Distant Supernova Surveys for cosmological expansion measurements using Subaru

Jul.6, 2006
at Indian Institute of Astrophysics

Mamoru Doi

Institute of Astronomy

School of Science

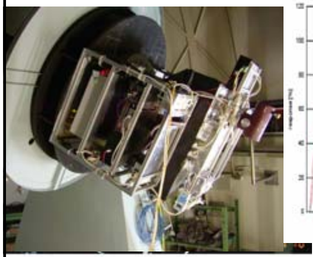
Univ. of Tokyo

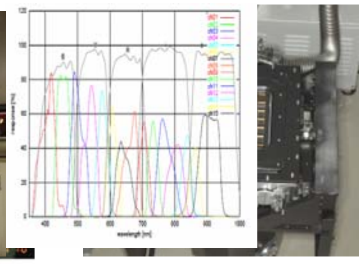
Kisshoten (a national treasure)

Lakshmi

→

Dichroic Mirror Camera (15 band imager)



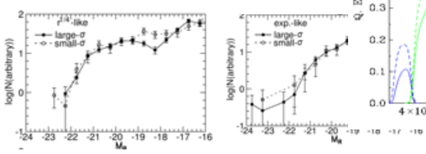


1991 1kx1k CCDx16
1.05m Kiso Schmidt

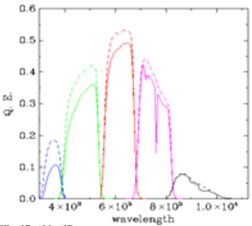
1994 1kx1k CCDx40
Las Campanas 1m
WHT 4.2m

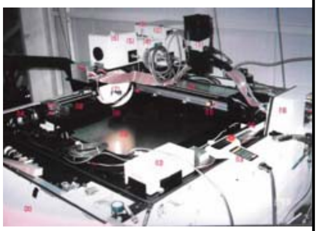
2000 4kx2k CCDx10
8.2m Subaru

Japanese Wide Field Cameras
(PI Prof. Sadanori Okamura



Luminosity function of galaxies





1999 2kx2k CCD x30
2.5m Sloan Digital Sky Survey

Contents

I. Measuring Expansion of the Universe with SNIa

Basic methods
GOODS(Higher z) searches etc. (-2004)

II. New SN surveys

SNFactory, SNLS, ..

SDSS, Suprime-Cam, HST, etc.

III. Future Prospects

I Measuring Expansion of the Universe with SNIa

Einstein eq.

General Relativity

→ Homogeneous, isotropic

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2} + \Lambda/3$$

a: scale factor ρ : density k: curvature ±1 or 0

H: (scale expansion rate)／(scale) ⇔ Hubble's law

$\Lambda (\neq 0)$: Einstein's cosmological constant

Dark Energy

Expressions in "look back" formula, using Ω

normalization: $\rho_c = 3H_0^2/8\pi G$ (critical density)

$$H^2 = H_0^2\{\Omega_M(1+z)^3 + \Omega_R(1+z)^4 + \Omega_\Lambda - \kappa_0(1+z)^2\}$$

where $1+z = a_0/a$ (z: redshift)

$\kappa_0 = kc^2/a(t_0)^2H_0^2$

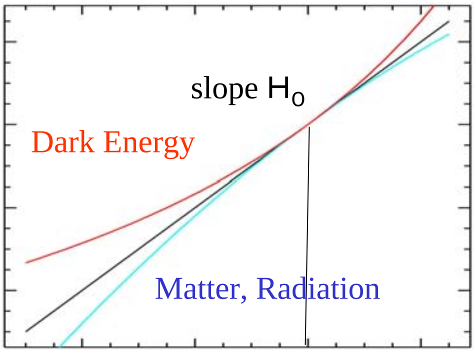
Ω_M : matter (density)∝(volume)$^{-1}$

Ω_R :radiation (density)∝(volume)$^{-4/3}$

Ω_Λ :dark energy (density)∝(volume)^0

Acceleration/Deceleration

$a \propto (1+z)^{-1}$



time present

Deceleration parameter

$$q_0 \equiv -\ddot{a}(t_0)a(t_0)/\dot{a}^2(t_0)$$

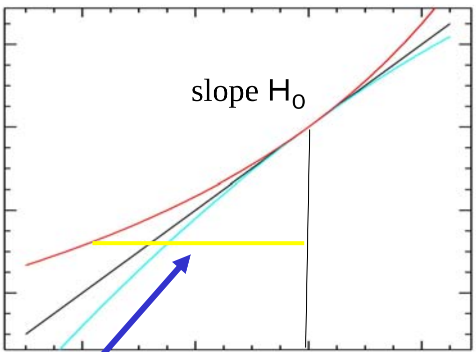
$$= ½(\Omega_M - 2\Omega_\Lambda + 2\Omega_R)$$

Redshift and Distance

to measure expansion of the universe

$a \propto (1+z)^{-1}$

spectroscopy

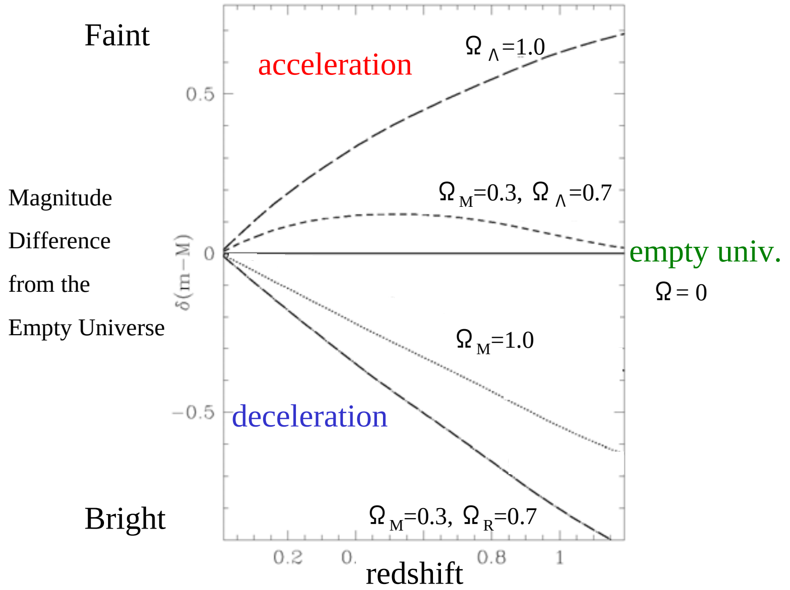


time present

(time) = (distance)/c → Flux

photometry

Ω, z dependence of apparent magnitude of a standard candle



Type Ia Supernova

- Standard Candle (Luminosity~constant)
  →WD (@binary system) exceeds
  Chandrasekar mass (1.4solar mass)
  ⇔ Core collapse SNe Type II, Ib, Ic
- Large Luminosity (~whole galaxy)
  → measurable at cosmological distance

Luminotity of SNIa:

not exactly constant

brighter SNIa

→ larger time scale

in light curve

Correction based on light curve is possible.

intrinsic scatter ~ 15%

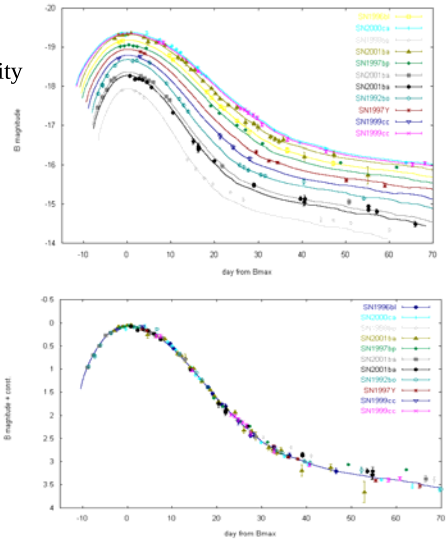
e.g. Phillips et al. 1993
Perlmutter et al. 1997
Hamuy et al. 1999

B-band Light curve of nearby SNIa

by Takanashi

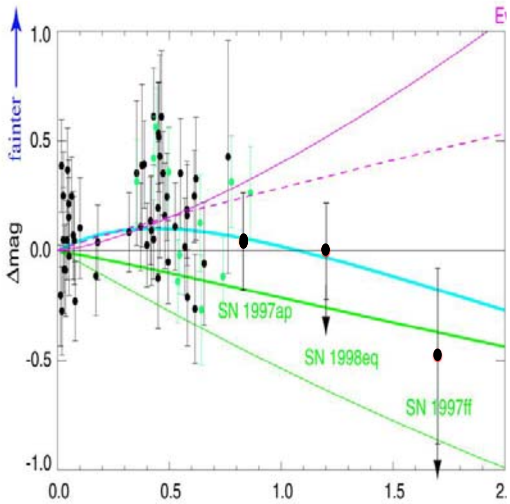
absolute

luminosity



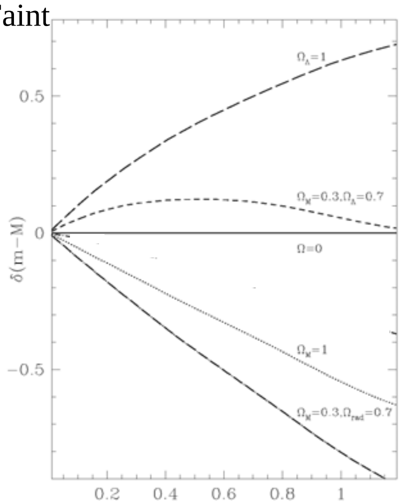
Universe is accelerating! Perlmutter et al.1999

Riess et al. 1998, Schmidt et al. 1998



redshift

Faint



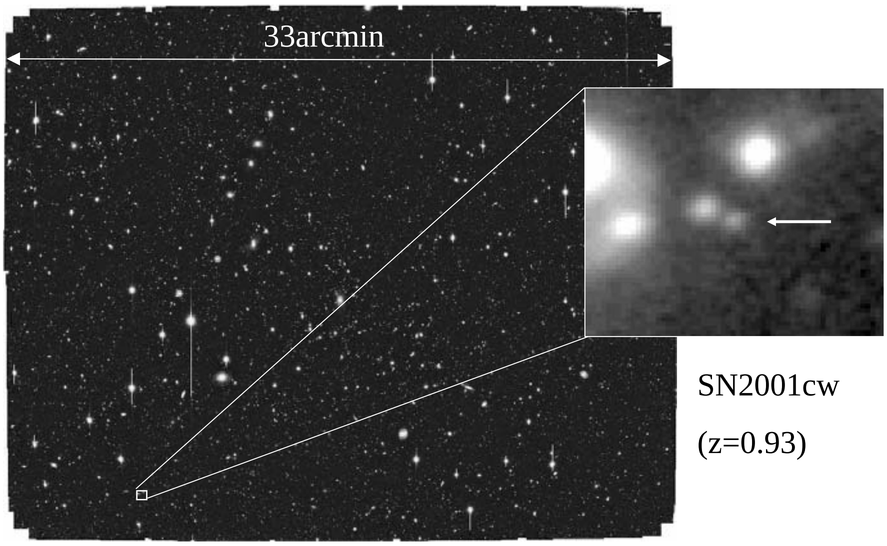
Bright

redshift

Standard Observing Method

- Wide-Field imaging
  imaging with ~1months interval
  → find candidates (significant increase in luminosity)
- Spectroscopy
  confirmation of SN spectrum（⇔AGN, variable stars）
  SN type and redshift determination
- follow-up photometry
  optical: light curve → luminosity
  K correction
  evaluation of dust extinction $R_\lambda \equiv A_\lambda / E(B-V)$

Wide-Field Imaging



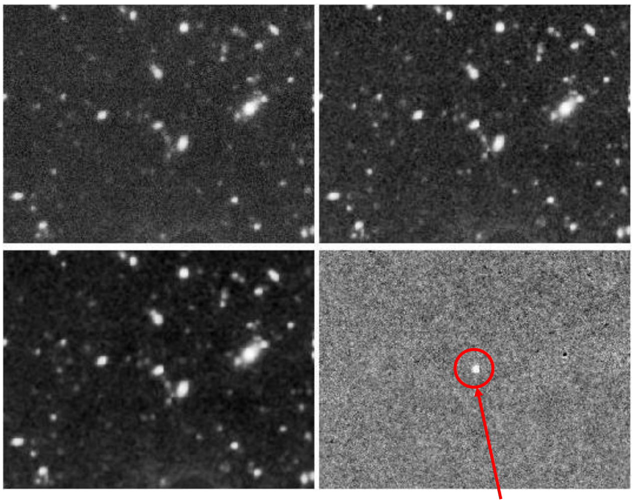
SN2001cw

(z=0.93)

Image Analysis

April

May

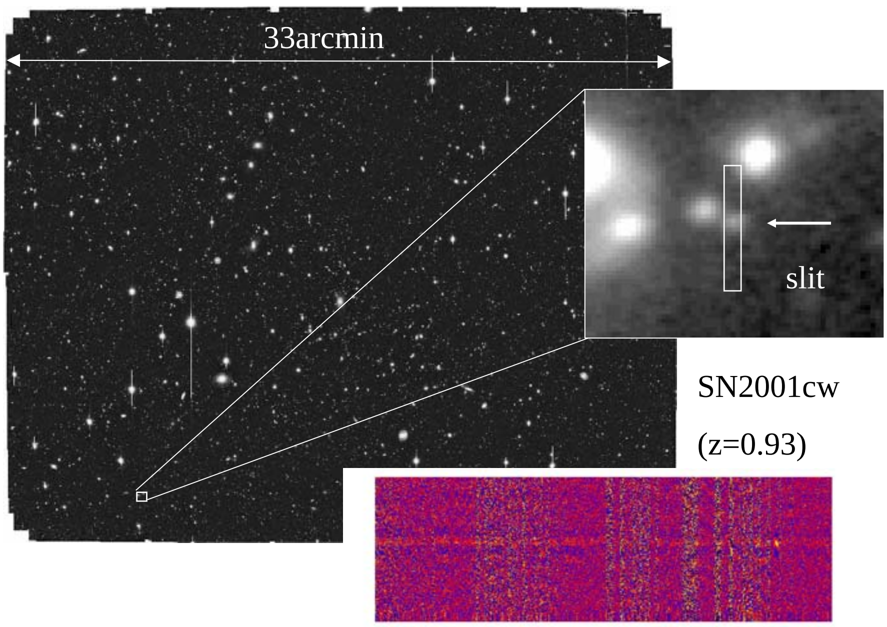


May images
PSF matched
with April
images

May - April

(Ref.Alard, C. and Lupton, R. H. 1998)

SN2001cv (z=1.039)



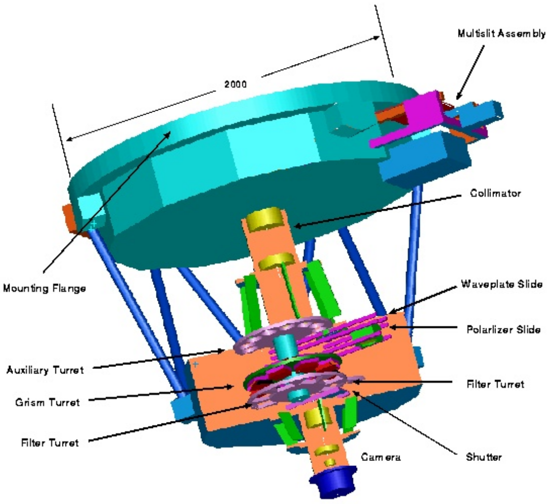
SN2001cw

(z=0.93)

FOCAS: (Faint Object Camera And Spectrograph)

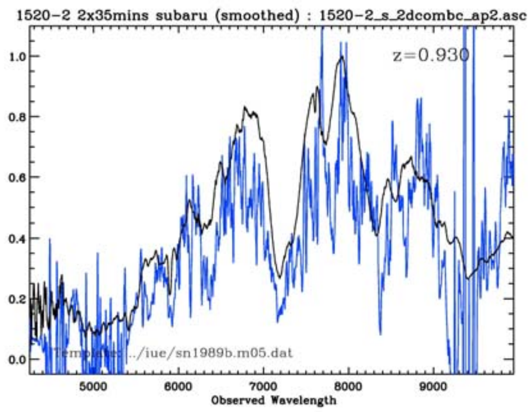
low resolution optical spectrograph

at Cas. Focus of Subaru



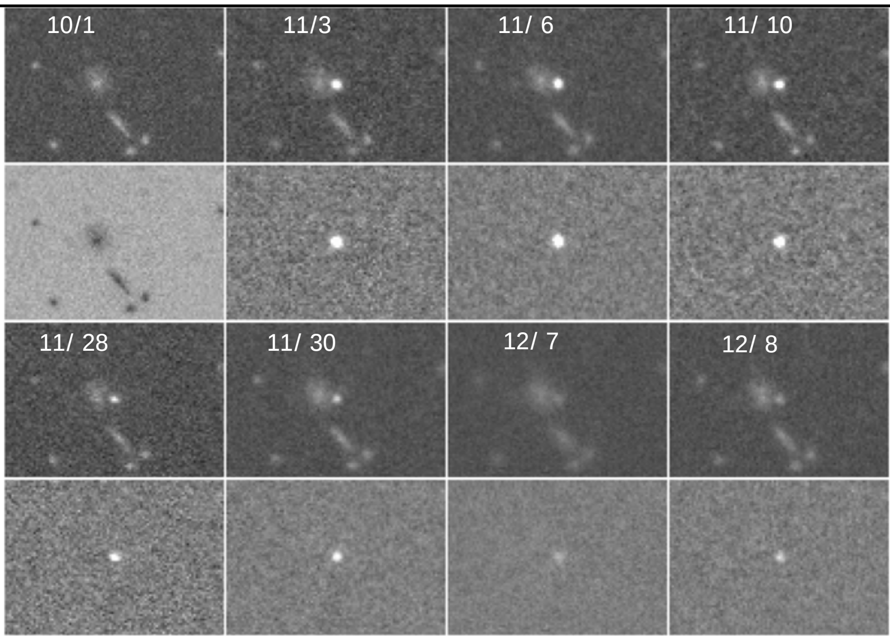
Spectroscopy

SN Type and redshift



SN2001cw(z=0.93) taken with FOCAS/Subaru

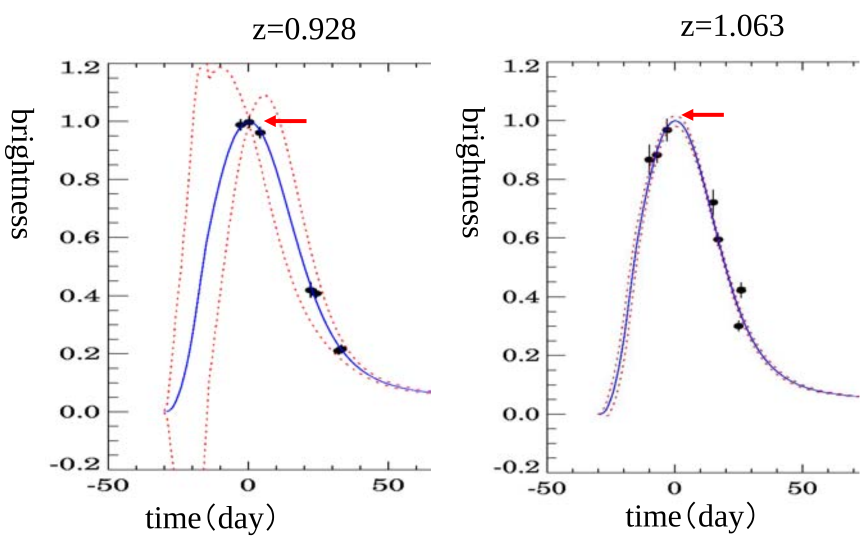
superposed on SN1989b (nearby)



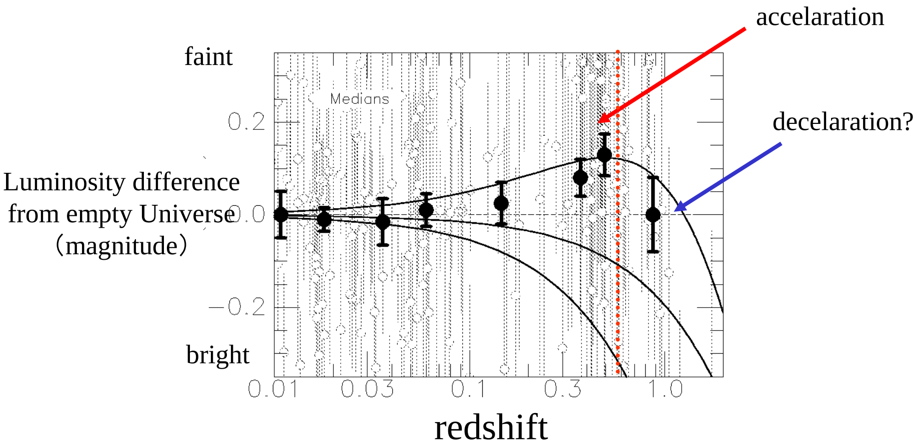
SN2002kp (z=0.928) Suprime-Cam, i' band

upper panels : original images   lower panels : image of Oct.1 subtracted

Light curves (example)

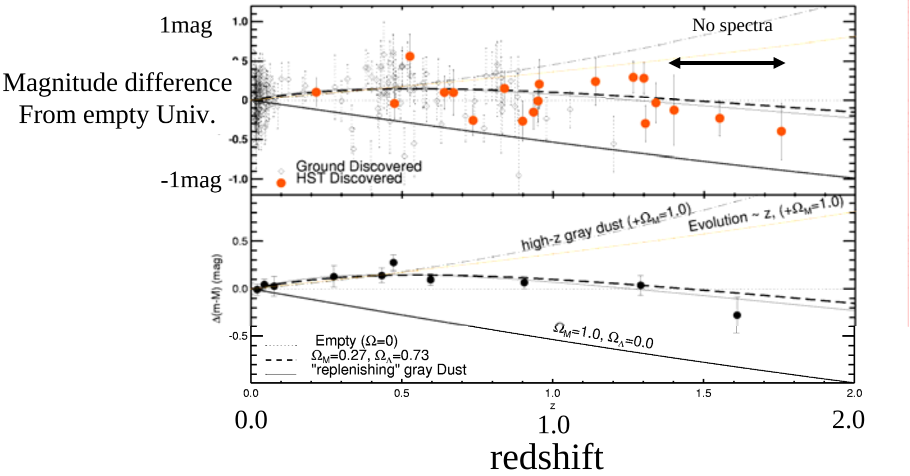


Suprime-Cam i' band



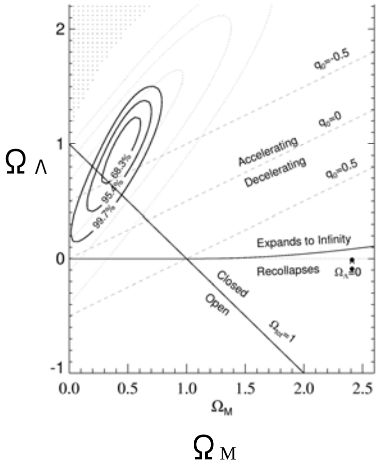
Tonry et al. 2003

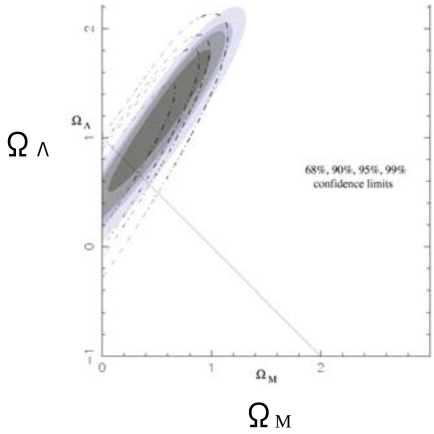
HST measurements (Riess et al. 2004)



Measurements of Ωs with SNe only
(Riess et al. 2004)

(Knop et al. 2003)

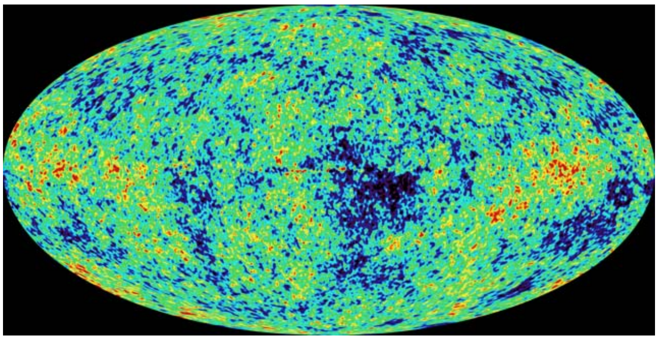


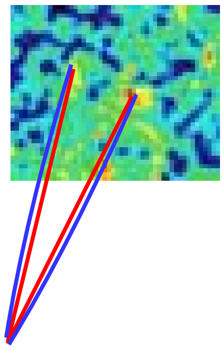


Not inconsistent with “Flat Universe”

Analysis of CMB fluctuation shows

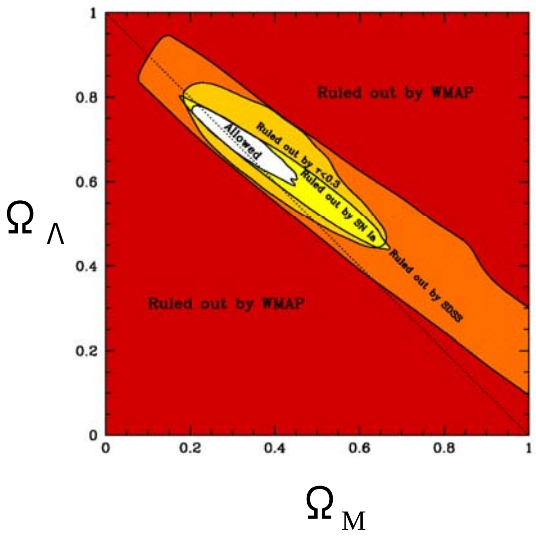
→ “Flat Universe”





Spergel et al. 2003

WMAP+SDSS+SN Tegmark et al. 2003



Ω_Λ 70%
Ω_M 30%
(dark matter 25%)

Age of the Univ. 14.1 by

II New SN Surveys

Ω_Λ : Cosmological Constant

Energy Density constant ⇔ expansion of Univ.

Is it constant? → dark energy

time variation?

density $\rho \propto a^{-3(1+w)}$

w = -1 : constant （$w=p/\rho=-1$）

On going Large surveys

redshift	Projects
z~0-0.3 (imaging)	Supernova Factory
~1-2.5m	SDSS
z~0.3-0.8	SN Legacy
~4m	Essence
z~0.5-1.5	SCP (HST/GOODS)
~8m, HST	Higher-z

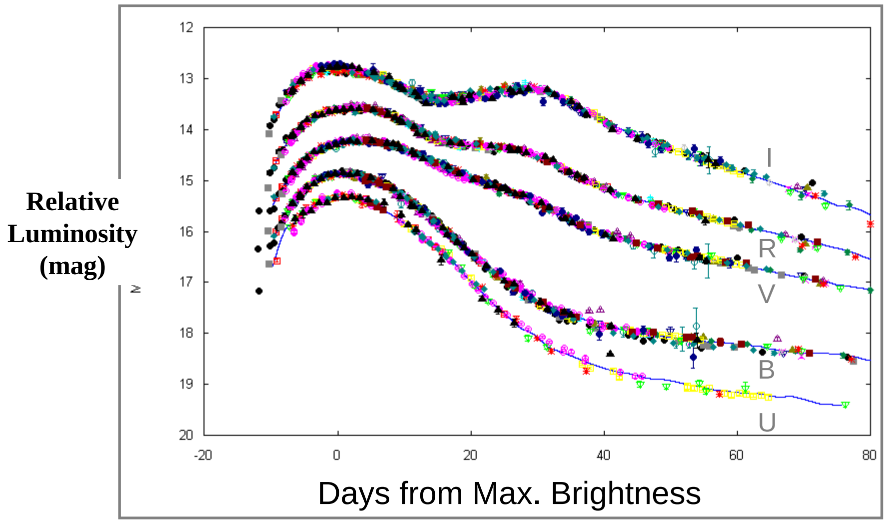
accurate measurements of SNIa at various epochs

cosmological constant more effective

look back time larger

Averaged light curves of nearby SNIa

Using published ~100 SN light curves

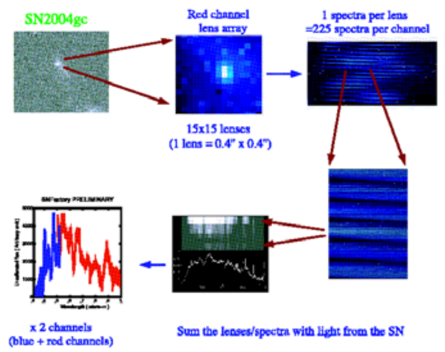


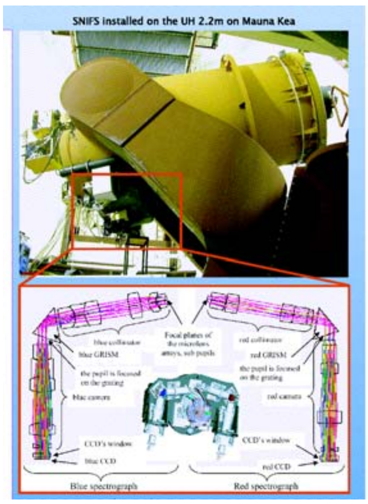
Takanashi,N., 2005, M.thesis, Univ.of Tokyo

NearbySNFactory

goal:300SNe @z=0.03-0.08

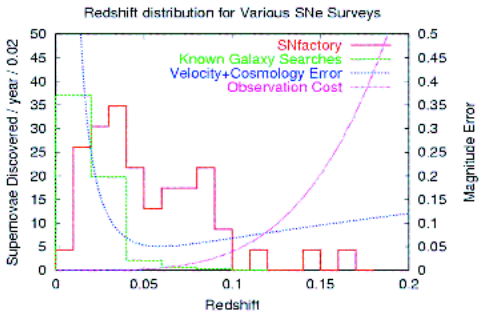
Finding SNe with 1m class telescopes
NEAT(NEAR-EARTH ASTEROID TRACKING)
QUEST(Palomar Schmidt)

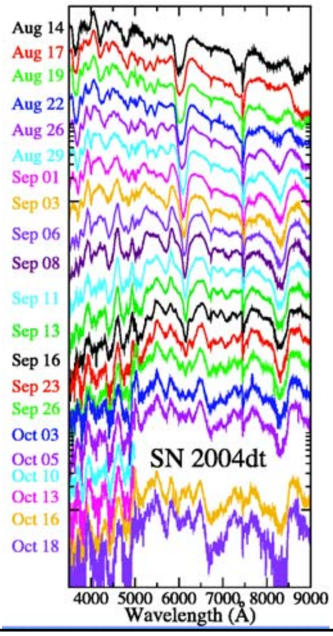




Spectroscopy with
SNIFS
At UH88 telescope

Preliminary Results from Nearby SNFactory
(AAS poster, 2005)





Results of SNLS 1st year
(goal: 700SNe? in 5 years)

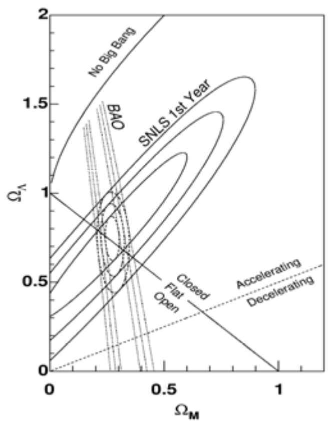


Fig. 5 Contours at 68.3%, 95.5% and 99.7% confidence levels for the fit to an (Ω_M, Ω_Λ) cosmology from the SNLS Hubble diagram (solid contours), the SDSS baryon acoustic oscillations (Eisenstein et al. 2005, dotted lines), and the joint confidence contours (dashed lines).

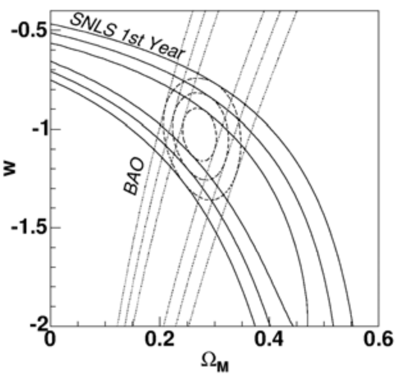
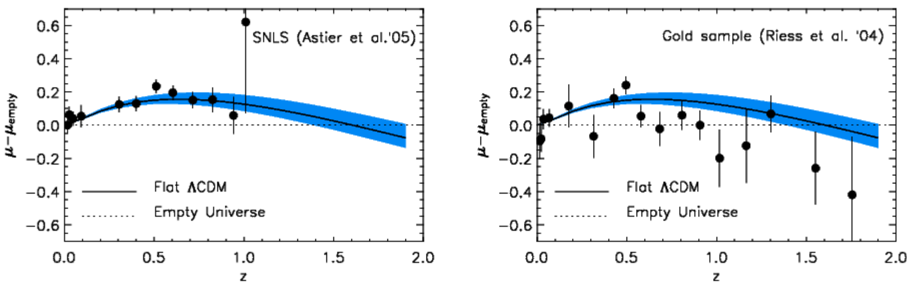


Fig. 6 Contours at 68.3%, 95.5% and 99.7% confidence levels for the fit to a flat (Ω_M, w) cosmology, from the SNLS Hubble diagram alone, from the SDSS baryon acoustic oscillations alone (Eisenstein et al. 2005), and the joint confidence contours.

Astier et al. 2005 astro-ph/0510447

WMAP 3years results
(Spergel et al. 2006, …)



On going Large surveys

redshift	Projects
z~0-0.4 (imaging)	Supernova Factory
~1-2.5m	SDSS
z~0.3-0.8	SN Legacy
~4m	Essence
z~0.5-1.5	SCP (HST/GOODS)
~8m, HST	Higher-z

accurate measurements
of SNIa at various epochs

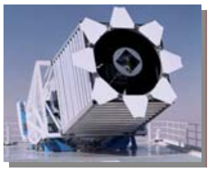
cosmological
constant
more effective

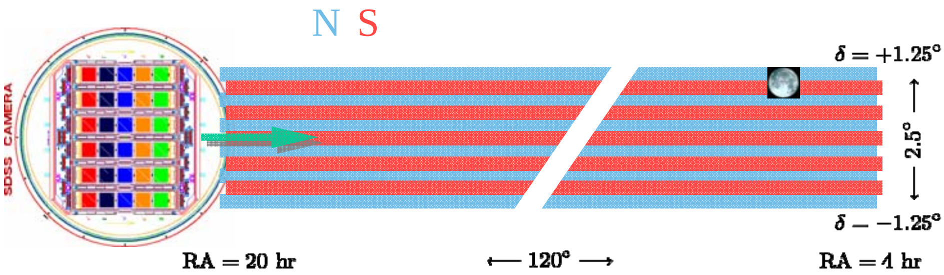
look back
time
larger

Survey area = “stripe 82”

(southern equatorial stripe)

(Sako et al. 2006, AAS)





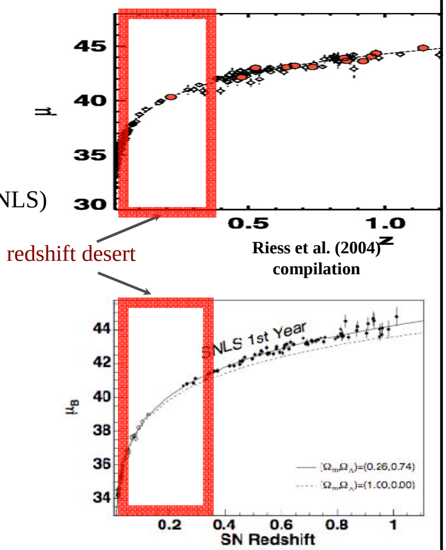
- Use the SDSS 2.5m telescope
  - during September 1 - November 30 of 2005-2007
  - to scan 300 square degrees of the sky every 2 days
  - discover supernovae and obtain multi-color light curves

Follow-up

ARC, UH88, Subaru, NMSU, HET, VATT, MDM, (CSP), WHT, (Keck)

Science goals

- Type Ia supernovae (SNe)
  - “well-measured” light curves of ~200 SN Ia from z = 0.05 ~ 0.4
  - bridge low-z (z<0.05; LOSS, SNF) and high-z (0.3<z<1.0; ESSENCE, SNLS)
  - understand and minimize systematics of SN Ia as distance indicators
- SN Ib/c, II, rare types
- Other transients

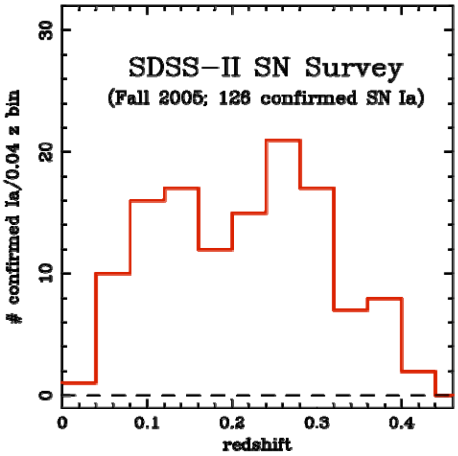


Riess et al. (2004) compilation

Astier et al. (2005)

Results from Fall 2005

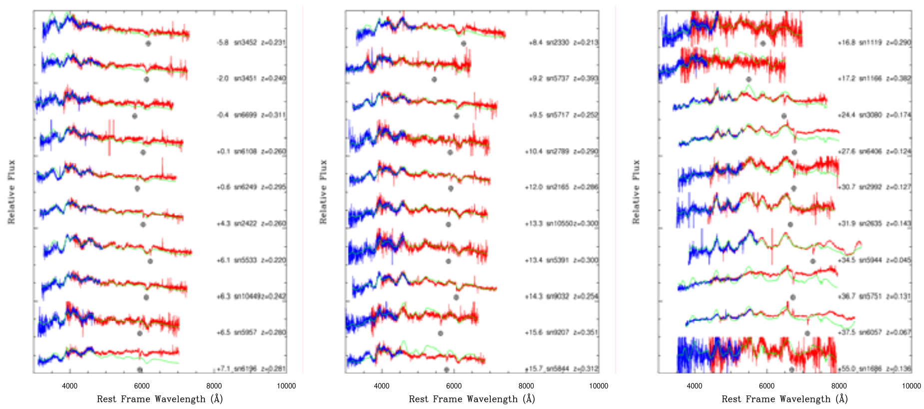
- 126 spectroscopically confirmed SN Ia
- 13 spectroscopically probable SN Ia
- 6 SN Ib/c (3 hypernovae)
- 10 SN II (4 type IIn)
- 5 AGN
- ~hundreds of other unconfirmed SNe with good light



SDSS SN spectra with Subaru

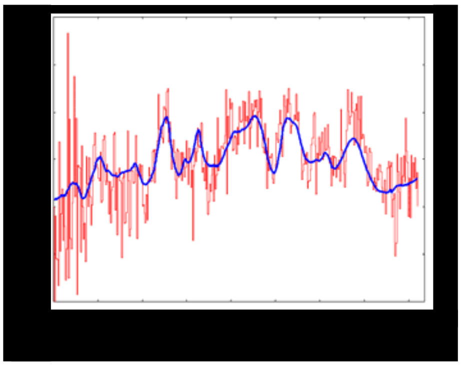
(preliminary, Yasuda et al.)

2005: 23 new confirmed SNIa



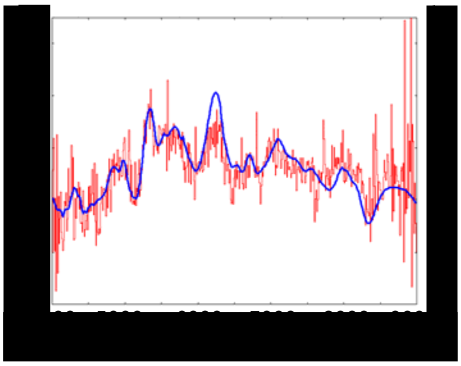
χ 2 fitting of a SN (+ galaxy) template （Tokita et al. 2006）

SN1686



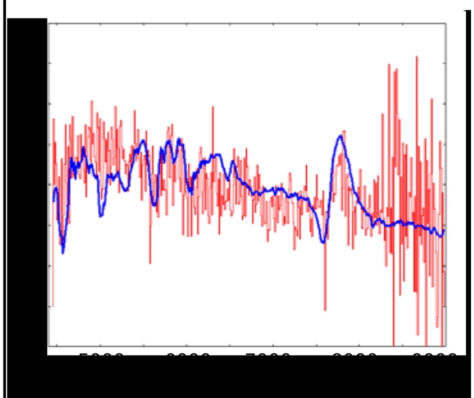
Best Fit : SN1994D (Ia)
z~0.14
t=54 day

SN1688



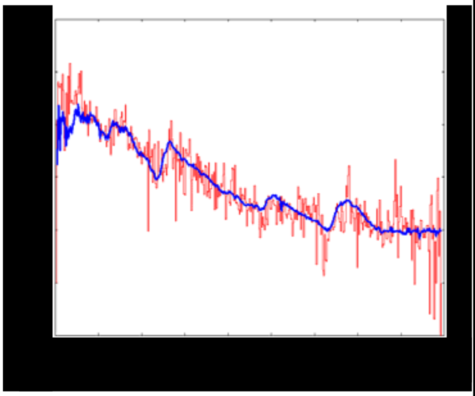
Best Fit : Nugent model (Ia)
z~0.36
t=11 day

SN2661



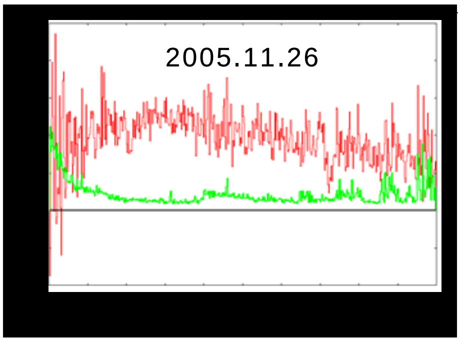
Best Fit : SN1992H(II)
z~0.19
τ =30 day

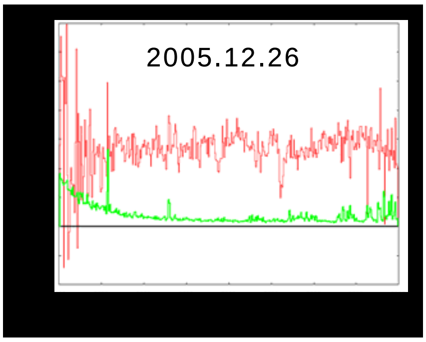
SN6471



Best Fit : SN1999em(II)
z~0.20
t=1day

SN10450

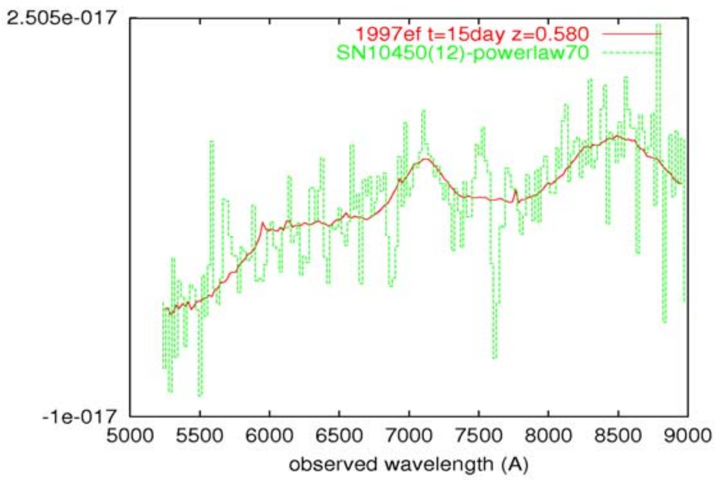




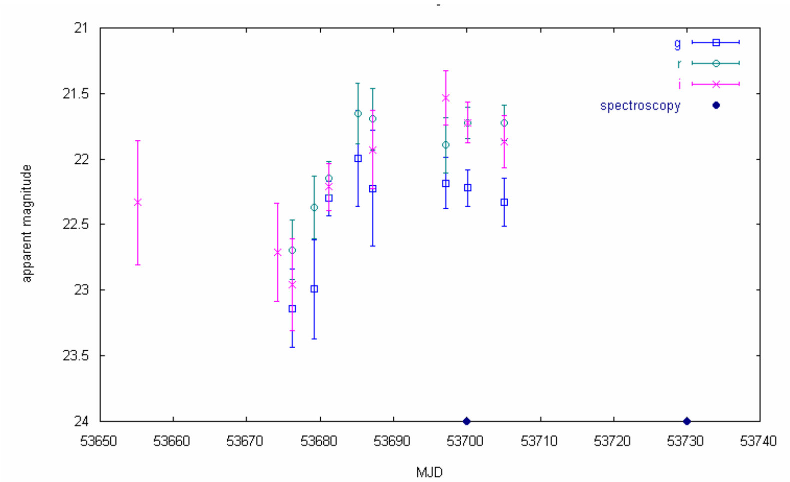
- spectra are featureless (even 2weeks past maximum)
- ~ 1mag brighter than typical SNIa (if z=0.54 by galaxy)

→ hypernova ?、 GRB？

an example spectrum of power-low subtracted



Follow-up photometry was not enough!



SDSS 2005 imaging ended

On going Large surveys

redshift imaging	Projects
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~1-2.5m	SDSS
z~0.3-0.8	SN Legacy
~4m	Essence
z~0.5-1.5	SCP (HST/GOODS)
~8m, HST	Higher-z

accurate measurements of SNIa at various epochs

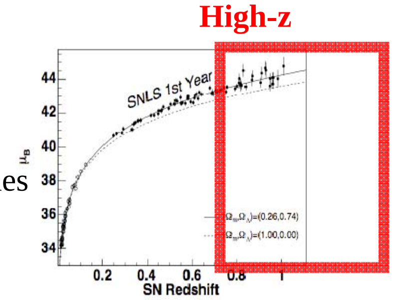
cosmological constant more effective

look back time larger

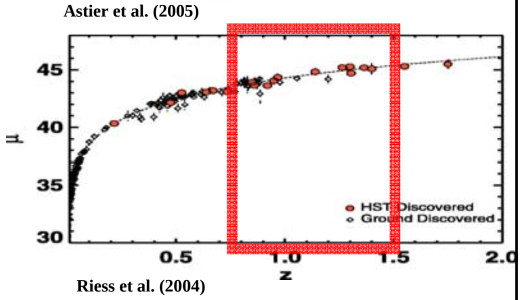
High–z SNe by Supernova Cosmology Project

1. Suprime-Cam Searches
   2001-2002

2. HST/ACS cluster Searches
   2005-2006



Astier et al. (2005)



Riess et al. (2004) compilation

Suprime-Cam SN Searches

2001 April,May 3 SupC FoV
Suprime-Cam 8hours (GTO)
FOCAS 2 nights
HST ~5 orbits

2002 March,April-May 7 SupC FoV
Suprime-Cam 4.5 nights
FOCAS 1 night, KECK/ESI 6nights , GEMINI(N)/GMOS~2nights, VLT/FORS2 ~3nights,
HST ~30? orbits, VLT/ISAAC ~2 nights

2002 Oct., Nov., Dec. 5 SupC FoV
Suprime-Cam 9 nights
FOCAS 1night , KECK/ESI 4nights , GEMINI(N)/GMOS~2nights, VLT/FORS2 ~3nights
HST ~100 orbits, Subaru/CISCO ~2 nights, VLT/ISAAC ~2 nights

green: telescope time from Supernova Cosmology Project

Collaborators for Supernova Observations with Suprime-Cam 2001-2002

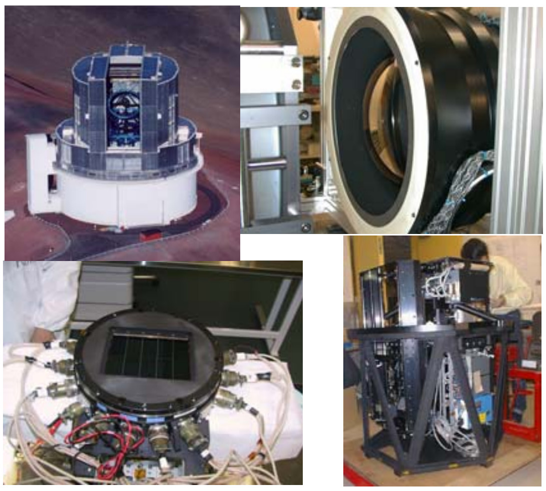
Mamoru Doi[1], Naoki Yasuda[2], Nobunari Kashikawa[2],
Kentaro Motohara[1], Tomoki Morokuma[1],
H.Furusawa[2], K.Aoki[2], Y.Ohyama[2], K.Nomoto[1],
Saul Perlmutter[3], Greg Aldering[3], Isobel Hook[4],
Christpher Lidman[6] , ……

Supernova Cosmology Project
Subaru Big Project Team
(Subaru Deep Field, Subaru XXM/Newton Deep Survey)
Suprime-Cam Instrument Group
Satoshi Miyazaki[2], Yutaka Komiyama[2], Sadanori Okamura[1]

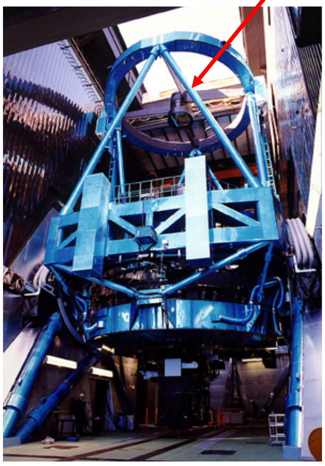
[1]Univ. of Tokyo, [2]NAOJ, [3]LBNL,
[4]Univ. of Oxford, [5]ESO,

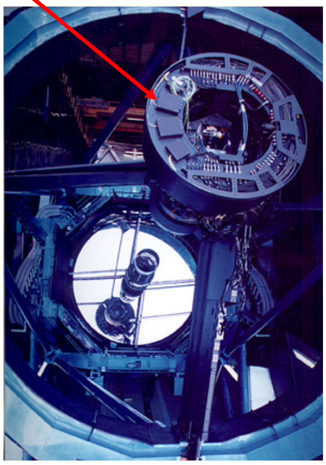
Suprime-Cam

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



Prime Focus





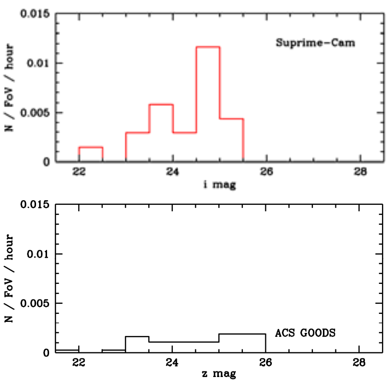
・easy to have wide field of view (short focal length)

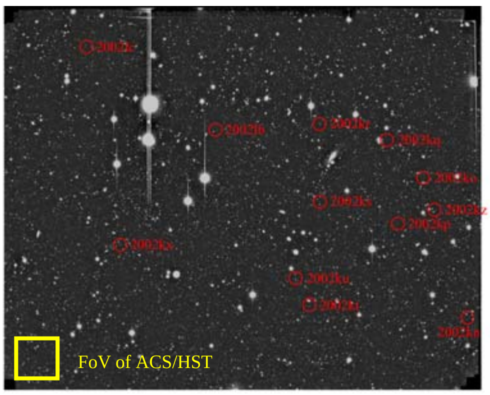
・only Subaru has Prime Focus among 8-10m class telescopes

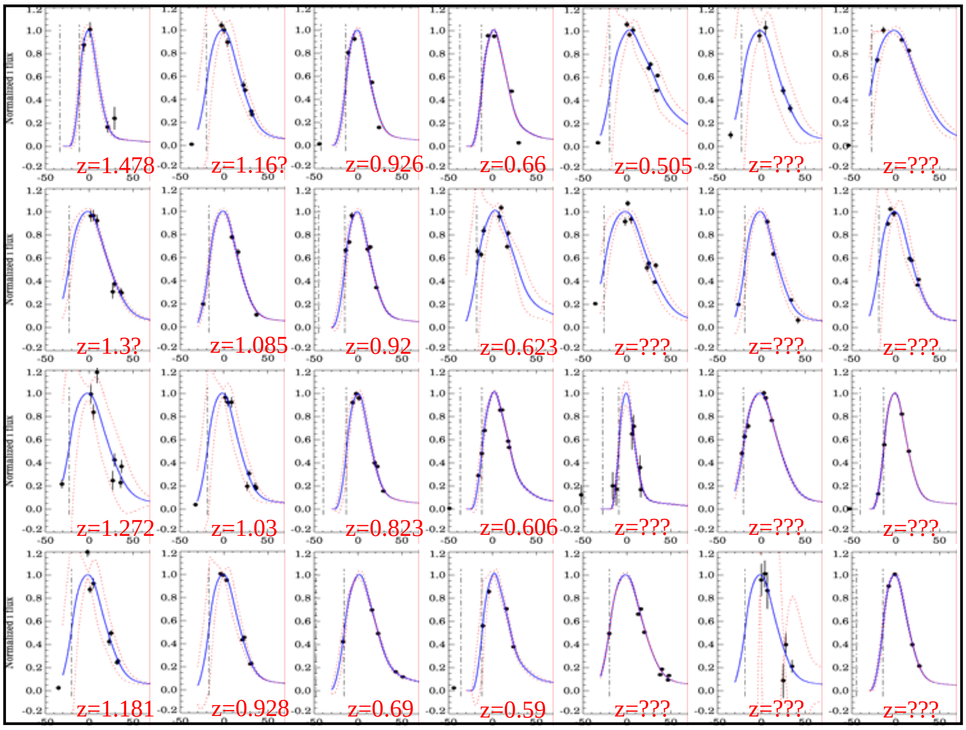
Suprime-Cam@Subaru :

~20 times more effective than ACS@HST

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

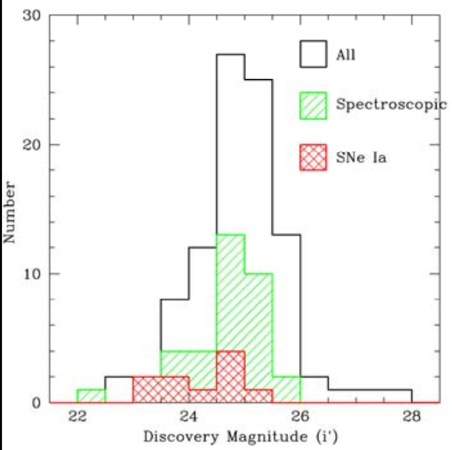


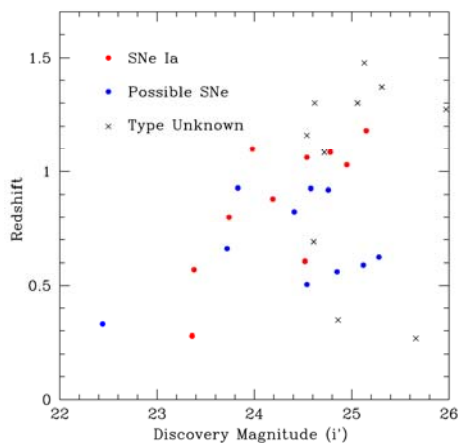


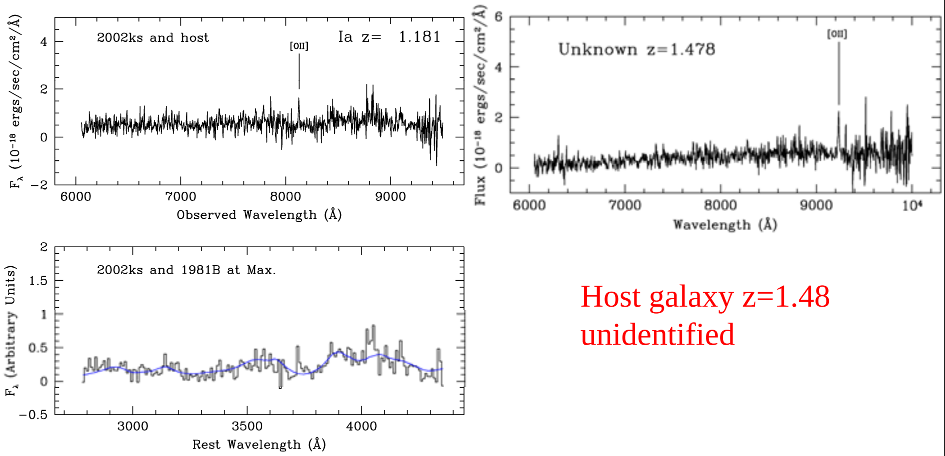


Suprime-Cam searches 2002

Yasuda et al. 2004







Host galaxy z=1.48
unidentified

Ia at z=1.18

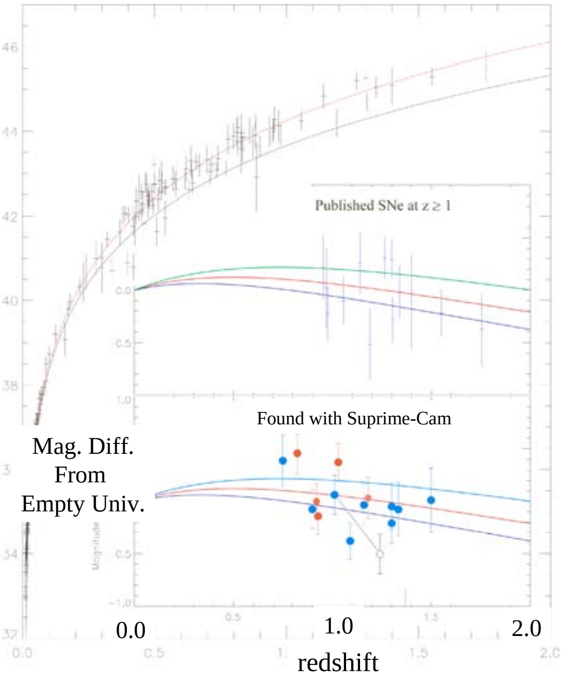
(with VLT, Lidman et al. 2004)

SNe found with Suprime-Cam

	Candidates	Spectr.	Confirmed SN Ia	HST followup
2001 Spring	22	8	3	1
2002 Spring	55	13	5	4
2002 Fall	44	27	5	3
Total	121	48	13	8

↓ Final analysis On going

Supernova Cosmology Project
follow-up observations with Keck, VLT, Gemini, HST



Very preliminary Results
(no HST data)

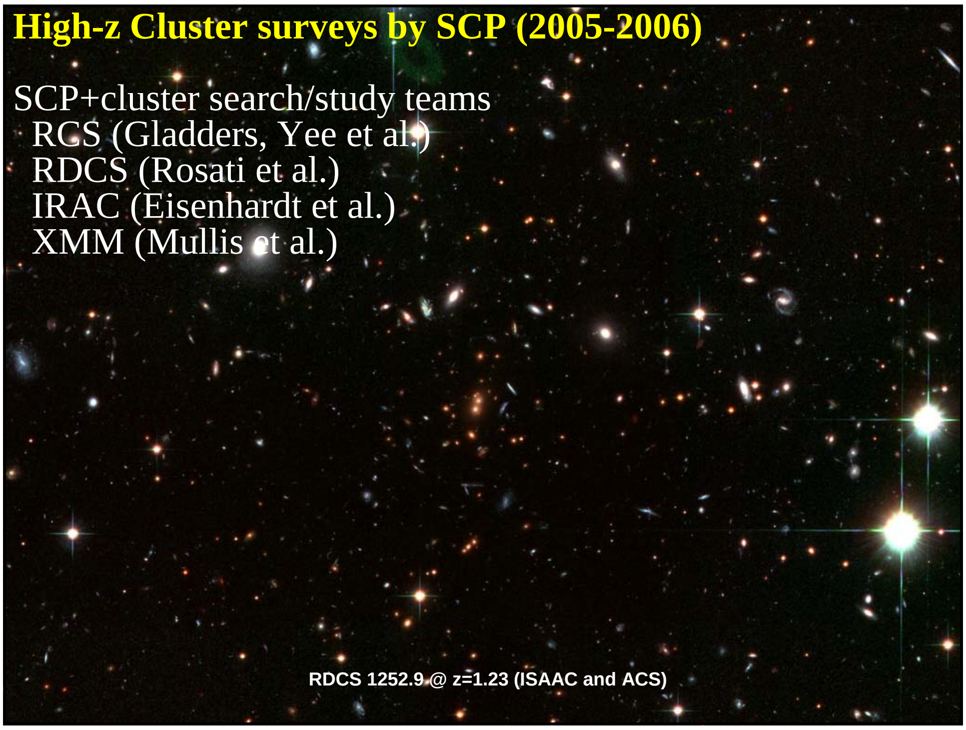
Still need
Accurate photometry
k-corrections
…

- Observations completed
- More observations/analysis necessary

Dark energy 70%
Matter 30%

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

SCP+cluster search/study teams
RCS (Gladders, Yee et al.)
RDCS (Rosati et al.)
IRAC (Eisenhardt et al.)
XMM (Mullis et al.)



Possible Problems

→ systematic errors

・SNIa as a Standard Candle

homogeneity

(host environment, binary evolution)

possible evolution

・K-correction

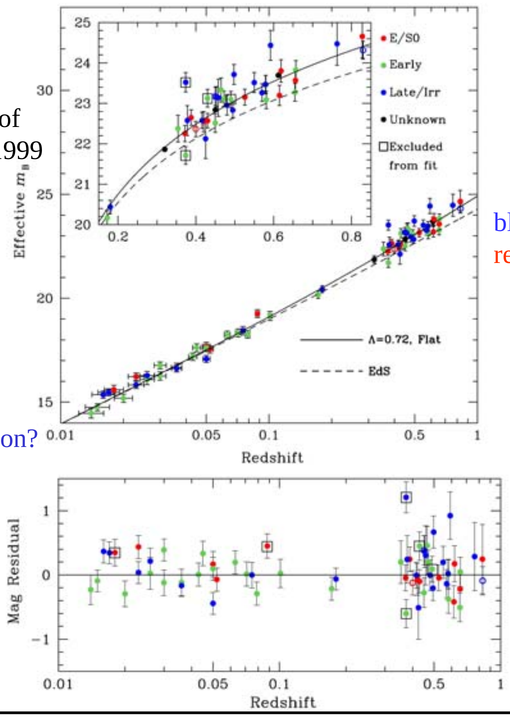
different observed wavelengths → correction

・Dust extinction due to host galaxy

Sullivan et al. 2003

Host galaxy morphology of SNe by Perlmutter et al. 1999 with HST

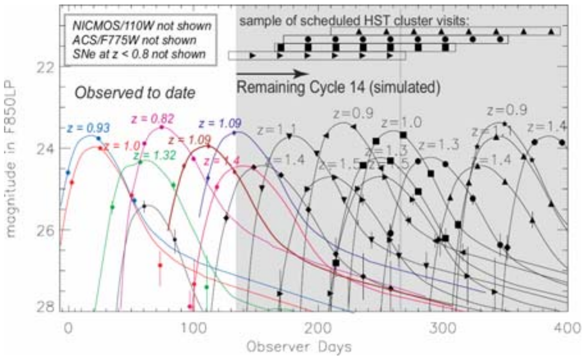
Small offset between
（SNIa fainter for early type host?
Reindl et al. 2005
Mannucci et al 2005
Sullivan et al. 2006）
Prompt & Old Ia population?



blue : late type
red : E/S0

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

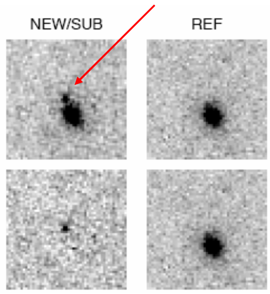
Observing Program: 24 massive galaxy clusters at z ≥ 1
Perlmutter et al. Cycle 14



HST Rolling Search
20 day cadence
ACS z’, i’ bands.
(219 orbits approved!)

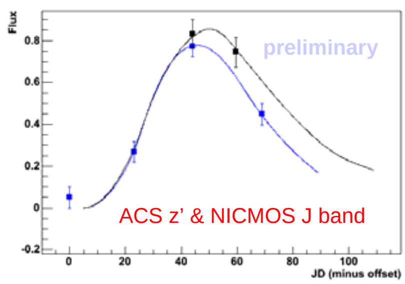
Followup:
NICMOS J-band
Spectroscopy:
Subaru 20 half nights
Keck 4 nights
VLT 16 hours +DDT

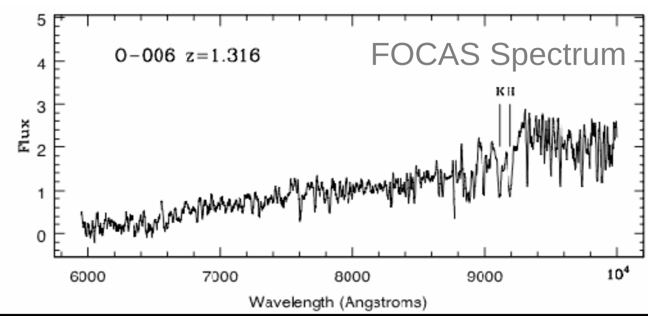
Field SNe discovered in ongoing search



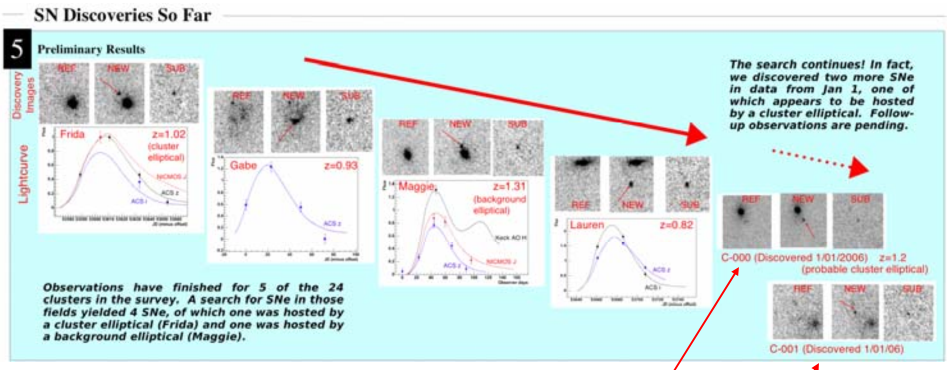
O-006:
z=1.316

Elliptical
field
galaxy





Survey ends this September



C-000, z=1.092, background elliptical

C-001, z=0.98, at the cluster redshift

K-000, z=1.41 (?)

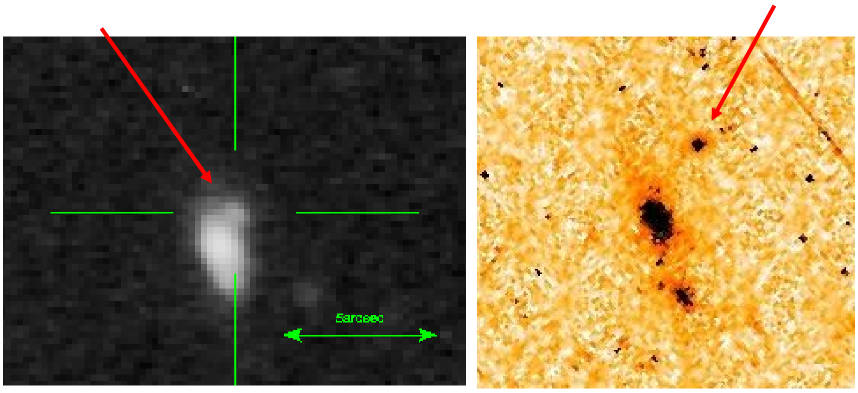
III Future Prospects

From Space : 2-m class telescope (e.g. SNAP)

From Ground

- Wider Imagers
- Multi Fiber Spectrographs & AO

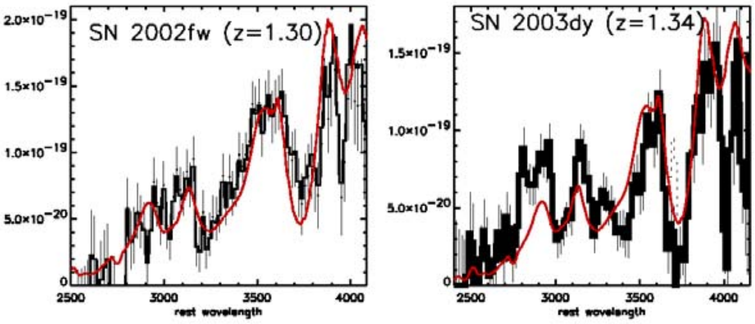
Space is powerful (HST)



~1hour exposure time
Suprime-Cam

~15min exposure time
HST/ACS

Highest-z SN spectra by HST "Higher-Z" team
(Riess et al. 2004 from GOODS)



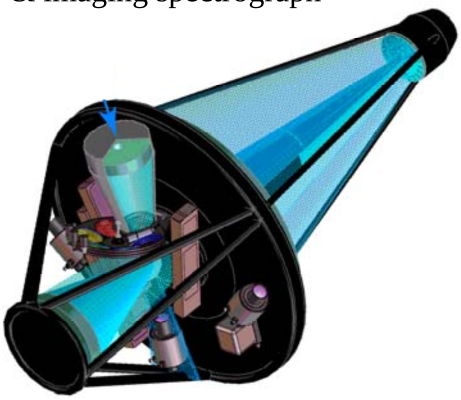
grism spectrum of SNIa at z=1.3
15000 sec

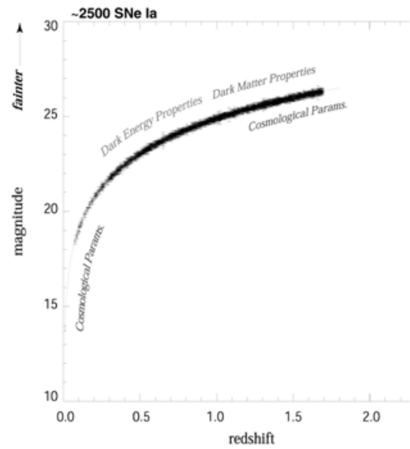
SNAP(SuperNova Acceleration Probe)

- 2m wide-field telescope

~10 years later?

Wide-field camera
& imaging spectrograph





Ground based projects

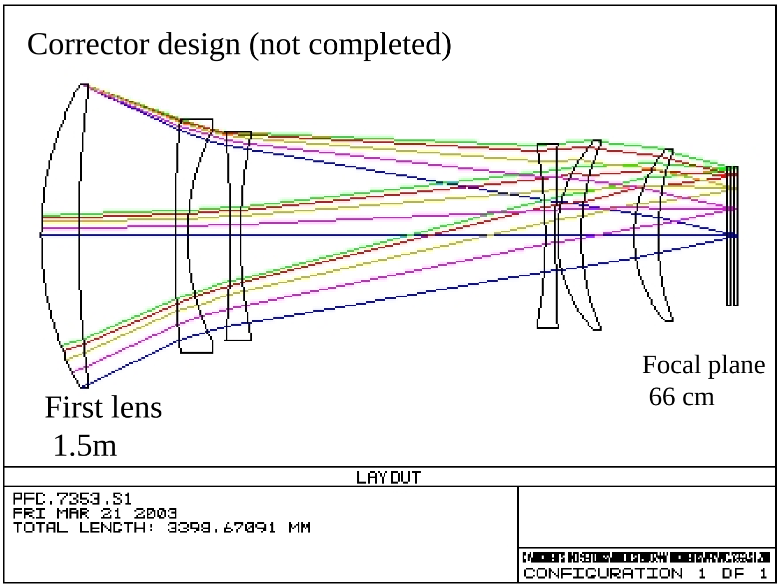
Survey power
(for same image quality)

Camera	Telescope			CCD			FOV		First Light
Name	D [m]	A [m^2]	F	Vendor	Format	N_{CCD}	Ω [deg^2]	$A\Omega$	
WFPC2	2.5	3.46	12.9	Loral	800×800(15)	3	0.0015	0.01	Dec-93
UH8K	3.6	9.59	4.2	Loral	4k2k(15)	8	0.25	2.40	Sep-95
SDSS	2.5	3.83	5	SITe	2k2k(24)	30	6.0	22.99	May-98
NOAO8K	3.8	9.98	2.7	SITe	4k2k(15)	8	0.36	3.59	Jul-98[a]
CFH12K	3.6	9.59	4.2	MIT/LL	4k2k(15)	12	0.375	3.60	Jan-99
Suprime-Cam	8.2	51.65	2.0	MIT/LL	4k2k(15)	10	2.555	13.17	Jul-99
MegaCam	3.6	9.59	4.2	Marconi	4.5k2k(13.5)	40	1	9.59	Jan-03
VISTA Opt.	4.0	11.33	1.0	Marconi	4.5k2k(13.5)	50	2	22.67	2010?
LSST[b]	8.4	46.34	1.25				(7.1)	329	2012?
PanSTARRS	3.6(4)	10		MIT/LL			7	50	2006-09?
DarkEnergyS.	4.0	10		LBNL			3	30	2009?

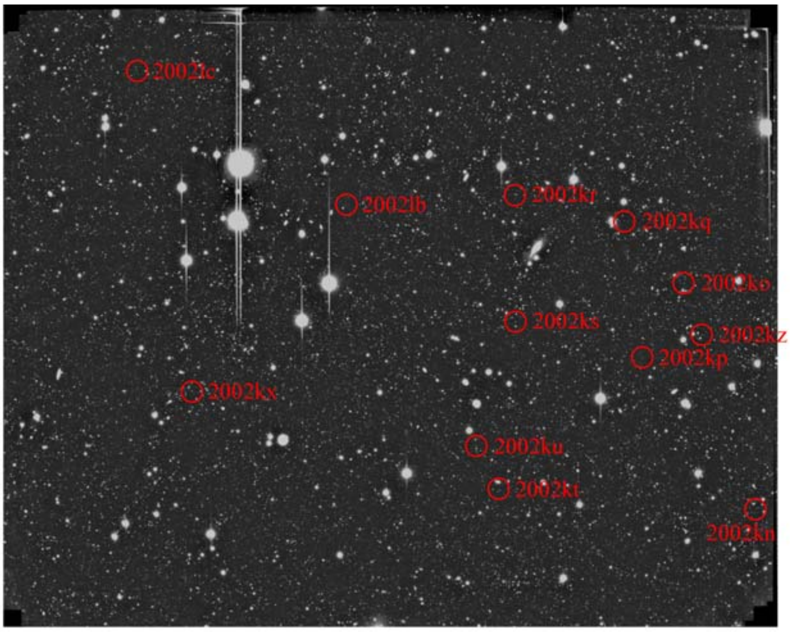
Hyper Suprime: New Wide Field Corrector for Subaru ~1.5° ϕ

AΩ~100 (FoV ×9 of Suprime-Cam)

Preliminary Optical design for 2 deg Φ



By Y.Komiyama and S.Miyazaki



12 SNe reported in 1 Suprime-Cam FoV

Ground-based High-z SNe

HyperSuprime

can find

~500 SNe / night

~5000 SNe/ 10 nights

← ~1 hour exposure / epoch

can follow

~50 SNe / night

~500 SNe / 10 nights

← ~8 hour exposure / epoch

Spectroscopy

multi-fiber spectrograph (mid-z)

with Adaptive Optics (high-z)

→ well controled good candidates (LC, color, host)