Limits on Lorentz Invariance in Electrodynamics

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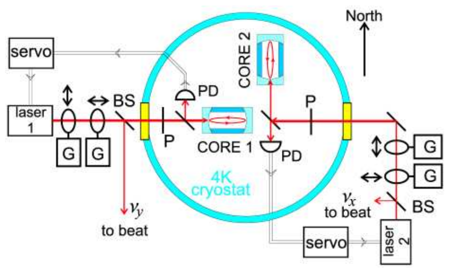
Increasingly accurate tests of special relativity (constancy of speed of light and Lorentz invariance) are imperative as it underlies all accepted physical theories. Many test theories exist to model and interpret experiments that test Lorentz invariance. I explain a kinematical framework known as Robertson-Mansouri-Sexl framework. This framework assumes a preferred frame Σ (usually cosmic microwave background) in which the speed of light c is constant. In a frame S moving with velocity $\overrightarrow{v}$, speed of light $c(\theta, v)$ depends on the angle of propagation of light with respect to $\overrightarrow{v}$, and the magnitude v of $\overrightarrow{v}$ [2, 4, 1].

$$\frac{c(\theta,v)}{c} = 1-(A+Bsin^2\theta)\frac{v^2}{c^2}; \qquad A=\alpha-\beta+1\ ,\ B=\beta-\delta-1/2 \tag{1}$$

α is time dilation parameter, β is length contraction parameter parallel to $\overrightarrow{v}$, δ is length contraction parameter parallel to $\overrightarrow{v}$.

Modern Michelson-Morley experiments determine the coefficent B of the direction dependent term. Kennedy-Thorndike experiments measure the coefficient A of the velocity dependent term. Finally, clock-comparison and Doppler shift (Ives-Stilwell) experiments measure α [3]. I will discuss a modern Michelson-Morley experiment [1] in which $\overrightarrow{v}$ is the Earth's velocity (taken as velocity of solar system $\approx$ 369km/s) with respect to CMB Σ. The concept is to measure the difference in speed of light in two orthogonal directions (hence the analogy to original MM experiment) using resonating frequency $\nu = mc/2L$ of two orthogonal optical cavities.



Two lasers are actively locked by servo control to the resonating frequencies of the two cavities. The cavities are cooled to 4.2K in a cryostat to ensure low frequency drift of $<$ 0.1Hz/hr. Galvanometer mounted glass plates are used to actively maximise the coupling between the lasers and the cavities despite mechanical deformations of the cryostat. The beat frequency between these two lasers is measured separately (not shown in the figure) over a more than 1 year period. $\overrightarrow{v}$ is assumed constant. The rotation of earth varies θ differently for the two cavities as the direction of light w.r.t. $\overrightarrow{v}$ varies causing beat frequency to vary as below (neglecting smaller Fourier components).

$$\frac{\nu_x-\nu_y}{\bar{\nu}} = -B\frac{1}{2}\,(1+cos^2\chi)\,cos^2\xi\,cos(2\omega T_M S) \tag{2}$$

χ is lab's colatitude, ξ is $\overrightarrow{v}$'s declination. $T_M S$ is time with zero chosen suitably.

Using this, B is obtained as $(-2.2 \pm 1.5)\cdot 10^{-9}$. This has an inaccuracy about 3 times lower than the previous results of two different experiments $(-3.0 \pm 4.9)\cdot 10^{-9}$ [4] and $(-1.5 \pm 4.2)\cdot 10^{-9}$ [3].

References

[1] Holger Muller, et al., Phys. Rev. Lett. 91, 020401 (2003).

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[3] Peter Wolf, et al., Phys. Rev. Lett. 90, 060402 (2003).

[4] A. Brillet, and J.L.Hall, Phys. Rev. Lett. 42, 549 (1979).