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Chandra X-ray counterpart of KS 1741–293
(*Research Note*)

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ABSTRACT

Aims. We aim to investigate the nature of the high energy source KS 1741−293 by revisiting the radio and infrared associations proposed in the early 1990s.
Methods. Our work is mostly based on the analysis of modern survey and archive data, including the NRAO, MSX, 2MASS and Chandra archives, and catalogues. We also have obtained deep CCD optical observations by ourselves.
Results. The coincidence of KS 1741−293 with an extended radio and far-infrared source, tentatively suggested in 1994, is no longer supported by modern observational data. Instead, a Chandra source is the only peculiar object found to be consistent with all high-energy error circles of KS 1741−293 and we propose it to be its most likely X-ray counterpart. We also report the existence of a non-thermal radio nebula in the vicinity of the KS 1741−293 position with the appearance of a supernova remnant. The possibility of being associated to this X-ray binary is discussed.

Key words. X-rays: binaries – radio continuum: stars – ISM: supernova remnants

1. Introduction

KS 1741−293 ($l^{\rm II} = 359\overset{\circ}{.}56$; $b^{\rm II} = -0\overset{\circ}{.}08$) is a X-ray transient first detected in 1989 by the X-ray widefield camera TTM in the KVANT module of the Mir space station (in't Zand et al. 1991) and located with arc-minute accuracy. The KVANT position had some degree of overlap with the X-ray sources MXB 1742−29 and MXB 1743−29, detected in 1976 by the Third Small Astronomy Satellite (SAS-3). At the time of its discovery, KS 1741−293 was also considered as a bursting source based on two burst events with single peak structure. The bursting nature of the source strongly pointed to a neutron star low-mass X-ray binary (LMXB), and it appears to be classified as such in the Liu et al. (2001) catalogue.

KS 1741−293 has been observed by different satellites over the years and its detection history is summarized in Table 1. While most space observatories agree about the fact that this is a highly absorbed source ($N_{\rm H} \simeq 10^{23}$ cm^{-2}), its position has unfortunately remained poor at the $\lesssim$1 arcmin level. For instance, the BeppoSAX detection (Sidoli et al. 1999) was reported using not its own data but the more accurate original KVANT position. All detections are with a comparable flux and power-law index (when available), thus reinforcing the idea that the observed source is actually the same.

The optical, infrared, and radio counterparts of KS 1741−293 were searched for and investigated by Cherepashchuk et al. (1994). Among possible identifications, they tentatively quoted the extended radio G359.54−068 and far-infrared FIR5 sources, as well as IRAS 17417−2919. However, no firm candidate resulted from their work and this remains unchanged since then.

The fact that KS 1741−293 is today known to be among the high energy sources dominating the Galactic center sky in hard X-ray/soft γ-rays (Bélanger et al. 2006), strongly supports calls for the revision of these associations proposed more than one decade ago. This goal is at present a much more feasible task thanks to the availability of modern radio, infrared, and X-ray surveys with excellent sensitivity and angular resolution. For instance, the early suggestion of possible radio/infrared coincidences were based on single telescopes with arcminute angular resolution.

In this paper, we use improved multi-wavelength data, free from the severe confusion problems of previous work, allowing us to propose an arc-second accurate location for the KS 1741−293 counterpart. Originally, our attention was called to KS 1741−293 in the course of a cross-identification exercise between X-ray binaries from the Liu et al. (2001) catalogue and radio sources from the Multi-Array Galactic Plane Imaging Survey (MAGPIS) at 6 cm (Helfand et al. 2006). While KS 1741−293 is not catalogued as a radio-emitting X-ray binary, it was intriguing that the MAGPIS radio source 359.558−0.077, with a 6 cm peak flux density of 5.5 mJy beam^{-1}, was remarkably consistent with all error boxes listed in Table 1. Despite the minor coordinate difference, the MAGPIS object is most likely the same radio source originally quoted by Cherepashchuk et al. (1994). From this starting point, we conducted a follow up investigation whose results are presented in the following sections.

Table 1. History of X-ray/low energy γ-ray detections of KS 1741−293 in the literature.

Instrument	Energy range (keV)	Flux (erg s^{-1} cm^{-2})	Spectral info	$N_{\rm H}$ (cm^{-2})	$\alpha_{\rm J2000}$, $\delta_{\rm J2000}$	90% error radius ($''$)	Ref.
KVANT	2–30	96×10^{-11}	kT = 9 keV	$\leq 10^{23}$	$17^{\rm h}44^{\rm m}49^{\rm s}.25$ $-29^{\circ}21'06''.3$	60	1
BeppoSAX	2–10	$(14.5^{+2.0}_{-0.6}) \times 10^{-11}$	$\Gamma = 2.0 \pm 0.2$	$(20 \pm 2) \times 10^{22}$	$17^{\rm h}44^{\rm m}49^{\rm s}.25$ $-29^{\circ}21'06''.3$	60	2
ASCA	0.7–10	9.1×10^{-11}	$\Gamma = 2.12^{+0.20}_{-0.19}$	$(20.3^{+1.7}_{-1.6}) \times 10^{22}$	$17^{\rm h}44^{\rm m}53^{\rm s}.49$ $-29^{\circ}21'15''.9$	40	3
INTEGRAL	20–40 40–100	$(6.66 \pm 0.08) \times 10^{-11}$ $(7.35 \pm 0.19) \times 10^{-11}$	–	–	$17^{\rm h}44^{\rm m}52^{\rm s}.8$ $-29^{\circ}20'24''$	64.4	4,5
CHANDRA	0.5–8	2.1×10^{-10}	$\Gamma = 2$ assumed	–	$17^{\rm h}44^{\rm m}51^{\rm s}.06$ $-29^{\circ}21'16''.8$	1.3	6,7

(1) in't Zand et al. (1991); (2) Sidoli et al. (1999); (3) Sakano et al. (2002); (4) Bélanger et al. (2006); (5) Bird et al. (2006); (6) Muno et al. (2006); (7) this paper.

Table 2. VLA archive observations used in this paper.

Date	λ (cm)	VLA conf.	IF# and width*	# vis.	Project id.
1984 Apr. 10	6	C	2, 25	5245	A044
2003 Feb. 25	6	D	2, 50	34 088	AL587
2003 Mar. 10	6	D	2, 50	39 283	AL587
2004 Jan. 30	20	BC	2, 50	50 691	AL617
2004 Jan. 31	20	BC	2, 50	88 518	AL617
2004 May 27	20	CD	2, 50	29 511	AL617
2004 Aug. 23	20	D	2, 50	30 897	AL617

(*) Frequency width given in MHz.

2. KS 1741–293 in the radio

We searched and downloaded several Very Large Array (VLA) observation projects from the NRAO data archive covering the KS 1741−293 position at the 6 and 20 cm wavelengths, as listed in Table 2. The idea was to produce radio maps at different wavelengths with similar synthesized beams for reliable spectral index measurement. The data were edited and calibrated using standard procedures with the AIPS package of NRAO. In some data sets, the pointing position was slightly different and the visibilities had to be corrected for the offset. This was achieved using the AIPS task UVFIX before data sets being concatenated into a single archive with the AIPS task DBCON. Such a procedure is likely to induce some minor errors when correcting for primary beam response, but we estimate this should not affect the conclusions based on this work.

The final maps were produced with the AIPS task IMAGR using uniform weight for enhanced angular resolution. We present them in Figs. 1 and 2 together with the 90% confidence error circles of Table 1. The location of Chandra X-ray sources, that will later be relevant for the discussion, are also plotted on these maps. It is remarkable that a peak of radio emission (centered at $\alpha_{\rm J2000.0} = 17^{\rm h}44^{\rm m}51^{\rm s}.96 \pm 0^{\rm s}.02$ and $\delta_{\rm J2000.0} = -29^{\circ}21'14''.8 \pm 0''.4$) is clearly visible within the overlapping region of the KVANT, ASCA, and INTEGRAL IBIS/ISGRI circles. This maximum, together with the nearby extended radio emission, are very likely to conform the arc-minute extended radio source quoted by Cherepashchuk et al. (1994) based on single-dish observations. A spectral index map shown in Fig. 3 was computed by combining matching beam images made from the same visibility data of Figs. 1 and 2 after correction for primary beam response. As a result, negative spectral index values significantly dominate the field, which is indicative of the fact that that the whole radio source is of non-thermal (i.e., synchrotron) origin.

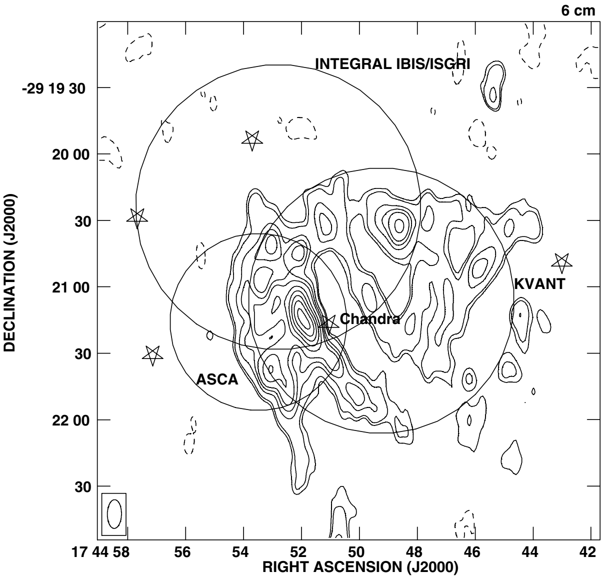

Fig. 1. VLA map of the KS 1741−293 field at the 6 cm wavelength using visibilities obtained in C and D configurations of the array. Contours are −4, 4, 5, 8, 10, 12, 16, 20, 24, 28, and 32 times 0.4 mJy beam^{-1}, the rms noise. The synthesized beam is shown as an ellipse at the bottom left corner measuring $12''.96 \times 6''.37$ with position angle of −1°. The 90% confidence error circles of the KVANT, ASCA, and INTEGRAL IBIS/ISGRI are also plotted and labeled accordingly. The positions of Chandra sources in the field are indicated by the small star symbols whose uncertainties are smaller than the symbol size. The Chandra label is reserved for the proposed X-ray counterpart of KS 1741−293.

3. KS 1741–293 in X-rays

The recent Chandra Galactic Central 150 pc Source Catalogue (Muno et al. 2006) shows several X-ray sources in the KS 1741−293 field. Only one of them, namely CXOGC J174451.0−292116, is consistent with the overlapping region of all error circles plotted in previous figures. This fact certainly appears remarkable and leads us to propose this Chandra source as the most likely X-ray counterpart candidate to KS 1741−293. The Chandra detection appears to

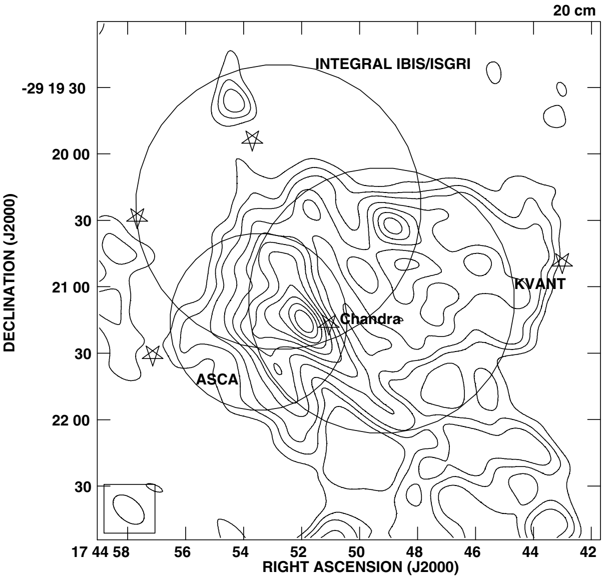

Fig. 2. The same KS 1741−293 field and labels as in Fig. 1 observed with the VLA at 20 cm. This map has been computed by combining visibilities obtained in the BC, CD, and D configurations of the array. Contours are −4, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, and 22 times 1.5 mJy beam^{-1}. The synthesized beam is shown as an ellipse at the bottom left corner and corresponds to 16.″54 × 9.″95 with position angle of 48.°6.

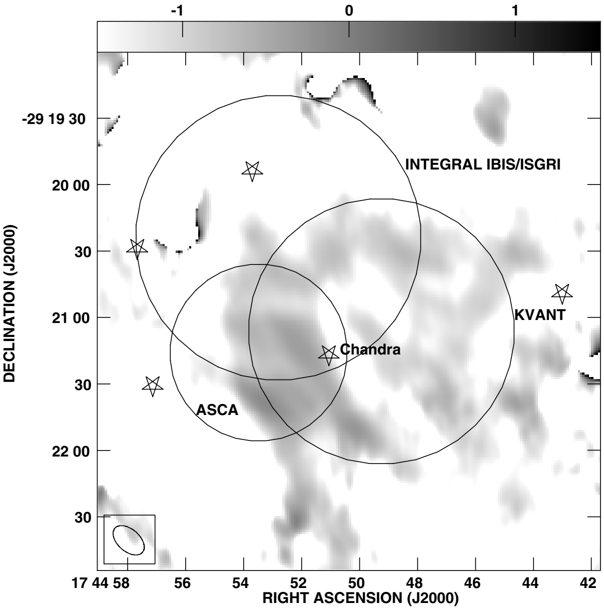

Fig. 3. Spectral index map in gray scale made combining the same 6 and 20 cm visibility data of Figs. 1 and 2. The individual maps were restored with the same 20 cm synthesized beam (i.e., the one with lower angular resolution) and primary beam corrected prior to being combined in spectral index mode with the AIPS task COMB. Labels are the same as in previous figures.

have a negligible count rate in the softest energy band of the satellite. This fact is well consistent with a highly absorbed source.

4. KS 1741–293 in the infrared and optical

In the left panel of Fig. 4 we show the 21.3 μm image of the KS 1741−293 region as observed by the NASA Midcourse Space Experiment (MSX). Here, there is also an obvious source, of point-like appearance, within the common area of error circles. It is named as G359.5609−00.0810 in the MSX catalogue and is located at $\alpha_{\rm J2000.0} = 17^{\rm h}44^{\rm m}53\overset{\rm s}{.}28 \pm 0\overset{\rm s}{.}03$ and $\delta_{\rm J2000.0} = -29^\circ21'10\overset{\prime\prime}{.}8 \pm 0\overset{\prime\prime}{.}2$. The rising flux density of this mid-infrared source across the MSX bands is suggestive of being a highly absorbed object. Its position is within the large uncertainty of the far-infrared source FIR5 proposed by Cherepashchuk et al. (1994). However, looking at the original FIR5 data (Odenwald & Fazio 1984), one cannot rule out confusion problems when trying to associate it with a single MSX source. A key point here is the fact that the MSX source G359.5609−00.0810 is not consistent in position with the peak of radio emission in the VLA maps, suggesting that they could be unrelated objects.

The Chandra position has a 90% confidence error circle of 1.″3 thus enabling accurate searches for counterparts at other wavelengths that could confirm the identification. A preliminary inspection of the 2 Micron All Sky Survey (2MASS, Skrutskie et al. 2006) images and a deep CCD optical integration reveal no near infrared or optical counterpart for CXOGC J174451.0−292116 (see middle and right panels of Fig. 4). This is not a surprising result given the large absorption expected in this field. The currently available magnitude limits are about $I \geq 20.5$, $J \geq 18$, $H \geq 15$, and $Ks \geq 14$.

5. Discusion and conclusions

Our main argument to claim the identification of KS 1741−293 with the Chandra source CXOGC J174451.0−292116 is a positional coincidence with all error circles available. The unabsorbed flux from CXOGC J174451.0−292116, in the 0.5–8 keV band, is relatively faint for accurate spectral analysis and amounts to 4.1×10^{-6} photon cm^{-2} s^{-1}. Assuming a conceivable photon index $\Gamma = 1.5$ and hydrogen column density $N_{\rm H} = 1.0 \times 10^{23}$ cm^{-2}, the corresponding unabsorbed energy flux in the 2–10 keV band is 9.6×10^{-10} erg s^{-1} cm^{-2}. At a Galactic center distance of 8.5 kpc, this corresponds to a luminosity of 8.3×10^{36} erg s^{-1}, which appears as a reasonable value for the quiescent emission of a X-ray binary. For the hydrogen column density adopted above, the deepest Ks-band upper limit would translate into absolute magnitudes of $Ks_{\rm abs} \geq -6$ at the Galactic center distance. This value safely excludes at least all supergiant and late giant stars and would be fully in agreement with the suspected LMXB nature of KS 1741−293.

If our identification is correct, any association with the Cherepashchuk et al. (1994) radio and far-infrared is definitely ruled out. This is because CXOGC J174451.0−292116 is not positionally consistent with either the radio peak or the MSX source discussed above. On the other hand, the fact the Chandra source itself is not detected at 6 cm above 1.2 mJy (3σ) is compatible with the usually low radio luminosities of neutron star X-ray binaries (Muno et al. 2005).

The morphology of the extended radio emission around the Chandra source is very reminiscent of a supernova remnant (SNR). This is also supported by the non-thermal spectral index estimated from 20 and 6 cm maps. Therefore an interesting scenario is that this extended radio source, first pointed out by Cherepashchuk et al. (1994), could be the SNR where KS 1741−293 was originated.

The association between LMXBs with SNRs could be the result of supernova explosions due to the accretion induced

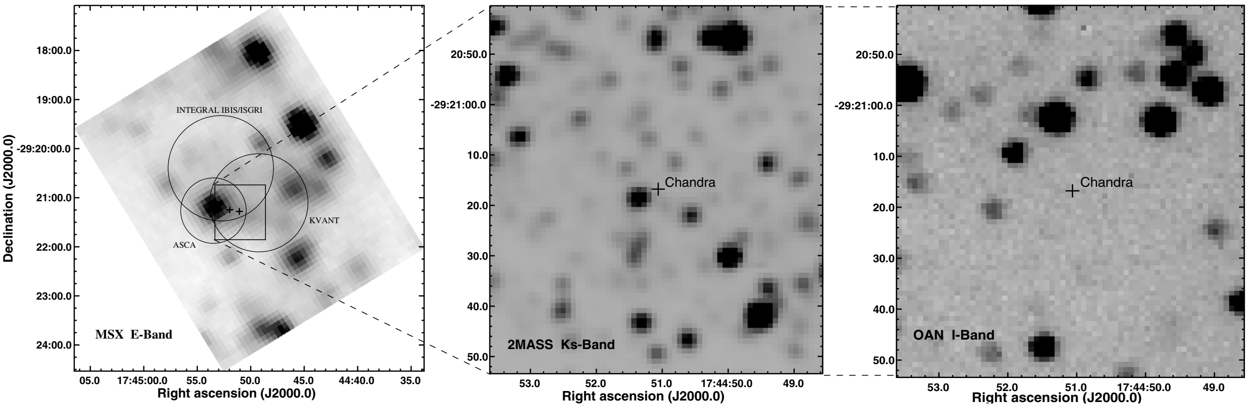

Fig. 4. *Left*: the field of KS 1741−293 as observed with MSX in the infrared E-band (21.3 μm). The same KVANT, ASCA, and INTEGRAL IBIS/ISGRI error circles are plotted as in previous figures. The small left and right central crosses mark the location of the radio peak and the Chandra X-ray source discussed in the text, respectively. *Middle*: zoomed 2MASS image in the near infrared Ks-band centered around the proposed Chandra counterpart of KS 1741−293. The location and uncertainty of the Chandra X-ray source is indicated by the small cross. *Right*: the same as in the middle panel observed in the optical I-band. This frame was obtained on August 28th, 2006, with the OAN 1.52 m telescope in Calar Alto (Spain).

collapses, a really rare event. Searching for LMXBs projected on SNRs in the Galaxy, Tuncer et al. (2000) found that of six positional coincidences only one of them is likely to be real. This is the case of the LMXB 2259+587 and the SNR G109.1-1.0 (CTB 109) (Gregory & Fahlman 1980; Hughes & Smith 1994), a system that lies at 3 kpc. In our case, adopting a distance for the possible LMXB/SNR system of ~8.5 kpc, the SNR radius should be of 3.8 pc. If the expansion is adiabatic, it can be modeled by the standard Sedov solutions (Sedov 1959). Considering the SNR expansion in a homogeneus medium with density ~ 1 cm^{-3} around the galactic center and an SN energy of the explosion $E \sim 10^{51}$ erg (Spitzer 2004), the age of the SNR would be $t \sim 500$ yr. This age is very low for a LMXB, so that the association of KS 1741−293 with the SNR does not seem very likely unless the source is very young.

In summary, we have revisited the previous radio and mid-infrared associations for KS 1741−293 showing that they are not sustained by the modern observational data. Instead, we propose a Chandra X-ray source as a likely counterpart. Our candidate is surrounded by extended non-thermal radio emission, with a very likely SNR origin, although a physical association is not yet clear. Further progress on unveiling the true nature of KS 1741−293 is needed given that it is one of the conspicuous objects in the Galactic center that also appears superposed to the TeV emission from the Galactic Ridge (Aharonian et al. 2006). This could be achieved by deeper infrared observations.

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