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BEAMING AND PRECESSION IN THE INNER JET OF 3C273

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RESUMEN

Empleamos todos los datos VLBI disponibles para determinar la evolución cinemática del jet interior de 3C273. Los ángulos de posición, las velocidades y épocas de formación de las distintas componentes superlumínicas son compatibles con un jet en precesión. Se calculó la dependencia temporal del factor Doppler de este jet y se discuten sus implicaciones sobre la emisión de rayos γ. Adicionalmente, el modelo, considerado junto con observaciones simultaneas de variabilidad en radio y rayos X, provee un límite superior a la constante de Hubble ($H_0 \lesssim 80$ km/s/Mpc).

ABSTRACT

We have used all the available VLBI data to determine the kinematical evolution of the inner jet of 3C273. The position angles, velocities and formation epochs of different superluminal components are compatible with a precessing inner jet. The time dependence of the Doppler factor for this jet is computed and the implications for the gamma-ray emission are discussed. Additionally, the model, when considered along with simultaneous radio and X-ray variability observations provides an upper bound to the Hubble constant ($H_0 \lesssim 80$ km/s/Mpc).

Key Words: **GAMMA RAYS: THEORY — QUASARS: 3C273 — RADIO CONTINUUM: GALAXIES**

1. INTRODUCTION

Superluminal features in the inner jets of quasars are generally interpreted as shock waves propagating along relativistic jets which form a small angle with the line of sight (e.g., Marscher 1987). The observed jets are not straight, which can be due either to the movement of the individual features in ballistic trajectories, each along a different straight line, or to the motion of each feature along the same intrinsically curved path. In 3C273 the superluminal features seem to have constant velocity along their trajectories, but the value of this velocity is different for different features. The value of the velocity β depends on the Lorentz factor γ, on the angle between the jet and the line of sight ϕ and on the Hubble constant H_0. The position angles, η, in the plane of the sky are also different for each feature (Abraham et al. 1996). This behavior will be explained in terms of a precessing jet, as it was done for 3C279 (Abraham & Carrara 1998) and OJ 287 (Abraham 1999). The variations in the viewing angle cause large changes in the Doppler factor δ, having strong implications in the beaming of the radiation at different wavelengths.

2. JET MODEL AND BEAMING

3C373 has at least 10 identified superluminal features, labeled C1-C10, 8 of them with well determined superluminal velocities and position angles in the plane of the sky. The values of ϕ and η of each feature represent the position of the jet at the epoch in which they were formed. This epoch can be obtained by extrapolating the distance of the feature to the core as a function of epoch to zero separation. If we define Ω as

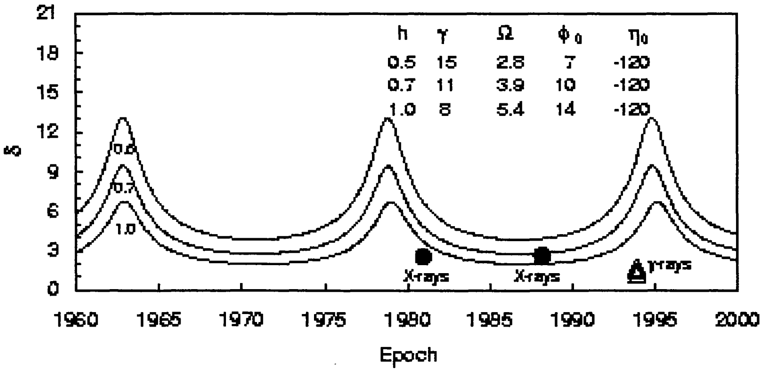

Fig. 1. Doppler factor as a function of epoch for three values of h. Filled circles are the calculated lower limits from X-ray observations, triangles lower limits from γ-rays.

the aperture of the precessing cone, ϕ_0, and η_0 as the position of its axis and $\omega = 2\pi/T$ its angular velocity we can fit a jet model to the data, for different values of γ and the Hubble parameter $h = H_0/100$. The parameters which fit the data, together with the values of the Doppler factor δ as a function of epoch, are presented in Figure 1 for three values of h (0.5, 0.7 and 1.0). The period was found to be $T \sim 16$ years.

Beaming is important in the X-ray emission produced by the inverse Compton process and has been frequently used to estimate the lower limit of the Doppler factor. Its calculation is based on the knowledge of several uncertain factors: (1) the flux density of X-rays (measurable but possibly contaminated by other emission processes), (2) the frequency of the maximum in the radio spectrum (not always known because it falls at very high frequencies), (3) the radio flux density at the maximum (also badly known, for the same reason) and (4) the size of the source (obtained only through VLBI observations, which should be simultaneous with the X-ray measurements). Since we are comparing radio and X-ray fluxes, the determination of δ is independent of the Hubble constant. Unwin et al. (1985) calculated the Doppler factor from the X-ray observations in 1981, epoch in which C5 was formed, obtaining a minimum value of 2.5 for δ. We repeated the calculations for the 1988 observations, when a new component, C9 was formed and a X-ray flare was detected. For that epoch, high frequency VLBI observations were made, providing reliable values of the angular size of the emitting region and almost simultaneous values of the frequency and flux density of the maximum in the radio spectrum are also available. Using these data we obtained a lower limit of 1.1 for δ, as shown in Figure 1, where we can see that the only models allowed correspond to $h < 0.8$. The γ-ray emission also provides a lower limit for δ. If the radiation originates in the jet, for any emission mechanism, the media should be optically thin for the γ-ray photons to escape. The calculation of the optical depth requires the knowledge of the emitting region. Assuming $\tau = 1$, it is possible to obtain the size from the intensity of the radiation. This size can be compared to the size obtained from variability considerations ($R < c\Delta t\delta$) and from here, obtain the value of δ. Since the observations involve only the flux density in γ-rays, the lower limit for δ depends on the Hubble constant (Mattox et al. 1993). The dependence on h is not very strong, resulting in an increase of the minimum value of δ as h decreases, as can be seen in Figure 1 for the γ-ray burst of 1993.9.

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