X-Ray Spectral Behavior of the Relativistic Jet Source Cygnus X-3

M. L. McCollough¹, C. R. Robinson¹, S. N. Zhang¹, B. A. Harmon², W. S. Paciesas³, S. Dieters³, S. Phengchamnan³, R. M. Hjellming⁴, M. Rupen⁴, A. J. Mioduszewski⁵, E. B. Waltman⁶, F. D. Ghigo⁷, G. G. Pooley⁸, R. P. Fender⁹, W. Cui¹⁰, S. Trushkin¹¹

¹) Universities Space Research Association, Huntsville, AL 35806, U.S.A. ²) ES84 NASA/Marshall Space Flight Center, Huntsville, AL 35812, U.S.A. ³) University of Alabama in Huntsville, Huntsville, AL 35899, U.S.A. ⁴) National Radio Astronomy Observatory/VLA, Socorro, NM 87901, U.S.A. ⁵) JIVE/National Radio Astronomy Observatory/VLA, Socorro, NM 87901, U.S.A. ⁶) Naval Research Laboratory, Washington, D.C. 20375, U.S.A. ⁷) National Radio Astronomy Observatory/GBI, Green Bank, WV 24944, U.S.A. ⁸) Mullard Radio Astronomy Observatory, Cambridge, U.K. ⁹) University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands ¹⁰) Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A. ¹¹) Special Astrophysical Observatory, Nizhnij Arkhyz, 357147, Russia

ABSTRACT Cyg X-3 is an unusual X-ray binary which shows remarkable correlative behavior between the hard X-ray, soft X-ray, and the radio. We present an analysis of these long term light curves in the context of spectral changes of the system. This analysis will also incorporate a set of pointed RXTE observations made during a period when Cyg X-3 made a transition from a quiescent radio state to a flaring state (including a major flare) and then returned to a quiescent radio state.

KEYWORDS: Cygnus X-3; X-Ray Binary; Radio Source; Relativistic Jets.

1. INTRODUCTION

Cyg X-3 is a very unusual X-ray binary (see Bonnet-Bidaud & Chardin 1988 for a review) which does not fit well into any of the established classes of X-ray binaries. Cyg X-3 is also a very active radio source which has shown the presence of relativistic jets (Mioduszewski et al. 1998).

In recent studies (McCollough et al. 1997a, 1997b, 1998) the following discoveries were made: (a) During times of moderate radio brightness (∼ 100 mJy), and low variability the hard X-ray (HXR) flux anticorrelates with the radio. (b) During periods of major flaring activity in the radio the HXR flux switches from an anticorrelation to a correlation with the radio. (c) The HXR flux has been shown to anticorrelate with the soft X-ray (SXR). This occurs in both the low and high SXR states.
2. LIGHTCURVES AND HARDNESS RATIOS

To better understand the behavior of Cyg X-3 in the X-ray, lightcurves and hardness ratios have been created from the CGRO/BATSE and RXTE/ASM data:

(a) BATSE Hardness Ratio: In Fig. 1 is the $(50–100 \text{ keV})/(20–50 \text{ keV})$ hardness ratio as a function of the $20–100 \text{ keV}$ flux. One can see from this plot the HXR spectrum becomes harder during flaring activity in the radio.

(b) ASM Lightcurves/Hardness Ratios: From the three ASM energy bands two hardness ratios can be created $[H_{\text{low}} = (3.0–4.8 \text{ keV})/(1.3–3.0 \text{ keV}), \ H_{\text{high}} = (4.8–12 \text{ keV})/(3.0–4.8 \text{ keV})]$. In Fig. 2 are time histories of the ASM flux and the hardness ratios. $H_{\text{low}}$ shows no trend with activity in the radio. But $H_{\text{high}}$ becomes softer during radio flaring and becomes harder during periods of radio quiescence.

(c) BATSE/ASM Hardness Ratio: Fig. 3 is a $(20–50 \text{ keV})/(4.8–12 \text{ keV})$ hardness ratio as a function of the total ASM flux. The spectrum becomes softer as the ASM flux increases.

The anticorrelation between the HXR and SXR in Cyg X-3 indicates a pivoting behavior similar to that seen in Cyg X-1 (Zhang et al. 1997). However, BATSE hardness ratios indicate that the spectrum above $20 \text{ keV}$ becomes softer during times of radio quiescence, which implies something more complicated than simple spectral pivoting.

3. POINTED RXTE OBSERVATIONS

To probe the various X-ray/radio states of activity in Cyg X-3 a series of target of opportunity observations, with RXTE, were made starting during an extended quenched radio state and following Cyg X-3 through a large flare and into radio quiescent state.

Cyg X-3’s X-ray spectrum is known to be complicated with several different components (Nakamura et al. 1993). The most dominant component is an absorbed power-law with an exponential cut-off at high energy (a Comptonized spectrum). In Fig. 4 we shown three count spectra overlayed which show a pivoting around 10 keV. During radio quiescent activity the spectrum hardens but above 15 keV the spectrum rolls over and becomes steeper, explaining the softening seen in the HXRs. It can be seen that the X-ray spectrum substantially changes for the different radio states in a way consistent with both ASM and BATSE hardness ratios.

REFERENCES

Bonnet-Bidaud, J.M. & Chardin, G. 1988, Physics Reports, 170, 326.
McCollough, M.L., et al. 1997a, in “Transparent Universe”, ESA, SP-382, p. 263.
McColough, M.L., et al. 1997b, 4th Compton Symposium, (AIP Press) p. 813.
McColough, M.L., et al. 1998a, ApJ, submitted.
Mioduszewski, A.J. et al. 1998, Proc. of IAU Colloquium 164, 351.
Nakamura, H., et al. 1993, MNRAS, 261, 353.
Zhang, S. N., et al. 1997, ApJ, 477, L95.
FIGURE 1. Plot of the (50–100 keV)/(20–50 keV) hardness ratio as a function of the 20–100 keV flux, determined from the BATSE data, using 3 day averages. In red are times of quiescent activity in the radio and in blue are times of flaring activity.

FIGURE 2. **Top:** Plot of time histories of the ASM flux (1.3–12 keV) and the (3.0-4.8 keV)/(1.3–3.0 keV) hardness ratio, using 3 day averages. The periods denoted in red are periods of radio quiescence and periods denoted in blue are times of flaring activity. **Bottom:** Plot of time histories of the ASM flux (1.3–12 keV) and the (4.8-12.0 keV)/(3.0–4.8 keV) hardness ratio.
FIGURE 3. Plot of the (20–50 keV)/(4.8–12 keV) hardness ratio determined from the BATSE and ASM data. Three day averages of the data were converted to Crab units and a hardness ratio was calculated. The red are times of quiescent activity in the radio and the blue are times of flaring activity.

FIGURE 4. RXTE/PCA Count spectra are shown for three observations of Cyg X-3. The spectrum in red is the PCA observations taken just after the radio had come out of a state of quenched emission. The spectrum in green is the PCA observation taken just after a major radio flare. The spectrum in blue is the PCA observation taken during a radio quiescent state. Each spectrum is a 500 second integration performed near the intensity peak of each observation.