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# LONG-TERM BEHAVIOR OF MXB 1730−335

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## ABSTRACT

The rapid burster MXB 1730−335 was detected on at least two occasions in 1971 and 1972 by *Uhuru*, and coverage is available from late 1970 to early 1973. Combined with ANS coverage in 1975 and 1976, as well as published SAS-3 and *Ariel V* observations (1976–1977), a unique record of long-term burst activity is now available for this source. There appear to be burst-active states of ~one to two months' duration that occur with a ~15% duty cycle. The burst activity appears to be recurrent with a ~0.5–1 yr time scale. Implications for burster models are discussed.
*Subject headings:* X-rays: bursts — X-rays: sources

After the discovery of X-ray bursts in the ANS data (Grindlay *et al.* 1976), similar events were found in the earlier *Uhuru* data (Grindlay and Gursky 1976*a*). The *Uhuru* analysis was conducted by visually examining computer plots of the count rate data from the 5° detector for individual ~12 minute spin periods during galactic plane observations.

During the total period of operation of *Uhuru* (1970 December–1973 April; see Forman *et al.* 1978), approximately 62 days of exposure were obtained with the scan direction aligned along the galactic plane. Data from ~42 days of exposure, distributed uniformly throughout the entire coverage, were examined in this study. Given the (usual) 12 minute spin period, detector field of view, and Earth-blocking time, approximately 3600 scans over a given source position in the plane were available. The total exposure time on a given source was then ~0.5–0.7 days. Unambiguous X-ray bursts were found in these data from three regions: the Norma burster XB 1608−52 = (?) 4U 1608−52 (Grindlay and Gursky 1976*a*) and the galactic center at $l^{II} = 0° \pm 1°$ and at $l^{II} = 354.5° \pm 1°$. The latter position contains at least two known burst sources—the rapid burster MXB 1730−335 (Lewin *et al* 1976*b;* Heise *et al.* 1976) and MXB 1728−34 (Hoffman *et al.* 1976). We can clearly distinguish these sources, however, by their very different burst recurrence times, which are typically 0.5–2 minutes for the rapid burster versus ~2–5 hours for MXB 1728−34 (see above references). Thus when the rapid burster is "on," multiple bursts are easily seen in the spin plots for at least several orbits, and bursts on consecutive spins are not uncommon. An example of such a record, which also shows how the bursts are distinguished from scans over "steady" sources, is given in Figure 1.

A total of 41 bursts were identified in all the galactic scans examined. Of these, four were from the Norma source (Grindlay and Gursky 1976*a*), and 28 were most likely from the rapid burster in that they were all detected between 1971 March 20–21 (seven bursts) and 1972 May 11–17 (21 bursts). The 90% error box derived for the source of these bursts is the region $l^{II} = 354.7° \pm 0.4°$, $b^{II} = 0.0° \pm 1.6°$, which includes MXB 1730−335 (Lewin *et al.* 1976*b;* Heise *et al.* 1976). One burst was detected from within ~1° of the galactic center on 1972 May 29 and was presumably due to one of the burst sources now known (Lewin *et al.* 1976*c*) in the GCX source complex.

The remaining bursts could be from another of the two bursters near $l^{II} = 354°$ but are most likely due to MXB 1728−34, since they were almost all single isolated bursts detected within ~2 day coverage periods. The one exception to this was on 1972 January 30, when two bursts were detected within 3.4 hours (i.e., two orbits), which suggests that the rapid burster may have been active. However, we regard this as *un*likely, since no other bursts were detected in the 4 day coverage at that time, whereas more than 10 would have been expected from the repetition rate (usually implying a ~30 s burst interval) otherwise observed for MXB 1730−335.

The time history of observation coverage and detection of bursts from MXB 1730−335 by *Uhuru* is shown in Figure 2. The durations of the scan data intervals examined are indicated by the width of the rectangles; the shading marks those intervals where bursts from MXB 1730−335 were definitely observed. The diagonal-shaded interval in early 1972 represents the double-burst observation mentioned above, while the intervals with a single diagonal are those in which only a single burst (presumably MXB 1728−34) was detected. An upper limit of ~10 *Uhuru* counts $s^{-1}$ (2–6 keV) was established with the 0.5° collimator data for any "steady" emission from MXB 1730−335 during the periods of *Uhuru* coverage shown in Figure 2.

We also show the record of burst activity in 1975 as determined by ANS (no bursts were observed in 1975 observations of 3U 1727−33 when MXB 1730−335 was also included in the field of view for some pointing positions). In 1976 the burst activity record is from the (February–April) discovery observations of SAS-3 (Lewin *et al.* 1976*b*) and the (March) positional determinations by ANS (Heise *et al.* 1976) and *Ariel V* (Carpenter *et al.* 1976). No bursts were detected in 1976 May



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(Hoffman 1976) or August (Lewin *et al.* 1976*a*). *Ariel V* observations revealed that the rapid burster had turned back on by 1977 mid-April (White, Burnell, and Carpenter 1977), whereas no bursts were observed by SAS-3 in late May or June and July (Lewin and Hoffman 1977). Bursts were again observed, however, in 1977 September (Joss *et al.* 1977).

The data reveal that the rapid burster shares one feature with other bursters (see discussion below); namely, it is inactive more frequently than it is active. The duty cycle, i.e., the ratio of times of burst activity to no activity, is about 15%. We derived this number in two ways. First, we simply compared the times that bursts were recorded with the total observing time, counting the extended burst activity periods of 1976 and 1977 as only ~0.06 and ~0.04 yr, respectively, since these are the actual approximate total observing times obtained in these periods. Second, we assumed that the burst-active state persists for ~0.1 yr and counted the number of independent 0.1 yr intervals during which bursts had been seen compared with the total number of such intervals. Because of the small numbers involved and these assumptions, a large uncertainty—about a factor of 2—must be assigned to this duty cycle. In the case of the Norma burster we also derived a duty cycle of 10%.

Despite the incomplete coverage (especially in 1973–1974) it is interesting that the source was always defi-

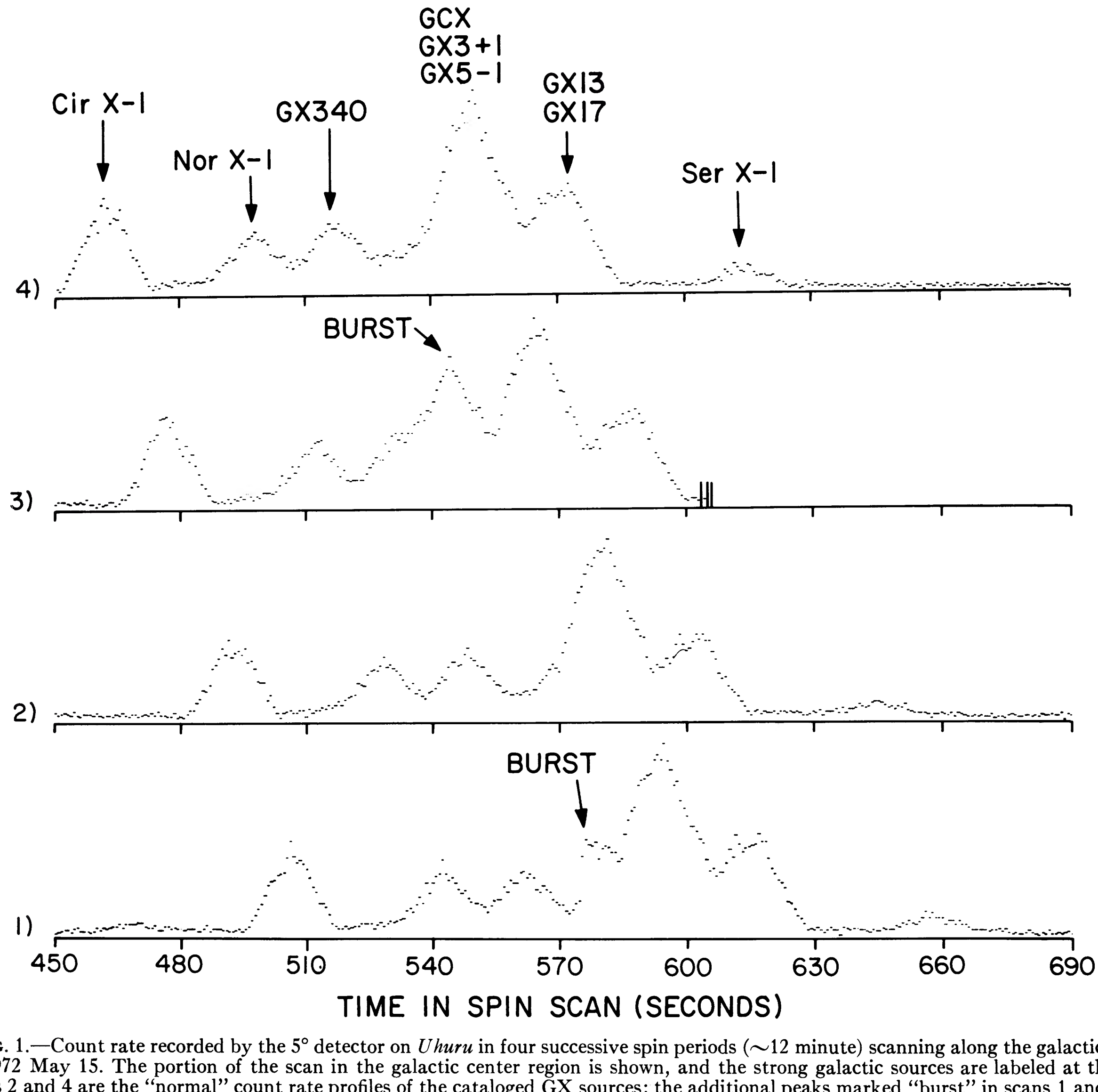


FIG. 1.—Count rate recorded by the 5° detector on *Uhuru* in four successive spin periods (~12 minute) scanning along the galactic plane on 1972 May 15. The portion of the scan in the galactic center region is shown, and the strong galactic sources are labeled at the top. Scans 2 and 4 are the "normal" count rate profiles of the cataloged GX sources; the additional peaks marked "burst" in scans 1 and 3 are bursts from MXB 1730−335. Note that the burst in scan 1 was detected (at ~04:22:01) on the rise (with rise time ~1 s), whereas the burst in scan 3 was detected (at 04:46:40) during the decay (the collimator triangular response is evident) of duration greater than 10 s. The peak burst count rates are, respectively, ~280 and ~490 counts $s^{-1}$ above the approximate local source background.

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nitely burst-active within the interval 0.16–0.40 of each year. Indeed the burster was definitely active only once (1977 September) at any other time, though more than 1.5 times more total observing time was accumulated outside the 0.16–0.40 interval than within it. Thus, the burst activity cycle appears to be recurrent, with active states recurring every ~0.5–1 yr and lasting ~0.15 yr. When the burster "turns off," it appears to stay off for at least as long as it was "on." Obviously, occasional monitoring of the source over several years (and especially in March–May) is needed to confirm this suspected activity cycle.

Since the activity is not periodic (and, probably, not even quasi-periodic), our results could limit models which would have burst activity triggered by periodic changes in accretion rate, e.g., from an eccentric binary companion. Models involving magnetospheric instabilities in accretion on neutron stars (e.g., Lamb *et al.* 1977) should, however, seek to explain the apparent duty cycle and typical time scales of "on" versus "off" burst activity for bursters such as MXB 1730−335.

If burster "off" states are usually longer than "on" states (i.e., duty cycles $\lesssim 50\%$), then a feedback mechanism may be operating between burst activity and the "ambient" source conditions. We point out one such mechanism which is consistent with the suggestion (Grindlay and Gursky 1976*b*) that bursters indicate spherical accretion from the interstellar medium onto a massive black hole. This is, changes in the accretion rate at the accretion radius $r_a$ could be induced by hot gas forced out by the bursts themselves such that the supercritical accretion rate, which may lead to bursts, can be self-regulating (Grindlay 1978). The ~0.5–1 yr recurrence time $t_r$ would then correspond to the free-fall time $t_f$ from $r_a$, or $t_r \approx t_f \approx 2.8 \times 10^5\, M/V_{15}^3$ s where $M$ is in solar masses and $V_{15}$ is the gas velocity in units of 15 km s$^{-1}$. If $V_{15} > 1$, as for gas heated to above $10^4$ K by both X-ray heating and blast wave heating by the hot gas expelled from previous bursts, then $M > 1\, M_{\odot}$. Supercritical accretion could resume when the gas at $r_a$ cools some time after passage of the additional blast wave heating contribution, and the source could begin bursting after $t_f$. The ~0.1 yr burst activity duration could then correspond to the transit time $t_g = r_a/v_{15}$ of hot gas (at velocity $v_{15}$) from the source out to $r_a$ where blast wave heating might be most effective, since the density profile changes from a decreasing ($\sim r^{-3/2}$) to a constant value in the (for MXB 1730−335) globular-cluster core.

The above relations and the observed duty cycle then give $t_g/t_r \approx 1.3\, V_{15}/v_{15} \approx 0.1$. With gas expelled at an averaged (for cooling during expansion) temperature of less than or approximately 3 keV or $v_{15} \lesssim 60$ by a burst at effective temperature ~10 keV (Grindlay 1978), we obtain $V_{15} < 4.8$ (or $T \approx 10^4$–$2 \times 10^5$ K at $r_a$) and $M \leq 100\, M_{\odot}$. The fact that a moderately massive black hole is suggested by this interpretation is also consistent with the relatively constant burst duty cycle and activity

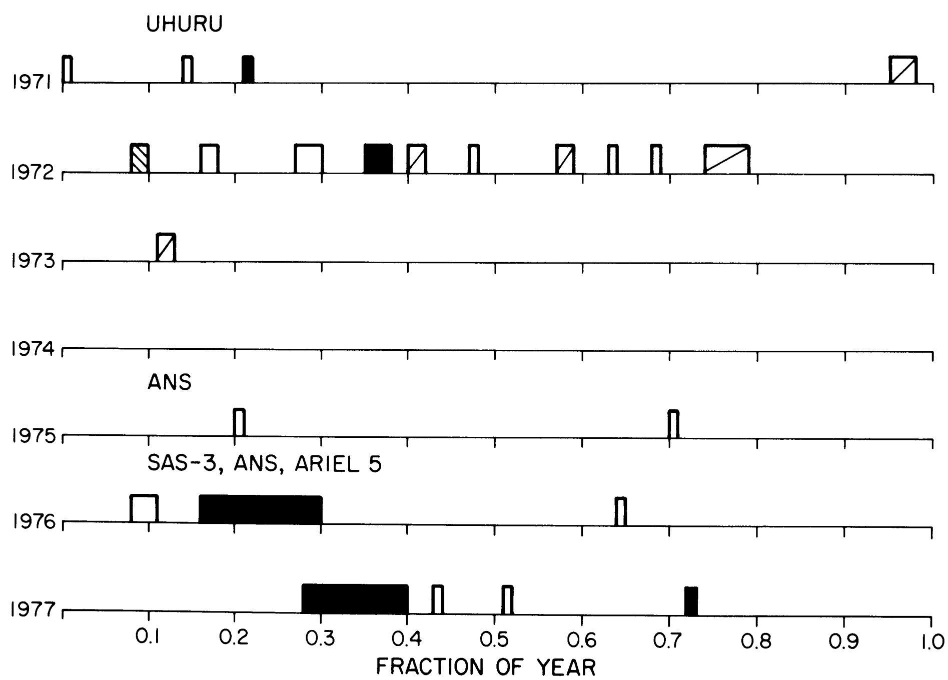


FIG. 2.—Total record of burst activity of MXB 1730−335. Periods of coverage where bursts were not observed are the open rectangles, whereas multiple bursts were detected (indicating certain MXB 1730−335 activity) in the periods marked by solid rectangles. The exact start and stop times of burst activity are uncertain in most cases (owing to incomplete coverage), and observation limits are shown. For the extended activity periods in 1976 and 1977, the actual total observing time within these periods is estimated to be ~0.06 and ~0.04 yr, respectively. The *Uhuru* observations marked by the multiple and single diagonal lines recorded double and single bursts, respectively, which were probably from the neighboring burst source MXB 1728−34 (see text).

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recurrence rate possibly indicated by the data. This is because the time constant for change in the average accretion rate (and thus the longest time scales for the source) is expected to be much longer for spherical accretion from an interstellar cloud than from a binary star companion. Known binaries (e.g., Cen X-3 or Cyg X-1) are usually erratic in their long-term variability between sustained high and low states, presumably reflecting the chaos in their stellar wind gas supplies. In this case, one may expect totally random occurrence times *and* durations of burst activity.

Other bursters may also reveal similar duty cycles and relative time scales for recurrence of burst activity. For example, 3U 1820−30 (NGC 6624) may be "on" for only ~4 days (bursts have been observed only for short periods) and "off" for more than 30 days, whereas MXB 1728−34, MXB 1837+04, or MXB 1916−05, which are now usually "always" bursting (Lewin and Hoffman 1977), still do not have well-determined burst activity duty cycles on time scales greater than or approximately months or years. The duration of burst activity, or total number of consecutive bursts in a given activity period, for these objects may already be long enough (if the activity observed [Lewin and Hoffman 1977] in 1977 June and July was continuous) to rule out even "battery" nuclear burning models (Lamb and Lamb 1977) for these bursters, as has been done for MXB 1730−335. More comprehensive and longer-term observations of the burst activity cycles of MXB 1730−335 and other bursters could further test these conclusions, and more detailed consideration of long-term activity in burster models is needed.

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