

On the application of the mirror model for gamma-ray flare in 3C 279

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Abstract. Multiwavelength observations of high energy flare in 1996 from 3C 279 seems to favour the so called mirror model between different inverse Compton scattering models proposed as a possible explanation of gamma-ray emission in blazars. We performed kinematic analysis of the relativistic blob - mirror system and found that only part of the mirror located very close to the jet axis (very likely inside the jet cone) can re-emit soft photons which serve as a target for production of γ -rays by relativistic electrons in the blob. Since the presence of well localized scattering mirror inside the jet is problematic, this makes problems for the mirror model. The time scale and the shape of the γ -ray flare should reflect, in terms of the mirror model, the blob dimensions and the longitudinal distribution of relativistic electrons inside the blob. For the γ -ray light curve of the type observed in 1996 from 3C 279, i.e. the rising time of the flare during a few days with a sharp cut-off towards the end of the flare, the density of electrons inside the blob should increase exponentially starting from the front of the blob and reach maximum towards the end of the blob. Such distribution of electrons is difficult to explain in a model of a relativistic shock moving along the jet, which would rather inject electrons more efficiently at the front of the blob with a trail of particles on its downstream side.

Key words: galaxies: active – galaxies: jets – galaxies: individual: 3C 279 – gamma-rays: theory

1. Introduction

About 50 blazars have been detected by the Compton Gamma Ray Observatory in the MeV - GeV energy range (Fichtel et al. 1994, von Montigny et al. 1995, Thompson et al. 1995, Mukherjee et al. 1997), and 3 blazars, of the BL Lac type, are discovered in the TeV γ -rays by the Whipple Observatory (Punch et al. 1992, Quinn et al. 1996, Catanese et al. 1997). These blazars can reach very high γ -ray luminosities which are variable on time scales as short as a part of a day, in the case of optically violent variable quasars, or even several minutes, in the case of BL Lacs. These observations strongly suggest that γ -ray emission from blazars is collimated towards the observer within a

small angle as a result of relativistic motion of plasma in the jet or directional acceleration of particles.

High energy processes occurring in blazars are popularly explained in terms of the inverse Compton scattering (ICS) model in which γ -rays are produced in ICS of soft photons by electrons in a blob moving relativistically along the jet. Different modifications of this general model mainly concern the origin of soft photons, i.e. whether they come internally from the blob in the jet (synchrotron self-Compton (SSC) model, e.g. Maraschi et al. 1992, Bloom & Marscher 1993), directly from the disk (e.g. Dermer et al. 1992, Bednarek et al. 1996a,b), are produced in the disk but reprocessed by the matter surrounding the disk (external comptonization (EC) model, e.g. Sikora et al. 1994, Blandford & Levinson 1995), or produced in the jet but reprocessed by the matter surrounding the jet (the so-called mirror model, Ghisellini & Madau 1996, henceforth GM). In this last paper it is mentioned that SSC model and external comptonization of photons produced by the broad line region clouds (BLR) illuminated by the disk (EC model) may also contribute to the γ -ray emission producing a first γ -ray pre-flare. For the SSC model the amplitude of the γ -ray variation is expected to be proportional to the square of the variation observed in IR-optical-UV energy range. For the EC model the γ -ray emission should vary linearly with the low energy synchrotron emission. Such behaviour is not observed in the case of the 1996 flare from 3C 279 in which the γ -ray variation is more than the square of the synchrotron variation. Moreover, in the γ -ray light curve of this flare (see Fig. 1 in Wehrle et al. 1997), there is no clear evidence for a double peak structure which could eventually correspond to the first γ -ray flare produced in terms of SSC or EC models and the second γ -ray flare produced in terms of the mirror model. Therefore, although the SSC model cannot be completely rule out, Wehrle et al. (1997) concludes that the mirror model is favourite by the multiwavelength observations of a strong flare in February 1996 from 3C 279 since it predicts γ -ray flare with observed features.

In this paper we test the mirror model by comparing predictions of the kinematic analysis with the observational results. The possible contributions from SSC and EC models to the γ -ray production during this flare are neglected since, as we mentioned above, there is no observational support for their importance. Simultaneous analysis of all these models will require

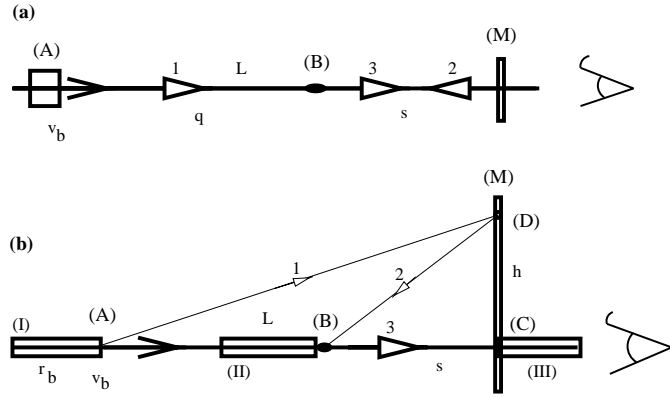


Fig. 1a and b. Schematic representation (not to scale) of the mirror model with a simple geometry, i.e. a single thin blob and a one dimensional mirror on the jet axis **(a)**, and with a realistic geometry, i.e. an extended blob and a two dimensional plane mirror **(b)**. The mirror (M) is located at the distance l from the base of the jet (A). We assume that first synchrotron photons (marked by 1) are produced by the blob in (A). First γ -rays (marked by 3) are produced by ICS of soft photons (marked by 2) re-emitted by the mirror, at the distance s from the mirror (B) and the distance q from the base of the jet. In Fig. 1b the synchrotron photons illuminate the mirror at different locations (D) which are at a distance h from the jet axis. Different critical locations of the blob are marked by: (I) - the blob is at the base of the jet; (II) - the blob starts to produce first γ -ray photons; (III) - the back of the blob crosses the mirror located at (C). The blob moves with velocity v_b towards the mirror and has longitudinal extent r_b in case **b** and negligible longitudinal extent in case **a**

an introduction of additional free parameters (density of electrons in the blob, the perpendicular extent of the blob, definition of the disk radiation) which are not all well constrained by the observations.

2. Gamma-ray production in the mirror model

According to Ghisellini & Madau model, a blob containing relativistic particles moves along the jet with the Lorentz factor γ and velocity normalized to the speed of light β . The synchrotron radiation produced by electrons in the blob illuminates the BLR cloud(s) (the mirror), located at a distance l from the center of active galaxy. This radiation photoionizes the cloud(s) which re-emit isotropically broad line emission. The relativistic blob approaching the mirror will see its radiation significantly enhanced because of decreasing blob-mirror distance and relativistic effects. In order to understand the features of this model we start this analysis from a simple picture, i.e. a single blob with negligible longitudinal extent along the jet (in respect to l) and a one dimensional mirror located on the jet axis. Since this picture is not successful in explanation of the features of γ -ray flare in 3C 279, we discuss more realistic case in which extended blob scatters radiation reflected by the two dimensional mirror.

2.1. A single thin blob and a one dimensional mirror

Let us discuss the simplest possible case in which the blob, the mirror, and the observer are located on the jet axis (see Fig. 1a and ba). We assume that the blob has negligible dimensions in respect to the other dimensions of considered system. First synchrotron photons are emitted by the blob at the distance marked by (A) which has been chosen as located at the base of the jet. These photons (marked by 1) excite the mirror (marked by (M)), which is at a distance l . The photons, re-emitted by the mirror (marked by 2), meet the blob again at a place marked by (B) which is at the distance s from location of the mirror. In (B) blob starts to produce γ -rays (marked by 3). The production of γ -rays stops when the blob passes through the mirror. The path, s , on which γ -rays are produced by the blob is given by

$$s = \beta(1 + \beta)\gamma^2 c\tau_\gamma, \quad (1)$$

where τ_γ is the observed rise time of the γ -ray flare, and c is the velocity of light. First γ -rays are produced at the distance q from the base of the jet, which is equal to $l - s$ and given by

$$q = 2\beta s / (1 - \beta) = 2(1 + \beta)^2 \beta^2 \gamma^4 c\tau_\gamma. \quad (2)$$

The time lag, $\tau_{\text{opt}-\gamma}$, between the beginning of synchrotron flare, which ionizes the cloud(s), and the beginning of γ -ray flare is

$$\tau_{\text{opt}-\gamma} = 2(1 + \beta)\gamma^2 \tau_\gamma. \quad (3)$$

Eqs. (2) and (3) show that for the case of γ -ray flares observed from 3C 279 (Kniffen et al. 1993, Wehrle et al. 1997) which has the rising time of a few days ($\tau \approx 6 - 8$ days in February 1996) and, the blob moving with typical Lorentz factor of the order of ~ 10 ($\gamma > 8.5$ for 3C 279, Wehrle et al. 1997), the distance from the base of the jet to the place of γ -ray production should be of the order of a few hundred pc ($q \sim 200$ pc for 3C 279, see Eq. (2)). The corresponding time delay between synchrotron and γ -ray flare should be of the order of a few years ($\tau_{\text{opt}-\gamma} \sim 2 - 3$ years for 3C 279). The distance q is about three orders of magnitudes larger than the typical dimension of the BLR (see GM). Therefore the rise time of γ -ray flare observed in 3C 279 cannot be explained as a result of relativistic effects connected with the time of flight of a single thin blob in the radiation reflected by the BLR clouds. However a few day time scale of the flare might be connected with the longitudinal extension of the blob. Small inhomogeneities in such extended blob can be responsible for a short time scale variability of γ -ray emission (flickering) as a result of kinematic effects discussed in this subsection. In terms of the mirror model we can estimate the flickering time of the γ -ray emission during the rising time of the flare in the case of 3C 279 by reversing Eq. (2). Assuming $q = 3 \times 10^{17}$ cm and $\gamma = 8.5$, we estimate the time scale for the shortest possible flux variability caused by these effects as equal to $\tau_\gamma \approx 4$ min.

2.2. An extended blob and a two dimensional mirror

Let us assume that the blob has longitudinal extent along the jet r_b (see Fig. 1a and bb), and negligible perpendicular extent. Its perpendicular dimension do not introduce interesting effects if the observer is located at small angles to the jet axis. As in the picture considered above, electrons produce synchrotron radiation which is reflected by the mirror located at a distance l from the place of first injection of electrons (assumed at the base of the jet). The mirror is two-dimensional with negligible thickness and extends in perpendicular direction in respect to the jet axis. Note that Ghisellini & Madau considered the spherical mirror. However our assumption on the plane mirror simplifies the formulas derived below, because of simpler geometrical relations (rectangle triangles) and does not introduce any additional artifact features since only the part of the mirror located close to the jet axis is important. For simplicity we assume that the observer is located on the jet axis. The synchrotron photons (marked by 1, in Fig. 1a and bb), which are produced by electrons at the place marked by (A), illuminate the mirror (M) at any place (D). The photons reprocessed by the mirror (marked by 2) meet at the first time the blob at the distance s from the mirror,

$$s = \frac{1 - \beta}{1 + \beta} l. \quad (4)$$

At this place first γ -rays (marked by 3) are produced by the blob and the γ -ray flare begins to develop. The γ -ray emission increases very fast up to the moment when the front of the blob meets the mirror. This happens at the time

$$t_{\text{inc}} = (1 - \beta)s/\beta c = l/\gamma^4(1 + \beta)^3\beta c, \quad (5)$$

measured from the beginning of the γ -ray flare. The flare finishes at the time

$$t_{\text{end}} = t_{\text{inc}} + r_b/\beta c, \quad (6)$$

when the back of the extended blob crosses the place of location of the mirror. This equation simply relates the expected time scale of the flare to the length of the extended blob r_b and the distance l of the mirror from the base of the jet. For relativistic blob ($\gamma \gg 1$) and the γ -ray flares occurring on a time scale of days (as observed in blazars) the dependence of t_{end} on l is not important (see Eqs. (5) and (6)). The full γ -ray flare is then produced on a distance, r_γ , measured from the mirror, which is given by

$$r_\gamma = s + r_b/(1 + \beta) \approx r_b/2. \quad (7)$$

Eq. (6) shows that duration of the γ -ray flare can be consistent with the mirror model for reasonable dimensions of the blob. However the question arises if the observed γ -ray light curves of flares in blazars can be explained in such a model. Below we analyse this problem assuming different geometries of the blob with different density distributions of relativistic electrons.

2.2.1. Gamma-ray light curve produced by extended blob

In order to determine the evolution of γ -ray power emitted in time t by the blob, the following formula has to be integrated

$$N_\gamma(t) = 2\pi \int_{x_d}^{x_u} n_\gamma n_e(r', t') \int_{\mu_m}^1 \int_{r_d}^{r_u} I_{\text{ill}} \gamma^2 (1 + \beta \mu)^2 dr d\mu dx, \quad (8)$$

where $\mu = \cos \phi$, and ϕ is the angle CBD defined in Fig. 1b. The first integral has to be performed over distances of γ -ray emission region (part of the blob) from the mirror x . The second integral is over different paths (defined by the cosine angle μ) which has to be passed by synchrotron photons and reprocessed photons in order to produce γ -ray photon found in time t at the location of the mirror. This integral is equivalent to the integration over contributions from different scattering centers of the mirror defined by the height h (see Fig. 1a and bb). Therefore the limits of integration over μ can be changed to integration over h by using

$$d\mu = -xh(x^2 + h^2)^{-3/2} dh. \quad (9)$$

The third integral has to be performed over the regions in the blob, r (measured from the front of the blob), emitting synchrotron photons which can produce reprocessed photons serving next as a target for relativistic electrons at x .

At a point defined by h , the mirror is illuminated by the synchrotron radiation from the blob with the flux (see GM)

$$F_{\text{syn}} = \frac{1}{\gamma^4(1 - \beta \cos \eta)^4} \frac{L_{\text{syn}}}{4\pi d^2}, \quad (10)$$

where $d = (h^2 + z^2)^{1/2}$ is the distance between the regions of synchrotron emission and the scattering centers on the mirror, z is the distance of the place of production of synchrotron photons from the mirror, and $\cos \eta = z/d$. The synchrotron luminosity in the blob frame can be expressed by

$$L_{\text{syn}} = 4\pi r_b^2 c n_{\text{syn}} n_e(r, t''). \quad (11)$$

n_{syn} describes the synchrotron power emitted by average relativistic electron, and $n_e(r, t'')$ is the electron density in the blob as a function of r at the moment $t'' = t - (d + \sqrt{h^2 + x^2 - x/\beta})/c$. For distances d smaller than r_b , we take in Eq. (10) $d = r_b$, since the synchrotron luminosity cannot exceed the maximum possible value determined by the dimension of the blob r_b .

The points on the mirror at the distance, h , re-emits a part a of incident flux F_{syn} isotropically (GM),

$$I_{\text{ill}} = \frac{a}{4\pi} F_{\text{syn}}. \quad (12)$$

The relativistic electrons with density $n_e(r', t')$, responsible for production of γ -ray photons at the time t (Eq. 8), has to be counted at the moment $t' = t - x/c$ and at place in the blob measured from its front $r' = \beta ct - (1 - \beta)(x - s)$.

The limits of integration over distances of parts of the blob from the mirror x , which produce γ -rays observed at time t at

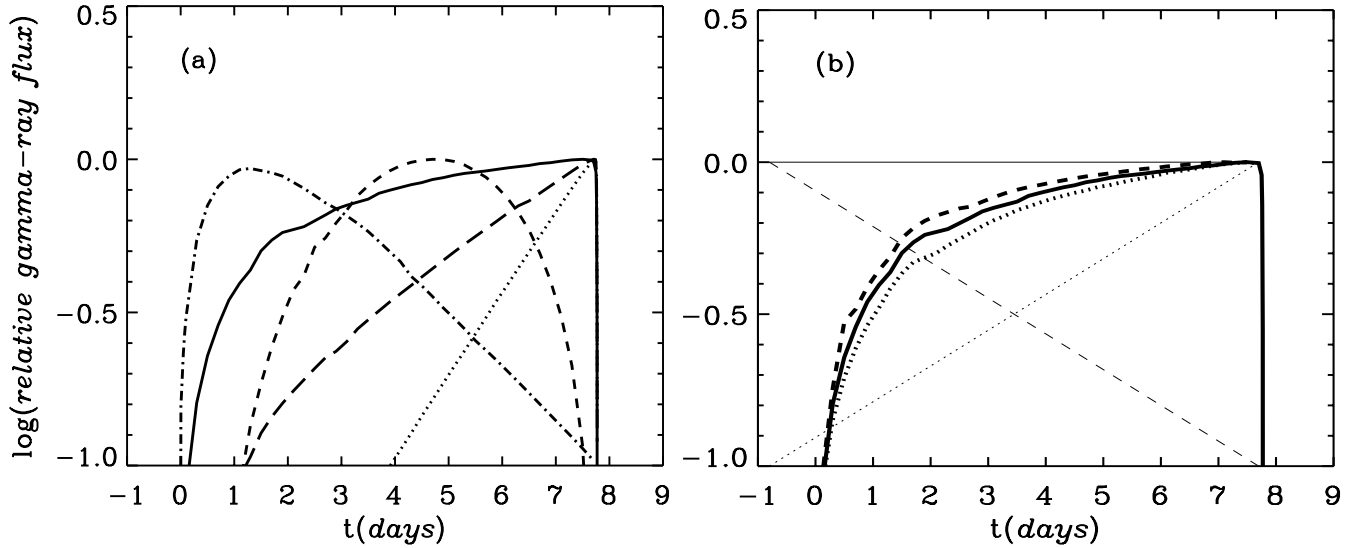


Fig. 2a and b. Gamma-ray light curves produced by a blob with different geometries and distributions of relativistic electrons. It is assumed that the mirror is located at the distance $l = 3 \times 10^{17}$ cm from the place where first synchrotron photons are produced by the blob (close to the base of the jet). The blob has longitudinal extent $r_b = 2 \times 10^{16}$ cm and moves along the jet with the Lorentz factor $\gamma = 8.5$. **a** Different curves show the γ -ray light curves in the case of: a spherical, homogeneous blob (dashed curve), a cylindrical, homogeneous blob (full curve), and inhomogeneous blobs for the distribution of electron densities given by Eq. (24) (dot-dashed curve), and Eq. (25) with $\sigma = 10$ (dotted curve) and $\sigma = 2.718$ (long-dashed curve). **b** The γ -ray light curves are shown by the thick curves for a cylindrical, homogeneous blob in which the density of electrons depends on the distance x from the mirror according to: Eq. (26) (dotted curve), Eq. (27) (dashed curve) and $n_e = \text{const}$ (full curve). The corresponding synchrotron flares are marked by the thin curves.

the location of the mirror, can be found from the analysis of propagation of the front and the back of the blob. The lower limit is

$$x_d = \begin{cases} 0, & \text{if } p \geq s; \\ s - p, & \text{if } p < s. \end{cases} \quad (13)$$

where $p = \beta ct / (1 - \beta)$, and the upper limit is

$$x_u = \begin{cases} s + 0.5ct, & \text{if } r_b \geq w; \\ s + (r_b - \beta ct) / (1 - \beta), & \text{if } r_b < w. \end{cases} \quad (14)$$

where $w = 0.5ct(1 + \beta)$.

Only photons reprocessed by the part of the mirror at a distance from the jet axis smaller than h_m can contribute to the γ -ray production by the parts of the blob located at the distance x from the mirror. This maximum height h_m can be found by analysing the time of flights of photons and the blob (Fig 1a and bb) and depends on l and x . It has to fulfil the following equation,

$$l + 2s + ct = (l^2 + h_m^2)^{1/2} + (x^2 + h_m^2)^{1/2} + x, \quad (15)$$

which has the solution

$$h_m = [0.25(l + B + \frac{l^2 - x^2}{l + B})^2 - l^2]^{1/2}, \quad (16)$$

where $B = 2s + ct - x$. h_m takes the maximum possible value, h_u , if the synchrotron photons, produced on the front of the blob at the distance l from the mirror, excite parts of the mirror which produce reprocessed photons serving next as a target for production of γ -rays by electrons at the moment when the back

of the blob crosses the location of the mirror. For this constraint, following condition has to be fulfilled

$$(l^2 + h_u^2)^{1/2} + h_u = (l + r_b) / \beta. \quad (17)$$

The above equation has the solution

$$h_u = [(l + r_b)^2 - \beta^2 l^2] / 2\beta(l + r_b). \quad (18)$$

For the relativistic blob ($\gamma \gg 1$) and $l/\gamma^2 \ll r_b \ll l$,

$$h_u \cong r_b. \quad (19)$$

Hence for the parameters of the γ -ray flares observed in 3C 279, only parts of the mirror close to the jet axis (laying mainly inside the jet) can re-emit soft photons which serve as a target for production of γ -rays. Therefore the limits of integrations in Eq. (21) of the paper by Ghisellini & Madau (GM) are not correct because they do not take into account the dynamics of the blob. From this reason, the energy densities of photons re-emitted by the mirror, but observed in the blob frame, are time independent and overestimated in that paper.

For given x and h , we determine the part of the blob (its longitudinal extent r) which emits synchrotron photons. These photons initiate next the production of γ -ray photons observed at the moment t . As before we analyse the time of flights of photons and the blob and obtain the lower limit on the longitudinal extent of the blob in Eq. (8)

$$r_d = \begin{cases} 0, & \text{if } E < m; \\ \beta(E - h) - l, & \text{if } E \geq m. \end{cases} \quad (20)$$

where $m = l/\beta + h$, and $E = l + B - (x^2 + h^2)^{1/2}$, and the upper limit

$$r_u = \begin{cases} r_b, & \text{if } r_b < r_g; \\ r_g, & \text{if } r_b \geq r_g. \end{cases} \quad (21)$$

where $r_g = \beta[E - (h^2 + l^2)^{1/2}]$. Finally we find the distance z of the blob from the mirror at the moment of emission of synchrotron photons which initiate the production of γ -ray photons at the time t . For given x , h and r , we determine z from the following condition

$$F + z/\beta = (h^2 + z^2)^{1/2}, \quad (22)$$

with $F = E - (l + r)/\beta$. The solution of this equation is

$$z = (0.5\sqrt{\Delta} - \beta F)\gamma^2, \quad (23)$$

where $\Delta = 4\beta^2[\beta^2 F^2 + (1 - \beta^2)h^2]$.

Since we want to know the relative change of the γ -ray flux with time, the computations of the γ -ray light curves have been performed assuming that the parameters describing the reflection, and γ -ray and synchrotron efficiencies of a single relativistic electron in the blob are $an_\gamma n_{\text{syn}} = 1$. In principle the values of n_γ and n_{syn} may depend on the blob propagation, e.g. if the spectrum of electrons in the blob depends on its propagation along the jet. We do not consider such cases in order not to complicate the model too much. First we investigate the dependence of the γ -ray light curve on the longitudinal distribution of electrons in the blob, $n_e(r)$. In general n_e may depend on the blob geometry and electron density as a function of r . The results of computations of the γ -ray light curves for a few different cases are shown in Fig. 2a and ba. The dashed curve in this figure shows the γ -ray light curve in the case of cumulative distribution of electrons in the blob (integrated over perpendicular extent of the blob), $n_e(r) \propto \sqrt{r_b^2 - (2r - r_b)^2}$, corresponding to the homogeneous, spherical blob with longitudinal extent $r_b = 2 \times 10^{16}$ cm, moving with the Lorentz factor $\gamma = 8.5$. The mirror is located at the distance $l = 3 \times 10^{17}$ cm from the base of the jet. The expected light curve in this case is almost symmetrical with the maximum corresponding to the center of the blob. The full curve shows the light curve for the homogeneous, cylindrical blob with other parameters of the model as in previous case. The dot-dashed curve shows the γ -ray light curve produced by the blob with cylindrical geometry but with exponential decrease of density of relativistic electrons. We apply the following distribution

$$n_e(r) \propto 10^{(r_b - r)/r_b}, \quad (24)$$

which might correspond to the distribution of electrons, produced by the relativistic plain shock, with the maximum on the front of the cylindrical blob and exponentially decreasing tail towards the end of the blob. In contrary, the density of electrons could increase exponentially with r , e.g. according to

$$n_e(r) \propto \sigma^{r/r_b}. \quad (25)$$

We consider the cases with $\sigma = 10$ and $\sigma = e \cong 2.718$, for which the γ -ray light curves are shown in Fig. 2a and ba by the dotted and long-dashed curves, respectively.

Fig. 2a and bb shows the γ -ray and corresponding synchrotron light curves assuming that the density of electrons in the blob depends on the distance x from the mirror but is homogeneous inside the blob. These light curves are normalized to the flux at their maximum. The dotted curves corresponds to the continuous increase of density of relativistic electrons in the blob according to

$$n_e(x) \propto 10^{(l-x)/l}, \quad (26)$$

and the dashed curves to the case when the electron density decreases according to

$$n_e(x) \propto 10^{x/l}. \quad (27)$$

These γ -ray light curves are very similar to the γ -ray light curve (full curve) obtained in the case with constant electron density in the blob during its propagation in the jet. Small differences between these γ -ray light curves are due to the fact that the blob reaches the mirror after very short time t_{inc} measured from the beginning of the γ -ray flare. For $t > t_{\text{inc}}$, the radiation field seen by relativistic electrons do not change significantly. Note that the production of γ -ray photons in the blob occurs at small distance from the mirror (given by Eq. (7)) in comparison to the distance l of the mirror from the base of the jet. The beginning of the γ -ray flare is delayed in respect to the synchrotron flare by $t_d = 2l/[(1 + \beta)^2 \gamma^2 c]$. For the parameters considered in Fig. 2b this delay is of the order of ~ 0.8 day.

In all discussed above cases the γ -ray flux increases initially on a very short time scale (given by Eq. (5)). For the parameters applied above this time is $t_{\text{inc}} \approx 8$ min. The γ -ray flare finishes at time t_{end} given by Eq. (6), which for these parameters is ~ 7.7 days.

3. Confrontation with the γ -ray light curve of 1996 flare from 3C 279

The γ -ray blazar 3C 279 is one of the best studied up to now. It was the first blazar detected by the Compton GRO in June 1991, showing the bright flare with the γ -ray light curve which increased for a few days and finished on a much shorter time scale (Kniffen et al. 1993, Hartman et al. 1996). Its γ -ray emission in December 1992 - January 1993 was about an order of magnitude lower (Maraschi et al. 1994). However on February 1996, 3C 279 again shows strong flare with the light curve very similar to this one observed in 1991 (Wehrle et al. 1997, Collmar et al. 1997). Significant variability of the γ -ray flux during this flare has been measured on a time scale of ~ 8 hr. The γ -ray flux increased continuously for about an order of magnitude during 6 – 8 days and later dropped sharply during ~ 1 day (see Fig. 1 in Wehrle et al. 1997). The rapid γ -ray variability, simultaneous variability of X- and 10 GeV γ -rays, and the condition that the γ -ray emission region should be transparent, requires for the Lorentz factor of relativistic blob $\gamma > 8.5$ (Wehrle et al. 1997). According to Wehrle et al., the multiwavelength observations of this flare (the lack of evident simultaneous variations of the optical - UV flux and the γ -ray flux) favour the mirror model for the γ -ray production in this source.

As we already mentioned in Sect. 2.1, the γ -ray flare of the type observed in 3C 279 cannot be produced by a single blob with negligible dimension moving with the Lorentz factor $\gamma = 8.5$, provided that the mirror is located from the base of the jet at a characteristic distance of the BLR clouds $\sim 3 \times 10^{17}$ cm. The rise time scale of the flare has to be connected with the longitudinal extent of the blob in the jet. The observed time scale of the flare requires that the extent of the blob should be of the order of $r_b \sim 2 \times 10^{16}$ cm, if the mirror is at the distance $l = 3 \times 10^{17}$ cm and $\gamma = 8.5$. However the requirements on the time of flight of photons and the blob show that only soft photons re-emitted by the parts of the mirror within radius $h_u \approx r_b$, centered on the jet axis (see Eq. (19)), can contribute to the observed γ -ray flux. Therefore the scattering mirror has to be located within the jet cone, provided that the jet typical opening angle is of the order of $\sim 1/\gamma$. This conclusion is inconsistent with the assumptions made by Ghisellini & Madau (GM) in their computations of the density of reprocessed photons seen by relativistic electrons in the blob frame.

The shape of the γ -ray light curve can be explained in terms of the mirror model if the density of relativistic electrons increases exponentially towards the end of the blob. Good consistency with the observed rise time scale of the γ -ray flare in February 1996 from 3C 279 is obtained for the density distribution of electrons in the blob of the type $n_e(r) \propto \exp(r/r_b)$ (see long-dashed curve in Fig. 2a and ba) where r is measured from the front of the blob. However such distribution of electrons along the blob is difficult to motivate in terms of the standard relativistic shock model moving along the jet. The electron distributions with the maximum on the front of the blob and the trail streaming away from the shock on its downstream side seems to be more likely (Mastichiadis & Kirk 1996, Kirk et al. 1998). However such electron distribution gives rapidly rising and exponentially decaying light curve (see dot-dashed curve in Fig. 2a and ba), which is in contrary to the observations of 3C 279. Therefore, the γ -ray light curve of 3C 279 suggests that for the mirror model the single large scale shock front is not likely mechanism of injection of relativistic electrons along the blob. The sequence of smaller scale shocks or another mechanism of acceleration of particles (magnetic reconnection in the jet ?) might give more appropriate explanation.

4. Conclusion

We discuss details of the mirror model proposed by Ghisellini & Madau. This model seems to be favourite by the multiwavelength observations of the γ -ray flare in 1996 from 3C 279 (Wehrle et al. 1997). Based on the analysis of the kinematics of the emission region (a blob moving relativistically along the jet) we come to the conclusion that only relatively small part of the mirror is able to re-emit soft photons which serve as a target for production of γ -rays. For the parameters of the γ -ray flare observed in 1996 from 3C 279, the radius of this part of the mirror should be comparable to the longitudinal extent of the blob. It has to be of the order of 2×10^{16} cm in order to be consistent with the rising time of the flare. This part of the

mirror should lay inside the jet cone provided that its opening angle is of the order of $\sim 1/\gamma$. As mentioned in Ghisellini & Madau (GM), the physical processes in the jet may prevent the presence of the well localized mirror inside the jet.

The calculations of density of photons re-emitted by the mirror are done by Ghisellini & Madau (see Fig. 2 in GM) in a time independent picture which do not take into account the dynamics of the blob. As a consequence they integrate over the parts of the mirror at distances from the jet axis which are much larger than the maximum distance h_u (Eq. (19)), found in our dynamical (time dependent) analysis. The photon densities seen by the blob cannot be directly compared with those obtained by us in a time dependent version of the mirror model. Ghisellini & Madau results are only correct for the continuous (time independent) flow of relativistic plasma along the jet axis but overestimates the density of soft photons seen by the relativistic electrons in the blob with limited longitudinal extent. The relativistic blobs in blazars has to be confined to the part of the jet in order to produce the γ -ray flares with the observed rising time scale.

We computed the γ -ray light curves expected in the dynamical version of the mirror model for different distribution of relativistic electrons inside the blob and assuming that the density of electrons in the blob changes during propagation along the jet. Slowly rising γ -ray flux with sudden cut-off towards the end of the flare, as observed in 3C 279, is obtained in the case of inhomogeneous blob with electron densities exponentially rising towards the end of the blob. Such electron distribution is difficult to understand in the popular scenario for γ -ray production in which relativistic shock moves along the jet. It seems that such shock should rather inject relativistic electrons with high efficiencies close to the front of the blob, with the trail of electrons on its downstream side (Kirk, Rieger & Mastichiadis 1998). However the γ -ray light curve expected in this case is different from that observed during the flares in the blazar 3C 279.

Since γ -rays are produced in a region which is close to the mirror, therefore the shape of the γ -ray light curve is not very sensitive on the variations of the density of electrons during the time of propagation of the blob between the base of the jet and the mirror. Of course the absolute γ -ray fluxes produced by the blobs with different evolutions of electron densities in time may differ significantly.

The γ -ray light curves presented in Figs. 2a and b show very sharp cut-offs towards the end of the flare due to our assumption on the negligible thickness of the mirror. In fact, the observed width of the peak in the γ -ray light curve of 3C 279, of the order of $t_m \sim 1$ day (see Fig. 1 in Wehrle et al. 1997), may be related to the time in which relativistic blob is moving through the mirror with the finite thickness. If this interpretation is correct then the thickness of the mirror has to be limited to $\rho_m \approx ct_m\beta(1 + \beta)\gamma^2 \approx 4 \times 10^{17}$ cm which is comparable to the distance of the mirror from the base of the jet.

In this analysis we do not consider production of γ -rays in terms of the SSC and EC models simultaneously with the mirror model since there is no clear evidence of their importance in the γ -ray light curve and the multiwavelength spectrum observed in 1996 from 3C 279 (Wehrle et al. 1997). The γ -ray

light curves reported in Figs. 2 show only relative change of the γ -ray flux with time. They are not straightforwardly dependent on the parameters of the blob (the magnetic field, electron density, blob perpendicular extent, disk radiation) which are not uniquely constrained by the observations. The SSC and EC models will require to fix these parameters in order to guarantee reliable comparisons.

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