Analysis and Effects of Dark Energy Measurements

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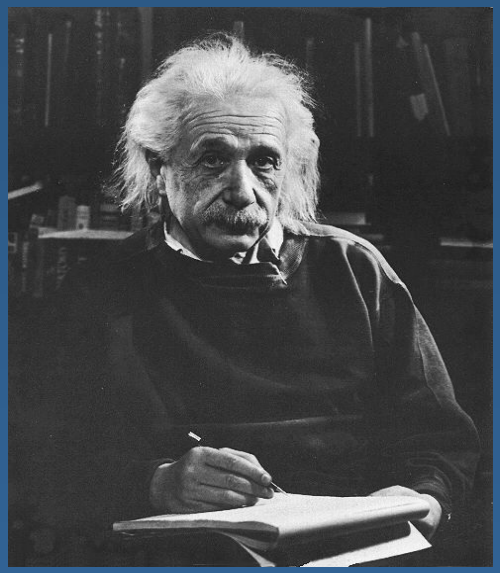
The Quest for Dark Energy

Standard Model: General Relativity + FRW

- Necessity for an exotic component to account for CMB+LSS, SN Ia and ISW-correlation



- Simplest scenario to account for the observations: Λ in GR

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

- So why to bother?

Einstein-De Sitter correspondence

(credit to Rob Caldwell for finding it in the Einstein archive)

"It cannot be denied that the introduction of the constant… detracts from the simplicity and elegance of the original theory…one of whose great charms was that it embraced so much without introducing a new empirical constant."

(Letter to Einstein 1917)

"In any case, one thing stands. The general theory of relativity allows the addition of the [cosmological constant] in the field equations. One day, our actual knowledge of the composition of the fixed-star sky, the apparent motions of the fixed stars, the position of the spectral lines as a function of distance, will probably have come far enough for us to be able to decide empirically the question of whether or not vanishes."

(Letter to De Sitter 14 April 1917)

"The main point in our 'difference in creed' is that you have a specific belief and I am a skeptic. Observations will never be able to prove that vanishes, only that is smaller than a given value. Today I would say that is certainly smaller than 10^{-45} cm^{-2} and is probably smaller than 10^{-50} cm^{-2} . Maybe one day observations will also provide a specific value, but up to know I have no knowledge of anything pointing to this."

(Letter to Einstein 18 April 1917)

A physical explanation for Λ: QFT Vacuum Energy

- Consequences of the identification:

$$\frac{\rho_{\Lambda_{eff}}^{Obs}}{\rho_{Vacuum}} = 10^{-(121 \div 60)}$$

- Perhaps there is a symmetry or mechanism which guarantees $\rho_{Vacuum}=0$, hence no need of Λ in GR and DE is something else

Alternative Proposals

Beyond Standard Model:

$$G_{\mu\nu} = 8\pi G \left[T^{SM}_{\mu\nu} + T^{DM}_{\mu\nu} + T^{DE}_{\mu\nu} \right]$$

- Quintessence Models
- PNG-Boson
- Interacting DE-DM/Neutrino
- ....

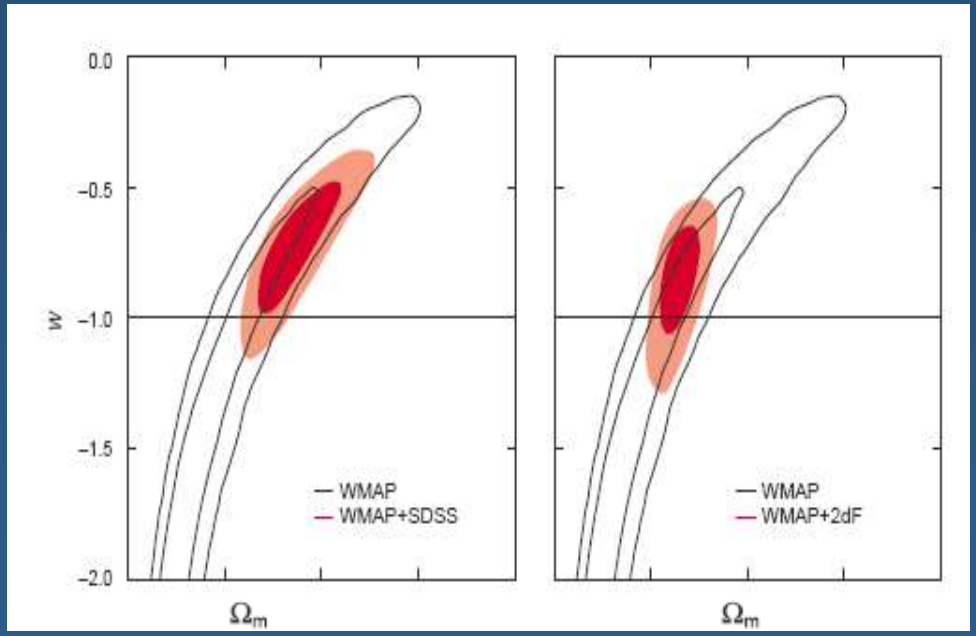
Generic feature w = w(z)

Beyond Einstein Gravity:

$$\tilde{G}_{\mu\nu}(k) = 8\pi G T^{Matter}_{\mu\nu}$$

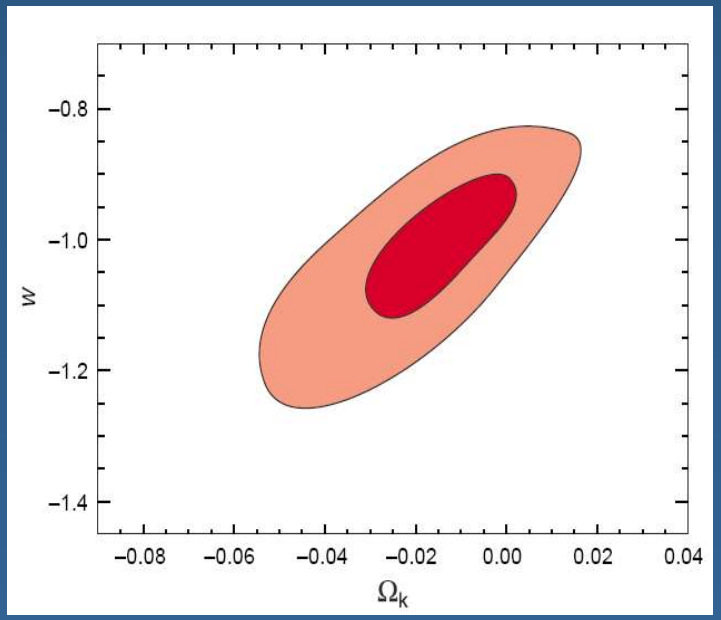
- Higher Order Corrections to GR
- Gravity in Extra-Dimension: RS, DGP

Constraints from WMAP



(Spergel et al. 2006)

- Flatness Prior
- Degeneracy in w -Ω_m
- w is poorly constrained by CMB alone

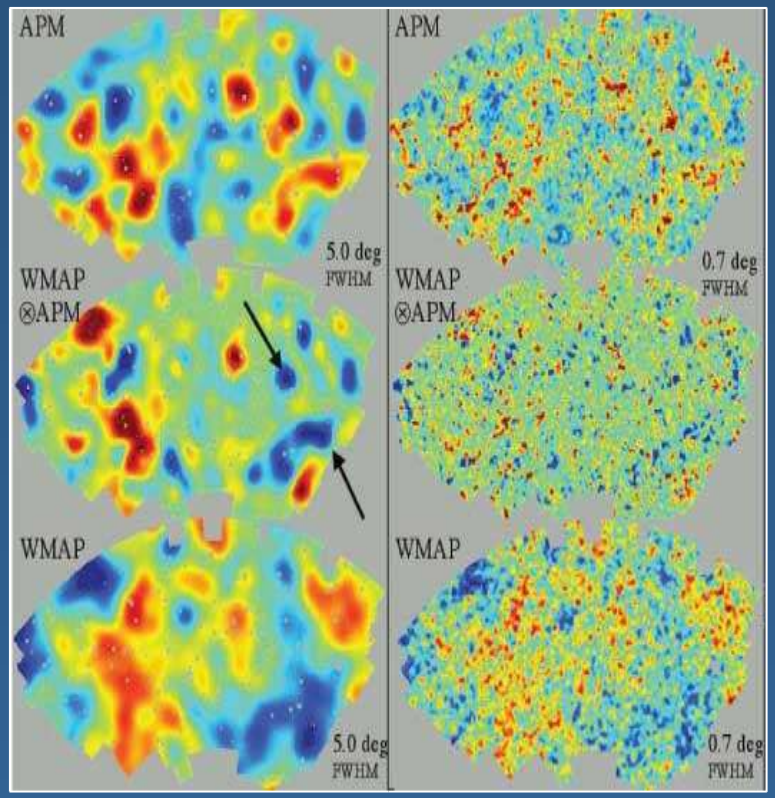


(Spergel et al. 2006)

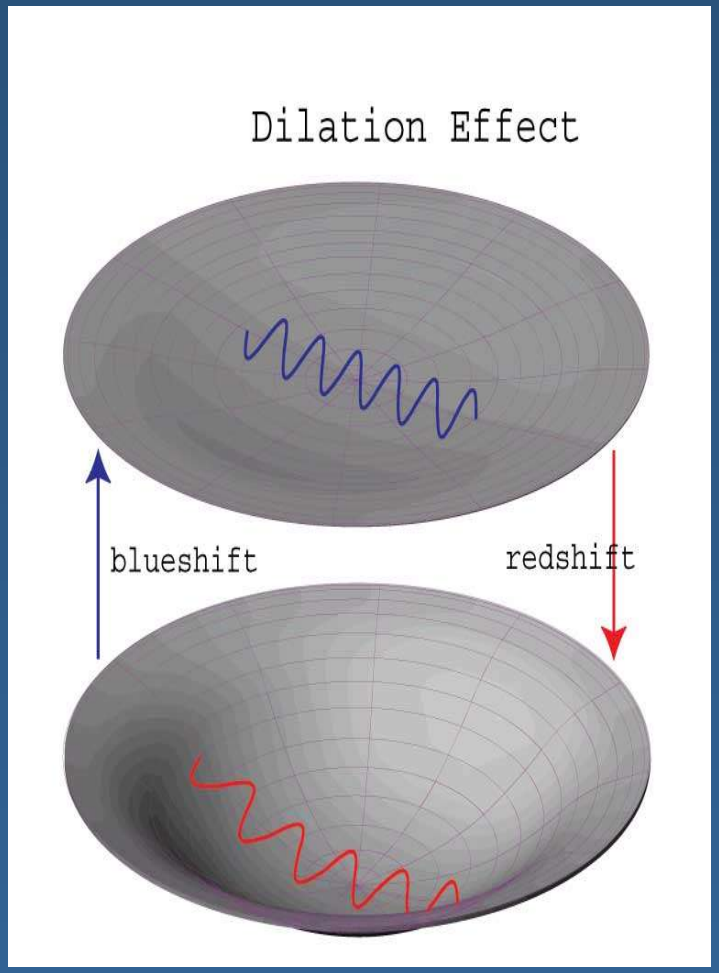
- DE perturbations should always be included in the CMB calculation
- Sensitivity to small curvature

ISW-galaxy Correlation

ISW-effect:



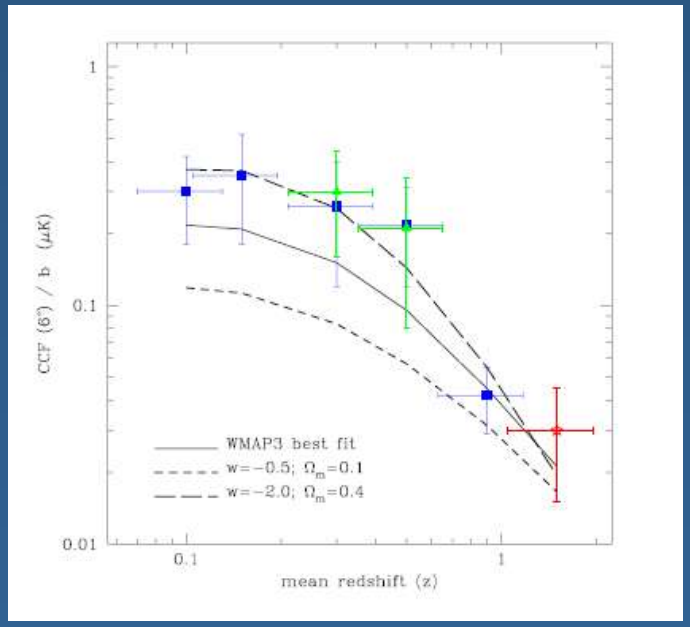
(Gaztanaga et al. 2003)



Constraints from ISW-galaxy

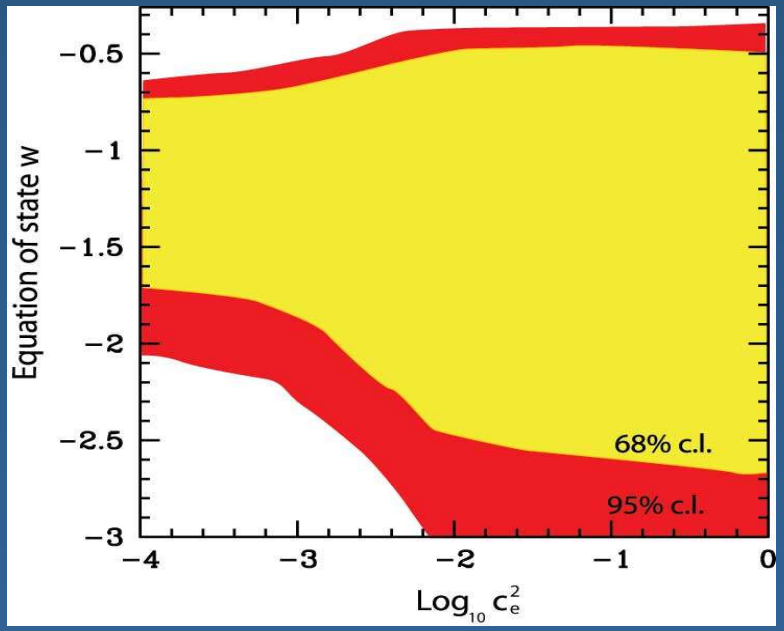
CMB-LSS correlation:

- Several Detections



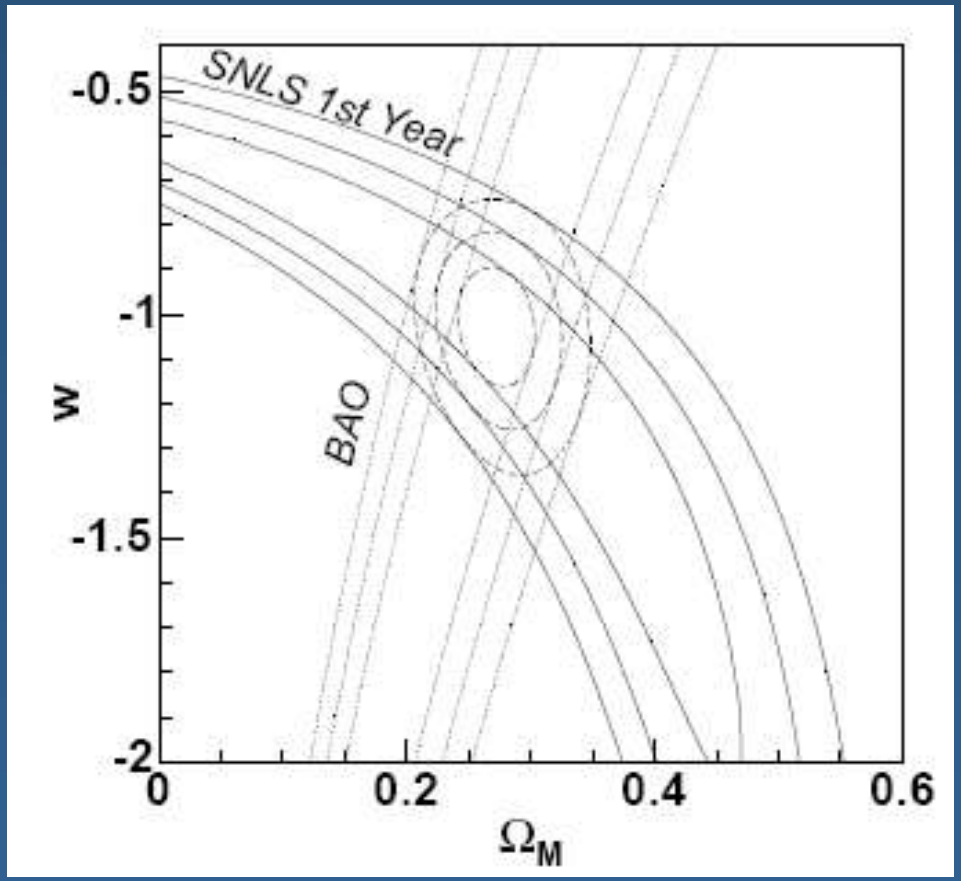
(Giannantonio et al. 2006)

- Correlated with angular distribution of structures
- Reshift dependent amplitude
- No constraints on $w\text{-}c^2_s$



(Corasaniti et al. 2005)

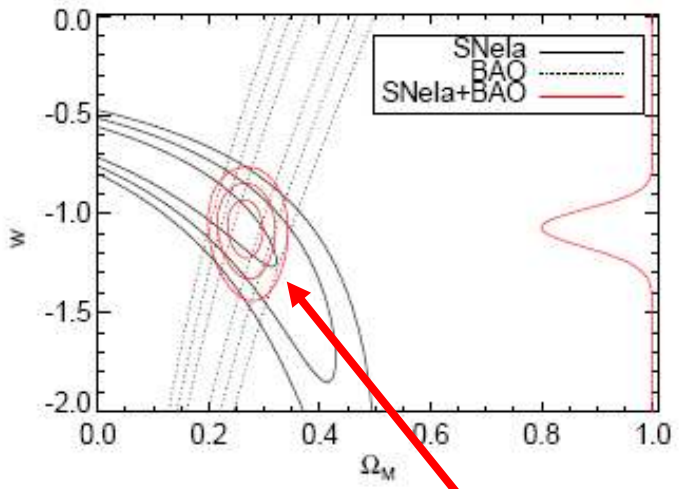
Limits from SN Ia



(Astier et al. 2006)

- Observations from several independent groups: HST, SNLS, ESSENCE, and many others over the next few years
- Luminosity distance has degeneracy in w - Ω_m orthogonal to the BAO
- BAO has a fixed value of Ω_m (and w=-1) built in (z-space to real-space conversion)

Reducing Systematics



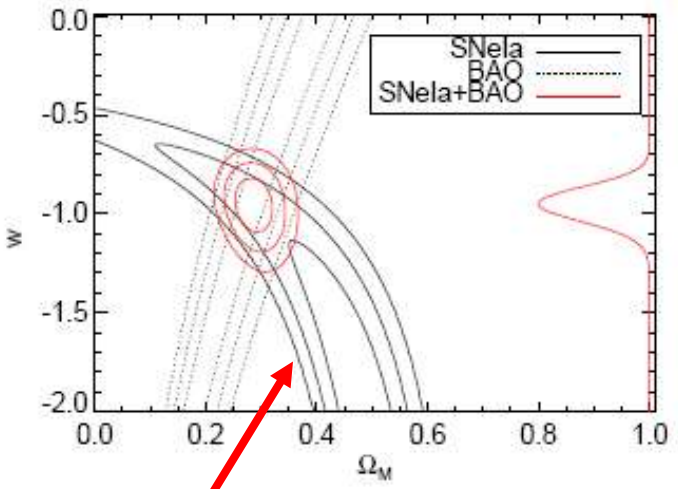


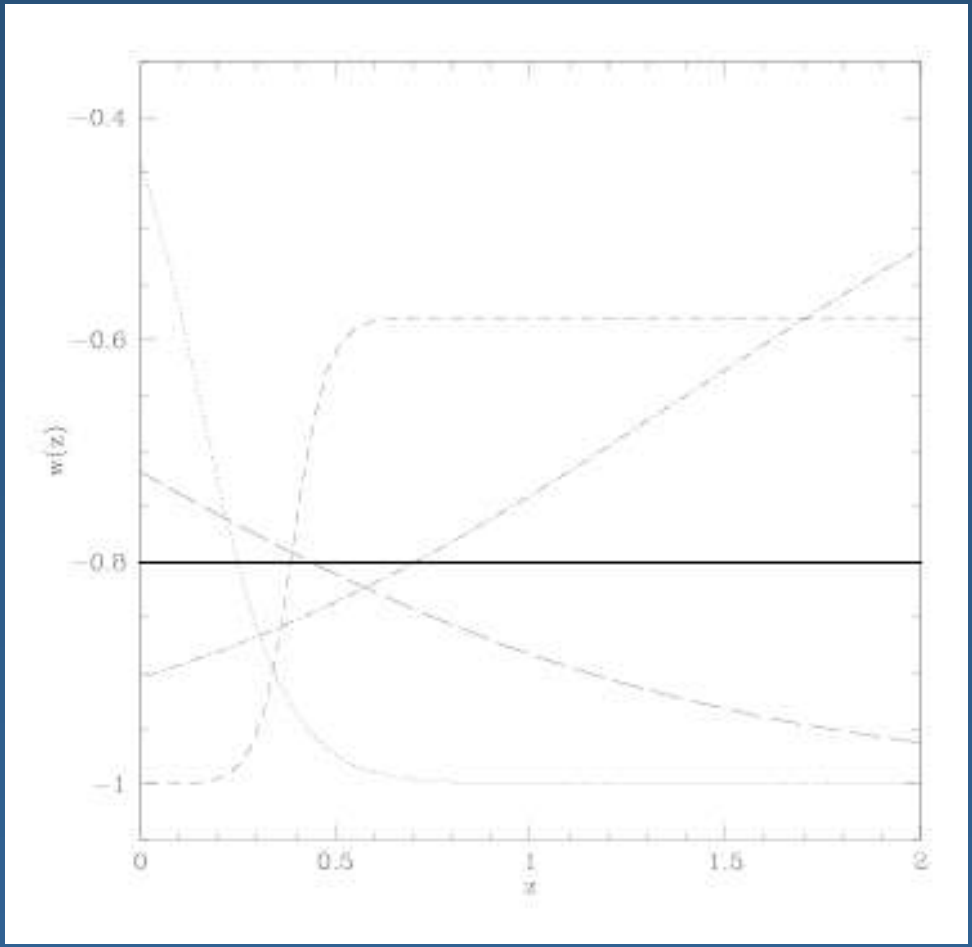
Fig. 11.— The Ω_M-w contours from the SNLS + ESSENCE + nearby sample for MLCS2k2 with "glosz" A_V prior and for the SALT fitter. The baryon acoustic oscillation (BAO) constraints are from Eisenstein et al. (2005).

(Wood-Vasey et al. 2007)

Warning: the structure of the posterior seems sensitive to the data reduction methods

What about w(z)?

- w can be thought as <w(z)>
- w is therefore not very indicative of dark energy dynamics
- a given value of w, even close to –1, corresponds to many dynamical behaviors



(Pogosian 2004)

How to test w(z)?

Standard Practice: Taylor Expansion **Danger**

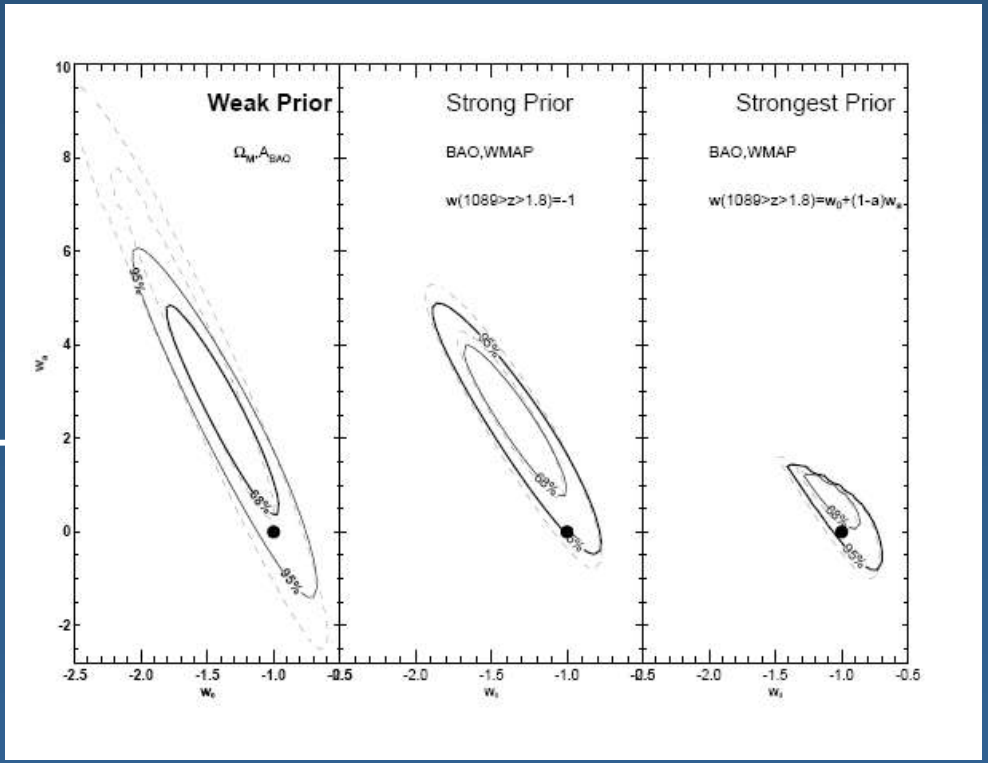
$$w = w_0 + w_1 z$$

$$w = w_0 + w_1 z/(1+z)$$

$$w = w_0 + w_1 \ln(1+z)$$

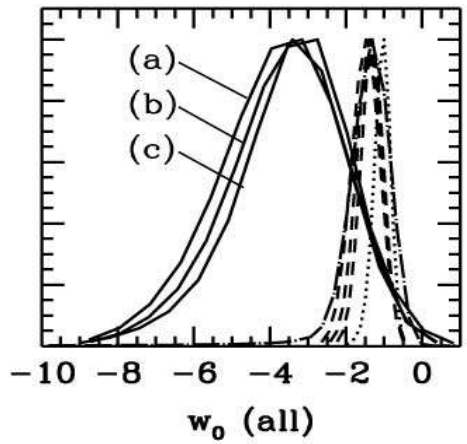
- $w_0 = -1.31 \pm 0.28$
- $w_1 = -1.48 \pm 0.90$

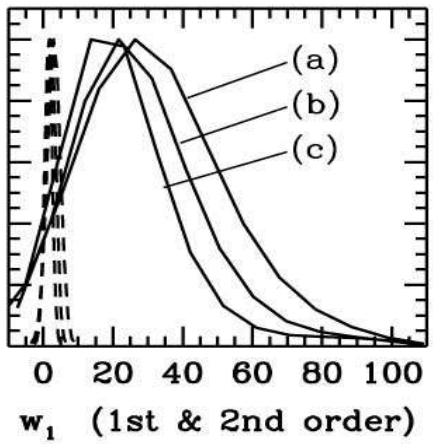
First order term is O(1)!!

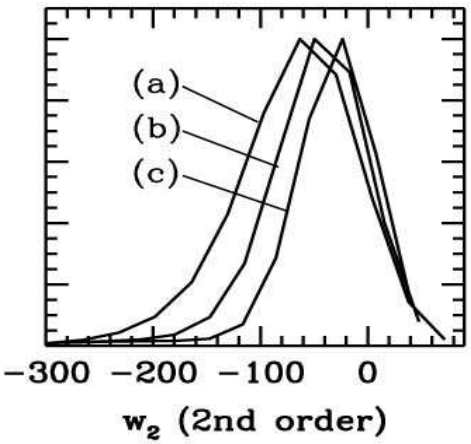


(Riess et al. 2006)

Pitfall of simple Taylor expansion



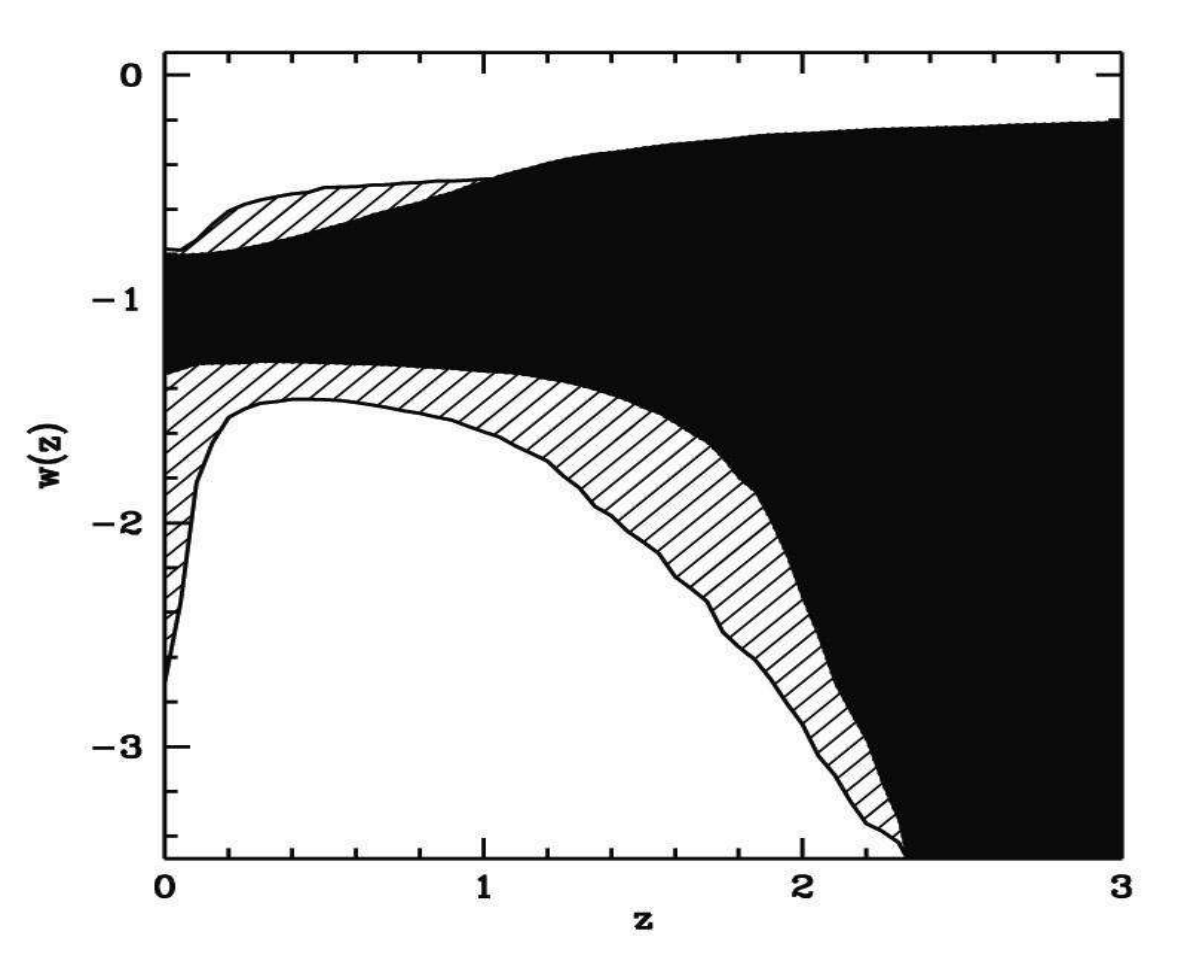




(Bassett, Corasaniti & Kunz 2004)

- Higher Order Cancellations
- The series does not converge
- Expansion cannot be tested against CMB, LSS since $z >> 1$

Constraints from model parametrized w(z)



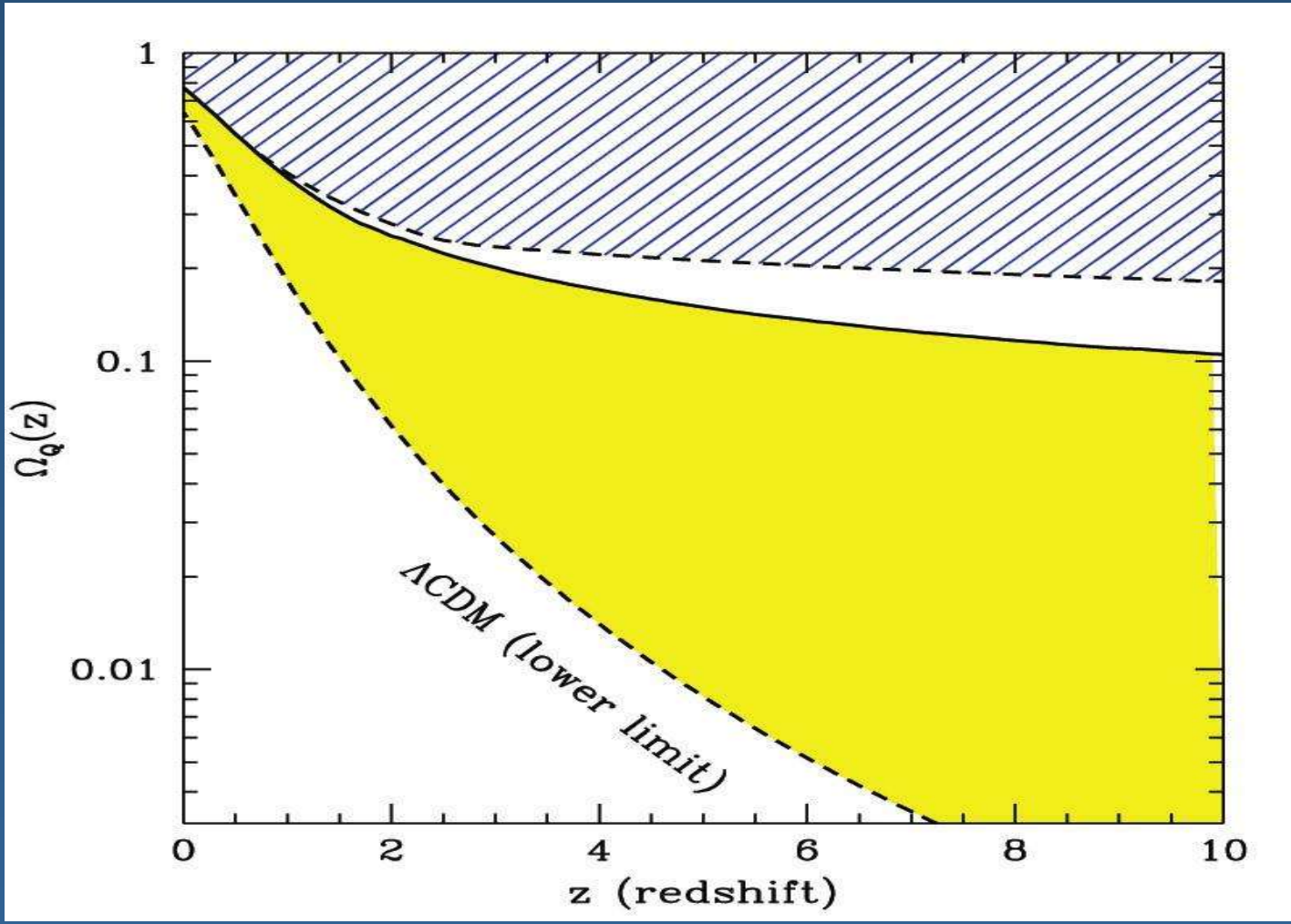
(Corasaniti et al. 2004)

- Convergent parameterized w(z) formula accounting for a large class of proposed DE models

CMB & SN Ia:

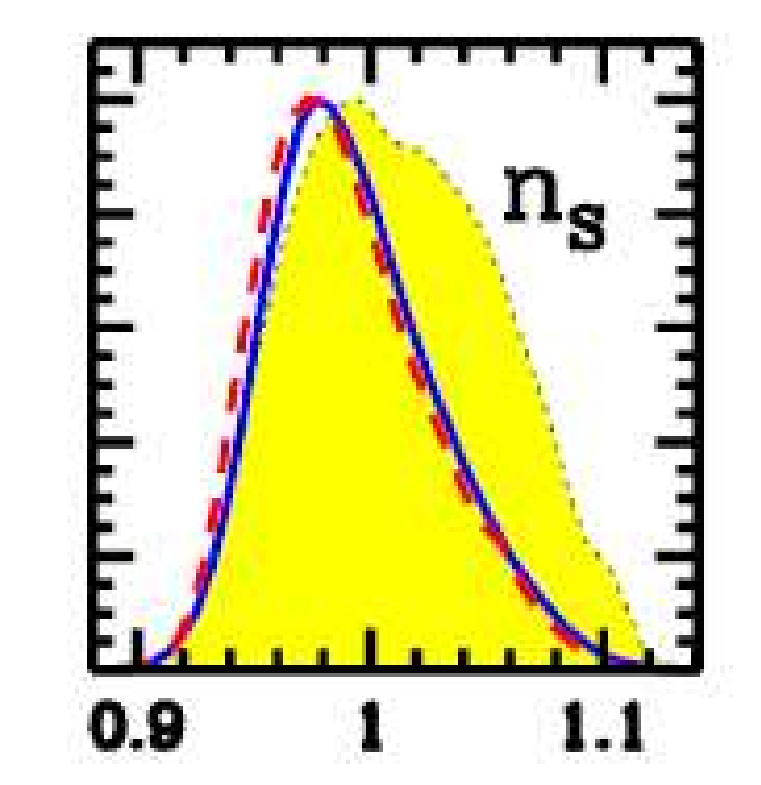
- $-1.5 < w_0 < -0.8$
- $w(z>1) < -0.1$
- $\Omega_{DE}(z>>1) < 0.1$

Constraints on $\Omega_{DE}(z)$



(Corasaniti et al. 2004)

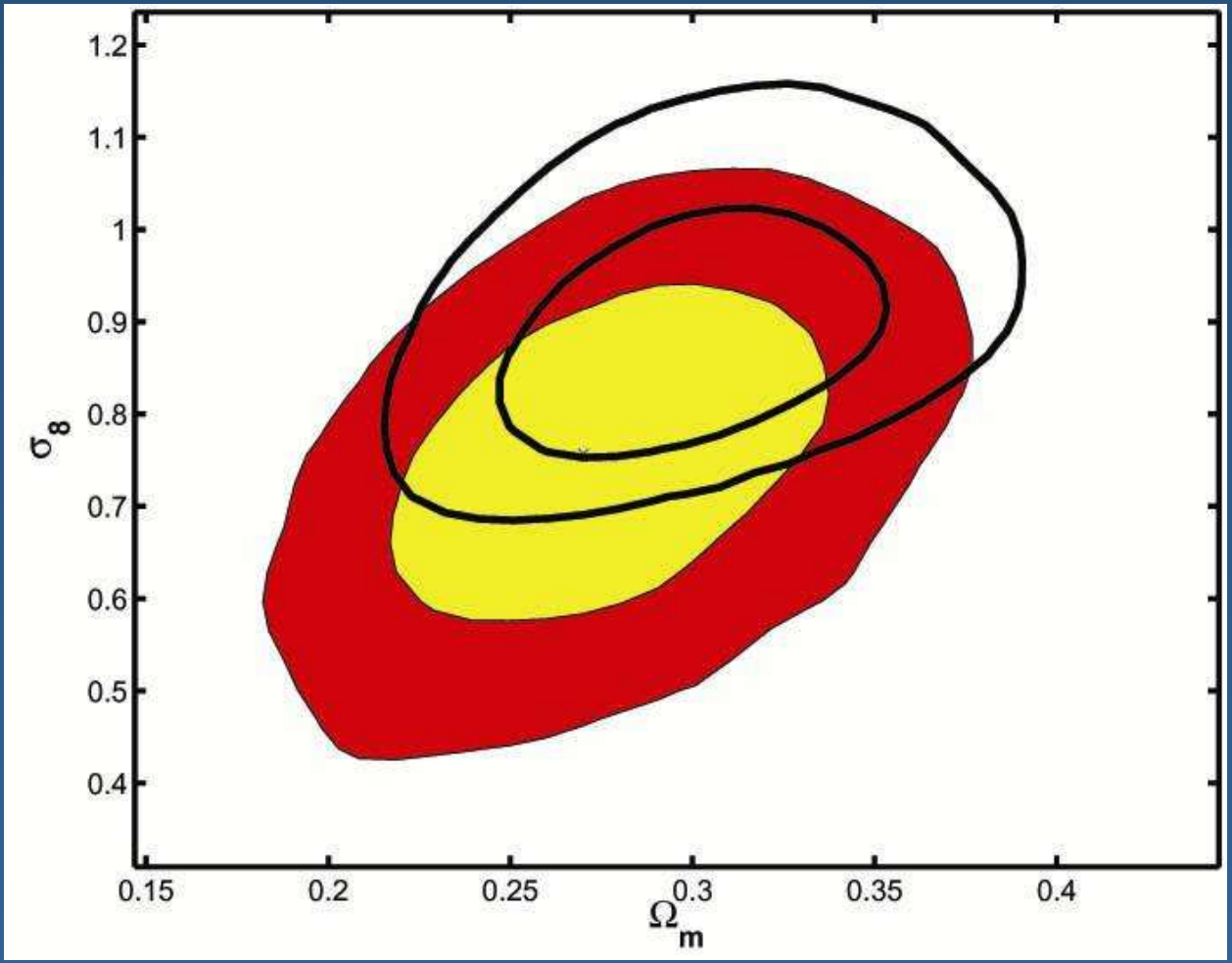
Consequence for Inflationary Parameters



(Corasaniti et al. 2004)

- Inflationary Parameters are degenerate with DE
- Larger values of n_s are allowed
- The degeneracy is stronger if running allowed

Testing Dynamics with σ_8



(Kunz et al. 2004)

List of Experiments

Ongoing or in phase of completion:

- SNLS, ESSENCE, SDSS-II, NSF, KAIT, CSP, QUEST, HST, PanSTARRS-1 (SNIa)
- SPT, ACT, XCS, RCS2, KIDS2, DEEP2 (Cluster)

Proposed (BAO, WL, CL, SNIa):

(incomplete)

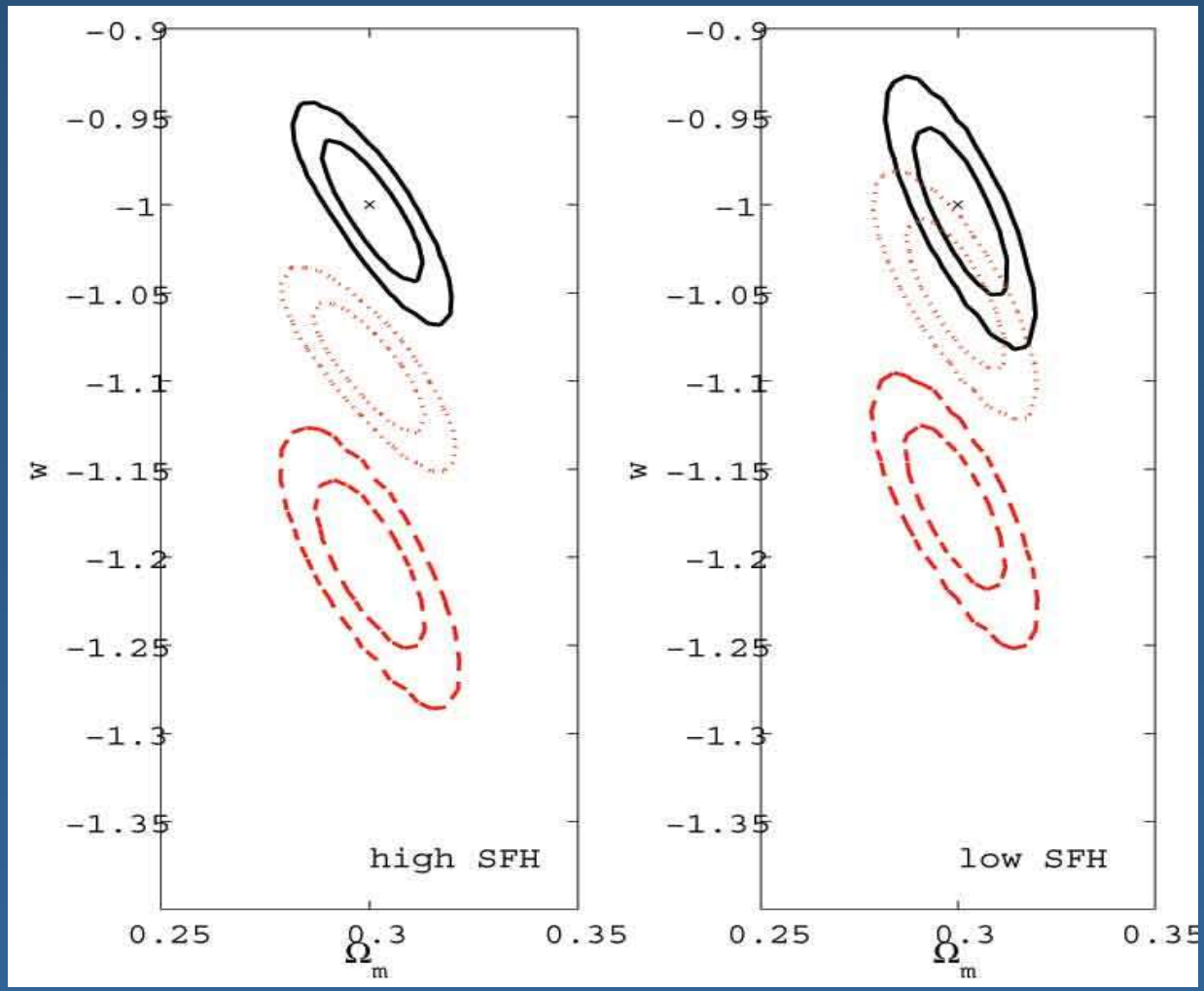
- DES, WFMOS, HETDEX, ALPACA, PanSTARRS-2, ODI, LSST (Ground); JEDI, DESTINY, DUNE, SNAP (Satellite)

Challenges:

- Control of instrumental systematics
- Lots of Astrophysics to be understandood

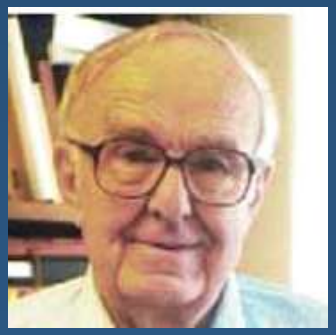
Example of systematics in SN: IGM dust

- **If dust in the IGM it would dim SN Ia**
- **Current limits $\Omega_{dust} < 10^{-6}$**
- **MC SNAP data simulations for several IGM dust models**
- **If we do not account for it, we could be in trouble**



(Corasaniti 2006)

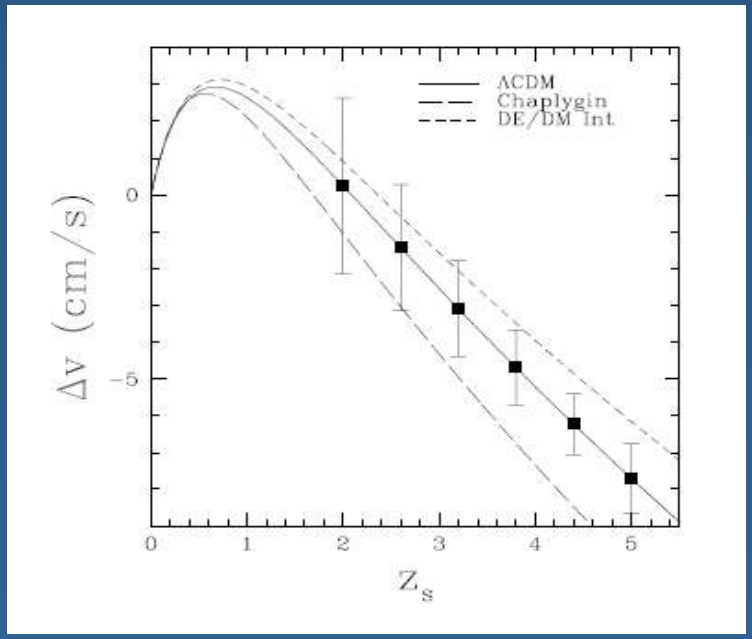
For the future generations: S-L Test



- Allan Sandage (1962) explored the possibility of directly measuring the time variation of redshifts of distance sources observed at different times

Impossible with technology available at the time

- **Loeb (1998) suggested it could be possible with high resolution spectroscopy developed for extra-solar planet search to Lyman-alpha absorption lines of distance QSO**
- **CODEX spectrograph at ELT by observing few hundred QSO over 10 yrs time can detect the expansion with S/N ~3000 (Pasquini et al 2007)**
- **Can be used to test DE at 2<z<5**



(Corasaniti et al 2007)

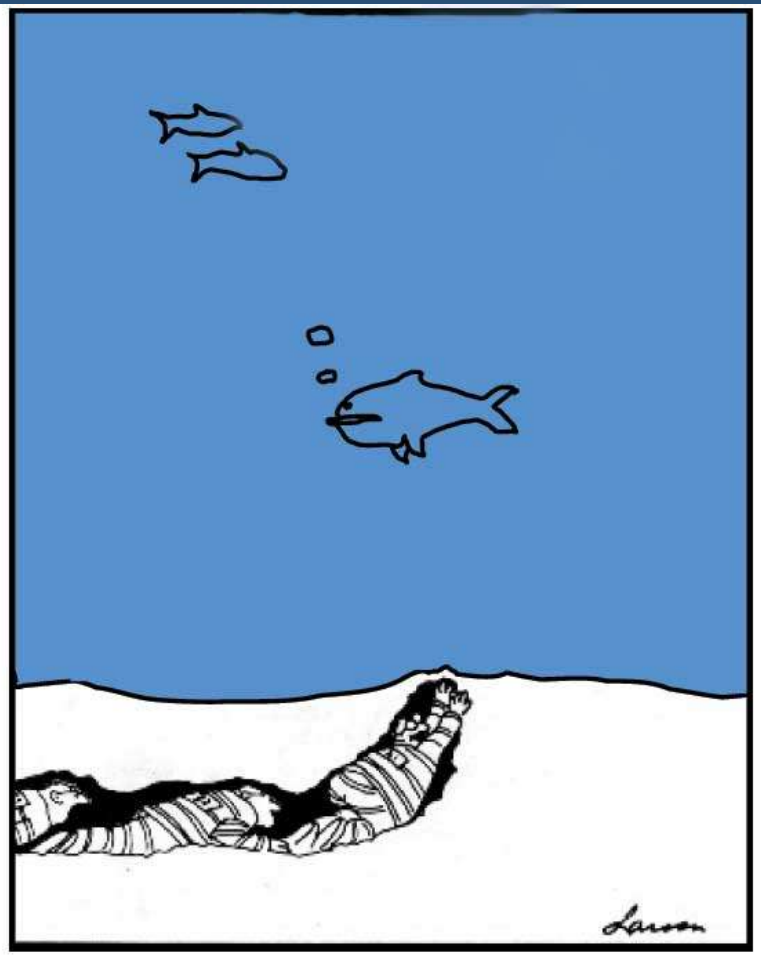
Conclusions

- Current observations are not accurate enough to provide deeper insight on dark energy

- Inflationary model parameter uncertainties are larger if the LCDM assumption is relaxed

- The future looks promising as several astrophysical experiments will provide several cosmological tests

- Systematics need to be kept under control for a robust dark energy inference



We're almost free, I just felt the first drops of rain