Constraining cosmological parameters by gamma-ray burst X-ray afterglow light curves

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ABSTRACT

We present the Hubble diagram (HD) of 66 gamma-ray bursts (GRBs) derived using only data from their X-ray afterglow light curve. To this end, we use the recently updated \( L_X\)–\( T_a \) correlation between the break time \( T_a \) and the X-ray luminosity \( L_X \) measured at \( T_a \) calibrated from a sample of Swift GRBs with light curves well fitted by the Willingale et al. model. We then investigate the use of this HD to constrain cosmological parameters when used alone or in combination with other data showing that the use of GRBs leads to constraints in agreement with previous results in literature. We finally argue that a larger sample of high-luminosity GRBs can provide a valuable information in the search for the correct cosmological model.

Key words: cosmological parameters – gamma-rays: bursts: general.

1 INTRODUCTION

That the universe is spatially flat, has a subcritical matter content and is undergoing a phase of accelerated expansion are nowadays globally accepted ideas. Strong evidence for this scenario comes from the anisotropy and polarization spectra of the cosmic microwave background radiation (de Bernardis et al. 2000; Brown et al. 2009; Komatsu et al. 2010), the galaxy power spectrum (Tegmark et al. 2006; Percival et al. 2007) with its baryonic acoustic oscillations (BAO) (Eisenstein et al. 2005; Percival et al. 2010) and the Hubble diagram (HD) of Type Ia supernovae (SNeIa) (Kowalski et al. 2008; Hicken et al. 2009; Kessler et al. 2009). What is driving this cosmic speed up and dominating the energy budget is, on the contrary, a still hotly debated question with answers running from the classical cosmological constant (Carroll, Press & Turner 1992; Sahni & Starobinsky 2000), scalar fields (Peebles & Ratra 2003; Copeland, Sami & Tsujikawa 2006) and higher order gravity theories (Capozziello & Francaviglia 2008; Nojiri & Odintsov 2008; De Felice & Tsujikawa 2010; Sotiriou & Faraoni 2010). In order to break the degeneracies among model parameters and go to the next level of model selection, it is mandatory to probe the background evolution up to very high redshift so that the onset of the acceleration epoch and the transition to the matter-dominated regimes may be directly investigated.

Thanks to their enormous energy release, gamma-ray bursts (GRBs) are visible up to very high \( z \), the largest one being at \( z = 8.2 \) (Salvaterra et al. 2009; Tanvir et al. 2009), hence appearing as ideal candidates for this task. Unfortunately, GRBs are everything but standard candles because their peak luminosity spans a wide range. There have nevertheless been many attempts to make them standardizable candles resorting to the use of empirical correlations among distance-dependent quantities and rest-frame observables (Fenimore & Ramirez-Ruiz 2000; Norris, Marani & Bonnell 2000; Ghirlanda, Ghisellini & Lazzati 2004; Liang & Zhang 2005; Amati et al. 2008). Such empirical relations allow one to infer the GRB rest-frame luminosity or energy from an observer frame measured quantity so that the distance modulus can be estimated with an error mainly depending on the intrinsic scatter of the adopted correlation. Combining the estimates from different correlations, Schaefer (2007) first derived the GRB HD for 69 objects, while Cardone, Capozziello & Dainotti (2009) used an enlarged sample and a different calibration method to update the GRB HD. Many attempts on using GRBs as cosmological tools have since then been performed (see e.g. Firmani et al. 2006; Izzo et al. 2009; Qi & Lu 2010; Liang, Wu & Zhang 2010, and references therein) showing the interest in this application of GRBs.

In this paper, we rely on the \( L_X\)–\( T_a \) correlation (Dainotti, Cardone & Capozziello 2008) to build the HD of 66 GRBs from their X-ray afterglow light curves observed with the Swift satellite (Evans et al. 2009). We then present a preliminary application of the derived GRB
HD showing how this data set can help constrain the parameters of some dark energy models.

2 THE $L_X$–$T_a$ CORRELATION

We use the updated version of the $L_X$–$T_a$ correlation between the luminosity $L_X$ at the break time $T_a$ and $T_a$ itself. We first remind the reader that $T_a$ is defined as the time marking the passage from the plateau to the power-law decay in the GRB X-ray afterglow light curve as described by the universal fitting function proposed by Willingale et al. (2007, hereafter W07). Using a sample of 34 GRBs with light curve measured by the Swift satellite, Dainotti et al. (2008) first discovered that $L_X$ and $T_a$ are anticorrelated, as later confirmed by the semi-empirical models of Ghisellini et al. (2009) and Yamazaki (2009). Recently, we have increased the GRB sample and redrew the $L_X$–$T_a$ correlation (Dainotti et al., hereafter D10). Introducing the error parameter $u = \sqrt{\sigma^2_{L_X} + \sigma^2_{T_a}}$, D10 have also selected a class of high-luminosity long GRBs with very well-measured ($L_X$, $T_a$) parameters ($u < 0.095$) and light curve closely matching the W07 model. Referring to this class of objects as canonical GRBs, D10 have demonstrated that they define an upper envelope for the $L_X$–$T_a$ correlation with the same slope, but a higher intercept than the one for the full sample. In order to avoid mixing objects possibly belonging to two different classes, we divide the 66 GRBs in two subsamples according to the value of $u$ being smaller or larger than 0.095.1 In the first case, we select eight GRBs which we will refer to as the canonical (C) sample, while the remaining 58 will form the non-canonical (NC) one. Adopting a flat Lambda cold dark matter ($\Lambda$CDM) model with ($\Omega_M$, $h$) = (0.278, 0.699), we use the Bayesian method2 of D’Agostini (2005) to fit a linear relation, $\log L_X = a \log [T_a/(1+z)] + b$. We thus get

$$\log L_X = -1.00 \log \left( \frac{T_a}{1+z} \right) + 49.26$$

(1)

with intrinsic scatter $\sigma_{int} = 0.66$ for the NC sample and

$$\log L_X = -1.04 \log \left( \frac{T_a}{1+z} \right) + 50.22$$

(2)

with $\sigma_{int} = 0.23$ for the C sample. Note that these are the best-fitting values which have to be used in the later determination of the GRB distance modulus. However, the Bayesian approach allows us to get the constraints on each one of the single ($a$, $b$, $\sigma_{int}$) by marginalizing over the other two. We thus find

$$a = -1.00^{+0.21}_{-0.21} +0.42^{+0.42}_{-0.42} \quad b = 49.26^{+0.70}_{-0.60} +1.41^{+1.41}_{-1.37}$$

$$\sigma_{int} = 0.70^{+0.13}_{-0.11} +0.30^{+0.30}_{-0.20}.$$  

1 The choice of this threshold value is motivated in D10 which we refer to for details. One could wonder whether this cut picks out bright GRBs just because Swift can spend more time on them thus leading to a better sampled light curve. Actually, since the $L_X$–$T_a$ correlation has a negative slope, bright GRBs have a also shorter light curve so that the number of points can also be smaller for low-$L_X$ GRBs. Moreover, we have found bright GRBs with large $u$ values thus making us confident that no such selection effect is at work here.

2 The D’Agostini method provides a well-established approach to deal with the problem of fitting a linear relation when the uncertainties on both the $(x, y)$ variables are comparable. Such a linear relation can be the outcome of a theoretical model so that one can expect that deviations from the underlying assumptions lead to the point scattering around the best-fitting line. This is what we refer to as intrinsic scatter. The D’Agostini method allows us to take care of this term and estimate it in an unbiased way.

for the NC sample and

$$a = -1.04^{+0.23}_{-0.22} +0.66^{+0.66}_{-0.65} \quad b = 50.19^{+0.77}_{-0.76} +1.55^{+1.55}_{-1.50}$$

$$\sigma_{int} = 0.41^{+0.38}_{-0.16} +1.18^{+0.37}_{-0.25}.$$  

for the C sample, where we have reported the median value3 and the 68 and 95 per cent confidence ranges. In agreement with D10, we find that the slope is the same for the two samples, but the canonical GRBs are shifted to higher luminosities thus giving a larger zero-point and defining an upper envelope for the $L_X$–$T_a$ correlation. Note that the intrinsic scatter for the canonical GRBs is much smaller thus leading to lower uncertainties on the estimated distance modulus. It is worth stressing that, although derived assuming a fiducial $\Lambda$CDM model, this has a negligible impact on the determination of the distance modulus (Cardone et al. 2009). To strengthen this result, we have determined the best-fitting parameters ($a$, $b$, $\sigma_{int}$) and the rms of the residuals for the C sample assuming a CPL (Chevallier & Polarski 2001; Linder 2003) model and varying the parameters ($\Omega_M$, $w_0$, $h$) while $w_a = -w_0$ (see later for the definition of these quantities). Fig. 1 shows that the best-fitting calibration parameters have a clear trend with ($\Omega_M$, $w_0$), but the end-to-end variation of ($a$, $b$), which enter the distance modulus estimate, is less than 3 per cent. This is well within the uncertainties on the ($a$, $b$) coefficients so that we are confident that the choice of the fiducial cosmological model used in the calibration procedure has a negligible impact on the derivation of the HD. However, should future data allow us to increase the precision on ($a$, $b$), one should likely re-address this problem looking for a model-independent calibration.

In order to infer the distance modulus of each GRB, we then simply note that $L_X$ is related to the luminosity distance $d_L(z)$ as (Dainotti et al. 2008; Cardone et al. 2009)

$$L_X = 4\pi d_L^2(z)(1+z)^{-2(\beta+1)} F_X,$$

(3)

with $\beta$ the slope of the energy spectrum (modelled as a simple power law) and $F_X$ the observed flux both measured at the break time $T_a$. Having measured ($T_a$, $\beta$, $F_X$) and inferred $L_X$ using equation (1) or (2), we can then estimate the GRB distance modulus as

$$\mu(z) = 25 + 5 \log d_L(z) = 25 + \frac{5}{2} \log \left[ \frac{L_X}{4\pi(1+z)^{-2(\beta+1)} F_X} \right],$$

(4)

where $d_L(z)$ is in Mpc. The uncertainty is estimated by propagating the errors on ($\beta$, $F_X$, $L_X$). Note that, when computing the error on $L_X$, we add in quadrature the uncertainty coming from $T_a$ and $\sigma_{int}$ to take care of the intrinsic scatter. When resorting to equation (4), we take care of the different calibration parameters for the two subsamples thus using equation (1) for the objects in the NC sample and equation (2) for the C sample ones. The combined HD, shown in Fig. 2, covers the wide redshift range (0.033, 8.2) thus showing that the $L_X$–$T_a$ correlation could allow us to probe both the dark energy epoch and the matter-dominated era with a single tracer. The error bars are, however, quite large so that GRBs alone are unable to discriminate among different cosmological models. For instance, Fig. 2 shows that the theoretically predicted $\mu(z)$ for a $\Lambda$CDM and a matter-only model both cross the data within the large error bars [although the $\Omega_M = 1$ case systematically underestimates $\mu(z)$ for large $z$]. It is the combination with other constraints that help us to

Note that, because of parameter degeneracies, the marginalized likelihoods are not symmetric functions so that the median value may differ from the maximum likelihood one and the confidence ranges be asymmetric. See Dainotti et al. (2008) and references therein for a discussion of this issue.
Figure 1. Best-fitting calibration parameters \((a, b, \sigma_{int})\) and rms of the residuals for the \(L_X-T_a\) correlation fitted to the eight canonical GRBs as a function of the matter density parameter \(\Omega_M\) for three different values of \(w_0\), namely \(w_0 = -1.25\) (short-dashed line), \(w_0 = -1.0\) (solid line), \(w_0 = -0.75\) (long-dashed line). We use a CPL model with \(h = 0.70\) and set \(w_a = -w_0\) to have a matter-dominated era at high redshift.

Figure 2. GRB HD for the combined NC + C (black points) and C (red points) samples. The theoretically predicted \(\mu(z)\) curves for models with \((\Omega_M, \Omega_X) = (1.0, 0.0), (0.263, 0.737), (0.0, 1.0)\) are superimposed to the data with short-dashed, solid and long-dashed lines, respectively.

definitely rule out some models (e.g. \(\Omega_M = 1.0\) is excluded by the measured value of \(h\) and \(\Omega_M h^2\)).

3 GRB HD AS A COSMOLOGICAL TOOL

Whatever is the tracer used, the HD is a primary tool to investigate the viability of a cosmological model. Indeed, the luminosity distance \(d_L(z)\) reads

\[
d_L(z) = \frac{c}{H_0} (1 + z) \int_0^z \frac{dz'}{E(z')}
\]

with \(E(z) = H(z)/H_0\) the dimensionless Hubble parameter. For a spatially flat universe made out of dust matter and dark energy with the CPL equation of state (EOS) \(w(z) = w_0 + w_0 a/ (1 + z)\), it is

\[
E^2 = \Omega_M (1 + z)^3 + (1 - \Omega_M)(1 + z)^{3(1+w_0 + w_a)} \exp \left( -\frac{3 w_0 z}{1 + z} \right).
\]

where \(\Omega_M\) is the present-day matter density parameter and one recovers the \(\Lambda\)CDM model for \((w_0, w_a) = (-1, 0)\). In order to constrain the model parameters, we use a Markov chain Monte Carlo (MCMC) algorithm to maximize the likelihood function \(L(p) \propto \exp \left[ -\chi^2(p)/2 \right]\), where \(p\) is the set of model parameters and the expression for \(\chi^2(p)\) depends on the data set used. Since we are here interested in testing the usefulness of the \(L_X-T_a\) correlation as a cosmological tool, we consider, as a first test, GRBs only thus setting

\[
\chi^2(p) = \sum_{i=1}^{N_{GRB}} \left[ \frac{\mu_{obs}(z_i) - \mu_{th}(z_i, p)}{\sigma_i} \right]^2
+ \left( \frac{h - 0.742}{0.036} \right)^2 + \left( \frac{\omega_M - 0.1356}{0.0034} \right)^2.
\]

Here, \(\mu_{obs}\) and \(\mu_{th}\) are the observed and theoretically predicted values of the distance modulus, while the sum is over the \(N_{GRB}\) GRBs in the sample. The last two terms are Gaussian priors on \(h\) and \(\omega_M = \Omega_M h^2\) and are included in order to help break the degeneracies among model parameters. To this aim, we have resorted to the results of the SHOES collaboration (Riess et al. 2009) and the 7-yr Wilkinson Microwave Anisotropy Probe (WMAP7) constraints (Komatsu et al. 2010), respectively, to set the numbers used.
Table 1. Constraints on the model parameters using GRBs and priors on \((h, \omega_M)\). Columns are as follows: (1) ID of the model, (2) maximum likelihood parameter, (3-6) median and 68 and 95 per cent CL after marginalization. Upper (lower) half of the table refers to the results using the NC + C (C only) sample. A sign ‘$\sim$’ means that the parameter is fixed to its theoretical value.

<table>
<thead>
<tr>
<th>ID</th>
<th>(p_{ML})</th>
<th>(\Omega_M)</th>
<th>(w_0)</th>
<th>(w_a)</th>
<th>(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Lambda CDM)</td>
<td>(0.248, 0.739)</td>
<td>0.246 $^{+0.022}<em>{-0.024}$ $^{+0.050}</em>{-0.039}$</td>
<td>–</td>
<td>–</td>
<td>0.742 $^{+0.040}<em>{-0.040}$ $^{+0.065}</em>{-0.065}$</td>
</tr>
<tr>
<td>(QCDM)</td>
<td>(0.248, –0.37, 0.741)</td>
<td>0.248 $^{+0.026}<em>{-0.024}$ $^{+0.052}</em>{-0.042}$</td>
<td>–0.52$^{+0.14}<em>{-0.38}$ $^{+0.19}</em>{-0.82}$</td>
<td>–0.61 $^{+2.10}<em>{-1.39}$ $^{+2.43}</em>{-2.21}$</td>
<td>0.739 $^{+0.035}<em>{-0.034}$ $^{+0.067}</em>{-0.067}$</td>
</tr>
<tr>
<td>(CPL)</td>
<td>(0.242, –0.34, 0.02, 0.751)</td>
<td>0.247 $^{+0.029}<em>{-0.023}$ $^{+0.066}</em>{-0.043}$</td>
<td>–0.48$^{+0.11}<em>{-0.38}$ $^{+0.14}</em>{-0.96}$</td>
<td>–6.10 $^{+2.31}<em>{-1.59}$ $^{+2.43}</em>{-2.21}$</td>
<td>0.740 $^{+0.037}<em>{-0.038}$ $^{+0.070}</em>{-0.080}$</td>
</tr>
<tr>
<td>(\Lambda CDM)</td>
<td>(0.246, 0.743)</td>
<td>0.246 $^{+0.027}<em>{-0.020}$ $^{+0.057}</em>{-0.037}$</td>
<td>–0.73$^{+0.15}<em>{-0.72}$ $^{+0.40}</em>{-0.91}$</td>
<td>–</td>
<td>0.743 $^{+0.031}<em>{-0.039}$ $^{+0.061}</em>{-0.067}$</td>
</tr>
<tr>
<td>(QCDM)</td>
<td>(0.244, –1.26, 0.745)</td>
<td>0.246 $^{+0.026}<em>{-0.024}$ $^{+0.055}</em>{-0.041}$</td>
<td>–0.73$^{+0.27}<em>{-0.43}$ $^{+0.38}</em>{-0.85}$</td>
<td>0.01 $^{+1.44}<em>{-1.00}$ $^{+2.55}</em>{-2.82}$</td>
<td>0.748 $^{+0.034}<em>{-0.036}$ $^{+0.077}</em>{-0.080}$</td>
</tr>
<tr>
<td>(CPL)</td>
<td>(0.245, –0.36, –2.89, 0.744)</td>
<td>0.242 $^{+0.028}<em>{-0.022}$ $^{+0.064}</em>{-0.046}$</td>
<td>–0.73$^{+0.27}<em>{-0.43}$ $^{+0.38}</em>{-0.85}$</td>
<td>0.01 $^{+1.44}<em>{-1.00}$ $^{+2.55}</em>{-2.82}$</td>
<td>0.748 $^{+0.034}<em>{-0.036}$ $^{+0.077}</em>{-0.080}$</td>
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</table>

\(^4\) Note that the 68 and 95 per cent CL on \(w_0\) in Table 1 are essentially driven by the assumption \(w_0 \leq -1/3\) we have imposed in order to have \(\rho + 3p \leq 0\) for the dark energy fluid.
we find that the $\Lambda$CDM model is still statistically favoured by the combined data set. The constraints on $(\Omega_M, h)$ for this case are almost unchanged by the addition of the other data. This is expected since the data we have added help break the degeneracy between the matter content and the EOS parameters. Since in the $\Lambda$CDM case the EOS is set from the beginning, the priors on $(h, \omega_M)$ we have used to get Table 1 are essentially equivalent to the full data set in Table 2. The situation is different for the QCDM and CPL models since the EOS is allowed to vary. The combined data set is now able to constrain $(w_0, w_a)$ thanks to the $H(z)$ and BAO data which probe the redshift range where dark energy drives the background evolution and hence complementing GRBs. In order to better show the impact of GRBs, we have repeated the fit excluding their HD. Considering, as a test case, the CPL model, we find for the maximum likelihood parameters $(\Omega_M, w_0, w_a, h) = (0.258, -1.52, 1.51, 0.739)$ close to that obtained using the GRBs. The marginalized constraints now read

$$\Omega_M = 0.263 \pm 0.033 \pm 0.062, \quad w_0 = -1.00 \pm 0.35 \pm 0.56, \quad w_a = -0.22 \pm 1.30 \pm 1.82, \quad h = 0.714 \pm 0.031 \pm 0.056.$$ 

Comparing these values to those in Table 2 shows that adding GRBs does not significantly narrow the parameters’ confidence ranges. This is actually expected since the present GRB data sets are affected by large errors (the NC sample) or few statistics (the C sample). However, it is worth noting that GRBs help push the constraints on $w_a$ towards zero thus suggesting that the inclusion of a large sample of canonical ($a < 0.095$) GRBs may strengthen the case for a constant EOS dark energy model.

Up to now, we have not used SNeIa since we have been mainly interested in investigating how GRBs (and the $L_{\text{GRB}}$–$T_{\text{GRB}}$ correlation) could be used as cosmological tools. Having demonstrated that the inclusion of GRBs does not bias the search for cosmological parameters, we finally add SNeIa to the above combined data set using the constitution sample (Hicken et al. 2009) comprising 397 objects over the range $0.015 \leq z \leq 1.551$. For the CPL model and the NC + C GRBs, we get $(\Omega_M, w_0, w_a, h) = (0.279, -1.00, 0.16, 0.708)$ as maximum likelihood parameters, while the marginalized constraints on the single quantities are as follows:

$$\Omega_M = 0.279 \pm 0.021 \pm 0.054, \quad w_0 = -1.00 \pm 0.15 \pm 0.32, \quad w_a = 0.09 \pm 0.68 \pm 1.16, \quad h = 0.703 \pm 0.019 \pm 0.035.$$ 

Not surprisingly, the maximum likelihood model is close to the $\Lambda$CDM ($w_0, w_a = (-1, 0)$ case), while the constraints on the parameters are in full agreement with those reported in Tables 1 and 2 being narrower thanks to the SNeIa data. In particular, the EOS parameters are now better constrained since the SNeIa HD mainly probes the low-redshift dark energy dominated universe. We have not tried to repeat this analysis using the C sample since, due to their high number and good accuracy, SNeIa actually dominate the fit as can be checked by fitting SNeIa only without the inclusion of GRBs or the other data.

### 4 Conclusions

A ground zero test of every cosmological model is its ability to fit the observed HD. Such a test tells us whether the model is able to give rise to the observed background evolution and select the region of the parameter space leading to the correct sequence of accelerating and decelerating expansion. Although still being the

<table>
<thead>
<tr>
<th>ID</th>
<th>$p_{\text{ML}}$</th>
<th>$\Omega_M$</th>
<th>$w_0$</th>
<th>$w_a$</th>
<th>$h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDM</td>
<td>(0.265, 0.709)</td>
<td>$0.263 \pm 0.026 \pm 0.054$</td>
<td>$-1.00 \pm 0.35 \pm 0.56$</td>
<td>$-0.22 \pm 1.30 \pm 1.82$</td>
<td>$0.714 \pm 0.031 \pm 0.056$</td>
</tr>
<tr>
<td>QCDM</td>
<td>(0.271, –0.98, 0.707)</td>
<td>$0.267 \pm 0.035 \pm 0.072$</td>
<td>$-1.00 \pm 0.15 \pm 0.37$</td>
<td>$-0.33 \pm 0.54$</td>
<td>$-1.45 \pm 2.44$</td>
</tr>
<tr>
<td>CPL</td>
<td>(0.262, –1.32, 1.01, 0.726)</td>
<td>$0.273 \pm 0.036 \pm 0.069$</td>
<td>$-1.01 \pm 0.47 \pm 0.64$</td>
<td>$-0.02 \pm 0.88 \pm 1.57$</td>
<td>$0.706 \pm 0.033 \pm 0.062$</td>
</tr>
<tr>
<td>CDM</td>
<td>(0.262, 0.710)</td>
<td>$0.263 \pm 0.022 \pm 0.049$</td>
<td>$-1.06 \pm 0.43 \pm 0.64$</td>
<td>$-0.02 \pm 1.06 \pm 1.54$</td>
<td>$0.717 \pm 0.033 \pm 0.059$</td>
</tr>
<tr>
<td>QCDM</td>
<td>(0.244, –1.26, 0.745)</td>
<td>$0.246 \pm 0.026 \pm 0.055$</td>
<td>$-0.73 \pm 0.35 \pm 0.40$</td>
<td>$-0.02 \pm 0.71 \pm 0.91$</td>
<td>$-0.05 \pm 0.10 \pm 0.14$</td>
</tr>
<tr>
<td>CPL</td>
<td>(0.249, –1.50, 1.40, 0.742)</td>
<td>$0.256 \pm 0.037 \pm 0.085$</td>
<td>$-0.73 \pm 0.35 \pm 0.40$</td>
<td>$-0.02 \pm 0.71 \pm 0.91$</td>
<td>$-0.05 \pm 0.10 \pm 0.14$</td>
</tr>
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Figure 3. Isolikelihood (68.95 and 99 per cent CL) contours for the fit to the NC + C GRB sample combined with SHOES, BAO, $\mathcal{R}$ and $H(z)$ data. Left-hand panel: $\Omega_M$ versus $w$ for the QCDM model. Middle panel: $\Omega_M$ versus $w_0$ for the CPL model. Right-hand panel: $w_0$ versus $w_a$ for the CPL model. In each panel, we marginalize over the not shown parameters. Contours for the fit to the C sample only are quite similar and therefore not reported.
primary tracer of the HD, SNeIa may trace cosmic evolution only up to $z \sim 2$ so that it is mandatory to look for a different class of astronomical objects to go beyond this limit and investigate the matter-dominated era. GRBs are considered the ideal candidates for this role thus motivating the hunt for a calibration method to make them standardizable candles. We have presented here the use of the $L_X-T_\alpha$ correlation as a valid method to infer the GRB HD up to $z \approx 8.2$ using data coming from the X-ray light curve. It is worth stressing that this is the only empirical law relating quantities measured from the afterglow light curve rather than being related to the prompt emission quantities. Moreover, differently from what has yet been done in the past (Schaefer 2007; Cardone et al. 2009), the HD for the NC + C sample is based on the use of a single correlation with a statistically meaningful number of objects. The use of the $L_X-T_\alpha$ correlation then avoids the need of combining different correlations to increase the number of GRBs with a known distance modulus. Each correlation is affected by its own possible systematics and characterized by different intrinsic scatter so that combining all of them in a single HD can introduce unexpected features and hence bias the constraints on the cosmological parameters.

The intrinsic scatter of the $L_X-T_\alpha$ correlation may be significantly reduced if one considers only its upper envelope defined by the canonical GRBs. On the other hand, using the full 66 GRBs, we have been able to get constraints on the matter content and the present-day Hubble constant comparable to those yet available in literature. Moreover, differently from what has yet been done in the past (Schaefer 2007; Cardone et al. 2009), the HD for the NC + C sample is based on the use of a single correlation with a statistically meaningful number of objects. The use of the $L_X-T_\alpha$ correlation then avoids the need of combining different correlations to increase the number of GRBs with a known distance modulus. Each correlation is affected by its own possible systematics and characterized by different intrinsic scatter so that combining all of them in a single HD can introduce unexpected features and hence bias the constraints on the cosmological parameters.

The intrinsic scatter of the $L_X-T_\alpha$ correlation may be significantly reduced if one considers only its upper envelope defined by the canonical GRBs. On the other hand, using the full 66 GRBs, we have been able to get constraints on the matter content and the present-day Hubble constant comparable to those yet available in literature. Such a preliminary investigation has convincingly shown that the $L_X-T_\alpha$ correlation may be used to construct a GRB HD which does not introduce any bias in the search for cosmological parameters. It is worth stressing that the same results have been obtained using the canonical GRBs despite the fact that they represent just $\sim 12$ per cent of the full sample. We therefore argue that an observational effort dedicated to look for canonical GRBs may turn them from ideal candidates to actual tools for efficiently investigating the dark energy puzzle.

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