THE ASTROPHYSICAL JOURNAL, 220: 600–605, 1978 March 1

X-RAY AND RADIO OBSERVATIONS OF GX 17+2 AND GX 13+1

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Received 1977 June 27; accepted 1977 September 12

ABSTRACT

X-ray data on the sources 3U 1813−14 (GX 17+2) and 3U 1811−17 (GX 13+1), obtained by *Copernicus* between 1975 and 1977, are examined. These reveal correlated intensity and spectral slope variations in GX 17+2 similar to those seen in Sco X-1 and four other galactic sources, 3U 0614+09, 3U 1702−36, 3U 1728−16, and 3U 1758−25. The new data on GX 17+2 have been unsuccessfully searched for further evidence of a shallow 31.9 minute modulation. In the case of GX 13+1 no significant variability was seen in either intensity or spectrum. A simultaneous search made from the NRAO simultaneously with some of the X-ray observations revealed no significant radio emission from either source.

Subject headings: radio sources: general — X-rays: sources

I. INTRODUCTION

Observations of GX 17+2 (3U 1813−14) reported by Tananbaum *et al.* (1971) have indicated that this source exhibits variations in intensity and spectral slope on time scales of an hour, similar to those previously seen in Sco X-1. Evidence for a regular 31.9 min modulation of the X-ray flux of amplitude 5% has been given in White *et al.* (1976*a*) (hereafter Paper I) based on a 1 day observation by *Copernicus* in 1975. A variable radio source was discovered at 2695 MHz (Hjellming and Wade 1971) and then at 1415 MHz (Braes and Miley 1971, 1973) coincident with the X-ray position of GX 17+2 (see also Doxsey 1975).

GX 13+1 (3U 1811−17) has also been observed to be variable by about a factor 2 on time scales of less than a day (Forman, Jones, and Tananbaum 1976), although with no evidence for regular pulsations (Paper I). There is no reported radio counterpart.

In 1976 and 1977 we have obtained further X-ray data on both GX 17+2 and GX 13+1 with *Copernicus* and the results of these observations are reported here. The NRAO[1] Green Bank interferometer obtained measurements at 2695 and 8085 MHz simultaneous with the X-ray observations on three dates in 1976 May.

II. THE OBSERVATIONS

The dates and durations of the *Copernicus* 3–8 keV observations are summarized in Tables 1 and 2. The observations of GX 17+2 and GX 13+1 reported in Paper I are included in these tables. The data accumulation time is 63 s followed by 24 s dead time. During two observing runs, 1976 April and September, each 63 s integration was subdivided in 9.6 s accumulations. Six channels of pulse-height information were also obtained every accumulation interval.

The NRAO Green Bank three-element radio interferometer was used in a configuration of spacings equal to 600, 1200, and 1800 m. It was directed to a field centered at $\alpha = 18^h11^m42^s$, $\delta = -17°11'06''$ (1950) for the attempt to detect GX 13+1 from 3 to 11 hours May 26 UT, integrating in 30 s periods alternately at 2695 MHz and 8085 MHz, with hourly interruptions for a few minutes of integration on a nearby, standard NRAO calibration source. The telescope, operating in the same mode, was then directed to a field centered at α $18^h13^m10^s.8$, $\delta = -14°03'13''$ (1950) for the attempt to detect GX 17+2 from 3 to 11 hours May 27 UT and from 3 to 12 hours May 28 UT. This is the position of Hjellming and Wade's (1971) radio counterpart to GX 17+2. The fields were 18′ square in the raw data maps at 2695 MHz and 6′ square at 8085 MHz. Thus, except for a change in the configuration of spacings, the radio telescope was used in a way very much like that described in previous work on globular clusters (Johnson 1976; Johnson *et al.* 1977), and described more generally by Hogg *et al.* (1969).

III. X-RAY RESULTS: GX 17+2 (3U 1813−14)

a) *Irregular Variability*

The second part of the 1976 May and all of the 1976 April observations are shown in Figure 1 with each 63 s accumulation plotted. In both cases flaring is present which involved up to a doubling of the flux within an hour. The source was less active during the remaining observations varying typically by about 10%, on time scales of several hours.

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

TABLE 1

GX 17+2 SPECTRA

Start Time (UT)	Duration (hr)	Best Fit A	kT (keV)	$N_H \times 10^{22}$ (cm^{-2})
1975:				
22 hr Jul 31	9	1.7	10.2 ± 2.5	0.5 (+2.0, −0.5)
7 hr Aug 1	5	1.9	9.4 (+4.0, −2.0)	1.5 ± 1.5
12 hr Aug 1	7	3.0	6.4 (+1.0, −0.8)	2.5 (+1.5, −1.0)
1976:				
0 hr Apr 12	10	3.2	5.8 (+0.8, −0.6)	3.5 ± 1.0
10 hr Apr 12	8	3.6	5.8 (+0.9, −0.8)	4.5 (+1.5, −1.0)
3 hr May 29	10	2.8	7.4 (+2.0, −1.2)	3.0 (+2.5, −1.5)
21 hr May 27	14			
(count rate bins):				
< 260	...	4.7	4.6 (+1.0, −0.6)	6.0 ± 2.0
260–300	...	3.7	6.0 (+1.6, −1.2)	5.0 (+2.5, −2.0)
300–350	...	5.4	5.4 (+2.4, −1.2)	7.5 (+5.0, −3.0)
350–400	...	3.9	7.8 (+5.0, −1.6)	5.0 ± 3.5
> 400	...	4.1	8.6 (+10.2, −3.0)	5.5 (+6.5, −3.5)
23 hr Sep 2	10	5.4	4.4 ± 0.6	7.5 (+2.5, −1.5)
18 hr Sep 3	10	4.4	5.0 (+0.9, −0.5)	6.5 (+1.5, −2.0)
1977:				
0 hr May 1	72	...	...	...
Typical spectrum	...	3.6	5.0 ± 1.0	2.0 ± 2.0

The ratio of the counts in the two halves of the pulse height analyzer (PHA) can be used as an indicator of spectral variability. This index has been plotted in Figure 1 for the 1976 May observations, when GX 17+2 was at its most active, and shows that the flaring is accompanied by a hardening of the spectrum.

The source spectrum was quantified by folding a thermal plus Gaunt spectral approximation (Tananbaum *et al.* 1971) through the detector response. The best fit to the data was found from the minimum of a two-dimensional χ^2 grid of temperature (kT) and hydrogen column density (N_H), the total predicted count in the detector being normalized to the observed count to give the normalization constant A. The results of this analysis are given in Table 1 with the 2 σ errors derived using the method of Avni (1976) and Cash (1976). The second half of the 1976 May observation was divided up according to the count rate, and this shows that the correlated changes in hardness ratio with flux are the result of an increase in kT. The column density did not vary significantly through this observation; thus it was fixed at the mean value of 6×10^{22} cm^{-2}, and kT rederived. These values are plotted as a function of count rate in Figure 2*a*, again with 2 σ errors.

TABLE 2

GX 13+1 SPECTRA

PARAMETER	STARTING TIME (UT): 1975 22 hr July 30	STARTING TIME (UT): 1976 2 hr May 26
Duration (hr)	24	9
Best fit A	3.1	3.9
T (keV)	4.5 ± 0.5	4.0 (+1.0, −0.4)
$N_H \times 10^{22}$ (cm^{-2})	6 ± 1	8 ± 2
Best fit A	16.6	21.0
Photon index	2.8 (+0.2, −0.1)	2.9 (+0.3, −0.1)
$N_H \times 10^{22}$	10 ± 2	12 ± 2

The statistical quality of the remaining data is sufficient to allow each observation to be split up into 8 hr segments. The temperatures seen on each occasion are plotted as a function of total count rate in Figure 2*b*. This shows that when GX 17+2 is in a quiescent state, the spectral slope is variable on this time scale and, in the present observations, over a range greater than during its flaring state. In particular for the first two-thirds of the 1975 July observation the temperature was ~10 keV, the highest we have observed. However, for the last part of that observing run it dropped to ~6 keV and was closer to that seen during other quiescent intervals. It is interesting to note that on one occasion Tananbaum *et al.* (1971) also observed a high temperature at a low intensity. Finally we note from Table 1 evidence for a factor 3 variability in absorption on a time scale of months.

b) The 32 Minute Periodicity

To investigate further the 32 minute periodicity originally found in the 1975 July 31–August 1 data, a periodogram was computed for each subsequent observation using the Fourier analysis technique described in Paper 1. There was no evidence from these periodograms for the 32 minute periodocity, with upper limits for the peak-to-peak amplitude of 6%, 10%, 5%, and 3.5% for 1976 April, 1976 May, 1976 September and 1977 May, respectively. The first three values indicate that the sensitivities of these observations were too low to detect a 5% modulation. However, in view of the upper limit obtained in 1977 May, we conclude that the 32 minute pulsation of GX 17+2 is not present continuously at the same depth of modulation. For two of the observations 10 s

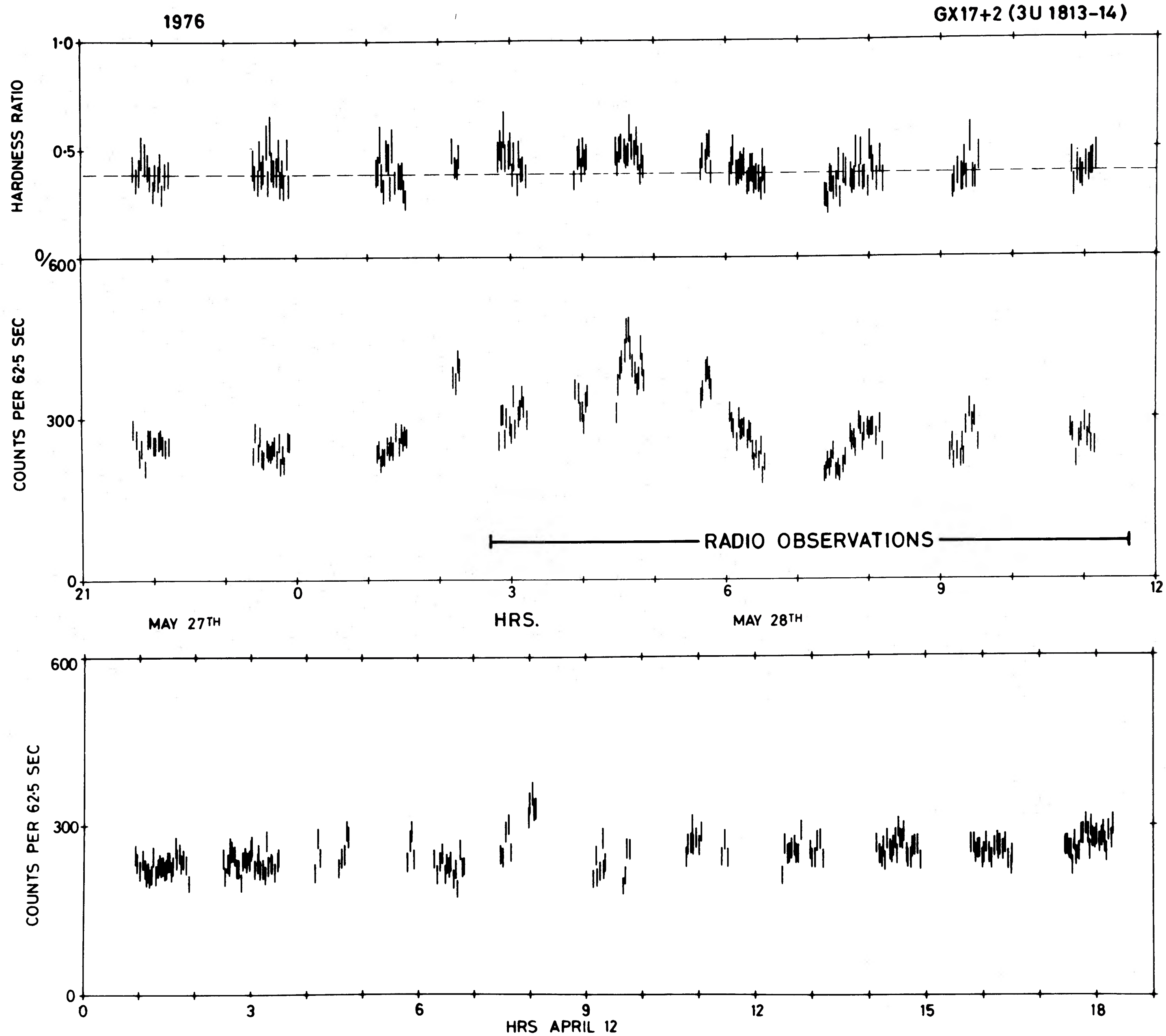

FIG. 1.—The count rate per minute seen by *Copernicus* from GX 17+2 in 1976 April and May. Also shown for 1976 May is the spectral hardness ratio.

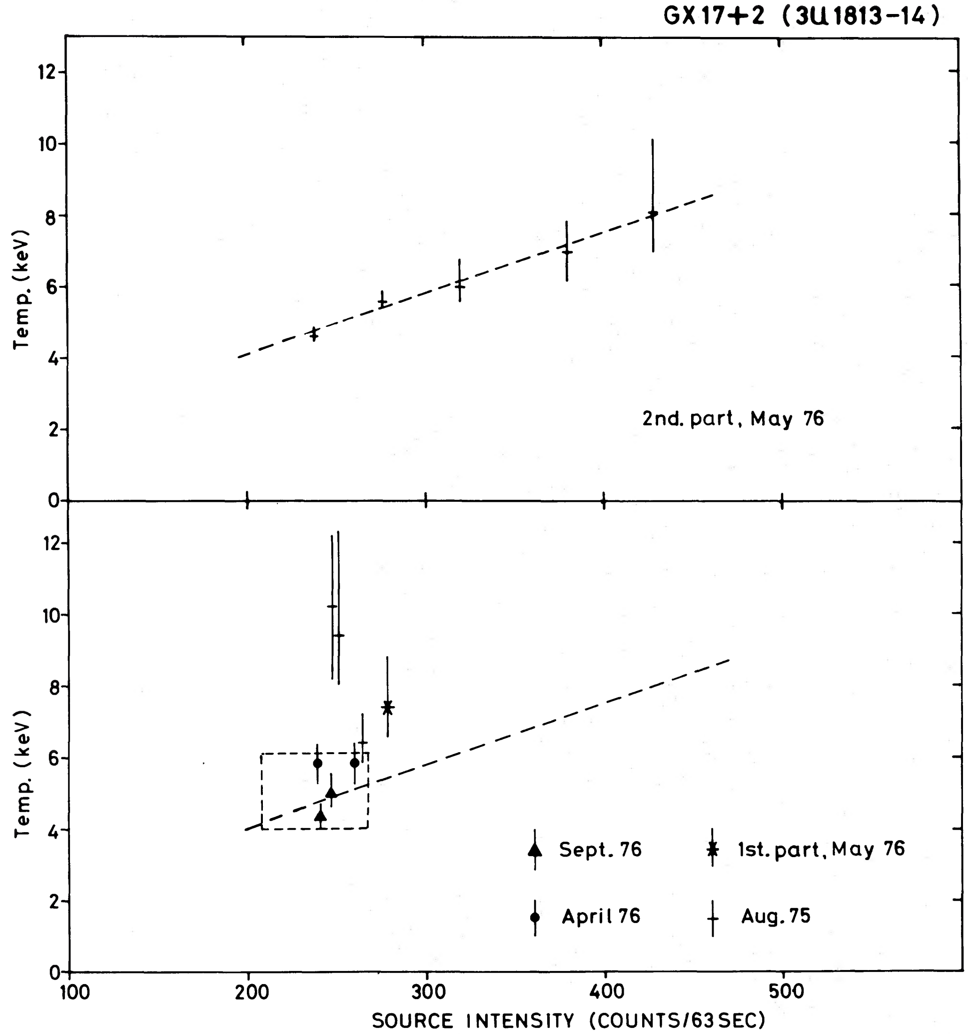

FIG. 2.—The temperature versus flux relation for all the *Copernicus* observations of GX 17+2 shown with 2 σ error bars. The box represents the range of count rate and temperature seen in 1977 May.

time resolution was available, and searches down to periods of ~20 s did not reveal any other periodicities, in particular the aliases to 32 minutes mentioned in Paper 1.

IV. X-RAY RESULTS: GX 13+1

Throughout both *Copernicus* observations this source was at about 135 counts (~270 *Uhuru*) and there was no significant variability. This is in contrast to the variability seen by Forman, Jones, and Tananbaum (1976), who reported intensities varying between 200 and 400 *Uhuru* counts on a time scale of several hours. In Paper I we searched with no success for periodic modulations of the flux down to 2.8 minutes. In 1976 May the higher time resolution allowed the search to be extended down to 20 s, and this again yielded only an upper limit to pulsations, of 7% of the mean flux. The spectra measured on each occasion were equally consistent with a thermal or power law model and did not differ significantly (Table 2). They are also in agreement with values derived by Jones (1977).

V. RADIO RESULTS

When a map is formed from the entire data set of May 27 and 28, there are two 2685 MHz beam-shaped (unresolved) images of 2.0 ± 1.0 mJy flux density near field center. They are located 4″ east × 8″ south and 13″ west × 13″ south, respectively, of Hjellming and Wade's (1971) radio counterpart of GX 17+2, on which they placed error bars of $\pm 0^{s}.2$ in α and $\pm 3''$ in δ. Two additional radio maps were formed from data acquired during the interval shown in Figure 1 when both X-ray and radio observations were conducted. These maps roughly correspond to the periods of X-ray flaring (0243–0631 UT) and quiescent X-ray emission (0643–1140 UT) from GX 17+2. Maps for each of these subsets of data naturally contain more noise than the map of all data. However, the all-data image nearest Hjellming and Wade's original radio counterpart of GX 17+2 is also present in the map for the period of X-ray flaring at an intensity of 4.4 ± 2.2 mJy. This higher intensity is consistent with the interferometer response to a variable radio source in a high state for only a portion of the entire data set. Because of the large uncertainties involved, however, it is not possible to conclude that simultaneously enhanced X-ray and radio emission have been observed.

The source detected in 1971 varied from 10 to 22 mJy and back during an 8 hour observation. Similar observations of this field 2 months earlier and 3 days later by Hjellming and Wade failed to detect a signal, placing an upper limit of 5 mJy on the radio emission from this source. While the sources found in our 1976 May observations are not statistically significant, one of them agrees with the position given by Hjellming and Wade within errors. This observation provides an upper limit to emission from the radio-counterpart of GX 17+2, and further indicates its range of variability. Both marginal sources in the present observation and that detected in 1971 are well centered within Doxsey's (1975) 3 arcmin^2 error box of 90% confidence around GX 17+2. The field of the 8085 MHz map contains no significant sources. Braes and Miley (1971) considered the radio frequency spectrum to be flat, by comparing their 1415 MHz data with Hjellming and Wade's (1971) data, but Hjellming (1973) called it nonthermal, presumably because of absence from NRAO 8085 MHz records.

There are one or two 2695 MHz peaks of 11 ± 2 mJy flux density within the 2 arcmin^2 *Uhuru* box of 90% confidence around GX 13+1, but the field is dominated by the diffraction pattern of a source centered at $\alpha = 18^h11^m31^s$, $\delta = 17°18'21''$ (1950). This is probably AGD 013.4+0.1 (Altenhoff *et al.* 1970), LMH 19 (Large, Mathewson, and Haslam 1961), or MSH 18−103 (Mills, Slee, and Hill 1958), which may be all one radio source. It may be that the small peaks we have mapped are merely parts of the pattern of this (non-point) source. Our 8085 MHz map shows no significant source.

VI. DISCUSSION

Many of the observed properties of GX 17+2 are similar to those of Sco X-1 which White *et al.* (1976*b*) have described, and to those of 3U 0614+09, 3U 1702−36 (Sco X-2), 3U 1728−16 (GX 9+9), and 3U 1758−25 (GX 5−1) which Mason *et al.* (1976) have described. In particular:

1. They all show flaring on a comparable time scale (~1 hour), during which the intensity is correlated with spectral slope.

2. GX 17+2 exhibits periods of relatively low activity which may be analogous to the quiescent states of Sco X-1.

3. The spectral slope of GX 17+2 during inactive periods varies by an amplitude as large as that seen in the flaring state but with little associated change in intensity. Similar behavior may have been observed from Sco X-1 (Kitamura *et al.* 1971) and GX 5−1 (Mason *et al.* 1976).

Scorpius X-1 remains the best studied of these sources, and optical observations indicate that it is a 0.79 day period binary system containing a compact object accreting matter from its companion (Crampton *et al.* 1976). Current models suggest that the X-ray source is embedded in an optically thick cloud (cf. Laros and Singer 1976). The flaring behavior may be caused by changes in the density and size of this cloud which modifies the emergent spectrum by Compton scattering (Illarionov and Sunyaev 1972; Felten and Rees 1972).

The 32 minute modulation observed from GX 17+2 in 1975 August, if it does represent a coherent periodicity, could reflect either orbital motion (e.g., Pringle and Webbink, 1975) or the spin period of an underlying white dwarf or neutron star. In the latter case, it might be expected that the underlying X-ray modulation would be smoothed out, and the emergent X-ray spectrum softened, by scattering in a relatively cool optically thick cloud (e.g., Elsner and Lamb 1976; Maraschi, Treves, and van den Heuvel 1977). It may be significant that the 5% modulation has been observed only when the value of kT for the X-ray spectrum was comparatively high. It will be important to search for the modulation again when kT is high.

N. E. W. and K. O. M. received financial support from the SRC. H. M. J. and R. C. C. were supported by NASA contract NAS5-23570 and by the Lockheed Independent Research Program.

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