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OBSERVATIONS OF OUTBURSTS FROM THE RECURRENT X-RAY TRANSIENT A0538−66 AND LMC X-4

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ABSTRACT

Nine X-ray outbursts from the LMC have been observed with the *HEAO 1* Large-Area Sky Survey Instrument. Some are shown to originate in the recurrent transient A0538 − 66, confirming the proposed 16 day periodicity and showing that the duration of the events can be as long as ∼14 days or as short as a few hours. Deviations from precise periodicity can be attributed to phase jitter or to a change in period occurring around the time of an exceptionally long outburst. Other outbursts which are irregular and consistently shorter originate in LMC X-4. A long-term light curve indicates that the LMC X-4 outbursts occur only when the source is in a high state, but are not strongly correlated with the binary phase.

Subject headings: galaxies: Magellanic Clouds — X-rays: binaries — X-rays: sources

I. INTRODUCTION

Four sources in the direction of the LMC, LMC X-1, X-2, X-3, and X-4 have been known since the early X-ray work on the region (Mark *et al.* 1969; Price *et al.* 1971; Leong *et al.* 1971) and have been well studied. Only LMC X-4 has a firm optical counterpart; confirmation resulted from the detection of X-ray eclipses (Li, Rappaport, and Epstein 1978; White 1978) corresponding to the 1.4 day optical period found by Chevalier and Ilovaisky (1977) for the candidate star proposed by Sanduleak and Philip (1976). LMC X-4 is generally weaker than LMC X-1, X-2, or X-3 and was not detectable during several observations by the *Copernicus* (Tuohy and Rapley 1975), and *OSO 7* (Markert and Clark 1975) satellites. However, both *SAS 3* and *Ariel 5* detected the source and found flares lasting ∼20 s (Epstein *et al.* 1977) and up to 20 minutes (White 1978).

Several other sources have been reported in the same part of the sky, but most have been observed only during one set of measurements or by one instrument and little information is available (e.g., "bar" emission: Rappaport *et al.* 1975 and McKee *et al.* 1979; LMC X-5: Markert and Clark 1975; LMC X-6/A0501 − 66: Griffiths and Seward 1977; H0544 − 665: Johnston, Bradt, and Doxsey 1979).

A source A0538 − 66, close to LMC X-4, was discovered with the *Ariel 5* satellite when two outbursts were observed in 1977 June and July (White and Carpenter 1978). Johnston *et al.* (1979) reported two further outbursts observed with the *HEAO 1* scanning modulation collimator in 1977 October and November and pointed out that the onsets of the outbursts were consistent with a period of 16.66 days. All four outbursts were brief, lasting ∼12 hr. These characteristics make A0538 − 66 a unique object among transient X-ray sources.

We report here observations made with the NRL Large-Area Sky Survey (LASS) instrument on *HEAO 1* of a number of further flares and outbursts from the region around A0536 − 66 and LMC X-4. From A0538 − 66 we have observed four further outbursts conforming to the 16.66 day periodicity. Two of these differ significantly in character from those reported previously. Other flares are shown to originate not in A0538 − 66 but from the vicinity of LMC X-4.

II. OBSERVATIONS

The main scan modules of the LASS experiment had a total effective area of 6400 cm^2. The detectors were proportional counters with thin plastic windows and a gas flow system supplying a mixture of 77.5% xenon, 22.5% methane at a pressure of 2.0 pounds per square inch absolute. The useful energy range was 0.5–20 keV. The scan module collimators had a field of view which was 1° (FWHM) in the scan direction by 4° (FWHM) normal to the scan. The spin axis was kept within $\frac{1}{2}°$ of the Sun direction, and so sources falling within 4° of a great circle passing through the ecliptic poles were observed for about 5 s out of every 30 minutes spin period (except during Earth occultations and passages of the satellite through the radiation belts). Many of the LMC sources lie sufficiently close to the south ecliptic pole that they were observed throughout the year; all were observable for at least 2 months out of every 6.

The data exist in two basic forms in the LASS data base. The first is the individual scans which provide high time resolution. The second, more compact form is the 12 hr sums for which counts have been put into standard bins of $0\overset{\circ}{.}1$ in scan azimuth after screening for Earth blockage and charged particle interference. In both forms, the data are summed over the energy range from 0.5 to 20 keV. The first 6 months of LASS observations, spanning the period from 1977 August 18 (day 230) to 1978 February 7 (day 38), have been processed into these forms and have been examined for the present work.

For either type of data, source positions and intensities can be obtained by means of a fitting procedure using the known collimator response. Models with up to seven sources have been used for the LMC region. Generally sources whose positions are known with high accuracy from other experiments are fixed in position in the model, and only their intensities are varied to obtain the best fit. The positions assumed are given in Table 1. At least one additional LMC source, H0523 − 697, has been detected in the LASS data, and its scan azimuth was allowed to vary during each fitting process to enable a position estimate to be made. From its location, it appears to be the same source detected by McKee *et al.* (1979) and tentatively identified as the LMC supernova remnant, N132D. The source is comparatively weak and is confused with the A0538 − 66/LMC X-4 region only for a few days. Therefore, its effect on the results presented here is minimal. (Since this data analysis was completed, Long and Helfand [1979] have definitely identified this source as the supernova remnant N132D using the *Einstein* observatory.)

All of the 12 hr sums during the period under consideration have been analyzed to derive source intensity estimates. Varying degrees of source confusion are encountered as the scan direction changes and different combinations of sources are observed at nearly the same scan azimuth angle. In particular from 1977 day 290 to day 365, A0538 − 66 and LMC X-4 are confused first with each other, and then both sources are confused successively with LMC X-1, LMC X-3, and H0523 − 697.

TABLE 1

LMC SOURCE POSITIONS

Source	(1950)	(1950)	Reference
LMC X-1	$5^{h}40^{m}04\overset{s}{.}8$	−69°46′04″	1
LMC X-2	5 21 16.5	−72 00 19	1
LMC X-3	5 38 38.2	−64 06 31	1
LMC X-4	5 32 54	−66 24 10	2
H0544 − 665	5 44 11.5	−66 35 24	1
A0538 − 66	5 35 42.5	−66 52 40	3
H0523 − 697	5 23 31	−69 42	4

REFERENCES.—(1) Johnston, Bradt, and Doxsey 1979. (2) Chevalier and Ilovaisky 1977. (3) Johnston *et al.* 1979. (4) This work.

The intensity measurements from the 12 hr sums were searched for times of exceptionally high flux from the A0538 − 66/LMC X-4 region. Where sources were confused, we have added the intensities of all sources which could not be separated in our model fits, and so during the last 75 days of 1977 our sensitivity is somewhat reduced. The sensitivity achieved varied, during the 6 month period, from 0.005 to 0.01 for the outburst intensity integrated over 12 hr in Crab days (1 Crab day = the intensity of the Crab Nebula for one day = 2.0×10^{-3} ergs cm^{-2} in the 2–10 keV band). A 12 hr sum comprises a number of short observations, each lasting a few seconds, spaced by at least 30 minutes and often by much longer periods because of Earth blockage, particle interference, etc. The average gap between observations of the LMC is 1.4 hr, but the distribution is irregular and much longer gaps occur. Thus, short outbursts could be missed even if their integrated intensity exceeded the above levels.

When times of high flux from the region were found in the 12 hr sum data, each individual scan around the time indicated was examined in detail. Source intensities were determined by the same model fitting technique, allowing peak times, peak intensities, and outburst durations to be found more accurately.

Individual scans were also examined both around the times when the ephemeris given by Johnston *et al.* (1979) predicted an outburst from A0538 − 66 even if none was observed in the 12 hr sums and at a number of other times during the 6 month period. No outburst was detected which had not been picked out from the 12 hr sum analysis. Similarly, visual screening of a large sample of microfilm plots of the individual scan data yielded no further outbursts, again indicating that even short outbursts are efficiently found by examining the 12 hr sums.

III. RESULTS

Table 2 lists the times and intensities of nine outbursts found during the 6 month period. Two outbursts (1977 days 280.48 and 313.80) are those from A0538 − 66 reported by Johnston *et al.* (1979); the remainder are new observations. The scan azimuth angles at which the events were observed are such that not all can originate from A0538 − 66. Figure 1 shows lines of position obtained by allowing the scan azimuth of the fitted source to vary during the fitting procedure.

With one possible exception, it is clear that the observations are consistent with each outburst originating either in A0538—66 or in a small region centered on LMC X-4. The line of position for the event on day 363 lies between the two sources, but we have reason to believe that there may be systematic errors in this case due to confusion with LMC X-3 (which is at nearly the same scan azimuth). There is strong independent evidence for attributing this event to A0538 − 66, both from the LASS 1° × $\frac{1}{2}$° detector

TABLE 2

OUTBURSTS FROM LMC X-4 AND A0538−66

Peak Time (day in 1977 1.00 = 0000 UT Jan. 1)	Peak Intensity ($\times 10^{-3}$ Crab)	Duration (days)	Source
232.1	49	14	A0538−66
248.3	36	3	A0538−66
261.382	88	<0.064	LMC X-4
280.48	100	0.6	A0538−66
291.176	69	<0.2	LMC X-4
313.80	50	<0.6 >0.1	A0538−66[a]
327.980	27	<0.36	LMC X-4[b]
329.729	51	<0.13	LMC X-4[b]
363.64	38	0.1	A0538−66[c]

[a] Position determination by Johnston *et al.* 1979.

[b] Some uncertainty, A0538−66 is only 0°25 away in the scan direction.

[c] Position determination using $1^\circ \times \frac{1}{2}^\circ$ detector and by *HEAO 1* modulation collimator (Johnston, private communication).

and from the *HEAO 1* modulation collimator experiment (M. D. Johnston 1979, private communication). In addition, it occurred very close to the time of an A0538−66 outburst predicted on the basis of the 16.66 day period. We shall discuss separately those outbursts which we attribute to A0538−66 and those we attribute to LMC X-4.

a) *A0538−66*

The first two outbursts from A0538−66 detected by the LASS were of much longer duration than any of the previously reported outbursts (White and Carpenter 1978; Johnston *et al.* 1979). For 22 days at the beginning of the *HEAO 1* operations the source was detected at a significant level. The 12 hr average intensities are shown in Figure 2. From the LASS data alone it is clear that the emission is from A0538−66, not LMC X-4. These outbursts have since been detected in the *HEAO 1* modulation collimator experiment data confirming this conclusion and allowing a refinement of the error box for the source (Johnston, Griffiths, and Ward 1979).

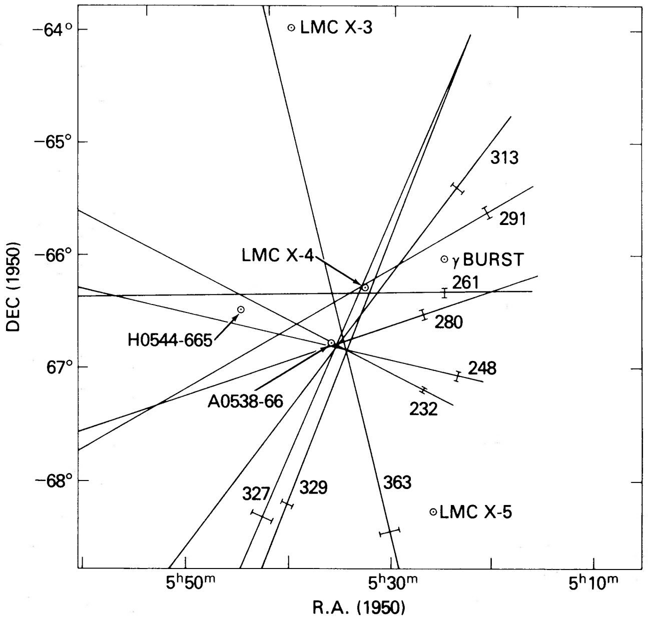

FIG. 1.—Lines of position for each of the 9 outbursts listed in Table 2. Lines are marked by the day in 1977 on which the outbursts occurred. Error bars are approximately $\pm 2\,\sigma$. The length of the line corresponds to the full 8° extent of the collimator response perpendicular to the scan direction. The positions of sources from Table 1 and of the 1979 March 5 γ-ray burst (Evans *et al.* 1979) are also shown.

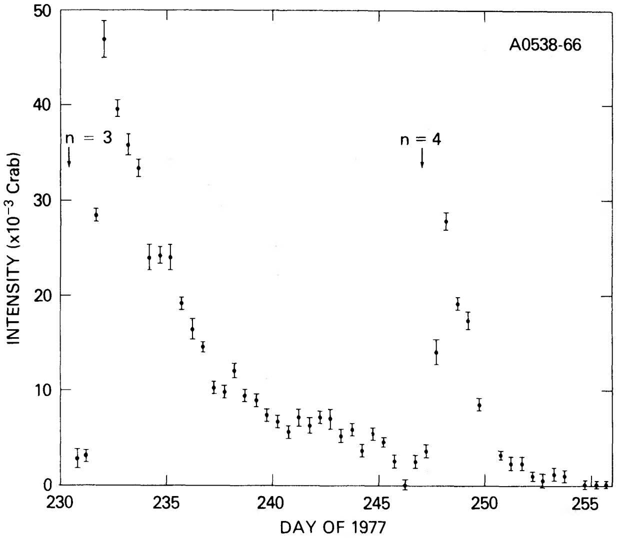

FIG. 2.—The intensity of A0538 − 66, averaged over 12 hr intervals, for the period from 1977 day 230 to day 256. The time of occurrence (*see text*) of the $n = 3$ and $n = 4$ outbursts is indicated by the arrows.

The expected times of the $n = 3$ and $n = 4$ outbursts based on the ephemeris suggested by Johnston *et al.* (1979) are also shown in Figure 2. Although the outbursts conform to the general pattern of the 16.66 day periodicity, they occur late by 1–1.5 days.

All five outbursts definitely attributed to A0538 − 66 are shown in Figure 3 with the time resolution available from individual scans. The different character of the $n = 3, 4$ outbursts is clearly seen, as is the fact that for the other three outbursts the time of the peak intensities agrees with the 16.66 day period to within about 0.1 days. Source confusion problems complicate the intensity estimates for $n = 6$ and $n = 8$. In the case of $n = 6$, we have plotted both the sum of the intensities of A0538 − 66 and LMC X-4 and also our best estimate of the A0538 − 66 intensity alone; for $n = 8$ no separation was possible, and only the sum is plotted.

In Table 3 we present both the positive detections of A0538 − 66 and upper limits that can be placed on predicted outbursts. Included in this compilation are the original *Ariel 5* observations of this source and a new upper limit from the *Ariel 5* RMC (rotating modulation collimator) data for the predicted $n = 2$ outburst.

The peak intensity limits for $n = 5, 7, 9, 10, 12, 13$ given in Table 3 are the limits on the intensity at any time when valid LASS scan data is available. An outburst comparable with the $n = 0, 1, 3, 4, 6, 8, 11$ ones would certainly have been detected had it occurred during LASS coverage. However, as noted above, although the mean time between scans for which data is available is about 1.4 hr, the coverage is irregular and long gaps occur. The integrated intensity limits in

TABLE 3

PREDICTED AND OBSERVED OUTBURSTS FROM A0538 − 66

Number	Predicted Time[a]	Peak Time	Peak Intensity $(\times 10^{-3}$ Crab$)$	Integral Intensity $(\times 10^{-3}$ Crab days$)$
		1977		
0	180.46	180.41	>92	>14
1	197.12	197.23	160	41
2	213.78	...	<60[b]	<10[e]
3	230.45	232.1	49	173
4	247.11	248.3	36	47
5	263.77	...	<13[c]	<26[f]
6	280.43	280.48	100	24
7	297.09	...	<13[c]	<10[f]
8	313.76	313.80	50	5
9	330.42	...	<14[c]	<19[f]
10	347.08	...	<13[c]	<51[f]
11	363.74	363.64	38	3.5
		1978		
12	15.40	...	<14[c]	<21[f]
13	32.07	...	<14[c]	<21[f]
14	48.73	...	[d]	[d]

[a] Using ephemeris of Johnston *et al.* 1979.

[b] One orbit (90 min.) integration.

[c] Assuming a LASS scan occurred during outburst.

[d] LASS detectors turned off.

[e] Assuming outburst lasted longer than *Ariel 5* Earth occultation (30 min.).

[f] Assuming outburst occurred during maximum LASS data gap with an intensity of 100×10^{-3} Crab.

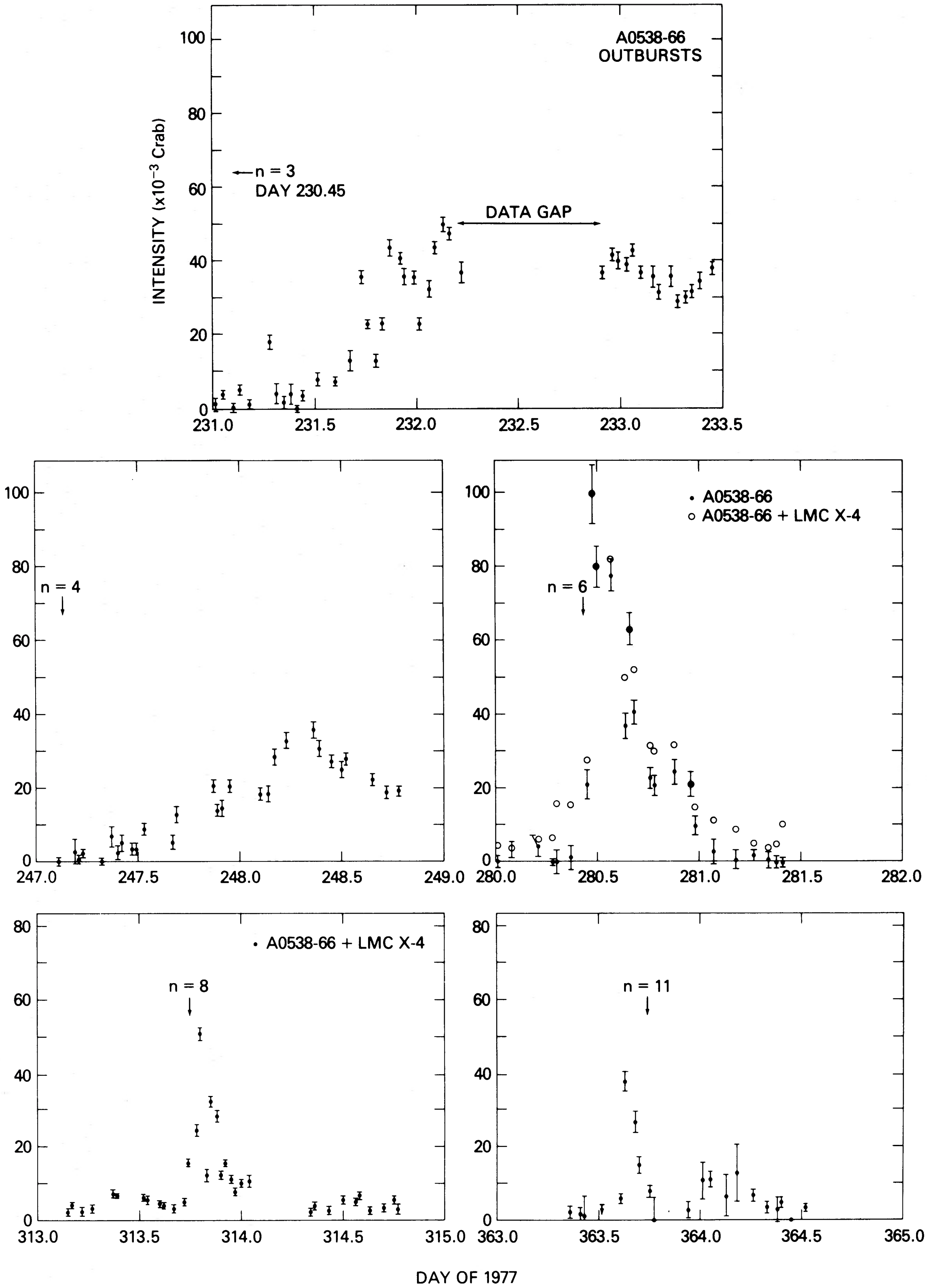

FIG. 3.—The intensity of A0538 − 66 from single 10 s scans through the source for a period around each of the detected outbursts. The arrows indicate the predicted times of outburst (*see text*). Because of source confusion problems for the $n = 6$ and $n = 8$ outbursts, we have plotted the sum of the intensities of LMC X-4 and A0538 − 66.

Table 3 have been calculated on the extreme assumption that an outburst might have lasted for the whole duration of the longest data gap with an intensity equal to the greatest value observed from the source by the LASS experiment. Clearly quite strong outbursts might have been missed during the longer gaps, which ranged from 0.1 to 0.5 days. Only in the case of the $n = 2$ result from *Ariel 5*, where the longest data gap is approximately 30 minutes, is the upper limit significantly lower than the levels of the adjacent outbursts.

The integrated intensities of the outbursts following the long $n = 3$ event show a monotonically decreasing trend. All LASS upper limits are consistent with the missing outbursts following the same decay profile but having been missed because of gaps in coverage.

As the $n = 3, 4$ outbursts clearly differ in character from all others observed, only the event on day 363.74, corresponding to $n = 11$, provides any opportunity for refining the ephemeris. Including this burst in the analysis and working in terms of peak times, which are better defined than onset times, we find:

$$T_p = (2{,}443{,}423.96 \pm 0.04) + (16.65 \pm 0.01)(n - 6)\,, \quad (1)$$

for the Julian day of the peak of the outburst n. This differs only marginally from the ephemeris given by Johnston *et al.* (1979).

Even the short outbursts used in the analysis have significant deviations from the nominal peak times (Fig. 4). The rms jitter is 0.10 days. It can be seen from the figure that the outbursts at $n = 6, 8, 11$ are in fact compatible with a strict period. Thus, as an alternative to jitter about a fixed period, the behavior could be described in terms of a model in which a change of period from (16.84 ± 0.05) days to (16.630 ± 0.013) days occurred at about the time of the exceptionally long outburst ($n = 3$).

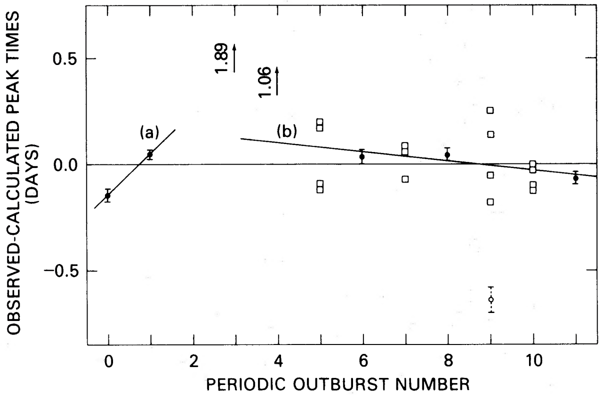

FIG. 4.—Deviations of the observed outburst peak times from the expected times calculated from eq. (1). Open squares indicate the available observations near the expected outburst when none was seen. Lines (*a*) and (*b*) correspond to periods of 16.84 days and 16.630 days, as described in the text. The timing of the event on day 329 is shown by the dashed bar.

Although no outburst was observed at $n = 9$, the event on day 329.729 occurred only 0.67 days before the predicted time, and the scan orientation was such that it could have originated in either A0538−66 or LMC X-4. In view of the large discrepancy compared with the jitter of the other short outbursts, we will discuss this event along with those from LMC X-4. We note, however, that its inclusion in the A0538−66 periodicity analysis would increase the rms jitter estimate without greatly affecting the best ephemeris.

b) *LMC X-4*

The lines of position for the four outbursts which we associate with LMC X-4 or for which no unique association can be made are labeled 261, 291, 327, and 329 in Figure 1.

If we assume that the bursts did not originate in

TABLE 4

LMC X-4 OUTBURSTS

Outburst Number	Observation Time (day in 1977)	LMC X-4 Phase[a]	Intensity ($\times 10^{-3}$ Crab)	Duration (days)
1	261.362	0.20	13 ± 2	<0.07
	261.382	0.22	88 ± 3	
	261.428	0.25	25 ± 6	
2	291.140[b]	0.35	<40	<0.10
	291.176	0.37	69 ± 2	
	291.239[b]	0.42	<30	
3	327.723	0.32	10 ± 1	<0.46
	327.980	0.51	27 ± 1	
	328.176	0.65	12 ± 2	
4	329.717[b]	0.74	<20	<0.05
	329.729	0.75	51 ± 2	
	329.767[b]	0.78	<15	

[a] From the ephemeris of Hutchings, Crampton, and Cowley 1978.

[b] *HEAO 1* modulation collimator 3 σ upper limits; M. D. Johnston 1979, private communication.

several different sources, then the common point of origin must have been at (or very close to) LMC X-4. We cannot exclude the possibility that the outburst on day 327, and perhaps that on day 329, may have come from A0538 − 66, but of the known sources only LMC X-4 could have produced the earlier events.

The phase of LMC X-4 at the time of the outbursts (Table 4) does not show any correlation which would confirm the association, and the fact that none of the four outbursts occurs during X-ray eclipse is not conclusive, since the eclipse duration is only 0.18 of the binary period (Hutchings, Crampton, and Cowley 1978). However, the previously reported flaring activity in LMC X-4 lends credibility to the identification.

While every outburst known to be from A0538 − 66 was seen on at least three LASS scans, the four outbursts under consideration here are also those for which we can only place an upper bound on the duration, because none was observed on more than one scan. Data from earlier and later LASS scans and from the *HEAO 1* modulation collimator experiment (M. D. Johnston 1979, private communication) have been used to set the limits given in Table 4. Only one outburst (day 327) could have been as long as 0.1 days, the shortest outburst seen from A0538 − 66.

To illustrate the magnitude of the outbursts relative to the normal intensity of LMC X-4, we have plotted all observations in the vicinity of the outbursts (Fig. 5). Except for that on day 327, each outburst exceeds the average LMC X-4 flux by a factor of more than 5. On day 327 the factor is only 2.3 for the available LASS data, but there is poor coverage. Even this represents a deviation of more than 10 times the usual short-term rms source variability.

The long-term behavior of LMC X-4 is shown in 1 day averages in Figure 6. The eclipse portions of the 1.4 day period have been included in these averages. Excluding these data would change the plotted points by less than 15%. The intensity varies between a low state of 2–4 × 10^{-3} that of the Crab Nebula and a high state of 10–20 × 10^{-3} that of Crab Nebula. The LASS outburst times, indicated by the arrows in Figure 6, all appear to correspond to times of relatively high LMC X-4 intensity. This is consistent with both the *Ariel 5* and *SAS 3* reports, which only presented observations of flares during the high-intensity state.

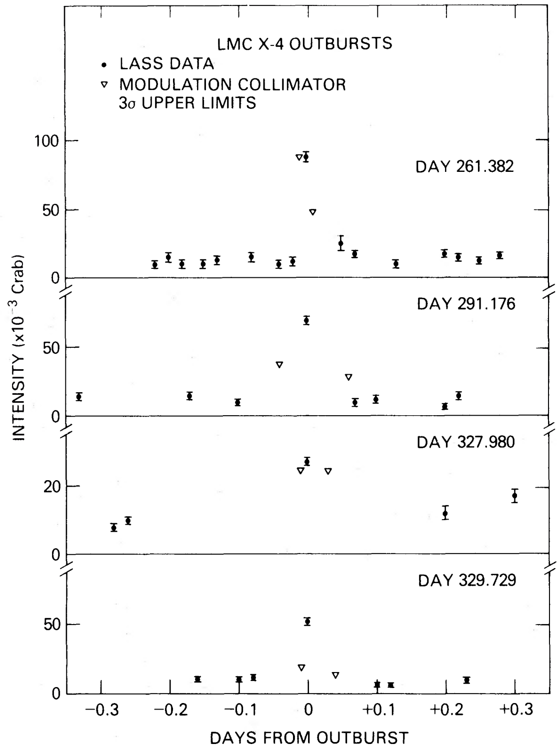

FIG. 5.—The intensity of LMC X-4 from single scan data for a period around each of the detected outbursts. The open triangles are upper limits from the *HEAO 1* modulation collimator experiment.

IV. DISCUSSION

a) *A0538 − 66*

Other observations of brief transient sources lasting from a few minutes up to a few hours have been reported (Ricketts, Cooke, and Pounds 1976; Canizares 1976; Rappaport *et al.* 1976; Holt 1976; Cooke 1976; Schrijver *et al.* 1978). Unlike the "classical" galactic X-ray transients lasting weeks or months, these events are not confined to the galactic plane and so presumably originate either comparatively close to us or at extragalactic distances. In one case, two events seem to have come from the same source (Cooke 1976).

The occurrence of repeated outbursts from the same source is a well-established feature of some of the

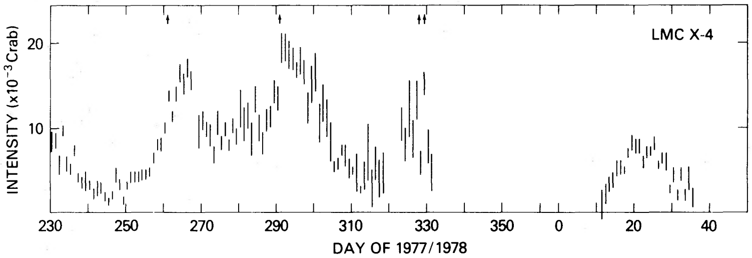

FIG. 6.—The intensity of LMC X-4 averaged over 1 day intervals for the period from 1977 day 230 to 1978 day 36. The large gap from 1977 day 333 to 1978 day 12 is due to source confusion between LMC X-4 and various combinations of A0538 − 66, LMC X-1, and LMC X-3.

longer-term galactic transients. A0535+26 has produced transient outbursts on several occasions (Rosenburg *et al.* 1975; Forman, Jones, and Tananbaum 1976; Ricker and Primini 1977; Kaluzienski and Holt 1978), 4U0115+63 (Forman, Jones, and Tananbaum 1976; Holt and Kaluzienski 1978; Cominsky *et al.* 1978) is another example.

Outbursts repeating with a fixed period have been reported from several galactic X-ray sources which may be regarded either as transients or simply as highly variable. 4U1630−47 undergoes transient-like outbursts every 615 ± 5 days (Jones *et al.* 1976). Aquila X-1 is a highly variable source which tends to flare into a high state with a mean interval between flares of 435 days and an rms scatter about the mean of 10% (Kaluzienski *et al.* 1977). The strict periodicity of Circinus X-1 basically takes the form of turnoffs every 16.58 days, but the source undergoes flares which, during the *Ariel 5* observations, tended to reach maximum intensity just before the turnoff (Laluzienski *et al.* 1976).

A0538−66 shares features with all of these types of sources. (*a*) It produces short outbursts which are remarkably similar to the brief high galactic latitude transients in duration and intensity. (*b*) The longest outburst ($n = 3$) is similar to that of a classical X-ray transient; the initial decay time constant, 4 days, is comparatively short for such a transient, but not without precedent (for example the initial decline of H1705−25, Watson, Ricketts, and Griffiths 1978). Like most transients there is a second, longer, time constant in the tail and even indications of a precursor. (*c*) The periodically recurrent nature of A0538−66 is very like that of the two galactic bulge sources 4U1630−47 and Aquila X-1, but the period involved is more like that of Circinus X-1 (in fact curiously close to identical with it).

Two questions dominate considerations of the nature of A0538−66. First is that of whether or not it is a member of the LMC. The refined error box of Johnston and Griffiths (1979) contains a candidate star which is an LMC member, and the identification may soon be confirmed if a 16 day optical periodicity is found. Until then, the scale of the phenomenon we are discussing is uncertain; the peak X-ray luminosity may be as high as 10^{39} ergs s^{-1}, if the distance is that of the LMC (55 kpc), or 4–5 orders of magnitude less if it is local (in which case the galactic latitude of −32° suggests a distance of less than a few hundred pc).

The other question concerns the nature of the clock controlling the periodicity of the outbursts. As noted by Johnston *et al.* (1979) the eccentric binary plus spherically symmetric wind model of Avni, Fabian, and Pringle (1976) will not produce sufficiently short, intense outbursts. If the source is at the distance of the LMC, however, the X-ray luminosity may be large enough to provide an additional wind-driving mechanism. Positive feedback could then cause the accretion rate to be modulated more rapidly than for a simple constant spherical wind. In this model, the most straight-forward explanation of the departure of the outbursts from the precise ephemeris is a random jitter which is expected to be large in a system with positive feedback. A 1% change in binary period is improbable, and, even should it occur, the mass loss or mass transfer would have to be so large that any X-rays produced would probably not escape from the system.

An alternative group of models rely on pseudo-periodic eruptions of the primary star. The key features that such models must account for are the large ratio between the period and the duration of the shortest events and the comparatively small changes of phase/period between very long and very short events.

b) *LMC X-4*

LMC X-4 exhibits variability on a variety of time scales. The long-term variability shown in Figure 6 confirms the general behavior reported by other observers using less sensitive instruments and shorter observing periods. Griffiths and Seward (1977), using the *Ariel 5* Sky Survey Instrument (SSI) reported detecting LMC X-4 on about 6 days out of 20 days total, at intensities ranging from about 3–15 × 10^{-3} that of the Crab Nebula (1–5.5 SSI counts s^{-1}). White's (1978) results using the *Ariel 5* proportional counter spectrometer showed intensities at the upper end of this range.

The low end of our intensity range corresponds to the *Ariel 5* upper limits during the time LMC X-4 was not detected and to the *SAS 3* low state.

The various observations of short-term variability are more difficult to reconcile. The best coverage is provided by the pointed observations of *SAS 3* (Epstein *et al.* 1977) and *Ariel 5* (White 1978). Each observed short-duration flares. The *SAS 3* observations were of four 20 s flares during a 45 minute high state. *Ariel 5* saw the same number of flares during 5 days of observations (during which LMC X-4 was in the high state), but each outburst lasted 10–20 minutes. Based on these figures the number of flares expected to be detected during the 20 days of LASS observations for which LMC X-4 was in the high state would be about 30 or 6, respectively. Four actually were detected, and so the rate of occurrence is more consistent with the *Ariel 5* data. In addition, our most intense outbursts appear to be closer to the *Ariel 5* flares, which reached a maximum of as much as 120 × 10^{-3} that of the Crab Nebula.

One possible way to relate all of these observations is by assuming that the short-duration high state observed by *SAS 2* (Epstein *et al.* 1977) may have been a longer lasting flare of the variety observed by *Ariel 5* (White 1978). The shorter time structure observed within the *Ariel 5* flares would then correspond to the 20 s flares observed by *SAS 3*. (The *Ariel 5* time resolution was only 64 s.) To fit the various observations together in this way requires that we give up the notion that flares only occur when LMC X-4 is in a high state. Whether we consider the 45 minute high state observed by *SAS 3* as either a flare from the low state or a short transition to the high state, this type of event must be quite rare, since we did not detect any such variability in at least 25 days of observing LMC X-4 in the low state.

V. CONCLUSION

Our observations of A0538 − 66 have confirmed the periodic nature of the outbursts and shown that their individual character varies enormously, from a classical transient type lasting ∼14 days to very brief events lasting only a few hours. Significant deviations of the outburst peak times from the best average ephemeris occur. These could be the result of an inherent jitter in the clock mechanism or a sharp change in period which occurred during the $n = 3$ and 4 events.

LMC X-4 observations have provided a long-term light curve covering approximately 120 days in 1977/1978. The source has extended lows and highs, as previously reported, lasting 10 or more days. The source is always detected, even in the extended low states (except during the binary eclipses), the lowest intensity being about 10% of the maximum intensity. On four occasions, outbursts occurred when LMC X-4 was in a relatively high state. The frequency of occurrence and intensity of these outbursts suggest that they are similar to those observed previously by *Ariel 5* (White 1978).

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