Newly Defined Spectral Quantities Characterizing Type Ia Supernovae: Correlations with Peak Luminosity

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Abstract

A novel method for quantitatively analysing spectra of Type Ia supernovae (SNe Ia) based on measurements similar to equivalent widths (EW) is introduced. This empirical method is motivated by the observation that different subtypes of SNe Ia generally show absorption features of different strengths. The EW's provide a measure of those absorption strengths. Their analysis was applied to a set of 166 spectra of nearby SNe ($z < 0.15$) and 13 spectra of high-z SNe ($0.21 < z < 0.91$) with the following goals:

- Provide a way to measure SN Ia spectral evolution with phase.
- Study the degree of homogeneity among SNe Ia.
- Search for spectral calibrators to further sharpen the standard candle properties of SNe Ia.
- Address the issue of spectral evolution with redshift.

Data Sets

Low-z SNe:

13 SNe from the *SCP* Spring '99 Nearby Supernova Campaign [1, 9].
8 well-observed SNe from the literature [2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13].
A total of 166 low-resolution, optical spectra.
$-15\,\mathrm{d} < \mathrm{epoch} < +60\,\mathrm{d}$
$z < 0.149$

High-z SNe:

12 SNe discovered by the *SCP* between 2000 and 2002.
A total of 13 low-resolution, optical spectra.
12 spectra at $-8\,\mathrm{d} < \mathrm{epoch} < +10\,\mathrm{d}$
1 spectrum at $+29.5\,\mathrm{d}$
$0.212 < z < 0.912$

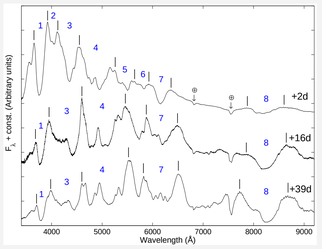
Data Treatment:

The spectra were reduced with special care in the estimation of observational uncertainties. Residual host-galaxy contamination was corrected through a statistically robust subtraction and fitting method.

Feature Definitions

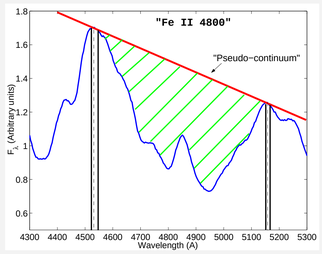
Based on the typical shape of near-maximum light spectra of SNe Ia, eight features are defined bounded by local flux peaks. They are given the following *mnemonic* names:

1 – "Ca II H&K"
2 – "Si II 4000"
3 – "Mg II 4300"
4 – "Fe II 4800"
5 – "S II W"
6 – "Si II 5800"
7 – "Si II 6150"
8 – "Ca II IR"



This definitions are followed along lightcurve phase.

"Equivalent Widths" (EW)



A *pseudo-continuum* (red line) is traced between bounding peaks.

The spectrum is divided by the pseudo-continuum, and the resulting area (hashed in green) is computed.

Thus defined, the EW's are distance-independent

Spectral Time Evolution and Homogeneity

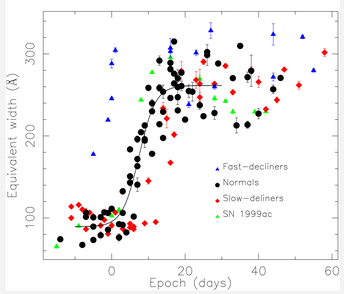
Though empirical, EW's are consistently measured, which allows a comparative analysis of their time evolution. The degree of homogeneity among SNe Ia and the deviation of peculiar objects from normal ones can thus be quantified.

In general, SNe with faster lightcurve evolution show higher EW values, and viceversa.

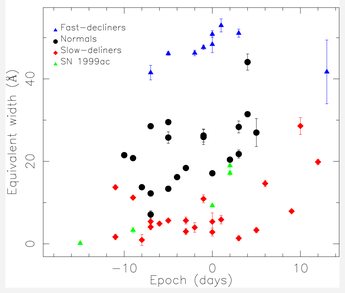
Normal SNe Ia show a remarkable homogeneity for features # 3, 4, 7 and 8. Average evolution curves can be given in those cases.

Examples:

"Mg II 4300"



"Si II 5800"

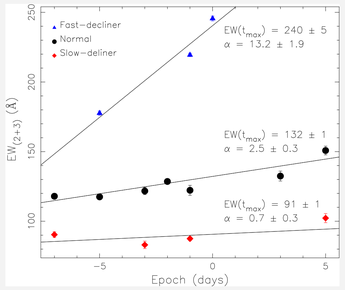


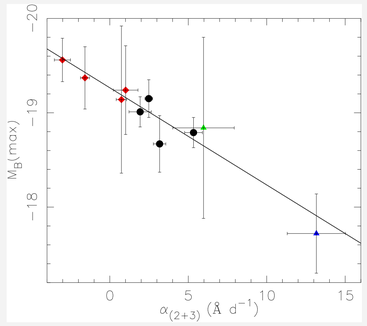
Correlations with Peak Luminosity

EW's provide spectral parameters that may further sharpen the standard candle properties of SNe Ia.

For instance, the EW at the time of B-band maximum light ($\mathrm{EW}^{t_{\max}}$) and the slope (α) of the EW evolution around that epoch, computed for sums of features in various combinations.

The example of the sum of features # 2 and 3 is presented.





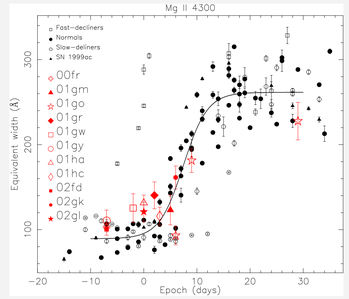
The correlation between B-band absolute peak magnitude $M_B^{\max}$ and $\alpha_{(2+3)}$ reduces the scatter in the former from 0.49 to 0.14 mag for a sample of 10 SNe Ia, including peculiar objects.

This correlation needs confirmation from a larger data set, for instance of SNe in the Hubble flow.

Application to High-z SNe

The sample of high-z spectra cover roughly between features # 1 and 5. EW measurements can cope with the low signal-to-noise ratios of this sample since an integration over many wavelength bins is performed.

The hypothesis of evolution with redshift can be tested through a robust quantitative comparison between low- and high-z samples. See the poster by Garavini *et al* for a more detailed analysis.



Possible Systematic Effects

A number of possible systematic effects on the EW measurements were tested:

Spectral resolution

It affects the height of flux peaks and thus the pseudo-continuum trace. For SN spectra, with broadened features, the resolution of the present spectra sample produces no significant effects.

Reddening

It affects the overall slope of the spectrum. Since the features cover up to a few hundred Å, this effect proves to be negligible for absorptions below $A_V = 1$ mag.

Noise

This can also affect the position of flux peaks that define the pseudo-continuum. The effect proves to be negligible for signal-to-noise ratios above 3 – 5 per 3 Å resolution element.

Host-galaxy contamination

This can be the most important effect, especially at high redshift where SN and host are not well resolved. Residual flux from the host galaxy would lower the measured EW's. The spectra in the present sample that showed contamination were corrected with an accuracy in the contamination level of 5% for the low-z, and 10% for the high-z sample. These uncertainties were added to the measurement errors. This effect is less likely to affect the slope parameters α.

Conclusions

- Spectral time evolution and the degree of homogeneity among SNe Ia was quantified through measurements similar to equivalent widths.
- Average evolutionary curves were given for some of the spectral features defined.
- Correlations between peak luminosity and spectral parameters were searched. The example of the slope parameter $\alpha_{(2+3)}$, which reduces the scatter in $M_B^{\max}$ to 0.14 mag for a sample of 10 SNe was presented.
- The measurements were applied to spectra of high-z SNe Ia with the goal of robustly testing possible traces of evolution with redshift.

References

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