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Probing Shocked Ejecta in SN 1987A with XRISM−Resolve: the effects of the gate valve closed

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ABSTRACT

Supernova (SN) 1987A is widely regarded as an excellent candidate for leveraging the capabilities of the freshly launched XRISM satellite. Recent researches indicate that the X-ray emission from SN 1987A will increasingly originate from its ejecta in the years to come. In a previous study, we thoroughly examined the proficiency of XRISM-Resolve in identifying signatures of shocked ejecta in SN 1987A, synthesizing the XRISM-Resolve spectrum based on a state-of-the-art magneto-hydrodynamic simulation. However, following the satellite's launch, a technical issue arose with the XRISM instrument's gate valve, which failed to open, thereby affecting observations with the Resolve spectrometer. Here, we update our analysis, reevaluating our diagnostic approach under the assumption that the gate valve remains closed. We find that, even with the reduced instrumental capabilities, it will be possible to pinpoint the ejecta contribution through the study of the line profiles in the XRISM-Resolve spectrum of SN 1987A.

1. INTRODUCTION

Supernova (SN) 1987A provides a unique opportunity to study the evolution of a SN into its remnant across the electromagnetic spectrum (McCray & Fransson 2016). The supernova remnant (SNR) is evolving in a clumpy equatorial ring within a diffuse H II region (Sugerman et al. 2005).

X-ray observations are crucial for studying the interaction between the shock front, the circumstellar medium (CSM), and the ejecta. Since the initial detection (Dotani et al. 1987; but see also Beuermann et al. 1994), the X-ray emission increased for about 25 years, confirming the shock's encounter with the equatorial ring (Borkowski et al. 1997,Park et al. 2005, Haberl et al. 2006, Zhekov et al. 2009, Maggi et al. 2012). Recent investigations in the past few years, hinted that the X-ray emission from the CSM is decreasing, leaving space to the X-ray emission from the ejecta (Frank et al. 2016, Sun et al. 2021, Ravi et al. 2021, Maitra et al. 2022).

3D hydrodynamic and magneto-hydrodynamic simulations have replicated the X-ray light curves, spectra and remnant morphology, as well as other observed properties of SN 1987A. Initially dominated by the shocked H II region, the X-ray emission later became influenced by the shocked equatorial ring, and is now driven by the outer ejecta heated by the reverse shock (Orlando et al. 2015, 2019, 2020).

A novel data analysis approach by Miceli et al. (2019) using *Chandra* data compared with 3D simulations provided insights into post-shock temperatures. The XRISM mission, launched on September 7, 2023, will offer high-resolution X-ray spectroscopy, allowing in-depth studies of SN 1987A. Using our in-house tool, we synthesized the XRISM-Resolve X-ray spectrum of SN 1987A from MHD simulations (Orlando et al. 2020; Ono et al. 2020), successfully tracing new ejecta diagnostics for future observations (Sapienza et al. 2024).

However, the XRISM Telescope safety gate valve for the Resolve instrument failed to open after launch. As a consequence, the effective area of XRISM-Resolve results degraded and severely compromised under 2 keV. Here we update the analysis in Sapienza et al. (2024) by adopting the updated response files (Section 2) and investigate the possibility of detecting the ejecta in SN 1987A with the gate valve closed (Section 3).

2. RESULTS

Following the same procedure described in Sapienza et al. (2024), we produced the synthetic spectrum of SN 1987A for the year 2024, using the new RMF and ARF files that take into account the effects of the gate valve closed, available in the HEASARC XRISM website[1].

Upper panel of Figure 1 shows the updated version of the synthetic spectrum, for an exposure time of 160 ks, which is the amended exposure time for the PV phase observation of SN 1987A, increased with respect to the original 100 ks to compensate the loss of effective area. Unfortunately, the effective area below 2 keV is severely compromised, hampering us to carry on the diagnostic procedure for the Mg and Si emission lines. However, the quality of the spectrum remains adequate for applying the same diagnostics to the S lines. In particular, it will be possible to reveal the ejecta through their enhanced line widths (with respect to the narrow lines stemming from the shocked ambient medium) associated with their large velocities. We then fitted the S line profiles adopting only 2 broad Gaussian components (due to the reduced statistic), for the S XV w-z and for the S XVI Lyα, modeling the continuum emission with a power law and accounting for the interstellar and intergalactic absorption. Similarly to Sapienza et al. (2024) $\sigma_2 = \sigma_1 \cdot E_2/E_1$, being $\sigma_{1,2}$ and $E_{1,2}$ the width and the centroid of the ejecta components in the lines of He-like and H-like species. Figure 1 (lower-left panel) shows a close-up view of the synthetic spectrum highlighting the S lines with the corresponding best fit model and residuals. The different components are detected with high significance (their normalization being larger than zero at more than the 5σ confidence level) and clearly show a large expansion velocity (3300^{+800}_{-700} km s^{-1}), which nicely accounts for the ejecta bulk motion.

3. DISCUSSION AND CONCLUSIONS

We synthesized the updated PV XRISM-Resolve X-ray spectrum for 2024, including the effects of the gate valve closed. Our analysis shows that the synthetic spectra still provides valuable diagnostics to measure the ejecta velocity from the broadening of sulfur emission lines, highlighting the continued utility of XRISM in studying SN 1987A.

Our results showcase the adaptability and resilience of our analytical methods and the importance of ongoing X-ray observations and simulations in unveiling the complex dynamics of supernova remnants. Future observations, leveraging both current and upcoming missions, are expected to provide deeper insights into the evolving nature of SN 1987A.

[1] https://heasarc.gsfc.nasa.gov/docs/xrism/proposals/responses.html

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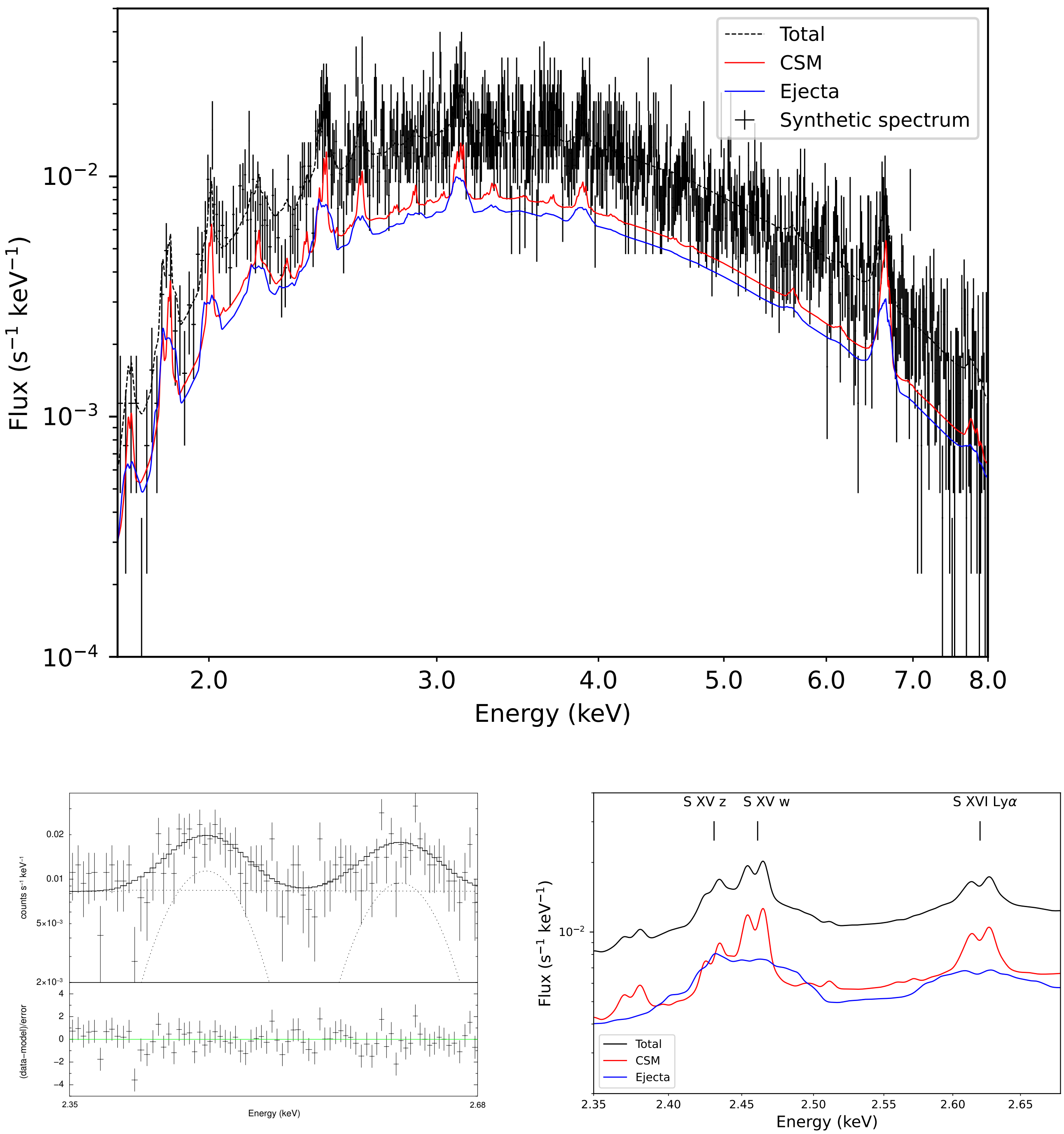

Figure 1. *Upper panel:*Synthetic XRISM-Resolve spectrum of SN 1987A for the year 2024 (assuming the gate valve closed) with an exposure time of 160 ks including bulk motion Doppler broadening and binned using the Kaastra & Bleeker (2016) optimal binning algorithm. The synthetic XRISM-Resolve spectral model is superimposed with a black dashed line. The red curve shows the contribution of the CSM (ER and H II) to the spectral model, while the blue curve shows the contribution of the ejecta. *Lower left panel:* Close-up view of the spectrum shown in upper panel in the $2.38 - 2.65$ keV band with best-fit model and residuals. *Lower right panel:* Close-up view of the spectral model shown in upper panel in the $2.38 - 2.65$ keV band.

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