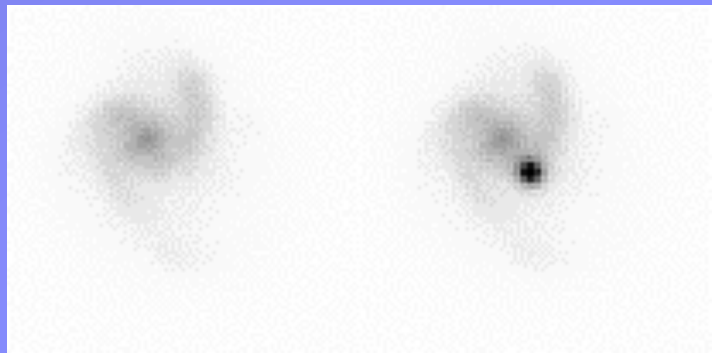
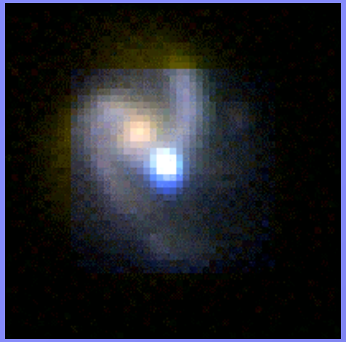
Probing Dark Energy with Supernovae



Reynald Pain
LPNHE, CNRS/IN2P3 & Univ. Paris 6, France

Outline



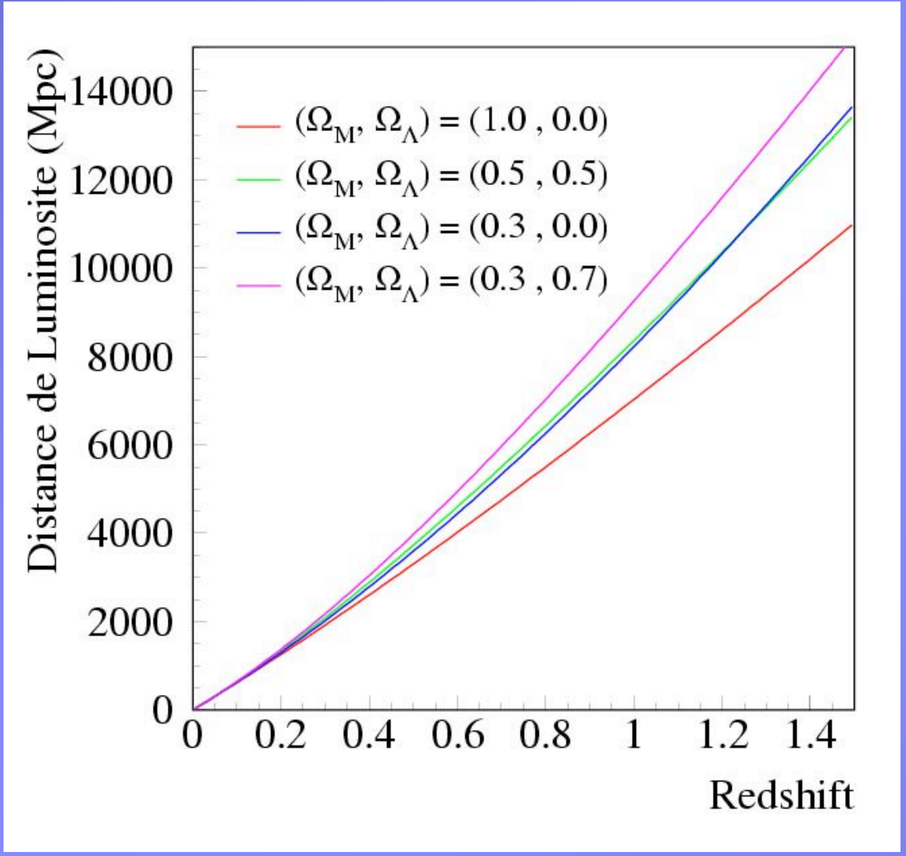
- Why/how supernovae ?
- Past and more recent SN constraints
- 2nd Generation programs: ESSENCE, SNLS, SLOAN/SN
- Expected constraints from future SN programs

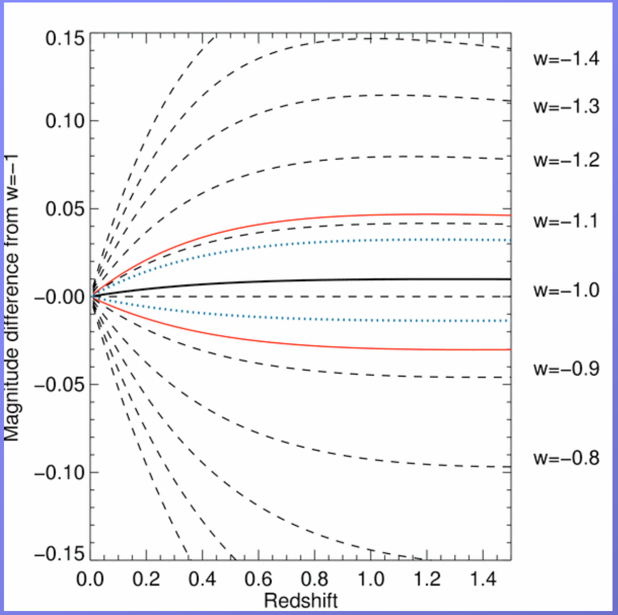
Cosmology with SNe Ia

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

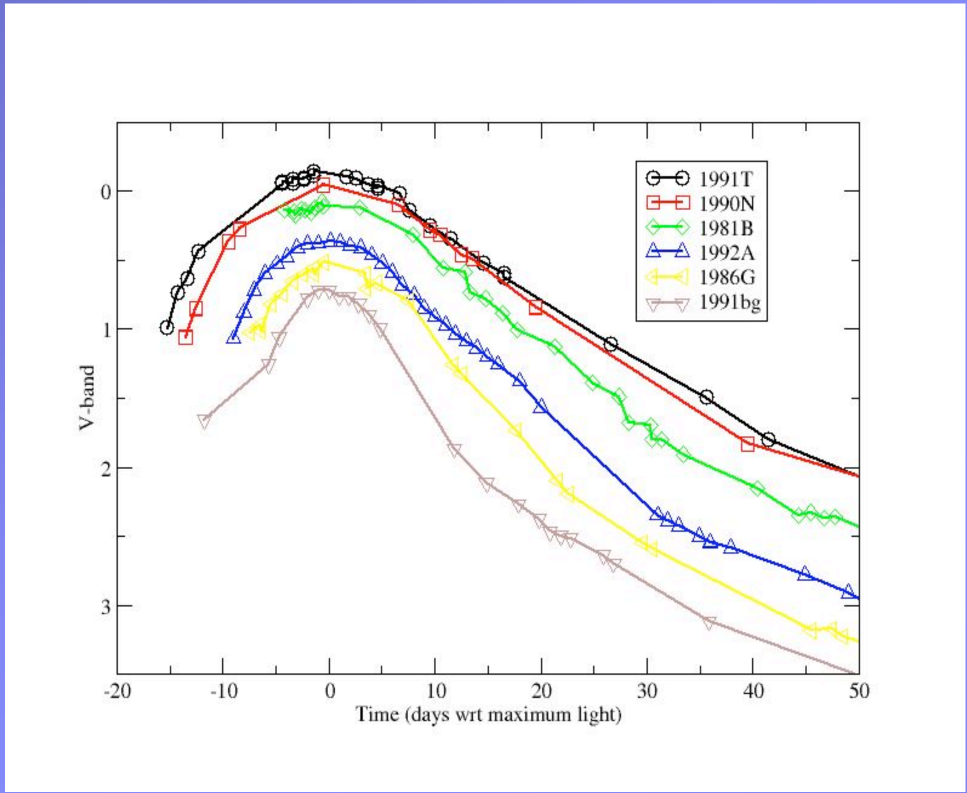
$$w = \frac{p}{\rho}$$

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



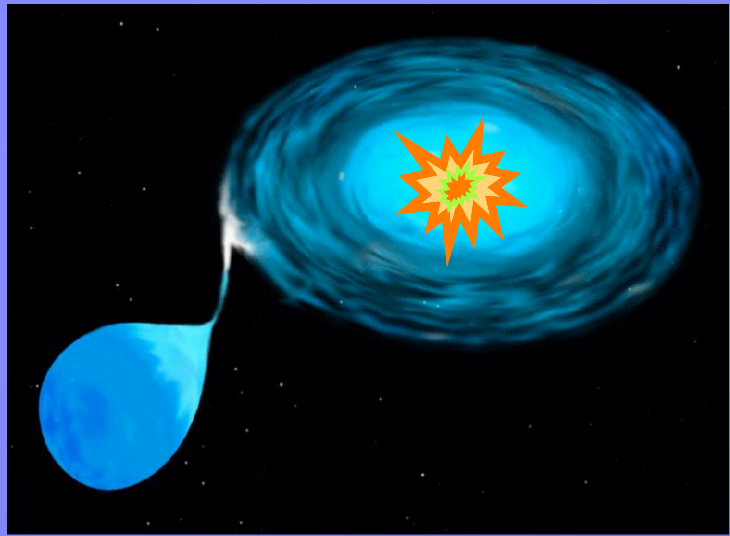


SNe Ia are NOT standard candles



Very Luminous events

⇒ visible at cosmological distances

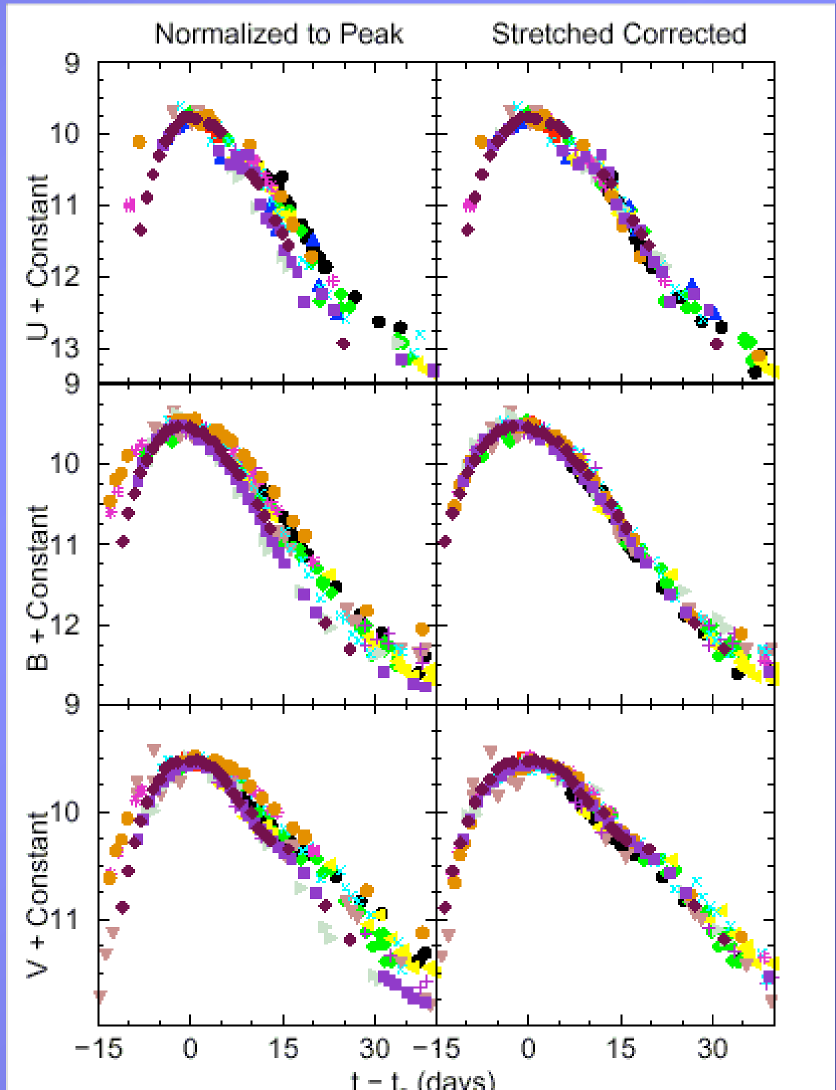


Show little intrinsic dispersion

Measuring distances

SNe Ia Show Light Curve Shape Relationships (similar to Cepheids P-L relation)

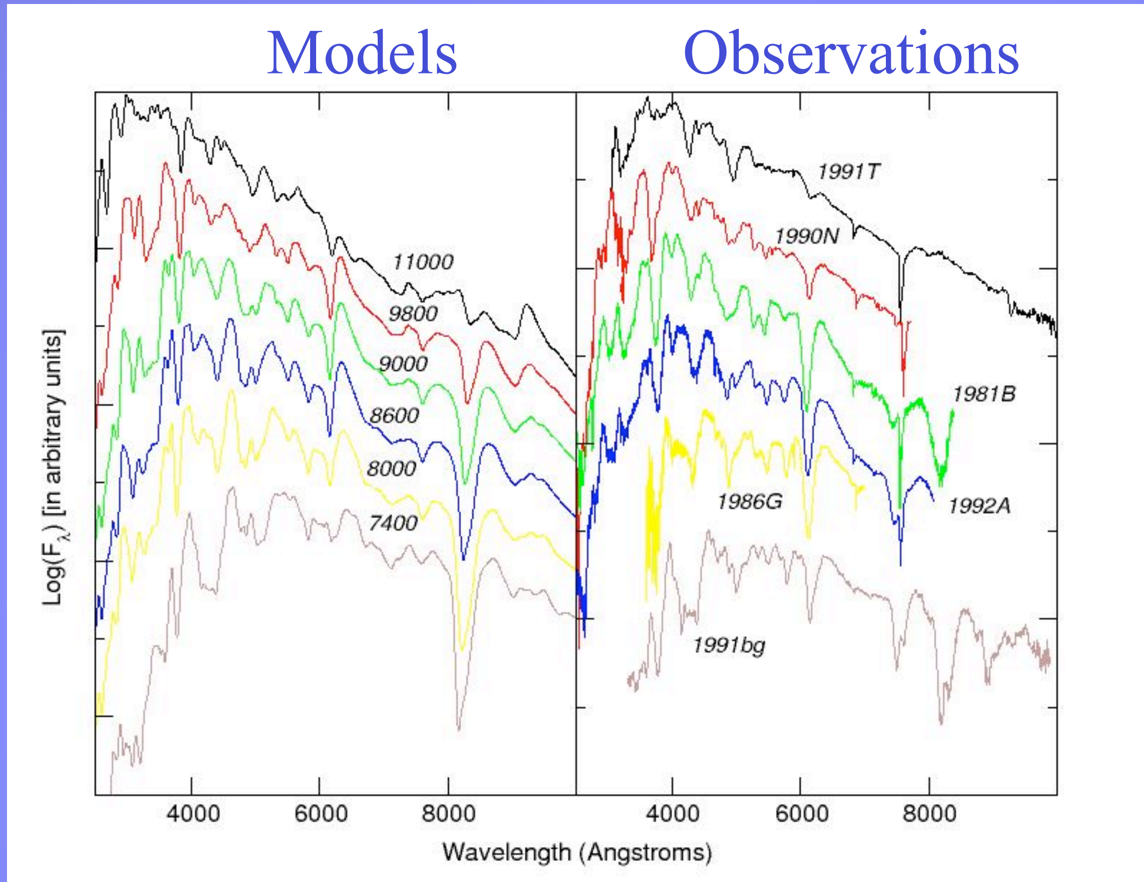
=> Allows us to measure distances to 5-8% precision



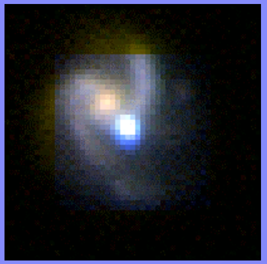
SNe Ia modelisation

Using radiative transfer codes, this relationship is reproduced simply by increasing the abundance of ^{56}Ni in the explosion.

Here this is characterized by increasing the effective temperature of the atmosphere.



Past and more recent SN projects

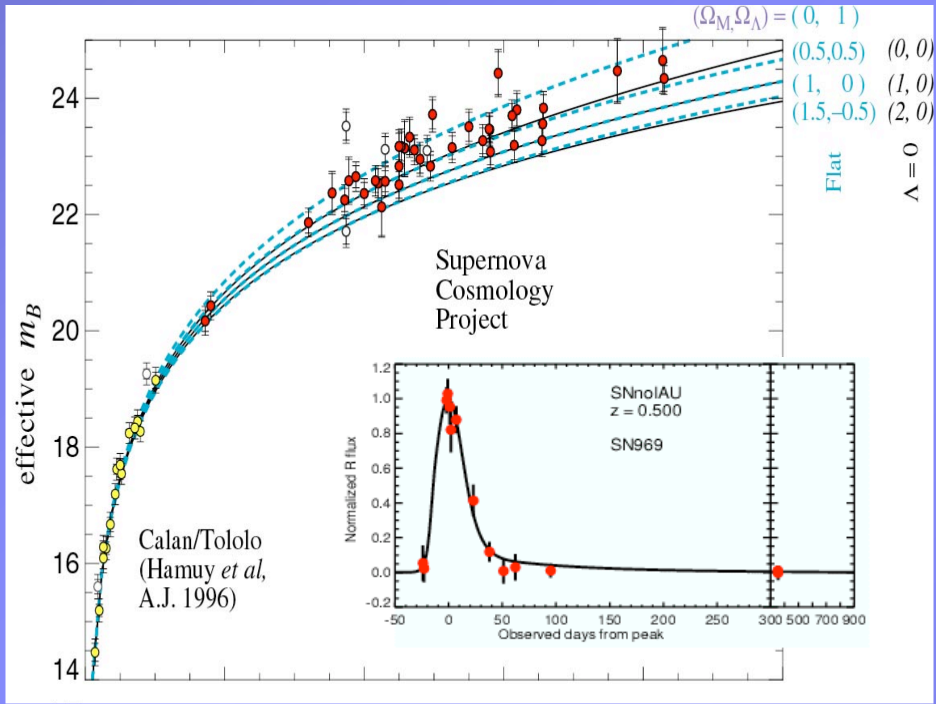


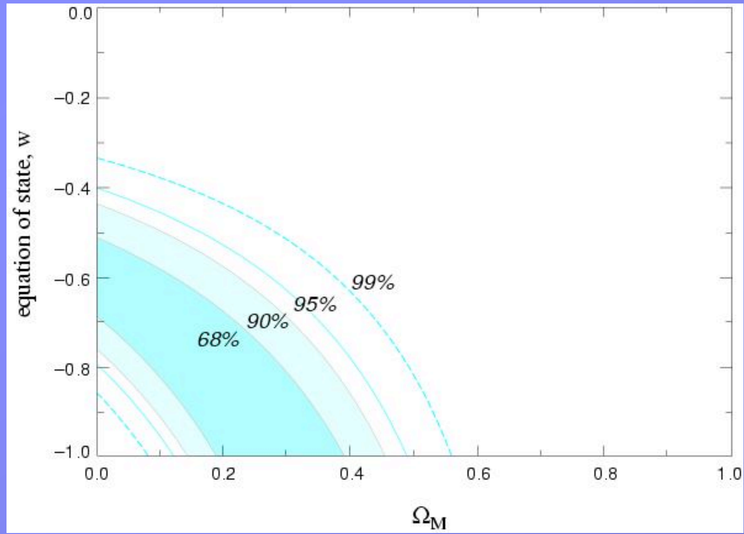
- ~1990->1998 :
  pioneer work : find distant SNe, measure LC, z
  => Discovery of the acceleration of the expansion of the Universe

- 1999 -> 2004 :
  More supernovae, higher redshifts
  Study of systematics (measure color, host galaxy types
  HST follow-up observations
  Search/discoveries with HST
  => confirmation, first constraints on w

1998: first (weak) constraints on w

2 (independent) groups (High-z Team and SCP) present new results based on 42 (SCP) and 10 (HZT) high-redshift SNe and 20-40 low-redshift SNe.



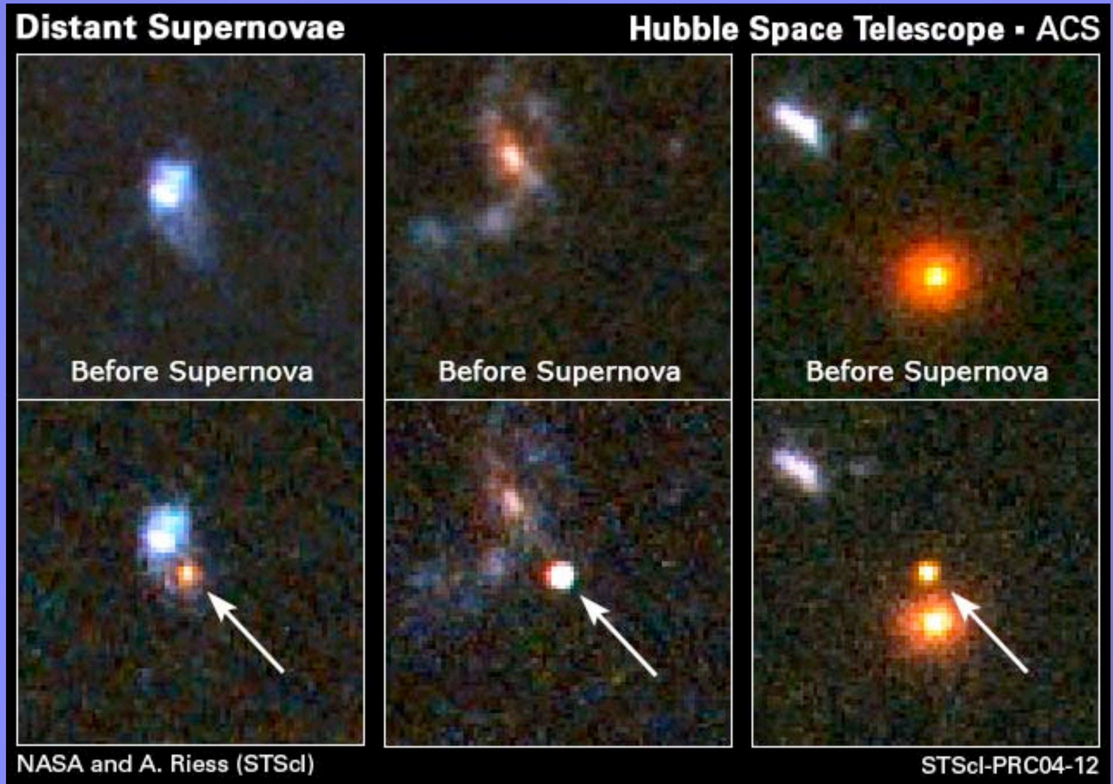


w < -1/3 (90% CL)

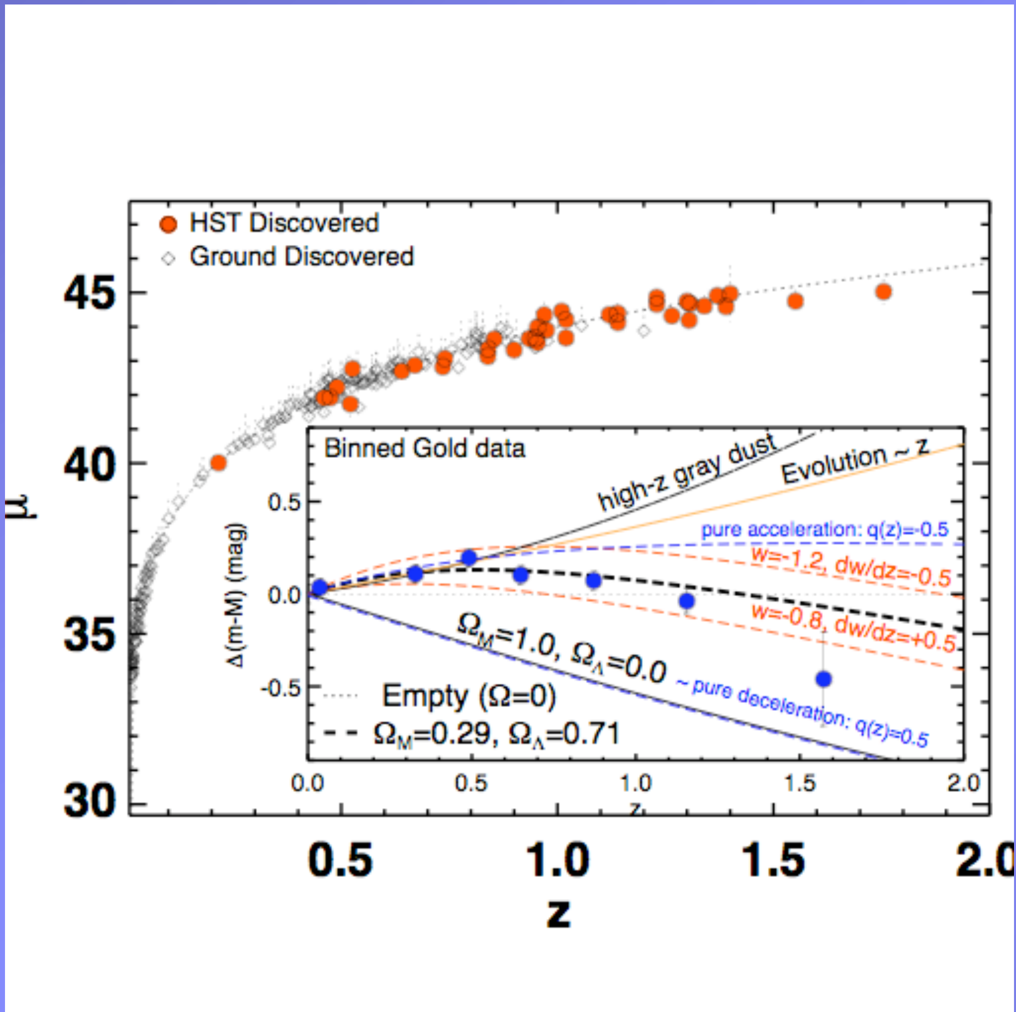
2004 : SNe from space (Goods/ACS survey)

Probe the deceleration era

Find SN at z>1.2 using HST



GOODS/ACS 2004-2006 : HST Supernovae



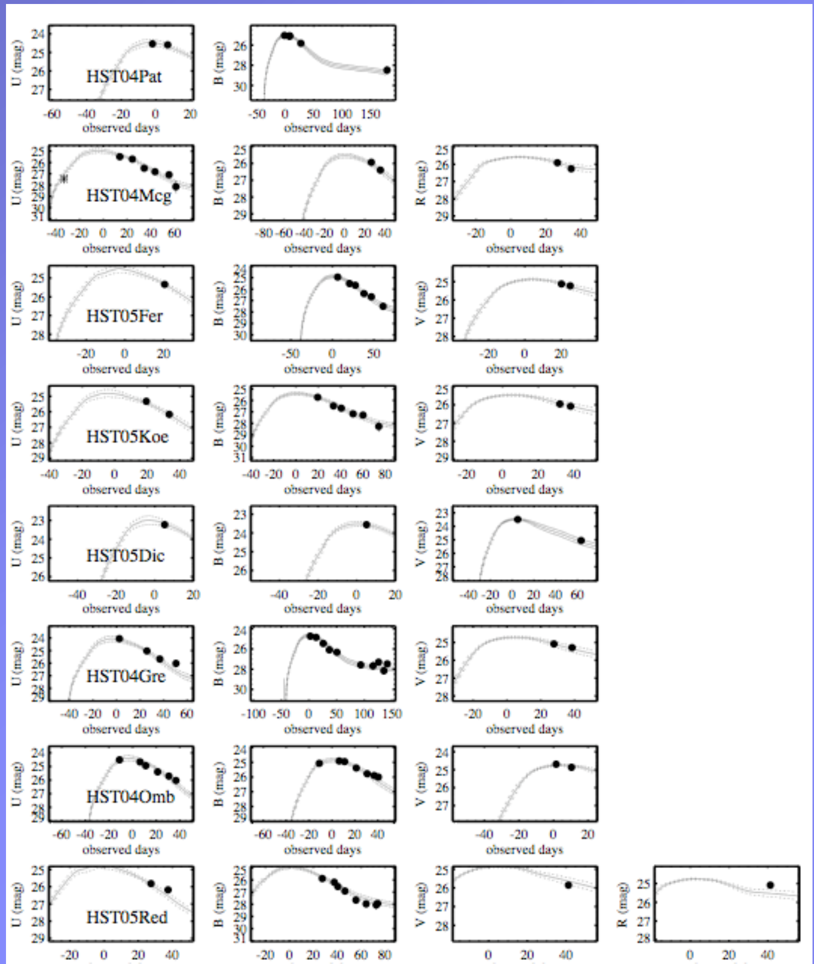
- 16+21 SN Ia ACS found
Including 23 z>1

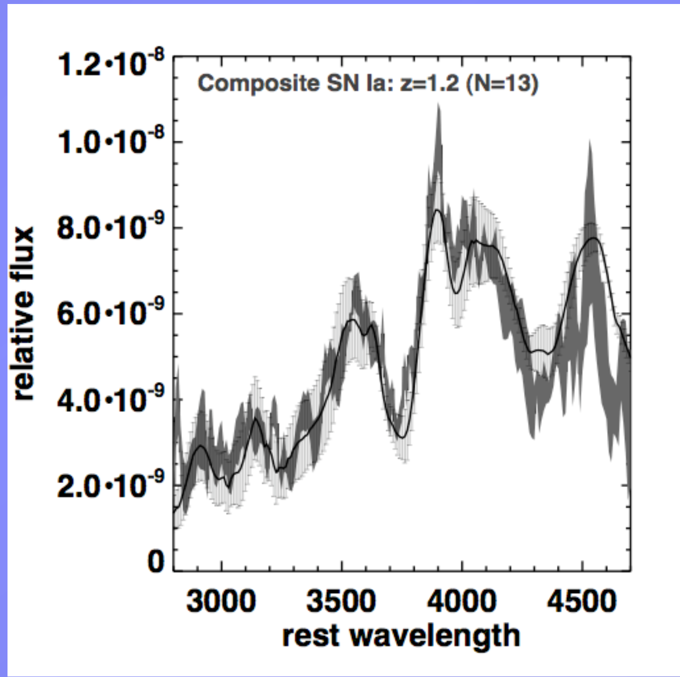
=> Hubble diag. Up to z~2

Expansion went from deceleration to acceleration

Exclude grey dust

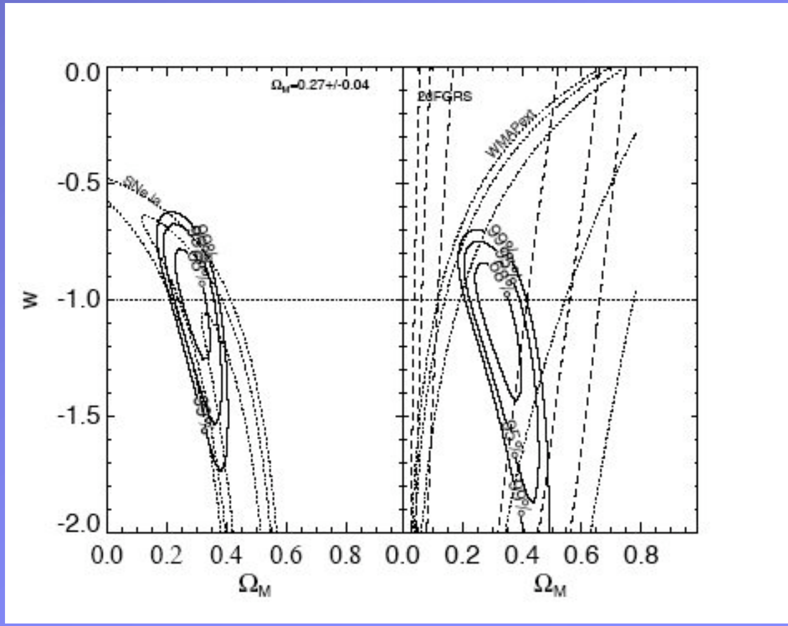
ACS Light-curves (restframe U, B) & Spectra

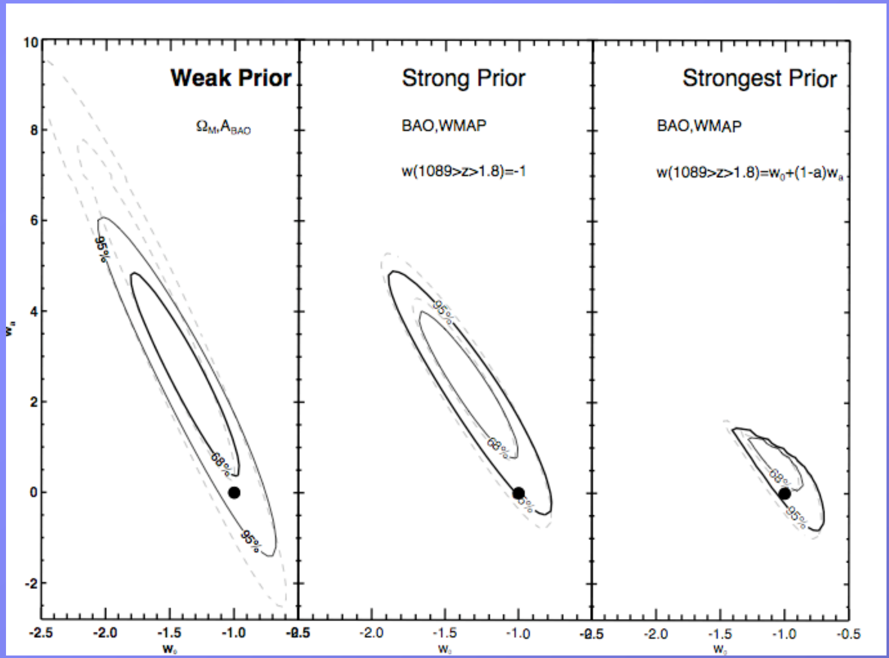




Limited statistics
Limited time coverage
“Large” Calibration uncertainty

HST SNe : Riess et al. 2004-2006 (GOODS/ACS)





- δw (flat+CMB+LSS) = 0.12
- weak “constraints” on w’

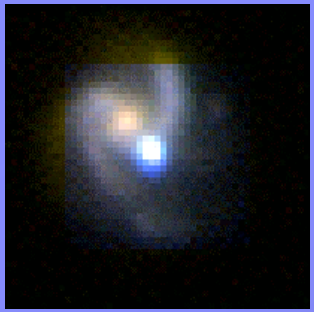
1990-2004: the discovery phase

The « 1st generation » High-z SN projects (SCP, HZT, HHZT) have collected o(200) SN Ia up to z=1.7 (about 30 above z=1). The statistical uncertainties matches estimated level of systematic uncertainties

⇒ Need « 2nd generation » experiments with both high statistics o(1000) and better control of possible systematics

for both high-redshift and low-redshifts SNe

Current/ongoing SN programs



low-z (z<0.1):
- CFA
- KAIT (UCB)
- Carnegie (+IR)
- SN Factory/SNIFS

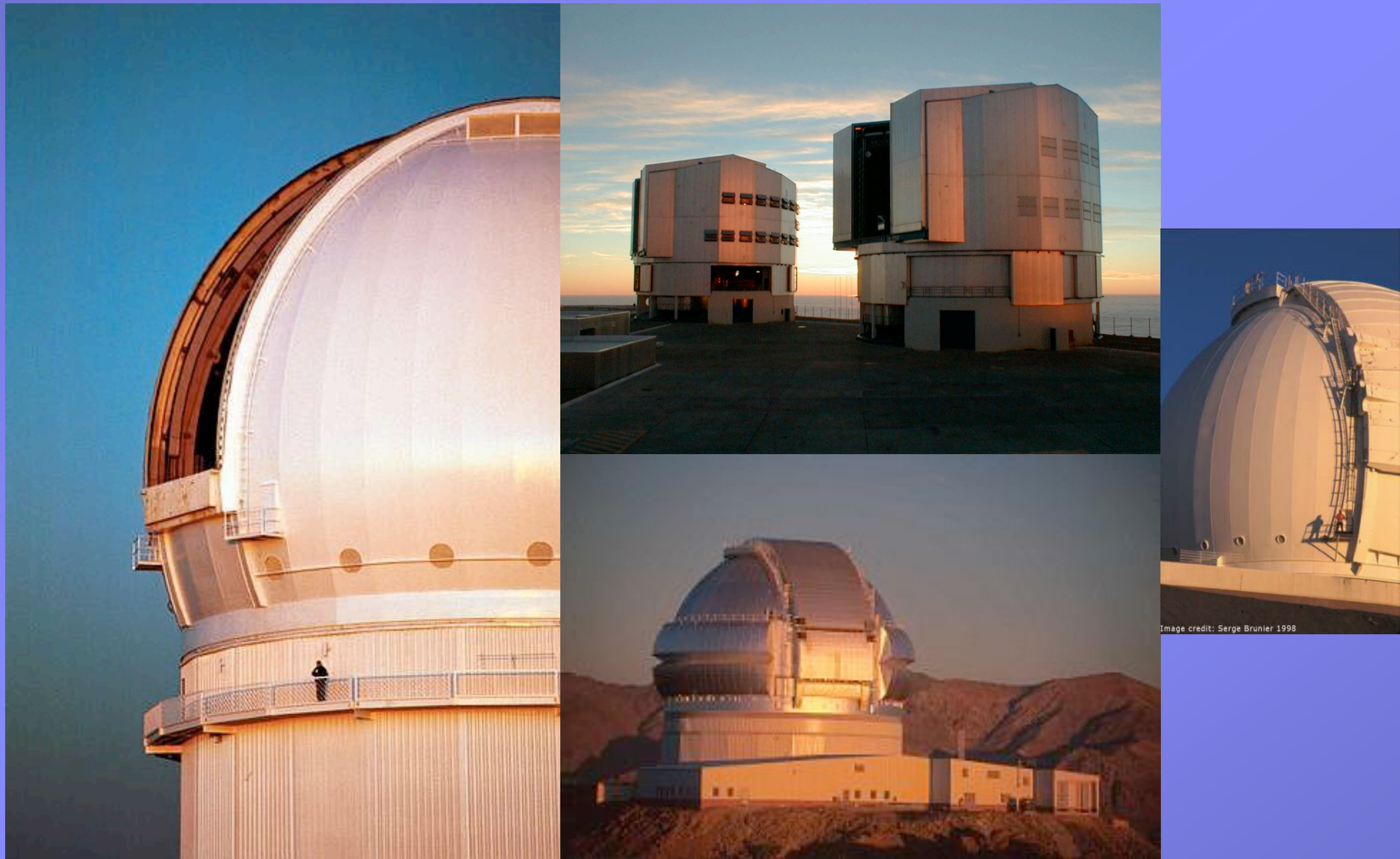
z ~ 0.1-0.3 :
- SDSS/SN

"high- z":
- ESSENCE
- SNLS

will end by 2008-9 …

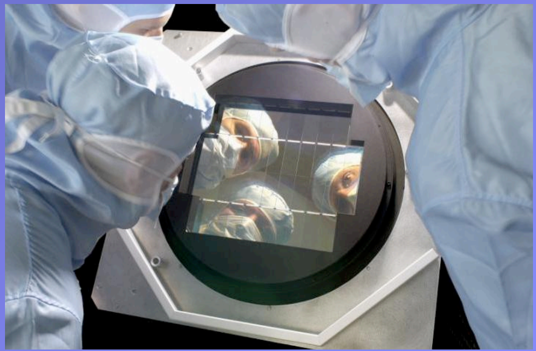
Ongoing space pgm with ACS/HST :
- PANS (Riess et al)
- Clusters (Perlmutter et al) now stopped due to ACS failure

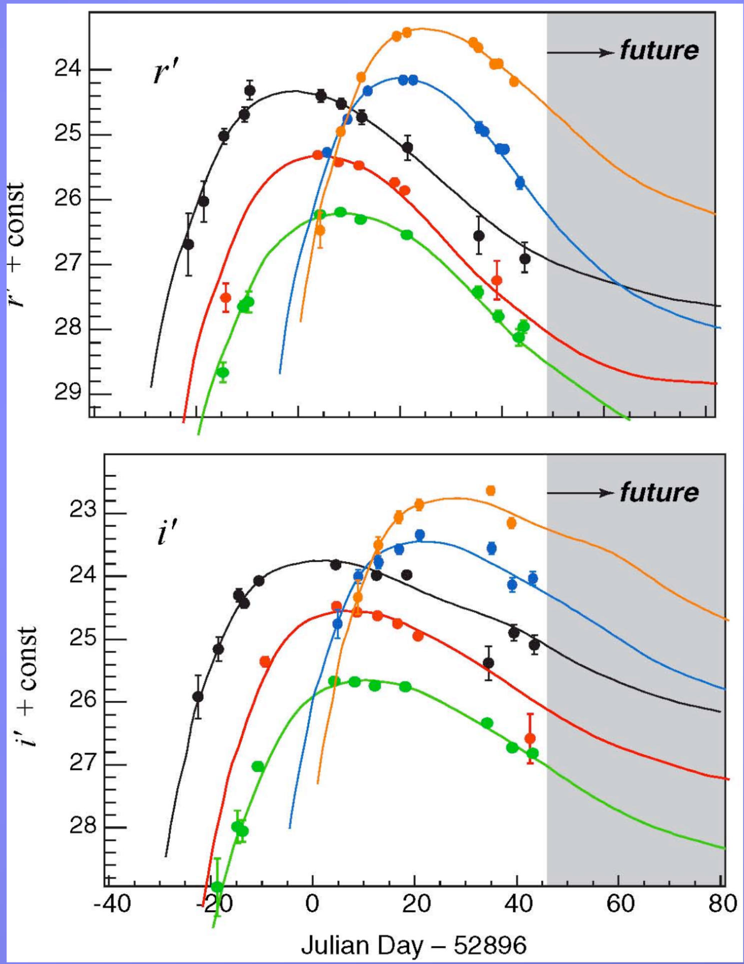
SNLS – The SuperNova Legacy Survey



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

Imaging observing strategy : "Rolling Search"

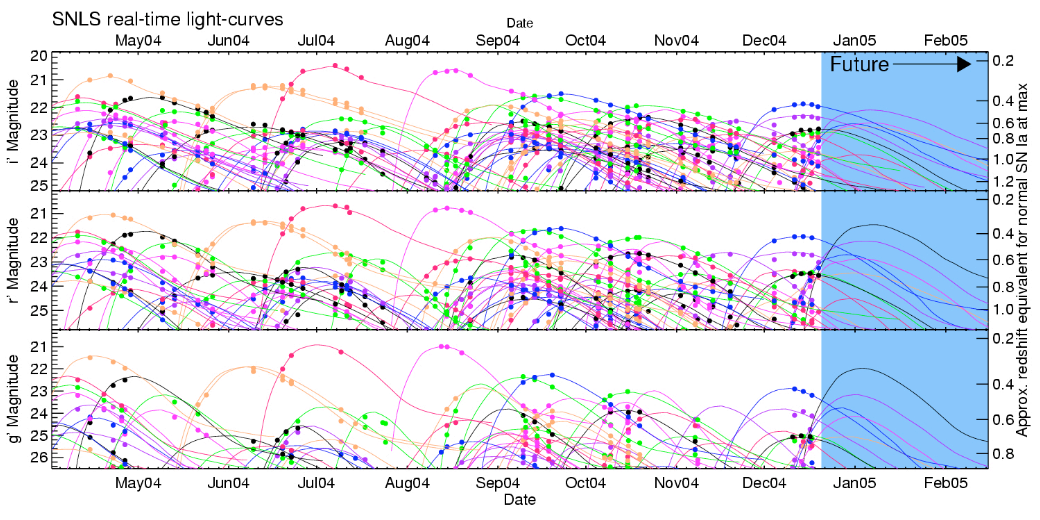




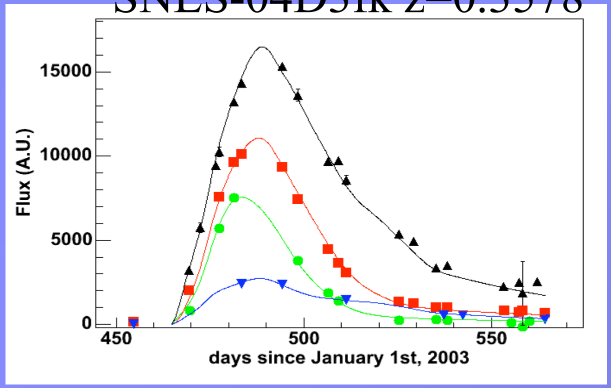
Each lunation (~18 nights) :
repeated observations
(every 3-4 night) of
2 fields in four bands (griz)+u
for as long as the fields stay
visible (~6 months)

for 5 years: expected total nb of SN :
~2000 (detected)

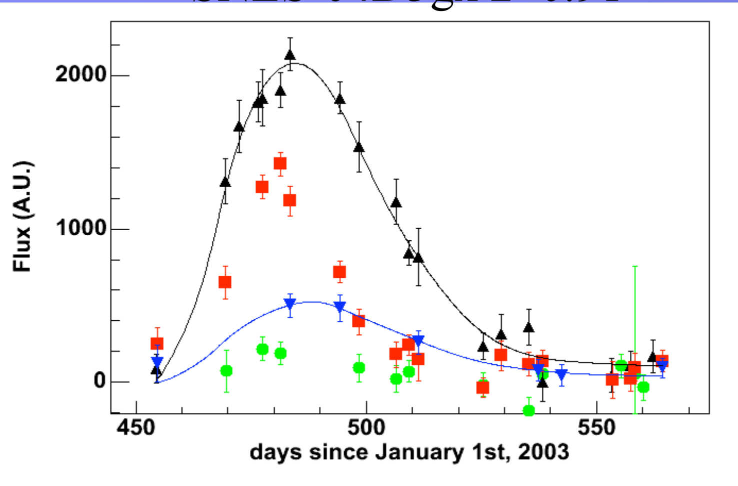
SNLS :example of 2nd generation high-z survey



SNLS-04D3fk z=0.3578



SNLS-04D3gx z=0.91



As of Dec, 2006 ~350 SNe Ia

Expect ~500 by survey end (2008.5)

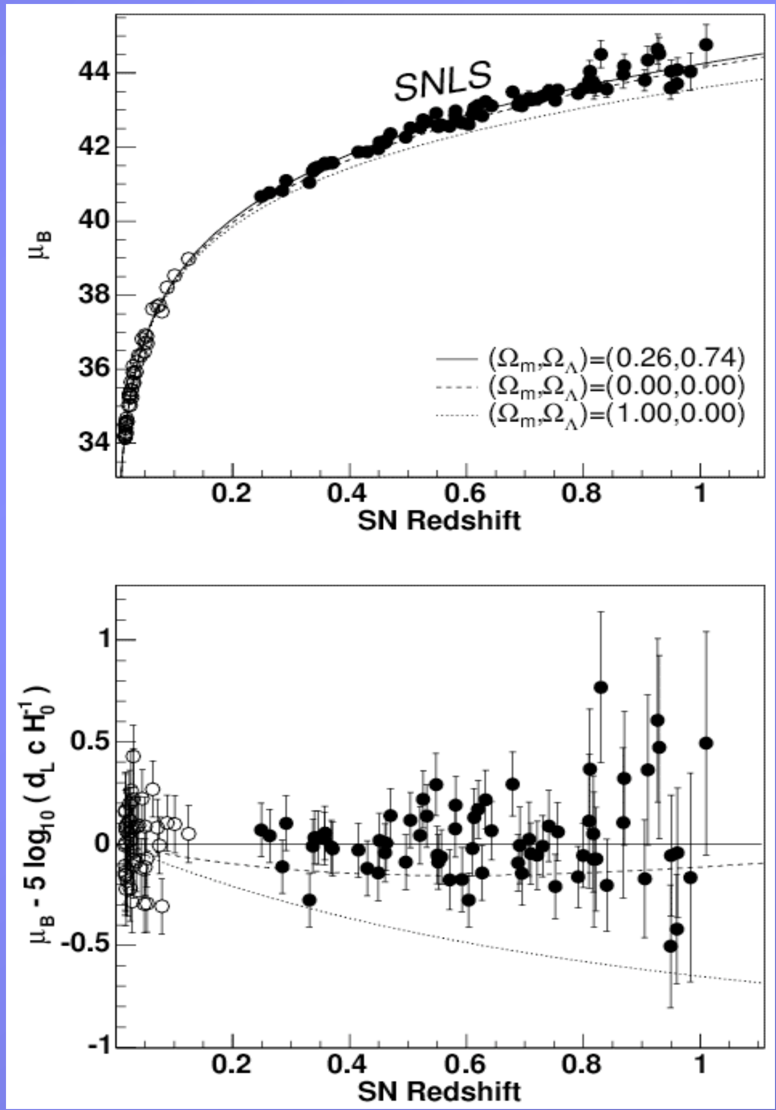
SNLS First year Hubble diagram

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

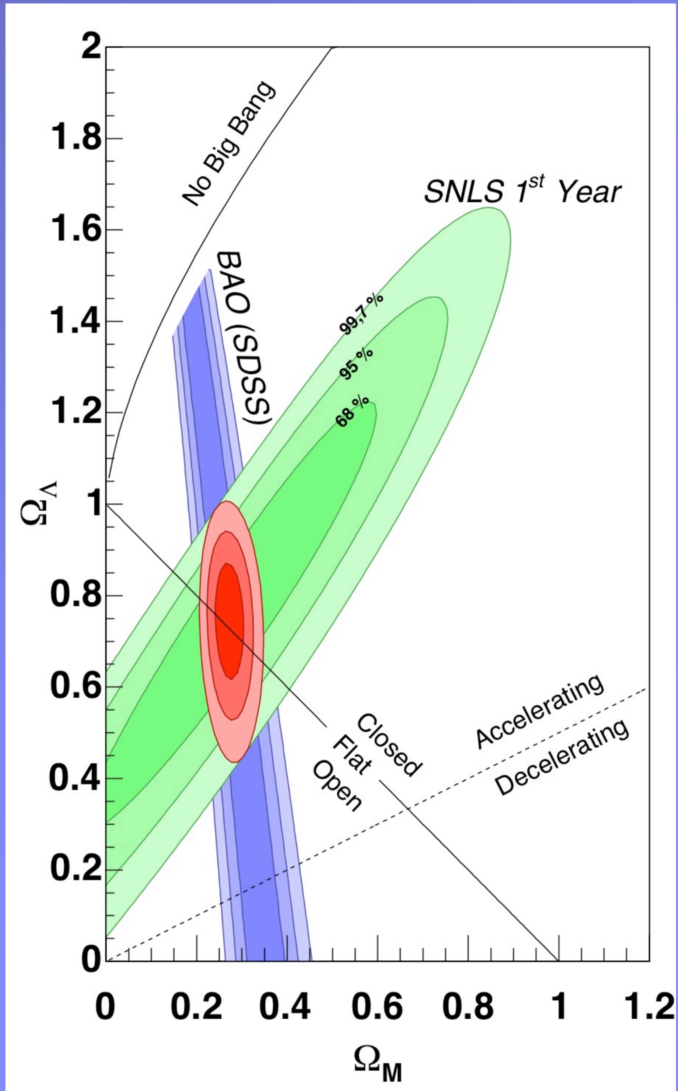
$$\mu_B = m_B^* - \mathcal{M} + \alpha(s-1) - \beta c$$

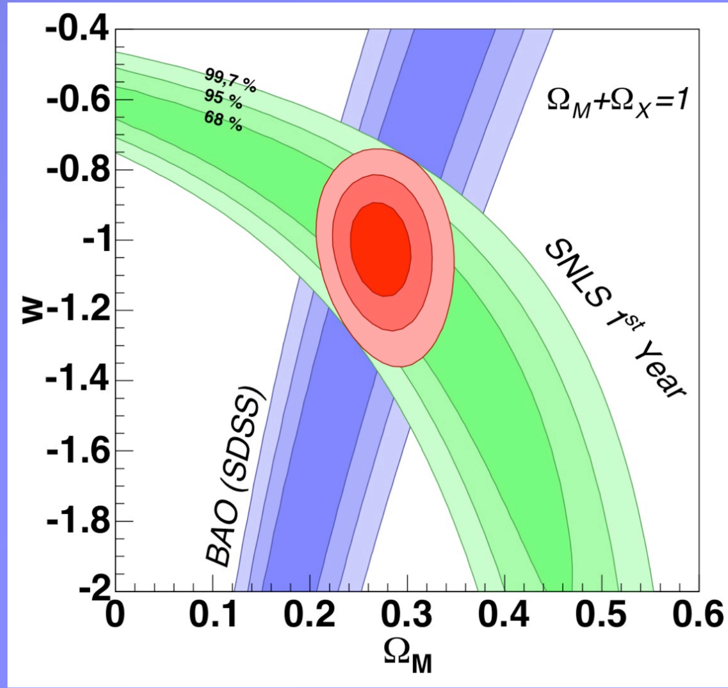
$$\chi^2 = \sum_{objects} \frac{(\mu_B - 5\log_{10}(d_L(\theta, z)/10pc))^2}{\sigma^2(\mu_B) + \sigma_{int}^2}$$

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)



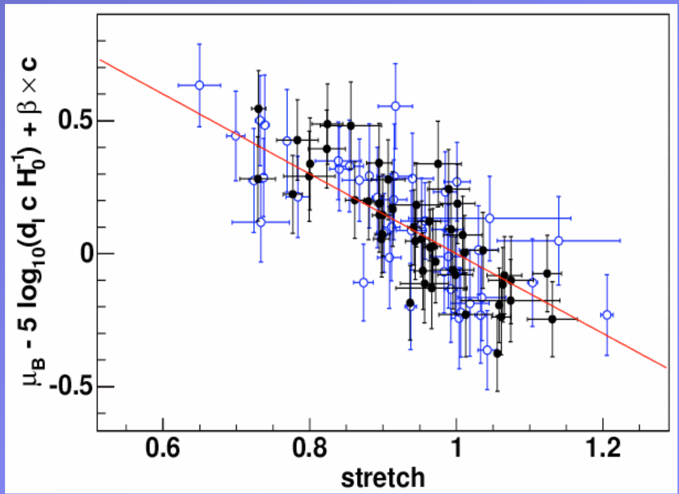


68.3, 95.5 and 99.7% CL
Green SNLS, Blue SDSS/BAO 2005

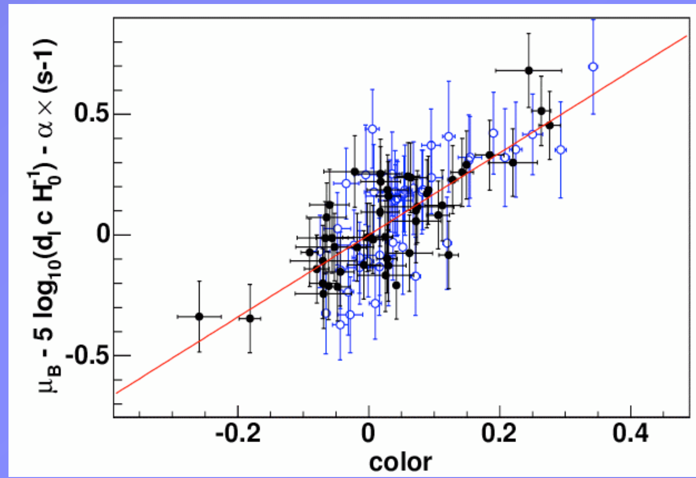
Ω_M = 0.271 +/- 0.021 (stat) +/- 0.007 (syst)
w = -1.023 +/- 0.090 (stat) +/- 0.054 (syst)

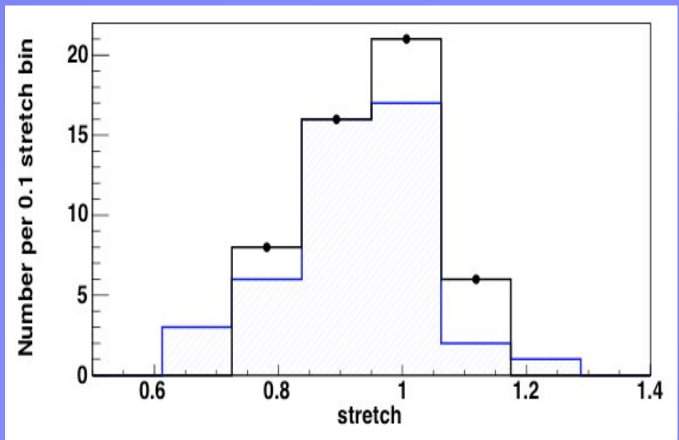
Are local and distant SN Ia alike ?

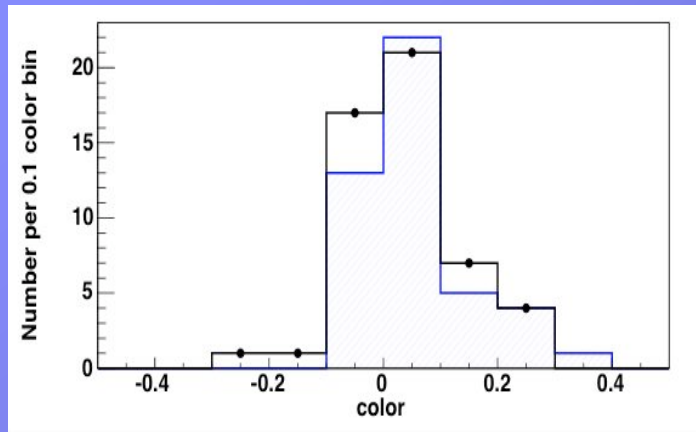
Brighter- Slower



Brighter-Bluer



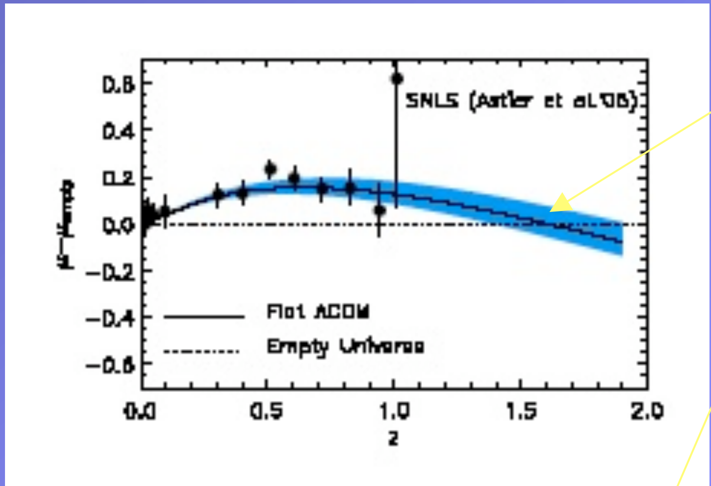


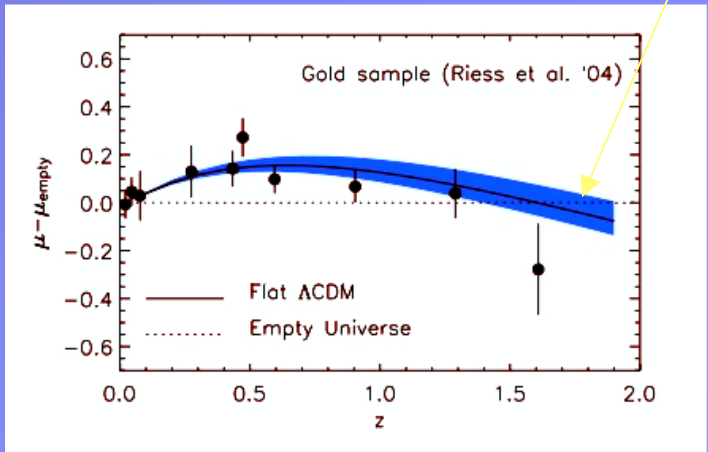


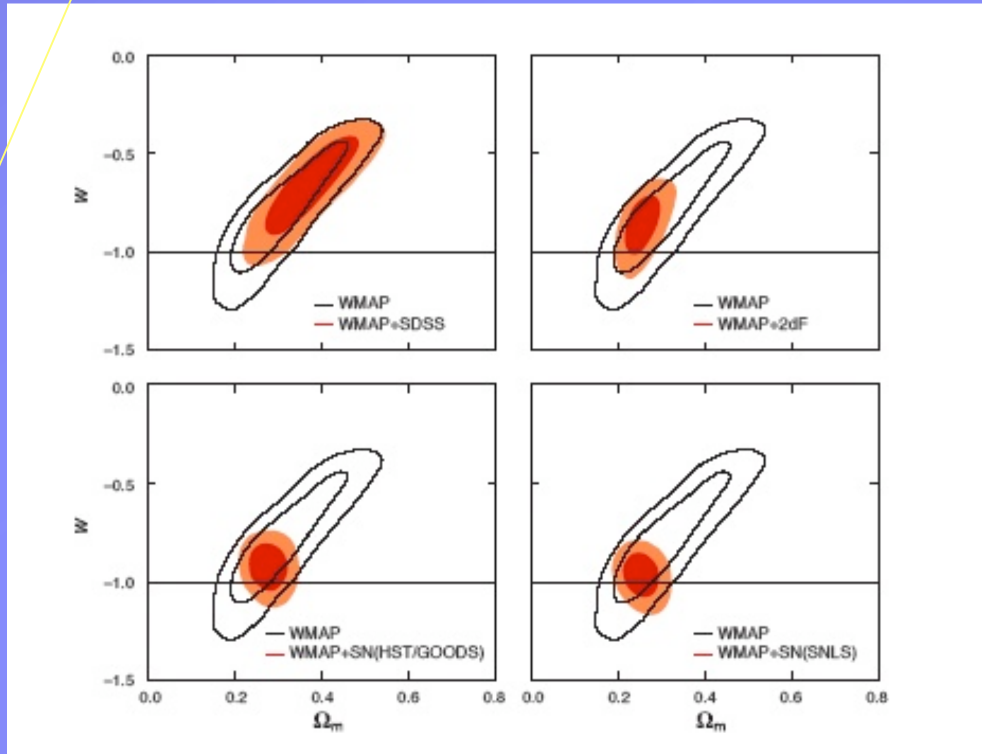
black: SNLS
blue: Nearby

SNLS-WMAP

WMAP prediction





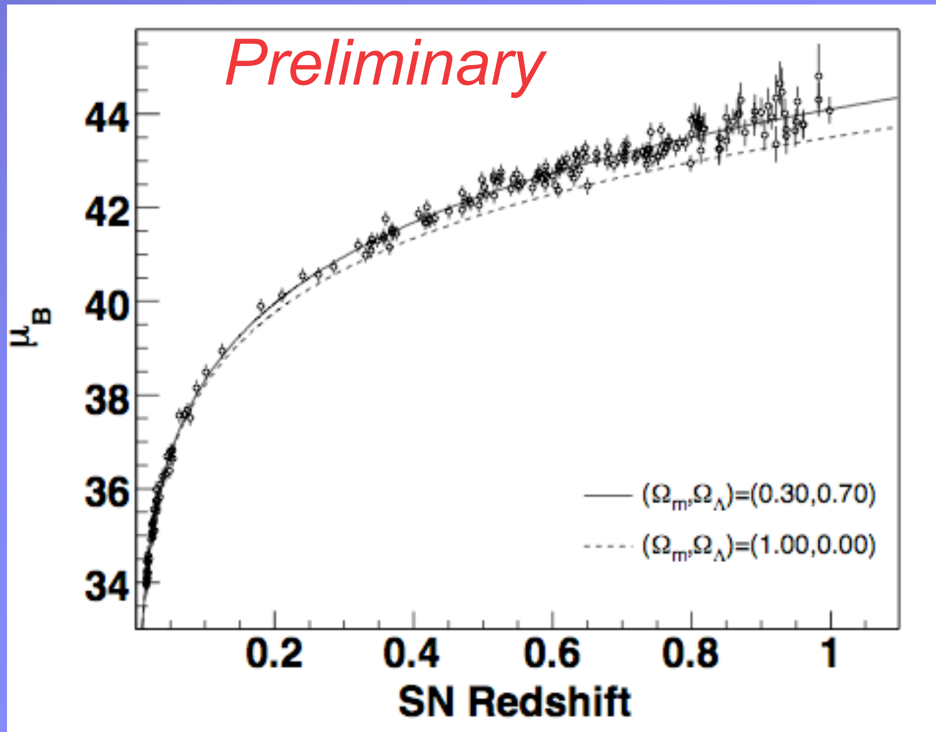


Spergel et al. 2006:

w (cte) = -0.97 +0.07 - 0.09

Ω_k=-0.015+0.020-0.016

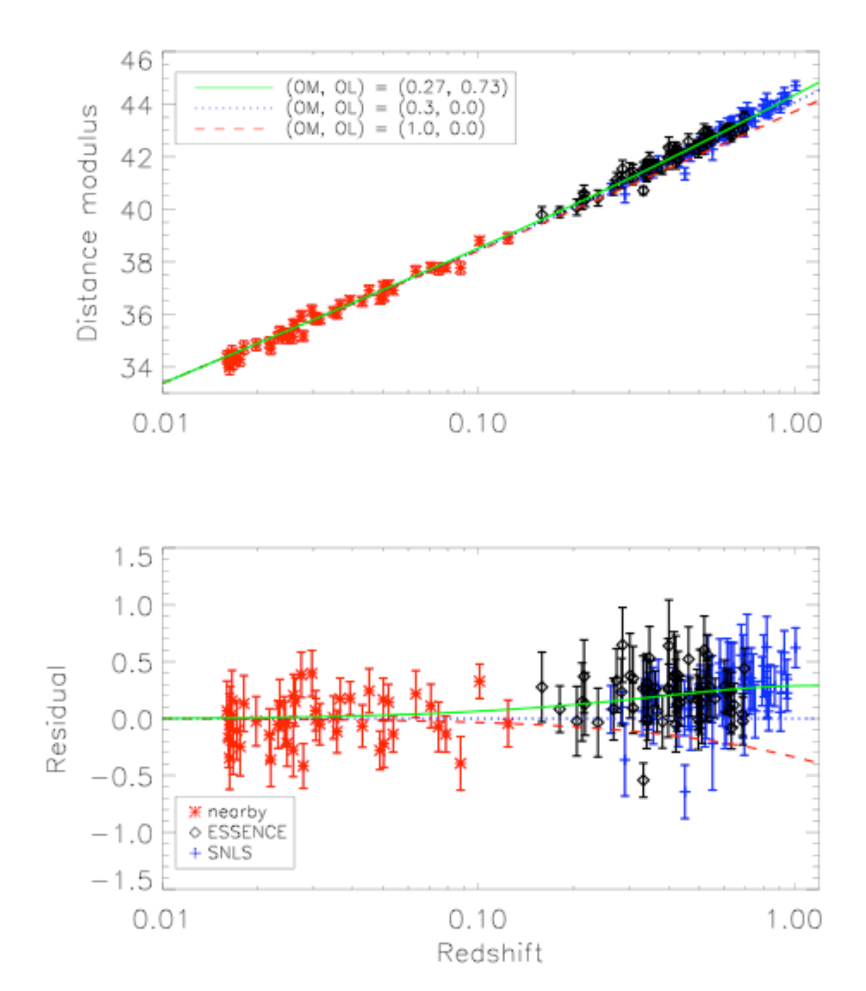
SNLS Preliminary 2 yr Hubble diagram



Updated Hubble diagram with ~200 SN Ia.

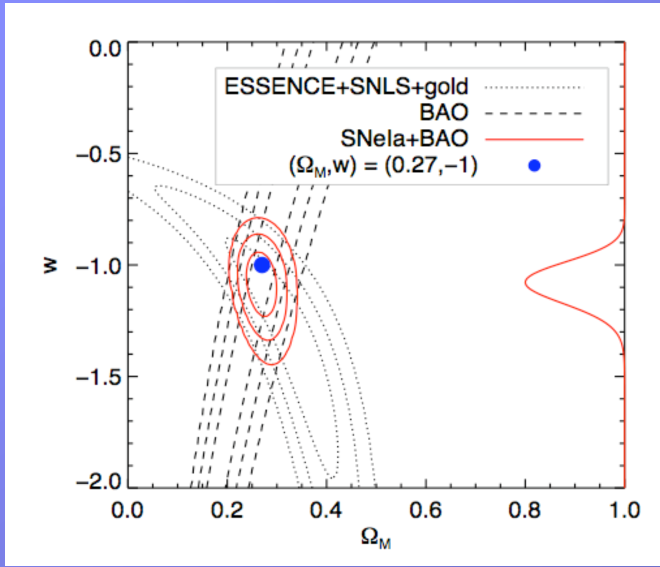
Goal is now to publish (<2007) a 3 year update (~250 SNe) of the cosmological constraints

ESSENCE (2007)

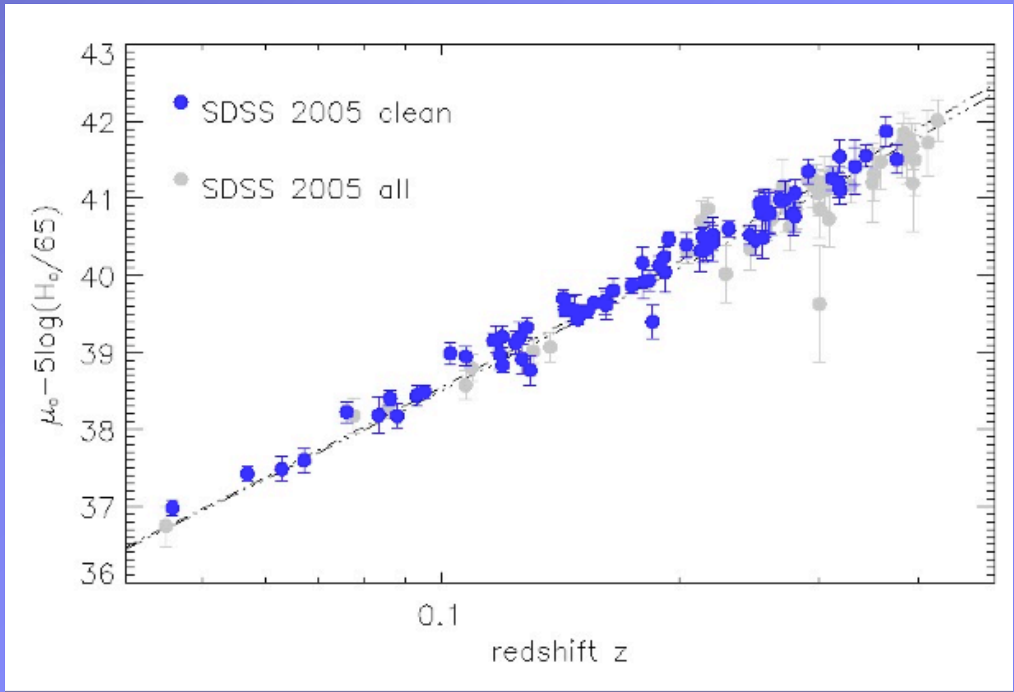


Data from 2002-2005
Imaging at CTIO 4m
Spectroscopy at VLT, Gemini, Keck
60 new SN 0.15<z< 0,70
Combine their data with SNLS, HST
+ BAO, WMAP

(Wood-Vasey et al. Submitted)



SLOAN SN program (2005-2007)



AAS 2007 (H.Lampeitl et al.)

"Rolling" 250 deg2

0.1<z<0.4

In 2005 :

~130 SNe id

~75 with good LC

Combined with SLOAN/BAO (measure at z~0.35) δw (w=cte)~0.15

More in 2006+2007

~ 300 expected by end

Can one do better ?

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

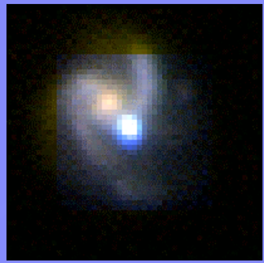
Calibration

Nearby sample !

SN modelling

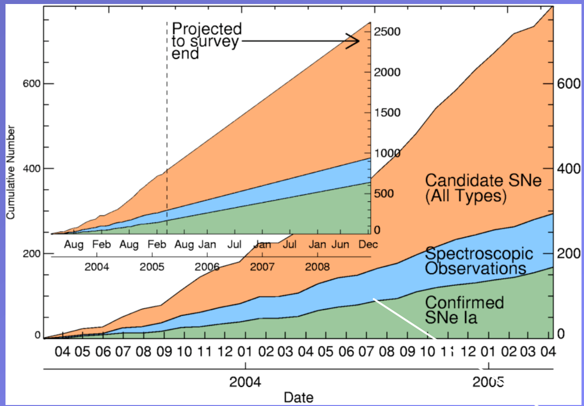
dominant ones will improve with statistics

Future SN programs



- Precision expected by SNLS/ESSENCE/SLOAN end
- Stage III (DETF) projects
- future ground and space based projects

Expected near term precision on w (~2008)



Expected « realistic » statistical improvements on Ω_M and w

+KAIT+SNF+SDSS+SNLS

# 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

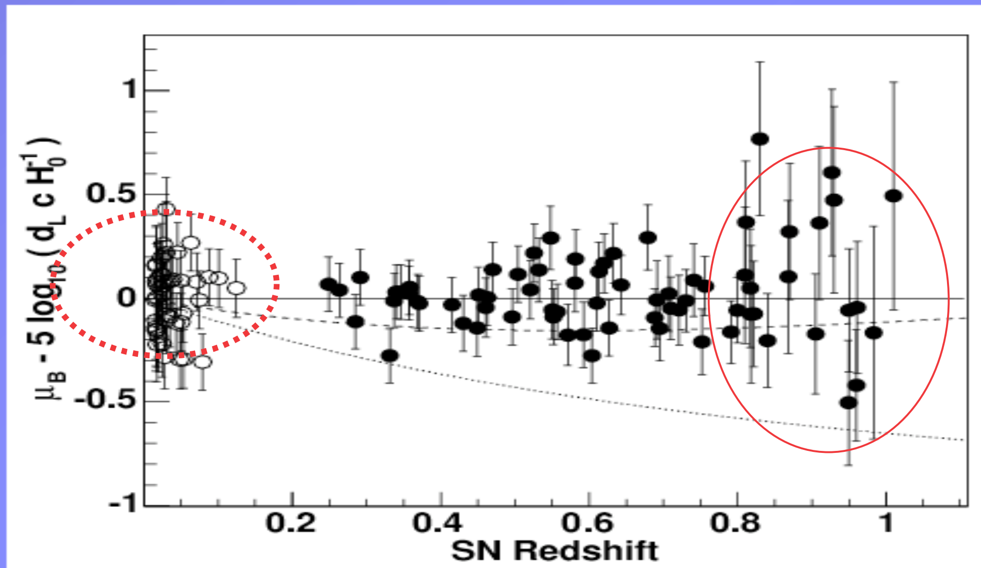
+ systematics…

Future SN programs

By 2008-9 SNLS/ESSENCE + Nearby SNe

- should reach δw (cte)~0.07
- obtain no (significant) constraints on w' (wa)

and will (most probably) have reached their systematic floor



=> also very difficulty for upcoming projects

STAGE III (DETF) SN programs

Pan-starrs PS1: 1.8m + 7 deg2
2007-2010? (primarily weak lensing)
goal : o(1000) up to z=1

DES : CTIO+new 3deg2 mosaic camera
2010-2015 (primarily weak lensing)
goal: 2000 SN 0.15<z>0.75 (ESSENCE+)

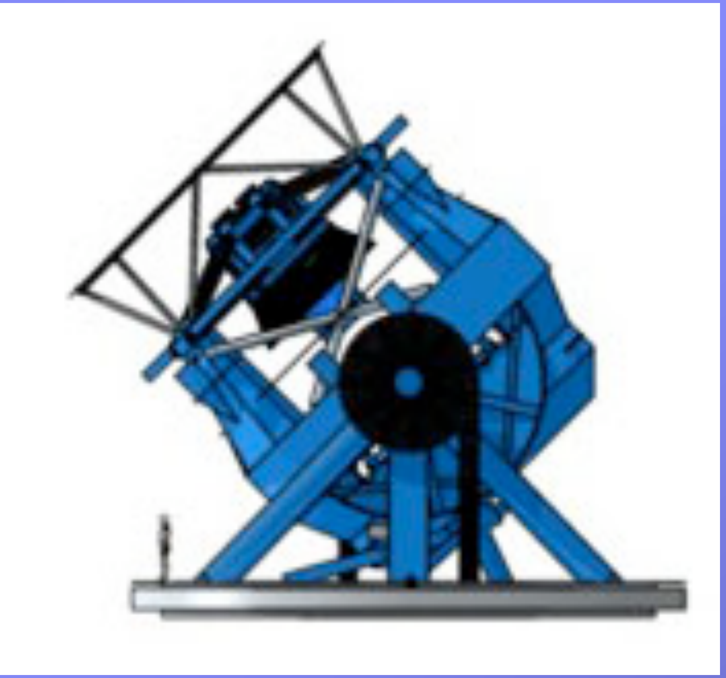
⇒ Skymapper : 1.35m MSSO (Australia)
Rolling nearby (z~0.1) - yield ~100 SN Ia /yr
2008-2010 => needed to complement current high-z samples

Very difficulty to significantly improve (wrt stage II) on cosmological constraints

Stage IV ground based SN projects

- Pan Starrs 4 :

Simultaneous observing with
Four 1.8m telescopes of
3 deg2 fov (0.3'' pixels)



- LSST :

One 8m telescope with
9 deg2 fov

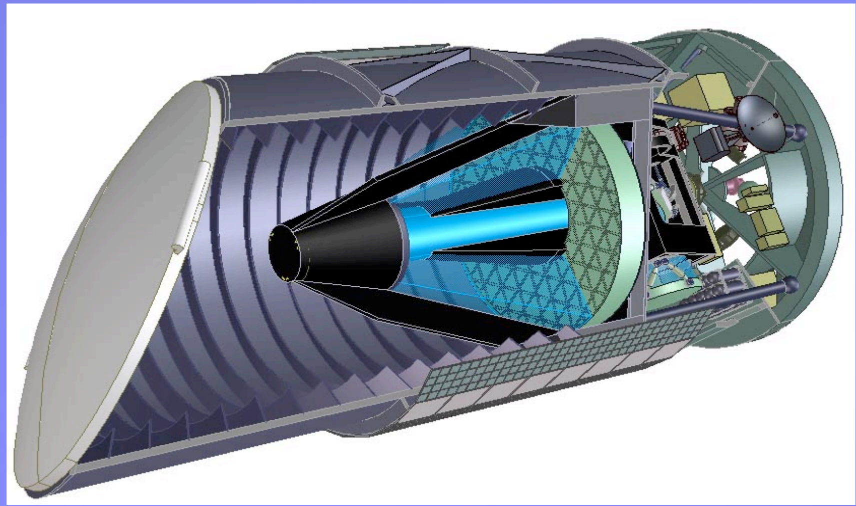
=> 250000 SN/an !

- low AND high-z Sne from the same instrument …
- repeat imaging (calibration <1%) + « sky calib. »

Space based cosmology with SN Ia

Detect/follow
SN Ia from Space

e.g. SNAP
Proposed 1999
Now running/waiting for
NASA/DOE JDEM AO
(2008+)



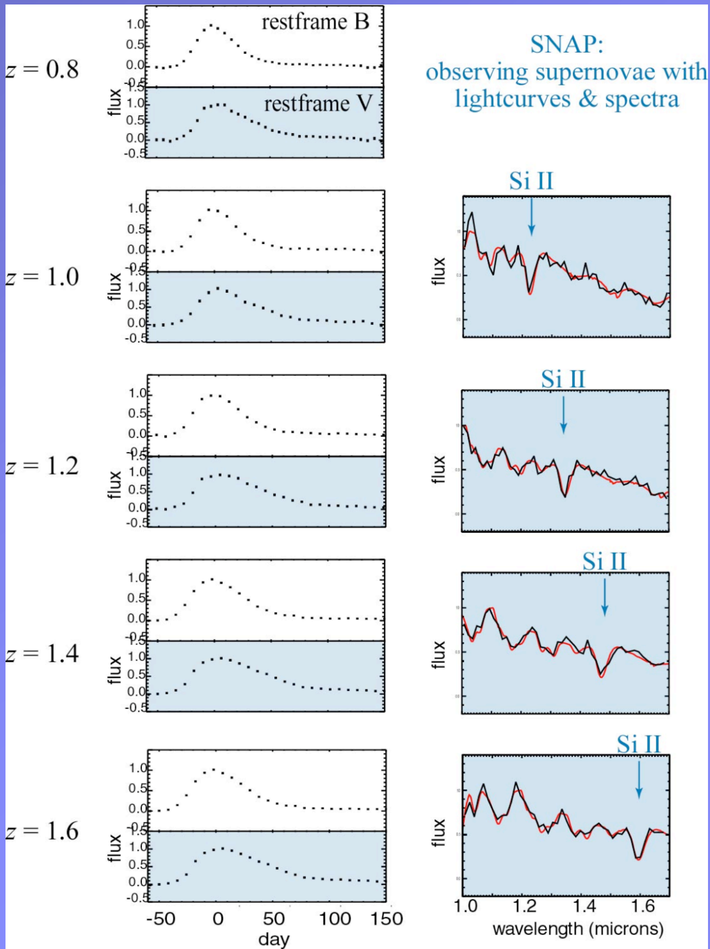
- **~2 m aperture telescope**
  Can reach very distant SNe.
- **1 square degree mosaic camera, 1 billion pixels**
  Efficiently studies large numbers of SNe.
- **0.35um -- 1.7um spectrograph**
  Detailed analysis of each SN.

Dedicated instrument designed to repeatedly observe an area of sky.

Essentially no moving parts.

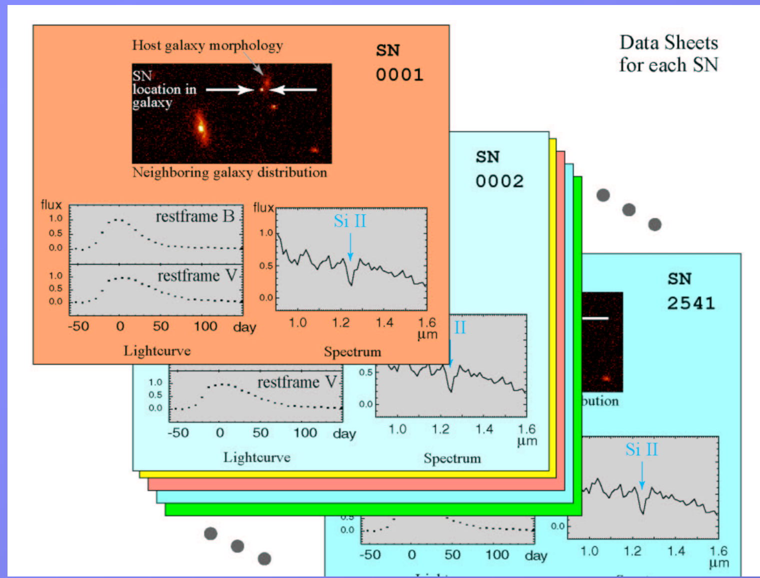
3-year operation for experiment (lifetime open-ended).

Lightcurves and Spectroscopy from space



- Multicolor high S/N lightcurves up to z~2

- SN spectral identification up to redshifts z~1.7



SNAP: strategy - precision on w, w'

Area : 2x7.5 sq. deg.

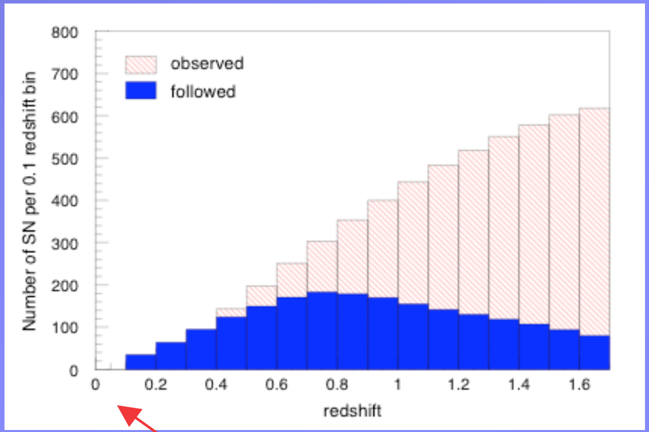
Cadence : 4 days

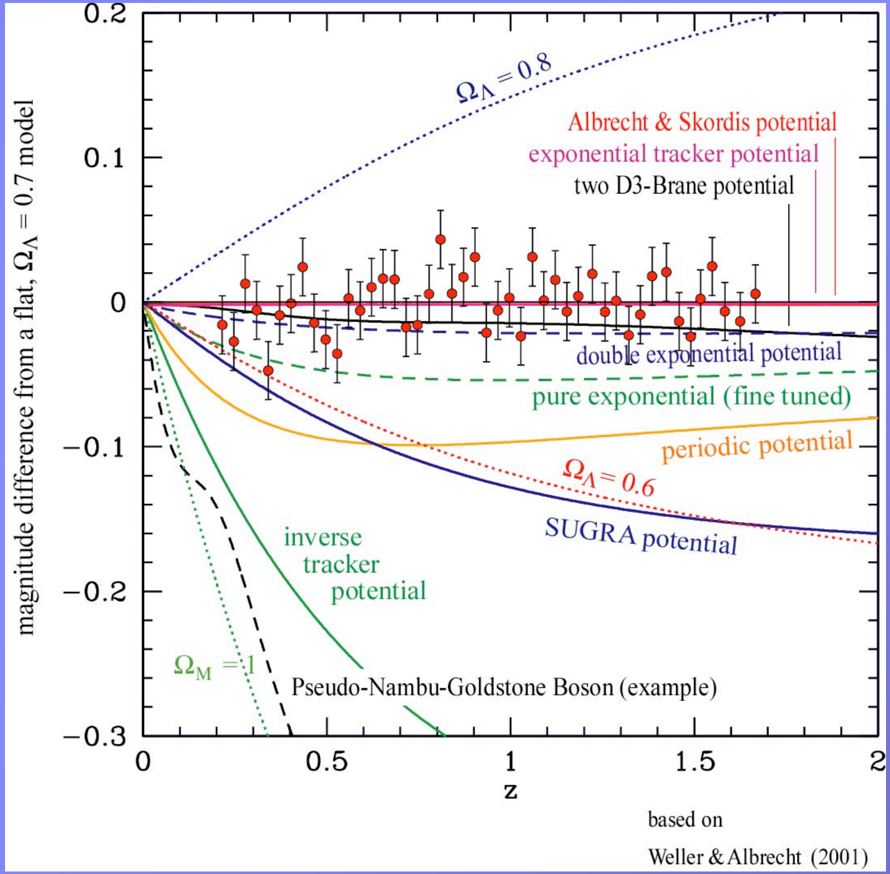
Total duration : 3+ yr

60% imaging - 40% spectro

Total nb of SN : ~ 2000

Expected % precision on w, ~0.1 on w'/wa





+ 300 nearby Sne (ground) z~0.1

JDEM/DESTINY

Selected by NASA for « Einstein Probes 2yr Conceptual Studies »

ϕ=1.8m telescope

0.25 deg. carrés - NIR 0.9->1.7 μ

all grism R=100 (spectrophotometry)

L2 orbit

Survey:

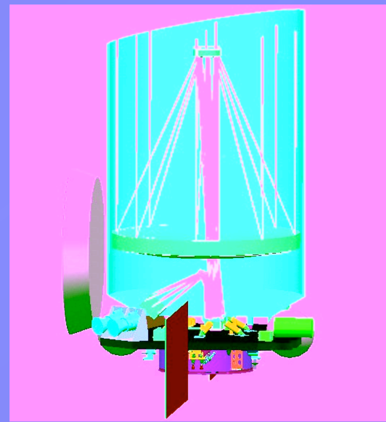
4 h exposure

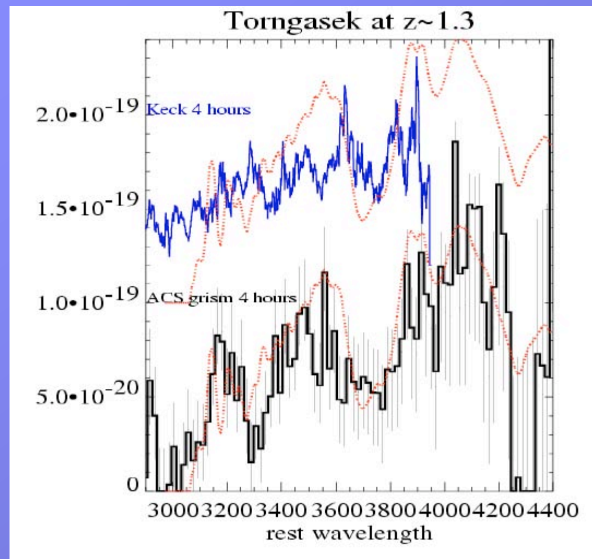
7.5 sq. deg.

1.5 sq. deg./day (cadence 5 days)

2000 SNe 0.5<z<1.7 in 2 yrs

Calibration with ESSENCE/LSST (z<1)

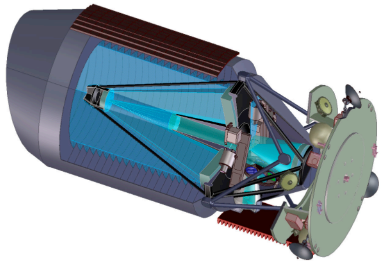




Dark Universe Explorer (DUNE)

Proposed (2004) as weak lensing probe
- 1.2 m telescope 0.5 sq. deg. Imager
- visible only - 1 filter

2005 phase O study at French Space Agency
- DUNE SN program (add filter wheel)
- 2x60 sq deg. (UBVRIZ, I=26) - cadence: 4days
- Photométric id of SNe (UBV restframe)
- Ground based spectroscopy (host galaxies)
- => 10000 SNe 0.1<z<1 in ~18 months
- statistical uncertainties on w, w' o(80%xSNAP)
  - calibration/systematic uncertainties ?



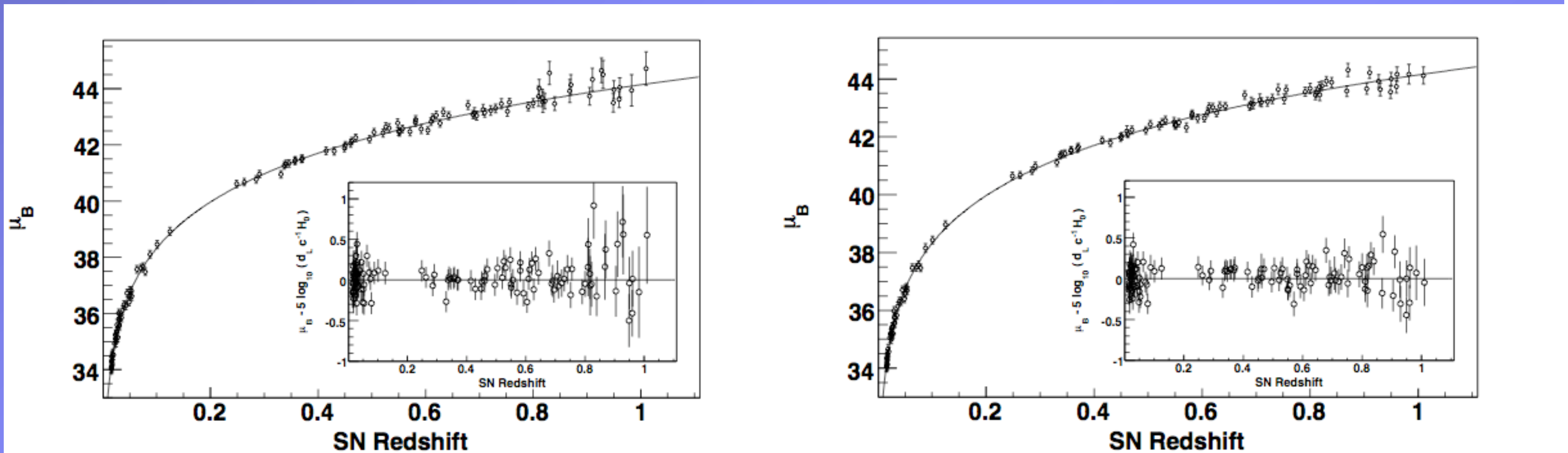
2007: AO cosmic vision
- DUNE+ : 1.4-5 m
- add IR module

Summary

- SNe Ia are excellent distance indicators. Significant constraints on w require combining with constraints from other experiments ($\sim\Omega_M$)
- 2nd generation projects (ESSENCE, SNLS, SLOAN/SN) are getting more and higher quality data. Toward building a systematic limited Hubble diagram with ~1000 SN Ia

  Expected precision on (flat Univ., constant) w by 2008-9 :

  +/- 0.05 (stat) +/-0.05 (syst)
- More and improved quality nearby sample needed (~1000)
- Percent precision on w and significant precision on w' (wa) with SN will require exquisite control of systematics


44
42
40
38
36
34
μ_B
0.2
0.4
0.6
0.8
1
SN Redshift
μ_B - 5 $\log_{10}$ (d_L c^{-1} H_0)
SN Redshift

(outstanding) Question

What's limiting the precision ?

- SN Ia population Light-curve + Spectra modelling (including identification), contamination by II, Ib/c
- Mosaic imager calibration
  - mosaic uniformity & stability
  - atmosphere (space repeat imaging on the ground)
- Improved distance indicator (color/extinction)
- Malmquist bias (low-z sample)

- Lensing (z>1, low statistics) space (futur projets)
- Precision on photo-identification/redshift (futur projects)