Diversity of Type Ia Supernovae in the Intermediate Redshift

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ABSTRACT

We obtained observed optical spectra of 59 normal SNe Ia with Subaru/FOCAS as a followup program of SDSS-II Supernova Survey. We derived lightcurve parameters (x_1 and c_{salt}) by using SALT2 and spectroscopic parameters (*vabs* and *EW*). Correlating these parameters, for the first time, we find that x_1 is the best correlated with *vabs* of "SiII 4130". We also find that c_{salt} is the best correlated with EW of "Fe 4800" but more data are needed to verify this relation.

These findings suggest that one spectrum per a SN Ia might be a substitute for multiple photometric observations to derive empirical correction of maximum brightness if it is taken around the time of maximum brightness. One could enable SN cosmology using correctly flux-calibrated spectra only.

A possible correlation of absorption feature(s) with the B-V excess c_{salt} might show that SNe Ia have the intrinsic color diversity. This makes the interpretation of observed color excess more complex.

Background

The observational spectroscopic diversity of SNe Ia has been investigated from many years ago (e.g. Branch et al. 1981). Exploring the observational diversity has been done by many researchers these days. Hachinger et al. (2006) presented correlations between a decline rate of lightcurves and a line velocity or an equivalent width of some optical absorption lines using nearby SNe Ia. On the other hand, Bronder et al. (2008) found another correlation using a subsample of high-z SNe Ia used for SN cosmology.

In spite of these various investigation, few of SNe Ia characteristics has been understood in the intermediate redshift range (z = 0.1 – 0.4) SNe Ia due to shortage of data (Coil et al. 2000; Balland et al. 2006, 2007).

Type Ia Supernova as "Standardizable" Candle

A Type Ia Supernova is one of the best candidates for the cosmological standard candle. However, it can not be used realistically for cosmology without corrections for peak brightness. Corrections have been made by using parameters derived from lightcurve fitting. One of such lightcurve fitters is SALT2 (Guy et al. 2007).

Lightcurve Fitting

Multi-band lightcurves were fitted by SALT2:

3 prameters for each SNIa

$$F(SN,p,\lambda) = x_0 \times [M_0(p,\lambda) + x_1 M_1(p,\lambda) + \ldots] \times \exp(c_{salt} CL(\lambda))$$

Average spectrum — 1st deviation — Average color law

where *p* is the rest frame time since the date of B-band maximum brightness m_B, x_0 the normalization of the SED, x_1 the first correcting factor of the deviation from the SED and *csalt* the color (B-V) offset from its average at *p* = 0. A corrected maximum brightness is derived as $m_B + \alpha x_1 - \beta c$. x_1 is related with lightcurve shape parameters. The variation of c_{salt} may be explained by the intrinsic color variation of SNe Ia and/or the dust extinction within host galaxy.

Candidate detections

SNe Ia candidates were searched by photometric observations of the Sloan Digital Sky Survey (SDSS) II Supernova Search (Frieman et al. 2008, Sako et al. 2008).

- redshift range 0.1 < z < 0.4
- 3 months (Sep - Nov) of 3 year (2005-2007)
- dense photometric observations: same field in every 2 nights
- 5-band (ugriz) lightcurves derived by scene modeling photometry (Holtzman et al. 2008), 3 (gri) of which were used for SALT2, since u and z-band photometry were not of as high quality as gri-band data.

Follow-up Spectroscopy

We acquired the telescope time in advance (PI:Yasuda). Receiving announcements from our identifier (M. Sako), we took spectra of those candidates with Subaru/FOCAS. A typical redshift of our data is 0.25. Optical observations of SNe Ia at these redshifts enables us to obtain spectra ranging from UV to "SiII6355" (characteristic line of SN Ia) features, over which more features can be examined.

■ Subaru/FOCAS parameters
- L600/SY47 (4000 - 9000 Ang) for 2005yr, L550/SY47 (3600 - 9000 Ang) for 2006yr
- 15 minutes exposure per a candidate
- 59 normal SNe Ia of 71 candidates
- 0.312 arcsec per pixel after readout (3 pix binned), 1.3 Ang/pix

The Subaru telescope made an excellent contribution to the spectroscopic follow-up programs:
- The data have high signal-to-noise ratios in the whole SDSS followup spectra in spite of higher redshifts.
- The data cover the UV wavelength in which spectroscopic studies have been hardly done.

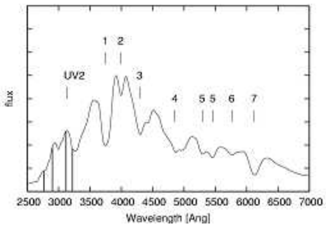
Motivation for Study of SNIa Spectral Features

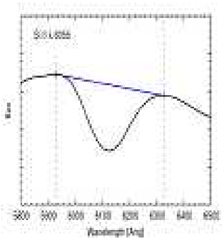
Current SN cosmology needs continuous photometric observations in order to obtain dense (multi-band) lightcurves spanning a long period, say ideally 1 month (e.g. Riess et al. 1998, Kowalski et al. 2008). If some spectroscopic feature may well correlate with lightcurve correction parameters, only one spectrum might be the substitute or, at least, it might provide us independent information for standardizing m_B.

The dust property within host galaxies may be different from that of Milky Way. The color diversity was presented by e.g. Nobili & Goobar (2008). If some SN spectroscopic feature correlates with *csalt*, it will confirm that the color diversity exists.

Spectral Features

SNIa Spectra are dominated by resonance lines, Doppler broadened due to large expansion velocities in SN ejecta (P Cygni profile). Spectroscopy has advantage over photometry in that one can examine more subtle features. Here, we focus on spectral absorption features. 1-"CaII 3945", 2-"SiII 4130", 3-"MgII 4300", 4-"FeII 4800", 5-"SII W", 6-"SiII 5972", 7-"SiII6355" (Garavini et al. 2007)





Line Velocities

We measured the wavelengths of absorption minima (green dotted line). Absorption line velocities (*vabs*) were calculated using the relativistic Doppler formula. Features UV2, 1, 2, 5, 6 and 7 were measured.

Equivalent Widths

We measured the equivalent widths (EWs). Feature boundaries of absorption lines are determined as the flux peaks (red line of left figure) within certain wavelength ranges. Continuum flux is assumed to vary linearly (blue line) between the two feature boundaries. Features 1-7 were measured.

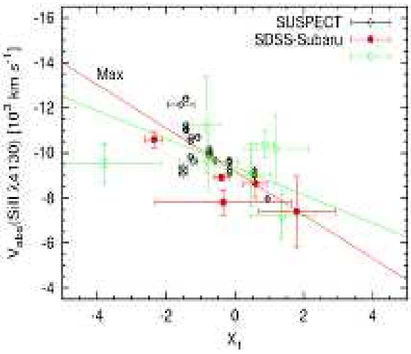
Target selection

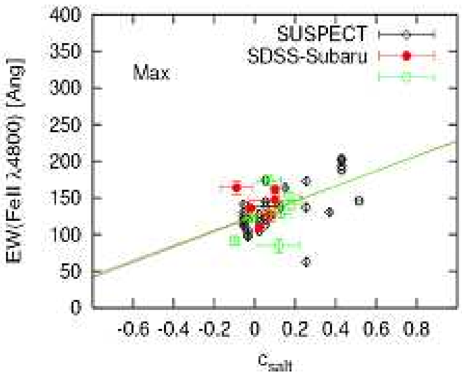
We divided our sample into 3 groups, according to *p* [days]: *early* (*p* < -3), *max* (-3 < *p* < +3) and *later*.

Lightcurves may be too poor to derive the lightcurve parameters. SN Spectra also may suffer from remaining light of host galaxy. So we tagged each SN as "*gold* (●)" or "*silver* (○)". The "gold" sample fulfills all the criteria below:

- lightcurve criteria
  - >=1 points (at *p* < -4), >=1 points (at +4 < *p*), >=5 points (at -20 < *p* < 60)
  - reasonably fitted by SALT2
- spectrum criteria
  - apparent distance between the SN position and the host galaxy center is >= 3 pixels.

Well observed nearby Ia are marked with ◇ (SUSPECT).





Correlation

We calculated every correlation coefficient of "x_1 - *vabs*", "x_1 - *EW*", "c_{salt} - *vabs*" and "c_{salt} - *EW*" (features 1 - 7).

At the *max*, x_1 is the best correlated with the *vabs* of "SiII 4130" (feature 2) and c_{salt} is the best correlated with the EW of "FeII 4800" (feature 4).

We should notice that the color range of our sample is restricted. c_{salt} < 0.7 are reported in the Union sample, a compilation of every SNe Ia data literally available (Kowalski et al. 2008). More data with wider c_{salt} are needed to verify this relation.