UV Spectroscopy of Type Ia Supernovae at Low- and High-Redshift

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Abstract.
In the past three years two separate programs were initiated to study the restframe UV properties of Type Ia Supernovae. The low-redshift study was carried out using several ground-based facilities coupled with HST/STIS observations. The high-redshift program is an offshoot of the CFHT Legacy Survey and uses Keck/LRIS to obtain spectra. Here we present the preliminary results from each program and their implications for current cosmology measurements.

Introduction

Two independent research groups have recently presented compelling evidence for an accelerating universe from the observation of high-z SNe Ia (Riess et al. 1998; Perlmutter et al. 1999). The highest redshift SNe-Ia to date, SN 1997ff at z 1.7 (Riess et al. 2001), has begun the process of putting constraints on the epoch of transition from a matter-dominated to a dark-energy dominated universe, which has continued with the success of the GOODS survey(Riess et al. 2004). These results have important ramifications for the entire field of cosmology. Coupled with the importance of SNe Ia in the field of nucleosynthesis and as a tracer of star formation, an improved understanding of SNe Ia is invaluable to almost all fields of astronomy.

Our current knowledge of the behavior of SNe Ia in the UV is quite limited, but is slowly improving. Due to the rare nature of bright events (about one every two years for $V < 14$ mag), IUE observed only a handful of SNe Ia from 1981-1992 (Cappellaro, Turatto, & Fernley 1995), and until this past year HST had observed just one, SN 1992A (Kirshner et al. 1993). With few exceptions these spectra were obtained near maximum light, restricting our knowledge of the UV temporal evolution of SNe Ia. In addition, most of these SNe Ia were reddened by dust, obscuring the true UV colors of these objects. This extremely sparse data set imposes severe limitations on our ability to use observations of SN Ia rest-frame UV photometry for cosmological measurements.

To improve our understanding of these events in the UV two separate programs were constructed in order to address the following: (1) Calibration of the rest frame UV light curves of SNe Ia and an assessment of their potential use as distance indicators through UV light curve shape analyses. (2) Improvement in our understanding of the physics of SNe Ia, metallicity/evolutionary effects and correlations between peak brightness and UV spectral features. (3) Calibration of the SNe Ia previously observed by HST at high-redshift and the implications for cross-filter K-corrections and calibration of the supernova photometry. The first program was carried out through *HST/STIS* observations of a handfull of nearby, Hubble-flow SNe Ia while the second one fed of the SNLS survey (see Sullivan et al. in these proceedings) and involved Keck/LRIS observations of more than 20 $z \sim 0.4$ SNe Ia. Eventually the goal will be to compare these data sets against each other to look for potential signs of evolution in the UV properties of SNe Ia.

By the end of the next cycle of HST observations (assuming another major high-redshift program is again awarded time) over 100 SNe Ia will have been observed with WFPC2, ACS and NICMOS. Most, if not all, have major portions of their rest-frame light curves observed in the UV. Interpretation of this data (as well as hundred of hours of ground-based observations) requires an expanded sample of rest-frame UV photometry and spectroscopy. In Figure 1 we see the rest-frame spectral regions covered by the F675W and F814W filters for observations taken at redshifts of $z = 0.85$, $z = 1.2$ and $z = 1.7$ respectively. Because of the necessarily imperfect match between rest-frame filter functions and the light captured by observations of redshifted SNe Ia, one relies on their ability to make corrections (i.e., K-corrections) for added or lost light. Such corrections for most of the current HST observed SNe Ia will rely on accurate spectrophotometry down to ≈ 3000 Å. For those at the highest redshift (found by HST) it is necessary to go down to ≈ 2500 Å.

In addition to the nearby HST studies, we have for the first time probed the rest-frame UV region at moderate z in our SNLS survey using Keck/LRIS, providing sensitivity to metallicity and untested progenitor physics (Lentz et al. 2000). We find a striking diversity in the UV behavior is not correlated with the normal light curve stretch parameter (see Figure 2). As precise knowledge of the K-correction is needed to use SNe Ia to trace the deceleration expected beyond z =1 (Riess et al. 2004), understanding the nature of this diversity is crucial in the quest for measuring dark energy.

As there is no theoretical consensus on the origin of this diversity, our strategy for exploring systematic biases must necessarily be empirical. Thus it is important to correlate the UV properties with environmental and other factors to see if, for example, the diversity originates as a result of more than one explosion mechanism. CFHTLS is the definitive database for conducting this exercise; it will ultimately collect > 700 well-measured SNe Ia in a variety of environments (see Figure 3).

1. Conclusions

We finish with a final note on the rates of SNe Ia. In the past few years it has become apparent that the rates of SNe Ia as a function of z might be the best way to constrain possible progenitors scenarios. Presently, all high-z SNe Ia searches are conducted in the optical. The highest redshift SNe Ia are always discovered by their rest-frame UV light. Even when NGST starts to search for SNe in the near IR, it will only push the redshift limit out farther and once

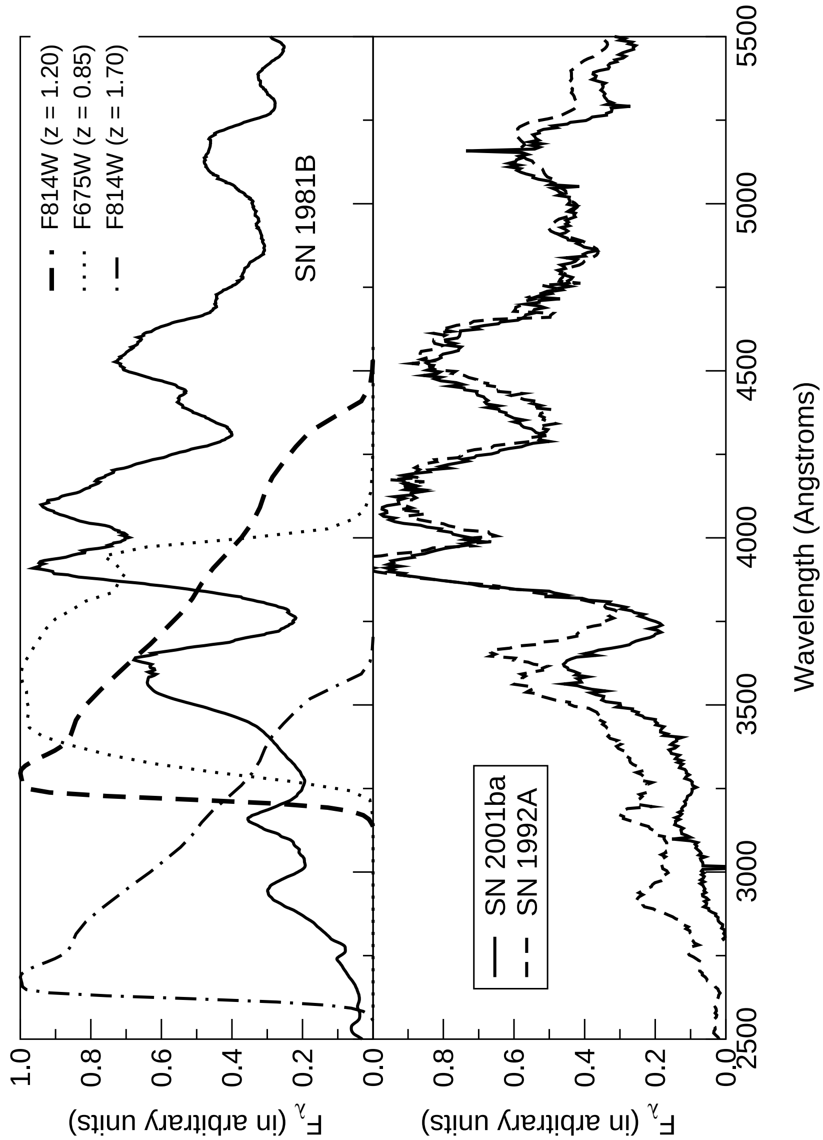

Figure 1. *Top Panel*: The IUE + ground based spectrum of SN 1981B (Branch et al. 1983) along with two of the most common filters used with WFPC to observe high-z SNe Ia. The current lack of ground based spectra of low-z SNe Ia blueward of 3700 Å makes it impossible to correct the highest-redshift light to the rest-frame U-band. *Bottom Panel*: A comparison of SNe 1992A and 2001ba (observed under our cycle 9 HST program). Note that while the relative optical fluxes are very similar the UV shows strong differences (0.3 mag. in U-band).

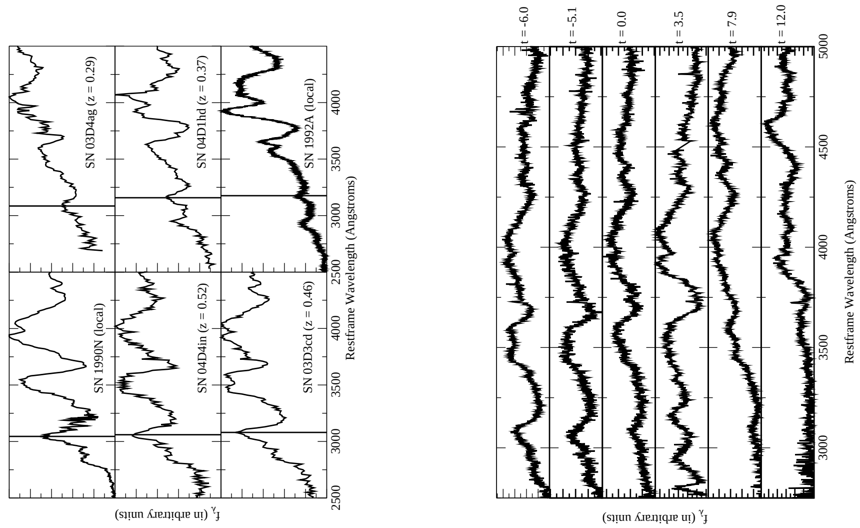

Figure 2. Diversity and evolution in the UV spectra of SNe Ia. (Left) Comparison of Keck spectra of distant CFHTLS SNe Ia with local IUE (SN 1990N) and STIS (SN 1992A) spectra. Wavelength shifts in prominent UV features arise from blends of Fe/Co (Lenz et al. 2000) and signal differences in progenitor metallicity. (Right) Distant SNe Ia spectra at similar phase showing diversity in the strength and location of these UV features. Correlating these features with ACS images taken in the COSMOS Field will quantify possible environmental biases in the context of the Hubble diagram and directly test for progenitor evolution.

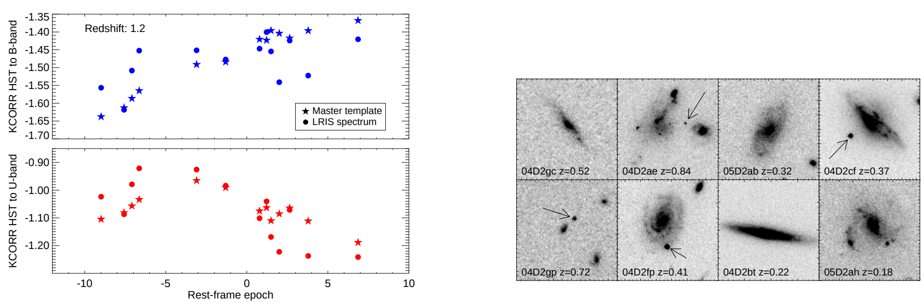

Figure 3. (Left) Effect of UV diversity and evolution on the quest for dark energy. Serious (0.2 mag) errors in the K-corrections are implied by differences between the standard UV SNe Ia spectral template (Nugent, Kim, & Perlmutter 2002) used by Riess et al. (2004) and that implied by the best quality color-corrected LRIS-B spectra at $z = 0.5$ (Right) ACS imaging of CFHTLS SNe Ia in the COSMOS field. As the ACS data was being taken during the SNLS campaign, several images capture the SN directly (arrows).

again the highest redshift SNe Ia will be found with their rest-frame UV light. In order to obtain any plausible observed rates for SNe Ia at high-z we will always be forced to work with the UV (see Gilliland, Nugent, & Phillips (1999) for a more complete discussion concerning this matter). Therefore to properly address the question of progenitors for SNe Ia through their rates, in addition to refining the measurements of the cosmological parameters, we must be able state with some certainty how they behave in the UV. These two programs will, in the very near future, do just that.

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