Using radio OH lines to measure changes in fundamental constants

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Much interest has recently centred on the possibility that fundamental "constants" such as the fine structure constant α, the electron-proton mass ratio m_e/m_p, etc might vary with cosmic time. Many theoretical models, including Kaluza-Klein theories and superstring theories, predict spatio-temporal variation of these constants. While terrestrial experiments have so far shown no evidence for such changes, these measurements only probe a tiny fraction of the age of the Universe. Astrophysical studies of redshifted spectral lines provide a powerful probe of putative changes in fundamental constants over large fractions of the age of the Universe. Unfortunately, most of the astrophysical techniques used to measure (or constrain) such changes involve a comparison between the redshifts of transitions of different species (e.g. the HI 21cm line, millimetre-wave molecular lines and optical fine structure lines). These species are unlikely to all arise at the same physical location in a gas cloud and might thus have systematic velocity offsets relative to each other; the redshift differences may thus be dominated by these effects rather than the measurement errors (i.e. the spectral resolution, which can be quite small, $\sim$ few km/s, for HI 21cm and mm-wave molecular absorption spectra). Conclusions drawn from a comparison between different species might thus well be incorrect.

I describe here a new technique to estimate variations in fundamental constants, using multiple radio OH lines. This allows a simultaneous measurement of changes in the fine structure constant α, the proton gyromagnetic ratio g_p and the electron-proton mass ratio m_e/m_p, using redshifted OH lines from a single cosmologically distant object. The technique makes use of the fact that radio OH lines arise from two very different physical mechanisms, Lambda-doubling and hyperfine splitting, and thus have very different dependences on α, m_e/m_p and g_p. It has the advantage that all lines arise in the same species, allowing a relatively clean comparison between the measured redshifts. Further, a comparison between OH column densities obtained from each line can be used to test whether the lines arise from the same gas.

I will present the first application of this technique, to the $z \sim 0.685$ gravitational lens toward 0218+357. We have detected the "main" 1665 MHz and 1667 MHz ground state OH lines in this system; however, the satellite ground state lines, which are necessary for the technique, have so far not been found. We hence use the "main" OH lines in conjunction with published HI 21cm and HCO^+ redshifts to constrain changes in α, g_p and m_e/m_p over the redshift range $0 < z \lesssim 0.68$. This involves the usual assumption that all three species (OH, HI and HCO^+) are at the same physical location in the cloud. While the constraints are relatively weak ($\lesssim 1$ part in 10^3), this is the first simultaneous constraint on the variation of all three parameters. Further assuming (as is often done) that g_p is constant allows us to place very strong constraints on changes in α and m_e/m_p.

Finally, I will also present the first detection of the 18cm OH satellite lines at a cosmological distance, from the $z \sim 0.25$ source PKS 1413+135. The 1720 MHz and 1620 MHz profiles are perfectly conjugate, in that the sum of their optical depths is consistent with noise; this implies that the lines arise in precisely the same gas. This allows us to test for any changes in the values of fundamental constants, without being affected by systematic uncertainties arising from relative motions between the gas clouds in which the different lines arise. The redshifts of the line peaks are found to agree with each other, within the error bars; this is used to place strong constraints on changes of α, g_p and m_e/m_p, consistent with no evolution in their values over the redshift range $0 \lesssim z \lesssim 0.25$.