Discrete Gauge Symmetry and Aharonov-Bohm Radiation in String Theory

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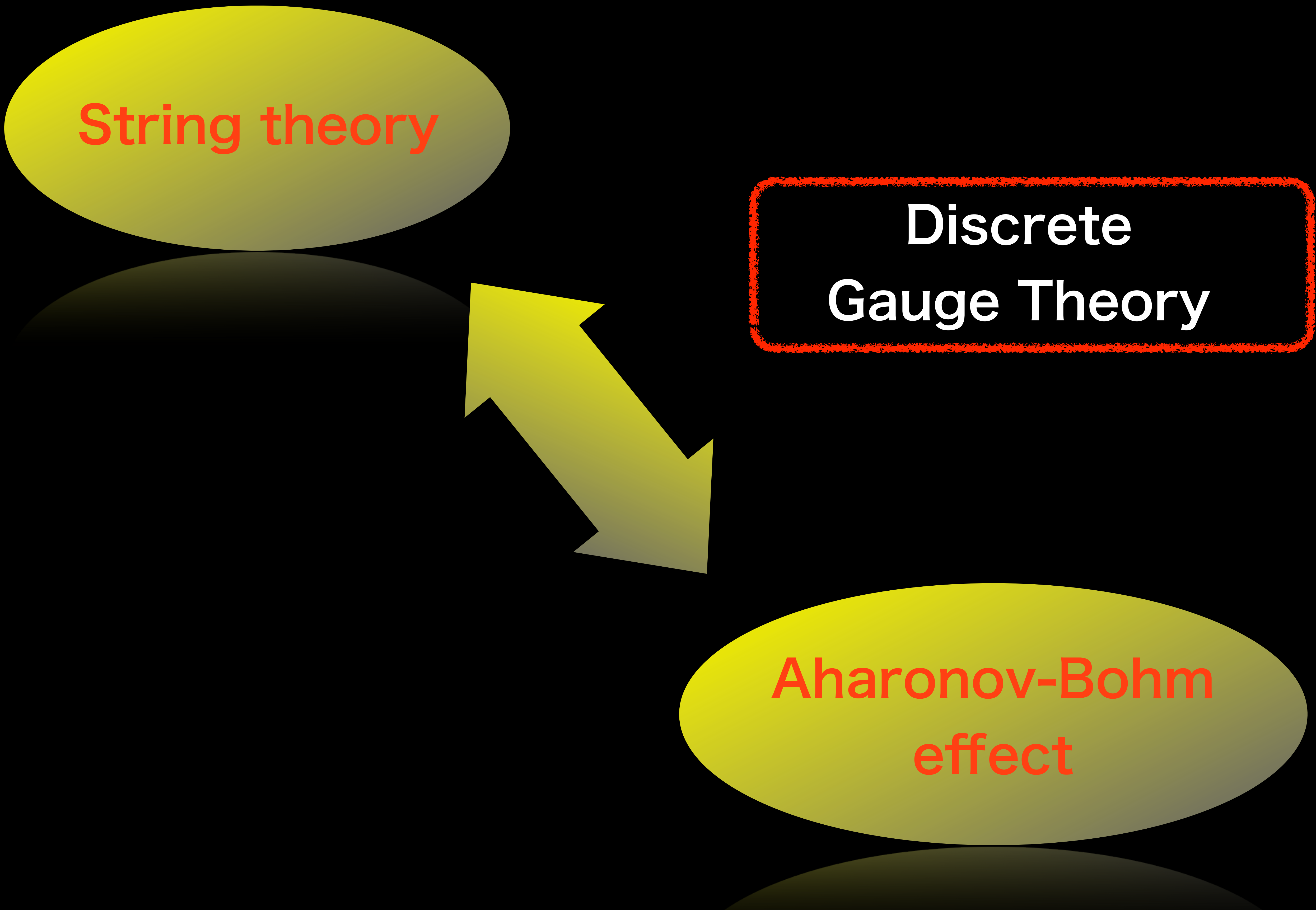
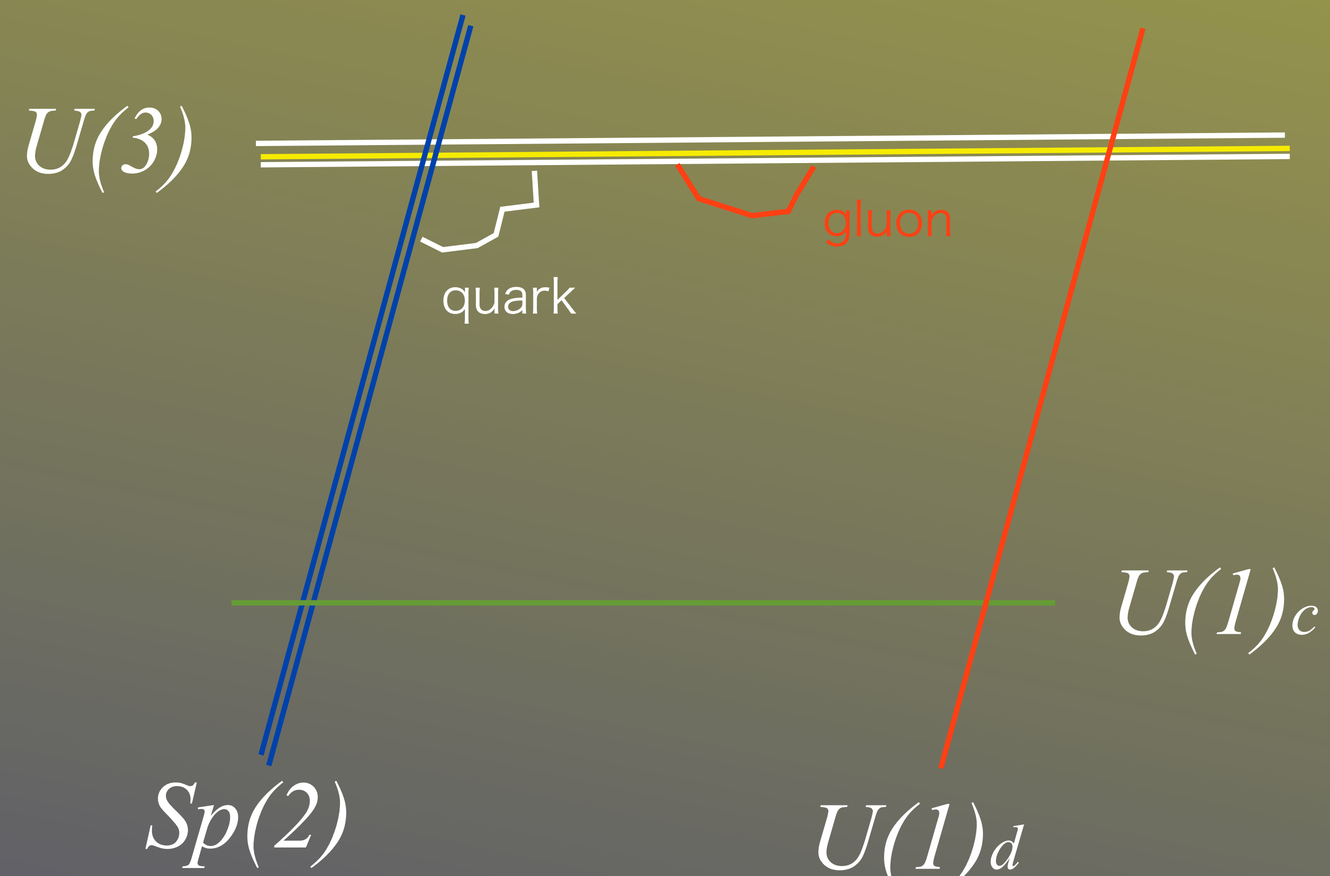
1310.4026 [hep-th], Published in JHEP


String theory
Discrete
Gauge Theory
Aharonov-Bohm
effect

Discrete gauge sym. is ubiquitous

Consider prototype intersecting D-brane model

$$U(3) \times Sp(2) \times U(1)_c \times U(1)_d$$



Extra U(1)s are massive

$$U(3) \times Sp(2) \times U(1)_c \times U(1)_d$$

Stuckelberg coupling

$$\mathcal{L} \sim t^2 (d\phi - pA) \wedge *(d\phi - pA)$$

In E<< t, massive field does not play any role?

Claim:

massive objects contribute to low energy physics via Aharonov-Bohm effect!

Discrete symmetry in pheno.

Discrete gauge symmetries are used for model building

- stabilizing baryons
- suppressing FCNC
- fixing quark and lepton mixing angle

Banks-Seiberg gave a new argument on this subject from quantum theory of gravity

[Banks-Seiberg `10]

"No global symmetry" theorem

Banks-Seiberg extended "no global symmetries" theorem to also include discrete symmetries

In embedding a phenomenological model in string theory, such a discrete symmetry have to be gauged (if not broken explicitly)

Discrete

$$\mathcal{L} \sim t^2 (d\phi - pA) \wedge *(d\phi - pA)$$

$$*d\phi = dB_2$$

Universal Lagrangian of Zp gauge theory

$$p \int_{4D} B_2 \wedge F_2 \qquad F_2 = dA$$

Gauge transformation is

$$A \to A + d\lambda, \quad \phi \to \phi + p\lambda,$$

$$B_2 \to B_2 + d\Lambda, \quad V \to V + p\Lambda,$$

Z_p particle (AB particle)

$$p \int_{4D} B_2 \wedge F_2 \qquad F_2 = dA$$

an object electrically couples to the massive gauge field

$$e^{-i \int_{\Sigma_1} A} \qquad \Sigma_1 \text{ world-line}$$

Z_p string (AB string)

$$p \int_{4D} B_2 \wedge F_2 \qquad F_2 = dA$$

an object electrically couples to Kalb-Ramond field

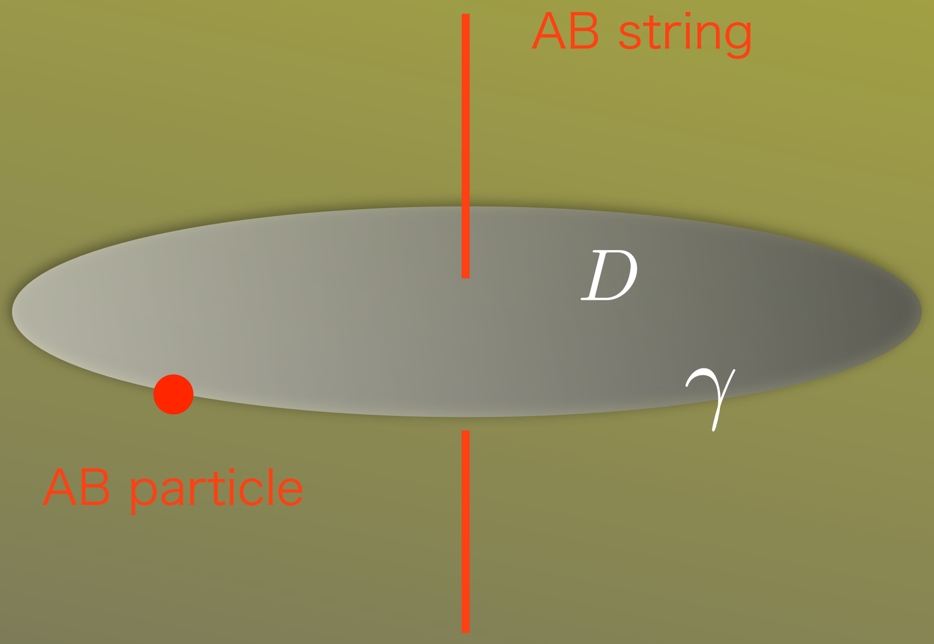
$$e^{-i \int_{\Sigma_2} B_2}$$

Σ_2 world-sheet

Aharonov-Bohm effect

To see an interaction of AB string with AB particle, put an AB string in space-time

$$p\int_{4D} B_2 \wedge dA + \int_{\Sigma_2} B_2$$



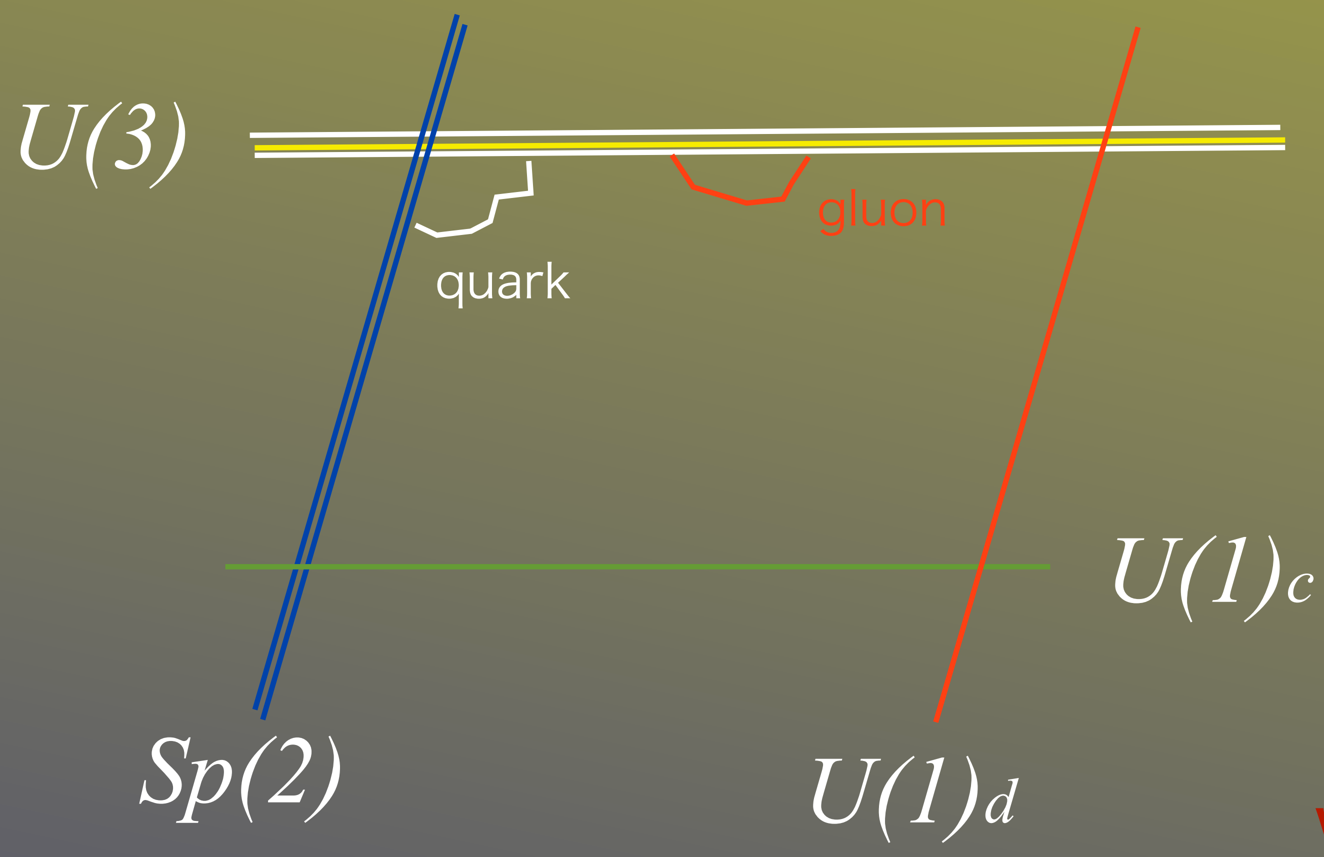
Consider the holonomy around the string

$$\mathrm{hol}(\gamma) \equiv \exp\left(\int_\gamma A\right) = \exp\left(\int_D F\right) = \exp\left(\frac{2\pi i}{p}\right) \equiv \exp(i\Phi),$$

Back to string theory

Toroidal orientifold models in IIA string theory

the simplest standard-like model



D6 branes

wrapping on 3-cycles

Chern-Simons terms

[Berasaluce-Gonzalez, Ibanez, Soler, Uranga `11]

Chern-Simons terms in D6 brane action

$$S_{CS} = \frac{1}{2}\left(\int_{\Gamma_A} C_5 \wedge F_A - \int_{\Gamma_A^*} C_5 \wedge F_A\right),$$

ex $\Gamma_A = k\beta$

Γ_A^* stands for the mirror image of A.

$$k\int_{4D} \widetilde{C}_2 \wedge dA, \qquad \text{where} \qquad \widetilde{C}_2 = \int_\beta C_5,$$

Aharonov-Bohm particle

AB particle in this model

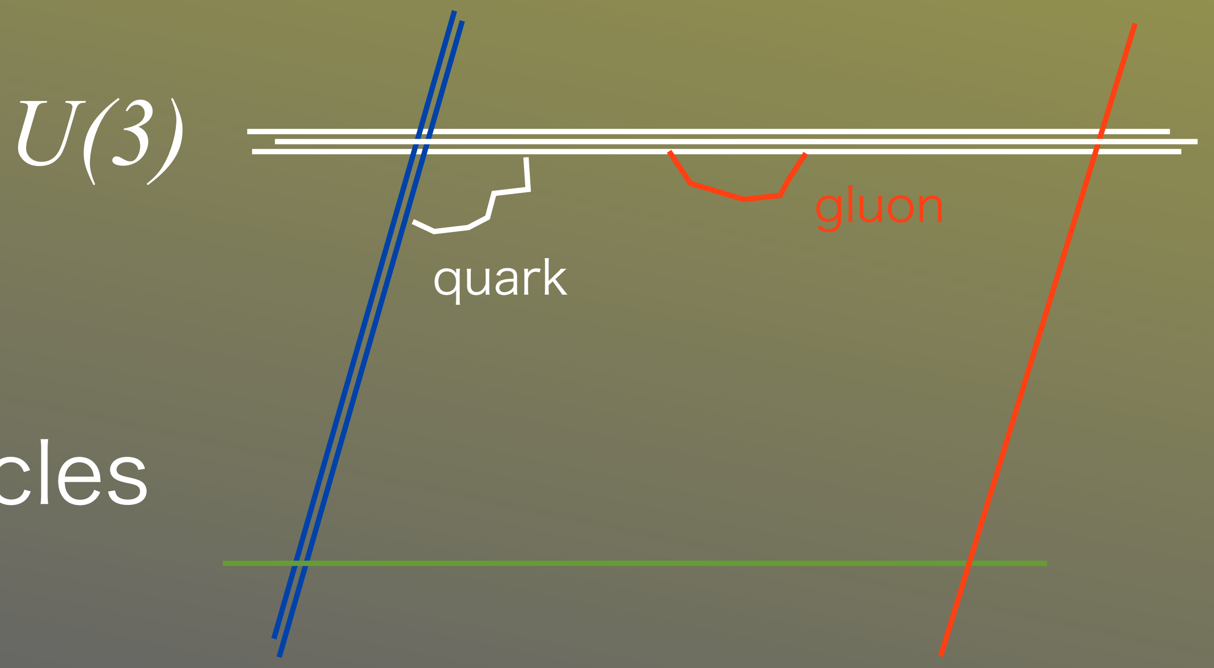
$$\mathcal{O}_{\text{AB particle}} \sim \exp\left(i \int_{\Sigma_1} A\right).$$

An object electrically coupling to gauge field

on D6-brane

F1 string ending on D6

= Standard model particles



Aharonov-Bohm string

AB string in this model

$$\mathcal{O}_{\text{AB string}} \sim \exp\left(i \int_{\Sigma_2} \widetilde{C}_2 \right),$$

$$\widetilde{C}_2 = \int_\beta C_5,$$

An object electrically coupling to C_5

D4-brane wrapping on β

$$\mu \equiv T_{D4} V_3 = \frac{V_3}{(2\pi)^4 g_s l_s^5}.$$

String network

After AB string creation, cosmic string network is formed

- A long string
- Small loops

Aharonov-Bohm radiation

Massive radiation from cusps

radiation power from a single cusp

$$\int_{4D} A \wedge *_4 \mathcal{J}.$$

$$\mathcal{J}_\mu = \sum_a \bar{\psi}_a \gamma_\mu \psi_a.$$

explicit calculations for solenoid

[Jones-Smith, Mathur, Vachaspati **Nov/2009**]

Aharonov-Bohm radiation

radiation of massless particles

$$P_{\mathrm{AB}} \simeq \Gamma_{\mathrm{AB}} \frac{\Phi^2}{L^2} N_{\mathrm{max}} = \Gamma_{\mathrm{AB}} \frac{\Phi^2 \sqrt{\mu}}{L}.$$

[Jones-Smith, Mathur, Vachaspati **Nov/2009**]

In our model

mass of AB particle << energy scale of AB string

we can apply the results to our model

String Network

the number density of the loop size between L and $L + dL$

$$n_L dL = \frac{\xi\sqrt{\alpha}}{p^b L^{5/2} t^{3/2}},$$

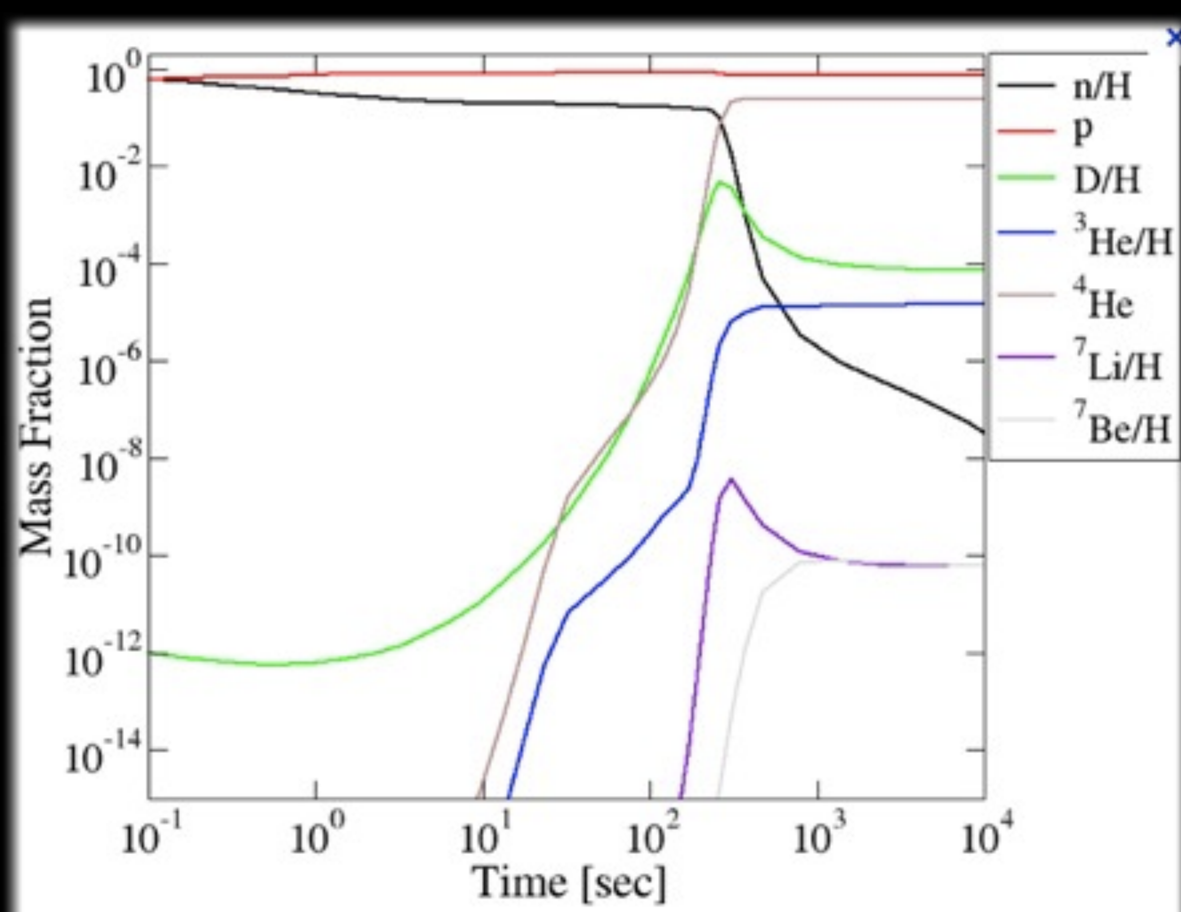
$$10^{-3} \leq p \leq 1$$

$\rightarrow$ sever constraint

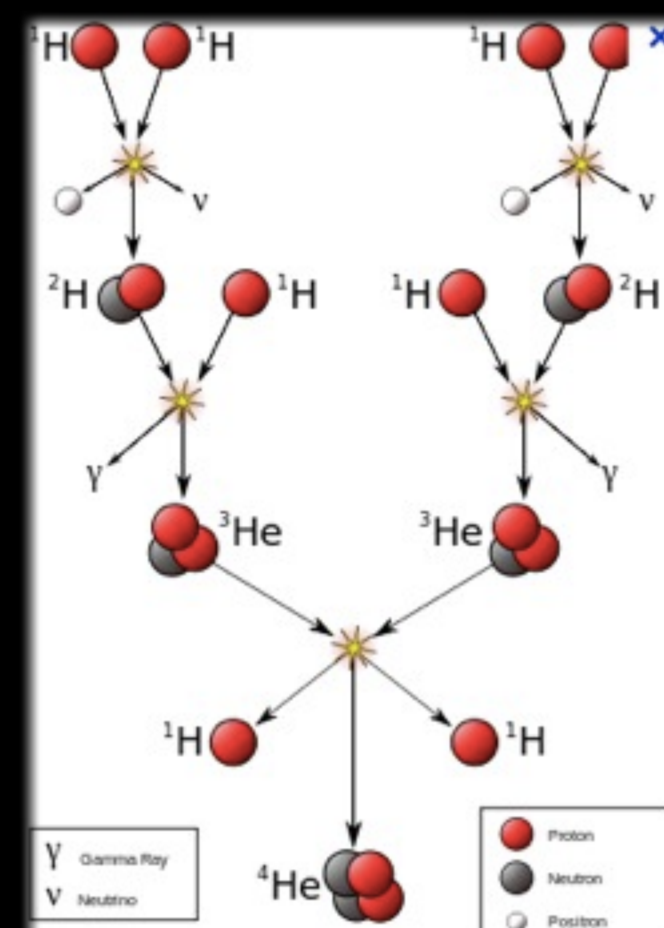
$$\dot{\rho} = \int_{L_{\min}}^{L_{\max}} dL\, n_L P_{\mathrm{AB}}.$$

Big Bang Nucleosynthesis

Radiative emissions of electrons or muons are constrained

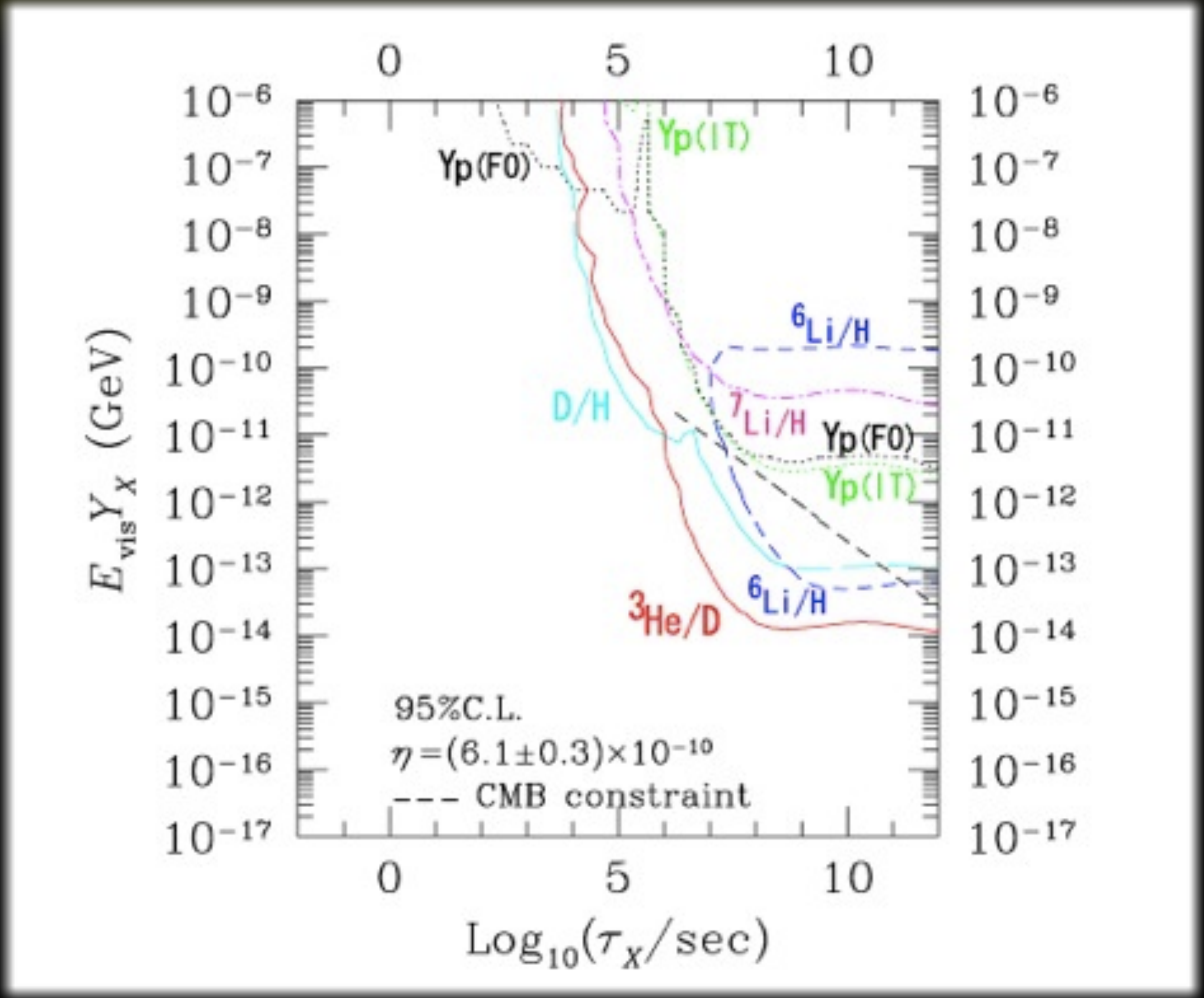


http://astrog.phys.kyushu-u.ac.jp/index.php/標準・非標準ビッグバンモデル



http://en.wikipedia.org/wiki/Stellar_nucleosynthesis

Big Bang Nucleosynthesis



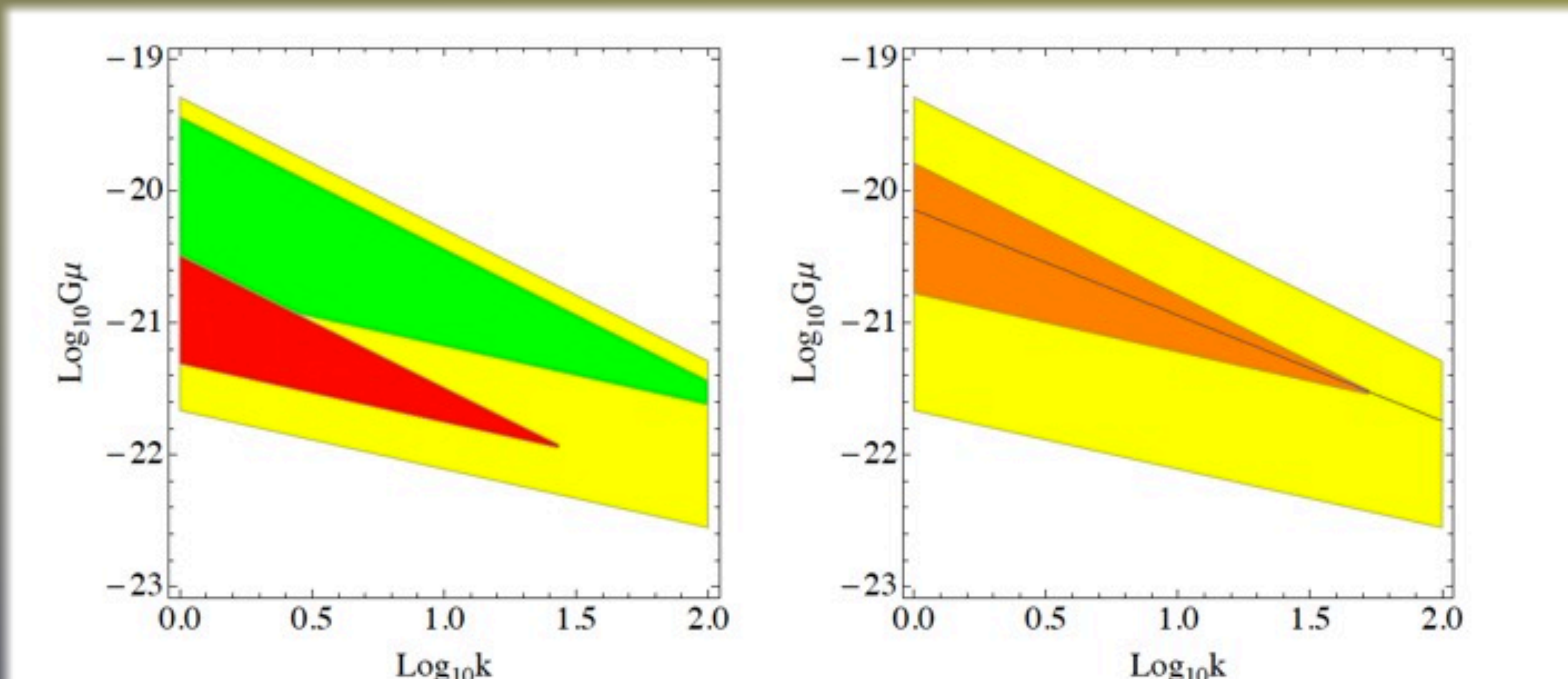
[Kawasaki, Kohri and Moroi `04]

$$B_{\rm r}\frac{\rho_a}{s} \lesssim \begin{cases} 10^{-8}\mathrm{GeV}\left(\frac{\tau_a}{10^4\mathrm{s}}\right)^{-2}, & \text{for} \quad 10^4\mathrm{s} < \tau_a < 10^7\mathrm{s} \\ 10^{-14}\mathrm{GeV}, & \text{for} \quad 10^7\mathrm{s} < \tau_a < 10^{12}\mathrm{s} \end{cases}$$

BBN constraint

$$\frac{\rho_{AB}}{s} \simeq \begin{cases} 4.6\times 10^{-46}\left(\frac{1[\mathrm{s}]}{t}\right)^{3/2}\left(\frac{10.75}{g_*}\right)^{1/4}\frac{\xi\sqrt{\alpha}}{p^b}\frac{\Phi^2\Gamma_{\mathrm{AB}}}{\Gamma_{\mathrm{GW}}^{5/2}}(G\mu)^{-2}[\mathrm{GeV}] & \text{for } L_{\min}=L_{\mathrm{GW}} \\ 5.5\times 10^{8}\left(\frac{1[\mathrm{s}]}{t}\right)^{1/4}\left(\frac{10.75}{g_*}\right)^{1/4}\frac{\xi\sqrt{\alpha}}{p^b}(\Phi^2\Gamma_{\mathrm{AB}})^{-1/4}(G\mu)^{9/8}[\mathrm{GeV}] & \text{for } L_{\min}=L_{\mathrm{AB}}. \end{cases}$$

$$B_{\mathrm{r}}\frac{\rho_a}{s} \lesssim \begin{cases} 10^{-8}\mathrm{GeV}\left(\frac{\tau_a}{10^4\mathrm{s}}\right)^{-2}, & \text{for } 10^4\mathrm{s} < \tau_a < 10^7\mathrm{s} \\ 10^{-14}\mathrm{GeV}, & \text{for } 10^7\mathrm{s} < \tau_a < 10^{12}\mathrm{s} \end{cases}$$



Summary

1) Radiation of SM-particles from Aharonov-Bohm strings in intersecting D-brane models

2) non-trivial cosmological constraints from BBN and γ-ray background are sever in string theory due to small reconnection probability

Application of our analysis to SUSY phenomenology
LSP radiation from AB R-string

→ **Yonemoto's poster presentation on Friday**