Type Ia Supernova Cosmology

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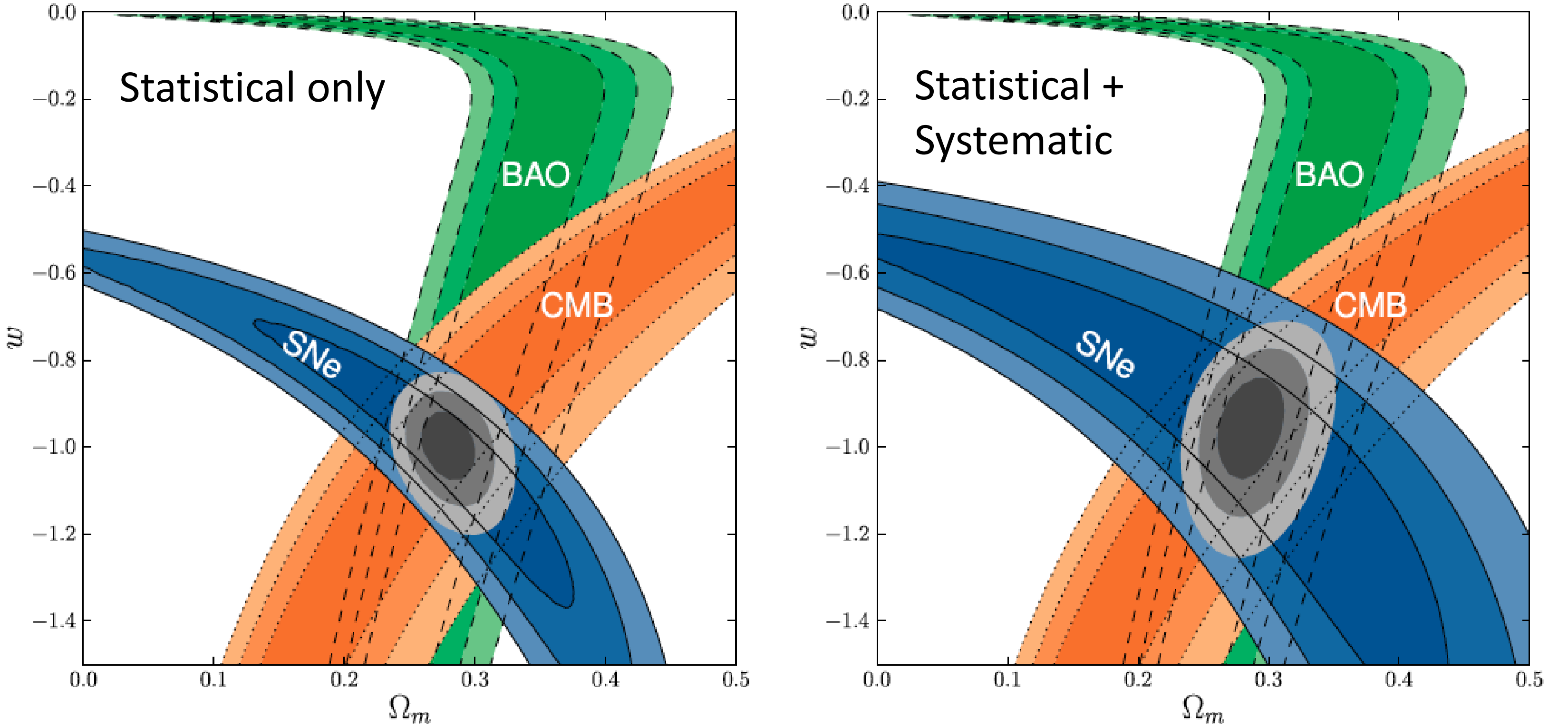
Current Cosmological Constraints

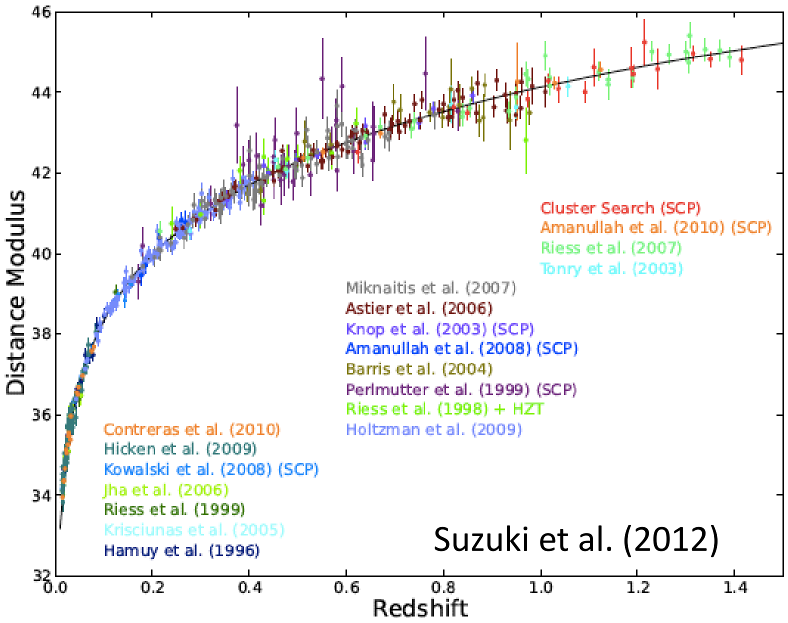
Suzuki et al. (2012)



wCDM model: 68.3%, 95.4%, and 99.7% confidence regions in the (Ω_m, w) plane from SNe Ia, BAO, and CMB are shown in both panels
ws the SN Ia confidence region for statistical uncertainties only, while the right panel shows the confidence region including both statistical and s
ies. We note that CMB and SN Ia constraints are orthogonal, making this combination of cosmological probes very powerful for investigating the
gy.

For SN Ia cosmology, systematic error is comparable with statistical errors.

SN Ia Hubble Diagram



- Low-z: Various
- SDSS: 0.05 < z < 0.4
- SNLS: 0.3 < z < 1.0
- HST: z > 1.0

- DES: 0.05 < z < 1.2
  - ~4000 SN Ia
  - ~150 SN Ia at 1 < z < 1.2

Cosmological Analysis

χ^2 minimization / marginalization problem

$$\chi^2 = \sum_{\mathrm{SNe}} \frac{(m_B - m_{\mathrm{mod}})^2}{\sigma^2},$$

color - luminosity

$$m_{\mathrm{mod}} = 5\log_{10} \mathcal{D}_L\left(z_{\mathrm{hel}}, z_{\mathrm{cmb}}, w, \Omega_m, \Omega_{DE}\right) - \alpha\,(s-1) + \beta\mathcal{C} + \mathcal{M}.$$

stretch - luminosity

In more general expression

$$\chi^2 = \Delta\vec{\mathbf{m}}^T \cdot \mathbf{C}^{-1} \cdot \Delta\vec{\mathbf{m}}.$$

$$\mathbf{C} = \mathbf{D}_{\mathrm{stat}} + \mathbf{C}_{\mathrm{stat}} + \mathbf{C}_{\mathrm{sys}}.$$

$$\mathbf{D}_{\mathrm{stat},\,ii} = \sigma^2_{m_B,i} + \alpha^2\sigma^2_{s,i} + \beta^2\sigma^2_{\mathcal{C},i} + \sigma^2_{\mathrm{int}} + \left(\frac{5\,(1+z_i)}{z_i\,(1+z_i/2)\log 10}\right)^2 \sigma^2_{z,i} + \sigma_{\mathrm{lensing}} + \sigma_{\mathrm{host\ correction}} + C_{m_B s\mathcal{C},i}.$$

$$\mathbf{C}_{\mathrm{sys},\,ij} = \sum_{k=1}^{K} \left(\frac{\partial m_{\mathrm{mod}\,i}}{\partial S_k}\right)\left(\frac{\partial m_{\mathrm{mod}\,j}}{\partial S_k}\right)(\Delta S_k)^2$$

Systematic Uncertainties

Table 7: Identified systematic uncertainties

Conley et al. (2011)

Description	Ω_m	w	Rel. Area [a]	w for Ω_m=0.27	Section
Stat only	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1	-1.031 ± 0.058	
All systematics	0.18 ± 0.10	$-0.91^{+0.17}_{-0.24}$	1.85	$-1.08^{+0.10}_{-0.11}$	§4.4
Calibration	$0.191^{+0.095}_{-0.104}$	$-0.92^{+0.17}_{-0.23}$	1.79	-1.06 ± 0.10	§5.1
SN model	$0.195^{+0.086}_{-0.101}$	$-0.90^{+0.16}_{-0.20}$	1.02	-1.027 ± 0.059	§5.2
Peculiar velocities	$0.197^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.03	-1.034 ± 0.059	§5.3
Malmquist bias	$0.198^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.07	-1.037 ± 0.060	§5.4
non-Ia contamination	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1	-1.031 ± 0.058	§5.5
MW extinction correction	$0.196^{+0.084}_{-0.100}$	$-0.90^{+0.16}_{-0.20}$	1.05	-1.032 ± 0.060	§5.6
SN evolution	$0.185^{+0.088}_{-0.099}$	$-0.88^{+0.15}_{-0.20}$	1.02	-1.028 ± 0.059	§5.7
Host relation	$0.198^{+0.085}_{-0.102}$	$-0.91^{+0.16}_{-0.21}$	1.08	-1.034 ± 0.061	§5.8

Calibration Systematic

Conley et al. (2011)

Table 9: Calibration Systematics

Description	w for Ω_m=0.27	Rel area	Section
Stat only	-1.031 ± 0.058	1	
All calibration	-1.06 ± 0.10	1.79	§5.1
Colors of BD 17° 4708	-1.075 ± 0.075	1.31	§5.1.7
SED of BD 17° 4708	-1.026 ± 0.073	1.23	§5.1.8
SNLS Zero Points	-1.030 ± 0.069	1.21	§5.1.1
low-z Zero Points	-1.044 ± 0.065	1.13	§5.1.2
SDSS Zero Points	-1.028 ± 0.060	1.02	§5.1.4
MegaCam Bandpasses	-1.017 ± 0.066	1.20	§5.1.5
low-z Bandpasses	-1.027 ± 0.059	1.04	§5.1.6
SDSS Bandpasses	-1.026 ± 0.059	1.02	§5.1.6
HST Zero Points	-1.027 ± 0.058	1.03	§5.1.3
NICMOS Nonlinearity	-1.029 ± 0.059	1.05	§5.1.3

Difficulty of Calibration (Regnault et al. 2009)

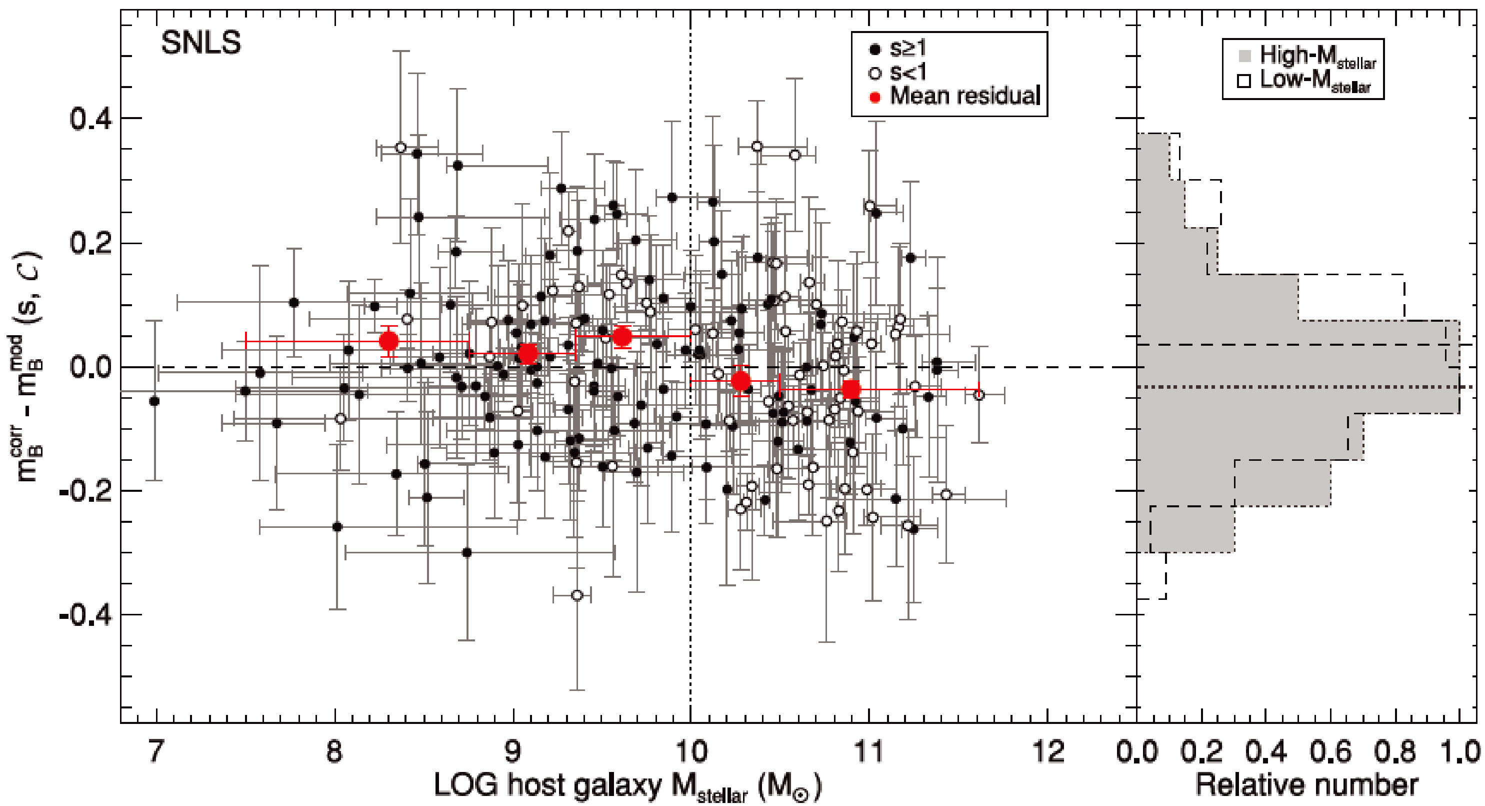
Data of low-z SNe are reported in UBV (Vega- or Landolt-system)

We have to compare the fluxes of low-z SNe and higher-z SNe

Their procedures are

1. Define MegaCam natural magnitude system
2. Define transformation with Landolt system using Landolt starts
3. Pick up a standard star with spectrophotometric observation and broad-band magnitudes in Landolt system
They adopted BD +17 4708 not Vega
4. Estimate magnitudes in MegaCam system using transformation defined in 2.
Also consider about the characteristics of BD +17 4708
BD +17 4708 is known to be a binary system.
5. Covert every magnitude to flux based on spectrophotometry of BD +17 4708

Correction for Host-galaxy Properties



0.075mag

~3.9σ

Sullivan et al. (2010)

The same offset can be seen for stellar mass, specific SFR, and metallicity. Physical explanations are not yet known.

How to reduce systematics (Conley et al. 2011)

Main cause is the transformation between Landolt and MegaCam
- Bandpasses are very different
- Bandpasses of Landolt are not well understood
- Original Landolt system no longer exists

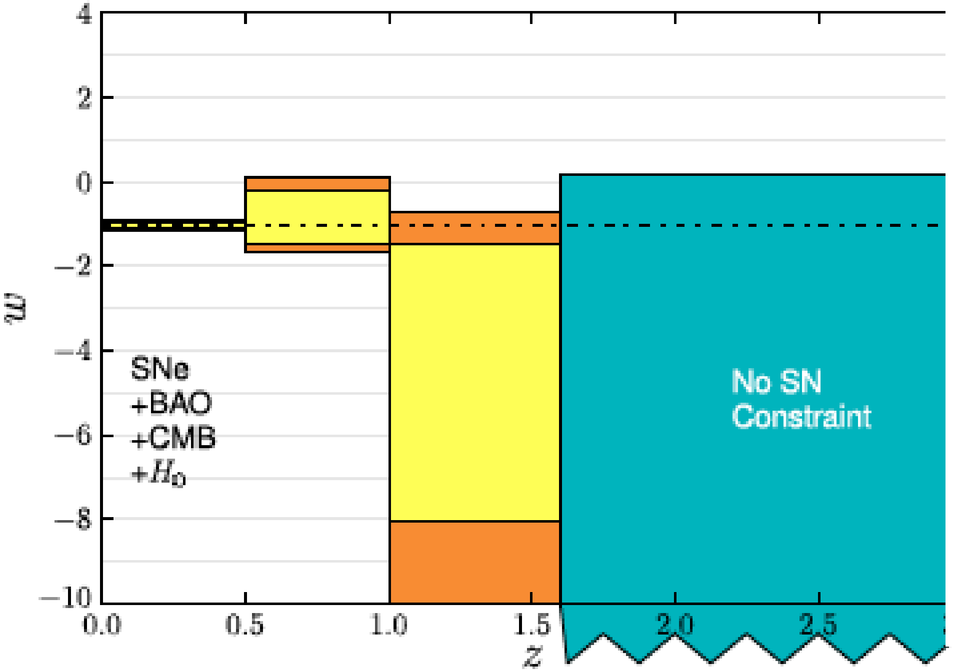
Nearby Data in a better understood system (like SDSS) will be great help

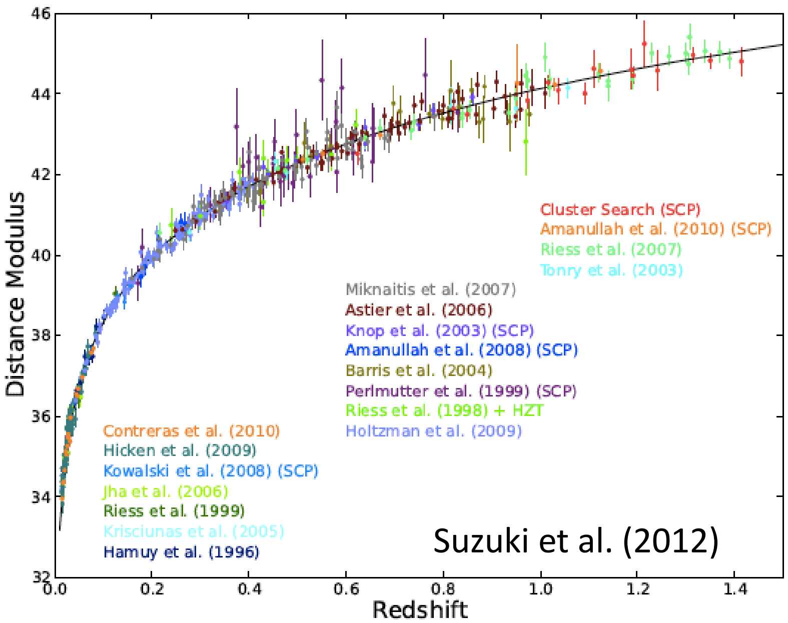
Better understanding of SN properties from nearby sample
- intrinsic color and extinction
- luminosity predictor beyond stretch and color

Cross calibration between SNLS, SDSS, and CSP

CALSPEC calibration for more stars
- BD +17 4708 is too bright for MegaCam

w constraints as a function of *z*





Basically there is no constraint on *w* from SN Ia above z ~ 1

We are still missing high-z (z > 1.0) SN Ia data

HSC SN Survey

- One component of Ultra-Deep layer of HSC Survey
- Extensive multi-band rolling search over 4 months for 2 fields (UltraVista and UDS)
- Down to 26.6, 25.6, 24.3 mag for i, z, y-bands

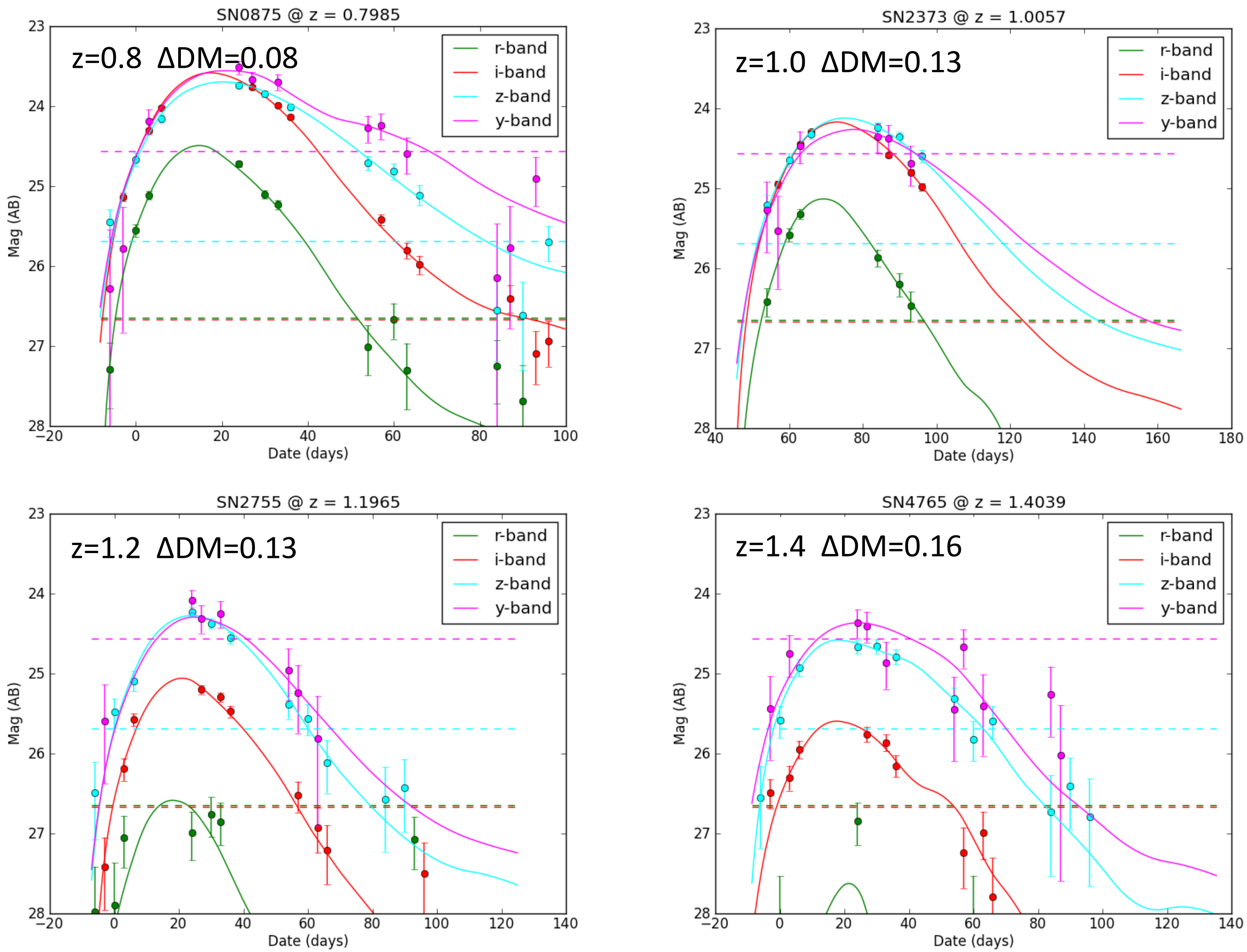
Day	g	r	i	z	y
-6		30		81	81
-3	30		60		81
0	30	30		81	
+3		30	60		81
+6	30		60	81	

Day	g	r	i	z	y
-6		30		81	81
-3	30		60		81
0	30	30		81	
+3		30	60		81
+6	30		60	81	

Day	g	r	i	z	y
-6		30		81	81
-3	30		60		81
0	30	30		81	
+3		30	60		81
+6	30		60	81	

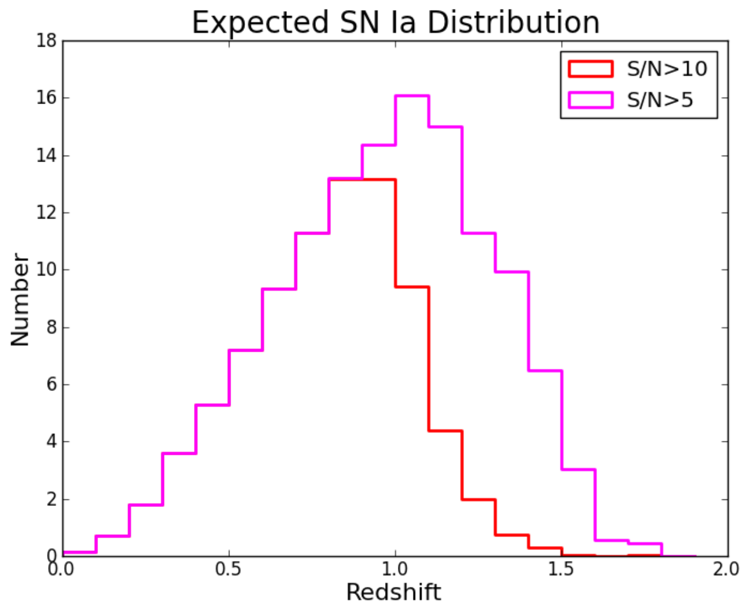
Day	g	r	i	z	y
-6		30		81	81
-3	30		60		81
0	30	30		81	
+3		30	60		81
+6	30		60	81	

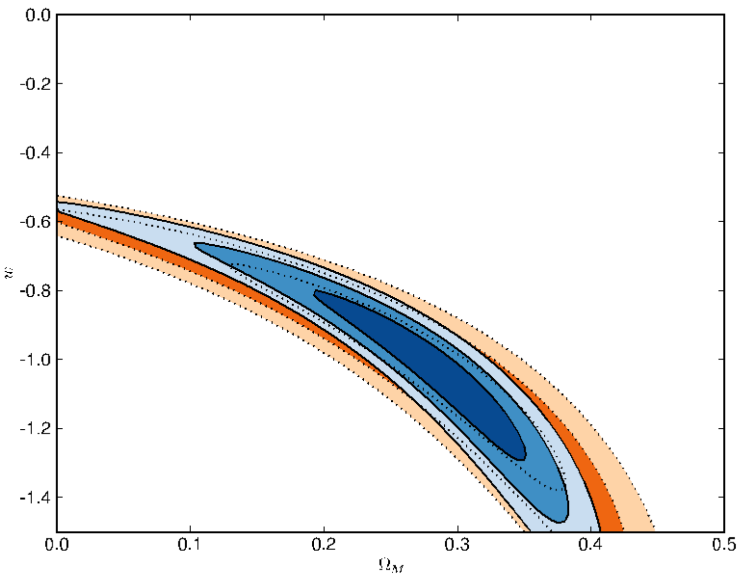
Simulated Light Curves



Horizontal dotted lines are S/N=5 limit

HSC SN Survey (Expected Results)



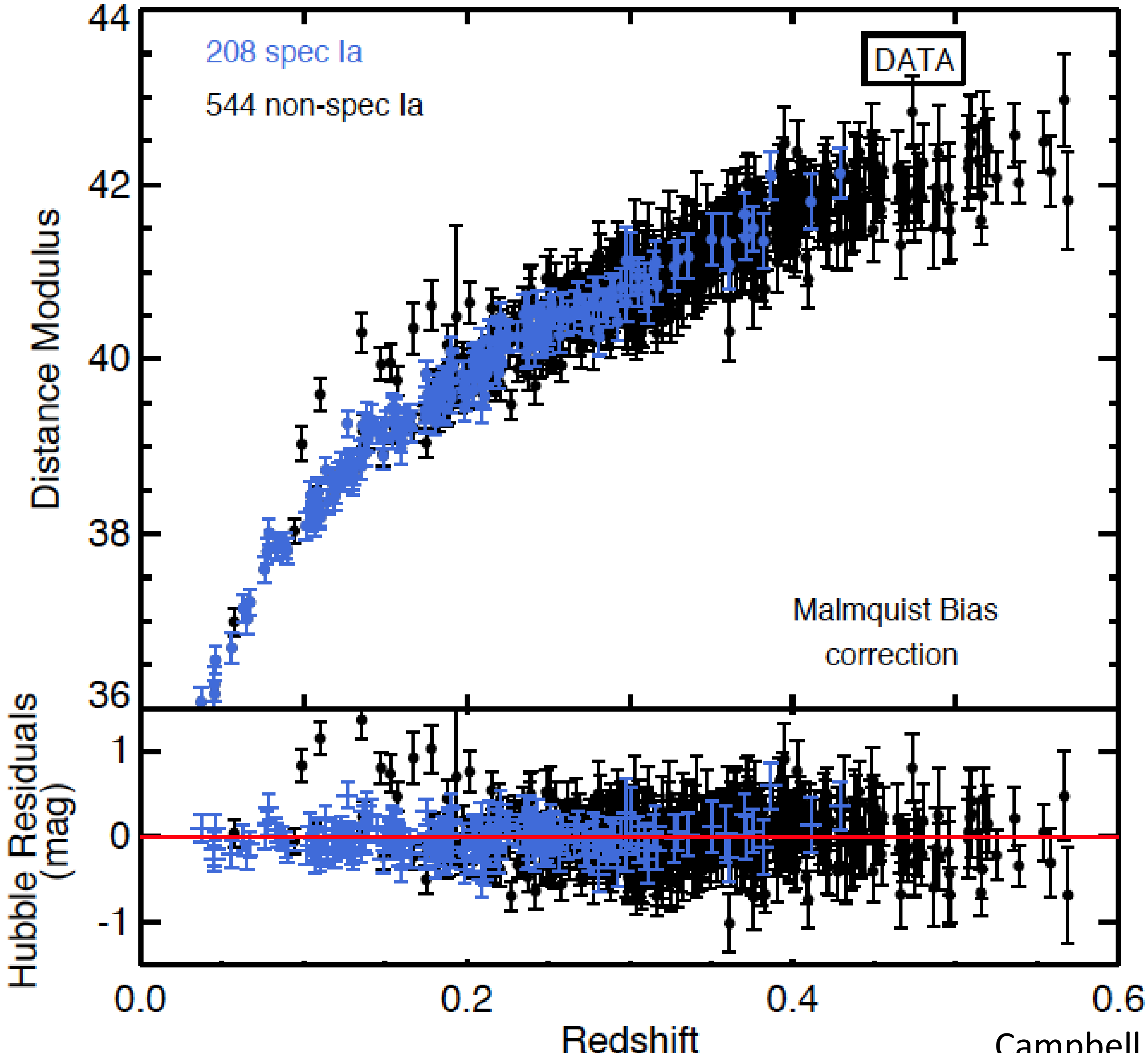


From 4 months campaigns for 2 FoV

~130 SN (~60 at z > 1) for S/N>5 at 3 bands
~80 SN (~20 at z > 1) for S/N>10 at 3 bands

S/N is at peak magnitude
The latest SN Ia rate model with power-law DTD

If we can use all S/N>5 sample in addition to UNION2 sample, error on Ω_M and w will be decreased by a factor of 2

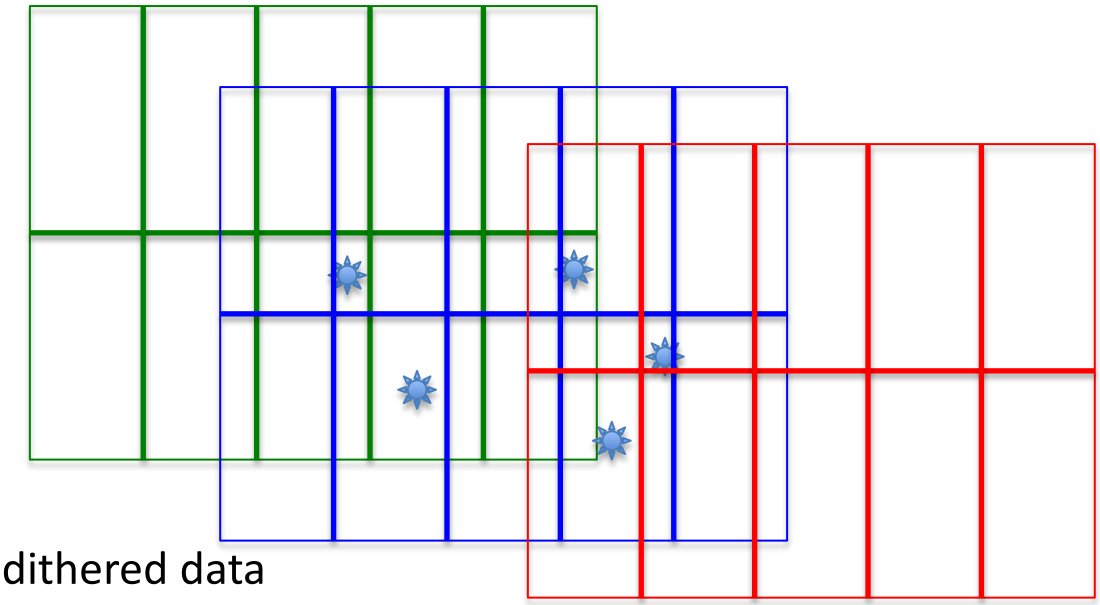


Campbell et al. 2012

Flux calibration procedure

We are planning to use stars to find out the relative calibration over entire FoV.

- "Stellar flat", "ubercalibration"



Need large dithered data

$$m_0^{star} = m_{obs}^{star,exp,chip} + dm^{exp} + dm^{chip} + dm(u^{star}, v^{star})$$

True magnitudes of stars

Observed instrumental magnitudes

Correction over focal plane

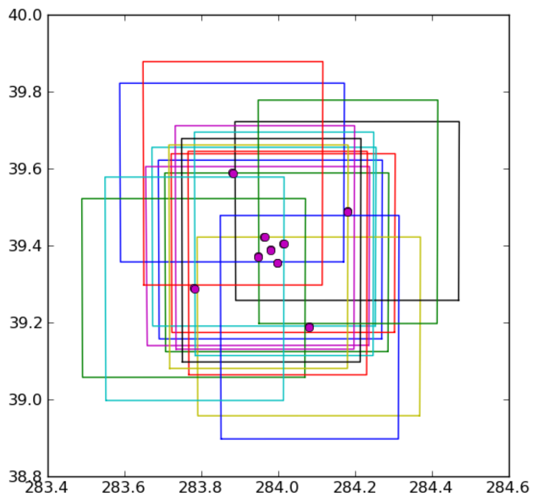
$$dm(u,v) = \sum_{i+j \le n} f_{i,j} \times u^i \times v^j$$

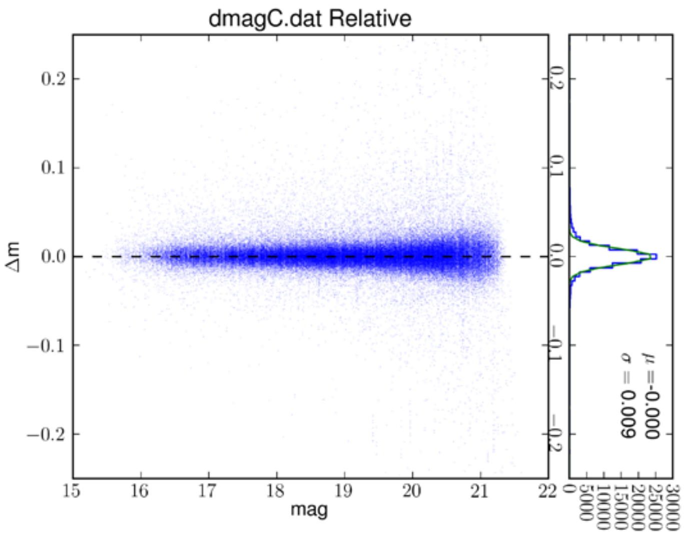
Observation

Aug 12th, 2012 during Suprime-Cam engineering time

30 sec exposures in i-band for a stellar dense field (~600 reference stars per chip)

Data are taken with various offsets and PAs





Internal Comparison

Dispersion ~ 0.01 mag

Achieve less than 1% relative photometry

Summary

- Modern nearby SN Ia samples are important
  - Reduce calibration errors with better understanding of magnitude systems
  - Replace old Landolt based dataset
  - Better understandings of the nature of SN Ia and possible luminosity estimator
- Good spectrophotometric standards stars have to be prepared to convert magnitudes to fluxes
- HSC SN survey will supply ~50 SN Ia sample above z~1 with good photometry.
  - Spectroscopic follow-up is always problem