New Advances in Unified Field Theory and Particle Physics

Tian Ma & Shouhong Wang (Supported by NSF, ONR and Chinese NSF)
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- **Principle of Interaction Dynamics (PID):** Least action with energy-momentum conservation constraints. With PID applied to the Einstein-Hilbert functional, e.g., we derive the following gravitational field equations:

$$(\delta L_{EH}(g_{ij}), X) = 0 \quad \forall\, D^i X_{ij} = 0 \implies R_{ij} - \frac{1}{2} g_{ij} R = -\frac{8\pi G}{c^4} T_{ij} - D_i D_j \varphi,$$

  leading to a unified theory for dark matter and dark energy.

- **Principle of Representation Invariance (PRI):** Physical laws for an $SU(N)$ gauge theory should be covariant under different representations of $SU(N)$.

Unified field model based on PID & PRI: $G^w_{ab}=\frac{1}{8}\lambda^c_{ad}\lambda^d_{cb}, G^s_{ab}=\frac{1}{12}f^c_{ad}f^d_{cb}$

$$(1)\quad R_{\mu\nu}-\frac{1}{2}g_{\mu\nu}R+\frac{8\pi G}{c^4}T_{\mu\nu}=\left[\nabla_\mu-\frac{e\alpha^E}{\hbar c}A_\mu-\frac{g_w\alpha^w_a}{\hbar c}W^a_\mu-\frac{g_s\alpha^s_k}{\hbar c}S^k_\mu\right]\Phi_\nu,$$

$$(2)\quad \partial^\nu F_{\nu\mu}-e\bar{\psi}\gamma_\mu\psi=\left[\nabla_\mu-\frac{e\alpha^E}{\hbar c}A_\mu-\frac{g_w\alpha^w_a}{\hbar c}W^a_\mu-\frac{g_s\alpha^s_k}{\hbar c}S^k_\mu\right]\phi^E,$$

$$(3)\quad G^w_{ab}\left[\partial^\nu W^b_{\nu\mu}-\frac{g_w}{\hbar c}\lambda^b_{cd}g^{\alpha\beta}W^c_{\alpha\mu}W^d_\beta\right]-g_w\bar{L}\gamma_\mu\sigma_aL$$
$$=\left[\nabla_\mu+\frac{1}{4}\left(\frac{m_Hc}{\hbar}\right)^2x_\mu-\frac{e\alpha^E}{\hbar c}A_\mu-\frac{g_w\alpha^w_b}{\hbar c}W^b_\mu-\frac{g_s\alpha^s_k}{\hbar c}S^k_\mu\right]\phi^w_a,$$

$$(4)\quad G^s_{kj}\left[\partial^\nu S^j_{\nu\mu}-\frac{g_s}{\hbar c}\Lambda^j_{cd}g^{\alpha\beta}S^c_{\alpha\mu}S^d_\beta\right]-g_s\bar{q}\gamma_\mu\tau_kq$$
$$=\left[\nabla_\mu+\frac{1}{4}\left(\frac{m_\pi c}{\hbar}\right)^2x_\mu-\frac{e\alpha^E}{\hbar c}A_\mu-\frac{g_w\alpha^w_a}{\hbar c}W^a_\mu-\frac{g_s\alpha^s_j}{\hbar c}S^j_\mu\right]\phi^s_k,$$

$$(5)\quad (i\gamma^\mu\tilde{D}_\mu-\tilde{m})\Psi=0.$$

• **Duality:** The unified field model induces a **natural duality** between $\{g_{\mu\nu}\}$, A_μ, W^a_μ, S^k_μ (on the left) and their dual fields (on the right).

• **Decoupling and Unification:** The unified model can be easily decoupled to study individual interactions.

• **Origin of mass:** Obtained a much simpler mechanism for mass generation and energy creation, based only on first principles.

• Derived different levels of strong and weak interaction potentials, which explains e.g. quark confinement, asymptotic freedom, and the short-range nature of strong and weak interactions.

• Derived a weakton model of elementary particles, which can explain the mechanism of all sub-atomic decays.

Summary: Theoretical and experimental studies on models based only on first principles, such as PID and PRI, are crucial for particle physics in the next decade, and for understanding the deepest secrets of Nature.