Erratum: Upconversion Loop Oscillator Axion Detection Experiment: A Precision Frequency Interferometric Axion Dark Matter Search with a Cylindrical Microwave Cavity [Phys. Rev. Lett. 126, 081803 (2021)]

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We have found a sign error in our sensitivity calculation. Our results still experimentally demonstrate the feasibility of exploiting upconversion and downconversion to search for axions, but the sensitivity to low mass axions claimed in [1,2] and quoted in [3–5] must be substantially reduced by 4 orders of magnitude to 3×10^{-3} 1/GeV between 7.44 and 19.38 neV and by up to 11 orders of magnitude for the lowest axion masses in the theoretical projections in the left panel of Fig. 3 in the main text. Conversely, the sensitivity to high mass axions must be increased to 10^{-2} 1/GeV between 74.4 and 74.5 μeV. With this correction, our results show that calculating sensitivity using the photon-axion interaction Hamiltonian is consistent with using a derivative coupling to the axion, showing suppressed sensitivity as $m_a\to0$. This is consistent with other work on axion searches in excited cavities [6,7]. Thus, our conclusion that measuring axion induced frequency shifts was much better than measuring axion induced power was in fact wrong.

The sign error occurs in Eq. (11) of the Supplemental Material, where the normalized unit vectors for the $\mathrm{TE}_{0,1,1}$ mode are given. Here, the negative sign before the z component of $\boldsymbol{b}_1$ was missed. The correct expressions are

$$\boldsymbol{e}_1=-\frac{\sqrt{2}J_1(\frac{\chi'_{01}}{a}r)\sin(\frac{\pi z}{L})}{J_0(\chi'_{01})}\hat{\varphi}\quad\text{and}\quad\boldsymbol{b}_1=\frac{\sqrt{2}\frac{a\pi}{L\chi'_{01}}J_1(\frac{\chi'_{01}}{a}r)\cos(\frac{\pi z}{L})}{\sqrt{1+(\frac{a\pi}{L\chi'_{01}})^2}J_0(\chi'_{01})}\hat{r}-\frac{\sqrt{2}J_0(\frac{\chi'_{01}}{a}r)\sin(\frac{\pi z}{L})}{\sqrt{1+(\frac{a\pi}{L\chi'_{01}})^2}J_0(\chi'_{01})}\hat{z}. \tag{1}$$

These expressions are used to derive the form factors $\xi_\pm$ and hence the conversion factors $k_{a\pm}$, which determine the sensitivities to downconverted (sum frequency) and upconverted (difference frequency) axions, respectively. The error therefore exchanges the values of $\xi_\pm$, which are correctly written as

$$\xi_-=\xi_{12}-\xi_{21}=\xi_{12}\left(1-\frac{f_2}{f_1}\right)\quad\text{and}\quad\xi_+=-(\xi_{12}+\xi_{21})=-\xi_{12}\left(1+\frac{f_2}{f_1}\right), \tag{2}$$

which is the corrected Eq. (14) in the Supplemental Material. Also, the error exchanges the values of $k_{a\pm}$,

$$k_{a\pm}^2=\frac{32\chi'^2_{01}}{(\chi_{02}^2-\chi'^2_{01})^2}\frac{\beta_1P_1Q_{L1}(\beta_2+1)^2}{\beta_2P_2Q_{L2}(\beta_1+1)^2}\frac{(f_2\pm f_1)^2}{f_1f_2}, \tag{3}$$

which is the corrected Eq. (18) in the Supplemental Material. The quoted conversion factors in Table I of the main text should be reversed, with $k_{a+}=5.5$ and $k_{a-}=8.4\times10^{-4}-1.1\times10^{-3}$, and Fig. 3 in the Supplemental Material should be replaced by Fig. 1.

Hence, the quoted SNRs for the free running loop oscillator [Eq. (8) in the main text and Eq. (22) in the Supplemental Material) and the stabilized loop oscillator [Eq. (25) in the Supplemental Material] are written incorrectly. When the modes are closely tuned, the equations give the sensitivity to downconverted axions, with f_{a_-} replaced with f_{a_+}. Thus, given the condition that $f_1=f_2+\delta f_{12}$ is tuned slightly away from f_2 so that $\delta f_{12}/f_2\ll1$, and assuming $\beta_1=1$, the corrected Eq. (8) in the main text [or Eq. (22) in the Supplemental Material] is

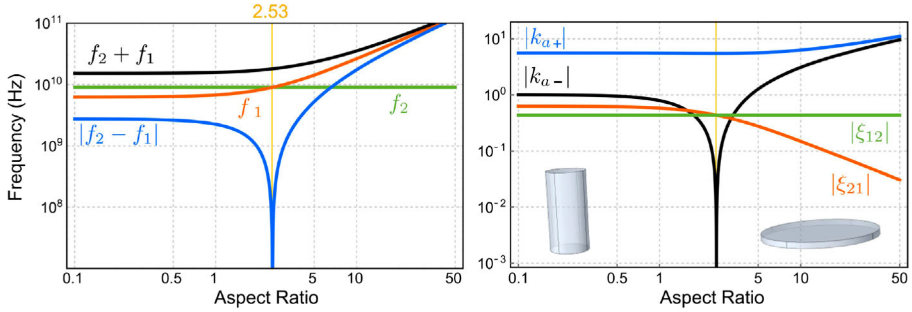

FIG. 1. Corrected Fig. 3 in the Supplemental Material of $k_{a\pm}$ conversion factors versus aspect ratio. Upconversion sensitivity is suppressed in the low axion mass case when the aspect ratio is 2.53, as in the reported experiment.

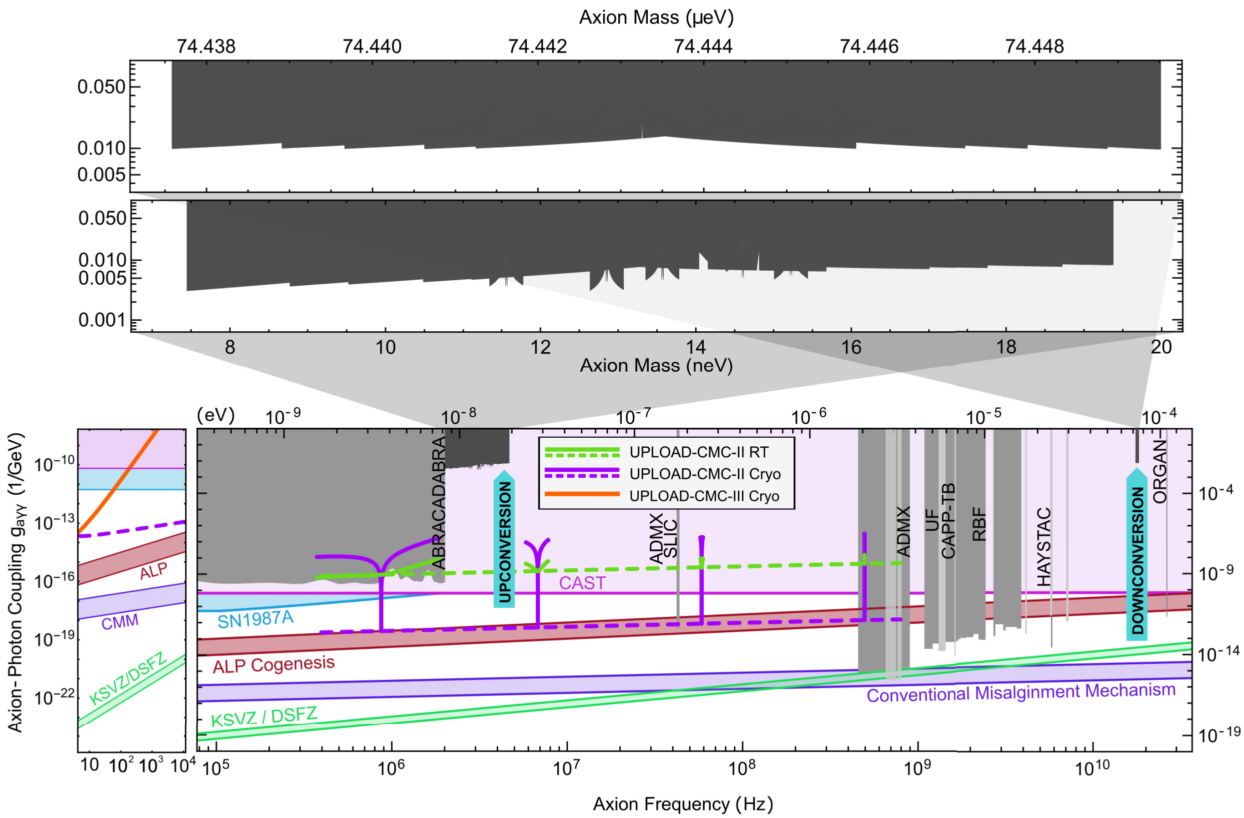

FIG. 2. Updated 95% confidence exclusion zones for $g_{a\gamma\gamma}$ for the measured upconversion and downconversion mass ranges (above), with CAST's helioscope limits in pink and QCD axion models in green (KSVZ and DSFZ) [8,9], purple (conventional ALP misalignment), and red (ALP cogenesis) [10,11]. Corrected upconversion limits are dashed, assuming 1 Hz tuning steps (30 days per Hz): UPLOAD-CMC-II-RT, a copper resonator with frequency stabilized (FS) loops at room temperature (RT); and UPLOAD-CMC-II-Cryo, cryogenic Nb with FS loops. We also present examples of 30 day measurements covering 1 MHz in Fourier space in bold. The left subplot displays (in orange) a 30 day measurement projection for UPLOAD-CMC-III-Cryo, which is simply the cryogenic FS setup when modes are tuned just 5 Hz apart. The results are compared to ADMX [12–15], ORGAN [16], ABRACADABRA [17], ADMX-SLIC [18], HAYSTAC [19], UF [20], CAPP-8 TB [21], and RBF [22].

$$\mathrm{SNR}_{-} = g_{a\gamma\gamma}\frac{2.7(\frac{10^6 t}{f_{a_-}})^{1/4}\sqrt{\rho_{\mathrm{DM}}c^3}}{2\pi f_{a_-}}\sqrt{\frac{Q_{L2}P_{\mathrm{amp}}(\beta_2+1)^2}{(Fk_BT_0)\beta_2 P_2}}\sqrt{P_1 Q_{L1}}\sqrt{\frac{1}{(2Q_{L2}\frac{f}{f_2})^2+1}}\left(\frac{|\delta f_{12}|}{\sqrt{2}f_2}\right), \tag{4}$$

which has an extra term at the end proportional to the detuning between the two modes. Likewise, Eq. (25) becomes

$$\mathrm{SNR}_{-} = g_{a\gamma\gamma} \frac{3.9(\frac{10^6 t}{f_{a_-}})^{1/4}\sqrt{\rho_{\mathrm{DM}} c^3}}{2\pi f_{a_-}} \sqrt{\frac{Q_{L1} P_1}{k_b T_{\mathrm{RS}}}} \sqrt{\frac{\beta_2 Q_{L2}}{(2Q_{L2}\frac{f}{f_2})^2 + 1}} \left(\frac{|\delta f_{12}|}{\sqrt{2} f_2}\right). \tag{5}$$

Thus, we present the corrected exclusion plot for $g_{a\gamma\gamma}$ according to the corrected SNR equations in Fig. 2.

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