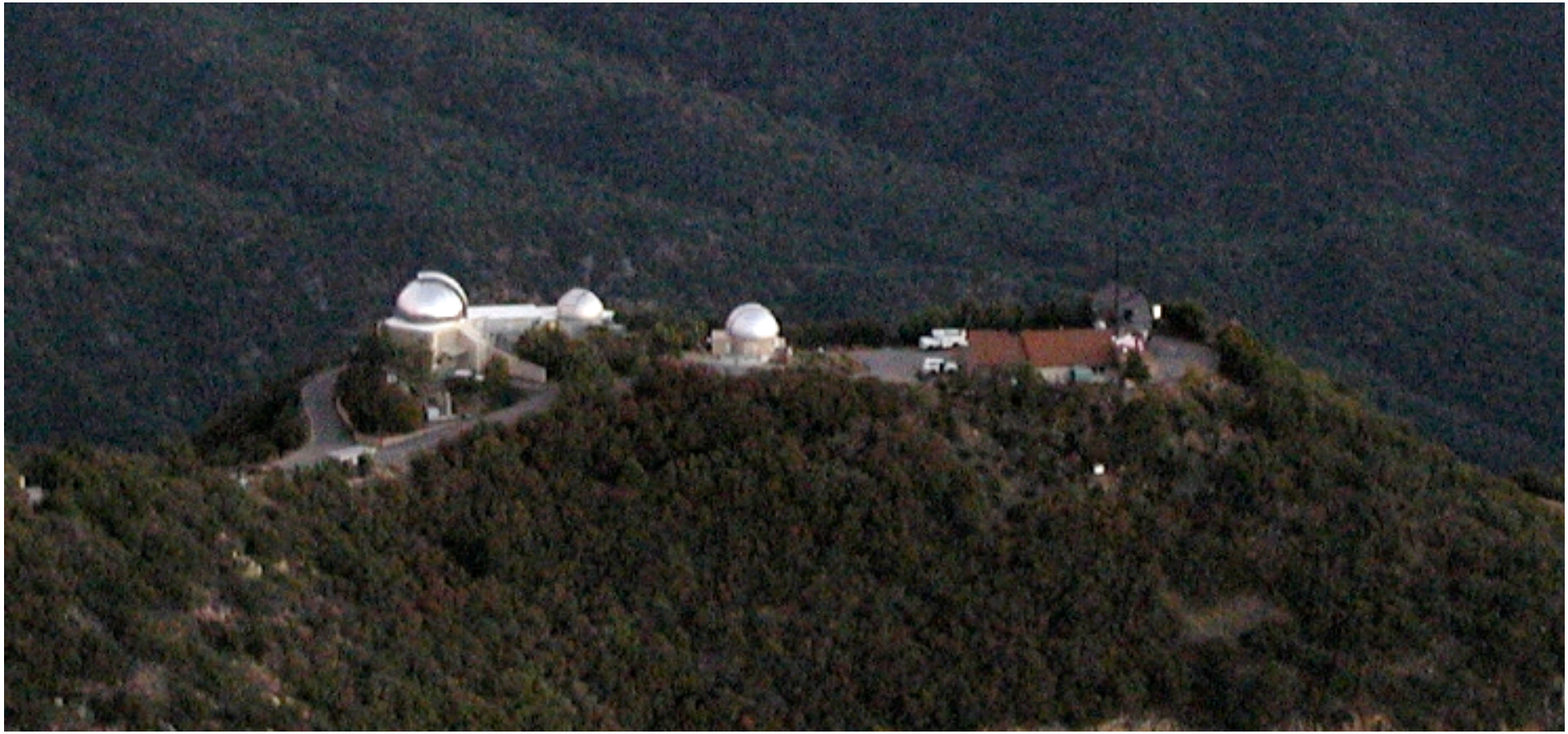
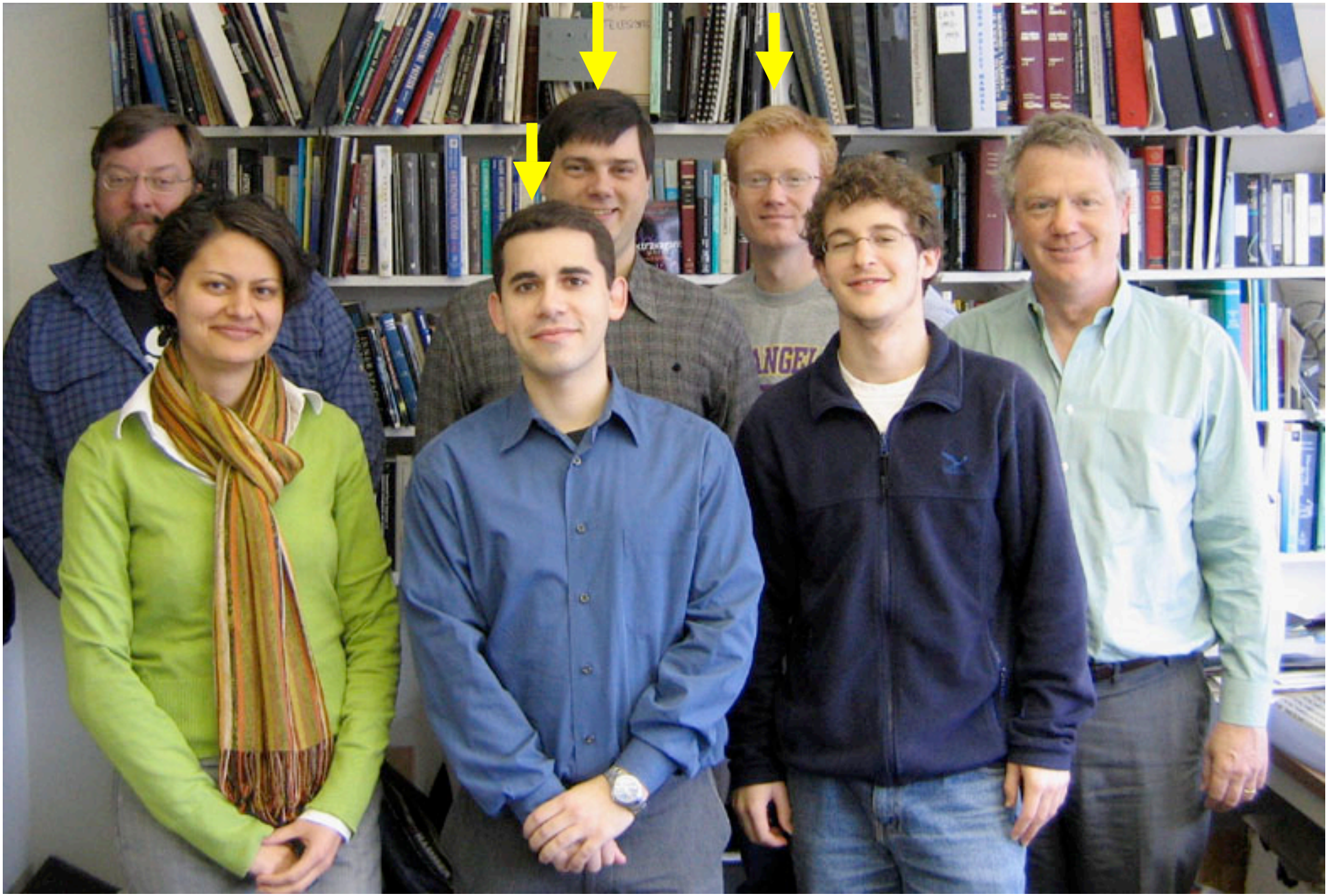
Some recent results on SN Ia as distance indicators



Robert P. Kirshner
Harvard-Smithsonian
Center for Astrophysics

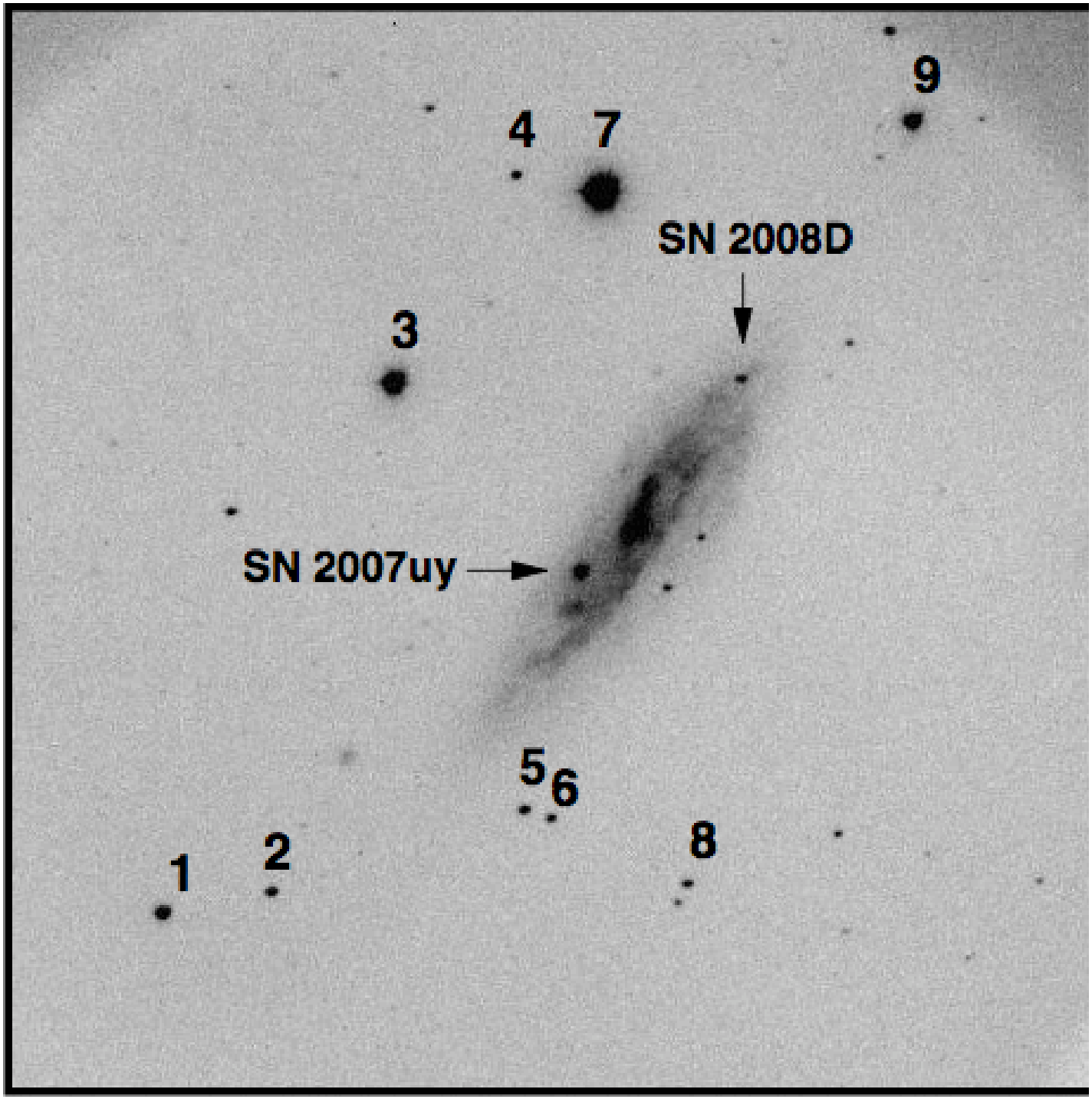
CfA Supernova Group



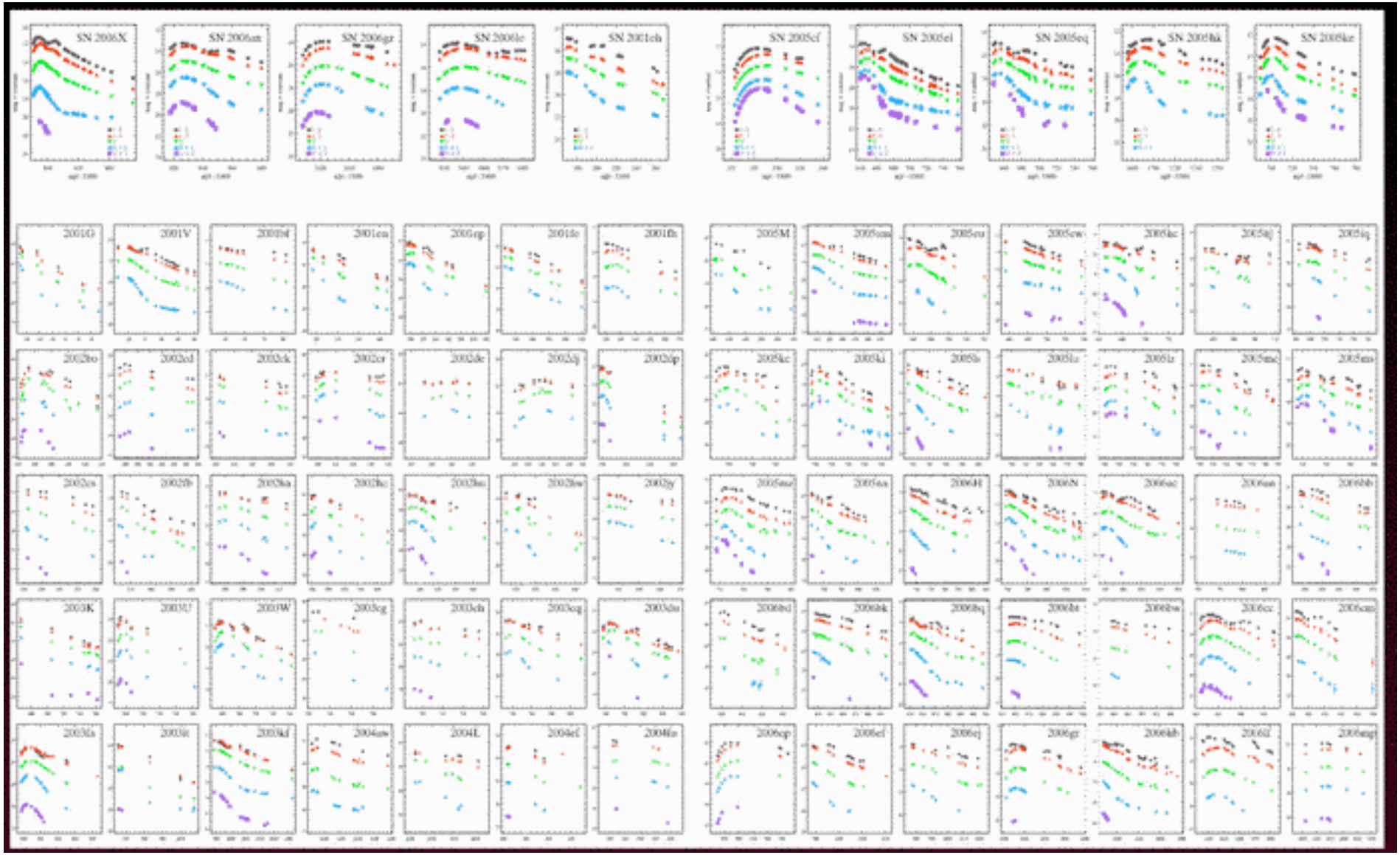
Observatory

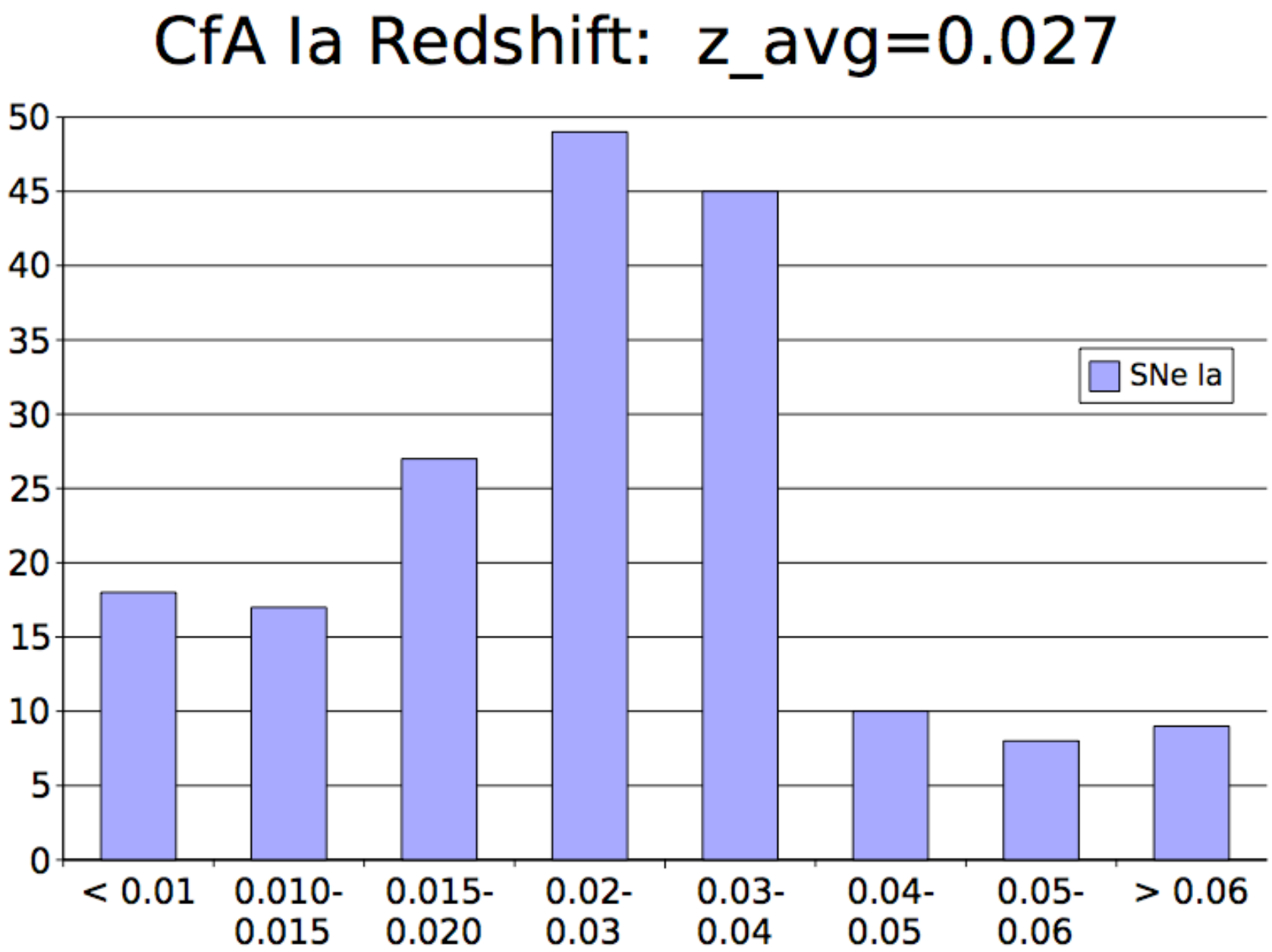
UBVri on demand

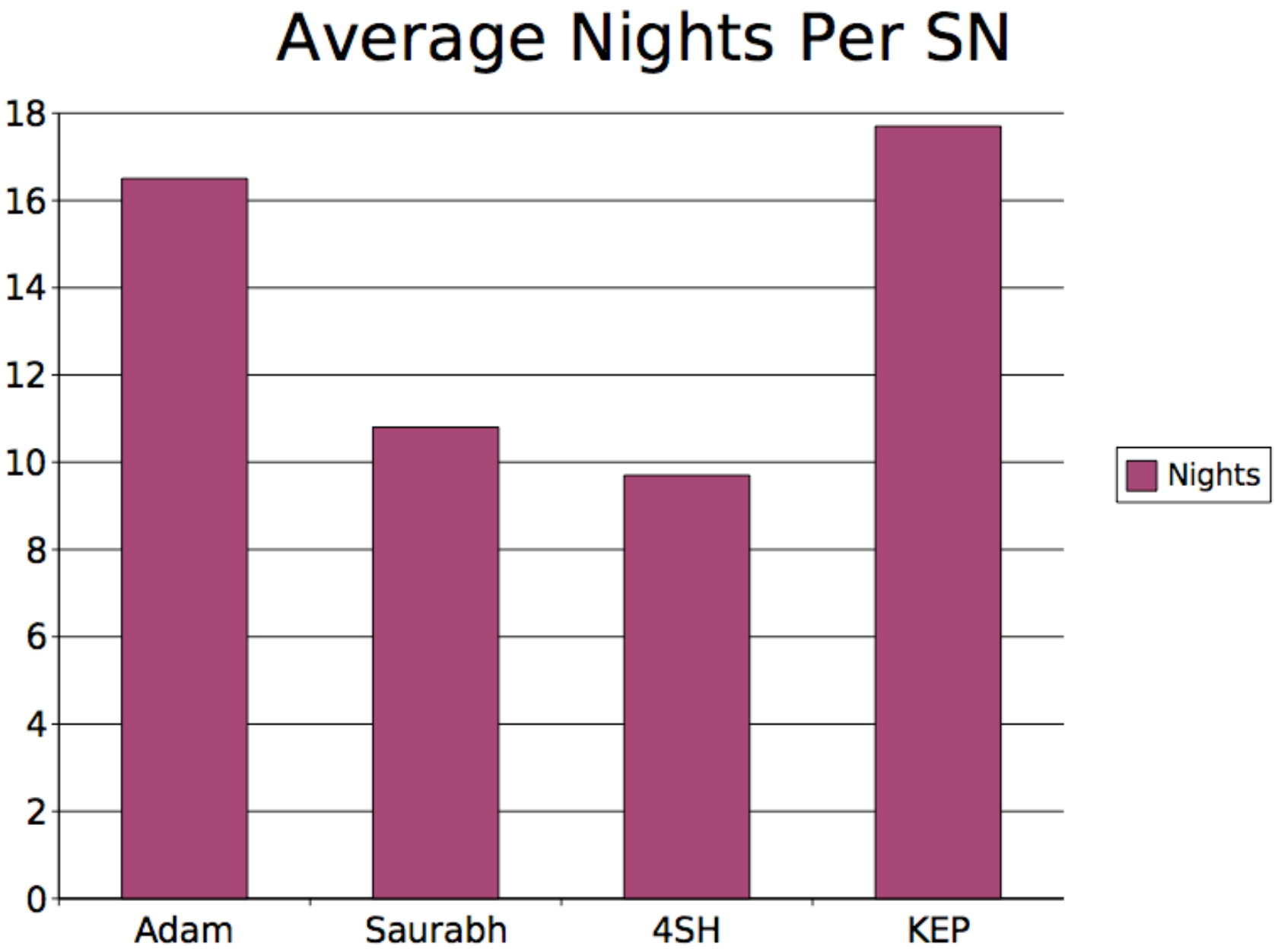
SN from Lick search, amateurs around the world

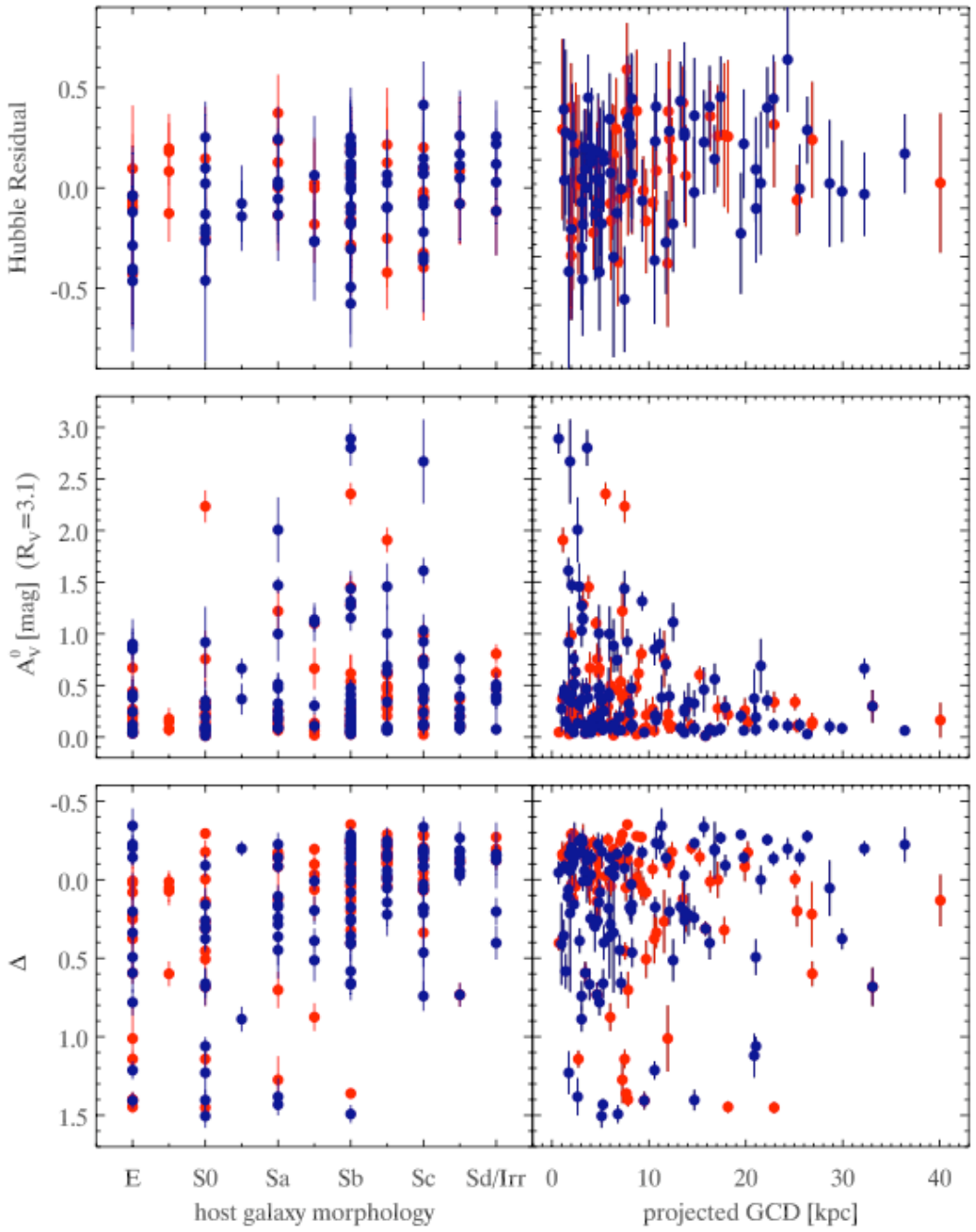


Malcolm Hicken's Ph.D. Thesis




CfA Ia Redshift: z_avg=0.027
50
45
40
35
30
25
20
15
10
5
0
SNe Ia
< 0.01
0.010-0.015
0.015-0.020
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
> 0.06


Average Nights Per SN
18
16
14
12
10
8
6
4
2
0
Adam
Saurabh
4SH
KEP
Nights



CfA 3
150 SN Ia
UBVri

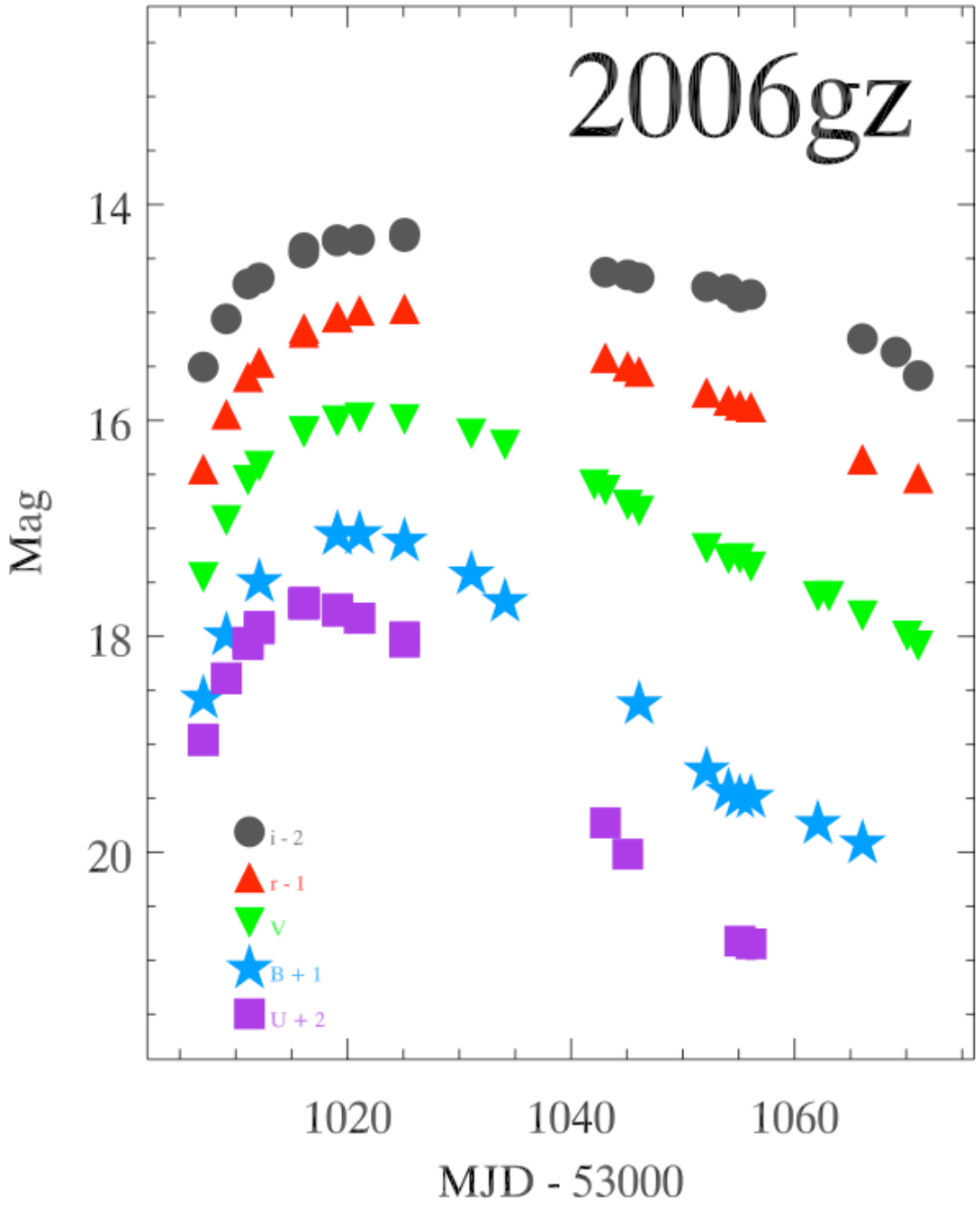
- CfA 1
  Riess et al (1999)
- CfA 2
  Jha et al (2007)
- CfA 3
  Hicken et al (coming soon!)

Note spread in E's,

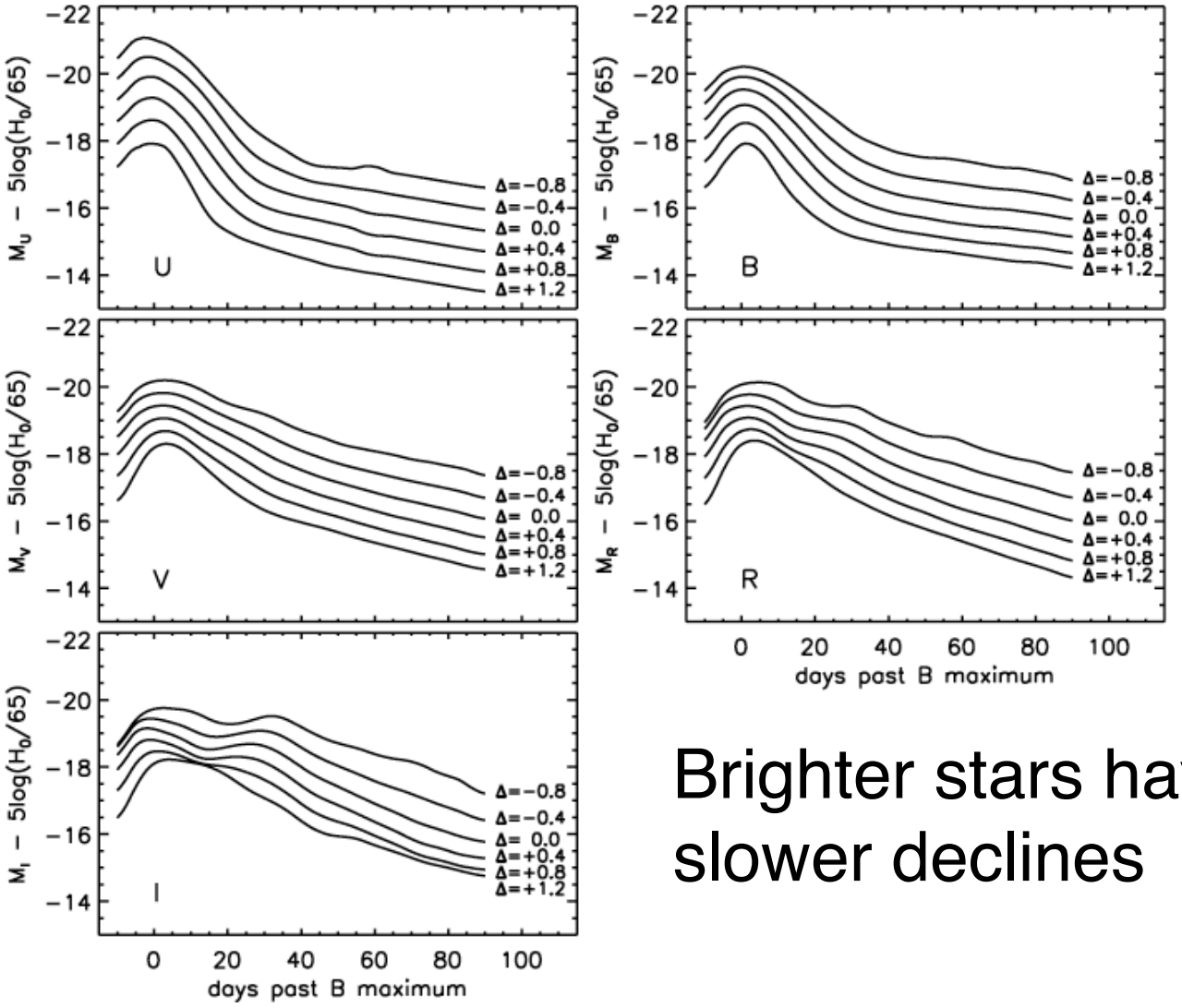
Absence of fast decliners in Sd,

Small scatter at larger projected distance

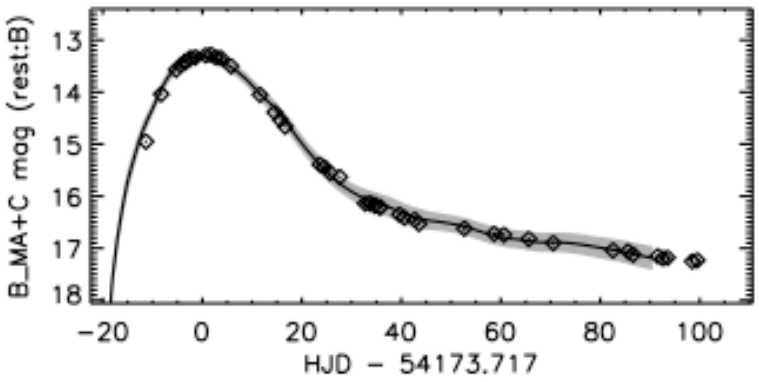
CfA:
Following up with light curves

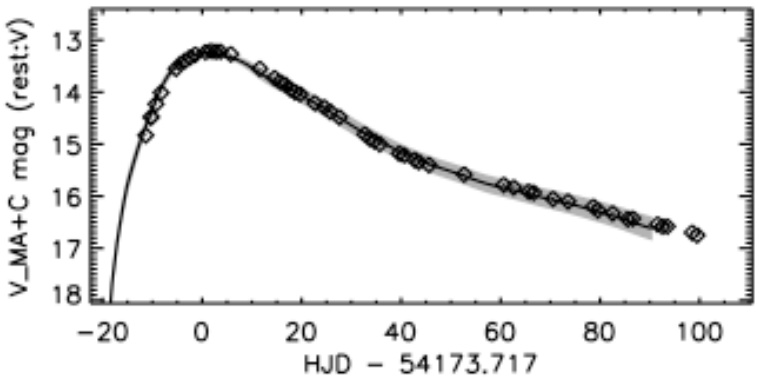

2006gz
14
16
18
20
Mag
i - 2
r - 1
V
B + 1
U + 2
1020
1040
1060
MJD - 53000

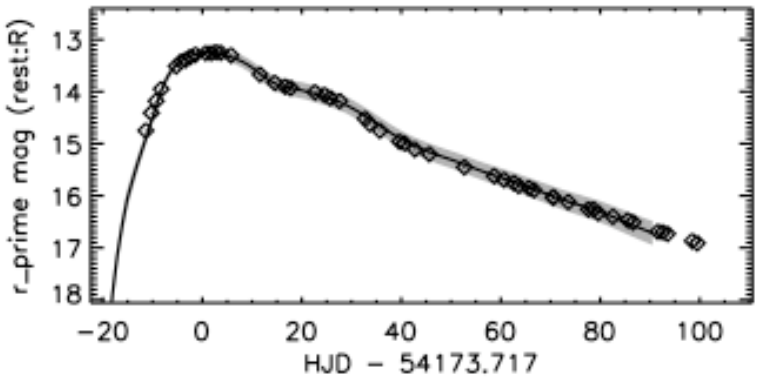
Light Curve Shapes => L

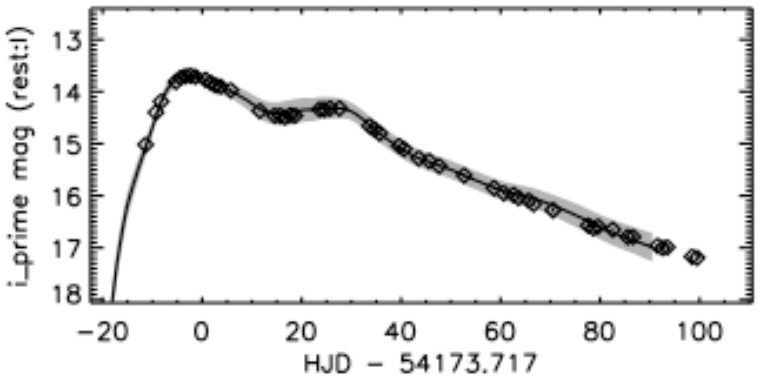


Brighter stars have slower declines









MLCS 2k2 fits

SALT, SALT2

sn07af.df.k20080602.la.c

t_0 = 54173.717 R_v = 3.10

Δ = −0.06 A_v = 0.39

μ_0 + 5 log (H_0/65) = 32.38

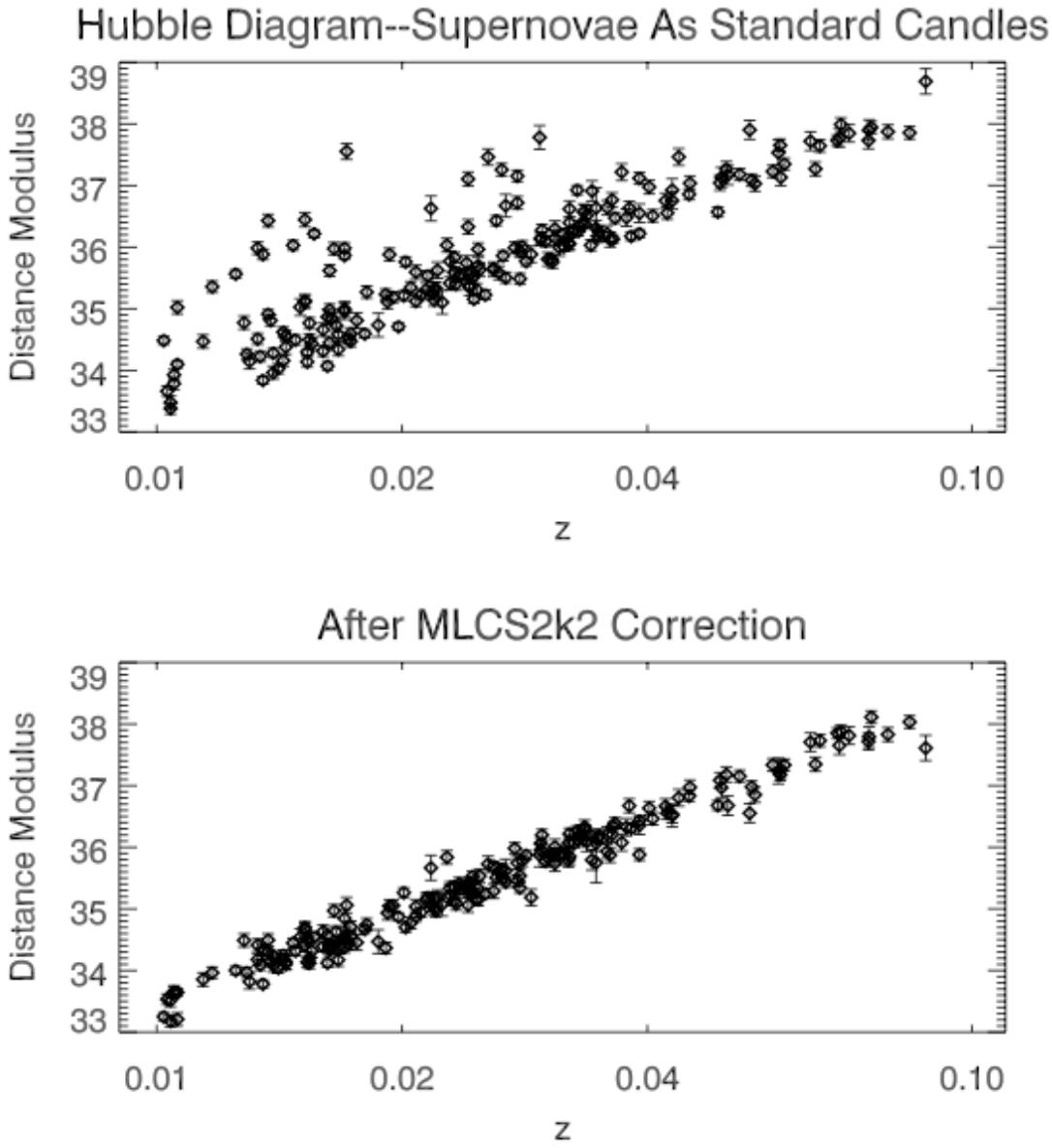
$E(B-V)_{MW}$ = 0.04 z = 0.0055

χ^2/ν = 28.41/202

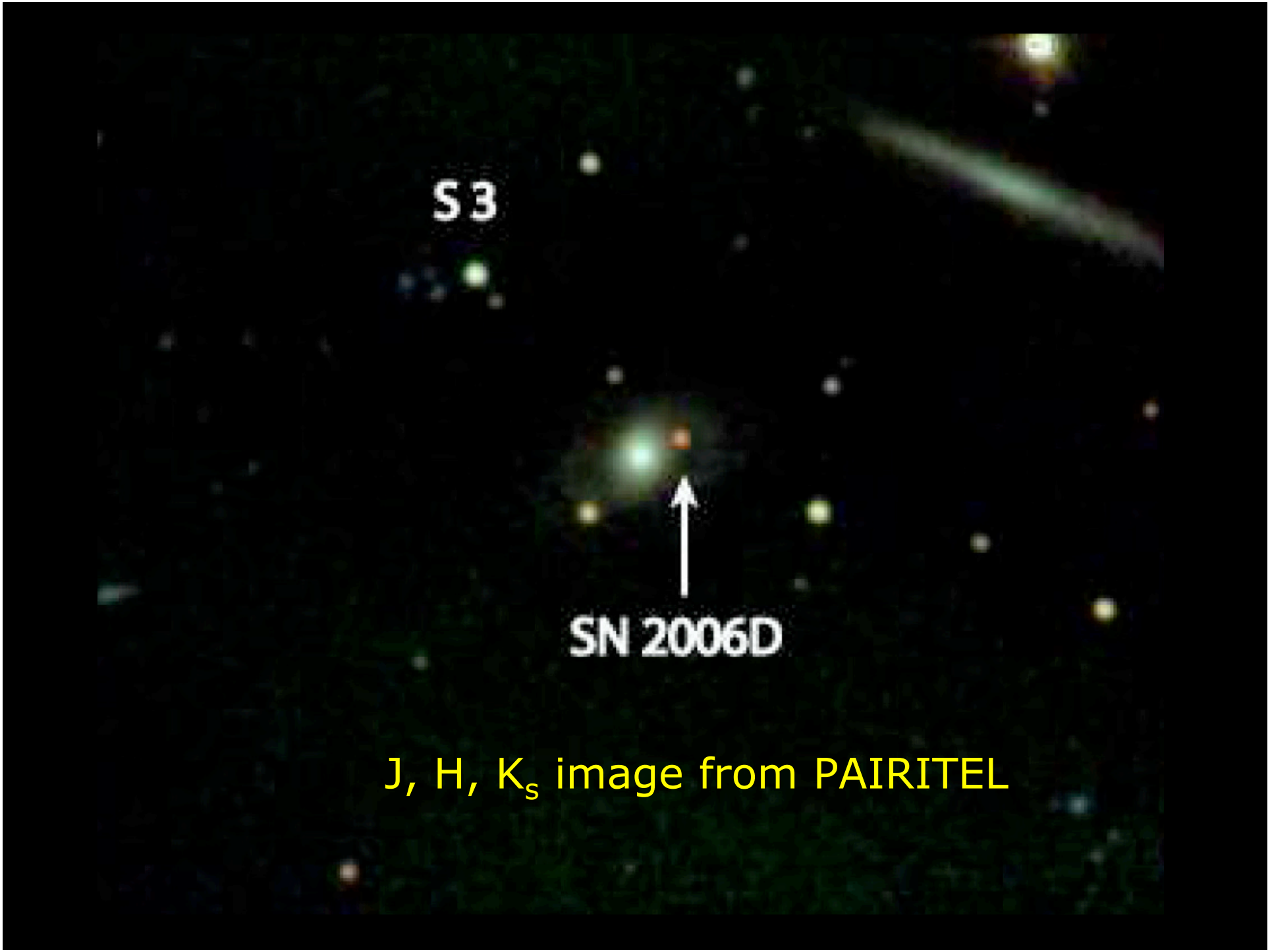
N~150
Approaching the end of statistical limits-- now the errors are systematic.

The largest of these is due to light curve fitting + dust properties.

See Conley et al (2007)

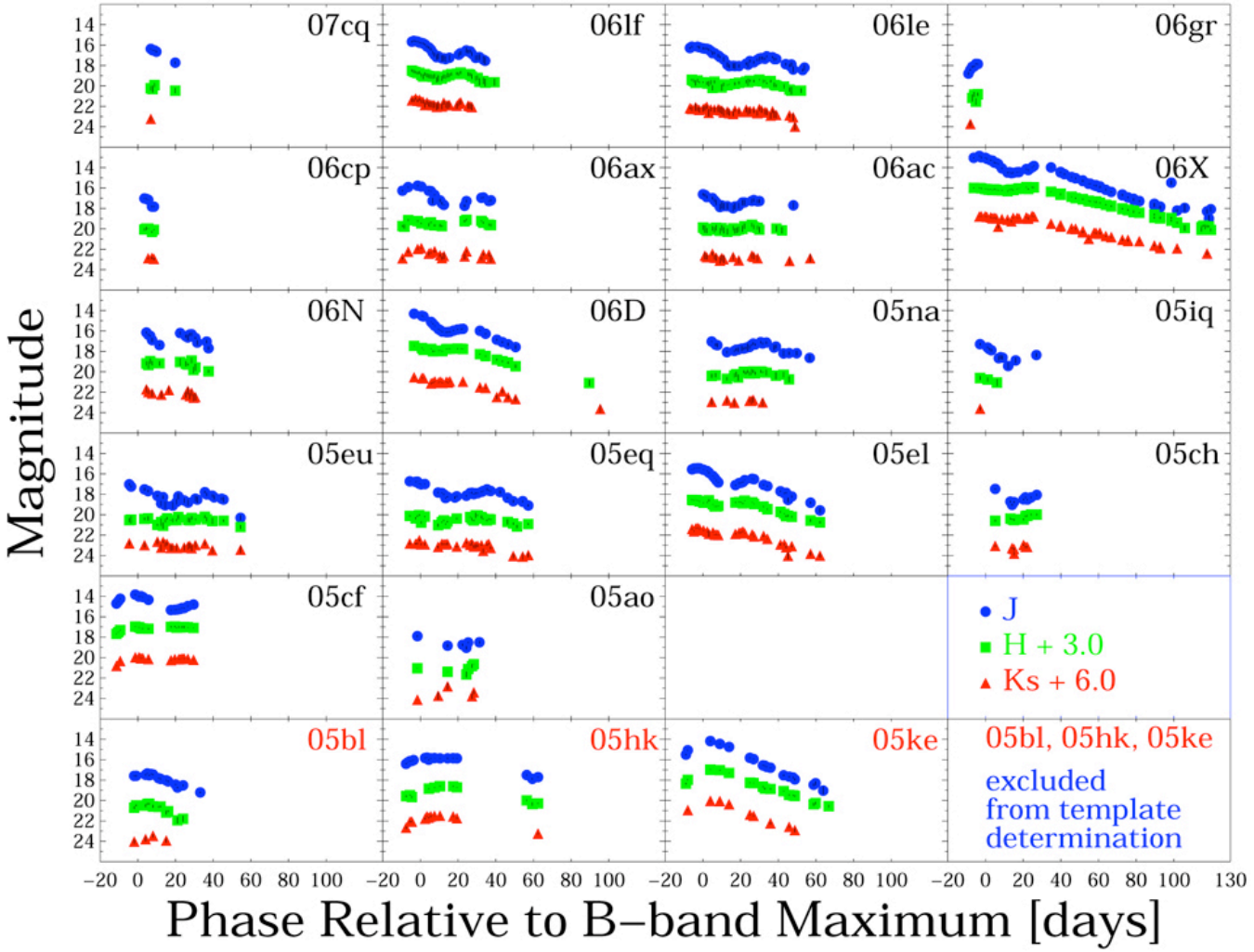


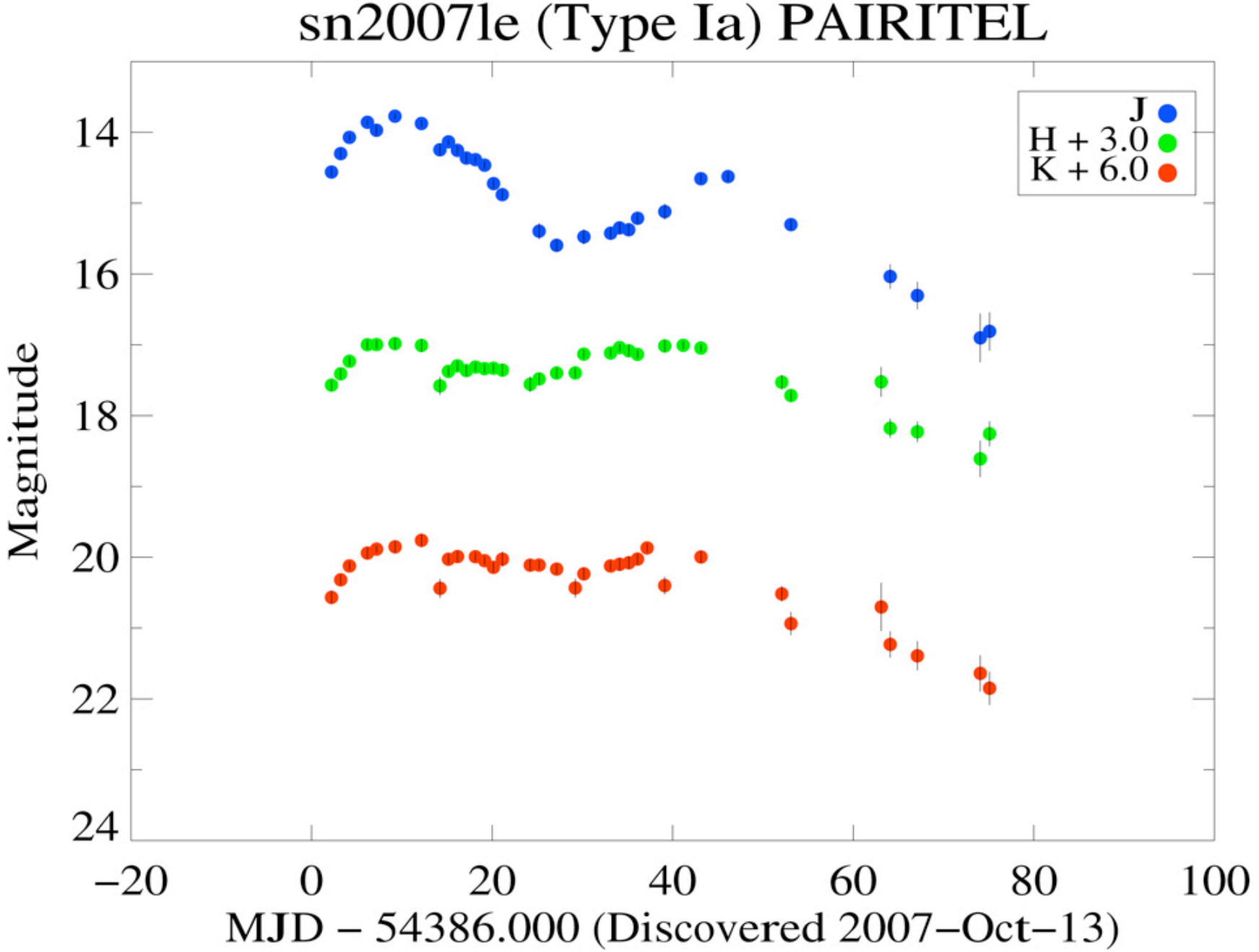
CfA:
Following up with IR light curves



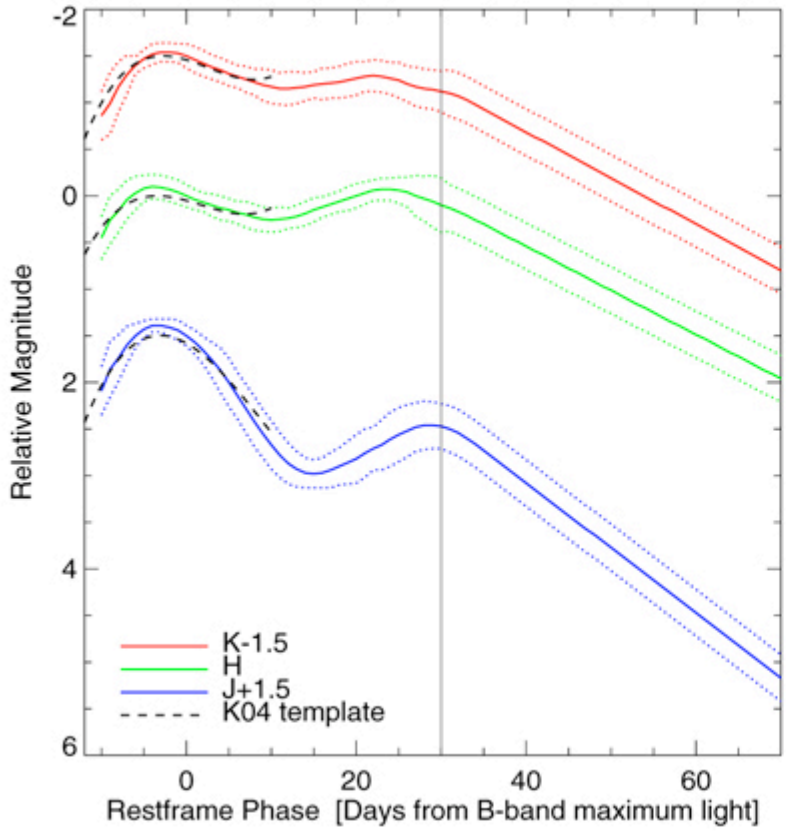
J, H, K_s image from PAIRITEL

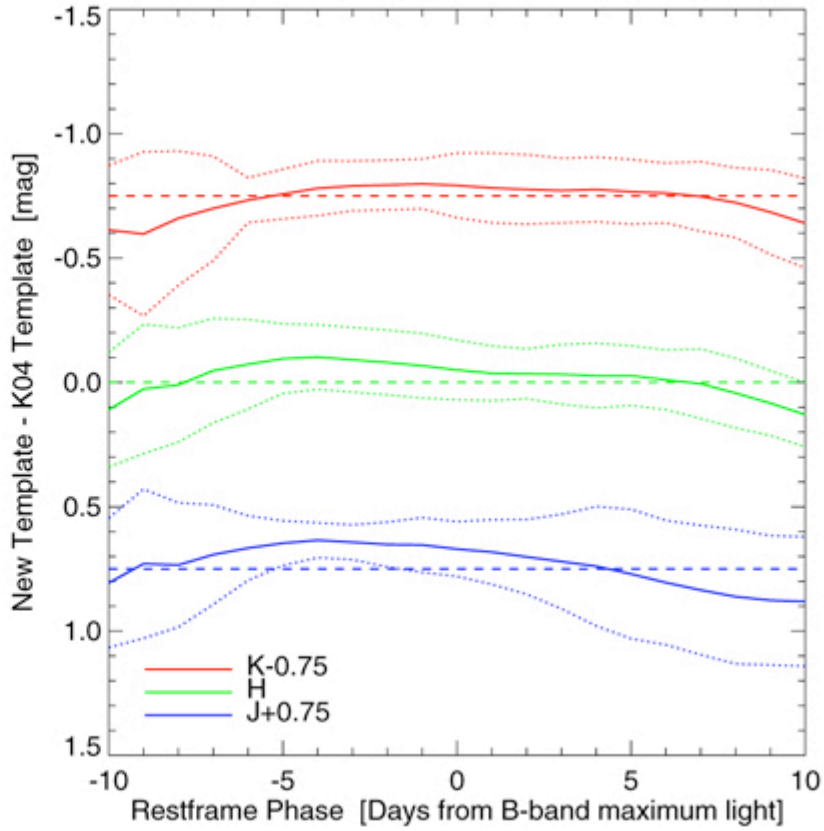
Some PAIRITEL Lightcurves
J, H, K_s




sn2007le (Type Ia) PAIRITEL
J
H + 3.0
K + 6.0
Magnitude
14
16
18
20
22
24
−20
0
20
40
60
80
100
MJD − 54386.000 (Discovered 2007−Oct−13)

Infrared Templates





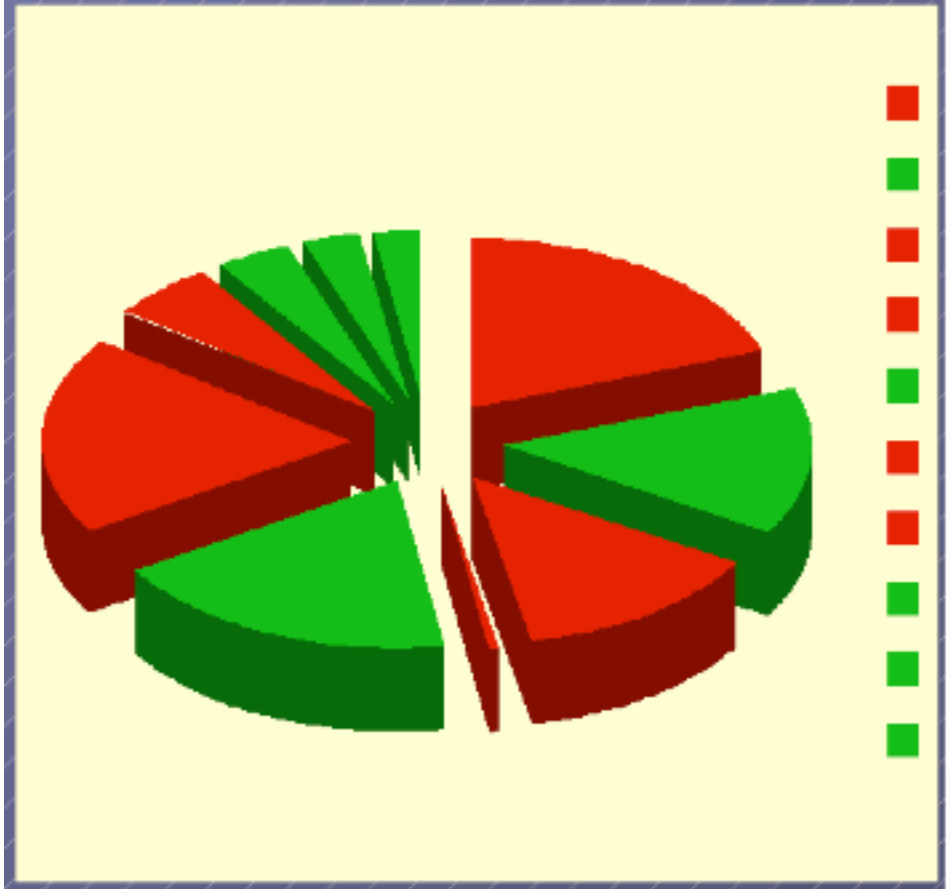
Wood-Vasey et al
(arXiv:0711.2068)

Systematic Errors: the name of this game!

Source	dw/dx	Δx	Δ_w	Notes
Phot. errors from astrometric uncertainties of faint objects	1/mag	0.005 mag	0.005	
Bias in diff im photometry	0.5 / mag	0.002 mag	0.001	
CCD linearity	1 / mag	0.005 mag	0.005	
Photometric zeropoint diff in R,I	2 / mag	0.02 mag	0.04	
Zpt. offset between low and high z	1 / mag	0.02 mag	0.02	
K-corrections	0.5 / mag	0.01 mag	0.005	
Filter passband structure	0 / mag	0.001 mag	0	
Galactic extinction	1 / mag	0.01 mag	0.01	
Host galaxy R_V	0.02 / R_V	0.5	0.01	"glosz"
Host galaxy extinction treatment	0.08	prior choice	0.08	different priors
Intrinsic color of SNe Ia	3 / mag	0.02 mag	0.06	interacts strongly with prior
Malmquist bias/selection effects	0.7 / mag	0.03 mag	0.02	"glosz"
SN Ia evolution	1 / mag	0.02 mag	0.02	
Hubble bubble	$3/\delta H_{\rm effective}$	0.02	0.06	
Gravitational lensing	$1/\sqrt{N}$ / mag	0.01 mag	< 0.001	Holz & Linder (2005)
Grey dust	1 / mag	0.01 mag	0.01	
Subtotal w/o extinction+color	...	...	0.082	
Total	...	...	0.13	
Joint ESSENCE+SNLS comparison	...	...	0.02	photometric system
Joint ESSENCE + SNLS Total	...	...	0.13	

(Wood-Vasey et al., astro-ph/070141)

Identified systematics in SNLS3 (preliminary)

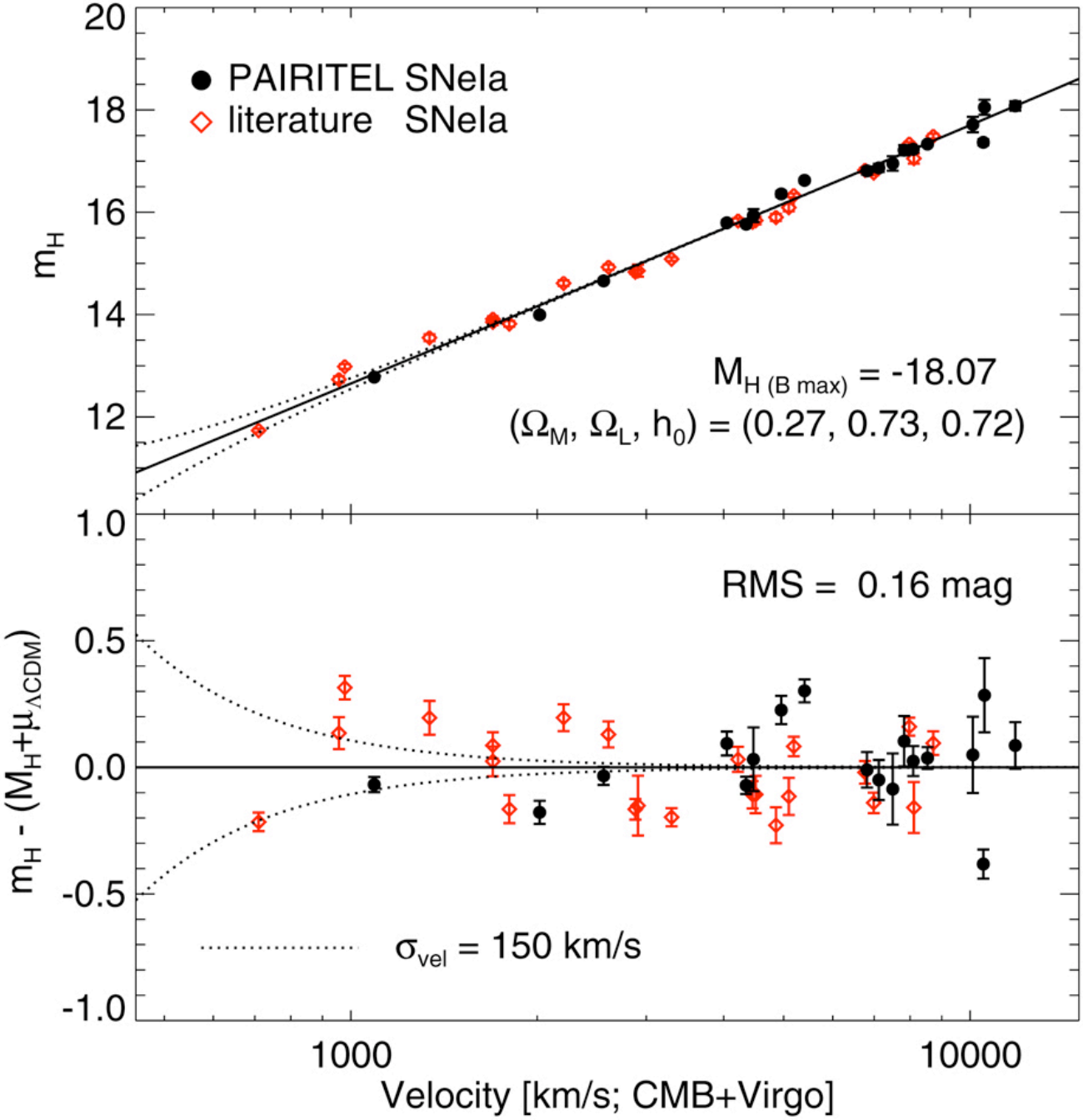


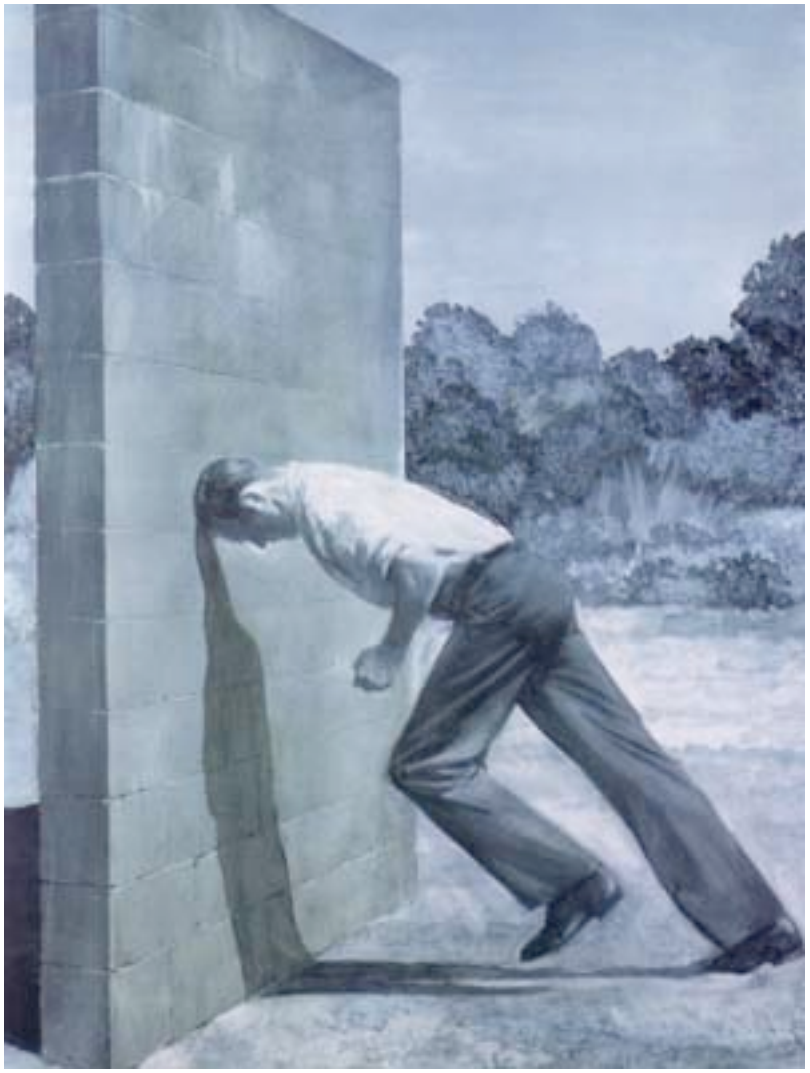
Guideline numbers

Systematic	% <w> error	Extra
Statistical only	0.059	…
SNLS zero points	0.069	0.031
SNLS filters	0.065	0.023
External zero points	0.064	0.021
External filters	0.061	0.010
SN color relation	0.067	0.027
Vega colours	0.068	0.030
Vega SED	0.061	0.009
Peculiar velocities	0.061	0.006
Malmquist bias	0.061	0.005
Nicmos non-linearity	0.060	0.004
All systematics	**~0.09**	**0.068**
All systematics	**~0.07**	**0.042**

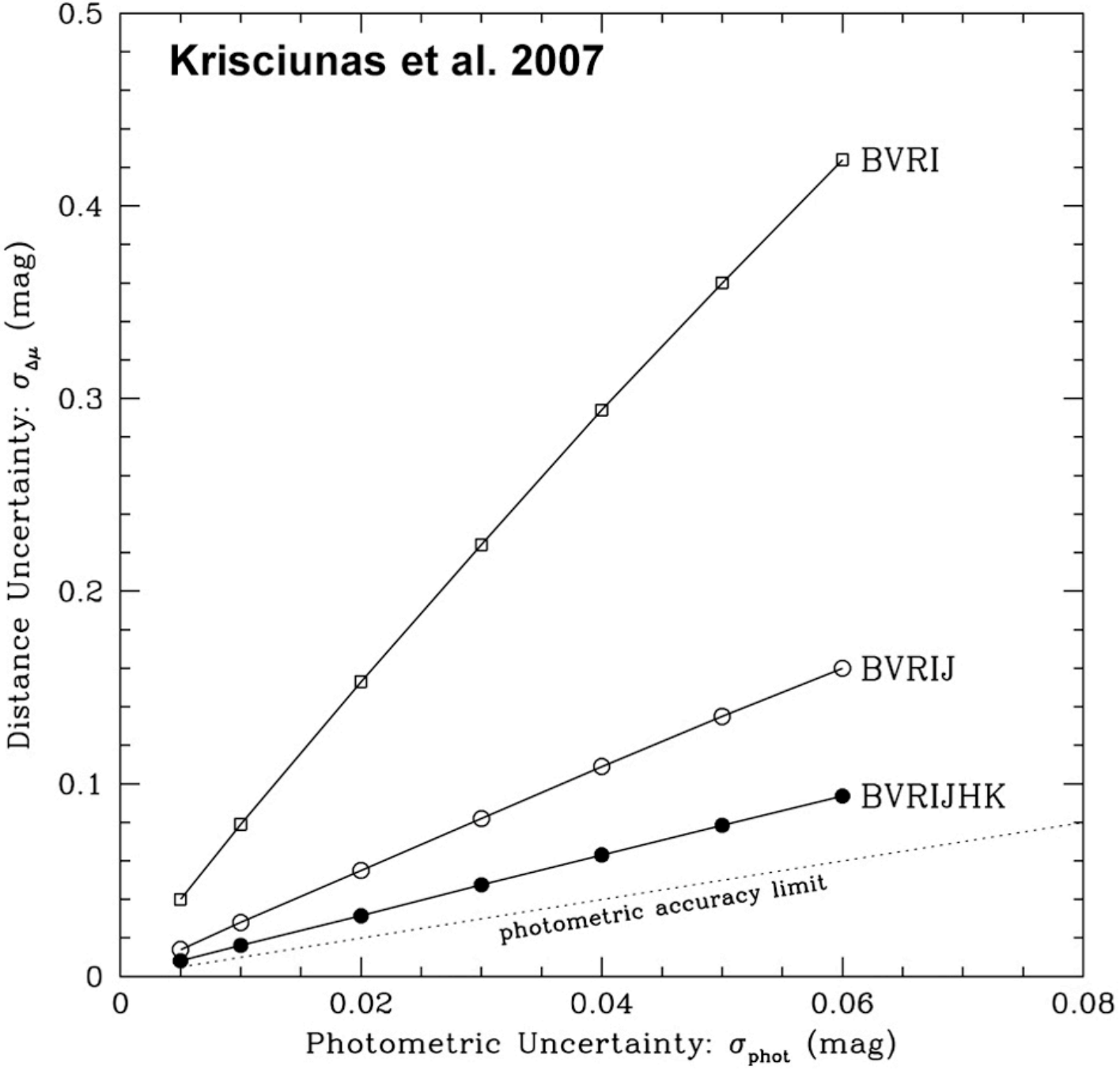
When low-redshift sample is replaced, systematics should drop to 4-5%

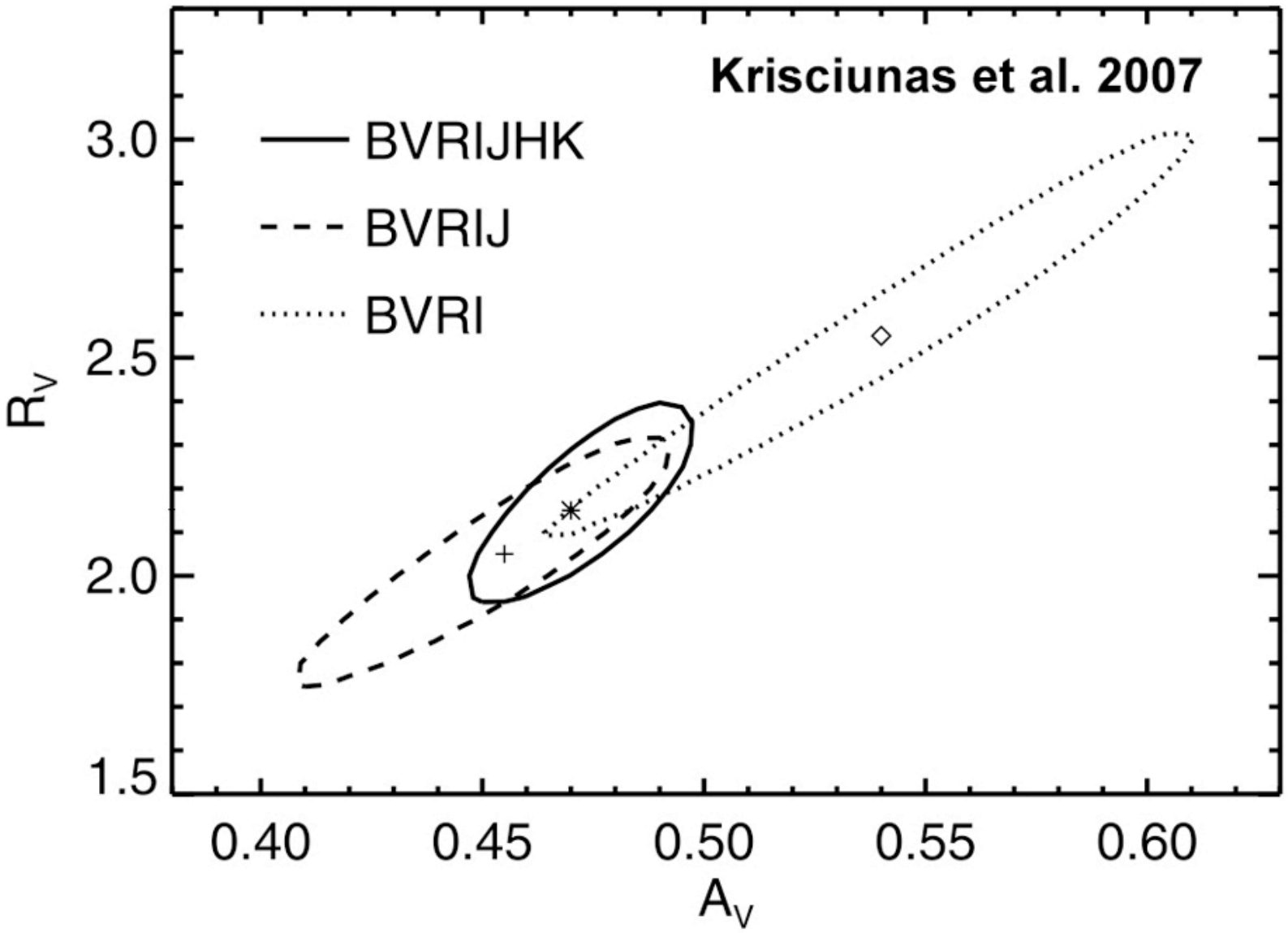
Need for a "rolling" low-z survey (e.g. CSP, Skymapper/PTF, SDSS?)


PAIRITEL SNIa
literature SNIa
$M_{H\ (B\ max)}$ = -18.07
$(\Omega_M, \Omega_L, h_0)$ = (0.27, 0.73, 0.72)
RMS = 0.16 mag
σ_{vel} = 150 km/s
m_H
$m_H - (M_H+\mu_{\Lambda CDM})$
Velocity [km/s; CMB+Virgo]
20
18
16
14
12
1.0
0.5
0.0
-0.5
-1.0
1000
10000

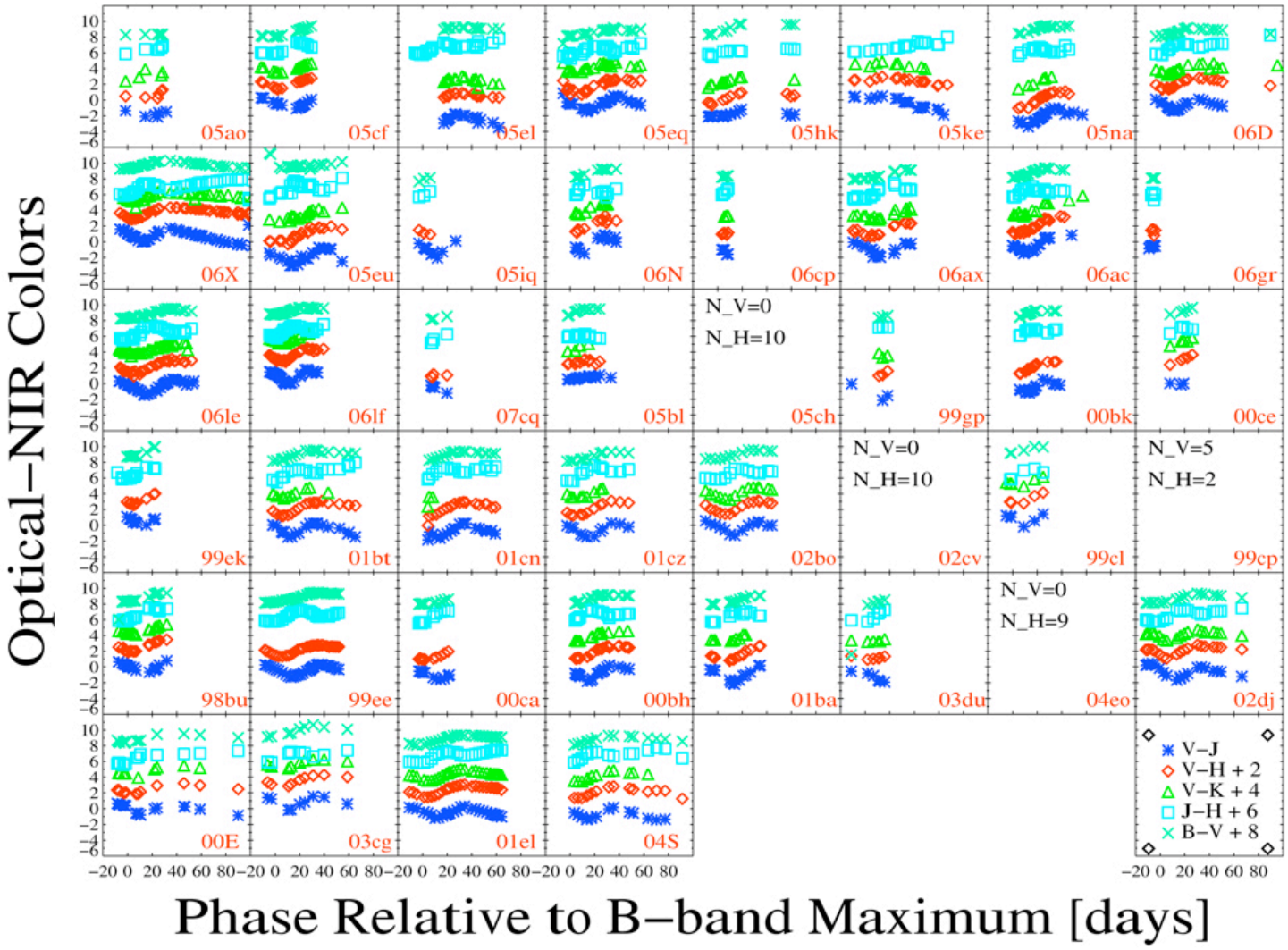


Something to avoid!

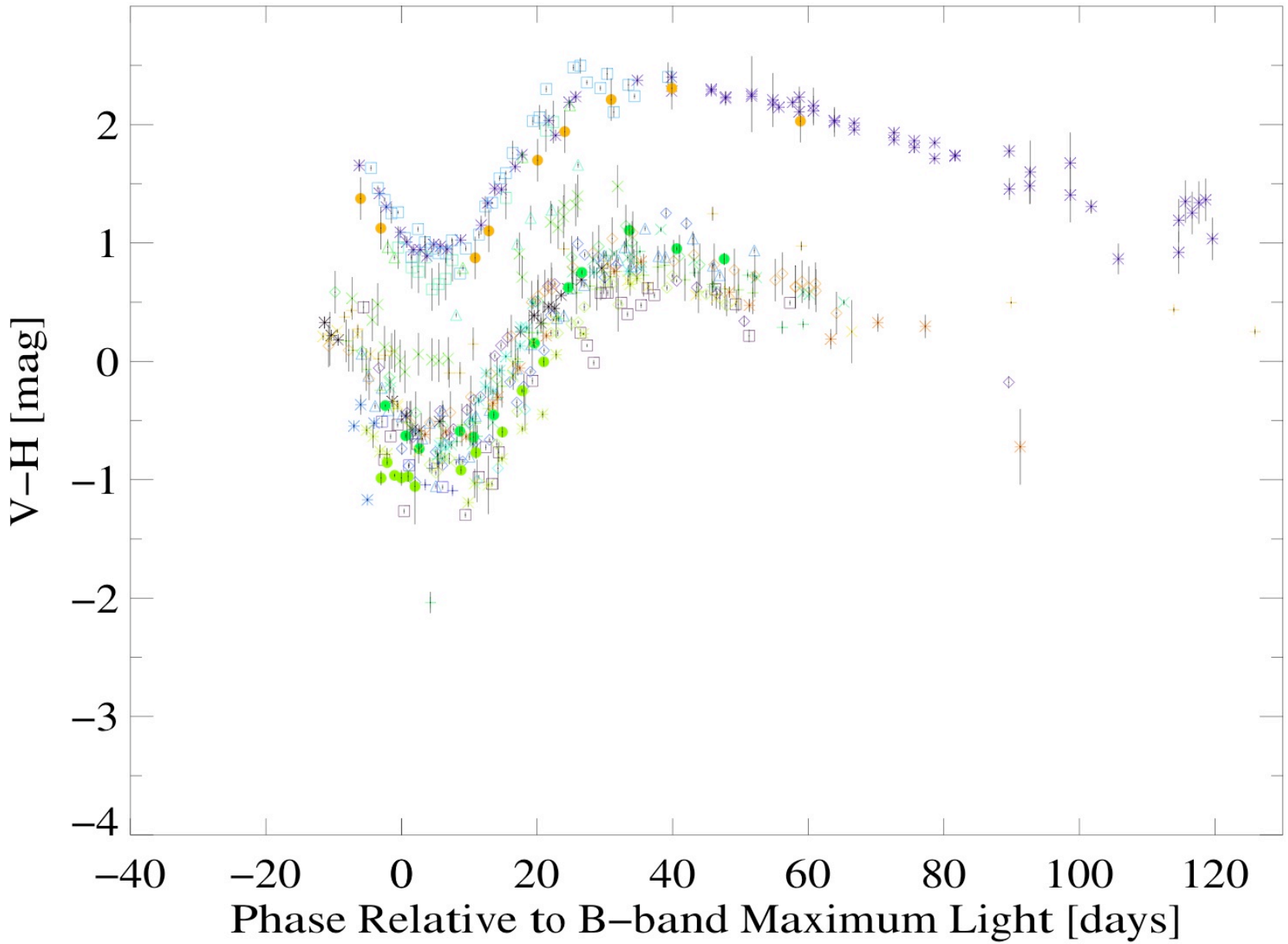

Krisciunas et al. 2007
BVRI
BVRIJ
BVRIJHK
photometric accuracy limit
Distance Uncertainty: $\sigma_{\Delta\mu}$ (mag)
Photometric Uncertainty: σ_{phot} (mag)
0
0.1
0.2
0.3
0.4
0.5
0.02
0.04
0.06
0.08



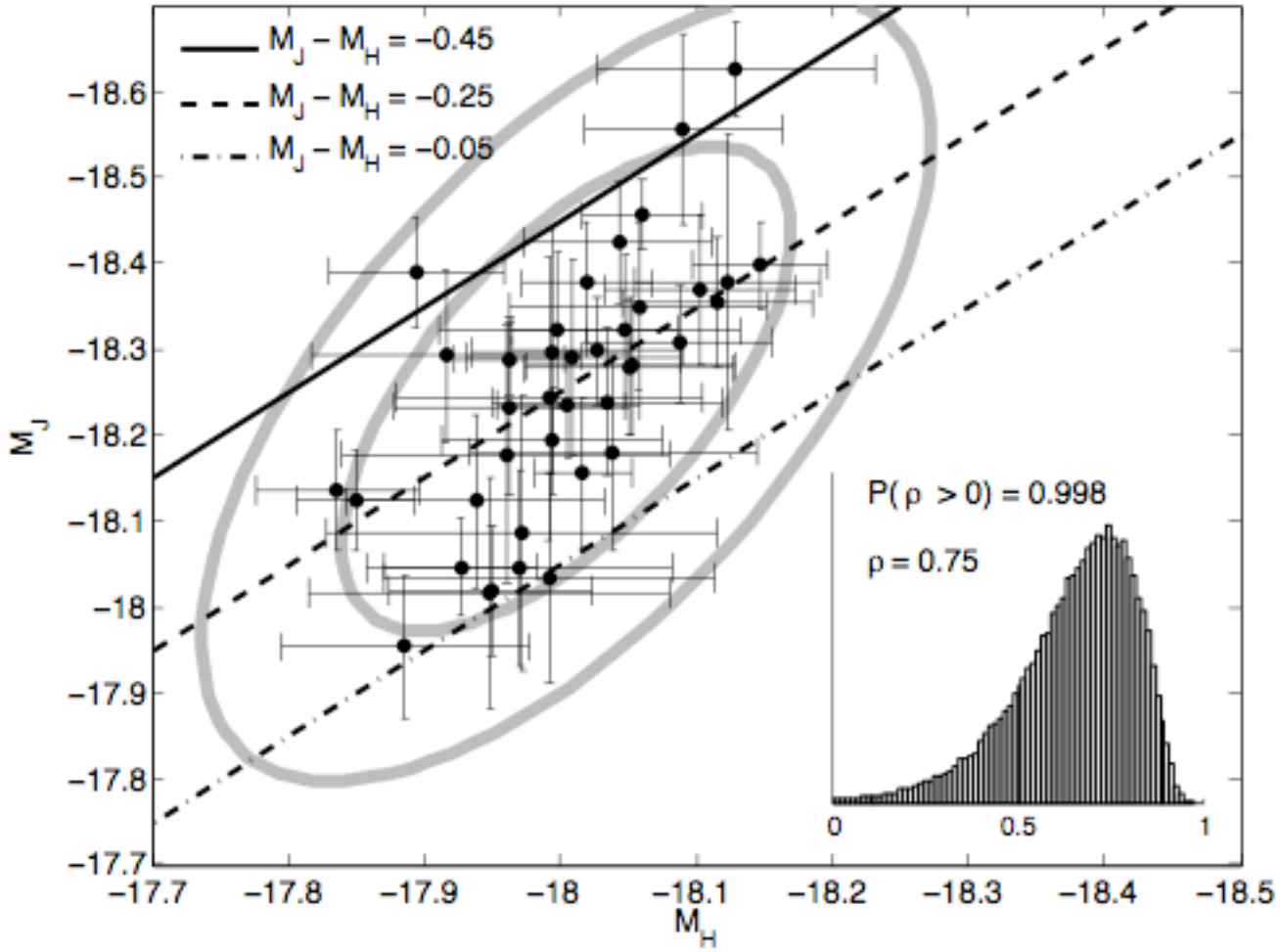
IR observations help pin down the properties of the dust obscuring supernovae

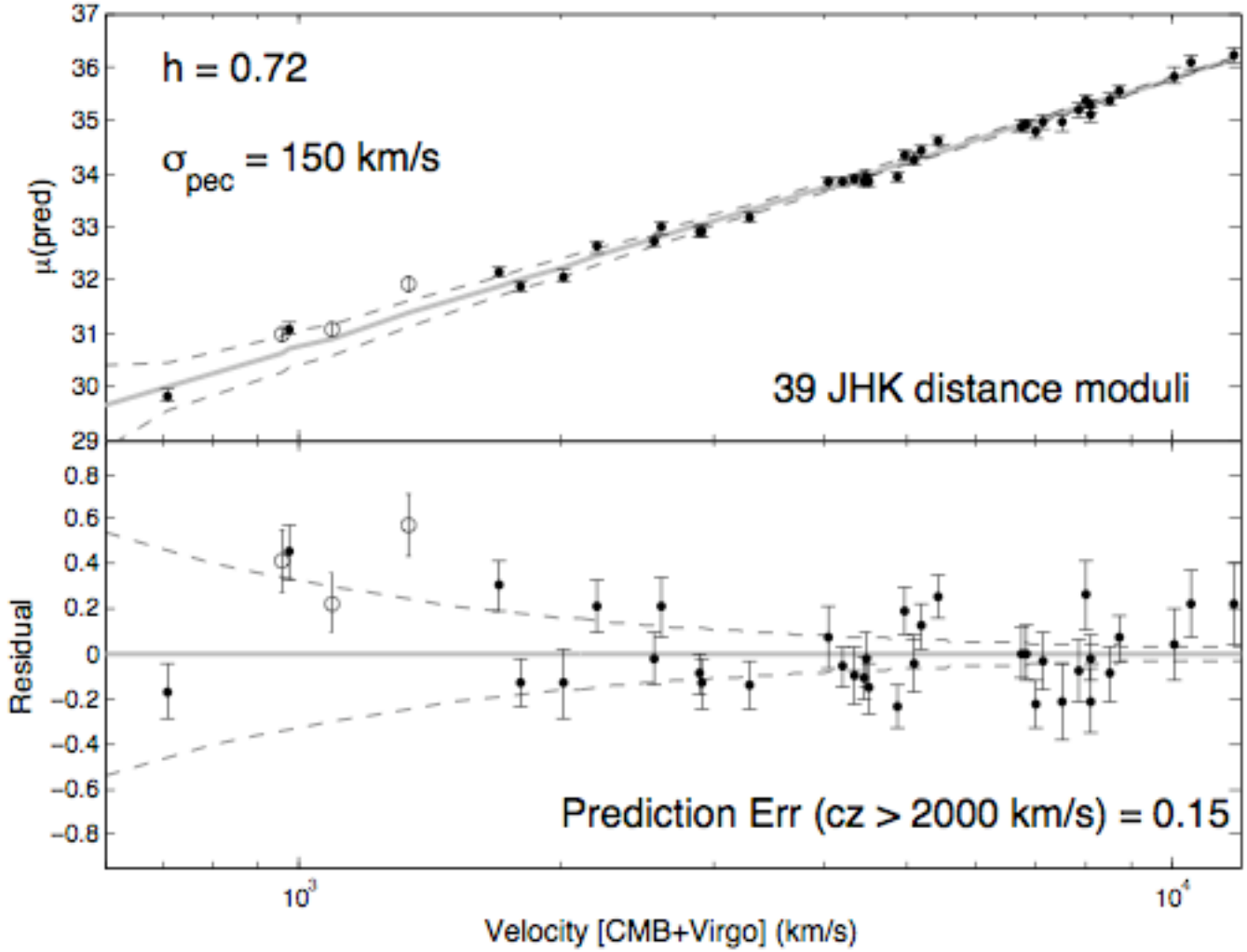


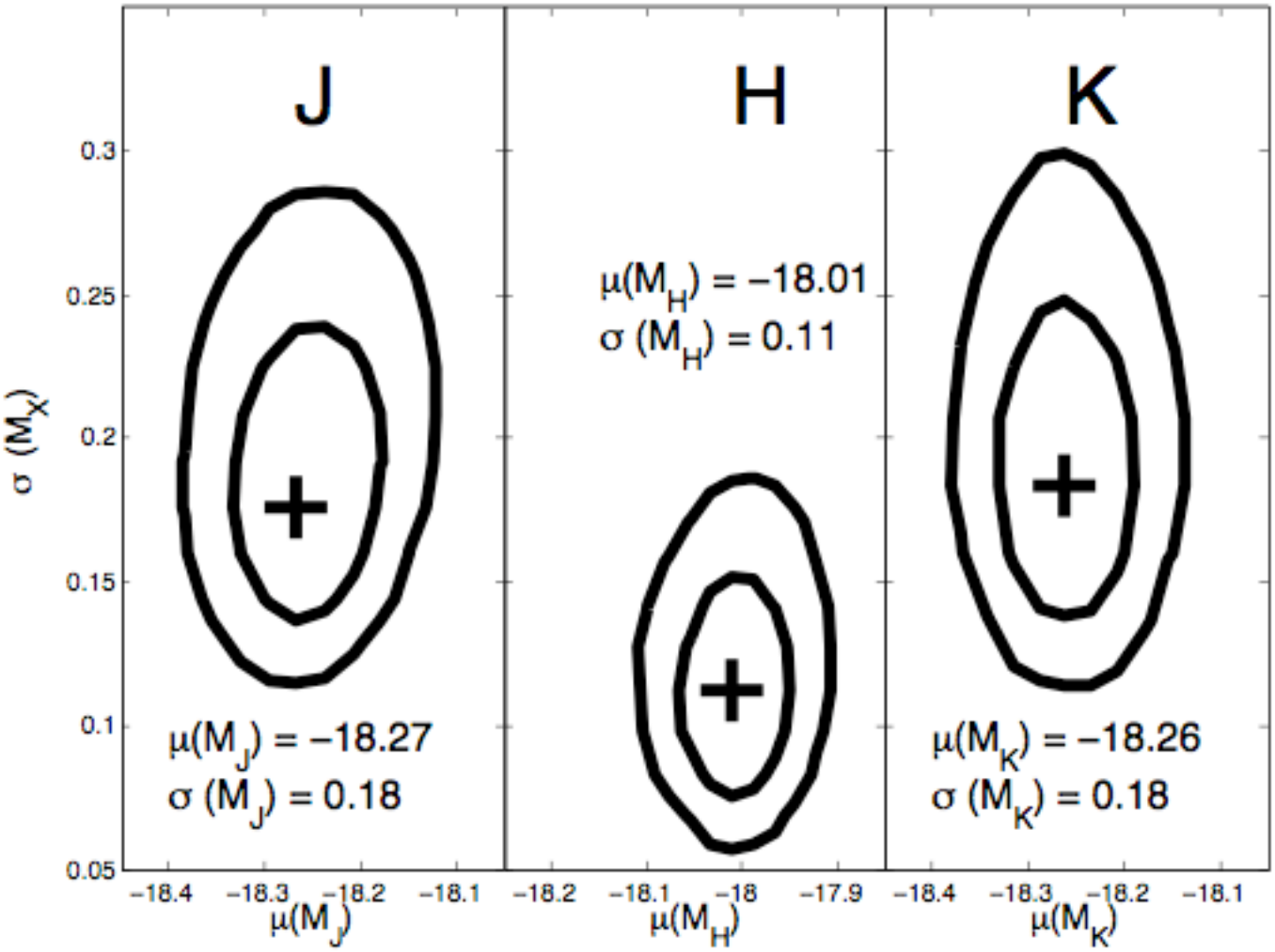
Andy Friedman's data set--constraints on dust coming soon!

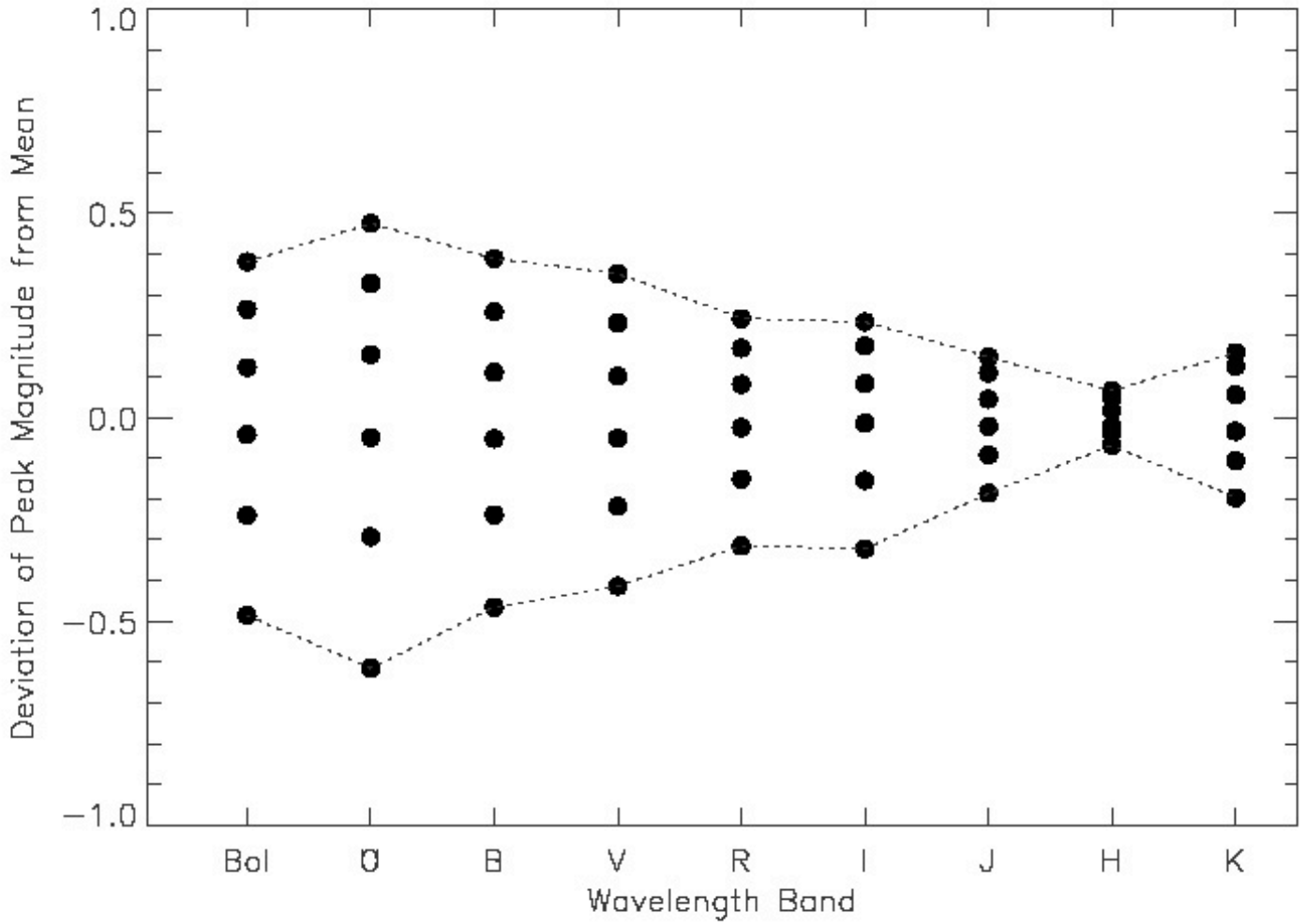

V−H [mag]
2
1
0
−1
−2
−3
−4
−40
−20
0
20
40
60
80
100
120
Phase Relative to B−band Maximum Light [days]

Kaisey Mandell: A Bayesian Approach to using all the IR data-- BayeSN




h = 0.72
σpec = 150 km/s
39 JHK distance moduli
μ(pred)
Residual
Prediction Err (cz > 2000 km/s) = 0.15
Velocity [CMB+Virgo] (km/s)


J
H
K
0.3
0.25
0.2
0.15
0.1
0.05
σ (M_X)
μ(M_H) = −18.01
σ (M_H) = 0.11
μ(M_J) = −18.27
σ (M_J) = 0.18
μ(M_K) = −18.26
σ (M_K) = 0.18
−18.4
−18.3
−18.2
−18.1
μ(M_J)
−18.2
−18.1
−18
−17.9
μ(M_H)
−18.4
−18.3
−18.2
−18.1
μ(M_K)



Work by Dan Kasen (2006)

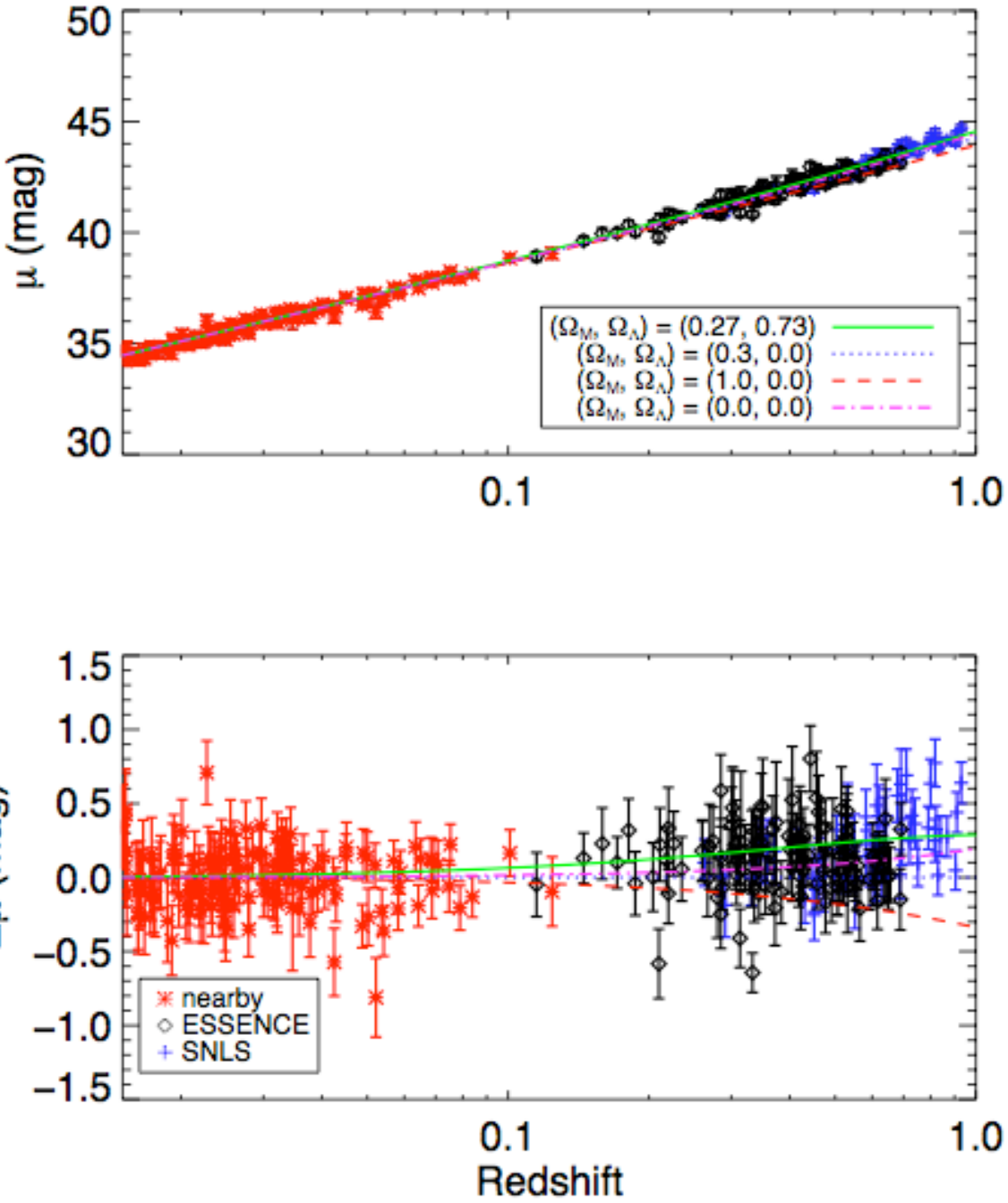
Preliminary ESSENCE Hubble Diagram from Michael Wood-Vasey

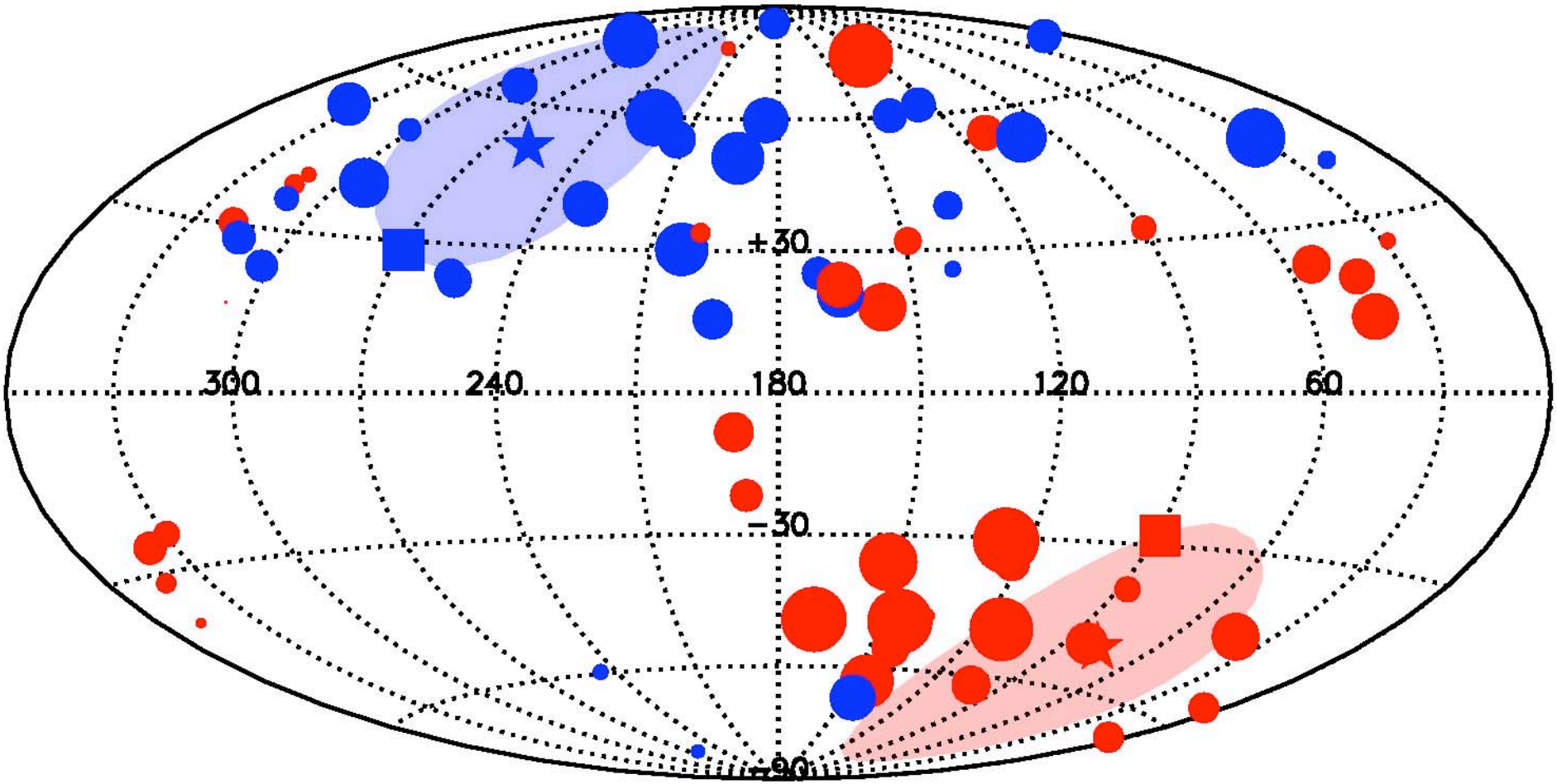
ESSENCE (latest) + Astier06 + Jha07 + Hicken08

Consistent with w = -1 precision better than 10%

Headed for the systematic limit at all redshifts z <1

Implications for JDEM





MLCS2k2 69 SN Ia Local Group frame

1500 km s^{-1} ≦ $H_0 d_{SN}$ ≦ 7500 km s^{-1}