1 Introduction

Experiments can be described in any inertial frame using the space time transformation of the special theory of relativity (SRT) as far as gravitational effects can be neglected. The existence of a preferred cosmological frame of reference [1] would violate the underlying symmetries of the theory. The natural candidate for such a preferred frame would be the the 3K cosmic background radiation horizon with a relative velocity to the solar system of \( v' = 300 \text{ km/s} \) [2, 3].

All known experiments are in agreement with the special theory of relativity. Local deviations due to the general theory of relativity are beyond the limitations of present experiments. Nevertheless, it is an experimental challenge to establish new upper limits for any deviation from the special theory of relativity.

In a historical key experiment in 1938 Ives and Stilwell [4] have determined the Doppler shifted spectrum of a fast hydrogen beam as a function of its kinetic energy. In this experiment the time dilation factor

\[
\gamma_{\text{SRT}} = (1 - \beta^2)^{-1/2},
\]

where \( \beta = v/c \) is the atoms’ velocity \( v \) measured in units of the speed of light \( c \), was tested for any additional terms which could be present as a result of a hypothetical deviation from the Lorentz transformation between two inertial reference frames.

Mansouri and Sexl [5] have developed a test theory for deviations induced by the presence of any preferential frame with relative velocity \( \beta' \) with respect to the laboratory and a moving clock with relative velocity \( \beta \) in the laboratory frame. These small and hypothetical deviations can be expressed in general as a function \( f(\beta, \beta') \) which modifies the time dilation factor to

\[
\gamma = (1 - \beta^2)^{-1/2} \cdot (1 + \alpha \cdot f(\beta, \beta'))
\]

where \( \alpha \) is a parameter measuring this deviation ( \( \alpha = 0 \) for SRT).
In the original experiment $\alpha$ could be determined to < 0.01. Modern modifications have used highly relativistic hydrogen beams. At the Los Alamos Meson Physics Facility (LAMPF) in New Mexico, USA, a limit of $\alpha < 1.9 \cdot 10^{-4}$ was found for $\beta = 0.84$ [6]. At the NASA Jet Propulsion Laboratory an upper limit of $\alpha < 1.8 \cdot 10^{-4}$ could be established with $\beta = 0.0016$ [7].

Among the most accurate tests, Mößbauer rotor experiments using fast moving disks yielded $\alpha < 10^{-5}$ [8]. The space born experiment "Gravity Probe A", employing highly stable hydrogen maser clocks, determines from the frequency residuals between experiment and theory an upper limit of $\alpha < 2.1 \cdot 10^{-6}$ [9]. It also produced today's most stringent test on gravitational red shift [1].

In a laser spectroscopy experiment using the $3s^{[3]}[3]^{0} - 4d^{[5]}[5]^{0}$ transition in $^{20}$Ne atoms at $\beta = 3.6 \cdot 10^{-3}$ the limit for the existence of any preferred frame of reference was set to $\alpha < 1.4 \cdot 10^{-6}$ [10]. An atomic two-photon transition is induced by two counter-propagating laser beams. This technique is considered "Doppler free" spectroscopy, since the first order terms $(1 + \beta)$ and $(1 - \beta)$ cancel and the resonance condition is given through $\nu_0 = 2\gamma \nu_{\text{laser}}$.

With the realization of heavy ion storage rings like the Test Storage Ring (TSR) in Heidelberg a new generation of experiments became feasible. A relativistic $^{7}$Li$^{+}$ ion beam with well defined velocity, i.e. small momentum spread, can be used for high resolution laser spectroscopy at the TSR. These ions had been investigated before at many places with high accuracy as they are fundamental two electron systems, e.g. in the laboratory of G. zu Putlitz [11]. The $^{7}$Li$^{+}$ ions are stored as fast moving clocks at 13.3 MeV particle energy corresponding to $\beta = 0.064$. Two transitions with frequencies $\nu_1$ and $\nu_2$ in the rest frame are used in the experiment, as explained in Sec. 2. The first one is observed with a laser beam parallel to the ion beam, the second one with an antiparallel laser beam. In the laboratory frame, the resonance frequencies are Doppler-shifted to $\nu_a$ and $\nu_p$, respectively. They are compared with two clocks at rest, realized by single-mode lasers stabilized to calibrated transitions in molecular $^{127}$I$_2$, in order to determine the frequencies $\nu_a$ and $\nu_p$ on an absolute scale. According to SRT they are related to the resonance frequencies $\nu_1$ and $\nu_2$ in the particle rest frame by

$$\nu_p = \nu_1 \gamma (1 - \beta)$$
$$\nu_a = \nu_2 \gamma (1 + \beta)$$

(3)

In the special theory of relativity the relation between the clock rates in the moving system and the laboratory system is

$$\nu_a \nu_p = \nu_1 \nu_2$$

(4)

since $\gamma^2 (1 - \beta)(1 + \beta) = 1$, independent of the clock's velocity. Any deviation of the time dilation factor from Eq. (1) may be written as

$$\tilde{\gamma} = \gamma_{\text{SRT}} (1 + \alpha \beta^2 + \text{higher order corrections})$$

(5)