New model of massive spin-2 and its possible application

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The free massive spin-2 theory

In general, the mass term is given by a linear combination of quadratic terms.

$$\mathcal{L}_{mass} \sim h_{\mu\nu}h^{\mu\nu} - ah^2$$

The mass term, however, generally leads to a ghost.

There is the unique linear combination to eliminate the ghost.

The Fierz-Pauli theory

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

- The massive spin-2 has 5 d.o.f in 4 dim.
- This system does not have any gauge symmetry due to the non-derivative terms.

Non-linear terms for spin-2 fields

Massless spin-2

Interactions keeping the gauge symmetry lead to Einstein-Hilbert action.

Massive spin-2

Interactions generally lead to a ghost, but there is a certain class of interactions prohibiting the ghost.

1. The background independent massive spin-2

de Rham, Gabadadze, Tolley Phys.Rev.Lett. 106 (2011) 231101

$$S = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\left[R + \frac{m^2}{4}\sum_{n=2}^{4}\alpha_n e_n(\mathcal{K})\right]$$

$\alpha_2 = 1$ $\alpha_3,\ \alpha_4$: free parameters

$$e_2(\mathcal{K}) = [\mathcal{K}]^2 - [\mathcal{K}^2]$$
$$e_3(\mathcal{K}) = [\mathcal{K}]^3 - 3[\mathcal{K}][\mathcal{K}^2] + 2[\mathcal{K}^3]$$
$$e_4(\mathcal{K}) = [\mathcal{K}]^4 - 6[\mathcal{K}^2][\mathcal{K}]^2 + 8[\mathcal{K}^3][\mathcal{K}] + 3[\mathcal{K}^2]^2 - 6[\mathcal{K}^4]$$

$$\mathcal{K}^\mu{}_\nu = \delta^\mu{}_\nu - \sqrt{g^{-1}\eta}^\mu{}_\nu$$ $\eta_{\mu\nu}$: Minkowski metric

The bracket means the trace w.r.t the metric g

The fully non-linear massive spin-2 theory without the ghost.

2. New model of massive spin-2

In 4 dim, there exist two types of non-derivative interactions for the Fierz-Pauli theory. Hinterbichler, JHEP 10 (2013) 102

Cubic term : $\sim h^{\mu_1}{}_{[\mu_1}h^{\mu_2}{}_{\mu_2}h^{\mu_3}{}_{\mu_3]}$

Quartic term : $\sim h^{\mu_1}{}_{[\mu_1}h^{\mu_2}{}_{\mu_2}h^{\mu_3}{}_{\mu_3}h^{\mu_4}{}_{\mu_4]}$

[···] means the anti-symmetry in the indices.

We propose a new massive spin-2 model

Y.O, Akagi, Nojiri, arXiv : 1402.5737

$$\mathcal{L}_{\rm new} = \mathcal{L}_{\rm FP} - \frac{\mu}{3!}h^{\mu_1}{}_{[\mu_1}h^{\mu_2}{}_{\mu_2}h^{\mu_3}{}_{\mu_3]} - \frac{\lambda}{4!}h^{\mu_1}{}_{[\mu_1}h^{\mu_2}{}_{\mu_2}h^{\mu_3}{}_{\mu_3}h^{\mu_4}{}_{\mu_4]}$$

μ , λ : coupling constants

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

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Ghost-free theory

3. Gravity coupled massive spin-2

$$S = \int d^4x\sqrt{-g}\left\{\mathcal{L}_{\rm FP} - \frac{\mu}{3!}h^{\mu_1}{}_{[\mu_1}h^{\mu_2}{}_{\mu_2}h^{\mu_3}{}_{\mu_3]} - \frac{\lambda}{4!}h^{\mu_1}{}_{[\mu_1}h^{\mu_2}{}_{\mu_2}h^{\mu_3}{}_{\mu_3}h^{\mu_4}{}_{\mu_4]}\right\} + \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}R$$

The indices for h are raised with the metric g

h is not the perturbation of g but a independent tensor field of g.

Application of the new model

New model of spin-2 (the kinetic term and the potential term)

Scalar field theories having the same structure play an important role in particle physics and cosmology.

1. Accelerating expansion of the universe.

The equations of motion for $h_{\mu\nu}$ admit the following solution

$$h_{\mu\nu} = Cg_{\mu\nu}$$ C : constant

The reduced action

$$S = -\int d^4x\sqrt{-g}V(C) + S_{\rm EH} \qquad V(C) := -6m^2C^2 + 4\mu C^3 + \lambda C^4$$

V(C) plays a role of the cosmological constant.

- h can cause the accelerating expansion.
- The sign of V(C) depends on the parameters μ and λ.
- C can not be a propagating mode.

2. SUSY breaking

One of the SUSY breaking model uses V.E.V of a scalar field theory with the potential because V.E.V of the scalar field does not break the isotropy.

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The V.E.V of the trace part of the rank 2 tensor can break SUSY keeping the isotropy.

However, the dynamics realizing the V.E.V is still unknown.