Radio and X-ray Observations of Two Double-Shell Galactic Supernova Remnants

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INTRODUCTION

Galactic supernova remnants (SNRs) exhibit a wide variety of morphologies which may be the consequence of the type of progenitor star, the explosion mechanism, the presence of a central compact object or the physical conditions of the surrounding interstellar medium (ISM). Multi-wavelength observations are useful tools in the understanding of the role of these different factors and their relevance in the X-ray / radio emission distribution and spectra of the remnants. In this work we present radio and X-ray observations of the galactic SNRs G7.7-3.7 and G344.7-0.1, based on high quality XMM-Newton, VLA and ATCA archival data.

G7.7-3.7 (18:17:25, -24:04) is an extended remnant (~ 21' in size) located at a distance of ~ 5 kpc. A VLA image of this SNR obtained at 1.4 GHz with an angular resolution of 70"x35" (Dubner et al. 1996, AJ, 111, 1304) showed a nearly circular source with an unresolved peak on the eastern border and an apparent double-shell structure. Based on IRAS data, infrared emission with a spectrum characteristic of collisionally heated dust was reported towards the western side of G7.7-3.7 (Arendt 1989, ApJS 70, 181).

G344.7-0.1 (17:03:51, -41:42) appears in the radio band composed of a double asymmetric shell with a size of about 9' (Dubner et al. 1993, AJ 105, 2251). X-ray observations carried out with ASCA showed extended emission only towards the west of the remnant (Yamauchi et al. 2005, PASJ, 57, 459).

We have jointly analyzed new radio and X-ray images and spectra of both SNRs in an attempt to confirm the double-shell morphology and to understand the origin.

OBSERVATIONS

RADIO:
The images at 1.4 GHz of both remnants were obtained after reprocessing archival VLA data corresponding to observations carried out with the interferometer in the hybrid DnC configuration on February 23, 1991 (Program AD620). The image of G7.7-3.7 has an angular resolution of 30" and an rms noise of 0.4 mJy/beam, while the image of G344.7-0.1 has an angular resolution of 55"x26" and an rms noise of 0.6 mJy/beam.

For G344.7-0.1 the VLA observations were combined in the uv plane with archival data of the Australian Telescope Compact Array (ATCA), acquired on April 26, 2004 in the same radio band, with the interferometer operating in the 1.5 and 6A configurations. After this combination, we were able to produce an image with an improved angular resolution of 8" (rms noise of 0.4 mJy/beam). The resulting image allows us to resolve some of the more interesting structures.

X-RAYS:
The X-ray images and spectra of G7.7-3.7 were obtained by processing public data from XMM-Newton observations centred on the source AX J1817.6-2401. The observations were carried out on March 19, 2006 with the EPIC MOS1 and MOS2 cameras operating in Full Frame mode, and the EPIC pn camera operating in Small Window mode. Part of the G7.7-3.7 emission was outside the EPIC field of view. The net exposure time was about 9.5 ks.

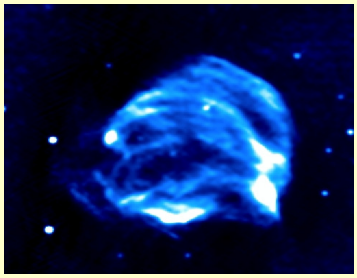
In the case of G344.7-0.1, the observations were carried out on:
- September 15, 2000 with the pn operating in the Extended Full Frame mode;
- August 28, 2001, with the pn in Extended Full Frame and the MOS1 and MOS2 cameras in Full Frame mode, and
- September 13, 2007 with the three EPIC cameras in Full Frame mode.

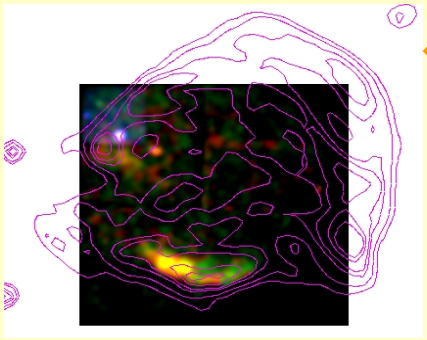
The total net exposure time was about 30 ks.
For both remnants the data were processed using SAS version 8.0 and the most recent calibration products. The spectra were analysed with Xspec version 11.3.2ag and ISIS version 1.4.9-30.

RESULTS FOR G7.7-3.7

NEW RADIO IMAGE

The new radio image shows considerable internal structure with several filaments aligned in an east-west direction and bright spots near the limbs. The high dynamic range attained in this image revealed for the first time the existence of faint extensions in the southeast, breaking the otherwise circular symmetry of this SNR.



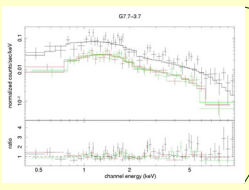


NEW X-RAY IMAGE

False colour image of G7.7-3.7 (red: 0.3-0.7 keV, green: 0.7-0.9 keV, blue: 0.9-8 keV) with radio contours overlaid. There are clearly two distinct X-ray emitting areas associated with the remnant:

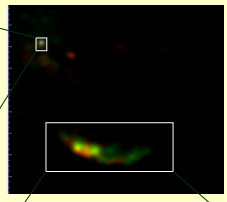
- a feature about 7' in size coincident with the bright radio emission on the southern limb of the SNR, and bright in the soft energy band, and
- an apparently point-like source, clearly hard in nature, centred at about 40" north of the eastern radio spot.

X-RAY SPECTRAL ANALYSIS

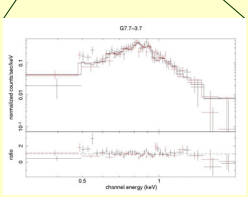


The X-ray spectrum of the point-like source has a featureless continuum which can be well fit by an absorbed power law. Its spectrum is compatible with that of a pulsar or pulsar wind nebula. More observations are needed to clarify the nature of this source.

Parameter	Value
n_H (cm^{-2})	$(0.28 \pm 0.1) \times 10^{22}$
PI	1.35 ± 0.15
norm	$(1.18 \pm 0.2) \times 10^{-4}$

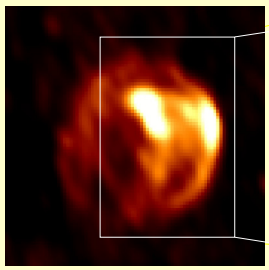


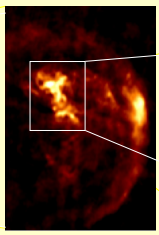
The data from the southern limb emission were fit in the 0.3-2.0 keV band with a non-equilibrium ionization collisional plasma model, assuming a constant temperature and single ionization parameter. We obtained a statistically good fit (reduced χ^2 of 0.92 for 138 d.o.f.) with parameter values listed in the table.
We are requesting more XMM-Newton observing time on this source better to constrain the emission models.



Parameter	Value
kT (keV)	0.51 ± 0.1
n_H (cm^{-2})	$(0.28 \pm 0.2) \times 10^{22}$
τ (s/cm^3)	$(6.1 \pm 3.5) \times 10^{10}$
norm	$(2.5 \pm 1.5) \times 10^{-3}$
O abundance	0.26 ± 0.1
Ne abundance	0.63 ± 0.2
Mg abundance	0.44 ± 0.35

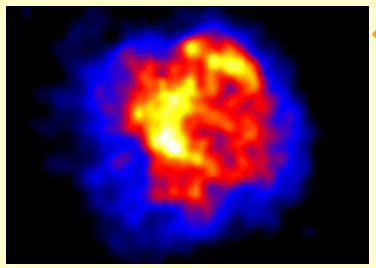
RESULTS FOR G344.7-0.1





NEW RADIO IMAGES

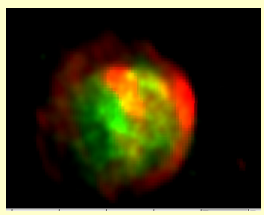
On a large scale, G344.7-0.1 has a morphology suggestive of a double-shell structure. However, the new high angular resolution image resolves the bright central feature in filaments and point-like sources, weakening the hypothesis of double-shell morphology.



NEW X-RAY IMAGE

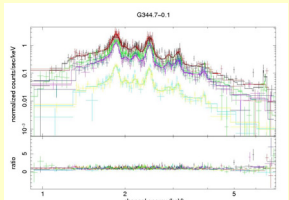
The figure shows the EPIC broad-band (0.3-8 keV) intensity image of G344.7-0.1. This new high angular resolution image reveals considerable clumpy structures and diffuse emission filling the interior of the remnant. The outermost and faintest X-ray emission traces an almost circular boundary about 7' in diameter. Most of the X-ray emission is concentrated in an incomplete shell-like feature.

The figure shows an X-ray / radio comparison of G344.7-0.1. Green corresponds to the X-ray emission in the broad-band energy range, while red indicates the 1.4 GHz radio continuum emission. The X-ray emission is confined within the outer radio shell, filling it completely. In general, there is no clear spatial correspondence between both spectral regimes.



X-RAY SPECTRAL ANALYSIS

The EPIC data of all three XMM-Newton observations were simultaneously fit in the 0.9-7.0 keV band with a non-equilibrium ionization collisional plasma model, assuming a constant temperature and single ionization parameter. An additional zero-width gaussian component was included to model the Fe-K emission resulting in a line centroid at 6.44 keV. We obtained a statistically good fit (with χ^2 of 1.04 for 2036 d.o.f.) the results of which are listed in the table and plotted in the figure. No significant spectral variations were found between different regions within the remnant.



Parameters	Values
kT (keV)	1.5 ± 0.1
n_H (cm^{-2})	$(4.5 \pm 0.3) \times 10^{22}$
τ (s/cm^3)	$(8.7 \pm 1.0) \times 10^{10}$
norm	$(4.3 \pm 0.2) \times 10^{-2}$
Ca abundance	3.8 ± 1.0
Ar abundance	2.41 ± 0.3
S abundance	1.81 ± 0.1
Si abundance	1.24 ± 0.15
Mg abundance	0.27 ± 0.1
Fe abundance	0.00 ± 0.1

Note:
The false colour X-ray images were obtained using the "`images`" script: http://xmm.esac.esa.int/external/xmm_science/gallery/utils/images.shtml
They were then adaptively smoothed using the "`asmooth`" SAS task, and the three smoothed layers were combined into the final RGB image.