A study of low-energy Type II supernovae

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Introduction

All stars with an initial mass greater than 8 $M_{\odot}$, but not massive enough to encounter the pair-production instability, eventually form a degenerate core and collapse into a compact object, either a neutron star or a black hole. At the lower mass end, these massive stars die as red supergiant stars (RSG) with large amount of hydrogen and give rise to Type II supernovae (SNe II). The diversity of observed properties of SNe II suggests a range of progenitor masses, radii and explosion energies. We have performed a large grid of simulations designed to cover this range of progenitor and explosion properties. Using `MESA STAR`, we compute a set of massive star models (12–30 $M_{\odot}$) from the main sequence until core collapse. We then generate explosions with `V1D` to produce ejecta within a range of explosion energies. Finally, all ejecta are evolved with `CMFGEN` to generate multi-band light curves and spectra. The goal is to understand the origin of the observed diversity of SNe II.

SN data set

Low-energy Type II-Plateau (II-P) SNe are on average 2 magnitudes fainter during the plateau phase than the normal SNe II-P (i.e. absolute magnitude is $\sim -15^{m}$ instead of $\sim -17^{m}$), they have low expansion velocities.

Low-energy Type II SNe could arise from high-mass ($\sim$20–25 $M_{\odot}$) [1, 2, 3] or low-mass ($\sim$7–9 $M_{\odot}$) [4, 5] progenitors. The data for most of SNe are taken from [6, 7].

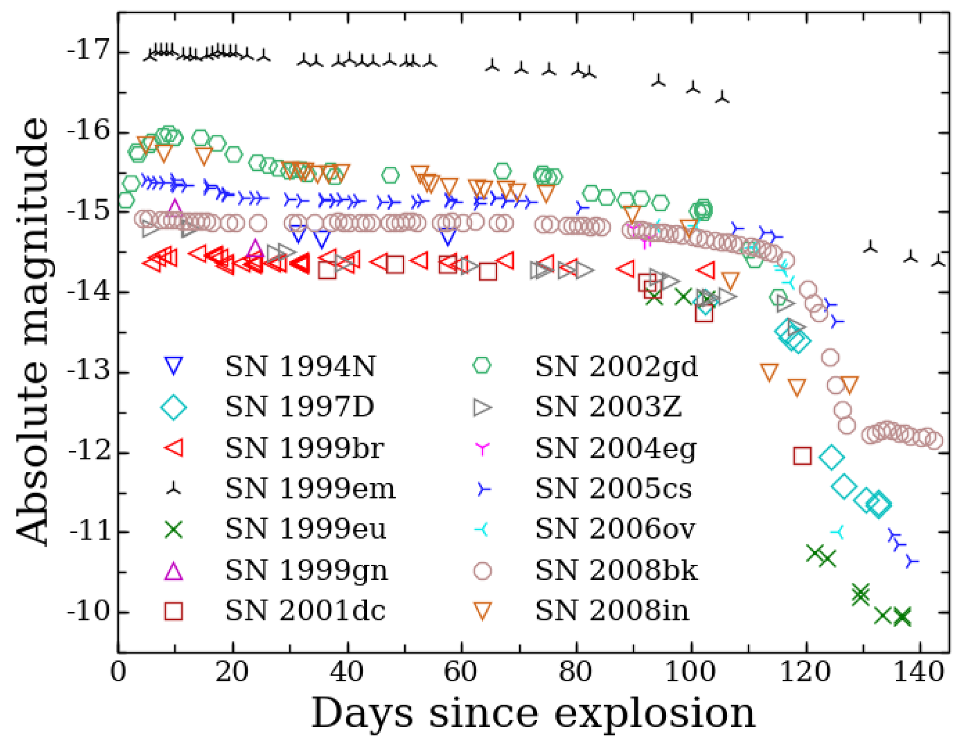

Figure 1: Light curves for low-energy Type II supernovae and comparison with Type II SN 1999em [13].

A comparison between models and data

The `CMFGEN` code [8, 9, 10, 11] computes the evolution of the ejecta and radiation properties at all depths within 10 to 300 days. A by-product of this is the emergent flux, which can be also used to compute multi-band light curves.

Model names have the following structure: m12 stands for 12 $M_{\odot}$, last letter stands for the explosion energy: `t` corresponds to 0.3 B, `z` to 0.6 B, `y` to 0.9 B, `x` to 1.2 B, where 1 B (Bethe) $= 10^{51}$ ergs. We have calculated models for 12, 14, 16, 18, 20, 25 and 27 $M_{\odot}$, with different explosion energies. All the models have solar metallicity.

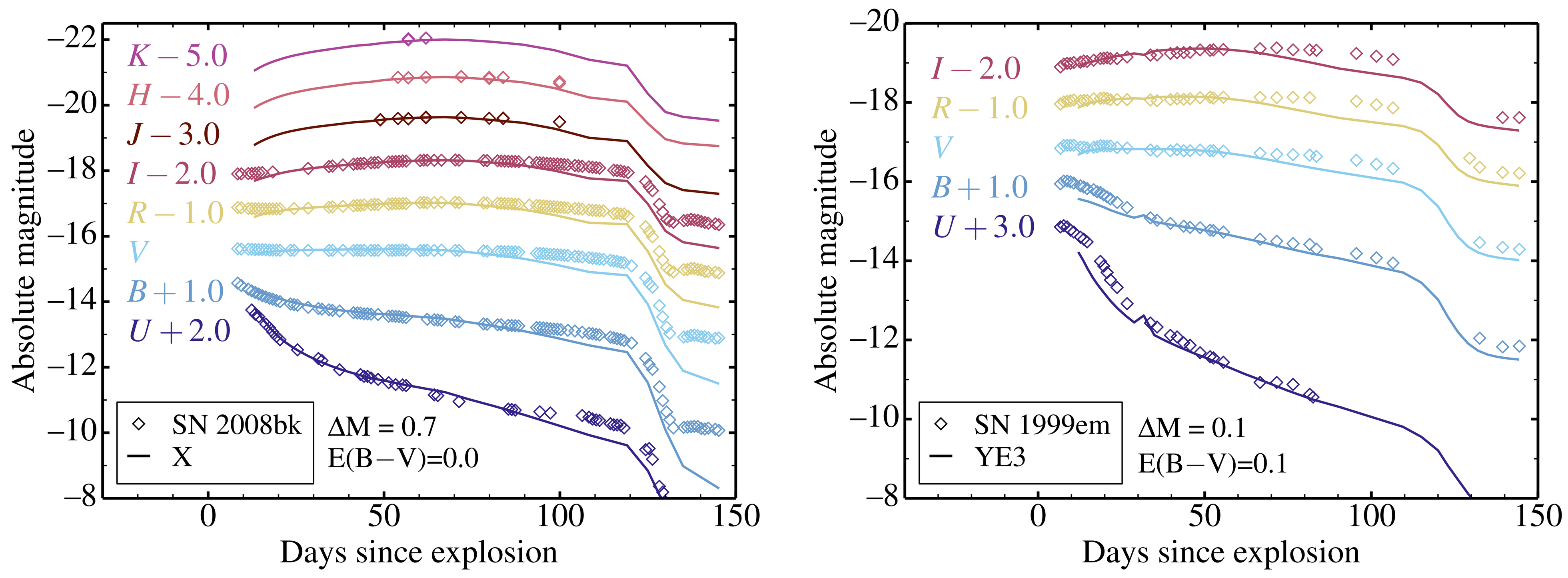

Figure 2: Comparison between models and data multi-band light curves. Left: SN 2008bk [12] is compared with the model X (12 $M_{\odot}$ progenitor, 0.25 $\times 10^{51}$ ergs explosion). Right: SN 1999em [13] is compared with the model YE3 (12 $M_{\odot}$ progenitor, 1.2 $\times 10^{51}$ ergs explosion).

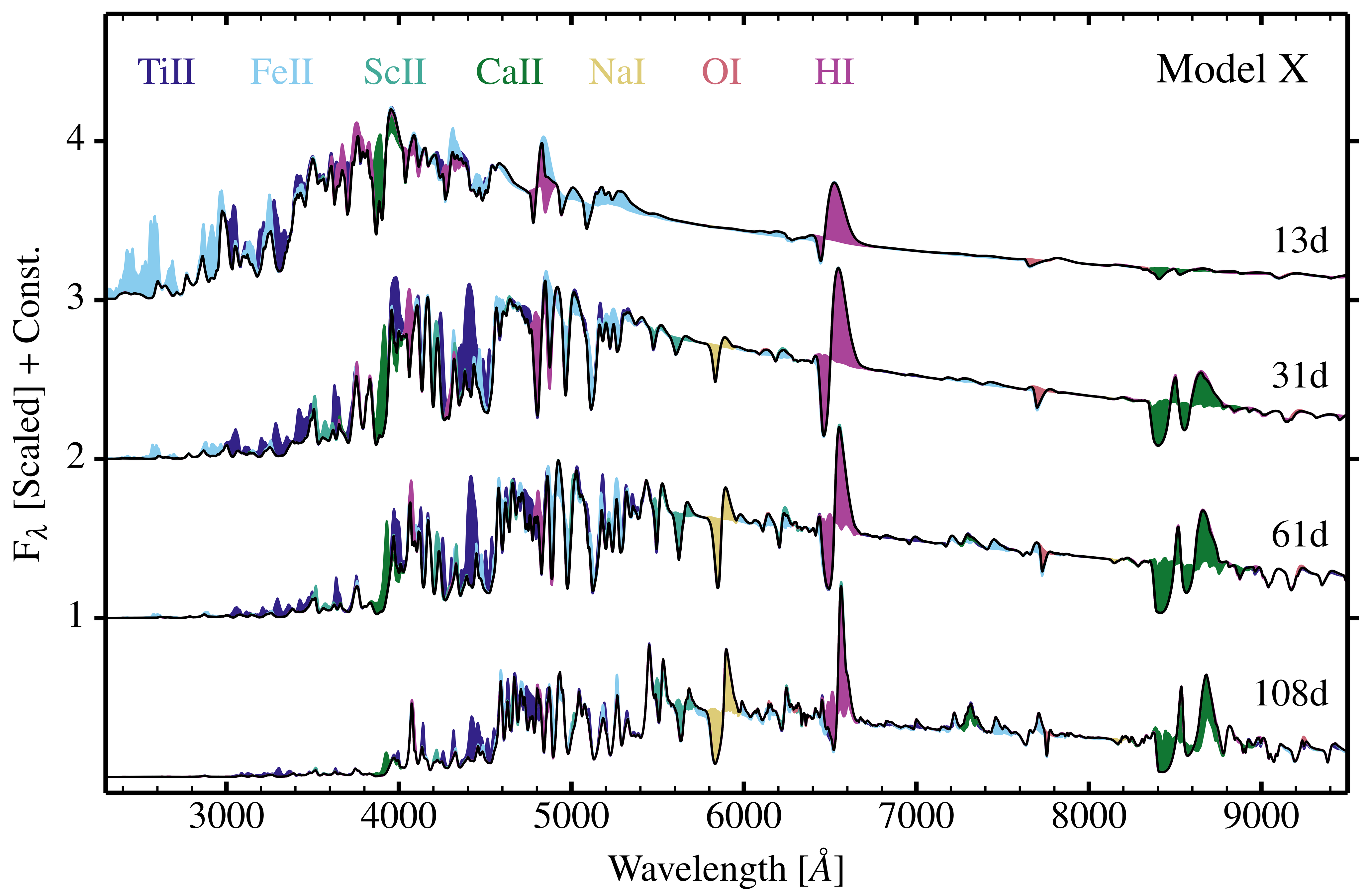

Figure 3: Left: we show the contributions from individual ions by omitting their bound-bound transitions in the formal solution of the radiative-transfer equation.

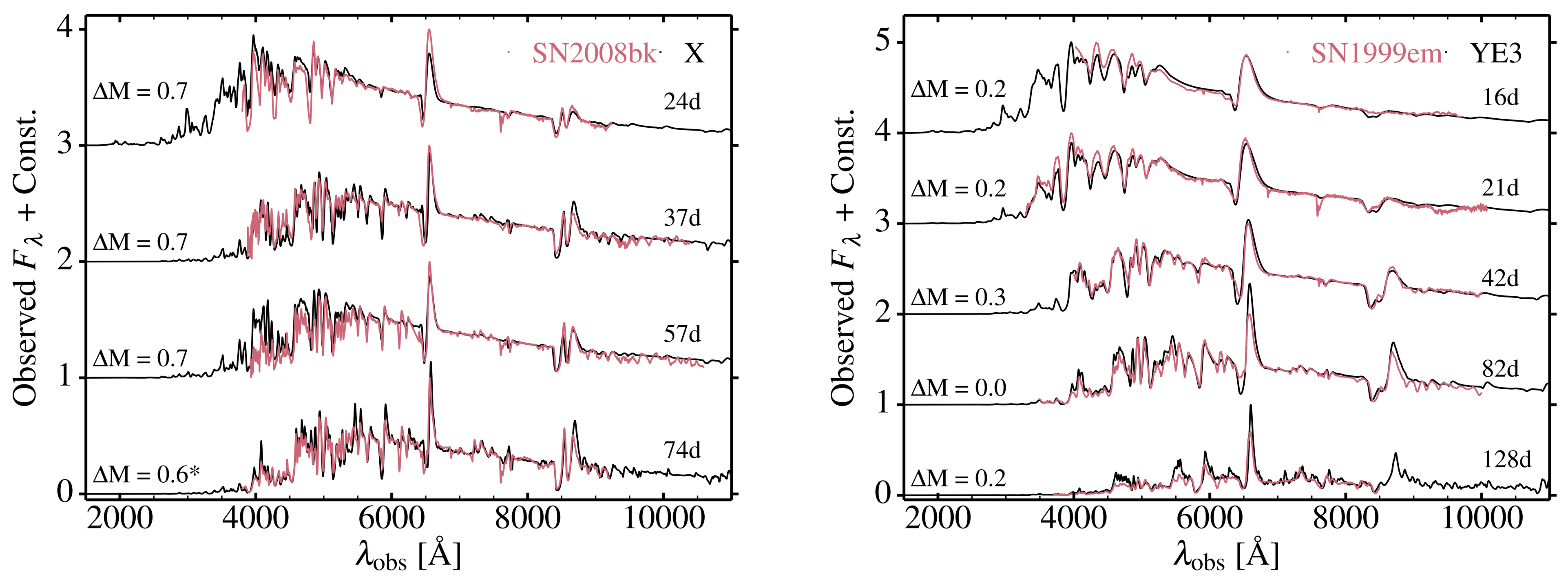

Figure 4: Left: spectra of SN 2008bk and model X. Right: spectra of SN 1999em and model YE3.

Conclusions. One of the key question is whether we can distinguish a low-energy explosion of a low-mass RSG and a high-mass RSG. Spectra of low-energy explosions have narrow lines, this type of objects is a good subject to exploration. Our model spectra fit the observational spectra closely, and all lines are predicted by the code during the plateau phase.

References

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