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An *XMM*-Newton study of the mixed-morphology supernova remnant W28

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Abstract. We perform an *XMM*-Newton study of the mixed-morphology supernova remnant (MMSNR) W28. The X-ray spectrum arising from the northeastern shell consists of a thermal component plus a non-thermal power-law component with a hard photon index (~ 1.5). Non-thermal bremsstrahlung is the most favourible origin of the hard X-ray emission. The gas in the SNR interior is centrally peaked and best described by a two-temperature thermal model. We found a non-uniform absorption column density and temperature profile for the central gas, indicating that the remnant is evolving in a non-uniform environment with denser material in the east. We argue that the cloudlet evaporation is an indispensable process to explain both the spectral properties and the clumpiness in the X-ray emission.

Keywords. Supernova remnants, ISM: individual (G6.4−0.1 = W28)

1. Introduction

Mixed-Morphology (or thermal composite) supernova remnants (MMSNRs) represent a class of SNRs that are shell-like in the radio but have a centrally-filled morphology in X-rays with a thermal spectrum (Jones *et al.* 1998; Rho & Petre 1998). W28 (G6.4−0.1) is an MMSNR with a double radio shell in its north. Two competitive scenarios were proposed to explain the X-ray emission in the SNR interior: thermal conduction (Cui & Cox 1992; Shelton *et al.* 1999) and cloudlet evaporation (White & Long 1991). However, the origin of the central X-ray emission is still not clear (Rho & Borkowski 2002).

W28 is interacting with molecular clouds (MCs) in the northeast, where GeV and TeV γ-rays have been detected (Aharonian *et al.* 2008; Abdo *et al.* 2010). Hadronic interaction of cosmic rays with the MCs are considered to produce the γ-rays (Li & Chen 2010) and several models are proposed to predict the broad-band spectrum generated in such sites (Bykov *et al.* 2000, Gabici *et al.* 2009). It is thus of great interest to explore in the X-ray band for the origin of the non-thermal emission from this particular shell.

2. Observation and results

Four archival *XMM*-Newton observations towards W28 were used for the analysis presented here. We here summarize briefly our results. A more detailed analysis and discussion will be presented in another paper (to be submitted to ApJ).

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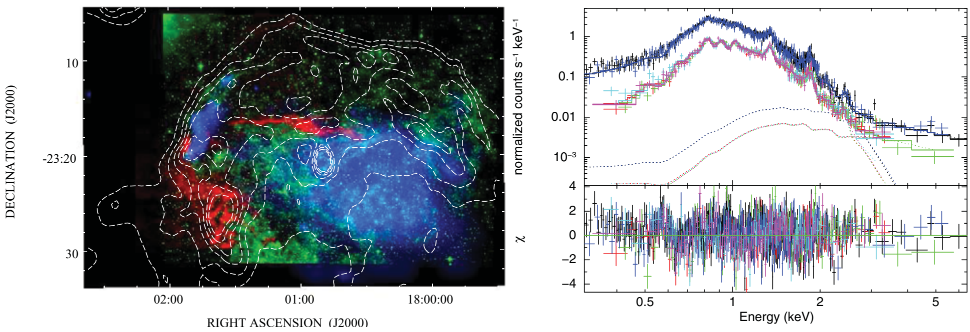

Figure 1. *Left panel*: Tri-color image of SNR W28. Red: The integrated JCMT intensity image of ^{12}CO $J = 3$-2 (-40–+40 km s^{-1}; Arikawa *et al.* 1999); Green: the Hα image from the archival SuperCOSMOS Hα Survey (Parker *et al.* 2005); Blue: *XMM*-Newton 0.3–7.0 keV X-ray map; and contours: 1.4 GHz radio continuum. *Right panel*: pn (upper) and MOS (lower) spectra and the fitted model (*vnei+power-law*, solid lines) of the northeastern shell. The short dashed lines show the components of the model.

As shown in the left panel of Fig. 1, the *XMM*-Newton image reveals blobby X-ray structures in the SNR interior and a deformed shell in the northeast. The remnant is evolving in a complicated environment with dense MCs in the east, explaining the difference in morphology between the northeast and south.

We have not found any evidence of ejecta inside the SNR. The X-ray spectra arising from the NE shell, where the shock-MC interaction is evident and γ-ray emission partly overlaps, consist of a thermal component with a temperature of ~ 0.3 keV and a non-thermal component with a hard photon index of ~ 1.5 (as shown in the right panel of Fig. 1). The non-thermal X-rays can not be explained by the secondary electrons from the hadronic interaction of cosmic-rays and the MCs Non-thermal bremsstrahlung from the cloud shock is the most favorable origin, at least in the view of the spectral slope.

The X-ray spectra in the central gas are well represented by a two-temperature thermal model *vnei+vmekal*. We performed a spatially resolved spectroscopy of the central gas and found variations of temperature, interstellar absorption and gas density across W28. The colder and denser gas are distributed to the north and east of the X-ray-brightness peak, where the X-rays suffer heavier absorption. We find that thermal conduction is not efficient in the SNR interior, while cloudlet evaporation is an indispensable process to explain both the clumpiness and some of the spectral properties of the X-ray emission.

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