Dark Energy from Supernova Surveys

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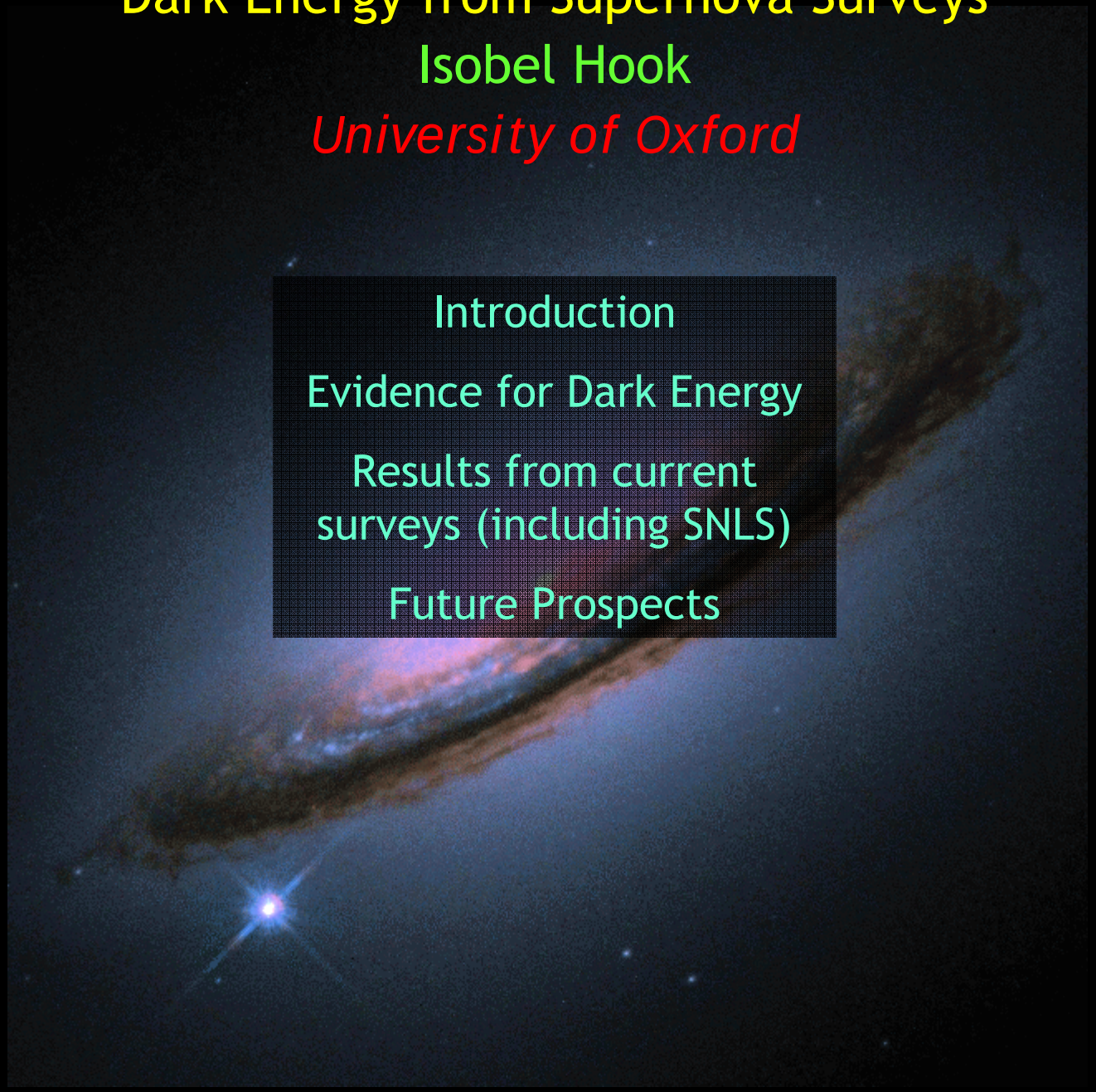


Introduction

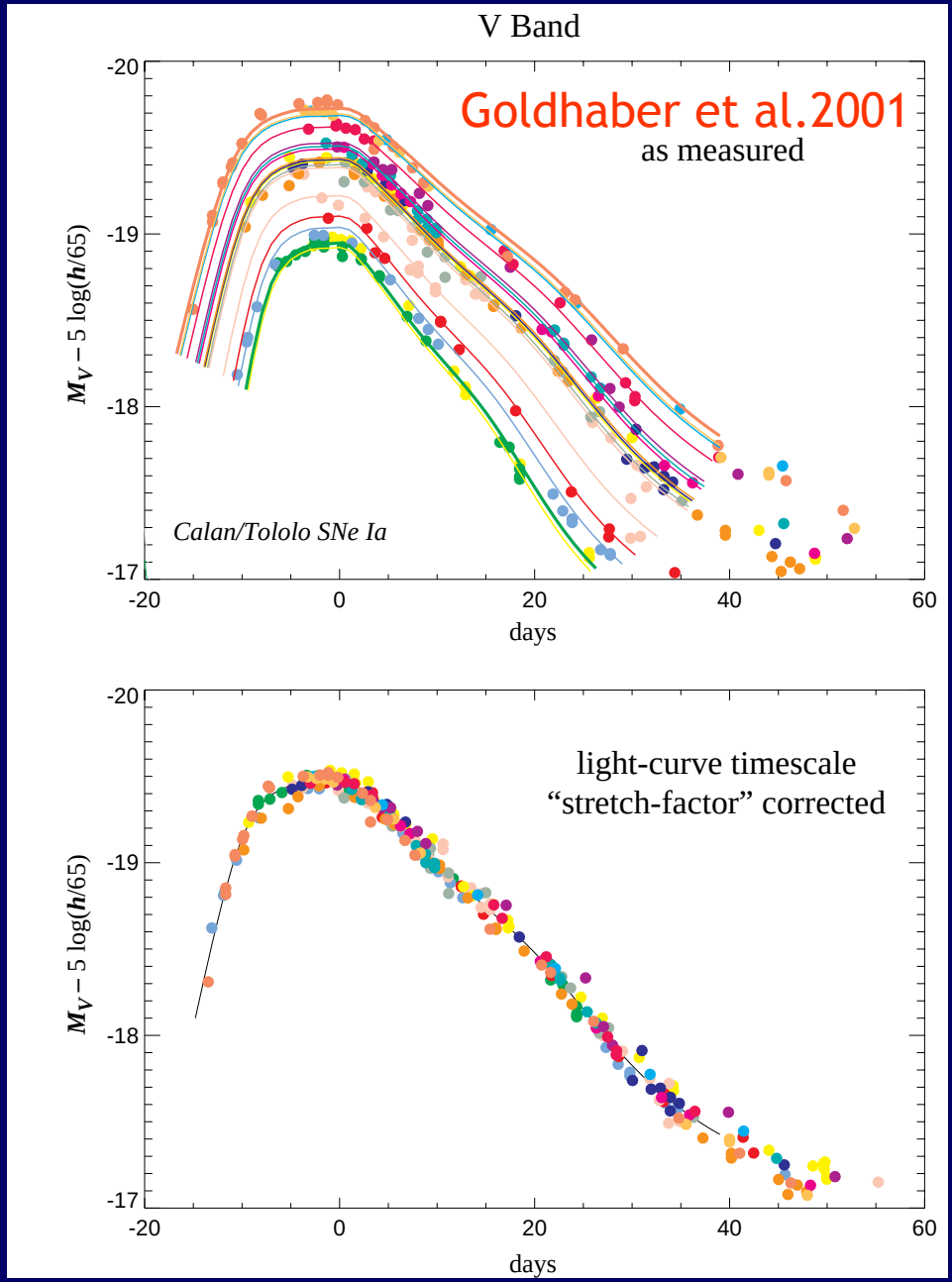
Evidence for Dark Energy

Results from current surveys (including SNLS)

Future Prospects

Type Ia SNe as Standard Candles

- SNe Ia are bright ⇒ visible at high-z
- Identified spectroscopically
- Small dispersion in M_{peak} : σ ~ 0.24 mag
- Further standardise using width-brightness relation: σ ~ 0.17 mag (Phillips 1993)

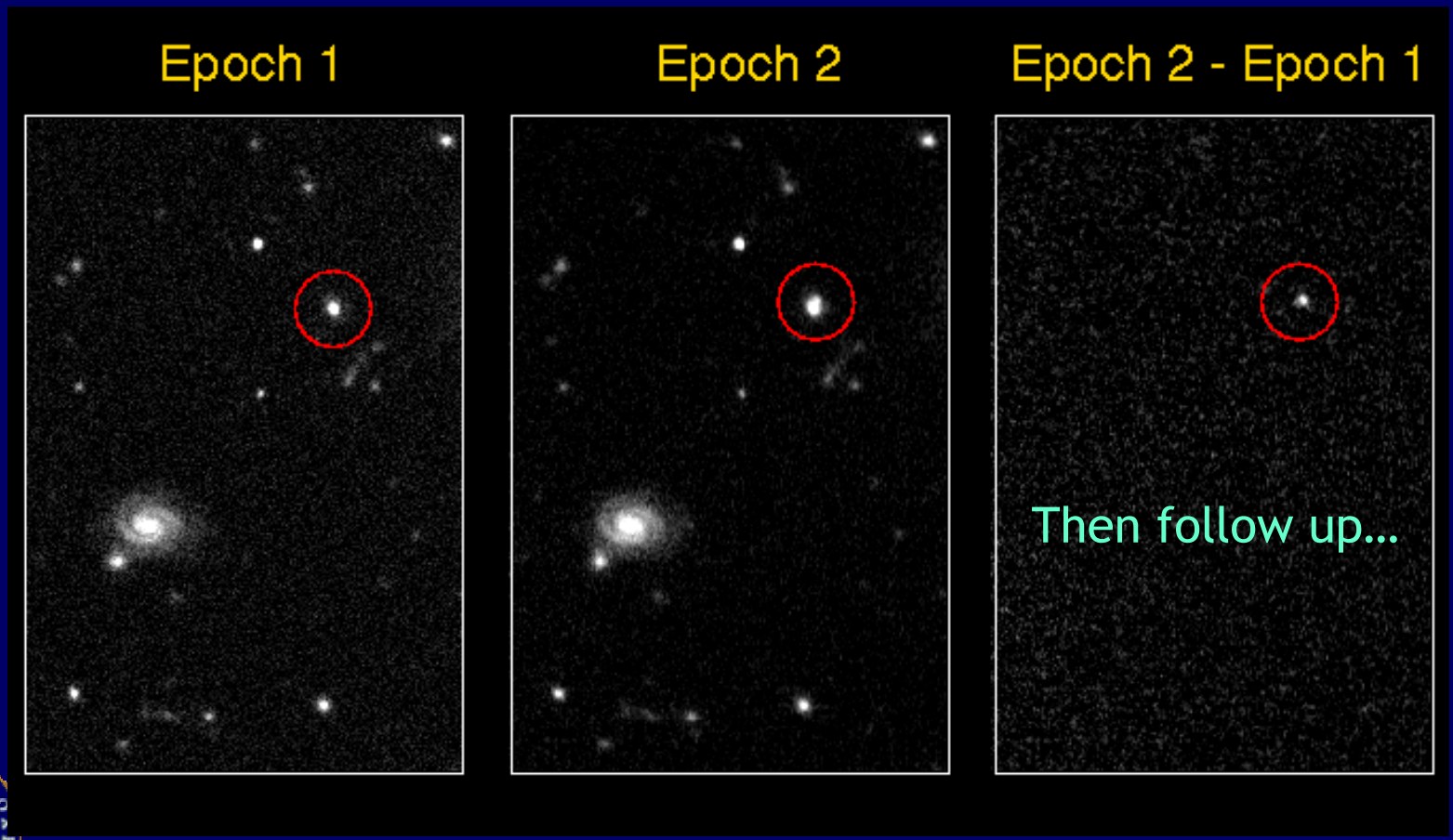


Ω, Λ (and H_0) from Standard Candles

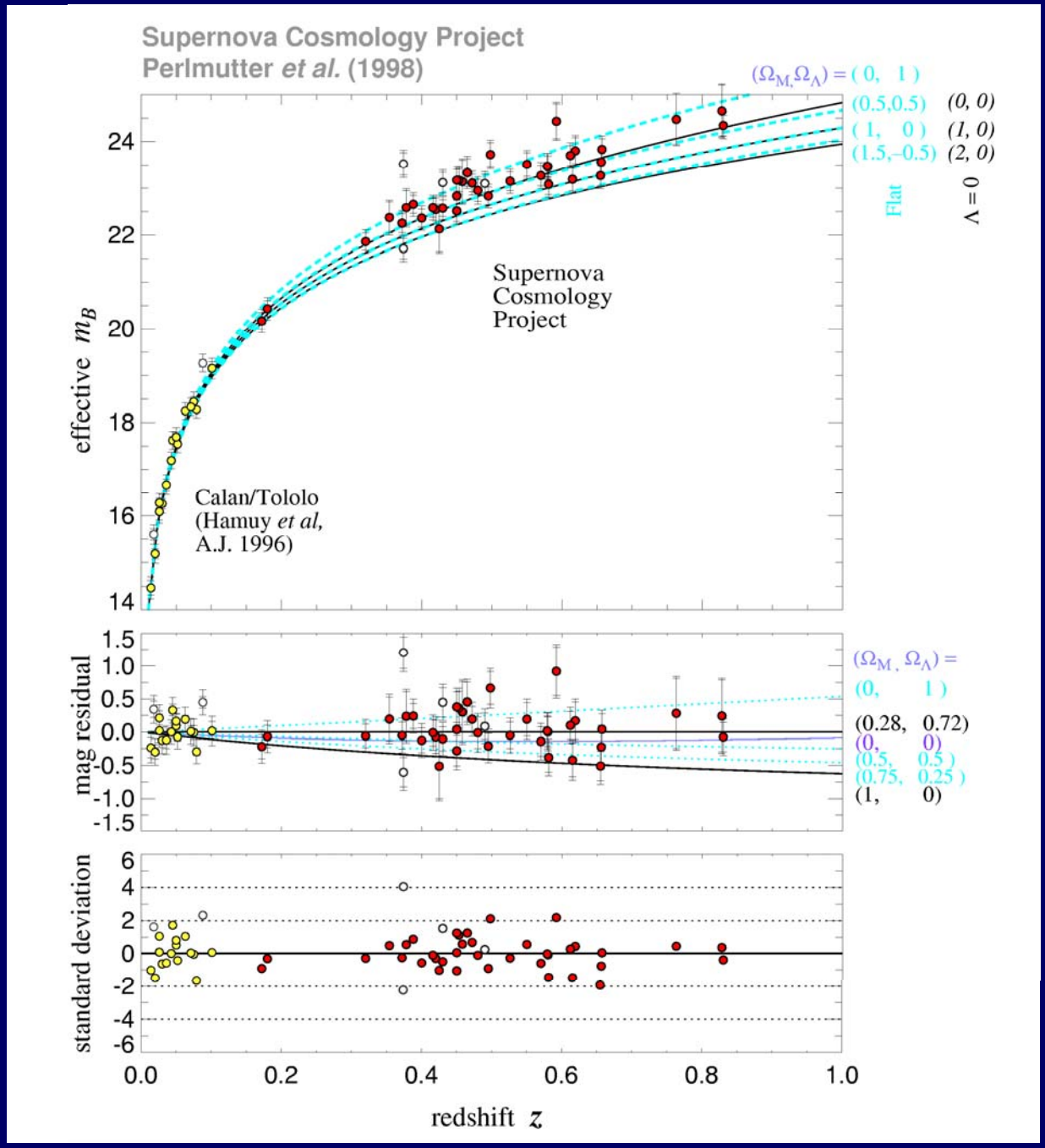
- *m-z* relation depends on geometry
- Assume homogeneous and isotropic universe
- $m = 5\log D_L(z,\Omega_M,\Omega_\Lambda) + M - 5\log H_0 + 25$
  - z redshift
  - m apparent magnitude
  - M absolute magnitude
  - $\Omega_\Lambda \equiv \Lambda/3H_0^2$ cosmol. const. energy density
  - Ω_M mass density
  - $D_L \equiv H_0 d_L$ luminosity distance
- Ω_M, Ω_Λ terms have different dependence on z

Finding Distant Supernovae

Supernova Cosmology Project — Perlmutter et al 1988
High-z team — Schmidt et al 1994



Examples from the High-z team (Schmidt et al)



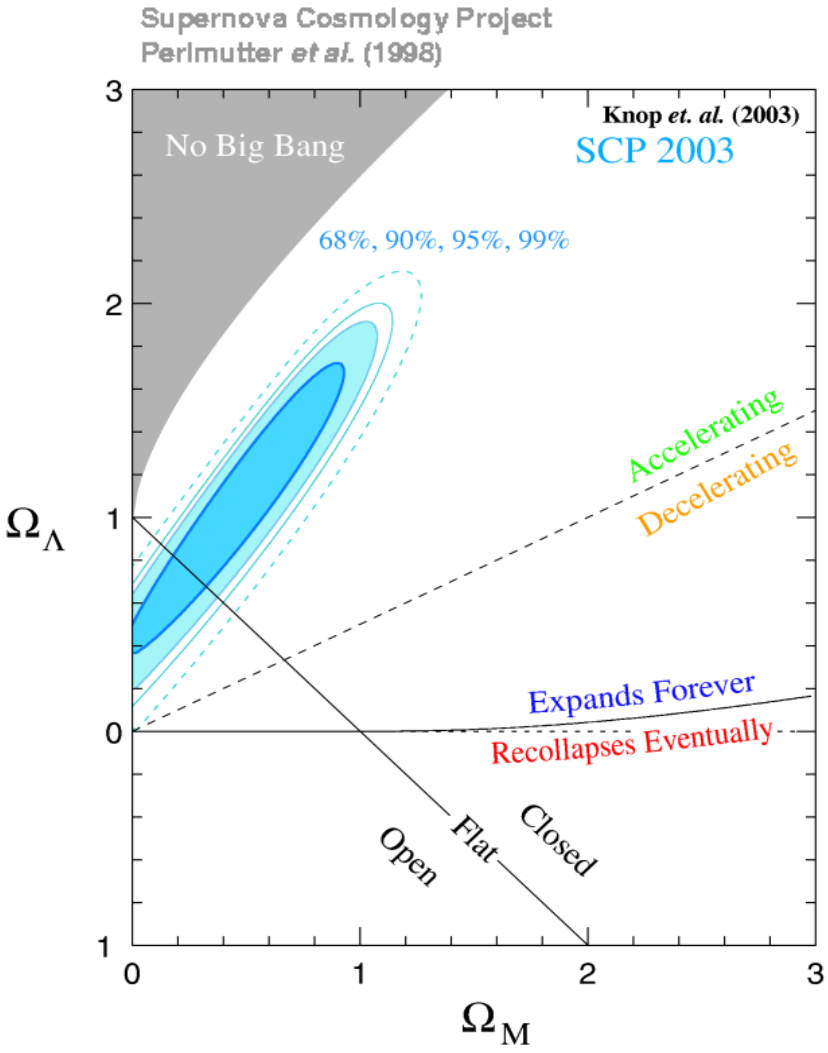
SNe Ia provide direct evidence for accelerating Universe

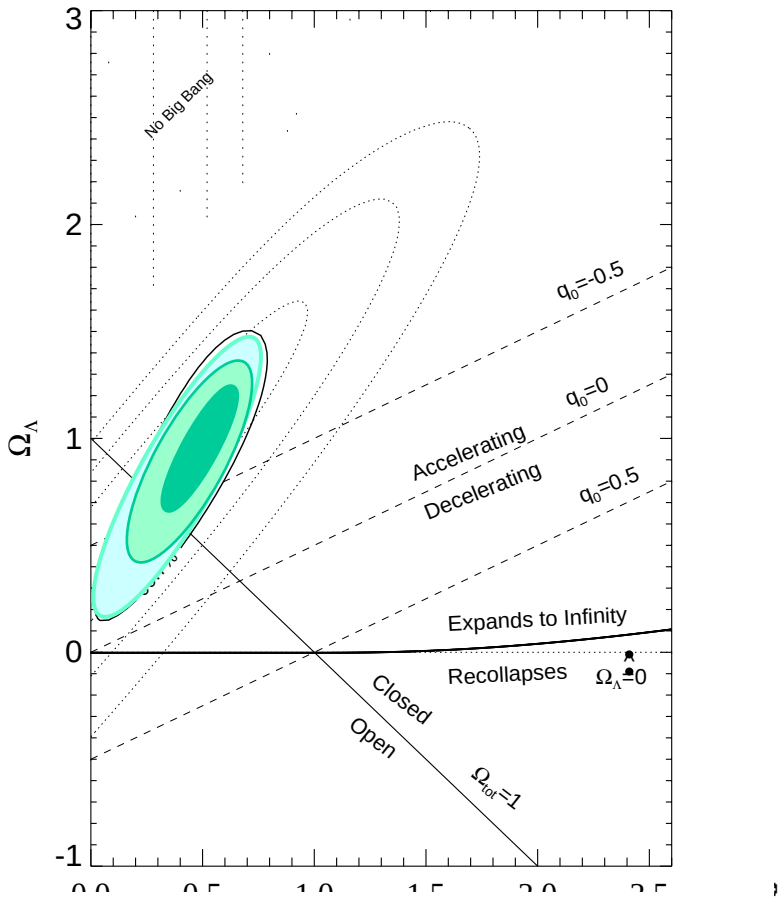
Results inconsistent with Ω_M=1 spatially flat cosmology

(SNe too faint)

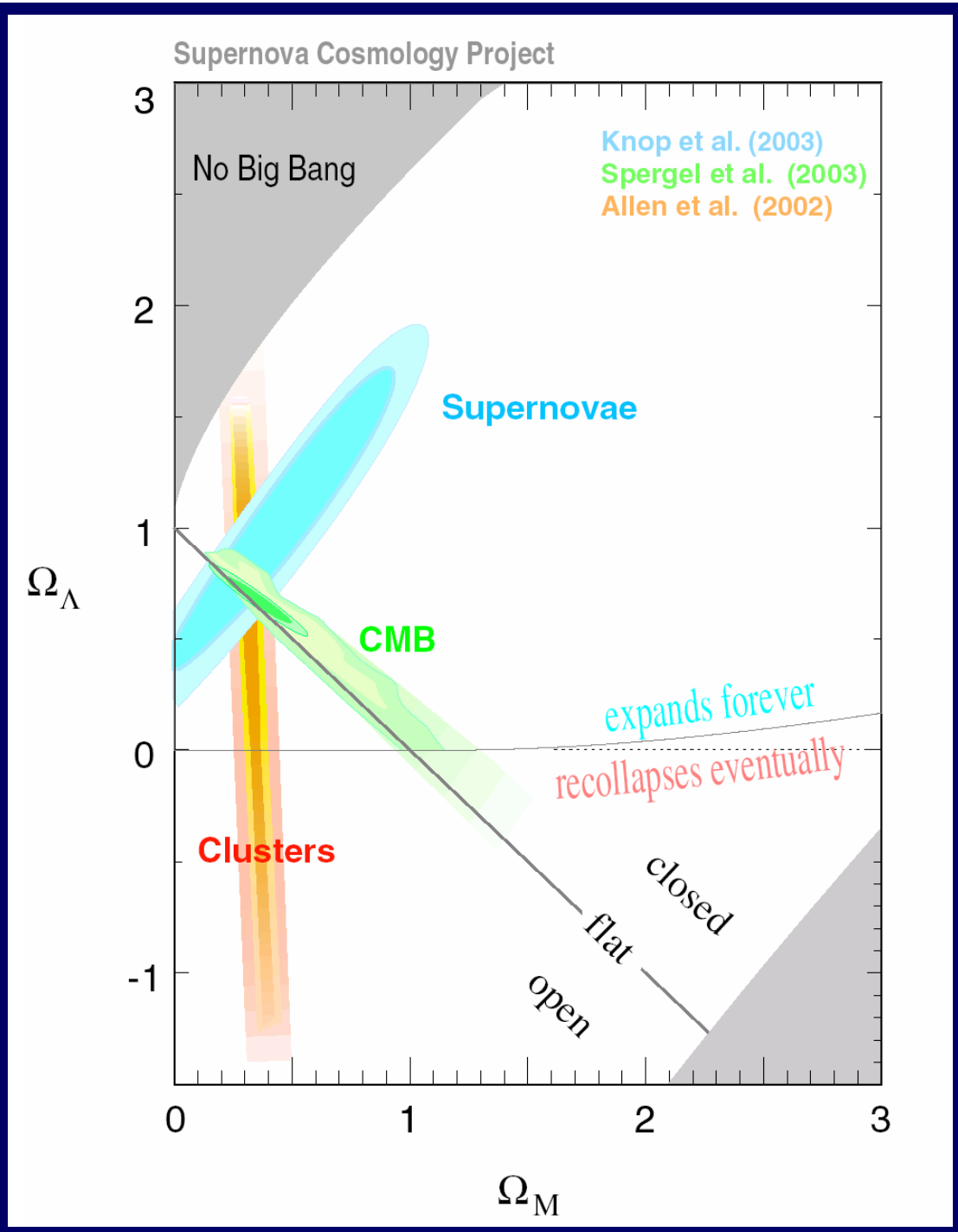
SN data favor Λ>0

with 16 ACS-discovered SNe
z<1.5 (Riess et al 2004)





If universe is flat then data require $\Lambda > 0$


Supernova Cosmology Project
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
3
2
1
0
-1
0
1
2
3
Ω_Λ
Ω_M

SN constraints on Ω_M (Ω=1)

SCP

- Perlmutter et al 1999:
  Ω_M=0.28 +0.09 -0.08
  + 0.05-0.04
- Knop et al 2004 :
  $\Omega_{M=}$ 0.25 +0.07-0.06
  +/-0.04

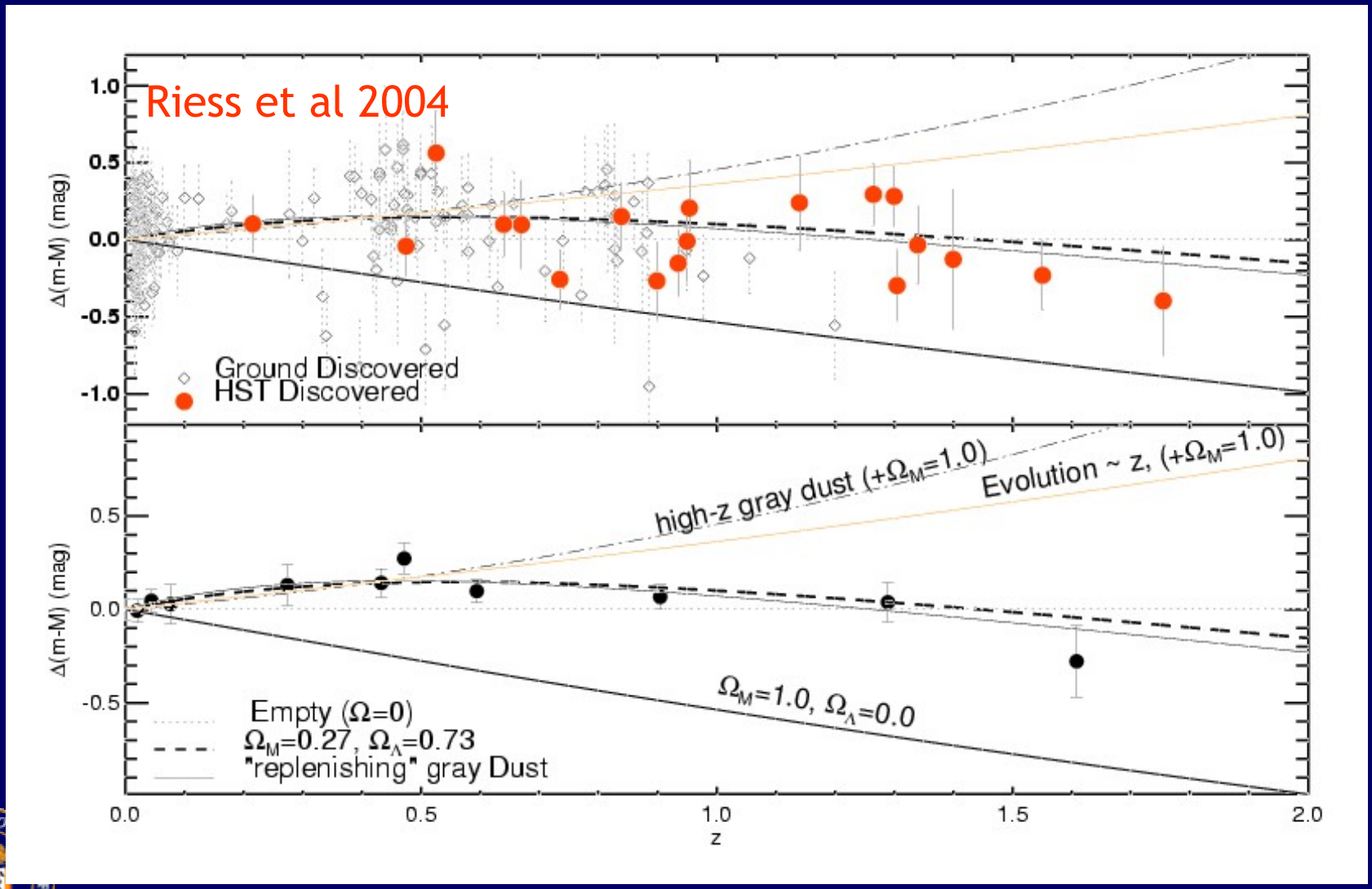
High-z Team

- Riess et al 1998:
  Ω_M=0.28 +/-0.1
- Tonry et al 2003
  Ω_M=0.28 +/- 0.05
- Riess et al 2004
  Ω_M=0.29 + 0.05-0.03

The rest made up by “dark energy”

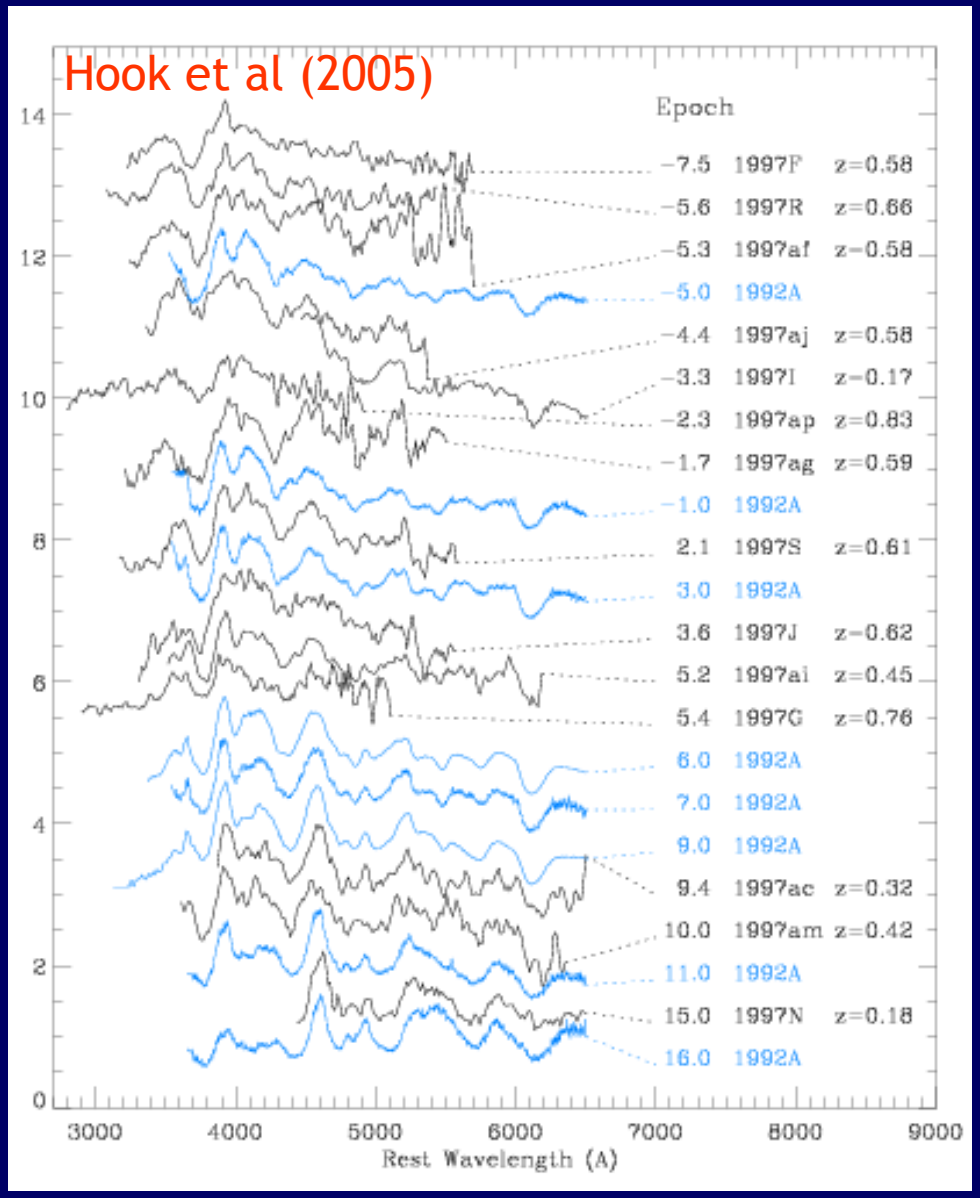
Systematic Effects and Checks

- Extinction by dust
  - Check colour distributions at low & high-z - no significant difference seen
  - Grey dust? Measure *shape* of Hubble line at $z>1$


Riess et al 2004
Δ(m-M) (mag)
1.0
0.5
0.0
-0.5
-1.0
Ground Discovered
HST Discovered
high-z gray dust (+Ω_M=1.0)
Evolution ~ z, (+Ω_M=1.0)
Ω_M=1.0, Ω_Λ=0.0
Empty (Ω=0)
Ω_M=0.27, Ω_Λ=0.73
"replenishing" gray Dust
0.0
0.5
1.0
1.5
2.0
z

Systematic Effects & checks: evolution

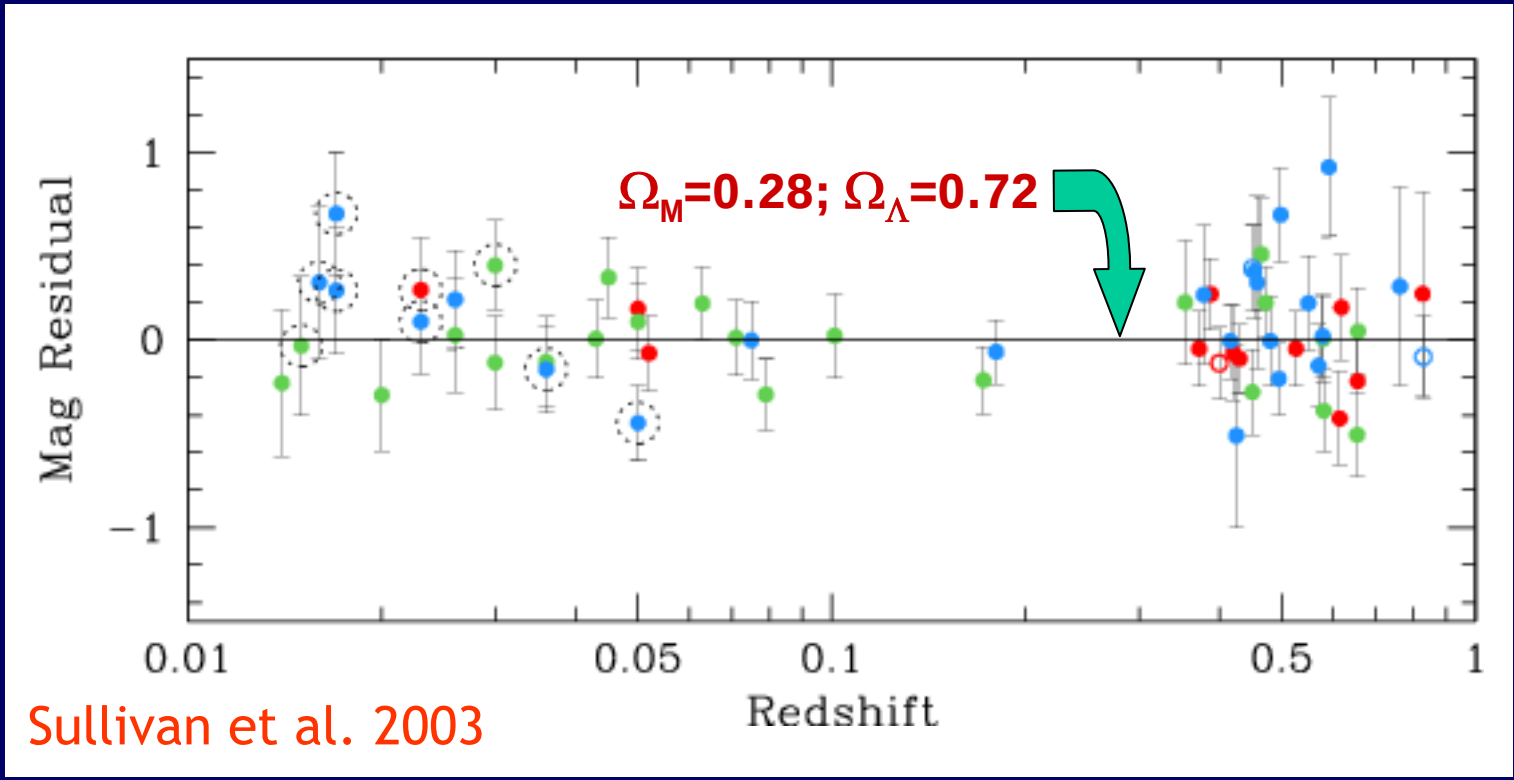
- Strength of SN Ia explosion should not depend strongly on progenitor & environment
- Check detailed spectra and lightcurves
- Study range of environments



Modified Hubble diagram

Sullivan et al : HST and Keck/ESI classification of 38 hosts

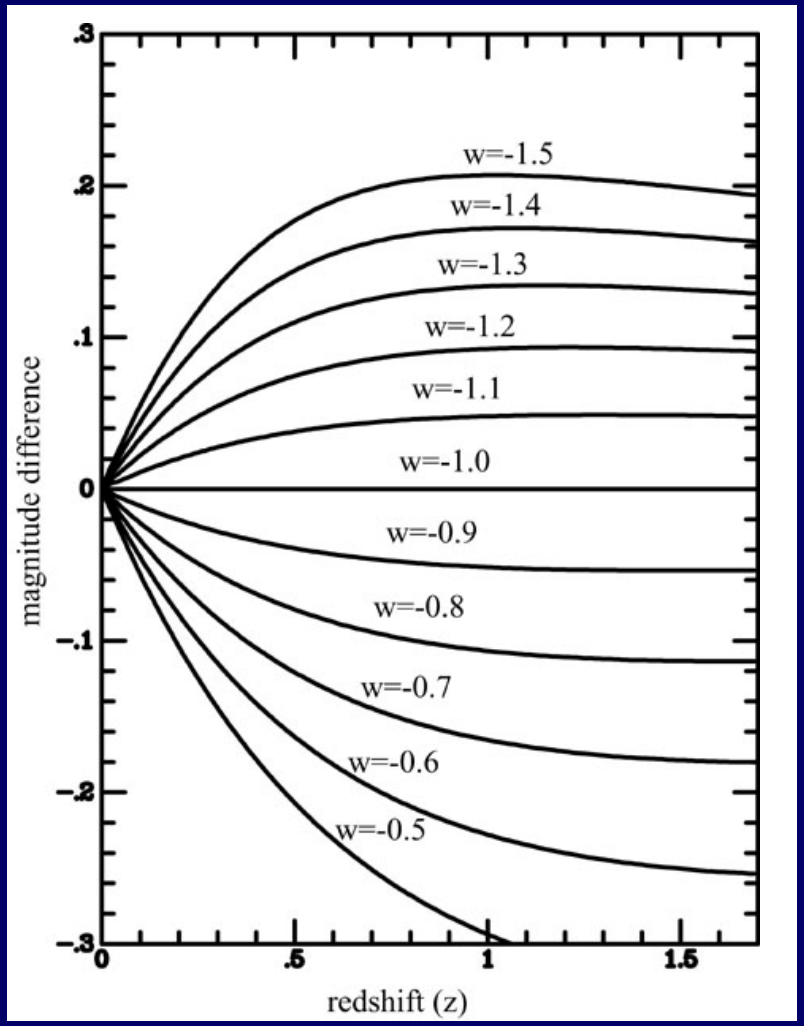
- Dust-free Early-type hosts confirm evidence for Λ
- Early type spirals
- Even Late-type hosts show only modest extinction



Sullivan et al. 2003

The nature of the dark energy

- Cosmological constant fits the data but…
  - Fine tuning problem?
- Other possibilities include quintessence…
- Differentiate via $\langle w=p/\rho \rangle$
- Distinguishing w=-0.8 and w=-1 at 3σ requires ≈700 SNeIa with $0.15<z<0.9$ – which SNLS will provide

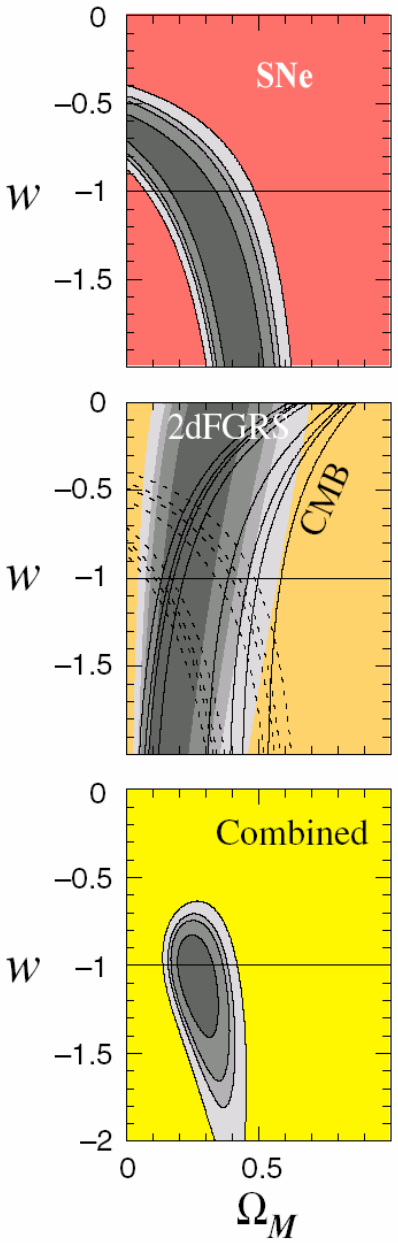


Current Constraints on w

Assumptions:

- Flat Universe
- w constant in time

- 2dF: $\Omega_M h = 0.2 \pm 0.03$
- KP: $h = 0.72 \pm 0.08$



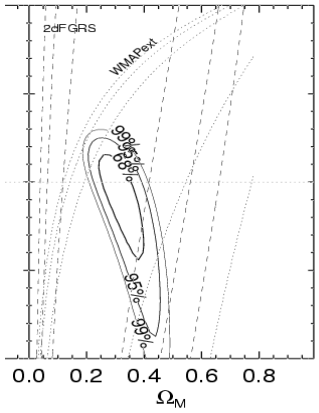
Supernova Cosmology Project

Knop et al 2003

With limits from;
2dFGRS (Hawkins et al. 2002)
and CMB (Bennet et al. 2003,
Spergel et al. 2003)

Riess et al 2004

$w = -1.02\ ^{+0.13}_{-0.19}$



$w = -1.05\ ^{+0.15}_{-0.20}$ (statistical)
± 0.09 (systematic)

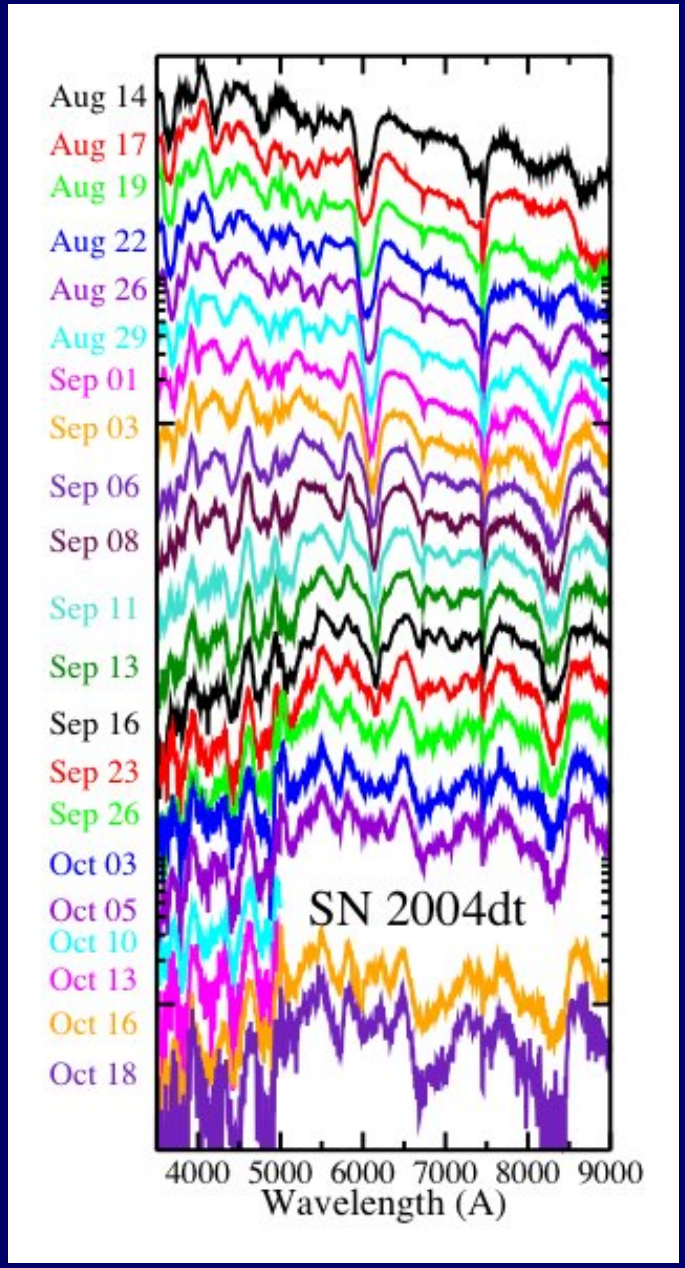
Current and Future Surveys

- SN Legacy Survey — 700 SNe 0.1<z<1
- ESSENCE survey — 200 SNe 0.1<z<0.8
- HST + GOODS — z >1 SNe
  - Talk by Adam Riess
- KAIT search — ~50 Ia/yr at v. low z (<0.03)
- Carnegie IR
- SN factory — 300 nearby SNe (0.03-0.1)
  - Poster by Richard Scalzo
- SDSS SN search — 0.1< z< 0.3
  - Talk by Josh Friemann
- High-z cluster SN search — z>1 SNe “dust free”
  - Talk by Marek Kowalski
- PAN-Starrs — > 10^4 SNe
- DES — 1900 SNe
- SNAP — several x 1000 SNe z < 1.7

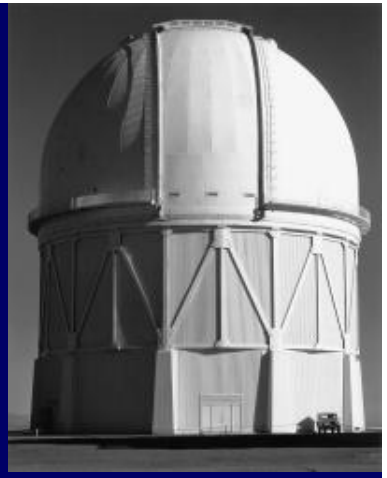
SN factory

Aldering et al, 2002 SPIE
Poster by Richard Scalzo

- Target : 300 SNeIa
  - 0.03 < z < 0.08
- US/French collaboration
- Imaging from NEAT on Palomar
- Frequent spectrophotometry
  - from SNIFS on UH 88”
  - 3200A – 1μm
- Running for ~ 1yr
  - Found more than 40 SNe Ia



Ground-based surveys - The acceleration epoch



Supernova Legacy Survey

- CFHT imaging (Megacam)
- Started March 03
- 40 nights/yr for 5 yrs
- 4 square degrees
- g',r',i',z' every 2-3 nights
- 8m spectroscopy
- Goal: 700 SNeIa
  $0.1 < z < 1$

ESSENCE

- CTIO photometry
- Started 2002
- 30 half nights/yr for 5 yrs
- 8 sq deg
- V,R,I + zJ
- 8m spectroscopy
- Goal: 200 SNeIa
  $0.15 < z < 0.75$

Should measure w to better than +/- 0.1

Test whether dark energy is Λ

SNLS Collaboration

http://cfht.hawaii.edu/SNLS/

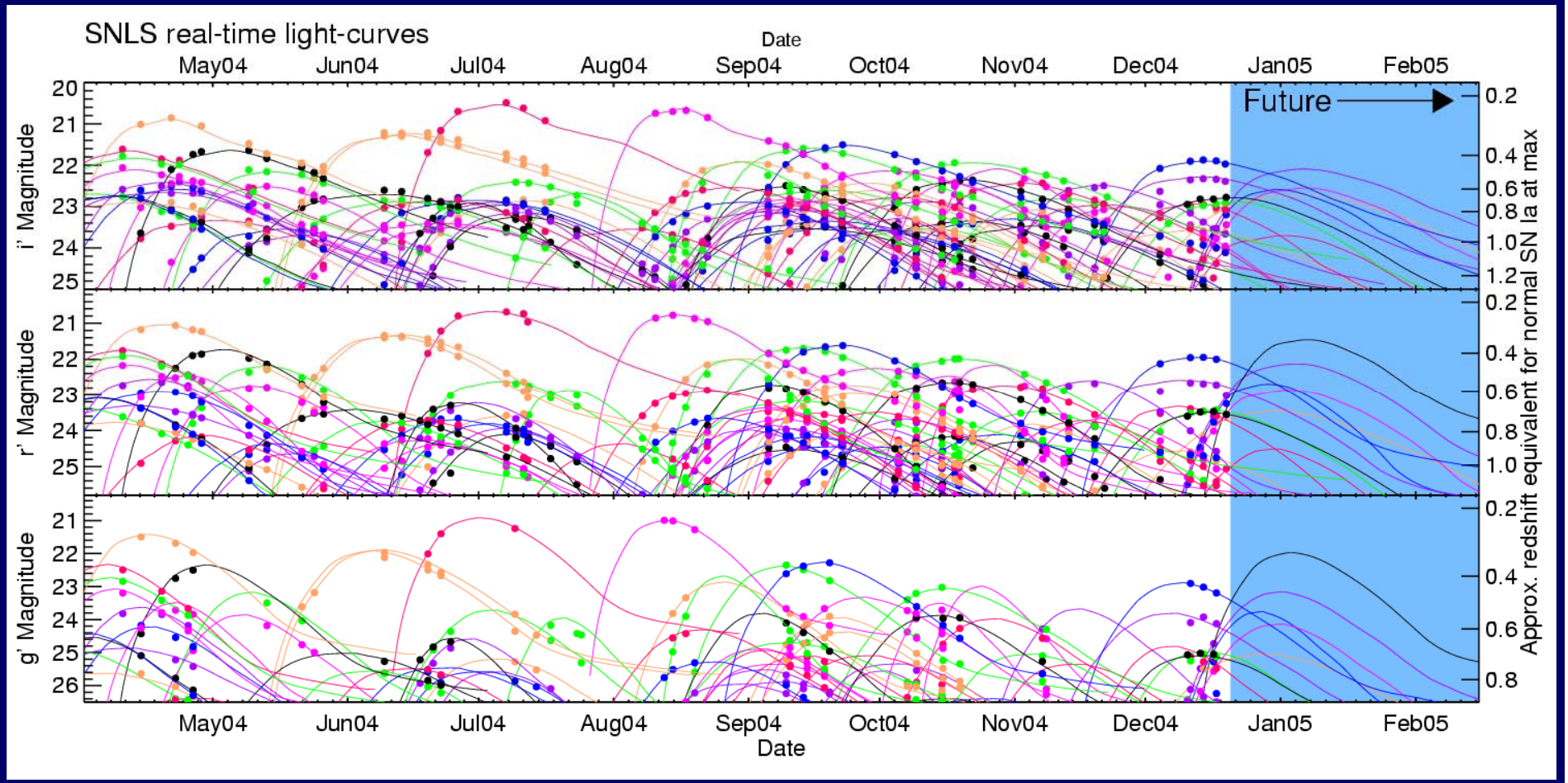
P. Astier, E. Aubourg, D. Balam, S. Basa, R. G. Carlberg, S. Fabbro, D. Fouchez, J. Guy, D. A. Howell, I. Hook, H. Lafoux, J. D. Neill, T. Merrall, N. Palanque-Delabrouille, R. Pain, K. Perrett, C. J. Pritchet, N. Regnault, J. Rich, M. Sullivan, R. Taillet

and

G. Aldering, C. d'Angelo, P. Antilogus, V. Arsenijevic, A. Babul, C. Balland, S. Baumont, J. Bronder, H. Courtois, A. Darbon, S. Ellison, M. Filliol, G. Garavini, A. Goobar, D. Guide, M. Graham, D. Hardin, F.D.A Hartwick, H. Hoekstra, E. Hsiao, R. Knop, E. Lesquoy, V. Lusset, C. Lidman, R. McMahon, A. Mazure, J. Navarro, S. Nobili, M. Mouchet, A. Mourao, S. Perlmutter, G. Sainton, K. Schahmaneche, D. Schade, L Simard, G. Soucail, P. Stetson, C. Tao, S. Van den Berg, N. Walton, J. Willis

Canada, France, UK, US, Sweden, Portugal

SNLS Rolling Search

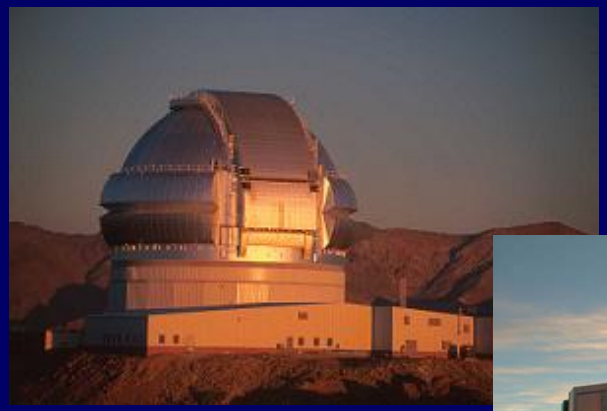


Real-time lightcurves from CFHT

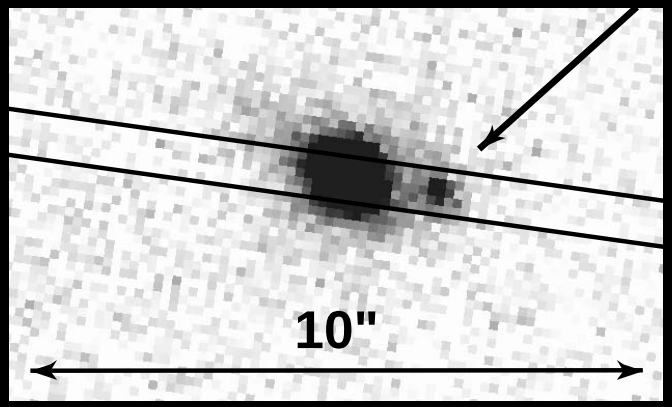
SNLS spectroscopy

Goal : measure redshifts and Types for SNLS candidates

- Fainter targets with Gemini, others at VLT
- Supplemented with spectra from Keck & Magellan
- See Sullivan et al (in press) for real-time selection method



SNLS Spectroscopic data



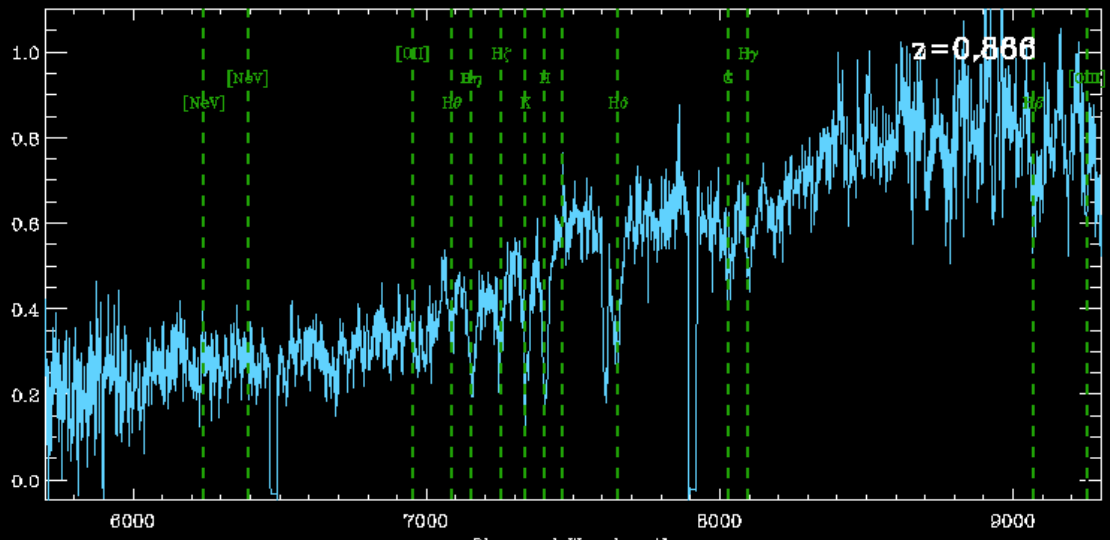
To Dec 2005:

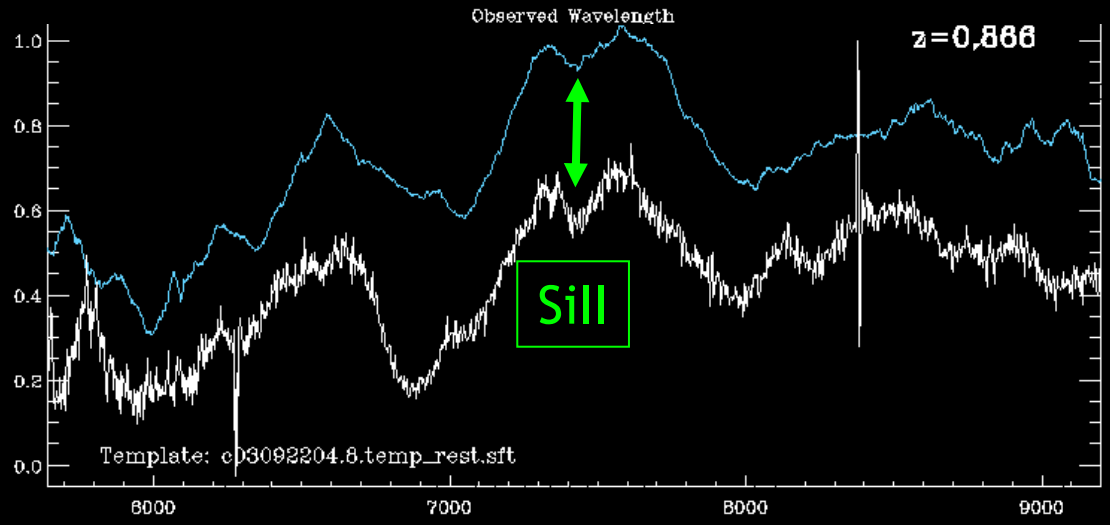
227 SNIa/Ia?

< z > = 0.60

All close to maximum light (within ~10 days)

See Howell et al 2005

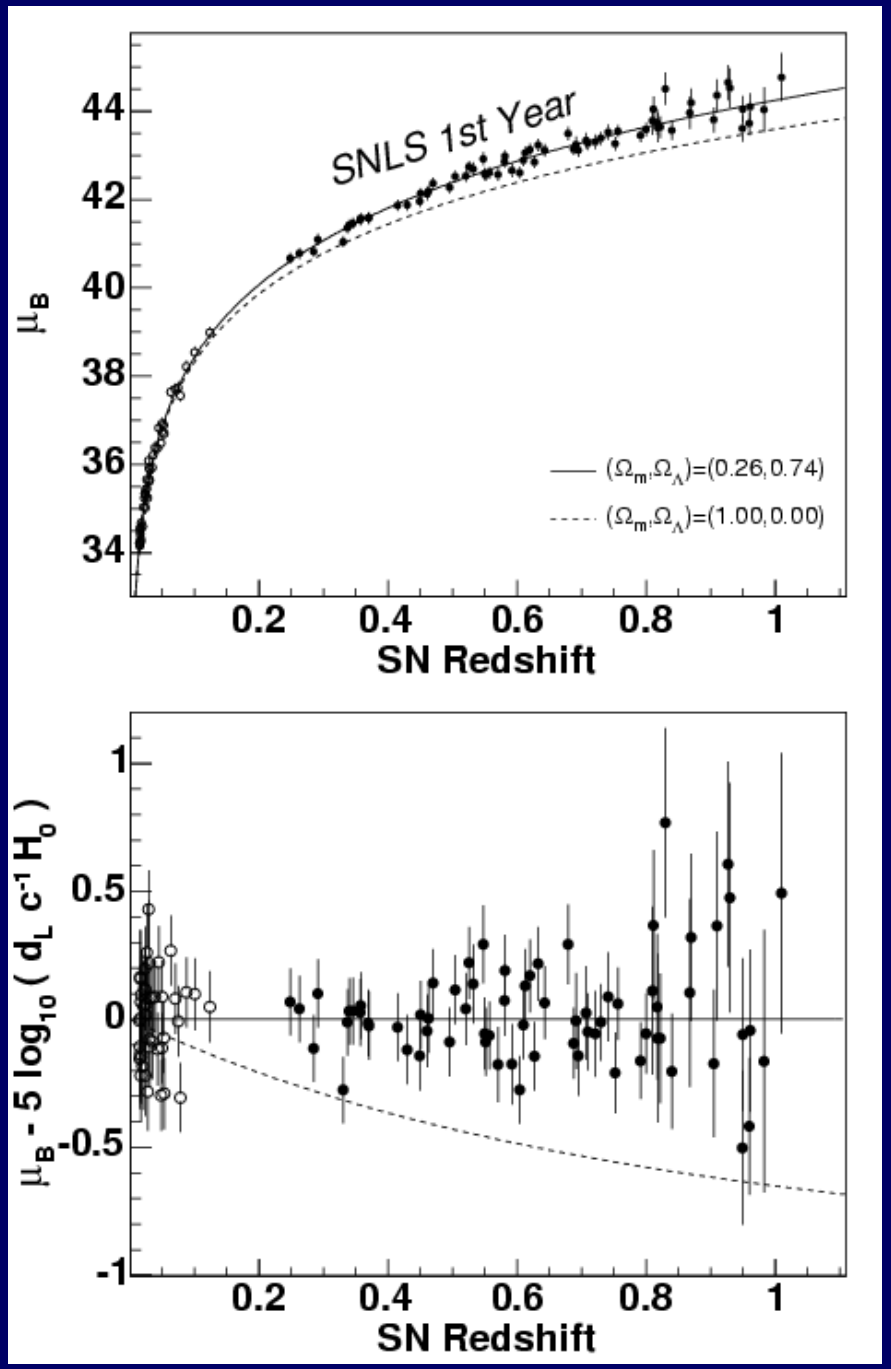




First Year Results - Hubble Diagram

(Astier et al. 2005, A&A)

- First year SNLS: 71 SNeIa
- Nearby sample: 44 SNeIa from the literature
- Hubble diagram consistent with an accelerating Universe

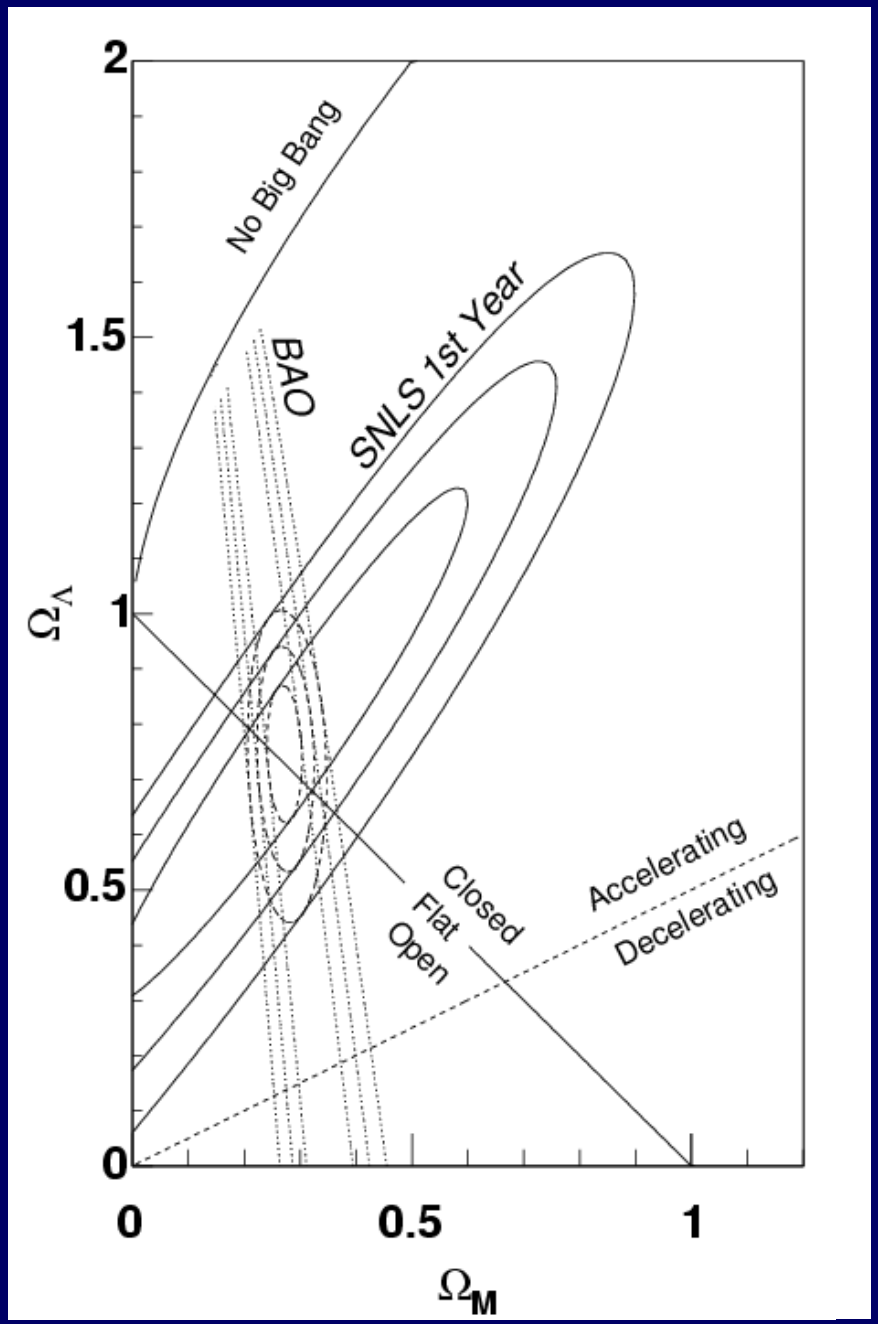


First Year Results - Contours

(Astier et al. 2005, A&A)

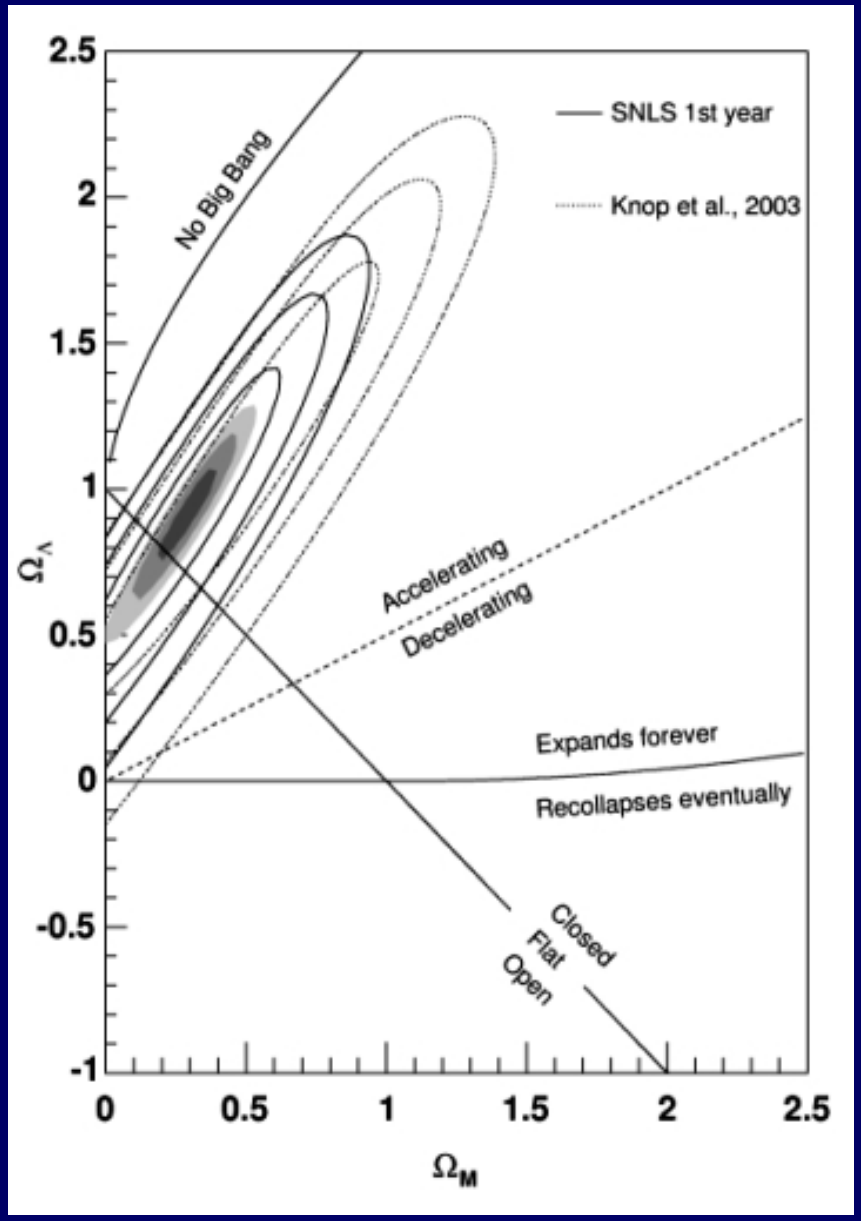
Ω_M = 0.263 +/- 0.042
+/- 0.032

(SN only) in a flat universe



Comparison with previous SN results

- SNLS first year (71 SNe) & Knop et al 2003 (~50 SNe)
- Superior colour and time sampling of SNLS allows tighter constraints on the cosmological parameters than any previous SN sample.
- Shaded area shows projected end-of-survey constraints



First Year Results – w

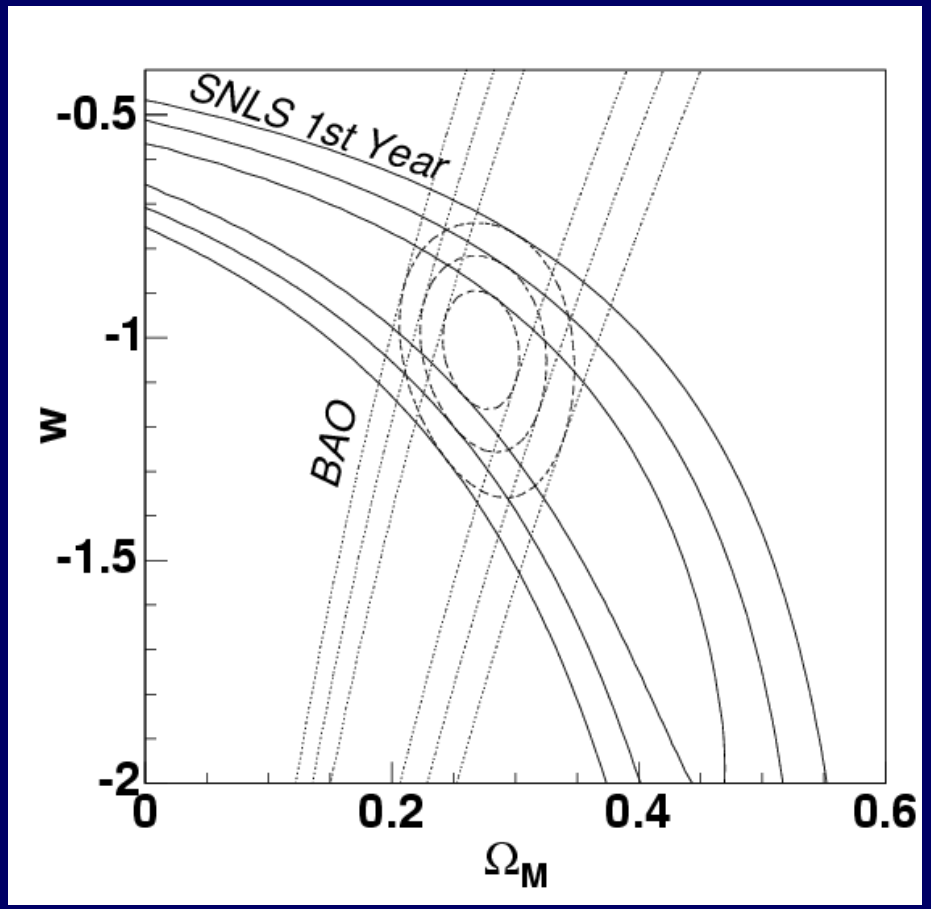
(Astier et al. 2005, A&A)

w = -1.023 +/- 0.09 +/- 0.054

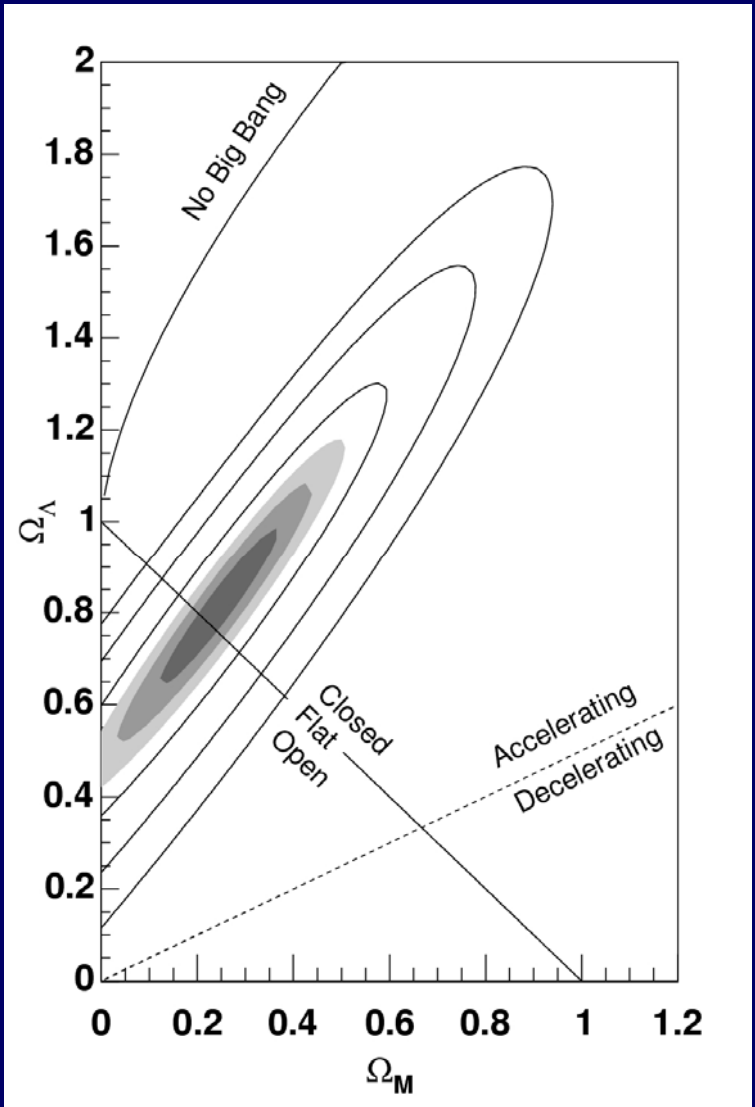
w < -0.85 (95% CL)

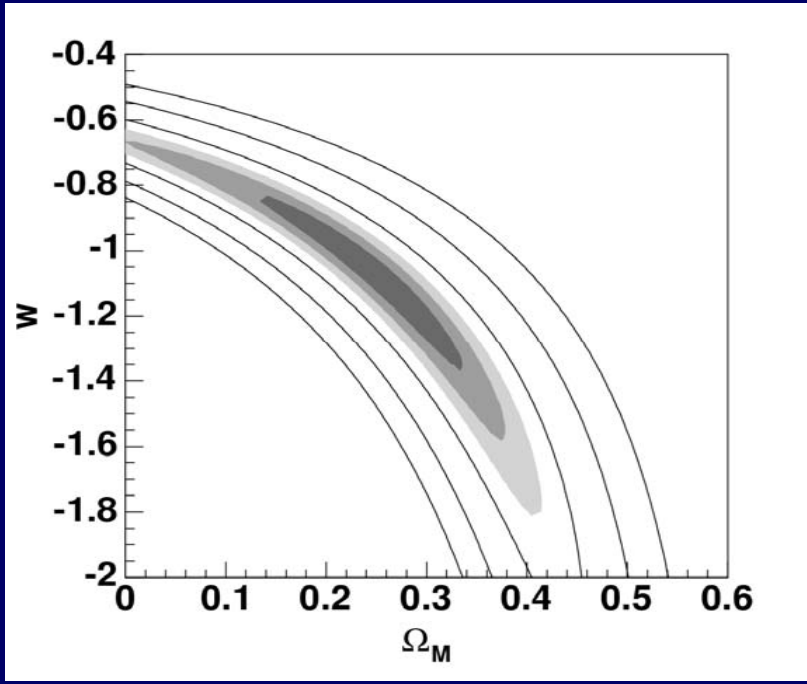
in flat universe with constant w

+ SDSS BAO constraint
(Eisenstein et al 2005)



Predictions for end of survey



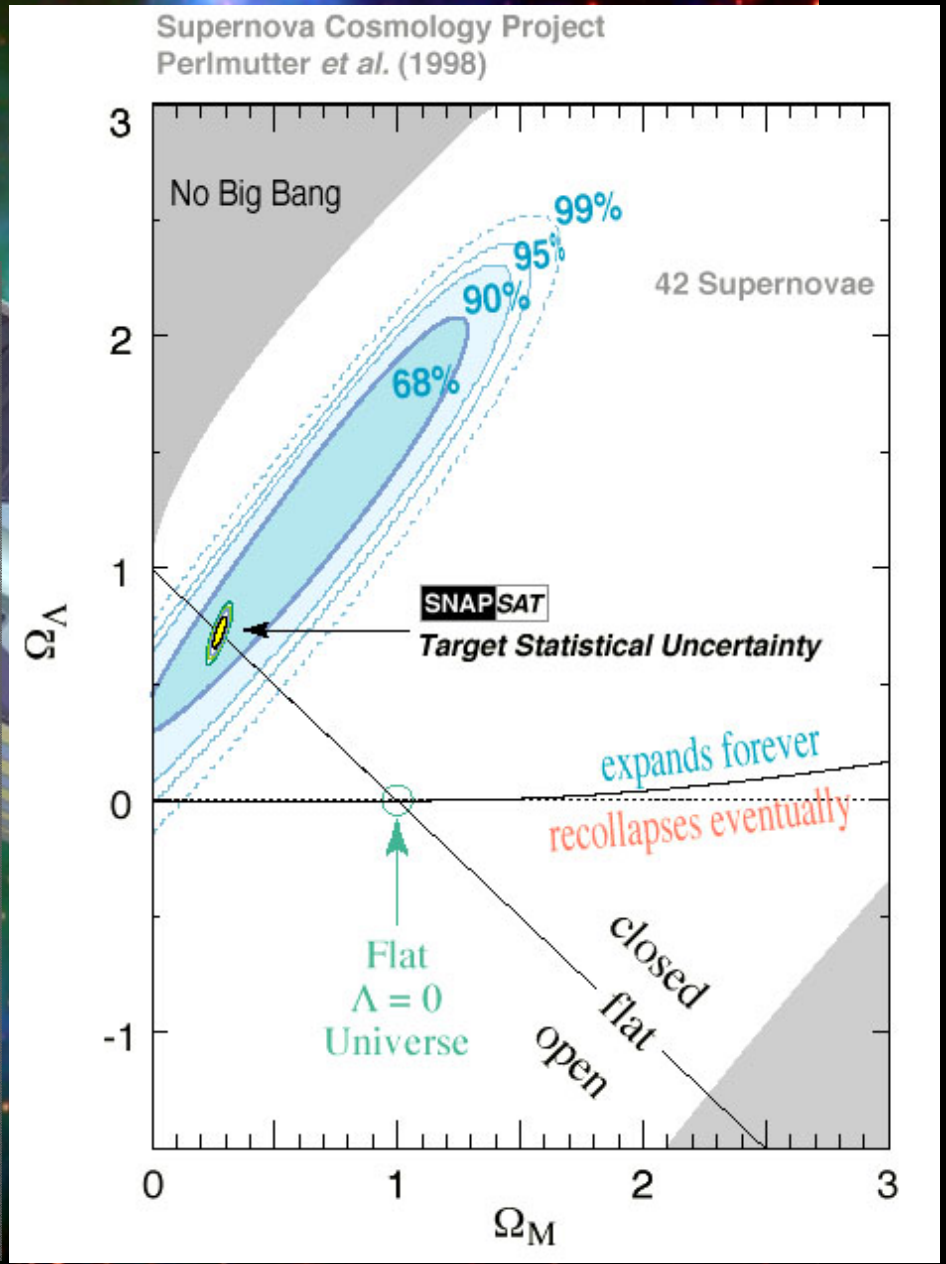


- w constraints with no prior on Ω_M
- Assumes flat universe
- With prior on Ω_M (e.g. from CFHT-LS weak lensing) should measure w to +/- 0.06 (stat)

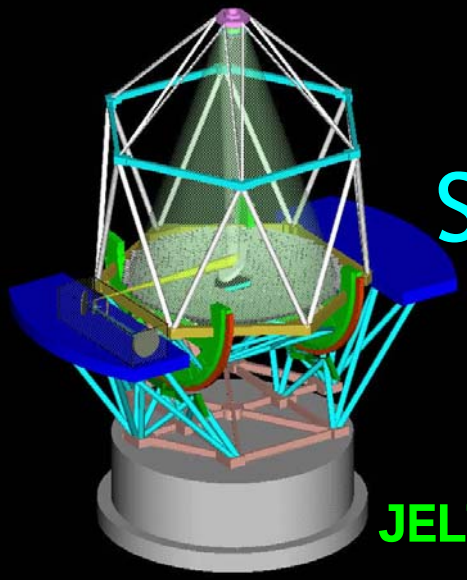
SNAP

SuperNova Acceleration Probe

- 2m telescope
- 1 sq deg camera
- 3-channel spectrograph
- >1000 SNe per yr for 3 yrs
- $z < 1.7$
- Ω_M to 2%, Ω_Λ to 5% (curvature to 5%)
- Measurement of w to 5%
- Constrain w'

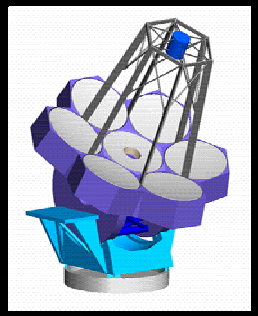


Some ELT Concepts

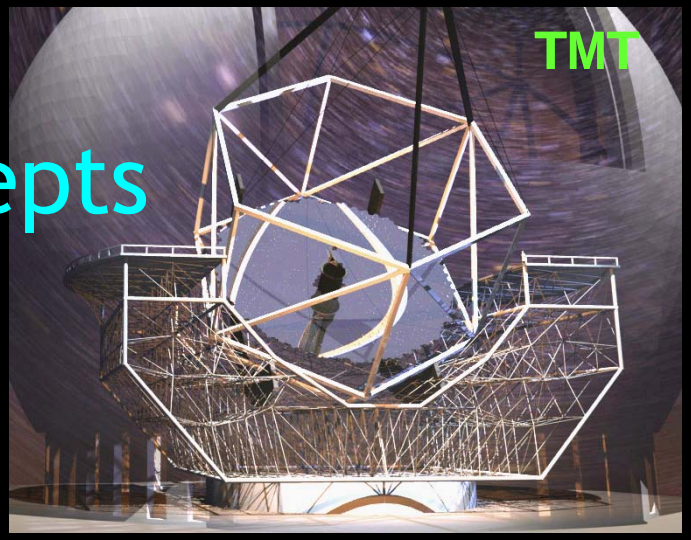


JELT

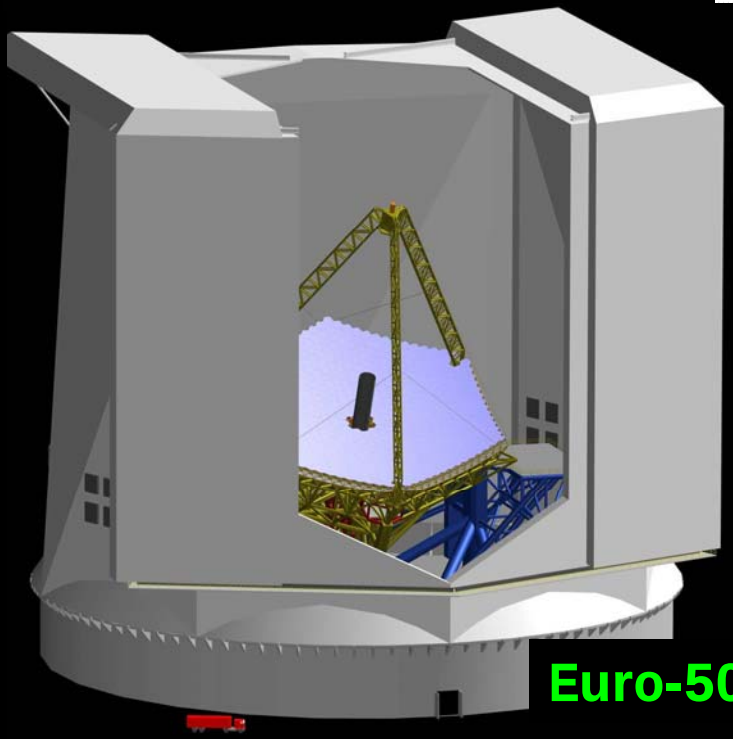
VLT UT1



GMT



TMT

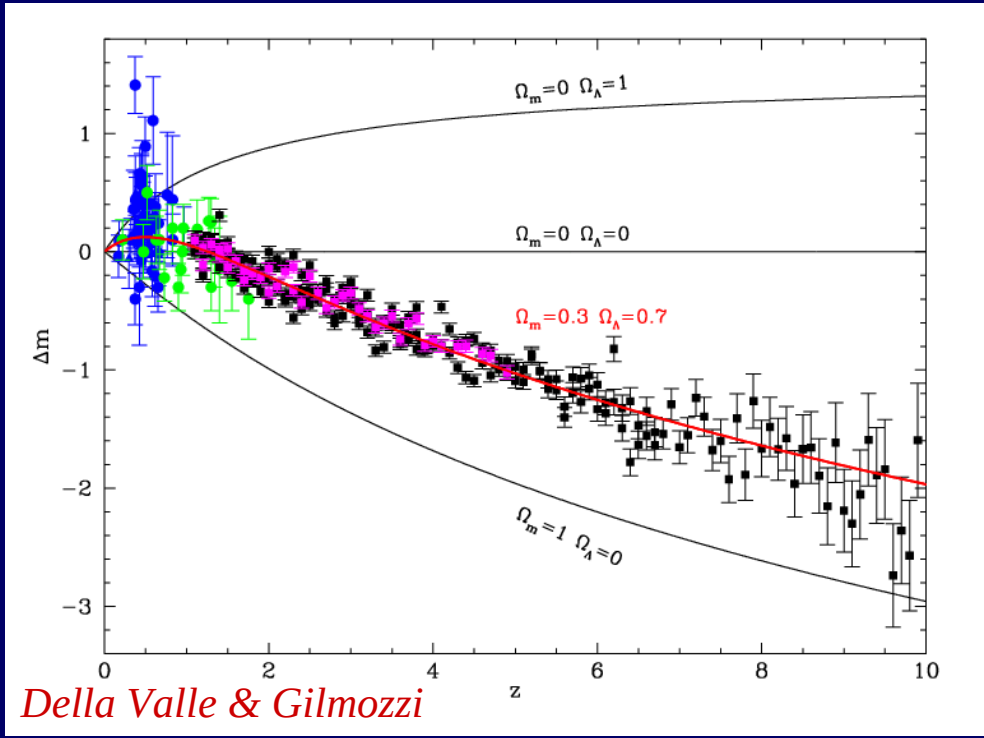


Euro-50

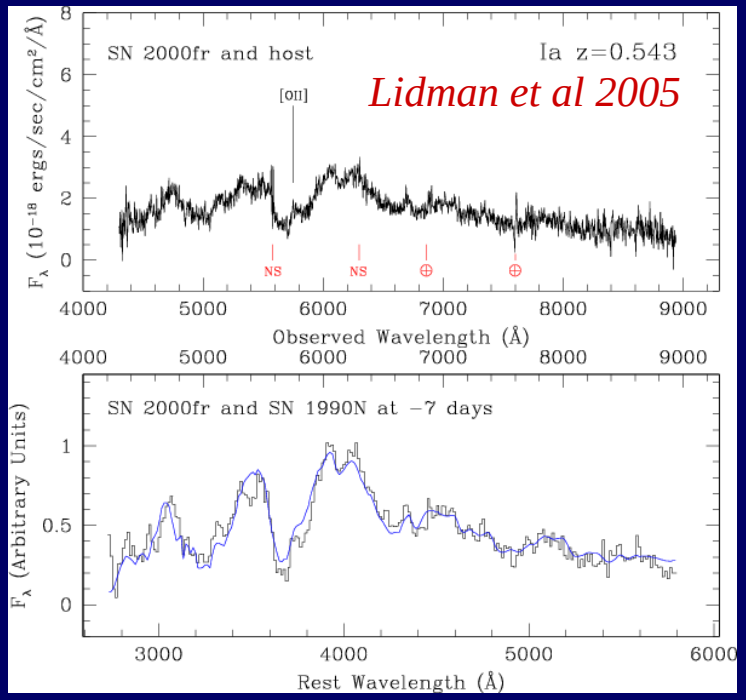
OWL

High-z Supernovae with ELTs

Simulated Hubble diagram for supernovae
Spectroscopy of SNe Ia to z~4 (100m)
[or z > 1.2 with GMT]



Della Valle & Gilmozzi



Lidman et al 2005

- Find the SNe with JWST or ELTs themselves?

Conclusions

- Measurements of *m* and *z* of Type Ia SNe provide direct measurement of the acceleration of the Universe

- Can measure Ω_M, w during the epoch of dark energy
- Independent and complementary technique to CMB and galaxy redshift surveys

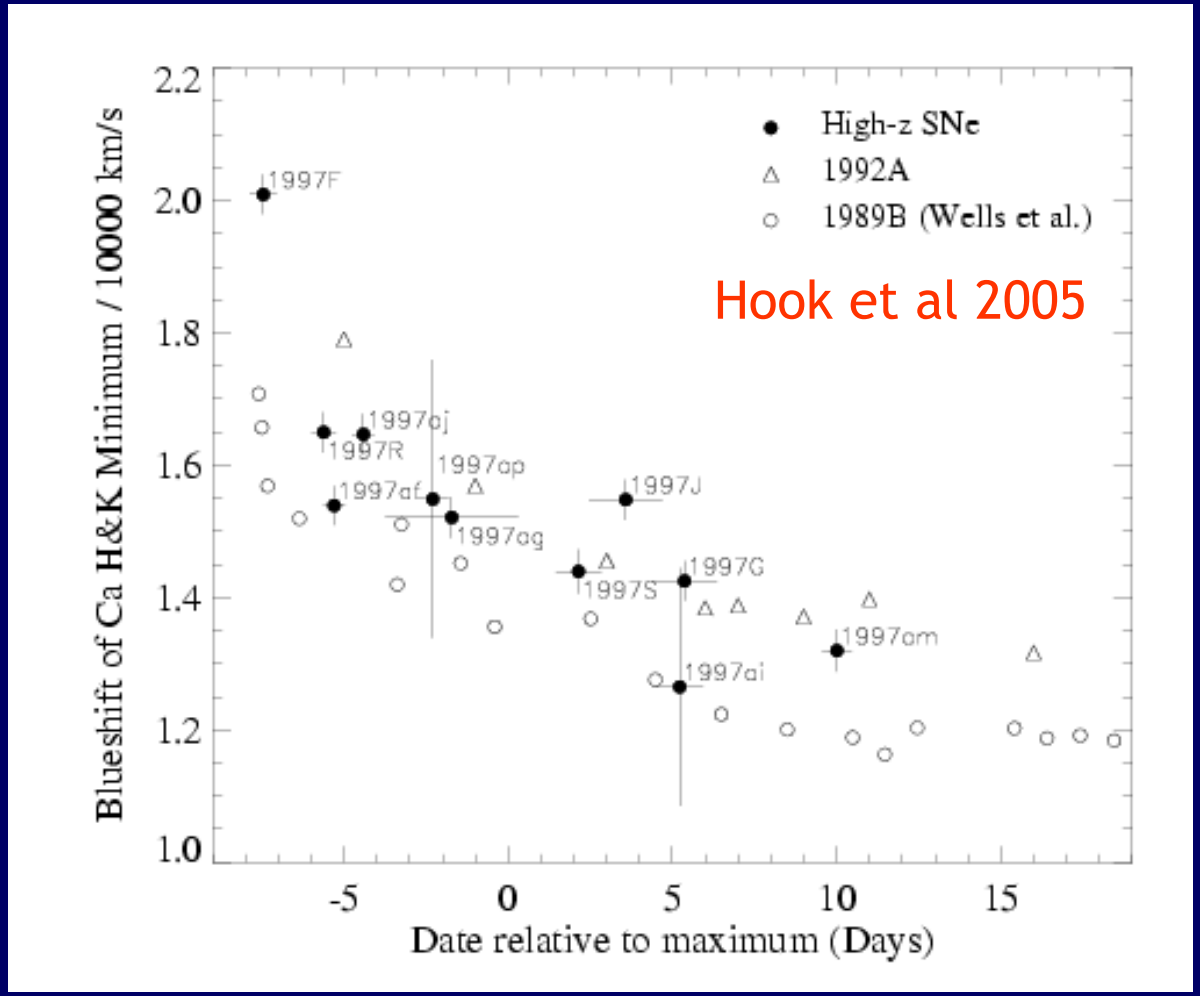
- SNLS will constrain w to ~ +/-0.06, & hence the nature of the dark energy (w=-1 or not)

- Powerful technique with great prospects

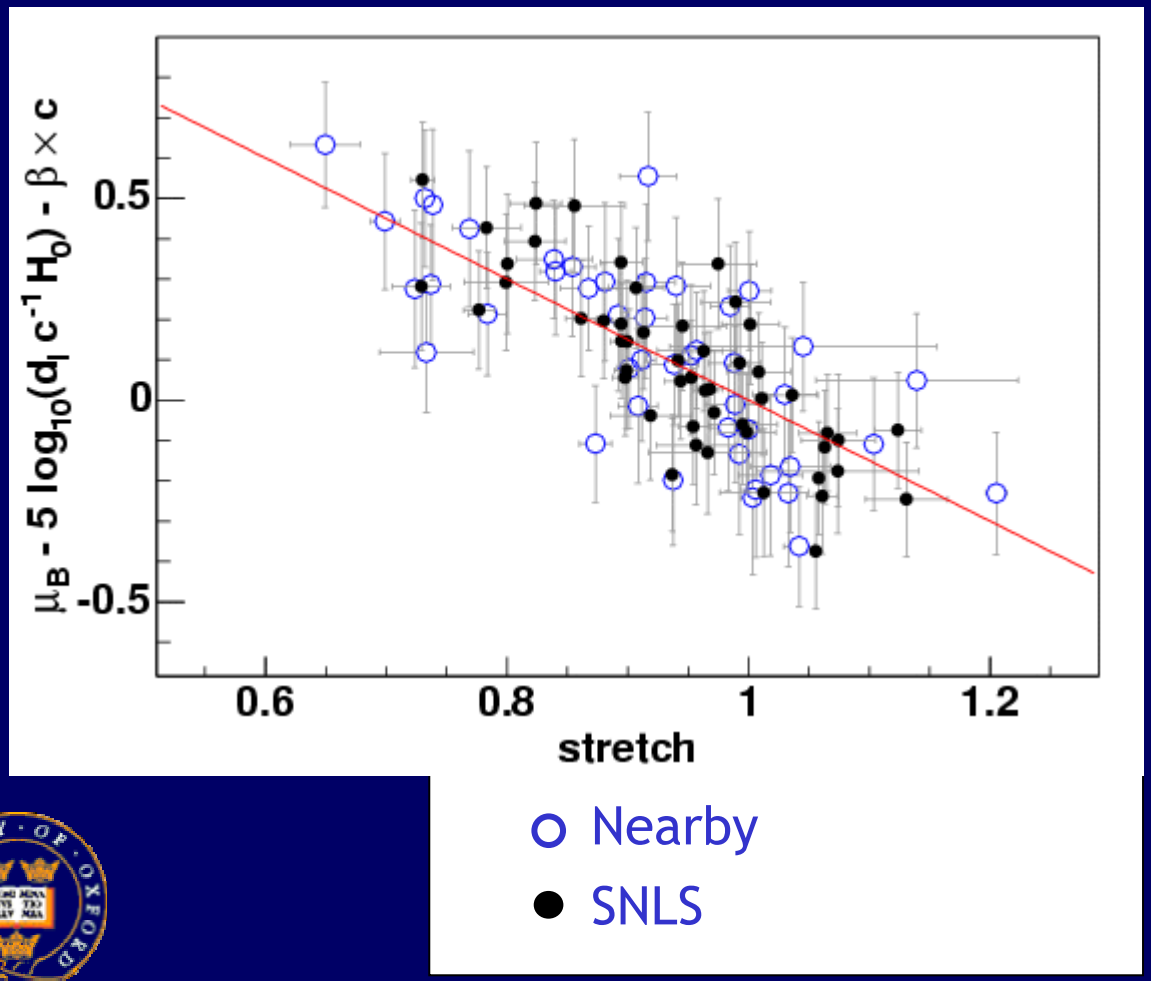
The End

Quantitative spectral tests

- Ca feature velocity



Stretch relation at high-z



Astier et al 2005

- Distance modulus without the stretch term
- Brighter objects have larger stretch
- Same at low & high-z