Explosion rate of type Ia supernovae as function of redshift from SuperNova Legacy Survey

INSTITUTE FOR NUCLEAR AND PARTICLE ASTROPHYSICS
JOURNAL CLUB MEETING
November 13th 2009

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SNLS SuperNova Legacy Survey

Summary

- Cosmology & Supernovae
  - Cosmology and Standard Candle
  - Type Ia supernova : Standardizable candle
  - From star to supernova
- Type Ia supernova explosion rate from SNLS
  - SuperNova Legacy Survey : overview
  - Supernova photometric detection and Identification
  - Simulation and Efficiency
  - Type Ia supernova explosion rate
  - Explosion Rate and Star Formation Rate

Summary

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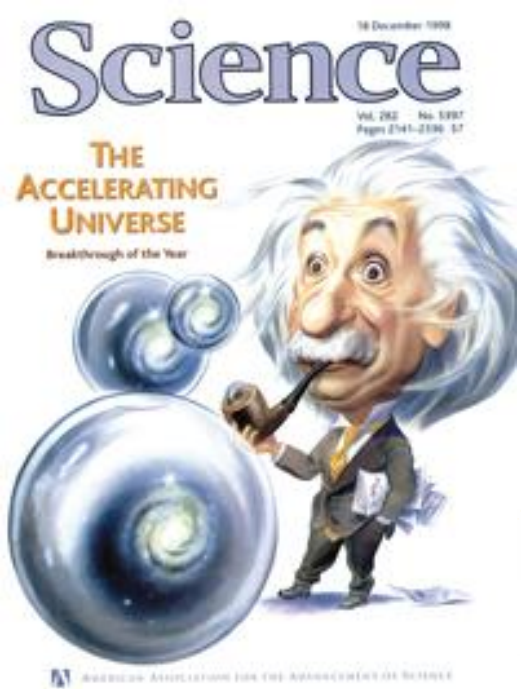
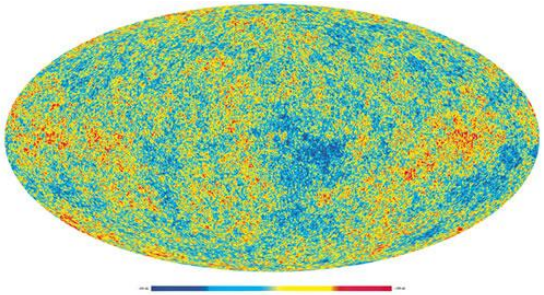
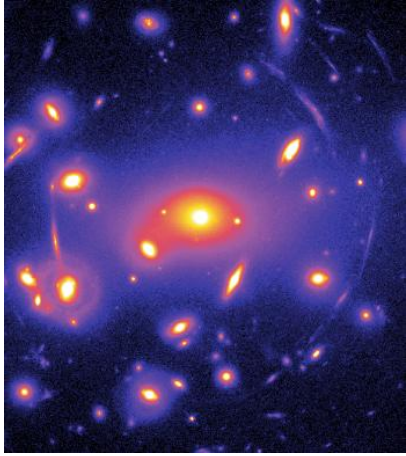
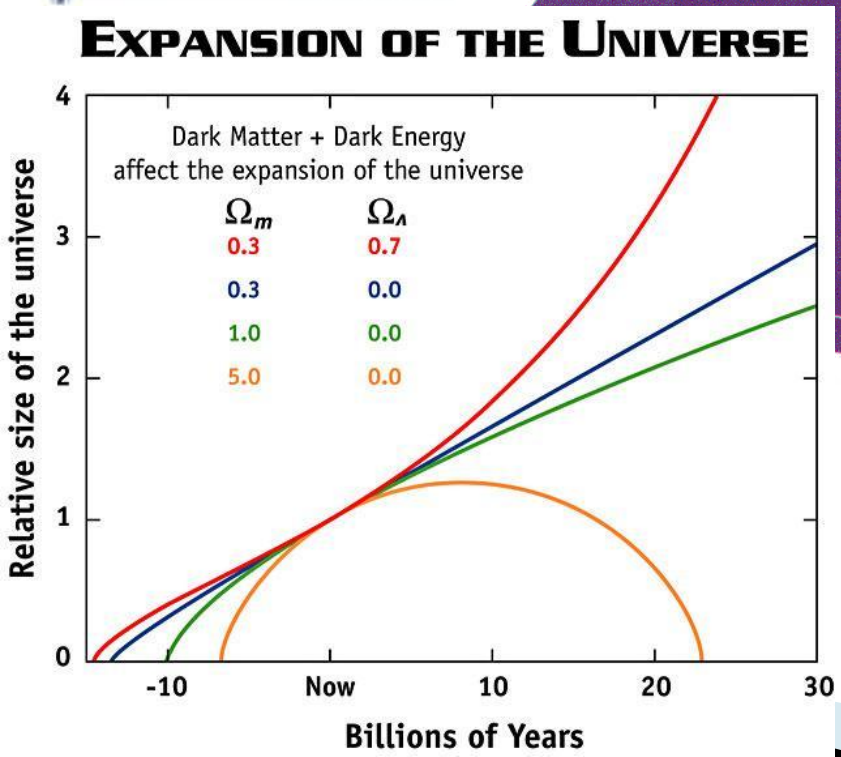


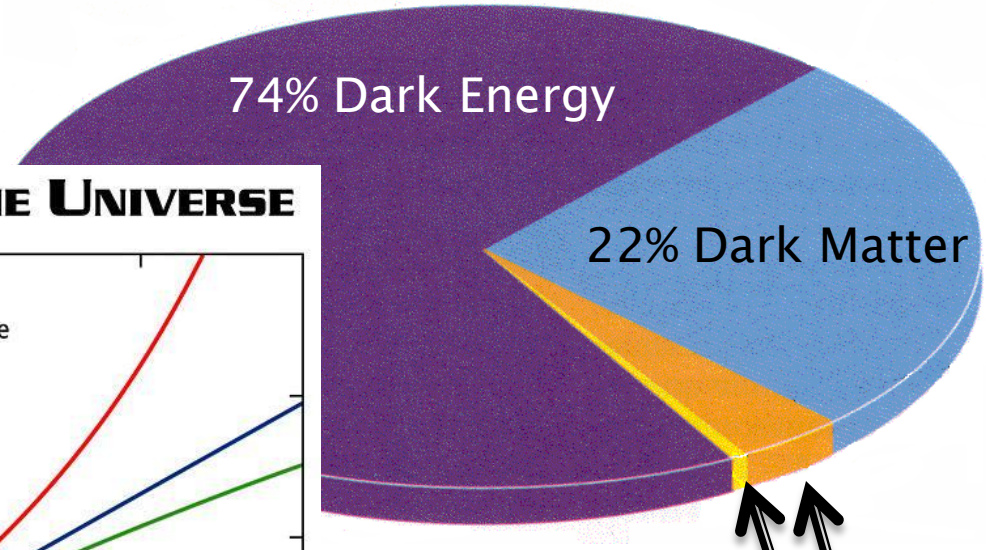


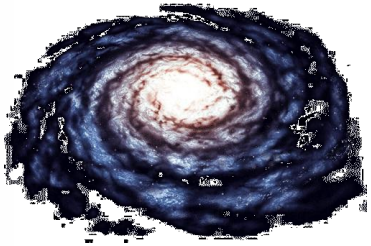
CMB



Gravitational lensing







Galaxy motion

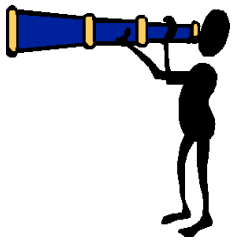
3.6% intergalactic Gas

0.4% Stars, Etc

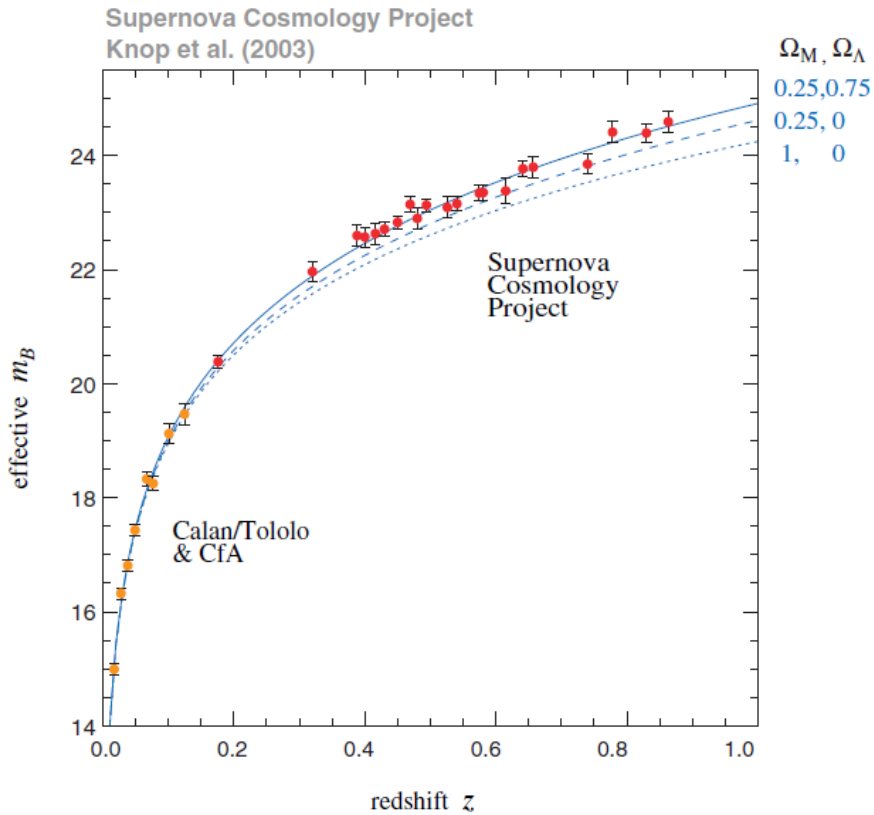
•BAO
•Cluster

Luminosity Distance and Cosmology

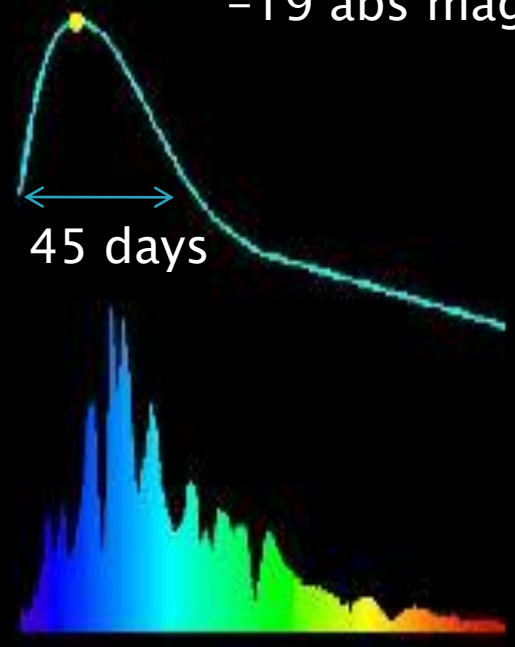
Intrinsic
Luminosity L



Flux f
Redshift z



Type Ia Supernova



Observed luminosity dispersion : 40%

Type Ia Supernoave as Standard(izable) Candle

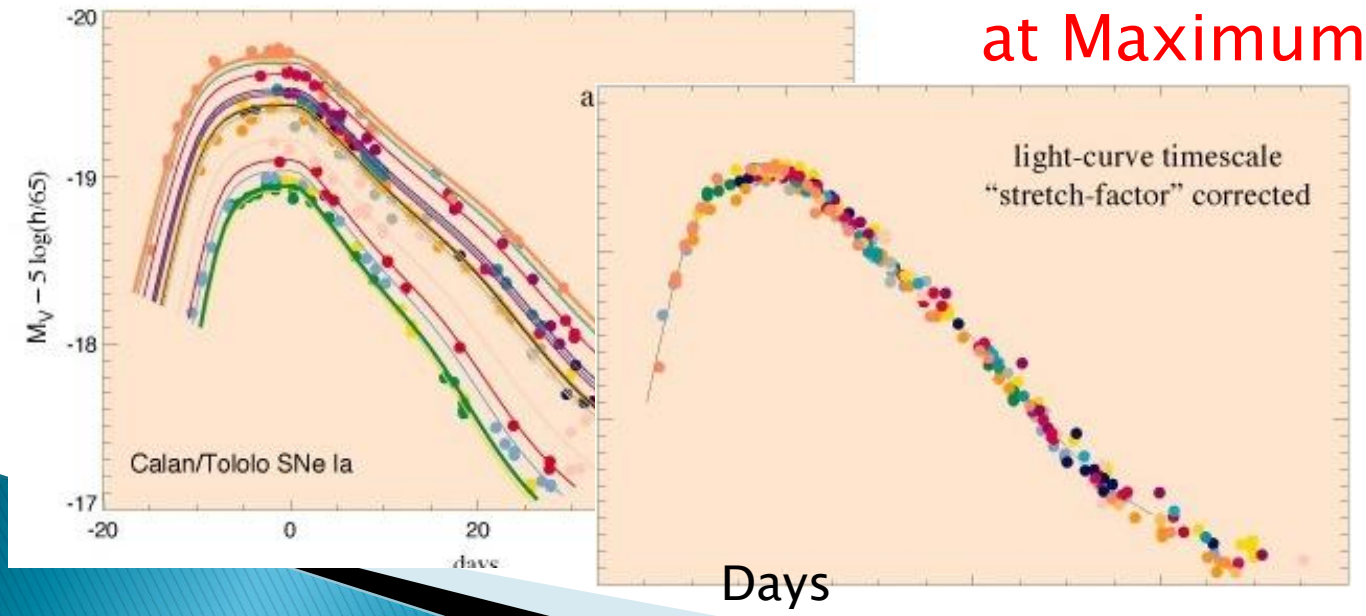
Slower–Brighter

- Stretch,…
- Nickel 56 Decay
- Progenitor metallicity

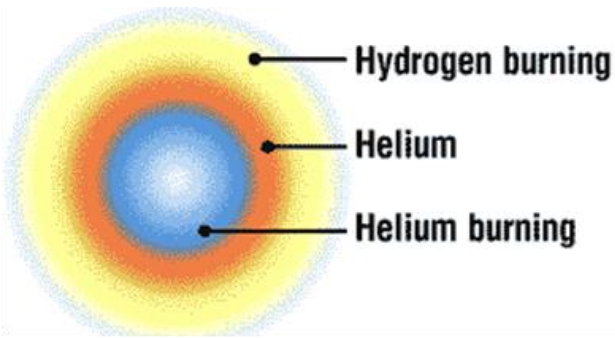
Redder–Fainter

- color/Extinction
- Dust
- Intrinsic Color

Luminosity Dispersion at Maximum : 10%

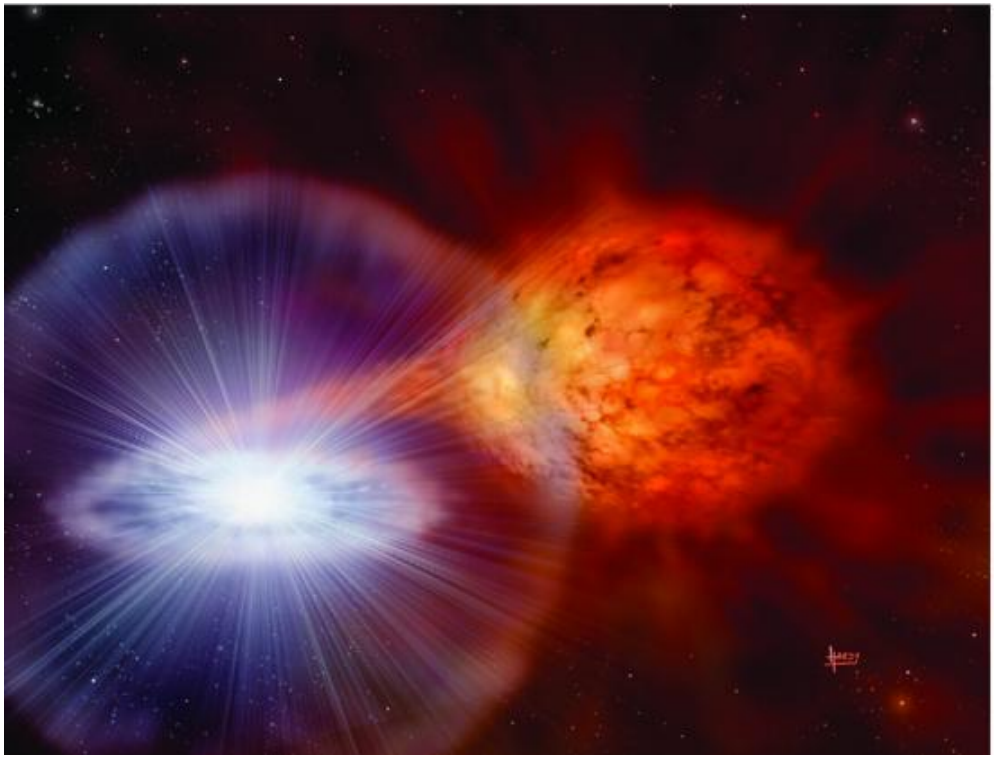


Type Ia Supernova



Light Star: up to 8 Solar masses

white dwarf
Degenerate C/O

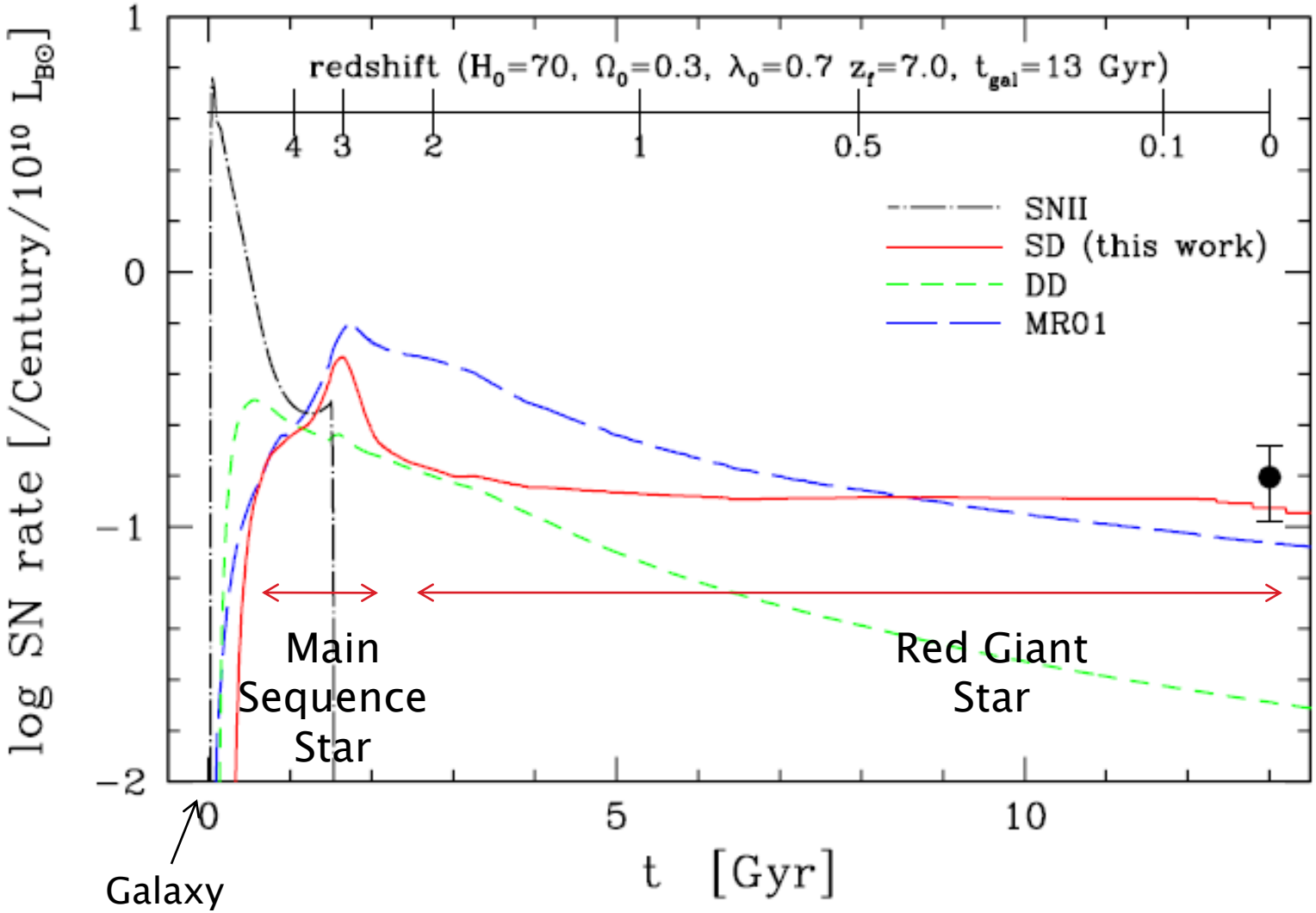


Accretion of a companion star
to Chandrasekhar mass : 1.4 Solar masses
➔ **thermonuclear explosion : Type Ia Supernova**

Type Ia Supernova ?

- Color
  - Intrinsic color
  - Dust Extinction
- Ignition and Explosion Mechanisms
  - Deflagration and/or detonation
- Progenitors
  - Single Degenerate (SD): Accretion of a red giant or main sequence star
  - Double Degenerate (DD): Coalescence of two white dwarves

The SN Ia rate history in ellipticals with different SN Ia models



Kobayashi et al. 2008

Why should we measure Type Ia supernova explosion rate ?

➔ constrain progenitor properties

Lifetime, metallicity…

➔ constrain ignition and explosion mechanisms

Understand supernovae to improve standardization

- Type Ia supernovae play a key role in heavy element galaxy enrichment
- Experiment design

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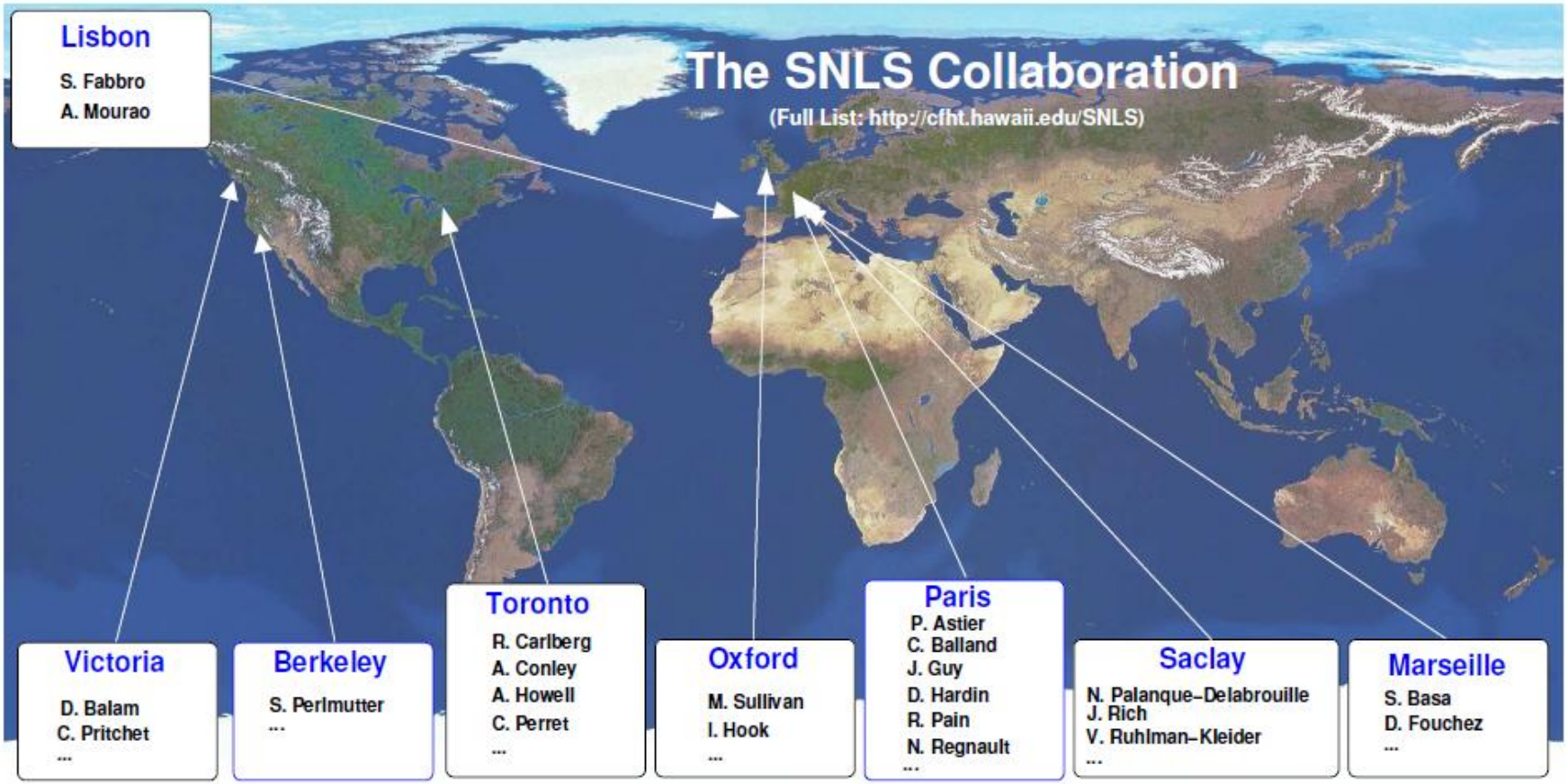
The SuperNova Legacy Survey



Main Goal : Measure cosmological parameters using Type Ia supernovae

SNLS : Survey Strategy

Photometric Detection

- CFHT (3.6m) 300h/year
- Wide field camera : Megacam
- Excellent image quality : 0.7” (FWHM)
- Four 1 square degree fields
- 4 bands (griz)
- Rolling search

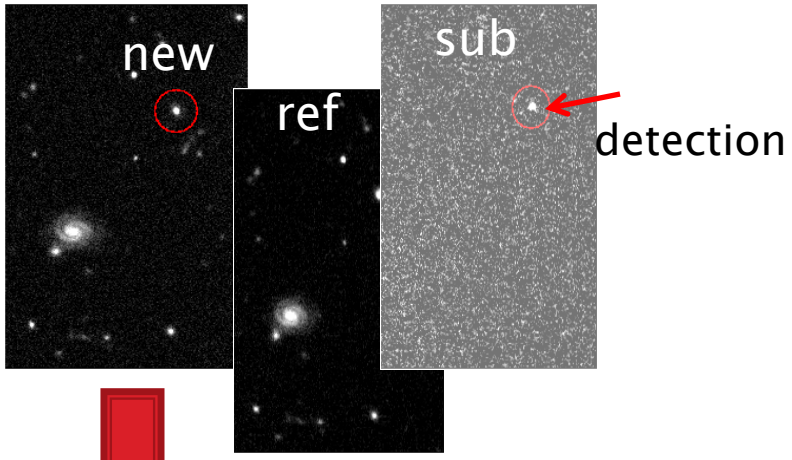
5 year survey

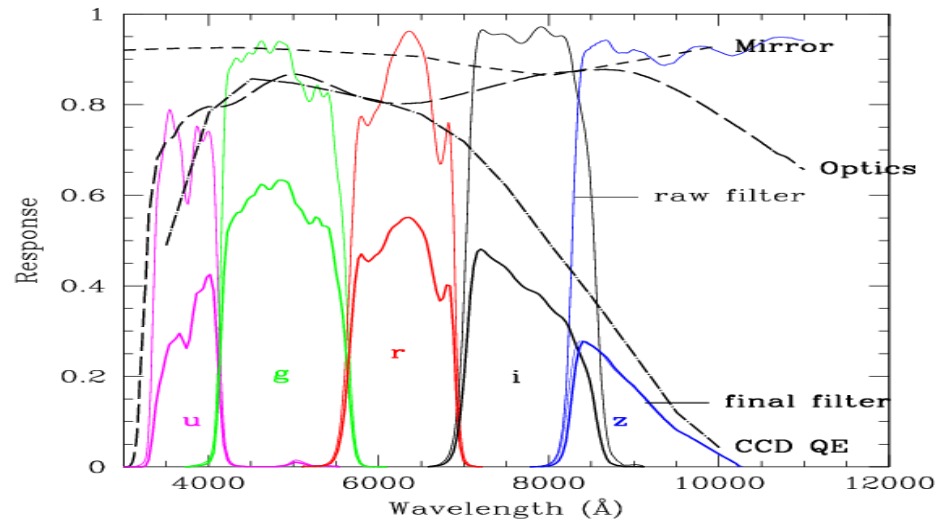
Spectroscopic Identification

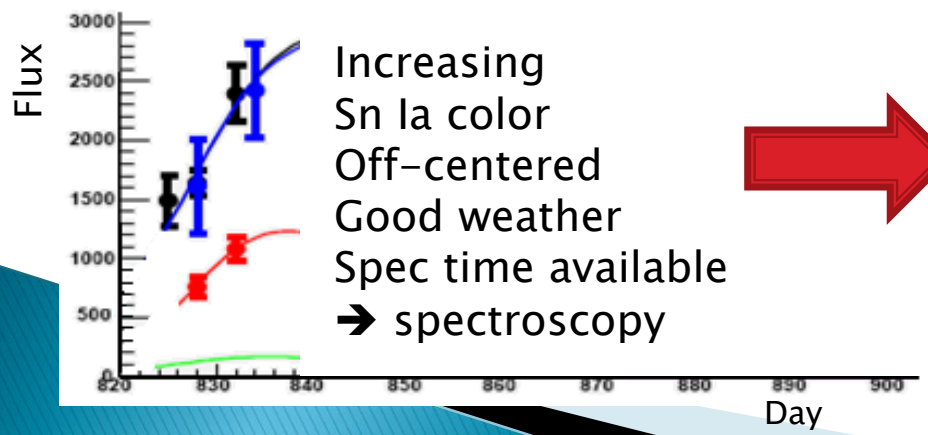
- 10m class telescope
- VLT 120h/year
- Gemini 120h/year
- Keck 30h/year
- Spectral Identification ($z<1$)
- Redshift determination

Real time detection Pipeline

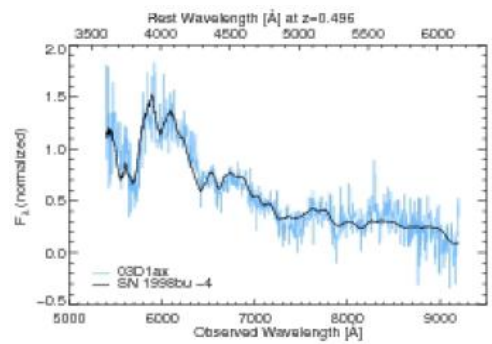
- 4 fields observed every 3-4 days in 4 bands ("rolling search")
- Variable object detection method : **PSF matched image subtraction**





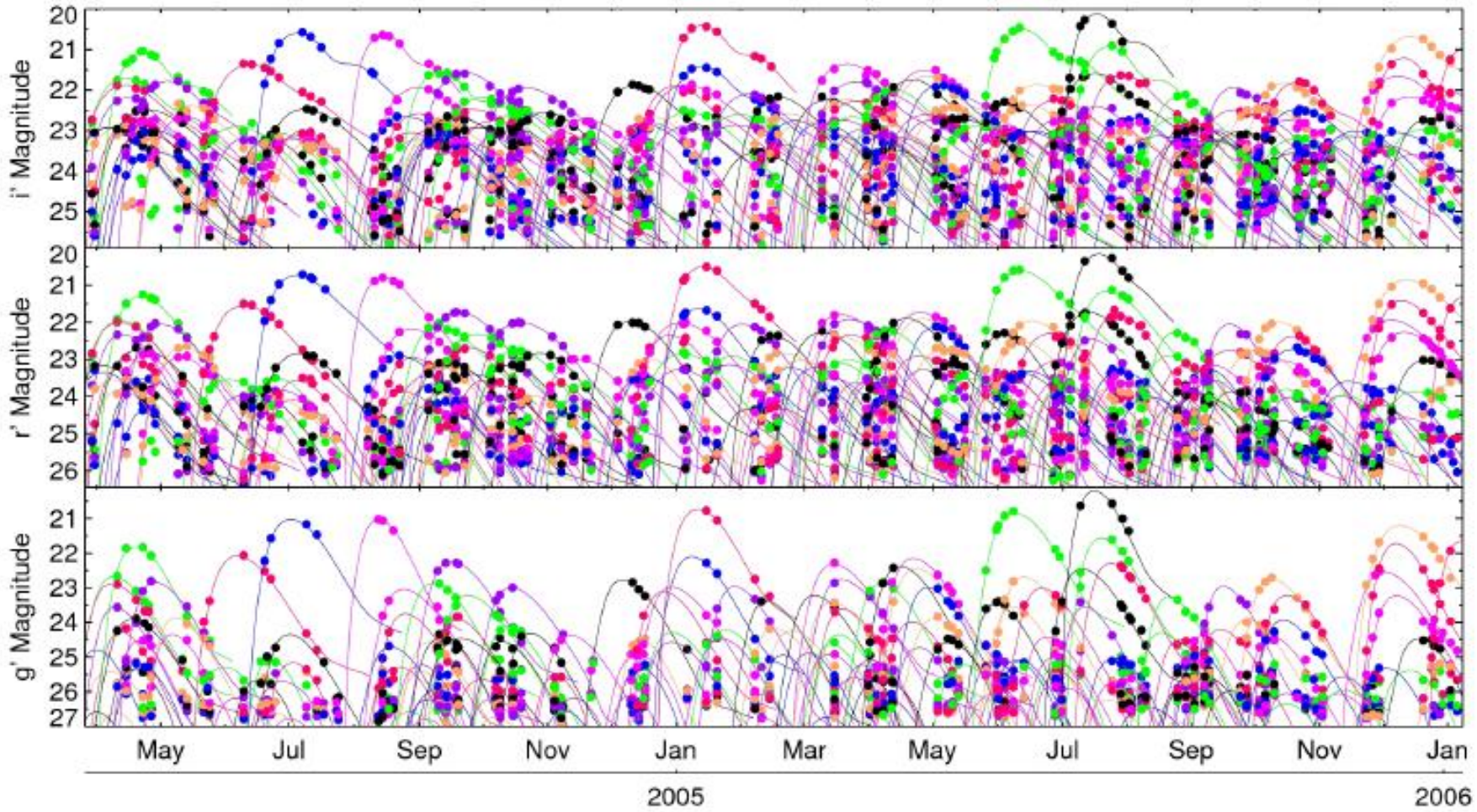


Increasing
Sn Ia color
Off-centered
Good weather
Spec time available
➔ spectroscopy

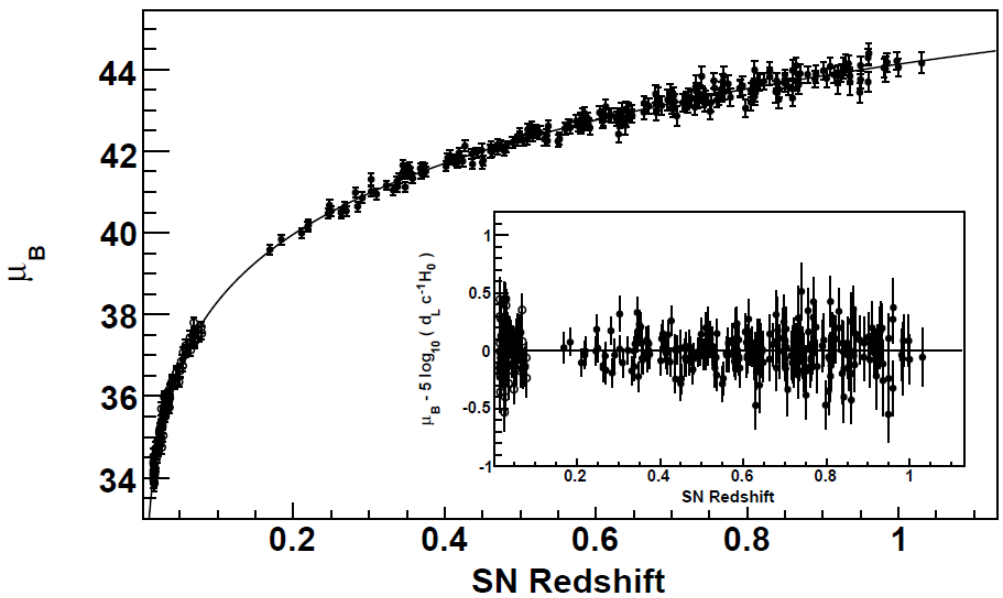


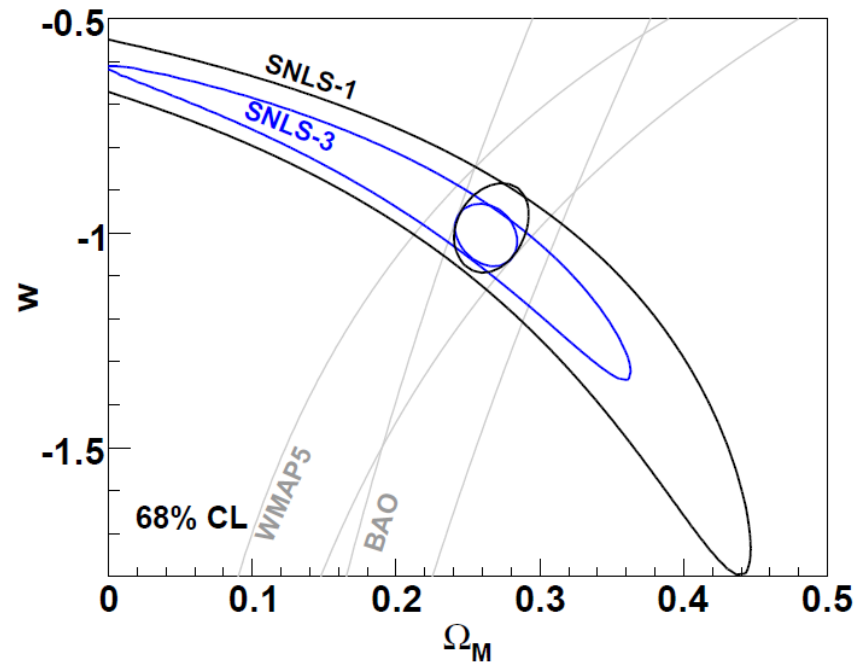
Spectroscopy:
Redshift
Identification

(Howell et al, 2005 – ApJ 634, 1190)


i' Magnitude
r' Magnitude
g' Magnitude
May
Jul
Sep
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
2005
2006

SNLS 3 years Results





- Largest homogeneous high-z sample $\sim$ 240 SNe Ia

$$w = -XX \pm 0.047(stat) \pm 0.069(sys)$$

How to measure supernovae explosion rate in the SNLS ?

A simple division :

$$Rate(z) = \frac{N_{SnIa}(z)}{eff(z)}$$

Observed type Ia supernovae sample

Detection/Identification efficiency

but Real Time spectroscopic identification efficiency is almost impossible to model due to spectroscopic selection (human selection, weather, available time,…).

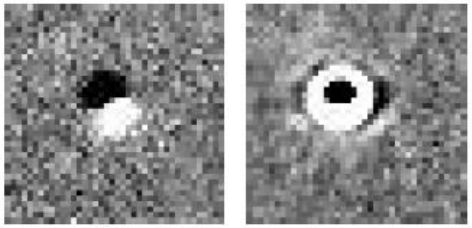
➔ Human free photometric detection/identification pipeline

Type Ia Supernovae Photometric Detection

Variable object detection

First level selection : Variables objects

- Images subtraction
- Each detection is scored with a neural network and shapelet to remove artifacts
- At least 5 good detections with S/N greater than 5.
- Cut on field area and date to avoid edge effects.

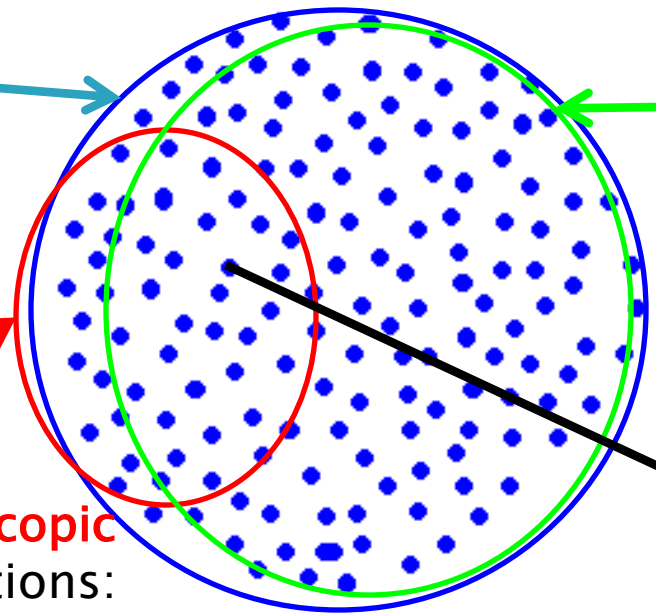


Spurious subtraction residuals

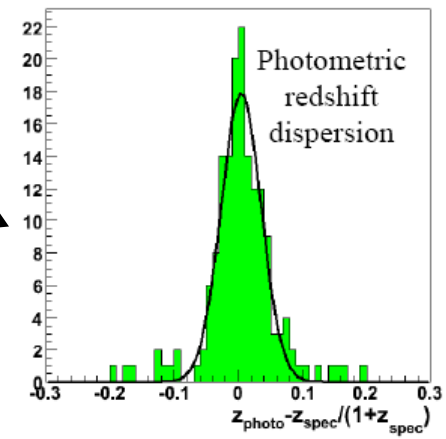
Selected objects are mostly physical objects (90%): AGNs, variable stars, supernovae (all types).

Selected objects

3051 variable objects



Host galaxy photometric redshift : Ilbert et al. 2006



$\sigma_{dz/1+z} = 0.03$ + outliers

289 objects with **spectroscopic data** from real-time operations: redshift and type (not always)
Used as **control sample**
Redshift accuracy : 0.001

SnIa	Sn?	SnII	SnI b/c	AGN
196	53	24	8	9

Dataset : 2.5 years of SNLS images reprocessed

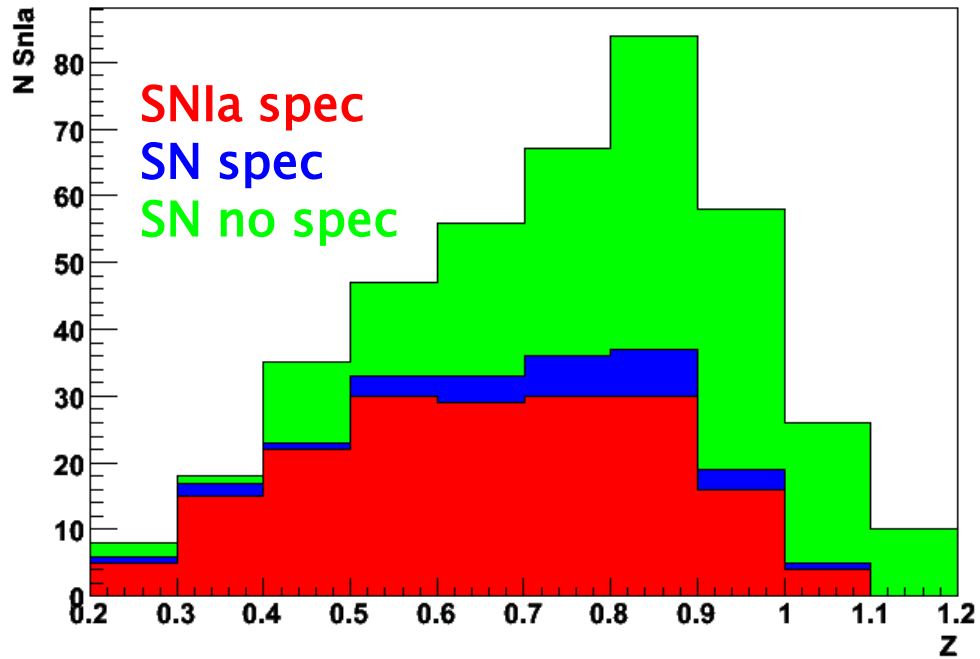
SN Ia photometric selection

Level II Selection : Type Ia supernovae

- **Cut I** : multi-color LightCurve fit (SALT2)
  - Redshift fixed (spectroscopic or photometric)
  - Fitted parameters : stretch, color and magnitude
  - ***X^2 selection***
- **Cut II** : Color Cut : $-0.4<\text{color}<0.4$
  - minimize contamination by type II
- **Cut III**: loose cut on brightness
  - gets rid of catastrophic redshift

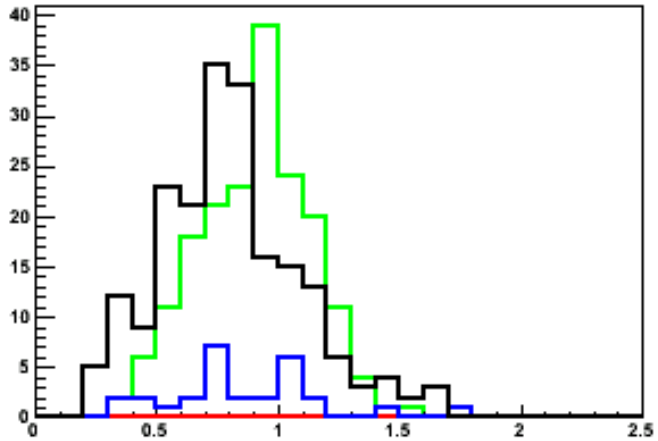
Results

- 409 selected objects
- No contamination with spectroscopic redshift
- Photometric redshift accuracy improved

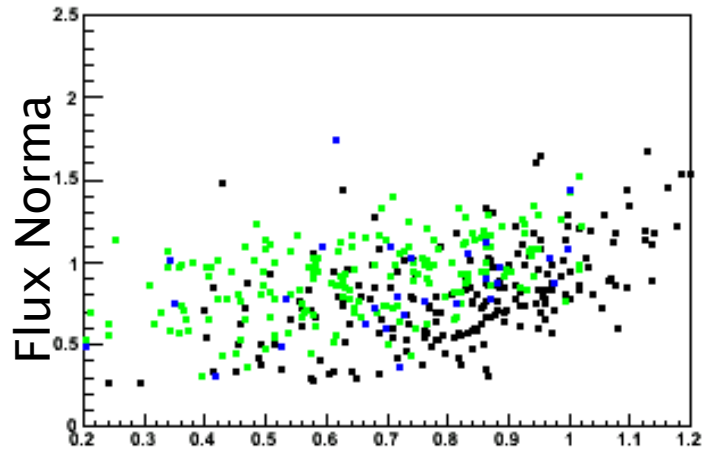


Spec type	Detected	Cut I	Cut II	Cut III	0.2<z<1.2
Sn Ia	196	187	185	184	181
Sn	53	37	28	28	28
Sn II	24	3	1	0	0
Sn Ib/c	8	1	0	0	0
AGN/Var	9	0	0	0	0
No Spec	2762	281	243	208	200

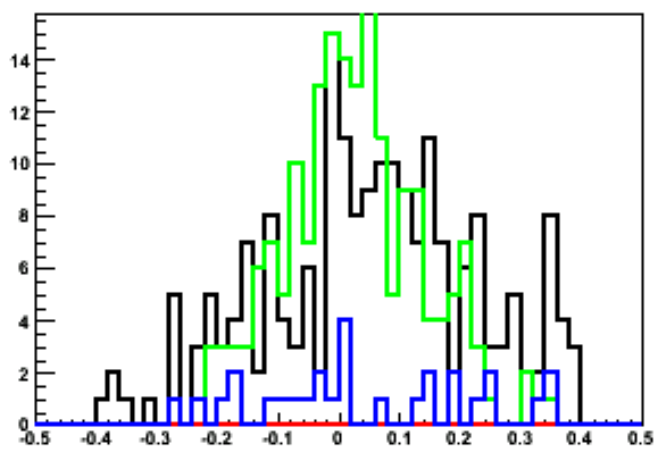
SNIa spec
SN spec
SN no spec



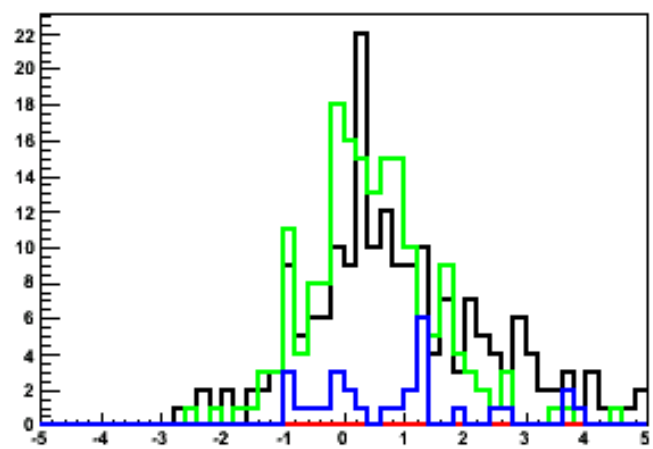
Flux Normalization



z



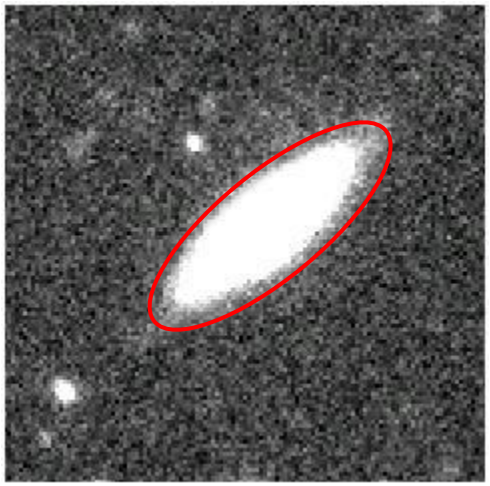
color



X1 i.e. stretch

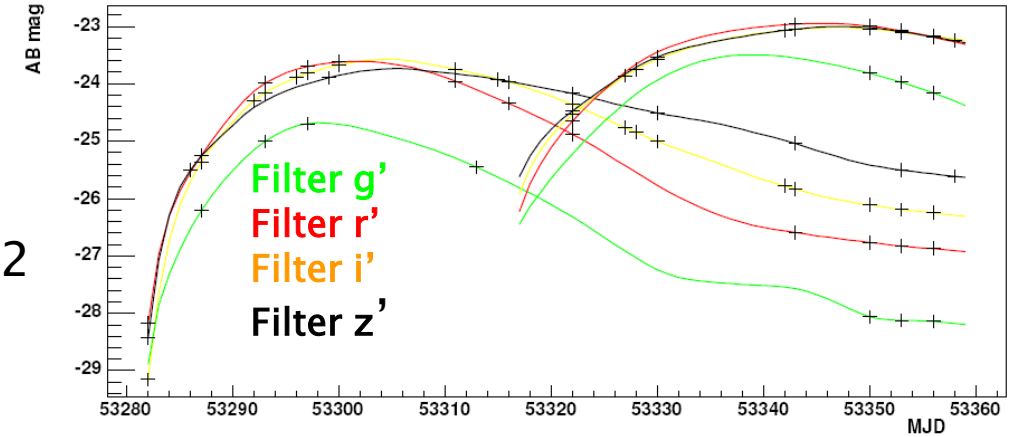
Detection and selection efficiency

On image SN Ia simulation



Main parameters:

- Ra/Dec: coordinates (on a host)
- z : Redshift (from photoZ catalogue)
- s : Stretch
- c : Color (extinction)
- disp : intrinsic dispersion
- D0: Date of maximum
- (α, β, Rv,…)



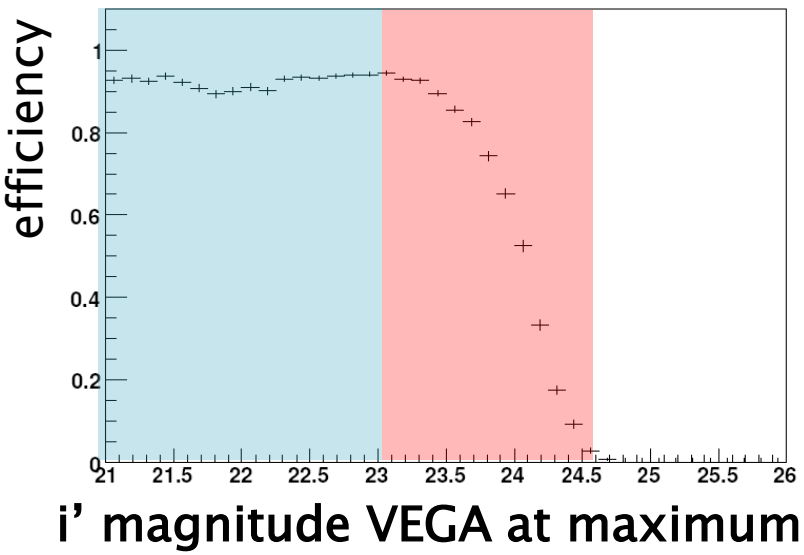
Lightcurves simulated with SALT2

Simulated supernovae added on all images

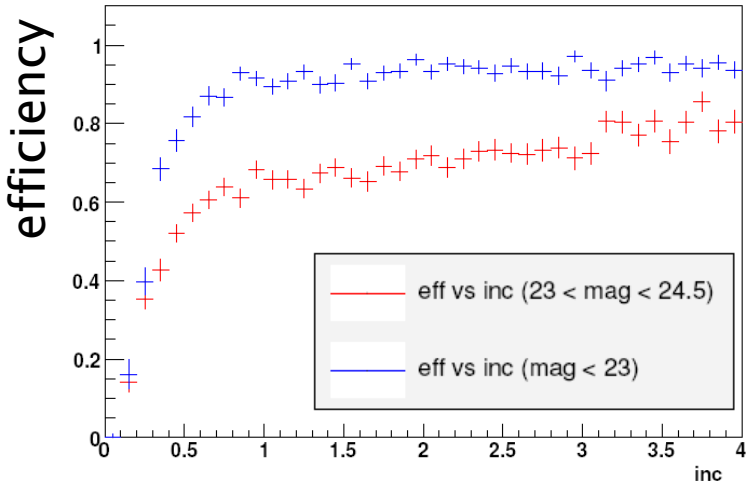
➔ Simulated images processed with the photometric detection pipeline

Magnitude and contrast

Magnitude i' at max



Contrast (increase i')

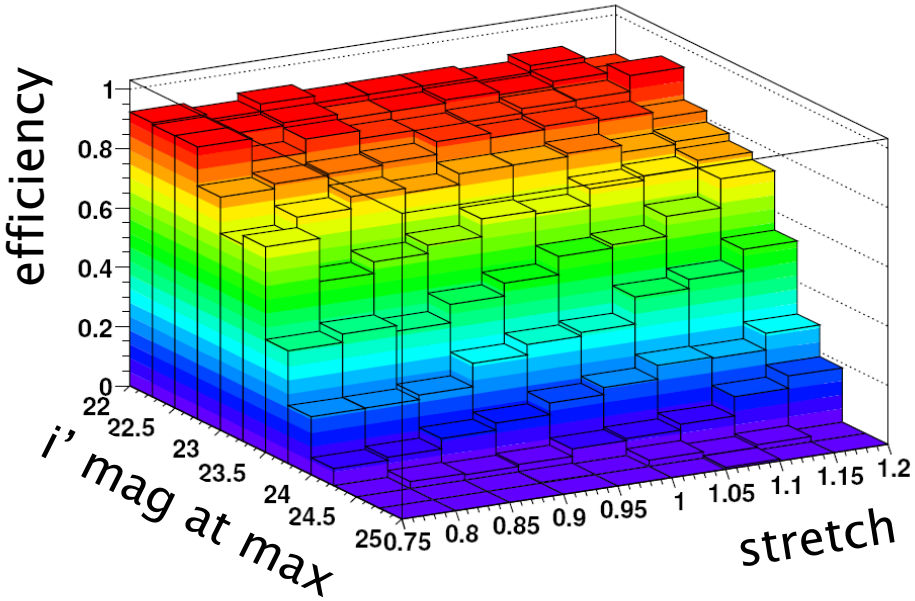


$$inc = \frac{flux_{\max}}{flux_{back}}$$

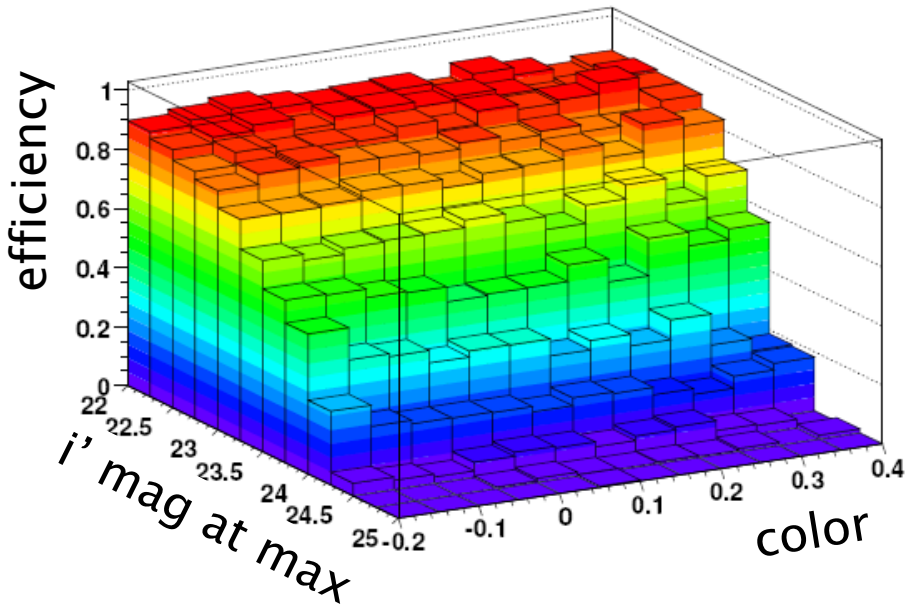
Effect independant to luminosity

Color and stretch

- Stretch



- Color



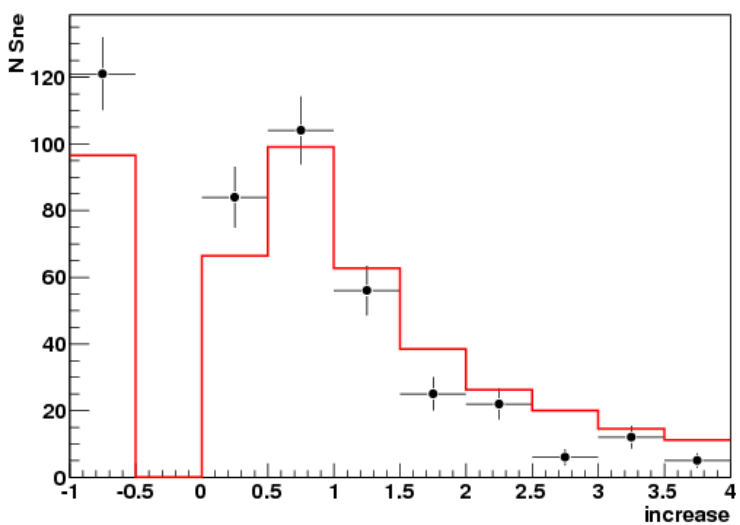
- i Mag < 23 : efficiency independent to stretch or color

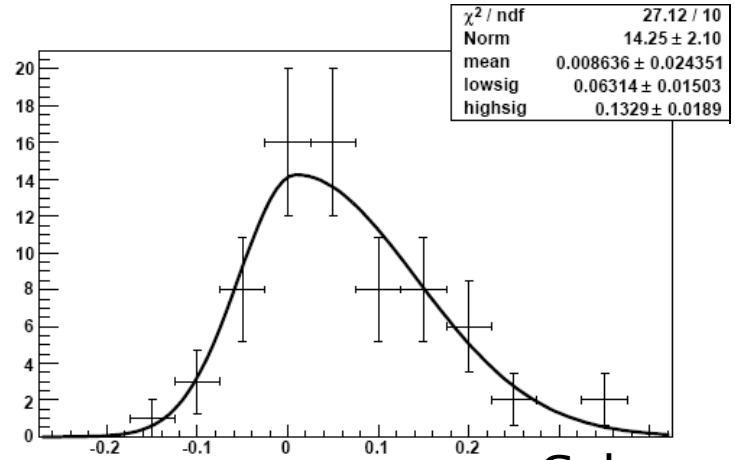
Simulation tuning

- Magnitude at Max
  - Color
  - Stretch
  - Intrinsic dispersion

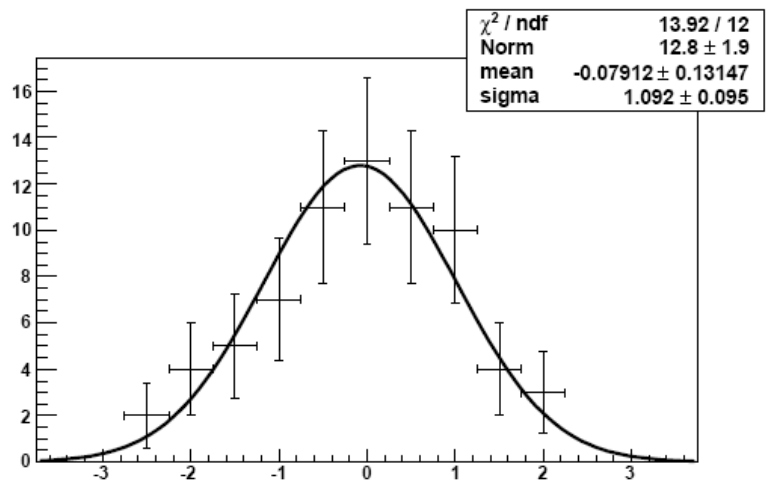
  Distribution tuned using low z (z<0.6) supernovae
- Increase (contrast)

  Distribution to match observed distribution





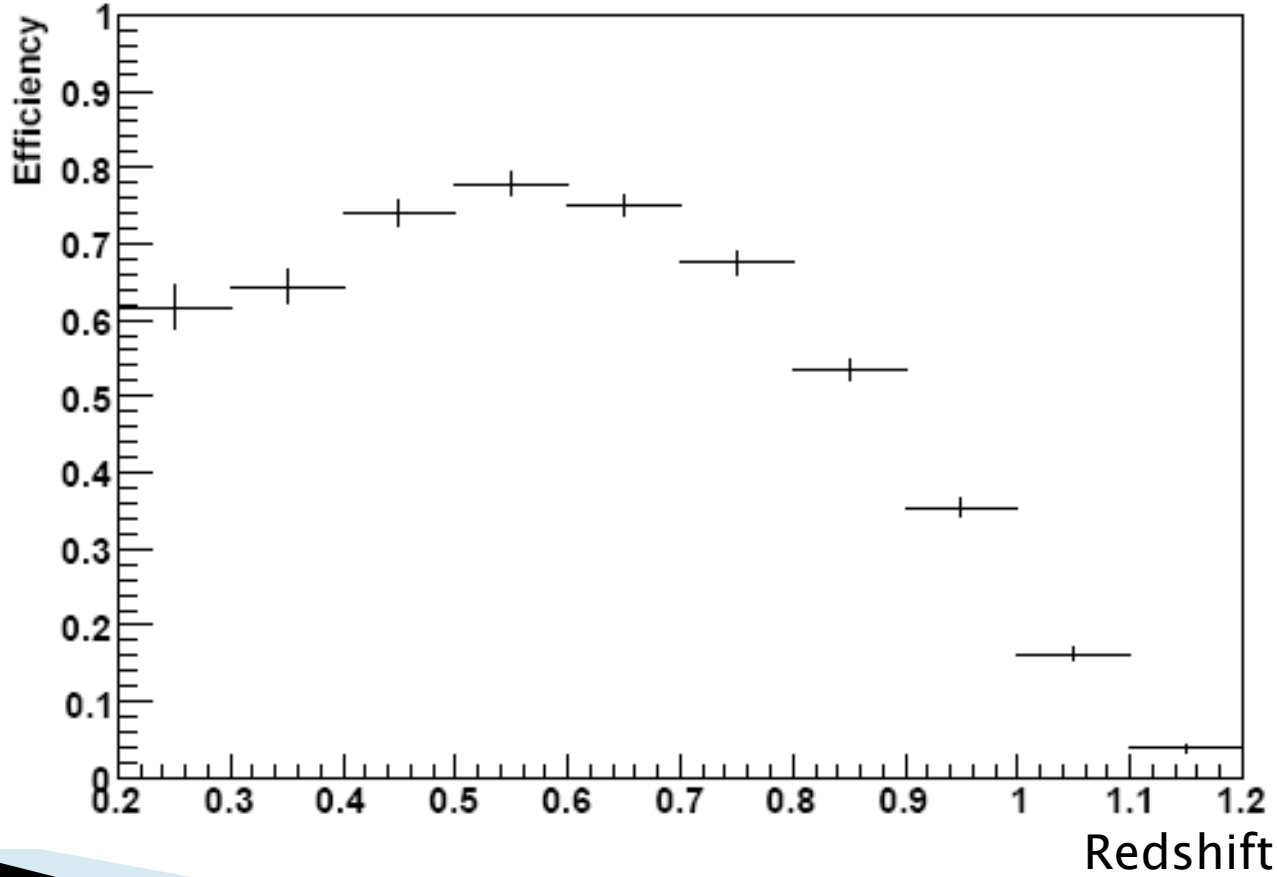
Color



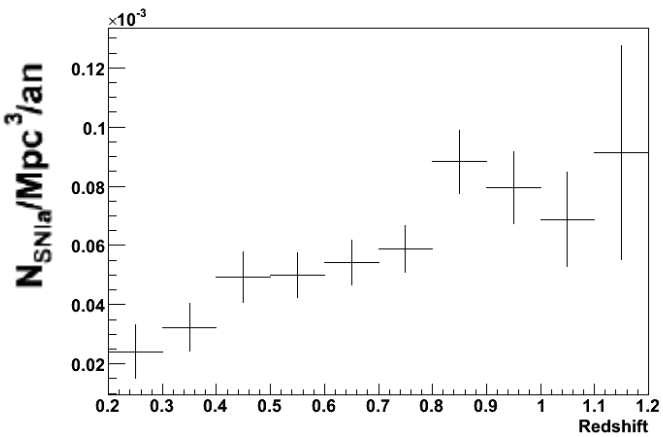
Stretch

SNLS Efficiency

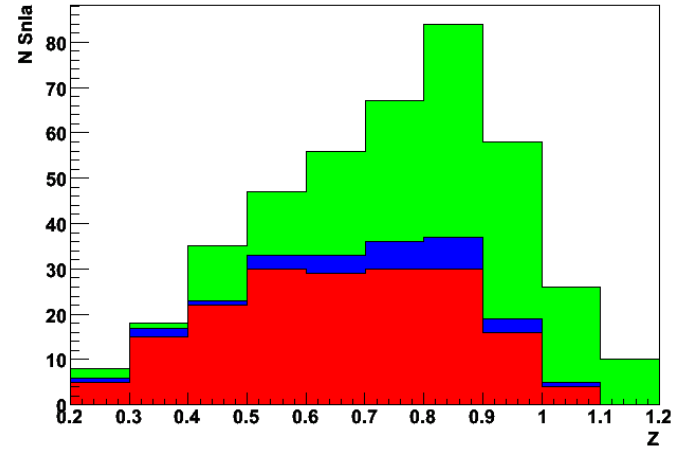
- 2.5 years of data processed (15 Tbytes)
- 720000 simulated supernovae
- Photometric pipeline



Rate calculation



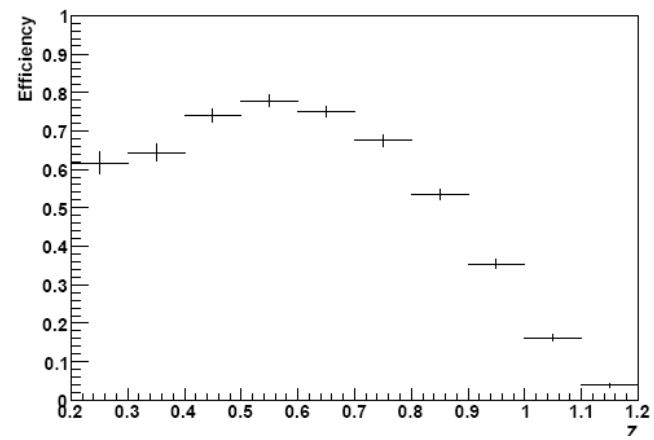
Time dilatation correction



$$Rate(z) = \frac{(1+z)}{\Delta t \times V(z,\Delta z)} \frac{N_{SnIa}}{eff(z)}$$

Correction:
Redshift
Dispersion
Systematics :
Contamination
Simulation

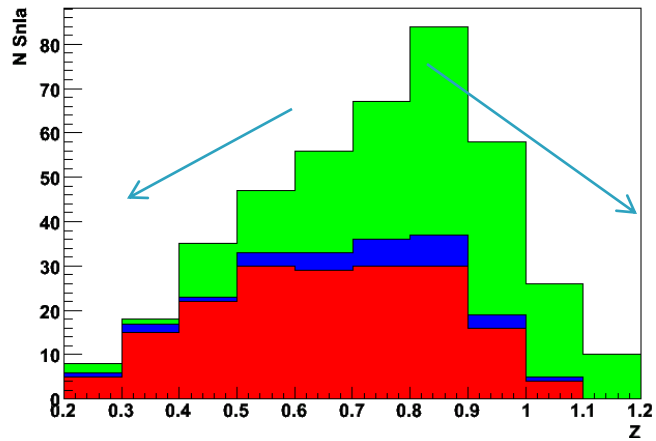
Comoving volume

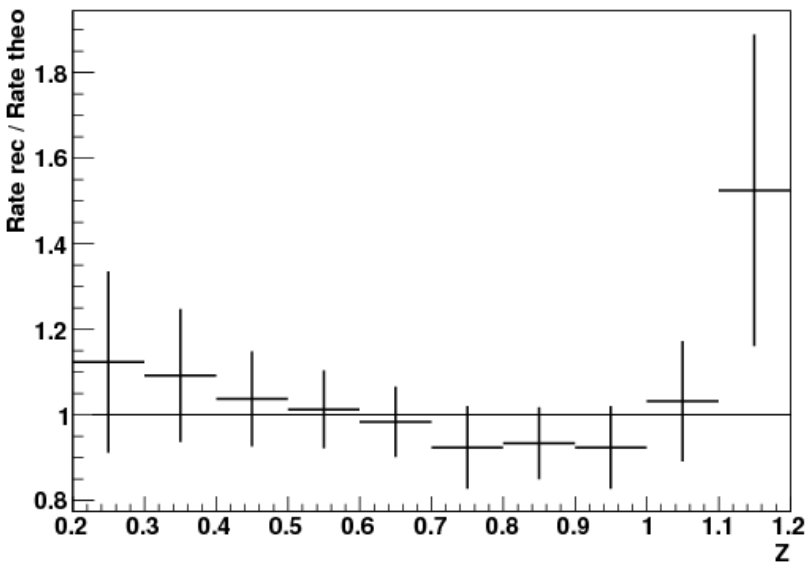


Photometric Redshift Corrections

- Dispersion
- Inefficiency due to bad redshift
- Method : simulation
  - Compute observed rate using a rate model and efficiency
  - Apply photometric redshift dispersion
  - Compute recovered rate
  - Loop 10 000

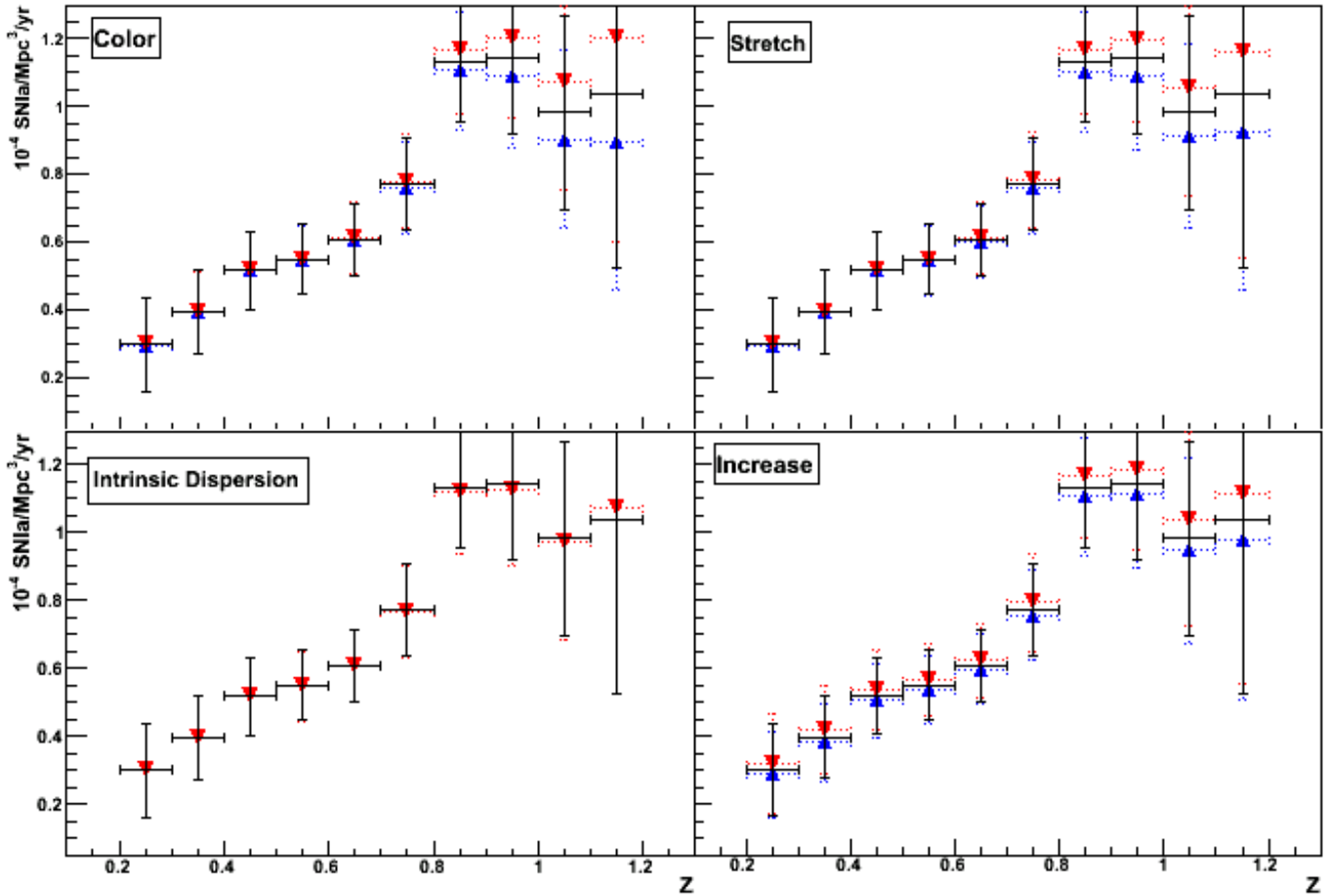
- Apply mean correction
- Add more statistical error





Systematic Errors (1)

- Efficiency calculation : distributions (stretch/dispersion/color/contrast)



Systematic Errors (2)

- Contamination

  Test sample

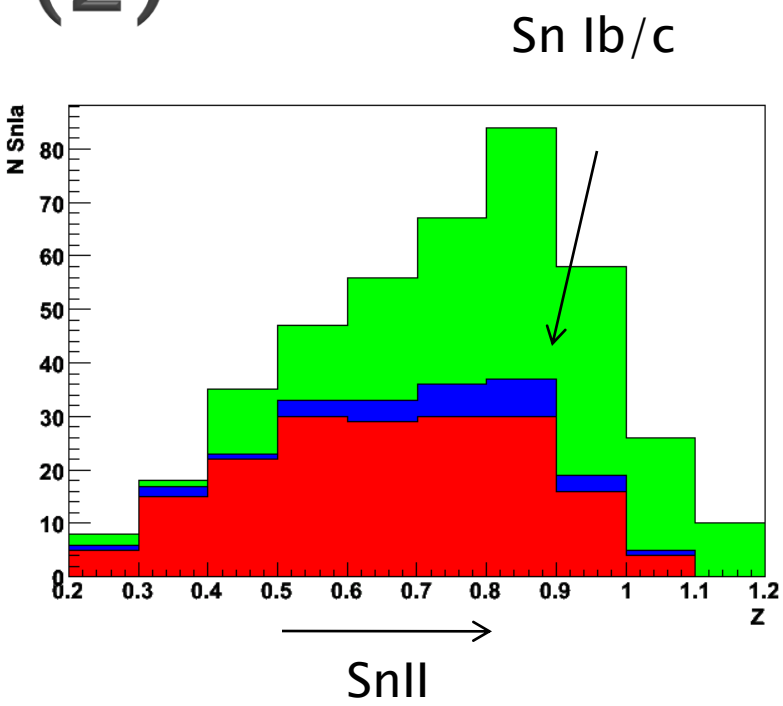
  Z spec : No Contamination

  Z phot : 2% Contamination

  High-z : No SNII

  Sn Ib/c : low rate

  Contamination : 2±2%

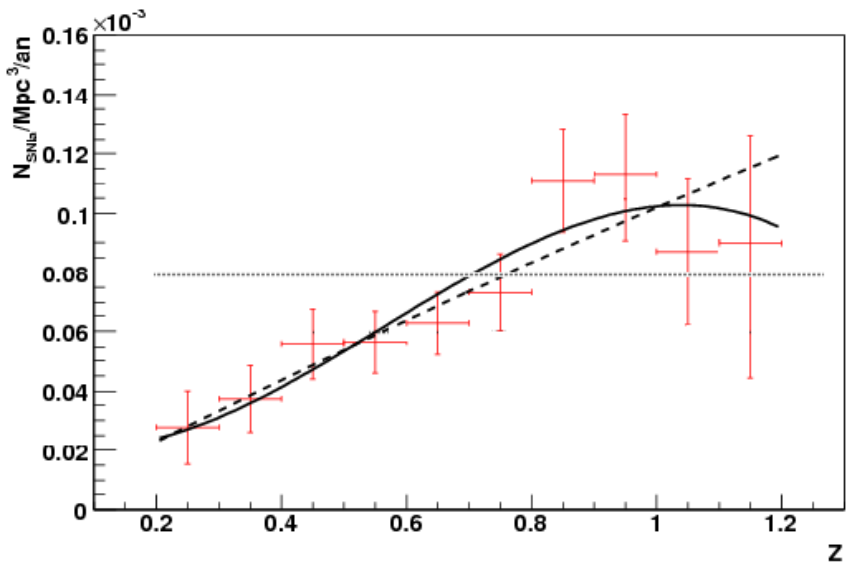


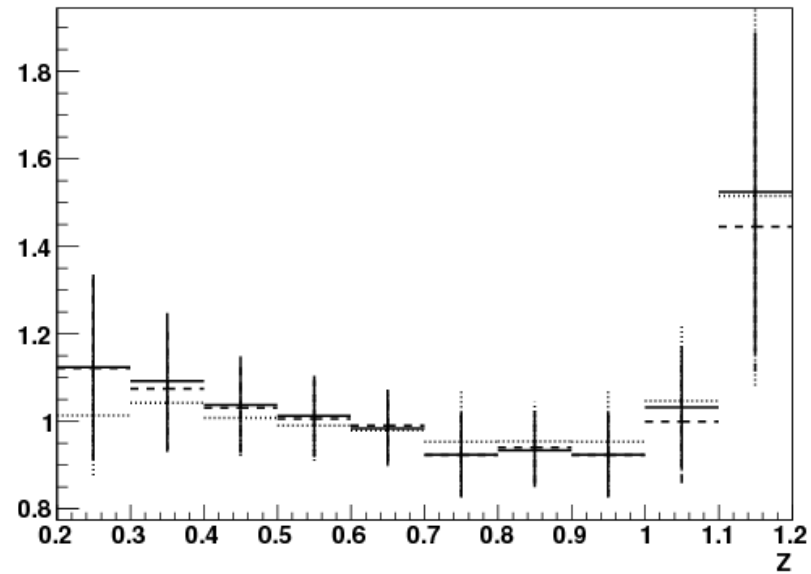
Spec type	Z spec	Z phot
Sn Ia	181	160
Sn	28	23
Sn II	0	1
Sn Ib/c	0	1
AGN/Var	0	0

Systematic Errors (3)

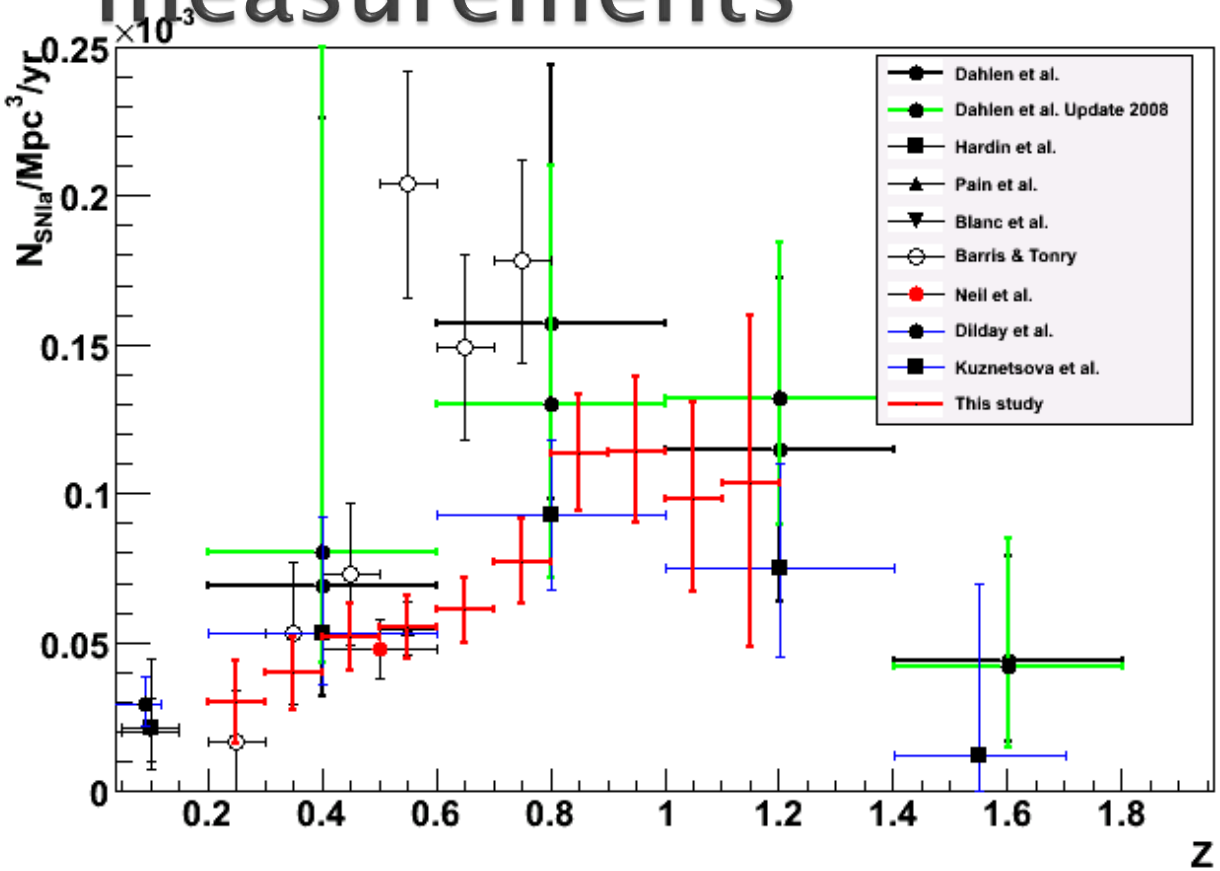
- Photometric Redshift dispersion correction

  Recompute correction using different rate models





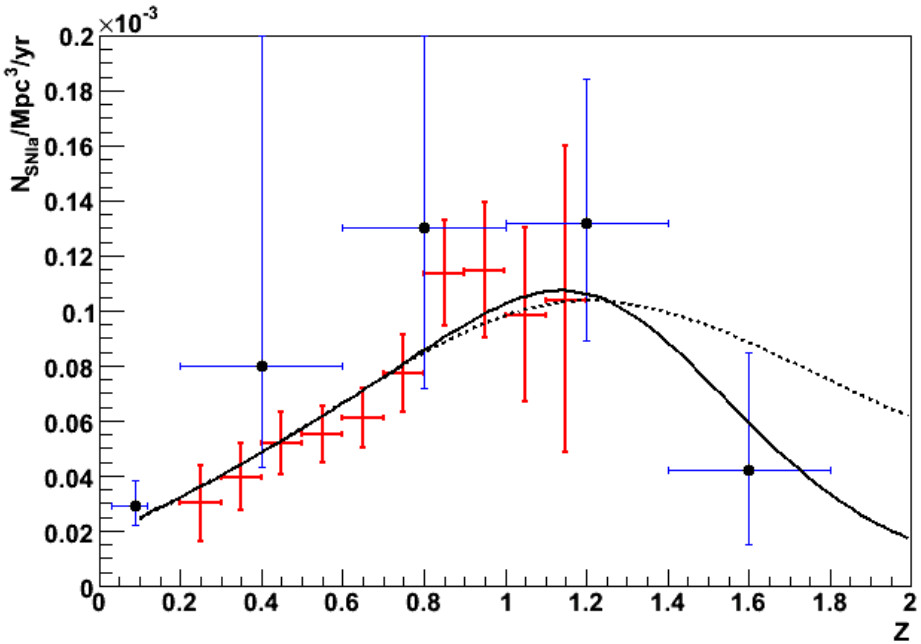
Comparison with previous measurements



Selection method	Spectro	mixed	Photo

Réf	Nb	Spec Ia
Hardin et al.	4	100%
Pain et al.	38	97%
Blanc et al.	16	100%
Barris & Tonry	98	23%
Niell et al.	77	75%
Dilday et al.	17	94%
Kuznetsova et al.	57	57%
Dahlen et al.	56	59%
This study	435	48%

Rate and Models



Rate = star formation rate (SFR) ∗ delay time function *Φ(t)*

$$Rate(t) = k\int_{tF}^{t} SFR(t')\times\phi(t-t')dt'$$

$$\phi(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}\left(\frac{t-\tau}{\sigma}\right)^2}$$

σ/τ=0.2 τ=2.52± 0.44 Gyr

σ/τ=0.7 τ=1.76±0.32 Gyr

(SFR from Hopkins and Beacom 2006])

Conclusion

- Photometric detection and Identification using 4 bands photometry
- Low contamination (~2%)
- We have derived a photometric SN Ia rate vs z up to redshift 1.2 (space-like)
- Tested against a spectroscopic sample (48%)
- Rate increase with redshift. Possible flattening around z = 1
- Single Degenerate scenario preferred