宇宙の進化と素粒子模型

令和１年度宇宙線研究所共同利用研究成果発表会

宇宙線研究所理論グループ　伊部昌宏

東大宇宙線研　：川崎、伊部、他

名古屋大：久野

金沢大：青木

KEK：郡

京都大学：瀬波

東北大：高橋

神奈川大：粕谷

（合計21名）

国内旅費：10万円

2019業績一部

1) Gauge Independence of Induced Gravitational Waves.
By Keisuke Inomata, Takahiro Terada.
[arXiv:1912.00785 [gr-qc]].

2) DANCE: Dark matter Axion search with riNg Cavity Experiment.
By Yuta Michimura et al..
[arXiv:1911.05196 [physics.ins-det]].

3) New Type of String Solutions with Long Range Forces.
By Takashi Hiramatsu, Masahiro Ibe, Motoo Suzuki.
[arXiv:1910.14321 [hep-ph]].

4) Oscillon of Ultra-Light Axion-like Particle.
By Masahiro Kawasaki, Wakutaka Nakano, Eisuke Sonomoto.
[arXiv:1909.10805 [astro-ph.CO]].

5) A Dynamical Solution to the Axion Domain Wall Problem.
By Masahiro Ibe, Shin Kobayashi, Motoo Suzuki, Tsutomu T. Yanagida.
[arXiv:1909.01604 [hep-ph]].

6) Fragileness of Exact I-ball/Oscillon.
By Masahiro Ibe, Masahiro Kawasaki, Wakutaka Nakano, Eisuke Sonomoto.
[arXiv:1908.11103 [hep-ph]].

7) Oscillating Composite Asymmetric Dark Matter.
By Masahiro Ibe, Shin Kobayashi, Ryo Nagai, Wakutaka Nakano.
[arXiv:1907.11464 [hep-ph]].

8) Charged black holes in non-linear Q-clouds with O(3) symmetry.
By Jeong-Pyong Hong, Motoo Suzuki, Masaki Yamada.
[arXiv:1907.04982 [gr-qc]].

9) Baryon-Dark Matter Coincidence in Mirrored Unification.
By Masahiro Ibe, Ayuki Kamada, Shin Kobayashi, Takumi Kuwahara, Wakutaka Nakano.
[arXiv:1907.03404 [hep-ph]].
10.1103/PhysRevD.100.075022.
Phys.Rev. D100 (2019) no.7, 075022.

10) Formation of supermassive primordial black holes by Affleck-Dine mechanism.
By Masahiro Kawasaki, Kai Murai.
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11) Constraining dark matter annihilation with HSC Low Surface Brightness Galaxies.
By Daiki Hashimoto, Oscar Macias, Atsushi J. Nishizawa, Kohei Hayashi,
Masahiro Takada, Masato Shirasaki, Shin'ichiro Ando.
[arXiv:1906.06701 [astro-ph.CO]].

12) Novel GUT with apparently complete SU(5) multiplets.
By Masahiro Ibe, Satoshi Shirai, Motoo Suzuki, Tsutomu T. Yanagida.
[arXiv:1906.02977 [hep-ph]].
10.1103/PhysRevD.100.055024.
Phys.Rev. D100 (2019) no.5, 055024.

13) Enhancement of Gravitational Waves Induced by Scalar Perturbations due to a Sudden Transition from an Early Matter Era to the Radiation Era.
By Keisuke Inomata, Kazunori Kohri, Tomohiro Nakama, Takahiro Terada.
[arXiv:1904.12879 [astro-ph.CO]].
10.1103/PhysRevD.100.043532.
Phys.Rev. D100 (2019) no.4, 043532.

14) Gravitational Waves Induced by Scalar Perturbations during a Gradual Transition from an Early Matter Era to the Radiation Era.
By Keisuke Inomata, Kazunori Kohri, Tomohiro Nakama, Takahiro Terada.
[arXiv:1904.12878 [astro-ph.CO]].
10.1088/1475-7516/2019/10/071.
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15) Fast-Rolling Relaxion.
By Masahiro Ibe, Yutaro Shoji, Motoo Suzuki.
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16) Muon $g-2$ in Split-Family SUSY in light of LHC Run II.
By Masahiro Ibe, Motoo Suzuki, Tsutomu T. Yanagida, Norimi Yokozaki.
[arXiv:1903.12433 [hep-ph]].
10.1140/epjc/s10052-019-7186-5.
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17) More about Q-ball with elliptical orbit.
By Fuminori Hasegawa, Jeong-Pyong Hong, Motoo Suzuki.
[arXiv:1903.07281 [hep-ph]].
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18) Effect of nonlinearity between density and curvature perturbations on the primordial black hole formation.
By Masahiro Kawasaki, Hiromasa Nakatsuka.
[arXiv:1903.02994 [astro-ph.CO]].
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19) Axion Dark Matter Search with Interferometric Gravitational Wave Detectors.
By Koji Nagano, Tomohiro Fujita, Yuta Michimura, Ippei Obata.
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20) Non-sphericity of ultralight axion dark matter haloes in the Galactic dwarf spheroidal galaxies.
By Kohei Hayashi, Ippei Obata.
[arXiv:1902.03054 [astro-ph.CO]].
10.1093/mnras/stz2950.

21) Decay of I-ball/Oscillon in Classical Field Theory.
By Masahiro Ibe, Masahiro Kawasaki, Wakutaka Nakano, Eisuke Sonomoto.
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GUT の再考

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Masahiro Ibe, Satoshi Shirai, Motoo Suzuki, Tsutomu T. Yanagida.

✓ ***Standard Model***

SU(3) x SU(2) x U(1) gauge theory

✓ ***Higgs boson has been discovered***

→ ***We understand the origins of the quark, lepton Z, W masses !***

✓ ***Quarks & Leptons in the Standard Model***

	SU(3)	SU(2)	U(1)
$q_L^{1,2,3} = \begin{pmatrix} u_L^{1,2,3} \\ d_L^{1,2,3} \end{pmatrix}$	3	2	1/6
$\bar{U}_R^{1,2,3}$	3^*	-	-2/3
$\bar{D}_R^{1,2,3}$	3^*	-	1/3
$l_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	-	2	-1/2
$\bar{E}_R$	-	-	1

x 3-generations

→ ***They look complicated and not very beautiful…***

Miraculous Unification

- ✔ ***SU(3) x SU(2) x U(1) gauge theory → SU(5) gauge theory?***

  (Minimal embedding into a non-abelian group)

- ✔ ***Quarks & Leptons are also unified into two representations!***

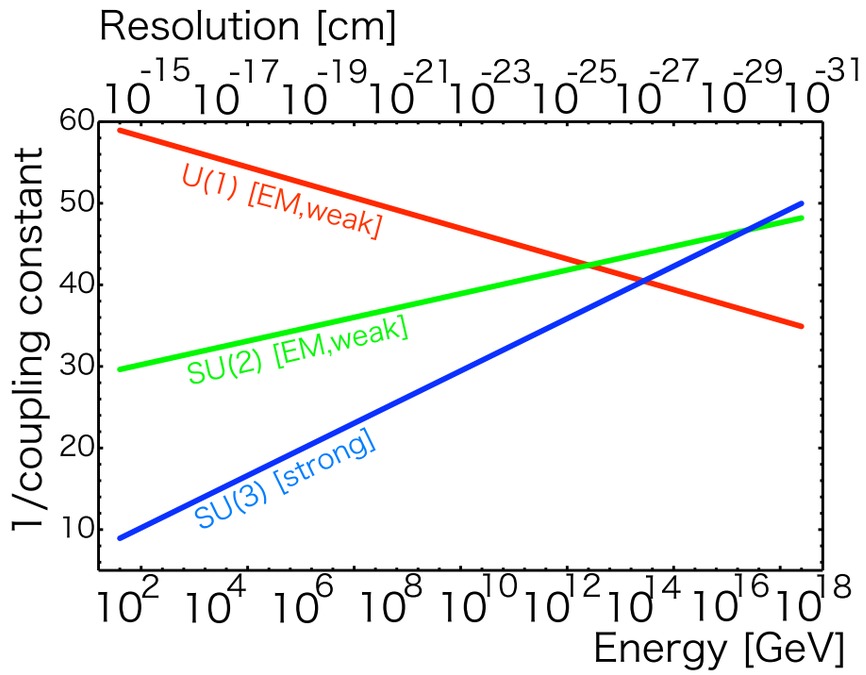
$$\psi(5^*) = \begin{pmatrix} \bar{D}_R^1 \\ \bar{D}_R^2 \\ \bar{D}_R^3 \\ L_L^1 \\ L_L^2 \end{pmatrix} \qquad \psi(10) = \begin{pmatrix} 0 & \bar{U}_R^3 & -\bar{U}_R^2 & U_L^1 & D_L^1 \\ -\bar{U}_R^3 & 0 & \bar{U}_R^1 & U_L^2 & D_L^2 \\ \bar{U}_R^2 & -\bar{U}_R^1 & 0 & U_L^3 & D_L^3 \\ -U_L^1 & -U_L^2 & -U_L^3 & 0 & \bar{E}_R \\ -D_L^1 & -D_L^2 & -D_L^3 & -\bar{E}_R & 0 \end{pmatrix}$$

x 3-generations

It should not be an accident !

Deterioration…

- ***Gauge coupling constants tend to unify but not very precise…***



Although it is basically consistent with the unification but seems not precise enough…

- ***Too rapid proton decay***

$$L \sim \frac{g_{GUT}^2}{M_{GUT}^2} [(\bar{5}\ 10)^\dagger(\bar{5}\ 10) + (5\ 10)^\dagger (10\ 10)]$$

$$\tau(p \to e+\pi^0) \sim 10^{26}\ \text{years} \times (M_{GUT}/g_{GUT}/10^{14}\text{GeV})^4$$

$$\leftrightarrow \quad \tau(p \to e+\pi^0) > 1.6 \times 10^{34}\ \text{years (90\%CL)} \quad \text{[SK 2017]}$$

Are we missing something ?

Conventional wisdom

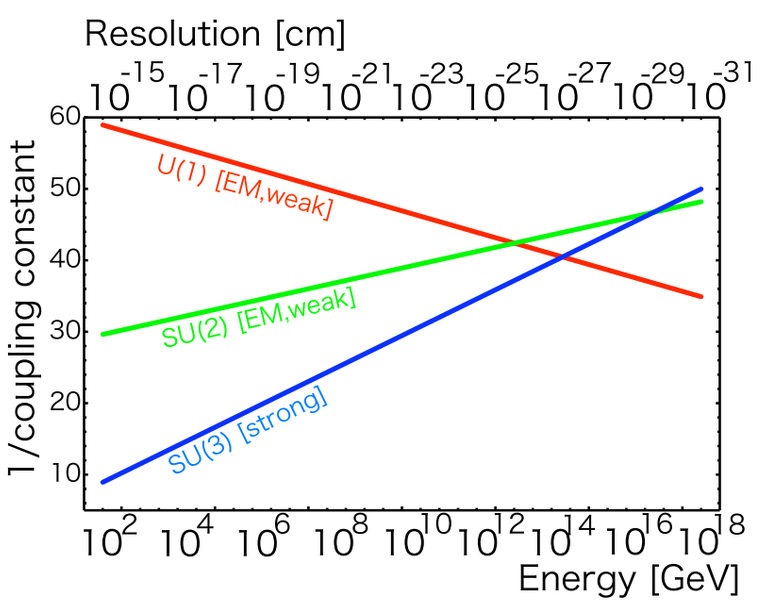
= New charged particles below the GUT scale

✓ ***Better unification***

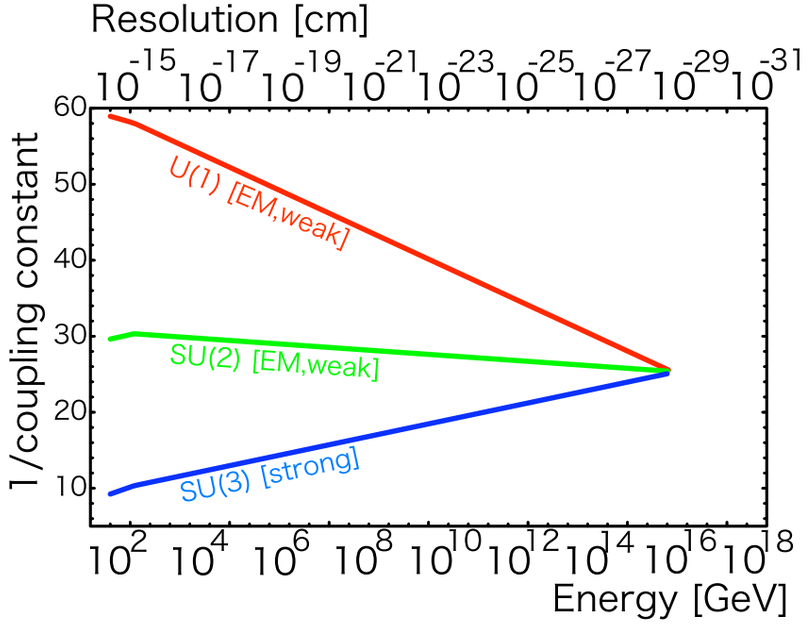
✓ ***Higher unification scale $M_{GUT} > 10^{16}$GeV***

→ proton lifetime is long enough!

Best Example = Supersymmetry !



Standard Model



Supersymmetric Standard Model

A twisted way of thinking ?

Fact :

Quarks&Leptons perfectly fit into the representations of SU(5).

Does this mean that Quarks & Leptons should be unified into the SU(5) representations ?

If not, what is the generic theory behind the Standard Model which explains the seeming unification of Quarks & Leptons ?

→ ***Fake GUT ?***

Fake GUT ?

Why SU(5) is successful ?

- ✔ ***ψ(5*) + ψ(10) fermions cannot obtain masses due to the mismatch between the gauge charges and their chiralities !***

  [*mass term of the fermions requires the fermion with the same chirality but with opposite gauge charges*]

  As a result, all the fermions in ψ(5*) + ψ(10) do not obtain masses at the GUT scale → They result in the Quarks&Leptons in the SM.

- ✔ ***Any GUT models in which the charge-chirarily mismatch happens only for SU(5) ψ(5*) + ψ(10) predict the Quarks&Leptons which apparently fit into ψ(5*) + ψ(10).***

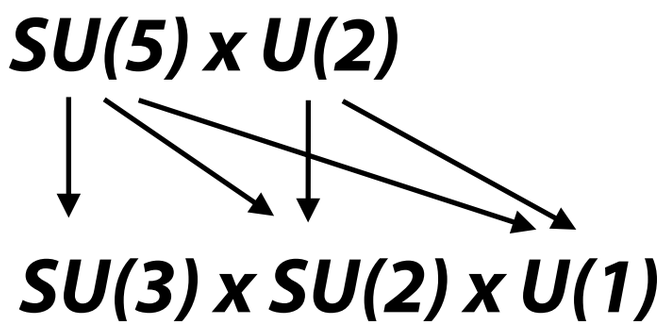
In general, however, it does not mean that Quarks&Leptons are actually embedded in ψ(5*) + ψ(10) in the GUT model!

Fake GUT ?

Example : SU(5) x U(2)$_H$ model

$$\langle \Phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 0 & v & 0 \\ 0 & 0 & 0 & 0 & v \end{pmatrix}$$

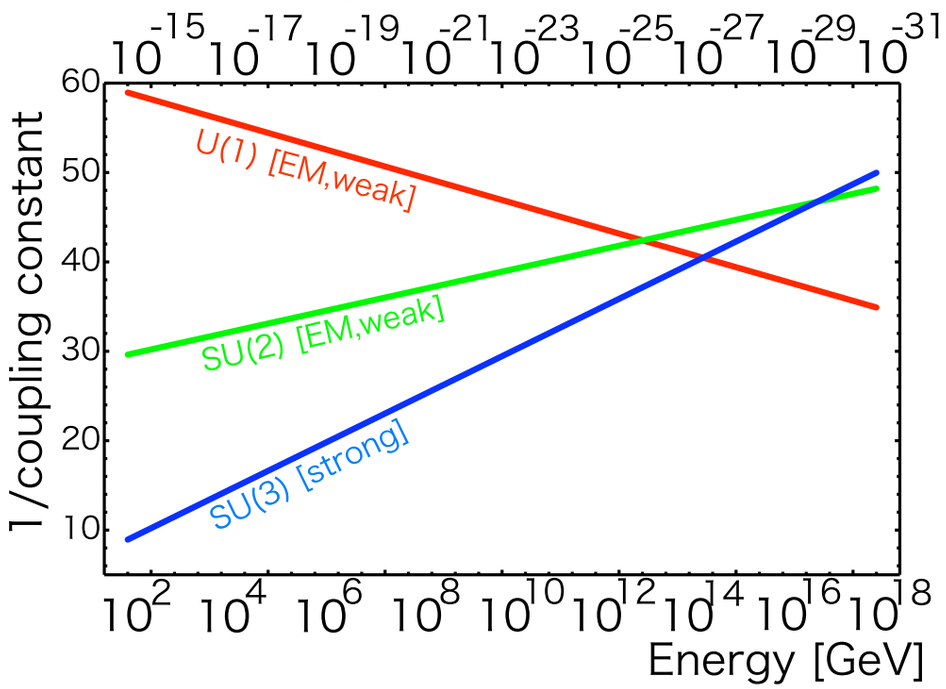
✔ **Gauge coupling non-unification is consistent !**



$1/g_1^2 = 1/g_{GUT}^2 + 3/(5g_{1H}^2)$

$1/g_2^2 = 1/g_{GUT}^2 + 1/(g2_H^2)$

$1/g_3^2 = 1/g_{GUT}^2$)



$1/g_{1,2}^2 > 1/g_3^2$ is predicted

$M_{GUT} \lesssim 10^{14}$GeV

Moderate unification is explained for $g_{1H,\,2H} >> g_5$

Fake GUT ?

Example : SU(5) x U(2)$_H$ model

$$\langle \Phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 0 & v & 0 \\ 0 & 0 & 0 & 0 & v \end{pmatrix}$$

✔ ***Lepton is not necessarily in ψ(5*) + ψ(10) in the presence of massive U(2)$_H$ charged particles.***

$$\mathcal{L} = m_L L_H \bar{L}_H + \lambda_L \bar{L}_H \Phi \bar{\mathbf{5}} + m_E E_H \bar{E}_H + \frac{\lambda_E}{\Lambda_{\rm cut}} E_H \mathbf{10} \Phi^\dagger \Phi^\dagger$$

(i) $m_{L,E}$ >> GUT scale → Quarks & Leptons in ψ(5*) + ψ(10)

(ii) $m_{L,E}$ << GUT scale → Quarks in ψ(5*) + ψ(10) , Leptons in L_H , E_H

Even for the case (ii), the model predicts the low energy fermions which fits in ψ(5*) + ψ(10) of SU(5)

= Fake matter unification !

✔ ***Proton decay rate is suppressed by ($m_{L,E}$/GUT scale)^2***

✔ ***$p \to \pi^0 + e^+$ is not necessarily the main mode.***

(e.g. $p \to \pi^0 + \mu^+$ can be the main mode !)

Summary

- ✓ ***Quarks & Leptons in the SM miraculously fit into ψ(5*) + ψ(10)***

  →In conventional GUT, Quarks & Leptons are embedded in ψ(5*) + ψ(10)

- ✓ ***Any GUT models in which only the charge-chirarily mismatch happens to SU(5) ψ(5*) + ψ(10) predict the Quarks&Leptons which apparently fit into ψ(5*) + ψ(10).***

= FAKE GUT !

- ✓ ***In Fake GUT, the gauge coupling unification is not predicted although Qaurks&Leptons inevitably fit into ψ(5*) + ψ(10).***

- ✓ ***As the matter unification is FAKE, the proton decay rate and the branching ratios are controlled by additional parameters such as the mass parameters of other vector-like fermions.***