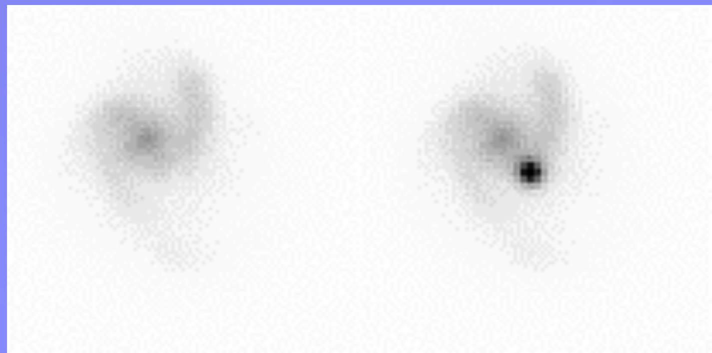
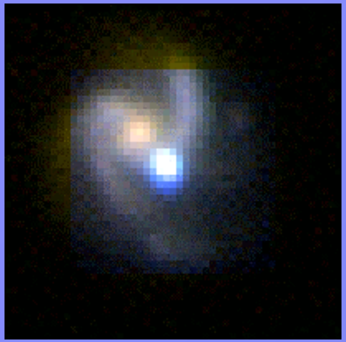
SNLS SuperNova Legacy Survey



http://www.cfht.hawaii.edu/SNLS

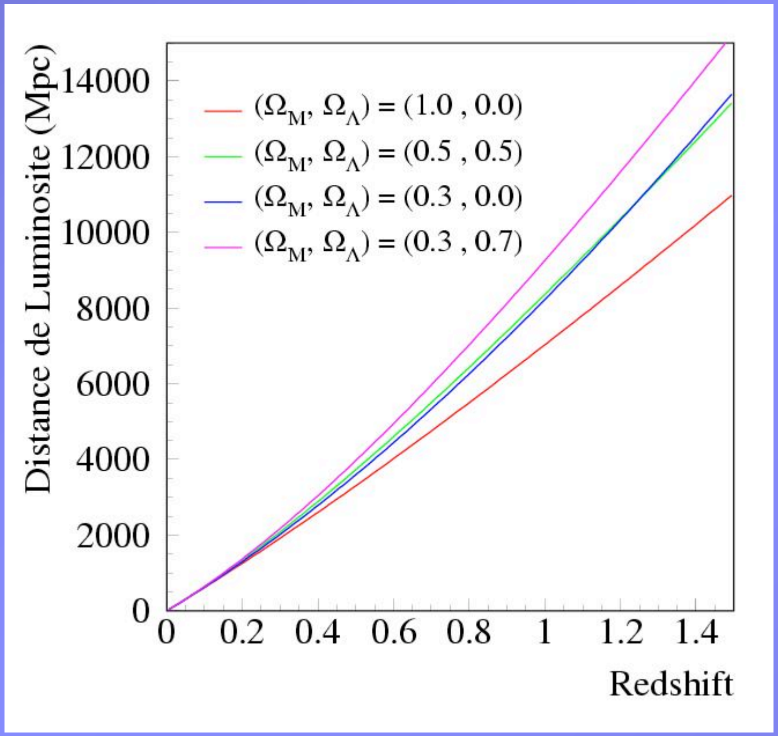
Outline



- SNLS : the SuperNova Legacy Survey
- Cosmological analysis & first results (+3yr update)
- Systematic uncertainties & expected precision

Cosmology with SNe Ia

$$d_L(z) = (1+z)\frac{c}{H_0}\int dz' \left(\Omega_M(1+z')^{-3} + (1-\Omega_M)\frac{\rho_X(z')}{\rho_X(0)}\right)^{-1/2}$$

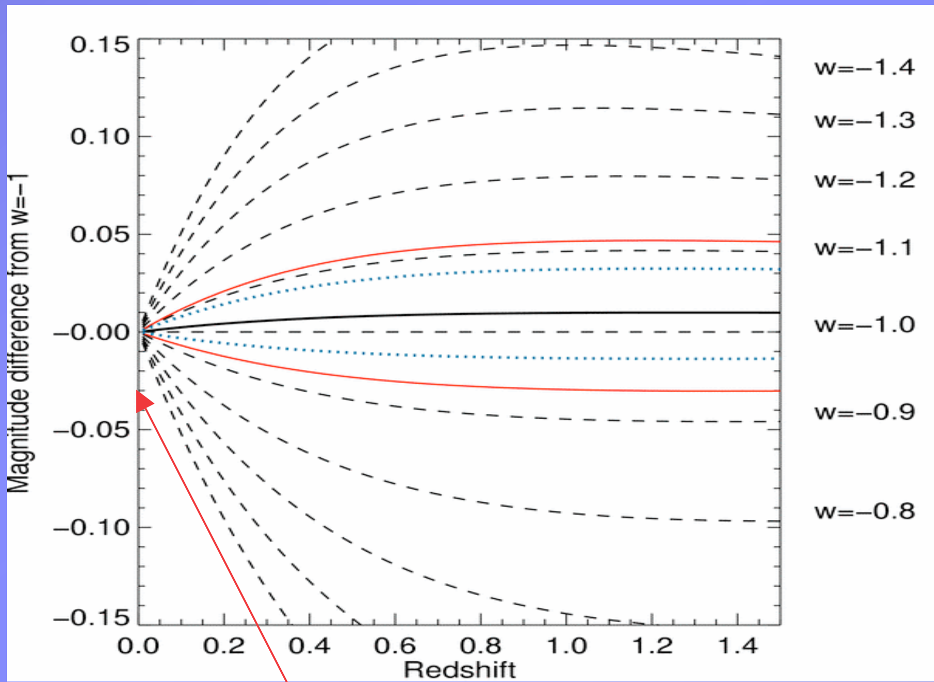


Type Ia Supernovae

What is dark energy ?

$$w = \frac{p}{\rho}$$

$$\rho(z) = \rho_0 \exp\left(\int 3\frac{w(z)+1}{1+z}dz\right)$$



Measurement ingredients:

- Low-z SNe
- High-z SNe => this experiment
- Ω_M prior or constraint => BAO

δw (w=-1) ~ 2 δm

SNLS – The SuperNova Legacy Survey

SNLS Collaboration (as of June 07)

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cea

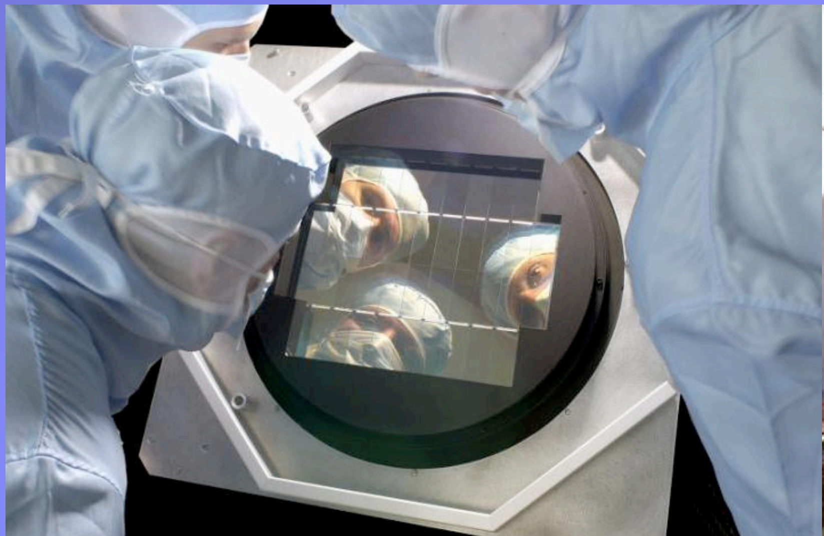
CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

NSERC CRSNG

Imaging survey with Megacam/Megaprime at CFHT

CFHT : ∅ 3.6 m (1979)

Megacam/Megaprime : 1 deg^2 , 36 CCD 2k*4K, = 328 Mpixel



First light : fall 2002

SNLS Imaging Survey : CFHTLS/deep

Part of CFHLS : 470 nights (dark-grey) over 5 years (2003-2008)
= ~50% of total CFHT dark-grey time

Four 1 deg² fields (0226-04, 1000+02, 1419+53, 2215-18)

- 0226-04: XMM deep, VIMOS, SWIRE, GALEX
- 1000+02: Cosmos/ACS, VIMOS, SIRTF, XMM …
- 1419+53: Groth strip, Deep2, ACS …
- 2215-18: XMM deep

- Excellent image quality (0.5-0.6 arc sec.)
- Queue scheduling,
- Excellent temporal sampling
- Depth i’>24.5 (S/N=8, 1 hr);
- r’ > 28 in final stacked image

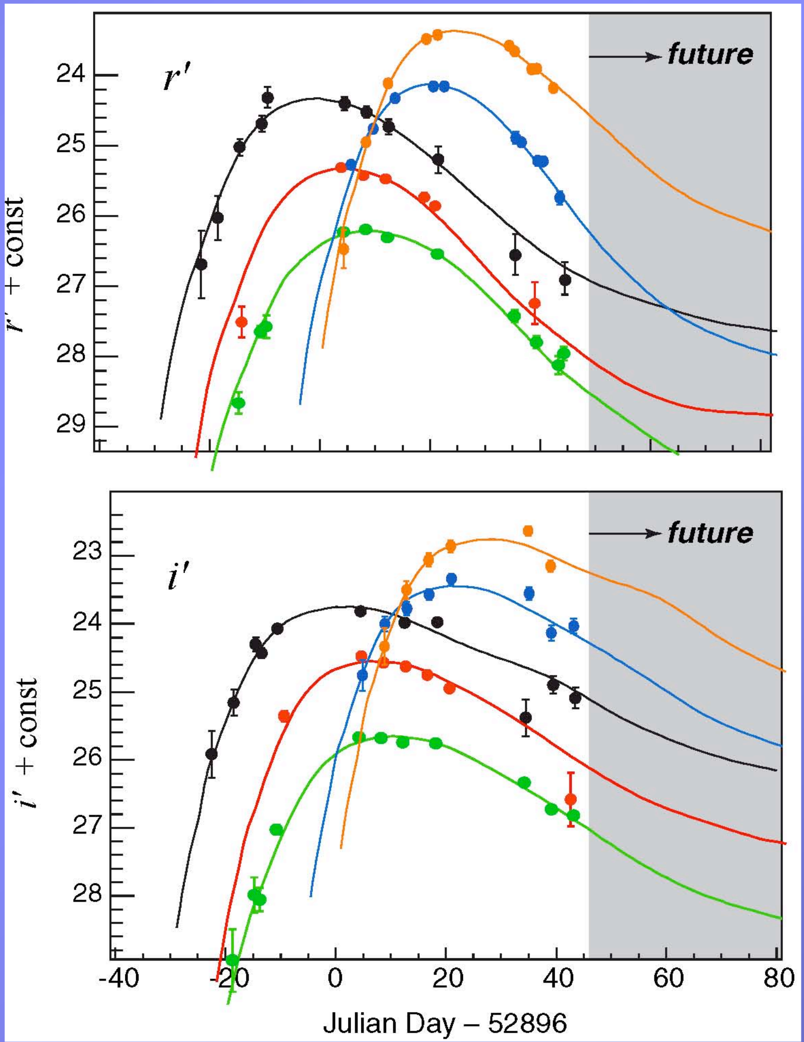
SNLS observing strategy : “Rolling Search”

Each lunation (~18 nights) :
repeated observations
(every 3-4 night) of
2 fields in four bands (griz)+u

for as long as the fields stay
visible (~6 months)

for 5 years

Expected total nb of SN :
~2000 (detected)



SNLS - The Spectroscopic survey

Goals :

- spectral id of SNe up to z~1
- redshift (host galaxy)
- detailled study of a subsample of Ia, Type IIs
  (complementary programs, …)

Where? :

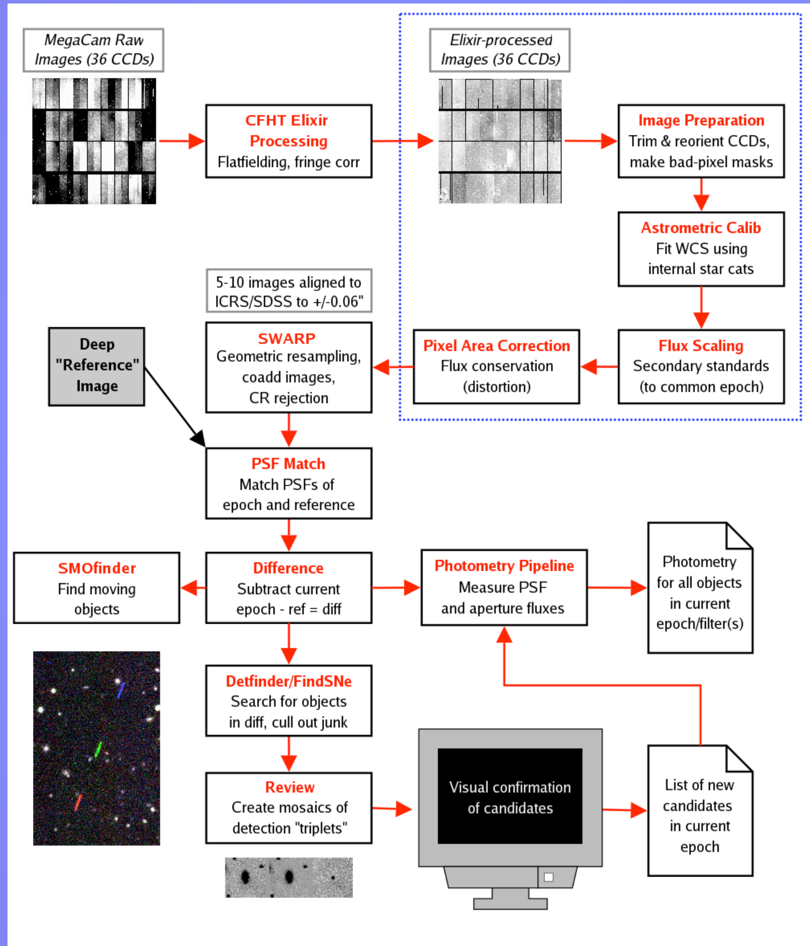
- VLT LPs : 60h/semester
- Gemini : 60h/semester
- Keck : 3n/year (1st semester)

Queue/service observing

"Real time" operations

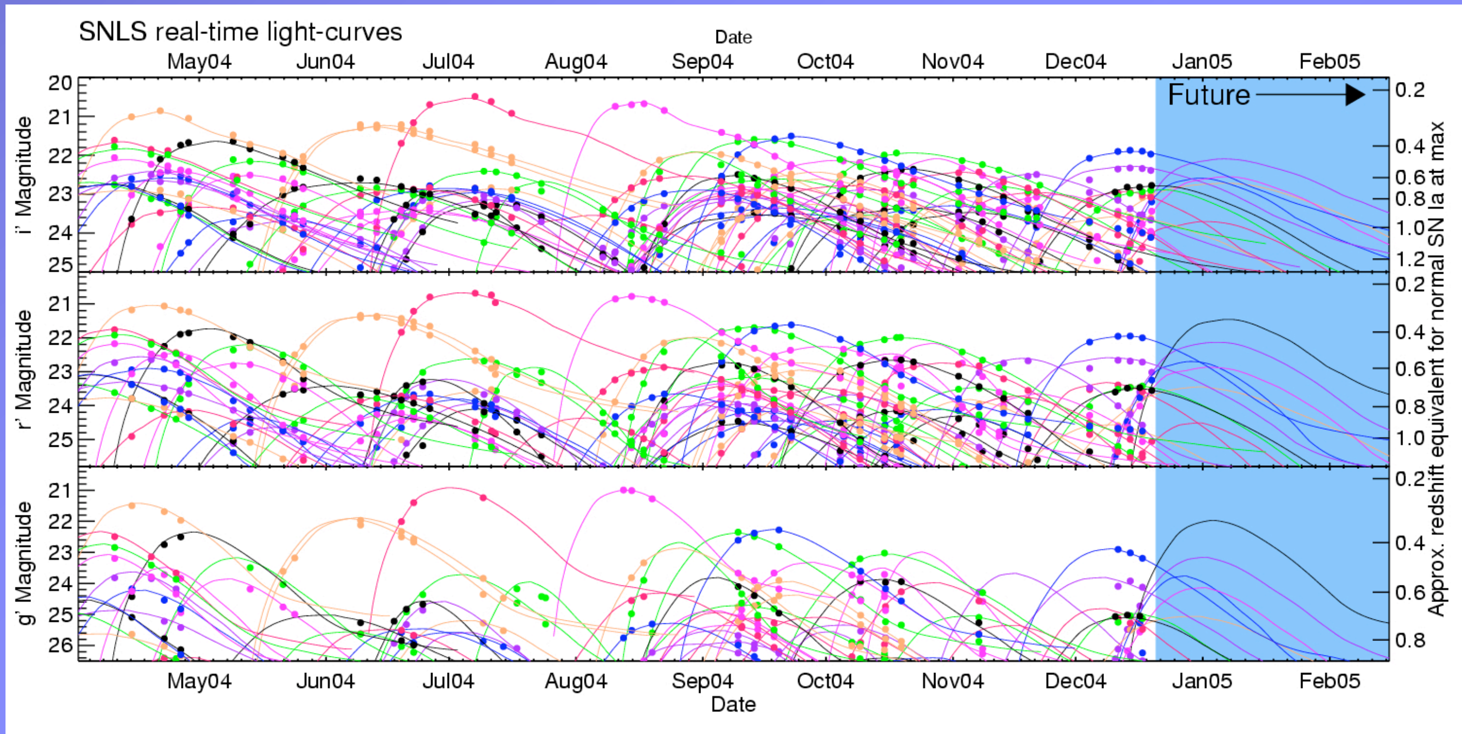
2 search pipelines (C & F) :

- Data stays in Hawaii, remote real-time access
- Short turnaround (6 hr to SN candidates)
- Pipelines output matched (95% overlap m<24.5)
- Candidates to be spectred ranked and dispatched to VLT, Gemini, Keck



SNLS Real Time Imaging

Typical time-sampling and light-curve coverage



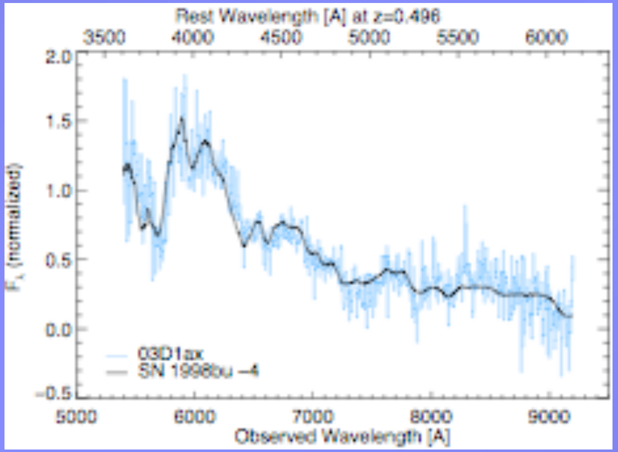
SNLS Real Time Spectral Identification

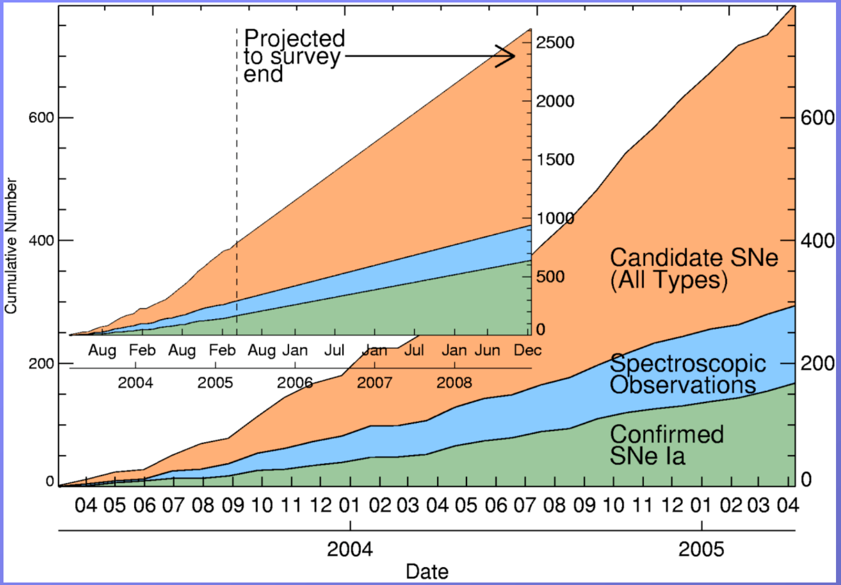
- Get redshift from host galaxy lines/spectrum
- Fit observed spectrum to a model made of SN+galaxy drawn from a database (about 200 templates of SNIa, SNIbc and II + galaxy templates):

$$M(\alpha,\beta,\lambda,z)=\alpha*SN(\lambda(1+z))+\beta*Gal(\lambda(1+z))$$

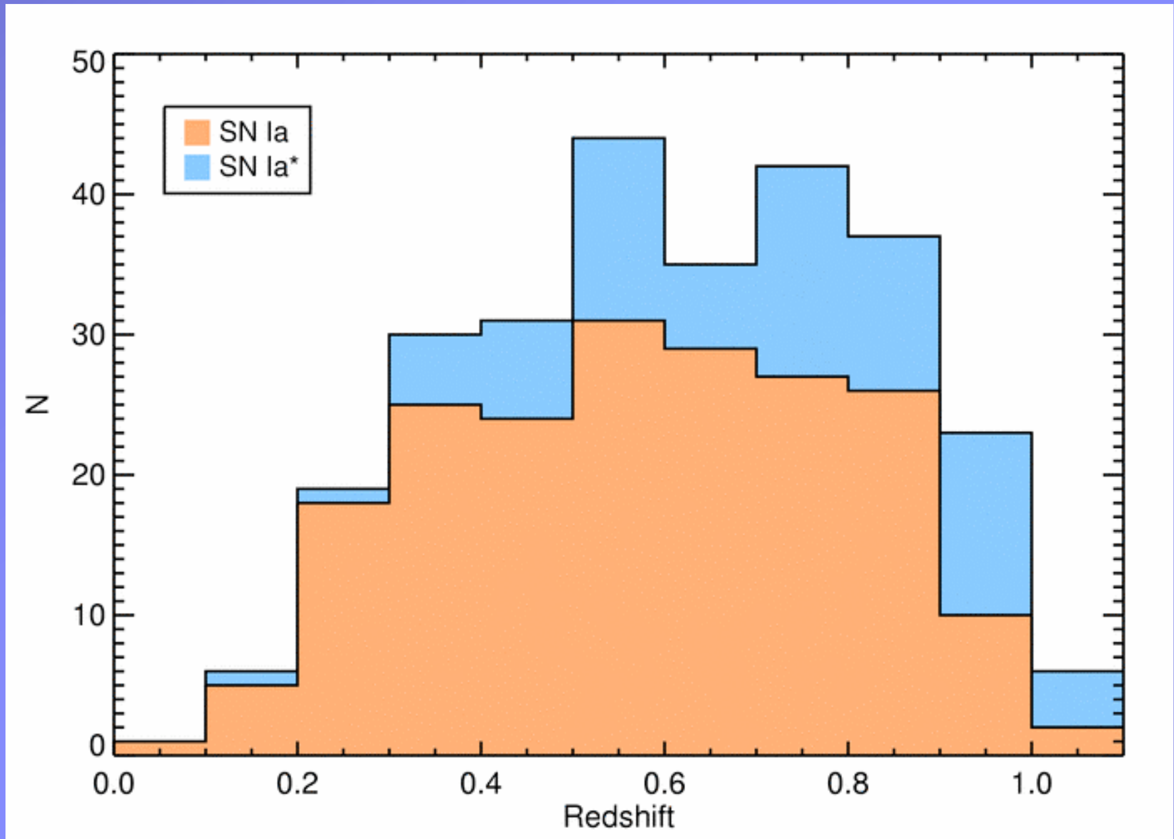
Use host galaxy observation when present

z, id made public within 24h





Redshift distribution (as of Mar 2007)



Cosmology Analysis

-2 independent analysis chains (C &F)

Main analysis steps :

- Differential photometry of SNe (and PSF photom. of stars)
-- Fit of multi-color light curves
- Calibration of Deep fields (anchored to Landolt system)
- cosmology fit
- control/evaluation of possible systematics

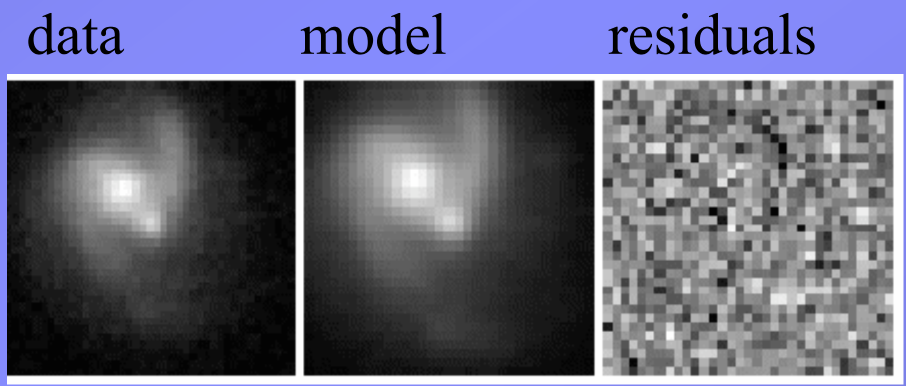
First year data set (published) : 72 high-z Ia analyzed

3 yr data set (up to July 2006) : ~250 Ia on Hubble diagram

Differential Photometry

- Optimal differential photometry:

$$\begin{aligned} I(x,y) &= \text{Flux} \times \left[\text{Kernel} \otimes \text{PSF}_{\text{best}}\right](x - x_{sn}, y - y_{sn}) \\ &\quad + \left[\text{Kernel} \otimes \text{Galaxy}_{\text{best}}\right](x,y) + \text{Sky} \end{aligned}$$



Final uncertainties ~ expected from pure photon statistics

Measurement of SN fluxes

Need a SN spectral model
- as a function of time (time sampling) and wavelength (because of redshift)

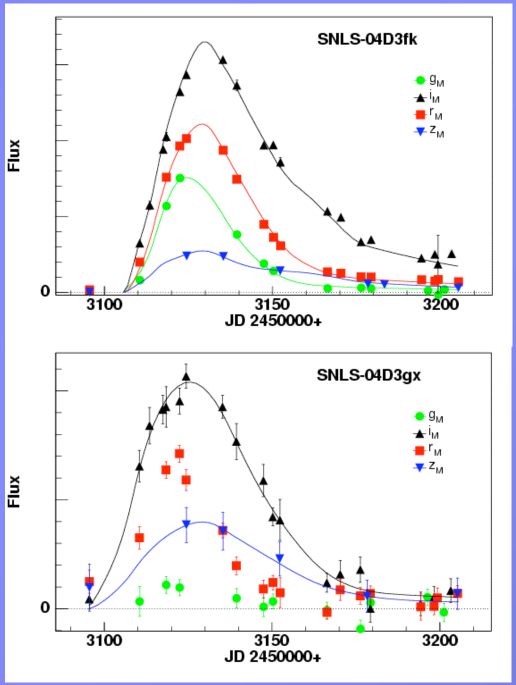
$$f(z, T_{rest}) = 10^{-0.4(m(T_{obs})-m_{ref}(T_{obs}))} \times \frac{\int \phi_{SN}(\lambda) T_{rest}(\lambda) d\lambda}{\int \phi_{SN}(\lambda) T_{obs}(\lambda(1+z)) d\lambda} \int \phi_{ref}(\lambda) T_{obs}(\lambda) d\lambda$$

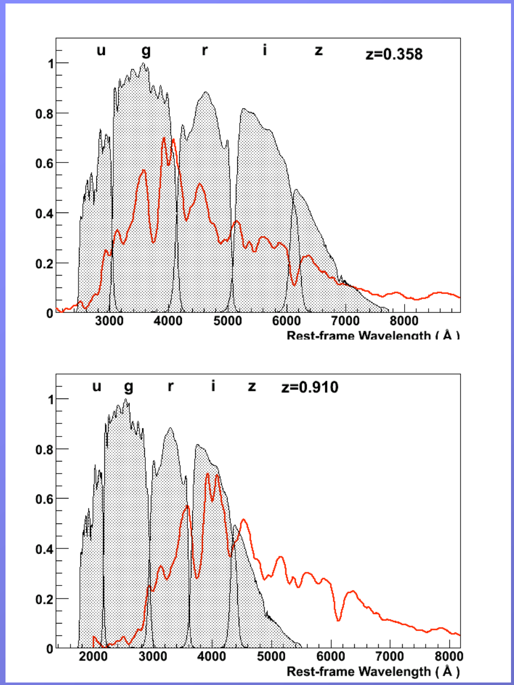
04D3fk at z=0.358

m^*_B=22.532+/- 0.005
s=0.913+/-0.005
c=0.149+/-0.006

04D3gx at z=0.91

m^*_B=24.708+/- 0.094
s=0.952+/-0.047
c=-0.202+/-0.163

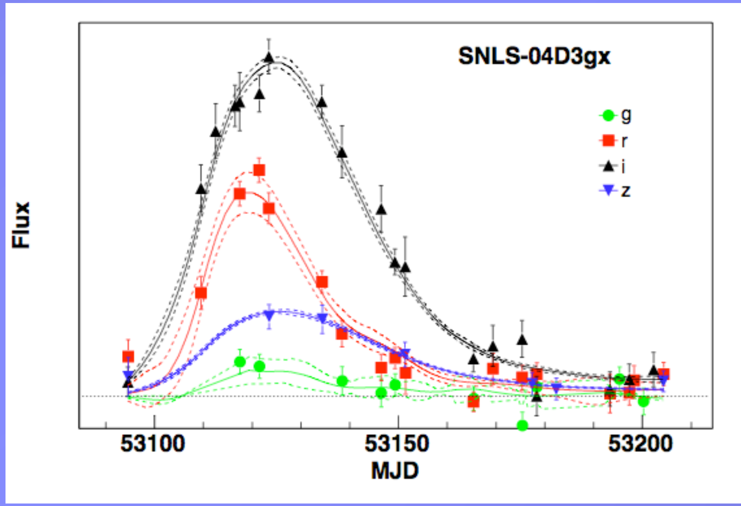


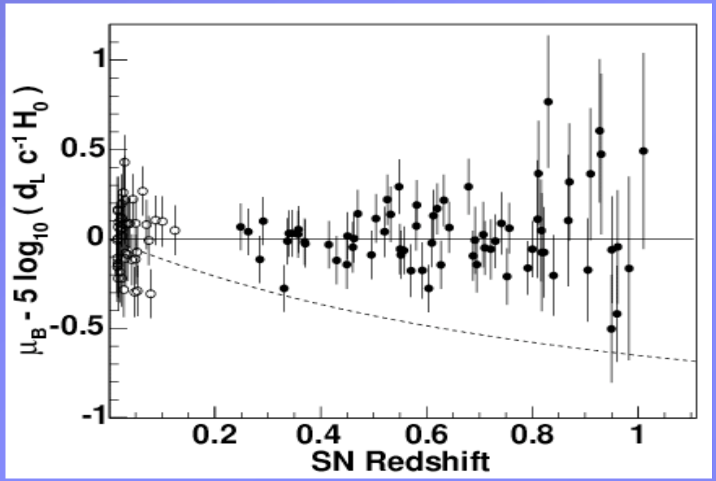


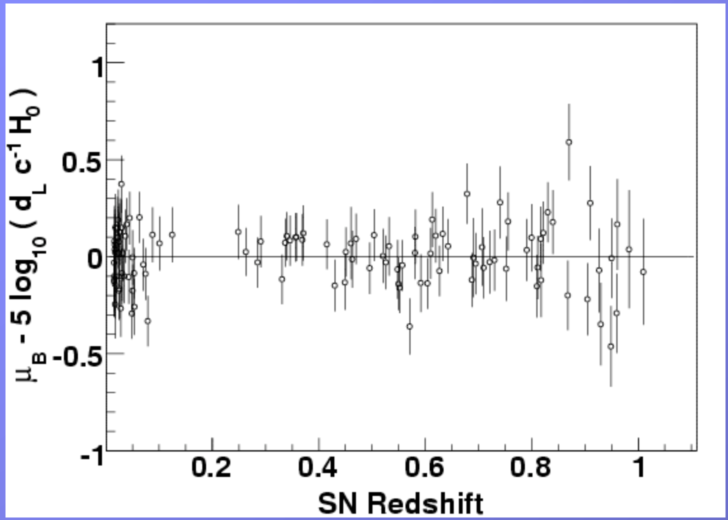
LC modelling does not (necessarily) carry systematic uncertainty:

The model can be adjusted on the survey data itself
-> errors ~ 1/sqrt(N)

Example with SNLS :
(astro-ph/0701828, A&A)







Photometric calibration

Recorded in the detector: ADU

-> physical flux (photons s^{-1} cm^{-2})

2 steps :

1) ADUs -> magnitude :

flux ratios to (secondary) stars calibrated on a primary star

2) magnitude -> flux :

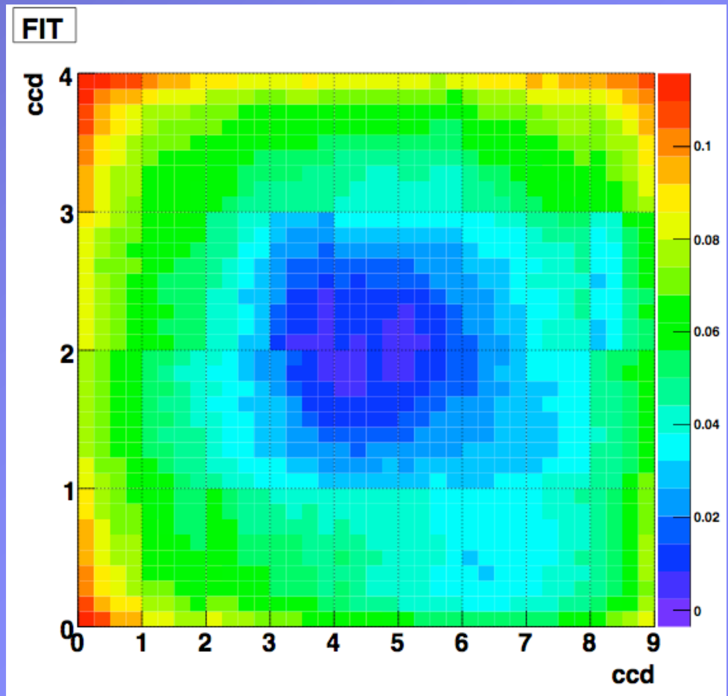
known primary spectrum integrated in the instrument response model

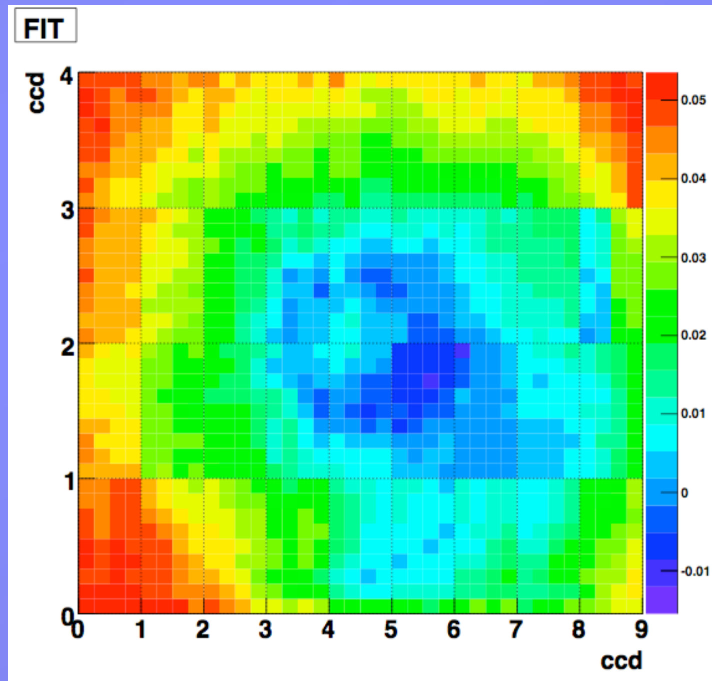
1 2

$$f(z, T_{rest}) = 10^{-0.4(m(T_{obs}) - m_{ref}(T_{obs}))} \times \frac{\int \phi_{SN}(\lambda) T_{rest}(\lambda) d\lambda}{\int \phi_{SN}(\lambda) T_{obs}(\lambda(1+z)) d\lambda} \int \phi_{ref}(\lambda) T_{obs}(\lambda) d\lambda$$

CFHT/Megacam mosaic
« natural » photometric
non uniformity

non uniformity after standard
« flat-field » correction



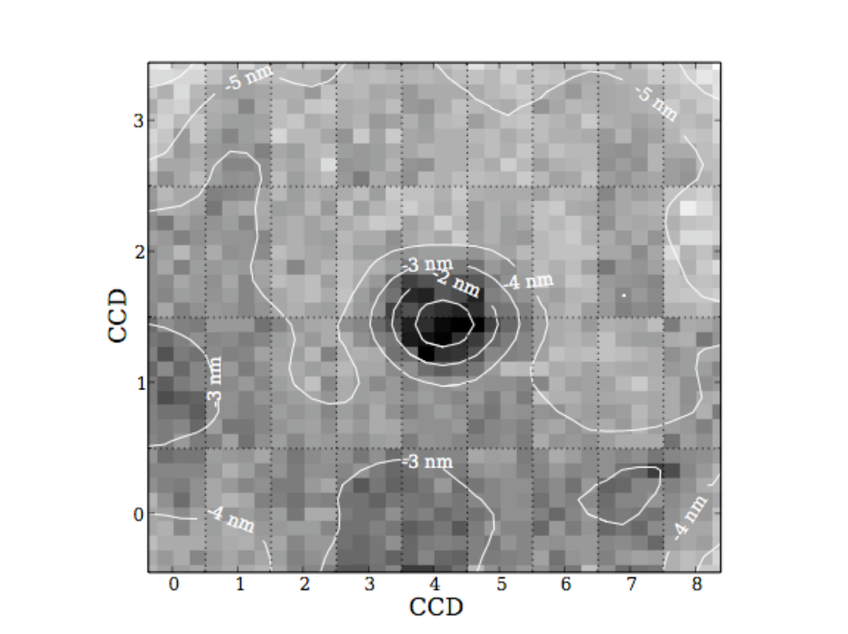


Measured using stars : residual dispersion ~0.02-3

Color non uniformity

Mean effective
(optics+filters+ccd)
color

Ex :g-gr



A few nm shift : marginally acceptable today

δzp~0.005 achievable today

Calibration : reference star

One needs to know the flux ratio of the reference star in 2 distinct filters ex :

$$\left(\frac{d_L(z_2=0.5)}{d_L(z_1=0)}\right)^2 = \frac{f_2(z_2=0.5,\hat{B})}{f_1(z_1=0,\hat{B})}$$
$$= 10^{-0.4\,[m_2(R)-m_1(B)]} \times \frac{\int \phi_{SN}(\lambda)B(\lambda(1+z_1))d\lambda}{\int \phi_{SN}(\lambda)R(\lambda(1+z_2))d\lambda}$$
$$\times 10^{0.4\,[m_{ref}(R)-m_{ref}(B)]} \times \frac{\int \phi_{ref}(\lambda)R(\lambda)d\lambda}{\int \phi_{ref}(\lambda)B(\lambda)d\lambda}$$

→ B-R color of the ref star (Vega)

Today : depends on white dwarf stellar models
-> HST (Bohlin)
-> compatible ~0.01 with black body calibration (Hayes 1985)

Close to the systematic limit:
(B-R) uncertainty of 0.01 <=> ~200 SN at <z>~0.5

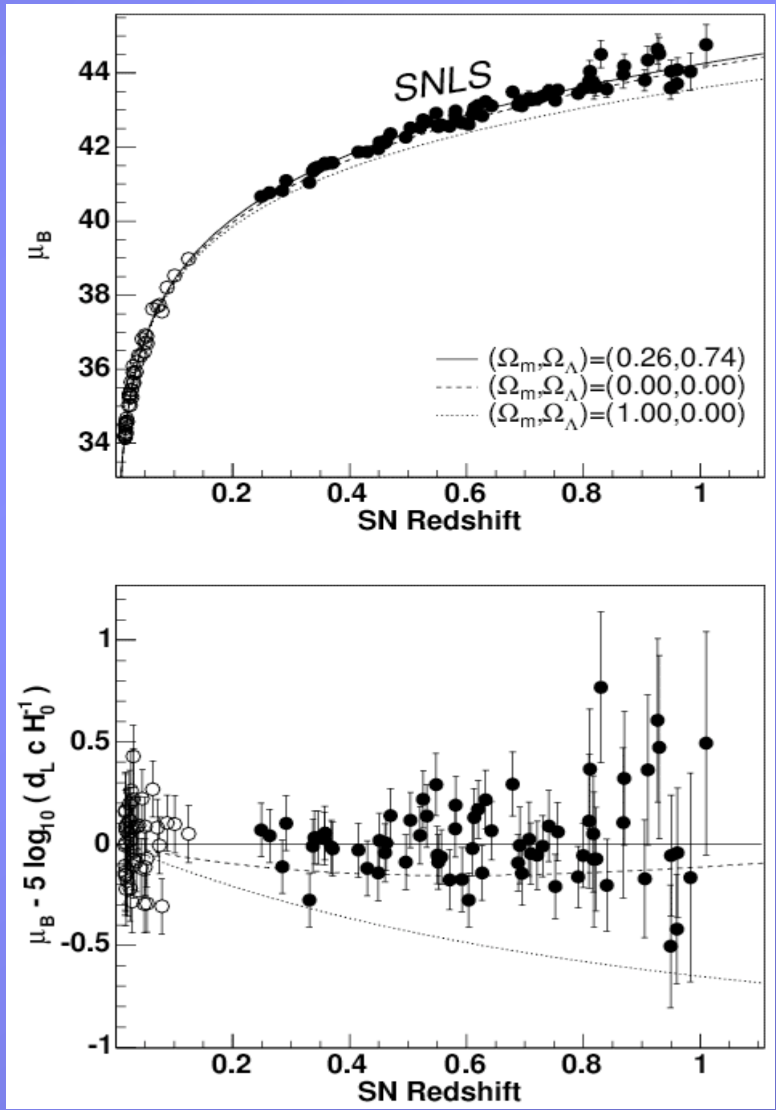
SNLS First year Hubble diagram

Final sample :
45 nearby SN from literature
+71 SNLS SN

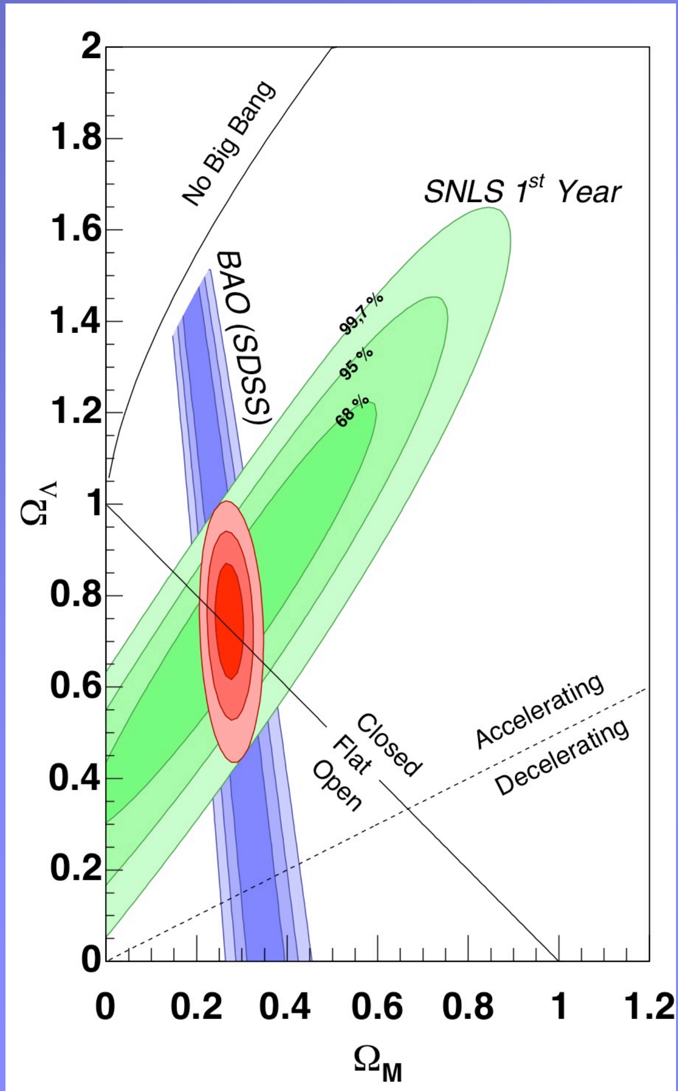
$$\mu_B = m_B^* - \mathcal{M} + \alpha(s-1) - \beta c$$

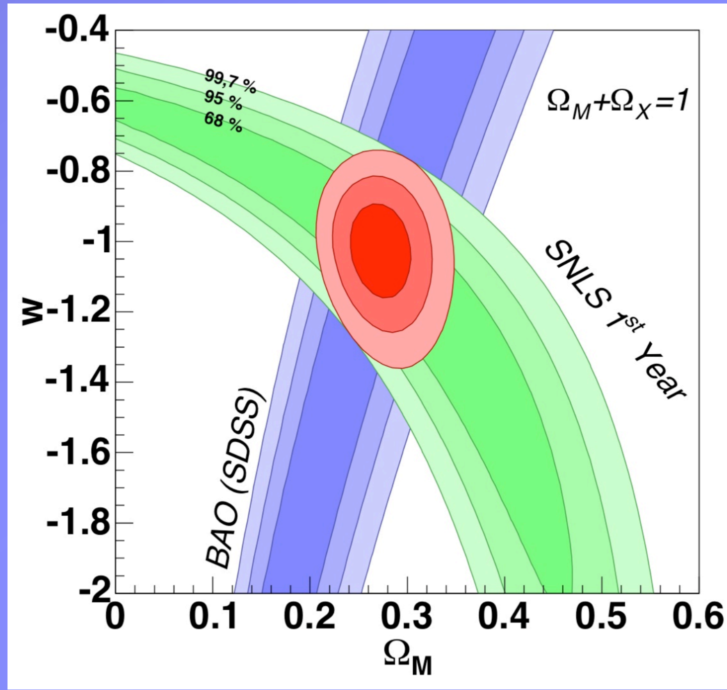
$$\chi^2 = \sum_{objects} \frac{(\mu_B - 5\log_{10}(d_L(\theta,z)/10pc))^2}{\sigma^2(\mu_B) + \sigma_{int}^2}$$

X^2/d.o.f=1 with an additionnal intrinsic dispersion σ_{int}~0.13 mag
(errors take into account covariance matrix of fitted parameters m_B,s,c)



Cosmological parameters (1st year)

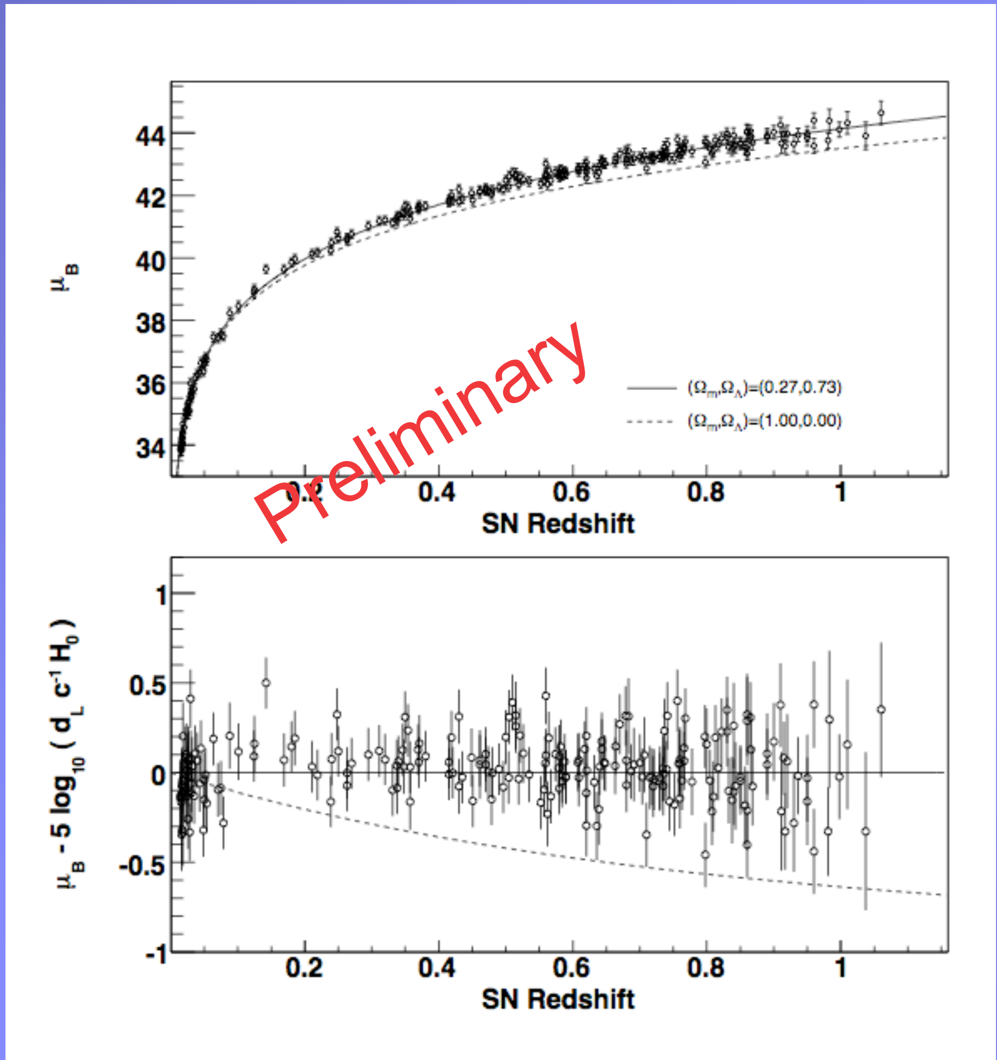




68.3, 95.5 and 99.7% CL
Green SNLS, Blue SDSS/BAO 2005

Ω_M = 0.271 +/- 0.021 (stat) +/- 0.007 (syst)
w = -1.023 +/- 0.090 (stat) +/- 0.054 (syst)

"Third year" SNLS Hubble Diagram



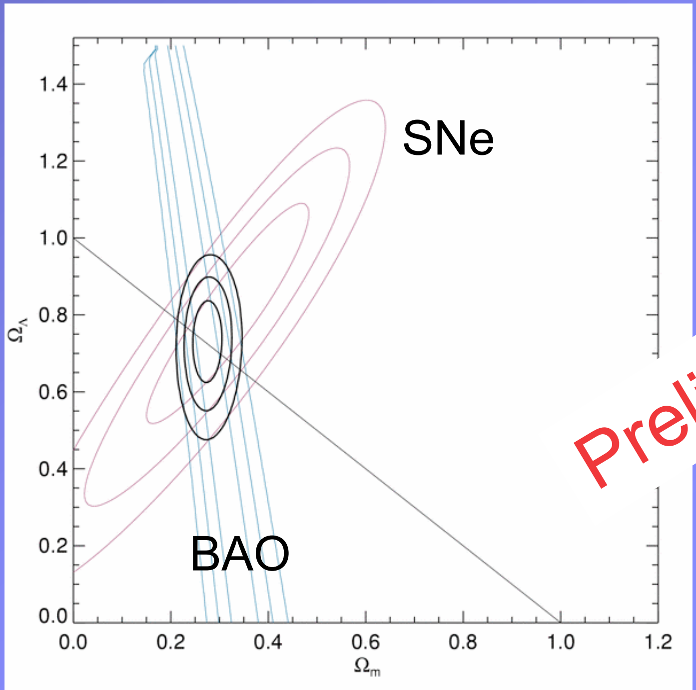
3/5 years of SNLS

~250 distant SNe Ia

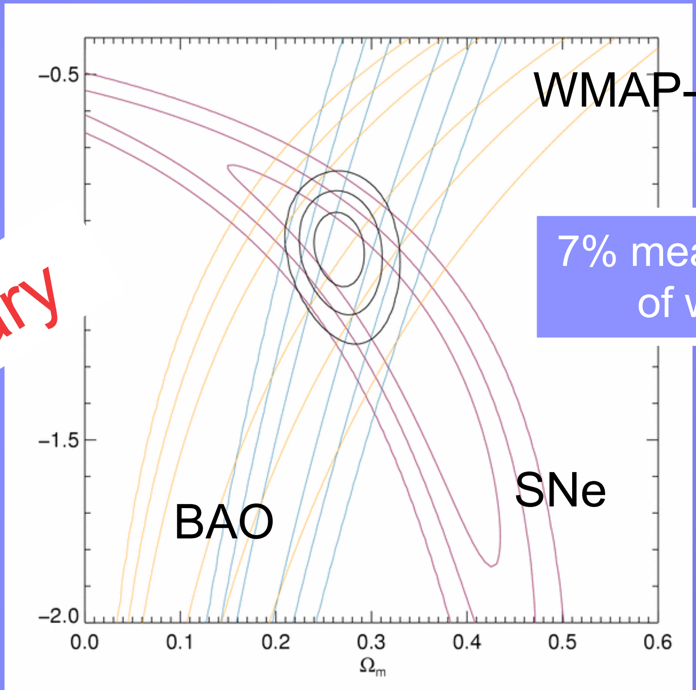
Ω_M=0.3, Ω_Λ=0.7

Ω_M=1.0, Ω_Λ=0

Preliminary 3-yr cosmological Constraints



Preliminary



7% measure of w

SNLS+BAO (No flatness)

SNLS + BAO + simple WMAP + Flat

SNLS 1st yr systematic uncertainties

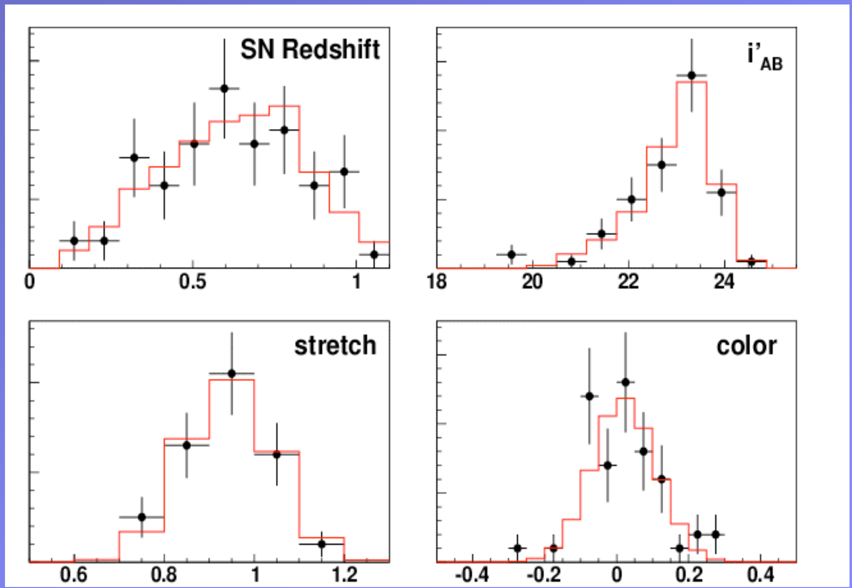
Source	$\sigma(\Omega_M)$ (flat)	$\sigma(\Omega_{tot})$	$\sigma(w)$	$\sigma(\Omega_M)$ (with BAO)	$\sigma(w)$ (with BAO)
Zero-points	0.024	0.51	0.05	0.004	0.040
Vega spectrum	0.012	0.02	0.03	0.003	0.024
Filter bandpasses	0.007	0.01	0.02	0.002	0.013
Malmquist bias	0.016	0.22	0.03	0.004	0.025
Sum (sys)	0.032	0.55	0.07	0.007	0.054
Meas. errors	0.037	0.52	0.09	0.020	0.087
U-B color(stat)	0.020	0.10	0.05	0.003	0.021
Sum (stat)	0.042	0.53	0.10	0.021	0.090

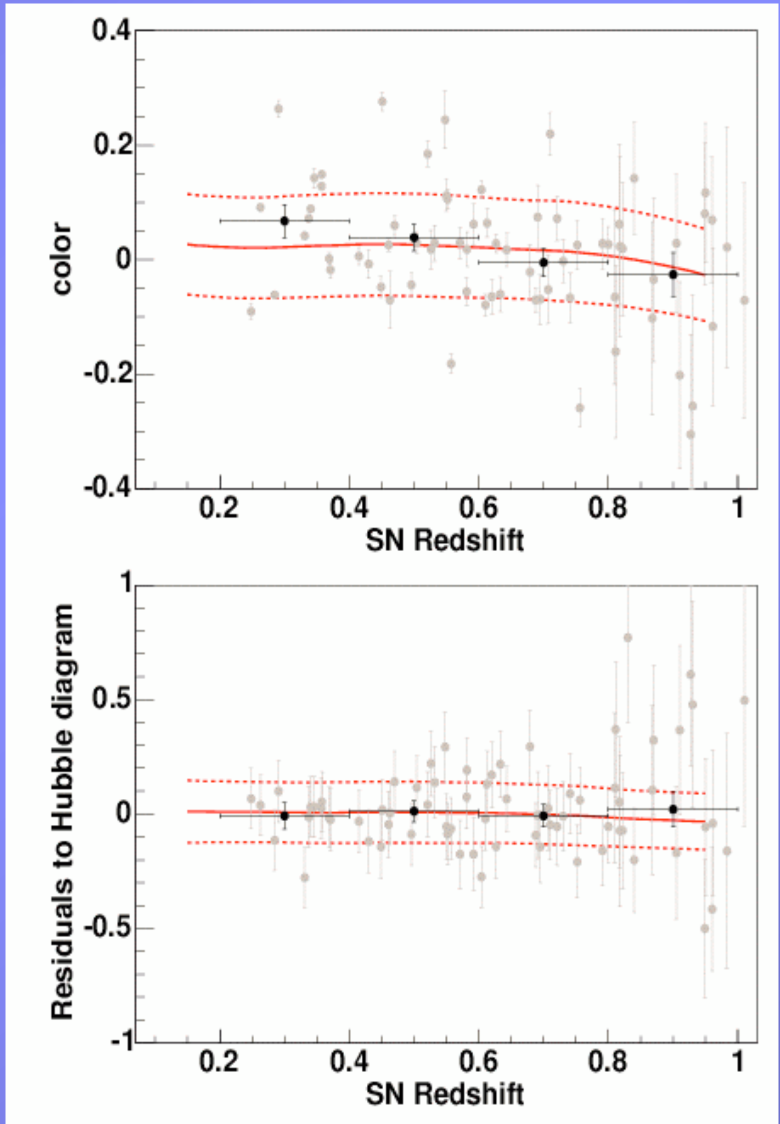
Calibration

Nearby sample !

SN modelling

Systematics : Malmquist Bias





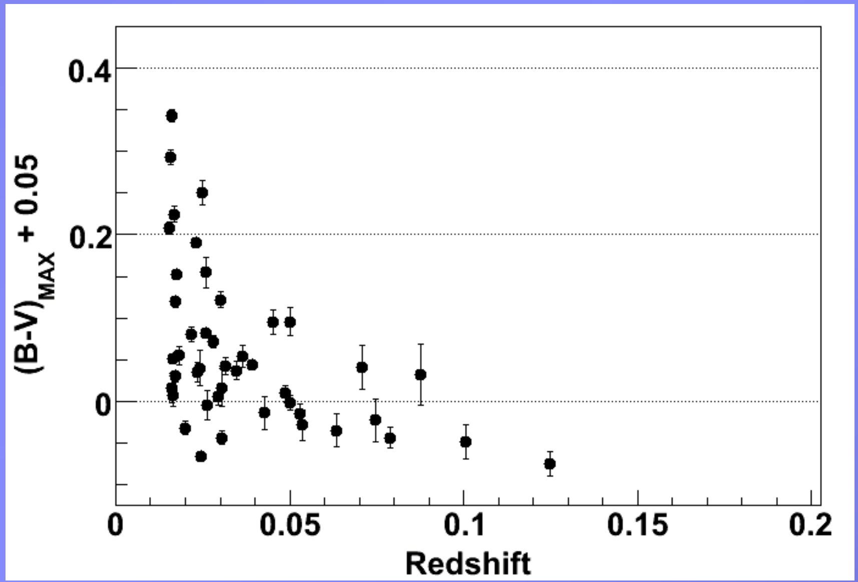
Impact on Ω_m (flat ΛCDM) :

SNLS SNe : - 0.02 +- 0.01

Selection bias in the nearby sample

“easy” to evaluate in SNLS (rolling search, one telescope).

For nearby SNe : sample built from several “surveys”



Becoming today’s largest “systematic” uncertainty
(everybody uses - approximately - the same nearby sample!)

A local Hubble bubble ?

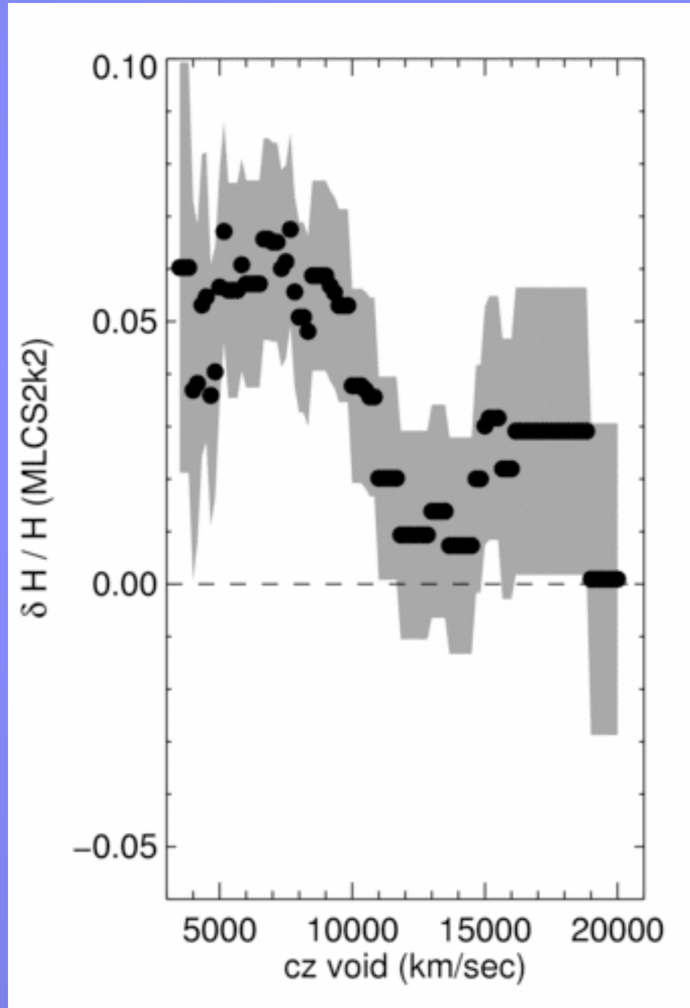
Latest MLCS2k2 paper (Jha 2007)

- MLCS2k2 attempts to separate intrinsic colour-luminosity and reddening

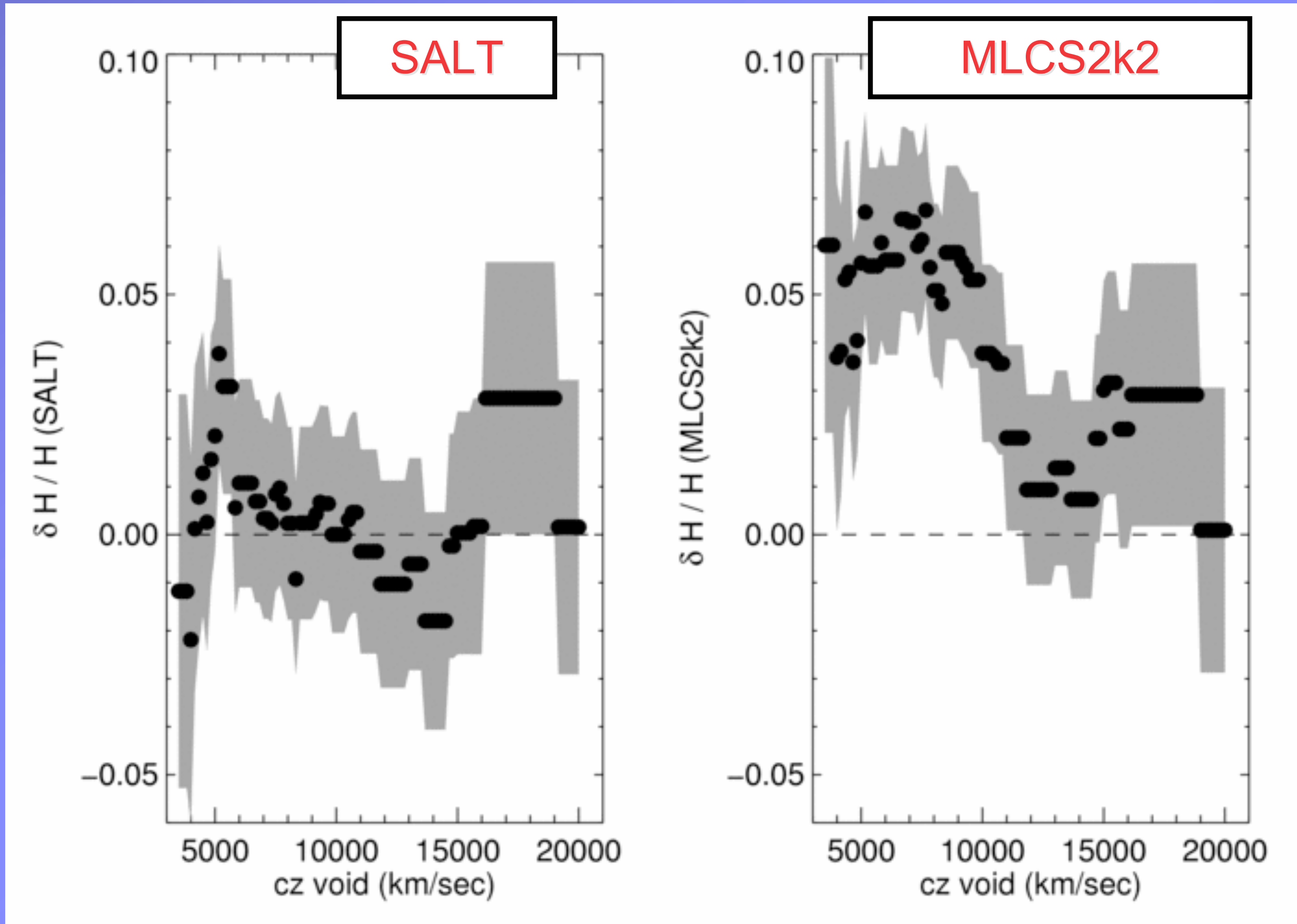
3σ decrease in Hubble constant at ≈7400 km/sec – local value of H_0 high; distant SNe too faint

Local void in mass density?

Could have significant effects on w measurement



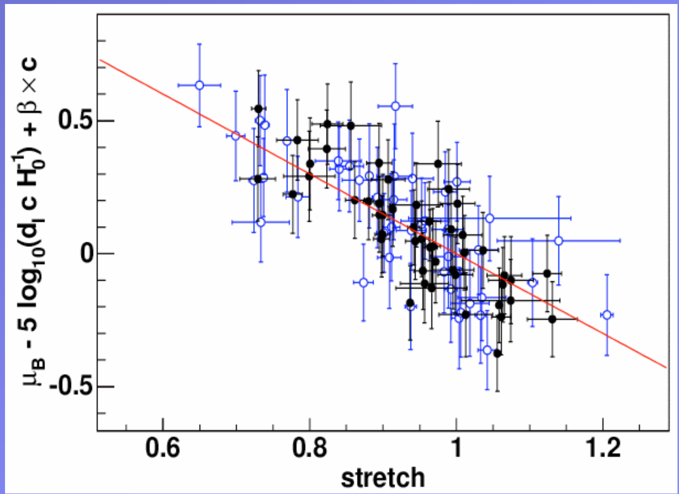
Hubble Bubble or color bias+LC fitter ?



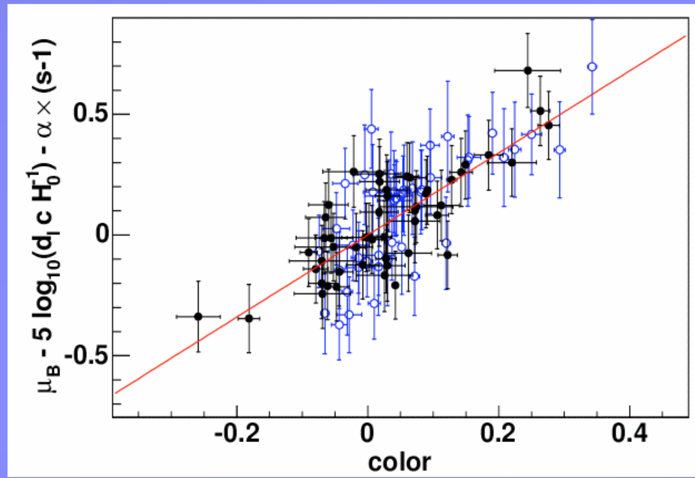
Conley et al. 2007

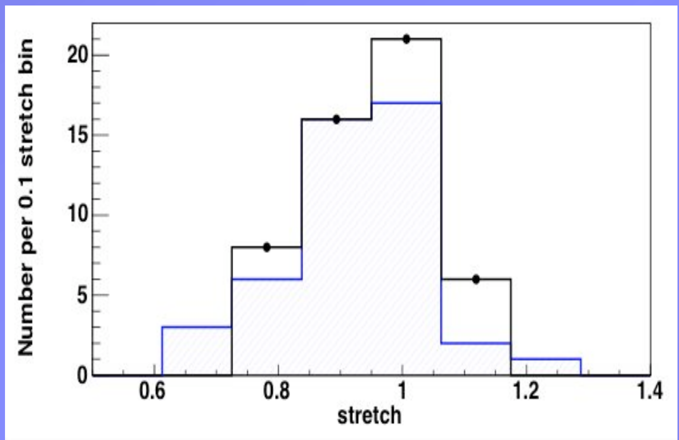
Are local and distant SN Ia alike ?

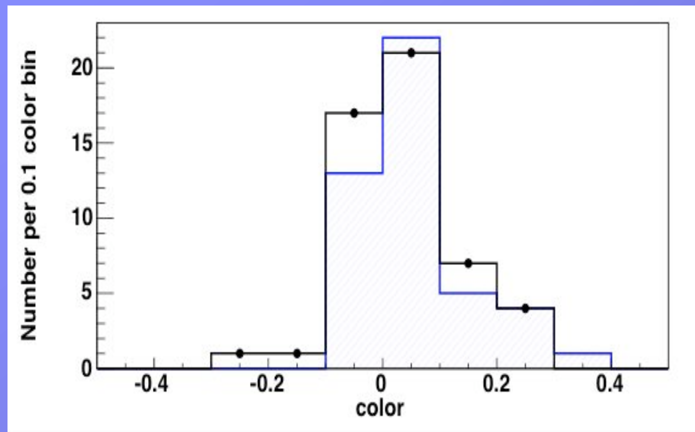
Brighter- Slower



Brighter-Bluer







black: SNLS
blue: Nearby

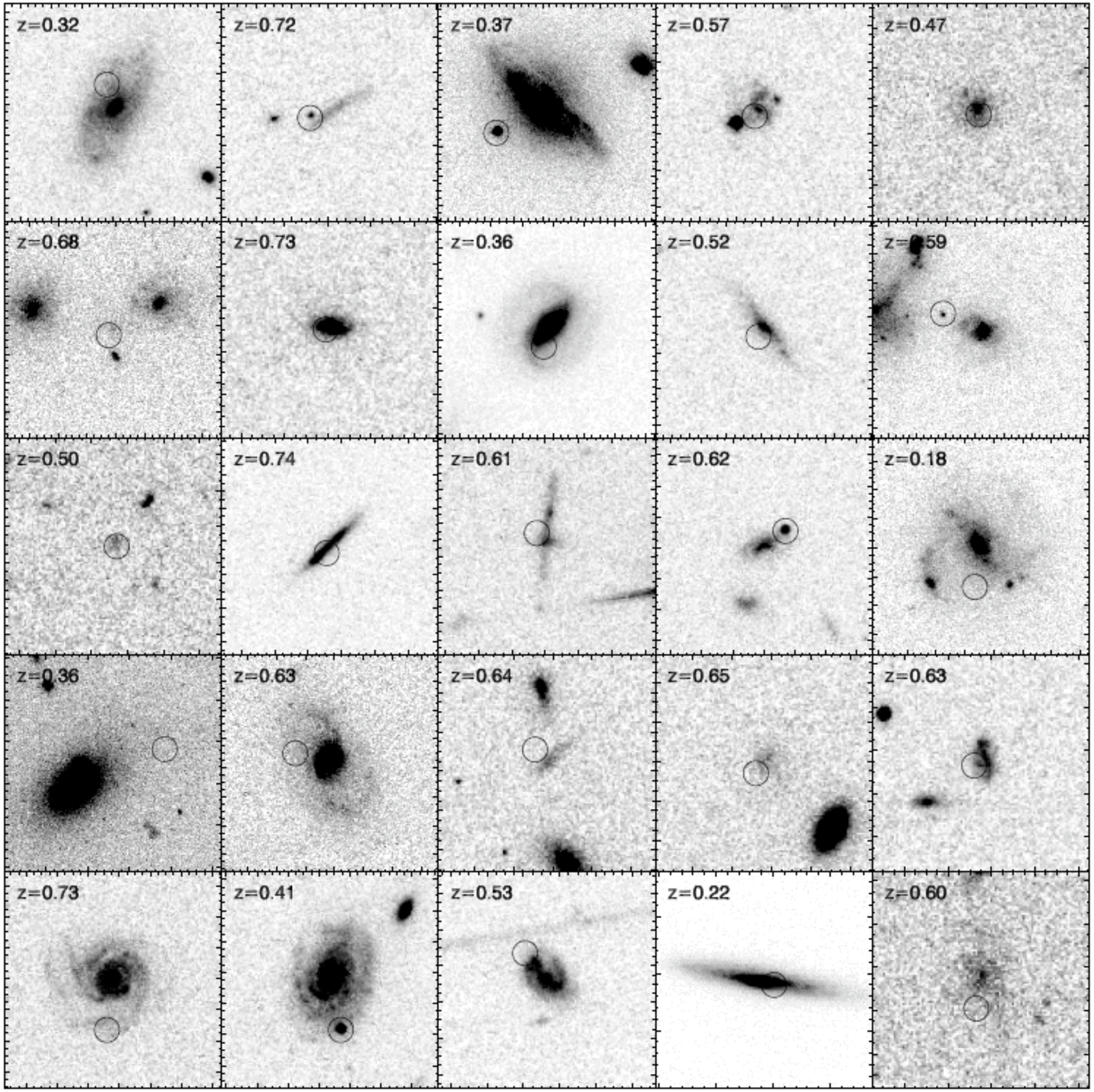
SNLS selection of hosts

D2 ACS imaging

Plenty of irregular/late-type systems

Few genuine ellipiticals

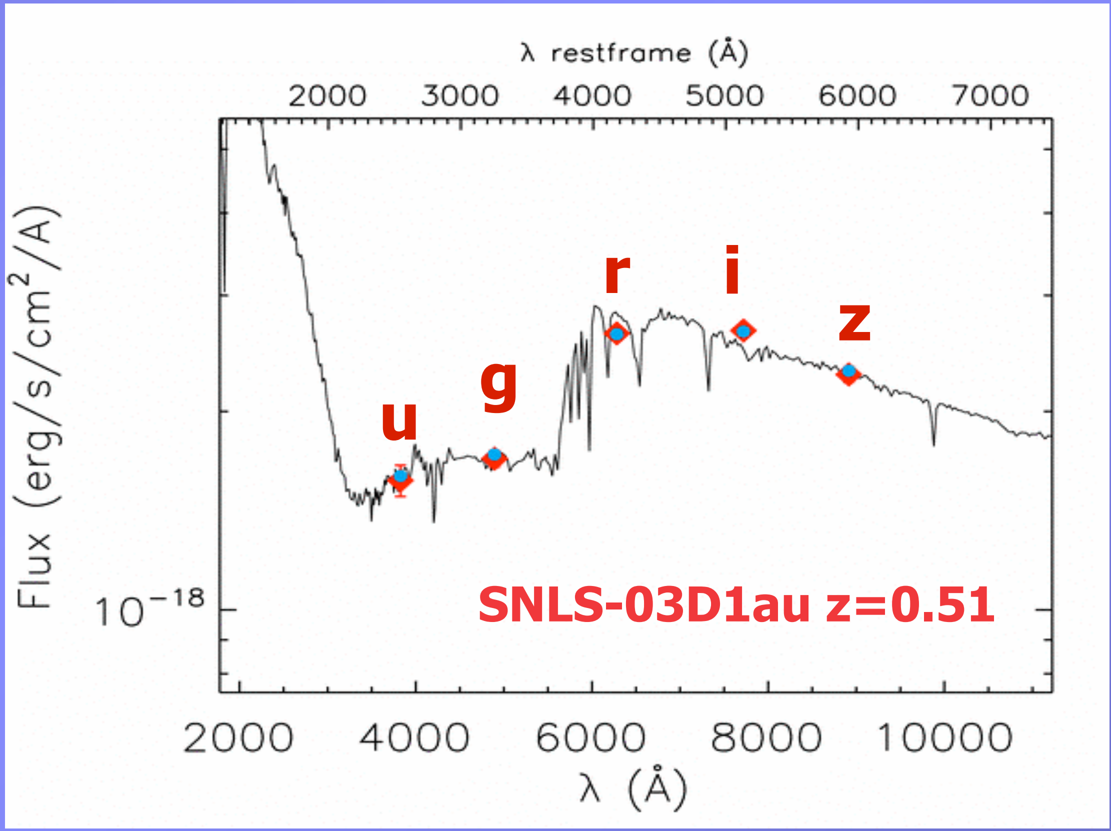
R. Pain



Testing the model: Environmental studies

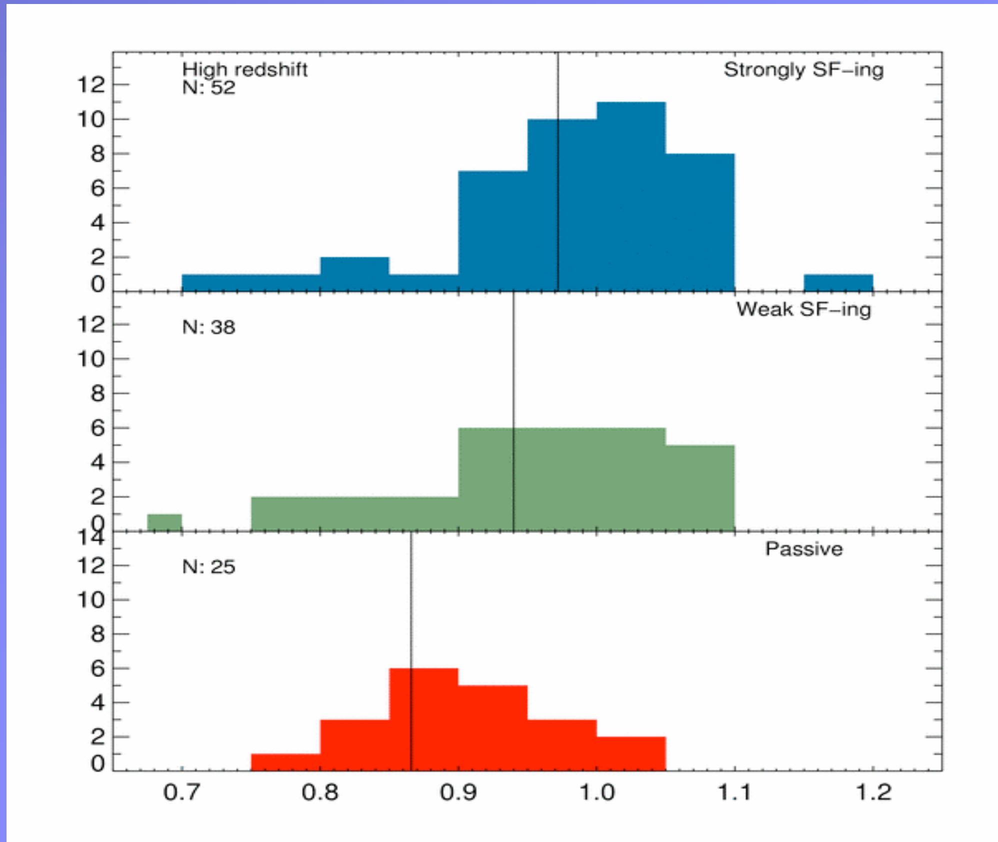
- How do we get host mass and host SFR estimates?

<u>Spectral template fitting:</u>
PEGASE-2 photometric redshift code takes galaxy spectral templates, and fits them to observed magnitudes (ugriz fluxes)



The evolutionary models give us the parameters that define the galaxy SED e.g.
- Integrated stellar mass,
- Average recent star-formation history

Stretch vs environment

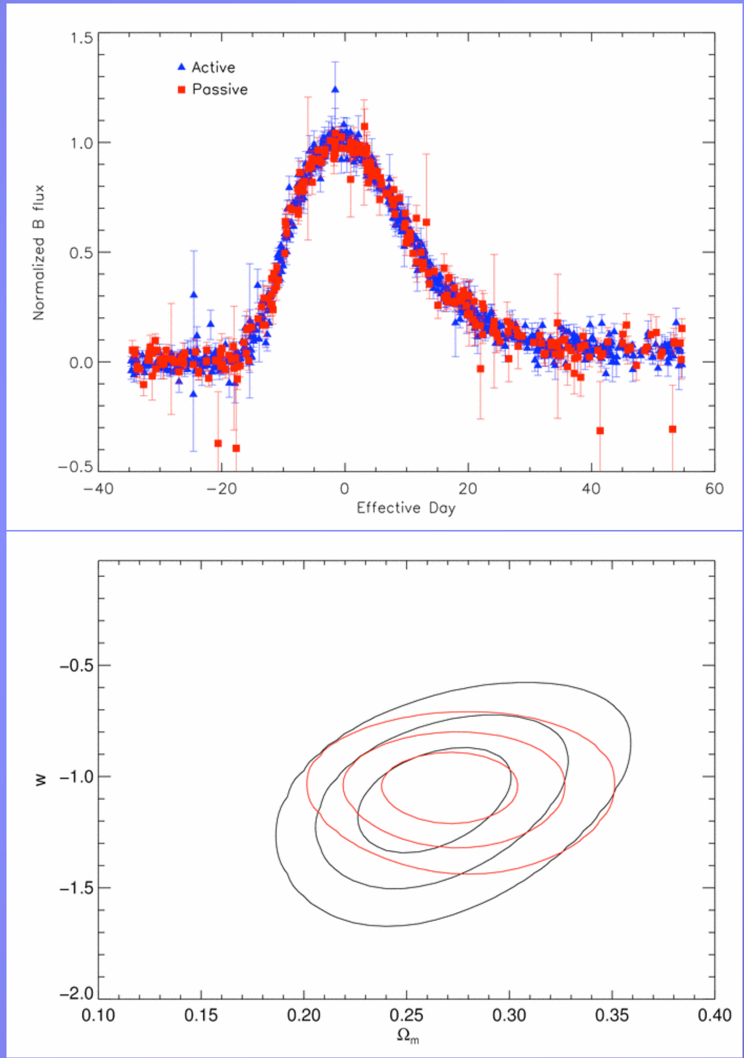


Stretch

←Fainter SNe Brighter SNe →

Environmental differences ?

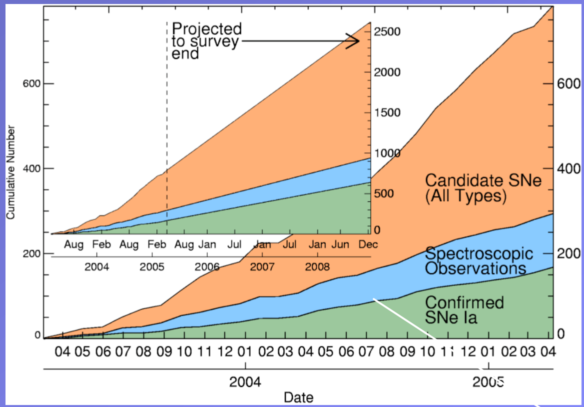
No evidence for differences between light-curves in passive and active galaxies



Black – passive

Red – active

Expected near term precision on w (~2008)



Expected « realistic » statistical improvements on Ω_M and w

KAIT+CFA+CSP+ SNF/(SDSS)

# nearby SNe	44	44	132
# distant SNe	71	213	500
$\sigma\Omega_M$ (current BAO)	0.023	0.019	0.018
σw (current BAO)	0.088	0.064	0.055
$\sigma\Omega_M$ (BAOx2)	0.016	0.014	0.013
σw (BAOx2)	0.081	0.054	0.044

+ systematics…

Conclusions 1/2

SNLS first year data (combined with low-z SNe and BAO) gives

- w (constant, flat) ~ -1 with δw(stat.)~0.10
- no significant constraint on w'

3yr update soon to come with ~30% improved statistical and systematic uncertainties. The dominant systematics comes from Neaby SN sample.

Expected precision on w(const.) by SNLS end (2008-9) :

+/- 0.04-5 (stat) and +/-0.05 (syst)

Conclusions 2/2

Lessons for future high-z SN projects:

More and better quality nearby SNe (badly) needed

Statistics matters: most of the (known) “systematic uncertainties” are not “systematics” since they can (in principle) be reduced with high statistics of both low- and high-redshift (well measured) SNe

Need to improve the photometric calibration uncertainty:
- internal (uniformity & stability)
- “external” (primary standard or physical (B-R))

which both will need to be controlled/understood at ~0.1% (~1% today)