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X-RAY SPECTRUM AND TIME VARIATION OF X1850−087 IN THE GLOBULAR CLUSTER NGC 6712

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ABSTRACT

We observed the energy spectrum and the time variation of the X-rays from X1850−087 in the globular cluster NGC 6712 with the Large Area Counter on board *Ginga*. The luminosity of X1850−087, when we observed it, was 1.3×10^{36} $(D/6.8 \text{ kpc})^2$ ergs s^{-1}. The X-ray energy spectrum can be represented by a single power-law type spectrum with a photon index of 2.3, with an interstellar absorption of less than 10^{21} H atoms cm^{-2}. A model consisting of disk blackbody and radiation from the neutron star requires an unphysically small inner-disk-radius and a small emission region on the neutron star surface where allowances have been made for the difference between the color temperature and the effective temperature. On the other hand, a model where the main X-ray formation mechanism is Compton scattering indicates that the plasma, which is responsible for Compton scattering, becomes thin and hot in the low accretion rate state. No significant periodic variation was detected, but a significant variation below 1 Hz was found, which is similar to a high-frequency noise observed in the island state of the atoll sources.

Subject headings: globular clusters: individual (NGC 6712) — stars: individual (X1850−087) — stars: neutron — X-rays: stars

1. INTRODUCTION

So far, at least two kind of models of the X-ray emission mechanism for the low-mass X-ray binaries have been proposed. One model (hereafter Model 1) was proposed by Mitsuda et al. (1984), where X-rays are emitted from both the inner region of the accretion disk and from the surface of the neutron star. The X-rays from the inner region of the accretion disk are described by a multicolor blackbody (disk-blackbody) (Mitsuda et al. 1984) with an inner edge temperature of about 1 keV. The X-rays from the surface of the neutron star are described by a blackbody spectrum with a temperature of about 2 keV. The X-rays from the neutron star, and probably also from the inner region of the accretion disk, undergo inverse Compton scattering by an accretion disk corona (Mitsuda et al. 1989; White & Holt 1982). Another model (hereafter Model 2) was proposed by White, Peacock, & Taylor (1985) and by White et al. (1986), in which the X-ray spectrum is described by unsaturated Comptonization (Sunyaev & Titarchuk 1980) of low-energy photons but without requiring a specific disk geometry. This model requires, for some high-luminosity, low-mass X-ray binaries, an additional blackbody component which may originate from an optically thick boundary layer between the accretion disk and the neutron star (White, Stella, & Parmar, 1988). Both models can describe the spectral shapes of almost all the bright low-mass X-ray binaries.

In general, low-luminosity, low-mass X-ray binaries tend to show a harder and more of a power-law type spectra than the brighter systems (e.g. White & Mason 1985; Mitsuda & Tanaka 1986). Mitsuda et al. (1989) studied the spectrum of the X-ray transient source X1608−522 as it varied through a wide range of the luminosity (6×10^{36}–3×10^{37} ergs s^{-1}), and argued that, in the low-luminosity state, the Comptonization parameter becomes large and, Model 1 can well explain the spectrum of the low-luminosity state of X1608−522. They also applied Model 2 and found that it requires a change in the amount of interstellar absorption in order to describe the low-luminosity state in spite of the fact that Model 1 does not require such a change. White, Stella, & Parmar (1988) applied Model 2 to a number of X-ray burst sources (moderate luminosity, low-mass X-ray sources with the luminosities ranging between 3.7×10^{36} and 2.7×10^{37} ergs s^{-1}), high-luminosity low-mass X-ray binaries (1.7×10^{38}–4.7×10^{38} ergs s^{-1}) and Galactic black hole candidates. They found that these sources could be well described by Model 2. Therefore, a generally accepted model for the low-mass X-ray binaries has not yet been established, but few low-luminosity X-ray sources of about 10^{36} ergs s^{-1} have been studied.

Hasinger & van der Klis (1989) have proposed that there were two kinds of sources from the patterns in spectral behavior in low-mass X-ray binaries: *Z* sources and atoll sources. In general, low-luminosity, low-mass X-ray binaries belong to the atoll sources. Unfortunately, this study included few low-luminosity sources of the order of 1×10^{36} ergs s^{-1}.

One possible theory of the formation of low-mass X-ray binaries is close encounters between neutron stars and main-sequence stars in globular clusters. Verbunt (1989) investigated some close encounters and the resulting orbital period for each encounter. Some interactions would result in ultrashort orbital periods of order 10 minutes like NGC 6624, but a larger fraction of them would have an orbital period greater than 1 hr. However, the orbital periods of only three X-ray binaries in globular clusters have been reported so far: NGC 6624 with 685 s (Stella, Priedhorsky, & White 1987), M15 with 0.35 day (Ilovaisky et al. 1987), and probably NGC 6441 (Parmar, Stella, & Giommi 1989) with 5 hr. Orbital periods from additional globular cluster sources are needed to verify the theory of the formation of low-mass X-ray binaries.

The star X1850−087 is an X-ray source located in the globular cluster NGC 6712, at a distance 6.8 kpc (Peterson & King 1975). Cominsky et al. (1977) report *Uhuru* quiescent luminosity variations ranging from 2×10^{36}–5×10^{36} ergs s^{-1} and an X-ray flare event with peak luminosity of 3.5×10^{37} ergs s^{-1}. X-ray bursts from X1850−087 have also been reported (Swank et al. 1976). Although searches for short-term periodic variability have been unsuccessful (Leahy et al. 1983; Parmar et al. 1989), Priedhorsky & Terrell (1984) report a possible long-term period of 0.72 yr. Lehto et al. (1990) and Machin et al. (1990) report detection of a radio counterpart, only the second known radio counterpart for a globular cluster X-ray source.

In this paper, we report the observations obtained for X1850−087 in the low-luminosity state [$1.3 \times 10^{36}(D/6.8$ kpc$)^2$ ergs s^{-1}] by the Large Area Counters on board *Ginga* in 1989 April, and 1990 September. Detailed studies of both the energy spectrum and flux time variability are presented. The spectrum is roughly described by a power-law spectrum. If the two most discussed models are fitted to the data, Model 1 yields a color temperature about 1.5 times larger than the effective temperature, while Model 2 requires a hot and thin plasma for Compton scattering. Significant temporal variation in the luminosity is detected, which is similar to the high-frequency noise for atoll sources.

2. OBSERVATION AND RESULTS

The source X1850−087 was observed with the Large Area Counters (Turner et al. 1989) on board *Ginga* (Makino & Astro-C Team 1987) between 1989 April 26 and 28 and between 1990 September 7 and 8. The observational mode and the time resolutions are summarized in Table 1. A total of 4200 s of data in 1989 and 16,700 s in 1990 were obtained in 48 energy channel spectral mode. Additional high time resolution observations using 12 energy channels were obtained in 1989. The background subtracted light curves are shown in Figure 1 as well as the hardness ratios. The energy spectrum and the variation of the flux are described later. The luminosity was 1.3×10^{36} $(D/6.8 \text{ kpc})^2$ ergs s^{-1} during our observation, where D is the distance to NGC 6712. No burst or flare activity was observed.

2.1. *X-Ray Energy Spectra*

Several types of spectral models were fitted to the X-ray energy spectra plotted in Figure 2. These data were obtained in 48 channel mode, but, the two energy channels below 1 keV were omitted in these fits because the detector efficiency is less than 0.1% in those energy channels (Turner et al. 1989). These results are summarized in Table 2. Initially, simple one-component model spectra [blackbody, thermal bremsstrahlung, power law, and disk blackbody (multicolor blackbody proposed by Mitsuda et al. 1984)] with interstellar absorption were fitted to these data. In all cases, the interstellar absorption has an upper limit of about 10^{21} H atoms cm^{-2}, which is

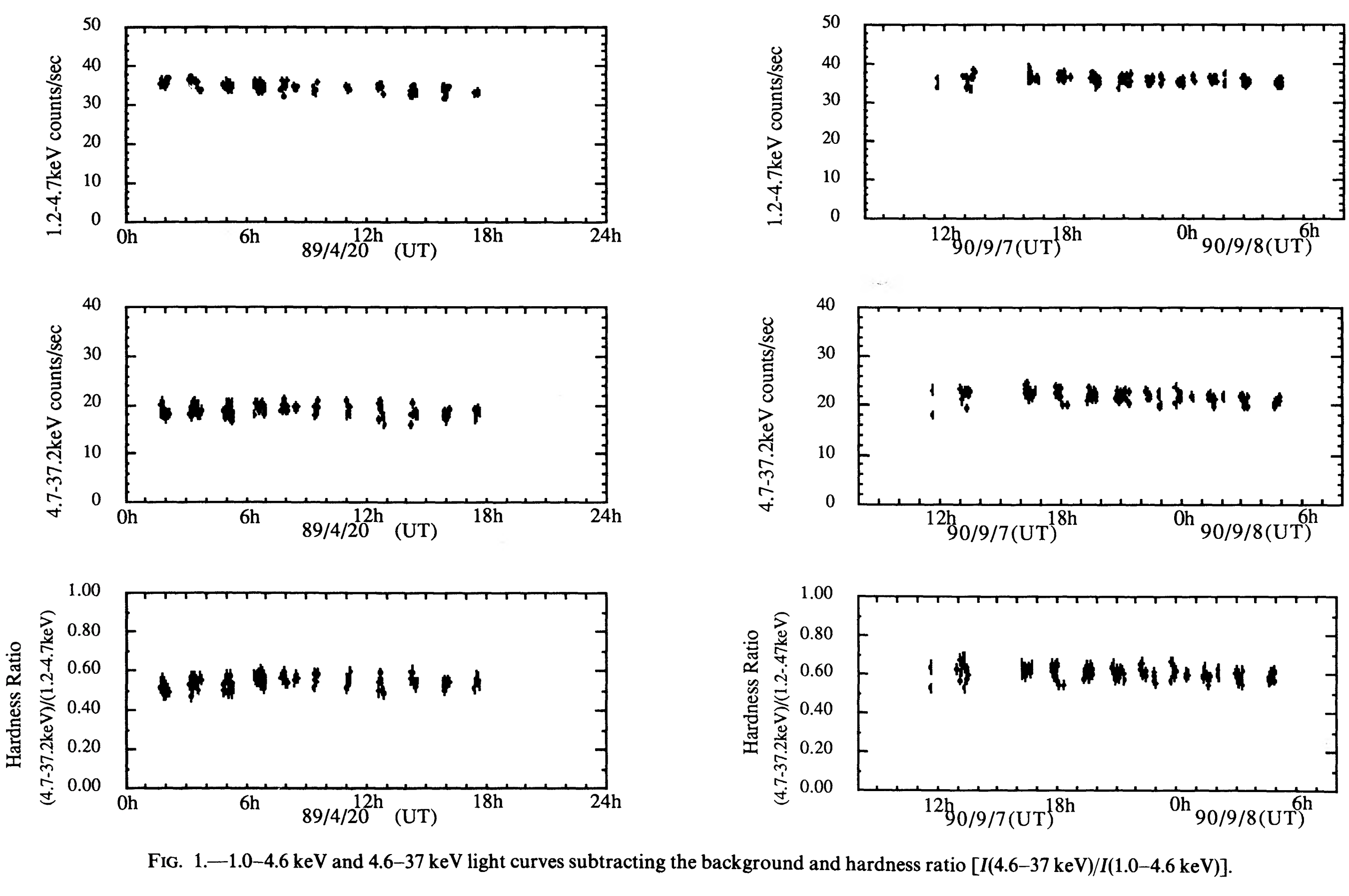

FIG. 1.—1.0–4.6 keV and 4.6–37 keV light curves subtracting the background and hardness ratio [I(4.6–37 keV)/I(1.0–4.6 keV)].

TABLE 1

OBSERVATION OF NGC 6712

Observation	Duration (s)	Time Resolution (s)	Energy Channel	Energy Range (keV)
1989 April 20–21	4140	0.0078	12	1–37
	1080	0.0625	12	1–37
	3120	0.0625	48	1–37
	1080	0.5	48	1–37
1990 September 7–8	1700	0.5	48	1–37
	6000	2.0	48	1–37
	9000	16.0	48	1–37

consistent with the interstellar extinction of 1.5 mag reported by Peterson & King (1975). From amongst these models, the power-law model with a photon index of 2.25–2.30 yields the smallest χ^2 value. In Figure 2, the best-fit model spectra and residuals are shown. This result is consistent with other observations and may be a common characteristic for low-luminosity, low-mass X-ray binaries (White & Mason 1985; Mitsuda & Tanaka 1985). We also found that the spectral fittings did not require the inclusion of the iron K emission line. The 90% upper limit equivalent width is 64 eV, assuming a narrow 6.7 keV line.

Next we applied more complex models to fit the observed

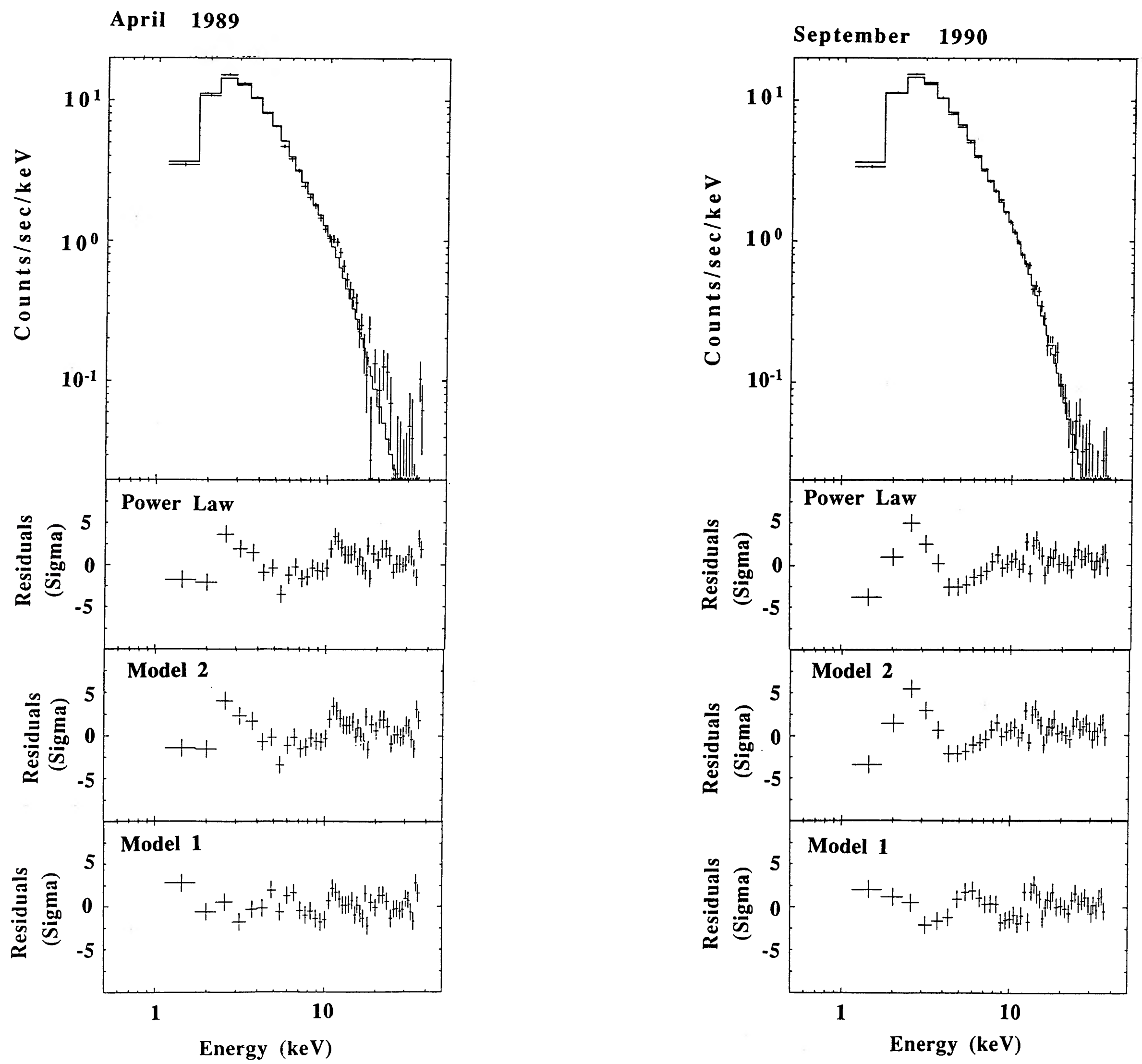

FIG. 2a FIG. 2b

FIG. 2.—Energy spectra observed in (*a*) 1989 April and (*b*) 1990 September and best-fit power-law model. Residuals for the models are shown in the lower panel for the power-law model, Model 1, and Model 2 (Sunyaev & Titarchuk 1980).

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TABLE 2

BEST-FIT PARAMETERS OF SPECTRAL FITTINGS

Model	1989	1990
Thermal-bremsstrahlung:		
Reduced χ^2	19	31
Blackbody:		
Reduced χ^2	105	204
Disk-blackbody:		
Reduced χ^2	55	100
Power-law:		
Photon index	2.301 ± 0.001	2.248 ± 0.001
Log (N_H)	<21.0	<21.0
Reduced χ^2	2.8	2.7
Power law with exponential cutoff (Model 2):		
Photon index	2.271 ± 0.001	2.212 ± 0.001
Cutoff energy (keV)	>30	>30
Log (N_H)	<21.0	<21.0
Reduced χ^2	2.9	3.1
Comptonization from Sunyaev & Titarchuk (Model 2):		
Electron temperature (keV)	51.42 ± 3.34	51.54 ± 2.51
Optical depth	3.167 ± 0.094	3.275 ± 0.074
Log (N_H)	<21.0	<21.0
Reduced χ^2	2.8	2.7
Comptonized blackbody (Nishimura, Mitsuda, & Itho 1986):		
Radius (km)	16.3 ± 1.5	19.1 ± 0.4
kT (keV)	0.441 ± 0.016	0.414 ± 0.005
Electron temperature (keV)	29.66 ± 2.25	28.49 ± 1.12
Optical depth	1.151 ± 0.082	1.234 ± 0.043
Log (N_H)	<21.0	<21.0
Reduced χ^2	2.1	1.0
Disk-blackbody + blackbody:		
R_{in}[a] $(\cos(i))^{0.5}$ (km)	2.062 ± 0.002	2.326 ± 0.002
kT_{in}[b] (keV)	0.9415 ± 0.0001	0.8901 ± 0.0001
Blackbody radius (km)	0.2372 ± 0.0002	0.2948 ± 0.0002
kT (keV)	2.793 ± 0.001	2.538 ± 0.001
Log (N_H)	<21.0	<21.0
Reduced χ^2	2.7	5.2
Blackbody + power-law:		
Blackbody radius (km)	4.25 ± 0.24	0.2234 ± 0.0002
kT (keV)	0.538 ± 0.010	0.7997 ± 0.0001
Photon index	2.049 ± 0.015	2.250 ± 0.001
Log (N_H)	<21.0	<21.0
Reduced χ^2	1.6	2.8
Disk-blackbody + power-law:		
R_{in}[a] $(\cos(i))^{0.5}$ (km)	1.940 ± 0.02	1.778 ± 0.003
kT_{in}[b] (keV)	0.806 ± 0.011	0.7646 ± 0.0001
Photon index	1.895 ± 0.016	2.019 ± 0.001
Log (N_H)	<21.0	<21.0
Reduced χ^2	1.5	1.3
Disk-blackbody + Comptonized blackbody (Model 1):		
R_{in}[a] $(\cos(i))^{0.5}$ (km)	2.41 ± 0.03	2.47 ± 0.03
kT_{in}[b] (keV)	0.8640 ± 0.0053	0.8553 ± 0.0040
Radius (km)	0.86 ± 0.02	0.72 ± 0.01
kT (keV)	1.893 ± 0.027	1.976 ± 0.015
Electron temperature (keV)	100.0 (fixed)	100.0 (fixed)
Optical depth	1.347 ± 0.06	0.973 ± 0.032
Log (N_H)	<21.0	<21.0
Reduced χ^2	1.7	1.7
GRD[c] + Comptonized blackbody (Ebisawa, Mitsuda, & Hanawa 1991) $i = 30°$:		
Scaling factor	0.0092 ± 0.0014	0.0096 ± 0.0013
Mass accretion rate (g s^{-1})	$(2.60 \pm 0.29) \times 10^{17}$	$(2.57 \pm 0.32) \times 10^{17}$
Radius (km)	0.536 ± 0.062	0.966 ± 0.073
kT (keV)	2.169 ± 0.111	2.057 ± 0.122
Electron temperature (keV)	100.0 (fixed)	100.0 (fixed)
Optical depth	0.769 (fixed)	0.973 (fixed)
Log (N_H)	<21.0	<21.0
Reduced χ^2	2.2	1.9

TABLE 2—*Continued*

Model	1989	1990
GRD[c] + Comptonized blackbody (Ebisawa, Mitsuda, & Hanawa 1991) $i = 70°$:		
Scaling factor	0.0330 ± 0.0033	0.0566 ± 0.0065
Mass accretion rate (g s^{-1})	$(1.47 \pm 0.18) \times 10^{17}$	$(0.86 \pm 0.09) \times 10^{17}$
Radius (km)	0.458 ± 0.051	0.860 ± 0.065
kT (keV)	2.350 ± 0.133	1.805 ± 0.065
Electron temperature (keV)	100.0 (fixed)	100.0 (fixed)
Optical depth	0.769 (fixed)	0.973 (fixed)
Log (N_H)	<21.0	<21.0
Reduced χ^2	1.9	1.9
Power-law + 12 keV Gaussian line (see text):		
Photon index	2.37 ± 0.02	2.30 ± 0.02
Line equivalent width (keV)	1.5 ± 0.5	0.7 ± 0.3
Line center energy (keV)	11.9 ± 0.6	11.9 (fixed)
Line width (keV)	1.5 ± 0.7	1.5 (fixed)
Log (N_H)	<21.0	<21.0
Reduced χ^2	1.9	2.4

[a] R_{in} means the inner disk radius.
[b] kT_{in} means the inner disk temperature.
[c] The distance and the mass of the central object are assumed to be 6.8 kpc and 1.4 $M_\odot$.

spectra. Simulating Model 2 (described above), a power-law type model with an exponential cutoff energy was fitted to the data and produced a reasonable fit. However, the cutoff energy for this model is much higher than the *Ginga* observing range (more than 30 keV) and the χ^2 value is not better than the power-law model value. The Comptonization model described by Sunyaev & Titarchuk (1980) and Sunyaev & Trumper (1979) also gives a reasonable fit. However, the electron temperature is higher than our observational range extends. The Thomson scattering optical depth is of order 3.2 and the Comptonization parameter y is about 4. It should be noted that their model is valid only for the large Thomson scattering depth ($\tau \gg 1$). Next we applied the Comptonized blackbody model described by Nishimura, Mitsuda, & Itoh (1986), which is valid even in the small optical depth ($\tau < 3$), and found that this model can also be fitted to the data. The incident blackbody has a reasonable radius of about 16–19 km, if we assume the emitting region is the inner disk radius and the surface of the neutron star. The Comptonization parameter y is 0.34.

Several two-component models were applied. The disk-blackbody + power-law model which is sometimes used to describe the spectrum of Galactic blackhole candidates (e.g., Kitamoto et al. 1990) also gives a reasonable fit. If we adopt this model the inner disk radius is less than $2/(\cos(i))^{0.5}$ km. The disk-blackbody + blackbody model, which is a precursor of Model 1 (Mitsuda et al. 1984), did not provide a good fit. Model 1, described above (Mitsuda et al. 1989), with the inclusion of Compton scattering yields an acceptable fit to the observed data. These best-fit parameters are summarized in Table 2 and the residuals are shown in Figure 2. This model again requires an inner disk radius and an emission region on the neutron star that is unphysically small. These results are discussed in § 3. The Comptonization parameter, y, is 0.7, which is comparable to the reported value of about 1.0 for the low-luminosity state of X1608−522 (Mitsuda et al. 1989).

A more sophisticated model has been proposed by Ebisawa, Mitsuda, & Hanawa (1991), where the emission from the surface of the neutron star is the same as for Model 1 (Comptonized blackbody) but where the emission from the accretion disk is derived accounting for effect of general relativity (the general relativistic accretion disk model, GRD). The free parameters are the distance to the source, the inclination of the accretion disk, the mass of the central object, the mass accretion rate onto the neutron star and a scaling factor, which is the ratio of the detected intensity to the expected intensity. For this case, the mass of the central object and the distance to the source were fixed to be 1.4 $M_\odot$ and 6.8 kpc, respectively. The temperature and the scattering depth of the electron cloud from the Comptonized blackbody spectrum resulting from emission from the surface of the neutron star are also fixed to be the same to the results of Model 1. As can be seen from the results of two fixed inclinations (70° and 30°), which are summarized in Table 2, this model fits the data well. The model determined parameters for the emission from the neutron star surface are almost the same for Model 1. The scaling factor determined to be 0.035–0.057 for $i = 70°$ and 0.010–0.015 for $i = 30°$ will be discussed in the next section.

As can be observed in both the spectra and the residuals in Figure 2, there appears to be an emission feature at about 12 keV in the 1989 data which is not clear in the 1990 data. Including a line feature to the power-law fit of the 1989 data significantly improved the reduced χ^2 (see Table 2). The emission feature as determined from the fit is located at 11.9 ± 0.6 keV and has FWHM of 1.5 ± 0.7 keV and an equivalent width of 1.5 ± 0.5 keV. A model of absorption feature around 9 keV was also applied but could not get a reasonable fit. Because there is a possibility that this feature is an activation line and these observations were obtained after a strong solar flare event that occurred in March, the line feature was carefully scrutinized. An investigation of the background and other sources observed at this time to see if a line feature was present in them was performed, however, no line feature was observed in any of them. The data from orbits which did and did not pass through the South Atlantic Anomaly were averaged into 5 minute time segments to look for a change in strength of the feature as a function of time indicative of an activation line with a decay time of order a few minutes. The line strength was consistent with a constant value at all times. On the other hand, the residuals on 1990 observation do not show a linelike structure, but show a small scatter around 12 keV (if a presence of a line feature with the same energy and the same width to those of the 1989 data is assumed, the equivalent width is

TABLE 3

SUMMARY OF THE PERIOD SEARCH

Method	Energy Range (keV)	Frequency Range (Hz)	Upper Limit (%)
FFT (0.0078 s bin, 1024 data, 506 ensembles)	1–37	62.5–1.25	14.4
FFT (0.0625 s bin, 1024 data, 241 ensembles)	1–37	7.81–0.781	4.2
FFT (0.5 s bin, 512 data, 61 ensembles)	1–37	1–0.00781	3.0
Folding (0.5 s bin, 7720 s data, 0.5 s step)	2.3–11.6	0.01–0.005	5.8
Folding (0.5 s bin, 7720 s data, 1.0 s step)	2.3–11.6	0.005–0.00143	6.5
Folding (0.5 s bin, 7720 s data, 2.0 s step)	2.3–11.6	0.00143–0.000769	6.5
Folding (0.5 s bin, 7720 s data, 4.0 s step)	2.3–11.6	0.000769–0.000588	5.2

0.7 ± 0.3 keV). Therefore, the nature of the line is still unknown, and we only note its presence in the 1989 observations.

2.2. *Time Variation*

Time variability of the total observed flux (1–37 keV) was studied via FFT and epoch folding analysis. First, the data were averaged into 0.5 s bins. FFT analyses over a frequency range of 1–0.00781 Hz were performed using data strings 512 long; 61 ensembles were used in this study. No significant periodicity was detected with an upper limit amplitude of 99% confidence level of 3% of the average intensity. Then, the 0.0625 s time resolution data was divided into 1024 data strings for FFT analysis; 241 ensembles were used. No significant pulsations were observed with an upper limit amplitude of 4.2% of the intensity in the frequency range 0.78–7.8 Hz. Finally, the 0.0078 s resolution data were analyzed in 1024 data strings utilizing 506 ensembles. Again, only an upper limit 14.4% of the intensity in the frequency range 1.25–62.5 Hz was obtained. These results are summarized in Table 3.

Periodicities of greater than several minutes were not found from epoch folding analysis. In Table 3, the upper limit modulations are listed. Between 100 s and 1700 s, the upper limit amplitude is 6.5%. These values are comparable with the reported values by Parmar et al. (1989).

From these analyses, we found a significant variation in the frequency range less than 1 Hz. The power spectrum of this variation is shown in Figure 3. This power spectrum can be fitted by a Lorentzian. The central frequency is consistent with 0 Hz (<0.01 Hz) and the width is 1.23 ± 0.48 Hz. This shape is quite similar to the high-frequency noise observed in the power spectra of the island state of the atoll sources (Hasinger & van der Klis 1989).

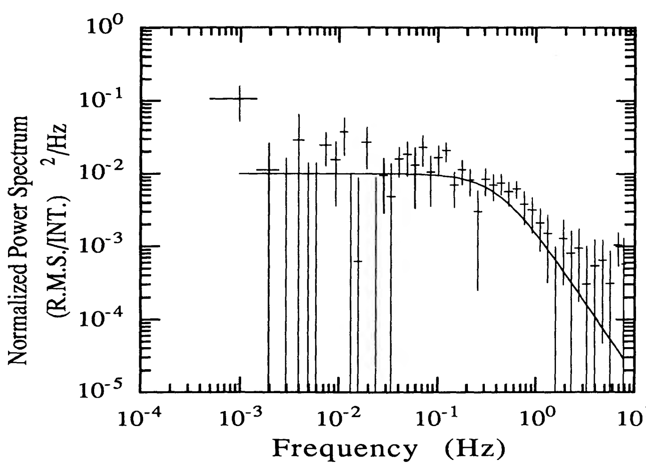

FIG. 3.—Power density spectrum between 0.001 and 8 Hz. The best-fit Lorentzian function is also plotted.

3. DISCUSSION

We have studied the energy spectra and time variability of a low-mass X-ray binary, X1850−087, while it was in a low-luminosity state (1.3×10^{36} ergs s^{-1}). The energy spectrum can be roughly described by a single power law, which is consistent with previously reported energy spectra of low-luminosity, low-mass X-ray binaries of luminosity range about 3.7×10^{36}–6×10^{37} ergs s^{-1} (White & Mason 1985; Mitsuda & Tanaka 1985; Mitsuda et al. 1989). Why the energy spectra of these types of systems can be described by a power-law is still not completely explained. Mitsuda et al. (1989) reported that the changes in the energy spectrum of the low-luminosity states of X1608−522 could be explained using Model 1 with a changing amount of Comptonization (y parameter). Model 1 can also fit the energy spectrum of X1850−087, but the derived parameters require an inner disk radius of about $2.4/(\cos(i))^{0.5}$ km and a neutron star emission region of less than 0.8 km. To be physically reasonable, these values require the inclination (i) to be greater than 87°, assuming the 10 km radius for the neutron star. Although the inclination of the X1850−087 system has not been determined observationally, the fact that X1850−087 does not exhibit eclipses implies that the inclination is not large.

However, if the electron scattering opacity is greater than the absorption opacity, this argument is incorrect and we need to instead consider the effects resulting from the differences between the color temperature and the effective temperature similar to the effect which has been observed in the tail of X-ray bursts (e.g., Nakamura et al. 1989) and has been discussed by Ebisuzaki & Nakamura (1988). Assuming the Roche lobe overflow scenario for this system and estimating 0.5 $M_\odot$ for the companion star, the ratio of the radius of the Roche lobe to the separation of the system can be estimated to be 0.32 (Paczynski 1971). Since no eclipse has been observed in X1850−087, the inclination must be less than 70°. Thus, to account for the unphysically small inner disk radius derived above, the color temperature should be about 1.5 times greater than the effective temperature, assuming a 10 km radius of the neutron star. The accretion disk model proposed by Ebisawa, Mitsuda, & Hanawa (1991) requires a small scaling factor even for the 70° inclination case. Difference between the effective temperature and the color temperature can likewise account for the calculated small scaling factor. Adjusting for these differences we calculate the ratio of the color temperature to the effective temperature to be 2.0–2.3 for the inclination of 70°. If inclination is smaller than 70°, an even larger ratio between them is required.

Model 2 (Sunyaev & Titarchuk 1980 model; power law with exponential cutoff) can also roughly describe the spectral shape for an electron temperature of more than 30 keV, Thomson scattering optical depth of 3.2 and a Comptonization parameter, y, of 4 with χ^2 values similar to those of the simple power-law model. Comparing to the published low-luminosity results of White, Stella, & Parmar (1988), we find that the X1850−087 values for the electron temperature and the optical depth are larger and smaller, respectively. They also reported that the low-luminosity state of X1608−522 is similar to our results for X1850−087, namely in the small accretion rate state the plasma, which is responsible for the Comptonization, becomes thin and hot. A Comptonized blackbody model also gave a slightly better fit.

No significant modulation in the frequency range between 0.000588 and 62.5 Hz are detected. Comparing previously reported results (Leahy et al. 1983; Parmar et al. 1989), our result provides lowest upper limit on the amplitude in the range greater than 0.00781 Hz. However, this upper limit is still large, compared to modulation amplitude of 3% (peak-to-peak) for the 685 s modulation found for NGC 6624 (Stella et al. 1987).

The classification of the low-mass binaries into "Z" and "atoll" sources based upon the power spectra and the spectral behavior has been studied by Hasinger & van der Klis (1989). In their classification scheme, low-luminosity sources belong to atoll sources. The island states of atoll sources exhibit high-frequency noise, which appears like white noise in the low-frequency part of the power spectrum with an exponential cutoff around 1 Hz. Similar results were obtained for X1850−087 in this study. Also, variability in the color-color diagram is small, which is similar to the island state of atoll sources. Therefore, based upon the power spectrum and the spectral variability, we conclude that X1850−087 was in an island state during the *Ginga* observation.

To date, cyclotron spectral line features have only been reported in a few X-ray systems: 4U 0115 + 63 (Wheaton et al. 1979; Nagase et al. 1991), Her X-1 (Trumper et al. 1978), X0331+53 (Makishima et al. 1990), Cep X-4 (Mihara et al. 1991), and 4U 1538+52 (Clark et al. 1990), all of which exhibit absorption lines. These are all systems which contain known pulsars. An emission line feature at 11.9 keV was observed in one set of X1850−087 observations. Although the identification of noncelestial origin of this line cannot be discarded, if this feature is due to the cyclotron emission, the required strength of the magnetic field is about 10^{12} gauss, which contradicts the canonical weakly magnetized neutron star model for low-mass X-ray binaries. However, recent results from 4U 1626-67 (Verbunt, Wijers, & Brum 1990) suggest that neutron stars can grow old without a loss of magnetic field strength. Also this system has exhibited a flare which lasted for up to 78 minutes (Cominsky et al. 1977), and during this flare, an indication of a 3.5 or 7 s pulsed emission was reported, although our observations did not find it. This pulsed emission detection along with the observations of the possible emission line may suggest that X1850−087 is a binary system with an underlying pulsar that is primarily obscured by an accretion disk.

4. CONCLUSION

We have studied the X-ray properties of X1850−087 in a low-luminosity state. These are the first results for low-luminosity, low-mass X-ray binaries in the luminosity range 1×10^{36} ergs s^{-1}, as previous work has focused on sources in the luminosity range 3×10^{36}–6×10^{37} ergs s^{-1}. The spectrum of X1850−087 exhibits an approximate power law spectrum. This characteristic is consistent with previous observation of the 3.7×10^{36}–6×10^{37} ergs s^{-1} sources. Numerous types of spectral models were fitted to the data. The two most discussed models are (1) Model 1 (disk-blackbody + Comptonized blackbody) which yields a color temperature about 1.5 times larger than the effective temperature and (2) Model 2 (unsaturated Comptonization) which requires a hot and thin plasma to be responsible for Compton scattering. No iron K emission line was required to fit the data, with a 90% upper limit equivalent width of 64 eV. However, an emission-line feature at 11.9 keV was observed in one set of observations. The origin of this feature is unknown. Significant temporal variation in the luminosity was also detected for X1850−087. This variability is similar to the high-frequency noise reported by Hasinger & van der Klis (1989) for atoll sources. Therefore, we would classify X1850−087 as an atoll source.

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