Scientific Requirements for Extremely Large Telescopes
Proceedings IAU Symposium No. 232, 2005
P. Whitelock, M. Dennefeld & B. Leibundgut, eds.

doi:10.1017/S1743921306000548

Most precise single redshift bound to the variability of the fine-structure constant

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Abstract. Verification of theoretical predictions of an oscillating behavior of the fine-structure constant, α, with cosmic time requires high precision measurements at individual redshifts, while in earlier studies the mean $\Delta\alpha/\alpha$ values averaged over wide redshift intervals were usually reported. This requirement can be met via the Single Ion Differential α Measurement (SIDAM) procedure. We apply SIDAM to the FeII lines associated with the damped Lyα system observed at $z = 1.15$ in the spectrum of HE0515–4414. The weighted mean calculated on the base of carefully selected 34 FeII pairs is $\langle\Delta\alpha/\alpha\rangle = (-0.07 \pm 0.84) \times 10^{-6}$. The precision of this estimate represents a large improvement over previous measurements of $\Delta\alpha/\alpha$.

Keywords. Cosmology: observations – Line: profiles – Quasars: absorption lines, individual (HE0515–4414)

1. Introduction

The Sommerfeld fine-structure constant, $\alpha \equiv e^2/\hbar c$, which describes electromagnetic and optical properties of atoms, is the most suitable for time variation tests in both laboratory experiments with atomic clocks and astronomical observations (for a review see, e.g., Barrow 2005).

The question whether or not the fine-structure constant varied at different cosmological epochs can be answered only through observations of quasar absorption-line spectra. The main requirement of such studies – precise line position measurements at the level of 10^{-7}-10^{-8} – can be fulfilled only at giant optical telescopes equipped by high resolution spectrographs.

Theoretically the effects of inhomogeneous space and time evolution of α were considered by Marciano (1984) and Mota & Barrow (2004). Most recently Fujii (2005) suggested a damped-oscillation-like behavior of α as a function of cosmic time t. It is apparent that to study such irregular changes in α, we need to achieve high precision in the measurements of $\Delta\alpha/\alpha$ at *individual* redshifts, contrary to the averaging procedure over many redshifts which is usually used to decrease uncertainties of the mean values $\langle\Delta\alpha/\alpha\rangle$ (Murphy *et al.* 2004, and references therein).

The uncertainties of individual values of $\Delta\alpha/\alpha = (\alpha_z - \alpha_0)/\alpha_0$, (here α_0 and α_z are the values of α at epoch $z = 0$ and at redshift z, respectively) are currently known at the level of a few ppm (parts per million) (Quast *et al.* 2004; Chand *et al.* 2004). In both cases the standard many-multiplet (MM) method (Dzuba *et al.* 2002) has been used. Further modification of the MM method (Levshakov *et al.* 2005) resulted in a new methodology for probing the cosmological variability of α on base of pairs of FeII lines observed in *individual exposures* from a high resolution spectrograph (henceforth referred to as SIDAM – Single Ion Differential α Measurement).

The basic idea behind SIDAM was to avoid the influence of small spectral shifts due to ionization inhomogeneities within the absorbers and due to non-zero offsets between different exposures. The individual offsets can affect the shape of the line profiles during rebinning and coadding procedures when exposures are combined together to increase the signal-to-noise (S/N) ratio (examples are given in Levshakov *et al.* 2005).

2. Results

In our recent paper (Levshakov *et al.* 2006) we showed that SIDAM can provide a sub-ppm precision in a single redshift $\Delta\alpha/\alpha$ measurement and that this level of accuracy is caused by *unavoidable* intrinsic instrumental imperfections and systematic errors inherited from the uncertainties of the wavelength scale calibration. We analyzed high quality spectra of the bright intermediate redshift quasar HE0515–4414 ($z_{\rm em} = 1.73$, $B = 15.0$; Reimers *et al.* 1998). The observations were acquired with the UV-Visual Echelle Spectrograph (UVES) at the VLT 8.2m telescope at Paranal, Chile, and the spectral data were retrieved from the ESO archive.

We found that the weighted mean of the ensemble of $n = 34$ $\Delta\alpha/\alpha$ values calculated on the base of carefully selected FeII lines from the $z = 1.15$ absorber is equal to $\langle\Delta\alpha/\alpha\rangle = -0.07 \pm 0.84$ ppm (1σ C.L.). This value is lower than 2 ppm expected at $z = 1.15$ from the damped-oscillatory model by Fujii (2005). However, the error of $\langle\Delta\alpha/\alpha\rangle$ is not small enough to verify or reject Fujii's model. To probe the oscillatory behavior of α, very accurate measurements at higher redshifts are required where the amplitude of $\Delta\alpha/\alpha$ is expected to be $\sim$5 ppm.

The value $\langle\Delta\alpha/\alpha\rangle = -5.7 \pm 1.1$ ppm found by Murphy *et al.* 2004 is based on a sample of 143 absorption systems observed with the HIRES/Keck spectrograph and ranging from $z = 0.2$ to 4.2. Now, the higher accuracy of $\langle\Delta\alpha/\alpha\rangle$ (better than 1 ppm) obtained from the analysis of the individual FeII system at $z = 1.15$ poses a problem whether the Keck ensemble average contains some undetected systematic errors.

As a conclusion, it is worthwhile to note that the achieved accuracy of $\Delta\alpha/\alpha$ is unique for the standard UVES configuration and that further improvement at the sub-ppm level can be attained only with increasing spectral resolution and instrumental stability performances such as, for instance, a fiber link producing a stable illumination at the entrance of the spectrograph and allowing continuous simultaneous comparison spectrum.

S. A. L. thanks the partial financial support of an IAU grant.

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