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Search for α variation in UVES spectra: Analysis of C IV and Si IV doublets towards QSO 1101-264 *,**

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Abstract. Motivated by previous studies of QSO spectra that reported a variation of the fine structure constant α, a search for C IV and Si IV doublets was conducted in the absorption spectrum toward QSO 1101-264, obtained by VLT-UVES during the Science Verification. Seven C IV and two Si IV systems were identified and accurate measurements of wavelengths over the redshift range $1.1862 < z < 1.8377$ were performed. After a careful selection of pairs of lines, the "Alkali Doublet" method with a derived analitical expression for the error analysis was applied to compute the α variation. The result according in magnitud order with previous doublets measurements, corresponds to one Si IV system: $\Delta\alpha/\alpha = (-3.09 \pm 8.46) \times 10^{-5}$.

Key words. quasars: individual: QSO 1101-264 – quasars: absorption lines – atomic processes

1. Introduction

Modern theories in physics (Super Symmetry Grand Unification Theory, Superstring and others) predict the dependence of fundamental physical constants on energy, a prediction supported by high energy experiments (Okun 1998), and have cosmological solutions where low-energy values of these constants vary with the cosmological time (Varshalovich et al. 2000).

Recent measurements of absorption lines in high resolution QSO spectra suggest the variation of the fine structure constant α throughout cosmological time (e.g. Webb et al. (2002) and refs. therein). The use of QSO spectra to search for an α variability takes advantage of the many absorption lines originated in clouds lying at various redshifts along the line of sight to the QSO. The measurements are performed by comparing wavelength separations of transitions observed at various redshifts with their corresponding laboratory values at $z = 0$. Two approaches exist for this study of $\Delta\alpha/\alpha$: the "Alkali Doublet"

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* Data from UVES-VLT.

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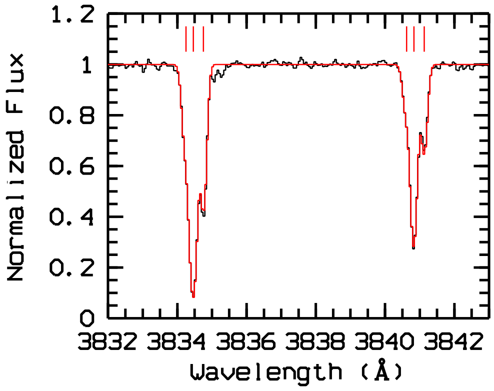

Fig. 1. Absorption of C IV at $z = 1.4767$. The leftmost line in both absorptions correspond to the blended and discarded line. Black: observed spectrum. Red: fitted spectrum.

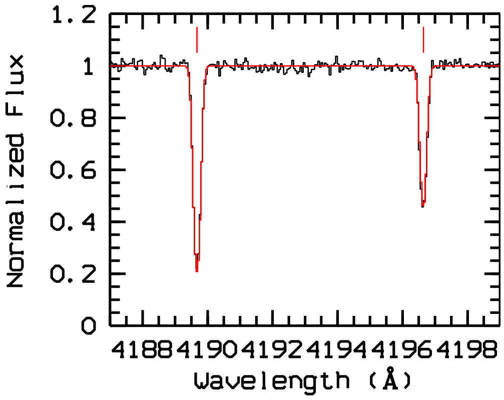

Fig. 2. Absorption of C IV at $z = 1.7061$. Black: observed spectrum. Red: fitted spectrum. The sharpness of the components allows us to determine the centroid accurately.

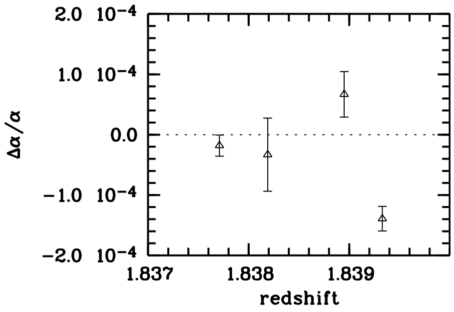

Fig. 3. Plot for the components of Si IV.

(AD) method and the "Many Multiplet" (MM) method. The former, first applied by Bahcall et al. (1967), considers alkaline-like ions to compare the wavelength separation of its doublets. The latter, developed by Dzuba et al. (1999a,b, 2001), uses wavelengths of various transitions from different multiplets and ions. In the AD method it is common to use doublets of ions like C IV and Si IV and the wavelength separation between λ_1 and λ_2, corresponding to the transitions $^2S_{1/2} \rightarrow {}^2P_{3/2}$ and $^2S_{1/2} \rightarrow {}^2P_{1/2}$ respectively, is proportional to α^2.

From a MM method analysis based on 128 systems, Webb et al. (2002) find $\Delta\alpha/\alpha = (-0.57 \pm 0.10) \times 10^{-5}$ over the redshift range $0.2 < z < 3.7$, indicating a smaller value of α in the past. From an AD method analsysis of 21 Si IV doublets Murphy et al. (2002) obtain a weighted mean $\Delta\alpha/\alpha = (-0.5 \pm 1.3) \times 10^{-5}$ at $\langle z_{abs} \rangle = 2.8$.

Bahcall et al. (2003) find $\Delta\alpha/\alpha = (-2 \pm 1.2) \times 10^{-4}$ from an analysis of strong nebular emission lines of [O III] (5007 Å and 4959 Å) in a QSO sample over $0.16 < z < 0.80$.

We have conducted a search for C IV and Si IV doublets in the absorption spectrum toward QSO 1101-264, obtained by VLT-UVES during the Science Verification. Seven C IV and two Si IV systems were identified and accurate measurements of wavelengths over the redshift range $1.1862 < z < 1.8377$ were performed. After a careful selection of pairs of lines, we applied the AD method, with an original expression for the error analysis, to compute the α variation. Here we present the results of this work.

2. Measurements and Analysis

QSO 1101-264 ($z_{em} = 2.145$) was observed for the Science Verification of the UVES Spectrograph at VLT. All the work done on the spectrum was performed under the MIDAS package. Data reduction was carried out by the Science Verification Team and for our purpose, the reduced spectrum was converted from air wavelengths to vacuum wavelengths.

A total of nine systems among the C IV (1548Å, 1550Å) and Si IV (1393Å, 1402Å) ions were identified. A code for line fitting considering Voigt profiles and based on the reduced χ^2 test as parameter of goodness of the fit was used. The laboratory wavelengths considered in the present analysis are: C IV (1548.204Å, 1550.781Å) and Si IV (1393.76018Å, 1402.77291Å) measured by Griesmann & Kling (2000), the best available up to date.

The sample contains a total of 47 doublets, not all suitable for the desired measure of $\Delta\alpha/\alpha$ due to complicated profiles, some of them contaminated or blended. For that reason a rigorous selection of lines was made, choosing the best resolved profiles, outside the Lyman forest to avoid contaminations, discarding asymmetric shapes and focusing on narrow absorptions because centroids are better determined than in broader ones. We present only those selected in Table 1.

The synthetic spectrum for every doublet was constructed by using the minimum number of components, until a very good shape reproducing the observed spectrum was reached.

The C IV system at $z = 1.4767$ in Figure 1 helps to illustrate the fitting procedure. After several line fitting runs with different starting guess values around the minima, a poor fit was obtained. To improve it, new lines were added, paying attention to the slightly asymmetric shape of the spectrum toward the left. It allows to determine better the wavelengths of the strong minima but the others do not represent a reliable absorption to be considered.

The C IV system at $z = 1.7061$ is a fortunate case because it is a simple pair of strong lines (see Figure 2). It is a very good example of the available high quality instruments displaying a spectrum with $R \approx 45000$ and $S/N \approx 60$. The selection of appropriate centroid wavelengths was based on this profile where the line fitting provided wavelengths uncertainties of $\sigma_{\lambda_{z1}} = 0.0015$Å and $\sigma_{\lambda_{z2}} = 0.0021$Å. Because, somehow, a complex velocity structure is present in all systems, the most symmetric shapes were selected qualitatively and the corresponding $\sigma_{\lambda_{z1}}$ and $\sigma_{\lambda_{z2}}$ values served as quantitative criterion to ensure the best wavelengths to be included in the calculations.

Considering a possible small variation of α, Varshalovich et al. (2000) use the approximate formula

$$\frac{\alpha_z - \alpha}{\alpha} = \frac{\Delta\alpha}{\alpha} = \frac{c_r}{2}\left[\frac{(\Delta\lambda/\lambda)_z}{(\Delta\lambda/\lambda)_0} - 1\right] \qquad (1)$$

where $\lambda = \frac{1}{2}(\lambda_1 + \lambda_2)$; $(\Delta\lambda/\lambda)_z$ and $(\Delta\lambda/\lambda)_0$ represent the doublet separation for the absorption at redshift z and at the laboratory, respectively; $c_r \approx (\delta q_1 - \delta q_2)\,/\,(\delta q_1 - 2\delta q_2)$ is a correction term given by Murphy et al. (2001), with q_1 and q_2 coefficients representing the relativistic correction to the energy for a particular transition, calculated for many elements by Dzuba et al. (1999b). The correction coefficients c_r are: 1.1758 for C IV and 0.8914 for Si IV. An analitic expression for the error analysis can be obtained through an aproximation for the standard deviation as $\Delta\alpha/\alpha = f(\lambda_{z1}, \lambda_{z2})$:

$$\sigma_f^2 \approx \sigma_{\lambda_{z1}}^2 \left(\frac{\partial f}{\partial \lambda_{z1}}\right)^2 + \sigma_{\lambda_{z2}}^2 \left(\frac{\partial f}{\partial \lambda_{z2}}\right)^2 + \cdots \quad (2)$$

which, with the derivatives of eq. (1), yields the error propagation equation for the AD method. Results appear in Table 1, a plot for components of Si IV is shown in Figure 3 and averaging the four values lead to: $\Delta\alpha/\alpha = (-3.09 \pm 8.46) \times 10^{-5}$, where the error is the standard deviation around the mean.

3. Conclusions

For the first time, UVES data have been employed to compute $\Delta\alpha/\alpha$ with the AD

Table 1. $\Delta\alpha/\alpha$ calculations with their corresponding standard deviations.

Ion, z	$\frac{\Delta\alpha}{\alpha}$	$\sigma_{\Delta\alpha/\alpha}$
CIV, 1.4767	-1.2330×10^{-3}	8.4913×10^{-5}
CIV, 1.4769	-5.0416×10^{-4}	1.9919×10^{-4}
CIV, 1.7061	-8.5510×10^{-4}	2.1750×10^{-4}
CIV, 1.8377	-9.4692×10^{-4}	1.1591×10^{-4}
CIV, 1.8385	-4.6644×10^{-4}	2.5231×10^{-4}
CIV, 1.8389	-1.0835×10^{-3}	1.0289×10^{-4}
SiIV, 1.8377	-1.8157×10^{-5}	1.7412×10^{-5}
SiIV, 1.8381	-3.3109×10^{-5}	6.0675×10^{-5}
SiIV, 1.8389	6.6867×10^{-5}	3.7639×10^{-5}
SiIV, 1.8393	-1.3921×10^{-4}	2.0282×10^{-5}

method. The spectrum under study has a very good quality, comparable, or better, than spectra used in previous work. Despite the stringent selection criteria applied to find suitable absorption profiles for measuring central wavelengths, an acceptable number of doublets was obtained to carry out the desired calculations.

Even if the absorption profiles of C IV have very high quality, the measurements errors obtained from this ion are bigger by one order of magnitude than those obtained from Si IV. In addition, the $\Delta\alpha/\alpha$ values provided by the C IV doublets disagree in order of magnitude with those provided by Si IV, that appear to be consistent with previous determinations (Murphy et al. 2002). These differences between C IV and Si IV data are probably due to the better determination of laboratory wavelengths of Si IV in comparison to C IV wavelengths. Until better laboratory data for C IV is available, we consider only the result obtained from the components of the Si IV system at $z \simeq 1.84$. The resulting $\Delta\alpha/\alpha = (-3.09 \pm 8.46) \times 10^{-5}$ does not support a change of α at such redshift. However, despite the result consistent with zero, our $\Delta\alpha/\alpha$ values show a negative sign, which is consistent with the findings of all previous determinations of $\Delta\alpha/\alpha$ (Varshalovich et al. 2000; Webb et al. 2002; Murphy et al. 2002; Bahcall et al. 2003). This remarkably consistent indication for a possible variation of α certainly deserves further investigation on a large number of systems, aimed at reducing the final error bar. The selection process of the best absorption lines, made to improve the $\Delta\alpha/\alpha$ determination, reduces the quantity of doublet systems available in a single QSO spectrum in a sensitive way. This is a motivation to study many more QSO's spectra to enhance the data sample, concentrating the analysis on the Si IV transitions, which have well determined laboratory data.

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