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The Structure of Overionized Plasma in SNR IC 443

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Abstract. During the last few years, overionized (recombining) plasmas were unexpectedly discovered in a few supernova remnants, but the origin is still unclear. In this contribution, we present a preliminary spectroscopic analysis of the X-ray emission from the north central region of IC443, one of the "recombining" remnants. An overionized NEI plasma model can reproduce well the Ly-alpha lines and the recombination edges in the spectrum. The ionization temperatures for the metals Mg, Si and S are much higher than the electron temperatures. which is a strong indication of overionization of these elements. The different spectral features of the recombining plasma are characterized on scales of a few arcmin, such as the increasing trend of the pre-cooling temperature and the ionization time from south to north, which may imply a pre-heating direction.

Keywords. ISM: individual (IC 443 (G189.1+3.0)), radiation mechanisms: thermal, supernova remnants, X-rays:ISM

1. Introduction

In recent decade, the overionized (recombing) plasma was discovered in several supernova remnants (SNRs), such as IC 443 (Kawasaki *et al.* 2003, hereafter K03; Yamaguchi *et al.* 2009, hereafter Y09), W49B (Ozawa *et al.* 2009, Miceli *et al.* 2010), G359.1-0.5(Ohnishi *et al.* 2011), W44 (Uchida *et al.* 2012) and W28(Sawada & Koyama 2012), challenging the understanding of the evolution of SNRs and its origin is still controversial. IC 443 (G189.1+3.0), in which the overionization was first detected (K03), presents strong recombing emission with *Suzaku* (Y09) while the *XMM-Newton* observation suggested only marginal overionized plasma (Troja *et al.* 2008). With new *XMM-Newton* observation we investigated the difference and the spatial resolved structure of the plasma.

2. Data Analysis and Results

Our *XMM-Newton* observation of IC 443 was performed on 2010 March 07 to March 09 (Obs-ID = 0600110101, PI: E. Troja). The observation data files (ODF) were reprocessed using the *XMM-Newton* Science Analysis System (SAS) version 11.0.0 task following the standard procedures and were screened for the flares using the *XMM-Newton* Extended Source Analysis Software (*XMM*-ESAS) version 4.3.

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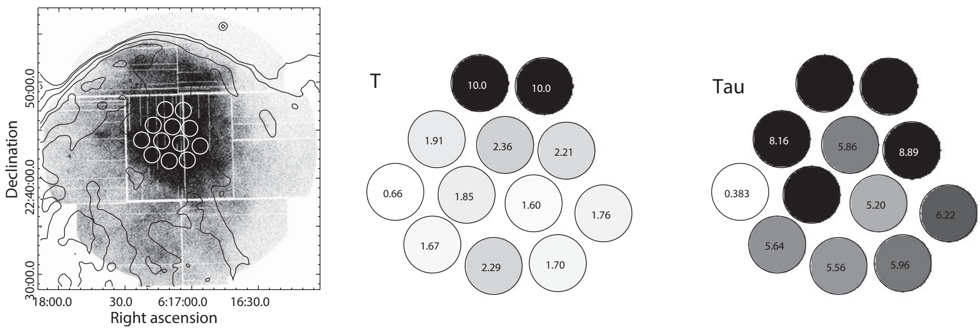

Figure 1. Left: Counts image of IC 443 (northern part) observed by *XMM-Newton* MOS2 in the 0.3-10 keV band, shown on an intensity color scale, superposed with VLA radio continuum at 1.4 GHz (contours) and the 12 regions (circles). Middel: the pre-cooling temperatures obtained from the overionized NEI plasma model for 12 regions in units of keV. Right: the same of the ionization timescales in units of 10^{11}s/cm^3 .

We searched for overionized plasma and successfully found it in the north central area of the remnant, around where the overionization was previously detected by K03 and Y09. This area was then divided into 12 arcmin-scale regions for further analysis (Fig. 1).

For all 12 regions, an overionized NEI plasma model can reproduce well Ly-alpha lines and the recombination edges in the X-ray spectra. Using the collisional ionization equilibrium model with one temperature component or two temperature components, the spectra can also be fitted with good χ^2 value, however, the Ly-α lines, especially of Si and S, are failed to be explained. We obtained the ionization temperatures for different metals with that of Mg, Si and S much higher than the electron temperature of the gas, strongly indicating of overionization of these elements. These results are roughly consistent with that in Y09. The electron temperatures obtained from the overionized NEI model, are almost uniform, around 0.5 keV, over all regions, while the distributions of the pre-cooling temperatures (ionization temperatures) and the ionization timescales (see Fig. 1) both indicate an increasing trend from south to north, which is probably the pre-heating direction.

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