# Cosmological 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 cosmic phenomena
- Conclusions

# Introduction

- For the last several years, this idea of varying $\alpha$ constant has got much attention, mainly because
  - String theory
  - Studies on absorption spectrum of quasars, 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).
  - $\alpha$: smaller in the past, at z = 1 - 3.5; $\frac{\delta\alpha}{\alpha} = (-0.570.10)10^{-5}$ .
- Motivated by this observation, Sandvik-Barrow-Magueijo extensively studied the varying alpha theory in 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).

# Varying $\alpha$ Theory

- The simplest way to introduce the variation of $\alpha$: Variation of electric charge as $e = e_0 e^{\phi(x)}$,
- $\phi(x)$: A dimensionless scalar field.
- Guiding principles: Shift symmetry and gauge invariance

$$\phi \rightarrow \phi + c \quad ; \quad e^{\phi} A_{\mu} \rightarrow e^{\phi} A_{\mu} + \chi_{,\mu}.$$

- The gauge invariant and shift symmetric action:

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

Where $F_{\mu\nu} = (e^{\phi} A_{\nu})_{,\mu} - (e^{\phi} A_{\mu})_{,\nu}$.
$\omega = \hbar c / l^2$, where $l$: Characteristic 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 in the parity violating effect on present high precession experimental observations to look for new physics
- To unify the different cosmic phenomena

# PCP violating model

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 that we can add

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

  $\beta$: A free dimensionless parameter

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

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

# Various cosmic phenomena

- 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

# Cosmological Birefringence

- Cosmological birefringence (CB) is a wavelength-independent rotation of photon polarization vector after traversing a long cosmic distance.
- The equations for the polarization states
  $b_{\pm}(\eta) = \mathbf{B}_{0x}(\eta) \pm i\mathbf{B}_{0y}(\eta)$

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

- Equation of motion for the scalar field in FRW background

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

- We use the WKB approximation in **large $\omega$** and **long wavelength** limit.

# Cosmological Birefringence

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

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

- Solution based on the above ansatz is

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

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

$$\Delta = 2\beta \int_{\eta_i}^{\eta_f} \dot{\phi} d\eta = 2\beta |\phi(\eta_f) - \phi(\eta_i)|,$$

where $\eta_i$ and $\eta_f$ are the initial and final time.

# CMB Power Spectrum and Parity violation

- CMB power spectrum is the various correlation functions among the temperature fluctuation and polarization tensors.
- 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 angular distribution of polarization tensor can also 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

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

# Varying $\alpha$ Cosmology

- Assuming FRW metric ansatz,

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

- Equation of motions are

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

where $\Lambda$: Cosmological constant; $\rho_\phi = \frac{1}{2}[\dot{\phi}^2 + V(\phi)]$.

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

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

# Varying $\alpha$ Cosmology

- With the suitable boundary condition,

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

- The evolution equation for $\phi$ now becomes

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

- By adopting self consistent approximation, to the leading order $t\to\infty$,

$$\alpha \sim \mathcal{A}\ln(t)\exp\Big[-\frac{2}{\ln(t)}\Big].$$

$\alpha$ increases logarithmically with time and controlled by the average energy density of the of the radiation and coupling,$\beta$.

# Conclusions

- For the last many years considerable interest on parity violating extension of standard models 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 $\alpha$, all these phenomena are unified in a single framework
- In our present study we did not mention anything about the observational constraints on our model parameter. This is our present interest of study.