Behaviour of a Parity and Charge-Parity Violating Varying Alpha Theory.

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Plan of my talk

- Introduction to Varying alpha theory
- Parity violating extension and motivation
- Effect of this violation in different phenomena
- Conclusions

Introduction

- Theoretical construction of Variation of fundamental constants has long history: L. Kelvin, Milne, Dirac, Teller, **Dicke, Brans**, Gammow, Bekenstein etc
- For the last several years, this idea of varying fundamental constant has got much attention, mainly because
  - String theory gives us a consistent framework where all the "fundamental constants" are emergent in four dimension after dimensional reduction. So in principle they could be spacetime varying field.
  - Studies of relativistic fine structure constant in the absorption lines of dust clouds around quasars, have led to widespread theoretical interest on the time variation of fine structure constant. M. Murphy etal, Mon. Not. R. astr. Soc., 327, 1208 (2001), PRL, 99, 239001,(2007); J.K. Webb etal, PRL 82, 884 (1999) and PRL 87, 091301 (2001).

Introduction

- Analysis shows that it has been smaller in the past, at z = 1 - 3.5. The shift in the value of for all the data sets is given provisionally by $\frac{\delta\alpha}{\alpha} = (-0.570.10)10^{-5}$.
- Motivated by this observation, Sandvik-Barrow-Magueijo have constructed a theory of varying alpha cosmology (Bekenstein-Sandvik-Barrow-Magueijo (BSBM) theory) H. B. Sandvik, J. D. Barrow and J. Magueijo, PRL, 88 (2002); PRD 65, 063504 (2002); PRD 65, 123501 (2002); PRD 66, 043515 (2002); PLB 541, 201 (2002)
- BSBM construction is based on a model of varying alpha proposed by Bekenstein. J.D. Bekenstein, PRD 25, 1527 (1982).

What is Varying alpha theory?

- The simplest way to introduce the variation of α: Variation of electric charge as $e = e_0 e^{\phi(x)}$,
  where e_0: Present value of electric charge

Varying α Theory

- $\phi(x)$: A dimensionless scalar field.
- So the fine-structure constant: $\alpha = e_0^2 e^{2\phi(x)}$.
- There is an arbitrariness involved in the definition of this variation. Which leads to the shift symmetry, i.e. $\phi \to \phi + c$.
- Potentially dangerous assumption behind this variation is the non-conservation of charge. But from the experimental point of view we can always set some limits on the amount of non-conservation.
- Gauge invariance is more important for consistency (BSBM theory).
- Guiding principles: Shift symmetry and local gauge invariance

Varying α Theory contd.

- In order to construct gauge invariant Lagrangian, take the physical gauge field being $a_\mu = e^\phi(x) A_\mu$
- The gauge transformation which leaves the action invariant would be

$$e^\phi A_\mu \to e^\phi A_\mu + \chi_{,\mu}.$$

- we will set $e_0 = 1$ for the convenience.
- Electromagnetic action,

$$S_{em} = -\frac{1}{4}\int d^4x\sqrt{-g}e^{-2\phi}F_{\mu\nu}F^{\mu\nu},$$

where the new electromagnetic field strength tensor is defined as

Varying α Theory contd.

$$F_{\mu\nu} = (e^{\phi} A_{\nu})_{,\mu} - (e^{\phi} A_{\mu})_{,\nu}.$$

- The dynamics of the $\phi(x)$ field is controlled by

$$S_{\phi} = -\frac{\omega^2}{2} \int d^4x \sqrt{-g}\,\phi_{,\mu}\phi^{,\mu},$$

  $\omega^2 = \hbar c / l^2$, where l is the characteristic length scale above which the electric field around a point charge is exactly Coulombic.

PCP Violating Extension

- Based on this varying alpha theory, we extend the theory to incorporate parity violation.
  Motivations of this simple extension are mainly
- Recent interest on the parity violating effect on cosmological observations
- To unify the different cosmic optical phenomena
- Parity violating effect on the cosmological and particle physics experimental observations is one of the interesting probes to look for new physics. Future high precession observation (CMB Planck, LHC) give us a hope to see some new physics.
- This new era of very high precession observation leads people to construct different phenomenological parity violating model
- Let me mention few of these which has gain significant interests

Some Examples on parity violating models

- In the photon sector, Coupling between the quintessence field and the pseudo-scalar field of electromagnetism: cosmological birefringence, [S. M. Carroll, PRL 81, 3067 (1998)]
- Parity violation has also been introduced in inflation models through modifications of gravity:
  - Addition of the Chern-Simons terms to the Einstein-Hilbert action. [A. Lue *etal*, PRL 83, 1506 (1999)]
  - Chiral gravity: Newton's constant is slightly different for R and L gravitational waves, [C. R. Contaldi *etal*, PRL 101, 141101 (2008)]
  - The gravity at a Lifshitz point, [T. Takahashi and J. Soda, PRL 102, 231301 (2009)]
  - Non-standard parity violating interactions have also been discussed. [DM *etal*, JCAP, 0406, 005 (2004); N.F. Lepora, gr-qc/9812077, 1998; K.R.S. Balaji *etal*, JCAP, 0312, 008, (2003)]

PCP violating model

- We want to propose a parity violating model in the framework of Varying alpha theory.

One of the assumptions of the above theory is time-reversal invariance. We will relax this assumption and try to analyse its implications.

- Obvious term in the original Lagrangian would be

$$S_{PV} = \frac{\beta}{8}\int d^4x\sqrt{-g}e^{-2\phi}F_{\mu\nu}\tilde{F}^{\mu\nu}$$

β: A free dimensionless parameter

- So, total Lagrangian violates both P and CP.
- So, our total Lagrangian looks like

$$\mathcal{L} \; = \; M_p^2 R - \frac{\omega^2}{2}\partial_\mu\phi\partial^\mu\phi \; - \frac{1}{4}e^{-2\phi}F_{\mu\nu}F^{\mu\nu} + \frac{\beta}{8}e^{-2\phi}F_{\mu\nu}\tilde{F}^{\mu\nu} \; + \; \mathcal{L}_m,$$

PCP violating Model

- Cosmic Birefringence Phenomena
- Non-vanishing effect on CMB polarization power spectrum because of parity violation
- Parity violating effect on Cosmic variation of fine structure constant
- Effect of **background magnetic field**
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Cosmological Birefringence

- Cosmological birefringence (CB) is a wavelength-independent rotation of photon polarization vector after traversing a long cosmic distance.
- The origin of this effect: either cosmic inhomogeneities or some non-trivial coupling of photon with other fields.
- We will see CB coming from our PCP violating term
- The wave equation for magnetic field $\mathbf{B}$ then becomes,

$$\ddot{\mathbf{B}} - \nabla^2 \mathbf{B} = 2\beta\dot{\phi}\nabla \times \mathbf{B}.$$

- We assume general wave solutions of the form

$$\mathbf{B} = \mathbf{B}_0(\eta) e^{-i\mathbf{k}\cdot\mathbf{z}},$$

where "z" is the propagation direction waves,

Cosmological Birefringence

- The equations for the polarization states $b_{\pm}(\eta) = \mathbf{B}_{0x}(\eta) \pm i\mathbf{B}_{0y}(\eta)$

$$\ddot{b}_{\pm} + \dot{\phi}\dot{b}_{\pm} + \left(\mathbf{k}^2 \mp 2\mathbf{k}\beta\dot{\phi}\right) b_{\pm} = 0,$$

- Equation of motion for the scalar field

$$\ddot{\phi} + 2\frac{\dot{a}}{a}\dot{\phi} = \frac{1}{\omega^2 a^2}[-(\mathbf{E}^2 - \mathbf{B}^2) + 2\beta\mathbf{B}\cdot\mathbf{E}].$$

- In the above set of equations we use FRW background in conformal time

$$ds^2 = a(\eta)^2(-d\eta^2 + dx^2 + dy^2 + dz^2),$$

- We use the WKB approximation in **large ω** and **long wavelength** limit of background field ϕ.

Cosmological Birefringence

- Assuming the form of solution for $b_\pm$ to be

$$b_\pm = e^{ikS_\pm(\eta)} \quad ; \quad S_\pm(\eta) = S^0_\pm + \frac{1}{k}S^1_\pm + \ldots$$

- Solution based on the above ansatz is

$$S^0_\pm = \eta \quad ; \quad S^1_\pm = -(\frac{i}{2} \pm 2\beta \int \dot{\phi} d\eta.$$

- So the expression for the optical rotation of the plane of polarization is

$$\Delta = 4\beta \int_{\eta_i}^{\eta_f} \dot{\phi} d\eta = 4\beta |\phi(\eta_f) - \phi(\eta_i)|,$$

where η_i and η_f are the initial and final time.

CMB Power Spectrum and Birefringence

What is CMB Power Spectrum?

- Polarized light is conventionally described in terms of the Stokes parameters.

$$E_x = a_x(t)\cos[\omega_0 t - \theta_x(t)] \quad ; \quad E_y = a_y(t)\cos[\omega_0 t - \theta_y(t)],$$

then Stokes parameters are defined as the following time average

$$\begin{aligned} I &= \langle a_x^2 \rangle + \langle a_y^2 \rangle \\ Q &= \langle a_x^2 \rangle - \langle a_y^2 \rangle \\ U &= \langle 2a_x a_y \cos(\theta_x - \theta_y) \rangle \\ V &= \langle 2a_x a_y \sin(\theta_x - \theta_y) \rangle \end{aligned}$$

The average are over time long compare to the inverse frequency of the wave.

What is CMB Power Spectrum?

Basic quantities of interests

- The parameter I gives the intensity for the radiation which is equivalent to the average temperature T_0.
- The other one is the polarization tensor

$$\mathcal{P}_{ab} = \begin{pmatrix} Q(\hat{\mathbf{n}}) & -U(\hat{\mathbf{n}}) \\ -U(\hat{\mathbf{n}}) & -Q(\hat{\mathbf{n}}) \end{pmatrix}$$

- CMB power spectrum is the various correlation function among the temperature fluctuation and polarization tensor.
- **Temperature fluctuation induced by Metric fluctuation**

  CMB Polarization is induced by Thomson effect at the last scattering surface.

What is CMB Power Spectrum?

- The angular distribution of CMB temperature anisotropy can be expanded as:

$$\frac{\Delta T}{T}(\mathbf{n}) = \sum_{l,m} a^T_{lm}\, Y^T_{lm}(\mathbf{n}) \ .$$

- The polarization of CMB in term of Stokes parameters can be decomposed into irreducible 'gradient' (or E) and 'curl' (or B) parts that have opposite spatial parities.
- The angular distribution of this polarization tensor can thus be expressed in terms of the matrix spherical harmonics

$$\begin{aligned} \mathcal{P}^E_{ab}(\mathbf{n}) &= \sum a^E_{lm}\, Y^E_{lm,ab}(\mathbf{n}) \\ \mathcal{P}^B_{ab}(\mathbf{n}) &= \sum a^B_{lm}\, Y^B_{lm,ab}(\mathbf{n}) \ . \end{aligned}$$

Birefringence on CMB anisotropy

- CMB power spectrum is defined as,

$$C_l^{XX'} \equiv \langle a_{lm}^{X}\, a_{lm}^{X'} \rangle \ ,$$

  where $X, X' = T, E, B$

- Now from the standard cosmological model

$$\langle a_{lm}^{T}\, a_{lm}^{B} \rangle = \langle a_{lm}^{E}\, a_{lm}^{B} \rangle = 0$$

- Due to explicit parity violating interaction, correlations such as C_l^{TB} and C_l^{EB} appear through the birefringence

$$\begin{aligned} C_l'^{TB} &= C_l^{TE} \sin 2\Delta \\ C_l'^{EB} &= \frac{1}{2}(C_l^{EE} - C_l^{BB}) \sin 4\Delta \end{aligned}$$

Observations: Cosmological Birefringence

Amount of rotation to the leading order in $1/\omega^2$ is

$$\Delta = 2\frac{h\beta}{H_0}\int_0^z \frac{(1+z)dz}{\sqrt{(\Omega_m+\Omega_{dm})(1+z)^3+\Omega_{de}}}$$

Where, h: Related to the energy density the scalar field.

z is cosmological red-shift.

- Using the expression for the energy density of the scalar field $\rho \simeq \frac{\omega^2 h^2 (1+z)^6}{2}$

$$\Delta \sim \frac{\sqrt{\rho}\beta}{\omega(1+z)^3}\delta T$$

where $\delta T = \frac{1}{H_0}\int_0^z \frac{(1+z)dz}{\sqrt{(\Omega_m+\Omega_{dm})(1+z)^3+\Omega_{de}}}$

Cosmological Birefringence and observation

$$\rho = \left(\frac{\omega}{M_p}\right)^2 \beta^2 \Delta^2 \times 3.2 \times 10^{-44} \text{GeV}^4$$

$$\rho_{cmb} \approx 4 \times 10^{-52} \text{GeV}^4$$

Current constraints on the polarization data from radio galaxies and quasars for the red shift $z \gtrsim 0.425$, $\Delta = -.60 \pm 1.50$.
The WMAP 7-years data suggests $\Delta = -1.10 \pm 1.30$, $z > 1000$

.T. Kahniashvili etal. PRD 78, 123009 (2008); J. Q. Xia et al., Astrophys. J. 679, L61 (2008); J. Q. Xia et al., Astron. Astrophys. 483, 715 (2008); E. Y. Wu et al. [QUaD Collaboration], PRL 102, 161302 (2009); L. Pagano et al., PRD 80, 043522 (2009); E. Komatsu et al., [WMAP Collaboration], arXiv:1001.4538.

- With the present experimental accuracy no direct signal of optical rotation.
- With greater precession PLANCK experiment can give us some information in near future.

Varying α Cosmology

Varying α Cosmology

- The observation on quasar absorption line says that α was smaller in the past, at z = 1 - 3.5.
- Motivated by this, cosmological variation of fine structure constant has extensively been studied:
  Bekenstein-Sandvik-Barrow-Magueijo (BSBM) theory.
- As we have mentioned

$$\alpha(t) = e^{2\phi(t)} \ .$$

- The observational upper limit puts a constraint on the variation of the scalar field,

$$\frac{|\delta\alpha|}{\alpha(t_0)} \simeq 10^{-5}$$

- We analyse the variation of induced by the PCP violating effect.

Varying α Cosmology

- Assuming FRW metric ansatz,

$$ds^2 = -dt^2 + a(t)^2(dx^2 + dy^2 + dz^2),$$

- Equation of motions are

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_p^2}\left[\rho_m\left\{1 + e^{2\phi}\zeta_m\right\} + \bar{\rho}_r + \rho_\phi\right] + \frac{\Lambda}{3}$$

where Λ: Cosmological constant; $\rho_\phi = \frac{1}{2}\dot{\phi}^2$. $\zeta_m = \frac{\mathcal{L}_{em}}{\rho_m}$

$$\ddot{\phi} + 3H\dot{\phi} = \frac{e^{-2\phi}}{\omega}[-2\zeta_m\rho_m + \frac{4}{a^3}\beta e^{2\phi}\langle\mathbf{E}\cdot\mathbf{B}\rangle],$$

where $H \equiv \dot{a}/a$, ζ_m is the fraction of matter carrying electric or magnetic charge.

Varying α Cosmology

- Now in the plane wave limit, one of the electromagnetic equation

$$\partial_0(a\mathbf{E}\cdot\mathbf{B}) = \dot{\phi}\mathbf{E}\cdot\mathbf{B} - 2\beta\dot{\phi}\mathbf{B}\cdot\mathbf{B}.$$

- It is clear that orthogonality is violated due to scalar field coupling.
- With the suitable boundary condition, to lnear order in ϕ Solution would look like

$$a\langle\mathbf{E}\cdot\mathbf{B}\rangle = -4\beta\langle\mathbf{B}\cdot\mathbf{B}\rangle\phi,$$

- So,parity violating parameter β causes $\mathbf{E}\cdot\mathbf{B}\neq 0$.
- Only during the radiation dominated era, we have a distinct parity violating effect on the variation of α.

Radiation dominated era

- The evolution equation for ϕ now becomes

$$\frac{d}{dt}(\dot{\phi}a^3) = -\frac{16\beta^2\langle \mathbf{B}\cdot\mathbf{B}\rangle}{a\omega}\phi.$$

- Difficult to solve analytically
- We adopt self consistent approximation
  - We demand background expansion is radiation dominated $a(t) \propto t^{1/2}$
  - Then we solve the scalar field equation in the asymptotic in time
  - Asymptotically Energy density should be sub-leading compared to radiation.

α variation in Radiation dominated era

- we finally arrive at

$$\alpha \sim \mathcal{C}_1(\log(t))^{-\alpha_+} + 2\mathcal{C}_2(log(t))^{-\alpha_-}.$$

where $\alpha_\pm = \frac{1}{4}\left(1 \pm \sqrt{1-4\mathcal{A}}\right)$

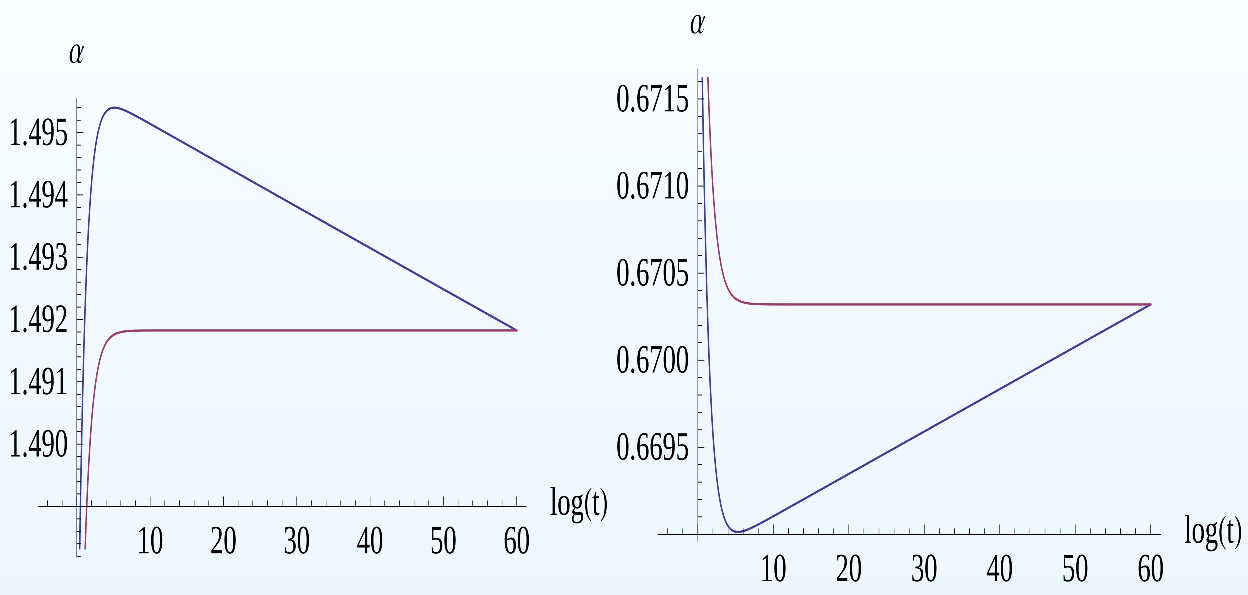
- Validity of our approximation: The leading order behaviour of the energy densities

$$\bar{\rho}_r \propto a^4 = \frac{1}{t^2}, \quad \rho_\phi = \frac{\omega}{2}\dot{\phi}^2 \propto \frac{{\mathcal{C}_1}^2}{t^2}\frac{1}{(\log(t))^{2\alpha_+ +2}}\,, \; \frac{{\mathcal{C}_2}^2}{t^2}\frac{1}{(\log(t))^{2\alpha_- +2}}$$

- Scalar density falls off faster than the radiation energy density as $t \to \infty$.
- α decreases in a power law with time and controlled by the average energy density of the of the radiation and coupling, β.

α variation in Radiation dominated era

The typical behaviour of alpha during radiation dominated universe



- In the above plot we consider $\mathcal{A} = \frac{16\beta^2\langle \mathbf{B}\cdot\mathbf{B}\rangle}{\omega} = 0.0001$ and $\delta\phi = 0.2, -.2$

α variation in matter and Λ era

- The behaviour of alpha during matter dominated universe
  $\alpha \sim= 1 - \frac{\zeta_m}{4\pi G\omega}\log(a(t))$ for $a(t) \sim t^{3/2}$
  So during matter domination: alpha varies slowly as logarithm of time
- The behaviour of alpha during cosmological constant dominated universe
  $\alpha \sim= 1 + \frac{\zeta_m}{4\pi G\omega}\left(\frac{8\pi G\rho_m}{3H}\right) Hte^{-3Ht}$ for $a(t) \sim e^{\sqrt{\Lambda/3}t}$
  where $H = \sqrt{\Lambda/3}$
  alpha quickly tends to a constant value during Λ dominated universe.
- From matter to present epoch, variation of α mostly guided by the nature of dark matter we have in our universe. Nature of dark matter parametrized by ζ_m

Observations on variation of alpha

- Oklo Natural Reactor in Gabon (2 Gyrs old, $z \sim 0.1 - 0.15$) $\frac{\delta\alpha}{\alpha} \simeq= (8.8 \pm 0.7) \times 10^{-8}$ Y. Fujii, Lect.Notes Phys.648:167-185,2004, hep-ph/0311026
- From BBN latest bound $-0.007 \leq \frac{\delta\alpha}{\alpha} \leq 0.017$ at 95% C.L, T. Dent etal Phys. Rev. D76, 063513 (2007).
- WMAP 7-year data study gives: $-0.005 \leq \frac{\delta\alpha}{\alpha} \leq 0.008$ at 95% C.L, S. J. Landau and C. G. Scoccola, arXiv:1002.1603
- Astrophysical constraints $\frac{\delta\alpha}{\alpha} \simeq= (.61 \pm 0.2) \times 10^{-5}$ for $z > 1.8$ J.K. Webb etal 1008.3907
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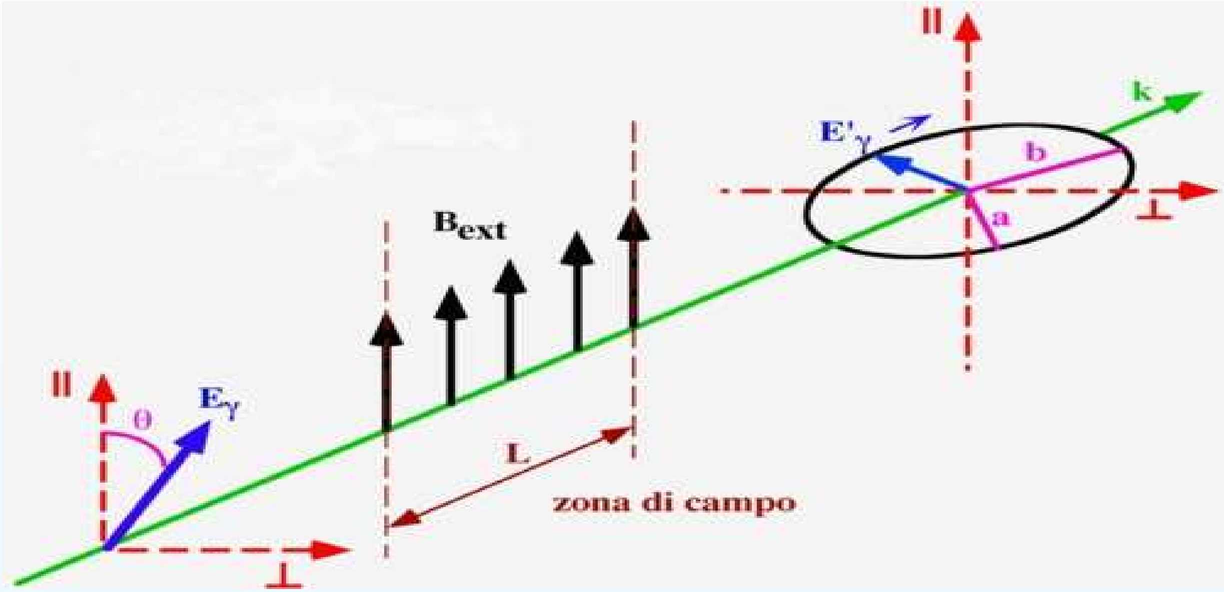
Constraining the parameters

- $\frac{\delta\alpha}{\alpha} \simeq \frac{\zeta_m}{4\pi G\omega} \simeq (.3 \pm 0.4) \times 10^{-7}$ from Oklo
- $\frac{\zeta_m}{4\pi G\omega} \simeq (.6 \pm 0.2) \times 10^{-6}$ for $z > 1.8$ from Astrophysical constraints
- How to constrain β?
  In the cosmological context β only contributes in radiation dominated era.
  Difference between BBN and WMAP observation may give us constraints about $-0.002 \leq \frac{\delta\alpha_{rad}}{\alpha} \leq 0.009$,
  From the cosmological observation it seems difficult?
- Laboratory experiment may help.

Strong Background Magnetic field effect

- Apart from the cosmological or astrophysical observations: Laboratory-based experiments: BFRT, PVLAS, Q & A, BMV
- Indirect detection of some new scalar fields, making use of photon to scalar field conversion in the presence of strong background magnetic field.
- In cosmological scale there exist background magnetic field which can effect the CMB polarization through scalar interaction.

Strong Background Magnetic field effect



The set of linear equations

$$(\nabla^2 + \varpi^2)\mathbf{A}_x = 2i\beta \mathbf{B}_0 \varpi \phi$$

$$(\nabla^2 + \varpi^2)\mathbf{A}_y = -2\mathbf{B}_0 \partial_z \phi$$

$$(\nabla^2 + \varpi^2)\phi = \frac{2\mathbf{B}_0^2}{\omega}\phi + \frac{2\mathbf{B}_0}{\omega}\partial_z A_y - \frac{2i\beta \mathbf{B}_0 \varpi}{\omega} A_x$$

Strong Background Magnetic field effect

Taking the ansatz to be

$$\mathbf{A}(z,t) = \mathbf{A}^0 e^{-i\varpi t + ikz} \quad ; \quad \phi(z,t) = \phi^0 e^{-i\varpi t + ikz}$$

Boundary conditions

$$\mathbf{A}_x(z=0, t=0) = \cos\theta \;\; ; \;\; \mathbf{A}_y(z=0, t=0) = \sin\theta \;\; ; \;\; \phi(z=0, t=0) = 0$$

The unique solution looks like

$$\begin{aligned}
\mathbf{A}_x &= (a_x e^{-i\varpi t} + b_x e^{-i\varpi_+ t} + c_x e^{-i\varpi_- t}) e^{ikz} \\
\mathbf{A}_y &= (a_y e^{-i\varpi t} + b_y e^{-i\varpi_+ t} + c_y e^{-i\varpi_- t}) e^{ikz} \\
\phi &= \phi_0 (e^{-i\varpi_+ t} - e^{-i\varpi_- t}) e^{ikz}
\end{aligned}$$

Strong Background Magnetic field effect

Optical rotation of the plane of polarization

$$\delta \simeq \frac{\sin(2\theta)}{4}\left(\frac{\mathcal{L}}{\cos^2(\theta)} - \frac{\Gamma}{\sin^2(\theta)}\right)$$

This is the quantity which establish the direct connection with the experimental data.
where

$$\mathcal{L} = 2a_x b_x \sin^2(\frac{\Delta_+}{2}) + 2a_x c_x \sin^2(\frac{\Delta_-}{2}) + 2c_x b_x \sin^2(\frac{\Delta}{2}),$$
$$\Gamma = 2a_y b_y \sin^2(\frac{\Delta_+}{2}) + 2a_y c_y \sin^2(\frac{\Delta_-}{2}) + 2c_y b_y \sin^2(\frac{\Delta}{2}),$$
$$\Delta_+ = \varpi_+ - \varpi \quad ; \quad \Delta_- = \varpi_- - \varpi \quad ; \quad \Delta = \varpi_+ - \varpi_-$$

Strong Background Magnetic field effect

Ellipticity

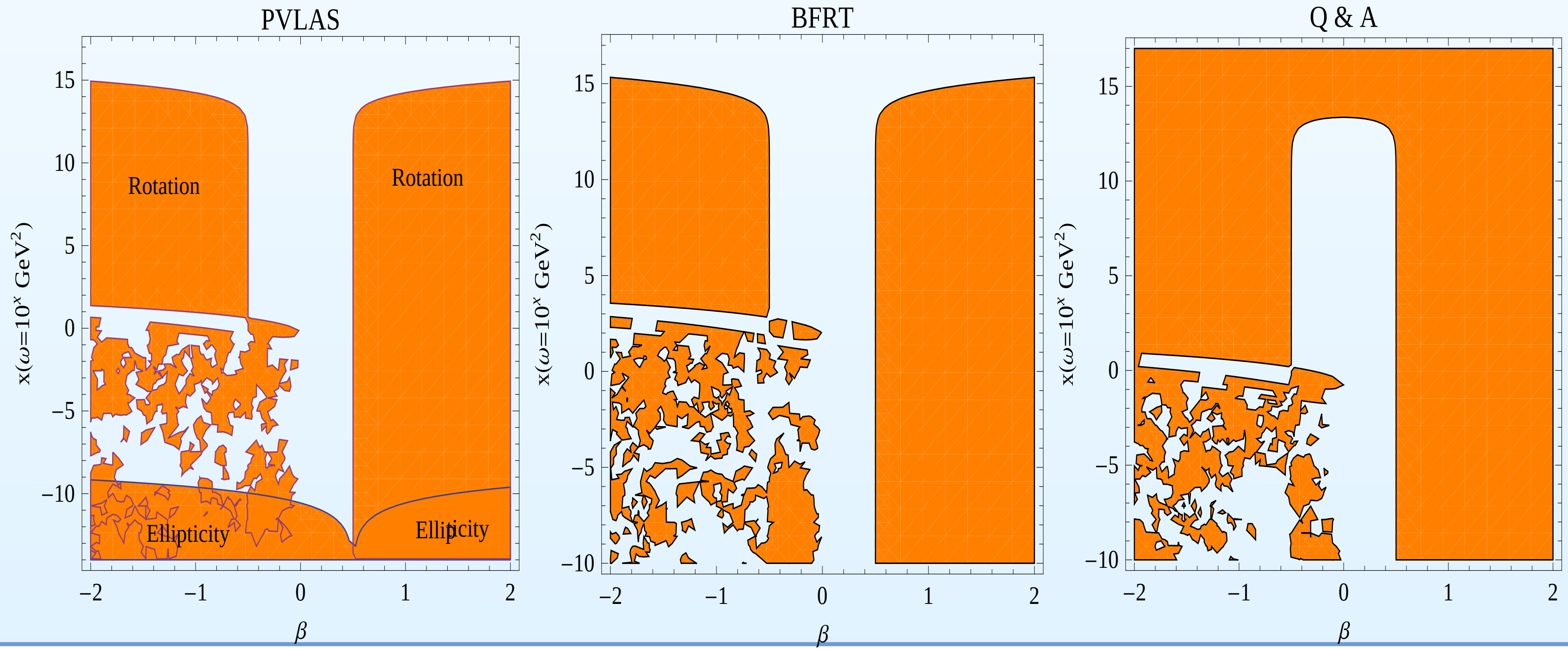
$$\epsilon \simeq \frac{1}{2}|\psi_x - \psi_y|$$

This is the quantity which establish the direct connection with the experimental data.
where

$$\psi_x = \tan^{-1}\left[\frac{bx\sin(\Delta_+ l) + cx\sin(\Delta_- l)}{ax + bx\cos(\Delta_+ l) + cx\cos(\Delta_- l)}\right]$$
$$\psi_y = \tan^{-1}\left[\frac{by\sin(\Delta_+ l) + cy\sin(\Delta_- l)}{ay + by\cos(\Delta_+ l) + cy\cos(\Delta_- l)}\right]$$

Laboratory experiments and constraints

Experiment	$\lambda(nm)$	$\mathbf{B}_0(T)$	$L(m)$	N	Rotation/Ellipticity
BFRT	514	3.25	8.8	250	$3.5 \times 10^{-10}/1.4 \times 10^{-8}$
PVLAS	1064	2.3	1	45000	1.0×10^{-9}
Q & A	1064	2.3	0.6	18700	$(-0.375 \pm 5.236) \times 10^{-9}$



Conclusions

- We introduce the varying alpha theory: The construction was based on the local charge non-conservation but gauge invariance and shift symmetry.
- For the last many years Parity violating extension to standard cosmological model has gained considerable interest because of high precession cosmological observation.
- This leads us to consider parity violating extension of Varying alpha theory.
- Interesting points which is one of our motivations was that the model unifies different cosmic phenomena in a single framework.
- Cosmic birefringence, new non-vanishing multi-pole correlation in CMB and cosmic time variation of α, all these phenomena are unified in our single framework

Conclusions

- In addition to standard variation of alpha in Varying alpha theory, our model has a new prediction on this variation in radiation dominated era.
- From different laboratory based experiments we constrains our model parameters
  $-.5 < \beta < .5$ and $\omega > 10^{-10} GeV^2$
- We did not mention much about the cosmological constraints. We are presently working on this aspects