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OBSERVATIONS OF TWO X-RAY FLARES AND THE NEARBY SOURCE MX 1716−31*

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ABSTRACT

Observations of the X-ray source MX 1716−31 by the MIT detectors aboard OSO-7 are described. During the study of the MX 1716−31 data, an X-ray flare was discovered which was probably associated with the source. The flare had a total duration of about 10 minutes and reached a peak intensity twice that of the Crab Nebula in the 3–10 keV range. A search for similar events elsewhere turned up one other flare with a position inconsistent with MX 1716−31. Those features of both flare events which are relevant for comparison with other short-lived X-ray phenomena are discussed.
Subject headings: X-rays: sources — X-rays: variable

I. INTRODUCTION

One of the first reported examples of short-term X-ray emission from a cosmic origin was an X-ray flare from near MX 1716−31 observed by the M.I.T. detectors aboard OSO-7 and briefly described by McClintock (1974) and Canizares (1975). In light of the current interest in short-lived X-ray emission, we undertake here to discuss this and a similar event, as well as the nearby quiescent source with which they may be associated, in greater detail.

II. OBSERVATIONS

The M.I.T. OSO-7 experiment has been described elsewhere (Clark *et al.* 1973). In brief, the instrument consisted of two sets of five proportional counters sensitive between 1 and 60 keV. The two sets of detectors had fields of view of 1° and 3° FWHM and were pointed at directions of 75° and 105° with respect to the spin axis of the satellite. Each ~2 s revolution of the satellite was divided by the on-board logic into 256 azimuthal bins for each of the two small circles traced out on the sky by the detectors' viewing directions. Counts were accumulated in these bins for 190.08 s before being read out onto the on-board tape recorder.

A primary technique for analyzing this data was to divide the sky into cells of equal area and to assign the data in each azimuthal bin for each 190 s period to the appropriate cell. The information in the cells was then combined over several days of observations to form maps of selected regions of the sky. This mapping technique, described in detail by Markert *et al.* (1976), led to the discovery of nearly 20 previously unreported X-ray sources (Markert *et al.* 1975), one of which was MX 1716−31.

Following the discovery of MX 1716−31, we performed a detailed analysis of all of the M.I.T. data obtained at times when the object was in view. The data examined covered 11 separate observations of the source, each lasting several days and typically separated from one another by a few weeks. The total amount of data spanned 57.8 of the first 600 days of operation of the satellite. From our analysis we found a best-fit position for the source of $\alpha = 259^\circ\!.03$, $\delta = -31^\circ\!.82$ ($l^{II} = 354^\circ\!.45$, $b^{II} = 3^\circ\!.14$) with a 90 percent confidence uncertainty of $0^\circ\!.27$. This uncertainty includes an estimate of systematic aspect errors as well as statistical errors.

The results of our study of MX 1716−31 are summarized in Table 1. We can conclude from this table that the source was of moderate intensity (15–45 counts s^{-1} in the *Uhuru* system) and was variable by a factor of ~2 over periods of a few weeks or more. On four of the occasions when the source was in the field of view

TABLE 1

SUMMARY OF OBSERVATIONS OF MX 1716−31
A. COUNTING RATES† CORRECTED FOR COLLIMATOR RESPONSE (counts s^{-1})

E (keV)	Mean	Max†	Min‡
1–1.5..	0.17±0.12	...	...
1–6....	3.50±0.37	4.20±0.45	1.90±0.68
3–10...	1.80±0.15	2.53±0.40	0.90±0.29
15–40..	0.29±0.09	0.36±0.11	−0.37±0.37

B. SPECTRUM (thermal bremsstrahlung with absorption)

$kT = 17.3 \pm 5.8$ keV
$N_H \leq 0.60 \times 10^{22}$ atoms cm^{-2}

C. POSITION (90% confidence)

$\alpha = 17^h16^m\!.1 \pm 1^m\!.3$
$\delta = -31°49.2' \pm 16.2'$

† These may be converted approximately to photon flux by $\phi = \gamma S$, where ϕ = flux in photons cm^{-2} s^{-1} keV^{-1} and γ = 0.15(1–1.5 keV), 0.0069(1–6 keV), 0.0045 (3–10 keV) and 0.0013(15–40 keV).

‡ These extrema are the highest and lowest values of the intensities averaged over several consecutive days corresponding to a particular sighting of the source.

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of our instrument, no statistically significant detection was made. For these times, however, the 3 σ upper limit on the counting rate exceeded the minimum statistically significant result recorded in Table 1. On shorter time scales the source was too weak, except for one instance discussed below, to enable us to discern any intensity variations.

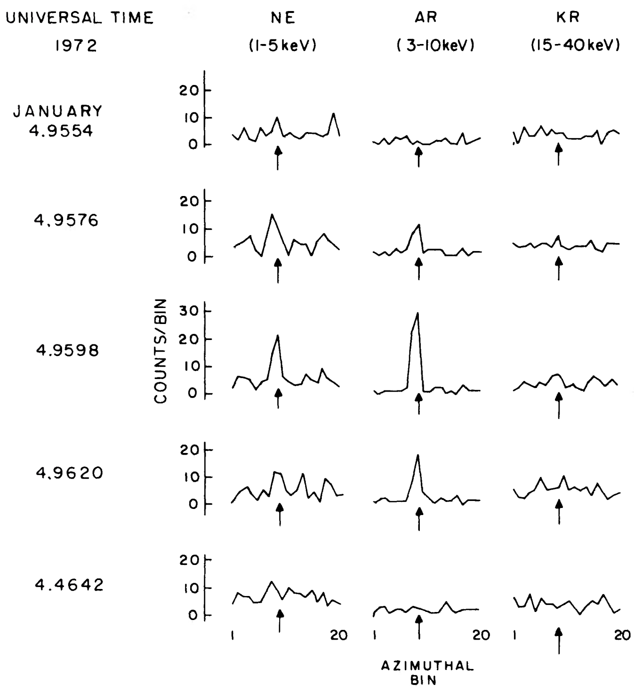

FIG. 1.—X-Ray intensity as measured during the flare of 1972 January 4. Five consecutive 190 s time intervals are shown for each of three energy ranges. The abscissa covers a range of 20 of the 256 azimuthal bins into which each satellite revolution is logically divided.

During an examination of the sighting of MX 1716−31 of 1972 January 4–6 we noticed a sharp increase in the counting rate over a few minutes in those azimuthal bins associated with the source. Figure 1 shows a section of the data for five consecutive 190 s intervals. Here we clearly see a rapid increase in the counting rate during a period of about 10 minutes, consistent with a large rise in the intensity of a point source. In the 3–10 keV range such a point source would be approximately twice as intense as the Crab Nebula. We performed a position fit on the three pieces of data in which this X-ray "flare" occurred. Since the satellite spin axis did not move appreciably during the period of the flare, we were unable to determine the elevation (in spacecraft coordinates) of the event to better than the full width of our small field-of-view detectors, a width of about 2°.4. Figure 2 is a plot in celestial coordinates showing the 90 percent confidence intervals of the flare source (designated "flare 1") and of MX 1716−31.

There are no X-ray sources other than MX 1716−31 within 2° of the error box for the flare. Furthermore, a search of star catalogs and lists of unusual objects revealed no likely counterparts for either the flare source or for MX 1716−31. We shall assume that the flare source and MX 1716−31 are identical in much of the following.

The data for the flare source are listed in Table 2. Comparing the flare with the quiescent behavior of MX 1716−31 (Table 1), we found that at its peak the flare was approximately 45 times more intense in the middle energies, but only 15 times more intense in the lower, 1–6 keV range. We performed a spectral fit to the flare data and found a best fit thermal bremsstrahlung (Chodil *et al.* 1968) temperature of $kT = 12.0 \pm 6.1$ keV, consistent with the quiescent value. The absorption for the flare was considerably higher, however, with a best-fit value of the hydrogen column density (Brown and Gould 1970) of $N_H = (8.9 \pm 3.8) \times 10^{22}$ atoms cm^{-2}.

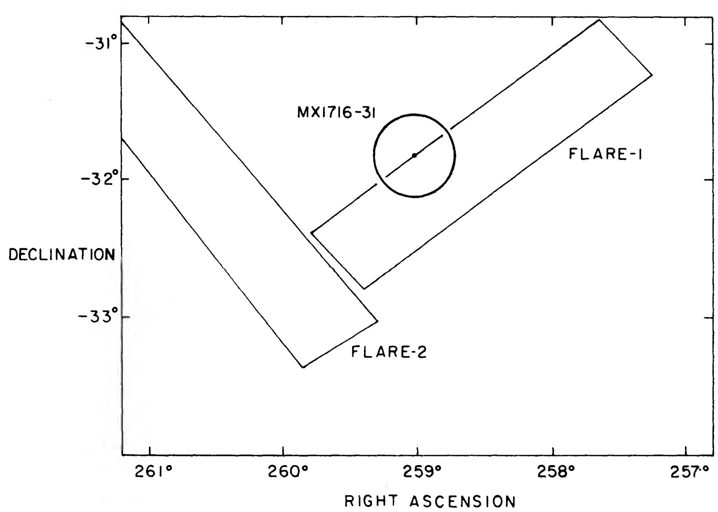

FIG. 2.—90% confidence error contours for MX 1716−31 and the flare of 1972 January 4 (flare 1). A section of the 90% confidence error box for the flare of 1972 November 8 (Flare 2) is also pictured. The corners of the error box for flare 2 which are not shown are at $(\alpha, \delta) = (263°.31, -28°.12)$ and $(263°.81, -28°.14)$. All three uncertainties include an estimate for the systematic uncertainty in the aspect determination.

TABLE 2

SUMMARY OF FLARE OBSERVATIONS

Time (UT)	1–6 keV	3–10 keV	15–40 keV
Flare 1 (1972)			
Jan. 4.9576:			
(*a*).........	25	18	10
(*b*).........	3.9±0.5	1.0±0.2	3.3±0.4
(*c*).........	40.0±11.6	37.2±9.8	7.9±7.4
Jan. 4.9598:			
(*a*).........	35	52	13
(*b*).........	4.7±0.5	1.1±0.3	3.3±0.4
(*c*).........	61.8±13.8	115.8±16.7	14.9±8.4
Jan. 4.9620:			
(*a*).........	23	25	11
(*b*).........	4.4±0.5	1.3±0.3	4.9±0.5
(*c*).........	56.2±13.3	52.1±11.6	2.8±7.7
Flare 2 (1971)			
Nov. 8.5049:			
(*a*).........	48	23	29
(*b*).........	12.9±0.8	2.7±0.4	6.6±0.6
(*c*).........	6.2±4.6	9.9±3.2	6.1±3.3
Nov. 8.5071:			
(*a*).........	96	73	27
(*b*).........	13.6±0.8	3.1±0.4	9.3±0.7
(*c*).........	36.8±6.5	42.3±5.7	−0.6±3.3
Nov. 8.5093:			
(*a*).........	65	43	33
(*b*).........	14.1±0.8	3.1±0.4	9.3±0.7
(*c*).........	15.1±5.4	22.5±4.4	3.4±4.0

NOTE.—(*a*) Total number of counts in azimuthal bins containing event. (*b*) Mean background (counts per bin) determined by averaging 20 nearby azimuthal bins uncontaminated by X-ray sources. (*c*) Counting rates (counts s^{-1}) after correcting for total exposure and background. Flare 1 was assumed to come from MX 1716−31 and had a total exposure of 0.43 s for each 190 s accumulation interval. Flare 2 was assumed to occur at the center of the error box (Fig. 2) and had a total exposure of 1.5 s.

In order to determine the frequency of events such as that observed on 1972 January 4, we examined nearly all of the data taken by the M.I.T. experiment when the region of MX 1716−31 was in view. The data were inspected by eye, one 190 s accumulation interval at a time. After eliminating those intervals for which the region near MX 1716−31 was occulted by the Earth or contaminated by the effects of trapped particles or solar X-rays, we were left with 7106 intervals (15.63 days) in which a flare event as weak as one-third of the Crab and lasting for at least one 190 s interval would have been easily discernible. Flares lasting between 2 s (the rotation period of the satellite) and 190 s (the time resolution of the instrument) would naturally have to be more intense in order to have been detected. Within the body of data we found evidence for only one event similar to that of 1972 January 4. This flare began at about 8.505 1971 November (UT) and maintained an intensity which was significantly above background for about 9 minutes. Its peak intensity was about one-third that of the flare of 1972 January 4, assuming that both events were observed at the peak of their collimator response functions.

We performed a position fit to this event but, since the flare was observed with the wide field-of-view detectors, we could not determine its position with the same precision as for the previously discussed flare. The section of the fitted error box (90% confidence) closest to MX 1716−31 is shown in Figure 2 (denoted "flare 2"). From this diagram one notes that the location of the second flare is inconsistent with MX 1716−31. Our data for flare 2 are summarized in Table 2. Although we were unable to fit a spectrum to this event, it is apparent that the two flares have similar spectra at their peaks. The ratio of 3–10 keV counts to 1–6 keV counts is about the same for both flares and is considerably higher than for the quiescent MX 1716−31 (Table 1).

The statistical likelihood of the two flares originating from the same source is only a few percent, although the scarcity of similar events elsewhere in the galactic bulge region and the similarity of the spectra of the events may argue against two different, relatively nearby flare sources. If both flares did originate from the same source, it is statistically quite unlikely that this source is MX 1716−31. One is not forced to conclude, however, that the two flares originated at the same site. There are a number of plausible candidates for flare 2 independent of those for flare 1. The error box of flare 2 is quite large (3.6 deg^2), includes 41 SAO stars, and intersects the error box of the transient X-ray source 3U 1735−28 (Kellogg *et al* 1971). Furthermore, if the flares originated from two different sources but had essentially the same *physical* origin, it would not be surprising for them to exhibit similar spectra.

III. DISCUSSION

Short-lived celestial phenomena at X-ray energies have recently received a great deal of attention. X-ray bursts or flares have been reported at time scales ranging from several seconds (e.g., Clark *et al.* 1976) to a few minutes (e.g., Rappaport *et al.* 1976; Lewin 1976*a*). Such events have been associated, although not as yet firmly identified, with globular clusters (e.g., Grindlay *et al.* 1976; Jones and Forman 1976), the galactic center (Lewin, 1976*b*), and UV Ceti–type flare stars (Heise *et al.* 1975).

The flares of 1972 January 4 and, to a lesser extent because less information is available, of 1971 November 8 have several features which are relevant for comparison with the other types of short-term phenomena:

1. *Duration.*—Both flares 1 and 2 lasted between about 5 and 10 minutes and are thus some of the longest-lived of these kinds of events.

2. *Frequency.*—Flares of this nature are apparently relatively rare. We have set limits on the occurrence of events of similar magnitude and duration in the vicinity of MX 1716−31. Furthermore, we have never seen similar events elsewhere in our data (although we have not performed a systematic search); and, to our knowledge, no other groups have reported flares of this nature. Some of the shorter period burst sources, on the other hand, can recur every few minutes (e.g., Lewin 1976*c*).

3. *Location.*—The flares occurred in the direction of the galactic bulge, in common with several of the burst sources. MX 1716−31 is only about 4° from MXB 1730−335, one of the most prolific burst sources studied thus far (Lewin 1976*c*).

4. *Counterparts.*—If we are correct in associating flare 1 with MX 1716−31, then this source is one of several short-term transients associated with less radically varying X-ray sources.

5. *Spectrum.*—Many of the bursting and flaring sources have been reported to have relatively hard ($\gtrsim$10 keV) spectra (Rappaport *et al.* 1976; Grindlay *et al.* 1976; Clark *et al.* 1976; Grindlay and Gursky 1976). In some cases the spectra of these sources change considerably during the course of the event, sometimes becoming harder (Grindlay *et al.* 1976), and sometimes exhibiting a greater low-energy cutoff (Jones and Forman 1976). In comparison, both flares 1 and 2 are relatively hard (Table 2), but the spectrum of flare 1 seems to become either softer or less absorbed at the end of the event. If flare 1 occurred at MX 1716−31, it was considerably more absorbed than the quiescent source.

Much more study of all the short-term transient sources is required before they can be understood. Two important questions relevant to the events reported here which can be answered by satellites currently in orbit are: (1) Are there flares associated with MX 1716−31? (2) Are there flares of shorter duration or lesser intensity from the same source, and how often do they occur?

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