Tests of Lorentz Symmetry in the Spin-Coupling Sector

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Abstract. An overview is given of recent and ongoing experiments constraining Lorentz violation in the spin-coupling sector, with particular focus on the author's tests of Lorentz symmetry using a $^{129}Xe/^{3}He$ Zeeman maser and an atomic hydrogen maser.

1 Introduction

Experiments involving spin-polarized systems provide some of the most sensitive tests of Lorentz symmetry. Most commonly, these spin-coupling experiments are modern versions of Hughes-Drever experiments, in which devices related to highly-stable atomic clocks are used to search for a sidereal variation of an atomic Zeeman splitting as the apparatus is rotated and/or boosted by the Earth's motion or by a movable platform. Such experiments usually have several important features:

(1) *High-sensitivity to absolute changes in spin precession frequency*, which generally entails a narrow-bandwidth spin resonance, a large signal-to-noise ratio, and stability over the sidereal modulation period.
(2) *Suppression of sensitivity to magnetic fields*, often by using a co-magnetometer that does not eliminate sensitivity to Lorentz violation.
(3) *Careful engineering to minimize systematics*, e.g., diurnal and seasonal environmental changes for experiments that exploit the Earth's motion to rotate and boost the apparatus.
(4) *A simple spin structure*, to allow a clean interpretation of the experimental results for possible Lorentz-violation of electrons, neutrons, and/or protons.

In the following I provide a brief discussion of six recent and ongoing tests of Lorentz symmetry in the spin-coupling sector, giving particular focus to the experiments with which I am most familiar – i.e., the experiments performed by my group. The results from these experiments are interpreted in terms of the Standard-Model extension (SME) [1], which is reviewed extensively by R. Bluhm in this volume on page 191.

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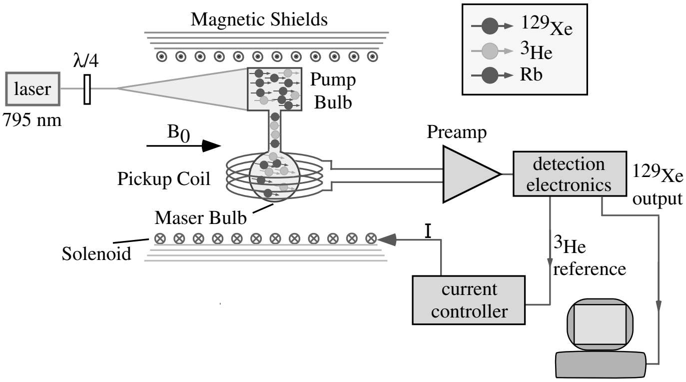

Fig. 1. Schematic of the Harvard-Smithsonian ^{129}Xe/^{3}He Zeeman maser

2 ^{129}Xe/^{3}He maser (Harvard-Smithsonian Center for Astrophysics)

Using a two-species ^{129}Xe/^{3}He Zeeman maser, the author and collaborators at the Harvard-Smithsonian Center for Astrophysics placed a limit on rotation-dependent Lorentz violation involving the neutron of 10^{-31} GeV [2], improving by more than an order of magnitude on the best previous measurement [3, 4]. With the same device we performed the first clean test for the fermion sector of the symmetry of spacetime under boost transformations, placing a limit on boost-dependent Lorentz violation involving the neutron of 10^{-27} GeV [5].

We provide here a brief review of the design and operation of the two-species ^{129}Xe/^{3}He maser. (See the schematic in Fig. 1.) Co-located ensembles of ^{129}Xe and ^{3}He atoms at pressures of hundreds of mbar are held in a double-chamber glass cell placed in a homogeneous magnetic field of ∼1.5 G. Both species have spin-1/2 nuclei and the same sign nuclear magnetic dipole moment, but no higher-order electric or magnetic nuclear multipole moments. In one chamber of the glass cell, the noble gas atoms are nuclear-spin-polarized by spin-exchange collisions with optically-pumped Rb vapor [11]. The noble gas atoms diffuse into the second chamber, which is surrounded by an inductive circuit resonant both at the ^{3}He and ^{129}Xe Zeeman frequencies (4.9 kHz and 1.7 kHz, respectively). For a sufficiently high flux of population-inverted nuclear magnetization, active maser oscillation of both species can be maintained indefinitely.

Due to the generally weak interactions of noble gas atoms with the walls and during atomic collisions, the ^{3}He and ^{129}Xe ensembles can have long Zeeman coherence (T_2) times of hundreds of seconds. It is possible to achieve excellent absolute frequency stability with one of the noble-gas masers by using the second maser as a co-magnetometer. For example, Zeeman frequency measurements with sensitivity of ∼100 nHz are possible with averaging intervals of about an hour. This two-species noble gas maser can also serve as a sensitive NMR gyroscope [12]: the above quoted frequency stability implies a rotation sensitivity of about 0.6 μrad/s averaged over an hour.

In the context of the SME, the neutron – and hence the noble-gas maser – is sensitive to Lorentz violation controlled by the coefficients b_Λ, $d_{\Lambda\Sigma}$, $H_{\Lambda\Sigma}$, and $g_{\Lambda\Sigma\Gamma}$ of the SME [1]. We assume that these coefficients are static and spatially uniform in the Sun frame, at least over the course of a solar year. Thus, the frequencies of the noble-gas masers acquire a time dependence as a consequence of the Earth's rotation and its revolution around the Sun.

In the completed Lorentz-symmetry test, the ^{129}Xe maser was phase-locked to a signal derived from a hydrogen maser in order to stabilize the magnetic field which was oriented along the east-west direction. The leading Lorentz-violating frequency variation of the free-running ^{3}He maser was given by:

$$\delta\nu_{\mathrm{He}} = \delta\nu_X \ \sin\ \omega_\oplus T_\oplus + \delta\nu_Y \ \cos\ \omega_\oplus T_\oplus \ , \tag{1}$$

where

$$\begin{aligned} \delta\nu_X &= k\ (\lambda_s + \beta_\oplus(\Lambda_{ss}\sin\Omega_\oplus T + \Lambda_{sc}\cos\Omega_\oplus T))\ , \\ \delta\nu_Y &= k\ (\lambda_c + \beta_\oplus(\Lambda_{cs}\sin\Omega_\oplus T + \Lambda_{cc}\cos\Omega_\oplus T))\ . \end{aligned} \tag{2}$$

Here λ_c, λ_s, Λ_{ss}, $\Lambda_{sc}, \ldots$ are combinations of Sun-frame SME coefficients mentioned above [5]; $\omega_\oplus$ is the Earth's sidereal angular rotation frequency; $\Omega_\oplus$ is the angular frequency of the Earth's orbital motion; the time $T_\oplus$ is measured in the Sun-centered frame from the beginning of the sidereal day; the time T sets the timescale in the Sun-centered frame (see [5]); $\beta_\oplus$ is the ratio of the Earth's orbital speed to the speed of light; and $k = -8.46 \cdot 10^{32}$ nHz/GeV [2].

We note that (1) and (2) cleanly distinguish the effects of rotation alone (terms proportional to λ_c and λ_s) from the effects of boosts due to the Earth's motion (terms proportional to Λ_{cc}, Λ_{cs}, Λ_{sc}, Λ_{ss}). These equations also indicate that the sensitivity of our experiment to violations of boost-symmetry is reduced by a factor of $\beta_\oplus \simeq 10^{-4}$ with respect to the sensitivity to rotation-symmetry violation.

As discussed in [2] and [5], we acquired noble-gas maser data in four different runs spread over about 13 months (see Fig. 2). Each run lasted about 20 days, and we reversed the direction of the magnetic field about halfway through each run to help distinguish possible Lorentz-violating effects from diurnal systematic variations. We fit this data to (1). Figure 2 shows, for each run, the mean values we determined for $\delta\nu_X$ and $\delta\nu_Y$, the amplitudes of sidereal-day modulations of

Table 1. Bounds from the competed noble gas maser experiment on 17 SME coefficients among the 44 coefficients describing possible leading-order Lorentz- and CPT-violating coupling of the neutron

SME Coefficients	GeV
$\tilde{b}_X, \tilde{b}_Y$	$[10^{-31}]$
$\tilde{d}_X, \tilde{d}_Y, \tilde{g}_{DX}, \tilde{g}_{DY}$	$[10^{-28}]$
$\tilde{b}_T, \tilde{d}_{XY}, \tilde{d}_{YZ}, \tilde{d}_+, \tilde{d}_-, \tilde{d}_Q, \tilde{g}_T, \tilde{g}_c, \tilde{H}_{XT}, \tilde{H}_{YT}, \tilde{H}_{ZT}$	$[10^{-27}]$

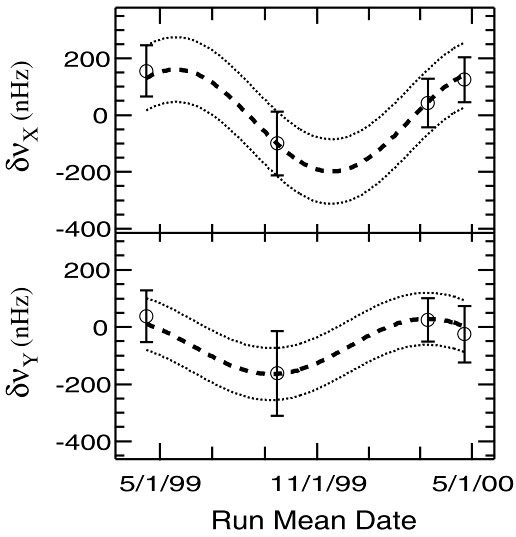

Fig. 2. Time course of the mean values of $\delta\nu_X$ and $\delta\nu_Y$ from the completed noble gas maser Lorentz symmetry test. For each plot the dashed line is the best fit obtained from (2), using the fit parameters λ_c, λ_s, Λ_{cc}, Λ_{cs}, Λ_{sc}, Λ_{ss}. Dotted lines indicate the $1\,\sigma$ confidence bands for the fit model

the ^{3}He-maser frequency due to Lorentz-violating coefficients in the $\hat{X}$ and $\hat{Y}$ directions (Sun-centered frame). For each run, $\delta\nu_X$ and $\delta\nu_Y$ correspond to a very good approximation to a single high-precision measurement of the X and Y components of $\delta\nu_{He}$ performed at the run's mean time.

Next, we fit the experimental values of $\delta\nu_X$, $\delta\nu_Y$ to (2), thus obtaining the fit shown graphically in Fig. 2, and the corresponding bounds on the SME coefficients of Table 1. We treated all fit parameters as independent and we extracted energy bounds for SME coefficients disregarding the possibility of accidental mutual cancellations. This analysis yielded no significant violation of rotation invariance with a limit of about 70 nHz on the magnitude of the daily sidereal variation in the ^{3}He-maser frequency and no significant violation of boost invariance, with a limit of about 150 nHz on the magnitude of an annual modulation of the daily sidereal variation. This experiment was not limited by systematic effects.

We expect an order of magnitude or more improved sensitivity to Lorentz violation of the neutron using a reengineered version of our ^{129}Xe/^{3}He maser – a project currently underway. The new device has been designed to improve the frequency stability of the noble gas masers, which limits the current sensitivity to Lorentz violation. Improved temperature control of the pump and maser regions, better co-magnetometry through optimized gas pressures and cell geometry, and the use of a narrow spectrum laser for optical pumping should help achieve this goal. Further improvements in sensitivity may be possible with a ^{21}Ne/^{3}He

Zeeman maser [13], with masers located on a rotating table, or with space-based clocks [14].

3 Hydrogen Maser (Harvard-Smithsonian Center for Astrophysics)

The author and collaborators employed atomic hydrogen masers to set an improved clean limit on rotation-violation of the proton, at the level of nearly 10^{-27} GeV [6].

Hydrogen masers operate on the $\Delta F = 1$, $\Delta m_F = 0$ hyperfine transition in the ground state of atomic hydrogen [15]. Hydrogen molecules are dissociated into atoms in an RF discharge, and the atoms are state selected via a hexapole magnet (Fig. 3). The high field seeking states, ($F = 1$, $m_F = +1, 0$) are focused into a Teflon coated cell which resides in a microwave cavity resonant with the $\Delta F = 1$ transition at 1420 MHz. The $F = 1$, $m_F = 0$ atoms are stimulated to make a transition to the $F = 0$ state by the field of the cavity. A static magnetic field of ~1 milligauss is applied to maintain the quantization axis of the H atoms.

The hydrogen transitions most sensitive to potential Lorentz violations are the $F = 1$, $\Delta m_F = \pm 1$ Zeeman transitions, which are effectively degenerate (with frequency $\nu_Z < 1$ kHz) for the typical static magnetic field. We utilize a double resonance technique to measure the Zeeman frequency with a precision of ~1 mHz [6, 16, 17]. We apply a weak oscillating magnetic field perpendicular to the static field, and slowly sweep the oscillating field's frequency through the Zeeman transition. This audio-frequency driving field couples the three sublevels

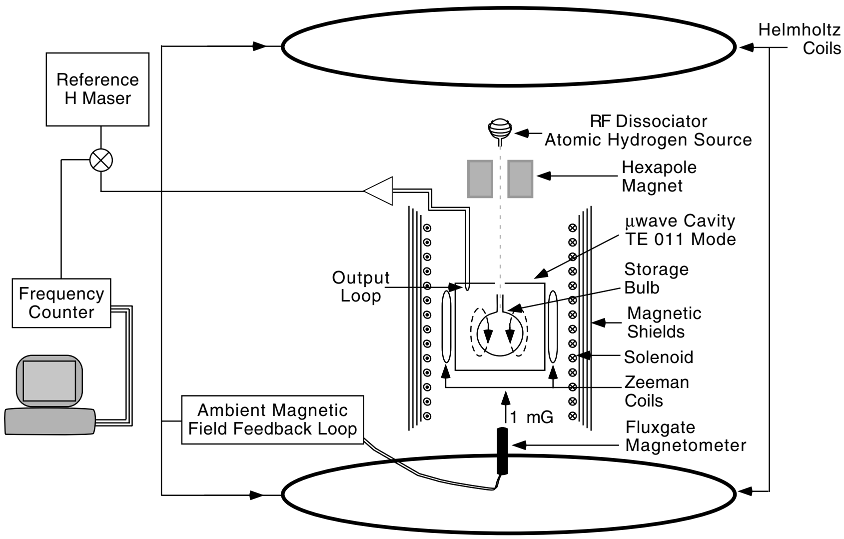

Fig. 3. Schematic of the Harvard-Smithsonian H maser in the ambient field stabilization loop used for Lorentz symmetry tests

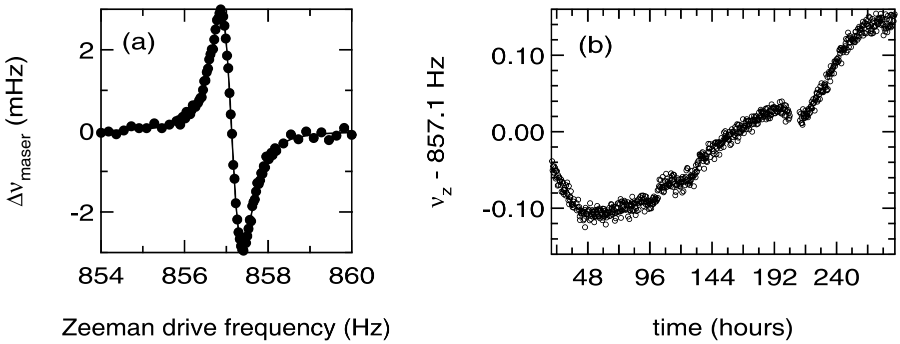

Fig. 4. (**a**) An example of a double resonance measurement of the $F = 1$, $\Delta m_F = \pm 1$ Zeeman frequency in the hydrogen maser. The change from the unperturbed maser frequency is plotted versus the driving field frequency. (**b**) Zeeman frequency data from 11 days of the completed Lorentz symmetry test using the H maser

of the $F = 1$ manifold of the H atoms. Provided a population difference exists between the $m_F = \pm 1$ states, the energy of the $m_F = 0$ state is altered by this coupling, thus shifting the measured maser frequency in a carefully analyzed manner [6, 16, 17] described by a dispersive shape (Fig. 4a). Importantly, the maser frequency is unchanged when the driving field is exactly equal to the Zeeman frequency. Therefore, we determine the Zeeman frequency by measuring the driving field frequency at which the maser frequency in the presence of the driving field is equal to the unperturbed maser frequency.

We employ an active stabilization system to cancel external magnetic field fluctuations (Fig. 3). A fluxgate magnetometer placed within the maser's outer magnetic shield controls large (2.4 m dia.) Helmholtz coils surrounding the maser via a feedback loop to maintain a constant ambient field. This feedback loop reduces the fluctuations at the sidereal frequency to below the equivalent of 1 μHz on the Zeeman frequency at the location of the magnetometer.

In the completed H maser Lorentz symmetry test, the hydrogen Zeeman frequency was measured for 32 days using the double resonance technique. During data taking, the maser remained in a closed, temperature controlled room to reduce potential systematics from thermal drifts which might be expected to have 24 hour periodicities. The feedback system also maintained a constant ambient magnetic field. Each Zeeman measurement took approximately 20 minutes to acquire and was subsequently fit to extract a Zeeman frequency (Fig. 4a). Also monitored were maser amplitude, residual magnetic field fluctuation, ambient temperature, and current through the solenoidal coil which determines the Zeeman frequency (Fig. 3).

The data were then fit to extract the sidereal-period sinusoidal variation of the Zeeman frequency. (See Fig. 4b for an example of 11 days of data.) In addition to the sinusoid, piecewise linear terms (whose slopes were allowed to vary independently for each day) were used to model the slow remnant drift of the

Zeeman frequency. No significant sidereal-day-period variation of the hydrogen $F = 1$, $\Delta m_F = \pm 1$ Zeeman frequency was observed, setting a bound on the magnitude of such a variation of $\delta\nu_Z^H \leq 0.37$ mHz (one-sigma level). This experiment was not limited by systematic effects.

In the context of the SME, the H maser measurement constrains Lorentz (rotation) violation of the proton parameter $|\tilde{b}^p_{x,y}| \leq 2 \cdot 10^{-27}$ GeV at the one sigma level (Earth-centered frame), given the much more stringent limits on Lorentz violation of the electron set with spin-torsion pendula (see discussion below).

We expect that the sensitivity of the H maser Lorentz symmetry test can be improved by more than an order of magnitude through technical upgrades to the maser's thermal and magnetic field systems; better environmental control of the room housing the maser; and a longer period of data acquisition. Such improvements are underway.

4 Spin-Torsion Pendula (University of Washington and Tsing-Hua University)

In separate research efforts, groups at the University of Washington (Adelberger, Gundlach, Heckel et al.) and Tsing-Hua University in Taiwan (Hou, Ni, and Li) each employ a spin-torsion pendulum to search for Lorentz violation of the electron. The Univ. Washington effort is the most established, and has achieved sensitivity to certain SME rotation-violation parameters for the electron ($\tilde{b}^e_{x,y}$) at the level of 10^{-30} GeV [18]. The Taiwan experiment, which is not reviewed here, has set somewhat less-stringent bounds for rotation-violation of the electron: $|\tilde{b}^e_{x,y}| < 3 \times 10^{-29}$ GeV [19]. (Here, an Earth-centered frame is used, with the $\hat{z}$ axis taken to lie along the rotational north pole.)

The Univ. Washington group employs a pendulum test mass with a large net electron spin dipole moment but a small magnetic moment, thereby enabling a sensitive search for Lorentz-violating spin-coupling with minimal confounding magnetic interactions. The pendulum has a toroidal (ring) geometry constructed fromeight sections of two different kinds of permanent magnets: four sections of an aluminum-nickel-cobalt-iron alloy (Alnico) and four sections of a samarium-cobalt magnet ($SmCo_5$). The magnetization in Alnico comes primarily from electron spin while the magnetization in $SmCo_5$ is produced both by electron spin and the orbital angular momentum of the Sm ions. The octagon magnet ring is assembled with the Alnico pieces on one side and the $SmCo_5$ pieces on the other. The Alnico is then magnetized to the same degree as the $SmCo_5$, with the result that the magnetization runs azimuthally within the ring. Thus there is both near perfect cancellation of the net magnetic moment of the pendulum and also a net electron spin excess within the Alnico side. Four such rings are stacked in an ABBA pattern with their net electron spin axes aligned, to form a pendulum with a net spin dipole of $(8 \pm 1) \times 10^{22}$ electron spins pointing perpendicular to the central axis of the magnet stack. The basic layout and principle is illustrated in Fig. 5.

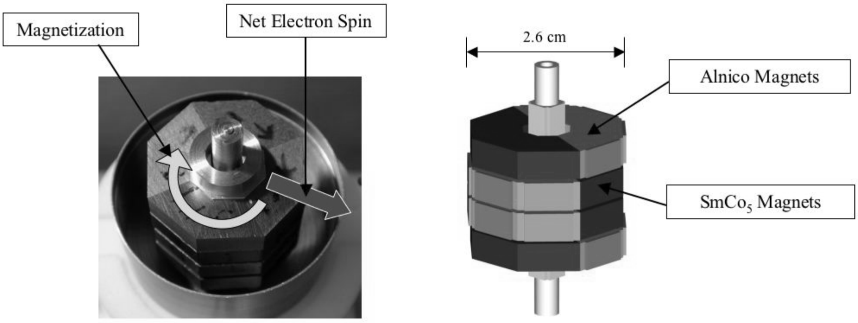

Fig. 5. (*Left*) Top of the stack of four magnet rings that consitute the University of Washington spin pendulum. Superimposed arrows indicate the directions of the (azimuthal) magnetization and the large net electron spin. (*Right*) Stack of 4 magnet rings in an ABBA pattern, which constitute the spin pendulum. Small plates are added to the Alnico sections to give them the same mass as the SmCo sections

The spin pendulum is suspended from a tungsten torsion fiber and centered within four layers of high permeability magnetic shields. The pendulum and shields are housed within a vacuum chamber, which is mounted on a turntable that rotates at a constant rate of approximately 4 rev/hr. A feedback loop locks the output of a precise rotary encoder attached to the rotating vacuum chamber to the frequency of a crystal oscillator to ensure a constant rotation rate. Diode laser light is doubly reflected from one of four mirrors mounted on the pendulum, and the reflected beam is focused onto a linear position sensitive photodiode to monitor the angular position of the pendulum, with a sensitivity of a few nanoradians. The apparatus is surrounded by three-axis Helmholtz coils and carefully positioned masses to reduce magnetic and gravitational field gradients. As the vacuum chamber and pendulum within it rotate relative to the laboratory, any Lorentz-violating field coupling to electron spin induces a torque on the pendulum modulated at the rotation period of the turntable. In about one hundred days of preliminary data acquisition in 2004/05, no such rotation-violation was observed, at the level of approximately 10^{-30} GeV; also, no evidence has been found of systematic error, e.g., from temperature effects, magnetic coupling to the pendulum, and gravitational gradients [18]. The Univ. Washington group is currently acquiring an additional year of data, with an expected sensitivity of $|\tilde{b}^e_{x,y}| \approx 3 \times 10^{-31}$ GeV, as well as potential sensitivity of $\sim 10^{-27}$ GeV to boost symmetry violation in the electron sector.

^{199}Hg/^{133}Cs co-magnetometer (Amherst College)

An experiment is underway at Amherst College (Hunter and collaborators) to compare the precession frequencies of ^{199}Hg and ^{133}Cs magnetometers as a function of the sidereal rotation and boost of the system's quantization axis (set by a weak applied magnetic field). This experiment is a successor to a high-precision test of Lorentz symmetry performed in 1995 [3], which provided the most sensitive limits for rotation-symmetry-violation of the neutron ($\sim 10^{-30}$ GeV) prior to the noble gas maser experiment discussed above. Both the 1995 and current Amherst experiments employ optically-pumped Hg and Cs magnetometer cells, which are specially prepared to provide long spin-relaxation times. Each cell is probed independently as a light-absorption oscillator, which allows sensitive measurement of the associated spin precession frequency and thus the average magnetic field at each cell. A series of coils and several layers of surrounding magnetic shields create a very homogeneous magnetic field (~ 5 mG) across all magnetometer cells. Typically, one Cs cell is placed between two Hg cells, such that the average magnetic field at the Hg cells is the same as the field at the Cs cell if there is any remnant, linear gradient of the magnetic field. See Fig. 6. The signature of Lorentz-violation is a modulation of the Hg and/or Cs spin precession frequencies as the quantization axis rotates or boosts sidereally. ^{199}Hg has no electron spin and nuclear spin 1/2 (with the dominant contribution coming from a valence neutron), whereas ^{133}Cs has electron spin 1/2 and nuclear spin 7/2 (with complicated nuclear structure and contributions from both neutrons and protons).

The 1995 experiment had excellent short-term sensitivity to effects coupling to the nuclear and electronic spins of ^{199}Hg and ^{133}Cs; however, the experiment relied on the Earth's rotation and the long-term stability was compromised by its environmental sensitivity and drift in operational parameters. Improvements

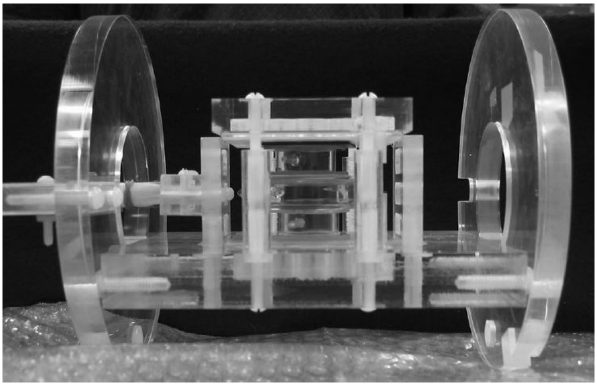

Fig. 6. Magnetometer cell assembly for the Lorentz symmetry test currently being performed at Amherst College. One Cs cell resides between two Hg cells in a vertical stack at the center of the assembly

in the new experiment include a solid state laser system, which has replaced the earlier experiment's Hg discharge lamp. The intensity, frequency and polarization of the laser light are carefully regulated and should result in improved long-term stability of the Hg magnetometer. In addition, the entire new apparatus (save the first two stages of the Hg laser) has been mounted on a rotation table, and assembled vertically in the lab such that the magnetic shields rotate about their axis of symmetry. The apparatus is rotated between two positions approximately every 6 minutes to take advantage of the Hg/Cs co-magnetometer's excellent short-term sensitivity. These positions correspond to the applied magnetic field pointing either perpendicular or parallel to the rotation axis of the Earth. The parallel position provides a fixed reference direction (i.e., with no leading-order Lorentz-violation effect). Taking the difference between measurements made in these two positions allows removal of contributions from slow drifts in the apparatus over a sidereal-day-period, which is the signature of a preferred spatial direction. These technical upgrades are expected to enable two orders of magnitude greater sensitivity to Lorentz violation than the 1995 measurement, with the greatest sensitivity being for the neutron.

5 K/^{3}He Co-Magnetometer (Princeton University)

At Princeton University, Romalis and collaborators are currently pursuing a promising Lorentz symmetry test using co-located K and ^{3}He atoms, which together act as a zero-field, self-compensating magnetometer and provide excellent sensitivity to non-magnetic fields that couple differently to the K and ^{3}He spins [20–22]. Optical pumping by a strong pump laser spin-polarizes the K atoms along the longitudinal axis (the direction of the pump beam's propagation). Any small transverse component of the K spin-polarization (e.g., induced by Lorentz-violating fields) is measured by optical rotation of a weak probe laser beam directed orthogonal to the pump beam. The K atoms are maintained at relatively high-density ($\sim 10^{13}\,\mathrm{cm}^{-3}$) and near-zero magnetic field in order (i) to eliminate decoherence of K spin-precession due to K-K spin-exchange collisions [23], and (ii) to provide excellent signal-to-noise for measurement of transverse K spin-polarization. K-^{3}He collisions polarize the ^{3}He nuclei through a transient hyperfine interaction, and also enhance the dipolar interaction between K and ^{3}He atoms. The spin-polarized ^{3}He gas is at high density ($\sim 10^{20}$ cm^{-3}), and thus develops a significant magnetization which imposes an effective magnetic field $\sim$1 mG on the K atoms. A longitudinal magnetic field is applied to cancel this effective ^{3}He field, such that the total magnetic field experienced by the K atoms vanishes. The ^{3}He magnetization adiabatically follows slow changes in the transverse magnetic field, thereby compensating for magnetic field drifts and maintaining the K atoms in a highly-stable zero field. Thus, transversely-directed Lorentz-violating fields that couple differently to the K and ^{3}He spins will induce a small transverse K spin-polarization, both through a direct torque on the K spins, and through an induced misalignment of the ^{3}He magnetization

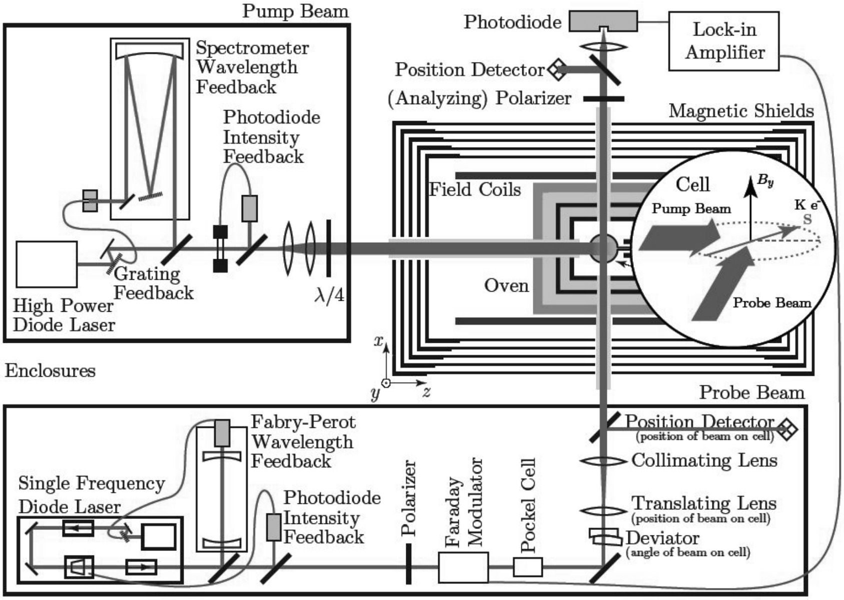

Fig. 7. Schematic of the K/^{3}He co-magnetometer at Princeton University currently being used in a high-precision test of Lorentz symmetry

and the applied magnetic field with a resultant torque of the net magnetic field on the K spins. The Princeton group relies on the Earth's motion to rotate and boost the apparatus; hence signals for Lorentz violation would include a sidereal day and year period modulation of the transverse K spin-polarization.

A schematic of the Princeton experiment is shown in Fig. 7. A near-spherical 2.5 cm diameter glass cell holds the K and ^{3}He atoms, along with 50 Torr of N_2 gas to inhibit radiation trapping in the optical pumping process. A blown-air oven heats the magnetometer cell to about 175°C to create the appropriate K density. Five-layer magnetic shields provide isolation of $\sim 10^6$ to external magnetic fields, and precision coils create a uniform longitudinal magnetic field (to balance the effective ^{3}He magnetic field experienced by the K atoms). A 770 nm, 1 W broad area diode laser provides optical pumping on the K $D1$ line; a single-mode diode laser with a tapered amplifier produces the 50 mW probe beam, which is linearly polarized and detuned about 1 nm to the blue of the $D1$ line. Both the pump and probe beams have active control of their wavelength and intensity. The probe beam polarization is weakly modulated before passing through the magnetometer cell, and lock-in detection is used to measure any optical rotation induced by a transverse component of the K spin-polarization. With this system, the Princeton group has achieved short-term sensitivity of $\sim 10^{-31}$ GeV for anomalous fields coupling to the neutron spin, and $\sim 10^{-28}$ GeV for anomalous fields coupling to the electron spin. To realize precision tests of rotation and boost symmetry, this excellent short-term sensitivity must be realized over periods of a sidereal day and year. The Princeton group is currently working to stabilize long-term drifts in system parameters and to characterize systematic effects. For example, small motions of the pump and probe beams, driven by drifts in environmental temperature, have proven to be a primary source of systematic error. Once these effects are reduced or controlled, it is expected that the K/^{3}He co-magnetometer will enable sensitivity to rotation (boost) violation up to $\sim 10^{-33}$ GeV ($\sim 10^{-29}$ GeV) for the neutron, and $\sim 10^{-30}$ GeV ($\sim 10^{-26}$ GeV) for the electron.

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