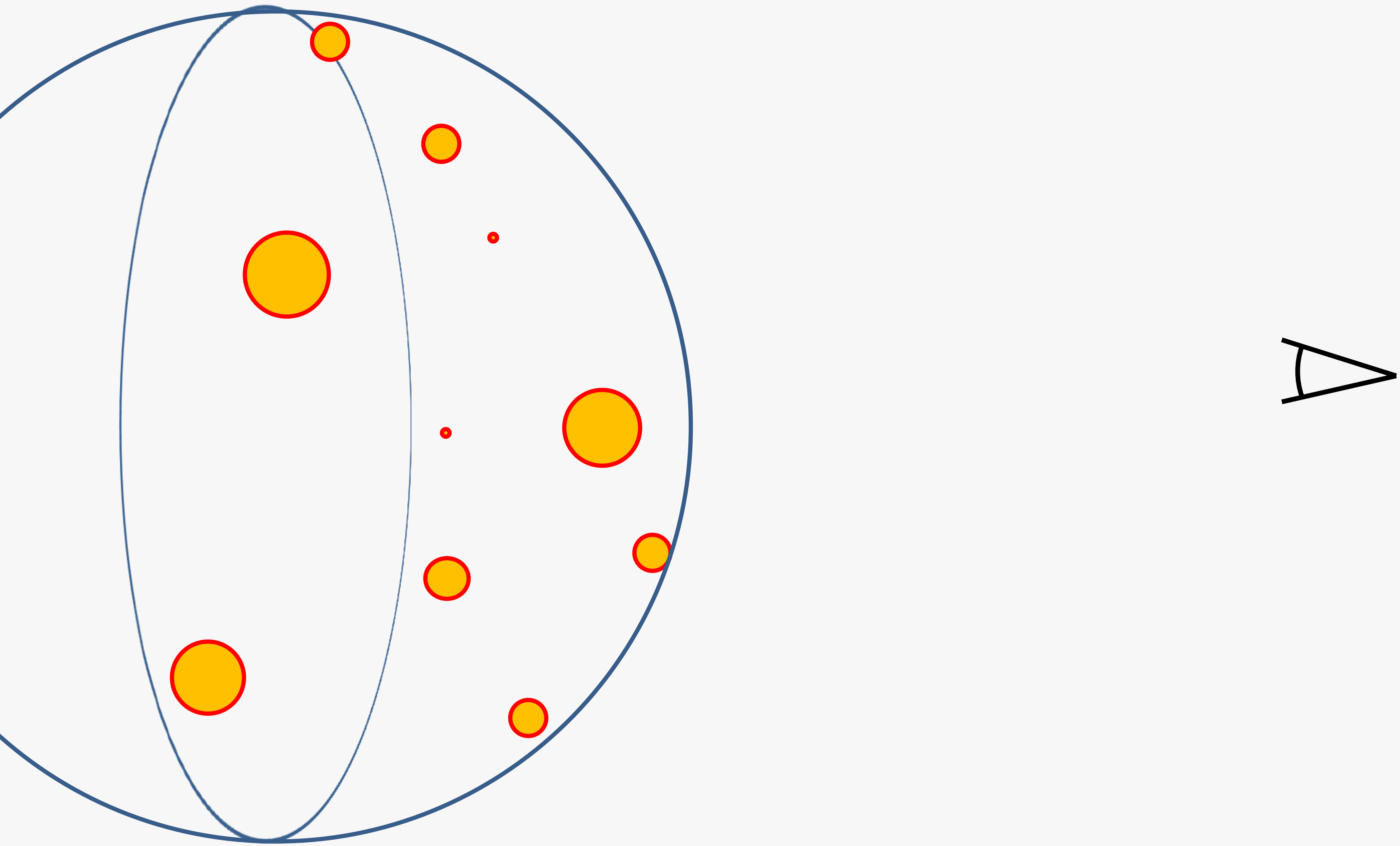


Possible explanation of variability

Example of simulation in 2D



Simulated lightcurves



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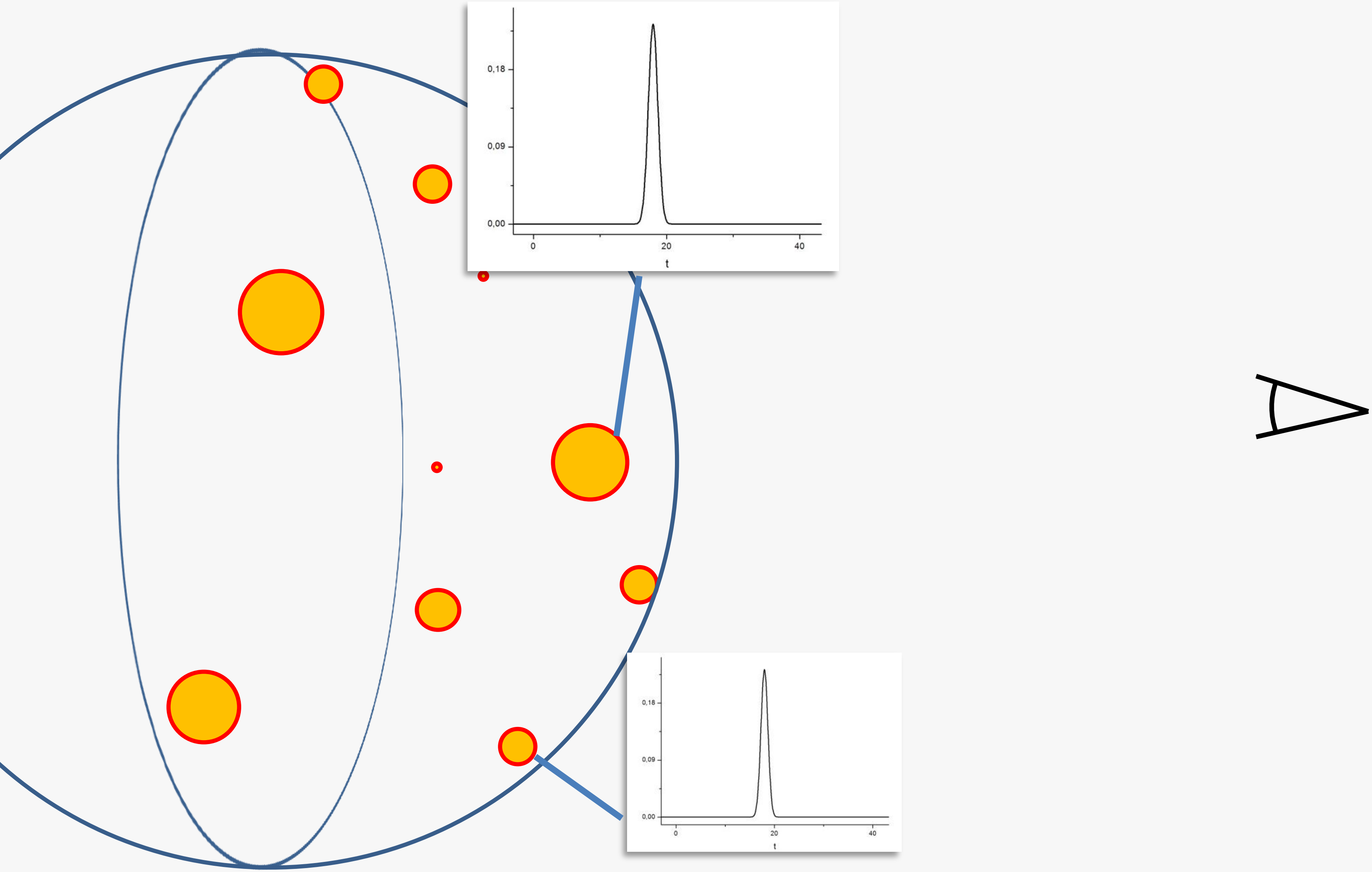

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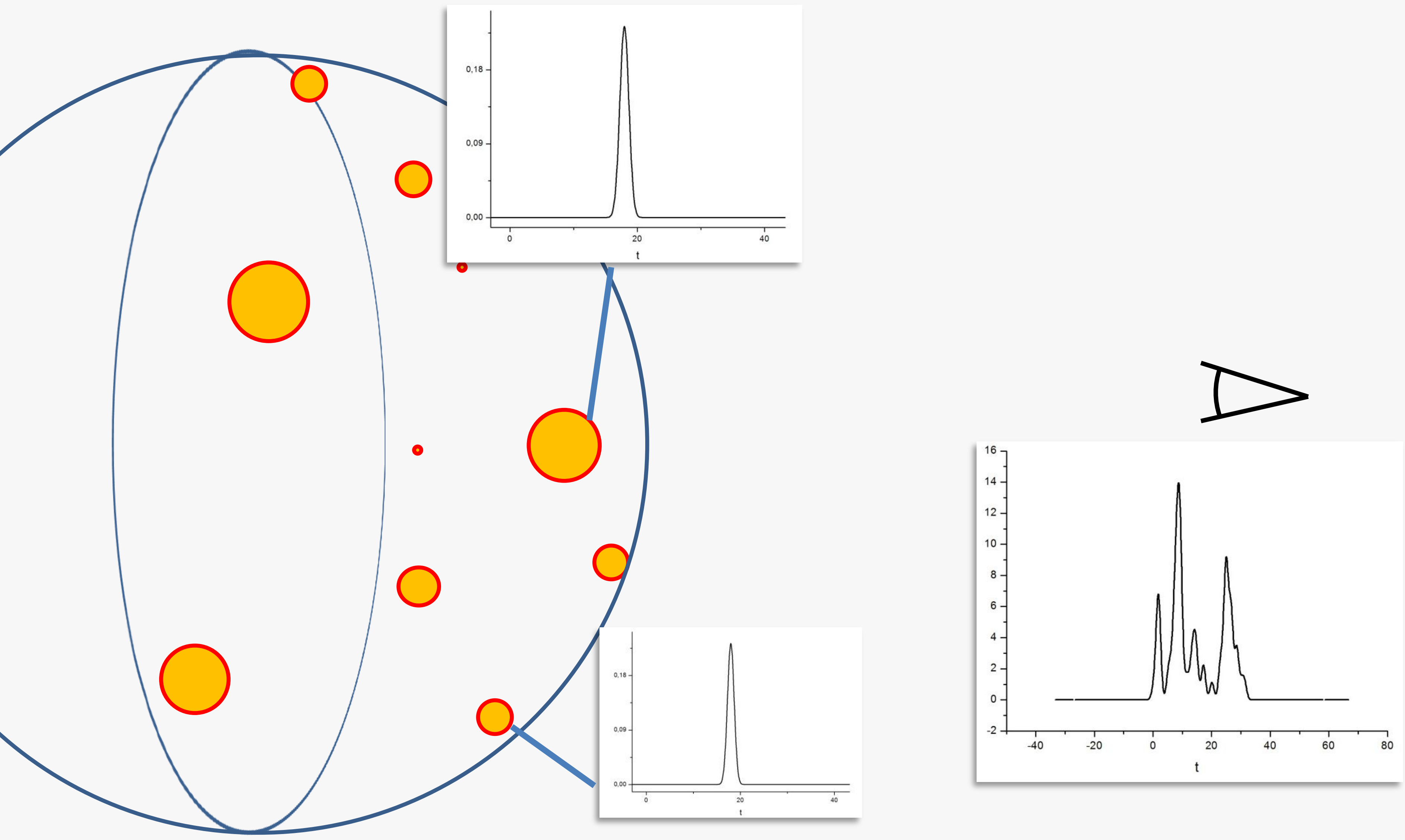

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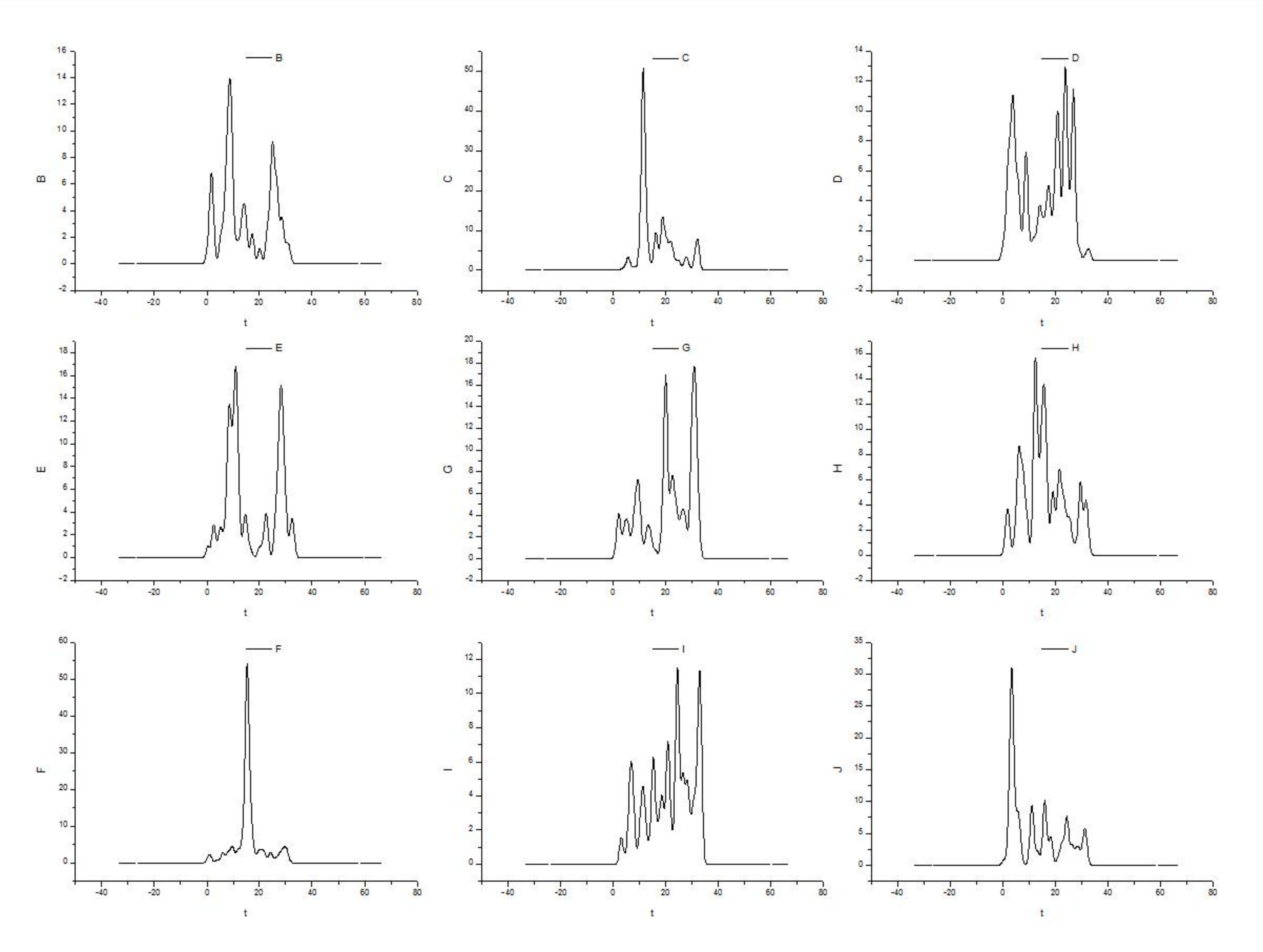


Some predictions

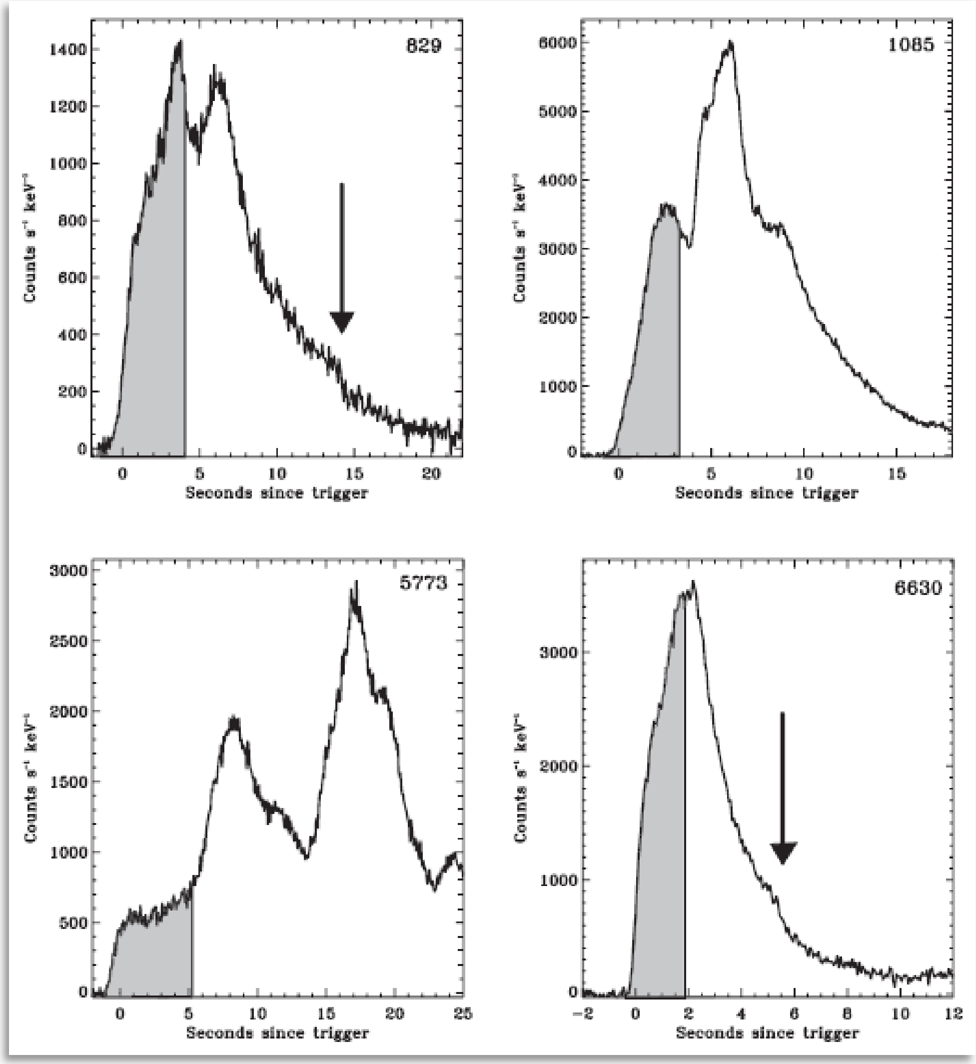
- Relative number of GRBs to Ibc SNe is about 0.4% - 3% [Guetta and Della Valle (2007)]. Using Salpeter's function $dN \propto M^{-2.35} dM$, a typical mass of GRB progenitor $\sim 200 M_\odot$, and $\sim 20 M_\odot$ for the SN, one can obtain that the GRB-Sne number ratio is about 0.4% [Chardonnet et al. 2009]
- PISNe are related to POP III stars. It is expected to have more GRBs with high z

Conclusions

- New scenario of GRBs is proposed. Explosive phenomena different from core-collapse SN
- 1D simulations: peak energy, timescale and energy budget are consistent with parameters of GRBs
- Distribution of peak energy around 300 keV is exlained by temperatures of nuclear burning
- Amati relation could be related to the mass of the progenitor and to the mechanism of energy production
- Ongoing work: multidimensional simulations and spectra analysis

Thank you for your attention!

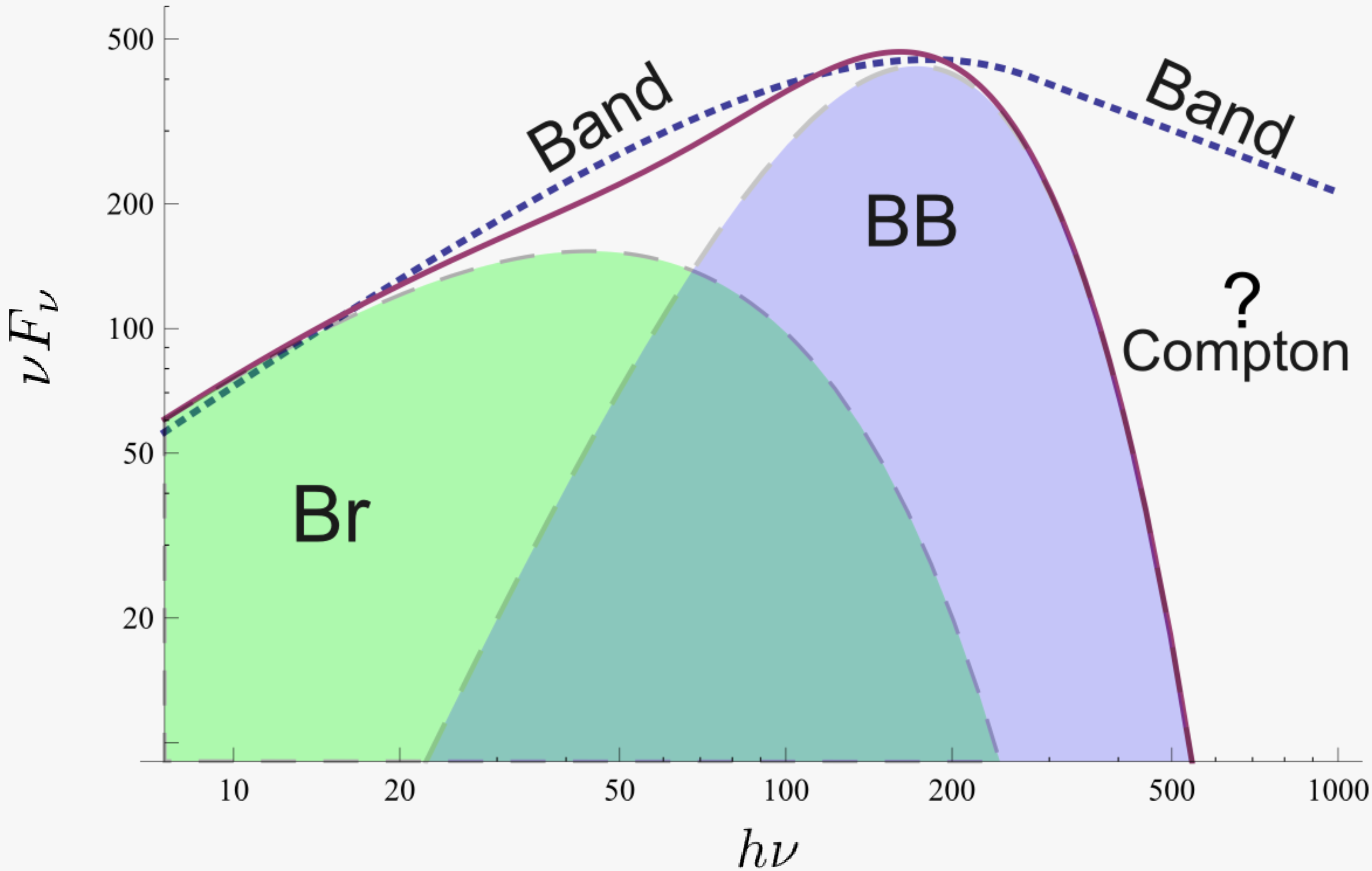
A1: Spectrum
Black body component



[F. Ryde (2004)]

A1: Spectrum

Possible fit



A2: On a physical interpretation of the Amati Relation

Since source of energy is nuclear burning

$$L \sim E_{Nucl} \sim M \cdot q, \qquad [q] = \frac{ergs}{g \cdot s}$$

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