REVIEW OF SNLS RESULTS

V. RUHLMANN-KLEIDER
Service de Physique des Particules, DSM/Irfu, CEA/Saclay,
F-91191 Gif-sur-Yvette, France

The SuperNova Legacy Survey was in operation from 2003 to 2008 at the Canada-France-Hawaii telescope. The aim of the survey was to detect around 500 supernovæ of type Ia (SNe Ia) in the redshift range between 0.2 and 1, to confirm them with spectroscopic data and to measure their multicolor lightcurves with unprecedented precision and time sampling. Results obtained by the collaboration encompass measurements of the cosmological parameters Ω_M, Ω_Λ and w, as well as SNIa explosion rate measurements and comparisons between different sub-samples of SNe Ia events in order to search for possible biases in the use of SNe Ia as cosmological probes. The main results relevant to cosmology are hereafter reviewed.

1 The SuperNova Legacy Survey

The SuperNova Legacy Survey (SNLS) is a second generation experiment of cosmology with high redshift type Ia supernovæ (SNe Ia). It benefits from the excellent sky at the Mauna Kea site in Hawaii and from an optimised observing strategy at the Canada-France-Hawaii telescope. The same fields of view are repeatedly observed every 3 or 4 nights during dark time, allowing lightcurves to be measured with very good time sampling. These measurements rely on the MegaCam imager, a 1 square degree CCD array of 340 million pixels, and use four broadband filters from 400 to 1000 nm. A high detection efficiency together with good photometric precision (from 1 to 3% at maximum light) are thus achieved. In addition, a large amount of spectroscopic time is allocated to the survey on 8-10 m class telescopes to derive type and redshift measurements in a large fraction of the detected events. At the end of the survey in June 2008, SNLS collected around 500 spectroscopically confirmed SNe Ia in a redshift interval between 0.1 and 1.2. This sample represents ten times that collected by the previous high redshift supernova experiments.

2 Cosmology results

Cosmology derived from SNe Ia rely primarily on their lightcurves. Points in the rise part of the curves are used at detection time to trigger the spectroscopic observations. For each spectroscopically confirmed event, the complete multiband lightcurves are used to test the event compatibility with a type Ia supernova (SNIa) at the measured redhshift z, using a SNIa model trained on a large set of lightcurves and spectra (see e.g. [1]). From this test, the event apparent B-band magnitude at maximum light, m_B^*, is derived, as well as two parameters describing the intrinsic properties of the SNIa. These are a colour index, c, and a time dilation or stretch factor, s. SNe Ia are assumed to be generated by an explosion mechanism which leads to reproducible luminosities with a dispersion of a few tens of %, attributed to intrinsic variability in colour and

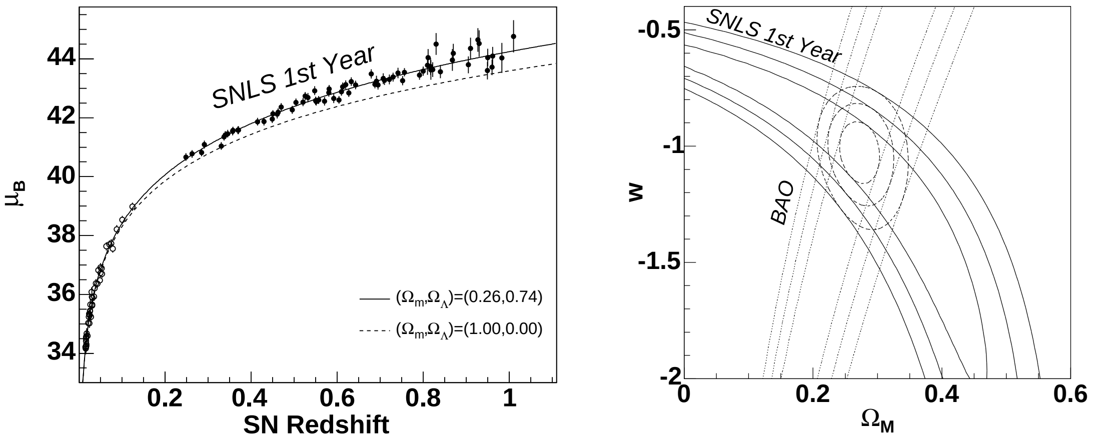

Figure 1: Left: Hubble diagram of type Ia supernovæ from the SNLS first year dataset combined with low redhift data. A flat matter-dominated universe (dashed line) is ruled out by data, which prefer a flat universe with matter and dark energy (solid line). Right: constraints on Ω_m, the matter density, and w, the dark energy equation of state parameter, derived from the SNLS first year dataset combined with SDSS results on baryonic acoustic oscillations. A flat universe is assumed.

stretch. As a consequence, their B-band flux at rest, Φ^*_B, depends mainly on the distance to the observer, $\mathrm{d_L}$, which is determined by cosmology through the Hubble constant $\mathrm{H_0}$, the matter and dark energy densities at present time, Ω_m and Ω_Λ, and the constant dark energy equation of state, w. If L(c,s) is the supernova luminosity, assumed to be a function of c and s, we have:

$$\Phi^*_\mathrm{B} \sim \mathrm{L(c,s)}/4\pi \mathrm{d}^2_\mathrm{L} \qquad\qquad \text{with} \qquad\qquad \mathrm{d_L}(\mathrm{z},\mathrm{H_0},\Omega_\mathrm{m},\Omega_\Lambda,\mathrm{w})$$

Rather than fluxes, magnitudes are used to build a distance estimator, μ_B, defined as:

$$\mu_\mathrm{B} = \mathrm{m}^*_\mathrm{B} - \mathrm{M_B} + \alpha(\mathrm{s}-1) - \beta\mathrm{c} \qquad (1)$$

where $\mathrm{M_B}$ is the average SNIa absolute B-band magnitude and the last two terms account for SNIa variability due to colour or stretch. Note that the colour term can describe intrinsic colour effects as well as host galaxy dust extinction. Values of $\mathrm{M_B}$, α and β are derived in fits to the cosmological parameters. In these fits, an intrinsic dispersion term, σ_int, is also added to the error budget to describe our lack of knowledge about SNe Ia, besides the two empirical colour and stretch terms in Eq. 1.

Cosmological fits from the first year SNLS dataset[2] are presented in Fig. 1. In a flat universe with w$= -1$, the best fit to data corresponds to a matter density $\Omega_\mathrm{m} = 0.263 \pm 0.042(\mathit{stat.}) \pm 0.032(\mathit{syst.})$. Relaxing the assumption about w, these supernova data, combined with SDSS results on baryonic acoustic oscillations, lead to w$= -1.023 \pm 0.090(\mathit{stat.}) \pm 0.054(\mathit{syst.})$ in agreement with the hypothesis of a pure cosmological constant for the dark energy density Ω_Λ.

A preliminary Hubble diagram from the analysis of the first three years of SNLS data is shown in Fig. 2. Besides the gain in statistics, this analysis benefits from improved flux calibrations, improved SNIa modelling and from a better understanding of selection biases. The best fit results agree with the first year results. In particular, w is found to be consistent with -1 within a (statistical) uncertainty of 6%. The estimate of systematic uncertainties is under progress.

3 Are SNe Ia usable for precision cosmology ?

The main source of systematic uncertainty in cosmology results with SNe Ia lies in the assumption that these have reproducible luminosities. The distance estimator in Eq. 1 compares

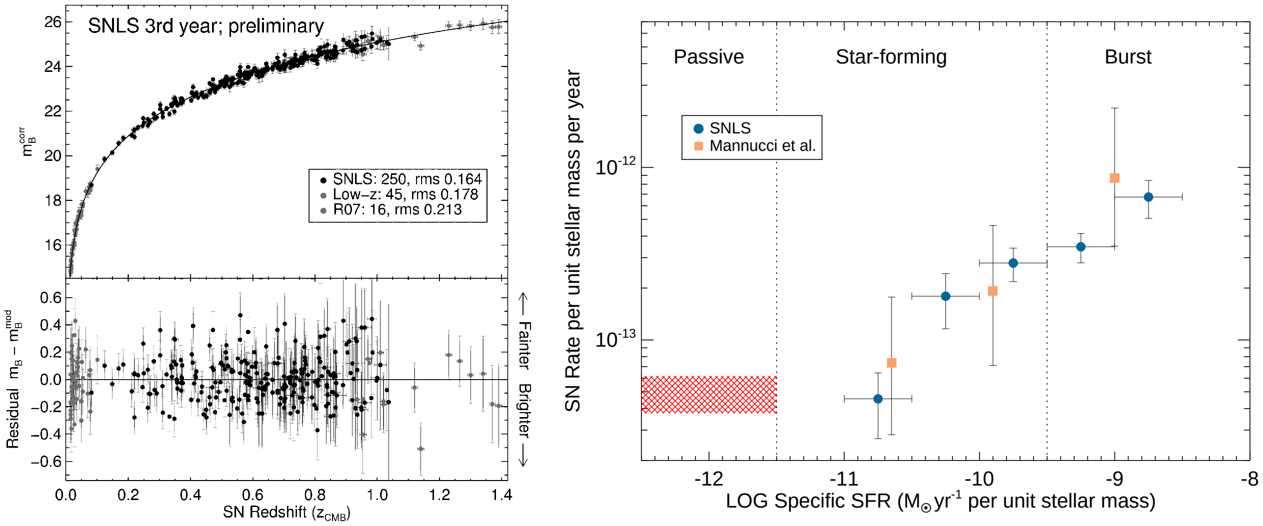

Figure 2: Left: Hubble diagram from SNLS three years of data combined with lower and higher redhift data. The best fit cosmology, which corresponds to a dark-energy-dominated universe, is superimposed (solid line). Right: SNIa explosion rate as a function of the star formation rate of the host galaxy. SNLS results from two years of data (hatched band and filled circles) are compared with results from low redshift SNe (filled squares).

the measured apparent B-band magnitude m_B^* to the absolute B-band magnitude, estimated as $M_B - \alpha(s-1) + \beta c$ where M_B, α and β are assumed to be redshift-independent, as expected if SNe Ia have reproducible luminosities.

A first qualitative test of this hypothesis was performed with the first year dataset using Hubble diagram residuals to the best fit cosmology. Subtracting the stretch (resp. color) term from the residuals, the luminosity-to-stretch (resp. color) law for the SNLS events was obtained and found to be similar with that for lower redshift SNe (see Fig. 9 and 10 in Ref.[2]). Further tests were undertaken with the second year dataset. Rest-frame stretch-corrected lightcurves from SNLS and from low redshift SNe were compared. Within 1 sigma, no difference was found between lightcurves from supernovæ at different redshifts or from different host galaxy stellar activities (see Fig. 3 and 5 in Ref.[3]). Measurements of spectral features like ejection velocities or equivalent widths also show no significant difference between supernovæ at different redshifts[4].

SNIa explosion rate measurements allowed to investigate further the connection between SNe Ia and their host galaxies[5]. Fig. 2 shows that the SNIa rate correlates with the stellar activity of the host galaxy, confirming a trend already observed in supernovæ at low redshift. Splitting the SNLS sample by host activity leads to different stretch distributions, as shown in Fig. 3. Passive hosts give supernovæ of lower stretch than active hosts, which means that brigther SNe Ia occur mostly in star-forming galaxies. In order to check whether this effect changes with redshift, SNLS rate measurements were used to model the redshift dependence of the SNIa rate[5]. A two-component model was used, to describe rates due to passive and star-forming hosts separately. This model agrees with data, as shown in Fig. 3, at least at the level of the present statistics. It predicts that the mix of the two components evolves with redshift, with SNe Ia from star-forming galaxies becoming dominant above 0.7 in redshift.

As a consequence, the average SN stretch is expected to evolve with redshift. This question was adressed in Ref.[6], where the two-component model was used to predict stretch distributions at different redshifts which were compared and found in agreement with data (see Fig. 2 in Ref.[6]). The mean stretch increases by 8% in the redshift range from 0.03 to 1.12, which represents an increase in brightness of 12%. But this evolution will not affect cosmology if the value of α in Eq. 1 is the same for the two components of the SNIa population. This issue is under study

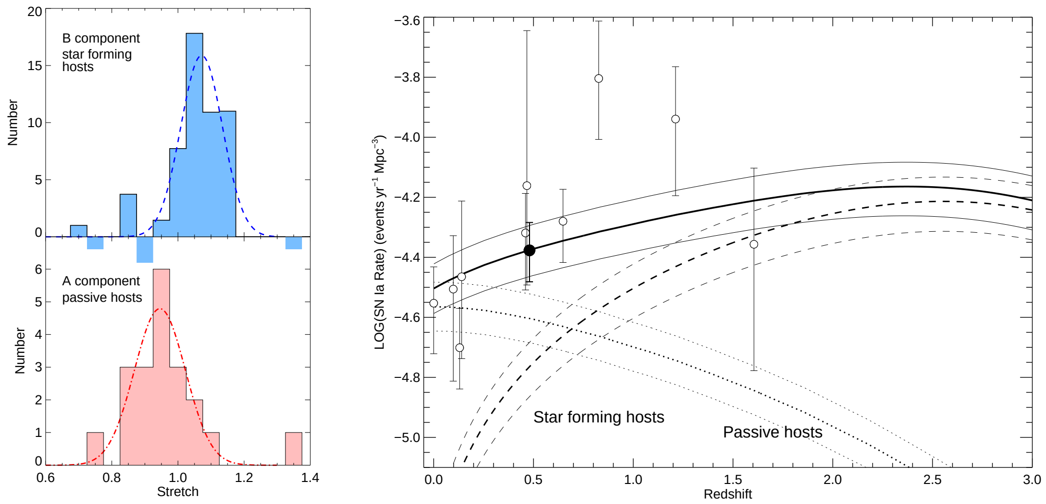

Figure 3: Left: Stretch distributions of SNLS SNe Ia split by different host galaxy stellar activities. Predicted distributions are superimposed (dashed lines). Right: SNIa rate as a function of redshift. Rates expected from passive galaxies (dotted line) and from star-forming ones (dashed line) add up to a total expected rate (solid line) which is compared to data. The filled circle stands for the SNLS measurement.

with the first three years of SNLS data.

In addition to the above tests, efforts were also put to reduce systematic uncertainties in the way SNe Ia are modelled to derive m_B^*, c and s for each SN candidate (see Sec. 2). As an example, precise measurements of the UV part of the SNIa spectrum were performed on a few SNLS events [7]. This part of the spectrum was poorly known from low redshift data and is responsible for large uncertainties in the modelling at high redshift. These measurements are also a first step to improve our knowledge of the SNIa physics, since the UV part of the spectrum may be sensitive to parameters like progenitor metallicity.

4 Conclusions

In five years, the SuperNova Legacy Survey collected a large set of spectroscopically confirmed SNe Ia at high redshift, increasing by a factor 10 the sample collected by the previous generation of experiments. With 70 SNe in the first year, SNLS confirmed the accelerated expansion of the universe and, when combined with other cosmological probes, measured the dark energy equation of state w to be consistent with -1 within 9%. The 250 SNe of the first three years give consistent results, with improved accurarcy. Based on this dataset, the SNIa properties were studied and found to evolve on average with redshift. But so far, after empirical luminosity corrections are applied, no bias in cosmology has been detected. Larger samples are needed to check if the current empirical corrections have to be refined.

References

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