Constraining a model of varying alpha with PCP violation.

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DM, P. Chen, Phys.Rev.D83:083516,2011.; Phys.Rev.D84:026008,2011.;

Phys.Rev.D85:043512,2012.

Plan of my talk

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

Introduction

- Lord Kelvin, Milne, J.B.S. Haldane, Dirac, E. Teller, Gammow, Jordan, Brans and Dicke, Bekenstein
- For the last several years, this idea of varying fundamental constant has got much attention, mainly because
  - String theory
  - Studies of absorption lines of dust clouds around 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).
  - 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 $\frac{\delta\alpha}{\alpha} = (-0.570.10)10^{-5}$.

Introduction

- Motivated by this observation, Sandvik-Barrow-Magueijo 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: $\alpha = e_0^2 e^{2\phi(x)}$.
- Arbitrariness involved in the definition of this variation : Shift symmetry, i.e. $\phi \to \phi + c$.
- Guiding principles: Shift symmetry and local gauge invariance
- 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.

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

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

- 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

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

- Parity violating effect on Cosmic variation of fine structure constant.
- Effect of **background magnetic field** on photon
  - Laboratory experiments
  - CMB passing through the intra-galactic magnetic field (SZ-like 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; $\rho_\phi = \frac{1}{2}\dot{\phi}^2$. $\zeta_m = \frac{\mathcal{L}_{em}}{\rho_m}$

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

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 linear 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

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

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

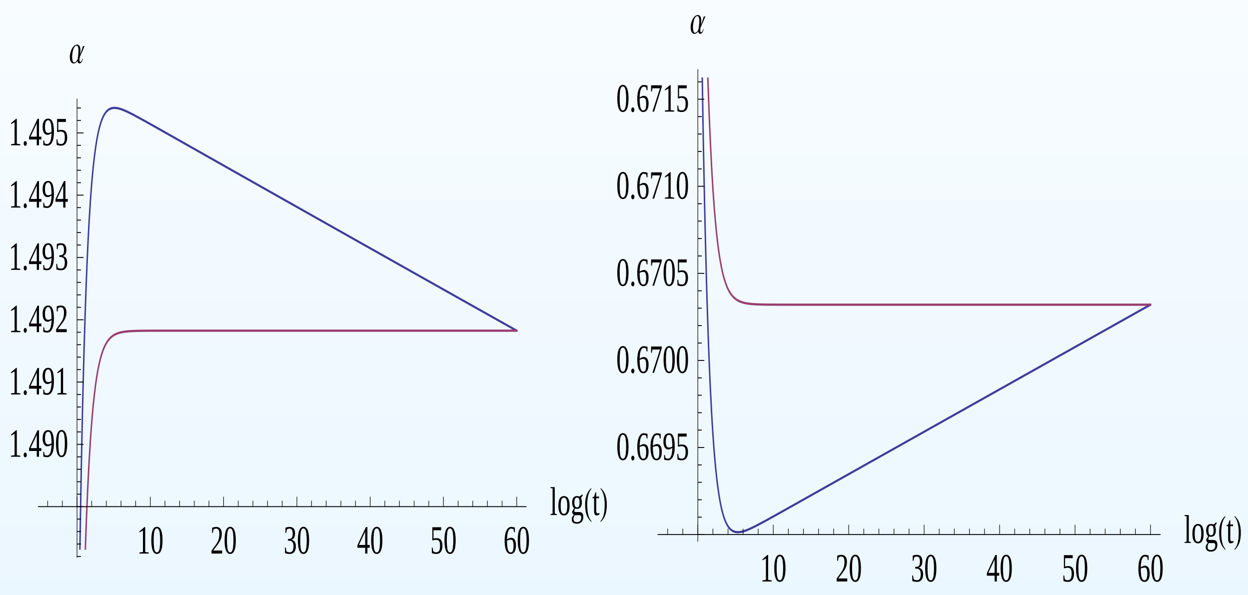
- Validity of our approximation: The leading order behaviour of the energy densities

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

- Scalar density falls off faster than the radiation energy density as $t \to \infty$.
- α decreases in an logarithmic 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

J. D. Barrow etal Phys.Rev. D65 (2002) 063504

- 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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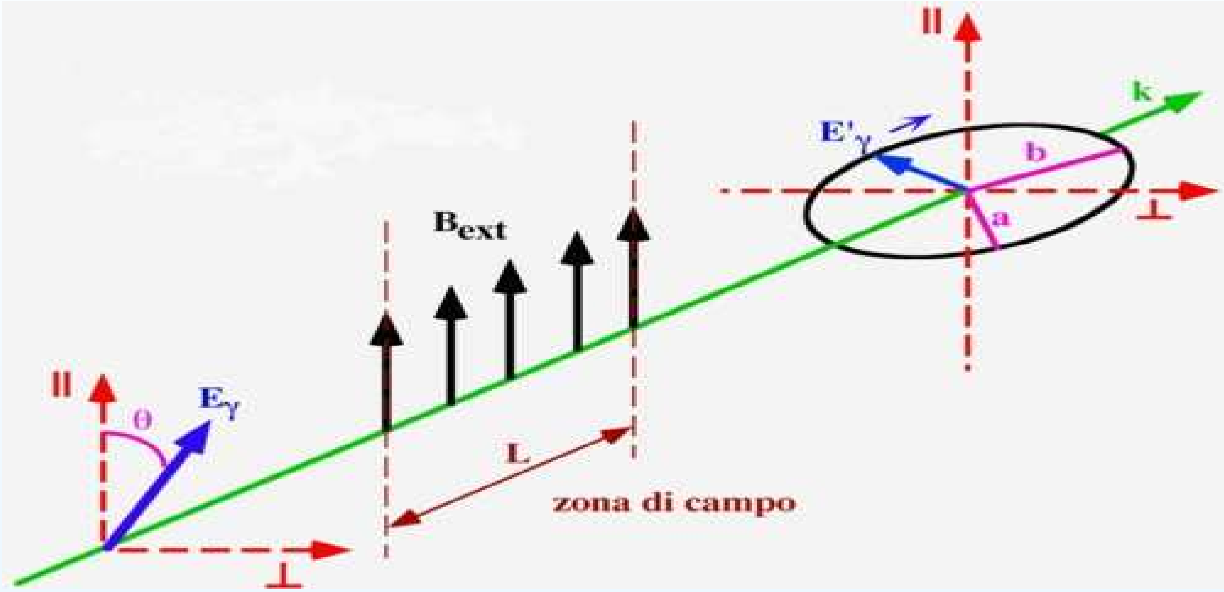
Constraining the parameters

- $\frac{\delta\alpha}{\alpha} \simeq \frac{\zeta_m}{4\pi G\omega^2} \simeq (.3 \pm 0.4) \times 10^{-7}$ from Oklo
- $\frac{\zeta_m}{4\pi G\omega^2} \simeq (.6 \pm 0.2) \times 10^{-6}$ 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!

Strong Background Magnetic field effect

- Indirect detection of some new scalar fields, making use of photon to scalar field conversion in the presence of background magnetic field.
- Laboratory-based experiments: BFRT, PVLAS, Q & A, BMV
- 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

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

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

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

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

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

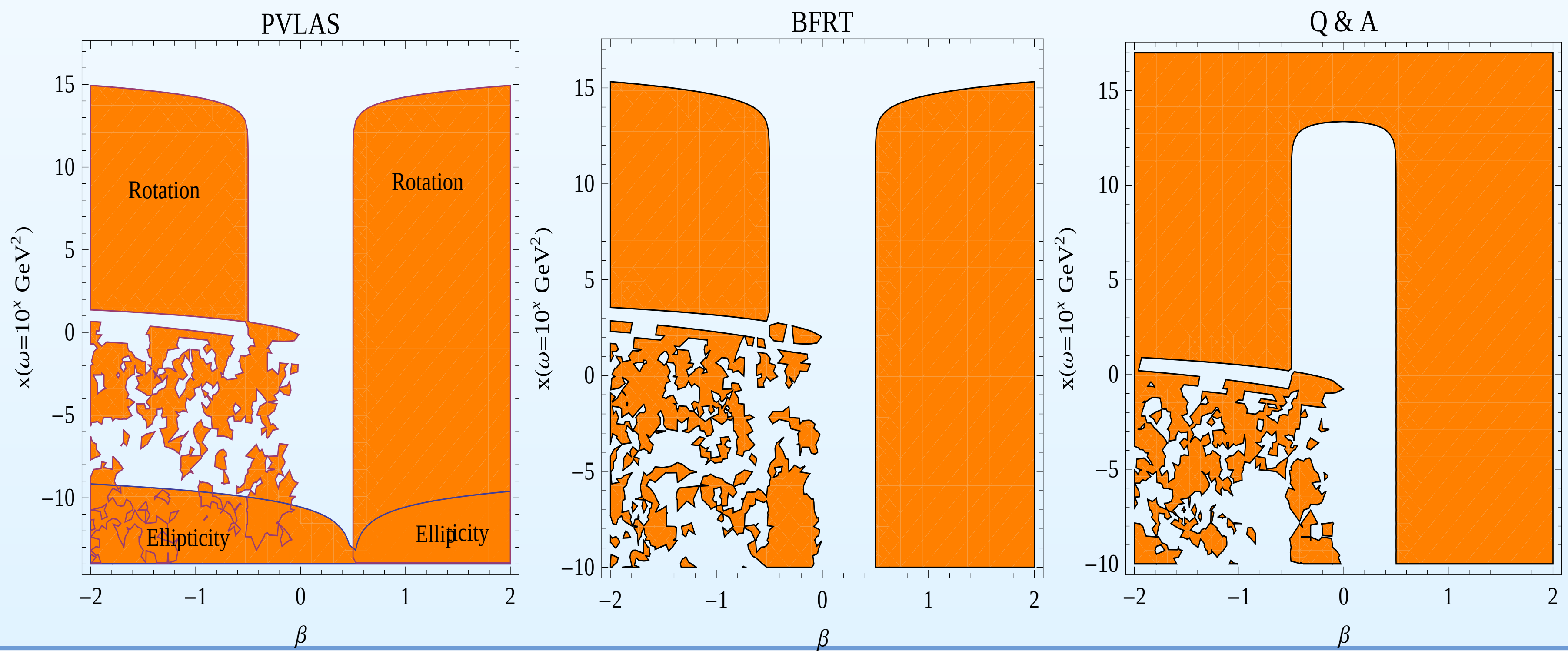
This is the quantity which establish the direct connection with the experimental data.
where

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

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

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	$(-0.375 \pm 5.236) \times 10^{-9}$



Constraining β and ω

Range of ω in GeV	Bound on β	Experiment
$10^{-5} \lessapprox \omega \lessapprox 10$ $\omega \lessapprox 10$	$0 \leq \beta \leq 0.5$	PVLAS BFRT, Q&A
$10 \lessapprox \omega \lessapprox 3.3 \times 10^6$	$-0.5 \leq \beta \leq 0.5$	PVLAS, BFRT, Q&A
$\omega \gtrapprox 10^7$	$\lvert\beta\rvert \geq 1$	PVLAS, BFRT

- From Coulomb force law, $\omega = \hbar c/l > 10 \times$ MeV.
- From the ellipticity measurement of PVLAS, this scale woulde be $\approx 10^{-2}$ MeV,
- If $\omega \approx 10^3$ MeV, PVLAS would not be able to measure the ellipticity down to the level of $\epsilon \simeq 1 \times 10^{-17}$.

Constraining β and ω

- This value is significantly lower than the present PVLAS bound of $\epsilon \simeq 1.4 \times 10^{-8}$.
- For $\omega \gtrsim 10^7$ GeV, $|\beta| \geq 1$
- If we assume $\beta < 1$, the most reasonable bounds on both of our model parameters: $1 \leq \omega \leq 3.3 \times 10^6$ GeV and $-0.5 \leq \beta \leq 0.5$.

CMB in the background of Magnetic field

- In our universe magnetic field is omnipresent at all scales (Galactic, Intra-galactic,...) from (G to μG).
- CMB is an important probe in cosmology.
- Effect on CMB passing though Intra-galactic medium(ICM) (SZ-like effect)
  - Optics in the presence of magnetized plasma
  - ICM: Power spectrum model
  - Constraining through observations on Coma galaxy cluster

Photon through magnetized plasma

- Equation of motion in a suitable form

$$(i\frac{d}{dz} + \mathcal{M}) \begin{pmatrix} \mathbf{A}_x \\ \mathbf{A}_y \\ \Phi \end{pmatrix} = 0$$

$$\mathcal{M} = \begin{bmatrix} \varpi + \Delta_{plasma} & 0 & -i(\mathbf{B}_y + 2\beta\mathbf{B}_x) \\ 0 & (\varpi + \Delta_{plasma}) & i(\mathbf{B}_x - 2\beta\mathbf{B}_y) \\ \frac{i}{\omega^2}(\mathbf{B}_y + 2\beta\mathbf{B}_x) & -\frac{i}{\omega^2}(\mathbf{B}_x - 2\beta\mathbf{B}_y) & \varpi - \frac{\mathbf{B}^2}{\omega^2\varpi} \end{bmatrix}.$$

$\mathcal{M}$: Scalar and photon mixing matrix.

$$\Delta_{plasma} = -\frac{\varpi^2_{plasma}}{2\varpi} = 4\alpha_0\frac{\rho_e}{m_e}\frac{1}{2\varpi},$$

Stokes parameters

- Properties of light is conventionally described by 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

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

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

Stoks parameter: CMB

- Change of intensity and polarization after traversing distance z

$$I(z) \simeq I(0)(1 - P_{\gamma\to\phi}) \quad ; \quad Q(z) \simeq I(0)\mathcal{Q}(z)$$
$$U(z) \simeq I(0)\mathcal{U}(z) \quad ; \quad V(z) \simeq I(0)\mathcal{V}(z)$$

Assuming initial polarization is small compared to the intensity

$$P_{\gamma\to\phi} = \tfrac{1}{2\omega^2} < (|\mathcal{B}_x|^2 + |\mathcal{B}_y|^2) > \ ; \ \mathcal{Q}(z) = \tfrac{1}{2\omega^2} < (|\mathcal{B}_x|^2 - |\mathcal{B}_y|^2) >,$$
$$\mathcal{U}(z) = \tfrac{1}{2\omega^2} < (\mathcal{B}_x^*\mathcal{B}_y + \mathcal{B}_y^*\mathcal{B}_x) > \ ; \ \mathcal{V}(z) = \tfrac{1}{2\omega^2} < (\mathcal{B}_x^*\mathcal{B}_y - \mathcal{B}_y^*\mathcal{B}_x) >,$$

$$\mathcal{B}_i = \int_0^z (\mathbf{B}_i - 2\beta\epsilon^{ij}\mathbf{B}_j)e^{iS}dx \quad ; \quad S(z) = -\int_0^z \left(\frac{\varpi_{plasma}^2}{2\varpi} - \frac{\mathbf{B}^2}{\omega^2\varpi}\right)dx$$

$$< \phi^*(0)\mathbf{A}_i(0) >= 0 \ ; \quad < \mathbf{A}_i^*(0)\phi(0) >= 0 \ ; \quad < \phi^*(0)\phi(0) >= 0$$

Intra-galactic Magnetic field: Power Spectrum

- A realistic model for the magnetic field $\mathbf{B}$ and the electron density ρ_e: power spectrum model.

$$\mathbf{B} = \mathbf{B}_0 + \delta\mathbf{B} \quad ; \quad \rho_e = \rho_{e0} + \delta\rho_e$$

- Two point correlation functions of $\delta\mathbf{B}_i$ and $\delta\rho_e$, defined by

$$< \delta\mathbf{B}_i(y)\delta\mathbf{B}_i(x+y) >= \frac{1}{4\pi}\int d^3k P_{\mathbf{B}ij}(k) e^{i\mathbf{k}\cdot\mathbf{x}},$$

$$< \delta\rho_e(y)\delta\rho_e(x+y) >= \frac{1}{4\pi}\int d^3k P_e(k) e^{i\mathbf{k}\cdot\mathbf{x}}.$$

- Magnetic field fluctuations Gaussian random variable, $< \delta\mathbf{B}_i >= 0$, $\implies P_{\mathbf{B}ij}(k) = \frac{1}{3}\delta_{ij}P_{\mathbf{B}}(k)$.

Intra-galactic Magnetic field: Power Spectrum

- The correlation length

$$L_{\mathbf{B}} = \frac{\int_0^\infty kdkP_{\mathbf{B}}(k)}{2\int_0^\infty k^2dkP_{\mathbf{B}}(k)} \quad ; \quad L_e = \frac{\int_0^\infty kdkP_e(k)}{2\int_0^\infty k^2dkP_e(k)}$$

in terms of two power spectra $P_{\mathbf{B}}(k)$ and $P_e(x)$.

$$k^2P_{\mathbf{B}}(k) = \mathcal{P}_{\mathbf{B}}k^\gamma \quad ; \quad k^2P_e(k) = \mathcal{P}_ek^\gamma,$$

where $\mathcal{P}_{\mathbf{B}}$ and $P_e(k)$ are the normalization constants.
$-2 < \gamma < -1$. A special universal value $\gamma = -5/3$; Kolmogorov exponent.

$$G_{ij}(x) =< \mathcal{B}_i^*(y)\mathcal{B}_j(y+x) > .$$

SZ-like effect on CMB

- Final expressions for the stokes parameters

$$\bar{P}_{\gamma\to\phi} = \bar{P}^{reg}_{\gamma\to\phi} + \bar{P}^{ran}_{\gamma\to\phi} + \frac{8\beta^2}{3}\left(\int_{\bar{\Delta}}^{\infty} + \int_{\bar{\Delta}'}^{\infty}\right) kdk\mathcal{F}^k_{(1)},$$

$$\bar{V}(L) \simeq -\beta I(0)\bar{P}^{ran}_{\gamma\to\phi},$$

$$\bar{Q}(L) \simeq I(0)\bar{P}^{reg}_{\gamma\to\phi}(\cos 2\theta - 4\beta\sin 2\theta),$$

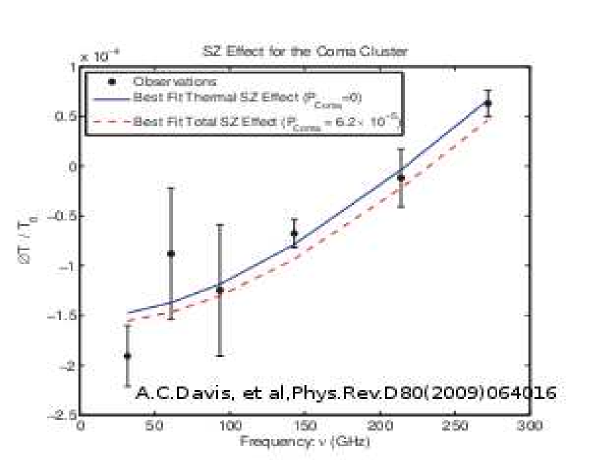
$$\bar{U}(L) \simeq I(0)\bar{P}^{reg}_{\gamma\to\phi}(\sin 2\theta + 4\beta\cos 2\theta).$$

- SZ like Effect:

$$\frac{\delta T}{T_0} \approx \frac{(e^{-\mu\varpi} - 1)}{\mu\varpi}\bar{P}_{\gamma\to\phi}(L).$$

The Boltzmann factor $\mu = \frac{1}{k_B T_0}$

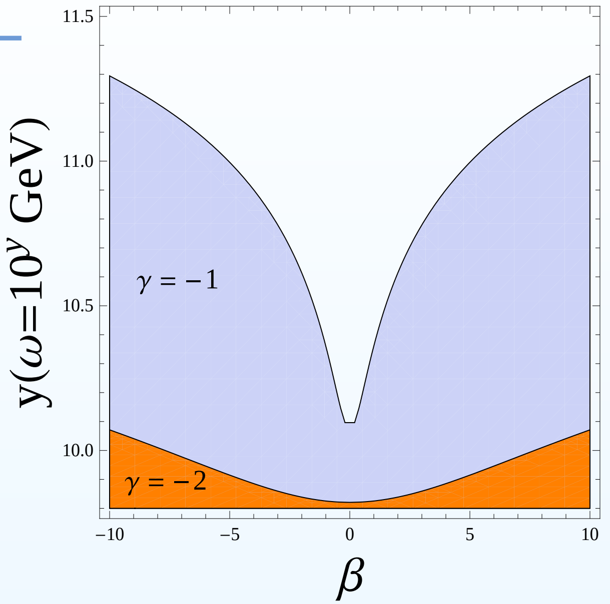
Coma Galaxy cluster: Conversion probability



$$P^{coma}_{\gamma\to\phi}(204GHz) < 6.2 \times 10^{-5} \;\; (95\%)$$

Constraining β and ω for Coma

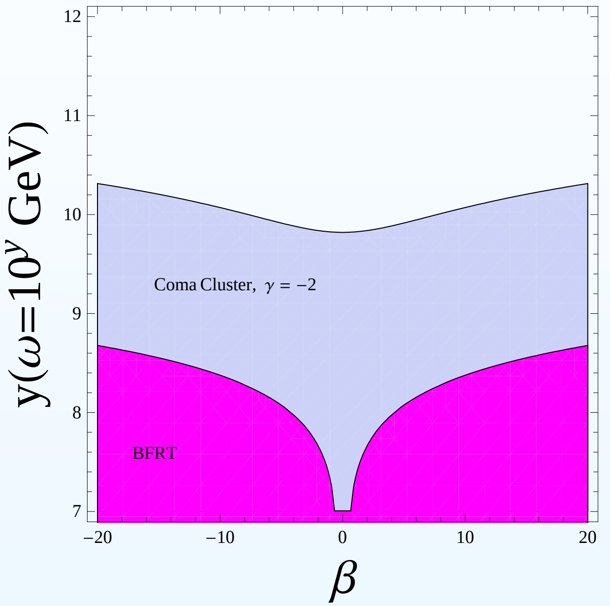
- $\varpi \simeq 2\pi\ 204$GHz ; $\rho_{0_e} \simeq 4 \times 10^{-3}$cm^{-3}
- $\delta\mathbf{B} = 8.5\mu$G ; $L_{\mathbf{B}} \simeq 1$kpc
- $L = 200$kpc



$\omega \geq (0.66 - 4.04) \times 10^{10}$ GeV.

If β increases lowe bound on ω also increases.

Combined constraint on β and ω



$$\omega \geq (0.66 - 4.04) \times 10^{10} \text{ GeV.}$$

Comments on CMB Polarization

- Induced polarization

$$\bar{V}(L) \simeq -\beta I(0)\bar{P}^{ran}_{\gamma\to\phi},$$
$$\bar{Q}(L) \simeq I(0)\bar{P}^{reg}_{\gamma\to\phi}(\cos 2\theta - 4\beta \sin 2\theta),$$
$$\bar{U}(L) \simeq I(0)\bar{P}^{reg}_{\gamma\to\phi}(\sin 2\theta + 4\beta \cos 2\theta).$$

- Linear polarization proportional to

$$\bar{P}^{reg}_{\gamma\to\phi}(L) \leq (0.89 - 1.51) \times 10^{-10}.$$

- The circular polarization:

$$\bar{P}^{ran}_{\gamma\to\phi}(L) \leq 6.2 \times 10^{-5} \gg \bar{P}^{reg}_{\gamma\to\phi}(L)!!,$$

Comments on CMB Polarization

- No polarization observation so far in the direction of galaxy cluster (Experimental limitation)
- Fractional intrinsic polarization $\langle Q(0)^2\rangle^{1/2}/I(0), \langle U(0)^2\rangle^{1/2}/I(0) \sim \mathcal{O}(10^{-7})$, $\langle V(0)^2\rangle^{1/2}/I(0) \ll \mathcal{O}(10^{-7})$.

$$\beta \simeq 0 \text{ ?}$$

Measurement Issues:

- Angular resolution should be $\theta < 0.03$ arcmin (Coma Cluster)
- Spectral resolution should be $\delta\lambda/\lambda < 10^{-6} - 10^{-7}$
- Typical value in an experiment: several arcmin, for CMB experiments $\delta\lambda/\lambda < 10^{-4} - 10^{-2}$
- SPT-Pol, ALMA

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.
- Combing both laboratory and SZ-like effect

$$\omega \geq (0.66 - 4.04) \times 10^{10} \text{ GeV}.$$

- Future experiments such as ALMA can shed light on the polarization