SNLS - The SuperNova Legacy Survey: First Year Operation

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Type Ia supernovae (SNe Ia) currently provide the most direct evidence for an accelerating Universe and for the existence of an unknown "dark energy" driving this expansion. The 5-year Supernova Legacy Survey[1] (SNLS) will deliver ∼1000 SN Ia detections with well-sampled $g'r'i'z'$ light curves. Using this definitive dataset, we will obtain a precise measurement of the cosmological parameters (Ω_m, Ω_λ); our goal is to determine the cosmological equation of state parameter "w" to a statistical precision of ±0.07, testing theories for the origin of the universal acceleration. In this proceeding, we summarize the progress made during the first full year of the survey operation.

1. Introduction

The Hubble diagram for high-redshift Type Ia supernovae (SNe Ia) provides the most direct current measurement of the expansion history of the universe – and hence the most direct evidence for an accelerating expansion. The "first generation" of SN Ia cosmology work developed a systematic approach to this measurement [Riess et al. 1998, Perlmutter et al. 1999] that led to astonishing results ruling out a flat, matter-dominated Universe. This indicated the presence of a new, unaccounted-for "dark energy" driving the cosmic acceleration.

One of the most pressing questions in cosmology now is: "What is the dark energy that causes this acceleration?". There are fundamental differences between a Cosmological Constant and other proposed forms of dark energy (see Peebles and Ratra [2003] for a comprehensive review). The distinction can be addressed by measuring the dark energy's average equation-of-state, $<w>=<p/\rho>$, where $w=-1$ corresponds to a Cosmological Constant – current measurements of this parameter (e.g., Knop et al. [2003], Tonry et al. [2003], Riess et al. [2004]) are consistent with a very wide range of dark energy theories. The importance of improving measurements to the point where $w=-1$ could be excluded has led to a second-generation of SN cosmology studies: large multi-year, multi-observatory programs benefiting from major commitments of dedicated time. These "rolling searches" find and follow SNe over many consecutive months of repeated wide-field imaging, with redshifts and SN type classification from coordinated spectroscopy.

The five-year CFHT "Supernova Legacy Survey" (SNLS) is one such ambitious project. It is made of two components: an imaging survey to detect supernovae and monitor their light curve and a large spectroscopic survey to identified supernova candidates and measure their redshifts. The imaging survey is built on the Canada-France-Hawaii Telescope (CFHT) Legacy Survey conducted in 4 SDSS filters ($g'r'i'z'$), utilizing an imager field three times larger than used in the next largest survey, with around twice as much time devoted to the survey. The spectroscopic survey requires observations on the world's largest (8-10 meter class) telescopes, because of the faintness of distant supernovae. SNLS will provide the biggest improvement in the determination of the dark energy parameters achievable over the next decade, using an order-of-magnitude larger statistical sample (i.e. ∼700) of SNe in the redshift range z=0.3-0.9 where w is best measured. With this sample, we aim to answer the key question: Is the dark energy something other than Einstein's Λ?

Table I SNLS field locations

Field	RA (J2000)	DEC (J2000)
SNLS-D1	02:26:00.00	−04:30:00.0
SNLS-D2	10:00:28.60	+02:12:21.0
SNLS-D3	14:19:28.01	+52:40:41.0
SNLS-D4	22:15:31.67	−17:44:05.7

2. Survey overview

The SNLS survey began in June 2003 (with a pre-survey period from March 2003) using the queue-scheduled one square-degree imager "megacam" on CFHT. In a typical month, each available field (Table I) is imaged on five epochs in a combination of $g'r'i'z'$ ($r'i'$ are always observed; $g'z'$ are arranged according to the lunar phase), each of the observations spaced 4-5 days apart (∼3 days in the SN rest-frame). Each field is typically searched for 5 continuous months, giving around 20 "field-months" in a

[1] see `http://cfht.hawaii.edu/SNLS/`

given calendar year – and consequently high-quality and continuous light-curves for each SN candidate lasting many months (Fig. 1).

On a given night, data is taken, pre-processed (using the CFHT-developed data processing system[1]), aligned, psf-matched and candidates located and placed in our database within 12 hours, allowing a rapid prioritisation for spectroscopic followup. The spectroscopic time comes via an international collaboration, with allocations on Gemini (60 hours/semester), VLT (60 hours/semester) and Keck (3 nights in the "A" semester for coverage of the northern-most D3 Groth Strip field).

The amount of successful spectroscopic follow-up performed will define the success of SNLS, and with many hundreds of candidates to select from every month, locating probable SNe Ia (and rejecting AGN and other variable objects) is essential. We have developed a SN photometric redshift technique which performs a light-curve fit to 2-3 epochs of multi-band real-time data, and returns a probability that the candidate is a SN Ia, as well as predictions of redshift, stretch and phase. This technique is very successful; since it was implemented our SN Ia fraction is around 80%, with an excellent agreement between photometric and spectroscopic redshift.

3. Current Status

As of December 2004, SNLS has located ∼650 SN candidates, with ∼140 spectroscopically identified as SNe Ia and ∼30 core-collapse SNe. We currently obtain an average of 11 spectroscopically confirmed SNe Ia per month; at this current rate ∼700 SNe Ia will be spectroscopically identified over the 5 years of the survey ending in 2008.

The detection of new SN candidates is done using two independent real-time analysis pipelines which analyze the data as it arrives from Mauna Kea at the CFHT headquarters. Detection are performed by subtracting an image to a reference one computed by stacking previous images of the same field. The two pipelines produce lists of candidates, and magnitudes, in about 4–6 hours, and agree quite well down to about $i'_{AB} = +24.5$ (redshift about 1 for a typical SNIa). The key element of these pipelines is matching the point spread function of an exposure to a reference image. This is done using the Alard algorithm [Alard and Lupton 1998, Alard 2000] for one of the pipelines, and using a non-parametric approach for the other one [Pritchet 2005]. A complication is the large (∼ 1.5 arcmin) dithering pattern that is used to "fill in" the two 80 arcsec wide gaps in the MegaCam mosaic. This prevents the use of a chip-by-chip analysis of the mosaic, because much of the area of each CCD chip would be lost because of the dithering. Instead it is necessary to "align" each individual exposure of a sequence to an astrometric reference frame, prior to combining and PSF-matching.

Figure 2 displays the cumulative number of SN discovered to December 2004 and the predicted numbers to the survey mid-point. This data set will form the largest and most homogeneous high-z SN sample available over at least the next decade. Our current number-redshift ($N(z)$) distribution (together with some predictions based on published high-redshift SN Ia rates and our spectroscopic efficiency) is shown in Fig. 3. This distribution is well understood in terms of our spectroscopic selection function, coupled wih incompletness at high redshift.

Follow up of already detected supernovæ is performed on the same image thanks to the wide field of view of the MegaCam camera. This greatly improves the building of light curve photometry compared to previous measurements where photometric follow-up had to be performed on different telescopes and instruments. Photometry and calibration pipelines are operational in Canada and France. We are currently investigating both the internal photometric alignment and the external photometric calibration – both are critical for an accurate determination of w. Internally, after Elixir data-processing, the 36 chip array is photometrically aligned to ∼0.01 mag in all 4 filters, and internal colour-terms appear negligible. As we are continually observing the same four deep fields, an internal field-to-field calibration of better than 0.01 mag is achievable. Beyond the internal calibration, we are in the process of defining a "natural megacam" system onto which we will place our SN photometry; in the meantime an overlap of the D2 field with the SDSS data release allows a calibration of our data onto the SDSS system beyond that obtained by observing SDSS secondary standards.

Figure 4 shows our preliminary Hubble diagram, constructed from SNe observed up to July 2004 and for which at observations could be performed in at least 2 bands, corresponding to either $U + B$, $B + V$ or $U + B + V$ rest frame. Points reported on the graph are stretch and color corrected.

4. Discussion

The 700 well-measured SNe Ia, together with an Ω_m prior known to ±0.03 (i.e. 10%), will allow us to determine w to a statistical precision of ±0.07, distinguishing between $w > -0.8$ and $w = -1$ at 3σ. Clearly, with 700 SNe Ia, controlling (and understanding) systematics in the SN sample is of the utmost importance. Our rolling search with multiple filters ($g'r'i'z'$) will generate the first large high-z SN Ia dataset with

[1] http://www.cfht.hawaii.edu/Instruments/Elixir/

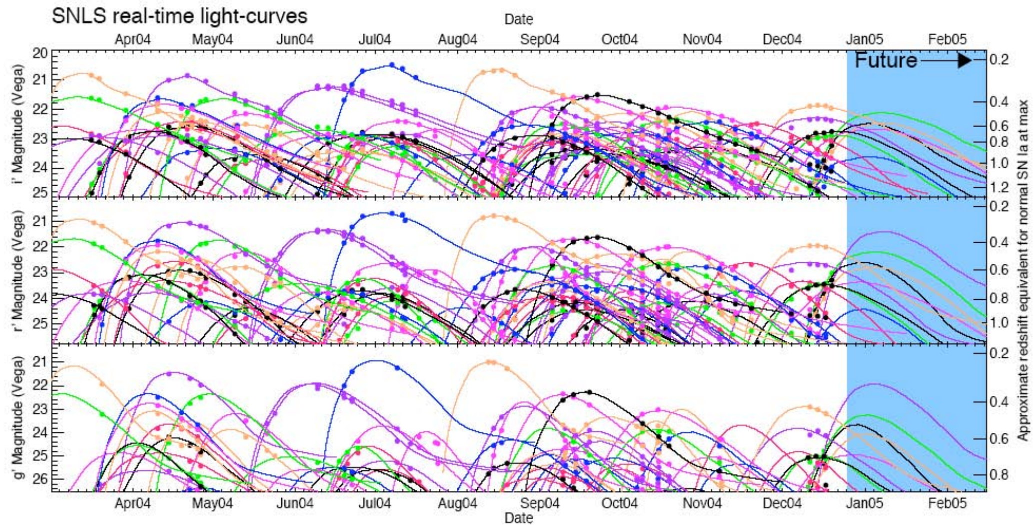

Figure 1: A selection of real-time light-curves in the $g'r'i'$ filters for confirmed SNe Ia discovered over the period April–December 2004, demonstrating the quality of typical light-curves in the survey. At any given lunar phase candidates at maximum light are available for follow-up programs. For clarity only around a third of the SNe Ia followed during this period are shown.

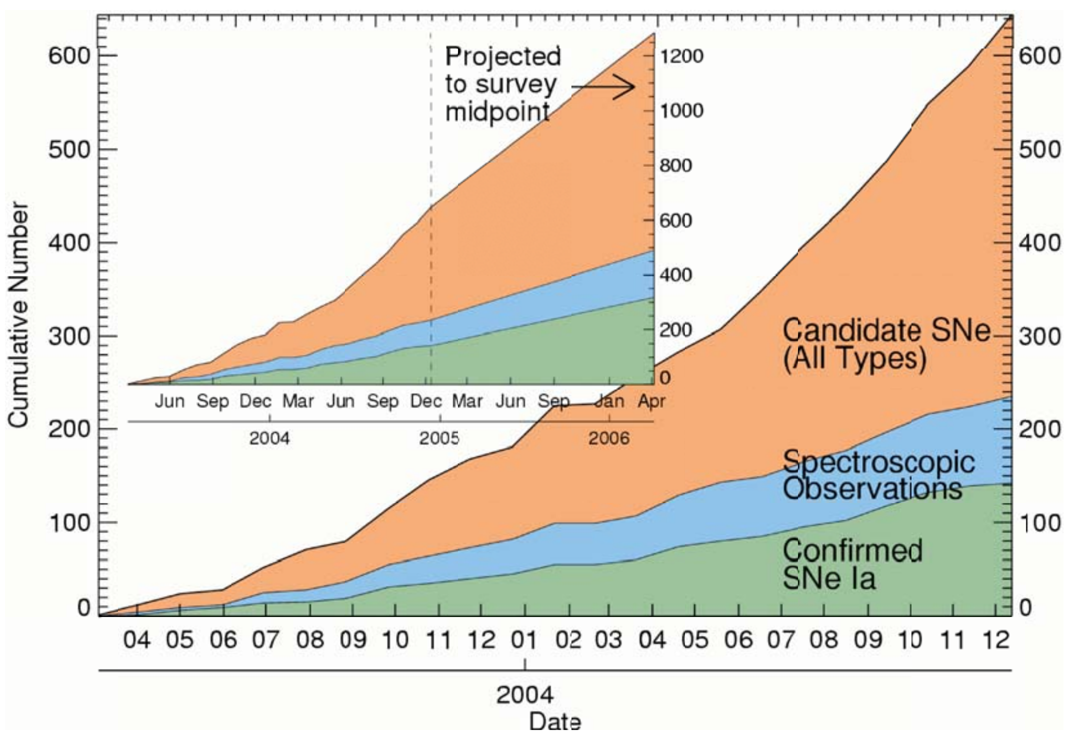

Figure 2: The survey progress as of December 2004. The main panel shows the number of SN candidates, spectroscopic observations, and SNe Ia for the 18 month of the survey. The inset shows predicted numbers to the survey mid-point based on the last six months of the survey.

complete colour coverage throughout the lightcurves (see Fig. 1), enabling comprehensive extinction studies since all the SNe are sampled over a wide, rest-wavelength baseline. Additionally, the narrow galaxy emission and absorption lines detectable with spectroscopy of SN+host, plus the extremely deep ground-based optical coverage due to the rolling-search (and some *HST* coverage), provide valuable constraints on host galaxy stellar populations, and allow construction of SN sampled based in different host galaxy

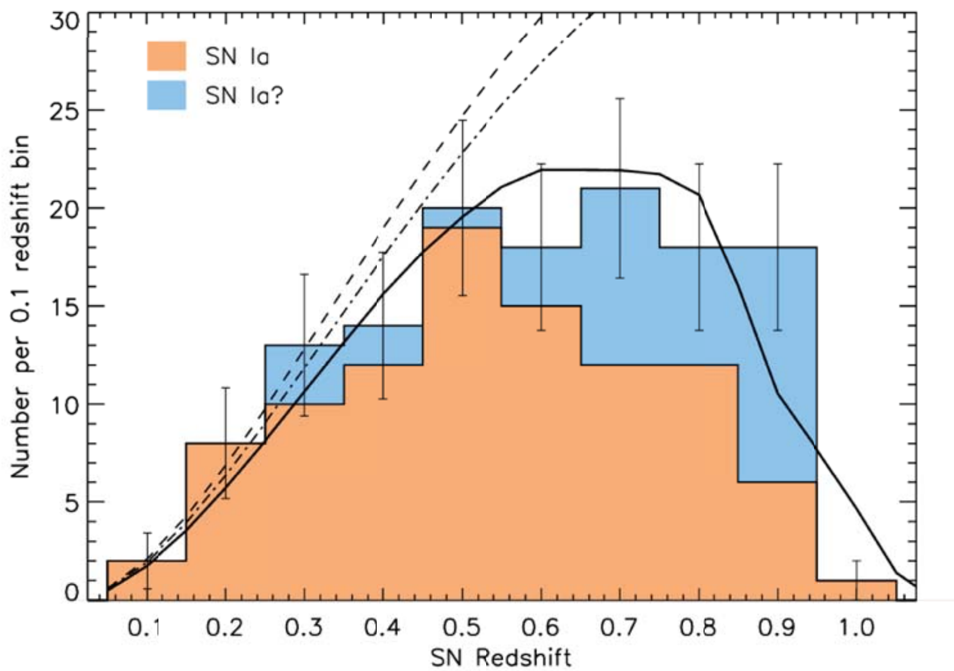

Figure 3: The measured $N(z)$ of the SNe Ia distribution compared to simple predictions based on the search limiting magnitudes and completeness, and the spectroscopic efficiencies of the survey. The dot-dash line shows the predicted number of SNe Ia candidates detected as a function of redshift; the solid line shows the expected distribution of confirmed SNe Ia after one year based on the amount of spectroscopic time available and our follow-up strategy.

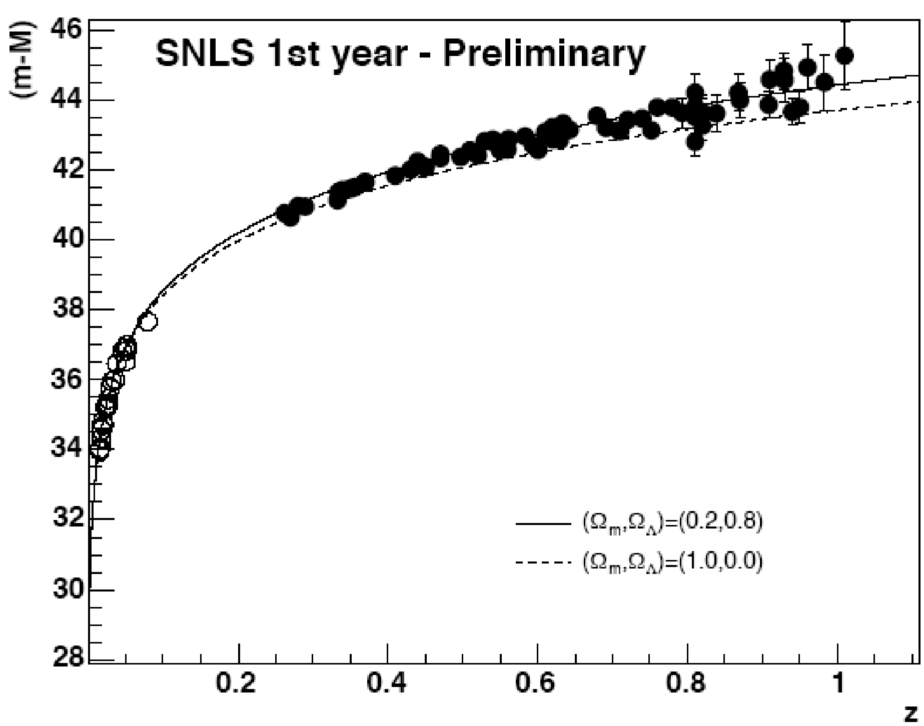

Figure 4: Preliminary SNLS 1st year Hubble diagram for SNe observed from the start of the survey up to July 2004. Also shown are the predictions for a flat universe with $\Omega_m = 0.2$ (solid line) and $\Omega_m = 1$ (dotted line).

classes (e.g, presumed “dust-free” ellipticals). Thus, SNLS will provide the biggest improvement in the determination of the dark energy parameters achievable over the next decade.

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