1983ApJ...267..310M

THE ASTROPHYSICAL JOURNAL, **267**:310-314, 1983 April 1

DISCOVERY OF X-RAY BURSTS FROM GX 3+1 (4U 1744−26)

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Received 1982 February 23; accepted 1982 September 17

ABSTRACT

During the *Hakucho* observations of the galactic center region in 1980 July–August, 15 X-ray bursts were observed for the first time from a bright bulge source GX 3+1 (4U 1744−26). These bursts exhibit characteristics typical of type I cosmic X-ray bursts. No bursts, however, were observed from GX 3+1 in previous *Hakucho* observations conducted in 1979 and early 1980. The persistent X-ray flux of GX 3+1 in 1979–1980 was roughly half the value obtained in 1971–1978 by other observers.

Subject headings: X-rays: bursts — X-rays: sources

I. INTRODUCTION

Dozens of intense galactic X-ray sources with $|l^{\rm II}| \lesssim 30°$, often called bright bulge sources, share many common properties. The most prominent of these properties are (*i*) a soft, thermal X-ray spectrum (typically $kT = 3$–10 keV), (*ii*) high X-ray luminosities around $(2\text{–}20) \times 10^{37}$ ergs $\rm s^{-1}$ at an assumed distance of 10 kpc, and (*iii*) a moderate, irregular intensity variation (factor ~ 3) with apparent lack of periodic behavior. Some of them are identified with faint, blue stellar objects.

Another important characteristic of these sources is their potential to be X-ray burst sources. At least five of them, namely 4U 1636-53, 4U 1728−33, 4U 1735−44, 4U 1820−30 (located in NGC 6624), and 4U 1837+04 (Ser X-1) emit X-ray bursts (Lewin and Joss 1981).

In 1980, July–August, the *Hakucho* satellite observed 15 X-ray bursts from the bright bulge source GX 3+1 (4U 1744−26) (Oda 1980), for which no X-ray burst activity had so far been reported. In this observation, the persistent X-ray flux of GX 3+1 was roughly half the value observed previously. This discovery provides an important key to the conditions required for X-ray sources to emit X-ray bursts.

II. OBSERVATIONS

The observation was carried out from 1980 July 19 to August 30, using the *z*-axis burst monitor systems (CMC and FMC) aboard *Hakucho* (Kondo *et al.* 1981). The CMC system consists of a pair of rotating modulation collimators with 17°.6 FWHM field of view. During this period the spin axis of the satellite was pointed to several sky regions around the galactic center, and GX 3+1 was continuously in the CMC field of view. In addition to X-ray bursts from MXB 1728−34, XB 1745−25 in the globular cluster Terzan 5 (Makishima *et al.* 1981) and the galactic center bursters (Lewin and Joss 1981), the CMC system recorded 15 X-ray bursts with sharp profiles, presumably from a single source. The correlation map analysis of the CMC data (Tanaka 1979; Kondo *et al.* 1981) revealed that their locations were all consistent with that of GX 3+1 (4U 1744−26; Doxsey *et al.* 1977) within the positional accuracy of the CMC map (about 0°.5).

Among these 15 bursts, eight bursts were detected also with the FMC system when the satellite spin axis was close to GX 3 + 1. The FMC system consists of a pair of Xe-filled proportional counters (FMC-1 and FMC-2) with a common field of view (5°.8 FWHM). The FMC-1 is equiped with a fine rotating modulation collimator (0°.54 pitch angle), while the FMC-2 has no modulation collimator. Analysis of the FMC-1 data for the eight bursts improved their positional coincidence with GX 3+1 to $\sim 2'$. Thus it is concluded that all these 15 bursts were in fact from GX 3+1. Examples of the burst profiles, as observed with the FMC-2, are presented in Figure 1.

Prior to the present observation, the *Hakucho* CMC observed GX 3+1 three times without detecting X-ray bursts; these observations occurred on 1979 July 20–25, 1979 August 5–21, and 1980 April 14–19. In these periods,

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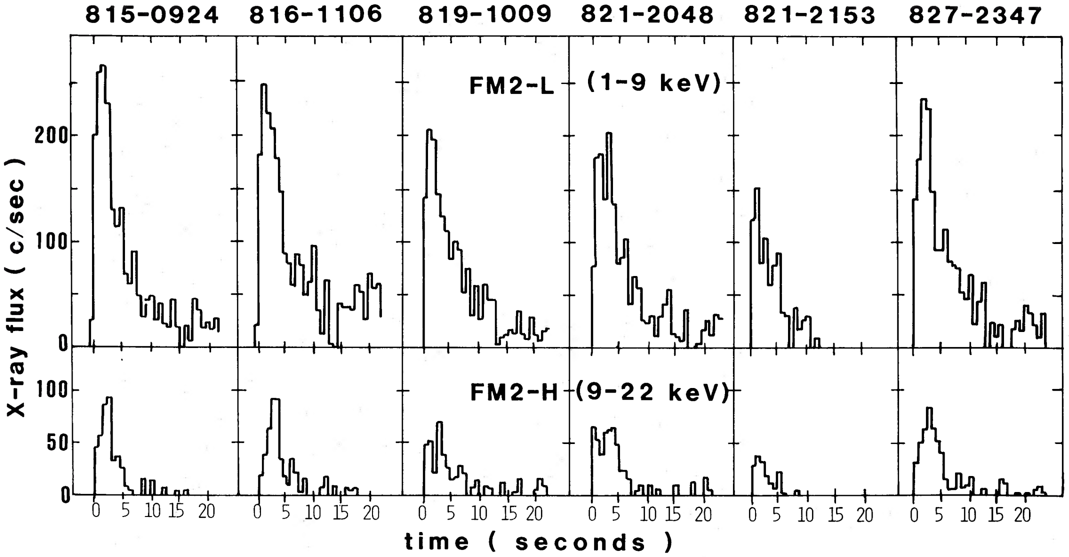

FIG. 1.—Examples of X-ray burst profiles from GX 3+1 observed with the *Hakucho* FMC-2 in two spectral channels. The count rate is background-subtracted and corrected for aspect. The number at the top indicates the onset time of each burst: e.g., 815-0924 stands for 1980 August 15, UT 0924.

both the net exposure efficiency and the average aspect transmission of the CMC were roughly similar to those of the 1980 July–August observation. This indicates that GX 3+1 was in a state of no, or at most very low, burst activity during these previous *Hakucho* observations.

III. BURST CHARACTERISTICS

The burst occurrence from GX 3+1 is summarized in Figure 2. Roughly one burst per day was observed for August 14–30, when the burst activity was highest. The true burst interval is hence estimated to be about 5–8 hours, after correcting for the net exposure efficiency of *Hakucho* (about 300–450 minutes a day). It is also suggested that the burst occurrence was less frequent before August 13, considering the fact that the net exposure efficiency was roughly constant through the observation.

The 15 bursts observed from GX 3+1 have intensities, profiles and durations very similar to one another (see Fig. 1). They show a clear spectral "softening" as evidenced by the faster decay in the higher energy band, which is characteristic of type I X-ray bursts (Hoffman, Marshall, and Lewin 1978).

Assuming a blackbody spectrum and a 10 kpc distance, the burst temperature and luminosity can be calculated from the FMC-2 data in two spectral channels (1–9 and 9–22 keV). A peak burst temperature of 2.5–3.0 keV has been obtained, together with a peak luminosity of (5–10) × 10^{38} ergs s^{-1} and an integrated energy release of (3–4) × 10^{39} ergs per burst. The inferred blackbody radius (van Paradijs 1978) is about 10 km at an assumed distance of 10 kpc. A more detailed discussion on these burst parameters is given by Inoue *et al.* (1981), as well as by Hayakawa (1981), in connection with the other burst sources around the galactic center.

As can be seen in Figure 1, one particular event, namely 821-2153, had a significantly lower peak luminosity (3 × 10^{38} ergs s^{-1}) and consequently a lower integrated energy (1.5 × 10^{39} ergs) compared to other events. It is interesting to note that this event was preceded by another burst from GX 3+1 (821-2048) by only 65 minutes; this is the shortest burst interval observed from GX 3+1 and is in fact considerably shorter than the average interval as estimated above. The lower luminosity of this particular event may be explained in terms of the nuclear flash model (Joss 1978; Lewin and Joss 1981) that the available nuclear "fuel" for that event was less than average because of the short accumulation time. Similar cases were previously reported for MXB 1636−53 (Hoffman, Lewin, and Doty 1977; Ohashi 1981).

IV. PERSISTENT X-RAY LUMINOSITY OF GX 3+1

The persistent X-ray lightcurve of GX 3+1 during 1980 July–August is presented in Figure 2. It was determined with the CMC and is expressed in units of CMC counts s^{-1} in the 3–10 keV range. The Crab Nebula gives ~98 CMC counts s^{-1}. The interference from a neighbouring bright source 4U 1758−25 (GX 5−1) was resolved successfully by means of a χ^2 fitting technique to the CMC data. For those periods when GX 3+1 was also in the FMC field of view, the results of Figure 2 were confirmed independently using FMC-1 data in which the interference between GX 3+1 and GX 5−1 is negligible. Figure 2 shows that the persistent flux of GX 3+1 was mostly in the range 10–35 CMC counts s^{-1} (0.10–0.36 Crab unit) in 3–10 keV, with several flare events up to 50 CMC counts s^{-1} (0.51 Crab unit) on time scales of ~1 day. The average over this period is 22 CMC counts s^{-1} (0.22 Crab unit).

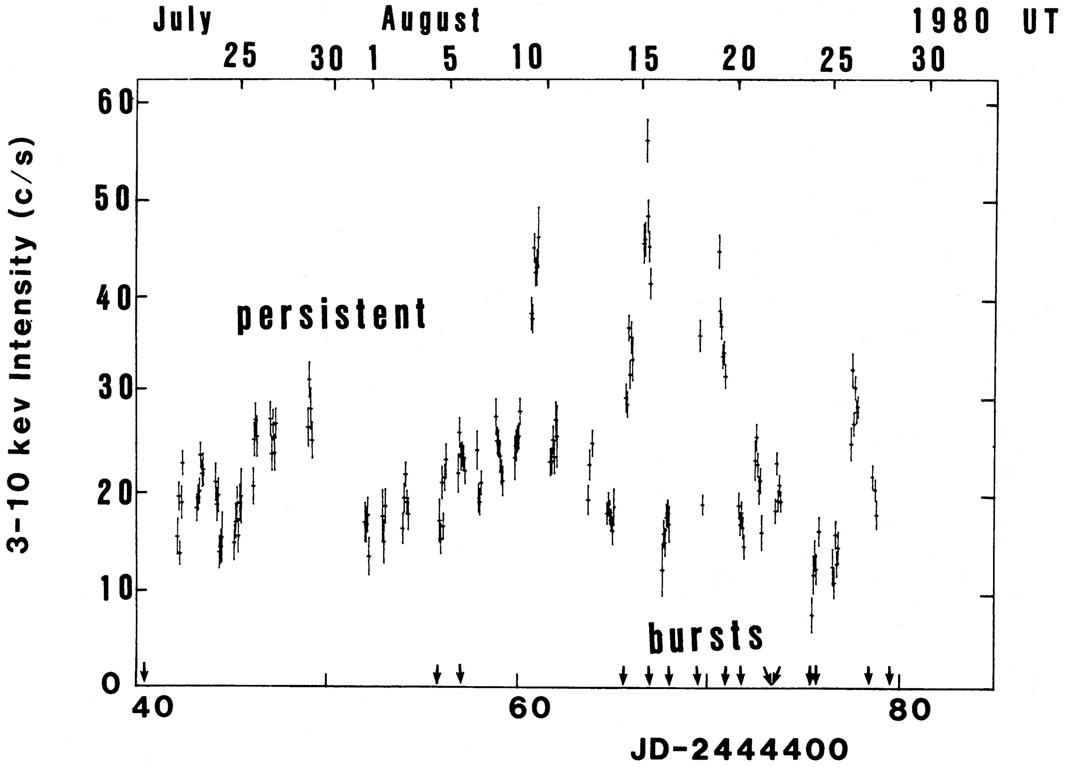

FIG. 2.—The 3–10 keV persistent flux and the X-ray burst occurrence (*solid arrows*) from GX 3+1 in 1980 July–August. The persistent flux was determined with the CMC as an average over about 20 minutes. The Crab Nebula flux is about 98 CMC counts s^{-1}.

In a similar way, the persistent intensity of GX 3+1 during the previous *Hakucho* observations was determined. The results are shown in Figure 3 together with those from other satellites. In order to avoid complication in comparing the absolute and spectral sensitivities of different experiments, all the results are expressed in Crab flux units. In addition, the results for GX 5−1, which has a spectrum similar to that of GX 3+1, are shown for comparison. Figure 3 indicates that the intensity of GX 3+1 as observed with *Hakucho* in 1979–1980 is about one-half that observed previously, whereas GX 5−1 shows no apparent change in the flux over the same time span.

Figure 4 shows the correlation plot between the 3–10 keV X-ray intensity and the spectral hardness ratio (the photon flux ratio in 6–10 keV to 3–6 keV) for the persistent component of GX 3+1 during the summer of 1980. No apparent correlation is seen. This is in contrast to the results of Parsignault and Grindlay (1978), who found a clear positive correlation between these two quantities in 1975, for GX 3+1 as well as for several other nonbursting bright bulge sources. In the *Hakucho* observations of GX 3+1 in 1979 and 1980 April, the relation between these two quantities was roughly similar to that shown in Figure 4. Correlation between the flux and hardness ratio was not observed with *Hakucho* for other burst sources (e.g., MXB 1728−34 and MXB 1636−53), either.

V. DISCUSSION

Previously, GX 3+1 had all features of a typical nonbursting bright bulge source (Lewin and Clark 1979; Parsignault and Grindlay 1978). The present results show

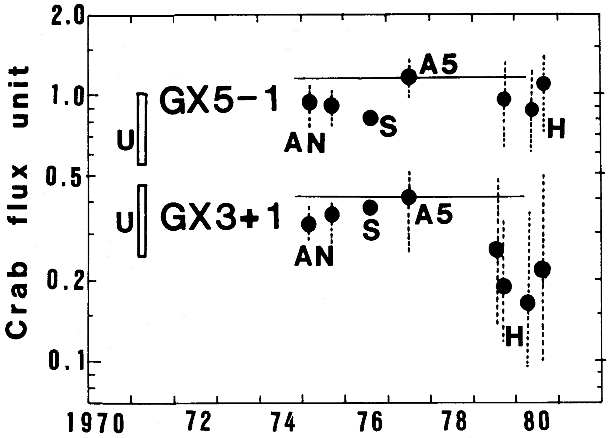

FIG. 3.—The long-term light curve of GX 3+1 during the last decade, observed with *Uhuru* (U; 2–6 keV, Forman, Jones, and Tananbaum 1976), *ANS* (AN; 1.4–7.2 keV, Parsignault and Grindlay 1978), *SAS 3* (S; 2–11 keV, Doxsey *et al.* 1977, Jernigan *et al.* 1978), *Ariel 5* (A5; 2–18 keV, Warwick *et al.* 1981) and *Hakucho* (H; 3–10 keV, this work). The results for GX 5−1 are also shown for comparison. The filled circles stand for the average, and vertical bars indicate the range of intensity variation.

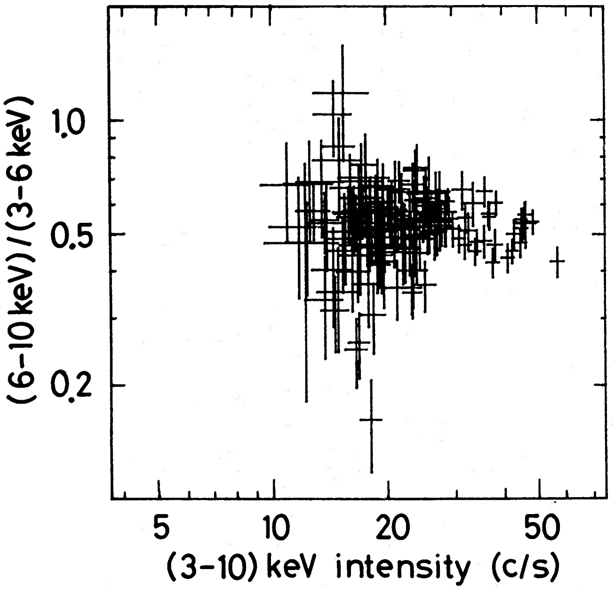

FIG. 4.—The correlation plot between the 3–10 keV flux and the hardness ratio (photon flux ratio in 6–10 keV to 3–6 keV) for the persistent X-ray emission from GX 3+1. This diagram corresponds to the 1980 July–August observation, when the source was bursting. No apparent correlation is seen.

that this source has undergone significant changes in recent years; these changes include commencement of burst emission, the decrease in luminosity, and the disappearance of the positive correlation between flux and hardness ratio.

Based on the results of *SAS 3* observations, van Paradijs *et al.* (1979) pointed out that a high persistent luminosity of an X-ray source tends to suppress its burst activity, which they interpreted in terms of the thermonuclear flash model (Joss 1978; Lewin and Joss 1981, and references therein). Two outstanding examples are MXB 1820−30 (Clark *et al.* 1977) and MXB 1659−29 (Lewin and Joss 1981), which were found to be burst inactive when the persistent luminosity was high. They also argued that the bursting and nonbursting bright bulge sources have no intrinsic difference except for the mass accretion rate. The present results for GX 3+1 provides another valuable example to confirm their viewpoint, since it is quite likely that the extended low state of GX 3+1 is related to the start of its burst activity.

In spite of many observations with *SAS 3* and *Hakucho*, it has remained uncertain whether there are some preferred time scales on which the burst activity of an X-ray source is correlated to its persistent luminosity (or more properly, its mass accretion rate). On one hand, a clear short-term (~days) correlation was observed between these quantities for MXB 1820−30 (Clark *et al.* 1977). On the other hand, a factor ~4 change in the intensity of MXB 1636−53, on ~10 day time scale, induced no correlated change in its burst activity during a ~1 month *Hakucho* observation (Ohashi 1981). In addition, lack of short-term (~days) correlation between the burst frequency and the persistent X-ray luminosity has been reported for MXB 1735−44 (Lewin *et al.* 1980), as well as for Ser X-1 (Li *et al.* 1977), though the range of variation in the persistent flux was rather small (about a factor of 2) in both cases.

In the above respect, the present results for GX 3+1 may give another complication: in fact, the long-term history in Figure 3 suggests that this source had already been in a low state in 1979 July, accompanying no, or at most very sparse, burst emission. This could be explained if the burst emission from GX 3+1 was correlated with its persistent X-ray flux on a rather long (~years) time scale, in such a way that its transition into a low state was followed by the start of frequent burst emission after a certain time delay. Another explanation is that the burst occurrence from GX 3+1 is very irregular, and that the 1980 July–August observation happened to coincide with its active phase. In any case, further observational data, as well as theoretical studies, are required to fully understand the effect of the mass accretion rate on the X-ray burst phenomenon.

The authors are grateful to J. M. Grunsfeld for his contribution in data analysis and discussion.

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