# XMM-NEWTON ANALYSIS OF THE SUPERNOVA REMNANT W44

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## ABSTRACT

We present here our analysis of XMM-Newton observation of the Supernova Remnant (SNR) W44 and its associated pulsar PSR 1853+01. The remnant was observed with XMM-Newton in two separate observations for a total of 36 ks. We have also added to our analysis a short observation (7ks) centered on the pulsar position. Our observation was conducted with the MOS 1 in timing mode and the MOS2 and PN in full window mode. We present here the spectral analysis of all the full window mode data available. There is no trace of pulsed X-ray emission from PSR 1853+01 in the available data.

Key words: Supernova remnants; W44 ; X-rays.

## 1. INTRODUCTION

W44 (Westerhout, 1958) shows highly polarized nonthermal radio emission (Kundu & Velusany, 1972). OH and H I absorption measurements ((Knapp & Kerr, 1974) and references herein) have resulted in a mapping of the heavily obscured surroundings of the SNR and lead to the accepted distance to the remnant of 3 kpc. A 20 cm VLA image (Jones, Smith, & Angellini, 1993) shows a roughly elliptical limb-brightened radio shell (a total flux of about 200 Jy) with major and minor semi-axes of $17'$ and $11.45'$. In X-rays. the remnant is quite bright, a total flux of about $6\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$ derived from our *ASCA* analysis (Harrus et al., 1997) between 0.4 and 2.0 keV, and centrally peaked. A radio pulsar, PSR B1853+01, associated with W44 was discovered in 1991 (Wolszcan, Cordes, & Dewey, 1991) and its X-ray counterpart was detected in 1996 using *ASCA* data (Harrus, Hughes, & Helfand, 1996). It is quite weak, its luminosity accounting for only about 3% of the total X-ray luminosity of the remnant in the 0.4–2.0 keV band.

Here we report on an XMM-Newton observation of the remnant. The initial observation (36 ks) was split into two observations which suffered from contamination from soft protons to a different extent. This contamination does not affect the analysis of PSR B1853+01 (because the source's extent is smaller than $30''$) but only about one-thirst of the data were usable for analysis of the extended emission from the SNR.

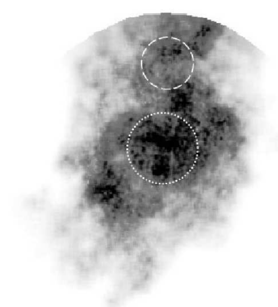

*Figure 1. XMM-Newton MOS2 image of W44 in the 1.2 to 2.0 keV energy band. The circles marked with dotted lines defines regions used in the spectral analysis below.*

## 2. SNR DIFFUSE EMISSION

All the observations were reprocessed from the raw data (ODF) using the most recent version of the SAS software (version SAS 6.5). The MOS1 data are in timing mode and not used in this analysis. After standard cleaning procedures, cuts for the soft protons contamination and merging of all the observations, we end up with a total of 69894(135564) events in the MOS2 (PN). Events from a region of $30''$ around PSR B1853+01 were excluded. As expected, the spectrum from the entire SNR is thermally dominated. We find that its principal characteristics can be described by a simple thermal model with absorption (tbabs*mekal) associated with a column density and a temperature compatible with our previous ASCA analysis, i.e. a column density, $N_{\rm H}$, of $(1.7\pm0.6)\times10^{22}$ cm$^{-2}$ and an emissivity-weighted temperature $kT$, of (0.6$\pm$0.3) keV. The unabsorbed total fluxes computed in this case (neglecting the pulsar contribution) are $8\times10^{-10}$ erg cm$^{-2}$ s$^{-1}$, $1.8\times10^{-11}$

erg cm$^{-2}$ s$^{-1}$, and 6.1×10$^{-13}$ erg cm$^{-2}$ s$^{-1}$ between [0.5-2.0], [2.0-4.0], and [4.0-10.0] keV respectively. We analyzed the spectra from two different regions in the remnant. One is defined as the brightest knot in the center and the other is the extended faint emission in the northern part of the remnant (see Fig. 1). The emission in the bright knot can be best characterized by a mekal model with variable abundances (associated with absorption). In our analysis, any element for which the error on its abundances included its solar value was kept at its solar abundance. We find an absorption just above 1.2×10$^{22}$ cm$^{-2}$ and the same emissivity-weighted temperature as in the general case ($kT \sim$ 0.6 keV). Only Ar (about 25% solar) and Fe (less than 15% solar) are clearly depleted (in agreement with previous studies). Si and S are marginally depleted (80% and 60% solar respectively) and we cannot draw any definite conclusion for any other elements. Our analysis of the PN data yields the same results. The analysis of both the MOS2 and the PN data from the second region reveal that both the column density and the temperature stay roughly the same but the abundances vary. In this region, it seems that Ne, Mg, Si, S, Ar and Fe are all depleted compared to solar abundances and significantly lower than in the bright region defined above.

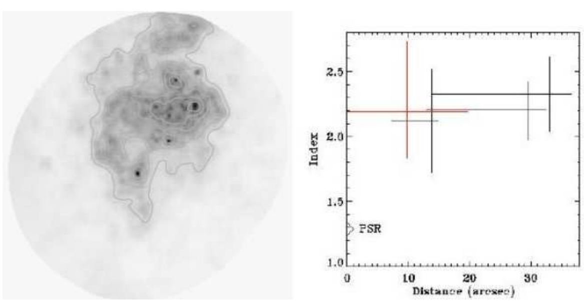


*Figure 2. (Left) W44 between 2 and 8 keV. The image is background subtracted, exposure corrected and adaptively smoothed. PSR B1853+01 is detected as the emission in the lower part of the remnant. (Right) Photon index as a function of the distance from the PSR. The graph is from Petre, Kuntz, & Shelton (2002). This XMM-Newton analysis is marked at 10″ and 2.2.*

## 3. ANALYSIS OF THE PULSAR EMISSION

PSR B1853+01 is clearly detected in our observation (see Fig. 2 left panel). We extracted the spectrum from a radius of 20″centered at $18^{\rm h}56^{\rm m}11^{\rm s}$, 1°13′24″ (J2000). This is about 6″ away from the catalogued position of PSR B1853+01 and 4″away from the Chandra identification of the PSR. The background is extracted from an annulus between 45″and the chip border at 87″. The background extraction region is chosen so to be outside the PSR emission region but inside the SNR to subtract as much as possible of the SNR emission. The spectrum extracted contains 600 photons. We find that the emission from the PSR region can be best described by a power law of spectral index $2.2^{+0.49}_{-0.42}$, associated with a slightly lower column density than the entire remnant ( $N_{\rm H}$ = (0.6±0.2)×10$^{22}$ cm$^{-2}$). This is in agreement with our *ASCA* analysis in which we found a photon index of about 2.3, but much lower than the value of 1.29±0.45 found by a more recent Chandra analysis (Petre, Kuntz, & Shelton, 2002).This is not so surprising considering that Chandra can isolate the emission at a much smaller level while the XMM-Newton point spread function results in a larger portion of the outer emission to being included in our analysis. This explanation is confirmed by comparing our result to the Chandra-derived variation of the spectral index as a function of the radial distance to the PSR (see Fig. 2 right). We find that the unabsorbed flux from the central source is about 2.6×10$^{-13}$ erg cm$^{-2}$ s$^{-1}$ between 2.0 and 10 keV. At a distance of 3 kpc, this translates to a total luminosity of 6.5×10$^{32}$ erg s$^{-1}$, which, along with the $\dot{\rm E}$ of 4×10$^{35}$ erg s$^{-1}$ measured for the PSR B1853+0, gives us a $\rm L_X/\dot{E}$ of 0.0016. This is much smaller than the measured values for the Crab Nebula (0.05) or 3C58 (0.006).

## 4. UV EMISSION FROM W44 REGION

We used the Optical Monitor with the UVW1 filter (2000 Å to 4000 Å). The data are recombined at the end of the processing in one image per filter both at low and high resolution. We kept all of the observation because the OM data are largely unaffected by the flares (soft protons) that wreak such a havoc in the X-ray data analysis. However, the effective area of the OM for the UVW1 filter is quite small (peaking at about 20 cm$^{-2}$ around 3000 Å). We find that both the remnant and the PSR B1853+01 are undetected.

## ACKNOWLEDGMENTS

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