1992ApJ...392L..19B

THE ASTROPHYSICAL JOURNAL, 392:L19–L22, 1992 June 10
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SIGMA OBSERVATION OF HARD X-RAY EMISSION FROM THE ULTRASOFT X-RAY TRANSIENT TRIANGULUM AUSTRALE X-1 (A1524−62)

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Received 1992 February 14; accepted 1992 March 24

ABSTRACT

While monitoring the region of the sky containing Cir X-1, the SIGMA telescope detected a new hard X-ray source whose position is compatible with that of TrA X-1 (A1524−62), an ultrasoft X-ray transient discovered 15 years ago by *Ariel 5*. The SIGMA result supports the idea that TrA X-1 may be powered by accretion onto a black hole, as previously proposed by White and coworkers on the basis of its soft X-ray spectral properties. Since none of the X-ray all-sky monitors operating at the time of the SIGMA observation has reported a bright state for TrA X-1, the high-energy emission detected by SIGMA seems more likely to be related to a low-intensity outburst, further characterized by a hard spectrum with a weak soft X-ray component.

Subject headings: black hole physics — stars: individual (Triangulum Australe X-1, A1524−62) — X-rays: stars

1. INTRODUCTION

The X-ray transient TrA X-1 (A1524−62), discovered by *Ariel 5*, is located in the Triangulum Australe constellation near the well-known X-ray source Cir X-1. TrA X-1 was first observed to be at maximum on 1974 November 22 by the *Ariel 5* sky survey instrument (SSI; 2–18 keV; Pounds 1974). Subsequent observations by the SSI and the *Ariel 5* all-sky monitor (ASM; 3–6 keV) revealed that the November 22 maximum was only the peak of a precursor to a prolonged outburst of the source. TrA X-1 exhibited its maximum brightness on 1974 December 4, reaching a level of 0.9 crab in the 3–6 keV energy band (Kaluziensky et al. 1975). This maximum was followed by a slow decay, with an *e*-folding time of about 2 months (Kaluziensky et al. 1975). The spectra obtained by the SSI during the 1 month long precursor showed a slight softening with time, the data at the November 22 maximum being well fitted with a power-law spectrum of index 2.5 (Kaluziensky et al. 1975). This spectral softening was later confirmed by postpeak observations performed by the *Ariel 5* proportional counter spectrometer (experiment C, 1.5–20 keV) from 1975 February 6 to 8. The average power-law spectrum corresponding to these observations was indeed considerably steeper, with an index of 4.2 (Maraschi et al. 1976). It is worth stressing that neither X-ray pulsations nor type I X-ray bursts have been recorded from TrA X-1 during any of the *Ariel 5* observations.

The identification of TrA X-1 with an optically faint nova was first proposed by Murdin et al. (1977) and confirmed by Bradt et al. (1977), who derived the position $\alpha = 15^h24^m06^s.9$, $\delta = -61°42'41''$ with a 90% confidence error radius of 20″. From a consideration of the optical and X-ray light curves, as well as the optical-to-X-ray luminosity ratio, the source was found to be very similar to A0620−00 (Murdin et al. 1977). Using these similarities, they estimated the distance of TrA X-1 to be greater than 3 kpc. More recently van Paradijs & Verbunt (1984) proposed a distance of 4.4 kpc assuming $M_v(\max) = 1.0$ and $E(B-V) = 0.7$. At this distance the X-ray luminosity of the December 4 maximum was 7×10^{37} ergs s^{-1} (van Paradijs & Verbunt 1984).

Since the last positive detection by the rotating modulation collimators on *SAS 3* in 1975 June (Jernigan 1975; Bradt et al. 1977), TrA X-1 was detected neither by *HEAO 1* A-4, by *EXOSAT*, nor, more recently, by *Ginga*. In this paper we report on the reappearance of TrA X-1 as well as its detection at hard X-ray energies ($E > 35$ keV) for the first time. The observations were carried out by the French telescope SIGMA aboard the Soviet *GRANAT* spacecraft.

2. OBSERVATIONS AND RESULTS

The SIGMA coded-mask telescope, operating in the 35–1300 keV energy range, provides sky images with an angular resolution of about 15′. The full description, as well as the in-flight performance of the instrument, has been presented in detail previously (Paul et al. 1991; Mandrou et al. 1991). Briefly, as far as the image acquisition is concerned, two different kinds of images are recorded simultaneously during a standard observation: (1) fine images (FIs; 248 × 232 1′.6 pixels), taken in four adjacent energy bands, which allow source location with a positional accuracy of a few arcminutes depending on the source strength, and (2) spectral images (SIs; 124 × 116 3′.2 pixels), a set of 95 images taken in 95 consecutive energy channels covering the whole SIGMA energy range.

On 1990 August 27, the telescope observed the region of the sky centered on Cir X-1 for the first time. TrA X-1, which is

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TABLE 1

INTENSITIES DERIVED FROM THE FIRST TWO FINE IMAGES[a]

Date of Observation	Duration of Observation (s)	TrA X-1 (A1524−62) 41–75 keV	TrA X-1 (A1524−62) 75–152 keV	Cir X-1 41–75 keV	Cir X-1 75–152 keV
1990 Aug 27	59038	0.23 (0.04)	0.087 (0.06)	<0.057	<0.085
1991 Jan 21	57976	<0.09	<0.139	<0.061	<0.091

[a] For the 1990 August 27 observation, 1 σ errors for the detected counts from TrA X-1 are given. When a source is not detected, the 2 σ upper limits are listed. Intensities are given in counts per second.

about 5° from Cir X-1, was then located in the partially coded field of view, and therefore imaged with a sensitivity reduced by a factor of 0.71. In order to search for significant peaks we usually look first at the FI time-integrated over the whole session. A strong peak at 5.8 σ was found at the position $\alpha = 15^h24^m35^s$, $\delta = -61°39'51''$ (equinox 1950) in the FI corresponding to the first energy range (e.g., 41–75 keV). The uncertainty in the position associated with such a strong excess is typically 5′ at the 90% confidence level. Because the position of the SIGMA source is fully compatible with the optical position of TrA X-1 reported in Bradt et al. (1977), we will assume in the following that the hard X-ray emission originates in TrA X-1 (Sunyaev 1990). The probability of finding a 5.8 σ excess in the SIGMA error box of TrA X-1 has been estimated to be less than 5×10^{-6}. We computed this upper limit by multiplying the normal probability of having a 5.8 σ excess by the number of pixels inside the SIGMA error box of TrA X-1 and by the number of potential sources present in the field of view. In Table 1 we report the count rate of TrA X-1 as derived from the first FI (41–75 keV). The upper limit for Cir X-1, which was not detected, is also given.

The observed spectrum is obtained by taking the detected counts in the pixel corresponding to the SIGMA position of TrA X-1, in the 95 SI. Extending the energy band to 99 keV increases the significance level of the source up to 7.9 σ. The SI corresponding to this energy range is shown in Figure 1. Since no significant flux was found above 99 keV, the observed count spectrum of TrA X-1 has been fitted only between the low-energy threshold (37 keV) and 113 keV. The corresponding 24 channels have been regrouped into 12 wider channels and fitted with an incident power law folded with the detector energy response matrix (Barret & Laurent 1991). The best-fit power-law parameters are a flux at 70 keV of 1.1 ($\pm$0.26) $\times 10^{-4}$ photons cm^{-2} s^{-1} keV^{-1} and a spectral index of 1.8 ($\pm$0.7) with a reduced χ^2 value of 1.7 for 10 dof. The errors are given at the 68% confidence level for joint variation of two fitting parameters. In the 37–100 keV energy range, this best fit corresponds to an integrated flux of 9×10^{-3} photons cm^{-2} s^{-1} and an associated X-ray luminosity of 2×10^{36} ergs s^{-1} for a distance of 4.4 kpc.

The photon spectrum is then obtained from the observed spectrum through a process based on the maximum-entropy method. Figure 2 shows the SIGMA data points together with the best-fit power-law model. Note that the last point of this spectrum, which is a 2 σ upper limit, may indicate the presence of a spectral break around 90 keV.

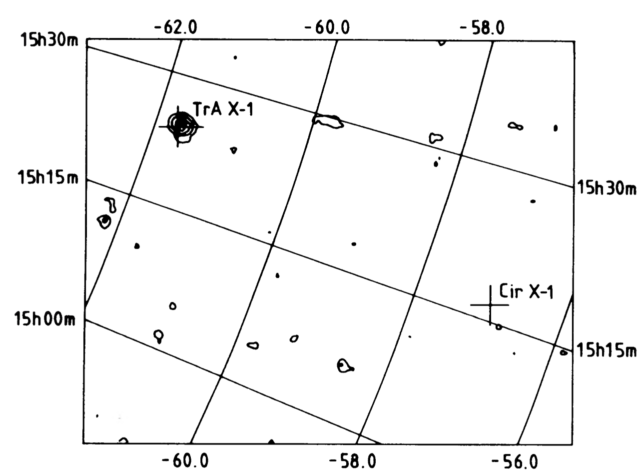

FIG. 1.—SIGMA 41–99 keV image of the Cir X-1 region. The position of Cir X-1 is indicated by a cross. The SIGMA source whose error box (5′) contains the optical counterpart of TrA X-1 (Bradt et al. 1977) is approximately 5° away. The contour intervals represent significance steps from 2.5 to 7.5 σ in increments of 1.25 σ.

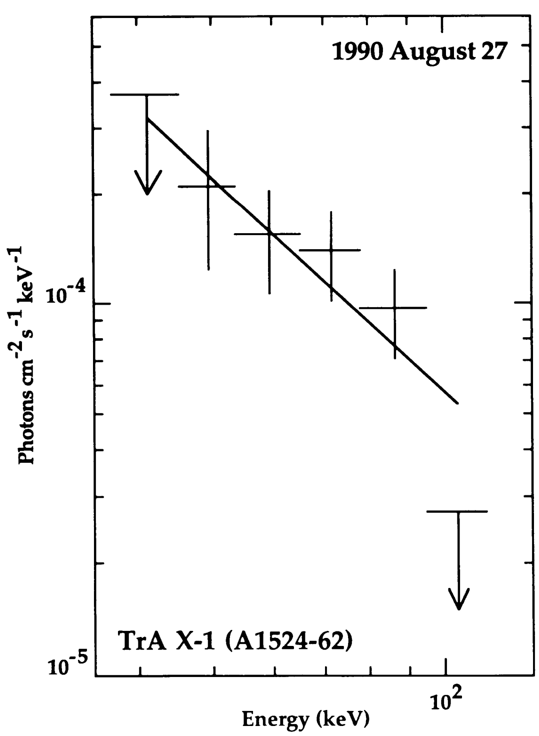

FIG. 2.—SIGMA spectrum of TrA X-1 (A1524−62) obtained during the 1990 August 27 observation. The continuous line is the best-fitting power-law spectrum. The upper limits are given at the 2 σ confidence level.

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TABLE 2

2σ Upper Limits on Hard X-Ray Emission from TrA X-1 and Cir X-1[a]

Source	40–60 keV	60–80 keV	80–100 keV
TrA X-1 (A1524−62)[b]	16.4	6.3	4.8
Cir X-1[c]	7.2	2.8	2.2

[a] Assuming a Crab-like spectrum (photon index = 2). Units are 10^{-5} photons cm^{-2} s^{-1} keV^{-1}.

[b] Upper limits calculated for the 1991 January 21 session.

[c] Upper limits calculated for the sum of the 1990 August 27 and the 1991 January 21 observations.

The region of the sky containing Cir X-1 and TrA X-1 was subsequently observed by the SIGMA telescope on 1991 January 21. Neither TrA X-1 nor Cir X-1 was detected (see Table 1). The upper limits to the hard X-ray emission from TrA X-1 using this observation are reported in Table 2. For Cir X-1 we have added together the 1990 August 27 and the 1991 January 21 observations to get more significant upper limits. The values so obtained are listed in Table 2.

3. DISCUSSION

Among transient X-ray sources, the so-called ultrasoft X-ray transients (USFXT) deserve particular attention, since they are thought to be accreting black holes in binary systems. However, dynamical evidence for a compact object mass in excess of 3 $M_{\odot}$, the largest value currently believed possible for a stable neutron star, has been obtained so far for only two USFXTs: the well-known A0620−00 (McClintock & Remillard 1986) and, very recently, GS 2023−338 (Casares, Charles, & Naylor 1992). For the remaining USFXTs, the hypothesis that they may be powered by accretion onto a black hole is simply based on the fact that during outburst they display X-ray spectral and timing signatures similar to those of Cyg X-1: (1) a bimodal spectral behavior with an ultrasoft high state; (2) at least for the brightest sources, an unsaturated Comptonized hard tail extending up to a few hundred keV; and (3) millisecond flickering (Tanaka 1989). Along this line of argument, TrA X-1 was initially proposed as a black hole candidate (White et al. 1984) on the basis of its ultrasoft spectrum and bimodal spectral behavior, observed by *Ariel 5* during the 1974 outburst (Kaluziensky et al. 1975; Maraschi et al. 1976). However, since then, type I X-ray bursts, the unmistakable signature of an accreting neutron star, have been detected from Cir X-1, which also exhibits flickering and bimodal spectral behavior (Tennant 1988). Following this discovery, McClintock (1991) suggested that among the above signatures of a black hole, the power-law tail may be the only reliable one. A power-law tail extending up to 150 keV has been reported recently from the soft transient type I X-ray burster KS 1731−260 (Barret et al. 1992) Therefore, it appears that none of the proposed X-ray signatures taken separately is conclusive evidence for a black hole. However, the conjunction of some of them may still be. In particular, a power-law tail and a bimodal spectrum have never been observed from a binary system containing a clearly identified neutron star. In the case of TrA X-1, the hard tail observed by SIGMA, together with the *Ariel 5* observations, would therefore suggest consideration of TrA X-1 as a black hole candidate.

Among the common features of the USFXTs, and more generally of the soft X-ray transients, previous observations performed at optical wavelengths as well as in the X-ray domain have shown that they rise from quiescence to the maximum brightness in a few days. They remain bright enough to be detectable for a few weeks to a few months, with typical peak X-ray luminosities of 10^{37}–10^{38} ergs s^{-1}. On the other hand, the quiescent phase lasts considerably longer, up to a few tens of years, but is also much fainter, with X-ray luminosities well below 10^{34} ergs s^{-1}. In the context of these observational properties, the SIGMA result may provide evidence for a previously unknown state of USFXTs. Indeed, without any doubt the hard X-ray emission detected by SIGMA from TrA X-1 is not related to a classical outburst phase, since none of the X-ray all-sky monitors operating at the time of the SIGMA observation has reported a bright state for TrA X-1. In particular, the *Ginga* all-sky monitor observed the region surrounding TrA X-1 2 days after our observation, setting a 3 σ upper limit of 50 mcrab in the 2–10 keV energy range (Makino 1992, private communication). Moreover, the *GRANAT* all-sky monitor WATCH designed for the localization of X-ray transient sources (Lund 1991), providing a typical sensitivity of about 100 mcrab in the 6–60 keV energy range, did not detect the source either before or after the SIGMA August 27 observation. On that day, however, WATCH marginally detected an episode of weak, short (3 hr duration) soft X-ray emission attributed to TrA X-1 (N. Lund 1991, private communciation). In any case, these soft X-ray observations rule out the hypothesis of a bright outburst of TrA X-1 with an intensity comparable to that observed by *Ariel 5* in 1974 (i.e., up to 900 mcrab in the 3–6 keV range). The SIGMA detection appears more likely to be associated with a low-intensity outburst, further characterized by a hard spectrum with a weak soft X-ray component. Although the SIGMA and *Ginga* observations are not strictly simultaneous, comparison of their results is still valid, since the 2 day interval between them is small compared with the typical time scale of an outburst. Moreover, we note that the *Ginga* upper limit lies very close to the extrapolation in the low-energy range of the SIGMA best power-law fit. It is unfortunate that TrA X-1 was outside the 3° × 3° field of view of the *GRANAT* soft X-ray telescope ART-P (4–30 keV), which was also pointed toward Cir X-1, during the SIGMA observation.

In fact, it is worth stressing that a hard tail with a weak soft X-ray component below 10–20 keV is a common spectral property of bright X-ray transients during the decay phase. Indeed, numerous observations, performed over a wide energy band, have clearly shown that the overall shape of the spectrum is strongly variable within the outburst (Tanaka 1989). In particular, it is found that while the soft X-ray flux follows a smooth exponential decay, the hard component becomes comparatively stronger as the X-ray luminosity (i.e., the accretion rate) decreases (Parmar, Stella, & White 1986 for 4U 1630−47). This is also exemplified by recent SIGMA observations of a new USFXT: the Nova Muscae (Goldwurm et al. 1992; Sunyaev et al. 1992). Therefore, if we hypothesize that a low-intensity outburst is a classical outburst for which the accretion rate is not excessively high, one might expect the emergent spectrum to be hard during the active phase. This is strengthened by theoretical works predicting that at low accretion rate the inner parts of the accretion disk are hot and optically thin (Ichimaru 1977; White & Lightman 1989).

4. CONCLUSION

The SIGMA telescope has detected the ultrasoft X-ray transient TrA X-1, discovered 15 years ago by *Ariel 5*, for the first time at hard X-ray energies. The SIGMA result supports the

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hypothesis that TrA X-1 may be powered by accretion onto a black hole. Further observations of this source at various wavelengths are therefore highly encouraged. The fact that X-ray all-sky monitors (*Ginga* and WATCH) did not report the detection of the source clearly indicates that the hard X-ray emission seen by SIGMA is not related to a classical outburst phase of the source. The observed hard tail may be the signature of a new class of low-intensity outburst, with the hard X-ray emission dominating the spectral formation. The existence of such a new class of hard outbursts must be confirmed by other observations, performed simultaneously in the soft and hard X-ray ranges. This may be achieved by the two imaging instruments SIGMA and ART-P aboard the *GRANAT* satellite.

We acknowledge the outstanding contribution of the SIGMA project group of the CNES, as well as the laboratory staffs, to the overall success of the mission. We also thank the staffs of the Baïkonour Space Center, the Lavotchkine Space Company, the Babakin Space Center, and the Evpatoria ground station for their unfailing support throughout the conception, the integration, and the operational phases.

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