Erratum: Constraints on dark photon dark matter using data from LIGO's and Virgo's third observing run

The LIGO Scientific Collaboration, The Virgo Collaboration, and The KAGRA Collaboration*
(Dated: December 8, 2023)

An oversight in the analysis presented in [1] led to an overly optimistic estimate of the sensitivity of the cross-correlation search to a dark photon dark matter signal. Specifically, the overlap reduction function (ORF) used for the contribution of the finite light speed effect ("common-mode" mirror motion within either interferometer arm leading to an apparent differential strain) [2] was taken to be the same as the ORF for the true differential-mode mirror motion. As reported in [3], the ORF for the finite speed effect (-0.18) is, instead, significantly smaller than that for true differential motion (-0.9). Since the ORF values are squared in computing the coupling strength ϵ^2, the sensitivity reduction of the cross-correlation results depicted in Figure 3 in [1] is substantial. Hence, we include here a revised Figure 3 to supersede that in [1]. Because the relative importance of the finite speed contribution is larger at higher frequencies, the sensitivity degradation is greater at higher frequencies. The results from the BSD analysis, which does not rely upon cross correlation, are unchanged from those shown in [1], and now provide more constraining upper limits on the coupling strength of dark matter to baryons across most of the frequency range.

Following the same notations in [1], the square root of the amplitude ratio of the cross-correlation for two signal channels in the frequency domain is given by

$$\sqrt{\left|\frac{\langle h^*_{C,I}(f)h_{C,J}(f')\rangle}{\langle h^*_{D,I}(f)h_{D,J}(f')\rangle}\right|} \simeq \frac{\sqrt{3}}{2}\frac{2\pi f L}{v_0}\alpha_{IJ}, \tag{1}$$

where $v_0 \simeq 220$ km/s is the velocity of dark matter orbiting around the galaxy center, L is the arm length of the interferometer, $I,\ J$ are the detector indices, α_{IJ} is the factor effectively taking into account the ratio of ORFs between the two signal channels, which is given by

$$\alpha_{IJ} = \sqrt{\frac{\delta_{ab}(\hat{X}^a_I - \hat{Y}^a_I)(\hat{X}^b_J - \hat{Y}^b_J)}{\delta_{ac}\delta_{bd}(\hat{X}^a_I\hat{X}^b_I - \hat{Y}^a_I\hat{Y}^b_I)(\hat{X}^c_J\hat{X}^d_J - \hat{Y}^c_J\hat{Y}^d_J)}}, \quad a,b,c,d = 1,2,3, \tag{2}$$

where $\hat{X}^a_I(\hat{Y}^a_I)$ is the a-component of the unit vector of the x-arm (y-arm) of the interferometer I. For the LIGO-Hanford (H1) and LIGO-Livingston (L1) detectors,

$$\delta_{ab}(\hat{X}^a_{\rm H1} - \hat{Y}^a_{\rm H1})(\hat{X}^b_{\rm L1} - \hat{Y}^b_{\rm L1}) \simeq -0.059, \tag{3}$$

$$\delta_{ac}\delta_{bd}(\hat{X}^a_{\rm H1}\hat{X}^b_{\rm H1} - \hat{Y}^a_{\rm H1}\hat{Y}^b_{\rm H1})(\hat{X}^c_{\rm L1}\hat{X}^d_{\rm L1} - \hat{Y}^c_{\rm L1}\hat{Y}^d_{\rm L1}) \simeq -1.8, \tag{4}$$

and thus

$$\alpha_{\rm H1L1} \simeq 0.18. \tag{5}$$

The relation between the cross-correlation for two signal channels and the coupling strength ϵ is

$$\begin{aligned}\langle h^*_{{\rm tot},I}h_{{\rm tot},J}\rangle &= \langle h^*_{C,I}(f)h_{C,J}(f')\rangle + \langle h^*_{D,I}(f)h_{D,J}(f')\rangle \\ &\simeq \gamma_{D,IJ}\left[6.58\times 10^{-26}\alpha^2_{IJ} + 6.56\times 10^{-27}\left(\frac{100\ \text{Hz}}{f}\right)\right]^2\left(\frac{\epsilon}{10^{-23}}\right)^2,\end{aligned} \tag{6}$$

where $\gamma_{D,\rm H1L1} = -0.9$ is the ORF of the differential-mode signal for the LIGO-H1 and LIGO-L1 detector pair.

We see here that the reduced ORF, i.e., $\gamma_{D,\rm H1L1}\times\alpha^2_{\rm H1L1} \sim 0.03\gamma_{D,\rm H1L1}$ instead of $\gamma_{D,\rm H1L1}$ for the ORF of the common-mode signal, implies a larger upper limit on ϵ^2 – see Fig. 1 in this erratum.

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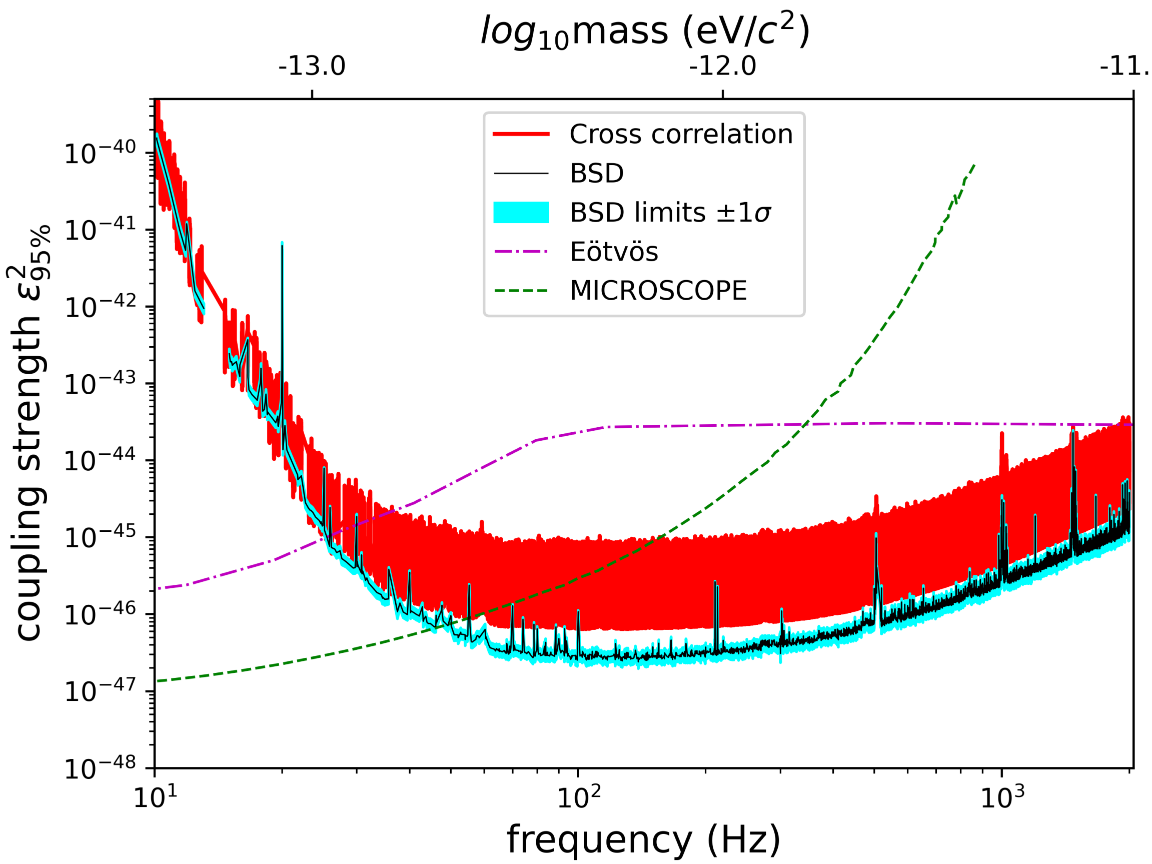

FIG. 1. Updated Fig. 3 of [1], showing the effect of the reduced ORF on the cross-correlation upper limits (BSD limits remain the same). Even though the fast Fourier Transform length $T_{\rm FFT}$ is lower (compared to that of cross correlation) at higher frequencies, the improvement factor resulting from the finite time correction is orders of magnitude larger than the reduction in sensitivity due to a shorter $T_{\rm FFT}$.

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