DARK ENERGY CONSTRAINTS FROM THE ESPRESSO FUNDAMENTAL PHYSICS GTO

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ESPRESSO is a high-resolution-ultra-stable spectrograph for the VLT, whose commissioning will start in early 2017. One of its key science drivers is to test the stability of fundamental couplings such as the fine structure constant with unprecedented accuracy and control of possible systematics. Specifically, a total of 27 nights of the ESPRESSO Consortium's guaranteed time observations (GTO) will be spent in testing the stability of the fine-structure constant and other fundamental couplings. A set of 14 priority optimal targets have been selected for the GTO period. In this contribution I present the forecasts of the impact that observations will have on fundamental physics and cosmology, focusing on dark energy constraints and further discuss the synergies with future supernova type Ia surveys.

1 Target list for ESPRESSO GTO on Fundamental Physics

ESPRESSO is a high-resolution-ultra-stable spectrograph that will be installed in VLT in early 2017 and will contribute to test the stability of fundamental couplings[1]. The Fundamental Physics Guaranteed time of observation (GTO) to this purpose will have 27 nights and a list of 14 "ideal" targets was put together. In order to achieve higher constrains on the variation of the fine structure constant, α, an ideal target should present simple and strong absorption features of transitions with high sensitivities to variations of α.

To select the list of targets for the GTO of ESPRESSO we considered previous measurements from UVES and Keck spectrographs and took into account the transitions not observed because of the shorter wavelength coverage of ESPRESSO. In Fig 1 this effect is illustrated in redshift coverage for transitions usually used to do variation of α measurements. In the same Figure each transition is colored by the corresponding sensitivity, q, on α variation. In order to have a sensitive measurement on α with a better control of systematics one should ensure to have at least one anchor, one blue and one red shifter, this sets Δq on a given system to be large.

We chose the targets able to be observed from the VLT site with a $\Delta q > 2000$ and a reported uncertainty of $\sigma_{\Delta\alpha/\alpha} < 5ppm$. This last criteria comes from the fact that simple spectra should have already produced measurement with statistically lower uncertainties. The 14 targets selected are presented in Table 1. The first measurement on the table doesn't fulfil the criteria, but is a system where proton to electron mass ratio and the T_{CMB} relation to redshift can also be measured. This fact makes this an interesting target to investigate the nature of the fundamental constants variation testing different theories where a relation between these three constants are predicted.[6] These type of measurements are important by themselves for testing

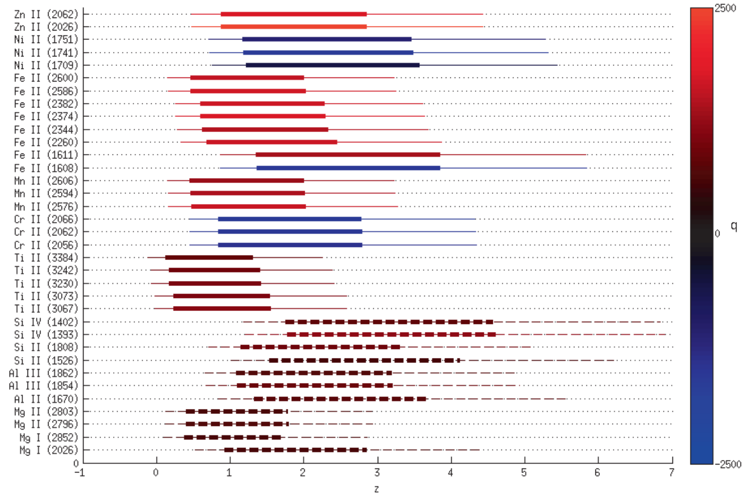

Figure 1 – Redshift coverage of ESPRESSO and UVES of common transitions used to do measurements of the variation of α. Thinner lines represent the coverage of UVES, the thicker part is representative of ESPRESSO's. The colour code is indicative of the q sensitivity parameter, each transition has the colour according to their shift to the blue or red on spectra and by how much. The dashed transitions correspond to anchors, i.e. transitions that don't shift much.

the stability of α but even a non-detection of variation can be used to constrain dark energy. In the next section we will describe the impact that this measurements can have in the study of the properties of Dark Energy

2 Forecasts on Dark Energy constraints

Our formalism to perform the forecast is described in Amendola et al.[7], to which we refer the reader for further details. We consider models for which the variation of α is linearly proportional to the displacement of a scalar field, and further assume that this field is a quintessence type field, i.e. responsible for the current acceleration of the Universe. We take the coupling between the scalar field and electromagnetism to be:

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

where the gauge kinetic function $B_F(\phi) = 1 - \zeta(\phi - \phi_0)$, $\kappa^2 = 8\pi G$ and ζ is a constant to be marginalized over. This can be seen as the first term of a Taylor expansion, and should be a good approximation if the field is slowly varying at low redshift. Then, the evolution of α is given by

$$\frac{\Delta\alpha}{\alpha} \equiv \frac{\alpha - \alpha_0}{\alpha_0} = \zeta\kappa(\phi - \phi_0)\,. \tag{2}$$

For a flat Friedmann-Lemaître-Robertson-Walker Universe with a canonical scalar field, $\dot{\phi}^2 = (1+w(z))\rho_\phi$, hence, for a given dependence of the equation of state parameter $w(z)$ with redshift, the scalar field evolves as

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

where we have chosen the positive root of the solution.

Table 1: List of the best measurements of the variation of the fine structure constant considering the wavelength coverage of ESPRESSO. Column 1 gives the quasar name; the redshifts of the absorption system are given in Column 2; Column 3 and 4 gives the value of the measurement and the correspondent uncertainty. The last Column gives the references for each measurement. Flagged measurements - * - mean that the measurement lost transitions due to the wavelength range of ESPRESSO

Name	z_{abs}	$\frac{\Delta\alpha}{\alpha}$ (10^{-6})	$\sigma_{\frac{\Delta\alpha}{\alpha}}(10^{-6})$	Ref.
J034943-381031	3.02	-27.9	34.2	3
J040718-441013	2.59	5.7	3.4*	2
J043037-485523	1.35	-4.0	2.3*	2
J053007-250329	2.14	6.7	3.5*	2
J110325-264515	1.84	5.6	2.6	4
J115944+011206	1.94	5.1	4.4*	2
J133335+164903	1.77	8.4	4.4	2
HE1347-2457	1.43	-21.3	3.6	4
J220852-194359	1.92	8.5	3.8	2
HE2217-2818	1.69	1.3	2.4	5
Q2230+0232	1.86	-9.9	4.9	3
J233446-090812	2.15	5.2	4.3*	2
J233446-090812	2.28	7.5	3.7*	2
Q2343+1232	2.43	-12.2	3.8*	3

From this, one can calculate the Fisher matrix to infer the precision on the measurement of w using standard techniques[7], obtaining from a set of observables and its uncertainties, the eigenvalues λ_i of the diagonalized Fisher matrix (ordered from best determined modes to worst ones) and the variance of the new parameters, $\sigma_i^2 = 1/\lambda_i$. To reconstruct the fiducial equation only the best determined modes are used.

We will consider three fiducial forms, presented in that same work, for the equation of state parameter: $w_c(z) = -0.9$, $w_s(z) = -0.5 + 0.5tanh(z - 1.5)$ and $w_b(z) = -0.9 + 1.3exp(-(z - 1.5)^{2/0.1}))$. In what follows we will refer to these cases as the constant, step and bump fiducial models.

2.1 Results

We applied this Principal Component Formalism to the 14 Targets on α and a set of future Sna Ia Surveys. For the α measurements we assumed two different scenarios: **Baseline**, in which we use measurements with uncertainty of $\sigma_{\Delta\alpha/\alpha} = 0.6ppm$; and **Ideal** in which the measurements are set to have uncertainties of $\sigma_{\Delta\alpha/\alpha} = 0.2ppm$. For Type Ia supernovas we consider the following datasets: **LOW**: A low-redshift sample, of 3000 supernovas uniformly distributed in the redshift range $0 < z < 1.7$, with an uncertainty on the magnitude of $\sigma_m = 0.11$; **MID**: An intermediate redshift sample, of 1700 supernovas uniformly distributed in the redshift range $0.75 < z < 1.5$ and the same σ_m as before.

We assumed 7 redshift bins with 2 α measurements each for the reconstructions with the ESPRESSO GTO Target List (**GTO**), and for the type Ia supernovas we used 20 redshift bins in the covered redshift. In order to quantify gains in sensitivity for each case using the PCA, we counted the number of modes with uncertainty under 0.3. This value is somewhat arbitrary, but serves our purpose comparing this number on different combinations of future datasets.

We present in Table 2 the number of modes with uncertainty under 0.3 for the reconstruction of the different fiducial parametrizations with the 14 Target List for ESPRESSO GTO and the combination with the **LOW** and **MID** Supernovas Type Ia samples. On its own, the reconstruction with the Target List for the GTO is not good compared with the one's from the Supernova data. It should be pointed that the reconstruction using Supernova only gain when

Table 2: The table indicates how many modes have an error below the threshold value $\sigma = 0.3$ considering the constant, step and bump fiducial parametrizations in the baseline and ideal scenarios for the uncertainty on the variation of α measurements expected for ESPRESSO. SNAP, and SNAP+MID are not affected by the baseline vs ideal scenario, since that refers to the uncertainties on α measurements

	Baseline			Ideal		
	constant	step	bump	constant	step	bump
GTO	1	-	1	3	1	2
LOW	4	4	4	4	4	4
GTO + LOW	4	4	4	9	4	5
LOW + MID	4	4	5	4	4	5
GTO + LOW + MID	4	4	5	9	4	6

combined with the GTO target list, and since they probe different redshifts this combination allows to get the behaviour of the equation of state of Dark Energy from redshift 0 to 3.

3 Conclusion

The ESPRESSO target selection for the GTO has been put together, the exploitation of the different modes of operation of the instrument will be explored in the future. The classical way to study the equation of state parameter is using type Ia Supernovas, but they are for now limited in redshift ($z \sim 1.7$) using fine structure constant measurements allows to parametrize it to higher redshifts, and in particular, just from the GTO from ESPRESSO we will be able to do it till $z \sim 3$. Previous work[7,8,9] using the PCA-based forecast technique showed that the reconstruction of dark energy equation of state has improvements when combining the Type Ia Supernovas with measurements on the stability of fine-structure constant. These 14 measurements expected from the GTO of ESPRESSO will not be able to reconstruct the equation of state and distinguish models in a convincing manner by themselves. However, improvements can be achieved by combining these with Supernova type Ia data.

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