Chemical properties of long gamma-ray bursts progenitors in cosmological simulations

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We investigate the chemical dependence of the progenitors of long gamma ray bursts (LGRBs). Using hydrodynamical cosmological simulations consistent with the concordance Λ-CDM model which include star formation, chemical enrichment and supernova feedback in a self-consistent way, and assuming that LGRBs are produced by massive stars with a possible chemical dependence, we compute the LGRB rate at different redshifts. Introducing a prescription for their peak luminosity function and intrinsic spectrum, and using a Monte Carlo scheme to model their detectability by different high-energy observatories, we compute the distribution of their observables (peak flux, spectral peak energy). Here we present our preliminary results compared with current observations.

Introduction

The nature of the progenitors of long gamma-ray bursts (LGRBs) and the LGRB-star formation connection has been investigated both observationally and theoretically for the last decade (e.g., Vedrenne & Atteia 2009, and references therein). Several studies have been devoted to investigate LGRBs as possible star formation tracers obtaining dissimilar results, which still makes the topic a matter of discussion. Although it is clear now that LGRBs are generated by massive stars, and consequently can be associated to star forming regions, the dependence of LGRB production on the chemical abundances of the progenitors is still controversial. Some authors propose that the chemical-dependence hypothesis would allow to explain both the properties of the hosts, and the LGRB redshift and peak flux distributions (Daigné et al. 2006; Salvaterra & Chincarini 2007; Li et al. 2008), while others claim that an LGRB rate that follows star formation (i.e., with no dependence on the abundances of the progenitors) does the same job (Porciani & Madau 2001, Elliott et al. 2011). There are several reasons behind this disagreement, among them the poorly constrained star formation rate at high redshift, its chemical dependence, the amount of dust obscuration in LGRB hosts, and the lack of a large sample of LGRBs confirmed to be at high redshift.

One approach to the problem is to assume a comoving LGRB rate proportional to the comoving star formation rate (SFR), eventually with a redshift or metallicity-dependent proportionality factor, compute a simulated LGRB population (redshifts, peak luminosities, intrinsic spectral parameters), and compare the predictions of the model to gamma-ray observables such as the distributions of peak fluxes, redshifts and observed spectral parameters (Daigne et al. 2006; Salvaterra & Chincarini 2007; Pellizza et al. 2008). In this approach, the comoving SFR and its metallicity dependence are usually obtained from analytical models (e.g., Hopkins 2006). In this work, we apply the aforementioned method to the SFR provided by hydrodynamical cosmological simulations of galaxy formation and evolution consistent with the concordance Λ-CDM. These simulations include star formation, chemical enrichment and supernova feedback in a self-consistent way, hence they provide a consistent description of the evolution of the SFR and the chemical abundances of the newborn stars. In this poster we present our preliminary results.

Cosmological simulations

*We use a hydrodynamic cosmological simulation consistent with the concordance Λ-CDM model, run with a version of GADGET-3 which includes star formation, metal-dependent cooling, chemical enrichment, multiphase treatment for gas particles and Supernovae feedback (SNII, SNIa) (Scannapieco et al. 2005, 2006).

*The simulation begins with 2×230^3 total particles, with initial masses of 5.93×10^6 $M_\odot$ for dark matter particles and 9.12×10^5 M for gas particles.

*Initially the code has: X_H=0.76 and X_{He}=0.24 for gas particles and follows chemical enrichment of: ^{1}H, ^{2}He, ^{12}C, ^{16}O, ^{24}Mg, ^{28}Si, ^{56}Fe, ^{14}N, ^{20}Ne, ^{32}S, ^{40}Ca y ^{62}Zn.

*The cosmological parameters are: $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$, $\Omega_b = 0.04$, $\sigma_8 = 0.9$ and $H_0 = 100\, h$ km s^{-1} Mpc^{-1} with $h = 0.7$.

* For this work we used 3 simulations (A, B, C) with different star formation and Supernova feedback parameters, which results in different star formation and chemical enrichment histories for the ISM. Simulations A and B form stars when the ISM density is above the critical density $\rho_c > 0.032$ g/cm^3, while simulation C uses a critical density 10 times higher. The energy feedback to the ISM per Supernova (in units of 10^{51} erg) is 0.7 for simulations A and C, but 0.4 for simulation B. Finally, the mass of metals that goes to the cold phase of the ISM in a Supernova explosion is 50%, 80% and 70% in simulations A, B and C respectively.

GRB population properties:

* LGRBs are formed in stars with mass $M > M_{min}$ and metallicity $Z < Z_{max}$. Z_{max} was varied from 1 (i.e. no chemical dependence) to 0.0002 (~0.01 Z_{Sun}). M_{min} is required in each case to fit the BATSE LGRB rate $\psi'(z) = \psi(\rho_{sfr}(z))$.

*Using the above prescription, we computed the number of LGRBs in each stellar population of the simulation taking into account the cosmological volume correction for detectors observing a fixed solid angle in the sky.

*The (peak isotropic) luminosity function of the LGRBs is assumed to be log-normal with $\langle \log L_{iso} \rangle$ and $\sigma_{logLiso}$ as free parameters.

*The intrinsic spectral energy distribution is that proposed by Band et al. (1993), with spectral parameters $\alpha = -1$ and $\beta = -2.25$ and the spectral peak energy E_p log-normally distributed around $\langle \log E_p \rangle$ and σ_{logEp}, which are free parameters.

*For each burst in the population with (L_{iso}, E_p, z) we calculate the observed spectral peak energy, and the peak photon flux observed by BATSE and Swift.

*We use a Monte Carlo scheme to take into account the detectability of both experiments (Stern et al. 2001; Daigné et al. 2006), discarding unobservable bursts.

*The properties of the final sample of observable bursts is compared to the distributions of peak flux and spectral peak energy observed by BATSE and of peak flux observed by Swift.

Preliminary results:

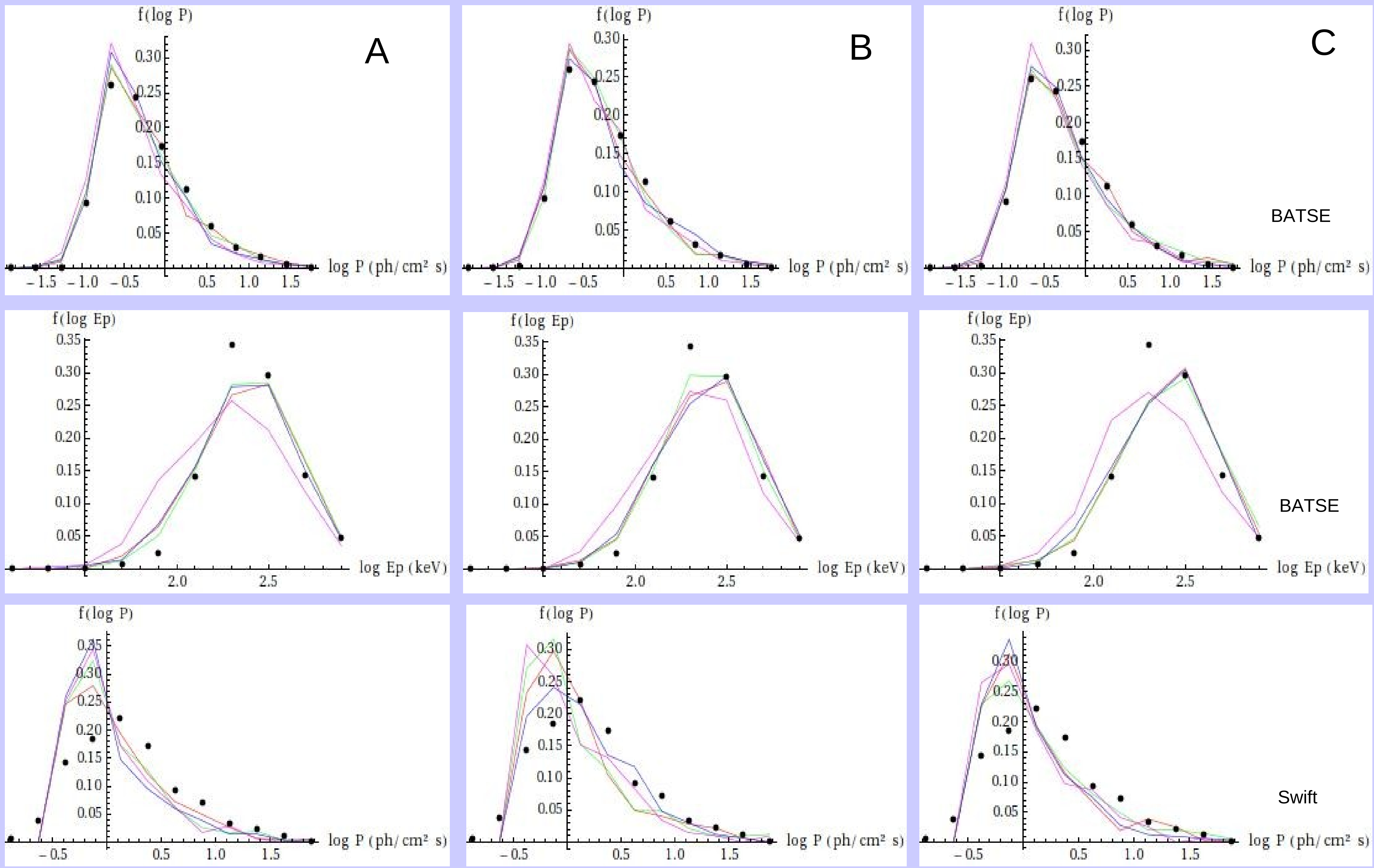
The Figure shows our preliminary results. Upper, middle and lower panels present the BATSE peak flux distribution, BATSE spectral peak energy distribution and Swift peak flux distribution, respectively. Each column shows the result of a different simulation (A, B, C from left to right). Black dots represent the actual data, while red, green, blue and magenta lines represents the outcome of our models with Z_{max} = 1, 0.01, 0.005 and 0.0002 respectively.

* The agreement between results from different simulations is clearly seen for all distributions, showing that our results are robust.

* BATSE results are be described by any model regardless of the metallicity of the progenitors. Best-fit parameters are $\langle \log L_{iso} \rangle = 49.5$, $\sigma_{logLiso} = 1.0$, $\langle \log E_p \rangle = 2.85$, $\sigma_{logEp} = 0.2$, similar to those of Daigné et al. (2006).

* Swift observations are not well fit by any model. An overabundance of low-flux LGRBs is seen in every model.

* Our preliminary results can neither confirm nor rule out a metallicity dependence of the LGRB progenitors, is the latter is described by a simple cut-off. However, the discrepancy of Swift data with every model suggests that more complex metallicity dependencies might be necessary to give an answer to these question.



References:

Atteia J. & Vedrenne G., 2009, Gamma-ray bursts, Springer Praxis Books, Astronomy and Planetary Sciences, Jointly published with Praxis Publishing, UK
Band, D., Matteson, J., Ford, L., et al., 1993, ApJ, 413, 281
Daigné F., Rossi E. M., Mochkovitch R., 2006, MNRAS, 372, 1034
Elliott J., Greiner J., Khochfar S., Schady P., Johnson J. L. & Rau A., 2012, A&A, 2012, 539, 113
Hopkins P. F., Robertson B., Krause E., Hernquist L., Cox T. J., 2006, ApJ, 652, 107
Li A., Liang S. L., Kann D. A., Wei D. M., Klose S. & Wang, Y. J., 2008, ApJ, 685, 1046
Pellizza, L., Nuza, S., Tissera, P., et al. 2008, en Proceedings of the First La Plata International School: "Compact Objects and their Emission", eds. G.E. Romero & I. Andruchow.
Porciani, C. & Madau, P. 2001, ApJ, 548, 522
Salvaterra R. & Chincarini G., 2007, ApJ, 656, L49
Scannapieco C., Tissera P. B., White S. , Springel V., 2005, MNRAS, 364, 552
Scannapieco C., Tissera P. B., White S. , Springel V., 2006, MNRAS, 371, 1125
Stern, B., Tikhomirova, Y., Kompaneets, D., et al., 2001 ApJ, 563, 80