Unburned Material in the Ejecta of SNe Ia

G. Folatelli (U. de Chile) on behalf of the MCSS and CSP
gaston@das.uchile.cl

Introduction

The detection of unburned material and its radial location in the ejecta of Type Ia supernovae (SNe Ia) play a critical role in our understanding of the explosion process. While pure deflagration models [6] predict substantial amounts of unburned C and O in the outermost ejecta (with pockets of this material mixed downward in 3-dimensional models [3, 7]), delayed-detonation models [4] predict washed-out inhomogeneities and very little unburned material present at the surface. We have searched for signatures of C II features in a large sample of pre-maximum spectra of SNe Ia with the aim of assessing how often unprocessed material is present and how it is distributed.

Data Sample

The Carnegie Supernova Project (CSP) and the Millennium Center for Supernova Science (MCSS) obtained over 500 spectra of about 90 SNe Ia between 2004 and 2009. We have selected the earliest observations: a sample of 70 spectra of 33 SNe Ia obtained before 3 days prior to B-band maximum light.

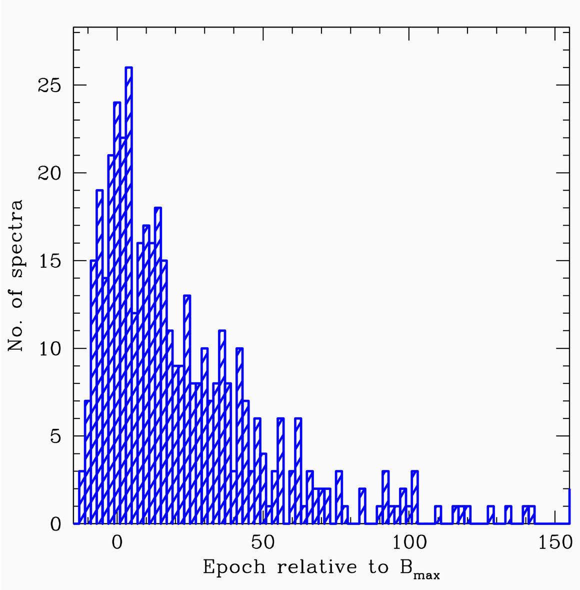

Fig. 1: Distribution of phases relative to B-band maximum light for the CSP/MCSS sample.

Carbon Detection

An absorption at ≈6300 Å present in some pre-maximum spectra may be due to C II λ6580. Other C II lines should be too faint to be clearly identified.

According to simplified models in the Sobolev approximation (**Fig. 2**) carbon would appear slightly detached above the photosphere by ≈1000 km s^{-1}, although a definitive identification would require more detailed models including non-LTE effects.

The 6300 Å absorption may also be due to hydrogen near the photosphere, but this is unlikely in SNe Ia.
The absorption may be due to clumps of unburned material mixed into the ejecta, as predicted by 3-D deflagration models [3, 7].

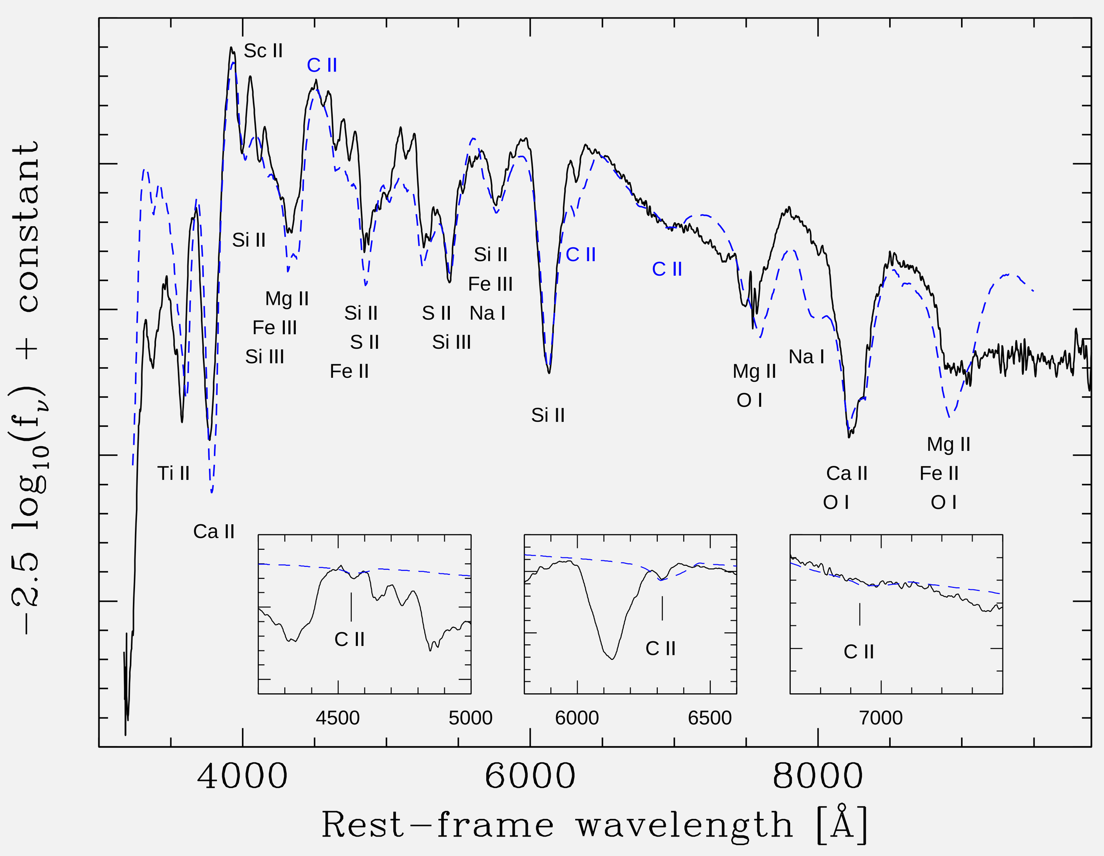

Fig. 2: SYNOW [1] model (**dashed blue**) of the spectrum of SN 2006D at −6 days (**black**). The insets show a carbon-only synthetic spectrum at the location of the C II lines.

A weak absorption at ≈6300 Å which is probably due to C II λ6580 can be seen in 11 out of 33 SNe (**Fig. 3**). In other cases the feature may be lost in the noise or washed out by the P-Cygni emission from Si II λ6355. If confirmed, this would be an unexpectedly large fraction SNe Ia with carbon [5, 8]

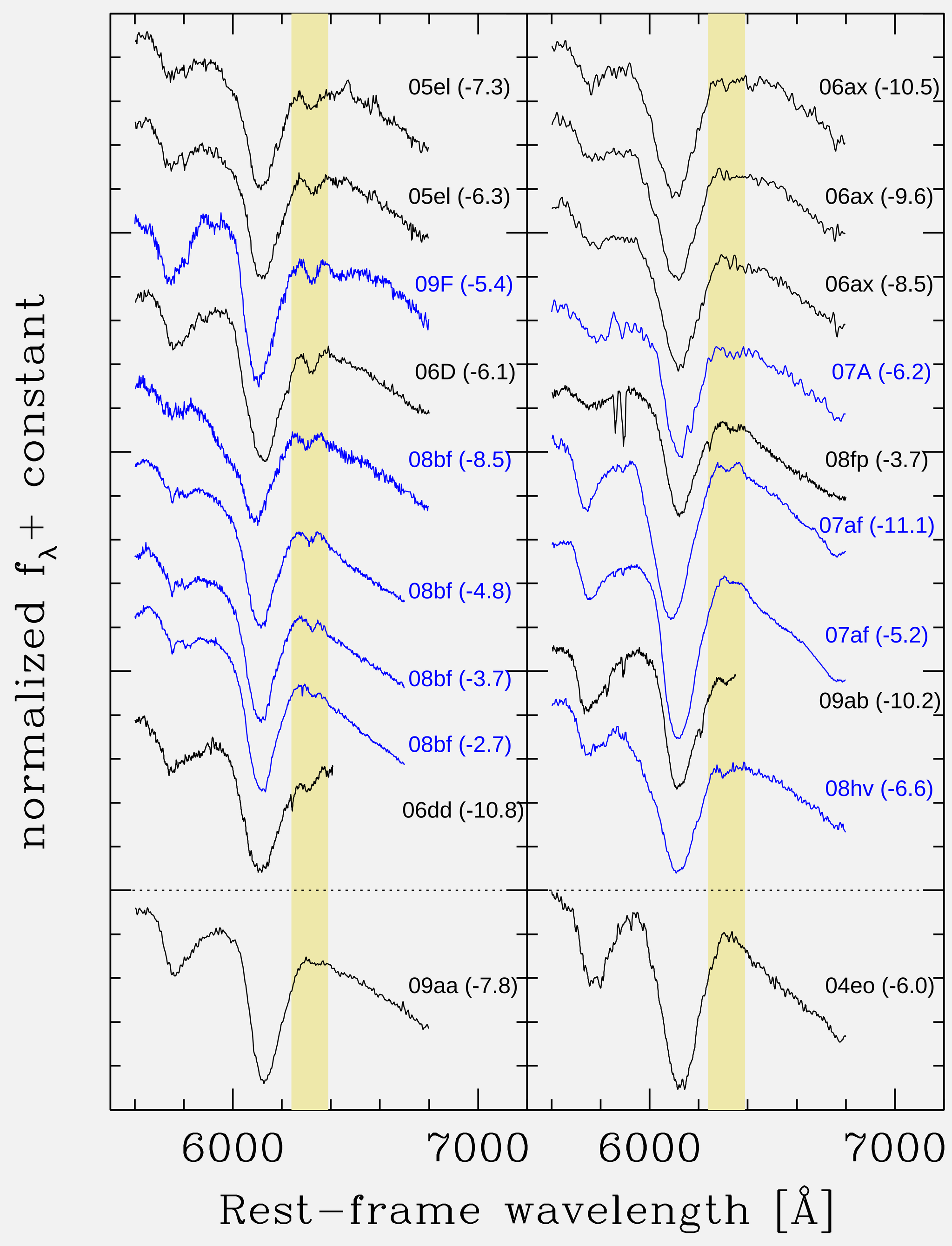

Fig. 3: Pre-maximum spectra of 11 SNe Ia showing C II λ6580 absorptions (**upper panels**). Two examples of non-detections are also shown (**lower panels**). The colored bands mark the position of the C II λ6580 for expansion velocities between 9,000 and 15,000 km s^{-1}.

Photometric Properties

SNe with C II show a wide range of decline rates, consistent with the complete sample and including one fast-declining object (SN 2009F) with $\Delta m_{15}(B) = 1.7$ (**Fig. 4**).

Although the sample is small, there is a trend toward faint SNe, with respect to the best-fit Hubble Law [2] (**Fig. 5**).

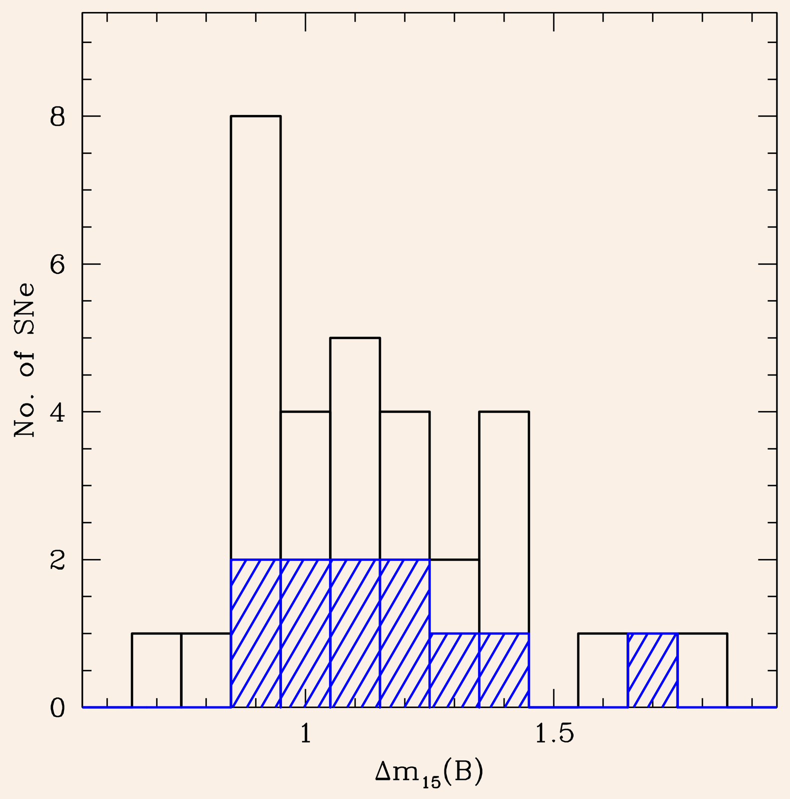

Fig. 4: Distribution of decline rates $\Delta m_{15}(B)$ for the 33 SNe Ia (**black**) and the SNe with C II detections (**blue**).

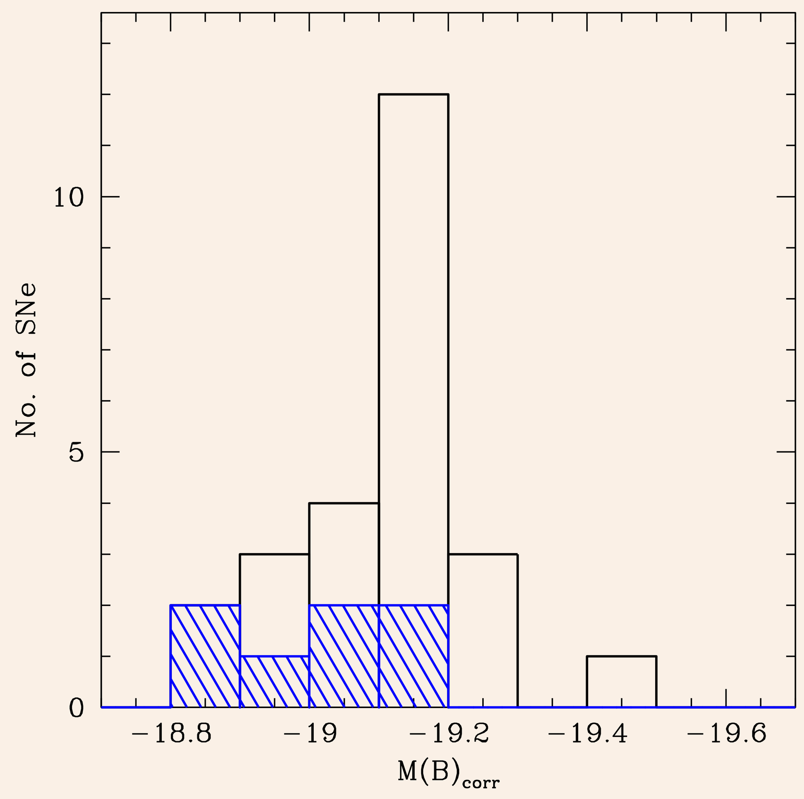

Fig. 5: Distribution of absolute peak magnitudes in B after correcting for decline rate and color. Colors as in **Fig. 4**.

Line Velocities

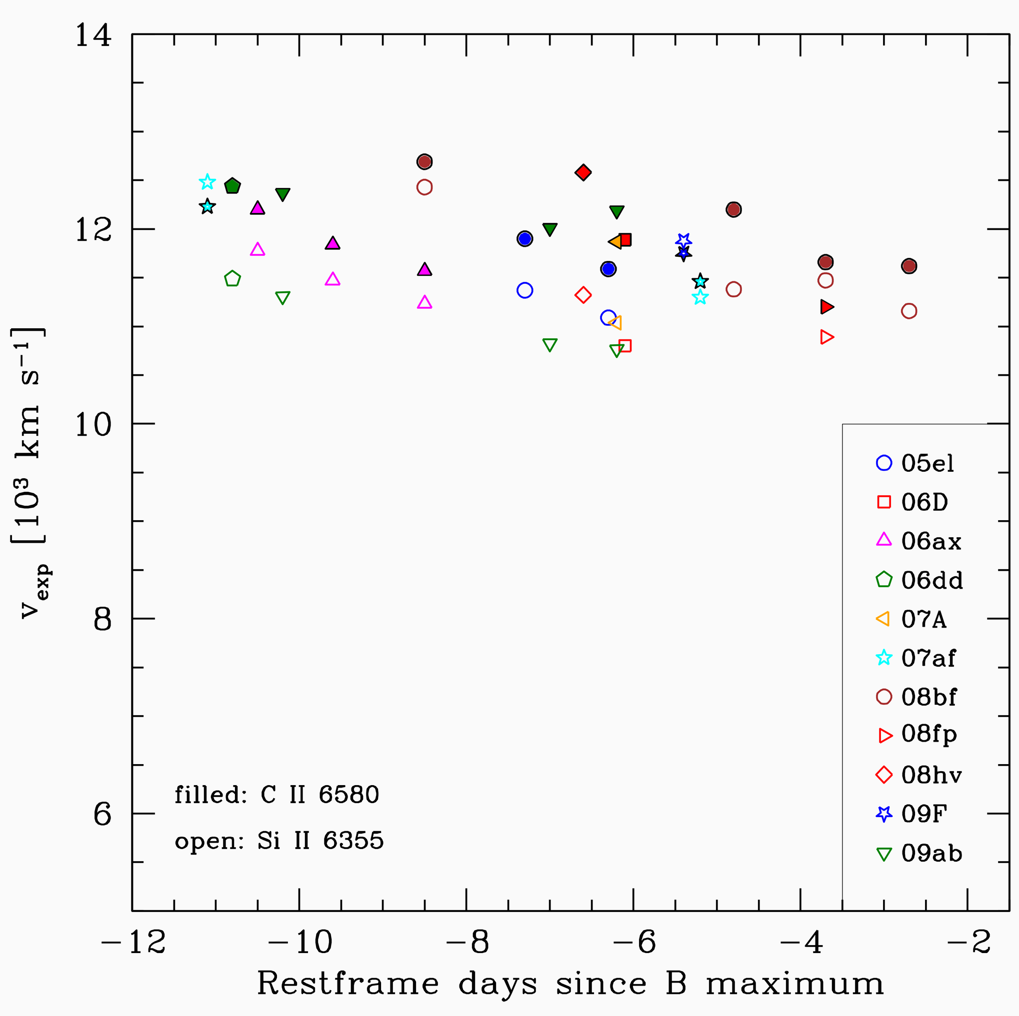

Fig. 6: C II λ6580 and Si II λ6355 expansion velocities as a function of the SN phase.

(**Fig. 6**) *If the absorption is due to C II λ6580*, carbon appears only up to 1500 km s^{-1} above the silicon layer and always below 13000 km s^{-1}.

Pseudo Equivalent Widths

(**Fig. 7**) The strength of the detection is represented by the *pseudo* equivalent width of the absorption relative to the surrounding flux. The feature weakens with time.

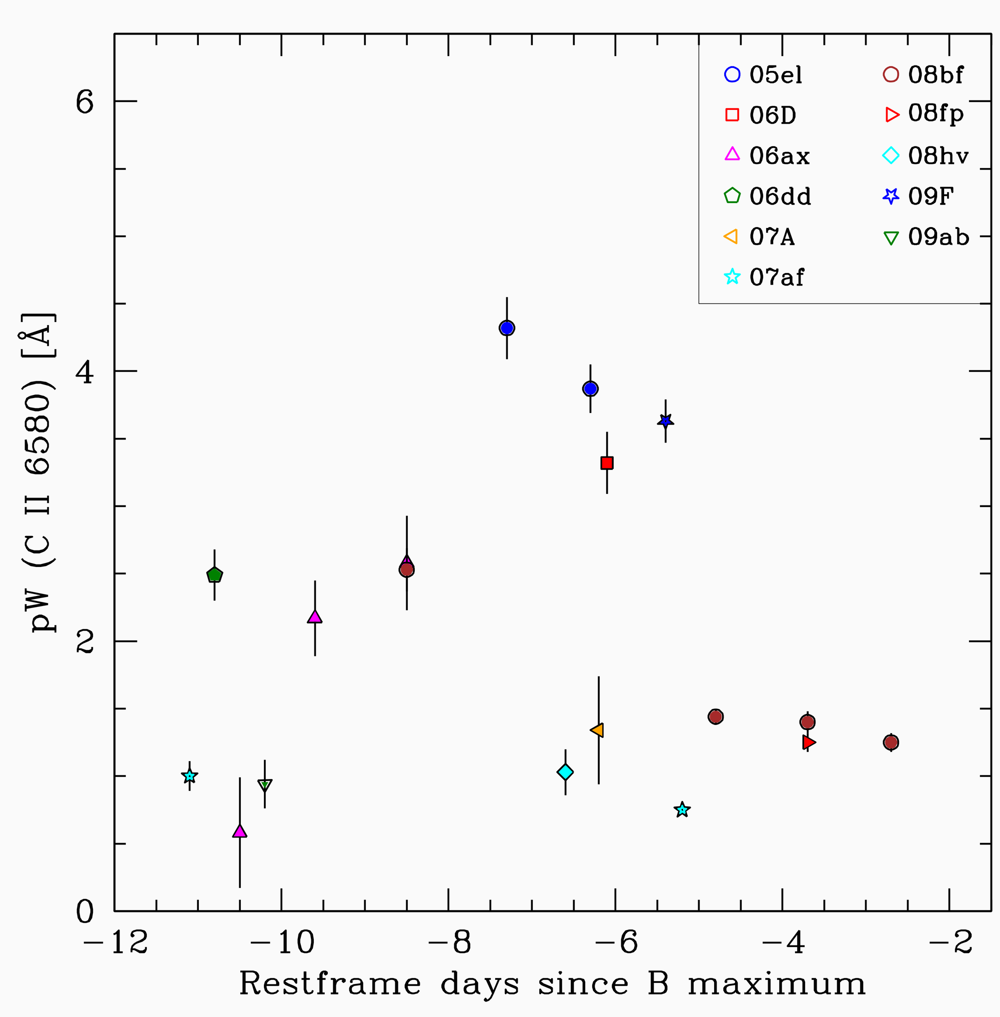

Fig. 7: Evolution of the C II λ6580 pseudo equivalent widths.

Conclusions

At least one third if the SNe Ia from a homogeneous sample show an absorption which could be identified with C II λ6580 in spectra obtained between 11 and 3 days before B-band maximum light.
These SNe show a wide range of decline rates ($0.85 < \Delta m_{15}(B) < 1.75$) and a possible trend toward positive (faint) Hubble residuals.
If carbon is present, it appears detached from the photosphere by ≈1000 km s^{-1} and between 11,000 and 13,000 km s^{-1}.
Such low velocities would be in agreement with 3-D deflagration models.

References

[1] Branch, D., et al. 2003, AJ, 126, 1489
[2] Folatelli, G., et al. 2010, AJ, 139, 20
[3] Gamezo, V. N., et al. 2003, Science, 299, 77
[4] Khokhlov, A. 1991, A&A, 245, 114
[5] Marion, G. H., et al. 2006, ApJ, 645, 1392
[6] Nomoto, K., et al. 1984, ApJ, 286, 644
[7] Röpke, F. K. & Hillebrandt, W. 2005, A&A, 431, 635
[8] Thomas, R. C., et al. 2007, ApJL, 654, 53