Millicharged Dark Matter in Quantum Gravity and String Theory

Fang Ye

Department of Physics, University of Wisconsin-Madison

Department of Physics and Institute for advanced Study,
The Hong Kong University of Science and Technology

G. Shiu, P. Soler, FY, arXiv:1302.5471
B. Holdom, Phys. Lett. B 166, 196(1986)

Introduction

- Millicharge: small electric charges carried by dark matter (DM) particles
- First proposed by Holdom in 1986
- Study such scenarios from Stuckelberg U(1)'s from string theory perspective (natural, elegant, clean)

Setup

N U(1) fields A_a: $\vec{A}^T = (A_1, \ldots, A_N)$

$$\mathcal{L} = -\frac{1}{4}\vec{F}^T \cdot f \cdot \vec{F} - \frac{1}{2} G_{ij} \left(\partial\phi^i - k_a^i A_a\right) \left(\partial\phi^j - k_b^j A_b\right) + \overline{\psi}\left(i\partial\!\!\!/ + \vec{q}_\psi^T \cdot \vec{A}\!\!\!/\right)\psi \tag{1}$$

Normalized s.t. k_a^i, $q \in Z$ (compactness of U(1)'s)
Gauge mass squared matix $M^2 = K^T \cdot G \cdot K$
Diagonalize the gauge kinetic and mass matrices $\Rightarrow$
Final basis: matter charges $\vec{q}' \ni$ continuous parameters. $\Rightarrow$
Matter charges generically not quantized. Contradicting the "folk theorem" of quantum gravity?

A single massless U(1)

Go to IIB string compactification. Take D6-branes wrapping 3-cycles for simplicity.
Zero mode $\vec{v}$ of M^2: $K \cdot \vec{v} = 0$ ($\vec{v}$: linear combination of 3-cycles wrapped by D6s which is trivial in homology; with integer entries)
$\Rightarrow$ Get zero mode in the final basis with charges $q'_{\vec{v}}$: all continuous parameters in a prefactor - quantized (not contradicting “folk theorems")
$\Rightarrow$ Millicharges cannot arise from models with a single massless U(1).

2 massless U(1)'s

- 2 zero modes of M^2: $\vec{v}_{1,2}$
- 2 orthogonal zero modes in the final basis with charges: q'_1: quantized; q''_2: milicharge shift.

Conclusion

- Appearance of millicharges requires at least 2 massless U(1)'s
- Massive U(1)'s are not quantized.