Type Ia SN and Dust Extinction

Oct.26, 2007
“Decrypting the Universe
Large Surveys for Cosmology”
at ROE

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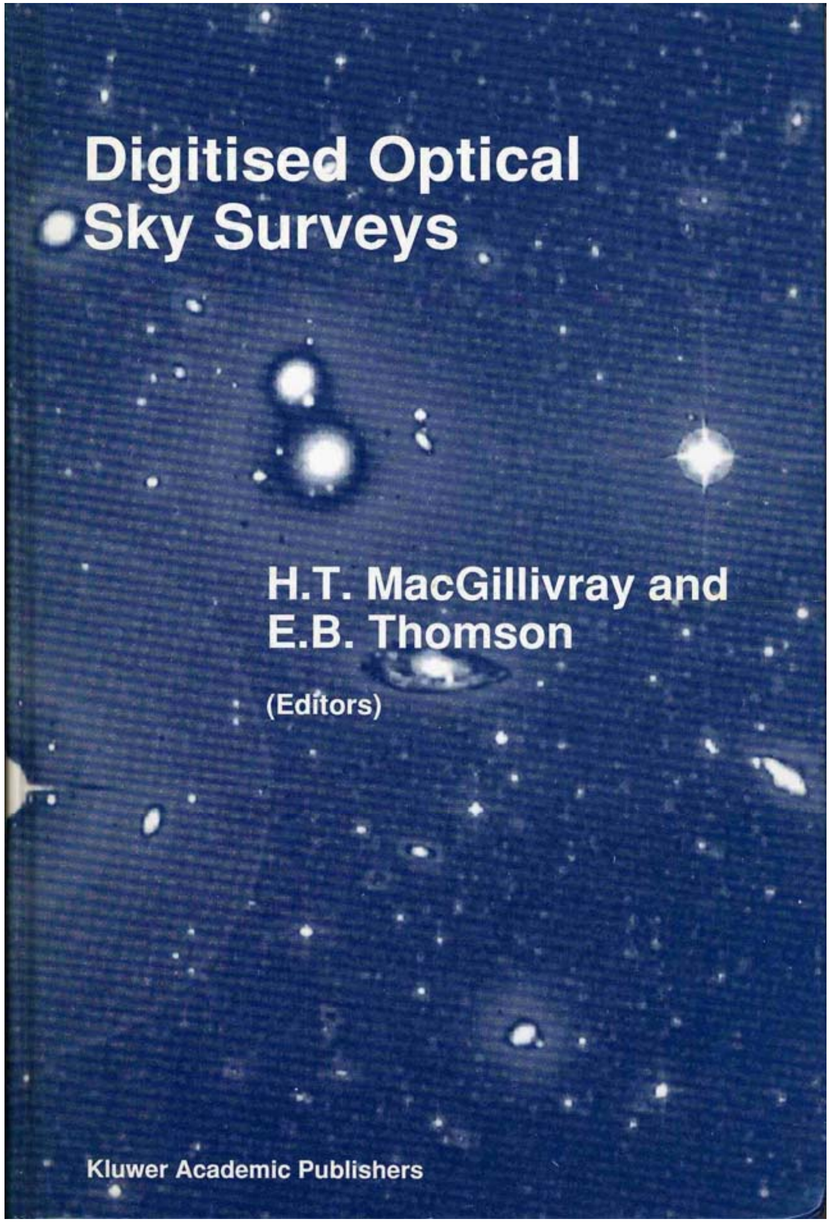
Saul Perlmutter, Chris Lidman, and Supernova Cosmology Project Team



Held in Edinburgh in June, 1991

208 *Doi et al.*

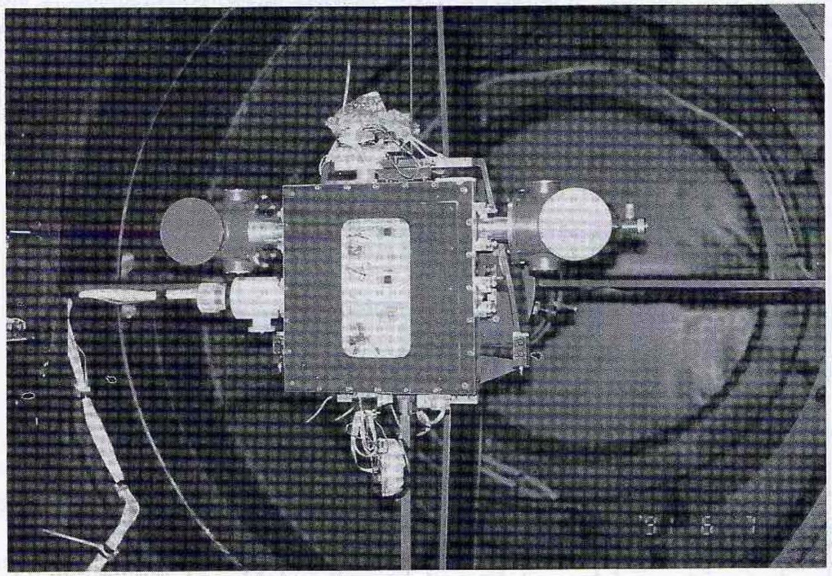
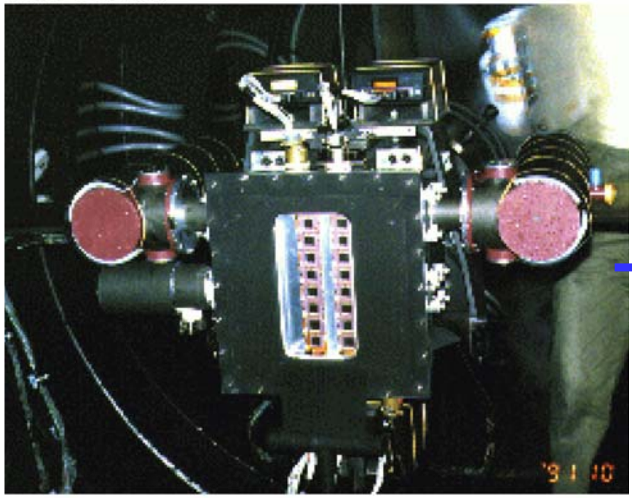


Fig. 6. Mosaic CCD camera as of June 6, 1991, when 'first light' was taken. The camera was mounted on the prime focus of the Kiso Schmidt telescope. Two CCD chips were actually equipped. They can be seen inside the dewar window. Cylindrical dewars attached on both sides are used as liquid nitrogen tanks.

S.Okamura →

S. Miyazaki



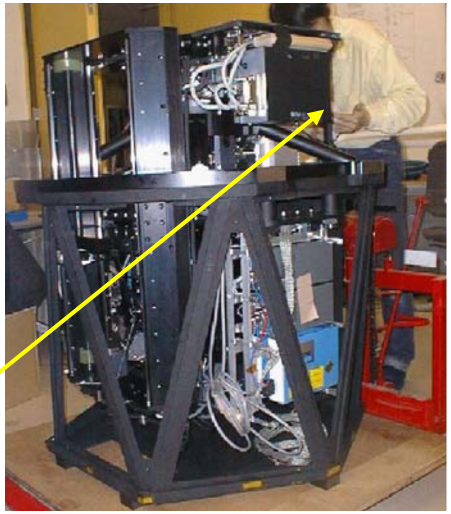
1991 1kx1k CCDx16

1.05m Kiso Schmidt Tel.

1994 1kx1k CCDx40

Las Campanas 1m

WHT 4.2m (UK-Jpn.)



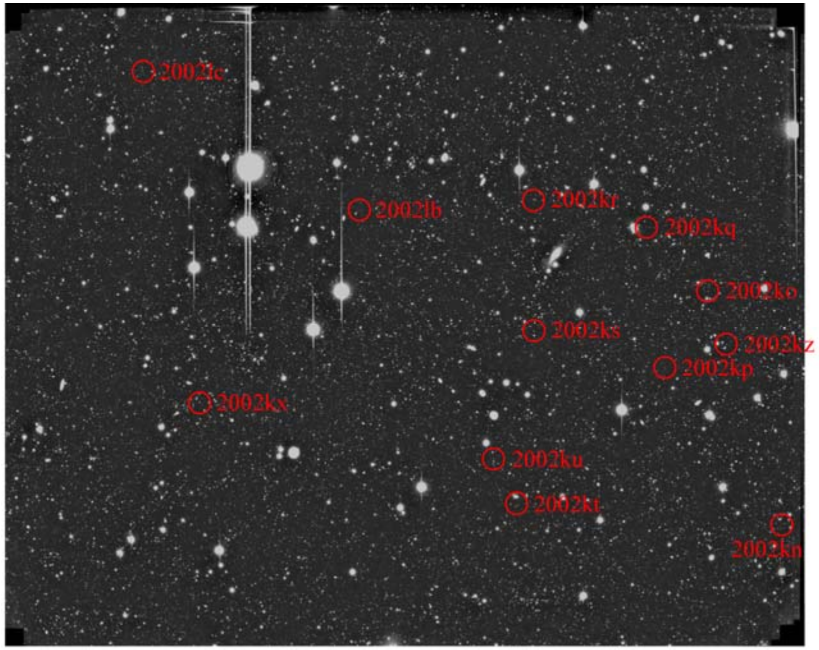
2000 4kx2k CCDx10

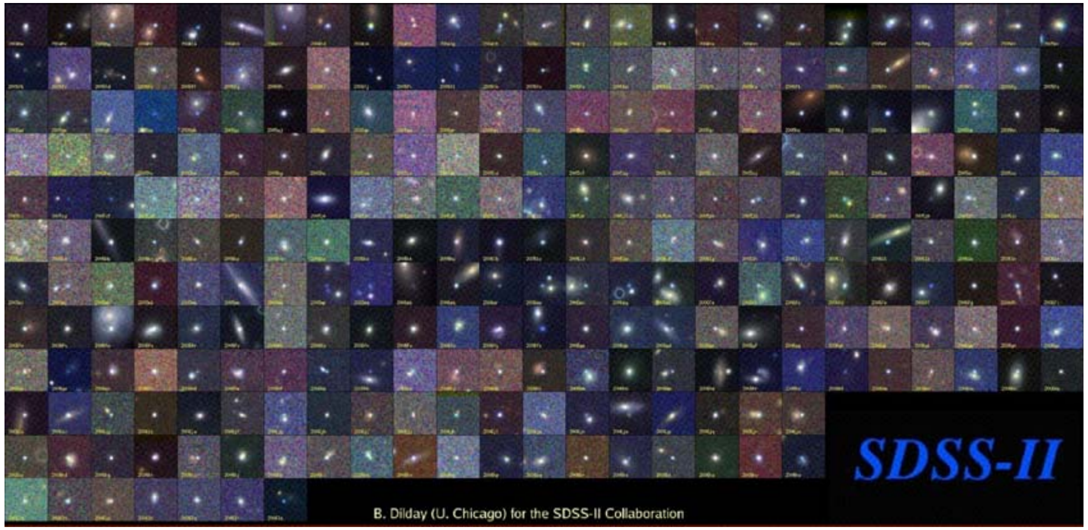
8.2m Subaru

Dr. Maki Sekiguchi

1999 2kx2k CCD x30 J. Gunn

2.5m Sloan Digital Sky Survey





Suprime-Cam
12 (IAU) SNe / field

SDSS-II SN survey
327 spectroscopicall confirmed SNe
in 2005 - 2006

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II. From Suprime-Cam to HyperSuprimeCam

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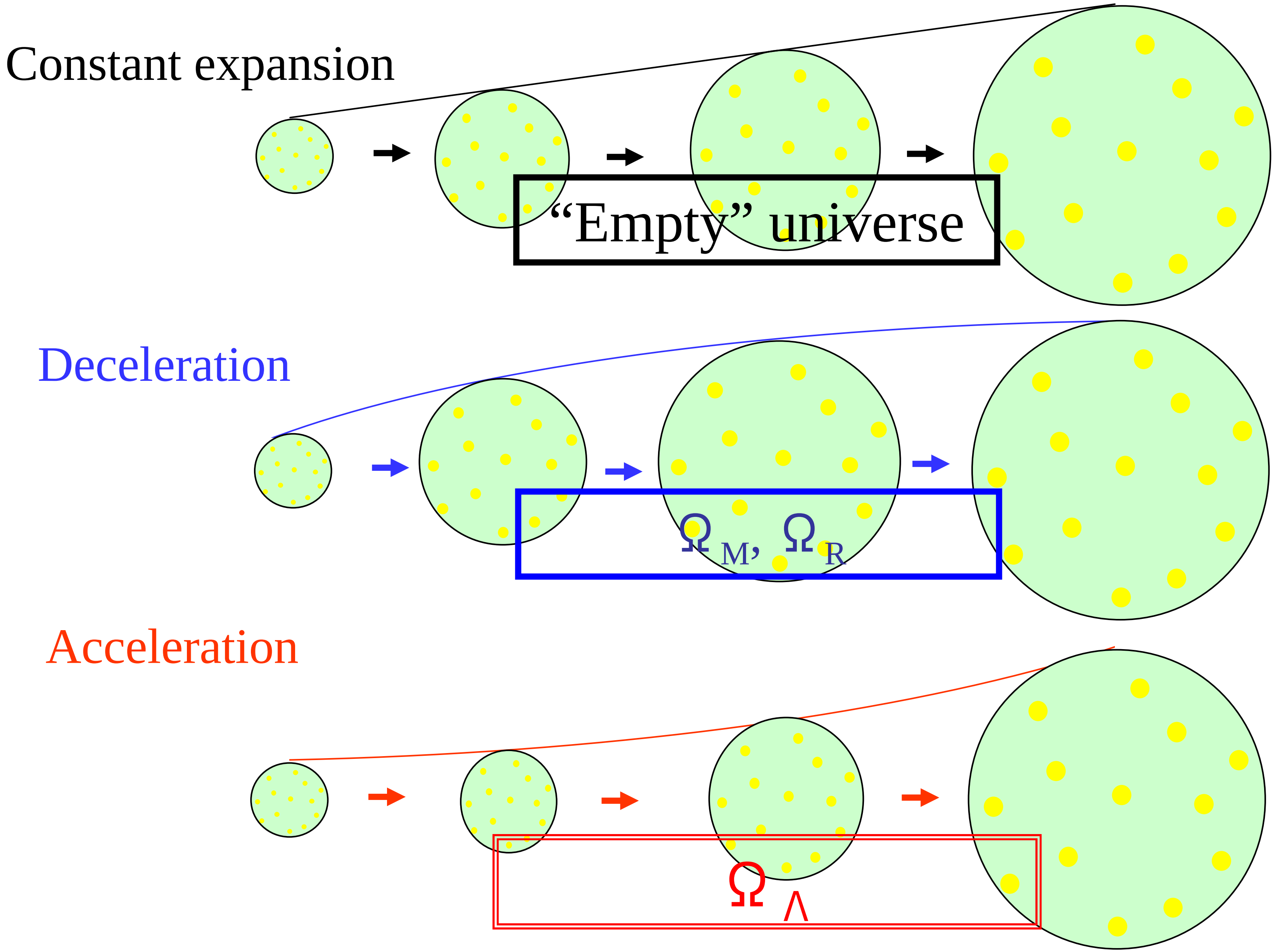
Dust extinction

I Measuring Expansion of the Universe with SNIa



Luminosity Disntance D_L

$D_L=(4\pi F)^{1/2}$

(F: flux)

→

$$D_L=c(1+z)/(H_0\sqrt{\Omega_k})\cdot$$

$$\chi(\sqrt{\Omega_k}\int_0^z dz'\{\Omega_k(1+z')^2+\sum_i(\Omega_i(1+z')^{3(1+\omega_i)}\}^{1/2})$$

$\Omega_k=1-\Omega_{total}$

$\chi(x)$: sinh(x) for $\Omega_k>0$

x for $\Omega_k=0$

sin(x) for $\Omega_k<0$

i

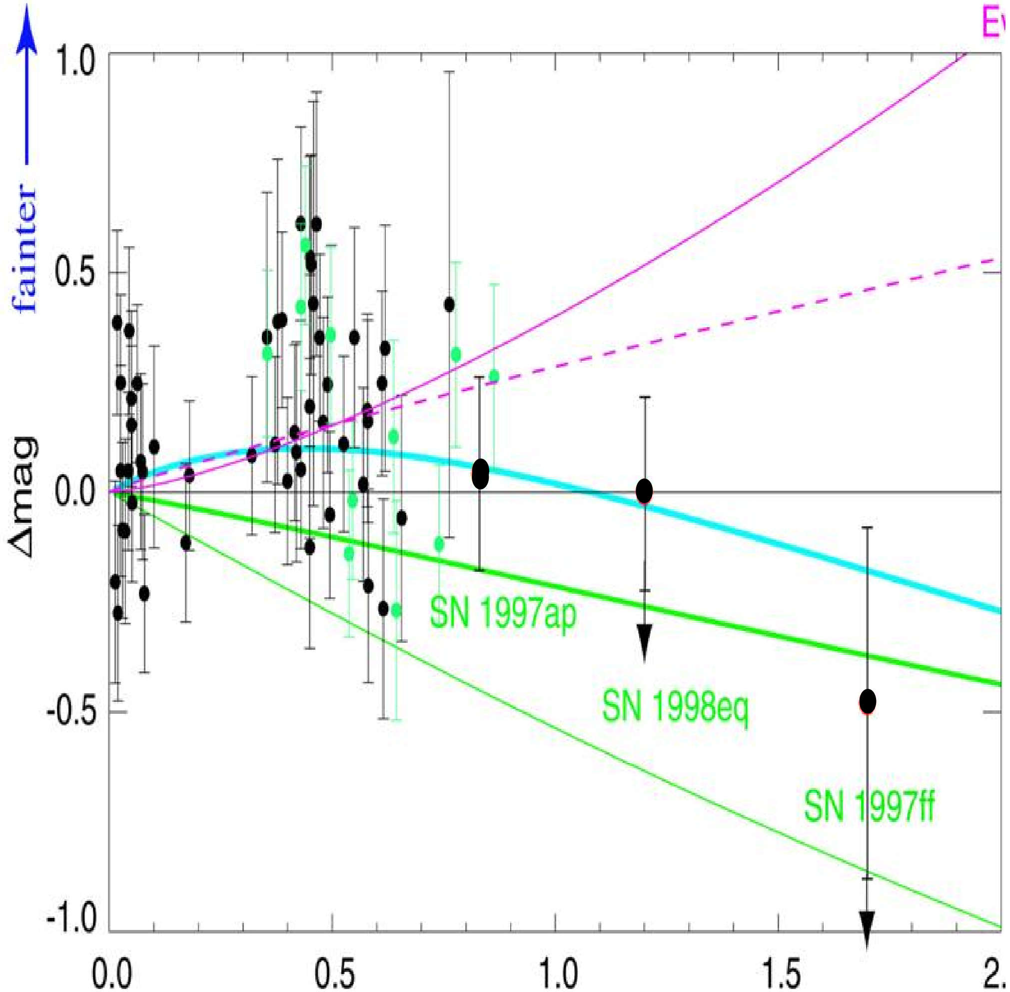
Matter: $\omega_i=0$

Radiation: $\omega_i=-1/3$

Cos. Const.: $\omega_i=-1$

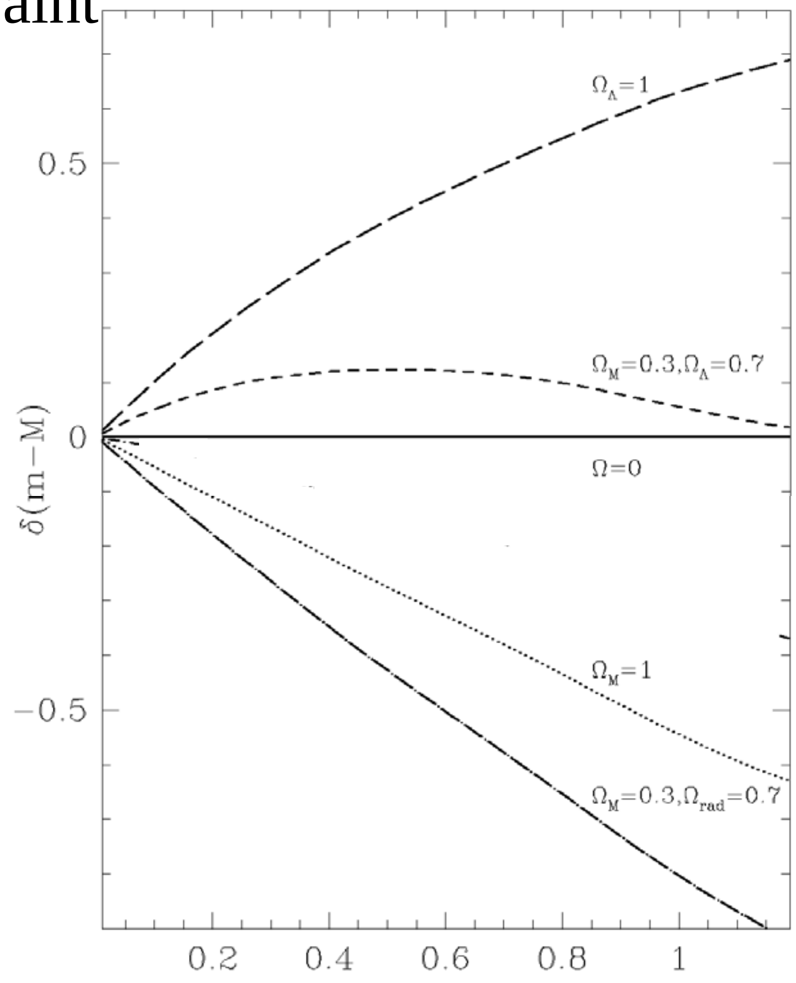
Universe is accelerating! Perlmutter et al.1999

Riess et al. 1998, Schmidt et al. 1998



redshift

Faint



Bright redshift

Type Ia Supernova

- Standard Candle（Luminosity~constant）

  →WD（@binary system）reaches

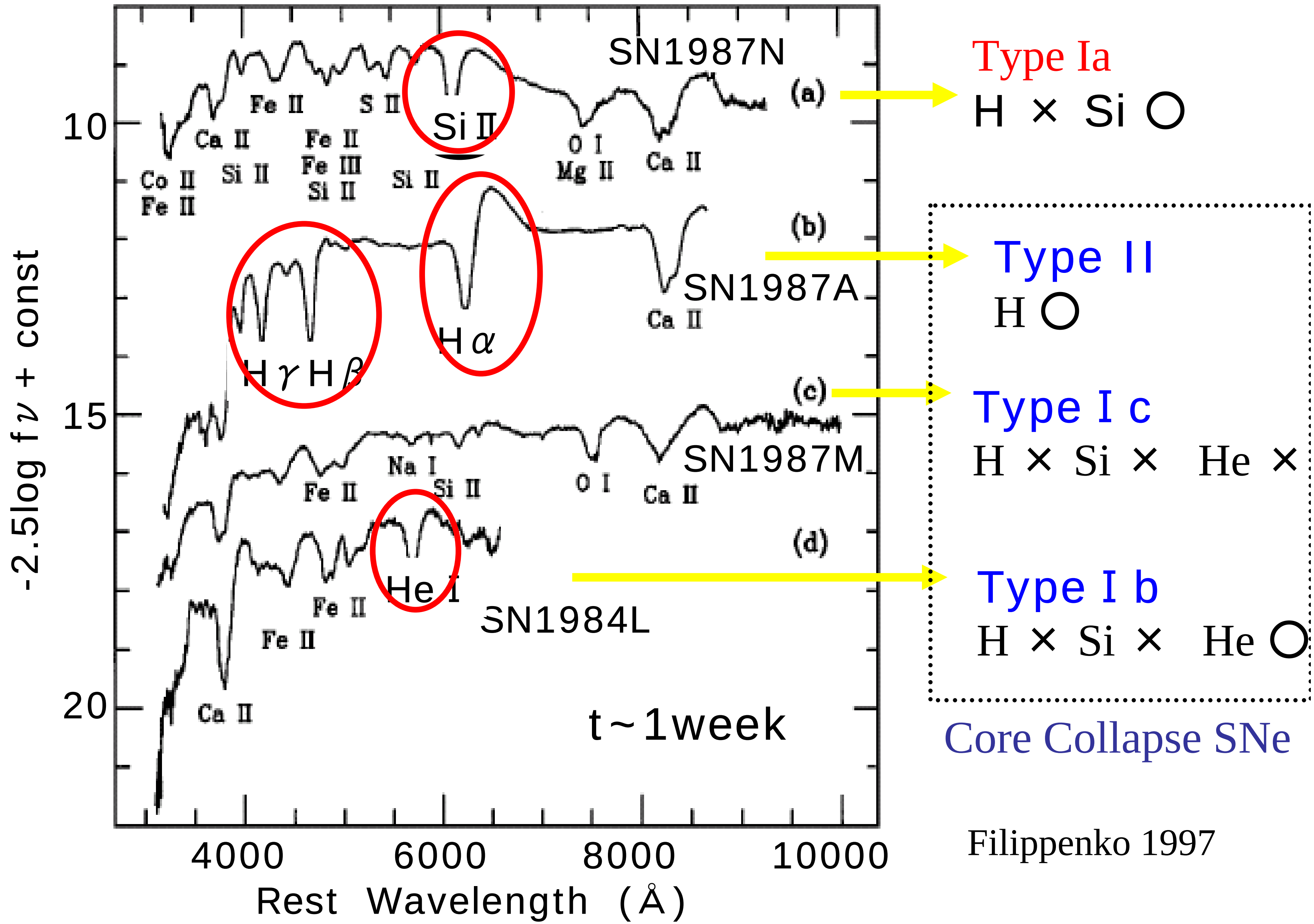
  Chandrasekar limit（~1.4solar mass）

  ⇔ Core collapse SNe Type II, Ib, Ic

- Large Luminosity (~whole galaxy)

  → measurable at cosmological distance

Spectral Types of Supernovae



Filippenko 1997

Standard Observing Method

- Wide-Field imaging

  imaging with ~1months interval or “rolling”

  → find candidates

- Spectroscopy

  confirmation of SN spectrum（⇔AGN, variable stars）

  SN type and redshift determination

- follow-up photometry, color

  light curve → luminosity

  K correction

  evaluation of dust extinction of host galaxy

Luminotity of SNIa:

not exactly constant

brighter SNIa

→ larger time scale

in light curve

(larger stretch factor)

Correction based on light

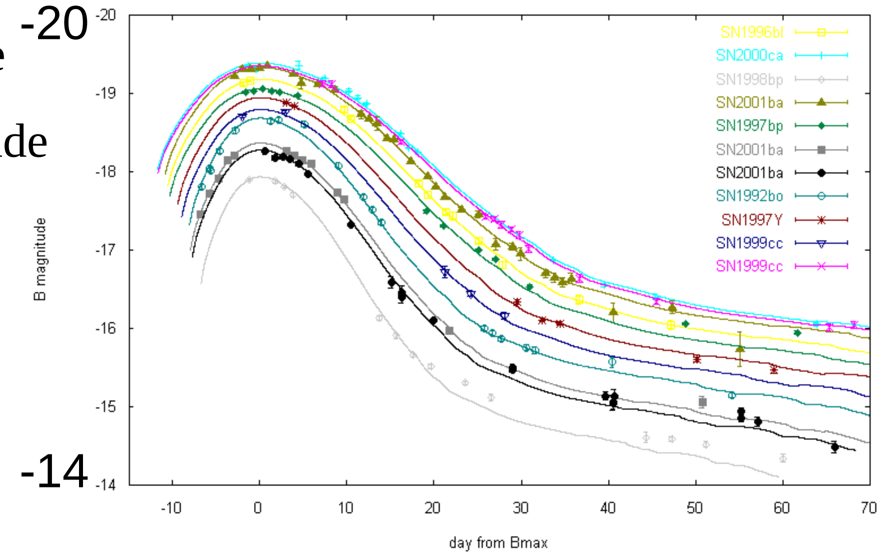
curve is possible.

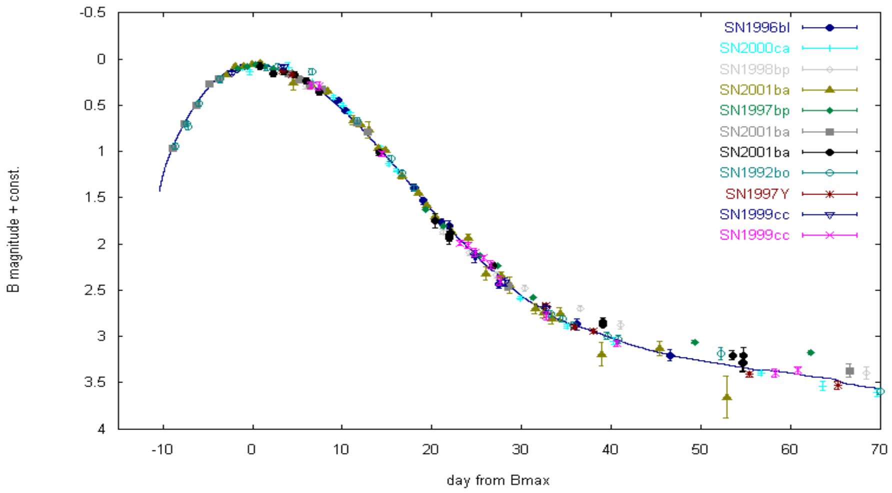
intrinsic scatter ~ 15%

e.g. Phillips et al. 1993
Perlmutter et al. 1997
Hamuy et al. 1999

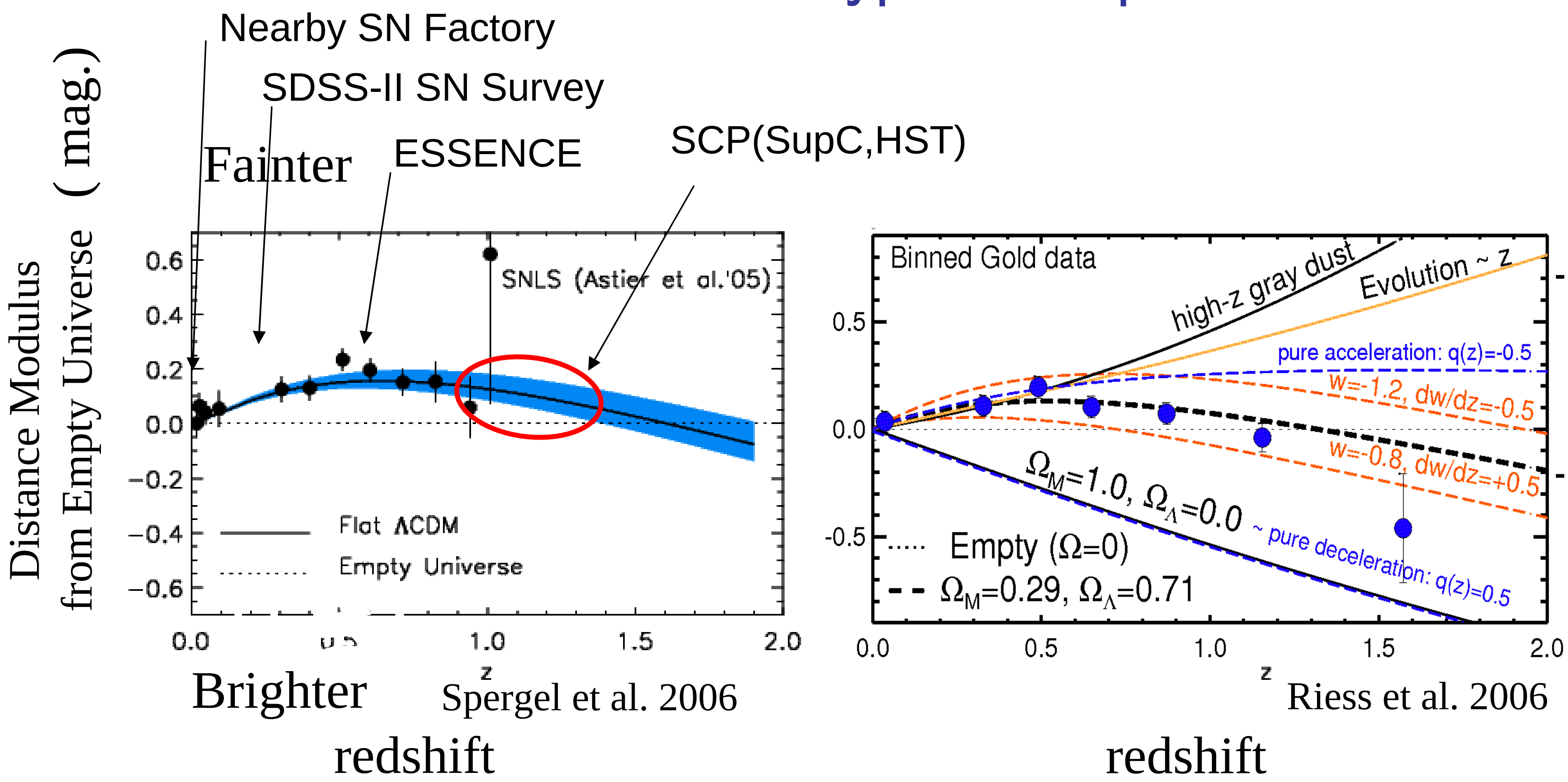
B-band Light curve of nearby SNIa

by Takanashi





Recent Results from Type Ia Supernovae

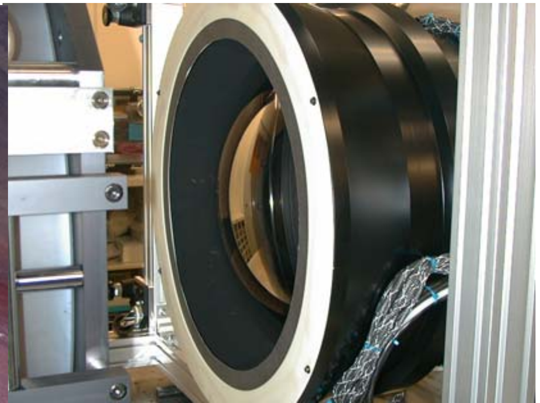
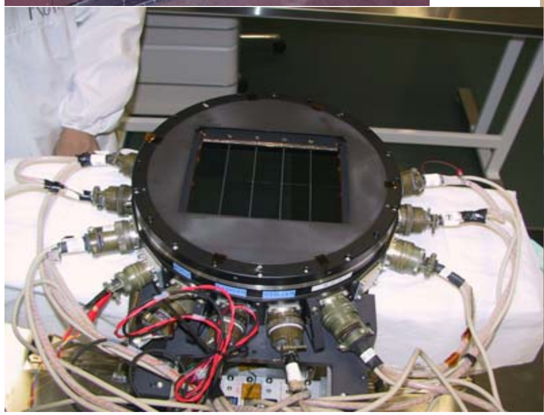
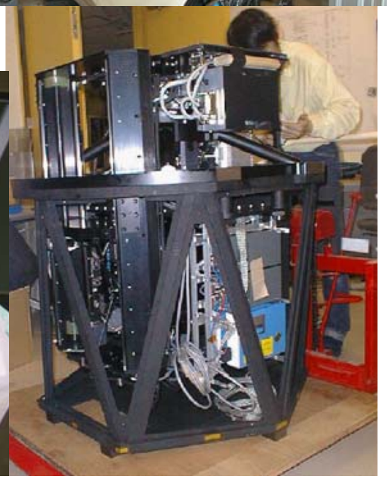


Consistent with $\Omega_\Lambda \sim 0.7$ $\Omega_M \sim 0.3$

II. From Suprime-Cam to HyperSuprimeCam

Suprime-Cam

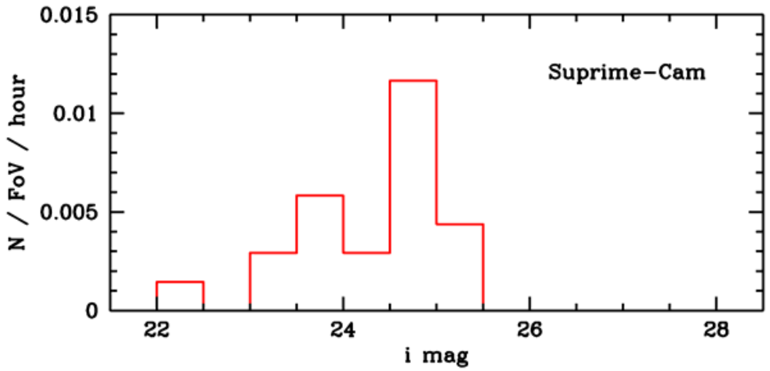
SUBARU 8.2m
33×27 $arcmin^2$ Field of View
the largest among 8-10m telescopes

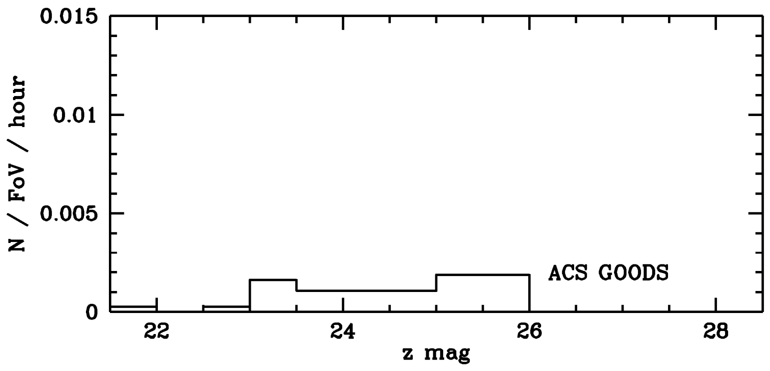





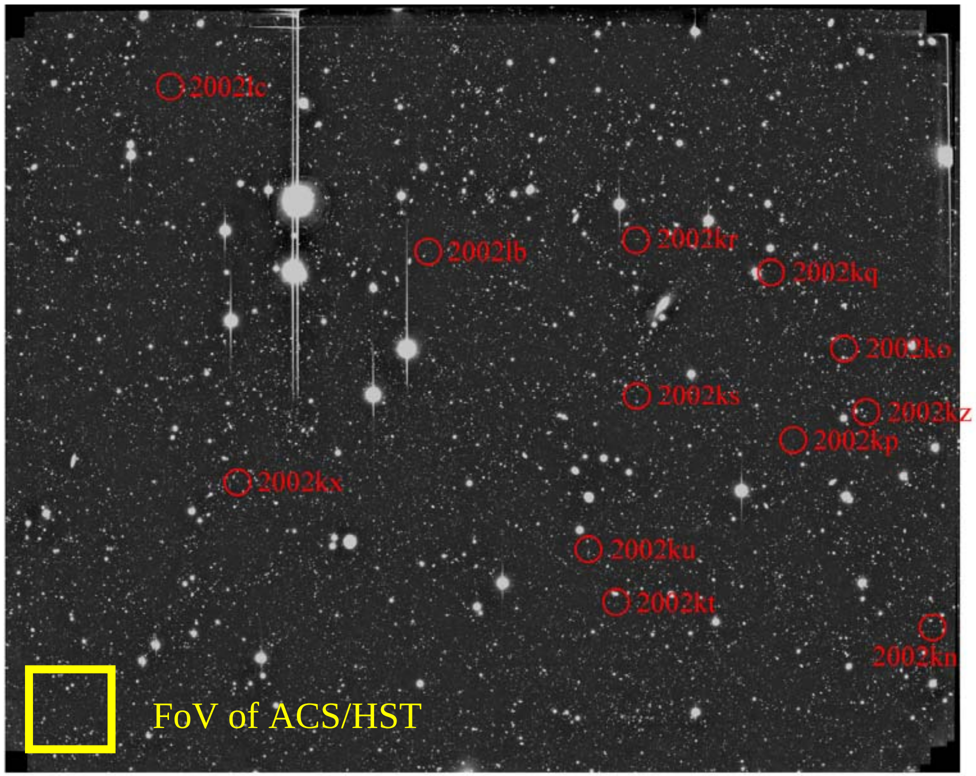
Suprime-Cam@Subaru :

~20 times more effective than ACS@HST

Field of View : x100   integration time : ×1/5 (Yasuda et al. 2004)





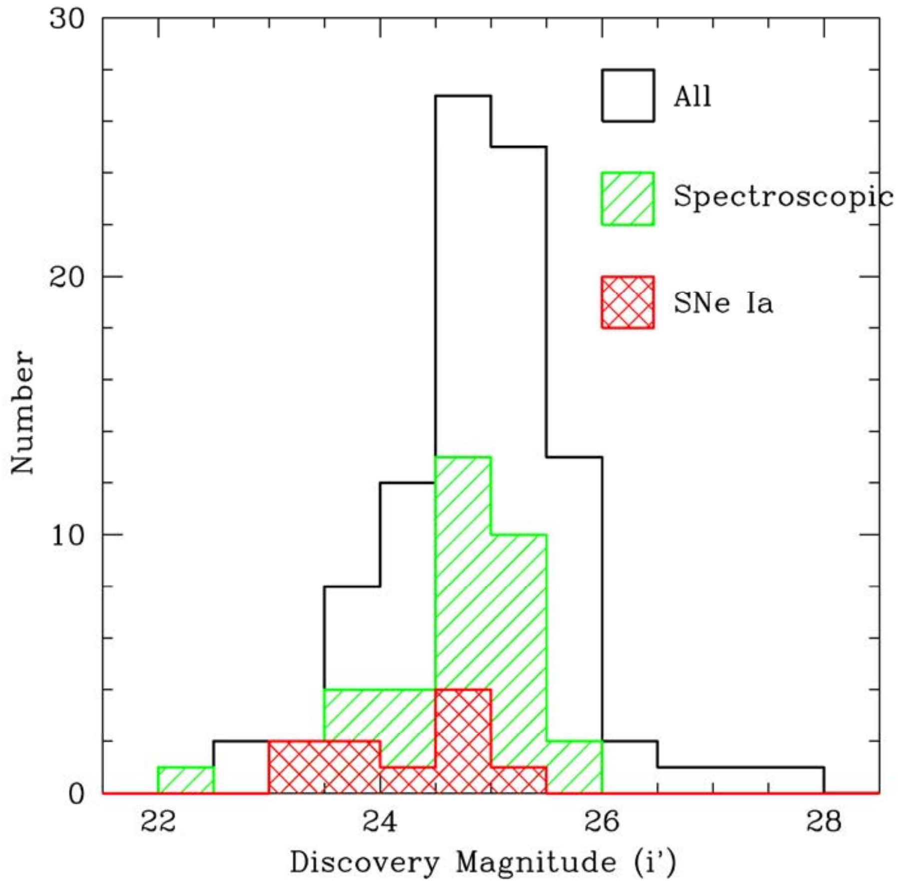


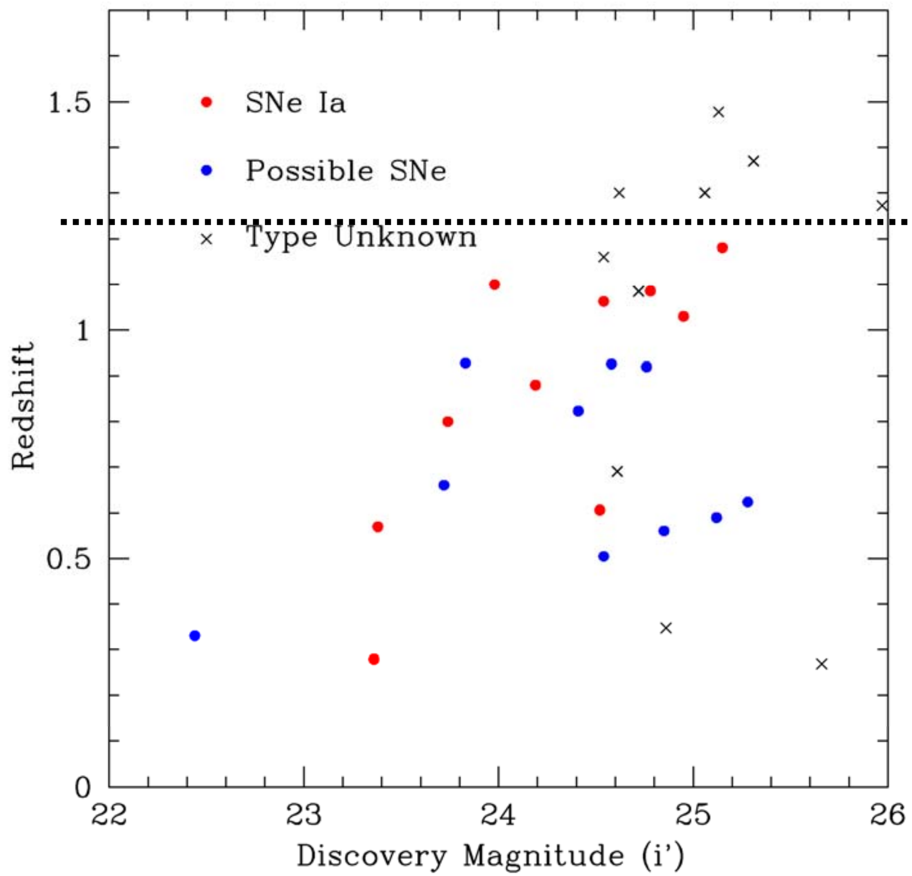
Suprime-Cam searches 2002

~1 hour / exposure, ~5epochs, 5 SupC fields

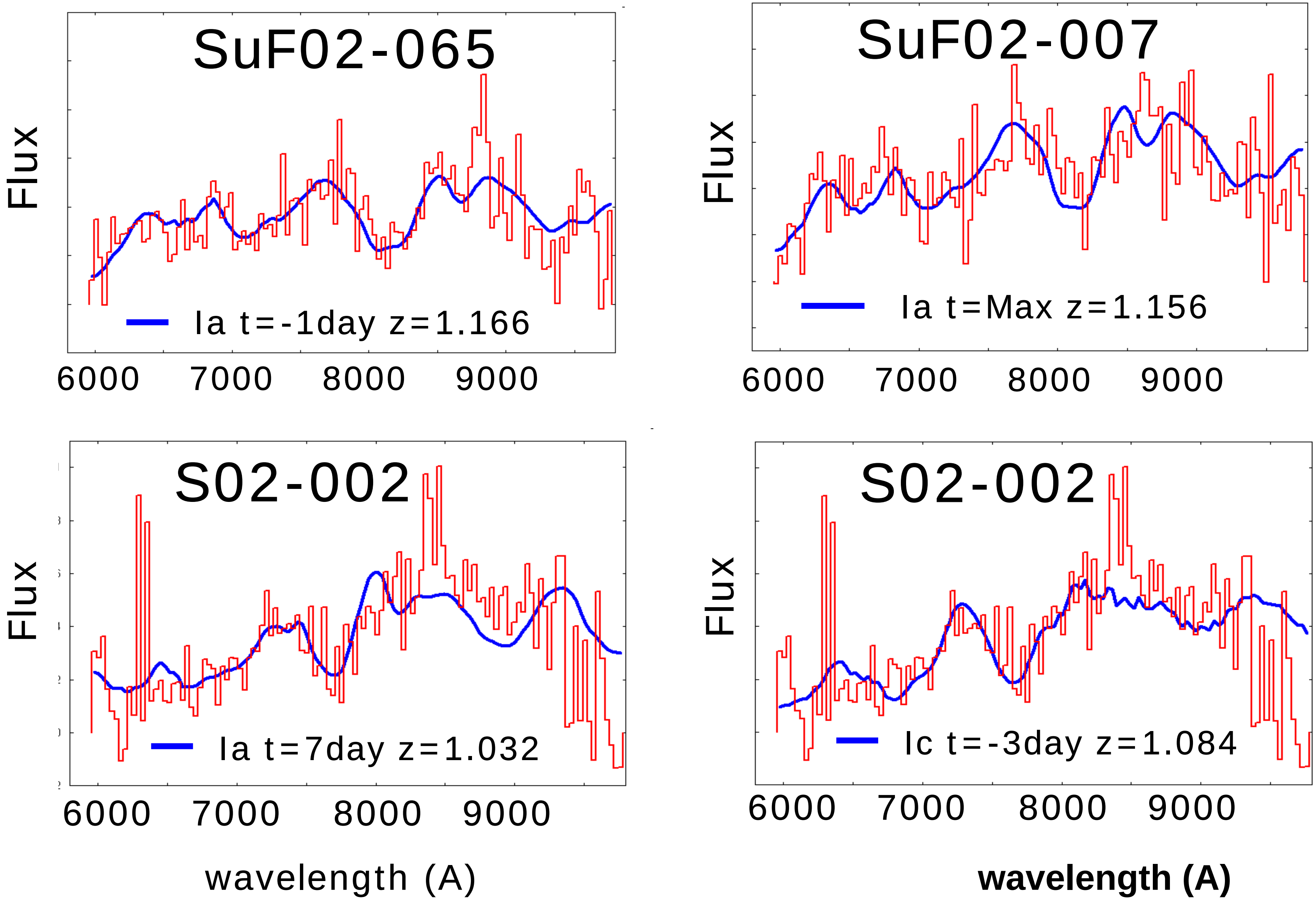
Spectroscopy: Subaru, Keck, VLT ,Gemini, HST

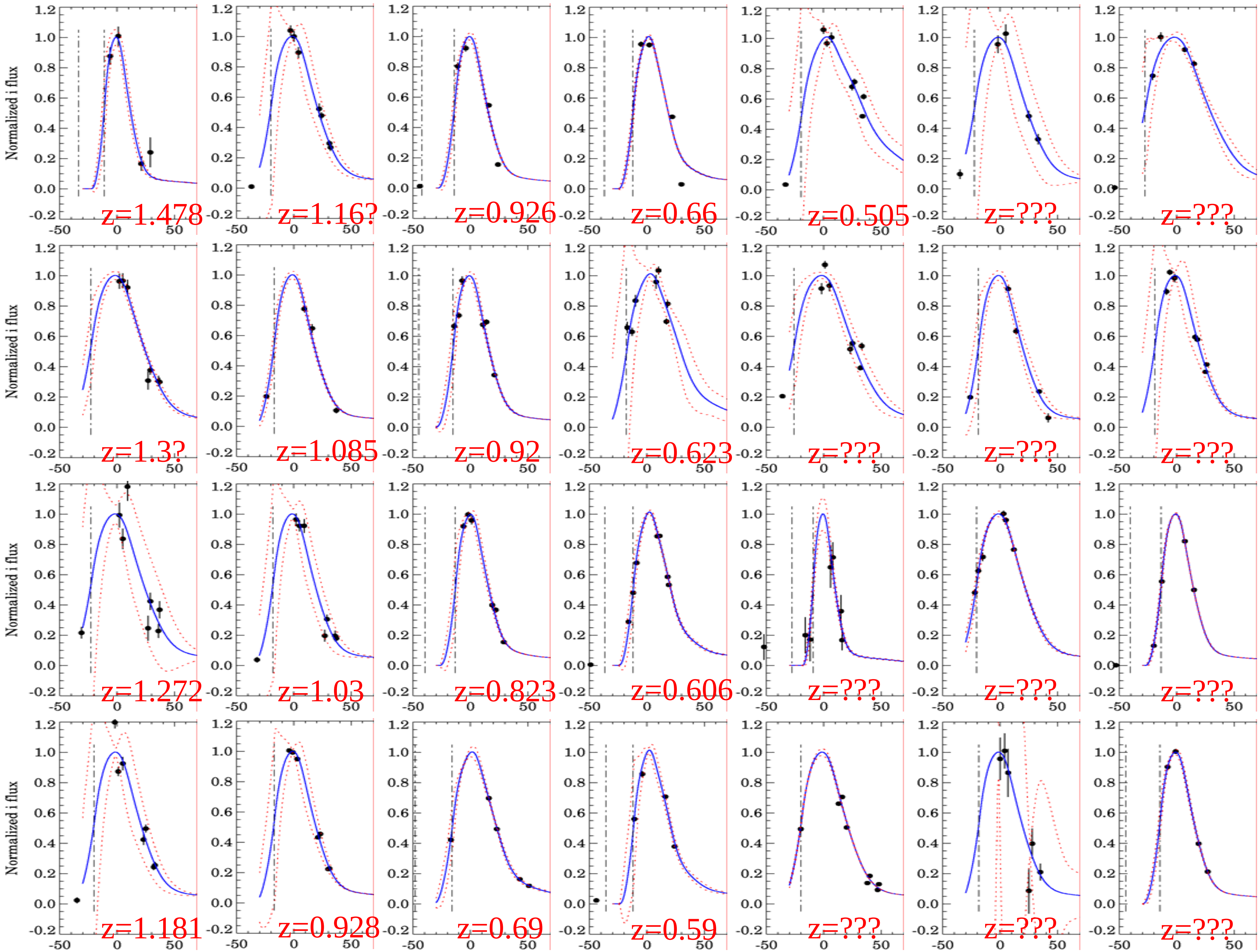
Yasuda et al. 2004





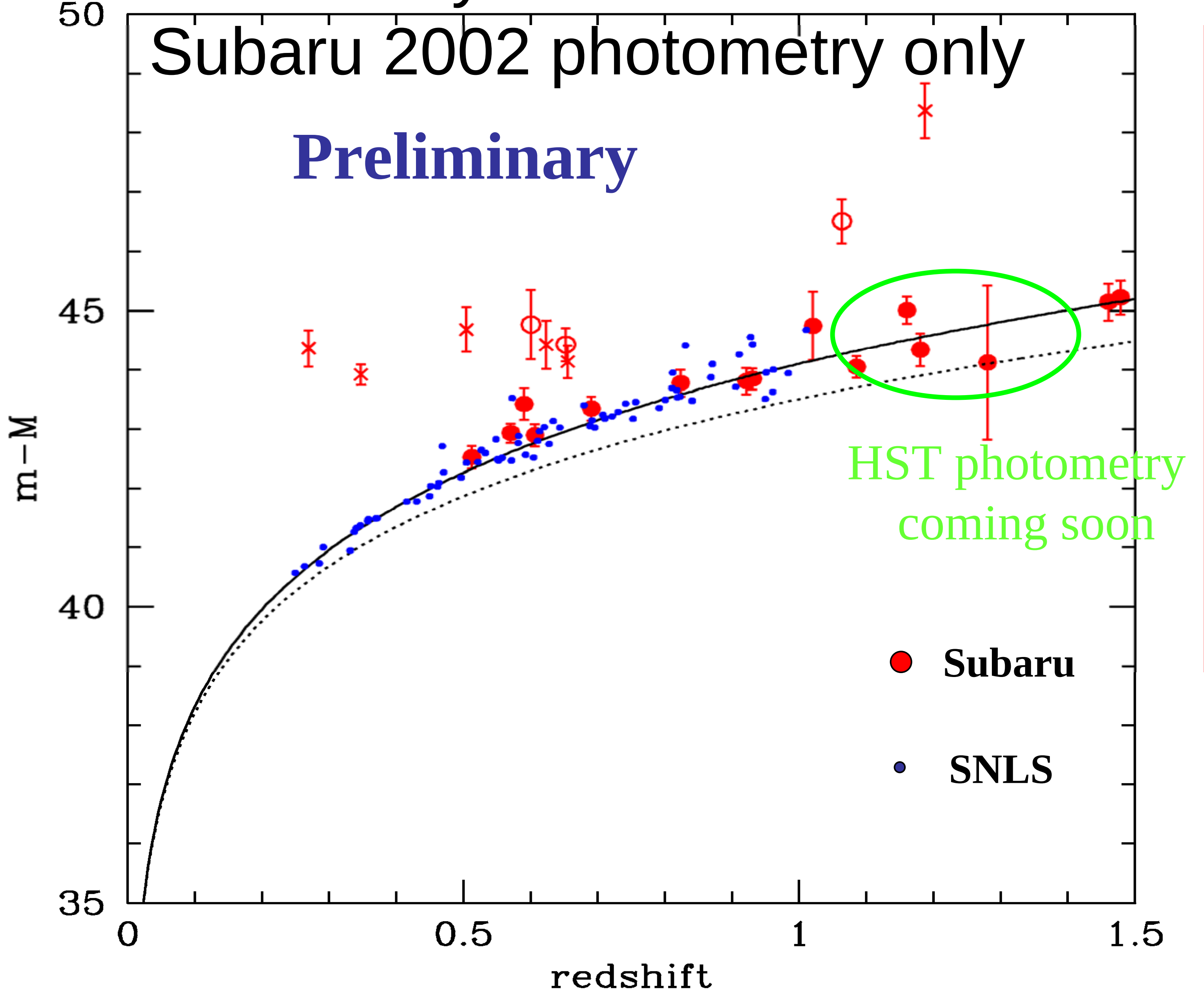
Least χ^2 fitting of Spectra



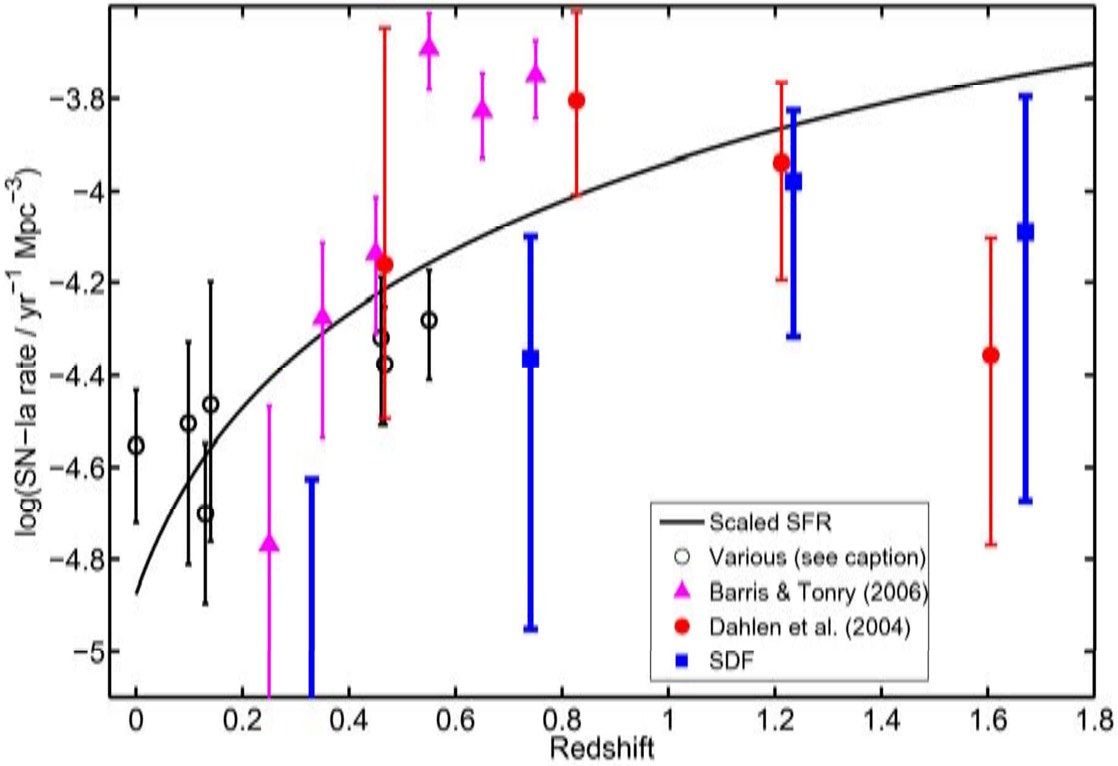


Normalized i flux
z=1.478
z=1.16?
z=0.926
z=0.66
z=0.505
z=???
z=???
Normalized i flux
z=1.3?
z=1.085
z=0.92
z=0.623
z=???
z=???
z=???
Normalized i flux
z=1.272
z=1.03
z=0.823
z=0.606
z=???
z=???
z=???
Normalized i flux
z=1.181
z=0.928
z=0.69
z=0.59
z=???
z=???
z=???

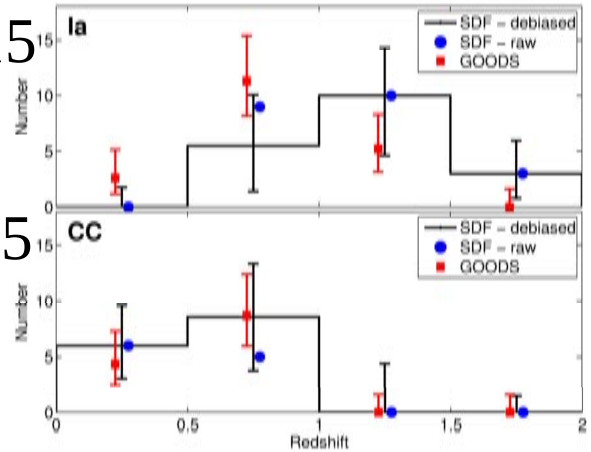
Preliminary results with SALT



SN Rate Studies with SuprimeCam



33 SNe with SupC



SNIa 55%
SNII 45%

Poznanski et al. 2007

SN Rate studies

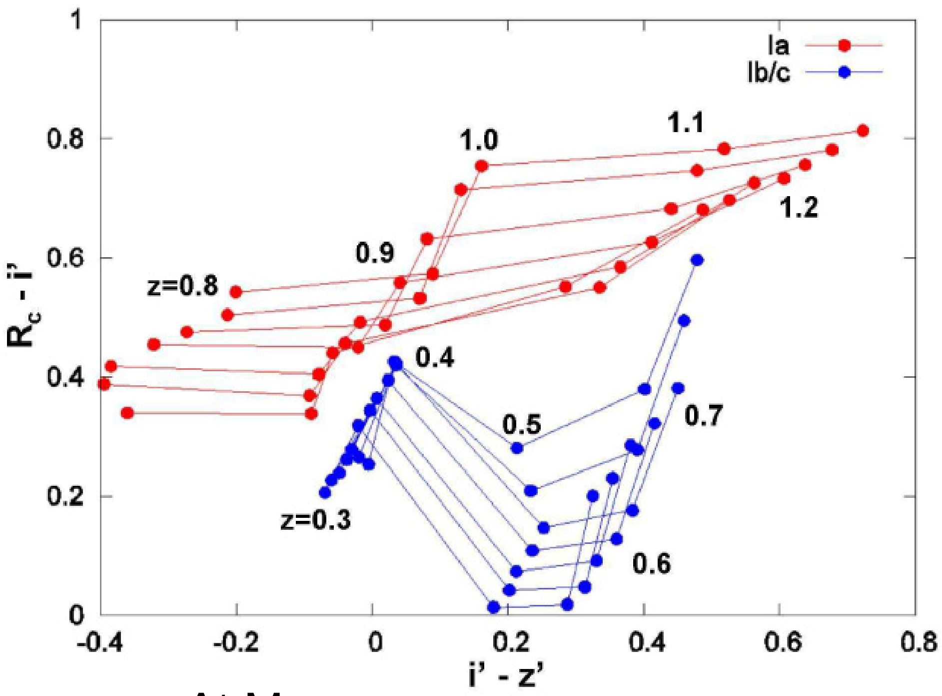
SN rate with photometric classifications of SN types

Poznanski et al. 2007 Oda et al. in prep.

2002 SXDF campaign → >~ 5 epochs, ~100SNe

Light Curve Shape type I ⇔ type II (⇔AGN)

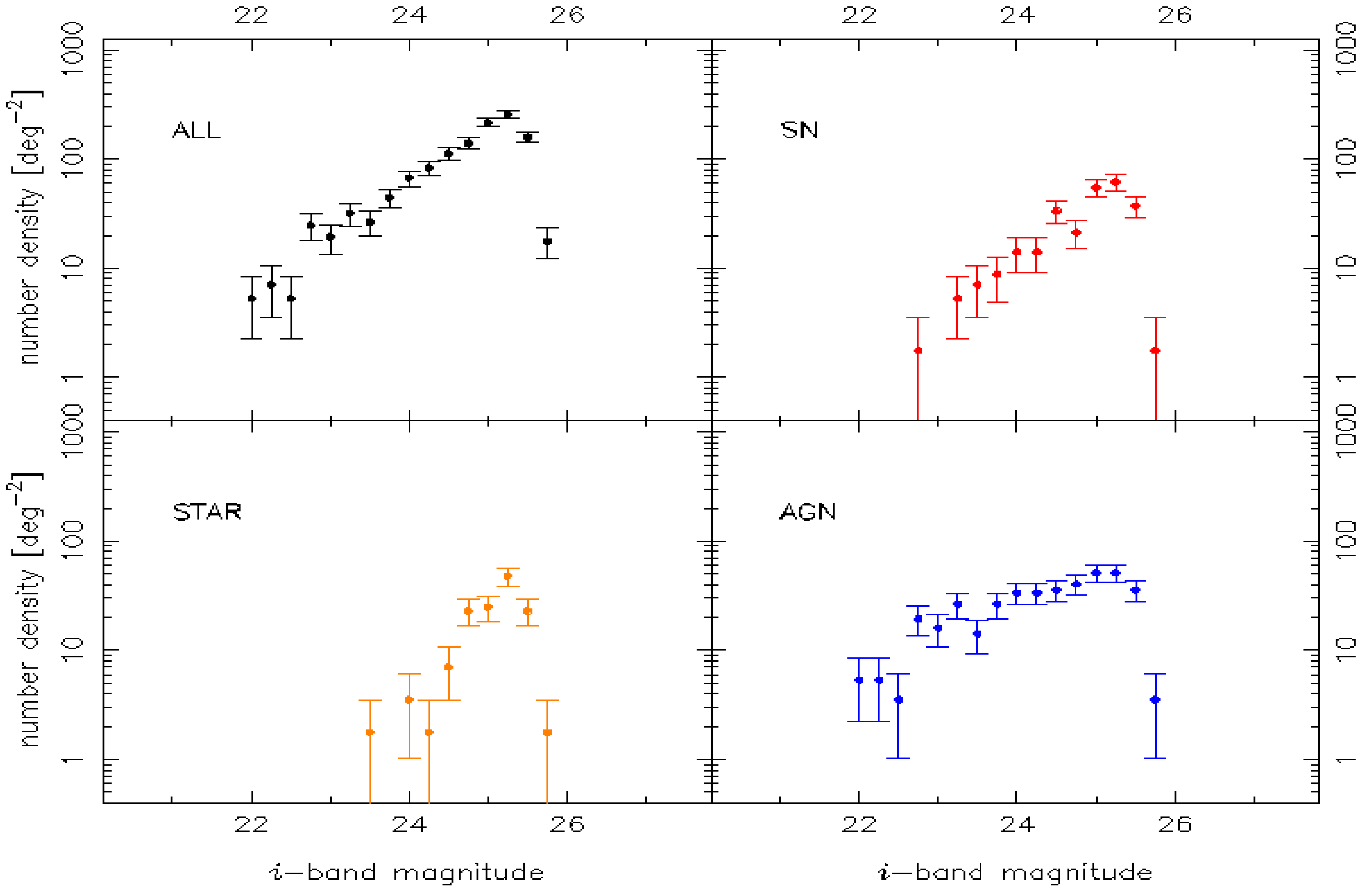
Color Ia ⇔ Ib/Ic



At Max.

by Y.Ihara

Variable objects found in multi-epoch imaging of Suprime-Cam



Morokuma et al. submitted

Variable component only

→ HyperSuprime ~1000 variable objects / FoV
spectroscopic follow-up with WFMOS, FMOS, …

Hyper Suprime Cam
(×~10 SupC FoV)

can find
- ~500 SNIa / night (0.5 <~ z <~ 1.5)
- ~5000 SNIa / 10 nights
  - ← ~1 hour exposure / epoch

Hamamatsu CCD
red sensitive

can follow
- ~50 SNIa / night
- ~500 SNIa / 10 nights
  - ← ~8 hour exposure / epoch

Spectroscopy
- bright targets
  - multi-fiber spectrograph (WFMOS) ~100 fibers/FoV
- faint targets
  - with Adaptive Optics e.g. Melburne et al. 2006
  - HST including NIR photometry

→ large and well controlled sample (LC, color, host)

rate measurements

check evolution

III. On-going improvements

On-going surveys: 200-700 SNIa in several years

→ systematic errors, high redshift(>0.8)

- SNIa as a Standard Candle

  homogeneity

  (host environment, progenitor)

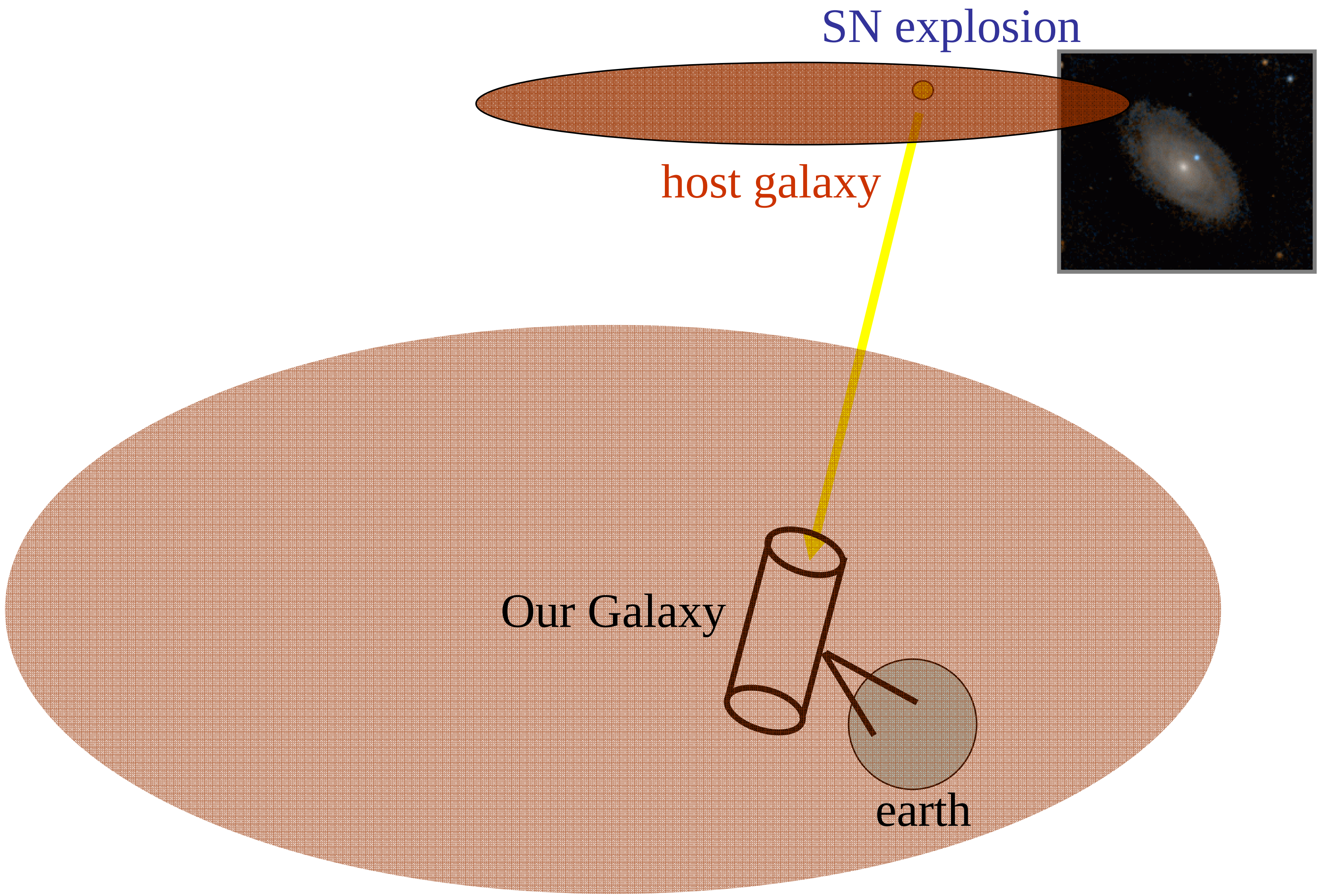
  possible evolution

- Dust extinction due to host galaxy
- K-correction

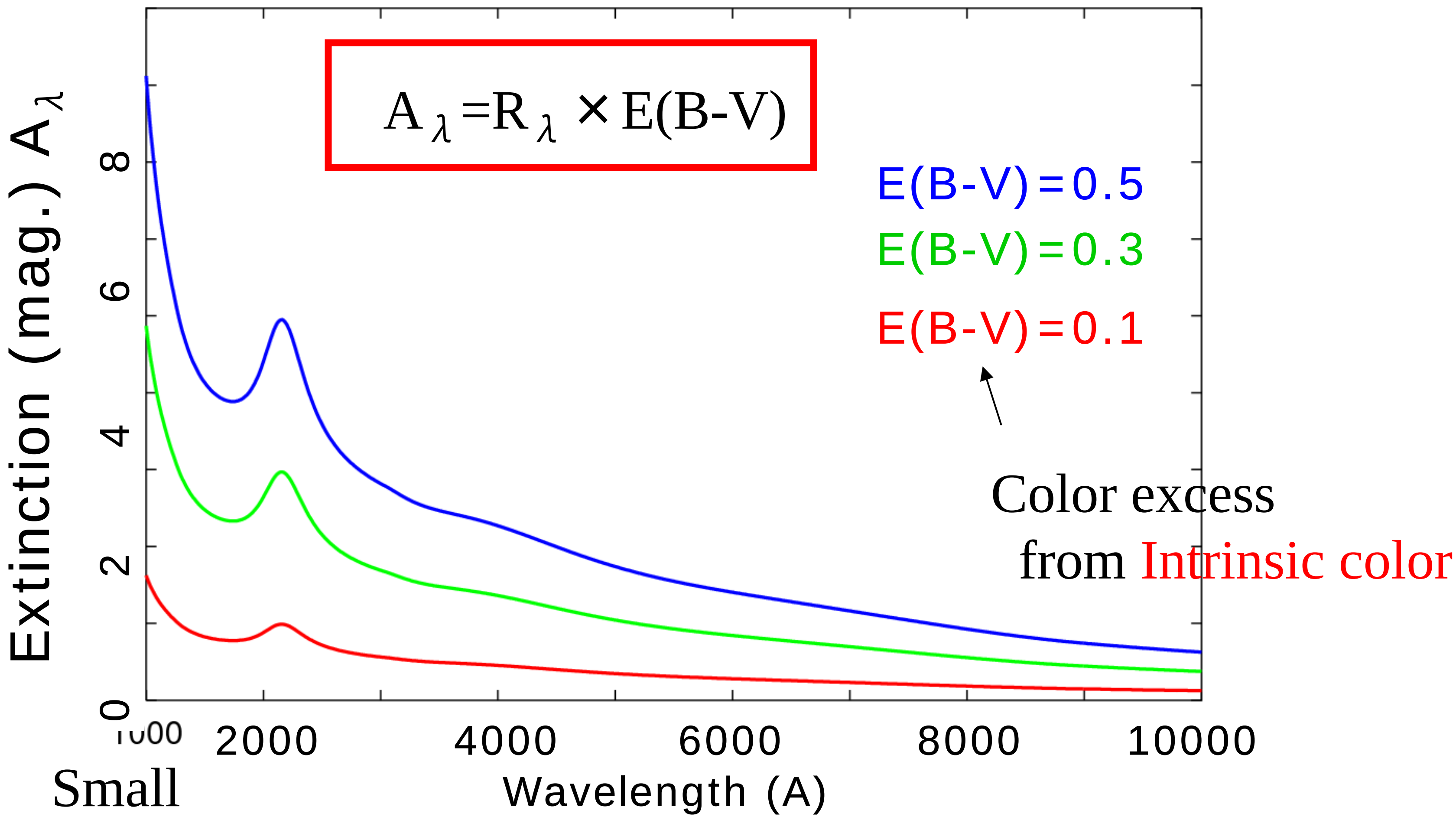
  different observed wavelengths → correction

- accurate photometric zeropoints

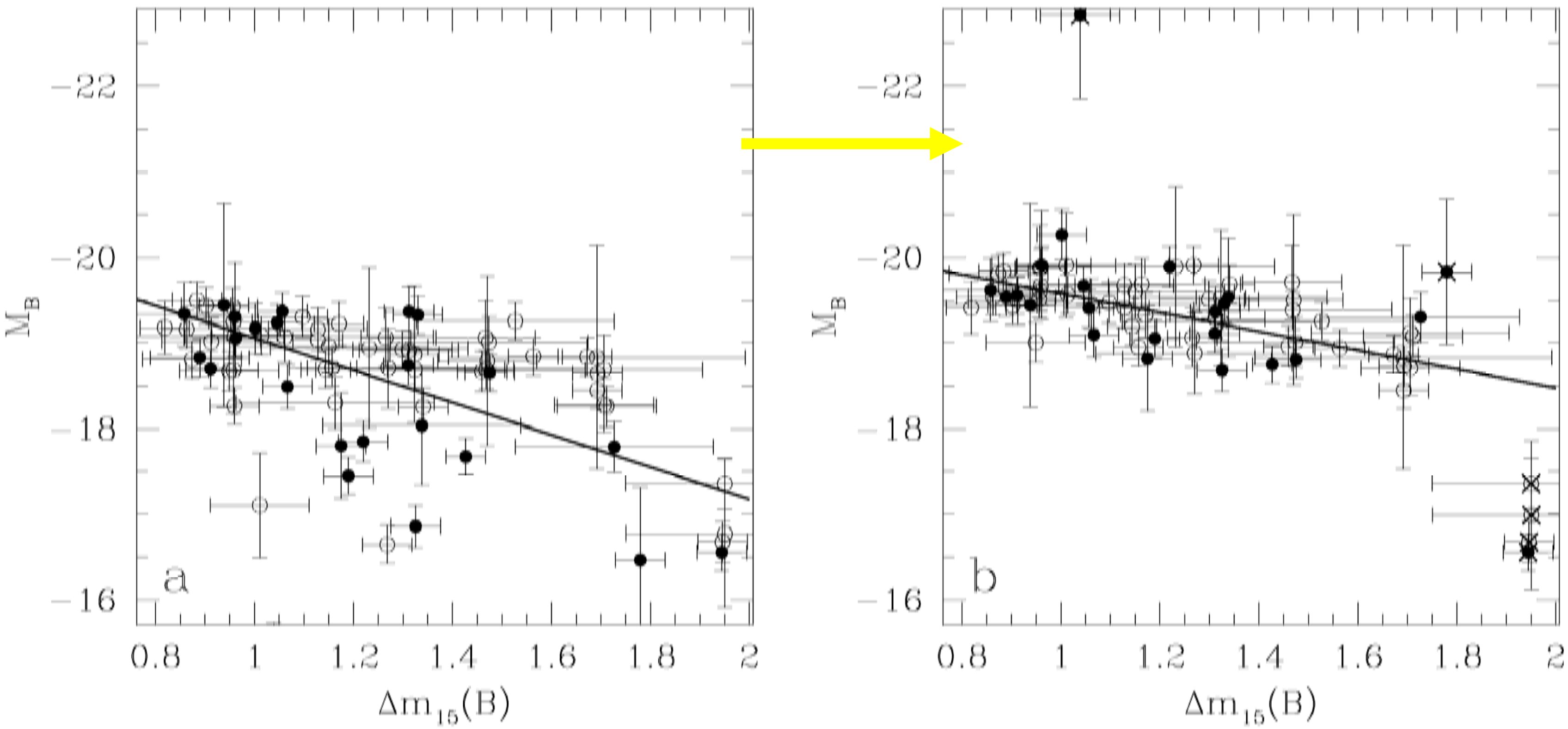
Dust Extinction



Reddening law (normal galaxy)



Different Extinction Correction
among different analysis code (MLCS2k2, SALT, SALT2, …)



R_B~3.5 : Optimal?

⇔ R_B ~ 4.3 : MW

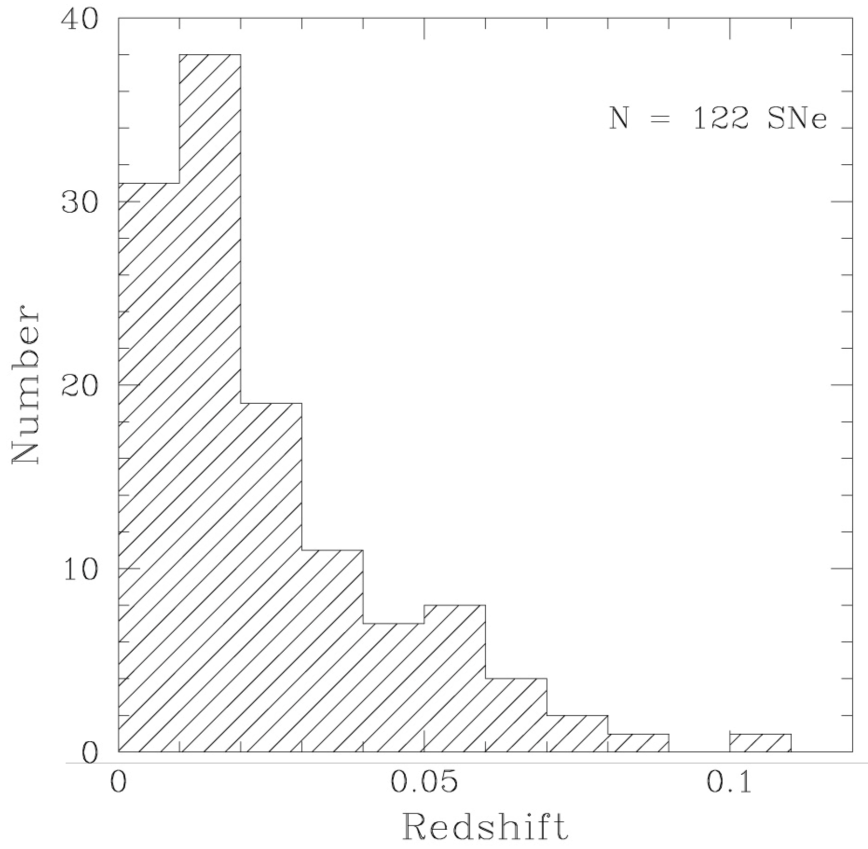
78 Nearby SNeIa B,V Altavilla et al. 2004

Light curve studies of nearby Type Ia Supernovae with a Multi-band Stretch method

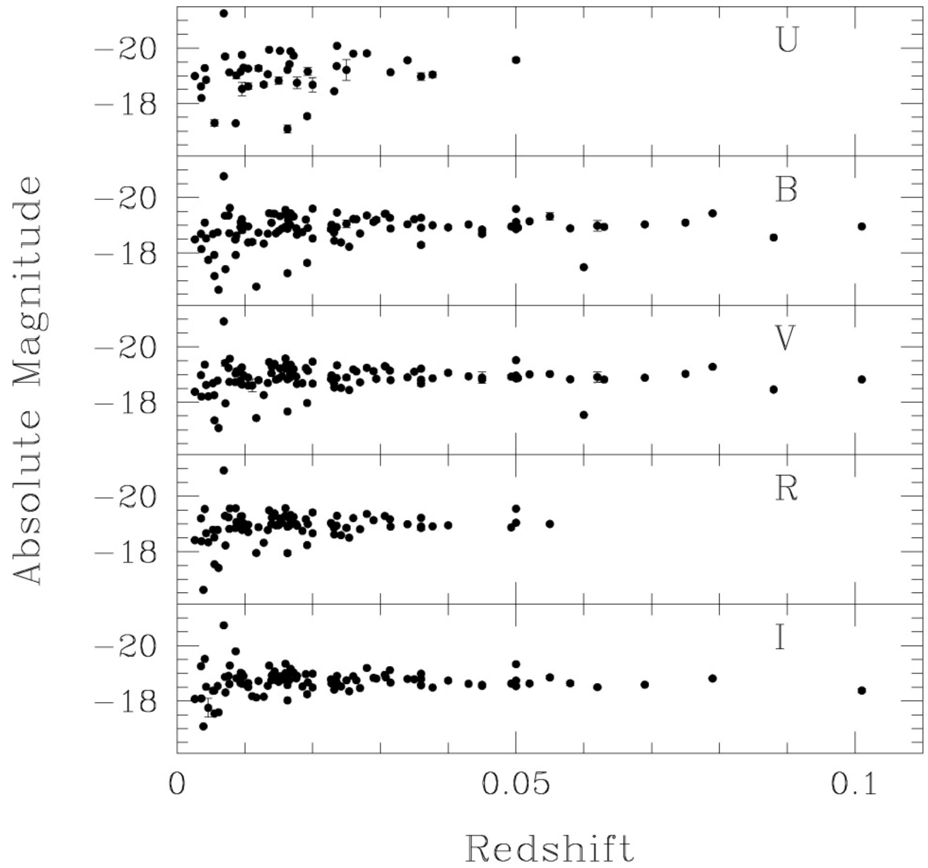
N. Takanashi[1*], M. Doi[1] and N. Yasuda[2]

In prep.

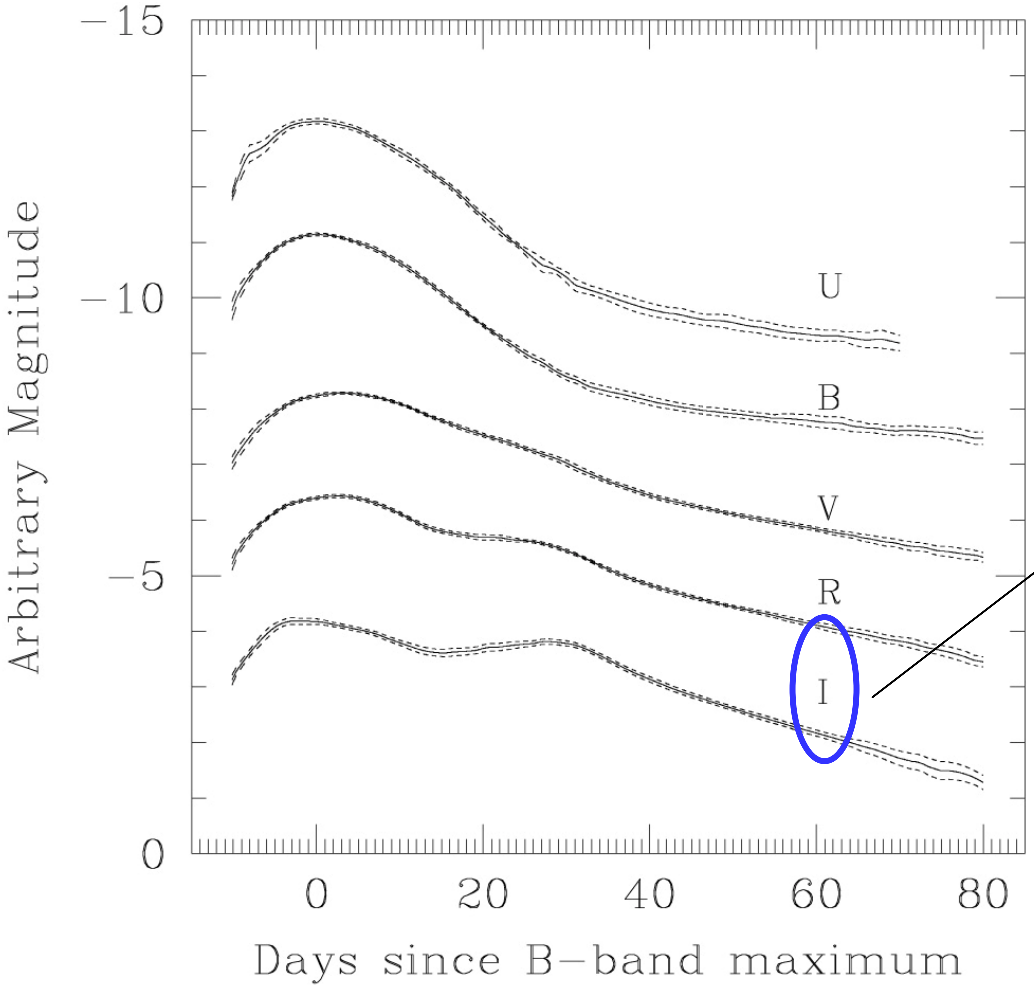
122 SNeIa from published data

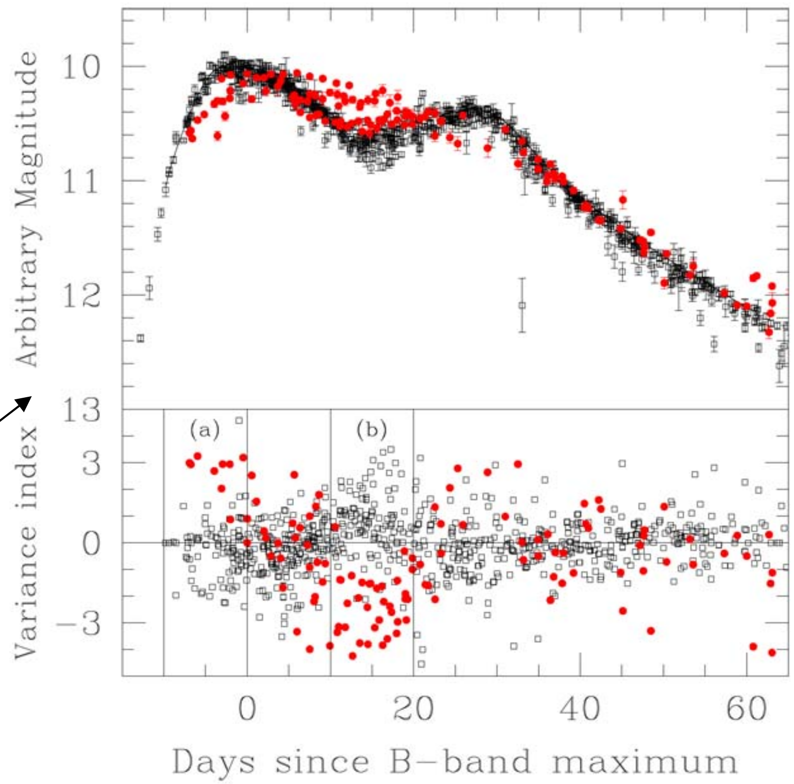


Hubble flow



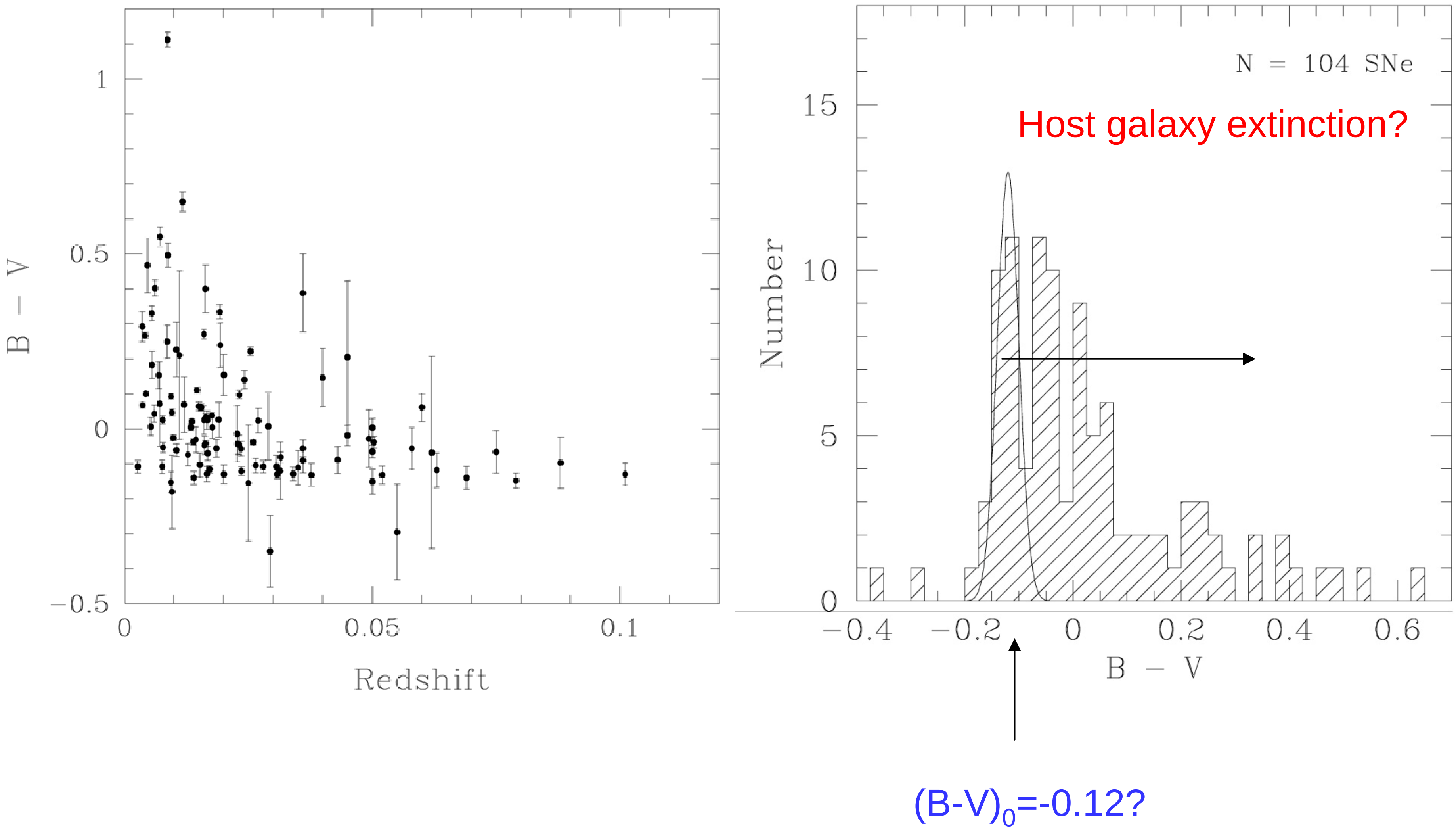
New Light Curve Templates ← stretch method (Perlmutter et al. 1997)



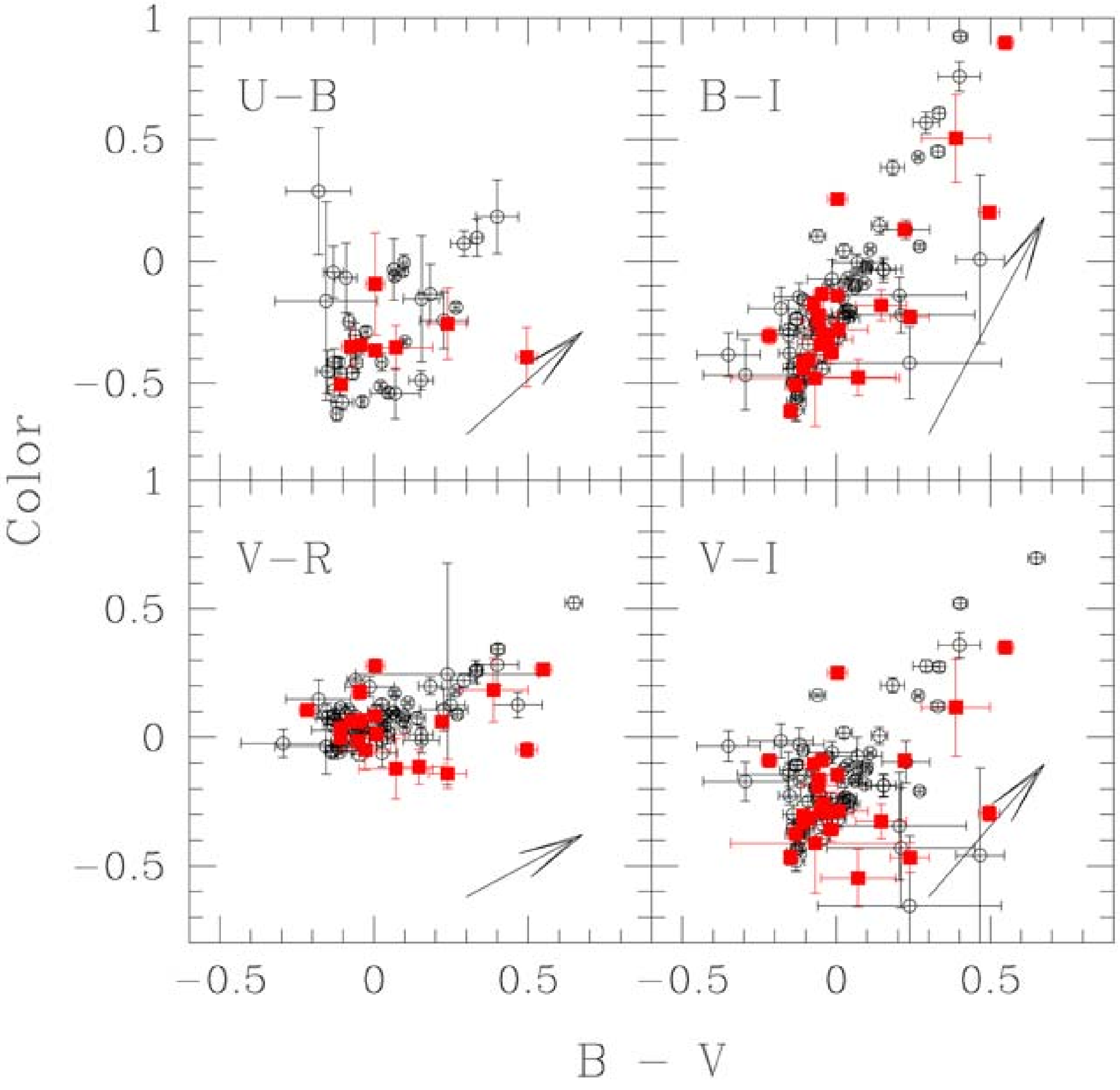


90% fitted reasonably well

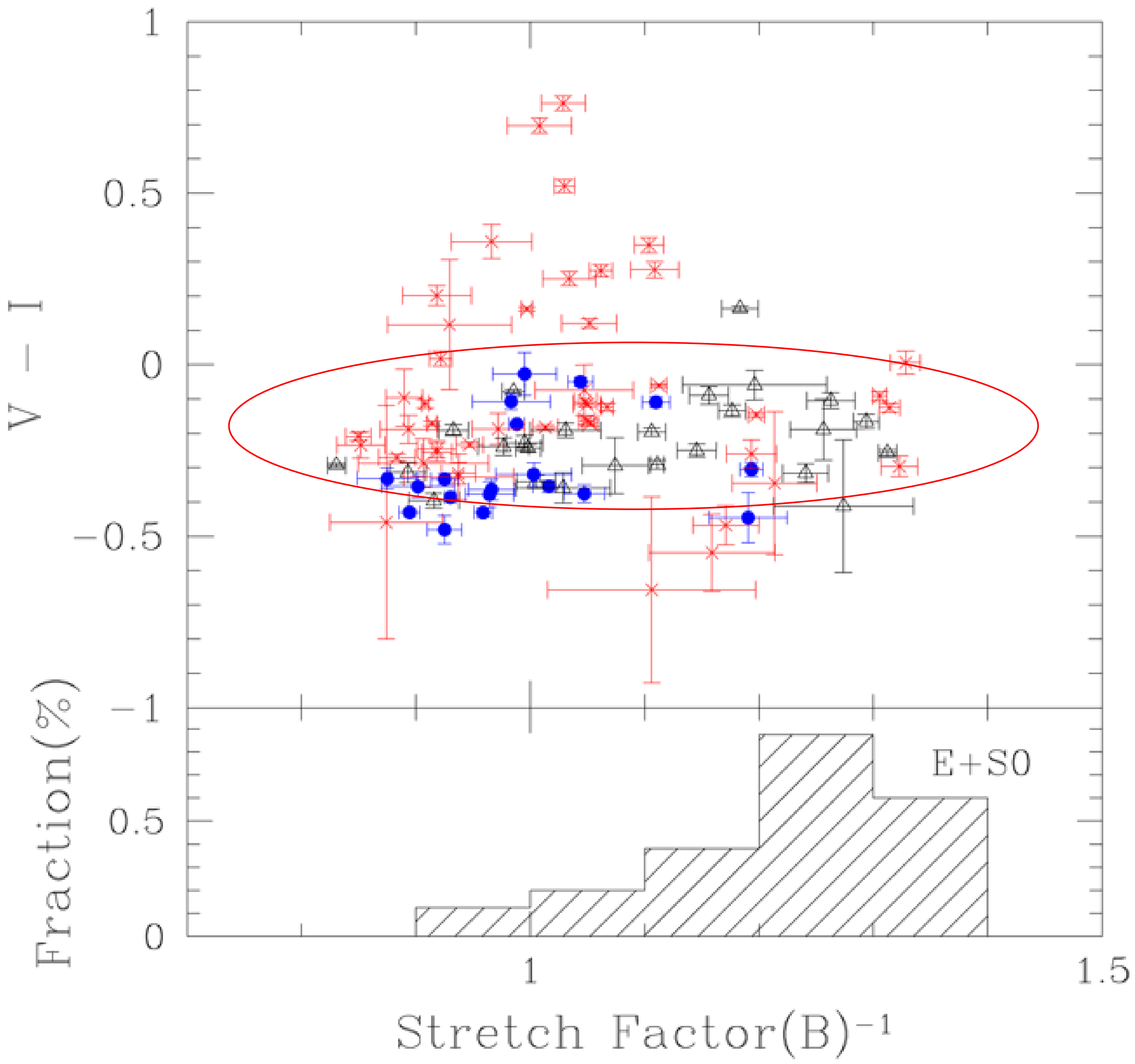
Rest frame B - V



Color-Color : Consistent with MW dust extinction



● E, S0 host



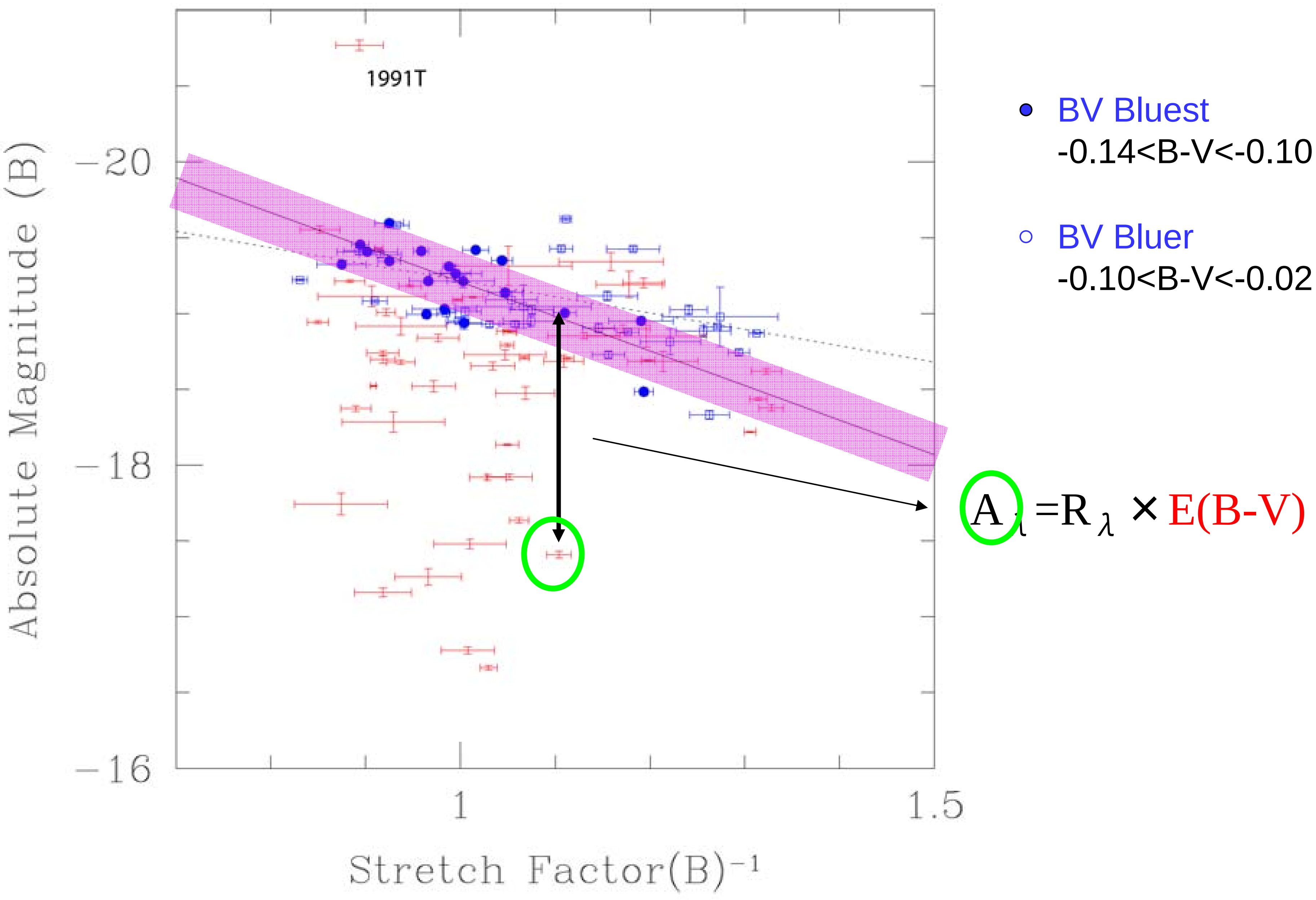
BV Bluest
-0.14<B-V<-0.1

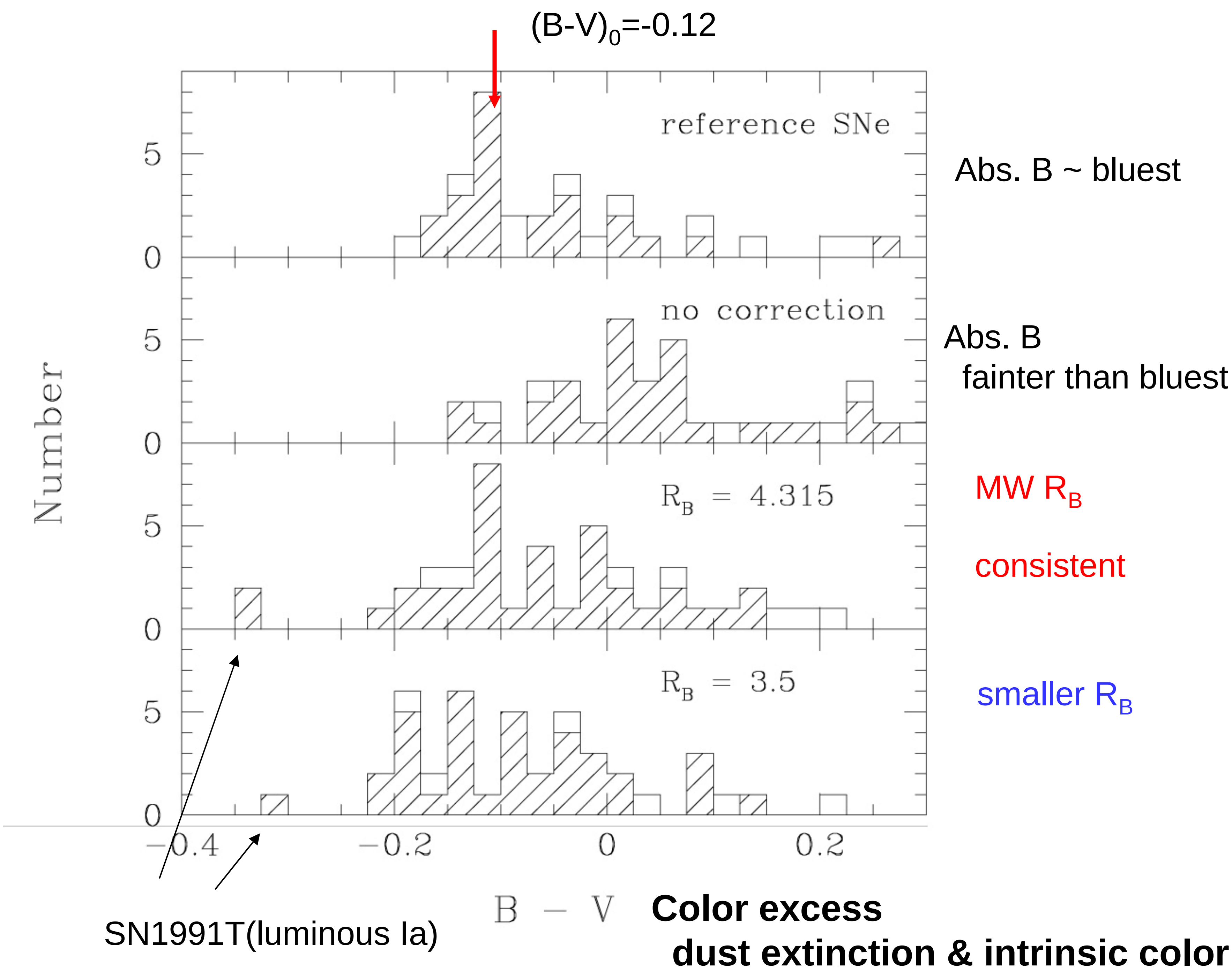
BV Red
0.0<B-V

Red in B-V
Not red in V-I

↓

Not All are reddend
by dust in host


1991T
Absolute Magnitude (B)
−20
−18
−16
1
1.5
Stretch Factor(B)⁻¹
BV Bluest
-0.14<B-V<-0.10
BV Bluer
-0.10<B-V<-0.02
A λ =R λ × E(B-V)


(B-V)0=-0.12
reference SNe
no correction
RB = 4.315
RB = 3.5
Number
5
0
−0.4
−0.2
0
0.2
B − V
Abs. B ~ bluest
Abs. B
fainter than bluest
MW RB
consistent
smaller RB
SN1991T(luminous Ia)
Color excess
dust extinction & intrinsic color

For cosmological distance indicator
SNeIa on E, S0 smallest scatter

Sample	relation	r.m.s. (mag)	Number
9A	$0.96 \times B_{s.f.}^{-1} - 2.51 \times (B-V)_{max} - 20.26$	0.48	104
9B	$0.98 \times B_{s.f.}^{-1} - 2.28 \times (B-V)_{max} - 19.95$	0.27	45
9C	$1.09 \times B_{s.f.}^{-1} - 1.78 \times (B-V)_{max} - 20.15$	0.33	28
9D	$0.99 \times B_{s.f.}^{-1} - 2.23 \times (B-V)_{max} - 20.10$	0.12	16
9E	$1.25 \times B_{s.f.}^{-1} - 0.71 \times (B-V)_{max} - 20.40$	0.21	46

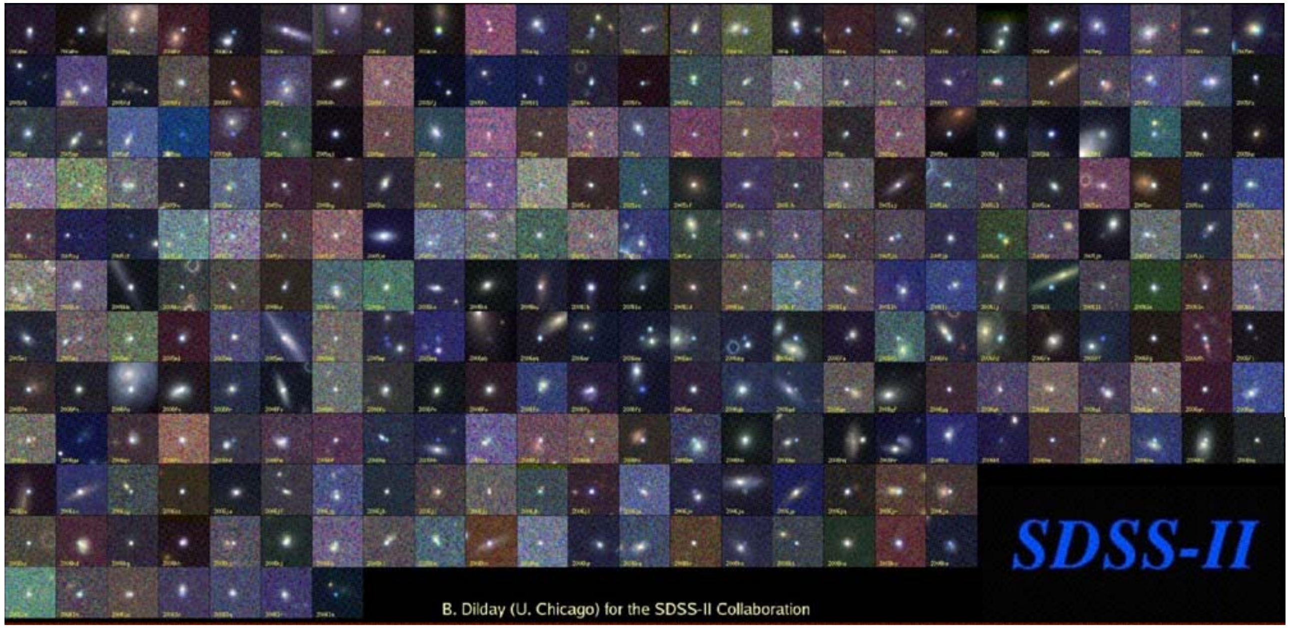
9A is all SNe Ia.
9B is SNe Ia of $z > 0.02$.
9C is SNe Ia hosted by E or S0 galaxies.
9D is SNe Ia of $z > 0.02$ hosted by E or S0 galaxies.
9E is "BV bluest"+"BV bluer" sample, which $-0.14 > (B-V)_{max} > -0.02$.

Blue

E, S0 host

Empirical color correction

Our next step → SDSSII SNe

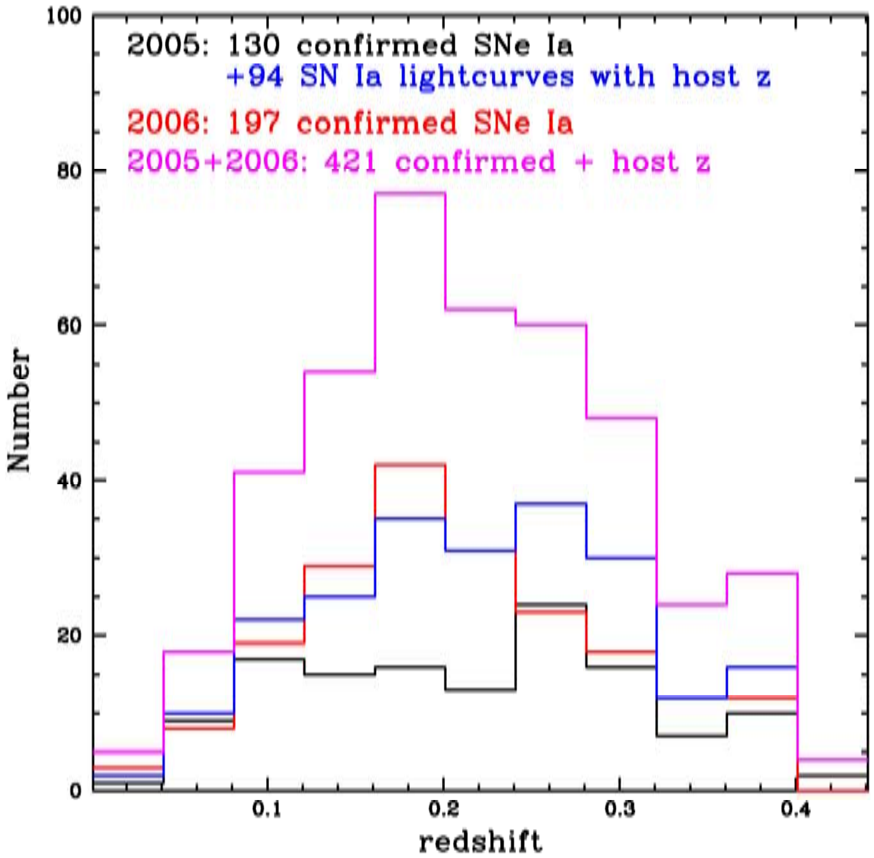


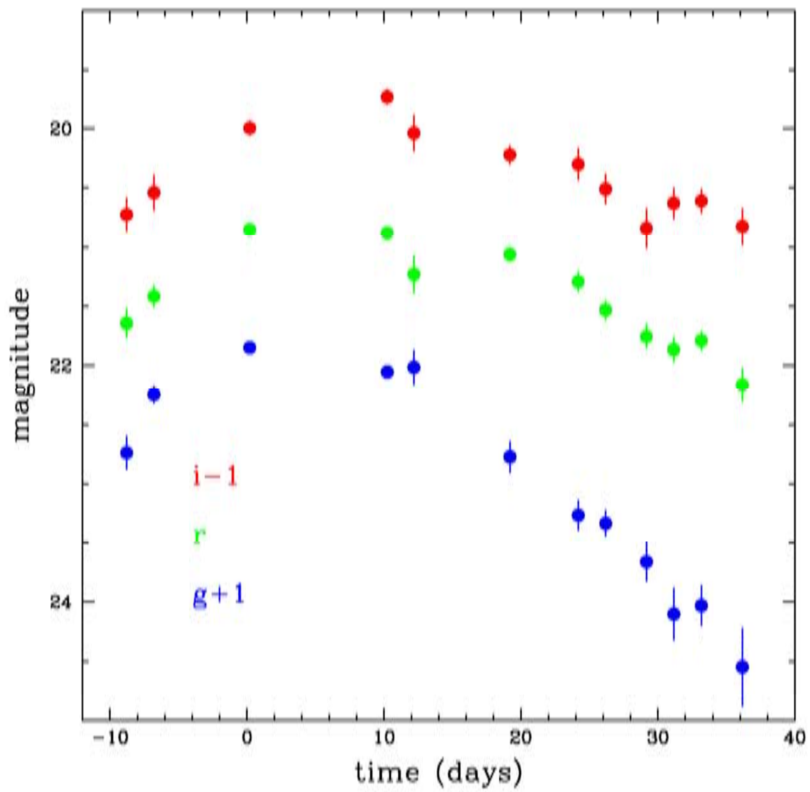
SDSS-II SN survey
327 spectroscopicall confirmed SNe
in 2005 - 2006

Homogeneous Data set in 5 colors

"SDSS Standard Star Catalog for Stripe 82:Dawn of Industrial 1% Optical Photometry" Ivezic et al. 2007

SDSS SN survey 2005-2006





light curves

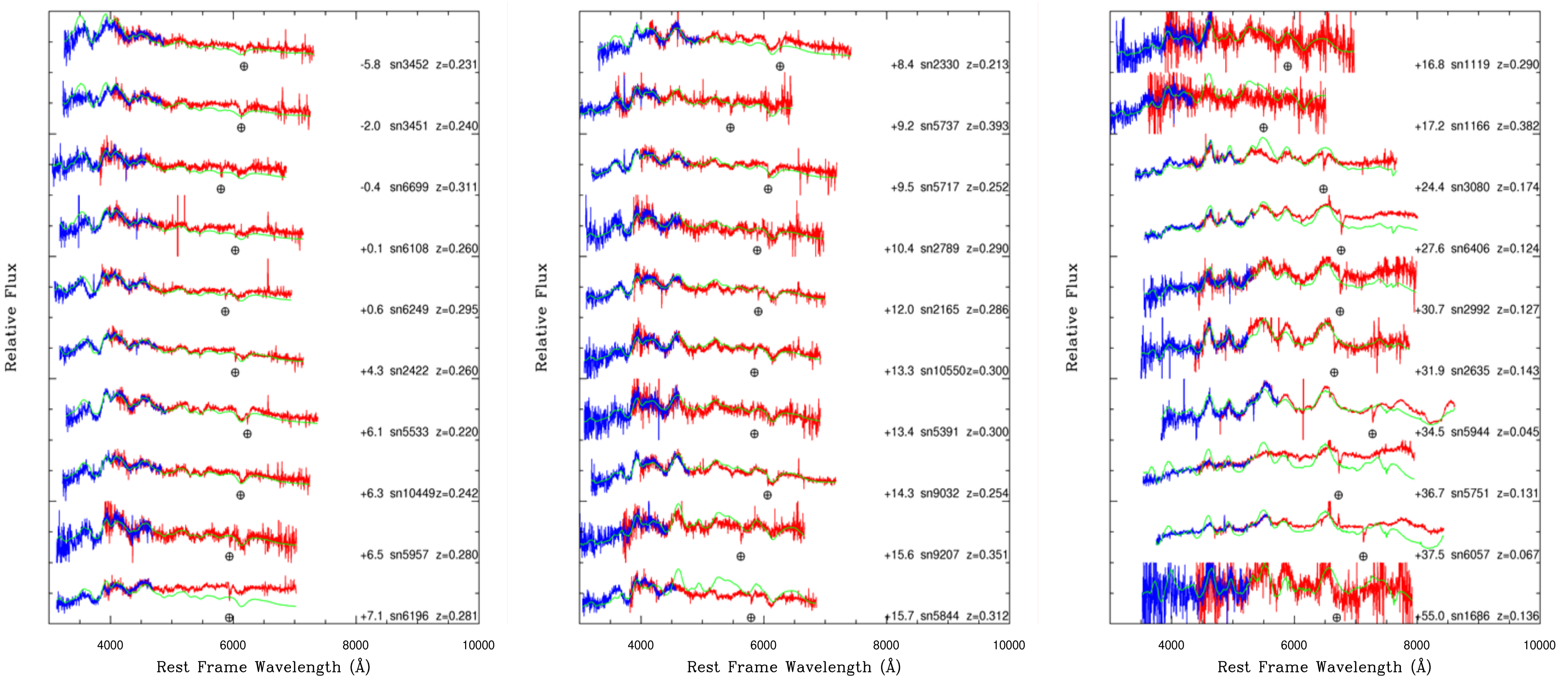
327 spectroscopicaly
Confirmed SNIa

Frieman et al. 2007

Spectroscopy for SDSS SNe →classified ~327 SNIa in 2005-2006

MDM 2.4m NOT 2.6m APO 3.5m NTT 3.6m KPNO 4m

WHT 4.2m Subaru 8.2m HET 9.2m Keck 10m SALT 10m



SDSS SN spectra with Subaru(Yasuda et al.)

→ nearby SN Ia

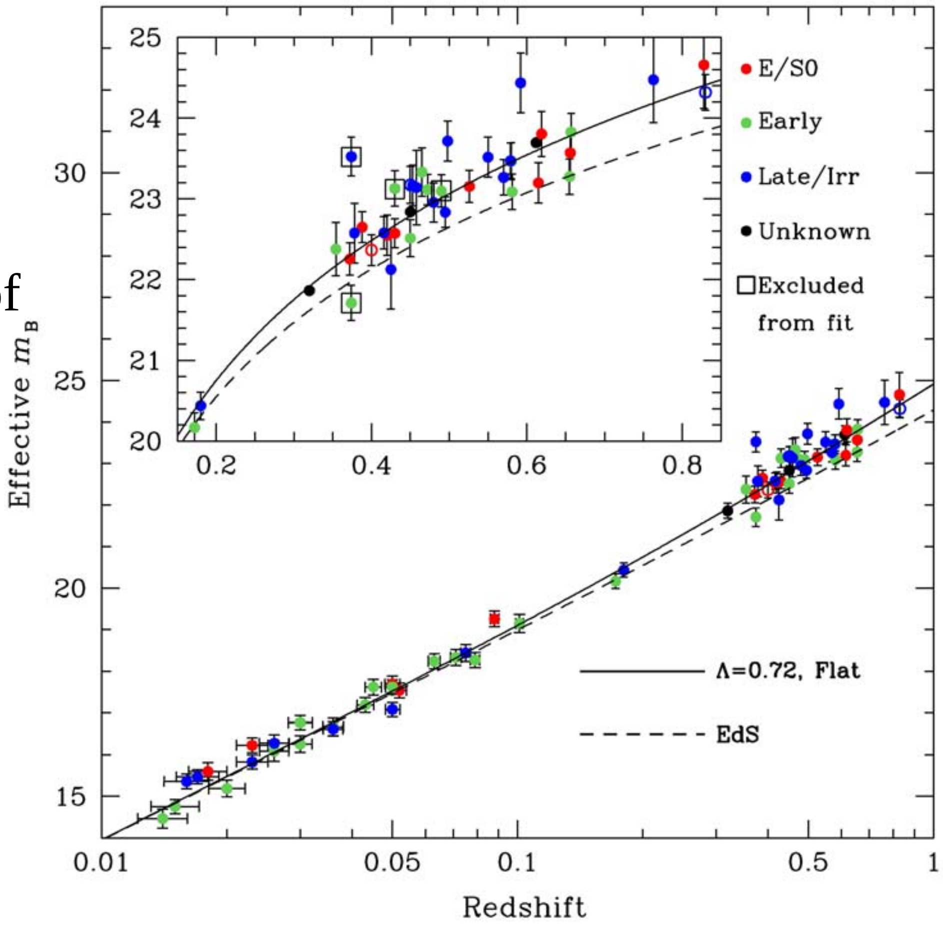
2005-2006: 50 new SNIa

Frieman et al. 2007, Sako et al. 2007

Host extinction

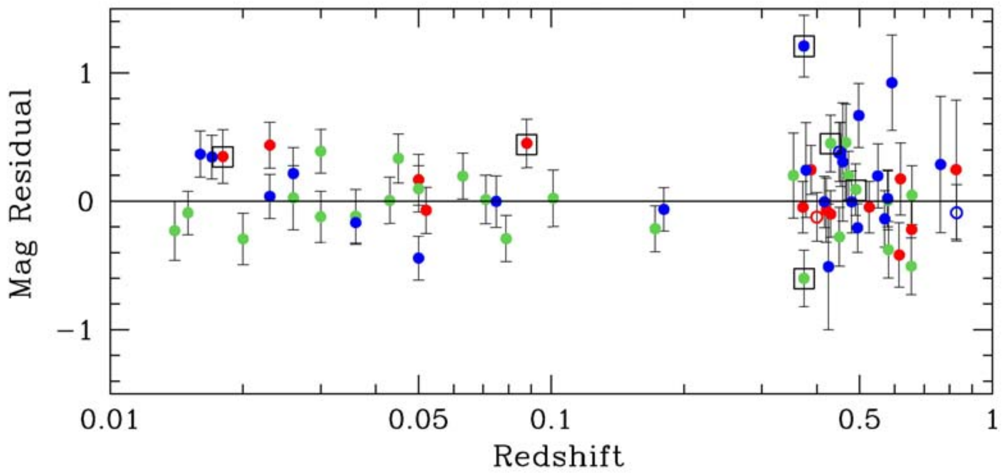
Sullivan et al. 2003

Host galaxy morphology of SNe with HST



blue : late type
red : E/S0

E/S0
σ =0.16 mag
⇔
All sample
σ ~0.5 mag

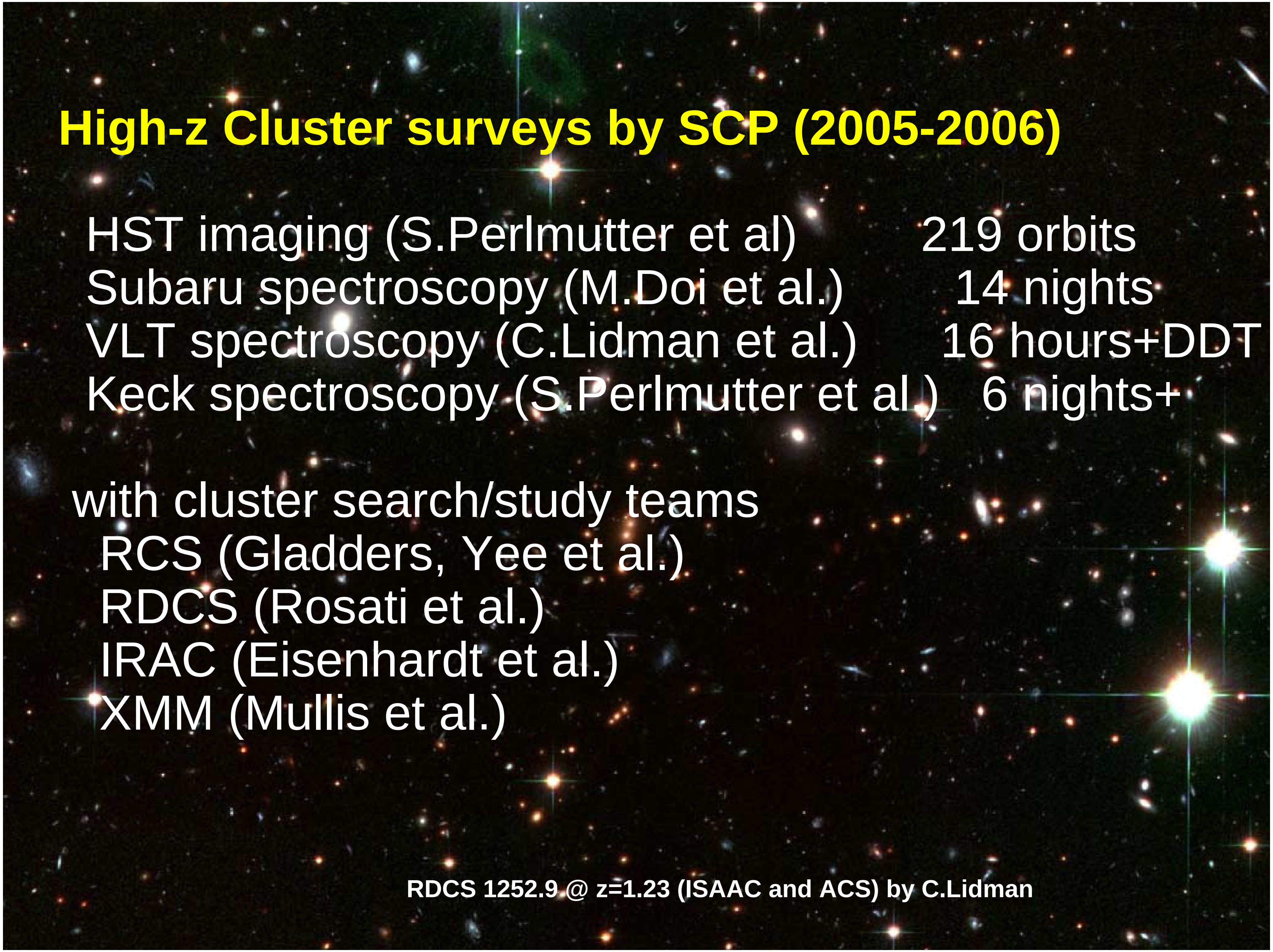


High-z Cluster surveys by SCP (2005-2006)

HST imaging (S.Perlmutter et al)	219 orbits
Subaru spectroscopy (M.Doi et al.)	14 nights
VLT spectroscopy (C.Lidman et al.)	16 hours+DDT
Keck spectroscopy (S.Perlmutter et al.)	6 nights+

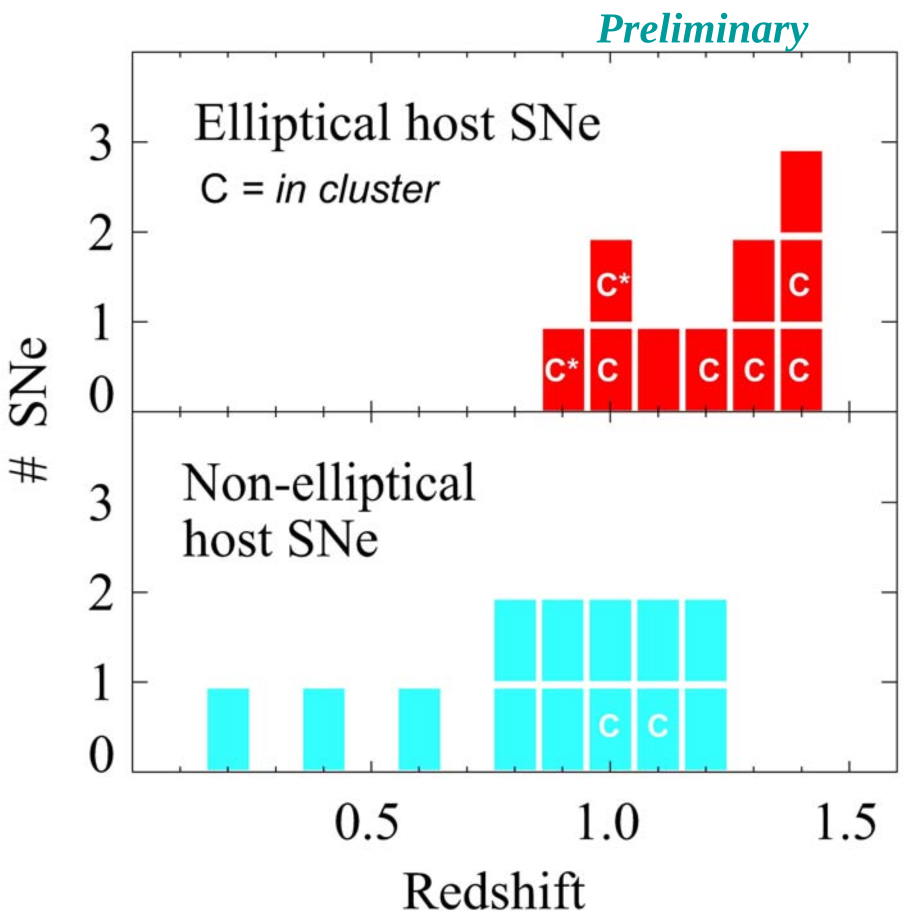
with cluster search/study teams

- RCS (Gladders, Yee et al.)
- RDCS (Rosati et al.)
- IRAC (Eisenhardt et al.)
- XMM (Mullis et al.)



RDCS 1252.9 @ z=1.23 (ISAAC and ACS) by C.Lidman

SNe Discoveries in HST Program



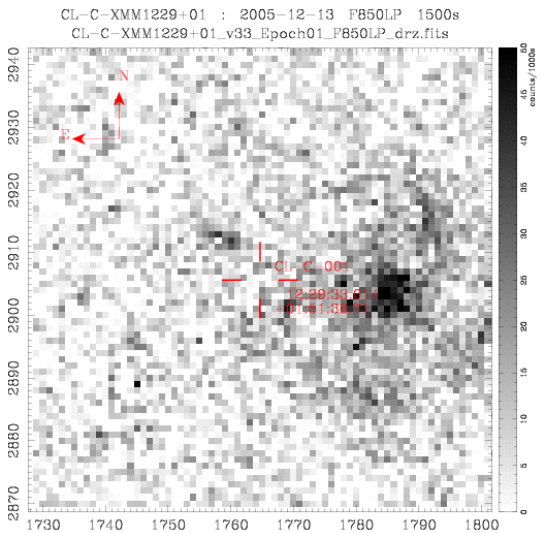
Efficiency to find SNe on ellipticals

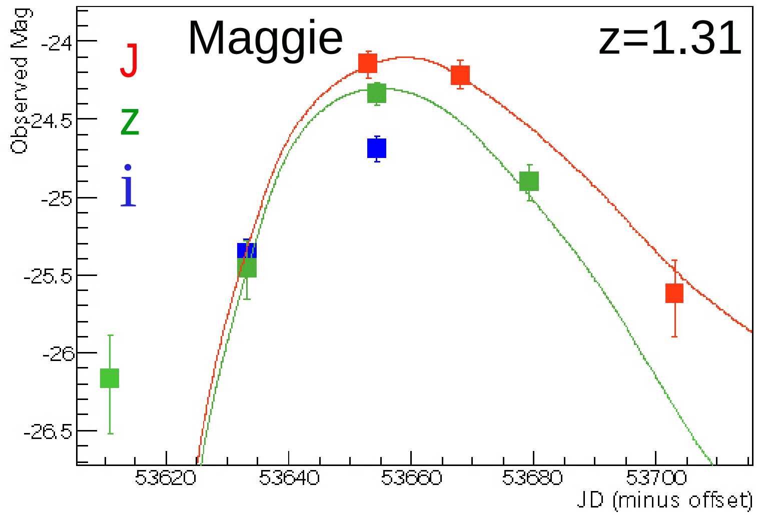
higher ← clusters

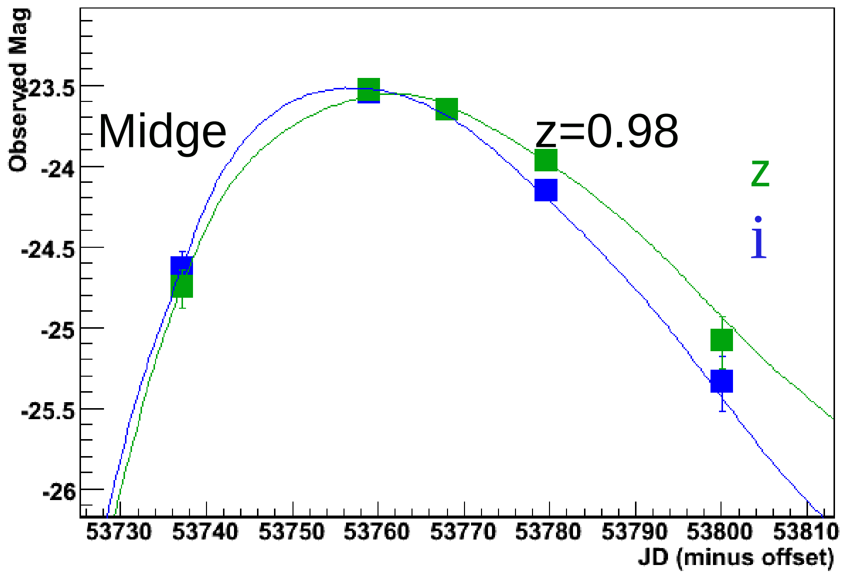
Successfully 10 SNe found on ellipticals

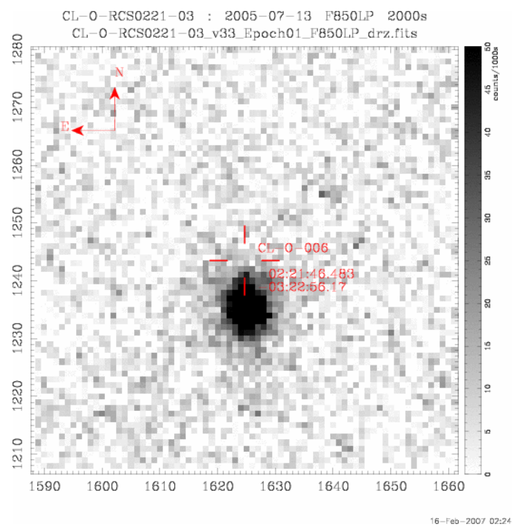
SCP

SN Lightcurves

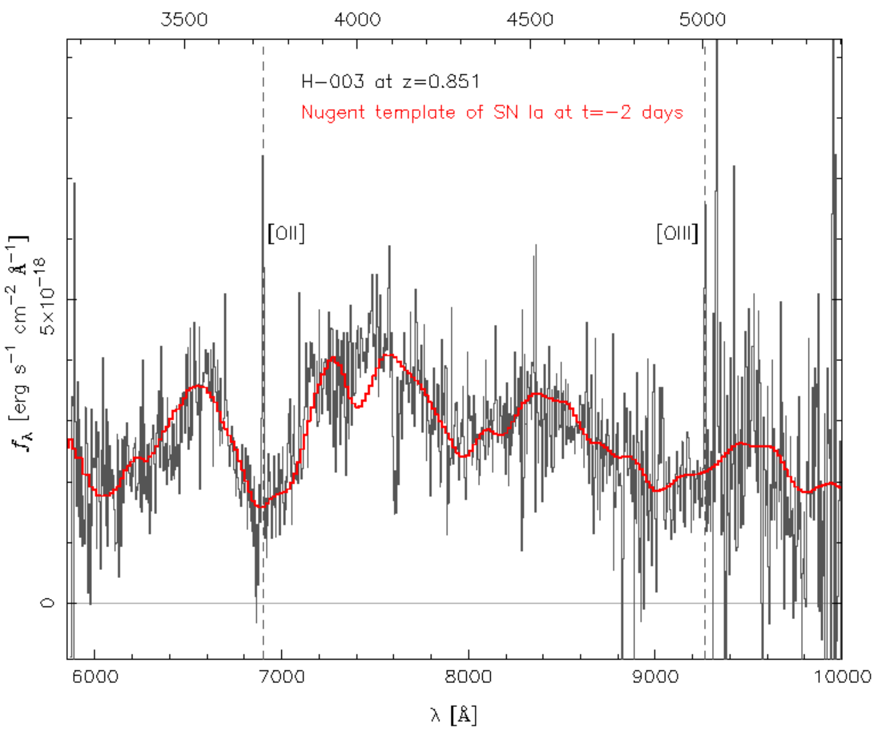




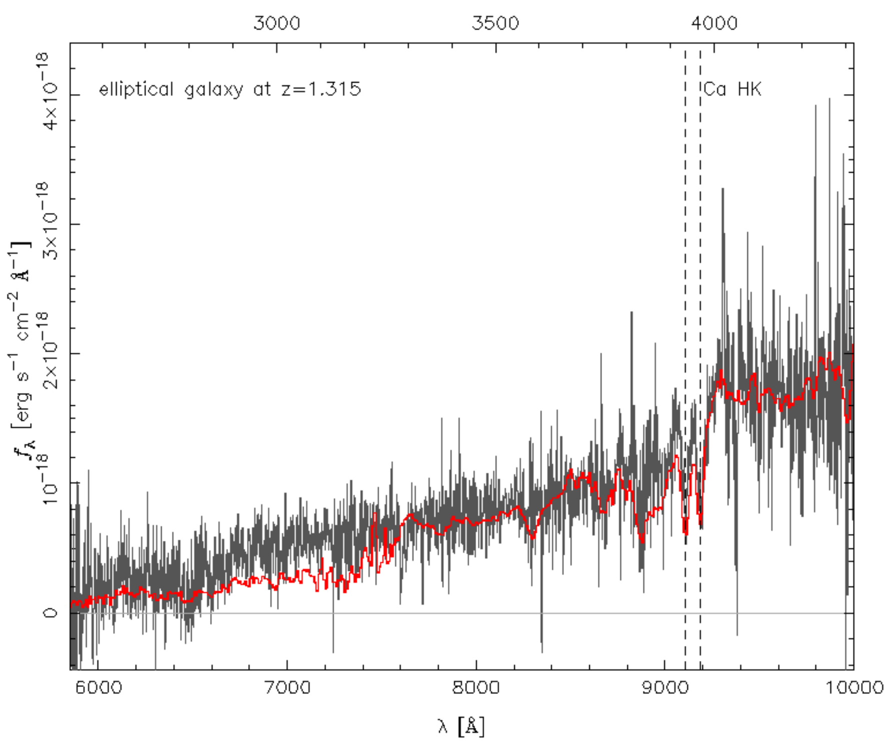




Example spectra with FOCAS



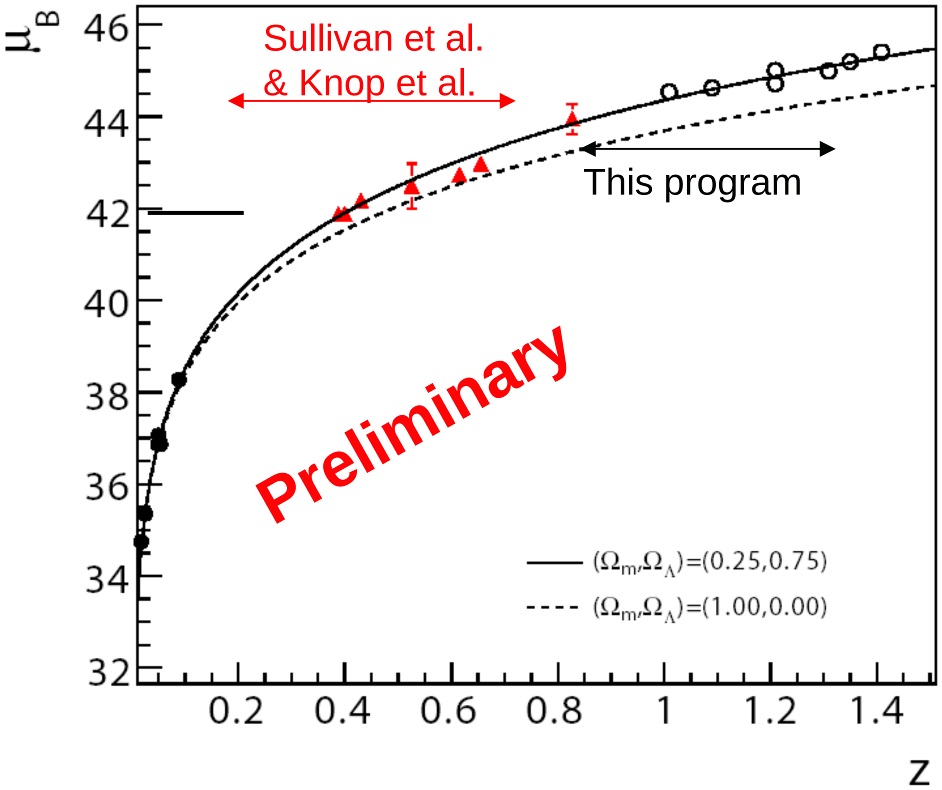
z=0.851



z=1.3

The Elliptical host Hubble Diagram

Example of E–only Hubble Diagram



7 SNe Ia from this program.

Another 13 SNe Ia at lower z from published works.

No extinction correction

Surprisingly small scatter

Blind analysis (we will not know the answer until we remove the blind).

Unfortunately HST/ACS is broken!

SCP

summary

HyperSuprime

can easily make a large(>1000) SN sample

using just a few 10 nights ←SuprimeCam

○Follow-up spectroscopy

WFMOS, FMOS etc. for brighter SNe

LGAO for fainter SNe

○Photometric Studies → SN rate

→ SNIa cosmology at z>~1

well selected/controlled sample

(e.g. E host only)

◎Dust Extinction ⇔intrinsic scatter of SNIa color

a key to improve accuracy