Abstract: After several decades of study, the progenitor stars of supernovae (SNe) have still proven difficult to identify. The identification of progenitors has generally been the purview of optical astronomy, aided by stellar evolution models. But observations at other wavelengths can provide important clues about the progenitors. We have aggregated together data available in the literature, or analysed by us, to compute the X-ray lightcurves of most SNe. We use these, coupled with analytical calculations and numerical simulations, to explore the various SN types, investigate SN expansion, explore the characteristics of the medium into which SNe are expanding, and examine the implications for their progenitors. The low X-ray luminosity of IIPs sets a limit on the mass-loss rate, and constrains the maximum initial mass of a red supergiant star which can become a Type IIP SN to < 19 M⊙. We discuss the relationship between stellar evolution models and the X-ray emission from various SN types.

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Why do Type IIPs have the lowest luminosities?
1. The emission is due to thermal bremsstrahlung.
2. IIPs do not arise from RSG stars. Our understanding of stellar evolution is incomplete.
3. We don’t have a large enough statistical sample to judge.
4. The higher density, that results in the higher emission, also results in higher absorption (if the surrounding medium is not fully ionized). Maybe the high emission ones are totally absorbed?

Exploiting The AboveSuggestions

1. Chevalier et al. (2006, ApJ, 641, 1029) emission from IIPs not thermal; due to Inverse Compton Scattering. But in a high density region (~10^5 M⊙ yr^-1), why is thermal bremsstrahlung not dominating? Perhaps density, and mass-loss rate, is not that high?
2. IIPs have the only observationally determined progenitors (aside from 87A and 93J and all of them are RSG stars (Smartt 2009, A&A)). Strangely, all progenitor stars appear to have initial mass < 17 M⊙. This relates the fact to next question. From the X-ray lightcurves (Fig.1), it is clear that we detect other SNe with high mass-loss rates. Why IIPs be preferred to not detected? Serendipitous surveys have not detected them either. Also absorption should decrease with time, so high mass-loss rate ones should be detectable at late times (< a few months).

Is all the emission from high mass-loss rate IIPs absorbed? Close to the SN, the ambient medium during the first 100 days is ionized by the SN flash. Due to the high densities close to the stars (v/2 < 1), this material recombines quickly. However X-ray emission itself can ionize the circumstellar medium.

GRB SNe not included. The dotted lines indicate the approximate mass-loss rate to produce the observed luminosity, assuming bremsstrahlung emission.

Massive Stars: Core-Collapse SN Progenitors

• Cool Massive Stars (Red Supergiants (RSGs)): Single stars (~810-307 M⊙) initial mass end their life as Red Supergiants.
• RSGs have dense, low velocity winds (~10-50 km s^-1, 10^4-10^5 M⊙ yr^-1).
• Single Massive stars (solar metallicity) > above 30-35 M⊙ may explode as Wolf-Rayet (W-R) stars.
• W-R stars have fast, dense winds (10000-30000 km s^-1, 10^-2 -10^-5 M⊙ yr^-1).
• One SN whose progenitor is known reasonably well, SN 1987A, had a blue supergiant, with a wind velocity in the range of 500 km s^-1, and a mass-loss rate < 10^-5 M⊙ yr^-1.

IIPs have densities much higher than RSGs.

Maximum Mass of IIP Progenitors

Geneva mass-loss rate relation for RSGs: M = 4.7 x 10^-7 (L/L^* 1/4)^1


What about Type IIL and Type Ibb?

Type IIb SN:

We know that SN 1993J, a Ibb, arises from a binary, which may be the reason for its high mass-loss rate. Its X-ray emission is definitely thermal. It is possible that all extended (Type IIL) SNe come from binaries, have high mass-loss rates and show thermal emission. While the compact (Type Ibb) are the more traditional ones that arise from a single W-R progenitor with fast shocks, and probably show non-thermal emission. Not clear where ILLs fit. They presumably arise from a more massive RSG or YSG progenitor that ended its life in a WR phase but has a dense envelope surrounding it.

As a class, they presumably have multiple progenitors (Dwarkadas 2011, MNRAS, 412, 1639). Many show clear thermal emission, but it may be that in a few cases the emission is non-thermal. For some type IILs like SN 1988Z and SN 1986e, steep X-ray decreases cannot be fitted with any known analytic model. These may perhaps be better fitted by a two-component model, consisting of dense clumps in a less dense wind medium (Chatzopoulos & Dwek 1994, MNRAS, 268, 173). Others such as SN 2005dQ and SN 2005kdr need high densities that are consistent with W-R stars, for one or two component media, and require a different progenitor.

One SN with a possible W-R star progenitor is SN 1996cr. Using the increasing X-ray and radio emission, coupled with a 485 ks HETG spectrum, Dwarkadas et al. (2010, MNRAS, 407, 812) showed that the SN evolved in a low density windblown medium before impacting a dense shell 0.03pc away from the star. Further studies showed that the wind properties of the star were consistent with a W-R progenitor, although they could not rule out a SN 1987A-type progenitor (Fig.4).

Fig.4 (Left): The expected structure of the circumstellar medium around a RSG star, the presumed progenitors of Type IIP SNe. Fig. (2b) (Right): Structure around a Wolf-Rayet star, the progenitors of IILc SNe. From Dwarkadas (2007, ApJ, 667, 226). Red: density; green: pressure; title: Time in years. SN first expands into freshly expanding wind. Since RSG wind velocity is lower, expected wind density is higher.

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