THE ASTROPHYSICAL JOURNAL, 207:L177–L180, 1976 August 1

UHURU OBSERVATIONS OF AN X-RAY BURST AT HIGH GALACTIC LATITUDE CENTERED ON THE X-RAY GLOBULAR CLUSTER NGC 1851

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Received 1976 April 7

ABSTRACT

We have detected an X-ray burst from a 0°.5 × 10° region centered near NGC 1851 (MX 0513−40) in observations made with the *Uhuru* X-ray observatory on 1972 September 19. The source was observed for 15 seconds with a peak rate of 0.5 that of the Crab (2–6 keV) and was not detected above 0.01 of the Crab in observations 4.5 minutes before or after this event. During the observation the spectrum developed a low-energy cutoff. NGC 1851 is the second globular cluster identified as a source of X-ray bursts, which suggests that all X-ray bursts may originate in globular clusters, some of which may be optically obscured.

Subject headings: X-rays: variable — clusters: globular

I. INTRODUCTION

X-ray bursts were discovered by Grindlay *et al.* (1976) from the globular cluster X-ray source 3U 1820−30 = NGC 6624 and by Babushkina *et al.* (1975) from two other locations. These bursts appeared as sudden increases in the X-ray flux which then decayed exponentially with a time constant of 5–10 seconds. Additional bursts from NGC 6624 and other locations near the galactic plane, particularly in the direction of the center, also have been reported (Belian, Conner, and Evans 1976; Clark *et al.* 1976; Lewin *et al.* 1976; Doty 1976).

In this *Letter* we report the observation of an X-ray burst from an uncongested region of the sky (l^{II} = 244°.5, b^{II} = −34°.9) centered on NGC 1851 = MX 0513−40, one of the five known globular cluster X-ray sources.

Detection of X-ray emission from NGC 1851 was first reported by Clark, Markert, and Li (1975) using OSO-7 observations. They reported intensity variability by a factor of 5 over 16 days. No variability on time scales of minutes was detected.

Our observations demonstrate intensity variability of almost two orders of magnitude or more on a time scale less than 5 minutes—the maximum time for the source to increase and again decrease in intensity. This behavior is similar to that of other reported bursts and is very different from other types of X-ray variability, including the rapid transient reported by Rappaport *et al.* (1976) which was constant during a 45 s observation.

II. OBSERVATIONS

On 1972 September 18–20 the *Uhuru* X-ray observatory was scanning a region of the sky containing the globular cluster NGC 1851. The satellite was in the so-called cross-switched observing mode which permitted the acquisition of data with the wide collimator (5° × 5° FWHM) and high time resolution (0.096 s) with 2–20 keV pulse-height analysis electronics. The spin rate of the satellite was approximately 0°.7 s^{-1}. During these 3 days we obtained ≈45 observations of MX 0513−40 lasting 15 s (wide collimator) and ~45 observations of 1.5 s (narrow collimator). X-rays from a region about MX 0513−40 were detected during only one 15 s observation. This observation shown in Figure 1 has a 2–6 keV counting rate of 250 counts s^{-1} which converts to an intensity of 500 counts s^{-1} when corrected for the elevation of MX 0513−40 in the collimator field of view. The source was not observed above background with a 3 σ upper limit of 10 counts s^{-1} either 4.5 minutes before or after this single outburst. The average intensity, omitting the burst, for the 3 day period was less than ~2 counts s^{-1} (3 σ upper limit).

We determined the location of the source using only our knowledge of the expected duration of the observation as determined from the equation of motion of the spacecraft. This approach is valid because of the fact that emission from the source persists for the entire expected duration (as can be seen in Fig. 1). The procedure is to slide a window representing the duration of the observation through the data until it contains the maximum number of counts. As a result the source will be centered in the collimator. Figure 1 shows the collimator location resulting from this simple analysis. The importance of this procedure is that it is insensitive to any variations in intensity during the observation. The accuracy of this procedure is difficult to evaluate since it depends on the observed counts at the edges of the collimator field of view. Shifting the collimator location two bins to the left (earlier in time) would require the background to be responsible for the 14 counts observed in the two bins adjacent to the collimator when 4.6 are expected (mean background rate). The probability of this is 0.0003. A similar shift in the opposite direction would require 10 counts when the mean is 4.6, which has a probability of 0.020. Corresponding shifts of 1 bin would yield probabilities of 0.01 and 0.08. Therefore, we estimate an approximate uncertainty of no more than ±2 bins or ±0°.13 in the determination of the source location.

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1976ApJ...207L.177F

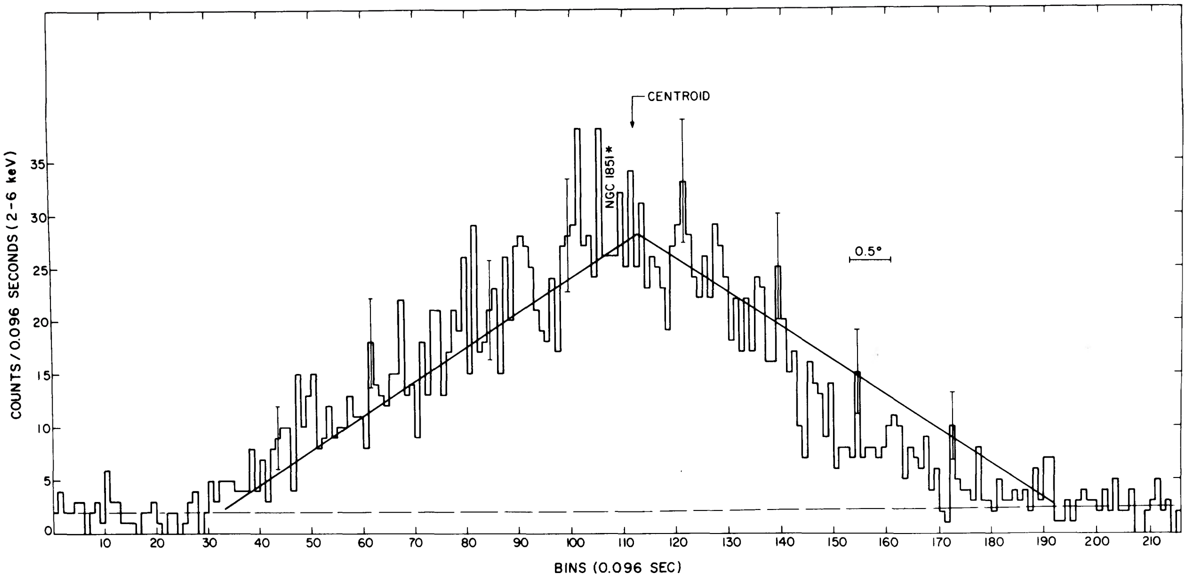

FIG. 1.—The raw 2–6 keV counting rate is shown starting at 85,232.152 s (UT) on 1972 September 19. The triangular collimator response is shown along with the background rate. The location of NGC 1851 is indicated.

The uncertainty in the location on the sky of the observed centroid due to possible systematic errors in the magnetometer equation of motion for the satellite is no larger than $\pm 0\overset{\circ}{.}2$ based upon a comparison of single-spin azimuthal aspect solutions with known X-ray source locations. The globular cluster NGC 1851 lies $0\overset{\circ}{.}28$ from the centroid determined above and is well within the $\pm 0\overset{\circ}{.}33$ uncertainty allowed from statistical and systematic uncertainties.

We have searched through other *Uhuru* observations of the region containing NGC 1851. The source was detected above background on seven occasions lasting approximately 1 day each. The intensities from each source sighting were consistent with the average value of 3.3 ± 0.4 counts s^{-1} (2–6 keV). The source was not detected above background on several occasions, but this is expected in view of its low intensity. The maximum flux observed by OSO-7 (Clark, Markert, and Li 1975) is equivalent to ~ 20 counts s^{-1}, about 6 times stronger than our average value, which suggests that either the source intensity is variable, in addition to the bursts, or that several bursts were included in the OSO-7 observations.

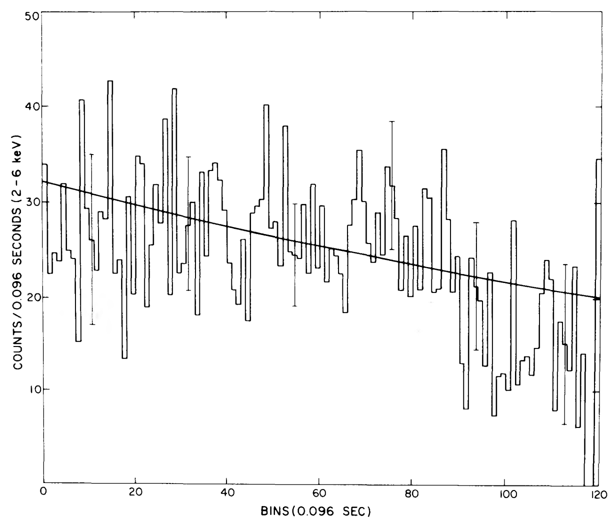

FIG. 2.—The central three fourths of the burst observation. have been rectified to remove the collimator response. The solid line represents the intensity of an exponential with decay time of 24 s normalized to the average counting rate at the midpoint of the observation.

III. STRUCTURE OF THE X-RAY BURST

Figure 2 shows the observation of the burst with the triangular collimator response deconvolved. This deconvolution, or rectification, used the centroid determined by sliding the window, and it is insensitive to changes in the centroid within the uncertainties.

One can see from Figure 2 that the intensity of the source does not increase during any portion of our observation; therefore, we conclude we have not observed the presumed rapid rise of this burst. The time constant of the decay is slow compared to the duration of the observation with the intensity changing by roughly a factor of 2 from beginning to end. Because of the slow decay, we are not sensitive to its actual form. If, however, the decay is exponential as is observed in NGC 6624 (Grindlay *et al.* 1976; Clark *et al.* 1976), then the decay time is $\sim 24 \pm 5$ s and is shown by the solid line in Figure 2.

To analyze the spectrum of this burst, we divided the observation into four equal sections lasting almost 4 s each. Background was determined from data both before and after the X-ray burst and was subtracted from each of the spectra which were also corrected for the triangular response of the collimator. During each of the four quarters of the burst the temperature of the best-fit exponential spectrum was consistent with a constant value of $\sim$7.5 keV. However, there appears to be an increasing deficiency or absorption at low energies with time. Figure 3 shows three spectra—the first quarter, the average of the second and third (because of their similarity), and the fourth. The increased low-energy absorption is apparent in the figure since the data in the higher two channels are consistent, within the uncertainties, while the data in the lower two channels differ substantially. In the last quarter of our observation the best-fit low-energy absorption is 4.0 $\pm$ 1.0 keV (with the average 7.5 keV temperature). Some of this low-energy absorption could be accounted for by a higher temperature spectrum.

We have checked for possible systematic problems with our spectral analysis by analyzing spectral observations of Cas A made on the same day as the burst. No effects such as those reported above were observed.

IV. DISCUSSION AND SUMMARY

We have described an X-ray burst from a region centered near the X-ray globular cluster NGC 1851 = MX 0513$-$40. In spite of the large area of the error box, we feel confident in the identification for two reasons. First, Grindlay *et al.* (1976) have observed similar X-ray bursts from 3U 1820$-$30 = NGC 6624, a globular cluster X-ray source, and NGC 1851 is another of these relatively unusual systems. Second, the region of the sky to which this burst is localized is in an uncrowded region (galactic coordinates $l^{\mathrm{II}} \approx 244°$ and $b^{\mathrm{II}} = -34°$).

The most important consequence of this observation is that both identified sources of bursts are X-ray globular clusters: NGC 1851 = MX 0513$-$40 and NGC 6624 = 3U 1820$-$30.

We did not observe the onset of the burst, so calculations such as were done for NGC 6624 by Grindlay and Gursky (1976) and Canizares (1976) involving accretion from a cloud onto a central collapsed object are not possible. Several comparisons of this burst in relation to those from NGC 6624 are important. If the burst reported here is decaying exponentially, then the decay time is $\sim$25 s which is significantly longer than that reported by Grindlay *et al.* (1976) and Clark *et al.* (1976) for the bursts from NGC 6624 = 3U 1820$-$30. If a model involving a massive black hole is invoked, then this implies either a larger cloud surrounding the black hole at the center of the cluster or a larger electron-scattering optical depth. The low-energy deficiency or absorption which develops during this burst could not be produced by the hot cloud postulated in this model and appears to present a difficulty for the model. As Canizares (1976) points out, any low-energy absorption tends to decrease with time in this model.

The total energy from NGC 1851 was $\lesssim 7 \times 10^{38}$ ergs with the peak rate of $\lesssim 7 \times 10^{37}$ ergs s^{-1} using a distance of 10.6 kpc (Illingworth and Illingworth 1976). The actual values could have been substantially higher if the burst began much before our observations.

The burst sources so far observed (Lewin *et al.* 1976 and references therein; Clark *et al.* 1976; Doty 1976) are distributed like the galactic X-ray sources with concentrations in the galactic plane and toward the galactic center. This distribution is similar to that of globular clusters (Ostriker 1975). We suggest, therefore, that all X-ray bursts are originating in X-ray globular clusters whose average intensities are often below the limits of sensitivity of existing X-ray observatories and which are located in regions of the sky where optical obscuration would hamper detection of globular clusters.

The association of X-ray bursts with globular clusters implies that these clusters contain a unique object or environment for the production of X-rays. If the X-rays are produced in an X-ray binary system, then the cluster environment must significantly modify its behavior. Alternatively, the cluster could contain an object not present in the usual X-ray binary system—a massive black hole—as has been suggested (Bahcall and Ostriker 1975; Silk and Arons 1975; Grindlay and Gursky 1976).

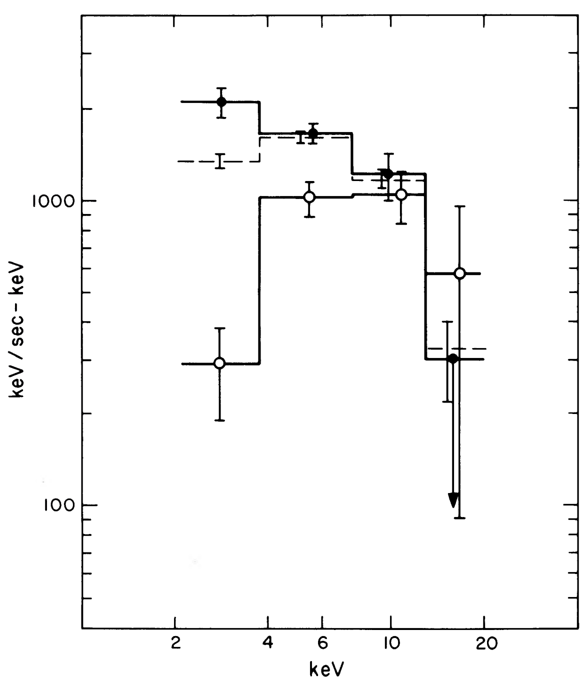

FIG. 3.—Three spectra from 2 to 20 keV are shown. The spectrum of the first quarter of the 16 s observation is shown as a solid line, the average of the second and third quarters as a dashed line, and the fourth quarter as a solid line with open circles. We have combined the seven *Uhuru* spectral channels into the four shown, to simplify the figure.

We thank Drs. H. Gursky, H. Tananbaum, J. Grindlay, and R. Giacconi for their interest and suggestions. We thank M. Twomey for help in preparing this manuscript.

This work was supported under NASA grant NAS5-20048.

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