The UVES LP for Testing Fundamental Physics: Status and Dark Side Constraints

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So What's Your Point?

- We all know that fundamental couplings run with energy
- Moreover, in many (or arguably most?) models they will equally naturally roll in time and ramble in space
- Therefore astrophysical (and local) tests of their stability provide us with optimal probes of fundamental cosmology
- In this talk I will present the state-of-the-art astrophysical measurements, and highlight some of their implications

The UVES Large Program for Testing Fundamental Physics

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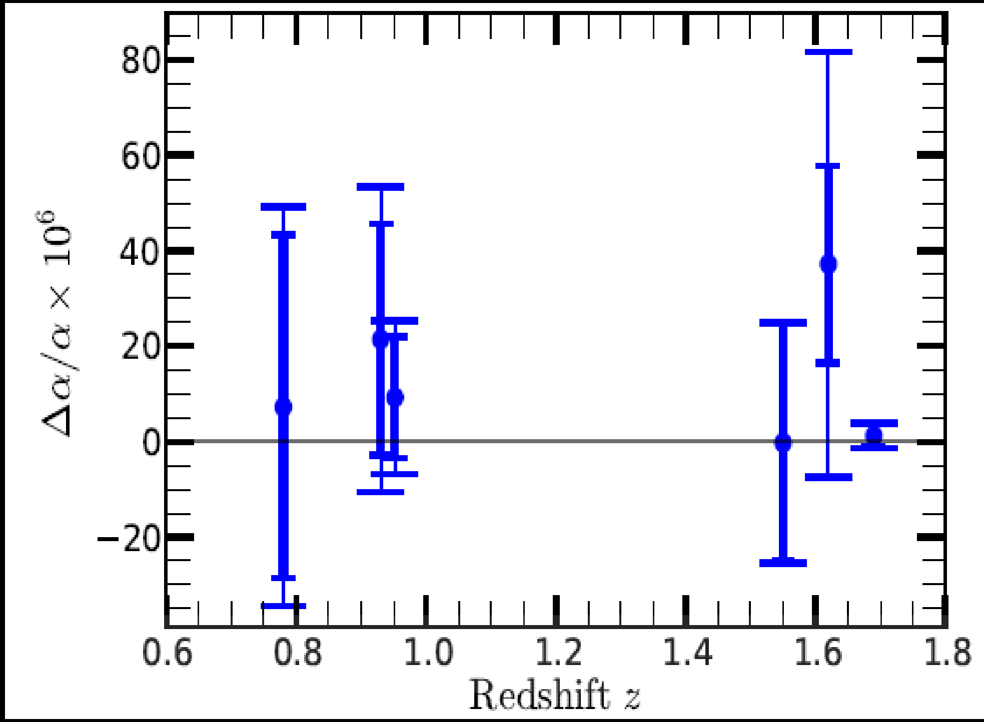
LP Plan & Goals

- Only program dedicated to varying couplings, with optimized data acquisition and reduction: ca. 40 nights in 2010-13
  - Calibration lamps attached to science exposures (in same OB): don't reset x-disperser encoding position for each exposure
  - Observe bright (mag 9-11) asteroids at twilight, to monitor radial velocity accuracy of UVES and the optical alignments
- R~60000, S/N~100; potential accuracy is 1-2ppm/system, where photon noise and calibration errors are comparable
  - Our goal: 2ppm per system, 0.5ppm for full sample
  - All active groups involved, multiple blind independent analyses
- Target selection discussed in *[Bonifacio et al. 2014]*
  - 13 targets for α, 2 targets for μ=mp/me
  - Already out: HE2217-2818 HE0027-1836, HS1519+1919
  - Raw data in ESO archive, reduced data to come – have fun!

Understanding the Data

- HE2217-2818, z_{abs}~1.69:
  $\Delta\alpha/\alpha$ = 1.3 $\pm$ 2.4$_{sta}$ $\pm$ 1.0$_{sys}$ ppm
  - Paper I: P. Molaro et al., A&A 555 (2013) A68
  - Dipole fit: (3.2–5.4)±1.7 ppm depending on model; our measurement does not confirm this, but is not inconsistent with it either



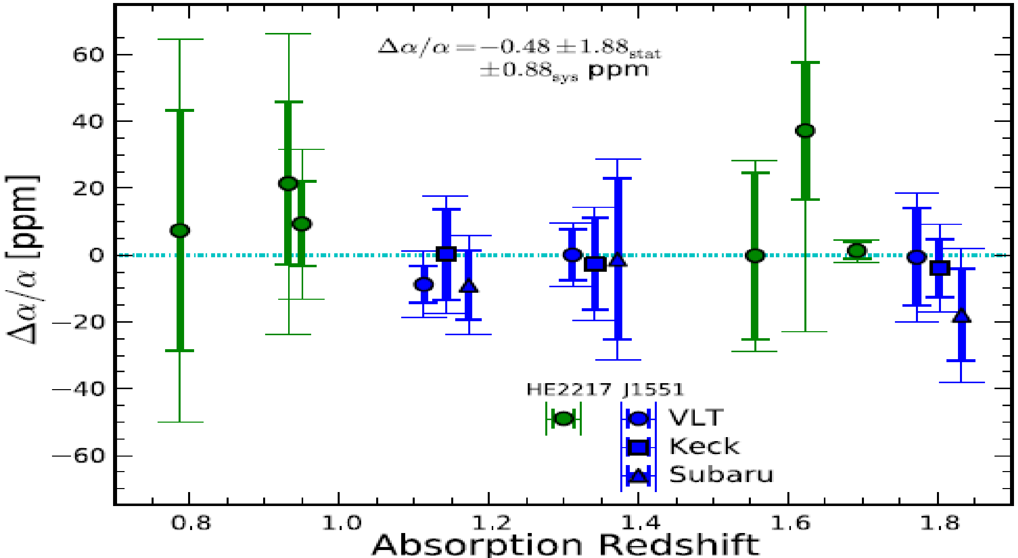
- HE0027-1836, z_{abs}~2.40: $\Delta\mu/\mu$ = -7.6 $\pm$ 8.1$_{sta}$ $\pm$ 6.3$_{sys}$ ppm
  - Paper II: H. Rahmani et al., MNRAS 435 (2013) 861
  - Identified wavelength-dependent velocity drift (corrected with bright asteroid data)
- Bottleneck: intra-order distortions (~200m/s) & long-range distortions on UVES, discussion in Paper IV *[Whitmore et al.]*
  - Also identified in HARPS and Keck-HIRES

A Triple Check of Distortions

- HS1519+1919: 3 absorbers at z_{abs}~1.1, 1.3 & 1.8, observed with 3 top optical telescopes: $\Delta\alpha/\alpha$ = -5.4 ± 3.3_{sta} ± 1.5_{sys} ppm
  - Paper III: T. Evans et al., MNRAS 445 (2014) 128
  - Directly comparing spectra and 'supercalibrating' with asteroid and iodine-cell tests, allows removal of long-range distortions

	$\Delta\alpha/\alpha \pm \sigma_{stat} \pm \sigma_{sys}$ [ppm]														
Absorption Redshift	Keck/HIRES			χ^2_ν	VLT/UVES			χ^2_ν	Subaru/HDS			χ^2_ν	Absorber Average		
$z_{abs} = 1.143$	+0.20	13.63	3.97	1.18	−8.80	5.60	4.36	1.45	−9.04	10.41	4.34	1.59	−7.49	4.63	3.02
$z_{abs} = 1.342$	−2.77	13.71	3.16	1.20	+0.02	7.64	1.85	1.53	−1.29	24.04	6.04	1.23	−0.70	6.43	1.55
$z_{abs} = 1.802$	−3.92	8.61	4.69	0.75	−0.66	14.65	4.54	0.98	−17.98	13.67	6.45	0.76	−6.42	6.52	3.16
Weighted mean	−2.64	6.43	2.54	–	−4.71	4.31	2.36	–	−11.20	7.83	2.44	–	−5.40	3.25	1.53

- Current status: compatible with null result and dipole…
  - Full sample analysis ongoing
  - Papers IV-VII should be appearing soon

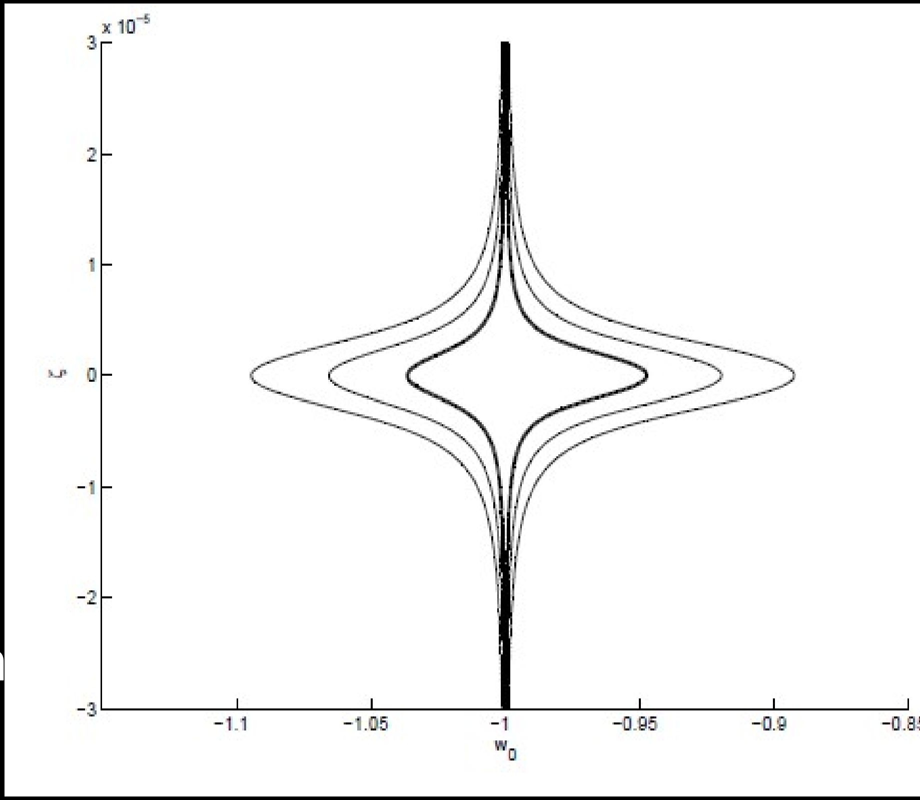


Dark Energy & Varying Couplings

- Universe dominated by component whose gravitational behavior is similar to that of a cosmological constant
  - A dynamical scalar field is (arguably) more likely
- Such a field must be slow-rolling (mandatory for $p<0$) and be dominating the dynamics around the present day
- Couplings of this field will lead to potentially observable long-range forces and varying 'constants' *[Carroll 1998]*
  - These measurements (whether they are detections of null results) will constrain fundamental physics and cosmology
  - This ensures a 'minimum guaranteed science'

Taxonomy: Class I

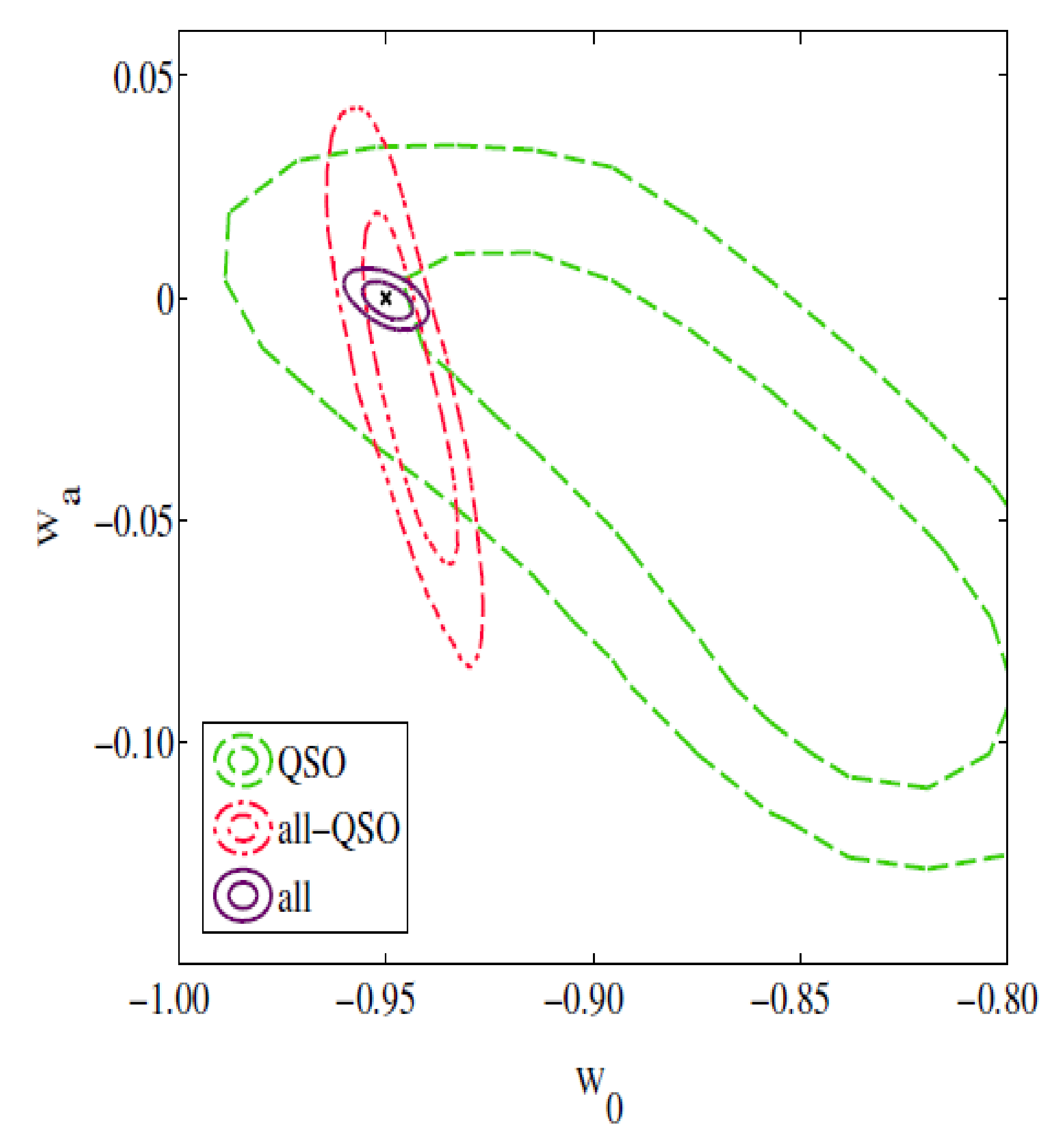
- If the same degree of freedom is responsible for dark energy and varying α, its evolution is parametrically determined
- Current QSO + Clocks + Cosmo marginalized constraints are *[Martins & Pinho 2015]*
  - $|\zeta| < 5\text{x}10^{-6}$ (2 sigma)
  - $|1+w_0| < 0.06$ (3 sigma)
  - Atomic clocks currently provide the tightest constraint...
  - ...but this will likely change when further LP results come out



- ALMA, ESPRESSO and ELT-HIRES will map the dark side out to z~4 *[Amendola et al. 2012, Leite et al. 2014]*
  - Key synergies with other probes (cf. Ana Catarina Leite's talk)
  - For a roadmap in an E-ELT context see *[Martins 2014]*

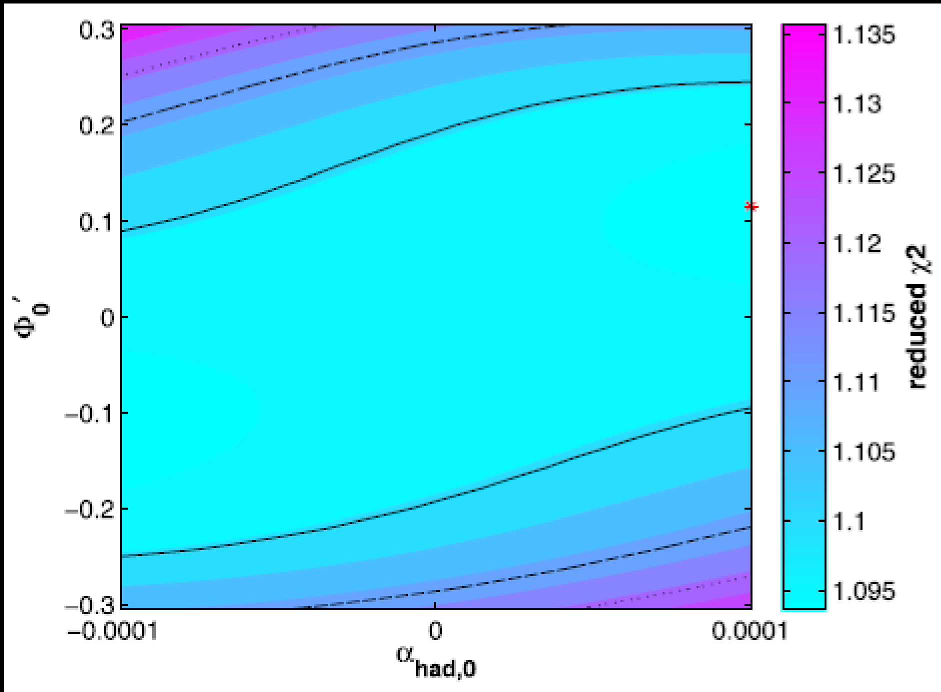
Euclid & Varying α

- The weak lensing shear power spectrum + Type Ia SNe can constrain Class I models
  - …with external datasets
- Example for a CPL fiducial
  - Euclid WL + DESIRE SN Ia data *[Astier et al. 2014]*
  - ELT spectroscopic data (+ atomic clock prior)
- For a full analysis see *[Calabrese et al. 2014]*
  - Key synergies between Euclid and the various E-ELT instruments are currently being quantified



Taxonomy: Class II

- Models where α field does not provide all dark energy can be identified via w(z) consistency tests *[Vielzeuf & Martins 2012]*
  - BSBM models *[Sandvik et al. 2002, Leal et al. 2014]*
  - Runaway dilatons *[Damour et al. 2002, Martins et al. 2015]*



- Even if this degree of freedom does not dominate the universe at low z, it can bias cosmological parameter estimations
  - Several effects already quantified within Euclid Consortium *[Calabrese et al. 2014, Avgoustidis et al. 2014]*
  - Tests of the CMB temperature-redshift relation will be a key external dataset *[Avgoustidis et al. 2012, de Martino et al. 2015, Luzzi et al. 2015]*

So What's Your Point?

- Observational evidence for the acceleration of the universe demonstrates that canonical theories of cosmology and particle physics are incomplete, if not incorrect
  - Fundamental coupling stability is optimal probe of new physics
- The story so far: nothing is varying at $\sim 10^{-5}$ level, already a very significant constraint (stronger than the Cassini bound)
  - At 10^{-6} level things are currently less clear...
  - ...but significant improvements are coming
- Forthcoming instruments will lead to a new generation of precision consistency tests
  - Complementarity: Equivalence Principle, Redshift drift, ...
  - Synergies with other facilities, including ALMA, Euclid & SKA