Two Distinct-Absorption X-Ray Components from Type IIn Supernovae: Evidence for Asphericity in the CSM

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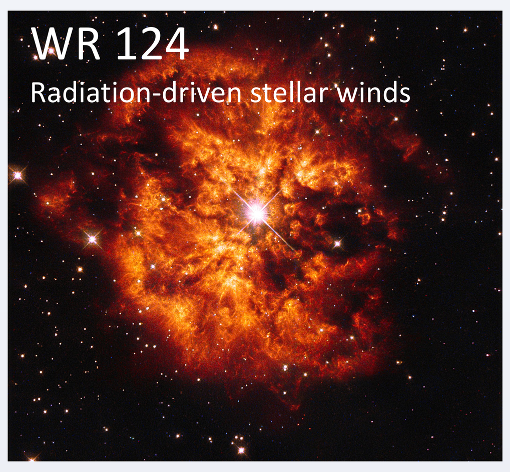
The Astrophysical Journal, 832:194 (2016)

Introduction

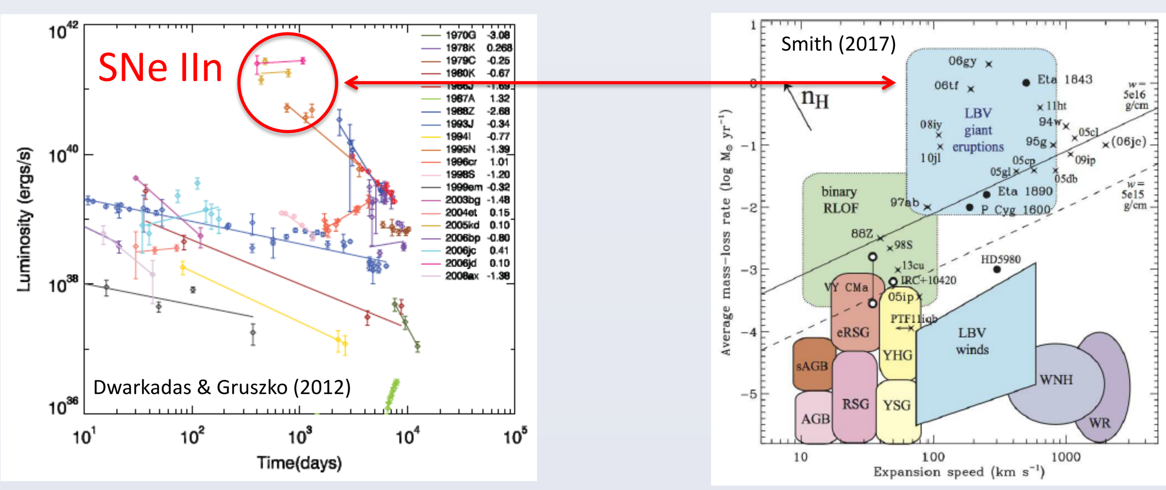
Mass loss from massive stars

Mass loss is a key phenomenon in a massive stars' evolution [e.g., 1]. In addition, mass-loss in the final stage affects subtypes of supernovae (SNe).



Mass-Loss in the Final Stage Measured in SNe

Mass loss influences the stellar environments, forming the circumstellar medium (CSM) around the progenitor star. The CSM will be excited by the collision with the SN ejecta, and emit intense radiation, allowing us to reveal the CSM properties and the mass-loss history of the progenitor. Thus, many SNe have been providing us with mass-loss rates during the final phase of stellar evolution. In particular, interacting SNe (Type IIn SNe) gave us evidence for extreme mass-loss (just before SNe), similar to those for LBV stars.



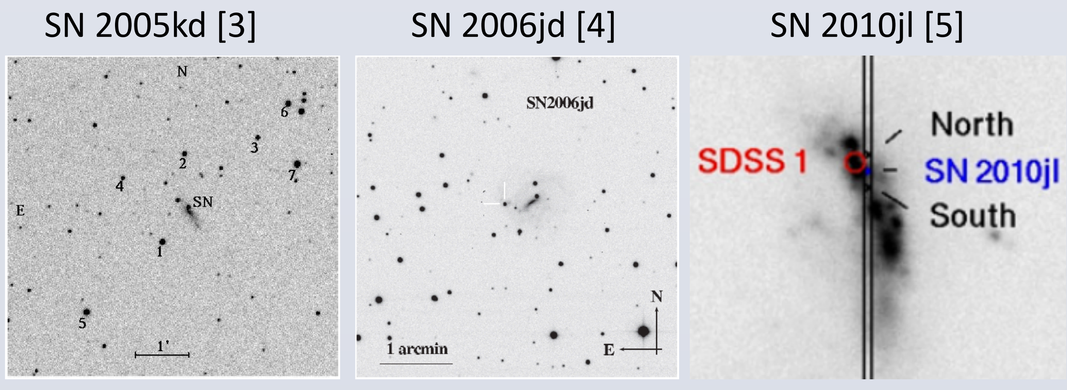
Geometries of the Circumstellar Medium

CSM geometries are important to understand the last evolution of massive stars. So far, spectro-polarimetry allows us to probe geometries of ejecta and CSM [e.g., 2]. But such measurements require substantial amounts of photons, hence successful observations are still scarce.

Observations and Analysis

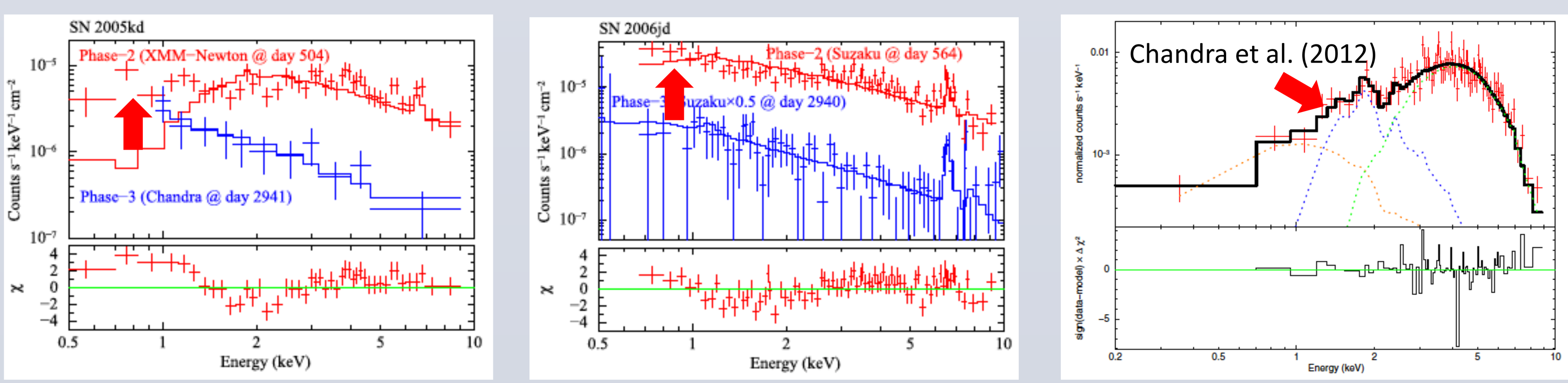
We analyzed all X-ray observations (including some data already published in the literature) for three Type IIn SNe 2005kd, 2006jd, and 2010jl.

SN 2005kd [3] SN 2006jd [4] SN 2010jl [5]



	SN 2005kd	SN 2006jd	SN 2010jl
Explosion date	2005-11-10	2006-10-06	2010-10-01
Distance	64.2 Mpc	79 Mpc	49 Mpc

We discovered a soft X-ray component in the early phases of both SNe 2005kd and 2006jd, which is similar to that found in SN 2010jl [6].

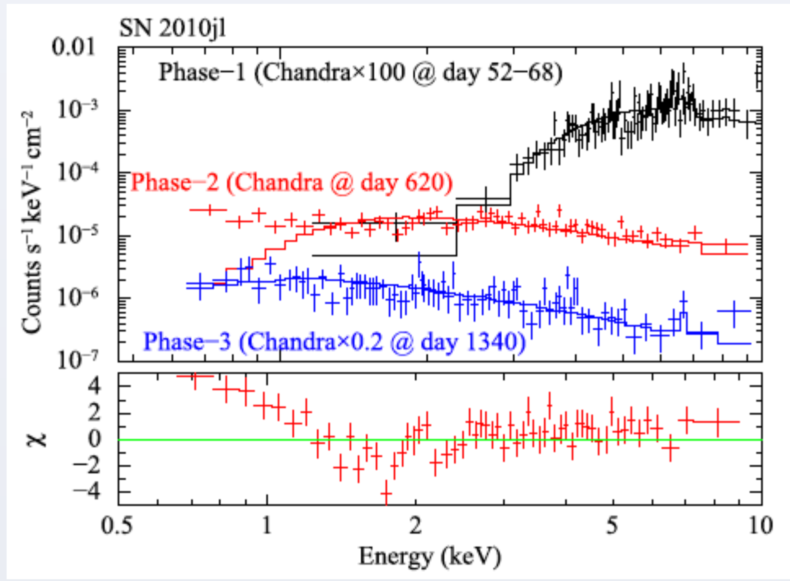


We considered three possibilities for the soft X-ray component:
1) Power-law
2) Low-T thermal
3) High-T thermal with much less absorption than the hard X-ray component

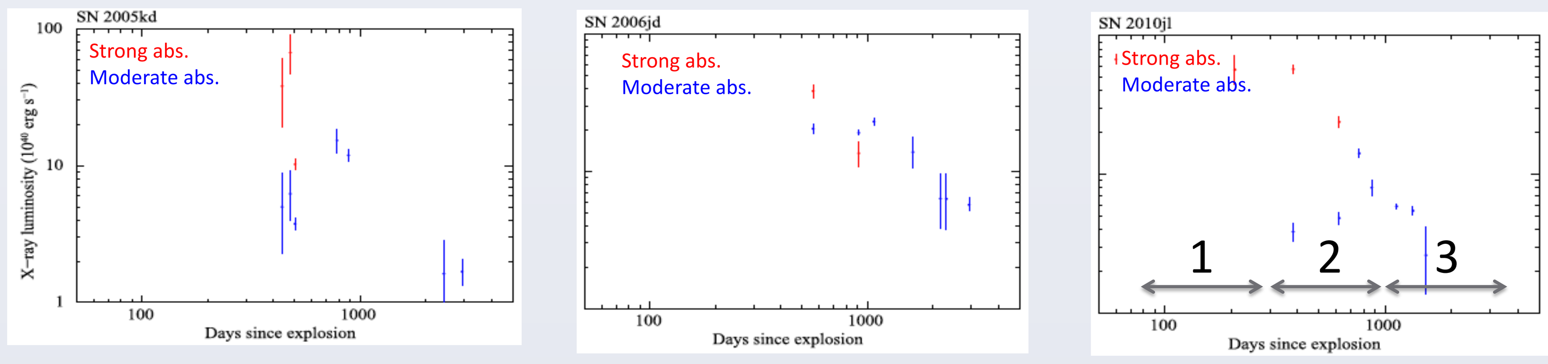
Of these, only the last possibility seems to be viable. If power-law, the X-ray fluxes are far higher than the extrapolation of the radio fluxes (whether the power-law component is inverse-Compton scattering or synchrotron). If low-T VNEI, it would originate from either the reverse shock or clumpy CSM, and is expected to be more absorbed than the high-T VNEI, which conflicts with the observation.

Interpretation

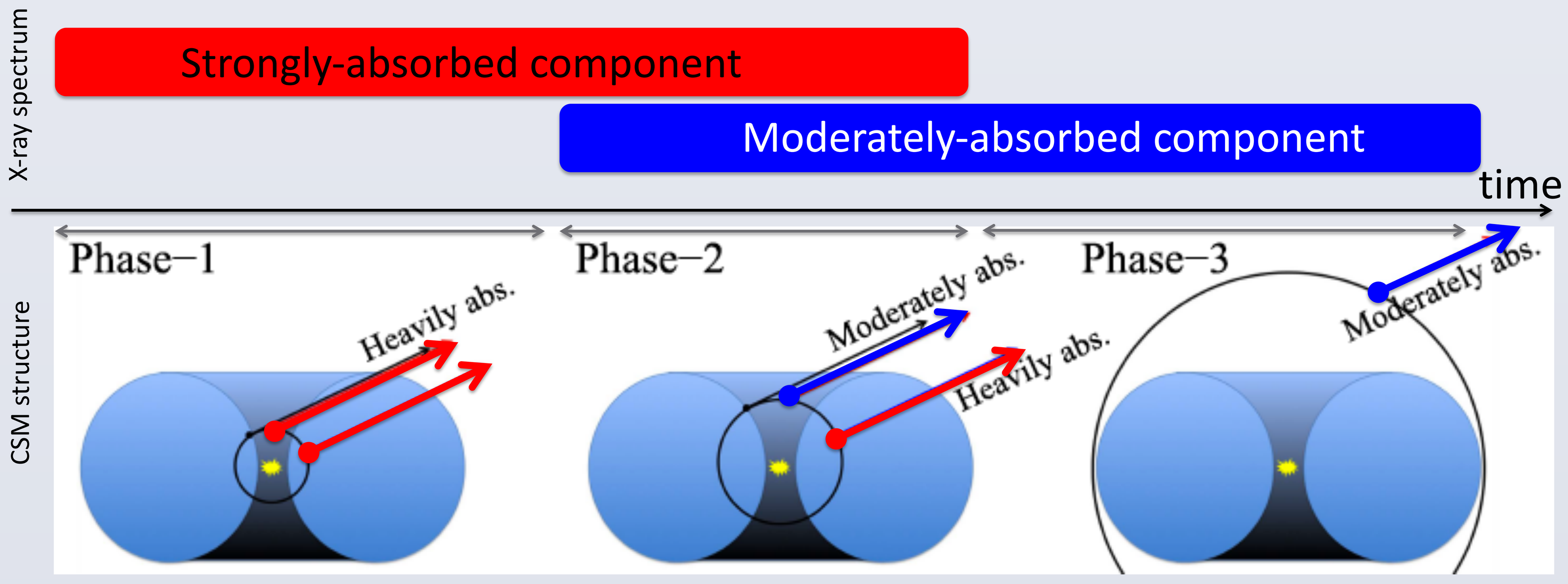
Based on our time-resolved spectral analyses, we identified three characteristic evolutionary phases:
Phase-1) Only a strongly-absorbed X-ray component is present.
Phase-2) A moderately-absorbed component emerges. Two-component phase.
Phase-3) Only the moderately-absorbed component remains.



Left: SN 2010jl's X-ray spectra for the three phases with the best-fit single component model. In phase 2, soft excess emission can be readily seen.
Lower three panels: X-ray luminosities as a function of time for the three SNe IIn.



Schematic Evolutionary View of a Shock Propagation into a Dense CSM Torus



Estimating the Size and Mass of the CSM Torus

The radius of the CSM torus can be estimated to be ~5×10^{16} cm (V_{shock}/8000 km s^{-1}) (t / 2 yr), by multiplying an assumed shock speed of 8000 km s^{-1} and a period of 2 yr during which we detect the strongly-absorbed component.
The mass of the CSM torus can be estimated to be 4—9 $M_{\odot}$ (V_{wind}/100 km s^{-1}) and 2—6 $M_{\odot}$ (V_{wind}/100 km s^{-1}) for SN 2010jl and the other two SNe, respectively, based on mass-loss rates from X-ray luminosities.
These radii and masses are an order of magnitude and two orders of magnitude smaller and larger than those found in SN 1987A [e.g., 7], respectively. Such big differences suggest different natures of the progenitors.

Summary

Based on multi-epoch spectral analyses of three SNe IIn, SN 2005kd, SN 2006jd, and SN 2010jl, we have studied their X-ray spectral evolution. We found that: Initially, X-ray spectra can be represented by a single, strongly-absorbed thermal component (Phase-1). Subsequently, the spectra start to show two components, comprised of one strongly-absorbed, and another moderately absorbed components (Phase-2). Finally, the strongly-absorbed component disappears, leaving only the moderately-absorbed component (Phase-3).

The spectral evolution observed can be reasonably understood by considering a torus-like geometry of the CSM (see the figure below). In Phase-1, the radius of the forward shock is so small that the entire emission is heavily absorbed by the near-side of the CSM torus. When the forward shock radius increases enough to be observed over the dense CSM torus (Phase-2), we see both of the soft (moderately absorbed) and hard (heavily-absorbed) components. In the last stage (Phase-3), the forward shock breaks out the dense CSM torus, leaving only the soft (moderately-absorbed) component. Therefore, we found a new observational support to the mounting evidence for the asphericity of the CSM.

References

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