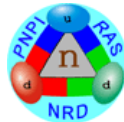


Atomic and molecular spectra as probes for fundamental constants

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Azores, 10 July 2009

Fundamental constants in atomic physics

There are three fundamental constants, which influence atomic and molecular spectra:

- Fine structure constant $\alpha = e^2/(\hbar c)$;
- Electron to proton mass ratio $\beta = m_e/m_p$;
- Nuclear gyromagnetic ratio g_n .

When we are studying variation of fundamental constants, we are looking for lines with high sensitivity to the variation of fundamental constants. The dimensionless sensitivity coefficients are defined as:

$$\frac{\delta\omega}{\omega} = K_{\alpha} \frac{\delta\alpha}{\alpha} + K_{\beta} \frac{\delta\beta}{\beta} + K_g \frac{\delta g_n}{g_n}.$$

In astrophysics such frequency shifts lead to the difference between the apparent and actual redshifts z' and z :

$$\frac{\delta\omega}{\omega} = -\frac{z' - z}{1 + z'}$$

When we observe two lines with different sensitivities, their apparent redshifts will differ if fundamental constants has changed during the time passed:

$$\frac{\delta z'}{1 + z'} = -\Delta K_{\alpha} \frac{\delta\alpha}{\alpha} - \Delta K_{\beta} \frac{\delta\beta}{\beta} - \Delta K_g \frac{\delta g_n}{g_n}.$$

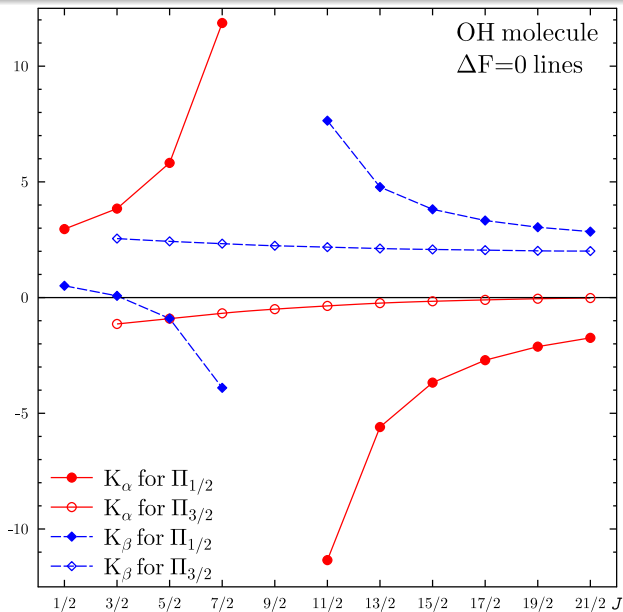
Sensitivity coefficients for different wavebands

Transition	K_α	K_β	K_g
<i>Optical and UV bands</i>			
typical E1-transition in atoms	$10^{-2} - 10^{-1}$	10^{-3}	10^{-7}
electronic transitions in molecules	10^{-2}	10^{-2}	10^{-7}
<i>Microwave and FIR bands</i>			
fine-structure M1-transitions	2	0.0	0.0
vibrational transitions	0.0	0.5	0.0
rotational transitions	0.0	1.0	0.0
21-cm hyperfine transition in hydrogen	2.0	1.0	1.0
18-cm Λ -doublet line in OH	-1.14	2.55	0.0
1.25-cm inversion line in NH ₃	0.0	4.5	0.0

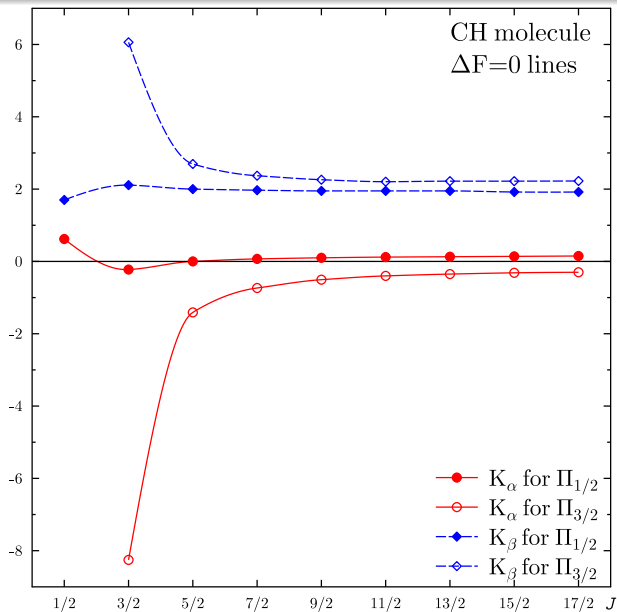
One of the best studied extragalactic microwave spectra belongs to the object B0218+357 at $z = 0.68$ (look-back time of approximately 6.3 Gyr). This spectrum includes 21-cm Hydrogen line, several rotational lines of OH, HCO⁺, and HCN molecules, 18-cm Λ -doublet lines of OH molecule, and several inversion lines of NH₃. These lines were used to place limits on variations of all three fundamental constants:

$$\left\{ \begin{array}{l} \delta\beta/\beta = (-0.6 \pm 1.9) \times 10^{-6}, \\ \delta\alpha/\alpha = (0.9 \pm 6.4) \times 10^{-6}, \\ \delta g_n/g_n = (0 \pm 17) \times 10^{-6}. \end{array} \right.$$

Λ -doublet transitions (spin decoupling)



Λ -doublet transitions (spin decoupling)



Λ -doublet transitions (hyperfine anomaly)

