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

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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.

Introduction

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.

<table>
<thead>
<tr>
<th>SNe</th>
<th>Explosion date</th>
<th>Distance</th>
</tr>
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<tbody>
<tr>
<td>2005kd</td>
<td>2005-11-10</td>
<td>64.2 Mpc</td>
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<tr>
<td>2006jd</td>
<td>2006-10-06</td>
<td>79 Mpc</td>
</tr>
<tr>
<td>2010jl</td>
<td>2010-10-01</td>
<td>49 Mpc</td>
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</tbody>
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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

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-3: Only the moderately-absorbed component remains.

Estimating the Size and Mass of the CSM Torus
The radius of the CSM torus can be estimated to be ~5x10^{16} cm (V_{VNEI}/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_{V}, (V_{VNEI}/100 km s^{-1}) and 2—6 M_{V}, (V_{VNEI}/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 absorbing 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).

References