SPECTRAL FEATURES FROM ULTRARELATIVISTIC IONS IN GAMMA-RAY BURSTS?

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ABSTRACT

Gamma ray burst outflows may entrain small blobs or filaments of dense, highly ionized metal rich material. Such inhomogeneities, accelerated by the flow to Lorentz factors in the range 10-100, could have a significant coverage factor, and give rise to broad features, especially due to Fe K-edges, which influence the spectrum below the MeV range, leading to a progressively decreasing hardness ratio.

Subject headings: Gamma-rays: Bursts - Line: Formation - Cosmology: Miscellaneous

1. Introduction

Gamma-ray bursts (GRB) have been detected in the past year at X-ray, as well as optical and radio frequencies (e.g. Costa, et al. 1997, Sahu, et al. 1997, Frail et al. 1997; recent results are summarized in Meegan, Preece & Koshut, 1997). A cosmological origin is indicated by the measurements of redshifts in at least two objects (Metzger, et al. 1997, Kulkarni, et al. 1998). The radiation is generally interpreted in terms of nonthermal continuum emission from shocks in a relativistic fireball outflow, both in the early high energy emission (Rees & Mészáros, 1992; Mészáros & Rees, 1993; Piran, Shemi & Narayan, 1993; Katz, 1994; Rees & Mészáros, 1994; Sari & Piran, 1995; Papathanassiou & Mészáros, 1996; Panaitescu, Wen, Laguna & Mészáros, 1997) and in the subsequent afterglows at longer wavelengths (Mészáros & Rees, 1997a; Vietri, 1997; Waxman, 1997; Wijers, Rees & Mészáros, 1997). While the outflow is typically assumed to be chemically homogeneous and smooth on average (except for instabilities and shocks), it could have a substantial component of blobs of denser material (e.g. from the small mass fraction near the surface of a disrupted neutron star torus) which are entrained by the average outflow, and coexist with it in pressure equilibrium. This denser material would be richer in heavy elements,
and could have significant spectral effects caused by absorption edges from metals such as Fe, with consequences for the early $\gamma$-ray and X-ray emission from GRB (the related effects in GRB afterglows will be discussed elsewhere). In what follows we investigate the physical conditions in such blobs, and calculate the effects they have on the observed spectrum associated with internal shocks in GRB.

2. Baryonic Outflow and Dense Blob Entrainment

In a fireball outflow arising from the disruption of a compact binary or the collapse of a fast rotating stellar core, internal shocks and nonthermal radiation leading to $\gamma$-ray emission arise at radii $r_{sh} = ct_v \eta^2 = 3 \times 10^{14} t_v \eta_2^2$ cm, where $t_v \gtrsim 10^{-3}$ s is the variability timescale and $\eta = 10^2 \eta_2$ is the terminal coasting bulk Lorentz factor, determined by the baryonic loading of the outflow. We do not know to what extent the outflow is beamed, but for the present discussion we suppose it is confined inside channels of solid angle $\theta^2$. For a total luminosity $L = 10^{51} L_{51}$ and mass outflow rate $\dot{M} = L/(c^2 \eta)$ lasting for a time $t_w \gtrsim t_v$, the mean comoving density of nuclei in the smooth outflow is

$$n_o = (L/4\pi \theta^2 r^2 \eta^2 A_o m_p c^3) = 3 \times 10^{12} L_{51} \theta^{-2} r_{13}^{-2} A_o^{-1} \eta^{-2} \text{ cm}^{-3},$$

(1)

where $r = 10^{13} r_{13}$ and $A_o$ is the mean particle atomic weight. The total baryonic mass per unit logarithmic radius is $M_o = 4\pi \theta^2 r^3 \eta^{-1} n_o A_o m_p = 4 \times 10^{26} L_{51} \theta^{-1} r_{13}^{-3} A_o$ g, and the corresponding smoothed-out column density of nuclei is

$$\Sigma_o = 3 \times 10^{23} L_{51} r_{13}^{-1} \theta^{-1} A_o^{-1} \eta^{-3} \text{ cm}^{-2}. $$

(2)

The outflow can also carry magnetic fields whose comoving energy density in the frame moving with $\eta$, expressed as a fraction $\xi_B$ of the total energy density, gives $B = 3 \times 10^5 L_{51}^{1/2} \xi_B^{1/2} \theta^{-1} r_{13}^{-1} \eta^{-1}$. If the outflow is magnetically-driven from the central object, then $\xi_B$ would be not much less than unity. An important consequence of such strong fields is that the gyroradii are small. This means that the flow can be treated as fluid-like. Moreover, conductivity and diffusion are severely inhibited, at least across the field, so that blobs or filaments of cooler and denser material could exist, in pressure balance with their surroundings. (This possibility has been discussed in other contexts by Celotti et al., 1998).

In addition to a smooth distribution of baryons, dense blobs of (possibly Fe-enriched) matter may be able to survive and be entrained in the flow. A small blob moving with bulk Lorentz factor $\Gamma_b$ (possibly less than $\eta$) whose gas temperature was of order of the comoving photon temperature $T \sim 10^7 T_7 \Gamma_b^{-1}$ K (or $\sim 100$ keV in the observer frame) could have a particle density (measured in its own comoving frame) of up to

$$n_b \simeq 2 \times 10^{18} L_{51} \theta^{-2} r_{13}^{-2} T_7^{-1} \Gamma_b^{-2} \text{ cm}^{-3},$$

(3)

This maximum density would be reached if its internal pressure balanced the total external (magnetic and particle) pressure. If the blobs were composed of iron-rich material from
neutron-star debris, the density of nuclei would be lower than \( n_b \) by a factor \( 1/Z_b \), the average charge of the ions. Such blobs are much denser than the corresponding “background” baryon density given in equation (1). We return in §.4 to discuss the internal thermal balance, and to show that they could indeed remain with \( T_7 \ll 1 \). However, we first consider the geometry and dynamics of such blobs.

Suppose the blobs have a volume filling factor \( f_v = \bar{n}_b/n_b \). This is of course likely to be a very small number. However, if the blobs are individually very small, the surface covering factor \( f_s \) can nonetheless be substantial. If the blobs were spheres of characteristic radius \( r_b \) then \( r_b n_b f_s \) would equal the smoothed-out column density over one comoving length scale \( c t_{\exp} = r/r_b \) in the frame of the blobs, \( \bar{\Sigma}_b = \bar{n}_b(r/r_b) \). We obtain \( r_b = (r/r_b) (\bar{n}_b/n_b) f_s^{-1} = (r/r_b) f_v f_s^{-1} \). If one sets the smoothed-out density of blobs moving at \( \Gamma_b \), as seen in the flow frame \( \eta \), equal to a fraction \( \alpha \) of the average flow comoving particle density, \( \bar{n}_b = \alpha n_o \eta \Gamma_b^{-1} \), the volume filling factor is \( f_v = 1.510^{-6} \alpha \eta_2^{-1} \Gamma_b L_{62} A_{10}^{-1} T_7 \). The blob size \( r_b = \bar{\Sigma}_b/(n_b f_s) \) is given by

\[
r_b = \bar{\Sigma}_b/(n_b f_s) = 1.5 \times 10^5 \alpha r_{13} \eta_2^{-1} A_{10}^{-1} T_7 f_s^{-1} \text{ cm ,}
\]

while the column density through a single blob is just \( \Sigma_b = r_b n_b = \bar{\Sigma}_b f_s^{-1} \), and the average smoothed-out column density from blobs is \( \bar{\Sigma}_b = \alpha \Sigma_o (\eta/\Gamma_b)^2 \) in the \( \Gamma_b \) frame. In order to have a surface covering factor \( f_s > 1 \), there is an upper limit \( r_b < \bar{\Sigma}_b/n_b \) on the blob sizes. Realistically, the blobs are likely to be streaks or filaments elongated along the magnetic field direction, the field itself being predominantly perpendicular to the radial direction. The above formulae carry over provided we identify \( r_b \) with the smallest dimension: this is likely to be the dimension transverse to the field, and can readily be small enough to permit a large covering factor, while nonetheless being large enough (compared to the gyroradius) to ensure a fluid-like behavior.

3. Blob Velocities

The blobs, even if consisting of gas entrained from a slower moving environment, will tend to be accelerated by the mean MHD jet outflow. This flow starts at some lower radius \( r_l = 10^{6} \text{r}_{16} \text{ cm} \), and reaches its saturation bulk Lorentz factor \( \eta = L/(\dot{M}c^2) = 10^2 \eta_2 \) well before internal shocks reconvert a significant fraction of the bulk kinetic energy into radiation at radii \( r_{sh} \sim 10^{13} \text{r}_{13} \text{ cm} \); still further out, there may be a deceleration shock where the ejecta encounter the external medium. Blobs entrained into the flow near \( r_l \), or from the boundary of the channel at larger radii, are accelerated by the flow; at or above the shock radius Compton scattering of the intense photon flux is of comparable importance for the dynamics.

The comoving radiation energy density in the flow is \( u_\gamma = L/(4\pi \theta^2 r^2 c \eta^2) = 3 \times 10^9 L_{51} \theta_{12}^{-2} \eta_2^{-2} \text{ erg cm}^{-3} \). The radiation pressure would accelerate any optically-thin blob into a frame in which the net Compton drag were zero, on a timescale \( t_{dr} = Am_o c^2/(\sigma_T c u_\gamma) = 4 \times 10^1 L_{51}^{-1} \theta_{12} \eta_2 A \) s . This timescale (calculated taking account of the inertia of the ions, which are, on the macroscopic level, constrained to move with the leptons) is
shorter than the comoving expansion (dynamic) time of the flow $t_{ex} = r(\eta)_{-1} = 3 r_{13} \eta_{2}^{-1}$ s for radii $r_{13} \lesssim 0.75 \times 10^{-1}$ $L_{51} \eta_{2}^{-3} \theta^{-2} A_{-1}^{-1}$. For an optically thin blob released at some radius $r_{o}$ the terminal Lorentz factor achievable is (Phinney 1987) $\Gamma_{b,max} = (L/L_{Ed})^{1/3} \sim 2 \times 10^{4} L_{51}^{1/3}$. For an optically thick blob, the effective acceleration is lowered by a factor $\mathcal{N}_{o}^{-1} = (\Sigma_{bo}/1.5 \times 10^{24} \text{cm}^{-2})^{-1}$, so $\Gamma_{b,max} = (L/L_{Ed})^{1/3} \mathcal{N}_{o}^{-1/3} = 2 \times 10^{4} L_{51}^{1/3} \mathcal{N}_{o}^{-1/3}$. Although the above expressions refer to radiation-pressure acceleration, similar considerations apply to acceleration by the ram pressure and Poynting flux of the smooth relativistic outflow. If $L$ is defined as the total energy flux, the results are identical provided that $\mathcal{N}_{o}$ exceeds $1.5 \times 10^{24}$.

A blob immersed in a hydromagnetic flow carrying a flux $L$ behaves in a similar way. If its column density is sufficiently low, its motion adjusts to the same Lorentz factor as the surrounding flow. The condition for this to happen is that

$$\mathcal{N}_{o} < (L/L_{Ed})(r/r_{o})^{-1} \Gamma_{b}^{-3}.$$  \(5\)

Note that the dependence on $\Gamma_{b}$ arises because, if the blob moved with a slightly different speed from the mean flow, the drag force on it (in the comoving frame) scales as $r^{-2} \Gamma_{b}^{-2}$ and the time available, at a given $r$, scales as $r \Gamma_{b}^{-1}$.

A blob for which $\mathcal{N}_{o}$ is low enough to satisfy the condition (5) at the radius where the velocity of the mean outflow saturates will coast stably outwards in pressure balance with its surroundings. Blobs with higher $\mathcal{N}_{o}$, for which (5) is not satisfied, would be accelerated by the ram pressure associated with the energy flux $L$, but would not attain the same Lorentz factor as their surroundings. The thickness of such blobs would adjust to be equal to the scale height corresponding to the acceleration, which would be proportional to the blob temperature $T$, and also proportional to $\mathcal{N}_{o}$ times $\Gamma_{b}^{2}$.

Thus we expect that the flow, out at radii $\sim 10^{13}$ cm, would contain small blobs with Lorentz factor of order $\eta$, and also larger blobs with lower Lorentz factors. As we discuss later, this slower-moving material could have an important effect on the time-evolution of the spectra of gamma ray bursts.

The proportions of slow-moving and fast-moving blobs would depend on the uncertain details of how the initial entrainment occurs, and also on the effects of instabilities during the outflow. Blobs small enough to satisfy the condition (5), which in effect constitute a “mist” of clouds or filaments embedded in the flow (preserved by strong magnetic fields against diffusion effects), are not subject to any obvious dynamical instability. Larger blobs, on the other hand, would seem in principle vulnerable to both Rayleigh-Taylor and Kelvin-Helmholtz instabilities.

However, in a magnetically-dominated outflow, acceleration of blobs could plausibly occur without triggering Rayleigh-Taylor instability. The situation could be analogous to, for instance, solar prominences, where magnetic stresses support cool gas against gravity (c.f. the classic work of Kippenhahn & Schlüter, 1957, and many later variants). Kelvin-Helmholtz instabilities are more problematic: even though these tend to be suppressed by magnetic fields with a component
along the flow direction (e.g. Hardee, et al., 1992) or by fields in the blobs themselves, it is unclear to what degree they are, and it is unlikely that they can be eliminated completely. What we are envisaging is a more extreme version of what we know is going on in SS433 (where a combination of mass flux and emissivity constraints forces one to a model involving cool blobs with small volume-filling factor accelerated to 10,000 times their internal sound speed).

The range of blob sizes (and blob Lorentz factors) at $10^{13}$ cm will therefore depend on (a) the nature of the entrainment process; (b) the extent to which slower (heavier) blobs are shredded by Kelvin-Helmholtz instabilities; and (c) the possible countervailing effect of coalescence, which can be important when the covering factor is of order unity and a range of velocities is present. We regard this as an open question, and turn now to consider the thermal equilibrium within blobs, which depends primarily on the radiation field and the pressure.

4. Temperature and Ionization State

The ionization rate is expected to be extremely high in a GRB outflow, but the blobs are so dense that the recombination rate is exceptionally high as well. This has two important consequences. First, the 'ionization parameter', which depends on the ratio of ionization and recombination rates, and determines the equilibrium state of ionization in the blobs, is not vastly different from what is familiar in some X-ray sources. Second, because the recombination timescale is so short, each electron can recombine (and be reionized) during the outflow timescale, so the blobs can reprocess most of the photon flux from a burst, even though their total mass is low.

The ionization parameter $\Xi = L/n_b r^2$ (e.g. Kallman & McCray, 1982), evaluated in the comoving frame, is $\Xi = L/n_b r^2 \Gamma_b^2 = 5 \times 10^2 \theta^2 T_7$. For $\Xi \gtrsim 10^3$, most Fe would be present as FeXXVI (i.e. H-like) or fully stripped; this would still be true if the material were so enriched in Fe that this is the dominant species. Self-shielding would be inevitable if the total number of recombinations became comparable with the number of ionizing photons available. The total number of recombinations per second per unit logarithmic radius for a plasma with mean ionic charge $Z_b$ is $R_r \sim \alpha n_e n_i V f_r$, where $V = 4\pi r^2 \eta^{-1}$, $n_e \simeq n_b$ is electron density, $n_i = n_b/Z_b$ is ion density, and $\alpha \sim 2 \times 10^{-11} Z_b^2 T_7^{-1/2}$ is the recombination coefficient for hydrogenic ions. The total number of ionizations per second in the same volume will be approximately equal to the number of ionizing photons injected per second above the shock region, $R_i \sim L/(\Gamma_b^2 h \nu_i)$, where, for 10 KeV photons in the comoving frame, $h \nu_i \sim 10^{-8} \epsilon_{10} \text{erg}$. Thus

$$R_r \simeq 4 \times 10^{54} \alpha L_5 \xi_{13} \theta^{-2} n_e^{-2} \Gamma_b^{-3} A_{-2} A_{7}^{-3/2} Z_b \text{ s}^{-1};$$

$$R_i \simeq 10^{55} \Gamma_b^{-2} \epsilon_{10}^{-1} \text{ s}^{-1}. \quad (6)$$

If the blob parameters were such that $R_r \gtrsim R_i$, the optically thin assumption would not be self-consistent, and self-shielding could be important. Bound-free and bound-bound line cooling could then have an additional effect in determining the blob temperature. However,
the blobs cannot cool below the black-body temperature of the comoving radiation field
\[ u_\gamma = 3 \times 10^9 L_{51} r_{13}^2 \theta^{-2} n_2^{-2} \text{ erg cm}^{-3} \],
which is \( T_{bb} \sim 10^6 L_{51}^{1/4} (r_{13} \theta n_2)^{-1/2} \text{ K} \); this suggests that H will always be almost completely ionized by collisions. Note also that absorption by ions in the diffuse flow is negligible, because for a given total mass the recombination rate in blobs is larger by the same ratio as the densities.

We have already shown that small blobs could contribute a covering factor of order unity. In conjunction with the above inference that the recombination rate can be comparable with the total photon production rate, this tells us that the blobs could ‘reprocess’ much of the radiation. The optically thin estimate (7) and the above temperature estimates indicate that, independently of any self-shielding, substantial recombinations of highly ionized heavy elements such as Fe would be expected. They can thereby create absorption features, the absorbed energy being re-emitted as (very broadened) lines.

5. Optical Depth and Spectral Widths

Absorption edges are expected to form at energies corresponding to the K-\( \alpha \) absorption of hydrogenic ions. The hydrogenic photoionization cross section is \( \sigma_{\text{th}} \simeq 8 \times 10^{-18} Z^{-2} \text{cm}^2 \) at the threshold \( h\nu_{\text{th}} \simeq 13.6 Z^2 \text{ eV} \), decreasing above that as \( (\nu/\nu_{\text{th}})^{-3} \). E.g., for FeXXVI the threshold in the blob frame is at 9.28 KeV, and the cross section is \( \sigma_{\text{th}} \sim 1.2 \times 10^{-20} \text{ cm}^2 \). Multiplying by the mean ion column density from blobs \( \bar{\Sigma}/Z_b = \alpha \Sigma o Z^{-1}_b (\eta_2/\Gamma_{b2})^2 \) (equation [2]), for hydrogenic ions the mean optical depth and the observer frame threshold energy are

\[
\tau_{\text{th}} \simeq 1.4 \times 10^2 \alpha L_{51} r_{13}^{-1} \theta^{-2} A_o^{-1} \eta_2^{-1} \Gamma_{b2}^{-2} x_i (Z_b/26)^{-3} ;
\]

\[
h\nu_{\text{th}} \simeq 0.928 (Z_b/26)^2 \Gamma_{b2} \text{ MeV} ,
\]

where we normalized to Fe XXVI blobs, \( x_i \) being the ionic abundance fraction by number. For Fe XXV the optical depth would be similar, modulo the ionization fraction, and the threshold is at \( .883 \Gamma_{b2} \text{ MeV} \), while for HeII the optical depth could be larger, if \( \Xi < 10^2 \), and the edge would be at \( 0.544 \Gamma_{b2} \text{ KeV} \). (An HI edge at \( 0.136 \Gamma_{b2} \text{ KeV} \) might just be possible if \( \Xi \lesssim 50 \) for cooler blobs at larger radii). Bluewards of the absorption edges one would expect the flux to be blanketed up to a comoving photon energy \( \nu_{\text{max}} \) such that \( \sigma_{\text{th}} (\nu_{\text{max}}/\nu_{\text{th}})^{-3} (\bar{\Sigma}/Z_b) = 1 \), where it gradually rejoins the continuum level.

In addition to edges, K-\( \alpha \) resonant features are also expected at energies redwards of the edges, e.g. at comoving energies of 6.9 KeV for FeXXVI, or 0.69\( \Gamma_{b2} \text{ MeV} \) in the observer frame. The expected equivalent width in the damping wing dominated regime is \( (W_{\nu}/\nu) \simeq 0.15 \alpha L_{51} r_{13}^{-1} \theta^{-2} A^{-1} Z_b^{-1} \eta_2^{-1} \Gamma_{b2}^{-2} x_i x_{i-1} \) 1/2, if we normalize to abundances \( x_i \sim 10^{-1} x_{i-1} \); there would be similar resonant lines for other ion species, since hydrogenic ions have similar \( f \) and \( A_{ul} \lambda_u^2 \) values. While such widths would be significant, bulk velocity broadening (see below) would smear out any line features even more. Moreover, absorption lines would be partially compensated by emission from the blobs.
It would be tempting to speculate that such features could be associated with the lines reported by Ginga (e.g. Murakami et al., 1988, Fenimore, et al., 1988). However, this would require special circumstances leading to a fairly narrow range of blob velocities, which might only be present in a small fraction of all cases. In general, any spectral features will be spread out due to the range of bulk Lorentz factors $\Gamma$ sampled by the line of sight. Emission line features associated with recombination will be further broadened because, even for a given $\Gamma$, there would be contributions with different Doppler blue-shifts from material with velocity making different angles with our line of sight. Even for a single value of $\Gamma_b$, this would introduce a broadening by $(\Delta \nu/\nu)_{\text{ang}} \sim 0.3 - 0.5$. The effect of this is to smear by this amount the red wing of any of the above spectral features. This smearing, however, would not be as important for the deep edges discussed above (equation [8]), which would be expected to survive. The maximum blob Lorentz factor is $\eta$, but there would be a spread below this maximum, given by values of $\Gamma_b$ for which $N_\text{ex}$ exceeds the value (5). Slower blobs moving towards the observer take longer ($\propto \Gamma_b^{-2}$ in observer time) to reach a given radius. Therefore, early in the burst only high-$\Gamma$ blobs will have reached the radius ($\sim c t_{\text{e}} \eta^2$) where internal shocks occur. However, when the burst has been active for times $\gg t_v$, slower blobs whose Lorentz factor is of order $\eta(t_{\text{ob}}/t_v)^{-1/2}$ will have had time to reach the location of the emission, where $t_{\text{ob}}$ is the observer frame time measured from the start of the burst. This leads to an increasing spread of absorbing blob Lorentz factors

$$(\Delta \Gamma/\Gamma)_b \simeq (\Gamma_{b,f} - \Gamma_b(t_{\text{ob}}))/\Gamma_{b,f} = 1 - (t_{\text{ob,o}}/t_{\text{ob}})^{1/2},$$

where $t_{\text{ob,o}} \simeq 10^{-1} r_{13} \Gamma_b^{-2} s$ is the observer frame blob dynamic time at $r_{13} \sim 1$ (which in the wind regime used here is unrelated to the burst duration). All lines, edges and maximum blanketing energies will therefore have an increasing spread $\Delta \nu/\nu \sim (\Delta \Gamma/\Gamma)_b$ with the time dependence of equation (10), extending from an upper value corresponding to $\Gamma_{b,f}$ down to a lower limit which moves to softer energies in time. The FeXXVI bound-free absorption will therefore move from blanketing the range $0.9\Gamma_2 - 2.2\Gamma_2$ MeV down to blanketing the range $0.09\Gamma_2 - 2.2\Gamma_2$ MeV in a time $\sim 10 r_{13} \Gamma_b^{-2}$ s after the burst starts.

6. Conclusions

Even though the emission from gamma-ray bursts is primarily non-thermal, we have shown that the observed spectrum may be substantially modified by the presence of highly ionized thermal plasma, with blueshifts of 10-100. The rate of absorption and re-emission by a thermal plasma, per unit mass, scales with density; the high ambient and ram pressure of the relativistic outflow can confine plasma to such high densities that only a very small total mass can have conspicuous effects. The material would be in a ‘mist’ of blobs or filaments filling a small fraction of the volume, but which are individually so small that they provide a significant covering factor. Even though small, these blobs can be envisaged as fluid-like because the gyroradius in megagauss magnetic fields is much smaller still. They can be accelerated to relativistic speed, without necessarily being disrupted, by the momentum of the jet-like outflow or by radiation pressure.
This material may be debris from a disrupted neutron star, e.g. Mészáros & Rees, 1997b (in which case it could be highly enriched in heavy elements), or entrained from the boundaries of the jet in a 'hypernova' (e.g. Paczyński, 1998) model.

We obviously cannot predict how much material would be expelled in this form, nor how the conditions near the central engine may evolve over the duration of long bursts. Nor do we know how the blobs would be distributed across the jet, though entrained material would tend to be more prominent near the boundaries (i.e. angles of order $\theta$ from the axis) rather than on the axis. However, some general trends seem generic to this picture.

The most prominent feature would be absorption above the photoionization edge of FeXXVI, leading to a feature at this energy (i.e. 9.3 Kev multiplied by the appropriate Doppler shift). In prolonged and complex bursts, it is likely that the primary emission comes from a series of internal shocks, at a distance $10^{13} - 10^{14}$ cm from the compact object. We would expect the feature to shift towards lower energies, becase later in the burst there would be time for lower-$\Gamma$ material to have reached the location of the reverse shock. (If different sub-bursts occur in shocks at different radii, then the absorption effects should be more conspicuous in those close in, and this may introduce a scatter about the general tendency for the cut-off to soften towards the end of long bursts. Spectra as observed by BATSE (most photons measured being in the range 50 - 500 KeV) would tend therefore to indicate, for objects with Fe-rich blobs, a spectral softening in time. Initially the burst would be classified as an HE (having a high energy component in the fourth LAD channel above 350 KeV), later to become an NHE (without significant emission above 350 KeV), with departures due to the previous scatter, e.g. as reported by Pendleton, et al. 1998. Also, when an average temporal evolution of many bursts is considered, it has been shown by Fenimore, 1998 that there is a clear trend towards softening as the burst progresses. While there are alternative explanations for this softening, such as slowing down and cooling of the emitting material, we suggest that absorption of the kind discussed in this paper (characterized by the time dependence of equation [10]) may be relevant to such correlations.

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