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Spatial and temporal variations of fundamental constants

S. A. Levshakov[1], I. I. Agafonova[1], P. Molaro[2] and D. Reimers[3]

[1]Ioffe Physical-Technical Institute, St. Petersburg, Russia
email: lev@astro.ioffe.rssi.ru, ira@astro.ioffe.rssi.ru

[2]INAF – Osservatorio Astronomico di Trieste, Trieste, Italy
email: molaro@oats.inaf.it

[3]Hamburger Sternwarte, Hamburg, Germany
email: st2e101@hs.uni-hamburg.de

Abstract. Spatial and temporal variations in the electron-to-proton mass ratio, μ, and in the fine-structure constant, α, are not present in the Standard Model of particle physics but they arise quite naturally in grant unification theories, multidimensional theories and in general when a coupling of light scalar fields to baryonic matter is considered. The light scalar fields are usually attributed to a negative pressure substance permeating the entire visible Universe and known as dark energy. This substance is thought to be responsible for a cosmic acceleration at low redshifts, $z < 1$. A strong dependence of μ and α on the ambient matter density is predicted by chameleon-like scalar field models. Calculations of atomic and molecular spectra show that different transitions have different sensitivities to changes in fundamental constants. Thus, measuring the relative line positions, ΔV, between such transitions one can probe the hypothetical variability of physical constants. In particular, interstellar molecular clouds can be used to test the matter density dependence of μ, since gas density in these clouds is ~15 orders of magnitude lower than that in terrestrial environment. We use the best quality radio spectra of the inversion transition of NH_3 $(J, K) = (1, 1)$ and rotational transitions of other molecules to estimate the radial velocity offsets, $\Delta V \equiv V_{\rm rot} - V_{\rm inv}$. The obtained value of ΔV shows a statistically significant positive shift of $23 \pm 4_{\rm stat} \pm 3_{\rm sys}$ m s^{-1} (1σ). Being interpreted in terms of the electron-to-proton mass ratio variation, this gives $\Delta\mu/\mu = (22 \pm 4_{\rm stat} \pm 3_{\rm sys}) \times 10^{-9}$. A strong constraint on variation of the quantity $F = \alpha^2/\mu$ in the Milky Way is found from comparison of the fine-structure transition $J = 1 - 0$ in atomic carbon C I with the low-J rotational lines in carbon monoxide ^{13}CO arising in the interstellar molecular clouds: $|\Delta F/F| < 3 \times 10^{-7}$. This yields $|\Delta\alpha/\alpha| < 1.5 \times 10^{-7}$ at $z = 0$. Since extragalactic absorbers have gas densities similar to those in the ISM, the values of $|\Delta\alpha/\alpha|$ and $|\Delta\mu/\mu|$ at high-z are expected to be at the same level as estimated in the Milky Way providing no temporal dependence of α and μ is present. We re-analyzed and reviewed the available optical spectra of quasars to probe $\Delta\alpha/\alpha$ from intervening absorbers. The Fe I system at $z = 0.45$ towards HE 0000–2340 provides one of the best opportunities for precise measurements of $\Delta\alpha/\alpha$ at low redshift. The current estimate is $\Delta\alpha/\alpha = (7 \pm 7) \times 10^{-6}$. With the updated sensitivity coefficients for the Fe II lines we re-analyzed the $z = 1.84$ system from the high-resolution UVES/VLT spectrum of Q 1101–264 ($FWHM = 3.8$ km s^{-1}) and found $\Delta\alpha/\alpha = (4.0 \pm 2.8) \times 10^{-6}$. The most accurate upper limit on cosmological variability of α is obtained from the Fe II system at $z = 1.15$ towards the bright quasar HE 0515–4414 ($V = 14.9$): $\Delta\alpha/\alpha = (-0.12 \pm 1.79) \times 10^{-6}$, or $|\Delta\alpha/\alpha| < 2 \times 10^{-6}$. The limit of 2×10^{-6} corresponds to the utmost accuracy which can be reached with available to date optical facilities.

Keywords. line: profiles – techniques: radial velocities – ISM: molecules – quasars: absorption lines – cosmology: observations