Distant SN Observations with Subaru

Messengers of Supernova Explosions @ IPMU
Nov. 18, 2009 Kashiwa campus

Mamoru Doi
Institute of Astronomy
Graduate School of Science
University of Tokyo
(IPMU)
Naoki Yasuda, Kohki Konishi (ICRR, Univ. of Tokyo)
Tomoki Morokuma, Naohiro Takanashi (NAOJ)
Koichi Tokita, Yutaka Ihara (IoA, Univ. of Tokyo)
Tomo Totani (Kyoto Univ.), Chris Lidman (ESO),
Supernova Cosmology Project :Saul Perlmutter(LBNL),,
SDSS-II SN survey: Josh Frieman(FNAL) , ….

Co.Chajnantor

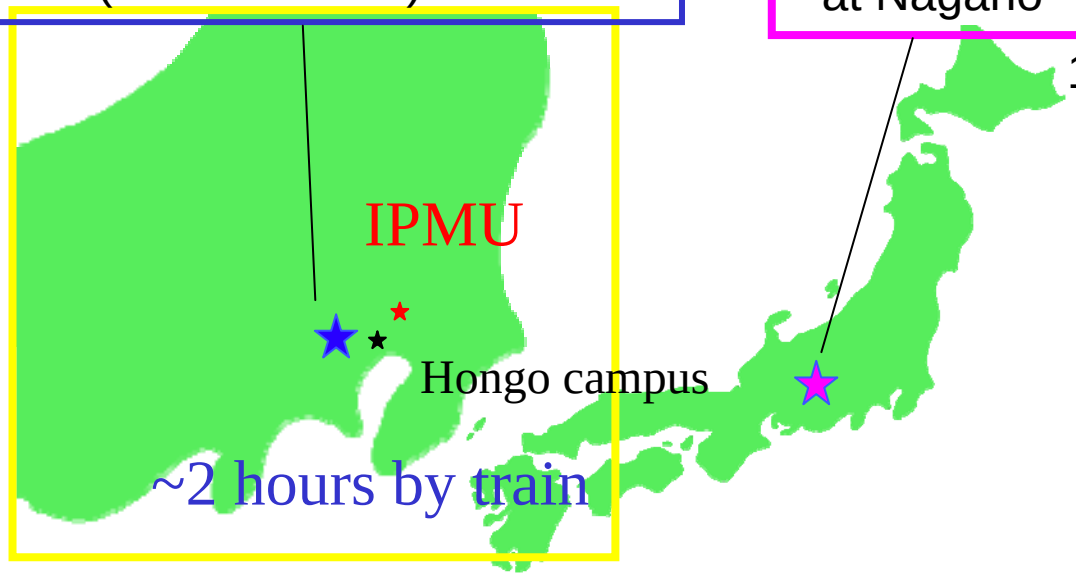
Institute of Astronomy

Graduate School of Science, University of Tokyo

Headquarters at Mitaka, Tokyo
(Next to NAOJ)

Kiso Observatory
at Nagano

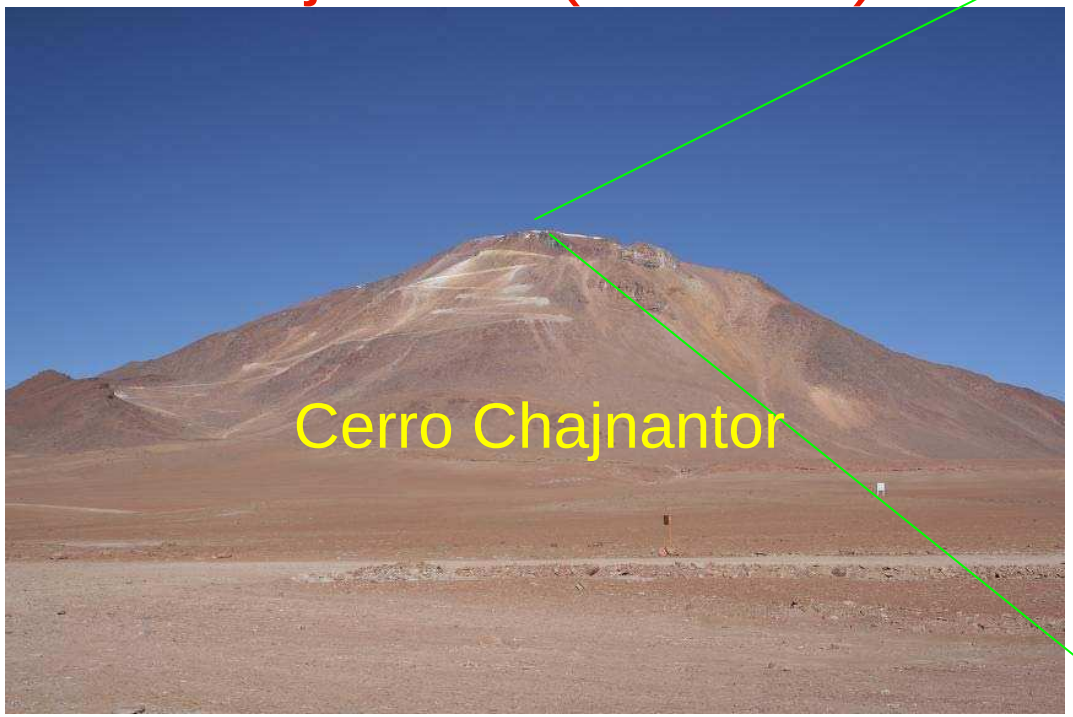
1.05m Schmidt Telescope

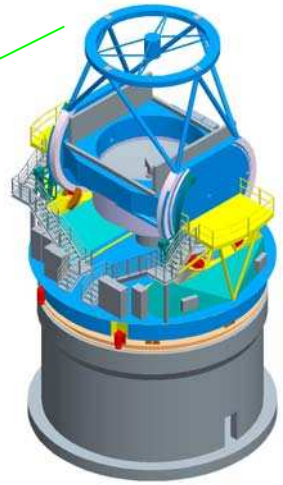


Prof. 3
Associate prof. 4
Assistant prof. 5
Techinicians 4

University of Tokyo Atacama Observatory (TAO) Project

A 6.5m Infrared/Optical Telescope at Cerro Chajnantor (~5600m)





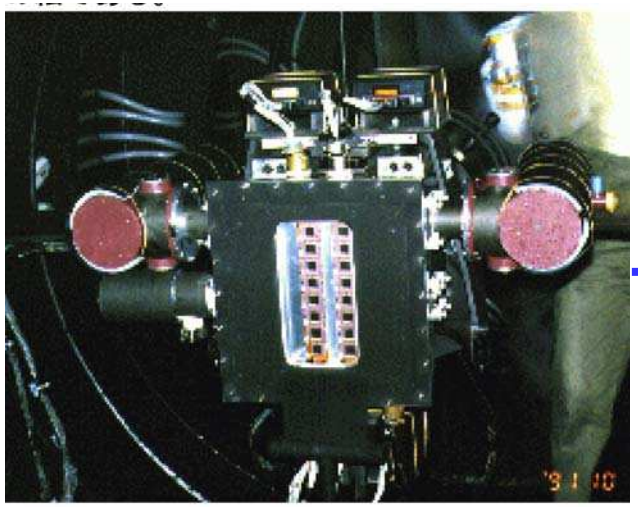
6.5m TAO telescope

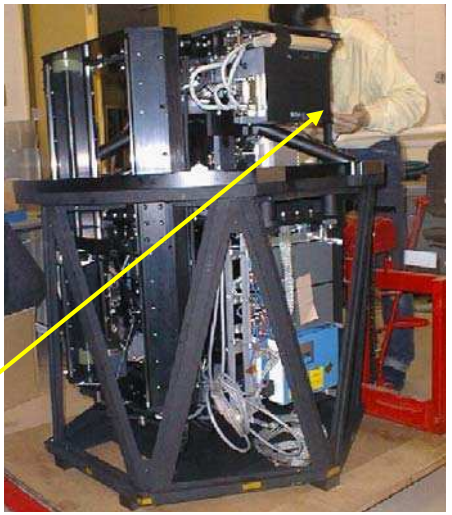
1m miniTAO telescope
Apr.2009 -

Northern Atacama (above ALMA site), Chile
Collaboration with Univ. of Chile

S.Okamura →

S. Miyazaki





1991 1kx1k CCDx16

1.05m Kiso Schmidt Tel.

1994 1kx1k CCDx40

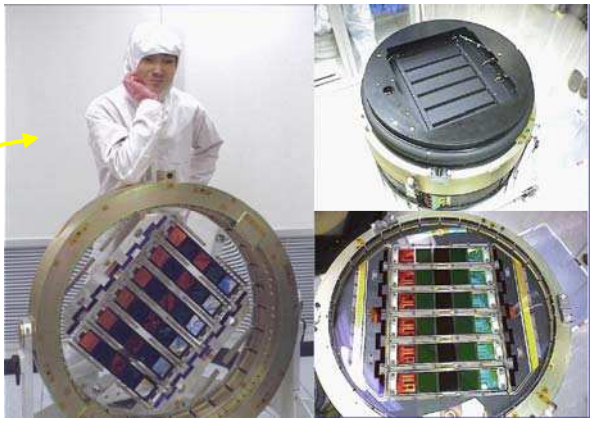
Las Campanas 1m

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

Topics today

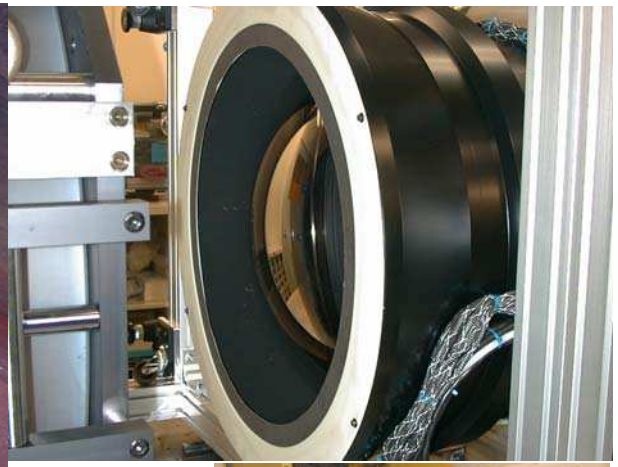
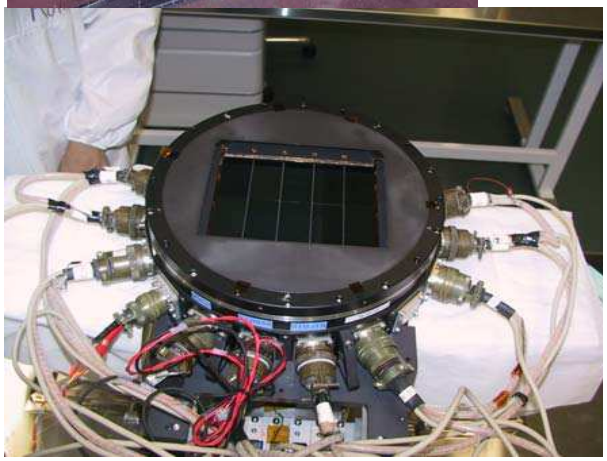
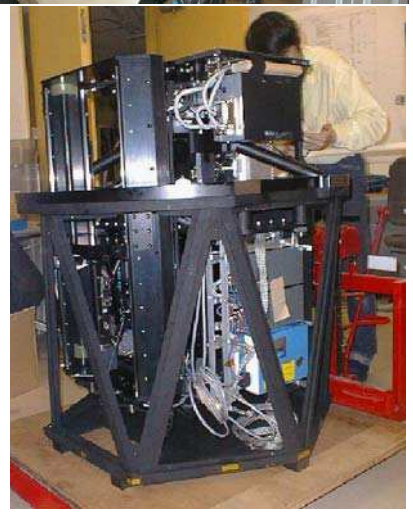
- Subaru Suprime-Cam distant SN searches
  Statistics of faint optical variables
  SNIa observational limits and rate studies
- SDSS low-redshift searches
  Subaru Spectroscopy
  SN color and host extinction
- Instrumentations for near future

  miniTAO telescope

  Dichroic Mirror Camera: 15-band simultaneous imager

Subaru Telescope
Suprime-Cam

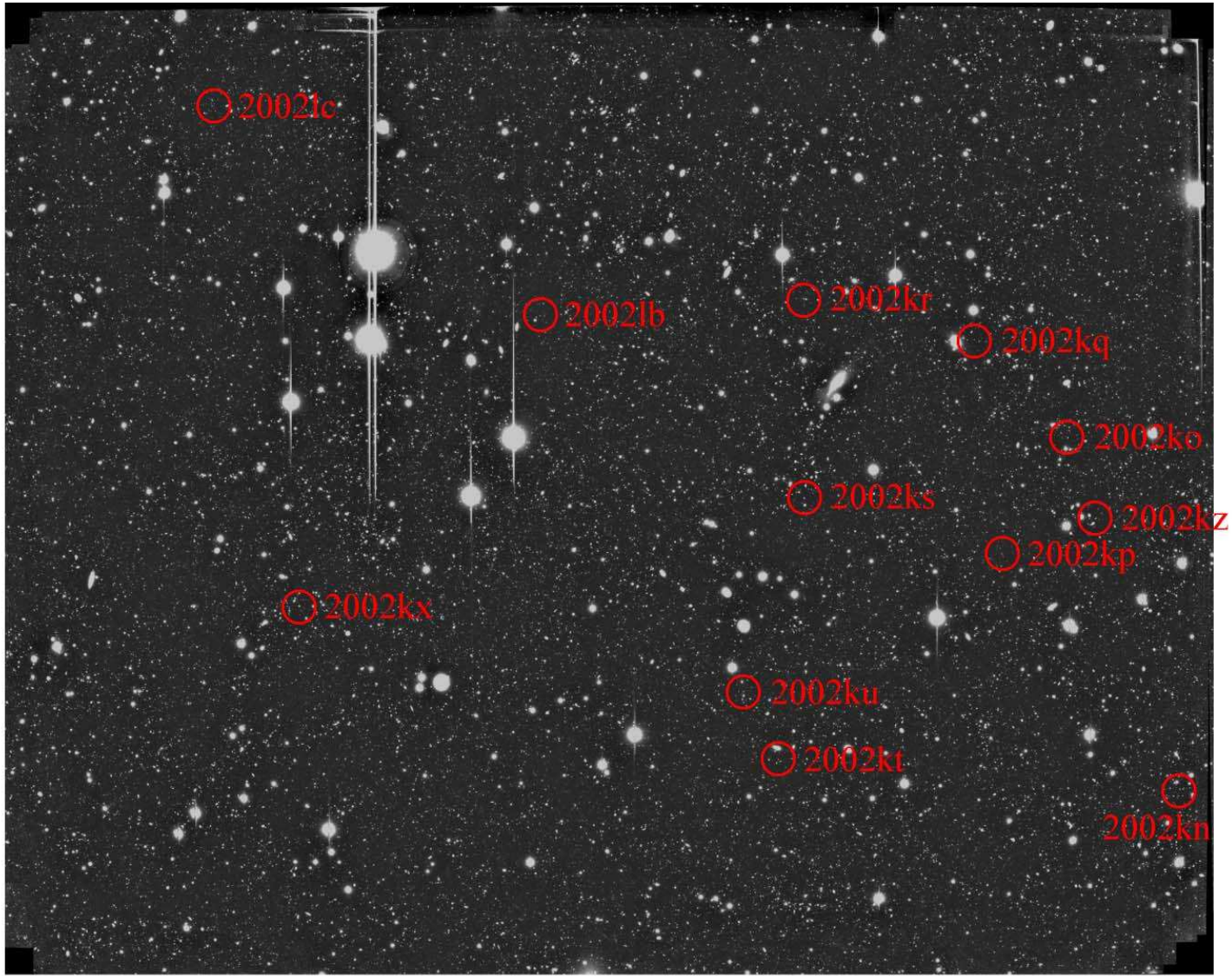
SUBARU 8.2m telescope
33×27 arcmin^2 Field of View
the largest among 8–10m telescopes

Suprime-Cam

12 SNe per “Shot”

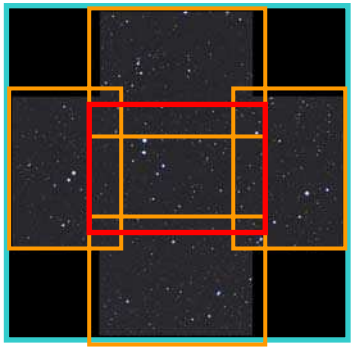
Doi et al. 2002

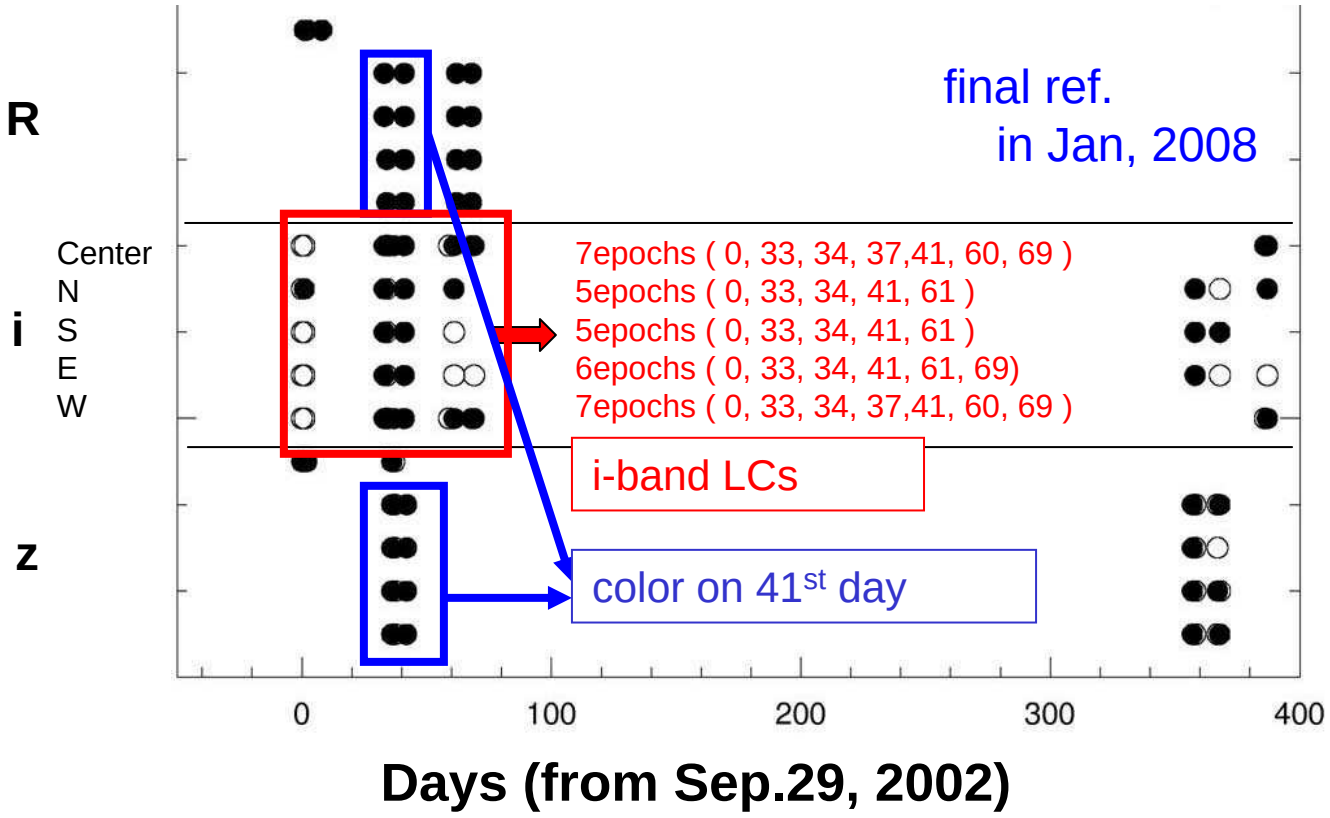


Subaru XMM/Newton Deep Survey

SXDF consists of 5 fields of view of Suprime-Cam
= 0.918 deg² B, V, R, i', z'

Observing Date **2002.9.30.~12.10. = about 70days**
(i obs.) 5~7 epochs → Light curves
(R and z obs.) 2~4 epochs → Color





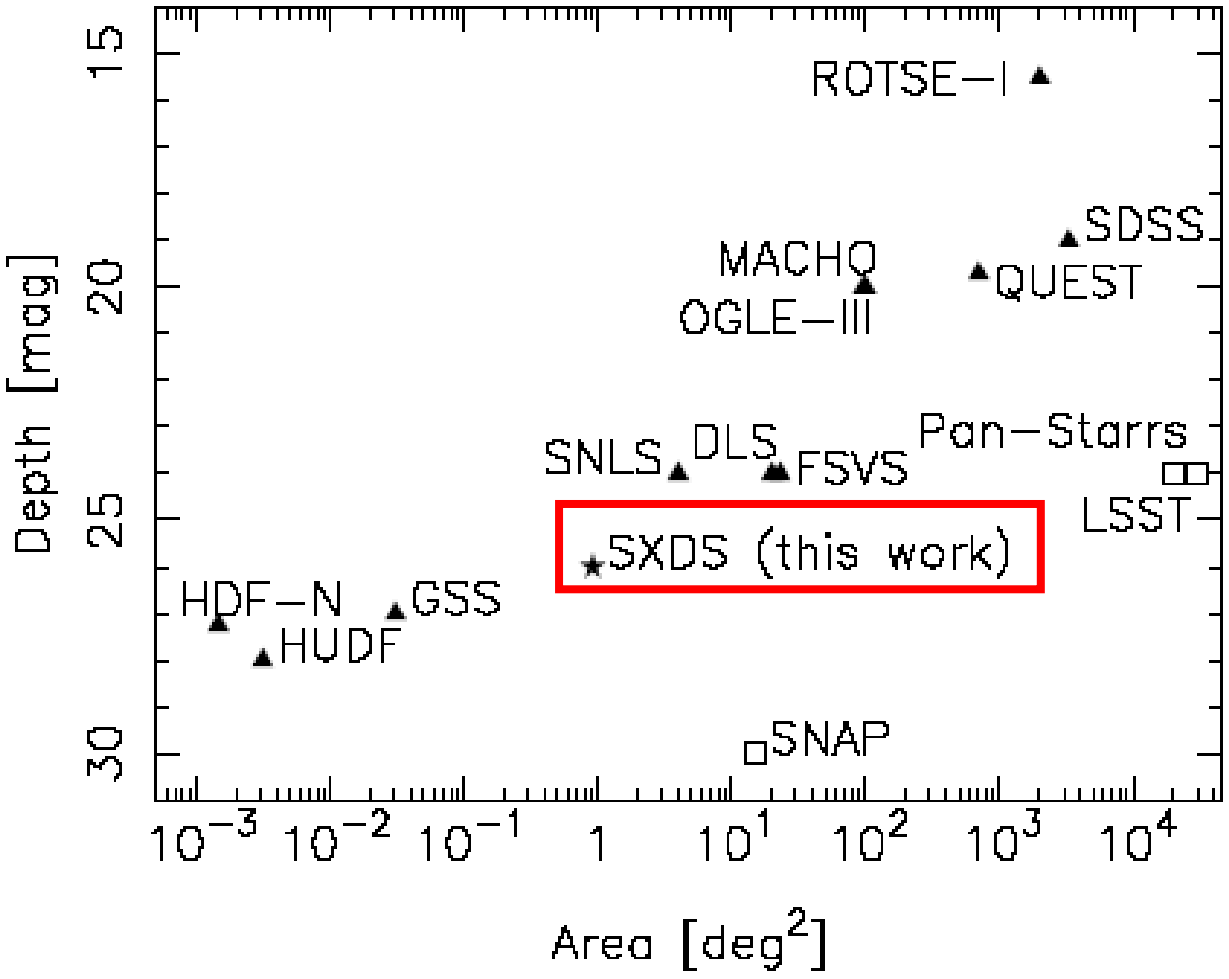
● **Exp.time>30min**
○ **Exp.time<=30min**

X-ray: Newton
MIR: Spitzer
NIR: UKIRT

Sekiguchi et al. in prep.
Furusawa et al. 2008
Ueda et al. 2008

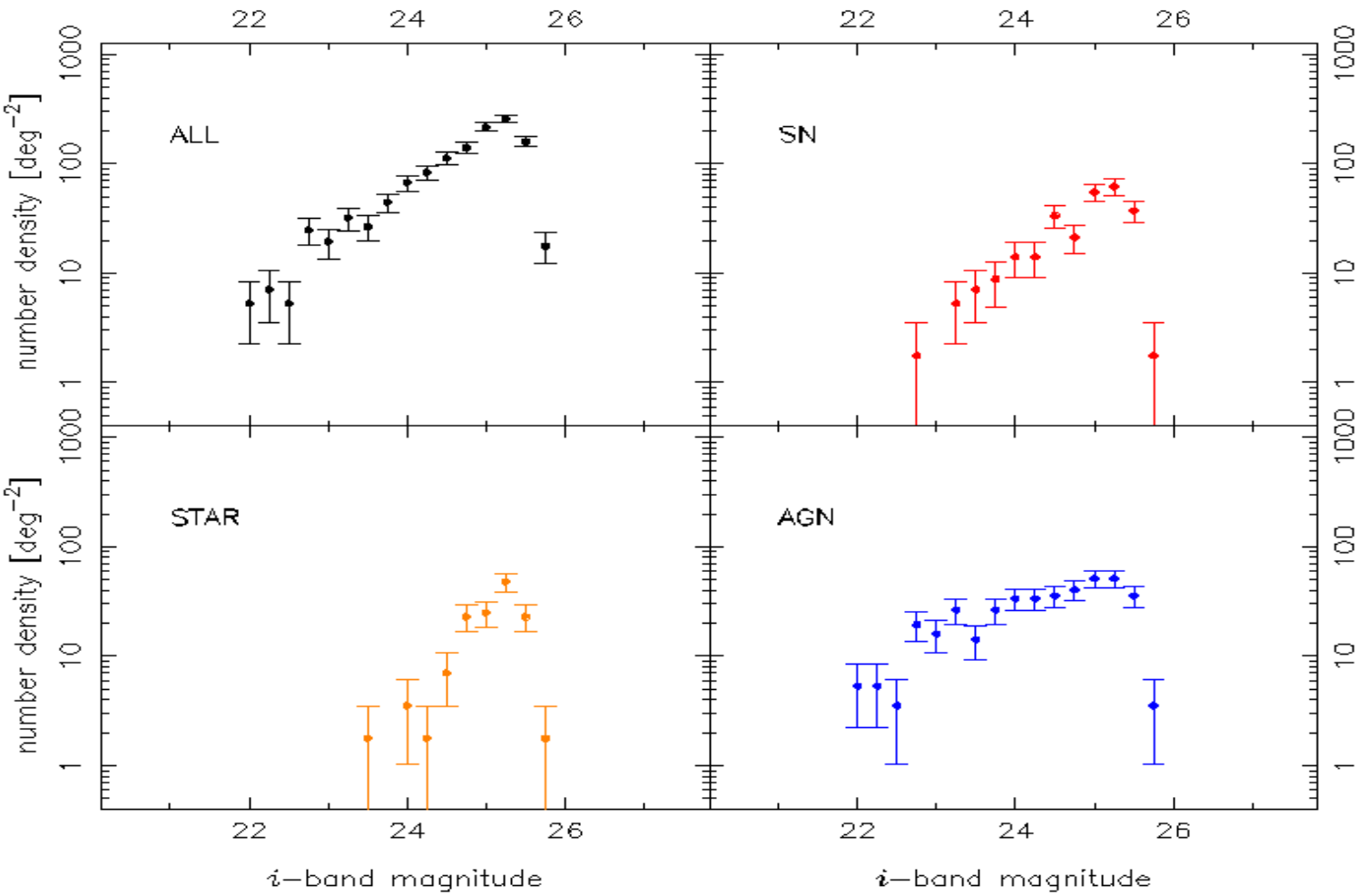
Optical variable searches

Morokuma et al. 2008

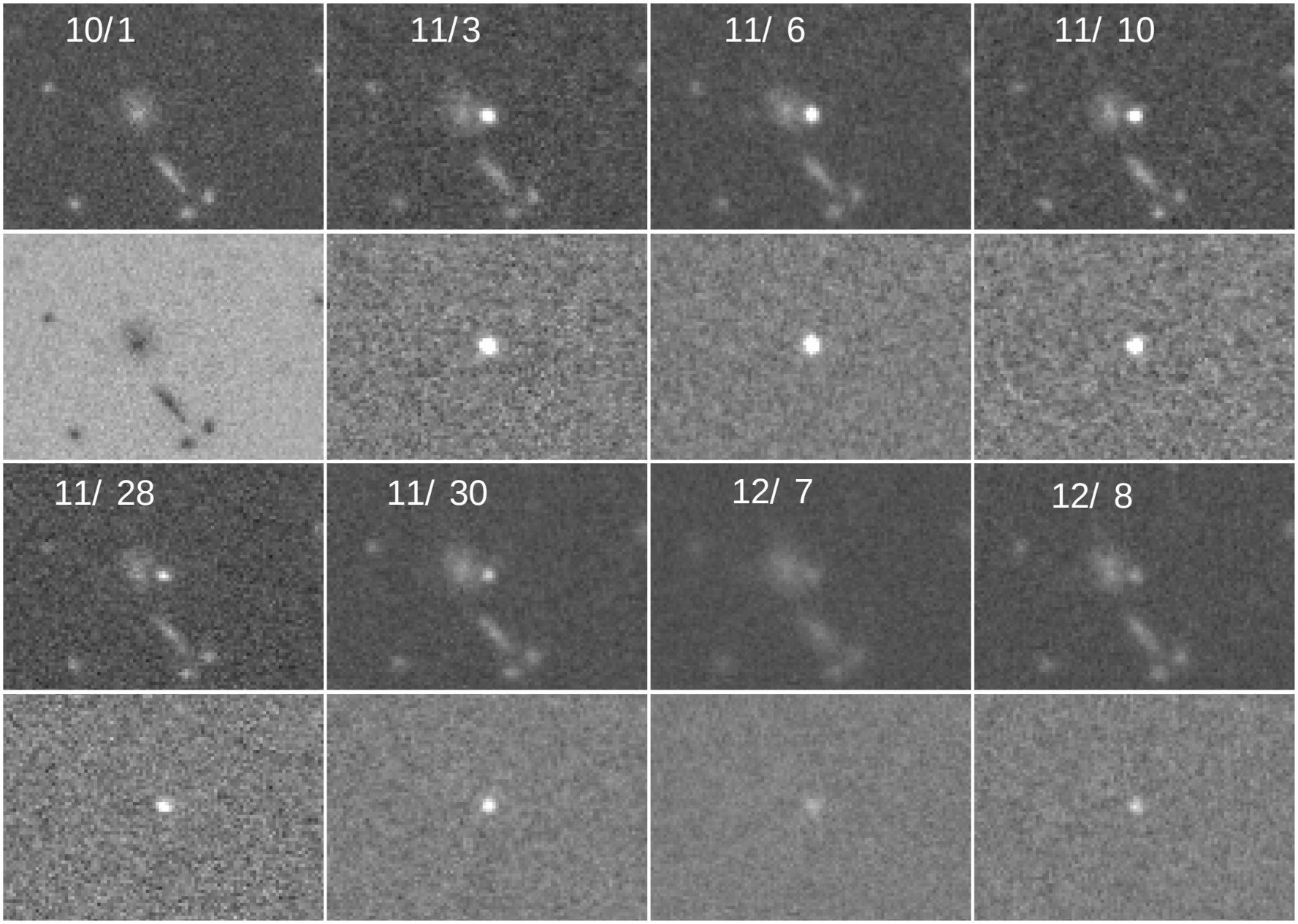


Faint optical variable objects (i-band selection)

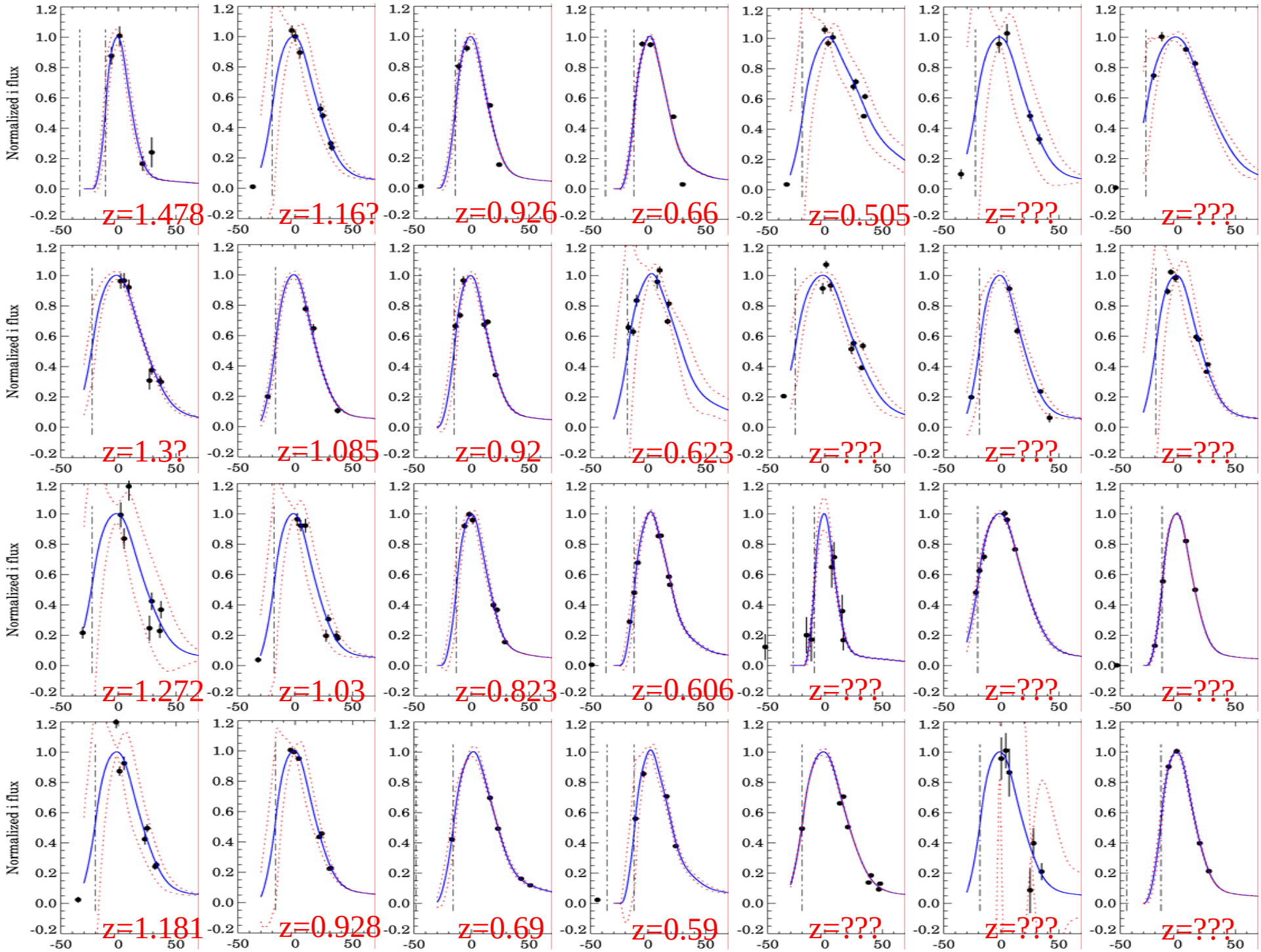
Morokuma et al. 2008



- **540 AGN/deg^2, 400 SNe/deg^2, 170 variable stars/deg^2 @ i_{AB} ~26 mag limit**



SN2002kp（z=0.928）

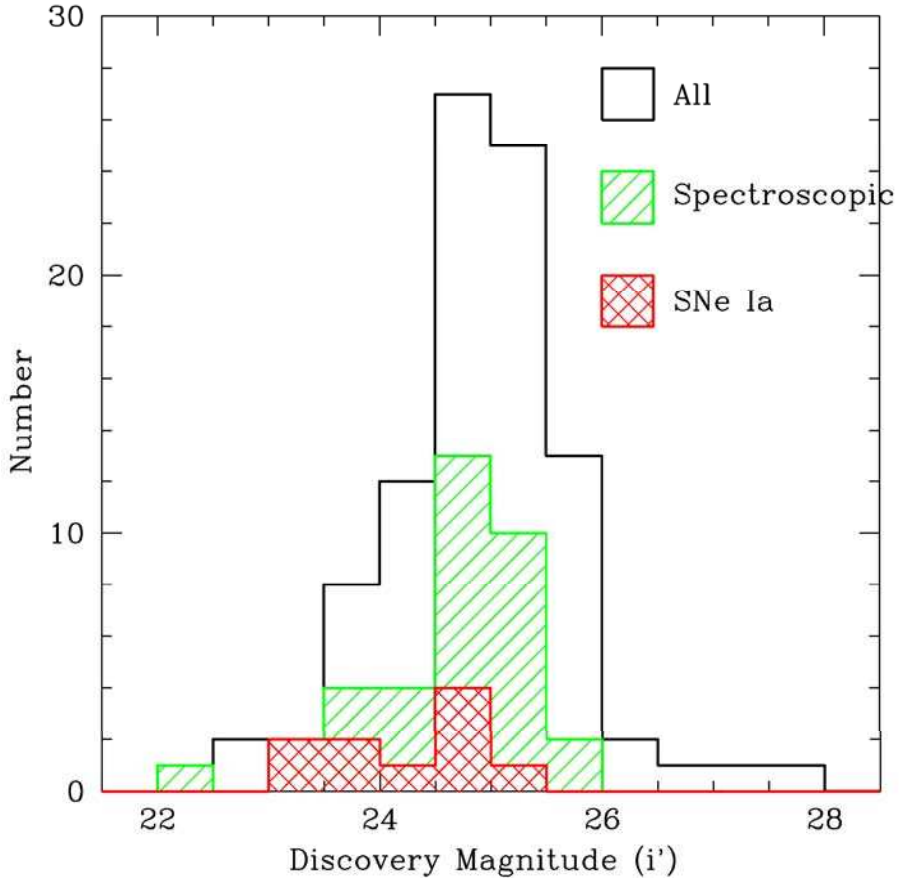

Normalized i flux
z=1.478
z=1.16?
z=0.926
z=0.66
z=0.505
z=???
z=???
z=1.3?
z=1.085
z=0.92
z=0.623
z=???
z=???
z=???
z=1.272
z=1.03
z=0.823
z=0.606
z=???
z=???
z=???
z=1.181
z=0.928
z=0.69
z=0.59
z=???
z=???
z=???

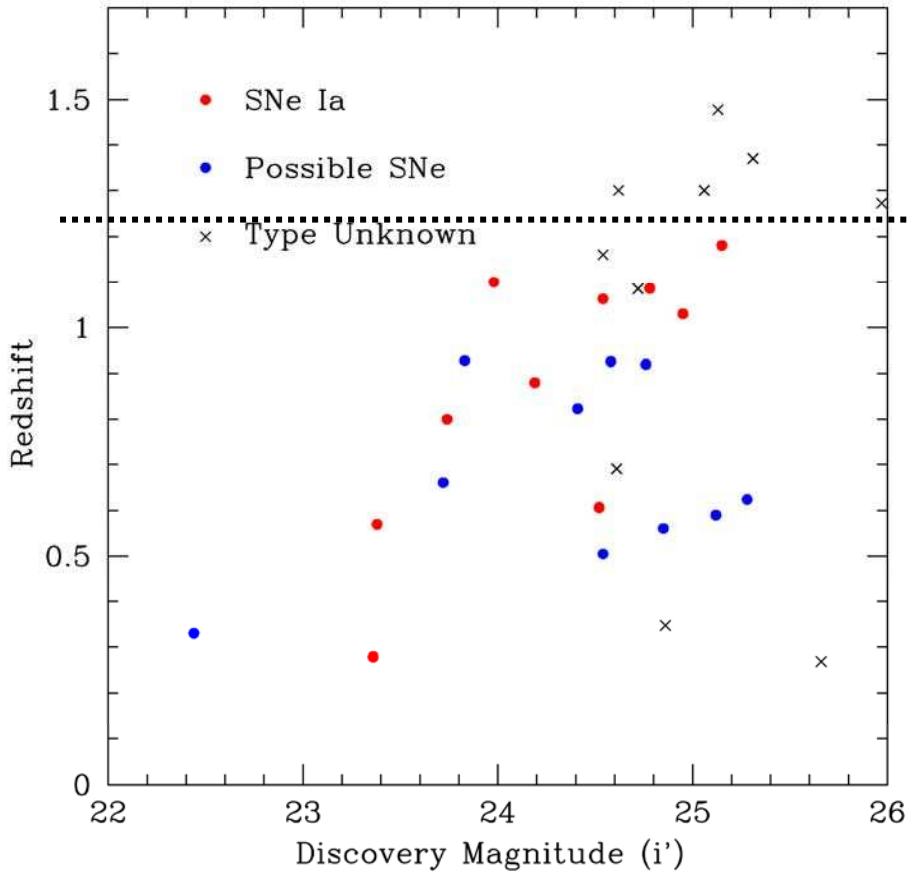
Suprime-Cam SN searches 2002 @ SXDS

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

SCP Spectroscopy: Subaru, Keck, VLT ,Gemini, HST

Yasuda et al. 2004

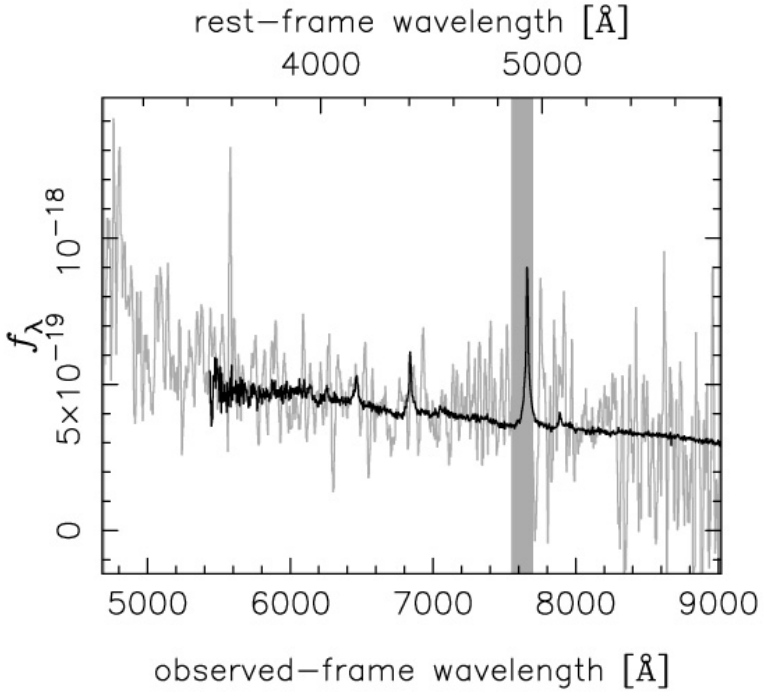




Lidman et al. 2005

Morokuma et al. in prep.

IIn @ z ~0.55?



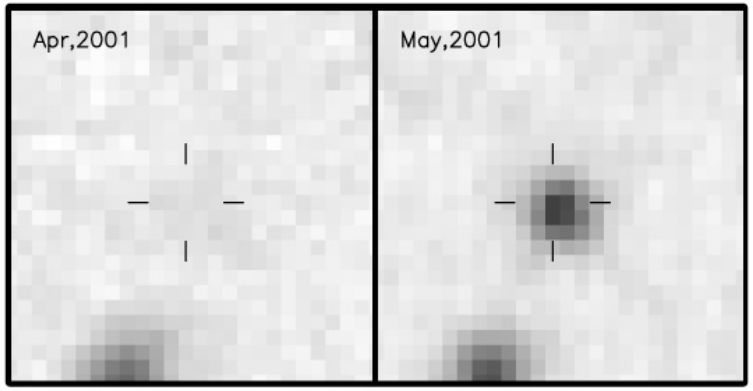
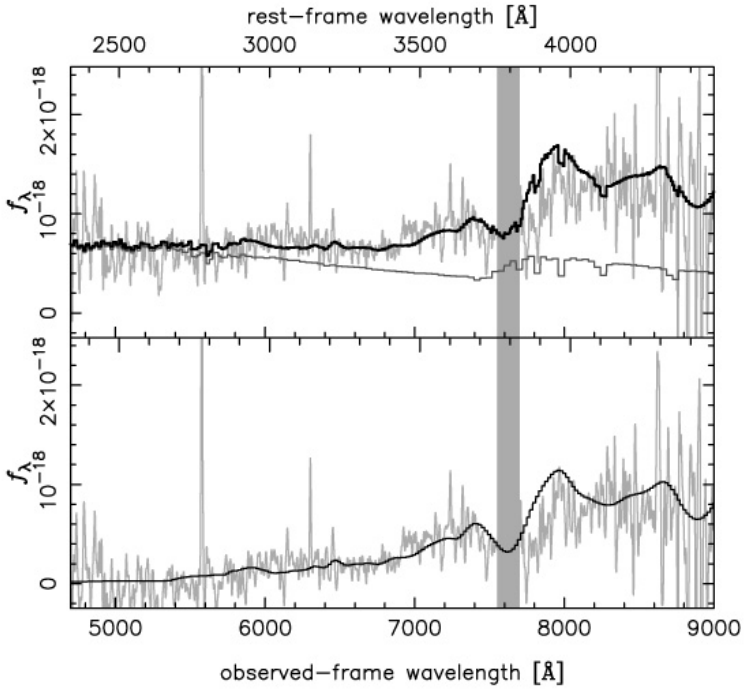


Fig. 5. (top): Spectrum of SDF2 (SN 2001ct, gray) and SN 2005kd spectrum at $\tau \sim 10$ days at $z_{\rm SN} = 0.553$. (bottom): Finding charts of SDF2.

Morokuma et al. in prep.

Ia? @ z ~1.04



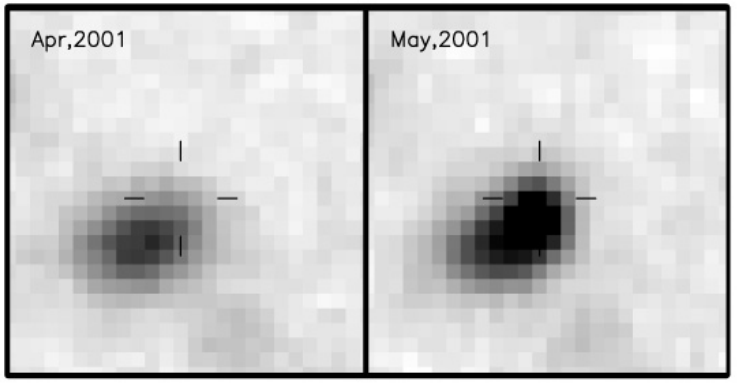
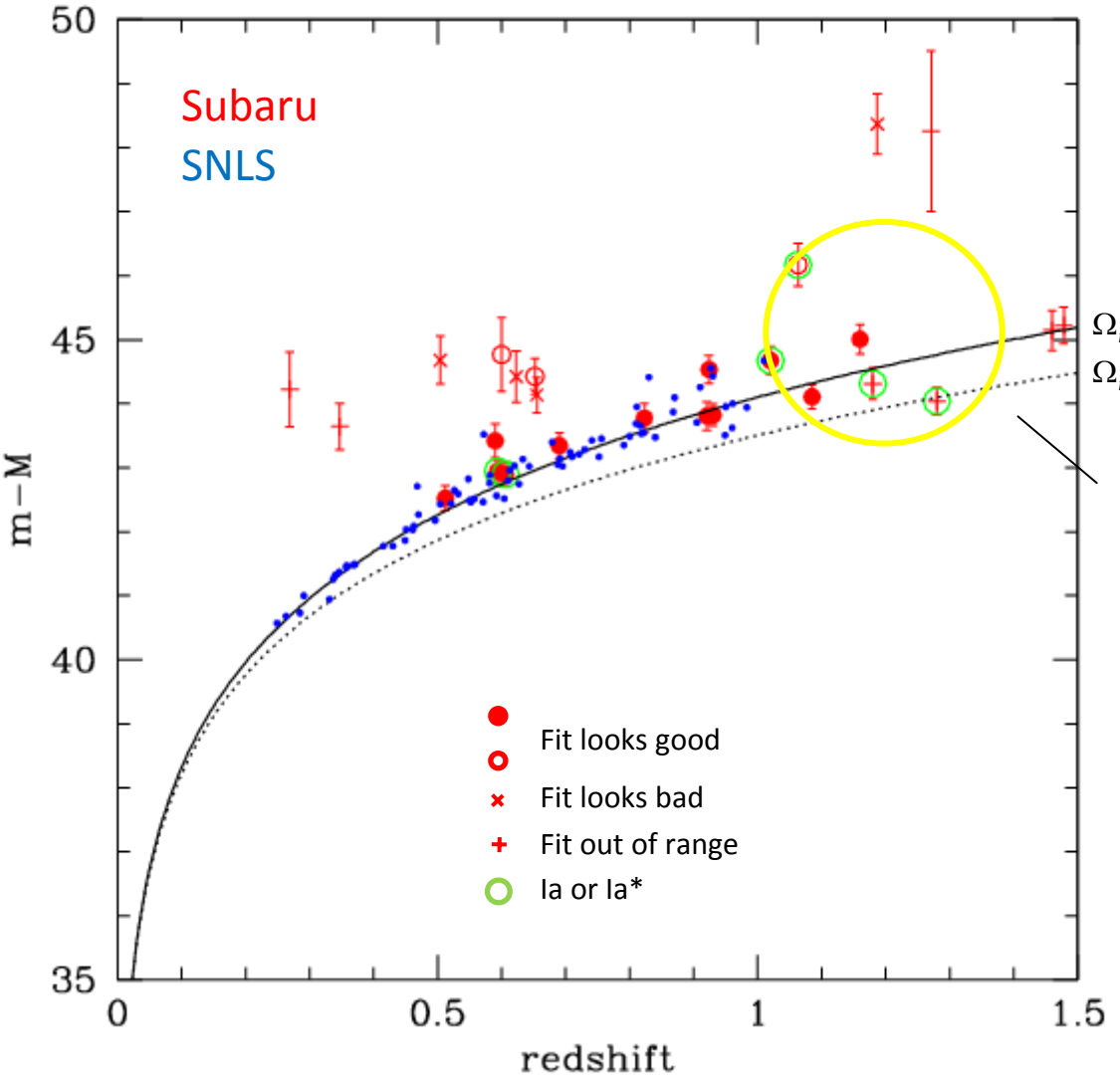


Fig. 7. (top): Spectra of SDF5 (SN 2001cv) at $z_{\rm gal} = 1.039$ (red) and SN 1999ee at $t \sim 0$ days at $z_{\rm SN} = 1.038$ (black). (bottom): Finding charts of SDF5.

See also Lidman et al. 2005

Preliminary Hubble Diagram (by N.Yasuda)

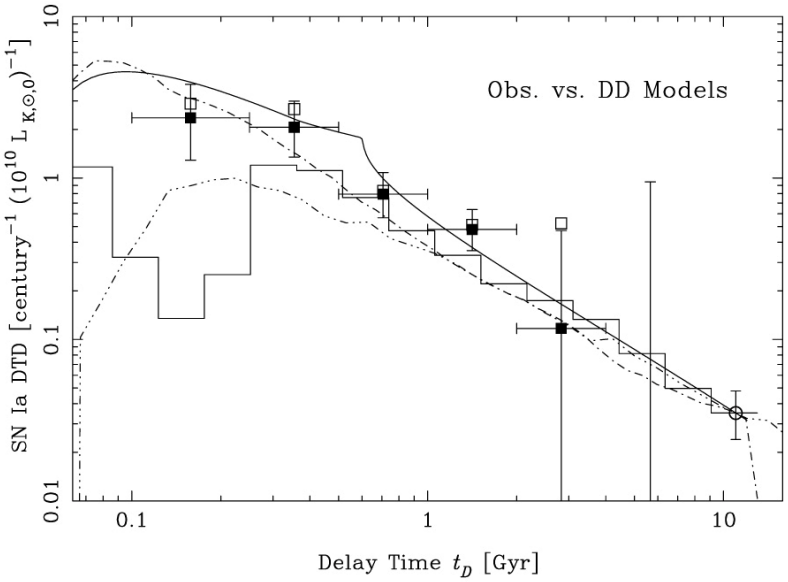


Preliminary!

to be compared with
HST photometry

Consistent with flat-Λ
Cosmology model

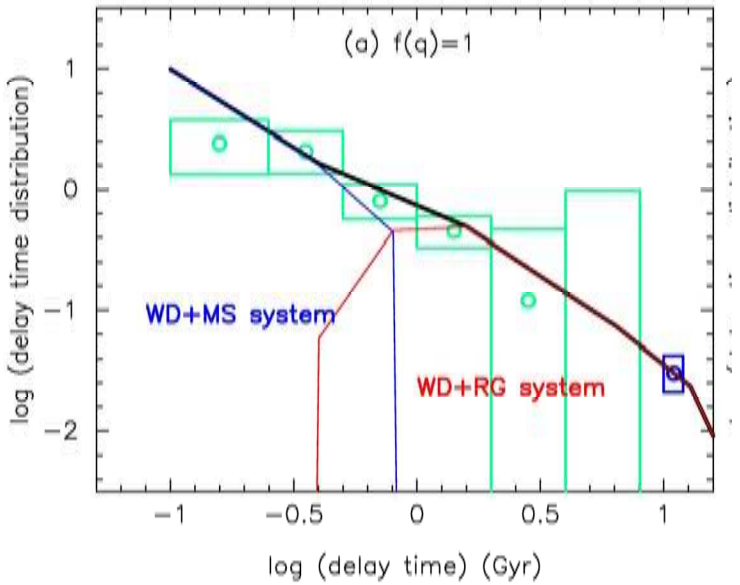
Delay Time Distribution



$\sim t^{-1}$

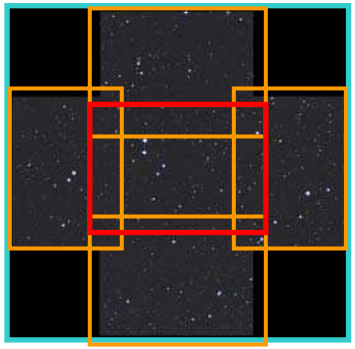
Totani, Morokuma, Oda, Doi &Yasuda 2008
Last starburst epoch of passive host galaxies
← SED

cf. Pritchet et al. 2008 $t^{-0.5\pm0.2}$



Comparison with SD model
Hachisu et al. 2008

SN Rate Analysis with Light Curves

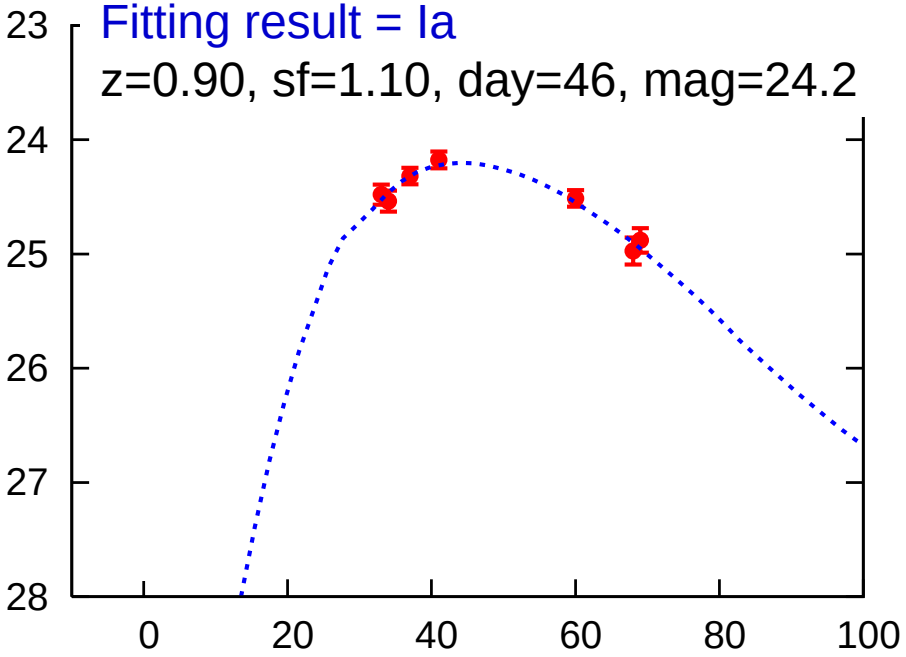


~200 SN-like objects were found at SXDF in 2002.
→50 are SNe Ia
All of 9 confirmed spec-Ia samples are identified as Type Ia by the LC fitting.

Ihara et al. in prep.

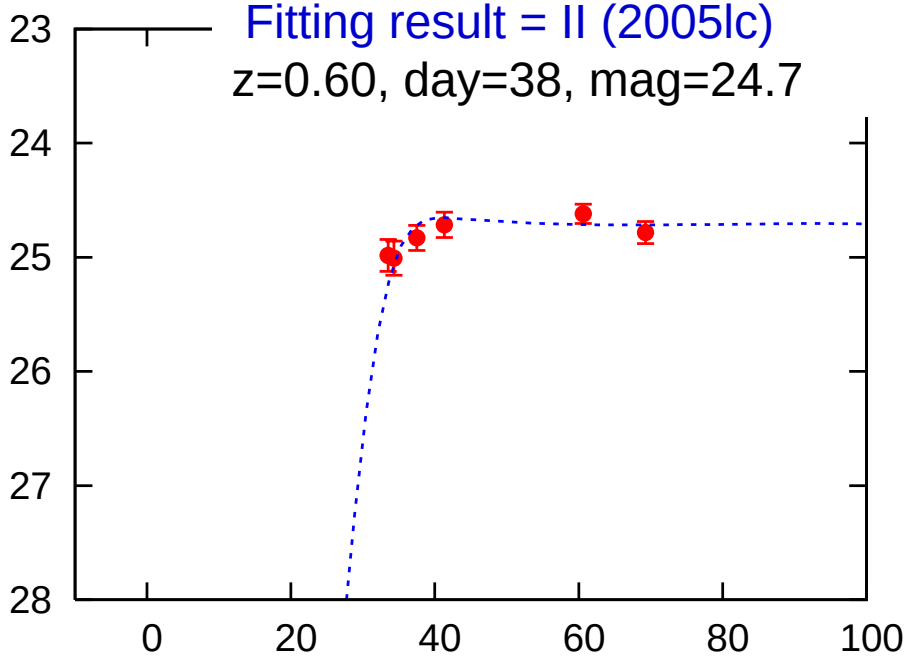
○ Confirmed Ia

Ex.1 1-175 (spec-Ia)
z=0.921 i' max = 24.16



○ Type II

Ex.2 1-045 (?)
z=0.625 i' max = ?



Raw number of SNe Ia in SXDF

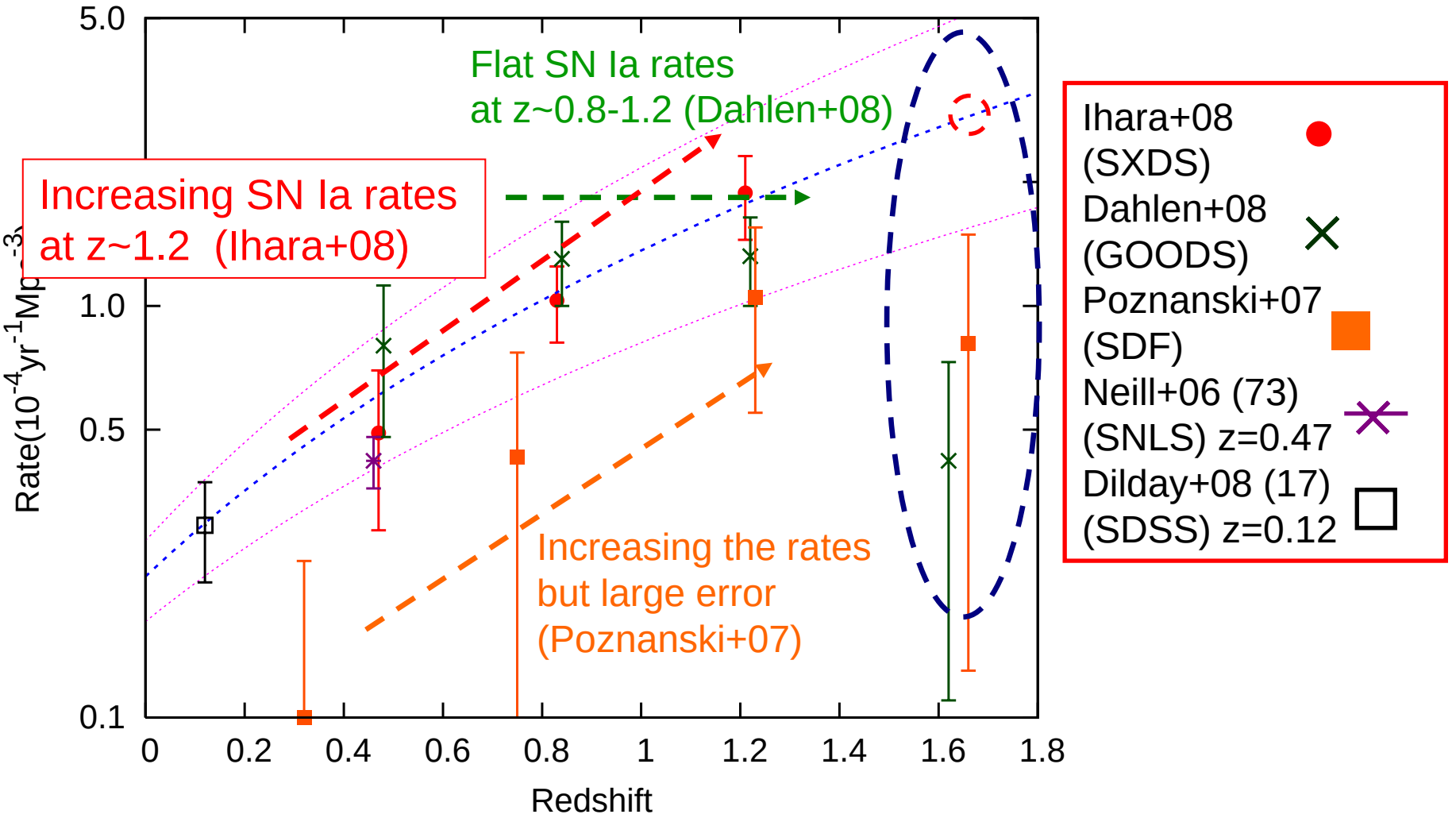
	0.2-0.6	0.6-1.0	1.0-1.4	1.4-1.8
SXDF(50)	6	25	19	—
Dahlen+04(25)	3	14	6	2
Poznanski+07(22)	0 (-0.5)	9 (0.5-1.0)	10 (1.0-1.5)	3 (1.5-2.0)
Dahlen+08(56)	8	25	20	3

Simulation based on observation parameters

⇒ SNIa Rate

SN Ia rate in SXDF

2008-2009 z-band searches
with Suprime-Cam



Sloan Digital Sky Survey (SDSS)

International collaborations (US, Japan, Germany,..)

2.5m wide-field telescope

wide field imager : 54 CCDs

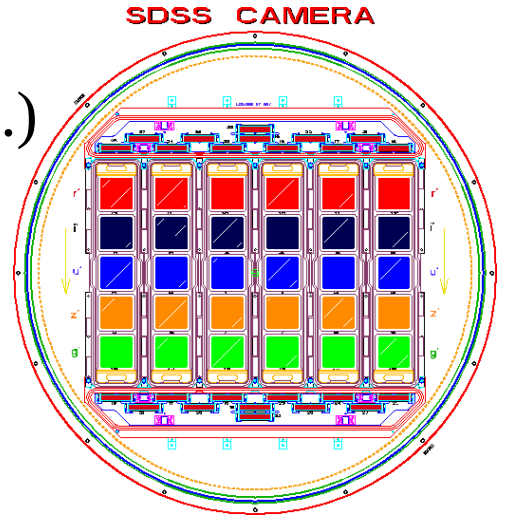
SDSS-II SN survey

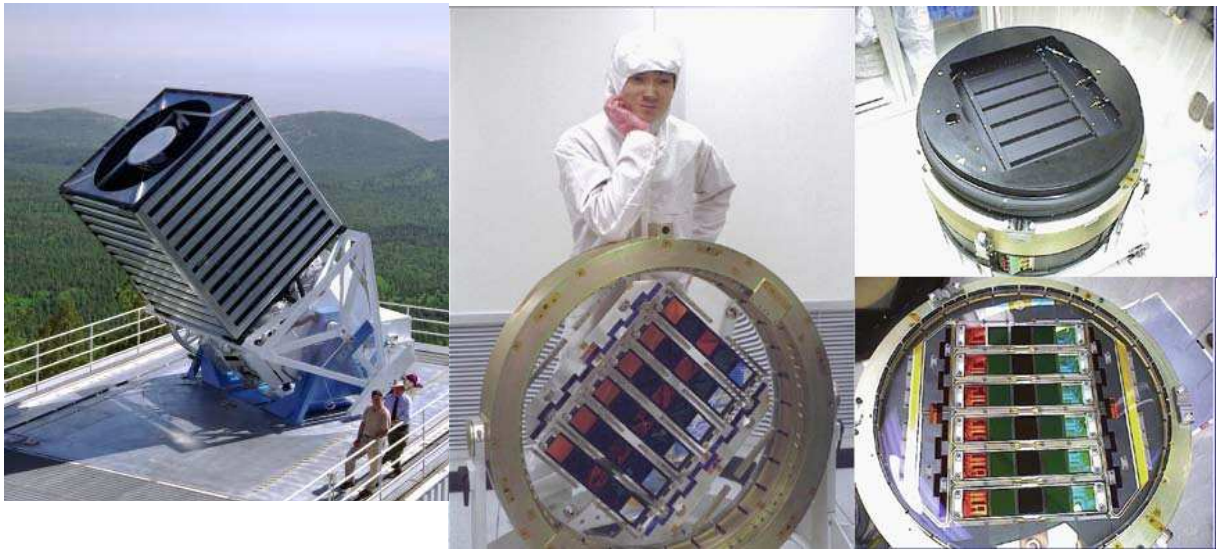
5-band photometry

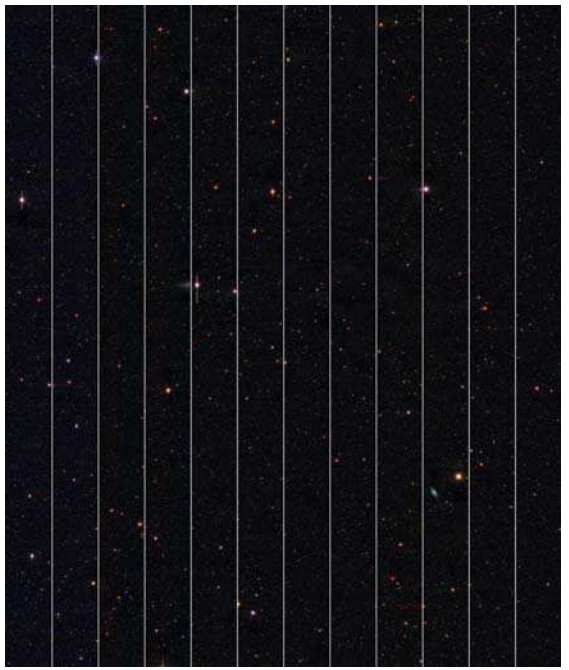
find and measure brightness of SNe

~500 SNIa ← 2005-2007

Frieman et al. 2008, Sako et al. 2008, ..





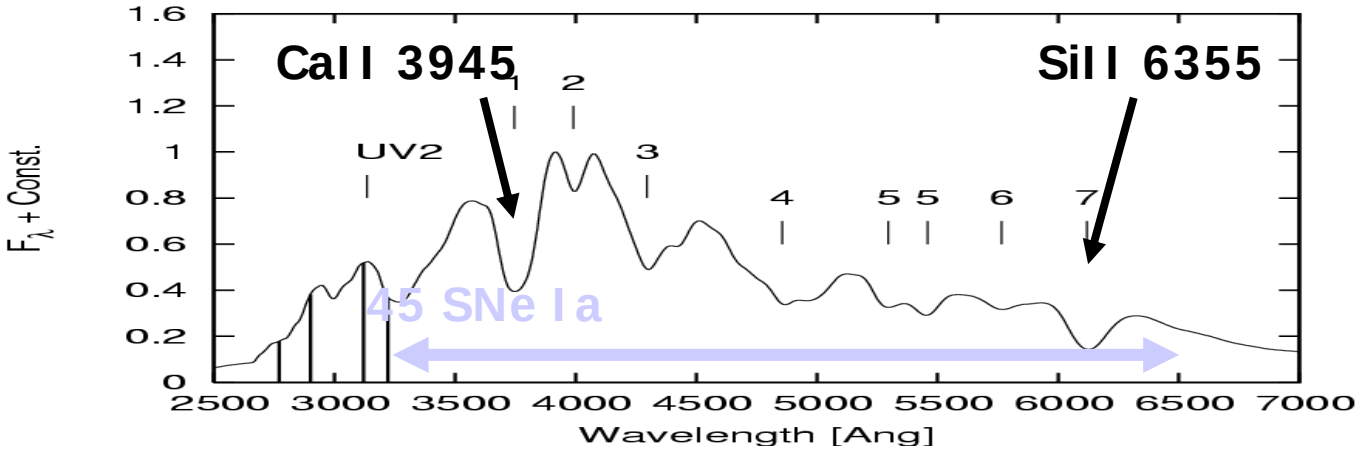


2.5 degree

UV/Optical property of SNe Ia

Kohki Konishi, Koichi Tokita,
Naoki Yasuda, …

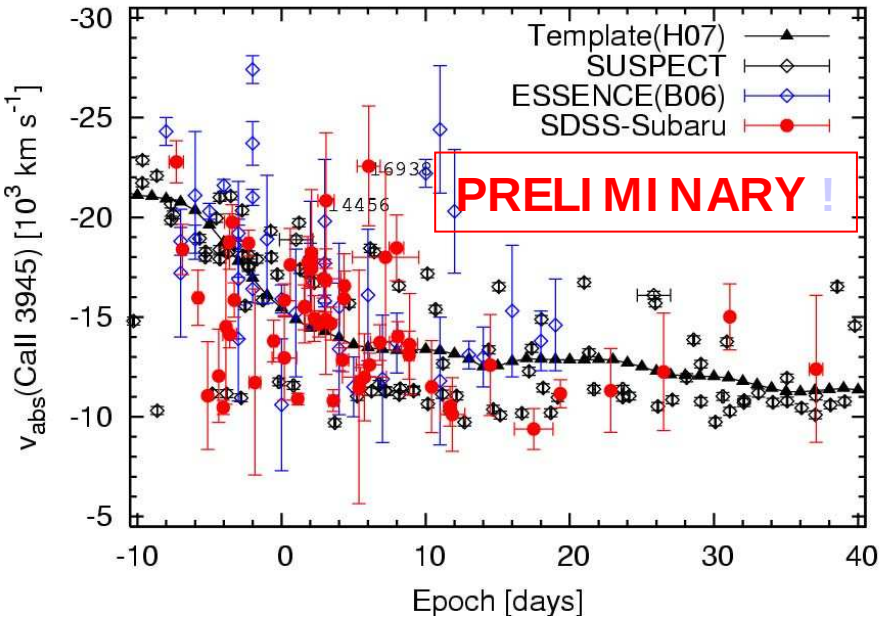
- Subaru followed up ~60 SNe Ia spectra found by SDSS-II Supernova Survey
- Redshift 0.1 – 0.4
- Spectra taken at ~ t_max
- Wide spectral coverage: 3000-7000 An

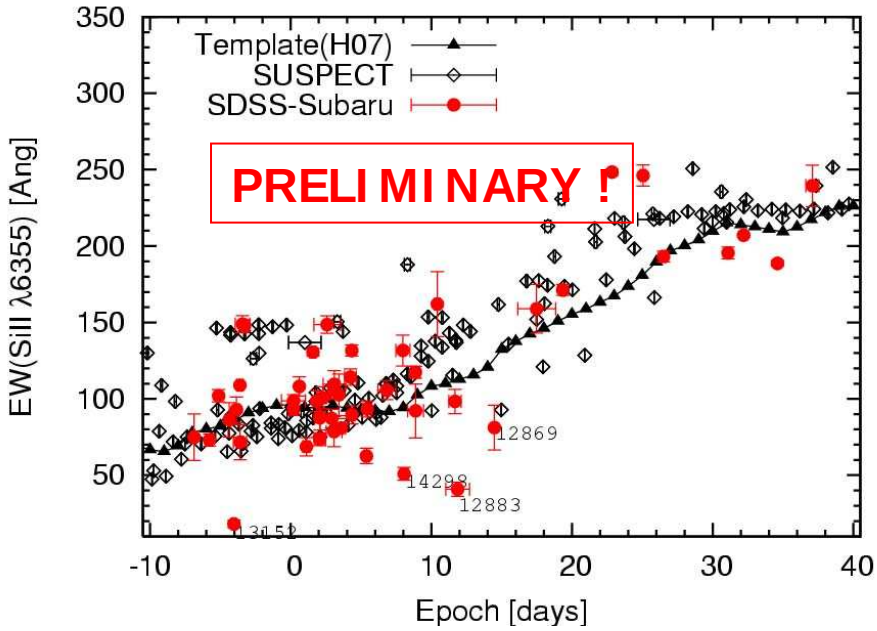


Kohki Konishi

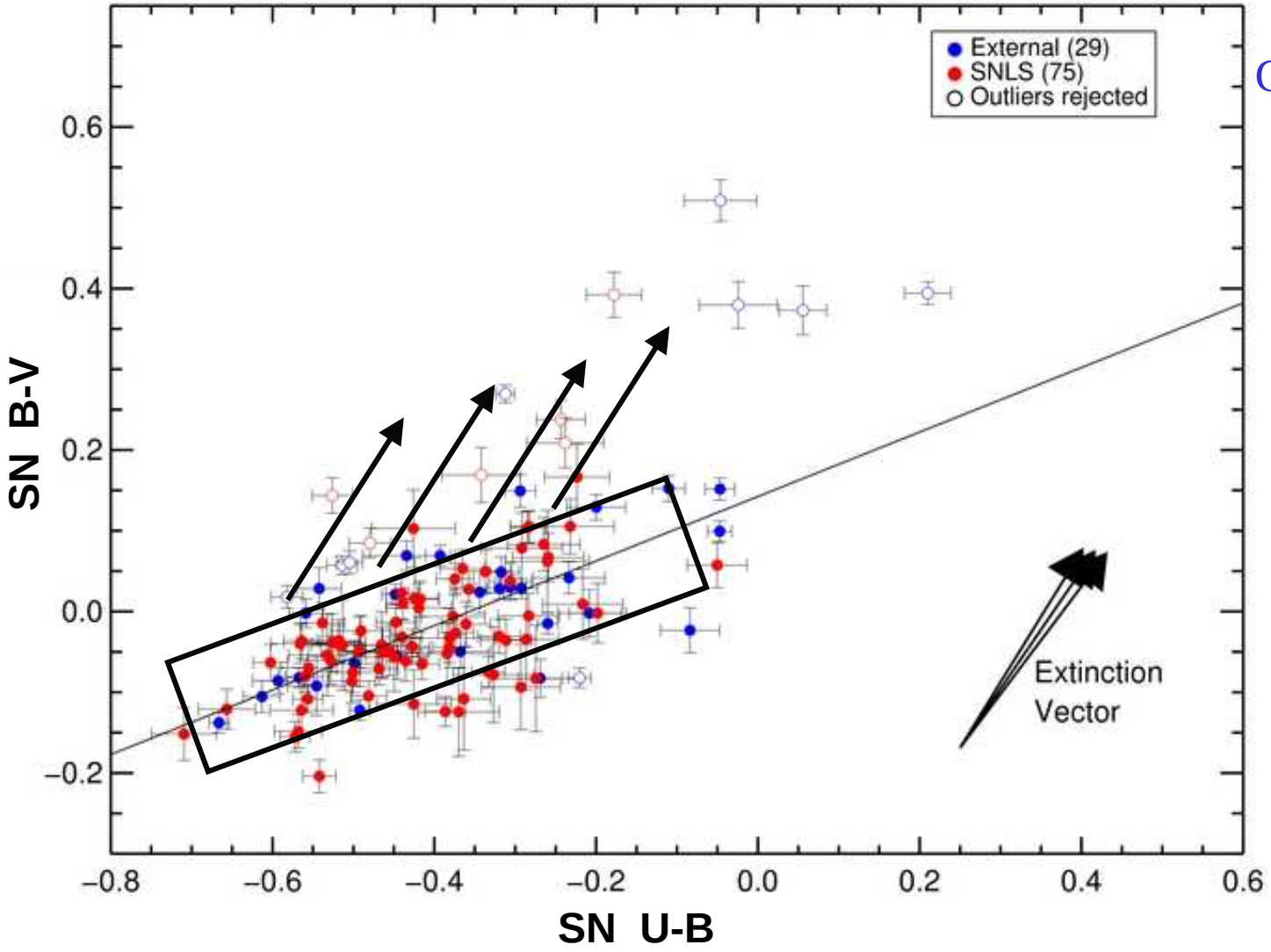
UV/Optical property of SNe Ia / Kohki Konishi

- Line velocities
  - for CaII 3945
- Equivalent widths
  - for SiII 6355





Combination of dust+intrinsic?



Conly et al. 2008
SNLS 1st year

In colour colour space, MW-type extinction laws also don't work

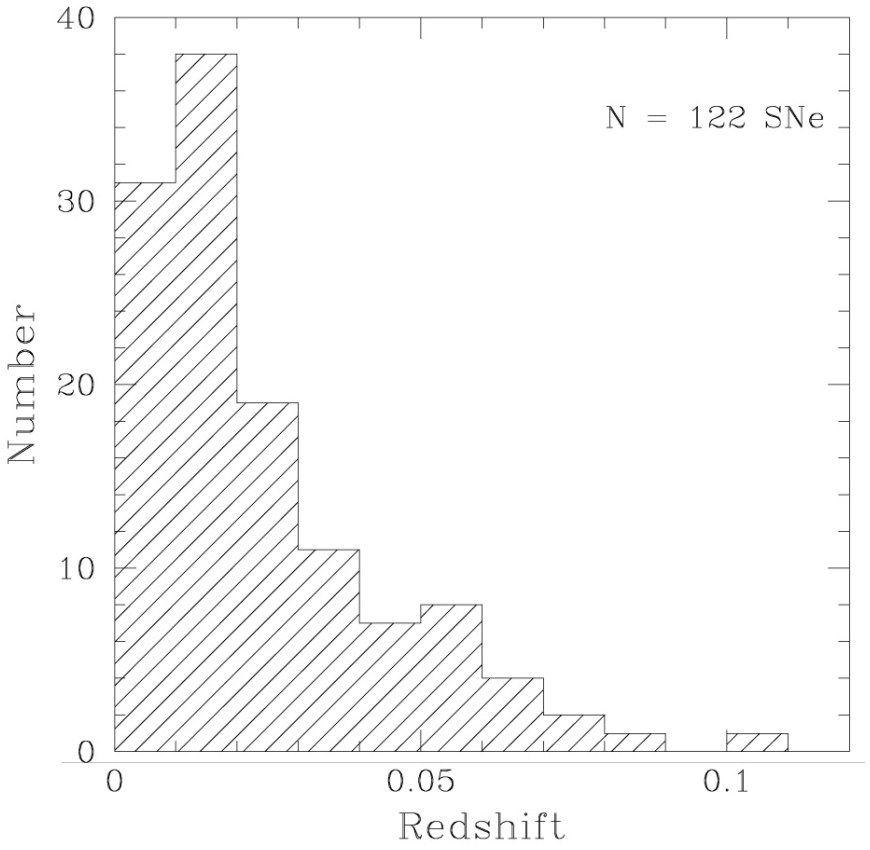
SDSS Subaru spectroscopy: similar results …

Photometry: Takanashi et al. in prep. Spectroscopy: Tokita et al. in. prep.

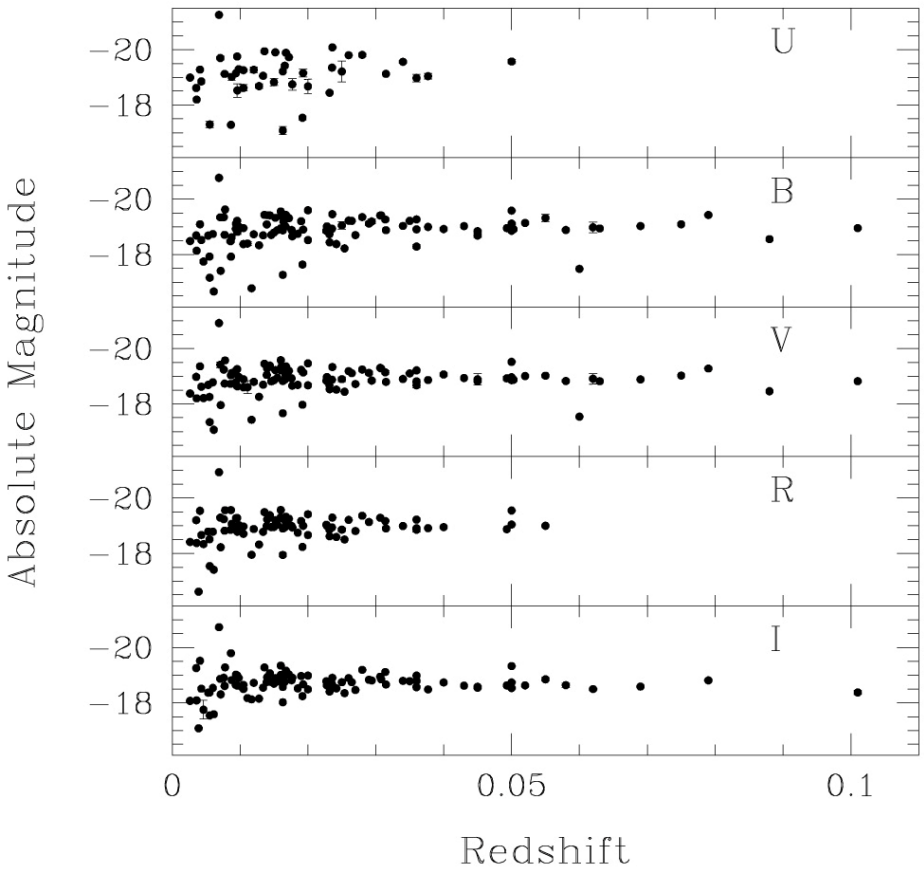
Light curve studies of nearby Type Ia Supernovae with a Multi-band Stretch method

Takanashi et al. 2008

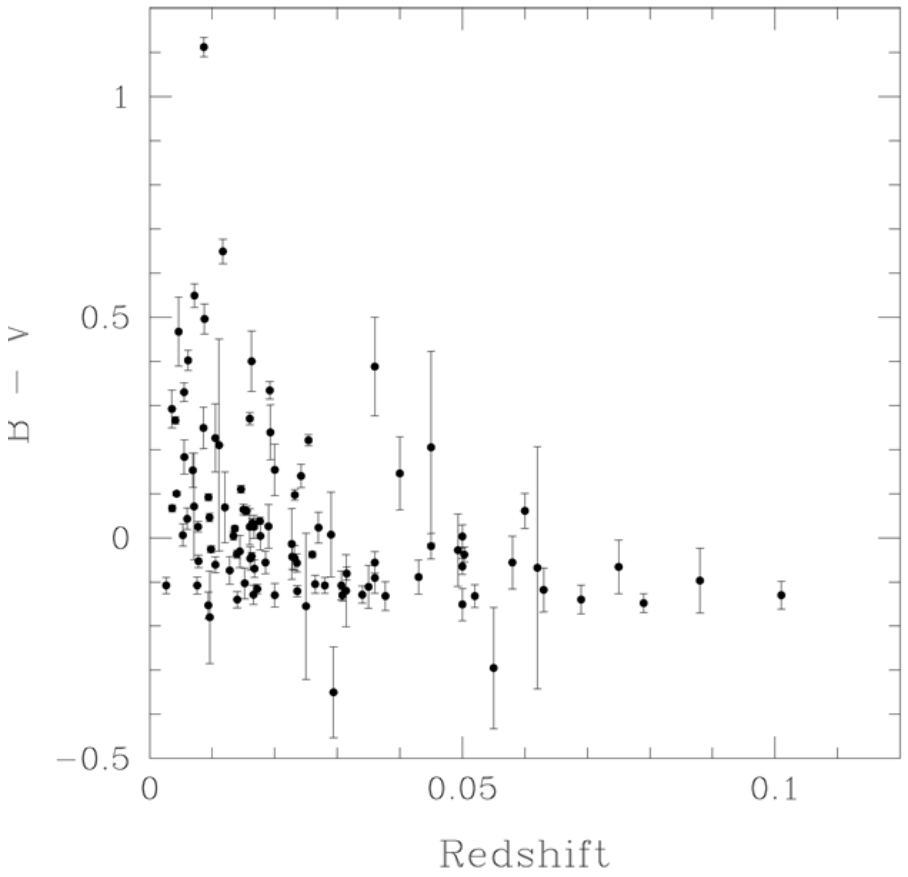
122 SNeIa from published data

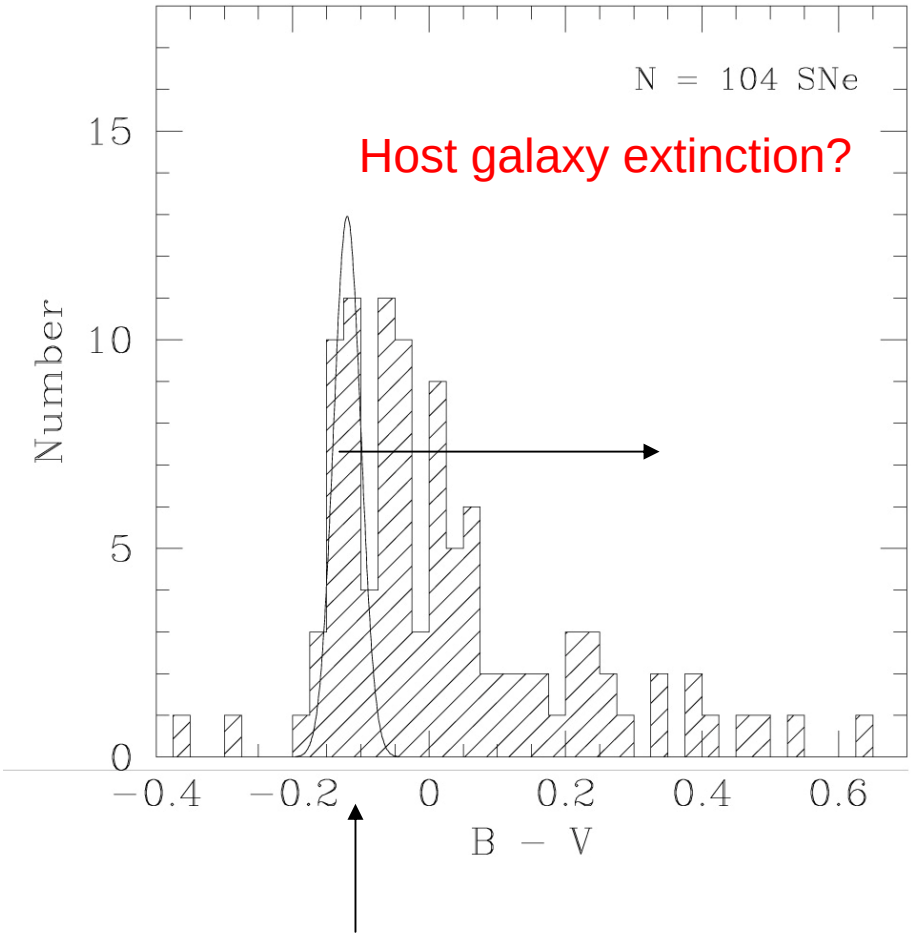


Hubble flow



Rest frame B - V





$(B\text{-}V)_0$=-0.12?

Altavilla et al. 2004, Reindl et al. 2005, ..

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

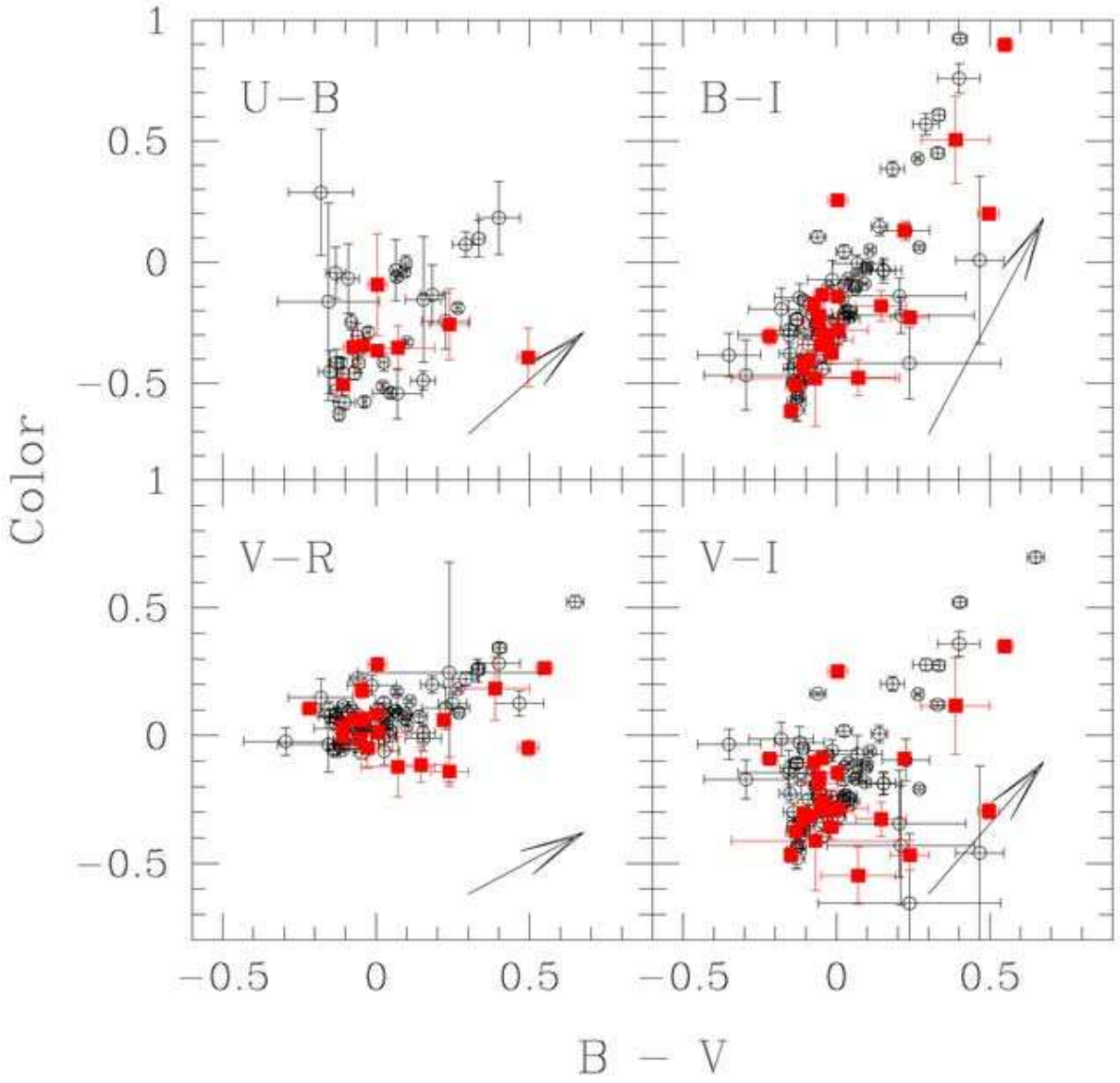
9A is all SNe Ia.
9B is SNe Ia of z $>$ 0.02.
9C is SNe Ia hosted by E or S0 galaxies.
9D is SNe Ia of z $>$ 0.02 hosted by E or S0 galaxies.
9E is "BV bluest"+"BV bluer" sample, which $-0.14 > (B-V)_{max} > -0.02$.

Blue

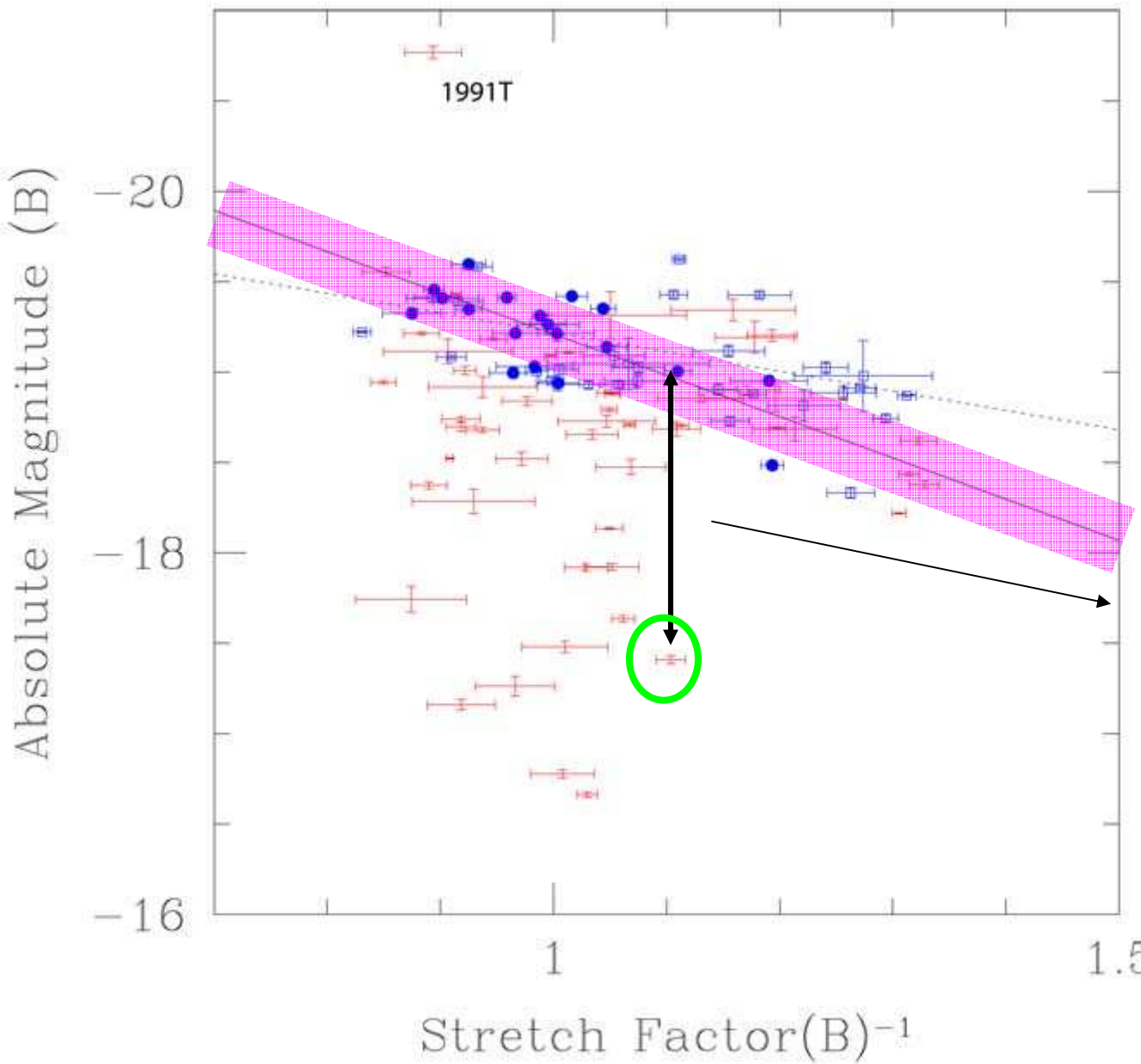
E, S0 host

Empirical color correction

Color-Color : Consistent with MW dust extinction

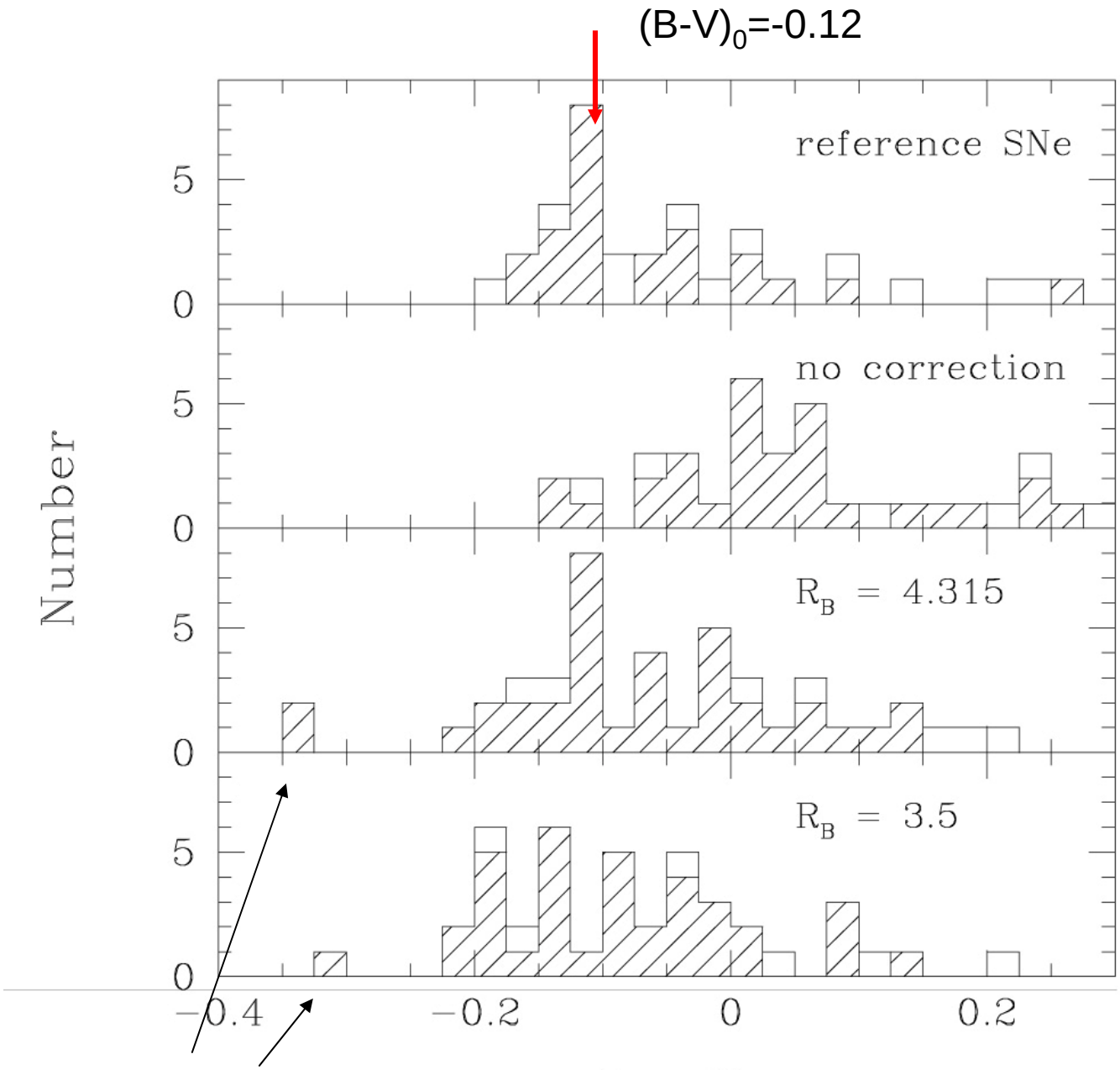


- E, S0 host



- BV Bluest
  -0.14<B-V<-0.10
- BV Bluer
  -0.10<B-V<-0.02

$A_\lambda = R_\lambda \times E(B\text{-}V)$



Abs. B ~ bluest

Abs. B
fainter than bluest

MW R_B

consistent

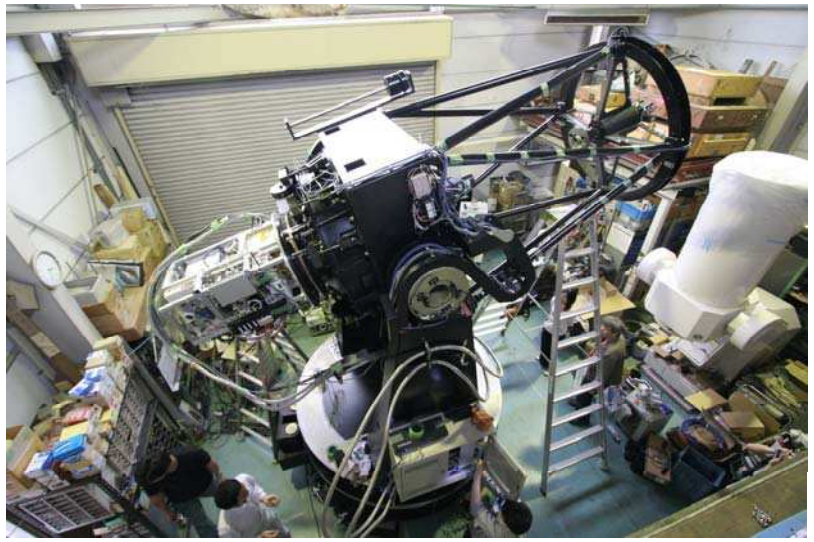
smaller R_B

SN1991T(luminous Ia)

Color excess
dust extinction & “intrinsic” color

Mini-TAO(1m Pilot Telescope)

- Funded by JSPS grant
- May 2007: Completed at Kyoto
- Apr. 2009? : First Light
- Primary targets
  - NIR Pa α/β cloud survey
  - MIR 30μm imaging
  - Experiment of telescope operation at 5600m altitude



- Manufactured by Nishimura Co. LTD.

2-m mediumTAO telescope (← MAGNUM @ Haleakala) ?

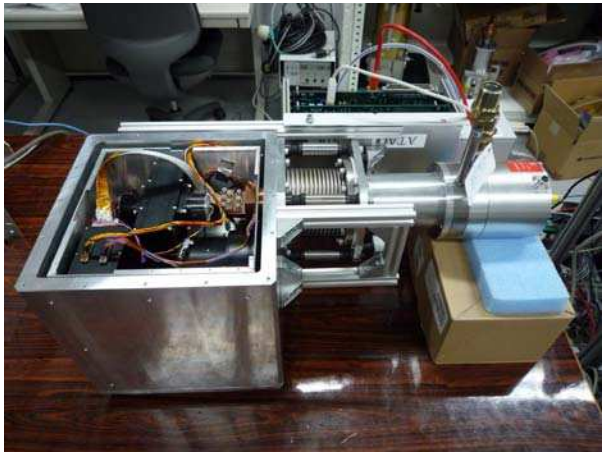
Instruments for mini-TAO 1m : NIR

- ANIR (Atacama Near-InfraRed camera)
  - 0.3”/pix, 5’x5’ FOV
  - Filters :

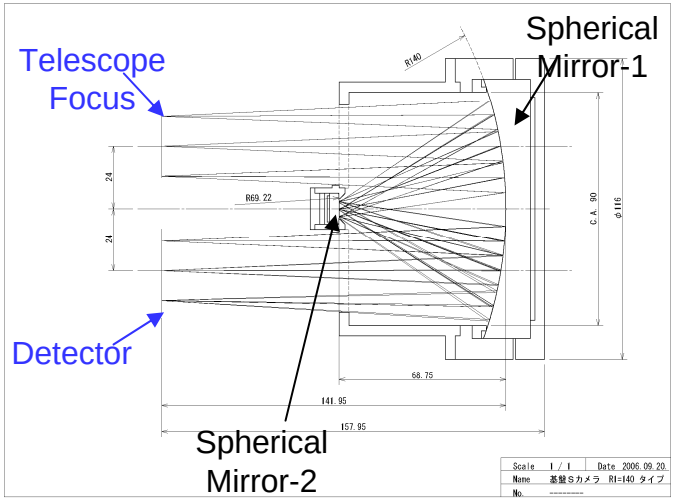
    NIR:Pa α/βNBF, zJHK

    Opt:B,V,R,I

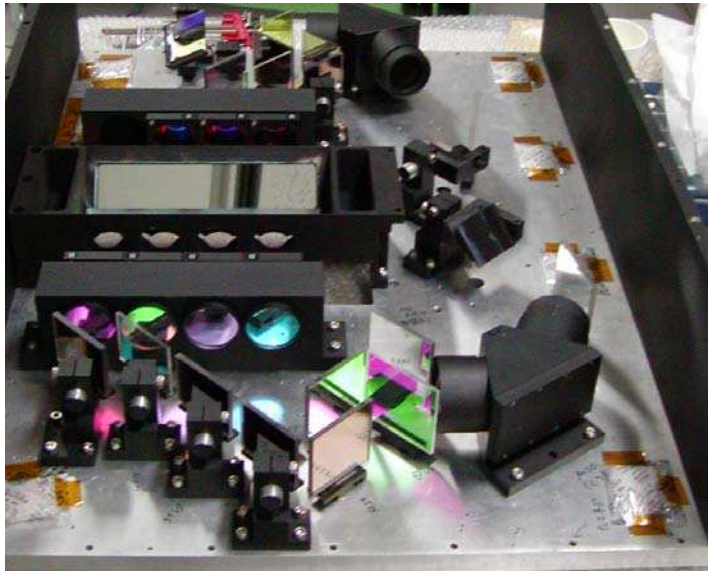
- First Scientific Observation of Paα from the Ground
  - Probe Deeply Dust Embedded Star Formation
- Variable Starts
- Photometry of SNe and Host Galaxies



Dewar Under Development



First Light of UT 15-band Dichroic-Mirror Camera

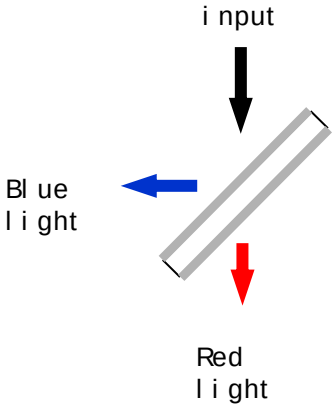


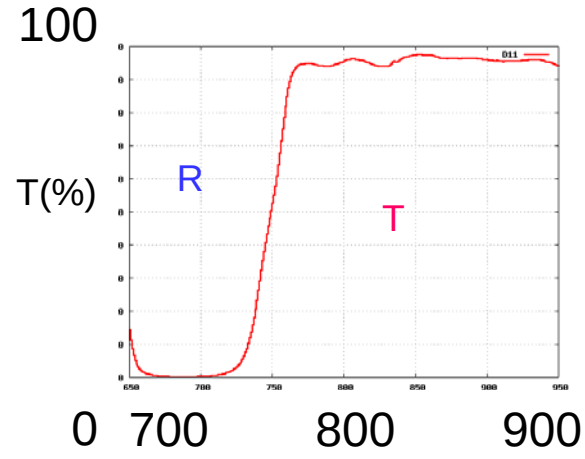
Mamoru Doi (Institute of Astronomy, School of Science, University of Tokyo)

Hayano, Utsunomiya, Ihara, Tokita, Sako, Okamura (Univ. of Tokyo),
Takanashi, Morokuma, Furusawa, Nakaya, Komiyama, Yagi, Okada (NAOJ),
Arai, Uemura, Kawabata, Yamashita, Osugi (Hiroshima Univ.)
Ito (Graduate Univ. for Advanced Studies), Kuncarayakti (Institut Teknologi Bandung),
Abe, Hasegawa (JAXA), Takeyama (GENESIA), Yamamuro (Optcraft), and Iwamura (MRJ)

SPIE Astronomical Instrumentation 2008 in Marseille, France, 23-28 June

Idea:Multi-band simultaneous imaging using many dichroic mirrors

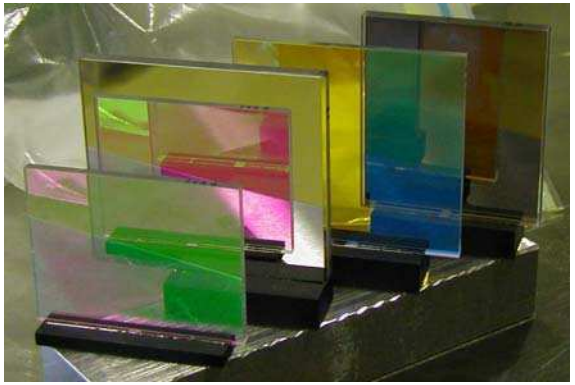


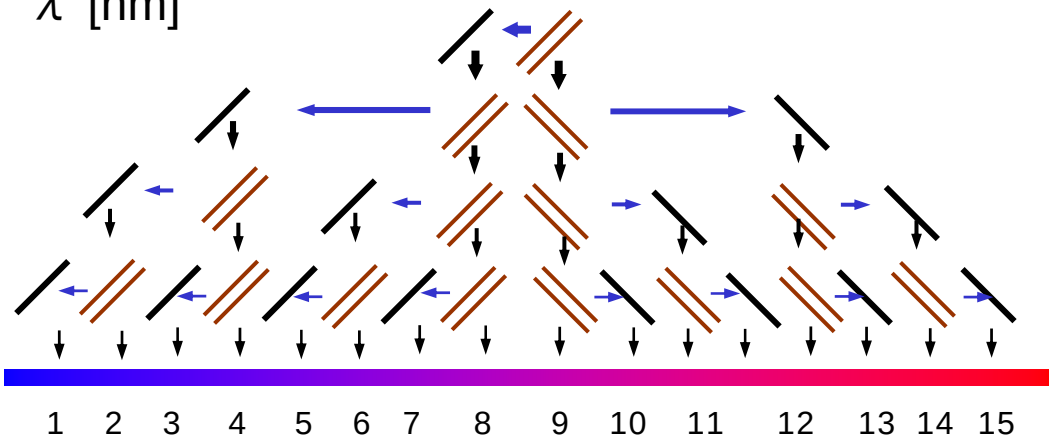


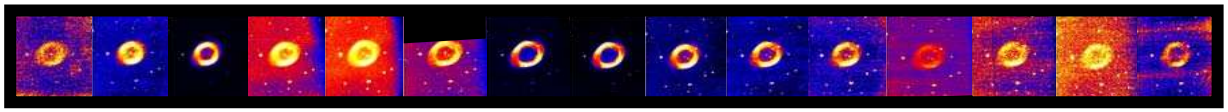
From telescope

Dichroic mirror

Mirror

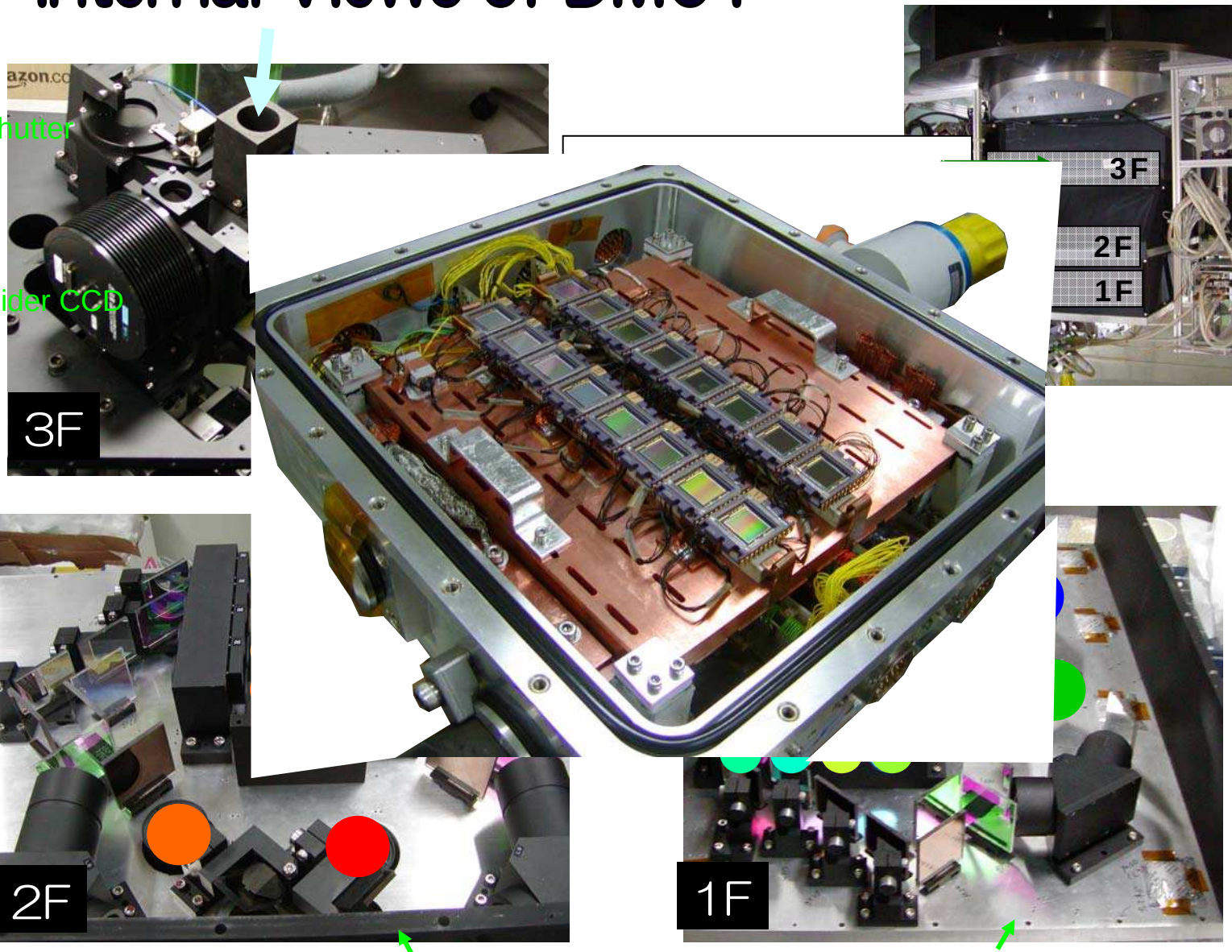






Internal Views of DMC1

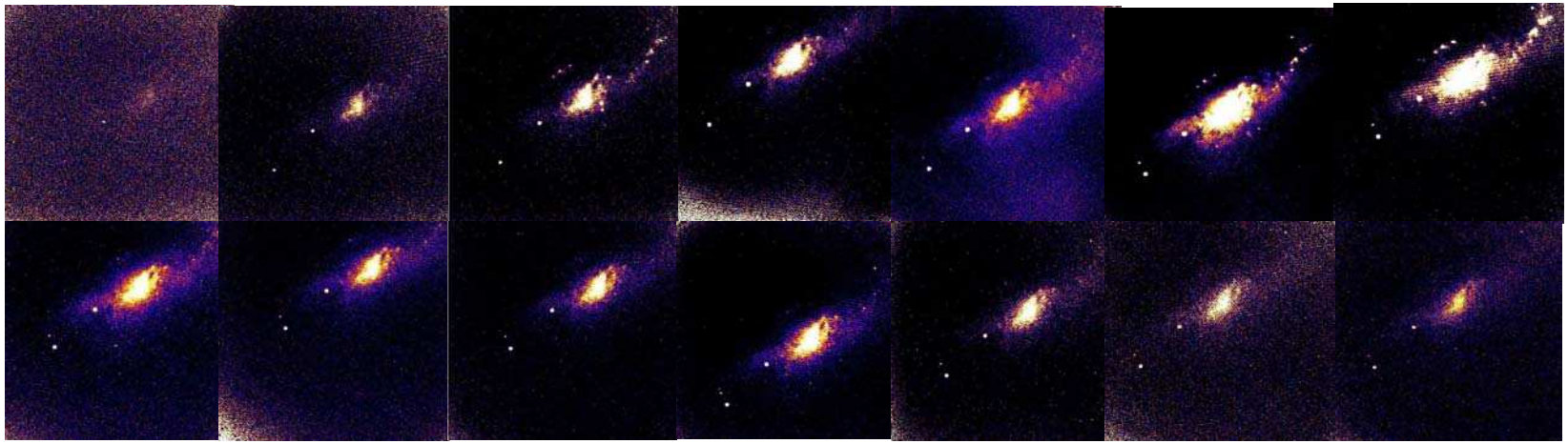
>100 optical components!



Dichroic Mirror Camera

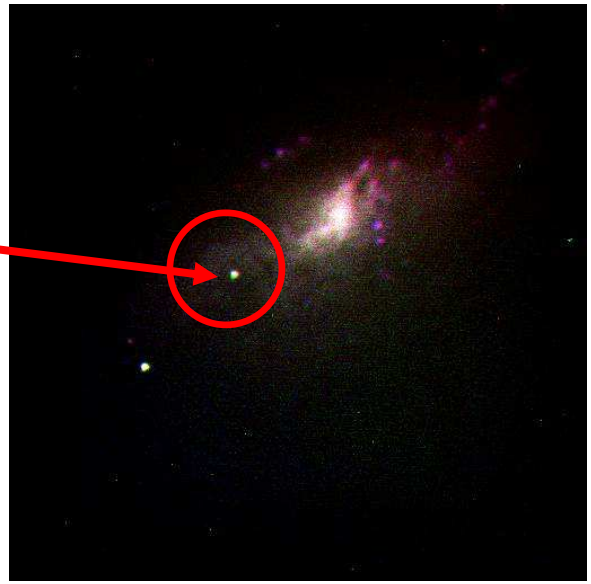
SN2008ax (V~16mag) & NGC4490 (2008/03/08) exp=1200sec at 1.5m Kanata

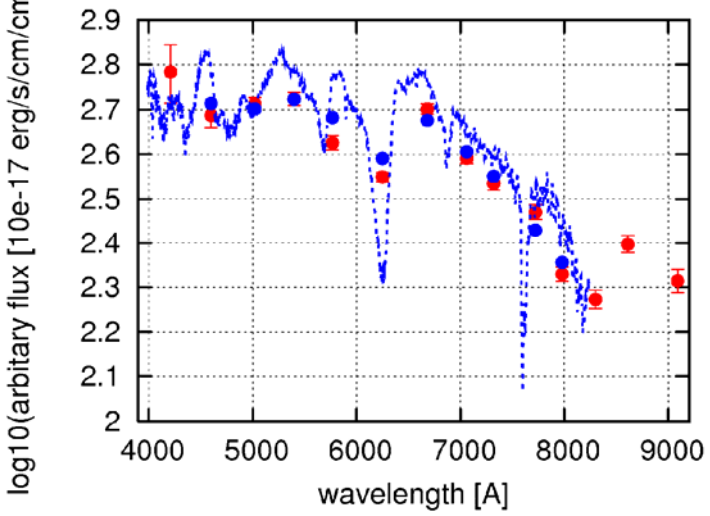
Ch01(420nm) Ch02(Hβ) Ch03(OIII) Ch04 Ch05 Ch06+07 Ch08(Hα)



Ch09 Ch10 Ch11 Ch12 Ch13 Ch14 Ch15(900nm)

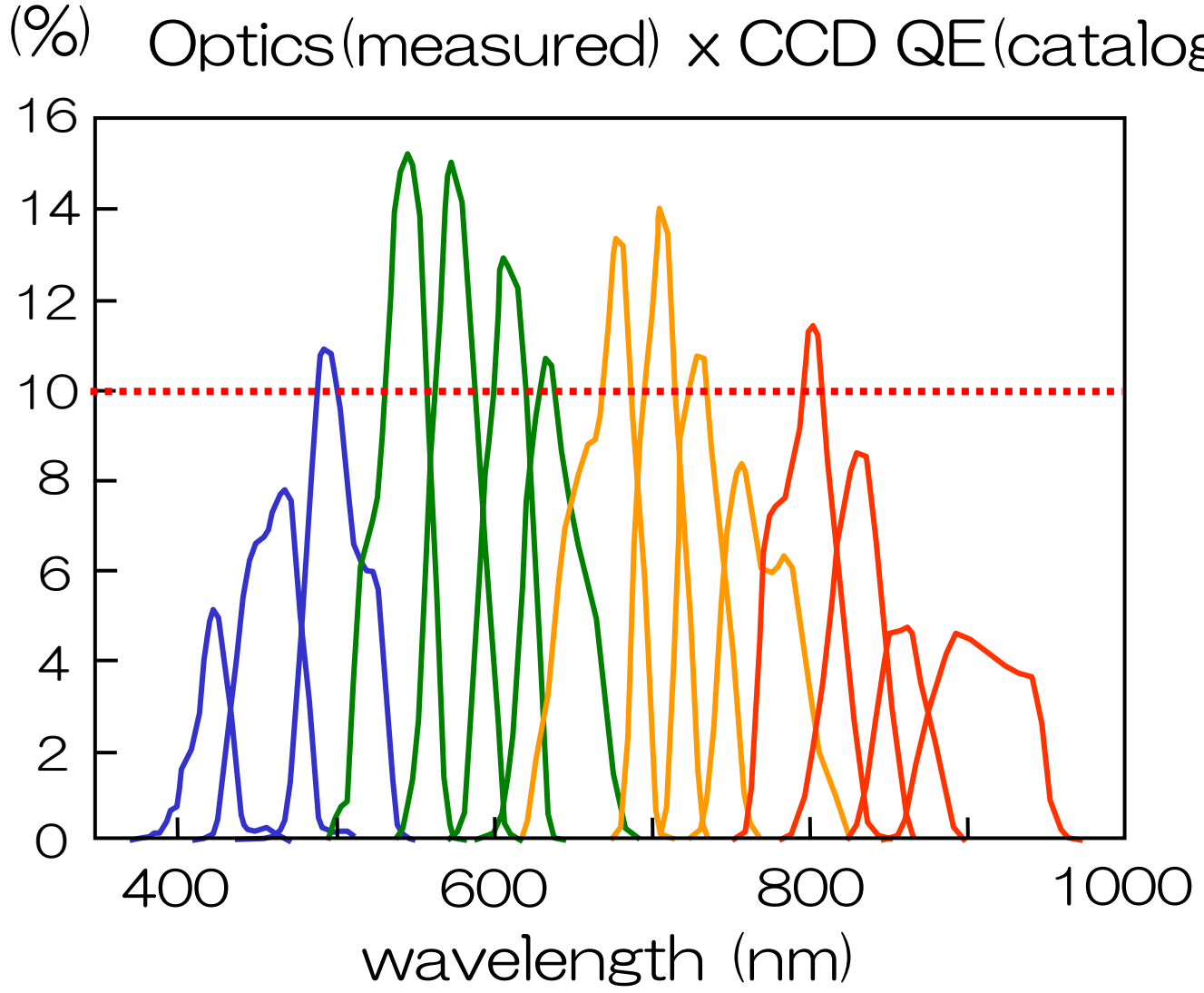
SN2008ax





Red:DMC Blue: Pastorello et al. 2008

Expected Response with CCD QE



2-m mediumTAO 6min exposure ⇒S/N~20 for 19 mag