ESSENCE: Spectroscopy of High-Redshift Type Ia Supernovae

July 2007-January 2008

We propose to continue our long-term project of spectroscopic follow-up of high-redshift Type Ia supernovae (SNe Ia) discovered by our ESSENCE (Equation of State SupErNova Cosmology Experiment) team with the CTIO 4m telescope. This is the last year of the ESSENCE project. Spectroscopy of the high-redshift SNe is used to determine redshifts, to ensure that the sample consists of normal (i.e., SNe whose luminosity can be determined) Type Ia SNe, to reveal possible effects of evolution, and to control systematic errors.

Background

The last ten years have seen one of the great revolutions in our understanding of cosmology. Two groups, one with deep roots at the CFA, have provided credible evidence for cosmic acceleration based on luminosity distances to Type Ia SNe (the High-Z Supernova Search Team—Riess et al. 1998 and the SCP—Perlmutter et al. 1999). The SNe are about 0.25 mag fainter than they would be in a matter-dominated universe ($\Omega_M = 0.3$ and Ω_Λ=0), implying that the expansion of the Universe since the explosion of the supernova is greater than in any decelerating model. The acceleration indicated by the SNe could have its origin in negative pressure associated with "dark energy." Recent results from even higher redshift SNe indicate that the dark energy is likely to be the cosmological constant (Riess et al. 2004).

There is indirect evidence for a Universe dominated by dark energy in the studies of the cosmic microwave background at high angular resolution. These maps, most recently from WMAP (Spergel et al. 2003) show the Universe is flat ($\Omega_0 = 1.02 \pm 0.02$). In addition, mass estimates from clusters of galaxies and the field density of galaxies (e.g., Mohr et al. 1998) indicate $\Omega_M = 0.3$. These measurements, along with the results from Type Ia SNe, imply that the Universe is about 2/3 dark energy and 1/3 matter (most of which is dark).

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What is the dark energy? It could be the cosmological constant, but there are many other candidates (quintessence, X-matter, domain walls, k-essence, etc.). The purpose of ESSENCE is to constrain the properties of the dark energy by looking at the variation of pressure with density, the cosmic equation of state. We parameterize the equation of state by $w \equiv p_X/\rho_X c^2$ where p is pressure, implying that $\rho \propto a^{-3(1+w)}$, where a is the scale factor. Matter has $w = 0$, the cosmological constant has $w = -1$, while any other form of dark energy that causes acceleration must have $w < -1/3$.

The goal of ESSENCE is to find ∼200 Type Ia SNe distributed over the redshift range 0.15 to 0.75 and to measure their luminosity distances. This will test whether the onset of acceleration at $z \approx 0.7$ is or is not consistent with the cosmological constant as the dark energy. Either way, this would be very important. To that end, ESSENCE has begun a survey program using the 4m telescope at CTIO to search for and follow up on Type Ia supernovae. Our first results, soon to be published in ApJ (see astro-ph/0701041), show the dark energy to be consistent with a cosmological constant ($w = -1.05 \pm 0.12$, see Figure 1).

We are using thirty half-nights a year during the months of October-December until 2007. Each ESSENCE field is observed with a cadence of four days. This ensures discovery over the redshift range desired, as well as automatically provides the follow-up photometry in RI. From 2002-2006 we have spectroscopically confirmed 171 SNe type Ia. Our growing Hubble diagram from ESSENCE and the nearby CfA SNe sample is shown in Figure 2.

Our limiting factor continues to be the lack of adequate spectroscopic follow-up, a situation that observing time at Magellan can alleviate. So far, Magellan has provided 35 SN Ia spectra, plus an additional 25 redshifts of ESSENCE supernova host galaxies. Recent spectra are show in Figure 3. The results of the first 2 years of all ESSENCE spectroscopic observations have been recently published by Matheson et al. (2005) which shows that the high-redshift SNe Ia match well with low-redshift templates.

Spectroscopy with Magellan

As our part of ESSENCE, we propose to use Magellan to assist in this investigation into the nature of the dark energy. Spectroscopy with LDSS3 can get the redshifts and confirm supernovae to indeed be of Type Ia. We request three half-nights with LDSS3 per dark run in the months when the ESSENCE search is underway (October, November, and December). If LDSS3 is not available, IMACS would be an acceptable replacement as we have had excellent success using IMACS in either f/2 or f/4 to obtain the spectra. We are requesting half nights as our search fields have a limited RA range 23:00 - RA 02:30. We will concentrate on the lower end of the redshift range, while the Keck 10m, Gemini 8m, and VLT 8m telescopes will be used for the higher end. The $z \sim 0.2 - 0.5$ objects are well within the capability of the Magellan telescopes and reasonable S/N ratio can be obtained with about 1 hour of exposure per target. We will not request time for ESSENCE during the next semester Jan 2007 - June 2007.

Spectra give the redshifts of the supernovae so we can map the relation of redshift with the luminosity distance to see the onset of acceleration. Spectra will also show how the SNe compare with the local sample. Luminosities of nearby Type Ia SNe are correlated with light-curve shape. This relation allows the calibration of the luminosity of high-redshift SNe based on light-curve shape alone. Work at Mount Hopkins and elsewhere shows that the spectra of Type Ia SNe that are not of normal luminosity also show peculiarities that can be used to distinguish brighter and fainter events. This will provide a further check on the SNe to ensure that accurate luminosities are used. This parallel path to understanding systematic errors of the Type Ia calibration is crucial to the goals of ESSENCE.

Signs of evolution in the spectra of Type Ia SNe would be interesting on their own, but would also have a large impact on cosmological interpretation of the evidence shown by SNe. Sampling this redshift range will allow us to study a set of Type Ia SNe over a look back time of $\sim$6 Gyr. Earlier examinations of spectra of Type Ia SNe at $z = 0.46$ and $z = 1.2$ have not shown any obvious systematic shift (Coil et al. 2000). This is confirmed in a more detailed analysis of the first two years of ESSENCE spectroscopic data (Matheson et al. 2005), based on line-velocity diagnostics (Blondin et al. 2006). One source of potential systematic errors in ESSENCE is the K-corrections used to transform the observed magnitudes to the rest-frame for comparison with the nearby sample of Type Ia SNe. High-quality spectra of each high-redshift supernova enable us to improve our knowledge of the K-correction errors for each object. Comparison with the spectra of nearby Type Ia SNe will allow us to reduce the overall impact of K-correction problems.

Other Science

Although we are confident that we will have high-redshift SNe to observe, there may be times when weather limits the number of targets discovered at CTIO. On those occasions, our backup projects will be either spectroscopic observations of supernovae host galaxies from previous ESSENCE years. The spectroscopic observations would allow us to confirm the redshift, as well as providing data to characterize the properties of the hosts themselves. The continued monitoring of these fields will build up a tremendous photometric database on all the objects present. We will select samples galaxies from our database to examine the evolution of clustering with redshift (e.g., Peacock et al. 2001).

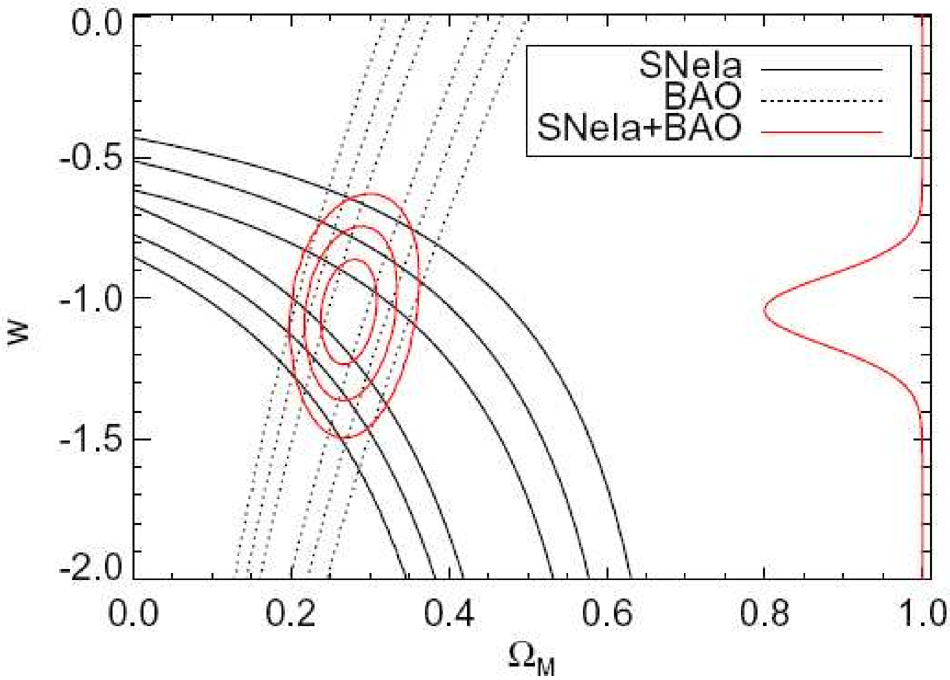

Figure 1: From Wood-Vasey et al. 2007, showing the $\Omega_{\rm M}$-w contours from the ESSENCE + SNLS + nearby sample for MLCS2k2 fitter. The baryon acoustic oscillation (BAO) constraints are from Eisenstein 2005.

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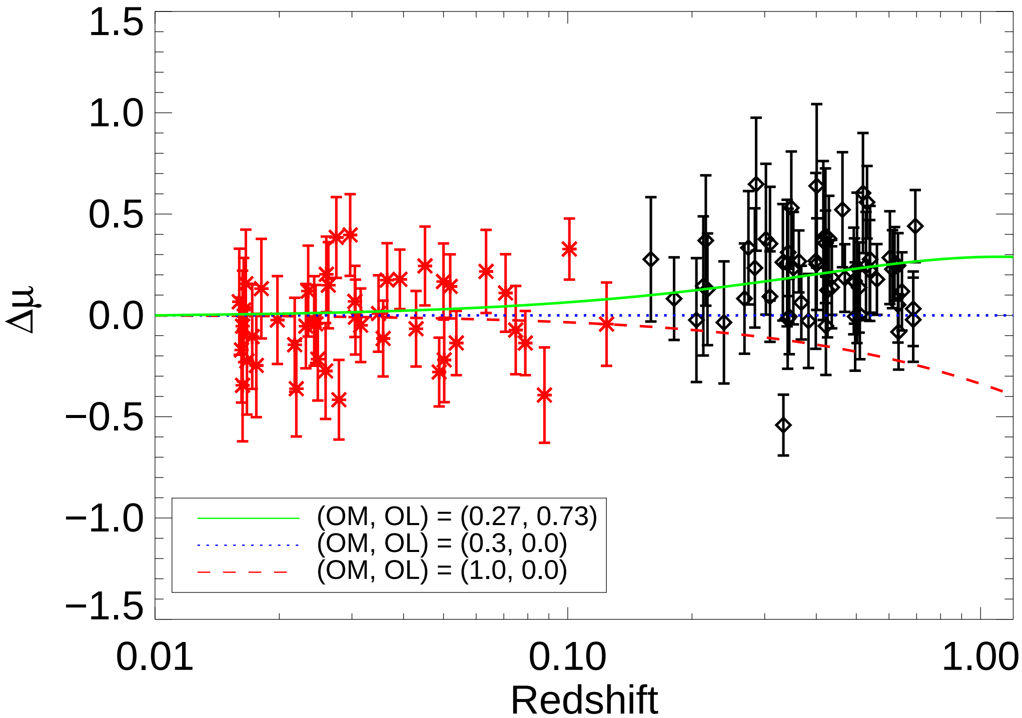

Figure 2: Also from Wood-Vasey et al. 2007, showing the relative luminosity distance modulus vs. redshift for 57 high-redshift ESSENCE (2002-2004) + and 45 low-redshift CFA SN Ia with MLCS2k2 fitter. For comparison the over-plotted solid line and residuals are for a ΛCDM (w, Ω_M, Ω_Λ) = (-1, 0.27, 0.73) Universe.

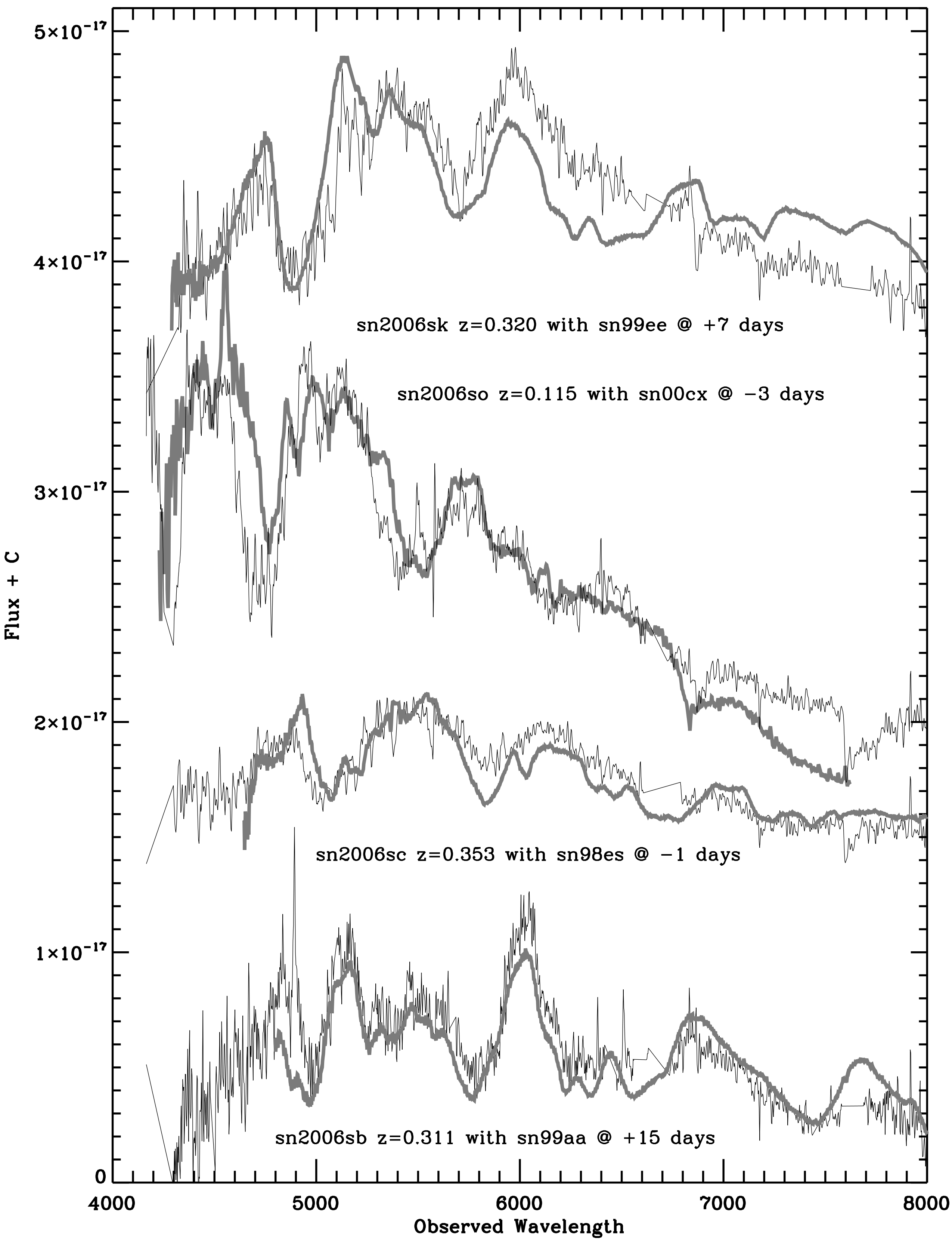

Figure 3: Spectra of four Type Ia supernovae from the ESSENCE project obtained with the Magellan telescope during the 2006B semester using the IMACS f/2 spectrograph. The observed spectra are over plotted with best matching low-redshift spectra (grey thick line) as determined from SNID see Blondin and Tonry 2007.

Supernova Publications

ESSENCE Publications

Wood-Vasey, W. M. et al., Submitted to ApJ. 2007astro.ph..1041W, "Observational Constraints on the Nature of the Dark Energy: First Cosmological Results from the ESSENCE Supernova Survey."

Davis, T. M. et al., Submitted to ApJ., 2007astro.ph..1510, "Scrutinizing Exotic Cosmological Models Using ESSENCE Supernova Data Combined with Other Cosmological Probes."

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SNe and Cosmology Publications

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Supernova Publications

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