Population of Short γ-ray Bursters – Result of Gravitational lensing of "Quiet" γ-ray Sources in Remote Galaxies

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1 Introduction

We consider the hypothesis of the existence of a class of short (10^{-2}–10^{-3}s) and weak (10^{-6}–10^{-7}erg/s$\cdot$ cm^2) γ-bursts of cosmological origin. These events arise from gravitational microlensing of bright, quiet γ-ray sources (with luminosity about $3{\cdot}10^{38}$erg/s) located in distant ($z \geq 1$) galaxies by stars inside foreground galaxies. If the size of the γ-ray sources is 10^4–10^6cm, motion with respect to the observer or the intermediate galaxy may bring them close to the neigborhood of cusps along critical curves generated by individual stars (corresponding to caustics in the observer's plane). In these cases the observed fluxes increase by a factor 10^{11}–10^{13}, the temporal variation of intensity being due to the brightness distribution in the source and to the distance from the cusp (in the source plane). Using standard assumptions for the number and sizes of "quiet" γ-ray sources, the number and characteristics of galaxies, we estimate the observed burst rate to be between 1 and 10 bursts per year (see below). Their temporal and spectral properties are determined by the nature of sources (ejecting pulsar, accreting neutron star with a weak or strong magnetic field, black hole) and by their velocity relative to the cusp. Similar effects have been discussed in the context of flux variability and structure studies of quasars (e.g. Schneider & Weiss 1986, Grieger et al. 1988, Refsdal & Surdej 1994). However, in these cases the source sizes were larger than 10^{14}cm^3 and amplification did not exceed 10^2.

2 Maximum amplification and light curves

The effects of microlensing, splitting of the image of a distant object and amplification of its brightness, are determined by the combined action of a smoothed gravitational potential of the lensing galaxy and of the stars nearest to the line of sight. A system of intersecting caustics and cusps is formed in the observer's plane, while in the source plane a corresponding system of critical lines (anticaustics) and cusps is formed (Chang & Refsdal 1984, Paczynski 1986, Schneider & Weiss 1986). We introduce the following notation: D_S – distance to a remote

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galaxy, D_L – distance to the intermediate galaxy, $D = (D_S - D_L)D_L/D_S$ – effective distance and R_g - Schwarzschild radius ($R_g = \frac{2GM}{c^2} = 3 \cdot 10^5 M/M_\odot$cm for a star with mass M).

The amplification, $K(x)$, for a point source near the cusp is a complex function of x(x is the distance to the cusp in the direction along the normal to the critical curve) (Blanford & Narayan 1986, Schneider & Weiss 1986), which for $x \to 0$ has the asymptotic behavior: $K_0(x) \approx (D_S/D_L) \cdot (\sqrt{2R_gD}/x)$ For the purpose of this study it is important that $K(x)$ is proportional to $A = (D_S/D_L) \cdot \sqrt{2R_gD}$, which determines the amplification factor. Let us evaluate A for $z_S \sim 2$, $z_L \sim 0.5$, employing the expression for the angular distance in a cosmological model with $\Omega = 0$ (Turner et al. 1984): $D_z = (c/2H_0) \cdot [1-(1+z)^{-2}]$, where c is the velocity of light, $H_0 = 50 km/s \cdot$ Mpc. In that case, $A \sim 5.5 \cdot 10^{16}$, and at $x \sim 10^4 - 10^5$ cm (the probable size of a "quiet" source), we have $K_0 \sim 5 \cdot 10^{12}$ - $5 \cdot 10^{11}$. The light curve of the source is determined by a convolution of its brightness distribution with the amplification function $K_0(x)$.

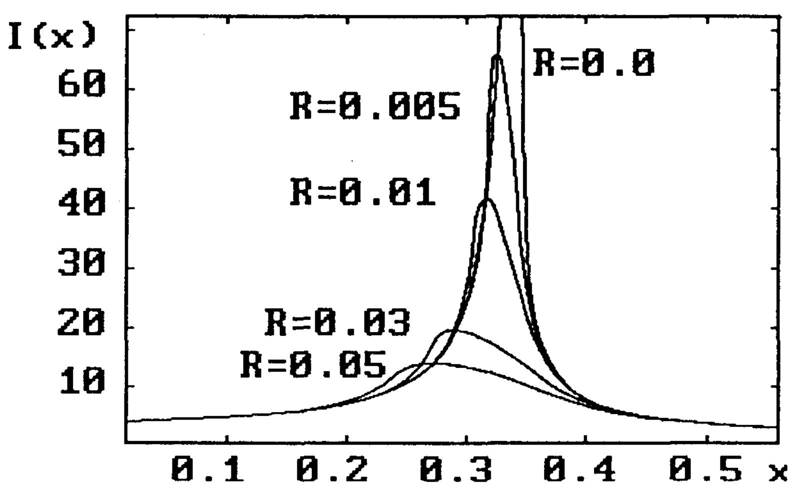

Fig. 1. Light curves of sources with uniform surface brightness (R is the size of the source region).

In the figure (taken from Schneider & Weiss 1986) curves are shown for different sizes of a source of uniform surface brightness (R and x are measured in $\sqrt{2R_gD} \sim 3 \cdot 10^{16} cm$ for the cases considered here). With decreasing R

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the maximum intensity rises steeply and it is believed that at $R \sim 3 \cdot 10^{-12}$ (or 10^5 cm) amplification could reach 10^{12}. It should be emphasized that this situation may occur when the distance of a γ-ray source moving with respect to the axis "observer – lensing star" does not exceed the proper size of the source. In this case the "strong effect zone" scans the region of the observer. The dimension of this zone, d_{obs}, is simply related to the diameter of the source d_S: $d_{obs} = d_S \cdot D_L/(D_S - D_L)(1 + z_L)$, and since the velocities of source and observer along the cusp normal are related in a similar manner (Griger et al. 1988), the duration of the burst is given by the transit time of the observer across the "strong effect zone" $\tau \sim d_{obs}/v_{obs} = d_S/v_S$. Taking $v_S \sim 10^8 cm/s$, a typical velocity for intergalactic motions, we obtain $\tau \sim 10^{-3}\left(d_S/10^5\right) s$

Thus, if the real luminosity of the γ-source is close to the Eddington limit ($3 \cdot 10^{38}$erg$/s$), it may be observed as an amplified burst with maximum luminosity of $\sim 10^{51}$erg/s. To detect such events at cosmological distances the flux must exceed a threshold of $\sim 10^{-7}$erg$/cm^2 \cdot s$ (Mao & Paczynski 1992).

3 Number of events

The number of γ-bursts of the kind considered here registered during a time T is $N_0 = \alpha N_G N_\gamma N_C$, where N_G is the number of galaxies which contain N_γ γ-sources of Eddington luminosity each; α is the degree of overlap of remote galaxies and intermediate galaxies; N_C is the number of cusps passed by the γ-source.

It is clear that $N_C = mN_*$, where m is the mean number of cusps per star $(m \sim 3-6), N_* = n_* d_S v_S T$, where n_* is the surface density of stars in the intermediate galaxy.

At $n_* \sim 4 \cdot 10^3 pc^{-2}$ (Refsdal & Surdej 1994), $v_S \sim 10^8$ cm/s, $T \sim 1$ year $= 3 \cdot 10^7 c$, we obtain $N_c \sim 10^{-13} \cdot (d_s/10^5)$ year^{-1}. Counts of faint galaxies ($V > 25^{\mathrm{m}}$) suggest that the total number of galaxies with $z \geq 0.5$ is $10^{10} - 10^{11}$, and one can argue that the degree of their overlap is close to unity (Tyson 1988, Lilly et al. 1991, Peterson et al. 1991). Assuming that $\alpha \sim 1, N_G \sim 10^{11}$ and $N_\gamma \sim 5 \cdot 10^2$, we obtain finally $N_0 \sim 5$ year^{-1}. Taking into account the approximate character of these estimates, we suggest a possibility of detecting from 1 to 10 γ-ray bursts per year.

4 Critical tests

We point out some properties of γ-ray bursts of the type considered in this work:
(a) An inverse correlation between the duration and peak intensity should be observed.
(b) In most cases the spectrum must be harder at the peak of the intensity.

As has already been pointed out, the "strong effect zone" of gravitational lensing shifts moves to the neighbourhood of the observer, similar to the beam pattern of a pulsar, as a result of the relative motion of the γ-ray source, lensing star and observer.

If the distance "lens – γ-ray source" and "observer – lens" is of the same order, the size of the zone and the speed of its movement are close to the size of the source and the velocity of its motion relative to the lens. According to the properties of cosmological γ-ray bursts it follows that they could not be observed simultaneously by several cosmic detectors in the *KONUS* experiment. Such events have probably already been registered by single γ-ray telescopes.

To critically test this γ-burst model we suggest to measure the time delay when the same events are registered with detectors separated in space. If the increase of the counting rate is associated with the time variations of the radiation flux in the spherical wave, the time delay τ_d is determined by formula $\tau_d = l_a/c$, where l_a is the distance between detector and γ-burst and c is the velocity of light. However, when the γ-burst is caused by detectors passing through the zone of strong effects, one finds $\tau_d = l_t/v$, where l_t is the distance between detectors perpendicular to the γ-ray burst direction, v is the velocity of the strong effect zone. To carry out the test, it is necessary to use at least four detectors, located at the tips of an equilateral pyramid with sides of $\sim 10^5$ cm.

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