Properties of long-gamma ray burst progenitors in cosmological simulations.

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We study the nature of long gamma ray bursts (LGRBs) progenitors and their host galaxies (HGs) by means of cosmological simulations of structure formation and galaxy evolution. LGRBs are believed to be born in the last stages of very massive stars, which makes them possible good tracers of star formation. We develop a synthetic model of LGRBs based on the collapsar model within cosmological hydrodynamical simulations. The observability of the simulated LGRBs and their host galaxies is calculated in order to compare the predictions of our models with observations. Observations have shown that LGRBs hosts are biased toward low metallicty galaxies; our investigation aims to distinguish between an intrinsic bias, where LGRBs progenitors are low metallicity stars and an alternative scenario, where dark LGRBs produced in dusty (high metallicity) galaxies account for the observed bias.

1. 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 (Daigné 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.

2. Simulation

- We use a hydrodynamic cosmological simulation consistent with the concordance $\Lambda-$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 2x230^3 total particles, with initial masses of 5.93×10^6 M$_\odot$ for dark matter particles and 9.12×10^5 M$_\odot$ 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.
- The simulation forms stars when the ISM density is above the critical density $\rho_c > 0.032$ g cm^{-3}. The energy feedback to the ISM per Supernova (in units of 10^{51} erg) is 0.7. Finally, the mass of metals that goes to the cold phase of the ISM in a Supernova explosion is 50%.

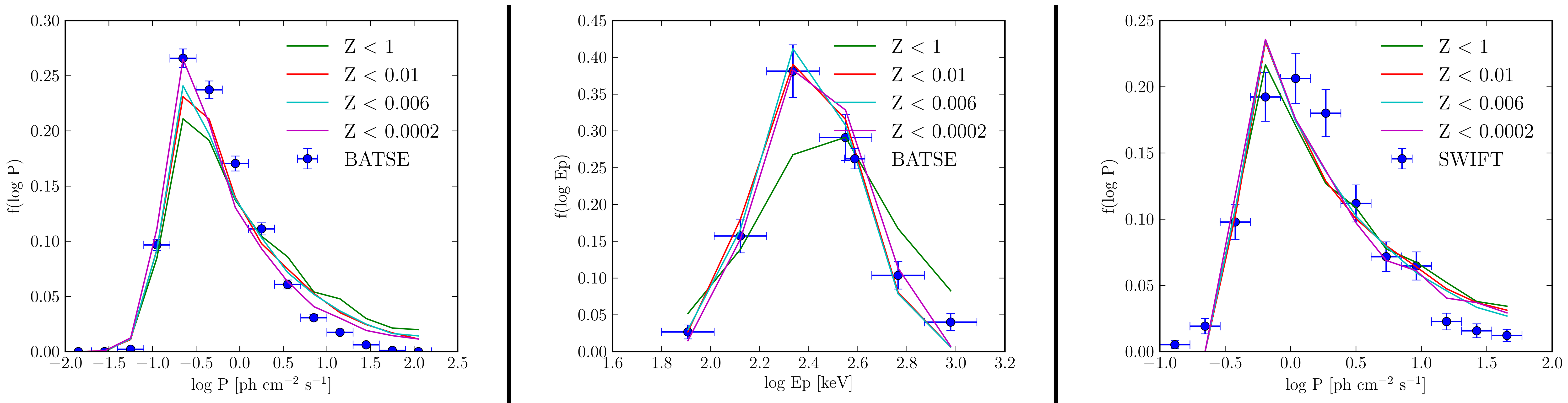
3. GRB population properties

- LGRBs are formed in stars with mass M $>$ M$_{\rm min}$ and metallicity Z $<$ Z$_{\rm max}$. Z$_{\rm max}$ was varied from 1 (i.e. no chemical dependence) to 0.0002 ($\sim$ 0.01 Z$_\odot$). M$_{\rm min}$ is required in each case to fit the BATSE LGRB rate.
- 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 natural stochasticity of the LGRBs progenitor populations was also taken into account.
- The (peak isotropic) luminosity function of the LGRBs is assumed to be a broken power-law with the break luminosity L$_{\rm b}$ and exponents ν_1 and ν_2 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 $<$log E$_p$$>$ and $\sigma_{\rm logEp}$, which are free parameters.
- For each burst in the population with (L$_{\rm iso}$, 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.

4. Results and future prospects

The Figure shows our preliminary results. Left and center panels present the BATSE peak flux distribution and BATSE spectral peak energy distribution respectively. The right panel presents the Swift peak flux distribution. Data points represent the actual data while colored lines represents the outcome of our models with Z$_{\rm max}$ = 1, 0.01, 0.006 and 0.0002.

- The agreement between results and simulation is clearly seen for all distributions, showing that our results are robust.
- BATSE results are be better described by models with a metallicity cut. Best-fit parameters are log L$_{\rm b}$ = 49.5, ν_1 = -1.67, $\nu_2 = -1.98$, $<$log$E_p$$>$ = 2.4, $\sigma_{\rm Ep}$ = 0.2, similar to those of Daigné et al. (2006).
- Our method allows us to define host galaxies from the simulated galaxy catalogues and to compute the probability that a given galaxy be detected as a LGRB host. This probability can be used to weight the properties of the simulated host sample in order to compare with observations.
- As the observed HGs properties might be biased by dust absortion it is important to model the dust effects in order to make a proper comparison with observations. A future version of our code will take these effects fully into account.



Acknowledgements

The authors acknowledge support from the European Commission's Framework Programme 7, through the Marie Curie International Research Staff Exchange Scheme LACEGAL (PIRSES-GA-2010-269264)

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