Self-interacting massive spin-two particles

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1.Introduction

The discovery of the late-time acceleration inspires development of theories of massive spin 2 fields as an alternative theory of gravity.

On the other hand, is it necessary that

Massive spin 2 particles =Massive gravitons ?

e.g.) Hadrons with higher-spin

We construct an alternative model of massive spin 2 fields without assumption Massive spin 2 particles =Massive gravitons.

2. Free theory of massive spin 2 fields

Massive spin 2 state is given by irreducible rep. of $SO(3)$ labeled by $j = 2$.

Free Theory (Fierz-Pauli Lagrangian)

$$\mathcal{L}_{\rm FP} = -\frac{1}{2}\partial_\lambda h_{\mu\nu}\partial^\lambda h^{\mu\nu} + \partial_\mu h_{\nu\lambda}\partial^\nu h^{\mu\lambda} - \partial_\mu h^{\mu\nu}\partial_\nu h + \frac{1}{2}\partial_\lambda h\partial^\lambda h - \frac{1}{2}m^2(h_{\mu\nu}h^{\mu\nu} - h^2)$$

- $h_{0\mu}$ is not dynamical due to the structure of the kinetic term.
- h_{00} is linear due to the structure of the mass term.

Realization of 5 DOF in 4 dimensions.

3. Interacting theory of massive spin 2 fields

U(1) gauge theory   P. Federbush, Il Nuovo Cimento Series 10 19 (1961) 572-573

Replacing partial derivatives with covariant ones in the Fierz-Pauli Lagrangian.

dRGT massive gravity   de Rham, Gabadadze, Tolley Phys.Rev.Lett. 106 (2011) 231101; S. F. Hassan and R. A. Rosen, JHEP **1107** (2011) 009

Adding nonderivative self-interactions to Einstein-Hilbert term keeping DOF of the system.

Is it possible to construct new theory ?

4. New Interacting theory

Assuming the linearized Einstein-Hilbert term as the kinetic term, we construct new theories.

"Ghost-free" interactions for Fierz-Pauli lagrangian

Hinterbichler, JHEP 10 (2013) 102

$$\mathcal{L}_{0,3} \sim \eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3} h_{\mu_1\nu_1}h_{\mu_2\nu_2}h_{\mu_3\nu_3}$$

$$\mathcal{L}_{0,4} \sim \eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3\mu_4\nu_4} h_{\mu_1\nu_1}h_{\mu_2\nu_2}h_{\mu_3\nu_3}h_{\mu_4\nu_4}$$

$$\mathcal{L}_{2,3} \sim \eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3\mu_4\nu_4} \partial_{\mu_1}\partial_{\nu_1}h_{\mu_2\nu_2}h_{\mu_3\nu_3}h_{\mu_4\nu_4}$$

$\eta^{\mu_1\nu_1\cdots\mu_n\nu_n}$ is products of Minkowski metrics anti-symmetrized over ν

The anti-symmetric property of the potential keeps h_{00} linear.

New model of massive spin 2 particles with Z_2 symmetry

$$\mathcal{L} = \mathcal{L}_{\rm FP} + \frac{\lambda}{4!}\eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3\mu_4\nu_4}h_{\mu_1\nu_1}h_{\mu_2\nu_2}h_{\mu_3\nu_3}h_{\mu_4\nu_4}$$

New model of massive spin 2 particles with $U(1)$ charge

$$\mathcal{L} = -\partial_\lambda h^\dagger_{\mu\nu}\partial^\lambda h^{\mu\nu} + 2\partial_\mu h^\dagger_{\nu\lambda}\partial^\nu h^{\mu\lambda} - 2\partial_\mu h^{\dagger\mu\nu}\partial_\nu h + \partial_\lambda h^\dagger\partial^\lambda h$$
$$- m^2(h^\dagger_{\mu\nu}h^{\mu\nu} - h^\dagger h) + \frac{\lambda}{3!}\eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3\mu_4\nu_4}h^\dagger_{\mu_1\nu_1}h^\dagger_{\mu_2\nu_2}h_{\mu_3\nu_3}h_{\mu_4\nu_4}$$

5. Property of new interacting theory

Due to the ghost-free potential terms, the theories can also be defined around VEV. We find some characteristic properties in nontrivial vacua.

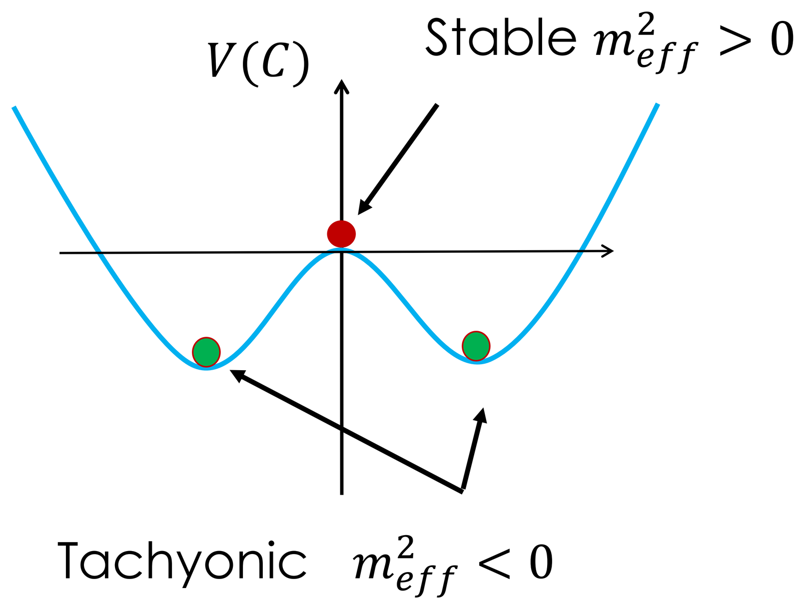
New model of massive spin 2 particles with Z_2 symmetry

Lorentz invariant vacuum $h^{\rm VEV}_{\mu\nu} \propto C\eta_{\mu\nu}$

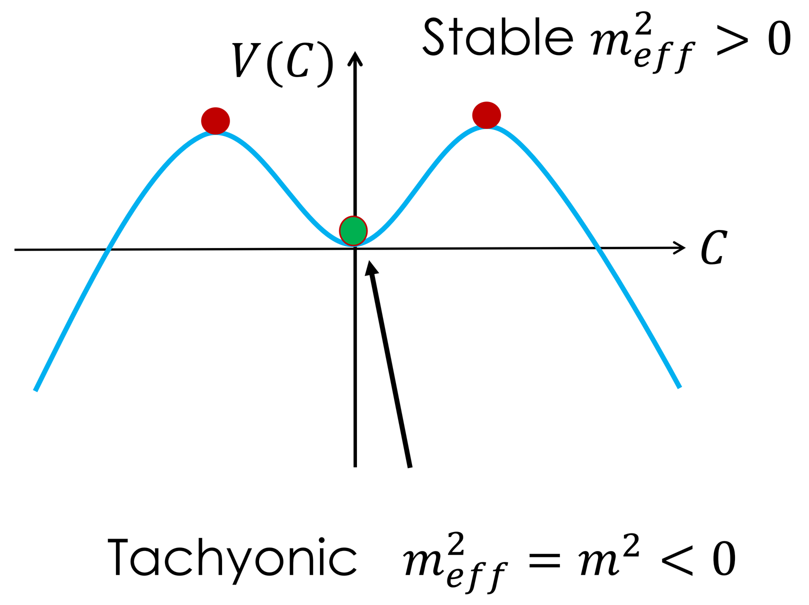
$$\mathcal{L} \to \mathcal{L} = -V(C)$$

$m^2 > 0, \lambda > 0$; $m^2 < 0, \lambda < 0$ — No nontrivial vacuum $C = 0$

✓ Case 1: $m^2 > 0, \lambda < 0$



✓ Case 2 : $m^2 < 0, \lambda > 0$



Vacua which have higher energy is stable in the sense that tachyonic state is absent.

New model of massive spin 2 particles with $U(1)$ charge

When $m^2 < 0, \lambda > 0$, can theories be defined around nontrivial vacua with NG bosons?

Expansion around VEV : $h_{\mu\nu} = h^{\rm VEV}_{\mu\nu} + a_{\mu\nu} + ib_{\mu\nu}$

$$\mathcal{L}_{\rm potential} = \frac{m_a^2}{2}\eta^{\mu_1\nu_1\mu_2\nu_2}a_{\mu_1\nu_1}a_{\mu_2\nu_2} + \frac{\sqrt{3|\lambda|}}{2\cdot 3!}m_a\eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3}a_{\mu_1\nu_1}a_{\mu_2\nu_2}a_{\mu_3\nu_3}$$
$$+ \frac{|\lambda|}{2\cdot 4!}\eta^{\mu_1\nu_1\mu_2\nu_2\mu_3\nu_3\mu_4\nu_4}b_{\mu_1\nu_1}b_{\mu_2\nu_2}b_{\mu_3\nu_3}b_{\mu_4\nu_4} + \cdots$$

$b_{\mu\nu}$ do not have a mass term but have potential terms .

The $U(1)$ theory is ill-defined around nontrivial vacua .

6. Summary

- We construct new theories of massive spin 2 fields.
- We study properties of nontrivial vacua and find that
  - stable vacua have higher energy for the neutral fields.
  - there is no stable, nontrivial vacua for the charged fields.