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OBSERVATION OF AN ABSORPTION DIP IN THE X-RAY INTENSITY OF CYGNUS X-1*

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ABSTRACT

On 1973 January 2 the MIT X-ray detectors on the OSO-7 satellite recorded a transient change in the X-ray spectrum of Cygnus X-1 indicative of an increase in absorption which lasted at least 37 minutes and occurred at a time near phase zero of the secondary of the likely optical counterpart, the spectroscopic binary system HD 226868. The effect is interpreted as a partial occultation by a stream of matter passing in front of the X-ray source and having a column density along the line of sight equivalent to $\sim 2 \times 10^{22}$ H atoms cm^2 of cold matter.

Subject headings: binaries — X-ray sources

The MIT X-ray detectors on the OSO-7 satellite scanned the X-ray source Cygnus X-1 from 1972 December 31 to 1973 January 5. The data provide a record of the average X-ray intensities in successive $\sim$3-minute intervals during continuous periods of 30–40 minutes separated by $\sim$1-hour gaps due to Earth occultation and occasional interference by Van Allen radiation. The observations were made with a bank of counters that have a 3° (FWHM) circular field of view and energy ranges of 1–6, 3–10, 15–40, and 25–60 keV. Details of the instrument and its performance are given elsewhere (Clark *et al.* 1973).

Large and apparently random intensity variations are observed on all time scales greater than the basic integrating time, in agreement with previous observations (Schreier *et al.* 1971). During one $\sim$37-minute period, however, a variation of unique appearance occurs when the average counting rates in the 1–6 and 3–10 keV energy ranges decreased by factors of 2.3 and 1.3, respectively, relative to the corresponding overall averages during a period of 2 days centered on the time of this anomaly. The relatively greater decrease in the low-energy X-ray intensity suggests that the cause of the anomaly was absorption, presumably by an intervening stream of matter.

Figure 1 is a time plot of the average counting rates during successive periods between Earth occultations in three energy ranges around the time of occurrence of the anomaly. The anomaly was observed 1973 January from $2^{d}031$ to $2^{d}057$. The expanded plot of the 1–6 keV data (fig. 2) shows that the lowest intensity occurred at $2^{d}046$. The counting rates are summarized in table 1. We derived the spectral parameters by fitting a power law (a thermal-bremsstrahlung spectrum cannot be satisfactorily fitted) with an absorption cutoff to the data. The results, summarized in table 2, show that the intensity dip can be accounted for as an increase in the cutoff energy, E_a, which would be produced by cold

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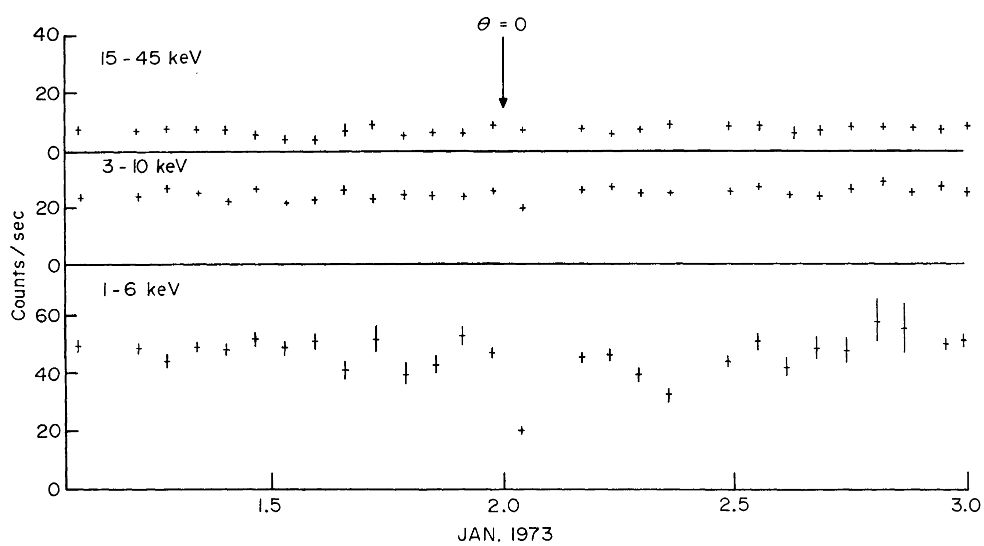

FIG. 1.—Time plot of the average counting rates in three energy ranges as determined once per orbit for $\sim$30-minute periods of observation. The indicated time of zero phase of HD 226868 is derived from the results of Brucato and Kristian (1973).

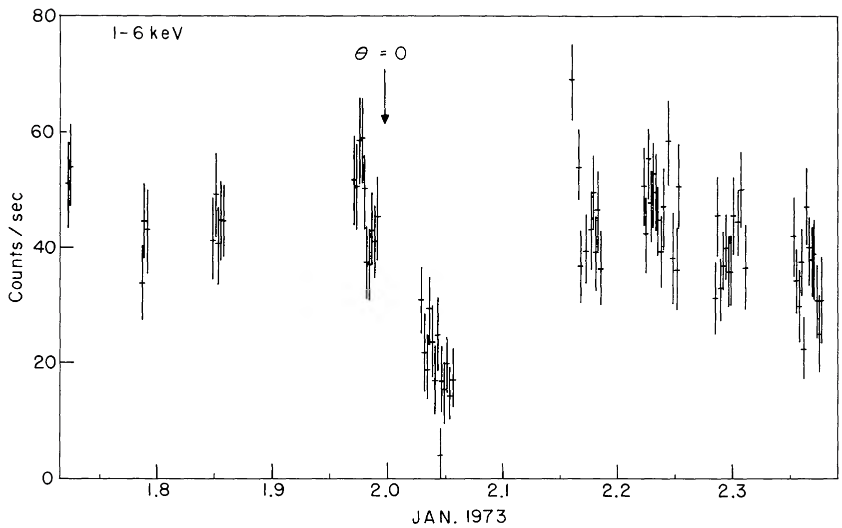

FIG. 2.—Time plot of the average counting rates in the 1–6 keV energy range for ~3-minute periods around the time of the absorption dip.

TABLE 1

AVERAGE COUNTING RATES DURING THE ANOMALY AND AT OTHER TIMES

Energy Range of Counter (keV)	Counts per Second	
	During Anomaly	Other Times
1–6.........	20.8±1.8	48.1±0.5
3–10........	19.8±1.2	25.0±0.3
15–40........	7.4±1.3	7.2±0.3
25–60........	4.1±1.6	4.4±0.6

TABLE 2

PARAMETERS OF FITTED POWER-LAW SPECTRA OF THE FORM $I(E)dE = I_0 \exp[-(E_a/E)^{2.67}]E^{-\alpha}dE$

Parameter	Counts per Second	
	During Anomaly	Other Times
I_0 (cm^{-2} s^{-1} keV^{-1}).............	1.24±0.33	1.75±0.10
α.............................	0.46±0.12	0.58±0.03
E_a (keV)......................	1.90±0.30	0.60±0.20
N_H (H atoms cm^{-2})$\times 10^{22}$.......	2.3 ±0.8	0.15±0.10

matter with a column depth of $2.3 \pm 0.8 \times 10^{22}$ H atoms cm^{-2}, assuming the absorption cross-sections of Brown and Gould (1970).

We note that the decrease in the average 1–6 keV intensity which occurs from $\sim 2^{\rm d}.30$ to $2^{\rm d}.35$ is neither as deep nor as rapid as the one at $2^{\rm d}.046$. Moreover, since no decrease is observed in the 3–10 keV range, and the 15–45 keV intensity actually increases, this latter variation is not explainable as a simple effect of absorption as is the case for the dip at $2^{\rm d}.046$.

The apparent absorption dip at $2^{\rm d}.046$ takes on special significance when its time of occurrence is compared with the phase of the radial-velocity curve of the spectroscopic binary HD 226868 which has a period of 5.6 days and is the likely optical counterpart of Cyg X-1. According to a projection based on the results of Brucato and Kristian (1973), zero phase of the secondary (X-ray source behind primary star) occurred at 1973 January $1^{\rm d}.994$ with an uncertainty that cannot be precisely stated for lack of quoted errors in the optical result, but which probably does not exceed $0^{\rm d}.1$. Projection of similar data of Bolton (1974) gives 1973 January $1^{\rm d}.924 \pm 0^{\rm d}.1$. Thus the dip appears to have occurred within $\Delta\theta \sim 0.02$ of zero phase when it would appear to be a likely time for matter streaming from the primary to the compact companion behind to cross the line of sight.

This X-ray observation strengthens the identification of Cygnus X-1 with HD 226868. If it is assumed that the dip is produced by absorption in matter streaming between the components of the close binary system, the results provide a measure of the location and column thickness of the matter. We note, however, that OSO-7 observations of Cyg X-1 near zero phase at two other times have not shown the occurrence of absorption dips, so that the phenomenon reported here is apparently not regular and periodic. Extensive additional observations will be required to determine whether absorption dips do occur repeatedly and with a probability that is correlated with the binary phase.

We thank T. Bolton for communicating his results on HD 226868 prior to publication, and P. Sanford for permission to quote the *Copernicus* results.

REFERENCES

Bolton, T. 1974, private communication.
Brown, R. L., and Gould, R. J. 1970, *Phys. Rev. D.*, **1**, 2252.
Brucato, Robert, and Kristian, Jerome 1973, *Ap. J.* (*Letters*), **179**, L129.
Clark, G. W., Bradt, H. V., Lewin, W. H. G., Markert, T. H., Schnopper, H. W., and Sprott, G. F. 1973, *Ap. J.*, **178**, 263.
Schreier, E., Gursky, H., Kellogg, E., Tananbaum, H., and Giacconi, R. 1971, *Ap. J.* (*Letters*), **170**, L21.

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Note added in proof.—Several absorption dips near phase zero, apparently similar to the one reported here, have been observed by the MSSL X-ray detector on the *Copernicus* satellite. These are described in a forthcoming paper by Mason *et al.* [1974, submitted to *Ap. J.* (*Letters*)] of which a preprint was kindly sent to us by P. W. Sanford.