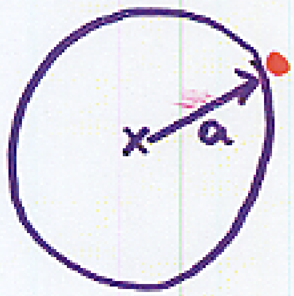
SNAP & Dark Energy
– Presentation to the PAC, 3/03

- Basics
- Dark Energy & particle physics
- 3 different ways to measure dark energy
- SNAP

Lam Hui
Peter Limon

Dynamics of the Universe



Energy conservation:

1. $\frac{1}{2}\dot{a}^2 - \frac{G(\frac{4\pi}{3}\rho a^3)}{a} = \text{const.} = 0$ (flat universe)

First law of thermodynamics:

2. $d(\rho a^3) = -P\, da^3$

Matter: $P = 0$, $\rho \propto a^{-3} \Rightarrow \dot{a}\downarrow$ as $a\uparrow$

Decceleration

Cosmological constant: $P = -\rho$. $\rho = \text{const.} \Rightarrow \dot{a}\uparrow$ as $a\uparrow$

Acceleration

General fluid: $P = w\rho$, $\rho \propto a^{-3(1+w)}$

$\Rightarrow$ if $w < -\frac{1}{3}$, $\dot{a}\uparrow$ as $a\uparrow$

Introducing Ω's

Rewrite eq. 1: $\frac{3}{8\pi G}\left(\frac{\dot{a}}{a}\right)^2 - \rho = 0$

Define $\rho_{crit.} \equiv \frac{3}{8\pi G}\left(\frac{\dot{a}}{a}\right)^2$

- $\Omega \equiv \frac{\rho}{\rho_{crit.}}$ (=1 for flat universe)

- $\Omega_m \equiv \frac{\rho_{matter}}{\rho_{crit.}}$ (~ 0.3)

- $\Omega_{de} \equiv \frac{\rho_{dark\ energy}}{\rho_{crit.}}$ (~ 0.7)

  (or Ω_q or Ω_Λ)

Questians:

1. How much dark energy is there?
2. What properties does it have? (e.g. what is w?)

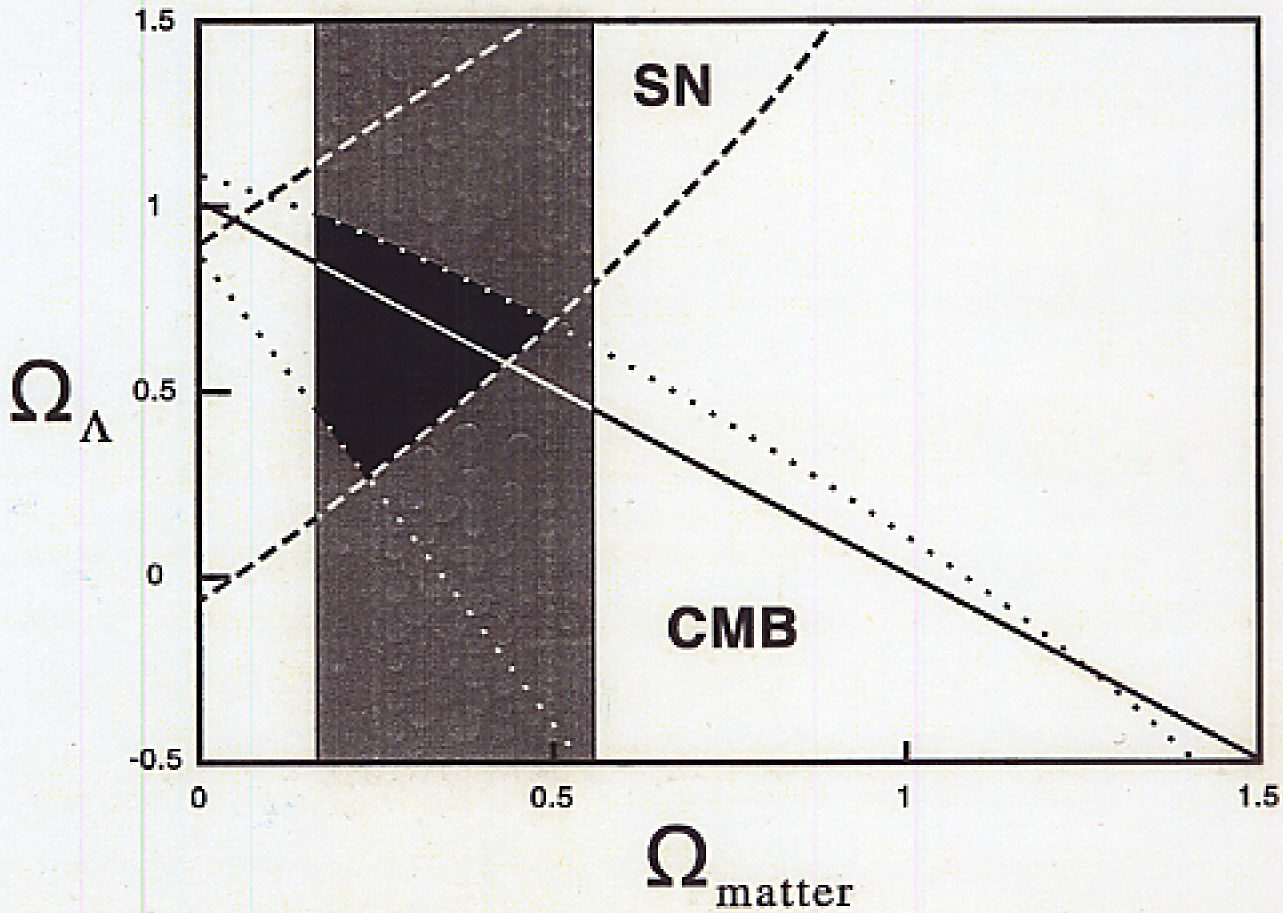


Figure 9: Constraints in the Ω_Λ vs Ω_M plane. Three different types of observations are shown: SNe Ia measures of expansion acceleration (SN); the CMB observations of the location of the first acoustic peak (CMB); and the determinations of the matter density, $\Omega_M = 0.35 \pm 0.07$ (dark vertical band). The diagonal line indicates a flat Universe, $\Omega_M + \Omega_\Lambda = 1$; regions denote "3-$\sigma$" confidence. Darkest region denotes the concordance region: $\Omega_\Lambda \sim 2/3$ and $\Omega_M \sim 1/3$.

Turner & Tyson

The Dark energy problems

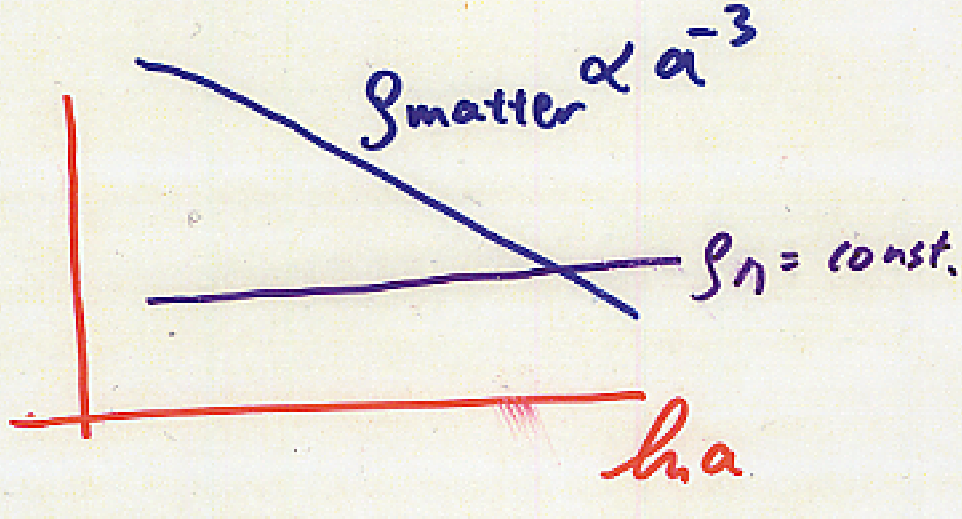
- Why so small, but non-zero?

  $\rho_{de} \sim 10^{-47}\ GeV^4$

  Naive expectations:

  - $\rho_\Lambda = \infty$ ($\therefore = 0$??)
  - $\rho_\Lambda = M_{pl}^4$
  - $\rho_\Lambda = TeV^4$ + ?

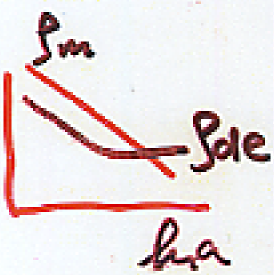
- Why now?



Ideas on dark energy

- cosmological constant
  variant: we live in a false vacuum.
  true vacuum has $\Lambda = 0$.
  have to explain small splitting
  (e.g. Bousso & Polchinski, Feng et al.)

- slowly rolling scalar field (quintessence)
  i.e. vac. energy = 0 ultimately.
  hope to use dynamics to explain
  why now.
  But introduce $m \lesssim H$ ($\sim 10^{-42}$ GeV).
  & need to suppress coupling to other things.
  (e.g. Frieman, Hill, Stebbins,
  Caldwell, Steinhardt
  (Carroll)



- modifying gravity on large scales
  (e.g. Deffayet, Dvali, Gabadadze)

- defect network
  (e.g. Pen & Spergel. Vilenkin)

Methods to measure dark energy

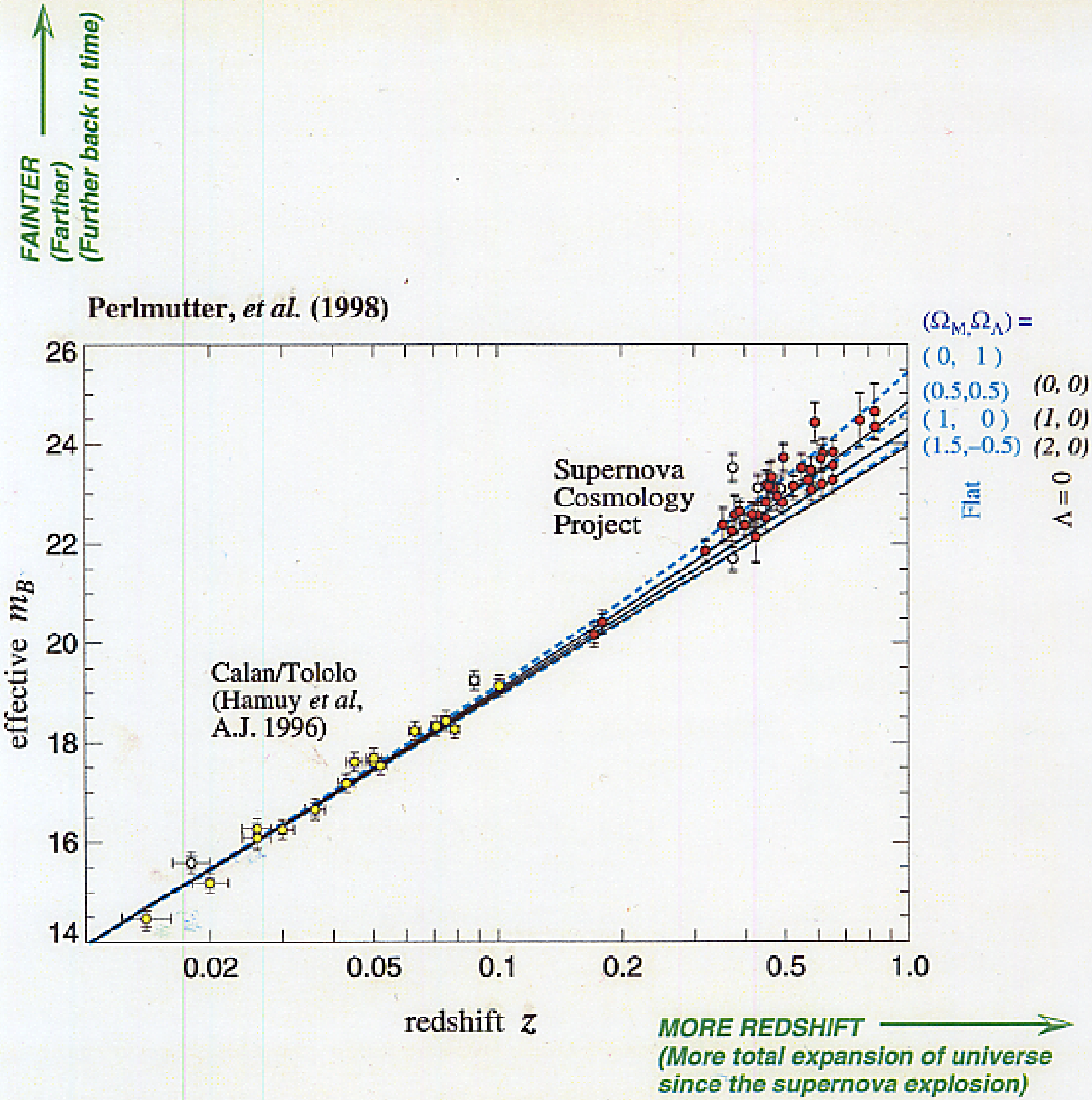
1. Supernova

- most direct: measure distance as a function of redshift z
  ($a = \frac{1}{1+z}$, convention: $a=1$, $z=0$ today)

- The idea:
  ↑ Ω_{de} , ↑ distance for a given z.
  ∴ dimmer supernova
  (similar effect as $w \to -1$)

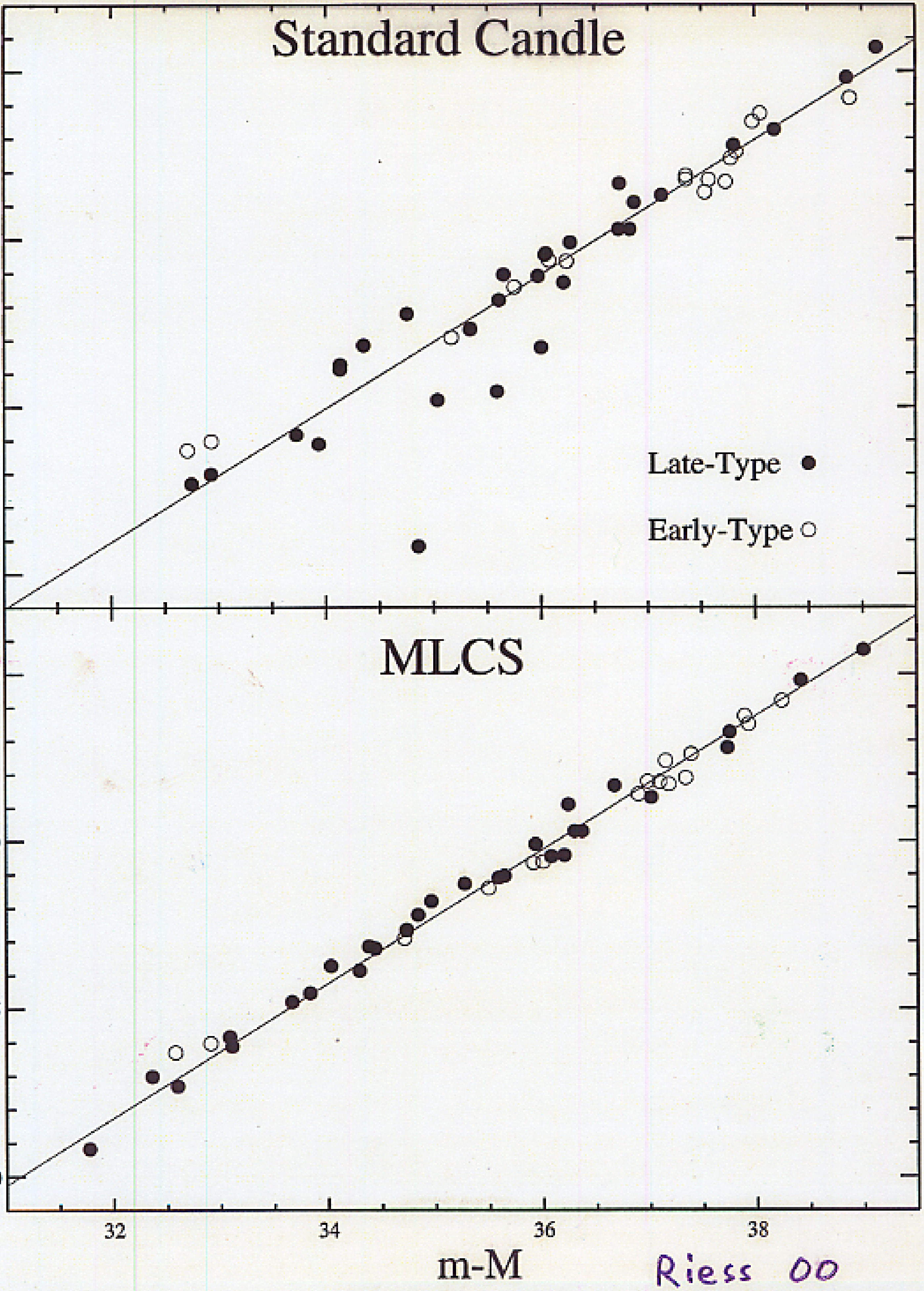
- innovation of 97:
  use light curve shape to correct luminosity (dimmer ⟷ faster decline)

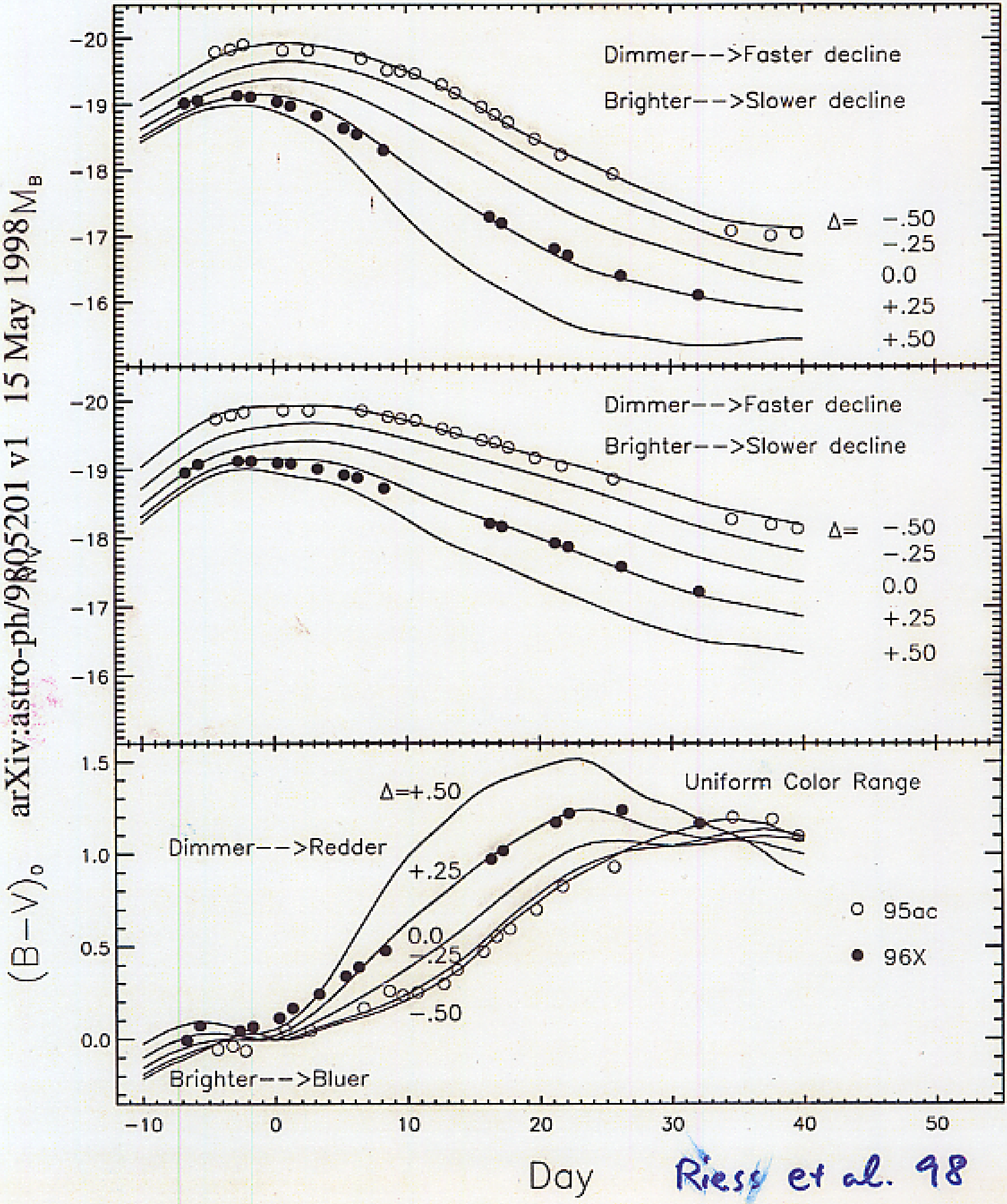
$$\text{Distance} \propto \int_0^{z_{SN}} \frac{dz}{\left[\Omega_m (1+z)^3 + \Omega_{de} (1+z)^{3(1+w)}\right]^{\frac{1}{2}}}$$



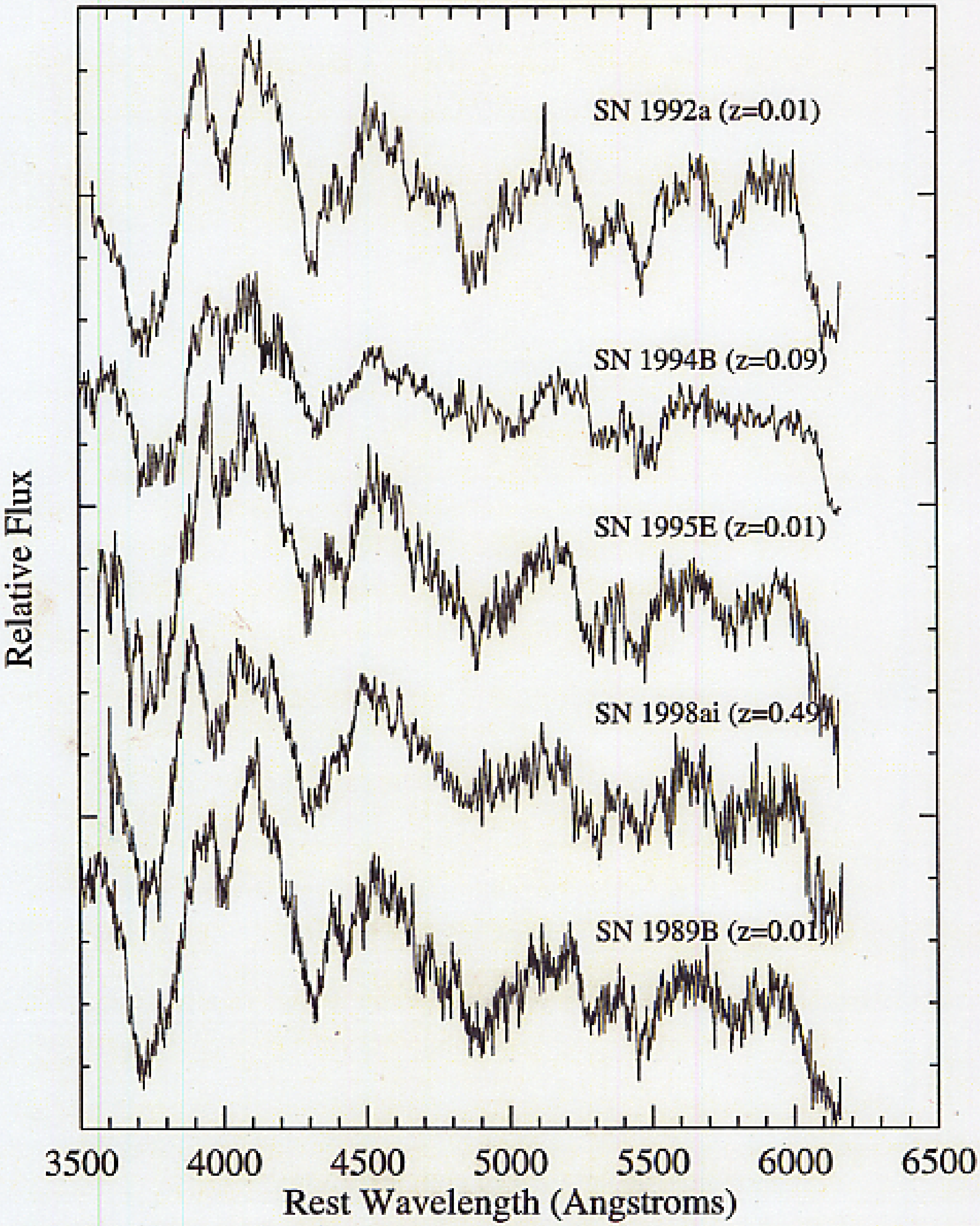
In flat universe: $\Omega_M = 0.28$ [± 0.085 statistical] [± 0.05 systematic]

Prob. of fit to $\Lambda = 0$ universe: 1%


Standard Candle
MLCS
LOG v (km/s)
Late-Type
Early-Type
4.5
4.0
3.5
3.0
32
34
36
38
m-M
Riess 00



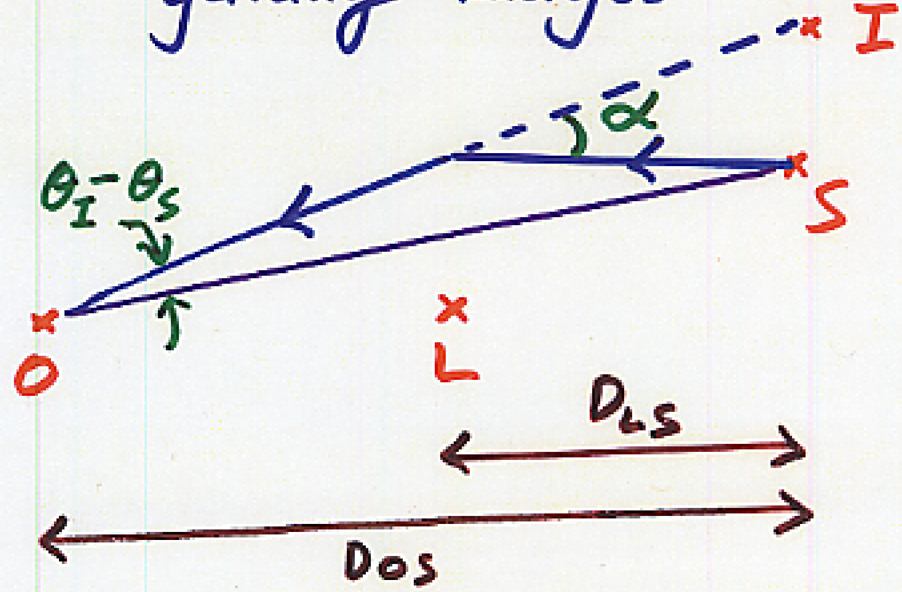
Riess et al. 98


SN 1992a (z=0.01)
SN 1994B (z=0.09)
SN 1995E (z=0.01)
SN 1998ai (z=0.49)
SN 1989B (z=0.01)
Relative Flux
3500
4000
4500
5000
5500
6000
6500
Rest Wavelength (Angstroms)

Riess 00

2. Method: Gravitational lensing

Idea: observe coherent distortions of galaxy images



$$D_{OS}(\theta_I - \theta_S) = \alpha D_{LS}$$

Distortion in shape of images

$\Longleftrightarrow$ $\theta_I \leftrightarrow \theta_S$ mapping

determined by 1. mass fluctuation

2. geometry (D_{OS}, etc.)

Dark energy affects both 1. evolution of mass fluc.

2. distances

Powerful ∵ can study dark matter as well,
But also more theoretical baggage.

Gravitational Lens
Galaxy Cluster 0024+1654

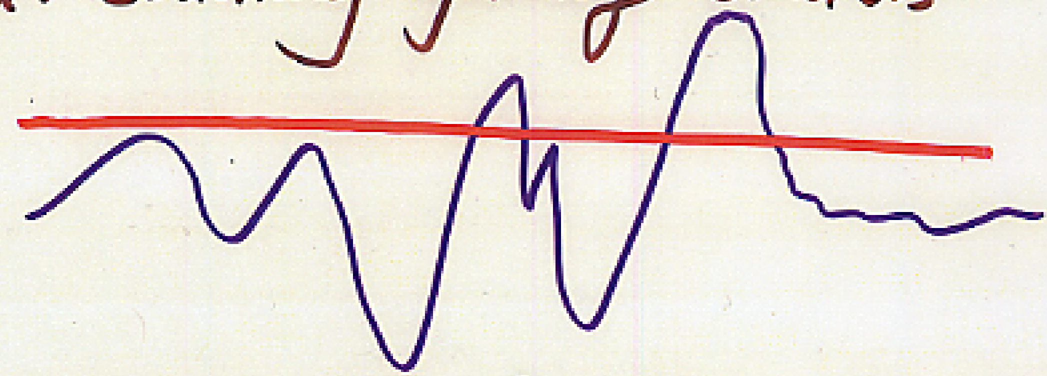
HST • WFPC2

PRC96-10 · ST ScI OPO · April 24, 1996

W.N. Colley (Princeton University), E. Turner (Princeton University), J.A. Tyson (AT&T Bell Labs) and NASA

3. Method: counting galaxy clusters

Idea:



Count clusters of galaxies above some given mass.

Observed # per unit redshift
per solid angle
is determined by
1. amplitude of mass fluctuation
2. geometry (i.e. dist. ⟷ z, dΘ)

Clusters are simple objects
but need to know their mass.

SNAP uses all 3 methods.

1. Supernovae

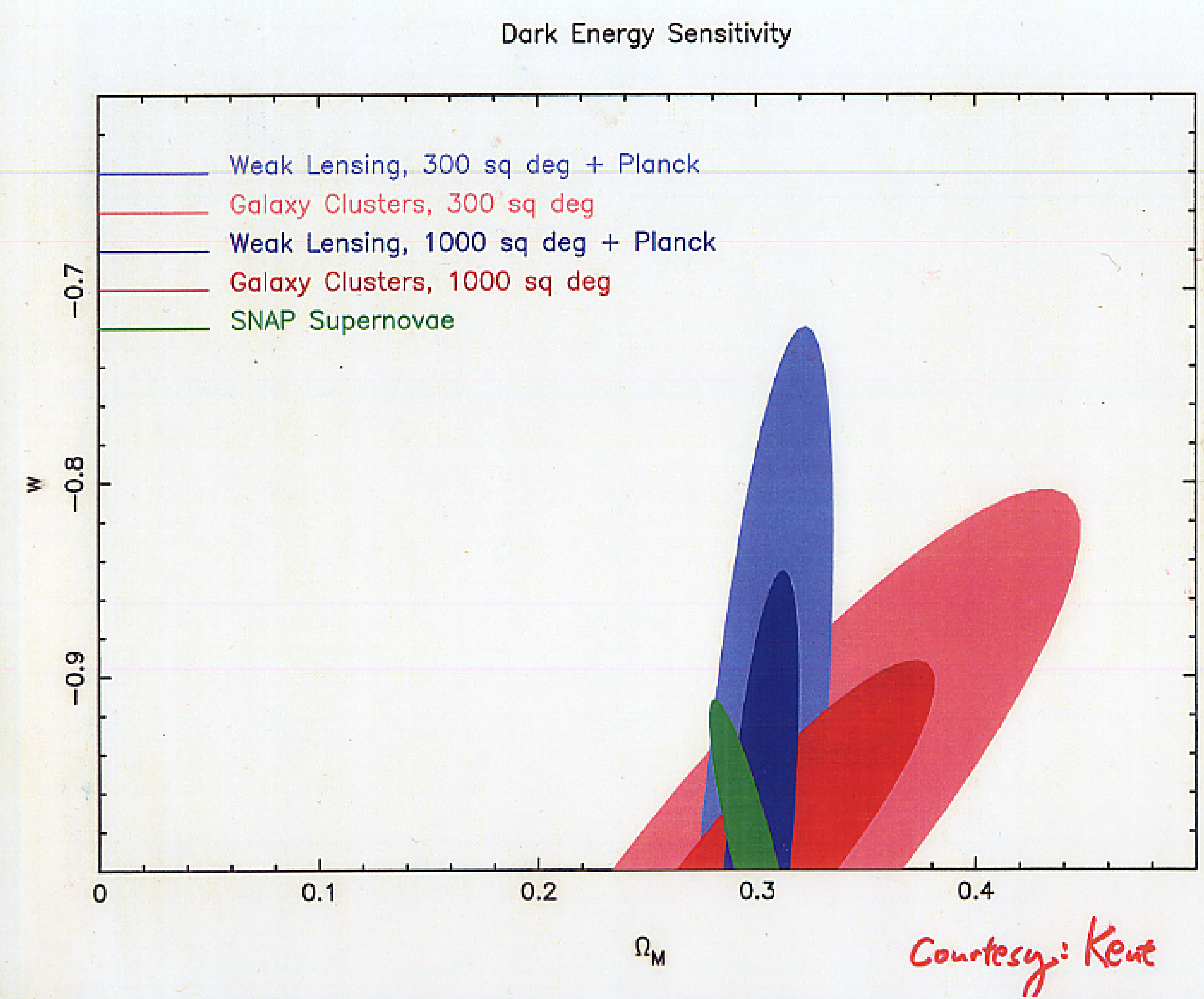
- 2000 SN's to $z \sim 1.7$
- light curves from −2 to +80 days
- infrared observations crucial (i.e. observe SN's in the same rest-frame wavebands)
- keep systematic photometric error $\lesssim 0.02$ mag. (intrinsic spread ~ 0.15 mag.)
- Ω_m to 2%
  Ω_Λ to 5%
  w to 5%
  w' to 20%

2. Lensing

- 300 to 1000 sq. degree wide field survey. (to R = 28)
- For galaxies fainter than R = 25, difficult to resolve from ground.
- No atmospheric distortion.
- Multiple passbands allow photometric z measurements.

3. Galaxy Clusters

- same survey allows search for clusters
- photometric z's.


Dark Energy Sensitivity
Weak Lensing, 300 sq deg + Planck
Galaxy Clusters, 300 sq deg
Weak Lensing, 1000 sq deg + Planck
Galaxy Clusters, 1000 sq deg
SNAP Supernovae
w
−0.7
−0.8
−0.9
0
0.1
0.2
0.3
0.4
Ω_M
Courtesy: Kent

LSST + HST + Keck/NGST
Case B results

- **We model the additional data from the HST as 150 z=1.25 supernovae with magnitude errors dominated by the 0.15 mag intrinsic dispersion.**
- **These additional data improves the error contour but with a much larger Malmquist bias from the input w_0=-1, w'=0 cosmology.**

These LSST + WFC3 measurements do not have the control of systematic uncertainties planned for SNAP, so also need to consider larger systematic uncertainty models.