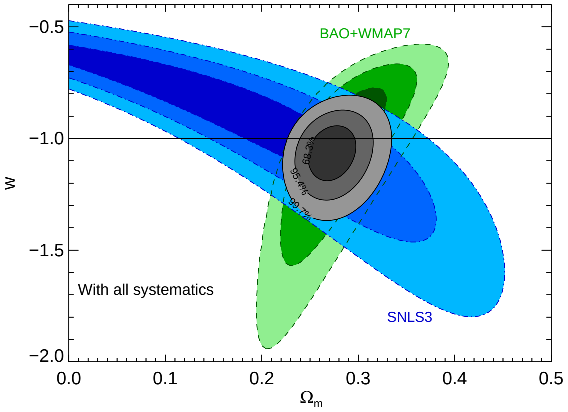
The supernova legacy survey: 3 year results and improvement prospects

Marc Betoule
SNLS collaboration

LPNHE

Rencontres de Blois, May 2012

Importance of type Ia SNe for dark energy science



68.3%, 95.4%, 99.7% confidence contours [Sullivan et al., 2011] (flat wCDM)

Most stringent constraints at that time on w

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

Large influence of systematics

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

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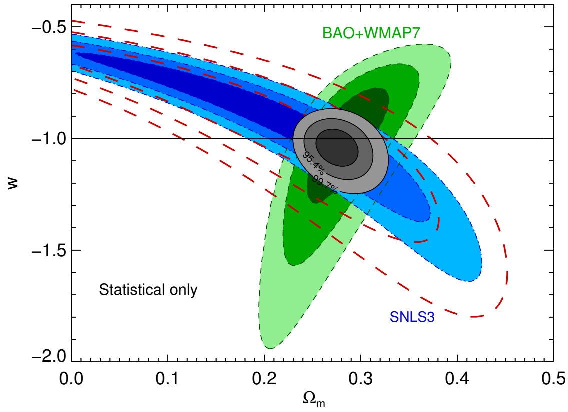

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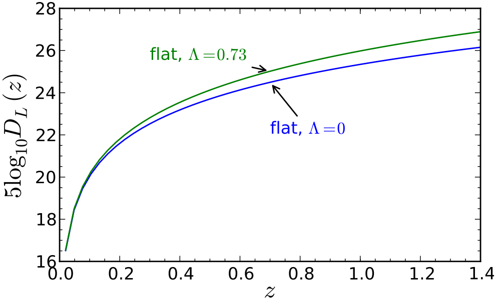
Outline

Cosmology with the Hubble diagram of SN-Ia

"Standardizable" candles probe the expansion history

- Thermo nuclear explosions of White Dwarfs
- Observables: Redshift z / Apparent relative flux
- Noisy Estimates of $D_L(z)$

$$D_L(z) = (1+z)\frac{c}{H_0}\int dz \left(\Omega_m(1+z)^2 + \Omega_k(1+z)^2 + \Omega_x \exp\left(\int_0^z dz' 3\frac{1+w(z')}{1+z'}\right)\right)^{-1/2}$$



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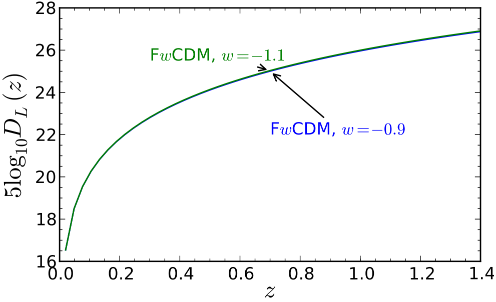

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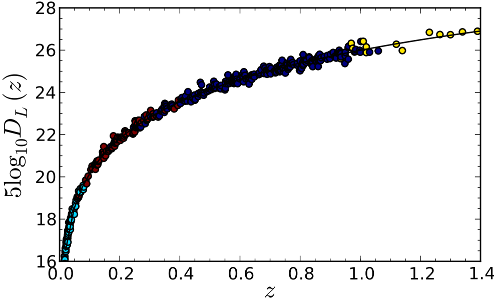
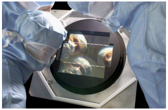


Two challenges

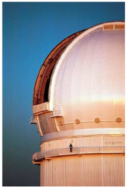
- Many events
- Consistently measured

The Supernovae Legacy Survey



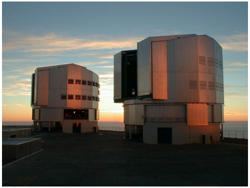
High-z supernovae search during 5 years (2003-2008)

- $0.3 < z < 1.0$
- Deep search in 4×1 deg^2 fields



Photometric survey

- Conducted at the 3.6m CFHT (40 nights/year)
- Rolling search
- Discovery of $\sim$ 2000 SN in image comparison
- Luminosity evolution (light-curve) in 4 bands (*griz*)



Spectroscopic follow-up

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

Outline

3 year analysis ingredients

Changes in 1 → 3 year analysis

1. Extended dataset: 71 → 252 ($0.15 < z < 1$) [Guy et al., 2010]
2. 2 independent analysis (Ca/Fr)
3. 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]
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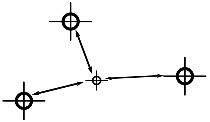
Photometry of SNIa in SNLS

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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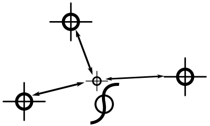

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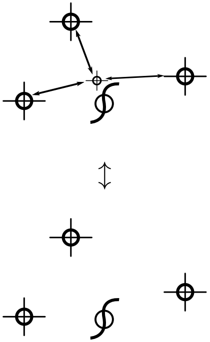
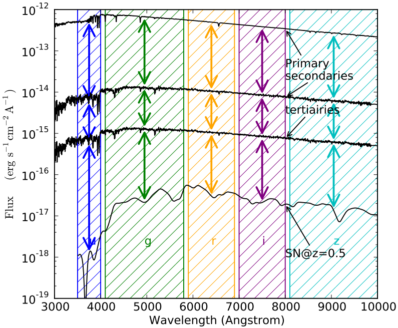


The SNLS photometric calibration



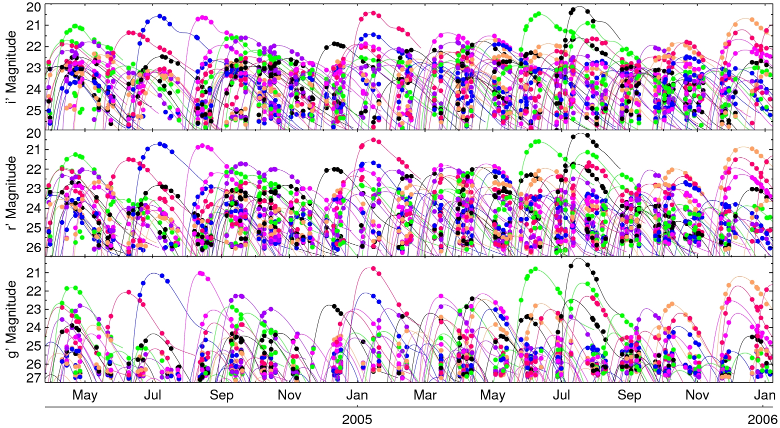
Broadband flux for field stars

- Flux ratio between field stars and primary standard
- Two step process
  - Tertiaries ↔ Secondaries (MegaCam)
  - Secondaries ↔ Primary (Landolt)

Improvements arise from

- Choice of BD+17 rather Vega
  - Directly observed by Landolt
  - Redder (closer in color to average stars and SN)
- Better understanding and characterization of the instrument photometric response.

3 year light curves

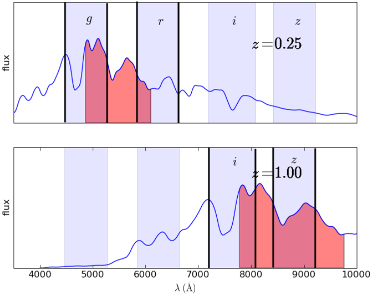


Regularly (every 3/4 days) samples the luminosity evolution of SN-Ia in 4 photometric bands.

Need for a model of the Supernova spectrum evolution

Interpolate between photometric points (in wavelength and time)

- Apparent luminosity *at maximum* and in the *same (rest-frame) photometric band*: m_B
- Color *at maximum*: C
- Time stretch of the light-curve: s



Used to derive (noisy) estimates of $\mu = 5\log_{10}(d_L/10\mathrm{pc})$:

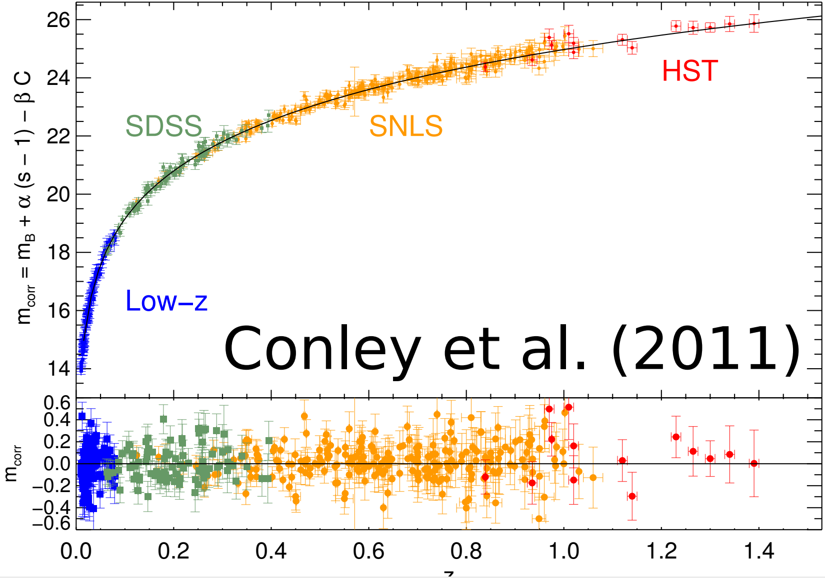
$$\mu(z; cosmo) \approx m_B^* - (M - \alpha s + \beta \mathcal{C})$$

M, α and β are nuisance parameter in the cosmological fit.

Two different models to estimate the resulting uncertainty

- SIFTO: Stretched spectral sequence + color variation
- SALT2: Data driven approach ($\sim$ PCA)

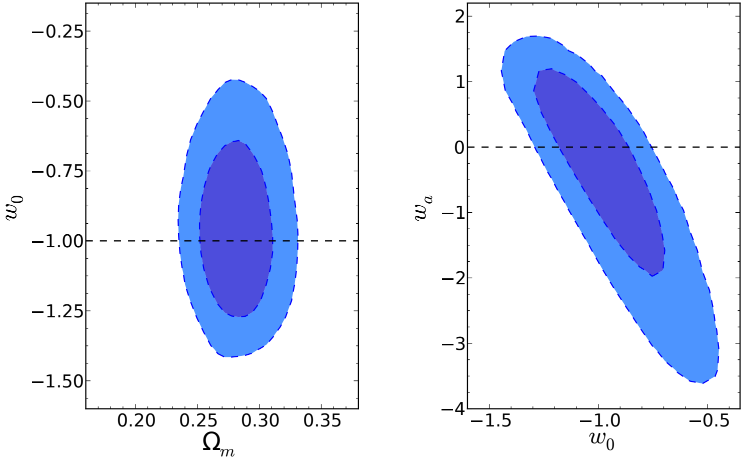
The combined Hubble diagram



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



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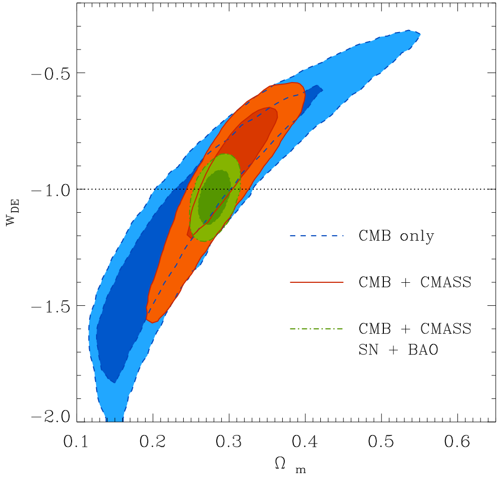
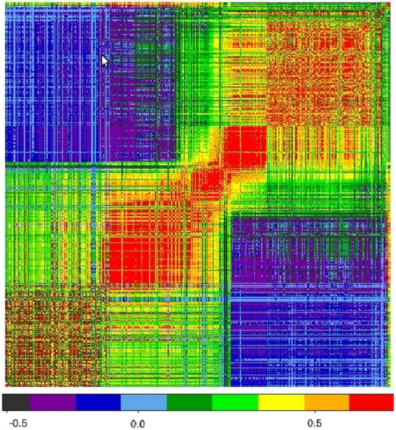


Boss results [Sanchez et al. 2012]

Outline

The distance moduli covariance matrix



https://tspace.library.utoronto.ca/snls

Exhaustive estimation of systematic uncertainties δS_k

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

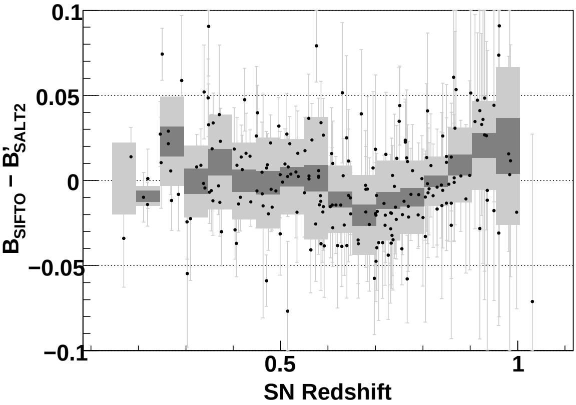
$$C_{ij} = \sum_k \frac{\partial \mu_i}{\partial S_k} \frac{\partial \mu_j}{\partial S_k} (\delta S_k)^2$$

Review of systematics

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

	Contribution to the uncertainty on w
Stat-only	5.4%
calibration	5.4%
light curve modeling	3%
Evolution of supernovae	$< 1\%$
Host-galaxy	$< 1\%$
Correction of Malmquist bias [Perrett et al., 2010]	$< 1\%$
Peculiar velocity of low-z	negligible
Core collapse contamination	negligible

Model uncertainty

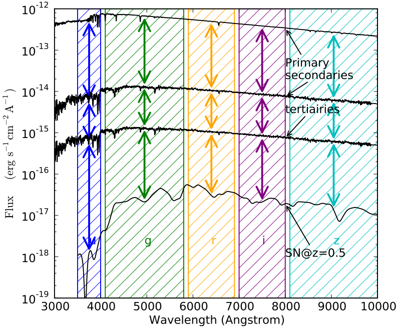


- Noise well below the "intrinsic" dispersion of SNe-Ia
- Small redshift-dependent differences
- Not the dominant systematic for the SNLS analysis

Future surveys

Can reduce the sensitivity to model specifics by extending the wavelength coverage in the infrared

Where do calibration uncertainties come from ?



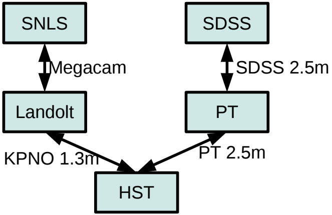
Uncertainty on the Primary standard SED

- Estimated around .3%
- But a tilt on the primary standard color as a consistent redshift-dependent effect on all SN
- Affect directly the cosmology

Uncertainties in the calibration transfer

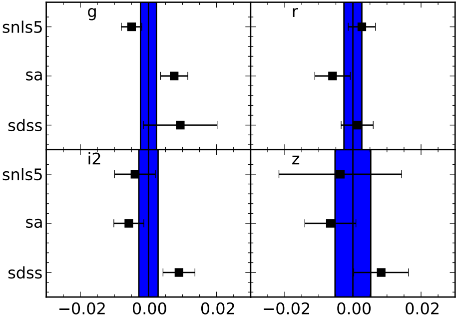
- Depending on the band: .3 to 1.8%
- Instrument response comprehension
  - Passbands
  - Response uniformity
- Different instruments involved

How to improve the calibration



Closing the loop

- 3 independant path
- Do agree within announced error bars



band	combined uncertainties
g	0.002
r	0.003
i2	0.003
z	0.006

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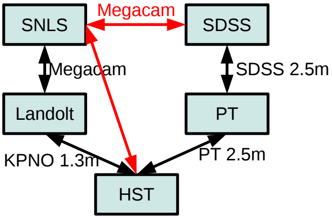

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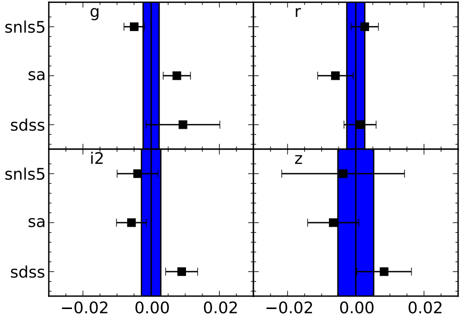

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Conlusion

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

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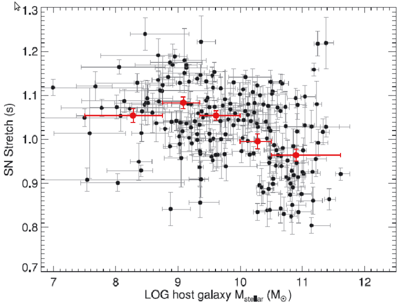
Supernovae luminosity evolution

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)



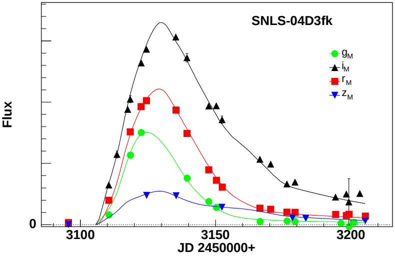
Introduction of the host mass as a extra parameter

- 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

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

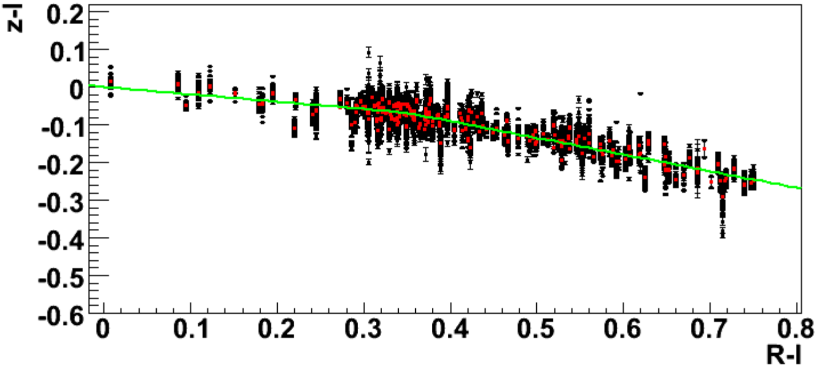
- Trained on SNLS + low-z sample
- Difference provide estimate of systematics

SNLS3: Photometric Calibration

Uncertainty Budget, Regnault et al. (2009)

	g	r	i	z
Zero Points (stat)	± 0.002	± 0.002	± 0.002	± 0.005
Aperture corr.	< 0.001	< 0.001	< 0.001	< 0.001
Background sub	< 0.001	< 0.001	± 0.005	< 0.001
Shutter	± 0.002	± 0.002	± 0.002	± 0.002
Linearity	< 0.001	< 0.001	< 0.001	< 0.001
2nd order airmass corr.	< 0.001	< 0.001	< 0.001	< 0.001
Grid reference colors	< 0.001	< 0.001	< 0.001	< 0.001
Grid color corrs	< 0.001	< 0.001	± 0.002	< 0.001
Landolt catalogs	± 0.001	± 0.001	± 0.001	± 0.002
Magnitudes of BD $+17$	± 0.002	± 0.004	± 0.003	± 0.018
Transfer to SNe	± 0.002	± 0.002	± 0.002	± 0.002
Total	± 0.005	± 0.006	± 0.007	± 0.019

MegaCam/Landolt transformations



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