

New methods in classical and quantum field theory with extended supersymmetry

Evgeny Alekseevich Ivanov (BLTP JINR),

Iosif Lvovich Buchbinder (Tomsk State Pedagogical University, BLTP JINR),

Boris Sergeevich Merzlikin (Tomsk State Pedagogical University),

Konstantin Viktorovich Stepanyantz (Department of Theoretical Physics, Moscow State University).

The work was reported at the seminar of the Department of Mathematical Physics
BLTP JINR October 20, 2022

Abstract

The cycle of topical research carried out for the last six years is aimed at developing the manifestly covariant and explicitly supersymmetric methods of constructing effective actions in the gauge theories with extended supersymmetry in diverse dimensions. The research is based on the harmonic superspace approach proposed earlier in BLTP JINR. The general motivation for the research and its goals are related to the study of low-energy consequences of the superstring theory by methods of supersymmetric field theory.

The main results of the research

- A method of superfield realization of hidden supersymmetries in $\mathcal{N} = 4, 4D$ and $\mathcal{N} = 2, 5D$ supersymmetric Yang-Mills theories formulated in terms of harmonic superfields is suggested. It is shown that this method makes it possible to reproduce in a unified way all the known superfield invariants in such theories and to construct new superinvariants.
- A new bi-harmonic superfield formulation of $\mathcal{N} = 4, 4D$ supersymmetric Yang-Mills theory is proposed and an approach for constructing $\mathcal{N} = 4$ supersymmetric effective actions is developed on this basis.
- A harmonic superfield approach to the $\mathcal{N} = 2, 4D$ supersymmetric theory of higher spin gauge fields is worked out. The $\mathcal{N} = 2$ supersymmetric free action of higher-spin gauge superfields and the cubic vertex of the interaction of such superfields with a hypermultiplet are explicitly constructed.
- A method for studying the quantum effective action in $\mathcal{N} = (1, 0), 6D$ and $\mathcal{N} = (1, 1), 6D$ supersymmetric gauge theories is developed. A superfield background field method is developed that provides the explicit gauge invariance and explicit $\mathcal{N} = (1, 0)$ supersymmetry, while calculating the effective action.
- A method to study the structure of the one-loop and two-loop divergences in the six-dimensional theories considered is worked out. It is shown that, although all such theories are index non-normalizable, the quantum $\mathcal{N} = (1, 1)$ theory can be completely finite in the one-loop approximation.

- A superfield proper time method is developed for the explicitly supersymmetric and gauge invariant calculation of the one-loop effective action in the $\mathcal{N} = 2, 5D$ and $\mathcal{N} = (1, 0), 6D$ supergauge theories.
- A one-loop $\mathcal{N} = (1, 1), 6D$ supersymmetric low-energy effective action (a generalization of the effective Heisenberg-Euler action for a constant electromagnetic field) is constructed, such that it depends on all fields of $\mathcal{N} = (1, 1), 6D$ gauge supermultiplet.

The research publications

1. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
One-loop divergences in the $6D, \mathcal{N} = (1, 0)$ Abelian gauge theory,
Physics Letters, Vol. B763, pp. 375 - 381, 2016.
2. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
One-loop divergences in the $6D, \mathcal{N} = (1, 0)$ and $\mathcal{N} = (1, 1)$ SYM theory,
Journal of High Energy Physics, 01 (2017), 128, 18 pages.
3. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
Supergraph analysis of the one-loop divergences in $6D, \mathcal{N} = (1, 0)$ and $\mathcal{N} = (1, 1)$ gauge theories,
Nuclear Physics, Vol. B 921, No 1, pp. 127 - 158, 2017.
4. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
On the two-loop divergences of the 2-point hypermultiplet supergraphs for $6D, \mathcal{N} = (1, 1)$ SYM theory,
Physics Letters, Vol. B.778, No 1, pp. 252 - 255, 2018.
5. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin,
Leading low-energy effective action in $6D, \mathcal{N} = (1, 1)$ SYM theory,
Journal of High Energy Physics, 09 (2018) 039, 14 pages.
6. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
Gauge dependence of the one-loop divergences in $6D, \mathcal{N} = (1, 0)$ Abelian theory,
Nuclear Physics, Vol. B936, pp. 638 - 660, 2018.
7. I.L. Buchbinder, E.A. Ivanov, I.B. Samsonov,
Low-energy effective action in $5D, \mathcal{N} = 2$ supersymmetric gauge theory,
Nuclear Physics, Vol. B940, No 1, pp. 54 - 62, 2019.

8. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
On gauge dependence of the one-loop divergences in $6D, \mathcal{N} = (1, 0)$ and $\mathcal{N} = (1, 1)$ SYM theories,
Physics Letters, Vol. B798, No 10 (2019) 134957, 6 pages.
9. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin,
Quantum calculation of the low-energy effective action in $5D, \mathcal{N} = 2$ SYM theory,
Physics Letters Vol. B802 (2020) 135218, 7 pages.
10. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin,
Low-energy $6D, \mathcal{N} = (1, 1)$ SYM effective action beyond the leading approximation,
Nuclear Physics, Vol. B 954 (2020) 114995, 16 pages.
11. I.L. Buchbinder, E.A. Ivanov, V.A. Ivanovskiy,
Superfield realization of hidden R symmetry in extended supersymmetric gauge theories and its applications,
Journal of High Energy Physics 04 (2020) 124, 23 pages.
12. I.L. Buchbinder, E.A. Ivanov,
Hidden supersymmetry as a key to constructing low energy superfield effective actions,
Proceedings of the Steklov Institute of Mathematics, Vol. 309 (2020) pp. 57-77.
13. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
Supergraph calculation of one-loop divergences in higher-derivative $6D$ SYM theory,
Journal of High Energy Physics, 08 (2020) 169, 19 pages.
14. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
The renormalization structure of $6D, \mathcal{N} = (1, 0)$ supersymmetric higher-derivative gauge theory,
Nuclear Physics, Vol. B 961 (2020) 115249, 17 pages.
15. I.L. Buchbinder, E.A. Ivanov, V.A. Ivanovskiy,
New bi-harmonic superspace formulation of $4D, \mathcal{N} = 4$ SYM theory,
Journal of High Energy Physics, 04 (2021) 010, 40 pages.
16. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
On the two-loop divergences in $6D, \mathcal{N} = (1, 1)$ SYM theory,
Physics Letters, Vol. B 820 (2021) 136516, 9 pages.

17. S. Buyucli, E. Ivanov,
Higher-dimensional invariants in $6D$ super Yang-Mills theory,
Journal of High Energy Physics, 07 (2021) 190, 29 pages.
18. Ioseph Buchbinder, Evgeny Ivanov, Nikita Zaigraev,
Unconstrained off-shell superfield formulation of $4D, \mathcal{N} = 2$ supersymmetric higher spins,
Journal of High Energy Physics, 12 (2021) 016, 27 pages.
19. I.L. Buchbinder, E. Ivanov, N. Zaigraev,
Off-shell cubic hypermultiplet couplings to $\mathcal{N} = 2$ higher spin gauge superfields,
Journal of High Energy Physics, 05 (2022) 104, 38 pages.
20. I.L. Buchbinder, E.A. Ivanov, N.G. Pletnev,
Superfield approach to the construction of effective action in quantum field theory with
extended supersymmetry,
Physics of Particles and Nuclei, Vol. 47, No 3, pp. 291 - 369, 2016.
21. I.L. Buchbinder, E.A. Ivanov, I.B. Samsonov,
The low-energy $\mathcal{N} = 4$ SYM effective action in diverse harmonic superspaces,
Physics of Particles and Nuclei, Vol. 48, No 3, pp. 333 - 388, 2017.
22. I.L. Buchbinder, E.A. Ivanov, B.S. Merzlikin, K.V. Stepanyantz,
Harmonic Superspace Approach to the Effective Action in Six-Dimensional Supersymmetric
Gauge Theories,
Symmetry, Vol. 11, No 1, pp. 1 - 29, 2019.

Conference talks on the research results

1. E. Ivanov, Superfield counterterms in $6D, N=(1,1)$ SYM theory from hidden $N=(0,1)$ supersymmetry, Ginzburg Centennial Conference on Physics, Lebedev Physical Institute, Moscow, Russia, May 31 – June 3, 2017.
2. E. Ivanov, Classical and quantum superfield invariants in $6D, \mathcal{N} = (1,1)$ SYM theory, XXV International Conference on Integrable Systems and Quantum symmetries, Prague, Czech Republic, June 06 - 11, 2017.
3. E. Ivanov, Implications of hidden $\mathcal{N} = (0,1)$ supersymmetry in $6D, \mathcal{N} = (1,1)$ SYM theory, X International Symposium “Quantum Theory and Symmetries” and XII International Workshop “Lie Theory and Its Applications in Physics”, 19 - 25 June 2017, Varna, Bulgaria.

4. E. Ivanov, Higher-dimensional invariants in 6D SYM theory, Quarks online workshops -2021 "Integrability, Holography, Higher-Spin Gravity and Strings" Dedicated to A.D. Sakharov's centennial, Lebedev Physical Institute, Moscow, Russia, May 29 – June 4, 2021.
5. E. Ivanov, $\mathcal{N} = 2$ supersymmetric higher spins from harmonic superspace, International Conference "Advances in Quantum Field Theory", Joint Institute for Nuclear Research, Dubna, Russia, October 11 - 14, 2021.
6. E. Ivanov, Higher spins from harmonic superspace, XVIII International Conference on Symmetry Methods in Physics, July 10 - 16, 2022, Yerevan, Armenia.
7. E. Ivanov, Supersymmetric higher spins from harmonic superspace, VII International Conference "Models in Quantum Field Theory" (MQFT-2022), Saint Petersburg State University, October 10 - 14, 2022, Saint Petersburg, Russia.
8. I.L. Buchbinder, One-loop divergences in 6D, $N=(1,0)$ and $N=(1,1)$ SYM theories, Ginzburg Centennial Conference on Physics, Lebedev Physical Institute, Moscow, Russia, May 31 – June 3, 2017.
9. I.L. Buchbinder, On-loop divergencies in the $N=(1,0)$ and $N=(1,1)$ supersymmetric gauge theories, International Workshop "Supersymmetries and Quantum Symmetries", Joint Institute for Nuclear Research, Russia, July 31-August 5, 2017.
10. I.L. Buchbinder, On one-loop divergences in six-dimensional supersymmetric gauge theories, 2nd International Conference on Symmetry, Centro De Ciencias De Benasque, Spain, September 01 - 07, 2019.
11. I.L. Buchbinder, Low-energy effective action in gauge theories with extended supersymmetry, Session-Conference of the Section of Nuclear Physics, Division of Physical Sciences of the Russian Academy of Sciences, Institute of Nuclear Physics SB RAS, Novosibirsk, Russia, March 10-12, 2020.
12. I.L. Buchbinder, Low-energy effective action in the gauge theories with extended supersymmetry, VI International workshop "Cosmology and Quantum Vacuum", In Honor of Professor Emilio Elizalde's 70th Birthday, Barcelona, Spain, 5th-8th March 2020
13. I.L. Buchbinder, On a structure of one- and two loop divergences in 6D maximally extended rigid supersymmetric Yang-Mills theory, International conference "Advances in Quantum Field Theory", Joint Institute for Nuclear Research, Dubna, Russia, October 11 - 14, 2021.
14. I.L. Buchbinder, Harmonic superspace approach to one- and two-loop divergences in 6D, SYM theories, The International Workshop "Supersymmetries and Quantum Symmetries" (SQS'22'), Joint Institute for Nuclear Research, August 8 - 13, 2022, Dubna, Russia.

15. I.L. Buchbinder, Superfield effective action in six-dimensional supergauge theories, VII International Conference “Models in Quantum Field Theory” (MQFT-2022), Saint Petersburg State University, October 10 - 14, 2022, Saint Petersburg, Russia.