Correlation of Linear Quasar Polarization : ALPs Revisited

XVI Lomonosov Conference On Elementary Particle Physics

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Asia Pacific Center For Theoretical Physics

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Features Of AGN

[1] B.M. Peterson, *An Introduction To Active Galactic Nuclei(CUP)*

[2] Accretion power in astrophysics-J. Frank, *A. R. King, Derek J. Raine (CUP)*

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Quasars

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  'Coherent Orientation Of The "Visible" Quasar Polarization On Cosmological Scale'
- Different AGN's
  1. Quasar
  2. QSO
  3. Seyfert
  4. Blazar
  5. BL Lac

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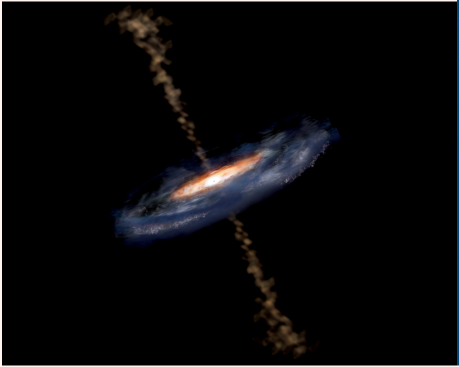
Here we include the artist impression of an AGN along with a physical schema.



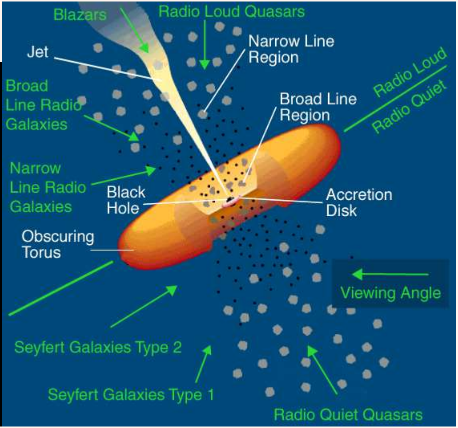
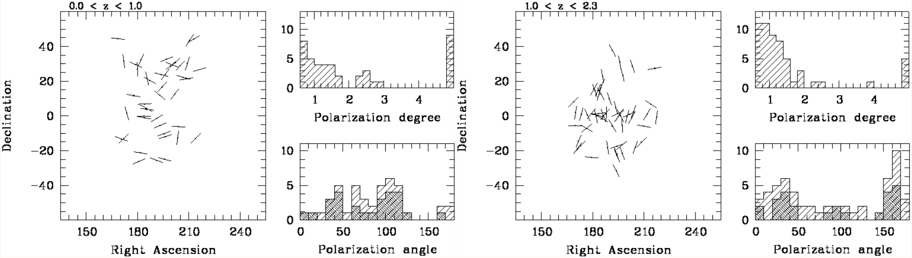


Figure: Left Handed is Artists Impression & Right Handed is Physical Schema
All the mentioned (or omitted) AGN types are just the same but orientaed differently along our line of sight - according to consensus(!) theory

" 'WE' [4] only consider objects which fulfil the criteria $p = 0.6\%$, $\sigma_\theta = 14^\circ$, and $|b_{II}| = 30^\circ$, where p is the polarization degree and σ_θ the uncertainty of the polarization position angle. These constraints ensure that most objects are significantly and intrinsically polarized with little contamination by the Galaxy, and that the polarization position angles are measured with a reasonable accuracy"



[4] D. Hutsemékers, R. Cabanac, H. Lamy and D. Sluse, Astronomy and Astrophysics, 441, 915, (2005)

Explanation

This curious effect has given way to several theories - such as -

[5] arXiv:0910.3036

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1. Instrumental Artefact

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2. Contamination By Intersteller Polarization Inside Milky Way

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3. Extinction By Dust Grains Aligned $\perp$ To Magnetic Field

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6. **Production Of ϕ In The Accretion Disk**

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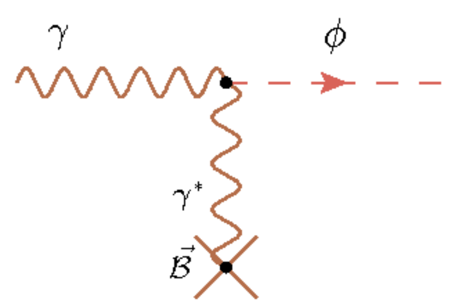
6. **Production Of ϕ In The Accretion Disk**
7. **Mixing Of γ to ϕ & Dust Extinction** [5]

[5] arXiv:0910.3036

This is how they mix



1. Dichroism
2. Birefringence

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  1. Single field ALPs with two photon coupling may not explain all of these at a time.
  2. We need at least two fields.!

There are some inherent problems with single field ALPs

[6]http://arxiv.org/pdf/1107.2013v1.pdf circ-pol-I circ-pol-II circ-pol-III
[7]http://arxiv.org/pdf/astro-ph/0507274.pdf dichro
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4. It fails to produce similar linear polarization for the case of mm wave radio frequencies as we know from recent data analysis. [8]

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Our Model.[10]

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_\phi^2\phi^2 + \frac{1}{2}\partial_\mu\phi'\partial^\mu\phi' - \frac{1}{2}m_{\phi'}^2\phi'^2 - \frac{1}{4}g_{\phi'}\phi' F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}g_\phi\phi F_{\mu\nu}\tilde{F}^{\mu\nu} \quad (1)$$

for the scalar equation -

$$\partial^2\phi' + m_a^2\phi' = -\frac{1}{4}g_{\phi'}F_{\mu\nu}F^{\mu\nu} \quad (2)$$

For the pseudoscalar one

$$\partial^2\phi + m_a^2\phi = -\frac{1}{4}g_\phi\epsilon_{\mu\nu\rho\sigma}F_{\mu\nu}F^{\rho\sigma} \quad (3)$$

Similarly, the equation for the photon may be written as,

$$\Box\vec{E}_{Tot} + \omega_p^2\vec{E}_{Tot} = g_\phi\vec{B}_{ext}\frac{\partial^2\phi}{\partial t^2} + g_{\phi'}\left(\vec{B}_{ext}\times\hat{n}\right)\frac{\partial^2\phi'}{\partial t^2}{}^{9} \quad (4)$$

[9] $\vec{n}$ is the unit normal in the direction of $\vec{\nabla}\phi$

[10] arXiv:1307.5994

It will lead to mixing matrix in a block diagonal form

$$M = \begin{bmatrix} \omega_p^2 & iM & 0 & 0 \\ -iM & m_{\phi'}^2 & 0 & 0 \\ 0 & 0 & \omega_p^2 & iN \\ 0 & 0 & -iN & m_\phi^2 \end{bmatrix}, \qquad (5)$$

Leading to a solution of these forms

$$\begin{aligned} \phi'(z) &= \frac{1}{2}\sin(2\theta')\left[e^{iz\sqrt{\omega^2+\lambda'_-}} - e^{iz\sqrt{\omega^2+\lambda'_+}}\right] A_\perp(0) \\ A_\perp(z) &= \left[\cos^2(\theta')e^{iz\sqrt{\omega^2+\lambda'_-}} + \sin^2(\theta')e^{iz\sqrt{\omega^2+\lambda'_+}}\right] A_\perp(0) \qquad (6) \\ \phi(z) &= \frac{1}{2}\sin(2\theta)\left[e^{iz\sqrt{\omega^2+\lambda_-}} - e^{iz\sqrt{\omega^2+\lambda_+}}\right] A_\parallel(0) \\ A_\parallel(z) &= \left[\cos^2(\theta)e^{iz\sqrt{\omega^2+\lambda_-}} + \sin^2(\theta)e^{iz\sqrt{\omega^2+\lambda_+}}\right] A_\parallel(0) \qquad (7) \end{aligned}$$

Where the mixing angle/s are given by -

$$\theta' = \frac{1}{2}\tan^{-1}\left[\frac{2g_{\phi'}Bk}{-\omega_p^2 + m_{\phi'}^2}\right] \tag{8}$$

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2g_{\phi}B\omega}{-\omega_p^2 + m_{\phi^2}}\right] \tag{9}$$

The eigenvalues are such to be -

$$\lambda'_{\pm} = \frac{1}{2}\left[\left(\omega_p^2 + m_{\phi'}^2\right) \pm \sqrt{\left\{\left(\omega_p^2 - m_{\phi'}^2\right)^2 + \left(2g_{\phi'}Bk\right)^2\right\}}\right] \tag{10}$$

$$\lambda_{\pm} = \frac{1}{2}\left[(\omega_p^2 + m_{\phi}^2) \pm \sqrt{\left\{\left(\omega_p^2 - m_{\phi}^2\right)^2 + (2g_{\phi}B\omega)^2\right\}}\right] \tag{11}$$

Correlators

Here we shall calculate all the correlators -

$$\langle A_\perp^*(z)A_\perp(z)\rangle = \frac{1}{2}\left(1+\cos^2 2\theta^{'} + \cos[z(\Delta\lambda^{'})/(2\omega)]\sin^2 2\theta^{'}\right) \quad (12)$$

$$\left\langle A_\parallel^*(z)A_\parallel(z)\right\rangle = \frac{1}{2}\left(1+\cos^2 2\theta + \cos[z(\Delta\lambda)/(2\omega)]\sin^2 2\theta\right) \quad (13)$$

$$\frac{\left\langle A_\parallel^*(z)A_\perp(z)\right\rangle}{\left\langle A_\parallel^*(0)A_\perp(0)\right\rangle} =$$

$$\left(\cos^2\theta^{'}\cos^2\theta\exp\left(i\Delta\lambda_- z/(2\omega)\right) + \sin^2\theta^{'}\sin^2\theta\exp\left(i\Delta\lambda_+ z/(2\omega)\right)\right)$$
$$+\left(\cos^2\theta^{'}\sin^2\theta\exp\left(i\Delta\lambda_\pm z/(2\omega)\right) + \sin^2\theta^{'}\cos^2\theta\exp\left(i\Delta\lambda_\mp z/(2\omega)\right)\right) \quad (14$$

We quote, the rest of the symbols for completeness -

$$\Delta\lambda = \lambda_+ - \lambda_- \quad ; \quad \Delta\lambda^{'} = \lambda_+^{'} - \lambda_-^{'} \quad (15)$$

$$\Delta\lambda_- = \lambda_- - \lambda_-^{'} \quad ; \quad \Delta\lambda_+ = \lambda_+ - \lambda_+^{'} \quad (16)$$

$$\Delta\lambda_\pm = \lambda_+ - \lambda_-^{'} \quad ; \quad \Delta\lambda_\mp = \lambda_- - \lambda_+^{'} \quad (17)$$

Formulas - to be plotted

For Degree of Linear Polarization we need to plot

$$p_{lin} = \frac{\sqrt{Q^2 + U^2}}{I}. \tag{18}$$

Individually, they are given as,

$$Q = \left\langle A^*_{\parallel}(z) A_{\parallel}(z) \right\rangle - \langle A^*_{\perp}(z) A_{\perp}(z) \rangle \tag{19}$$

$$U = 2 \times \text{Real}\left[\left\langle A^*_{\perp}(z) A_{\parallel}(z) \right\rangle\right] \times U_0 \tag{20}$$

The circular polarisation is given by

$$V = 2 \times \text{Imag}\left[\left\langle A^*_{\perp}(z) A_{\parallel}(z) \right\rangle\right] \times \frac{U_0}{I} \tag{21}$$

The Rotation Measure is given by -

$$\|\psi - \psi_0\| = \left\| \arctan \sqrt{\left\{ \frac{\left\langle A^*_{\perp} A_{\perp} \right\rangle (z)}{\left\langle A^*_{\parallel} A_{\parallel} \right\rangle (z)} \right\}} - \arctan \sqrt{\left\{ \frac{\left\langle A^*_{\perp} A_{\perp} \right\rangle (z_0)}{\left\langle A^*_{\parallel} A_{\parallel} \right\rangle (z_0)} \right\}} \right\| \tag{22}$$

The following values have been fed to the numerical code.

$y = z = 1.5e + 41 GeV^{-1}$

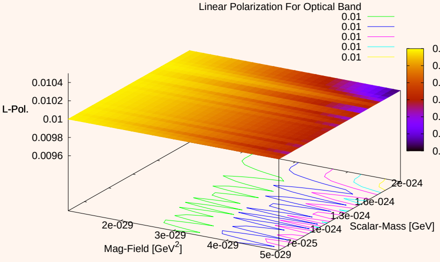
$\omega = 2.5 \times 10^{-9} / 3.7 \times 10^{-14} GeV$

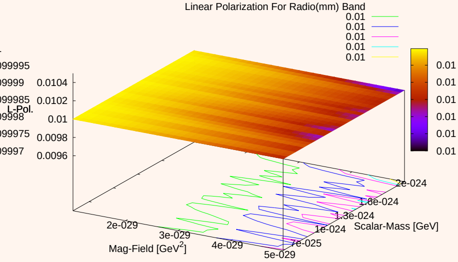
$\Lambda = 10^{+12} = \frac{1}{g_\phi} = \frac{1}{g_{\phi'}} GeV^{-1}$

$B = 1nG = 2 \times 10^{-29} GeV^2$ but is varied around this

$\omega_p = 4 \times 10^{-24} GeV$

$m_\phi = 1e - 24$ GeV& $m_{\phi'}$ *is varied around this*





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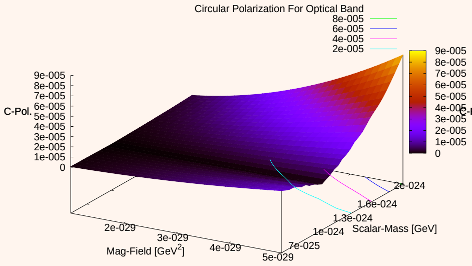

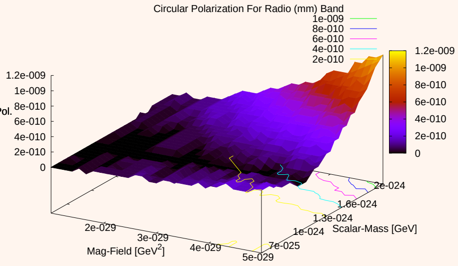

Stokes parameters : Case I

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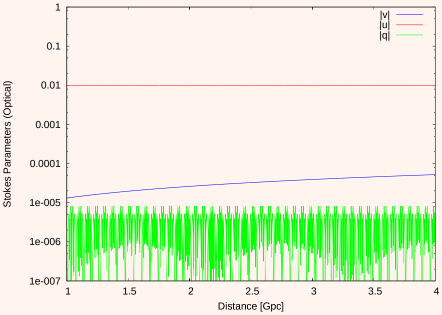

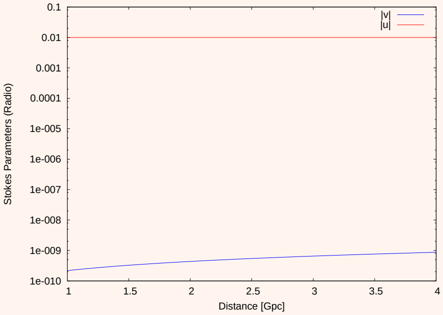

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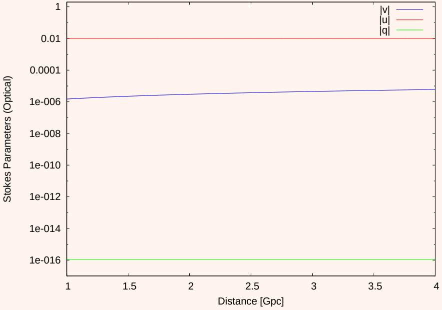
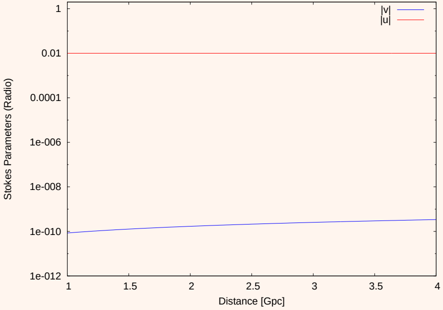
$m_\phi = 8e - 24 \quad GeV \& \quad m_{\phi'} = 8.3e - 24$





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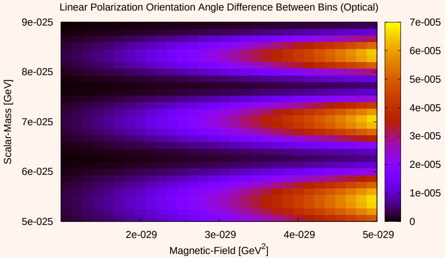

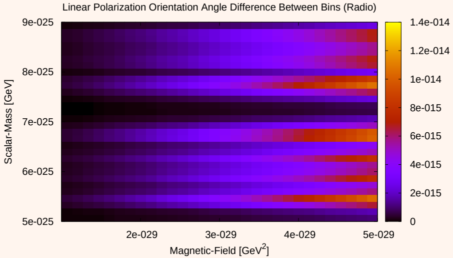

Correlation Of Linear Polarization : Case II

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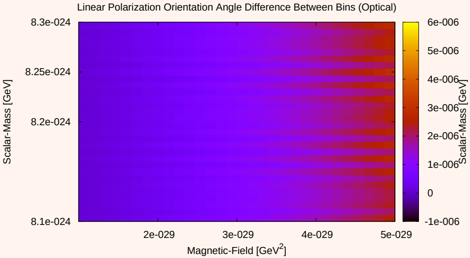

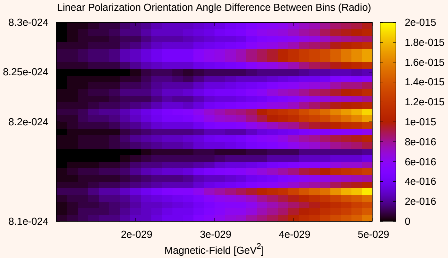

Discussions

Salient Features are such to be

[11] http://arxiv.org/pdf/astro-ph/9806099.pdf ; http://arxiv.org/pdf/1206.1809.pdf

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- Which however may be restricted by other considerations fifth force. [11]

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Thank You

I thank the following persons for their useful suggestions & help during the preparation of this presentation.

- Ki-young-Choi
- Chang-Sub Shin
- Soo A. Kim

$$\left(\mathbb{W}^2 + \partial_{\mathbb{Y}}^2\right) \begin{bmatrix} \phi(y) \\ A_y(y) \end{bmatrix} + \mathbb{M} \begin{bmatrix} \phi(y) \\ A_y(y) \end{bmatrix} = 0 \tag{23}$$

$$\mathbb{M} = \begin{bmatrix} -m^2 & 2gB\omega \\ 2Bg\omega & -\omega_p^2 \end{bmatrix} \tag{24}$$

$$\lambda_{\pm} = \frac{1}{2}\left[-m^2 - \omega_p^2 \pm \sqrt{\left(-m^2 - \omega_p^2\right)^2 + 4\left(-m^2\omega_p^2 + (2gB\omega)^2\right)}\right] \tag{25}$$

The eigenvectors would be given similarly as - The $|\lambda_{+/-} >$ is given as,

$$|\lambda_+ >= \frac{1}{\sqrt{(2gB\omega)^2 + (-m^2 - \lambda_+)^2}} \begin{pmatrix} 2gB\omega \\ -m^2 - \lambda_+ \end{pmatrix} \tag{26}$$

$$|\lambda_- >= \frac{1}{\sqrt{(2gB\omega)^2 + \left(-\omega_p^2 - \lambda_-\right)^2}} \begin{pmatrix} -\omega_p^2 - \lambda_- \\ 2gB\omega \end{pmatrix} \tag{27}$$

The normalisation constants are given by - $\frac{1}{\sqrt{(2gB\omega)^2+(-m^2-\lambda_+)^2}}$ as $\frac{1}{\sqrt{N_+}}$, & $\frac{1}{\sqrt{(2gB\omega)^2+(-\omega_p^2-\lambda_-)^2}}$ as $\frac{1}{\sqrt{N_-}}$ - then the transformation matrix would be given by -

$$S = \begin{bmatrix} \frac{2gB\omega}{\sqrt{N_+}} & -\frac{-\omega_p^2-\lambda_-}{\sqrt{N_-}} \\ -\frac{-m^2-\lambda_+}{\sqrt{N_+}} & \frac{2gB\omega}{\sqrt{N_-}} \end{bmatrix} = \begin{bmatrix} \alpha & \gamma \\ \beta & \delta \end{bmatrix} \tag{28}$$

The explicit form of the final equations are,

$$\phi(y) = \frac{\alpha\beta}{\alpha\delta - \beta\gamma}\left[e^{iy\sqrt{\omega^2+\lambda_-}} - e^{iy\sqrt{\omega^2+\lambda_+}}\right] A_y(0)$$
$$A_y(y) = \frac{1}{\alpha\delta - \beta\gamma}\left[\alpha\delta e^{iy\sqrt{\omega^2+\lambda_-}} - \beta\gamma e^{iy\sqrt{\omega^2+\lambda_+}}\right] A_y(0) \tag{29}$$

The mixing angle would be given by -

$$\Theta_{\mathbb{M}} = \frac{1}{2}\tan^{-1}\left[\frac{2gB\omega}{m^2 - \omega_p^2}\right] \tag{30}$$

The probability expression stays the same -

$$\mathcal{P}_{A\to\phi} = \sin^2(2\theta_{\mathbb{M}})\sin^2\left\{\frac{\Delta\lambda y}{2\omega}\right\} \tag{31}$$

Finally, we quote the mixing length formula in its extended form -

$$\lambda_{osc} = \frac{4gBk}{\sqrt{\left(\omega_p^2 - m_\phi^2\right) + 4g^2B^2\omega^2}} \tag{32}$$

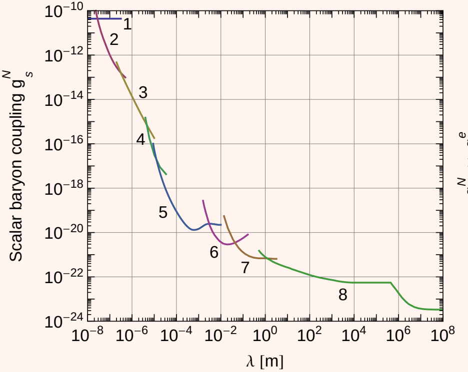
$$\begin{aligned}
I(z) &= I_0 - \tfrac{1}{2}\left(I_0 + Q_0\right)\mathcal{P}_{A\to\phi} \\
Q(z) &= I(I_0 \longleftrightarrow Q_0) \\
U(z) &= U_0\{(\mathfrak{S}_{\theta_{\mathbb{M}}})^2\cos\left((\mathfrak{C}_{\theta_{\mathbb{M}}})^2\ \frac{\Delta\lambda}{\omega}y\right) + (\mathfrak{C}_{\theta_{\mathbb{M}}})^2\cos\left((\mathfrak{S}_{\theta_{\mathbb{M}}})^2\ \frac{\Delta\lambda}{\omega}y\right)\} \\
&\quad -V_0\{(\mathfrak{S}_{\theta_{\mathbb{M}}})^2\sin\left((\mathfrak{C}_{\theta_{\mathbb{M}}})^2\ \frac{\Delta\lambda}{\omega}y\right) - (\mathfrak{C}_{\theta_{\mathbb{M}}})^2\sin\left((\mathfrak{S}_{\theta_{\mathbb{M}}})^2\ \frac{\Delta\lambda}{\omega}y\right)\}\text{sgr} \\
V(z) &= U(U_0 \to V_0, V_0 \to -U_0),
\end{aligned}$$

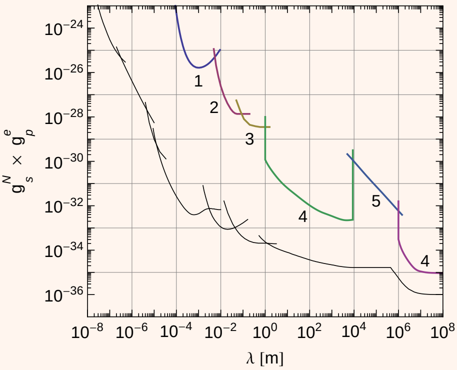
Abstract : Based on a new sample of 355 quasars with significant optical polarization and using complementary statistical methods, we confirm that quasar polarization vectors are not randomly oriented over the sky with a probability often in excess of 99.9%. The polarization vectors appear coherently oriented or aligned over huge (~ 1 Gpc) regions of the sky located at both low ($z \sim 0.5$) and high ($z \sim 1.5$) redshifts and characterized by different preferred directions of the quasar polarization. In fact, there seems to exist a regular alternance along the line of sight of regions of randomly and aligned polarization vectors with a typical comoving length scale of 1.5 Gpc.

Furthermore, the mean polarization angle $\bar{\theta}$ appears to rotate with redshift at the rate of $\sim 30^\circ$ per Gpc. ——-

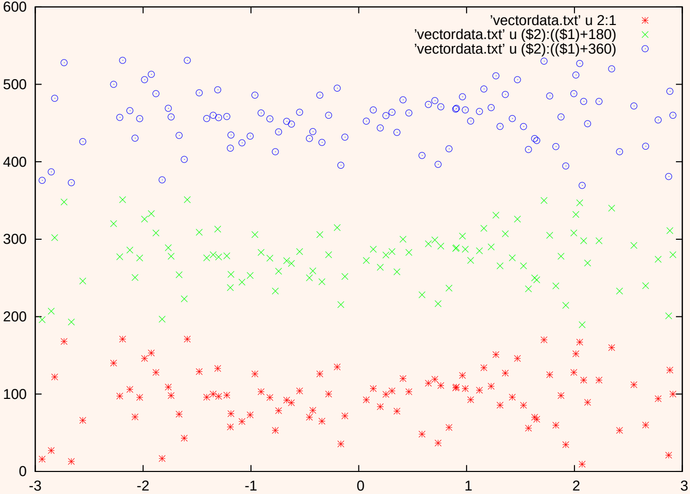
ABSTRACT We present a detailed statistical analysis of the alignment of polarizations of radio sources at high redshift. We use the JVAS/CLASS 8.4-GHz surveys for our study. This study is motivated by the puzzling signal of alignment of polarizations from distant quasars at optical frequencies. We explore several different cuts on the polarization flux for our analysis. We find that the entire data shows a very significant signal of alignment on very large distance scales of order 500 Mpc. The alignment starts to decay only at much larger distances of order Gpc. If we only consider data with polarization flux greater than 1 mJy, we find alignment at distance scales less than 150 Mpc. We also find that data with polarization flux less than 0.5 mJy does not show significant alignment. Similar results are seen for data with degree of polarization less than 0.01, although here a mild signal of alignment is observed for a narrow range of angular separations. We argue that the signal cannot be explained in terms of bias due to systematic errors in removal of instrumental polarization. We also find that the degree of polarization shows a strong negative correlation with the total flux. The data appears to fall into two classes, one of which shows such a correlation. The remaining set, which has total flux greater than 100 mJy and degree of polarization lying between 0.01 and 0.1, shows a more random behaviour. The latter set is also found to show no alignment

1. Both the Scalar & Pseudoscalar couplings may be bounded from above by long range force experiments.
2. However, pseudoscalars are best constrained by astrophysical consideration.
3. We shall compare here the product of the restrictive upper bounds of these two pitched against the experimental bound on the same product.





Full Data [12]



[12] For the original data cf. D. Hutsemékers, R. Cabanac, H. Lamy and D. Sluse, Astronomy and Astrophysics, 441, 915, (2005)