Research Plan

What are the progenitor stars of core-collapse (CC) supernovae (SNe)? In spite of observational and theoretical advancements in the field this basic question is still, in many aspects, unsolved. Much of the work in Paper I-VII have been devoted to this issue, and in the near (few-years) future I plan to advance this work further. Paper I-V focused on the nearby Type IIb SN 2011dh, and using hydrodynamical lightcurve modelling, nebular spectral modelling and stellar evolutionary progenitor analysis the progenitor star was found to have relatively low initial mass (12 solar masses). The analysis is extended to a sample of Type IIb SNe in Paper VI, where a grid of hydrodynamical SN models is used to fit the observed bolometric lightcurves and photospheric velocities using an automated procedure. According to these results about 50 percent of the SNe in the sample have an initial mass below 15 solar masses (see Fig. 2), suggesting that Type IIb SNe lose their hydrogen envelopes due to Roche-lobe overflow in binary systems rather than through stellar winds, as would be the case for isolated stars. Previous sample studies like Lyman et al. (2014) use approximate methods (e.g. Arnett 1982) and the use of a hydrodynamical model grid based on evolutionary stellar models greatly improve the reliability of the results. My first priority would be to develop this method further and to apply it to samples of SNe of other types, in particular Type Ib and IIL SNe. The progression of SN types IIP-IIL-IIb-Ib-Ic is commonly thought to reflect the continues stripping of the hydrogen and helium envelopes of the progenitor stars (see Fig. 1). Which mechanism is removing the envelopes is less clear and can be either stellar winds or Roche-lobe overflow in binary systems. As mentioned, it is likely that a large fraction of Type IIb SNe originates from binary systems, and there is indications that this could also be the case for Type Ib and Ic SNe. My second priority would be to further develop the multi-method approach used in Paper I-V. This method requires collaboration though, so the progress is partly beyond my control. Below I discuss the hydrodynamical grid and multi-method approaches in a bit more detail as well as a number of concrete science cases.

The hydrodynamical model grid

The use of hydrodynamical model grids to determine the progenitor characteristics have been explored before (e.g. Litvinova & Nadezhin 1983, 1985) with somewhat mixed results (e.g. Hamuy 2003), but the decreasing computational cost and the increasing amount of data obtained by surveys like the Palomar Transient Factor (PTF) and the Carnegie Supernova Project (CSP), motivates a renewed interest in this approach. In Paper VI the hydrodynamical code HYDE is used to construct a grid of SN models based on bare helium cores evolved with MESA STAR (Paxton et al. 2011) , and in Paper IV and VI this grid is used to fit the bolometric lightcurves and photospheric velocities of SN 2011dh and a sample of Type IIb SNe, respectively. Although the method is superior to approximate lightcurve modelling (e.g. Arnett 1982), there is a number of simplifications involved and further development of the method would be one of my priorities. For example the treatment of lines opacities and the optically thin region could be improved following e.g. Blinnikov et al. (1998). Use of spectral Monte-Carlo modelling (see Paper II) to better estimate of the photospheric velocities, is another potential improvement. Finally, expanding the grid with additional parameters would widen the range of applicability (see below). This comes at a cost, however, as the the computational time increase in an exponential way.

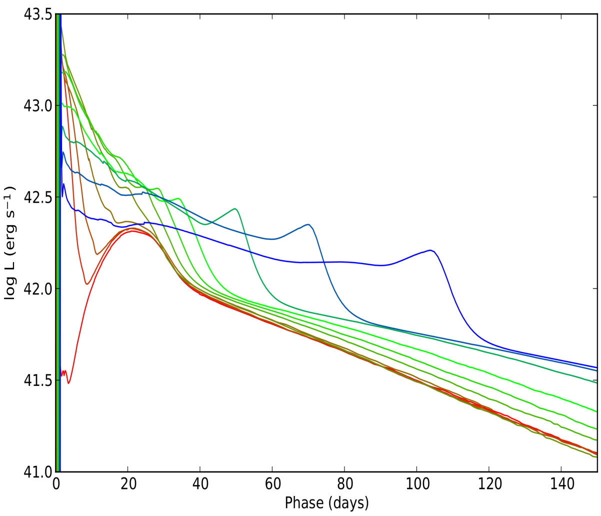

Fig 1: Bolometric lightcurves calculated with HYDE for a 15 solar mass star gradually stripped off its hydrogen envelope (from Paper VI).

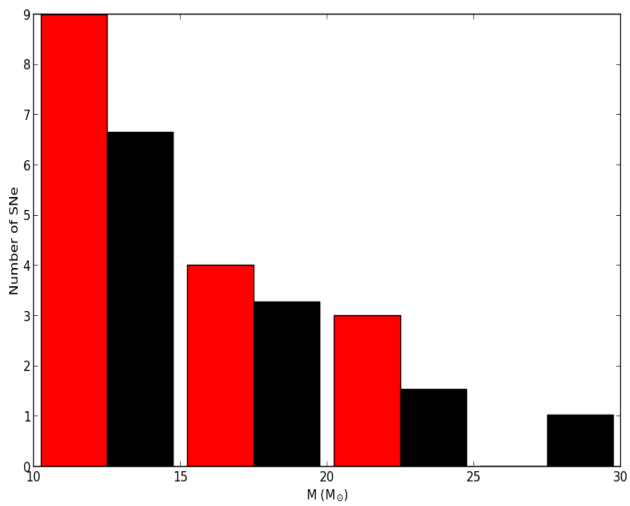

Fig 2 : Initial masses for a sample of Type IIb SNe (red) determined by fits to the model grid, as compared to a standard Salpeter IMF (black) (from Paper VI).

Multi-method modelling

In Paper I-V hydrodynamical lightcurve modelling, nebular spectral modelling and stellar evolutionary progenitor analysis is used to determine the characteristics of the progenitor star for SN 2011dh, which gives a confidence in the obtained results otherwise not possible. Such investigations requires cooperation between scientists with different expertise, and during my PhD I have established a close collaboration with the Belfast group, in particular with Anders Jerkstrand, with respect to nebular spectral modelling, and Justyn Maund, with respect to progenitor analysis. Progenitor analysis and nebular spectral modelling have the advantage to provide estimates of the initial mass of the progenitor star, whereas hydrodynamical modelling (except for Type IIb SNe) can only well constrain the ejecta mass. Progenitor detections is only possible in nearby galaxies, whereas nebular spectral modelling is feasible for SNe at larger distances. This could be stretched further by using R-band photometry, as the flux of the OI 6300,6364 Å line, which is very sensitive to the initial mass of the progenitor stars, falls within this band. A range of possibilities to directly couple the hydrodynamical modelling with nebular spectral modelling also exist. For example, in Paper IV a bolometric correction determined with nebular spectral modelling was used to fit the observed <400 days optical to MIR pseudo-bolometric lightcurve of SN 2011dh to the hydrodynamical model grid.

Type Ib SNe.

In order to model Type Ib SNe the hydrodynamical model grid need to be expanded with a parameter for the helium envelope mass. Such an expanded grid could be used to model the entire literature sample of Type Ib SNe. Given the recently published Modjazz et al. (2014), Bianco et al. (2014) and Sako et al. (2014) this sample consists of ~35 SNe, although some of these would likely need to be excluded due to poor quality. Previous sample studies exist (e.g. Lyman et al. 20114 and Taddia et al. 2014), but these are based on approximate modelling and smaller samples. There will probably be a strong degeneracy between the CO core and helium envelope masses, so that only the ejecta mass, and not the initial mass, can be well constrained, which should be kept in mind. To improve on this the work could be coordinated with modelling of nebular spectra or R-band photometry, for the SNe where such observations are available.

Type IIL SNe and SN 2009kr.

In order to model Type IIL SNe the hydrodynamical model grid needs to be expanded with parameters for the hydrogen envelope mass and helium abundance (see Swartz et al. 1991). I have reduced a high quality dataset for the Type IIL SN 2009kr which could provide a starting point for this work. Potentially it could result in two papers, one investigating Type IIL SNe lightcurves in general, and one aimed at SN 2009kr specifically. The SN 2009kr dataset includes nebular spectra, so in this case nebular spectral modelling could strengthen the conclusions obtained from the hydrodynamical modelling. A progenitor candidate for SN 2009kr was identified by Fraser et al. (2010) and Elias-Rosa et al. (2010), but the identification have not (yet) been confirmed by its disappearance.

The hydrogen envelopes of Type IIb SNe

As mentioned the hydrodynamical model grid used to model Type IIb SNe in Paper IV and VI is based on bare helium core models, and the characteristics of the hydrogen envelope can not be determined. To improve the grid in this respect the hydrogen envelope needs to be parametrized with its mass and helium abundance. As discussed in Paper VI the addition of a hydrogen envelope to the models could also improve the reliability of the derived explosion energy. A systematic study of Type IIb SNe hydrogen envelopes have not been published before and cold provide further clues on their binary or single star origin. Spectral Monte-Carlo modelling (see Paper II) of the H-alpha line could also be used to further constrain the results.

Mixing of the nickel in Type IIb SNe

In Paper IV mixing of the nickel to high velocities was found to be required to fit the rise to peak luminosity for SN 2011dh, whereas the FeI line emitting region was estimated to have a radius of only ~1500 km/s. This apparent contradiction could be solved if a small fraction of high-velocity nickel is sufficient to reproduce the lightcurve, but to investigate this a more elaborate parametrization of the distribution of the nickel is required. In Paper VI mixing of the nickel to high velocities is found to be required for most of the SNe in the Type IIb sample, which motivates a further investigation of the range of nickel distributions that could reproduce the lightcurves.