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THE DECELERATION AND UNIFICATION OF JETTED OBJECTS

Stanisław Ryś

Astronomical Observatory, Jagiellonian University, ul. Orla 171, 30-244 Kraków, Poland

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Abstract. The widely accepted AGN unification model has been developed by introduction of a constant factor representing deceleration. Assuming special relativity formulae and the orientation of the outflow with respect to the observer, we are able to model the main shapes of the radio emission structures of FR 1 and FR 2 types. The differences of radio structures of both types can be reproduced by changing the model parameters.

Key words: galaxies: active, jets – quasars: general – radio continuum: galaxies

1. INTRODUCTION

For explanation of a radio source structure it is not enough to take into account simple Lorentz transformation between two frames moving relatively with constant velocities. We should discuss the influence of deceleration on the observed properties of radio structure (its brightness distribution). We are interested in the description of the observed brightness of a moving plasma element watched by an observer located at the Earth inertial rest frame, using Lorentz transformation rules. Having such a description we will be able to test the predictions of the model with the observed properties of the radio structure. We can expect an important modification because velocities of plasma elements are not constant along the jet.

Since we accept that the bulk motions are relativistic, we have to do all mathematical calculations according to the special theory of relativity. The simplest version of the motion equation happens in the case of constant deceleration in the rest frame of the plasma element. The deceleration vector is assumed to be parallel to the velocity vector. A useful formula for the coordinate and time transformations can be taken from Rybicki & Lightman (1979):

$$r = G^{-1}(\gamma_0 - \gamma) \qquad\qquad t = G^{-1}c^{-1}(\beta_0\gamma_0 - \beta\gamma) \tag{1}$$

where $G = g/c^2$, $\gamma = (1-\beta^2)^{-1/2}$, $\beta c = dr/dt$, $\beta_0 = \beta(t=0)$, $\gamma_0 = (1-\beta_0^2)^{-1/2}$, g is an amplitude of constant deceleration factor, and the time t is measured in the observer's rest frame (Ryś & Maślanka 2003). Equations (1) describe the position of the moving blob as a function of time, $r(\gamma(t))$.

The signal travel time corrections should be made when the observer sees the moving blob. Taking into account the geometry in the considered problem we obtain the equation connecting the position and age of the plasma element: $t - (r/c)\cos(\theta) = t_{\rm obs}$. Using equations (1) and having $t_{\rm obs}$ we solve this equation for

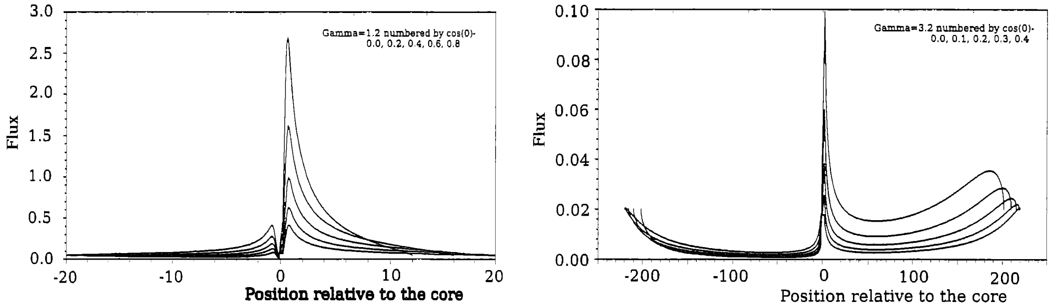

Fig. 1. The fluxes of radio waves received by the observer from plasma elements moving along the path of radio-jet. See the differences between the jet and counter-jet.

$\gamma(t_{\rm obs})$. For the given values of the parameters γ_0, g, $\cos(\theta)$ and $t_{\rm obs}$ we are able to calculate the position at which we expect to find all the plasma elements inside the jet.

The brightness evolution of a plasma element is determined by the adopted type of evolution in the frame of radiating object. We assume that the evolution of a flux of photons is described by the power law $F(\tau) \sim \nu^{-\alpha}\tau^{-\mu}$, in the rest frame of the blob, where α is a spectral index, μ is an index of the flux decline, and τ is the time elapsed in the plasma element frame. Therefore the flux of photons received by the observer is $f(r(t_{\rm obs})) = f_0 \cdot D^{3+\alpha} \cdot \tau^{-\mu}$. Now, contrary to the kinematical model the Doppler-Lorentz factor, D depends on the positions of the blob inside of the investigated structure. The transformation rule for the time between the observer (t) and the plasma element (τ) rest frames is: $d\tau = dt/\gamma(t)$, and after integration we put $\tau(\gamma)$ into equation describing the flux evolution and obtain:

$$f = f(0)\left[\gamma(1+\beta\cdot\cos\theta)\right]^{-(3+\alpha)}\left(\log\frac{(\beta_0+1)\gamma_0}{(\beta+1)\gamma)}\right)^{-\mu} \tag{2}$$

which allows us to calculate a temporal or positional prediction of brightness of the plasma element inside of the structure. We assume that for $\tau(t_{\rm obs} = 0) = 0$ the plasma element has $\gamma = \gamma_0$ (c.f., Ryś & Maślanka 2003).

The shape of the structure implied by (2) is determined by the values of $\cos\theta$, α, μ and γ_0. The deceleration parameter (g/c) has no influence on the curve shape but only on the extension of the structure. We can expect that inclusion of deceleration gives a strong and important modification of brightness distribution inside the radio source structure.

2. SPATIAL PATTERN OF THE JET AND ITS LIGHT CURVE SHAPE.

The formulae which describe position $r(t)$ and the flux $f(t)$ of a plasma element seen in the observer's rest frame, allow us to generate a simple picture of the radio structure as a set of plasma elements subsequently ejected by the central engine (assuming a Lagrangian description of fluid motion). We are able to produce both types of the structures, i.e., FR 1 and FR 2 (Fanaroff & Riley 1974) by the change of the value of γ_0. One-dimensional profiles of such a structure are presented in Figure 1. In particular, plasma outflow (the jet) consists of 100 plasma elements ejected over the period of activity. All elements have the same value of $f(0)$, and we assume that there are no interactions between them. The profiles in Figure 1

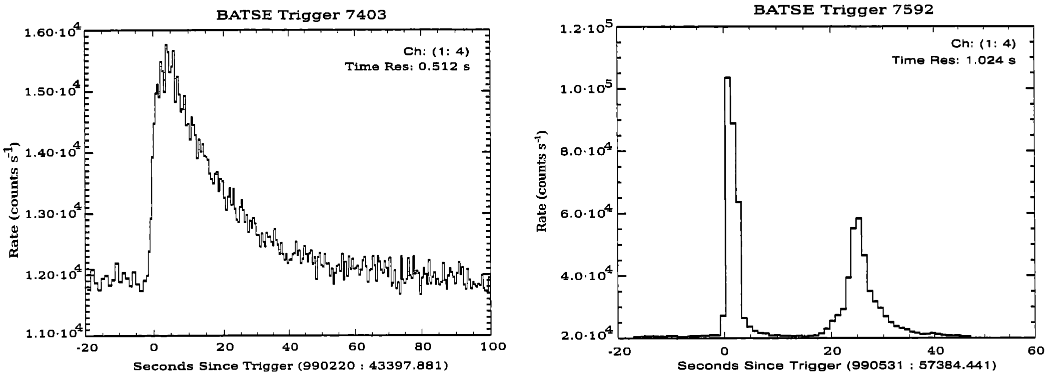

Fig. 2. Light curves of two gamma-ray bursts detected by BATSE. Taking into account that in temporal domain the jet and counter-jet overlap each other, we can easily find similarities between the light curves and the FR 1 or FR 2 shapes of radio structures.

are numbered by the parameter $\cos(\theta)$.

If we consider the structure with an extension of the order of 100 kpc and $\gamma_0 = 5$, then the expected deceleration parameter takes a value of $g = 1.2 \cdot 10^{-6}$ m/s^2. When the jet has a length of 1 kpc, we need a stronger deceleration – $g = 1.2 \cdot 10^{-4}$ m/s^2. Both structures have the same shape and differ only by their spatial extension.

We know that the shortest jets should possess a much stronger deceleration factor. Such a jet could be very short, and we would never see its spatial structure. The shortest jet will be never seen as an extended bright pattern, because such a jet evolves very fast. However, we are able to see its temporal evolution looking at the object's flux variability. At present we have a few predictions that gamma-ray bursts are produced in the jetted outflows. Therefore, it is not surprising that among light curves of GRB's registered by BATSE onboard the *Compton* observatory, we can find the shapes which look very similar to the presented one-dimensional maps of radio structure. For this the change of the spatial coordinate to the temporal one is sufficient. In Figure 2 light curves of GRB 990220 and GRB 990531 are given as examples (from Mallozzi & Six 1999).

We realize that the constant deceleration factor assumed here hardly can take place in reality and it comes from our oversimplification. However we conclude that the deceleration should be taken into account in transformation of physical quantities (and processes) between the event and the observer frames.

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