Recent progress about CP violation in cosmology

韩成成

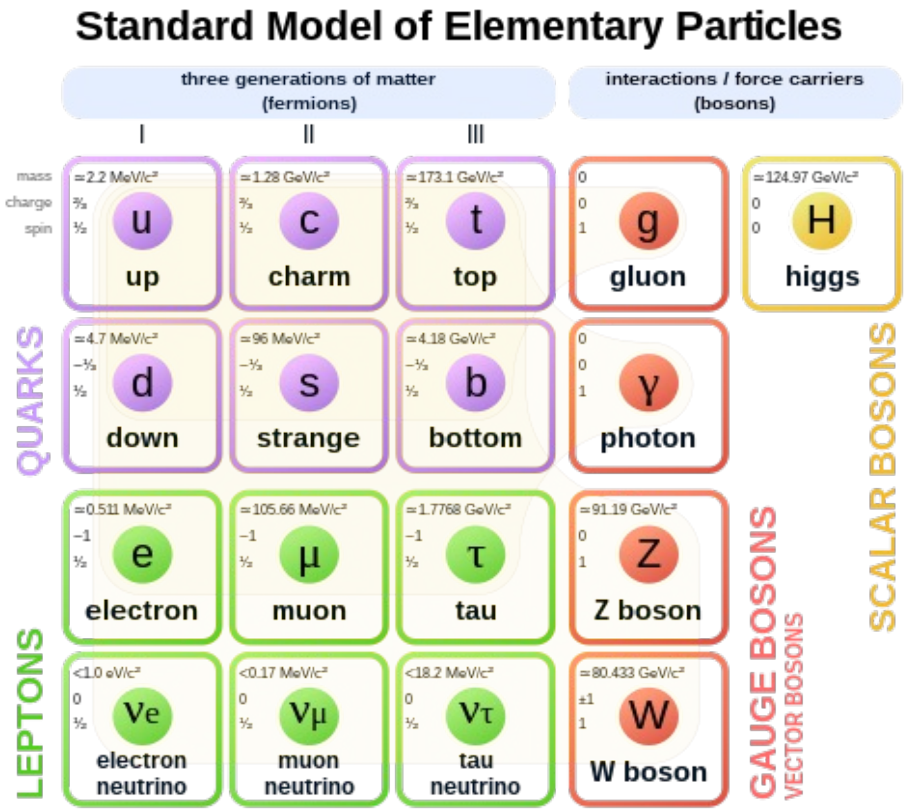
中山大学

味物理前沿研讨会

2026.1.31

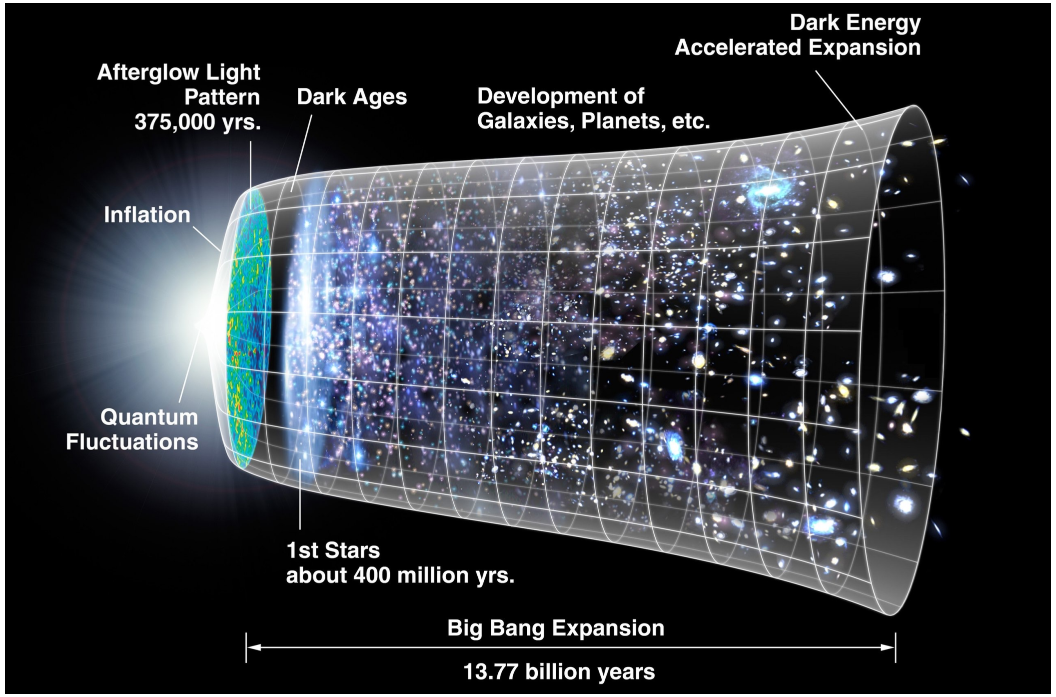
研究背景

粒子物理标准模型/宇宙学标准模型



物质的基本组成及其相互作用

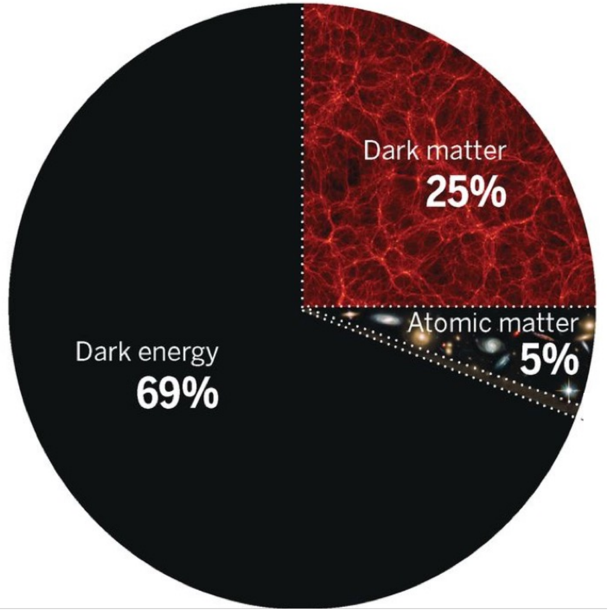
ΛCDM+Inflation



物质的起源与演化

研究背景

What is the Universe made of?



- 暗能量是什么？与粒子物理标准模型有何关联？
- 暗物质是什么？它是不是一种基本粒子？
- 为什么可见物质都是重子，反重子去哪了？

(重子不对称性 or 正反物质不对称性)

粒子物理和宇宙学面临的共同问题！

如何产生重子不对称性?

如果宇宙创生初期就有这个不对称性，这个不对称性会在暴胀时期抹平掉(宇宙膨胀了至少e^{60})

如何从正反物质对称的宇宙演化到正反物质不对称的宇宙？

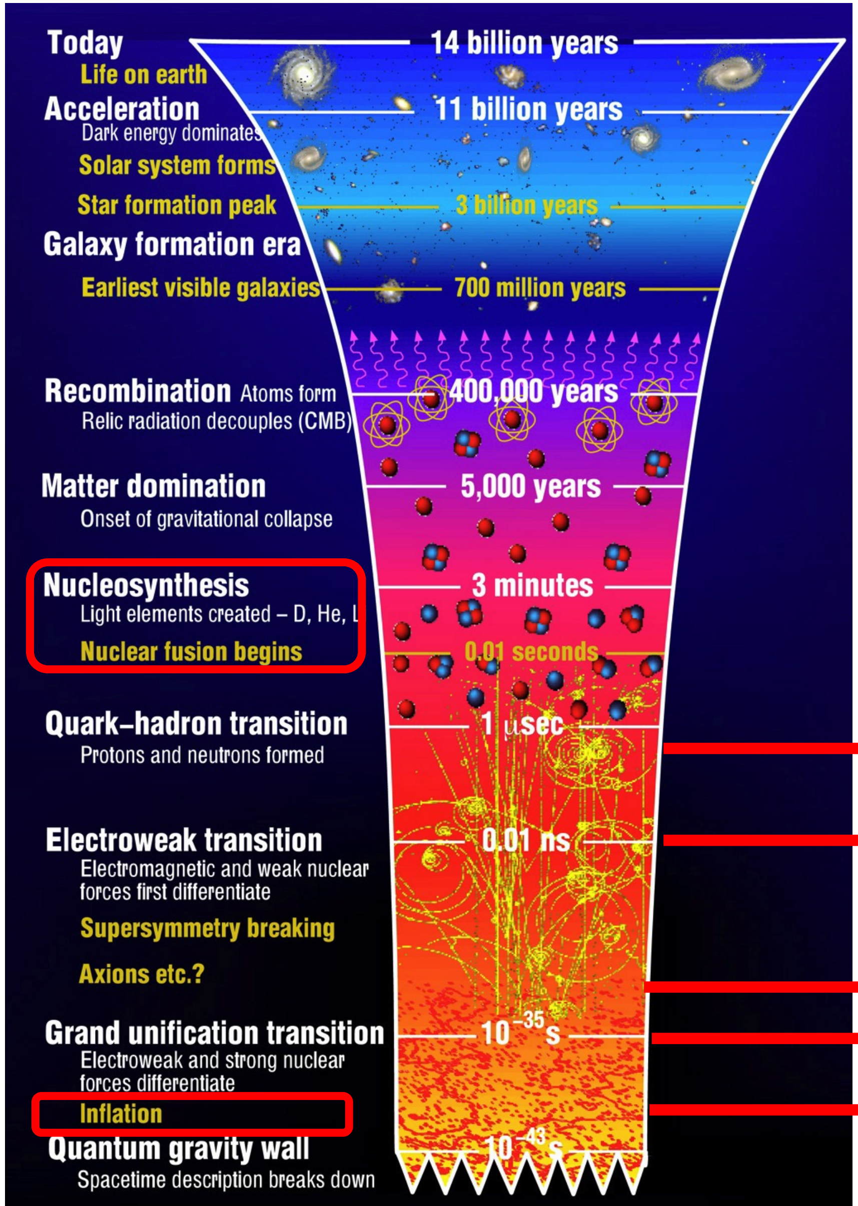
Sakharov 三条件	标准模型
● 重子数破坏过程	✓
● C 和 CP 破坏	✓✗
● 脱离热平衡	✗

- 无法提供脱离热平衡条件(QCD相变和电弱相变均为 cross over)
- 即使有强一阶相变，夸克部分提供CP破坏太小，不足以解释现在的观测

新的CP破坏源+脱离热平衡条件!

重子不对称性何时产生？

不能晚于原初核合成，否则元素丰度不一致



B-mesogenesis

EW Baryogenesis

Leptogenesis

GUT Baryogenesis

Baryogenesis from inflation

不能早于暴胀，因为宇宙在很短时间内膨胀了 e^{60} 倍，任何早期的不对称性都变的极小

CP violation in baryon decay

nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > articles > article

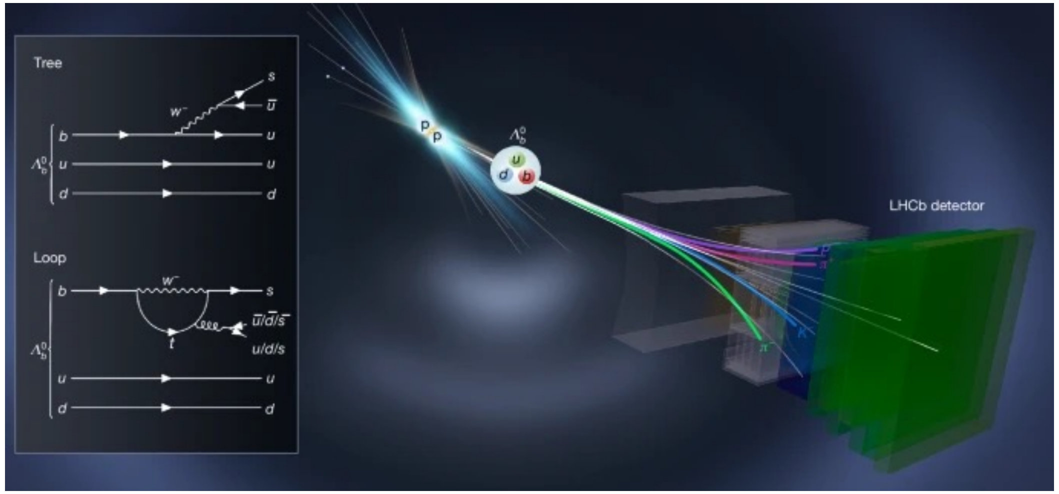
Article | Open access | Published: 16 July 2025

Observation of charge–parity symmetry breaking in baryon decays

LHCb Collaboration

Nature **643**, 1223–1228 (2025) | Cite this article

67k Accesses | **16** Citations | **1220** Altmetric | Metrics



$$\mathcal{A}_{\mathrm{CP}} \equiv \frac{\Gamma(\Lambda_b^0 \to pK^-\pi^+\pi^-) - \Gamma(\bar{\Lambda}_b^0 \to \bar{p}K^+\pi^-\pi^+)}{\Gamma(\Lambda_b^0 \to pK^-\pi^+\pi^-) + \Gamma(\bar{\Lambda}_b^0 \to \bar{p}K^+\pi^-\pi^+)}$$

$$\mathcal{A}_{\mathrm{CP}} = (2.45 \pm 0.46 \pm 0.10)\%$$

How is it related to the baryon asymmetry of our universe?

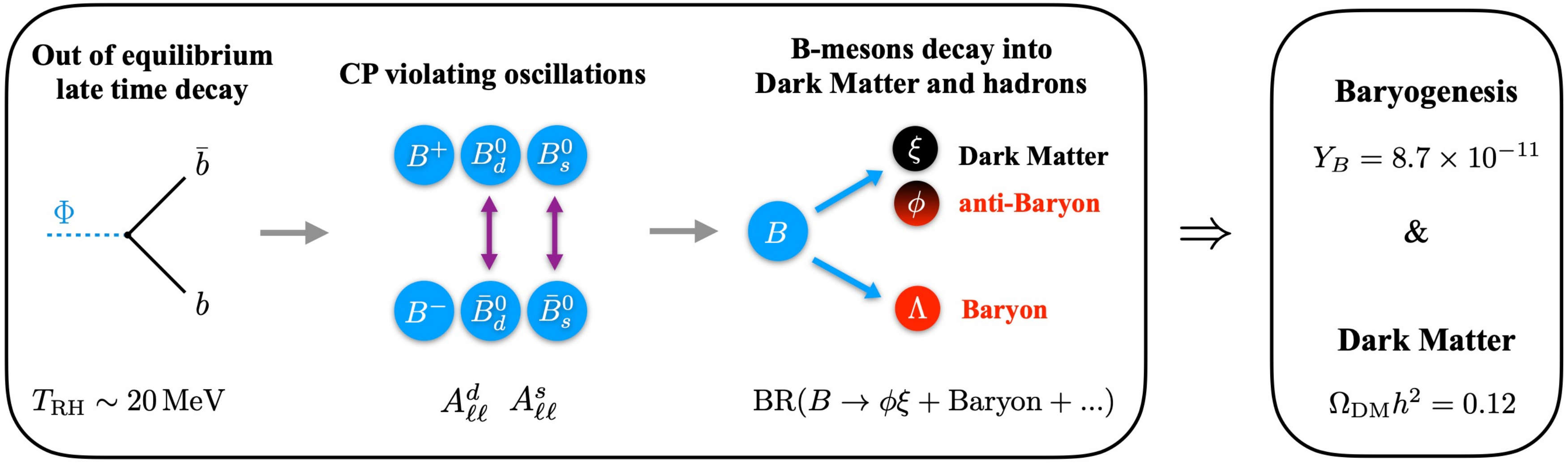
CP violation in baryon decay

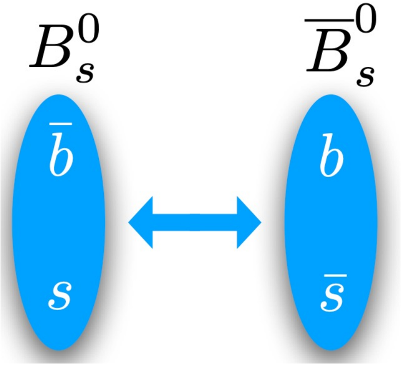
Related but not directly related

- CP violation exists in baryonic systems, not just mesons   Sakharov condition 2
- Λ_b form at T~ Λ_{QCD}, decay long after EWSB, CP asymmetry from Λ_b decay does not help
- Baryon number conserved in Λ_b decays, no baryon number violation
- It is consistent with that CP violation is from CKM, and furtherly confirms that CP violation is not enough for baryogenesis in SM, New physics is needed.

B-mesogenesis

G. Elor, M. Escudero, A. E. Nelson, Phys. Rev. D 99, 035031 (2019)





- A long-lived particle decays and produce B-mesons and anti-mesons out of equilibrium
- CP violation from $B^0 - \bar{B}^0$ oscillations generates a matter-antimatter asymmetry
- B meson (5.3 GeV) decays into baryon + anti-baryon(dark matter)+ dark matter
- Yields net excess of baryons in the visible sector and excess anti-baryons in the dark sector
- Baryon number in the whole universe is conserved

B-mesogenesis

The baryon asymmetry is related to the B meson decay rate into baryon+invi and B meson oscillation CP violation A_{SL}

$$Y_B \simeq 8.7 \times 10^{-11} \frac{\mathrm{Br}(B \to \psi + \mathcal{B} + \mathcal{M})}{10^{-2}} \sum_q \alpha_q \frac{A^q_{\mathrm{SL}}}{10^{-4}}$$

$$A^q_{\mathrm{SL}} = \mathrm{Im}\left(\frac{\Gamma^q_{12}}{M^q_{12}}\right) = \frac{\Gamma(\overline{B}^0_q \to B^0_q \to f) - \Gamma(B^0_q \to \overline{B}^0_q \to \bar{f})}{\Gamma(\overline{B}^0_q \to B^0_q \to f) + \Gamma(B^0_q \to \overline{B}^0_q \to \bar{f})}$$

SM prediction:

$$A^d_{\mathrm{SL}}|_{\mathrm{SM}} = (-4.7 \pm 0.4) \times 10^{-4}$$

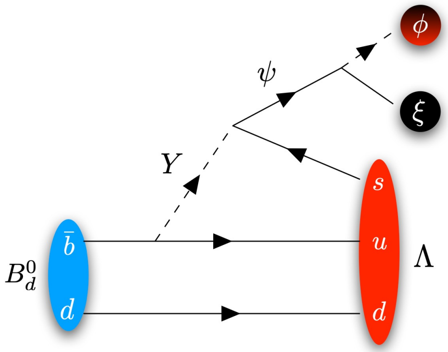
$$A^s_{\mathrm{SL}}|_{\mathrm{SM}} = (2.1 \pm 0.2) \times 10^{-5}$$

EXP:

$$A^d_{\mathrm{SL}} = (-2.1 \pm 1.7) \times 10^{-3}$$

$$A^s_{\mathrm{SL}} = (-0.6 \pm 2.8) \times 10^{-3}$$

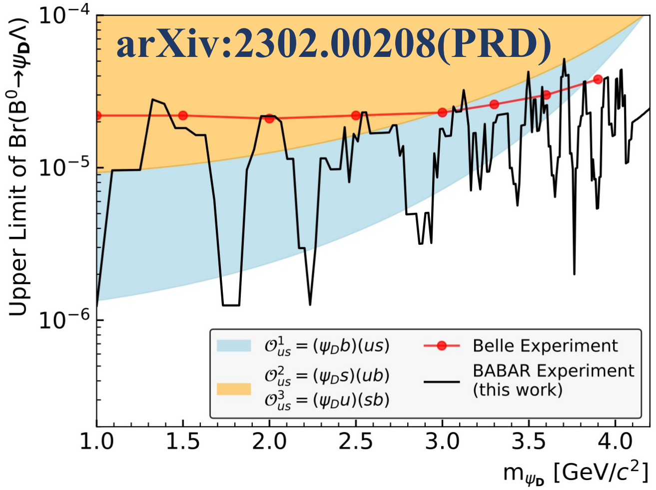
- **SM CKM is enough to provide the CP violation，but**
- **B meson decay into baryon+invisible (BaBar，Belle，LHCb)**
- **Measurement of the CP violation of B meson is important**

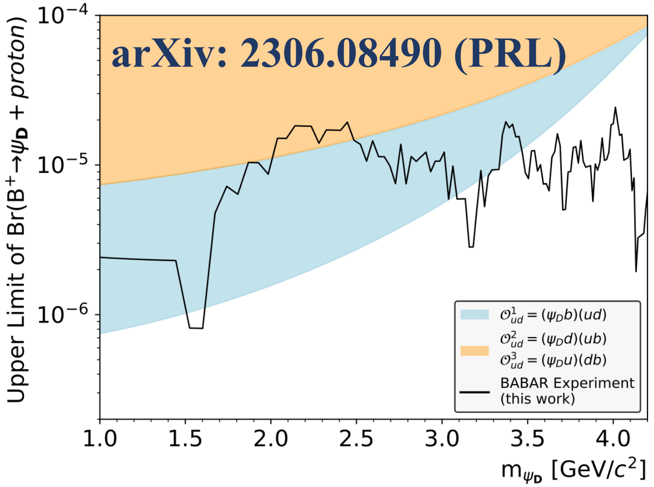


B-mesogenesis

Collider Signals of Baryogenesis and Dark Matter from B Mesons: A Roadmap to Discovery，G. Alonso-Álvarez, G. Elor, M. Escudero, Phys. Rev. D 104, 035028 (2021)

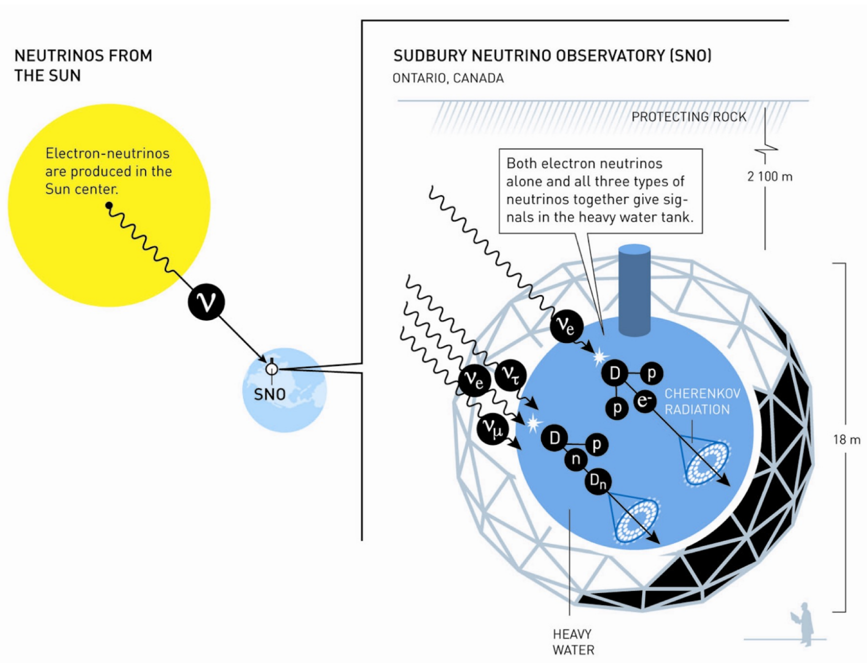
Operator and Decay	Initial State	Final State	ΔM (MeV)
$\mathcal{O}_{ud} = \psi\, b\, u\, d$ $\bar{b} \to \psi\, u\, d$	B_d	$\psi + n\,(udd)$	4340.1
	B_s	$\psi + \Lambda\,(uds)$	4251.2
	B^+	$\psi + p\,(duu)$	4341.0
	Λ_b	$\bar{\psi} + \pi^0$	5484.5
$\mathcal{O}_{us} = \psi\, b\, u\, s$ $\bar{b} \to \psi\, u\, s$	B_d	$\psi + \Lambda\,(usd)$	4164.0
	B_s	$\psi + \Xi^0\,(uss)$	4025.0
	B^+	$\psi + \Sigma^+\,(uus)$	4090.0
	Λ_b	$\bar{\psi} + K^0$	5121.9
$\mathcal{O}_{cd} = \psi\, b\, c\, d$ $\bar{b} \to \psi\, c\, d$	B_d	$\psi + \Lambda_c + \pi^-\,(cdd)$	2853.6
	B_s	$\psi + \Xi_c^0\,(cds)$	2895.0
	B^+	$\psi + \Lambda_c^+\,(dcu)$	2992.9
	Λ_b	$\bar{\psi} + \overline{D}^0$	3754.7
$\mathcal{O}_{cs} = \psi\, b\, c\, s$ $\bar{b} \to \psi\, c\, s$	B_d	$\psi + \Xi_c^0\,(csd)$	2807.8
	B_s	$\psi + \Omega_c\,(css)$	2671.7
	B^+	$\psi + \Xi_c^+\,(csu)$	2810.4
	Λ_b	$\bar{\psi} + D^- + K^+$	3256.2



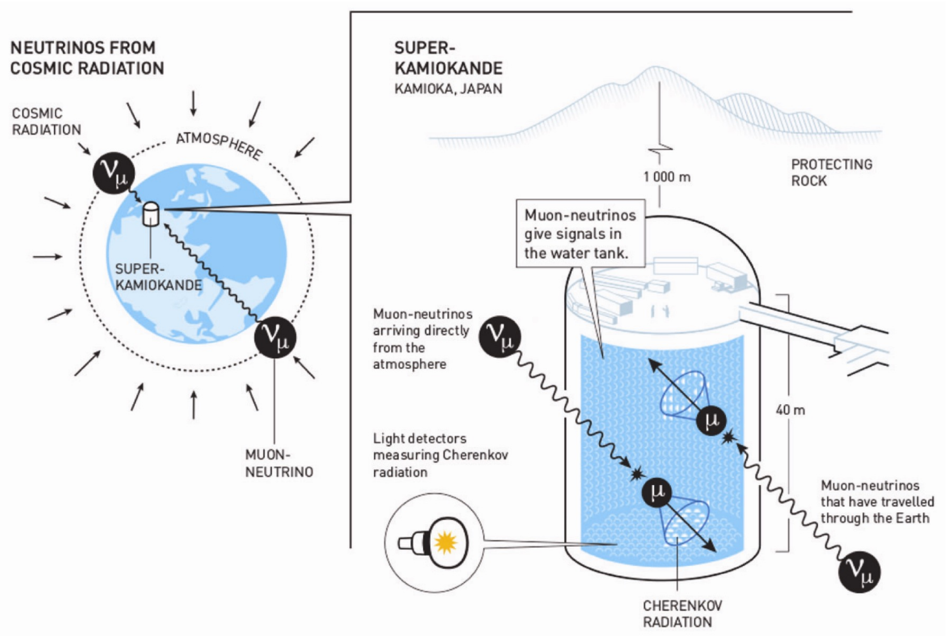


中微子质量

太阳中微子之谜

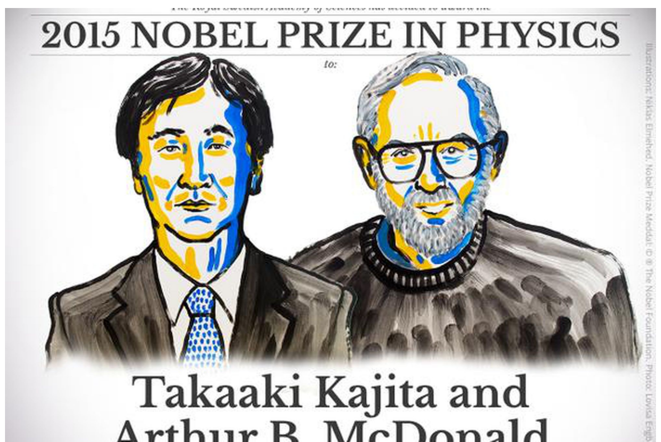


大气中微子反常



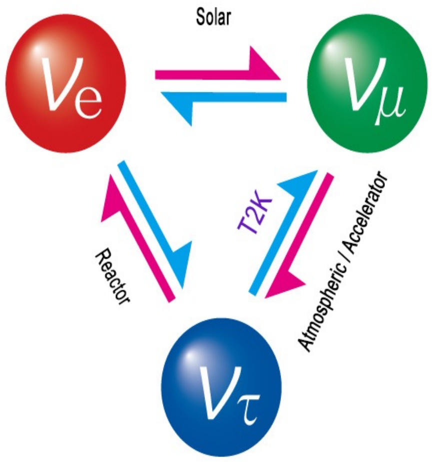
三代中微子之间会互相振荡转化

中微子存在质量！(~0.05 eV)



中微子质量

Kobayashi and Maskawa(2008 Nobel prize) 机制告诉我们，如果中微子有质量，轻子部分可能有CP破坏



$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

I. Esteban, M.C. Gonzalez-Garcia, M. Maltoni, T. Schwetz, A. Zhou，JHEP 09 (2020) 178

NO

$$\theta_{12} = 33.44^{\circ}{}^{+0.77^{\circ}}_{-0.74^{\circ}}$$
$$\theta_{23} = 49.2^{\circ}{}^{+0.9^{\circ}}_{-1.2^{\circ}}$$
$$\theta_{13} = 8.57^{\circ}{}^{+0.12^{\circ}}_{-0.12^{\circ}}$$
$$\delta_{CP} = 197^{\circ}{}^{+27^{\circ}}_{-24^{\circ}}$$

IO

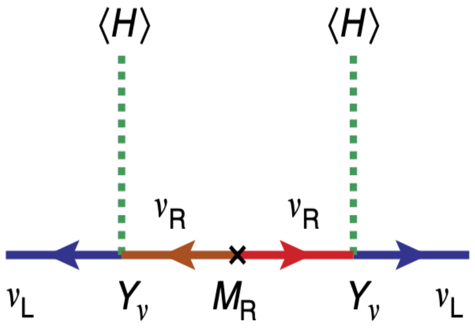
$$\theta_{12} = 33.45^{\circ}{}^{+0.78^{\circ}}_{-0.75^{\circ}}$$
$$\theta_{23} = 49.3^{\circ}{}^{+0.9^{\circ}}_{-1.1^{\circ}}$$
$$\theta_{13} = 8.60^{\circ}{}^{+0.12^{\circ}}_{-0.12^{\circ}}$$
$$\delta_{CP} = 282^{\circ}{}^{+26^{\circ}}_{-30^{\circ}}$$

轻子部分提供了新的CP破坏源(T2K实验暗示中微子部分可能存在CP破坏)，正反物质不对称性可能从轻子部分开始，再由sphaleron过程传递给重子——轻子生成机制（leptogenesis）

跷跷板机制

为了解释中微子质量，必然引入新的粒子

Type I

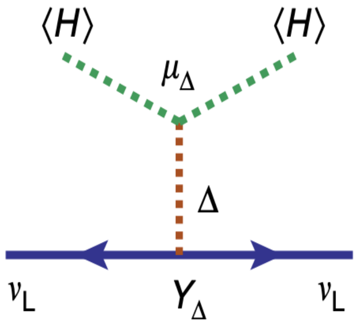


$$M_\nu = -\langle H\rangle^2 Y_\nu M_R^{-1} Y_\nu^T$$

SM+3 singlets fermions

Minkowski, Gell-Mann, Glashow, Yanagida

Type II

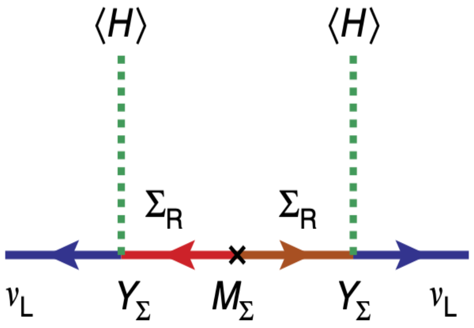


$$M_\nu = \langle H\rangle^2 Y_\Delta \mu_\Delta / M_\Delta^2$$

SM+1 triplet Higgs

Magg, Wetterich

Type III



$$M_\nu = -\langle H\rangle^2 Y_\Sigma M_\Sigma^{-1} Y_\Sigma^T$$

SM+3 triplet fermions

Foot, Lew, He, Joshi

引入的新粒子可以在宇宙早期会热退耦——脱离热平衡条件

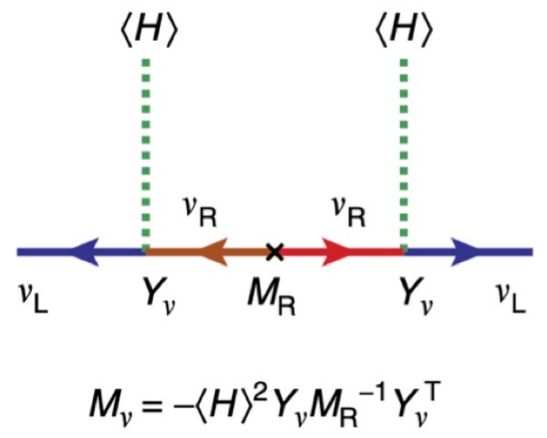
第一类跷跷板机制

加入三个单态中性右手中微子 N(1，1，0)

$$\mathcal{L} = \mathcal{L}_{SM} + y_\nu \tilde{H}\bar{L}N - M_R \bar{N}^c N$$

$$M = \begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix}$$

$$m_\nu \sim \frac{m_D^2}{M_R} = \frac{1}{2}\frac{y_\nu^2 < H >^2}{M_R}$$



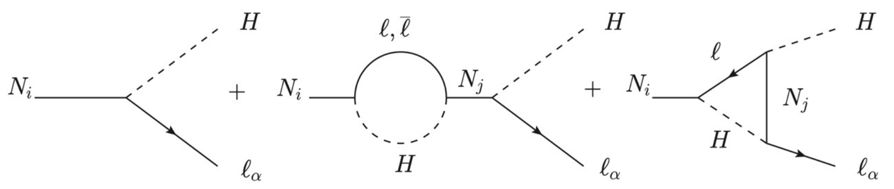
中微子质量被压低!

轻子生成机制

Leptogenesis in Type I seesaw

Baryogenesis Without Grand Unification (4000+ citations), Fukugita and Yanagida, 1986'

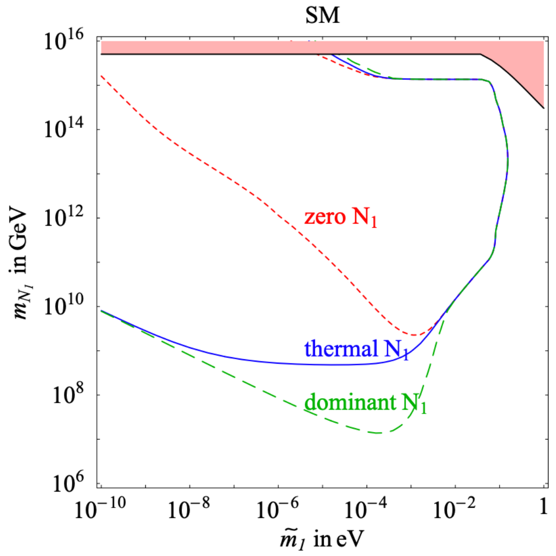
$$\mathcal{L}_I = \mathcal{L}_{SM} + i\overline{N_{R_i}}\partial\!\!\!/ N_{R_i} - \left(\frac{1}{2}M_i\overline{N^c_{R_i}}N_{R_i} + \epsilon_{ab}Y_{\alpha i}\overline{N_{R_i}}\ell^a_\alpha H^b + h.c.\right)$$



$$\epsilon_{i\alpha} = \frac{\gamma\left(N_i \to \ell_\alpha H\right) - \gamma\left(N_i \to \overline{\ell_\alpha} H^*\right)}{\sum_\alpha \gamma\left(N_i \to \ell_\alpha H\right) + \gamma\left(N_i \to \overline{\ell_\alpha} H^*\right)}$$

$$Y_{\mathcal{L}_i} = Y_{N_1} \times \epsilon \times \eta \qquad n_B = \frac{28}{79}(\mathcal{B} - \mathcal{L})_i$$

G.F. Giudice, et al,
Nucl.Phys.B 685 (2004) 89-149



一般要求右手中微子质量超过10^7GeV, 很难进行检验

Type III seesaw情形与Type I 类似

Testing high scale seesaw

CH, H. He, L. Song, J. You, arXiv: 2412.21045(PRDL)，2412.16033(PRD)

Minimal model incorporates inflation and seesaw

$$\Delta\mathcal{L} = \sqrt{-g}\Bigg[-\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) + \overline{N}_{\mathrm{R}} \mathrm{i}\partial\!\!\!/ N_{\mathrm{R}} + \frac{1}{\Lambda}\partial_\mu\phi\,\overline{N}_{\mathrm{R}}\gamma^\mu\gamma^5 N_{\mathrm{R}} + \left(-\frac{1}{2}M\overline{N^{\mathrm{c}}_{\mathrm{R}}}N_{\mathrm{R}} - y_\nu \overline{L}_{\mathrm{L}}\tilde{\mathbb{H}}N_{\mathrm{R}} + \mathrm{H.c.}\right)\Bigg]$$

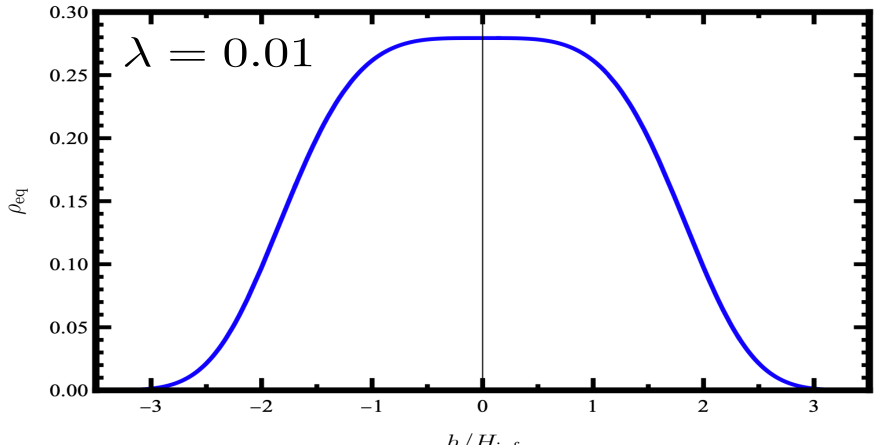
Consequence of the seesaw mechanism

$$\mathcal{L} \supset \frac{1}{2}\bar{\psi}_L \mathbf{M}_\nu \psi_R + \mathrm{h.c.}, \qquad \mathbf{M}_\nu = \begin{pmatrix} 0 & \frac{y_\nu h}{\sqrt{2}} \\ \frac{y_\nu h}{\sqrt{2}} & M \end{pmatrix}$$

$$m_\nu \simeq -\frac{y_\nu^2 h^2}{2M}, \qquad M_N \simeq M + \frac{y_\nu^2 h^2}{2M} \qquad\qquad \Gamma \simeq \frac{m_\phi M^2}{4\pi\Lambda^2}\left[1 + \frac{1}{4}\left(\frac{y_\nu h}{M}\right)^2\right]$$

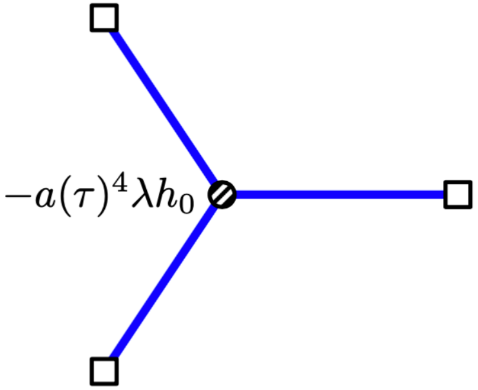
Testing high scale seesaw

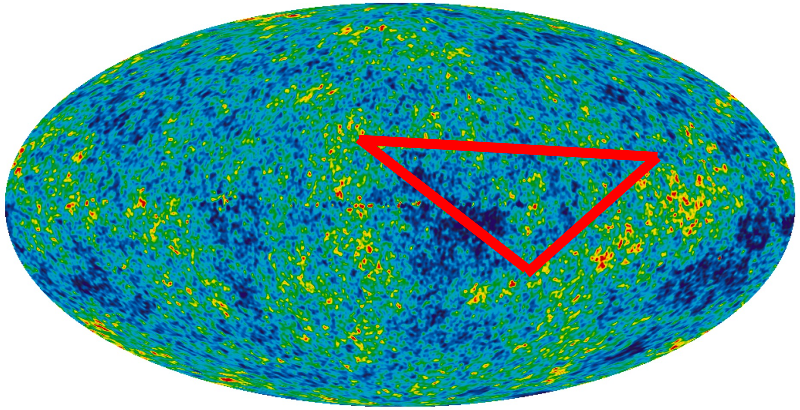
CH, H. He, L. Song, J. You, arXiv: 2412.21045(PRDL)，2412.16033(PRD)

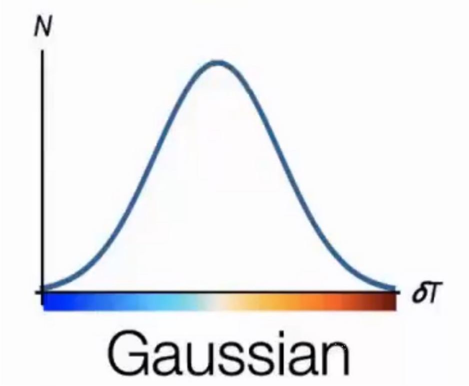


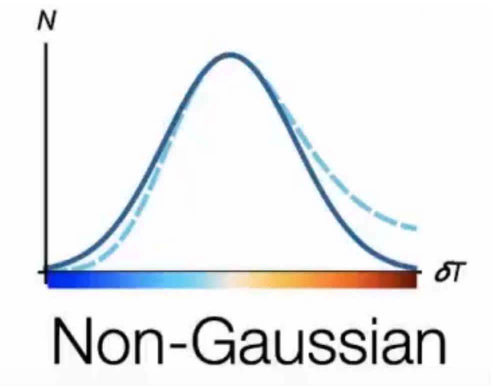
$$\rho_{eq}(h) = \frac{2\lambda^{1/4}}{\Gamma(1/4)}\left(\frac{2\pi^2}{3}\right)^{1/4}\exp\left(\frac{-2\pi^2\lambda h^4}{3H_{\rm inf}^4}\right)$$

Due to the Higgs self-coupling

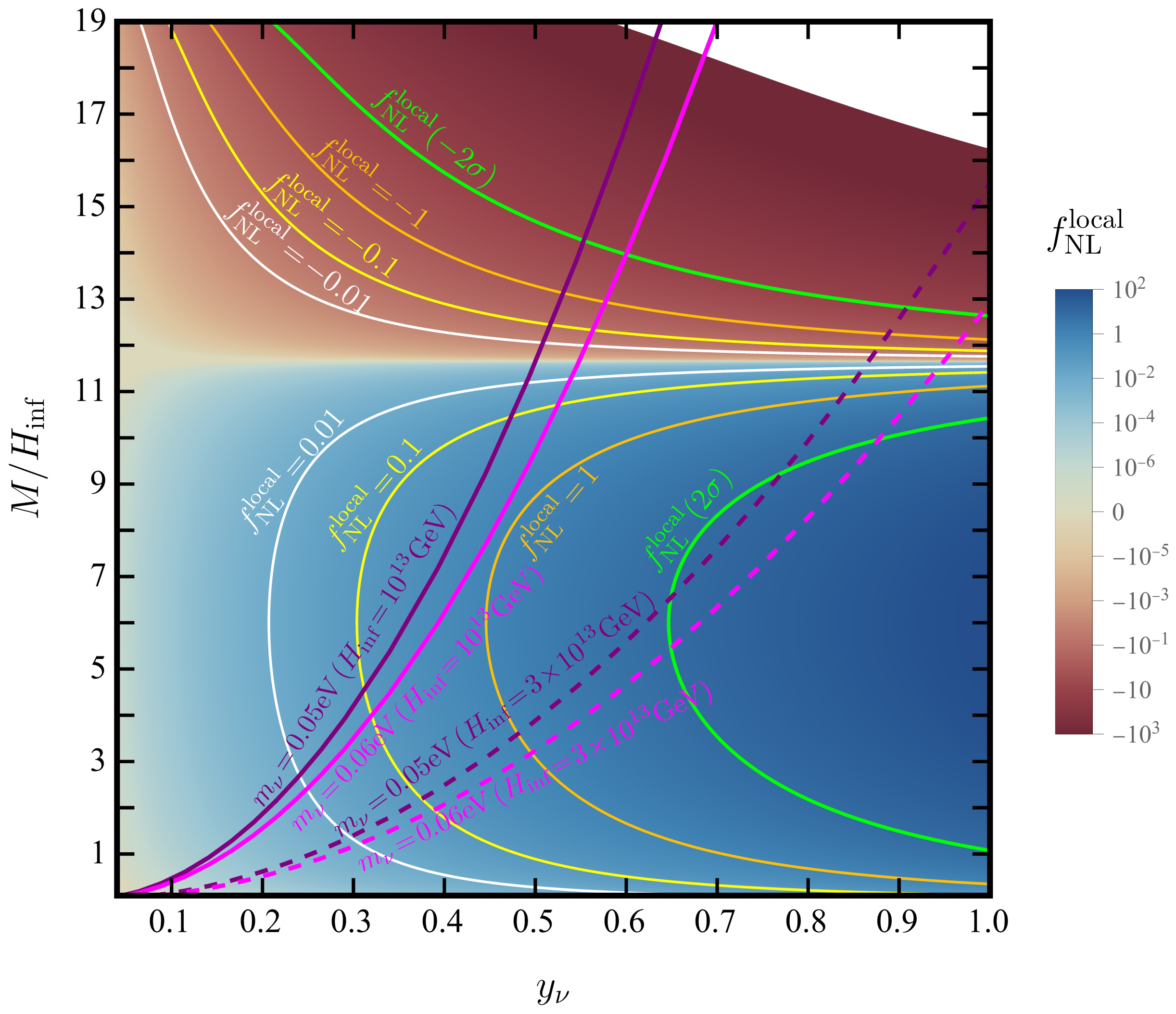








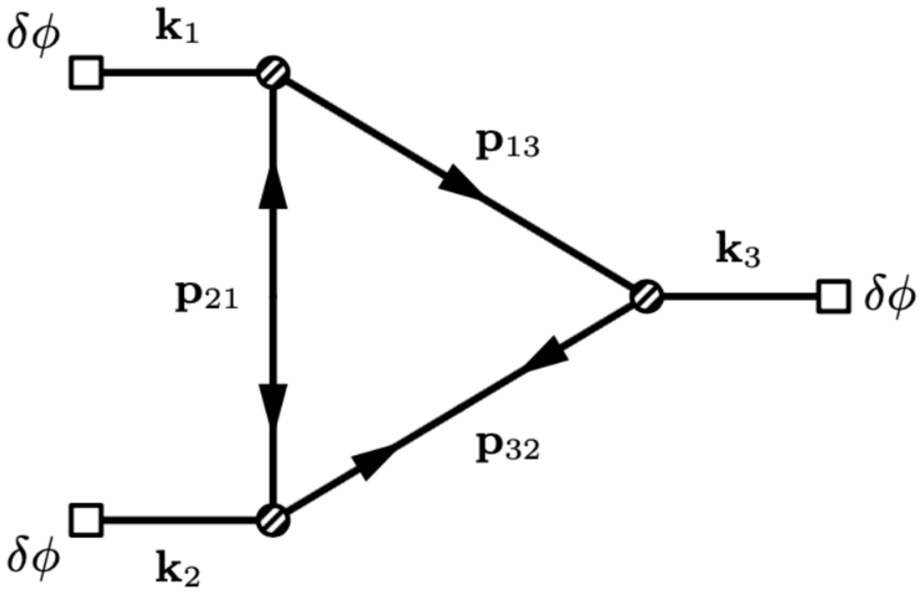
Testing high scale seesaw

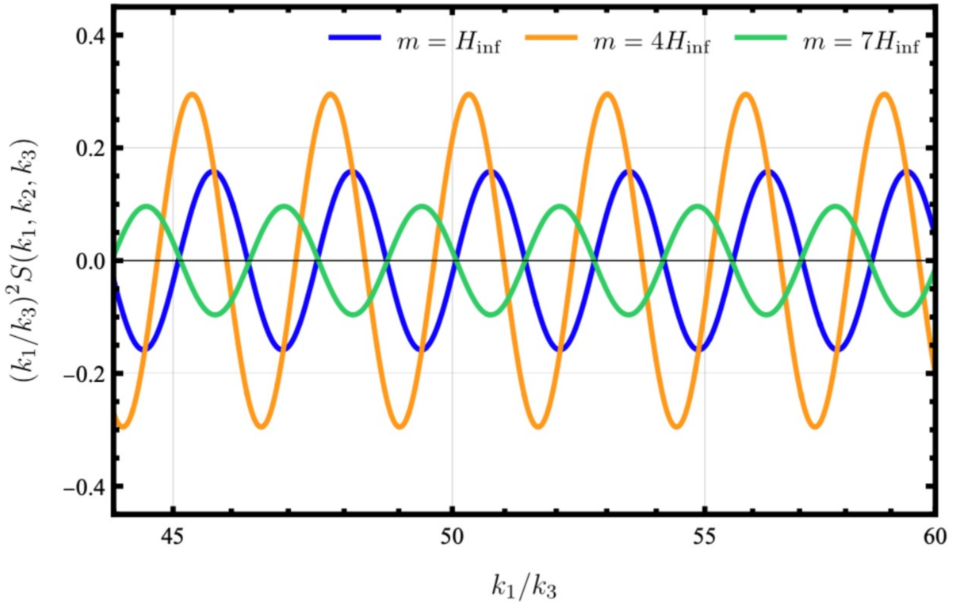


- Colored curves indicating future searches
- Parameter space with Yukawa O(1) could be probed by future observations
- Interplaying with neutrino experiments(JUNO, DUNE for neutrino ordering)

Cosmological collider signal

Prediction of cosmological collider signal: help to identify the mass of the right-handed neutrino

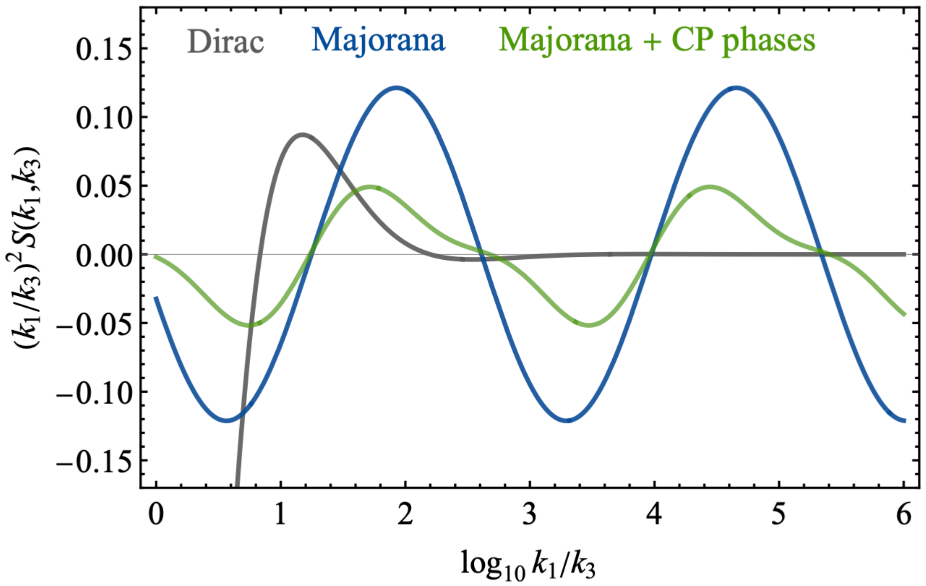


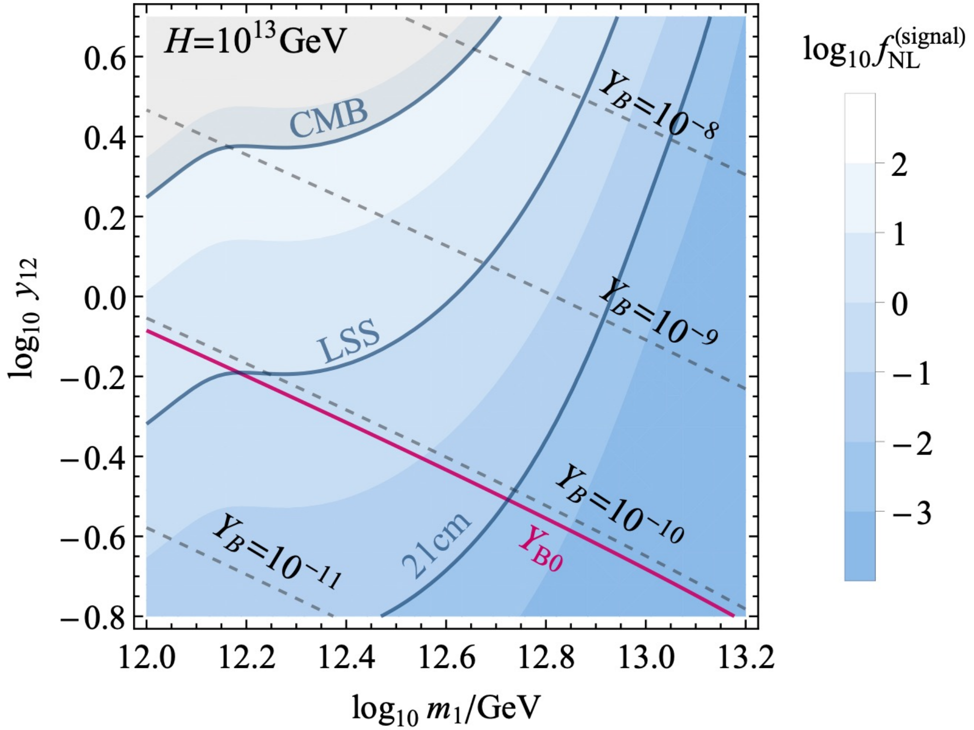


CH, H. He, L. Song, J. You, appear soon

Probing leptogenesis with cc

Yanou Cui, Zhong-Zhi Xianyu, Phys.Rev.Lett. 129 (2022) 11, 111301





第二类跷跷板机制

$$H(2,1/2),\ \Delta(3,1),\ L(2,-1/2) \qquad H = \begin{pmatrix} h^+ \\ h \end{pmatrix},\quad \Delta = \begin{pmatrix} \Delta^+/\sqrt{2} & \Delta^{++} \\ \Delta^0 & -\Delta^+/\sqrt{2} \end{pmatrix}$$

$$\mathcal{L}_{Yukawa} = \mathcal{L}^{\mathrm{SM}}_{\mathrm{Yukawa}} - \frac{1}{2} y_{ij} \bar{L}_i^c \Delta L_j + h.c.$$

$$\frac{1}{2} y_{ij} \Delta^0 \bar{\nu}^c \nu + h.c.$$

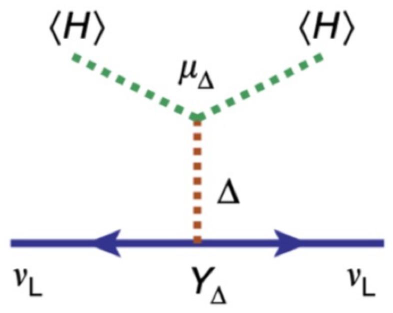
- **Giving neutrino mass matrix with vev of Delta**
- **Delta get a lepton number -2**

第二类跷跷板机制

$$V(H,\Delta) = -m_H^2 H^\dagger H + \lambda_H (H^\dagger H)^2 + m_\Delta^2 \mathrm{Tr}(\Delta^\dagger \Delta) + \lambda_1 (H^\dagger H)\mathrm{Tr}(\Delta^\dagger \Delta)$$
$$+\lambda_2 (\mathrm{Tr}(\Delta^\dagger \Delta))^2 + \lambda_3 \mathrm{Tr}(\Delta^\dagger \Delta)^2 + \lambda_4 H^\dagger \Delta \Delta^\dagger H$$
$$+ \left[\mu (H^T i\sigma^2 \Delta^\dagger H) + h.c.\right] + \ldots$$

U(1)L breaking term

$$\langle \Delta^0 \rangle \simeq \frac{\mu v_{\rm EW}^2}{2 m_\Delta^2}$$



$M_\nu = \langle H \rangle^2 Y_\Delta \mu_\Delta / M_\Delta^2$

EW precision measurement

$$\mathcal{O}(1)\ \mathrm{GeV} > |\langle \Delta^0 \rangle| \gtrsim 0.05\ \mathrm{eV}$$

required by neutrino masses

轻子生成机制

Leptogenesis in Type II seesaw ?

VOLUME 80, NUMBER 26 PHYSICAL REVIEW LETTERS 29 JUNE 1998

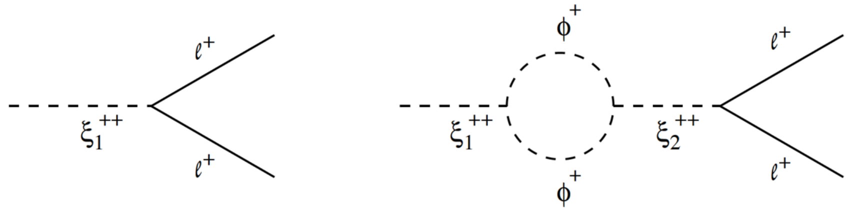
500+ citations

Neutrino Masses and Leptogenesis with Heavy Higgs Triplets

Ernest Ma
Department of Physics, University of California, Riverside, California 92521

Utpal Sarkar
Physical Research Laboratory, Ahmedabad 380 009, India

希格斯三重态质量需要超过10^{10} GeV



$$\delta_i = 2\left[B\left(\psi_i^- \to ll\right) - B\left(\psi_i^+ \to l^c l^c\right)\right]$$

$$\delta_i = \frac{Im\left[\mu_1 \mu_2^* \sum_{k,l} y_{1kl} y_{2kl}^*\right]}{8\pi^2 (M_1^2 - M_2^2)} \left[\frac{M_i}{\Gamma_i}\right]$$

一个希格斯三重态无法传递CP破坏，单纯第二类跷跷板机制不能实现(热)轻子生成机制

Affleck-Dine 机制

Assuming phi is a complex scalar with B charge

$$V(\phi) = \frac{1}{2}m^2|\phi|^2 + [c_{n,m}\phi^n(\phi^*)^m + h.c] \quad m \neq n$$

↓

(B/L violation)

$$j_B^\mu = i(\phi^*\partial^\mu\phi - \phi\partial^\mu\phi^*)$$

ϕ is spatially constant

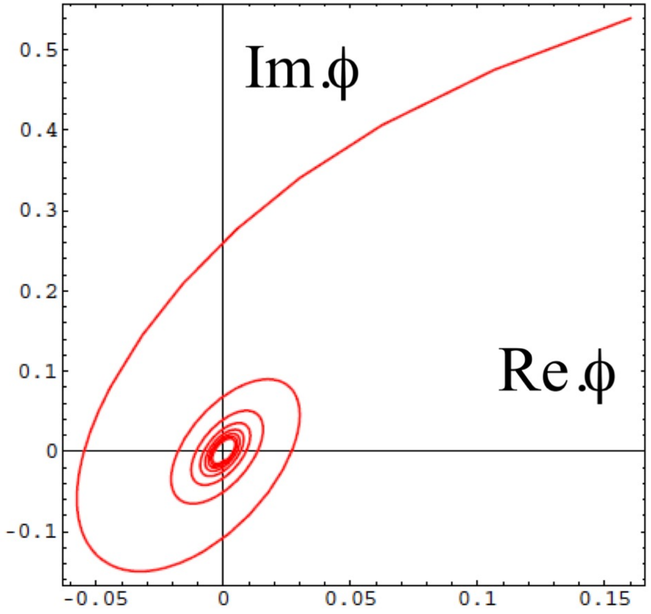
$$n_B = i(\phi^*\dot{\phi} - \phi\dot{\phi}^*) = \rho^2\dot{\theta} \qquad \phi = \frac{1}{\sqrt{2}}\rho_\phi e^{i\theta}$$

$$\dot{n}_B + 3Hn_B = \mathrm{Im}\left(\phi\frac{\partial V}{\partial \phi}\right)$$

Only from U(1) breaking term

A motion of theta will generate baryon number(CP is violated when theta is non-vanishing)

Affleck-Dine 机制



- Scalar particle taking B/L charge
- Small B/L violation term in the potential(charge neutral)
- Scalar particle with initial displaced vacuum

Affleck-Dine 机制

- **Scalar**
- **Taking baryon(lepton) charge**
- **Charge neutral, otherwise no breaking team**

First two conditions seem easy

- Leptoquarks $y\phi\overline{u_R^c}e_R$
  - color triplet, charge 1/3
- Diquarks $y\phi\overline{u_R^c}d_R$
  - charge -1/3
- Double charged scalar $y\phi^{++}\overline{e_R^c}e_R$
  - charge 2

None of above works!

Affleck-Dine 机制

超对称中有很多例子

- Many scalars take B/L charge
- Flat directions(quartic coupling vanish, no charge)

	$B-L$
H_uH_d	0
LH_u	-1
$\bar{u}\bar{d}\bar{d}$	-1
$QL\bar{d}$	-1
$LL\bar{e}$	-1
$QQ\bar{u}\bar{d}$	0
$QQQL$	0
$QL\bar{u}\bar{e}$	0
$\bar{u}\bar{u}\bar{d}\bar{e}$	0

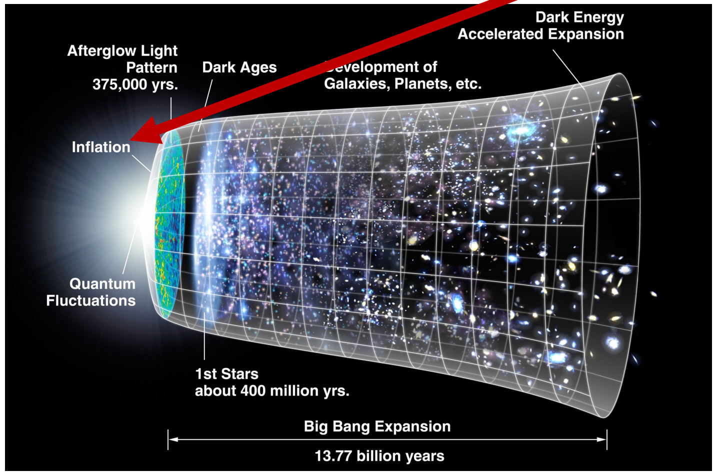
$$H_u = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ \phi \end{pmatrix}, \quad L = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi \\ 0 \end{pmatrix}$$

$$V = m^2|\phi|^2 + \left[\frac{A}{M^{n-3}}\phi^n + h.c\right]$$

Affleck-Dine 机制

	Type II seesaw
● Scalar particle taking B/L charge	✓
● Small B/L violation term in the potential(charge neutral)	✓
● Scalar particle with initial displaced vacuum	?

If the scalar plays the role of inflaton-Higgs inflation



第二类轻子生成机制

Type II seesaw leptogenesis

希格斯三重态是标量粒子，在宇宙早期拥有大的真空期望值(可以提供暴胀)，满足脱离热平衡条件，从而实现轻子生成机制(通过AD机制)

PHYSICAL REVIEW LETTERS **128,** 141801 (2022)

Affleck-Dine Leptogenesis from Higgs Inflation

Neil D. Barrie,[1,*] Chengcheng Han,[2,†] and Hitoshi Murayama[3,4,5,‡]

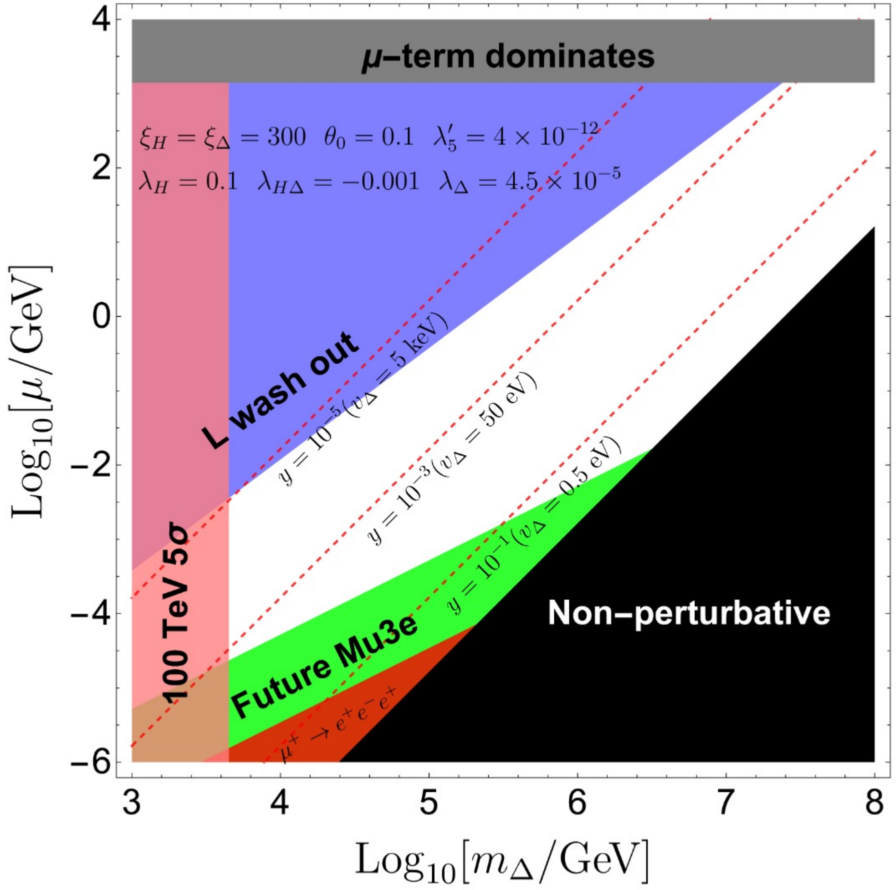
We find that the triplet Higgs of the type-II seesaw mechanism can simultaneously generate the neutrino masses and observed baryon asymmetry while playing a role in inflation. We survey the allowed parameter space and determine that this is possible for triplet masses as low as a TeV, with a preference for a small

Type II Seesaw leptogenesis

JHEP

Neil D. Barrie,[a] Chengcheng Han[b] and Hitoshi Murayama[c,d,e,1]

第二类轻子生成机制



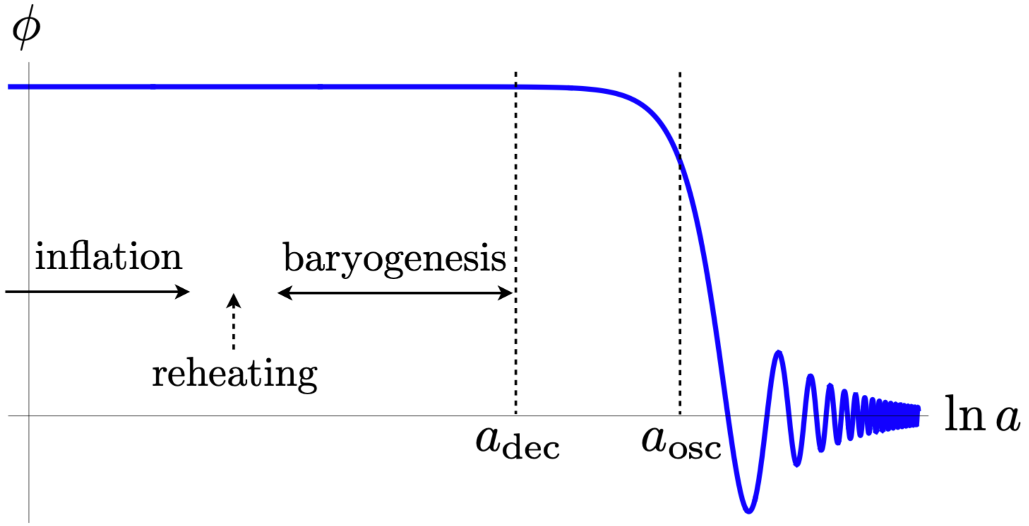
- 希格斯三重态质量可以轻至 TeV，可以在对撞机直接寻找
- 与轻子有相当的耦合, 轻子味破坏过程对其进行检验
- 中微子为Majorana粒子: 无中微子双beta衰变

Spontaneous baryogenesis

A. G. Cohen and D. B. Kaplan, Phys. Lett. B 199, 251 (1987)

$$S = \int d^4x\sqrt{-g}\left\{-\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi) - \sum_i c_i\frac{\partial_\mu\phi}{f}j_i^\mu + \cdots\right\}$$

- phi在暴胀期间获得很大真空期望值
- phi跟重子流耦合,运动时提供化学势 $\mu_i = c_i\frac{\dot{\phi}}{f}$
- 存在重子数破坏过程
- 重子数破坏过程退耦



根据phi起源的不同，各种变种：Axiogenesis, Majoron-genesis, Lepto-axiogenesis

Keisuke Harigaya, Wei Chao, Eung Jin Chun...

Majoron-genesis

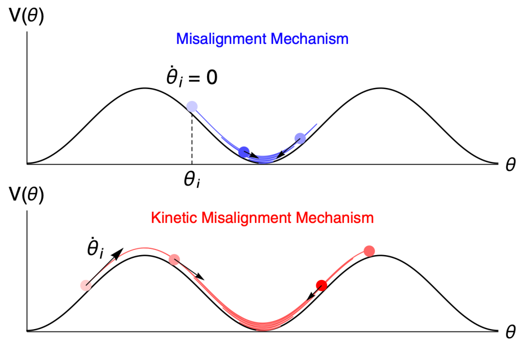
Global U(1)B-L model

Eung Jin Chun, Tae Hyun Jung, 2311.09005
Patrick Barnes, Raymond T. Co, Keisuke Harigaya, Aaron Pierce, 2402.10263

$$-\mathcal{L}_{\rm int} = \frac{1}{2}\sum_I y_{N_I}\Phi\bar{N}_I^c N_I + \sum_{\alpha, I} Y_{N,\alpha I}\bar{l}_\alpha \tilde{H} N_I + h.c.,$$

$$\Phi \to \frac{f_J}{\sqrt{2}} e^{iJ/f_J}$$

- Lepton number wash out process + sphaleron process
- When T< 100 GeV, baryon number fixed
- Some problem with majoron life time too long
- Need kinetic misalignment



重子不对称性与原初黑洞

英国皇家学会贝克尔奖章及格鲁伯宇宙学奖得主J. Silk等在2022年提出一个非常具有吸引力的想法

PHYSICAL REVIEW LETTERS **128**, 031102 (2022)

Editors' Suggestion

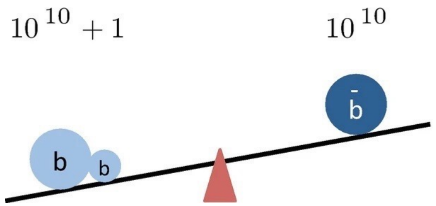
被PRL Editor 推荐发表

Cosmic Coincidences of Primordial-Black-Hole Dark Matter

Yi-Peng Wu,[1,*] Elena Pinetti,[1,2,6] and Joseph Silk[3,4,5]

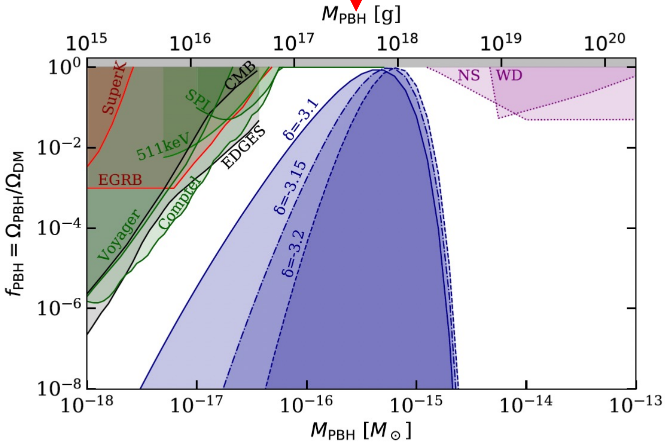
如果宇宙早期经历超慢滚暴胀 → **诱导标量场产生非零真空期望值**

如果带重子数，产生重子不对称性

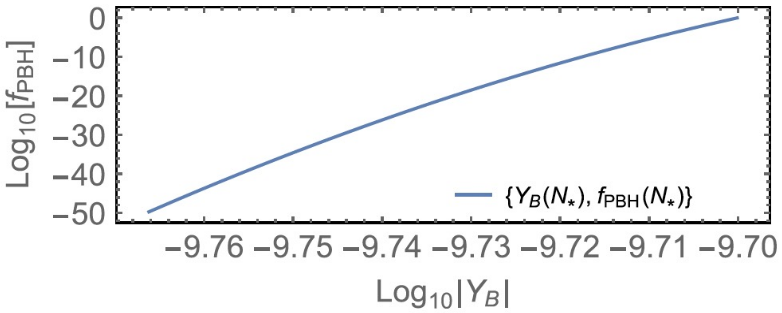


产生原初黑洞

解释暗物质

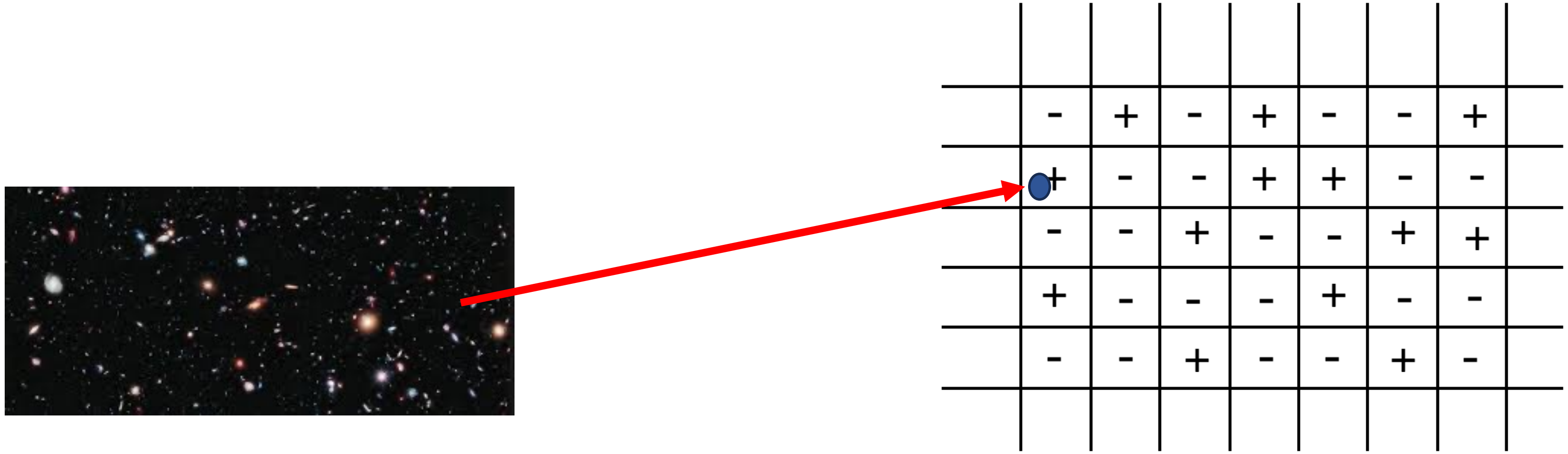


→



重子不对称性与原初黑洞

由于诱导出的标量场真空期望值相位随机 → 整个宇宙分为正、反物质部分，整体平均重子数为零



如果我们的可观测宇宙只是正物质区域的一部分，则理论是自恰的

正反物质对称的宇宙

核心问题是这个区域到底多大(关联长度)?

重子不对称性与原初黑洞

JHEP
Published for SISSA by Springer
Received: October 14, 2021
Revised: December 17, 2021
Accepted: December 20, 2021
Published: January 5, 2022

Baryogenesis from ultra-slow-roll inflation

Yi-Peng Wu,[a] Elena Pinetti,[a,b,c] Kalliopi Petraki[a,d] and Joseph Silk[e,f,g]

他们的长文中给了一个解释：如果相互作用是近似U(1)对称性，区域大小远比我们的可观测宇宙大

negligible. In contrast to the presence of "flat directions" in higher-order non-renormalizable potential [7], θ may not have a well-defined coherent value in this scenario, yet one can easily check that the effective mass of the angular mode at the maximal CP violation is given by $m_\theta^2 \sim \partial_\theta\partial_\theta V(R,\theta)|_{\theta=\theta_{\max}} \to 0$. The correlation length x_c for a massive scalar in de Sitter, defined from $G(x_c) = G(0)/2$, is $x_c/x_{\rm ref} = 2^{3H_*^2/(2m^2)}$ [54, 69], where m is the scalar mass, $x_{\rm ref}$ is a reference length scale and $G(x) \equiv G(|\vec{x}_1 - \vec{x}_2|)$ is the two-point spatial correlation function. Since we are interested in long wavelength modes that have exited the horizon by the time of USR transition (namely $x_{\rm ref} \sim 1/k_{\rm CMB}$ can be a good choice), the condition $m_\theta \to 0$ implies that baryon asymmetry from θ picked up by the choice (2.5) for the mass eigenstates has a correlation length much larger than the Hubble scale, which ensures that a local patch of the Universe is left with a pure (anti)matter (see also the

关联长度： $R_c \sim H^{-1} \exp(H^2/m^2)$

重子不对称性与原初黑洞

Physics Letters B 839 (2023) 137816

Contents lists available at ScienceDirect

Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

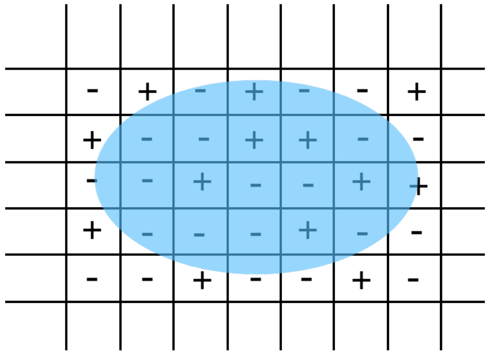
Correlation length of the angular mode for an approximate $U(1)$ symmetry during inflation

Chengcheng Han

arXiv:2206.06142

θ is long (see the last paragraph of Sec. 3.2 in [13]). The main argument is that $m_\theta^2 \sim \partial_\theta \partial_\theta V(R,\theta) \to 0$ and the correlation length of θ is long due to the formula $R_c \sim H^{-1} \exp(H^2/m^2)$. However, since θ is not a canonical field and as we calculated in the work, the correlation length of θ is not decided by the θ mass, therefore their argument is wrong and their result is doubtable.

但是theta不是正则的场，不能直接使用公式 $R_c \sim H^{-1} \exp(H^2/m^2)$



完整的计算需要解随机过程中的Fokker-Planck方程

$$\frac{\partial \rho(\varphi,t)}{\partial t} = \frac{1}{3H}\left[\rho(\varphi,t)\nabla^2 V(\varphi) + \nabla V(\varphi)\cdot\nabla\rho(\varphi,t)\right] + \frac{H^3}{8\pi^2}\nabla^2\rho(\varphi,t)$$

我们的宇宙是由~e^{100}个这样的区域组成，平均重子数密度几乎为零，因此他们结论是值得怀疑的

重子不对称性与原初黑洞

Referee意见

In short, I strongly recommend this manuscript for publication. The claims of [12-14] are obviously and hopelessly incorrect, and publication of this manuscript is necessary to prevent people from going any further in the wrong direction. I recommend publication after the following minor revisions:

“我强烈建议此文章发表，文献[12-14]是明显错误和无希望的，这篇文章的发表可以阻止大家在错误的方向上走的更远”

[12] Y.-P. Wu, K. Petraki, Stochastic baryogenesis, J. Cosmol. Astropart. Phys. 01 (2021) 022, arXiv:2008.08549.

[13] Y.-P. Wu, E. Pinetti, K. Petraki, J. Silk, Baryogenesis from ultra-slow-roll inflation, J. High Energy Phys. 01 (2022) 015, arXiv:2109.00118.

[14] Y.-P. Wu, E. Pinetti, J. Silk, Cosmic coincidences of primordial-black-hole dark matter, Phys. Rev. Lett. 128 (2022) 031102, arXiv:2109.09875.

THANK YOU