

Resonant photon-axion conversion driven by axion dark matter oscillationsRun-Min Yao^{1,2,*}, Xiao-Jun Bi^{2,3,†}, Peng-Fei Yin^{3,‡} and Qing-Guo Huang^{1,2,4,§}¹*School of Fundamental Physics and Mathematical Sciences, Hangzhou Institute for Advanced Study, UCAS, Hangzhou 310024, China*²*University of Chinese Academy of Sciences, Beijing 100049, China*³*State Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*⁴*Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*

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Wave propagation in periodically time-dependent media can exhibit driven mode conversion that is absent in static or adiabatic descriptions. We show that coherent axion dark matter provides an intrinsic realization of this dynamics for photons propagating in a magnetic field. The background's periodic birefringence continuously rotates the photon polarization and thereby drives magnetic photon-axion mixing. Using Floquet theory, we derive resonant photon-axion conversion when integer harmonics of the axion oscillation frequency compensate the dispersion mismatch, $\Delta_\gamma - \Delta_a \approx nm_a$ with $n \in \mathbb{Z}$. This resonance enables efficient mixing far from conventional level crossing and is lost when the periodic drive is averaged out of the propagation Hamiltonian. The resulting conversion is bounded and unitary, distinct from parametric instability or axion decay. Our framework describes photon propagation in coherent oscillating axion backgrounds and predicts characteristic polarization signatures, which we illustrate in a blazar environment.

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Introduction. Periodically driven media can support resonant mode conversion even when the corresponding static system is far from resonance. Floquet theory organizes this dynamics into harmonics of the drive and provides a standard description in condensed matter and quantum optics [1–5]. A natural setting for such propagation is a coherent axion dark matter (DM) background. Axions and axionlike particles are well-motivated extensions of the Standard Model [6–10] and candidates for DM [11–22]. Their coherent oscillations make the optical properties of the background periodic, with a frequency set by the axion mass.

Two familiar consequences of the axion-photon interaction suggest different propagation pictures. In a static magnetic field, photons mix with axions, but a dispersion mismatch suppresses coherent conversion [23–27]. Conventional resonant conversion removes this mismatch

at a level crossing, as in neutron-star magnetospheres where the plasma frequency equals the axion mass [28,29]. A coherent axion background, meanwhile, rotates photon polarization [30–32] and can modify photon trajectories [33–36]. Viewed separately, these effects describe conversion and background optics. Their coexistence motivates examining whether oscillating birefringence can itself drive conversion where static mixing is suppressed.

We demonstrate that periodic birefringence drives resonant photon-axion conversion through its noncommuting interplay with magnetic mixing: the background continuously changes the photon state that couples to the axion. Thus birefringence actively drives the conversion dynamics. For high-frequency photons propagating through a magnetized plasma, a corotating basis exposes Bessel-weighted harmonics of the mixing, with resonances at $\Delta_\gamma - \Delta_a \approx nm_a$ ($n \in \mathbb{Z}$). The nonzero harmonics enable efficient conversion far from conventional level crossing, even with a static magnetic field. Floquet theory determines the harmonic couplings, resonance widths, and bounded conversion probabilities. The central result is the identification and quantitative description of this resonant interplay between background birefringence and photon-axion conversion.

In terms of phase matching, the periodic coupling compensates the phase mismatch accumulated between photon and axion amplitudes during propagation.

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Externally imposed magnetic modulation can also compensate a dispersion mismatch, through alternating-polarity magnets [37], time-dependent fields [38], or spatial and temporal modulation underlying axion magnetic resonance [39]. Here the drive arises intrinsically from the axion background, which fixes its frequency and harmonic weights. The resonance locations and relative harmonic strengths therefore offer a potential probe of the axion mass and DM density, with the latter also dependent on the axion-photon coupling. Earlier studies with both an axion background and a magnetic field addressed mixed modes and polarimetry, as well as temporal-periodicity effects [40]. Our focus is the resulting coherent, high-frequency forward-conversion regime in plasma and its polarization consequences.

Periodic axion backgrounds can also give rise to instabilities, in which electromagnetic perturbations grow by drawing energy from the background. Earlier work used Floquet theory to determine instability bands in the coupled axion-photon system with a magnetic field [41], and studied parametric amplification in axion clumps [42,43], stimulated radio decay [44,45], and the axion-induced electromagnetic echo [46]. These photon-production processes differ from the unitary, bounded conversion of an incident beam described by our Hermitian forward-propagation Hamiltonian. We connect the harmonic resonances to conversion and circular polarization along an inhomogeneous line of sight, illustrating the effect in a blazar jet. The 3C 279 estimate is a source-dependent consistency example of the mechanism's observational consequences.

Driven photon-axion mixing. The axion may couple to electromagnetism through the operator $\mathcal{L} \supset -g_{a\gamma} a F \tilde{F}/4$, where $g_{a\gamma}$ is the photon-axion coupling with units of GeV^{-1} , a is the axion field, and F is the electromagnetic field tensor. We consider photon propagation in the presence of a magnetic field and a coherently oscillating axion background. The axion-photon mixing equations in the presence of an external magnetic field can be reduced to a system of first-order differential equations via the WKB approximation, assuming the beam energy ω is much larger than the axion mass m_a . We consider photon propagation along the z -axis in the presence of a transverse magnetic field $\mathbf{B}_T$. In the linear polarization basis, the photon-axion system obeys the Schrödinger-like propagation equation,

$$i\partial_z \Psi = [\mathcal{H}_0 + \mathcal{H}_1] \Psi \quad (1)$$

where the state vector Ψ denotes the two photon polarization states and the axion field. The photon components correspond to linear polarizations oriented perpendicular and parallel to the direction of the external magnetic field. The dynamics is governed by a Hermitian mixing Hamiltonian with an explicit periodic time dependence.

The static part $\mathcal{H}_0$ describes conventional photon-axion mixing in a magnetized medium and is given by [23–25]

$$\mathcal{H}_0 = - \begin{pmatrix} \Delta_{\perp} & 0 & 0 \\ 0 & \Delta_{\parallel} & \Delta_B \\ 0 & \Delta_B & \Delta_a \end{pmatrix}. \quad (2)$$

Throughout this work, all dispersion and mixing effects are parametrized in terms of Δ -parameters following the standard photon-axion mixing notation. Here, $\Delta_{\perp,\parallel}$ represent the photon dispersion for the two linear polarizations, accounting for both plasma effects and vacuum birefringence. In the systems considered here, vacuum QED effects are included in $\Delta_{\perp,\parallel}$ but remain subdominant to the plasma contribution, $\Delta_{\perp,\parallel} \simeq -\omega_{\text{pl}}^2/(2\omega)$. The effective plasma frequency is $\omega_{\text{pl}} = \sqrt{4\pi\alpha n_e/m_e}$, where α is the fine-structure constant and n_e and m_e denote the electron number density and mass, respectively. The axion mass-induced dispersion is given by $\Delta_a = -m_a^2/(2\omega)$, while the photon-axion mixing is governed by $\Delta_B = g_{a\gamma} B_T/2$. The conventional plasma Faraday contribution is subleading for the effect of interest and can be neglected for the energy regime and the transverse magnetic field considered in this paper.

The axion background field is treated as classical and homogeneous,

$$\bar{a}(t, z) = m_a^{-1} \sqrt{2\rho_{\text{DM}}} \cos(m_a t + \varphi_a) \quad (3)$$

where ρ_{DM} is the DM density, and φ_a is an *a priori* unknown phase.

In addition to the usual photon-axion mixing, the oscillating axion background induces a periodic birefringence for the photon, through the gradient coupling $g_{a\gamma} \partial_{\mu} \bar{a}$. In the linear polarization basis used here, the same effect appears as explicitly time-dependent terms in the photon subspace

$$\mathcal{H}_1(z) = - \begin{pmatrix} 0 & \Delta_F & 0 \\ \Delta_F^* & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad (4)$$

with

$$\Delta_F = i g_{a\gamma} (\partial_t \bar{a} + \partial_z \bar{a})/2. \quad (5)$$

This birefringence term is purely imaginary, reflecting that it generates photon polarization rotation, analogous to but distinct from plasma Faraday rotation. We retain this periodic birefringence as the driving term Δ_F in the coupled propagation problem.

The driven contribution does not commute with the static mixing Hamiltonian, $[\mathcal{H}_0, \mathcal{H}_1(z)] \neq 0$. Averaging the full

time-ordered evolution operator therefore does not, in general, give the evolution generated by the averaged Hamiltonian, $\langle \mathcal{T} e^{-i \int \mathcal{H}(z) dz} \rangle \neq e^{-i \int \langle \mathcal{H}(z) \rangle dz}$, where the brackets denote an average over the background phase and $\mathcal{T}$ orders the Hamiltonians along the photon trajectory. Replacing Δ_F by its vanishing cycle average removes the periodic coupling from the propagation equation and eliminates the harmonic resonance derived below.

The Hamiltonian is manifestly Hermitian, and its only explicit time dependence originates from the oscillating axion background through the birefringence term,

$$\Delta_F = -i\Delta_{\text{DM}} \sin(m_a t + \varphi_a), \quad (6)$$

where $\Delta_{\text{DM}} \equiv g_{a\gamma} \sqrt{\rho_{\text{DM}}/2}$ sets the amplitude of the axion-induced drive. This term oscillates at frequency m_a and acts as a coherent temporal drive of the photon-axion system. Along the photon trajectory we adopt the eikonal approximation $t \simeq z$ (with $c = 1$), appropriate for forward-propagating waves with a well-defined carrier frequency. In this limit, the temporal oscillation of the axion background translates into a periodic modulation along the propagation direction with period $T = 2\pi/m_a$.

The resulting propagation equation describes a three-level system subject to coherent periodic driving. A transformation to a corotating frame that follows the axion-induced phase modulation transfers the time dependence into the mixing terms. This allows the driven nature of the mixing to be made explicit while leaving the physical propagation amplitudes unchanged.

We therefore perform a time-dependent unitary transformation $\Psi(z) = U(z)\Phi(z)$ with $U = u \oplus 1$, where u acts on the photon subspace as

$$u(z) = \exp[-i\theta(z)\sigma_y], \quad (7)$$

with σ_y the second Pauli matrix. The rotation angle $\theta(z) = \alpha \cos \phi(z)$, with $\alpha = \Delta_{\text{DM}}/m_a$ and $\phi(z) = m_a z + \varphi_a$, is chosen such that the contribution from $U^\dagger i\partial_z U$ exactly compensates the rapidly oscillating birefringence term Δ_F . This transformation is algebraically exact and merely redistributes the periodic dependence among the Hamiltonian matrix elements.

In the following we neglect QED vacuum birefringence, assuming $|\Delta_\perp - \Delta_\parallel|/2 \ll m_a, \Delta_{\text{DM}}$. This condition ensures that the two photon polarization states remain effectively degenerate on the scale of the axion-induced modulation, so that the driven mixing dynamics is not suppressed by polarization dephasing. We define $\Delta_\gamma \equiv (\Delta_\perp + \Delta_\parallel)/2$ as the average photon dispersion. Then the effective Hamiltonian becomes

$$\mathcal{H}'(z) = - \begin{pmatrix} \Delta_\gamma & 0 & \Delta_B \sin \theta \\ 0 & \Delta_\gamma & \Delta_B \cos \theta \\ \Delta_B \sin \theta & \Delta_B \cos \theta & \Delta_a \end{pmatrix}. \quad (8)$$

The unitary transformation leaves the physical propagation unchanged, but renders the periodic structure of the driven photon-axion mixing explicit, providing a natural starting point for the Floquet analysis below.

The full dynamics is a three-level Floquet problem, with the two photon modes coupled to the same axion through $G^{(1)} = \Delta_B \sin \theta(z)$ and $G^{(2)} = \Delta_B \cos \theta(z)$. To identify when an effective two-level description applies, we first resolve these periodic couplings into harmonics.

The axion-induced phase modulation is periodic, so the couplings can be expanded in a discrete set of harmonics with amplitudes controlled by Bessel functions $J_\ell(\alpha)$. Explicitly, this follows from the standard Jacobi-Anger expansion,

$$e^{i\alpha \cos \phi} = \sum_{\ell \in \mathbb{Z}} i^\ell J_\ell(\alpha) e^{i\ell \phi}. \quad (9)$$

Writing $\sin \theta$ and $\cos \theta$ in terms of $e^{\pm i\theta}$, the couplings can be decomposed into discrete Fourier harmonics,

$$G(z) = \sum_{\ell \in \mathbb{Z}} g_\ell e^{i\ell m_a z}. \quad (10)$$

Here $g_\ell^{(1)}$ ($g_\ell^{(2)}$) is nonzero only for odd (even) ℓ , reflecting the parity structure of the two photon polarizations, and the magnitude of each harmonic scales as $g_\ell \sim \Delta_B J_\ell(\alpha)$ up to phase factors. The parameter α controls the strength of the Floquet modulation, and multiple harmonics become relevant for $\alpha \gtrsim 1$.

In this corotating basis, the driven photon-axion system naturally acquires a Floquet-harmonic structure [5]: the oscillating axion background provides a discrete ladder of harmonic driving channels separated by integer multiples of m_a . These harmonics shift the effective detuning between the dressed propagation modes by ℓm_a , so that a harmonic can become resonant even when the undriven modes are far from a level crossing.

For either photon-axion channel, we remove the free propagation phases and move to the interaction picture by defining $\Phi = \text{diag}(e^{i\Delta_\gamma z}, e^{i\Delta_a z}) \tilde{\Phi}$. The ℓ th Fourier component of the coupling then acquires a phase factor $e^{i\delta_\ell z}$, with detuning $\delta_\ell = \Delta_\gamma - \Delta_a - \ell m_a$. Resonant mode mixing occurs when this phase is stationary, yielding the Floquet resonance condition

$$\Delta_\gamma - \Delta_a \approx n m_a, \quad n \in \mathbb{Z}, \quad (11)$$

corresponding to vanishing detuning δ_n . In static mixing, the dispersion mismatch causes conversion amplitudes

generated at different positions to accumulate different phases, limiting their coherent buildup. The n th harmonic of the periodic coupling changes this relative phase evolution by offsetting the mismatch by nm_a . Near resonance, the residual phase varies slowly, allowing successive contributions to add coherently even when $\Delta_\gamma \neq \Delta_a$. Periodic magnetic-modulation schemes likewise restore coherent conversion by compensating the propagation-phase mismatch [37–39]. In the present system, the modulation follows from axion-induced birefringence, so the available harmonics and their strengths are determined by the coherent background.

Near an isolated Floquet resonance labeled by n , retaining only the corresponding Fourier component constitutes a rotating-wave approximation, valid when the nonresonant harmonics in both photon channels satisfy $|\delta_\ell| \gg |g_\ell|$ for $\ell \neq n$. The odd or even parity of n selects the photon mode coupled through $G^{(1)}$ or $G^{(2)}$, respectively. The other photon mode decouples at this order, leaving a two-level system undergoing coherent Rabi oscillations [47,48] with frequency

$$\Omega_R = \sqrt{|g_n|^2 + (\delta_n/2)^2}. \quad (12)$$

The photon-axion conversion probability takes the standard form

$$P_{\gamma \rightarrow a} \approx \frac{|g_n|^2}{\Omega_R^2} \sin^2(\Omega_R z). \quad (13)$$

Here γ denotes the photon mode selected by the resonant harmonic in the corotating basis. For fixed local parameters, the peak conversion probability attained over a Rabi oscillation is at least 50% when $|\delta_n| \leq 2|g_n|$. This interval defines the local mixing bandwidth, with full width $4|g_n|$ in detuning. Conversion during passage through a varying medium also depends on the accumulated propagation phase.

Removing the axion-induced drive, $\Delta_{DM} = 0$, recovers conventional photon-axion mixing. For weak modulation, $\Delta_{DM} \ll m_a$, only the lowest harmonics contribute, and the driven resonance reduces to a small, single-frequency perturbation of the standard oscillation probability.

Additional derivations are provided in the Supplemental Material [49], where we also discuss an equivalent formulation in the circular polarization basis. In that representation, the axion background appears as a periodic modulation of the refractive indices, providing an alternative but equivalent perspective on the driven mixing.

This equivalent optical description also clarifies the relation to earlier axion-background studies. Ray evolution and polarization-dependent dispersion [35], mixed modes and polarimetry [40], and temporal instability bands [41] address related aspects of axion electrodynamics. To obtain

the conversion considered here, the periodic optical response must be retained in the coupled evolution of photon and axion amplitudes. The near-resonant solution then determines how this response changes the buildup of conversion over a finite propagation distance.

The resulting resonance describes coherent transfer between forward photon and axion modes. Near an isolated resonance, their effective 2×2 Hamiltonian is Hermitian, and the probability derived above oscillates with propagation distance while remaining bounded. Periodic driving therefore enhances mode conversion without producing exponential growth of the propagating amplitudes.

An instability requires a different dynamical channel. In parametric amplification, the background couples positive- and negative-frequency sectors and can transfer energy into photon-pair production, as near $m_a \simeq 2\omega$ [43]. The forward, high-frequency approximation adopted here excludes this channel. The resonance condition instead matches the difference between photon and axion dispersion terms to a harmonic of the background, yielding oscillatory conversion of an incident beam. The two effects arise from periodic backgrounds but involve different modes and resonance conditions.

Throughout this treatment, the axion condensate is a prescribed coherent background, with recoil and depletion neglected. Its oscillation enters the propagation Hamiltonian through the Fourier coefficients g_n . The harmonic index thus labels Fourier components of the coherent drive, whose amplitudes determine the conversion strength in each channel. Further details are given in the Supplemental Material [49].

Representative propagation. To illustrate the physical consequences of Floquet resonances, we consider photon propagation in a medium with a slowly varying dispersion $\Delta_\gamma(z)$, in the presence of a coherent axion background over the relevant length scale. This setup isolates the driven resonance mechanism without reliance on detailed source modeling.

The local detuning now changes along the trajectory. As the photon propagates, the dispersion mismatch can pass through the Floquet resonance condition $\Delta_\gamma(z) - \Delta_a \simeq nm_a$, activating resonant photon-axion mode conversion. Conversion is enhanced wherever the difference between the plasma and axion dispersion terms is compensated by a harmonic of the axion background, without requiring a crossing of the dispersion terms. A slowly varying profile can therefore bring the beam through successive resonances, with conversion building up coherently around each crossing.

Figure 1 shows the resulting photon-axion conversion probability $P_{\gamma \rightarrow a}$ as a function of propagation distance for representative parameters, specifically $\omega \sim \text{eV}$, $m_a = 10^{-22} \text{ eV}$, $g_{a\gamma} = 5 \times 10^{-11} \text{ GeV}^{-1}$, $\rho_{DM} = 1 \text{ GeV} \cdot \text{cm}^{-3}$. The driven Floquet case (blue) exhibits

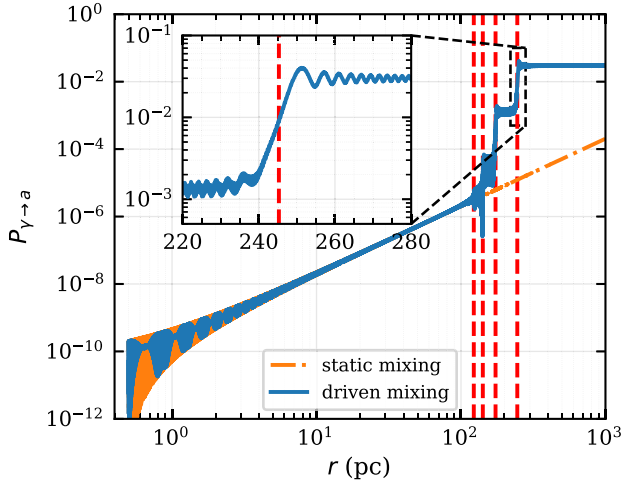


FIG. 1. Photon-axion conversion probability $P_{\gamma \rightarrow a}$ along a representative blazar jet. The blue line shows the case of driven Floquet mixing with an oscillating axion background, while the orange line indicates the conventional adiabatic conversion obtained from the static mixing problem. Vertical red dashed lines mark locations where $\Delta_\gamma(r) - \Delta_a \approx nm_a$, corresponding to $n = -1, -2, -3, -4$ from right to left under our negative plasma-dispersion convention.

sharply enhanced conversion when the dispersion mismatch crosses a resonance band, whereas standard static mixing (orange) remains oscillatory and strongly suppressed. The vertical dashed lines indicate the locations where $\Delta_\gamma(z) - \Delta_a \simeq nm_a$, where the electron density $n_e \sim 0.1 \text{ cm}^{-3}$ (corresponding to $\omega_{\text{pl}} \sim 10^{-11} \text{ eV}$) and the magnetic field is $\sim 1 \text{ mG}$ at the resonance position $\sim 10^2 \text{ pc}$. Since $|\Delta_\gamma(r)| \gg |\Delta_a|$, the resonances occur where $|\Delta_\gamma(r)| \simeq |n|m_a$.

The local Rabi expression characterizes mixing at fixed parameters. During resonance passage, the conversion amplitude accumulates with the phase integral of the varying detuning. For an isolated resonance with locally linear detuning, define $\beta_n = |\partial_r \delta_n|_{r_{\text{res}}}$. In the weak-coupling regime $|g_n|^2/\beta_n \ll 1$, phase accumulation gives a characteristic conversion formation length $L_{\text{form}} \sim \beta_n^{-1/2}$. This length can exceed the spatial interval defined by the local half-maximum mixing bandwidth, as derived in the Supplemental Material [49].

For the dominant $n = -1$ resonance in Fig. 1, $L_{\text{form}} \sim 3 \text{ pc}$ is much smaller than the jet scale ($\sim \text{kpc}$). Coherent buildup requires the DM field to remain coherent across this formation region. Its spatial coherence length ($\sim 64 \text{ pc}$ for a virial velocity $v \sim 10^{-3}$) exceeds L_{form} , and the photon crossing time ($\sim 9 \text{ yr}$) is much shorter than the DM coherence time ($\sim 2 \times 10^5 \text{ yr}$), supporting the coherent Floquet treatment of this passage. We have verified that the resonance persists under moderate variations of $\Delta_\gamma(z)$ and in the presence of stochastic fluctuations, provided that the axion field remains coherent across the resonance region.

These tests support persistence within the sampled environmental variations; more rapid variations that disrupt coherent accumulation across the layer can suppress the enhancement. Further numerical details are presented in the Supplemental Material [49].

The same resonance crossings also affect polarization. In the circular basis, the axion-induced modulation enters with opposite signs for the two photon states, making their conversion histories sensitive to the background phase and the propagation environment. This can generate circular polarization even from initially unpolarized radiation. For a given source, the axion phase is definite but observationally unknown and remains effectively fixed over the observations within the adopted coherence regime. The example below therefore assumes a uniform distribution over possible phases and uses the resulting spread in predicted circular polarization for an illustrative statistical consistency analysis.

Blazar 3C 279 as an illustration. We validate this theoretical framework with full numerical solutions and demonstrate that the driven mixing mechanism can imprint characteristic signatures on photon polarization during propagation. As a concrete realization, we apply the formalism to optical polarimetry of the blazar 3C 279, with source-specific modeling details provided in the Supplemental Material [49].

To illustrate the potential observational impact of the mechanism, we adopt an illustrative statistical consistency criterion based on the spread of circular-polarization predictions over possible axion phases. Specifically, we require that the standard deviation of the axion-induced circular polarization, σ_{std} , does not exceed the characteristic observational uncertainty of a given source. For 3C 279, we take $\sigma_{\Pi_C} \approx 0.30\%$ [57]. For each fixed phase φ_a , the propagation model predicts a definite polarization. We assume a uniform distribution over the observationally unknown phase, obtaining a distribution of predictions with vanishing mean and nonzero variance. This comparison assesses the spread of predictions under the assumed phase distribution. Assigning a confidence level would require a statistical treatment of the source data and the unknown phase.

Applying this criterion yields an illustrative consistency contour for the axion-photon coupling, shown in Fig. 2 together with CAST constraints [58] for reference. For axion masses in the range $m_a \in [10^{-23}, 10^{-20}] \text{ eV}$, the contour reaches $g_{a\gamma} \lesssim 2 \times 10^{-11} \text{ GeV}^{-1}$ for the adopted source parameters. Since $J_n(\alpha)$ is maximized for $\alpha = \mathcal{O}(1)$, the conversion is most efficient when $m_a \sim \Delta_{\text{DM}}$. For the benchmark coupling $g_{a\gamma}$ and dark-matter density, this condition selects the resonance region around $m_a \sim 10^{-22} \text{ eV}$ in Fig. 2. While the numerical reach of the contour depends on the specific noise properties of 3C 279, its qualitative structure is set by the underlying driven mixing dynamics.

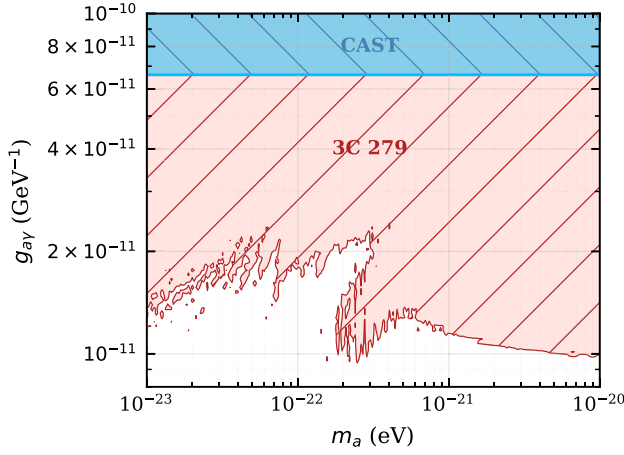


FIG. 2. Illustrative consistency contour for the axion-photon coupling $g_{a\gamma}$ derived from 3C 279 optical polarimetry. The shaded region indicates parameters for which the standard deviation of predicted circular polarization over an assumed uniform axion-phase distribution exceeds the adopted observational uncertainty. The driven mixing mechanism gives rise to a distinctive band structure in parameter space, directly reflecting the discrete Floquet resonance condition $\Delta_\gamma - \Delta_a \approx nm_a$.

In particular, the banded pattern in parameter space directly reflects the discrete Floquet resonance condition associated with the periodic axion background. As m_a varies, the dominant contribution shifts between different resonance orders n , leading to alternating regions of enhanced and suppressed conversion. Near resonance, the driven mixing efficiently generates circular polarization, whereas off-resonant mixing between bands is suppressed. This characteristic structure is a direct consequence of the time-dependent Floquet driving and does not rely on fine-tuned phase alignment.

The contour provides an order-of-magnitude illustration within the adopted source model and phase-distribution assumption. It demonstrates that the driven mixing mechanism can lead to observable, mechanism-specific polarization signatures at realistic sensitivity levels. The band structure and phase-dependent circular polarization connect the driven conversion to observables, with their magnitude determined by the adopted propagation environment.

Conclusions. Coherent axion DM can drive resonant photon-axion conversion through its periodic birefringence in a magnetized plasma. Retaining this drive yields a Floquet description with Bessel-weighted harmonic

couplings and the resonance condition $\Delta_\gamma - \Delta_a \approx nm_a$. The nonzero harmonics enable bounded conversion away from conventional level crossing. By continuously rotating the photon polarization that participates in magnetic mixing, the background birefringence opens a resonant conversion channel that is missed when the two effects are treated separately. Its resonance scales and harmonic weights are tied to the axion background's mass, density, and coherence.

The forward-propagation regime studied here describes unitary mode conversion, distinct from photon-pair production and temporal instability. In a nonuniform medium, the changing dispersion mismatch brings the beam through harmonic resonances. Conversion accumulates across a finite formation region around each crossing, so its effectiveness depends on coherence across that region. Environmental variations that disrupt this accumulation can suppress the effect.

In the representative jet model, these crossings generate circular polarization with a definite prediction for each axion phase. To assess the possible observational consequences when that phase is unknown, the 3C 279 example assumes a uniform phase distribution and compares the resulting spread of predictions with polarimetric sensitivity. The contour depends on this statistical assumption as well as the adopted source model. The broader result is a connection between coherent background oscillations, resonant conversion, and polarization observables. The harmonic structure offers access to the axion mass and to the combination of coupling and DM density that sets the modulation strength, motivating further applications in environments where propagation and coherence can be constrained.

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Data availability. The numerical data and code that support the findings of this article are available from the corresponding authors upon reasonable request.

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