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SIGMA observations of X-ray Nova Velorum 1993 (GRS 1009−45)

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Abstract. We report on hard X-ray observations of X-ray Nova Velorum 1993 (GRS 1009-45) performed with the SIGMA coded mask X-ray telescope in January 1994. The source was clearly detected with a flux of about 60 mCrab in the 40-150 keV energy band during the two observations with a hard spectrum ($\alpha \sim -1.9$) extending up to ~ 150 keV. These observations confirm the duration of the activity of the source in hard X-rays over 100 days after the first maximum and suggest a spectral hardening which has already been observed in Nova Muscae. These and other characteristics found in these observations strengthen the case for this Nova to be a black hole candidate similar to Nova Muscae.

Key words: Black hole physics – gamma rays: observations – novae – stars: Nova Vel 1993=GRS 1009−45 close

1. Introduction

X-ray Novae have provided some of the best galactic black hole candidates from their dynamical mass determinations. Among them Nova Velorum 1993 (GRS 1009-45) is one of the least known. It was detected by GRANAT/WATCH between the 12th and the 13th September 1993 (Lapshov et al., 1993) and subsequently confirmed by BATSE (Fishman et al., 1989) with an improved source location (Harmon et al., 1993). It appeared first in the 20-60 keV band at 0.18 Crab reaching shortly after 0.7-0.8 Crab in the 8-60 keV total band of the WATCH instrument.

BATSE detected the source at the same level between 20 and 500 keV and the spectrum was a power law with a photon index $\alpha \sim -2.5$.

About a month later, in October, the TTM team established that the source spectrum was similar to the ones of GS2000+25 and Nova Muscae, both dynamically proven black hole candidates (Kaniowsky et al., 1993). In the 2-200 keV band, the object presented a soft component approximated with a black body spectrum with kT$\sim$0.52 $\pm$0.03 keV which dominates between 2 and 10 keV. At higher energies the spectrum is well approximated by a power law with a photon index $\alpha \sim -2.53 \pm 0.05$ (Sunyaev et al., 1994). The source had a 1 Crab flux at 3 keV and a 0.1 Crab flux at 20 keV indicating clearly the softness of its emission (Kaniowsky et al., 1993).

In November the flux decreased by 25 % in the 2-6 keV band (at 0.5 Crab) but it remained soft (Borozdin et al., 1993). No reliable absorption column density could be established. However the column density can be considered less than about 10^{23} cm^{-2} due to the absence of heavy absorption features in the spectrum (K. Borozdin, private communication).

A week later ASCA confirmed this result giving a blackbody spectrum with kT $\sim$ 0.6 keV and $F_x \sim$ 0.8 Crab (1-10 keV) (Tanaka Y., 1993). The absorption column density found in this observation is 3 (-0.14,+0.22) $\times$ 10^{21} cm^{-2} (Ueda Y., private communication). This value points toward a relatively nearby source with a distance of a few kiloparsec.

The optical identification was performed by Della Valle and Benetti (1993): they identified the source with a V$\sim$14.6 late-G/early K type star with a broad double-peaked Hα emission on 17 Nov. 1993 at the ESO/MPI telescope. Baylin & Orosz (1995) observed the source between 150 and 200 days after the outburst and found evidence for a secondary optical outburst and for repeated mini outbursts, similar to those observed in Nova Persei 1992, with V-mag varying between 16 and 20. Very recently Shahbaz et al. (1996) have reported the discovery of an orbital, ellipsoidal modulation with an amplitude of 0.23 magnitudes and a period of 6.86 $\pm$ 0.12 hrs. However it is not possible to derive a mass function yet as there is no available radial velocity curve for the secondary.

High energy (>20 keV) monitoring of the source have been performed by BATSE which produced a light curve and spectral indices for the source in the 20-100 keV band during about 150 days following the first maximum (Paciesas et al., 1995, Harmon et al., 1994). The overall form of the light curve is similar to the Nova Muscae 1991 one, with two later maxima in mid-October

Table 1. SIGMA observation log of GRS 1009-45

Session	Date(U.T.)	Exposure (hrs)
691	1994 Jan 10.48 − 11.69	19.81
692	1994 Jan 11.82 − 12.77	15.87

Table 2. Detected flux of GRS1009-45. Errors quoted are 1σ errors.

Obs. Session	Energy band	Fluxes (mCrab)	Errors
691	$40-75keV$	57	14.7
691	$75-150keV$	39.4	20.4
692	$40-75keV$	63.9	15.8
692	$75-150keV$	97.8	22.7

(∼ 30 days after the primary) and in early December (∼ 85 days after the primary), although the Nova Muscae maxima occurred later (Paciesas et al., 1995). The spectrum softens during the primary rise reaching $\alpha \sim -2.5$ and then remains relatively constant within errors until the December maximum. During the latter the spectrum becomes harder (although the statistics is worse) reaching $\alpha \sim -2.1$ and remains at that level until the end of observations in January (Paciesas et al., 1995, see their Fig. 3).

2. Observations, data analysis and results

The French coded mask telescope SIGMA provides high resolution images n the hard-X/soft γ-ray band from 30 keV to 1300 keV, with a typical angular resolution of 15' and a 20 hour exposure sensitivity of ∼ 26 mCrab in the 40-150 keV band (Paul et al., 1991). Launched the 1st December 1989 onboard the Russian Granat Space observatory, SIGMA detected a fair number of galactic X-ray novae during its seven year lifetime (Roques et al., 1994, Gil'fanov et al., 1993a, Trudolyubov et al., 1996, Vargas et al., 1996, Vargas et al, 1997, Revnivtsev et al., 1997). This class of sources is one of the primary targets of this telescope due to its high precision localization capability unprecedented in this energy band.

The observations we report were performed after the third outburst, about 120 days after its discovery, on the 11th and 12th of January 1994 (JD 2449364-5). The campaign consisted of two distinct observation sessions with the telescope pointed in the source direction, both performed in spectral-imaging mode (Paul et al., 1991), for a total effective time of ∼ 35 hours. The parameters of the observation are listed in Table 1.

Fig. 1 shows the source image in the 40-75 keV energy band. GRS 1009-45 appears at a 6σ confidence level. To estimate the best source position, we selected data in the 60-120 keV energy band. This choice was made in order to find a compromise between the higher statistics of the low energy band and the narrower instrument PSF at higher energies. A least square fit taking into account the instrumental PSF gives a source position at 10h 11m 26.4s(± 4'), − 44 ° 49' 20"(± 4'), in complete agreement with the optical counterpart position (Della Valle et al., 1993, 1997).

Table 3. Results of the spectral analysis for GRS1009-45. 1σ errors are quoted. The flux units are 10^{-5} ph cm^{-2}s^{-1} keV^{-1}.

Power	$F_{100\ keV}$	3.51 ± 0.5
Law	α	1.9 ± 0.4
	χ^2_ν	0.78(18 $d.o.f.$)

Table 2 shows the flux intensities of the source during the two observing sessions. There is a considerable rise in the hard band flux during the second observation session, the flux rising from ∼ 40 mCrab to ∼ 100 mCrab. However, the flux in the soft band is constant within the errors, and the hardness ratios of the two observing sessions are respectively HR(691) = 0.69 ± 0.4 and HR(692) = 1.53 ± 0.5. So there is no conclusive spectral change of the source between the two observations. Given the relative faintness of the source, we consider this difference not significant and the source flux being essentially constant during the whole observation.

We thus summed the spectra obtained during the two observations. We have performed spectral fit to the data using a power law model, the results are presented in Table 3. The average spectrum is fitted with a power law with spectral index $\alpha = -1.9 \pm 0.4$ and an integrated energy flux of ∼ 6.9 (± 1.7) $\times 10^{-10}$ ergs cm^{-2} s^{-1} in the 40-150 keV energy band. The resulting spectrum is shown in Fig. 2 along with the best fit, the parameters and errors of the fit are listed in Table 3

The distance to the source has been estimated with the optical observations by Della Valle et al. (1997) as being between 1.5 and 4.5 kpc. Vargas et al. 1997 on the basis of the hard X-ray outburst luminosity estimated a distance of 2.6 kpc, with a 100 % uncertainty, fully compatible with the previous one. Both of these values are compatible with the hydrogen absorption column density previously quoted. Adopting these distance estimates we obtain an X-ray luminosity L_X(40-150 keV) $\sim 10^{35}$-10^{36} ergs^{-1}.

This hard X-ray luminosity is similar to the Nova Muscae one detected by SIGMA about 150 days after the outburst, L_x(40-150 keV)$\sim 10^{35}$ erg s^{-1}. (Goldwurm et al., 1993, Sunyaev et al., 1992).

3. Discussion

X-ray Nova Velorum 1993 is a soft X-ray transient which displayed during its outburst a fair number of characteristics in common with well known black hole candidates. TTM and ASCA observations shorly after the primary outburst showed that it displayed ultrasoft X-ray emission along with a hard power law spectrum extending up to ∼ 500 keV. This spec-

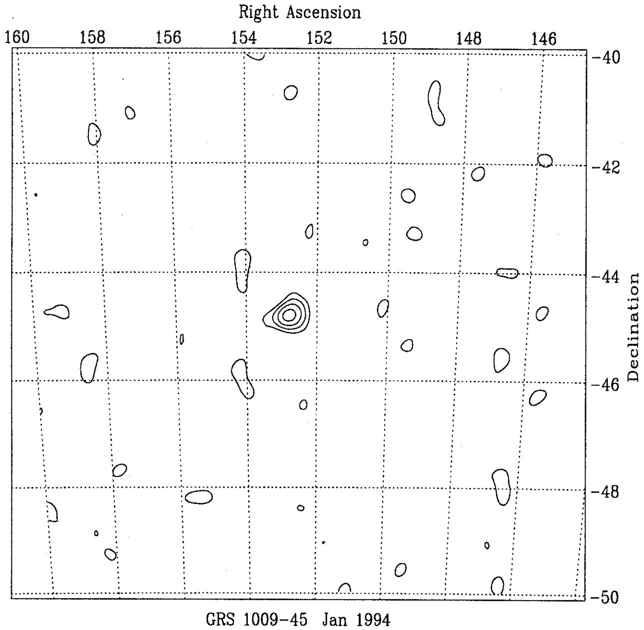

Fig. 1. Contour image of the sky region observed by SIGMA. Confidence levels start from 2σ with 1σ step.

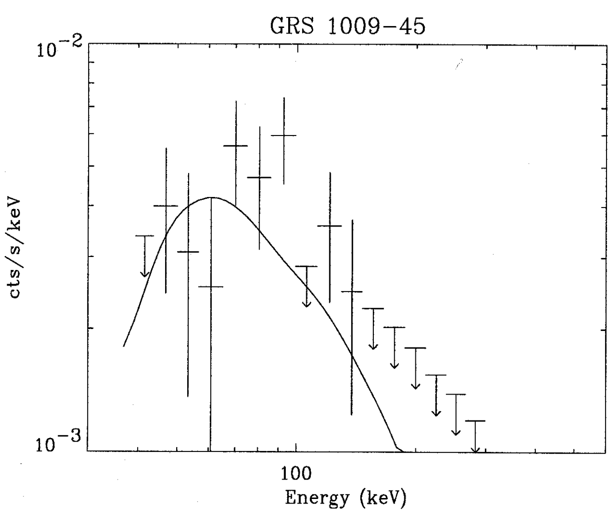

Fig. 2. X-ray spectrum of GRS 1009-45 as detected by SIGMA.

trum is thought to be a good black hole indicator even if it is not considered to be conclusive (Tanaka & Shibazaki, 1996). Our observation showed that the source emitted hard X-rays at least up to $\sim$ 150 keV more than $\sim$ 100 days after the outburst.

The 2-200 keV outburst spectrum of GRS 1009-45 was similar to the ones of GS2000+25 (Nova Vul 88, Tsunemi et al., 1988) and GS/GRS1124-68 (Nova Mus 1991, Goldwurm et al., 1992, Sunyaev et al. 1992, Ebisawa et al., 1994), both dynamically proven black hole candidates (Remillard et al., 1992, Casares et al., 1995). The primary outburst was similar to the Nova Muscae one. However two later maxima in the hard X-ray band occurred at $\sim$ 30 and $\sim$ 85 days after the primary maximum. Both occurred sooner than the secondary maximum observed in GS1124-68 (Paciesas et al, 1995). No type I X-ray burst, the best observational signature of a neutron star in an X-ray transient, was detected.

Indeed a similar X-ray outburst light curve characterized by a fast rise (few days) followed by a relatively smooth exponential decay with a similar time constant (around 30-100 days) and at least one secondary outburst has been observed in other X-ray novae both neutron stars and black holes. In a recent review (Tanaka & Shibazaki, 1996) four well known objects having a similar light curve are quoted. They are the above mentioned GS2000+251 and GRS1124-68, A0620-00 and GROJ0422+32 and are all strong black hole candidates. This classification is based on soft (2-10 keV) monitoring for three of these objects, the exception being GROJ0422+32, while for Nova Velorum 1993 only hard X-ray monitoring has been performed. So while Nova Velorum cannot be firmly associated at this group, it is worth mentioning its similarity to these objects.

With this observation we monitored Nova Velorum 1993 during the final phases of its outburst. Its luminosity was similar to the Nova Muscae one as detected with SIGMA about 100 days after its primary outburst. The hard X-ray spectral index that we detected, $\alpha =- 1.9 \pm 0.4$, is harder than the spectral index measured during the primary outburst ($\alpha = -2.5 \pm 0.03$) and it agrees with the spectral index measured by BATSE after the December maximum.

We remark that a similar phenomenon possibly appeared also in Nova Muscae 1991 for which Paciesas et al. (1995) and Ebisawa et al., (1994) reported a harder X-ray spectrum near the end of the outburst. The same phenomenon was detected by the SIGMA and ART-P instruments onboard the GRANAT observatory (Gil'fanov et al., 1993b).

We conclude that the hard X-ray emission of Nova Velorum 1993 looks similar to the ones of well established black hole candidates, especially Nova Muscae 1991.

In summary, we have shown with the result of SIGMA observations that GRS1009-45 was active over 100 keV about 120 days after the primary outburst. Its hard X-ray luminosity was comparable to the one of Nova Muscae $\sim$ 150 days after the outburst. Its hard X-ray spectrum was on average harder than the one detected during the primary outburst.

If we put our results together with all the other X-ray characteristics displayed by this source during its active phase, mainly the outburst ultrasoft spectrum and the 20-100 keV light curve, we believe that our observations strengthen the case for GRS 1009-45 to be a black hole X-ray Nova.

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