The Supernova Legacy Survey

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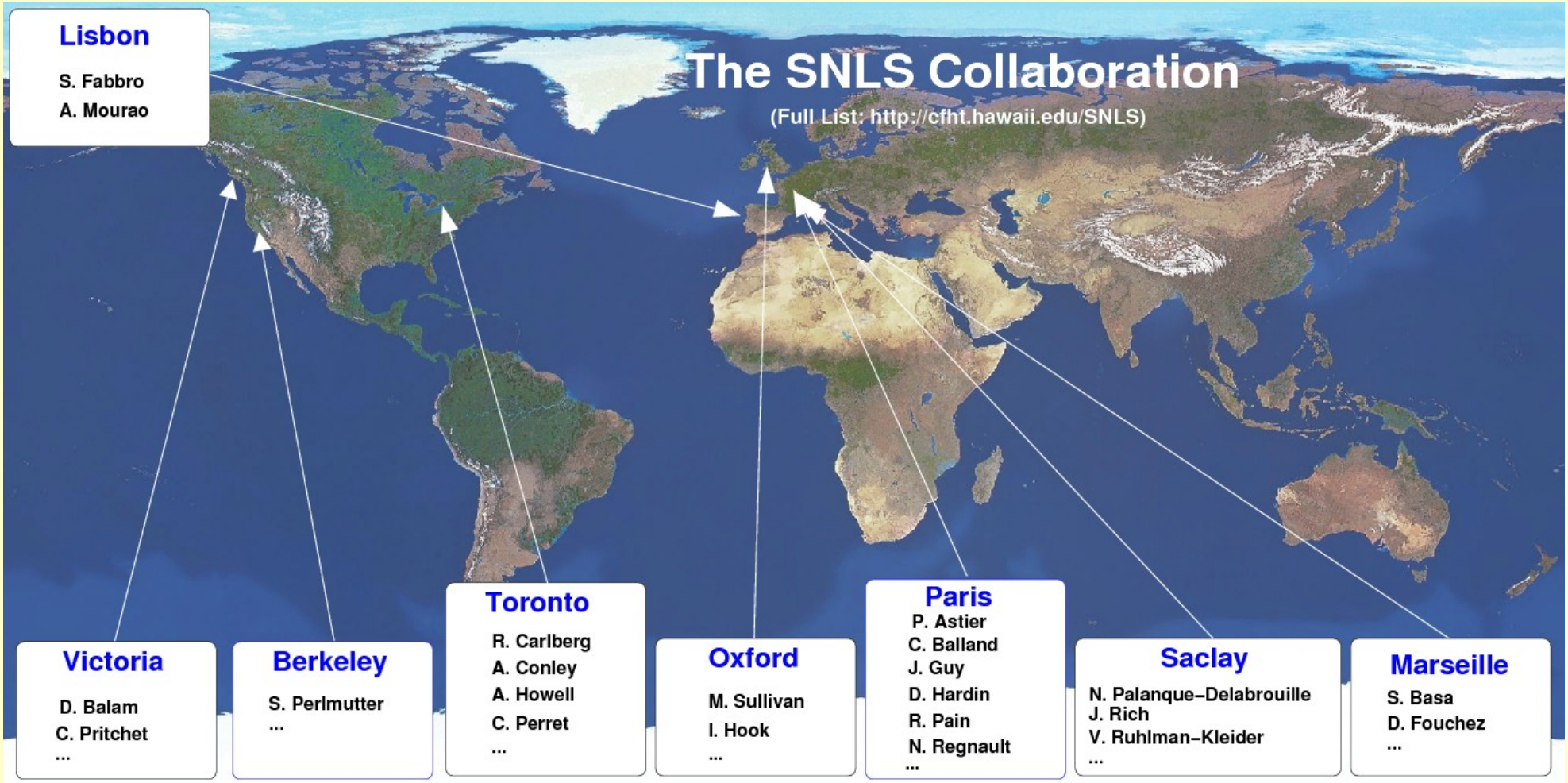
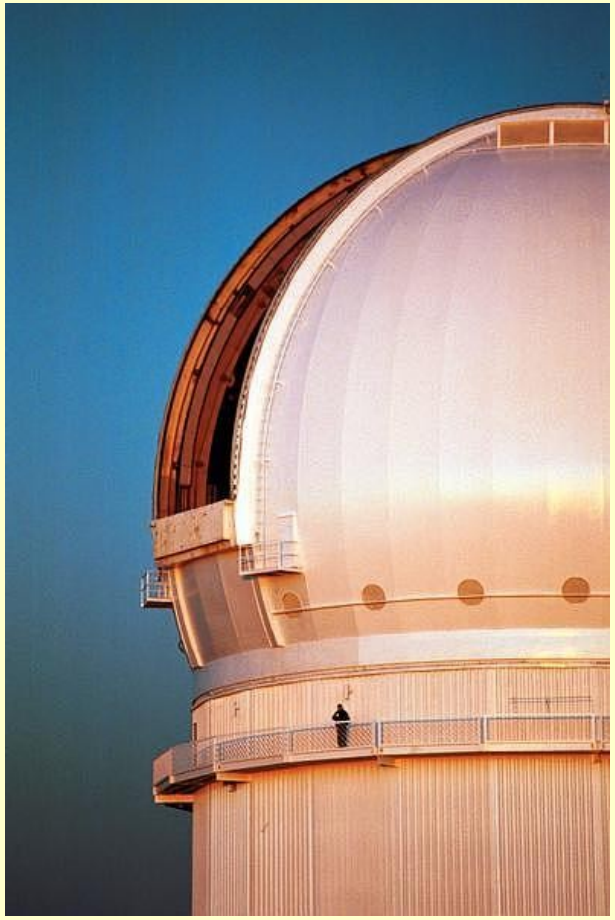
3rd Leopoldina conference

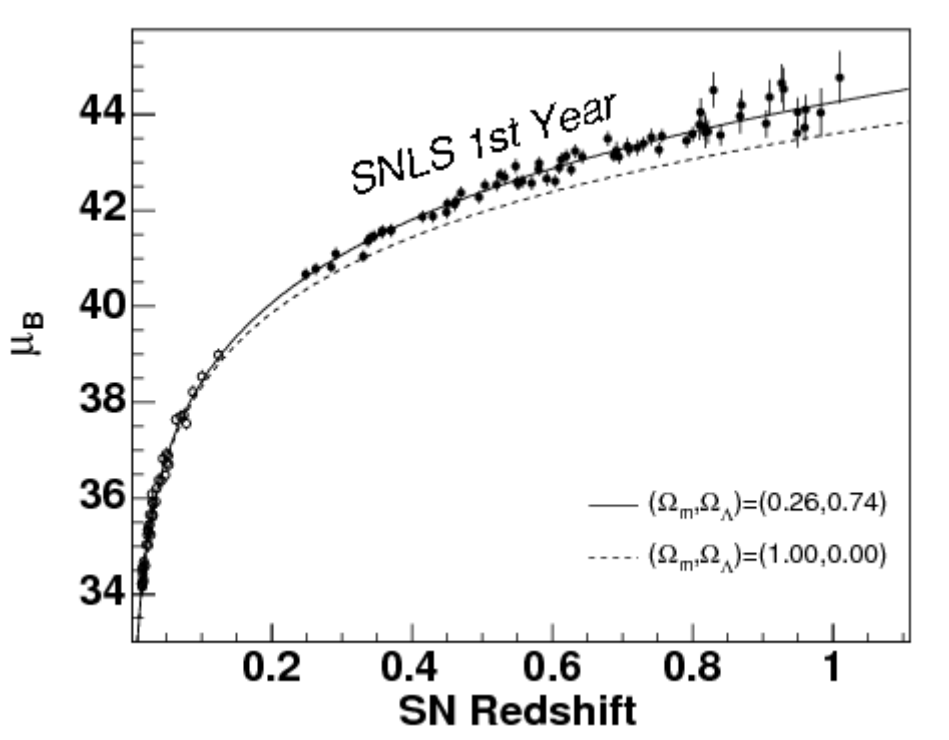
The SNLS Collaboration



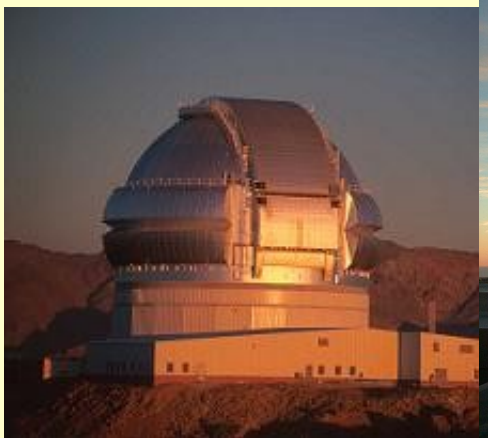
SNLS: SNe Ia at 0.2<z<1

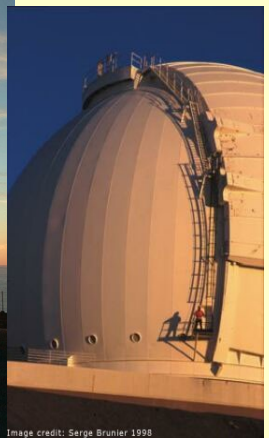
Photometry
(CFHT, 3.6m)





Spectroscopy (VLT, Gemini, Keck)





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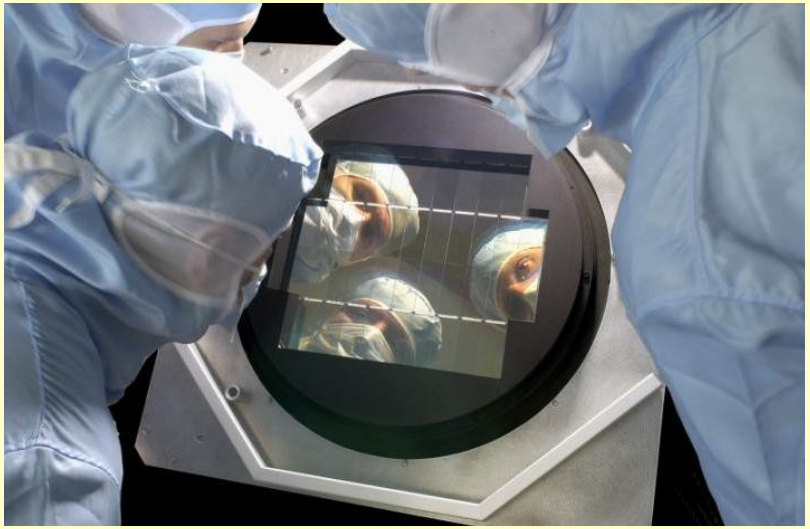
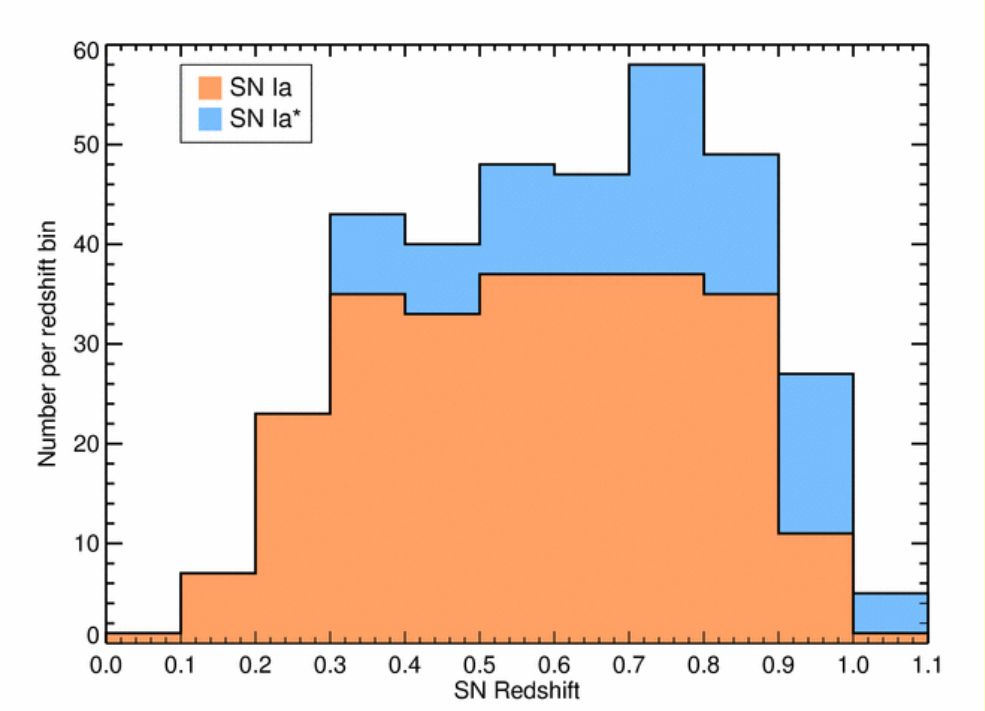
SNLS: vital statistics

- 5 year "rolling" SN survey (within CFHTLS)
- Goal: ~500 high-z SNe to measure "w"
- Uses "Megacam" imager on CFHT

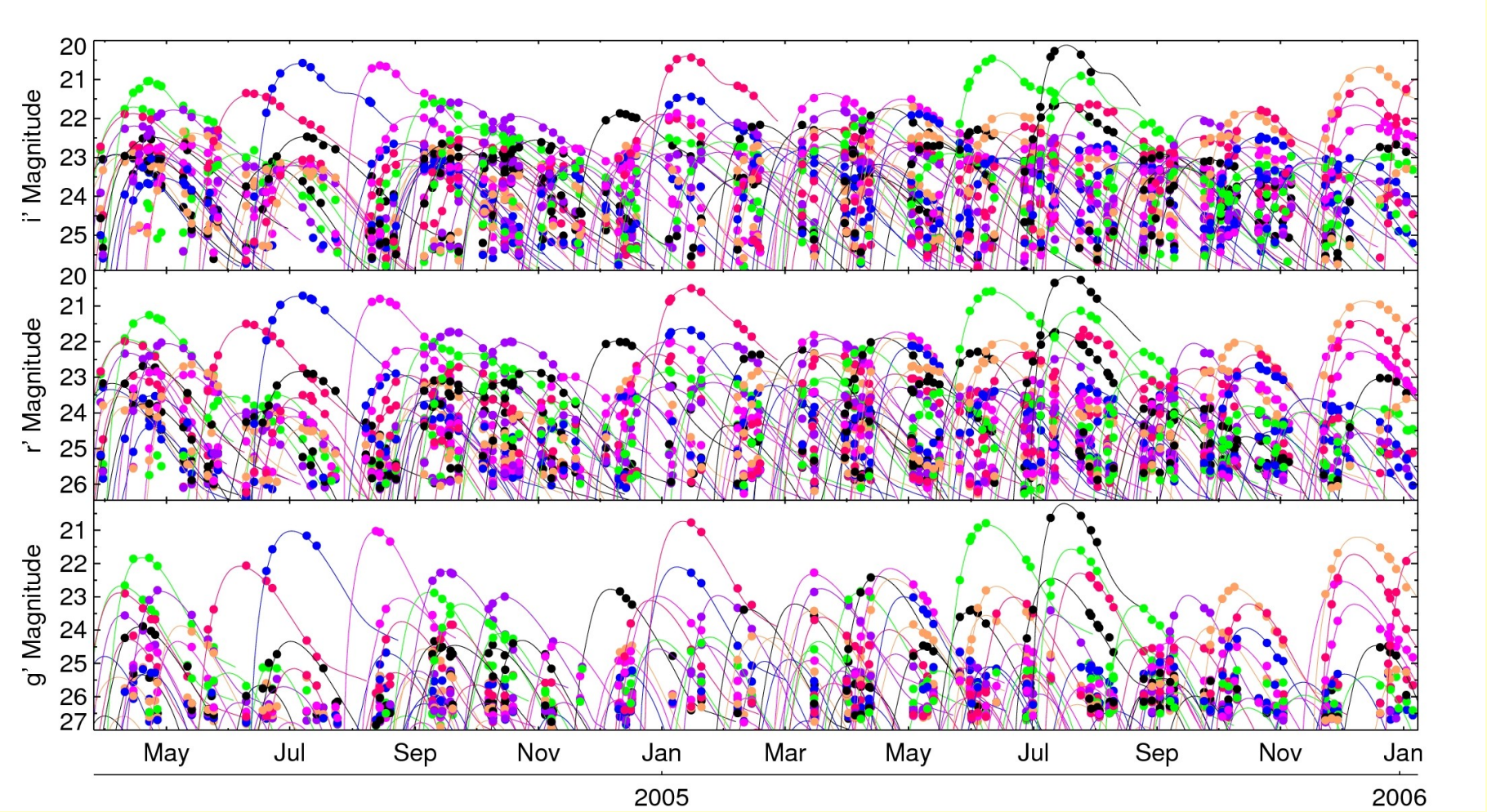
  griz bands every 4 nights in queue mode
- Spectroscopy on VLT,Gemini & Keck.



- SN Survey now complete
- ~400 confirmed z>0.1 SNe Ia
- ~1000 SN detections in total



Rolling Search

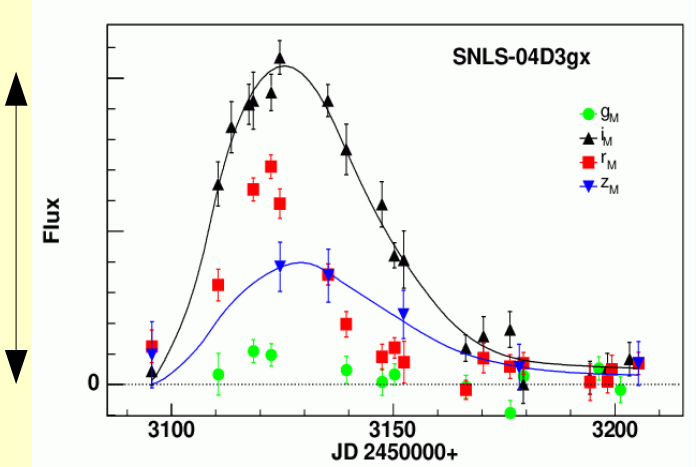


About 20 months – 1/3 – of all data

SNLS images the same fields 5 times per month in 4 filters

SNe provide luminosity distances

Primary distance indicator:
peak flux
(scatter ~ 50%)

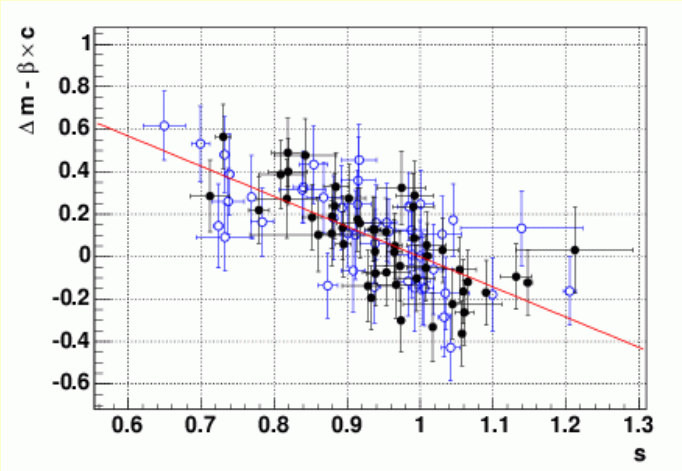


Improved distance indicator :
account for luminosity variations

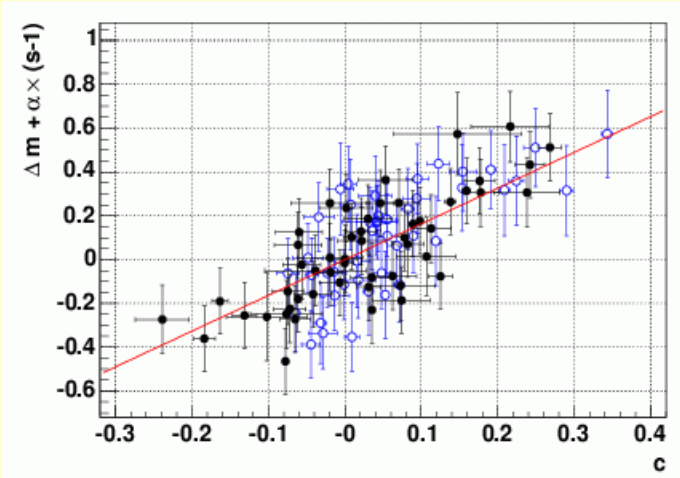
Empirical luminosity indicators

Brighter – slower
(Phillips 1993)

Brighter - bluer



brighter



slower (lightcurve width)
e.g stretch factor s

bluer (B-V color at peak)
rest-frame color c

SNLS empirical distance estimator

supernova measurements

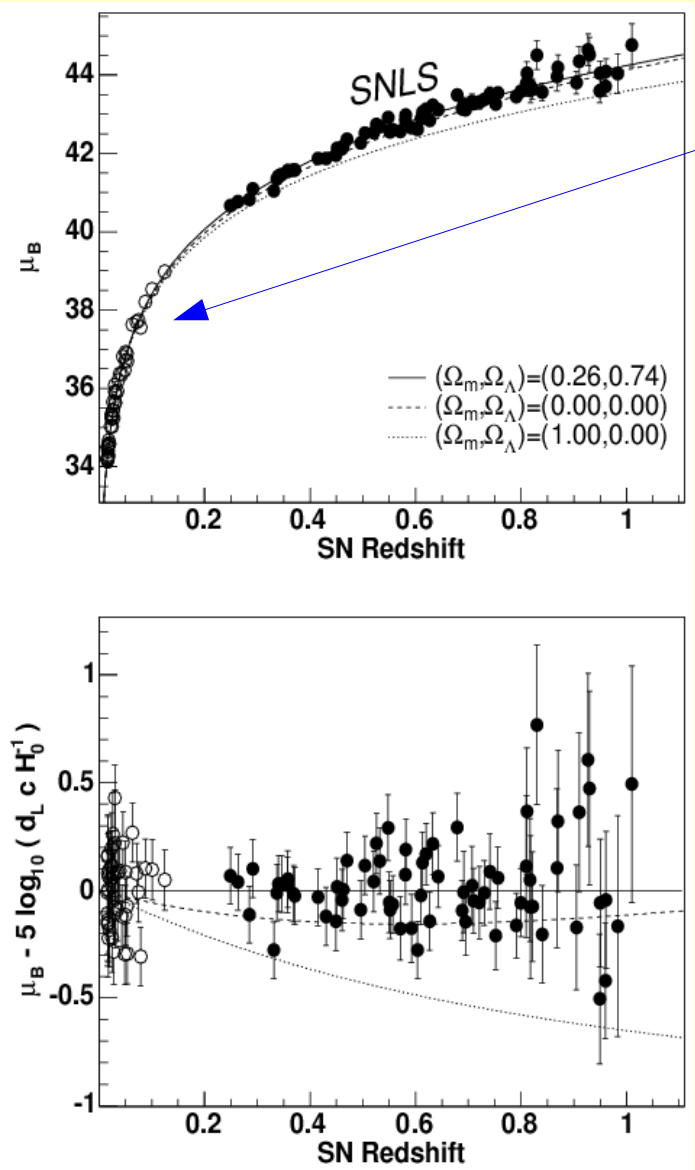
$$\mu_B = m_B - M + \alpha(s-1) - \beta c$$

Distance modulus

Global parameters
fitted together with cosmological parameters

Tripp (1998)

Hubble diagram of SNLS (first year)



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

Distance estimator:

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

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

- minimize w.r.t θ, $\mathcal{M}$, α ,β
- compute σ_{int} so that $\chi^2 = N_{dof}$ ($\sigma_{int} = 0.13$)
- marginalize over $\mathcal{M}$ α ,β to draw contours
- residual r.m.s = 0.20

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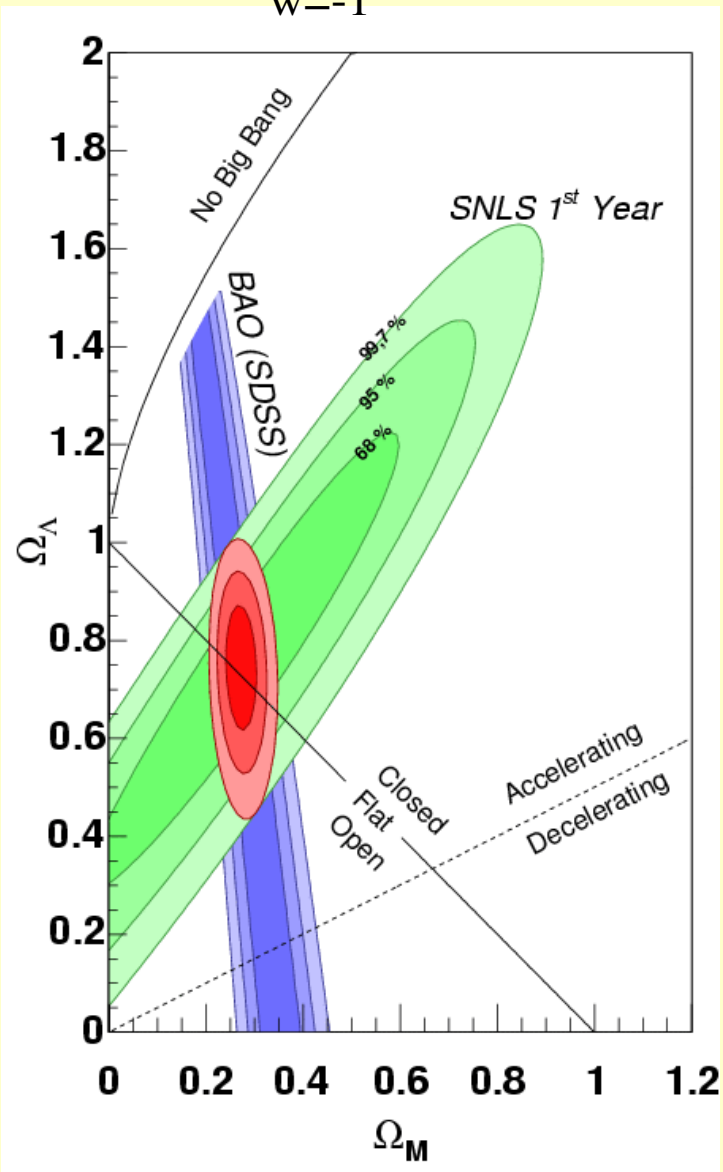
SNLS (1 year) confidence Contours

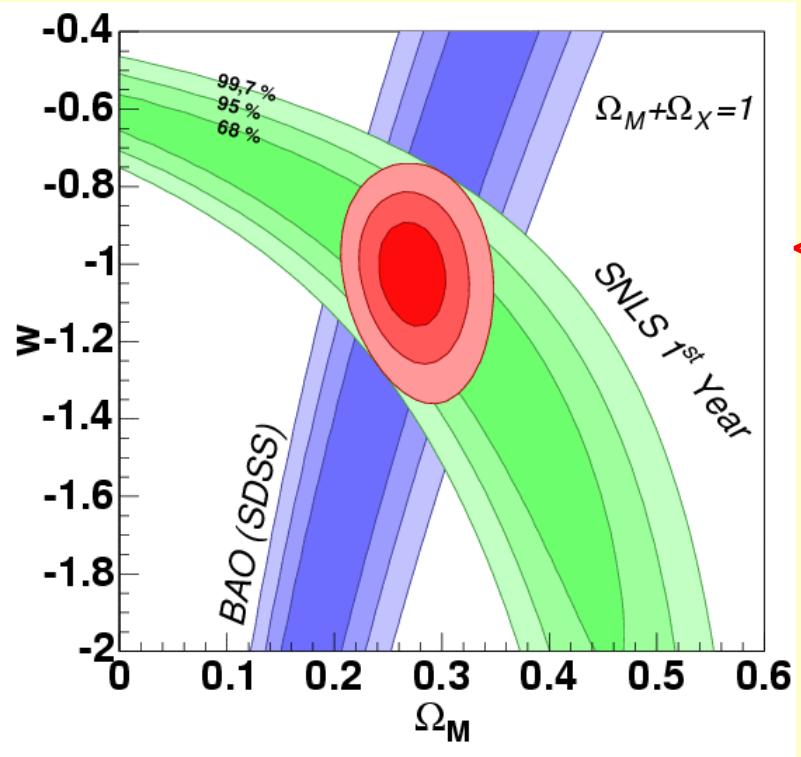
(astro-ph/0510447)

w=-1



68.3, 95.5 et 99.7% CL

$\Omega_T=1$



<-- Λ

BAO: Baryon Acoustic Oscillations
(Eisenstein et al 2005, SDSS)

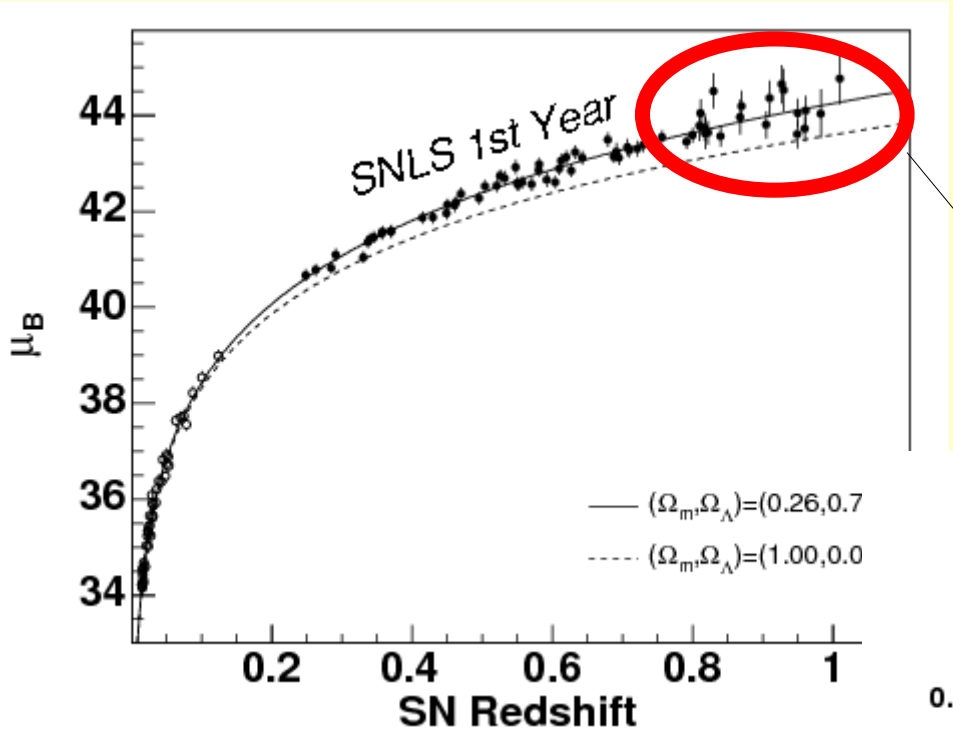
SNLS SNe + nearby SNe + BAOs :

$$\Omega_M = 0.271 \pm 0.021\ (stat) \pm 0.007\ (sys)$$
$$w = -1.02 \pm 0.09\ (stat) \pm 0.054\ (sys)$$

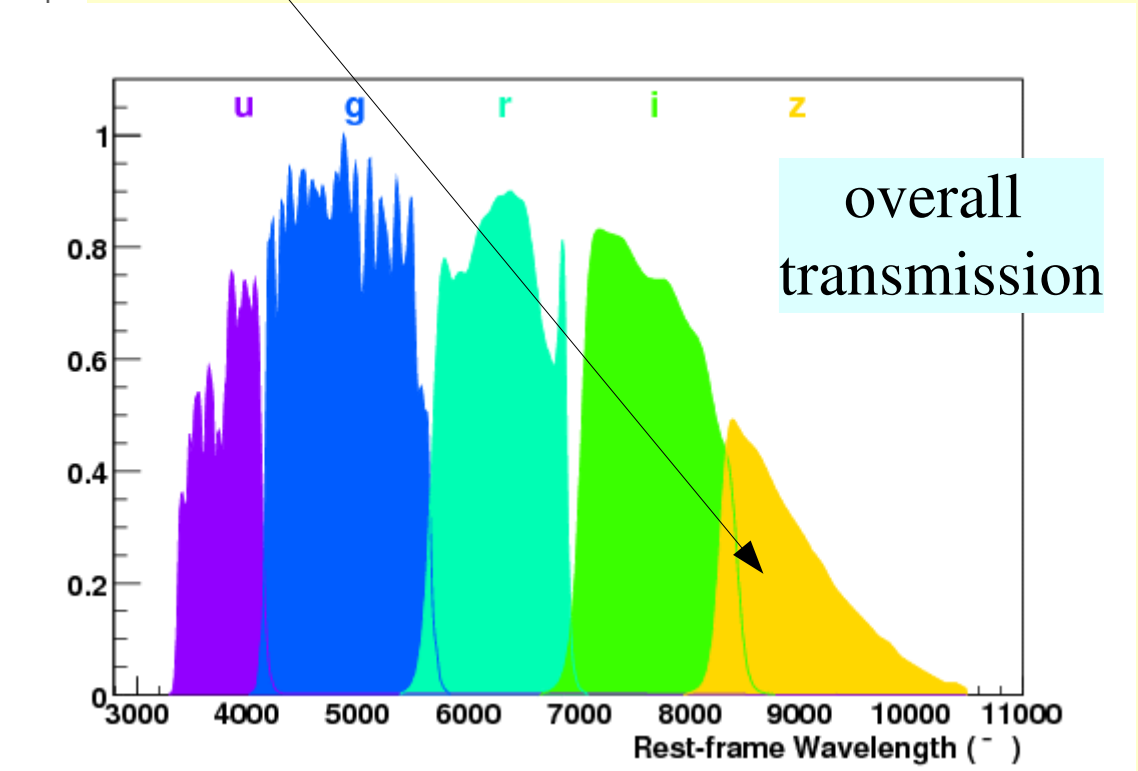
From first year to 3rd year analysis

- More supernovae : about 250 events
- Improved modeling of SN Ia
  - New techniques exploit SN data at λ<4000A (restframe)
- Optimized survey calibration
  - Better characterization of Megacam array
  - 3-year monitoring of fields
- Independent analyses ("French" and "Canadian")
  - All aspects of analysis cross-checked independently
- Systematics included directly in cosmological fits
  - Covariance matrix will be provided
- WMAP5 now available

Red sensitivity of Megacam



Poor Megacam sensitivity in z band



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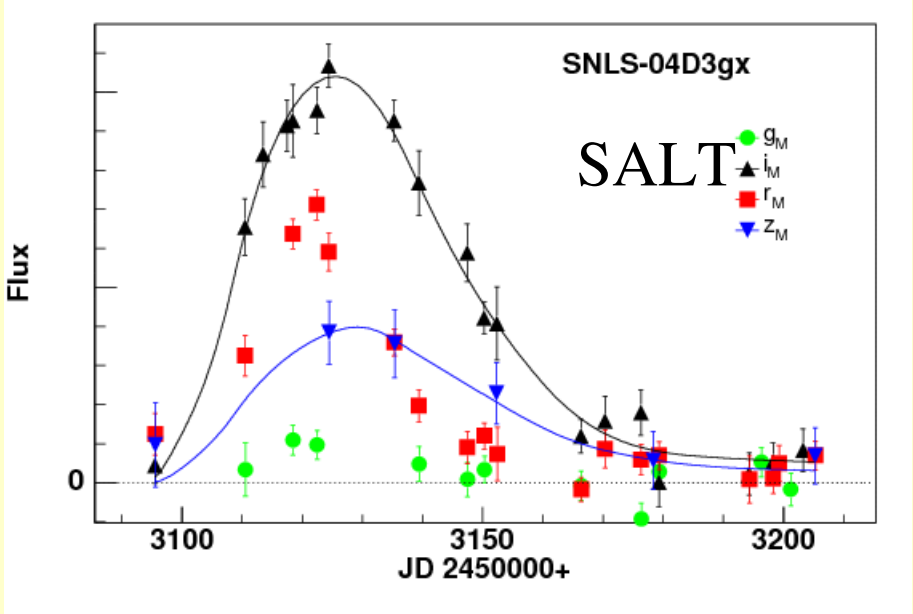
Extend SN modeling towards blue

SALT2 (Guy et al, 2007) & SIFTO (Conley et al, 2008)

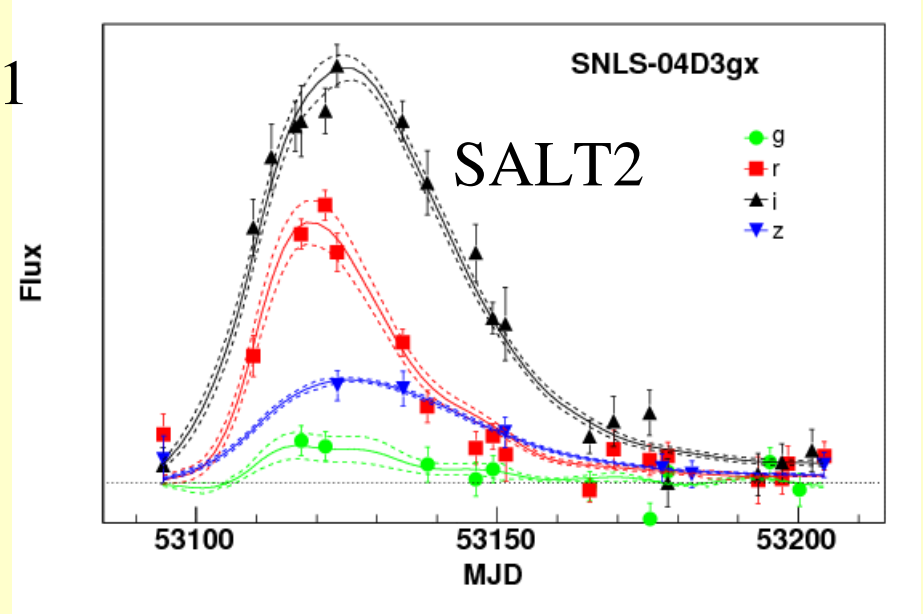
- No assumed relation between redshift and flux

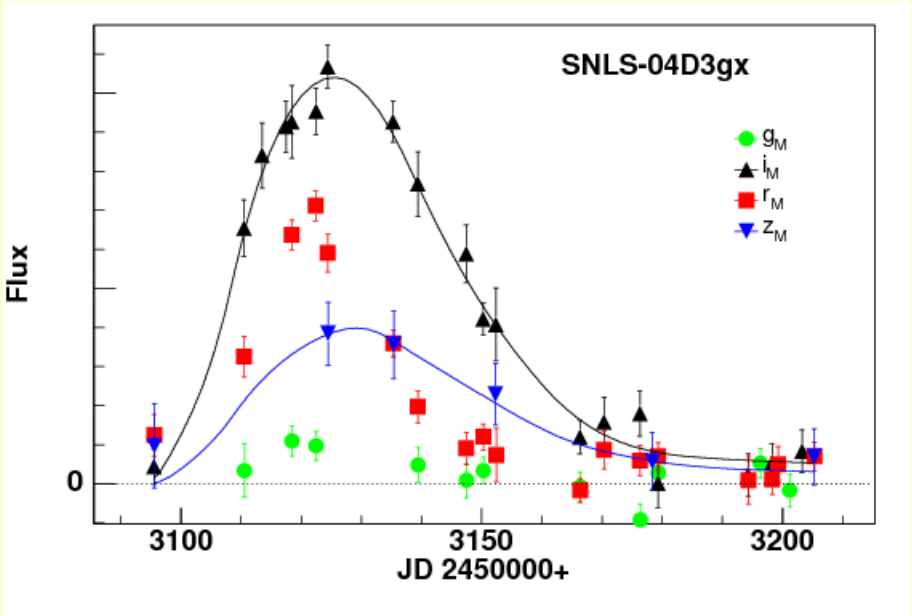
--> can train with (very) nearby SNe and SNLS data.

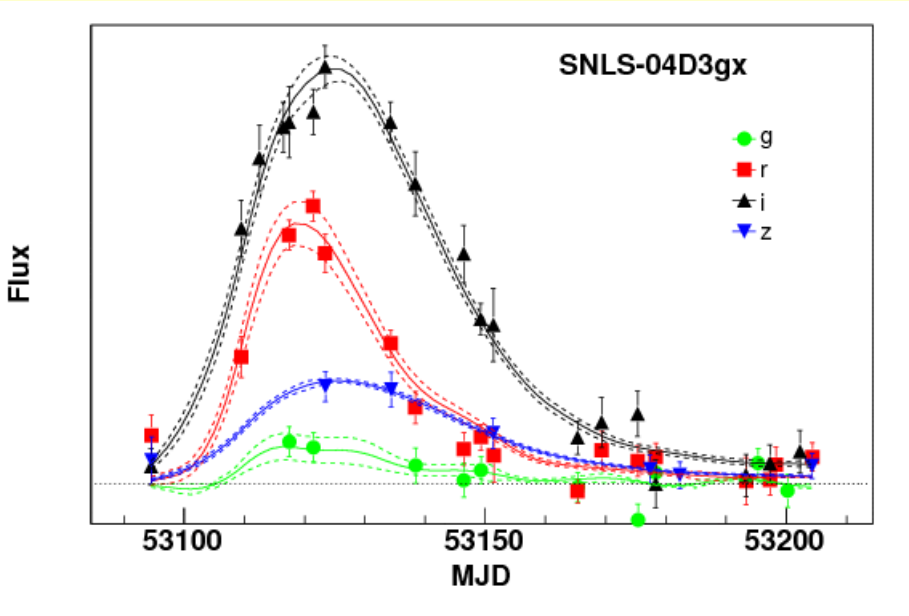
- Spectrophotometric models

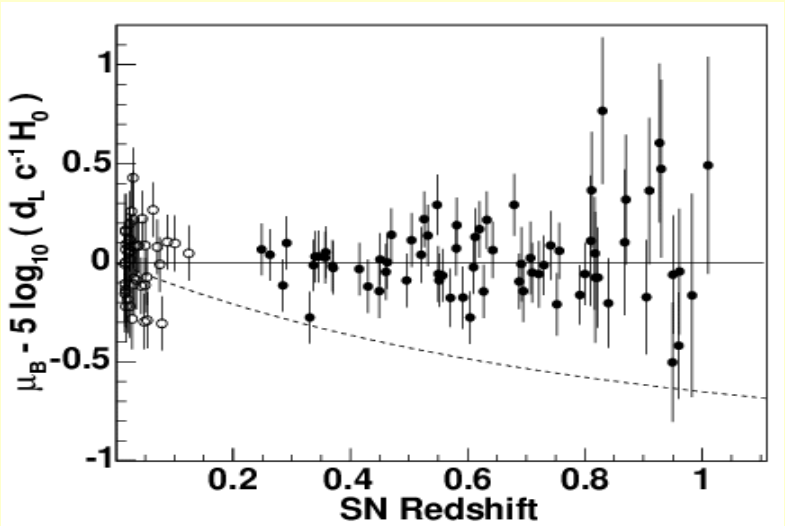


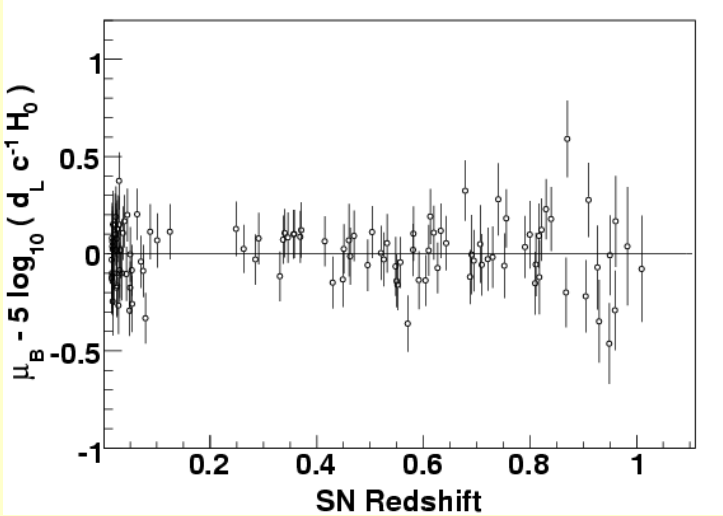
z=0.91











$\sigma = 0.20$

$\sigma = 0.16$

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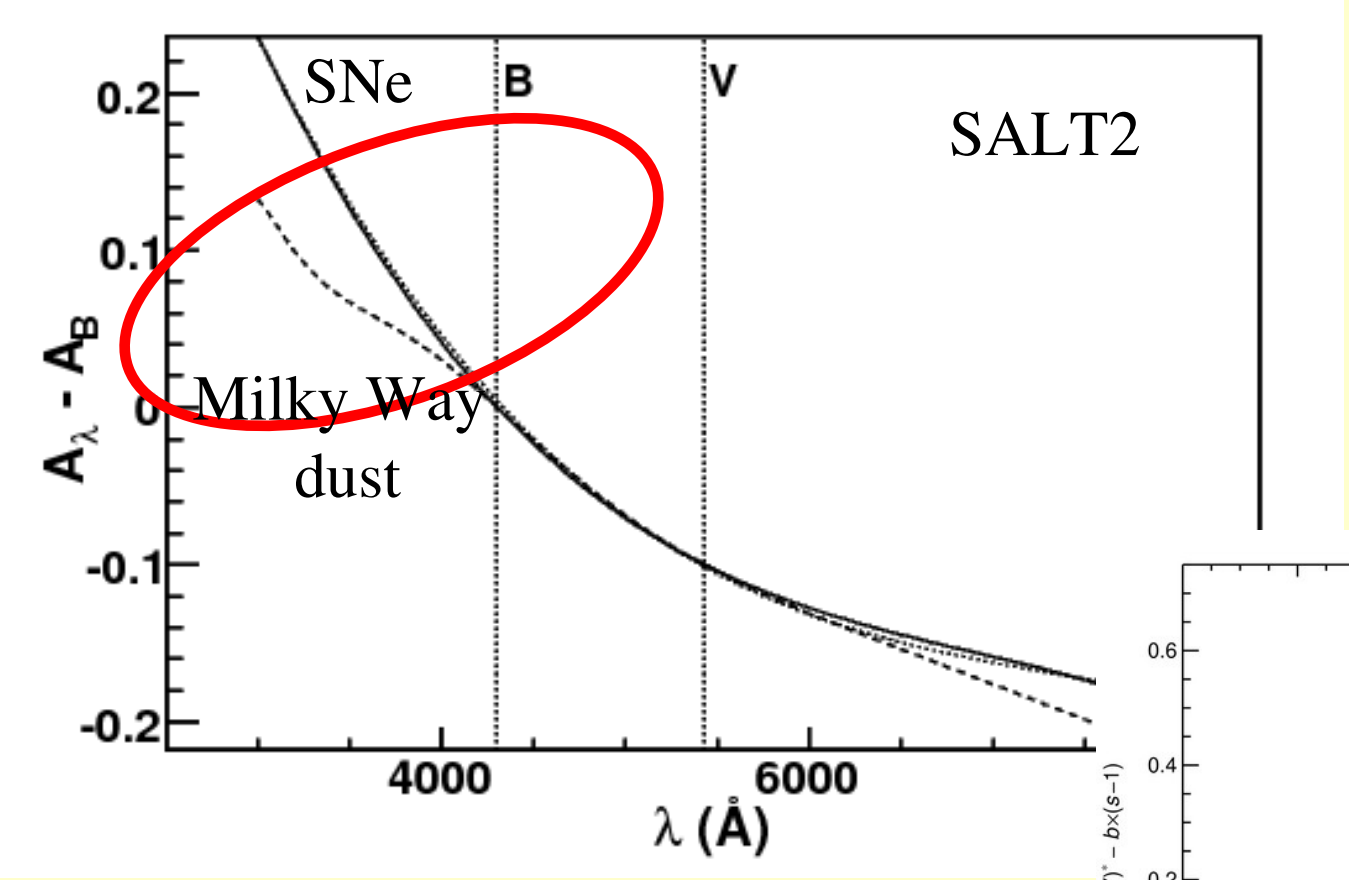
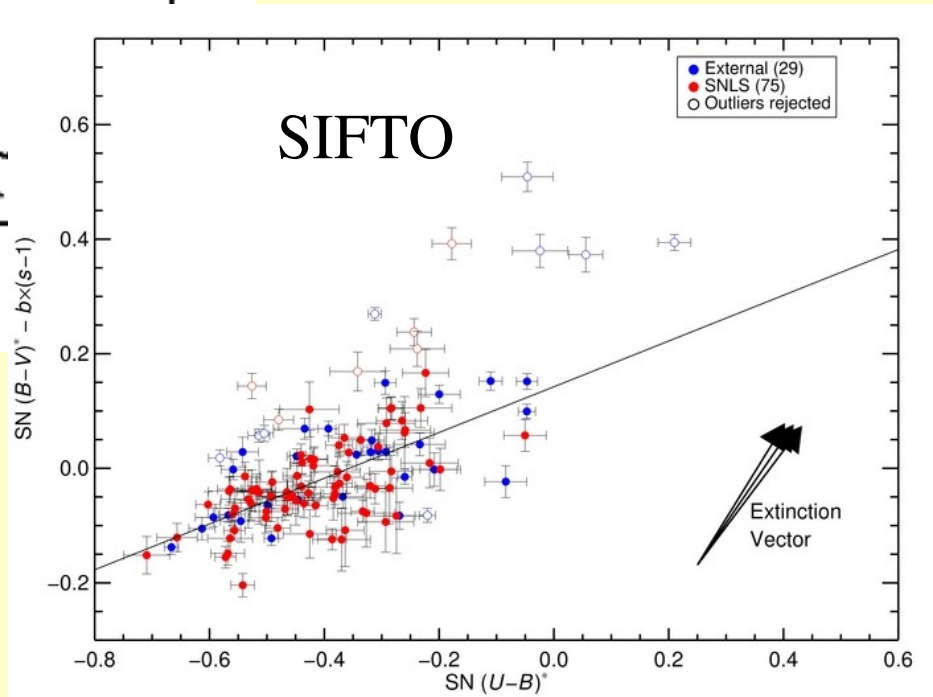
SNe Ia color relations: “color law”



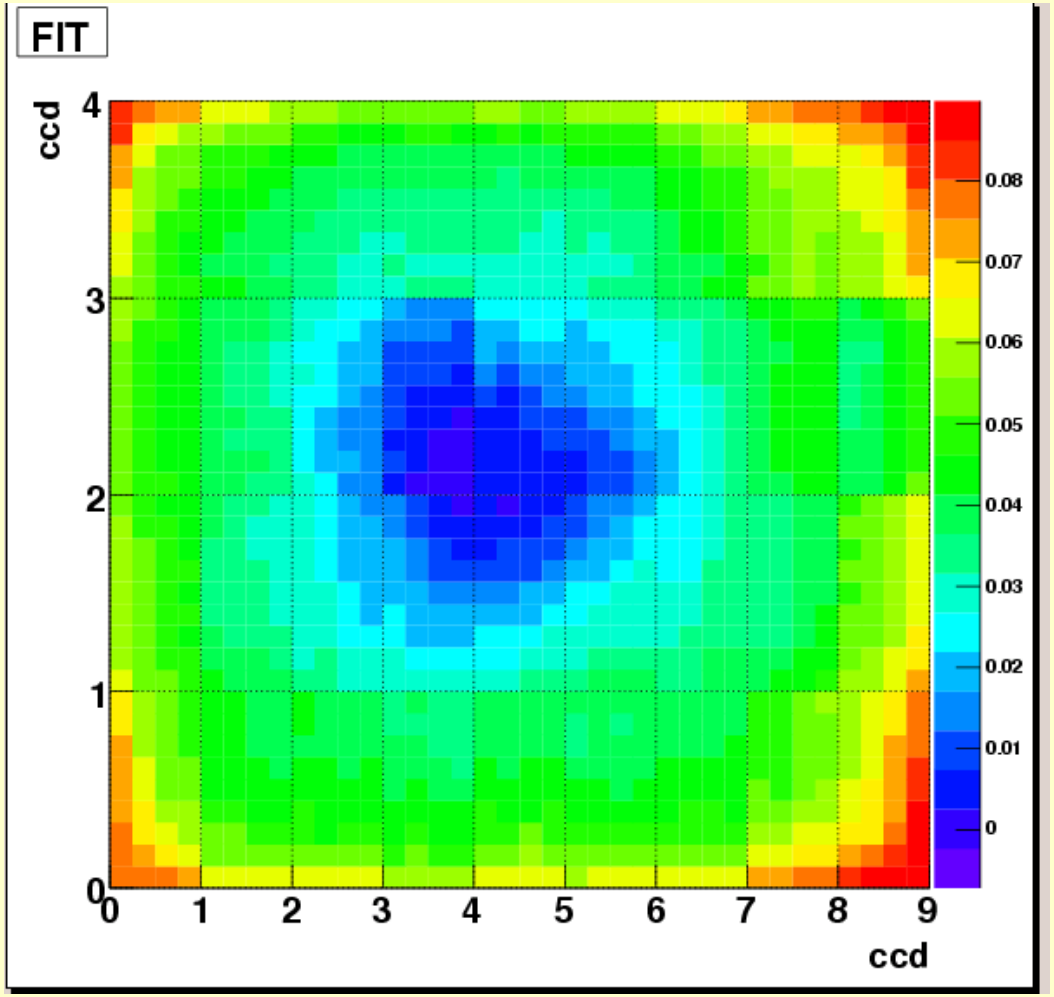


Both models cannot accommodate dust driven color relations (as modeled by Cardelli 93)

Megacam array (non) uniformity

photometric response

- After "standard" flat-fielding 8% variations remain
- After CFHT "standard" corrections, ~3% remain
- Now fixed in our analysis
- Differential uncertainty (noise) below 1%

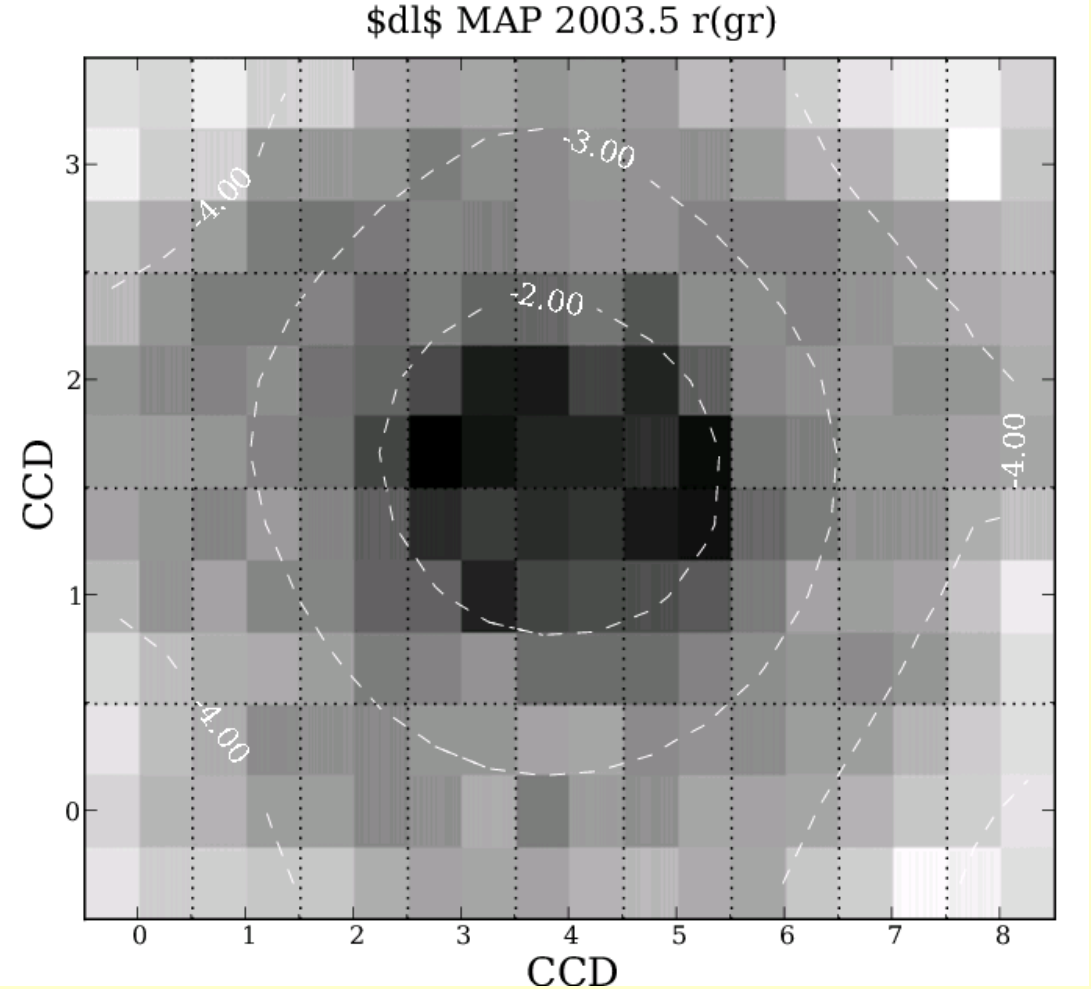


Regnault et al (2009)

Megacam array (non) uniformity

passbands

- The effective central wavelength of passbands varies across the focal plane
- Measured on the sky, and checked in the lab.
- Shifts are accounted for when measuring stars and SNe.



r band : shift of 5 nm center to corner due to thinner layers on the filter edges

Regnault et al (2009)

Photometric calibration

- To fit cosmology, all supernovae fluxes should be expressed on the same scale
- Nearby supernovae are (up to now) measured against the Landolt stars
- **Presently**, SNLS has to be calibrated against Landolt

We need :

- "Zero points" (signal of a zero magnitude star in the instrument)
- Effective wavelengths of Landolt BVRI magnitude measurements
- Fluxes of the primary standard (indeed only colors matter)

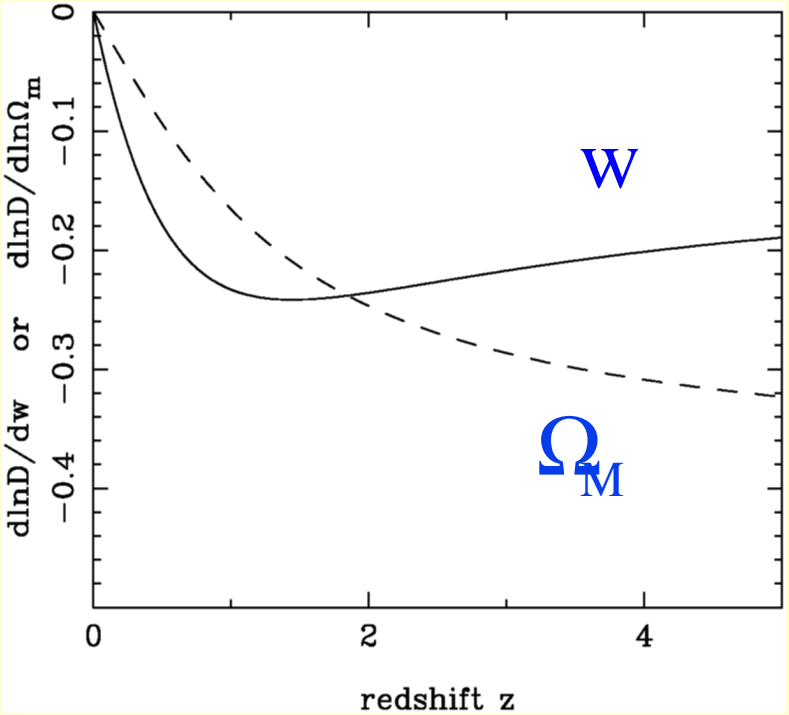
Sensitivity of distances

- Rule of 5 :

  w to 0.05 <=> distances to 1%
  fluxes to 2%
  0.02 mags

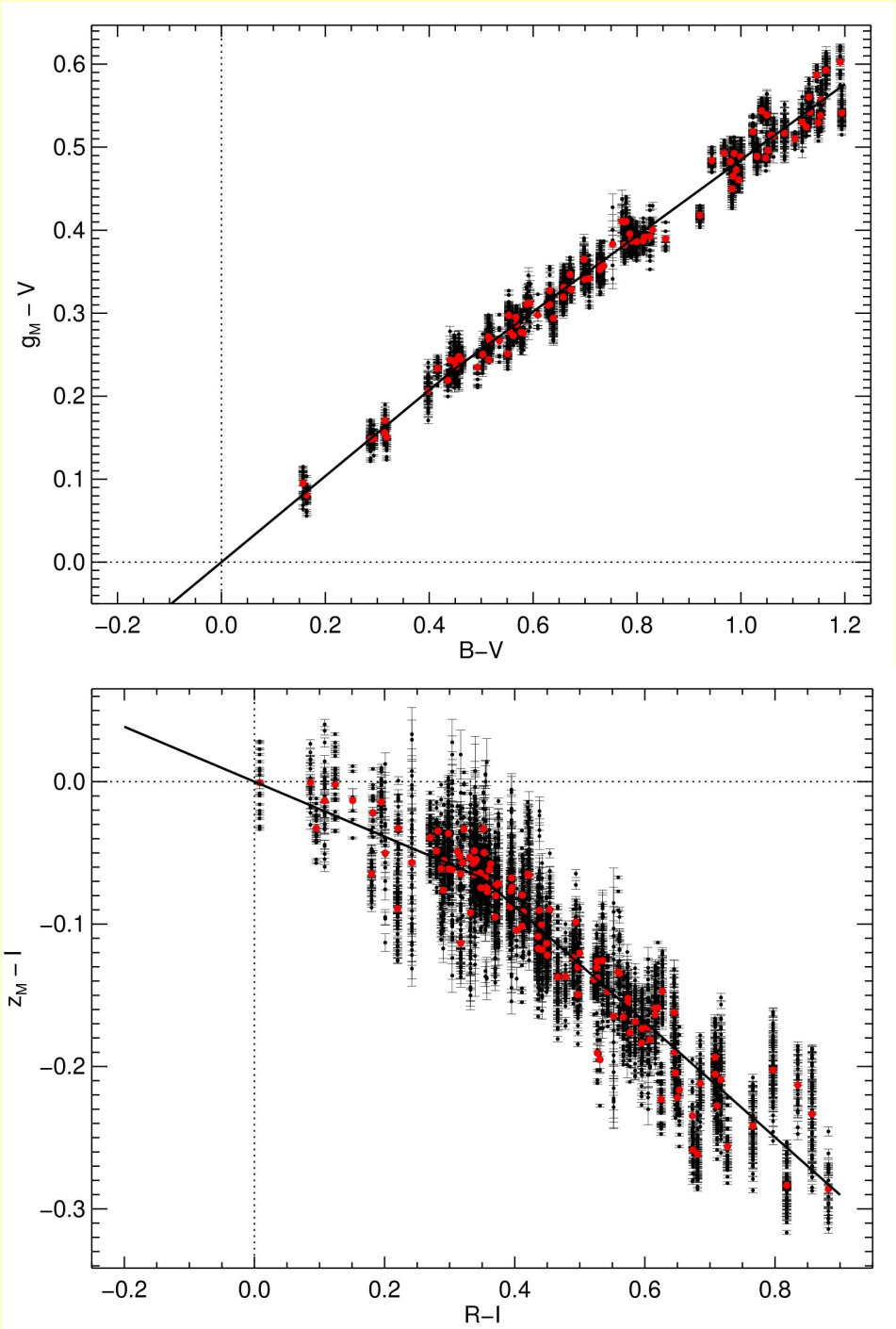
Since colors enter the distance estimates, things are indeed worse.

- Changes in w are almost degenerate with changes in Ω_M



(flat universe)

Zero points



- Obtained by fitting color-color plots of Landolt stars
- Large and non-linear color terms
- Fitting methods checked against synthetic data
- overall accuracy below 1% (2% in z)

Calibration uncertainty budget

r.m.s uncertainties on w

SNLS zeropoints	0.032
Megacam filters	0.027
External zeropoints	0.033
Landolt filters	0.015
Vega colors	0.039
Vega SED	0.015
Total	**0.069**

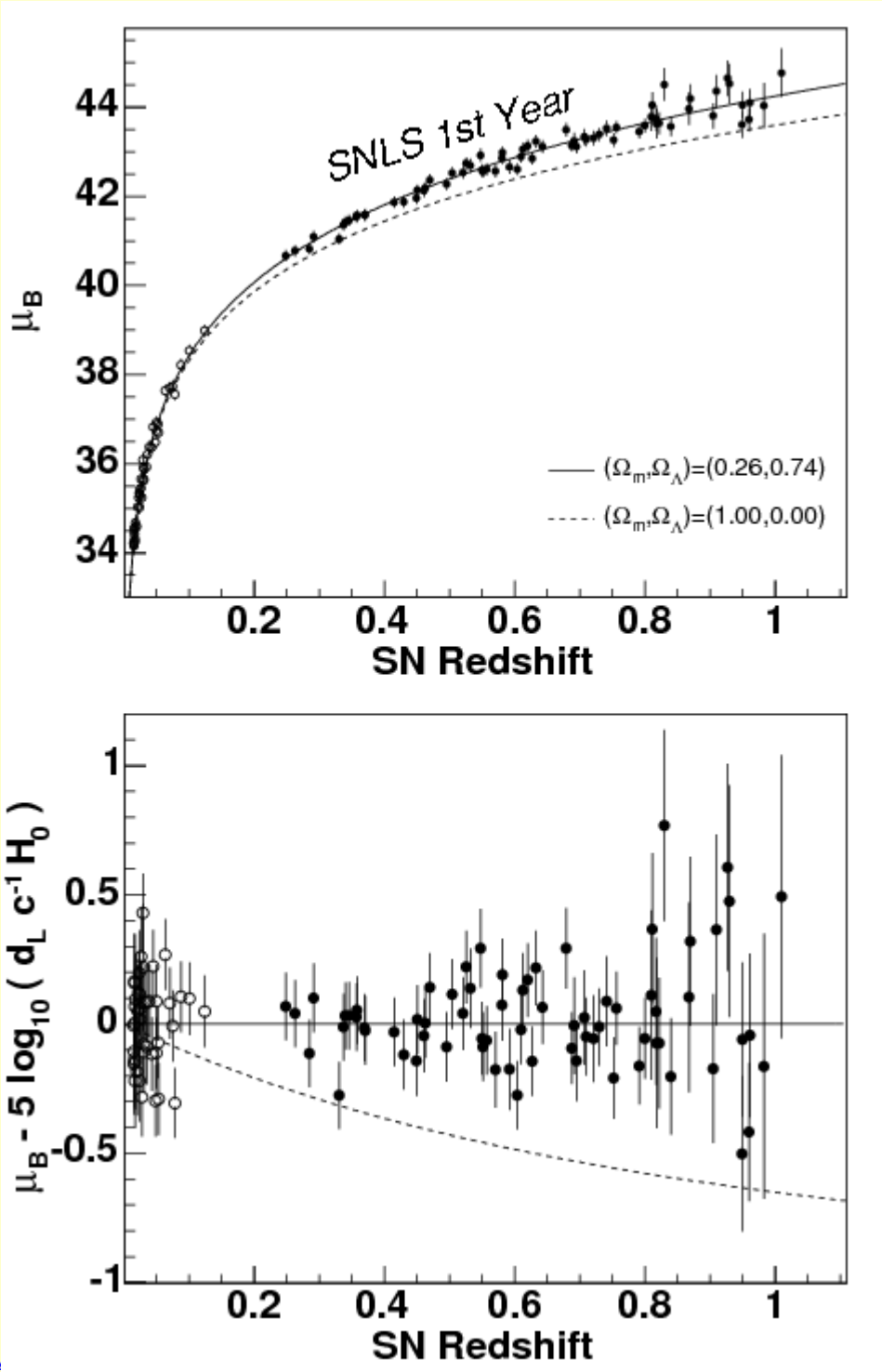
When the low-z sample is replaced by an SNLS-like sample (SDSS?, skymapper/PTF), the budget drops to ~0.04, using current calibration techniques

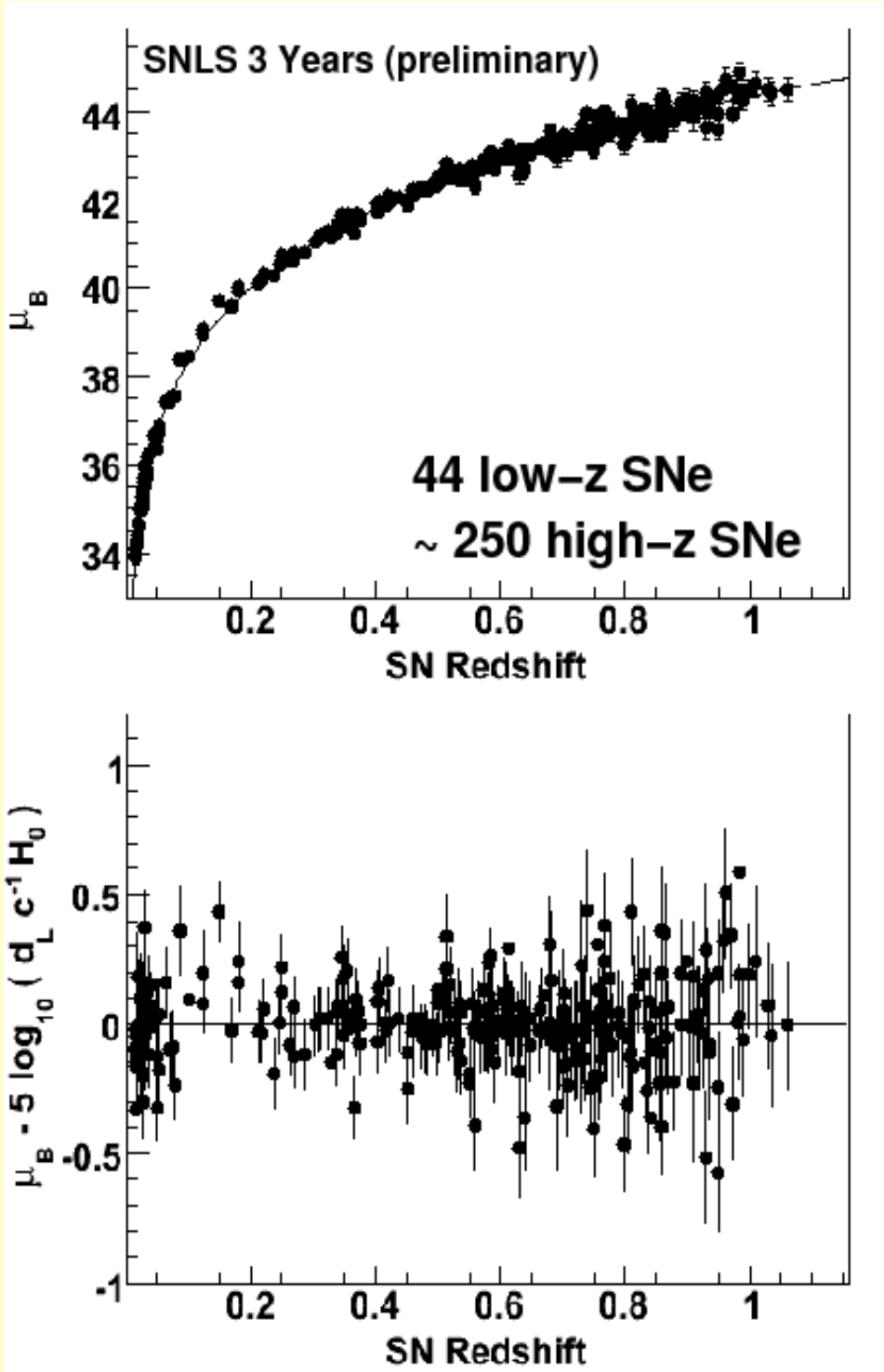
- indicative numbers, they will change

- Dominated by Landolt system uncertainties.
Driven by the low-z samples

- Most figures go down when we calibrate on a SDSS-like system.

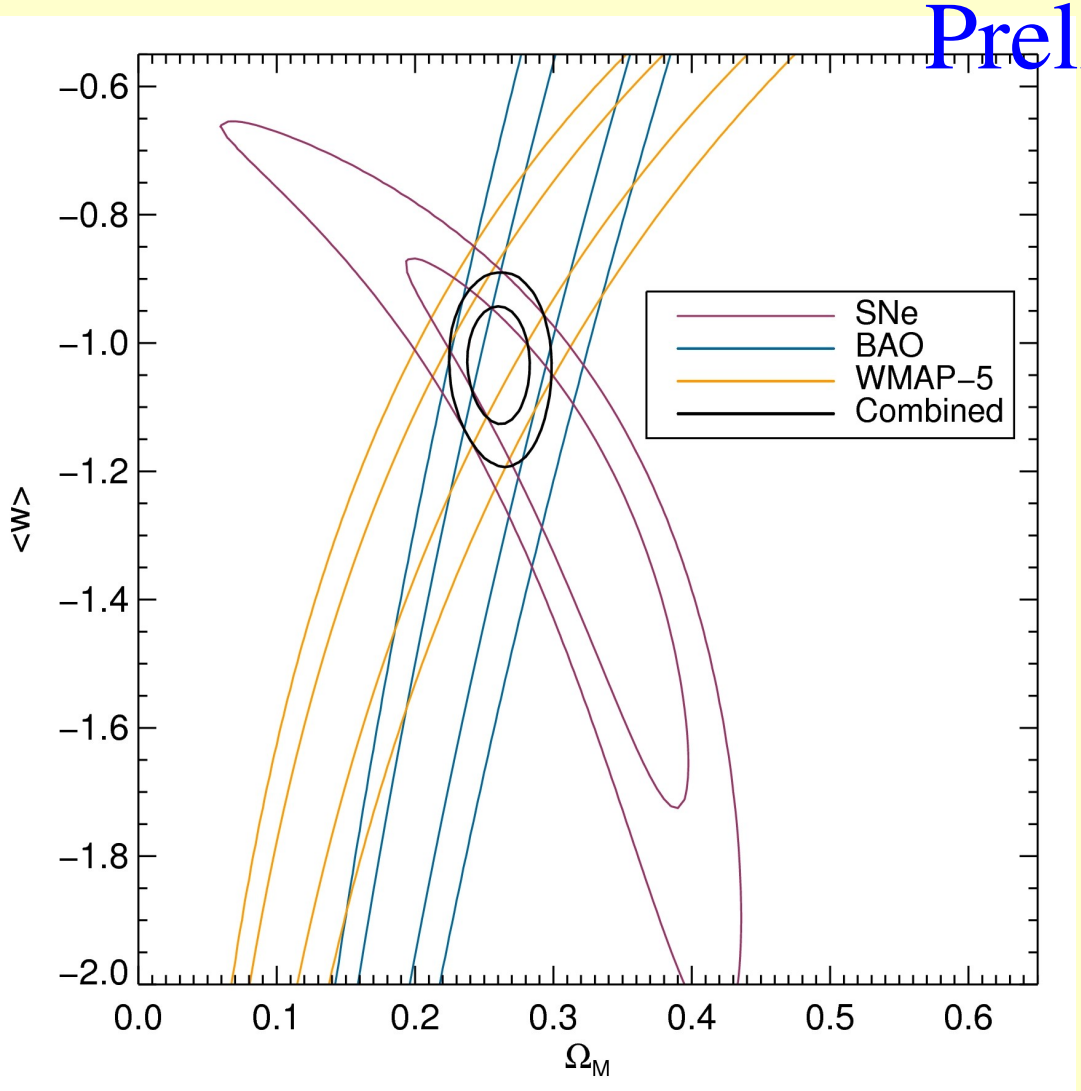
- CFHTLS/SDSS cross-calibration underway


SNLS 1st Year
μ_B
SN Redshift
$(\Omega_m,\Omega_\Lambda)=(0.26,0.74)$
$(\Omega_m,\Omega_\Lambda)=(1.00,0.00)$
$\mu_B - 5\log_{10}(d_L c^{-1} H_0)$


SNLS 3 Years (preliminary)
44 low–z SNe
~ 250 high–z SNe
μ_B
SN Redshift
$\mu_B - 5\log_{10}(d_L c^{-1} H_0)$

Cosmological constraints

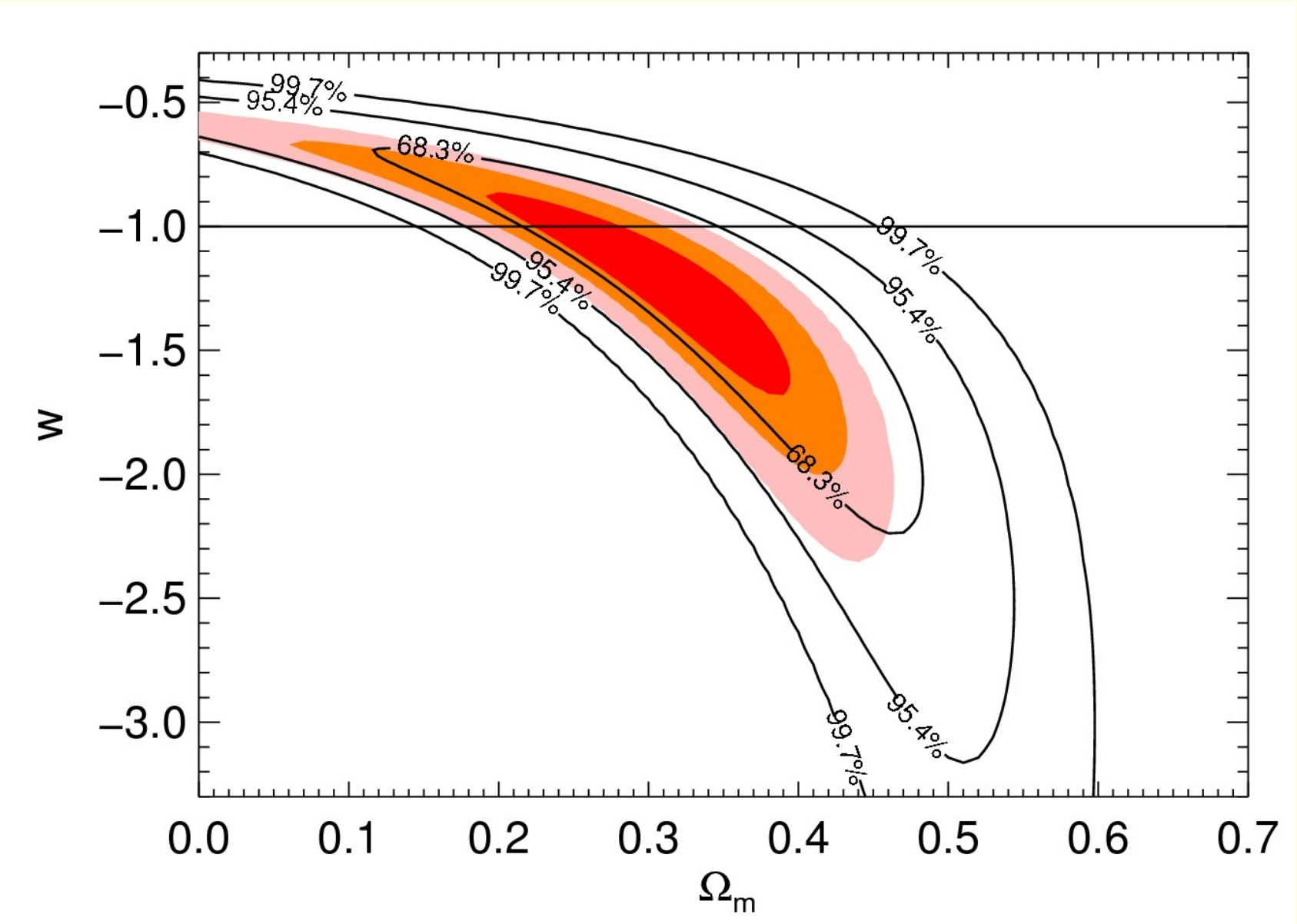
Preliminary



SNLS+nearby+BAO
+WMAP5 “shift”

Raw statistical uncertainty
w = -1.xx +/- 0.06

Should add +/- 0.03
for lightcurve fitter
training (mainly SN
color relations)



Systematic errors included in the error contours.
Filled are statistical only.

Brighter-bluer relation

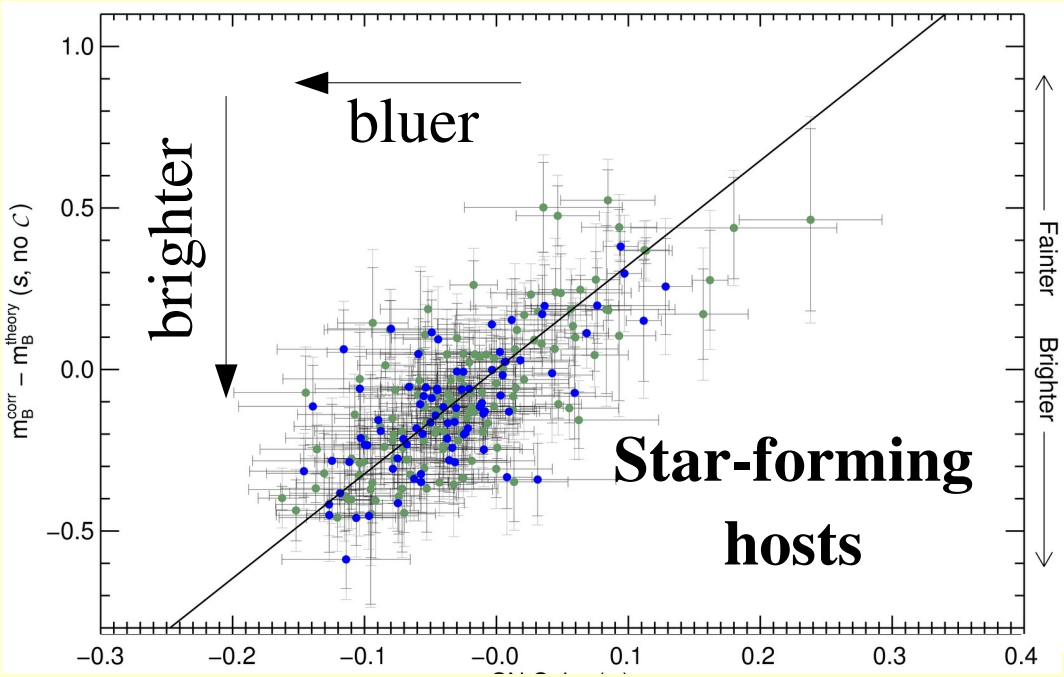
- SNLS (and many other) <u>measure</u> a brighter-bluer relation incompatible with $R_v = 3.1$ (MW dust)

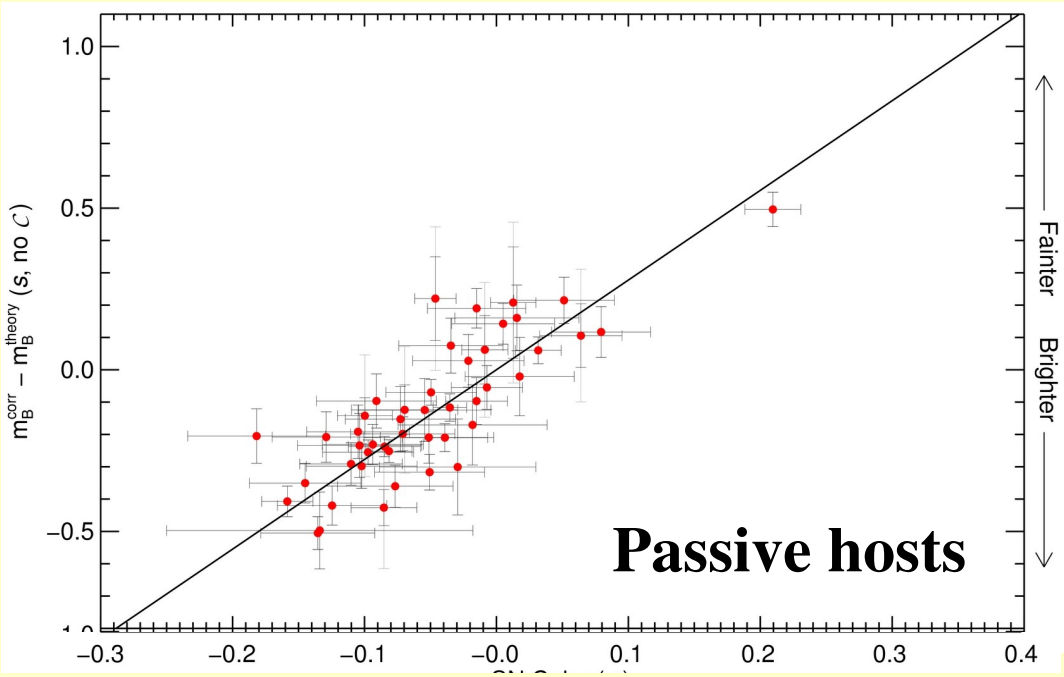
- Numerical values of the SNe brighter-bluer correlation depend on:
  - The chosen definition of color.
  - The assumed color relations.
  - The way it is fitted.

- SN color relations seem as well incompatible with Cardelli law.

Extinction ? SN intrinsics ? mixture ?

Brighter-bluer relation : split by host types





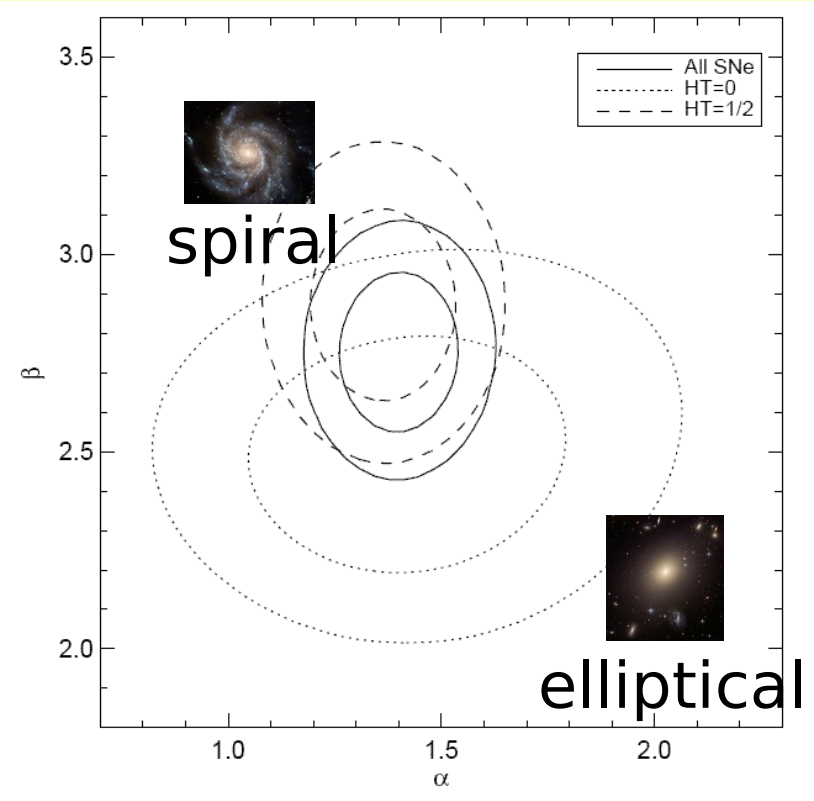
Either:

- Passive hosts have dust?
- An intrinsic relation dominates over dust?

Rest-frame NIR bands should help sorting this out.

Sullivan et al (2006,2009)

Determine α (brighter-slower), β(brighter-bluer), from subsamples split by host type :



==> No indication of different populations

==> SNLS approach is robust to an evolving admixture of hosts.

Sullivan et al (2006,2009)

3rd year analysis : where do we stand?

Characterization of Megacam : OK

Comparisons:

- Light curve modeling and fits : OK (Conley et al, 2008)
- Dual approach to calibration : now essentially in agreement
- Photometry of supernovae : done

Papers are sketched and partly written.

We are eager to finish of the 3rd year analysis to embark on the whole survey analysis

The key people for the cosmological analysis:
Alex Conley, Julien Guy, Nicolas Regnault, Mark Sullivan

Summary/conclusions

3rd year analysis:

- We anticipate (SNLS+nearby SNe +BAO +WMAP5):
  w = something +/- 0.065 (stat) + 0.069 (sys)
- Photometric calibration is our first single systematic source
  Changing the nearby sample could reduce uncertainties to ~0.04
- Our approach to the brighter-bluer correlation is empirical:
  we measure everything we can and marginalise over

Next steps :

- 5th year reduction
- SDSS/CFHTLS cross-calibration
- switch to modern low-z sample(s) : SDSS, SNF(?)

Guess : w = something +/- 0.05 (stat) + 0.05 (sys)