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A NEW HARD X-RAY SOURCE 15′ AWAY FROM 3C 273?

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ABSTRACT

We report the detection of hard X-ray emission (40–80 keV) from a location 15′ away from 3C 273 at a 5.5 σ confidence level during a 16 hr observation of a 5×5 deg^2 sky region containing the QSO 3C 273 and at a less significance level (≈ 3 σ) in two other pointings. The analysis done on the SIGMA images is briefly described in order to assess the reality of this detection. The source is certainly variable in the SIGMA operational band by a factor of 2. The search for likely counterparts at other wavelengths has indicated interesting objects, especially in the X-ray band. The implications of this report with respect to source confusion in previous X-ray measurements of 3C 273 are of course extremely important.

Subject headings: quasars: individual (3C 273) — X-rays: galaxies

1. SIGMA OBSERVATIONS

On 1990 November 28 the SIGMA telescope on board the *GRANAT* satellite devoted 16 hr of useful observing time to the sky region containing 3C 273. A full discussion of the instrument, its operational modes, and in-flight performances can be found in Paul et al. (1991), while details of this and three other 1990 observations of the same sky field are given in Bassani et al. (1992). In the first two pointings performed in the summer, 3C 273 was detected at the expected position at 4 and 5.4 σ confidence level in the 40–120 keV band, while a marginal detection (≤ 2.5 σ) was obtained during two November observations made on the 27 and 28 (Bassani et al. 1992). Although on this last measurement a clear 5.5 σ excess was present in the first high-resolution image (40–80 keV; Fig. 1) at a position close to that of the QSO, it was soon realized that its association with the extragalactic object was somehow problematic:

1. The excess was displaced from 3C 273 by $\approx 15'$, more than allowed by the point source location accuracy of the telescope ($\approx 5'$).
2. The excess was detected only in the lowest energy channels thus indicating a spectrum extremely soft.

Various hypotheses were analyzed to account for the excess, in particular, if due to 3C 273, a problem in the instrument performance and/or image reconstruction had to be assumed.

We have looked deeply into this possibility and have performed various checks to ensure that no problem was occurring during the observation or at the level of the attitude reconstruction and/or data treatment. In the following, we briefly show how the 5′ point source location accuracy is achieved by the SIGMA telescope.

Although the *GRANAT* satellite is stabilized only within 40′ square, the accuracy with which SIGMA locates a source is much better than this. The star tracker of the telescope monitors two stars in its field of view every 4 s, thus obtaining a precision which allows to correct the drift of the pointing axis of the telescope with an accuracy of 12″. These drift corrections are then transmitted to the electronics which promptly makes the appropriate shift in each count position. Each image, corrected for these drifts, is constructed with respect to a reference position given by the star tracker at the beginning of each measurement. This position is then converted on ground into equatorial coordinates, R.A. and decl., by identifying a number of stars seen by the star tracker. This attitude reconstruction introduces a further positional uncertainty of the order of $\approx 2'$, which also takes into account the nonperfect alignment between the star tracker and the telescope. As a result of all this, SIGMA can locate a strong source, like the Crab Nebula, with an accuracy of $\approx 2'$, corresponding to less than 2 pixels in the high-resolution images. For less intense sources (≈ 5 σ), this accuracy of course deteriorates but is still of the order of $\approx 5'$.

We have performed various checks to ensure that at every stage of the image reconstruction, no problem occurred. The eight stars seen by the star tracker were all identified with cataloged stars at the right position and with the proper magnitude. Also the on-board test of the analog electronics showed nominal values for all the relevant parameters. For the particular observation described, the data obtained in the spectral imaging mode were first corrected for background and detector nonuniformity (Laudet & Roques 1988) and then deconvolved using the finely sampled decoding technique of Fenimore & Cannon (1981). Statistical tests were also performed on the image corrected for nonuniformity defaults in order to evaluate the goodness of these corrections (the mean number of counts in each pixel is 52.83 and the variance for a total number of 248×232 pixels is 52.95, while the run test gives 28,808 runs for a theoretical value of $28{,}757 \pm 119$. In order to achieve a better sensitivity, a 31×29 pixel image

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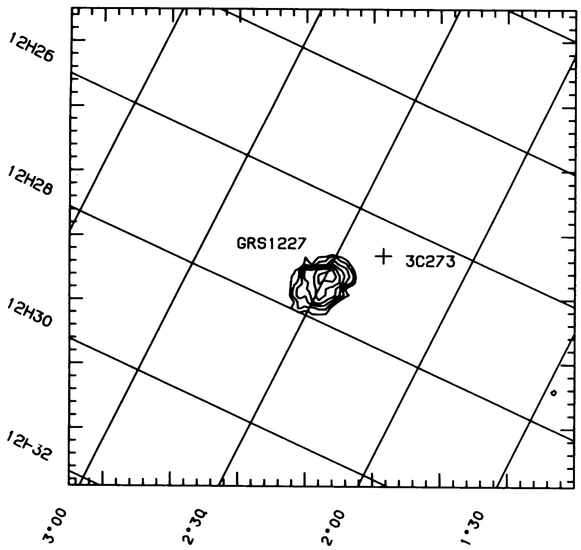

FIG. 1.—Contour plot of the sky region observed by SIGMA on 1990 November 28 in the 40–80 keV energy range. Only contours above the 2.5 σ level are shown with steps of 0.5 σ. As the 3C 273 flux is below this level for this particular observation, the source does not appear in the figure; however, its position is indicated by a cross.

obtained by an 8 × 8 grouping of the previous one can be tested. Here again, the run test gives a value compatible with the expected one within the 1 σ error bar.). Also the distribution of the excess counts, excluding the main excess, in the deconvolved image is fully compatible with the Poissonian statistics. Although the source shape is sharper than expected from the point-spread function of the detector, this effect might be of statistical origin due to the low significance of our detection.

In any case, the good quality of the image, the reliable performances of the instrument before and after this particular observation, as well as the use of an image and data treatment successfully tested in a number of sessions argue strongly against a technical or data analysis problem.

Having excluded this possibility, we then looked at the alternative explanation that the excess was due to a background fluctuation and evaluate the probability of such an occurrence. For a coded aperture telescope with a 29 × 31 element mask, an oversampling of 8 and having no "a priori" knowledge of the source position, we have estimated that a 5.5 σ excess corresponds to a chance probability of less than 10^{-2}. As 3C 273 is close by, we have also checked the possible contribution of the quasar at the position of the excess and we have estimated that this may reduce the detection at most by 0.7 σ.

As this may not be sufficient to claim the detection of a real celestial source, due to the possibility of detecting by chance such an excess over a large number of images, we have also analyzed all SIGMA observations so far performed on 3C 273 in order to check if excess count rates were present at the position of interest (R.A.[1950] = $12^h27^m20^s$, decl.[1950] = 02°30′ with an associated error radius of 5′). We have found that out of six other images, two show an excess at 3 σ confidence level in the same energy band and at a position compatible within 2 pixels (3′.2) with the one previously determined. As the probability of finding a 3 σ fluctuation at a known position is less than 6×10^{-3} and having found two such excesses in a sample of six observations, we estimate that the probability that these two detections are of statistical origin is less than 10^{-3}. This strongly reinforces the reality of the source, which we tentatively name GRS 1227+025.

2. LIKELY COUNTERPARTS

One of the SIGMA observations, for which there is evidence for the source at the 3 σ level, was made contemporaneously with the ART-P X-ray imaging detector on board *GRANAT* (Sunyaev et al. 1990). The source was not detected at X-ray energies by this instrument which sets 3 σ upper limits to the source flux in two consecutive energy bands: 1.6×10^{-3} and 2.6×10^{-4} photons cm^{-2} s^{-1} keV^{-1} in the 4–15 keV and 15–30 keV bands, respectively (Grebenev & Pavlinsky 1991). These values should be compared with our flux of 5×10^{-5} photons cm^{-2} s^{-1} keV^{-1} in the 40–80 keV band and a 3 σ upper limit of 2×10^{-5} photons cm^{-2} s^{-1} keV^{-1} between 80 and 120 keV for the same date (note, however, that ART-P covers only 5 hr of the 16 hr of the SIGMA observation). The first value obtained in 1991 July is approximately a factor of 2 lower than the highest detection made in 1990 November. All together SIGMA observations of this source indicate variability on long time scale of typically a factor of 2.

The finding chart from the Palomar Survey (POSS) plate of the sky region containing both 3C 273 and the new source is shown in Figure 2 (Plate L33) (the circle indicates the SIGMA uncertainty). Of the various objects inside the SIGMA error box, six are also present in the Hubble Space Telescope Guide Star Catalog (GSC) and are listed in Table 1. This catalog contains all sources with magnitude between 8.5 and 15 and therefore the majority of the objects inside our uncertainty circle are fainter than 15th mag. At this high Galactic latitude (60°) and inside a 5′ error box, we expect to find about five stars brighter than 15th mag; this value however increases to ≈100 for magnitudes < 21. We therefore expect a number of objects inside the SIGMA circle to be stars. The brightest object (object 199) is in fact a star of spectral type F5 (SAO 119431, BD 032657, AG 021581). We have also searched for optical counterparts in several catalogs available in computer readable format and enquired the SIMBAD and NED data base at Strasbourg and IPAC, respectively; we have found only a 20.2 mag quasar (1227+024) at $z = 2$ which is cataloged in Hewitt & Burbidge (1987).

We have also searched the whole region at far-infrared energies using the *IRAS* data bank at IPAC (both BIGMAP and ADDSCANS data were analyzed), but no positive detection has been obtained.

More fruitful was the search for X-ray counterparts (Table 1B). Grindlay (1992) has recently pointed out that an uncata-

TABLE 1A

OBJECTS IN SIGMA ERROR BOX: OPTICAL

Source	Position (1950) R.A.	Position (1950) Decl.	Magnitude	Comments
4[a]	$12^h27^m08^s.1$	02°32′35″	14.6	GSC
74[a]	12 27 14.2	02 29 52	14.5	GSC
245[a]	12 27 29.1	02 33 02	12.3	GSC
268[a]	12 27 31.0	02 31 43	14.7	GSC
251[a]	12 27 31.1	02 30 41	11.4	GSC
199[a]	12 27 37.2	02 30 27	9.5	GSC
50[a]	12 26 33.3	02 19 44	12.3	3C 273/GSC
H&B 87	12 27 35.0	02 28 47	20.2	QSO ($z = 2$)

[a] As numbered in the Hubble Guide Star Catalog (GSC).

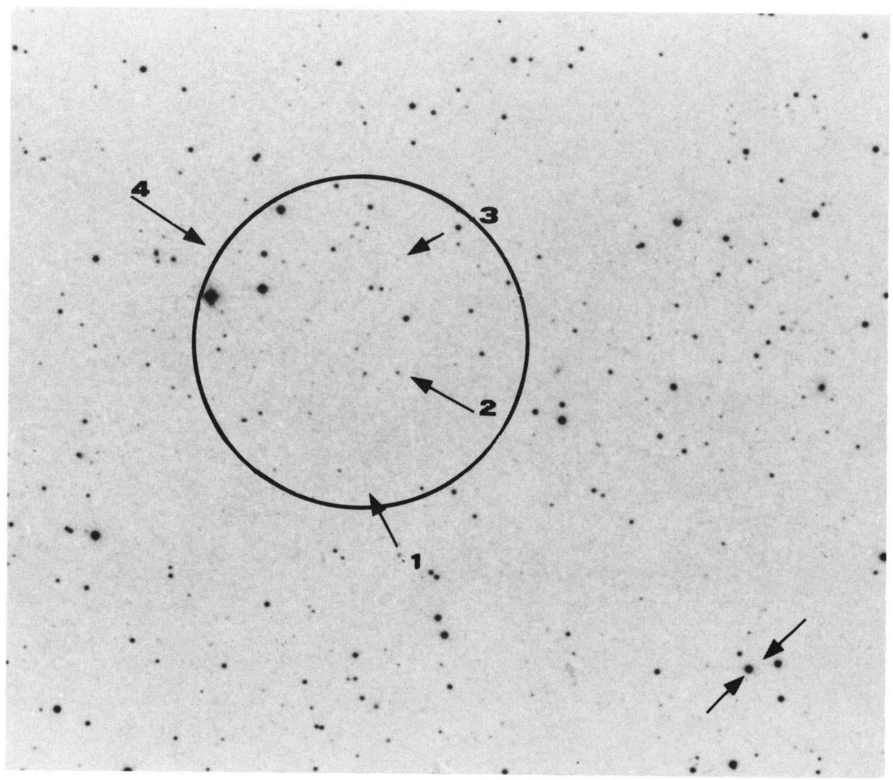

FIG. 2.—Finding chart of the sky region of interest from the Palomar Survey (red plate). The circle corresponds to the SIGMA positional uncertainty while arrows indicate the position of the X-ray sources discussed in the text and listed in Table 1B with the same number. The two arrows at the bottom of the figure indicate the quasar 3C 273.

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TABLE 1B

OBJECTS IN THE SIGMA ERROR BOX: X-RAY

Source	Position (1950) R.A.	Position (1950) Decl.	Flux (10^{-13} ergs cm^{-2} s^{-1})	References
1a *Einstein* (HRI)	$12^h27^m19^s.9$	02°24′40″	4.4 (0.1–4.5 keV)	1
1b *ROSAT* (PSPC)	12 27 19	02 24 54	1.3 (0.1–2.4 keV)	2
2 *EXOSAT* (CMA)	12 27 15.7	02 28 26	5.4 (0.05–2.0 keV)	3
3 *ROSAT* (PSPC)	12 27 16	02 31 26	1.0 (0.1–2.4 keV)	2
4 *ROSAT* (PSPC)	12 27 42	02 31 55	2.4 (0.1–2.4 keV)	2

REFERENCES.—(1) Grindlay 1992; (2) Staubert 1992; (3) *EXOSAT* data base and Giommi et al. 1991, assuming spectral parameters $\alpha = 2.5$ and $N_H = 1.8 \times 10^{20}$ cm^{-2}.

loged X-ray source detected by *Einstein* lies inside our error box. Tananbaum et al. (1979) reported this detection, but the source was never subsequently entered into the *Einstein* data base because it was not automatically found in the routine analysis programs. Tananbaum et al. reported it as a quasar at $z = 0.5$, and this optical identification has been recently confirmed by Grindlay (1992) who finds $z = 0.57$. The object appears to be variable between several IPC and one HRI pointings carried out during the period 1978–1981.

We have also been informed that during an observation devoted to 3C 273, *ROSAT* with its improved sensitivity has detected new X-ray sources nearby the quasar: two of these sources lie inside our error box, and a third one is just at the border (Staubert 1992). The positions of these *ROSAT* sources have a typical uncertainty of $\pm 30''$, and so it is evident from Table 1 that one of them corresponds to the *Einstein* source. This *ROSAT*/*Einstein* source coincides on the Palomar print with a 19–20 mag blue object.

Also, an X-ray object was found in the *EXOSAT*-CMA data base. The count rate is at threshold sensitivity, and so the source may be spurious (in fact, it is not included in the *EXOSAT* high Galactic latitude survey by Giommi et al. 1991); however, we mention it here because its position is compatible within the respective uncertainties with another *ROSAT* source detected in a follow-up deep observation of this sky region (R.A. = $12^h27^m16^s.8$ and decl. = 02°29′18″; Staubert 1992). Furthermore, this source corresponds on the finding chart to a faint object.

Note that all the soft X-ray sources mentioned above are between 100 and 1000 times less luminous than 3C 273, while our GRS source when bright has a hard X-ray intensity comparable to that of the quasar. Based on past observations of 3C 273 made by the *EXOSAT* and *Ginga* satellites, which also had our source in their fields of view and did not detect excess emission below 10 keV, we can deduce that the GRS source is much weaker than 3C 273 at these energies. This suggests either extreme variability or more likely an unusual spectral shape, which may be cut off below few tens of keV by strong absorption.

3. CONFUSION PROBLEMS IN PAST OBSERVATIONS

Analysis of all the SIGMA observations of this sky region indicates that on a few occasions both 3C 273 and GRS 1227+025 are present at around the 3 σ level; thus, source confusion may have affected previous estimates of the quasar flux, particularly in the SIGMA energy band. Various authors have in fact reported a "hard tail" above $\approx$10 keV in the spectrum of 3C 273 since this feature was first detected by the A-2 instrument (Worrall et al. 1979). In particular, recent evidences for this tail have been given by Damle et al. (1987) and Dean et al. (1990). These hard X-ray measurements have contemporary (within a few days) *EXOSAT*/*Ginga* observations (Turner et al. 1990): in both cases the hard X-ray data points were in excess of the low-energy power-law extrapolation. The angular resolution of all these instruments was such that they would not distinguish between 3C 273 and the GRS source, thus implying that they too may have earlier detected this new object. The excess flux from these observations is estimated to be less or equal to 9×10^{-4} photons cm^{-2} s^{-1} keV^{-1} in the 15–25 keV band, and although this is compatible with the flux detected by SIGMA in 1990 November, it is above the ART-P limit of 1991 July, thus suggesting variability above 10 keV. The comparison between low- and high-energy data further indicates that the tail varies on time scales less than a few days ($\leq$5–6), in agreement with SIGMA results. The source was visible at $\approx$3 σ level just the day before we detected it at the 5.5 σ level. We also note that the discrepancy found between observations of 3C 273 made contemporaneously by the A-2 and SMC instruments on board *HEAO 1* could be explained in terms of source confusion in one of the two telescopes but not in the other (Worrall et al. 1979; Bradt et al. 1979). Finally, the possible existence of a variable source 15′ away from 3C 273 casts some doubts on the study of X-ray intensity variations of the QSO if performed with nonimaging instrument. In particular, the isolated detection of a half-day flare in 3C 273 made by the *Ariel V* satellite (Marshall, Warwick, & Pounds 1981) may find a natural explanation if the variation is attributed to the GRS source.

Confirmation of this detection is certainly needed to firmly establish the reality of this new source which promises to be highly interesting from the astrophysical point of view. SIGMA will certainly keep monitoring 3C 273 and the surrounding region, thanks to its angular resolution during its lifetime. Observations of all objects in the SIGMA error box at various wavelengths are at this stage highly encouraged.

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