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Hydrodynamical models of young SNRs

D.I. Kosenko[1,2], S.I. Blinnikov[1,2,3], K.A. Postnov[1], and E.I. Sorokina[1]

[1] Sternberg Astronomical Institute, Universitetskij pr., 13, 119992, Moscow, Russia e-mail: lisett@xray.sai.msu.ru
[2] Institute for Theoretical and Experimental Physics, Bolshaya Cheremushkinskaya, 25, 117218, Moscow, Russia
[3] Max-Planck-Institut fur Astrophysik, Karl-Schwarzschild-Str. 1, D-85741 Garching bei Munchen, Germany

Abstract. X-ray observations of the Tycho supernova (SN) remnant by XMM-Newton telescope present radial profiles of the remnant in emission lines from silicon and iron (Decourchelle et al. 2001). To reproduce observed spectrum and X-ray profiles hydrodynamical modelling of the remnant was performed by Sorokina et al. (2004). Standard computational SN models cannot reproduce observed spacial behavoir of the X-ray profiles of the remnant in the emission lines. We perform analysis of these numerical models and find conditions under which it is possible to reproduce observed profiles.

Key words. supernovae type Ia – hydrodynamical modelling: Tycho SN remnant – X-ray emission: models of SNIa explosion

1. Introduction

Due to the role, that plays SN type Ia in cosmology, it becomes more important to investigate the SN penomena and its observational features. Numerical simulations of supernovae remnants (SNR) are crutial for understanding physics of the SN explosion.

To reproduce in simulations a structure of SN Ia remnant and emission from a SNR, one needs an initial model of WD burning, that contains elements distribution and density/velocity profile of the ejecta. Then it is important to have good hydrodinamical model for describing of SN propagation into circumstellar medium (CSM) and model of ionization evolution to describe X-ray emission from a remnant.

Send offprint requests to: D. Kosenko

To test the feasibilty of a numerical model one should compare it with observations of real objects. In case of supernova there are (at least) two phases when there is an opportunity to compare simulations with observational data. Several months after the explosion light curve of SN can be examined and compared with computational one. Hundreds of years later, SN ejecta is heated up by reverse shockwave propagating inwards from contact discountinity. Thus, it starts to produce X-ray emission. At this stage, a new one can compare calculated X-ray spectrum with observable from a SN remnant.

There is another observational data, that can help to test SN Ia models. Recent observations of Tycho remnant, performed by XMM-Newton (EPIC) observatory, contain a good X-ray spectrum and detailed images and azimuthally averaged profiles of the remnant in emission lines of silicon and iron.

2. Numerical models of SN Ia

We consider recent calculations of SN expansion into CSM perfomed by Sorokina et al. (2004). Authors employ 1D spherically symmetrical hydrodynamical calculations, with number of important physical processes taken into account. The following properties of shocked gas were examined:

- possible diference in temperatures of ion and electron components
- influence of radiative losses
- the account for electron thermal conduction
- time-dependent ionization processes

Two models of SN Ia explosion were considered in these calculations. It is

- W7 - classical (Nomoto et al. 1984), $M_{WD} = 1.38 M_{\odot}, E_0 = 1.2 \times 10^{51}$ergs, $M(^{56}Ni) = 0.6\, M_{\odot}$;
- MR0 - 3D model from MPA (Reinecke et al. 2002), $M_{WD} = 1.38 M_{\odot}, E_0 = 4.6 \times 10^{50}$ergs, $M(^{56}Ni) = 0.43\, M_{\odot}$;

The main difference beetween these models is that 3D model from MPA is much more mixed and less energetic compared to W7 model. Modelling of cosmological SN's light curves shows that 3D model from MPA describes better SN Ia light curves then W7 model (Sorokina et al. 2000)

3. X-ray observations of a young SNR

Consider recent X-ray observations of a young SNR — Tycho remnant. The supernova was observed approximately 430 years ago. Now remnant has angular size 8', which is about 5-6 pc, depending on adopted distance. Observations were performed by XMM-Newton observatory (Decourchelle et al. 2001) and contain X-ray spectrum integrated over all remnant and azimuthally averaged profiles of the remnant in X-ray emission lines of silicon and iron.

Observed and calculated spectra are presented on Fig.1 (Decourchelle et al. 2001) and Fig.2 (Sorokina et al. 2004). These figures demonstrate, that MR0 model shows bright iron emission lines, while W7 model does not show any. Thus the real model of explosion should lie somewhere in between these two (Sorokina et al. 2004).

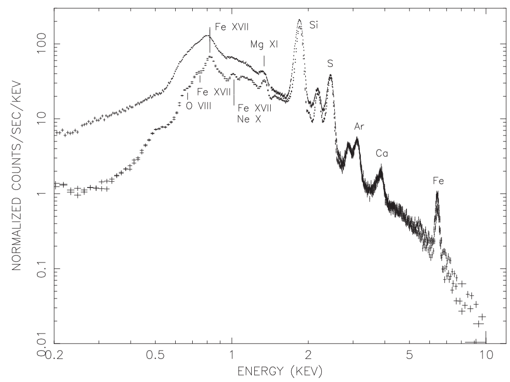

Fig. 1. X-ray spectrum of the Tycho remnant obtained by XMM-Newton (EPIC) integrated over the whole remnant.

On Fig.3 radial profiles of the remnant in emission lines of iron and silicon are presented. While calculated spectra look very similar to the observed one, modelled radial profiles of the remnant in emission lines demonstate noticable discrepance between models and observations. This discrepance concerns relative positions of the peaks on the right panels of Fig.3 (these panels show profiles in FeK and FeL emission lines. Observation shows that innermost layer of swept up material mostly shine in FeK lines, while FeL lines come mostly from outer layers (Decourchelle et al. 2001). Numerical models demonstate quite opposite situation: FeK lines come from inner layers, FeL — from outer layers of the swept up ejecta.

4. Time-dependent ionization processes in the SNR

In Sorokina et al. (2004) in most cases consecutive ionization processes were considered,

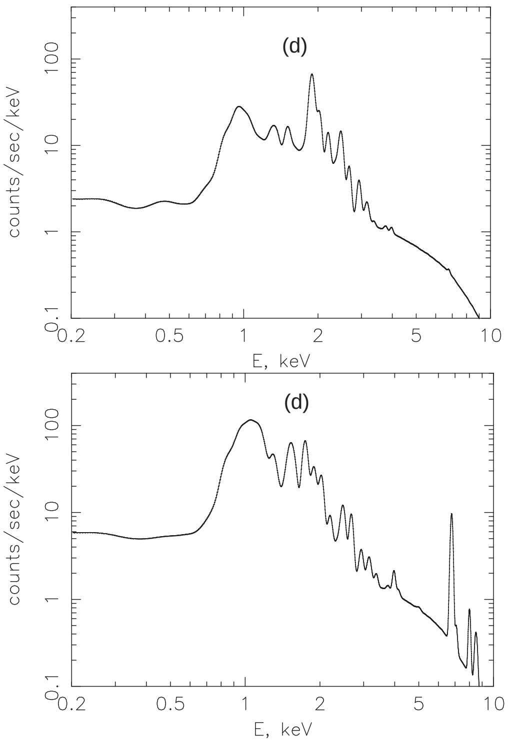

Fig. 2. Calculated X-ray spectra of the Tycho remnant from W7 model (upper graph) and MR0 model (lower graph). Hydrodynamical models were calculated in assuption of depressed electron conductivity and full energy exchange between ion and eletron components (a full allowance for the possible effect of magnetic field).

thus it was assumed that FeK emission lines originate mostly in highly ionized ions and transitions from intermediate Fe ions were not taken into account. In this approach, the following considerations describe the numerically calculated X-ray profiles.

Lets examine evolution in time of FeXVII, SiXIII and FeXXVI ions in the swept up SN ejecta. Consider cold gas with temperature 10^4 K that was instantly heated up to 10^9 K. Evoluiton of ions depending on ionization timescale $n\,t$ (n — number density, t — time, passed after heating) after the heating is presented in figure Fig.4. The figure clearly shows that FeXXVI ion appears noticable later then ions of SiXIII and FeXVII.

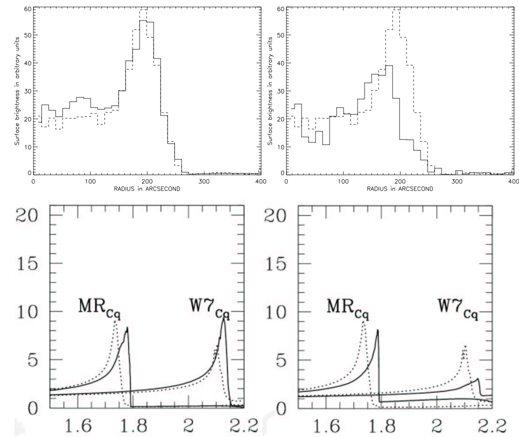

Fig. 3. Radial profiles of the Tycho remnant in emission lines of silicon and iron. Upper plots — XMM Newton observations (Decourchelle et al. 2001), lower plots — results of numerical modelling (Sorokina et al. 2004). Left hand plots — profiles in SiK emission lines (solid) and FeL emission lines (dotted), right hand plots — profiles in FeK emission lines (solid) and FeL emission lines (dotted).

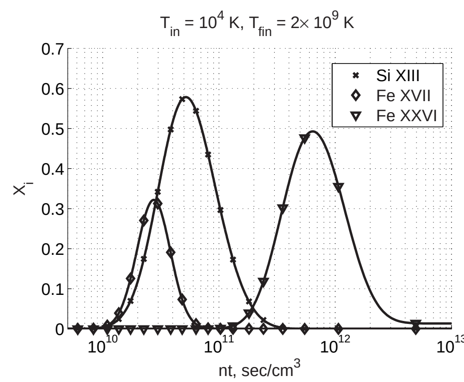

Fig. 4. Evolution of ions depending on ionization timescale *nt*.

On contact discontinuty in the ejecta ionization time much higher then at reverse shock front. Thus innermost layers of supernova emitting shell should produce FeL lines (FeXVII ions appears at lower ionization age), while outermost layers of swept up ejecta produce FeK lines (these are at higher ionization age), SiK goes from intermediate layers of swept up ejecta. This effect is presented in the simulated profiles (Fig.3).

Table 1. Parameter $M_{\mathrm{b}rk}$ and explosion energy for modified models

MR0 explosion model	Power	Exponential
$M_{\mathrm{b}rk},\ M_{\odot}$	0.8	0.5
$E_0,\ ergs$	5.3×10^{50}	1.2×10^{51}

5. Modification of initial density distribution

One of the ideas to overcome this contradiction between observation and numerical experiment was to modify density profile in the SN explosion model. We applied modification of initial density for outer layers of exploded white dwarf (3D model from MPA), innermost layers stays intact. If $\rho_0(m)$ — is an initial density profile, depending on Lagrangian mass coordinate m (m runs through 0..1.4 $M_{\odot}$), then the modification looks like the following

$$\rho'(m) = \begin{cases} \rho_0(m) & \text{if } m < M_{\mathrm{b}rk} \\ f(\rho_0(m),\ \alpha) & \text{if } m > M_{\mathrm{b}rk} \end{cases} \qquad (1)$$

here f — is some transformation law, and α — some set of additional parameters. abs

Two modification laws were considered: power and exponential cut off. Table 1 shows corresponding values of $M_{\mathrm{b}rk}$, and explosion energy for these modified models. Thus the MR0 model became more depressed in outer layers.

Results of the hydrodynamical calculations based on these models are presented in Fig.5. Figures show profile of the Tycho remnant in emission lines from FeXXVI, SiXIII and FeXVII ions and profile of the density distribution (thin line) in the remnant. Relative positions of peaks in the profiles correspond to the observed one, but now emission in these lines produced by swept up circumstellar medium. It is worth noting that such a profile requires values of parameters α and $M_{\mathrm{b}rk}$ at high presicion (with accuracy about 3%, higher or lower values of these parameters cause ejecta to shine), i.e. a some kind of "fine tuning" take place.

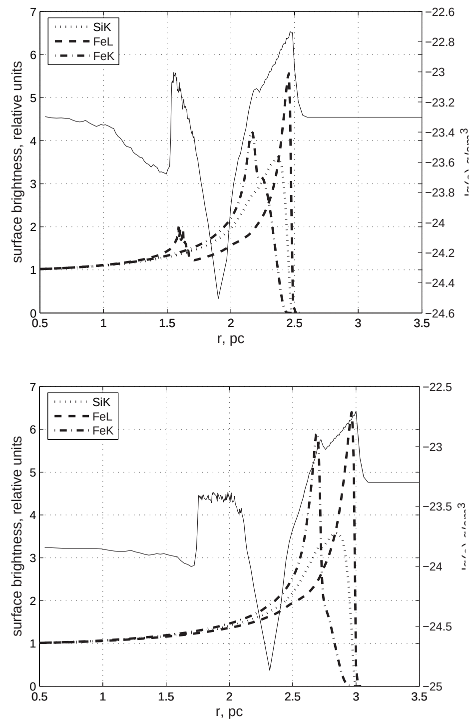

Fig. 5. Calculated X-ray profiles of the Tycho remnant from modified MR0 model. Upper plot — power law tail, lower — exponential tail.

6. Discussions

Analysis of the results, presented in Sorokina et al. (2004) shows that to satisfy X-ray observations of Tycho SNR in framework of Sorokina et al. (2004) at least modification of SN type Ia model is required. As a result — X-ray emission (with energy higher then 4 KeV) of the remnant are produced by swept up circumstellar medium. Thus some of emission lines in high energy tail of the spectrum become noticably weaker.

These facts clearly show that FeK blend may be produced by intermediate iron ions in Tycho SNR. FeXXVI ion should not have enough ionization time to emerge in the SN ejecta. In future we plan to include a calculation of FeK emission from iron in lower ionization states in order to improve simulated X-ray spectrum and X-ray profiles of the remnant.

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