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### 3C 120 and the Disk-Jet Connection

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**Abstract.** The radio galaxy 3C 120 continues its pattern of low X-ray flux states preceding the appearance of superluminal knots in the radio jet. The rapid variability of the X-ray flux plus the presence of an iron line indicate that the main source of X-ray emission is the accretion disk/corona. A plausible cause of the X-ray dips is a decrease in the viscosity during episodes of enhanced poloidal magnetic field. The same condition could divert extra energy into the jet, causing a shock to propagate downstream, eventually appearing as a superluminal feature.

#### 1. Introduction

The FR I radio galaxy 3C 120 provides an excellent opportunity to study the relationship between events in the accretion disk and those in the jet. In the optical and X-ray, it is similar to a Seyfert galaxy, with spiral structure and an iron K $\alpha$  emission line (e.g., Grandi et al. 1997). The latter suggests that much of the X-ray emission arises from the accretion disk and its immediate surroundings. Supporting this is a break observed in the X-ray power spectral density (Marshall et al. 2004), similar to that seen in Seyferts and X-ray binaries (McHardy et al. 2004). At cm- and mm-wave radio frequencies, however, 3C 120 acts as a blazar, with a bright jet in which knots move away from the nucleus at apparent superluminal speeds (Gómez et al. 2001). Monitoring with NASA's *Rossi* X-ray Timing Explorer (RXTE), the National Radio Astronomy Observatory's Very Long Baseline Array (VLBA), the Metsähovi Radio Observatory, and the University of Michigan Radio Astronomy Observatory has revealed that the two are connected: a low X-ray state precedes the appearance of new superluminal knots by several weeks (Marscher et al. 2002).

The main task now is to determine how events in the accretion disk end up shooting extra energy down the jet. This should be intimately related to the processes that generate jets from magnetized accretion flows (see Meier, Koide, & Uchida 2000). To accomplish this, we have resumed our monitoring of 3C 120, with more intense X-ray time coverage, starting in March 2002. We identify two more episodes of X-ray dips followed by superluminal ejections, as well as a new pattern of behavior in the X-ray light curve in late 2003. We apply recently proposed theoretical ideas to the 3C 120 disk-jet system and find that they at least qualitatively explain the observational behavior.

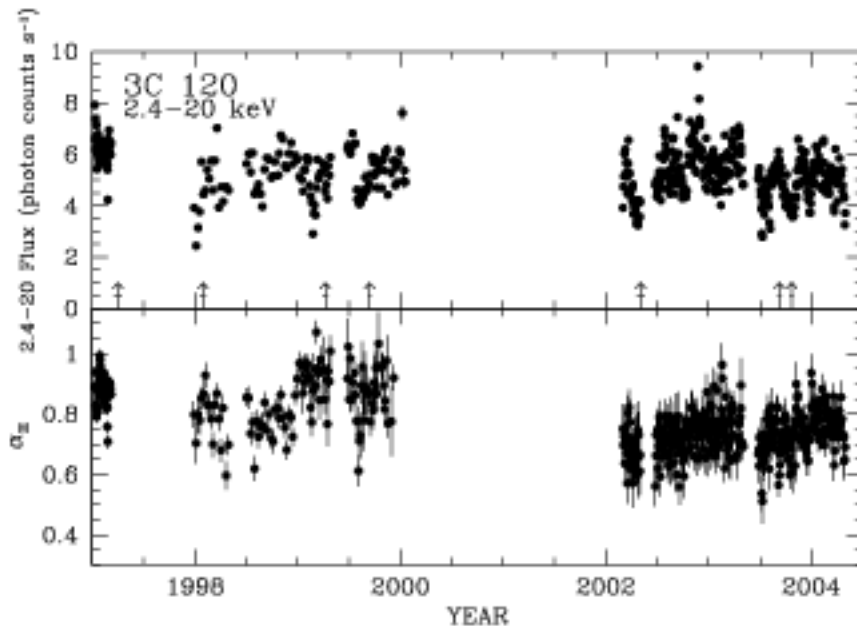


Figure 1. X-ray light curve and “energy” spectral index vs. time of 3C 120. Note the tendency for the spectrum to be flatter during periods of lower flux. The extrapolated times when the positions of superluminal radio knots coincided with the core are marked by vertical arrows, with horizontal bars giving the uncertainty in the time of coincidence.

## 2. Observations

The X-ray data are from the RXTE PCA detector *pcu2*. We use standard FTOOLS software to subtract a model of the background from the raw spectrum at each epoch. The model used is the November 2003 version of the faint source model provided by C. Markwardt and available at the RXTE website, <http://hea-www.gsfc.nasa.gov/users/craigm/pcu-bkg-tdrift/>. We employ the program XSPEC to model the spectrum from 2.4 to 20 keV as a single power law with low-energy photoelectric absorption. This provides an excellent fit, as judged by the  $\chi^2$  statistic; the iron line and other departures from a power law are minor contributors to the flux at these photon energies.

The VLBA observations are at a frequency of 43 GHz, which affords angular resolution of  $\sim 0.1$  milliarcseconds (mas) in the direction of the jet, corresponding to 0.064 pc for Hubble constant  $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . This is  $4.4 \times 10^4$  Schwarzschild radii for a  $3 \times 10^7 M_\odot$  black hole (Marshall et al. 2004; Wandel, Peterson, & Malkan 1999).

## 3. Results

As seen in Figure 1, there are two periods of low X-ray flux between 2002.15 and 2003.7: a long dip in early 2002 and a double-dip in summer 2003. The first preceded the appearance of a bright superluminal radio knot with an unknown

delay owing to the interruption of the X-ray monitoring by the sun-avoidance period. The latter was followed by the ejection in rapid succession (1.5-month interval) of two bright superluminal knots. The apparent velocities of the knots remains at  $4.7c$ , similar to the 1997-1999 period (Gómez et al. 2001; Marscher et al. 2002). In addition, the 37 GHz flux rose dramatically from 2003.65 to 2003.7 (Ogle et al. 2004) to herald the ejection of the first knot, and then maintained a high flux state well into 2004. The delay of 0.04 yr between the start of the 37 GHz flare and the coincidence of the knot with the core (obtained by a straight-line extrapolation of the core-knot separation vs. time plot) probably corresponds to either (1) half the light-travel time across the knot, (2) the time it takes for the knot to become energized (or optically thin) as it enters the core region, or (3) the bulk acceleration time of the knot. For any of these, the time interval measured in the observer's frame must be corrected for the Doppler effect.

We associate the start of the 37 GHz flare at 2003.65 with the edge of the enhanced jet flow created by an event in the accretion disk identified by the start of the X-ray dip at 2003.50. We then infer a travel time of 0.15 yr between the disk and the position of the compact radio core as measured at 43 GHz. This is 1.5 times longer than the value derived in Marscher et al. (2002) from the minima of the X-ray dips. The new method should be more accurate, or at least less *ad hoc*. We therefore raise the estimate of the distance of the  $\sim 40$  GHz core to  $> 0.6$  pc. This corresponds to the distance traveled down the jet in 0.15 yr:  $4.7 \times 0.15 \times (\sin \theta)^{-1}$  lt-yr, where the angle between the velocity vector and the line of sight  $\theta \leq 20^\circ$  (Gómez et al. 2001). If the jet accelerates or if the viewing angle  $< 20^\circ$ , the core must be farther downstream from the black hole. Ogle et al. (2004) report that the flux density at 250 GHz was very high before the onset of the 37 GHz flare, hence the “true” core—where the jet plasma is energetically excited or where it reaches its asymptotic flow velocity (Marscher 1995), as opposed to the boundary where the optical depth  $\sim 1$  at the frequency of observation—is probably closer to the black hole.

After the appearance of the first superluminal knot in 2003.7, the X-ray flux varied more smoothly than seen previously until the end of 2003. This is corroborated by a change in the break in the structure function, which occurs at 13 days during most of the observations but lengthens to 39 days during the above interval. Furthermore, the X-ray flux shows a mild correlation (with a coefficient  $\sim 0.5$ ) with the 37 GHz radio flux (Ogle et al. 2004) over the 0.3-year time range. This implies that a substantial fraction of the X-rays may have been emitted by the jet, probably via inverse Compton scattering, during this period. In this case, the iron line equivalent width should have been lower, a possibility that we are currently checking through stacking of the spectra from our rather short RXTE exposures.

#### 4. Discussion

Our observations have established a connection between low X-ray states and enhanced flow of energy into the relativistic jet in a radio galaxy. This is very roughly similar to the behavior of microquasars (e.g., Mirabel & Rodríguez 1998). In the latter, however, the dips are much more prolonged relative to

the high X-ray states. Furthermore, the intensity of the jet in 3C 120 fluctuates with position but never goes to zero, while the microquasar jet flows seem to be more episodic. It therefore appears that the systems do not scale precisely as one goes from a 10-20  $M_{\odot}$  to a  $3 \times 10^7 M_{\odot}$  black hole. This could perhaps result from the changing ratio of cooling time relative to the dynamical time of the plasma at a given number of gravitational radii as one considers higher black-hole masses. That is, the inner accretion disks of the supermassive black holes of active galactic nuclei should be less hot than those in microquasars. Unfortunately, our modeling is not yet sufficiently sophisticated to understand how the differences might be manifested in X-ray states and jet flows.

Although the Marscher et al. (2002) paper appeals to chunks of disk material plunging into the black hole as a possible mechanism for the X-ray dips, there is little evidence in the X-ray spectrum for this interpretation. Another scenario that seems more appealing is a change in the magnetic field structure in and above the disk. As discussed by Livio, Pringle, & King (2003), a turbulent magnetic field, which presumably provides the main source of viscosity in the disk, can spontaneously align in the poloidal direction. This would decrease the viscosity at the same time as it facilitates flow of energy into the jet. The lower viscosity would decrease the dissipation of energy and therefore lower the optical, ultraviolet, and X-ray flux. Unfortunately, we have very few optical measurements during our monitoring and therefore cannot test whether optical dips accompany those in the X-ray. We hope to add more optical monitoring in the future, and ask observers for help in doing so.

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