Astron. Astrophys. 355, 454–460 (2000)

ASTRONOMY AND ASTROPHYSICS

BeppoSAX spectrum of GRB971214: evidence of a substantial energy output during afterglow

D. Dal Fiume[1], L. Amati[1], L.A. Antonelli[2,3], F. Fiore[2,3], J. M. Muller[2,4], A. Parmar[5], N. Masetti[1], E. Pian[1], E. Costa[6], F. Frontera[1,7], L. Piro[6], J. Heise[4], R.C. Butler[8], A. Coletta[3], M. Feroci[6], P. Giommi[2], L. Nicastro[9], M. Orlandini[1], E. Palazzi[1], G. Pizzichini[1], and M. Tavani[10]

[1] Istituto di Tecnologie e Studio delle Radiazioni Extraterrestri (TeSRE), C.N.R., via Gobetti 101, 40129 Bologna, Italy
[2] Beppo-SAX Scientific Data Center, Via Corcolle 19, 00131 Roma, Italy
[3] Osservatorio Astronomico di Roma, Via Frascati 33, 00044 Roma, Italy
[4] Space Research Organization Netherlands, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands
[5] Astrophysics Division, Space Science Department of ESA, ESTEC, P.O. Box 299, 2200 AG Noordwijk, The Netherlands
[6] Istituto di Astrofisica Spaziale (IAS), C.N.R., Via Fosso del Cavaliere, 00133 Roma, Italy
[7] Dipartimento di Fisica, Università di Ferrara, Via Paradiso 12, 44100 Ferrara, Italy
[8] Agenzia Spaziale Italiana, Viale Regina Margherita 202, 00198 Roma, Italy
[9] Istituto di Fisica Cosmica con Applicazioni all'Informatica (IFCAI), C.N.R., Via U. La Malfa 153, 90139, Palermo, Italy
[10] Istituto di Fisica Cosmica "G. P. S. Occhialini", C.N.R., via Bassini 15, 20133 Milano, Italy

Received 4 August 1999 / Accepted 26 November 1999

Abstract. We report the X/γ-ray spectrum of GRB971214 and of its afterglow. The afterglow was measured few hours after the main event and for an elapsed time of more than two days. The measure of this GRB and afterglow is relevant due to its extreme, cosmological distance (z=3.42). The prompt event shows a hard photon spectrum, consistent with a broken power law with photon indices $\Gamma_X \approx 0.1$ below $\sim$20 keV and $\Gamma_\gamma \approx 1.3$ above 60 keV. The afterglow spectrum, measured with the MECS and LECS BeppoSAX telescopes, is consistent with a power law with spectral photon index Γ=1.6. Within the statistical accuracy of our measure no spectral evolution is detected during the observation of the afterglow. When integrated during the time span covered by BeppoSAX observations, the power in the afterglow emission, even with very conservative assumptions, is at least comparable with the power in the main event. The IR-to-X rays broad band spectrum is also presented, collecting data from the literature and adding them to the BeppoSAX measure. It shows that the predictions from synchrotron emission models is qualitatively confirmed. The BeppoSAX measurement of the X and γ ray spectrum of this GRB/afterglow is discussed in the framework of current theoretical models

Key words: gamma rays: bursts – gamma rays: observations – X-rays: general

1. Introduction

The discovery of X-ray afterglows from Gamma-ray Bursts (GRBs) (Costa et al. 1997) is a major step forward to understand this still mysterious phenomenon. The detection of the faint, fading X-ray counterparts of GRBs poses tight constraints to the models for the emission. Multiwavelength studies discovered optical, IR and radio transients associated with the X-ray afterglow, thanks to the unprecedented positioning accuracy obtained with BeppoSAX. The discovery of a substantial redshift (Kulkarni et al. 1997, 1998) in the absorption and emission lines in the spectra of the host galaxies associated with the GRBs optical transients puts these catastrophic events at a cosmological distance and results in an extreme energy output from each GRB, if the emission is isotropic.

The recent advances in our knowledge about the cosmic events known as GRBs were mainly due to the accurate positioning allowed by BeppoSAX (Boella et al. 1997a). This satellite carries on board an optimal set of instruments to detect GRBs (the Gamma Ray Burst Monitor - GRBM Frontera et al. 1997, Feroci et al. 1997), to position them within a few arcminutes (the Wide Field Cameras - WFC; Jager et al. 1997) and finally to pinpoint the positions down to tens of arcseconds thanks to rapid (few hours) follow-up observations with the Narrow Field Instruments (Low Energy Concentrator Spectrometer - LECS; Parmar et al. 1997; Medium Energy Concentrator Spectrometer - MECS; Boella et al. 1997b; High Pressure Gas Scintillation Proportional Counter - HPGSPC; Manzo et al. 1997; Phoswich Detection System - PDS; Frontera et al. 1997)

The positions given by BeppoSAX (e.g. Piro et al. 1998 for GRB960720) allowed prompt ground based observations with telescopes in optical, radio, IR. Up to now thirteen Optical Transients (OT) were discovered in the error boxes of the X-ray afterglows (van Paradijs et al. 1997, Bond 1997, Halpern et al. 1998, Groot et al. 1998, Palazzi et al. 1998, Galama et al. 1998, Jaunsen et al. 1998, Hjorth et al. 1998, Bloom et al. 1998, Kulkarni et al. 1999, Galama et al. 1999, Palazzi et al. 1999,

Send offprint requests to: D. Dal Fiume — daniele@tesre.bo.cnr.it

Bakos et al. 1999). After the fading of the OT in most cases a faint galaxy was detected. The detection of the putative host galaxy of GRB971214 is particularly intriguing as the estimate of the redshift is z=3.42, locating this event at an extreme cosmological distance (Kulkarni et al. 1998).

We observed with BeppoSAX a GRB on December 14.97272 UT 1997 (Heise et al. 1997). A follow-up pointing performed 6.67 hours after the main event detected the faint and fading X-ray source 1SAX J1156.4+6513 (Antonelli et al. 1997). After the fading of the optical transient, spectroscopic observations of the associated host galaxy tentatively put it at cosmological distance, as the estimate of its redshift is z=3.42 (Kulkarni et al. 1998), that corresponds to a luminosity distance $>$30 Gpc (for H_0=65 km s^{-1} Mpc^{-1} and Ω_0=0.2). The complete evolutionary history of the emitted spectrum from X to γ rays up to 2.5 days after the main event suggests that the afterglow in X-rays begins immediately. The energy output in the afterglow results to be comparable to that in the prompt event. With the new wealth of data on optical counterparts and X–ray afterglows, a major revamping of theoretical models is occurring. With the extragalactic origin firmly established on the basis of observations of host galaxies (Metzger et al. 1997, Kulkarni et al. 1998, 1999), the cosmological fireball model (e.g. Cavallo & Rees 1978, Mészáros & Rees 1997a) gives predictions that reasonably fit to observational data. In this paper we discuss the details of the prompt and delayed emission from GRB971214, with emphasis on the X and γ ray spectrum and on its evolution with time. Implications on the models of the prompt event and of the afterglow are discussed.

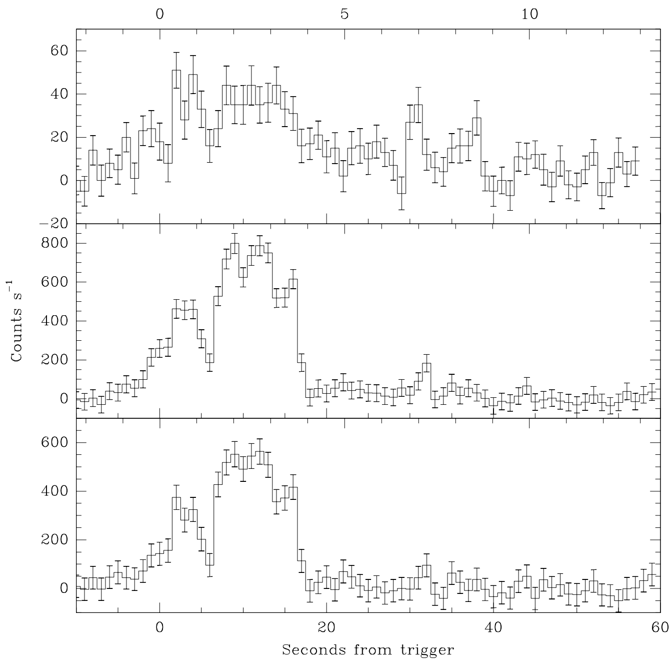

Fig. 1. GRB971214 as observed by BeppoSAX. Top panel: WFC1 (1 second time resolution – E=1–26 keV). Middle panel: GRBM LS1 ratemeter (1 second time resolution – E=40–700 keV). Bottom panel: GRBM LS1 AntiCoincidence ratemeter (1 second time resolution – E$>$100 keV). Zero time corresponds to the GRBM BeppoSAX trigger time. Top scale: time in the GRB reference frame (assuming z=3.42). Bottom scale: time in the Earth reference frame.

2. Observations

GRB971214 was detected in Lateral Shield 1 of GRBM and in WFC 1 on December 14.97272 UT. The burst lasted approximately 30 s, with two leading broad peaks (3s and 10 s FWHM) and a third fainter and sharper peak (1s FWHM) 34s after trigger. The GRB profile is shown in Fig. 1, as measured by GRBM LS1 and WFC1.

The analysis of the WFC data was performed using WFC data reduction software version 103106. Data reduction, background subtraction and spectral analysis of GRBM data were performed using dedicated SW tools (Amati et al. 2000) The latest release of the WFC and GRBM response matrices were used. All the spectral fits reported in this article were performed using XSPEC, version 10.0 (Arnaud 1996).

We fitted the joint spectrum with the spectral shape of Band et al. (1993) ($\chi^2_{\rm dof}$=1.99 for 22 degrees of freedom) and with a power law with exponential cutoff ($\chi^2_{\rm dof}$=1.98 for 22 degrees of freedom). Both give systematic residuals in the WFC energy band. The best fit is obtained using a broken power law ($\chi^2_{\rm dof}$=1.6 for 21 degrees of freedom). An F–test shows that the improvement is not significant. The average joint Wide Field Camera/Gamma Ray Burst Monitor spectrum during the burst can be well described by a broken power law with photon indices Γ_1=0.13 and Γ_2=1.3 and a break energy at $\sim$10 keV. Given the gap between WFC and GRBM spectra, approximately between 10 and 50 keV, a large uncertainty in the position of the break is present and must be added to the statistical uncertainty quoted in Table 1. The fits with all the above functions are statistically unacceptable, but we estimate that a substantial contribution to the high value of $\chi^2_{\rm dof}$ is due to systematic uncertainties in the spectral deconvolution. Therefore we do not consider to add further components to improve the fit. The results from all the spectral fits we performed are reported in Table 1. In Fig. 2 we report the count rate spectrum from WFC1 plus GRBM LS1. In the same figure we report the joint confidence contours for the two spectral indices of the broken power law.

The joint confidence contour between Γ_2 and the break energy (not reported in Fig. 2) suggests that the GRB spectrum shows a bending above $\approx$ 10 keV but the hard X-ray/γ ray spectrum above 50 keV is consistent with a single power law. A fit with a power law plus exponential cutoff gives an e-folding energy of $\sim$300 keV. This is in the "hard" tail of the distribution from statistical studies of BATSE GRB spectra (Band et al. 1993), in which a broad interval of break energies from 50 keV to more than 1 MeV was found, with the majority of GRBs having a cutoff energy below 200 keV, and confirms that this GRB has a very hard spectrum.

We analyzed separately the spectra of the first and of the second peak. We find evidence that the second peak is at least as hard as the first one. This result is different from the hard-to-soft evolution that seems to be present in most GRBs (Preece

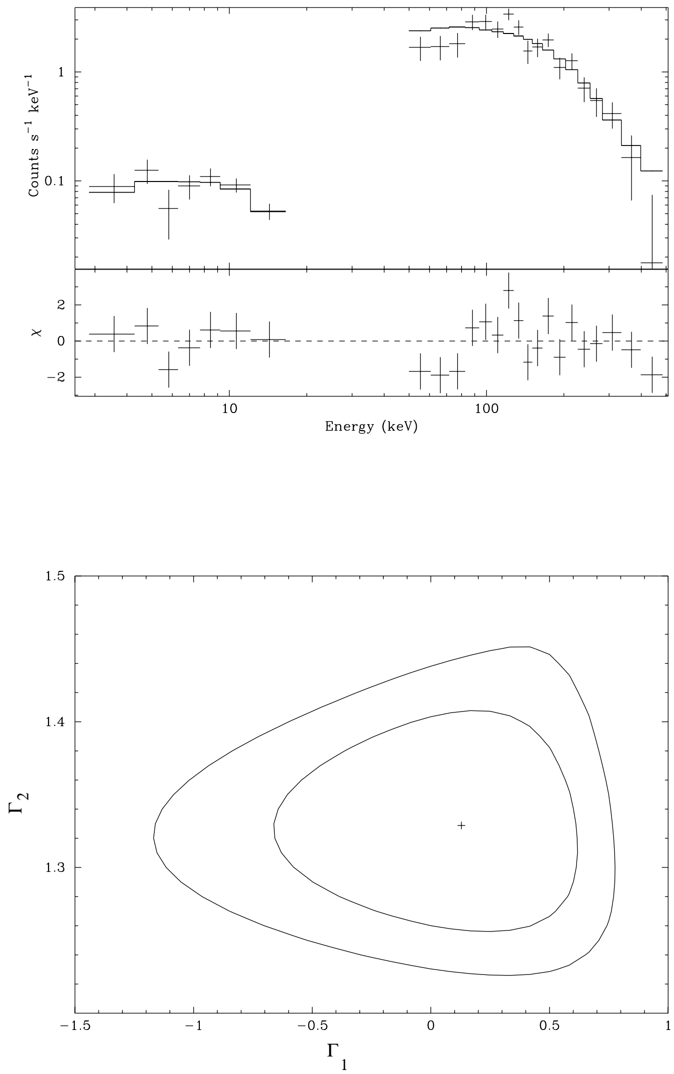

Fig. 2. Top panel: the emitted spectrum of GRB971214 in the γ-ray and X-ray band. A fit with a broken power law is indicated as a solid line. Bottom panel: the joint confidence contour for Γ_1 and Γ_2. 68% and 90% confidence levels are shown.

Table 1. Spectral fit parameters

Start$^{(1)}$ time	End$^{(1)}$ time	Γ_1	Γ_2	E_{cut} (keV)	χ^2_{dof} (dof)
		Average spectra			
0	35	$0.13^{+0.33}_{-0.47}$	1.33±0.05	$10^{+2.3}_{-1.5}$	1.6(21)
23300	215000	1.6±0.2			0.94(20)
		Time resolved spectra			
0	9	0.37±0.23	1.4±0.11	95±14	0.64(12)
9	20	0.33±0.27	1.0±0.02	50±4	0.63(12)
23300	75000	$1.9^{+0.39}_{-0.34}$			0.7(11)
75000	125000	$1.42^{+0.85}_{-0.68}$			0.28(5)
125000	215000	$1.23^{+0.75}_{-0.91}$			0.44(2)

$^{(1)}$ Seconds from trigger time

NOTE: errors are single parameter 68% confidence level

et al. 1998). In this respect the properties of GRB971214 are distinct from those observed on the average in GRBs.

The burst fluences are 1.9 $\pm 0.4 \times 10^{-7}$ $\mathrm{erg\ cm^{-2}}$ in 2-10 keV and 8.8 $\pm 0.8 \times 10^{-6}$ $\mathrm{erg\ cm^{-2}}$ in 40-700 keV. The fluence in hard X-rays/γ rays is in good agreement with that measured with BATSE (Kippen et al. 1997). Assuming a redshift z=3.42 (Kulkarni et al. 1998) in a standard Friedmann cosmology (with H_0=65 km s^{-1} Mpc^{-1} and Ω_0=0.2) the luminosity distance is 1.05×10^{29} cm. At this distance the observed fluences correspond to 6 $\pm 1.2 \times 10^{51}$ ergs in 2-10 keV and $2.8 \pm 0.25 \times 10^{53}$ ergs in 40-700 keV for an isotropically emitting source. Here we assume that $\mathrm{L_{grb}} = \mathrm{F_{\oplus}} 4\pi \mathrm{D_L^2}(1+\mathrm{z})^{-1}$ (e.g. Hakkila et al. 1996). If we assume the measured slope of the GRB spectrum (see Table 1), $\mathrm{L_{grb}} = \mathrm{F_{\oplus}} 4\pi \mathrm{D_L^2}(1+\mathrm{z})^{-1.3}$ and the luminosity is a factor 1.6 lower in the hard band. The energy ranges correspond to 4.4-44 keV and 180-3090 keV at the source. The X-to-γ fraction is therefore 0.02. This can be compared to other fractions measured for other GRBs as reported in Frontera et al. (2000 that range from 0.39 for GRB970508 to 0.01 for GRB980329. Therefore this GRB shows one of the lowest ratios, i. e. the hardest spectrum, amongst those observed with BeppoSAX. Of course such a comparison is made *without* taking into account possible substantial differences in redshift amongst the different GRBs. If the emitted X-γ ray spectrum has a break somewhere above 10 keV, the redshift due to the extreme cosmological distance shifts this break to a lower energy in the spectrum as observed at earth, possibly affecting the fluence ratio.

After the detection of GRB971214 and its positioning using WFC1 (Heise et al. 1997), BeppoSAX was rescheduled to point the center of the WFC error box. The observation started on December 15.24583 UT ($\sim$6.5 hours after the gamma–ray burst) and lasted until December 17.50069 UT for a total elapsed time of 2.25 days. A faint source, 1SAX J1156.4+6513 at α_{2000}= 11$^{\mathrm{h}}$ 56$^{\mathrm{m}}$ 25$^{\mathrm{s}}$ and δ_{2000}=+65$^{\mathrm{o}}$ 13' 11" (Antonelli et al. 1997), was clearly detected in the center of the MECS/LECS field of view. The accuracy in the position is $\sim$1'. This accuracy is largely dominated by uncertainties in the reconstructed BeppoSAX attitude in the new 1-gyro mode that is implemented since summer 1997. The S/N ratio for the entire observation is $\sim$12 in the MECS. Therefore the source is detected with high significance. The following data analysis was performed using the SAXDAS data reduction software, version 1.2, and the latest release of the LECS and MECS response matrices.

The X-γ decay curve is discussed in more detail in Heise et al. (in preparation). The source faded smoothly during the observation. A S/N analysis of the count rates accumulated in twenty time intervals spanning the entire observation shows that the source is visible up to the end of the NFI observation. A χ^2 test against constant count rate gives a chance probability $< 10^{-5}$ ($\chi^2_{\mathrm{dof}} = 3.7$ for 19 dof). The same test performed on a light curve extracted in a source free region is consistent with a constant count rate ($\chi^2_{\mathrm{dof}} = 0.76$ for 19 dof).

The spectrum averaged on the entire observing time is consistent with a single power law with spectral index $\Gamma = 1.6 \pm 0.2$ (see Table 1). The measured value of $\mathrm{N_H}$ ($1^{+2.3}_{-1} \times 10^{21}$) cm^{-2}

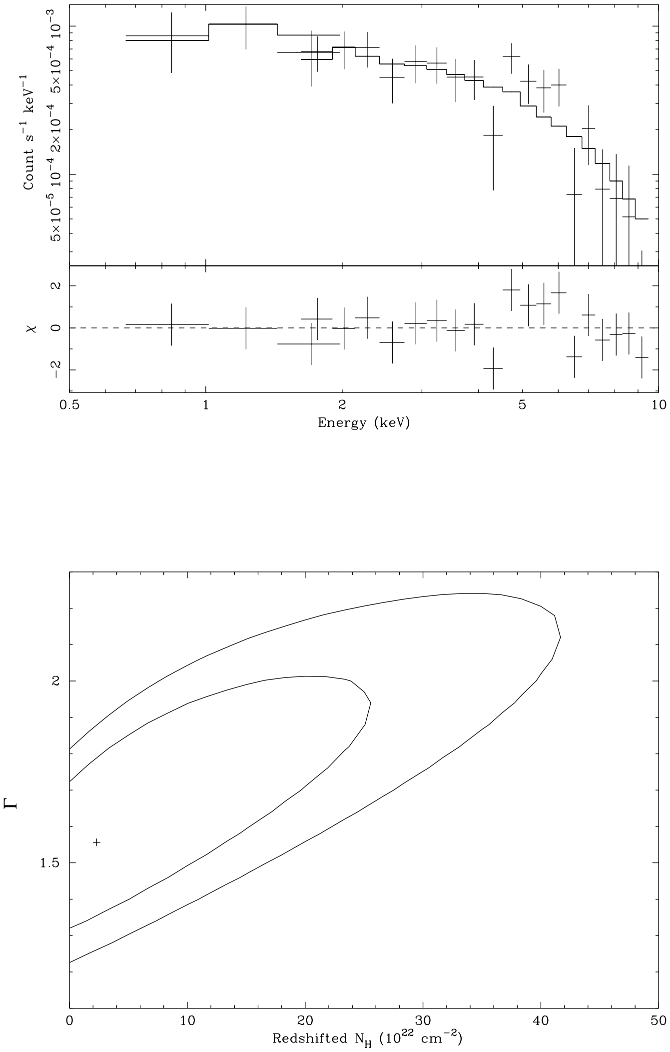

Fig. 3. Top panel: the emitted spectrum of 1SAX J1156.4+6513 in the 0.7-10 keV energy band as measured with the LECS and MECS telescopes. Bottom panel: the joint confidence contour for Γ and N_H. 68% and 90% confidence levels are shown.
Note that the model assumes a redshift *z*=3.42.

is completely consistent with the expected value due to galactic absorption along the line of sight $N_H \approx 1.6 \times 10^{20}$ cm^{-2}. To have a meaningful upper limit for N_H at the GRB frame, if the association of GRB971214 with the host galaxy is correct and therefore its redshift is 3.42, the measure of N_H coming from the formal fit with a non-redshifted function is useless. We therefore performed also an analysis using a redshifted model. The power law index is obviously unchanged, while the N_H value is completely not determined. The measured 2-10 keV flux is $2.55 \pm 0.2 \times 10^{-13}$erg cm^{-2} s^{-1}, corresponding to a total 2-10 keV fluence of 4.9×10^{-8} erg cm^{-2} from 23300 s to 215000 s after the GRB. In Fig. 3 we show the count rate spectrum with the fitted power law and the joint confidence contours (68% and 90%) for Γ and N_H.

We analyzed separately the spectrum in three time intervals, to search for spectral variations. Within the accuracy of our detection, the three time resolved spectra are consistent with no spectral variation.

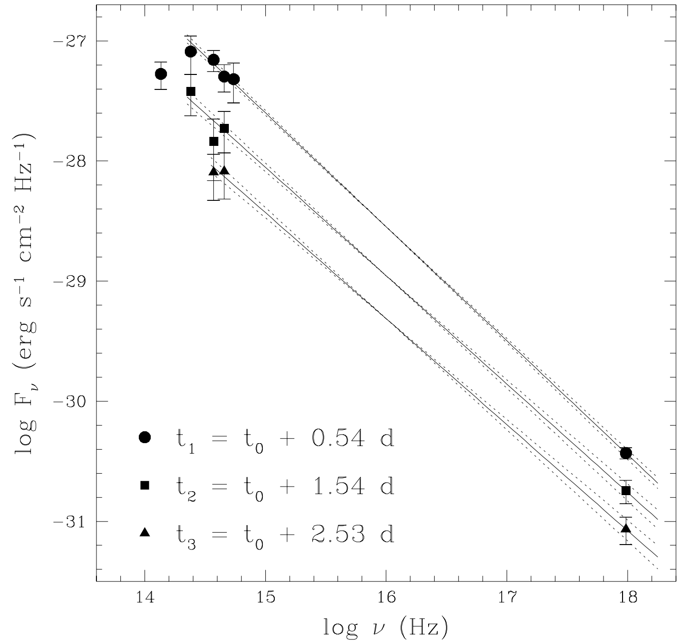

Fig. 4. Near-infrared, optical and X-ray data of the afterglow of GRB971214 at three epochs. Optical/IR data are from Diercks et al. (1998), Halpern et al. (1998), Ramaprakash et al. (1998) and Kulkarni et al. (1998). The IR and optical data have been corrected for Galactic and intrinsic absorption (see text). The X-ray data are corrected for Galactic extinction. The power law fits to the simultaneous J-band-to-X-ray data are shown (solid lines) along with their 1σ confidence ranges (dotted lines). The GRB trigger time is defined as t_0.

3. The broad band spectrum of the afterglow

For the afterglow of GRB971214, we collected from the literature (see caption of Fig. 4 for references) optical and near-IR data taken on 1997 Dec 15, 16 and 17 to construct broad-band spectra from IR to X-rays. To determine the magnitudes of the Optical Transient (OT), we first subtracted from the measurements the contribution of the host galaxy, for which we considered V=26.5 (Odewahn et al. 1998), R=25.6 (Kulkarni et al. 1998), I=25.4, J=25.0, K=24.5, estimated from $H_{\rm host} = 23.7$ by Fruchter et al. (in preparation) assuming a flat IR spectrum. Next, we corrected the resulting OT magnitudes for the foreground Galactic absorption using A_V = 0.1 (from Dickey & Lockman 1990) and the extinction law by Cardelli et al. (1989). For each of the three considered epochs, we referred all data points taken on that night to the dates 1997 Dec 15.51 (t_1), 16.51 (t_2), and 17.50 (t_3), respectively. If needed, we rescaled the data to the corresponding reference date using a power law decay with index $\beta_{\rm t\_opt} = -1.2 \pm 0.02$ (Diercks et al. 1998).

We also considered a possible dust obscuration at the source redshift, based on the hypothesis that GRBs could be associated with star formation (e.g. Paczyński 1998), and applied to the OT data the extinction law of Calzetti (1997) for a typical starburst galaxy at z=3.42 (details about this correction will be reported in

Masetti et al. in preparation).The corrected data together with the 2-10 keV fluxes observed at epochs t_1 and t_2 and the extrapolation at epoch t_3 of the X-ray flux in the same band are reported in Fig. 4.

The optical and X-ray data are well fitted, in a F_ν versus ν diagram, by single power laws with slopes $\alpha_{\rm opt\_X} = -0.95 \pm 0.02$ (t_1), $\alpha_{\rm opt\_X} = -0.90 \pm 0.04$ (t_2), and $\alpha_{\rm opt\_X} = -0.88 \pm 0.04$ (t_3). These values are all marginally consistent among each other within the 1σ uncertainties and with the slope of the 2-10 keV X-ray spectrum $\alpha_{\rm X} = -0.6 \pm 0.2$, and are compatible with the value $\alpha_{\rm exp} = -0.8$, expected for $\beta_{\rm t} = -1.2$ if the peak frequency $\nu_{\rm m}$ of the afterglow multiwavelength spectrum, produced by a single synchrotron radiation component, has already passed the optical/IR band and the cooling frequency $\nu_{\rm c}$ has not (*slow cooling case*, Waxman 1997a, 1997b, Sari et al. 1998).

The presence of a spectral turnover in the IR, already noted by Ramaprakash et al. (1998), who applied *a posteriori* an extinction correction to the optical/near-IR afterglow data, could be identified with the change of spectral slope at the frequency $\nu_{\rm m}$ in the framework of the above-mentioned model (see however Wijers & Galama 1999). The rather low statistical quality of the IR data prevents an accurate measure of the spectral index $\alpha_{\rm IR} = 0.75^{+1.05}_{-1.15}$ for epoch t_1, that is consistent with the expected value 0.33.

Afterglow data shown in Fig. 4 are quite remarkable. The broad-band spectrum over four decades of photon energy clearly shows that the optical and X-ray emission vary in a coordinated way. The deduced broad-band energy index $\alpha'_{\rm opt\_X} \sim -1$ (within uncertainties) indicates a *flat* $\nu\,F_\nu$ *spectrum for three decades of photon energy*. In a model for which the optical and X-ray afterglow emission is produced by a single distribution of energized particles, the flatness of the $\nu\,F_\nu$ spectrum can be obtained only by a very efficient acceleration process that has to operate despite the radiation and adiabatic losses. In our data extending up to 2.5 days after the prompt burst emission, there is no sign of a spectral break due to a transition between fast and slow cooling. Other bursts behave differently, with breaks observed both in the lightcurves and spectra at late times (e.g. GRB990123, Akerlof et al. 1999, GRB990510, Harrison et al. 1999).

4. Discussion

Various authors have discussed the emission in the afterglow (e.g. Tavani 1997, Vietri 1997, Mészáros & Rees 1997b, Sari et al. 1998, Waxman 1997a, 1997b), giving a convincing answer to the problem of light curve modeling.

The observed decay during the afterglow (Heise et al. in preparation) smoothly reconnects with the observed X-ray flux during the burst. In the hypothesis that the afterglow starts a few seconds after the end of the main event, we can estimate the total fluence in the afterglow, to be compared with the X-ray luminosity during the prompt event. This hypothesis is supported by the recent detection of an optical afterglow in GRB990123 a few seconds after the burst trigger (Akerlof et al. 1999) and by the interpretation of the observed complex light curve (Sari & Piran 1999). Also the detection of an early power–law–like tail from GRB920723 (Burenin et al. 1999) supports the hypothesis that the afterglow starts immediately after the GRB, and probably without any interruption in the X–ray flux. Of course this assumption adds further uncertainty to the total estimate. As an example, assuming that the afterglow starts $\sim$1000 s after the trigger of the main event (and not a few seconds after *the end* of the main event) the total integral differs by a factor $\sim$2.

In doing this estimate we have to assume a spectral shape and slope. Assuming a time decay law $\propto {\rm t}^{-\beta_{\rm t\_X}}$ with $\beta_{\rm t\_X}$ $\sim$1.2 (Heise et al. in preparation), we obtain that the total fluence in the afterglow between 2 and 10 keV uncorrected for redshift is 4.1×10^{-7} erg cm^{-2}. It corresponds to a luminosity of 1.3×10^{52} erg. This is 2 times the total luminosity in the same energy band during the burst. This is a lower limit, as we do not add any time evolution of the spectral shape, but we conservatively adopt the measured spectral index during the afterglow, much steeper than that measured during the prompt event.

If we assume a similar, or even steeper, spectral slope in the 2-700 keV energy interval (uncorrected for redshift), the total energy output from the afterglow is substantial. For the same power law index measured in the 2-10 keV energy band, we obtain a fluence in the afterglow 4.5×10^{-6} erg cm^{-2}. Using a more conservative assumption, adding an exponential cutoff with folding energy $\sim$50 keV, the total fluence in the afterglow up to 2.5 days after the main event is 1.15×10^{-6} erg cm^{-2}. We conclude that the *radiated* X and γ total luminosity in the afterglow may be estimated to be between 3.6×10^{52} ergs and 1.4×10^{53} ergs. This is comparable to the total radiated power in the main GRB event. This estimate is only speculative, as the spectral data of the afterglow are consistent with any cutoff energy above $\sim$2 keV (90% confidence) but it points out the need for prompt measurements of the afterglow that can give a good estimate of the spectral shape above 10 keV.

Unfortunately the spectral evolution in hard X-rays (above 10 keV) of most GRBs seems unaccessible to the present generation of telescopes operating in this energy band. This is a very important observational point that cannot be fulfilled up to the next generation of focusing hard X-ray telescopes, maybe at least for a decade.

The time resolved spectral analysis of the afterglow reported in Table 1, even if of low statistical quality, do suggest that the spectral shape remains stable during our observation of the afterglow. While these data cannot be profitably used to constrain the spectral evolution of the afterglow in X–rays, they confirm the stability of the *engine* that is producing the observed X–ray emission in spite of the substantial power–law decline with time in the observed X–ray luminosity.

The spectral evolution from GRB to the X-ray afterglow indicates that the energy distribution shifts towards lower energies, as expected from theoretical models. The model for spectral evolution of Sari et al. (1998) suggests that the high energy tail of the emitted photon spectrum of the afterglow has a power law slope $\sim -\frac{\rm p}{2} - 1$ in the case of fast cooling, where p is the index of a power law distribution of the electrons. Our measurement of a power law slope ~ -1.6 implies p~ 1.2, a value that would give a non-finite energy in the electrons. In this case the observations can be reconciled with theory assuming that a suitable cutoff, e.g. exponential, in the energy distribution of the parent electron population is present. The observation of this cutoff in the produced photon distribution is however beyond the capability of the present generation of X–ray telescopes and may be accessible to the new missions like *XMM* and *Chandra* if it is substantially below 100 keV. Our data support (as suggested also by Waxman 1997a, 1997b) that we observe a regime where the synchrotron cooling time is long compared to the dynamical time. In this regime $\Gamma = -\frac{(p-1)}{2} - 1$, and for a finite power in the electrons one obtains $\Gamma < -1.5$, definitely compatible with our measurement. A caveat must be added to this interpretation: as the adiabatic losses become dominant in this regime, the observed *radiated* luminosity is produced via synchrotron losses in much an inefficient way. This brings down the efficiency of the radiative process and in parallel rises accordingly the total energy budget in the afterglow.

The slope of the NIR-to-X-ray afterglow spectrum, corrected for Galactic and local extinction, and its temporal evolution are in fair agreement with models of expanding fireballs. Our assumption on the intrinsic extinction reasonably conforms with the proposal that GRBs are connected with star formation, and therefore expected to reside in star forming regions of their host galaxies (though not necessarily in extreme starburst galaxies, see Odewahn et al. 1998). We note that the local extinction correction we adopted has the advantage, with respect to other approaches, of using a specific model curve and of making the spectrum consistent with a single radiation component over more than three decades of frequency.

If the emission is isotropic the total X-γ luminosity in GRB971214, if at redshift z=3.42, is quite higher than 10^{51} ergs, as already pointed out by Kulkarni et al. (1998). Our analysis shows that a substantial fraction, more than 60%, of the total radiated energy in 2-10 keV is in the afterglow. In addition a reasonable guess of a high energy exponential cutoff, with a folding energy of 50 keV, brings us to conclude that the total power in GRB971214 may be grossly underestimated if based only on the prompt event.

If the efficiency to convert the total energy output from the GRB in the afterglow is low, e.g. $\sim$10%, as usually assumed in most theoretical models of fireball expansion, our measure of a substantial energy output in 2–10 keV during afterglow shows that the total energy balance of a GRB is grossly underestimated. Furthermore, if we consider the probable presence of a high energy tail of the afterglow, a conservative estimate may bring the total energy output from GRB971214 to more than 10^{54} erg for an isotropically emitting source. Alternatively, one may more comfortably stay with a luminosity of 10^{53} erg assuming a more efficient mechanism to effectively extract radiative power from the expanding fireball or assuming an extreme cutoff to the high energy spectrum.

A way out of this deadlock may be beaming (Yi 1994, Shaviv & Dar 1995). Different authors have discussed the "beaming solution" to the GRB/afterglow observational problem (Dar 1998, 1999, Rhoads 1997, Mészáros & Rees 1997b, Drodzova & Panchenko 1997, Panaitescu et al. 1998). If the emitted power is strongly beamed, and therefore not isotropically distributed, the total power in the GRB may be reduced by orders of magnitude, depending on the beam open angle. Of course this has some major and obvious impacts. The number of GRBs (not detected at earth) rises by the same orders of magnitude. Limb darkening (due to the random distribution of viewing angles inside the emission cone), time dependent (due to different beaming at different times after the main event) and energy dependent (due to the time–dependent photon energy distribution) effects should be observable once the afterglow sample is large enough. Examples of such effects are discussed in Panaitescu et al. (1998), including a mixed case with a collimated jet and a contribution from isotropic ejecta.

Assuming a jetlike outflow, the models (Panaitescu et al. 1998, Rhoads 1999, Sari et al. 1999) predict a steeper decay in the light curve, depending on the jet opening angle. This steepening compared to an isotropic fireball expansion occurs for a 10^{o} opening angle at approximately 6 days after the event, earlier for smaller angles. We do not detect such a steepening in the X–ray light curve up to 2.5 days after the main event. If we assume a beam open angle $\theta \geq 10^{o}$ the total energy in the event is reduced accordingly, compared to the isotropic case.

An argument to assess jetlike or spherical emission is proposed by Sari et al. (1999), using the decay slope of the high energy afterglow. As reported by other authors (see above), they suggest that the power law decay for a jetlike emission is appreciably steeper. For an isotropic fireball the expected decay is $t^{-\beta_X}$ with $\beta_X \sim 1.1 - 1.3$, while for an expanding jet the decay follows a power law with $\beta_X \sim$ 2.4.
This effect is purely geometrical, as it is geometrical the effect of the jet *"spillover"* (Rhoads 1999) expanding sideways at the local sound speed. In order to maintain the observed time decay power law $\propto t^{-1.2}$, the Lorentz factor γ must be $> \theta^{-1}$ during all the afterglow observation (see e.g. Piran 1995). In the case of GRB971214, this must hold up to the last observation of the power law decay, performed approximately 2.5 days (60 hours) after the prompt event. Following Sari et al. (1999 this translates in a lower limit to the beam opening angle $\theta_0 > 0.1 \times (6.2 \times 60 \times (E_{52}/n_1)^{\frac{1}{3}})^{\frac{3}{8}} \approx 0.2$, assuming the total "isotropic" energy in the afterglow is $\sim 10^{53}$ ergs. This lower limit in beaming angle translates into a lower limit in the total radiated power from this GRB (prompt+afterglow) $\sim 10^{52}$ ergs.

If the effect of beaming is comparable during the prompt event and the afterglow, the conclusions we draw on the relative *observed* energy output apply also directly to the total energy balance in the two cases. If the effect of beaming is evolving from an extremely beamed emission during the event to a relatively hollow beaming during the part of the afterglow we observed, the relative energy balance between the two cases should scale accordingly. As a consequence, the energy budget in the afterglow may increase substantially with respect to that in the prompt event.

In conclusion the measurement of the spectrum during the prompt event and during the afterglow strongly supports the models for synchrotron emission from GRB afterglows, with an agreement both in the X-ray band and in a broader NIR-to-X-rays band (see Fig. 4). The measured spectral slope is in fair agreement with the requirements of the models of expanding fireballs, considering also the observed temporal decay. A simple argument, based on recent models on jetlike emission and on the expected temporal decay in this case, supports the observation of a spherical expanding shell or of a moderate beaming ($\theta > 0.2$). If this is the case, the observed radiated power in the afterglow is substantial and should be accordingly reproduced in any model for X-ray afterglow from GRBs.

Acknowledgements. This research is supported by the Agenzia Spaziale Italiana (ASI) and the Consiglio Nazionale delle Ricerche (CNR) of Italy. BeppoSAX is a joint program of ASI and of the Netherlands Agency for Aerospace Programs (NIVR). We wish to thank all the people of the BeppoSAX Scientific Operation Centre and the Operation Control Centre for their skillful and enthusiastic contribution to the GRB research program.

References

Akerlof C.W., Balsano R., Barthelmy S., et al., 1999, Nat 398, 400
Amati L., Frontera F., Costa E., et al., 2000, A&AS 138, 403
Antonelli A., Butler R.C., Piro, L., et al., 1997, IAU Circ. 6792
Arnaud K.A. 1996, in Astronomical Data Analysis Software and Systems V, Jacoby G.H., Barnes J., (eds.) ASP Conf. Series volume 101, p. 17
Bakos G., Sahu K., Menzies J., et al., 1999, GCN Circular 387
Band D., Matteson J., Ford L., et al., 1993, ApJ , 413, 281
Bloom J.S., Frail D. A., Kulkarni S.R., et al., 1998, ApJ 508, L21
Boella G., Butler R. C., Perola G.C., et al., 1997a, A&AS 122, 299
Boella G., Chiappetti L., Conti G., et al., 1997b, A&AS 122, 327
Bond H.E. 1997, IAU Circ. 6654
Burenin R. A., Vikhlinin A. A., Gilfanov M. R., et al., 1999, A&A 344, L53
Calzetti D., 1997, AJ 113, 162
Cardelli J.A., Clayton G.C., Mathis J.S., 1989, ApJ 345, 245
Cavallo G., Rees M., 1978, MNRAS 183, 359
Costa E., Frontera F., Heise J., et al., 1997, Nat 387, 783
Dar A., 1998, ApJ 500, L93
Dar A., 1999, A&AS 138, 505
Dickey J.M., Lockman F.J., 1990, ARA&A 28, 215
Diercks A., Deutsch E.W., Castander F.J., et al., 1998, ApJ 503, L105
Drodzova N.D., Panchenko I.E., 1997, A&A 324, L17
Feroci M., Frontera F., Costa E., et al., 1997, in EUV, X-Ray, and Gamma-Ray Instrumentation for Astronomy VIII, Siegmund O.H., Gummin M.A., (eds.) SPIE Proceedings 3114, p. 186
Frontera F., Costa E., Dal Fiume D., et al., 1997, A&AS 122, 357
Frontera F., Amati L., Costa E., et al., 2000, ApJ in press
Galama T., Vreeswijk P.M., Van Paradijs J., et al., 1998, Nat 395, 670
Galama T., Vreeswijk P.M., Rol E., et al., 1999, GCN Circular 313
Groot P.J., Galama T.J., Vreeswijk P.M., et al., 1998, ApJ 502, L123
Hakkila J., Meegan C.A., Horack J.M., et al., 1996, ApJ 462, 125
Halpern J. P., Thorstensen J.R., Helfand D.J., et al., 1998, Nat 393, 41
Harrison F.A., Bloom, J.S., Frail, D.A., et al., 1999, ApJ 523, L121
Heise J., in't Zand J, Spoliti G., et al., 1997, IAU Circ. 6787
Hjorth J., Andersen M.I., Pedersen H., et al., 1998, GCN Circular 109
Jager R., Mels W.A., Brinkman A.C., et al., 1997, A&AS 125, 557
Jaunsen A.V., Hjorth J., Andersen M. I., et al., 1998, GCN Circular 78
Kippen R.M., Woods P., Connaughton V., et al., 1997, IAU Circ. 6789
Kulkarni S.R., Adelberger K L., Bloom J.S., et al., 1997, GCN Circular 029
Kulkarni S.R., Djorgovski S.G., Ramaprakash A.N., et al., 1998, Nat 393, 35
Kulkarni S.R., Djorgovski S.G., Odewahn S.C., et al., 1999, Nat 398, 389
Manzo G., Giarrusso S., Santangelo A., et al., 1997, A&AS 122, 341
Mészáros P., Rees M.J., 1997a, ApJ 476, 232
Mészáros P., Rees M.J., 1997b, ApJ , 482, L29
Metzger M.R., Djorgovski S.G., Kulkarni S.R., et al., 1997, Nat 387, 261
Odewahn S.C., Djorgovski S.G., Kulkarni S.R., et al., 1998, ApJ 509, L5
Paczyński B., 1998, ApJ 494, L48
Palazzi E., Pian E., Masetti N., et al., 1998, A&A 336, L95
Palazzi E., Masetti N., Pian E., et al., 1999, GCN Circular 377
Panaitescu A., Mészáros P., Rees M.J., 1998, ApJ 503, 314
Parmar A., Martin D.D.E., Bavdaz M., et al., 1997, A&AS 122, 309
Piran T., 1995, Proceedings of the Second Huntsville Workshop, Fishman G.J., Brainerd J.J., Hurley K., (eds.) AIP Conference Proceedings 307, p. 495
Piro L., Heise J., Jager R., et al., 1998, A&A 329, 906
Preece R.D., Pendleton, G.N., Briggs, M.S., et al., 1998, ApJ 496, 849
Ramaprakash A.N., Kulkarni S.R., Frail D.A., et al., 1998, Nat 393, 43
Rhoads J.E., 1997, ApJ 487, L1
Rhoads J.E., 1999, ApJ , submitted (*astro-ph/9903399*)
Sari R., Piran T., 1999, ApJ 517, L109
Sari R., Piran T., Halpern J.P., 1999, ApJ 519, L17
Sari R., Piran T., Narayan R., 1998,ApJ 497, L17
Shaviv N.J., Dar A., 1995, ApJ 447, 863
Tavani M., 1997, ApJ 483, L87
van Paradijs J., Groot P. J., Galama T., et al., 1997,Nat 386, 686
Vietri M., 1997, ApJ 488, L105
Waxman E., 1997a, ApJ 485, L5
Waxman E., 1997b, ApJ 489, L33
Wijers R.A.M.J., Galama T.J., 1999, ApJ 523, 177
Yi I., 1994, ApJ 431, 543