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Testing the Fine-Structure Constant for a Possible Cosmological Variation from the Analysis of Quasar Spectra

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Abstract – A possible spatial and temporal dependence of the fine-structure constant $\alpha = e^2/\hbar c$ was investigated. For this purpose, the fine doublet splitting of absorption lines in quasar spectra was statistically analyzed on the basis of observational data published before March, 1994. Lines with redshifts z ranging from 0.2 to 3.7, corresponding to the interval from 0.8 to 0.1 of the total age of the Universe t_0, were considered. The α value over this period is shown to be coincident with the modern value (within statistical uncertainties). At a 95% significance level, the following upper limits were set:

$$|\alpha^{-1} d\alpha/dz| < 6 \times 10^{-4};$$

$$|\alpha^{-1} d\alpha/dx| < 1.2 \times 10^{-4}, \text{ where } x = \ln(1+z);$$

$$|\dot{\alpha}/\alpha| < 1.5 \times 10^{-3} t_0^{-1} \sim 10^{-13} \text{ year}^{-1}.$$

These are the most stringent limits for the range of z under investigation. Furthermore, the sky distribution of α values at larger z was studied. Within a relative statistical uncertainty $3\sigma \leqslant 1\%$, the α values were found to be identical in causally unconnected spatial regions. However, at a 2σ level, the fine splitting of Si IV lines at $z = 2.2$ in the hemisphere $\alpha_{1950} = (9-21)^h$ and $\delta_{1950} = (0 \pm 90)^\circ$ (and in the opposite hemisphere) proved to be, respectively, systematically smaller and larger than the laboratory splitting. More precise observational data are required to verify this result at a higher significance level. The derived upper limits serve as criteria for the selection of theoretical models predicting the variation of α with cosmological time t. In particular, these limits exclude Teller's hypothesis of a logarithmic dependence, whereas for power laws of the form $\alpha \propto t^n$, they lead to the constraint $|n| < 8 \times 10^{-4}$.

1. INTRODUCTION

Starting from a well-known paper by Dirac [1], the problem of a possible inconstancy of fundamental physical constants has been attracting attention up to the present day. Various theoretical models for the unification of electromagnetic, weak, strong, and gravitational interactions predict different laws for the variation of the corresponding dimensionless parameters that determine the strength of interaction. Therefore, experimental restrictions on the rate of possible change in these parameters serve as important criteria for the selection of such models. Specifically, the rate of change in the constant of electromagnetic interaction $\alpha = e^2/\hbar c$, which is a key parameter of quantum electrodynamics, can be directly measured by spectroscopic means. If the α value varies with time, the relative fine splitting of multiplets should also vary. Therefore, by comparing the fine splitting for various cosmological redshifts z, one can either detect the variation of α or set an upper limit for such a measurement. Savedoff [2] was the first to use this method; he derived the estimate $\Delta\alpha/\alpha = 0.0018 \pm 0.0016$ for $z = 0.057$ from observations of the emission lines ${}^1D_2 \longrightarrow {}^3P_1$ and ${}^1D_2 \longrightarrow {}^3P_2$ of the N II and Ne III ions in the spectra of two Seyfert galaxies. Hereafter, $\Delta\alpha = \alpha_z - \alpha_0$ denotes the deviation of α at some redshift z from a laboratory value corresponding to $z = 0$.

In contrast to the astrophysical method in question, the majority of local (referring to the Earth and the Solar system) tests of the fine-structure constant for any change are model dependent. Restrictions imposed by these tests may break down, if other physical constants vary simultaneously with α. This is also true in the case of the most stringent restriction $|\dot{\alpha}/\alpha| < 10^{-17}$ yr^{-1} [3]. Having analyzed a large number of local tests with due allowance for a possible synchronous change of constants, Sisterna and Vucetich [4] obtained the upper bound $|\dot{\alpha}/\alpha| < 1.4 \times 10^{-15}$ yr^{-1}. This result refers to an epoch for which the redshifts $z < 0.2$.

The discovery of quasars made it possible to derive estimates for large redshifts. According to Bahcall and Schmidt [5], Wolfe *et al.* [6], and Bahcall *et al.* [7], $|\Delta\alpha/\alpha| < 0.005$, 0.04, and 0.1 (at a 2σ level) for $z = 0.2$, 0.52, and 1.95, respectively. A large number of high-quality spectra of quasars have been obtained in recent years, which allow the fine doublet splitting to be statistically analyzed in an effort to derive more accurate and reliable estimates covering a longer time interval of the life of the Universe. This possibility was used for the first time in Levshakov's works [8, 9], where it was estimated that $\alpha^{-1}d\alpha/dz = (2 \pm 1) \times 10^{-4}$ and

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$(3 \pm 1) \times 10^{-3}$, which suggests that α is not constant. However, having analyzed possible random and systematic errors, Potekhin and Varshalovich [10] pointed out the factors making the quoted estimates unreliable and performed a detailed analysis on the basis of extensive observational material. This analysis yielded $\alpha^{-1}d\alpha/dz = (-0.6 \pm 2.8) \times 10^{-4}$.

In this paper, we analyze new observational data that confirm the estimate derived in [10]. A refined statistical analysis of the fine doublet splitting in quasar spectra was performed using three different regression models. In addition, a possible spatial inhomogeneity of α was studied for large z. Some consequences were deduced from the results obtained for a number of theoretical model dependences of the fine-structure constant α on the age of the Universe.

2. DATA ANALYSIS

A catalog of wavelengths of the doublet absorption lines λ_1 ($^2S_{1/2} \longrightarrow {}^2P_{3/2}$) and λ_2 ($^2S_{1/2} \longrightarrow {}^2P_{1/2}$), supplemented by new data [11 - 13], which contains 1487 pairs of the lines of C IV (780 doublets), N V (50), O VI (13), Mg II (414), Al III (46), and Si IV (184 doublets) ions, serves as a data base for our analysis.[1] The advantage of absorption lines is that they are usually considerably narrower than emission lines. In addition, the merit of the above transitions is that they originate from the same level, and, consequently, λ_1 and λ_2 undoubtedly originate in the same regions of the interstellar medium.

The relative magnitude of fine splitting

$$y = \lambda_2/\lambda_1 - 1 \tag{1}$$

is proportional to α^2. By comparing its value y_z for some z with the laboratory y_0, we can estimate the change of the fine-structure constant:

$$Y(z) = \frac{1}{2}(y_z/y_0 - 1) \approx \frac{\Delta\alpha}{\alpha}. \tag{2}$$

The quantity $Y(z)$ defined by relation (2) is more suitable for analysis than $((y_z/y_0)^{1/2} - 1)$ used in [10] because (2) makes it possible to reduce the effect of nonlinear dependence of the observed Y values on random errors, when determining λ_1 and λ_2, to a minimum. Levshakov [14] pointed out that such nonlinearity could result in a systematic shift in Y when analyzing a large data set. In the analysis performed in [10], this shift was small compared to rms errors in the derived estimates. However, the systematic shift due to nonlinearity could be significant when analyzing lower resolution data. Therefore, it seems reasonable to minimize it by making use of relation (2).

[1] The catalog of doublet-line wavelengths λ_1 and λ_2 with $z > 0.2$, which were observed in quasar absorption spectra between 1980 and 1992 at a spectral resolution not lower than 6 Å, and with a sufficiently high signal-to-noise ratio ($\gtrsim 10$), was published as an Appendix to [10], accessible via electronic mail.

Another possible source of systematic errors is related to the fact that we know the laboratory wavelengths λ_1 and λ_2 with insufficient (within several mÅ) accuracy. If different types of ions are handled in a separate way, these systematic errors are eliminated by including the laboratory point $Y_0 = 0$ ($z_0 = 0$) with a relative weight of ~100 [10] in the set of analyzed data points.

Errors due to possible variations in isotopic composition are negligible. The energies of the $P_{1/2}$ and $P_{3/2}$ levels are virtually identical for all isotopes of a given ion. Therefore, when going to another isotope, the relative change in y is equal to the relative change in energy of the $S_{1/2}$ level, which does not exceed 3×10^{-6} for the ions in question.

Collisional broadening and shifts in the measured absorption lines produce even smaller errors, because the lines are formed in a tenuous interstellar medium with a number density of less than 1 cm^{-3}, so that the probability for a collision with an ion over the lifetime in the $^2P_{3/2}$ and $^2P_{1/2}$ states is negligible.

When observing a single absorption system, the most important sources of possible systematic errors may be blending of the observed doublet lines with other absorption lines and possible λ-calibration inaccuracies. However, the random orientation of absorbing clouds with respect to the line of sight makes both the increase and decrease in the measured λ due to blending equally probable. Taking into account the fact that absorption systems with different z are observed in different spectral regions, one may conclude that the errors resulting from blending and calibration inaccuracies cease to be systematic when a fairly large number of observations of different absorption systems are processed.

In [10], various statistical estimates of the quantity $\alpha^{-1}d\alpha/dz$ were made using a variety of more or less homogeneous subsamples from our catalog of doublet lines. It was shown that the best results were obtained using an estimate of the coefficients of linear regression

$$Y(z) = a + b(z - \bar{z}) \tag{3}$$

by Conquer–Basset's method [15] applied to a data subsample corresponding to an instrumental resolution FWHM (full width at half maximum) < F_m, where F_m is an empirical value corresponding to a minimum rms error. Conquer–Basset's method generalizes the method of a truncated mean [16] to the case of linear regression and involves data selection according to a certain rule ("truncation" of the sample "from top" and "from bottom"). In our analysis, the cutoff level ranged from 0.20 to 0.25. For the N V, O VI, and Al III ions, whose number of measured doublet lines is relatively small, we used all the data presented in the catalog (the F_m parameter was 6 Å). For the C IV, Mg II, and Si IV ions, the sample was restricted by the results of more accurate observations with FWHM < F_m = 3 Å. Increasing the number of data points by including the wavelengths measured with lower spectral resolution in the sample does not lead to a decrease in the resulting uncertainty. It should be noted that the number of data points must not be too small; otherwise, the possible errors due to blending and inaccurate calibration would become systematic.

Recently, it became possible to verify the results presented in [10] using a more homogeneous data set. Such a set consists of the results of observations of the quasars 0424-131 and 0450-131 with FWHM = 0.25 Å (see Table 1 in [13]). These observations have the same accuracy (by order of magnitude) in the determination of $Y(z)$ as the accuracy achieved in the analysis of the remaining data set. In this respect, we processed these high-quality data separately using the least-squares procedure.

The remaining data, however, are still useful. First, they cover a wider range of redshifts. Second, they provide information on other parts of the sky and thus allow investigation of a possible anisotropy in the distribution of the fine-structure constant, which is also performed in this paper.

3. RESULTS

Based on the techniques described in section 2, we statistically analyzed the quantity $Y(z)$ defined by expression (2) using an enlarged catalog of wavelengths of the doublets measured in quasar spectra. The following three different regression models were considered.

3.1. Redshift Dependence

Table 1 gives the estimates of weighted means for a and slope b for regression model (3). The resulting estimate yields the bound

$$|\alpha^{-1} d\alpha/dz| < \varepsilon_1 = 6 \times 10^{-4} \quad (4)$$

at a 95% significance level.

3.2. Dependence on the Logarithm of (1 + z)

A variety of time variations in the fine-structure constant are theoretically possible [17]. Therefore, in addition to (3), it makes sense to consider other regression models. Table 2 gives the results for the logarithmic dependence

$$Y(x) = a + b(x - \bar{x}), \quad x = \ln(1+z). \quad (5)$$

The corresponding bound at a 95% significance level is

$$|\alpha^{-1} d\alpha/dx| < \varepsilon_2 = 1.2 \times 10^{-3}. \quad (6)$$

Table 1. Parameters of linear regression $Y = a + b(z - \bar{z})$

Ion	a, 10^{-4}	b, 10^{-4}
C IV	2.5 ± 8.6	−0.1 ± 8.3
N V	−8 ± 11	−18 ± 11
O VI	1.6 ± 5.9	10.6 ± 8.9
Mg II	7.9 ± 8.0	11 ± 14
Al III	2 ± 12	20 ± 15
Si IV	−2.0 ± 4.2	−2.8 ± 3.5
	Resulting estimate	
	0.3 + 2.8	−1.4 ± 2.8
	Estimate from data in Table 4	
	−0.3 ± 0.7	−2.1 ± 1.8

Table 2. Parameters of linear regression $Y = a + b(x - \bar{x})$, where $x = \ln(1 + z)$

Ion	a, 10^{-4}	b, 10^{-4}
C IV	2.4 ± 8.4	3 ± 17
N V	−10 ± 11	−44 ± 23
O VI	1.6 ± 6.0	21 ± 19
Mg II	7.4 ± 8.4	19 ± 24
Al III	3.0 ± 8.9	10 ± 21
Si IV	−2.6 ± 3.9	−6.9 ± 6.6
	Resulting estimate	
	−0.2 ± 2.7	−3.3 ± 5.3
	Estimate from data in Table 4	
	−0.3 ± 0.7	−4.4 ± 3.2

Table 3. Parameters of linear regression $Y = a + b(\xi - \bar{\xi})$, where $\xi = 1 - (1 + z)^{-3/2}$

Ion	a, 10^{-4}	b, 10^{-4}
C IV	2.1 ± 7.7	5 ± 21
N V	−6 ± 10	−39 ± 31
O VI	1.6 ± 6.2	30 ± 29
Mg II	7.9 ± 9.8	27 ± 32
Al III	3.0 ± 8.8	18 ± 29
Si IV	−2.9 ± 3.8	−8.8 ± 9.3
	Resulting estimate	
	−0.5 ± 2.6	−2.8 ± 7.4
	Estimate from data in Table 4	
	−0.3 ± 0.8	−6.6 ± 4.3

Table 4. Values of $Y = \frac{1}{2}\{(\lambda_2 - \lambda_1)_z/[(\lambda_2 - \lambda_1)_0(1+z)] - 1\}$ calculated from data in [13]

Ion	Quasar	z	λ_1	λ_2	Y
C IV	PKS 0424–131	1.5544	3954.67	3961.24	0.0000
		1.5557	3956.79	3963.37	0.0005
		1.5613	3965.42	3971.98	−0.0021
		1.5632	3968.28	3974.88	0.0006
		1.7157	4204.45	4211.41	−0.0018
		1.7885	4317.20	4324.33	−0.0029
		1.7904	4320.04	4327.28	0.0044
		2.1000	4799.44	4807.44	0.0017
		2.1329	4850.47	4858.43	−0.0061
		2.1728	4912.14	4920.32	0.0012
	Q 0450–131	1.4422	3781.09	3787.31	−0.0049
		1.6967	4175.10	4182.02	−0.0012
		1.9985	4642.34	4649.92	−0.0086
		2.0666	4747.78	4755.62	−0.0030
		2.1050	4807.19	4815.16	−0.0010
		2.1066	4809.58	4817.59	0.0012
		2.2311	5002.24	5010.76	0.0126
N V	Q 0450–131	2.2312	4002.85	4015.69	−0.0011
Mg II	Q 0450–131	0.4939	4177.57	4188.27	−0.0011
		0.5481	4328.95	4339.98	−0.0037
Al III	PKS 0424–131	1.0341	3772.66	3789.02	−0.0020
		1.0348	3773.94	3790.33	−0.0012
	Q 0450–131	1.1742	4032.54	4050.04	−0.0016
		1.3107	4285.60	4304.25	−0.0002
Si IV	PKS 0424–131	2.1000	4320.69	4348.61	−0.0004
		2.1728	4422.15	4450.81	0.0010
	Q 0450–131	2.0666	4274.15	4301.80	0.0001
		2.1050	4327.59	4355.58	0.0000
		2.1068	4330.19	4358.07	−0.0022
		2.2302	4502.11	4531.22	−0.0001

3.3. Dependence on Cosmological Time

According to the standard cosmological model, the time elapsing from the instant of spectrum formation is related to cosmological redshift z by

$$t_0 - t = t_0(1 - (1+z)^{-3/2}), \quad (7)$$

where $t_0 \sim 1.5 \times 10^{10}$ years is the current age of the Universe. Accordingly, it is of interest to consider the regression dependence

$$Y(\xi) = a + b(\xi - \bar{\xi}), \quad \xi = 1 - (1+z)^{-3/2}. \quad (8)$$

The results listed in Table 3 yield the limit

$$|\alpha^{-1} d\alpha/d\xi| < \varepsilon_3 = 1.5 \times 10^{-3}, \quad (9)$$

hence, we have the bound

$$|\dot{\alpha}/\alpha| < \varepsilon_3/t_0 \sim 10^{-13}\text{yr}^{-1}. \quad (10)$$

3.4. Analysis of a Set of High-Resolution Data

The spectroscopic data from [13], given in Table 4, were handled in a separate way. They yield the estimate $\bar{Y} = (-5.8 \pm 3.4) \times 10^{-4}$ for $\bar{z} = 1.86$. Thus, this series of measurements of 30 line pairs with FWHM = 0.25 Å provides an accuracy comparable to the resulting accuracy of the above analysis of a large number of other observations. The estimates of linear-regression coefficients for the three models in question, obtained from these data by applying the least-squares procedure, are given in the lower rows of Tables 1 - 3. They again yield bounds (4), (6), and (9), but for a narrower range of redshifts and only for two close directions in the sky.

3.5. Spatial Dependence

Data contained in our catalog of doublet wavelengths allow us to investigate not only the dependence of the fine-structure constant α on redshift z, averaged over the sky, but also a possible anisotropy in the distribution of α at large z. For this purpose, we arbitrarily

Table 5. Parameters of linear regression $Y = a + b\,(z - \bar{z})$ for eight quadrants covering the celestial sphere

α_{1950}	δ_{1950}	Number of doublets	a, 10^{-4}	b, 10^{-4}
First division				
0^h - 6^h	−90° - 0°	358	13 ± 10	14 ± 9
	0 - 90	183	8 ± 17	23 ± 19
6 - 12	−90 - 0	65	−5 ± 7	−22 ± 11
	0 - 90	229	0 ± 12	−15 ± 12
12 - 18	−90 - 0	34	17 ± 28	50 ± 59
	0 - 90	299	−12 ± 8	−17 ± 9
18 - 24	−90 - 0	90	0 ± 8	−2 ± 8
	0 - 90	113	−2 ± 15	1 ± 19
Second division				
-3^h - 3^h	−90° - 0°	50	8 ± 14	21 ± 23
	0 - 90	91	−2 ± 14	1 ± 19
3 - 9	−90 - 0	175	11 ± 11	15 ± 10
	0 - 90	148	1 ± 14	−1 ±16
9 - 15	−90 - 0	92	−1 ± 9	−25 ± 13
	0 - 90	288	−1 ± 9	−14 ± 9
15 - 21	−90 - 0	23	−13 ± 24	−29 ± 21
	0 - 90	143	−7 ± 9	−18 ± 11

divided the celestial sphere into eight quadrants and estimated the parameters of regression (3) for each of them. The total number of observations in individual quadrants proved to be small. Therefore, we used the catalogued data for those C IV, Mg II, and Si IV (the most representative) ions for which the number of doublets in a given quadrant exceeded ten without any additional selection, and applied the least-squares procedure. The derived estimates for two methods of sky division are summarized in Table 5. As seen from the table, no statistically significant (at a level $3\sigma \leqslant 0.01$) difference of slope b from zero is found in any individual quadrant, which suggests that α is direction-independent at $z \sim 2$ within the level of accuracy currently attainable. Thus, the fine splitting proved to be identical in both regions that were causally unconnected at the epoch of spectrum formation.

Taking into consideration the fact that the estimates of b for four contiguous quadrants (the last four rows in Table 5) have the same sign, we analyzed the available data with FWHM $\leqslant$ 3 Å using the C IV, Mg II, Si IV, and N V ions for the corresponding hemisphere ($\alpha_{1950} = 9^h - 21^h$, $\delta_{1950} = (0 \pm 90)°$) by applying the method of a truncated mean. This hemisphere is oriented approximately in the direction of the motion of the Local group of galaxies relative to the relict microwave background. Table 6 gives the results of our analysis. It follows from them that the regression coefficient b for the above hemisphere is negative at a statistical significance of the order of 3σ, with the Si IV lines making the largest contribution to this estimate. As seen from the same table, slope b is positive at a 2σ level for the opposite hemisphere. To elucidate whether this deviation is real, more accurate observations, for which the linearity of calibration of the wavelength scale would be thoroughly verified, are required.

4. CONSEQUENCES FOR THEORETICAL MODELS

The results obtained make it possible to select a number of theoretical models for the dependence of α on cosmological time $t = t_0(1 + z)^{-3/2}$. Consider the power-law dependence

$$\alpha \propto t^n. \tag{11}$$

According to this hypothesis,

$$\alpha = \alpha_0 (1+z)^{-3n/2}. \tag{12}$$

It follows from inequalities (4), (6), and (9) that n should be much smaller than $n = 1$, suggested by Gamov [18] when developing the Dirac large-number hypothesis [1]. From formulas (6) and (12), we have the bound

$$|n| < \frac{2}{3}\varepsilon_2 \approx 8 \times 10^{-4}. \tag{13}$$

This bound excludes the values $n = 1, -1/4$, and $-4/3$ derived by Chodos and Detweiler [19], Freund [20], and Maeda [21] from theoretical Kaluza–Klein and superstring models.

The hypothesis of the logarithmic dependence

$$\alpha^{-1} \propto \ln(t/\tau). \tag{14}$$

can also be excluded. Teller [22] suggested this dependence on the basis of the large-number hypothesis, whereas Dyson [23] showed that it could be supported by considerations that follow from the method of renor-

Table 6. Number of doublets N, mean redshift $\bar{z}$, and slope b of linear regression $Y = a + b\,(z-\bar{z})$ for the hemispheres (a) $\lambda_{1950} = (9-21)^h$, $\delta_{1950} = (0 \pm 90)°$ and (b) $\alpha_{1950} = (21-24)^h$ and $(0-9)^h$, $\delta_{1950} = (0 \pm 90)°$

Ion	Hemisphere (a)			Hemisphere (b)	
	$\bar{z}$	N	b, 10^{-4}	N	b, 10^{-4}
C IV	2.0	255	-1 ± 10	285	17 ± 8
N V	2.3	24	-28 ± 31	24	-10 ± 12
Mg II	1.0	57	14 ± 24	71	9 ± 10
For three ions			-1 ± 9		9 ± 6
Si IV	2.2	71	-12 ± 4	64	7 ± 3

malization in the field theory. In the standard cosmological model, hypothesis (14) gives rise to the dependence

$$\frac{\Delta\alpha}{\alpha_0} = \left[1 - \frac{3}{2}\ln(1+z)/\ln(t_0/\tau)\right]^{-1} - 1 \approx \frac{3}{2}\,(\ln(t_0/\tau))^{-1}\ln(1+z). \quad (15)$$

Therefore, limit (6) leads to the bound

$$|\ln(t_0/\tau)| > \frac{3}{2}\,(\varepsilon_2)^{-1} = 1250. \quad (16)$$

However, the age of the Universe is $t_0 \sim 5 \times 10^{17}$ s, and the unknown time scale τ cannot be smaller than the Planck time $\tau_P = [G\hbar/c^5]^{1/2} = 5 \times 10^{-44}$ s; consequently, we arrive at the maximum possible value $\ln(t_0/\tau) = 140$ (this value would be consistent with Teller's hypothesis). Thus, condition (16) cannot be satisfied.

5. CONCLUSION

Our statistical analysis, based on a catalog of 1487 absorption doublets in quasar spectra with cosmological redshifts $0.2 < z \leqslant 3.7$, shows that there is no statistically significant variation of the fine-structure constant α. We considered three regression models and obtained the bounds $|d\ln\alpha/dz| < 6 \times 10^{-4}$, $|d\ln\alpha/d\ln(1+z)| < 1.2 \times 10^{-3}$, and $|\dot{\alpha}/\alpha| < 1.5 \times 10^{-3} t_0^{-1} \sim 10^{-13}$ yr^{-1}. These bounds were confirmed by an independent analysis of 30 pairs of doublet wavelengths measured with an especially high resolution [13].

The results obtained make it possible to reject the model dependences $\alpha^{-1} \propto \ln(t/\tau)$ [22], $\alpha \propto t$ [18], $\alpha \propto t^{-1/4}$ [20], and $\alpha \propto t^{-4/3}$ [21]. For the hypothesis $\alpha \propto t^n$, the derived estimates yield the bound $|n| < 8 \times 10^{-4}$.

Furthermore, the distribution of α depending on direction was studied. The fine splitting of Si IV lines in the celestial hemisphere $\alpha_{1950} = (15 \pm 6)^h$ and $\delta_{1950} = (0 \pm 90)°$ for $\bar{z} = 2.2$ was found to be systematically smaller (and systematically larger in the opposite hemisphere) than the laboratory value at a significance level exceeding 2σ. In order to verify this result at an even higher significance level, more accurate observational data are required. It is shown in this paper that, within a relative uncertainty of $3\sigma \leqslant 1\%$, the fine-structure constant at a cosmological epoch of $z \sim 2$ in each of the eight sky quadrants did not differ from its modern laboratory value. This suggests the constancy of α not only in time, but also in space (within the quoted limits).

Despite the fact that our restriction on $|\dot{\alpha}/\alpha|$ is not as severe as the limit obtained by Sisterna and Vucetich [4] from the analysis of local tests (for $z < 0.2$), our result is of independent importance because it refers to an earlier cosmological epoch ($z \leqslant 3.7$) and to more distant regions of the Universe that were causally unconnected at the epoch of the formation of the observed spectra.

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