PVLAS Experiment: Some Astrophysical Consequences

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July 7, 2018

Abstract

The birefringent effects of photon-pseudoscalar boson (Goldstone) particle mixing in intergalactic magnetic field are calculated for cosmological objects. We use the recent results of PVLAS collaboration that reported recently the observation of a rotation of the polarization plane of light propagating through a transverse static magnetic field. Such results which were interpreted as arising due to conversion of photon into pseudoscalar with coupling strength $g_{a\gamma} \sim 4 \times 10^{-6} \text{GeV}^{-1}$ allows us to estimate the intergalactic magnetic field magnitude as $\sim 10^{-16} \text{G}$ based on Hatsemekers et al. observations of extreme-scale alignments of quasar polarization vectors. We have analyzed some additional results of astronomical observations that could be explained by axion interpretation of the PVLAS data: a sharp steepening of the QSO continuum short ward of $\sim 1100 \AA$, observed circular polarization of AGNs and QSOs, discrepancy between observed intrinsic polarization of stars in the Local Bubble and stellar spectral classification. The observed polarization of stars in the Local Bubble can’t be explained by interstellar origin.

Key words: polarization, axion, quasar, intergalactic magnetic field.

1 Introduction

Recently Zavattini et al. (2005b) have reported in the PVLAS experiment a rotation of polarization of light in vacuum in the presence of a transverse magnetic field. The PVLAS experiment (Zavattini et al., 2005a) operates an ellipsometer acting with a superconducting dipole magnet that can measure ellipticity and the polarization plane rotation induced by the magnetic field onto linearly polarized laser light. The sensitivity of the instrument is about $10^{-12} \text{rad Hz}^{-1/2}$.

The experimental result of Zavattini et al. (2005b) proves the effect of light polarization rotation in vacuum in the transverse magnetic field. The averaged measured rotation is $(3.9 \pm 0.5) \times 10^{-12} \text{rad/pass}$, at 5T magnetic field strength with 44000 passes through 1m long magnet. The probable interpretation that was presented by Zavattini et al. (2005b) is the magnetic conversion process of photons into light, neutral, pseudoscalar particles (see, for example, the reviews Raffelt & Stodolsky (1988); Raffelt (1999); Gnedin & Krasnikov (1992); Gnedin (1994)). The birefringent effects in vacuum in the presence of a magnetic field may be produced by mixing between the Nambu-Goldstone bosons (NGB) and photons. There exist various ideas in favor of the existence of light and ultra-light pseudoscalar particles beyond the Standard Model. These particles are remained undetected due to their weak coupling to ordinary matter including the electromagnetic field. The NGB and axion were postulated to explain why the strong interaction conserves CP (combined particle-antiparticle exchange and space conversion) in spite of the fact that the weak interactions violate this symmetry. Axion is the very popular candidate into the dark matter (DM) particles. The typical values of standard axion mass lie in the range $m_a \approx 10^{-5} \div 1 \text{eV}$.

Cosmic NGBs and axions are produced in various Big Bang scenarios (see reviews Turner (1990); Raffelt (1996, 1999); Sikivie (1998)). Typically these are inflation and cosmic strings. In cosmic strings scenario with the high $T \gg T_{QSD}$ temperatures massless bosons are produced. For low $T \ll T_{QSD}$ temperatures NGBs acquire a mass. In inflation models the nonmassless particles are presumably produced with a mass scale lying in $\mu \text{eV}$ range. Nevertheless, the chaotic inflation models with high values of the Hubble parameter during inflation $H_1 \sim 10^{13} \div 10^{14} \text{GeV}$ provide the very low mass range $m_a \leq 10^{-16} \text{eV}$, that is practically massless bosons.

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NGBs and axions can be detected through their coupling to photons. Nonmassless axion can decay into two photons. This $a \rightarrow 2\gamma$ coupling arises due to two different decay mechanisms: through axion-pion mixing and via the electromagnetic (EM) anomaly of PQ symmetry. But there is more effective process of coupling between NGBs (axions) and photons in a magnetic field (Primakoff process). This process can lead to photon production with energy compared to the total boson energy. There exists certainly the inverse process of transformation (conversion) of a photon into NGB or axion in a magnetic field. These both processes are effectively used for the search of the relic and stellar origin axions (Raffelt, 1999; Gnedin, 1994; Turner, 1990; Raffelt, 1990, 1996; Sikivie, 1998).

The interpolations of pseudoscalars with Standard Model particles are model dependent. The strongest constraints come from pseudoscalar coupling to photon: $g_{a\gamma}$. The corresponding term of Lagrangian is

$$L_{\text{int}} = \frac{1}{4} g_{a\gamma} A_{\mu\nu} \tilde{F}^{\mu\nu} = g_{a\gamma} A \tilde{E} \tilde{B}$$

where $A$ is the pseudoscalar field.

The PVLAS experiment derives the mean value of coupling constant as $g_{a\gamma} \approx 4 \times 10^{-6} \text{GeV}^{-1}$ (Zavattini et al., 2005b,a).

We consider the astrophysical consequences of the PVLAS experiment, namely: (a) alignment of quasar polarization vectors discovered recently by Hutsemekers (1998); Hutsemekers et al. (2005); (b) probable circular polarization from distant ($z \sim 1$) quasars; (c) a sharp steepening of the QSO continuum shortward of $\lambda \simeq 1100\,\AA$; (d) the origin of linear polarization of stars in the Local Bubble.

## 2 Photon-Goldstone Boson Mixing and Birefringent Effects in a Magnetic Field

The probability of the magnetic conversion of photons into lowmass bosons were calculated by Raffelt & Stodolsky (1988) (they considered also the conversion process of axions) and Anselm & Uraltsev (1982) (see also Gnedin & Krasnikov (1992)).

$$P(\gamma|| \leftrightarrow a) = \frac{1}{1 + x^2} \sin^2\left(\frac{1}{2} B_\perp g_{a\gamma} L \sqrt{1 + x^2}\right)$$

where

$$x = \bar{\varepsilon}\omega / B_\perp g_{a\gamma}, \quad \bar{\varepsilon} = (\varepsilon - 1)/2$$

$\omega$ is the radiation frequency, $\varepsilon$ is the dielectric function of a medium that the light is propagating through, $B_\perp$ is the magnetic field component perpendicular to the photon direction, $g_{a\gamma}$ is the coupling constant between photons and pseudoscalars.

There are three main features of this probability function.

(a) Probability function has the oscillatory character.

(b) The sinus phase depends on the product of the magnetic strength $B$, the size of the region $L$ where the magnetic field is approximately homogeneous and the coupling constant of pseudoscalar boson with photon $g_{a\gamma}$.

(c) The conversion process is very sensitive to the polarization state of the photon since only a single polarization state with the electric vector oscillating into the plane of the directions of the magnetic field and the photon propagation is subject to the conversion.

The conversion probability depends strongly on the dielectric function of a medium. The most expression of this function was given by Raffelt & Stodolsky (1988) and Gnedin & Krasnikov (1992). Assuming that the medium is a plasma with an electron density $N_e$ and a neutral gas (for example, hydrogen) with density $N_H$, we find

$$1 - \varepsilon = \frac{\omega_p^2}{\omega^2} - 4\pi\beta N_H - \frac{28\alpha^2}{45m_e^2} B^2 - \frac{m_a^2}{\omega^2}$$

The first term in (4) describes the contribution of the plasma polarizability; the second one describes the contribution of a neutral gas; the third one describes the contribution of, so called, polarizability of vacuum in a magnetic field and is important only for a plasma in the vicinity of neutron stars and magnetic white dwarfs (see Pavlov & Gnedin (1984)). The last term in (4) is the contribution of vacuum boson field. In a case of pure NGBs $m_a = 0$. 

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In Eqs.(2)-(4) we use the Lorentz-Heaviside system of units with $\hbar = c = 1$ and a fine structure constant $\alpha = e^2/4\pi = 1/137$. In this system of units, the unit for the magnetic field $B$ is $(eV)^2$, and the unit of length is $(eV)^{-1}$. Then one gauss corresponds to $6.9 \times 10^{-2}(eV)^2$ and 1cm corresponds to $5 \times 10^4(eV)^{-1}$.

The various terms in (4) have opposite signs, so there is the possibility that they would cancel out completely, and the Eq.(4) and, therefore, $x$ would be equal to zero. This case corresponds to the resonance in the probability function (2).

Gnedin (1997) has considered the case of resonance magnetic conversion of photons into massless bosons from QSOs in the regions of Damped Lyα systems with a noticeable Faraday rotation measure discovered by Wolfe et al. (1992). He interpreted with this process the appearance of striking feature in polarized light of some QSOs (see recent review by Koratkar & Blaes (1999)). His case was a compensation of first two terms in (4).

Raffelt & Stodolsky (1988) and also Gnedin & Krasnikov (1992) have discussed another possibility of the resonance magnetic conversion process with compensation of the first and last terms of Eq.(4). Naturally, such kind process can take place only for a case of conversion into nonmassless bosons (axions).

It appears the photon-boson mixing in a magnetic field provides birefringent effects that are a rotation of polarization plane and production of small amount of circular polarization.

Let remind that a plasma in a magnetic field possesses two important magneto-optical effects: dichroism, i.e. the dependence of extinction of light on its polarization state, and birefringency, i.e. the difference of the refraction indexes or phase velocities of polarized electromagnetic waves. In a strong magnetic field of neutron stars and white dwarfs even the electron-positron vacuum behaves as an anisotropic medium with the birefringent properties (Pavlov & Gnedin, 1984).

Photon-Goldstone boson (axion) mixing also yields birefringent effects in a magnetic field because the change of parallel polarization mode is produced via the conversion process of photons into bosons (see Eq.(2)). Therefore the plane of polarization will be rotated (oscillated) and ellipticity will be acquired by a linear polarized beam propagated across magnetic field lines in vacuum. Both effects were calculated by Maiani et al. (1986) and by Raffelt & Stodolsky (1988).

In a result one can present the following expressions for the rotation angle $\theta$ and circular polarization Stokes parameter $V$:

$$\tan \theta(L) = \frac{1/2}{(1 + x^2)} \sin^2 \left( \frac{1}{2} B_{\perp} a_\gamma L \sqrt{1 + x^2} \right)$$  \hspace{1cm} (5)

$$P_C(L) = \frac{B_{\perp}^2}{2} a_\gamma L \sqrt{1 + x^2} \left[ 1 - \frac{\sin \left( \frac{B_{\perp}^2 a_\gamma L \sqrt{1 + x^2}}{2} \right)}{\left( \frac{B_{\perp}^2 a_\gamma L \sqrt{1 + x^2}}{2} \right)^2} \right]$$  \hspace{1cm} (6)

In our case of a vacuum the weak mixing is most important so that is a case $L \ll L_{Osc} = (B g a_\gamma \sqrt{1 + x^2})^{-1}$.

$$\theta(L) \approx \frac{1}{8} g a_\gamma^2 B_{\perp}^2 L^2$$ \hspace{1cm} (7)

$$P_C(L) \approx \frac{(B_{\perp} m_0)^2}{48 \omega} g a_\gamma^2 L^3$$ \hspace{1cm} (8)

Eqs.(5)-(8) mean that ellipticity is acquired only for nonmassless axions. Also there is a most important fact that the rotation angle does not depend on photon frequency and boson mass.

3 Cosmological Alignments of Quasar Optical Polarization Vectors

Recently Hutsemekers (1998) and Hutsemekers et al. (2005) have considered a sample of 170 optically polarized quasars with accurate linear polarization measurements and discovered that quasar polarization vectors are not randomly oriented over the sky as naturally expected. It appeared that in some regions of three dimensional Universe (i.e. in regions delimited in right ascension, declination and redshift) the quasar polarization position angles are concentrated around preferential directions, suggesting the existence of very large-scale coherent orientation or alignment of quasar polarization vectors. The existence of coherent orientations of quasar polarization vectors have been later on confirmed in series of works by Hutsemekers & Lamy (2001) and Jain et al. (2004) with use of a sample of 213 quasars. The final sample that was used for analysis includes 355 objects (see Hutsemekers et al. (2005)). Hutsemekers et al.
used this sample of quasars with significant optical polarization and using complementary statistical methods they confirmed that quasar polarization vectors are not randomly oriented over the sky with a probability often in excess of 99.9%. The polarization vectors seem coherently oriented or aligned over huge (∼1Gpc) regions of the sky located in both low (z ∼ 0.5) and high (z ∼ 1) redshifts and looked characterized by different preferred directions of the quasar polarization.

The linear dichroism of aligned interstellar dust grains in our Galaxy produces linear polarization along the line of sight. This polarization contaminates to some extent the quasar measured data and may change their position angles. [Słuse et al. 2005] have shown that interstellar polarization has a little effect on the polarization angle distribution of significantly polarized (pi ≥ 0.6%) quasars.

The interpretation of such large-scale alignment is difficult within the commonly accepted cosmological models. Ongoing theoretical works develop the idea that one might detect a specific property of dark matter or dark energy. Preliminary possible interpretations of the alignment effect have been discussed by [Hutsemekers 1998], [Hutsemekers & Lamx 2001] and more recently by [Jain et al. 2002, 2004] and [Hutsemekers et al. 2005]. Since the alignments occur on extremely large scales one must seek for global mechanisms acting at cosmological scales.

From this point of view photon-pseudoscalar (ultra light axion or axion-like pseudoscalar particle) mixing with a magnetic field seems as a quite promising interpretation (see [Harari & Sikivie 1992]; [Gnedin & Krashnikov 1992]; [Gnedin 1994]; [Das et al. 2005]) especially because many of the observed properties of the alignment effect were qualitatively predicted.

Recently the exciting event have been taken place in the photon-pseudoscalar mixing science. PVLAS Collaboration [Zavattini et al. 2005a] reported the experimental observation of a laser light polarization rotation in vacuum in the presence of a transverse magnetic field. They claimed that the average measured rotation is \( (3.9 ± 0.5) \times 10^{-15} \text{rad/pass} \), at 5T with 44000 passes through a 1m long magnet. Using Eq.(8) one can estimate the value of the constant coupling of photon-axion mixing \( g_{\alpha \gamma} \). We estimate its value as

\[
g_{\alpha \gamma} \approx 3.8 \times 10^{-6} (\text{GeV})^{-1}
\]

This value seems extremely higher than the corresponding value for Peccei-Quin axion.

First all we may estimate the strength of the intergalactic (IG) magnetic field using this value of the coupling constant \( g_{\alpha \gamma} \), the characteristic size of alignment region \( L \sim 1\text{Gpc} \) and the rotation rate of position angle \( \Delta \theta \sim 30^\circ (\text{Gpc})^{-1} \) (Hutsemekers et al. 2005). The Eq.(7) gives the following value of the IG magnetic field:

\[
B \approx 10^{-16} G
\]

This magnitude appears significantly less than the magnitude predicted by some current works (≤ 10^{-9} see, for instance, [Kronberg 1994]; [Furlanetto & Loeb 2001]; [Berezhiani & Dolgov 2004]; [Dar & De Riyula 2005]; [Xu et al. 2006]; [Kashniashvili 2005]; [Hanayama et al. 2005]; [Bertone et al. 2006]; [Semikoz & Sokoloff 2003]).

Nevertheless, Langer et al. (2005) presented a new model for generating magnetic fields of cosmological interest. They have shown that the photoionization process by photons from the first luminous sources provides the magnetic field amplitudes as high as \( 2 \times 10^{-16} G \). [Takahashi et al. 2006] discussed generation of magnetic field from cosmological perturbations. They computed numerically the magnitudes of the various contributions in the generation process (three component plasma (electron, proton and photon) evolution, the collision term between electrons and photons) and showed that the amplitude of the produced magnetic field could be about \( 10^{-15} G \) at 10kpc co-moving scale at present.

Siegel & Fry (2005) examined the generation of seed magnetic fields due to the growth of cosmological perturbations. In the radiation era, different rates of scattering from photons induce local differences in the ion and electron density and velocity fields. The currents due to the relative method of these fluids generate magnetic fields on all cosmological scales. They estimated the peak of a magnitude of these fields of \( \sim 10^{-30} G \) at the epoch of recombination. The major source of amplification of an initial seed field comes from dynamo effect. A main problem is connected with many mechanisms that produce quite weak seed fields at times insufficiently early for dynamo amplifications. As an example one should mention the Biermann mechanism that can produce seed fields of order \( 10^{-15} G \), but only at redshift of \( z \sim 20 \). It is remarkable that this magnitude is to be close to our estimation (10) of intergalactic magnetic field strength.

Rogachevskii et al. (2005) have discussed a new mechanism of generation of intergalactic large-scale fields in colliding protogalactic clouds and emerging protostellar clouds. Their mechanism is due to a “shear-current” effect (“vorticity-current” effect) caused by the large-scale shear motions of colliding
clouds. Self-consistent plasma-neutral gas simulations by Birk et al. (2002) have shown that seed magnetic field strengths \( \leq 10^{-14} \) G arise in self-gravitating protogalactic clouds of spatial scales of 100pc during \( 7 \times 10^6 \) years.

Thus, we can conclude that the intergalactic magnetic field magnitude is quite probably to be \( \sim 10^{-16} \) G, i.e. it is keeping the value of early cosmological origin. Below we analyse some additional observational consequences of positive PVLAS experiment for astronomy.

4 Cosmological Rotation of Polarization Plane in Radio Waves

Nodland & Ralston (1997) have claimed that they found a systematic rotation of the plane of polarization of electromagnetic radiation propagating over cosmological distances. They have examined experimental data on polarized radiation emitted by distant radio galaxies. After extracting intergalactic Faraday rotation effect, the residual rotation was found to follow a dipole rule. This residual rotation appeared linear in the distance \( L \) to the galaxy source and not depending on a frequency of radiation. They claimed that this effect could not be explained by uncertainties in subtracting Faraday rotation. They determined a birefringence scale of order \( 10^{25} h^{-1} m \). Their claimed effect appears large, requiring the plane of polarization from high redshift objects to be rotated by as much as 3.0 rad - an extremely detectable signature.

However, Wardle et al. (1997) and Carroll & Field (1997) reexamined the same data and argued that there is no statistically significant signal present. Wardle et al. (1997) reported new optical data taken with the Keck Telescope, and radio observations made with the VLA which showed that any such rotation is less than 3 degrees out to redshifts in excess of two.

This lower bound can be used for estimation of the photon-to-Goldstone boson coupling constant \( g_{a\gamma} \) using Eq.(7) for intergalactic space. Nodland & Ralston (1997) and Carroll & Field (1997) mentioned very shortly on chiral effects, including axions, that could produce the claim effect of polarization plane rotation, but they did not make real estimations.

We use the Eq.(7) for cosmological distances, but at first it is necessary to explain the validity of this Eq., because by Eq.(7) the rotation angle depends on the square of a distance \( \sim L^2 \). The Eq.(7) was given only for a homogeneous magnetic field.

But the real extragalactic magnetic field changes with a distance. For example, the magnetic field strength of the Local Super Cluster (LSC) that is extending for \( \sim (30 \div 40) Mpc \) differs of the magnetic field strength present over cosmological distances (Blasi & Olinto, 1998). Of course, the magnetic field structure either of the LSC, or of cosmological distance are very poorly known. Direct measurements through Faraday rotation give upper limits to fields averaged along the line of sight to particular background radio sources. The rough estimations of observational data show that at distance scale \( \sim 10 Mpc \) the magnetic field is constrained to have \( B_0 \leq 10^{-8} \) G, while for cosmological distances to the present horizon \( L \sim 1 Gpc \), the magnetic field strength \( B \leq 10^{-11} \) G. Thus we can suggest the simple law for the change of the intergalactic magnetic field with a distance \( B = B_0 (L/L_0) \).

It allows us to obtain by Eq.(7) the following estimation of the photon-to-Goldstone boson coupling constant for \( z = 2 \):

\[
g_{a\gamma} \approx \frac{3.8 \times 10^{-6}}{1 GeV} \left( \frac{\theta}{30'} \right)^{\frac{1}{2}} \left( \frac{L_0}{10 Mpc} \right) \left( \frac{10^{-15}}{B_0} \right) h^{-50} \]

5 Some Additional Results

5.1 UV break in SED of QSOs

The ultraviolet energy distribution of quasars is characterized by a sharp steepening of the continuum shortward of the so-called "big blue bump". The quasar "composite" spectral energy distribution exhibits a steepening of the continuum at \( \sim 1100 \) A (Binette et al. 2005 and refs. therein). A fit of this composite SED using a broken power-law reveals that the power-law index changes radically from approximately (-0.69) in the near UV to (-1.78) in the far UV. Binette et al. 2005 label this observed sharp steepening the "far UV break". They suggested that this break could be caused due absorption by crystalline carbon dust. We suggest another explanation of this observed break as being due to the magnetic conversion of UV photons into extremely low mass axions into the intergalactic magnetic field. It is remarkable
that the probability of such conversion process increases really with the increase of photon energy and becomes more stronger really in far UV range (see Eqs. (2), (3) and (4)).

Using the VLAS experimental value of $g_{a\gamma}$ and the characteristic length magnitude of $\sim 1Gpc$ one can estimate the optical depth of photon conversion into axion as

$$\tau \sim g_{a\gamma} B l = 3 \times 10^3 \times 3.8 \times 10^{-15} \times 10^{-16} \times 3 \times 10^{27} \approx 3.42$$

(12)

that becomes noticeable greater that unit. It means that this conversion process can provide the observable sharp steepening of UV continuum of QSOs.

5.2 Polarization of stars in the Local Bubble

Another the intrigue problem is due to the observations of intrinsic polarization of stars located in the Local Bubble. The low density region of the local interstellar medium (ISM) where the Sun is located is called the local cavity or bubble. This region is partially filled with hot ($\sim 10^6 K$) low number density ($\leq 0.005 cm^{-3}$) coronal gas detectable in soft X-rays [Vallerga et al. 1996; Frisch 2001; Maiz-Apellaniz, 2001]. The Local Bubble is the interstellar material that resides in close ($< 100 pc$) proximity to the Sun. Leroy (1993a,b) has prepared and analyzed the catalogue of optical polarization measurements for 1000 stars closer than 50pc from the Sun. He founded the discrepancy for a number of stars between the measured polarization magnitude and stellar spectral classification. It is difficult to explain the observable polarization degree by interstellar polarization origin because of the well known depletion of dust in the Sun’s vicinity.

We suggest the process of photon conversion into extremely low mass axions in the Local Bubble magnetic field as the probable mechanisms of production of observable stellar polarization. Let us estimate the characteristic oscillation lengths.

The value of plasma oscillation length is

$$L_P = \frac{2\pi \omega}{\omega^2_P} \approx 40 \left(\frac{\omega}{3 eV}\right) \left(\frac{0.005}{N_e}\right) pc$$

(13)

The real magnetic conversion oscillation length is

$$L_B = \frac{2\pi}{g_{a\gamma} B} = 0.1 \left(\frac{10^{-6}}{B}\right) pc$$

(14)

Conversion theory allows to get constraints on the axion mass. The oscillation length due mass of an axion is (see, for example, Gnedin (1997)):

$$L_A = 20 pc \left(\frac{10^{-12}}{m_a}\right)^2 \left(\frac{h\omega}{3 eV}\right)$$

(15)

For the effective conversion photons into axions in the interstellar medium of the Local Bubble we need

$$L_B \ll L_P, L_m$$

(16)

It means that the mass of axion should be equal to $m_a < 2.6 \times 10^{-11} eV$.

5.3 The circular polarization of radiation of AGNs and QSOs

Raffelt & Stodolsky (1988) have shown in their classical work that light may acquire a circular polarization through the effect magnetic conversion of light into axions in the case of very small axion masses. The magnitude of polarization acquired along the path length $L$ in a result of magnetic conversion is determined by Eq. (8).

At last time it is received the evidence according to which the extragalactic objects (AGN and QSO) may show a substantial degree of circular polarization not only in radio waves but even at high (optical) frequencies (see Rieger & Mannheim (2005)). Recent high resolution observations of the quasar 3C279 with the FORS polarimeter at the ESO-VLT indicated a variable optical circular polarization occasionally exceeding 1%. One can expect that appearance of circular polarization is connected with the relativistic jets from AGN and QSO. Recent observations made at Russian BTA-6m telescope with the SCORPIO
detector give evidence of circular polarization of the blazar candidate S5 0716+714 at the level \( \sim 0.5\% \) (Afanasiev and Amirkhanyan, private communication). A key open question arises in the study of circular polarization, namely, on the origin of its physical mechanism. Circular polarization in AGN may be produced either as an intrinsic component of synchrotron radiation or through Faraday conversion of linear polarization into circular one. The last mechanism requires a large number of low energy relativistic particles in the radiation region (presumably jet or corona) to do the effective conversion and hence a relatively low cutoff in particle energy spectrum, approximately at the Lorentz factor \( \gamma \leq 20 \) (Wardle et al., 1998). Theoretically it appears easier to generate large amounts of circular polarization through the Faraday conversion process but direct observational evidence is absent now (see Homan, 2004). The key moment is the frequency dependence of observed circular polarization that is yielded with diversity of its frequency dependence for various objects.

Using Eq.(8) and PVLAS data for the coupling constant \( g_{a\gamma} \), one can estimate constraints on an axion mass from polarimetric observation of AGN and QSO made by Hutsemekers et al. (2003). Expected circular polarization value from \( z \leq 1 \) QSOs at the level \( P_V \sim 0.1\% \) gives the constraints at an axion mass as \( m_a \approx 3 \times 10^{-16} eV \). That mass values lies out the limits of standard PQ axion theory. It is curious that this axion mass value corresponds to the magnitude obtained by Czaki et al. (2002) from supernovae dimming.

6 Conclusions

Photon-pseudoscalar boson mixing birefringent effects for cosmological distances have been considered and estimated. Effect of cosmological alignment and cosmological rotation of polarization for distant QSOs discovered by Hutsemekers et al. (2005) can be explained in terms of birefringent phenomenon due to photon - low mass axion (Goldstone boson) mixing in a cosmological magnetic field.

Using axion interpretation of the PVLAS data we estimate the intergalactic magnetic field magnitude as \( \sim 10^{-16} G \).

The net circular polarization of distant AGN radiation crossing an interstellar medium can be explained as a result of magnetic conversion of photons into extremely low mass axions. In a result one can get the strong constraints on the nonstandard axion mass as \( m_a \leq 3 \times 10^{-16} eV \).

The observations of intrinsic polarization of stars located in the Local Bubble showed the discrepancy between the measured polarization degree and stellar spectral classification. This fact can’t be explained by interstellar polarization. If one should suggest the magnetic conversion process as an origin of this discrepancy it is possible to estimate also the upper limit on an axion mass value that appears at the level \( m_a \leq 2 \times 10^{-11} eV \).

Acknowledgments

This research was made with financial support by Program of Prezidium of Russian Academy of Sciences "Origin and Evolution of Stars and Galaxies" and Program of the Department of Physical Sciences of RAS "Extended Objects..." and by the LOT of Russian Ministry of Education and Science.

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