The supernova legacy survey: 3 year results and perspectives

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SNLS collaboration

LPNHE

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Importance of type Ia SNe for dark energy science

Most stringent constraints at that time on $w$

- $w = -1.021^{+0.078}_{-0.079}$
- $a \sim 2$ improvement wrt CMB+BAO+H0

Large influence of systematics
- Careful estimation of their amplitude
- Active work to improve the situation

68.3%, 95.4%, 99.7% confidence contours [Sullivan et al., 2011] (flat $w$CDM)
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Outline

1. Introduction
   - The Supernovae Legacy Survey

2. The SNLS 3 year analysis
   - Analysis ingredients
   - Photometry
   - Empirical light curves models
   - Hubble diagram

3. Error propagation
   - Review
   - Light curve model
   - Calibration uncertainties

4. SNLS 5: Ongoing work and perspectives
   - SNLS 5 years analysis

5. Conclusion
The Supernovae Legacy Survey

High-z supernovae search during 5 years (2003-2008)

- $0.3 < z < 1.0$
- Deep search in $4 \times 1 \text{ deg}^2$ fields

Photometric survey

- Conducted at CFHT
- Rolling search
- Discovery of $\sim 2000$ SN in image comparison
- Luminosity evolution (light-curve)

Spectroscopic follow-up

- On 8m class telescope (Gemini, VLT, Keck)
- Confirm identification as SN Ia
- Deliver redshifts
The photometric survey

Megaprime/MegaCam

- 1 deg$^2$, $36 \times 2k \times 4.6k$ CCDs $\rightarrow$ 300Mpixels
- 0.7” resolution (Image quality FWHM)
- Good sampling: 1 pix = 0.2”

40 nights/year on the 3.6m CFHT (Rolling search)

- One point every 3-4 nights
- In 4 photometric bands $griz$
Rolling search
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3 year analysis ingredients

Changes in 1 → 3 year analysis

- Extended dataset: 71 → 252 (0.15 < z < 1) [Guy et al., 2010]
- Exhaustive estimate of systematics included in the fit [Conley et al., 2011, Sullivan et al., 2011]

Key ingredients

1. Supernovae spectroscopy [Balland et al., 2009, Bronder et al., 2008]
2. Supernovae photometry
   - Method mostly unchanged [Astier et al., 2006]
   - Calibration strongly improved [Regnault et al., 2009]
3. Supernovae light curves models
   - Two fitters: Sifto [Conley et al., 2008], Salt2 [Guy et al., 2007]
   - Trained on high-z SN
Photometry of SNIa in SNLS

Relative measurement: Flux ratio between SNIa to surrounding stars

- Robust to many problems
- One subtlety: The galaxy subtraction
- Many observations of the galaxy without supernovae
- Well controlled

Need: broadband flux of field stars
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Need: broadband flux of field stars
The SNLS photometric calibration

Broadband flux for field stars
- Flux ratio between field stars and primary standard
- Two step process
  - Tertiaries ↔ Secondaries (MegaCam)
  - Secondaries ↔ Primary (Landolt)
- Choice of BD+17 rather Vega
  - Directly observed by Landolt
  - Redder (closer in color to average stars and SN)
Making the response uniform to 0.5% over 1 deg²

Dedicated observations

- Dithered observations of dense stellar fields (∼ 30 stars per arcmin²)
- 1 every year and after every instrumental setup change
- Uniformity solution at ∼ 2 arcmin resolution
- Filter passbands variations at ∼ 5 arcmin resolution
The supernova spectral time sequence model

Used to derive (noisy) estimates of $\mu = 5 \log_{10}(d_L/10\text{pc})$ from the measured observer frame fluxes

$$\mu(z; \text{cosmo}) \approx m_B^* - (M - \alpha s + \beta C)$$

$M$, $\alpha$ and $\beta$ are nuisance parameter in the cosmological fit.

Light curve fit provides:
- shape parameter $s$
- color parameter $C$
- rest frame $B$ apparent magnitude $m_B^*$ at maximum
Two fitters

**Salt2**
- Data driven approach (PCA)
- The spectral sequence is modeled as:
  $M(p, \lambda; x_0, x_1, c) = x_0[M_0(p, \lambda) + x_1 M_1(p, \lambda)] \exp(c CL(\lambda))$

**Sifto**
- Spectral sequence from (Hsiao, 2007)
- Stretch model
  $M(p, \lambda; s) = M(p/(s(\lambda) - 1), \lambda)$
- Color relations

**Both fitters**
- Trained on SNLS + low-z sample
- Difference provide estimate of systematics
The combined Hubble diagram

\[ m_{corr} = m_B + \alpha (s - 1) - \beta C \]

Conley et al. (2011)
Cosmological constraints

- $w = -1.021^{+0.078}_{-0.079}$
- Not much on a varying $w$ $w(a) = w_0 + w_a z/(1 + z)$

SNLS3+WMAP7+SDSS DR7 LRGs
How did we estimate uncertainties?

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The distance moduli covariance matrix

Exhaustive estimation of systematic uncertainties $\delta S_k$

- Around 120 potential systematics identified and estimated
- For the whole dataset
- Delivered as covariance matrix of $\mu_i$ (first order)

$$C_{ij} = \sum_k \frac{\partial \mu_i}{\partial S_k} \frac{\partial \mu_j}{\partial S_k} (\delta S_k)^2$$

https://tspace.library.utoronto.ca/snls
Review of systematics

Combined with WMAP7 and BAO (Percival et al., 2010) in FwCDM

<table>
<thead>
<tr>
<th>Contribution to uncertainty on $w$</th>
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</thead>
<tbody>
<tr>
<td>Stat-only</td>
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<tr>
<td>calibration</td>
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<tr>
<td>light curve modeling</td>
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<tr>
<td>Evolution of supernovae</td>
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<td>Host-galaxy</td>
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<td>Correction of Malmquist bias</td>
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<td>Peculiar velocity of low-z</td>
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<td>Core collapse contamination</td>
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</table>
Model uncertainty

- Noise well below the “intrinsic” dispersion of SNe-Ia
- Small redshift-dependent differences
Model differences

### SiFTO vs. SALT2

![Graph showing comparison between SiFTO and SALT2 models](image-url)

- SiFTO stat
- SALT2 stat
Supernovae luminosity evolution

Concern: evolution with environmental parameters

- Redshift-related parameters, e.g. Metallicity
- The most sensitive test at this stage: Compare events at similar redshifts as a function of their environment
- Proxy for the host properties: the galaxy mass (correlates with metallicity: bigger–older)

Introduction of the host mass as a extra parameter

- After stretch correction, SN appears brighter in massive hosts at 4.5σ (Sullivan, 2010)
- Taken into account as an extra parameter in the cosmo fit
- Upper bound on non measurable evolutions included in systematics
Where do calibration uncertainties come from?

For SNLS
- Reliance on secondary standards
- Instrument response comprehension
  - Passbands
  - Response uniformity

Low-z
- U-band anomaly → not used
- Improvement in photometric calibration as modern survey release data
  - photometry comparison shows agreement at 1 to 2%

For SNLS
- Reliance on secondary standards
- Instrument response comprehension
  - Passbands
  - Response uniformity
SED model of the primary standard

- Uncertainty estimated below 1%
- But a tilt on the primary standard color as a consistent redshift-dependent effect on all SN
- Affect directly the cosmology
Can we do better?

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The five years data set

Available datasets

- 450 spectroscopically confirmed SN-Ia
- \( \sim 500 \) in the SDSS
- Statistical constraining power on \( w \): 4.5%
- Current systematics: 5% uncertainty

Collaboration with the SDSS

For a 1000 SNe-Ia Hubble diagram still dominated by statistical uncertainty

- Internal improvements on SNLS
- Intercalibration with SDSS
5 years calibration I/II: Internal SNLS improvements

5-6 independent realizations of the calibration on the course of the survey

- Quantify all internal uncertainties
- RMS < 0.3% in all bands

Ongoing program: direct observations of primary standards

- Observations of 3 CALSPEC primary standard
- Preliminary analysis
- Solar Analogs/White dwarfs
5 years calibration II/II: Inter-calibration with the SDSS

Drastic shortcut
- Inter-calibrating with similar data is easier
- Short observing block
- $\sim 5$ h program on engineering time at CFHT
- 0.5% inter-calibration

Checking of systematics
- Small uniformity problem in the SDSS tertiary catalogs (2%) (Correction proposed)
- Consistency between passbands at the 1nm level

Betoule LPNHE
Polishing methods

Differential photometry without resampling [P. El-Hage (poster)]

- Better error propagation
- Proper motion of stars
- Agreement at the 0.001 level
- Photometry of point-like objects on CCDs matrix well understood

Light-curve fitters validation on realistic simulations

- Understanding remaining problems
- Influence of regularization?
- Influence of uncertainty modeling?
Conclusion

An efficient probe for DE science

- SNLS photometry represents $\sim 1500$ h on a 3.6m
- $a \sim 8\%$ measurement of $w$ when combined to CMB alone

Constraining power hindered by reducible systematics

- Short term: Joint SDSS/SNLS effort
  - Small dedicated calibration programs
  - Polishing work on methods
- Mid-term:
  - Dark Energy Survey (DES)
  - More efficient in red
- Long term:
  - LSST-EUCLID: better situation by survey design (infrared)
  - R&D: Calibration from artificial sources (see e.g. SNDICE poster)
Bibliographie

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<td><strong>Total</strong></td>
<td>±0.005</td>
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MegaCam/Landolt transformations
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What is the exact relation for the primary standard?