CP violation in modular invariant flavor models

Hikaru Uchida[A]

The collaborators
T. Kobayashi[A], Y. Shimizu[B], K. Takagi[B], M. Tanimoto[C], T. H. Tatsuishi[A]

[A]Dept. of Phys. Hokkaido Univ.
[B]Grad. Sch. of Sci. Hiroshima Univ.
[C]Niigata Univ.

arXiv:1910.11553 [hep-ph]

Mystery of Flavor

■mystery of Standard Model

$\supset$ mystery of *"Flavor"*

- Origen of 3 generation
- Origen of mass hierarchy
- Origen of flavor mixing
- Origen of CP violation

e.g.) A_4

Discrete symmetry broken by VEV of *"flavon"*

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Compact space

Modular symmetry

$M_{ij}(\tau)\Phi_i\Phi_i$

$M_{ij}(\tau) \to M'_{ij}(\tau')$

$M'_{ij}(\tau')\Phi'_i\Phi'_i$

e.g.) A_4

Discrete symmetry
broken by VEV of
"modulus" τ
$\langle M_{ij}(\tau) \rangle$

Compactification from superstring theory

Superstring theory
10D space-time

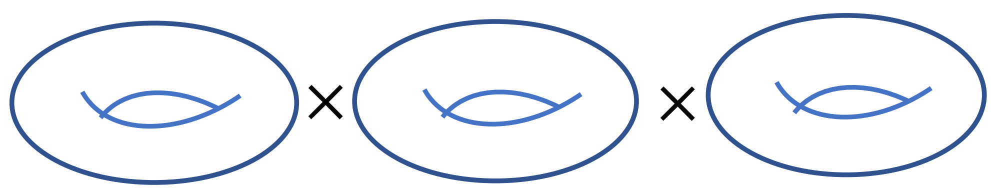
⟺

We observe
4D space-time

+

6D compact space

(ex) $T^6 = T^2 \times T^2 \times T^2$

$=$ 

4D CP embedded in 10D proper Lorentz

10D proper Lorentz transformation $\supset$ 4D CP transformation

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6D transformation Λ_6

$\det \Lambda_6 = -1$

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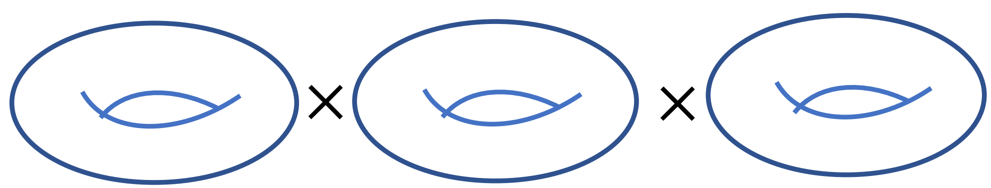
$=$ 

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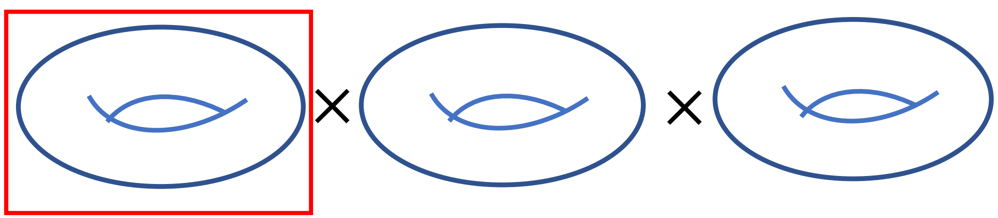
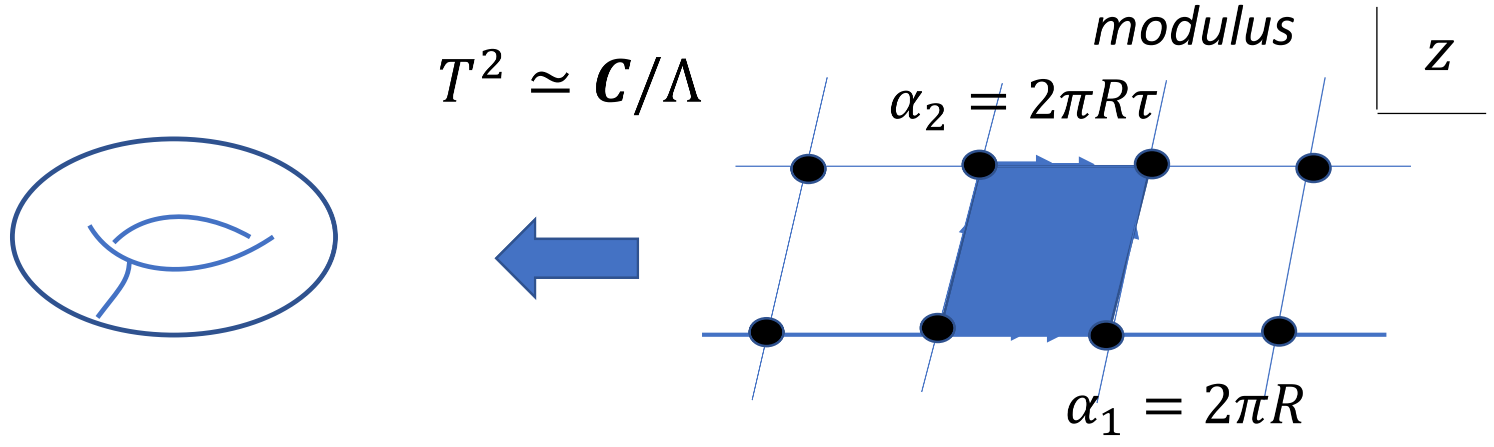
$=$ 

4D space-time with 2D torus T^2



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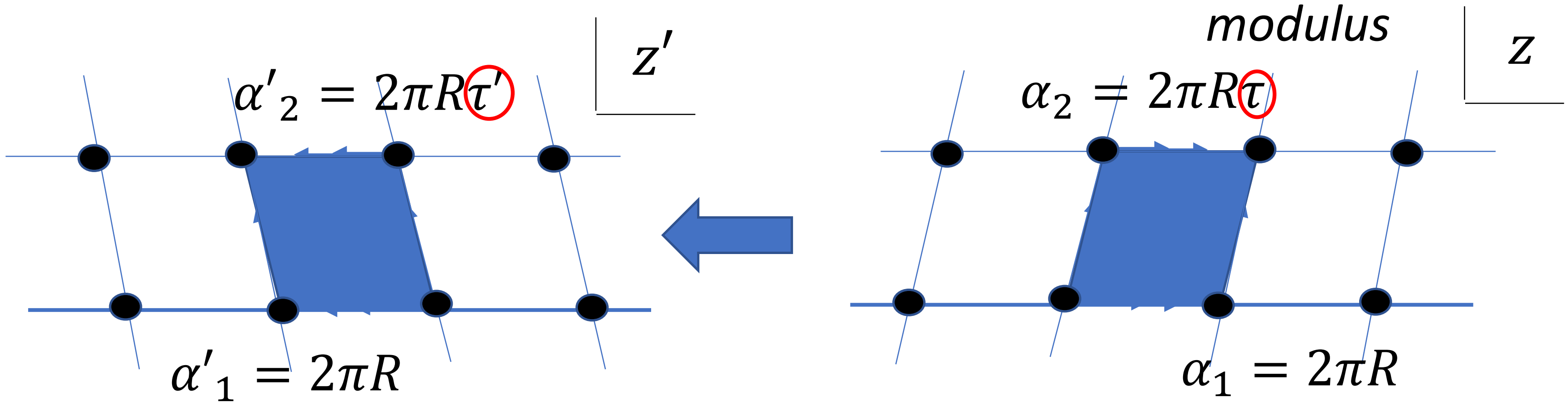

$$\det\Lambda_2 = -1$$

4D CP ✚ $\Lambda_2: z \to z' = -\bar{z},$ $\tau =\to \tau' = -\bar{\tau}$ $\subset$ 6D proper Lorentz

P. P. Novichkov, J. T. Penedo, S. T. Petcov and A. V. Titov, JHEP 1907, 165 (2019) [arXiv:1905.11970 [hep-ph]].

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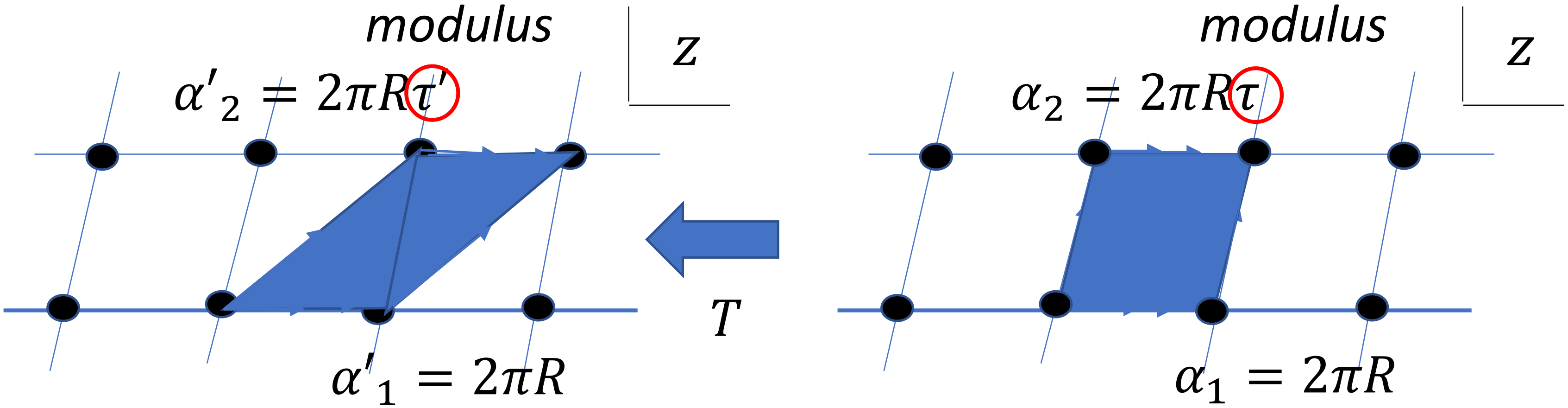


Modular symmetry $\quad T: \tau \to \tau' = \tau + 1 \qquad S: \tau \to \tau' = -\dfrac{1}{\tau}$

$\supset$ Finite modular subgroup Γ_N (ex) $\Gamma_3 = A_4$

$\Downarrow$

Many flavor models $\quad M_{ij}(\tau) \to M'_{ij}(\tau')$

In fact, modulus τ is fixed $\quad \langle M_{ij}(\tau) \rangle$

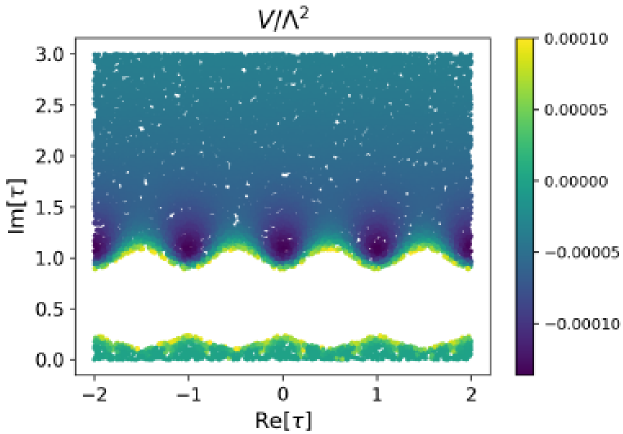
CP symmetry may be violated $\quad (\tau = \!\!\to -\bar{\tau})$

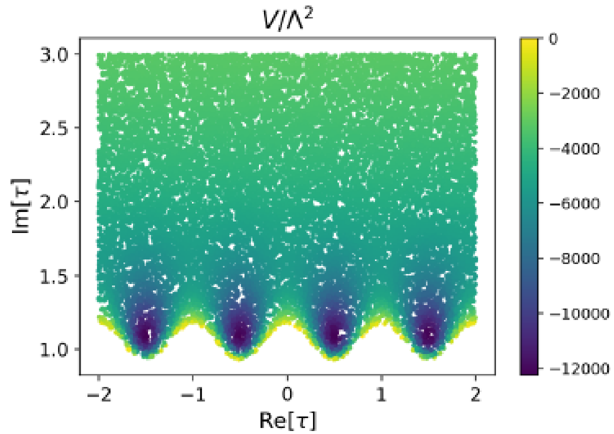
Modulus stabilization

Supergravity potential $V = e^G (G_{\tau\bar{\tau}}^{-1} |G_\tau|^2 - 3)$ $G = K + \ln|W|^2$

A_4 model *T* and *CP* invariant $K = -\ln|i(\bar{\tau} - \tau)|$

Model 1) $W = \Lambda\left(Y_1^{A_4,\mathbf{4}}(\tau)\right)$ Model 2) $W = \Lambda\left(Y_1^{A_4,\mathbf{4}}(\tau)\right)^{-1}$





Minimum at $\mathrm{Re}[\tau] = 0, \frac{1}{2}$

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In General

$$W = \sum_m c_m q^m \qquad q = e^{2\pi i\tau}$$

$$|W|^2 \sim (C_0 + C_1 \cos 2\pi \mathrm{Re}[\tau])^{\pm 1} \qquad |q| \ll 1$$

Minimum at $\mathrm{Re}[\tau] = 0, \frac{1}{2}$

CP symmetry seems to be violated $(\tau \to -\bar{\tau})$

CP violation in modular invariant flavor models

$$W \supset M_{ij}(\tau)\Phi_i\Phi_i$$ Modular invariant

$$T:\ \Phi_i \to e^{2\pi i k_i/N}\Phi_i\,,\quad M_{ij} \to e^{-2\pi i(k_i+k_j)/N}M_{ij}$$

$$\mathrm{Re}[\tau]=0,\frac{1}{2} \Longrightarrow q\in\mathbf{R}$$

$$M_{ij}=m_{ij}(q)e^{-2\pi i(k_i+k_j)\tau/N}$$

$$\mathrm{Re}[\tau]\neq 0,\frac{1}{2} \Longrightarrow q\in\mathbf{C} \qquad q=e^{2\pi i\tau} \qquad q^n \ni \qquad n\in\mathbf{Z}$$

$$\langle\mathrm{Re}[\tau]\rangle=\frac{1}{2} \Longrightarrow M_{ij}=\tilde{m}_{ij}(q)\,e^{-\pi i(k_i+k_j)/N}$$

$$\tilde{m}_{ij}=m_{ij}e^{-2\pi(k_i+k_j)\mathrm{Im}[\tau]/N}\in\mathbf{R}$$

vanished after rephasing

$$\Phi_i \to e^{-\pi i k_i/N}\Phi_i$$

⇒ *There is no physical phase*

$\langle\mathrm{Re}[\tau]\rangle=0,\frac{1}{2}$ dose not break *CP* symmetry

T invariance

Conclusion

We have studied the CP violation in modular invariant flavor models through the modulus stabilization.

- The CP and T invariant potential has the minimum at $\mathrm{Re}[\tau] = 0$ or $1/2$.
- Under the T invariance, there is no physical CP phase through rephasing.

Therefore, the T invariance prevents the CP violation.

Thank you for your attention