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Ginga Observation of the 2S 0114+650 System

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Abstract

We report on the results of observations of the 2S 0114+650 system using the X-ray satellite Ginga. The X-ray flux was highly variable with flare-like activity. The spectrum shows the typical shape of the usual X-ray pulsars having a power-law index of about 1 with an exponential cutoff at an energy of about 7 keV. The iron emission line at about 6.4 keV, which is also common among X-ray pulsars, was discovered for the first time. We found possible pulsation with a period of 850 s. Other than this, no significant periodic pulsation was detected in the range from 125 ms to about 1000 s.

Key words: X-ray binaries; X-ray pulsars.

1. Introduction

The X-ray source 2S 0114+650 was discovered in the SAS 3 galactic survey and its position was determined to be $\alpha_{1950.0} = 0^{\rm h}14^{\rm m}44^{\rm s}.3$, $\delta_{1950.0} = 65°01'34''$ (R. Dower and R. Kelly, *IAU Circular*, No. 3144, 1977). B. Margon and H. Bradt (*IAU Circular*, No. 3144, 1977) identified its optical counterpart as an 11th magnitude B star with a broad Hα emission line in its spectrum. Since the distance was estimated to be 1.4 kpc (Margon 1980), 2S 0114+650 is located in the Perseus spiral arm, an outer arm of the Galaxy. From an optical observation, Crampton et al. (1985) reported an orbital period of 11.6 d and that the optical properties of this system resemble those of supergiant X-ray binary systems. They also noted the absence of an eclipse, thus inferring that the inclination angle is less than $\sim 76°$.

Since its discovery, 2S 0114+650 has been observed by OSO 8, HEAO-1, and the Einstein Observatory (Koenigsberger et al. 1983). Because of a similarity with X Per and γ Cas, they suggested that 2S 0114+650 is a Be star - neutron star X-ray binary. Thus, many attempts have been made to detect coherent pulsation. A possible 894 s periodic pulsation was found in the Einstein MPC data. However, this was not detected with OSO 8 and HEAO-1 (Koenigsberger et al. 1983).

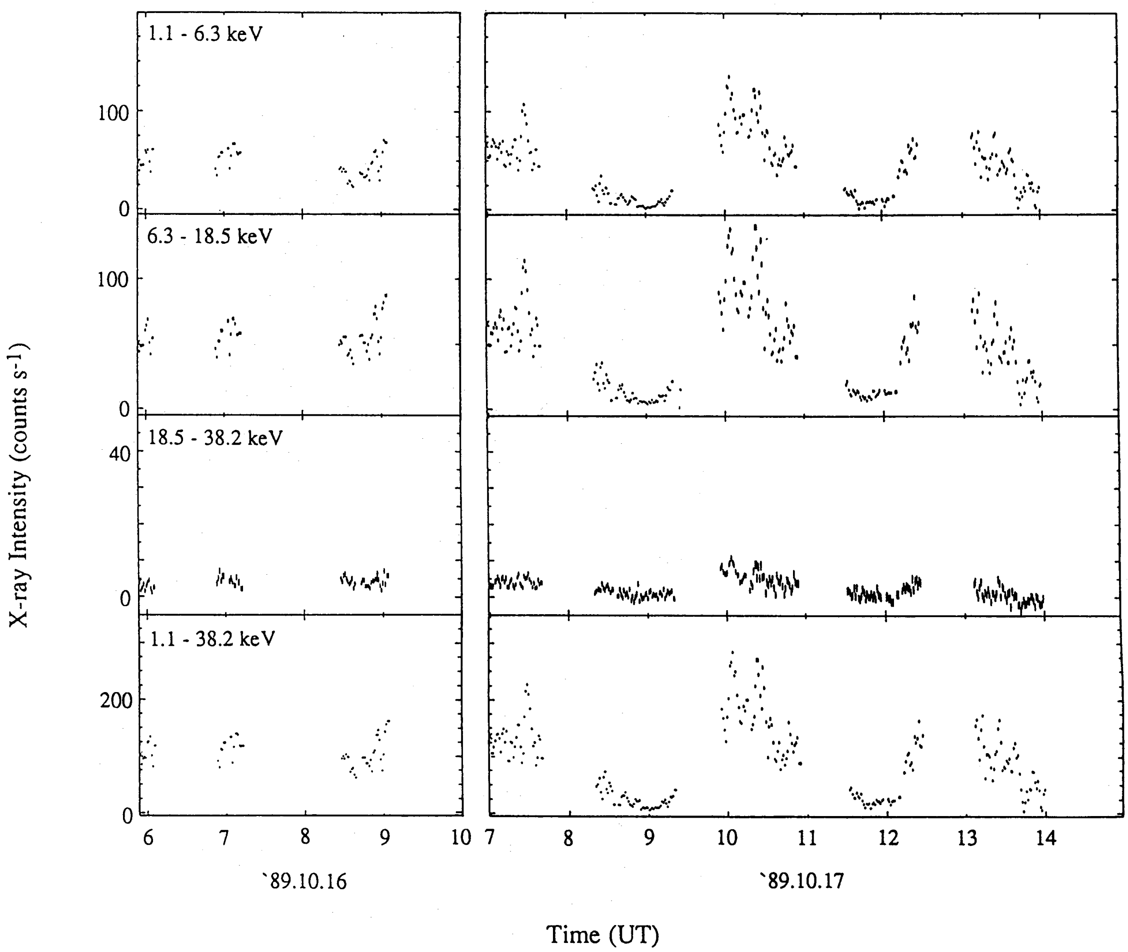

Fig. 1. The X-ray light curve for 2S 0114+650 averaged over 64 s within four energy bands: 1.1–6.3, 6.3–18.6, 18.6–38.2, and 1.1–38.2 keV.

Since the X-ray flux of 2S 0114+650 is relatively low (about 10 mCrab), more sensitive instruments are needed to study the nature of 2S 0114+650. In this letter, we report on the X-ray properties observed with the Large-Area proportional Counters on board the X-ray satellite Ginga.

2. Observations and Results

The observations of 2S 0114+650 were carried out on October 16 and 17 in 1989 with the Large-Area Counters (LAC) (Turner et al. 1989) aboard the X-ray astronomy satellite Ginga (Makino and the ASTRO-C team 1987). The total effective area of the LAC and the energy range are 4000 cm^2 and 1–38 keV, respectively. The LAC field of view is about $1° \times 2°$ (FWHM). The data were taken in the 48 energy channel mode (MPC-1 or 2 mode) with a time resolution of 4, 0.5 or 0.0625 s.

The nearby 3.6 s X-ray pulsar 4U 0115+63 was in the LAC field of view during the observation made on 16 October. As mentioned later, however, the pulse fraction

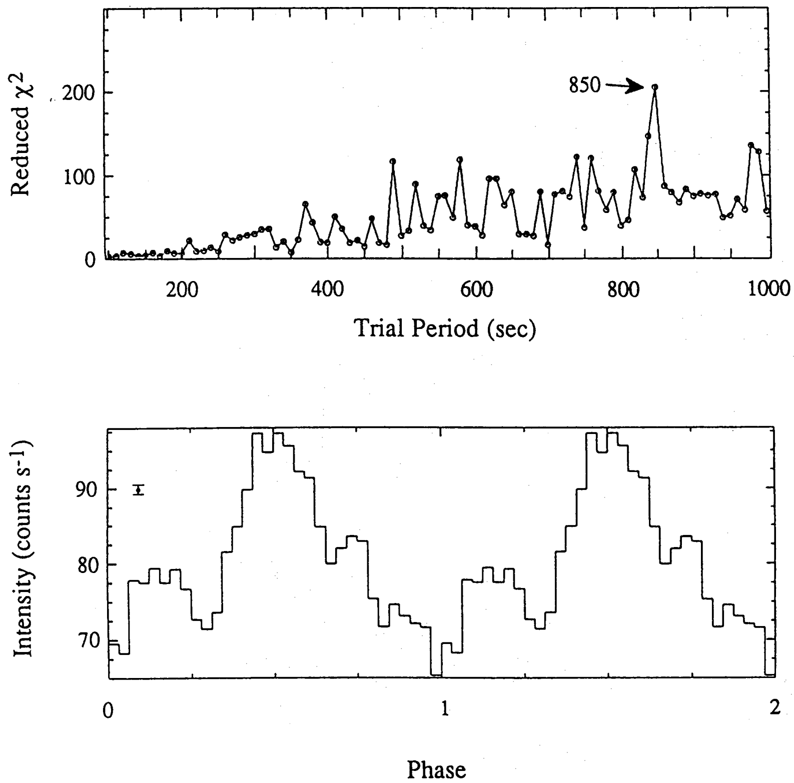

Fig. 2. Reduced χ^2 value distribution of a folding technique (d.o.f.=31). A significant peak is seen around 850 s (upper panel). A folded light curve with 850 s is given in the 3.4–18.6 keV energy band (lower panel).

of 3.6 s was not observed with an upper-limit of 0.7 count s^{-1} within the range 3.4–18.6 keV (90% level). Since the pulse fraction of 4U 0115+63 was reported to be about 50% of the 3–18 keV total flux (Rose et al. 1979), we have estimated that the X-ray contamination of 4U 0115+63 was less than 1.4 counts s^{-1}. No catalogued X-ray source other than 2S 0114+650 was in the LAC field of view during the following observation on 17 October. The total observation times were 3500 and 15500 s on 16 and 17 October, respectively.

Figure 1 is a light curve of 2S 0114+650 averaged over 64 s after background subtraction and aspect correction. Three flares were observed on 17 October 1989, each lasting for about 1 hr, with intervals of about 3 hr. A flare interval of about 3 hr is much shorter than that found by the Einstein MPC observation (Koenigsberger et al. 1983). The peak luminosity of the flare, 2×10^{35} erg s^{-1} at 2–10 keV, and a distance of 1.4 kpc (Margon 1980), is about 15-times stronger than the quiescent level. The hardness ratio at 6.3–18.6 keV and 1.1–6.3 keV did not change during these observations.

In order to search for coherent pulsation, we carried out a Fourier analysis in the range from 125 ms to 128 s for both the flare and the quiescent states. No significant coherent pulsation was found, and the 90% upper limit of the pulse fraction was 1 and

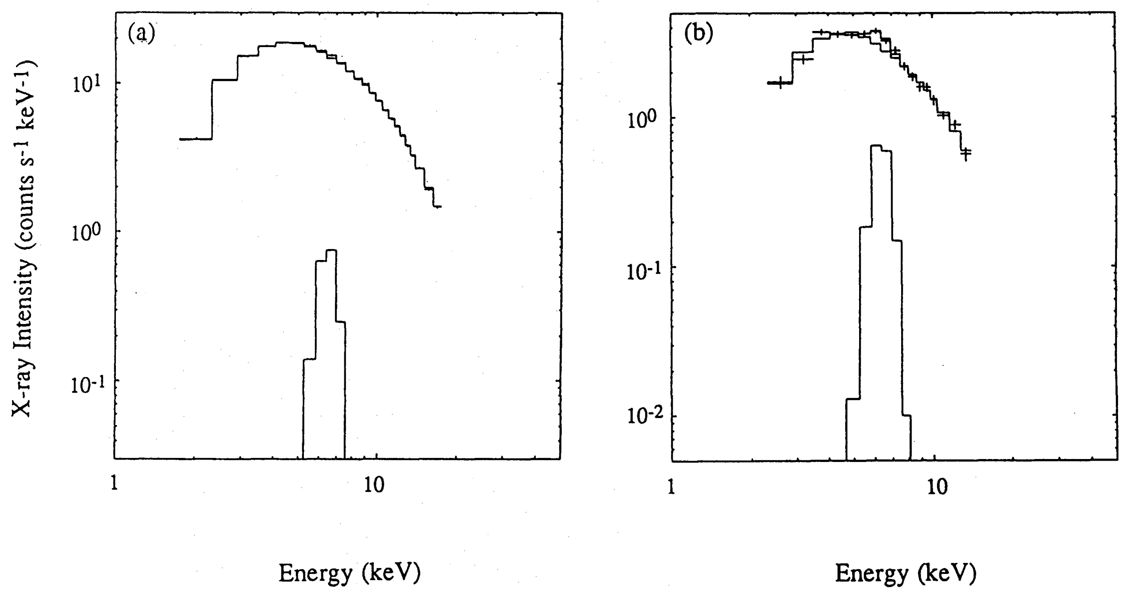

Fig. 3. X-ray spectra in the flare state (a), and in the low state (b), with the best-fit curves (the histogram).

5% of the 3.4–18.6 keV total flux in the flare and the quiescent states, respectively. For a pulsation search within a time scale longer than 128 s, we folded all of the data with a trial period and examined the reduced χ^2 value on the assumption of constant intensity. We found a significant peak at about 850 s, as indicated by the arrow in figure 2. The folded light curve with an 850 s period is also given in figure 2. Since the duration of the continuous observation was not sufficiently long (less than 3×10^3 s) compared to the 850 s period, neither the artifact to produce a spurious pulsation nor the probability of quasi-periodic oscillations is not completely removed. Therefore, we still can not argue strongly that 850 s is the real pulse period.

The X-ray spectra of the flare and low states are given in figure 3. We carried out model fittings on these spectra. In the flare state, a power-law with an exponential high-energy cutoff with an iron emission line and low-energy absorption gave an acceptable fit. The spectrum of the low state was also fitted with the same model, although a thermal bremsstrahlung model was not rejected. An emission line at about 6.4 keV was also detected for the first time with equivalent widths of 0.07 and 0.34 keV, for the flare and the low states, respectively. The best-fit power-law models and their parameters are given in figure 3 and table 1.

3. Discussion

Owing to the high sensitivity of the LAC instruments, we have obtained a more accurate X-ray spectrum than that of the previous observations. Koenigsberger et al. (1983) reported that the X-ray spectrum above 1 keV was fitted by a single power-law with a photon index of about 1.2 and a cutoff energy higher than 15 keV. From the present observation, we have found that the best-fit power-law index and the cutoff

Table 1. Results of spectral fitting.

	Flare state	Quiescent state
Energy range (keV)	1.7–17.3	2.2–13.8
Photon index	0.92±0.02	1.07±0.03
Cutoff energy (keV)	7.1±0.3	6.8±1.0
Folding energy (keV)	16.1±0.8	15.4±4.0
$N_{\rm H}$ (cm^{-2})	$(2.9\pm0.2)\times10^{22}$	$(4.7\pm0.6)\times10^{22}$
Line intensity (photons s^{-1} $beam^{-1}$)	1.2±0.5	1.1±0.3
Line energy (keV)	6.4±0.2	6.2±0.2
Reduced χ^2/d.o.f.	1.154/17	1.663/10

90 % confidence level.

energy are about 1 and 7 keV, respectively. These parameter values are well within the range of those from typical X-ray pulsars (Nagase 1989). We also found that the X-ray spectrum in the quiescent state is almost the same as that in the flare state.

Although 2S 0114+650 was found to have the typical spectrum shape of usual X-ray pulsars, no clear pulsations were observed. We have set a more severe constraint for the upper limit of regular pulsations in the range from 125 ms to 128 s than that of the previous observations (Koenigsberger et al. 1983). For a longer time scale, we observed a likely pulsation of about 850 s. The folded light curve shows two peaks (see figure 2), which are similar to those obtained by the Einstein Observatory at 894 s (Koenigsberger et al. 1983). Such profiles of two peaks are often observed in the pulse profile of typical X-ray pulsars (White et al. 1983b). If we assume that the 894 s (the Einstein Observation) and the 850 s (Ginga Observation) periods are due to the rotational period of a neutron star of the 2S 0114+650 system, we can derive the spin-up rate to be $|\dot{P}/P| \sim 5 \times 10^{-3}$ yr^{-1}, which is not exceptionally large for the usual X-ray pulsars (Hayakawa 1985).

The flare-like activities and the X-ray spectral shape are very similar to those of a supergiant X-ray binary 4U 1700−37. No clear pulsation from 4U 1700−37 has yet been established (Gottwald et al. 1986). The intensity variations are believed to represent an inhomogeneity of the stellar wind density. The lack of apparent pulsations is either due to a longer spin period than about 1000 s or to an alignment of the magnetic dipole and the rotation axis (White et al. 1983a).

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