ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

SEPTEMBER **1999**, PAGE 587

Astron. Astrophys. Suppl. Ser. **138**, 587–588 (1999)

Catching the light curve of a flaring GRB. The opportunity offered by gravitational lensing

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Received December 29, 1998; accepted June 3, 1999

Abstract. The photometric history of the events related to Gamma–Ray Bursts can be studied from the very beginning, or even before, if they are repeated (at least two times after the first event) by effect of gravitational lensing. These possibilities are analyzed for different kinds of lensing galaxies in the frame of their simple models.

Key words: gravitational lensing, gamma-rays: bursts

1. Introduction

There are at least two possibilities to obtain information on the behaviour of X–ray, optical and radio transients connected with GRBs during or after the γ event. The first way is the continuous monitoring of the sky region coinciding with the field of view of the γ–ray detectors. In this case we must use telescopes with maximum field of view, equipped with high temporal resolution panoramic detectors.

Another opportunity is offered by cosmological GRBs in the case of repetition of the event, if a repetition of the event occurs, as a result of gravitational lensing produced by an interposed galaxy. The shape of the repeated light curves is identical to the original one, taking into account the galaxy absorption effects. By summing the information obtained in all the wavelength ranges during one or two repetitions it might be possible to reconstruct the behavior of the variable source during, after and also before the γ burst. The main difficulty is to predict the time of the first repetition with good accuracy (the delay is caused by several parameters; most of them are unknown, such as redshifts of the GRB source and of the lens galaxy, characteristics of the lens galaxy structure and so on). For this reason, in order to detect the first repetition we need to monitor the transient throughout long periods of time. If a repetition is registered, we can estimate some parameters and predict the time of the second repetition with good enough accuracy. We already discussed this problem with respect to GRB 970508 (Beskin et al. 1998a); now, a wider sample of galaxies and GRBs configuration is analyzed.

2. Gravitational lensing

2.1. The model of lens

As a model of mass distribution in the lens galaxy, we will use the so-called Isothermal Sphere with Core (ISC), which gives a quite good description of the matter distribution in galaxies of different types (Hinshaw & Krauss 1987). We use a standard set of parameters: $D_{\rm d}$, $D_{\rm s}$, $D_{\rm ds}$ (linear distances to the lens galaxy, to the GRB source and between the lens galaxy and the GRB source, respectively), $\sigma_{\rm v}$ (velocity dispersion in the lens galaxy), $r_{\rm c}$, $\theta_{\rm c} = \frac{r_{\rm c}}{D_{\rm d}}$ (linear and angular radius of galaxy core), $\beta_0 = \frac{\beta}{\theta_{\rm c}}$ and $\theta_0 = \frac{\theta}{\theta_{\rm c}}$ (real and visual angular position of the source from the "observer–lens" axis in units of $\theta_{\rm c}$).

The lens equation is the following (see e.g. Wu 1989):

$$\theta_0 = \beta_0 + D\frac{\sqrt{1+\theta_0^2}-1}{\theta_0}, \tag{1}$$

where

$$D = \frac{4\pi\sigma_{\rm v}^2}{c^2}\frac{D_{\rm d}D_{\rm ds}}{r_{\rm c}D_{\rm s}} \tag{2}$$

is a dimensionless parameter. This equation can have 1 or 3 real solutions, which correspond to 1 or 3 source images or one or three bursts (i.e. two repetitions). It can be shown that this equation has three real roots when $D > 2$. To obtain these roots, an additional restriction for β_0 is necessary (Beskin et al. 1998a,b):

$$\beta_0 < \beta_{0\rm max} = \tag{3}$$

$$= \frac{-2D + 0.5 + \sqrt{D+0.25} + D\sqrt{D + 0.5 - \sqrt{D+0.25}}}{\sqrt{D - 0.5 - \sqrt{D+0.25}}}.$$

This means that we will have 3 GRBs from one source if its angular position β_0 is less than $\beta_{0\rm max}$.

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Table 1. Probability P of repetitions for GRB lensed by elliptical galaxies of size $\sim$ 15 kpc for different z_d and z_s

z_d	z_s	D	$\beta_{0\max}$	P
0.1	$0.5-4$	$20-30$	$11-20$	4%
$0.5-1.0$	$1-4$	$30-50$	$20-35$	15%
$0.5-1.0$	$5-10$	$50-70$	$35-55$	40%
$2-3$	$3-4$	$10-20$	$4-11$	1%
$2-3$	$5-10$	$15-40$	$8-28$	8%

2.2. The application to real galaxies

Let us give quantitative estimates assuming $\Omega = 1$ and $H_0 = 50$ km s^{-1} Mpc^{-1}. For the distances we have

$$D_{\mathrm{d,s}} = 12\left[1-(1+z_{\mathrm{d,s}})^{-1/2}\right](1+z_{\mathrm{d,s}})^{-1}\ \mathrm{Gpc}. \qquad (4)$$

It can also be shown that

$$D_{\mathrm{ds}} = 12\left[\left(\frac{1+z_\mathrm{s}}{1+z_\mathrm{d}}\right)^{1/2}-1\right](1+z_\mathrm{s})^{-3/2}\ \mathrm{Gpc}. \qquad (5)$$

To estimate D we take $\sigma_\mathrm{v} \sim 300$ km s^{-1} and $r_\mathrm{c} \sim 0.2$ kpc for elliptical galaxies, $\sigma_\mathrm{v} \sim 150$ km s^{-1} and $r_\mathrm{c} \sim 1$ kpc for spirals (Fukugita & Turner 1991; Hinshaw & Krauss 1987). As it is shown in Table 1, elliptical galaxies can give three images of GRB for any combination of z_d and z_s. In the case of a spiral galaxy, $D \gtrsim 2$ only for $z_\mathrm{d} \sim 0.5-1$ and $z_\mathrm{s} \sim 2-4$. We estimated the probability P of GRB repetitions for elliptical galaxies of size $\sim$ 15 kpc, if the GRB is seen through it (see Table 1). We used for P the expression $P \sim (\beta_{0\max} r_\mathrm{c}/R)^2$, where R is the size of the galaxy.

From Table 1 we see that about 40% of the most distant GRBs will be repeated if their emissions pass close to elliptical galaxies placed not far from us.

2.3. Relative intensities and delay times of repeated bursts

As an example, we now compute the parameters of repeated transients — intensities and delay times between two subsequent repetitions — for $D \sim 60$. The estimate of the intensity ratios is obtained according to the expression of lens magnification (Wu 1996):

$$\mu = \left|\frac{\beta_0}{\theta_0}\left[1+(\theta_0-\beta_0)\,\theta_0^{-1}D^{-1}-D\left(1+\theta_0^2\right)^{-\frac{1}{2}}\right]\right|^{-1}. \qquad (6)$$

The time delay is instead defined with the expression (Beskin et al. 1998a):

$$\Delta t_{ij} = \frac{4\pi\sigma_\mathrm{v}^2}{c^3} r_\mathrm{c}(1+z_\mathrm{d})\left\{\frac{1}{2}(\theta_{0i}-\theta_{0j}) \times \right.$$
$$\times\left[\frac{\sqrt{\theta_{0i}^2+1}-1}{\theta_{0i}}+\frac{\sqrt{\theta_{0j}^2+1}-1}{\theta_{0j}}\right]+$$
$$\left.+\sqrt{\theta_{0j}^2+1}-\sqrt{\theta_{0i}^2+1}+\ln\frac{1+\sqrt{\theta_{0i}^2+1}}{1+\sqrt{\theta_{0j}^2+1}}\right\}, \qquad (7)$$

Table 2. Parameters of the repeated GRBs with respect to the first one

Number	1	2
magnitude difference	4.7	7.2
angular distance	$3''\!.1$	$2''\!.9$
time delay (days)	367	368.5

which is obtained with the help of the Fermat's potential (see e.g. Schneider et al. 1992).

In Table 2 are reported the parameters of the repeated GRBs for $D \sim 60$ (the source is assumed at $z \sim 4$, while the elliptical galaxy has $z \sim 0.5$). Thus, repeating transients can be perfectly observed, although they would be $4-7$ magnitudes fainter than the first event. Delay times cover the range from days to years, while characteristic times of physical intensity variations span from days to months. For this reason, light curves can have complicated structures. To distinguish repeating transients we need to analyze all the available data, such as variations of intensity, astrometry and spectroscopy. It is necessary to note that observable angular distances between the first GRB and the repeated transients are $0''\!.2-3''$ i.e. they can be separated.

3. Discussion

Let us briefly discuss about the probability to observe repeating GRBs. This eventuality has been debated by different authors in the framework of several (more or less simple) theoretical models. For example, to use a single isothermal sphere, the probability of a single repetition is $0.05-0.4$% (Mao 1992). Using the estimate of the observation probability of QSO gravlensing of 1% (Wu 1996), we obtain that $0.1\%-0.3\%$ of cosmological GRBs can be repeated twice.

Finally we stress that the possibility to analyze the problem of obtaining GRBs light curves by means of gravlensing is the result of the detection of the optical transient with high spatial accuracy.

Acknowledgements. This investigation was supported by the Russian Fund of Fundamental Researches (grant 98–02–17570), by the Educational–Scientific centre "Cosmion", by the Italian Ministry of Foreign Affairs, and by the University of Bologna (Funds for selected research topics).

References

Beskin G.M., Shearer A., Redfern M., et al., 1998a, Nucl. Physics B (Proc. Suppl.) 69/1–3, 703
Beskin G.M., et al., 1998b (in preparation)
Fukugita M., Turner E.L., 1991, MNRAS 253, 99
Hinshaw G., Krauss L.M., 1987, ApJ 320, 468
Mao S., 1992, ApJ 389, L41
Schneider P., Ehlers J., Falco E.E., 1992, Gravitational Lenses. Springer–Verlag, Berlin
Wu X.P., 1989, A&A 214, 43
Wu X.P., 1996, Fundam. Cosm. Phys. 17, 1