Complete-Coverage Searches for Lorentz Violation in the Minimal Matter Sector

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Abstract

Over the past several decades, dozens of tests have sought Lorentz violation in the nonrelativistic limit of the minimal matter sector of the Standard-Model Extension. Of the 132 Lorentz-violating degrees of freedom that are observable in this limit, 43 remain unconstrained. In this work, we demonstrate how existing experiments and data sets can be used to generate relevant sensitivities to all of these remaining degrees of freedom. We extract limits on all 43 of the previously unconstrained degrees of freedom and make additional improvements on 13 existing limits using published data. Our methods also offer the potential of improvements for 49 degrees of freedom in suitable future experiments. Further, the approach introduced here can be used to leverage data taken at different locations on Earth to achieve independent sensitivities to additional linear combinations of coefficients providing expanded discovery potential.

I. INTRODUCTION

Several decades ago, the identification of Lorentz violation as a possible signal of new physics at the Planck scale [1] initiated a renewed interest in tests of Lorentz symmetry. A framework for organizing a systematic search for Lorentz violation across all of physics has been developed and is known as the Standard-Model Extension (SME) [2]. Lorentz violation can be triggered by various mechanisms [3], but generally can be modeled via a condensate of background vectors and tensors called coefficients for Lorentz violation. The coefficients provide preferred directions in empty spacetime and hence generate violations of rotation and boost invariance for systems involving particles that couple to the backgrounds resulting in broken global Lorentz symmetry [4].

The SME is constructed as an effective field theory that provides an expansion about known physics in operators of increasing mass dimension. The additional terms are constructed from the known fields in the Standard Model and General Relativity along with the coefficients for Lorentz violation. The terms in this expansion with the same mass dimension as the operators in known physics are known as the minimal SME [5].

Because of the relative simplicity of the terms involved in the minimal SME, and the

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fact that precision experiments involving ordinary matter are relatively common, dozens of searches for coefficients for Lorentz violation in the minimal SME associated with ordinary matter (protons, neutrons, and electrons) in flat spacetime have been performed. These tests have now reached truly impressive levels of sensitivity. For example, some coefficients with units of mass are limited to less than 10^{-29} times the mass of the electron, which by conventional thinking is well beyond one Planck suppression. Despite this effort, a significant number of coefficients in this sector remain unconstrained [6].

In nonrelativistic studies involving protons, neutrons, electrons and their antiparticles, there are 132 independently observable coefficients for Lorentz violation, among which 43 remain unconstrained [6]. In this work, we provide a complete approach to addressing this deficiency, which utilizes existing high-precision experiments analyzed to higher order in their boost velocities. In addition to providing 43 new constraints, we improve existing limits on 13 coefficients and provide a template for improving sensitivities to 49 coefficients in future experiments. This approach also expands discovery potential by providing independent access to the full set of minimal matter-sector coefficients through searches with additional characteristic time dependence.

II. BACKGROUND

The Lagrange density for the minimal matter sector of the SME takes the form [2]

$$\mathcal{L} = \tfrac{1}{2} i\overline{\psi}(\gamma_\nu + c_{\mu\nu}\gamma^\mu + d_{\mu\nu}\gamma_5\gamma^\mu + \tfrac{1}{2} g_{\lambda\mu\nu}\sigma^{\lambda\mu}) \overset{\leftrightarrow}{\partial^\nu} \psi - \overline{\psi}(m + b_\mu\gamma_5\gamma^\mu + \tfrac{1}{2} H_{\mu\nu}\sigma^{\mu\nu})\psi. \qquad (1)$$

Here ψ is the fermion field, γ^μ denotes the standard Dirac matrices, m is the conventional Lorentz-invariant mass, and the objects b_μ, $c_{\mu\nu}$, $d_{\mu\nu}$, $g_{\lambda\mu\nu}$, and $H_{\mu\nu}$ are the coefficients for Lorentz violation. For brevity, we omit coefficients a_μ, e_μ, and f_μ, which can be removed from the theory in the limit considered here [2, 7]. We avoid further discussion of $c_{\mu\nu}$ because all of its components have been probed already by existing analysis [6]. We also omit the trace of $d_{\mu\nu}$ from consideration as it is not Lorentz violating. The coefficients have no special symmetries beyond the defining antisymmetry of $g_{\lambda\mu\nu}$ and $H_{\mu\nu}$ on the first two indices. The 44 observable degrees of freedom per fermion are chosen as combinations of the coefficients above denoted with a related letter and an overtilde, the so-called "tilde coefficients" [6].

For example, the combination $\tilde{b}_J$, which will play a key role in this work, takes the form

$$\tilde{b}_J = b_J - \tfrac{1}{2}\varepsilon_{JKL}H_{KL} - m(d_{JT} - \tfrac{1}{2}\varepsilon_{JKL}g_{KLT}). \tag{2}$$

The complete set of tilde-coefficient definitions, as well as the inverse transformations can be found in Tables P56 and P57 of Ref. [6].

By convention, the coefficients for Lorentz violation are taken as spacetime constants in Cartesian coordinates in a standard Sun-centered reference frame, which is inertial to a good approximation over the time scale of the relevant experiments [6]. The coefficients are then time-dependent in the frame of Earth-based laboratories due to various motions that include the sidereal rotation of the laboratory, the time-dependent boost of Earth as it revolves around the Sun ($\beta_\oplus \sim 10^{-4}$) at the annual frequency Ω, and the time-dependent boost of the laboratory as it revolves around Earth's rotation axis ($\beta_L \sim 10^{-6}$) at the sidereal frequency ω_L. In the presence of Lorentz violation, these motions typically generate periodic signals in laboratory systems at the associated annual and sidereal frequency and harmonics and combinations of them, which form the potential experimental signatures of Lorentz violation that we exploit. In this work, we denote components of vectors and tensors in the Sun-centered frame with capital indices and components in the lab frame with lower-case indices. Nonzero values for the coefficients for Lorentz violation generally result in violations of both boost and rotation invariance. It is only in special limits of the SME where special frames can be found in which rotation invariance is preserved.

III. EXTENDED FRAME TRANSFORMATIONS

When signals are sought via boost effects, they are suppressed compared to rotation-invariance tests by multiples of the boost velocities involved. For this reason, along with the complicated nature of the frame transformations, most tests have focused on signals associated with Earth's rotation or one power of $\beta_\oplus$ (see, e.g., Refs. [8–12]). To date only two analyses have considered effects at second order in the boost velocities: one in the context of the $c_{\mu\nu}$ coefficients in the matter sector [13] and the other in the photon sector [14]. In this work, we exploit effects that arise with suppression factors of up to 20 orders of magnitude coming from one boost suppression by $\beta_\oplus$ or β_L as well as by combinations arising at second $\{\beta_\oplus^2, \beta_L\beta_\oplus, \beta_L^2\}$, third $\{\beta_\oplus^3, \beta_L\beta_\oplus^2, \beta_L^2\beta_\oplus, \beta_L^3\}$, fourth $\{\beta_\oplus^4, \beta_L\beta_\oplus^3, \beta_L^2\beta_\oplus^2\}$, and fifth $\{\beta_\oplus^5\}$ order in the boost factors. Note that combinations at fourth and fifth order that would generate a suppression by more than 20 orders of magnitude are not considered here. Though a circular model for Earth's orbit is sufficient for most purposes, we use an eccentric model of a Kepler orbit here taking into consideration the time-dependent variations of $\beta_\oplus$. The eccentricity of Earth's orbit $\varepsilon \sim 10^{-2}$ can be treated as an additional small quantity in our perturbative analysis generating an additional set of suppression factors that can be obtained from the above lists via the replacement $\beta_\oplus^p \to \varepsilon^{2q}\beta_\oplus^{p-q}$ for integer powers $p > 1$ and integers $1 \leq q < p$. Our work takes into account the precession of the Earth's spin axis since the year 2000, the time origin of the standard coordinate system for SME studies. This is relevant because experiments seeking sidereal effects performed at different times are sensitive to different linear combinations of coefficients. We also consider the impact of Earth's equatorial bulge on β_L, but find no significant effects.

We choose to end our perturbation series at 20 orders of suppression as it allows the inclusion of terms that are necessary and sufficient to provide complete coverage in the matter sector. Further, when applied to the most sensitive experiments, limits emerge that are competitive with other existing limits on coefficients for Lorentz violation.

At the level of the nonrelativistic Hamiltonian relevant for laboratory experiments that results from Eq. (1), a number of terms appear that can be useful in probing Lorentz violation [15]. In this work, we focus on the term

$$H \supset H_b = \tilde{b}_j(t)\sigma^j, \tag{3}$$

where $\tilde{b}_j(t)$ is the lab-frame version of $\tilde{b}_J$ and σ^j are the Pauli matrices. While consideration of additional terms in H is of definite interest, we focus on H_b due to the high sensitivities to this term that have been achieved [11, 16, 17], the large number of relevant experiments that have been done [6], and the breadth and depth of sensitivities that result from the current study when this term is considered.

Since $\tilde{b}_J$ is a vector under observer rotations, $\tilde{b}_j(t)$ can be achieved from $\tilde{b}_J$ via the application of a simple rotation matrix when boosts are ignored. To achieve the form of $\tilde{b}_j(t)$ to arbitrary order in the boosts parameters, we proceed by applying the full transformation from the Sun-centered frame to the lab frame to each of the coefficients $\{b_J, d_{TJ}, H_{KL}, g_{KLT}\}$.

For a coefficient with a generic number of indices $t_{\Sigma\Xi\ldots}$ this transformation can be written

$$t_{\sigma\xi\ldots} = \Lambda^{\Sigma}{}_{\sigma}\Lambda^{\Xi}{}_{\xi}t_{\Sigma\Xi\ldots}, \tag{4}$$

where $\Lambda^{\Sigma}{}_{\sigma}$ is the full transformation matrix including a boost from the Sun-centered frame to the Earth-centered frame, a boost from the Earth-centered frame to a frame traveling with the laboratory on the surface of the Earth, and finally a rotation that aligns the coordinates with the standard fixed choice in the lab [18]. The results of this transformation applied to each coefficient are then inserted into the lab-frame definition of $\tilde{b}_j(t)$ to achieve its form in terms of the constant Sun-centered frame coefficients and its explicit time dependence. The transformation to tilde coefficients can then be used to write the Lorentz-violating degrees of freedom in the standard form used in the literature. This approach allows us to extend the existing work, which treats experiments as occurring in instantaneous Lorentz frames within special relativity (see, e.g., Ref. [19]), to arbitrary powers in a series expansion in the relevant boost parameters. The consideration of non-inertial frame effects as well as the effects of gravity may also be of interest, but are beyond our present scope [20].

IV. CONSTRAINTS AND SUGGESTED SEARCHES

A given experiment can potentially make a large number of independent measurements by seeking each of the relevant Fourier components of $\tilde{b}_j(t)$ for each of the three Cartesian components in the lab. At the order to which we work, signals can be found at frequencies

$$\omega = n_1\omega_L \pm n_2\Omega \tag{5}$$

for $n_1 \in \{0, 1\}$ and $n_2 \in \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$, or $n_1 \in \{2\}$ and $n_2 \in \{0, 1, 2, 3, 4, 5, 6\}$. Moreover, the amplitude of a signal typically depends on the colatitude at which the experiment is performed. Hence, experiments at different colatitudes probe different linear combinations of coefficients. As one example of the structures that arise, which are in general quite lengthy, we present explicitly the leading contributions to $\tilde{b}_x$ that vary as $\sin(2\omega_L t + \Omega T)$ in a simpler circular orbit model that is independent of the precession of the Earth's spin axis:

$$\tilde{b}_x \supset \tfrac{1}{4}\beta_L\beta_\oplus \cos(\chi)[\sin^2(\tfrac{\eta}{2})(\tilde{b}_Y - 2\tilde{d}_Y + \tilde{g}_{DY} + \tilde{g}_{TY}) + 2\sin(\tfrac{\eta}{2})\cos(\tfrac{\eta}{2})\tilde{g}_{TZ}]\sin(2\omega_L t + \Omega T). \quad (6)$$

Here T is the time coordinate of the Sun-centered frame, t is measured from one of the times at which the local coordinates align with the Sun-Centered frame coordinates, η is the inclination of Earth's orbit, χ is the colatitude of the laboratory, and $\tilde{d}_Y$, $\tilde{g}_{DY}$, $\tilde{g}_{TY}$, and $\tilde{g}_{TZ}$ are additional tilde coefficients that emerge as observables in this double boost-suppressed contribution.

In the context of a test framework such as the SME that is broad and general so as to capture the physical effects of many possible models, one must decide how many degrees of freedom to fit at one time. One popular approach is to consider the coefficients one Lorentz-violating degree of freedom at a time in a so-called maximum reach analysis [10]. The other approach, known as a coefficient separation approach, is to consider some larger subset, such as all of the components of a single coefficient, or all of the minimal coefficients associated with a particular particle, etc. [10]. In this work, we present results in the context of a maximum reach analysis. However, our methods enable exciting new possibilities in the context of a coefficient separation approach as well.

We perform a maximum reach analysis for all three species of ordinary matter using experimental data from Ref. [17] for the neutron; Ref. [11] for the electron; and Ref. [17], as adapted in Ref. [21], for the proton. Each of these experiments used H_b to measure some combination of $\tilde{b}_{x,y}(t)$ at the sidereal frequency to extract limits on $\tilde{b}_J$. In this work, we extract real maximum-reach bounds in Table I by reinterpreting the published bounds on $\tilde{b}_J$ as bounds on the additional tilde coefficients that appear in $\tilde{b}_{x,y}(t)$ with boost suppression at the sidereal frequency. These amount to 43 new first-ever maximum-reach limits on coefficients, as well as 13 improvements on previous bounds. For coefficients that appear at frequencies other than the sidereal frequency that have not been studied experimentally, we provide estimated sensitivities based on the assumption that the appropriate amplitudes could be extracted with an intrinsic experimental sensitivity similar to existing results at the sidereal frequency. The best sensitivities that can be achieved for the relevant coefficients using the methods presented here are also reported in Table I along with a frequency at which they can be found. In total, this results in 67 coefficients whose bounds are either newly constrained, improved over prior limits, or could be improved via an analysis at a suitable additional frequency.

Note that when near-sidereal frequencies are used, care must be taken to decide if these signals are sufficiently close to the sidereal frequency such that they would be detected in a sidereal search, or if they are separable and require specific consideration of these Fourier components. The former perhaps offers some simplicity in extracting maximum-reach bounds while the later provides more independent measurements useful in simultaneously fitting multiple coefficients. These ideas have already been exploited for one suppression by $\beta_\oplus$ using the frequencies $\omega_L \pm 2\Omega$ in electron experiments [9]. It is also possible to deal with partially overlapping Fourier components [22]. When similar sensitivities to a given coefficient could be achieved at multiple different frequencies, Table I presents the frequency that is likely to be the easiest to separately observe.

Perhaps even more interesting than extracting the new limits is the additional discovery potential provided by studies at higher powers of the boost. This potential arises from two basic sources: seeking time dependence at additional frequencies and performing experiments at different latitudes. Consider first the additional frequencies in Eq. (5). The estimated sensitivities in Table I are arising because additional coefficients are appearing at these additional frequencies that have not yet been explored in the data. Hence exploring these frequencies offers discovery potential. Similarly, β_L is a function of latitude – experiments closer to the equator experience a higher boost than those near the poles. In some cases additional latitude dependence arises due to experimental considerations associated with the alignment of the experiment with the local vertical direction. Hence, otherwise identical experiments at different latitudes can measure linearly independent combinations of coefficients. Fundamentally, this implies that Lorentz violation can evade detection in an experiment at one latitude while being detected in an experiment at another latitude.

Turning to a constraint-based perspective on this line of thinking, if Lorentz violation is not seen, we can ask how many Lorentz violating degrees of freedom can be simultaneously probed using H_b experiments and the powers of the boost considered here. Of the 132 degrees of freedom observable with nonrelativistic ordinary matter, we excluded the 27 that are associated with $c_{\mu\nu}$ which are not relevant in the context of H_b experiments. This leaves 35 degrees of freedom per fermion. By considering the dimension of the null space of distinct sets of measurements, we find that independent sensitivities to all 35 tilde coefficients can be achieved when a set of suitable H_b experiments are performed at different latitudes and/or extract the amplitudes of the signals from a variety of the Fourier components associated with the frequencies in Eq. (5). It is also worth noting that which set of frequencies and latitudes is sufficient to constrain the entire space is dependent on the maximum order of magnitude chosen for the series expansion of the boost parameters.

By including up to 24 orders of suppression, using two experiments at different latitudes involving the same species extracting signals at both the sine and cosine phases of the frequencies ω, 2ω, Ω, 2Ω, 3Ω for both horizontal lab directions suffices to span the full space of 35 coefficients. This same outcome can also be achieved using a single experiment, extracting signals at the same phases and directions of 12 different frequencies instead of five. One example of a suitable set of frequencies is ω, 2ω, Ω, 2Ω, 3Ω, $\omega + 2\Omega$, $\omega - 2\Omega$, $\omega + 3\Omega$, $\omega - 3\Omega$, $2\omega + 2\Omega$, $2\omega - 2\Omega$, $2\omega - 3\Omega$, but not all combinations of 12 frequencies are necessarily sufficient. For experiments capable of extracting both phases of both horizontal lab directions, see Refs. [11, 16].

V. CONCLUSION

We perform an analysis that obtains sensitivities to all of the remaining unmeasured coefficients in the minimal matter sector of the SME based on a reinterpretation of published results. The complete coverage of this coefficient space is a significant milestone given the dozens of experiments that have been done since this sector of the SME was first developed more than 25 years ago. We also provide estimates for numerous significant improvements that could be obtained from additional analysis of existing experimental data sets or the analysis of feasible new experiments. Such analysis would offer added discovery potential. This work demonstrates the impact that consideration of boost effects beyond first order can have in the ongoing search for Lorentz violation as a signal of Planck-scale physics. Similar consideration in other sectors, as well as in the context of operators beyond the minimal level, offers a considerable space for further exploration.

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Coeff	Electron			Proton			Neutron		
	Current	Feasible	Frequency	Current	Feasible	Frequency	Current	Feasible	Frequency
$\tilde{b}_X$	10^{-31}	-	-	10^{-32}	-	-	10^{-33}	-	-
$\tilde{b}_Y$	10^{-31}	-	-	10^{-32}	-	-	10^{-33}	-	-
$\tilde{b}_Z$	10^{-29}	-	-	$\mathbf{10^{-29}}$	-	-	$\mathbf{10^{-30}}$	-	-
$\tilde{b}_T$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	$\omega_L + \Omega$	$\mathbf{10^{-27}}$	$\mathbf{10^{-29}}$	$\omega_L + \Omega$
$\tilde{b}^*_X$	10^{-22}	-	-	10^{-24}	-	-	$\mathbf{10^{-12}}$	$\mathbf{10^{-16}}$	$\omega_L - 2\Omega$
$\tilde{b}^*_Y$	10^{-22}	-	-	10^{-24}	-	-	$\mathbf{10^{-15}}$	$\mathbf{10^{-16}}$	$\omega_L - 2\Omega$
$\tilde{b}^*_Z$	10^{-23}	-	-	10^{-24}	-	-	$\mathbf{10^{-15}}$	-	-
$\tilde{d}_+$	10^{-27}	-	-	$\mathbf{10^{-27}}$	$\mathbf{10^{-28}}$	Ω	10^{-27}	$\mathbf{10^{-29}}$	Ω
$\tilde{d}_-$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	$\omega_L + \Omega$	$\mathbf{10^{-27}}$	$\mathbf{10^{-29}}$	$\omega_L + \Omega$
$\tilde{d}_Q$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	Ω	$\mathbf{10^{-27}}$	$\mathbf{10^{-29}}$	$\omega_L - \Omega$
$\tilde{d}_{XY}$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	$\omega_L + \Omega$	10^{-27}	$\mathbf{10^{-29}}$	$\omega_L + \Omega$
$\tilde{d}_{YZ}$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-27}}$	$\omega_L + \Omega$	$\mathbf{10^{-27}}$	$\mathbf{10^{-28}}$	$\omega_L + \Omega$
$\tilde{d}_{ZX}$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	Ω	$\mathbf{10^{-27}}$	$\mathbf{10^{-29}}$	Ω
$\tilde{d}_X$	10^{-22}	-	-	10^{-27}	-	-	10^{-28}	-	-
$\tilde{d}_Y$	10^{-22}	-	-	10^{-27}	-	-	10^{-28}	-	-
$\tilde{d}_Z$	$\mathbf{10^{-22}}$	-	-	$\mathbf{10^{-23}}$	-	-	$\mathbf{10^{-24}}$	-	-
$\tilde{H}_{XT}$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	Ω	$\mathbf{10^{-27}}$	$\mathbf{10^{-29}}$	Ω
$\tilde{H}_{YT}$	10^{-26}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	Ω	$\mathbf{10^{-27}}$	$\mathbf{10^{-29}}$	Ω
$\tilde{H}_{ZT}$	10^{-26}	$\mathbf{10^{-27}}$	$\omega_L - \Omega$	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	$\omega_L - \Omega$	10^{-27}	$\mathbf{10^{-29}}$	$\omega_L - \Omega$
$\tilde{g}_T$	10^{-27}	-	-	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	Ω	10^{-27}	$\mathbf{10^{-29}}$	$\omega_L + \Omega$
$\tilde{g}_c$	10^{-26}	$\mathbf{10^{-27}}$	$\omega_L + \Omega$	$\mathbf{10^{-26}}$	$\mathbf{10^{-28}}$	$\omega_L + \Omega$	10^{-27}	$\mathbf{10^{-29}}$	$\omega_L + \Omega$
$\tilde{g}_Q$	$\mathbf{10^{-21}}$	-	-	$\mathbf{10^{-23}}$	-	-	$\mathbf{10^{-24}}$	-	-
$\tilde{g}_-$	$\mathbf{10^{-21}}$	$\mathbf{10^{-22}}$	2Ω	$\mathbf{10^{-23}}$	$\mathbf{10^{-24}}$	2Ω	$\mathbf{10^{-24}}$	-	-
$\tilde{g}_{TX}$	$\mathbf{10^{-22}}$	-	-	$\mathbf{10^{-23}}$	-	-	$\mathbf{10^{-24}}$	-	-
$\tilde{g}_{TY}$	$\mathbf{10^{-22}}$	-	-	$\mathbf{10^{-23}}$	$\mathbf{10^{-24}}$	$\omega_L - 2\Omega$	$\mathbf{10^{-24}}$	-	-
$\tilde{g}_{TZ}$	$\mathbf{10^{-21}}$	$\mathbf{10^{-22}}$	2Ω	$\mathbf{10^{-23}}$	$\mathbf{10^{-24}}$	2Ω	$\mathbf{10^{-24}}$	-	-
$\tilde{g}_{XY}$	10^{-17}	$\mathbf{10^{-18}}$	Ω	$\mathbf{10^{-18}}$	$\mathbf{10^{-20}}$	Ω	$\mathbf{10^{-18}}$	$\mathbf{10^{-20}}$	Ω
$\tilde{g}_{YX}$	10^{-17}	$\mathbf{10^{-18}}$	Ω	$\mathbf{10^{-18}}$	$\mathbf{10^{-20}}$	Ω	$\mathbf{10^{-19}}$	$\mathbf{10^{-20}}$	Ω
$\tilde{g}_{ZX}$	10^{-18}	-	-	$\mathbf{10^{-18}}$	$\mathbf{10^{-20}}$	$\omega_L - \Omega$	$\mathbf{10^{-19}}$	$\mathbf{10^{-20}}$	3Ω
$\tilde{g}_{XZ}$	10^{-17}	$\mathbf{10^{-18}}$	$\omega_L - 3\Omega$	$\mathbf{10^{-18}}$	$\mathbf{10^{-19}}$	3Ω	$\mathbf{10^{-18}}$	$\mathbf{10^{-20}}$	Ω
$\tilde{g}_{YZ}$	10^{-17}	$\mathbf{10^{-18}}$	$\omega_L - 3\Omega$	$\mathbf{10^{-17}}$	$\mathbf{10^{-19}}$	3Ω	$\mathbf{10^{-18}}$	$\mathbf{10^{-20}}$	$\omega_L - 3\Omega$
$\tilde{g}_{ZY}$	10^{-18}	-	-	$\mathbf{10^{-18}}$	$\mathbf{10^{-19}}$	3Ω	$\mathbf{10^{-19}}$	$\mathbf{10^{-20}}$	3Ω
$\tilde{g}_{DX}$	10^{-22}	-	-	10^{-27}	-	-	10^{-28}	-	-
$\tilde{g}_{DY}$	10^{-22}	-	-	10^{-27}	-	-	10^{-28}	-	-
$\tilde{g}_{DZ}$	10^{-22}	-	-	$\mathbf{10^{-23}}$	-	-	$\mathbf{10^{-24}}$	-	-

TABLE I. The matter sector summary table reproduced from Ref. [6] with the omission of $c_{\mu\nu}$ and the addition of the results of this work. The "Current" columns list new limits obtained in this work from published results of searches at the sidereal frequency alongside existing limits in Ref. [6]. The "Feasible" columns list estimated sensitivities that could be achieved in a suitable analysis conducted at the suggested frequency. Boxed results are new limits on coefficients that have not yet been constrained. Boldface indicates an improvement from the current best bounds in Ref. [6]. All numeric values reported are in units of GeV.