Astron. Astrophys. 331, 557–563 (1998)

ASTRONOMY
AND
ASTROPHYSICS

Hard X-ray observations of X-ray Nova Ophiuchi 1993 (GRS 1716-249) with GRANAT/SIGMA

M. Revnivtsev[1], **M. Gilfanov**[1,2], **E. Churazov**[1,2], **R. Sunyaev**[1,2], **K. Borozdin**[1], **N. Alexandrovich**[1], **N. Khavenson**[1], **I. Chulkov**[1], **A. Goldwurm**[2], **J. Ballet**[2], **M. Denis**[2], **P. Laurent**[2], **J-P. Roques**[3], **V. Borrel**[3], **L. Bouchet**[3], **and E. Jourdain**[3]

[1] Space Research Institute, Russian Academy of Sciences Profsoyuznaya 84/32, 117810 Moscow, Russia
[2] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85740 Garching, Germany
[3] CEA, Centre d'Etudes de Saclay Orme des Merisiers, F-91191 Gif-sur-Yvette, Cedex, France
[4] Centre d'Etude Spatiale des Rayonnements 9, avenue du Colonel Roche, BP 4346, F-31029 Toulouse Cedex, France

Received 5 May 1997 / Accepted 20 October 1997

Abstract. The results of observations of X-ray Nova Ophiuchi 1993 (GRS 1716-249) in the hard X-ray/low γ-ray energy domain with the SIGMA telescope aboard the GRANAT observatory are reported. The hard X-ray emission from the source has been observed by SIGMA during the bright flare in 1993 and one year later-during the reappearance of the source in 1994.

The SIGMA data combined with results of quasi simultaneous TTM (MIR-KVANT) observations, give a possibility to study the spectral behavior of the source in the 2-300 keV energy band. Both in 1993 and 1994 the broad-band spectrum of GRS 1716-249 was quite similar to the low (hard) state spectrum of Cyg X-1, although subtle spectral variations, possibly correlated with the luminosity, were clearly detected.

The results of timing analysis are also presented. Along with a turnover of the power density spectrum at high frequencies (above 0.2 Hz), typical for black hole candidates, a strong decline of the power density towards lower frequencies was found at $\nu < 0.01$ Hz. This behavior of the PDS differs from the PDS observed for Cyg X-1 and resembles those observed for X-ray Nova Per 1992.

Key words: accretion disks – black hole physics – gamma-rays: observations – X-rays: stars

1. Introduction

The X-ray Nova Ophiuchi (GRS1716-249 = GRO J1719-24) has been discovered on Sept. 25, 1993 simultaneously by the SIGMA telescope aboard GRANAT (Ballet et al. 1993) and BATSE aboard CGRO (Harmon et al. 1993). The new source has been localized by SIGMA with 1′ accuracy (90% error circle radius) at R.A.=$17^h16^m34^s.3$, Dec.=-24°57′45″(1950 equinox). Follow up optical observations revealed an optical counterpart of the new source with optical light curve being very similar to that of Nova Muscae 1991 (Della Valle et al. 1994). The optical data support the idea that GRS 1716-249 is a low-mass X-ray binary system (Della Valle et al. 1994). The distance estimates range from 2 to 2.8 kpc (Della Valle et al. 1994).

During Sept.- mid Dec. 1993 the X-ray Nova, located 7°.0 from the Galactic Center, was the brightest hard X-ray source in this region with peak flux of $\sim$ 1.2 Crab 35-150 keV (Harmon et al. 1993, Van der Hooft et al. 1996). Observations in the standard X-ray band performed in 1993 with the TTM telescope aboard MIR-KVANT did not find any indication for a soft spectral component (Sunyaev et al. 1994), the overall source spectrum resembling the γ_2/γ_3 state spectrum of Cyg X-1 and the spectra of other X-ray Novae lacking the soft component (e.g. Nova Perseus 1992 = GRO J0422+32).

Though the initial behavior of the GRS 1716-249 was very similar to that of other X-ray Novae its further evolution was quite unusual (e.g. Goldwurm et al. 1994; Vargas et al. 1996a for comparison with KS/GRS 1730-312). According to BATSE data (Van der Hooft et al. 1996) obtained during $\sim$ two and a half months in Sept.– mid Dec. 1993 the hard X-ray flux from the source declined at a very low rate: between October 1 and November 22 hard X-ray flux decreased by only $\sim 15 \pm 3\%$ (Van der Hooft et al. 1996, cf. $\sim 30^d$ typical exponential decay time for other X-ray Novae) and then dropped quickly within a week below the sensitivity level of the BATSE instrument.

BATSE timing analysis of the 1993 flare showed, that power density spectrum of the source has a significant quasiperiodic oscillation peak, the centroid frequency of which increased from $\sim$ 0.04 Hz at the onset of the outburst to $\sim$ 0.3 Hz at the end (Van der Hooft et al. 1996). It was also found that evolution of PDS can be described as a gradual stretching by a factor of $\sim$ 7.5 in frequency of the power spectrum, accompanied by a decrease of the power level by the same factor, such that the integrated power in a scaled frequency interval remains constant.

One year later, in the Fall of 1994, the source was detected again by all three instruments – SIGMA (Churazov et al. 1993,

Send offprint requests to: M. Revnivtsev(revnivtsev@hea.iki.rssi.ru)

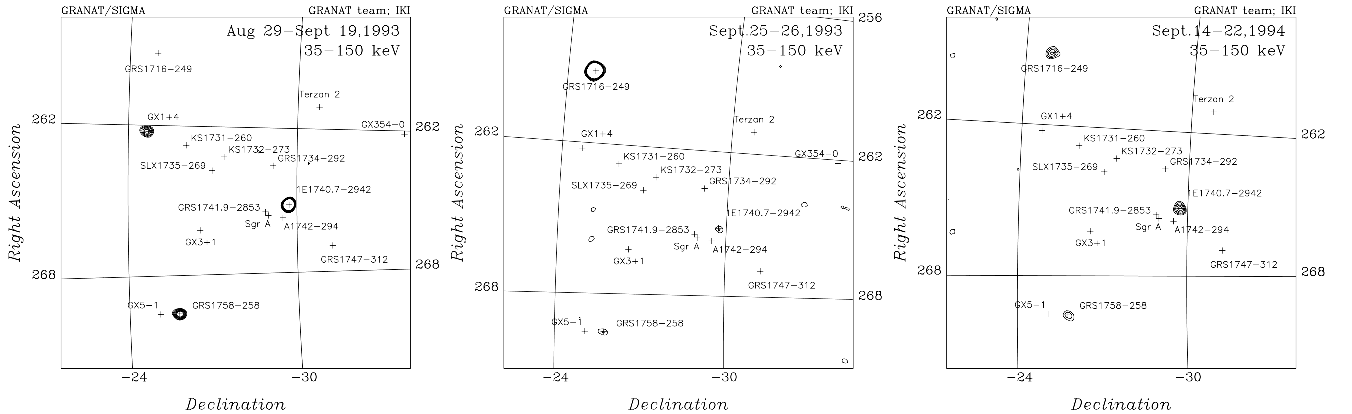

Fig. 1. The 35-150 keV band images of the GC region obtained by SIGMA in 1993 and 1994. The SIGMA data were summed over Aug. 28-Sept. 19, 1993 – *left* (all 1993 Fall observations prior to flare, 1σ at the position of the source corresponds to 6 mCrab), Sept 25-26, 1993 – *middle* (first detection of the source, 1σ=17 mCrab) and Sept 14-22, 1994 – *right* (a set of observation in 1994 Fall, 1σ=13 mCrab). The contours go from 4σ through 9σ and are spaced by 1σ

Vargas et al. 1996b), TTM (Borozdin et al. 1994) and BATSE (Harmon et al. 1994) at the level of $\sim$ 10% of its 1993 value. In 1995 the telescope TTM aboard MIR-KVANT observed this region of sky on several occasions, each time detecting positive 2-30 keV flux from GRS 1716-249 (Borozdin et al. 1995). Radio and X-ray observations of the source in 1995 revealed a relation between X-ray and radio events similar to that observed for superluminal radio jet source GRO J1655-40 (Hjellming et al. 1996).

Below we report the results of hard X-ray observations of the GRS 1716-249 with GRANAT/SIGMA during its bright flare in 1993 Fall, the recurrent flare in 1994 Fall, results of monitoring this region in 1990-1993 prior to the first detection of GRS 1716-249 and resent observations in 1995-1997. The broad-band (2-400 keV) spectral behavior of the source is studied combining the SIGMA data and results of the TTM observations (Sunyaev et al. 1994) of GRS 1716-249 for 1993 and 1994 flares.

2. Instrument and observations

The GRANAT observatory was launched on a high apogee orbit on December 1, 1989. It carries the SIGMA coded-mask telescope (Paul et al. 1991) which is capable of obtaining sky images in the 35-1300 keV energy band divided into 95 energy channels. The nominal angular resolution (corresponding to the mask pixel size) is approximately 13 arcmin . The point source localization accuracy varies from 3-4 arcmin to less than 1 arcmin, depending on the brightness of the source and the number of observations. Half-sensitivity boundary of the instrument field of view (FOV) is a $11\overset{\circ}{.}5 \times 10\overset{\circ}{.}9$ rectangle of which the central $4\overset{\circ}{.}7 \times 4\overset{\circ}{.}3$ correspond to fully coded field of view with constant sensitivity. The energy resolution of the instrument at 511 keV is $\sim$ 8 %.

Since GRS 1716-249 is located $7\overset{\circ}{.}0$ from the Galactic Center, it was within field of view of SIGMA telescope (close to its edge though) during almost all observations constituting the Galactic Center survey conducted by SIGMA during 1990-1997. These observations were carried out yearly during the Spring and Fall. Each observational set consisted of from a few to several tens of observations and lasted from $\sim$ week to $\sim$ 2 months. The typical duration of each individual observation was $\sim$ 20 hours. This crude "set-wise" observational schedule is presented in Table 1, where observation start/end date and the exposure time of the data used for analysis of GRS 1716-249 are given for each observational set. The observations excluded from the analysis (e.g. due to uneven background conditions or GRS 1716-249 being too close to the edge of the field of view) were not included in summing the exposure time. The GRS 1716-249 flare began in the middle of 1993 Fall set, which is accordingly divided into two parts in Table 1. The detailed observational schedule for the part of this set corresponding to the first bright flare is presented separately in Table 2.

Fig. 1 shows three 35-100 keV images of $12\overset{\circ}{.}4$ by $13\overset{\circ}{.}0$ region of the sky, containing the GRS 1716-249 position. These three images correspond to the first half of the 1993 Fall observations prior to flare, the first observation when GRS 1716-249 had been detected and the summed set of observations in 1994 Fall when the source had been detected again.

3. Light curve

3.1. 1993 Fall bright flare

The source was positively detected for the first time during the observation which started on Sept. 25.5 1993 (see Table 2 and Fig. 1 and 2). No statistically significant (above 3σ) hard X-ray emission from GRS 1716-249 had been detected by SIGMA during previous observations (Fig. 1), with a 2σ upper limit on the 40-150 keV flux of 40 mCrab (Sept.18.4-19.3 – the last observation prior to discovery of the source) and 12 mCrab (Aug.28-Sept.19, averaged). The analysis of the entire dataset

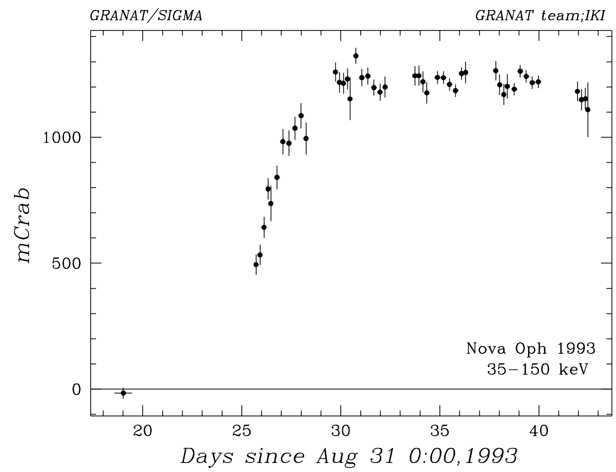

Fig. 2. The 35-150 keV light curve of GRS 1716-249 during the 1993 Fall flare

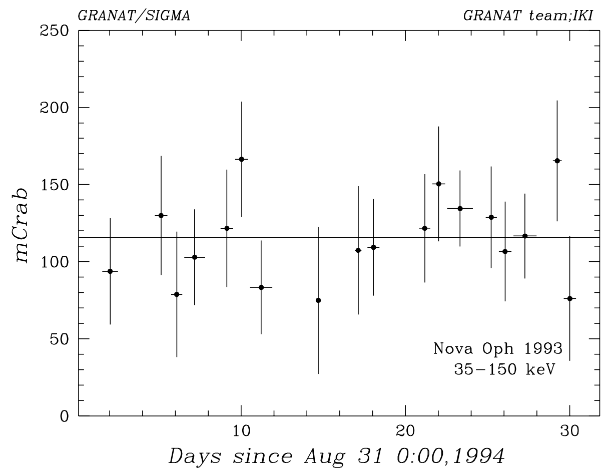

Fig. 3. The 35-150 keV light curve of GRS 1716-249 during the 1994 Fall flare. The solid line represents the average flux level of 115 mCrab

Table 1. GRS 1716-249 observations schedule

Date, UT	Exp. time hours	40-150 keV flux mCrab
Mar 24.7 – Apr 9.6, 1990	58.5	6.7 ± 7.3
Aug 23.7 – Oct 19.2, 1990	109.2	-3.6 ± 5.6
Feb 22.4 – Apr 2.6, 1991	112.7	10.6 ± 7.3
Aug 30.7 – Oct 19.3, 1991	132.2	1.1 ± 5.6
Feb 17.5 – Apr 9.7, 1992	272.5	9.6 ± 4.7
Sep 14.5 – Sep 23.3, 1992	104.0	18.2 ± 8.6
Feb 17.7 – Apr 16.5, 1993	292.0	2.3 ± 5.6
Aug 28.6 – Sep 19.3, 1993	290.7	4.4 ± 5.8
Sep 25.5 – Oct 14.1, 1993	240.1	[a]
Feb 24.5 – Mar 25.5, 1994	319.0	15.8 ± 5.5
Sep 1.4 – Sep 30.2, 1994	329.4	115.9 ± 8.1
Sep 9.5 – Sep 21.3, 1995	139.7	20 ± 11
Mar 15.6 – Mar 30.5, 1996	210.1	-20 ± 11
Mar 14.3 – Mar 28.6, 1997	197.9	-17 ± 20
Sep 16.4 – Sep 26.3, 1997	132.9	40 ± 16

1 mCrab corresponds to 1.4×10^{-11} ergs/s/cm^2 for 40-150 keV band for a crab-like spectrum.
[a] See Table 2

Table 2. GRS 1716-249 detailed observations schedule during 1993 Fall flare

Date, UT	Exp. time hours	40-150 keV flux mCrab
25.5 – Sep 26.4, 1993	17.5	641 ± 21
Sep 26.5 – Sep 28.2, 1993	34.0	995 ± 22
Sep 29.5 – Sep 30.4, 1993	17.0	1238 ± 21
Sep 30.5 – Oct 2.2, 1993	34.0	1235 ± 15
Oct 3.5 – Oct 4.3, 1993	16.0	1222 ± 21
Oct 4.6 – Oct 6.2, 1993	32.0	1232 ± 11
Oct 7.6 – Oct 8.4, 1993	15.0	1219 ± 22
Oct 8.5 – Oct 10.0, 1993	30.0	1230 ± 12
Oct 11.7 – Oct 12.4, 1993	12.6	1155 ± 24
Oct 12.5 – Oct 14.1, 1993	32.0	1152 ± 11

acquired prior to Sept.25, 1993 (Mar. 25,1990 – Sept. 19, 1993) does not give statistically significant value of the flux from the source (3.8 ± 2.0 mCrab at the position of GRS 1716-249; 40-150 keV).

The typical upper limit on the 40-150 keV flux obtained for a one day integration (individual observations) is $\sim 35 - 45$ mCrab (2σ).

The 40-150 keV light curve of the source observed during the bright flare in 1993 Fall (Fig. 2) is characterized by a gradual increase of the hard X-ray flux during $\sim$ 5 days, followed by a plateau with nearly constant flux at the level of $\sim$ 1.2 Crab, which was observed till the end of this GC region survey (finished on Oct.14). The exponential decay time, calculated over Sept.29.5-Oct.12.4, is 210^{+90}_{-50} days. A notable feature of the light curve shown in Fig. 2 is its smooth behavior on hours-days time scale. The relative *rms* of the points on the plateau of the light curve is 3.5%. It should be noted though, that the light curve in Fig. 2 was not corrected for small systematic variations of the detector gain, occurring during observational session, therefore the above value of relative *rms*, should be treated as an upper limit to the intrinsic variations of the source flux.

3.2. 1994 Fall flare

Due to the spacecraft navigational constraints the 1993 Fall observations of GRS 1716-249 were discontinued on Oct.14. During the next observational set in the spring of 1994, the 40-150 keV flux registered at the source position was 15.8 ± 5.5 mCrab, i.e. below 3σ, (see Table 1) but in the course of the 1994 Fall GC survey it has been statistically significantly detected again at a flux level of $\sim$ 115 mCrab (Fig. 1), i.e. at $\sim$ 10% of its 1993 Fall value. The 1994 Fall light curve is presented in Fig. 3. No statistically significant day-to-day flux variations were observed during this second flare, the data points being compatible with constant flux of 115 mCrab. However, due to GRS 1716-249 location close to the edge of the field of view, the upper limit on

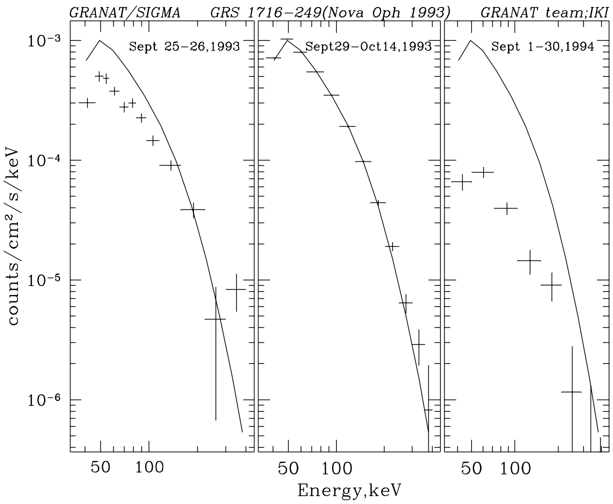

Fig. 4. The pulse-height spectra of GRS 1716-249 obtained by SIGMA during different time intervals: Sept. 25-26, 1993 (*left*), Sept.29 - Oct.14, 1993 (*middle*) and Sept. 1-30, 1994 (*right*). The solid line corresponds to the bremsstrahlung spectrum with kT = 85 keV – best fit to Sept.29 – Oct.14, 1993 data ("plateau" of the light curve)

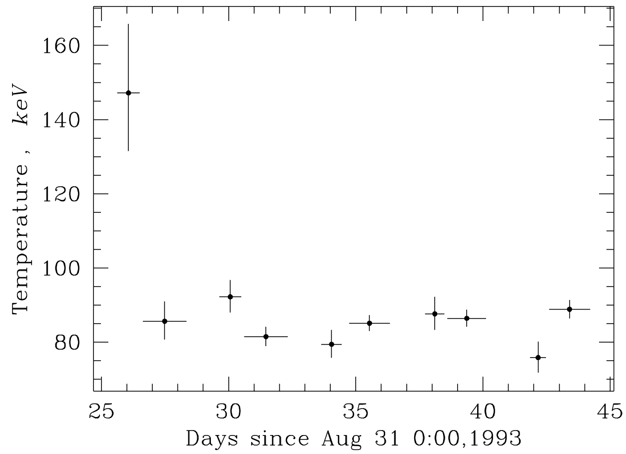

Fig. 5. The best fit bremsstrahlung temperature for individual observations during the 1993 Fall flare

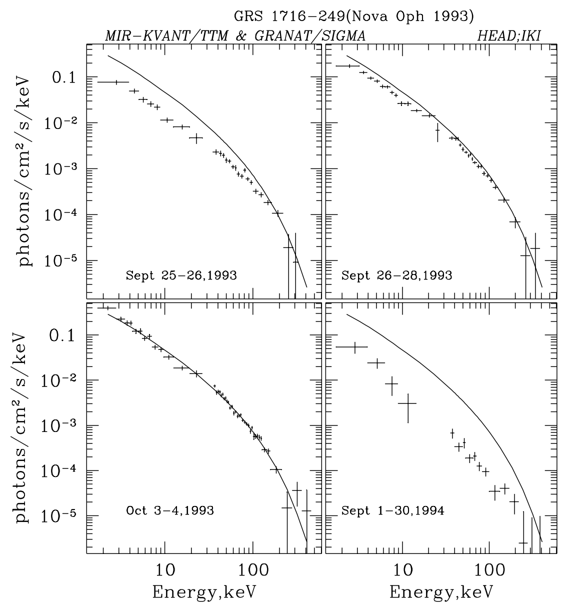

Fig. 6. The broad band spectra of GRS 1716-249 (combined data of TTM and SIGMA) at different dates. The solid line corresponds to the bremsstrahlung photons spectrum with kT = 81 keV – best fit to Oct. 3-4, 1993 data ("plateau" of the light curve) in the 2-400 keV energy range.

such variations is quite large, the 1σ flux error corresponding to $\sim$ 30% of the mean flux. The source remained bright till the end of this set of the GC observations, which finished on Sept.30, 1994.

4. Spectra

The pulse-height spectra of GRS 1716-249 obtained by SIGMA during the 1993 and 1994 flares are shown in Fig. 4. Solid line in Fig. 4 represents the best fit bremsstrahlung model for the spectrum of the source on the plateau of the lightcurve (Sept.29 – Oct.14, 1993). These spectra were collected over three different time intervals - Sept. 25-26, 1993 (the observation when the source was detected for the first time), Sept. 29 – Oct.14, 1993 (the "plateau" of the light curve, see Fig. 2) and Sept. 1-30, 1994 (all 1994 Fall data averaged). The results of spectral fitting these data are presented in Table 3.

The results of optically thin bremsstrahlung approximation (Kellogg et al. 1975) of individual observations during 1993 Fall are shown in Fig. 5. As is clearly seen from Fig. 2 and 5 the increase of the 40-150 keV flux was accompanied by a softening of its spectrum. No statistically significant variations of the best fit bremsstrahlung temperature have been detected on the "plateau" of the light curve (Sept.29-Oct.14, 1993). The 1993 Fall spectra are statistically significantly better fit by thermal models (comptonization model – Sunyaev&Titarchuk 1980 – or thermal bremsstrahlung) than by power law.

Relatively low intensity of the source and its location close to the edge of the SIGMA field of view did not give a possibility to study spectral variability of the source. No statistically significant variations of the spectral shape have been detected during this flare: the power law fit to 1994 Fall data divided into halves (Sept.1-17 and Sept.17-30) gives best fit values of the photon index 2.29 ± 0.25 and 2.10 ± 0.18 for the first and second half correspondingly (94^{+33}_{-26} and 112^{+38}_{-26} keV for optically thin bremsstrahlung model).

The TTM coded mask telescope aboard MIR-KVANT observed the GC region on several occasions in 1993 Fall and 1994 Fall (see Sunyaev et al. 1994 for a detailed description of the observations and results). Several of these observations were quasi-contemporaneous with SIGMA observations (namely Sept 26, 27; Oct 3, 7 1993; Sept 23, 26, 27, 28 1994), giving an opportunity to study broad band (from 2 keV to hundreds keV) spectral behavior of the source. The spectra and

Table 3. GRS 1716-249 spectral fit parameters (35-400 keV band, SIGMA data)

	1993 Fall			1994 Fall
Par.	Sept.25-26	Sept.26-28	Sept.29-Oct.14	Sept.1-30
	Power law			
α	2.00 ± 0.07	2.33 ± 0.05	2.34 ± 0.01	2.19 ± 0.15
F_{100}^a	3.94 ± 0.15	5.44 ± 0.16	6.63 ± 0.04	0.66 ± 0.06
χ^2(dof)	76.0(57)	88.2(57)	430.8(57)	60(57)
	Optically thin thermal bremsstrahlung			
T, keV	147^{+19}_{-16}	86 ± 5	85 ± 1	104^{+21}_{-20}
F_{100}^a	4.34 ± 0.15	5.97 ± 0.18	7.28 ± 0.04	0.74 ± 0.06
χ^2(dof)	72.0(57)	67.1(57)	127.5(57)	58.4(57)
	Comptonization model (Sunyaev Titarchuk,1980,[b])			
T, keV	55^{+33}_{-10}	37^{+6}_{-4}	$42.6^{+1.4}_{-1.3}$	$68^{+\infty}_{-28}$
τ	$2.4^{+0.6}_{-0.7}$	2.7 ± 0.4	2.3 ± 0.1	1.7 ± 1.2
F_{100}^a	4.27 ± 0.23	6.05 ± 0.21	7.25 ± 0.05	0.70 ± 0.06
χ^2(dof)	73(56)	66(56)	90(56)	59(56)

[a] Spectral flux at 100 keV, 10^{-4}/s/cm^2/keV
[b] This model use spherical geometry

Table 4. GRS 1716-249 spectral fit parameters (2-300 keV band, TTM and SIGMA data)

	1993 Fall			1994 Fall
Par.	Sept.25-26	Sept.26-28	Oct.3-4	Sept.22-30
	Comptonization model			
T, keV	33 ± 2	25 ± 1	27 ± 1	42^{+36}_{-12}
τ	4.4 ± 0.2	4.7 ± 0.2	4.2 ± 0.1	2.9 ± 0.9
F^a	18 ± 1	28 ± 1	38 ± 2	4.8 ± 1.3
χ^2(DOF)	117(93)	127(93)	171(147)	275(249)
	Optically thin thermal bremsstrahlung			
T, keV	154 ± 11	98 ± 3	81 ± 3	82^{+25}_{-16}
F^a	20 ± 2	32 ± 1	41 ± 1	4.2 ± 0.5
χ^2(DOF)	108(94)	107(94)	170(146)	281(250)

[a] Energy flux in 2-300 keV energy band, 10^{-9} erg/s/cm^2
The hydrogen column density was fixed at $N_H = 4 \times 10^{21}$ atoms/cm^2 as measured by ASCA in Oct. 1993 (Tanaka 1993)

results of their approximations by various models are shown in Fig. 6 and Table 4. For three 1993 Fall spectra in Fig. 6 the closest SIGMA observation has been chosen, the 1994 Fall spectrum is an average over all TTM and SIGMA observations performed between Sept. 22 and Sept. 30, 1994. It should be noted that the addition of TTM data to SIGMA data sufficiently reduces the confidence intervals, especially for comptonization model parameters (see Tables 3 and 4). Fig. 6 and 7 (where $F_E \times E^2$ vs. photon energy is plotted) demonstrate clearly the evolution of the broad band source spectrum possibly correlated with its luminosity. From the Fig. 7 one can see that the peak of the emitted energy is shifting toward lower energies with the increase of the luminosity (see also Table 4).

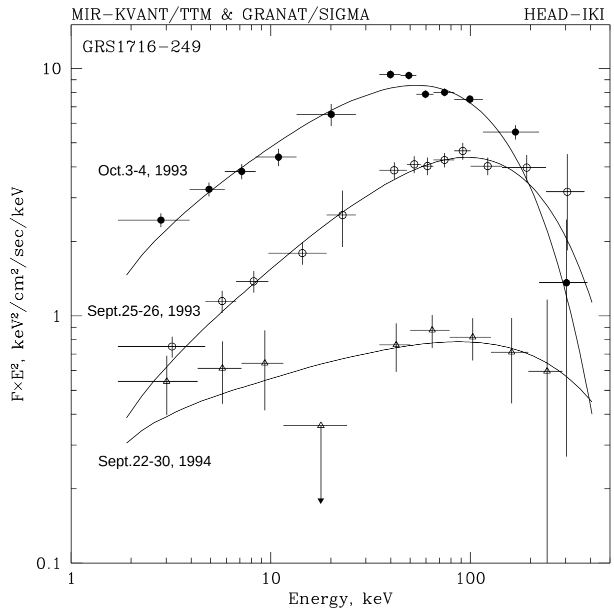

Fig. 7. The distribution of emitted energy ($F_E \times E^2$) over photon energy in the 2-400 keV band (TTM and SIGMA data) at different luminosity states of the source. The solid lines show best fit model spectra (power law with high energy cutoff).

Total luminosity of the source corrected for low energy absorption in the 2-300 keV energy band equals $\sim 2 \times 10^{37}$ erg/s for Oct.3-4,1993 and $\sim 2 \times 10^{36}$ erg/s for Sept.22-30, 1994, assuming a source distance of 2 kpc (Della Valle et al. 1994), or $L \sim 0.03 L_{crit} \frac{5M_\odot}{M}$ and $L \sim 0.003 L_{crit} \frac{5M_\odot}{M}$ respectively.

5. Timing analysis

Almost all observations of the GRS 1716-249 in 1993 and 1994 were performed in the spectroscopy/imaging mode – the standard operation mode of the SIGMA telescope. In this mode the only type of information suitable for the timing analysis is the "slow variability" data. This type of information gives the total count rate registered by the entire detector with 4 sec time resolution in 4 broad energy channels. The data of the two lowest channels corresponding to the 40-150 keV energy range were used for the analysis. The observation during which GRS 1716-249 was outside the Fully Encoded Field of View of the telescope were excluded from the analysis. One short observation on Oct. 4.4-4.5 1993 was performed in the "fast variability" mode. This mode provides information about photon energy and arrival time with 1/1024 sec time resolution.

In order to estimate the contribution of background events (contribution of other sources is not important since they are at least ten times weaker then the contribution of GRS 1716-249) a number of observations of weak sources and empty fields performed in both spectroscopy/imaging and fast variability mode was analyzed.

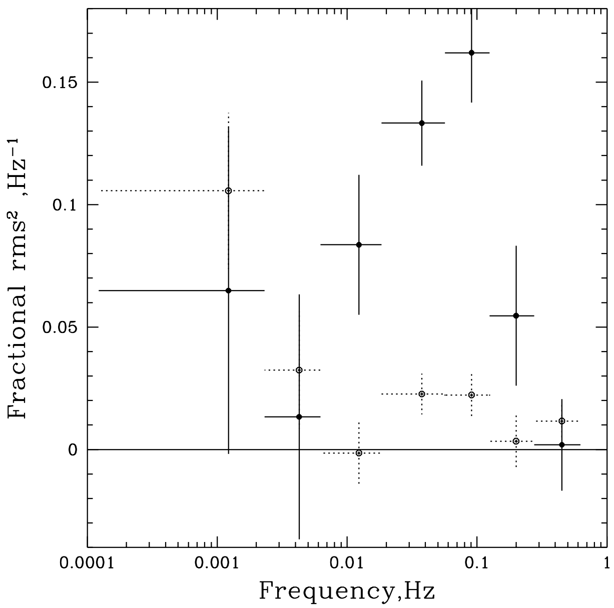

Fig. 8. Power Density Spectrum for Nova Oph. Data above 0.1 Hz are from "fast variability" mode data. Dotted crosses show the PDS of the SIGMA background.

The combined power density spectrum (source + background) is shown in Fig. 8. Typical background PDS is shown in Fig. 8 by dashed crosses. The integrated fractional rms (0.005-0.5 Hz) is 8.5 $\pm$ 0.4 %.

Fig. 8 demonstrates clearly, that PDS of GRS 1716-249 declines at high frequencies. In addition the PDS of the source decreases towards low frequencies. Somewhat similar behavior of the power density spectrum was observed for another X-ray Nova, GRO J0422+32 (Vikhlinin et al. 1995). In general, the shape of obtained PDS is consistent with a QPO peak present in the PDS based on BATSE data (Van der Hooft et al. 1996), but unlike BATSE result SIGMA data shows that there is no strong VLFN (very low frequency noise).

6. Discussion

The X-ray Nova Ophiuchi had been discovered on Sept. 25, 1993 simultaneously by SIGMA/GRANAT and BATSE/CGRO. The light curve of the source was quite unusual. The source flux quickly ($\sim 5^d$) rose up to $\sim$ 1.2 Crab and remained at about this level during all SIGMA observation, until Oct. 14, 1993 (exponential decay time $\approx 210^d$). According to the BATSE data the source remained at approximately this level during $\sim$ two and a half month. It is the only X-ray Nova known so far showing this slow decay of the luminosity. The SIGMA data show a quite smooth behavior of the hard X-ray flux from the source on a time-scale of hours. The relative *rms* of the points on the plateau of the light curve is less than 3.5%.

During the initial rise, SIGMA clearly detected a softening of the spectrum. The best fit bremsstrahlung temperature dropped from $\sim$ 150 keV on Sept. 25, 1993 to $\sim$ 85 keV on Sept. 27, 1993 and remained at about this value until the end of the SIGMA observation. Comptonized fit to the spectrum of the source observed during the plateau of the light curve gives $T \sim 25$ keV, $\tau \sim 5$ (TTM+SIGMA data, spherical geometry). The peak 2-300 keV luminosity of the source was $\sim 2 \times 10^{37}$ erg/s (assuming 2 kpc distance).

During Fall 1994 observational set Nova Oph 1993 was detected again at a flux of $\sim$ 115 mCrab. The data do not allow us to state the presence of any flux or spectral variations during this set. A bremsstrahlung fit to the Sept.1-30, 1994 averaged spectrum gives $T \sim 80$ keV, the best fit parameters for the comptonization model are $T \sim 42$ keV and $\tau \sim 3$ (TTM+SIGMA data).

The extremely hard spectrum of GRS 1716-249 is very similar to spectra of those galactic binary X-ray sources for which the nature of the black hole in the binary system is proven dynamically (e.g. Cyg X-1, GRO J0422+32, GS 2023+338). It is therefore plausible that GRS 1716-249 is yet another X-ray binary system harboring a black hole.

It was noted before, that black hole X-ray Novae can be roughly divided into two groups according to their X-ray spectral and timing properties at the maximum of the light curve, in particular according to presence or absence of the soft spectral component. In general, the absence of the soft spectral component and smooth hour time scale behavior of the hard X-ray flux are very similar to properties of e.g. Nova Persei 1992 (Vikhlinin et al. 1995) and strongly differ from those of e.g. Nova Muscae 1991 (for observations in the hard X-rays see Gilfanov et al. 1991, Goldwurm et al. 1993, for properties of the soft spectral component see Grebenev et al. 1992, Sunyaev et al. 1992, Ebisawa et al. 1994).

In the case of at least two black hole X-ray Novae without strong soft spectral component – Nova Persei 1992 (Vikhlinin et al. 1995) and Nova Oph 1993 (this paper) – a decline of the power density towards low frequencies was found at $\nu < 0.01$ Hz. The very smooth hard X-ray light curves of both sources on several hours time scale ($\nu \sim 10^{-4}$ Hz) might be another manifestation of extremely weak very low frequency noise in these sources. The existence of such a decline toward low frequencies can not be explained within framework of the standard shot-noise model. As known an intrinsic property of any process, composed of independent randomly occurring events (shots) is a non-decreasing (i.e. flat or increasing towards low frequencies) behavior of the power density spectrum below the frequency corresponding to inverse duration of the individual event. One of the possible explanations – a sequence of non independent shots – was suggested by Vikhlinin et al. 1994.

The likely reason for difference between two types of black hole X-ray Novae might be the peak value of the dimensionless mass accretion rate $\dot{m} = \dot{M}/\dot{M}_{Crit}$ (Gilfanov et al. 1996). The X-ray Novae supposedly having higher $\dot{m}$ (e.g. Nova Vul 1989, Nova Mus 1991), pass through the entire range of spectral states during their evolution, undergoing spectral transitions similar to that observed for Cyg X-1 and GX 339-4. The less luminous X-ray Novae (lower value of $\dot{m}$; e.g. Nova Per 1992, Nova Oph

1993) never show strong soft spectral component and apparently are in the low/hard spectral state during the entire outburst.

Zhang et al. (1997) considered an alternative explanation of absence or presence of the soft spectral component at the maximum of the light curve of black hole X-ray Novae. It has been suggested that the strength of the soft component depends on the specific angular momentum of the BH and the orientation of its spin axis with respect to that of the accretion disk. In particular, the black holes with no detectable ultrasoft component above 1-2 keV in their high luminosity state may contain a fast-spinning black hole but with a retrograde disk. However, ASCA observation of Nova Ophiuchi 1993 performed during the plateau of the light curve set strong upper limit on the luminosity of possible soft spectral component. This upper limit, combined with the measurement of the total X-ray flux from the source in the 0.5-300 keV energy band constrains the inner radius of the geometrically thin optically thick part of the accretion disk: $R_{in} \gtrsim 900\ km^1 \sim 60GM/c^2$ for $10M\odot$ black hole (see Gilfanov et al. 1996 for details). This lower limit exceeds significantly the maximum possible radius of the last marginally stable Keplerian orbit achieved in the case of retrograde disk around fast spinning black hole: $R_{last} = 9GM/c^2$. Thus, we may conclude that in the particular case of Nova Oph 1993, the black hole spin only cannot explain the absence of detection of the soft spectral component.

Acknowledgements. This work was supported in part by the RBRF grant 96-02-18588 and INTAS grant 93-3364-ext.

References

Ballet, J. et al. 1993, IAU Circ. 5874
Borozdin, K. et al. 1994, IAU Circ. 6083
Borozdin, K. et al. 1995, IAU Circ. 6141
Churasov, E. et al. 1993, IAU Circ. 6083
Della Valle, M. et al. 1994 A&A, 290, 803
Ebisawa, K. et al. 1994, PASJ, 46, 375
Gilfanov, M. et al. 1991, SvAL, 17, 1059
Gilfanov, M. et al. 1996, Lecture Notes in Physics, 487, Proceedings of the EARA Workshop,1996, Garching, Germany
Goldwurm, A. et al. 1993, ApJS, 97, 293
Goldwurm, A. et . 1994, Nature, 1994, 371, 587
Grebenev, S. et al. 1992, , 18, 11
Harmon, B.A. et al. 1993, IAU Circ. 5874
Harmon, B.A. et al. 1994, IAU Circ. 6104
Hjellming, R.M. et al. 1996, ApJ, 1996, L105
Kellogg, E. et al. 1975, ApJ, 199, 299
Paul, J. et al. 1991, Advances In Space Research, 11, 289
Sunyaev, R.&Titarchuk, L. 1980, A&A, 86, 121
Sunyaev, R. et al. 1992, ApJ, 398L, 75
Sunyaev, R. et al. 1994, Pis'ma v Astronomicheskii Zhurnal, v.20, No.12, p.890
Tanaka Y, 1993, IAU Circ. 5877
Van der Hooft, F. et al. 1996, ApJL, 458, L75
Vargas, M. et al. 1996a, A&A, 313, 828
Vargas, M. et al. 1996b, A&AS, 120, 291
Vikhlinin, A. et . 1994, A&A, 287, 73
Vikhlinin, A. et al. 1995, Ap.J 441, 779
Zhang, S. et al. 1997, Ap.JL 482, 155

[1] This value was calculated without any relativistic or colour correction. A proper account for these corrections gives even larger value of R_{in}

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.