Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: LONG-TERM OBSERVATIONS OF CYG X-3 WITH VELA 5B

LA-UR--84-4011

AUTHOR(S): W. Friedhorsky

DE85 005556

SUBMITTED TO: Proceedings of the 18th ESLAB Symposium on X-Ray Astronomy
The Hague, Netherlands
November 5-9, 1984

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

LONG TERM OBSERVATIONS OF CYG X-3 WITH VELA 5B

W. Friedhorsky
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT. We present long-term (1969-1979) observations of Cygnus X-3, obtained by the Vela 5B satellite. The 3-12 keV light curve has 10 day time resolution. Cyg X-3 is a peculiar high-luminosity X-ray source, radiating from the radio region to hard gamma rays of more than 10^{16} eV. It has a 4.8 hour period, probably orbital, which is not resolved by our present analysis. Long term periodicities of ~17, 20, and 33-34 days have been reported by several authors, and explained as the effects of apsidal motion, precession, or an eccentric orbit. We do not observe the ~17 and 33-34 day variations, and set upper limits significantly lower than the reported amplitude of the 33-34 day variation. There is weak evidence for a 20 day flux variation. The light curve shows high and low states which alternate with a characteristic timescale of ~1 year. There is no counterpart, at this time resolution, of the giant radio outburst of 1972 September.

I. INTRODUCTION

Cyg X-3 is a unique Galactic object. Though distant, it is one of the brightest objects in the sky in several bands ranging from the radio to 10^{16} eV gamma rays. Cyg X-3 behaves like a fairly normal X-ray binary in the X-ray band, but its emission at other wavelengths suggests it may not be one. In an X-ray binary model there are possible long-term periodic variations which could be searched for with long-term monitoring instruments. Apsidal motion in the Cyg X-3 system could have periods from ~weeks (for a main sequence companion) to ~decades (for a helium-star companion; Ghosh *et al.* 1981). Disk precession, as observed in several X-ray binaries, could have a period in the range of a few days to a few weeks. Finally, there is the possibility that the 4.8 hour X-ray period is not the orbital period, and the true, longer period would be evidenced by Doppler phase variations or an overall flux variation (especially for an eccentric orbit).

Long-term periodic variations have indeed been reported for Cyg X-3. The Ariel 5 All-Sky Monitor (ASM) provided 3-6 keV coverage over the period 1974-1979; analysis of these data suggested a periodic variation. This was first reported as a 16.75-day flux variation (Holt

et al. 1976), while Holt et al. (1979) refined the period to 33.0 ± 0.2 days. Molteni et al. (1980) reported a 34.1 ± 0.1 day flux variation, based on COS-B X-ray monitor data (2-12 keV). They also found a variation in the phase of 4.8 hour minimum, which they ascribed to Doppler motion; these effects were explained by postulating a 34.1 day orbital motion for the system. Dolan et al. (1982) reported a possible correlation of the 23-73 keV pulsed fraction with the 34.1 day period. Douthwaite et al. (1983) found that positive detections at 10^{12} eV tended to be correlated with the 34.1 day period. However, analysis of more extensive COS-B data by Bonnet-Bidaud and van der Klis (1981) showed no strong increase in flux at the predicted 34.1 day maximum. The phase of minimum of their 4.8 hour light curves varied in a fashion consistent with apsidal motion in a slightly eccentric orbit of period ~ 20 days.

II. VELA OBSERVATIONS

A small scintillator-photomultiplier detector on the Vela 5B satellite provided scanning 3-12 keV all-sky coverage for the period 1969-1979 with incomplete data acquisition after 1976. Sources were observed for ~ 1 s each 64 s satellite spin period for about 2-3 hours out of each 56 hour scan cycle. Data are summed into 10-day sky maps from which individual source histories can be calculated. Sensitivity of the instrument was limited by its small area (27 cm^2) and also by its high background, which averaged 0.8 Crab. The experiment and analysis technique are discussed in more detail in Terrell et al. (1982) and Friedhorsky, Terrell, and Holt (1983).

Figure 1 shows the 1969-1976 time history of Cyg X-3. One Vela count s^{-1} corresponds to $4.5 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the 3-12 keV band for a Crab-like spectrum. The Crab nebula gives ~ 40 Vela counts s^{-1} . The Vela data are compared in figure 2 to overlapping Ariel 5 ASM observations (Holt et al. 1979; Holt private communication). The agreement is good; the two 1975 outbursts and the 1976 minimum were observed by both instruments.

III. ANALYSIS

Figure 1 suggests a two-state behavior for Cyg X-3, with rapid step-like changes between high and low levels. Figure 3 shows a histogram of Cyg X-3 count rate vs. occurrences (number of 10-day bins with a given count rate). The histogram shows a broad distribution of flux levels, with only a hint of bimodality. This is consistent with Figure 1, where it can be seen that there is a wide variation in the flux level within the high and low states. Detailed spectral analysis by White and Holt (1982) shows that high and low X-ray levels differ in X-ray luminosity. Since the X-ray emission dominates the bolometric output of this system, the change of state appears to reflect a change in the rate of energy conversion in the "central engine" of this object.

Figure 1. 3-12 keV flux history of Cyg X-3, in 10-day averages, from the Vela 5B satellite. Arrows mark the giant radio outburst of 1972 September, and the 1973 SAS-2 and 1975 COS-B gamma observations.

Figure 2. Comparison of the 3-12 keV Vela 5B and 3-6 keV Ariel 5 measurements of Cyg X-3. The Ariel 5 points (3-6 keV photons $\text{cm}^{-2} \text{s}^{-1}$) have been scaled by a factor of 40, in the ratio of the mean signals, to allow comparison on the same figure.

Figure 3. Histogram of Vela count rates from Cyg X-3. The ordinate indicates the number of 10-day averages with mean flux in each bin.

The long-term variation in flux level can be explained by a change in the accretion rate of a compact object, but is more difficult to explain in a pulsar model where the energy source is internal to the compact object.

The time of the 1972 giant radio outburst is marked on figure 1. There is no unusual variation in the X-ray flux correlated with this event, at least on timescales of ~ 10 days. This is consistent with the unremarkable X-ray behavior observed by Uhuru around the time of outburst (Parsignault et al. 1972). Also indicated is the time of the reported SAS-2 100 MeV detection (Lamb et al. 1977). The source was in an X-ray high state at the time, while it was in a low state during the COS-B observations of 1975 December, 1977 June, and 1978 November (Swanenburg et al. 1981). This might explain the discrepancy between the SAS-2 and COS-B observations; however, there is reason to believe that most of the excess flux reported by SAS-2 was diffuse gamma radiation from gas and dust in the Cygnus arm (Hermesen 1985).

Three sets of data were Fourier analyzed to search for periodic variation: the complete set, and subsets chosen to segregate high state and low state data. Mean fluxes for the high and low states, and the total data set, were 13.0, 5.3, and 10.4 Vela counts s^{-1} . The transforms are plotted in figure 4. The irregular transitions between states are represented in the "all" transform as excess Fourier power at

Figure 4. Fourier transform of Cyg X-3 data. The three data sets include all the data, selected high state data, and selected low state data. The vertical lines indicate previously reported periods of 34.1, 33.0, and 16.75 days (aliased in this analysis).

periods of 1/2 to 2 years. There is no coherence to this variation: analysis of the Ariel 5 ASM data (Holt, private communication) shows excess power in the same frequency range; however, the peaks are not at the same frequencies.

Previously reported periods of 34.1, 33.0, and 16.75 days are indicated in the figure (10.71, 11.07, and 14.72 (aliased) cycles yr^{-1}). There is no significant variation at any of these frequencies. At 33 and 34.1 days, the 2σ limits on the pulsed amplitude are 11%, 16%, and 9% for the high, low, and complete data sets. This compares to amplitudes of 16% and 55% reported by Holt et al. (1979) and Molteni et al. (1980) respectively. The 33 or 34.1 day periods, if real, are not always present at the reported amplitudes. We are less sensitive to a 16.75 day period. The Vela limits (2σ) are 22%, 33%, and 19%, not small enough to rule out the published light curve (Holt et al.) which had a 16.75 day amplitude of 18%.

Two periods are suggested at low significance. There is a peak in the high state transform consistent with the Nyquist frequency, at 18.26 ± 0.03 cycles yr^{-1} (20 days). Despite the suspicious frequency, it could not be duplicated in simulations which scrambled the data (with the same sampling), and does not appear in analysis of any other Vela source. Its proximity to the period reported by Bonnet-Bidaud and van der Klis (1981) is intriguing; the chance of it appearing randomly in the period range 20 ± 2 days is only 0.7%. If real, it corresponds to a pulsed amplitude greater than 7%. The 11-year time history (figure 2) shows flux minima in late 1971 and late 1976, and broad maxima in 1969, 1973-1974, and 1978-1979. This suggests a very long-term (~ 5 years) cycle which could only be confirmed by more long-term monitoring.

IV. CONCLUSIONS

Data from the Vela 5B satellite allow a unique long look at the flux history of Cyg X-3. Irregular transitions between high and low levels take place on a timescale of $1/2$ --2 years. There are no significant periodic variations with periods greater than 20 days. Previously reported 33 and 34.1 day variations are not confirmed. The ~ 20 day periodic phase shift reported by Bonnet-Bidaud and van der Klis (1981) cannot be ruled out; in fact, there is weak evidence for a 20 day flux variation in the high state. Re-analysis of the Vela data with finer time resolution can test the reality of this effect.

The Vela 5B X-ray experiment was designed and implemented by W. D. Evans, J. P. Conner, R. D. Belian, J. A. Bergey, H. C. Owens, and E. R. Tech of Los Alamos, and the staff of Los Alamos National Laboratory. J. Terrell reduced the 10-year mass of data to produce the 10-day skyrap. F. Cordova made useful comments on the manuscript. The work was performed under the auspices of the U. S. Department of Energy.

REFERENCES

- Bonnet-Bidaud, J. M., and van der Klis, M. 1981, Astron. Astrophys., 101, 299.
- Dolan, J. F., Crannell, C. J., Dennis, B. R., Frost, K. J., and Orwig, L. E. 1982, Astrophys. Lett., 22, 147.
- Dowthwaite, J. C. et al. 1983, Astron. Astrophys., 126, 1.
- Grindlay, J. E. 1982, Proc. International Workshop on High Energy Gamma Ray Astron. (TIFR, Bombay), 178.
- Hermesen, W. 1985, these proceedings.
- Holt, S. S. et al. 1976, Nature, 260, 592.
- Holt, S. S., Kaluzienski, L. J., Boldt, E. A., and Serlemitsos, P. J. 1979, Ap. J., 233, 344.
- Lamb, R. C., Fichtel, C. E., Hartman, R. C., Kniffen, D. A., and Thompson, D. J. 1977, Ap. J. Lett., 212, L63.

Molteni, D., Rapisarda, M., Robba, N. R., and Scarsi, L. 1980,
Astron. Astrophys., 87, 88.
Parsignault, D. R. et al. 1972, Nature Phys. Sci., 239, 123.
Priedhorsky, W. C., Terrell, J., and Holt, S. S., Ap. J., 270, 233.
Swanenburg, B. N. et al. 1981, Ap. J. Lett., 243, L69.
Terrell, J., Fenimore, E. E., Klebesadel, R. W., and Desai,
U. D. 1982, Ap. J., 254, 279.
White, N. E., and Holt, S. S. 1982, Ap. J., 257, 318.