X-RAY EMISSION FROM THE 3C 273 JET

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ABSTRACT

We present results from four recent *Chandra* monitoring observations of the jet in 3C 273 using the ACIS detector, obtained between November 2003 and July 2004. We find that the X-ray emission comes in two components: unresolved knots that are smaller than the corresponding optically emitting knots and a broad channel that is about the same width as the optical interknot region. We compute the jet speed under the assumption that the X-ray emission is due to inverse Compton scattering of the cosmic microwave background, finding that the dimming of the jet X-ray emission to the jet termination relative to the radio emission may be due to bulk deceleration.

Key words: X-rays; quasars, jets; 3C 273.

1. INTRODUCTION

Marshall et al. (2001) showed that X-rays from the 3C 273 jet follow the optical emission fairly well. However, the X-ray emission is significantly brighter at the beginning of the jet than at the end while the optical knots are of similar brightness along the jet. Optically, the width of the jet is well resolved at the 0.1″ level using the Hubble Space Telescope (HST) and we find that it is now resolved in the X-ray band in the cross-jet direction. Assuming that the X-ray emission arises from inverse Compton scattering of cosmic microwave background photons (IC-CMB) (Tavecchio et al., 2000; Celotti et al., 2002), we can compute the jet speed for a given (small) angle to the line of sight that is approximately constant along the jet.

2. CROSS-JET PROFILE

Results from fits of Gaussians to the X-ray cross-jet profiles are shown in Fig. 1. The profiles are adaptively binned to maintain > 15 counts per bin so there are 7-30 bins per profile. For comparison, the ACIS readout streak from the quasar core was fit to a Gaussian, providing a good value for the Gaussian width, $\sigma = 0.34''$ (or FWHM = 0.80″), of a point source. Except in the centers of knots A and B (about 13″ and 15.5″ from the core), the jet is resolved. The reduced χ^2 is near unity except at the positions of the X-ray bright knots because the 1D profile of a point source does not match a Gaussian function. The residuals of the Gaussian fits are very similar to those of unresolved sources, confirming that knots A and B are point-like. The size of knot A's X-ray emission region ($< 0.2''$ FWHM) is distinctly smaller than found optically, where knot A was easily resolved using HST to be about 0.4″ across and 0.7″ long (Bahcall et al., 1995). The physical size differences between optical and X-ray emission regions are not expected in the IC-CMB model.

For an average observed σ of 0.45″ and the value for a point source of 0.35″, the inferred intrinsic FWHM of the X-ray emission outside knots A and B is 0.62″. This width is comparable to that of the optical emission between knots (Bahcall et al., 1995). Thus, the X-ray emission comes in two components: unresolved knots that are smaller than the corresponding optically emitting knots and a broad channel that is about the same size as the optical interknot region.

3. JET SPEED

We use the profile of the X-ray emission from the jet, which we compare to the radio profile to obtain the flow speed along the jet if we accept the hypothesis that the X-rays are produced by inverse Compton scattering of microwave background photons in a relativistic jet. Following Harris & Krawczynski (2002), Marshall et al. (2005) showed that the beaming parameters - the cosine of the angle to the line of sight $\cos\theta = \mu$ and the jet speed βc - are related to a function, K, of the observables. See Marshall et al. (2005) for details. We can solve their Equation 4 for β, giving

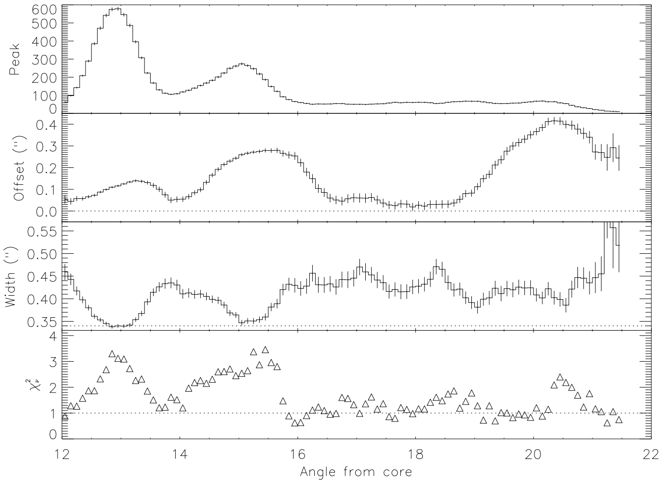

Figure 1. Results from fitting Gaussians to the X-ray cross-jet profiles. From the top, the panels are: Gaussian normalization (counts per 0.1″ bin), angular deviation from PA=-137.5°, the Gaussian dispersion parameter ($\sigma \equiv$ FWHM/2), and the reduced χ^2. The dotted line in the width panel shows the Gaussian dispersion obtained for an unresolved source. Except at 13″ and 15.5″ from the core (knots A and B), the jet is resolved in the cross-jet direction.

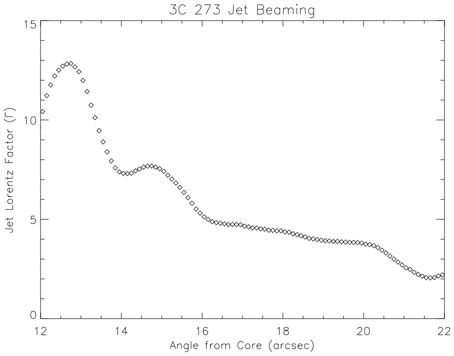

Figure 2. Jet beaming factor assuming the IC-CMB model of the X-ray emission. The X-ray to radio flux ratio is used as in the anaysis by Marshall et al. (2005) but using equation 1 to compute the jet speed and Lorentz factor. In this model, the jet dimming results from bulk deceleration.

$$\beta = \frac{-1 - \mu + 2K\mu \pm (1 + 2\mu - 4K\mu + \mu^2 + 4K\mu^3)^{1/2}}{2K\mu^2} \tag{1}$$

Using the ratio of the X-ray and radio fluxes as a function of position along the jet and Equation 1 above, we compute the jet $\Gamma = (1 - \beta^2)^{(-1/2)}$ upon setting the angle to the line of sight and using the magnetic field from Jester et al. (2002), which seems to be nearly constant along the jet. We find a good solution for a very small angle to the line of sight, 2.5°, where the jet bulk Γ drops from a maximum of 18 down to 2 at the terminal hotspot. Thus, the dimming of the jet to the end relative to the radio emission may be due to bulk deceleration.

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