HARD X-RAY VARIABILITY OF CYGNUS X–3

S. M. Matz, D. A. Grabelsky, W. R. Purcell, M. P. Ulmer
Department of Physics and Astronomy
Northwestern University, Evanston, IL 60208

W. N. Johnson, R. L. Kinzer, J. D. Kurfess, M. S. Strickman
E. O. Hulburt Center for Space Research
Naval Research Laboratory, Washington DC 20375

ABSTRACT

The OSSE instrument on the *Compton Gamma-Ray Observatory (GRO)* made 4 observations of Cygnus X−3 between May 1991 and December 1992. OSSE observed a substantial change in the average hard X-ray flux, which has previously been observed to be stable (variations $< 20\%$). Over a 2–3 day period the flux above ~ 50 keV decreased by roughly a factor of 3. This occurred about 15 days prior to a large radio flare from this source. OSSE detected the 4.8 hr period and observed significant orbital modulation of the hard X-ray ($\gtrsim 50$ keV) flux, in conflict with some extrapolations from lower energies. The spectrum in the high state is consistent with a power law, $\propto E^{-3.0}$.

1. INTRODUCTION

Cygnus X–3 is a bright X-ray source located in the plane of the Galaxy behind enough material to make it effectively unobservable at optical wavelengths. Soft X-ray and infrared observations have established that it has a very stable 4.8 hour period and an asymmetric light curve. The period probably corresponds to the orbit of a compact source around a primary star. This period is typical of low-mass X-ray binaries; however, there is evidence that the companion is actually a high-mass Wolf-Rayet star (van der Kerkwijk et al. 1992). Cyg X–3 produces occasional, very intense radio flares, reaching levels up to 20 Jy (e.g., Waltman et al. 1991), with associated jets (Geldzahler et al. 1983; Molnar, Reid, & Grindlay 1988). Bonnet-Bidaud & Chardin (1988) have published a valuable review of Cyg X–3 observations and theories.

2. OBSERVATIONS

The Oriented Scintillation Spectrometer Experiment (OSSE) on *GRO* (Johnson et al. 1993) consists of 4 large, independent NaI/CsI phoswich detectors collimated to $3.8° \times 11.4°$ fields of view and covering the energy range 50 keV to 10 MeV. OSSE observed Cyg X–3 four times: 1991 May 30 – Jun 15 (viewing period 2), Aug 8 – 15 (VP 7), Nov 28 – Dec 11 (VP 15), and 1992 Dec 9 – Dec 15 (VP 203). Spectral data were accumulated in two-minute intervals, alternating between source and background pointings. There was no significant contamination from Cyg X–1 in any of the pointings. Using the standard OSSE analysis techniques, estimated background spectra were subtracted from each source spectrum. OSSE detected significant flux from Cyg X–3 up to ~ 200 keV.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**
4. TITLE AND SUBTITLE **Hard X-Ray Variability of Cygnus X-3**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,E.O. Center for Space Research,4555 Overlook Avenue, SW,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

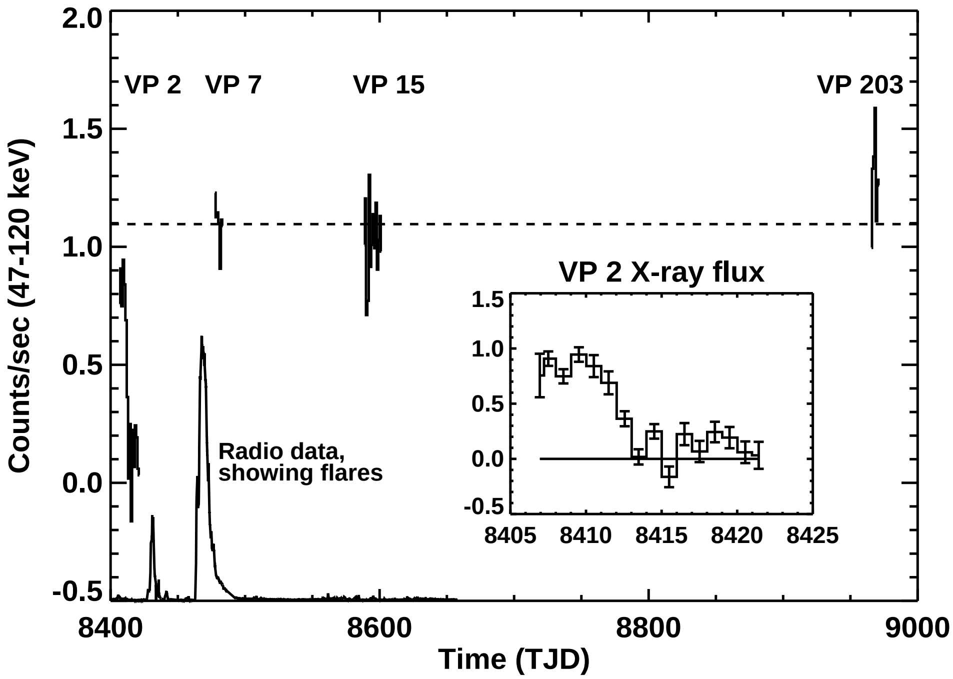

Figure 1: The daily average Cyg X–3 intensity, 47–120 keV, for the four OSSE observations. The inset shows an expanded view of the decrease during VP 2. Also included at the bottom of the plot is the 2.25 GHz radio intensity, showing the flares following the hard X-ray decrease.

3. HARD X-RAY STATE CHANGES

The soft X-rays from Cyg X–3 have two distinct intensity states, with state changes occurring on times scales of $\sim$ 0.5–2.0 years (Smale & Lochner 1992; Priedhorsky & Terrell 1986). Prior to OSSE, all hard X-ray experiments measured approximately the same average flux from Cyg X–3 with no significant variations during their observations, even when the soft X-ray flux changed state (e.g., White & Holt 1982; Hermsen et al. 1987). This suggests that the hard X-rays may represent a separate physical component.

OSSE observed about a factor of 3 decrease in the average hard X-ray intensity of Cyg X-3 over a period of several days during VP 2 (Fig. 1). The flux remained low for the rest of the observation. When OSSE observed this source again the flux had risen to a level higher than that seen prior to the decrease. The flux in the final three observations was roughly constant. The X-ray decrease occurred about 15 days prior to an intense (5 Jy) radio flare (R. Fiedler, private communication).

4. ORBITAL LIGHT CURVES

The two-minute integrated background-subtracted count rates (47–120 keV) during each of the four observation intervals were epoch folded using both the quadratic and cubic X-ray ephemerides of van der Klis & Bonnet-Bidaud (1989) to produce orbital light curves. The EXOSAT template light curve (van der Klis

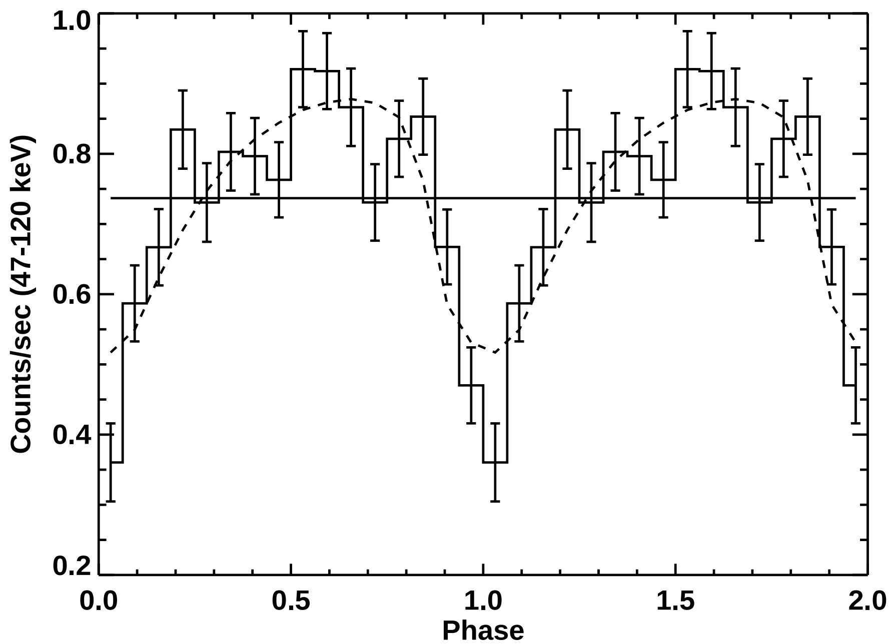

Figure 2: The average Cyg X–3 high-state light curve, 47–120 keV, folded using the cubic X-ray ephemeris of van der Klis & Bonnet-Bidaud (1989).

& Bonnet-Bidaud 1989) was fit to the OSSE light curve for each observation, allowing the phase, amplitude, and background (DC) level to vary. The "zero phase" of the fitted light curve produced using the cubic ephemeris (0.046 ± 0.015) was marginally consistent with 0 but the phase using the quadratic ephemeris (0.879 ± 0.016) was not. The average light curve in the high state is shown in Figure 2, along with the best fit of the soft X-ray light curve from EXOSAT.

EXOSAT measured the modulation ((max - min)/max) in the orbital light curve as a function of energy (Willingale, King, & Pounds 1985) and found only weak modulation in the 20–50 keV band. In contrast, OSSE observed strong modulation of the $\gtrsim 50$ keV flux as seen in the average light curve (Fig. 2). The average value of the modulation is 0.38 ± 0.04 for all the observations. There is no statistically significant variation in this value between observations. The amplitudes of the EXOSAT template fitted to the OSSE light curves are also consistent with a constant value for all the observations. The statistics are not adequate to determine if the light curve amplitude changes with the drop in DC flux during VP 2.

5. SPECTRA

The integrated spectrum from each interval was consistent with a photon power-law, though other models cannot be excluded. The spectral index during all the high state observations (VP 7, 15, and 203) was -3.0 ± 0.1. The index in the low state was -2.2 ± 0.4, consistent with the high state value at the 2σ level. The index for the first part of VP 2 was -2.5 ± 0.1, marginally ($\sim 4\sigma$) harder than that seen in the high state. This may be a third distinct state or a mixture of the high and low states. Figure 3 compares the high and low state spectra.

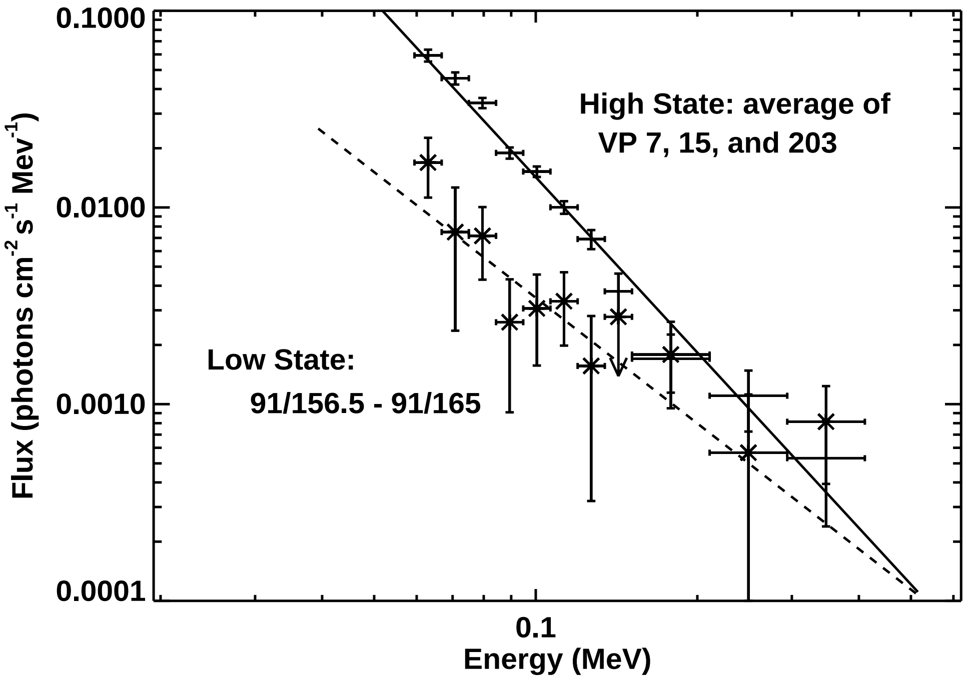

Figure 3: The hard X-ray spectra of Cyg X–3 in both the high and low states.

We accumulated the two-minute background-subtracted spectra for each observation interval into 8 orbital phase bins. The spectra from each interval and phase bin were then fit to a power-law photon spectrum. We saw no statistically significant phase variation of the spectral hardness $\gtrsim$ 50 keV in the high state.

ACKNOWLEDGEMENTS

We thank R. Fiedler and E. Waltman for supplying the NRL-GBI radio data for Cyg X–3. This work was supported by NASA grant DPR S–10987C.

REFERENCES

Bonnet-Bidaud, J. M. & Chardin, G. 1988, Physics Reports, 170, 326
Geldzahler, B. J., et al. 1983, ApJ, 273, L65
Hermsen, W., et al. 1987, A&A, 175, 141
Johnson, W. N., et al. 1993, ApJS, 86, 693
Molnar, L., Reid, M. J., & Grindlay, J. E. 1988, in The Impact of VLBI on Astrophysics and Geophysics, ed. M. J. Reid & J. M. Moran (Dordrecht: Reidel), 279
Priedhorsky, W. & Terrell, J. 1986, ApJ, 301, 886
Smale, A. P. & Lochner, J. C. 1992, ApJ, 395, 582
van der Kerkwijk, M. H., et al. 1992, Nature, 355,703
van der Klis, M., & Bonnet-Bidaud, J. M. 1989, A&A, 214, 203
Waltman, E. B., et al. 1991, ApJS, 77, 379
White, N. E. & Holt, S. S. 1982, ApJ, 257, 318
Willingale, R., King, A. R., & Pounds, K. A. 1985, MNRAS, 215, 295