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PERIODIC MODULATION OF THREE GALACTIC X-RAY SOURCES

N. E. WHITE, K. O. MASON, H. E. HUCKLE, P. A. CHARLES, AND P. W. SANFORD
Mullard Space Science Laboratory
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ABSTRACT

We report the results of a search for periodicities on time scales of minutes in the flux from eight X-ray sources. We find evidence for regular modulations in the sources 3U 1223−62, 3U 1728−24 and 3U 1813−14, with periods of 11.6, 4.3 and 31.9 minutes, respectively. In the case of the latter two sources, the modulation observed could be the alias of the true modulation which is beyond the Nyquist frequency of the data. The modulation periods of both 3U 1223−62 and 3U 1728−24 are variable. A measurement of the X-ray column density of 3U 1728−24 supports its suggested identification with a heavily reddened star in the X-ray error box.

Subject headings: X-rays: sources — X-rays: variable — X-rays: binaries

I. INTRODUCTION

Regular modulations on time scales of minutes have previously been found in the flux from four galactic X-ray sources (Ives, Sanford, and Bell-Burnell 1975; Rosenberg *et al.* 1975; Rappaport and McClintock 1975; White *et al.* 1976*b*). We have analyzed the data on a number of other sources to search for similar periodicities in the range ∼2 to 40 minutes. A preliminary report of this work was contained in White *et al.* (1975). Positive results were obtained for 3U 1223−62 (GX 301+0), 3U 1728−24 (GX 2+5), and 3U 1813−14 (GX 17+2), along with upper limits on five other sources. All the sources were studied with the X-ray instrumentation on the *Copernicus* satellite, except 3U 1223−62, which was observed with *Ariel-5* experiment C. The *Copernicus* 2.5–7.5 keV detector is fully described by Sanford (1974) and Bowles *et al.* (1974). Data are integrated for 63 s followed by 24 s dead time, giving a sampling interval of 86.509 s. The *Ariel-5* detector (Sanford and Ives 1976), in the mode used for the present observations, accumulates data in intervals of 64 s.

Sources are not viewed continuously because of Earth occultations and regions of high charged-particle background, nor are the batches of data regularly spaced. We have therefore used the periodogram analysis technique of Gray and Desikachary (1973) to search for periodic modulation. In this technique the data are prewhitened by fitting a low-order polynomial and the power spectrum of the residuals computed. Periodic modulations show up in the periodogram as a convolution of the power at the modulation frequency with peaks in the window spectrum (i.e., that due to the sampling pattern). The latter is computed separately by repeating the analysis with all the data points set to a constant value. The results of the analysis are summarized in Table 1 while below we discuss in detail those sources for which a modulation was detected.

II. 3U 1223−62

Ariel-5 observed 3U 1223−62 on two occasions in 1975, on January 3 and December 8, for about 1 day in each case. The energy ranges were 2.8–8.9 keV and 2.2–7.0 keV, respectively. There are significant peaks in the periodograms of both observations at about 11.6

TABLE 1

SUMMARY OF RESULTS

Source	Satellite	Date	Duration (days)	Period (minutes)	Probability of* Randomness	Mean Count per Minute	Peak to-Peak-Amp. (%)
3U 1223−62 (GX 301+0)	Ariel	1975 Jan. 5	1	{ 5.826±0.005 11.667±0.021	7×10⁻⁴ 7×10⁻⁷		
		Weighted mean	...	11.655±0.009	...	52	65±12
		1975 Dec. 8	1	11.613±0.025	6×10⁻²	37	55±17
3U 1728−24 (GX 2+5)...	Cop	1972 Sep. 11	0.7	4.30 ±0.01	1×10⁻³	47	22±8
		1972 Sep. 18	0.5	4.32 ±0.02	4×10⁻²	47	18±10
		1973 Mar. 25	0.1	4.39 ±0.14	8×10⁻¹	31	22±16
3U 1813−14 (GX 17+2)..	Cop	1975 Aug. 1	1	31.88 ±0.12	4×10⁻²	254	5.0±0.6

NOTE.—Five sources, 3U 1516−56, 3U 1728−16, 3U 1758−25, 3U 1811−17, and 3U 2142+38, showed no detectable modulation with upper limits to the amplitude of 10, 10, 8, 6, and 16%, respectively. The mean flux in each case was 84, 93, 253, 147, and 180 counts per minute.

* The probability of randomness represents the probability of the reported peak occurring by chance at *any* period.

minutes (Fig. 1*a* and Table 1) with, in January only, a further system of peaks at one-half and one-third this period. Where possible, we have identified the primary peaks and those caused by convolution of this power with the window spectrum. The uncertainties in the period are standard errors primarily determined by the length of the observation. There is therefore a significant difference between the fundamental modulation period in January and December (Table 1).

The data from each observation have been folded into 15 bins about the optimum 11.6 minute period and are shown thus in Figure 1*b*, repeated twice for clarity. A constant background level has been subtracted. This was determined from observations of the source made in spectral mode, both before and after the time mode data, where the background is determined directly (Sanford and Ives 1976). The overall reduction in flux between the two observations can be accounted for by the different energy ranges sampled. The January data clearly show a subsidiary peak or interpulse corresponding to the power in the periodogram at 5.8 minutes. A similar feature is seen in the light curve of 3U 0900−40, whose flux is modulated with a period of 4.7 minutes (McClintock *et al.* 1976; Charles *et al.* 1976).

III. 3U 1728−24 (GX 2+5, GX 1+4)

This source was observed by *Copernicus* on two occasions in 1972 September to improve its location (Hawkins, Mason, and Sanford 1973). The observations were short (16 and 11 hours, respectively); and since the source was comparatively weak (30–40 *Copernicus* counts per minute), the data are not optimum for the present investigation. Nevertheless, the strongest peak in the periodogram of each of the two runs of data occurs at the same period, 4.3 minutes (Fig. 2). Figure 3 demonstrates that the distribution of power within the various frequency bins follows the expected exponential law for random fluctuations (Middleditch and Nelson 1973) except for the two peaks at 4.3 minutes. A third, shorter ($\sim 1\frac{1}{2}$ hour) observation of 3U 1728−24 was made in 1973 March. Again the strongest peak in the power spectrum was at 4.3 minutes, but its significance was very low due in part to the length of the data run, and also to the fact that the source was 35 percent weaker than in 1972 September. The probability of these peaks occurring by chance at 4.3 minutes in three independent data sets is 10^{-8}.

The peak-to-peak modulation depth of 3U 1728−24 in 1972 is 20 percent of the mean flux. However, the period, 4.3 minutes, is close to the Nyquist frequency of our data (2.9 minutes), so we cannot derive a meaningful light curve. Neither can we eliminate the possibility that we are observing an alias of a modulation which is below our Nyquist frequency (Table 2). If this were the case, the true modulation period could be, for instance, 2.17 minutes with a modulation depth of 30 percent. We note that this is close to the period of 2.3 minutes suggested by Lewin, Ricker, and McClintock (1971) on the basis of 18–50 keV balloon data, and also the period of 2.04 minutes reported by Doty (1976). However, there is a significant difference between the period measured by Doty and that inferred from our data.

IV. 3U 1813−14 (GX 17+2)

This source was observed for one day in 1975 August immediately following a 1 day observation of the nearby and comparable source 3U 1811−17. The periodograms for both sources are shown in Figure 2. The strongest peak in the periodogram of 3U 1813−14 occurs at a period of 31.9 minutes, and it deviates significantly from the expected random exponential distribution of power (Fig. 3). This peak is not present in the periodogram of the 3U 1811−17 data, and cannot therefore be a modulation in the background. Further, the 31.9 minute peak was detected equally strongly in both halves of the data set, indicating that the modulation was present continuously. The prewhitened data on both 3U 1813−14 and 3U 1811−17 are folded into 10 bins about the 31.9 minute period in Figure 4. The peak-to-peak depth of modulation in 3U 1813−14 is about 13 counts, roughly 5 percent of the mean flux, with no similar structure apparent in the case of 3U 1811−17. This is an extremely weak modulation and, as for 3U 1728−24, we cannot exclude the possibility that we are observing an alias of a periodicity less than the Nyquist frequency (Table 2).

V. DISCUSSION

Optical counterparts have been suggested for 3U 1223−62 (Vidal 1973; Bord *et al.* 1976), 3U 1728−24 (Glass and Feast 1973; Davidsen, Malina, and Bowyer 1976*b*) and 3U 1813−14 (Tarenghi and Reina 1972;

TABLE 2

Possible Periods Greater than ~30 Seconds That Would Be Aliased to the Period We Observe, Given a Sampling Interval of 86.51 Seconds

Period (min)	Attenuation of Modulation
3U 1728−24	
4.31	+0.91
2.17	+0.66
1.08	+0.04
0.87	−0.15
0.62	−0.16
0.54	−0.04
0.43	+0.13
3U 1813−14	
31.88	+1.00
1.51	+0.38
1.38	+0.29
0.74	−0.22
0.70	−0.21
0.49	+0.06
0.47	+0.09

Note.—If the periodicity we report for 3U 1223−62 was an alias, the amplitude of modulation of any fundamental would be greater than 100%.

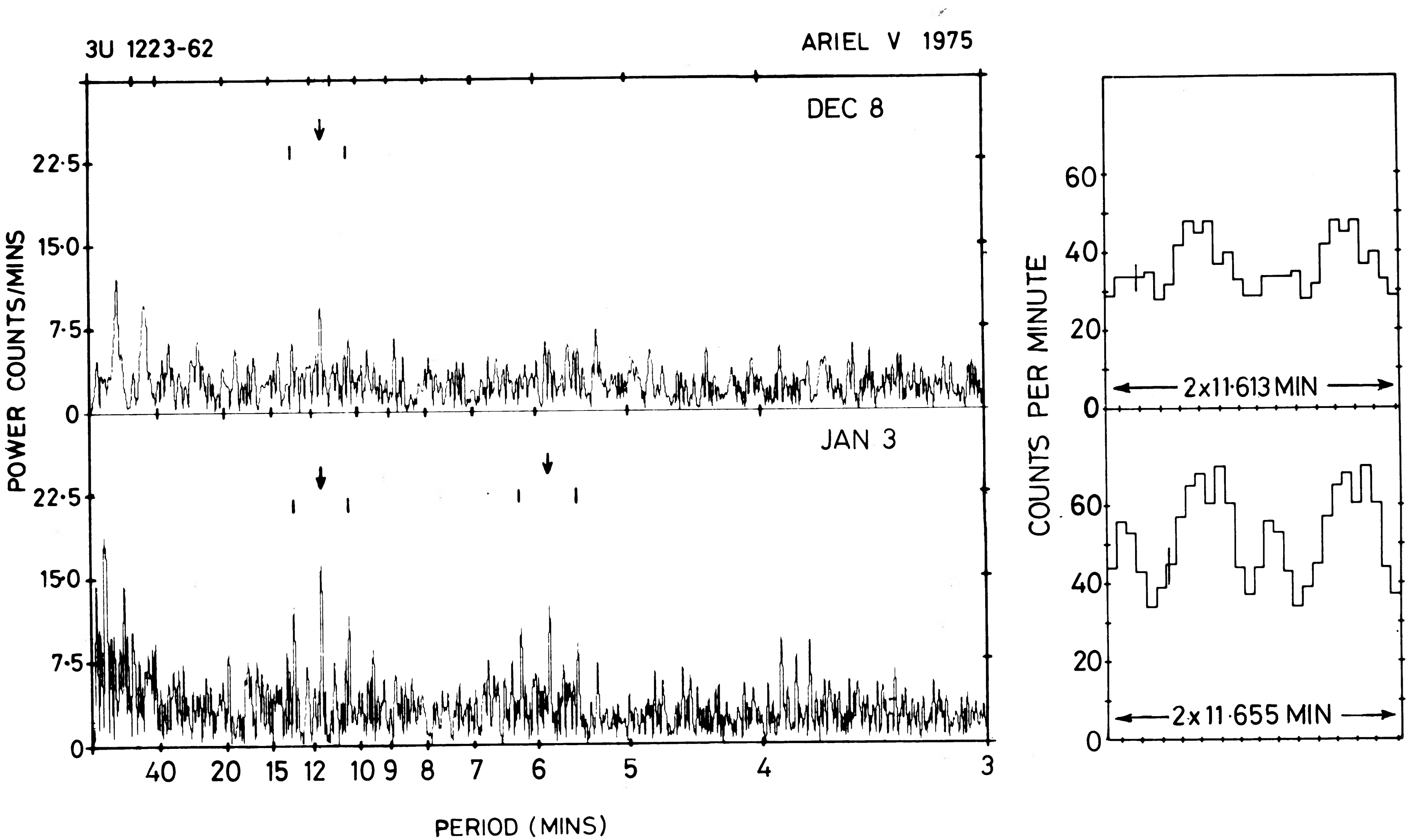

FIG. 1.—(*a*) The two periodograms for 3U 1223−62. Primary peaks are marked by arrows and those resulting from convolutions with the window spectrum by bars. Power at periods $\gtrsim$40 minutes results from both the effects of the orbital period of the satellite and long term variability of the source. (*b*) The data for 3U 1223−62 folded into 15 bins and repeated twice.

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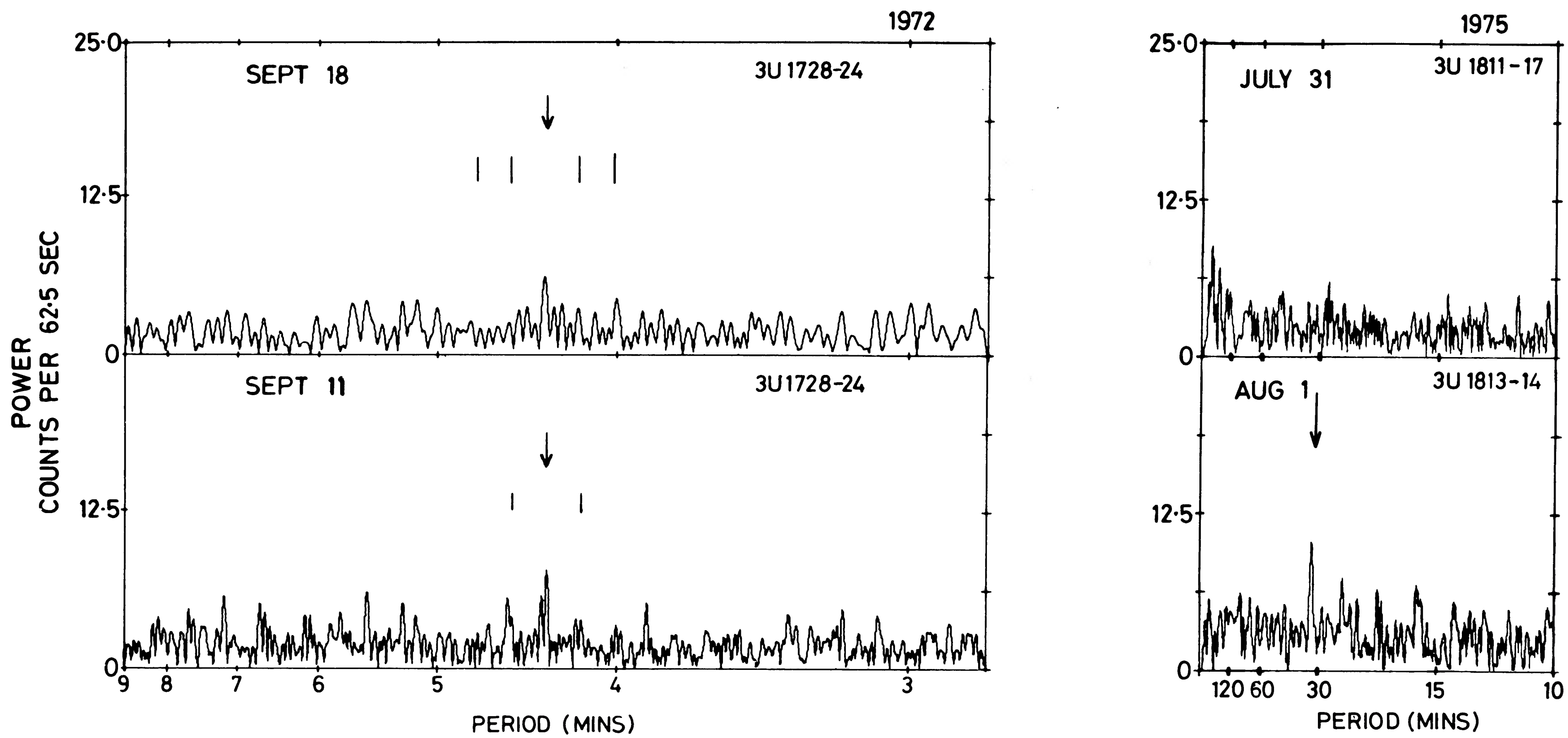

FIG. 2.—Periodograms of the two 1972 observations of 3U 1728−24 and the 1975 observations of 3U 1811−17 and 3U 1813−14. The principal peaks are marked with arrows while the expected positions of peaks resulting from convolutions with the window system are marked with bars. When the primary peaks are relatively weak, the window peaks are difficult to distinguish above the noise.

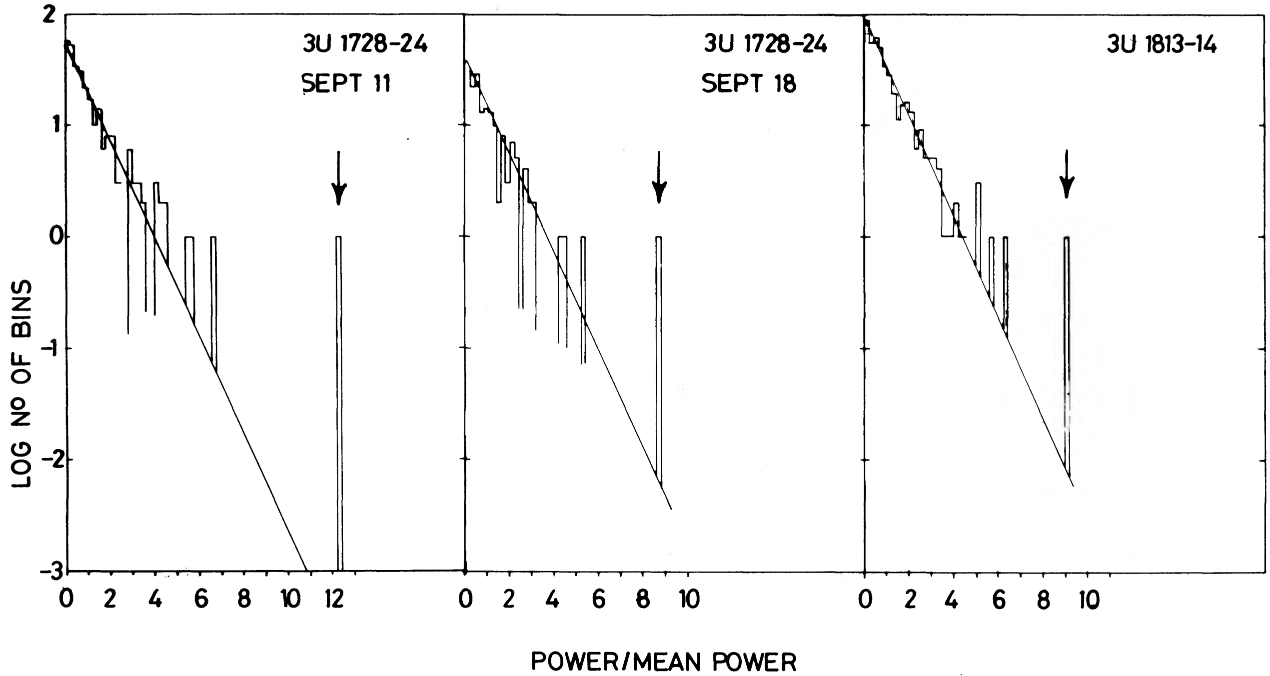

FIG. 3.—The distribution of power in all bins from ~40 minutes up to the Nyquist frequency for the 3U 1728−24 and 3U 1813−14 data.

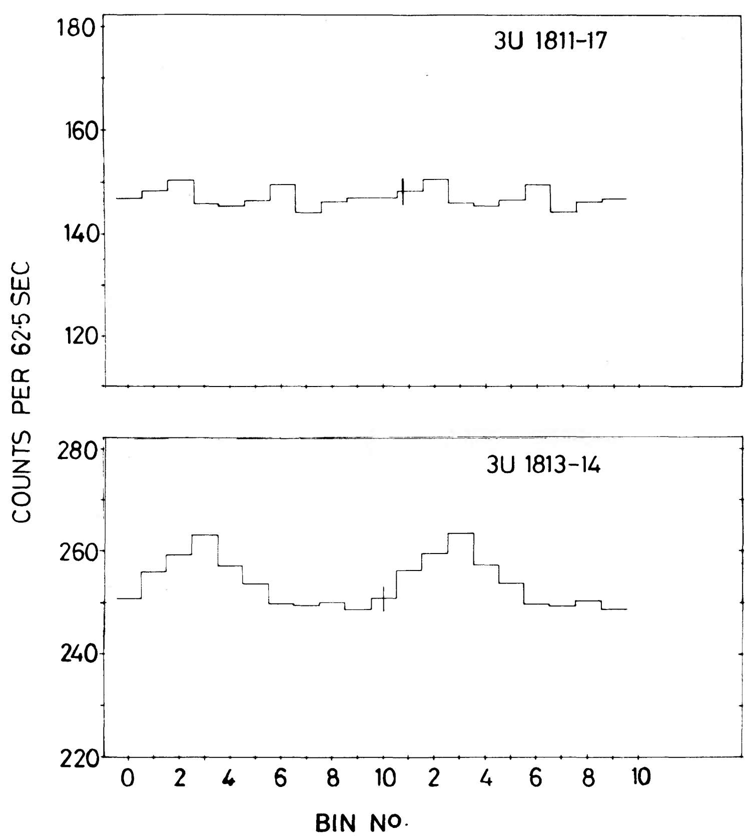

FIG. 4.—The data for both 3U 1813−14 and 3U 1811−17 folded into 10 bins modulo 31.9 minutes and repeated twice

Davidsen, Malina, and Bowyer 1976*a;* Doxsey 1975). A search for covariability of X-ray and optical wavelengths could potentially lead to confirmation of these suggested identifications (cf. Mauder 1976).

We note that two of the three sources discussed, 3U 1728−24 and 3U 1813−14, belong, on the basis of their position, to the galactic center population. If they are true members of this population and not field objects, this is the first time that periodic phenomena have been identified in any of these enigmatic sources. During the observation of 3U 1728−24 in 1973 March, we obtained data with the *Copernicus* 0.6–1.5 and 1.0–3.1 keV telescopes. By combining this with six-channel pulse-height-analyzed data obtained simultaneously in the 2.5–7.5 keV range we can estimate the column density to the source. For both power-law and exponential spectral approximations our data require, at the 2 σ level, a column density of between 4×10^{22} and 1×10^{23} atoms cm^{-2}. This column density is consistent with the degree of reddening found in Glass and Feast's candidate star (Davidsen, Malina, and Bowyer 1976*b;* Ryter, Cesarsky, and Audouse 1975).

Finally we note that the discovery of periodic modulation in the three sources discussed above increases to eight the total number of X-ray sources known to be modulated on time scales of minutes (cf. White *et al.* 1976*a*). In view of the number already discovered, this phenomenon is likely to be a common feature among galactic sources not yet investigated.

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P. A. Charles, H. E. Huckle, K. O. Mason, P. W. Sanford, and N. E. White: Mullard Space Science Laboratory, Holmbury St. Mary, Dorking, Surrey, England