

**SUPERNOVAE** →  
DARK ENERGY

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Center for Astrophysics

Einstein™ ↓ de Sitter (1932) [... of  $\Lambda$ ]

"... an increase in the precision of data derived from observation will enable us in the future to fix its sign and determine its value."

# The High-Z SN Search



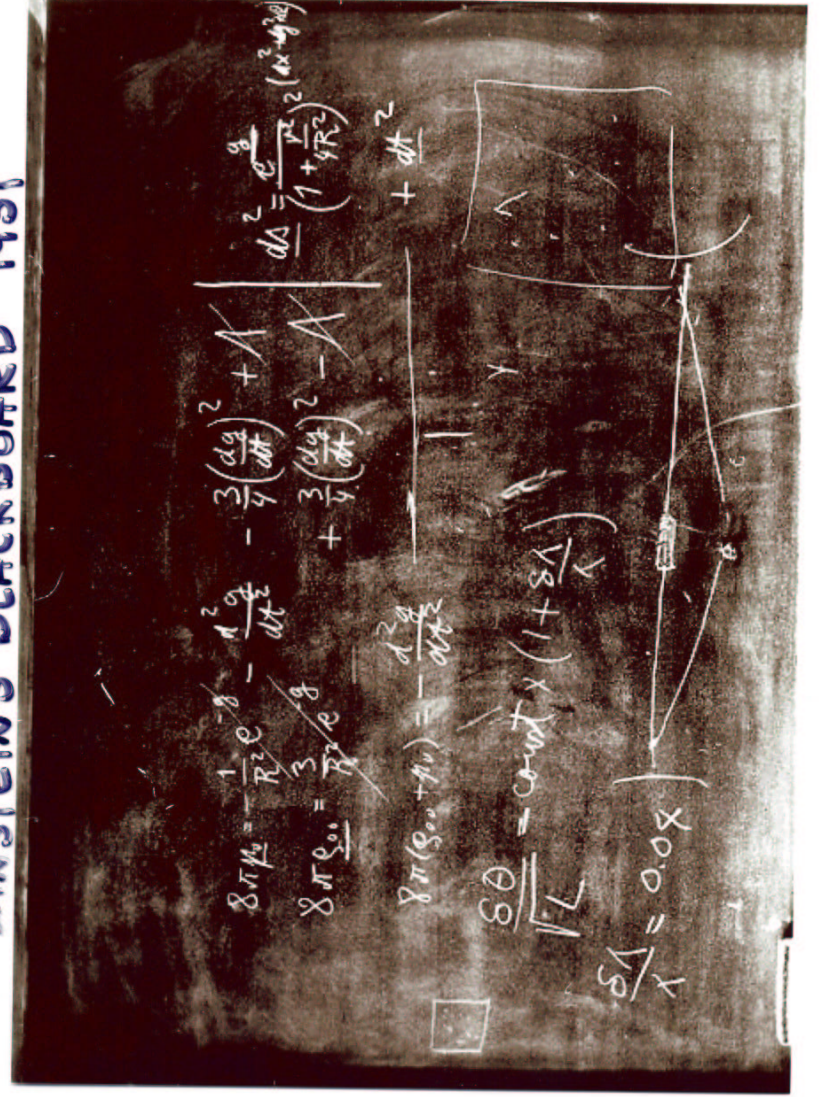
## Measuring the Cosmic Deceleration and Global Geometry of the Universe with Type Ia Supernovae

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EINSTEIN'S BLACKBOARD 1931



## Plan of the Talk

- SN studies are thriving
- Doubled sample at low redshift explored  $U$ -band properties
- SNIa as the best standard candles
- Hubble diagram for SNIa: evidence for  $\Lambda$
- Measuring the cosmic equation of state  
 CTIO "ESSENCE": 200 SNIa @  $z \sim 0.5$   
 HST ~~SN~~ GOODS SNIa @  $z \sim 1-1.8$

## SN Studies:

Nearby - automated search by KAIT  
 Weidong Li & Alex Filippenko UCB

	Kait	All others	
1997	1	27	
1998	20*	39	
1999	40*	43	
2000	38	47	
2001	68*	70	
2002	56 (Aug 15)	38	* world record

CFA: 1.5<sup>m</sup> SPECTRA + 1.2<sup>m</sup> LIGHT CURVES

78 IAU Circulars in past year

SN Ia: 93 SN II: 76 SN IIc: 12

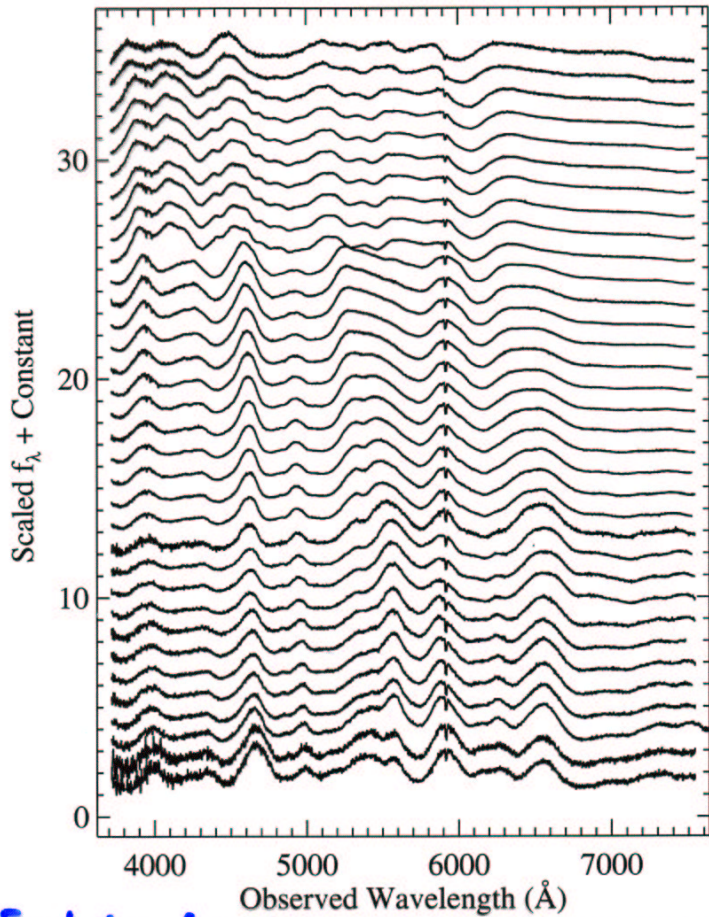
SN IIb: 1 SN Ib: 12 SN Ic: 16

unknown: 6



CFA: 34 Epochs of Spectroscopy for a SNIa

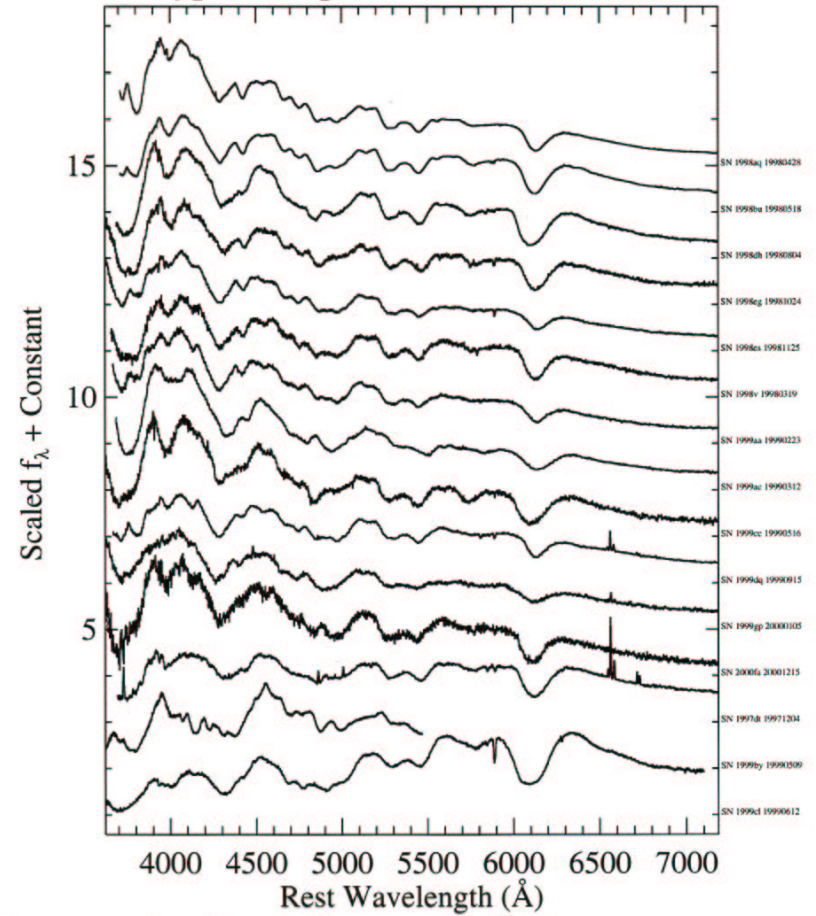
SN 2002bo



Explosion of a C-O white dwarf: NO HYDROGEN

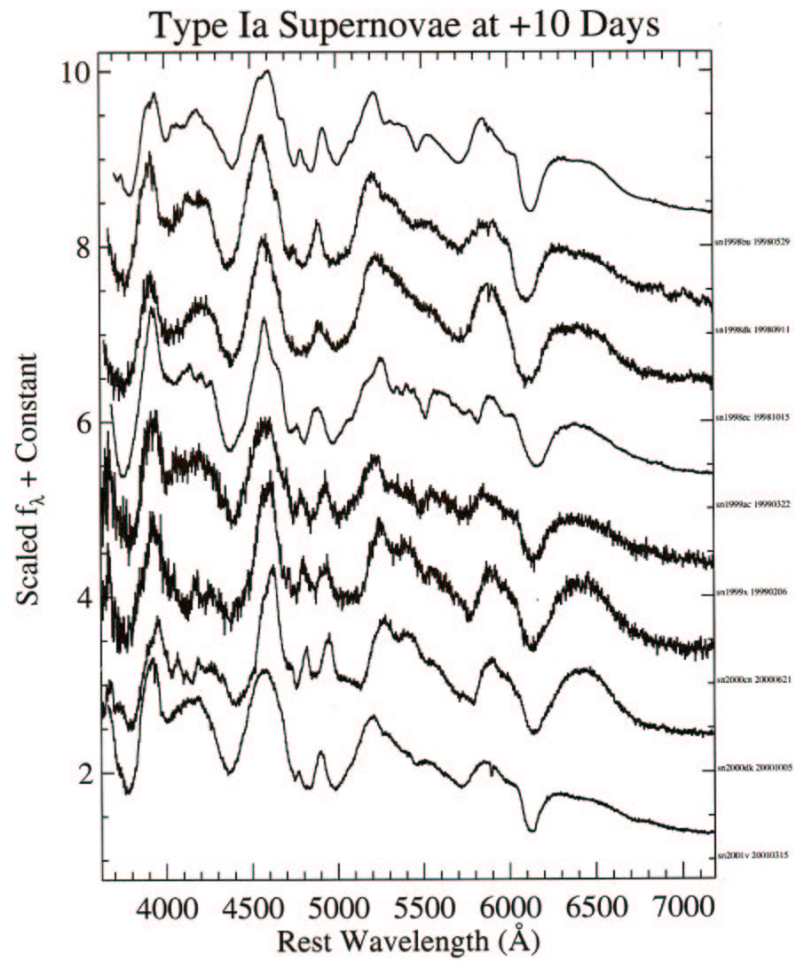
T. Matheson

Type Ia Supernovae at Maximum

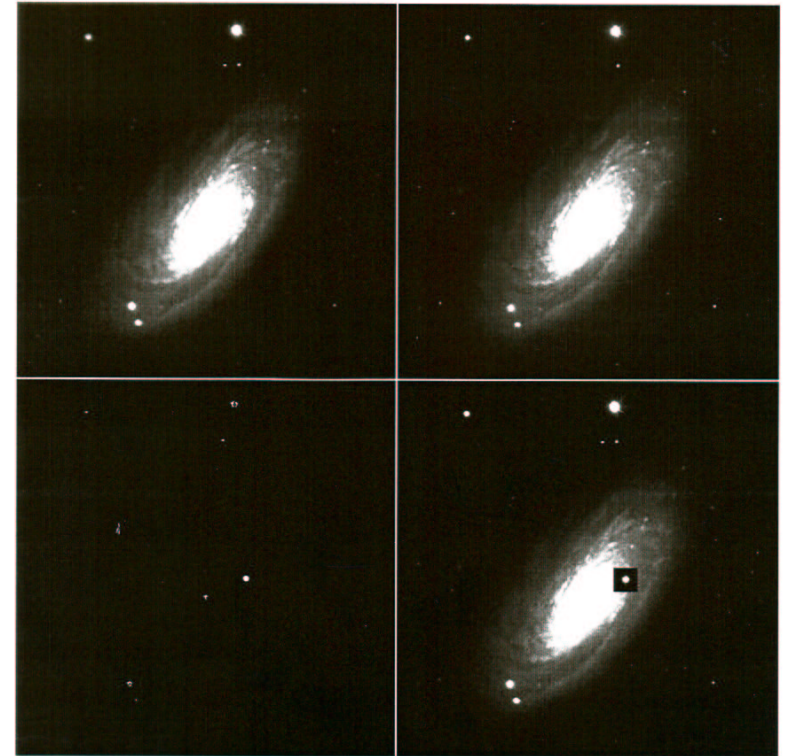


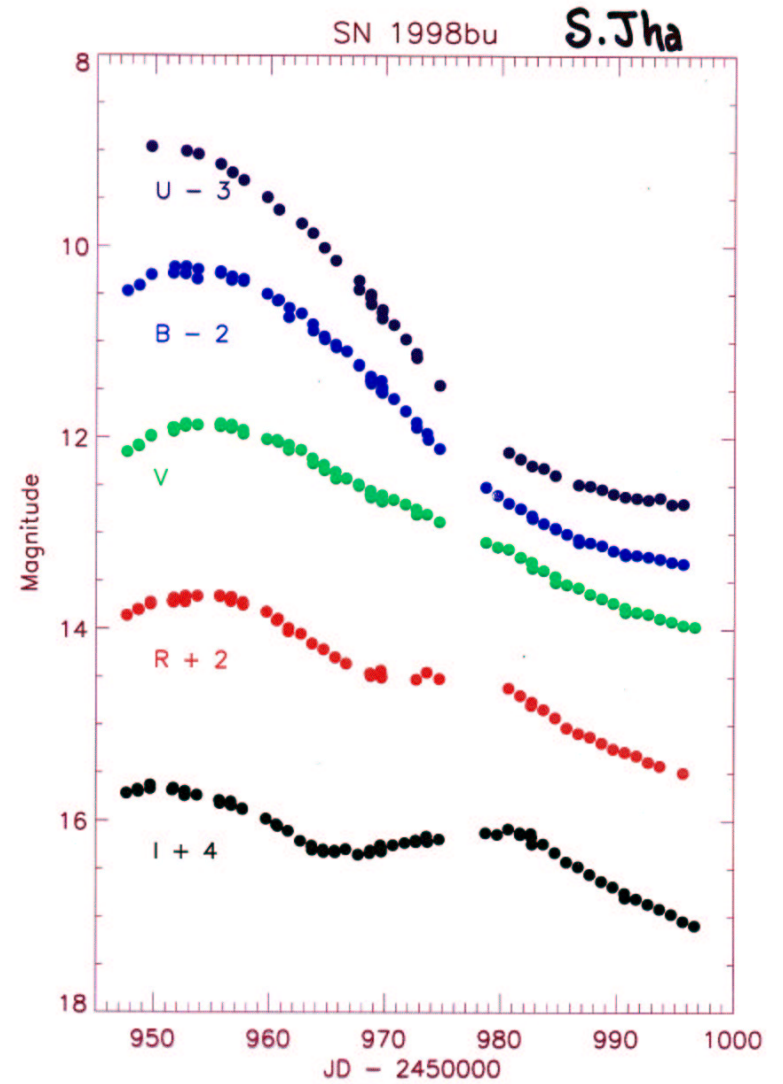
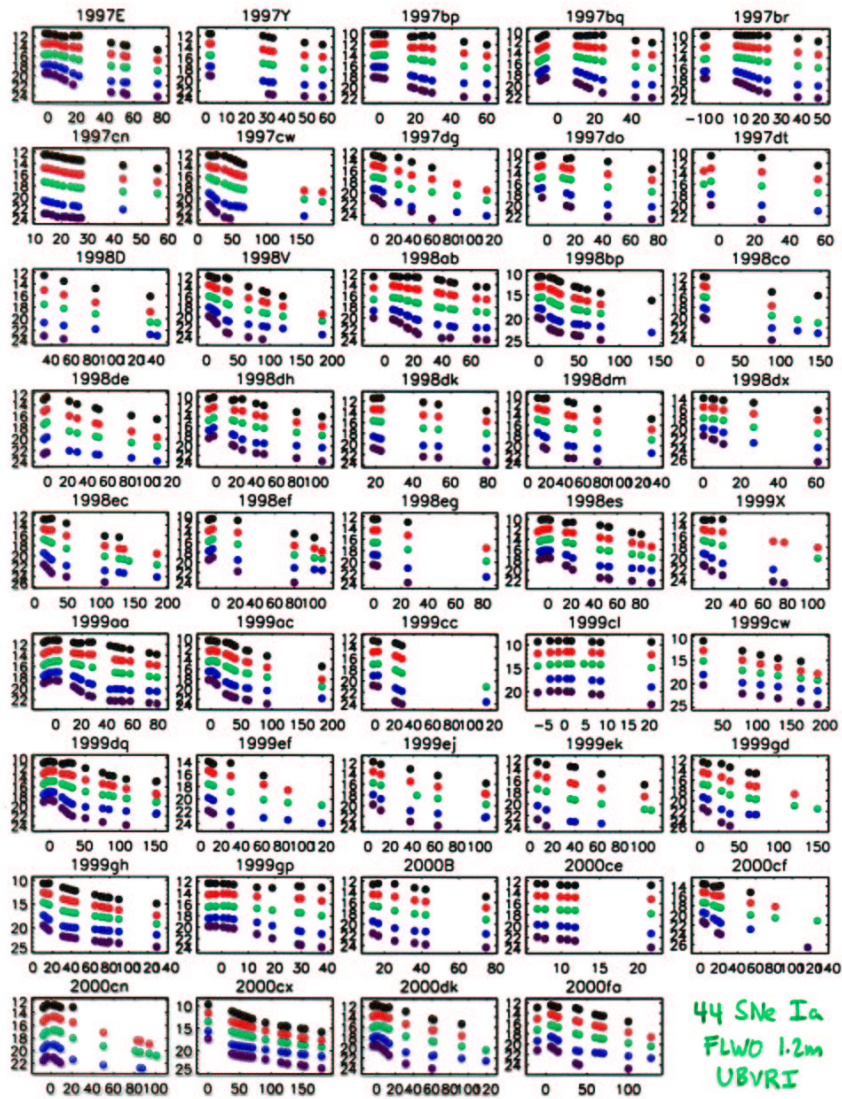
Not identical - but very similar





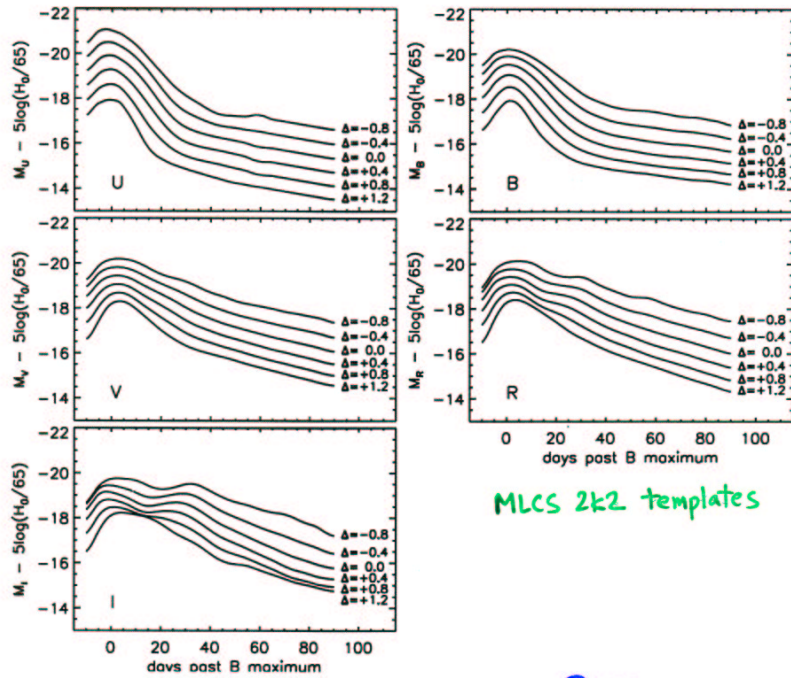
SN 1999cl in NGC 4501 (M88)





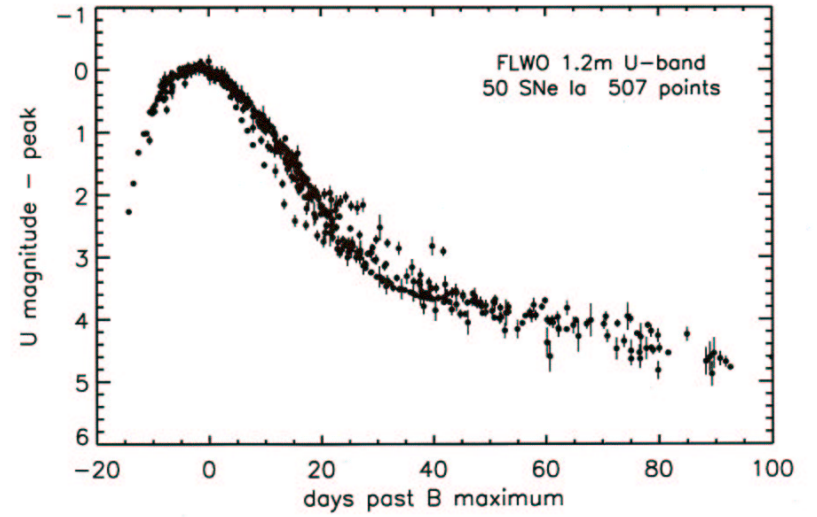


Saurabh Jha, Ph.D.



MLCS 2k2 templates

$M_{15}$  Phillips  
Hamuy  
SCP "stretch"



Emitted Frame

U B V R I

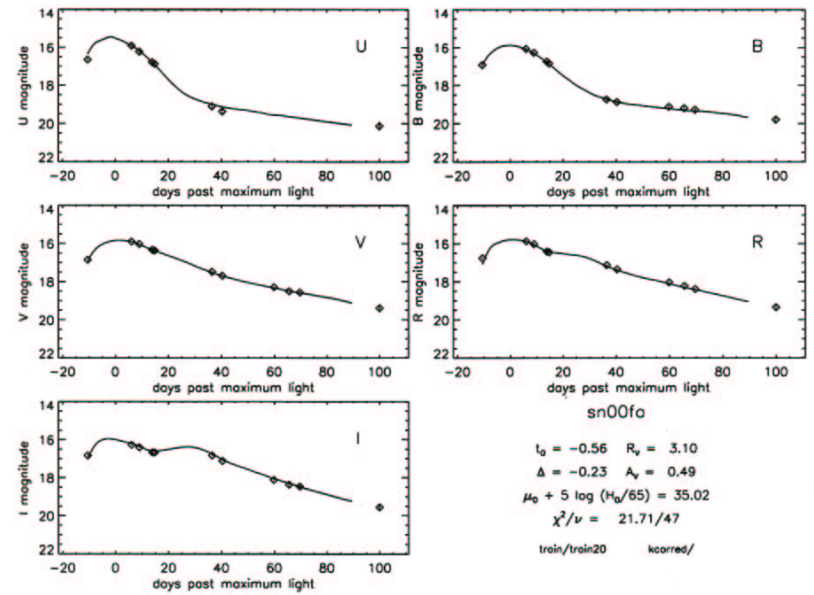
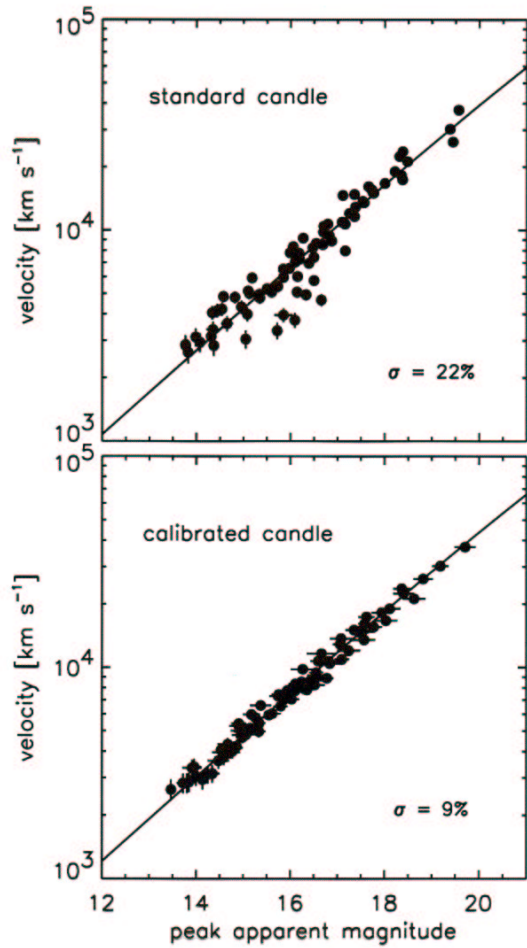
1.00705 0.2 0

Observed Frame

U B V R I

$\square$  z = REDSHIFT





MLCS 2k2 UBVRI fit to SN 2000fa

Why is  $U$  Important?

Chemical Composition -  
change in the UV only

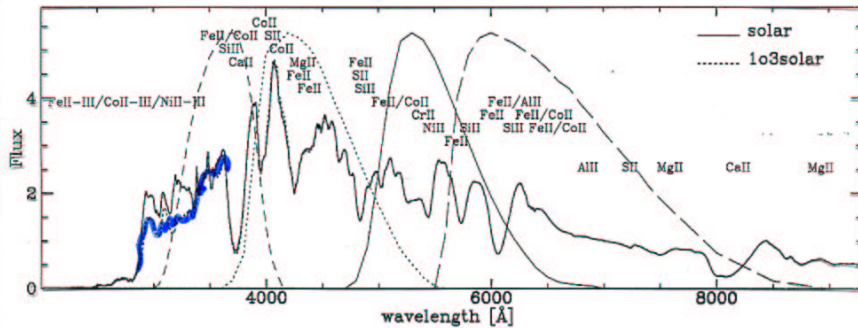
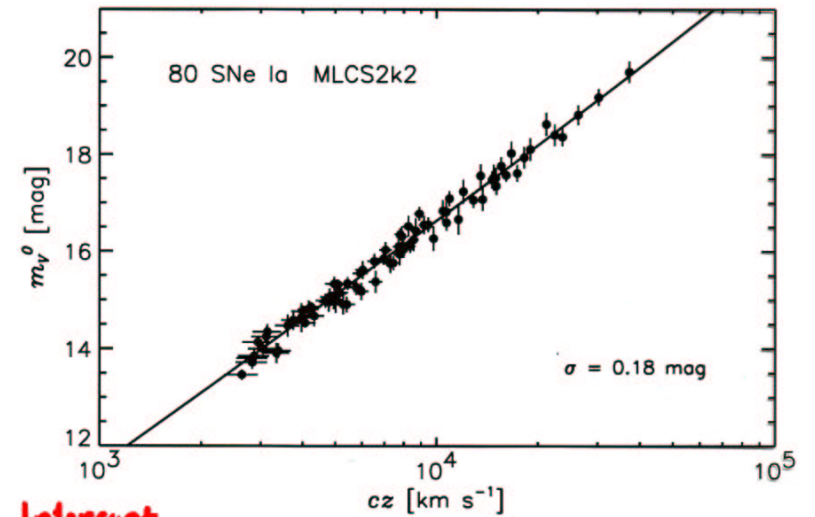


Fig. 3.— Type Ia supernova model spectral energy distributions for solar and  $\frac{1}{3}$  metallicities

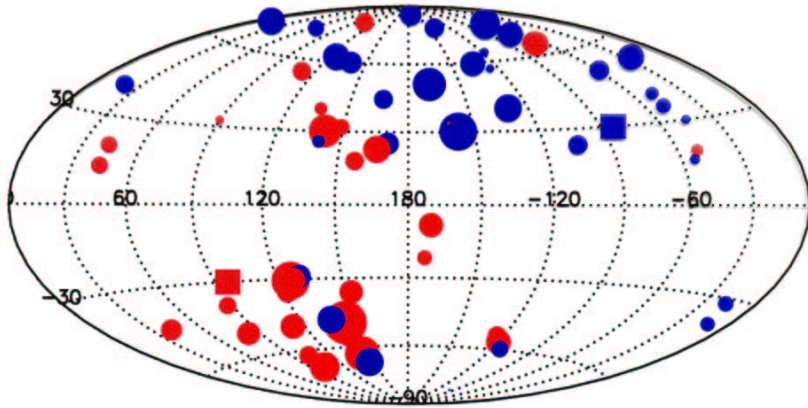
$\sim 20$  in 1995

$\sim 40$  in 1998

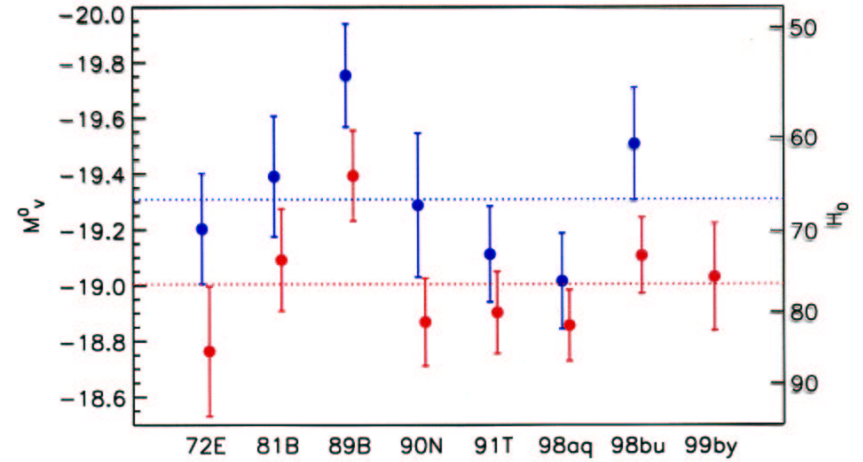


Intercept  
gives  $H_0$  (if you know the luminosity of  
a SNIa)





MLCS2k2 66 SNe Ia Local Group  $cz \leq 6000 \text{ km s}^{-1}$

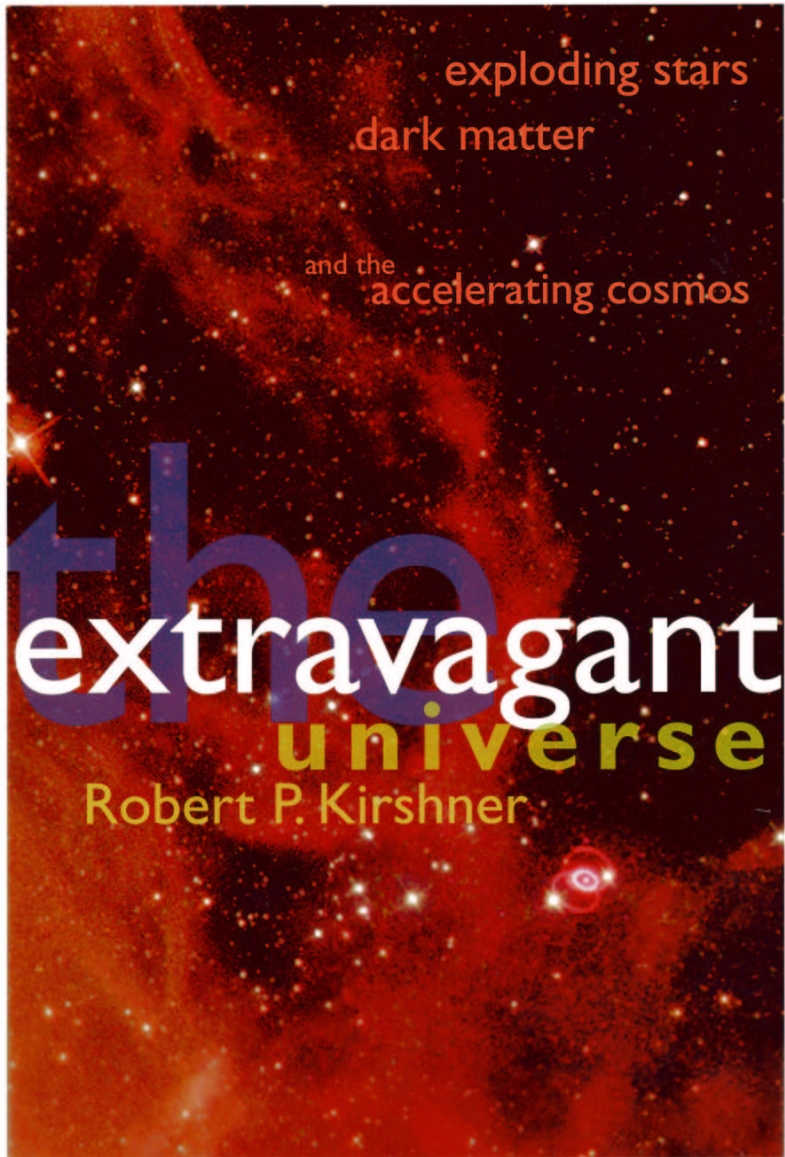


SN Ia Project (Saha et al. 2001)

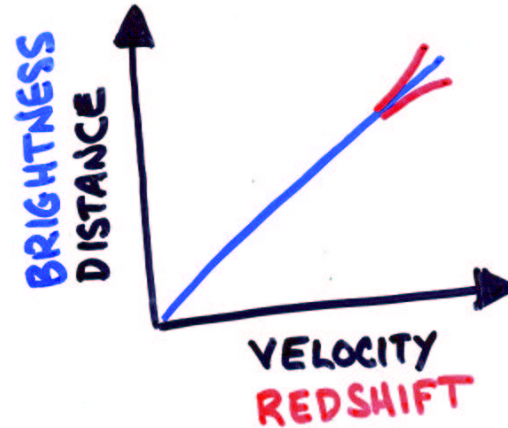
Key Project (Freedman et al. 2001)

All the uncertainty is in the Cepheid distances!

[Also distance to the Large Magellanic Cloud]

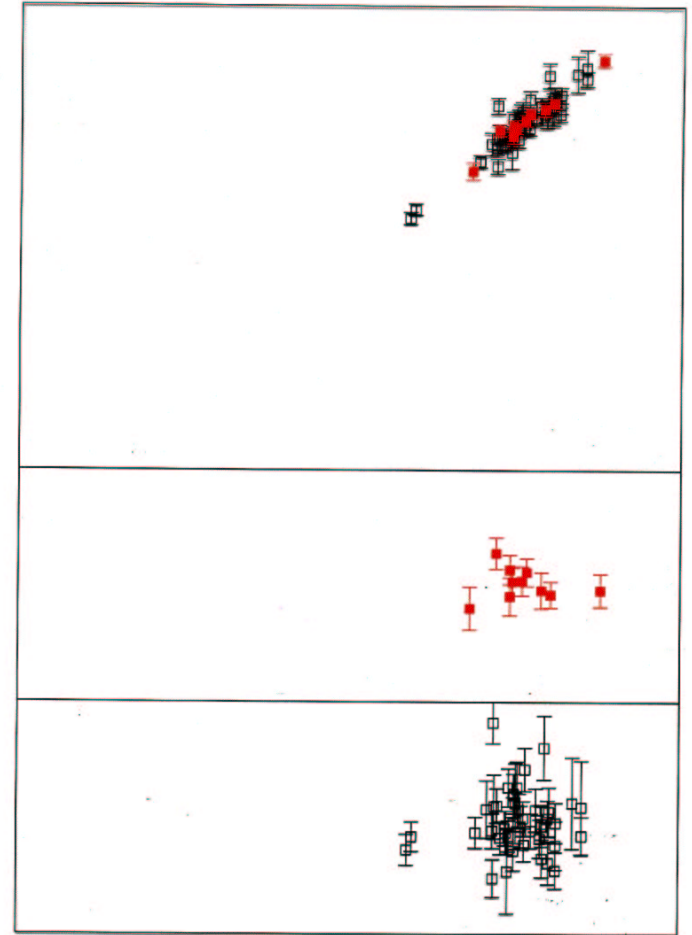
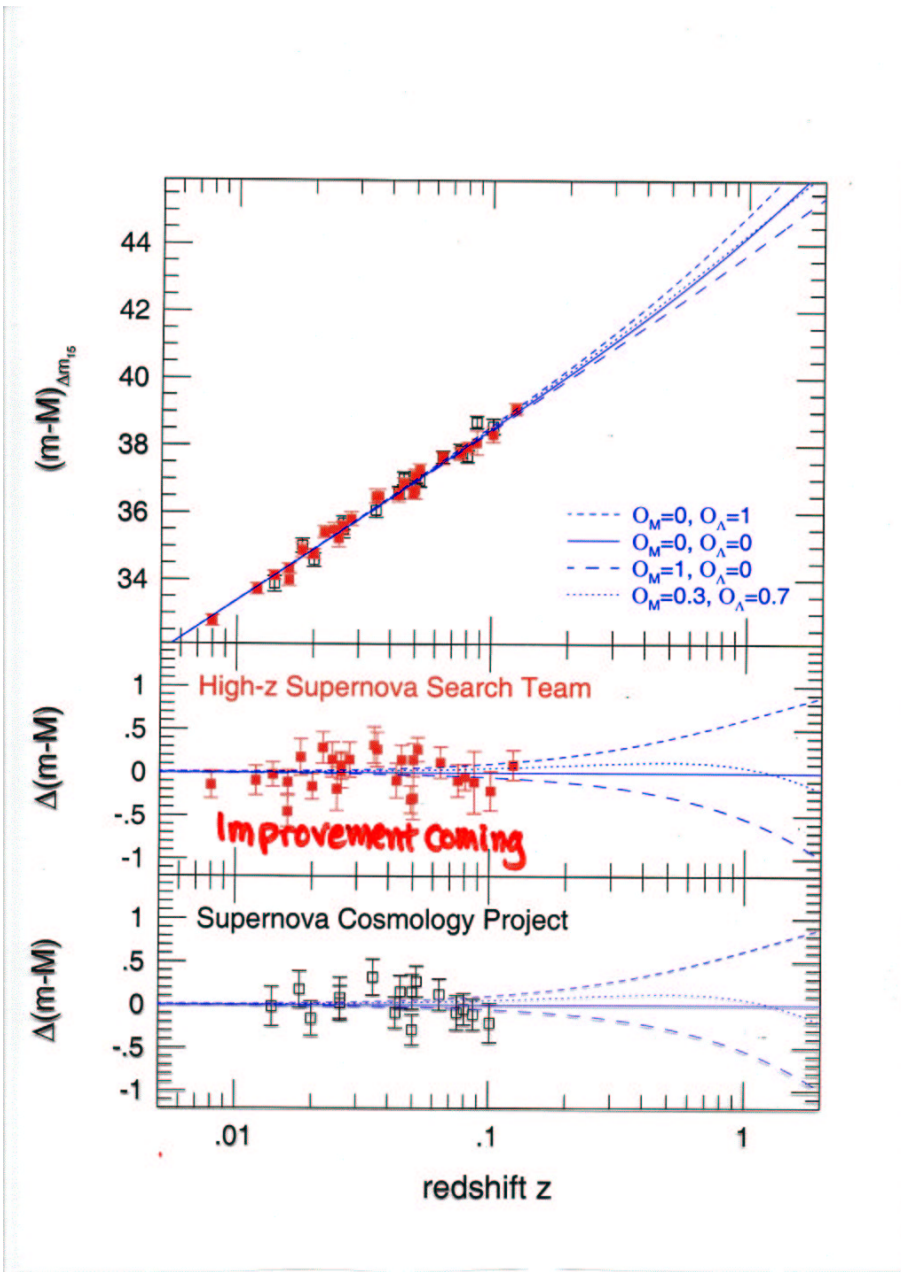


## A GLOBAL TEST:



NEED A VERY BRIGHT AND  
RELIABLE STANDARD CANDLE





High-z: few points but smaller errors

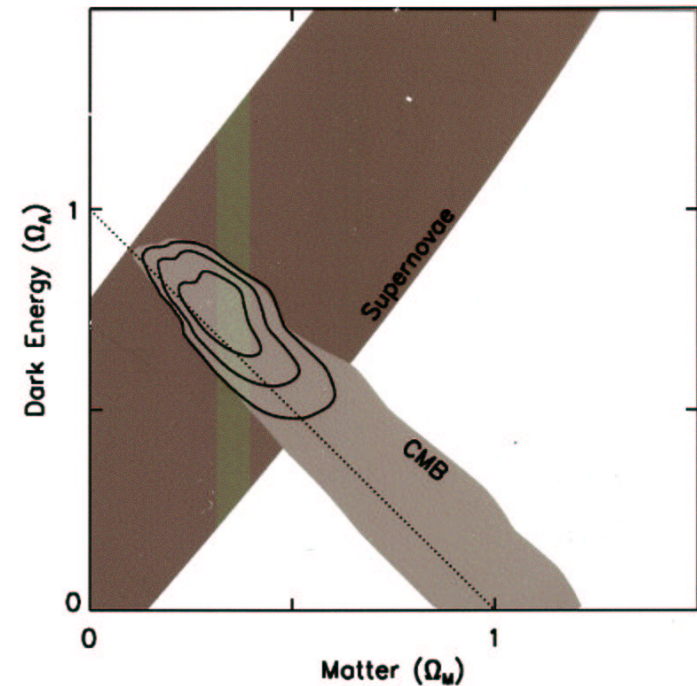
## SUPERNOVA OBSERVATIONS

PROVIDE THE ONLY EVIDENCE  
FOR ACCELERATION.

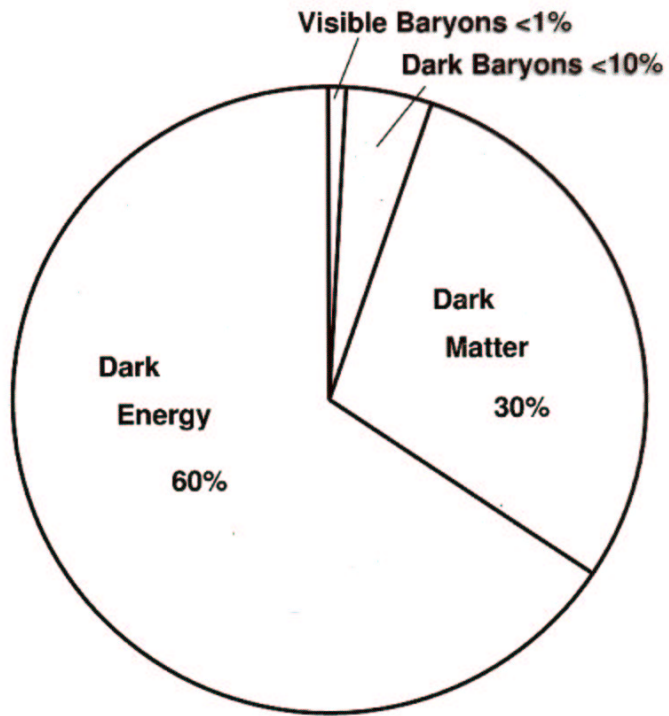
COMBINING CMB + SNIa  $\Rightarrow$   
A CONSISTENT PICTURE

$$\Omega_m \sim 0.3 \quad \Omega_\Lambda \sim 0.7$$

Cluster dynamics  $\Rightarrow \Omega_m \sim 0.3$







Contents of the Universe

Go To Higher  $z$ !

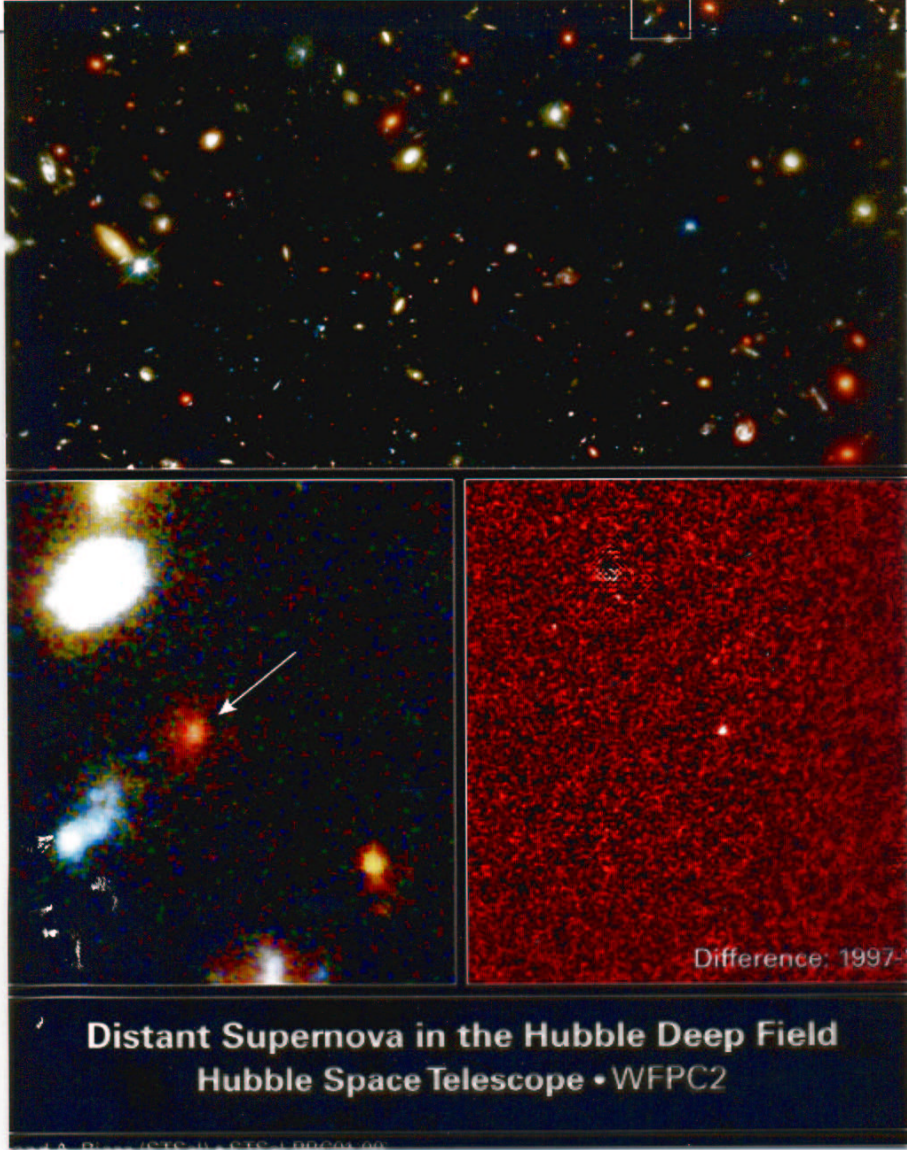
$$\frac{\Omega_m}{\Omega_\Lambda}$$

$$\rho_m \sim (1+z)^3$$

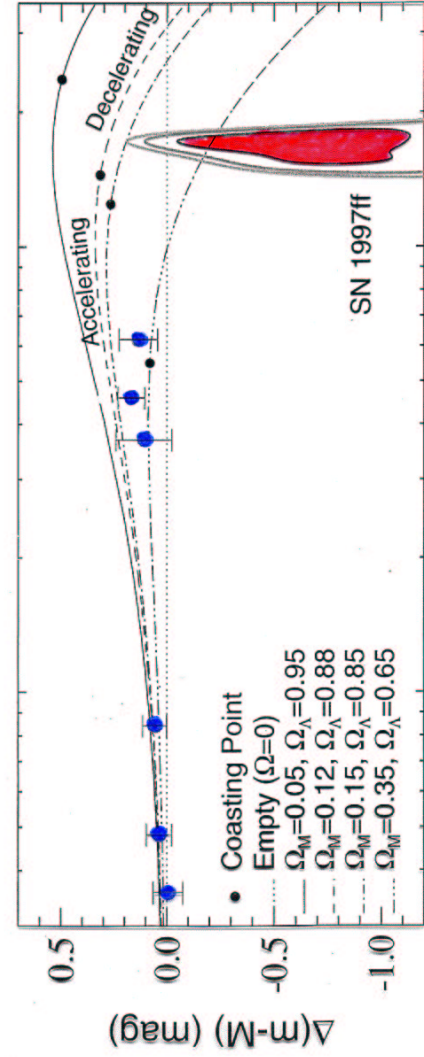
$$\frac{\Omega_m}{\Omega_\Lambda}$$

See deceleration by  $z \sim 1$

Change of sign for effect on SNIa magnitudes

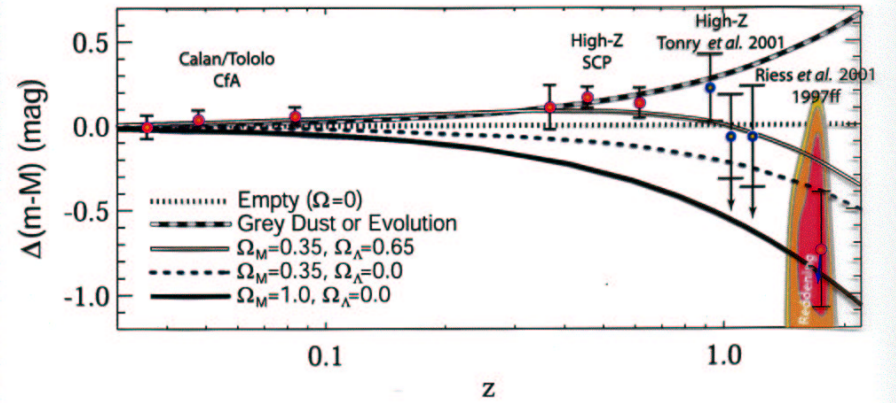
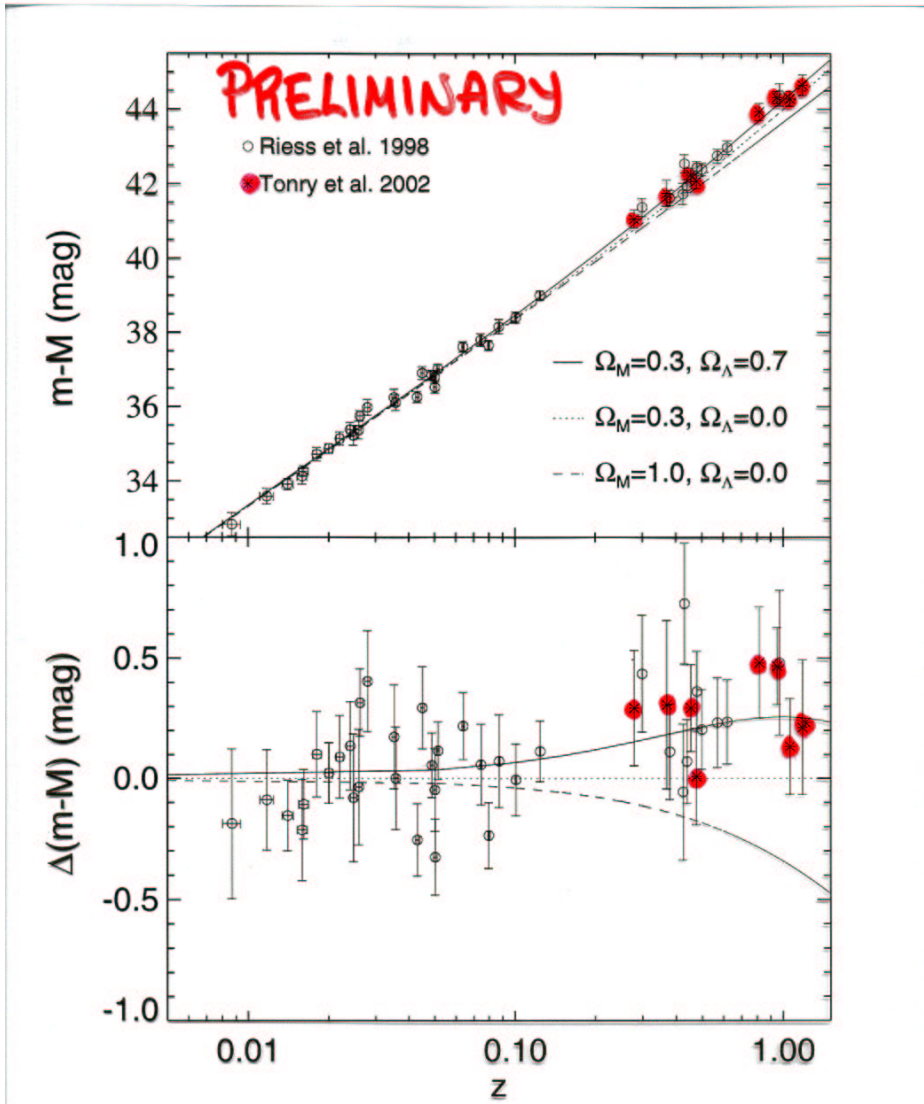


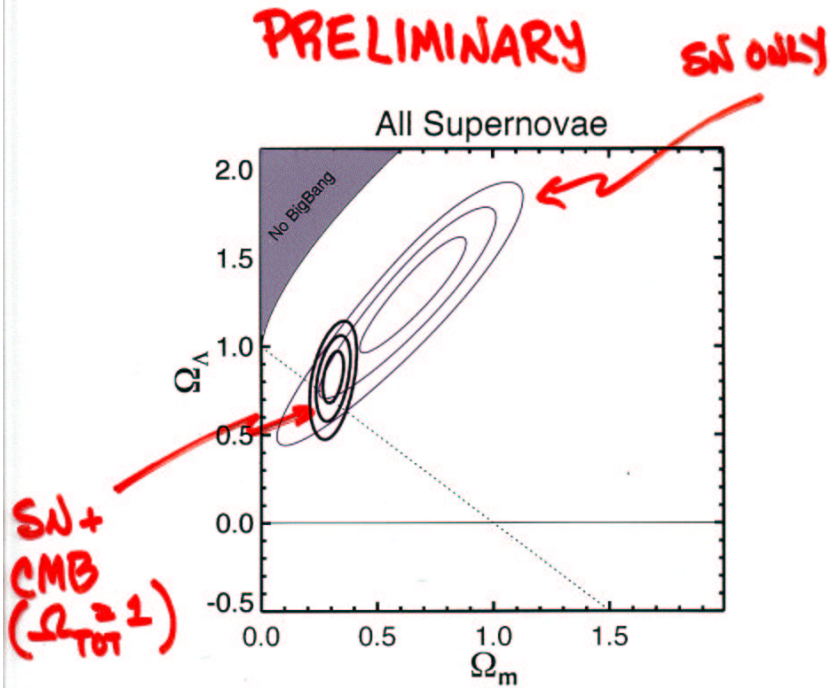
Riess et al. astro-ph/0104445



SN @  $z=1.7$  from the epoch of deceleration!







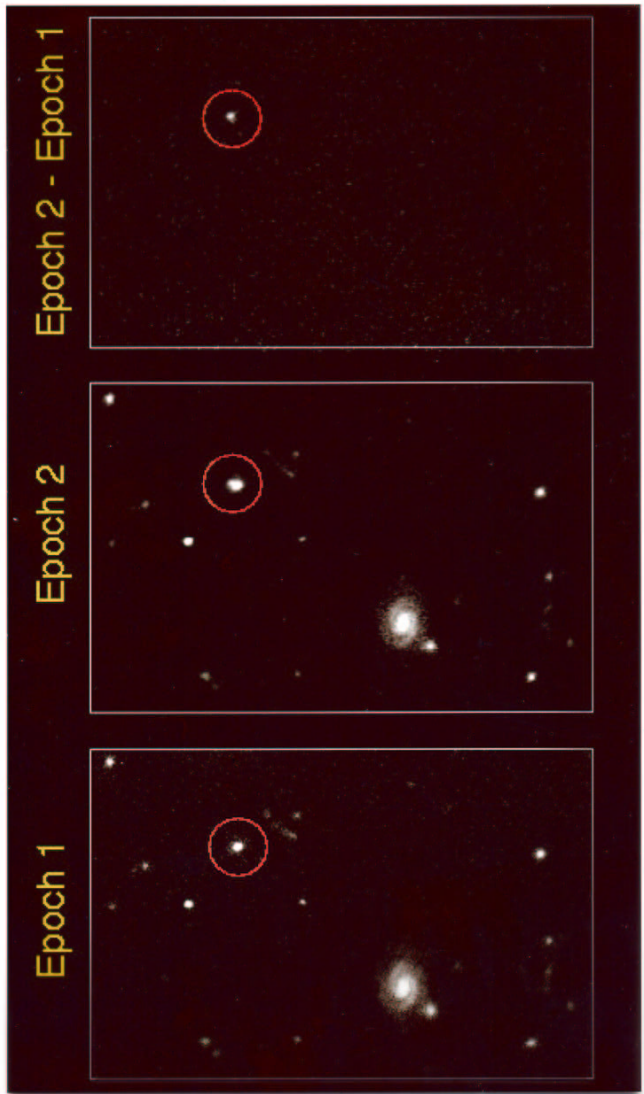
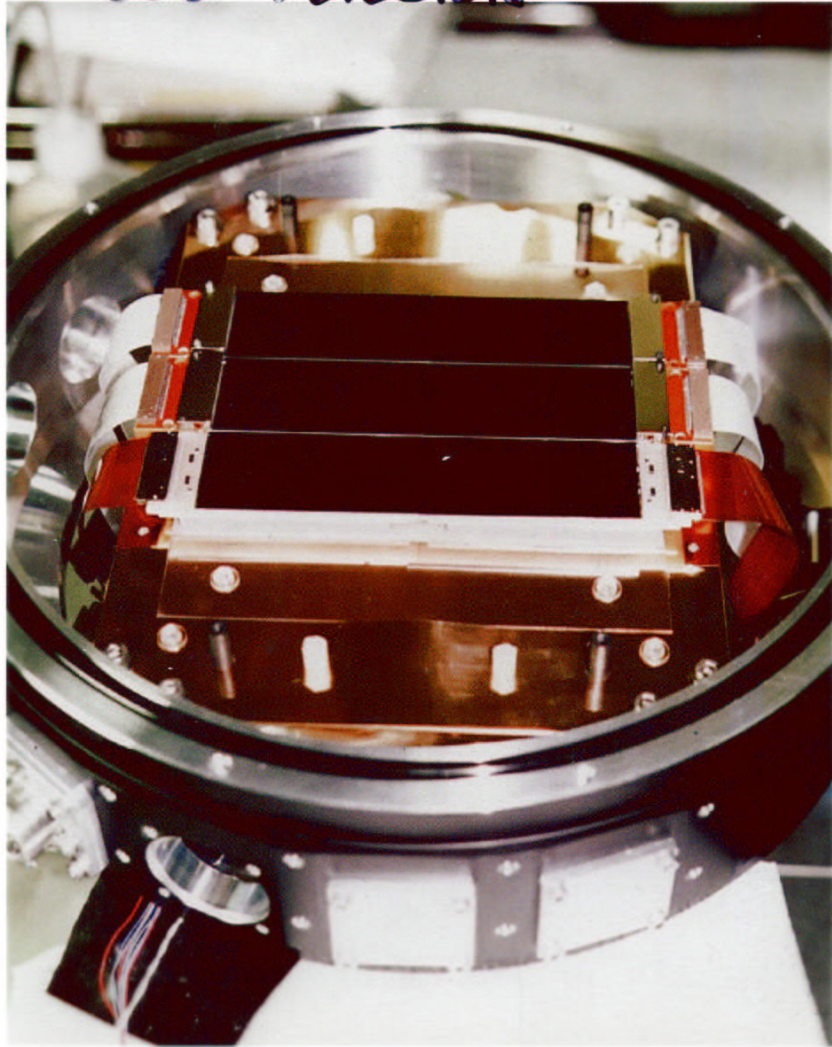
BUILDING UP THE SAMPLE

NOT JUST "BEFORE" AND  
"AFTER"  $\Rightarrow$  A CAMPAIGN  
TO MONITOR SN

JOHN TONRY } 2001  
BRIAN BARRIS } @ SUBARU



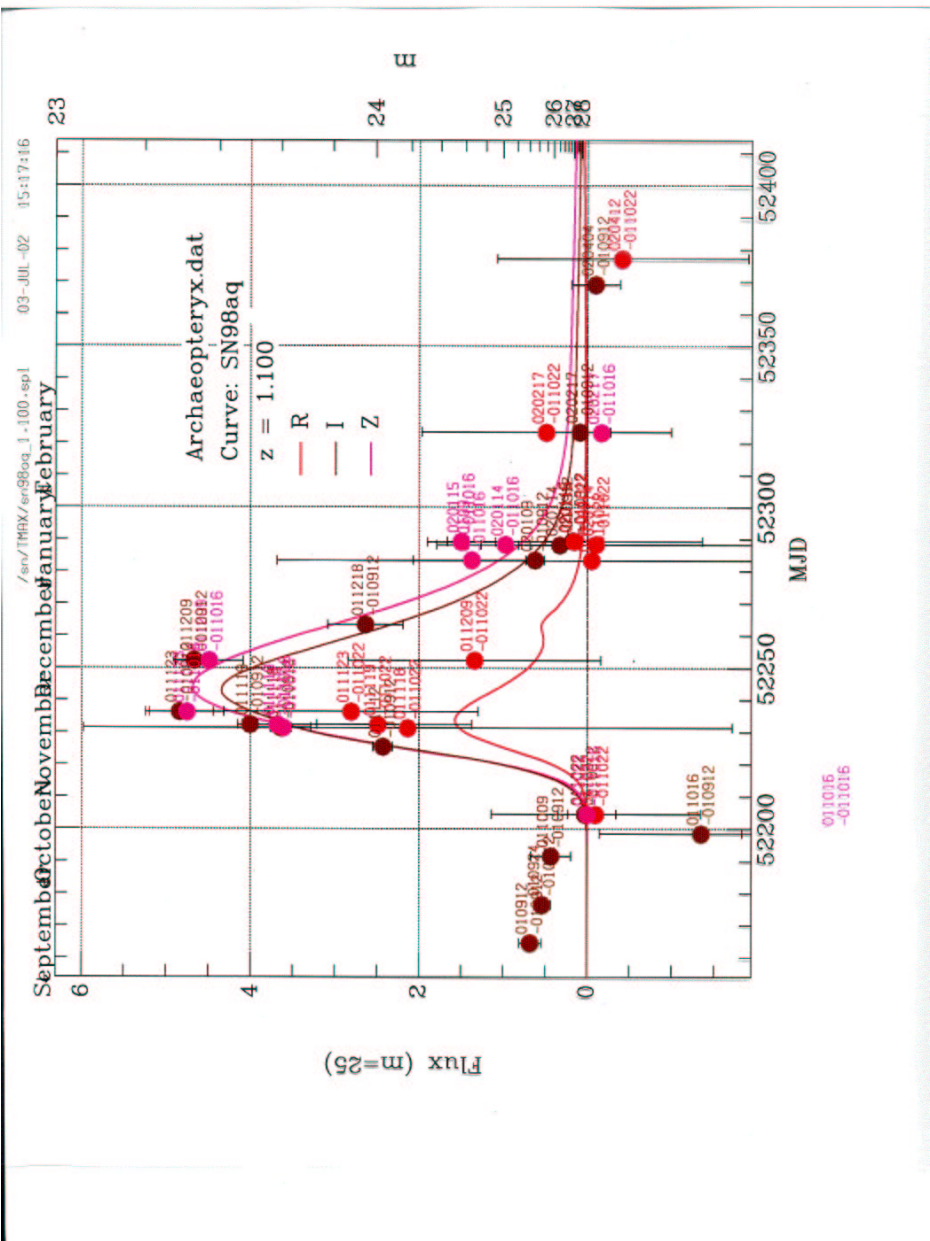
CCD DETECTOR



Epoch 2 - Epoch 1

Epoch 2

Epoch 1



COMING SOON

"ESSENCE"

Nick Suntzeff, Brian Schmidt, Chris Stubbs ...

CTIO 4<sup>m</sup> + MOSAIC CCD

1/2 a night every other night

~200 SNIa  $0.3 < z < 0.8$

Higher precision on equation of state  
by building up the sample where  
the effect of dark energy is largest

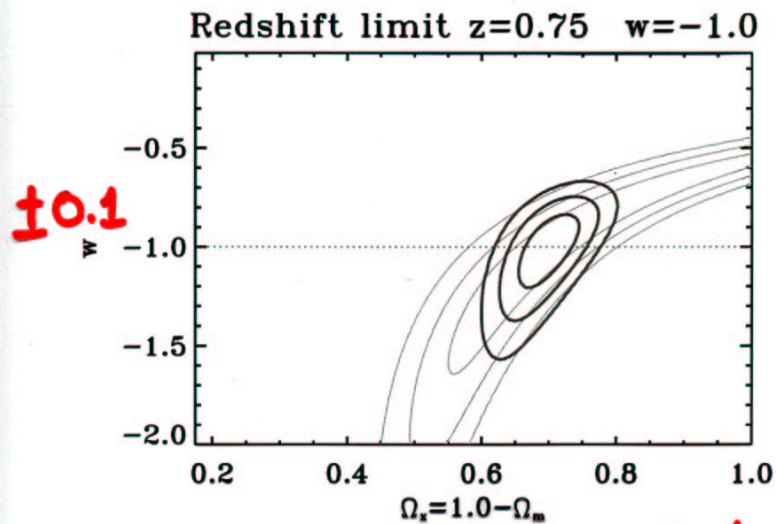
Onset of acceleration

First data: Oct 2002

Measuring  $w$

$\frac{p}{\rho}$

$-1 = \text{cosmo constant}$



If  $w = -1$ , good. If  $w \neq -1$  better!

But what about  
 $w(z)$ ?

Go deep!

Adam Riess @ STSCI

use the new camera on  
HST to find very distant  
Supernovae ( $z: 1.0-1.8$ )

U-band light curves with CCD  
camera

B, V with Infrared Camera  
NICMOS on HST



### The GOODS ACS Supernova Survey

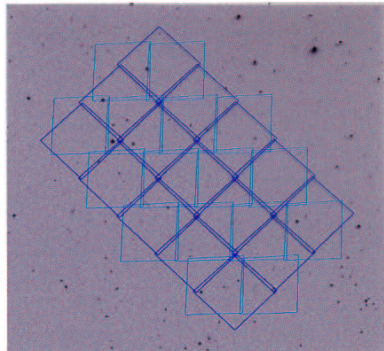
Hubble Deep Field North

Each 3x5 mosaic will be observed every ~45 days in the z-band ( $m \sim 26.5$ ) in 5 epochs

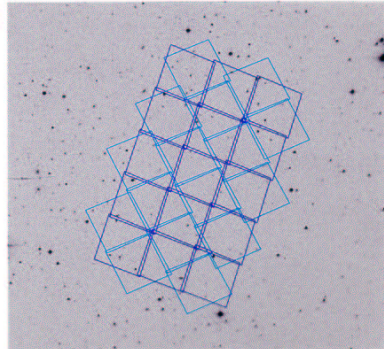
Simultaneous V,i colors

Photometric redshifts available from near-IR optical, and UV data

6 ToO triggers with HST for follow-up of SNe Ia at  $1.0 < z < 1.8$



Chandra Deep Field South



### A Higher-z Supernova Search by Piggybacking on the GOODS ACS Survey

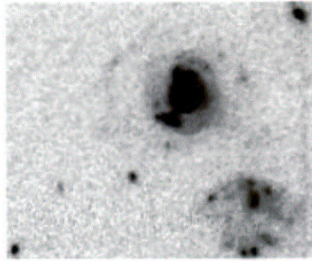


The **GOODS survey** includes 5 z-band epochs of a 3x5 mosaic of the HDFN and CDFS (including simultaneous colors and phot-z's)

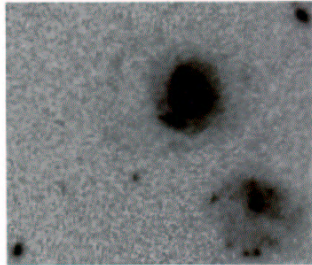
The **SN follow-up** consists of 6 TOO for SNe Ia at  $1.0 < z < 1.8$

GTO SN Ia at  $z=1.06$  in HDFN

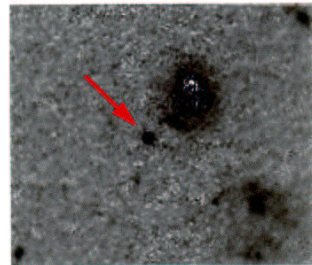
Original HDFN  
F814W



Original HDFN  
F606W

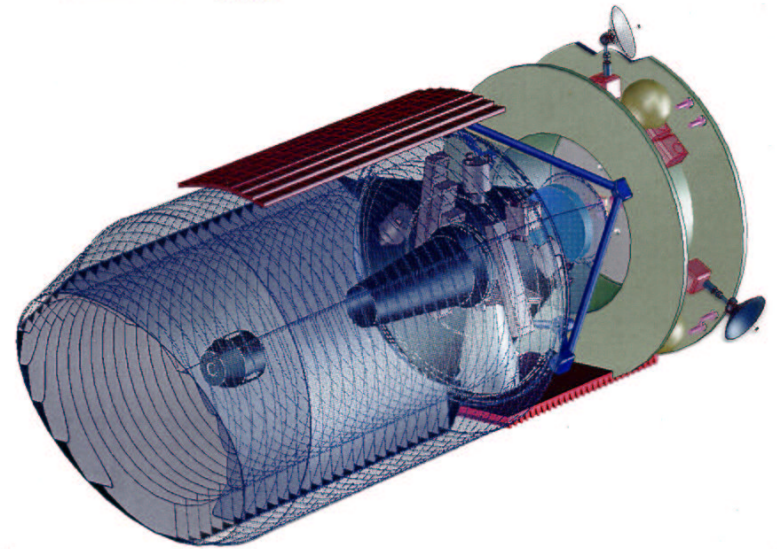


GTO HDFN  
May, 2002  
F775W



High- $z$  program starts Oct 2002

**SNAP** SuperNova  
Acceleration  
Probe



LBL  
PerkinElmer & Co.

## SUMMARY

- low  $z$  data improving 2x + U-band
- Middle  $z$  data being published soon!  
     $\Omega$  looks good
- ESSENCE to get  $w$  to  $\pm 0.1$
- HST SN to see SN at  $z \sim 1-1.8$

[SNAP to do this better]

Concordance of SNIa, CMB,  
 $\Omega_m$  from clusters more convincing  
than any single approach.