Effective field theory for spacetime symmetry breaking[†]

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Symmetry and its spontaneous breaking play an important role in various areas of physics. In particular, the low-energy effective field theory (EFT) based on the underlying symmetry structures provides a powerful framework for understanding the low-energy dynamics in the symmetry broken phase.

For internal symmetry breaking in Lorentz invariant systems, the EFT based on coset construction had been established in 1960's[1,2]. When a global symmetry group G is broken to a residual symmetry group H, the corresponding Nambu-Goldstone (NG) fields $\pi(x)$ are introduced as the coordinates of the coset space G/H and the general effective action can be constructed from the Maurer-Cartan one form,

$$J_\mu = \Omega^{-1}\partial_\mu \Omega \quad \text{with} \quad \Omega(x) = e^{\pi(x)} \in G/H\,. \tag{1}$$

Such a coset construction was also extended to spacetime symmetry breaking[3,4] accompanied by the inverse Higgs constraints[5] and has been applied to various systems. Although the coset construction captures certain aspects of spacetime symmetry breaking, its understanding seems incomplete compared to the internal symmetry case.

For example, a naive counting of broken spacetime symmetries based on the global symmetry picture contains redundant fields and causes a wrong counting of NG modes. For conformal symmetry breaking, it is known that the inverse Higgs constraints compensate such a mismatch of NG mode counting. It is also argued recently that the inverse Higgs constraints eliminate not only the redundant fields but also the massive modes, which nonlinearly transform under the broken symmetries (see, e.g.,[6–8]). In addition to the massless modes, such massive modes associated with the symmetry breaking can be relevant in the construction of phenomenological models (e.g. massive fields with a Hubble scale mass are nonnegligible in cosmology).

In this work, we discussed the effective field theory for spacetime symmetry breaking from the local symmetry point of view. By gauging spacetime symmetries, the identification of NG fields and the construction of the effective action are performed based on the breaking pattern of diffeomorphism, local Lorentz, and (an)isotropic Weyl symmetries as well as the internal symmetries including possible central extensions in nonrelativistic systems. Such a local picture distinguishes, e.g., whether the symmetry breaking condensations have spins and provides a correct identification of the physical NG fields, while the standard coset construction based on global symmetry breaking does not. We illustrated that the local picture becomes important in particular when we take into account massive modes associated with symmetry breaking, whose masses are not necessarily high.

We also revisited the coset construction for spacetime symmetry breaking. Based on the relation between the Maurer-Cartan one form and connections for spacetime symmetries, we classify the physical meanings of the inverse Higgs constraints by the coordinate dimension of broken symmetries. Inverse Higgs constraints for spacetime symmetries with a higher dimension remove the redundant NG fields, whereas those for dimensionless symmetries can be further classified by the local symmetry breaking pattern.

We are now working on several applications of our approaches for spacetime symmetry breaking. For example, there are some recent discussions that inhomogeneous chiral condensations may appear in the QCD phase diagram. Using our EFT framework, we discuss the dispersion relation of the NG field in such a phase. Another ongoing application is inflation. We are e.g. trying to classify the source of primordial gravitational waves (which potentially affect the B-mode polarization of cosmic microwave backgrounds) by the symmetry breaking point of view. We hope to report those applications in near future.

References

1) S. R. Coleman, J. Wess and B. Zumino, Phys. Rev. **177**, 2239 (1969).
2) C. G. Callan, Jr., S. R. Coleman, J. Wess and B. Zumino, Phys. Rev. **177**, 2247 (1969).
3) D. V. Volkov, Sov. J. Part. Nucl. **4**, 3 (1973) .
4) V. I. Ogievetsky, Proc. of X-th Winter School of Theoretical Physics in Karpacz **1**, 117 (1974).
5) E. A. Ivanov and V. I. Ogievetsky, Teor. Mat. Fiz. **25**, 164 (1975).
6) A. Nicolis, R. Penco, F. Piazza and R. A. Rosen, JHEP **1311**, 055 (2013) [arXiv:1306.1240 [hep-th]].
7) S. Endlich, A. Nicolis and R. Penco, Phys. Rev. D **89**, no. 6, 065006 (2014) [arXiv:1311.6491 [hep-th]].
8) T. Brauner and H. Watanabe, Phys. Rev. D **89**, no. 8, 085004 (2014) [arXiv:1401.5596 [hep-ph]].

† Condensed from the article in arXiv:1412.5601.

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