A&A 399, 505–509 (2003)
DOI: 10.1051/0004-6361:20021825

Astronomy & Astrophysics

Observing scattered X-ray radiation from gamma-ray bursts: A way to measure their collimation angles

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Received 1 July 2002 / Accepted 22 November 2002

Abstract. There are observational facts and theoretical arguments for an origin of gamma-ray bursts (GRBs) in molecular clouds in distant galaxies. If this is true, one could detect a significant flux of GRB prompt and early afterglow X-ray radiation scattered into our line of sight by the molecular and atomic matter located within tens of parsecs of the GRB site long after the afterglow has faded away. The scattered flux directly measures the typical density of the GRB ambient medium. Furthemore, if the primary emission is beamed, the scattered X-ray flux will be slowly decreasing for several months to years before falling off rapidly. Therefore, it should be possible to estimate the collimation angle of a burst from the light curve of its X-ray echo and a measured value of the line-of-sight absorption column depth. It is shown that detection of such an echo is for the brightest GRBs just within the reach of the Chandra and XMM-Newton observatories.

Key words. gamma rays: bursts – scattering

1. Introduction

One of the fundamental questions relating to the gamma-ray burst (GRB) phenomenon is how much energy is released during a GRB. Given a measured burst fluence, the inferred energy release is proportional to $\theta_0^2/2$, where θ_0 is the opening angle of the collimated relativistic fireball (Piran 1999) that is probably small ($\theta_0 \ll 1$). Apart from constraining the burst energetics, θ_0 also determines the event rate of GRBs in the universe (which is proportional to θ_0^{-2}). Thus, the beaming angle is a very important quantity in GRB research.

There have been attempts to estimate θ_0 via observing a break in GRB afterglow light curves and interpreting this break as due to a slowing down of the jet to $\Gamma < \theta_0^{-1}$ (here Γ is the bulk Lorentz factor of the jet). Summarizing the information on jet break times in more than a dozen of GRBs Frail et al. (2001) have inferred values for θ_0 ranging from 1° to more than 25°. These authors came to the conclusion that the gamma-ray energy release is narrowly clustered around 5×10^{50} ergs. However, since their derivation was based on a particular interpretation of the observed breaks and that other explanations for such breaks exist (as mentioned by Frail et al. 2001), these measurements of θ_0 should necessarily be considered tentative for the time being.

Another fundamental issue is the environment in which GRBs occur. High gas column densities ($N_{\rm H} \sim 10^{22}$ cm^{-2}) toward GRB locations have been inferred from a spectral analysis of a sample of X-ray afterglows observed with BeppoSAX (Owens et al. 1998; Galama et al. 2001; Reichart & Price 2002). Such values of $N_{\rm H}$ are typical of Galactic giant molecular clouds and therefore a strong indication that GRBs occur in star forming regions of their host galaxies, which in turn argues for collapse of massive stars as their sources (Woosley 1993; Paczyński 1998).

In this paper we propose an observational test that enables direct determination (with some reservations) of both the collimation angle of a GRB and the typical density of the medium surrounding it on scales of pcs to tens of pcs typical of molecular clouds and complexes. This method consists of observing the location of a bright GRB with a powerful X-ray telescope several times during the first months to years after the burst. We predict that in such observations a weak X-ray flux may be detected, which will be radiation from the burst reaching us, delayed by scattering from the ambient medium.

The idea at the basis of the proposed method – to search for scattered GRB radiation – is not new. The theme of scattered X-ray emission was first introduced by Dermer et al. (1991) in the context of the then popular model of the galactic stellar binary origin of GRBs. Madau et al. (2000) considered Compton echoes from gamma-ray bursts arising in the circumburst environment within a fraction of a pc of the GRB site. These authors focused on the case where the primary burst emission is collimated away from us. Ramirez-Ruiz et al. (2001) further elaborated this scenario. Esin & Blandford (2000) studied the

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Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20021825

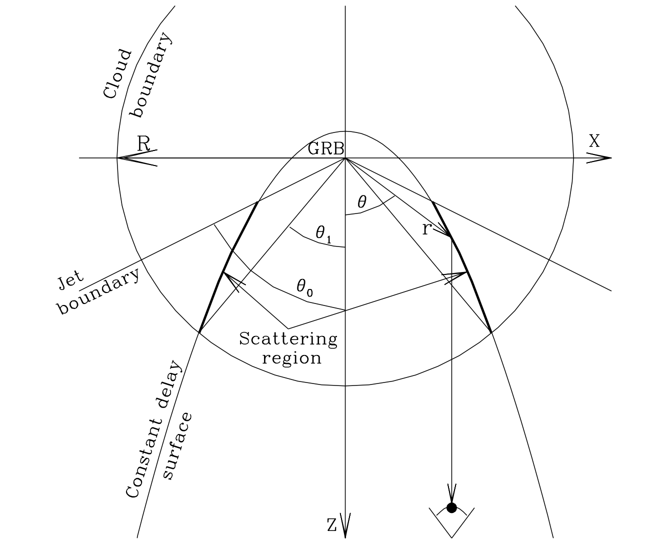

Fig. 1. Schematic diagram (cross section) of the model in which a collimated GRB occurs at the center of a molecular cloud and the observer sees GRB X-ray radiation scattered by the gas. The scattering sites contributing to the detected flux at a given time lie on a constant-delay paraboloid between the jet and cloud boundaries.

scattering of GRB early optical emission on the surrounding dust, while Mészáros & Gruzinov (2000) considered a similar phenomenon – small-angle scattering of X-rays by dust.

Ghisellini et al. (1999) and Böttcher et al. (1999) have computed the time dependence of fluorescence emission in the iron $K\alpha$ line resulting from the interaction of the GRB radiation with the surrounding matter under the assumption that the burst emission is isotropic. Detection of such a fluorescent line would make it possible to determine the redshifts of GRBs with invisible optical afterglows. However, the predicted flux in the line is apparently too low to be detected with the current generation of X-ray telescopes unless the density of interstellar material at the GRB site is very high ($n \gtrsim 10^4$ cm^{-3}). We note here (see Sect. 2) that the scattered X-ray flux in the relevant 0.3–5 keV band will typically be an order of magnitude higher than the flux of fluorescence emission in the same band. As we shall see, this enhancement factor proves crucial for the problem at hand, as it makes the emergent signal detectable with the present-day X-ray telescopes provided that GRBs indeed originate within molecular clouds.

2. Delayed scattered X-ray emission from GRB

We base our treatment on a simple model depicted in Fig. 1. A GRB occurs at the center of a spherical cloud of gas of constant density n (equivalent number density of hydrogen atoms; the gas may be a mixture of atoms and molecules) and radius R. The host galaxy is located at a redshift z. The blastwave expands into a cone with an opening angle θ_0, so that only observers located within this cone can directly receive X-ray and gamma-ray radiation from the burst. Note that since the bulk Lorentz factors of GRB fireballs are believed to be very large ($\Gamma \sim 10^2$–10^3), observers in other directions will detect very low fluxes of radiation and at energies below X-rays. In our model, we are located exactly on the symmetry axis of the jet. Another parameter of the model is the GRB fluence, S_X, in some specified X-ray band $[E_1, E_2]$.

The scattered X-ray emission is observed from Earth at a time t after the GRB. The scattering surface of constant delay will be a paraboloid with its focus at the GRB site and its axis along our line of sight,

$$r = \frac{ct}{(1+z)(1-\cos\theta)}, \quad (1)$$

(Blandford & Rees 1972), where θ is the scattering angle and c is the speed of light. The factor $(1+z)^{-1}$ takes into account cosmological time dilation. As is detailed below (in Sect. 3), the fluence of the early X-ray afterglow ($t \lesssim 10^4$ s) may for some GRBs constitute a significant fraction of the X-ray fluence of the burst itself. The usual interpretation for such early afterglow emission is that it arises from the interaction of the jet with the external medium at a distance of 0.01–0.1 pc from the site of the burst. Therefore, Eq. (1) will remain an appropriate approximation when considering the echo associated with the early afterglow if $R \gtrsim 1$ pc, which we assume to be the case.

Only positions ($r < R, \theta < \theta_0$) will contribute to the scattered X-ray flux. The corresponding range of scattering angles is $\theta_1 < \theta < \theta_0$, where the critical angle (see Fig. 1)

$$\theta_1 = \arccos\left(1 - \frac{ct}{R(1+z)}\right). \quad (2)$$

The scattered X-ray flux in $[E_1, E_2]$ is then

$$F_X = S_X n \int_{\theta_1}^{\theta_0} \frac{d\sigma}{d\Omega}\frac{dr}{dt}\, d\Omega, \quad (3)$$

where $d\Omega = 2\pi\, d\cos\theta$ and $dr/dt = c(1+z)^{-1}(1-\cos\theta)^{-1}$. The differential cross section for scattering, which includes coherent (Rayleigh) and incoherent (Raman and Compton) scattering, is given by

$$\frac{d\sigma}{d\Omega} = A(\theta)\frac{3\sigma_T}{16\pi}(1+\cos^2\theta), \quad (4)$$

where σ_T is the Thomson cross section. The coefficient $A(\theta)$ allows for the fact that Rayleigh scattering of X-rays through small angles on molecules of hydrogen and atoms of heavier elements, most importantly helium, is more efficient (calculated per electron) than scattering on atomic hydrogen. $A(\theta)$ takes values between 1 and 2 for $\theta \to 0$, depending on the fraction of molecular hydrogen and helium in the interstellar medium, and is close to 1 for large scattering angles (e.g. Sunyaev & Churazov 1996). As we are primarily interested in situations where the jet opening angle is small ($\lesssim 30°$) and the scattering medium is a molecular cloud, we shall adopt $A(\theta) \sim 1.5$ for our estimates below.

On integrating over the solid angle in Eq. (3) we get

$$F_X = \frac{3}{8} A S_X n (1+z)^{-1} c\sigma_T f(\theta_0, \theta_1) \quad (5)$$

$$f(\theta_0,\theta_1) = \frac{(\cos\theta_0 - \cos\theta_1)(\cos\theta_0 + \cos\theta_1 + 2)}{2} + 2\ln\frac{1-\cos\theta_0}{1-\cos\theta_1}. \quad (6)$$

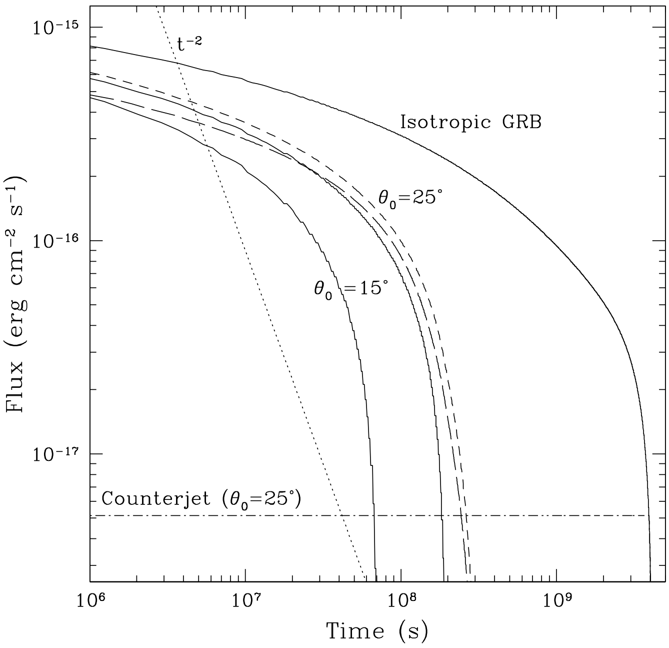

Fig. 2. Scattered X-ray flux as a function of elapsed time after a GRB at $z = 1$ with $S_X = 10^{-5}$ erg cm^{-2}. The different solid lines correspond to a GRB origin in the center of a uniform molecular cloud with R = 10 pc and $n = 10^3$ cm^{-3}, and different burst collimation angles: $\theta_0 = \pi$, 25° and 15°. Also shown are the light curves for a GRB with $\theta_0 = 25°$ located at $x = 0.5R$, $z = -0.5R$ (see Fig. 1) in the same uniform cloud (short-dashed line) and in a cloud of radius R = 10 pc with a density law $n(r) = n_0(R/r)$, $n_0 = 5 \times 10^2$ cm^{-3} (long-dashed line). The horizontal dash-dotted line represents the scattered signal from the counterjet. The dotted line represents X-ray afterglow emission with parameters similar to the afterglow of the bright GRB 000926 observed with Chandra at a late time $t \sim 10^6$ s.

The function $f(\theta_0, \theta_1)$ carries information on the time dependence of the scattered flux. Introducing a critical time

$$t_1 = \frac{R(1+z)(1-\cos\theta_0)}{c}, \tag{7}$$

we may rewrite Eq. (6) as

$$f = 2\ln\frac{t_1}{t} - \frac{1-\cos\theta_0}{2}\left(1-\frac{t}{t_1}\right) \times\left[4-\left(1+\frac{t}{t_1}\right)(1-\cos\theta_0)\right] \rightarrow 2\ln\frac{t_1}{t} \text{ for } t_{\rm GRB} \ll t \ll t_1, \tag{8}$$

where $t_{\rm GRB}$ is the duration of the burst. We notice that the scattered flux tends to infinity as $t \rightarrow 0$, being limited only by the finite GRB duration. This reflects the fact that at early times the dominant contribution to the flux comes from small scattering angles while the scattering front sweeps rapidly through the cloud toward us: $\mathrm{d}r/\mathrm{d}t \propto \theta^{-2} \propto t^{-1}$. We also see that if the GRB emission is collimated in a narrow cone, then the slow (logarithmic) decline of F_X will be followed by a rapid drop to zero when the critical angle $\theta_1(t)$ approaches the jet opening angle θ_0. The scattered flux will vanish completely at $t = t_1$.

Equations (5), (7) and (8) provide a complete description of the scattering effect. Substituting some values for the parameters, we get

$$F_X = 5\times10^{-16}\,\mathrm{erg\,cm^{-2}\,s^{-1}} \times\frac{A}{1.5}\frac{S_X}{10^{-5}\,\mathrm{erg\,cm^{-2}}}\frac{n}{10^3\,\mathrm{cm^{-3}}}\frac{1}{1+z}\frac{f(t)}{4} \tag{9}$$

for

$$t < t_1 = 10^9\,\mathrm{s}\frac{R}{10\,\mathrm{pc}}(1+z)(1-\cos\theta_0), \tag{10}$$

and $F_X = 0$ for $t > t_1$. Note that $f \sim 4$ corresponds to $t \sim 0.1t_1$.

Figure 2 shows examples of light curves of scattered GRB X-ray emission. One of the light curves represents the echo from a possible counterjet expanding away from us; the corresponding flux is very weak. Also plotted is the extrapolated light curve of the X-ray afterglow of the bright GRB 000926. This afterglow was observed with Chandra two weeks ($t \sim 10^6$ s) after the GRB, when the flux was still decaying as a power-law with an estimated index $\alpha \sim -2$ (Piro et al. 2001). This is the latest performed measurement of a GRB X-ray afterglow to our knowledge and as such it may be indicative of how steep the decay of X-ray afterglows is at $t \gtrsim 10^6$ s. Clearly, observations aimed at detecting the scattered radiation should be scheduled for a not too early moment of time, so that the afterglow signal has faded away. It appears that waiting for a few months after the GRB should typically be enough.

Suppose now that it is possible in an experiment to measure S_X, z, $F_X(t)$ and t_1. One will then be able to make the following estimates:

$$\theta_0 = \arccos\left(1-\frac{ct_1}{R(1+z)}\right) \approx 25°\left(\frac{t_1}{10^8\,\mathrm{s}}\right)^{1/2}\left(\frac{10\,\mathrm{pc}}{R}\right)^{1/2}(1+z)^{-1/2} \tag{11}$$

and

$$n = 2\times10^3\,\mathrm{cm^{-3}}\frac{1.5}{A}(1+z) \times\frac{10^{-5}\,\mathrm{erg\,cm^{-2}}}{S_X}\frac{F_X(t)}{10^{-15}\,\mathrm{erg\,cm^{-2}\,s^{-1}}}\frac{4}{f(t)}, \tag{12}$$

with $f(t)$ being given by Eq. (8).

It is evident that by performing one or two measurements of the scattered flux at well separated times $t \ll t_1$, i.e. in the quasi-flat part of the light curve, it should be possible to estimate the density of the cloud, or at least an upper limit on it, to within a factor of 2. The second (later) measurement is desirable because it enables us to roughly constrain the shape factor $f(t)$. To determine the collimation angle θ_0 it is necessary to have a better estimate of t_1, which requires at least three flux measurements at different times to be carried out, and also to know the radius of the cloud R. One can estimate the latter quantity, which is of interest in its own right, by measuring the absorption column density toward the GRB or its afterglow: $R = N_{\rm H}/n$. It is of crucial importance that the dependence of θ_0 on all parameters is fairly weak – see Eq. (11).

The actual environment of a GRB may differ significantly from our simplified model. However, we expect that the shape of the light curve of the scattered emission will not be affected dramatically by this. To illustrate this point we have plotted in Fig. 2 three different computed light curves corresponding to the case of $\theta_0 = 25^\circ$ and $R = 10$ pc, one of which is described by our analytic solution. We see that these curves are very similar despite the significant differences in the setup. This has a straightforward explanation: the signal detected at a given time results from integration over scattering sites, satisfying the condition $\theta_1 < \theta < \theta_0$, that are located at different distances and in different directions from the center of the cloud. Therefore, the scattered flux is proportional to some weighted average, $\langle n\rangle$, of the gas density over the scattering surface, which only weakly responds to changes in the geometry and distribution of gas.

Although we have so far only considered the scattering process, the GRB radiation can also be photoabsorbed by the neutral (or weakly ionized) matter, giving rise to fluorescence emission, mainly in the Fe Kα line (Ghisellini et al. 1999; Böttcher et al. 1999). Given the dependence of the photoabsorption cross section on energy, $\sigma \approx 3.5 \times 10^{-20}$ cm^2 $(7.11\,{\rm keV}/E)^{2.8}$, and the fluorescence yield of 0.34 (e.g. Vainshtein & Sunyaev 1981), assuming that the spectrum of primary X-ray emission is ${\rm d}N_{\rm photon}/{\rm d}E \propto E^{-\gamma}$ with γ close to 1 (as typically observed, see e.g. Amati 2002), and assuming solar abundance of iron, we find that fluoresence radiation contributes a fraction $\sim 0.2A^{-1}(1 + \cos^2\theta)^{-1}$ to the total detectable flux at 0.3–5 keV (which corresponds to the rest-frame 0.6–10 keV at $z = 1$), i.e. ~7% for the most interesting angles $\theta \to 0$ and a molecular fraction $A \sim 1.5$. This estimate is valid so far as the X-ray spectrum is not heavily absorbed, i.e. for $N_{\rm H} \lesssim$ a few $\times 10^{22}$ cm^{-2}, and is not strongly dependent on γ and z. We may therefore conclude that the fluorescence emission, although interesting, will typically be an order of magnitude fainter than the scattered component.

3. Detectability of the effect

A key question is of course the detectability of the X-ray echo. Equation (9) indicates that the effect should be just within the reach of the currently flying Chandra and XMM-Newton observatories for bursts with $S_{\rm X} \sim 10^{-5}$ erg cm^{-2} occuring in molecular clouds with $n \gtrsim 10^3$ cm^{-3}. How realistic are these values for both parameters?

First, we know that GRBs having $S_{\rm X} \sim 10^{-5}$ erg cm^{-2} do occur from time to time. Note that it is the X-ray fluence, rather than the total fluence, which is important for us. To make an estimate we have taken information (Amati et al. 2002) on the fluxes and spectra at >2 keV of twelve bright GRBs observed with the BeppoSAX satellite, then extrapolated the spectral fits to lower energies and calculated the fluences in the 0.3–5 keV band, where both Chandra and XMM-Newton have good sensitivity. We find two bursts among this sample with a sufficiently high X-ray fluence: GRB 990712 ($S_{\rm X} = 5\times10^{-6}$ erg cm^{-2}) and GRB 010222 ($S_{\rm X} = 7\times10^{-6}$ erg cm^{-2}). Other gamma-ray burst detectors with sensitivity in the X-ray band such as the one on Ginga (Yoshida et al. 1989), GRANAT/WATCH (Sazonov et al. 1998) and recently HETE/FREGAT (Barraud et al. 2002) have also detected a few GRBs with $S_{\rm X} \sim 10^{-5}$ erg cm^{-2}.

Fluence values quoted in the literature usually pertain to the prompt GRB emission. However, there are indications (Burenin et al. 1999; Giblin et al. 1999; Tkachenko et al. 2000) that a comparable X-ray fluence may be contained in early ($\sim 10^4$ s) GRB afterglows, during which the energy spectrum is much softer than during the burst proper. Without attracting spectral information it cannot be possible to separate the contributions of the prompt and early afterglow emission to the X-ray echo at early times ($t \ll t_1$), as the scattered X-ray flux will be simply proportional to the total of the X-ray fluences of the burst proper and its early afterglow. However, there are two possibilities for the light curve of the X-ray echo. In the case where the early afterglow emission is beamed exactly as the prompt radiation, the conclusions of Sect. 2 all remain true, except that in Eq. (12) one should understand $S_{\rm X}$ as the combined X-ray fluence of the GRB and the early afterglow. If, on the other hand, the early afterglow is characterized by its own beaming angle $\theta_{\rm a} \neq \theta_0$ the light curve of the X-ray echo will be a sum of two similarly shaped light curves (like those shown in Fig. 2), one corresponding to θ_0 and the other to $\theta_{\rm a}$, with their relative weights being proportional to the fluences of the prompt and early afterglow X-ray emission. Therefore, it should be in principle possible to estimate from the scattered light curve the angle $\theta_{\rm a}$ in addition to θ_0.

As regards the amplitude of the effect, we should also mention that Galactic absorption will lead to a reduction of the GRB fluence and similarly of the scattered flux in the 0.3–5 keV band. This, however, will only affect the flux near the lower boundary of the quoted spectral range, so the net effect is expected to be small (~10%).

Let us next consider the gas density. This is of course a quantity which the proposed effect enables to constrain. We may, however, speculate a little given the information available now. As mentioned in Sect. 1, X-ray spectral measurements reveal substantial optical depths to photoabsorption, $N_{\rm H} \sim 10^{22}$ cm^{-2}, in the directions of GRBs. Such column densities are similar to those of giant molecular clouds in the Milky Way and therefore imply number densities $n \sim 3\times10^2\,{\rm cm}^{-3}(N_{\rm H}/10^{22}\,{\rm cm}^{-2})(10\,{\rm pc}/R)$. This is about what is needed for the scattered X-ray emission from the brightest GRBs to be detectable. There is ongoing debate (e.g. Galama et al. 2001) as to why measured optical extinctions tend to be small even when the corresponding $N_{\rm H}$ is large. A possible explanation is that the UV and X-ray radiation from the GRB and its afterglow evaporates dust out to a few times 10 pc (Waxman & Draine 2000; Fruchter et al. 2001). We should also mention the issue of "dark bursts", i.e. GRBs with undetected optical afterglows. It is possible that such bursts occur in very dense clouds so that their optical afterglow emission is extinguished (e.g. Reichart & Yost 2001; Ramirez-Ruiz et al. 2002).

It is interesting to consider here again (see Sect. 2) the case of GRB 000926, whose afterglow was observed by BeppoSAX and Chandra. From analysis of X-ray and optical data, Piro et al. (2001) have inferred that the jet had an opening angle of $\theta_0 \sim 25°$ and expanded into a dense medium with $n = 4 \times 10^4$ cm^{-3} (see, however, Harrison et al. 2001; Panaitescu & Kumar 2002). At the time of the latest Chandra observation ($t \sim 10^6$ s), the afterglow emission was still easily detectable, with the flux at 0.2–5 keV being 8×10^{-15} erg cm^{-2} s^{-1}. GRB 000926 was discovered by the Interplanetory Network (Hurley et al. 2000), and its 25–100 keV fluence was 6.2×10^{-6} erg cm^{-2} (Piro et al. 2001). Assuming different values for the slope γ of the X-ray part of the GRB spectrum we may estimate that the GRB 000926 fluence at 0.3–5 keV was 4×10^{-7}, 2×10^{-6} erg cm^{-2} and 1.2×10^{-5} erg cm^{-2} for $\gamma = -1$, -1.5 and -2, respectively. We can then estimate from Eq. (9) the scattered X-ray flux during the last Chandra observation (assuming that $t \ll t_1$ so that $f(t) \sim$ a few): $F_X \sim 10^{-16}(1+z)^{-1}$, $4 \times 10^{-15}(1+z)^{-1}$ and $2 \times 10^{-14}(1+z)^{-1}$ erg cm^{-2} s^{-1} for the γ values given above. Therefore, if the density of the medium around GRB 000926 is indeed as high as implied by the analysis of Piro et al. (2001), then the scattered flux already could have constituted a significant fraction of the observed X-ray flux two weeks after the burst. In this case, however, the size of the scattering cloud must not be too large ($R \lesssim 10$ pc). Otherwise, it would be difficult to explain the marginally detected column density $N_H \approx 4 \times 10^{21}$ cm^{-2} (Piro et al. 2001), even taking into account the photoionization effect of the GRB on the ambient medium (Böttcher et al. 1999).

4. Conclusions

We have described a new observational method that enables us to determine the typical ambient medium density of bright GRBs as well as their degree of collimation in an almost model-independent way. This method can hopefully be employed with the existing Chandra and XMM-Newton X-ray telescopes.

A suitable observational strategy would be to schedule an observation of the site of a very bright ($S_X \sim 10^{-5}$ erg cm^{-2}) GRB a few months after the burst. Should some X-ray flux be detected during this observation, an additional one or two observations should be carried out several months or years later so that the light curve of the scattered emission could be roughly reconstructed and the GRB opening angle could be estimated (from Eq. (11)). If the first observation fails to yield a significant flux, an interesting upper limit, $\sim 10^3$ cm^{-3}, on the density of the medium surrounding the GRB on parsec scales can be derived (from Eq. (12)). It will take a 10^5 s observation with Chandra or XMM-Newton to detect a scattered flux of a few $\times 10^{-16}$ erg cm^{-2} s^{-1} at 0.3–5 keV. We emphasize that it is sufficient to collect a total of several photons from the GRB direction, as no detailed spectral information is needed. We also note that a flux of 5×10^{-16} erg cm^{-2} s^{-1} corresponds to an equivalent isotropic luminosity of order 10^{42} erg s^{-1} for a burst at $z \sim 1$. Therefore, the scattered GRB emission should outshine the X-ray emission of any non-active host galaxy.

Since GRBs with $S_X \sim 10^{-5}$ erg cm^{-2} are very rare events (at best a few per year), constant monitoring of the whole sky with an instrument sensitive to X-rays is crucial. After the end of the CGRO mission, such a capability will be provided by the Swift satellite[1].

Acknowledgements. We thank Eugene Churazov and Rodion Burenin for helpful comments. SS acknowledges support from a Peter Gruber Foundation Fellowship. This research was partly supported by the Russian Foundation for Basic Research (projects 00-02-16681 and 00-15-96649) and by the program of the Russian Academy of Sciences "Astronomy (Nonstationary astronomical objects)".

References

Amati, L., Frontera, F., Tavani, M., et al. 2002, A&A, 390, 81
Barraud, C., Olive, J-F., Lestrade, J. P., et al. 2002 [astro-ph/0206380]
Blandford, R. D., & Rees, M. J. 1972, Astrophys. Lett., 10, 77
Böttcher, M., Dermer, C. D., Crider, A. W., & Liang, E. P. 1999, A&A, 343, 111
Burenin, R. A., Vikhlinin, A. A., Gilfanov, M. R., et al. 1999, A&A, 344, L53
Dermer, C. D., Hurley, K. C., & Hartmann, D. H. 1991, ApJ, 370, 341
Esin, A. A., & Blandford, R. 2000, ApJ, 534, L51
Frail, D. A., Kulkarni, S. R., Sari, R., et al. 2001, ApJ, 562, L55
Fruchter, A., Krolik, J., & Rhoads, J. 2001, ApJ, 563, 597
Galama, T. J., & Wijers, R. A. M. J. 2001, ApJ, 549, L209
Ghisellini, G., Haardt, F., Campana, S., Lazzati, D., & Covino, S. 1999, ApJ, 517, 168
Giblin, T. W., van Paradijs, J., Kouveliotou, C., et al. 1999, ApJ, 524, L47
Harrison, F. A., Yost, S. A., Sari, R., et al. 2001, ApJ, 559, 123
Hurley, K., Mazets, E., Golenetskii, S., & Cline, T. 2000, GCN Circ. 801
Mészáros, P., & Gruzinov, A. 2000, ApJ, 543, L35
Madau, P., Blandford, R. D., & Rees, M. J. 2000, ApJ, 541, 712
Owens, A., Guainazzi, M., Oosterbroek, T., et al. 1998, A&A, 339, L37
Paczyński, B. 1998, ApJ, 494, L45
Panaitescu, A., & Kumar, P. 2002, 571, 779
Piran, T. 1999, Phys. Rep., 314, 575
Piro, L., Garmire, G., Garcia, M. R., et al. 2001, ApJ, 558, 442
Ramirez-Ruiz, E., Dray, L. M., Madau, P., & Tout, C. A. 2001, MNRAS, 327, 829
Ramirez-Ruiz, E., Trentham, N., & Blain, A. W. 2002, MNRAS, 329, 465
Reichart, D. E., & Price, P. A. 2002, ApJ, 565, 174
Sazonov, S. Y., Sunyaev, R. A., Terekhov, O. V., et al. 1998, A&AS, 129, 1
Sunyaev, R. A., & Churazov, E. M. 1996, Astron. Lett., 22, 648
Tkachenko, A. Yu., Terekhov, O. V., Sunyaev, R. A., et al. 2000, A&A, 358, L41
Vainshtein, L. A., & Sunyaev, R. A. 2001, Sov. Astron. Lett., 6, 353
Waxman, E., & Draine, B. T. 2000, ApJ, 537, 796
Woosley, S. E. 1993, ApJ, 405, 273
Yoshida, A., Murakami, T., Itoh, M., et al. 1989, PASJ, 41, 509

[1] http://swift.gsfc.nasa.gov/