COSMO-15 - Warsaw

MAPPING DARK ENERGY WITH FUNDAMENTAL COUPLINGS

Ana Catarina Leite

Carlos Martins

Relevant references:

- **Amendola et al. Phys. Rev. D 86, 063515 (2012)**
- **Leite et al. Phys. Rev. D 90, 063519 (2014);**
- **Leite and Martins, Phys. Rev. D 91, 103519 (2015);**

Centro de Astrofísica da Universidade do Porto

FUNDAÇÃO CALOUSTE GULBENKIAN

Echelle SPectrograph for Rocky Exoplanet- and Stable Spectroscopic Observations

- 380-700nm spectral coverage
- High resolution and stability (Laser Frequency Comb)
- 80% Rocky Planets, 10% Varying Constants, 10% to be decided: ToO + Exquisite Science

α measurements from absortion systems in Quasar Spectra

Priority Sistems:

- Uncertainty lower than 10ppm
- Measurements with anchors and sensitivity transitions (ΔQ)
- Brighteness
- Sky position
- Simplicity of the spectra

Formalism

Coupling between the scalar field and the electromagnetism

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

Gauge kinetic function is linear

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

$$\frac{\Delta\alpha}{\alpha} \equiv \frac{\alpha - \alpha_0}{\alpha} = \zeta\, k(\phi - \phi_0)$$

For a flat Friedmann-Lemaître-Robertson-Walker Universe with a canonical scalar field

$$\dot{\phi}^2 = \big(1 + \omega(z)\big)\rho_\phi$$

$$\phi(z) - \phi_0 = \frac{\sqrt{3}}{k} \int_0^z \sqrt{1 + \omega(z)} \left(1 + \frac{\rho_m}{\rho_\phi}\right)^{-1/2} \frac{dz}{1 + z}$$

Previous work

PHYSICAL REVIEW D **86**, 063515 (2012)

Variation of fundamental parameters and dark energy: A principal component approach

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(Received 12 October 2011; revised manuscript received 8 August 2012; published 17 September 2012)

We discuss methods based on principal component analysis to constrain the dark energy equation of state using a combination of Type Ia supernovae at low redshift and spectroscopic measurements of varying fundamental couplings at higher redshifts. We discuss the performance of this method when future better-quality data sets are available, focusing on two forthcoming European southern observatory (ESO) spectrographs—Echelle spectrograph for rocky exoplanet and stable spectroscopic observations (ESPRESSO) for the very large telescope (VLT) and Cosmic dynamics explorer (CODEX) for the European extremely large telescope (E-ELT)—which include these measurements as a key part of their science cases. These can realize the prospect of a detailed characterization of dark energy properties almost all the way up to redshift 4.

DOI: 10.1103/PhysRevD.86.063515 PACS numbers: 98.80.−k, 98.80.Jk

PHYSICAL REVIEW D **90**, 063519 (2014)

Fundamental cosmology from precision spectroscopy: Varying couplings

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[1]*Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, 4150-007 Porto, Portugal*
[2]*Centro de Astrofísica, Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal*
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(Received 2 July 2014; published 22 September 2014)

The observational evidence for the acceleration of the Universe demonstrates that canonical theories of cosmology and particle physics are incomplete, if not incorrect, and that new physics is out there, waiting to be discovered. Forthcoming high-resolution ultrastable spectrographs will play a crucial role in this quest for new physics, by enabling a new generation of precision consistency tests. Here we focus on astrophysical tests of the stability of nature's fundamental couplings, and by using principal component analysis techniques further calibrated by existing VLT data we discuss how the improvements that can be expected with ESPRESSO and ELT-HIRES will impact on fundamental cosmology. In particular we show that a 20 to 30 night program on ELT-HIRES will allow it to play a leading role in fundamental cosmology.

DOI: 10.1103/PhysRevD.90.063519 PACS numbers: 98.80.-k, 98.80.Jk

Principal Component Analysis

- Likelihood function

$$L(\omega_i) = \sqrt{\frac{2\pi}{A}} \exp\left[-\frac{1}{2}\sum_{i,j=1}^{N}(\mu - \mu_F)_i \, D_{ij}{}^{-1}(\mu - \mu_F)_j\right]$$

$$A = \sum_{i,j} C_{i,j}{}^{-1} \qquad D_{ij}{}^{-1} = C_{ij}{}^{-1} - \frac{1}{A}\sum_{k,l=1}^{N} C_{kj}{}^{-1} C_{li}{}^{-1}$$

- Fisher's Matrix

$$F_{kl} = -\left.\frac{\partial^2 \ln L}{\partial \omega_k \partial \omega_l}\right|_{\omega^F}$$

- Dark energy parameterization, ω(z)

$$\omega(z) = \sum_{i=1}^{N} \omega_i \theta_i(z) \longrightarrow \omega(z) = \sum_{i=1}^{N} \alpha_i e_i(z)$$

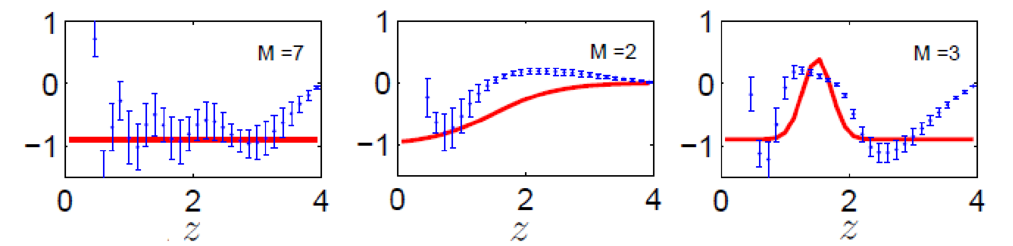
Sample Result

- **Baseline**
  - ESPRESSO: N=30 ; $\sigma_{\Delta\alpha/\alpha}$=6×10^{-7}
  - ELT-HIRES: N=100; $\sigma_{\Delta\alpha/\alpha}$=1×10^{-7}
- **Ideal**
  - ESPRESSO: N=100; $\sigma_{\Delta\alpha/\alpha}$=2×10^{-7}
  - ELT-HIRES: N=150; $\sigma_{\Delta\alpha\alpha}$=3×10^{-8}

Model	ESPRESSO	ELT-HIRES
Constant	649.8	19.5
Step	2231.6	66.9
Bump	1420.1	42.6

Nº of nights needed to achieve an uncertainty equal to that expected from a SNAP-like dataset of 3000 Type Ia supernovas,

$$
\begin{aligned}
w^F(z) &= -0.9, \\
w^F(z) &= -0.5 + 0.5\tanh(z-1.5), \\
w^F(z) &= -0.9 + 1.3\exp\left(-(z-1.5)^2/0.1\right)
\end{aligned}
$$



Supernova Surveys

- **LOW (SNAP)** - 3000 SN - z: 0 - 1.7
- **MID (EUCLID)** - 1700 SN - z: 0.75 - 1.5
- **ELT** - 50 SN - z: 1 - 5
- **TMT** - 250 SN - z: 1 - 3

Figure of Merit = $1/(\sigma_1 \sigma_2)$

TABLE V. Figures of merit for the dark energy equation of state, assuming the 'Ideal' scenario for α measurements and 30 redshift bins. For each pair of entries the top and bottom lines respectively correspond to the Constant and Step fiducial models.

	Sne only	Sne + ESP	Sne + HRS
LOW (c)	409	996	58684
LOW (s)	404	554	11228
LOW + MID (c)	839	1352	58737
LOW + MID (s)	831	955	11295
LOW + ELT (c)	881	1515	79431
LOW + ELT (s)	881	1064	18176
LOW + MID + ELT (c)	1973	2357	79639
LOW + MID + ELT (s)	1971	2133	18652
LOW + TMT (c)	631	1089	58740
LOW + TMT (s)	634	712	11335
LOW + MID + TMT (c)	1253	1443	58846
LOW + MID + TMT (s)	1260	1328	11514

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- Supernova type Ia + α meaurements (ESPRESSO, HIRES)

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- Supernova type Ia + α meaurements (ESPRESSO, HIRES)
- Euclid survey
- ELT and TMT gains
- High number of measurements vs redshift coverage

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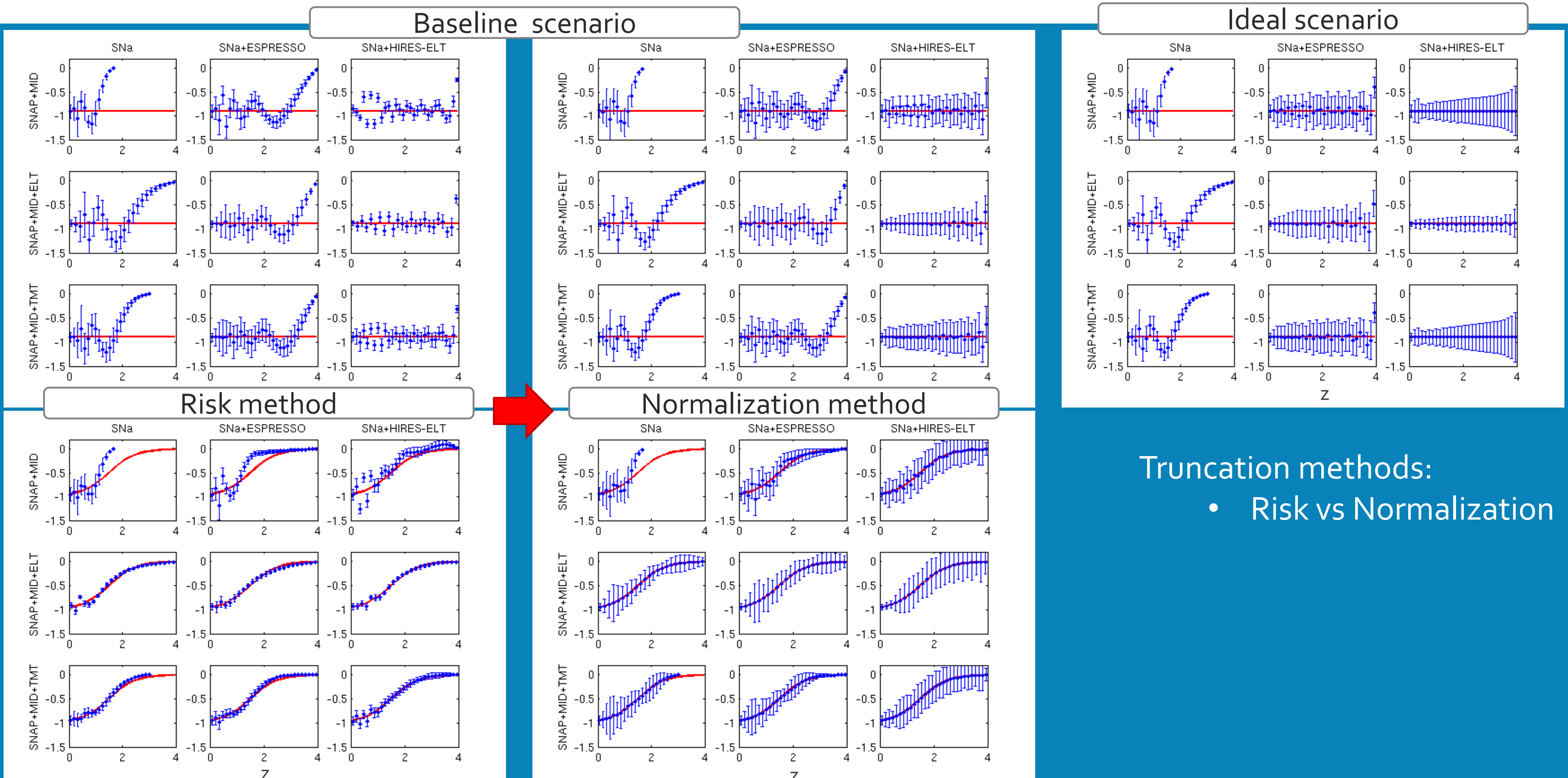
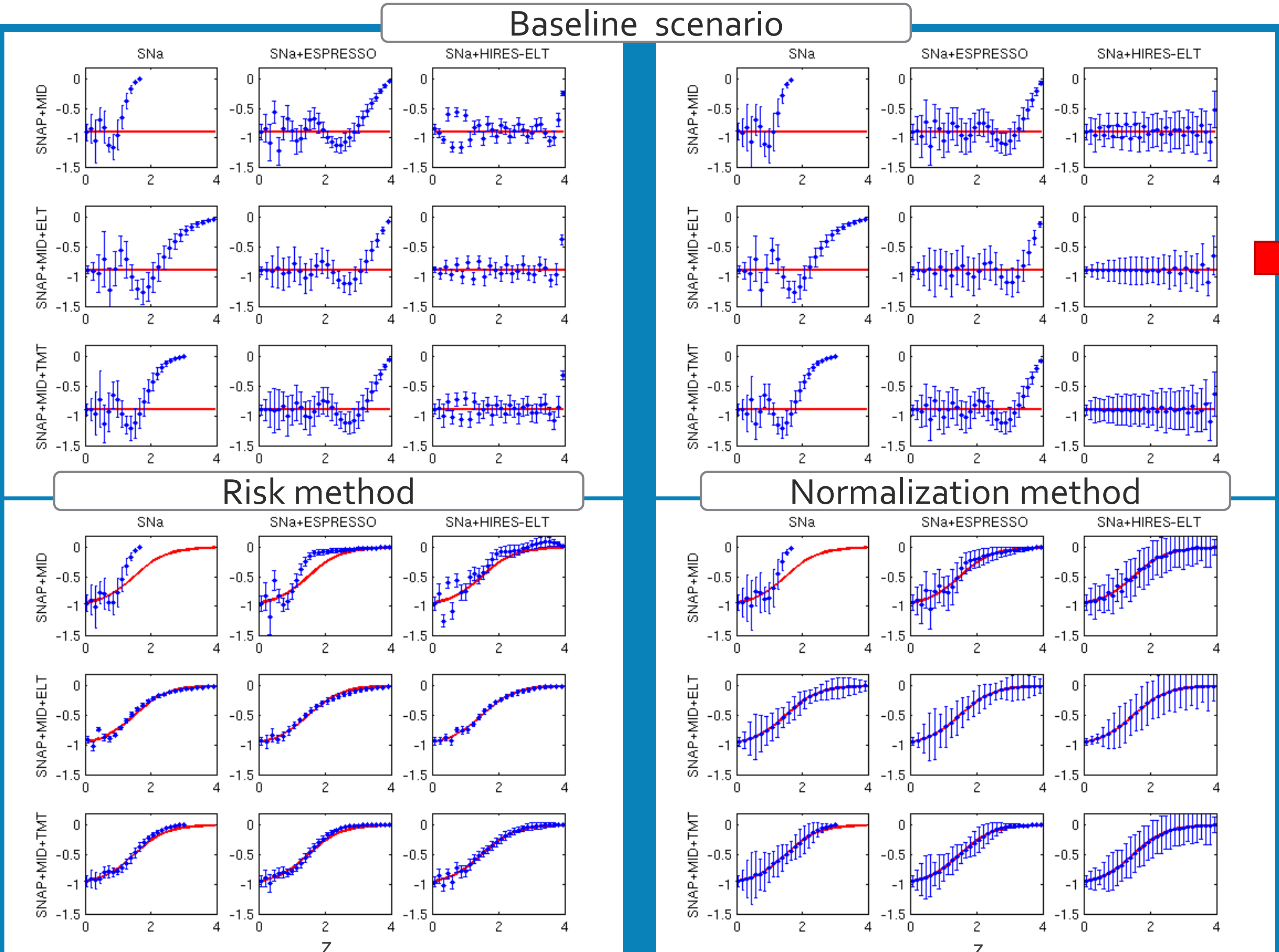
Supernova Surveys

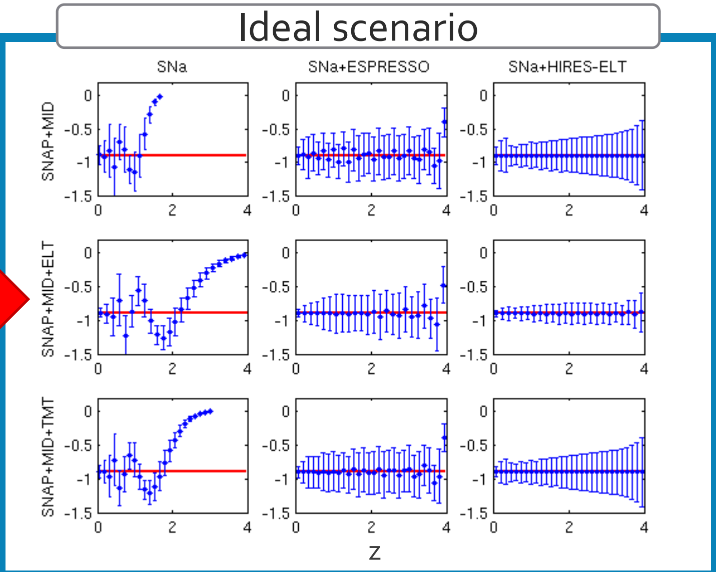


Truncation methods:

- Risk vs Normalization

Supernova Surveys





Truncation methods:

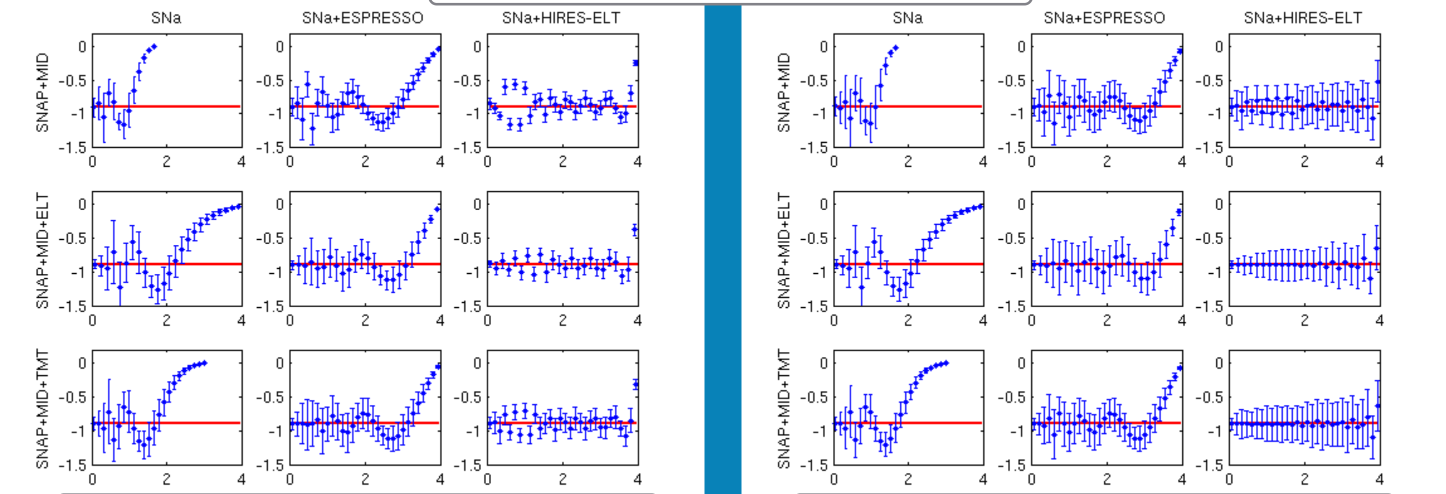
- Risk vs Normalization

Scenarios:

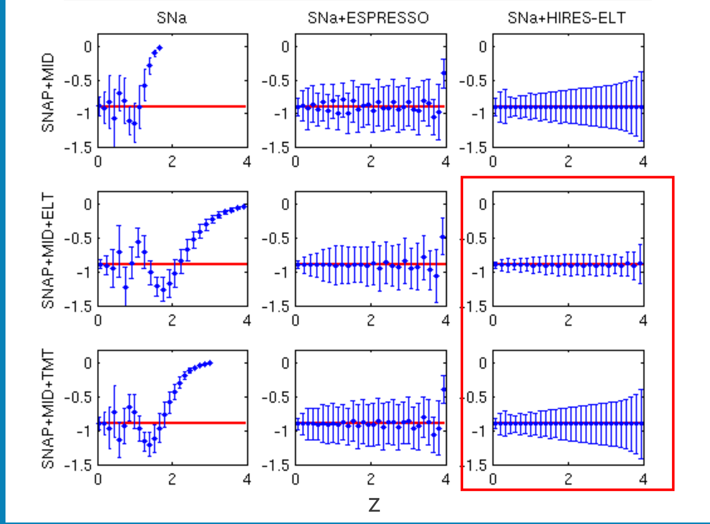
- Baseline vs Ideal

Supernova Surveys

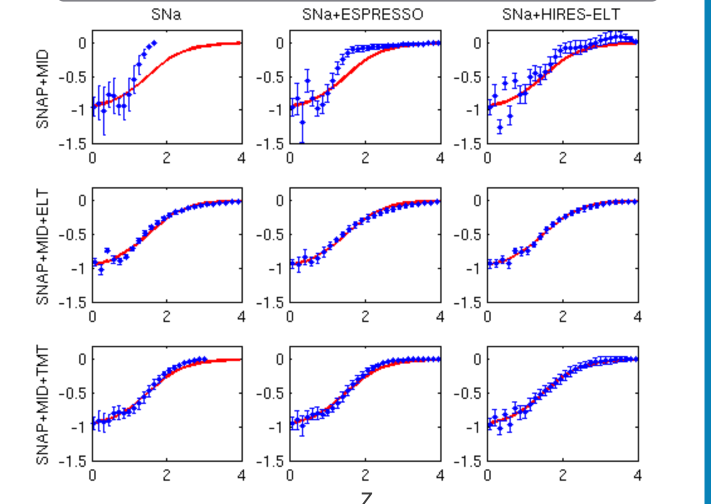
Baseline scenario



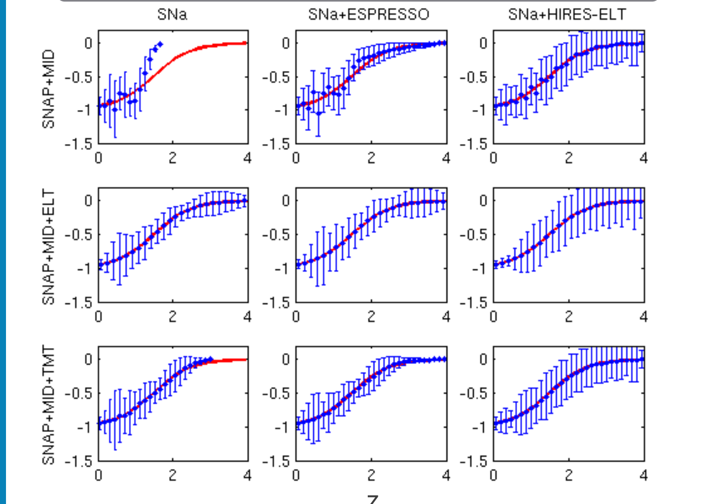
Ideal scenario



Risk method



Normalization method



Truncation methods:

- Risk vs Normalization

Scenarios:

- Baseline vs Ideal

Importance of high redshift (TMT vs ELT)

Conclusions

- Measurements of α can be used to constrain dark energy, complementing supernovas with the advantage of a larger redshift lever arm
- Dark energy equation of state reconstruction improves when we combine the Supernova datasets with α measurements
- ELT will be important to reconstruct the equation of state at high redshift $(z > 2)$
- Existing VLT datasets, although not ideal, give clues on what we will be able to achieve with future Spectrographs