Probing Dark Energy with Varying Fundamental Parameters

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Three important assumptions

1. Dark energy is the result of a slowly rolling scalar field.

2. The scalar field is coupled to electromagnetism.

3. There is a cosmological evolution of α.

Coupling quintessence to electromagnetism

1. The action

$$S = -\frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\,R + \int d^4x\sqrt{-g}\,(\mathcal{L}_\phi + \mathcal{L}_M + \mathcal{L}_{\phi F})$$

2. The coupling

$$\mathcal{L}_{\phi F} = -\frac{1}{4}B_F(\phi)F_{\mu\nu}F^{\mu\nu}$$

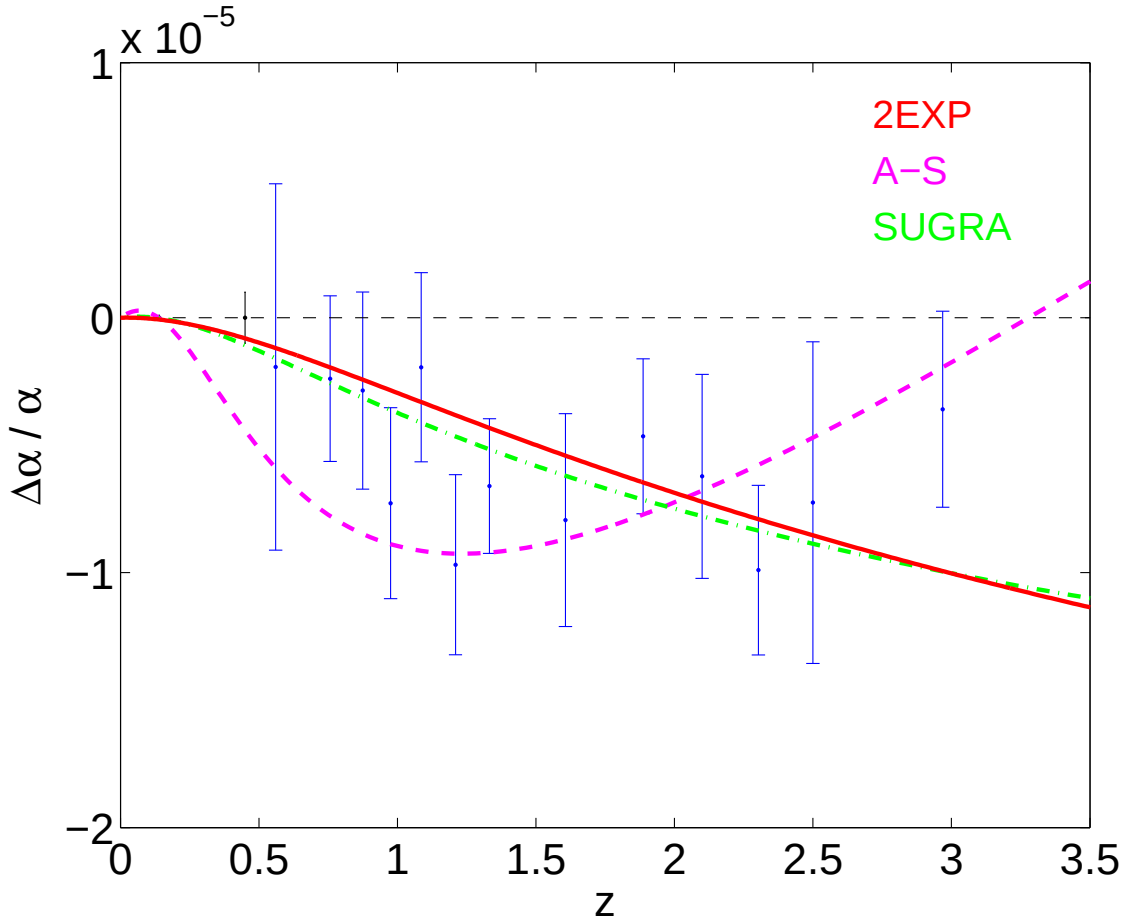
3. Gauge kinetic function

$$B_F(\phi) = 1 - \zeta\kappa(\phi - \phi_0)$$

4. Variation in α

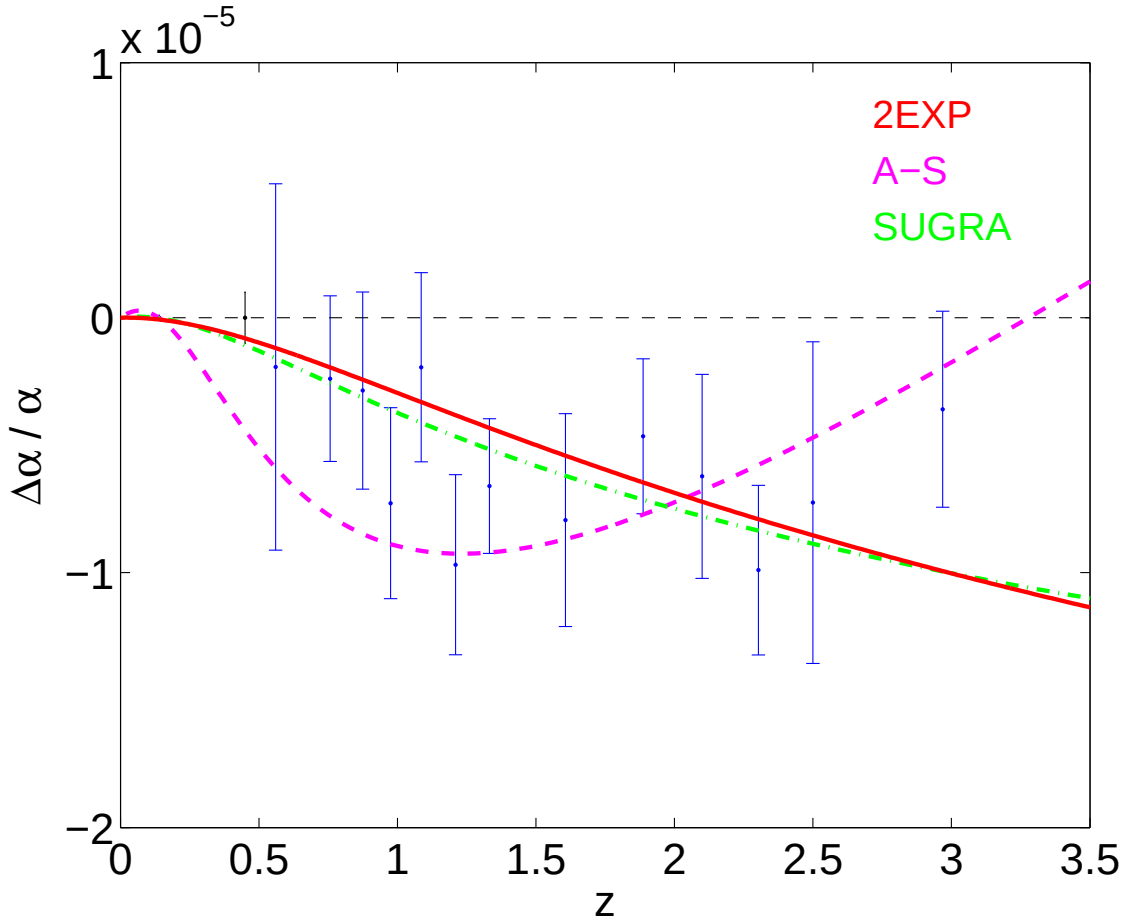
$$\alpha = \frac{\alpha_0}{B_F(\phi)} \qquad \Rightarrow \qquad \frac{\Delta\alpha}{\alpha} \equiv \frac{\alpha - \alpha_0}{\alpha_0} = \zeta\kappa(\phi - \phi_0)$$

$\Delta\alpha/\alpha$ for some quintessence models



Anchordoqui, Goldberg (2003)
Copeland, NJN, Pospelov (2003)
Bento, Felipe (2009)

$\Delta\alpha/\alpha$ for some quintessence models



Rosenband bound from atomic clocks:

$$\dot{\alpha}/\alpha = (-1.6 \pm 2.3) \times 10^{-17}\mathrm{yr}^{-1}$$

Reconstruction procedure

Continuity and Friedmann equations

$$\dot{\rho}_\phi = -3H\dot{\phi}^2\,, \qquad 3H^2 = \kappa^2(\rho_m + \rho_\phi)$$

Rewrite as

$$\sigma' = -(\kappa\phi')^2(\sigma + a^{-3})$$

where $\sigma = \rho_\phi/\rho_{m0}\,, \qquad ' = d/d\ln a$

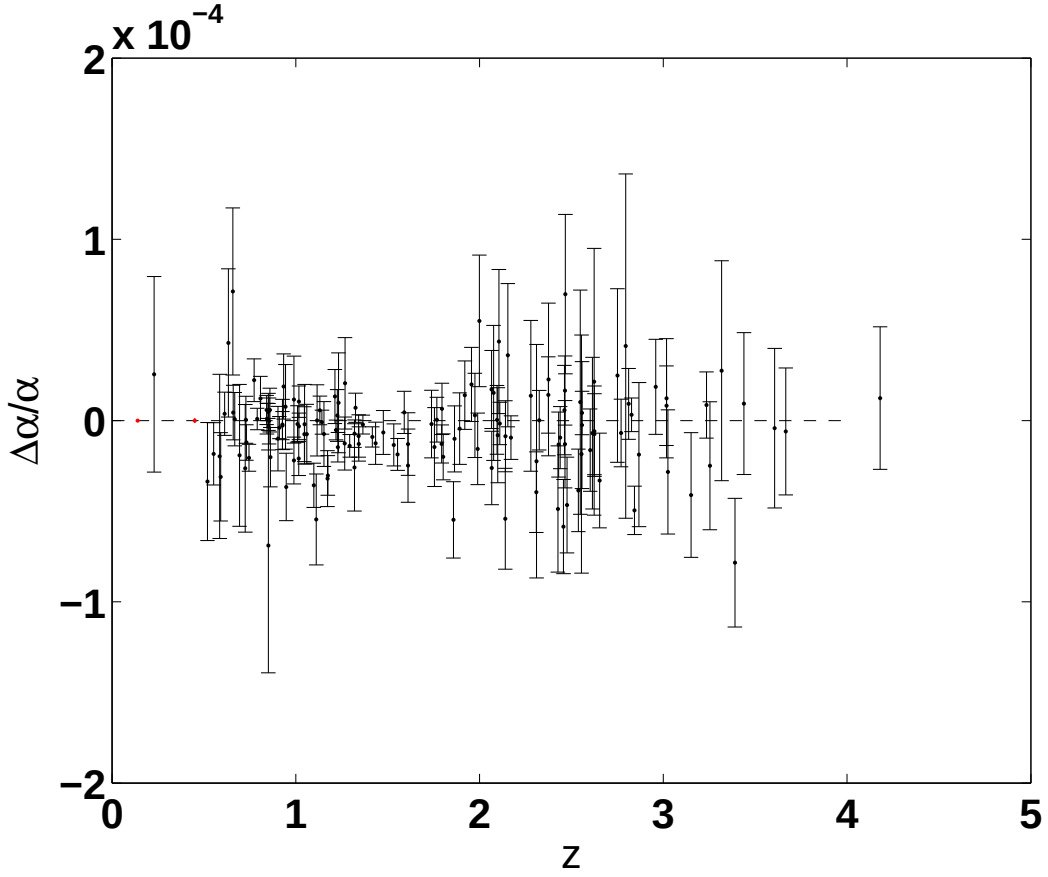
Equation of state parameter

$$\begin{aligned} w_\phi &\equiv p_\phi/\rho_\phi = -1 + \frac{\dot{\phi}^2}{\rho_\phi} \\ &= -1 + \frac{(\kappa\phi')^2}{3}\left(1 + \frac{1}{\sigma a^3}\right) \end{aligned}$$

where using $\Delta\alpha/\alpha = \zeta\kappa(\phi - \phi_0)$

$$\kappa\phi' = \frac{1}{\zeta}\left(\frac{\Delta\alpha}{\alpha}\right)'$$

Current Keck data



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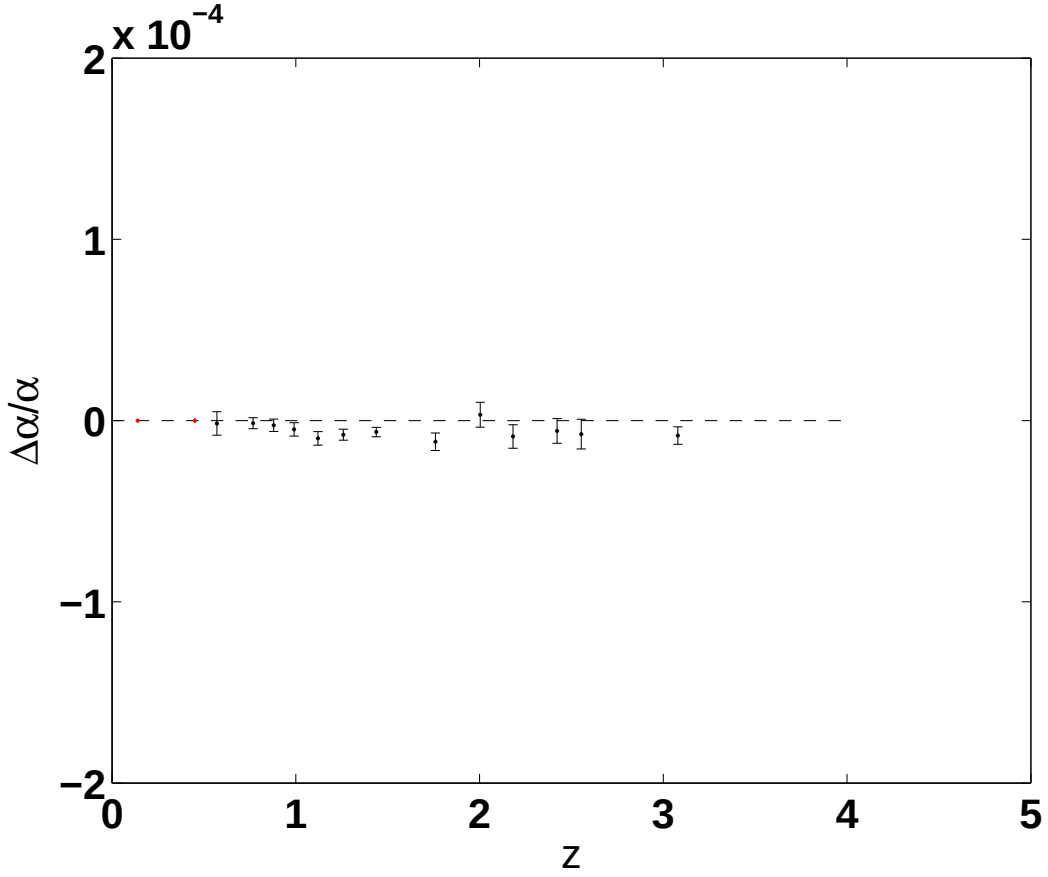

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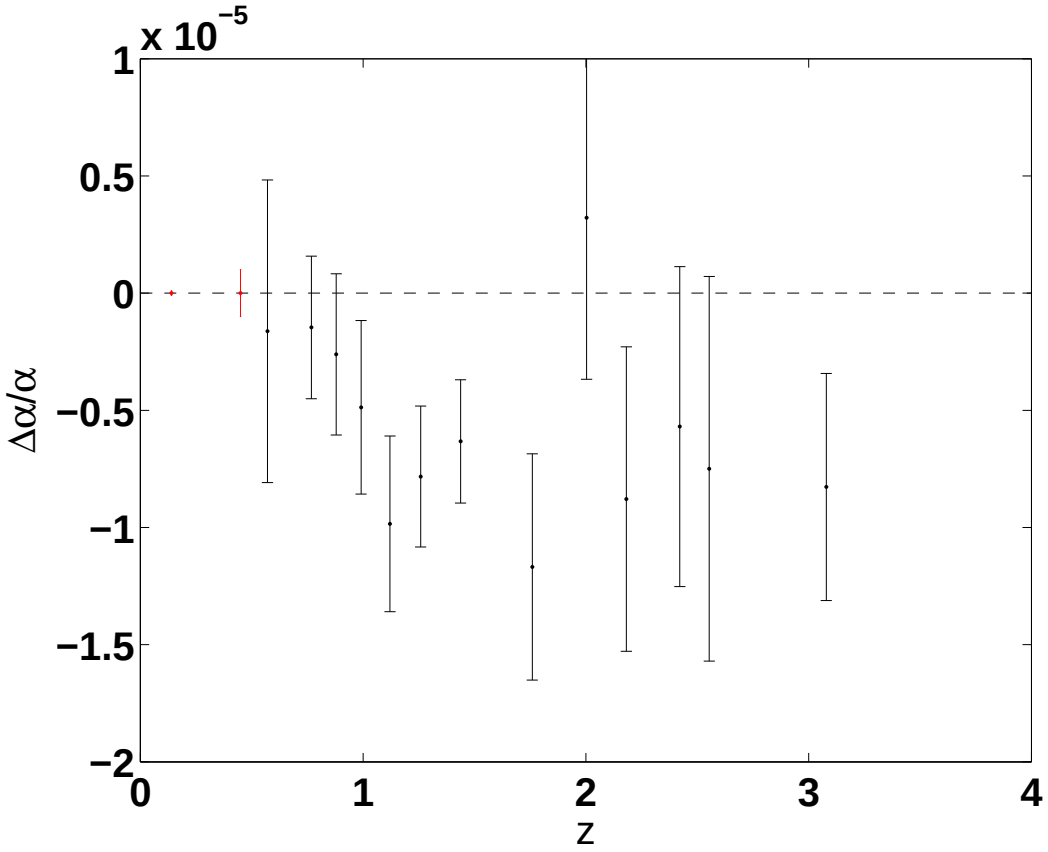

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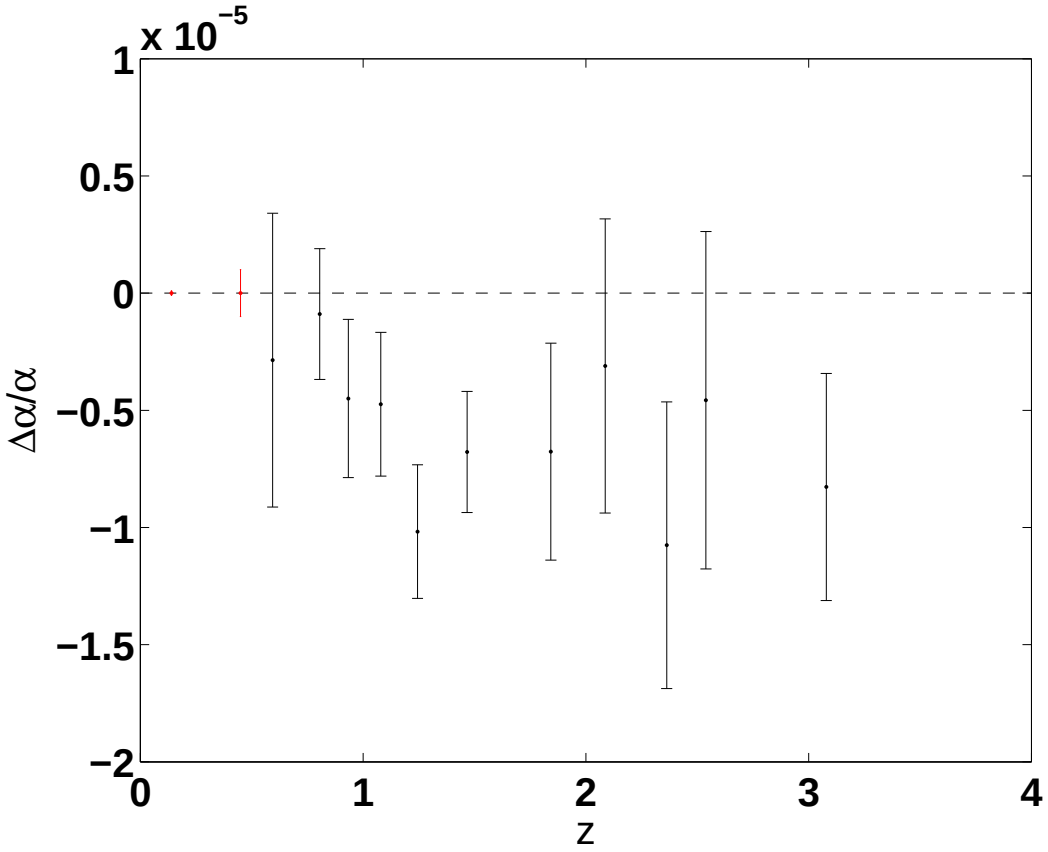

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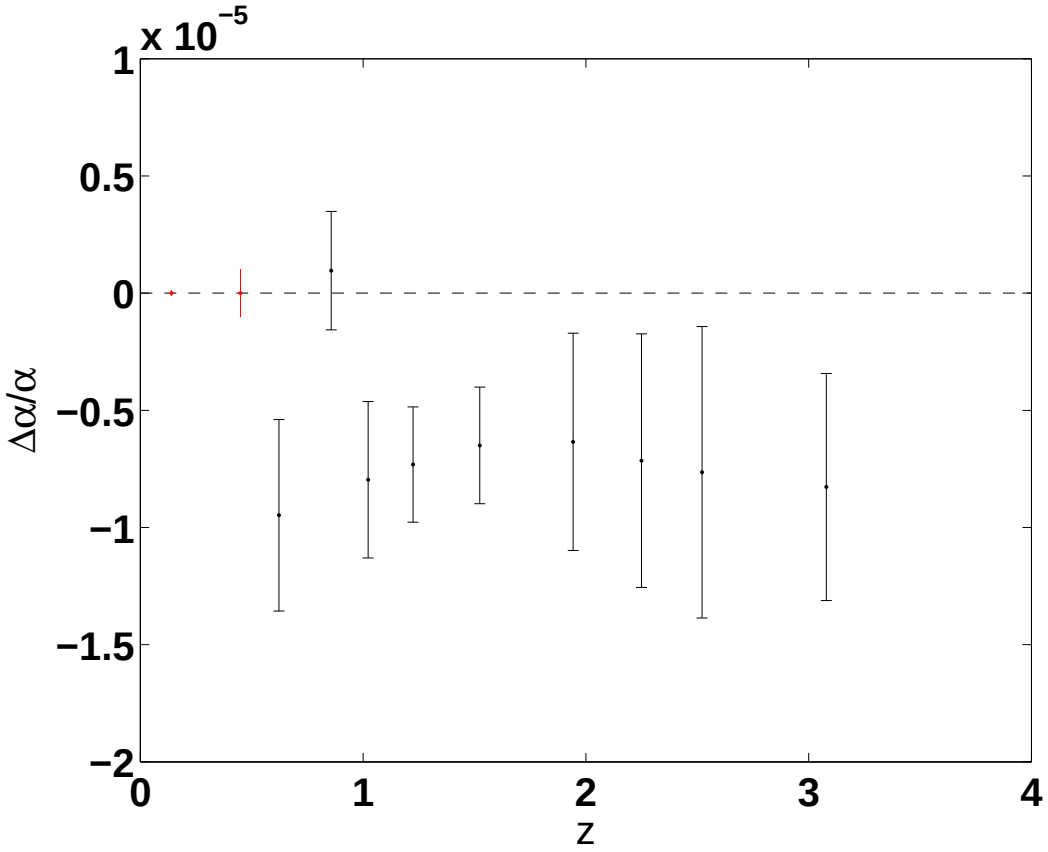

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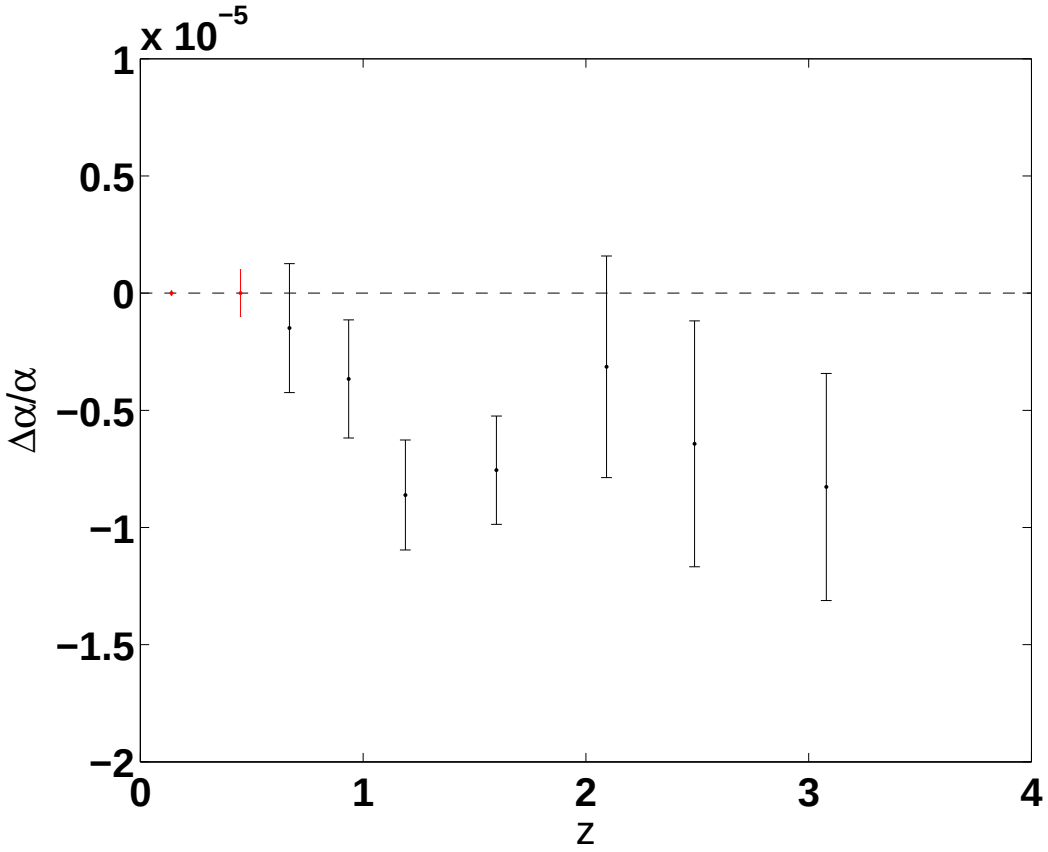

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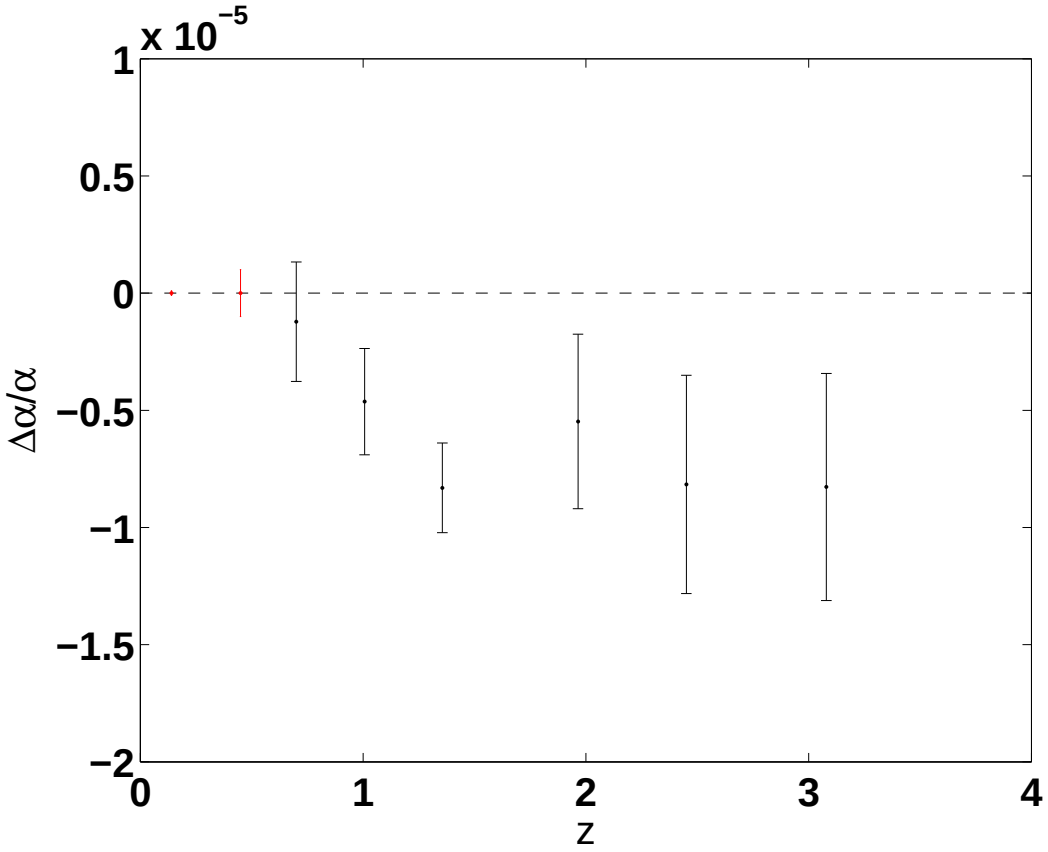
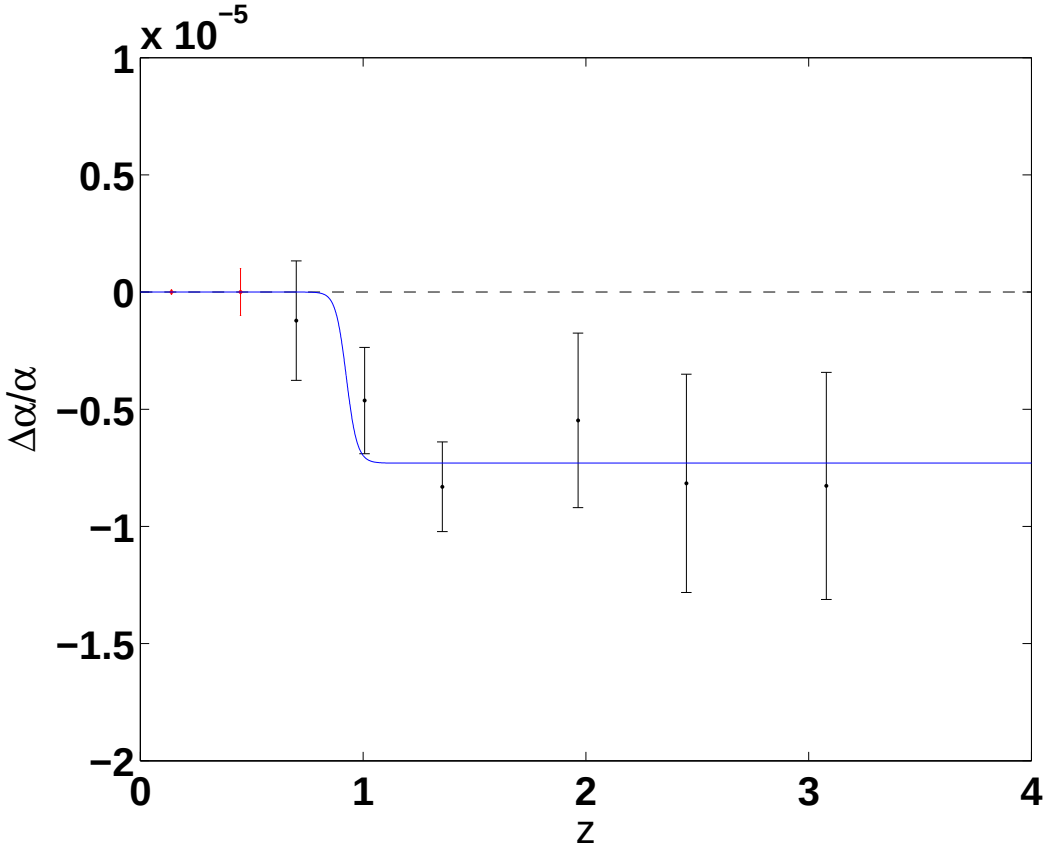
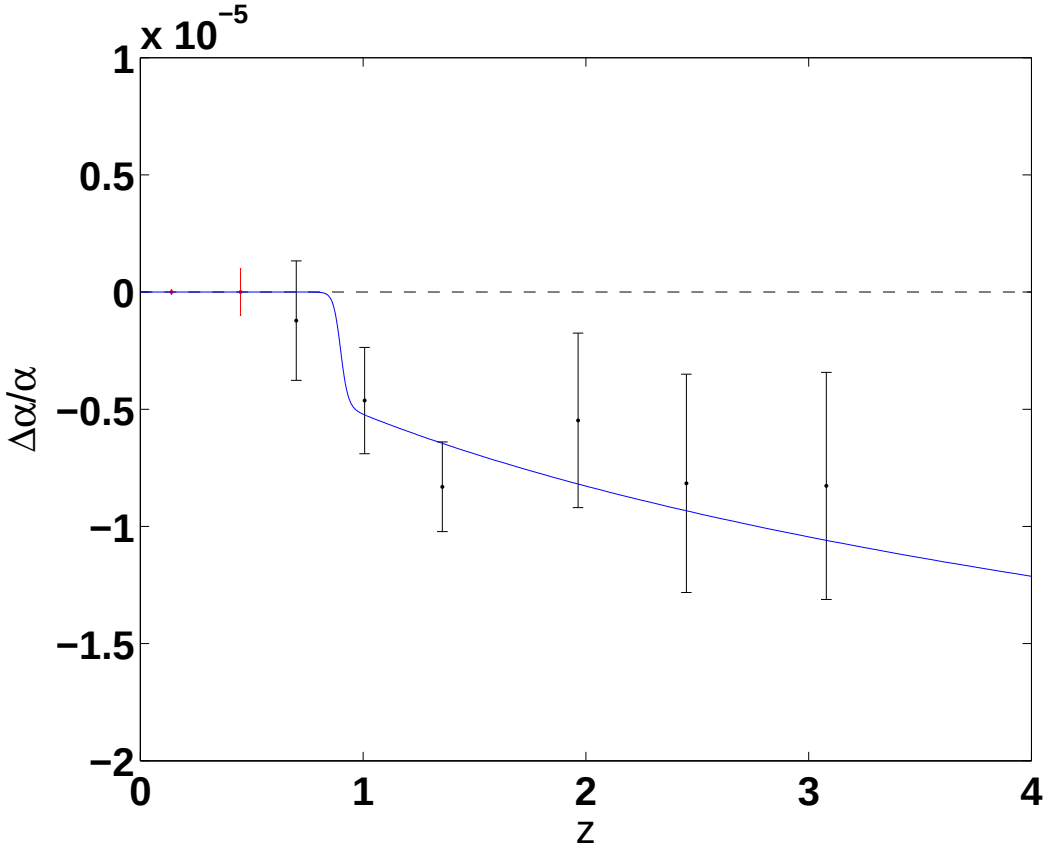


1st parametrization



$$\phi - \phi_0 = c\left[\tanh\left(\frac{N - N_t}{\Delta}\right) - \tanh\left(-\frac{N_t}{\Delta}\right)\right], \qquad \frac{\Delta\alpha}{\alpha} = \zeta(\phi - \phi_0)$$

2nd parametrization



$$\phi - \phi_0 = c\,\frac{N}{N_t}\left[\tanh\left(\frac{N-N_t}{\Delta}\right) - \tanh\left(-\frac{N_t}{\Delta}\right)\right], \qquad \frac{\Delta\alpha}{\alpha} = \zeta(\phi - \phi_0)$$

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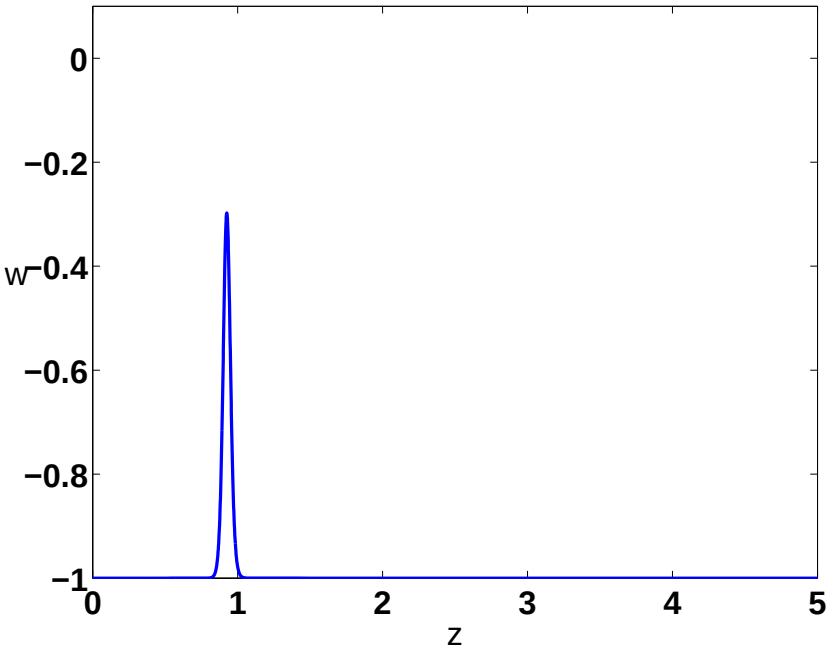

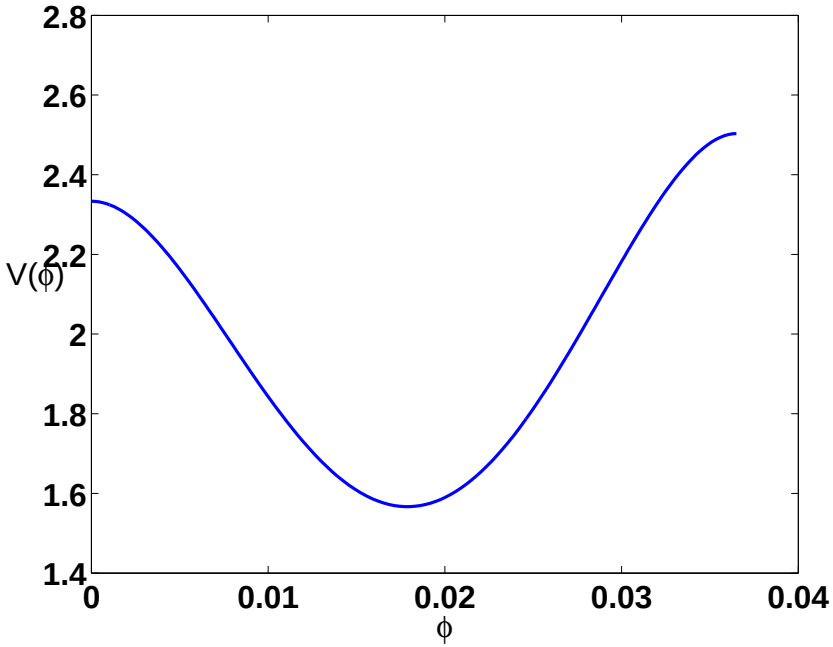

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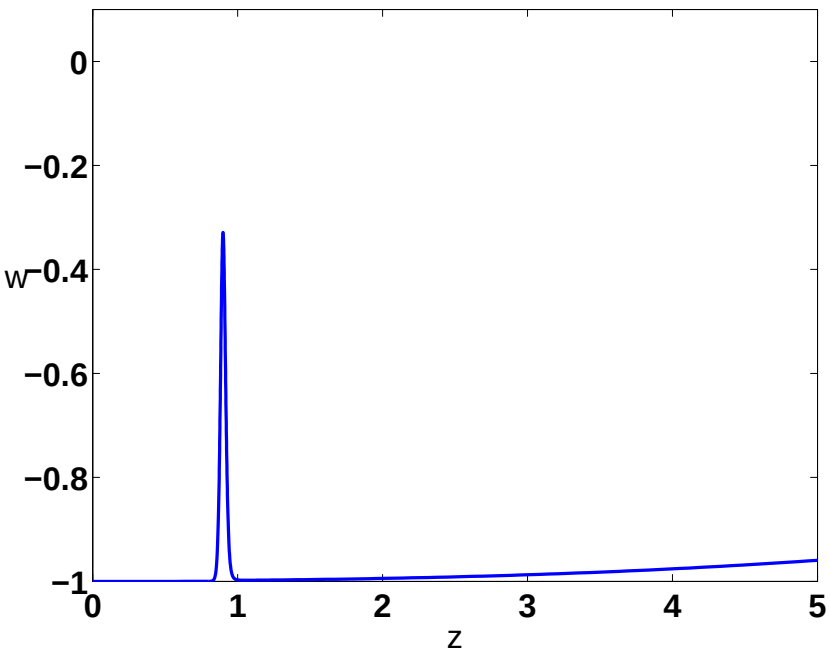
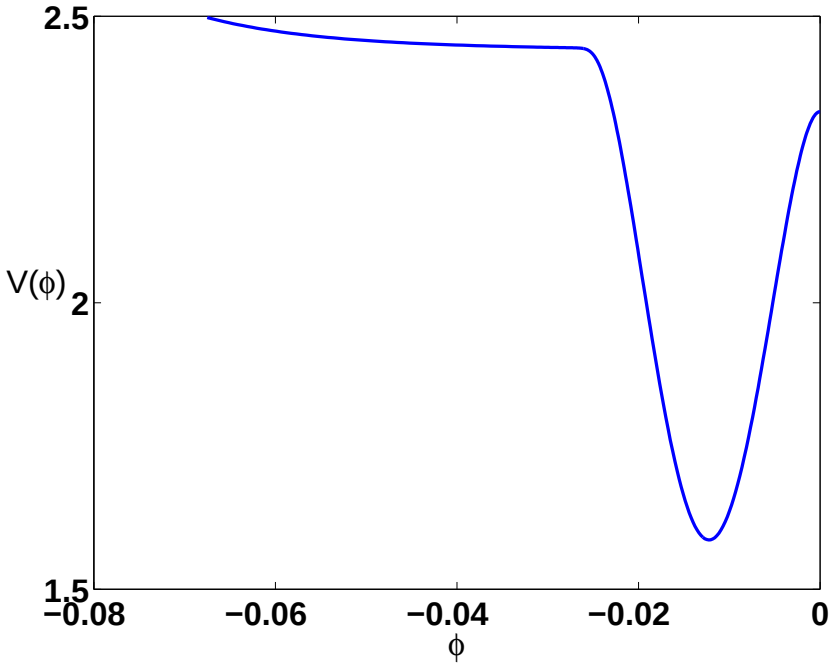
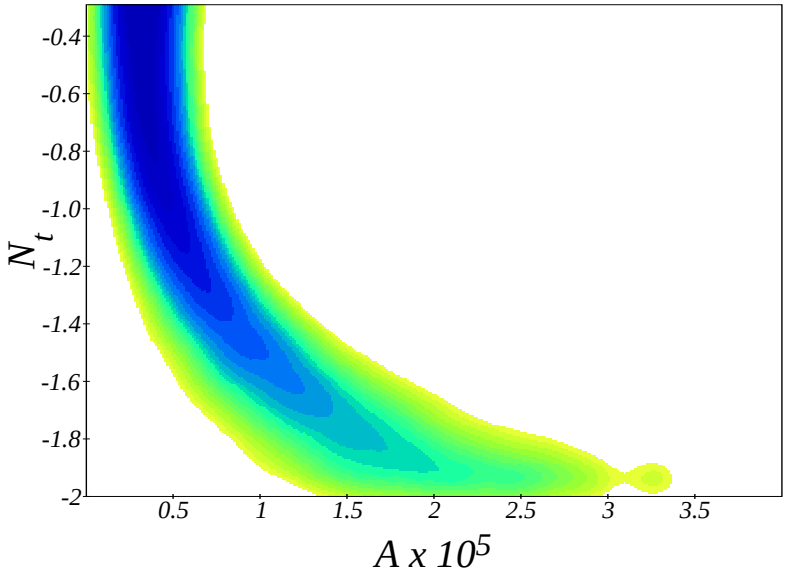




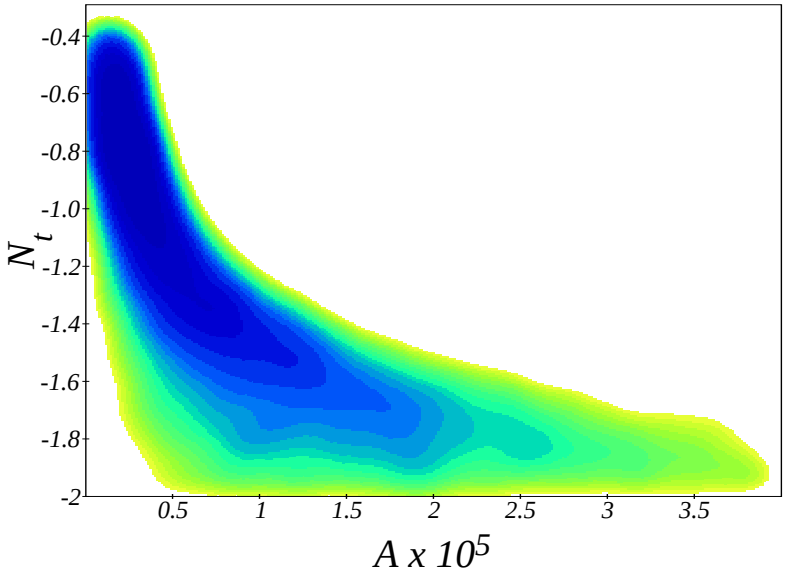
$$\phi - \phi_0 = c\,\frac{N}{N_t}\left[\tanh\left(\frac{N-N_t}{\Delta}\right) - \tanh\left(-\frac{N_t}{\Delta}\right)\right], \qquad \frac{\Delta\alpha}{\alpha} = \zeta(\phi-\phi_0)$$

Preliminary constraints

Only QSO

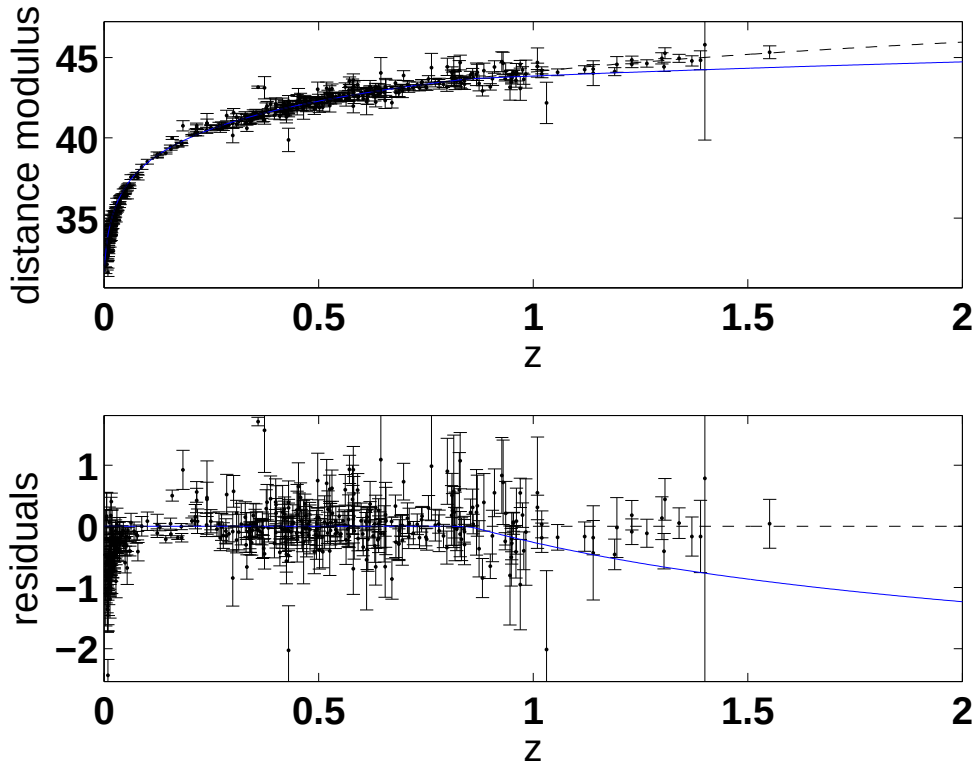


QSO + Oklo +
Meteo. + Atom. clocks



QSO = Murphy + Rev. Chand + Quast + Levshakov

In combination with SnIa

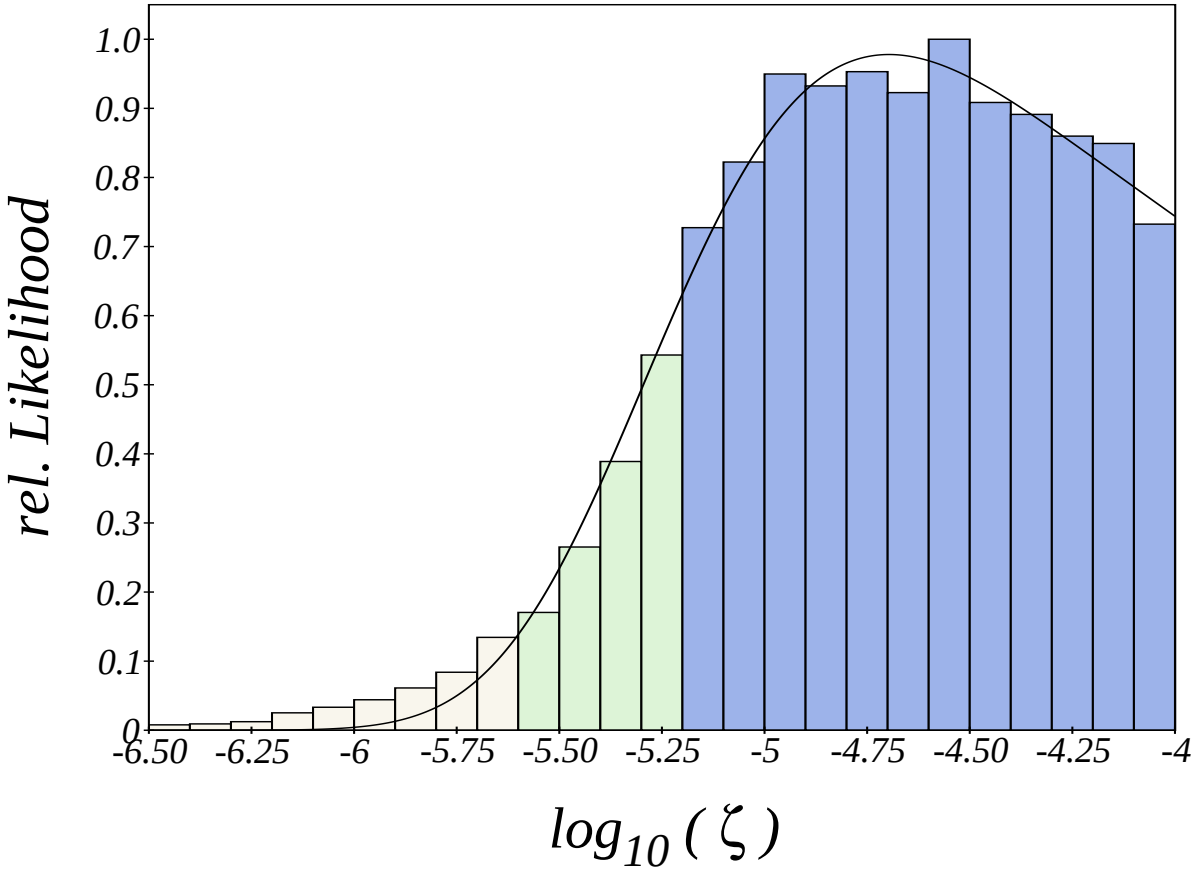


$$\frac{\Delta\alpha}{\alpha} = \zeta\kappa(\phi - \phi_0)$$

- $c\,\zeta$ is determined by $\Delta\alpha/\alpha$.
- Cosmology constrains c and therefore ζ .
- ζ large $\Rightarrow$ $w(z) \approx -1$.
- ζ too small $\Rightarrow$ incompatible with observations.

Current constraints on ζ

... + Sne Union data



Equivalence principle tests $\Rightarrow$ $|\zeta| < 10^{-3}$ (Olive and Pospelov, 2002)

Conclusions

- Qualitative shape of $w(z)$ can be reconstructed by observing cosmological variations of fundamental parameters;
- Reconstruction up to higher redshifts ($z \gtrsim 4$) than the ones probed using supernovas ($z < 1.7$);
- Cheaper than satellite based observations.
- Test other models: Coupling with matter, tachyon dark energy, ...
- Make forecasts for ESPRESSO and CODEX spectrographs (mock data, Principal Component Analysis (with Amendola and Pedrosa)).

Conclusions

ESPRESSO
spectrograph for VLT:
200 objects in α
$\sigma = 5 \times 10^{-7}$

CODEX
spectrograph for E-ELT:
500 objects in α
$\sigma = 10^{-8}$