Probing Galaxies through Quasar Absorption Lines
Proceedings IAU Colloquium No. 199, 2005
P. R. Williams, C. Shu, and B. Ménard, eds.

doi:10.1017/S1743921305002917

Probing the variation of the fine-structure constant using QSO absorption lines

H. Chand[1], R. Srianand[1], P. Petitjean[2] and B. Aracil[2]†

[1]IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India

[2]Institut d'Astrophysique de Paris – CNRS, 98bis Boulevard Arago, F-75014 Paris, France

Abstract. Search for the time variation of the fundamental constants is motivated by various unification theories. Here we present constraints on the variation of the fine-structure constant $\alpha(\equiv e^2/\hbar c)$ obtained using UVES/VLT samples of QSO absorption systems. We find $< \Delta\alpha/\alpha >_w = (-0.06 \pm 0.06) \times 10^{-5}$ using 23 Mg II systems and the many-multiplet (MM) method. Well selected 15 Si IV systems provide $< \Delta\alpha/\alpha >_w = (0.15 \pm 0.43) \times 10^{-5}$. Absence of detectable variation in α is also confirmed by our new very high resolution ($R \sim 100,000$) observation of $z_{\rm abs}$=1.1508 toward HE 0515−4414 using HARPS on the ESO 3.6m telescope.

1. Search for α variation using VLT/UVES sample

Testing the variation of the fundamental constants is important for the understanding of fundamental physics (Uzan *et al.* 2003). Absorption lines seen in QSO spectra serve as a laboratory to test the variation of α as they allow its measurements at different redshifts (Bahcall *et al.* 1967). The recently devised many-multiplet method (Dzuba *et al.* 1999) has been shown to improve the accuracy of $\Delta\alpha/\alpha$ measurements by an order of magnitude (Webb *et al.* 2001). Based on this method the analysis of a Keck/HIRES sample has resulted in the detection of the variation of α, $\Delta\alpha/\alpha = (-0.54 \pm 0.12) \times 10^{-5}$, over a redshift range of $0.2 < z < 3.7$ (Murphy *et al.* 2003). The motivation of our VLT/UVES search is to either confirm or refute the Keck/HIRES result of α variation using high quality data and independent analysis.

Our sample consists of 18 QSO, observed using the UVES on the ESO-VLT Large Programme "QSO absorption lines". The data reduction was performed using the UVES pipeline (Aracil *et al.* 2004) having typical spectral S/N$\sim 60-80$, R $\geqslant 44,000$ and wavelength calibration error $\leqslant$ 3mÅ (Chand *et al.* 2004). Detailed descriptions of our method can be found in Chand *et al.* (2004). In brief, we used a trial value of $\Delta\alpha/\alpha$ to modify the laboratory wave number ω_0 of the multiplets to its rest frame value at z_{abs}, ω_z, using $\omega_z = \omega_0 + q[(\Delta\alpha/\alpha + 1)^2 - 1]$, where q is the sensitivity coefficient (Dzuba *et al.* 1999). Then the absorption systems were modelled for different values of $\Delta\alpha/\alpha$ to get the curve of χ^2_{min} as a function of $\Delta\alpha/\alpha$ (Fig. 2 of Chand *et al.* 2004). From such a curve we derive the best-fit value and error of $\Delta\alpha/\alpha$, using $\chi^2_{min} + 1$ statistics.

The simulated data set was used to validate our procedure and devise the proper selection criteria. As a result we avoid (a) blended systems (b) weak N(Fe II)$\leqslant 2 \times 10^{12}$ cm^{-2} as well as saturated systems. Application of these selection criteria allows us to choose 23 out of a total of 50 Mg II/Fe II systems for the MM method and 15 out of 33 Si IV doublets for the AD method.

† Present address: Department of Astronomy, University of Massachusetts, 710 North Pleasant Street, Amherst, MA 01003-9305, USA.

Table 1. Summary of recent astrophysical results

Species	z	$\Delta\alpha/\alpha\ /\times10^{-5}$	Reference
AD-method (21 Si IV, HIRES)	2.0-3.0	-0.5 ± 1.3	Murphy *et al.*, 2001, MNRAS, 327, 1237
MM-method (128 system, HIRES)	0.2-3.7	-0.54 ± 0.12	Murphy *et al.*, 2003, MNRAS, 345, 609
Fe II(1 system, UVES)	1.1508	-0.01 ± 0.17	Quast *et al.*, 2004, A&A, 415, L7
MM-method (23 system, UVES)	0.4-2.3	-0.06 ± 0.06	Srianand *et al.*, 2004, PRL, 92121302 Chand *et al.*, 2004, A&A, 417, 853
AD-method (15 Si IV, UVES)	1.59-2.82	0.15 ± 0.43	Chand *et al.*, 2005, A&A, 430, 47
Fe II(2 system, UVES)	1.15,1.84	0.04 ± 0.15	Levshakov *et al.*, 2005, A&A, in press
H I 21-cm+ CO	0.25,0.69	$\leqslant 1.68$	Carilli *et al.*, 2000, PRL, 85, 5511
H I 21-cm	0.25	-0.10 ± 0.22	Murphy *et al.*, 2001, MNRAS, 327, 1244
	0.69	-0.08 ± 0.27	
OH	0.25	$+0.60 \pm 1.00$	Kanekar *et al.*, 2004, PRL, 93, 051302
	0.25	$+0.51 \pm 1.26$	Darling *et al.*, 2004, ApJ, 612, 58
O III (73 QSOs)	0.16-0.80	$+7.0 \pm 14.0$	Bahcall *et al.*, 2004, ApJ, 600, 520

2. Results and discussion

Results obtained from the 23 Mg II/Fe II systems using the MM-method and that from the literature are summarised in the upper panel of Fig. 1. The shaded region marks the 3σ range around the weighted mean. The simple mean, weighted mean, and standard deviation around the mean obtained for our sample are $(-0.02 \pm 0.10) \times 10^{-5}$, $(-0.06 \pm 0.06) \times 10^{-5}$, and $0.41{\times}10^{-5}$ respectively (Chand *et al.* 2004; Srianand *et al.* 2004). The 3σ constraint corresponds to $-0.24 \leqslant \Delta\alpha/\alpha$ (in 10^{-5}) $\leqslant +0.12$ over the redshift range of $0.4\leqslant z \leqslant 2.3$. The distribution of our 15 measurements using Si IV is shown in the lower panel of Fig. 1. For comparison on the same scale, the measurements using the MM method are also shown. The weighted mean value obtained from the AD-method over the redshift range $1.59 \leqslant z \leqslant 2.82$ is $\Delta\alpha/\alpha = (0.15 \pm 0.43) \times 10^{-5}$. The 3σ range $(-1.14 \times 10^{-5} \leqslant \Delta\alpha/\alpha \leqslant 1.44 \times 10^{-5})$ is shown by the wider shaded region.

In addition we have also carried out our study by using very high resolution spectrum ($R \sim 100,000$) of HE 0515-1444 observed using HARPS, by analysing its absorption system at $z_{\rm abs}$=1.1508. The preliminary result, $\Delta\alpha/\alpha = (-0.10 \pm 0.25) \times 10^{-5}$ was obtained using only Fe II multiplets as is shown by an asterisk (*) in the upper panel of Fig. 1, is also found to be consistent with our UVES samples results of no detectable variation in α (Chand *et al.* 2005, in preparation).

From Table 1, that summarises all the recent measurements by different methods and/or by independent analysis, it is evident that, except for the MM-method result of HIRES sample, there is no evidence for time variation of α. The increased accuracy in our result from the UVES sample is mainly due to the better quality of the data and using the proper sample selection criteria.

Acknowledgements

Based on observations collected at the European Southern Observatory (ESO), under the Large Programme ID No. 166.A-0106 with UVES on the 8.2m Kuyen telescope operated at the Paranal Observatory, Chile. HC thanks CSIR, INDIA for the grant award No. 9/545(18)/2KI/EMR-I. We gratefully acknowledge support from the Indo-French

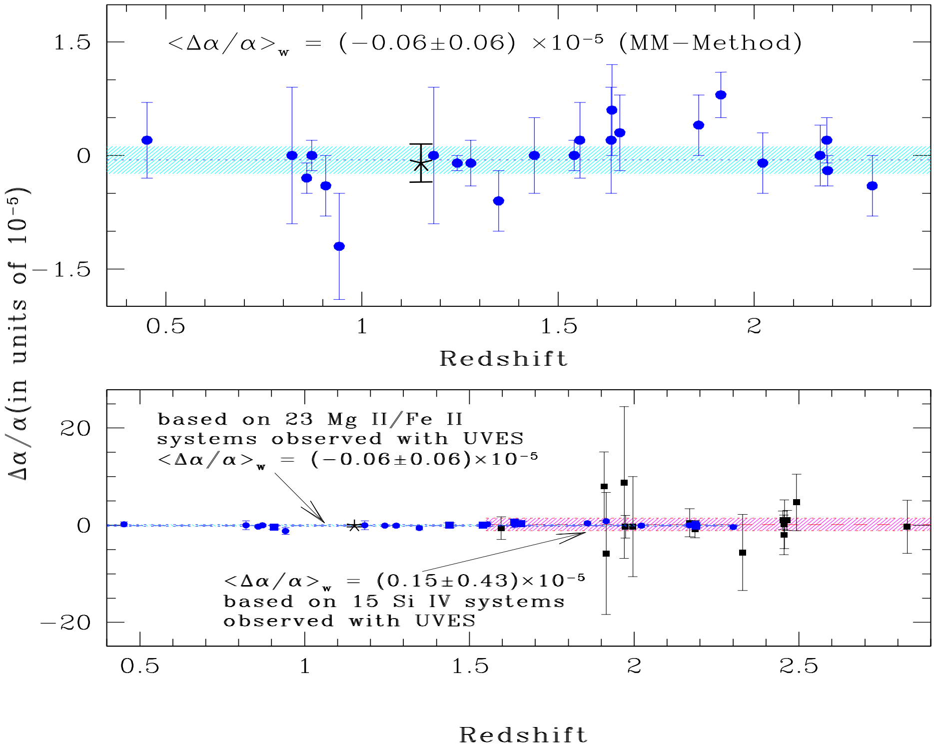

Figure 1. In the upper panel the results from the MM-method (using 23 Mg II/Fe II systems) are shown by filled circle. Shadow regions mark the 3σ range around the weighted mean. An asterisk (*) shows our preliminary result based on the analysis of Fe II multiplets in $R \sim 100,000$ spectrum of HE 0515-1444, obtained using HARPS. In the lower panel solid squares show the measurements using Si IV doublets (AD method). The measurements using the MM-method are also shown in this panel for comparison, by filled circles and the narrow shaded region.

Centre for the Promotion of Advanced Research (Centre Franco-Indien pour la Promotion de la Recherche Avancée) under contract No. 3004-3.

References

Aracil, B., Petitjean, P., Pichon, C., Bergeron, J., 2004, A&A, 419, 811
Bahcall, J. N., Sargent, W. L. W., Schmidt, M., 1967, ApJ, 149, L11
Chand, H., Petitjean, P., Srianand, R., Aracil, B., 2005, A&A, 430, 47
Chand, H., Srianand, R., Petitjean, P., Aracil, B., 2004, A&A, 417, 853
Dzuba, V. A., Flambaum, V. V., Webb, J. K., 1999, Phys. Rev. Lett., 82, 888
Murphy, M. T., Webb, J. K., Flambaum, V. V., 2003, MNRAS, 345, 609
Murphy, M. T., Webb, J., Flambaum, V., *et al.*, 2001, MNRAS, 327, 1237
Quast, R., Reimers, D., Levshakov, S. A., 2004, A&A, 415, L7
Srianand, R., *et al.*, 2004, Phys. Rev. Lett., 2004, 92121302
Uzan, J., 2003, Rev. Mod. Phys., 75, 403
Webb, J. K., Murphy, M. T., Flambaum, V. V., *et al.*, 2001, Phys. Rev. Lett., 87, 091301