# Cosmology and TeV Physics

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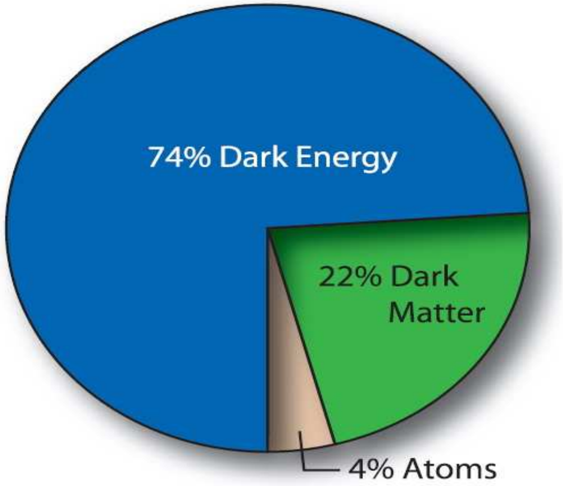
**Talk given at**
**“1st CFHEP Symposium on circular collider physics”**
**Beijing, Feb 24-25, 2014**

# Outline of the talk



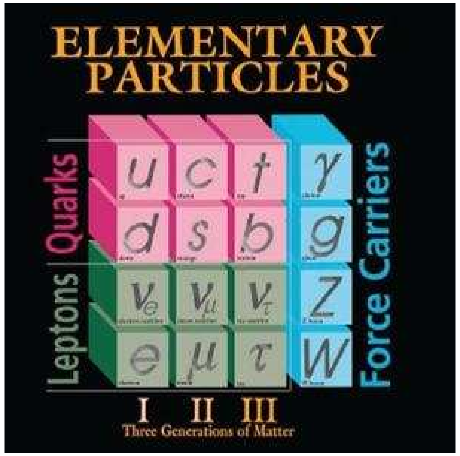
0) Dark matter (see talk by Liantao Wang)

1) Dark energy

- i) Current status of observational constraints on dark energy models
- ii) Quintom cosmology

**2) Baryogenesis**

- i) Electroweak baryogenesis and Higgs factory
- ii) Leptogenesis
- iii) Quintessential baryo/leptogenesis



**3) Conclusion and discussions**

**Why the Higgs is 125 GeV? If not, what's wrong to our universe**

Much relevant to CEPC/SPPC :

Electroweak baryogenesis

**Higgs: origin of mass**

**CEPC/SPPC: origin of matter**

WIMPs dark matter

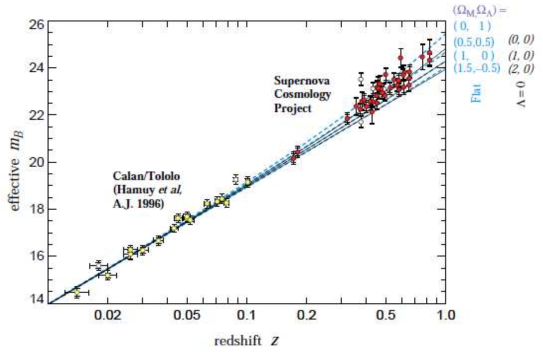
# Brief Introduction to Dark Energy

## 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)

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

$$\downarrow$$

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

Neutrino Dark Energy?!

Gu, Wang, Zhang, 2003

**Fardon, Nelson, Weiner 2004**

……..

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

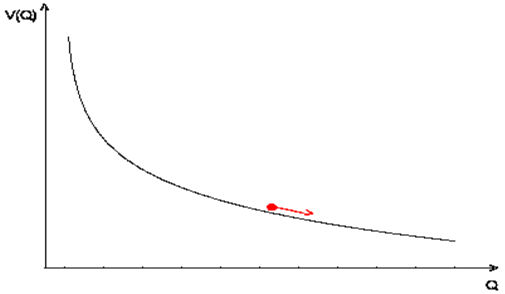
$$\rho^{th}/\rho^{ob} \sim 10^{120}$$

**cosmological constant problem!**

## II Dynamical Field: Quintessence, Phantom, Quintom….

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

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



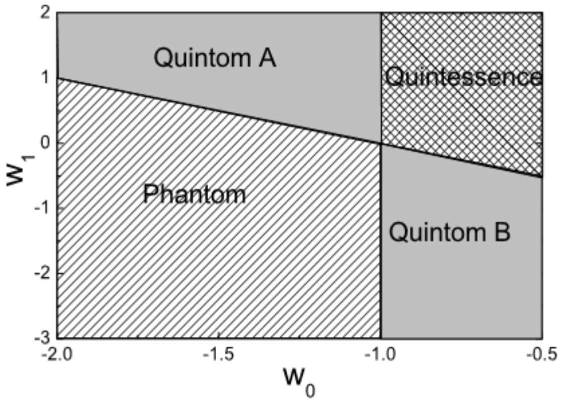
## Equation of state w=p/ρ: characterize the properties of the dark energy models

| | |
|---|---|
| * 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…}

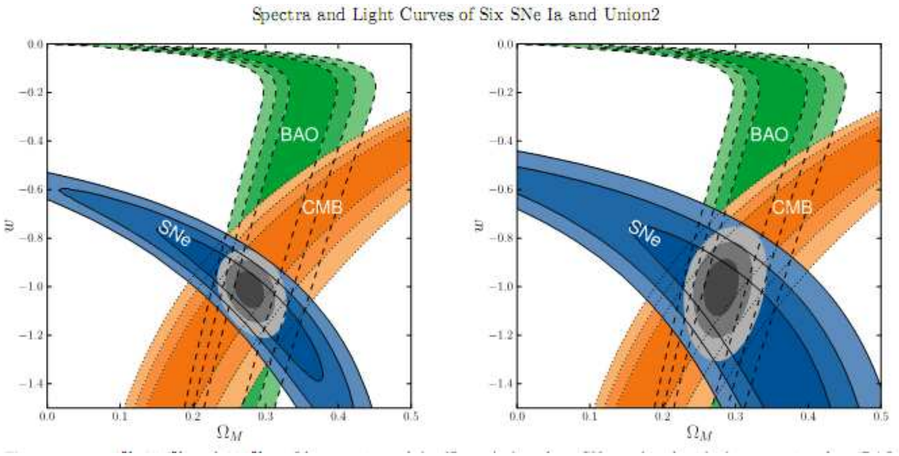
Cosmological Parameters:

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

II) Global analysis with
current astronomical
observational data:

SN (Union2.1, SNLS3)
LSS (SDSS),
CMB(WMAP, Planck ...)

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)

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

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

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

# Perturbation with Quintom dark energy

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

$$\begin{aligned}\dot{\delta}_i &= -(1+w_i)(\theta_i - 3\dot{\Phi}) - 3\mathcal{H}(1-w_i)\delta_i - 3\mathcal{H}\frac{\dot{w}_i + 3\mathcal{H}(1-w_i^2)}{k^2}\theta_i \\ \dot{\theta}_i &= 2\mathcal{H}\theta_i + \frac{k^2}{1+w_i}\delta_i + k^2\Psi\ .\end{aligned}$$

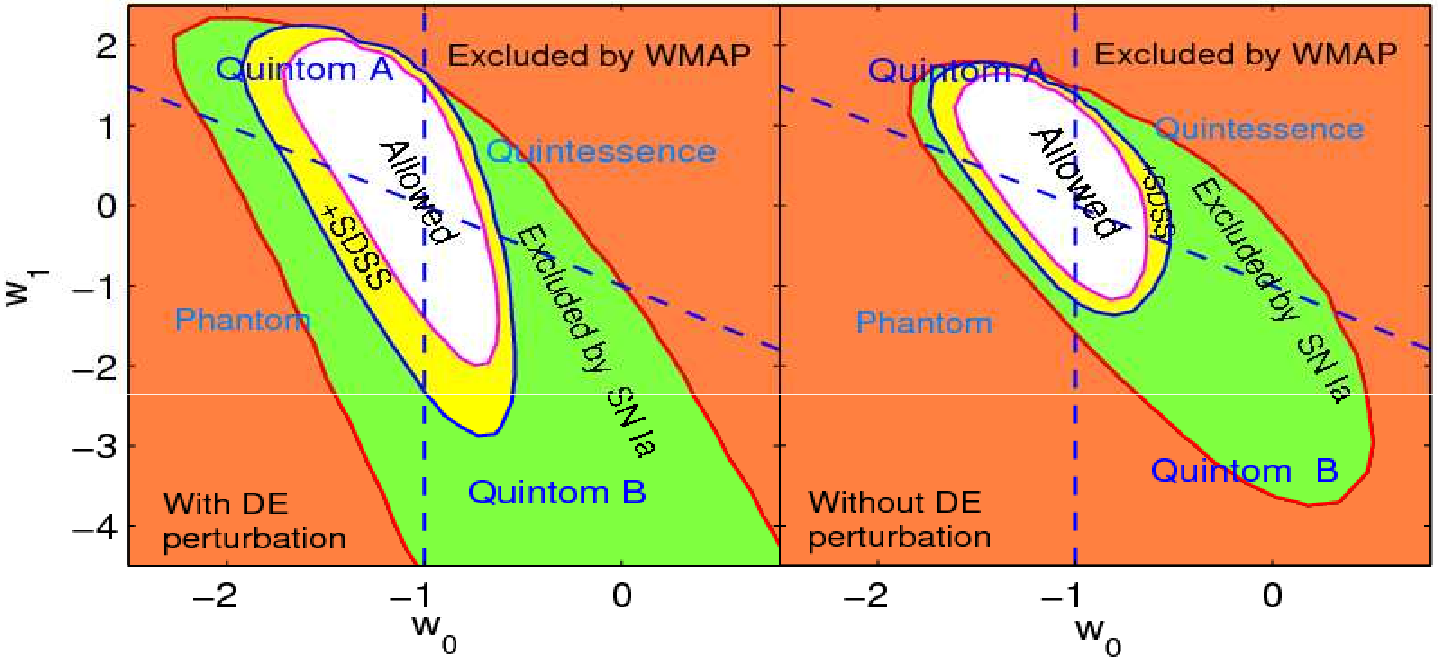
$$w_{quintom} = \frac{\sum_i P_i}{\sum_i \rho_i} \qquad \delta_{quintom} = \frac{\sum_i \rho_i\delta_i}{\sum_i \rho_i} \qquad \theta_{quintom} = \frac{\sum_i(\rho_i + p_i)\theta_i}{\sum_i(\rho_i + P_i)}$$

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)**

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

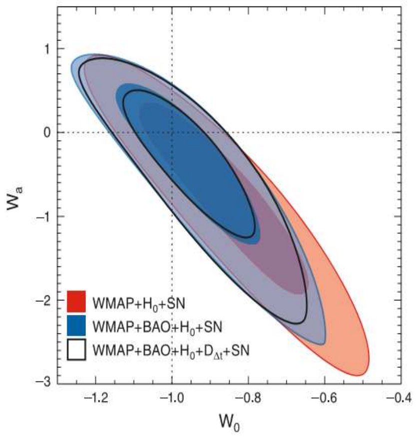


**Observing dark energy dynamics with supernova, microwave background and galaxy clustering**

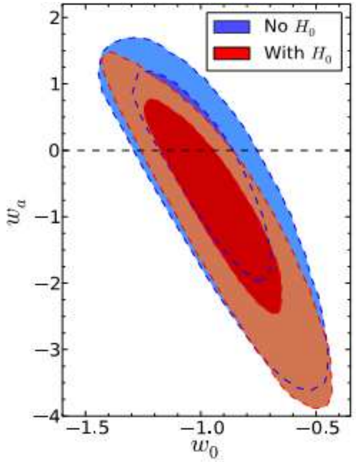
Jun-Qing Xia, Gong-Bo Zhao, Bo Feng, Hong Li and Xinmin Zhang

**Phys.Rev.D73, 063521, 2006**

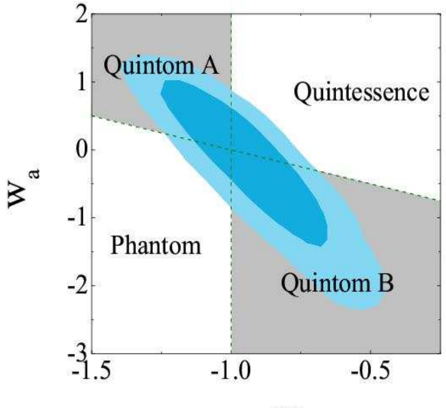
# Status in determining the EoS of dark energy



**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 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；**

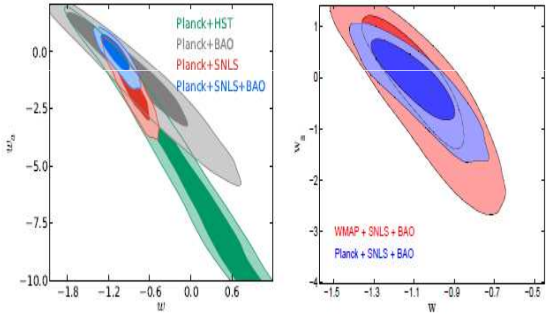
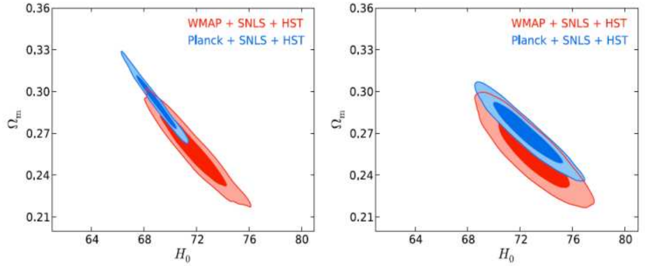
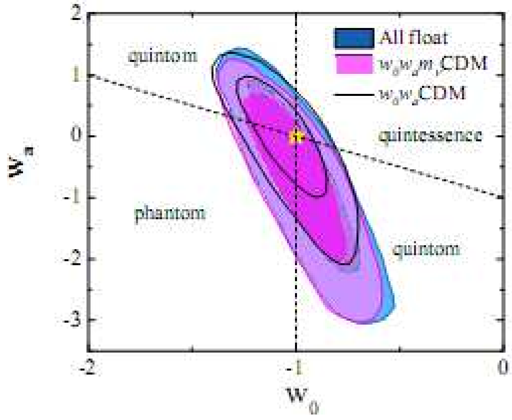
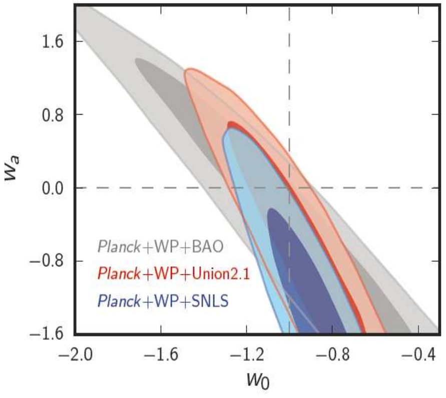


FIG. 4: Marginalized two-dimensional likelihood (1, 2$\sigma$ contours) constraints on the time-evolving EoS of dark energy from different data combination.



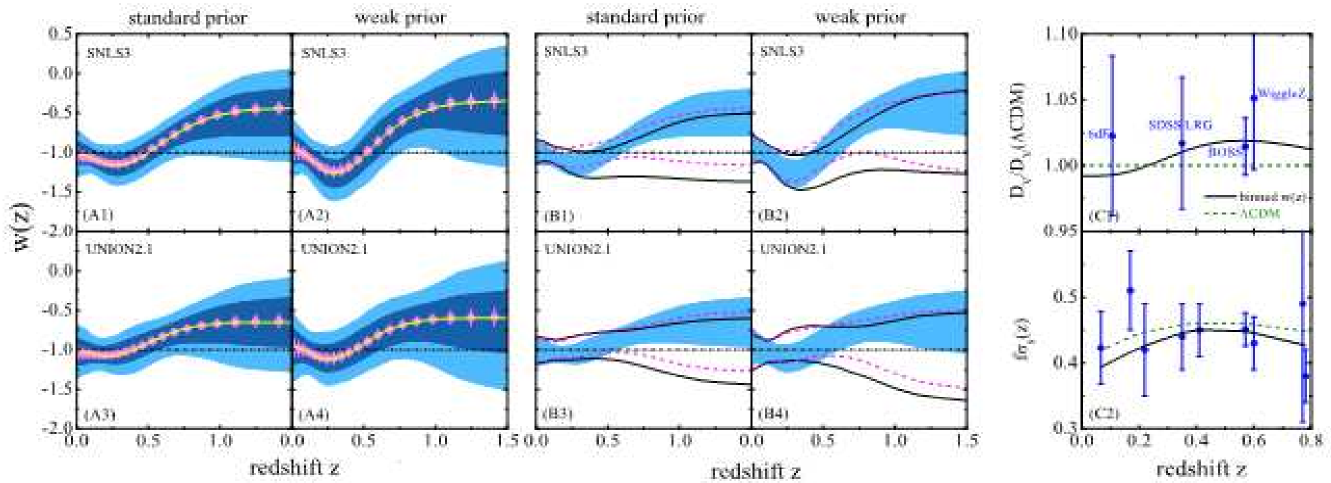


Zhao et al (BOSS collaboration)
arXiv:1211.3741



**Planck, 2013**

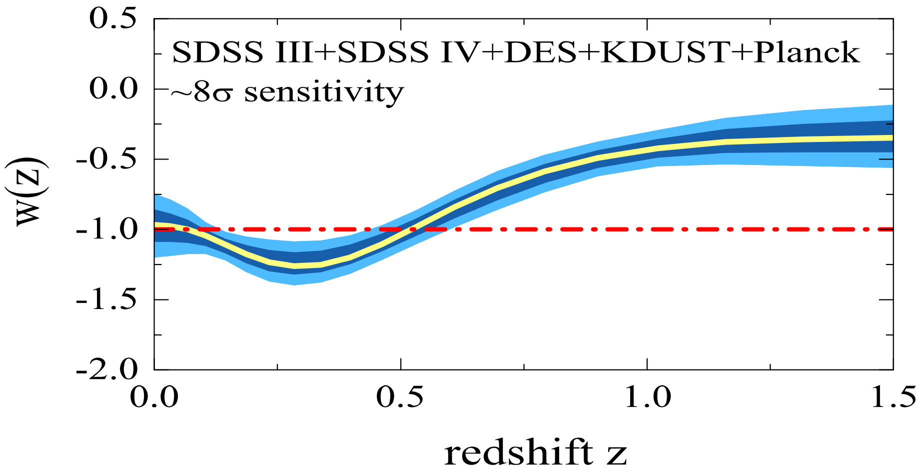
**Li, Xia, Zhang, 2013**



**2.5 sigma for dynamical dark energy with w crossing -1**

**the Quintom scenario !**

**Gongbo Zhao, R. Crittenden, L. Pogosian and Xinmin Zhang, PRL (2012)**



**Forecast for w(z) constraint using CosmoFish package (GBZ et al, in prep)**

# More on Quintom Cosmology

for a review, see:

"Quintom cosmology: theoretical implications and observations"
Cai et al, Phys Rept. 439 (2010) 1-60

Quintom scenario:

w crosses over w=-1 during the evolution

Why interested ?

**1)** Solving the divergence problem of the dark energy perturbation! Data mildly favored

2) Challenges to theoretical model buildings
(no-go theorem and examples of quintom models)

3) Interesting implications for early universe
standard cosmology-→singular
quintom cosmology-→non-singular ?

# NO-GO Theorem

- For theory of dark energy in the 4D Friedmann-Roberston-Walker universe described by a single perfect fluid(1) or a single scalar field with a lagrangian $\mathcal{L} = \mathcal{L}(\phi, \partial_\mu\phi\partial^\mu\phi)$ (2), which minimally (3) couples to Einstein Gravity (4), its equation of state cannot cross over the cosmological constant boundary.

Feng, Wang & Zhang, Phys. Lett. B 607:35, 2005, **astro-ph/0404224** ;
Vikman, Phys. Rev. D 71:023515, 2005, **astro-ph/0407107** ;
Waye Hu， Phys. Rev. D 71:047301, 2005;
Caldwell & Doran, Phys. Rev. D 72:043527, 2005;
Zhao, Xia, Li, Feng & Zhang, Phys. Rev. D 72:123515, 2005;
Kunz & Sapone, Phys. Rev. D 74:123503, 2006;

……

Xia, Cai, Qiu, Zhao, & Zhang, Int.J.Mod.Phys.D17:1229,2008

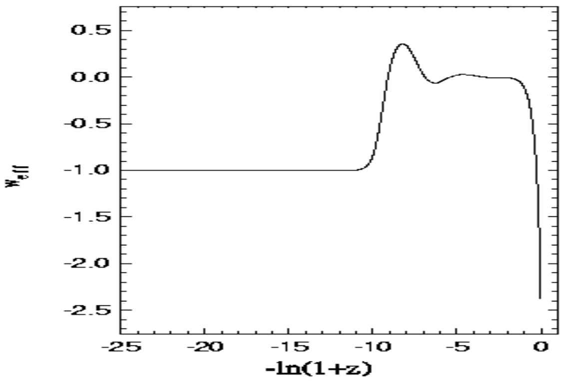
To realize Quintom, one of the conditions should be violated

# Examples of model with w across -1

## 1) Two scalar fields:

(Feng, Wang, Zhang 2004;
Guo, Piao, Zhang, Zhang 2004)

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi_1\partial^\mu\phi_1 - \frac{1}{2}\partial_\mu\phi_2\partial^\mu\phi_2 - V_0\left[\exp\left(-\frac{\lambda}{m_p}\phi_1\right) + \exp\left(-\frac{\lambda}{m_p}\phi_2\right)\right]$$



## 2) Single scalar with high derivatives:

(Li, Feng, Zhang, 2005)

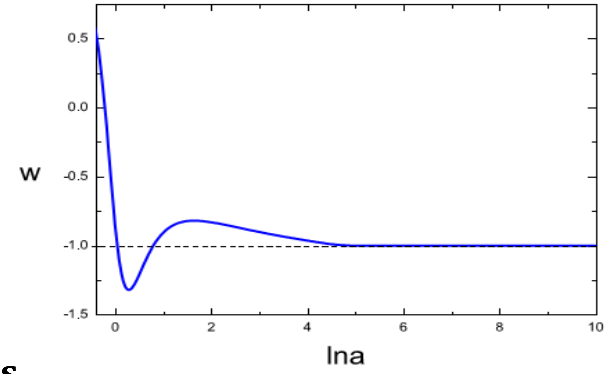
$$\mathcal{L} = \frac{1}{2}A(\phi)\nabla_\mu\phi\nabla^\mu\phi + \frac{C(\phi)}{2M_{pl}^2}(\Box\phi)^2 - V(\phi)$$

## 3) Modified Born-Infeld action:

(Cai, Li, Lu, Piao,
Qiu, Zhang,
2007)

$$\mathcal{L} = -V(\phi)\sqrt{1 - \alpha'\nabla_\mu\phi\nabla^\mu\phi + \beta'\phi\Box\phi}$$

$$V(\phi) = \frac{V_0}{e^{-\lambda\phi} + e^{\lambda\phi}}$$



=➔ **Ghost free single scalar field theory**

i) "ghost condensate" + "box operator" (?)

ii) Galileon Model: Lagrangian with higher derivative operators, but the equation of motion remains second order, so the model can have w cross -1 without ghost mode.

Example:

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{16\pi G} + F^2e^{2\Pi}(\partial\Pi)^2 + \frac{F^3}{M^3}(\partial\Pi)^2\Box\Pi + \frac{F^3}{2M^3}(\partial\Pi)^4\right]$$

C. Deffayet et al., Phys.Rev.D79:084003, 2009.
A. Nicolis et al., Phys.Rev.D79:064036, 2009
………

# More on Quintom Cosmology

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**1)**

2)

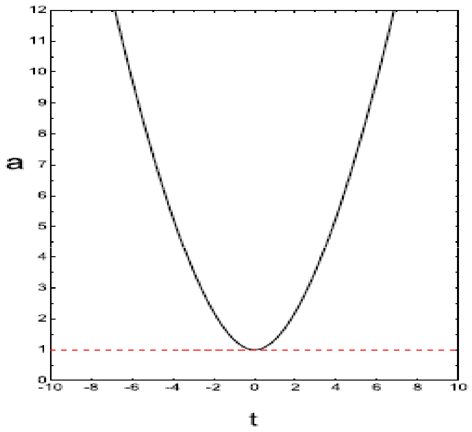
3) Interesting implications for early universe

standard cosmology-→singular
quintom cosmology-→non-singular ?

# Non-singular universe models

# and Quintom matter

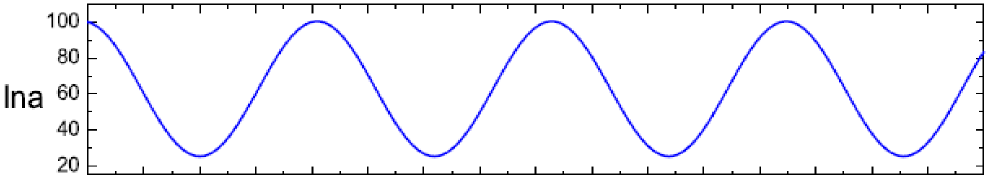
- Bounce models



- The emergent universe

$$\boxed{t \in (-\infty, \infty);\quad a \sim \mathrm{const}, t \to -\infty;\quad \dot{H} > 0.}$$

==➔ Cyclic universe



**Ekpyrotic Model:** **collision of two M branes in 5D**
**description of effective field theory in 4D is**

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

**===➔ singular bounce !!!**

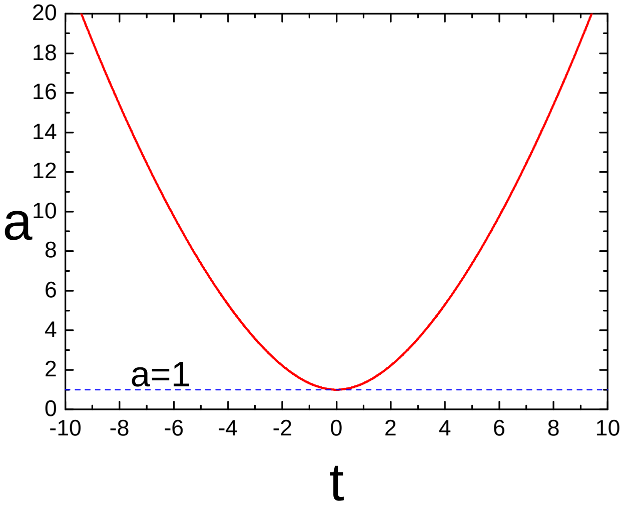
# Quintom Bounce

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!

**Y. Cai, T. Qiu, Y. Piao, M. Li, X Zhang, JHEP 0710:071(2007).**
**Y. Cai, T. Qiu, R. Brandenberger, Y Piao, X. Zhang JCAP 0803:013(2008).**
**………….**

# On Perturbations of a Quintom Bounce

Yi-Fu Cai[1*], Taotao Qiu[1†], Robert Brandenberger[2,3‡], Yun-Song Piao[4§], Xinmin Zhang[1,5¶]

[1] *Institute of High Energy Physics, Chinese Academy of Sciences, P.O. Box 918-4, Beijing 100049, P. R. China*
[2] *Department of Physics, McGill University, Montreal, QC, H3A 2T8, Canada*
[3] *Kavli Institute for Theoretical Physics, Zhong Guan Cun East Street 55, Beijing 100080, P.R. China*
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[5] *Theoretical Physics Center for Science Facilities (TPCSF), CAS, P. R. China*

## 2 Review of the Quintom Bounce in a Double-Field Model

### 2.1 Equations of Motion of Double-Field Quintom

To start, we take a Quintom model consisting of two fields with the Lagrangian

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}\partial_\mu\psi\partial^\mu\psi - V(\phi) - W(\psi)\,, \tag{1}$$

where the signature of the metric is $(+,-,-,-)$. Here the field $\phi$ has a canonical kinetic term, but $\psi$ has a kinetic term with the opposite sign and thus plays a role of a ghost field. In the framework of a flat Friedmann-Robertson-Walker (FRW) universe, the metric is given by $ds^2 = dt^2 - a^2(t)dx^idx^i$. By varying the corresponding matter action, we easily obtain the following expressions for the energy density $\rho$ and pressure $p$ of this model,

$$\rho = \frac{1}{2}\dot{\phi}^2 - \frac{1}{2}\dot{\psi}^2 + V(\phi) + W(\psi)\,, \quad p = \frac{1}{2}\dot{\phi}^2 - \frac{1}{2}\dot{\psi}^2 - V(\phi) - W(\psi)\,, \tag{2}$$

# Geodesically Complete Analytic Solutions for a Cyclic Universe [1]

**Itzhak Bars**[*#] , **Shih-Hung Chen**[†#] and **Neil Turok**[#]

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*University of Southern California, Los Angeles, CA 90089-2535 USA*

[†]*Department of Physics and School of Earth and Space Exploration*
*Arizona State University, Tempe, AZ 85287-1404 USA*

[#]*Perimeter Institute for Theoretical Physics*
*Waterloo, ON N2L 2Y5, Canada*

conformally coupled to gravity as follows

$$S=\int d^4x\sqrt{-g}\left(\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi-\frac{1}{2}g^{\mu\nu}\partial_\mu s\partial_\nu s+\frac{1}{12}\left(\phi^2-s^2\right)R\left(g\right)-\phi^4 f\left(\frac{s}{\phi}\right)\right). \qquad (5)$$

The field $\phi\left(x\right)$ has the wrong sign in the kinetic term, so it is a ghost (negative norm[4]). This sign of the kinetic term is required by the Weyl symmetry if the sign in front of the

## B. Braneworld origin

A cyclic model, inspired by D-branes in M-theory [8], was developed in [2] where it was discussed for a very different potential than Eq.(2). However, it is possible to recover

---

[4] There are models of cosmology based on the notion of "quintom matter" [18] which also introduce a negative norm ghost field. We should emphasize that those models have actual ghosts and therefore are non-unitary and fundamentally flawed. Despite some similarity, our model is fundamentally different because of the Weyl symmetry that eliminates the ghosts, thus having fewer degrees of freedom. Our action, our solutions which do not violate the null energy conditions, and the discussion of the physics are also different.

# Nonperturbative analysis of the evolution of cosmological perturbations through a nonsingular bounce

BingKan Xue,[1] David Garfinkle,[2,3] Frans Pretorius,[1] and Paul J. Steinhardt[1,4]
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*Princeton, New Jersey 08544, USA*
[2] *Department of Physics, Oakland University, Rochester, Michigan 48309, USA*
[3] *Michigan Center for Theoretical Physics, Randall Laboratory of Physics,*
*University of Michigan, Ann Arbor, Michigan 48109, USA*
[4] *Princeton Center for Theoretical Physics,*
*Princeton University, Princeton, New Jersey 08544, USA*

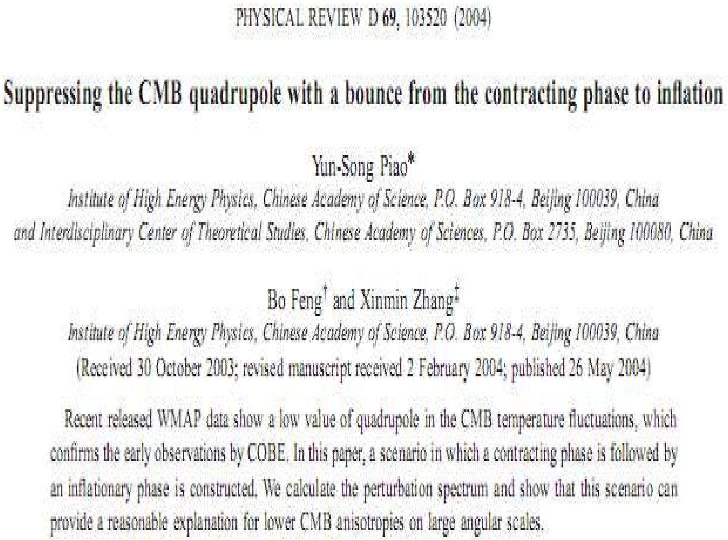
(Dated:)

## II. NONSINGULAR BOUNCING MODEL

For the nonsingular bounce, we consider a model with two scalar fields $\phi$ and $\chi$ minimally coupled to gravity, described by the Lagrangian

$$\mathcal{L} = -\tfrac{1}{2}(\partial\phi)^2 - V(\phi) + \tfrac{1}{2}(\partial\chi)^2. \tag{1}$$

Here $\phi$ is a canonical scalar field with a potential $V(\phi) = V_0\, e^{-c\phi}$, and $\chi$ is a ghost field with a wrong-signed kinetic term. The conditions are chosen so that the universe is dominated by the normal scalar field $\phi$ during the contraction phase. Under such conditions, the $\phi$ field has a scaling solution in which its energy density scales as $1/a^{3(1+w_\phi)}$ with a constant



PHYSICAL REVIEW D **69**, 103520 (2004)

## Suppressing the CMB quadrupole with a bounce from the contracting phase to inflation

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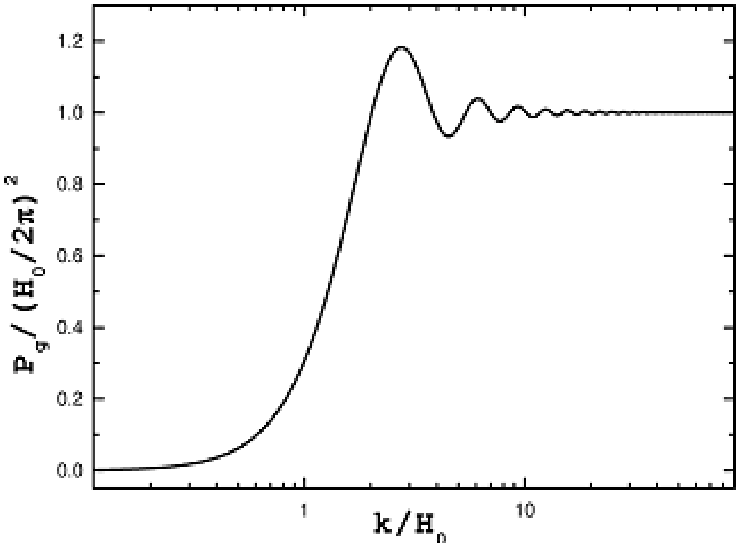
*Institute of High Energy Physics, Chinese Academy of Science, P.O. Box 918-4, Beijing 100039, China*
*and Interdisciplinary Center of Theoretical Studies, Chinese Academy of Sciences, P.O. Box 2735, Beijing 100080, China*

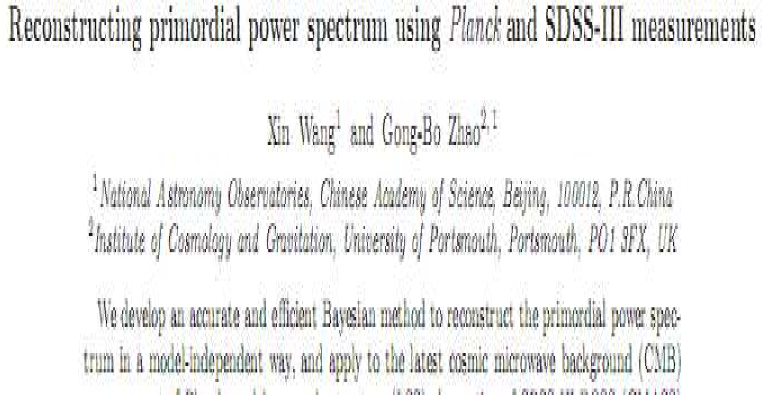
Bo Feng† and Xinmin Zhang‡
*Institute of High Energy Physics, Chinese Academy of Science, P.O. Box 918-4, Beijing 100039, China*

(Received 30 October 2003; revised manuscript received 2 February 2004; published 26 May 2004)

Recent released WMAP data show a low value of quadrupole in the CMB temperature fluctuations, which confirms the early observations by COBE. In this paper, a scenario in which a contracting phase is followed by an inflationary phase is constructed. We calculate the perturbation spectrum and show that this scenario can provide a reasonable explanation for lower CMB anisotropies on large angular scales.

PHYSICAL REVIEW D **69**, 103520 (2004)





## Reconstructing primordial power spectrum using *Planck* and SDSS-III measurements

Xin Wang[1] and Gong-Bo Zhao[2,1]
[1]*National Astronomy Observatories, Chinese Academy of Science, Beijing, 100012, P.R.China*
[2]*Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth, PO1 3FX, UK*

We develop an accurate and efficient Bayesian method to reconstruct the primordial power spectrum in a model-independent way, and apply to the latest cosmic microwave background (CMB)

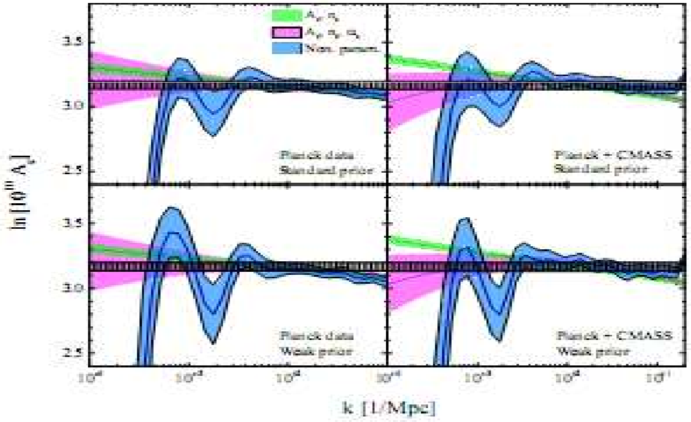


FIG. 1. The best fit (solid curves) and 68% CL error (shaded bands) of the reconstructed primordial power spectrum using the power law parametrization (green and purple shaded) and free form with correlated priors (blue shaded). Different datasets and correlation priors are used as illustrated in the legend. The horizontal bands with pattern show the 68% CL reconstruction of the HZ model.

# Comments on bouncing cosmology

i) Important progress made in recent years

on non-singular bounce by making use of matter

with w crossing -1;

However, need further study ……

ii) In general

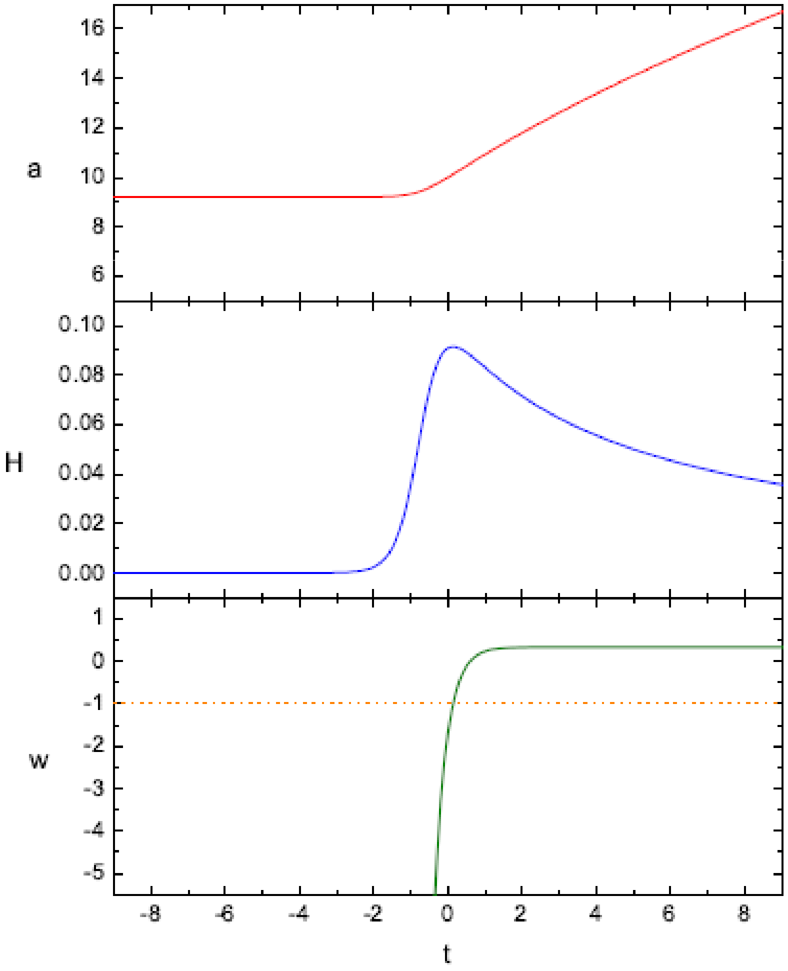
[A final theory for non-singular cosmology]

~ [ GR] + [something] ( like quintom matter with w across -1)

-----one of the reasons why I believe in the quintom scenario

# Quintom Emergent Universe

**This is an alternative paradigm to bouncing cosmology to avoid the Big Bang singularity, which suggests that our universe was initially emergent from a non-vanishing minimal radius and experienced a enough long quasi-Minkowski phase and then entered the normal thermal expansion.**



**Emergent phase:**

$$w = -1 - \frac{2\dot{H}}{3H^2} \ll -1$$

**Thermal expansion:**

$$w > -1$$

**Quintom Scenario: w crosses -1**

**Cai, Li & Zhang, 1209.3437**
**Cai, Wan & Zhang, 1312.0740**

# 2) Baryogenesis

i) Electroweak baryogenesis
and Higgs factory

ii) Leptogenesis

iii) Quintessential baryo/leptogenesis

# Higgs Factory and Electroweak Baryogenesis

**Higgs Factory**: precisely measuring the Higgs couplings

**Anomalous Higgs couplings**: (form factors?)
appropriately described **by Effective theory**
See: Isidori and Trott, arXiv:1307.4051 （2013)

i）SU_L(2) X U_Y(1) nonlinearly realized
see, Peccei and Zhang ( 1989)
Xinmin Zhang （Ph.D thesis，UCLA, 1991）
C.-P. Yuan et al (including a singlet scalar, Higgs-like particle )

ii) SU_L(2)XU_Y(1) linearly realized
see, Buchmuller and Wyler (1986)

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

**Question:** How large is the \Lambda?
Electroweak Baryogenesis puts an upper limit on \Lambda
around TeV, so **Cosmology ======➔ TeV physics!**

# Baryogenesis

Andrei Sakharov （1967）

i) B violation

ii) C and CP violation

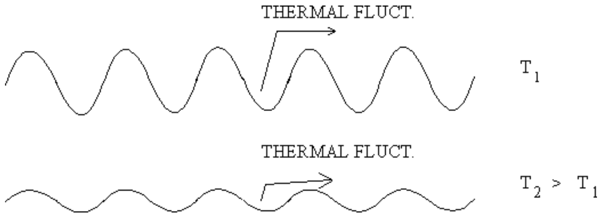
iii)Out of thermo-equilibrium (CPT conserved)

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

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

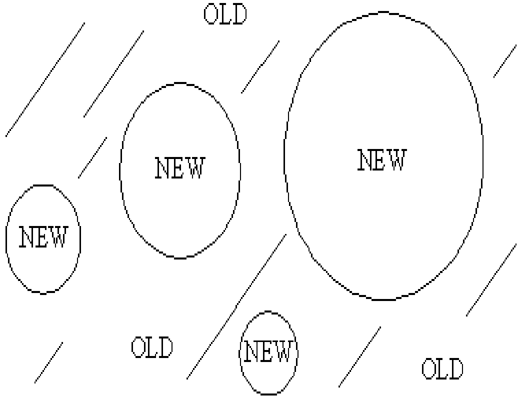
# Electroweak baryogenesis

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



Requiring
Higgs mass
< 35 GeV !

==➔Need new physics

# Electroweak Baryogenesis and New Physics

**i) Early 90’s and later on, many studies with new physics models**
**like 2- Higgs，L-R symmetry, SUSY**

**ii) Effective Lagrangian Method**

1) Xinmin Zhang, Phys. Rev. D47, (1993) 3065 (**hep-ph/9301277** **)**
**“Operator Analysis for the Higgs Potential and**
**Cosmological Bound on the Higgs-Boson Mass”**

2) Bing-Lin Young and Xinmin Zhang, PRD49 (1994) 563 (**hep-ph/9309269**)
**“Effective Lagrangian Approach to Electroweak Baryogenesis:**
**Higgs mass limit and Electric dipole moments of fermion “**

**3) Xinmin Zhang, S.K. Lee, K. Whisnant and B.-L. Young**
**Phys.Rev. D50 (1994) 7042-7047 (hep-ph/9407259)**
**“Phenomenology of a non-standard**
**top quark Yukawa coupling “**

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

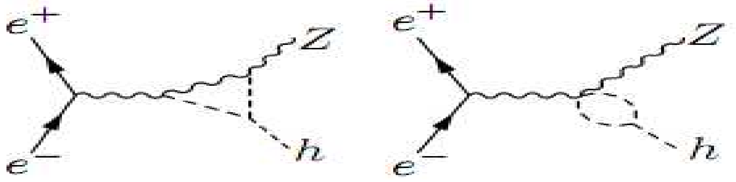
# Operator relevant to Higgs mass limit

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

**Working in detail on the effective potential with the higher dim operator**

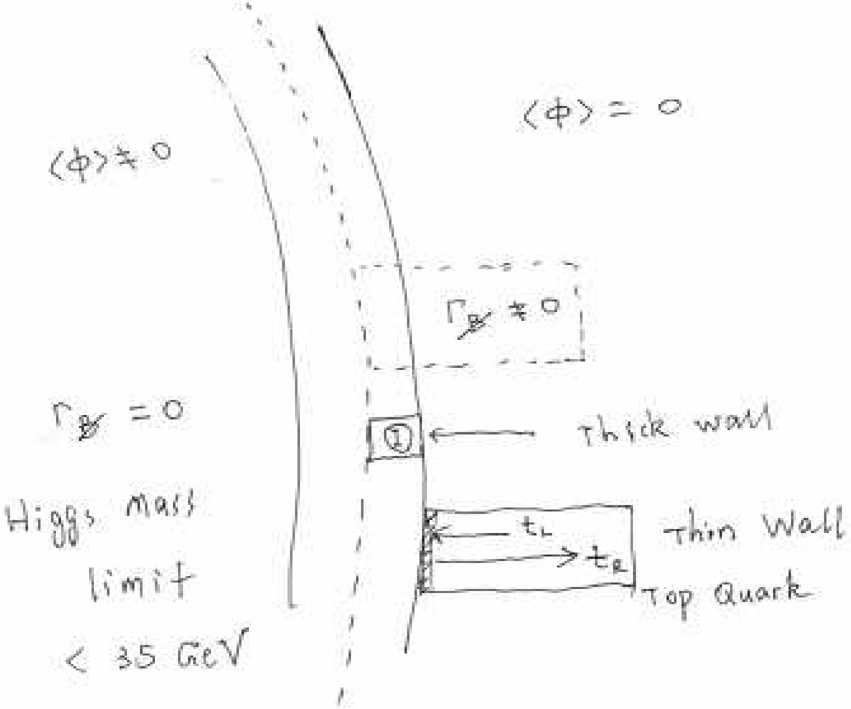
**My result in 1993:** $m_H^2 < (35\ GeV)^2 + 8\alpha \frac{v^4}{\Lambda^2}$

**requiring a light Higgs and when**
**taking Higgs mass 125 GeV, I obtain \Lambda should be**
**no more than 1.5 TeV for \alpha ~ O(1)**
**which gives a correct to the triplet Higgs coupling about 90%**
**My result is consistent with the recent analysis (**C. Grojean G. Servant J. Wells; S. W. Ham S. K. Oh; Dietrich Bodeker Lars Fromme Stephan J. Huber Michael Seniuch ; Daniel J. H. Chung Andrew J. Long Lian-Tao Wang …… )
**The anomalous Higgs self coupling is claimed to be measured with precision O ( 30 %) at TLEP in Matthew McCullough arXiv:1312.3322**
**(see Xiaojun Bi's talk for details)**



# Electroweak Baryogenesis

## 机制



$$\Gamma_{\not B} \sim e^{-\phi(T)/T}$$

# Operator relevant to baryon number generation

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

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

**Anomalous top-Higgs couplings:**

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

**For \Lambda ~ 1 TeV.**

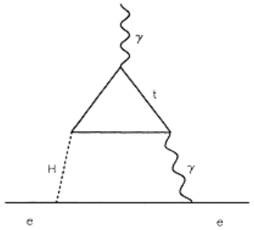
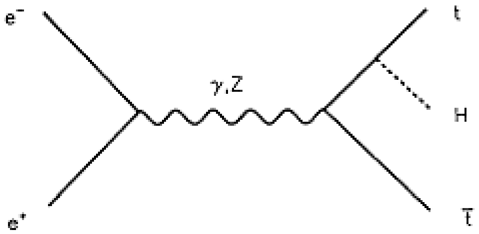


FIG. 1. Dominant contribution to $d_e$, the electric dipole moment of the electron.



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

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

**Lianyou Shan et al (In preparation)**

**Note: Non-universal couplings induce FCNC couplings**

**t t\bar h ( \gamma, Z) --→ t\bar c h (\gamma, Z)**

**T. Han, R. Peccei, X. Zhang et al…..**
**C.-P., Yuan et al**

**At Higgs factory: single top production e^+e^- --→ Z (or gamma) -→ t \bar c**

# Comments

## I) Electroweak baryogenesis predict

anomalous Higgs couplings

anomalous htt couplings

FCNC top couplings

(with and without CP violation)

## II) Large enough to be measured experimentally;

If not, rule out electroweak baryogenesis

General argument ---→ circular collider, a machine for electroweak baryogenesis (origin of matter !) discovering the anomalous couplings or new particles which contribute to the anomalous couplings

## III) Other possibilities for baryogenesis

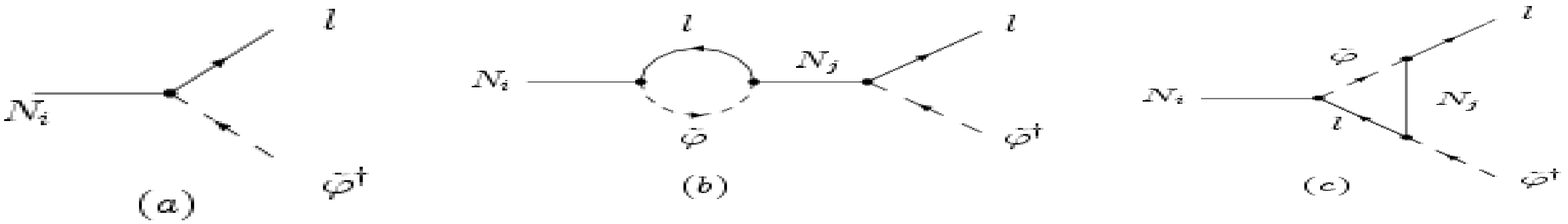
## two examples

# Other possibilities for Baryogenesis
------Leptogenesis

$$\begin{aligned}\delta\mathcal{L} &= i\bar{\nu}_{Ri}\gamma^{\mu}\partial_{\mu}\nu_{Ri} - \frac{1}{2}M_{ij}\bar{\nu}^{C}_{Ri}\nu_{Rj} - y^{\nu}_{\alpha i}\bar{l}_{L\alpha}\tilde{\varphi}\nu_{Ri} + h.c. \\ &= \frac{i}{2}\bar{N}_{i}\gamma^{\mu}\partial_{\mu}N_{i} - \frac{1}{2}M_{i}\bar{N}_{i}N_{i} - y^{\nu}_{\alpha i}\bar{l}_{L\alpha}\tilde{\varphi}N_{i} + h.c.\end{aligned}$$

$$N_i = \nu_{Ri} + (\nu_{Ri})^C$$

$$m_\nu \simeq -(m_D)^* M^{-1} (m_D)^\dagger \qquad m_D = y^\nu v \qquad v \equiv \langle \tilde{\varphi} \rangle \simeq 174\mathrm{GeV}$$



$$\varepsilon_i = \frac{\sum_\alpha \left[\Gamma\left(N_i \to l_\alpha + \tilde{\varphi}^\dagger\right) - \Gamma\left(N_i \to \bar{l}_\alpha + \tilde{\varphi}\right)\right]}{\sum_\alpha \left[\Gamma\left(N_i \to l_\alpha + \tilde{\varphi}^\dagger\right) + \Gamma\left(N_i \to \bar{l}_\alpha + \tilde{\varphi}\right)\right]}$$

**M. Fukugita and T. Yanagida, Phys. Lett. B 174, 45 (1986);**

**P. Langacker, R.D. Peccei, and T. Yanagida, Mod. Phys. Lett. A 1, 541 (1986);**

**M.A. Luty, Phys. Rev. D 45, 455 (1992);**

**R.N. Mohapatra and X. Zhang, Phys. Rev. D 45, 2688 (1992).**

**………..**

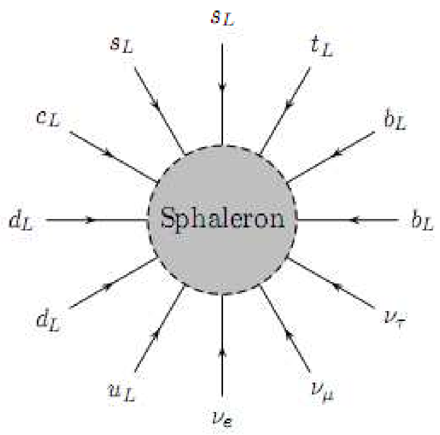
# Comment: How the Lepton number asymmetry （B-L）is converted to Baryon number asymmetry? And how much?

**B= ½ （B+L）+ ½ （B-L）？？**

Need to consider Electroweak Sphaleron process

$$100\text{GeV} < T < 10^{12}\text{GeV}$$

$$B = \frac{28}{79}(B-L)$$



**And also the gauge interaction, Yukawa interaction and also QCD sphaleron**

V.A. Kuzmin, V.A. Rubakov and

M.E. Shaposhnikov, Phys. Lett. B **155**, 36 (1985)**;**

**R. Mohapatra and Xinmin Zhang, Phys.Rev.D45,**

**2699- 2705, (1992)**

# Other Possibilities for Baryogenesis : 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)*

**I)** $L_{\rm int} = c\frac{\partial_\mu Q}{M} J^\mu_B \Rightarrow \mu_b = c\frac{\dot{Q}}{M} = -\mu_{\bar{b}}$ **In thermo equilibrium⇒**

***Cohen & Kaplan***

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

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

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

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

**II)** $\partial_\mu J^\mu_{(B-L)_{\rm L}} \sim -\frac{e^2}{12\pi^2}F_{\mu\nu}\tilde{F}^{\mu\nu} = -\frac{\alpha_{\rm em}}{3\pi}F_{\mu\nu}\tilde{F}^{\mu\nu}$ $\quad J^\mu_{(B-L)_{\rm L}} = (1/2)J^\mu_{(B-L)} - (1/2)J^{5\mu}_{(B-L)}$


**Leptogenesis**
**Anomaly for CMB**

**Cosmological CPT violation, baryo/leptogenesis and CMB polarization**
**M. Li, J. Xia, H. Li and X. Zhang**
**Phys. Lett. B651, 357 (2007)**

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

**CPT violation** $\longrightarrow$ $\Delta\alpha \neq 0$

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

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

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

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

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

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

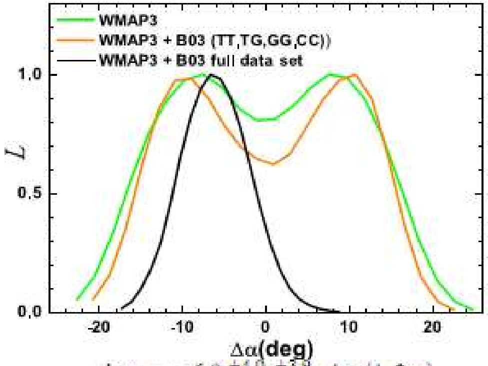
$$C'^{TB}_l = C^{TE}_l \cdot \sin 2\Delta\alpha$$

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

(Note here the notation: G ~ E, C~ B)

**1) Gravitational leptogenesis and its signatures in CMB.**
**Bo Feng, Hong Li, Ming-zhe Li, Xin-min Zhang,**
**Phys.Lett.B620:27-32,2005.**

**2）Bo Feng, Mingzhe Li ,**
**Jun-Qing Xia,**
**Xuelei Chen and Xinmin Zhang**
**Phys. Rev. Lett. 96,**
**221302 (2006)**



$$\Delta\alpha = -6.0^{+4.0}_{-4.0}{}^{+3.9}_{-3.7}\ \mathrm{deg}(1,2\sigma)$$

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).

# Current status on the measurements of the rotation angle

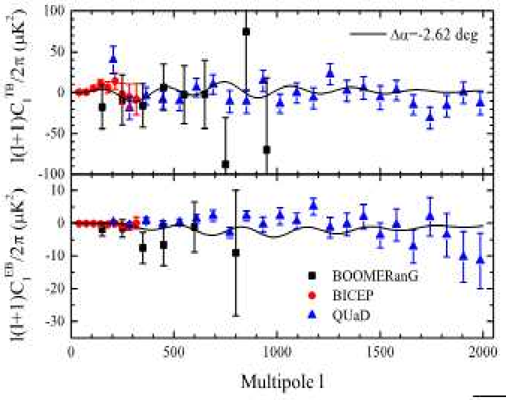
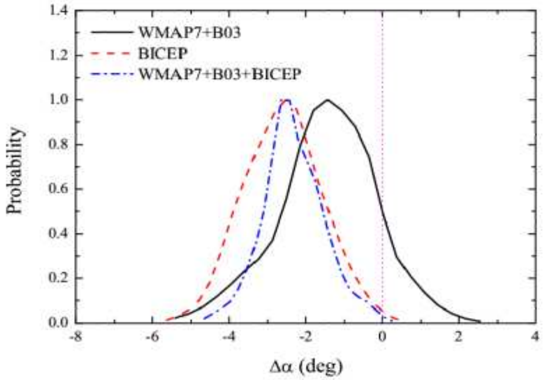


**Fig. 1.** The binned TB and EB spectra measured by the small-scale
of BOOMERanG (black squares), BICEP (red circles) and QUaD (b
black solid curves show the theoretical prediction of a model with
(For interpretation of colors in this figure, the reader is referred t
of this Letter.)



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

$3\sigma$ detection ===➔

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

# Conclusion and discussions

1) For the past 10 years, WMAP….Planck =➔
Precision cosmology
(like in 90’s of particle physics)
----→ success of the cosmology theory
( perturbation theory for CMB, LSS)

2) Strong motivations for new physics
*differing from (may stronger than) the naturalness argument ….*
Dark matter、Dark energy、Baryogenesis、Inflation …
Singularity of the big-bang cosmology

3) Cosmology and collider physics

Much relevant to **CEPC/SPPC : i) Electroweak baryogenesis, ii) WIMP dark matter**
**Higgs: mass generation to matter and also anti-matter! (Origin of mass)**
**CEPC/SPPC: Why no anti-matter? Origin of matter**
**What is dark matter made of ? WIMP dark matter**

**( see talk by Xiaojun Bi for more on**
**“working group report” )**

Thank You !