1993A&AS...97....1M

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **97**, 1-4 (1993)

Overview of two-year observations with SIGMA on board GRANAT

P. Mandrou[1], E. Jourdain[1], L. Bassani[1], G. Vedrenne[1], J. Paul[2], J.-P. Leray[2], F. Lebrun[2], J. Ballet[2], E. Churazov[3], M. Gilfanov[3], R. Sunyaev[3], A. Bogomolov[3], N. Khavenson[3], N. Kuleshova[3], I. Tserenin[3] and K. Sukhanov[3]

[1] Centre d'Etude Spatiale des Rayonnements (CNRS-UPS), BP4346, 31029 Toulouse Cedex, France
[2] Service d'Astrophysique du CEA, CE Saclay, 91191 Gif sur Yvette Cedex, France
[3] IKI, Profsouznaya 84/32 - 117810 Moscow, Russia

Received June 3; accepted June 9, 1992

Abstract. — The hard X-ray, low-energy gamma-ray telescope SIGMA, one of the main instruments on board the Soviet satellite GRANAT, has performed sky observations in the 35 keV - 1.3 MeV range both on galactic and extragalactic objects with unprecedent angular resolution in such an energy domain. New results have been obtained by mapping the Galactic Center region with a 1.6 arc minute accuracy during more than 500 hours distributed in five periods which took place in early Spring and fall Summer from 1990 to 1992. Hard X-ray binaries and bright extragalactic objects have also been analysed and monitored during these observations. The main result obtained by SIGMA was to point out the variability of the sky in the hard X-ray domain.

Key words: gamma-ray astronomy, gamma-ray imagery, hard X-ray sources.

1. Introduction.

The SIGMA telescope was first proposed to CNES, the French Space Agency in June 1981 by two laboratories : the Centre d'Etude Spatiale des Rayonnements at Toulouse and the Service d'Astrophysique of CEA at Saclay.

This hard X-ray, soft gamma-ray instrument is the first coded aperture telescope sensitive to radiation in the 35 keV - 1.3 MeV energy range operating in space. The coded aperture mask, with a basic pattern of 29 x 31 Uniformly Redundant Array (URA) known to have ideal properties (Fenimore & Cannon 1978), is located 2.5 m from a position-sensitive detector based on the principle of the Anger Camera. A heavy CsI active shield surrounds the detector and limits the background contribution. The experiment is described in details in Paul *et al.* 1991 and inflight performances in Mandrou *et al.* 1991.

The telescope was launched on board the Soviet space observatory GRANAT on December 1st, 1989. Since this time, the telescope has provided us with sky images with unprecedented high angular resolution (1.6 arc minute).

2. Observations and results.

At the end of January 1992, about 250 successful sessions lasting approximately 24 hours have been already performed on about 60 different astrophysical targets.

More than 22 high-energy emission sources were observed and analysed during this period. New exciting results have been obtained on various objects : the Galactic Center Region, hard X-ray binaries, Active Galactic Nuclei, X-ray transients exhibiting unexpected hard tails and Nova Muscae. We present here the most prominent results obtained on some of these objects.

2.1. The galactic center region.

During the last 25 years, the Galactic Center region has been observed many times both by balloon-borne telescopes and spacecraft experiments, in the hard X-ray and low-energy gamma-ray domain.

The most prominent result obtained was the discovery of a narrow (511 keV) $e^+ - e^-$ annihilation line emission associated with this region (Haymes *et al.* 1975). A comparative review of all the different results accumulated during this long period has been presented by Lingenfelter and Ramaty 1989 (references therein).

During 1990 and 1991, two series of observations have been performed each year (March/April and September/October), with the SIGMA telescope. More than 500 hours of useful observing time were accumulated on this region.

Six different sources : 1E 1740.7–2942, GRS 1758–258, GX 1+4, X1724–308 (Terzan 2), KS 1731–260 and GX

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1993A&AS...97....1M

354–0 have been detected above 40 keV, in a 6° × 6° area centered on the radio source Sgr A* and monitored continuously by SIGMA. These objects have experienced long duration "outbursts" as well as long duration quiet states.

In the early 1990, the first result obtained was to demonstrate that two sources were dominating the emission above 40 keV, in a field of view centered on the radio source SgrA*. The most luminous was the "EINSTEIN" object 1E1740.7–2942 (Sunyaev *et al.* 1991). The other one, so-called GRS 1758–258 (Sunyaev *et al.* 1992), was discovered 45 arc minutes away from GX 5–1, thanks to the high angular resolution of the telescopes on board GRANAT. Its spectrum, variable in intensity, is well fitted by a comptonized disk model of Sunyaev and Titartchuck (1980) with a characteristic electron temperature of KTe = 33 keV. GRS 1758–258 disappeared at the 1991 fall and was not reobserved in the Spring of 1992.

The hard nature of 1E1740.7–2942 was previously demonstrated, during observations of the Galactic Center region, by imaging coded mask instruments in the 3–30 keV domain (Skinner *et al.* 1987), or above 30 keV by GRIP (Cook *et al.* 1991).

Our observations of this object (March/April 1990) located 48 arc minutes from SgrA* led us to believe that it had a persistent constant emission. The energy spectrum obtained in Spring is well fitted by a comptonized disk model with an electron temperature $KTe \sim 32$ keV (Fig. 1, diamonds). It was quite similar to that of Cyg X-1 in the low state, rescaled to the Galactic Center distance.

This sequence of observations was suddenly disrupted by a spectacular event during the October 13–14th observation (Bouchet *et al.* 1991). The source emission spectrum was found to exhibit an unexpected feature above 200 keV up to 700 keV (Fig. 1, crosses). This bump observed during all the session (4.5×10^4 sec) is unambiguously apparent at the source position in the 330-540 keV image band, showing that this effect is not an artifact.

This feature is well represented by a Gaussian line centered at 480 keV with a FWHM of 240 keV. It should be stressed that it is well resolved and can't result simply from a narrow line convolved with the detector spectral resolution, which is 8 attributed to an electron-positron annihilation process in the vicinity of the source, coming from a massive production of a hot pair plasma with a characteristic temperature estimated around 5×10^8 K, in a region limited to few 10^{15} cm as deduced from an evaluation of the phenomenon duration between 18 hours and 70 hours.

During the Spring of 1991 the source intensity decreased by a factor of approximately 4, and at the end of Summer the source was totally absent from the SIGMA images. It reappeared recently in the images of the Galactic Center region showing that it could recover its "nominal" state in a few days period.

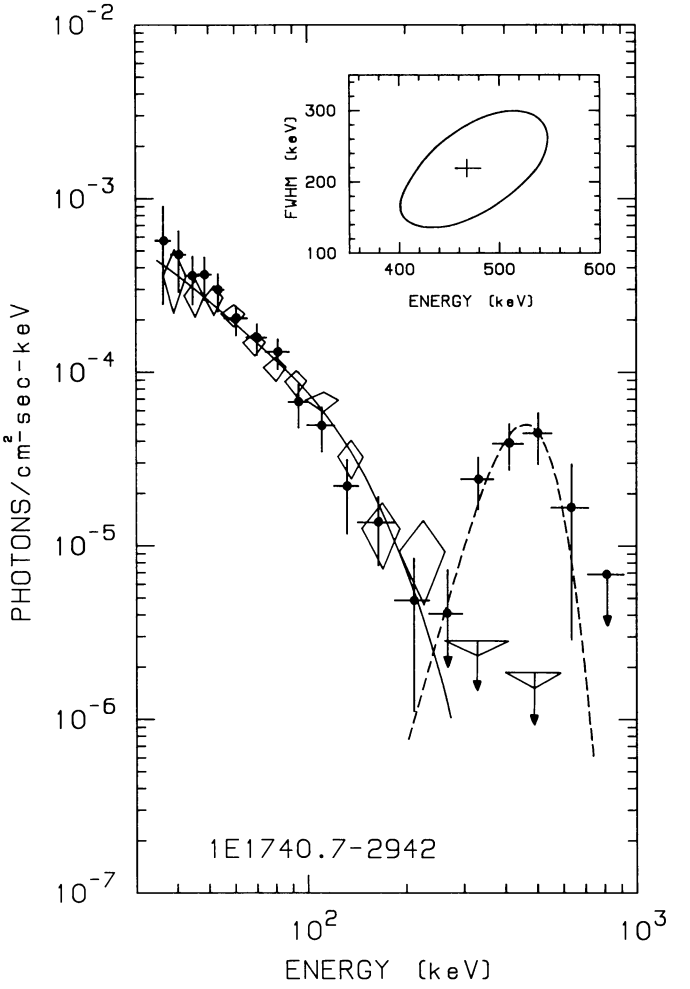

FIGURE 1. Energy spectrum of 1E 1740.7-2942 observed in fall summer 1990 (diamonds) and during the event of Oct. 13th, 1990 (crosses).

2.2. ACTIVE GALACTIC NUCLEI.

During the first year of exploitation, SIGMA was pointed towards many extragalactic objects considered as interesting candidates for an emission in the gamma-ray domain. Up to now, SIGMA has only detected three extragalactic objects : NGC 4151, 3C 273 and CEN-A, with good statistical significance. Nevertheless extragalactic sites are always scheduled for SIGMA observations.

About a hundred of hours have been spent on NGC 4151 in 1990. The source was detected up to 200 keV and well identified to the Seyfert Galaxy, thanks to the SIGMA angular resolution (Jourdain *et al.* 1992). The photon spectrum is found unusually soft ($\alpha \sim 3$), when compared with results obtained by previous instruments up to few MeV. Nevertheless the SIGMA detection is in agreement with previous HEAO A-4 observation (June 1978) (Baity *et al.* 1984). An interesting result must be pointed out. A break in the emission spectrum around 50 - 60 keV appears

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1993A&AS...97....1M

when these results are compared to the spectrum obtained by the ART-P telescope operating on GRANAT at lower energies, in the same time (Apalkov *et al.* 1991) (Fig. 2). This break is predicted by recent models (Zdziarsky *et al.* 1990) including Compton reprocessing by cold optically thick material, very close to the central engine. This result is interesting to understand the contribution of the Seyfert Galaxies to the Cosmic Diffuse Background which also presents a break around 60 keV. During the November 1991 session on NGC 4151, its flux increased by a factor of 1.5 compared to the previous 1990 session, demonstrating the variability of this object.

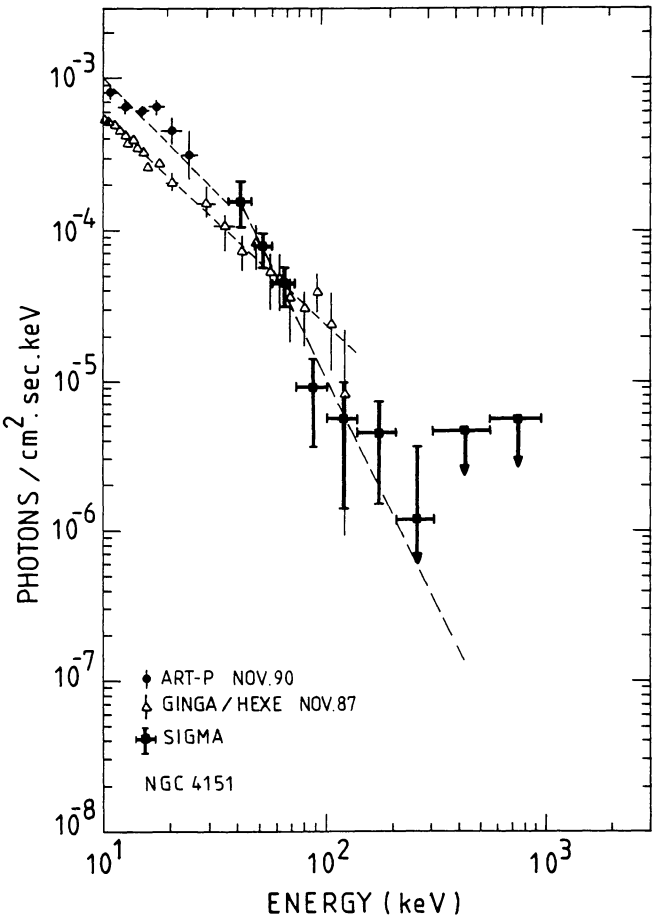

FIGURE 2. Spectrum of NGC 4151 obtained with GRANAT.

The Quasar 3C 273 has also been one of the main extragalactic objectives of SIGMA. It was also found to be highly variable over the 8 sessions performed in 1990-1991. It was easily detected during one session in 1990 and two others in 1991 with fluxes variations of a factor of $\sim$ 2 (Bassani *et al.* 1992). During the remaining 5 sessions, limit flux could only be determined. Variations are observed on timescales as short as 40 days. The data are well fitted by a power law of photon index $\alpha \sim 1.5$ up to 500 keV which is in agreement with previous results in the X-ray domain.

Another interesting result derived from 3C 273 observations was obtained during November 1990 . SIGMA images revealed a 5.5σ excess in a location RA(1950) = 12h 27mn 21s, DEC(1950) = 02°29'12" with an associated error circle of ± 5' (Fig. 6). This source, named GRS 1227+0229, situated only 15' away from 3C 273 has been detected up to 120 keV (Jourdain *et al.*, 1992).

CEN-A has been observed by SIGMA, during a flaring phase in July 1991. It is possible to say that a flux variation of a factor of $\sim$ 2 has been observed during 4 days in the SIGMA energy range, which is an unprecedent result in such a domain.

2.3. NOVA MUSCAE.

A day after its discovery by the all-sky instrument WATCH on board GRANAT, the X-ray Nova GRS 1124–684 (in the Musca constellation) was detected on January 9^{th}, 1991 by SIGMA at the edge of its field of view. The source was observed in the 40-150 keV band, at 55σ significance level and located at RA(1950) = 11h 24mn 08s, DEC(1950) = -68°23'06" with a square error box of 3.3 arc minute size, fully compatible with the identification at other wavelengths. The 40-150 keV flux quickly decreased from 1 Crab to 0.4 Crab within six days. Later on, the flux decreased continuously, with irregularities on timescales of several days.

The Nova was detected up to 300 keV with a spectrum well fitted by a power-law model with a spectral index $2.3 < \alpha < 2.6$.

During the January 20^{th} session the spectrum was found to exhibit a spectacular feature around 480 keV for 13 hours. An image made in the 430-530 keV band presents a 5.1σ excess located 3 arc minutes from GRS 1124–684, showing that this line is not due to a background artifact (Goldwurm *et al.* 1992).

The line width of 23 ± 23 keV is compatible with the instrument spectral resolution.

Another feature seems to be present in the spectrum close to 200 keV and could correspond to the back-scattering peak. As this line appears in the images thus it cannot be attributed to the 500 keV back-scattered photons in the instrument. It could be explained by a retrodiffusion effect of high energy photons in the source itself.

The Nova Muscae progenitor is probably a K5-M0 late-type star at a distance of < 3 kpc. At 1 kpc, the 40-300 keV luminosity is 1.70 (± 0.09) × 10^{36} erg/sec.

If the line at 480 keV is interpreted as a positron annihilation line, then GRS 1124–684 could contain a black hole like soft X-ray transients are thought to contain.

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1993A&AS...97....1M

2.4. X-RAY TRANSIENT SOURCES.

During these two-years observations, SIGMA has spent an important fraction of its time to the exploration of both the Galactic Center regions and the Galactic disk. Thanks to the wide field of view of the telescope ($\sim$ 12° x 12°), large parts of the sky have been monitored during several days with good sensitivities. This led to the observation of random outbursts of binaries such as 4U1700–377 (Laurent *et al.* 1991) GX 339–4, as well as period variation of X-ray pulsars like OAO1657–415 (Mereghetti *et al.* 1991) or GX 1+4 (Denis *et al.* 1991). One of the most surprising results obtained from the processing of such large images, was the discovery of a hard X-ray emission up to $\sim$ 150 keV from soft X-ray transients or X-ray bursters. The duration of such hard tails is typically of a few days. SIGMA evidenced the hard X-ray emissions from the type I X-ray burster KS1731–260 (Barret *et al.* 1992a), the ultra soft X-ray transient TRA X-1 (Barret *et al.* 1992b) the transient X-ray burster GX 354+0. SIGMA also detected an emission from the globular cluster Terzan 2 (Barret *et al.* 1991) which could be associated with the X-ray burster X 1724–308. From the spectral analysis it seems that the hard tails observed by SIGMA on these objects, strongly suggest that a part of X-ray burst sources become hard X-ray emitters when reaching a low soft X-ray luminosity state.

3. Conclusions.

This review shows that SIGMA is obtaining unprecedent exciting results on different types of objects. The image performance of the instrument insures high reliability in the experimental analysis. Emitting objects are clearly identified avoiding artifacts. All phenomena are clearly apparent in the images at the correct source positions. SIGMA is providing major contribution to the understanding of the complex region of the Galactic Center. The most fundamental result which comes out from two years of SIGMA successful operation is the high variability of the sky in hard X-rays and soft gamma-rays. One surprising result was the discovery of the high state of 1E1740.7–2942, attributed to a hot pair plasma production in the vicinity of a black hole.

SIGMA had the opportunity to witness the spectacular flare of the Nova Muscae and, thanks to its instrumental capabilities, discovered a strong 480 keV line, probably narrow, interpreted as a 511 keV line production gravitationally redshifted by the presence of a compact object.

The study of extragalactic objects with a break around 50 keV in the spectrum of the NGC 4151 Seyfert Galaxy could characterize a particular state of this kind of objects and could have interesting implications on the origin of the Cosmic Diffuse Background.

The soft gamma-ray tails discovered by SIGMA in some transient sources, identified as soft X-ray transients seem to be a common characteristic of these objects in their low state. If such effects are expected they have to be explained in the light of these new results.

Except for the Crab Nebulae and Cyg X-1, which until now are considered persistent, all sources appear and disappear in a few days period. Spectacular phenomena can be observed on timescales of a few hours.

Thus we must always be wary of crediting an object with some observed peculiar emission simply because that object is the brightest or most well-known in the field-of-view.

Acknowledgements.

The authors acknowledge the outstanding contribution of the CNES staff, as well as the Baikonour Space Center, the Lavotchkine company, the Babakine Space Center and the Evpatoria Ground Station for their unfailing support during all the phases of the project.

References

Apalkov Y. *et al.*, 1991, Proc. of 28th Yamada Conference, in press
Baity W.A. *et al.*, 1984, ApJ 279, 555
Barret D. *et al.*, 1991, ApJ 379, L21
Barret D. *et al.*, 1992a, to be published in ApJL
Barret D. *et al.*, 1992b, to be published in ApJL
Bassani L. *et al.*, 1992, to be published in ApJ
Bouchet L. *et al.*, 1991, ApJ 383, L45
Cook W.R. *et al.*, 1991, ApJ 372, L75
Denis M. *et al.*, 1991, 22nd ICRC, 1, 161
Fenimore E.E. and Cannon T.M., 1978, Apl. Opt. 17, 336
Goldwurm A. *et al.*, 1992, to be published in ApJL
Haymes R.C. *et al.*, 1975, ApJ 201, 593
Jourdain E. *et al.*, 1992, to be published in A&A
Jourdain E. *et al.*, 1992, to be published in ApJL
Laurent Ph. *et al.*, 1991, to be published in A&A
Lingenfelter R.E. and Ramaty R., 1989, ApJ 343, 686
Mandrou P. *et al.*, 1991, in Gamma-ray line Astrophysics, Proc. of AIP Conference n° 232, p. 492. Eds Durouchoux P., and N. Prantzos
Mereghetti S. *et al.*, 1991, ApJ 366, L23
Paul J. *et al.*, 1991, Adv. Space Res. 11 (8) 289
Skinner *et al.*, 1987, Nat 330, 554
Sunyaev R. and Titartchuk L., 1980, A&A 86, 121
Sunyaev R., *et al.*, 1991, A&A 247, L29
Sunyaev R. *et al.*, 1992, submitted to ApJ
Zdziarsky A. *et al.*, 1990, ApJ 363, L1

© European Southern Observatory • Provided by the NASA Astrophysics Data System