Type Ia Supernova Spectra from the CfA Supernova Program

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Since 1994, the CfA supernova group has obtained ∼2400 optical spectra of ∼450 low-redshift ($z \lesssim 0.05$) Type Ia supernovae (SN Ia) with the 1.5 m Tillinghast telescope at the Fred Lawrence Whipple Observatory (FLWO; Mount Hopkins, AZ) using the FAST spectrograph. The uniformity of this large data set represents a key asset to study the spectroscopic properties of SNe Ia and their variation with physical parameters (e.g. peak luminosity). Here we present some results based on studies of Si II λ6355 line-profile morphology and its connection to peak luminosity. We also present recently-published results on the nature of Na I D variability in SN Ia spectra.

Spectroscopic Data

The majority of the spectra presented here were obtained with the 1.5 m Tillinghast telescope at FLWO using the FAST spectrograph. The setup used yields a resolution of ∼7 Å, with a wavelength range of ∼3500 to ∼7400 Å (**Fig. 1**). Several spectra were published in studies of specific supernovae, while 432 spectra of 32 SNe Ia have recently been published by Matheson et al. (2008). We also have complementary multi-band optical photometry for most objects (e.g., Hicken et al. 2009). All published data are available via the CfA Supernova Archive (see *References*).

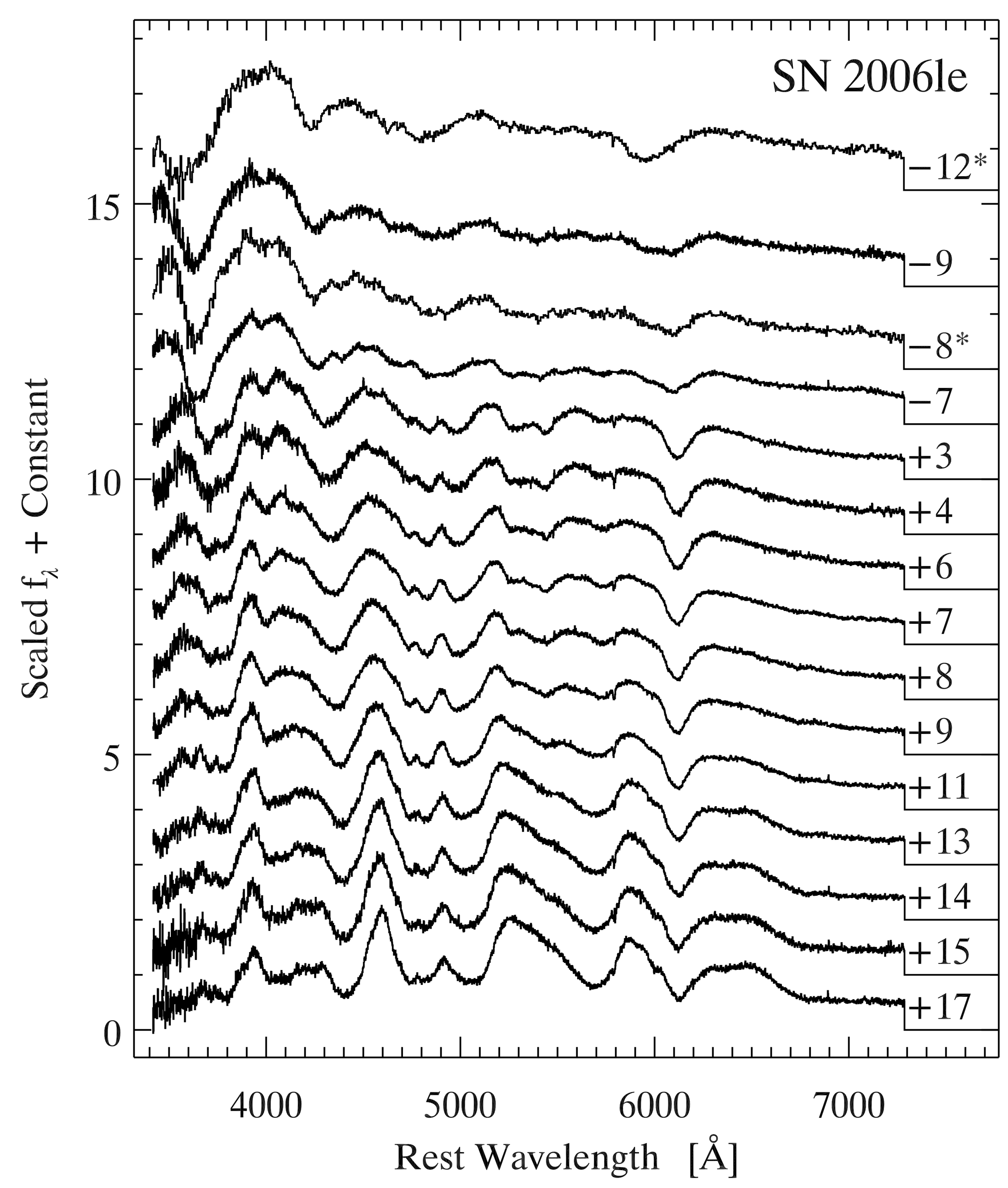

Fig. 1: Early-time spectra of the Type Ia SN 2006le. The age of each spectrum (in days from B-band maximum) is indicated. The horizontal line extending to the right corresponds to the zero-flux level of each spectrum.

Line-profile Morphology

In **Fig. 2** we show the time-evolution of the velocity at maximum absorption ($v_{\rm abs}$) of the Si II λ6355 line, for all the SNe Ia in our sample in the age range $-15 \leq t \leq +25$ d. The points are color-coded according to the MLCS17 light-curve shape parameter Δ as determined by Hicken et al. (2009). Intrinsically fainter SNe Ia have larger values of Δ, and appear to form a sequence at smaller $|v_{\rm abs}|$, as expected from an explosion with lower kinetic energy.

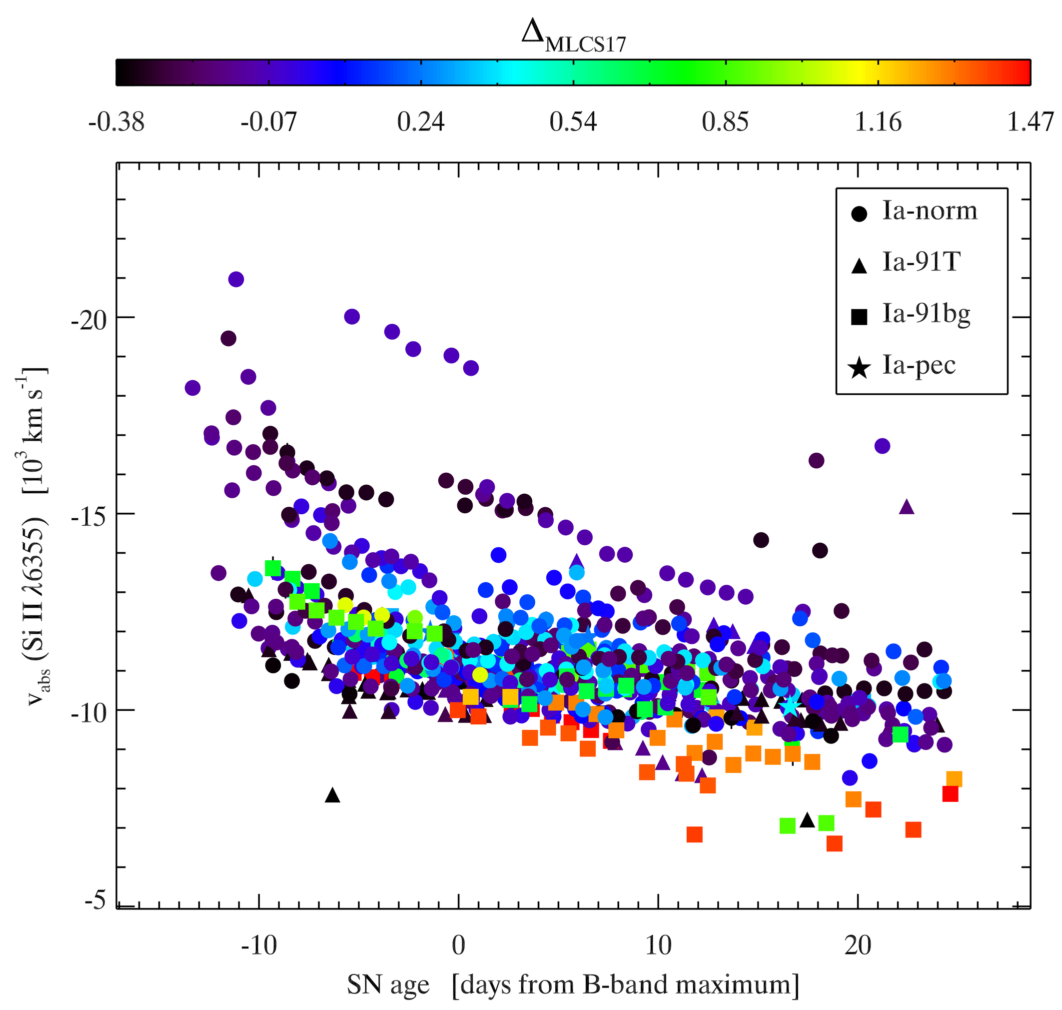

Fig. 2: Time-evolution of the velocity at maximum absorption ($v_{\rm abs}$) of the Si II λ6355 line for all the SNe Ia in our sample.

A closer look at the variation of $v_{\rm abs}$ at maximum light with Δ (**Fig. 3**, *top*) shows that optical-depth effects are also at play. The intrinsically faint 91bg-like SNe Ia (*red squares*) indeed display lower $|v_{\rm abs}|$ values on average, but so do the intrinsically bright 91T-like SNe Ia (*blue triangles*). The Si II λ6355 line is usually weaker in these objects, hence the location of maximum absorption is deeper down in the ejecta where the expansion velocities are lower. A similar trend emerges when considering the FWHM variation of this line with Δ at maximum light (**Fig. 3**, *bottom*).

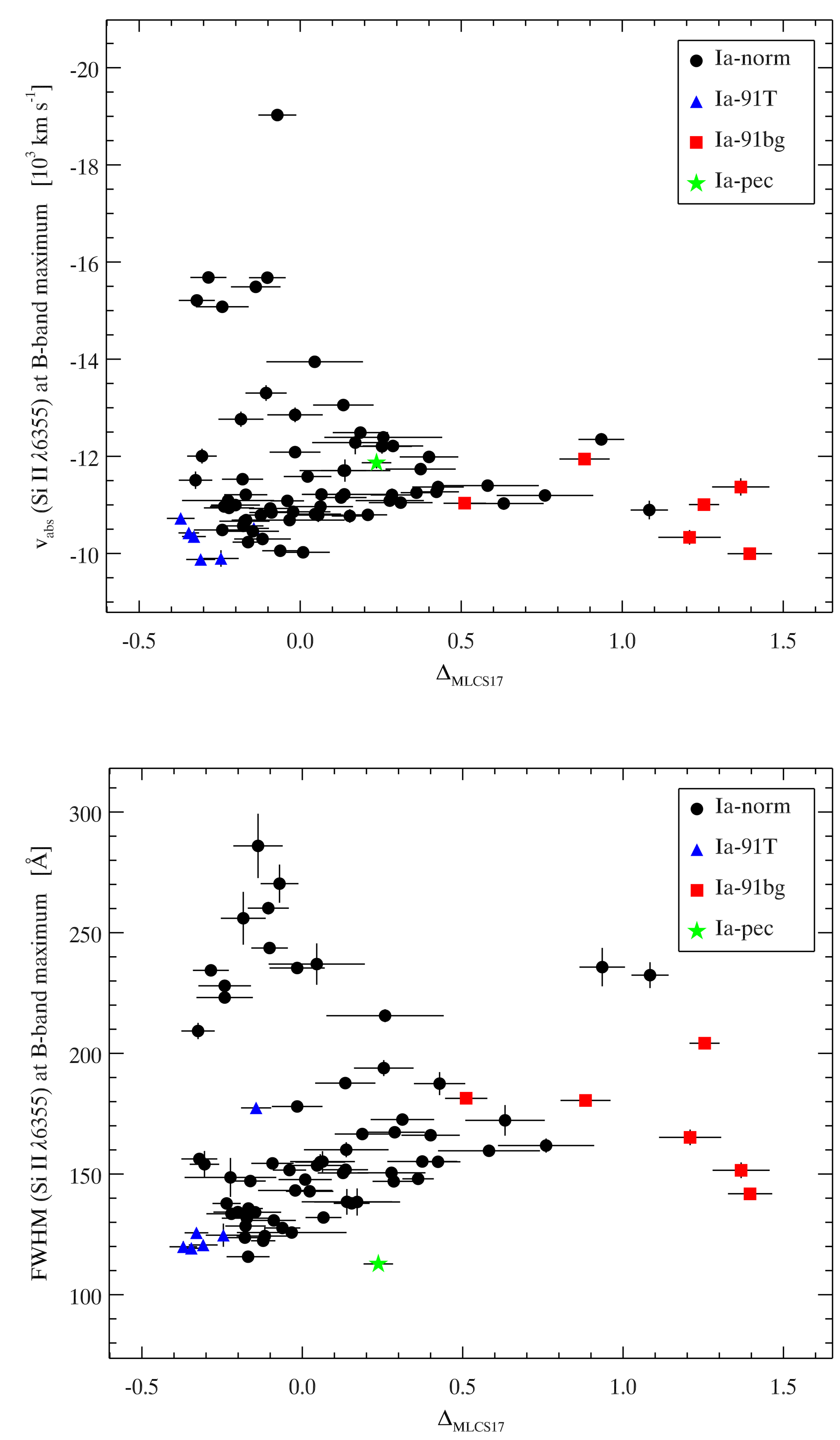

Fig. 3: Variation of $v_{\rm abs}$ (*top*) and FWHM (*bottom*) of the Si II λ6355 line at maximum light with the MLCS17 light-curve shape parameter Δ.

Variable Na I D Absorption

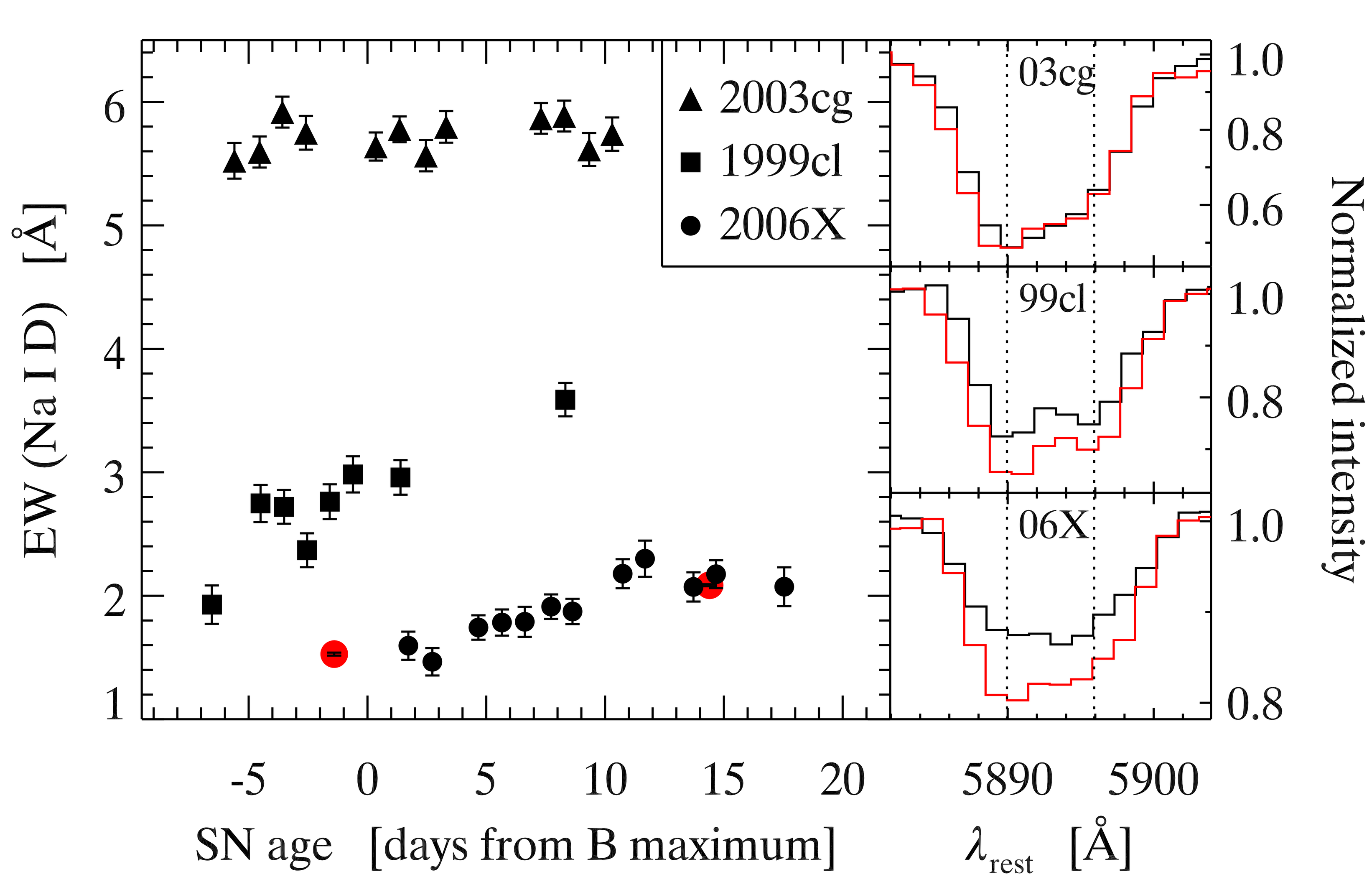

Fig. 4: *Left:* Time-evolution of the equivalent width of the Na I D doublet for the three most highly-reddened SNe Ia in our sample: SNe 2003cg (*filled triangles*), 1999cl (*filled squares*), and 2006X (*filled circles*). Both SNe 1999cl and 2006X exhibit a variable Na I D EW, while that of SN 2003cg remains constant over time. The larger filled circles at -2 d and +14 d correspond to EW measurements on high-resolution (FWHM ≈ 7 km s^{-1}, or ~ 0.14 Å, at Na I D) VLT+UVES spectra of SN 2006X published by Patat et al. (2007). *Right:* Normalized Na I D profiles for SN 2003cg (*top*), SN 1999cl (*middle*) and SN 2006X (*bottom*), plotted in rest-frame wavelength. The black and red lines correspond to the smallest and largest EW, respectively. Note the difference in ordinate range, decreasing from top to bottom. The vertical dotted lines indicate the wavelength positions of the individual D_1 and D_2 lines. *Figure taken from Blondin et al. (2009).*

Recent high-resolution spectra of the Type Ia SN 2006X have revealed the presence of time-variable and blueshifted Na I D features, interpreted by Patat et al. (2007) as originating in circumstellar material within the progenitor system. The variation seen in SN 2006X induces relatively large changes in the total Na I D equivalent width (ΔEW ~ 0.5 Å in just over two weeks), that would be detectable at lower resolutions. We have searched for variable Na I D features in the CfA spectroscopic data set. Out of the 31 SNe Ia (including SN 2006X) in which we could have detected similar EW variations, only one other (SN 1999cl) shows variable Na I D features, with an even larger change over a similar ~ 10-day timescale (ΔEW $= 1.66 \pm 0.21$ Å; **Fig. 4**).

Interestingly, both SN 1999cl and SN 2006X are the two most highly-reddened objects in our sample, raising the possibility that the variability is connected to dusty environments. This interpretation has also been put into question with the recent discovery of variable Na I D features in the low-extinction SN 2007le (Simon et al. 2009).

References

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