# 粒子宇宙学研究进展

中科院高能所
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2012年4月9日 杭州

# 报告提纲

## 1）暗能量

SDSS-III新数据，宇宙学参数新结果

。。。Gongbo Zhao, arXiv:1203.6616

Quintom-Galileon 理论: **On dark energy models of single scalar field**

**Mingzhe Li et al, arXiv:1112.4255** [hep-th]

Bouncing Galileon Cosmologies , T, Qiu et al, JCAP 1110:036,2011

## 2）中微子宇宙学

宇宙学中微子质量限; 中微子暗能量

Baryo/Leptogenesis

## 3）暗物质: Cold or Warm WIMPs

**CosRayMC: a global fitting method in studying the properties of the new sources of cosmic e$^{\pm}$ excesses**

**Jie Liu et al, Phys.Rev.D85:043507,2012**

**Gamma-rays From Warm WIMP Dark Matter Annihilation**

Qiang Yuan, Yixian Cao, Jie Liu, Pengfei Yin, Liang Gao, Xiao-Jun Bi, Xinmin Zhang

e-Print: **arXiv:1203.5636** [astro-ph.HE]

## 暗能量：迷，什么都不知道？

存在：一定

Candidates：cosmological constant？

Dynamical 。。。。？

Nobel Prize; precision cosmology;

## 弱电对称性破缺：迷，什么也不知道？

存在： W, Z, 粒子质量，Universality

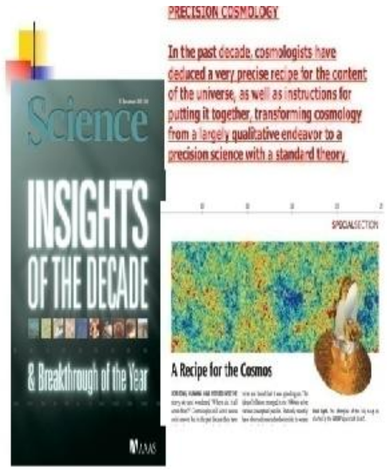
Candidates： Higgs, Two-Higgs, SUSY,

Composite Higgs, Technicolor….

Nobel Prize: Weinberger…

‘t Hooft, Veltman….

# 过去十年“宇宙学”研究进展




## 1） 本世纪前十年十大科学成就：精确宇宙学

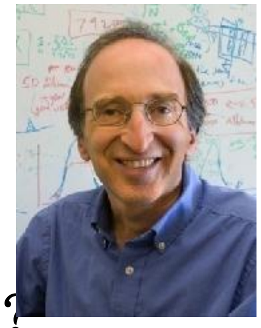
本世纪首个十年即将结束之际，《科学》杂志审视了进入新千 年以来的那些改变科学面貌的进步，评选出了十项科学成就作为“本十年卓见”（**Insights of the Decade**）。

精确宇宙学：在过去十年中，研究人员非常精确地推测出宇宙物质的成分是普通物质、暗物质和暗能量。同时，他们阐述了将这些成分组成宇宙的方法。这些进展将宇宙学转变成为一种有着标准理论的精确科学，而留给其他理论的活动空间已十分狭小。

(注：**WMAP 贡献巨大**！中国科学家贡献不可忽略！)

**-------对暗能量宇宙学研究的直接肯定 ！**

## 2）2011年度诺贝尔物理奖：宇宙加速膨胀



ICFA 2011” meeting
CERN, 3-6 October, 2011

与暗能量有关吗？

**YES!** （暗能量领域的第一个诺奖？）

十年的“精确宇宙学”成就了今年的诺奖！！！

# 今年诺奖与暗能量有关吗?

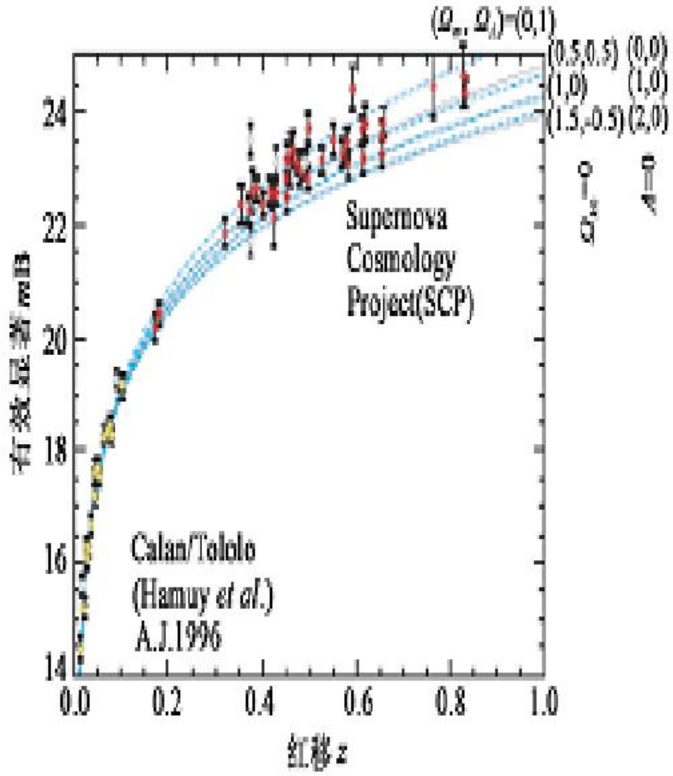



图 2 1998 年 SCP组观测得到的哈勃图. 取自文献[2]

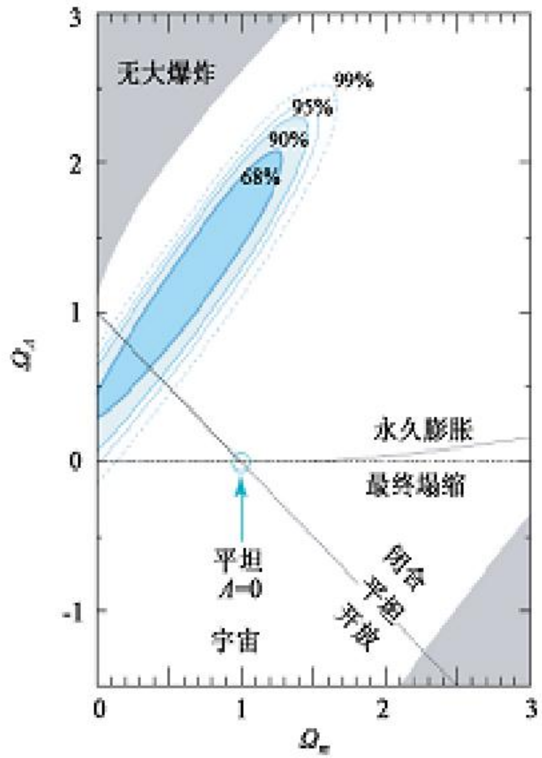



图 3 1998 年 SCP 研究组的数据拟合以 99% 的置信度排除了 $\Omega_\Lambda \leq 0$ 的情形. 取自文献[2]

# SN=〉加速？ (CMB, LSS同样或更重要!)

VOLUME 88, NUMBER 16 PHYSICAL REVIEW LETTERS 22 APRIL 2002

## Dimming Supernovae without Cosmic Acceleration

Csaba Csáki,[1,*] Nemanja Kaloper,[2] and John Terning[1]

[1]*Theory Division T-8, Los Alamos National Laboratory, Los Alamos, New Mexico 87545*

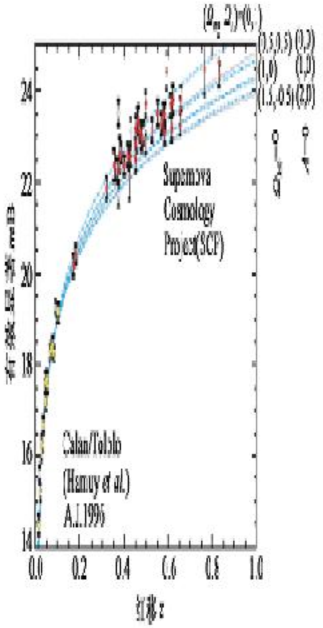
[2]*Department of Physics, Stanford University, Stanford, California 94305*

(Received 6 December 2001; published 9 April 2002)

We present a simple model where photons propagating in extragalactic magnetic fields can oscillate into very light axions. The oscillations may convert some of the photons, departing a distant supernova, into axions, making the supernova appear dimmer and hence more distant than it really is. Averaging over different configurations of the magnetic field we find that the dimming saturates at about one-third of the light from the supernovae at very large redshifts. This results in a luminosity distance versus redshift curve almost indistinguishable from that produced by the accelerating Universe, if the axion mass and coupling scale are $m \sim 10^{-16}$ eV, $M \sim 4 \times 10^{11}$ GeV. This phenomenon may be an alternative to the accelerating Universe for explaining supernova observations.

DOI: 10.1103/PhysRevLett.88.161302 PACS numbers: 98.80.Cq, 14.80.Mz, 97.60.Bw

# 十年精确宇宙学成就了2011年的诺奖



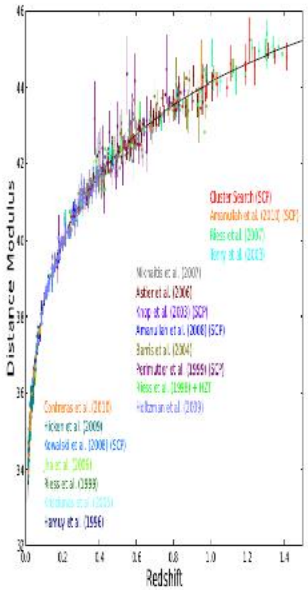




图2 1998年SCP组观测得到的哈勃图.取自文献[2]

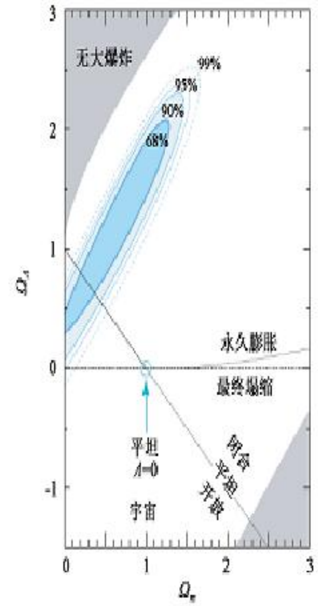



图3 1998年SCP研究组的数据拟合以99%的置信度排除了$\Omega_\Lambda \le 0$的情形.取自文献[2]

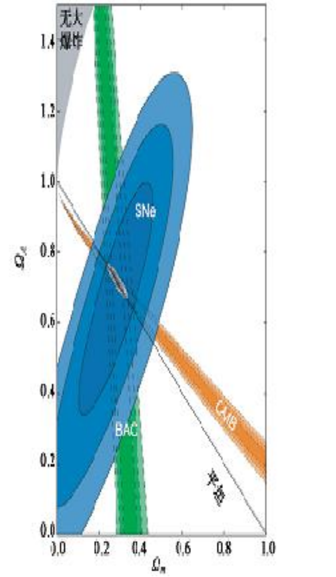



图4 截至2011年,超新星(UNICN2.1)、宇宙微波背景辐射(WMAP7)和大尺度结构(SDSS DR7)观测对暗能量的限制.取自文献[3]

union2.1 580 SN Ia, arxiv: 1105.3470

\rho_DE 确定很好，

但w误差大。

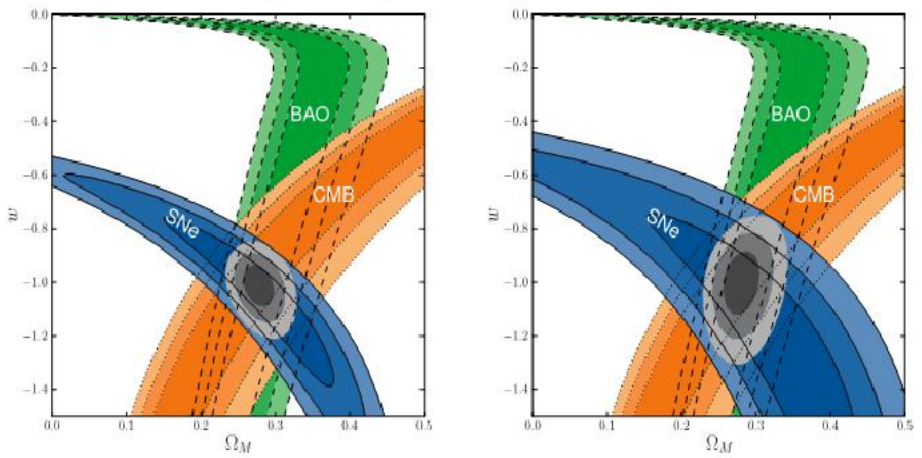
====〉存在证据（诺奖）

性质？？

（ w 常数，动力学？

修改引力？。。。）

Spectra and Light Curves of Six SNe Ia and Union2



# 诺奖颁发的“合理与不合理”

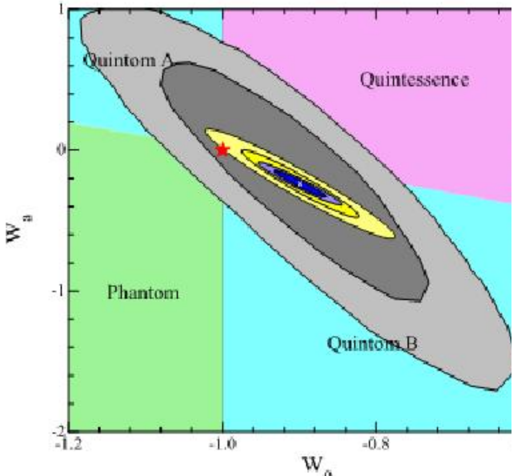
“不合理”：之后大量的工作，CMB,
LSS, SN 等 ===〉
精确宇宙学？

“合理”：原创，冒‘风险’
如果没有证实怎么办？

**诺奖：原创 + “运气”**

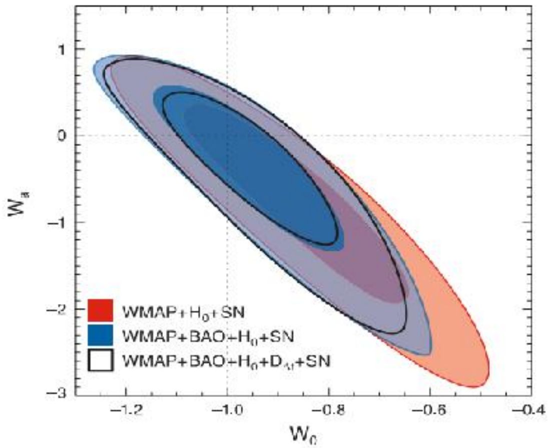
（98年: SN， oscillation Neutrino;
2011年：中微子超光速？？
理论：新思想，计算正确
实验：新设计，系统误差控制 ）

# Current status in determining the EoS of dark energy



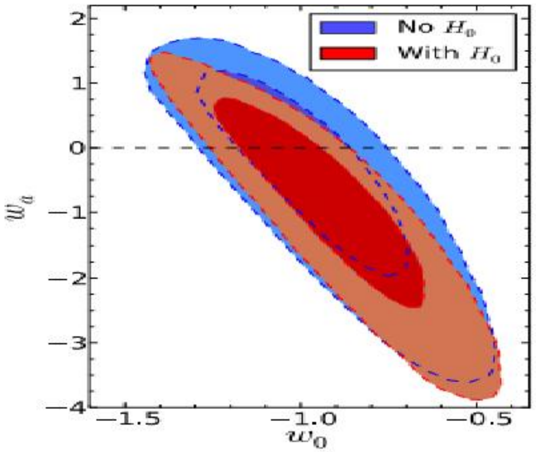

G. Zhao and X. Zhang

**Phys.Rev.D81:043518,2010**



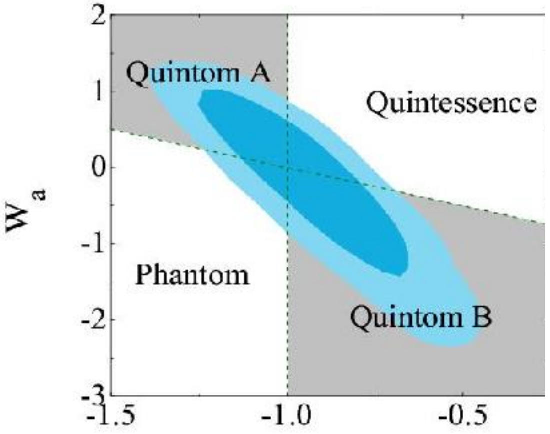

WMAP7 E. Komatsu *et al.*

e-Print: **arXiv:1001.4538**



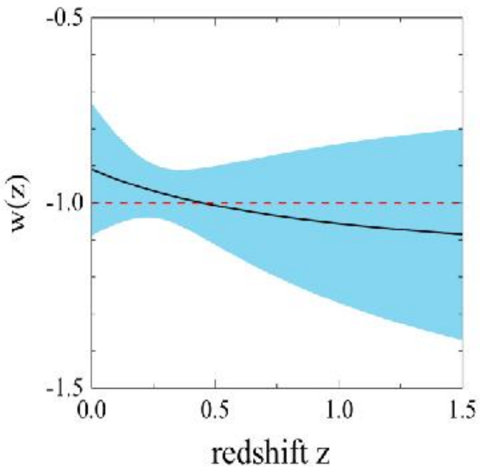

**SNLS3，**

**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;**

# The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological implications of the large-scale two-point correlation function



Ariel G. Sánchez[1*], C. G. Scóccola[2,3], A. J. Ross[4], W. Percival[4], M. Manera[4], F. Montesano[1], X. Mazzalay[1], A. J. Cuesta[5], D. J. Eisenstein[6], E. Kazin[7], C. K. McBride[6], K. Mehta[8], A. D. Montero-Dorta[9], N. Padmanabhan[5], F. Prada[9,10,11], J. A. Rubiño-Martín[2,3], R. Tojeiro[4], X. Xu[8], M. Vargas Magaña[12], E. Aubourg[12], N. A. Bahcall[13], S. Bailey[14], D. Bizyaev[15], A. S. Bolton[16], H. Brewington[15], J. Brinkmann[15], J. R. Brownstein[16], J. Richard Gott, III[13], J. C. Hamilton[12], S. Ho[14,17], K. Honscheid[18], A. Labatie[12], E. Malanushenko[15], V. Malanushenko[15], C. Maraston[4], D. Muna[19], R. C. Nichol[4], D. Oravetz[15], K. Pan[15], N. P. Ross[14], N. A. Roe[14], B. A. Reid[14,20], D. J. Schlegel[14], A. Shelden[16], D. P. Schneider[21,22], A. Simmons[15], R. Skibba[8], S. Snedden[15], D. Thomas[4], J. Tinker[19], D. A. Wake[23], B. A. Weaver[19], David H. Weinberg[24], Martin White[14,25], I. Zehavi[26], and G. Zhao[4,27]

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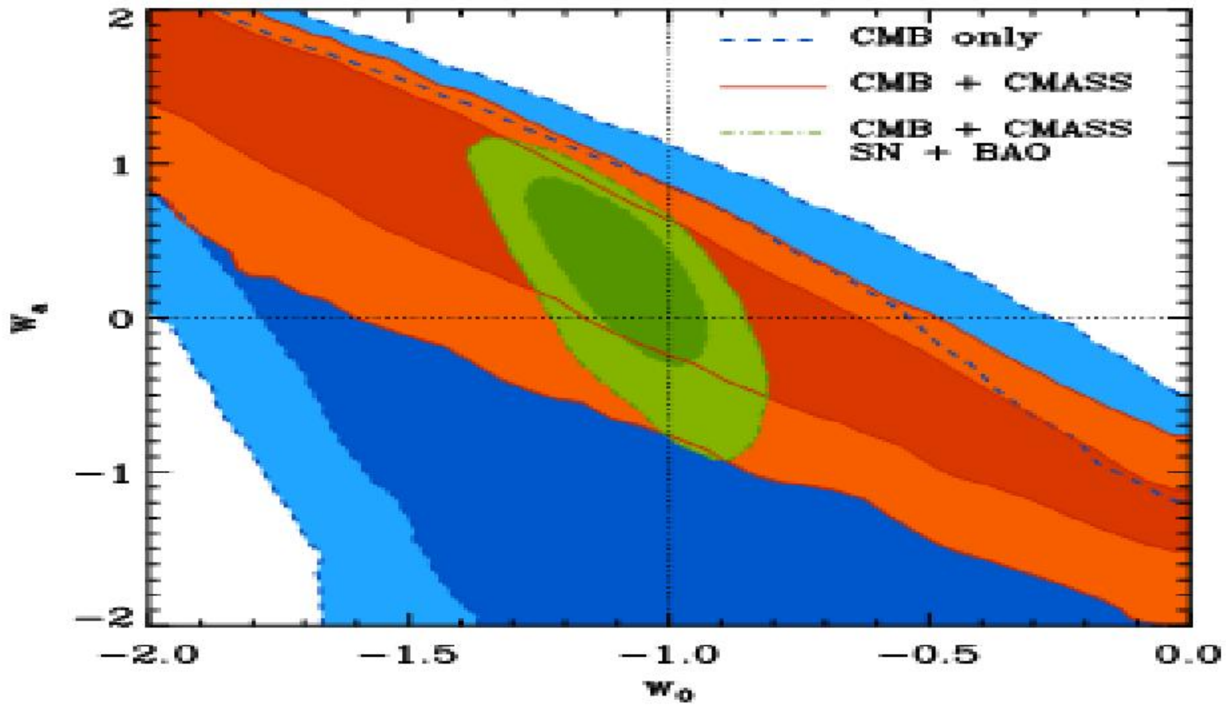



**Figure 12.** The marginalized posterior distribution in the $w_0 - w_a$ plane for the ΛCDM parameter set extended by allowing for variations on $w_{DE}(a)$, parametrized as in equation (12). The dashed lines show the 68 and 95 per cent contours obtained using CMB information alone. The solid contours correspond to the results obtained from the combination of CMB data plus the shape of the CMASS $\xi(s)$. The dot-dashed lines indicate the results obtained from the full dataset combination (CMB+CMASS+SN+BAO). The dotted lines correspond to the canonical values in the ΛCDM model.

**Table A6.** The marginalized 68% allowed regions on the cosmological parameters of the ΛCDM model extended by allowing for variations on $w_{\rm DE}(a)$ (parametrized according to equation 12), obtained using different combinations of the datasets described in Section 2.1 and 3.

| | CMB | CMB + CMASS | CMB + CMASS +SN | CMB + CMASS +BAO | CMB + CMASS + BAO + SN |
|---|---|---|---|---|---|
| $w_0$ | $-1.12^{+0.52}_{-0.51}$ | $-1.12^{+0.61}_{-0.58}$ | $-1.09^{+0.11}_{-0.11}$ | $-0.95^{+0.27}_{-0.27}$ | $-1.08^{+0.11}_{-0.11}$ |
| $w_a$ | $-0.3^{+1.2}_{-1.7}$ | $0.32^{+0.98}_{-0.99}$ | $0.12^{+0.48}_{-0.47}$ | $0.05^{+0.82}_{-0.81}$ | $0.23^{+0.42}_{-0.42}$ |
| $100\Theta$ | $1.0409^{+0.0016}_{-0.0016}$ | $1.0409^{+0.0016}_{-0.0016}$ | $1.0408^{+0.0015}_{-0.0016}$ | $1.0409^{+0.0016}_{-0.0016}$ | $1.0408^{+0.0016}_{-0.0016}$ |
| $100\omega_b$ | $2.219^{+0.042}_{-0.042}$ | $2.218^{+0.042}_{-0.041}$ | $2.215^{+0.040}_{-0.040}$ | $2.218^{+0.00042}_{-0.042}$ | $0.0221^{+0.041}_{-0.041}$ |
| $100\omega_{dm}$ | $11.22^{+0.47}_{0.47}$ | $11.31^{+0.46}_{-0.46}$ | $11.40^{+0.45}_{-0.45}$ | $11.28^{+0.48}_{-0.47}$ | $11.38^{+0.47}_{-0.47}$ |
| $\tau$ | $0.0852^{+0.0061}_{-0.0069}$ | $0.0833^{+0.0062}_{0.0067}$ | $0.0823^{+0.0058}_{-0.0067}$ | $0.0833^{+0.0061}_{-0.0068}$ | $0.0825^{+0.0060}_{-0.0068}$ |
| $n_s$ | $0.965^{+0.011}_{-0.011}$ | $0.965^{+0.011}_{-0.011}$ | $0.963^{+0.011}_{-0.011}$ | $0.965^{+0.011}_{-0.012}$ | $0.963^{+0.011}_{-0.011}$ |
| $\ln(10^{10}A_s)$ | $3.083^{+0.030}_{-0.029}$ | $3.082^{+0.030}_{-0.030}$ | $3.083^{+0.029}_{-0.029}$ | $3.080^{+0.029}_{-0.029}$ | $3.083^{+0.030}_{-0.029}$ |
| $\Omega_{\rm DE}$ | $0.760^{+0.081}_{-0.087}$ | $0.722^{+0.081}_{-0.091}$ | $0.730^{+0.016}_{-0.016}$ | $0.706^{+0.032}_{-0.032}$ | $0.724^{+0.014}_{-0.014}$ |
| $\Omega_{\rm m}$ | $0.239^{+0.087}_{-0.081}$ | $0.278^{+0.091}_{-0.081}$ | $0.269^{+0.016}_{-0.016}$ | $0.294^{+0.032}_{-0.032}$ | $0.276^{+0.014}_{-0.014}$ |
| $\sigma_8$ | $0.87^{+0.12}_{-0.12}$ | $0.82^{+0.11}_{-0.11}$ | $0.832^{+0.049}_{-0.049}$ | $0.792^{+0.057}_{-0.057}$ | $0.821^{+0.048}_{-0.048}$ |
| $t_0/{\rm Gyr}$ | $13.64^{+0.22}_{-0.22}$ | $13.79^{+0.16}_{-0.16}$ | $13.763^{+0.089}_{-0.091}$ | $13.827^{+0.085}_{-0.086}$ | $13.80^{+0.083}_{-0.083}$ |
| $z_{\rm re}$ | $10.4^{+1.2}_{-1.2}$ | $10.3^{+1.2}_{-1.2}$ | $10.2^{+1.2}_{-1.2}$ | $10.3^{+1.2}_{-1.2}$ | $10.3^{+1.2}_{-1.2}$ |
| $h$ | $0.78^{+0.14}_{-0.14}$ | $0.72^{+0.11}_{-0.11}$ | $0.712^{+0.020}_{-0.020}$ | $0.680^{+0.038}_{-0.038}$ | $0.070^{+0.016}_{-0.016}$ |
| $D_V(z_m)/{\rm Mpc}$ | $1974^{+86}_{-83}$ | $2040^{+47}_{-45}$ | $2027^{+25}_{-25}$ | $2046^{+20}_{-20}$ | $2038^{+19}_{-19}$ |
| $f(z_{\rm m})$ | $0.733^{+0.077}_{-0.078}$ | $0.770^{+0.064}_{-0.069}$ | $0.766^{+0.022}_{-0.022}$ | $0.753^{+0.040}_{-0.040}$ | $0.771^{+0.019}_{-0.019}$ |

### 5.5 The dark energy equation of state

Until now we have assumed that the dark energy component corresponds to a cosmological constant, with a fixed equation of state specified by $w_{\rm DE} = -1$. In this Section, we allow for more general dark energy models. In Section 5.5.1 we explore the constraints on the value of $w_{\rm DE}$ (assumed redshift-independent). In Section 5.5.2 we obtain constraints on the time evolution of this parameter, parametrized according to equation (12). Section 5.5.3 deals with the effect of the assumption of a flat universe on the constraints on $w_{\rm DE}$.

In these tests we consider models with $w_{\rm DE} < -1$, corresponding to phantom energy (see Copeland et al. 2006, and references therein). When exploring constraints on dynamical dark energy models, these are allowed to cross the so-called phantom divide, $w_{\rm DE} = -1$. In the framework of general relativity, a single fluid, or a single scalar field without higher derivatives, cannot cross this threshold since it would become gravitationally unstable (Feng et al. 2005; Vikman 2005; Hu 2005; Xia et al. 2008), requiring at least one extra degree of freedom. However, models with more degrees of freedom are difficult to implement in general dark energy studies. Here we follow the parametrized post-Friedmann (PPF) approach of Fang et al. (2008), as implemented in CAMB, which provides a simple solution to these problems for models in which the dark energy component is smooth compared to the dark matter. Alternatively, as proposed by Zhao et al. (2005), it is possible to consider the dark energy perturbations using a two-field model, with one of the fields being quintessence-like and the other one phantom-like (e.g. the quintom model proposed in Feng et al. 2005) without introducing new internal degrees of freedom. Both approaches give consistent results.

- 发件人： Komatsu Eiichiro <komatsu@astro.as.utexas.edu>
- 时　间： 2010年02月26日 13:34:27 (星期五)
- 收件人： xmzhang@ihep.ac.cn
- 抄　送： Gong-Bo Zhao, Junqing Xia

Dear Xinmin, Thank you for your message. Hope is all is well with you. Many thanks for sending me the references and I apologize for my oversight - these papers should have been cited and they will be cited at the next round of revision. Sorry again.

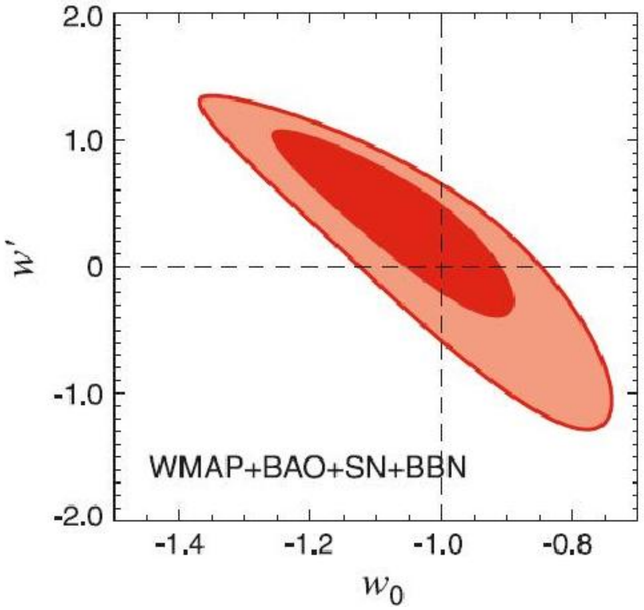
Best regards, Eiichiro

Dear Eiichiro,

We have read your WMAP7 paper (arXiv:1001.4538) with great interest. I wish to discuss with you on the global fitting of the parameters ( w_0, w_a) for the equation of state of the dark energy. As we all know, the traditional CAMB/CosmoMC codes suffer from the problem of the divergence of the dark energy perturbation when w crosses over -1. In your paper this year for the WMAP7, you have taken the approach from the paper by Fang, Hu and Lewis's paper in 2008. I wish to point out to you that several years earlier than their paper we wrote a paper (see paper 1) enclosed below) with a detailed description of the method how to deal with this problem with w across -1. With our method we performed in 2005 a global analysis with WMAP1 (see the paper 2) enclosed below), and have kept updating our results with WMAP 3-year and 5-year data (please see the paper 3) and 4) enclosed below). I recall that we discussed some of these issues before and I wish to remind you in this email. And comments and suggestions, please let me know.

Thanks, Xinmin

# WMAP normalization priors:
# drived distance information from CMB




WMAP5 result E. Komatsu et al.,

**Astrophys.J.Suppl.180:330-376,2009**

normalization priors given by WMAP group include the "shift parameter" $R$, the "acoustic scale" $l_A$ decoupling epoch $z_*$. $R$ and $l_A$ correspond to the ratio of angular diameter distance to the decoupling horizon and sound horizon at decoupling respectively, given by

$$R(z_*) = \sqrt{\Omega_m H_0^2} r(z_*) \,, \quad (13)$$

$$l_A(z_*) = \pi \chi(z_*)/r_s(z_*) \,, \quad (14)$$

where $r(z_*)$ and $r_s(z_*)$ denote the comoving distance to $z_*$ and comoving sound horizon at $z_*$ respectively. The decoupling epoch $z_*$ is given by [57]

$$z_* = 1048[1 + 0.00124(\Omega_b h^2)^{-0.738}][1 + g_1(\Omega_m h^2)^{g_2}] \,, \quad (15)$$

where

$$g_1 = \frac{0.0783(\Omega_b h^2)^{-0.238}}{1 + 39.5(\Omega_b h^2)^{0.763}}, \quad g_2 = \frac{0.560}{1 + 21.1(\Omega_b h^2)^{1.81}}. \quad (16)$$

- ◆They are widely used in fitting EoS of dark energy instead of full CMB data
- ◆Only handling the background cosmological parameters without calculate perturbations

**Be care of the models you are fitting with !!**

# ON USING THE *WMAP* DISTANCE INFORMATION IN CONSTRAINING THE TIME-EVOLVING EQUATION OF STATE OF DARK ENERGY

Hong Li,[1] Jun-Qing Xia,[2] Gong-Bo Zhao,[3] Zu-Hui Fan,[1] and Xinmin Zhang[2]

The Astrophysical Journal, 683: L1–L4, 2008 August 10

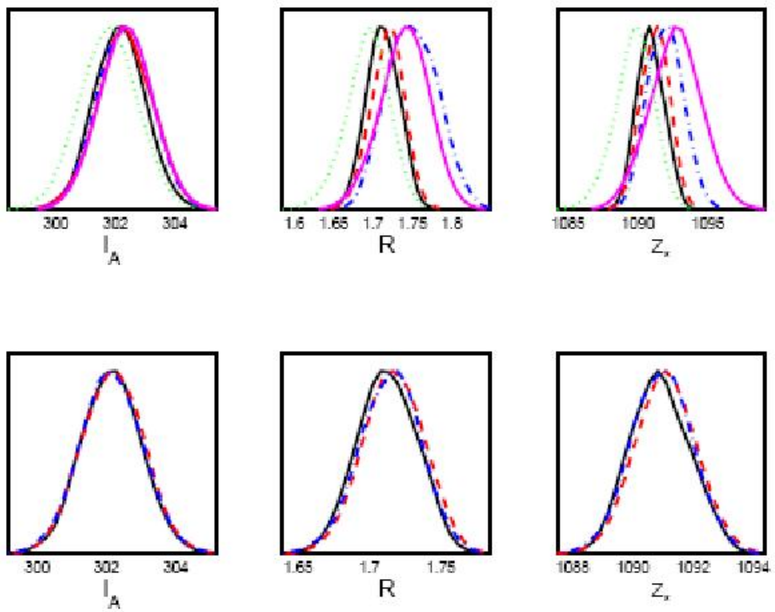
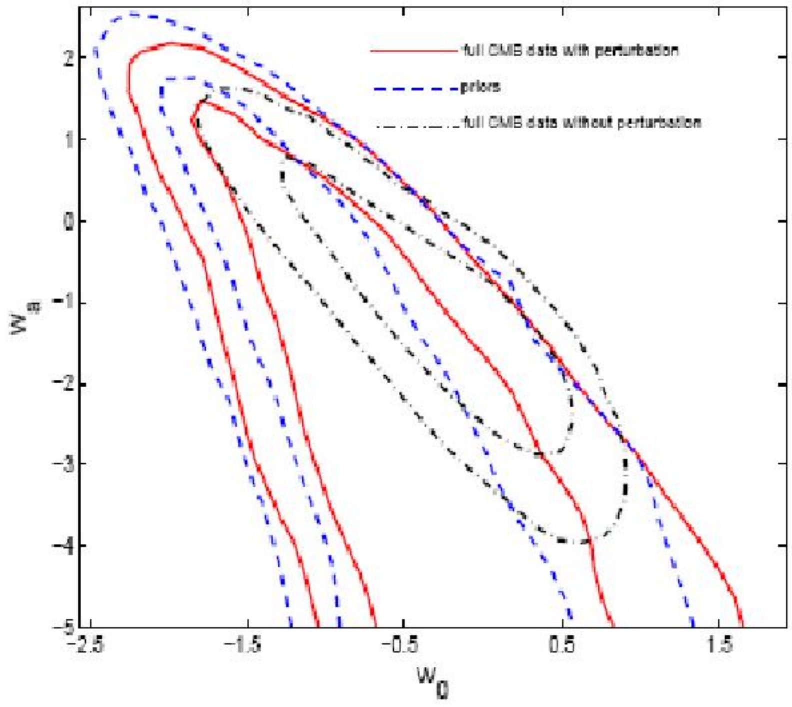


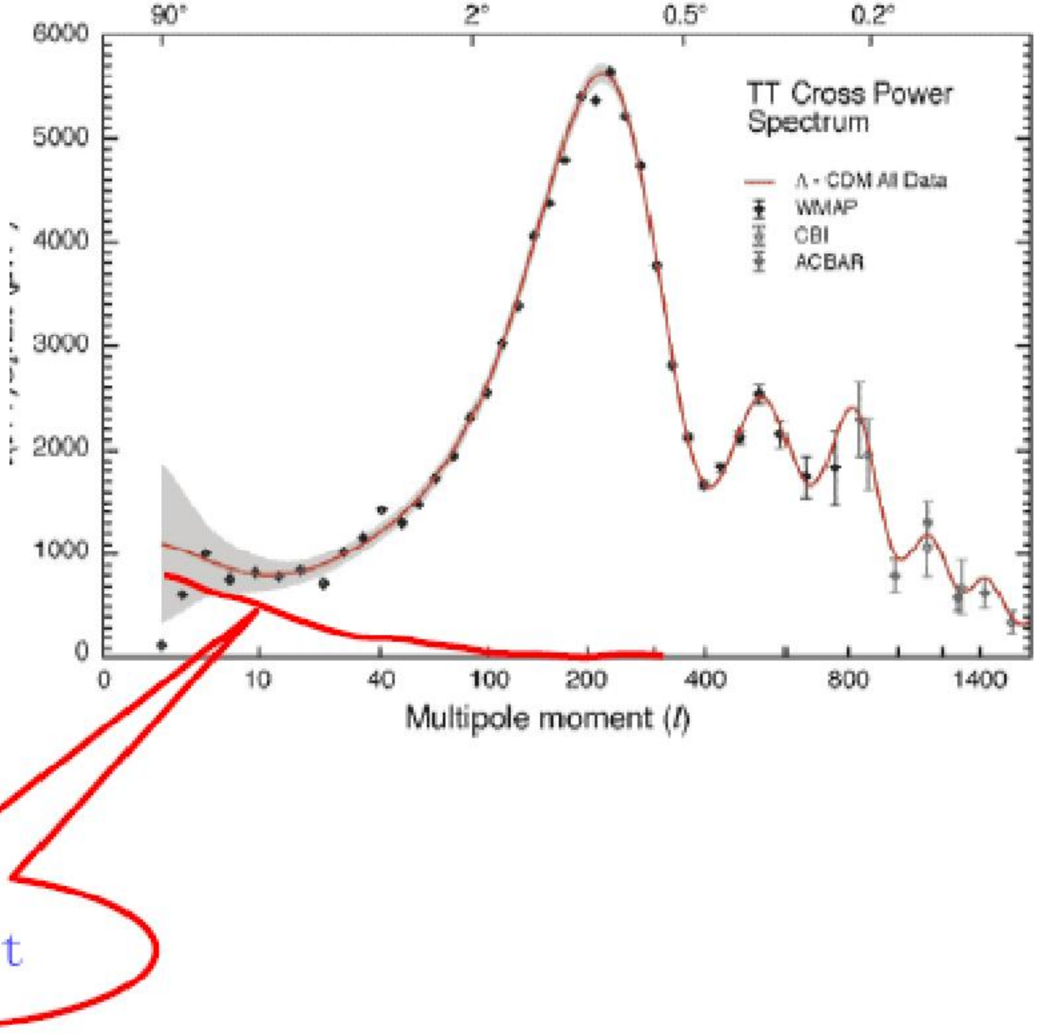

Fig. 1.— One dimensional posterior distributions of $l_A$, $R$ and $z_*$ with the WMAP5 data for different cosmological models. In the upper panels, the black solid line is given by the standard flat ΛCDM model, while the red dashed line, the blue dash-dotted line, purple solid line and the green dotted line are given by ΛCDM with non-zero $\Omega_k$, flat ΛCDM with $f_\nu$, with $\alpha_s$ and with $r$ respectively. In the lower panels, the black solid line is still from the standard ΛCDM model, while the red dashed line and the blue dash-dotted lines are given by the dark energy model with time evolving EoS (RunW model) with and (incorrectly) without dark energy perturbations respectively.

# On using the WMAP distance priors in constraining the time evolving equation of state of dark energy

Hong Li[1], Jun-Qing Xia[2], Gong-Bo Zhao[3], Zu-Hui Fan[1] & Xinmin Zhang[2]

APJ Lett. 683, L1, 2008



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- 发件人： Reynald Pain <reynald.pain@lpnhe.in2p3.fr>
- 时　间： 2011年04月12日 21:34:04 (星期二)
- 收件人： xmzhang@ihep.ac.cn
- 抄　送： Charling Tao

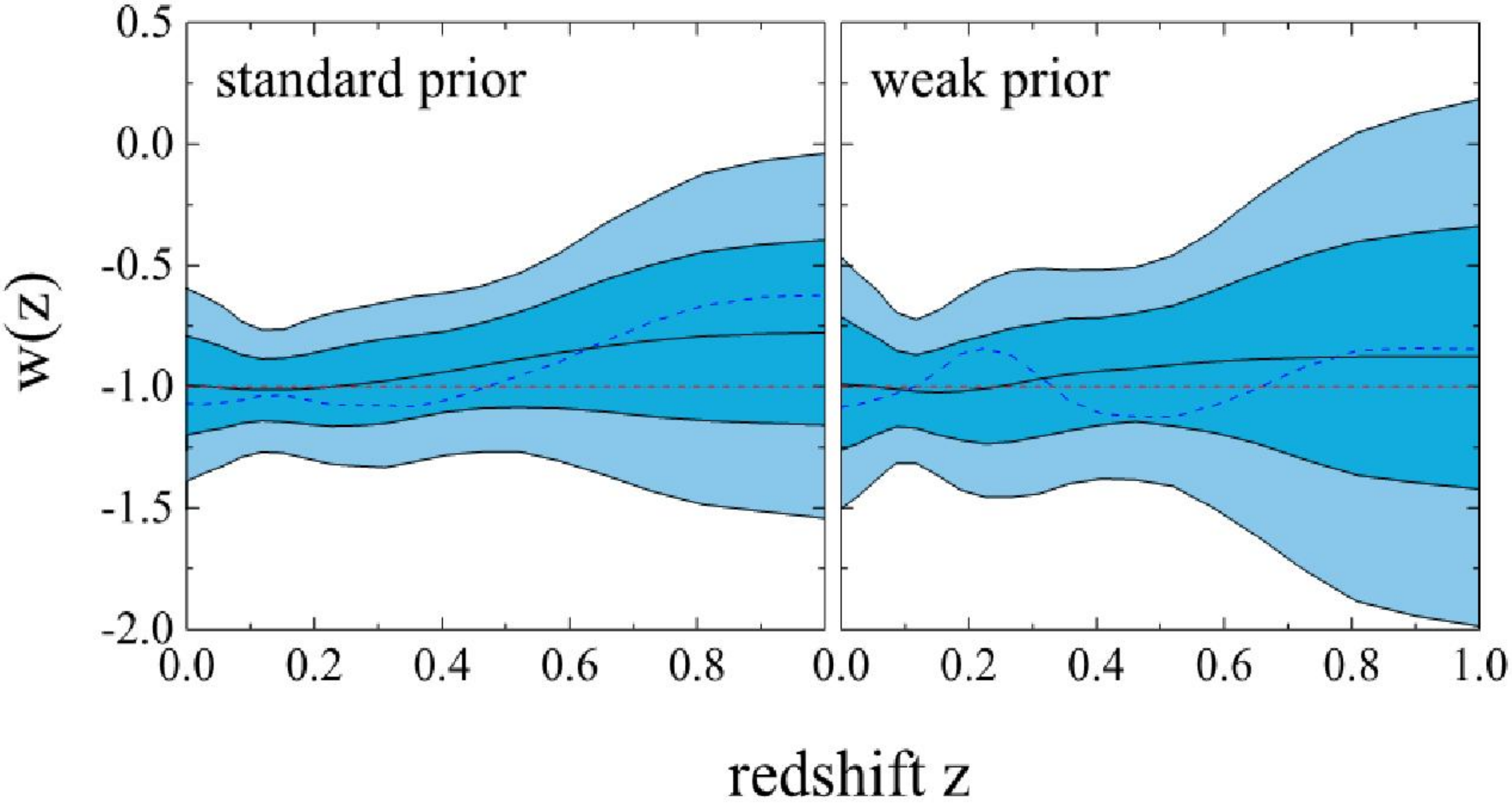
Dear Xinmin, Thanks for your email. Yes I remember our conversation on this. My apologies for our oversight. The paper is still in he referring process. I am forwarding your mail to the main authors and we'll make sure this is corrected.

Best, Reynald

Dear Reynald,

I just saw your new paper on the "SNLS3: Constraints on Dark Energy Combining the Supernova Legacy Survey Three Year Data with Other Probes (arXiv: 1104.1444)". I like it very much and fully agree with you on the point you made on the importance of the global analysis with the CosmoMC package. As you know, when working with the general dynamical dark energy especially when w crossing -1, the traditional CosmoMC will not work and the numerical calculation gives an divergent result. This requires a new part to the CosmoMC. In your paper you have taken the approach from the paper by Fang, Hu and Lewis's paper in 2008. I wish to point out to you that several years earlier than their paper we wrote a paper (see paper 1) enclosed below) with a detailed description of the method how to deal with this problem with w across -1. With the first year SNLS, we in paper 2) have done a global analysis on the determination of the dark energy equation of state. In papers 3) and 4) with Charling and others we have performed the analysis with the lateast data at that time. I recall we had some discussions during your past visits in China and wish to remind you again of these points here. It happens sometime that the original papers are missing in the reference. As another example, I enclose the email exchange with Komatsu of the WMAP collaboration on this point. Any comments and suggestions, please let me know. Thanks!

Best, Xinmin




Fitting w1--w20 with WMAP7 + H(z),+Union2.1 + BAO (SDSS DR7)

Gongbo Zhao et al (in preparation)

## Testing Einstein Gravity with Cosmic Growth and Expansion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2 Oct 2011



We test Einstein gravity using cosmological observations of both expansion and structure growth, including the latest data from supernovae (Union2.1), CMB (WMAP7), weak lensing (CFHTLS) and peculiar velocity of galaxies (WiggleZ). We fit modified gravity parameters of the generalized Poisson equations simultaneously with the effective equation of state for the background evolution, exploring the covariances and model dependence. The results show that general relativity is a good fit to the combined data. Using a Padé approximant form for the gravity deviations accurately captures the time and scale dependence for theories like $f(R)$ and DGP gravity, and weights high and low redshift probes fairly. For current observations, cosmic growth and expansion can be fit simultaneously with little degradation in accuracy, while removing the possibility of bias from holding one aspect fixed.


on modified gravity

a) GR works well;

b) Background evolution:

----〉Quintom behaviour

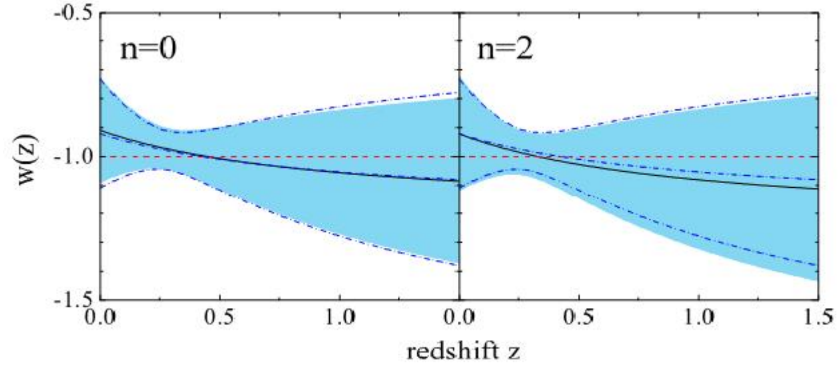



FIG. 4: The reconstructed $w(z)$ with 68% CL error are shown allowing for modified gravity (marginalized over $c, s$) in the scale independent (left panel) and scale-dependent $k^2$ (right panel) cases by the filled bands. The reconstruction for true dark energy, with gravity fixed to GR, is shown by the dash-dotted curves, the same in each panel.

- 自2004年，**w 越过 -1 研究形成热潮** ！？

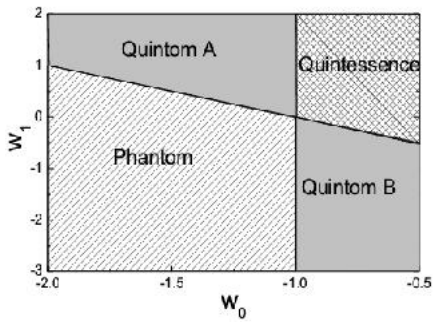
（**Quintom，Phantom divide, Crossing w=-1 ….**）

**i**）理论上的兴趣

（**no-go** 定理）

**ii**）拟合采用的参数化　**-----------------**〉

**(**解决扰动发散难题！）




**iii)**　拟合结果：

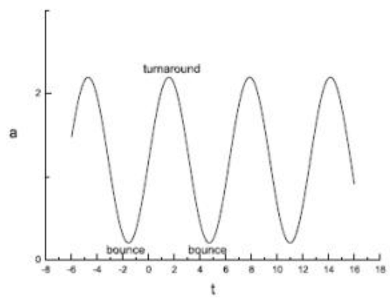
**W** 或 **MG** 中有效 **W ====➔ best fit:** 越过**-1**

**iv**）*宇宙演化作为整体考虑：*

*现在的大爆炸宇宙模型---》奇点*

***Quintom bounce*➔ *nonsingular cosmology***

*-------〉循环宇宙*



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# Quintom cosmology: Theoretical implications and observations

Yi-Fu Cai [a], Emmanuel N. Saridakis [b,*], Mohammad R. Setare [c,d], Jun-Qing Xia [e]

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# 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** ;
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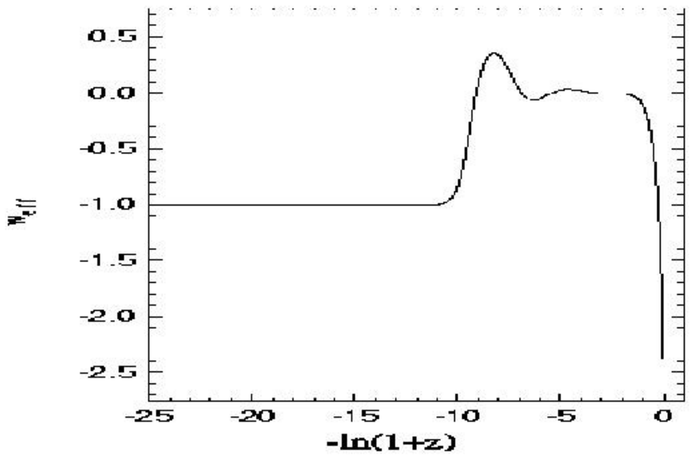
Caldwell & Doran, Phys. Rev. D 72:043527, 2005;
Zhao, Xia, Li, Feng & Zhang, Phys. Rev. D 72:123515, 2005;
Kunz & Sapone, Phys. Rev. D 74:123503, 2006;
……
Xia, Cai, Qiu, Zhao, & Zhang, Int.J.Mod.Phys.D17:1229,2008

To realize Quintom, one of the conditions should be violated

# Quintom 模型例子

1) Two scalar fields:

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



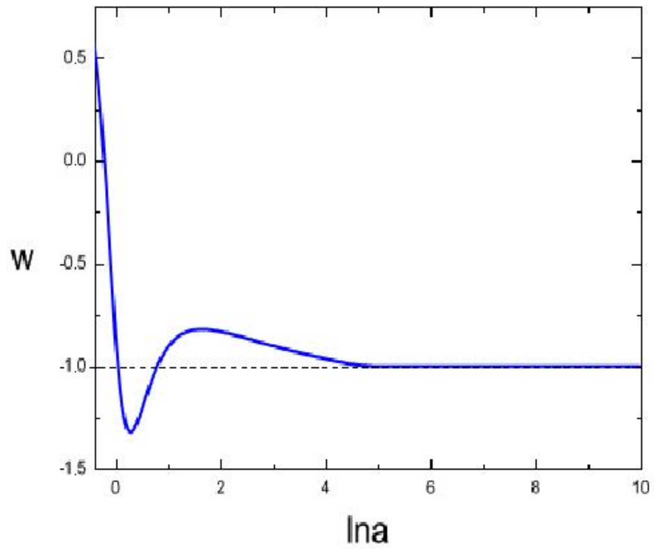

2) Single scalar with high derivatives:

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

3) Modified Born-Infeld action:

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

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



# Galileon Theories

**Galileon Models:** Lagrangian with higher derivative operator, but the equation of motion remains second order, so the model can have w cross -1 without ghost mode.

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

Basically 5 kinds of Galileon model:

$$\mathcal{L}_1 = \Pi \,, \quad \mathcal{L}_2 = \nabla_\mu \Pi \nabla^\mu \Pi \,, \quad \mathcal{L}_3 = \Box\Pi \nabla_\mu \Pi \nabla^\mu \Pi \,,$$

$$\mathcal{L}_4 = \nabla_\lambda \Pi \nabla^\lambda \Pi [2(\Box\Pi)^2 - 2(\nabla_\mu\nabla_\nu\Pi)(\nabla^\mu\nabla^\nu\Pi) - \frac{1}{2}R\nabla_\mu\Pi\nabla^\mu\Pi] \,,$$

$$\mathcal{L}_5 = \frac{5}{2}\nabla_\lambda\Pi\nabla^\lambda\Pi[(\Box\Pi)^3 - 3(\Box\Pi)(\nabla_\mu\nabla_\nu\Pi)(\nabla^\mu\nabla^\nu\Pi) + 2(\nabla_\mu\nabla^\nu\Pi)(\nabla_\nu\nabla^\rho\Pi)(\nabla_\rho\nabla^\mu\Pi) - 6G_{\nu\rho}\nabla_\mu\Pi\nabla^\rho\Pi(\nabla^\mu\nabla^\nu\Pi)] \,.$$

But can be generalized

C. Deffayet et al., arXiv:1103.3260 [hep-th]

$$\mathcal{L}_1 = P(X,\Pi) \,, \quad \mathcal{L}_2 = G_1(X,\Pi)\Box\Pi \,, \quad \mathcal{L}_3 = G_{2,X}(X,\Pi)[2(\Box\Pi)^2 - 2(\nabla_\mu\nabla_\nu\Pi)(\nabla^\mu\nabla^\nu\Pi)] + RG_2(X,\Pi) \,,$$

$$\mathcal{L}_5 = G_{3,X}(X,\Pi)[(\Box\Pi)^3 - 3(\Box\Pi)(\nabla_\mu\nabla_\nu\Pi)(\nabla^\mu\nabla^\nu\Pi) + 2(\nabla_\mu\nabla^\nu\Pi)(\nabla_\nu\nabla^\rho\Pi)(\nabla_\rho\nabla^\mu\Pi)] - 6G_{\mu\nu}(\nabla^\mu\nabla^\nu\Pi)G_3(X,\Pi) \,.$$

# An example of Galileon Theory

The action:

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

which was also used in arXiv: 1007.0027 for "Galileon Genesis".

Stress energy tensor:

$$\begin{aligned} T_{\mu\nu} &= -F^2 e^{2\Pi}[2\partial_\mu\Pi\partial_\nu\Pi - g_{\mu\nu}(\partial\Pi)^2] - \frac{F^3}{2M^3}(\partial\Pi)^2[4\partial_\mu\Pi\partial_\nu\Pi - g_{\mu\nu}(\partial\Pi)^2] \\ &\quad -\frac{F^3}{M^3}[2\partial_\mu\Pi\partial_\nu\Pi\Box\Pi - \partial_\mu\Pi\partial_\nu(\partial\Pi)^2 - \partial_\nu\Pi\partial_\mu(\partial\Pi)^2 + g_{\mu\nu}\partial_\sigma\Pi\partial^\sigma(\partial\Pi)^2]\,. \end{aligned}$$

From which we get energy density and pressure:

$$\begin{aligned} \rho &= F^2[-e^{2\Pi}\dot\Pi^2 + \frac{1}{\bar H^2}(\dot\Pi^4 + 4H\dot\Pi^3)] \\ P &= F^2[-e^{2\Pi}\dot\Pi^2 + \frac{1}{3\bar H^2}(\dot\Pi^4 - 4\dot\Pi^2\ddot\Pi)] \end{aligned}$$

where $\bar H \equiv \sqrt{\frac{2M^3}{3F}}$

# The Paths of Gravity in Galileon Cosmology

Stephen Appleby[1] and Eric V. Linder[1,2]
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[2] *Berkeley Lab & University of California, Berkeley, CA 94720, USA*
(Dated: December 12, 2011)

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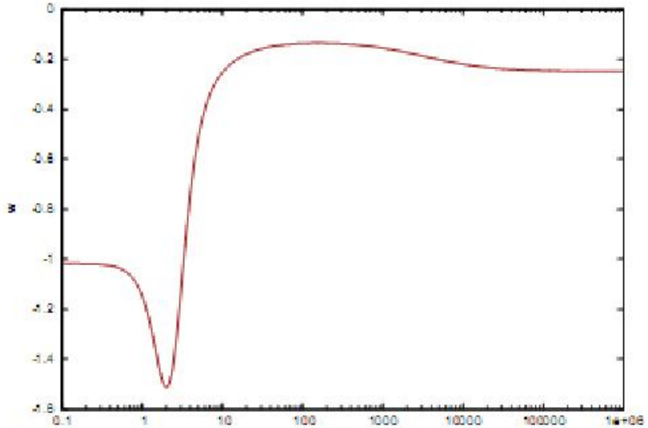

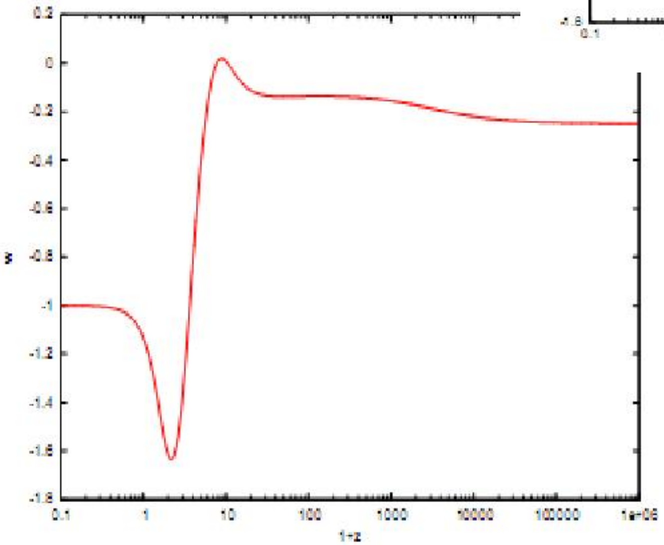

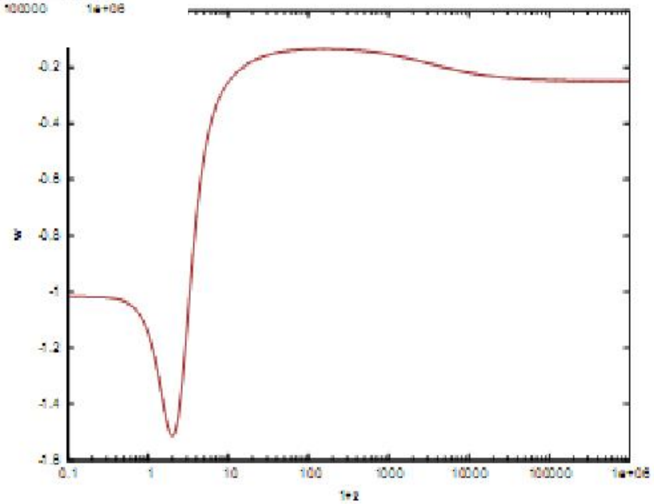

8

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

# Bouncing Galileon cosmologies

Taotao Qiu,[a] Jarah Evslin,[b] Yi-Fu Cai,[b,c] Mingzhe Li[d]
and Xinmin Zhang[b]

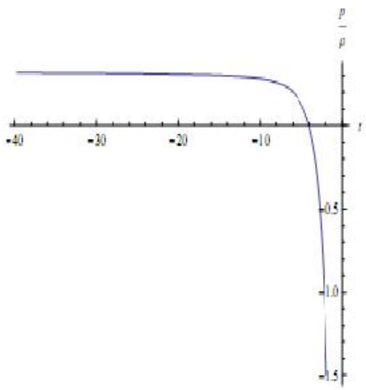


Figure 4. The ratio of the pressure to the density of the Galileon field begins at 1/3, which is the same as that of normal radiation. It steadily decreases and crosses $w = -1$ just before the bounce. In the numerical calculation, the values of parameters are listed in (3.18).

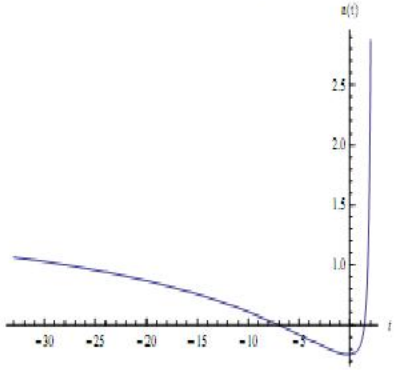


Figure 2. The scale factor $a(t)$ in a bouncing solution first shrinks as in a radiation dominated phase, then arrives at a nonzero minimal value at the bouncing point and after that enters an expanding phase. In the numerical calculation, the values of parameters are listed in (3.18).

Journal of Cosmology and Astroparticle Physics
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## A single scalar field model of dark energy with equation of state crossing −1

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## A string-inspired quintom model of dark energy

Yi-Fu Cai[a,*], Mingzhe Li[b,c], Jian-Xin Lu[d], Yun-Song Piao[e], Taotao Qiu[a], Xinmin Zhang[a]

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## On dark energy models of single scalar field

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In this paper we revisit the dynamical dark energy model building based on single scalar field involving higher derivative terms. By imposing a degenerate condition on the higher derivatives in curved spacetime, one can select the models which are free from the ghost mode and the equation of state is able to cross the cosmological constant boundary smoothly, dynamically violate the null energy condition. Generally the Lagrangian of this type of dark energy models depends on the second derivatives linearly. It behaves like an imperfect fluid, thus its cosmological perturbation theory needs to be generalized. We also study such a model with explicit form of degenerate Lagrangian and show that its equation of state may cross −1 without any instability.

PACS number(s): 98.80.Cq.

# On dark energy models of single scalar field

Mingzhe Li[1,5,*] Taotao Qiu[2,3,†] Yifu Cai[4,‡] and Xinmin Zhang[5,§]
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In this paper we revisit the dynamical dark energy model building based on single scalar field involving higher derivative terms. By imposing a degenerate condition on the higher derivatives in curved spacetime, one can select the models which are free from the ghost mode and the equation of state is able to cross the cosmological constant boundary smoothly, dynamically violate the null energy condition. Generally the Lagrangian of this type of dark energy models depends on the second derivatives linearly. It behaves like an imperfect fluid, thus its cosmological perturbation theory needs to be generalized. We also study such a model with explicit form of degenerate Lagrangian and show that its equation of state may cross $-1$ without any instability.

PACS number(s): 98.80.Cq.

For a scalar field with higher (but finite) derivatives, its Lagrangian generally has the form,

$$\mathcal{L} = \mathcal{L}(\phi, \phi_{\mu_1}, \phi_{\mu_1\mu_2}, ..., \phi_{\mu_1...\mu_N}) \ , \tag{6}$$

where $\phi_{\mu_1} \equiv \nabla_{\mu_1}\phi$, $\phi_{\mu_1\mu_2} \equiv \nabla_{\mu_2}\nabla_{\mu_1}\phi$ and so on are the covariant derivatives of $\phi$ and $N \geq 2$. The equation of motion from this Lagrangian is

$$\frac{\partial \mathcal{L}}{\partial \phi} + \sum_{n=1}^{N}(-1)^n \nabla_{\mu_1}...\nabla_{\mu_n}(\frac{\partial \mathcal{L}}{\partial \phi_{\mu_1...\mu_n}}) = 0 \ . \tag{7}$$

Generally this is a $2N$th order derivative equation, the whole system contains $N$ degrees of freedom and some of them are ghosts. In order to keep the discussions simple and without loss of general properties of higher derivative field theories, we only consider the case $N = 2$ in curved spacetime, the Lagrangian is a scalar function of $\phi$, $\phi_\mu$ and $\phi_{\mu\nu}$. The equation of motion is

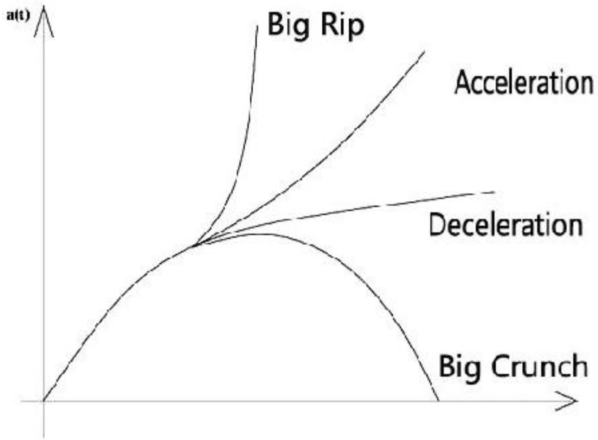
$$\frac{\partial \mathcal{L}}{\partial \phi} - \nabla_\mu(\frac{\partial \mathcal{L}}{\partial \phi_\mu}) + \nabla_\mu\nabla_\nu(\frac{\partial \mathcal{L}}{\partial \phi_{\mu\nu}}) = 0 \ . \tag{8}$$

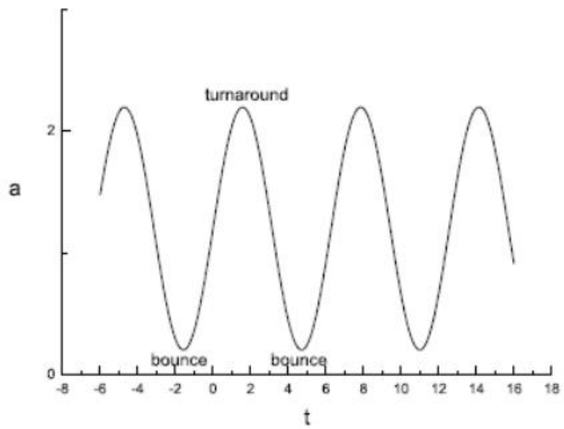
Expanding this equation and consider the symmetry $\phi_{\mu\nu} = \phi_{\nu\mu}$, we have the following equation,

$$\begin{aligned}
&\frac{\partial \mathcal{L}}{\partial \phi} - \frac{\partial^2 \mathcal{L}}{\partial \phi \partial \phi_\mu}\phi_\mu + (\frac{\partial^2 \mathcal{L}}{\partial \phi \partial \phi_{\mu\nu}} - \frac{\partial^2 \mathcal{L}}{\partial \phi_\nu \partial \phi_\mu})\phi_{\nu\mu} + \frac{\partial^3 \mathcal{L}}{\partial \phi \partial \phi \partial \phi_{\mu\nu}}\phi_\mu\phi_\nu + 2\frac{\partial^3 \mathcal{L}}{\partial \phi \partial \phi_\rho \partial \phi_{\mu\nu}}\phi_{\rho\mu}\phi_\nu + \frac{\partial^3 \mathcal{L}}{\partial \phi_\rho \partial \phi_\sigma \partial \phi_{\mu\nu}}\phi_{\sigma\mu}\phi_{\rho\nu} + \\
&\frac{\partial^2 \mathcal{L}}{\partial \phi_\rho \partial \phi_{\mu\nu}}(\phi_{\nu\rho\mu} - \phi_{\nu\mu\rho}) + 2\frac{\partial^3 \mathcal{L}}{\partial \phi \partial \phi_{\rho\sigma} \partial \phi_{\mu\nu}}\phi_{\rho\sigma\mu}\phi_\nu + 2\frac{\partial^3 \mathcal{L}}{\partial \phi_\alpha \partial \phi_{\rho\sigma} \partial \phi_{\mu\nu}}\phi_{\rho\sigma\mu}\phi_{\alpha\nu} + \frac{\partial^3 \mathcal{L}}{\partial \phi_{\alpha\beta} \partial \phi_{\rho\sigma} \partial \phi_{\mu\nu}}\phi_{\alpha\beta\mu}\phi_{\rho\sigma\nu} + \\
&\frac{\partial^2 \mathcal{L}}{\partial \phi_{\rho\sigma} \partial \phi_{\mu\nu}}\phi_{\rho\sigma\nu\mu} = 0 \ .
\end{aligned} \tag{9}$$

# 宇宙学常数还是动力学其物理意义

预言宇宙演化的不同行为



# Interacting Dark Energy

with derivatives couplings

* Direct coupling with ordinary matter

strongly constrained by the long-range force limits

large radiative corrections to the DE potential

* Interaction with derivative

Goldstone theorem: Spin-dependent force

$$\mathcal{L}_{\rm int} = \frac{c}{M}\partial_\mu \phi J^\mu$$

⇒ **CPT violation when rolling down**

⇒ **Baryo/Leptogenesis in thermo equilibrium**

**Quintessential Baryo/Leptogenesis**

⇓ **Anomaly Equation**

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

⇒ **CMB polarization and CPT test**

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

**Cosmological CPT violation:**

**strength ~ O( H ), unobservable in the laborary experiments**

**CMB: travelling around O(1/H),**

**so accumulated effect ~ O(1) observable !**

## 相互作用暗能量， Testing CPT symmetry with CMB

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + p_\mu A_\nu \widetilde{F}^{\mu\nu}$$

$p_\mu$ : (1) Constant; (2) $\frac{c}{M}\partial_\mu \phi$ ; (3) $\partial_\mu f(R)$

$$\Delta\alpha = \alpha_f - \alpha_i = \int_f^i p_\mu dx^\mu = \begin{cases} -p_0\Delta\eta \ ,(1) & p_i = 0 \\ -\frac{c}{M}\Delta\phi \ ,(2) & \\ -\Delta f(R) \ ,(3) & \end{cases}$$

i: source
f: observer

$$C_l'^{TT} = C_l^{TT}$$

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

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

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

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

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

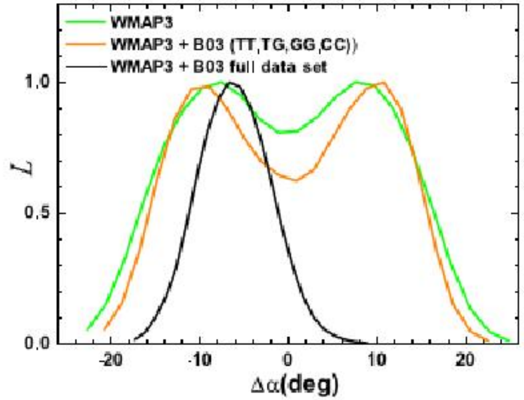



FIG. 1 (color online). One-dimensional constraints on the rotation angle $\Delta\alpha$ from WMAP data alone (green or light gray line), WMAP and the 2003 flight of BOOMERANG B03 TT, TG, GG and CC (orange or gray line), and from WMAP and the full B03 observations (TT, TG, GG, CC, TC, GC) (black line).

CPT violation
predicting <TB> and <EB>

**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)**

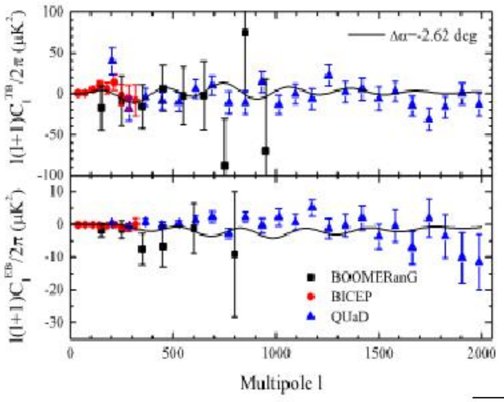
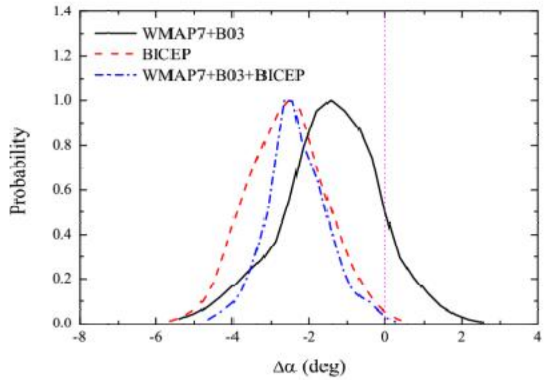



Fig. 1. The binned TB and EB spectra measured by the small-scale of BOOMERanG (black squares), BICEP (red circles) and QUaD (b black solid curves show the theoretical prediction of a model with (For interpretation of colors in this figure, the reader is referred t of this Letter.)

## Current status on the measurements of the rotation angle




| Group | $\Delta\alpha$ (degree) | Datasets |
|---|---|---|
| Feng et al | $-6.0 \pm 4.0$ | 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 ===➔ (Xia et al, $-2.33 \pm 0.72$, WMAP7+B03+BICEP)

$$PLANCK: \ \sigma = 0.057 \text{ deg}$$

# Test CPT with CMB

1) 特点：积累效应， 最灵敏

2）现状：evidence, but rotation angle measured still consistent with zero

3) 方法 accepted （WMAP组。。。。）:

i)rotation angle-→one of cosmological parameters

iI) B-mode: tensor perturbation r
rotation: E-→ B

iiI)实验上校准， 意义重大

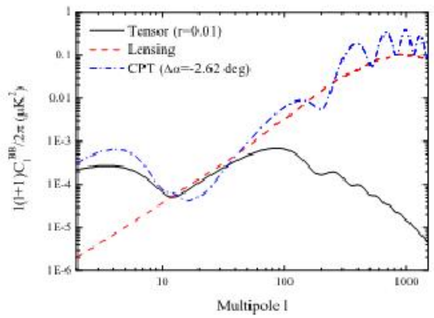



FIG. 4: The theoretical predictions of the BB power spectra from three different sources: primordial tensor B-mode with $r = 0.01$ (black solid line); lensing-induced (red dashed line) and rotation-induced (blue dash-dot line). The cosmological parameters used here are $\Omega_b h^2 = 0.022$, $\Omega_c h^2 = 0.12$, $\tau = 0.084$, $n_s = 1$, $A_s = 2.3 \times 10^{-9}$, and $h = 0.70$.

# 暗能量研究展望

i）理论研究　ii）探测：measuring W(z)

国外:

NEWS　　NATURE|Vol 466|19 August 2010

## US survey sets cosmic priorities

Dark energy rises to the top in decadal report ranking future astronomy and astrophysics projects.

Recently, a colleague of astronomer Claire Max jokingly told her that, come 13 August, half her friends would love her and half would never want to speak to her again.

That is because Max, of the University of California, Santa Cruz, has for the past two years been helping to craft US astronomy's latest decadal survey, an influential report prepared for the National Research Council that recommends which astronomy and astrophysics projects NASA, the National Science Foundation (NSF)

factors can be derived from a three-dimensional survey of the surrounding Universe that the LSST is well suited to provide.

"Increasingly, we are able to ask new questions by querying huge databases," says Tyson. "The key is to populate those databases with calibrated and trusted data."

The LSST is expected to help US astronomers regain some momentum in ground-based

Such data would contain subtle clues — in the distance–brightness relationships of supernovae, the bending of light (microlensing) from background galaxies and the three-dimensional clustering of matter in space — that can be used to independently measure dark energy.

WFIRST is effectively a rebranding of the Joint Dark Energy Mission, a NASA–DOE collaboration. The new name, says one survey reviewer, signals that the $1.6-billion telescope is not a one-trick pony, but a way of serving other

LSST CORP.

国内：　I）2004年9月9日：“暗能量研究和探测可行性”专题研讨会

高能所，理论所、国家天文台、上海天文台、紫金山天文台联合主办

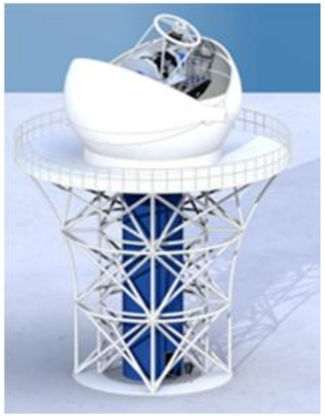
II)　2008年11月26日：暗物质暗能量探测路线图

“上天，　入地 到 南极”

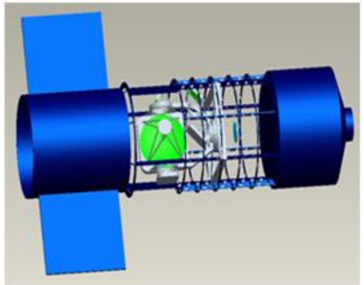
院创新三期方向性重点项目（高能所，　国台，　紫台，
上海台，　理论所。。）+ 院外合作+国内外合作
+理论实验天文观测合作

III）近年大量工作。。“二暗，　一黑，　三起源 ”

# 暗能量探测计划

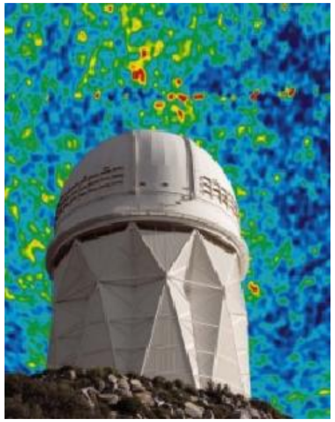


南极光学近红外
巡天望远镜

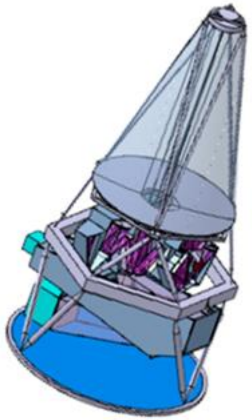


空间站大光学
平台

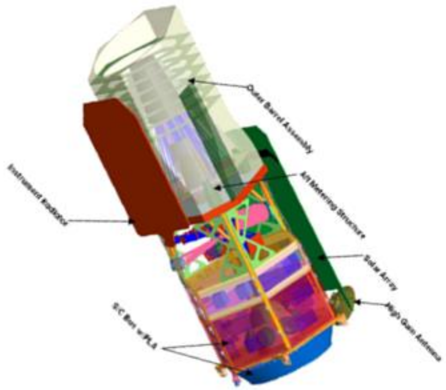
**Large Synoptic Survey Telescope**



**BigBOSS**



**Euclid**

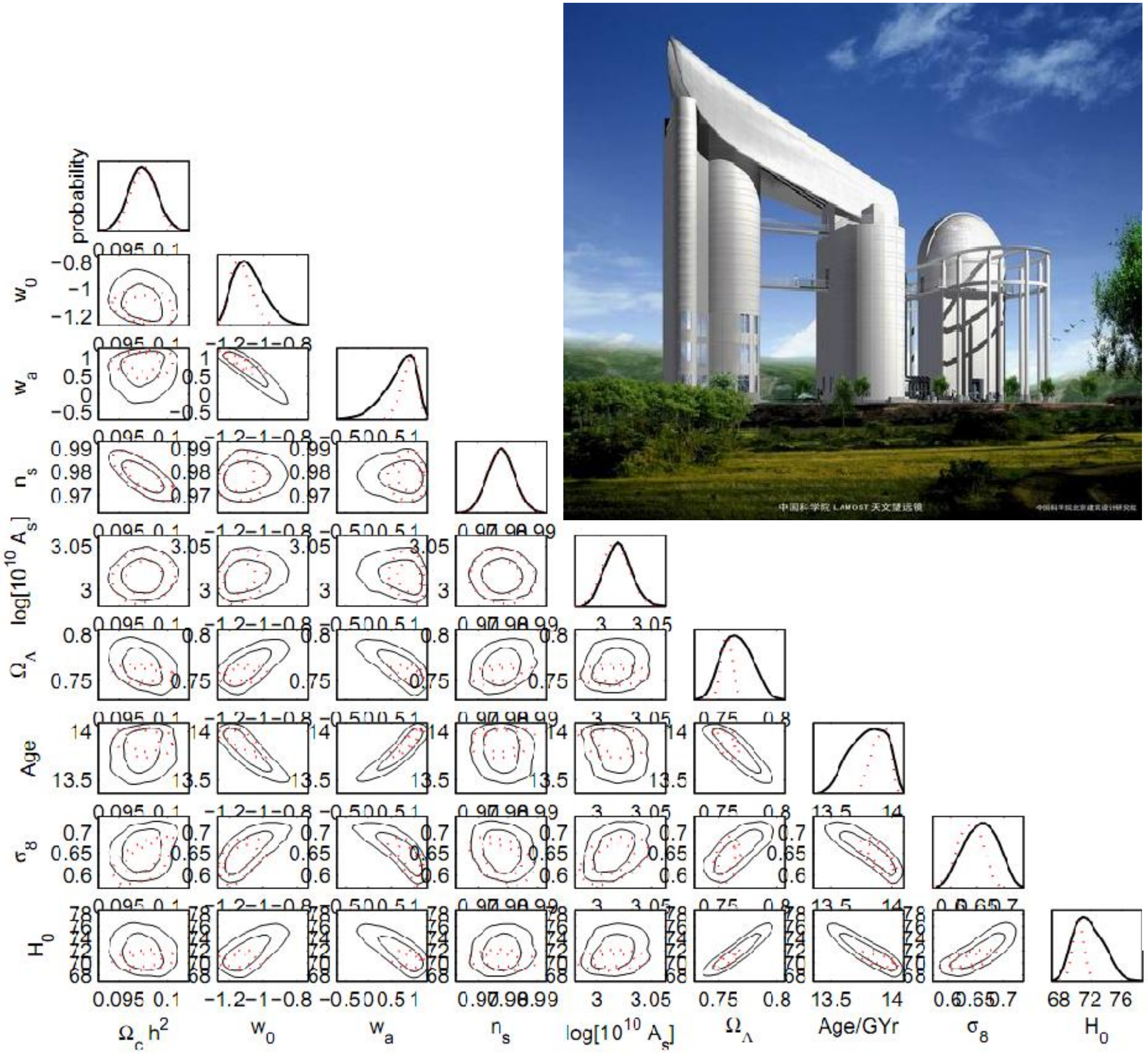


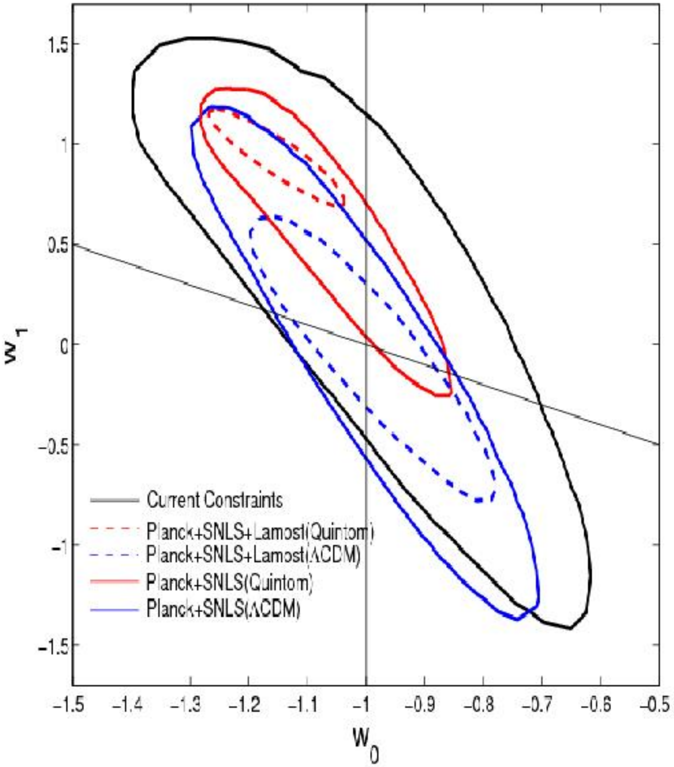
**Wide Field Infrared Survey Telescope**

~2020

# 我国暗能量探测
# 可行性研究—LAMOST

李虹等




$$w(z) = w_0 + w_a z/(1+z)$$

# PROBING DARK ENERGY WITH THE KUNLUN DARK UNIVERSE SURVEY TELESCOPE

GONG-BO ZHAO[1,2], HU ZHAN[3], LIFAN WANG[4], ZUHUI FAN[5], AND XINMIN ZHANG[1,6]

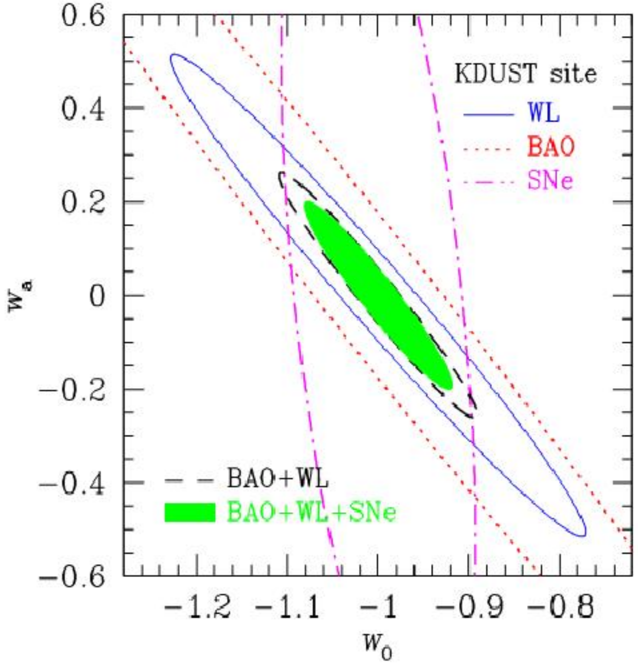



FIG. 3.— Forecasts of $1\sigma$ errors on the dark energy EOS parameters $w_0$ and $w_a$ for KDUST WL (solid line), BAOs (dotted line), SNe (dashed line), and the three combined (shaded area). We have included *Planck* priors in all the results. Although the CMB priors have a significant impact on the SN results and to a lesser degree on WL and BAO results, they have much smaller effect on the WL+BAO+SN joint constraints.

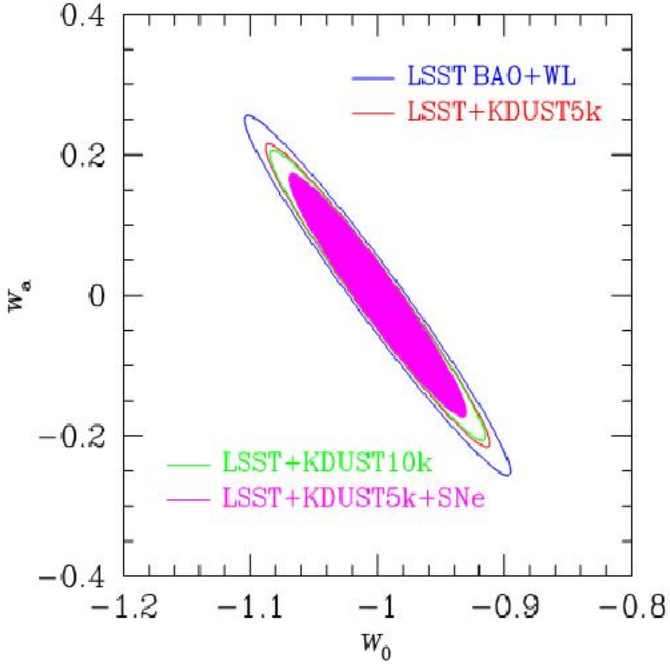
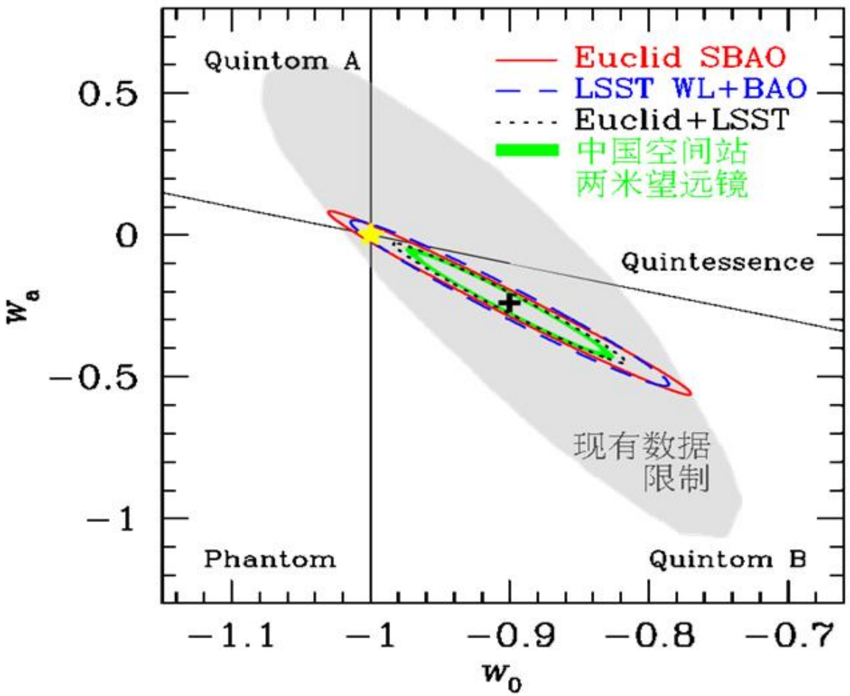



FIG. 4.— Forecasts of $1\sigma$ errors on the dark energy EOS parameters $w_0$ and $w_a$ for LSST BAO+WL (blue contour), a combination of LSST and KDUST 10,000 deg$^2$ *JH* survey (labeled as KDUST10k) as listed in Table 1 using BAO+WL (green contour), a combination of LSST and half of KDUST10k (labeled as KDUST5k) using BAO+WL (red contour), and a combination of LSST and KDUST5k using BAO+WL+SNe (magenta area).

# 中国空间站暗能量研究预期




对暗能量状态方程参数$w_0$与$w_a$的限制

# 再谈2011 年诺奖和精确宇宙学

**1998年SN 观测：**

i) 非加速膨胀： **axion-like**粒子造成；

ii）加速膨胀： 宇宙学常数**===**〉暗能量

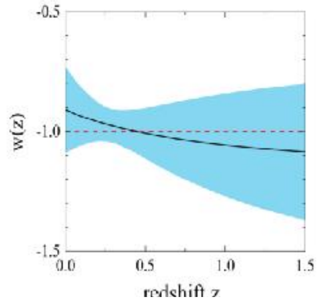
**Modified gravity**


**精确宇宙学：** （**WMAP**， **SDSS**， **SN** 观测等 **+**

宇宙学扰动理论 **+** 分析方法）

**WMAP** 贡献巨大， 已充分肯定！ 中国科学家贡献不可忽略！

i） “**axion-like**粒子造成” **impossible!**




ii) **DE:** \rho_de 已确定且精度高 （诺奖）；

**w(z)** --------------------------------------→

**c_s^2** 几乎没有限制

**MG:** =======→

**Einstein gravity +** “**effective DE**”

**consistent theory??**

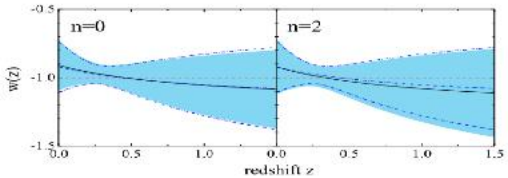



FIG. 4: The reconstructed $w(z)$ with 68% CL error are shown allowing for modified gravity (marginalized over $c_s$) in the scale independent (left panel) and scale-dependent $k^2$ (right panel) cases by the filled bands. The reconstruction for true dark energy, with gravity fixed to GR, is shown by the dash-dotted curves, the same in each panel.

International Journal of Modern Physics D
Vol. 17, No. 8 (2008) 1229–1243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# CONSTRAINTS ON THE SOUND SPEED OF DYNAMICAL DARK ENERGY

JUN-QING XIA, YI-FU CAI, TAO-TAO QIU, GONG-BO ZHAO and XINMIN ZHANG

*Institute of High Energy Physics, Chinese Academy of Science, PO Box 918-4, Beijing 100049, P. R. China*

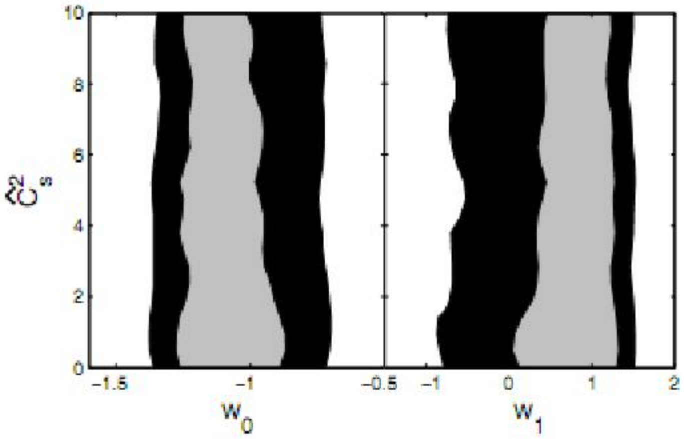



Fig. 2. Constraints in the $(w_0, \hat{c}_s^2)$ and $(w_1, \hat{c}_s^2)$ planes at 68% (dark) and 95% (light) CL from a combined analysis of CMB, LSS and SNIa observational data.

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

# On dark energy isocurvature perturbation

Jie Liu,[a] Mingzhe Li[b,d] and Xinmin Zhang[a,c]

(2011) 028

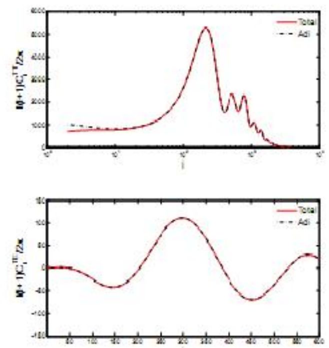


**Figure 1.** Top Panel: The angular power spectrum of CMB. Bottom Panel: The TE power spectrum of CMB. The red solid lines denote the spectrum obtained including the contribution of anti-correlated adiabatic and isocurvature perturbation, while the black dashed line is obtained by only including the adiabatic contribution.

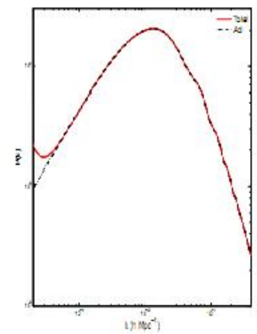


**Figure 2.** The matter power spectrum obtained with the cosmological parameters chosen to be the same as in figure 1. The red line denotes the total power spectrum and the black dash-dotted line is that with only the adiabatic component.

# 暗能量研究时间表？？

- **LSST……**能解决暗能量问题吗？

什么算解决了？

* 整个问题解决需要很长时间，但阶段性成果也很重要

（注意：**1998**年前，宇宙学常数问题已多年）

类似：旧量子论---〉量子力学----〉量子场论 ----〉

漫长但每一步都很重要，可能突破！！！

要充分肯定！

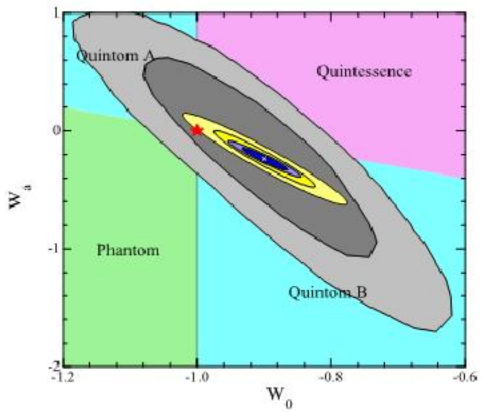
近十年目标：发现动力学或确定宇宙学常数==〉

即**Einstein**还是 非**Einstein ?!**

（当然确定哪一个动力学模型需更长时间）

目前：**(w_0, w_a) O(10%) ===**〉重要成果

不久将来：**at level of O(1%)===**〉重大成果




减小误差：系统误差; 统计误差

计算方法带来的误差

参数间简并性：曲率，中微子质量，张标比，

暗能量扰动， W 参数化，

Shift parameter or full data ======〉MCMC global fit (计算量大）

# Some Topics
# on Neutrino Cosmology

简介中微子与暗物质，暗能量及
宇宙正反物质不对称产生机制的联系

中科院高能所 **张新民**

**CCAST workshop on**
**“Neutrino Physics in the Daya Bay Era”**
2010年**11**月**4-5**日

# 中微子与宇宙学

## 中微子在宇宙学中至关重要

I. 中微子与 正反物质不对称（Leptogenesis）

II. 中微子和 暗能量 $\rho \sim (2*10^{-3} eV)^4$

III. 中微子和 暗物质

1）热暗物质 m_\nu < 0.51 eV （Li Hong et al)

2) ATIC and PAMELA Results on Cosmic e+- Excesses and Neutrino Masses

Bi, Gu, Li and Zhang

3) Steril neutrino as warm dark matter

4) Lepton asymmetry (Leptogenesis) and WIMP asymmetry

# baryogenesis
# 三个条件

Andrei Sakharov （1967年） 三个条件:

i) B violation ←----GUT theory

ii) C and CP violation ←-----K, B system …

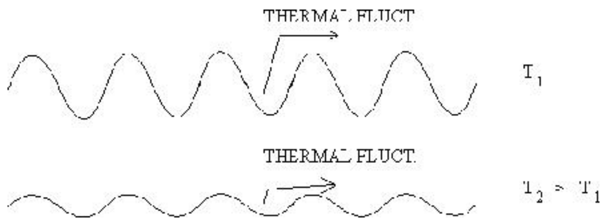
iii)Out of thermo-equilibrium (CPT conserved)
Freezing out of the heavy particles

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

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

# Electroweak baryogenesis

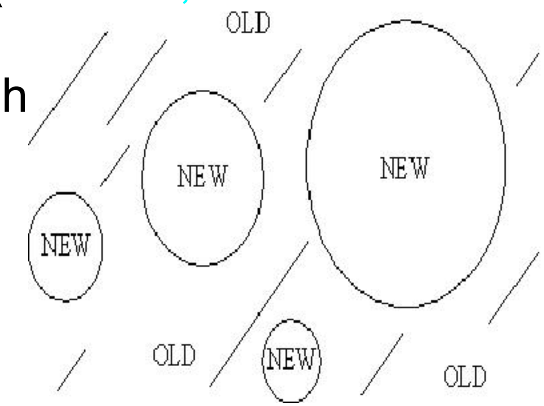
i)  B violation  ←----anomaly, non-trivial vacuum, sphaleron




87年，Peccei 研究组：Ringwald。。。Wetterich， Sola。。
X。 Zhang， M。 Carena， C. Wagner

ii) C and CP violation ←-----CKM mechanism
(however, too small-→new physics)

iii) First order ph




Need Higgs mass
< 40 GeV!→Need
New physics

# Electroweak Baryogenesis and New Physics

i) Need new physics

80年代末，2- Higgs，L-R symmetry, SUSY

ii) Effective lagrangian method ---→ anomalous couplings

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

Effective lagrangian approaches to EW baryogenesis

1) Higher dimensional operator relevant
to Higgs mass limit

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

Effective potential:

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

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 $\ln\alpha_F = 2\ln\pi - 2\gamma \simeq 1.14$.

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

$$O_3 = \alpha \frac{\phi^6}{\Lambda^2} \implies m_H^2 < (35\ GeV)^2 + 8\alpha \frac{v^4}{\Lambda^2}$$

Xinmin Zhang PRD47, 3065 (1993)
Cedric Delaunay, Christophe Grojean, James D. Wells
**JHEP 0804:029,2008**

Electroweak vacuum stability
A. Datta, B.-L. Young and X. Zhang
PLB385, 225 (1996)

Prediction for a light Higgs !

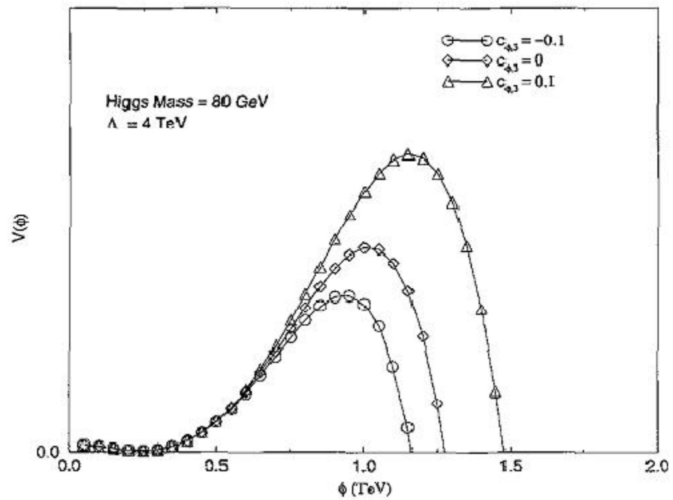



Fig. 1. The effective potential for various values of $c_{\phi,3}$. The Higgs mass is taken as 80 GeV and the scale of new physics $\Lambda = 4$ TeV. The curve with $c_{\phi,3} = 0$ corresponds to the standard model.

# 125 GeV Higgs and its implication in cosmology

i)Within the SM, it is all consistent:

precision measurement;

Vacuum stability;

Ii)Interesting implications for SUSY

iii) Implications for cosmology:

a) Supporting for the idea of building dark energy models with fundamental scalar fields;

b)Electroweak baryogenesis =➔low cutoff

2) Operator relevant to baryon number generation
(Why top? Interacting strongly with the bubble wall )

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

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

Anomalous top-Higgs couplings:

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

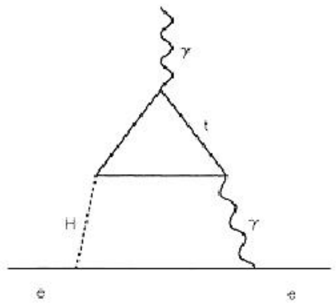
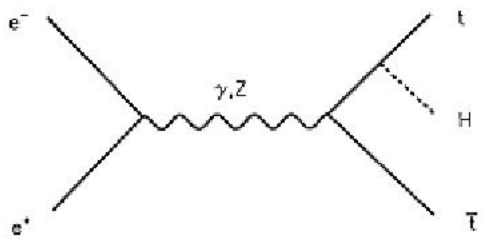



FIG. 1. Dominant contribution to $d_e$, the electric dipole moment of the electron.




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

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

## Electroweak baryogenesis

## and anomalous Top, Higgs coups

$$O_3 = \alpha \frac{\phi^6}{\Lambda^2} \quad \Longrightarrow \quad m_H^2 < (35\ GeV)^2 + 8\alpha \frac{v^4}{\Lambda^2}$$

$$\mathcal{O}^t = c_t\, e^{i\xi}\, \frac{(\phi^2 - \frac{v^2}{2})}{\Lambda^2}\, \Gamma_t\, \overline{\Psi_L} \tilde{\Phi} t_R \quad \Longrightarrow \quad \frac{n_B}{s} \sim \kappa\, c_t \sin\xi\; 10^{-9}$$

Probing for anomalous Top, Higgs couplings at Tevatron, LHC, ILC…

# Leptogenesis and Neutrino

1. 右手中微子的 Majorana 质量项破坏轻子数
2. 右手中微子的 Yukawa 耦合项破坏 C 和 CP
3. 右手中微子脱离热平衡

## Sphaleron 过程将部分轻子数转化为重子数

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

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

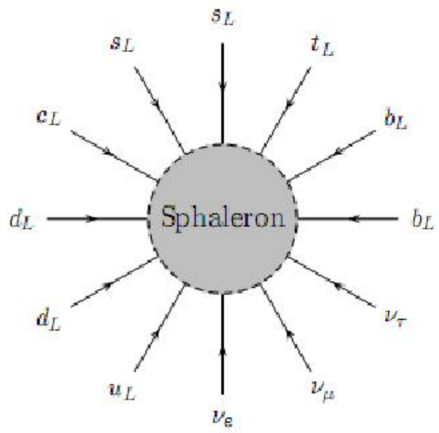
要考虑gauge interaction, Yukawa interaction and also QCD sphaleron

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

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

R. Mohapatra and X. Zhang, Phys.Rev.D45,

2699- 2705, (1992)

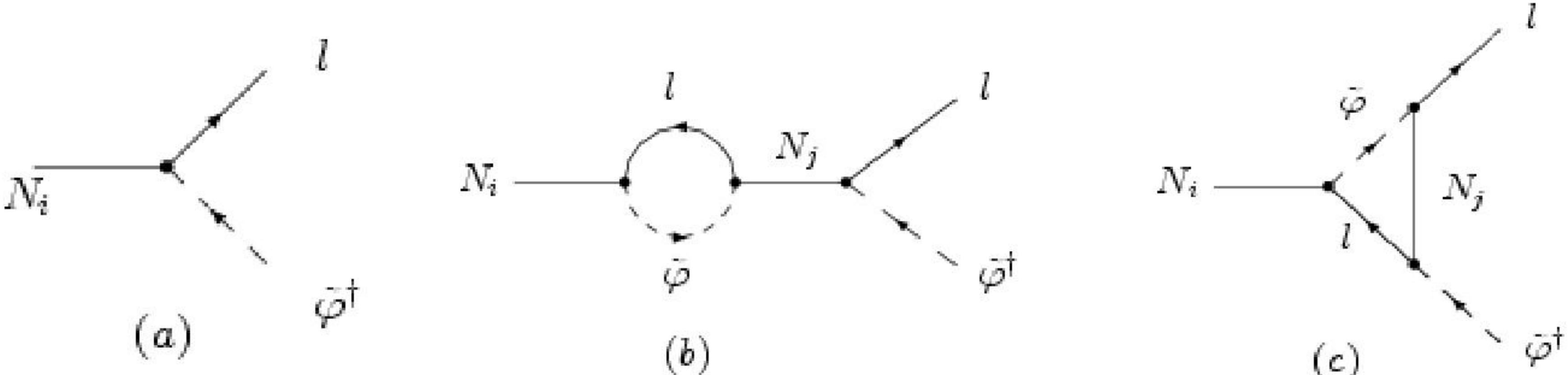


# Type-I Seesaw 模型下的 Leptogenesis 机制

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

$$= \frac{i}{2}\bar{N}_i\gamma^\mu\partial_\mu N_i - \frac{1}{2}M_i\bar{N}_iN_i - y^\nu_{\alpha i}\bar{l}_{L\alpha}\tilde{\varphi}N_i + h.c. \qquad N_i = \nu_{Ri} + (\nu_{Ri})^C$$

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




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

**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).**

90年代初，大家并不感兴趣！！？？

# Motivation for long-baseline neutrino oscillation experiments

- Neutrino CP violation
- Actually not direct, still interesting?
- LBL neutrino oscillating experiment in China!

# 中微子与暗能量

$$\frac{Q}{\Lambda}\ \frac{ll\,\phi\phi}{M}$$

$$Q\bar{N}_R^c N_R$$

→ $m_\nu$ mass varying neutrinos

**中微子与暗能量有关吗？**

1. ΛCDM: $\rho_\lambda \propto (10^{-3} ev)^4 \propto (m_\nu)^4$
2. QCDM: $m_Q \propto 10^{-33} eV \propto \frac{m_\nu^{\ 2}}{M_{pl}}$

*顾佩洪，王秀莲，张新民，PRD68, 087301 (2003)*

## 中微子与暗能量模型的特征:

1. 中微子是暗能量的一部分，决定宇宙的演化和命运

2. 中微子的质量改变，是时间和空间的函数，CMB, LSS 上的效应，可用天文观测和 中微子振荡检验

# Dark Energy and Neutrino Mass Limits from Baryogenesis

Peihong Gu,* Xiulian Wang,† and Xinmin Zhang‡
*Institute of High Energy Physics, Chinese Academy of Sciences,*
*P.O. Box 918-4, Beijing 100039, People's Republic of China*

In this brief report we consider couplings of the dark energy scalar, such as Quintessence to the neutrinos and discuss its implications in studies on the neutrino mass limits from Baryogenesis. During the evolution of the dark energy scalar, the neutrino masses vary, consequently the bounds on the neutrino masses we have here differ from those obtained before.

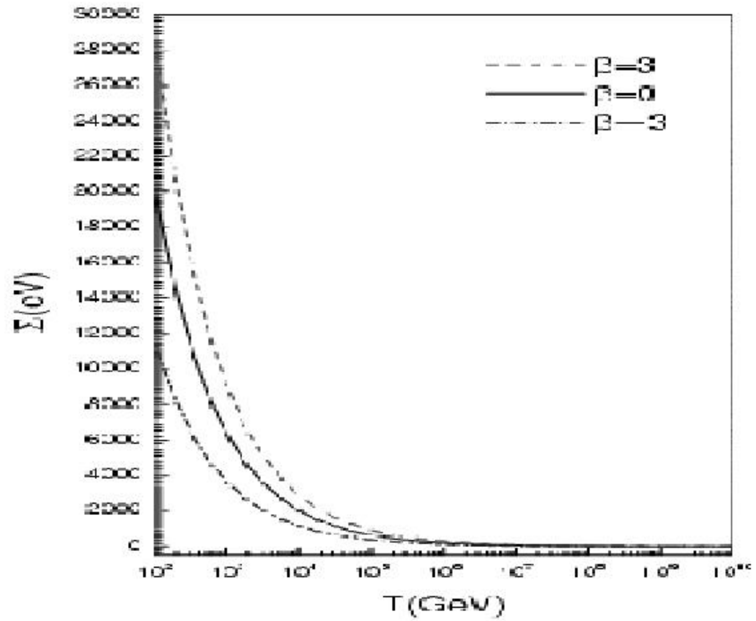


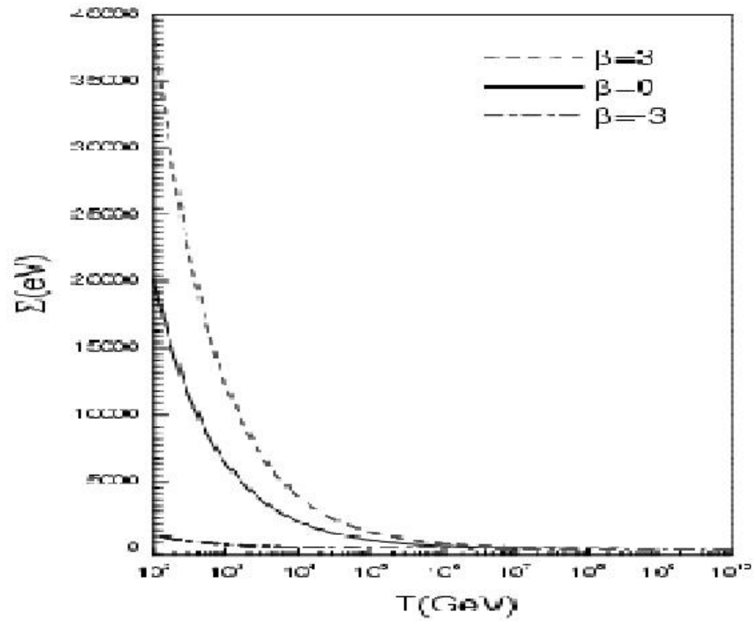
$$\beta \frac{Q}{M_{pl}} \frac{2}{f} l_L l_L \phi\phi + h.c, \qquad L_{\not{L}}(Q) = \frac{2C(Q)}{f} l_L l_L \phi\phi + h.c$$

Where, $C(Q) = 1 + \beta Q / M_{pl}$

Corresponding the formula for the neutrino mass upper limit now is:

$$\sum m_{\nu i}^2 = [0.2\text{eV}(\frac{10^{12}\text{GeV}}{T})^{\frac{1}{2}} \frac{C(Q_0)}{C(Q_T)}]^2$$



# Dark Energy from Mass Varying Neutrinos

Astro-ph/0309800

**Rob Fardon, Ann E. Nelson and Neal Weiner**

*Department of Physics, Box 1560, University of Washington,*
*Seattle, WA 98195-1560, USA*

ABSTRACT: We show that mass varying neutrinos (MaVaNs) can behave as a negative pressure fluid which could be the origin of the cosmic acceleration. We derive a model independent relation between the neutrino mass and the equation of state parameter of the neutrino dark energy, which is applicable for general theories of mass varying particles. The neutrino mass depends on the local neutrino density and the observed neutrino mass can exceed the cosmological bound on a constant neutrino mass. We discuss microscopic realizations of the MaVaN acceleration scenario, which involve a sterile neutrino. We consider naturalness constraints for mass varying particles, and find that both eV cutoffs and eV mass particles are needed to avoid fine-tuning. These considerations give a (current) mass of order an eV for the sterile neutrino in microscopic realizations, which could be detectable at MiniBooNE. Because the sterile neutrino was much heavier at earlier times, constraints from big bang nucleosynthesis on additional states are not problematic. We consider regions of high neutrino density and find that the most likely place today to find neutrino masses which are significantly different from the neutrino masses in our solar system is in a supernova. The possibility of different neutrino mass in different regions of the galaxy and the local group could be significant for Z-burst models of ultra-high energy cosmic rays. We also consider the cosmology of and the constraints on the "acceleron", the scalar field which is responsible for the varying neutrino mass, and briefly discuss neutrino density dependent variations in other constants, such as the fine structure constant.

# Cosmological evolution of Interacting Dark Energy models with massvarying neutrinos hep/ph/0412002

-Xiaojun Bi, Bo Feng, Hong Li, Xinmin Zhang

$$\mathcal{L} = \mathcal{L}_\nu + \mathcal{L}_\phi + M(\phi)\bar{\nu}\nu \qquad \mathcal{L}_\nu = \bar{\nu} i \not{\partial} \nu,$$

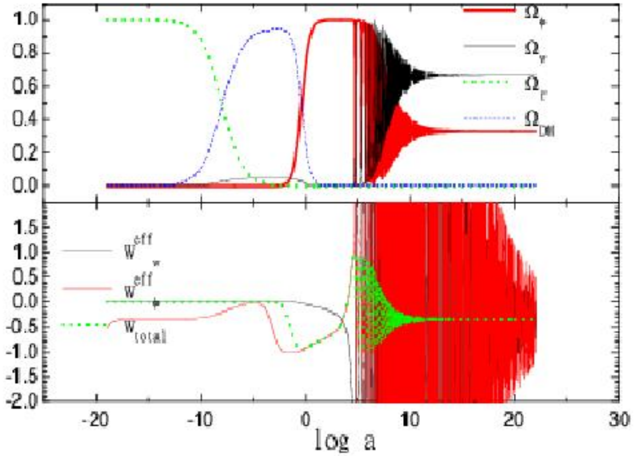



FIG. 3: The $\Omega$ and the effective equation of state $W$ as functions of the scale factor $\log a$ for $V = V_0\phi^4$ and $M = \bar{M}\phi^{-2}$.

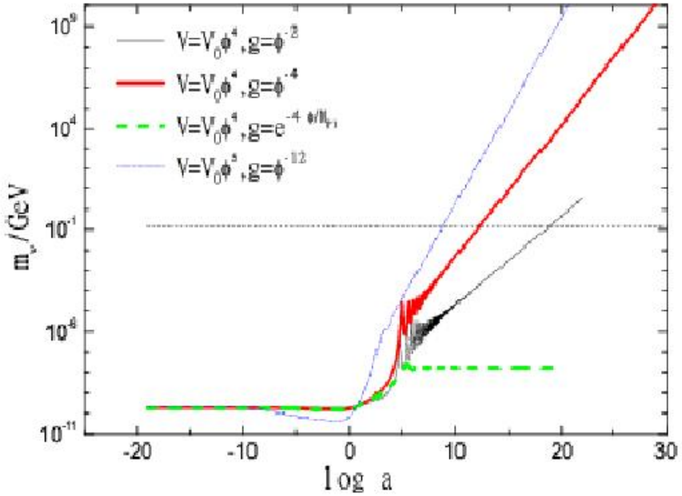



FIG. 6: The neutrino mass as functions of the scale factor $\log a$, where $g = M(\phi)/\bar{M}$.

# Cosmology with massive neutrinos coupled to dark energy

Astro-ph/0503349

A. W. Brookfield,[1] C. van de Bruck,[2] D. F. Mota,[3,4] and D. Tocchini-Valentini[4]

Cosmology with massive neutrinos coupled to dark energy is investigated. In such models, the neutrino mass is a function of a scalar field, which plays the role of dark energy. The background evolution, as well as the evolution of cosmological perturbations is discussed. A reduction of power in the anisotropy spectrum of the cosmic microwave background radiation at low multiploles is observed for some choices of parameters.

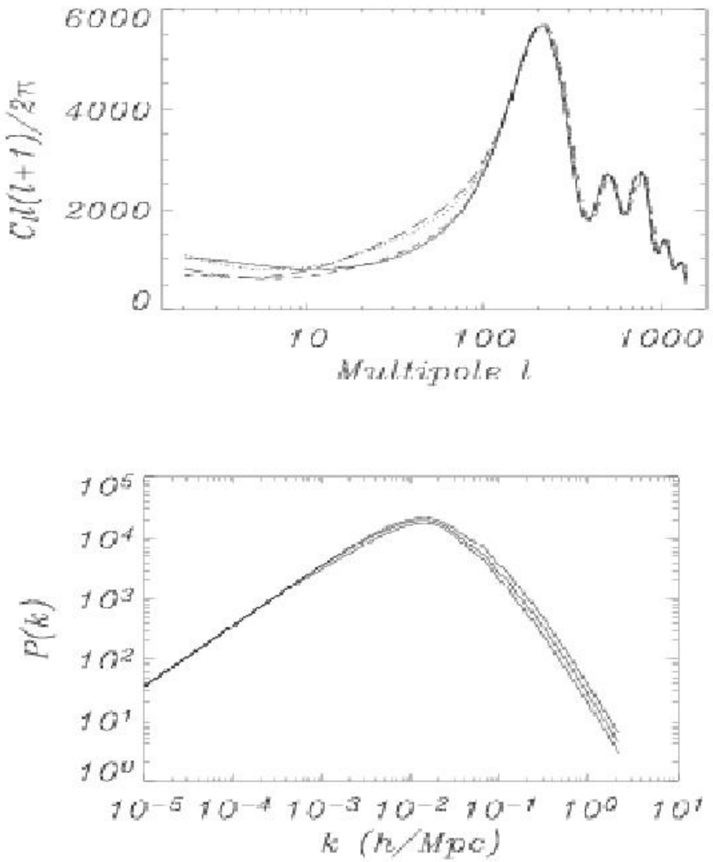


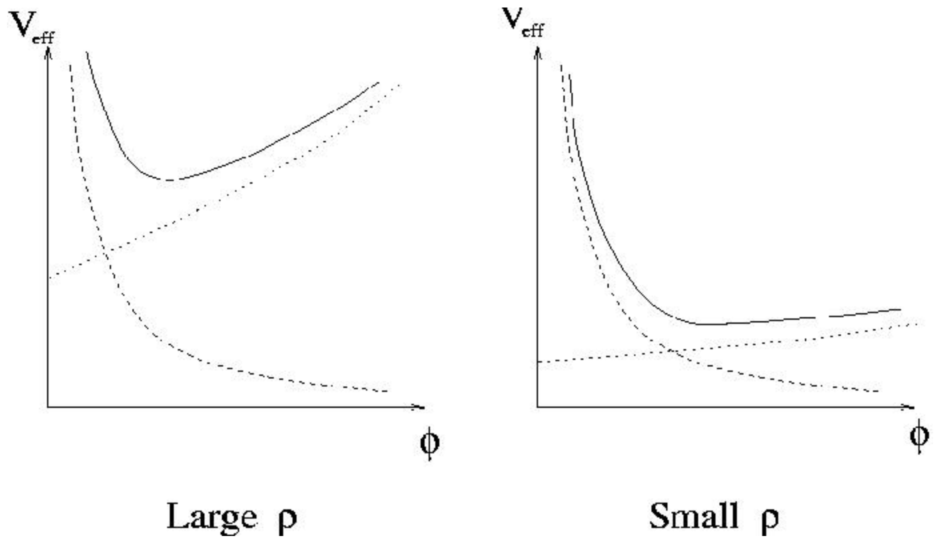

FIG. 3: Upper panel: the CMB anisotropy spectrum (unnormalized). Solid line: $\beta = 0$, $\lambda = 1$; short–dashed line: $\beta = 1$, $\lambda = 1$; dotted line: $\beta = -0.75$, $\lambda = 1$; long–dashed line: $\beta = 1$, $\lambda = 0.5$. The lower panel shows the matter power spectrum. From the top curve to the bottom curve: ($\beta = 0$, $\lambda = 1$), ($\beta = 1$, $\lambda = 0.5$), ($\beta = -0.75$, $\lambda = 1$). The matter power spectrum for ($\beta = 1$, $\lambda = 1$) is indistinguishable from the ($\beta = 0$, $\lambda = 1$) curve.

# 中微子振荡检验暗能量

基本想法: $m_\nu^{eff}(\phi) = m_\nu^0 - M_\nu(\phi)$

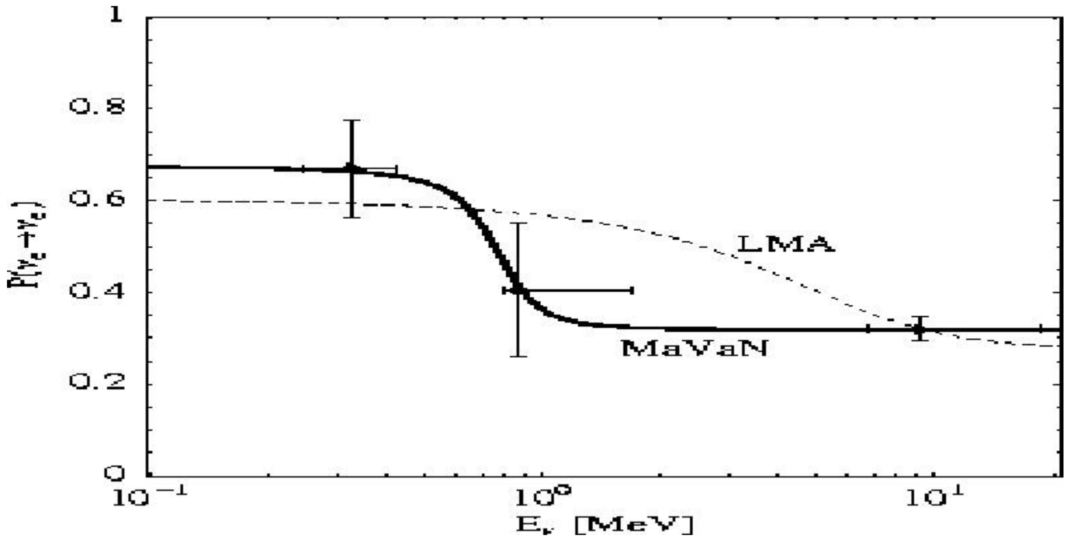
其中 $\phi$ 的值由势函数 $V_{eff}(\phi)$ 决定,

$$V_{eff}(\phi) = V(\phi) + \rho_i(\phi) \qquad i = \nu, e, p, n$$




太阳中微子振荡:

$$i\frac{d}{dr}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix} = \frac{1}{2E_\nu}\left[U\begin{pmatrix}(m_1^0 - M_1(r))^2 & (M_3(r))^2\\ (M_3(r))^2 & (m_2^0 - M_2(r))^2\end{pmatrix}U^+ + \begin{pmatrix}A(r) & 0\\ 0 & 0\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix}$$





D.B. Kaplan *et al.*, PRL 93,091801 (2003);

V. Barger *et al.*, hep-ph/0502196;

M. Cirelli *et al.*, hep-ph/0503028.

# Neutrino and dark matter

neutrino mass and abundance:

$$\Omega_\nu h^2 = \frac{\sum m_\nu}{92.5\ \mathrm{eV}},$$

*hot dark matter suppress power* at small scale

$$k_{\rm nr} \approx 0.026 \left(\frac{m_\nu}{1\,\mathrm{eV}}\right)^{1/2} \Omega_m^{1/2} h\,\mathrm{Mpc}^{-1}.$$

$$\left(\frac{\Delta P}{P}\right) \approx -8\frac{\Omega_\nu}{\Omega_m} \approx -0.8\left(\frac{m_\nu}{1\,\mathrm{eV}}\right)\left(\frac{0.1N}{\Omega_m h^2}\right).$$

O. Elgaroy et al (2dFGRS)
PRL 89, 061301 (2002)

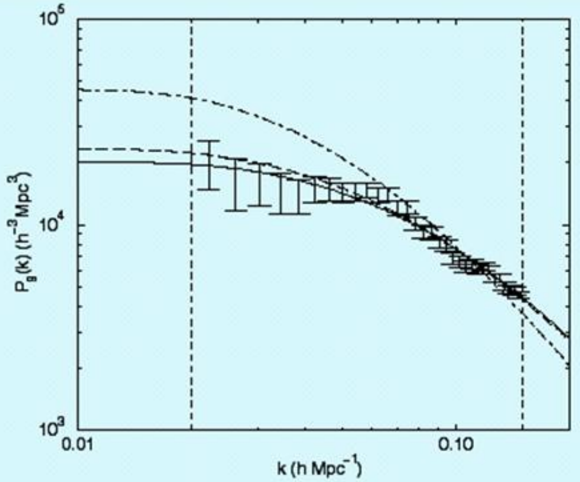
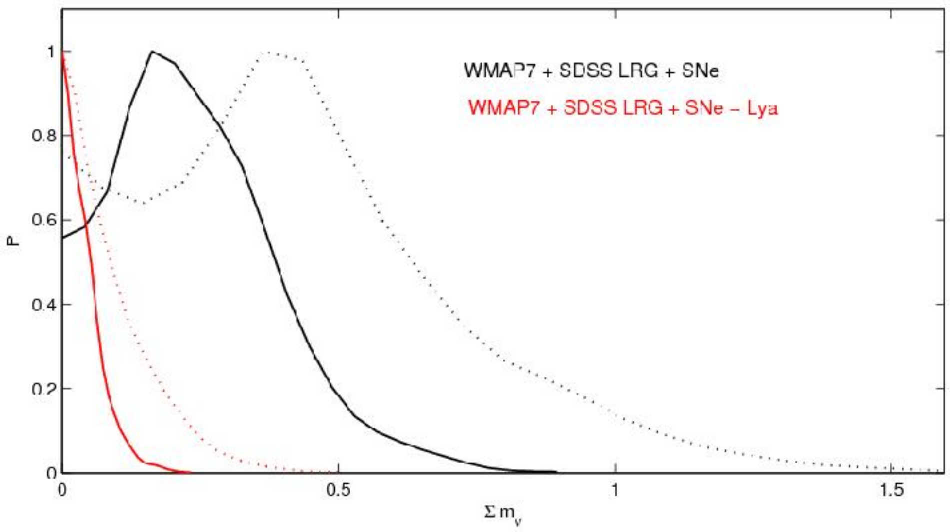
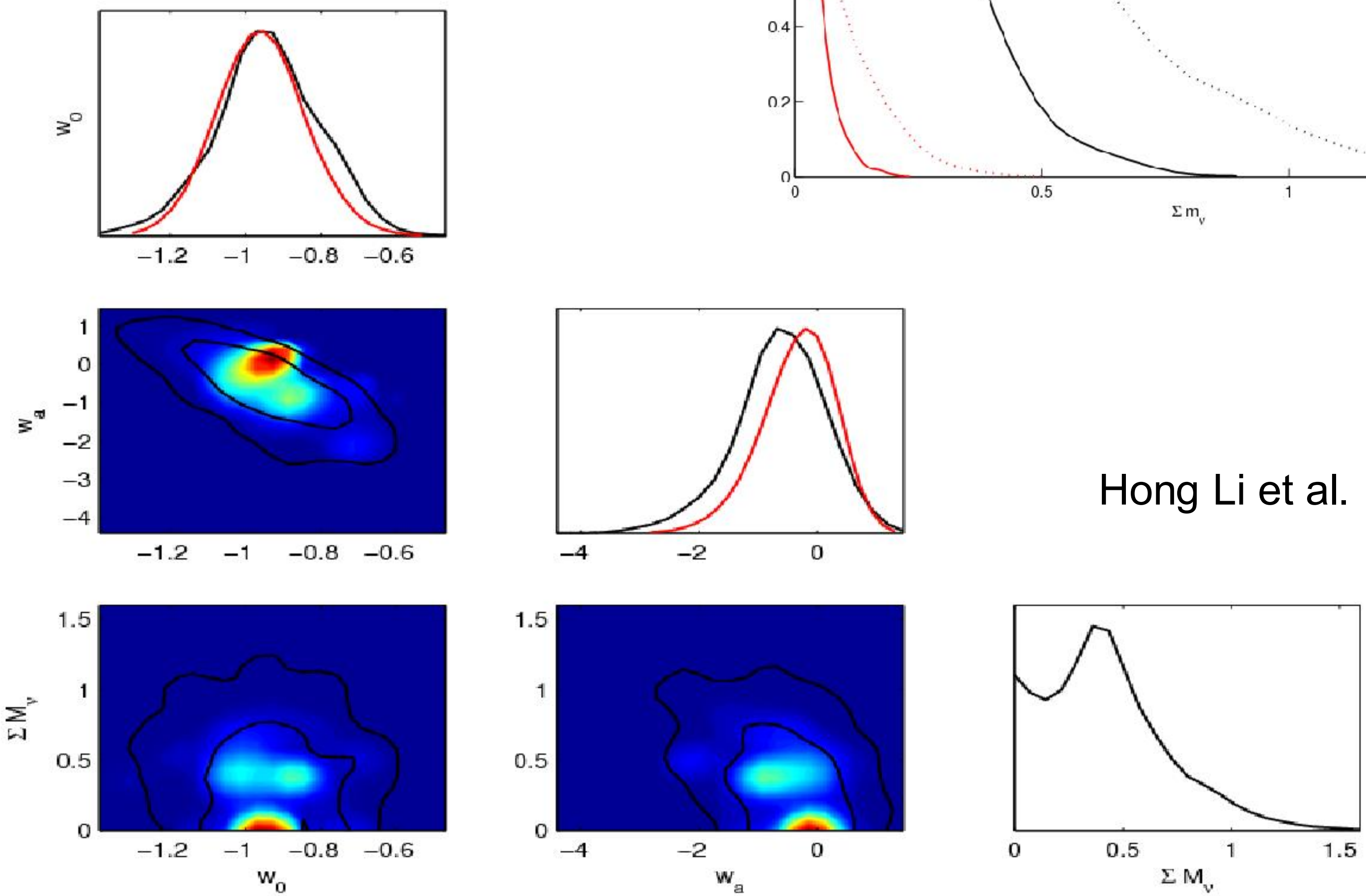



FIG. 1. Power spectra for $\Omega_\nu = 0$ (solid line), $\Omega_\nu = 0.01$ (dashed line), and $\Omega_\nu = 0.05$ (dot-dashed line) with amplitudes fitted to the 2dFGRS power spectrum data (vertical bars) in redshift space. We have fixed $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $h = 0.7$, and $\Omega_b h^2 = 0.02$. The vertical dashed lines limit the range in $k$ used in the fits.

$\Sigma m_\nu < 0.51$ eV ( ΛCDM )

$< 0.964$ eV ( w0,wa )




Hong Li et al.

# WIMPs 暗物质

李明哲　毕效军　张新民

摘要：

暗物质是21世纪宇宙学和粒子物理研究的热点问题。WIMPs是一种流行的暗物质粒子候选者，即weakly interacting massive particles的缩写，译为“弱作用重粒子”。目前我国计划中的暗物质粒子探测实验项目都是围绕着WIMPs暗物质开展的。本文将详细地阐述与WIMPs暗物质相关的基本问题，并力图澄清一些易于误解的概念。

《现代物理知识》2011年 第4期

# 介绍内容

- Cold WIMPs

- Warm WIMPs

  Boost factor?

- SuperWIMPs

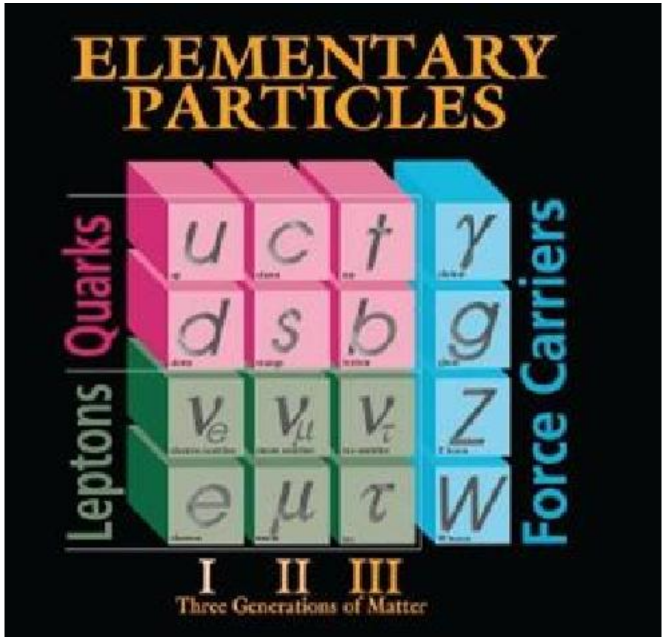
  Quintessino; heavy charged massive particles

- Asymmetric WIMPs

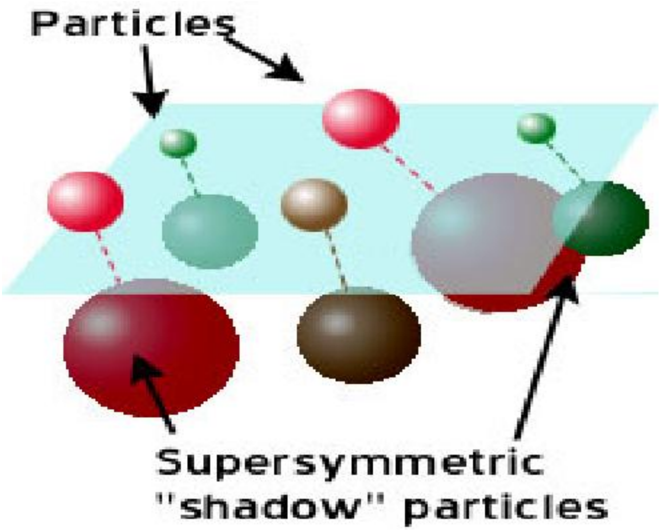
  Connecting to Baryo/Leptogenesis

# 暗物质：需要新物理

（有质量中微子：Hot DM）




# 候选者：




WIMP(弱作用重粒子)
代表一类模型

例如，超对称模型中的中性伴（neutralino）；
KK State in extra dimension theory

两种产生机制:

**1.** 热产生机制（**Thermal**）

（像光子退耦一样）

**=➔Cold WIMPs**

**2.** 非热产生机制 **(Non-Thermal)**

**(BBN** 中自由中子**decay)**

**==➔cold or warm WIMPs**

张新民等

**JHEP 9912:003,1999.**

**arXiv: hep-ph/9901357**

**Phys.Rev.Lett.86:954,2001.**

**arXiv: astro-ph/0009003**

张新民大会报告：**Cosmo99;  SUSY04**

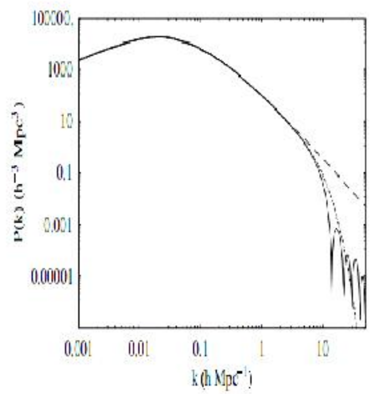



FIG. 1. Comparison of the power spectra of the CDM model (long-dashed curve), the WDM model with $m_W = 1$ keV (short-dashed curve), and the NTDM model with $r_c = 1.5 \times 10^{-7}$ (solid curve).

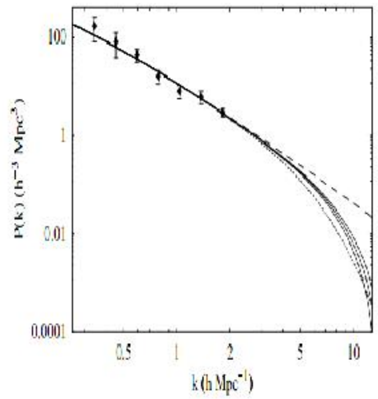



FIG. 2. The power spectra of the CDM model (long-dashed curve), the WDM model with $m_W = 750$ eV (short-dashed curve), and the NTDM models with $r_c = (1.3, 1.4, 1.5) \times 10^{-7}$ (solid curves, from top down), compared to the observed Lyman-$\alpha$ $P(k)$ at $z = 2.5$ (filled diamonds with error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

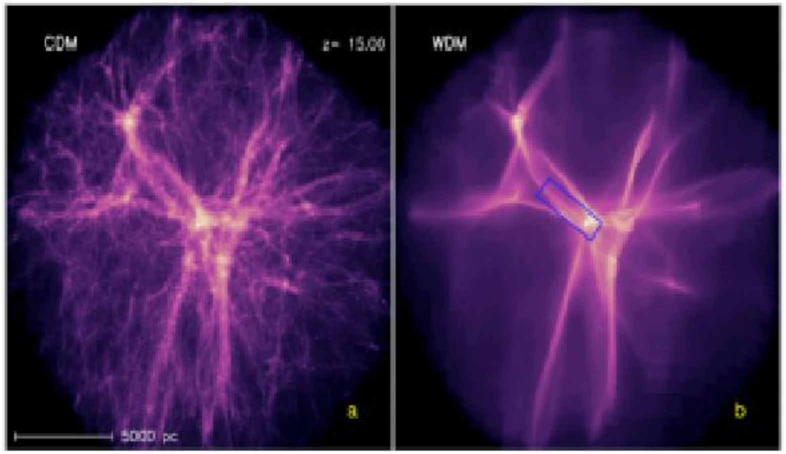



Figure 2. A comparison of small-scale structure from standard Cold Dark Matter (left) vs Warm Dark Matter with a 3 keV dark matter particle (Gao & Theuns 2007).

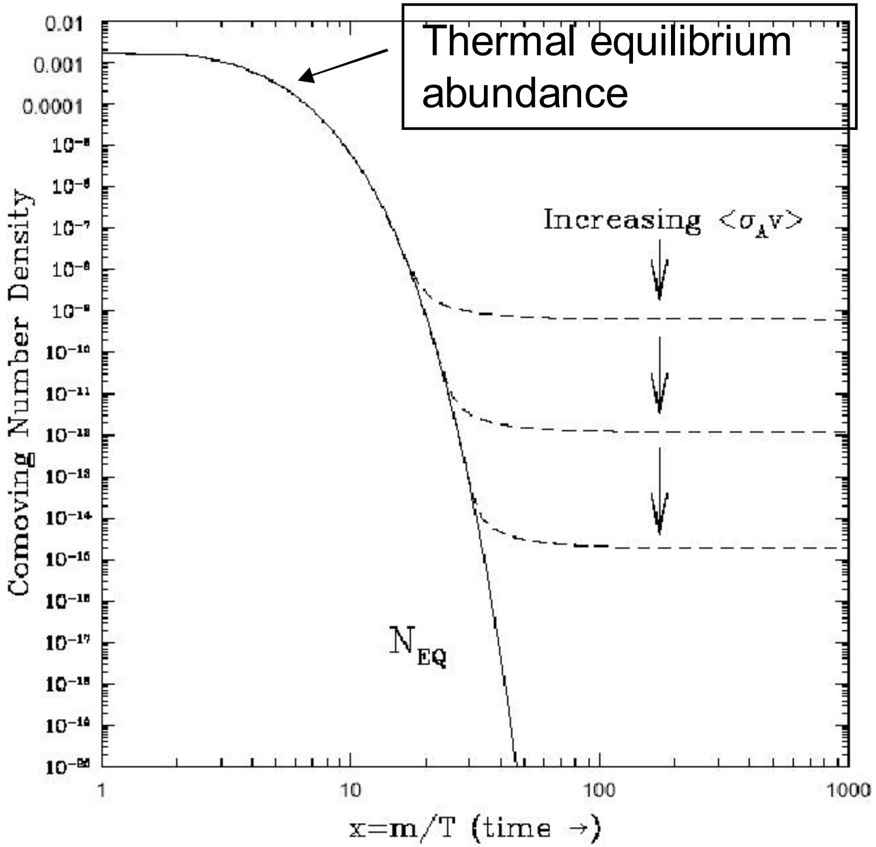
# WIMP Miracle

## WIMP thermal production

At T >> m, $f + \bar{f} \leftrightarrow \chi + \chi$

At T < m, $\chi + \chi \rightarrow f + \bar{f}$

At T ~ m/22, $\Gamma = n\langle \sigma v \rangle \sim H$, decoupled, relic density is inversely proportional to the interaction strength $\Omega_\chi h^2 \approx \frac{3 \cdot 10^{-27} cm^3 s^{-1}}{\langle \sigma v \rangle_{T_f}}$




For the weak scale interaction and mass scale (non-relativistic dark matter particles) $\langle \sigma v \rangle \sim 3 \cdot 10^{-26} cm^3 s^{-1}$ ,
if $\alpha \sim 10^{-2}$ $M_{\text{weak}} \sim 100 GeV$ and $v^2 \approx c^2 / 22$

**WIMP is a natural dark matter candidate giving right relic density**

## Difficulties with thermal WIMPs

1）Strong constraints on the model parameters

2) Cross section too small to account for the anomalous data observed by Heat, Pamela, ATIC, HESS ……

PHYSICAL REVIEW D **80,** 083529 (2009)

# Nonthermal "WIMP miracle"

Bobby Samir Acharya*
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Gordon Kane† and Scott Watson‡,§
*Michigan Center for Theoretical Physics, Ann Arbor, Michigan, USA*

Piyush Kumar‖
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(Received 4 September 2009; published 26 October 2009)

While this is an extremely compelling idea, it can often be difficult to implement in practice, with the relic density predicted by theory disagreeing with the data by a couple orders of magnitude in both directions. That is, the thermal "WIMP miracle" faces significant challenges when directly confronted with precision data. It is not clear at present if this should be viewed as a failure of the theoretical models or as a phenomenological guide to select particular classes of models. For example, in supersymmetric models, where the thermal relic idea has perhaps been most extensively explored, most of the parameter space yields an incorrect dark matter density, prompting attempts to look at special regions [2].

$$\Omega_\chi h^2 \approx 0.1 \times \left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)\left(\frac{10.75}{g_*}\right)^{1/4}\left(\frac{\sigma_0}{\langle\sigma v\rangle}\right) \times \left(\frac{100\ \mathrm{TeV}}{m_\phi}\right)^{3/2}, \qquad (16)$$

where $\sigma_0 = 3 \times 10^{-24}\ \mathrm{cm}^3\,\mathrm{s}^{-1}$ and we have assumed[2] the

PHYSICAL REVIEW D **74**, 023510 (2006)

# Neutralino with the right cold dark matter abundance in (almost) any supersymmetric model

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(Received 29 March 2006; published 7 July 2006)

We consider nonstandard cosmological models in which the late decay of a scalar field $\phi$ reheats the Universe to a low reheating temperature, between 5 MeV and the standard freeze-out temperature of neutralinos of mass $m_\chi$. We point out that in these models all neutralinos with standard density $\Omega_{\rm std} \gtrsim 10^{-5}(100\ {\rm GeV}/m_\chi)$ can have the density of cold dark matter, provided the right combination of the following two parameters can be achieved in the high-energy theory: the reheating temperature, and the ratio of the number of neutralinos produced per $\phi$ decay over the $\phi$ field mass. We present the ranges of these parameters where a combination of thermal and nonthermal neutralino production leads to the desired density, as functions of $\Omega_{\rm std}$ and $m_\chi$.

DOI: 10.1103/PhysRevD.74.023510 PACS numbers: 95.35.+d, 12.60.Jv, 14.80.Ly, 98.80.Cq

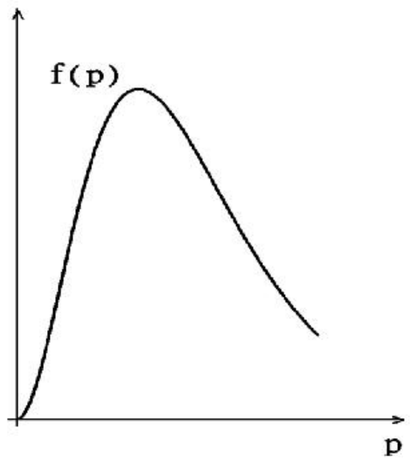
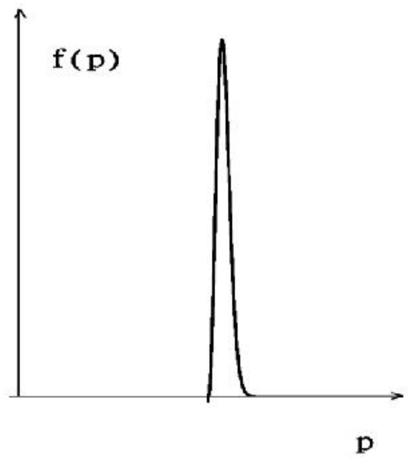
- **Non-thermal production of neutralino cold dark matter from cosmic string decays**
  R. Jeannerot, (ICTP, Trieste) , X. Zhang, (CCAST World Lab, Beijing & Beijing, Inst. High Energy Phys. & ICTP, Trieste) , Robert H. Brandenberger, (Brown U.) . BROWN-HET-1160, IC-98-236, Jan 1999. 4pp.
  Published in **JHEP 9912:003,1999**.
  e-Print: **hep-ph/9901357**

- **Nonthermal production of WIMPs and the subgalactic structure of the universe**
  W.B. Lin, (Beijing, Inst. High Energy Phys.) , D.H. Huang, (Peking U. & Beijing, Inst. High Energy Phys.) , X. Zhang, (Beijing, Inst. High Energy Phys.) , Robert H. Brandenberger, (Brown U.) . Sep 2000. 6pp.
  Published in **Phys.Rev.Lett.86:954,2001**.
  e-Print: **astro-ph/0009003**

  There is increasing evidence that conventional cold dark matter (CDM) models lead to conflicts between observations and numerical simulations of dark matter halos on sub-galactic scales. Spergel and Steinhardt showed that if the CDM is strongly self-interacting, then the conflicts disappear. However, the assumption of strong self-interaction would rule out the favored candidates for CDM, namely weakly interacting massive particles (WIMPs), such as the neutralino. In this paper we propose a mechanism of non-thermal production of WIMPs and study its implications on the power spectrum. We find that the non-vanishing velocity of the WIMPs suppresses the power spectrum on small scales compared to what it obtained in the conventional CDM model. Our results show that, in this context, WIMPs as candidates for dark matter can work well both on large scales and on sub-galactic scales.

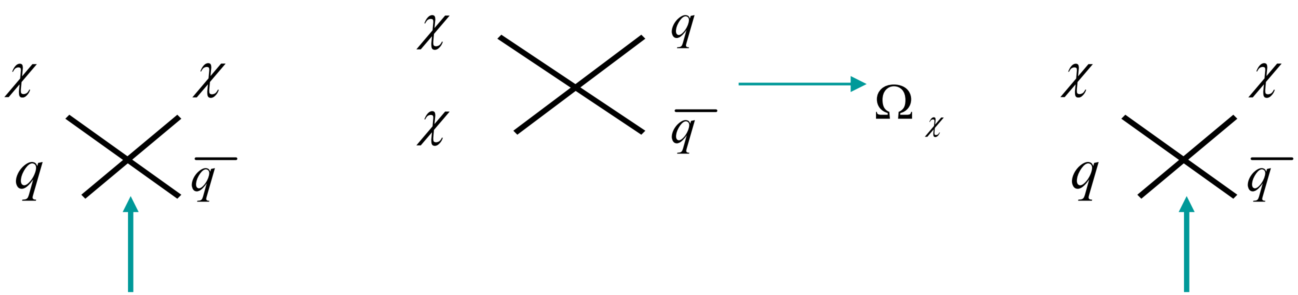
=======〉 Warm WIMPs model

张新民SUSY04大会报告

| | Thermal production | Non-thermal |
|---|---|---|
| 1， |  |  |



2， enhancing the parameter space




**Weak interactions** **“stronger” interactions**

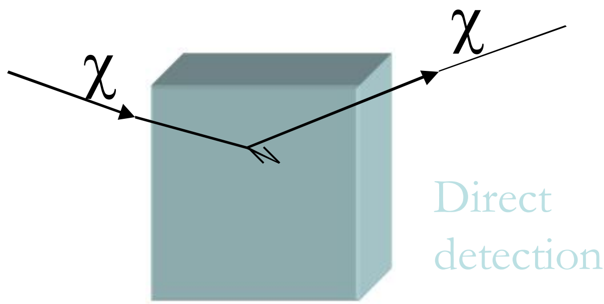
3， cold dark matter warm dark matter

# 暗物质粒子探测方法

- Collider: LHC（BEPC /BES?）
- 直接探测

  DAMA, CDMS 。。。

  （我国，地下实验室）

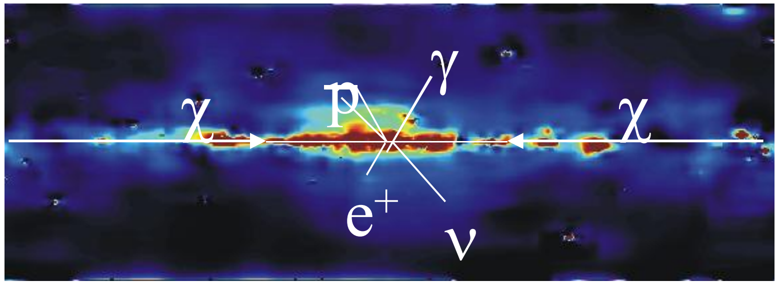



- 间接探测

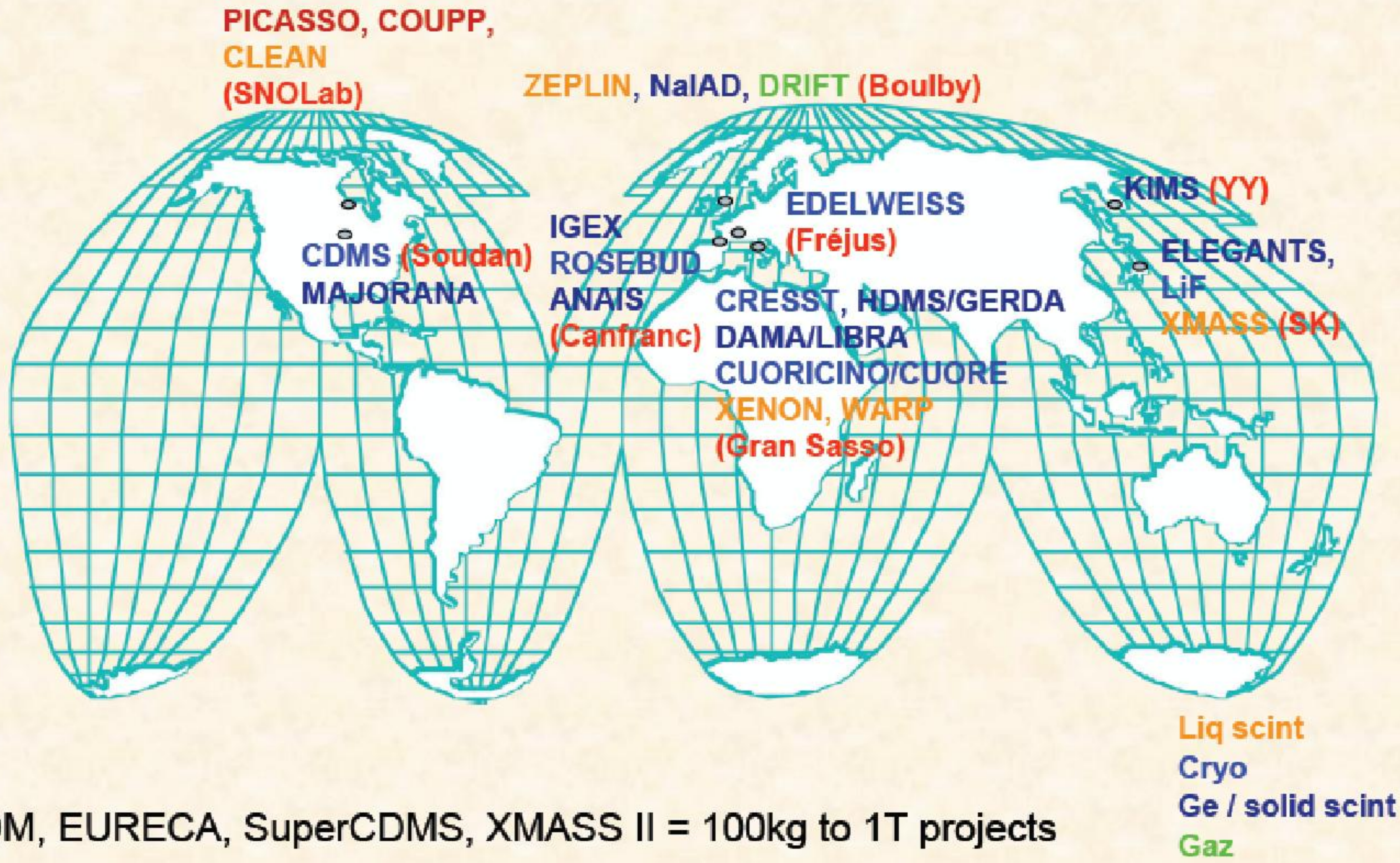
  空间： Pamela, ATIC, FERMI, AMS,

  (我国，小卫星，空间站)

  地面： H.E.S.S, 羊八井



# Wimp direct detection experiments



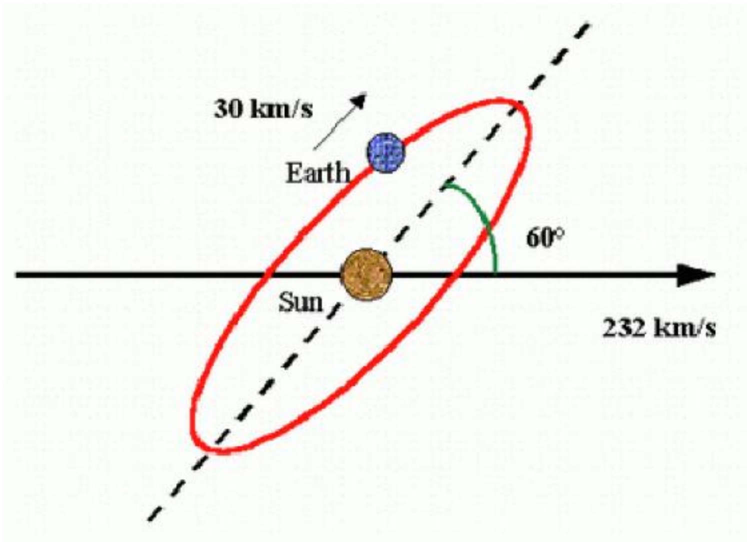

ArDM, EURECA, SuperCDMS, XMASS II = 100kg to 1T projects

# DAMA confirms the solar modulation signals at 9 σ

Velocity of the Earth and detection rate of DAMA can be given as

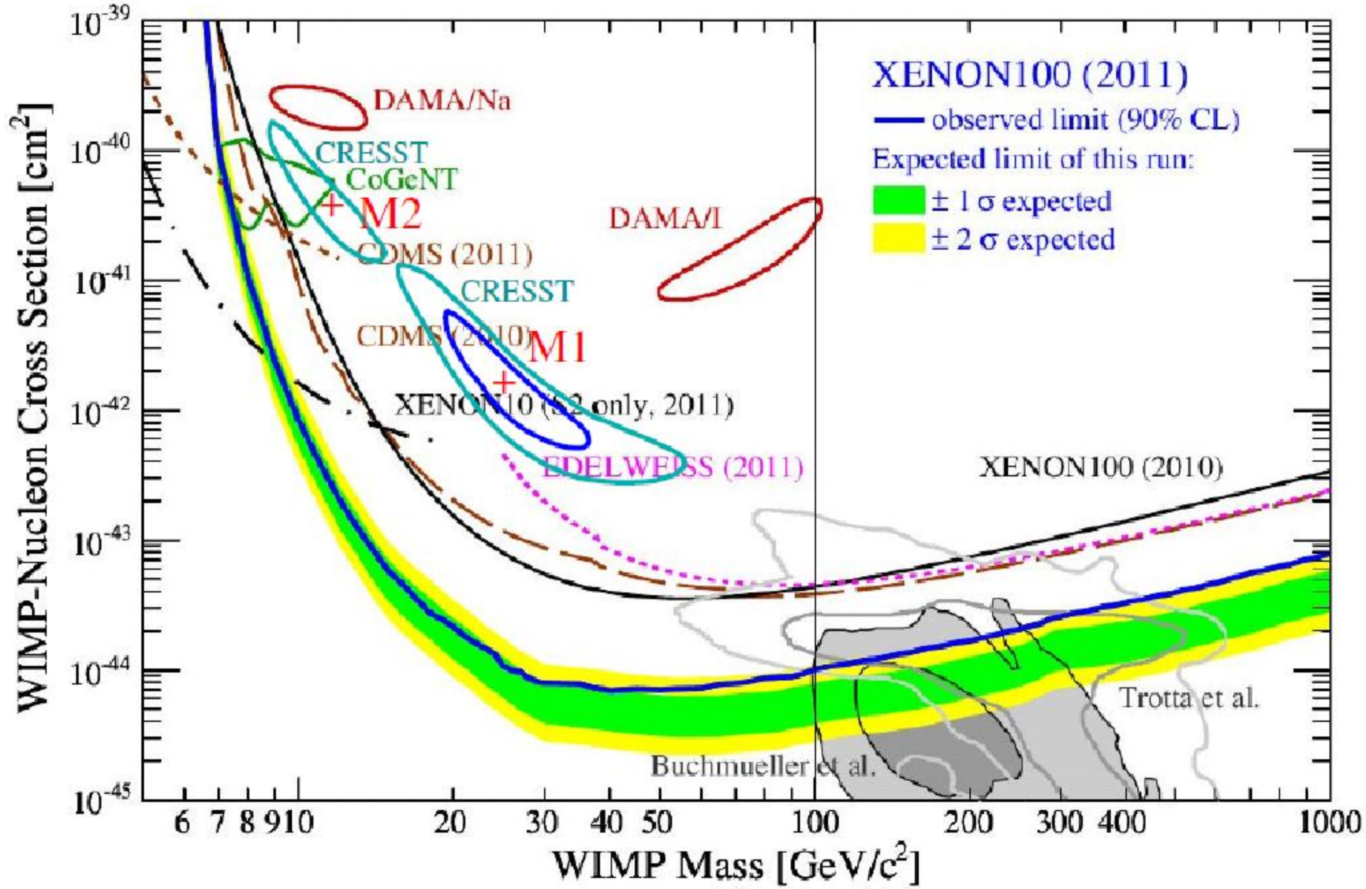
$$v_e = v_\odot + v_{orb} \cos\gamma \cos[\omega(t - t_0)]$$

$$R_i = R_i^0 + S_i^1 \cos[\omega(t - t_0)],$$

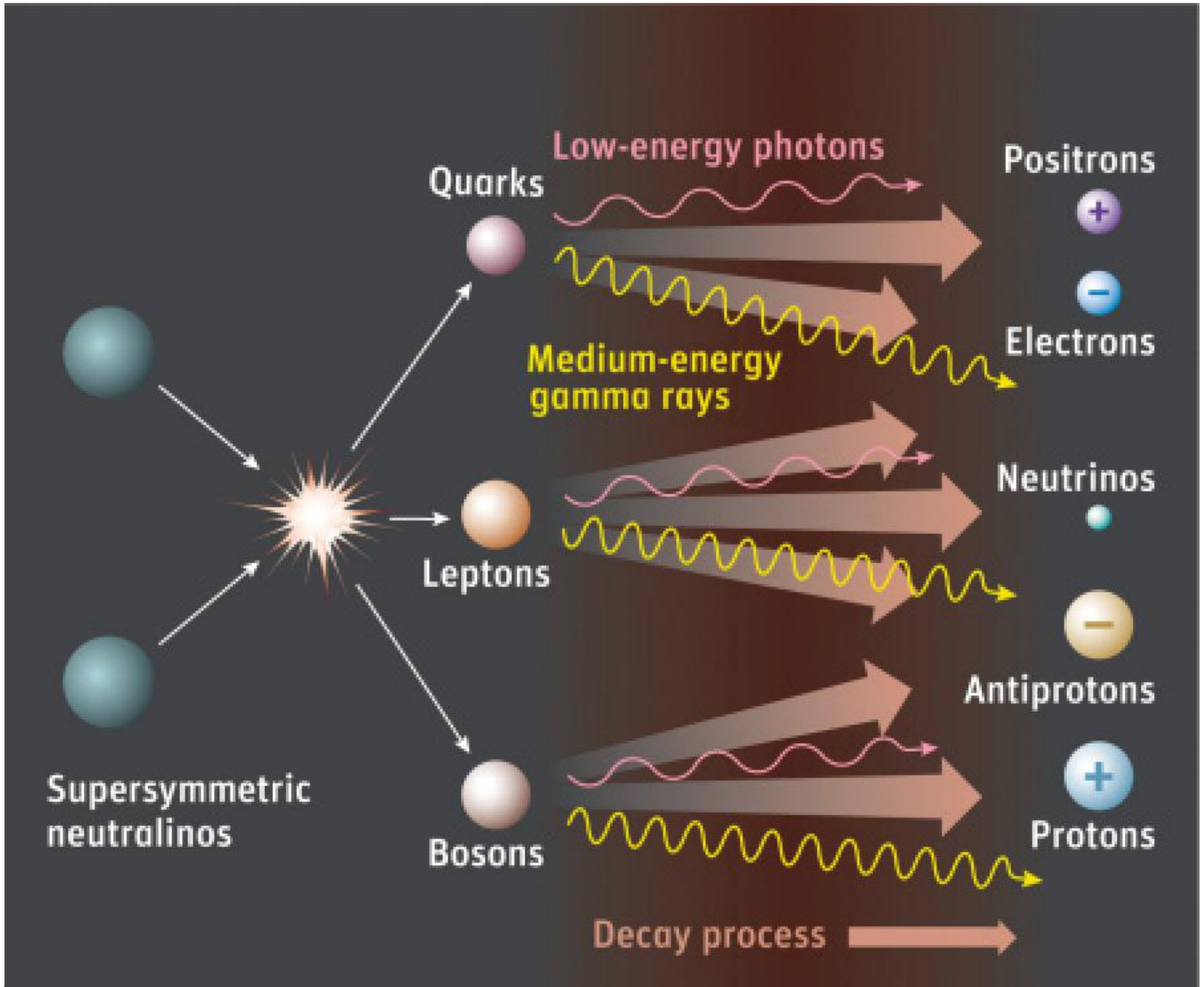


# Present status of direct detection

## The experimental situation



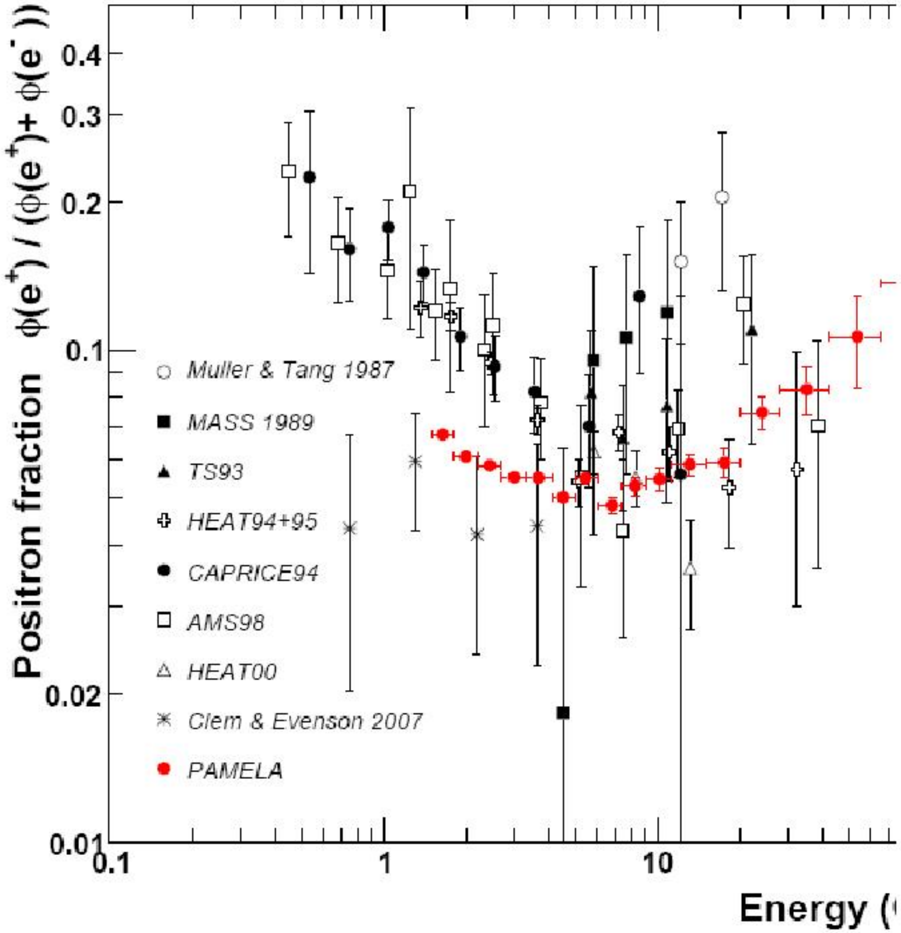
# 间接探测

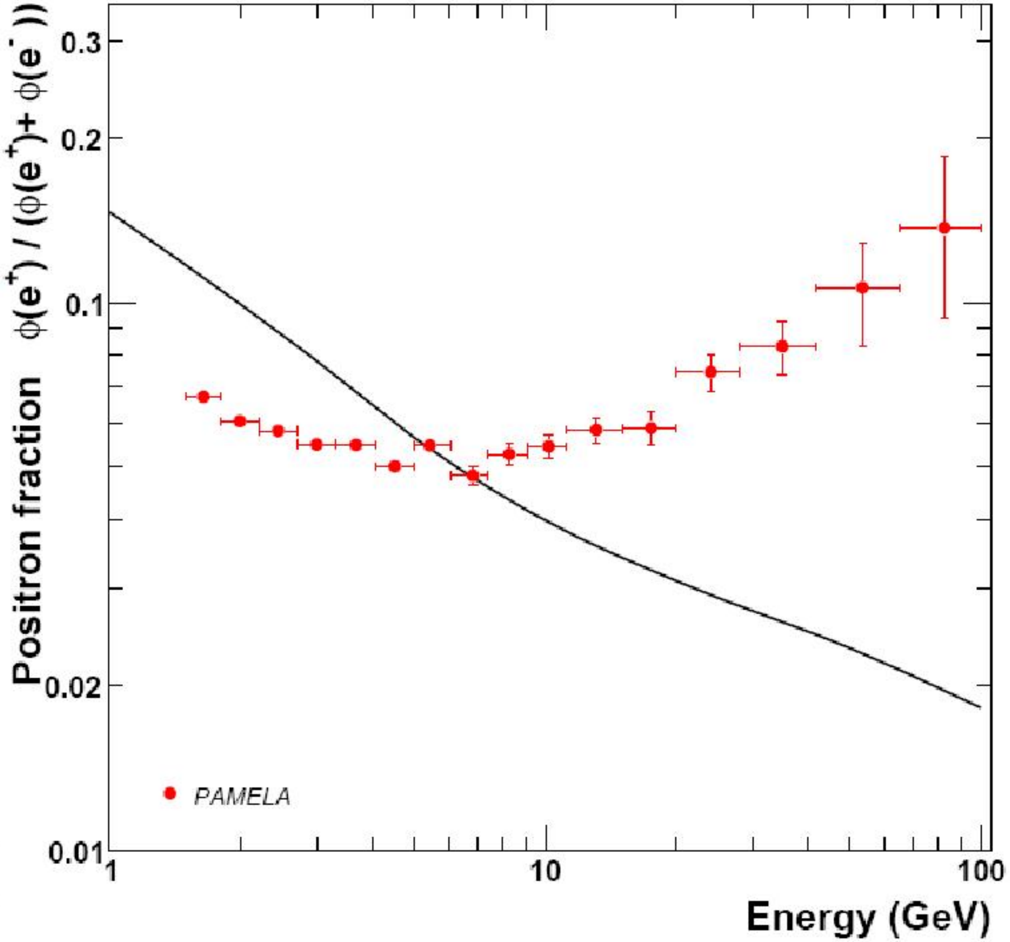



- 暗物质并不暗：它们湮灭后发出光，中微子，和带电粒子的宇宙线。

$$\chi^0\chi^0 \rightarrow l\bar{l}, q\bar{q}, 2W^{\pm}, 2Z^0, 2H^0, Z^0H^0, W^+H^-, gg$$

# PAMELA 结果（正电子超出）

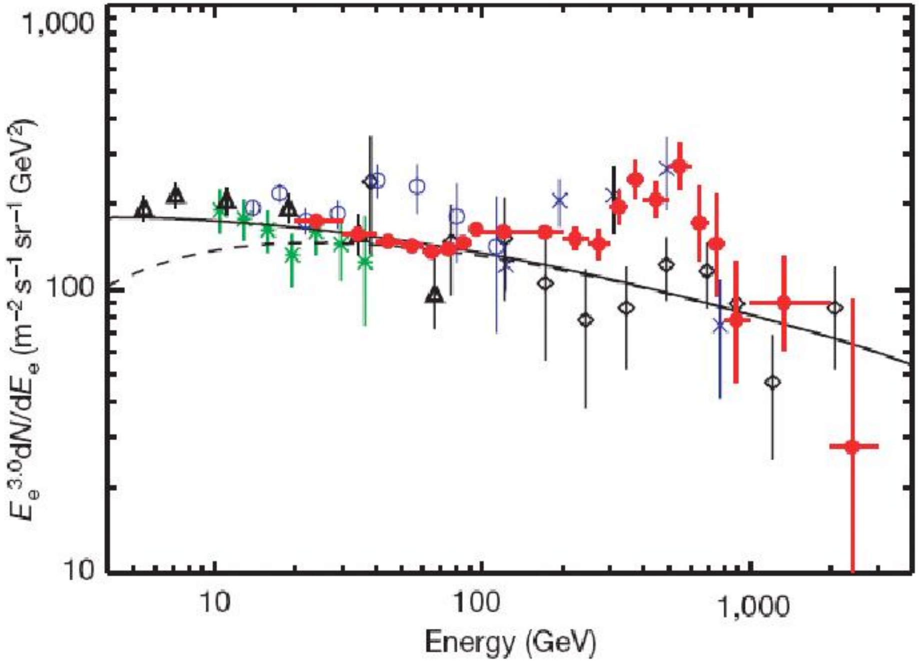


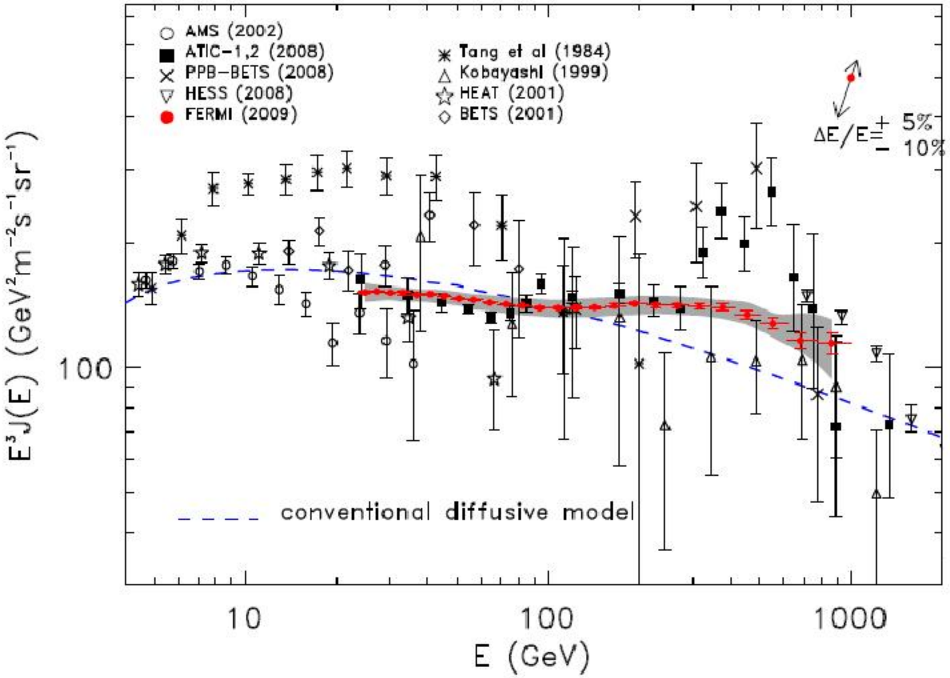



# The total electron+positron spectrum

ATIC bump

Fermi excess




Chang et al. Nature456, 362 2008

Phys.Rev.Lett.102:181101,2009

Physics Letters B 681 (2009) 151–160

Contents lists available at ScienceDirect

Physics Letters B

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# PAMELA satellite data as a signal of non-thermal wino LSP dark matter

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*Michigan Center for Theoretical Physics, University of Michigan, Ann Arbor, MI 48109, USA*

ARTICLE INFO

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ABSTRACT

Satellite and astrophysical data is accumulating that suggests and constrains interpretations of the dark matter of the universe. We argue there is a very well motivated theoretical framework (which existed before data) consistent with the interpretation that dark matter annihilation is being observed by the PAMELA satellite detector. The dark matter is (mainly) the neutral W boson superpartner, the wino. Using the program GALPROP extensively we study the annihilation products and the backgrounds together. A wino mass approximately in the 180–200 GeV range gives a good description of the PAMELA data, with antimatter and gammas from annihilating winos dominating the data below this energy range but not contributing above it. We explain why PAMELA data does not imply no antiproton signal was observed by PAMELA or earlier experiments, and explain why the antiproton analysis was misunderstood by earlier papers. Wino annihilation does not describe the Fermi $e^+ + e^-$ data (except partially below ~100 GeV). At higher energies we expect astrophysical mechanisms to contribute, and we simply parameterize them without a particular physical interpretation, and check that the combination can describe all the data. We emphasize several predictions for satellite data to test the wino interpretation, particularly the flattening or turndown of the positron and antiproton spectra above 100 GeV. It should be emphasised that most other interpretations require a large rise in the positron and antiproton rates above 100 GeV. We focus on studying this well-motivated and long predicted wino interpretation, rather than comparisons with other interpretations. We emphasize that interpretations also depend very strongly on assumptions about the cosmological history of the universe, on assumptions about the broader underlying theory context, and on propagation of antiprotons and positrons in the galaxy. The winos PAMELA is observing arose from moduli decay or other non-thermal sources rather than a universe that cooled in thermal equilibrium after the big bang. Then it is appropriate to normalize the wino density to the local relic density, and no "boost factors" are needed to obtain the reported PAMELA rates.

PHYSICAL REVIEW D 80, 103502 (2009)

# Nonthermal production of WIMPs, cosmic $e^{\pm}$ excesses, and $\gamma$ rays from the Galactic Center

Xiao-Jun Bi,[1,2] Robert Brandenberger,[3,4,5,6,7] Paolo Gondolo,[8,6] Tianjun Li,[9,10,6] Qiang Yuan,[1] and Xinmin Zhang[4,5,6]

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(Received 22 June 2009; published 4 November 2009)

In this paper we propose a dark matter model and study aspects of its phenomenology. Our model is based on a new dark matter sector with a $U(1)'$ gauge symmetry plus a discrete symmetry added to the standard model of particle physics. The new fields of the dark matter sector have no hadronic charges and couple only to leptons. Our model cannot only give rise to the observed neutrino mass hierarchy, but can also generate the baryon number asymmetry via nonthermal leptogenesis. The breaking of the new $U(1)'$ symmetry produces cosmic strings. The dark matter particles are produced nonthermally from cosmic string loop decay which allows one to obtain sufficiently large annihilation cross sections to explain the observed cosmic ray positron and electron fluxes recently measured by the PAMELA, ATIC, PPB-BETS, Fermi-LAT, and HESS experiments while maintaining the required overall dark matter energy density. The high velocity of the dark matter particles from cosmic string loop decay leads to a low phase space density and thus to a dark matter profile with a constant density core in contrast to what happens in a scenario with thermally produced cold dark matter where the density keeps rising towards the center. As a result, the flux of $\gamma$ rays radiated from the final leptonic states of dark matter annihilation from the Galactic center is suppressed and satisfies the constraints from the HESS $\gamma$-ray observations.

DOI: 10.1103/PhysRevD.80.103502 PACS numbers: 95.35.+d, 98.62.Gq, 98.70.Rz

PHYSICAL REVIEW D **81**, 023516 (2010)

# Markov chain Monte Carlo study on dark matter property related to the cosmic $e^{\pm}$ excesses

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(Received 26 June 2009; revised manuscript received 21 October 2009; published 19 January 2010)

In this paper we develop a Markov chain Monte Carlo code to study the dark matter properties in frameworks to interpret the recent observations of cosmic ray electron/positron excesses. We assume that the dark matter particles couple dominantly to leptons and consider two cases, annihilating or decaying into lepton pairs, respectively. The constraint on the central density profile from the H.E.S.S. observation of diffuse $\gamma$ rays around the Galactic center is also included in the Markov chain Monte Carlo code self-consistently. In the numerical study, we have considered two cases of the background: fixed $e^+e^-$ background and the relaxed one. Two data sets of electrons/positrons, i.e. PAMELA + ATIC (Data set I) and PAMELA + Fermi-LAT + H.E.S.S. (Data set II), are fitted independently, considering the current inconsistence between the observational data. We find that for Data set I, dark matter with $m_\chi \approx$ 0.70 TeV for annihilation (or 1.4 TeV for decay) and a non-negligible branching ratio to $e^+e^-$ channel is favored; while for Data set II, $m_\chi \approx 2.2$ TeV for annihilation (or 4.5 TeV for decay) and the combination of $\mu^+\mu^-$ and $\tau^+\tau^-$ final states can best fit the data. We also show that the background of electrons and positrons actually will significantly affect the branching ratios. The H.E.S.S. observation of $\gamma$ rays in the Galactic center ridge puts a strong constraint on the central density profile of the dark matter halo for the annihilation dark matter scenario. In this case the Navarro-Frenk-White profile, which is regarded as the typical predication from the cold dark matter scenario, is excluded with a high significance ($> 3\sigma$). For the decaying dark matter scenario, the constraint is much weaker.

DOI: 10.1103/PhysRevD.81.023516 PACS numbers: 98.80.Es, 98.80.Cq

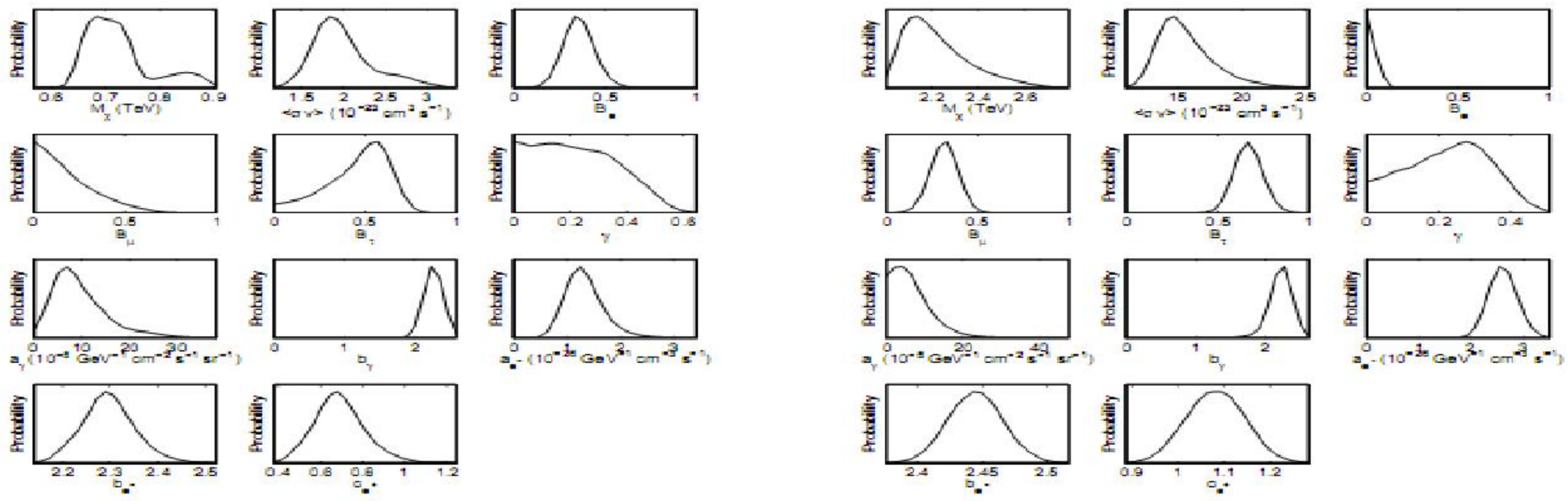


FIG. 5: Probability distributions of the eleven parameters in annihilation DM scenario used to fit Data set I (*left*) and II (*right*) respectively, for varying $e^+e^-$ background approach.

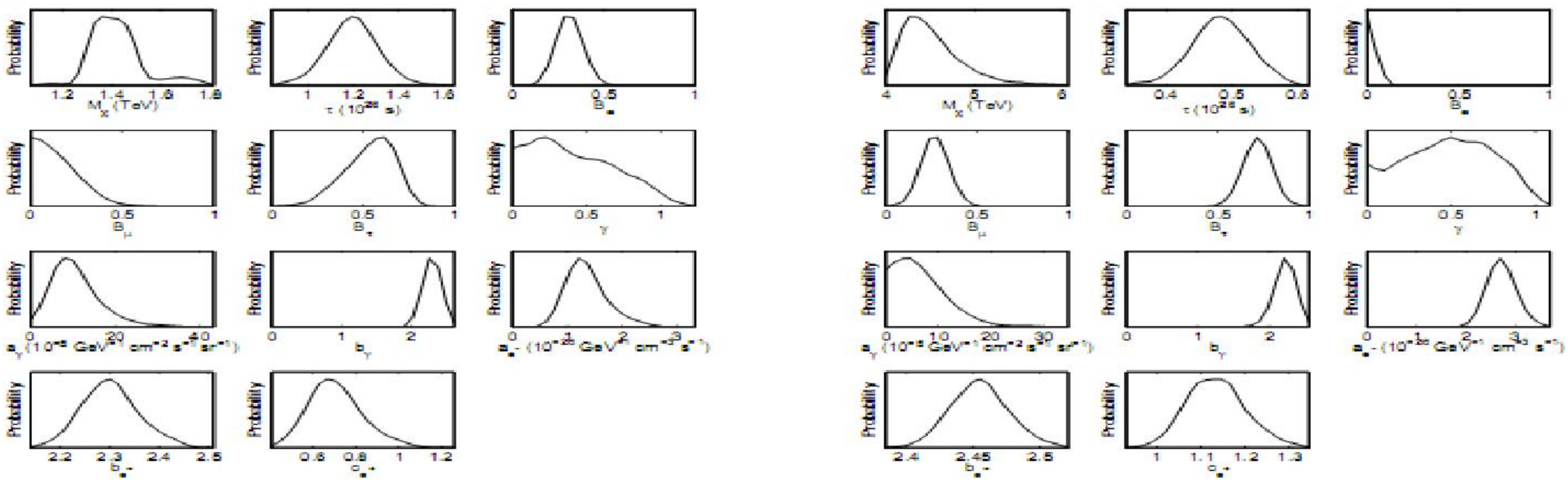
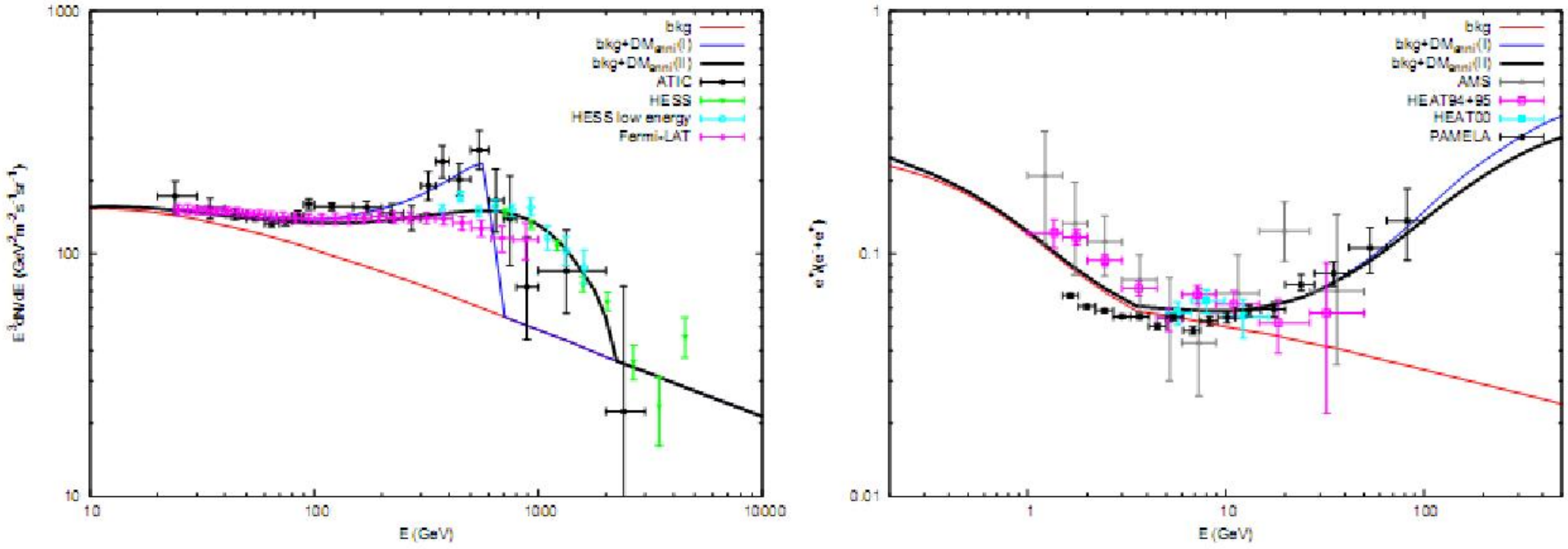


FIG. 6: The same as Fig.5 but for decaying DM scenario.




- The excess in the spectrum

1) Dark matter

2) Unknown astrophysical source（SN）

# 暗物质 CosRayMC

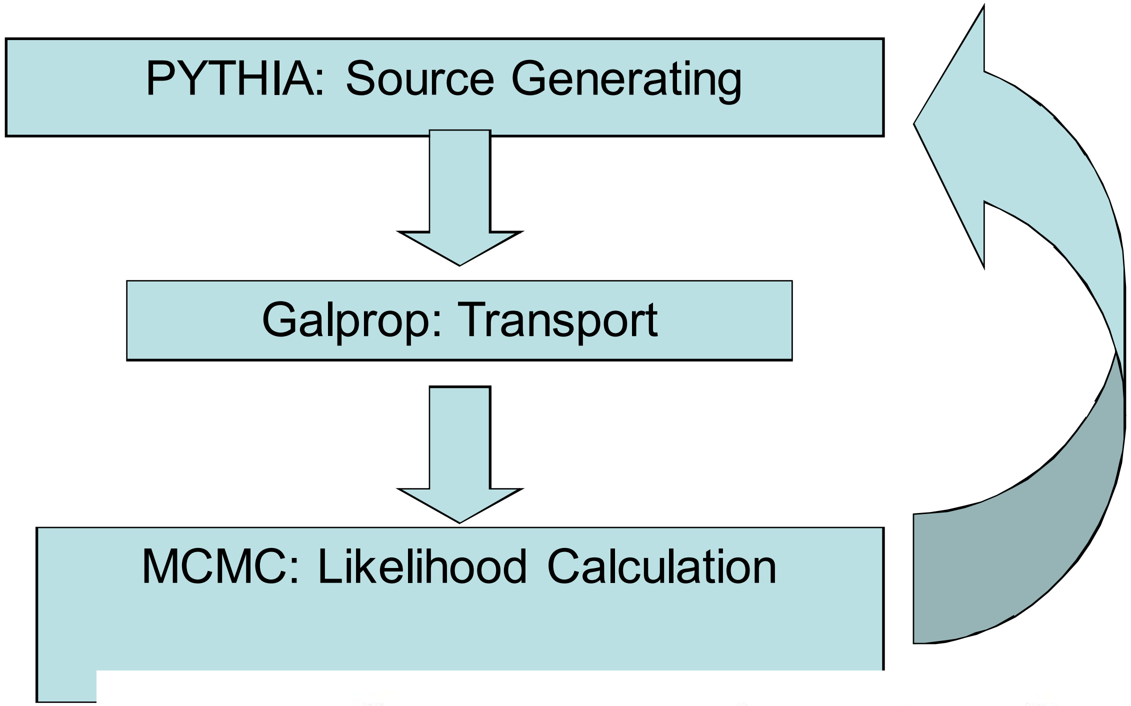
- CosRayMC (CosmicRay+MCMC)

Particle Physics: PYTHIA

Astrophysics : GalProp

Statistics : MCMC

# CosRayMC: Cosmic Ray MCMC

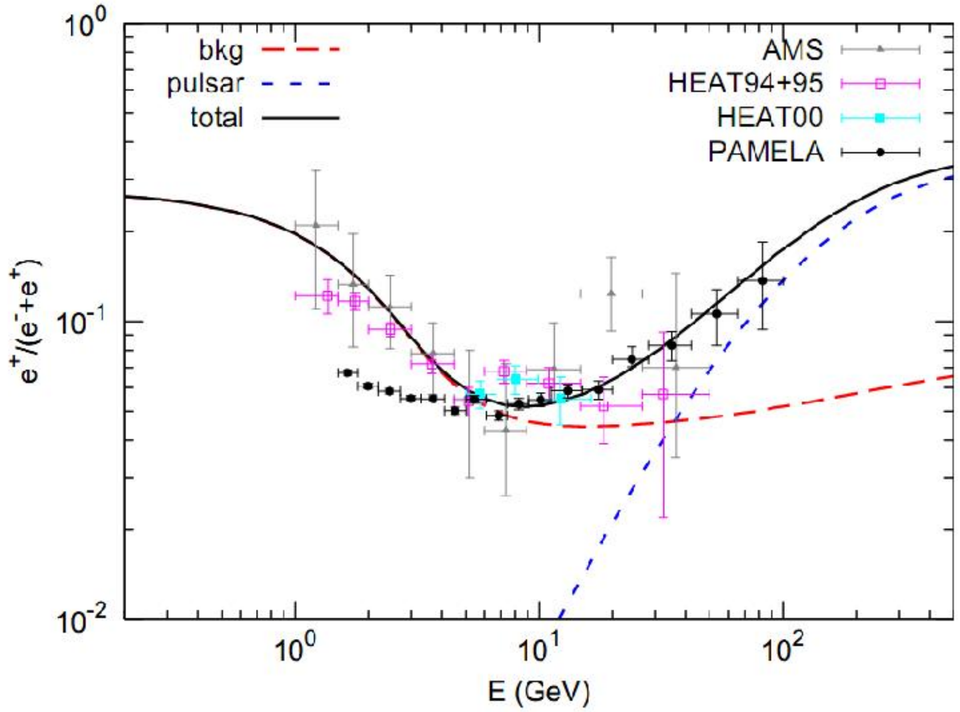


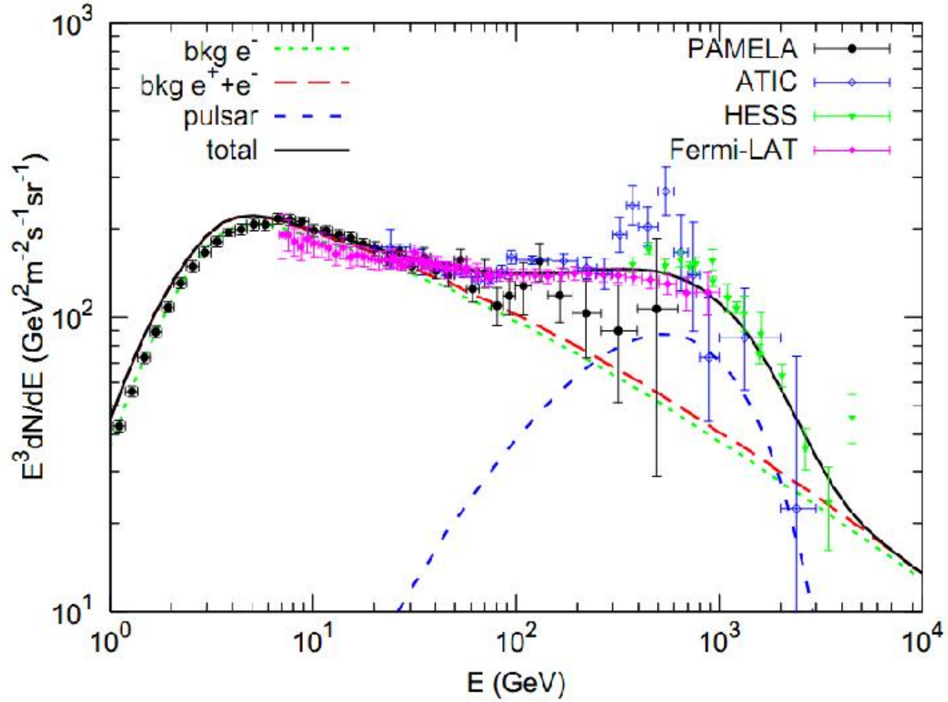

$$\mathcal{P}_{\rm bkg} = \{\gamma_1, \gamma_2, E_{\rm br}, A_{\rm bkg}, \phi, c_{e^+}\}$$

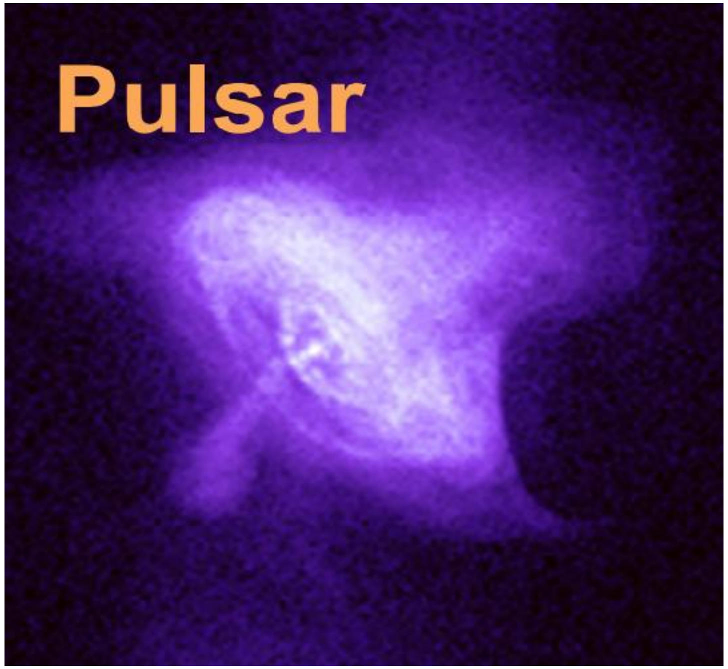
$$\mathcal{P}_{tol} = \begin{cases} \{\mathcal{P}_{\rm bkg}\}, & \text{background} \\ \{\mathcal{P}_{\rm bkg}, A_{\rm psr}, \alpha, E_c\}, & \text{pulsar} \\ \{\mathcal{P}_{\rm bkg}, c_{\bar{p}}, m_\chi, \langle\sigma v\rangle, B_e, B_\mu, B_\tau, B_u\}, & \text{DM.} \end{cases}$$

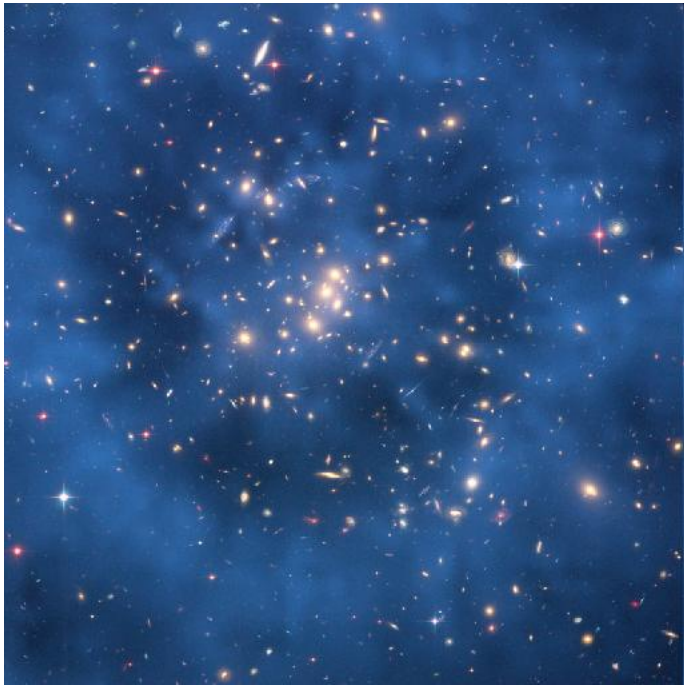
# Pulsar && Dark Matter

$$\chi^2_{\rm red} \approx 0.833$$





We can not distinguish dark matter from pulsar with present measurements

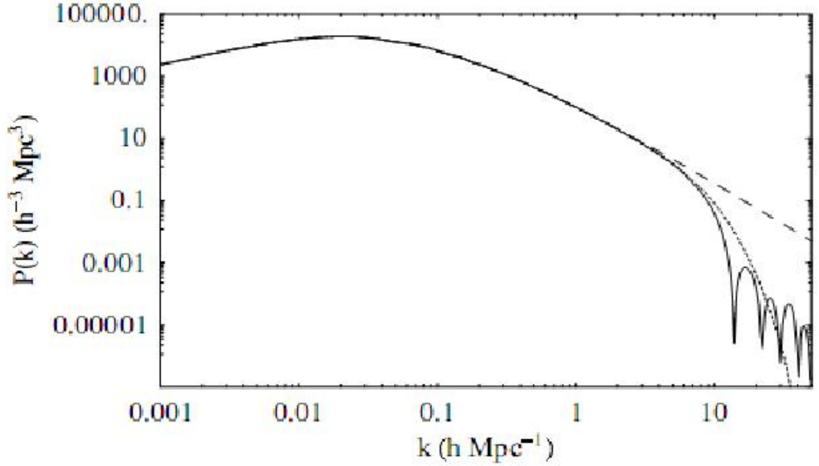



FIG. 1. Comparison of the power spectra of the CDM model (long-dashed curve), the WDM model with $m_W = 1$ keV (short-dashed curve), and the NTDM model with $r_c = 1.5 \times 10^{-7}$ (solid curve).

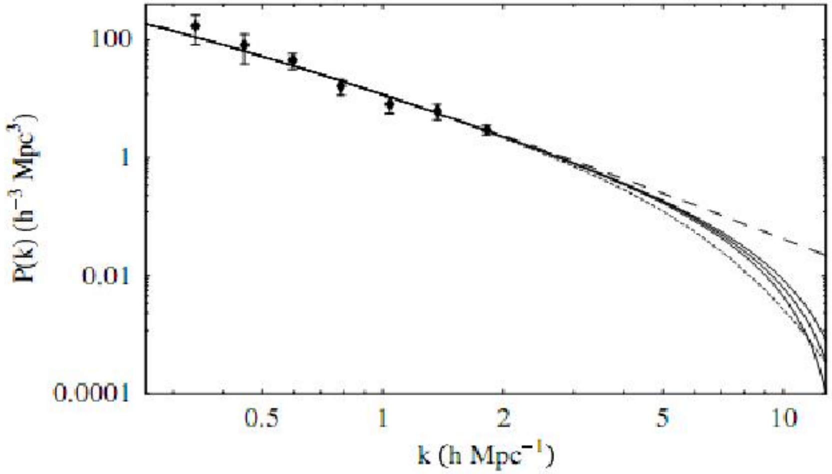
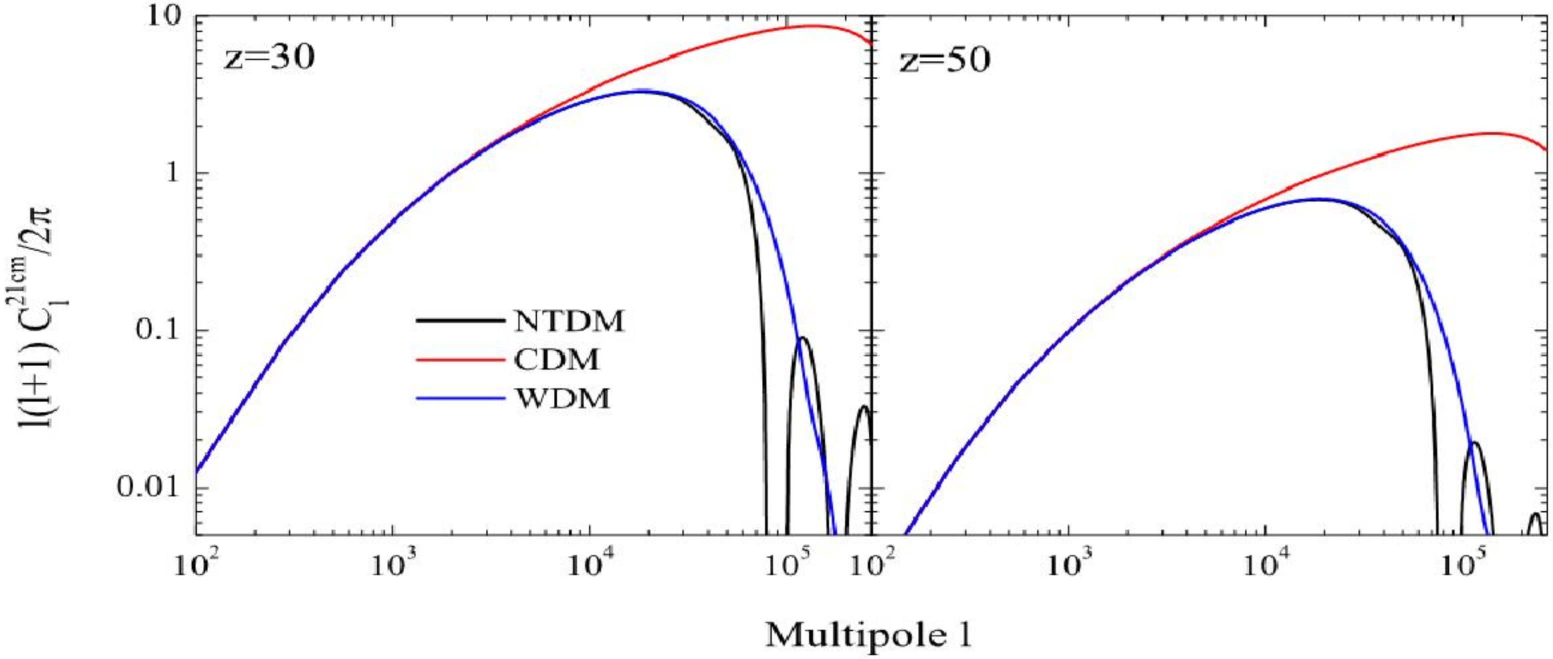



FIG. 2. The power spectra of the CDM model (long-dashed curve), the WDM model with $m_W = 750$ eV (short-dashed curve), and the NTDM models with $r_c = (1.3, 1.4, 1.5) \times 10^{-7}$ (solid curves, from top down), compared to the observed Lyman-$\alpha$ $P(k)$ at $z = 2.5$ (filled diamonds with error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

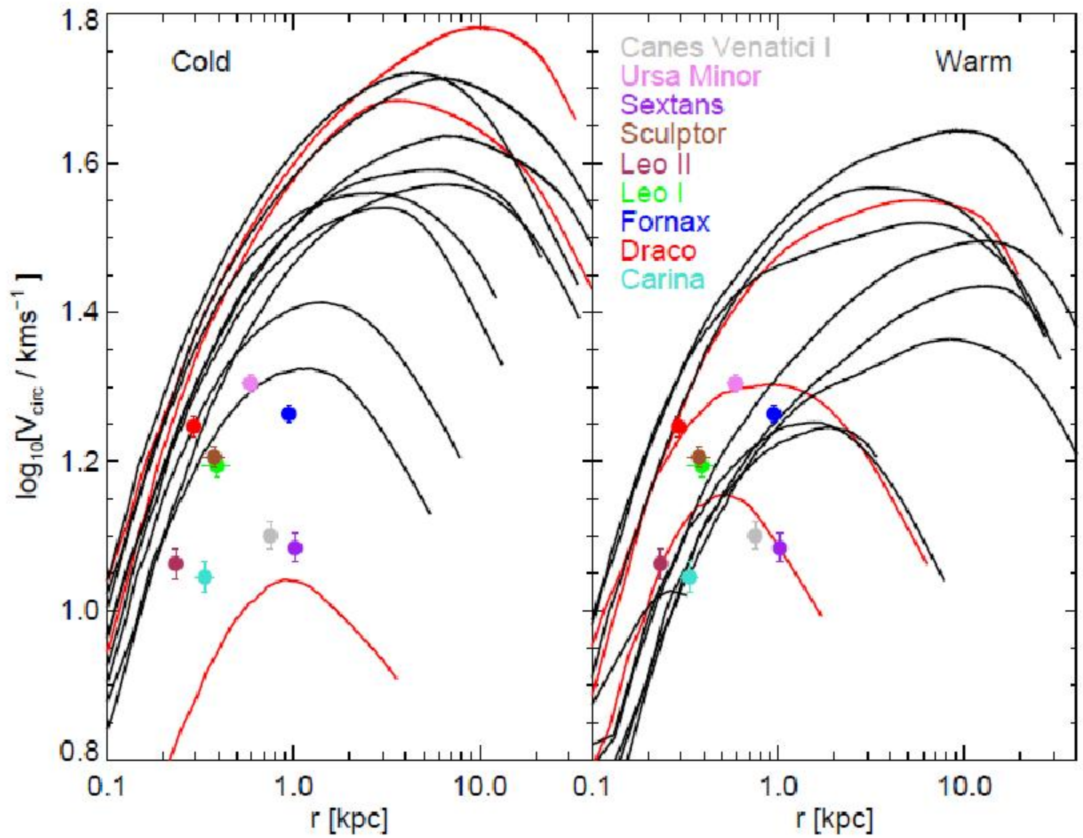
## 21 cm power spectra for sharp window



# How to define “cold”

- Definition of cold, warm or hot depends on the effect of their “free-stream” motion on the formation of objects
  - Hot dark matter (eV neutrinos) that washes out fluctuations on cluster scale (10 Mpc/h);
  - Warm dark matter (sterile neutrinos) that washes out fluctuations on galaxy scale (1 Mpc/h);
  - Cold dark matter that has effectively zero thermal velocity

# Circular Velocity of MW satellites compared with CDM and WDM predictions




**Lovell et al. 2012**

# 简要评述

- 冷暗物质的Concordance宇宙学模型：理论上由于大量数值模拟的工作对各种宇宙尺度的结构深刻的理解；在星系及更大的尺度上得到了大量观测数据的支持；
- 近期危机：在亚星系（sub－galactic）尺度上，温暗物质模型可能能够更好解释观测数据（在星系及更大的尺度上，与冷暗物质模型没有差异）
- 冷还是温：对粒子物理和暗物质探测具有重要的意义

# 近年实验对WIMP暗物质理论研究的推动

1）WIMPs: Thermal， Cold DM，(original motivation)
Non-thermal, Motivation: why not, Axion produced non-thermally

2) Warm DM: 天文界流行，但只知道sterial neutrino
non-thermal WIMPs as warm DM

3) Heat experiment: requiring boost factors:
substructure; non-thermal

4) Pamela, ATIC, Fermi, HESS experiments:
requiring large boost factors:
Substructure not enough; (毕效军等）
non-thermal, SF, BW effects

5）Gamma ray from galactic center,….-→Warm (non-thermal) WIMPs

6）Coupled dominantly to lepton:
Neutrino Physics----→Leptogenesis (why no antimatter? )
Dark Energy (Mass Varying Neutrino)
Dark Matter

# 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 $\gamma$-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 $\gamma$-ray signals from the dark matter annihilation. We illustrate these by comparing the the predicted $\gamma$-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 $\gamma$-ray telescope.

PACS numbers: 95.35.+d,95.85.Pw

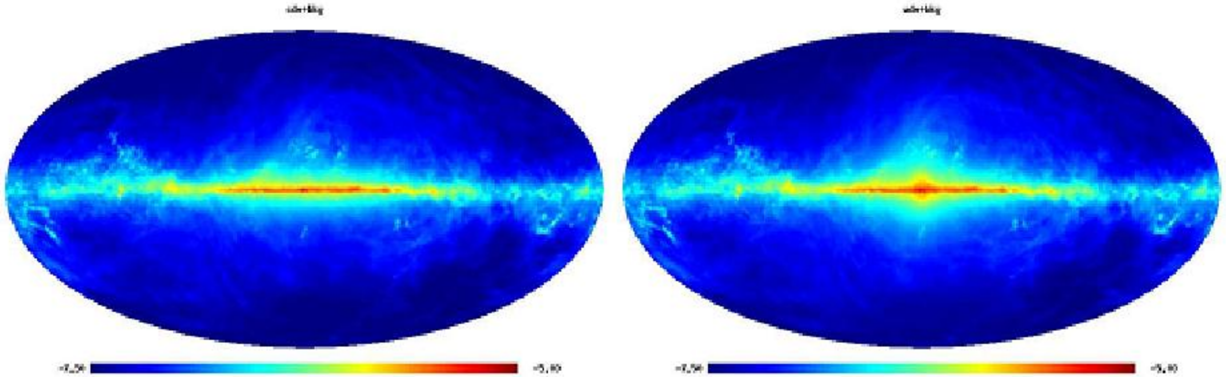


FIG. 5: Skymaps of the total $\gamma$-ray emission with background predicted by GALPROP included, for energies $E > 10$ GeV. The left panel is for the cold WIMP case, and the right panel is for the warm WIMP case.



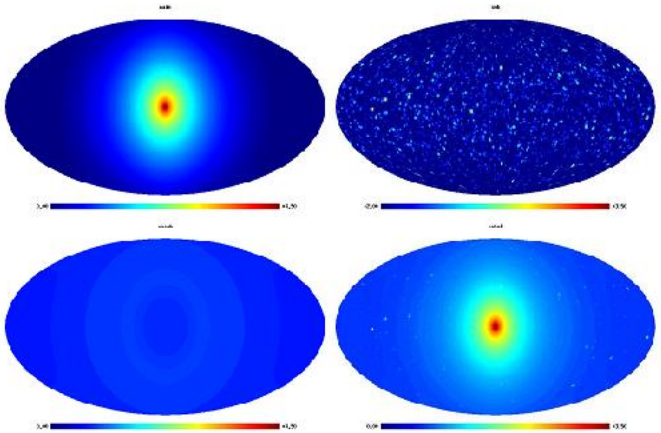


FIG. 8: Skymaps of the $J$-factors of the smooth halo (top-left), resolved subhalos (top-right), unresolved subhalos (bottom-left) and the total contribution (bottom-right) for CDM.

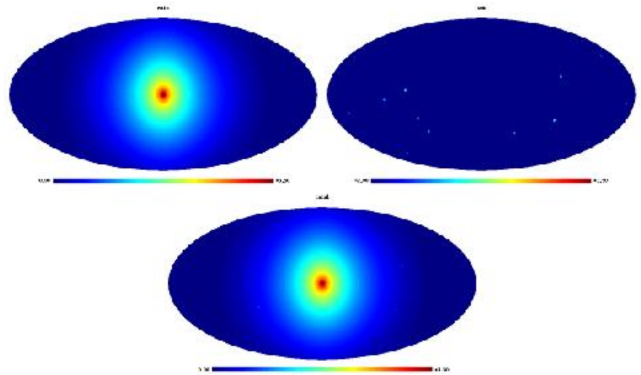


FIG. 2: Skymaps of the $J$-factors of the main halo (top-left), resolved subhalos (top-right) and total contribution (bottom) for WDM.

## *Comment on Thermal WIMPs Miracle and non-thermal WIMPs Miracle*

*i) Thermal WIMPs miracle:*

*Thermal production CMB, Hot Big-Bang*

*ii) Non-thermal processes:*

*Free neutron decay in BBN*

*reheating processes*

*Cosmic string decay*

*-----→ non-thermal WIMPs Miracle?!*

*If DM is warm, impacts on the current experiments*

*especially in China are very important*

*==========→Non-thermal WIMPs*

- 创新一期：粒子宇宙学
- 创新二期：方向性项目

高能天体物理：星系团、黑洞物理和早期宇宙

2004年9月9日“暗能量探测专题研讨会”

基金委重点项目

LAMOST 暗能量

- 创新三期：方向性项目

依托国内大科学装置的粒子物理、核物理和宇宙学的前沿理论研究

2008年11月26日：汇报暗物质暗能量探测路线图

“上天，入地 到 南极”

=====〉 创新文化建设：“天文+物理”交叉研究

# 路线图

暗物质探测：

近期：羊八井

中期：小卫星，地下实验室

长期：空间站

建议：启动小卫星、地下实验室预研究

暗能量探测：LAMOST, 南极DOME－A

近期：LAMOST

中期：南极DOME A四米光学望远镜

建议：启动南极DOME A四米光学望远镜预研究

# 十年中国宇宙学的发展和精确宇宙学

发展很快， 队伍壮大；

在计算宇宙学（数据分析，数值计算，模拟），

理论模型及（国际合作）

的实验，天文观测方面都取得了重要的成果；

“天文+物理”交叉研究的良好氛围已形成 ======〉创新文化重大成就；

i）暗物质暗能量探测路线图

ii）“两暗一黑三起源”的提出

**精确宇宙学 ===➔ 国际性重大成果--------》**

**中国人的贡献不能忽略！！！**


“国内研究展望

宇宙学暗物质暗能量研究很受重视；

支持力度大大的加强；

暗物质暗能量探测路线图---》各种规化

中的强调， 各类项目资助

但是， 有了钱 ====== 出重大成果 ？？？

十年后， 我国的宇宙学研究状况会怎样？？

继续追赶？占一席之地？

主导，领导地位？”

# *Thanks!*