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DETECTION AND PERIOD MEASUREMENTS OF GX1+4 AT HARD X-RAY ENERGIES WITH THE SIGMA TELESCOPE

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ABSTRACT

The galactic Low Mass X-ray Binary GX1+4 has been detected by the coded aperture hard X-ray/gamma-ray SIGMA telescope during the February/March/April 1991 observations of the galactic center regions. The source, whose emission varied during the survey of a factor greater than 40 %, reached a maximum luminosity in the 40-140 energy range of 1.03 10^{37} erg s^{-1} (D=8.5 kpc), thus approaching the emission level of the 1970-1980 high state. 2 minute flux pulsations have been detected on March 22 and on March 31/ April 1. Comparison with the last period measurements shows that the current spin-down phase of GX1+4 is ending. Concerning the proposed association of this source with the galactic center 511 keV annihilation emission, upper limits have been derived.

1 INTRODUCTION

GX1+4 is the X-ray pulsar nearest to the galactic center. It was discovered first at high energies (E>20 keV) by the MIT Balloon Group in 1970 [1] and later identified in the X-ray band (2-10 keV) with the source 4U1728-24 [2]. X-ray pulsations of about 2 minutes period were interpreted as the spin signature of a highly magnetized neutron star accreting matter from a normal companion. During all the 1970's GX1+4 maintained an average X-ray emission level of 100 mCrab that, for d=8 kpc, gives a typical luminosity of 10^{37}-10^{38} erg s^{-1}, while the pulsation period decreased steadily with a spin-up rate of dP/dt = -2.6 s yr^{-1}, the fastest among the known pulsars. As pointed out by the discoverer the energy spectrum stretches deeply to high energies (kT=30-50 keV for thermal bremmstrahlung models or, alternatively, α = -2.7 for a power law) making GX1+4 the hardest pulsar and one of the brightest sources of the galaxy also for E>30 keV.

In the early 1980's, however, GX1+4 faded away. Deep exposures performed by EXOSAT in 1983 and 1984 failed to reveal any signal down to an upper limit of 0.4 mCrab (2-7 keV band) [3]. It was only in 1987 that the source was again detected by

GINGA, but at the weak level of 3 mCrab [4]. GINGA and the X/gamma HEXE instrument onboard the MIR space station observed GX1+4 in 1987,1988 and 1989 [5][6][7][8] showing that, at X-ray energies, the source has brightened up to a level of about 15 mCrab and that the pulsation period had unambiguously reversed the spin up to a spin down at the quite steady rate of $dP/dt = +1.4\ s\ yr^{-1}$. The HEXE luminosity in the 20-100 keV energy band was $1.0\ 10^{37}\ erg\ s^{-1}$ on October 31, 1987, assuming a distance of 10 kpc.

In 1990, SIGMA has detected the pulsation of GX1+4, confirming the spin down phase but at a slower rate ($dP/dt = +0.9\ s\ yr^{-1}$)[9].

McClintock and Leventhal [10] made the hypothesis that this source could be the compact source responsible for the variable positron/511 keV galactic center line [11][12]. However, no decisive argument was given to rule out another hard source, 1E1740-2942, and the authors deferred the final word to observations carried out by imaging/high resolution gamma ray instruments.

In this paper we discuss the observations of GX1+4 at hard X/soft gamma energies (0.035-1.3 MeV) performed by the coded aperture SIGMA telescope during the winter/spring 1991 survey of the galactic center.

2 THE SIGMA TELESCOPE

The CEA/CESR/CNES imaging telescope SIGMA is the main payload of the Soviet scientific satellite GRANAT in orbit since December 1989. The detector is an Anger camera which measure energies and interaction points of photons in the 0.035-1.3 MeV energy range. The optical system is provided by an URA coded mask placed 2.5 m in front of the detector.

This arrangement features a Full Sensitivity Field of View (FSFOV) of 4.7°x 4.3°. In a wider external zone (11.5°x10.9° at half sensitivity), named Partially Coded Field of View (PCFOV), the incomplete shadowing progressively reduces the instrument sensitivity to zero.

During a typical SIGMA observation, lasting approximately one day, the telescope records three series of 'spectral' images (124 x 116 3.30 arcmin pixels) in 95 energy channels which cover the entire energy range varying with the energy resolution. In addition, the total camera counts are stocked every 4 s in four energy bands. Dead time information is also known every 4 s.

More details about the instrument and the data collection modes can be found in Paul et al. [13] while the in-flight performances are described by Mandrou et al. [14].

3 OBSERVATIONS

Figure 1 shows the strong variability of the Galactic Center region during Spring 90, Winter 91, and Spring 91 [15]. Contour levels are drawn every 0.1 cts/s starting at 0.25 cts/s.

The first image shows the well known source 1E1740.7-29.42 and the source GRS 1758-258, discovered by GRANAT. GX1+4 is not visible.

In the second image taken in Winter 91, appears only the GRANAT source. 1E1740.7-29.42 has faded away and GX1+4 is not yet visible.

GX1+4 dominates the third image taken in March/April 91. 1E1740.7-29.42 is still below the SIGMA detection limit and GRS 1758-258 is detected at the same flux level as it was observed in Spring and Fall 1990.

In order to better determine the source position as detected by SIGMA, the Spring 91 observations in the range 43-77 keV have been fitted with the SIGMA/URA point spread function having as additional free parameters the amplitude and the background level. Best fit equatorial coordinates are :

α_{1950}=262.26 ± 0.06 deg.

δ_{1950}=-24.74 ± 0.06 deg.

where the errors indicate the 95% confidence level. This position is fully compatible with the optical position.

A simple χ^2 analysis performed including all positive and negative observations in the 40-77 keV range reveals that

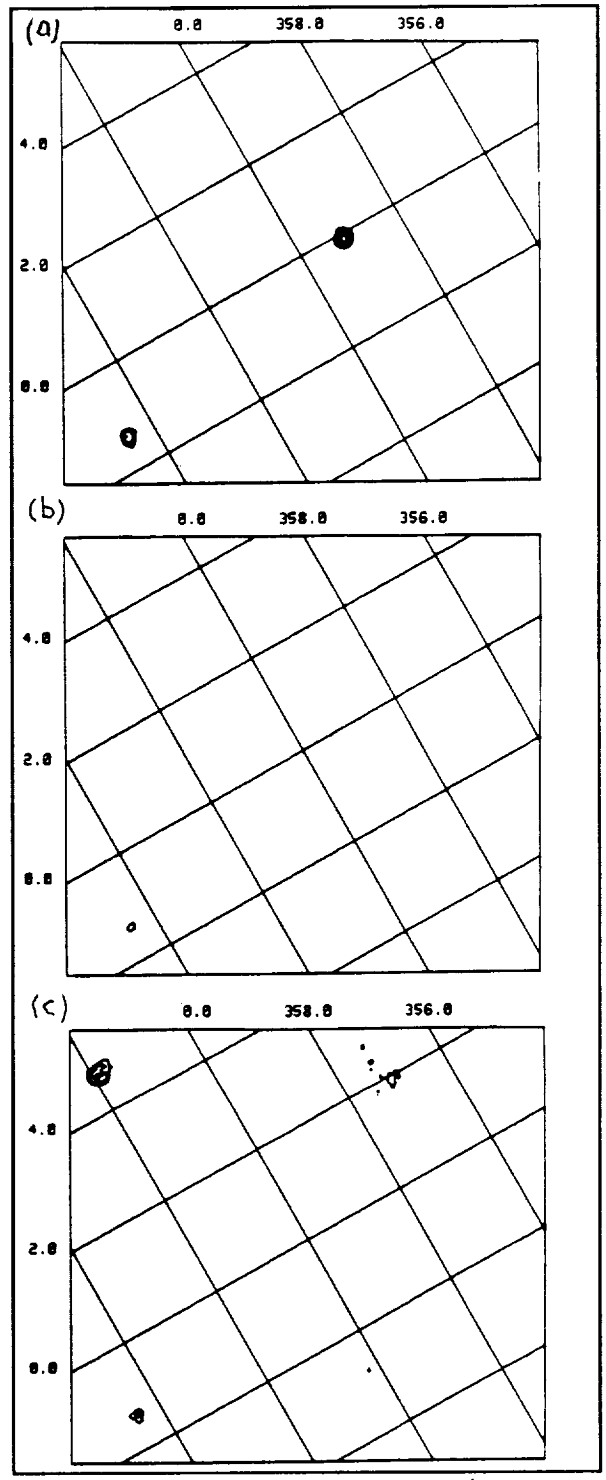

Figure 1 SIGMA observations of the Galactic Center region in the 40-110 keV energy band : (a) Spring 90. (b) Winter 91. (c) Spring 91.

during the Spring 91 survey the source was variable at a very high (99.95%) confidence level; taking into account only the positive observations the confidence drops to 95%. The mean positive count rate during the positive detections (0.27+/-0.03 cts/s) compared to the upper limits derived in the other cases suggests a variation of more than 40% of the hard flux.

An average raw energy spectrum of the source has been obtained regrouping the net source counts in 10 channels covering the band 40-140 keV. This spectrum has been fitted folding successively a power law and a thermal bremmstrahlung model with the detector response function [16]. The best fitting slope and electron temperature was -3.5 (-4.5:-2.8) and 28.4 (18.7:46.7) keV respectively. Errors are given at the one sigma confidence level.

The average flux in the 40-77 keV energy band was 125 mCrab on March/ April 1991. Assuming a distance of 8.5 kpc, the source luminosity reached on March 22 the level $L = 1.1 \pm 0.3\ 10^{37}$ erg s^{-1} in the 40-140 keV energy interval.

No statistically significant evidence of a peaked annihilation/511 keV emission has been found, at the source position, in individual observations of the survey nor in their sum which totals a dead-time corrected exposure time of about $2.3\ 10^{5}$ s. This enables to put an upper limit of $1.9\ 10^{-3}$ phot. cm^{-2} s^{-1} (90% confidence level) for a 511 keV emission from GX1+4.

4 THE PULSE PERIOD AND PROFILE

In order to measure the source pulsation we have used the epoch folding method applied on 4 s total camera counts computing the χ^2 statistic against the hypothesis of uniform distribution. The four accumulation energy bands have been held fixed at 40-77, 77-155, 155-290 and 290-630 keV throughout the whole survey.

As the spacing between statistically independent periods ($\Delta P = P^2/T_s$, T_s total time of observation) was, in all the cases, substantially greater than the period shift expected from the last measured period derivative [9] we have not used this term in the folding procedure.

We have detected the pulsation of GX1+4 in the first energy band, in two sets of observation.

The results are summarized in the following table :

Date	Time base T_s (10^4 s)	Epoch of observation (JD-2440000)	Period (s)
03/22/91	5.6	8338.59	115.06±0.03
03/31/91 & 04/01/91	19.6	8347.87	115.086±0.005

The light curve relative to the second period detection is traced in Fig. 2. It reveals a smooth profile with a broad single hump. The better defined March 31/ April 1 curve appears asymmetric about the peak position with a sharp drop on the right side. Contrary to previous detections [8][17] our results do not show any evidence of a double peak pulse confirming that the high energy profile is variable. The ratio of the modulated flux to the modulated+steady component for the March 22 observation was 0.54+/-0.15 while for the March 31/April 1 observation it was 0.67+/-0.14. These values indicate an highly modulated flux as already reported in the review of Frontera and Dal Fiume [18] at the same energies and by Kendziorra et al. [19].

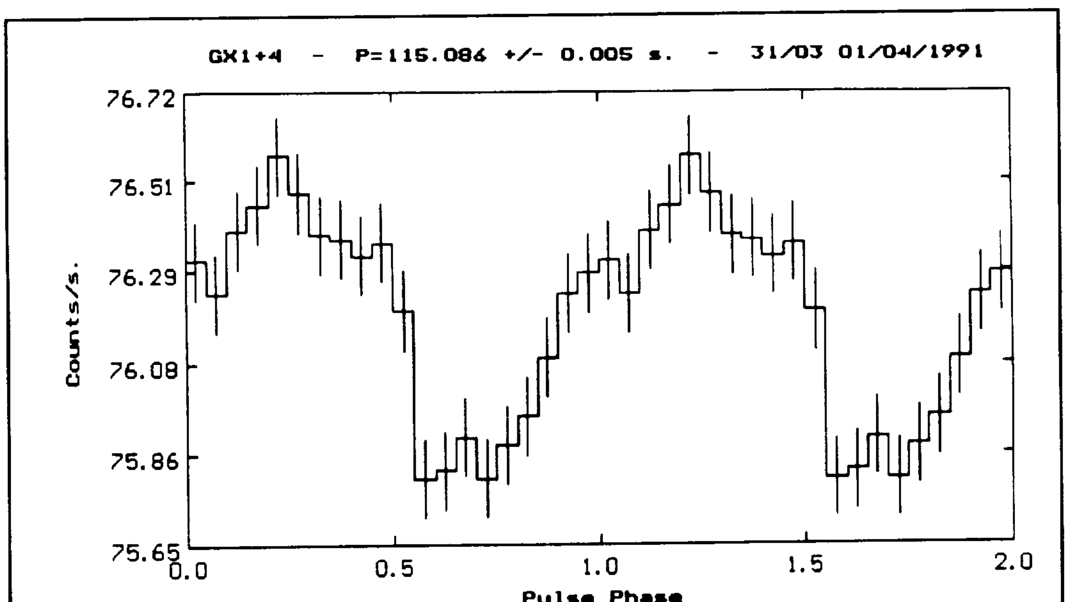

Figure 2 Light curve of GX1+4 during March 31 /April 1 observation.

It has been reported by some authors [20][21][22] that for E>20 keV there are significative differences between odd and even pulses and that the true pulsation has a period twice the 2 minute period. In this respect we have folded our data at the double of the periods reported into 20 bin light curves. Then, the two halves of the light curves have been compared by means of a standard χ^2 Test. Reduced χ^2 (10 d.o.f.) values were 1.51 and 0.57 for the March 22 and the March 31/April 1 respectively, i.e. values compatible with the null hypothesis.

5 PERIOD HISTORY

Since 1986 GX1+4 has showed a clear spin down behavior. Taking into account the Ginga and the Kvant measurements in 1986-1989 an average spin down rate of $dP/dt = 4.5\ 10^{-8}$ s s^{-1} has been derived with little deviations from the linear trend [8]. However the two GRANAT points in 1990 and 1991 (Barret et al. [9], and this paper) have significantly changed the scenario showing that the spin down rate is unambiguously lowering. In fact, comparing our March 31/April 1 measurement with the point obtained by Barret et al. [9] on August, 27th 1990, an average spin down rate of $dP/dt = 2.6 +/- 0.3\ 10^{-8}$ s s^{-1} is deduced, a value which further lower the last dP/dt ($3.1\ 10^{-8}$ s s-1) measured by Barret et al. [9]. The complete period history of GX1+4 is shown in Figure 3.

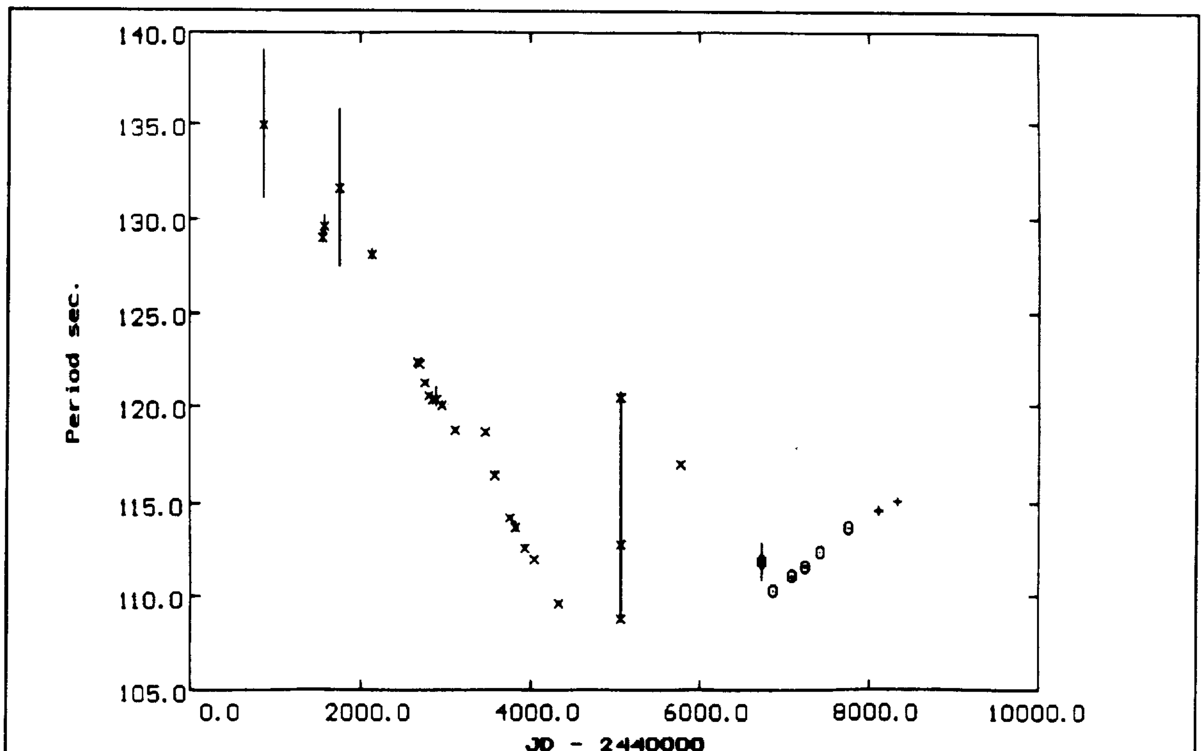

Figure 3 Period history of GX1+4.

6 CONCLUSIONS AND DISCUSSION

The winter/spring 1991 SIGMA survey has shown the strong variability of the Galactic Center region. For instance, the 40-77 keV flux from GX1+4 has varied by more than 40%. At maximum level the source luminosity reached $1.1\ 10^{37}$ erg s^{-1} (40-140 keV) assuming a distance of 8.5 kpc. Similar luminosity levels have been reported during the '70 when the source was in the high state.

The average energy spectrum has been found softer than expected and looks more similar to the steeply falling spectra typical of other known hard X-ray binaries (GX304-1, GX301-2, 4U1626-67) rather than to previously recorded spectra from GX1+4. Given the large error bars, our plasma temperature can be made consistent with the temperature of 41+/-8 keV measured by the AIT/MPI group [19] but a decrease is found if we compare our value with the more recent HEXE measurement [8].

We have obtained an upper limit for the annihilation emission coming from GX1+4 ($1.9\ 10^{-3}$ phot cm^{-2} s^{-1}) that does not rule out this source as the compact galactic center annihilation emitter, since reliable 511 keV fluxes from the compact component lower than 10^{-3} phot cm^{-2} s^{-1} have been recorded [23][24][25][26]. A more compelling limit ($0.6\ 10^{-3}$ phot cm^{-2} s^{-1}) was given by the OSSE instrument onboard the GRO satellite (this conference).

We have detected the 2 minute pulsation period in the 40-77 keV range on two occasions (considering the 03/31-04/01 observations as a single detection). Folded light curves reveal a broad single hump. There is no indication of the double peak structure previously detected at hard energies. Marginal evidence has been found concerning the differences between alternate pulses. Our result ($dP/dt = +0.8 \pm 0.09$ s yr^{-1}) confirms the spin down trend observed by GINGA and during the first SIGMA survey of the galactic center but at a slower rate [27][9]. The pulsation history clearly suggests that the current spin down phase of GX1+4 is ending.

The evolution we observed in GX 1+4 could be due to an increasing accretion rate as it is expected from a "fast rotator" with a magnetic field of $\approx 10^{12}$ Gauss [28]. As the luminosity of the source reaches the values obtained during the seventies, it seems reasonable to think that GX1+4 will end soon its spin down trend and perhaps go back to a spin up period.

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