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VLT and E-ELT spectrographs & fundamental-constants

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The fundamental dimensionless physical constants cannot be predicted by theory but can only be measured experimentally. And so it is of their possible variation where there are several theoretical predictions but unfortunately with little theoretical guidance on the expected rate of change. The role of fundamental constants in the representation of nature as well as the implications of their variability for the Equivalence Principle and cosmology have been highlighted in many contributions at this conference (cfr K. Olive and J.P Uzan, these proceedings). Measuring the variability of the fine structure constant α or the electron-to-proton ratio μ by means of absorption lines implies the measurement of a tiny variation of the position of one or a few lines with regard to other lines which are taken as reference. For the fine structure constant the relation between its change and the doppler velocity shift is:

$$\frac{\Delta\alpha}{\alpha} \approx \frac{\Delta v}{2c}\Delta Q \tag{0.1}$$

where Q are the coefficients which describe the sensitivity of the wavelength to α. The Q values are theoretically computed and typical values are of order ≈ 0.02. Given these sensitivities in order to reveal changes of one part per million in α we need to be able to detect relative shifts of about 20 $\mathrm{m\,s^{-1}}$. A similar relation holds for the line position the Lyman and Werner lines of molecular hydrogen and the sensitivity coefficients of to a change of μ are reflected in the K coefficients.

The precision with which the wavelength of a spectral transition can be determined from an absorption line depends on the signal-to-noise of the spectrum, the intrinsic width of the absorption line, the spectrograph resolution and pixel size. The wavelength error decreases with signal-to-noise with the decreasing intrinsic line width and with increasing spectrograph resolving power until the intrinsic line width is resolved. A convenient expression for the wavelength error of a gaussian line:

$$\sigma_0 = \frac{1}{(2\pi \ln 2)^{1/4}} \frac{1}{S/N} \sqrt{\Delta_{\rm pixel}\rm FWHM}.$$

However, in addition to photon noise there are the errors of instrumental origin and those coming from the wavelength calibration. It is rather questionable if these can be below 50 m/s, thus becoming the dominant source of uncertainty for measures of $\frac{\Delta\alpha}{\alpha}$ with the ambition to reach the 1 ppm level accuracy. An ideal instrument to probe fundamental constants such as the fine structure constant and the electron-to-proton mass ratio by means of absorption lines in QSOs spectra is a spectrograph which combine high throughput, high resolution and high stability and is compulsory attached to a telescope with a large photon collecting area. The ESPRESSO proposal for the incoherent combined VLT focus, and CODEX for the E-ELT, keep these recipes and, although not being optimized for this purpose, hold the promise to improve the present limits by about two orders of magnitude. Thus either these physical constants are varying within this range or they would likely escape astronomical detection.