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The physical connection between G337.2+0.1 and AX J1635.9−4719

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Abstract. We present evidence supporting a SNR origin for the radio source G337.2+0.1, which was discovered in the MOST 843-MHz radio survey. The radio source is spatially coincident with the unidentified ASCA source AX J1635.9-4719. A deep study of this latter source reveals that its X-ray spectrum, extended nature, and non-variable flux are consistent with what is expected for a SNR. In addition, we have used HI-line observations of the region to look for any effect of the presumed remnant in the ISM. We have found a well-defined minimum centered at the position of the radio source in the velocity range of −25 to −19 km/s. This feature appears as a sharp absorption dip in the spectrum that might be produced when the continuum emission from the SNR candidate is absorbed by foreground gas. Hence we have used it to constrain the distance to the source, which seems to be a young (age ~ a few 10^3 yr) and distant (d ~ 14 kpc) SNR. G337.2+0.1 and AX J1635.9-4719 would be the radio/X-ray manifestations of this remnant.

Key words. X-ray: individuals: AX J1635.9−4719 – radio continuum: ISM – ISM: supernova remnants – ISM: cosmic rays – X-rays: ISM – radiative mechanism: non-thermal

1. Introduction

Supernova remnants (SNRs) are widely believe to be the source of galactic cosmic rays (CRs) with energies up to the knee of the spectrum at ~ $10^{15.5}$ eV (Ginzburg & Syrovatskii 1964). First-order Fermi shock acceleration has been suggested as the most likely acceleration mechanism for charged particles in the shells of SNRs (Bell 1978). Evidence supporting the presence of TeV electrons in these objects comes from the detection of synchrotron X-rays in a number of sources such as G347.3−0.5 (Koyama 1997), SN 1006 (Koyama 1995), or Cas A (Allen et al. 1997), among others.

A decade ago the detection of SNRs at X-rays was difficult mainly due to the absorption of the soft (i.e., < 3 keV) X-ray emission by the large column density of gas and dust in the galactic plane. In recent years, with the advent of the new generation of X-ray satellites, the number of galactic SNRs detected in the

Send offprint requests to: J. A. Combi energy range above 3 keV has been increased considerably. Although the most complete catalog of SNRs is still compiled in the radio band (Green 2004), X-ray instruments such as *ASCA*, *XMM* and *CHANDRA* have provided an important new window to find yet undetected remnants or to confirm candidates originally found at other wavelengths.

In this paper we report the results of a multiwavelength study of the field containing the unidentified X-ray source AX J1635.9−4719 and the SNR candidate G337.2+0.1. In order to investigate the nature and possible physical connection between both sources, we have performed source cross-identifications with all available astronomical databases and we have re-processed all the relevant data. Our results support the identification of G337.2+0.1 as a new X-ray emitting SNR.

2. X-ray analysis of AX J1635.9−4719

The unidentified X-ray source AX J1635.9−4719 was discovered by the *ASCA* telescope during a survey of the central region of the galactic plane, performed in the 0.7–10 keV energy range (Sugizaki et al. 2001). The source is located at (l, b) =(337.°17, 0.°06) (1-σ uncertainty of $1'$). Its integrated flux is $\sim 1.21 \times 10^{-12}$ erg cm^{-2} s^{-1} in the observed X-ray band.

With the aim of studying in more detail the properties of the X-ray source, we have performed a more careful and thorough imaging and spectral analysis of the ASCA data. The observation of the source was carried out on September 7, 1997 with an exposure of 6.1 ks. The data reduction and the extraction of the event for the source were performed following procedures described in Sugizaki et al. (2001).

To investigate the spatial extent of the emitting region, we extracted the radial profile of the source in order to compare it with that of the point-spread function of the X-ray telescope. Fig. 1 shows the obtained radial profile of the GIS-2 image around AX J1635.9−4719, where the background components of the Galactic and the extra-galactic X-ray emissions are subtracted using the flat-field response. Non-X-ray events were also subtracted

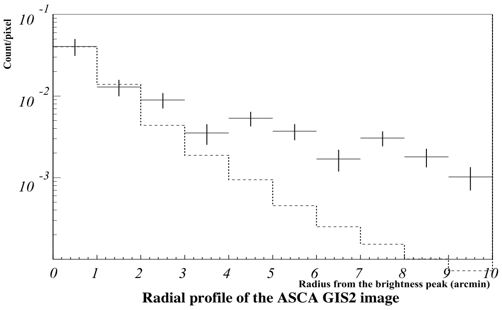

Fig. 1. Radial profile of the X-ray image by GIS-2 around AX J1635.9-4719. Dashed line represents the radial profile expected for a point source.

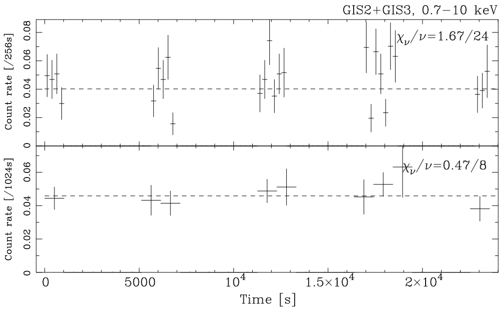

Fig. 2. X-ray light curve of AX J1635.9-4719 during the ASCA observation on Sep. 7, 1997.

following standard procedures. The central core in the inner 2 arcmin is well represented by a point source. However, an extended component clearly exists around the source as it can be seen from the figure.

To examine the X-ray flux variability of AX J1635.9−4719 in more detail, we extracted a light curve and fitted it with a constant model. There is no significant time variation. Coherent periodic pulsation was also investigated by the FFT method: no significant periodic signal can be seen in a period range of 0.5 – 1000 s. Fig. 2 shows the obtained light curve in the whole energy band of 0.7–10 keV. The best-fit constant model and the reduced chi-squared (χ^2_ν) of the curve are also shown on Fig. 2. The source is non-variable at a confidence above 95%.

We have also re-analyzed the X-ray spectrum of the source. All spectral uncertainties represent 90% confidence limits hereafter. Fig. 3 shows the obtained X-ray spectrum in the 0.7–10 keV energy range. The solid line represents the best-fit power-law model with interstellar absorption. The photon index and the absorption column density of the best-fit model are $\Gamma = 2.8^{+2.6}_{-1.6}$ and $N_{\rm H} = 15^{+15}_{-9} \times 10^{22}$ cm^{-2}, respectively.

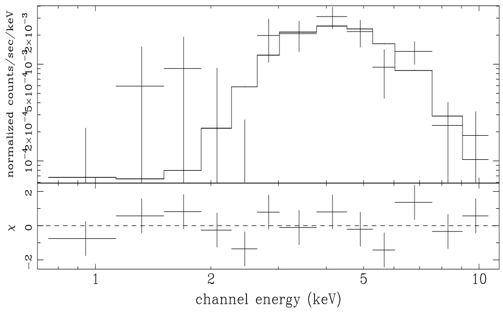

Fig. 3. Energy spectrum observed by *ASCA* GIS in 0.7–10 keV. The solid line represents the best-fit power-law model with interstellar absorption. The photon statistics is very poor, so it is difficult to constrain the spectral model.

It is worth noticing that G337.2−0.1 lies well within the 95% location contour of the unidentified γ-ray source 3EG J1639-4702 (Hartman 1999). It is located at $(l,\ b)$ = $(337\overset{\circ}{.}75, -0\overset{\circ}{.}15)$, and has a radius of about $0\overset{\circ}{.}6$. Its γ-ray flux is $(53.2 \pm 8.7) \times 10^{-8}$ ph cm^{-2} s^{-1}, and presents a steep γ-ray spectral index of Γ = 2.5 ± 0.18. The EGRET source is non-variable according to Nolan, et al. (2003). However, there is other potential counterpart within the error box like the microquasar candidate AX J1639.0-4642 (Combi et al. 2004).

3. Radio continuum and HI observations towards AX J1635.9−4719

G337.2+0.1 is a SNR candidate with an angular size of 2'×3' discovered in the MOST 843-MHz radio survey (Whiteoak & Green (1996)). The position of the source in galactic and equatorial coordinates is $(l,\ b)$ =(337.°18,+0.°06), The source has an integrated flux density

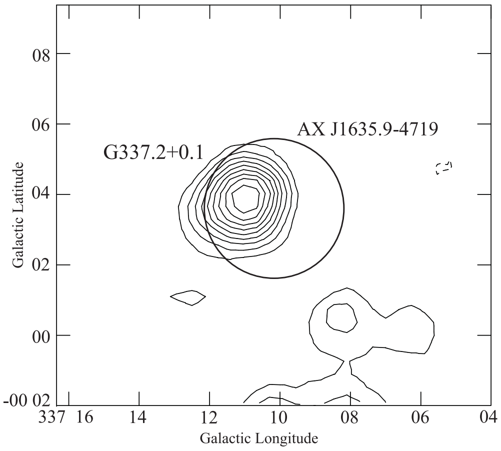

Fig. 4. Countour image of G337.2+0.1 obtained with MOST at 843 MHz. The image size is 12'×12'. Radio countours are 2, 3, 4, 5, 6, 7 and 8 times the rms noise level of 10 mJy. The location of AX J1635.9−4719 is also indicated.

of 1.6±0.2 Jy and a mean surface brightness of 2.6×10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 843 MHz. In Fig. 4 we show the radio map of G337.2+0.1 at this frequency together with the 2-σ circle of the best estimated position of AX J1635.9−4719.

In order to find the radio source at higher frequencies we have examined the data from the 4.85 GHz survey (Condon et al. 1993). Applying a filtering process to the data (see Combi et al. (1998) for details of the Gaussian filtering method) we have removed the galactic diffuse emission on scales larger than 8 arcmin and we found a weak and extended radio source coincident with the position of G337.2+0.1. The source has an integrated flux density of 0.39±0.02 Jy. Using the radio flux at 843 MHz and 4.85 GHz we estimate a mean spectral index for the source of ~ -0.78, confirming the non-thermal nature of the radio source.

Since a SN explosion is expected to produce some effect in the ISM, we have extracted a series of HI brightness temperature maps of the region in the velocity interval from −100 km s^{-1} to +20 km s^{-1} from the Southern Galactic Plane Survey (SGPS). (McClure-Griffiths 2001). The survey has an-

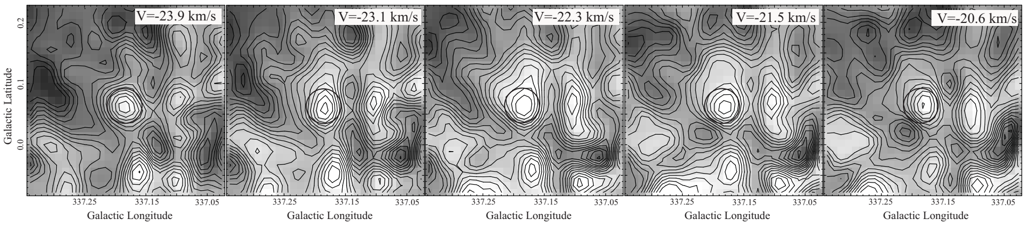

Fig. 5. HI brightness temperature map (contour labels in K) obtained for the velocity range -23.9 to -20.6 km s^{-1}. The black circle indicate the SNR position.

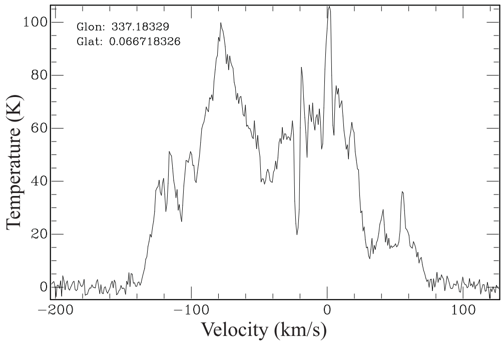

Fig. 6. HI spectrum towards G337.2+0.1. A sharp minimum is located at $v \sim -20$ km s^{-1}. Its shape is typical of an absorption feature

gular and velocity resolution of $\sim$ 2′ and $\sim$ 0.82 km s^{-1}, respectively.

A series of minima can be seen in the HI channel maps, when they are inspected at the highest velocity resolution. Only one of these minima is exactly coincident with the radio continuum source. The HI channels maps in the velocity range from -23.9 to -20.6 km s^{-1} are shown in Fig. 5, where we have superposed the location of the SNR candidate. In the HI spectrum, shown in Fig. 6, we have found a sharp minimum at $v \sim -20$ km s^{-1}. Its shape is typical of an absorption feature, hence it can be used to set a lower limit on the distance of the background continuum source. Using the galactic rotation studies of Russeil (2003), we get that the presumed SNR should be at least at 13.5 kpc.

4. Discussion

Several facts support the identification of the radio source G337.2+0.1 with a SNR. The non-thermal radio spectral index is typical of synchrotron emission from relativistic electrons. At X-rays the flux might also be non-thermal but with a steeper index. This is consistent with the fact that all non-thermal X-ray SNR spectra are substantially curved (Dyer et al. 2001). The high-energy steepening of the synchrotron spectrum can be due to the effect of losses, the presence of an exponential cut-off in the electron distribution resulting from the failure of the acceleration mechanism at high-energies, and/or non-linear effects. In the case of very young remnants, the particle spectrum can be limited by age (i.e. the remnant could be so young that there was no time to accelerate electrons beyond some maximum energy). However, at the present stage a thermal origin for the X-ray emission cannot be ruled out in this source.

The *ASCA* data do not allow to specify the morphology of the remnant, although seem to suggest the presence of a central contribution. This might be emission from a pulsar or the result of the low angular resolution and the distance to the source. We have not detected any pulsation in the data. In addition to the broadband spectrum and the extended, non-variable emission, we have found a sharp absorption feature in the HI distribution toward the continuum radio source. This can be used to impose a lower bound of 14 kpc on the distance to the SNR candidate. If the actual distance is 14 kpc, the angular size of the remnant would be ~12 pc, similar to that of SN 1006. Assuming adiabatic expansion in a medium of density

$n \sim 0.5$ cm^{-3}, the standard Sedov solutions (Sedov 1959) yield an age of $\sim$ 1500 yr and a shock front velocity of $\sim$ 215 km s^{-1}. At the same distance of 14 kpc, the X-ray luminosity of AX J1635.9−4719 is $\sim 4\times10^{34}$ ergs s^{-1}, a quite reasonable value for a young SNR.

5. Conclusions

We suggest that G337.2+0.1 is a SNR, being 13.5 kpc a lower limit on its distance, and that AX J1635.9−4719 is the X-ray counterpart of the radio source. G337.2+0.1 might have similar properties to other known galactic SNRs (e.g. SN 1006, G266.2-1.2, G347.3-0.5 and G156.2+5.7) which exhibit a curved broadband synchrotron spectrum. These objects have also high X-ray luminosity, faint radio flux and they are expanding into a low density medium (Allen et al. (2001), Bamba et al. (2001), Koyama (1995), Koyama (1997)). Future *XMM* and *Chandra* observations will provide a better determination of the spectrum and morphology of this interesting source. The electrons should also cool through inverse Compton scattering off CMB photons (Pohl 1996). This might result in a TeV gamma-ray source that might be detected with the *HESS* and CANGAROO III telescopes. Pion decays from interactions of relativistic protons might also contribute in this energy range.

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