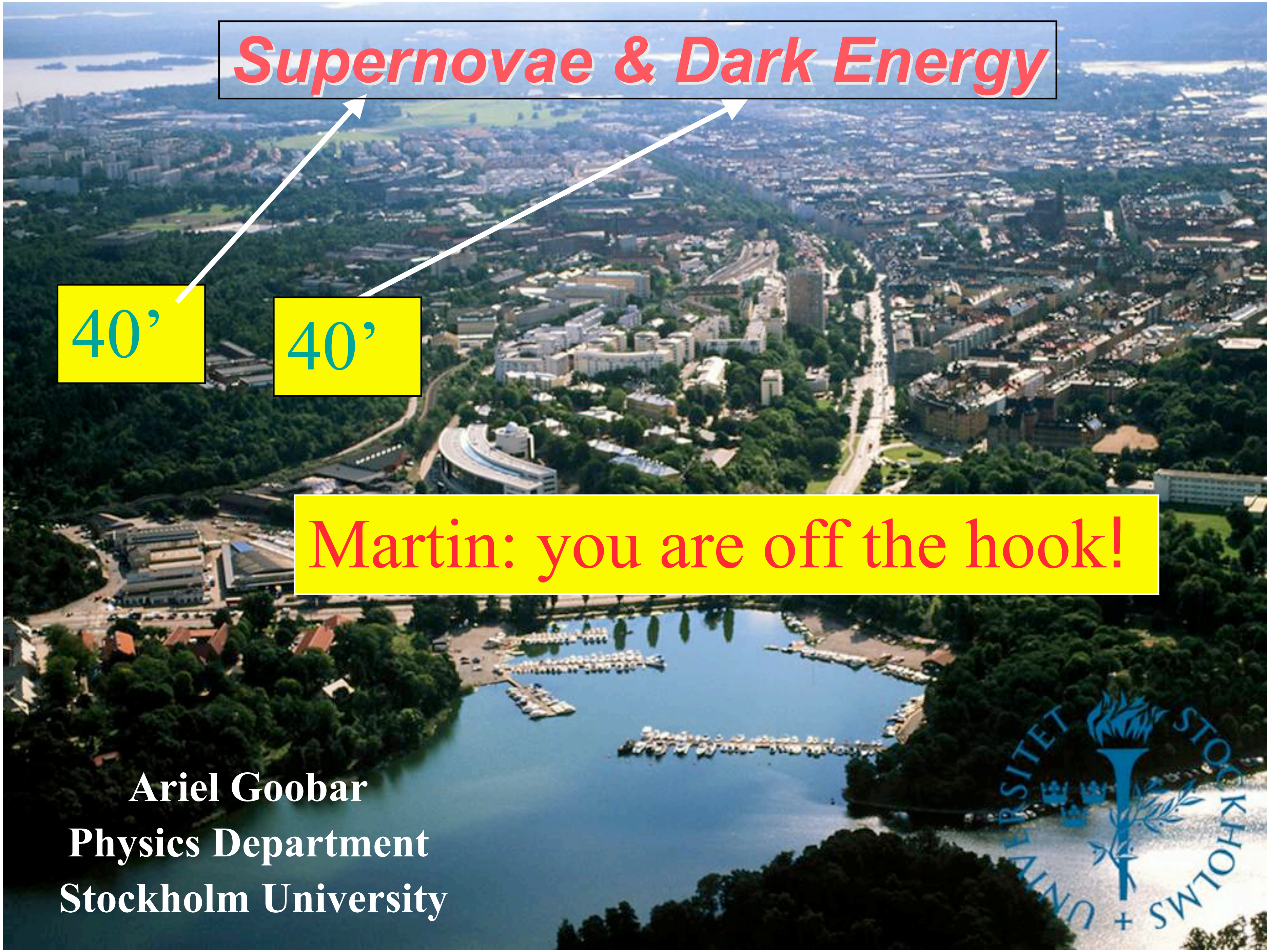


Supernovae & Dark Energy

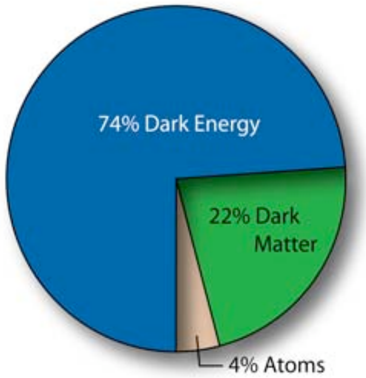
40'

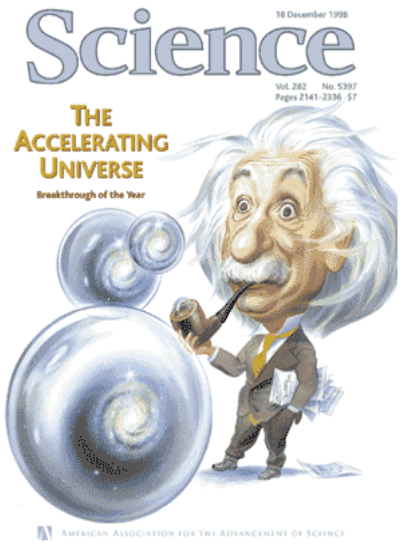
40'

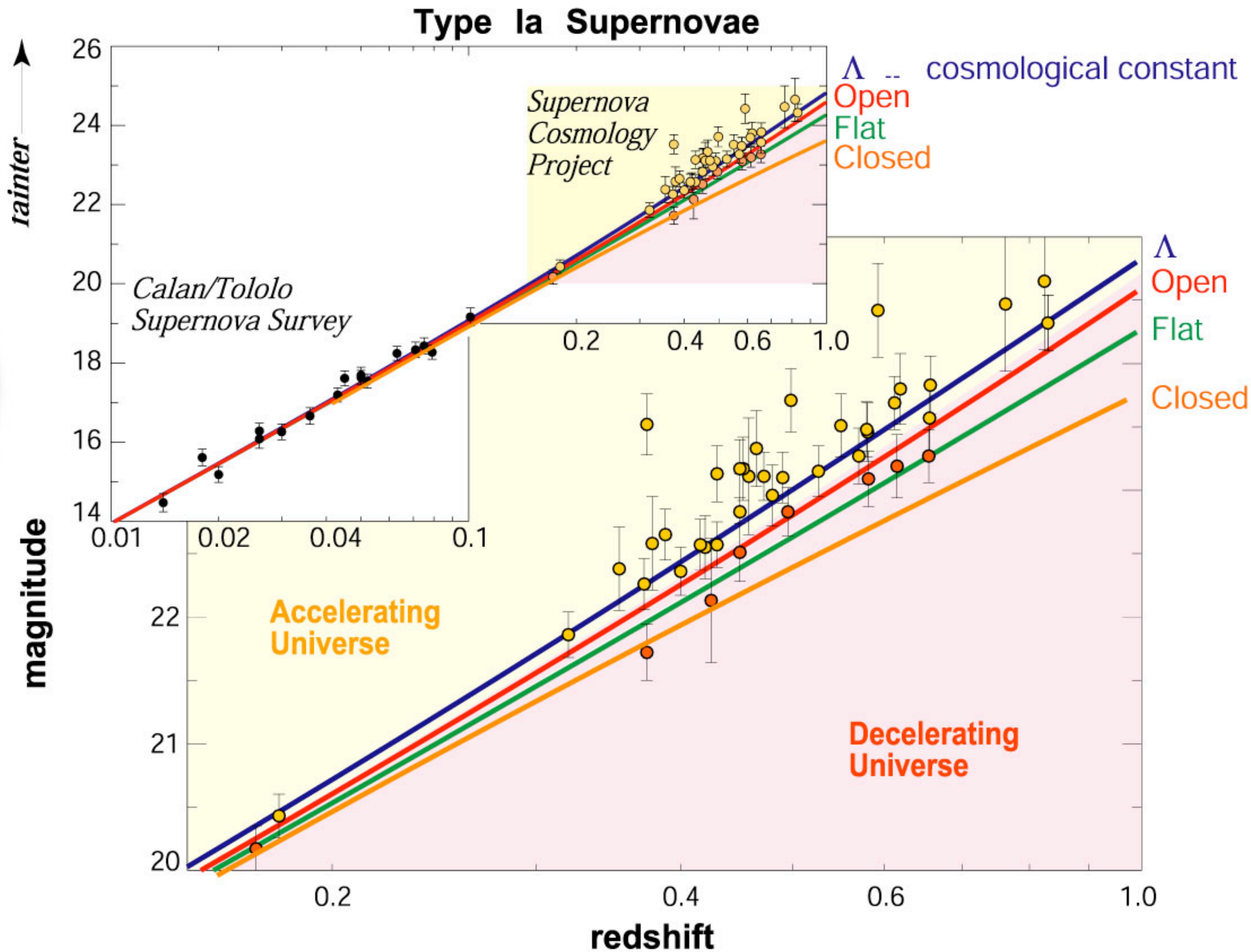
Martin: you are off the hook!

Ariel Goobar
Physics Department
Stockholm University

In 1998: SCP+ High-Z Team







By Year · Cosmology · Genetics · Neuroscience · Justice · Women's Rights · Young Scientists Awards

COSMOLOGY

2007 Gruber Cosmology Prize

Saul Perlmutter and Brian Schmidt and their teams: the Supernova Cosmology Project and the High-z Supernova Search Team, independently discovered that the expansion of the Universe is accelerating. Their discovery led to the idea of an expansion force, dubbed dark energy. And it suggested that the fate of the universe is to just keep expanding, faster and faster.

Saul Perlmutter & the Supernova Cosmology Project

Brian Schmidt & the High-z Supernova Search Team

By now many dark energy ”detections”

- Type Ia supernovae
- CMB power spectrum
- Large Scale Structure
- Baryon Acoustic oscillations
- Weak gravitational lensing
- Cluster abundances
- Cluster X-ray observations (f_{gas})
- Integrated Sachs-Wolfe effect
- Age of Universe

dark energy signal

- *Sunyaev-Zeldovich effect*
- *Strong gravitational lensing*

Around the corner

- *Tomography @ 21-cm (Hydrogen)*
- *Gravitational wave ”sirens”*
- *Laboratory tests of gravity?*

Potential tools for the future

SNIa & cosmological parameters: the luminosity distance

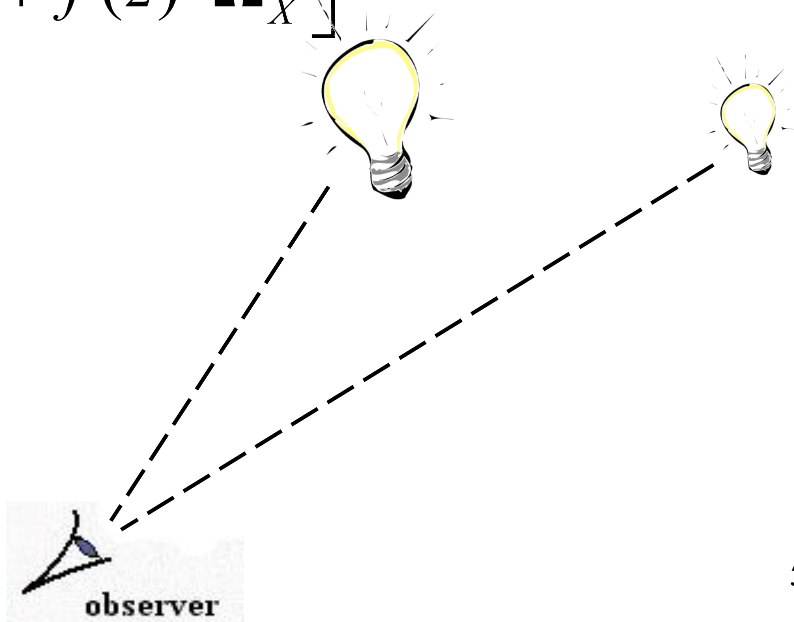
$$d_L = \frac{c \cdot (1+z_E)}{\sqrt{|\Omega_K|}} F\left(\sqrt{|\Omega_K|} \int_0^{z_E} \frac{dz}{H(z)} \right)$$

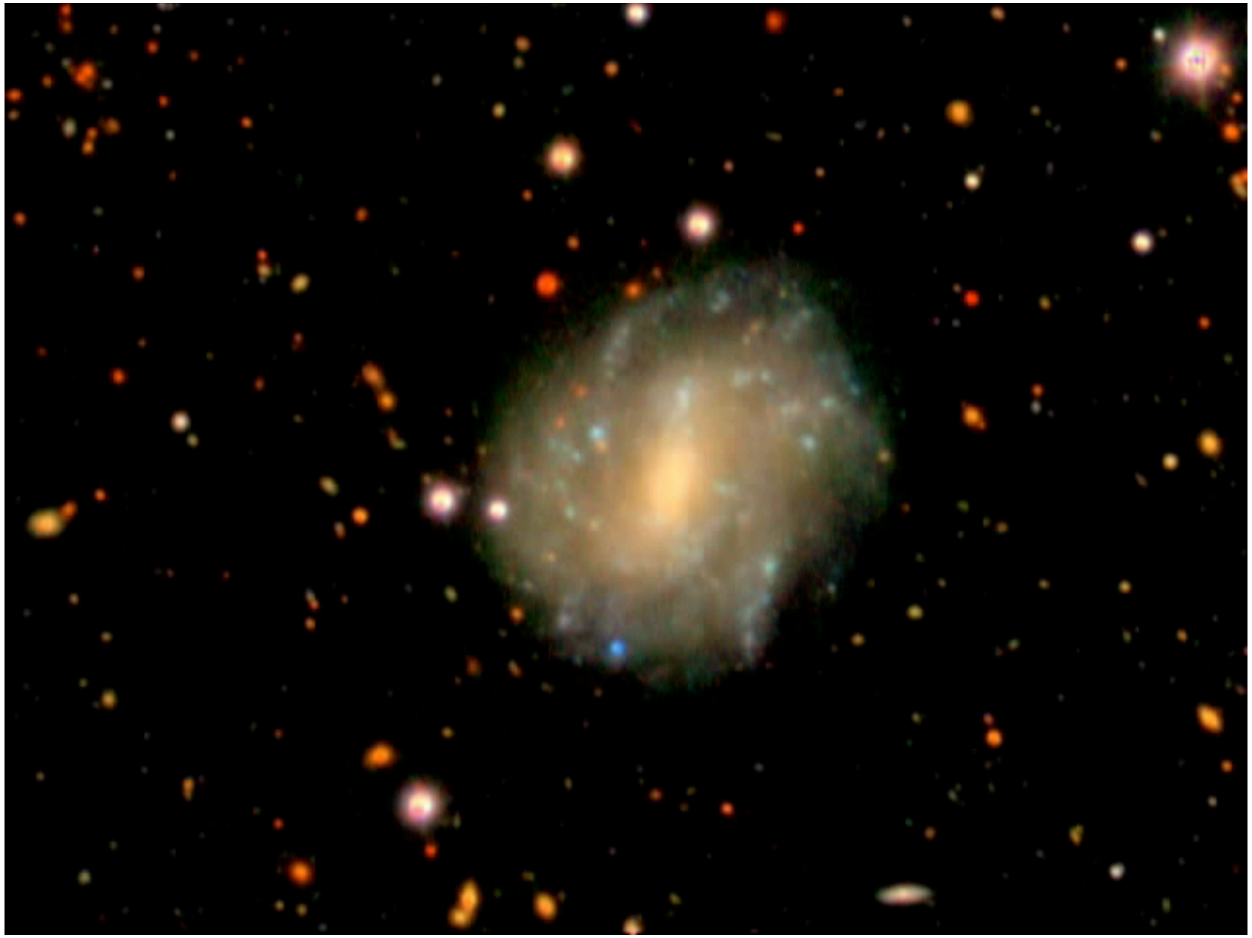
- where F(x) = sin(x) for a closed universe, sinh(x) for an open universe and x for a flat universe. In the latter case the Ω_K terms are set to 1.

$$H^2 = H_0^2 \left[\Omega_M (1+z)^3 + \Omega_K (1+z)^2 + f(z) \cdot \Omega_X \right]$$

where

$$f(z) = \exp\left[3 \int_0^z \frac{1+w(x)}{1+x} dx \right]$$

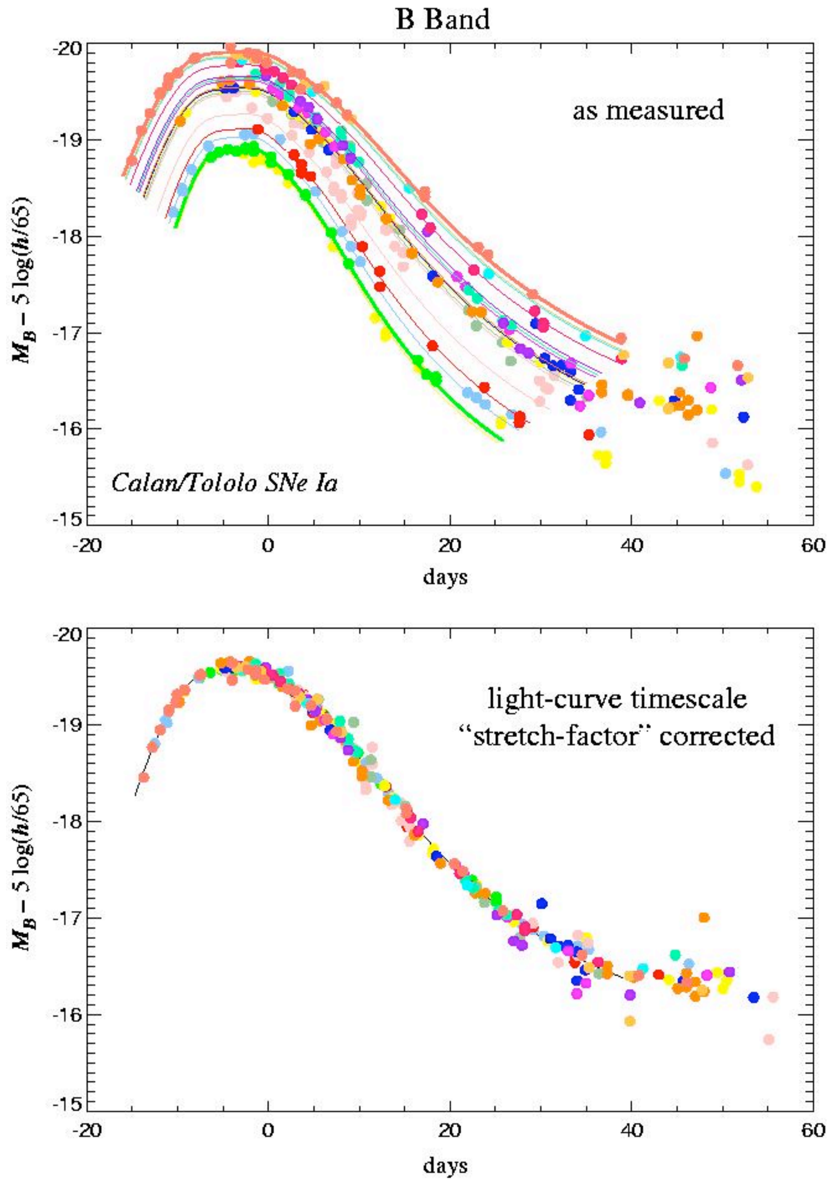




”Standarizeable” candle

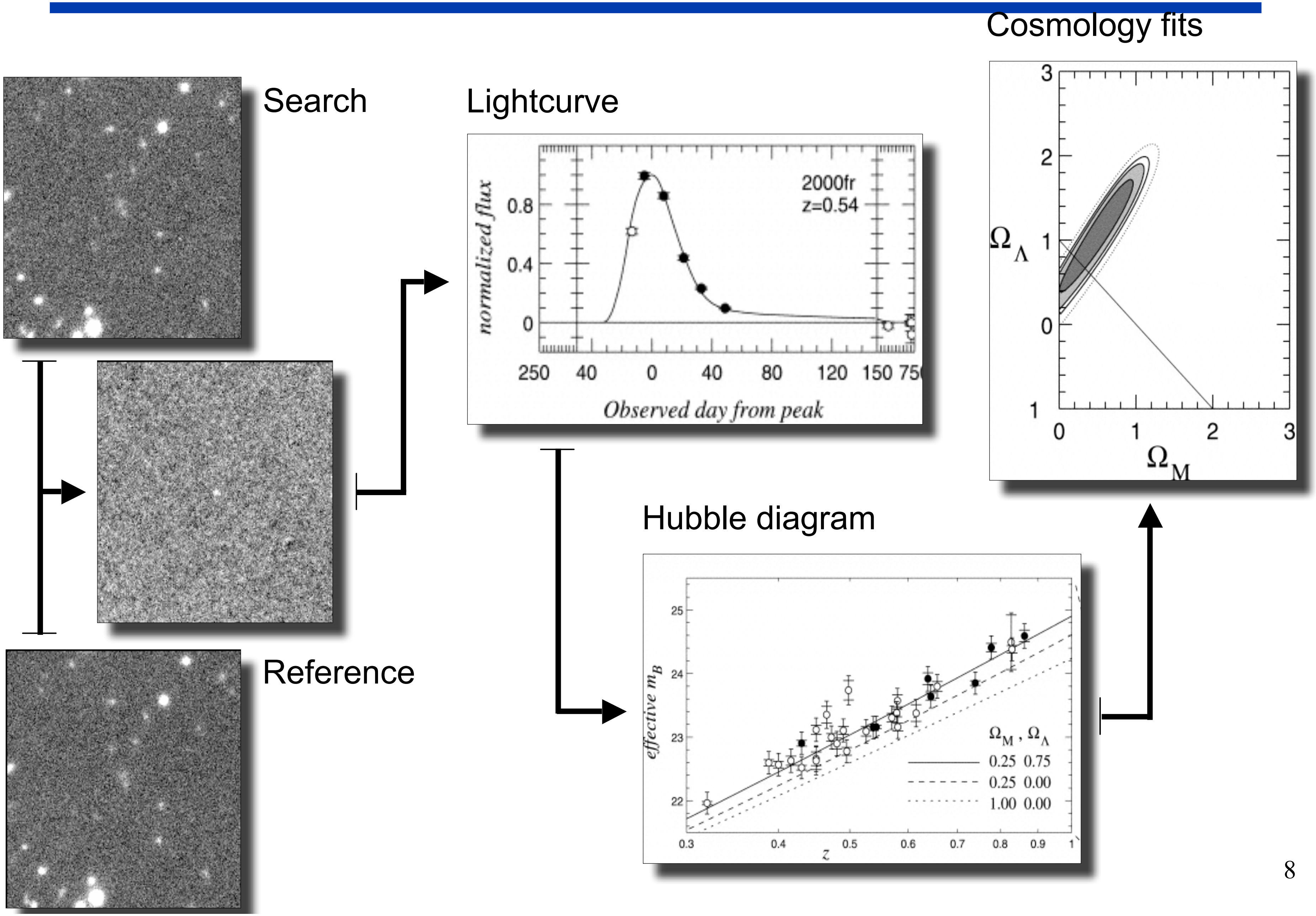
- Typical spread in Type Ia brightness is about 40%
- After shape-brightness correction, SNIa are standarized to about <15% standard deviation in brightness...

  ... Corresponding to ~7% precision in distance

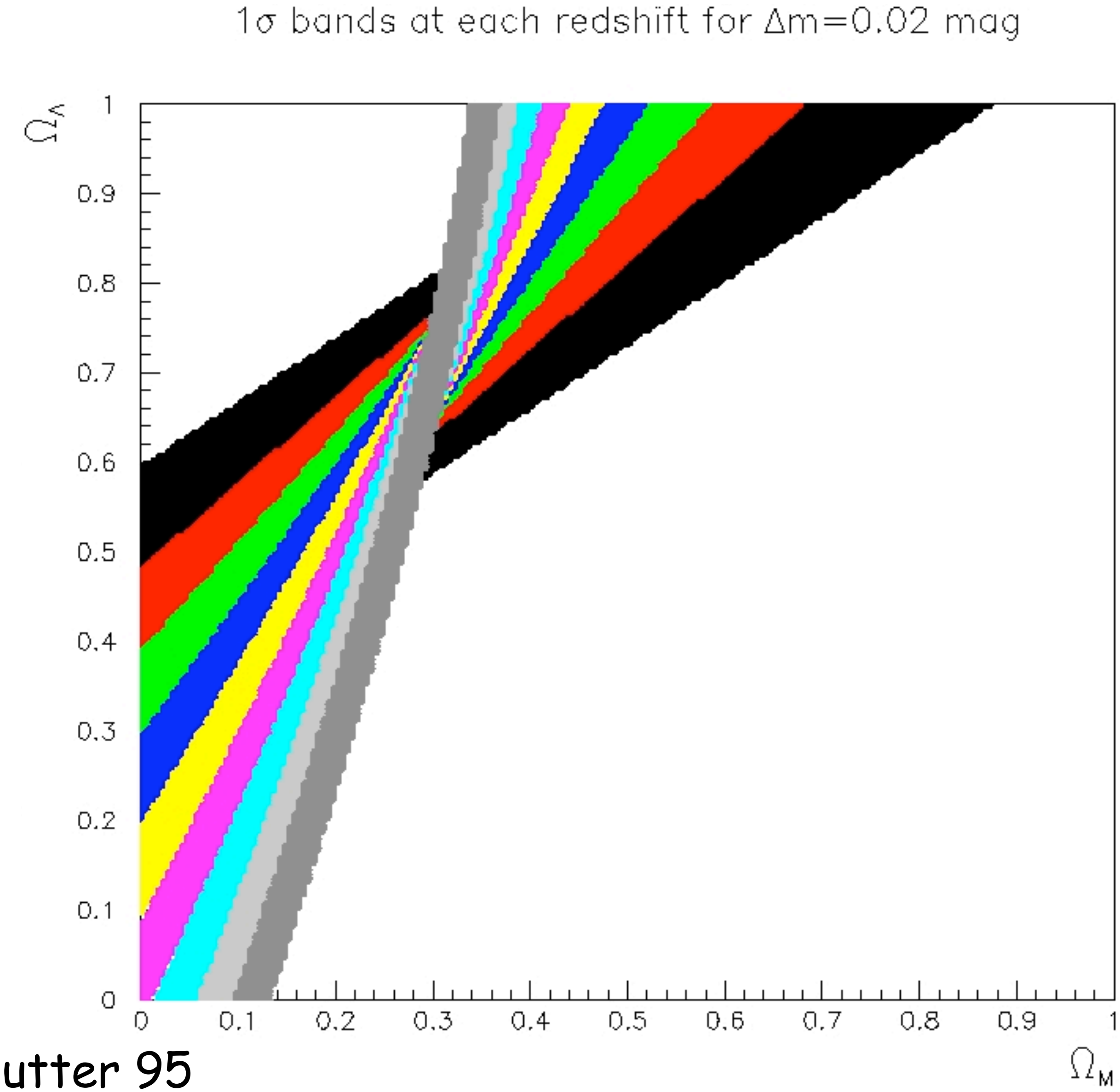


Kim, *et al.* (1997)

SN-cosmology tutorial



Statistical uncertainty: Redshift dependence



AG & Perlmutter 95

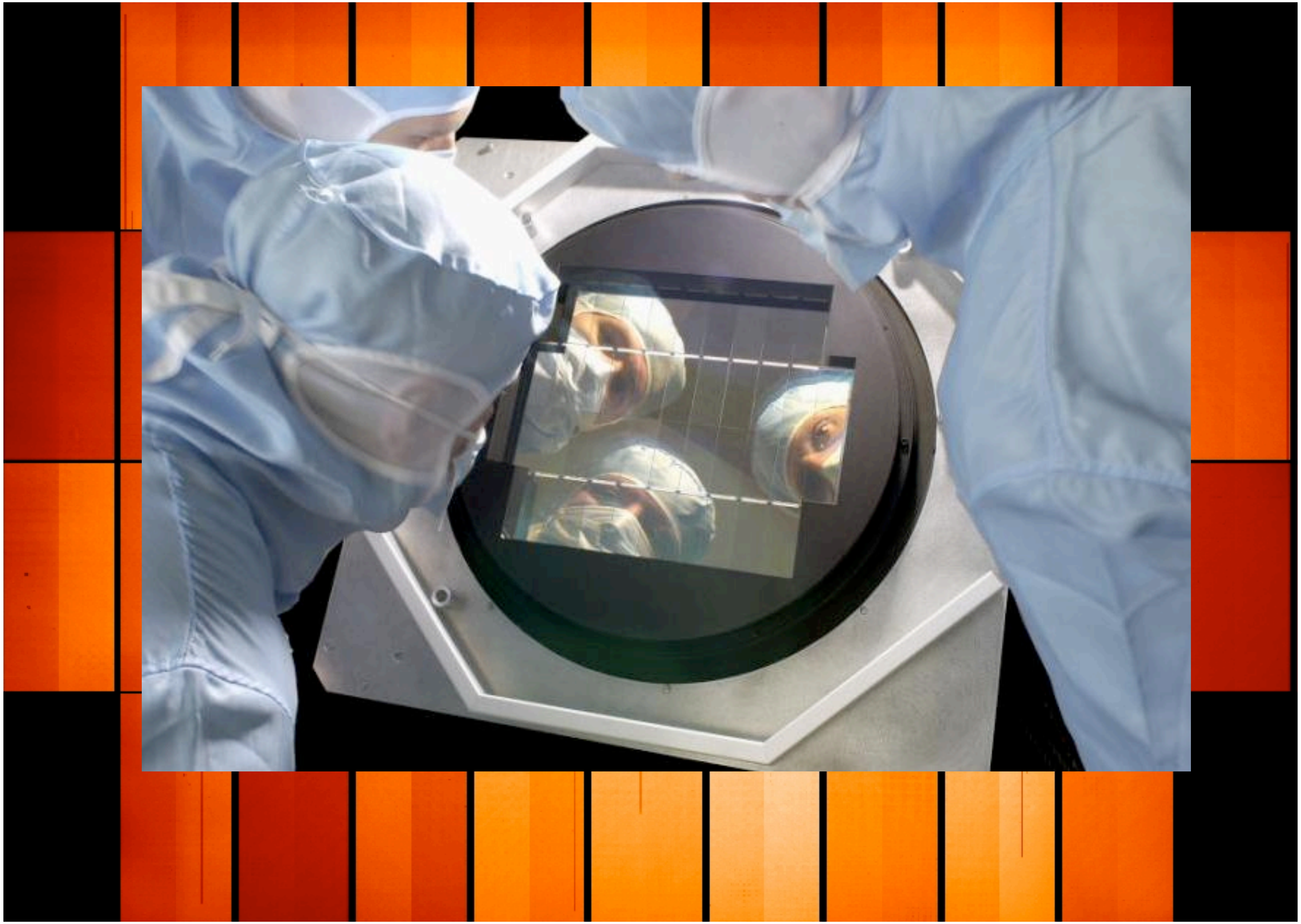
Large ongoing SNIa projects: $0.2<z<1$

- **ESSENCE at CTIO 4-m: to collect ~200 SNIa**

- **CFHT (3.7-m) SuperNova Legacy Survey: 5 year ”rolling search”in (u)griz. By 2008 ~500 spectroscopically confirmed SNIa.**

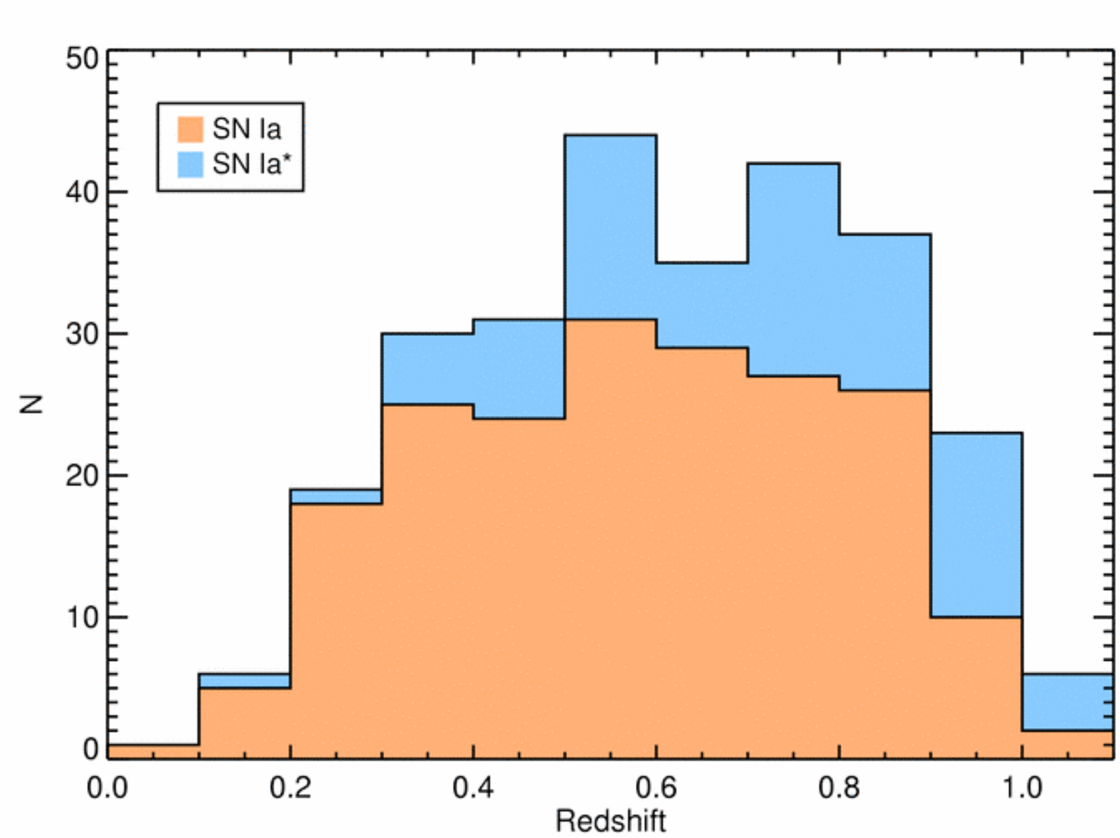
Huge Cameras! CTIO: 8 CCD's ½° x½°

CFHT-SNLS: 40 CCDs, 4 times bigger!

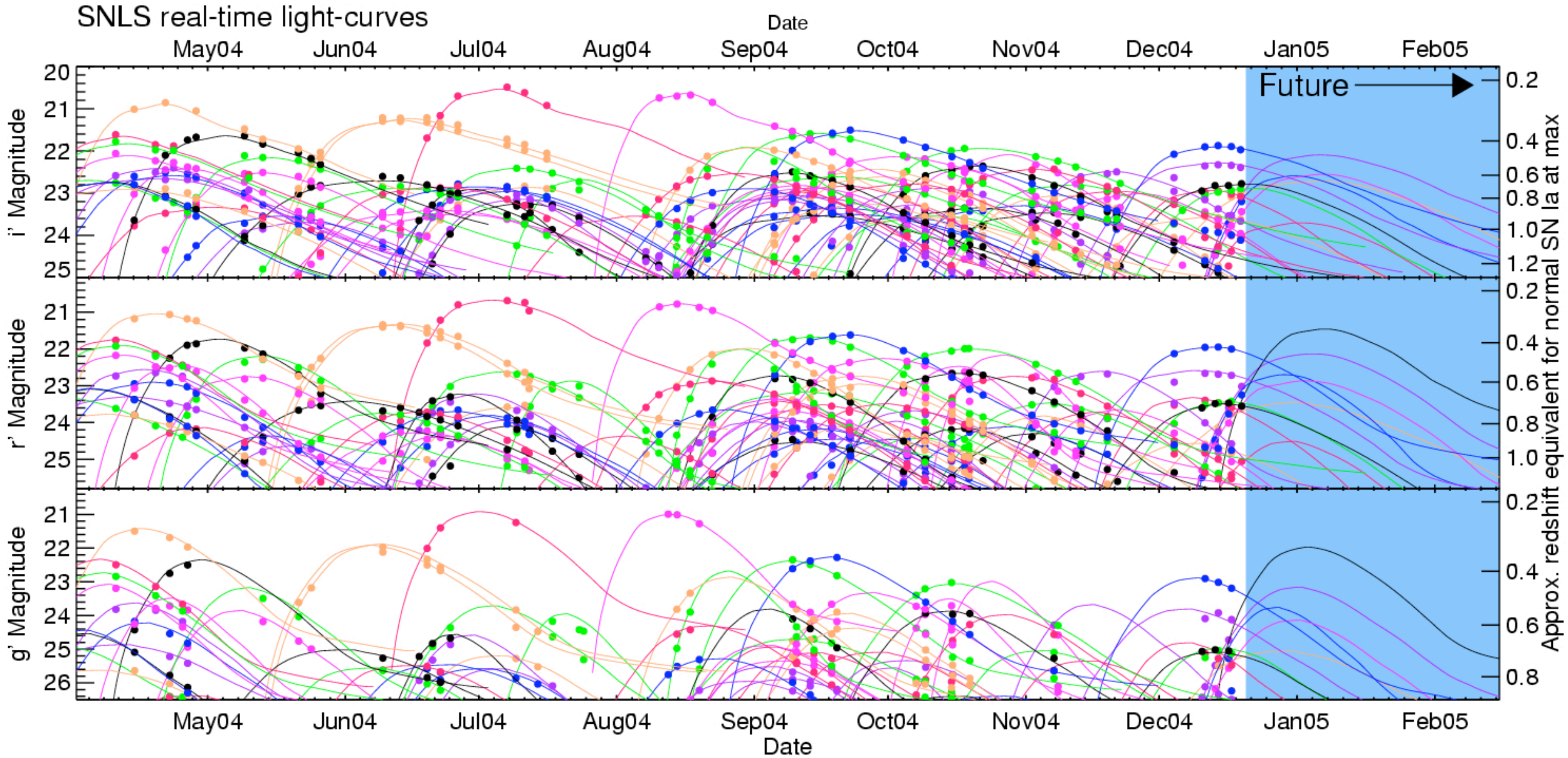


SNLS: Current status

- **Survey running for nearly 4 years**
- **~310 confirmed distant SNe Ia (+ 50-60 not yet processed)**
  - **~ Largest single telescope sample of SNe**
  - **"On track" for 500** spectroscopically confirmed **SNe Ia by survey end (>1000/>2000 total SNIa/All SN light-curves)**



SNLS

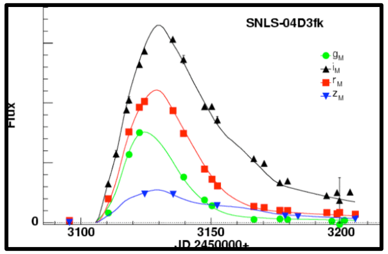


SNLS real-time light-curves
Date
May04
Jun04
Jul04
Aug04
Sep04
Oct04
Nov04
Dec04
Jan05
Feb05
Future
i' Magnitude
r' Magnitude
g' Magnitude
Approx. redshift equivalent for normal SN Ia at max
Date

SuperNova Legacy Survey (SNLS)

<u>Imaging</u>

CFHT Legacy Survey
Deep program

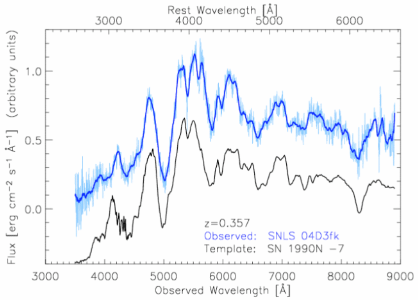


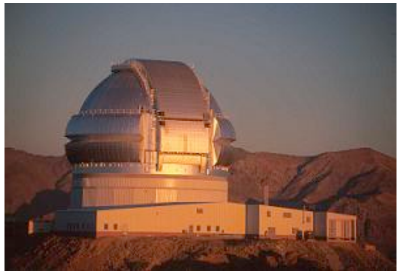
Discoveries **Lightcurves**

g'r'i'z' every 4 days during dark time

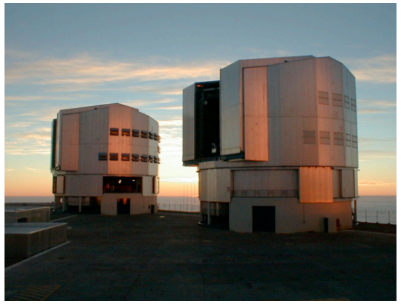
<u>Spectroscopy</u>

Types, redshifts from 8m-class telescopes





Gemini N & S (120 hr/yr)



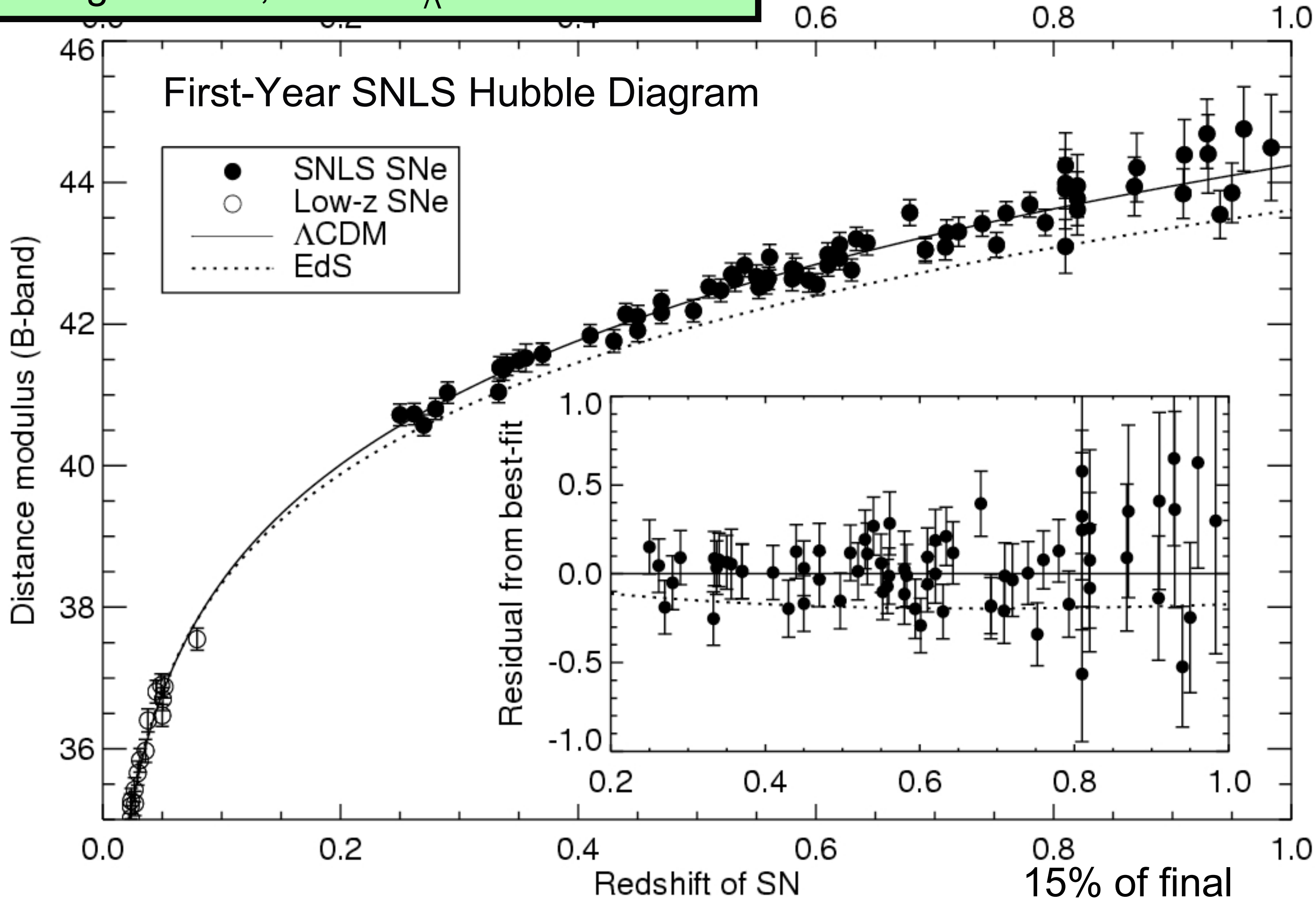
VLT (120 hr/yr)

Keck (8 nights/yr)

Magellan (15 nights/yr)

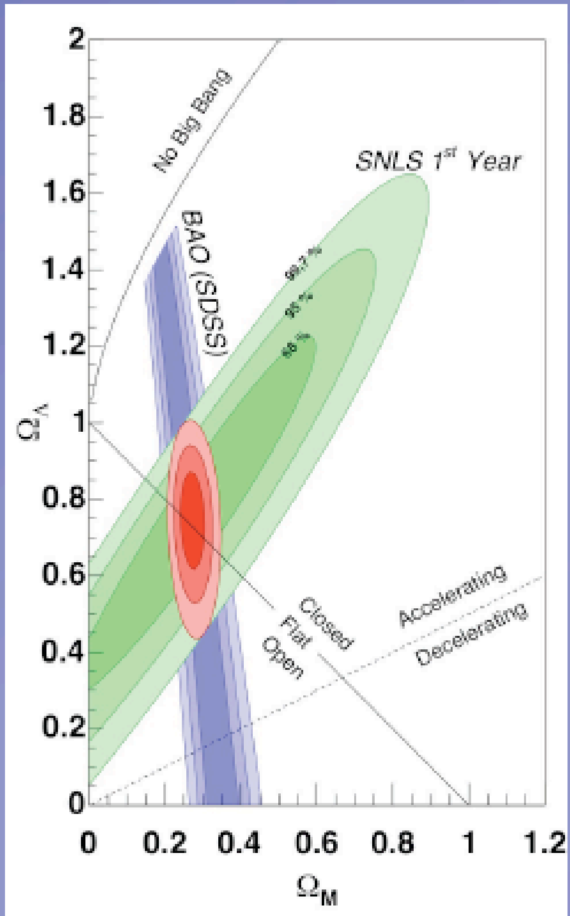
First Year Results (Astier et al. 2006):

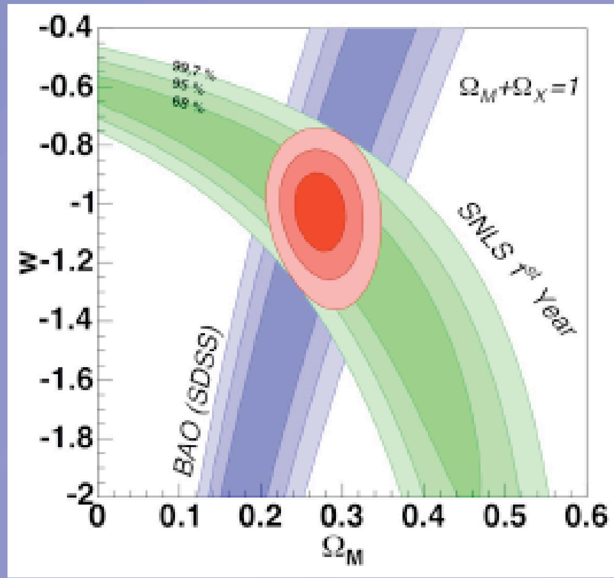
Assuming flatness, w=-1: $\Omega_\Lambda = 0.737 \pm 0.042$



15% of final sample

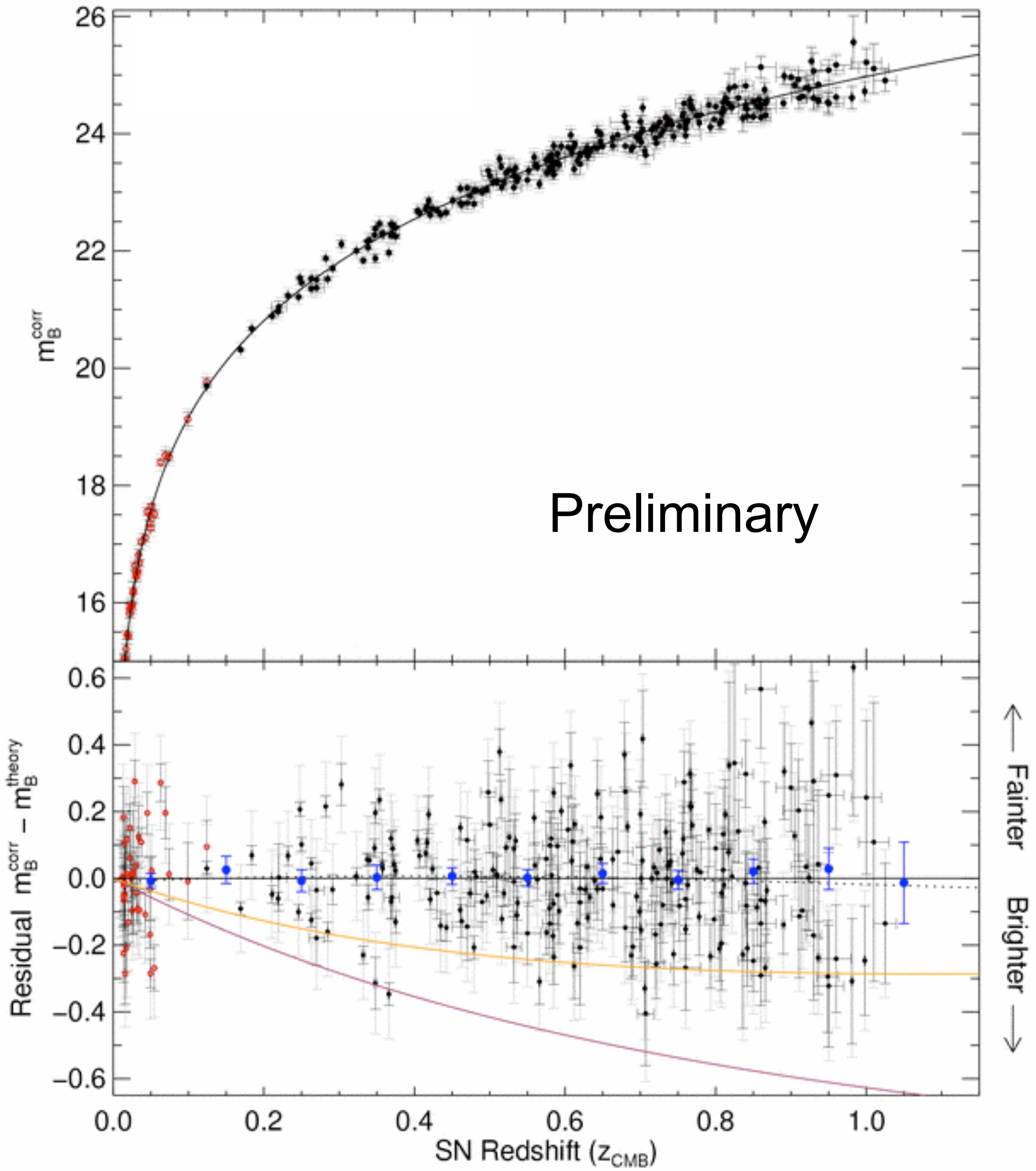
Cosmological parameters (1st year)





68.3, 95.5 and 99.7% CL
Green SNLS, Blue SDSS/BAO 2005

Ω_M = 0.271 +/- 0.021 (stat) +/- 0.007 (syst)
w = -1.023 +/- 0.090 (stat) +/- 0.054 (syst)



"Third year" SNLS Hubble Diagram
(preliminary)

3/5 years of SNLS

~240 distant SNe Ia

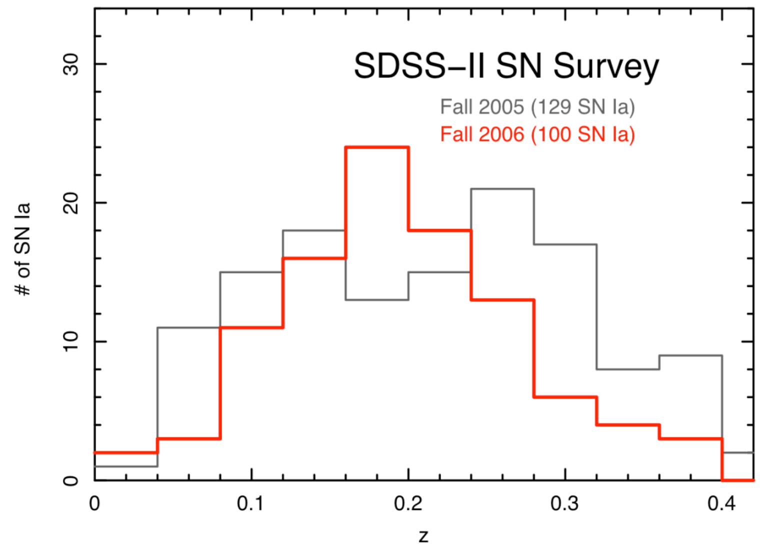
rms ~ 0.17mag

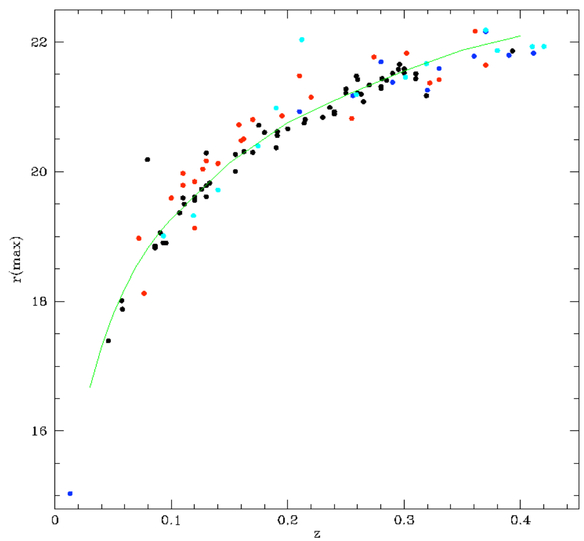
Credit: M.Sullivan

SDSS-SN

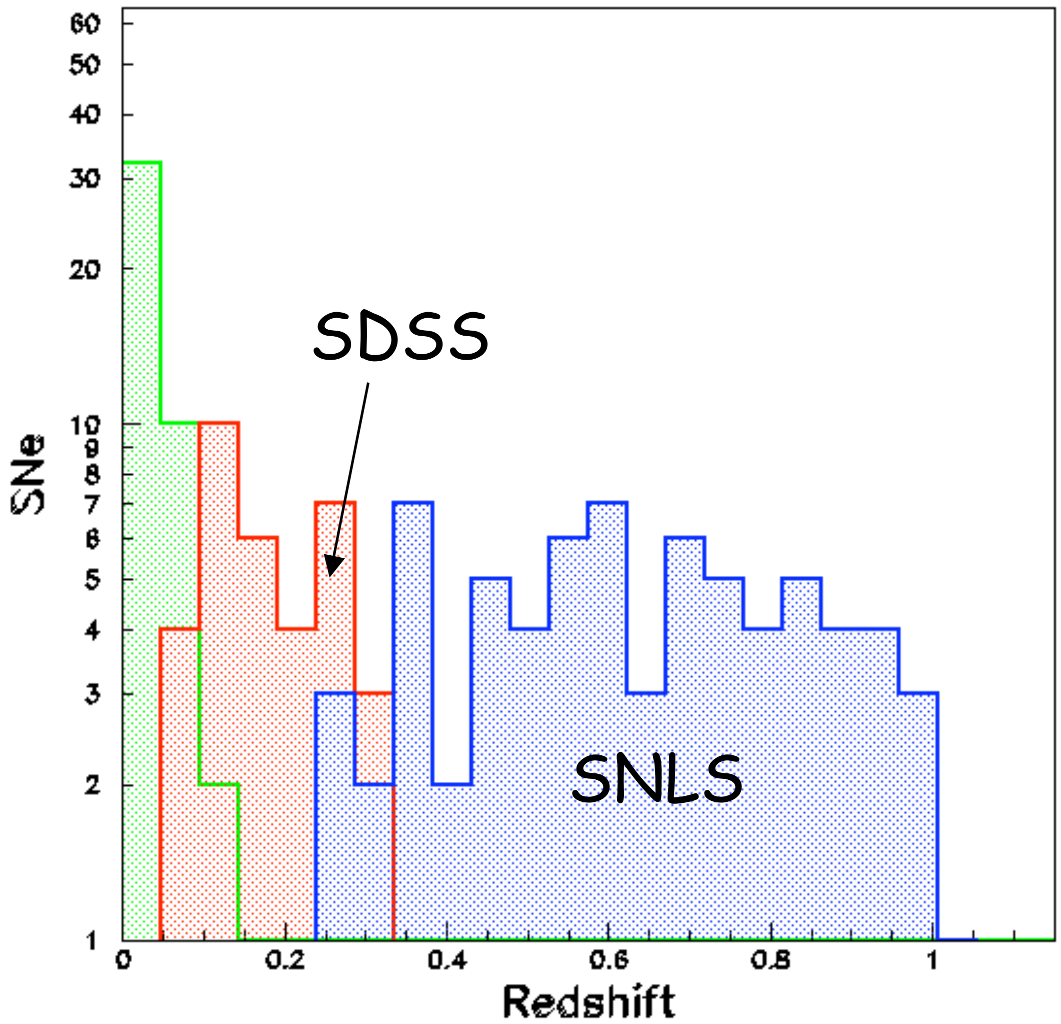
- **Rolling search completed for two years:**
- **Follow-up on NTT, WHT, Subaru, ARC3.5m, HET, MDM**
- **Dec 06:**

  321 spectroscopically confirmed SNIa (~100 ID at ESO)
- **Many Ia's now have multi-epoch spectra**
- **<z> = 0.21**





C-T/CfA low-z, SDSS 1-run + SNLS 1-yr

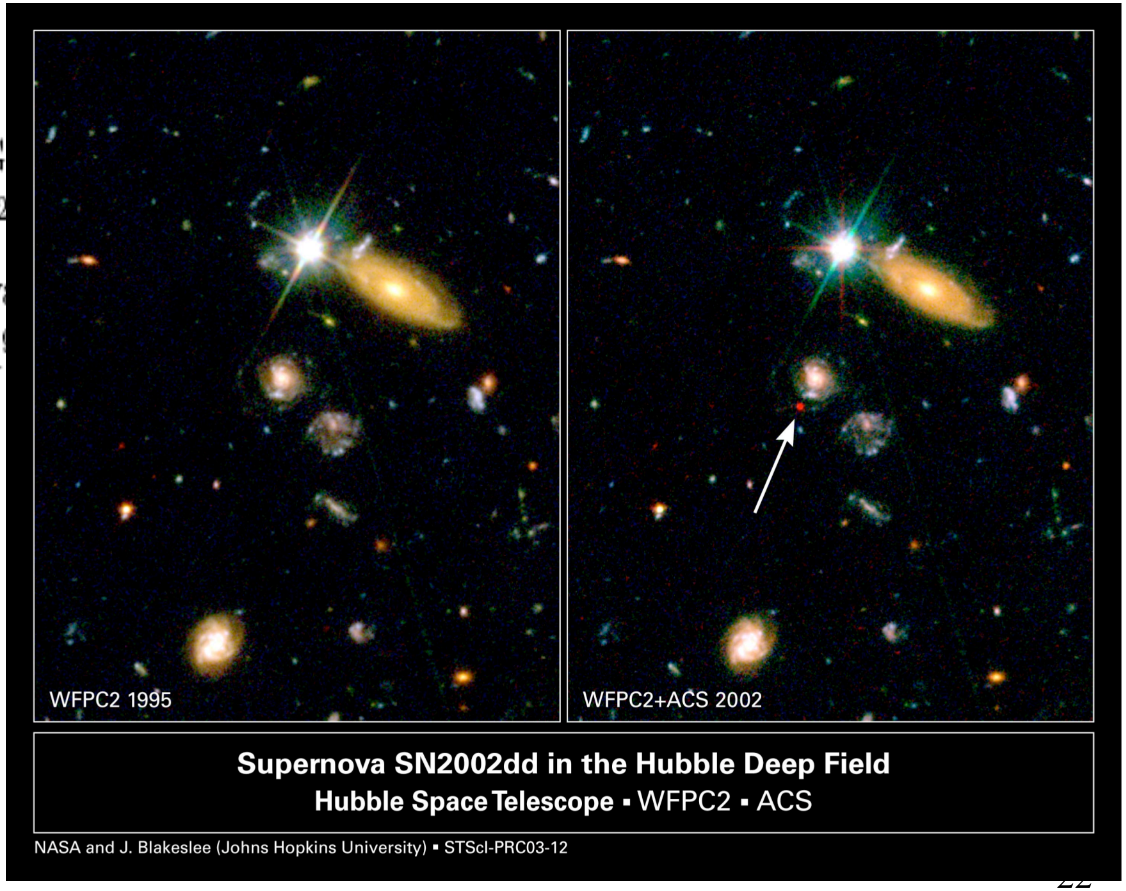


Very-high redshift supernovae from ACS/HST

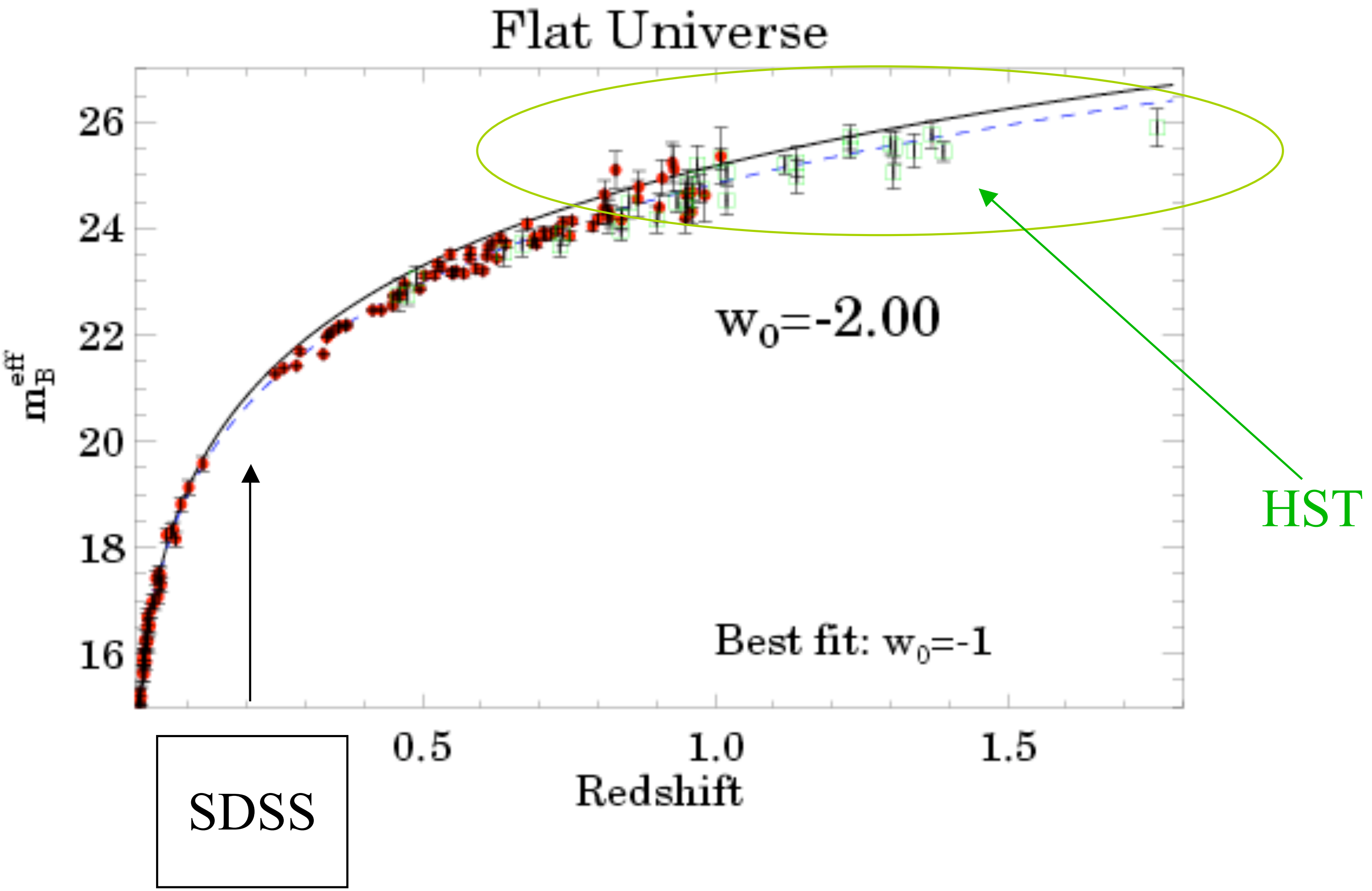
New *Hubble Space Telescope* Discoveries of Type Ia Supernovae at $z \geq 1$: Narrowing Constraints on the Early Behavior of Dark Energy[1]

17 Nov 2006

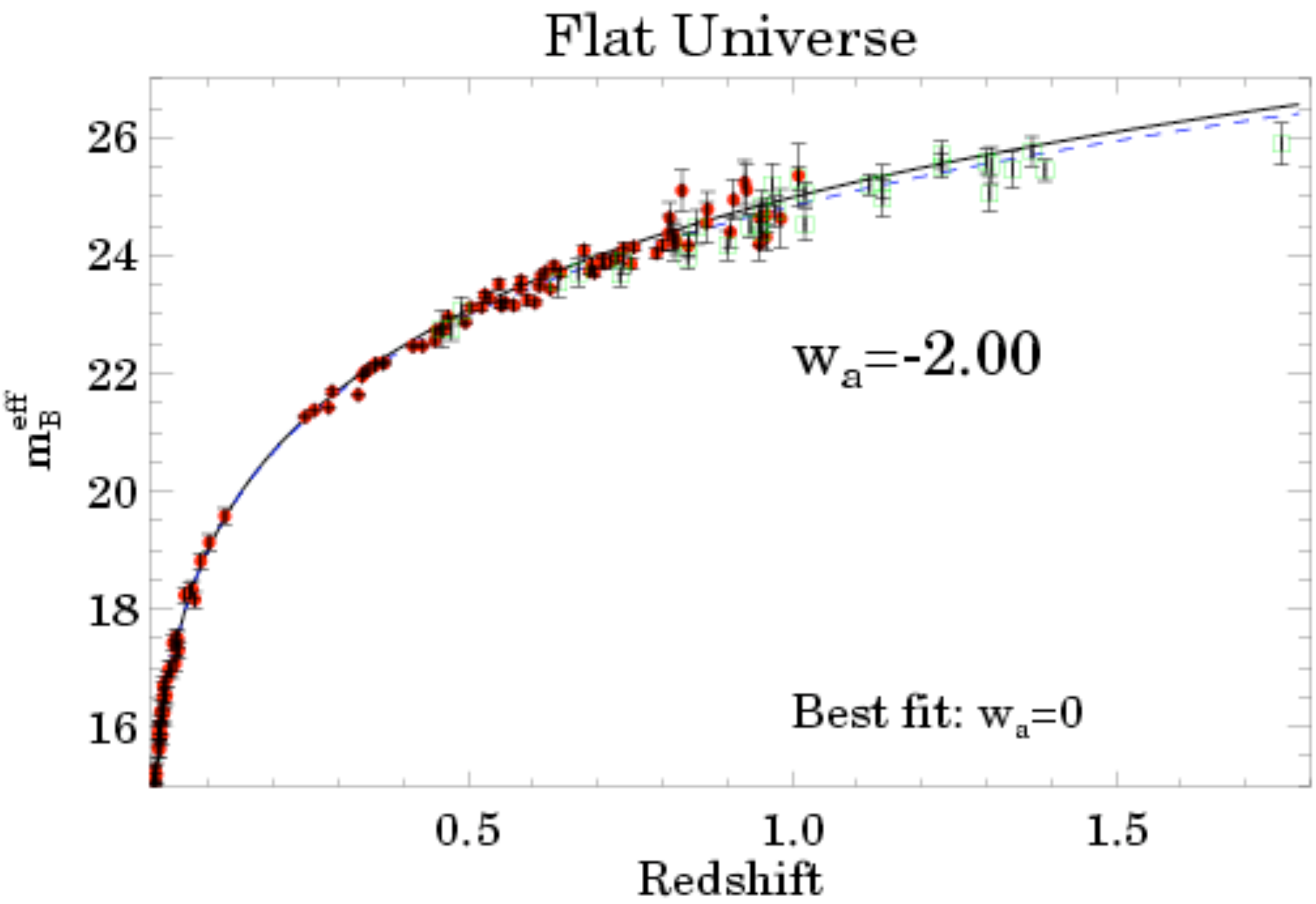
Adam G. Riess[2,3], Louis-G
Bahram Mobasher[3], Ben Gold[2
Weidong Li[6], John Tonry[7], Ry
MacDonald[8], Daniel Eisenstein
and Daniel Stern[10]



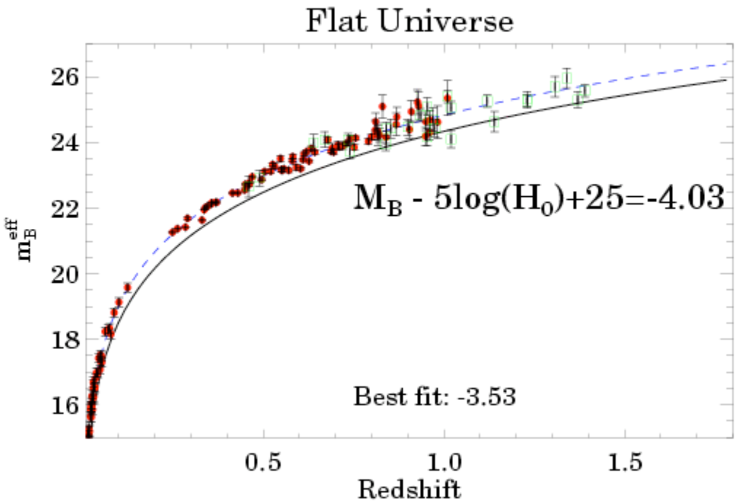
Constant dark energy

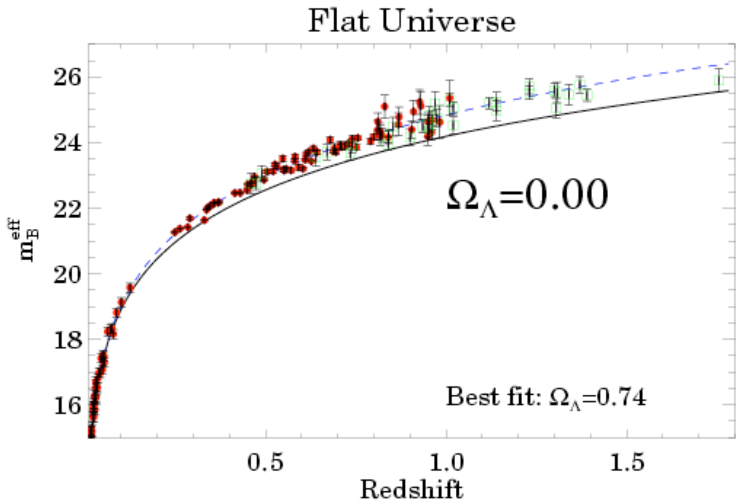


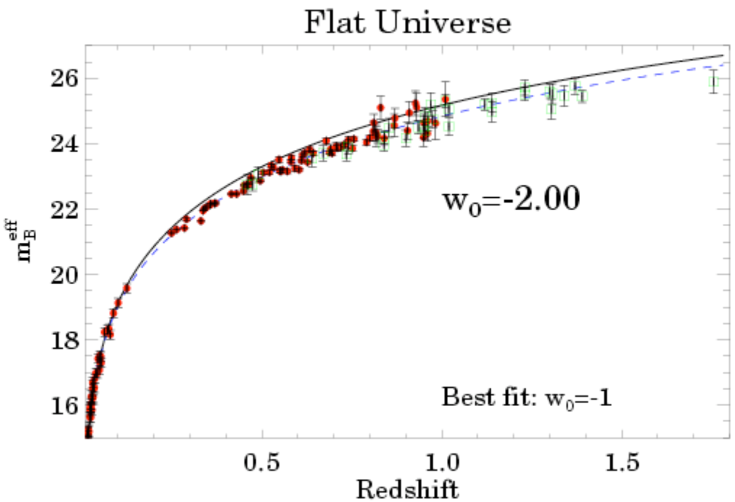
Current limits on dynamical DE are extremly weak: $w(a) = w_0 + w_a(1\text{-}a)$

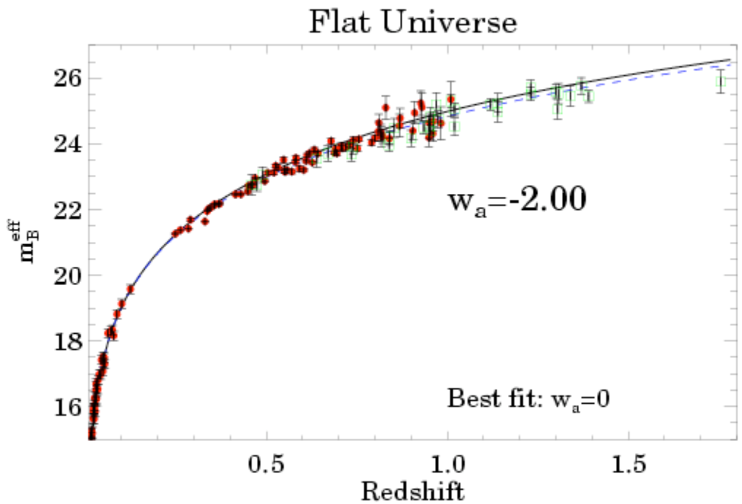


Multi-parameter problem









Gravitational leakage into X-dimension

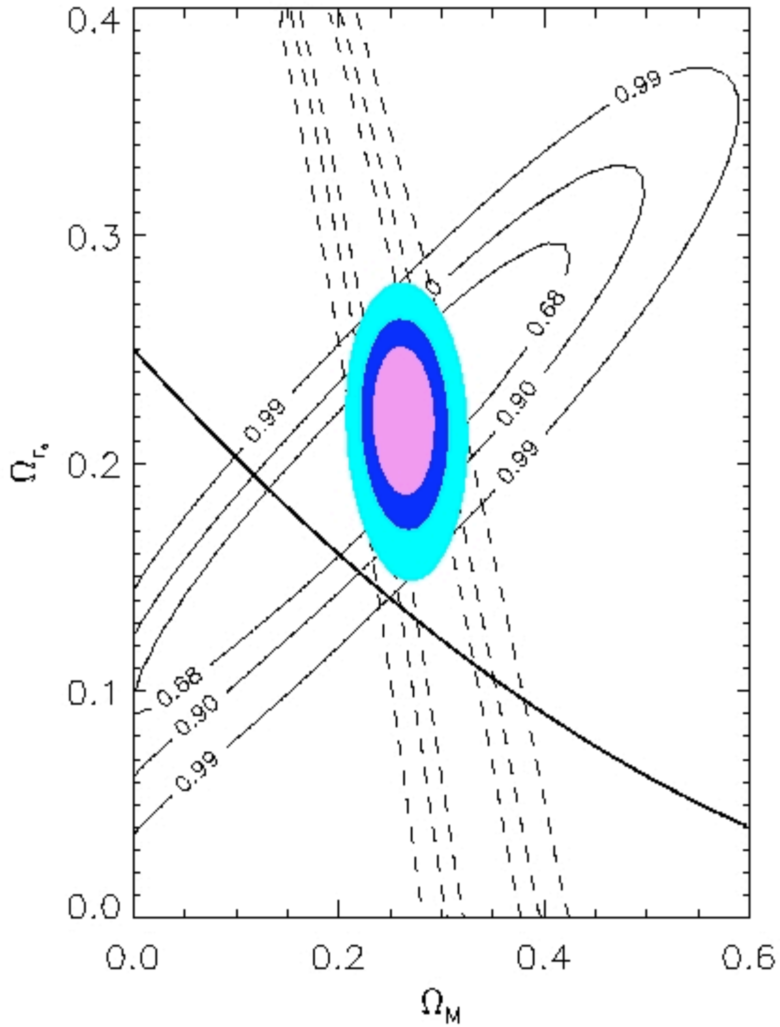
- **Use SNLS (Astier et al 2005) + Baryon oscillations (Eisenstein et al 2005) to examine 5D extention of Friedmann eqn suggested by Dvali, Gabadadge,Porrati 2000 (DGP); Deffayet, Dvali, Gabadadze 2001.**

$$H^2 \pm \frac{H}{r_c} = \frac{8\pi G}{3}\rho$$

$$H^2(z) = H_0^2\left\{\Omega_k(1+z)^2 + \left(\sqrt{\Omega_{r_c}} + \sqrt{\Omega_{r_c} + \Omega_M(1+z)^3}\right)^2\right\}.$$

We can compare this equation with the conventional Friedmann equation:

$$H^2(z) = H_0^2\left\{\Omega_k(1+z)^2 + \Omega_M(1+z)^3 + \Omega_X(1+z)^{3(1+w_X)}\right\}.$$



Fairbairn & AG, 2005

DGP: including ESSENCE + all data to date

6 Davis et al, 2007

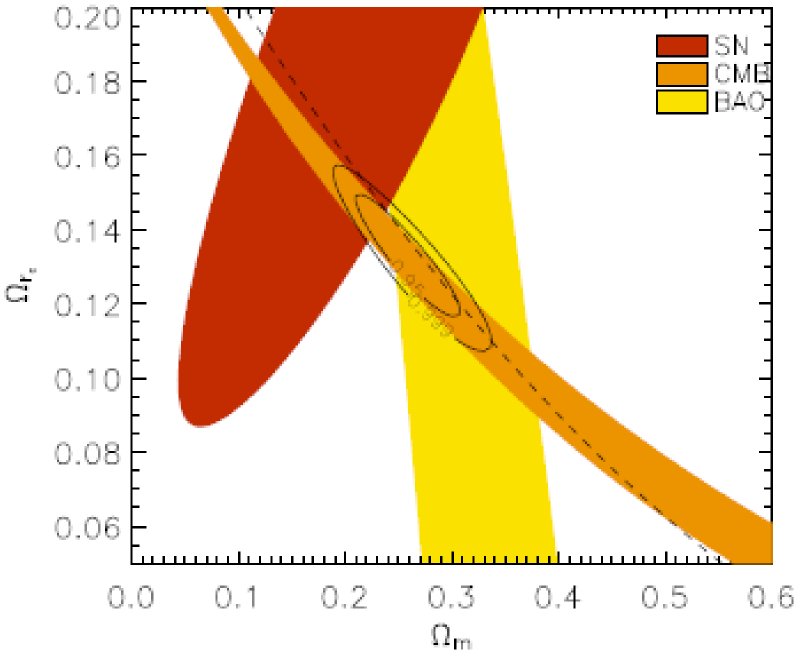
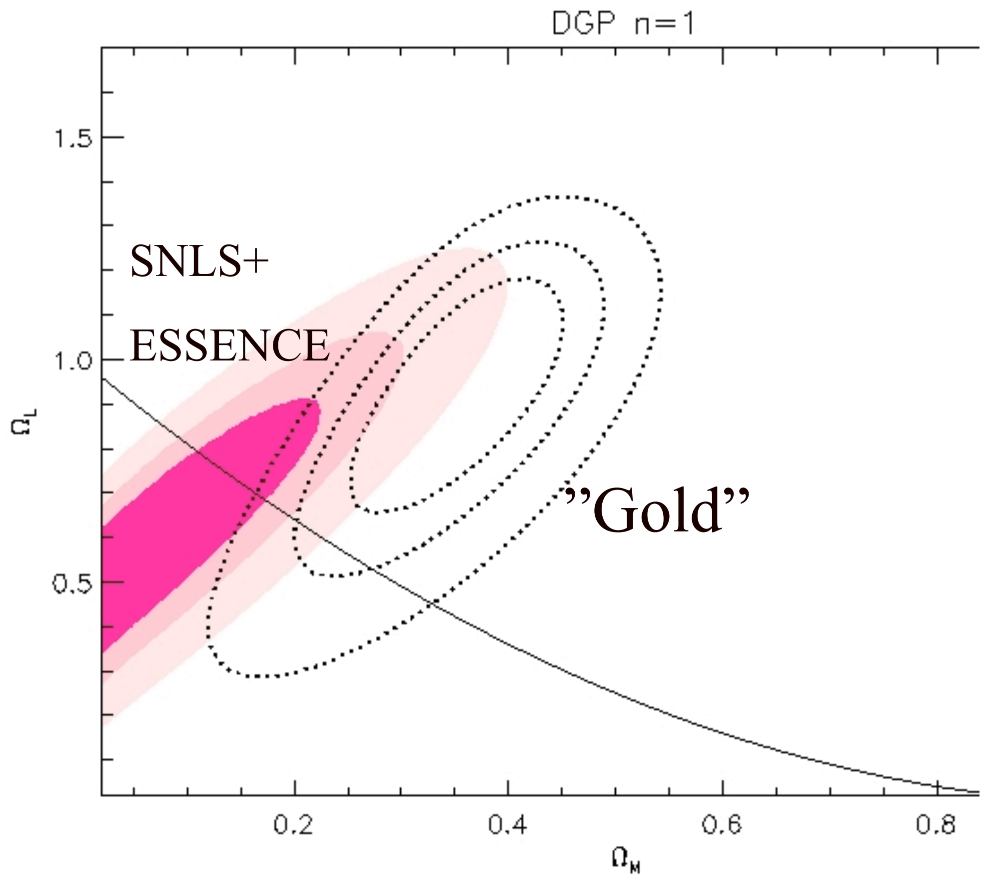


FIG. 3.— The general DGP model (Sect. 4.3.1). The dashed line shows the flat model. Here the contours from the different observational constraints disagree and the model is thus strongly disfavored.



Rydbeck, Fairbairn & AG, 2007

Need to worry about systematics!

(Known) systematic effects

- SN brightness evolution
- Shape-brightness relation
- K-corrections and SN colors

Astrophysics of supernovae

- Non-Type Ia contamination
- Malmquist bias

Selection effects,contamination

- Host galaxy dust properties
- Intergalactic dust
- Gravitational lensing
- Exotica:axion-photon oscillations, etc

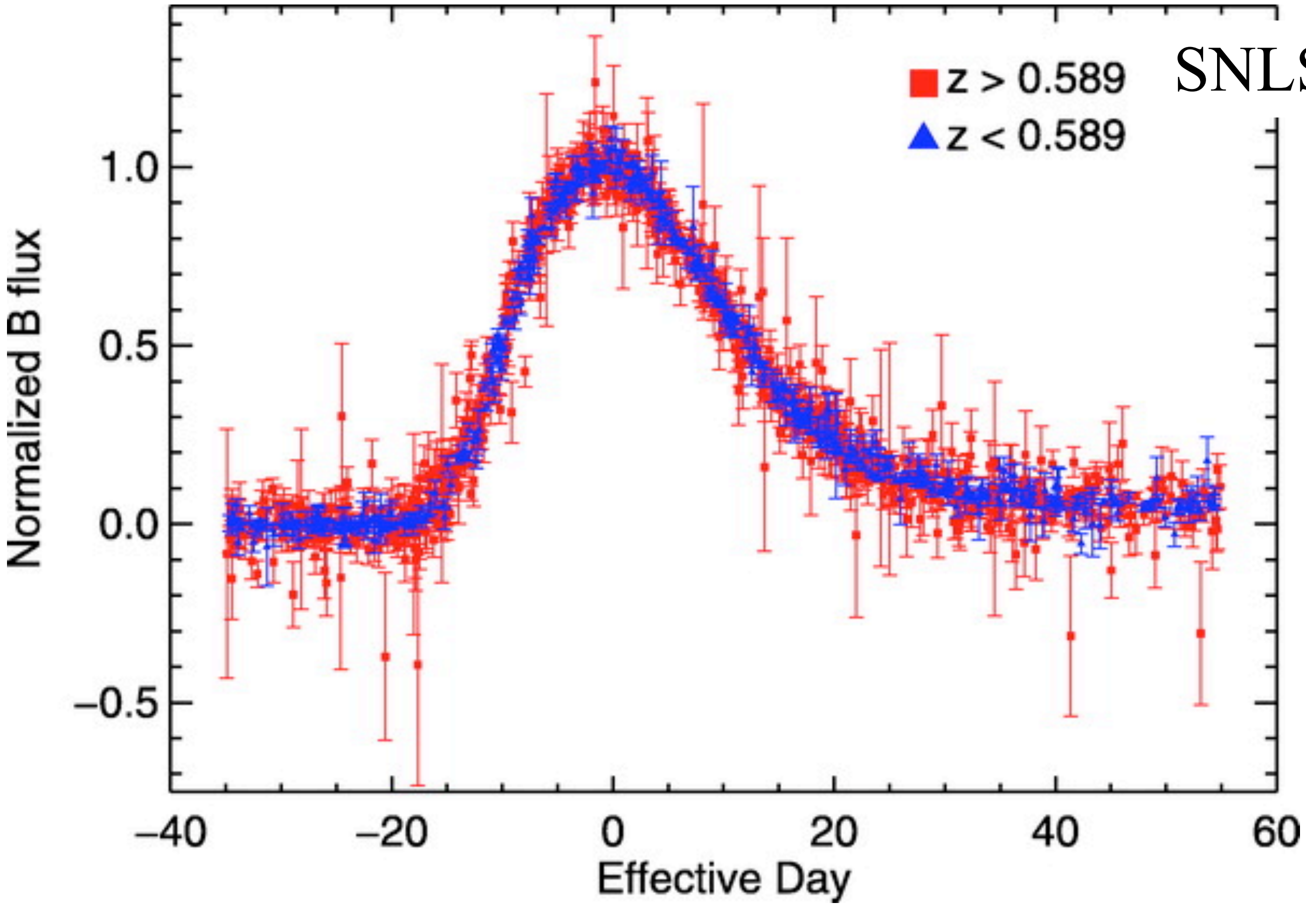
Line of sight effects

- Instrumental corrections
- Absolute calibration
- Lightcurve fitting technique/host galaxy subtraction

Measurement issues

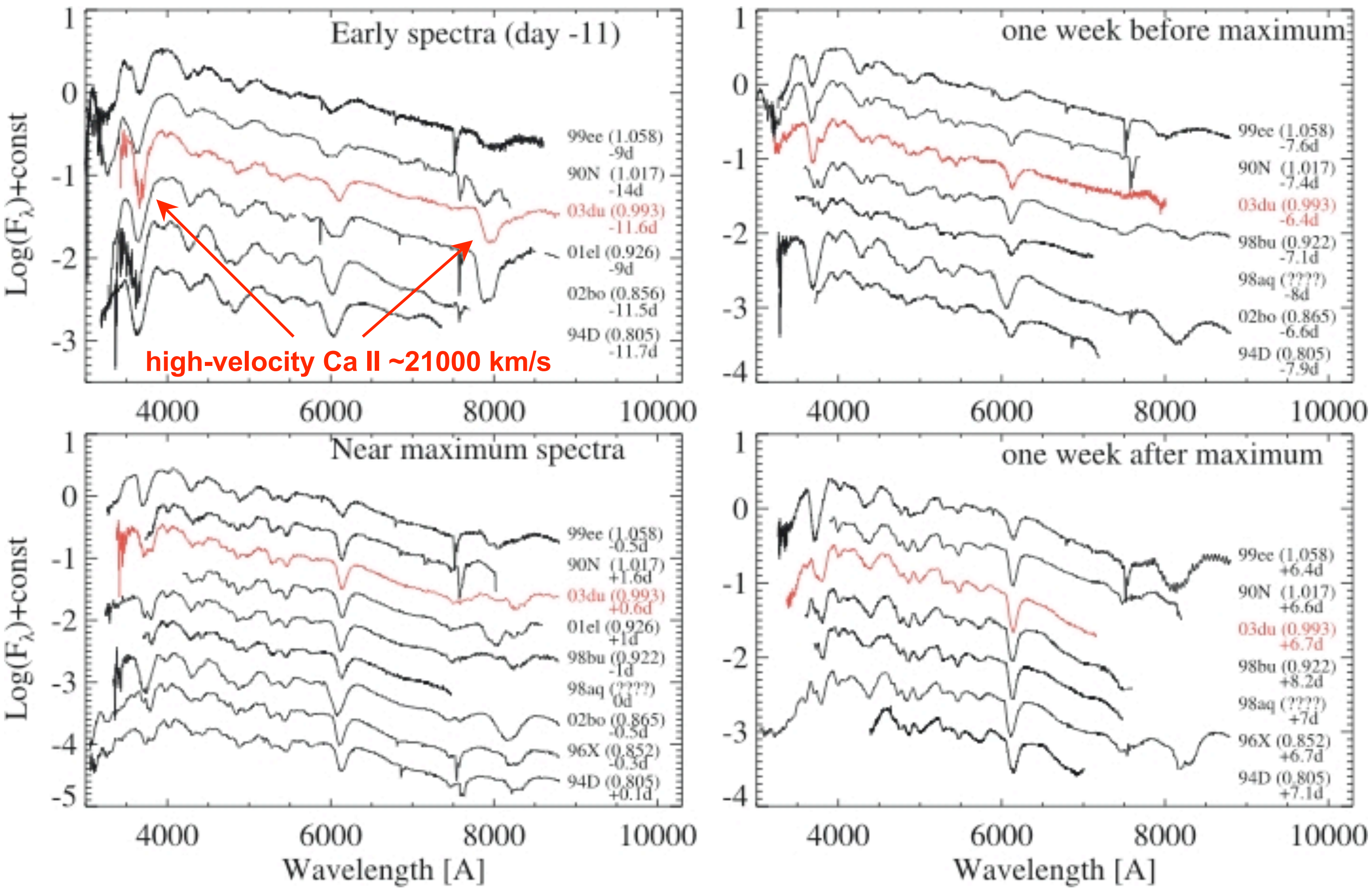
Exploring the ”Standard Candle”

Checking the standard candle: redshift dependence?

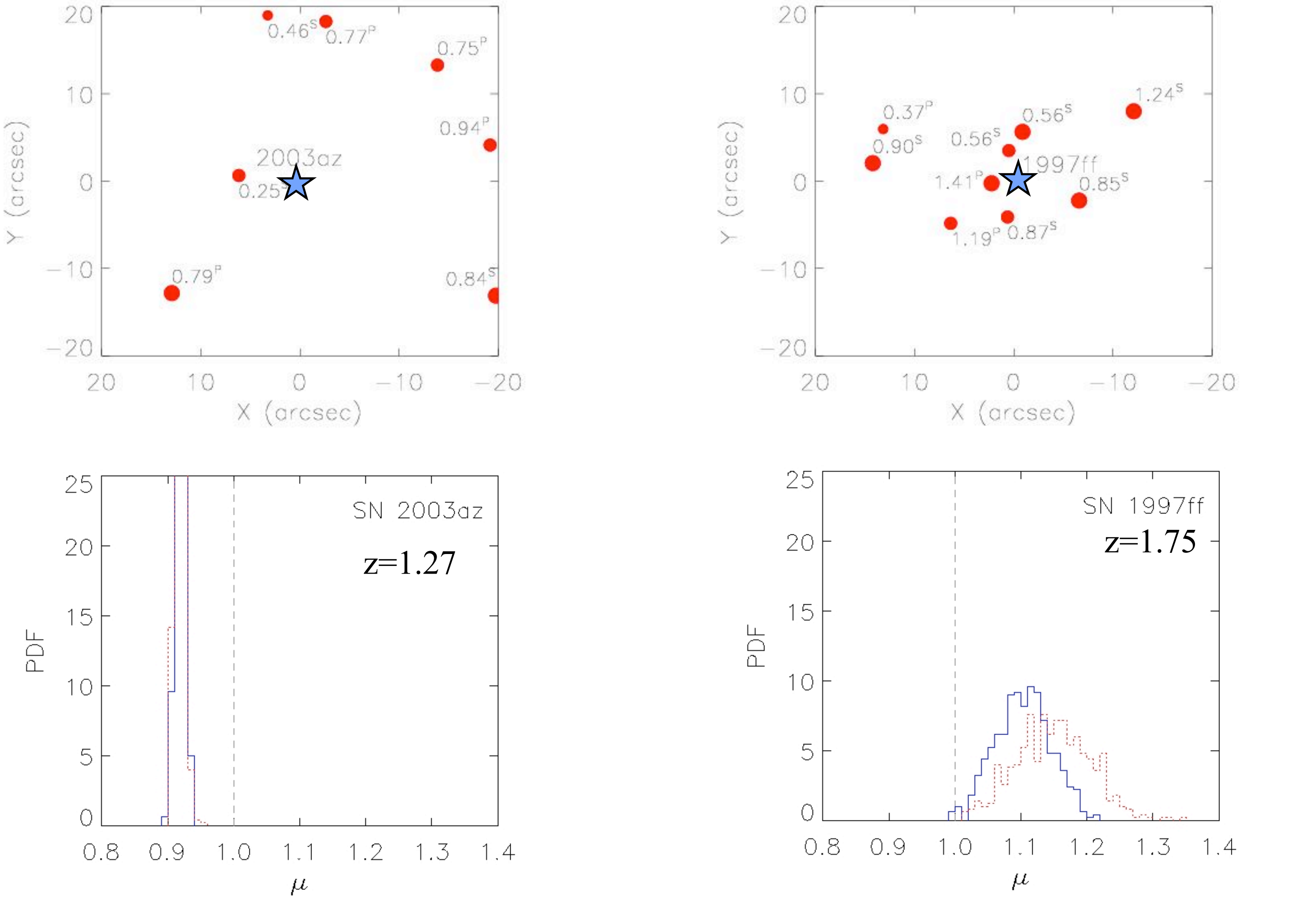


Conley el al 2006

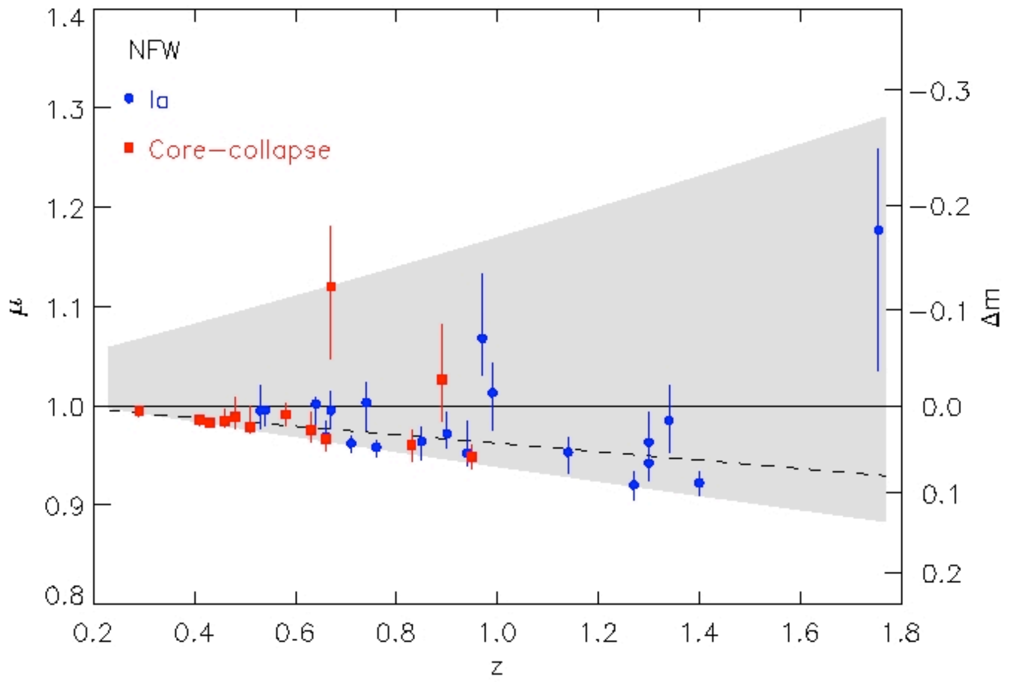
Spectral diversity: could be used to sharpen ”standard candle”?

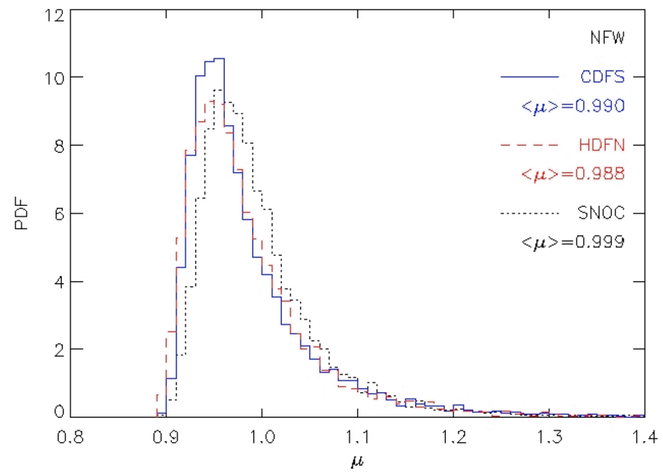


Lensing (de)magnification in the GOODS SN survey: a study case



Lensing PDFs for GOODS SN-sample

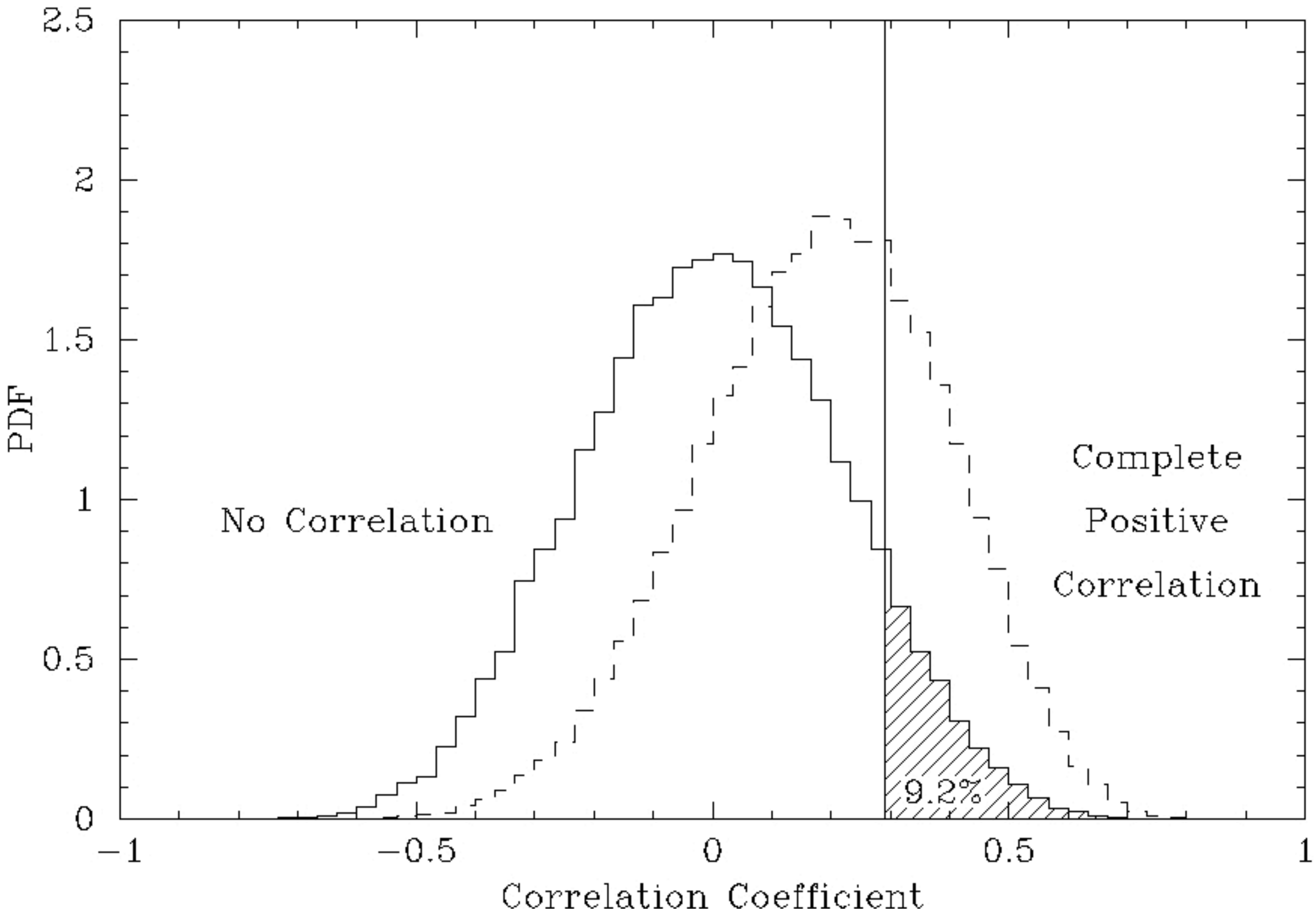




- We found NO evidence for selection effects due to lensing in the GOODS SN sample. Negligible corrections to Ωs & w.
- Expected lensing bias on SNLS results is also small: $|\delta\Omega_M|$ ~0.01 in Ω_M-Ω_Λ plane. Added uncertainty on w_0 is σ_w~0.014 for BAO prior (SNOC simulation)

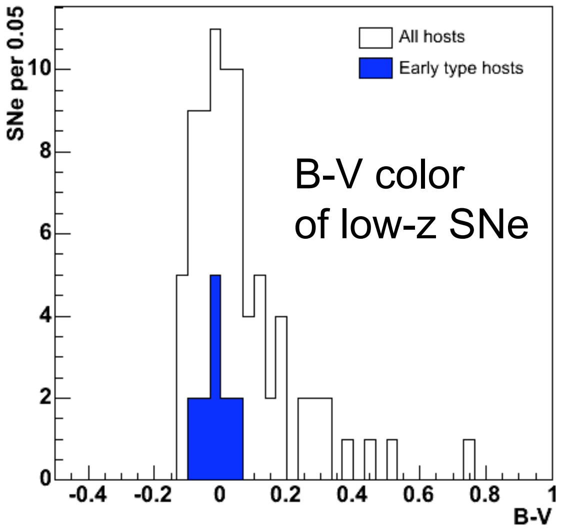
Jönsson et al, 2006

Tentative detection of correlation with residuals in Hubble diagram



Jönsson,Dahlen,AG,Mörtsell & Riess, 2007

Dust/reddening: a real problem!



- **Dust in SN host galaxy (or along line of sight)**
- **Correction assumes some reddening law, typically Galactic type dust -or average fit to any kind of reddening/blueing (SNLS)**
- **Can only be estimated for individual SNe with**

  a) accurate multi-wavelength data

  b) good knowledge of intrinsic "color" of SNe
- **Extinction probabilty in a given galaxy depends on where the SN explosion happens**

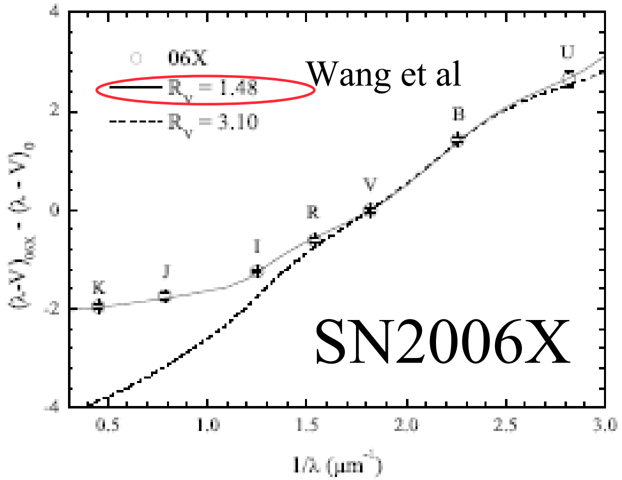
Extinction:

$\Delta M_B = R_B \cdot E(B-V)$ with $R_B \sim 2 - 5$

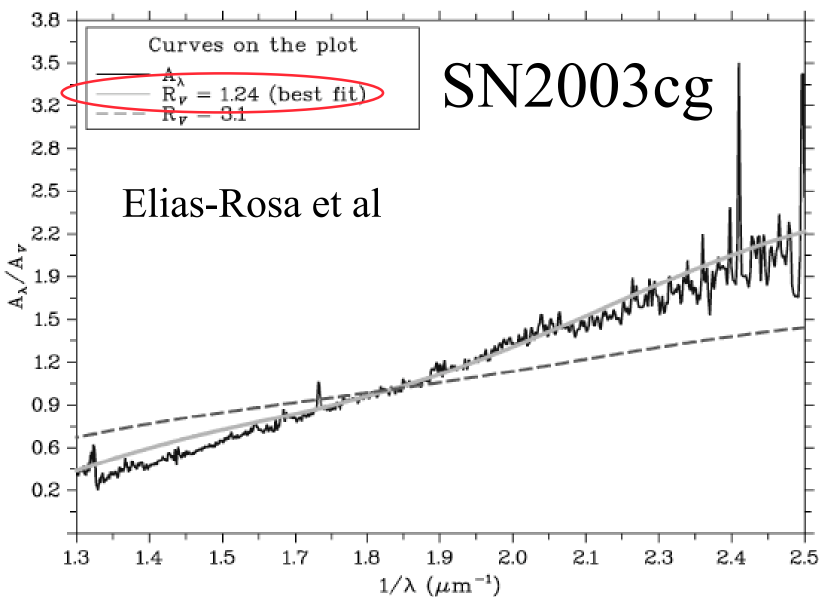
Extinction correction dominates measurement error!

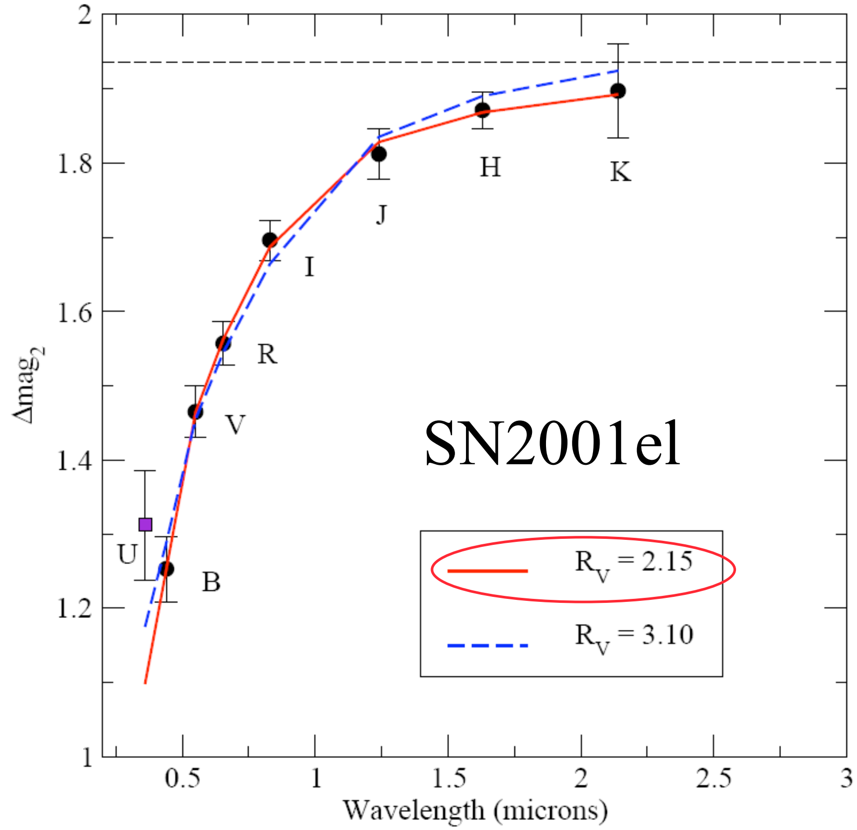
Exception: Elliptical galaxies (E/S0) have little star-formation & dust.

Varying dust properties in near-by SN hosts



Extinction curve





Krisciunas *et al.* Fig. 14

But for high-z SNe it is assumed all SNe hosts have same dust properties!

What is the impact of various sources of error on cosmological parameters for any given data-set?

Code in prep: allows for study of *correlated, non-gaussian* sources of error affecting groups of SNe.

Full chain of error propagation!

Almost the end…

- Dark Energy is inevitable!
- Λ looking OK – but so is almost any other DE models !
- Lots of ongoing SN-surveys targetting various redshifts: CSP,SNFACTORY,SDSS, SNLS,ESSENCE,PANS
- … and soon PanSTARRS,DES(?)
- In the longer term LSST(?) and/or JDEM(?) for primarily SN & Lensing+ lots of BAO ideas!
- Systematic effects are the bottle-neck… lots of work to do!

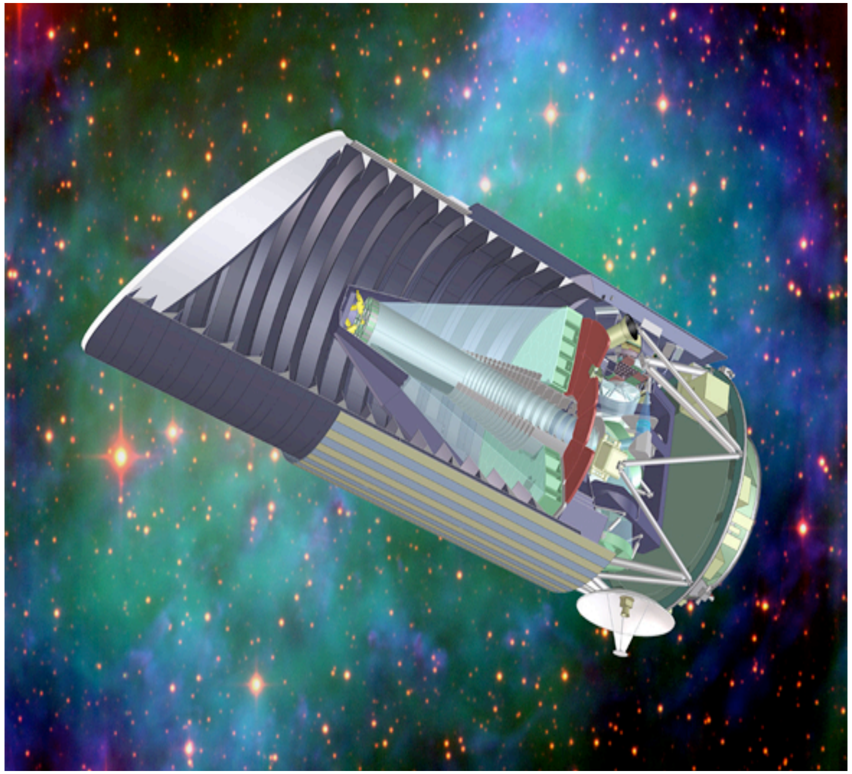
”Big” Future Projects

- **LSST: 8-meter class telescope with 10 sq.degrees FOV**

- **JDEM/SNAP: satellite mission:~2-meter class telescope reaching NIR. Optical+NIR imaging + spectrosocopy (SNAP)**

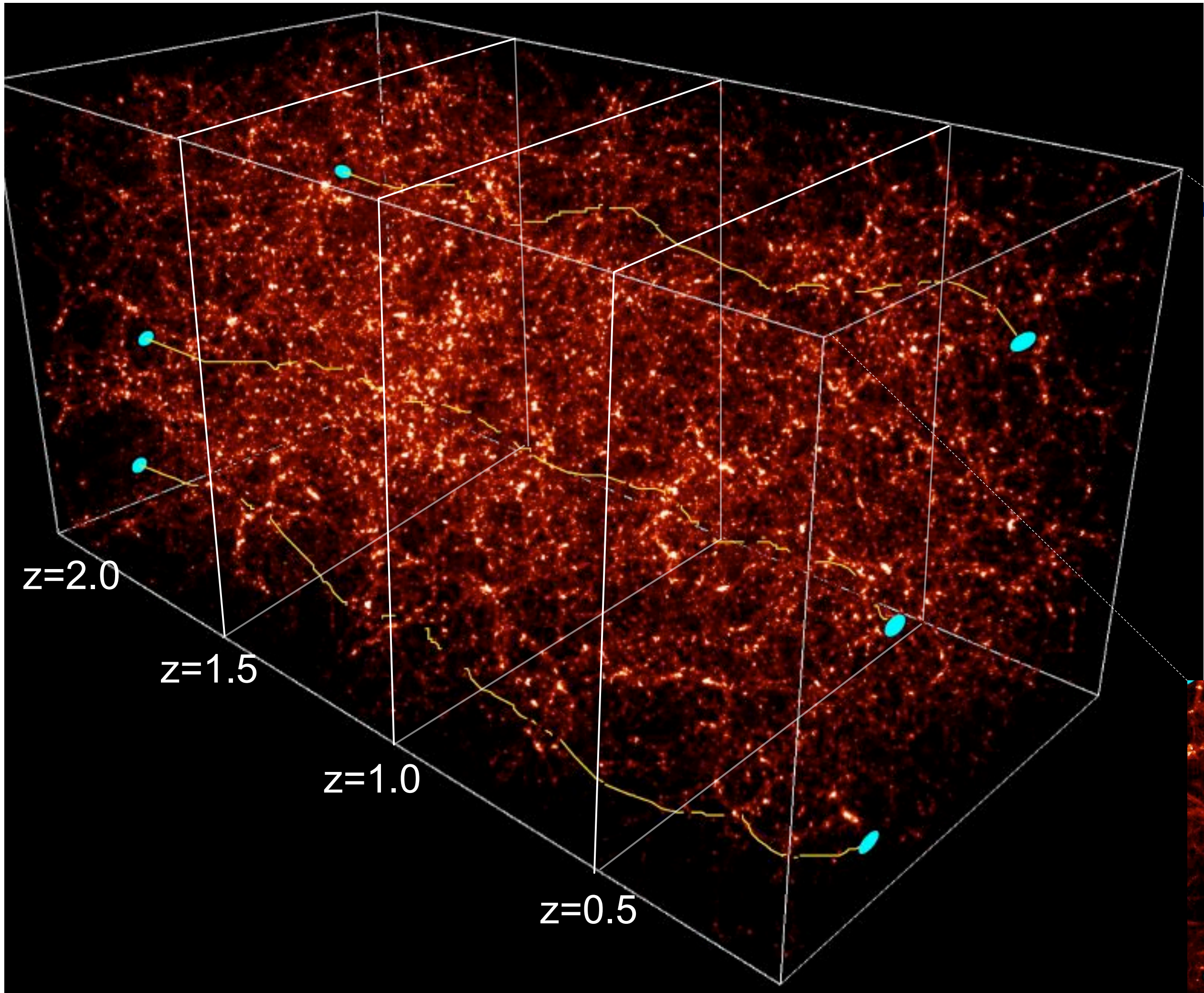
  It’s all about minimizing the systematics and (hopefully!) sharpen the standard candle by comparing ”like to like”

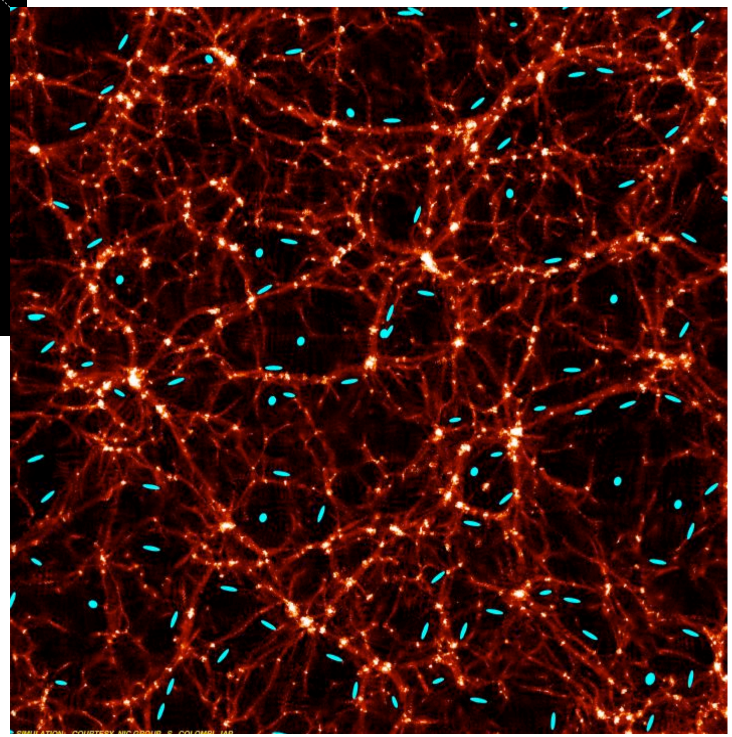
Excellent for weak lensing as well



SNAP

Weak Gravitational lensing

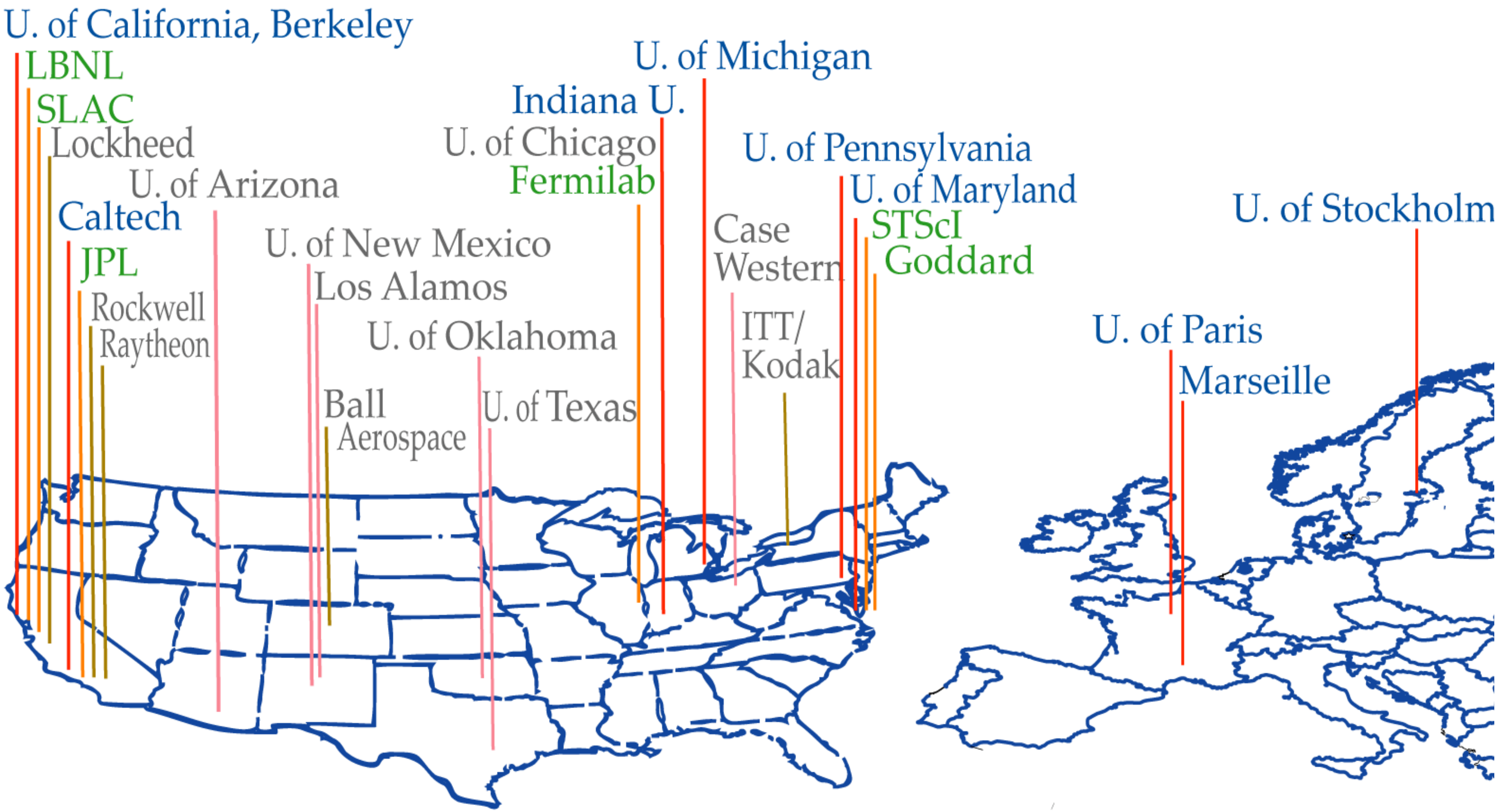




Gravitational weak lensing lets us study the expansion history and the growth of structure, and hence possible mods. to the theory of gravity. The mass structures that intervene between us and distant galaxies will grav. distort their apparent shape.

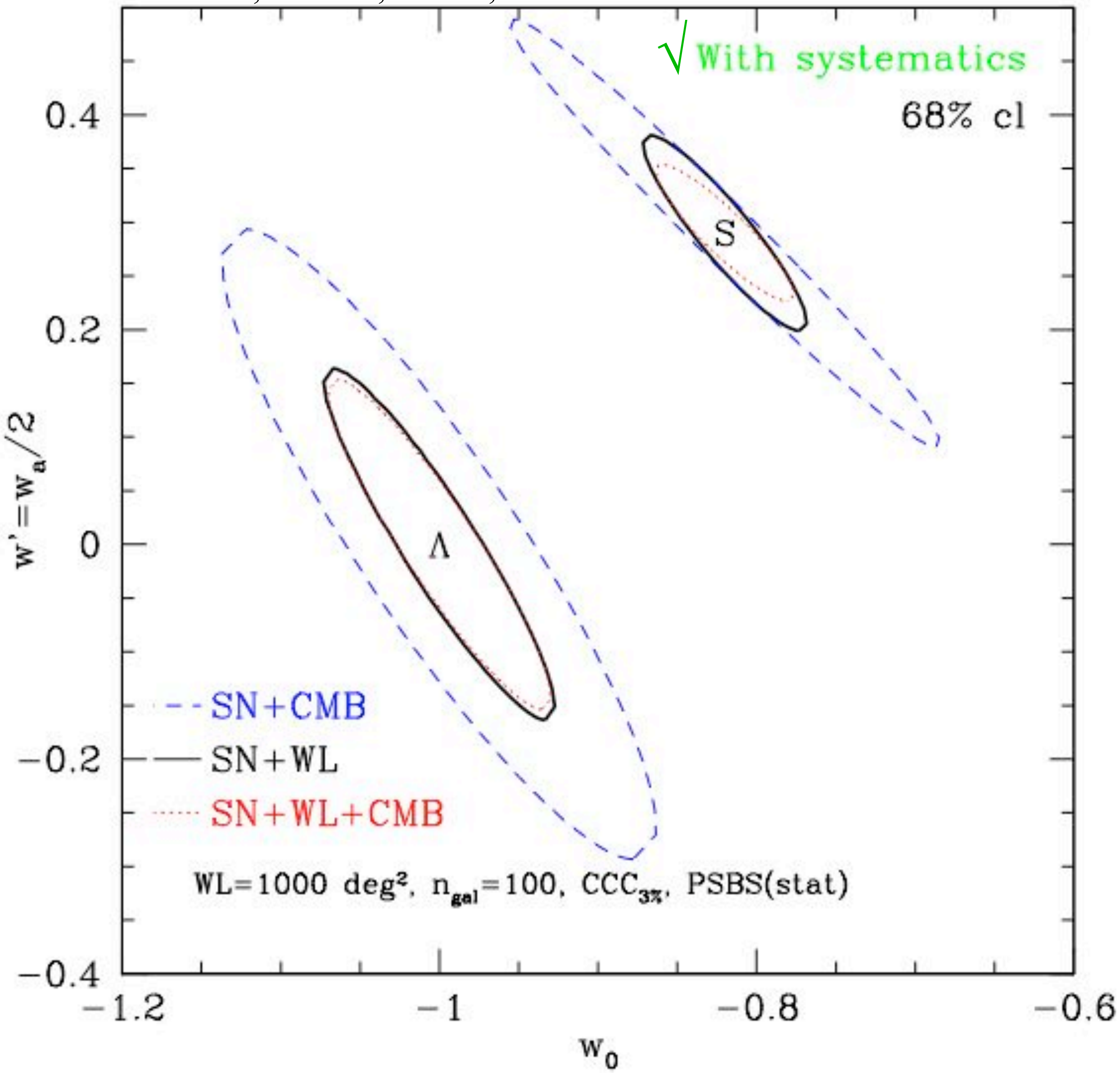
Apparent elongations of the galaxy shape, run parallel to the location of the projected mass. These effects are extremely small and they can only be detected by averaging.

SNAP: particle physics like experiment!



SNe + Weak Lensing

Bernstein, Huterer, Linder, & Takada



- **Comprehensive:** ***no external priors required!***
- **Independent test of flatness to 1-2%**
- **Complementary:**

***w_0* to 5%, *w'* to 0.11 (*with systematics*)**

+baryon oscillations?

The End