Abstract

Extreme-scale alignment of quasar optical polarization vectors at cosmological scales ($z \leq 2$) is also characterized by the rotation of mean position angle $\Delta \chi$ with $\Delta \chi \approx 30^\circ$ per 1 Gpc. For observing interval of $z$ the total rotation angle acquires the value $\sim 90^\circ$. We suggest the possible explanation of the half of this rotation as a consequence of physical transformation of initially vertical magnetic field $B_\parallel$, directed along the normal $N$ to the surface of accretion disk, into the horizontal (perpendicular to $N$) one. We found asymptotical analytical expressions for axially averaged polarization degree $p$ and mean position angle $\chi$ for various types of magnetized accretion disks. We found also that during the evolution can be realized the case $B_\perp \approx B_\parallel$ where position angle $\chi$ rotates from $45^\circ$ to zero. This rotation may occur during fairly great cosmological time (corresponding to $\Delta z \sim 1 - 2$). The part of rotation $\sim \Delta \chi \approx 45^\circ$ can be explained by a mechanism of alignment of polarization vectors, say distribution of the part of quasars as a spiral in the cosmic space with slow variation of rotation axis of corresponding accretion disks. Both mechanisms are mutually related one with another.

Keywords: polarization, magnetic fields, accretion disks, quasars, active galactic nuclei.

1 Introduction

Large scale alignments of quasar polarization vectors have been revealed by Hutsemekers (1998), looking at a sample of 170 QSO selected from various surveys. Hutsemekers & Lamy (2001) have confirmed this effect later on a larger sample. The departure from random orientation has been found at fairly well significance level. Hutsemekers and Lamy have concluded that these alignments seemed to come from high redshift regions, implying that the underlying mechanism might cover physical distances of gigaparsecs. Moreover, Hutsemekers et al. (2005) have estimated the rotation of mean position angle magnitude as $\Delta \chi \leq 30^\circ$ at the distance of $\sim 1$ Gpc. In this paper they presented the analysis of the alignment effect for a total sample of 355 quasars, comprising new polarization measurements both from observing runs 2001-2003 and new comprehensive data from surveys and the literature. The paper of Borquet et al. (2008) threw light on the new observational fact. They found a significant correlation between the polarization position angle and the

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redshift $z$. We use the results of calculation of polarization of radiation from optically thick magnetized accretion disks in quasars and active galactic nuclei. The presence of intrinsic magnetic field in an accretion disk produces a new effect, provided by the Faraday rotation of polarization plane along a photon mean free path in scattering medium (see, for example, Dolginov, Gnedin & Silant’ev (1993); Gnedin & Silant’ev (1997); Silant’ev (2002); Gnedin, Silant’ev & Shternin (2006)).

Due to these authors, a nontrivial wavelength dependence of polarization and position angle arises when the Faraday rotation angle $\Psi$ at the Thomson optical depth $\tau$ is sufficiently large:

$$\Psi = 0.4 \left( \frac{\lambda}{1 \mu m} \right)^2 \left( \frac{B}{1 G} \right) \tau \cos \theta = \frac{1}{2} \delta \tau \cos \theta. \quad (1)$$

Here, $\lambda$ is the radiation wavelength and $\theta$ is the angle between the line of sight $\mathbf{n}$ and magnetic field $\mathbf{B}$. Below we shall use the known Milne problem which corresponds to the case where the thermal sources are located far from the surface of optically thick accretion disk. The existence of Faraday rotation angle $\Psi$ gives rise to both the decrease of degree of polarization $p$ and the rotation of position angle $\chi$ (up to maximum value $\chi = 45^\circ$ as compared the usual Thomson scattering problem where $\chi = 0$ is assumed). The numerical solution of the Milne problem in the case of magnetized atmosphere with magnetic field directed along the normal to atmosphere has been early obtained by Silant’ev (1994, 2002); Agol & Blaes (1996) and Shternin, Gnedin & Silant’ev (2003).

Magnetic field in an accretion disk consists of two mutually perpendicular components $\mathbf{B} = \mathbf{B}_z + \mathbf{B}_\perp$. Here $\mathbf{B}_z \equiv \mathbf{B}_\parallel$ is directed along the normal $\mathbf{N}$ to the disk’s surface. The field $\mathbf{B}_\perp = \mathbf{B}_\theta + \mathbf{B}_\varphi$ is perpendicular to $\mathbf{N}$, and consists of the azimuthal $\mathbf{B}_\varphi$ and radial (in cylindrical system of references) $\mathbf{B}_\theta$ components.

We observe the azimuthally averaged Stokes parameters $\langle Q(n, B) \rangle$ and $\langle U(n, B) \rangle$. If $\mathbf{B}_\parallel = 0$, the observed position angle $\chi = 0$ due to symmetry of a problem (remember that tan $2\chi = U/Q$, and the direction with $\chi = 0$ is parallel to disk’s surface). In contrary, the case $\mathbf{B}_\parallel \neq 0$ gives rise to the rotation of position angle $\chi$ from zero at $B_\parallel = 0$ up to maximum value $\chi_{\max} = \pm 45^\circ$ for large values of $B_\parallel$. The signs $\pm$ depend on outside or inside the accretion disk orientation of magnetic field $\mathbf{B}_\parallel$. In both cases the increase of magnetic field value decreases the polarization degree $p$.

Note that Faraday rotation of polarization plane in intergalactic medium is too low to be considered as a possible mechanism of observed rotation of mean position angle.

The goal of the paper is to show that in general cases there exist situations where the position angle $\chi$ decreases, with the increase of $\mathbf{B}_\perp$ from initial value $\chi \approx 45^\circ$ (corresponding to large $B_\parallel$) up to $\chi \approx 0$. So, we shall demonstrate that the evolution of components $\mathbf{B}_\parallel$ and $\mathbf{B}_\perp$ can explain the observed large-scale position angle rotation due to intrinsic physical evolution of magnetic fields in accretion disks around of QSOs or AGNs. Below we present this in detail. We shortly discuss also the origin of possible mechanisms of transformation $\mathbf{B}_\parallel$ to $\mathbf{B}_\perp$.

## 2 Basic equations

Silant’ev (2002) obtained the analytical approximate formulae for the Stokes parameters of polarization of radiation emerging from optically thick accretion disk which for the Milne problem acquire the form:

$$I = \frac{F}{2\pi J_1} J(\mu),$$

$$Q = -\frac{F}{2\pi J_1} \frac{1 - g}{1 + g} \frac{(1 - \mu^2)(1 + C - k\mu)}{(1 + C - k\mu)^2 + (1 - q)^2 \delta^2 \cos^2 \theta},$$

$$U = -\frac{F}{2\pi J_1} \frac{1 - g}{1 + g} \frac{(1 - \mu^2)(1 - q) \delta \cos \theta}{(1 + C - k\mu)^2 + (1 - q)^2 \delta^2 \cos^2 \theta}. \quad (2)$$

where $\theta$ is the angle between the directions of magnetic field $\mathbf{B}$ and the line of sight $\mathbf{n}$, $\mu = \cos i$ (i.e. angle between normal $\mathbf{N}$ and $\mathbf{n}$), $q$ is the degree of true absorption: $q = \sigma_a / (\sigma_a + \sigma_s)$. The function $J(\mu)$ describes the angular distribution of emerging radiation, $F$ is the radiation flux emerging from the disk’s surface. The function $J(\mu)$ and the numerical parameters $g$, $J_1$, and $k$ are tabulated by Silant’ev (2002). The minus signs denote that Thomson polarization is perpendicular to the plane ($\mathbf{nN}$), i.e. has position angle $\chi = 0$. In the case of dominant electron scattering inside an accretion disk: $g = 0.83255$, $J_1 = 1.19400$, and $k = 0$. Dimensionless parameter $C$ arises in turbulent magnetized plasma (see Silant’ev (2003) and characterizes the new effect - additional extinction of parameters $Q$ and $U$ due to incoherent Faraday rotations in small turbulent eddies.

The parameters of the Faraday depolarization for $B_\parallel$ and $B_\perp$ can be introduced from Eq. (1):

$$\delta_\parallel = 0.8 \left( \frac{\lambda_{\text{rest}}}{1 \mu m} \right)^2 \left( \frac{B_\parallel}{1 G} \right),$$

$$\delta_\perp = 0.8 \left( \frac{\lambda_{\text{rest}}}{1 \mu m} \right)^2 \left( \frac{B_\perp}{1 G} \right). \quad (3)$$

The wavelength $\lambda_{\text{rest}}$ is derived in the rest system of quasar or AGN. The value $\delta \cos \theta$ in these notions has very simple form:

$$\delta \cos \theta = a + b \cos \Phi, \quad (4)$$

where dimensionless parameters $a$ and $b$ are connected with the parameters $\delta_\parallel$ and $\delta_\perp$

$$a = (1 - q)\delta_\parallel \mu, \quad b = (1 - q)\delta_\perp \sqrt{1 - \mu^2}, \quad (5)$$

with the angle $\Phi = \phi + \phi_\perp$, where $\phi$ being the azimuthal angle of radius-vector of observed point $r$ on the surface of an accretion disk. The angle $\phi_\perp$ is the angle between $\mathbf{B}_\perp$ and $\mathbf{B}_\parallel$. The azimuthal angle of line of sight $\mathbf{n}$ is taken zero.

Non-polarized light escape the optically thick disk basically from the surface layer with $\tau \approx 1$. The additional extinction of parameters $Q$ and $U$ in turbulent magnetized atmosphere means that linearly polarized light escape the disk surface mainly from the Thomson optical depth $\tau \approx 1/(1 + C)$. If the Faraday rotation angle $\Psi$ corresponding to this optical length becomes greater than unity, then the emerging radiation will
be depolarized as a result of summarizing of radiation fluxes with very different angles of Faraday rotation. For directions that are near perpendicular to the direction of the magnetic field in an accretion disk the Faraday rotation angle is too small to yield depolarization effect. Certainly, the diffusion of radiation in the inner parts of a disk depolarizes it even in the absence of magnetic field because of multiple scattering of photons. The Faraday rotation only increases the depolarization process. It means that the polarization of outgoing radiation acquires the peak-like angular dependence with its maximum for the direction perpendicular to the magnetic field. The sharpness of the peak increases with increasing magnetic field strength. The basic region of allowed angles appears to be \( \sim 1/\delta \). Another very important feature characterizing the polarized radiation is the wavelength dependence of polarization degree that is strongly different from that for Thomson scattering.

Formulae (2) give rise to the following expression for the polarization degree:

\[
p(\mu, B) = \frac{p(\mu, 0)}{\sqrt{1 + C - k\mu^2} + (1 - q)^2 \delta^2 \cos^2 \theta},
\]

where \( p(\mu, 0) \) means the polarization degree for pure Thomson scattering. Remind that \( p(\mu, 0) \) in conservative atmosphere \( (q=0) \) has the classical Sobolev-Chandrasekhar value, that is maximal and equal to 11.7% for \( \mu = 0 \) (i.e. for the inclination angle \( i = 90^\circ \)). We use the reference system with X-axis lying in the plane \((\mathbf{nN})\). In this system \( U(\mu, 0) = 0 \) and \( p(\mu, 0) = |Q(\mu, 0)| \). The position angle \( \chi \) of emerging radiation, as usually, is described by the known relation:

\[
\tan 2\chi = \frac{U}{Q} = \frac{(1 - q)\delta \cos \theta}{1 + C - k\mu},
\]

For strong magnetic field strength (or large wavelength, when \((1 - q)\delta \cos \theta \gg 1\), the simple asymptotic expressions take place:

\[
p(\mu, B) \approx \frac{p(\mu, 0)}{(1 - q)\delta \cos \theta}, \quad \chi \rightarrow 45^\circ.
\]

It is seen from Eq. (6) that small-scale magnetic turbulence (parameter \( C \)) decreases the observed polarization degree. This is because the polarized light (parameters \( Q \) and \( U \)) escape mainly from the level \( \tau \approx 1/(1 + C) \) where intensity is lesser as compared with the level \( \tau \approx 1 \), corresponding to escape of non-polarized light. In contrast, the existence of absorption \((q \neq 0, k \neq 0)\) increases polarization both due to existence the parameter \( k \) in the denominator of Eq. (6) and due to that \( p(\mu, q, 0) \) is higher than \( p(\mu, q = 0, 0) \) (see, for example, Silant’ev (1980)). The absorption gives rise to more sharp intensity (along the normal \( \mathbf{N} \)), and the situation look like the single scattering of a light beam in the surface layer of the atmosphere. So, at \( q = 0.1 \) the Milne problem has \( J(\mu = 1) = 4.39 \) and \( p(\mu = 0, 0) = 20.4\% \). The corresponding values for conservative atmosphere are 3.06 and 11.71%.

3 Polarization degree and position angle of observed accretion disk radiation

For an accretion disk the light depolarization depends on the geometry of magnetic field. Usually one observes the axially symmetric accretion disks as whole. In this case the observed integral Stokes parameters \( \langle Q(\mathbf{n}, \mathbf{B}) \rangle \) and \( \langle U(\mathbf{n}, \mathbf{B}) \rangle \) are described by the azimuthal averaged expressions. To obtain analytical formulae for \( Q \) and \( U \) we present expressions (2) for \( Q \) and \( U \) in a complex form:

\[
Q - iU = \frac{p(\mu, 0)}{G + ia + ib\cos \Phi}.
\]

Here and what follow we use the notion \( G = 1 + C - k\mu \). The azimuthally averaging of this formula gives rise to expression:

\[
\langle Q \rangle - i\langle U \rangle = \pm \frac{p(\mu, 0)}{G^2 + b^2 \cos^2 \theta},
\]

where sign plus corresponds to \(|\epsilon| < 1\), and minus corresponds to \(|\epsilon| > 1\).

Silant’ev (2005) has derived the next expression for the turbulent extinction parameter:

\[
C = 0.64(1 - q)\tau_1 \lambda_{\text{rest}}^4(\mu)(B^2)f_B/3
\]

Here, \( \tau_1 \ll 1 \) is the mean Thomson optical length of small turbulent eddies, the value \( B' \) denotes the fluctuating component of the magnetic field \((\mathbf{B} = \mathbf{B}_0 + \mathbf{B}')\). We omitted, for brevity, the subscript "0" in previous formulae. It means that the depolarization parameters \( a \) and \( b \) in Eq. (2) are determined only by the global magnetic field values. The numerical coefficient \( f_B \approx 1 \) is connected with the correlation function of fluctuating components \( \mathbf{B}' \) in neighboring points of turbulent atmosphere.

It is convenient to introduce the relative polarization degree \( p_{\text{rel}} = p(\mathbf{n}, \mathbf{B})/p(\mu, 0) \). By the usual way we obtain from Eq. (11) the following expressions:

\[
p_{\text{rel}} = \frac{1}{G^2 + 2G^2(a^2 + b^2) + (a^2 - b^2)^2}.
\]

The relative polarization degree \( p_{\text{rel}} \) does not depend on signs \( \pm \) in Eq. (11). The interesting property of expression (13) that it depends symmetrically on parameters \( a \) and \( b \), i.e. we have \( p_{\text{rel}}(\mu, a, b) = p_{\text{rel}}(\mu, b, a) \).

The position angle \( \chi \) is connected with the phase angle \( \phi \) of the complex expression inside the root in Eq. (11). Evidently we have

\[
\tan \phi = \frac{2Ga}{G^2 + b^2 - a^2}.
\]
If right side in Eq. (14) is positive (this corresponds to sign plus in Eq. (11)), then the position angle \( \chi \) is determined by expression:

\[
\tan 2\chi = \frac{\langle U \rangle}{\langle Q \rangle} = \frac{2Ga}{\sqrt{G^2 + 2G^2(a^2 + b^2) + (a^2 - b^2)^2 + (G^2 + b^2 - a^2)}}. \tag{15}
\]

For the negative \( 2Ga/(G^2 + b^2 - a^2) < 0 \) we have

\[
\tan 2\chi = \frac{2Ga}{\sqrt{G^2 + 2G^2(a^2 + b^2) + (a^2 - b^2)^2 - |G^2 + b^2 - a^2|}}. \tag{16}
\]

Evidently the position angle \( \chi \) is not symmetric function of parameters \( a \) and \( b \). The observed parameters \( \langle U \rangle \) and \( \langle Q \rangle \) are positive for our choice of the reference frame and corresponds to the case where \( \mathbf{B} \) is directed outside the accretion disk surface. If the magnetic field \( \mathbf{B} \) is directed inside the accretion disk, then the position angle \( \chi \) changes its sign (parameter \( U < 0 \)).

For a number of particular cases one can obtain fairly simple analytical expressions. First of all, for the case of pure vertical magnetic field (parameter \( b = 0 \)) we obtain directly from basic Eq. (9) the following expression:

\[
pr_{rel}(\mu, B_i) = \frac{1}{\sqrt{G^2 + a^2}}, \quad \tan 2\chi = \frac{a}{G}. \tag{17}
\]

For pure perpendicular magnetic field \( (a = 0) \) our general formulae give:

\[
pr_{rel}(\mu, B_{\perp}) = \frac{1}{\sqrt{G^2 + b^2}}, \quad \chi \equiv 0. \tag{18}
\]

The position angle \( \chi = 0 \) is due to symmetry of problem in this case. For the case \( a = b \), which approximately corresponds to equipartition \( B_i = B_{\perp} \) for \( i \approx 45^\circ \), the formulae for \( p \) and \( \chi \) acquire the forms:

\[
pr_{rel}(\mu, a = b) = \frac{1}{\sqrt{G^2(G^2 + 4a^2)^{1/4}}},
\]

\[
\tan 2\chi = \frac{2Ga}{\sqrt{G^2(G^2 + 4a^2)} + G^2}. \tag{19}
\]

Remember that \( G = 1 + C - k\mu \). It is easy check that for conservative atmosphere (\( k = 0 \)) the existence of \( b = a \) increases the relative polarization degree \( pr_{rel} \) as compared with the case pure parallel magnetic field \( (a \neq 0, b = 0) \):

\[
\frac{pr_{rel}(\mu, a = b)}{pr_{rel}(\mu, a = \hat{b})} = \left( \frac{G^2 + a^2}{G^2(G^2 + 4a^2)} \right)^{1/4} < 1. \tag{20}
\]

Below we present Tables 1 - 4, where \( pr_{rel} \) and \( \chi \) are given for different values of \( a, b \) and \( C \) in conservative atmosphere \( (q = 0) \).

The detailed numerical calculation (particularly presented in tables 1 - 4) demonstrate that the existence of \( B_{\perp} \) can increase the relative degree of polarization \( pr_{rel} \) compared with the case \( b = 0 \). This effect takes place for \( a \geq 1 - 3 \) and
plus corresponds to the case where the Faraday rotation from accretion disk where the Faraday rotation from the state \( \chi = 0 \) for particular quasars, corresponding to \( z \)-parameter, can explain the observed effect of rotation of the mean position angle.

The mentioned maximum angle of rotation \( \chi \approx 45^\circ \) due to intrinsic mechanism may not be realized in reality. In this case main part of observed total rotation will be due to kinematic mechanism of variations of the normals to accretion disks surfaces for particular quasars, with corresponding \( z \)-parameters. We only demonstrated above that the intrinsic mechanism exists, and it can explain rotation \( \lesssim 45^\circ \). According to \cite{Hutsemekersetal2005}, the mean degree of polarization of all the sample of quasars is equal to 1.38%. They mentioned also that the alignment effect is more efficient for the low polarization quasars than for the high polarization ones. This means that we can consider the rotations of position angle of quasars with the degree of polarization lesser than the value 1.38%.

Now we give some examples of values of rotation for \( i = 45^\circ, 60^\circ \) and \( 80^\circ \), using our tables 1 and 2, and that, according to \cite{Chandrasekhar1950}, the polarization degrees \( p(\mu, 0) \) for these inclination angles are 1.1%, 4.04%, and 6%, respectively. The accretion disk in the initial state \((a = 4, b = 0)\) has degrees of polarization 0.27%, 0.98% and 1.45%, respectively, and the position angle \( \chi = 38^\circ \). When the growing perpendicular magnetic field \( B_\perp \) gives rise to \( b = 2 \), accretion disk acquires the degrees of polarization 0.3%, 1.09%, and 1.63% with position angle \( \chi = 36^\circ \), i.e we have the rotation \( \Delta \chi = 2^\circ \). For \( b = 4 \) the corresponding values are 0.39%, 1.42%, 2.1%, with position angle \( \chi = 20.7^\circ \), i.e. have rotation \( \Delta \chi = 17.3^\circ \) from the state \((a = 4, b = 0)\), and the rotation \( \Delta \chi = 15.3^\circ \) from the state \((a = 4, b = 2)\). Remember that values of \( b \) depend on \( z \)-parameter, and belong to quasars with various \( z \), which are at different distances from an observer. Remind also that optical radiation escapes from accretion surface far from the centre of disk and magnetic field in this place is much lesser than that in the centre. The estimations give rise to the values \( B \approx 10^3 \) – \( 10^4 \) G in the central parts of a disk. The used value \( a = 4 \) correspond to \( B_\parallel \approx 16.5 \mu \) G for \( \lambda = 0.55 \mu \)m. It seems the process of diffusion of magnetic field from central part to the places where optical radiation arises can be slow. The increase of polarization degree with the grow of parameter \( b \) (up to \( b = a \)) is new effect which was explained in the end of the previous section.

Thus, the observed effect of the cosmological rotation of polarization vectors of QSOs can be explained partly by evolution of a magnetic field in accretion disks. As a result of such evolution the topology of magnetic field in AGNs is changed and implies the transition, for example, from the predominant vertical domain distribution to the predominant horizontal domain distribution. The ratio of domain sizes can be changed respect to the cosmological redshift \( z \).

The physical mechanism of magnetic inversion considered here can be the same one which was considered recently by \cite{Igumenshchev2009} for explaining the spectral transition of black holes binaries. The base for these phenomena can be the development of a magnetically arrested accretion disk attributable to the accumulation of a vertical magnetic field in a central part of this disk. The development and evolution of powerful jets provides also the evolution and inversion of

\[ b \leq a. \] The maximum polarization occurs at \( b = a \) (see tables 1 and 3). This effect stems some "resonant" regions in an accretion disk where the Faraday rotation from \( B_\parallel \) is balanced by opposite rotation from a perpendicular magnetic field \( B_\perp \).

For \( b > a \) polarization decreases quickly with growing of parameter \( b \). Note also that for \( b = a \gg 1 \) the position angle \( \chi \rightarrow 22.5^\circ \). For this case the transition of \( \chi \) from \( \approx 45^\circ \) to very small value occurs in the layer \( |a - b| \approx 2 - 5 \), i.e. we observe the rotation of position angle \( \chi \) from \( \pm 45^\circ \) (depending on the magnetic field direction) to \( \chi \approx 0 \) if \( b \gg a \).

Presented expressions and tables allow us to estimate the values of polarization degree and position angle. We shall use these expressions to explain the effect of the cosmological rotation of the position angle of polarized QSOs discovered by \cite{Hutsemekersetal2005}.

\section{Scenario of intrinsic mechanism}

The scenario of our explanation is the following. First of all, we assume that at early time of the QSOs evolution, corresponding to \( z > 2 - 3 \), the magnetic field in accretion disk is directed along the normal \( N \) to the surface, and the perpendicular magnetic field \( B_\perp \) is practically absent. The increase of \( B_\perp \) inside the accretion disk can be considered as due to large-scale diffusion process, i.e. one can assume \( B_\perp \sim Dt \). The time difference \( t \) is proportional to cosmological parameter \( z \) (remember that large \( z \) correspond to early time of the evolution of the Universe). The high values of \( B_\parallel \) \((a \geq 4)\) correspond to inclination angle \( \chi \approx \pm 45^\circ \) of electric field of the emerging radiation, as compared to the usual Thomson position angle, which is parallel to accretion surface. The sign plus corresponds to the case where \( B_\parallel \) is directed outside the surface. The minus sign corresponds to opposite field direction. As a result of large-scale diffusion magnetic field \( B_\perp \) acquires the values \( B_\perp \approx B_\parallel \), and the case \( b \approx a > 4 \) occurs. In small interval of growing of parameter \( b \) with \( |a - b| \approx 2 - 5 \), where position angle of outgoing radiation changes from initial value \( \approx 45^\circ \) to final zero value, the angle of rotation can be roughly approximated by linear dependence on value \( b \sim t \sim z \). Remember that usually position angle \( \chi \) is observed with fairly high error interval. So, evolution mechanism of the increase of perpendicular magnetic field inside of accretion disk presents simultaneously the intrinsic mechanism of rotation of observed position angle, which is proportional to cosmological parameter \( z \). Note that this mechanism is restricted by \( 45^\circ \) rotation.

The cosmological rotation of mean position angle, discovered by \cite{Hutsemekersetal2005}, corresponds to approximately linear growing from zero at \( z = 2 \) to \( \approx 90^\circ \) at \( z \approx 0 \). Our mechanism can explain only \( 45^\circ \) rotation. Evidently there is an additional mechanism of rotation, connected with the alignment of quasar polarization vectors discovered also by \cite{Hutsemekers1998}. Clearly, this alignment is due to some type of anisotropy of QSOs distribution in cosmic space. For example, we may assume that a part of quasars distribution presents spiral type form. In this case the local position \( \chi = 0 \) varies from one quasar to another. The simultaneous action of our intrinsic mechanism and variation of zero position

\[ \chi = 0 \] for particular quasars, corresponding to \( z \)-parameter, can explain the observed effect of rotation of the mean position angle.
magnetic field components in an accretion disk.

More interesting mechanism has been recently suggested by Lyutikov (2009). Strong magnetic field can modify motion in the curved space-time of spinning black holes and change the stability conditions of circular orbits. Magnetocentrifugal jet launching from accretion disks around black holes is also connected to topology of accretion disk magnetic field. According to Lyutikov (2009), magnetocentrifugal launching for a Schwarzschild black hole requires that the poloidal component of magnetic field makes an angle less that 60° with respect to the outward direction at the disk surface. For the prograde rotating disks around Kerr black holes this angle increases and becomes 90° for footpoints anchored to the inner region of an accretion disk for a limit spinning \( a_* = 1 \) black hole (\( a_* = a/M_{BH} \)). It means that the effect of cosmological rotation of QSO polarization plane can be interpreted as a result of spin evolution of QSO: \( a_* \approx 1 \) for \( z > 1 \) and \( a_* \ll 1 \) for \( z \ll 1 \). This suggestion has some evidence. Recently, the constraints on the spins of the black holes in the nearby QSOs have been obtained: \( a_* = 0.6 \pm 0.2 \) in the narrow-line Seyfert SWIPT 12127+5654 (Miniutti et al. 2009), \( a_* = 0.60 \pm 0.07 \) for the SMBH in Fairall 9 (Schnoll et al. 2009).

The another idea has been developed by Contopoulos et al. (2009). They developed the scenario in which cosmic magnetic fields are generated near the inner edges of accretion disks in AGNs by azimuthal electric currents due to difference between the plasma electron and ion velocities that arises when the electrons are retarded by interactions with X-ray photons. This mechanism namely relates the polarity of poloidal magnetic field to the angular velocity of the accretion disk, i.e. this polarity depends strongly on spin of a black hole. If the spin decreases at low redshifts \( z < 1 \), this effect produces magnetic inversion in the accretion disks.

Unfortunately, if the effect of rotation of polarization planes in QSOs can be partly explained in framework of our mechanism, the origin of cosmological alignment of polarization vectors becomes open. It is not except, that the mechanism of cosmological differential rotation produces such kind of alignment. It seems more probable supposition of alignment mechanism is the existence of turbulent motions of the huge scale.

Recently, the interesting idea of alignment of galaxies has been suggested by Trujillo, Carretero & Patri (2007). They claimed that galaxies are not distributed randomly throughout-out space but are arranged in "cosmic web" of filaments and walls. Unfortunately, there is still no compelling observational evidence of a link between the structure of the cosmic web and how galaxies form within it. The basis for this connection is the origin of galaxy angular momentum. The spin of galaxies can be generated by tidal torques operating in the early Universe on primordial material from which galaxy is formed. In its order, magnetic fields in QSOs and galaxies can correlate with galaxy rotation rate and its angular momentum. Trujillo, Carretero & Patri (2007) claimed that observational link between large-scale structure and the properties of individual galaxies has been definitively established. One should remind the result by Borquet et al. (2008). They found a correlation between the polarization position angle and the position angle of the major axis of the host galaxy extended emission. It seems that in the frame of this idea our intrinsic mechanism can explain the total rotation of the mean position angle if we shall suppose that position of zero’s \( \chi \) in neighboring "webs" has a jump \( \approx 45° \).

5 Conclusions

We showed that the observed by Hutsemekers et al. (2005) effect of cosmological rotation of polarization vectors of QSOs can be partly explained by the evolution of magnetic field in accretion disks around SMBHs. The evolution of topology of magnetic field in AGNs produces the transition from the predominant vertical domain distribution at \( z \geq 1 \) to the predominant horizontal domain distribution at \( z < 1 \). Such kind of transition can be explained by the cosmological evolution of spin of supermassive black holes from the Kerr case at \( z \geq 1 \) to Schwarzschild case at \( z < 1 \). The calculations show that this effect is able to provide the observed rotation measure at the level of 30° / Gpc. The alignment effect itself is leaving unexplained. One of possible scenarios is alignment of spins of galaxies with observed large-scale structure of the Universe, which possibly represent the turbulent eddies of the huge scale.

Acknowledgements

This research was supported by the RFBR (project No. 07-02-00535a), the program of Prezidium of RAS "Origin and Evolution of Stars and Galaxies", the program of the Department of Physical Sciences of RAS "Extended Objects in the Universe" and by the Grant from President of the Russian Federation "The Basic Scientific Schools" NS-6110.2008.2. M.Yu. Piotrovich acknowledges the Council of Grants of the President of the Russian Federation for Young Scientists, grant No. 4101.2008.2.

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