An independent estimate of the cosmological distance to GRB970228 and GRB970508

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Abstract. Assuming binary neutron star mergings as a standard-candle model for GRBs, an independent estimate is obtained for the redshift of GRB970228 and GRB970508 with optical counterparts, using mean statistical properties of GRBs observed by BATSE. We derive \( z = 0.7 ± 0.1 \) and \( z = 1.9 ± 0.1 \) for GRB970228 and GRB970508 respectively, depending on the power-law index of the GRB spectrum \( s = −1.1 ± 0.3 \) and the value of the redshift of the initial star formation \( z_s = 3 − 10 \) in a flat \( \Omega = 1 \) Universe with a cosmological term \( \Lambda = 0.7 \).

Key words: Stars: neutron — Gamma rays: bursts

A fading optical transient object (Groot et al. 1997a) has been found within gamma-ray and X-ray error boxes of GRB970228. Deep optical studies of this field with large telescopes revealed an elongated (1′ × 1.5′) faint (\( R \approx 24 \)) object coincident with the position of an optical transient source detected about one day after the gamma-ray burst (Groot et al. 1997b; Metzger et al. 1997b), X-ray spectra of the X-ray transient source accompanied GRB970228, obtained by BeppoSAX (Costa et al. 1997a), display soft X-ray absorption corresponding to the column density toward the source \( N_{HI} = 1.6 \times 10^{21} \text{ cm}^{-2} \) (which is in agreement with a galactic absorption in this direction of \( 1.44 \times 10^{21} \text{ cm}^{-2} \), as derived from neutron hydrogen emission (V.G.Kurt, private communication). Subsequent optical observations of the optical transient source with the Hubble Space Telescope (HST) on March 26, 1997, confirmed the presence of a faint star-like source (\( I \approx 24.2 \)) embedded into a dim nebula (Sahu et al. 1997). This makes GRB970228 the first GRB identified with some astronomical object, very likely a distant galaxy, and lends direct support to the cosmological origin of GRBs. Incidentally, one of the faint galaxies within the X-ray error box at 1′ distance from the optical transient has a redshift \( z = 0.498 \) (Metzger et al. 1997a). However, the redshift of the faint nebula associated with the optical transient has not been measured so far. More recent weaker GRB970508 is also associated with a variable optical (\( R \sim 20.5^{\prime\prime} \)) counterpart (Bond 1997), with a redshift of \( 0.835 < z < 2.1 \) (Metzger et al. 1997c), as measured by Fe and Mg absorption lines, the upper limit being due to the absence of Lyman-alpha forest in its spectrum.

Here we estimate of the redshift of GRB970228 and GRB970508 using the mean statistical properties of observed GRBs. We assume the cosmological origin of GRBs as standard-candle binary neutron star mergers. The peak gamma-ray flux from GRB970228 and GRB970508 measured at BeppoSAX Gamma Ray Burst Monitor (GRBM) was 3700 counts/s (Costa et al. 1997a) and 450 counts/s (Costa et al. 1997c), roughly corresponding to a 60-600 keV flux of 6 and 0.7 photons cm\(^{-2}\) s\(^{-1}\) respectively, assuming the conversion factor quoted in Piro et al. (1996) (note that this rate may be lower limits considering the off-set positions of the outbursts). Assuming rough correspondence of the BeppoSAX and BATSE photon counts (which would not be too far-off), we find the location of GRB970228 and GRB970508 on the log \( N - \log F_{\text{peak}} \) curve for 3B BATSE GRB catalog (256 ms channel) (Fig. 1). This curve can be fitted within the framework of cosmological model of GRBs as coalescing binary neutron stars (see Lipunov et al. 1995 for more detail) using: 1) cosmological model parameters (the total density in units of the critical density to close the Universe, \( \Omega \), the density of baryons, \( \Omega_b \), and cosmological constant term, \( \Omega_\Lambda \)); 2) evolutionary parameters (the fraction of elliptical galaxies among the total number of galaxies, \( \epsilon \), the redshift of the initial star formation, \( z_s \)). Assuming \( \Omega = 1 \), \( \Omega_b = 0.0046 \), \( \Omega_\Lambda = 0.7 \), \( \epsilon = 0.5 \), and approximating effective GRB spectrum as a single power law with a photon index \( s = −1.1 ± 0.3 \) (Mallozzi et al. 1996), we calculate the best-fit of the 3B log \( N - \log F_{\text{peak}} \) distribution for \( s = −1.1 \) and different values of \( z_s = 3, 5, 10 \) (Fig. 1, solid lines). The observed distribution is best-fitted by models.
with $z_* > 5$. The vertical arrows indicate the positions of GRB970228 and GRB970508.

This procedure allows us to determine the redshifts of GRB970228 and GRB970508 would have in models with different $z_*$ and $s$ (Table 1). The mean redshift of GRB970228 is $\langle z \rangle = 0.7 \pm 0.1$, and that of GRB970508 is $z \sim 1.9 \pm 0.1$ the error being formally due to variations in the spectral slope and $z_*$. The dependence of the redshift on the countrate observed is shown in Fig. 2 for various $z_* = 3, 5, 10$. If this model is correct, the brightest BATSE GRBs should be observed from redshifts $z_{min} \sim 0.1$. Assuming this GRB to be not selected in its luminosity, the redshift of the host galaxy is thus predicted to be about 0.7.

To conclude, we stress that the obtained redshift estimation of the possible host galaxy of GRB970228 $z = 0.7$ and its variance $\pm 0.1$ assumes the hypothesis of the standard candle. From this point of view, the direct measurement of the redshift of the nebula associated with the optical transient would be a crucial test of the cosmological origin of GRB970228 and is highly desirable. Our estimate of the redshift of GRB970508 $z = 1.9 \pm 0.1$ falls within the limits obtained from the spectroscopy of the optical counterpart $0.835 < z < 2.1$.

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### Table 1. Redshift of GRB970228 for different initial star formation redshifts $z_*$ and gamma-ray spectral photon index $s$

| $z_*$ | $z = 1.4$ | $z = 1.1$ | $z = 0.8$ |
|-------|----------|----------|----------|
| 10    | 0.79     | 0.80     | 0.80     |
| 5     | 0.70     | 0.80     | 0.73     |
| 3     | 0.64     | 0.64     | 0.57     |

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**Fig. 1.** The log $N - \log F_{peak}$ distribution of 3B BATSE GRBs from 256-ms 1-3 (50-300 keV) channels fitted with the cosmological model distributions in a flat $\Omega = 1$ Universe with a cosmological term $\Omega \Lambda = 0.7$ assuming gamma-ray photon power law $s = -1.1$. The locations of Beppo-SAX GRBs are shown. GRB970228 and GRB970508 are marked with asterisks.

**Fig. 2.** The redshift – peak flux dependence in the cosmological models assumed for different $z_*$ and $s = -1.1$. 3B BATSE catalog data are also plotted.
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