Dark Energy and Baryogenesis

Xinmin Zhang
Institute of high energy physics
Chinese Academy of Sciences, Beijing

Talk given at workshop on Tev Physics
Tsinghua University, Nov 12-15, 2012

Happy Birthday to

Prof. Yu-Ping Kuang !

More talks on Higgs and its properties: standard model Higgs or beyond ?

Strong motivations for new physics from cosmology:

Dark Matter------〉 WIMP Dark Matter

-------→ Cold WIMP Dark Matter

Warm WIMP Dark Matter (non-thermal Production)

Dark Energy

Baryogenesis

Dynamics of Inflation

Singularity of the Big-Bang cosmology (Quintom bounce ….)

…………..

Comments on thermal and non-thermal WIMPs

I) Thermal WIMP miracle

thermal production, relic photon, hot Big-Bang

II) Non-thermal Processes

Topological defects (cosmic string) decays

Reheating

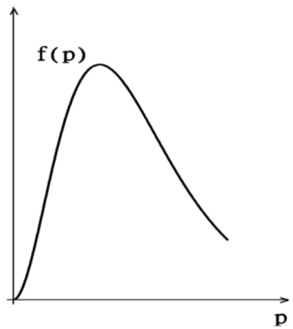
Heavy particles decays

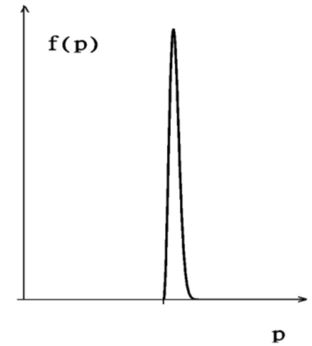
Free neutron decay in BBN

==➔ non-thermal WIMP miracle (G. Kane et al)

Thermal WIMPs | Non-thermal WIMPs

i) Distribution:





ii) Model parameter space constrained by relic density

a)Enlarging the parameter space;
b)Explaining the Boost factor required for Pamela ….

iii) Cold dark matter

Cold or Warm dark matter

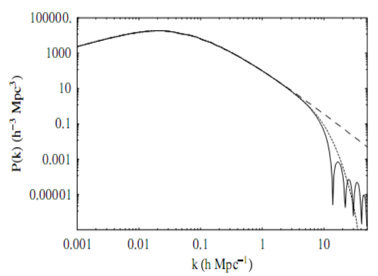


FIG. 1. Comparison of the power spectra of the CDM model (long-dashed curve), the WDM model with $m_W = 1$ keV (short-dashed curve), and the NTDM model with $r_c = 1.5 \times 10^{-7}$ (solid curve).

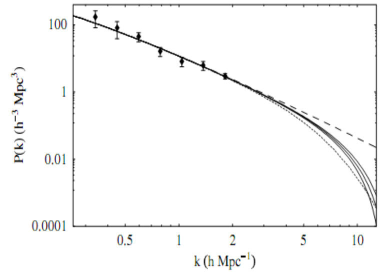


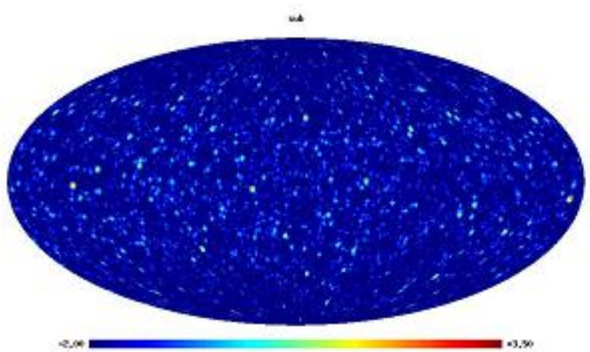
FIG. 2. The power spectra of the CDM model (long-dashed curve), the WDM model with $m_W = 750$ eV (short-dashed curve), and the NTDM models with $r_c = (1.3, 1.4, 1.5) \times 10^{-7}$ (solid curves, from top down), compared to the observed Lyman-α $P(k)$ at $z = 2.5$ (filled diamonds with error bars).

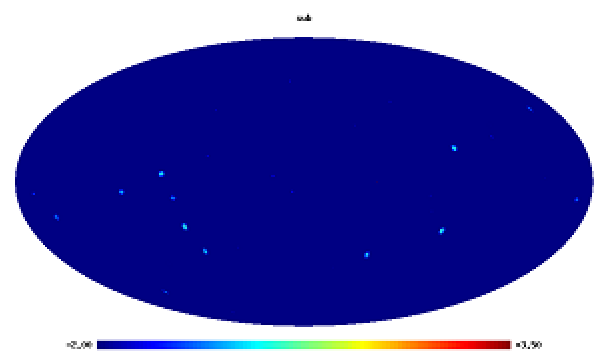
X. Zhang et al
JHEP 9912:003,1999.
arXiv: hep-ph/9901357
Phys.Rev.Lett.86:954,2001.
arXiv: astro-ph/0009003

Gamma-rays From Warm WIMP Dark Matter Annihilation

Qiang Yuan[1], Yixian Cao[2], Jie Liu[3], Peng-Fei Yin[1], Liang Gao[2], Xiao-Jun Bi[1] and Xinmin Zhang[3]
[1]*Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, P.R.China*
[2]*Partner Group of the Max Planck Institute for Astrophysics, National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, P.R. China*
[3]*Division of Theoretical Physics, Institute of High Energy Physics, Chinese Academy of Science, Beijing 100049, P.R.China*
(Dated: March 28, 2012)

The weakly interacting massive particle (WIMP) often serves as a candidate for the cold dark matter, however when produced non-thermally it could behave like warm dark matter. In this paper we study the properties of the γ-ray emission from annihilation of WIMP dark matter in the halo of our own Milky-Way Galaxy with high resolution N-body simulations of a Milky-Way like dark matter halo, assuming different nature of WIMPs. Due to the large free-streaming length in the scenario of warm WIMPs, the substructure contend of the dark matter halo is significantly different from that of the cold WIMP counterpart, resulting in distinct predictions of the γ-ray signals from the dark matter annihilation. We illustrate these by comparing the the predicted γ-ray signals from the warm WIMP annihilation to that of cold WIMPs. Pronounced differences from the subhalo skymap and statistical properties between two WIMP models are demonstrated. Due to the potentially enhanced cross section of the non-thermal production mechanism in warm WIMP scenario, the Galactic center might be prior for the indirect detection of warm WIMPs to dwarf galaxies, which might be different from the cold dark matter scenario. As a specific example we consider the non-thermally produced neutralino of supersymmetric model and discuss the detectability of warm WIMPs with Fermi γ-ray telescope.





To appear in Phys Rev. D

OUTLINE

I> Dark Energy

i) Brief review on dark energy study;

ii) New result: static or dynamical?

Zhao, Crittenden, Pogosian, Zhang, PRL (2012)

II> Baryogenesis

implications of light (125-126 GeV) Higgs in cosmology:

indirectly supporting for the idea of inflation and dark energy models buildingd with scalar fields

Electroweak phase transition -→ electroweak baryogenesis

===➔Effective theory (anomalous Higgs and Top couplings)

III> Interacting Dark Energy and Baryo/Leptogenesis

====➔ Cosmological CPT violation

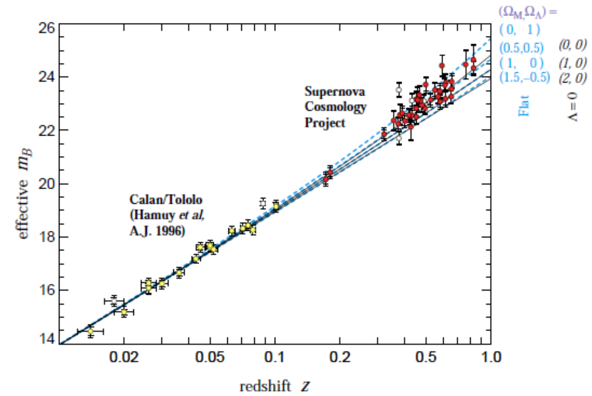
Current status on CPT test with CMB polarization and detection with Planck

Brief Introduction to Dark Energy

Negative pressure:

$$\ddot{a}/a = -\frac{4\pi G}{3}(\rho + 3p)$$

$$\ddot{a} > 0 \rightarrow \quad \rho + 3p < 0 \quad w = p/\rho < -1/3$$



* *Smoothly distributed, (almost) not clustering*

Candidates:

I Cosmological constant (or vacuum Energy)

$$T_{\mu\nu} = \frac{\Lambda}{8\pi G} g_{\mu\nu} \quad \rho = -p = \frac{\Lambda}{8\pi G} \approx (2\times 10^{-3} eV)^4$$

$$\downarrow$$

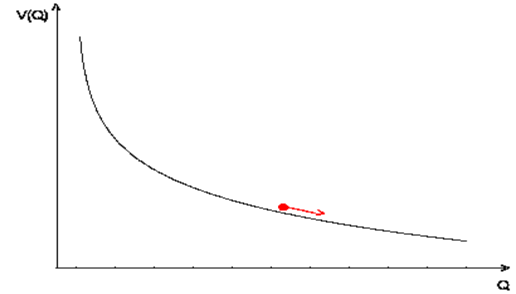
$$w = p/\rho = -1$$

$$m_\nu \sim 10^{-3} eV$$ Neutrino Dark Energy?!

$$\rho^{th}/\rho^{ob} \sim 10^{120}$$ cosmological constant problem!

II Dynamical Field: Quintessence, Phantom, Quintom….

$$L = \frac{1}{2}\partial_\mu Q \partial^\mu Q - V(Q) \quad \rho_Q = \frac{1}{2}\dot{Q}^2 + V, \; p_Q = \frac{1}{2}\dot{Q}^2 - V$$



$$W(Q) = \frac{\frac{1}{2}\dot{Q}^2 - V}{\frac{1}{2}\dot{Q}^2 + V} \qquad -1 \le w_Q \le 1$$

Equation of state $w=p/\rho$: characterize the properties of the dark energy models

* Vacuum : $w=-1$
* Quintessence: $w \geq -1$
* Phantom: $w<-1$
* Quintom: w across -1

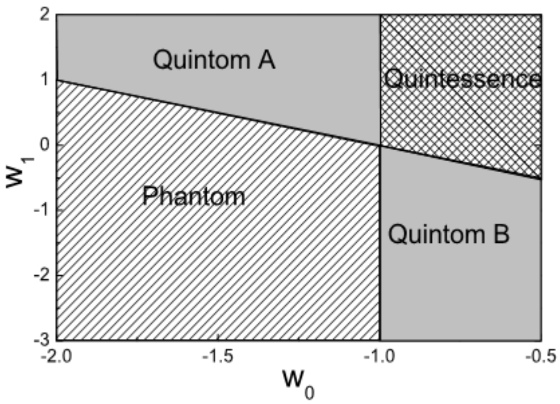
Important determining the equation of state of dark energy with cosmological observations

I) Parameterization of equation of state:

(very much like S.T.U parameters for the particle physics precision measurements)

A) w=w_0+w_1 z / (1+z) (used mostly in the literature)

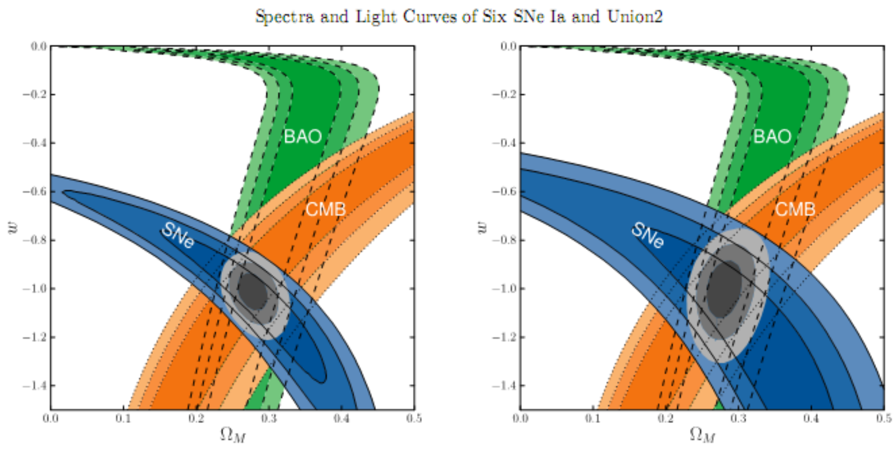
B) Model independent method { w_1…w_i…}



Cosmological Parameters:

$$\mathbf{P} \equiv (\omega_b, \omega_c, \Omega_k, H_0, \tau, w_0, w_1, \Sigma m_\nu, n_s, A_s, \alpha_s, r)$$

II) Global analysis with
current astronomical
observational data:
SN (Union2.1, SNLS3)
LSS (SDSS),
CMB(WMAP7, …)
And code used
CAMB/CosmoMC



However, difficulty with the dark energy perturbation
when w across -1 ==========➔ divergent
(like the infinity in massive W, Z
boson model)

$$\dot{\delta}_i = -(1+w_i)(\theta_i - 3\dot{\Phi}) - 3\mathcal{H}(\frac{\delta P_i}{\delta \rho_i} - w_i)\delta_i \quad ,$$

$$\dot{\theta}_i = -\mathcal{H}(1-3w_i)\theta_i - \frac{\dot{w}_i}{1+w_i}\theta_i + k^2(\frac{\delta P_i/\delta\rho_i}{1+w_i}\delta_i - \sigma_i + \Psi)$$

$$\boxed{1+w \to 0, \dot{w} \neq 0 \ \Rightarrow \ \dot{\delta}, \dot{\theta}, \delta, \theta \to \infty}$$

Perturbation with Quintom dark energy

(introducing an extra degree of freedom like the Higgs ….)

$$\dot{\delta}_i = -(1+w_i)(\theta_i - 3\dot{\Phi}) - 3\mathcal{H}(1-w_i)\delta_i - 3\mathcal{H}\frac{\dot{w}_i + 3\mathcal{H}(1-w_i^2)}{k^2}\theta_i$$

$$\dot{\theta}_i = 2\mathcal{H}\theta_i + \frac{k^2}{1+w_i}\delta_i + k^2\Psi \ .$$

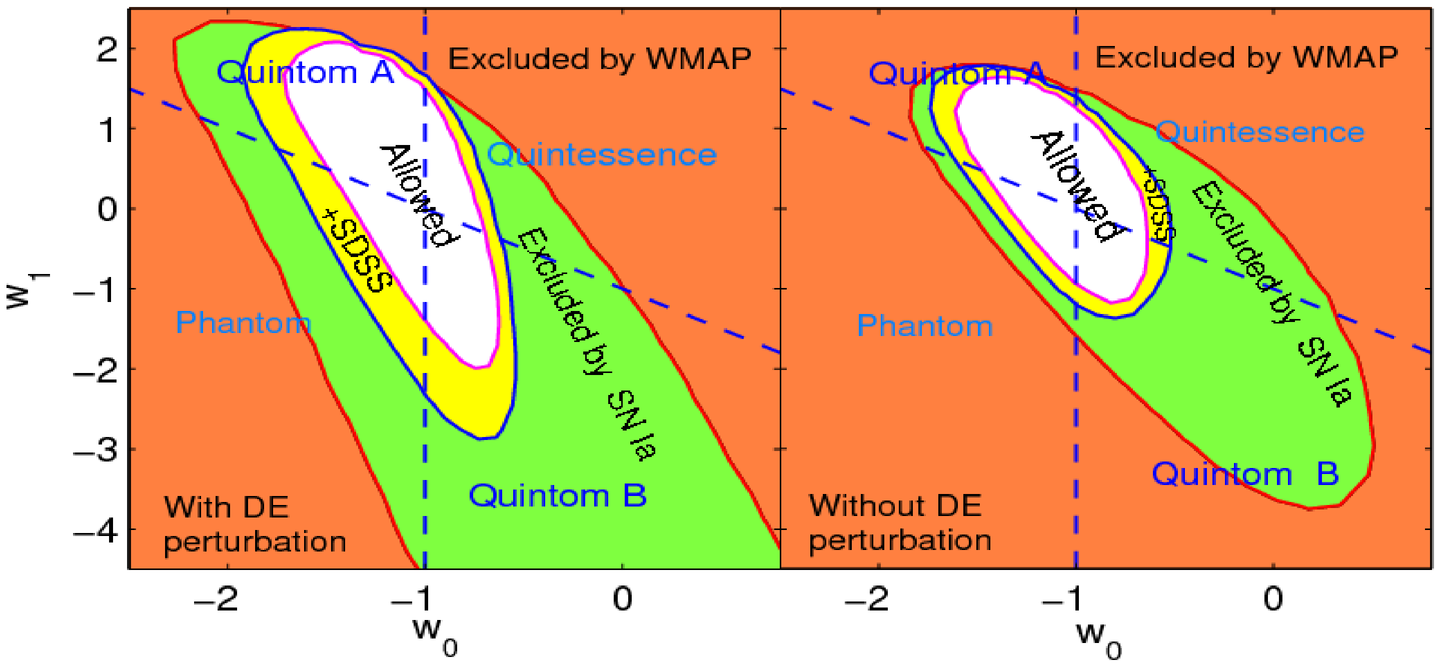
$$w_{quintom} = \frac{\sum_i P_i}{\sum_i \rho_i} \qquad \delta_{quintom} = \frac{\sum_i \rho_i \delta_i}{\sum_i \rho_i} \qquad \theta_{quintom} = \frac{\sum_i (\rho_i + p_i)\theta_i}{\sum_i (\rho_i + P_i)}$$

Here δ and θ are the density perturbation and the divergence of the fluid velocity respectively

Perturbation of DE is continuous during crossing!

Feng, Wang, Zhang, Phys. Lett. B607, 35 (2005)
Zhao et.al., Phys.Rev.D 72,123515, (2005)
Y. Cai et. al., Phys Rept. 493:1-60, (2010)

Constraints on dark energy with SN Ia + SDSS + WMAP-1

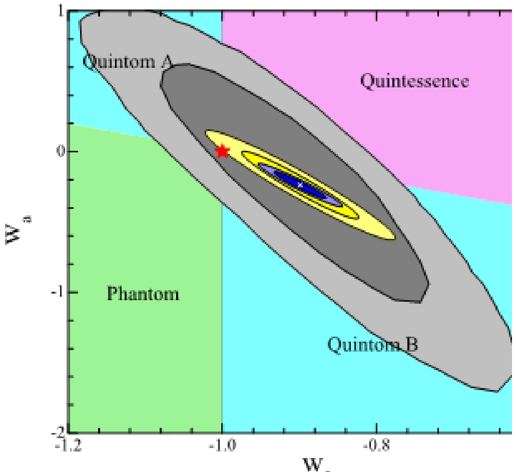


Observing dark energy dynamics with supernova, microwave background and galaxy clustering

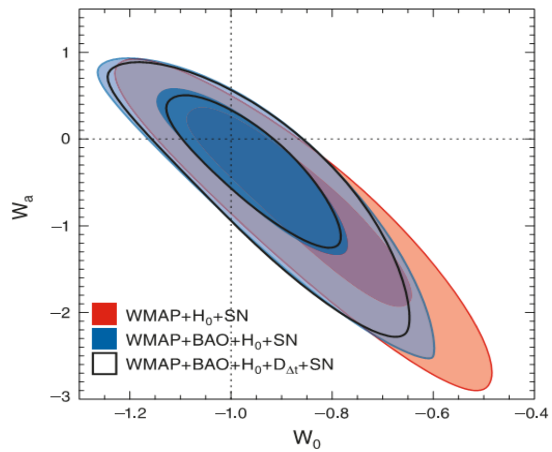
Jun-Qing Xia, Gong-Bo Zhao, Bo Feng, Hong Li and Xinmin Zhang

Phys.Rev.D73, 063521, 2006

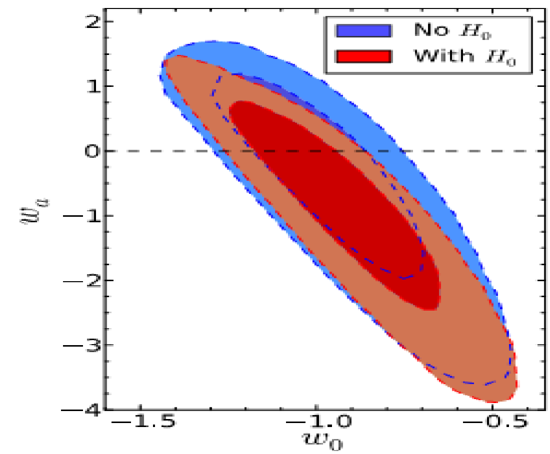
Current status in determining the EoS of dark energy



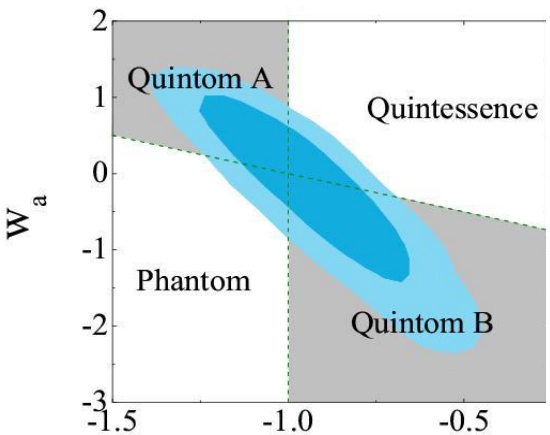
G. Zhao and X. Zhang
Phys.Rev.D81:043518,2010



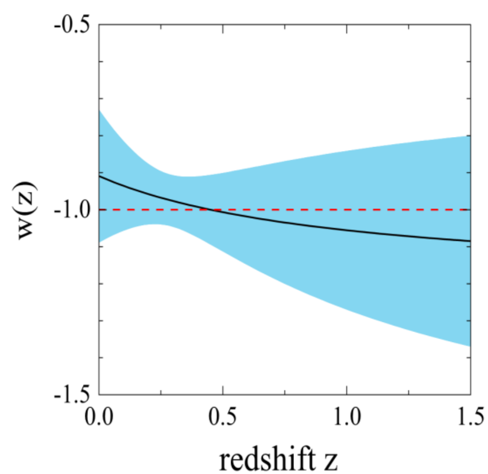
WMAP7 E. Komatsu *et al.*
e-Print: arXiv:1001.4538



SNLS3,
e-Print: arXiv:1104.1444



G. Zhao, H. Li, E. Linder, K. Koyama, D. Bacon, XZhang
arXiV: 1109.1846 Sep 2011
with WMAP7+Union2.1+BAO+…



Results:

1) Current data has constrained a lot of the theoretical models;

2) Cosmological constant is consistent with the data;

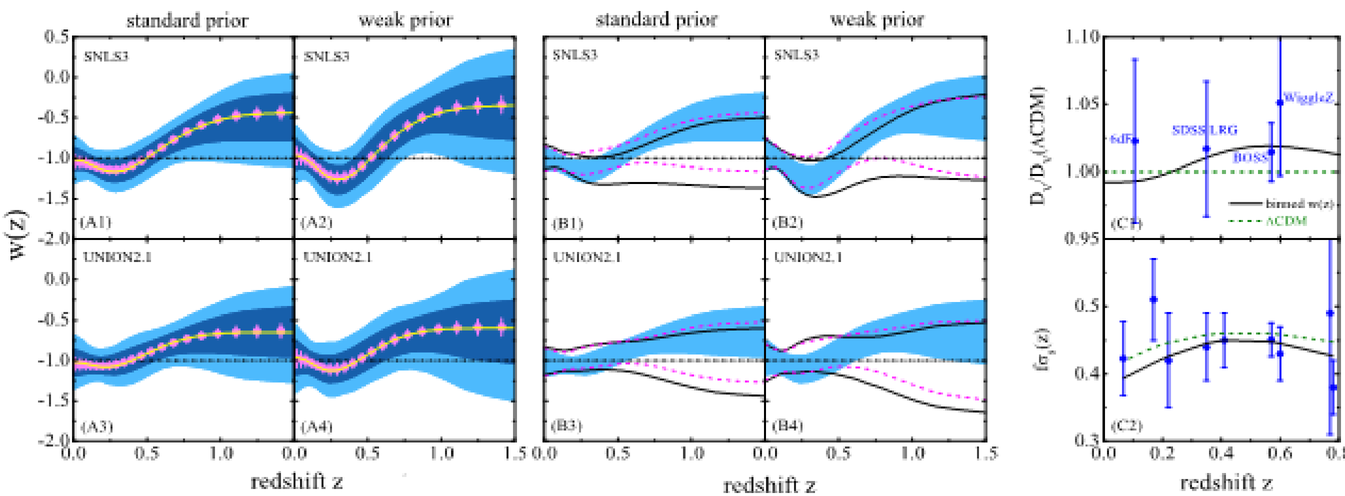
3）dynamical models are not ruled out; quintom scenario mildly favored;

PRL 109, 171301 (2012) PHYSICAL REVIEW LETTERS week ending 26 OCTOBER 2012

Examining the Evidence for Dynamical Dark Energy

Gong-Bo Zhao,[1,2] Robert G. Crittenden,[1] Levon Pogosian,[3,1] and Xinmin Zhang[4,5]

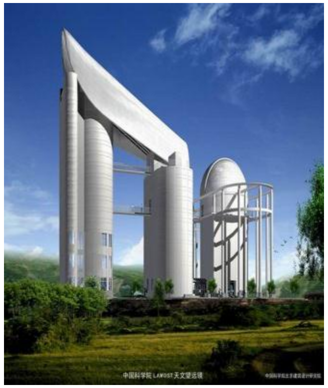
[1]*Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth PO1 3FX, United Kingdom*
[2]*National Astronomy Observatories, Chinese Academy of Science, Beijing 100012, People's Republic of China*
[3]*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6*
[4]*Institute of High Energy Physics, Chinese Academy of Science (CAS), P.O. Box 918-4, Beijing 100049, People's Republic of China*
[5]*Theoretical Physics Center for Science Facilities (TPCSF), CAS, Beijing 100049, People's Republic of China*
(Received 22 July 2012; published 26 October 2012)



2.5 sigma for dynamical dark energy with w crossing -1

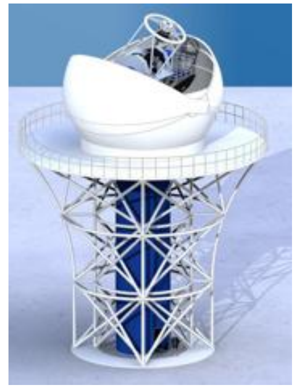
the Quintom scenario !

暗能量探测计划

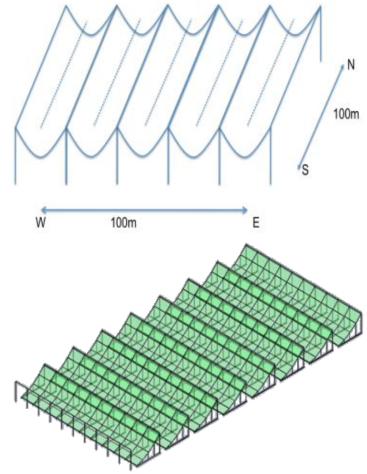


LAMOST 探测暗能量？

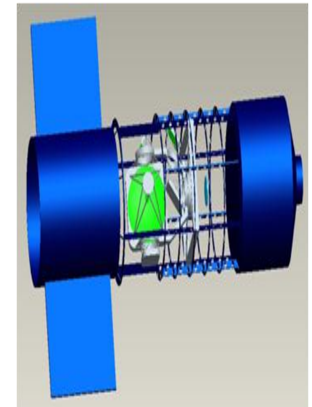
FAST 探测暗能量？



南极光学近红外巡天望远镜

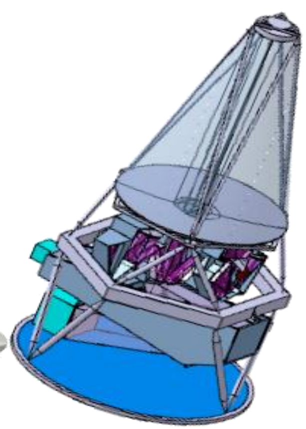


天籁计划

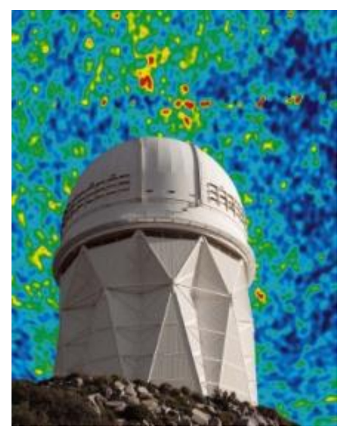


空间站大光学平台

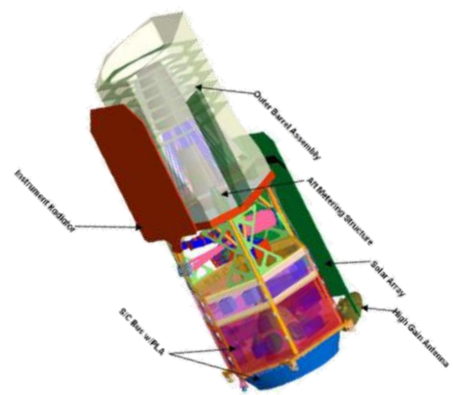
Large Synoptic Survey Telescope



Euclid



BigBOSS



Wide Field Infrared Survey Telescope

~2020

More on Quintom Cosmology

for a review, see:
"Quintom cosmology: theoretical implications and observations"
Cai et al, Phys Rept. 439 (2110) 1-60

Quintom scenario:
w crosses over w=-1 during the evolution

Why interested these years?

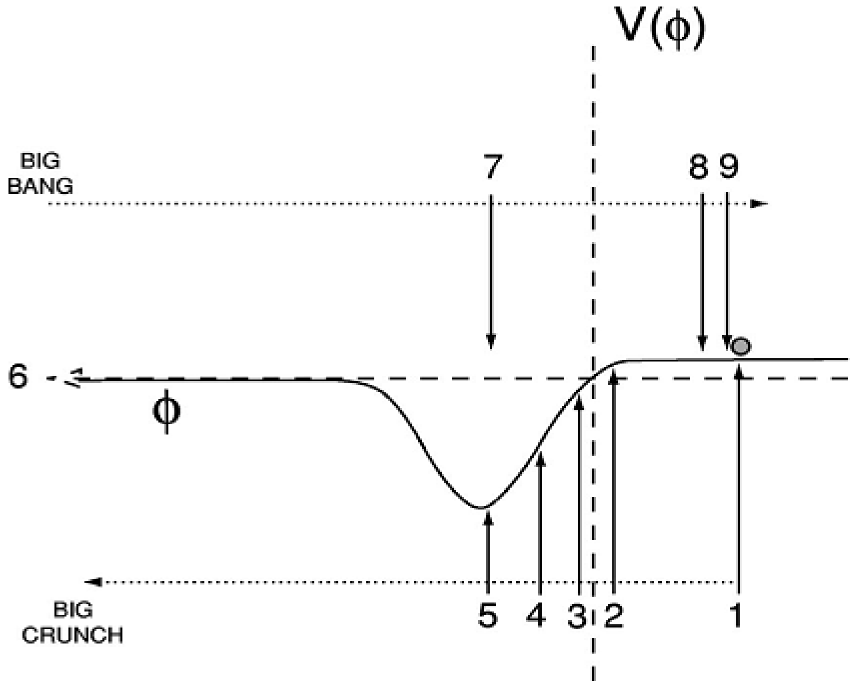
1)Challenges to the model buildings
theoretically interesting!
(no-go theorem)
and data favoring

2) Quintom bouncing cosmology
standard cosmology-→singular
quintom cosmology-→non-singular

Ekpyrotic Model

The collision of two M branes in 5D gives rise to a nonsingular cyclic universe, and the description of effective field theory in 4D is

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{16\pi G} \mathcal{R} + \frac{1}{2} (\partial\phi)^2 - V(\phi) + \beta^4(\phi)(\rho_M + \rho_R) \right)$$



1 DE domination
2 decelerated expansion
3 turn around
4 ekpyrotic contracting phase
5 before big crunch

6 a singular bounce in 4D

???

7 after big bang
8 radiation domination
9 matter

Quintom Bounce

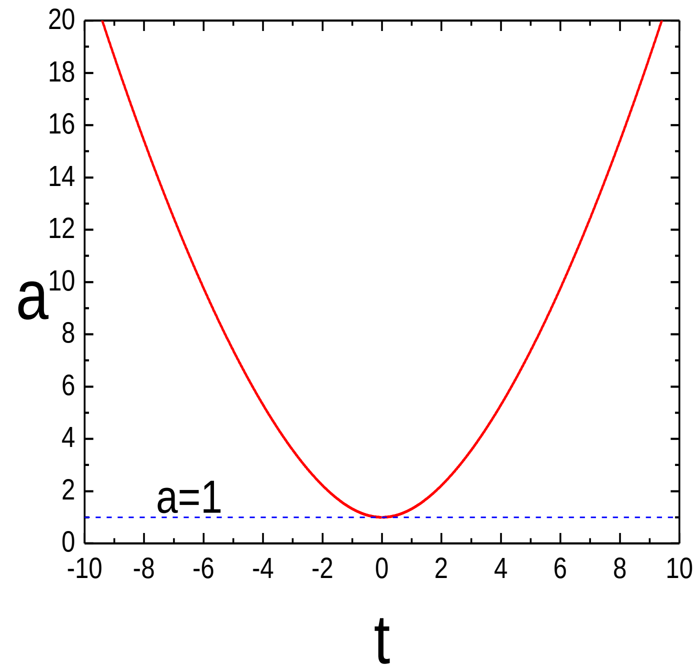
The expanding of the universe is transited from a contracting phase; during the transition the scale factor of the universe a is at its minimum but non-vanishing, thus the singularity problem can be avoided.

Contracting phase: $H < 0;$ Expanding Phase: $H > 0.$

At the bouncing point: $H = 0$ Around it: $\dot{H} > 0.$

$$\dot{H} = -4\pi G(\rho + p) \Rightarrow w < -1$$

Transition to the observable universe $w > -1.$
(radiation dominant, matter dominant,…)
So w needs to cross -1, and Quintom matter is required!



Yifu Cai et al., JCAP 0803:013(2008).
Yifu Cai et al., JHEP 0710:071(2007).

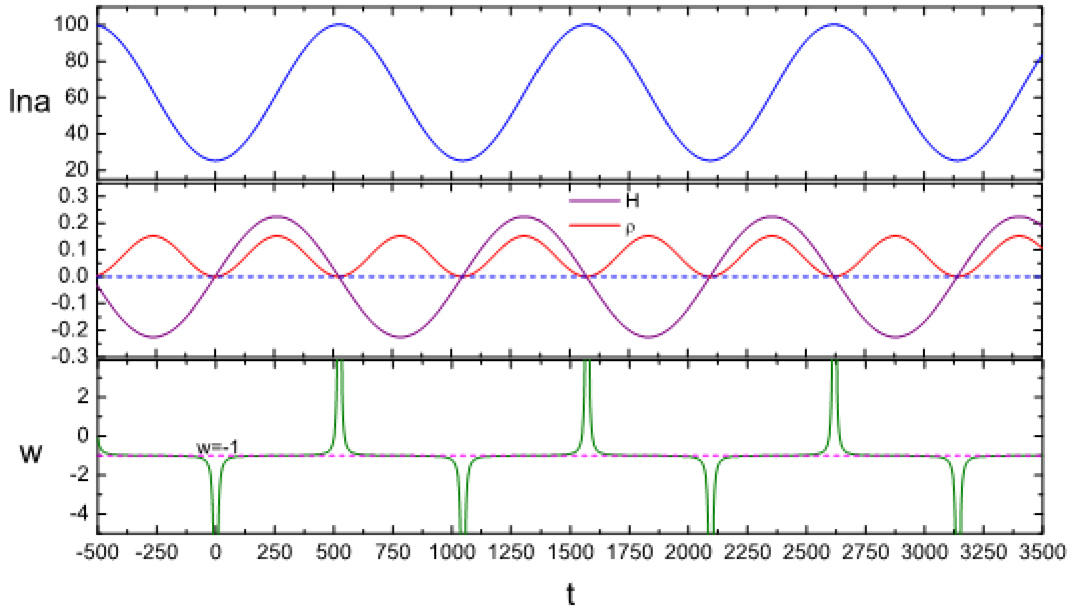
Oscillating universe with Quintom matter

Xiong et al., arXiv:0805.0413

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}\partial_\mu\psi\partial^\mu\psi - V(\phi,\psi)\right]$$

$$V(\phi,\psi) = (\Lambda_0 + \lambda\phi\psi)^2 + \frac{1}{2}m^2\phi^2 - \frac{1}{2}m^2\psi^2$$

Solution: $\phi = \sqrt{A_0}\cos mt\ ,\quad \psi = \sqrt{A_0}\sin mt \quad H = \frac{\sqrt{3}}{3M_p}(\Lambda_0 + \Lambda_1 \sin 2mt)$



Matter Antimatter Asymmetry and TeV Physics

1) **Our universe is matter antimatter asymmetric**

2）**Initial condition?**
In the framework of inflation, all of the matter created during or after reheating processes➔dynamical generation of baryon number asymmetry

3）**Dynamical degerated =➔Baryogenesis**
i) Electroweak baryogenesis → Generating matter asymmetry at the TeV scale =➔new physics tested by LHC
ii) Leptogenesis =➔Neutrino physics
iii) (Dark energy + Baryogenesis)
Quintessential Electro/Leptogenesis
====➔CMB polarization

Baryogenesis

by Andrei Sakharov （1967)

i) B violation

ii) C and CP violation

iii)Out of thermo-equilibrium (CPT conserved)

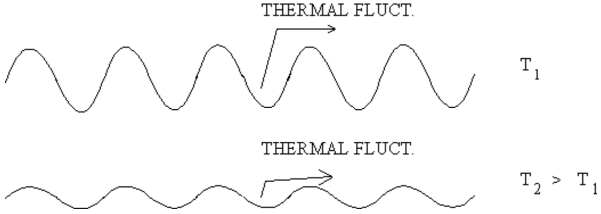
Freezing out of the heavy particles

$$\begin{aligned}\langle B\rangle &= \mathrm{Tr}(\rho B) = \mathrm{Tr}\left((CPT)(CPT)^{-1}\exp(-\beta H)B\right) \\ &= \mathrm{Tr}\left(\exp(-\beta H)(CPT)^{-1}B(CPT)\right) = -\mathrm{Tr}(\rho B) = 0\end{aligned}$$

If CPT is broken, can be generated in thermo-equilibrium

Electroweak baryogenesis

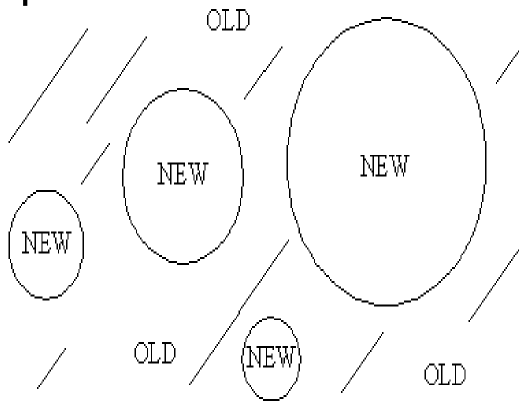
i) B violation ←----anomaly, non-trivial vacuum, sphaleron



ii) C and CP violation ←-----CKM mechanism

(however, too small-→new physics)

iii) First order phase transition



Need Higgs mass < 35 GeV!

→Need New physics

Electroweak Baryogenesis and TeV scale Physics

i) New Physics:

2- Higgs，L-R symmetry, SUSY ……

ii) Effective Lagrangian Method

Xinmin Zhang, Phys. Rev. D47, (1993)3065
Bing-Lin Young and Xinmin Zhang, PRD49 (1994) 563

$$\mathcal{L}^{\text{new}} = \sum_i \frac{c_i}{\Lambda^{d_i-4}} O^i ,$$

Anomalous couplings from higher dimensional operators
esspecially for Higgs and top quark

Operator relevant to Higgs mass limit

$$O_3 = \alpha \frac{\phi^6}{\Lambda^2} ,$$

Effective potential

$$V_T^{\mathrm{eff}} = D(T^2 - T_0^2)\phi^2 - ET\phi^3 + \tfrac{1}{4}\lambda_T \phi^4 ,$$

where

$$D = \frac{1}{8v^2}(2M_W^2 + 2m_t^2 + M_Z^2) ,$$

$$T_0^2 = \frac{1}{D}\left[\frac{m_H^2}{4} - 2Bv^2\right] ,$$

$$B = \frac{3}{64\pi^2 v^4}(2M_W^4 + M_Z^4 - 4m_t^4) ,$$

$$E = \frac{1}{6\pi v^3}(2M_W^3 + M_Z^3) ,$$

$$\lambda_T = \lambda - \frac{3}{16\pi^2 v^4}\left[2M_W^4 \ln\frac{M_W^2}{\alpha_B T^2} + M_Z^4 \ln\frac{M_Z^2}{\alpha_B T^2} - 4m_t^4 \ln\frac{m_t^2}{\alpha_F T^2}\right] ,$$

where $\ln\alpha_B = 2\ln 4\pi - 2\gamma \simeq 3.91$ and $\ln\alpha_F = 2\ln\pi - 2\gamma \simeq 1.14$.

$$V_3^{(r)} = \alpha \frac{v^2}{\Lambda^2}\phi^2 \left[-\phi^2 + v^2 + \frac{1}{3}\frac{\phi^4}{v^2} \right] .$$

$$m_H^2 < (35\ GeV)^2 + 8\alpha \frac{v^4}{\Lambda^2}$$

Xinmin Zhang PRD47, 3065 (1993)

Cedric Delaunay, Christophe Grojean, James D. Wells
JHEP 0804:029,2008

Operator relevant to baryon number generation

(top quark, large Yukawa coupling, interacts with bubble wall strongly, plays essential role for baryon number generation)

$$\mathcal{O}^t = c_t e^{i\xi} \frac{\phi^2 - v^2/2}{\Lambda^2} \Gamma_t \bar{\Psi}_L \tilde{\Phi} t_R, \quad \Longrightarrow \quad \Gamma_t^{\rm eff} = \Gamma_t \left\{ 1 + c_t e^{i\xi} \frac{\phi^2 - v^2/2}{\Lambda^2} \right\}.$$

$$\frac{n_B}{s} \sim \kappa c_t \sin\xi \times 10^{-9}. \quad \Longrightarrow \quad \kappa c_t \sin\xi \geq 4.$$

Anomalous top-Higgs couplings:

$$\mathcal{L}^{\rm eff} \sim \frac{m_t}{t} \bar{t} \left\{ \left[1 + \left(\frac{c_t}{16} \right) \cos\xi \right] + i \left(\frac{c_t}{16} \right) \sin\xi \gamma_5 \right\} t H,$$

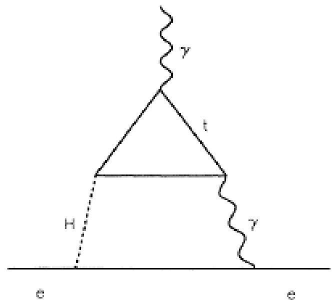
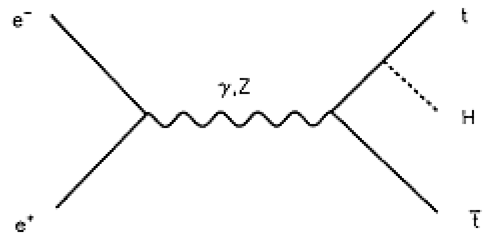


FIG. 1. Dominant contribution to d_e, the electric dipole moment of the electron.



X. Zhang et al, PRD 50, 7042 (1994)

Lars Fromme, Stephan J. Huber, JHEP 0703:049,2007

Interacting Dark Energy
----non-gravitational method

- Coupling constant vary： $QF_{\mu\nu}F^{\mu\nu}$
- Mass varying neutrino： P.Gu, X.Wang and X.Zhang ***PRD68, 087301 (2003)***

$$Q\bar{\nu}\nu$$

$$\rho = -p = \frac{\Lambda}{8\pi G} \approx (2\times10^{-3} eV)^4$$

$$\downarrow$$

$$m_\nu \sim 10^{-3} eV$$

Rob Fardon, Ann E. Nelson, Neal Weiner **JCAP 2004**.

G.Dvali, Nature 432:567-568,2004

- Quintessential Baryo/Leptogenesis，

$$\mathcal{L}_{\rm int} = \frac{c}{M}\partial_\mu\phi J^\mu$$ → **Baryo/Leptogenesis**

M.Li, X.Wang，B.Feng, X.Zhang, PRD65,103511(2002)；

B. Feng, H. Li, M. Li and XZ, PLB602, 27 (2005)

↓

$$\mathcal{L} \sim -\frac{1}{2}C\partial_\mu\phi K^\mu$$ → **CMB Pol**

$$K^\mu = A_\nu\tilde{F}^{\mu\nu} = \frac{1}{2}A_\nu\epsilon^{\mu\nu\rho\sigma}F_{\rho\sigma}$$

B.Feng ,et.al PRL**.96:221302,2006.**

Quintessential Baryo/Leptogenesis

M.Li, X.Wang, B.Feng, X. Zhang PRD65,103511 (2002)
De Felice, Nasri, Trodden, PRD67:043509(2003)
M.Li & X. Zhang, PLB573,20 (2003)

$$L_{\text{int}} = c\frac{\partial_\mu Q}{M} J_B^\mu \Rightarrow \quad \mu_b = c\frac{\dot{Q}}{M} = -\mu_{\bar{b}}$$

In thermo equilibrium⇒

Cohen & Kaplan

$$n_B = n_b - n_{\bar{b}} = \frac{g_b}{2\pi^2}\int_m^\infty E(E^2-m^2)^{1/2} dE \times [\frac{1}{1+\exp[(E-\mu_b)/T]} - \frac{1}{1+\exp[(E+\mu_b)/T]}]$$

$$= \frac{g_b T^3}{6}[\frac{\mu_b}{T} + O(\frac{\mu_b}{T})^3] \approx c\frac{g_b \dot{Q} T^2}{6M}$$

$$s \approx \frac{2\pi^2}{45} g_* T^3 \qquad \eta = n_B / s \approx \frac{15c}{4\pi^2}\frac{g_b \dot{Q}}{g_* M T}$$

$\dot{Q}$ depends on the model of Quintessence

Cosmological CPT violation!

Physics Letters B 651 (2007) 357–362

Cosmological CPT Violation, Baryo/Leptogenesis And CMB Polarization

Mingzhe Li[1], Jun-Qing Xia[2], Hong Li[3] and Xinmin Zhang[2]
[1]*Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany*
[2]*Institute of High Energy Physics, Chinese Academy of Science, P.O. Box 918-4, Beijing 100049, P. R. China and*
[3]*Department of Astronomy, School of Physics, Peking University, Beijing, 100871, P. R. China*

(Dated: November 14, 2006.)

In this paper we study the cosmological CPT violation and its implications in baryo/leptogenesis and CMB polarization. We propose specifically a variant of the models of gravitational leptogenesis. By performing a global analysis with the Markov Chain Monte Carlo (MCMC) method, we find the current CMB polarization observations from the three-year WMAP (WMAP3) and the 2003 flight of BOOMERANG (B03) data provide a weak evidence for our model. However to verify and especially exclude this type of mechanism for baryo/leptogenesis with cosmological CPT violation, the future measurements on CMB polarization from PLANCK and CMBpol are necessary.

$$\partial_\mu J^\mu_{(B-L)_L} \sim -\frac{e^2}{12\pi^2} F_{\mu\nu}\tilde{F}^{\mu\nu} = -\frac{\alpha_{em}}{3\pi} F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$J^\mu_{(B-L)_L} = (1/2)\, J^\mu_{(B-L)} - (1/2)\, J^{5\mu}_{(B-L)}$$

↓ Leptogenesis

↓ Anomaly for CMB

Cosmological CPT violation: predicting <TB> and <EB>

$$\partial_\mu Q \rightarrow \partial_\mu f(R)$$

Hong Li et al

$$\mathcal{L} \sim -\frac{1}{2} C \partial_\mu Q K^\mu \qquad K^\mu = A_\nu \tilde{F}^{\mu\nu} = \frac{1}{2} A_\nu \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}$$

$$\tan\alpha \equiv \frac{B_z}{B_y} = \ldots = \tan(\frac{1}{2} CQ + I) \qquad \alpha = \frac{1}{2} CQ + I \quad \Delta\alpha = \frac{1}{2} C \Delta Q$$

$$\begin{cases} Q' = Q\cos 2\Delta\alpha + U \sin 2\Delta\alpha \\ U' = -Q \sin 2\Delta\alpha + U \cos 2\Delta\alpha \end{cases}$$

$$C'^{TT}_l = C^{TT}_l$$

$$C'^{EE}_l = C^{EE}_l \cdot \cos^2 2\Delta\alpha + C^{BB}_l \sin^2 2\Delta\alpha$$

$$C'^{BB}_l = C^{EE}_l \cdot \sin^2 2\Delta\alpha + C^{BB}_l \cos^2 2\Delta\alpha$$

$$C'^{TE}_l = C^{TE}_l \cdot \cos 2\Delta\alpha$$

$$C'^{TB}_l = C^{TE}_l \cdot \sin 2\Delta\alpha$$

$$C'^{EB}_l = \frac{1}{2}(C^{EE}_l - C^{BB}_l) \sin 4\Delta\alpha$$

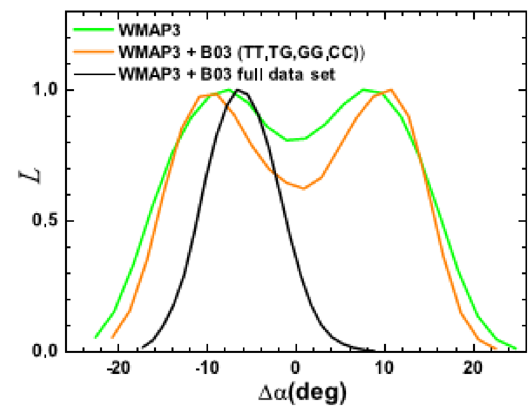


FIG. 1 (color online). One-dimensional constraints on the rotation angle $\Delta\alpha$ from WMAP data alone (green or light gray line), WMAP and the 2003 flight of BOOMERANG B03 TT, TG, GG and CC (orange or gray line), and from WMAP and the full B03 observations (TT, TG, GG, CC, TC, GC) (black line).

Bo Feng, Hong Li, Mingzhe Li and Xinmin Zhang
Phys. Lett. B 620, 27 (2005);
Bo Feng, Mingzhe Li , Jun-Qing Xia, Xuelei Chen and Xinmin Zhang
Phys. Rev. Lett. 96, 221302 (2006)

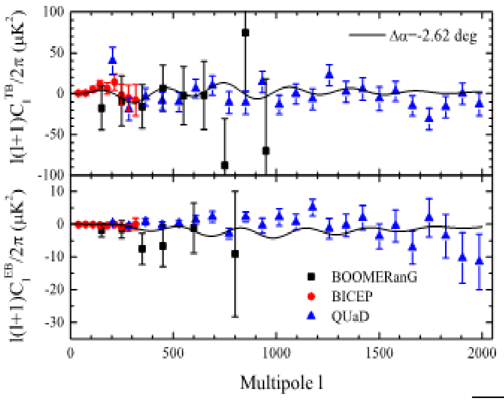
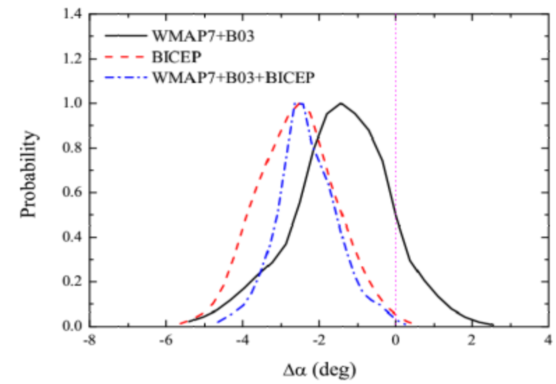


Fig. 1. The binned TB and EB spectra measured by the small-scale
of BOOMERanG (black squares), BICEP (red circles) and QUaD (b
black solid curves show the theoretical prediction of a model with
(For interpretation of colors in this figure, the reader is referred t
of this Letter.)

Current status on the measurements of the rotation angle



Group	$\Delta\alpha$ (degree)	Datasets
Feng et al	-6.0 ± 4.0	WMAP3+B03
Cabella et al	-2.5 ± 3.0	WMAP3
WMAP Collaboration	-1.7 ± 2.1	WMAP5
Xia et al	-2.6 ± 1.9	WMAP5+B03
WMAP Collaboration	-1.1 ± 1.4	WMAP7
QUaD Collaboration	0.64 ± 0.50	QUaD
Xia et al	-2.60 ± 1.02	BICEP
Xia et al	-2.33 ± 0.72	WMAP7+B03+BICEP
Xia et al	-0.04 ± 0.35	WMAP7+B03+BICEP+QUaD
Gruppuso et al	-1.6 ± 1.7	WMAP7

$3\,\sigma$ detection ===> (Xia et al, WMAP7+B03+BICEP)

$$PLANCK: \ \sigma = 0.057 \text{ deg}$$ （Xia et al ）

Interacting DE, Cosmological CPT violation
Baryo/Leptogenesis and CMB test

$$\mathcal{L}_{\rm int} = \frac{c}{M}\partial_\mu \phi J^\mu$$ → **Baryo/Leptogenesis**

↓ **Anomaly Equation**

$$\mathcal{L} \sim -\frac{1}{2} C \partial_\mu \phi K^\mu$$ → **CMB polarization and CPT test**

$$K^\mu = A_\nu \tilde{F}^{\mu\nu} = \frac{1}{2} A_\nu \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}$$

Features:

1) **Derivative couplings: no long range force limit;**
   No large radiative correction
2) **Cosmological CPT violation:**
   Many speculation theoretically on CPT violation:
   Evidence: expanding universe, matter-antimatter asymmetry

strength ~ O(H), unobservable in the laborary experiments
CMB: travelling around O(1/H),
so accumulated effect ~ O(1) observable !

Summary

1) Strong motivations for new physics
beyond standard model from cosmology

2) Dark matter: (cold and warm WIMPs…)
Dark energy:
Cosmological constant still consistent with data
Quintom scenario favored at 2.5 sigma

Baryogenesis:
===➔ new physics
Leptogenesis -→Neutrino physics
Electroweak scale --→New particles (light stop …)
-→ Anomalous Higgs and top couplings
detected at LHC and LC……

Thank You !