Optical Spectroscopy of Type Ia Supernovae

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Summary. The supernova (SN) group at the Harvard-Smithsonian Center for Astrophysics has been using the facilities of the F. L. Whipple Observatory to gather optical photometric and spectroscopic data on nearby supernovae for several years. The collection of spectra of Type Ia SNe is now large enough to allow a comprehensive analysis. I will present preliminary results from a study of a subsample of the CfA Type Ia spectroscopic database, with over 200 spectra of 31 Type Ia SNe. The SNe selected all have well-calibrated light curves and cover a wide scope of luminosity classes. The epochs of observation range from fourteen days before maximum to fifty days past maximum. All of the spectra were obtained with the same instrument on the same telescope, and were reduced using the same techniques. With such a large, homogeneous data set, the spectroscopic similarities and differences among Type Ia SNe become readily apparent.

1 Introduction

Type Ia Supernovae (SNe) have long been viewed as a homogeneous class (see, e.g., [8]) for a review of Type Ia SNe). This perception began to change when SNe appeared that were still of Type Ia, yet showed peculiarities that clearly set them apart from the standard picture. The first dramatic examples were the overluminous SN 1991T (e.g., [3, 12]) and the underluminous SN 1991bg (e.g., [2, 7]). Some differences were already apparent from earlier SNe such as SN 1986G [11]. In recent years, it has become clear that peculiar Type Ia SNe are more common than previously thought (e.g., [9]).

While the diversity has been broadly characterized by light-curve shape [6, 13, 14, 15], there are also spectroscopic differences (see [4] for a general review of SN spectroscopy). For example, overluminous SNe lack strong silicon and calcium lines while higher-excitation lines of iron are present, as in SN 1991T [3, 10], although sometimes calcium is strong as in SN 1999aa [9]. Underluminous SNe are characterized by strong absorptions of titanium, whose strength increases with decreasing temperature (e.g., [5]). The once homogeneous class is now quite diverse (Fig. 1).

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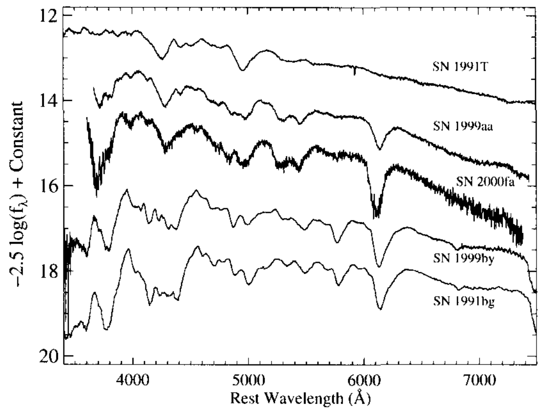

Fig. 1. Examples of Type Ia SNe with different Δm_{15} values and the spectroscopic differences that this implies.

2 Observations and Reduction

The SN group at the Harvard-Smithsonian Center for Astrophysics operates a long-term monitoring program for nearby SNe. We obtain low-dispersion spectra of two to three SNe per night with the FAST spectrograph [1] on the 1.5-m Tillinghast telescope at the F. L. Whipple Observatory (FLWO). The FAST spectrograph uses a 2688×512 Loral CCD with a spatial scale of 1.″1 per pixel in the binning mode used for these observations.

The data are reduced in the standard manner with IRAF[1] and our own routines. Wavelength calibration was accomplished with HeNeAr lamps taken immediately after each SN exposure. Small-scale adjustments derived from night-sky lines in the SN frames were also applied. All the data are from the same instrument/telescope combination and have been reduced in the same manner, ensuring consistency in the database.

For this sample, we selected Type Ia SNe for which we have well-sampled light curves from our complementary program of photometry with the FLWO 1.2-m telescope. With this data, the phase of each spectrum is known, as well as the value of Δm_{15}. The SNe chosen cover a wide range of Δm_{15} (0.85–1.93). In addition, all galaxy types are represented among the hosts. The current sample contains 387 spectra of 31 Type Ia SNe, with epochs from fourteen days before maximum to several months past maximum. There are 201 spectra within fourteen days of maximum (e.g., Fig. 2).

[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

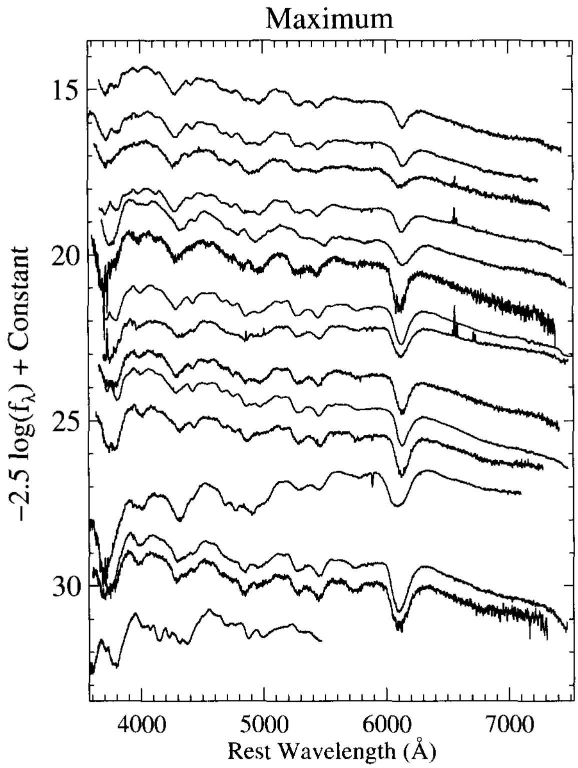

Fig. 2. Montage of Type Ia spectra at maximum. The value of Δm_{15} for each SN increases downward.

3 The CfA Type Ia Spectroscopic Database

We began our characterization of the Type Ia spectra in the database by selecting only those that were within fourteen days of maximum. The continuum was removed by selecting anchor points at regions of the spectrum that are not affected strongly by absorption lines. This removed some of the effects of reddening as well as issues related to differential light losses as a result of not observing at the same parallactic angle (which does affect some of our data). We then used a least-squares minimization technique to fit Gaussian profiles to the seventeen strongest lines in the spectrum. This was all done empirically, without any model of line formation. The result was a list of line depth, width, and position for each spectrum. Using plausible line identifications, we can then assign a velocity of expansion to each line.

One of the distinctive spectroscopic features of the peculiar Type Ia SNe, is the increase in strength of the titanium lines as Δm_{15} increases. The feature normally seen near 5800 Å is caused by silicon, but titanium begins to increase this absorption as the temperature decreases. This is shown in detail by [5],

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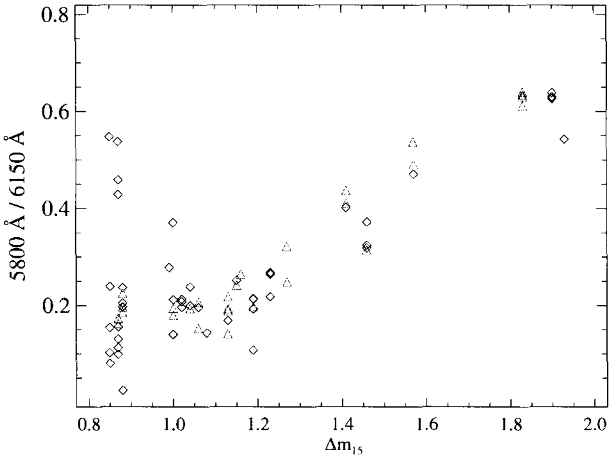

Fig. 3. Ratio of the depth of the 5800Å feature to the depth of the 6150 Å feature as a function of Δm_{15} for spectra taken within four days of maximum. The relative strength of the 5800 Å line increases as the SN becomes a faster decliner, and thus more underluminous. This has been attributed to a temperature sequence with the strength of a titanium absorption increasing as the temperature decreases.

and, using a different set of SNe, we can reproduce this effect (Fig. 3), with much more complete sampling for the underluminous SNe.

The velocity of expansion of the SN can be estimated from the minimum of the absorption lines. The Si II 6355 Å line that usually appears near 6150 Å is perhaps the most isolated feature in the spectral range that we observe. Using this line, we compared the velocity of expansion with Δm_{15}. As shown in Fig. 4, there is a large range in expansion velocity, but with a general

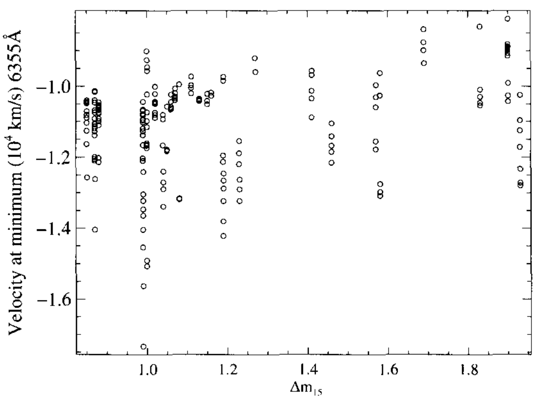

Fig. 4. Expansion velocity derived from the minimum of the 6150 Å feature as a function of Δm_{15}.

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trend that the overluminous and normal SNe tend to have higher expansion velocities. The width of the line, though, does not follow this trend.

4 Final Remarks

We have just begun to explore the CfA spectroscopic database. It is clear from these initial surveys that the Type Ia SNe can show a large degree of heterogeneity. There are some trends with the defined light-curve characterizations that will help to constrain the explosion models. In addition, there is spectroscopic variation for SNe with identical Δm_{15} values, implying that there is not just a simple one-parameter sequence that can explain Type Ia SNe.

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