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HARD X-RAY PULSATIONS IN GX 1+4

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ABSTRACT

The x-ray pulsar GX 1+4 was observed by us in four balloon- borne experiments carried out from Hyderabad, India during 1991-1995 period with a hard x-ray telescope. The x-ray telescope consists of two collimated large area xenon-filled proportional counters with an effective area of 2400 cm^2, a field of view of $5° \times 5°$ and sensitive in the energy band of 20 - 100 keV. The pulsar was detected in bright state in two of the four experiments and x-ray pulsations with 120 second period were detected clearly. Pulsation period, rate of change of period with time, pulse fraction, pulse profile and energy spectra of the source were determined from these studies. During March 1995 observation, the x-ray pulse of GX 1+4 was found to be double-peaked compared to a single-peak pulse profile detected in December 1993. Details of these results are presented and their interpretation discussed in terms of the current accretion models of x-ray binaries.

I. INTRODUCTION

The 121 sec x-ray pulsar GX 1+4, originally discovered in a balloon experiment, has been extensively studied in low as well as hard x-ray bands. This pulsar is distinguished by hardness of its spectrum and very high spin-up and spin-down rates. Till early eighties it was monotonically spinning-up, It then made a transition to a low state and when it again became observable in 1987, it was found to be spinning down (Makishima et al, 1988). BATSE experiment on the Compton Gamma-Ray Observatory (CGRO) has been regularly monitoring pulsations in GX 1+4. It has been found to be spinning-down continously since it entered the bright phase.

We carried out four balloon observations of this source since 1991 to study its hard x-ray pulsation characteristics. In two of the flights prior to 1993, it was found to be very faint in hard x-rays. However, in December 1993 and March 1995 observations, it was detected as a bright source. In this paper we report results of these observations, mainly from data in the bright state.

II. OBSERVATIONS

We observed GX 1+4 with a large area Xenon-filled multi-anode Proportional Counter (XMPC) telescope on four occasions during 1991-95. All the balloons were launched from Hyderabad (India). The XMPC telescope, sensitive in 20-100 keV energy band, consists of two identical collimated xenon-filled multi-layer proportional counters, with a field of view of $5° \times 5°$ and a total effective area of about 2400 cm^2. The energy resolution of the detectors is typically 13% FWHM at 22 keV. The x-ray telescope is mounted on an oriented platform and using an onboard automated tracking system, it can be programmed to continously track any source. Source and background observations in a nearby source-free region, are alternately carried out in studies of hard x-ray emission from discrete sources. For further details of the x-ray telescope and associated instrumentation refer to Rao et al (1991) and Agrawal et al (1994).

A summary of all the observations with the measured source count rates is given in table 1. It will be seen from the table that prior to December 1993, GX 1+4 was in a low intensity state in hard x-rays. Its flux increased by an order of magnitude some time during April 1992 to December 1993 period. It was still in a bright state when observed on March 22, 1995, although the count rate had declined by about 20% compared to that measured in December 1993. It may be pointed out that balloon launched on March 22, 1995 reached a ceiling altitude of corresponding to a residual atmosphere of 2.5 g cm^{-2}. A careful analysis of the background showed that it was constant during all the flights.

III. ANALYSIS AND RESULTS

(a) Study of Pulsations

Search for x-ray pulsations was made in the data from all the four observations using a FFT algorithm based on the Lomb-Scargle method (Scargle 1982). Since GX 1+4 was detected in a weak state during 1991 and 1992 observations, no pulsations could be detected from it. Strong pulsations with a period of 121.0 4$\pm$ 0.4 s were, however, detected in data from both the detectors in the observation of December 1993. Combining this pulse period with the BATSE measurement on 1993 September 5 (Finger et al 1993) a spin-down rate ($\dot{p}$) of 1.6 $\pm$ 1.4 s per year was derived (Rao et al 1994). Similar timing analysis of the March 1995 data of both the detectors gave a pulsation period of 121.88 $\pm$ 0.09 s. Combining the two measurements of December 1993 and March 1995, a spin-down rate of 0.72 $\pm$ 0.40 s per year is obtained which is smaller than the average spin-down rate of 1.4 s per year since 1987. This difference can be explained by BATSE observations which showed a temporary transition from spin-down to spin- up during the intervening period (Chakrabarty et al 1994).

Table 1. summary of observations and count rates.

Observation date	Duration of Source observations (seconds)	Source Count rate counts per sec.
1991 Dec. 11	3100	1.29 ± 0.15
1992 April 5	6307	1.14 ± 0.11
1993 Dec. 11	Det A 2775	10.1 ± 0.19
1995 March 22	7200	8.0 ± 0.20

Table 2. Summary of Pulsation Characteristics of GX 1+4

Observation date	Pulsation period(S)	Spin-down rate (p) (sec per year)	Pulse fraction in 20-100 keV
1993 Dec. 11	121.0 ± 0.4	1.6 ± 1.4	35%
1995 March 22	121.88 ± 0.09	0.72 ± 0.40	30%

Table 3. Summary of Spectral index and luminosity in 20-100 keV band for GX 1+4.

Date of observation	Power law photon index	χ^2 per degree of freedom	X-ray luminosity in 20-100 keV band (ergs per sec).
1991, Dec. 11	2.3 ± 0.9	0.58	1.0×10^{37}
1992, April 5	2.7 ± 0.9	1.19	1.60×10^{37}
1993, Dec.11	1.54 ± 0.18	1.15	$(7.9 \pm 0.3)\ 10^{37}$
1995, March 22	1.67 ± 0.11	1.10	$(2.5 \pm 0.3)\ 10^{37}$

Pulse profiles for the two bright state observations were constructed the in 20-100 keV band by folding the data with the measured pulsation periods. The pulse profile has a single broad peak in December 1993 but this changed to a double-peak pulse in March 1995 as shown in fig. 1. A similar double-peak pulse profile was earlier reported by Makishima et al (1988) in 2-20 keV band from Ginga observations. Average pulse fraction in 20-100 keV interval is estimated to be about 30% which is only slightly lower compared to a value of 35% measured in December 1993. Measurement of the pulse fraction in two energy bands showed no significant variation of pulse fraction with energy. A summary of the measured pulsation characteristics of GX 1+4 is given in table 2.

(b) Energy Spectrum

The energy spectra for GX 1+4 were derived from observed pulse height distributions using detector response function generated from a Monte Carlo analysis. Details of the Monte Carlo routine and spectral analysis procedure are given by Chitnis (1994). A power law model gave acceptable fit for all the observations. Best fit power law spectrum obtained from March 27, 1995 experiment is shown in Fig. 2. A summary of the photon spectral index with 90% confidence limits for all the observations is given in table 3. Using the best fit spectral values, the x-ray luminosity in 20-100 keV band has been estimated for all the observations and shown in table 3 for an assumed source distance of 10 kpc. No significant difference was detected in the energy spectrum of the pulsed and unpulsed components of GX 1+4 in March 27, 1995 flight.

It may be noted from table 3 that x-ray luminosity of GX 1+4 had declined by a factor of about 3 by March 22, 1995 compared to the one observed 15 months earlier. The count rate given in table 1 for March 22, 1995 is, lower by only 20% compared to that on December 11, 1993. This apparent anamoly is due to the fact that March 22, 1995 observations were made from a residual atmospheric depth of 2.5 g cm^{-2} compared to a value of 3.9 g cm^{-2} for the December 11, 1993 observation. This results in a larger fraction of the count rate of March 22, 1995 due to photon of less than 40 keV compared to the one on December 11, 1993.

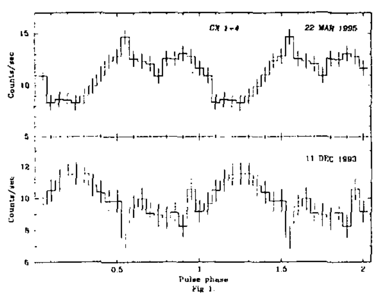

Fig. 1.— *Single and Double-peak pulse profiles of 121 s* pulsations in GX 1+4 as obtained from the observations of December 1993 and March 1995.

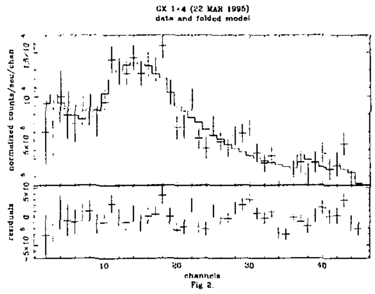

Fig. 2.— *Energy spectrum of* GX 1+4 derived from March 22, 1995 experiment. The crosses are the observed points and the continous curves show the best fit spectrum for a power law model.

IV. CONCLUSIONS

The x-ray pulsar GX 1+4 was detected as a bright hard x-ray source in two balloon observations and pulsations with a pulse fraction of about 30-35% were detected. From the measured pulsation periods a lower value of the spin-down rate has been measured compared to the one found by BATSE. This can, however, be explained as arising due to transitory change from spin-down to spin-up state as revealed by BATSE. There was a remarkable change in the shape of the pulse profile from a single peak pulse to a double-peak pulse in the intervening period of 15 months in 20-100 keV band. This change in the pulse profile can be explained in two possible ways. In one scenario, the asymmetrically located second magnetic pole of the neutron star becomes active due to increased accretion, producing the second peak in the pulse profile. Alternatively it is conceivable that the beam pattern changed from a pencil beam to a fan beam. More detailed low and hard x-ray observations should be carried out to understand these complex changes in this fascinating pulsar.

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