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A unified picture for gamma-ray burst prompt and X-ray afterglow emissions

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ABSTRACT

Data from the *Swift* satellite have enabled us for the first time to provide a complete picture of the gamma-ray (γ-ray) burst emission mechanism and its relationship with the early afterglow emissions. We show that γ-ray photons for two bursts, 050126 and 050219A, for which we have carried out detailed analysis were produced as a result of the synchrotron self-Compton process in the material ejected in the explosion when it was heated to a mildly relativistic temperature at a distance from the centre of explosion of order the deceleration radius. Both of these bursts exhibit rapidly declining early X-ray afterglow light curves; this emission is from the same source that produced the γ-ray burst. The technique that we exploit to determine this is very general and makes no assumption about any particular model for γ-ray generation except that the basic radiation mechanism is some combination of synchrotron and inverse Compton processes in a relativistic outflow. For GRB 050219A we can rule out the possibility that energy from the explosion is carried outward by magnetic fields, and that the dissipation of this field produced the γ-ray burst.

Key words: hydrodynamics – shock waves – gamma-rays: bursts.

1 INTRODUCTION

The successful launch of the *Swift* satellite in 2004 November filled a crucial gap in the γ-ray burst (GRB) data at early times – between a minute and a few hours – that existed in prior GRB missions. This has led to a number of very interesting discoveries regarding emission from GRBs on time-scales of minutes following a burst. One of these discoveries is that the very early X-ray light curve (LC) of many bursts falls off very rapidly: $f_x \propto t^{-3}$ (Tagliaferri et al. 2005; Goad et al. 2005; Burrows et al. 2005; Chincarini et al. 2005). This phase of rapid fall-off lasts for about 5 min, and is followed by the usual $f_x \propto t^{-1}$ behaviour. In most cases, no change to the spectral slope is seen accompanying the change to the light curve. In this paper, we discuss two bursts exhibiting such behaviour, GRBs 050126 and 050219A. We provide an argument that the γ-rays and the early X-rays (for the first ~5 min) have a common source, and we determine the physical properties of the source (next section).

2 MODELLING PROMPT γ-RAY AND AFTERGLOW EMISSIONS

We start with some very general physical considerations and describe a model with as few assumptions as possible to try to understand the γ-ray and X-ray emissions together.

We do not assume that γ-rays are produced in the internal shock or external shock or any other of a number of different models that have been suggested. We determine the properties of the γ-ray source from the data and use them to decide which of the proposed models, if any, work. The only assumption that we make is that γ-rays are generated by synchrotron or inverse Compton (IC) mechanisms – an assumption that is supported by their non-thermal spectrum and also indirectly by the excellent overall agreement between models based on synchrotron and IC emission and multiwavelength afterglow data for a large number of GRBs (Granot, Piran & Sari 1999; Mészáros & Rees 1999; Panaitescu & Kumar 2002; Piran 2005).

The two bursts considered here have γ-ray light curves dominated by a single peak and small fluctuations, and therefore much of the γ-ray flux is probably produced in a single source localized in space. In such a case the synchrotron and IC emissions from the object are completely determined if we know the magnetic field strength (B),

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the optical thickness of the object to Thomson scattering (τ_{e}), the speed of the object toward the observer (Lorentz factor, LF – Γ), the total number of radiating particles assuming an isotropic source (N), and the minimum energy for radiating particles, $\gamma_{\mathrm{i}} m_{\mathrm{e}} c^2$($m_{\mathrm{e}}$ is the electron mass and c is the speed of light). The particle energy distribution above γ_{i}, at the acceleration region where particles have not suffered appreciable loss of energy, is assumed to be a power-law function with index p. The energy distribution of particles for the entire population, however, is not a single power-law function due to the loss of energy via radiative processes. We determine this modified distribution numerically by carrying out a self-consistent calculation of synchrotron cooling and self-absorption frequencies as described by Panaitescu & Mészáros (2000) and McMahon, Kumar & Piran (2006).

The average energy per particle, at the acceleration site, in the comoving frame of the source is $\epsilon = \gamma_{\mathrm{i}} m_{\mathrm{e}} c^2 (p-1)/(p-2)$, and therefore $N \approx E_{\mathrm{iso}}/\epsilon\Gamma$, where E_{iso} is the isotropic equivalent of energy in γ-rays. The index p is determined by the observed spectral index; we take $p = 2.4$ when the spectrum above the peak is not known – results reported here have been checked for dependence on p, and found qualitatively to be insensitive to p.

So we are left with four unknown parameters, namely B, τ_{e}, Γ and γ_{i}. The observational constraints on these parameters are the γ-ray flux at the peak of the observed light curve, the frequency at which the spectrum peaks, the duration of the burst, the spectral index below the peak, and the optical flux limit (when available). The last two constraints are not independent and typically provide a limit on synchrotron cooling and/or injection frequencies.

The optical depth, τ_{e}, and N determine the distance of the γ-ray source from the centre of the explosion: $r = \sqrt{N\sigma_{\mathrm{T}}/4\pi\tau_{\mathrm{e}}}$; and the burst duration $t_{\mathrm{GRB}} \approx r/2\Gamma^2 c$. The parameters that we use describe the state of the γ-ray-producing source at the time of the peak of the observed light curve. The observed peak flux is the synchrotron or IC flux in the appropriate observer energy band which is determined from B, N (the total number of electrons/positrons in the source), τ_{e}, γ_{i} and Γ; the details of the calculation are described in Kumar et al. (in preparation). By searching the parameter space (B, τ_{e}, Γ, γ_{i}) for emission properties consistent with those observed for each burst, we can decide among various GRB models. As we shall see, we are led to more or less a unique solution: γ-rays are generated via synchrotron-self-IC (SSC) in a source with typical electron energy less than $10^3 m_{\mathrm{e}} c^2$ and with properties that favour the external reverse-shock or internal shocks. Moreover, the γ-ray source we thus find also accounts for the early X-ray afterglow in a natural way, as off-axis flux from the γ-ray-emitting material or flux from the adiabatically cooling source.

Results for 050126 and 050219A are discussed below.

2.1 GRB 050126

GRB 050126 was 25 s long with a fluence in the 15–350 keV band of $1.7 \pm 0.3 \times 10^{-6}$ erg cm^{-2}, and redshift 1.29 (Tagliaferri et al. 2005). The average spectral index β ($f_\nu \propto \nu^\beta$) during the burst was -0.34 ± 0.14, and during the X-ray afterglow the spectral index was $\beta = -1.35 \pm 0.3$ and the LC fell off as $t^{-2.52^{+0.5}_{-0.2}}$. We describe the results for γ-ray and X-ray emissions below.

2.1.1 *γ-ray generation via the synchrotron process*

Fig. 1 shows the parameter space allowed – for a source radiating via the synchrotron process – to explain the observed γ-ray data for 050126. In particular we show the allowed range for γ_{i}, B, Γ_1 (the lower limit to the LF of the unshocked shell which produced the γ-ray photons when it was shock-heated – we will refer to it as shell 1), and the upper limit to the LF of the shell or the medium with which shell 1 collided (Γ_2); the figure caption describes how Γ_1 and Γ_2 are calculated. These quantities are plotted against the radius, r, at which γ-rays are generated, to determine which GRB model could be described by the four-parameter solution space.

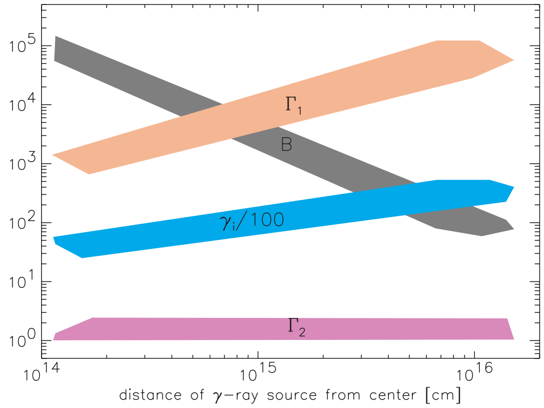

Figure 1. The parameter space for the synchrotron radiation solution to GRB 050126. The x-axis is the radial distance of the γ-ray source from the centre of explosion. Shown in the figure is the minimum energy of electrons divided by their rest mass (γ_{i}) at the location where these particles are accelerated in the source, i.e. where radiative losses are unimportant. Also shown are the comoving magnetic field (B) in gauss, and the LFs of the unshocked shells and medium, Γ_1 and Γ_2. $\Gamma_1 = \Gamma\Gamma_{\mathrm{sh}}(1 + vv_{\mathrm{sh}})$ is the LF of the inner unshocked shell, where $\Gamma_{\mathrm{sh}} = (p-1)\gamma_{\mathrm{i}}\, m_{\mathrm{e}}/(p-2)m_{\mathrm{p}}$ is the minimum LF of the shock front with respect to the unshocked shell – this assumes that electrons have the same energy as protons (Γ_{sh} will be larger if electrons have lower energy) – and Γ is the LF of the shocked material as seen by a laboratory frame observer. Γ_2 is the LF of the unshocked outer shell/medium and is given by $\Gamma\Gamma_{\mathrm{sh}}(1 - vv_{\mathrm{sh}})$. The calculations of Γ_1 and Γ_2 are valid when the γ-ray-producing shell/medium is the inner and the outer shell respectively, and they are also valid for most internal shell collision situations where the shock front speed in the two shells is about the same. For these calculations we took $E_{\mathrm{iso}} = 10^{52}$ erg, $p = 2.4$, $z = 1.29$, and the flux at 150 keV at the peak of the γ-ray LC (7 s) to be 0.2 mJy. We used a factor of 2 tolerance in all of the observational data such as γ-ray flux, burst duration etc. in constructing the acceptable solution parameter space.

The solutions that we find have $\gamma_{\mathrm{i}} > 3000$, and a high magnetic field strength is needed to explain the γ-ray emission for this burst if it were to arise as a result of synchrotron emission. The synchrotron cooling frequency is found to be less than a few eV, which is in part due to the constraint that the low-energy spectral index is -0.34 ± 0.14 (so all of the solutions are in the highly radiative cooling regime). The radius where the observed γ-rays could have been generated varies from the typical internal shock radius of $\sim 10^{14}$ cm to the external shock radius of $\sim 10^{16}$ cm; the lower limit to the radius is due to our choice of $\tau_{\mathrm{e}} < 0.1$ in order to avoid excessive Compton scattering – for $\tau_{\mathrm{e}} = 1$ the minimum r is a factor of 2 smaller. In the case of internal shocks we find that the LF of the two colliding shells must satisfy the conditions $\Gamma_1 \gtrsim 10^3$ and $\Gamma_2 \lesssim 3$ (see Fig. 1), which seems an unrealistic requirement for any central engine to meet, and in any case this situation would not be that different from the interaction of GRB ejecta with the interstellar medium where $\Gamma_2 = 1$. Note that the time interval between the ejection of the two shells (with $\Gamma_1 = 10^3$ and $\Gamma_2 = 2$) is larger than 500 s for the internal shock radius of $r \sim 10^{14}$ cm, while the duration of this burst was 25 s – this is another problem for this solution. Furthermore, the fact

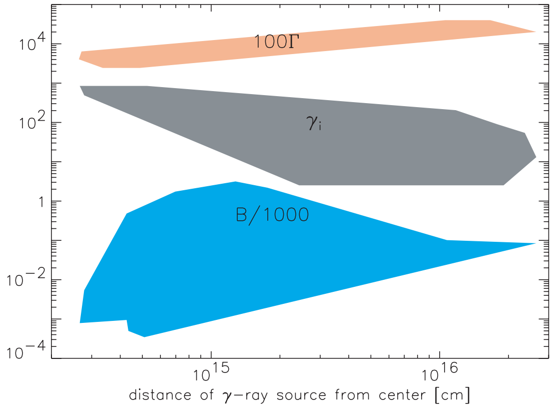

Figure 2. The parameter space for the synchrotron-self-IC solution to GRB 050126. Shown in the figure are the allowed range for $\gamma_{\rm i}$, Γ (the LF of the γ-ray source) and B (the comoving magnetic field strength in gauss). See the caption of Fig. 1 for some relevant details about the calculation.

that the GRB LC was a FRED (fast rise, exponential decline) means that internal shocks are not required to generate the γ-ray emission.

The allowed parameter space contains an external forward-shock solution as well ($r \sim 10^{16}$ cm; $\Gamma_2 = 1$). This solution, however, requires $\Gamma > 10^4$ (Fig. 1) which makes the already acute problem of baryonic loading much worse. Moreover, the deceleration radius for this large Γ, for a typical GRB–circumstellar medium density of $\sim 10\,{\rm cm}^{-3}$, is less than 10^{16} cm – the distance at which the γ-ray source according to our solution is located. Therefore we conclude that γ-rays from 050126 are unlikely to have been produced via the synchrotron process in internal or external shocks.

2.1.2 Gamma-ray production via the inverse Compton process

Fig. 2 shows the allowed parameter space for synchrotron-self-IC solutions. The entire solution space consists of mildly relativistic shocks with $2 < \gamma_{\rm i} < 1000$, and the LF of the source is between 20 and 300. Mildly relativistic shocks arise naturally in internal collisions (with the ratio of LFs for colliding shells of the order of a few) and the external reverse-shock (RS). A good fraction of the allowed parameter space has electron cooling time, due to radiative losses, of the order of the dynamical time or less, and the synchrotron cooling frequency is of the order of a few eV. The magnetic field strength is about 50 gauss (which corresponds to $\epsilon_B \sim 0.1$) and Compton $Y \sim 1$ for the part of parameter space corresponding to RSs, whereas B is between 1 and 10^3 gauss and $1 \lesssim Y \lesssim 10^4$ for internal shocks. The IC γ-ray light curve falls off very rapidly for both the internal and the RS emission, as does the observed LC (Kobayashi et al. 2005). Therefore γ-rays from 050126 could have been produced via SSC in either internal or external shocks, and we do not see any reason to prefer one solution over the other for this burst.

2.1.3 X-ray afterglow

Is it possible that the early X-ray afterglow was produced by the same source as the GRB IC photons? The IC cooling frequency, $\nu_{\rm c}^{\rm IC} \sim \nu_{\rm c}\gamma_{\rm c}^2$, at the GRB LC peak (7s) is typically of the order of a few hundred keV for the allowed parameter space for this burst. Since $\nu_{\rm c}^{\rm IC}$ shifts to lower energies because of adiabatic cooling, as $\sim t^{-2}$, at 100 s it will have dropped to $\sim$1 keV. In this case the flux in the *XRT* band at 100 s from the $\theta \lesssim \Gamma^{-1}$ part of the source will be very small, and will rapidly drop to zero on a short time-scale. The early X-ray LC could be explained by this adiabatically cooling γ-ray source provided that $\nu_{\rm c}^{\rm IC} \gtrsim 10$ MeV at 7 s, which is somewhat outside the parameter space that we find for this burst.

Could photons detected by the *XRT* in the 0.2–10 keV band at $t >$ 100 s be off-axis photons (Kumar & Panaitescu 2000) that originate at the source at an angle with respect to the line of sight $>\Gamma^{-1}$? The flux at 10 keV at the peak of the GRB 050126 light curve was 0.54 ± 0.08 mJy. This gives a flux[1] at 100 s due to off-axis emission of $1.1 \pm .15$ μJy, in rough agreement with the *XRT* measurement of 2.8 ± 1.2 μJy. The X-ray LC between 100 and 425 s declined as $t^{-2.52^{+0.5}_{-0.22}}$. This decline is also consistent with that expected of off-axis emission; $\beta = 1.26 \pm 0.22$ during this period would give rise to an off-axis LC decaying as $t^{-3.26\pm0.22}$. The spectral peak for the off-axis emission from a uniform jet decreases with time as $1/t$, and so the peak at 100 s is at $\sim$10 keV. The peak frequency decreases more rapidly when electron energy and/or magnetic field is smaller at higher θ. In this case the spectral peak will be below 10 keV, and β in the *XRT* band, for $t >$ 100 s, smaller than during the GRB. We note that a decrease of $\gamma_{\rm i}$ and B would not lead to a decrease in the flux in the *XRT* band so long as these changes were accompanied by an increase in the number of radiating particles as might be expected, for instance, when Γ decreases with θ but the energy per unit solid angle is roughly constant. The angular structure of the ejecta can be constrained by the difference between the observed spectral peaks at 100 s and during the burst.

2.2 GRB 050219A

GRB 050219A was 23.6 s long with fluence in the BAT/*Swift* 15–350 keV band of $5.2 \pm 0.4 \times 10^{-6}$ erg cm^{-2}. The average spectral index β during the burst was 0.75 ± 0.30 ($f_\nu \propto \nu^{0.75\pm0.30}$), and the peak of the spectrum was at 90 ± 9 keV (Tagliaferri et al. 2005). During the X-ray afterglow, the spectral index was $\beta = -1.1 \pm 0.2$ and the X-ray LC declined as $t^{-3.15\pm0.22}$. We describe below the mechanism for γ-ray, X-ray and optical emissions.

2.2.1 γ-ray production

The positive β during the GRB, although consistent with the synchrotron spectrum of $\nu^{1/3}$ to within 1.5σ, rules out the synchrotron process for the generation of γ-rays for 050219A. The reason is that the magnetic field required to produce a synchrotron peak frequency of 90 keV is sufficiently strong that electrons lose their energy on a time-scale much less than the duration of the burst (23 s), and in this case the spectrum below 90 keV would be $\sim\nu^{-1/2}$.[2] This is in conflict with the observed spectrum and rules out the synchrotron process for γ-ray generation.

The IC process, on the other hand, provides a very natural way of explaining the observed spectrum and other properties. The spectrum produced by IC scattering of a self-absorbed synchrotron

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[1] The off-axis flux falls off as $t^{-2+\beta}$ [see (Kumar & Panaitescu 2000)], where β is the spectral index, i.e. $f_\nu \propto \nu^{-\beta}$.

[2] A synchrotron frequency of 90 keV implies that $B\gamma_{\rm i}^2\Gamma = 10^{13}$ and the electron cooling LF is $\gamma_{\rm c}/\gamma_{\rm i} \sim 10^{-17}\gamma_{\rm i}^3\Gamma/t_{\rm GRB}(1+Y)$; the Compton parameter $Y \sim \tau_{\rm e}\gamma_{\rm i}\gamma_{\rm c}$, and therefore $(\gamma_{\rm c}/\gamma_{\rm i})^2 \sim 10^{-17}\gamma_{\rm i}\,\Gamma/(\tau_{\rm e}t_{\rm GRB})$, where $t_{\rm GRB}$ is the burst duration in the host galaxy rest frame. Since $\tau_{\rm e} > 10^{-8}$ and $t_{\rm GRB} \sim 10$ s, and $\gamma_{\rm i} < 10^3\Gamma$, we see that $\gamma_{\rm c}/\gamma_{\rm i} < 1$ unless $\Gamma >$ 3000 which is highly unlikely.

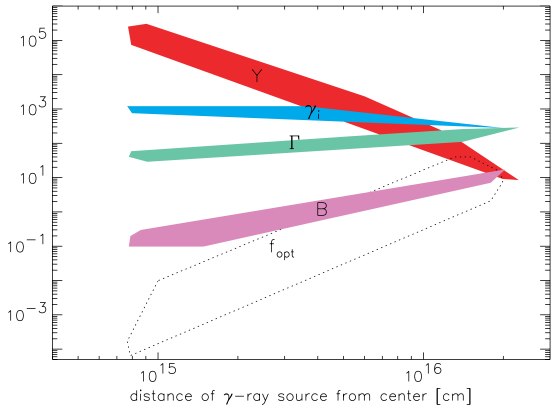

Figure 3. The parameter space for the synchrotron-self-IC solution to GRB 050219A. Shown in the figure are the allowed range of γ_i, Γ (the LF of the γ-ray source), the Compton Y parameter, B (the comoving magnetic field strength in gauss), and the predicted optical flux at 100 s for these solutions (assuming a burst redshift of 1 and no extinction). The solutions with $r < 4 \times 10^{15}$ cm have $Y \gtrsim 10^4$ and are physically unacceptable since the energy in the second Compton scattering will be of the order of 10^{54} erg which is too large to obtain from a stellar-mass object. Therefore, the only viable solution for the γ-ray emission is IC in the external RS. We took $E_{\rm iso} = 10^{53}$ erg, $p = 2.9$, $z = 1$, the peak of the spectrum at 90 keV, and the flux at the peak of the γ-ray LC (15 s) at 90 keV to be 1.2 mJy. We applied the condition that $\nu_{\rm a}^{\rm IC} \equiv \nu_{\rm a} \times \min\,(\gamma_{\rm i}, \gamma_{\rm c})^2 \sim 90$ keV; this automatically ensures that $\beta = 0.75 \pm 0.3$ as observed. We used a factor of 2 tolerance in all of the observational data such as γ-ray flux, burst duration, the peak frequency etc. in constructing the acceptable solution parameter space.

radiation is $f_\nu \propto \nu$ for $\nu < \nu_{\rm a} \times \min(\gamma_{\rm i}, \gamma_{\rm c})^2 \equiv \nu_{\rm a}^{\rm IC}$, where $\nu_{\rm a}$ is the synchrotron self-absorption frequency. For min $(\gamma_{\rm i}, \gamma_{\rm c}) \sim 300$ and $\nu_{\rm a} \sim 1$ eV, the peak of the IC spectrum at $\nu_{\rm a}^{\rm IC}$ is close to the observed value of 90 ± 9 keV. These parameters arise naturally in an external RS.

Fig. 3 shows the allowed parameter space for a SSC solution for GRB 050219A, assuming $z = 1$. The range of $\gamma_{\rm i}$ for the allowed solutions is 200–1500 which is typical for the external RS and for internal shocks, but not the external forward-shock. The magnetic field B is between 0.1 and 20 gauss. This is highly sub-equipartition ($\epsilon_B \lesssim 10^{-3}$), and therefore for 050219A we can rule out the possibility that the γ-ray burst was produced as a result of dissipation of magnetic field or that much of the energy of the explosion was carried outward by the magnetic field.

The Compton Y is rather large – of the order of 10–100 for an external shock ($r \sim 10^{16}$ cm), and larger than 10^4 for an internal shock radius of $r \sim 10^{14}$–10^{15} cm (Fig. 3). One might suspect that the large Y renders these solutions unphysical since the energy in the second Compton scattering, which produces >100 GeV photons, will far exceed the γ-ray energy. However, for low optical depth systems with $\Gamma \gg 1$ the radius of the system increases by about a factor of 2 in the time that it takes photons to traverse the shell. Therefore the optical depth for the second scattering is smaller than the first by a factor of 4, and the electron thermal energy has decreased because of adiabatic expansion during this period by a factor of about 4 for RS (the shell thickness for RS increases as $r^{7/2}$), and a factor of 2 for internal shocks. Thus the effective Y for the second Compton scattering is smaller than the first-scattering Compton Y by a factor of about 64 for the RS and 16 for internal shocks. For this reason $Y \sim 100$ for the external shock is quite acceptable, as the total energy requirement is of the order of 10^{51} erg. However, $Y > 10^4$ for internal shocks (see Fig. 3) would require the total energy in the explosion to be $\sim 10^3$ times larger than the energy in the γ-ray band and that is highly unlikely considering that $E_\gamma \sim 10^{51}$ erg. Therefore the only viable solution for the γ-ray production for 050219A is IC in the external RS-heated ejecta.

2.2.2 *X-ray afterglow*

There are two mechanisms that can explain the X-ray observations for this burst. One of these is the off-axis emission. The flux at the peak of the γ-ray LC (15 s) at 10 keV was ~300 μJy. Using this and $\nu^{0.75\pm0.3}$, we find the flux at 100 s, due to the off-axis emission mechanism ($f_\nu \propto t^{-2+\beta=-1.25\pm0.3}$), to be ~29 ± 7 μJy, which is consistent with the observed *XRT* flux (25 ± 9 μJy at 10 keV at 100 s). The LC decay according to the off-axis emission after the spectral peak falls through the *XRT* band is $t^{-2+\beta}$, where $\beta = -1.1 \pm 0.2$ is the spectral index for $t > 100$ s, and this is consistent with the observed decay of $t^{-3.15\pm0.22}$. The difference between the X-ray afterglow and γ-ray spectra can be understood in the same way as discussed for 050126, i.e. the peak of f_ν during the GRB (90 keV) is well below 10 keV at 100 s if $\gamma_{\rm i}$ and B decrease with θ slightly, and this changes the spectrum from $\sim\nu^{0.7}$ to $\sim\nu^{-1}$.[3]

The second possibility is that we continue to see radiation from within Γ^{-1} angle of the adiabatically cooling γ-ray source. We find that for a large part of the allowed parameter space for the γ-ray solution $\nu_{\rm c}^{\rm IC} \gtrsim 1$ MeV, and therefore we expect to receive emission in the 0.2–10 keV band for a period of about 5 min, during which time the flux decline will be $\sim t^{-2.8}$, which is consistent with the observed decay.[4] We note that the discontinuity in the BAT and *XRT* LCs for thisburst[1] could be due to an underestimation of the spectral evolution in the 20–50 s time interval where the BAT signal was low. A discontinuous jump can also arise in the off-axis model as a result of a rapid increase in jet energy for θ between γ^{-1} and $2\gamma^{-1}$.

Both of these solutions suggest a common source for the γ-ray burst and early X-rays.

2.2.3 *Optical observations*

The optical flux at 100 s from the γ-ray source is shown in Fig. 3. For the RS solution the flux is about 1 mJy whereas the observed UVOT/*Swift* upper limit at 96 s is 0.02 mJy (Schady et al. 2005). The much smaller optical flux could be due to absorption in the host galaxy. The total hydrogen column density for this burst was[1] $2.2 \pm 0.6 \times 10^{21}$ cm^{-2}, in excess of the Galactic value, which for a burst at $z \sim 1$ could give ~7 mag of optical extinction, more than sufficient to bring the optical flux below the observed upper limit.[5]

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[3] Angular variation is almost unavoidable, because in the absence of it the early X-ray LC would have declined as $t^{-1.25}$ because of the off-axis emission.

[4] The IC frequencies for adiabatically cooling ejecta shift with time as t^{-2}, so the 90-keV peak at 15 s would have shifted to 2 keV at 100 s. During the time when this peak is above the *XRT* band of 10 keV, the IC flux from the RS decreases very weakly with time ($\sim t^{-0.4}$), and subsequently the flux decreases as $t^{-2.8}$. The cross-over is expected at about 45 s. Thus the flux from the RS at 100 s at 10 keV is expected to be about 18 ± 4 μJy which is consistent with the *XRT* flux of 25 ± 9 μJy. The spectrum at 100 s will be as expected of IC above $\nu_{\rm a}^{\rm IC}$, i.e. roughly ν^{-1}.

[5] The Galactic correlation between $N_{\rm H}$ and extinction might not apply to GRBs owing to possible dust destruction by GRB emission (Galama & Wijers 2001). It is therefore difficult to say with confidence the amount of extinction for this burst in the V-band.

Alternatively, if the RS occurs at $r \lesssim 10^{16}$ cm the optical flux would be roughly consistent with the observed upper limit (see Fig. 3). However, in the case $Y \sim 300$ the energy in the second Compton-scattered photons at 100 GeV will be almost an order of magnitude larger than the energy in γ-rays.

3 CONCLUSIONS

We find that the prompt γ-ray and early (first few minutes) X-ray emissions for GRBs 050126 and 050219A are consistent with being produced by the same source. In the case of 050126, the emission is inverse Compton (IC) radiation from either internal shocks or the external reverse-shock (RS), and in the case of 050219A the photons are produced by IC in the external RS. The late-time X-rays ($t \gtrsim$ 5 min) are produced, as usual, in the forward-shock.

These results can be applied to the class of γ-ray bursts that consist of a simple, i.e. not highly variable, light curve (LC). For instance, our conclusion that γ-rays were generated via the IC process for GRB 050219A is valid for all those GRBs that, like GRB 050219A, have a positive low-energy spectral index for the prompt γ-ray emission ($f_\nu \propto \nu^\beta$ with $\beta > 1$). The allowed values for parameters – B, Γ and γ_i – for the source of γ-rays for any GRB consisting of a single peak in the γ-ray LC should be similar to that shown in Figs 1 and 3 for 050126 and 050219A.

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