XMM-Newton observations of the supernova remnant G8.7-0.1

G. Pühlhofer, T. Frech-Horn, M. Sasaki, D. Klochkov
(Institut für Astronomie und Astrophysik Tübingen)

Abstract

Many TeV sources detected over the past few years in the Galactic plane are still not identified. It is suspected that some of the sources are the relics of supernova remnants, only visible through the TeV emission from hadronic high energy particles that have not yet merged with the continuous sea of cosmic rays. To support such a scenario, middle-aged supernova remnants that show evidence for TeV emission should provide important clues, as the objects in this evolutionary stage still provide a wealth of observational data. We report on XMM-Newton observations of the 15,000-28,000 year-old supernova remnant G8.7-0.1, which is located in positional coincidence to one of the brightest unidentified TeV sources, HESS J1804-216. The Northern part of the remnant emits strong thermal emission as detected with XMM-Newton, whereas the Western part of the remnant is devoid of thermal emission but apparently a strong TeV gamma-ray emitter. We also report the discovery of a new X-ray pulsar wind nebula candidate, which appears presumably just by chance in positional coincidence with the supernova remnant.

The middle-aged supernova remnant G8.7-0.1

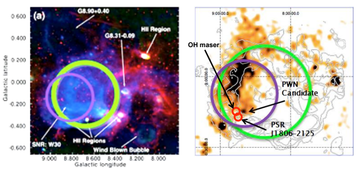

Fig. 1: *Sky images of SNR G8.7-0.1 in radio and X-rays (Galactic coordinates).*

Left panel: Three-color image, taken from [1]. Blue: VLA 90cm. Red: MSX 8μm. Green: SGPS + VLA 20cm.

Right panel: Color scale: ROSAT (originally published in [2]. Contours: VLA MAGPIS 1.4 GHz, with contour levels chosen to enhance the SNR's outer boundary.

Both panels: The green circle indicates the extent of G8.7-0.1, while the purple circle shows the field of the XMM-Newton observation discussed in this poster.

G8.7-0.1 is an extended radio source classified as a shock-driven supernova remnant (SNR) from its radio spectrum [3]. The SNR is middle-aged, 15,000 - 28,000 years old [2,4], at a distance of 4.5 .. 4.8 kpc [2,5]. The radio size therefore corresponds to $R \sim 30$ pc.

G8.7-0.1 is associated with the star forming region (SFR) W30. A detection of an OH maser at the Northern edge of the SFR confirms shock-cloud interaction [5], at least in that direction. PSR J1806-2125 is a background source (D ~ 10 kpc, [6]).

ROSAT observations have only revealed significant X-ray emission from the Northern SNR. Under the assumption of a thermal nature of the ROSAT source, the temperature was estimated to 0.3-0.7 keV and the pre-shocked gas density to 0.02-0.04 cm^{-3} [2].

The TeV source HESSJ1804-216 and its counterparts

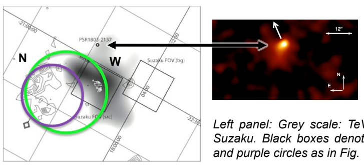

Fig. 2: *Sky maps with possible counterparts to the TeV source HESS J1804-216 (Galactic coordinates).*

Right panel: Chandra map of the asymmetric X-ray pulsar wind nebula around PSR B1800-21 (PSR J1803-2137) (image from [7]). The white arrow indicates the direction of the pulsar proper motion measured by [8].

Left panel: Grey scale: TeV (H.E.S.S.). Black contours: ROSAT. White contours: Suzaku. Black boxes denote the Suzaku XIS FoVs. Image taken from [9]. Green and purple circles as in Fig. 1.

Very high energy (E > 0.1 TeV) γ-rays have been detected in positional coincidence with the SNR with H.E.S.S. [10]. A high energy (E > 0.1 GeV) γ-ray counterpart to this source was recently detected with Fermi [11]. The emission of both γ-ray sources is predominantly associated with the Western part of the remnant, while no γ-ray emission is detected from the location of the ROSAT source (Fig. 2 left panel).

In turn, no X-ray emission in direct spatial correspondence to the extended γ-ray sources is detected. Two faint small sources (see Fig. 2) were detected with Suzaku [9]. The very large absorption column towards one of the sources ($N_H \sim 10^{23}$ cm^{-2}) could either indicate that the γ-ray sources stem from a high density region possibly interacting with the SNR (preferred interpretation for the Fermi source [11]), or point towards strong obscuration from a foreground molecular cloud recently observed with Nanten [12]. Thermal X-ray diagnostics from this part of the SNR seems in any case strongly impeded.

The energetic (log (dE/dt / (erg s^{-1})) = 36.3) pulsar PSR B1800-21 in positional coincidence with the Western boundary of the SNR could be associated with G8.7-0.1 [2], although proper motion measurements [8] do not strongly support this idea. [7] suggested an association of the asymmetric X-ray pulsar wind nebula driven by the pulsar with the TeV source, a hypothesis which is energetically plausible from a comparison with similar systems [13]. Therefore, the identification of the TeV source with the shell of G8.7-0.1 is not unambiguous.

Motivation for observing the Northern part of G8.7-0.1 with XMM-Newton

- *Confirm the thermal nature of the source discovered with ROSAT:* While ROSAT clearly detected extended emission from the North of G8.7-0.1, the data were presumably insufficient to distinguish between a hot thermal and a non-thermal spectrum (cf. e.g. to Vela Jr.).
- *Search for a possible non-thermal component:* Even if the source is predominantly thermal, non-thermal emission might be present and detectable above ~2 keV. Non-thermal processes might be detectable especially if HESS J1804-216 is indeed associated with G8.7-0.1.
- *Thermal plasma parameters:* Determine the nature of the thermal plasma (composition, ionisation timescale).
- *Association of the TeV source with G8.7-0.1:* The association of TeV sources to middle-aged SNR is often difficult. A better understanding of the state of G8.7-0.1 through X-ray observations could help supporting (or rejecting) the association.

References

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Overview of the field observed with XMM-Newton

XMM-Newton dataset: Obs. ID 0405750201, PI Pühlhofer, 16.8 ksec.

Data processing with *SAS 10.0*; standard flare, pattern filtering; vignetting correction with *evigweight*; spectral fitting with *xspec 12*. Details of the analysis are presented in [14].

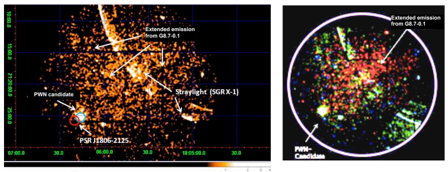

Fig. 3: *Sky image of the observed region (MOS 2, equatorial coordinates).*

Left panel: All energies.

Right panel: red 1-2 keV, green 2-4.5 keV, blue 4.5-12 keV.

In the soft energy band, extended emission from G8.7-0.1 dominates. At higher energies, a small but extended source is visible, a new pulsar wind nebula (PWN) candidate. Also evident is strong straylight contamination across large portions of the field of view (FoV), caused by the persistent LMXB Sgr X-1.

A new X-ray pulsar wind nebula candidate

I. Source extension and energy spectrum

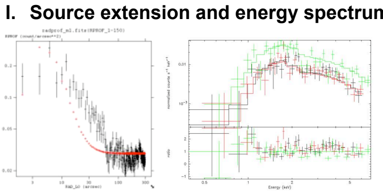

Fig. 4: *Analysis of the PWN candidate.*

Left panel: Radial profile (MOS1) of the source (black), compared to a point spread function simulation at the corresponding off-axis position (red).

Right panel: Fit of a power law to the energy spectrum of the source (PN green, MOS1 black, MOS2 red). Parameters for a combined fit (null hyp. prob. 17%):

$\Gamma = 1.62 \pm 0.32$

$N_H = (1.38 \pm 0.31) \times 10^{22}$ cm^{-2}

$F_{2\text{-}10\,keV} = (8.3 \pm 0.6) \times 10^{-13}$ erg cm^{-2} s^{-1}

The new source is clearly extended, as shown from the radial source profile (Fig. 4, left). The energy spectrum of the source (from an extraction region with radius 60'') is compatible with a power law (a blackbody assumption however cannot be rejected from statistical arguments). Morphology and power law index are typical for pulsar wind nebulae, therefore the source is classified as X-ray pulsar wind nebula candidate.

II. Association with PSR J1806-2125 ?

The PWN candidate is located at an angular distance of 55 arcsec from the radio pulsar PSR J1806-2125. At the pulsar distance (~10 kpc [6]), this corresponds to 2.7pc or ~9 light years. While such offsets are viable in *relic* PWN scenarios, the drop of the X-ray emission towards the position of the pulsar (see Fig. 5) speaks against an association.

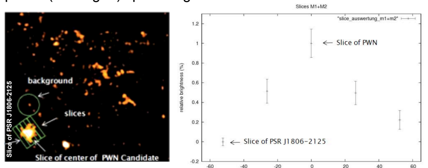

Fig. 5: *Test of the morphological connection of the PWN candidate with PSR J1806-2125.*

Left panel: Definition of slices.

Right panel: Relative source brightness along the axis connecting the radio pulsar and the X-ray PWN candidate center.

Also at odds with an association is the required efficiency of η~0.1 of pulsar spin down energy (log (dE/dt / (erg s^{-1})) = 34.6) into PWN X-ray luminosity (log (L_{PWN}/(erg s^{-1})) ~ 34 at 10 kpc), which would be unusual especially for pulsars with moderate spin-down power such as PSR J1806-2125 (cf. e.g. [15]).

➜ The source is most likely a PWN powered by a pulsar which so far has not been detected.

Extended X-ray emission from the North of G8.7-0.1

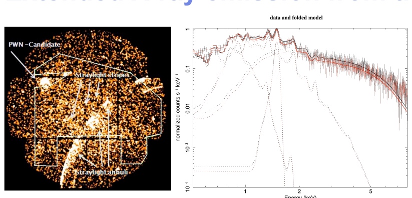

Fig. 6: *Soft thermal emission from G8.7-0.1.*

Left panel: Definition of the extraction region for the source spectrum, chosen to maximize source statistics (plot in detector coordinates).

Right panel: Data points are the source energy spectrum (MOS1 black, MOS2 red). Solid lines are from a combined background and source model fit, the components of which are shown as dotted lines. Source fit with nei model:

$kT = 0.5$ keV

$\tau = n_e \times t = 1.3 \times 10^{12}$ s cm^{-3}

$N_H = 1.3 \times 10^{22}$ cm^{-2}

Background determination: As can be seen from the ROSAT map of G8.7-0.1 (see Fig. 1, right panel), the extended emission from the SNR is expected to fill most of XMM-Newton's FoV. This is confirmed by the spread of soft emission across the XMM-Newton FoV (Fig. 3, right panel, red counts). Moreover, straylight from Sgr X-1 fills nearly the entire FoV as well, the straylight patterns indicate that not only the arc features but also more diffuse features ("stripes", see Fig. 6 left panel) are significant. Hence it is not possible to define background control regions in the FoV which would account for the entire background. Therefore, the background was not subtracted from the source spectrum but modeled with three different components, which were trained on FoV regions with low source counts.

Background model: The background model comprises three components:
Soft thermal plasma emission: A 0.1 keV equilibrium model describes plasma emission homogeneously spread across the FoV, either from the local bubble or from the source environment.
Hard power law: A power law with photon index Γ=1.3 essentially describes the straylight from Sgr X-1.
Gaussian line: Instrumental background was subtracted by properly scaled closed filter wheel data, but an instrumental line at 1.5 keV remains to be modeled.
For source fitting, the normalisation of all three background components is allowed to vary independently.

Extended emission from G8.7-0.1: The source is fit with a non-equilibrium thermal plasma model (nei, solar abundances). Parameters are listed in Fig. 6, without statistical errors (e.g. ~2% for N_H) since errors are dominated by background model uncertainties (the fit is in fact statistically not acceptable).

➜ The plasma is close to equilibrium, and parameters are fully compatible with what was derived from the ROSAT spectrum [2].
➜ A non-thermal component from G8.7-0.1 could not be identified. If present, it would in the current analysis not be distinguishable from the straylight component.
➜ Further analysis depends on improvements of the background model and is under investigation.