THE NATURE OF THE SHELL TYPE SNR X-RAY EMISSION

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ABSTRACT

Spatially resolved spectral analysis of XMM-EPIC observation of middle aged supernova remnant will lead to dramatic advances in the understanding of the physical conditions in shock regions. In particular, XMM will help to bridge the current gap existing between the spatial resolution of optical and X-ray data, allowing detailed multiwavelength approaches. ISM grain depletion, thermal evaporation of clouds, bow shocks, propagation of secondary shocks in clouds, inhomogeneities distribution are among the most interesting topics which could be addressed, and which have received limited observational support from previous X-ray missions. With the aid of realistic hydrodynamical simulations, we focus on some of the topics above, and we quantitatively show the contribution of the XMM-EPIC observations to investigate the nature of the X-ray emission from SNR shells.

1. THE OPEN QUESTIONS

The X-ray emission of the middle-aged SNR shells can be influenced by many effects, such as:

The structure of the local ISM which could be more or less clumpy;

The effect of plasma thermal conduction which, if significant, tends to smooth the temperature profiles and change the emissivity;

The occurrence and strength of bow shocks behind clouds ;

The occurrence and strength of secondary shocks in clouds ;

The presence of grains in the ISM , which slowly release the metals locked up, thus affecting the abundances;

Other physical effects such as fluorescence, resonant scattering, etc.

The current generation X-ray missions (ROSAT, ASCA, SAX) have given only limited observational constraints to the theoretical modeling of these contributors, because of the lack of an adequate spatially-resolved spectral analysis. As a consequence, the source and mechanism of the X-ray emission from small scale (few arcmin) features of SNR shells **is not clear**.

All the above topics will receive crucial support with the detailed observations of SNR structures on small spatial scales possible with XMM-EPIC.

2. STATE OF THE ART

Current studies of the shock-ISM interactions processes are often based on **multiwavelength observations** of SNR shells. Unfortunately, the spatial resolution of the X-ray spectral analysis is not comparable with the spatial resolution of optical data.

Figure 1 shows an X-ray (ROSAT) and optical observation of two regions in the Vela SNR shell, where there is evidence of interaction with an isolated cloud (~ 1 pc) and a larger feature ($\sim 4 - 5$ pc), perhaps a cavity wall.

In both regions, ROSAT reveals two thermal components which are temptatively associated one to the inhomogeneities and one to the "inter-cloud" medium, but the spatial resolution of the spectral analysis is coarser than the scale length of the density variations.

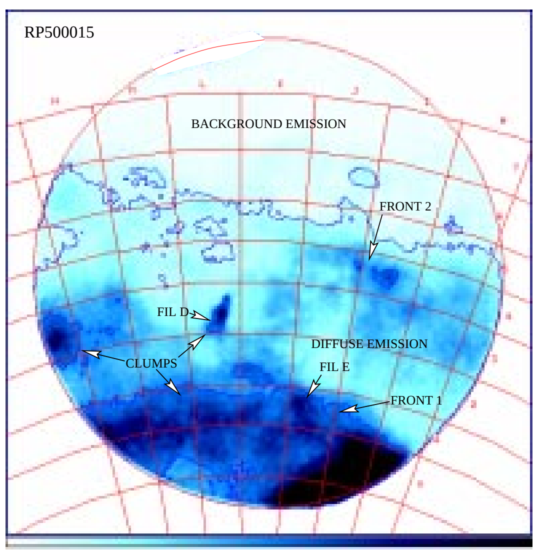

Fig. 1.— A ROSAT PSPC image of the North rim of the Vela SNR shell. The Filament D ("FilD") may be a region of interaction between the main shock and an isolated cloud, whereas the Filament E ("FilE") may be an interaction region with a larger ISM inhomogeneities. The red grid overimposed represents the smallest spatial bins on which the PSPC spectral analysis could be performed.

3. DETECTION OF ISM CLOUDS WITH XMM-EPIC

Given its unique combination of spatial and spectral resolution, XMM is expected to improve on the limitations of previous study of extended sources.

To understand what could be the quantitative XMM contribution to the study of shock-ISM interactions, we have realized a **simulated observation** of a typical post-shock region. We show that the spectral analysis of simulated data will allow us **to recover the structure of the post-shock region and to achieve plasma diagnostics at previously unexplored angular scale.**

We focus on the detection of isolated ISM clouds in middle-aged SNR, which should be possible if a strong secondary shock propagates in the cloud. The presence of secondary shocks is at least compatible with recent observations of the Cygnus-Loop and Vela SNR.

Our simulation is realistic although it neglects a few effects which could also give observable fingerprints, such as cloud evaporation, metal depletion and resonant scattering. In particular, we consider **a detailed 2-D hydrodynamical simulation** assuming realistic physical conditions and including **the non-equilibrium of ionization** in the resulting emission.

4. THE HYDRODYNAMICAL MODEL

A **spherical cloud** of density 0.1 cm^{-3} and 1 pc diameter, surrounded by the ISM with a density of 0.03 cm^{-3}, is hit by a hot Sedov shock ($T_s \sim 5 \times 10^6$ K) traveling at 500 km sec $^{-1}$ (e.g. the shock of a $\sim 10^4$ yr old remnant).

Figure 4 shows the temperature, density and ionization time profiles along an axis perpendicular to the shock front (**the Z-axis**) and passing through the center of the cloud, after $\sim 5 \times 10^5$ yr since the beginning of the simulation. Both the main and the secondary shock have already overrun the cloud and a weak bow shock develops behind the cloud. The simulation also shows that a substantial amount of localized and relatively cool ($T < 2 \times 10^6$ K) plasma survives for a non negligible fraction of the remnant age.

Figure 2 shows the temperature and density distributions from which the profiles in Figure 4 have been extracted.

The hydrodynamical simulation is performed with **a 2-D numerical model of compressible radiative plasma** in cylindrical geometry (R-Z). The shock propagates in the Z direction.

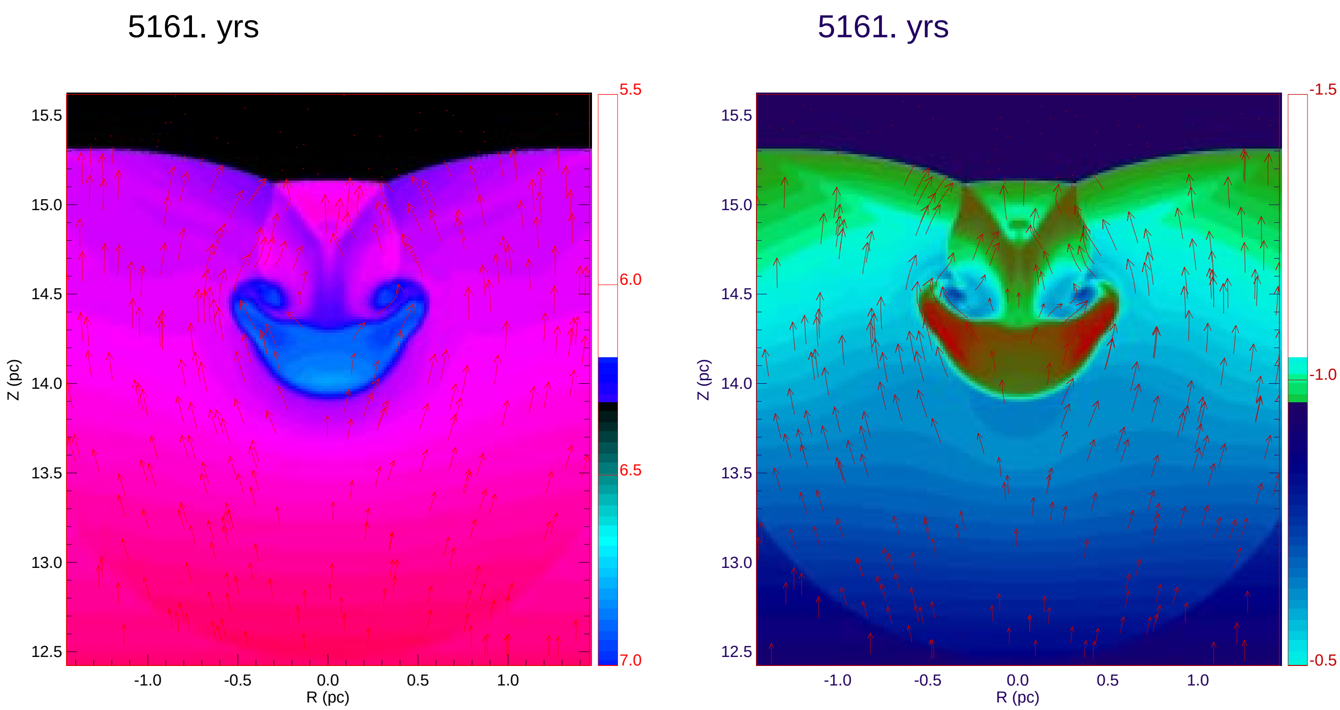

Fig. 2.— Temperature and density distribution from which the profile in Figure 4 have been extracted.

5. AN XMM EPIC-pn OBSERVATION OF EXTENDED SOURCE

We use the XMM simulator SCISIM v2.0 to simulate **an EPIC-pn observation of a narrow and long post-shock regions** which has the density and temperature profiles shown in Figure 4, placed at a distance of the Vela SNR (280 pc). In the R-direction (perpendicular to the profile), we assume that the source has no spectral variations and a width of 20″. In the Z-direction (along the profile), the source is 24′ long. The size of the source is marked in Figure 4 with two dashed lines.

The profiles were rebinned on 10″ bins and the emission measure inside each bin was computed assuming a line of sight of 3 pc, which is reasonable for the Vela SNR shell. The **flux** in each bin was computed using **a single-temperature non-equilibrium of ionization model**. The ionization time was computed in a zero-order approximation as a function of the distance from the main shock.

The extended source was approximated as a set of point sources aligned along the profile (the Z-direction). The effect of an extended source has been made more realistic by including, for each 10″ bin, two point sources, whose combined flux is equal to the expected flux in the bin.

Figure 3 shows the resulting EPIC-pn image of a 100 ksec observation of the extended source. The red circles (56″ radius) mark the extraction regions for the spatially resolved spectral analysis we show in the following.

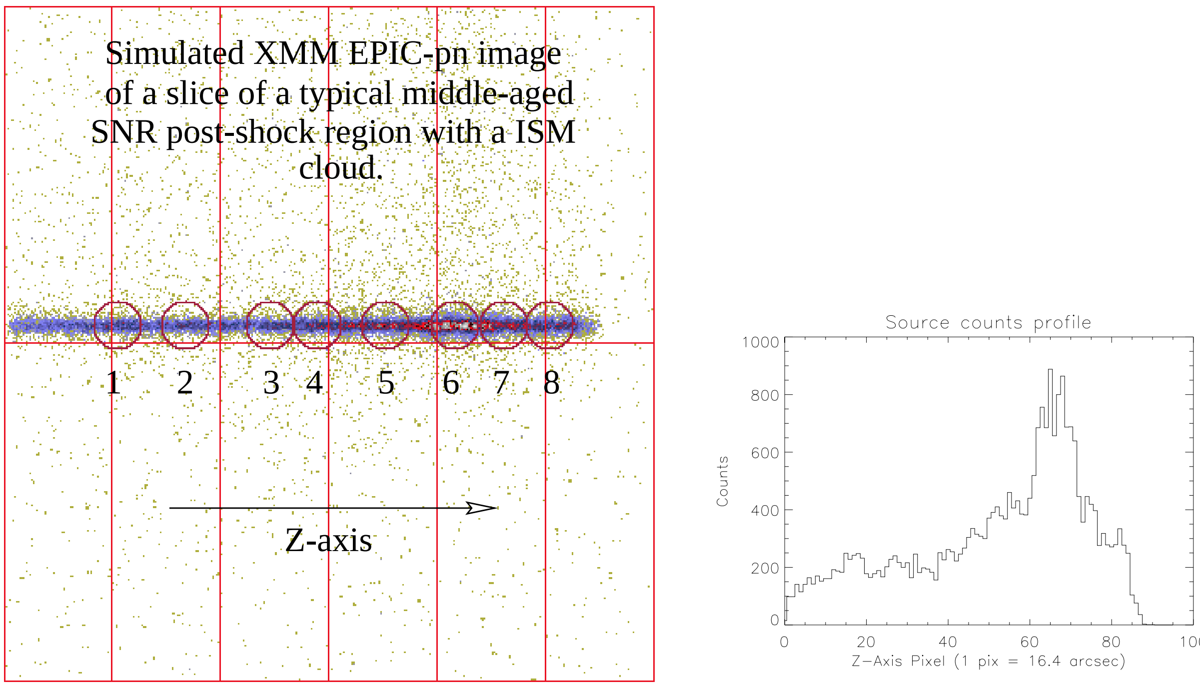

Fig. 3.— *Left:* the simulated EPIC image of the extended source which has the temperature and density profiles shown in Figure 4. *Right:* Number of observed counts along the Z-axis.

6. RESULTS AND DISCUSSION

The spectra extracted from Regions 1-8 in Figure 3 have between 2000 and 6000 counts in the 0.1-10 keV band. We fitted them with the input model, a single temperature NEI emission model.

Figure 4 shows the best fit values and statistical uncertainties over the input profiles. The bar along the Z-axis represent the size of the extraction region. **Figure 5** shows two spectra as examples with their best-fit models.

We point out that:

1. **the achieved spatial resolution allow us to detect an ISM cloud of 1 pc** at the distance of the Vela SNR.

2. **the high spectral resolution allow us to measure the density, ionization time and temperature with high accuracy**, except very few cases in which the statistics is very low;

3. our analysis of simulated data seems to indicate that **the brightest X-ray regions do not correspond to the bulk of the cloud mass**. The latter is localized only by the spectral analysis which reveals the cool plasma in the cloud which has interacted with the secondary shock.

4. **the main components of the post-shock region are resolved**, including the bow-shock and the structures formed by the main blast wave ahead of the cloud.

In **a real observation**, we expect a more complicated scenario, but our simulation indicates that **it should be at least possible to locate small regions of cool plasma inside ISM clouds**, and to study them in detail.

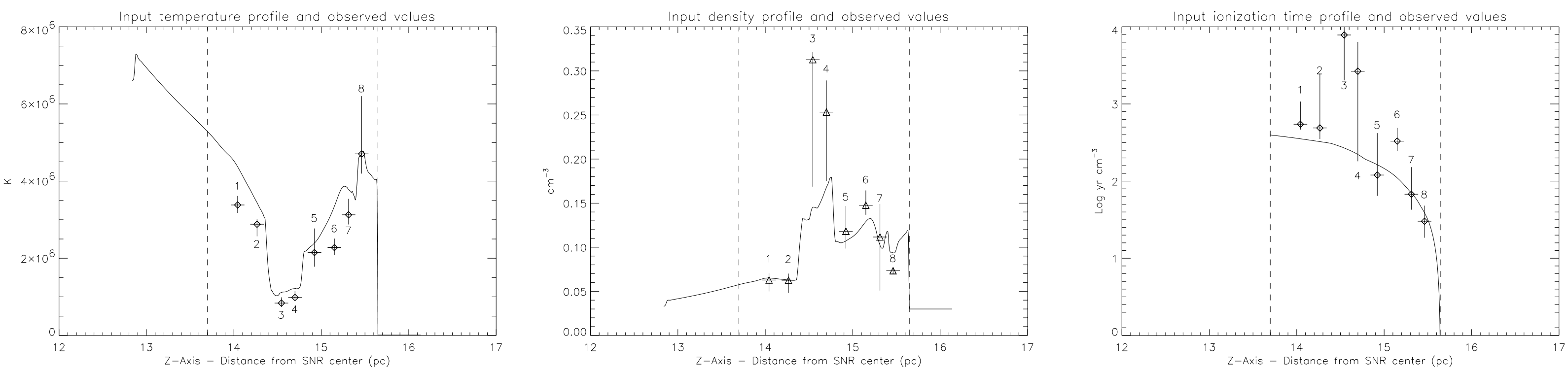

Fig. 4.— Input profile and observed values of the best-fit parameters. The extension of the simulated profile is shown by the dashed lines.

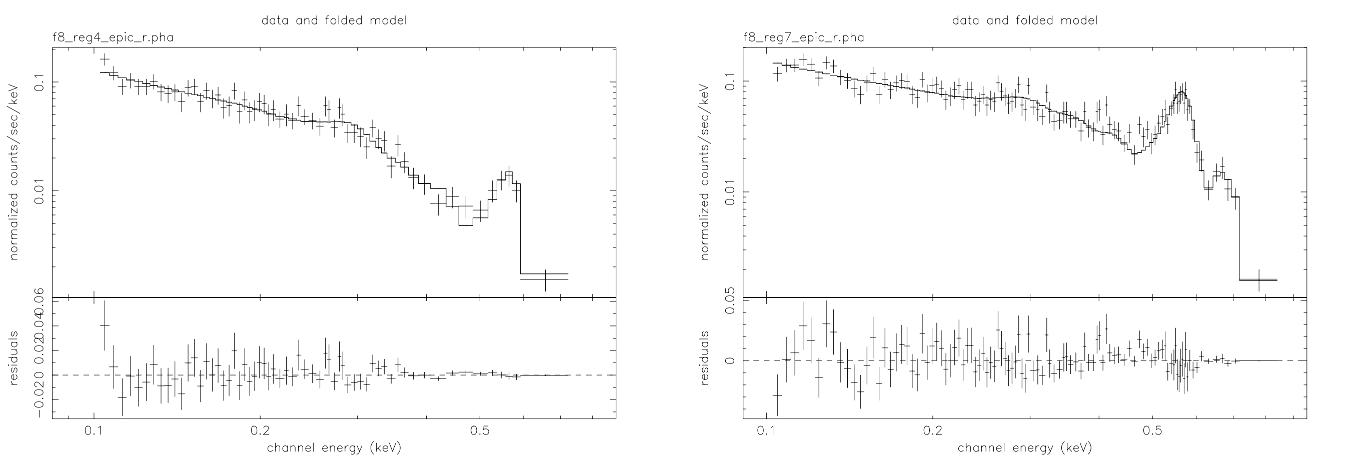

Fig. 5.— The EPIC-pn spectrum at position 4 (left) and 7 (right) of Figure 6 with their best-fit NEI model.